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OPERATED AS A JOINT VENTURE

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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

DECEMBER 2004

The contributions on individual experiments in this report are outlines intended to demonstrate the extent of scientific activity at TRIUMF during the past year. The outlines are not publications and often contain preliminary results not intended, or not yet ready, for publication. Material from these reports should not be reproduced or quoted without permission from the authors.

EXPERIMENTAL FACILITIES

Proton Irradiation Facility

(E.W. Blackmore, TRIUMF)

During the year there were six scheduled periods for proton testing on the low energy beam line BL2C, and during two of these periods the high energy beam line BL1B was also available. In addition the recently commissioned TNF neutron facility was used for single event testing by two outside groups.

The group from Sandia National Laboratories and CEA in France carried out Expt. 948, Proton Radiation Effects in Silicon-on-Insulator and Bulk-Silicon Devices, in two beam periods, one on BL2C at lower energies in May, and then on BL1B at energies up to 500 MeV in December. This experiment had a number of studies, including investigating the change in sensitivity of ICs to single-event latchup after extended proton irradiation. This group and the group from the Naval Research Laboratory used the higher fluence capability of both beam lines to irradiate at fluences up to 10^{14} protons/cm^2 at rates above 10^{10} protons/cm^2/s. The NRL group irradiated GaAs solar cells at energies of 115 MeV and 50 MeV. The Sandia group also used commercial time for single event testing of various devices.

Table XX lists the proton flux and beam sizes for the high intensity set-up with a range of scatterers.

Groups from MD Robotics visited the facility four times during the year, testing components of a LIDAR system, and various other cards and devices. A special set-up with a 15 cm by 15 cm beam spot was developed for one test. Other Canadian space companies using beam this year included UTIAS, XIPHOS, Bristol Aerospace and ABB Bomem.

The high energy beam time in September was used by two groups, one from Bubble Technologies, Inc. (BTI), to test a new design of neutron spectrometer for space, and the other from Johns Hopkins University Applied Physics Laboratory to measure neutron energy spectra after 200–500 MeV protons strike different shielding materials. The BTI test required very low fluxes to below 10^3 protons/cm^2/s. Another challenge was to reduce the effect of the 7–8 G cyclotron fringe field on the performance of the spectrometer, which used unshielded PMTs for readout.

The ATLAS group from the University of Alberta also used the beam session in September at lower energies for further testing of the readout electronics for the liquid argon calorimeters.

In May members of the Sandia group carried out a series of neutron single event effect tests using the TNF neutron beam line. Devices to be tested are lowered 5 m down a vertical slot in the TNF shielding to

Table XX. Proton flux and beam size measurements.

Beam line Energy MeV	I_{max} nA	Test energy MeV	Range shifter or absorber thickness mm	Scatterer material thickness mm	Proton flux per nA cm^{-2}s^{-1} $\times 10^8$	Beam size 80% uniform X mm	Y mm
BL2C							
70	10	63	0	0.8 Pb	1.4	25	25
		52	15.5*	0	24	7.3	7.3
		50	15.5*	0.3 Cu	6.0	10	10
		50	780	0.8 Pb	1.1	28	28
116	6	115	0	0	41	5.4	4.4
		115	0	0.3 Cu	29	6.4	6.4
		111	0	0.8 Pb	6.2	16	16
		105	0	2.4 Pb	1.6	27	27
		85.5	2000	2.4 Pb	1.3	>27	>27
		67	3800	2.4 Pb	1.1	>27	>27
BL1B							
200	4	198	0	0.63 Pb	3.5	19	19
354	3	352	0	1.3 Pb	3.5	25	25
493	2	491	0	1.3 Pb	5.0	19	19

*Lucite absorber placed directly in front of test point

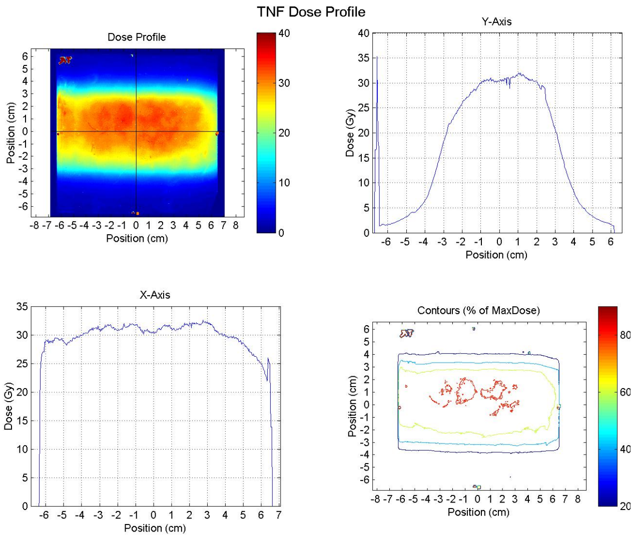

Fig. 182. The neutron beam profile at the TRIUMF neutron facility obtained by exposing GafChromic film at the test location.

intercept the neutron beam that is about 5 cm high and 12 cm wide (see Fig. 182). The flux of >10 MeV neutrons is $4{\times}10^6$ neutron/cm^2/s at a BL1A current of 140 μA. A unique feature of this beam is that it also contains thermal neutrons with a flux of $1.2{\times}10^6$ neutron/cm^2/s. The sensitivity of devices to thermal neutrons can be tested by measuring the SEU rate with and without a cadmium absorber covering the device. The difference is due to thermal neutrons. Figure 183 shows such a measurement made by the Sandia group. This figure also shows the agreement between the SEU rate measured at the WNR facility in Los Alamos and TRIUMF. The data agree when the WNR fluxes are multiplied by a factor 0.75. In both cases the calibration is for neutrons above 10 MeV. The difference is

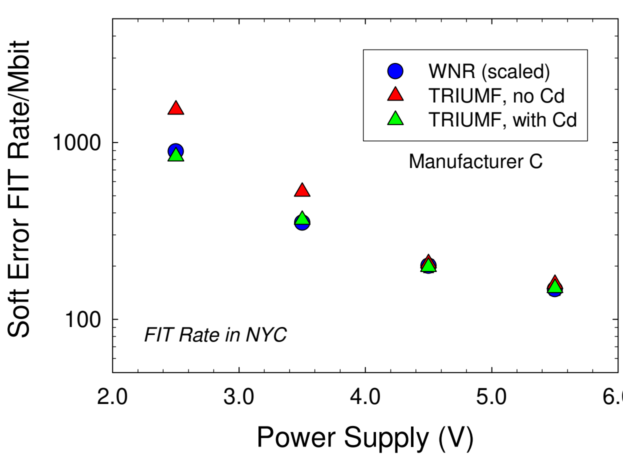

Fig. 183. Neutron-induced SER vs. power supply voltage in 4-Mbit SRAMs. The WNR data were multiplied by 0.75 to match the TRIUMF data. Note increased SER at low power supply due to thermal neutron contribution in TRIUMF spectrum.

partly due to the fact that the WNR neutrons extend to 800 MeV while the TRIUMF neutrons go to 450 MeV.

A similar set of measurements was carried out by the group from the Boeing Radiation Effects Laboratory in Seattle.

A paper titled "Improved capabilities for proton and neutron irradiations at TRIUMF" was presented at NSREC'03 and published in the IEEE Radiation Effects Data Workshop.

Proton Therapy Facility

(E.W. Blackmore, TRIUMF)

In 2003, there were 12 patients treated with protons during the seven scheduled treatment sessions. This brings the total number of patients treated at TRIUMF to 89 as shown in Fig. 184. This year all of the patients were treated for a choroidal melanoma.

The PC version of EYEPLAN, obtained last year from the Clatterbridge group in the UK, was used for the planning of patients. This PC version is much more user friendly than the previous VAX version. The tumour contouring and editing tools are more flexible and simpler to use. The X-rays taken for simulation can be scanned and digitized directly on the computer screen. This is much quicker and more reliable than the previous use of the digitizing tablet. The PC version also incorporates special features to plan for iris and ciliary body melanoma, thereby increasing our patient base.

The only interruption to treatments during the year was failure of the X-ray equipment on the scheduled simulation day in October. This equipment was installed in 1994 and had experienced no prior problems. The fault was corrected by the next morning. It was due to a corruption of data in the permanent memory of the X-ray controls, and it is not clear if this was due to an upset error from earlier running for PIF or due to a battery charging problem.

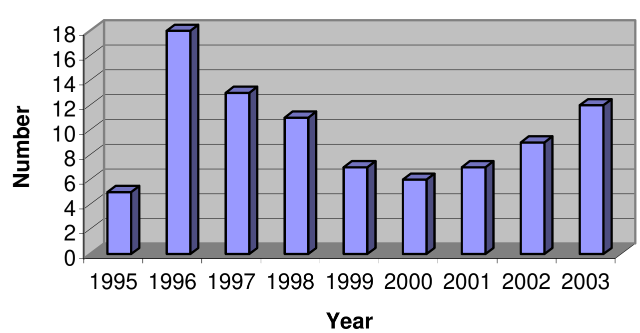

Fig. 184. Proton patients treated at TRIUMF.

μSR User Facility

(S. Kreitzman, TRIUMF)

Overview

Operations The μSR user facility operations in 2003 was a function of beam line availability and systems reliability. The former circumstance was characterized by the use of M20 during the first four weeks for tests on muon cooling. In the latter case the familiar situations concerning cyclotron operations were supplemented by the appearance of a leak in the final silver sintered heat exchanger in the DR (dilution refrigerator) just as it was being set down onto beam line for its summer run. This led to a hasty rescheduling of HiTime into the 6 weeks originally allocated to the DR. Successful repairs to the DR allowed those users who experienced the loss of that spectrometer in the summer to recoup it on a priority basis in the autumn. To that end, 62 beam weeks of μSR experiments were carried out. The major spectrometer utilization was found to be (all in weeks) HiTime 20, LAMPF 17, Helios 14, DR 6, and SFUMU/OMNI′ 5. In addition, 9 weeks of βNM/QR were carried out in the low energy ISAC facility.

Proposals, funding and future plans New and ongoing μSR experimental programs continue on their course. As in the previous year, 19 new proposals were submitted during the two semi-annual Experiments Evaluation Committee reviews. With respect to funding, a new MFA (Major Facility Access) grant application was prepared and submitted to support the facility operations for the three fiscal years beginning April 1, 2004. Also, TRIUMF and the facility were part of a major condensed matter physics CFI (Canadian Foundation for Innovation) application sourced at McMaster University.

This year's MFA application (with its CFI counterpart) had a markedly different emphasis than recent predecessors insofar as it marked a quantum leap in the quantity and nature of the requested support. The prime factor motivating this approach is the significant role that μSR assumes in TRIUMF's new 5 Year Plan (http://tcmms.ca/intro/ppt/TCMMS-Jeff/img0.html). The interested reader will first notice a new name for the facility – now to be called the TRIUMF Centre for Molecular and Materials Science (http://tcmms.ca/), a name inclusive to the science which is served by the current μSR, β-NMR and β-NQR program. More to the point, however, is the substance of TRIUMF's plan which includes approximately \$6.3 million in capital spending to increase and enhance μSR capability from T2 (see Fig. 185). Two additional surface muon beam lines are planned; one at the current location of M9A, the other a kicked Muons on Request (i.e. MORE) beam line. Fundamental flux, luminosity and transmission enhancements will come from a redesigned T2 target and the use of dual compensated separator pairs for M20 and the new M9A.

The underlying scientific motivation for all this activity is simply the rapid growth of the number of (primarily Canadian) μSR scientists who want to work in the field. This group now includes a rapidly expanding component of scientists who are not μSR trained. To this end the design and operational mandate of the new M9A beam line will be to provide turnkey μSR capability to an international community of the condensed matter researchers that are not μSR cognoscenti. The modernization of M20, with high laminotomy and MORE, will further provide the community with the resources to carry out state of the art experiments on small samples and/or for longer times.

This scientific case, coupled with TRIUMF's adoption of an aggressive μSR expansion in the upcoming 5 Year Plan, have together formed the underlying justification for the much broader MFA request. TRIUMF further provided the 60% matching funds commitment that is required for its portion of CFI request, an equipment grant which is meant to fund the new M9A spectrometer.

Facility developments

The major facility developments which highlighted the year were:

- Spectrometers: OMNI′, Helios, DR, and HiTime update.
- Universal mounting system (UMS).
- Experimental control enhancements.
- Data acquisition hardware; the NIM I-muSR module and the β-NQR frequency synthesizer.

The following report outlines these and related developments more fully.

Spectrometers

OMNI′ The road to a new OMNI′ spectrometer is progressing. The frame is built and the tables design is finished. Final detailing of the counter mounts should be completed by the first quarter in 2004.

Helios Helios has been adapted to run in M9A, and its initial run there was very successful. Maintenance to address the small helium leak, comprehensive temperature monitoring, and installation of vapour cooled superconducting leads is scheduled.

DR For the third time in its operational history, the DR developed a leak in the silver sintered heat exchanger which feeds into the dilution chamber. The occurrence of a leak just as the spectrometer was being set down into the M15 beam line for its spring scheduled run resulted in the last minute replacement of six weeks of DR experiments by ones which used HiTime.

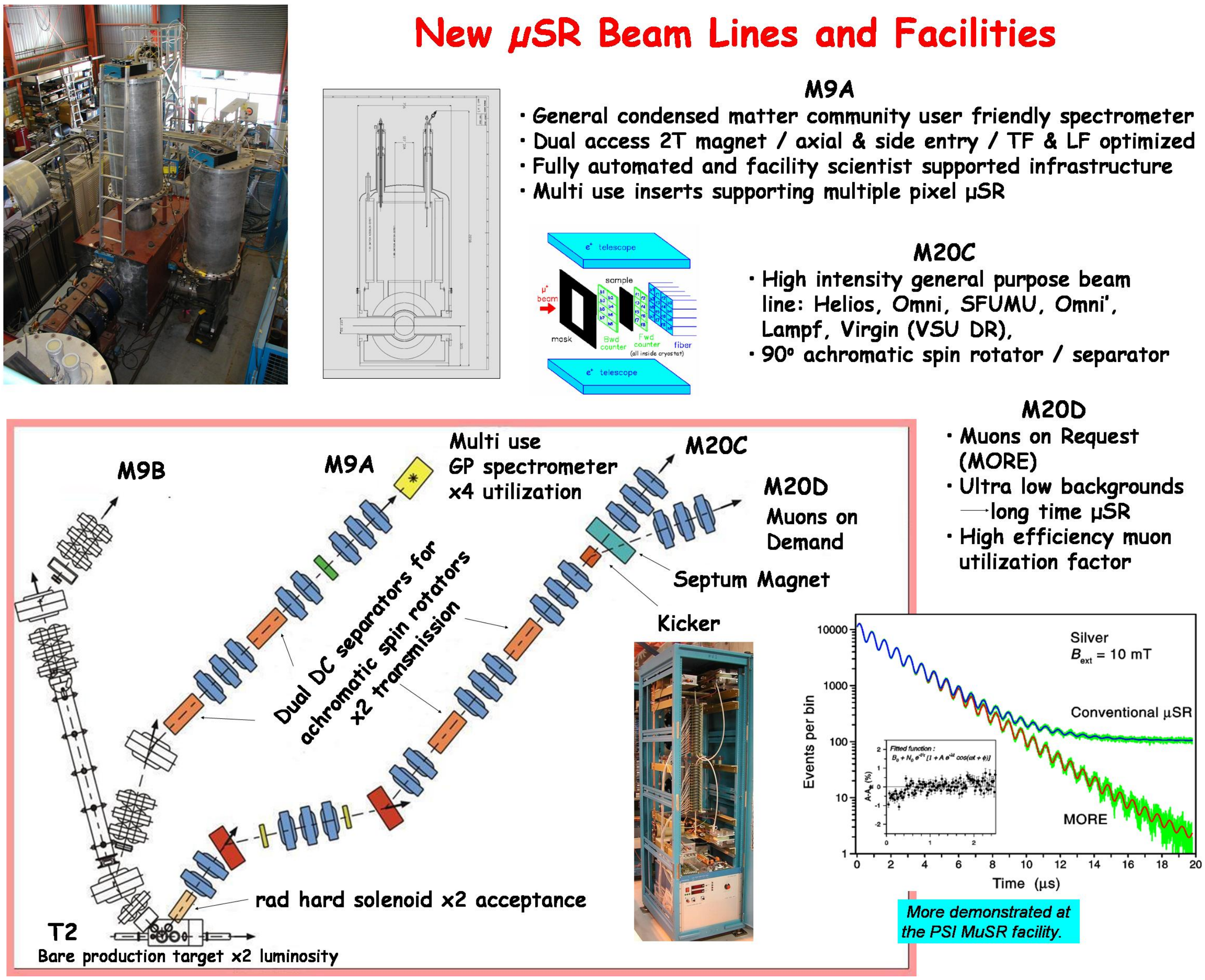

Fig. 185. A representation of the major μSR related items which TRIUMF has included in its current 5 Year Plan.

The leaks in this unit are occurring more frequently, each incident coming in about 50% of the previous time interval. Thus the first leak took about 6 years to manifest, the second three years after that, and the most recent leak, less than two years after the second one. The leaks are all scattered about a small area close to the original leak. A new heat exchanger (from Walter Hardy's UBC laboratory, see Fig. 186) seems to have been found and may provide an avenue to permanently repair the problem. Otherwise, the VSU DR will be retrofitted to become the operational μSR spectrometer for ultra low temperature physics.

HiTime Injecting the muon beam on axis into a high variable field spectrometer is a challenge if the geometry of the field distribution does not show perfect azimuthal symmetry. Due to the use of partially magnetic stainless steel in some aspects of the magnet construction, this is a problem which must be coped with in this spectrometer. The issue is further complicated by the fact that the wandering of the incoming muon beam is very field dependent. Our first approach was simply to mount the cryostat on an $X-Y$ table so that it could be moved to a position centred on the current beam location, but this approach results in the sacrifice of some homogeneity. A more successful strategy has now been found which has reduced the problem significantly. We have mapped both the fringe and central field regions to determine the locus of points which acts as the *significant* field axis. Adjusting the muon beam injection along this axis has substantially solved the injection problem, resulting in a radial beam wandering of less than ± 1 mm at all field values.

A program to enhance the timing resolution of this instrument is also proceeding.

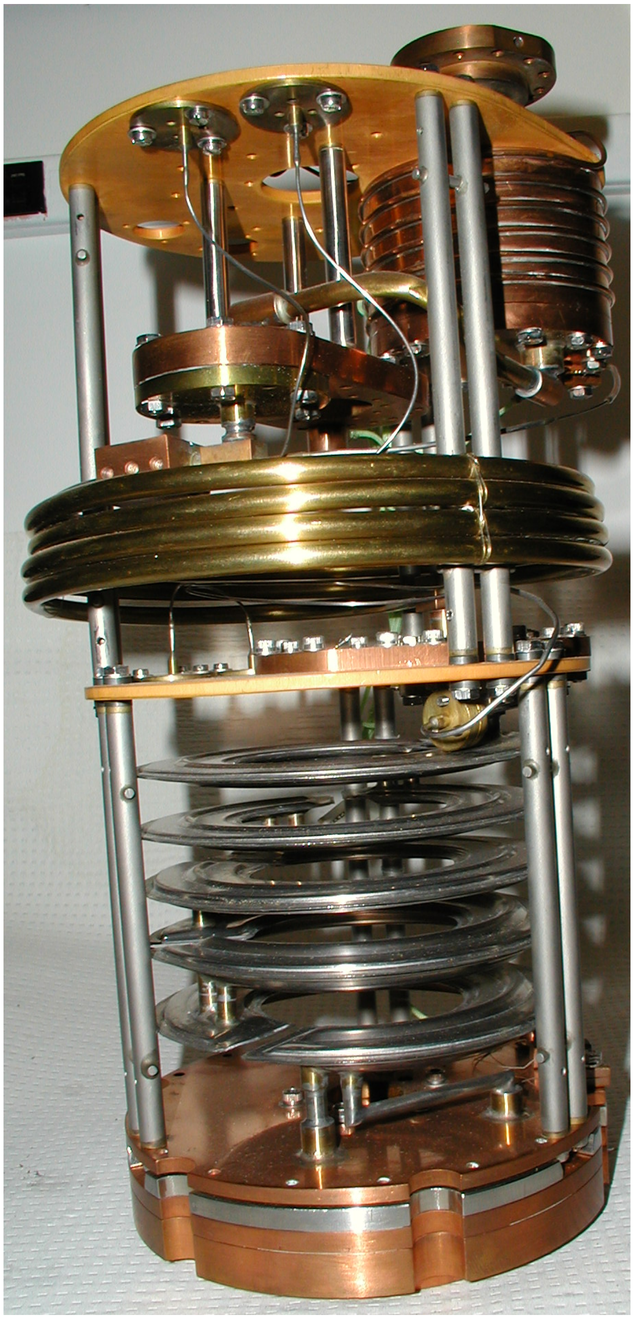

Fig. 186. A photograph of an unused, but with suitable vintage, dilution unit found in catacombs of the UBC Physics Department. It may prove to be transplantable into our current DR which is showing periodic arterial cryogenic failure.

μSR universal mounting system (MuUMS)

The mounting of the plethora of cryostats, ovens, rf, and other specialized inserts into the various spectrometers has always been somewhat ad-hoc. We have now designed a universal system in which all inserts can be easily and quickly mounted independent of spectrometer. This holder provides for easy height and angular theta/phi adjustment. Every insert has a customized adaptor that mounts on the universal holder and every spectrometer has its own holder. In those circumstances where two inserts must be mutually swapped during the run, each can be pre-aligned and reproducibly set down on the MuUMS holder at any time (see Fig. 187).

Experimental Controls

The facility has expanded its temperature control and monitoring equipment with the addition of a Thermo Haake Phoenix P1 circulator, and two multisensor Lakeshore 218 temperature monitors to be used with the Helios magnet and the Miss Piggy cryostat respectively (see Fig. 188).

DAQ

Integral μSR (I-muSR) now boasts a user interface that is integrated with the new Linux/Tkl GUI style that has proven to be so efficient and effective for the time differential μSR experiments. Hardware enhancements have also been made. For I-muSR, the large number of NIM modules required to provide a general functionality has been replaced by one unit that was specifically designed for work with the VME GGL board (see last year's Annual Report). This provides a permanent I-muSR set-up for each area with enhanced functionality, specifically the capability of three levels of looping coupled to three different external experimental parameters, i.e. RF + EF + UV. For the β-NQR program an integrated frequency synthesizer/control device (Pol Synth) was designed and built. Complex modulation capabilities, coherent frequency sweep and external gating capabilities have all been built into the device (see Figs. 189 and 190).

Future perspectives

As mentioned above, this is the last year that the μSR user facility name will grace the activities of the TRIUMF Centre for Molecular and Materials Science. Attendant with this name change is a purposeful change in orientation, one which will support a broader scientific community access to μSR resources. The degree and speed at which this can be carried out depends in part on the success of the current MFA and CFI funding initiatives. The former will primarily provide for the manpower required to fully support users from outside the μSR community while the latter will contribute to the construction of a state of the art μSR spectrometer on the new M9A beam line proposed in TRIUMF's upcoming 5 Year Plan.

Regardless of the outcome of these important funding decisions, the facility will continue to provide innovative avenues to enhance the experiment capabilities which it can provide. In particular, plans for an axial ultra low background set-up, and a dedicated 4-pixel

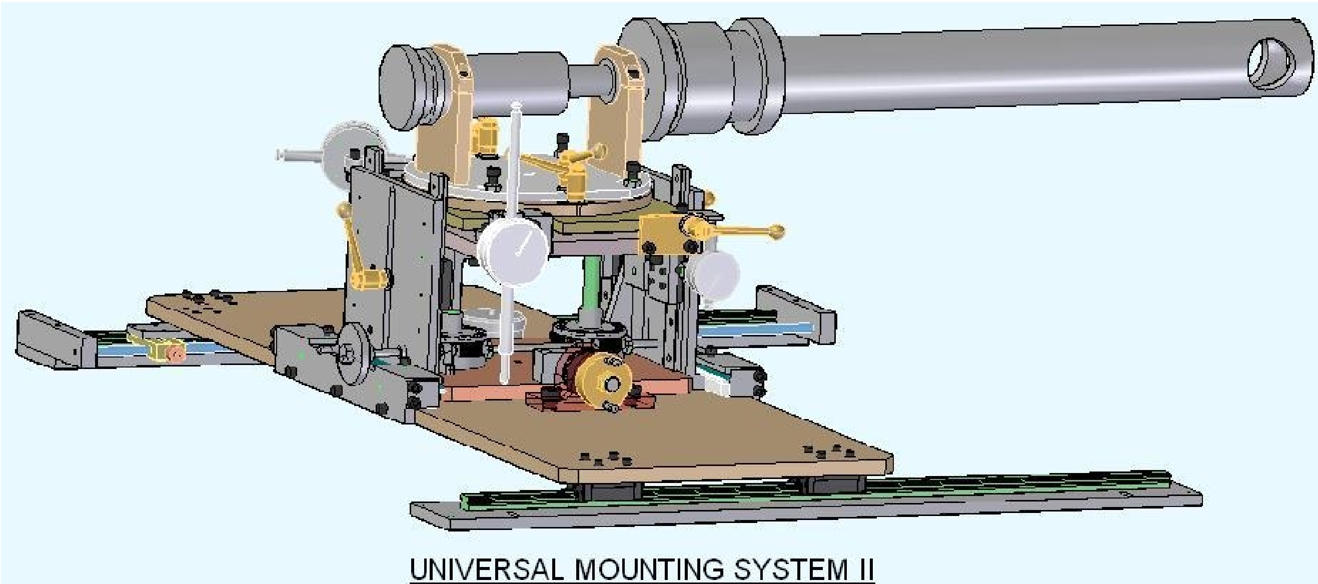

Fig. 187. A 3-D rendering of the μSR universal mounting system (MuUMS) with a typical axial cryostat attached.

Fig. 188. A modern temperature controlled circulation system (Thermo Haake Phoenix) widely used in the chemistry program to control sample temperature from -40 to 200°C.

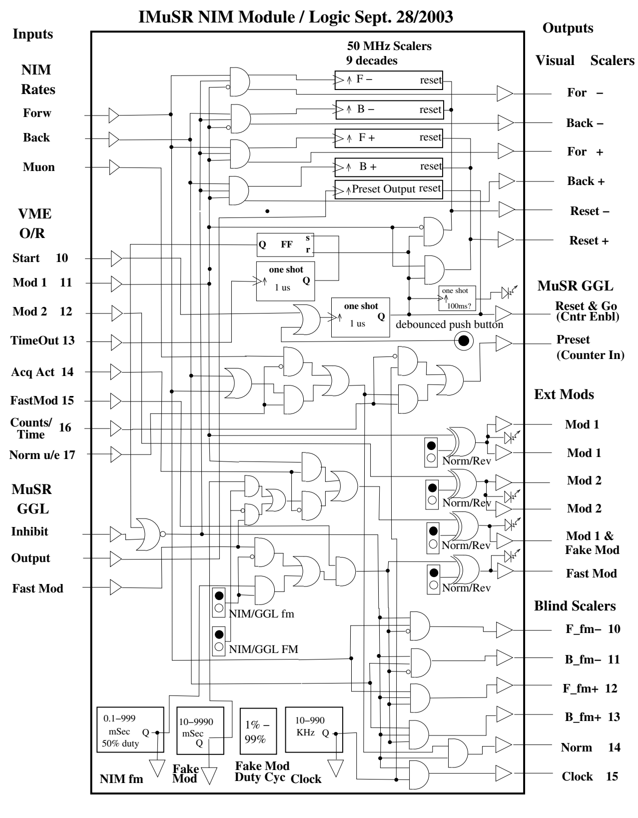

Fig. 189. The logic functionality contained in the I-muSR NIM module that provides the new I-muSR DAQ hardware.

version of the Multi insert will add additional capabilities to measure very small samples and efficiently carry out time differential experiments. The possibility of providing a He-3 cryogenic system for those experiments that would like to operate conveniently in the 0.3–100 K temperature range is also being considered. Further instrumental infrastructure support for the Physical Chemistry program will also be implemented.

The μSR $\rightarrow$ TCMMS facility therefore looks forward to a very dynamic juncture in its evolution and will, under any circumstance, continue to provide and facilitate access to the μSR and β-NMR facilities at TRIUMF.

Facility information and documentation

Please refer to our Web site http://musr.triumf.ca for full access to a broad range of facility resources and information.

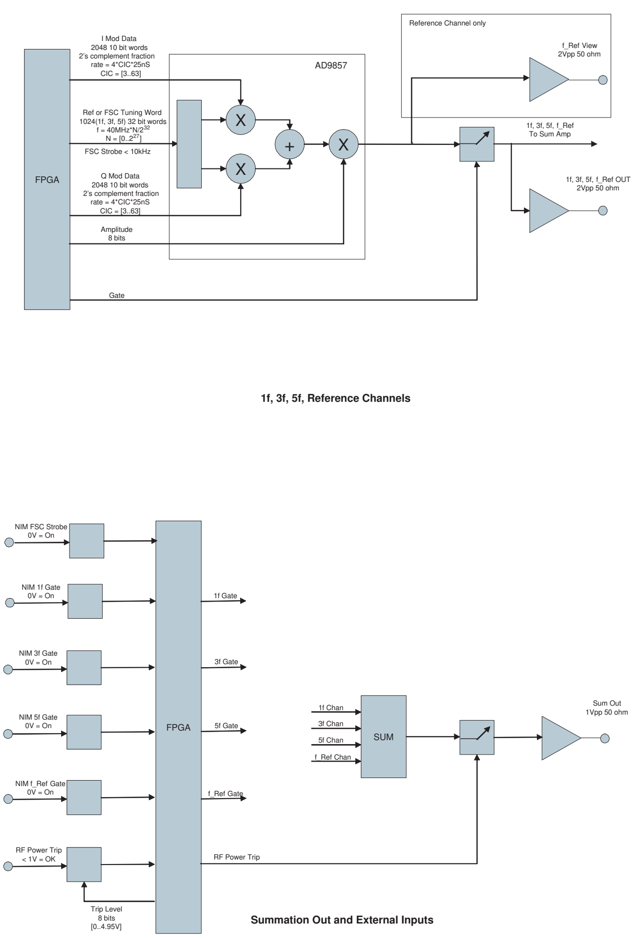

Fig. 190. The functionality of the β-NQR frequency synthesis and control VME board.

Cryogenic Targets

(C. Marshall)

Horizontal liquid hydrogen target

Installation and running was completed for a horizontal liquid hydrogen target used in Expt. 744 at M9. The 0.5 l target, designed and built at TRIUMF, incorporated a low mass vacuum structure manufactured from high strength foam (Divinycell) with a Kapton skin. The structure allowed a 360° scattering of particles with no intrusion from massive posts to support the vacuum load. The target cell had to be inserted 1.2 m horizontally within the M9 spectrometer, and allow a 5 cm clear path axially through the target's vacuum and refrigeration structures.

Liquid hydrogen target for Expt. 874

A rotatable liquid hydrogen target was designed and built for the muon-scattering experiment, Expt. 874. The target was rotatable to give full-length or half-length of a 0.5 l target.

Liquid xenon detector

A liquid xenon detector was designed for research into developing a better PET scanning machine. It is hoped with this detector to double the resolution as obtained with existing PET equipment.

Cryogenic engineering

Design work was carried out for the cryogenic components being built for the ISAC-II accelerator. The design involved cryogenic heat load, and flow calculations which were used to size the helium liquefier, and associated cryogenic distribution piping.

Computing Services

(C. Kost, TRIUMF)

Overview

The event of the year was moving Computing Services from the chemistry annex to the new ISAC-II building. That the final switchover was accomplished over the weekend preceding April 1 with little disruption to the site speaks volumes on the careful planning, expertise, and dedication of all those involved. This involved not only moving the people but also all the network equipment and computers (especially the Web, mail, Windows, print, and application servers). It was also necessary to complete the network infrastructure, not only for the new data centre but also for the many users, experiments and laboratories that would be occupying the new building. This meant the new building had to be cabled and patched for nearly 500 network connections. This was successfully completed by the April 1 deadline. The move was not without irony, however. After years of dealing with air conditioning problems in the old facility, the dual air conditioners in the new facility both broke down within hours of our moving in. It was even more ironic that this was mostly due to a single line of bad code in the air conditioner's control system.

The emphasis for the duration of the year was in upgrading the network as well as dealing with two highly successful workshops, GEANT4 in September and HEPiX/HEPNT in October.

The UBC-TRIUMF component of WestGrid, the core of which is the 1008 3.06 GHz Xeon CPU cluster called Glacier, has continued to have a number of teething problems. Nonetheless, a small number of Beta users, one being TWIST, have successfully used the new facility, which is scheduled to be in full production in early 2004.

IBM compute cluster

2003 saw the de-commissioning of the lin01 and lin01a public Linux compute machines. These machines were running the outdated Red Hat Linux 6.2 and needed both a hardware and software upgrade. One of the problems faced in providing a generic public computing environment for the TRIUMF site is that it needs major upgrades both in software and hardware at regular intervals. In the past, TRIUMF computing services has typically purchased a new machine consisting of the best hardware available at the time and installing the most recent CERN supported release of Red Hat Linux. The lifetime of such an investment was typically 18 months. This year a new approach was taken. It was decided to build a small cluster of Linux machines. This approach has several advantages: firstly, only one machine need be known to the TRIUMF site, namely the head node, additional nodes can be added to, and removed from, the cluster with almost complete transparency to the users. This increases computational resources as they are needed, or removes nodes when they fail, resulting in much greater flexibility and robustness. Only the head node needs to be managed and kept running at all times. For this reason the head node should be highly reliable, consisting of hardware raid, redundant power and a responsive support contract.

One might think that the head node should be upgraded at the same 18 month interval as in previous years. However, by implementing the Openmosix kernel, as we have done, this is no longer a necessary requirement. An Openmosix kernel is a modified Linux kernel that allows automatic process migration to participating cluster nodes. That is, when a user logs on to the head node, the processes started by that user will migrate automatically to the other nodes in the cluster, maintaining an even load across the cluster. As the computing demands increase, more compute nodes can be added to the cluster. This is not your traditional batch compute cluster, for if it were, then the head node would most likely need upgrading as in the past, since all interactive usage is constrained to the head node. By taking advantage of Openmosix, it is possible to spread the interactive usage across all nodes in the cluster.

In addition to the automatic migration properties of the cluster, it can also run as a traditional batch compute cluster, which most users are more familiar with. The cluster, which consists of six IBM x330's, having dual 1.4 GHz PIIIs, with 512 MB memory, also runs the PBS queuing system. This same queuing system is used on the large WestGrid cluster. It can do this by turning off or suspending the process migration properties of various cluster member nodes when PBS jobs have been submitted to them. This gives some cluster nodes the ability to run exclusively single large computational intensive applications, without affecting the responsiveness of interactive processes, such as PAW, Netscape and ROOT.

This ability to perform as a traditional batch compute cluster as well as an automatic load sharing interactive cluster, is both unique and advantageous. It allows TRIUMF computing services to grow the cluster as required with minimal effort and transparency to the user community. It also improves the reliability of the computing environment and abandons the expensive and disruptive tear-down and rebuild approach we have taken in the past.

Servers

Figure 191 shows the main components of the computing services facility – notably the time, name, backup, mail, print, Web, file, application, and compute servers now located in ISAC-II. These servers are periodically upgraded to meet increasing demands of the user community.

To provide an alternative to sending large e-mail messages to multiple recipients a server, TRSHARE, which is both a file and Web server for use by everyone with an e-mail account, has been commissioned. It has a terabyte of raided disk space (with a hot spare). Web access can thus be used for global sharing of files. TRSHARE can serve clients under Windows, Mac, and Linux (via Samba). It is hoped that this will relieve some of the CPU and storage requirements on our mail server.

Network

In September, 2002 TRIUMF's Network and Computing Services took part in the world's first intercontinental high-speed, large-volume data transfer using an end-to-end (e2e) light path between TRIUMF and CERN. As part of these trials, TRIUMF had the opportunity to upgrade its WAN connection to the

Fig. 191. Computing services servers.

Internet. A coarse wave division multiplexer (CWDM) capable of carrying four 1 Gbps wavelengths over a single pair of fibres was purchased which currently provides separate services for (a) research and educational Internet traffic, (b) traffic to WestGrid, (c) end-to-end light path tests and high-speed large volume data trials, and (d) a wavelength reserved for commercial and commodity traffic which is currently carried by a separate 100 Mbps fibre link to UBC.

However, as of April, 2004 the commodity traffic will need to be moved to the fourth wavelength and at that time all of TRIUMF's Internet traffic will be on a single point of failure circuit which will be difficult to repair in a timely manner. To correct this vulnerability it is planned to purchase new equipment, as soon as possible, which will not only cost less than having a hot spare of one end of the existing hardware, but will

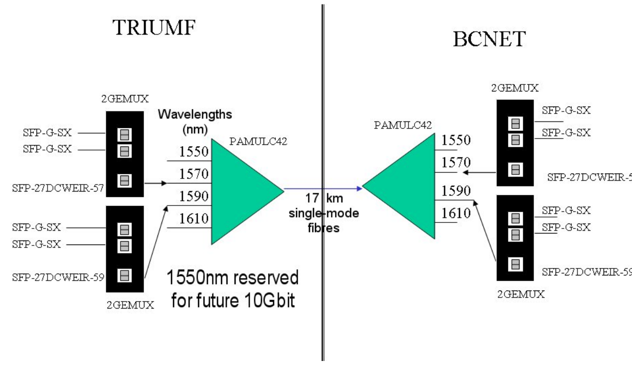

Fig. 192. Proposed CWDM solution.

provide growth to using 10 Gbps technology as well as allow capacity upgrades, while preserving the existing equipment as hot spares. The components are shown in Fig. 192.

Note that not only is the fibre multiplexed by using multiple wavelengths, but each wavelength is further time-division multiplexed by having two (SFP-G-SX) 1 Gbps circuits placed on each wavelength (each wavelength now handling 2.5 Gbps instead of just 1 Gbps on the current CWDM). It has been indicated that in the future it will be possible to do all this over a single fibre. Presently two fibres are used, one for sending and one for receiving the data. Essentially this would double the network capacity, yet again!

TRIUMF's Internet contract was also renegotiated through BCNET and not UBC. The 100 Mbps link to UBC, currently carrying TRIUMF's commercial and UBC traffic will be maintained but is currently unallocated. However, as of April 1, 2004, the commodity traffic will be moved onto one of the ports on the CWDM and the UBC traffic will be routed onto the research link. While this is a significant and desired improvement for all of TRIUMF's research and educational traffic, it has a potentially dangerous consequence for TRIUMF's commercial network traffic. As of April 1, 2004, TRIUMF will be volume charged for its commercial Internet traffic. Typical rates for commercial (or commodity traffic as it is sometimes called) is \$1 k per 1 Mbit of sustained traffic per month. With a gigabit connection to the Internet it is clear that TRIUMF needs to rate limit the traffic over this link. A 10 Mbps sustained network transfer over the commercial link for more than 36 hours would result in a monthly billing of \$10 k. Fortunately, all of TRIUMF research and educational network traffic is not volume charged; it is this research traffic which is generally the source of the large network transfers. However, applications such as Kazaa and E-donkey (which are contrary to TRIUMF's usage policy), typically associated with music and video file sharing as well as some Internet radio stations that use the chain casting technology, can result in large network transfers over the commercial link. If left unchecked, as mentioned above, this could result in significant costs to TRIUMF. To address this concern, TRIUMF network services has installed a Linux machine at the network border that rate limits all commercial Internet traffic. Unwanted peer-to-peer file transfers can now be readily identified and tagged so as to limit their bandwidth to 100 Kbps. At present the rate limiting is relatively simple. However, if the situation becomes more complex requiring advanced packet shaping, protocol prioritizing and detailed analysis of Internet traffic, a commercial product may be necessary.

With the exception of the move from the chemistry annex to ISAC-II, the TRIUMF network infrastructure saw little fundamental change this year. Over the past four years TRIUMF network services has been migrating from an FDDI shared 10 Mbit topology to a switched Ethernet network with a gigabit backbone and 100 Mbit connectivity to the desktop. The migration has all but been completed with the exception of a few locations, namely the machine shop and a few locations in meson and proton annexes. It is estimated that 99% of the nodes at TRIUMF are now on the new network with 100 Mbit switched connections to the gigabit backbone. The remaining machines are still on the older 10Base2 shared 10 Mbit connections. A number of high demand areas such as ISAC-I and the second floor of the main office building were upgraded. The new high density, low profile, Nortel BayStack 470 switches replaced the older 450 switches. This enabled these locations to be completely re-cabled, leaving additional room for improved cable management. Previously, cable management was virtually non-existent in these wiring closets. In the case of the second floor of the main office building this resulted in a tangle of over 200 CAT5 network cables. This made it virtually impossible to trace and troubleshoot some network problems. A similar situation existed in ISAC-I, where the demand for network connections was initially underestimated, and additional connections were added in ad hoc fashion. The experience gained in improving the network core in these areas will be applied to other areas of the TRIUMF site in 2004, namely trailers Hh, Ff and the ground floor of the main office building. The decision was also made to activate every wired Ethernet port, thereby removing the confusion over which ports were enabled.

An important expansion to the TRIUMF core network this year was the addition of a dedicated 1 Gbps network connection to the 1008 3 GHz Xeon processor WestGrid computing cluster, with 10 Tbytes of disk and 108 Tbytes of tape storage at UBC, and 24 Tbytes of disk and 135 Tbytes of tape storage at SFU. This was made possible because of the four-port CWDM described earlier. At the same time a second Nortel Passport router was purchased which allowed TRIUMF to separate the WAN (wide area network) connections from the LAN (local area network) connections. This was an important separation, as it allowed changes on the WAN router to be applied without affecting the local area traffic around TRIUMF. A third Nortel Passport router has been purchased for 2004. This will allow Network Services to add redundancy and reliability to the LAN network core. Details of our current configuration and further upgrades are shown in Fig. 193.

Computer security

As part of our "disaster recovery" plan, the most vital systems (Mailserver and Webserver) are now nightly backed up (RSYNCing) to other (slower) machines located in a different building and could be used for system recovery if disaster struck these servers. Slightly less critical machines (name and CUPS print servers) have their important files backed up every day. All this is in addition to our usual tape backup procedures.

Since air conditioners have by their nature been unreliable, networked sensors now monitor the main computing room temperature at two key locations and

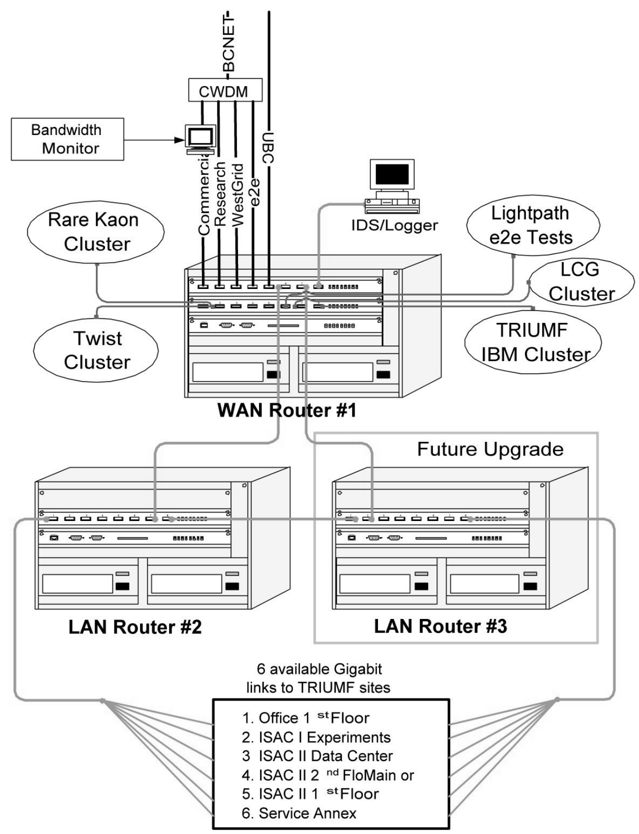

Fig. 193. Core network upgrades.

allow for e-mail and paging to alert staff should the temperature go outside the acceptable range.

On Friday, January 24 TRIUMF was hit by the Slammer worm. This was a rapidly spreading network worm affecting machines running Microsoft SQL server. Although only two machines on site were infected, the resulting large amount of traffic generated essentially halted the TRIUMF network overnight until the machines could be physically disconnected.

In the aftermath of this incident, we implemented procedures for notifying key personnel after hours independently of the network.

In August TRIUMF was affected by the Blaster worm, which affected machines running Microsoft Windows file sharing services. This occurred when some key personnel were on vacation but on-site staff were able to contain the problem. The network performance was unaffected but a large number of machines required updates. Though direct infection from the Internet was not possible, since we block these services from off site, it is believed that some infection occurred as a result of infected laptops being brought on site and connected to the TRIUMF network.

The PC Support group has installed a central server for Symantec AntiVirus. This allows efficient management of (about 250) systems running Microsoft Windows and for timely notification of infected systems. Together with the antivirus filter on the TRIUMF mail server this provides effective protection against the current generation of e-mail-borne viruses and worms – ones that require some human interaction (opening a message) to spread.

TRIUMF, and indeed all networked organizations, continues to be vulnerable to so-called Zero Day viruses and worms – a virus which is released as soon as a vulnerability is discovered, giving organizations no time to design and implement a patch.

In December an on-site machine was broken into and some critical passwords obtained. Over the Christmas vacation these were used to run an IRC chat room from a TRIUMF machine. No damage was done and security procedures have been re-evaluated.

The virus filter on the TRIUMF mail server reported some 19,000 infected machines to administrators during 2003, up from 900 in 2002.

Our computing security officer attended courses on computer security given by an internationally recognized organization, Global Information Assurance Certification (GIAC). The officer was awarded the GIAC Security Essentials Certification (GSEC) on September 30.

E-mail Again, TRIUMF continues to receive an ever-increasing amount of unsolicited commercial e-mail, or spam. The anti-spam tool SpamAssassin was upgraded in 2003 to a later version with some enhanced features. Nevertheless, some inappropriate mail escapes the filter. In 2003, one of the on-line databases (Osirusoft) which was used to help filter mail came under attack and was closed down. For a short period the service was marking all mail as spam, causing some inconvenience to TRIUMF users.

A scheme was implemented which temporarily rejects certain incoming mail messages which are believed to be spam, based on their address of origin. Since many spammers do not respond to temporary rejects this can result in a reduction of the amount of spam finally delivered. This method is used more aggressively at the University of Calgary, where all incoming mail is delayed unless from a trusted source. This marks a watershed in anti-spam measures at TRIUMF – previously we had immediately accepted all mail and relied on users to filter it if they wished.

Videoconferencing

A Webcast server was used to record and transmit a number of events, including the HEPiX 2003 conference, TUG meetings, and the EMMA workshop.

TRIUMF received funding from WestGrid to establish a facility, based on the Access Grid Project (see http://www.accessgrid.org) for collaboration and visualization. Our security officer built up this facility (the videoconferencing room) in the ISAC-II building. A plan view is shown in Fig. 194.

As provided by the contractors, the room was acoustically insulated from adjoining rooms but hard-surfaced and not an optimal shape for conferencing (rectangular). Acoustic panels and wall covering were installed to reduce echo and reverberation. The room has been set up to allow a variety of different video, audio and local conferencing methods to be used. Two high-quality (1280*1024) digital projectors each

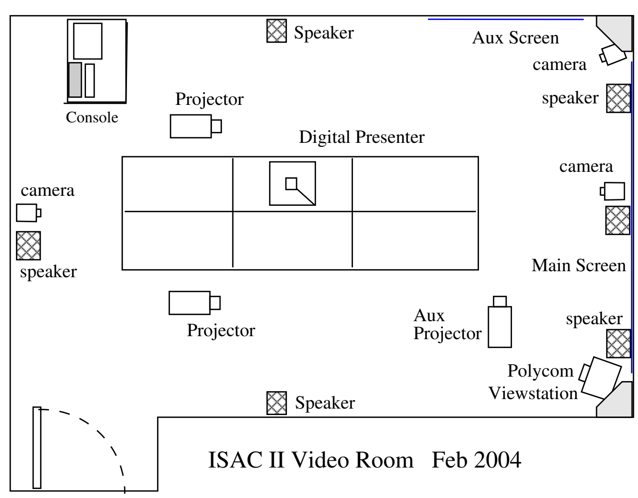

Fig. 194. Plan view of access grid facility for collaboration and visualization.

illuminate adjoining 2 m wide main screens while a third projector illuminates an auxiliary screen on the side wall. Each projector can be driven from a variety of sources including laptop computers. A multi-speaker surround sound system and multi-channel echo canceller with ceiling-mounted microphones allow sound from remote participants to be suitably positioned while ensuring adequate pickup from local participants around the room.

A "visual presenter" replaced the traditional overhead projector functionality for local meetings while allowing remote participants to see paper documents using a regular Web browser. ISDN and H.323 videoconferencing are provided by a Polycom Viewstation appliance; the ISDN telephone line has been rerouted to this room from its original location in the main office building.

VRVS and Access Grid conferencing are provided by a computer system which is capable of driving either one, two or all three projectors. All wiring is routed under the floor or above the ceiling to improve appearance and eliminate tripping hazards. The echo canceller, sound system and computers are located in an operator's console in the corner of the room, together with a wireless hub which provides 802.11 network capability for laptops. A Bluetooth wireless keyboard and mouse allow the main computer system to be operated from the conference table. A "roomwizard" panel by the door shows bookings and integrates with the TRIUMF on-line room allocation service.

The room is being used regularly by several groups at TRIUMF.

Network measurements

We continue to participate in the SLAC Pinger and other network measurement efforts.

Software developments

Physica and other data analysis Physica is an internationally popular, general purpose data analysis/visualization program running on UNIX/Linux platforms. The port of Physica to the program Extrema on the Windows platform has progressed to the release stage. This Windows version has new improved features not found in the UNIX/Linux versions. Work has now begun on porting Extrema back to Linux and converting it into an Open Source project, making it even more accessible for world wide use.

Work was started on writing a GUI utilizing ROOT for display and analysis of MIDAS data. Rewriting of the analyzer code for the DRAGON experiment, originally written in C, is being rewritten in object oriented C++. Assistance, by writing several scripts, was provided to allow Physica to perform spectral analysis of experimental data. Assistance was also provided in the conversion of neutrino simulation and analysis codes from the SUN-SPARC platform to Linux.

Beam dynamics

ACCSIM The multi-particle simulation code ACCSIM continues to be used in a wide variety of accelerator applications, principally for high-intensity proton synchrotrons and accumulator rings. The development of this type of simulation code, with self-consistent treatment of space charge, is now a very active field, as evidenced at the ICFA Mini-Workshop on Space Charge Simulation held at Oxford this year. A presentation on ACCSIM was given at this workshop and there was participation from many other institutions, with reports on new space-charge methods and advances in simulation software. One of the workshop goals was to produce a "master spreadsheet" of all known space-charge simulation codes, much of it done by direct interrogation of code authors or expert users who were present. The result can be found at http://www.isis.rl.ac.uk/acceleratortheory/chris/Space Charge HALO03/Space Charge Spreadsheet.xls.

Consultation and support activities with new and existing users continued. New ACCSIM applications emerging during the year included:

- High-intensity charge-exchange injection studies for the CERN PS booster;
- IHEP Beijing study of future Chinese Spallation Neutron Source rapid cycling synchrotron;
- Trapping in stable islands in the CERN PS;
- Intensity dependent emittance transfer in the CERN PS.

The latter two applications use a lattice description with nonlinear components based on measurements in the PS. Under an initiative from the ICFA workshop, this lattice, together with observation data from PS beam studies, will be used to benchmark and compare ACCSIM and other codes such as Orbit from ORNL. To accurately model the lattice requires adding a more general treatment of multipoles to ACCSIM, which is expected to be complete in early 2004.

Parallel Computing In conjunction with our contribution to the TRIUMF-CERN LHC collaboration beam dynamics tasks (reported elsewhere in this Annual Report), further experience in our group was gained with parallel computing on commodity clusters. The study of coherent beam-beam effects in the LHC involved large-scale multi-particle simulations with our parallel code BeamX, implemented on a small test-bed cluster at TRIUMF and on the THOR cluster at the University of Alberta Physics Department.

In the production phase of the study, jobs were run continuously in Vancouver and Edmonton over several weeks, with run control and analysis being done at CERN. With ∼50 Mbytes of data being generated per run, it was important to come up with a simulation protocol which would ensure data integrity and streamline the run management and post-processing. The methodology that evolved, using ssh (with non-interactive authentication) and rsync (with ssh tunnelling) allowed data to be rapidly and securely replicated across platforms and gave immediate access to results via Matlab graphics. The existence of high-speed research networks connecting the three sites was of course a great boon to this project.

Late in the year, the first trials of this application were conducted on the new WestGrid facilities at the University of Calgary, utilizing an HP "CluMP" (cluster of multi-processors) alpha-based system. Initial timings (with the unmodified MPI-based code) showed up to a factor of 2 performance improvement. In 2004 we intend to test BeamX and other applications on the other WestGrid platforms (shared-memory and blade systems) as well, to find the best match to the computational problem.

RELAX3D Improvements were made to the GUI front-end for RELAX3D, the 3-dimensional electrostatic field solver still in frequent use at TRIUMF and many other sites. The GUI allows rapid and efficient control of most of the commonly-performed functions of RELAX3D and is particularly helpful for visualization of results. Automatic plot features, allowing one-click navigation and plotting of 2-d slices through the solution domain, were added to the internal graphics facility (contour plots) as well as to the external interface to Matlab (surface, contour, pseudo-colour and waterfall plots).

In the Matlab interface an intermittent problem with communication hang-ups between the GUI and Matlab was resolved, and erratic plot window updating in Matlab 6 was also corrected. An axis lock feature, for making series of commensurate plots, and support for multiple figure windows, were also added.

Printing A pilot study of two possible vendors of digital "all-in-one" printing, copying, sending (scanning) units, to both replace our aging analogue photocopy machines and high volume public printers resulted in a dead-heat tie and a lease of a Xerox 555 to replace one of the two main photocopy machines as well as the lease of a Canon Imagerunner 5000i to replace the ISAC-II central printing station. Response by the user community has been extremely positive and similar replacements are planned for 2004, possibly extending to colour capable units.

The capability to rapidly scan material and e-mail the resulting pdf document, although currently limited to monochrome, has been particularly welcomed, as was the ability to scan a document only once to produce multiple copies, complete with optional hole punching and/or stapling.

To provide enhanced support for printing from Linux, the Common UNIX Printing System (CUPS) is now used for printing. It supports the new standard Internet Printing Protocol (IPP) which is now supported by nearly all printer manufacturers. With CUPS, users can now more readily manage and check their print status using their Web browser (eg. http://cups:631)

Miscellaneous Matlab 6.1 and Maple 8 were installed. These are site-licensed for unlimited use by both Linux and Windows environments. Due to high upgrade costs, Mathematica is now supported only as a legacy facility. Although not in the purview of our mandate, a novel way to address the need of multiple groups taking tours of the TRIUMF facility to be able to hear their guide, in what is often a very noisy environment, was to purchase 24 FRS (Family Radio Service, i.e. walkie-talkies) thereby enabling each tour member to clearly hear the presentations, no matter how distant they are from the speaker.

Data Acquisition Systems

(R. Poutissou, TRIUMF)

Overview

In 2003, the DAQ group introduced new systems for development of the TIGRESS detector and the T2K Neutrino group R&D while continuing to support a wide array of experimental groups and test stations. The DAQ group was involved in defining the next generation data acquisition system as a component of the Laboratory for Advanced Detector Development (LADD). The first phase of the development of MIROODAS, an on-line analysis package for replacement of NOVA, took place.

The TRIUMF data acquisition software package, MIDAS, is currently deployed over 34 stations managed by the DAQ group around the laboratory (see Table XXI). These machines also provide some off-line analysis resources and disk storage (see http://daq.triumf.ca/triumf_nodeinfo/).

MIDAS and MIROODAS

The core part of the MIDAS software has not changed much during this past year. There were minor changes, some bug fixes and support for new hardware. In particular, MIDAS was deployed and tested on a diskless VMIC/VME processor board. VMIC processors will be used in the future instead of PowerPC running the VxWorks operating system. Information about MIDAS can be found at http://midas.triumf.ca.

Table XXI. Computer systems managed by the DAQ group.

Name	Location	Type
isdaq01	ISAC-LE βNMR, TRINAT	2xPII/450
isdaq02	ISAC-LE, GP2, LTNO	PIII/500
isdaq03	ISAC-HE, TUDA	2xPIII/550
isdaq04	ISAC-HE, DRAGON	2xPIII/550
isdaq05	ISAC-LE, ISAC users	PIII/1000-256
isdaq06	ISAC-HE ISAC users	PIII/1000
isdaq08	ISAC-LE, 8π	2xPIII/1000
ltno01	LTNO CR DAQ	2xPIII/600
midtis01	TRINAT DAQ	2xPIII/550
midtis02	Detector Facility	Celeron 430
midtis03	LTNO platform DAQ	PII/350
midtis04	GP2 DAQ	2xPIII/550
midtis05	8π cryo	PII/300
midtis06	Neutrino Devel. DAQ	AMD/XP/350
midtig01	TIGRESS Devel. DAQ	2xAMD Ath/ 2000
midmes01	Detector Facility	PIII/500
midmes03	RMC DAQ	2xPIII/550
midmes04	M11 DAQ	PII/300
midmes05	Detector Facility	Celeron/335
midmes06	Neutrino Devel. DAQ	PII/400
e614slow	TWIST Slow Control	PII/400
midtwist	TWIST DAQ	2xPIII/1000
linm9b	M9B μSR users	AMD Ath/1500
linm15	M15 μSR users	AMD Ath/1500
linm20	M20 μSR users	AMD Ath/1500
midm9b	M9B μSR DAQ	2xPIII/1000
midm15	M15 μSR DAQ	2xPIII/1000
midm20	M20 μSR DAQ	2xPIII/1000
epicsm9b	M9B μSR EPICS	PIII/550
epicsm15	M15 μSR EPICS	PPro/200
epicsm20	M20 μSR EPICS	PPro/200
daqlabpc	DAQ lab machine	PII/232
dasdevpc	DAQ development and Web server	PIV/1700
ladd00	LADD server	2xAMD Opt/ 1800

While MIDAS is mainly a data acquisition package, it includes a simple framework mechanism to interface to an on-line data analyzer tool. Currently two different analysis packages are routinely in use at TRIUMF: NOVA and PAW (physics analysis workstation). While NOVA is no longer officially supported by the TRIUMF DAQ group anymore, it will remain available as long as no major upgrade of the operating systems would brake it. For the CERN package PAW, the lack of future support and the limitations of the system in some specific areas, such as the live display, prompted our group to look at the new CERN data analysis package ROOT. By using ROOT (fully OO compliant), TRIUMF will maintain its support capabilities for the next generation of experiments. ROOT is very flexible and already incorporates some of the current simulation tools like GEANT3. By providing a MIDAS/ROOT interface, the DAQ group feels that this package will keep MIDAS in the forefront of DAQ systems.

The status on that software interface at the end of 2003 includes: a mechanism in the MIDAS logger to save raw data in ROOT format (Tree), support for filling ROOT histograms in the standard MIDAS analyzer program and a simple on-line live ROOT histogram display GUI.

In parallel to this MIDAS/ROOT interface, the DAQ group has defined a new GUI ROOT application which will become a basic tool for on-line data display in the ROOT environment. This task was initiated with the help of Greg King (summer student) who developed an initial version. This work is also based on some major development done by the 8π group and their summer student (2002) Brian Eshpeter. Further development will continue in collaboration with TRIUMF Computing Services (Joe Chuma).

At the 2003 Real Time Conference, held in June in Montreal, Pierre Amaudruz, in collaboration with Stefan Ritt (PSI), gave a short course on MIDAS followed by a short course on ROOT given by its main author Rene Brun (CERN). Discussions on how to structure a MIDAS/ROOT connection took place between the experts. Rene Brun came to TRIUMF after the conference to give a seminar on ROOT and for further discussions with the DAQ group.

The LADD project

The Laboratory for Advanced Detector Development (LADD) is a CFI funded venture between TRIUMF and the University of Montreal. It provides infrastructure to support radiation imaging research in fields such as high energy and nuclear physics, materials and astrophysical sciences, and medical imaging applications. The LADD infrastructure at TRIUMF supports the development of new types of imaging detectors and systems for γ-rays and charged particles. One of the necessary components for detector development is a data acquisition system.

During 2003, the DAQ group, in collaboration with the first users of LADD, designed, specified and procured four new DAQ systems. Each consists of a VME crate with VMIC processor and readout modules and some NIM crates and NIM modules. The systems will be rolled out in 2004 for the KOPIO chamber tests, the T2K Neutrino photo detector tests, the liquid xenon prototype tests and a general use station. Since the VMIC processors are diskless, a disk and file server system was also set up (ladd00).

DAQ systems

βNMR and βNQR at ISAC The second DAQ system used by the βNMR group to acquire data on the second leg of the ISAC-I low energy polarized beam line was renamed βNQR. Both systems are similar in nature.

Improvements made this year include the following. The DAQ software was simplified by combining the two experimental modes (integral type and time differential type). This makes the DAQ system simpler for the users, and very much easier to maintain. New features were added to the software, including two new experimental modes: a CAMP magnet scan and mode FAST (TD and I-type combined). Stopping the run automatically on error or after a requested number of cycles was also implemented. The EPICS and CAMP scans were made more reliable by adding code to allow them to reconnect and continue to scan if the connection to EPICS or CAMP is lost. Conversion from MIDAS format to the μSR group's MUD format while a run is in progress (rather than from a saved file) was implemented.

μSR systems

The TD-μSR system continued to work well, and the new Linux-based Integral μSR DAQ system was installed on all the μSR beam lines (M15, M20, M9B). This system proved successful and as a result all the μSR DAQ VAXes were promptly retired.

The search continued to find a suitable TDC front end module to support a MULTI type μSR system. In this case, the detector is segmented in 8 sections and the DAQ has to handle the equivalent of 8 parallel experiments. We have chosen to use one of the new deadtimeless TDCs on the market. A first attempt at using a VME module developed in Japan around the ATLAS AMT chip proved unsuccessful due to bottlenecks in the readout part of the module. On the second attempt, we used a CAEN TDC built around the CERN HPTDC chip. This TDC used with a VMIC/VME processor appears to be fast enough to support the MULTI detector.

Other experimental stations

One major new system was requested last year by the TIGRESS group to study their first prototype detector. This required special software development for control of a scanning table. With the help of Dave Morris and his JACQ package, the system can be used to automatically scan the detector response over the full area of the detector. This DAQ is also used as a prototype to develop the full TIGRESS DAQ.

The newly formed Canadian T2K Neutrino group occupied the former ATLAS clean room to start detector development studies. Two standard CAMAC DAQ test stations were deployed. One of the stations will be replaced by a VME LADD system in the near future. This group is using the MIROODAS package for on-line analysis.

A special version of the polarimeter DAQ was set up for the McGill group (Expt. 920). On the TWIST system, new devices were added to the slow control front end programs as well as fine tuning of the beam line magnets for better stability. New slow control device servers were added to the LTNO system. KOPIO and DRAGON continued to use the test systems in the detector facility.

Support for external MIDAS users is still ongoing.

Detector Facility

(R.S. Henderson, TRIUMF)

This year has been an active one for the detector facility.

The TWIST project (Expt. 614) has been operating very well. This experiment at TRIUMF is a sophisticated attempt to measure the Michel parameters to ten times the precision they are now known. The various subsystems of this experiment continue to function extremely well. The detection system consists of scintillators, and 19 detector modules containing a total of 44 high-precision drift chambers (DC) and 12 MWPC planes (PC). In December, one of the MWPC planes failed – a broken wire is suspected. The spectrometer has been opened and the spare PC module will replace the damaged one, no beam time will be lost. A great deal of data has been collected already and the TWIST group is now involved in a massive blind analysis of the data sets. In addition, they spent several months of this year performing detailed measurements of the incoming muon beam characteristics. The TWIST experiment has been reviewed as extremely successful so far and its high priority has been reconfirmed.

A low pressure time expansion chamber (TEC) has also been designed by R. Henderson and G. Sheffer, for use just upstream of the TWIST spectrometer. It will be used to measure the muon beam properties. R. Openshaw designed the low pressure gas system. It was built and successfully tested in the facility. The TEC has also been built and is now being bench tested (Fig. 195). The beam line upstream of the TWIST magnet has been redesigned for the TEC. The new elements, including the TEC vacuum box and its stand, have all been installed, aligned and vacuum tested. The TEC is expected to be installed in Expt. 614 early in the next running period. If successful, a spare TEC will be fabricated and tested. This will probably mark the completion of the facility participation in the TWIST experiment, except for maintenance and repair.

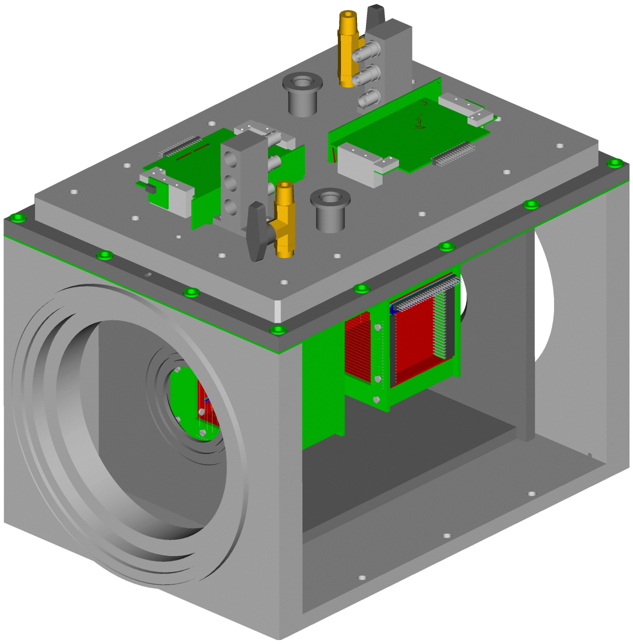

Fig. 195. A 3D rendering of the time expansion chamber (TEC) designed and built for the TWIST experiment (Expt. 614). The TEC is now undergoing bench tests and will soon be installed.

The scintillator shop continues to function as the heavily used machining centre for the facility. This year has seen a wide variety of scintillators fabricated for μSR, the $G\emptyset$ experiment (at TJNAF) and the 8π experiment (ISAC). The larger mill in the scintillator shop was previously refitted as a 4-axis NC mill for the TWIST project, and allows us to machine the complex curved scintillator pieces for $G\emptyset$. The $G\emptyset$ scintillator designs were significantly delayed by the $G\emptyset$ group. The first scintillator sector has been finished and we are waiting for the testing before producing the other seven sectors. More KOPIO prototype detectors continue to be fabricated in this shop.

A highly significant project was completed in the scintillator shop this year. This is the 8π vacuum/scintillator unit, which is the central part of the scintillating electron positron tagging array (SCEPTAR). This vacuum/scintillator unit, with the array of Compton suppressed HPGe detectors and the fast tape transport system, form the 8π γ-ray spectrometer. Many experiments have already been approved for this new spectrometer (see Fig. 196).

This 8π vacuum/scintillator unit consists of 20 complex shaped, tightly fitting scintillators/lightguides in two hemispherical vacuum/scintillator assemblies. These were designed by H. Coombes and S. Chan, then fabricated and assembled in the scintillator shop. Both hemispheres have now been installed and successfully tested in the 8π spectrometer.

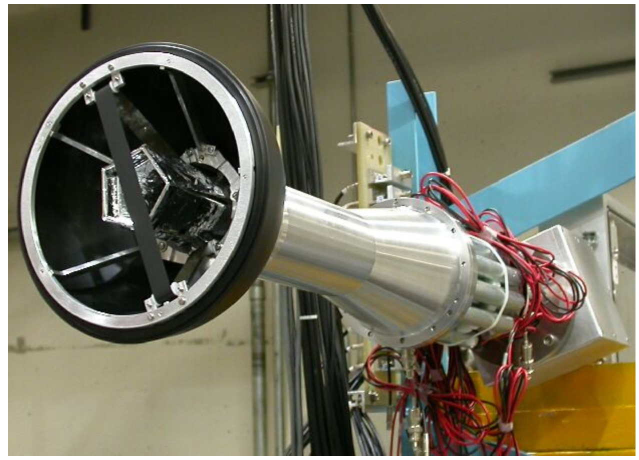

Fig. 196. Photograph of one half of the SCEPTAR vacuum/scintillator unit. The tape transport can be seen.

Design and prototyping have continued for the proposed KOPIO pre-radiator modules. KOPIO is awaiting approval by the US funding agencies. R. Henderson spent the majority of this year working in the KOPIO group. If approved, this project will be a very large detector project at TRIUMF, considerably larger and more complex than previous projects such as the ATLAS calorimeter fabrication, the BaBar drift chamber or the HERMES TRDs.

The present KOPIO design envisages having four quadrants of pre-radiator modules, each quadrant eight modules deep, for a total of thirty-two modules (plus two spares). Each of the modules would consist of two parts. The inner region (called the pre-radiator unit) is 2.15×2.15 m, and consists of eight drift chamber layers sandwiched between nine layers of extruded scintillator. The outer region (called the L-unit) would connect to, and support, the pre-radiator unit at the two orthogonal readout faces. Approximately fifty Shashlyk type calorimeter blocks would be mounted on these two edges of this L-unit, giving full calorimeter coverage in the experiment. Miniature coax cables will transport the 6,144 anode/cathode signals past the Shashlyk blocks to eight readout crates also mounted on the L-unit. In addition, both ends of approximately 1,800 WLS fibres will pass the Shashlyk blocks to over 300 PMTs (or APDs).

With each of the thirty-four pre-radiator modules $3.7 \times 3.7 \times 0.15$ m in size and weighing approximately 3 tons, the scale of the project becomes apparent. A great deal of development and testing is required. The detector facility is already contributing much of its manpower to this project in areas of design, mechanical mockup, thermal expansion testing, wirechamber structural tests and scintillator painting tests. A full size module is scheduled for completion in mid-2005. If NSERC and TRIUMF management give final

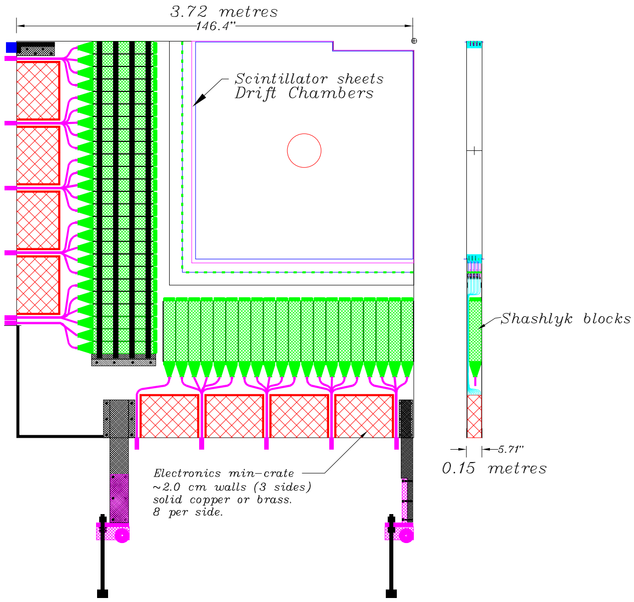

Fig. 197. Present design of KOPIO pre-radiator module.

approval, a full module production facility will also need to be implemented by mid-2005 (see Fig. 197).

CFI funding for LADD has been approved and spending has started. This money will be used to boost the detector development infrastructure at TRIUMF. LADD will take considerable time and effort to set up, and is planned to give TRIUMF a world class facility for continuing development of detector technologies, not just for physics experiments, but potentially for a wide range of R&D projects including a variety of medical detectors.

Experimental Support

(C. Ballard, TRIUMF)

The Experimental Support group provided technical assistance to experimenters and was responsible in part for the installation, alignment and maintenance of beam line elements and secondary channels. The Beam Lines group now has a permanent technical area complete with machine shop and welding room in the ISAC-II experimental hall. This allows better access for experimenters in search of technical assistance. For ISAC-I and ISAC-II, the Beam Lines group has provided technical support for the 8π detector as well as development for GPS, TITAN and TIGRESS. The group provided the layout of the "S" bend and helped plan the future installation of the transfer beam line scheduled for 2004. The Alignment group continued to provide precision alignment for TWIST, DRAGON, TUDA, Remote Handling and the RF group.

Routine preventative maintenance was performed in the vault, tunnel and other limited-access areas including the TNF and an improved Neutron Irradiation Facility. Repairs were made to filters, magnets, valves, beam blockers and interlocks. Water and vacuum leaks were also investigated and fixed.

Beginning January, 2003, efforts were focused on the replacement of the final triplet for beam line 1A. The magnet frame assembly, insulators and cooling system upgrades were among the group's contributions on this project.

Other projects in the meson hall included the continuation of the overhaul of the M9B solenoid and maintenance on the helium compressor and liquefier. New turbines were installed in the cold box as well as a new charcoal filter in the helium compressor room.

Improvements were made to the M15 and M20 separators. A new window assembly was installed in M20 that allows the thin window (isolating the separator vacuum) to be changed more efficiently with less experiment downtime.

The CERN Collaboration continued and involved three technicians on the assembly and testing of the PFN tanks destined for the CERN LHC. The same technicians also worked on the MULAN Kicker Magnet Project at PSI.

GEANT4

(P. Gumplinger, TRIUMF)

Modern particle and nuclear physics experiments require large-scale, accurate and comprehensive simulations of the particle detectors used in these experiments. The same is true for other disciplines, such as space science, nuclear medicine, accelerator design and radiation physics. In response to this demand, a new object-oriented toolkit, GEANT4, has been developed for the simulation of particles passing through matter. It provides a comprehensive, diverse, yet cohesive set of software components which can be employed in a variety of settings, from small standalone applications to large scale detector simulations for experiments at the LHC and other facilities. At the heart of this software system is an abundant set of physics models, including electromagnetic, hadronic and optical processes, over a wide energy range starting, in some cases, from 250 eV and extending in others to the TeV energy range.

GEANT4 was designed and is being developed by an international collaboration, formed by individuals from a number of cooperating institutes, HEP experiments, and universities. It builds on the accumulated experience in Monte Carlo simulations of many physicists and software engineers around the world. The origins of the collaboration go back to two independent studies done at CERN and KEK in 1993, which sought to investigate how modern computing techniques could be applied to improve what was offered by the existing GEANT3 program. These two activities merged in

1996 as CERN R&D project RD44, looking for additional collaborators with an interest in the LHC experimental program. TRIUMF was approached and joined this project almost immediately, in part because a number of its employees were experts in the field and were able to contribute immediately. This R&D phase was completed in late 1998 with the delivery of the first production release. The ambitious project, in terms of size and scope of code and the number of people involved, has demonstrated that rigorous software engineering practices and object-oriented methods can be profitably applied to the production of a coherent and maintainable software product, even with the fast-changing and open-ended requirements presented by physics research. Subsequently, the present collaboration was established to continue the development and refinement of the toolkit, and to provide ongoing maintenance and user support.

Although not a large contingent, the TRIUMF group has always been very active in some of the core activities of the collaboration and is represented in both the Technical Steering Board and in the Collaboration Board. The group had a strong voice in the discussion and design of the overall architecture of the program. One of our initial efforts was to port the hadron physics model GHEISHA from FORTRAN to C++, and its redesign to better match the object-oriented paradigm. Similar work was later done for part of the HETC (high energy transport code), originally developed at the Oak Ridge National Laboratory. We also implemented the hadronics portions of the test, validation and example suites that are part of the G4 distribution. TRIUMF collaborators have been active in many areas of user support, documentation, testing and quality assurance and in particular in the adaptation of associated tools from the Open-Source community: LXR, a www-based source code browser with cross-reference and full-text indexing; ViewCVS, a visual interface to a source-code and version management tool; and Tinderbox, an automated multi-platform system testing and reporting tool.

GEANT4 is an ideal framework for modelling the optics of scintillation and Čerenkov detectors and their associated light guides. This is founded in the toolkit's unique capability of commencing the simulation with the propagation of a charged particle and completing it with the detection of the ensuing optical photons on photo sensitive areas, all within the same event loop. This functionality of GEANT4 was developed exclusively by one developer at TRIUMF and is now employed world-wide in experimental simulations as diverse as ALICE, ANTARES, AMANDA, Borexino, Icarus, LHCb, HARP, KOPIO, the Pierre Auger Observatory, and the GATE (Imaging in Nuclear Medicine) Collaboration. This functionality is also exploited as part of the investigation to understand the optical properties of extruded plastic scintillator tiles for KOPIO and for the near detector of the long baseline neutrino experiment at J-PARC/SuperK. We are constantly responding to inquiries posted on the G4 Users Forum regarding the optical photon tracking. Questions and feedback arrive from people working in medical PET research, cosmic shower research, neutrino detectors, HEP experiments and also from cooperate research laboratories. We have prepared and presented invited tutorials at international user workshops held at SLAC, CERN, and most recently in early 2003, at the European Space Agency in the Netherlands.

The major players in the current collaboration are the international organizations: CERN and ESA/ESTEC; the national laboratories: INFN (Italy), IN2P3 (France), Helsinki Institut of Physics (Finland), Karolinska Institutet (Sweden), KEK (Japan), PPARC (UK), SLAC (USA) and TRIUMF (Canada); with strong support from these HEP experiments: BaBar (SLAC), ATLAS, CMS, HARP, LHCb (CERN). Additional expertise comes from 14 European, 4 Japanese, and 5 North American universities and 4 Russian institutes, for a total of about 150 collaborators. The TRIUMF participation in GEANT4 has fluctuated over the years, and is presently four researchers and software engineers. The toolkit is now in public release version 6.1 and is available for a variety of operating systems.

In summary, the GEANT4 project has brought a new level of computing expertise to our laboratory, one that has already filtered into the simulation efforts of TWIST, TIGRESS, T2K, LADD, KOPIO and plans for the BIG DRAGON.

GEANT4 collaborators: P. Gumplinger, F.W. Jones, C.J. Kost, M. Losty (TRIUMF).

Scientific Services

(M. Comyn, TRIUMF)

The Scientific Services group encompasses the Publications Office, Library, Information Office, and Conferences. Its activities during 2003 included: producing the 2002 Annual Report, the TRIUMF Review 1998–2003, conference proceedings, and the TRIUMF preprints; maintaining the Library; coordinating TRIUMF tours and assisting with the production of public relations materials; and supporting fifteen past, present and future conferences and workshops.

Publications Office

The TRIUMF Annual Report Scientific Activities has been truly electronic since 1998. Electronic files have been used throughout, from initial contributor submission, through editing, transmission to the printer, and subsequent direct printing on a Xerox Docutech system. The same files are used for the WWW versions of the report which are available at http://www.triumf.ca/annrep in both Portable Document Format and PostScript file formats. Unlike the monochrome paper version, the electronic versions allow those figures which were submitted in colour to be both viewed and printed in colour. The WWW version of the 2002 report was available to readers three weeks before the printed version. It contained a record 322 pages and 259 figures. The Annual Report mailing list has been reduced and the trend is expected to continue as people become more accustomed to accessing the information over the WWW. This will result in less copies having to be printed, with subsequent cost savings.

In an attempt to aid and encourage authors to submit contributions in the correct format, the instructions available on the WWW were refined. The LaTeX 2_ε skeleton file was changed slightly and the instructions document which all authors should consult was reworded to include more explicit information on the correct production of Encapsulated PostScript files for the figures and the submission of original file formats.

Illegal code embedded in Encapsulated PostScript files continues to be a major problem in electronic publishing. Some software packages, such as the TRIUMF graphics routines, fully conform to the Encapsulated PostScript specifications, whereas many do not. In order to alert authors to problems encountered with files they submitted the previous year, and in an attempt to prevent similar problems recurring, a post-mortem of the 259 figures in the 2002 Annual Report was produced. This analysis and explanation of solutions is viewed as an ongoing project which will evolve as new procedures are devised and software packages become available for editing bad PostScript code. Superior TRIUMF scientific publications should result. See http://www.triumf.ca/annrep/figures.html for details.

TRIUMF preprints are now only produced electronically, and immediately posted on the WWW at http://www.triumf.ca/publications/home.html to allow rapid dissemination of the publications. This has replaced the traditional distribution of paper copies by mail, resulting in significant savings of both cost and labour.

The year began on three fronts with the kickoff for the TRIUMF Annual Report Scientific Activities 2002 submissions, the publication in March of a conclusions and abstracts booklet for the Italian-Canadian Interface for the Development and Exploitation of Stable and Exotic Ion Beams, which was held at TRIUMF October 16–20, 2002, and the final work associated with the publication of the refereed proceedings of the 14$^{\text{th}}$ International Conference on Electromagnetic Isotope Separators and Techniques Related to Their Applications (EMIS-14), which was held in Victoria May 6–10, 2002. Extensive communications with Elsevier Science B.V. resulted in the publication of a special 846 page issue of Nuclear Instruments and Methods in Physics Research Section B, Beam Interactions with Materials and Atoms, Volume 204. It appeared in print in May and on the Web up to five months earlier.

In February work began on producing the TRIUMF Review 1998–2003, a companion document to the TRIUMF Five Year Plan 2005–2010. The scope of the document grew with time and its preparation became the main focus of the Publications Office for eight months. Initial work involved producing and approving templates in LaTeX 2_ε and MS Word for the submission of chapters and CVs. Chapters produced in MS Word were converted to LaTeX 2_ε to produce the final 232 page document which contained six chapters and two appendices. The task of producing Appendix A, Publications 1998–2003, was particularly onerous as it was derived from a compilation of the appendices in five annual reports, listings of life sciences and μSR publications, additional material reported in CVs, and other sources. The 82 CVs formed a separate document. A secure Web site was maintained for use by the authors and the peer review committee.

Web site and other support was provided for the Summer Nuclear Institute at TRIUMF (SNIT 2003), held July 21–August 1.

Work began on preparations for the Eighth International Symposium on Nuclei in the Cosmos (NIC8), to be held in Vancouver, July 19–23, 2004. Quotations were obtained for the publication of the proceedings, and template files were prepared for producing the abstracts. Many procedures to be used for producing the abstracts booklet and the proceedings will be based on those developed for the EMIS-14 conference.

Due to the workload this year, activities on the Joint Accelerator Conference Website (JACoW) committee were limited to assisting with the electronic publication of the proceedings of the Particle Accelerator Conference (PAC 2003), held in Portland, Oregon, May 12–16.

Library

The Library budget was increased in 2003 to compensate for rising journal subscription costs and unfavourable exchange rates for 2004 renewals, thereby maintaining the list of journals which have been acquired since the last cutbacks in 1998. However, the journal subscription budget and electronic access alternatives are constantly under review. The Library continues to rely on donations for most of its book acquisitions. The Library operates on a self-serve basis and manages with minimal support for day-to-day operations.

Information Office

The Information Office coordinated a record number of 261 tours for 2,019 people during 2003. The general public tours were conducted by a summer student during the June to August period when tours were offered twice a day. 255 people took a total of 65 tours during the three month period. Throughout the remainder of the year for the twice weekly general public tours, and for the many pre-arranged tours given to high school students and others, a small, dedicated group of TRIUMF staff acted as tour guides.

Table XXII shows the number of people taking tours, the number of tours, and the number of tour guides required to conduct them (groups of more than 15 require multiple tour guides) for each of the years 1999–2003 plus the totals. A steady increase can be observed. The numbers are broken down into four categories:

- General public: tours provided for members of the general public twice a week September–May, and twice a day June–August on a drop-in basis.
- Science: pre-arranged tours conducted for university/college physics, chemistry or science students with a specific interest in TRIUMF, scientists at TRIUMF for a conference or workshop, and scientific groups.
- Students: pre-arranged tours conducted for elementary and high school students and university/college non-science students.
- VIP: Specific tours, often conducted by senior management personnel, arranged for VIPs, review/advisory committee members, and the media.

The summer student also assisted with the production of presentation materials, with the Summer Nuclear Institute at TRIUMF, and as the coordinator of many student activities throughout the summer.

The TRIUMF Welcome Page, which is accessible directly at http://www.triumf.ca/welcome or via the TRIUMF WWW Home Page, continues to receive well over 5,000 visits each year. The series of WWW pages were developed by two co-op students and are intended to provide an overview of TRIUMF in a format understandable to the general public. The Information Office responds to any questions posed by visitors to the site. Some limited maintenance of the pages was performed during the year, but efforts began to totally overhaul those parts of the TRIUMF Web site directed at the general public.

Table XXII. Breakdown of TRIUMF tour numbers for the period 1999–2003.

Category	1999	2000	2001	2002	2003
General Public					
# people	350	368	421	499	482
# tours	96	107	110	131	126
# tour guides	96	107	111	134	126
Science					
# people	384	294	383	592	651
# tours	18	20	30	23	34
# tour guides	33	26	43	57	59
Students					
# people	794	612	839	894	626
# tours	46	40	30	40	38
# tour guides	70	53	60	70	50
VIP					
# people	145	171	258	193	260
# tours	37	37	59	53	63
# tour guides	38	40	65	55	71
Total					
# people	1,673	1,445	1,901	2,178	2,019
# tours	197	204	229	247	261
# tour guides	237	226	279	316	306

Various TRIUMF images found on the WWW pages continue to be in demand for use in text books and on other Web pages.

Support was provided to the TRIUMF Users' Group throughout the year by the TUEC Liaison Officer.

Conferences

Although TRIUMF did not host an international conference in 2003, it was still a busy year for workshops and meetings. Support was provided for seven workshops and meetings, along with preparations for six conferences and workshops in 2004 and beyond. Registration databases were created and managed for most of the workshops.

In addition, support was provided in the electronic proceedings office of the Particle Accelerator Conference (PAC 2003), held in Portland, Oregon, May 12–16.

TRIUMF hosted or supported the following conferences and workshops in 2003:

- Workshop on Functional Imaging in Basic Biomedical Research Through microPET Imaging, UBC, June 26–27 (57 delegates).
- Summer Nuclear Institute at TRIUMF (SNIT 2003), TRIUMF, July 21–August 1 (39 delegates plus 10 lecturers).
- GEANT4 2003 Workshop, TRIUMF, September 2–6 (53 delegates).

- International Union of Pure and Applied Physics (IUPAP) Meeting, TRIUMF, October 10–11 (24 delegates).
- HEPiX-HEPNT Autumn 2003 Meeting, TRIUMF, October 20–24 (76 delegates).
- TRIUMF Users' Group Annual General Meeting, TRIUMF, December 10 (55 delegates).
- EMMA Workshop, TRIUMF, December 11–12 (30 delegates).

In addition, preparations were made for the following future conferences and workshops.

- Fixed Field Alternating Gradient Workshop (FFAG 2004), TRIUMF, April 15–21, 2004.
- TRIUMF Summer Institute 2004, TRIUMF, July 5–16, 2004.
- Eighth International Symposium on Nuclei in the Cosmos (NIC8), Vancouver, July 19–23, 2004.
- Fifth International Symposium on Radiohalogens (5ISR), Whistler, September 11–15, 2004.
- 2005 CAP Congress, UBC, June 5–9, 2005.
- Particle Accelerator Conference (PAC 2009), Vancouver, 2009.

The DRAGON Facility

(D. Hutcheon, TRIUMF)

Introduction

DRAGON improvements included replacement of magnet power supplies, improved beam diagnostics and tuning methods, and development of a Web site containing information on how to use the facility. In addition there were developments specific to new experiments using stable beams: separator acceptance studies and a drive mechanism for solid targets.

General hardware improvements

Six of the separator magnets initially were given power supplies that were no longer needed on meson channels at TRIUMF. These power supplies proved to be unreliable, due to frequent water leaks developing in transistor pass-banks. During the winter shutdown they were replaced by new power supplies.

Addition of a dedicated CCD camera provided a valuable tool to aid in beam tuning. Light produced by passage of ion beams through hydrogen or helium gas targets could be detected in the camera which viewed the target from several metres downstream, through a magnet alignment port. This provided a non-destructive way to measure the beam position at the target, both for initial tuning and during production runs (Fig. 198).

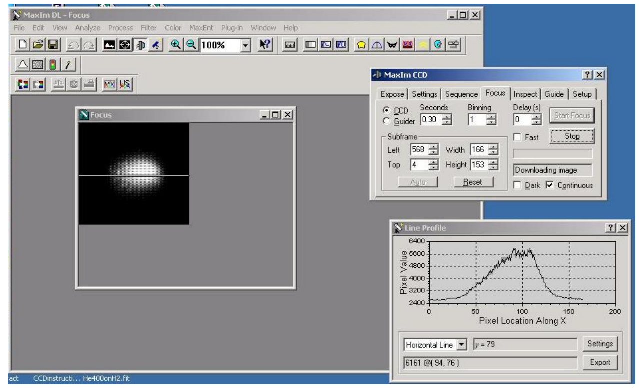

Fig. 198. CCD camera image of light produced by passage of a ^{12}C beam through a helium gas target. The beamspot is approximately 6 mm across at the base.

Under normal operation, the dry pump which backed the separator turbo pumps ran continuously, even though the amount of gas exhausted by the turbos was very small. To increase the time between expensive scheduled factory maintenance of the dry pump, a buffer tank was added to the turbo backing line. The vacuum control PLC was modified so that normally the backing dry pump was off, and was turned on only long enough to pump out the 200 l buffer tank when its pressure rose to 0.5 torr. Typically the backing pump would have to run for 2–3 min twice per day.

Information for users

Thanks to the efforts of several undergraduate students, a DRAGON Web site was made available to users. It has become the "instruction manual" of the facility, with detailed information about the use of hardware, data acquisition programs, beam tuning procedure, pre-run checklists, and links to useful ISAC Operations data. Its URL is http://www.triumf.ca/dragon.

Development for Expt. 952 (^{12}C(α,γ)^{16}O)

This experiment had two features not seen in earlier proton capture experiments: the mass of beam ions was only 75% of the mass of the capture product ions; high γ-ray energies could result in product cone angles greater than 20 mrad.

The 3/4 ratio of beam mass to recoil product mass resulted in a separation by 12 cm at the mass selection slits, instead of the 2 cm more typical of proton capture reactions. This meant that it was possible to install an additional, fixed-position Faraday cup which could collect beam ions without interference from the slits. This cup, called FCM2, was the primary monitor of beam intensity for the experiment.

The alpha capture data revealed that the target/separator system acceptance was not large enough to transmit ions of ≈20 mrad cone angle. Because good

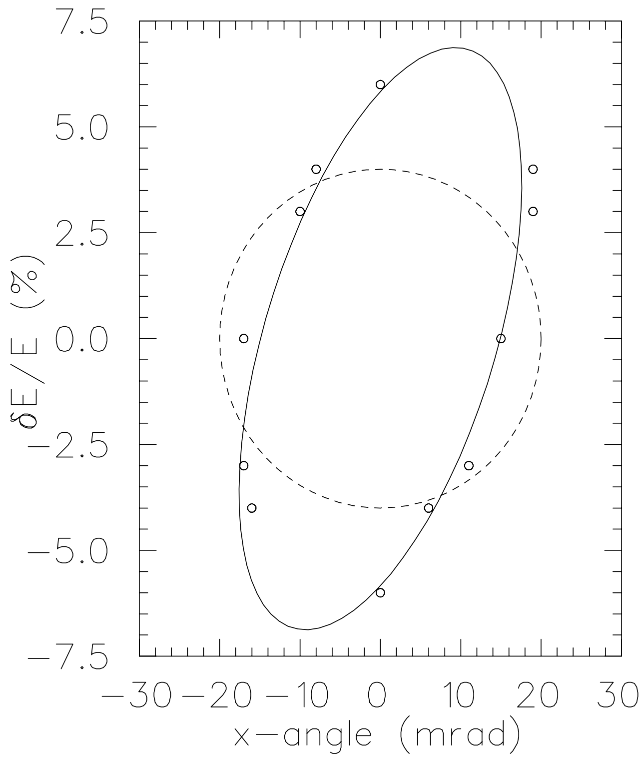

Fig. 199. Separator acceptance in horizontal angle and fractional change in ion energy, as measured using the wobbler magnet (open circles). The dashed circle indicates the angle-energy correlation of capture products having 20 mrad maximum emission angle. The solid line is an ellipse to guide the eye through the measured points.

transmission at 20 mrad and larger was important for Expt. 952, an extensive program was undertaken to understand where acceptance was being limited and how to improve it. One set of measurements consisted of replacing the gas target by a collimator and deflection magnet (the "wobbler") and deflecting an ion beam to map out the limits of transmission of a nearly "pencil" beam. Figure 199 shows one result from this study, the acceptance correlation between angle and energy.

The pumping tubes between stages of the differentially-pumped windowless gas target had been designed for a recoil cone angle of 20 mrad. The downstream tubes were replaced by a new set, allowing transmission within a 25 mrad cone half-angle. With this change, plus a slight tune change suggested by the wobbler work, the alpha capture product ions showed a more symmetric transmission of higher-energy vs. lower-energy ions. However, there was still a clear loss of particles at the largest angles (at the middle of the energy distribution).

Extensive ion-optics studies were done, both with GIOS and a GEANT-based raytracing simulation, to try to understand where ions were being lost in the separator. The GIOS work suggested that a modification of the standard separator tune might give better transmission, the trade-off being a possible reduction in the beam suppression factor. Measurements to validate the new tune were inconclusive due to unexpected fluctuations in resonant capture yields, possibly arising from beam energy instability during the course of measurements.

Several possible solutions have been considered, such as moving the gas target closer to the separator, adding quads between the target and separator, or replacing some existing quads with larger ones. Because of the cost and/or disruption to the radioactive beam program, there is no immediate plan to implement any of these solutions, until the cause of losses is better understood.

Solid target drive for Expt. 947 (^{12}C(^{12}C,γ)^{24}Mg)

For this experiment it was desired to have thin foils of carbon, enriched in ^{12}C or ^{13}C instead of the extended gas target used in radiative capture experiments. Furthermore, γ-ray detection by the BGO array was not to be obscured by the target-mounting mechanism. The resulting design was a compact, chain-driven set of nine targets, with a stepping motor to permit remote changing of targets via EPICS (Fig. 200). The

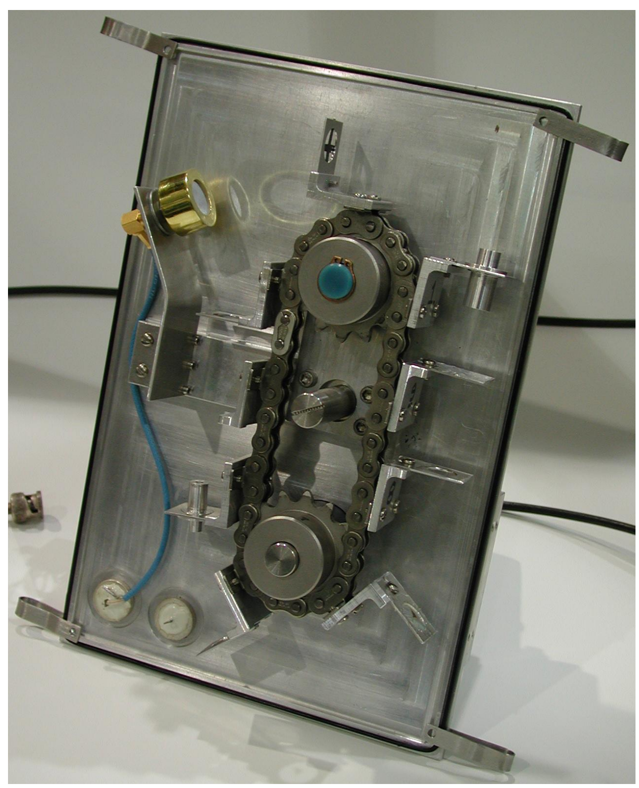

Fig. 200. Solid target changer mechanism. The mounting plate is a direct replacement for the gas target plate. The lower sprocket is driven by a stepping motor located outside the vacuum. A Si detector monitors beam intensity and target integrity by detection of products from elastic scattering.

system is mounted on a side-plate which mates to the standard target vacuum box in the same way as the gas target support plate does, making the change from gas target to solid targets relatively quick and easy.

Unlike gas targets of hydrogen or helium, the solid carbon foils did not emit enough light to be detected in the CCD camera when bombarded by heavy ion beams of a few nA intensity. It was discovered that microscope slide glass would give off sufficient light to be used for beam tuning at nA beam currents. At beam intensities of 50 nA or more the carbon foils did give off light at the beam position, probably incandescence due to heating by the beam.

8π Spectrometer
(G.C. Ball, TRIUMF)

During the past year the major accomplishment was the fabrication, installation and commissioning of the scintillating electron positron tagging array (SCEPTAR) that is required for β-γ coincidence studies with the 8π spectrometer. SCEPTAR was designed to provide high β detection efficiency, a low energy threshold, minimum sensitivity to γ-rays, high count rate capability and a detector granularity comparable to the HPGe array. A schematic view of SCEPTAR is shown in Fig. 201. It consists of twenty 1.5 mm thick BC404 plastic scintillator detectors arranged in 4 pentagonal rings centred at approximately the same angles with respect to the beam as the four rings of HPGe detectors. The detectors centred near 80 and 110° are rectangular in shape while those centred near 37 and 143° are trapezoidal. Light produced in the scintillators is collected from one edge by segmented 1.5 mm thick UVT acrylic light guides which are contoured and subsequently glued to 1 cm diameter UVT acrylic rods which transport the light to 13 mm diameter phototubes located outside the vacuum chamber. The SCEPTAR detector array is mounted inside a spherical 8 cm

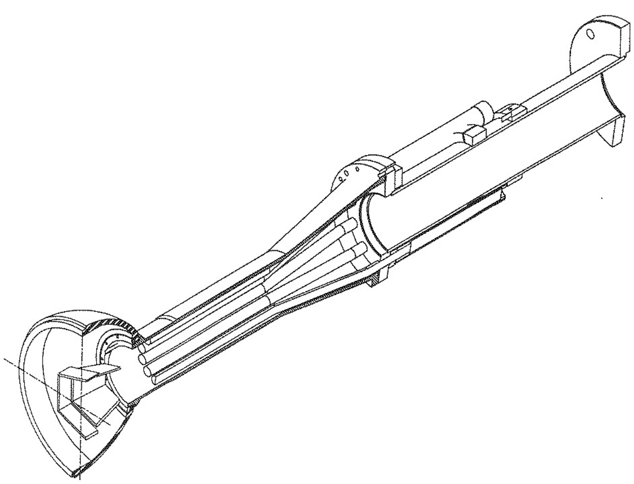

Fig. 201. Schematic view of one half of SCEPTAR.

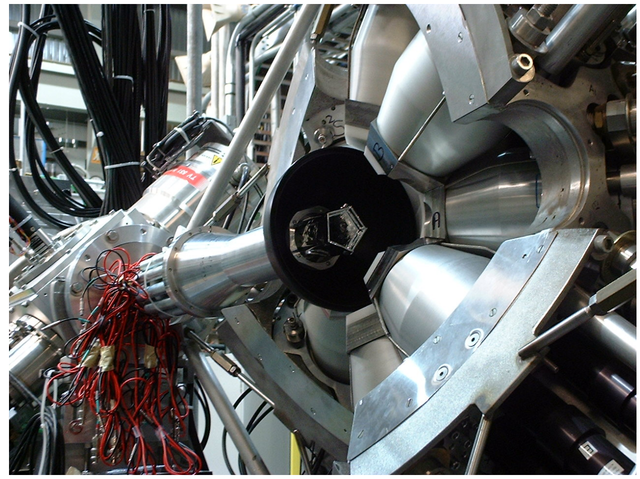

Fig. 202. Upstream view of SCEPTAR.

radius, 4 mm thick Delrin vacuum chamber divided into two hemispheres for easy access. The upstream half of SCEPTAR installed on the 8π beam line is shown in Fig. 202. An integral part of SCEPTAR is a moving tape collector system designed and built by E. Zganjar (LSU) to remove long-lived daughter activities from the focus of the array. The low energy beams from ISAC are focused at the centre of the SCEPTAR chamber and deposited onto a 12.7 mm wide, $\sim$50 μm thick tape that is fed from a large aluminum storage chamber connected to the vacuum chamber containing the downstream half of SCEPTAR. A 5 cm thick lead shielding wall located immediately in front of the tape storage chamber shields the HPGe detectors from long lived activity remaining on the tape. The entire assembly is mounted on a stand that is moveable via linear bearings. The downstream view of SCEPTAR and the moving tape collector system is shown in Fig. 203.

The upgraded data acquisition system for the 8π spectrometer described previously (TRIUMF 2002

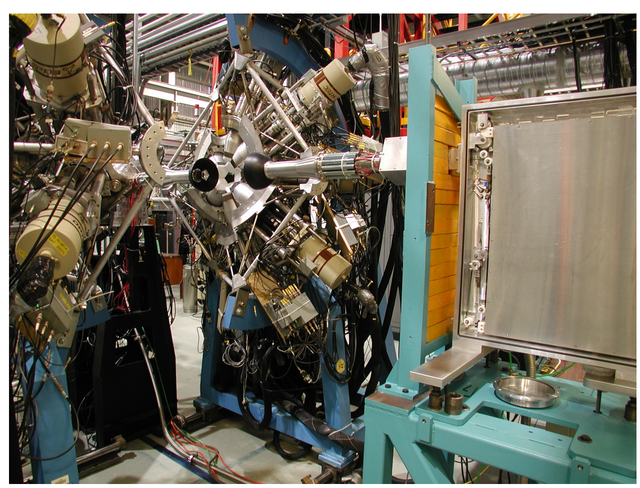

Fig. 203. Downstream view of SCEPTAR and the moving tape collector system.

Annual Report) was extended to include a separate FERA readout bus and VME triple port memory module for the SCEPTAR data stream. A second latching scaler was used to give an absolute time stamp required to correlate β-γ coincidence events. LeCroy 4300 FERA QDCs were used to encode the β energies and LeCroy multihit TDCs were used for the β times. The system also provided a number of possible hardware triggers to select the data that was readout. These included: γ, γ-γ, β, β-γ, and prescaled βs or γs. A VME 32 input multichannel scaler module was also used to record the singles betas detected in each of the 20 SCEPTAR detectors.

Initial tests of the performance of SCEPTAR were carried out using a beam of $\sim 10^5$ ^{26}Na. The energy signals obtained from the individual SCEPTAR detectors for high energy betas that deposit about 400 keV are shown in Fig. 204. The low energy signals observed in the energy spectra for the rectangular scintillators result from high energy betas that pass through a trapezoidal scintillator and then produce Čerenkov light in the light guide of the adjacent rectangular detector, which passes behind the trapezoid. Data were also obtained from a ^{28}Mg source prepared by depositing a beam of ^{28}Na from ISAC onto the collector tape for about 12 hours. This source is ideal for measuring the efficiency of SCEPTAR as a function of beta end point energy. In particular, the decay scheme is well known and contains transitions with Q_β values that range from 0.2 to 2.9 MeV, all decaying to excited states in ^{28}Al/^{28}Si that subsequently gamma decay. The analysis of these data is in progress and will be compared to Monte Carlo predictions.

The first two 8π experiments to use SCEPTAR and the moving tape collector system were carried out in

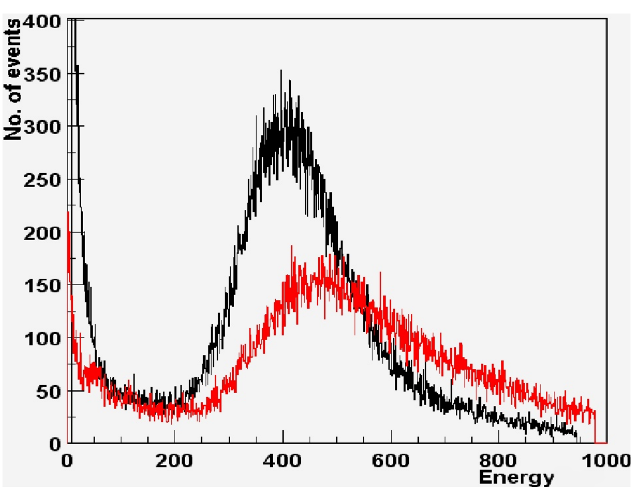

Fig. 204. Representative energy spectra obtained with SCEPTAR for high-energy betas from the decay of ^{26}Na. The rectangular detector is shown in black (upper curve), the trapezoidal detector in red (lower curve).

August–October. One of these (Expt. 921) was the search for new high-K isomers in the mass 170–180 region. A particular feature of this experiment was the detection of low energy $\sim$90 keV conversion electrons with SCEPTAR in coincidence with γ-rays from the decay of the well-known 8^-, 4s isomeric state in ^{178}Hf populated in the beta decay of ^{178}Lu. In the second experiment (Expt. 955) designed to investigate the shell structure of light neutron rich nuclei, the beta decay of ^{32}Na was studied using a beam of only 1–2 ion/s. This experiment demonstrated that SCEPTAR, in combination with the 8π spectrometer, is a powerful tool for studying exotic short-lived (<100 ms) nuclei produced at very low intensities. Both of these experiments are reported in more detail elsewhere in this Annual Report.

There are currently ten approved ISAC experiments that will use the 8π spectrometer (Expts. 823, 909, 921, 929, 954, 955, 957, 961, 984 and 988) including two which were approved by the TRIUMF EEC in December, 2003. The most recent proposals require the addition of a 10 element BaF_2 array and associated fast timing electronics that will allow the lifetime of γ-decaying states to be measured for states with lifetimes as low as 10 ps. For standard 8π spectroscopy experiments the time difference between the β particles detected in the plastic scintillators of SCEPTAR and the γ-ray detected in a BaF_2 detector will be used to measure lifetimes down to the sub-100 ps range. For shorter lifetimes down to 10 ps the time signal from the SCEPTAR array will be be replaced with that from a single fast-plastic scintillator mounted immediately behind the beam spot of the moving tape collector. Tests using a ^{26}Na beam will be carried out in 2004 to measure the time response of SCEPTAR and optimize the design of the BaF_2 detectors. This development project is being led by Paul Garrett from LLNL.

Finally, during the past year a total of 40 collaborators from 14 institutions actively participated in the development and/or use of the 8π spectrometer, including: 7 undergraduate students, 6 graduate students and 5 post-doctoral fellows.

TIGRESS

(G. Hackman, TRIUMF)

To take full advantage of the physics opportunities presented by ISAC-II beams, a state-of-the-art γ-ray detector array with high efficiency and high resolution is needed. In 2003 the TIGRESS (TRIUMF-ISAC gamma-ray escape suppressed spectrometer) team continued towards its goal of building the detector in stages for early implementation in 2005 and full implementation in 2009. Highlights of the year's progress include: 1) successful competition and release of funds for a Natural Sciences and Engineering Research Council (NSERC) RTI-3 Major Installation Grant; 2) testing of the HPGe prototype detector; 3) development of signal simulation codes; 4) receipt and initial testing of the BGO suppressors; 5) design of a single-unit detector stand; 6) fabrication and testing of a single-channel waveform capture board upon which the TIG-9 and TIG-10 DSP modules will be based.

1) NSERC funding: The TIGRESS RTI-3 proposal was reviewed first by a Technical Site Visit committee in January, the NSERC grant selection committee in February, and a prototype HPGe performance review (see Item 2) in July. Following the last review, funds were formally released for 12 units, amounting to $8.03 M over six years. In 2003, an RTI-2 proposal was submitted by A.A. Chen for a silicon array for the first two EEC-approved TIGRESS-ISAC-II experiments on ^{58}Zn (Chen) and neutron-rich Ca isotopes (Austin).

2) HPGe prototype testing: Tests on the prototype HPGe [G. Hackman, 2002 TRIUMF Annual Report, p. 165] were performed in 2003. Energy resolutions of the readouts from all detectors and sub-units met specifications, and the total efficiency (>36% relative to standard on each crystal), peak-to-total, and total efficiency with add-back of the clover (215%) also met expectations.

Since sub-segment first-interaction location by pulse-shape analysis is a major component of TIGRESS's performance in ISAC-II experiments, a number of studies investigated the position sensitivity of the detector. These measurements used a "scanning table" (Figs. 205 and 206) to move a 0.5 mCi ^{137}Cs source held in a Densalloy 1.5 mm bore collimation vessel with a 1.5 mm bore in a plane perpendicular to the detector unit. In the "singles" scan, the source was moved on a grid with 3 mm $x-y$ spacing and all γ-ray events were recorded. The total yield of 662 keV photopeak (full-

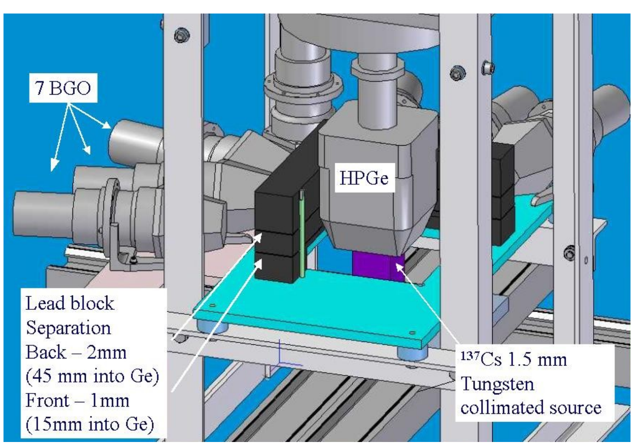

Fig. 205. Schematic rendering of the prototype HPGe scanning set-up.

Fig. 206. Photograph of the HPGe scanning set-up being assembled by TRIUMF undergraduate scholarship recipient Nick Cowan.

absorption in the clover unit) (Fig. 207) revealed the size of the inactive volume associated with the centre-contact bore and implantation. From these plots, the diameters of these dead volumes were deduced to be 11 to 13 mm, varying from crystal to crystal; this volume was largest on the crystals with the lowest

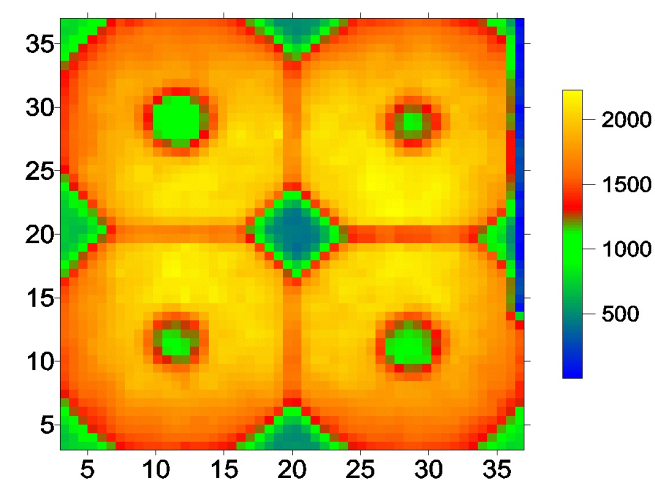

Fig. 207. Histogram of photopeak events as a function of (x, y) position of incident collimated 662 keV source. Horizontal and vertical axis labels identify discrete position number on a 3 mm square grid.

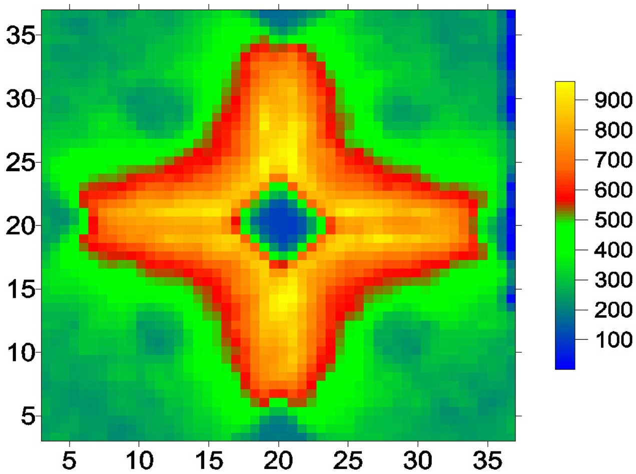

Fig. 208. As in Fig. 207, but selecting events with energy deposition in two or more crystals.

efficiency. By selecting those events where the full energy was absorbed in at least two or more crystals (Fig. 208), one observes that the "add-back" increase in total efficiency for a clover unit for 662 keV γ-rays comes dominantly from a narrow volume $\sim$1.5 cm deep along adjacent crystal surfaces.

The "coincidence" scan was used to test the maximum achievable position sensitivity. Events were selected where the 662 keV incident γ-ray scattered out of the HPGe at a right angle, through planar Pb collimators, and into scintillation detectors, with energy depositions in the HPGe and BGO consistent with a 90° Compton scattering. These conditions localized the events to a volume approximately $\sim$2 mm in each direction. Figure 209 shows a subset of the data from the

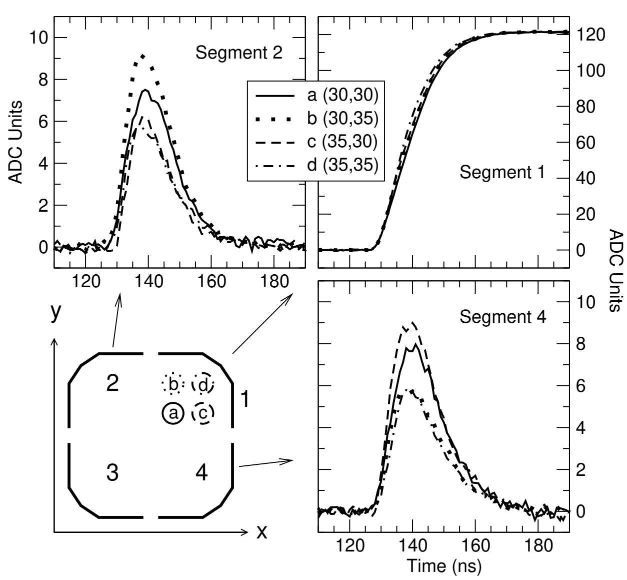

Fig. 209. Sample wave forms for select (x, y) positions collected in the coincidence scan measurement at a depth of z = 15 mm from the front of the crystal, with a sketch showing the relative positions of the sample positions and outer-contact segments for reference.

coincidence scan in the front segments of the detector. Following the definition of sensitivity proposed by Vetter *et al.* [Nucl. Instrum. Methods Phys. Res. **A452**, 223 (2000)], captured waveforms for a set of events at a given collimator position were averaged and the differences in waveforms from pairs of positions were compared with the baseline noise. In this analysis it was shown that the RMS position sensitivity is <1 mm, or $\sim$2 mm FWHM. This is well under the 5 mm FWHM that was used in modelling the performance of the array.

Manuscripts detailing the singles (H. Scraggs *et al.*) and coincidence (C.E. Svensson *et al.*) scans are being drafted.

3) Signal simulation codes: One strategy for analyzing the waveform data is to compare those waveforms captured in the experiment with a database of average waveforms from the scanning experiments, and perform a least-squares minimization to determine the interaction locations and energy depositions. However, such a strategy requires detailed knowledge of the waveforms throughout the entire detector. The coincidence scanning process itself is lengthy (1 point per day) and cannot access the innermost quarter of each crystal due to absorption of the scattered gamma. An alternative approach is to develop a reliable and verifiable means of calculating the waveforms generated over a fine and exhaustive grid. A first attempt at these calculations provided qualitatively correct overall waveform behaviour but did not achieve satisfactory agreement. Limitations were identified as including the precision of the RELAX3D electrostatics calculations, incomplete treatment of the drift velocities, and no considerations for crosstalk. These issues will all be addressed in 2004.

4) Receipt and testing of suppressor shields: One unit of BGO and CsI suppressor shields specified previously (Hackman, 2002) was received and tested for resolution and positional stability. A set of "first generation" charge-sensitive preamplifiers, based on a Swan Research design and fabricated at the University of Toronto, have been tested with these suppressors.

5) Design of a single-unit detector stand: Detailed design work on the full TIGRESS mechanical support structure continued this year. To facilitate installation of bottom detectors, the orientation of the inner structure is rotated 22.5° from the original conceptual design. To test the mechanical viability of the support structure design prepared in 2002 and to measure the performance of a full detector unit (HPGe plus suppressors), a single-unit stand mocking up 1/8 of the 90° ring of the full array has been designed (Fig. 210). Fabrication was scheduled to begin in early 2004 with all

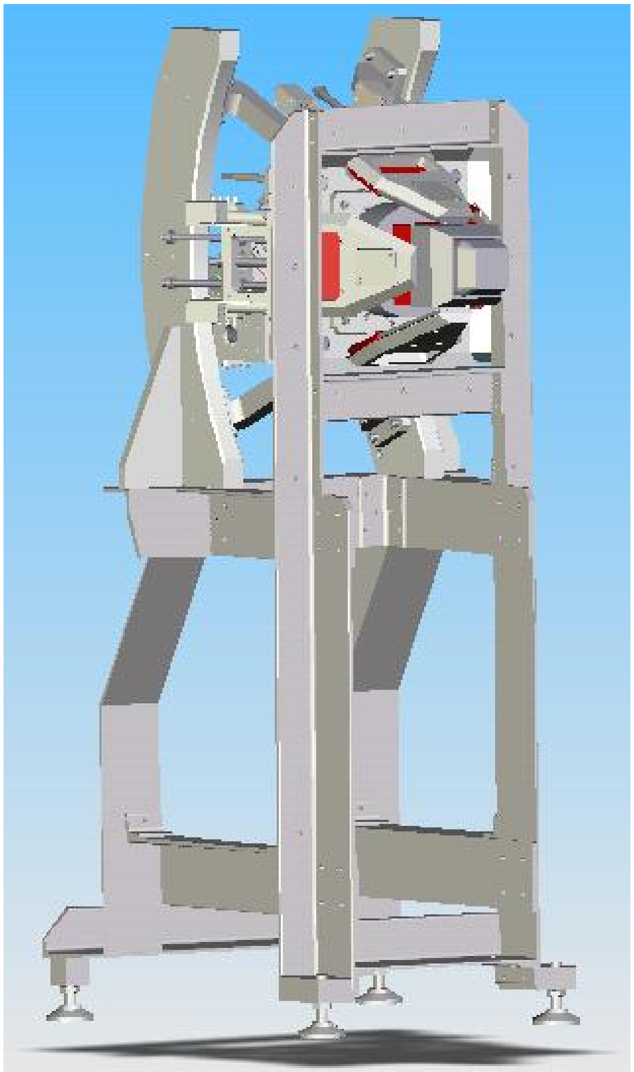

Fig. 210. Single-unit support and test stand.

mechanical, electrical, and detector performance tests scheduled to be completed in June, 2004. This single-unit test stand is conveniently designed so that the detector lies horizontally at the standard ISAC and ISAC-II beam line elevation.

6) Fabrication and testing of a single-channel waveform capture board: As part of parallel developments for KOPIO and TIGRESS, a single-channel waveform capture board was fabricated at Université de Montréal and tested with a large-volume HPGe detector at LTNO. These tests indicated a number of improvements needed in components to correct temperature-dependent gain drifts and susceptibility to power-supply noise and ground loops. These modifications will be incorporated into a full ten-channel card that should be ready for testing with the HPGe prototype in mid-2004.

Collaboration: The TIGRESS grant holders include 11 professors and staff from University of Guelph, McMaster University, Université de Montréal, University of Toronto, Université Laval, Simon Fraser University, and TRIUMF. The TRIUMF scientific team comprised G.C. Ball, G. Hackman, F. Sarazin, H. Scraggs, M.B. Smith, and undergraduate co-op students N. Cowan, G. Cronkhite, and L. Zimmerman. The collaboration has also benefitted from international collaboration with A. Boston of University of Liverpool, and C. Pearson and P.M. Walker of University of Surrey.

Status of the TITAN System
(J. Dilling, TRIUMF, for the TITAN Collaboration)

The TITAN (TRIUMF's ion trap for atomic and nuclear science) system at the ISAC low energy facility will allow high precision experiments in a variety of fields. Its main goal, however, is very precise mass measurements of short-lived isotopes, employing a Penning ion trap spectrometer. Different steps are needed in order to prepare the radioactive isotope beam from ISAC for those measurements, and therefore various ion traps are employed. The first step will be a linear gas-filled radio frequency quadrupole (RFQ) or Paul-trap system, which is used for cooling and converting the dc beam into a bunched beam. The next step is charge state breeding by use of an electron beam ion trap (EBIT). Presently these two systems are in the design and test phase, the RFQ system at TRIUMF and the EBIT system which is presently being built in Heidelberg, Germany in collaboration with the Max Planck Institute for Nuclear Physics. The Penning trap system is planned to be built and tested over the next two years (April, 2004 – April, 2006) and all components will move to their final location in the ISAC-I experimental hall in the spring, 2005. For this step a mezzanine will be erected above the existing low energy beam line area. In the following, the various components, which are presently under development or testing will be described in more detail.

The TITAN RFQ beam cooler and buncher
(J. Vaz, J. Dilling, TRIUMF; O. Hadari, UBC)

The TITAN RFQ beam cooler, designed for beam processing of the ISAC beam prior to injection into post apparatus, is currently being assembled in the TITAN test area. The radioactive ion beams (RIB) at RIB facilities are often of low quality due to the nature of the nuclear reaction mechanism of the production of the beams. A high beam quality, expressed in emittance or brilliance of the beam, is desired for optimal transfer of the precious ions to the various experiments. In order to achieve a better emittance, we employ a gas-filled RFQ cooler. It takes an energetic beam and through thermalizing collisions with a buffer gas, improves the beam quality. The use of this device as a temporary store is also exploited such that a dc beam can be converted into a pulsed beam. A combination of rf and dc fields provides the required axial and radial manipulation of ion motion. RFQ beam cooler development by the TITAN collaboration at TRIUMF will incorporate several novel features in the device. The system can be oriented both horizontally and vertically in its present configuration and housing. The latter is used to couple the ISAC beam line to the TITAN components situated on a mezzanine level in the ISAC-I experimental hall. Reverse extraction from the beam cooler enables the processed beam to be delivered to other beam lines on the ISAC floor. Individual dc supply modules on each of the 24 electrodes of the RFQ rod structure allow for a user defined potential profile to be superimposed along the ion traversal region. The ion collection or trapping can therefore be executed at either ends of the device. The trapped ions are then ejected towards the nearest transfer aperture. This allows for more experimental stations to have access to cooled and bunched beams. The RFQ system is presently in the assembly and testing phase. A photo of the structure mounted on to the lid of the vacuum vessel is shown in Fig. 211.

The rf fields required for the beam cooler operation are generated using a unique RFQ driver system adapted from existing TRIUMF technology. A configuration of fast switching FET boards designed by the TRIUMF Kickers group is employed to deliver a 1 kV (peak-to-peak) rectangular waveform oscillating up to 3 MHz. These operation parameters allow for a mass range between 6–200 u to be transported efficiently through the beam cooler. The use of low-level TTL signals as FET switching triggers enables the rf field to be instantaneously turned off at the trapping ends of the device during ion extraction. This provides TITAN with an opportunity to examine the beam quality during the extraction process without the influence of the rapidly changing rf field, often thought to be responsible for unwanted so-called rf heating. The careful investigation of this process would otherwise not be a trivial task, particularly when employing traditional transformer coupled sinusoidal rf drive systems.

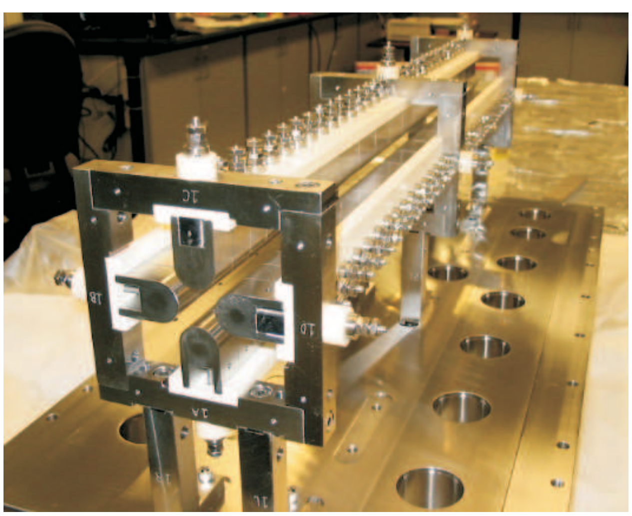

Fig. 211. Photo of the RFQ structure mounted on to the lid of the vacuum box.

Higher rf fields are required to effectively confine higher beam currents within the device. The higher fields counteract the space charge effects thus giving rise to a processed beam with a small emittance. This is crucial for experiments that require large samples of cooled bunched beam. A simple N (1 kV) stacking scheme of individual FET boards will yield higher rf voltages in the TITAN system. The current 1 kV drive can be scaled up as a test bed for an N (1 kV), N = 2 system at 3 MHz. This 1 kV base system will drive the RFQ cooler in the TITAN test area for an initial period to characterize injection/extraction optics in conjunction with the TITAN test ion source. Subsequently the entire RFQ assembly will form an injector system for the charge state booster (CSB) at the ISAC test stand location for tests on the effects of injection beam quality versus breeding efficiency, but ultimately, the RFQ will move to the ISAC-I hall in the spring, 2005.

Simulations of the RFQ buncher and cooler
(M. Smith UBC/TRIUMF; J. Dilling, TRIUMF)

Detailed simulations are crucial when designing and optimizing complex devices and systems that rely on electromagnetic fields to transport and store charged particles. Consequently, extensive simulations of injection/extraction of an ion beam into/out of the RFQ device were carried out using, in this case, the commercial software SIMION 7.0 3d. This ion optics package determines the electric field for a user-defined electrode geometry using the over relaxation method. It furthermore allows the user to map out ion trajectories through the calculated electric field. Time dependent potentials on the electrodes can be defined, thus simulating rf fields. Originally, simulations of the plain ion optics geometry were carried out without considering how the optics would be held in place. However, with the finalization of the mechanical design for the optics, it became possible to investigate the ion paths including all details of the cylindrical symmetric and non-symmetric part of the optics support, vacuum vessel, etc. These simulations show that with the RFQ's current ion optics it will be possible to both inject and extract beam from both ends of the RFQ (see Fig. 212).

The SIMION 7.0 3d package incorporates features to simulate the presence of buffer gas, by means of an added force in a viscous drag model. Earlier studies have shown, however, that this oversimplifies the actual interaction. The results, particularly for smaller mass

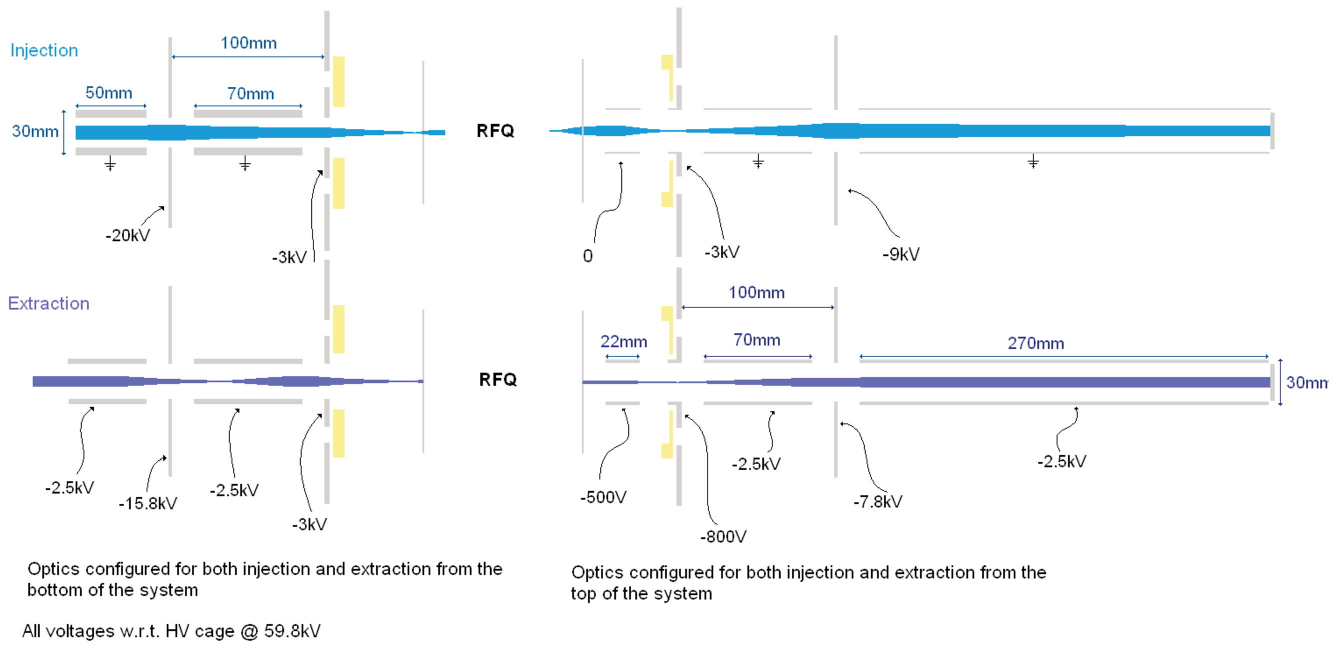

Fig. 212. Trajectories of ions injected (top) and extracted (bottom) at either end of the RFQ cooler and buncher, as simulated with the detailed geometry of the TITAN system.

differences between buffer gas and ions, differ dramatically from experimental observations. To overcome this problem, and to get more realistic results, in particular for the cooling of light ions like lithium, in helium buffer gas, a Monte Carlo code has been developed. It allows for the simulation of the collisional cooling process of the ions inside the gas-filled RFQ, employing documented ion-atom interaction potentials to calculate the scattering angle of an ion with respect to a gas atom in their centre of mass frame. Assuming a purely elastic collision, this scattering angle can be related to the energy lost by the ion during the collision. In order to test the precision of the code, simulations of the drift of ions in a gas-filled uniform electric field were carried out. It has long been known that a cloud of ions drifting in such a uniform electric field will move with an average velocity, the drift velocity, which is dependent on the ratio of the applied electric field to the gas number density. This velocity can also be related to a quantity known as the ion mobility which is the ratio of the drift velocity to the applied electric field. Such systems have been investigated and data exist for a large number of different ions drifting in various species of gas. The Monte Carlo simulation reproduced the experimental mobility data for both lithium and argon in helium to within experimental error. This code was then used to simulate the cooling of both lithium and argon ions inside the trap. It was found that for lithium ions cooled in helium at a pressure of 1.5×10^{-2} mbar with an applied rf field with a 400 V peak-to-peak voltage at a frequency of 2.7 MHz, a final cloud temperature of around 1400 K was reached in approximately 700 μs. This is expected to be significantly higher than room temperature due to the effect of rf heating. Although the average gain in energy for an ion oscillating in an rf field with no collisions is zero, when collisions are taken into account the particle's energy is scattered outside of the plane in which it is oscillating and hence the ion gains energy from the rf field. Figure 213 shows the velocity distribution or transversal energy of such a lithium ensemble after 2 ms. The temperature was taken from a 95% envelope of the distribution.

For argon ions in helium at 2×10^2 mbar with the rf field at 400 V peak-to-peak with a frequency of 1 MHz, a final temperature of under 900 K was reached in approximately 1000 μs. This is expected to be lower than the final temperature of lithium as argon is much

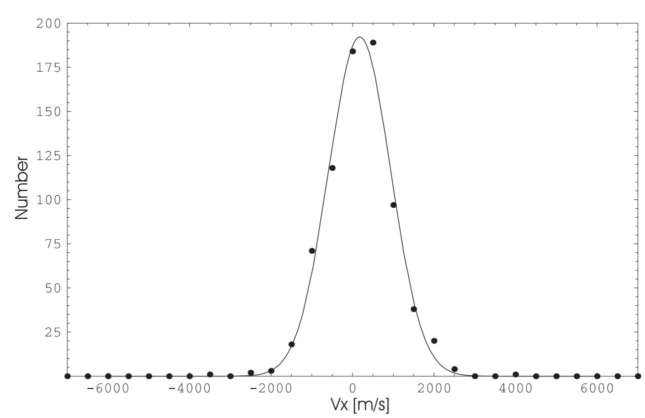

Fig. 213. Transversal emittance distribution of Li ions in a He buffer gas, as simulated with a collisional Monte Carlo code.

heavier than lithium and hence the average scattering angle is smaller, leading to a smaller probability of out-of-phase scattering.

Furthermore, simulations were carried out to investigate how driving the RFQ buncher with a square, as opposed to a sinusoidal, rf potential affects the final temperature of the trapped ion cloud. It was found that the final temperatures for argon were higher than those for the sinusoidally varying potential by around a factor of 2. This is due to the fact that the effective potential acting on the ions is steeper when trapping with a square wave as opposed to a sinusoid.

The code will now be used to look at the effect of cooling lithium in a trap driven with a square rf potential. The cooling of cesium will also be simulated such that results for heavy, medium and light mass ions are obtained. Furthermore the simulation of the extraction of the cooled ion clouds from the system will be carried out such that results can be compared to experimental data.

The TITAN high-current EBIT progress
(G. Sikler, TRIUMF; C. Osborne, Heidelberg/TRIUMF)

The main purpose of the TITAN electron beam ion trap (EBIT) is clearly the rapid charge-breeding of radioactive isotopes delivered by ISAC. In our planned system, a high-intensity electron beam is directed from an electron gun along the axis of a strong magnetic field, passing through the field and into a collector. Ions may then be injected into the field, and hence, into the path of the electron beam where they are radially trapped by the space-charge of the electron beam. Axial trapping is provided by potentials applied to drift tubes around the trap centre. The electron current will then ionize the atoms into higher charge-states, which may then be subsequently extracted and sent to the next trapping system of TITAN, the Penning trap, or examined *in situ.* The TITAN EBIT project is being built at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany. This EBIT is expected to produce an electron beam of up to 5 A in order to rapidly and highly ionize short-lived isotopes. The EBIT design is based upon the existing Heidelberg EBIT, with a few notable design modifications – in particular, the superconducting magnet is a cryogen-free system, where the magnetic coils are coupled to an external cryo-cooler system. This superconducting magnet (see Fig. 214), following recent post-delivery tests, has been found to be very robust and user-friendly, and exceeding the inital specifications. The magnet is capable of producing fields of up to 6 T, with the superconducting coils held at 4.6 K. Electron gun designs have been completed for three different sizes of cathodes (necessary to achieve a full range of currents up to 5 A) and are currently under construction.

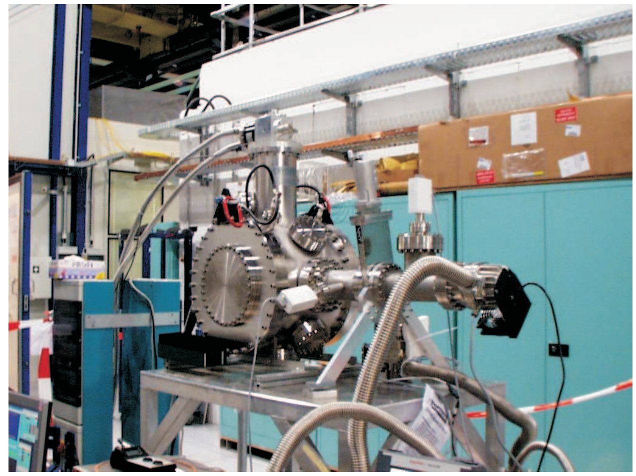

Fig. 214. Photo of the 6 T cryogen-free superconducing magnet, after delivery to the Max Planck Institute in Heidelberg, Germany.

The design of these guns has been driven largely by the results of simulations performed with the ion trajectory simulation software TRICOMP 5.0. With this software, the geometry of the EBIT (cylindrical symmetric) is defined using a triangular mesh in which electrodes are allocated potentials and magnet coils allocated currents. The software can, based on these parameters, calculate all of the electric and magnetic fields throughout the EBIT. Ion beam trajectories in the EBIT can then be evaluated, modelling space-charge-limited emission of electrons from a cathode surface. The passage of the electron beam through the EBIT is then determined, the electric fields being simultaneously recomputed to account for the local field modification due to the space-charge of the electron beam. The purpose of this is twofold: it facilitates design of electron gun components and other electrodes in order to deliver 100% of the electron beam cleanly through the EBIT, and produces space-charge-modified electric fields necessary for further modelling of injection and extraction of ions into and out of the trap. Figure 215 shows an example of electron beam trajectories for the medium-sized cathode, issuing from

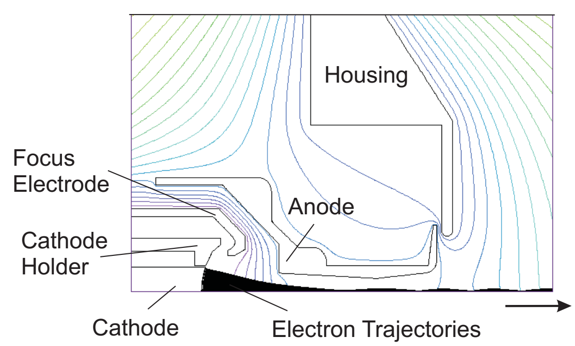

Fig. 215. Simulated electron trajectories calculated with the proposed TITAN-EBIT 5A e-gun geometry and including space charge effects. The X axis spans 5 cm.

the cathode surface and tracked beyond the electron gun aperture. The X axis spans 5 cm and electric field lines are traced on to the plot. So far these simulations have supported the design of all optical elements and determined optimal settings for all potentials and magnetic fields and their alignments relative to one-another. Component testing has shown that these optima all lie within the operating scopes of each element.

Beam monitoring system

(H. Sharma, Manitoba/TRIUMF; R. Cussons, TRIUMF)

The TITAN system is being set up for mass measurements of short-lived isotopes with high precision. The beam of radioactive nuclei from ISAC will be manipulated in various ways before transferring it to the Penning trap for the desired mass measurement. For this purpose the beam has to pass through devices such as a gas filled linear radio frequency quadrupole and an electron beam ion trap. For the optimal operation of these devices, and the subsequent beam transfer, it is important to monitor the beam characteristics at various stages. Hence, a general purpose beam monitoring detector has been developed which simultaneously allows an optical readout and digital recording of the beam profile and the beam intensity. It consists of micro-channel plates (MCP) in chevron arrangement, a phosphor screen and a fibre-optic image guide. The detector and a drift-tube have been mounted on an electrically isolated mechanically rotating feedthrough so that they can, alternatively, be brought in and out of the beam axis.

The beam impinging on the MCP produces a flux of secondary electrons which are further multiplied and subsequently accelerated towards the phosphor screen in order to produce a visual image of the beam. The beam image is transmitted to a view port via a fibre-optic image guide which is then recorded by a CCD camera and stored on a PC. Simultaneously, the current pulses from the aluminum-coded phosphor screen are processed by using a conventional electronic set-up, in order to estimate the beam intensity.

In order to observe the performance of the beam monitor, several test measurements have been carried out using a calibrated ^{241}Am alpha-source inside the vacuum chamber, at a pressure of about 3×10^{-8} mbar. The $57 \pm 4\%$ efficiency of the detector that was determined from these measurements was found to be in agreement with the 63% open area ratio quoted for the MCP. By using a mask with holes of 1, 2, and 3 mm the beam spots were resolved with a precision of 0.1 mm, as shown in Fig. 216.

The whole MCP surface was scanned using a mask with a grid of 1 mm holes, as shown in Fig. 217. The surface plot is in agreement with the intensity distribution of the incoming alpha particles.

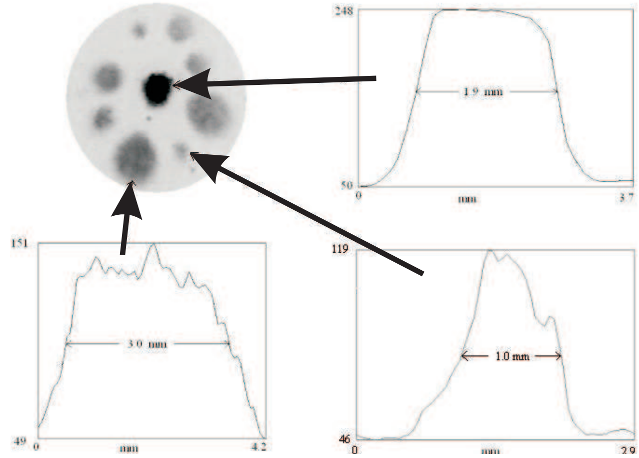

Fig. 216. Mask image with holes of different diameter and corresponding pixel intensity distribution for the beam spots.

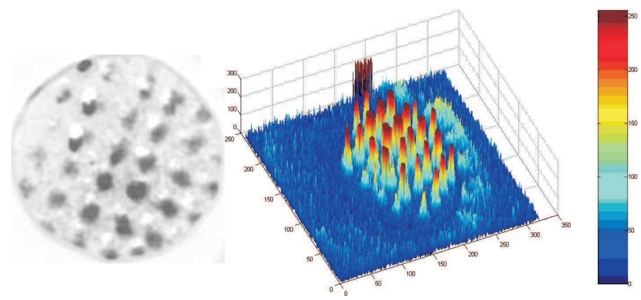

Fig. 217. The image of the mask (left) with equal-sized holes and corresponding surface plot. The lighter spots on the left image are artificial, due to the reduction of background.

R&D for the Time Projection Chamber for the International Linear Collider

(M. Dixit, Carleton/TRIUMF)

Introduction

The time projection chamber (TPC) is a prime candidate for the main charged particle tracker for the future international linear collider (LC). With more complicated event topologies and higher backgrounds than previous e^+e^- colliders, the LC TPC has to measure $\sim$200 track points with a resolution of less than 100 μm for the full 2.6 m drift. The ambitious resolution goal is close to the limit from the ionization electron statistics and transverse diffusion in the gas. The target resolution is more than two times better than can be achieved by the existing TPC readout technology based on multiwire proportional chambers.

Using micropattern gas detectors (MPGD), such as the gas electron multiplier (GEM) and the Micromegas, for the readout will almost entirely eliminate the large E$\times$B systematic effects which limit the performance of the proportional wire TPC systems. The MPGD-TPC has the potential to reach the LC resolution goal. With fast spatially confined charge signals, it also has the potential for a much better double track resolution (in r-ϕ and in z) than the wire chamber TPC.

Due to reduced transverse diffusion at high magnetic fields, the maximum charge cluster size arriving at the LC-TPC anode readout will be on the order of 0.5 mm. The conventional TPC can measure the avalanche centroid position on the anode wire precisely with several mm wide cathode readout pads. To reach the same precision, the MPGD-TPC with standard charge readout will require a fully instrumented sub-millimetre width anode pad structure resulting in a significant increase in the cost and complexity of the detector.

MPGD-TPC R&D at Carleton

Depending on the pad size and the diffusion properties of the gas, the MPGD anodes do share some of the track ionization charge. Using cosmic rays, we have systematically studied the limits of achievable spatial resolution for a GEM-TPC with wide anode pads using conventional charge readout techniques. With the aim to achieve better resolution with wide pads, a new concept of position sensing from charge dispersion has been developed where the MPGD anode plane is made of a high surface resistivity material. The preliminary results are quite promising. These R&D activities are described below.

Cosmic ray resolution studies with a GEM-TPC

A small 15 cm drift TPC with a double-GEM readout endcap was designed and built to study the spatial resolution that could be achieved with wide pads using standard charge readout electronics. There was no magnetic field.

Resolution was measured for two gas mixtures: Ar:CO_2/90:10 and Ar:CH_4/90:10 (P10). The differences in the transverse diffusion for the two gas mixtures helps to disentangle various effects contributing to the observed spatial resolution. In addition, ArCO_2 has a relatively low transverse diffusion which leads to measurement conditions similar to those in a high magnetic field.

The anode readout board had a total of 192 pads in 10 rows. The pad sizes were different for different rows so we could study the dependence of the spatial resolution on the pad geometry. Wire preamplifiers, borrowed from Aleph TPC at LEP, were used for charge amplification. After 3-fold multiplexing, the signals were digitized at 200 MHz by 64 FADCs designed and built at the University of Montreal.

The data analysis used the technique of track reconstruction where all the pad data for the event is fitted assuming a Gaussian track profile from diffusion. The resolution as a function of drift distance for 2×6 mm^2

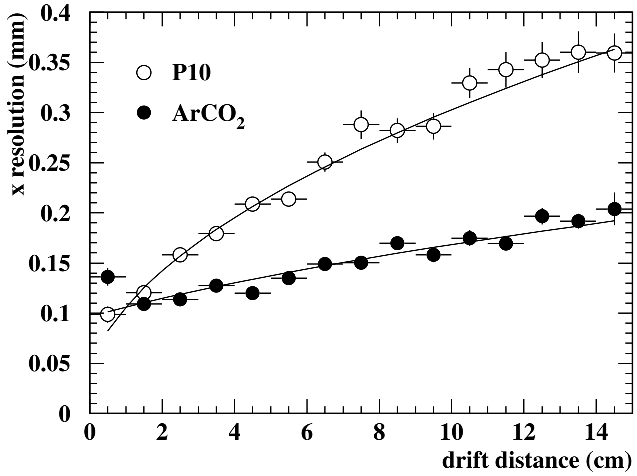

Fig. 218. Spatial resolution of the TPC as a function of drift distance for 2 mm wide pads for cosmic ray tracks with $|\phi| < 5°$.

pads for small angle tracks is shown in Fig. 218. The measured spatial resolution for short drift distances for both gases was about 100 μm. From studies of 2.5 and 3 mm wide pads we find that, to achieve the best resolution, the pad widths should not be more than three times larger than the RMS charge cloud width. The resolution was also measured as a function of the track crossing angle in good agreement with the theoretical prediction.

The measured resolution values are about 50% larger than the limit from the ionization electron statistics and transverse diffusion.

Position sensing from charge dispersion in micro-pattern gas detectors with a resistive anode

We have developed a new concept to measure the position of a localized charge cluster in an MPGD using wide pads similar to those used in previous wire/pad readout TPCs. A high surface resistivity film, used for the anode, is bonded to the readout plane with an insulating layer of glue (Fig. 219). The resistive anode film forms a distributed 2-dimensional resistive-capacitive network with respect to the readout pad plane. Any localized charge arriving at the anode surface will be dispersed with the RC time constant determined by the anode surface resistivity and the

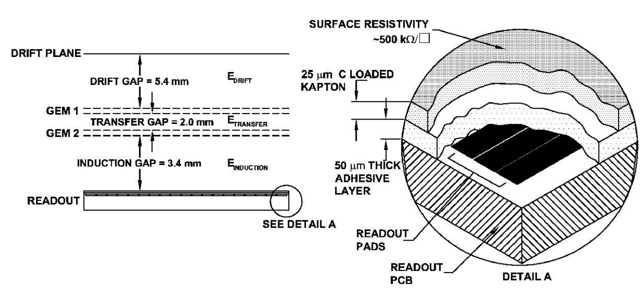

Fig. 219. Schematics of the resistive anode double-GEM detector for charge dispersion studies.

capacitance per unit area, the latter determined by the spacing between the anode and readout planes and the dielectric constant of the glue. With the initial charge dispersing and covering a larger area with time, wider pads can be used for position determination.

A simple model can explain the features of the new approach. Charge division, described by the well known Telegraph equation, is often used to measure the position of the avalanche on a proportional wire. We generalize the concept to 2-dimensions. At $t = 0$, a point charge is placed at the origin on a resistive anode surface of infinite radius (for simplicity). The space-time evolution of the charge density function ρ on the anode surface is given by the generalized 2-dimensional Telegraph equation:

$$\frac{\partial \rho}{\partial t} = h\left[\frac{\partial^2 \rho}{\partial r^2} + \frac{1}{r}\frac{\partial \rho}{\partial r}\right] \qquad \text{where} \qquad h = 1/RC$$

where R is the surface resistivity and C is capacitance per unit area.

The solution for the charge density function is given by:

$$\rho(r,t) = \frac{1}{2th}\exp(-r^2/4th)\,.$$

The time dependent charge density function for the resistive anode is capacitively sampled by the readout pads. The charge pulse on a pad can be calculated from the pad geometry, the location of the pad with respect to the initial charge and the RC time constant of the system.

The charge dispersion GEM studies were done with a Ar:CO_2/90:10 gas mixture. A 25 μm thick film with a surface resistivity of $\sim$500 kΩ per square was glued to the pad readout board. The spacing between the anode and readout planes was about 50 μm defined by the glue thickness.

A $\sim$45 keV bremsstrahlung X-ray source collimated to $\sim$50 μm was used for the measurements. A computerized translation stage moved the X-ray spot in small steps across a series of 2 $\times$ 6 mm^2 pads read out with Aleph TPC charge amplifiers. The signals were digitized using Tektronix digitizing oscilloscopes.

Figure 220 shows the measured spatial resolutions for several pads as the collimated X-ray spot was scanned across the detector. The standard deviations of the position measurements, all in the range of 60 to 80 μm, are consistent with the size of the collimated X-ray spot at the detector.

The charge dispersion concept has been tested with the Micromegas with measured spatial resolution close to that for the GEM. The resistive anode additionally suppresses HV breakdown in Micromegas. We have demonstrated stable detector operation at unprecedented high gains near 5–6 $\times$ 10^6 in the limited

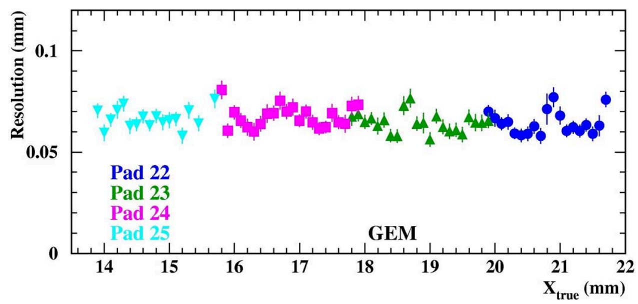

Fig. 220. Spatial resolution for 2 $\times$ 6 mm^2 readout pads with charge dispersion readout measured with a collimated X-ray source. The anode resistivity was 0.5 MΩ/square.

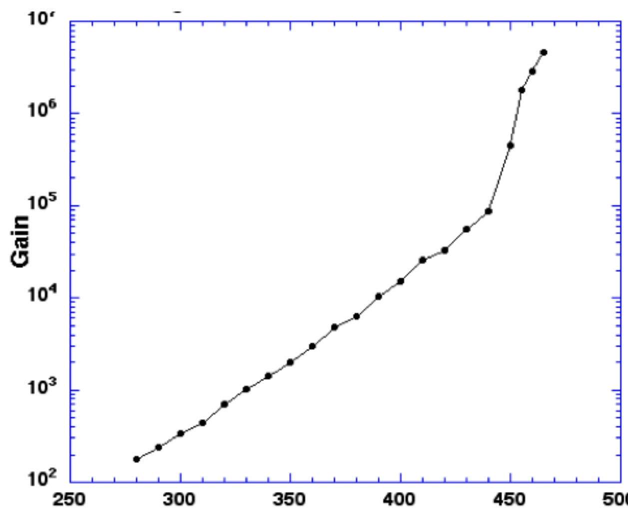

Fig. 221. Micromegas gain studies with a resistive anode. The resistive anode suppresses sparking and makes possible stable Micromegas operation at high gains in the limited streamer region.

streamer mode (Fig. 221). The Micromegas work is being done in collaboration with Saclay.

Future plans

The choice of technology decision for the LC accelerator will be made in 2004. A major LC TPC milestone goal is to test a realistic prototype by the year 2007.We expect to contribute significantly to this international effort. The following R&D steps are foreseen: i) completion of cosmic ray proof of principle spatial resolution tests of a small TPC with GEM and Micromegas with a resistive anode; ii) beam tests for two-track resolving power; and iii) magnetic field tests of a 50 cm diameter Saclay Micromegas TPC outfitted with a resistive anode.

Linear Collider TPC R&D group: R. Carnegie, H. Mes, K. Sachs (Carleton), M. Dixit (Carleton/TRIUMF), J.-P. Martin (Montreal), and D. Karlen (Victoria).

Linear Collider TPC Development

(D. Karlen, Victoria/TRIUMF)

In the summer, a time projection chamber with micropattern gas detectors was operated for the first time in a magnetic field, using the facilities at TRIUMF. This is an important step in demonstrating the capabilities of a new design for a large volume gaseous tracking system, suitable for large particle and nuclear physics experiments.

Introduction

A leading candidate for the central tracking system at a future linear collider experiment is a time projection chamber (TPC) readout by micropattern gas detectors (MPGDs), such as gas electron multipliers or micromegas detectors. This concept may offer two distinct benefits over traditional TPCs; improved tracking resolution and better two particle separation. When operated in a uniform magnetic field, the resolution of a traditional TPC, one with gas amplification provided by a wire grid, is limited by the so-called E×B effect. This refers to electric field components transverse to the magnetic field in the amplification region which cause segments of ionization to rotate. Since the ionization is not uniform along the track, the rotation results in degraded spatial resolution. The feature separation of an MPGD, the hole or mesh pitch, is much smaller than can be achieved with a wire grid. As a result, the transverse electric field components are much smaller and the E×B effect is significantly reduced. The electronic signals measured in a traditional TPC are primarily due to the motion of positive ions away from the anode wires. These signals tend to be relatively slow, are spread over a large region, and therefore limit the capability of separating two nearby tracks. The signals observed with a MPGD TPC are due to the motion of electrons across a small gap and by the collection of the electrons on pads, giving faster and narrower signals and therefore improved capability to separate two nearby particles.

The narrower signal distribution presents a new challenge for large scale TPCs, such as those being considered for a future linear collider. When operated in a strong axial magnetic field in a fast gas, the transverse width of the charge distribution as it reaches the TPC endplate may be only a few hundred microns across. Populating an endplate whose area is several square metres with pads with sub-millimetre dimensions would be cost prohibitive due to the associated electronic readout system. One solution to this challenge is to use gas diffusion in the region near gas electron multipliers (GEMs) to spread the charge over a wider area without sacrificing the track resolution.

Victoria TPC prototype

In order to demonstrate that the E×B effect is negligible and that gas diffusion after GEM multiplication can be used to spread the charge signals over multiple pads, a prototype TPC was designed for operation in a magnet at TRIUMF. The device, shown in Fig. 222, was constructed primarily of acrylic at the Science Technology Centre at Carleton University. A 30 cm long drift volume has a uniform electric field defined by 60 brass hoops connected to a voltage divider. Electrons produced in the ionization of gas by charged particles traversing this volume drift towards 2 GEMs separated by about 2 mm. The amplified electrons are then collected by pads 5 mm from the second GEM with dimension 2 × 7 mm^2. The charge signals on the pads are amplified and digitized using readout electronics developed for the STAR TPC.

Results from tests

The TPC prototype was installed in the TRIUMF magnet and operated with a traditional fast gas, P10 (Ar CH_4 90:10). A cosmic ray telescope was set up above and below the magnet in order to trigger the readout electronics when a cosmic ray particle passed through the TPC volume. The set-up is shown in Fig. 223.

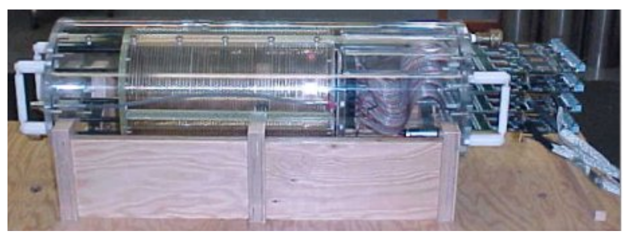

Fig. 222. Photograph of the prototype TPC constructed for magnetic field tests at TRIUMF. The outer diameter of 8.75 in. was chosen to fit inside the 9 in. bore, 0.9 T magnet. The drift volume is 30 cm long, followed by two GEM devices in front of an array of 256 pads, readout by front-end cards (on the right) produced for the STAR TPC.

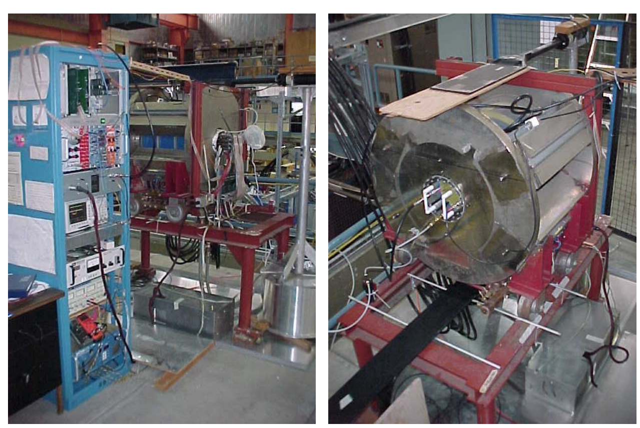

Fig. 223. Set-up of the TPC with the TRIUMF magnet. The cosmic ray telescope is visible in the photograph on the right.

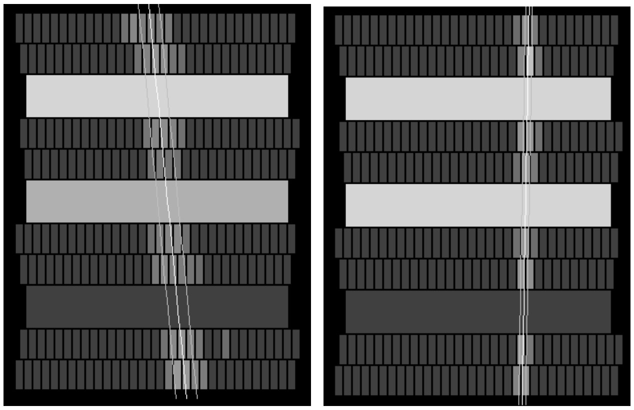

Fig. 224. Event displays from cosmic ray events recorded at zero field (left) and 0.9 T (right). The brightness of the pads represents the size of the signal recorded by the corresponding electronics channel. Each track drifted about 25 cm. The white lines show the results of track fits, with the outer lines showing the determined track widths. They are 2.3 mm and 0.8 mm for these events.

Event displays from cosmic ray events are shown in Fig. 224 for data recorded at zero and full magnetic field. For both events the drift distance was approximately 25 cm, and the reduction in transverse diffusion with magnetic field is easily seen. Eight rows of $2 \times 7\ \mathrm{mm}^2$ pads are sampled at 20 MHz and digitized to 10 bits by electronics developed for the STAR TPC at RHIC.

A track fitting program has been implemented using a likelihood method. It determines the track orientation and transverse width from the observed pattern of charge sharing across each row. The program is used to estimate the resolution of a single row by comparing the track found by the other 7 rows, to the track location determined by one row. The resolution as a function of drift distance is shown in Fig. 225 for zero, half, and full magnetic field. For full field operation, the contribution to the resolution from transverse diffusion is significantly reduced, but is still observable.

A simple Monte Carlo simulation program has been developed to understand the performance of the GEM TPCs. Primary ionization clouds of electrons are produced and diffused through the gas volumes, amplified at the GEM foils and collected by the pads. Signals are generated on the pads according to the arrival time of the electrons and the response of the electronics. The simulated and real events are analyzed by the same program, and the derived resolutions are compared in Fig. 226. The agreement between the data and simulated resolution estimates is good.

Next steps

After the successful tests at TRIUMF, the TPC was brought to the DESY Laboratory in Hamburg, Germany, in the late summer for tests in magnetic fields

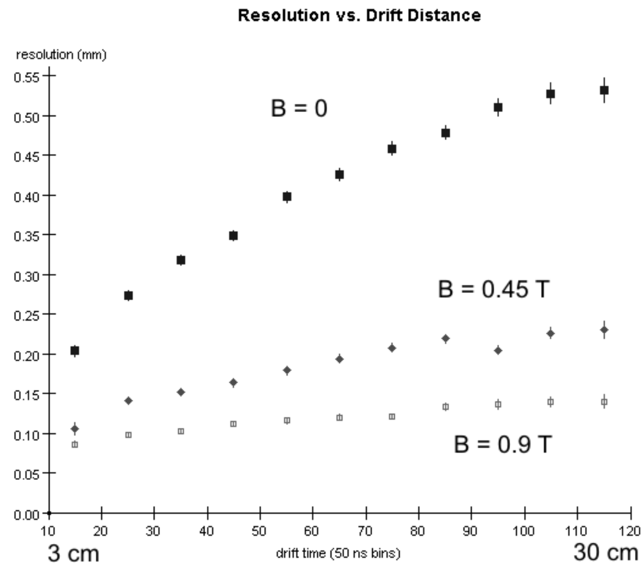

Fig. 225. Resolution (mm) is shown as a function of drift time (50 ns time bins). The horizontal axis corresponds to drift distances between 3 and 30 cm. The upper points are at zero field, the middle points are at 0.45 T, and the lower points are at 0.9 T. These data are from a preliminary analysis.

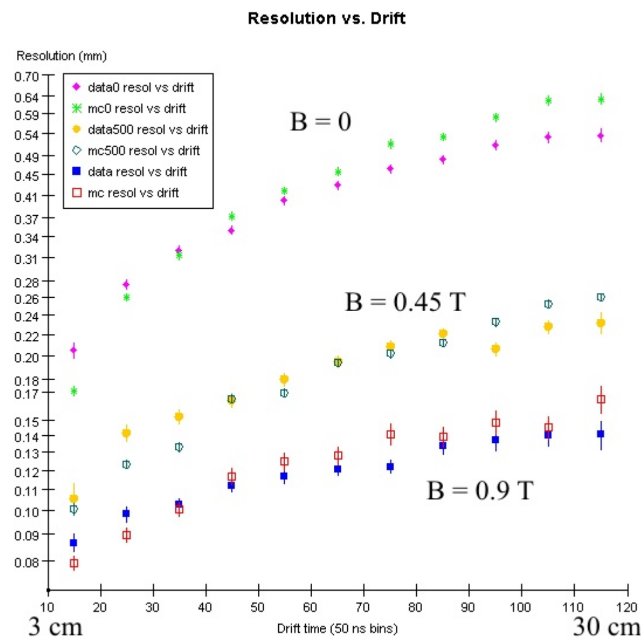

Fig. 226. Resolution (mm) is shown as a function of drift time (50 ns time bins). The horizontal axis corresponds to drift distances between 3 and 30 cm. The solid points correspond to real data, the open points are from simulated data. The results shown here are preliminary.

up to 5.3 T. A full analysis of these data is under way and a publication of this work is forthcoming.

In 2004, the group is preparing a second readout endplate to test with a micromegas device in place of the GEMs. Also, the TPC will be modified to allow tests with an ultraviolet laser. Data with consistent ionization patterns from the laser will be useful for calibration studies with the GEMs and to develop a tracking algorithm for the micromegas device.

In the coming years, a technology decision for the TPC readout will be made and a large prototype constructed, in collaboration with an international group working on TPC R&D for the linear collider.

University of Victoria LC TPC group in 2003: Dean Karlen, Paul Poffenberger, Gabe Rosenbaum. This work has benefitted from the work of collaborators in Canada: R. Carnegie, H. Mes, K. Sachs (Carleton), M. Dixit (Carleton and TRIUMF), J.-P. Martin (Montreal).