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CANADA'S NATIONAL LABORATORY
FOR PARTICLE AND NUCLEAR PHYSICS

OPERATED AS A JOINT VENTURE

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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

OCTOBER 2005

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 and Neutron Irradiation Facilities

(E.W. Blackmore, TRIUMF)

This year was the busiest year yet for proton and neutron irradiations. TRIUMF has become recognized as a premier test site for space radiation effects using variable energy protons and now, with the capability of providing a neutron energy spectrum similar to that found at aircraft altitudes and at ground level, neutron beam time is also becoming heavily subscribed. A large fraction of the proton users are Canadian space-related companies, while the neutrons are used primarily by foreign companies for avionics and microelectronics testing.

Proton irradiation facility

During the year there were five 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.

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 effects of total dose on single-event upsets, the effects of proton energy on single-event latchup and simulating the terrestrial neutron environment using protons. The Sandia group also used commercial time for single event testing of various devices.

Groups from MD Robotics visited the facility five 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 proton beam spot was used for one test. Other Canadian space companies using beam this year included Routes Astro Engineering and Xiphos. Tests of radiation effects on fibre optic cables were carried out for the space group at the University of Calgary. Foreign users included QinetiQ and BAE Systems from the UK.

Neutron irradiation facility

A schematic of the neutron facility is shown in Fig. 140. Protons are stopped in an aluminum plate beam dump located at the end of BL1A. The proton beam – 500 MeV and typically 120–140 μA – is degraded to about 400 MeV by passing through the T1 and T2 meson production and a series of isotope production targets. The beam dump is immersed in a cylindrical water tank and four horizontal neutron beam channels emerge from the steel shielding surrounding the beam dump. These 20 cm wide by 8 cm tall channels are offset vertically from the proton beam line so that they look at the water moderator below the beam dump. Neutrons must scatter in the water moderator at least once in order to enter the beam pipe. Thermalized neutrons are also present in this beam. One of the channels can be accessed through a vertical slot in the shielding and this is where devices are tested.

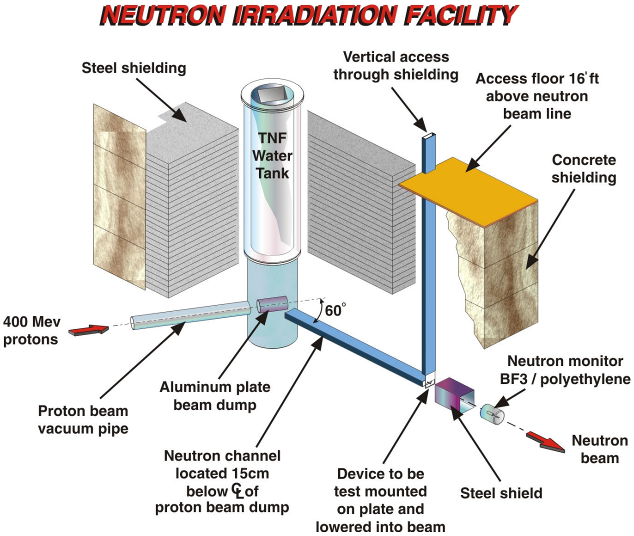


Fig. 140. The TRIUMF neutron irradiation facility.

The neutron spectrum follows the terrestrial spectrum from below 1 MeV to the highest neutron energies around 400 MeV. The rate is about 10^9 times higher than the ground level neutron fluence of about 20 neutrons/cm^{-2} s^{-1} above 10 MeV, so accelerated testing can be carried out very efficiently. The only other similar facility is at LANSCE in Los Alamos but it was shut down through most of 2004.

The users in 2004 included avionics testing by a Swedish/UK collaboration called SPAESRANE and a US company Smiths Aerospace, along with two microelectronics testing companies, HIREX from France and IROC Technologies from US/France.

Proton Therapy Facility

(E.W. Blackmore, TRIUMF)

In 2004 there were 6 patients treated with protons during four scheduled treatment sessions. This brings the total number of patients treated at TRIUMF to 95. This is a lower number than in previous years but seems to be just a statistical variation.

There were no significant changes made to the treatment system or the treatment planning software during 2004.

A radiobiology experiment was carried out using 50 MeV protons to compare the RBE (relative biological effectiveness) of protons to antiprotons to determine the effectiveness of antiprotons for cancer therapy. The antiproton measurements were carried out using the AD (antiproton decelerator) at CERN. The biological samples were Chinese hamster V-79 WNRE immobilized in gelatin, using a technique developed by L. Skarsgard of the BC Cancer Research Centre. To match the antiproton energy spread a one-step modulator was designed for the protons. This work is a collaboration of institutions in Europe, Canada and the United States. A publication of the results is being pursued.

Centre for Molecular and Materials Science (μSR + β-NMR) User Facility

(S. Kreitzman, TRIUMF)

Overview

Proposals and funding The primary news regarding Centre for Molecular and Materials Science (CMMS) operations was the coupled results of our 2004 Major Facilities Access Grant (MFAG) submission and the TRIUMF Five-Year Plan, also submitted in 2003. For the second time, our MFAG was renewed only for a single year, due to exactly the reasons that this occurred during our previous MFA application. The MFAG selection committee simply was not aware of the funding status of the Five-Year Plan, as this was to be announced after the MFAG selection committee concluded its decision making process.

As of the end of 2004, the TRIUMF Five-Year Plan is advocating two major μSR beam line facility upgrades. The M9A beam line is the highest priority and will provide a new high luminosity surface muon beam fitted with an achromatic spin rotator/separator. Further plans include a state-of-the-art turnkey spectrometer at the end of this beam line, suitable for the broad range of general researchers who wish to use μSR as one of many tools in the investigation of their materials of interest. The second μSR proposed beam line upgrade is to split M20 into two legs, one of which supports "muons on request", a configuration which allows one to do μSR experiments on a longer time scale. With these TRIUMF plans in place, the CMMS will again submit an expanded MFAG application to support the new planned infrastructure.

Funding support for our user groups continues to be strong, and major funding in the 2004 competitions has been received (including equipment and group operations) to support condensed matter high pressure work in exotic materials.

Beam utilization Browsing the beam scheduling Web pages http://tcmms.ca/sched/sch105a.html and http://tcmms.ca/sched/sch106a.html shows that apart from some lost time on M9B (due to solenoid difficulties) no other significant beam delivery losses impacted the CMMS μSR schedule in 2004. However, the β-NMR/β-NQR schedule was reduced from historical levels due to technical difficulties with targets. Summarizing this data, the schedules reflect experiments, taking 882 12 hour shifts or 73.5 beam weeks on four beam lines. The breakdown for the major spectrometers was (in weeks): OMNI′/SFUMU – 9; DR – 10; LAMPF – 12; HiTime – 14; Helios – 24.5; β-NMR/β-NQR – 4.

Developments

Significant facility developments may be categorized into two broad components, the first with evolutions in beam line operation and the second regarding technical progress on specific instruments or inserts.

Operational evolutions

- Spin rotated tunes for high-momentum muons in M9B are being developed utilizing a differentially powered split quad after the solenoid section. This allows for high muon momentum (but lower rate) tunes with predominantly left/right polarization. Such tunes are now routinely being used to do transverse field μSR in moderate to high fields without suffering the beam steering effects of injecting into a magnetic field perpendicular to the beam momentum.
- Switched and/or simultaneous β-NMR/β-NQR operation has led to much more efficient use of the precious ISAC unstable beams. Now T_1 spin lattice relaxation measurements can be done on one leg while simultaneous frequency scan (or T_1) techniques are carried out on the other.

Technical progress and developments

- The new high field, high timing front end for our DR is now in fabrication. It utilizes wave shifting technology for the backward and veto counters, and an optimized HiTime-like muon counter (see Fig. 141).
- With the significant field modelling efforts of Bassam Hitti, the problems at very high fields with respect to beam steering and inhomogeneity have been identified and corrected in the HiTime spectrometer. The field steering was due to a 1° misalignment of the magnet within the bore. A reorientation of the magnet now predominantly removes this effect. High field homogeneity (capability to lock an NMR probe from 2–7 T) has been achieved by appropriately placed magnetic shims within the bore.

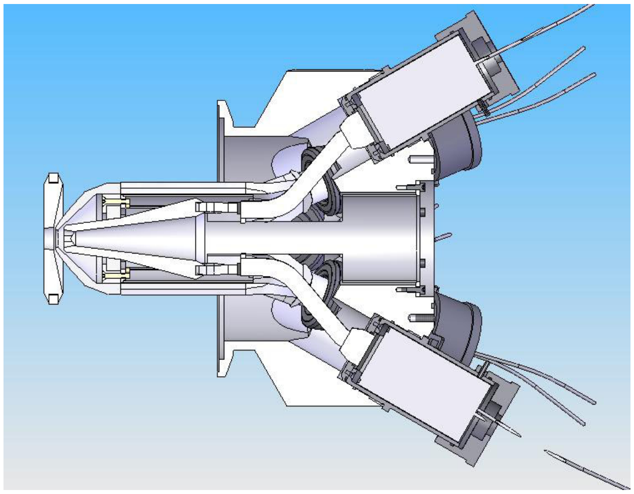


Fig. 141. A cut away view of the new high timing resolution front end for the DR. The back, muon and active collimator scintillators are shown.

- A high pressure cell cryogenic alignment insert for our gas flow cryostats has been designed and built. It contains two in-cryostat scintillators which help define and range the muon beam. Additionally, a dummy cell with a sanitization counter in the sample space of the high pressure cell is available to establish appropriate muon momenta for different cells (see Fig. 142).
- Design of a dual walled high pressure cell (capable of 2.5 GP) continues.
- A third generation temperature stable variable frequency microwave (0.8–2.5 GHz) transmitter/cavity system has been designed, and is now in fabrication.
- The new OMNI′ fabrication and assembly is complete and the spectrometer is in operation.
- A second generation β-NMR/β-NQR frequency synthesizer has now been designed and proof of principle tests successfully conducted. This allows for a single module to be utilized to generate the 1/3/5F β-NQR pulses and the 0/90/180/270° β-NMR pulses with the change of a switch and appropriate software initialization parameters.
- On a more prosaic level, scheduled maintenance on critical subsystems to minimize start-up or beam time problems is now being more widely implemented.

Future perspectives

The most significant future initiatives are the preparations to operate μSR at a higher level of user mode, initiated by the building of the new M9A beam line and spectrometer. The beam line will be unique at TRIUMF in so far as having extensive diagnostic and warning elements built into it so that nascent problems can be detected before they become serious. Its achromatic dual spin rotator/separators will yield high luminosity (comparable to M15) in both spin polarizations. The spectrometer will be a turnkey operation and it is anticipated that additional MFAG personnel increases will allow full facility support for novice users, including first pass data analysis.

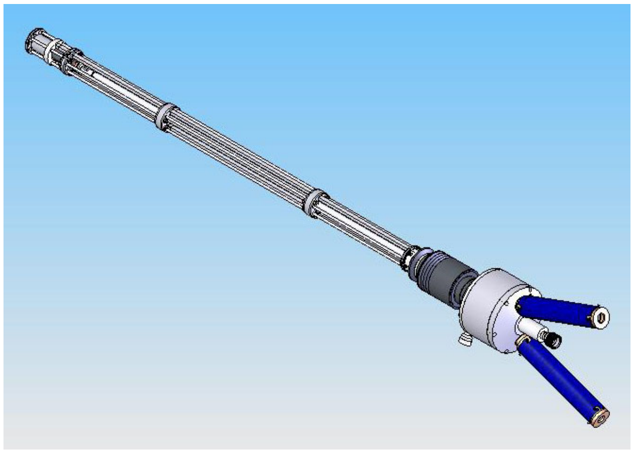


Fig. 142. The pressure cell insert showing muon entry and exit counters, with the centre removable cell rod.

The model set by this beam line will then filter into the operation of our legacy facilities, leading to increased efficiency and utility in the CMMS operation.

Information and documentation

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

Computing Services

(C. Kost, TRIUMF)

Overview

While 2003 was the year of the massive migration of Computing Services to the new ISAC-II building, 2004 was the year of consolidating and expanding the new network and computing infrastructure.

The UBC-TRIUMF component of WestGrid, the core of which is the 1008 3.06 GHz Xeon CPU cluster called Glacier, came into full operation in 2004 and was heavily used by TWIST – which was often the catalyst for both hardware and software upgrades to enable stable operation of Glacier. Migrating from NFS to IBM's GPFS and requiring raiding of the pair of disks in each node (due to the high failure rate of the Toshiba 40 GB drives) were just two examples.

The decision to have TRIUMF as the CERN ATLAS Tier1 for Canada is expected to have a significant impact on our group (and TRIUMF) as there are many elements that need to be integrated between our small service group and the expected much larger ATLAS team planned for TRIUMF.

To improve performance and reliability several servers were replaced with more powerful machines – mostly Dell 2650s.

Network

We successfully configured and tested the TRIUMF new secure wireless LAN (WLAN) router from Colubris. This device will be used to automate IP assignments to the TRIUMF users in general and visitors in particular, once the single flat B space IP addresses have been separated into VLANs.

To address the vulnerability of a single point of failure to all non-commodity network traffic to/from TRIUMF via the coarse wave division multiplexer (CWDM) a second, more powerful pair of CWDMs (see Fig. 143) was installed between TRIUMF and BCNET (located in downtown Vancouver). Contrary to plans envisioned last year, commodity traffic continued to be serviced via (now upgraded to a 1 Gbit link) UBC (which is supported by 3 redundant service providers) as the bandwidth manager effectively maintains this at an acceptable low rate.

Additional fibres were laid from the main office building to ISAC-II – providing full redundancy between almost all main nodes at TRIUMF.

Two students spent most of their summer designing and implementing Web based tools to build a network database of most of the equipment connected to the network backbone at TRIUMF.

Computer security

The reliability and regulation of the air-conditioners cooling the main compute server room in ISAC-II continue to be questionable and plans are under way for 2005 to address this with improved monitoring and supplementary heating to further reduce temperature excursions.

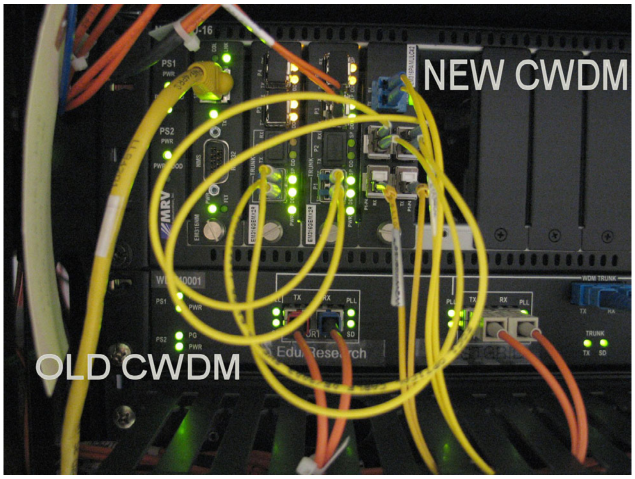


Fig. 143. New and old coarse wave division multiplexer (CWDM) connecting TRIUMF to BCNET.

In accordance with TRIUMF policy all Linux machines on the network now require “back-door” access – preferably privileged, but minimally with a normal user account to readily allow examination of any errant machine. It is also required that critical Windows updates be performed in a timely manner. The mandatory move to Windows SP2 has been deferred till sometime in 2005.

Although we avoided being infected by the Mydoom virus attacks of January, August was a busy month for viruses with some 20 PCs, either through lack of appropriate updates or the unauthorized use of KaZaA, infected with the w32.spybot.worm, while some were infected with W32.Mydoom, or W32.Beagle by running e-mail attachments before Symantec released a “cure”.

To further improve security we now require Linux on networked computers to be updated as much as possible to the latest Red Hat version or Scientific Linux (released on May 10, 2004 and generously provided through the joint efforts of Fermilab and CERN). Computing Services provides local users with the required kickstart CDs as well as maintains an on-site mirror of Scientific Linux.

E-mail

Due to both aggressive e-mail filtering (typically rejecting 6000 messages/day) before e-mail is passed to the end user, and increased use of e-mail filtering by the end user, unwanted e-mails have been steadily declining. Early in the year a dual CPU Dell 2650 mail server running Redhat 9 was installed to address poor disk I/O performance. However, due to heavy growth in this area, the long term solution will likely require two or more machines – splitting the load by having one machine handle incoming mail, AntiVirus, and AntiSpam filtering to a second machine for user mail access. A third machine would handle outgoing mail.

Servers

Figure 144 shows the current status of the main components of the Computing Services facilities. Almost all servers have two or more power supplies which are connected to two or more networked power bars so as to provide redundancy, remote current monitoring, and power control to the servers. As the year-end approached it was clear that more circuits would need to be provided than were available in the main server room. Plans are to double the number to this room by mid-2005.

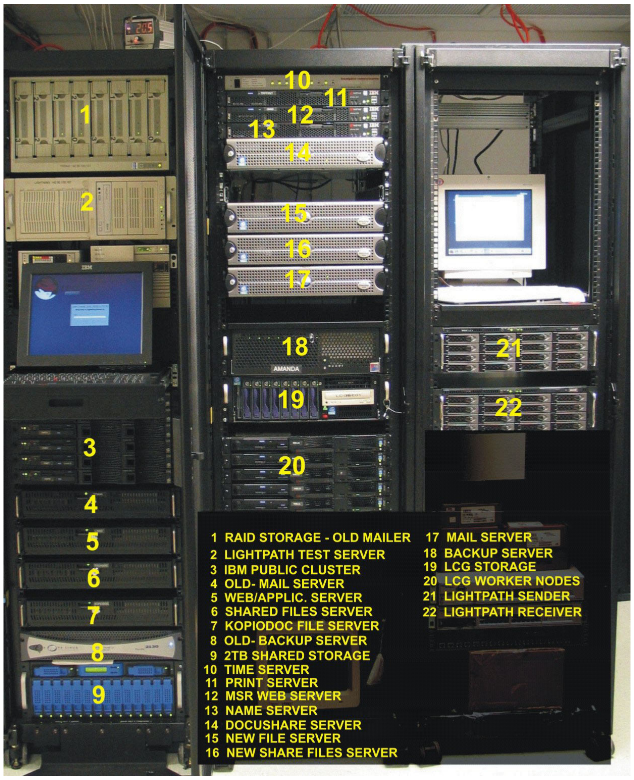


Fig. 144. Status of main components of the Computing Services hardware facilities.

CERN/ATLAS service challenges / IGT and 10 GbE developments

In order to develop an LCG presence at TRIUMF (reported elsewhere in this Annual Report) and in preparation for dealing with the upcoming service challenges relating to the CERN ATLAS experiment scheduled to start production mid-2007, two new staff members were hired. Hardware, based largely on the experiences acquired with the high-speed, long distance data transfers relating to the IGT developments (described below), is being ordered for delivery in early 2005.

A great deal of experience has been acquired as a result of various tests run over a 10 GbE linking TRIUMF and CERN. TRIUMF acquired two powerful servers with dual 3.2 GHz Xeon processors on a SuperMicro X5DPE-G2 motherboard with 4 GB of memory and 16 SATA150 120 GB disk drives connected to four 3Ware-9500S-4LP (later two 9500S-8) controllers as shown in Fig. 145.

Disk to disk I/O for the machines connected back-to-back via 10 GbE S2IO network cards transferred 10 TB in about 17 hours – an average rate of 180 MB/s. To test robustness a pair of 80 GB files were read continuously for 67 hours – some 120 TB, at an average rate of 524 MB/s. A short test was done to a single disk machine at CERN – limiting the rate to 30 MB/s – over a 10 GbE lightpath that was available for a limited time. Much was learned from back-to-back tests conducted between the two local servers in order to achieve sustainable, reliable, and cost effective high speed transfers across long distance networks.

Fig. 145. Servers used for back-to-back and TRIUMF–CERN data transfers over a 10 GbE lightpath.

Software developments

Physica and other data analysis Physica, is an internationally popular, general purpose data analysis/visualization program running on UNIX/Linux. The enhanced version for Windows, called Extrema, has now been largely ported back to Linux and converted to Open Source, making it more accessible to the global community.

Locally, this code was instrumental in merging the various field maps of the cyclotron's extraction region, contributing to the resolution of a long standing error in the transfer matrices used for extracted beam tuning.

User requested enhancements to Physica were added, including a new user interface based on the readline (FSF, Inc.) package and a new fitting technique based on the Marquardt algorithm. The libraries and executables are updated regularly on multiple platforms, and made available via anonymous ftp and download via the Internet.

Work continued on ROODY, a GUI written in C++ based on CERN-ROOT, which displays histograms and other objects (especially useful for monitoring on-line histograms). Significant enhancements were made to ROODY, including an XML save session facility, many on-line histogram display and control features, and context sensitive menu additions.

Beam dynamics

ACCSIM The multiparticle simulation code ACCSIM continues to be used in a wide variety of accelerator applications, principally for high-intensity synchrotrons and storage rings.

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

- J-PARC 50 GeV ring space charge studies;
- Beta beam decay ring for radioactive ions; and
- CERN-PS injection and acceleration of radioactive ions for beta beam.

The latter two applications are being prepared as part of TRIUMF's participation in the EURISOL beta beam study. This study, part of the four year EU-funded EURISOL project, will develop the design for a new type of neutrino factory using radioactive light ions, which are produced in an ISOL front end, accelerated to highly relativistic energies, and then injected into a racetrack-shaped storage ring where copious neutrinos will be produced from the ions via the beta decay process.

Numerical computing

FEMLAB The multi-physics PDE solver FEMLAB has a small but growing community of users at TRIUMF. It offers an interactive 2D and 3D modelling facility to define the geometry of the problem domain and boundary conditions, as well as the ability to import geometries from CAD systems. Via finite-element methods, solutions to a wide variety of physics problems can be efficiently obtained. The built-in graphics includes sophisticated 2D and 3D visualization and plotting capabilities.

For TRIUMF applications, there is a need for a scripting mechanism to control FEMLAB runs, and an efficient access mechanism to FEMLAB's data structures for accurate field interpolation and other post-processing. At present these functionalities are provided only through a third party product, Matlab, which fortunately is already licensed and available at TRIUMF. We have been in ongoing consultation with the maker of FEMLAB regarding performance and compatibility issues arising from this Matlab link. In the course of our discussions and local tests we upgraded FEMLAB to the new release 3.1 and Matlab to its latest release 7.0, which brought some performance improvement. Given effective scripting and application-programming aspects, and continued competitive pricing and support, FEMLAB has potential as an important scientific and engineering tool at TRIUMF.

Parallel computing Using a parallel application BeamX which simulates LHC beam-beam effects (see the CERN Collaboration section of this Annual Report), we conducted a benchmark survey of available parallel computing resources including the WestGrid Lattice CLUMP (CLUster of MultiProcessors) system at the Univ. of Calgary, the WestGrid Glacier facility at UBC, and the new Openlab cluster at CERN. Of these, the Lattice cluster was the clear leader, with performance at least a factor 2 better than the other clusters in a series of timing trials. The CLUMP architecture is designed to support rapid low-latency communication among small groups of processors in shared memory configurations, whereas the WestGrid-UBC and CERN clusters are based on commodity processors in blade or white-box packages, respectively. Additional performance tests on the blade system showed that the interprocessor communication speed for this application was independent of the location of processors. There was no performance advantage in allocating all processors within a single blade unit, utilizing only the blade's internal networking, as opposed to having them distributed among two or more blade units.

Infrastructure software

Agenda The TRIUMF Central Document Server Agenda was installed. It is a multi platform (Linux, Windows and Mac OS) tool used to help plan meetings, workshops and conferences, and associate for a long-term storage all possible attachments such as minutes of meetings, slides and even multi media. Agenda is used both to display schedules of meetings, and create and modify new ones. This tool, originally created at CERN for the CERN environment, required extensive modifications to many scripts and PHP files to make it useful for the TRIUMF users community.

The TRIUMF Central Document Server (TCDS), a product based on CERN's central document server (http://cdsweb.cern.ch) which uses a powerful search engine with Google-like syntax, electronic submissions and uploading of various types of documents, was initially proposed as the Central Document Server for hosting various kinds of collections. Creating it required a MySQL database, compiled PHP and Python applications. However, it was decided that Docushare, which can be found at http://documents.triumf.ca, would be used on site instead of TCDS until some real needs exceed Docushare's capabilities.

Docushare The document management system from Xerox, Docushare, was chosen largely because it was accessible for all platforms: Linux, Mac OS, as well as Windows. About $25 k was spent for a 100 user license and the Dell 2650 server running Redhat 8. So far the system has run smoothly for 6 months and it is planned to expand to a 200 user license early in 2005. There are currently about 3000 documents on the system.

Printing-Scanning-Copying

The new Kyocera colour printer has proven to be a reliable, cost effective alternative to the costly to run HP colour laser printers. In addition, a Xerox Pro40C colour laser printer/scanner/copier, installed in the office building mail room, is providing printing at a reduced overall cost – in the same manner as was done last year for monochrome printing. Due to the problematic and costly nature of printing, there is an ongoing process to review site printing-scanning-copying needs with the goal of reducing overall costs while improving capabilities.

Miscellaneous

After many years of neglect the public TRIUMF Web pages have been completely revamped – setting the stage for all the internal pages to be upgraded to this new style and standard in 2005.

TRIUMF, along with 11 other laboratories, submitted proposals to become the host site for a Central Design Team (CDT) of the next generation machine known as the International Linear Collider (ILC). This potentially enormous future project would have initially a very small management team coordinating resources in major laboratories around the world. If the CDT is awarded to TRIUMF, Computing Services would be involved with setting up infrastructure – mostly desktop computing and network connections to Paprican, a facility adjacent to TRIUMF.

Expanded support for videoconferencing included operating a Web cast server to record and transmit a number of events, including the EMMA review, TUG meetings, and some EEC sessions. In further support of videoconferencing at TRIUMF a second H.323 video appliance and projector were installed in the main office conference room, along with AccessGrid software on the PC used for VRVS video, which was moved from the adjacent small office. We continued to participate in the SLAC pinger and other network measurement efforts.

Data Acquisition Systems

(R. Poutissou, TRIUMF)

Overview

In 2004, the DAQ group continued to expand the number of DAQ systems around the site. Most of the new hardware deployed came from LADD purchases (see LADD section, p.128, this Annual Report). It now stands at 35 PCs (Table XXIII), 10 VME PowerPCs 604 and 9 VME VMICs, all managed by members of the group. These machines also provide some off-line analysis resources and disk storage (http://daq.triumf.ca/triumf_nodeinfo). Performance is monitored via Ganglia (http://daq.triumf.ca/ganglia).

Development of an on-line analysis package based on ROOT (http://root.cern.ch) continued. The package is now called ROODY.

MIDAS and ROODY

The basic MIDAS data acquisition package is in a stable condition and it is used throughout TRIUMF. Although its operation is stable, constant efforts are dedicated to improve MIDAS in order to keep it up-to-date with current analysis packages such as ROOT. This year this has been achieved with the help of Dr. Stefan Ritt and Matthias Schneebeli from PSI who came to TRIUMF for two weeks in September. The main improvements added are listed here. The MIDAS data logger can now produce ROOT files. On-line DAQ access to external databases such as MySQL (equivalent to the "runlog" option) has been added. The transition scheme has been modified allowing better control of the run transition sequences. The event builder scheme has been improved for simplified and more flexible handling of frontend equipment.

In parallel to these tasks, Matthias Schneebeli, the author of ROME, gave an introduction to this latest ROOT based stand-alone analyzer. ROME (http://midas.psi.ch/rome) is an OO generic analyzer framework builder, where the analysis definition is provided in XML format. The experiment specific class templates are then generated automatically, ready to receive the user code. ROME is fully MIDAS compatible for on-line and off-line data retrieval, and contains an interface to a standard database.

The other main project of the DAQ group is the development of a ROOT based GUI for histogram display. This is a continuation of the MIROODAS project started in 2003. This application has been renamed ROODY (ROOT display) to reflect the disconnect from MIDAS (http://midas.triumf.ca/roody/html). While ROODY can be used for on-line data display through the MIDAS analyzer, MIDAS is not a prerequisite for running ROODY. ROODY can also be coupled with the user specific ROME analyzer. Development and maintenance of ROODY is managed mainly by Joe Chuma.

DAQ systems

β-NMR and β-NQR at ISAC The operating system on all the DAQ machines for β-NMR and μSR experiments, and the test systems (dasdevpc, daqlabpc) were updated to Linux Red Hat 9. The DAQ systems had to be upgraded to work correctly under the new OS.

The "Dual Channel Mode" was proposed by the β-NMR group, where the beam will be alternated between the β-NMR and β-NQR beam lines. Required hardware modifications to the PPG boards for this mode were determined and made. The frontend code was modified to incorporate the Dual Channel Mode, and to ensure that the "Single Channel Mode" works in a similar way to the old code. Work began on the "randomized frequency scan" and the requested change in helicity flipping for mode 1g.

Table XXIII. Computer systems managed by the DAQ group.

Name	Location	Type
daqlabpc	DAQ lab machine	PII/232
dasdevpc	DAQ development Web server	PIV/1700
e614slow	TWIST Slow Control	2xPIII/750
epicsdragon	DRAGON EPICS Display	PII/300
epicsm15	M15 μSR EPICS	PIII/871
epicsm20	M20 μSR EPICS	PIII/400
epicsm9b	M9B μSR EPICS	PIII/550
isdaq01	ISAC-LE β-NMR TRINAT	2xPIII/450
isdaq02	ISAC-LE, GP2, LTNO	Cel/795
isdaq03	ISAC-HE, TUDA	2xPIII/550
isdaq04	ISAC-HE, DRAGON	2xAMD Ath/2000
isdaq05	ISAC-LE, ISAC users	PIII/1000-256
isdaq06	ISAC-HE ISAC users	PIII/1000
isdaq08	ISAC-LE, 8π	2xAMD Opt/2000
ladd00	LADD server	2xAMD Opt/1800
linm15	M15 μSR users	AMD Ath/1500
linm20	M20 μSR users	AMD Ath/1500
linm9b	M9B μSR users	AMD Ath/1500
ltno01	LTNO CR DAQ	2xPIII/600
midm15	M15 μSR DAQ	2xPIII/1000
midm20	M20 μSR DAQ	2xPIII/1000
midm9b	M9B μSR DAQ	2xPIII/1000
midmes01	Detector Facility	PIII/500
midmes03	RMC DAQ	2xPIII/550
midmes04	M11 DAQ	2xPIII/750
midmes05	Detector Facility	Celeron/335
midmes07	Neutrino Development DAQ	PII/400
midtis01	TRINAT DAQ	2xPIII/550
midtis02	Detector Facility	2xPII/450
midtis03	LTNO platform DAQ	PII/350
midtis04	GP2 DAQ	2xPIII/550
midtis05	8π Cryo	PII/300
midtis06	Osaka DAQ	AMD Ath/2000
midtis07	Pol/CFBS Slow Control	Cel/375
midtwist	TWIST DAQ	2xPIII/1000

Syd Kreitzman designed a new Pol Synth Module (PSM) which was built by the Electronics group. With the help of Syd, a new mode called the "Quadrature Modulation Mode" was implemented to exploit this new module, and the PSM was thoroughly debugged for use in the β-NQR experiment. The frequency scan code in the frontend was rearranged to incorporate the PSM code.

For POL, a new DAC scan was added to control the power supply for Expt. 920, replacing the old CAMP DAC scan. A readback of the DVM and Wavemeter was implemented. Support for a new experiment (P. Levy) to scan the NaCell was added, with a readback of the Faraday cup. A jump in the scan values (i.e. a discontinuous scan) was implemented for POL, also an up/down scan and a variable offset for the NaCell readback.

During 2004, Dave Morris continued to offer some much appreciated support to the DAQ group. In particular, we used his expertise with GPIB drivers on Linux and his knowledge of Agilent DVM instruments to set up hardware and software slow control for a high voltage unit. This HV provides retardation voltage for the collinear fast beam spectroscopy set-up and was a crucial element in the DAQ system used by Expt. 920 last year.

μSR systems

With the help of Stefan Ritt, during his September visit, the annoying μSR fragmented buffer problem for large data buffers was finally solved. The lastest version of MIDAS (1.9.5) was installed on all μSR DAQ machines. The μSR DAQ systems seemed to be quite stable throughout 2004, with relatively small modifications required.

No progress was made to commission a MULTI type μSR system due to the lack of a μSR software expert to write a suitable filter. In MULTI mode, the detector is segmented in 8 sections and the DAQ has to handle the equivalent of 8 parallel experiments.

TWIST DAQ activities

Ongoing modernization of the slow controls software was the main development activity on the TWIST DAQ in 2004. In particular, improvements to the M13 B1 and B2 dipole regulators were implemented. High precision measurements of muon polarization by the TWIST experiment require that the M13 beam line elements be controlled with precision and stability higher than that provided by standard TRIUMF magnet power supplies and power supply controls. We see 0.5–1 G changes in the magnetic field of the B1 and B2 dipoles caused by day-and-night temperature variations. We also see long term drifts in B1 and B2, up to 1–2 G over half a week. To improve the long term stability of B1 and B2, in 2002–2003, high precision fine DACs were added to the B1 and B2 magnet power supply controls and a closed-loop software regulation scheme was implemented. The MIDAS-based slow controls frontend reads the NMR probes installed inside the M13 B1 and B2 dipoles, filters the NMR readings, compares them with the NMR setpoints and minimizes the difference by adjusting the fine DAC controls via the M13 EPICS control system. Special care had to be taken to monitor and filter the NMR readings in order to avoid misregulation in the presence of spurious NMR readings caused by NMR signal degradation from radiation damage of the NMR probes. During the 2003 running of TWIST, B1 and B2 were regulated with a precision of 0.1 G, compared to the precision of 1–2 G without using the regulators. In early 2004 a hardware problem was identified and corrected in the implementation of the fine DAC controls, resulting in the improvement of controls precision from 0.03 G/LSB to 0.003 G/LSB. This resulted in an improvement of regulation precision from 0.1 G during 2003 to 0.02 G during the 2004 running of TWIST. The achieved regulation precision is better than what is required for TWIST. Further precision improvements are limited by the very-short-term stability of the magnet power supplies and by the quality of NMR measurements. The regulator system is highly robust and reliable and is now routinely used by experiment operators with minimal training and minimal expert intervention.

Another important improvement was the development of a “muon stopping position regulator”. The TWIST experiment stops the beam muons in a stopping target in the middle of the TWIST detector. To minimize the systematic errors in TWIST measurements, it is important to always stop the muons in the same place, to minimize any variation of the muon stopping position. The muon stopping position is controlled by adjusting the mixture of CO_2 and He gases in the gas degrader volume in the muon path: because muon loses more energy in CO_2, compared to He, increased CO_2 content makes the muons stop faster, moving their stopping position upstream. During off-line analysis, the muon stopping position is measured using one of several methods. While analyzing the 2003 data, we observed a correlation between the atmospheric pressure and the muon stopping position: the CO_2/He gas degrader is at atmospheric pressure and higher atmospheric pressure yields increased density of the CO_2 gas, with a bigger muon stopping power, so the muons stop faster and the stopping position moves upstream. This effect was estimated to be big enough to affect the ultimate precision of the experiment and, based on our positive experience with the B1/B2 magnet regulators, we decided to implement a regulator for the muon stopping position. This task turned out to be harder than expected. There is no direct control over the CO_2/He gas mixture: one controls only the gas flow rates into the degrader volume; gas mixture follows changes in flow rates, but the exact relation is unknown. There is no direct measurement of the muon stopping position: to obtain an adequate measurement, one has to analyze about 10–20 minutes worth of data, fill histograms and compute the average stopping position. Meanwhile, the atmospheric pressure changes and the stopping position moves. These difficulties with both controls and measurements reduce the reliability and robustness of normal proportional regulation schemes, like those used to control B1 and B2. Instead, a very simple relay regulator was used. If the muons stop too fast (too far upstream), the CO_2 flow is reduced by 1%, otherwise the CO_2 flow is increased by 1%. The gas flows are adjusted each time a new measurement of the stopping position is available from the on-line data analysis (QOD), with at least 20 minutes between subsequent adjustments, to let the gas mixture settle. The TWIST experimenters are presently assessing the effectiveness of this regulation scheme. Preliminary results indicate improved stability compared to 2002 operation.

Other experimental stations

The DRAGON system was upgraded from a standalone CAMAC system to a mixed VME/CAMAC system for additional functionality and speed increases.

The Canadian T2K Neutrino group which occupies the former ATLAS clean room continued their program of detector development studies. One of the standard CAMAC DAQ test stations deployed last year was replaced by a VME LADD system where software drivers were developed for the new hardware as well as support for on-line analysis and ROODY.

Support for external MIDAS users is still ongoing. Pierre Amaudruz spent one week at Los Alamos as a consultant on MIDAS.

Detector Facility

(R.S. Henderson, TRIUMF)

The TWIST experiment at TRIUMF (Expt. 614) is a sophisticated attempt to measure the Michel parameters to ten times the precision they are now known. The various subsystems of this experiment continued to function extremely well, but unfortunately, a human error with the gas system resulted in broken wires in 14 wire-planes from 11 detector modules. The cradle and detector stack were brought back to the facility for several months of module repair and bench testing. This has been completed. The cradle was returned to TWIST, the services connected. All detectors and readout channels are being tested prior to reinstallation in the magnet for upcoming data-taking.

A low pressure time expansion chamber (TEC) has also been built for use just upstream of the TWIST spectrometer. It will be used to measure the muon beam properties. The TEC was built and tested in the facility. These tests led Grant Sheffer to make some design changes that greatly improved performance. The TEC has also been thoroughly tested in the muon beam and will be used in the next data-taking run. A spare TEC will be fabricated and tested. This will mark the completion of the facility participation in the TWIST experiment, except for maintenance and repair.

The facility also had two other major repair efforts this year. The large drift chamber built and used for the RMC suffered major damage. The cause isn't certain, but a problem with the HV software is suspected. Many wires were broken and the repair took many months. This chamber has been re-installed and the readout is being checked for an upcoming experiment. Coincidentally, two of the MWPCs we built for the KVI spectrometer (Netherlands) also suffered damage. This was caused by the quenching gas running out. The two damaged chambers were shipped to TRIUMF, repaired and sent back to KVI.

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 and the $G\emptyset$ experiment (at TJNAF). The small 4-axis NC mill (refitted) in the shop allowed us to machine the complex curved scintillator pieces for $G\emptyset$. All seven scintillator sectors have been completed and shipped to TJNAF. Steve Chan also helped design a new yield station for the ISAC beam line and it was fabricated in the shop. More KOPIO prototype detectors were also fabricated in this shop, as were various pieces for the T2K liquid scintillator R&D.

The KOPIO experiment has been down-sized, the inner region (called the detector unit) was previously planned to have an active area of 2.1 m × 2.1 m. This has now been reduced to 1.5 m × 1.5 m, cutting the number of readout channels by approximately 25%. The updated design of the KOPIO module and components is complete and design studies for the difficult KOPIO installation issues are under way.

The KOPIO design (see Fig. 146) has four quadrants of preradiator 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 detector unit consists of eight drift chamber layers sandwiched between nine layers of extruded scintillator. The outer region (called the L-unit) will connect to, and support, the preradiator unit at the two orthogonal readout faces. Thirty-six Shashlyk calorimeter blocks will be mounted on these two edges of this L-unit, giving full calorimeter coverage in the experiment. Miniature coax cables will transport the 4608 anode/cathode signals past the Shashlyk blocks to six readout crates also mounted on the L-unit. In addition, both ends of approximately 1370 WLS fibres will pass the Shashlyk blocks to 40 PMTs (or APDs).

With each of the thirty-four preradiator modules 3.3 m × 3.3 m × 0.17 m in size and weighing approximately 1.8 tonnes, 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, prototyping, thermal expansion testing, wire-chamber structural tests and scintillator painting tests. A full size module is scheduled for completion in early 2006.

KOPIO is awaiting approval by the US funding agencies and NSERC. If approved, the KOPIO 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.

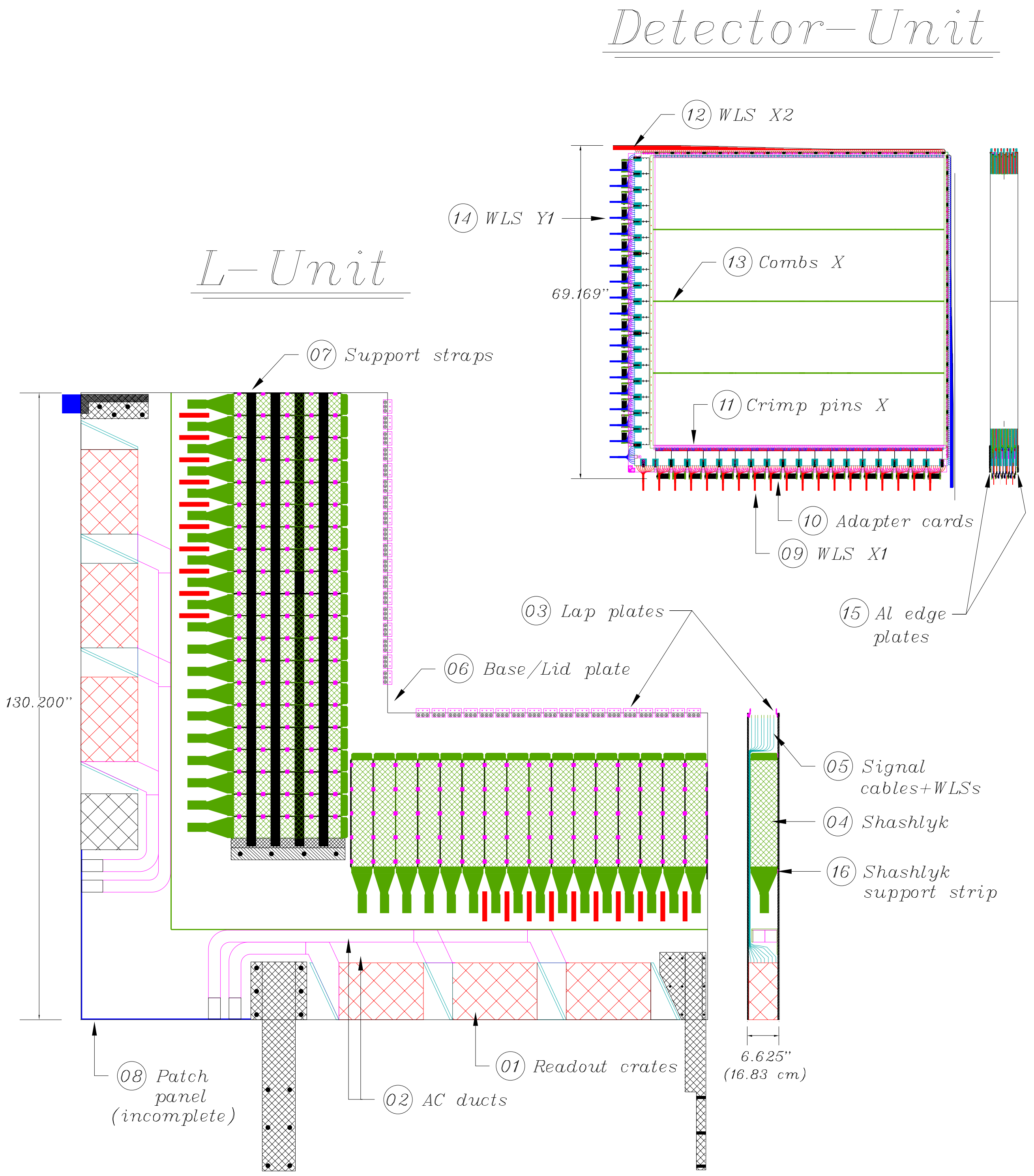


Fig. 146. Present design of KOPIO preradiator module.

A second major project is the T2K experiment planned for J-PARC in Japan. The TRIUMF T2K group and the detector facility are responsible for two of the major detector components. The first is the six large tracking TPCs (2.2 m × 1.25 m × 0.67 m). A small prototype of this TPC has been designed and is scheduled for fabrication by early 2006 (see Fig. 147).

The second is the two types of fine grain detectors (FGDs) that are between the three double-ended TPC gasboxes. These FGDs are ∼2 m × 2 m × 0.3 m. The

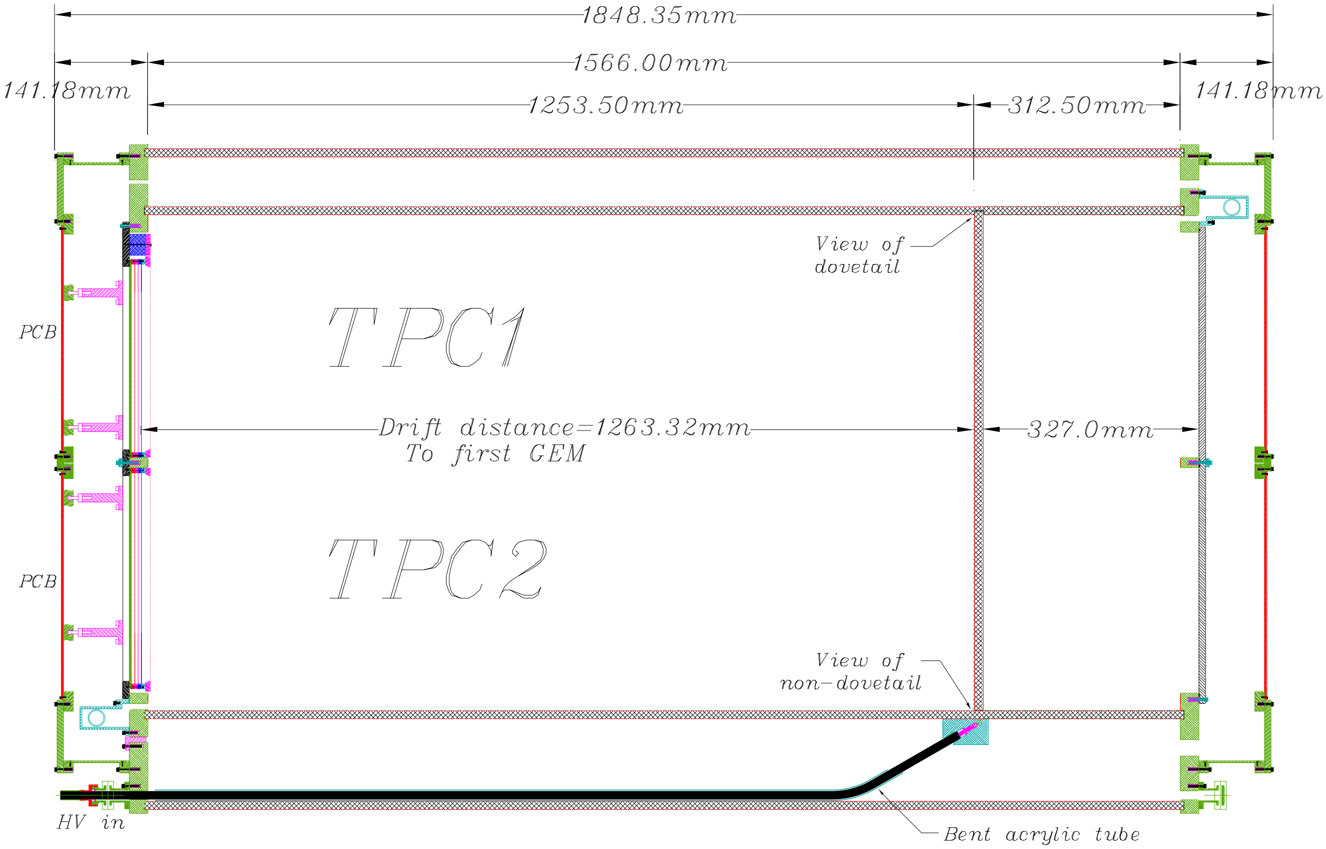


Fig. 147. Side view of T2K prototype TPC.

first type is made from thirty layers (alternating X and Y) made from extruded scintillator. Each layer would consist of two hundred 10 mm × 10 mm pieces with central holes). These 6000 scintillator pieces would be read out with WLS fibres and APDs. The second type of FGD would be thirty layers (alternating X and Y), each layer made from two extruded plastic panels (1 m × 2 m), each having one hundred 10 mm × 10 mm cells. These panels would be filled with liquid scintillator and read out with 1.5 mm diameter WLS fibres. Again, the 6000 fibres will be read out with APDs.

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. An important item that LADD will provide is a large (3 m × 3 m) router that will be used for both inspection and fabrication of the KOPIO and T2K detectors. Another LADD item already purchased and installed is a precision 5 ton crane in the large clean room.

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 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 group is active in some of the core activities of the collaboration, in areas of user support, documentation, testing and quality assurance. We have representation in the Technical Steering Board and in the Collaboration Board.

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 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 Base-Line 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. During the last year alone, we responded to inquiries from EXO (Enriched Xenon Observatory for Double Beta Decay), Milagro Gamma-Ray Observatory (a Water-Cherenkov detector in the Jemex mountains near Los Alamos), ICARUS (a LAr TPC proton decay and neutrino interactions detector at the Gran Sasso), from the LHC Physics Center (LPC) at FNAL, from CAST (CERN Axion Solar Telescope), n_TOF collaboration at CERN, the MACFLY project studying air fluorescence, the Panda experiment at GSI, Borexino, the LLNL/SNL Applied Antineutrino Physics Project, LHCb and CMS. We collected links to these experiments at http://www.triumf.ca/g4triumf/users/users.html

A computer science coop student from SFU, Trevor MacPhail, worked in our group for the first six months of 2004. As a result of his efforts, the G4 source distribution now comes with an excellent, extended, optical photon example. This application also helps the design of an advanced next generation LXe PET camera with improved background rejection. A phi-angle correlation exists in polarized Compton scattering between the two scattered annihilation photons because of their definite relative polarization at birth. This information becomes accessible in an active tracking medium where the photon interaction points can be observed individually. We also finalized the capability of spin tracking in GEANT4, spin precession at rest, followed by Michel decay relative to the momentary spin direction. This was a vital development before the TWIST experiment at TRIUMF could adopt GEANT4 as their simulation engine.

The G4 toolkit is now in public release version 7.0 and is available for a variety of operating systems.

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

Laboratory for Advanced Detector Development (LADD)

(J. McKay, TRIUMF; D. Bryman, UBC)

During the past year, LADD funds were used to purchase equipment to support a variety of detector development directions as indicated in the LADD CFI proposal.

The electronics laboratory component of LADD continued development of infrastructure for design and development of electronics readout systems. The KOPIO and Liquid Xenon projects will make particular use of this equipment. Purchases this year have focused mostly on additional test and measurement equipment (such as waveform/pulse generators and power supplies), tools, and parts storage. There have also been some new software items purchased to aid in design tasks.

The LADD electronics equipment has been extensively used for development and evaluation of detector components. KOPIO and T2K have instrumented their prototypes with LADD equipment such as NIM and VME crates, VME data acquisition modules, high voltage systems, etc. as well as auxiliary devices such as oscilloscopes, multimeters, power supplies and computers. The nature of this development requires advanced electronic equipment which is essential to a proper development set-up. The contribution of LADD has significantly facilitated this development by providing state of the art electronic infrastructure.

Equipment has also been purchased for the detector facility. Major purchases include a quadrupole mass spectrometer and a crane for the clean room. This equipment will be used to facilitate projects with large complex detectors such as KOPIO, Liquid Xenon, and neutrino detector projects.

As mentioned above, equipment purchased for the electronics laboratory and the detector factility are being used to support the KOPIO project. KOPIO chamber development and prototyping has been taking place. Mechanical development and prototype work has been aided by various hand tools, computers, and software. One large development project has been the fibreglass wire chamber frames and sheets. The maximum size of G10 sheets commercially available is too small for our chambers if we want to keep them joint free. Working with a Vancouver Island company (Profile Composites), a method has been developed to make G10 sheets and chamber frames as large as the wire chambers. This will result in chambers with higher mechanical strength and make the assembly easier and more economical.

Another part of KOPIO is scintillator development. KOPIO is developing a technique to produce extruded scintillator at a local company (Celco Plastics). The scintillator planks will be glued using a tongue and groove method to make large sheets of scintillator of the desired size. There is substantial cost savings in using this extrusion technique over buying cast scintillator sheets. These sheets will be machined at TRIUMF using a machine purchased by LADD. Research and testing to determine the best type of machine has been taking place. The machine will also be used to machine wire chamber frames and cathode strips, among other things. Good results have been achieved with a router, which will likely be purchased in 2005, and will double as an inspection table.

The Liquid Xenon facilities development project has also been made possible by LADD. Various materials (such as ceramic feedthroughs, UHV valves, UHC flanges, vacuum fittings, macor, and stainless) and instrumentation were purchased for building a cryostat and gas handling system. A control system has been developed, and assembly of the cryostat and gas handling system are well under way, with testing to start in 2005.

In addition, equipment has been purchased for DAQ systems, including VME scalers, high voltage modules, TDCs, ADCs, and VME crates. Another advanced detector development area that that is being enhanced by LADD infrastructure involves neutrino detectors.

During 2004, LADD funds were used to purchase extensive computing, real time data acquisition, high voltage supply equipment, and advanced photodetetors. This equipment was used to evaluate different photosensors for use in the fine-grained neutrino detector (FGD) to be built for the T2K neutrino oscillation experiment at Tokai in Japan. As part of the reference design for this detector, it is planned to use extruded bars of scintillator with either an active or passive water component, and with wavelength shifting (WLS) fibre used to transport the light to some kind of photon detector.

Measurements were carried out with this apparatus to compare the performance of the SiPMs with multiianode PMTs (MAPMTs). Work using LADD facilities has reached the following conclusions:

1. The SiPMs work best at a bias voltage of around 52 V, where the gain is a few $\times 10^5$. This is about an order of magnitude lower than that of a MAPMT, and will necessitate the use of a preamp with a gain of 20–30 if the SiPM is chosen.
2. The quantum efficiency of the SiPM is about 30% better than the MAPMT, and is about equivalent to that of a good green-extended PMT.
3. The pulse height resolution of the SiPM is much better than the MAPMT, and clear peaks corresponding to 1 pe, 2 pe, 3 pe... can be seen.
4. The timing resolution of the SiPM is adequate, and almost certainly better than the time spread produced by the WLS fibre at low light levels.
5. The single photoelectron noise (or dark current) count rate is substantially higher for the SiPM compared with the MAPMT. It is a function of bias voltage, and was measured to be about 1 MHz at 52 V.

Scientific Services

(M. Comyn, TRIUMF)

The Scientific Services group encompasses the Publications Office, Library, Information Office, and Conferences. Its activities during 2004 included: producing the 2003 Annual Report, conference abstract booklet and proceedings, and the TRIUMF preprints; maintaining the Library; coordinating TRIUMF tours and assisting with the production of public relations materials; and supporting eleven past, present and future conferences and workshops. The primary focus of the group throughout the year concerned all aspects of hosting the NIC8 conference in Vancouver in July.

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 2003 report was available to readers five weeks before the printed version. It contained a record 331 pages and 320 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 and mailed, with subsequent major cost savings.

TRIUMF preprints are 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 two fronts with the kickoff for the TRIUMF Annual Report Scientific Activities 2003 submissions, and the receipt and processing of abstracts for the Eighth International Symposium on Nuclei in the Cosmos (NIC8), which was held in Vancouver, July 19–23. Many aspects of handling the abstracts were based on those developed for the EMIS-14 conference in 2002. However, this time the abstracts were ranked by the International Advisory Committee via a secure Web form to determine which should be presented orally rather than as a poster. Although the abstract submission deadline was April 2, half of the 211 accepted abstracts were submitted later. A draft program was produced in late May by the local organizing committee, and an almost final version was posted on the conference Web site in early June. However, the program remained fluid with late cancellations, additions and changes, resulting in the final 224 page abstract booklet only being sent to the printer a week before the conference began. Publications Office staff manned the Proceedings Office during the conference, accepting manuscripts in both hardcopy and electronic formats. As the proceedings will be published as an edition of Nuclear Physics A in 2005, all contributions had to be refereed. This is a complex, time-consuming procedure which had still not been completed at year end. Unlike EMIS-14, no manuscripts were assigned to referees at the conference. Therefore, to speed up the process, nearly all communications with the referees were via e-mail with scanned manuscripts and referee information sheets being sent as PDF attachments. By avoiding the use of conventional mail (which often added a month in transit time for the EMIS-14 refereeing, even within North America), communications were much faster. All transactions were logged on a database.

Web site and other support was provided for the TRIUMF Summer Institute, held July 5–16.

Due to the workload this year, activities on the Joint Accelerator Conference Website (JACoW) committee were completely curtailed.

Library

The Library budget was increased in 2004 to compensate for rising journal subscription costs, 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 194 tours for 1663 people during 2004. The general public tours were conducted by a summer student during the June to August period when tours were offered twice a day. 153 people attended one of the 46 tours conducted 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 XXIV 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 1999–2004. 2004 saw a decline in all numbers in all categories, except for science, compared to recent years. The 2004 numbers were very similar to those for 1999. This can be ascribed to many factors. For the general public, TRIUMF had not featured so prominently in the local media during 2004. For students, the lack of a professional development day event for the BC physics teachers in October, 2003 undoubtedly had an effect. Finally, there were fewer VIP visitors in 2004 following increased numbers in the previous three years associated with ISAC-II construction and the Five-Year Plan review in 2003. The four categories are defined as follows:

- 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, scien-

tists 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 TRIUMF Summer Institute, 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, continues to receive well over 5000 visits each year. No maintenance was performed during the year as the content is being superceded by the new public Web site http://www.triumf.info which became operational during the year.

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

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

Table XXIV. Breakdown of TRIUMF tour numbers for the period 1999–2004.

Category	1999	2000	2001	2002	2003	2004
General Public						
# people	350	368	421	499	482	399
# tours	96	107	110	131	126	109
# guides	96	107	111	134	126	111
Science						
# people	384	294	383	592	651	729
# tours	18	20	30	23	34	36
# guides	33	26	43	57	59	70
Students						
# people	794	612	839	894	626	440
# tours	46	40	30	40	38	23
# guides	70	53	60	70	50	35
VIP						
# people	145	171	258	193	260	95
# tours	37	37	59	53	63	26
# guides	38	40	65	55	71	26
Total						
# people	1673	1445	1901	2178	2019	1663
# tours	197	204	229	247	261	194
# guides	237	226	279	316	306	242

Conferences

Support was provided for four conferences and workshops, along with preparations for seven conferences and workshops in 2005 and beyond. Registration databases were created and managed for all of the conferences and workshops.

TRIUMF hosted or supported the following conferences and workshops in 2004:

- Fixed Field Alternating Gradient Workshop (FFAG 2004), TRIUMF, April 15–21 (23 delegates).
- TRIUMF Summer Institute 2004 (TSI2004), TRIUMF, July 5–16 (38 delegates plus 8 lecturers).
- Eighth International Symposium on Nuclei in the Cosmos (NIC8), Vancouver, July 19–23 (237 delegates).
- Fifth International Symposium on Radiohalogens (5ISR), Whistler, September 11–15 (74 delegates).
- TRIUMF Users' Group Annual General Meeting, TRIUMF, December 8 (58 delegates).

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

- ICFA Workshop, February 10–11, 2005.
- Western Regional Nuclear and Particle Physics Conference (WRNPPC'05), Banff, AB, February 18–20, 2005.
- 2005 CAP Congress, UBC, June 5–9, 2005.
- TRIUMF Summer Institute 2005, TRIUMF, July 11–22, 2005.
- Trapped Charged Particles and Fundamental Interactions (TCPFI 2006), Parksville, September, 2006.
- Linear Accelerator Conference (LINAC08), Vancouver, September 29 – October 5, 2008.
- Particle Accelerator Conference (PAC09), Vancouver, May, 2009.

The DRAGON Facility

(D. Hutcheon, TRIUMF)

DRAGON is a facility at ISAC for the study of radiative capture reactions by inverse kinematics, in which the beam is the heavy reactant and the target is the lighter one. The focus of study is to measure reaction strengths of relevance in nuclear astrophysics, but the facility has been used for nuclear structure experiments as well.

The principal parts of the facility are a windowless gas target, an array of scintillators around the target to detect capture γ-rays, a mass separator to transmit heavy recoil products while suppressing beam particles, and a gaseous or solid-state detector of the recoil ions.

DRAGON was used to study radiative capture of protons by unstable beams of ^{21}Na (Expt. 821) or ^{26}Al (Expt. 989), capture of alpha particles by a stable beam of ^{12}C (Expt. 952) and capture of ^{12}C target nuclei by nuclei of a ^{12}C beam. Results from these experiments are presented elsewhere in this Annual Report. Here we describe improvements in the DRAGON facility in 2004 and tests aimed at possible future improvements.

Data acquisition system

Noise problems with elastic-scattering surface-barrier detectors were fixed, with implementation of a second surface-barrier detector at a higher lab angle with respect to the beam axis.

Electronics housed in one crate near the gas target were split between two crates, one still at the gas target and one at the tail of DRAGON. All required signal exchange between the two crates is now performed via ECL. Both crates are housed in racks which have improved cooling to suppress erratic behaviour of the electronics at high temperatures, a problem which can occur with hot weather in the summer months. The number of ADCs and TDCs in the tail crate was doubled to allow a more permanent addition of extra detectors. The existing scaler modules were upgraded, doubling the number of available scaler channels. The DSSSD electronics have been upgraded to allow readout of both front and back strips providing complete detector pixelization. MCP local time of flight has also been implemented and can be used in conjunction with other heavy-ion detectors at the tail of DRAGON to improve ion separation.

Traditional CAMAC readout of the data has been replaced in favour of readout through a vxWorks-based VME interface, decreasing dead-time on each memory module readout. The frontend software has been changed to run on the vxWorks system to enable the new readout scheme. The on-line analysis was rewritten using the ROOT framework in a totally object-oriented manner.

The HV calibration program has been rewritten to allow interaction with the new on-line system and to provide a quick means to change the BGO detector-array voltages rapidly.

Ion chamber gas control system

The ion chamber detector of recoil ions uses isobutane gas at pressures that are typically in the range 5 to 15 torr with gas flow of about 100 cc/min. Ions enter the gas through a window which must be as thin as possible to minimize energy straggling. The pump-down, filling, operation and venting of the ion chamber must be carried out very carefully to avoid destruction of the thin window. Initially, these operations were carried out by users operating manual valves and following a lengthy written procedure.

In order to make ion chamber operation easier and safer, the manual system was replaced by one controlled through EPICS and having interlock protection provided by a programmable logic controller (PLC). Some interlocks on valves had to change in a state-dependent way, according to whether the chamber was being roughed, filled, operated or vented. A different set of conditions had to be applied when the ion chamber was replaced by the vacuum box for solid-state detectors.

The connection of vacuum and gas handling devices to the PLC was accompanied by installation of a "burst-puck" and shield, as a safety measure for the (unlikely) scenario of formation and ignition of an air-isobutane mixture in the ion chamber. High voltage to the ion chamber grid wires is enabled only when there is an expected isobutane flow rate, indicating the absence of dangerous air leaks into the system.

Monitors of beam contamination

For certain experiments it is necessary to monitor the level of beam contamination. We have installed two additional diagnostics at the mass slit box to accomplish this feat: 1) a germanium detector mounted beside mass slit box at beam height, and 2) a positron-catcher plate coupled to two NaI detectors mounted oppositely in close geometry surrounding the plate on top of the mass slit box. These detectors take advantage of the mass dispersion at the mass slit box which causes the beam to be deposited on the left mass slit plate while passing recoils through the slit opening. These new detectors complement the pre-existing plastic scintillator for counting betas that is sensitive to both electrons and positrons. The positron catcher assembly can be used to identify positron emission only, while the germanium detector can be used to identify characteristic γ-rays emitted from either the beam or a contaminant thereof.

As an example, in the case of Expt. 989 (^{26}Al(p,γ)), two beam contaminants were identified in early running, first by our beta counter then later at the yield station and finally using our new set-up. The possible beam contaminants are ^{26}Na(β^-, $T_{1/2} = 1.08$s, $E_\gamma = 1.809$ MeV), $^{26\text{m}}$Al(EC, $T_{1/2} = 6.34$ s, β^+), ^{26}Si(EC, $T_{1/2} = 2.23$ s, β^+, $E_\gamma = 0.829$ MeV (BR = 21%)), and ^{26}Mg(stable). Due to the nature of the SiC surface ion source, the magnesium and silicon components are absent. Thus, the positron-catcher is used to determine the level of $^{26\text{m}}$Al contamination only, while the germanium detector monitors the level of ^{26}Na (via detection of $E_\gamma = 1.809$ MeV) and $^{26\text{m}}$Al (via detection of E_γ

= 0.511 MeV). The ^{26}Al beam with its 720,000 year half-life is effectively stable.

For a more detailed description visit http://dragon.triumf.ca/nai.html.

A “switchyard” for end detectors

Two vacuum enclosures have been used to contain recoil ion detectors: a machined box in the form of a 20 cm cube housed silicon strip detectors, and a 25 l cylinder enclosed a low-pressure gas ionization chamber. The two types of detector have been exchanged frequently, sometimes during the course of a single experiment. The ionization chamber was mounted on a trolley which could be rolled forward when that detector was to be used, but the heavy strip detector box had to be lifted into place by hand in a procedure that required two people.

The installation of the strip detector box was simplified by the addition of a linear bearing running at right angles to the trolley track. It allows the box to be moved into the correct position without lifting, so that one person can carry out a change of detectors much more easily and quickly than before.

Improved ion chamber energy resolution

Standard mylar windows with a thickness of 130 μg/cm^2 and thin polypropylene (PP) windows of 55 μg/cm^2 have been used as entrance window for the DRAGON ion chamber (IC) at higher energies with sufficient resolution (e.g. $\Delta E/E = 1.7\%$ FWHM for ^{28}Si at 750 keV/u) [Chen for the DRAGON collaboration, Nucl. Instrum. Methods **B204**, 614 (2003)]. However, for A > 20 ions at low energies the energy-loss straggling in the entrance window, about 24% for PP and 45% for mylar, degrades the energy resolution to 5–10%, not enough for a separation of recoils from leaky beam at the end detector. In order to improve the separation power of the IC at low energies (e.g. 188 keV/u ^{26}Al), new foils were tested.

Amorphous silicon nitride (SiN) membranes can be made as thin as a few times 10 nm. For our tests we used 50 nm (=17 μg/cm^2) SiN membranes with a size of 5 × 5 cm^2 up to pressures of a few 10s of torr. The anode of the IC was modified to have two main segments each of 10 cm length and a third segment of 5 cm length at the end as an optional veto. First spectra of ^{12}C and ^{16}O at 179 keV/u show the improved energy resolution of 3.1% and 2.6% (Fig. 148). Due to the high homogeneity of the SiN membranes, low-energy tails are significantly reduced. This is particularly important for proton capture reactions where the expected recoils have slightly less energy than the leaky beam. With this set-up the resolution is dominated by electronic noise, mainly from the preamplifier, which is in the order of 40 keV. As a next step we plan to install new low-noise preamplifiers directly onto the anode board, which will greatly reduce input capacitance and noise pick-up. For heavier ions at low energy it has been shown [Doebeli *et al.*, Nucl. Instrum. Methods **B219-220**, 415 (2004)] that an improved ion chamber with thin SiN entrance window can outperform silicon solid-state detectors, which suffer from relatively large intrinsic dead layers (about 600 nm Si equivalent).

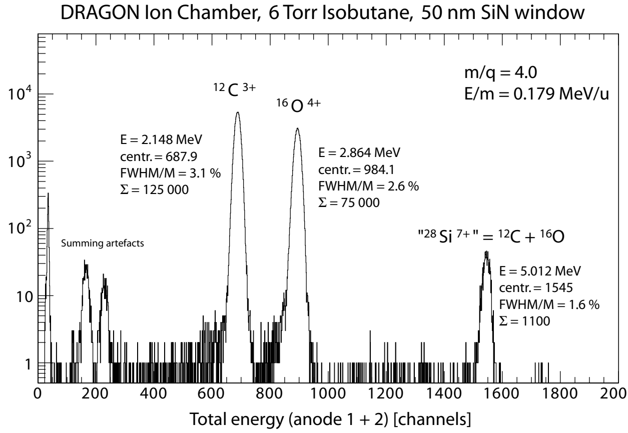


Fig. 148. DRAGON segmented ionization chamber response to C and O ions.

Local time of flight (TOF) can provide better separation than energy measurement at low ion energies, since flight time increases at lower energies, while the time resolution is independent of the flight time. Even with a moderate TOF resolution of 1.5 ns FWHM and a 0.5 m flight path, TOF gives better separation than E-detectors with 3% resolution for energies below 500 keV/u [Lamey, M.Sc. thesis, Simon Fraser University (2004)]. However, thin carbon foils (20 μg/cm^2) used for the start MCP detector can introduce significant energy-loss straggling and angular scattering. To improve the detector performance, we tested ultra-thin diamond-like carbon (DLC) foils having a thickness of only 0.6 μg/cm^2, which are supported by a mesh of about 80% transmission [Liechtenstein *et al.*, Nucl. Instrum. Methods **A521**, 197 (2004)]. With ^{21}Ne beam we could demonstrate negligible angular scattering compared to 20 μg/cm^2 carbon foils. However, the thickness of these DLC foils is less than the escape length of secondary electrons (about 5 nm), reducing the number of secondary electrons and thus the pulse height at the MCP anode, which is used for a position signal. For our planned second MCP we will install a large DLC foil with a thickness of about 4 μg/cm^2 and supported by a mesh of 99% transmission, a compromise between secondary electron yield and angular scattering.

Solid target mount

The 9-position solid target system was used successfully by Expt. 947, which required a target of ^{12}C in the form of a thin foil. Mounted on a plate which could replace the standard side-plate of the windowless gas target box, the chain of targets could be driven under EPICS control of a stepping motor to any one of 9 pre-set positions. Two target positions were dedicated to collimators used in beam tuning. A third target, a microscope glass slide coated by a thin carbon layer, gave a visible spot when struck by beam and was an additional beam-tuning diagnostic.

Beam visualization by CCD camera

A CCD camera viewing the target cell along the zero-degree axis is able to detect light produced when ion beams of nanoampere intensity pass through hydrogen or helium in the gas target. It is displayed using commercial software designed for amateur astronomers. Thanks to a custom modification of the software, it is possible to log beamspot intensities and $x - y$ centroids while data-collection runs are in progress.

8π Spectrometer

(G.C. Ball, TRIUMF)

During the past year the ancillary detector systems for the 8π spectrometer were further augmented with the fabrication, installation and commissioning of PACES, a pentagonal array of SiLi detectors for conversion electron spectroscopy measurements. A view of PACES, which replaces the upstream half of SCEPTAR, is shown in Fig 149. The first experiment to use PACES and SCEPTAR was the study of coexisting collective phases in ^{156}Dy from a detailed measurement of the β-decay of ^{156}Ho. The results of this experiment led by D. Kulp are reported separately (see Expt. 973, this Annual Report).

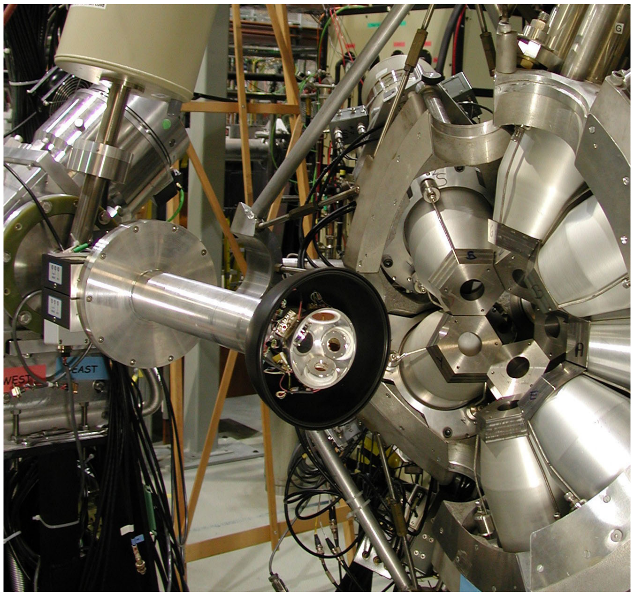


Fig. 149. Photo of PACES installed on the 8π beam line.

In June a ^{26}Na beam was used to measure the time response of SCEPTAR and characterize the performance of BaF$_2$ detectors when integrated into the 8π array. A proposal led by P. Garrett (see Expt. 984, this Annual Report for details) to build an array of 10 BaF$_2$ detectors for fast (down to 10 ps) lifetime measurements of gamma-decaying excited states populated in the β-decay of exotic nuclei was submitted to NSERC in October.

Once again, the 8π data acquisition system (see TRIUMF 2002 Annual Report for details) was extended to include separate FERA readout buses and VME triple port memory modules for both the PACES and BaF$_2$ arrays.

During the initial running of Expt. 921 (see Expt. 921, TRIUMF 2003 Annual Report) it was determined that to prevent contaminating the 8π vacuum chamber with small quantities of long-lived isobaric contaminants the vacuum in the section of LEBT immediately upstream of the 8π spectrometer had to be improved to reduce the probability of charge exchange collisions and subsequent loss of beam. As a result, an additional 550 l/s turbo pump was added and the 550 l/s turbo pump on the LEBT box connected to the 8π vacuum chamber was replaced with a 1000 l/s pump. In addition, the SCEPTAR array was removed and replaced with a simplified chamber with removable liners. In the spring, extensive measurements were carried out searching for new high-K isomers in the mass 170 region. A new 2.3 s isomer was discovered in ^{174}Tm (see Expt. 921, this Annual Report).

The use of the 8π γ-ray spectrometer for high-precision β-decay lifetime measurements is also being pioneered at ISAC. This lifetime technique has been investigated extensively for the β-decay of ^{26}Na (see Expt. 909, TRIUMF 2002–2003 Annual Reports). The first high-precision lifetime measurement of a superallowed β-emitter was carried out for the $T_z = 1$ nucleus ^{18}Ne for which the Fermi decay to the analogue 0^+ level in ^{18}F at 1042 keV is only a 7.7% branch. A beam of $\sim 4 \times 10^5$ ^{18}Ne ions/s was obtained during the first ECR ion source development run (see Expt. 985, this Annual Report for more details).

Two other 8π experiments received beam in 2004, namely a study of the beta-delayed neutron decay of ^{11}Li (Expt. 1008) and a high-precision measurement of the branching ratio for the superallowed β-emitter ^{62}Ga (Expt. 823). These experiments demonstrated that SCEPTAR, in combination with the 8π spectrometer, is a powerful tool for studying the beta decay of exotic nuclei. In particular, since the SCEPTAR array has approximately the same geometry as the HPGe detector array, by vetoing those events where the β particle and the γ-ray are detected in the corresponding

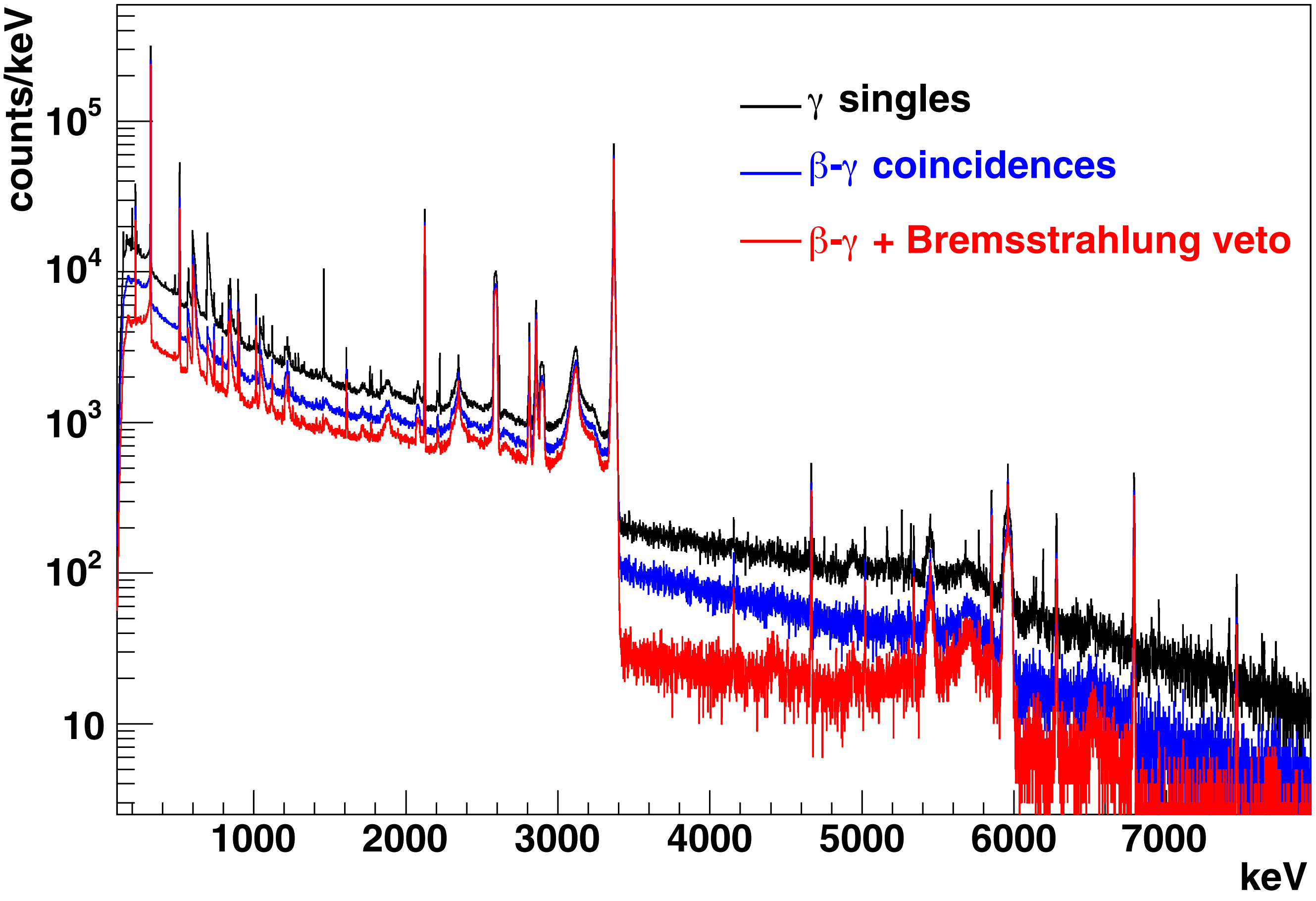


Fig. 150. γ-ray spectra observed in the β-decay of ^{11}Li: 1) the upper (black) histogram is γ singles, 2) the middle (blue) histogram is the γ spectrum obtained in coincidence with βs detected in SCEPTAR, and 3) the lower (red) histogram is the γ spectrum obtained in coincidence with SCEPTAR and with the bremsstralung veto condition applied.

plastic and HPGe detectors, the bremsstrahlung background can be reduced substantially. This is illustrated in Fig 150. Both of these experiments are reported in more detail elsewhere in this Annual Report.

There are currently 15 approved ISAC experiments that will use the 8π spectrometer (Expts. 823, 909, 921, 929, 954, 955, 957, 961, 973, 984, 985, 988, 1007, 1008, 1028) including three which were approved by the TRIUMF EEC in 2004. 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: 3 undergraduate students, 7 graduate students and 10 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 energy resolution is needed. TIGRESS (TRIUMF-ISAC gamma-ray escape suppressed spectrometer) will satisfy this need. Two key features of TIGRESS are: a) rapidly reconfigurable escape suppression, and b) digital sampling of waveforms from high-purity germanium signals. These have been discussed in previous Annual Reports.

In 2004 the collaboration has built on last year's accomplishments, highlighted by: 1) continued testing of the high-purity germanium (HPGe) clover, and specification and ordering of twelve clover germanium units; 2) assembly of the prototype support structure; 3) suppressor performance testing; 4) signal simulations; 5) production of the first, revision 0 TIG-10 card. Many of the details of these developments may be found in recent publications [Scraggs *et al.*, Nucl. Instrum. Methods **A543**, in press; Svensson *et al.*, Nucl. Instrum. Methods **A540**, in press].

HPGe clovers

The prototype HPGe was returned to France for installation of two retrofits, one for the side- and back-suppressor mounting hardware, and one for electromagnetic shielding between outer-contact FETs. On return, integrated noise spectra and position sensitivities were measured. The full results of all the prototype clover tests have now been published [Scraggs *et al., op. cit.*; Svensson *et al., op. cit.*]. Based on these tests, the production HPGe clover units were specified and ordered, to be delivered at a constant rate with the twelfth unit scheduled for arrival in 2009.

Support structure

One of the key features of TIGRESS is its ability to be redeployed from a close-packed, high-efficiency configuration to a fully-suppressed, high peak-to-total configuration (Fig. 151). This presents a mechanical design challenge, and a prototype single-detector stand was fabricated for this purpose. Components for the single-detector stand were fabricated at TRIUMF and the University of Guelph (Fig. 152).

The prototype identified several operational deficiencies, primarily in the motion of detectors in their fully-inserted configurations. For the clovers, this has been addressed by repositioning the stop rods on their carriages. The side shield mechanisms continue to be reviewed. Nevertheless, the overall support system is adequate, and a mechanical engineering analysis will be performed in parallel with detailed design in 2005.

Suppressor tests

The single-unit prototype support structure also facilitated measurements of suppressor performance. Prototype suppressor shields (Fig. 153) were mounted in the single-unit stand (Fig. 154). Figure 155 compares the spectral shapes for a typical monoenergetic source, while Table XXV gives efficiency and peak-to-total performance for the prototype clover and shields in the fully-suppressed, collimated, configuration. The full details of the analysis with a variety of sources and detector configurations are to be published in the Master's thesis of Mike Schumacker at the University of Guelph.

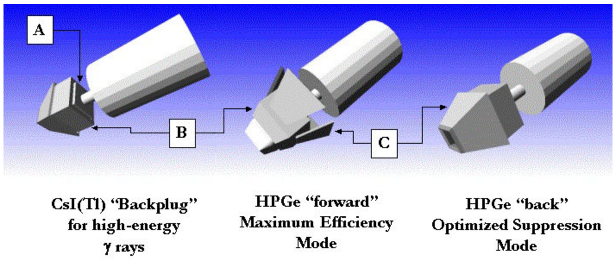


Fig. 151. Suppression scheme comprising three components: A) back-catcher, B) side shields, and C) front shields.

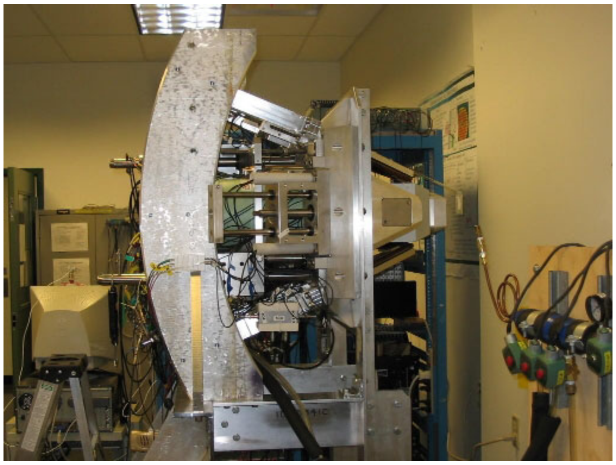


Fig. 152. Single-detector stand for testing mechanical mounting scheme and suppressor performance.

Fig. 153. Prototype suppressor shields.

Fig. 154. Close-up view of clover and front plates. The side and bottom plates in the picture are withdrawn to show the clover and top plate in their high peak-to-total configuration.

Revision 0 TIG-10 card

Because ISAC-II beams will approach 10% the speed of light, any nuclear reactions involving these beams will emit γ-rays from sources moving up to that speed as well. The Doppler shift in the resulting γ-rays can be corrected and transformed back to the source frame if the angle of emission relative to the source velocity direction is known. This requires knowledge

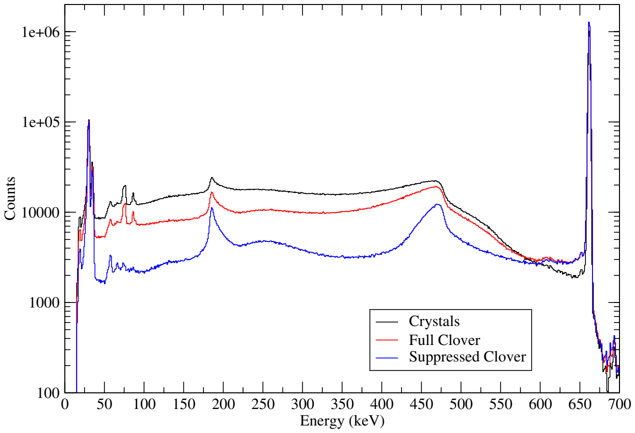


Fig. 155. Spectrum of a ^{137}Cs source with the detectors in the fully suppressed configuration, in single-crystal mode, addback mode, and addback with suppression.

Table XXV. Experimentally determined peak-to-total ratios (P/T) for test sources, measured with the prototype TIGRESS detector in the back (optimized peak-to-total) configuration, with hevimetal collimation.

Source	Parameter	Value
^{137}Cs	P/T crystals	24.9%
	P/T clover	39.7%
	Add-back factor	1.340
	P/T suppressed clover	59.9%
	Photopeak veto probability	0.19%
^{60}Co	P/T crystals	16.5%
	P/T clover	28.8%
	Add-back factor	1.437
	P/T suppressed clover	49.9%
	Photopeak veto probability	1.58%
^{88}Y	P/T crystals	16.0%
	P/T clover	27.7%
	Add-back factor	1.435
	P/T suppressed clover	47.7%
	Photopeak veto probability	1.39%

of the first interaction location of the γ-ray. The electrical waveforms generated by the nuclear event carry information about interaction locations, so that one can measure the emission angle of the γ-ray, in principle, with enough precision that the uncertainty introduces an error in energy comparable to the intrinsic energy resolution of germanium. The two key elements needed to realize this are sufficiently segmented outer contacts [Svensson *et al., op. cit.*] and waveform sampling and analysis.

In the case of TIGRESS, waveforms will be sampled and events compiled using technologies similar to those developed for KOPIO (see the Particle Physics section of this Annual Report). The TIGRESS data acquisition will be built on "TIG-10" modules, ten-channel 14-bit 100 MHz digitizers in VXI-C packages. The single-channel 14-bit 100 MHz flash-ADC sampler developed and tested last year has been integrated into a Rev 0 prototype TIG-10 module. This was delievered from Université de Montréal in late 2004. The prototype is configured and read out by a VME interface. By the end of the year, the TIG-10 prototype was incorporated into a TRIUMF-standard MIDAS set-up. Waveforms were captured and logged, demonstrating the basic functionality of the module. Futher testing to improve pole-zero corrections and to implement a low-voltage differential serial (LVDS) communication to so-called "collector" (TIG-COL) and master trigger cards will continue in 2005.

Signal simulations

To fully exploit the pulse shape analysis potential of TIGRESS, it is necessary to understand the response of the detector at all positions. While these responses can be measured, it is very time consuming, and it is impossible for the inner quadrants of each detector. Instead, the pulse shapes must be simulated. Although the theory for pulse shape generation is well established, the simulations must nevertheless be verified.

Work in 2004 focused on two major efforts. The first was to rewrite the codes to be more maintainable, in particular to perform the electrostatics calculations with FEMLAB and the charge-carrier dynamics and signal generation in C++. The second was to directly compare the simulations to selected data from the coincidence scans [Svensson *et al., op. cit.*].

Figure 156 demonstrates how the simulations compare to measurements of the centre-contact rise times in the outer quadrant of one crystal along the diagonal. Nominally these data points are along the ⟨100⟩

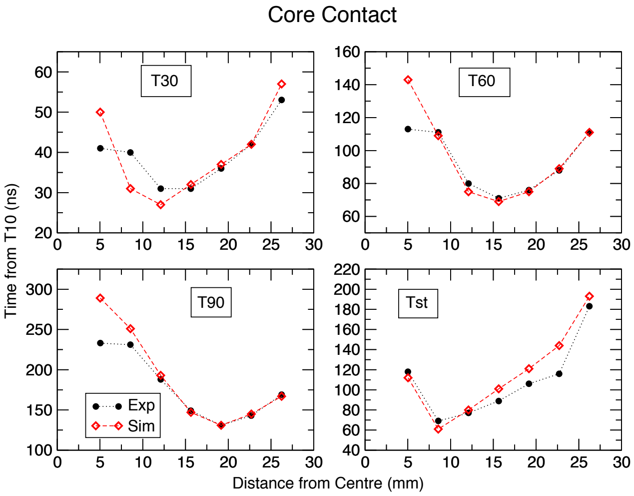


Fig. 156. Simulated vs. measured times to rise from 10% to 30%, 60%, and 90% of maximum, and to the time of steepest slope, for the core contact of one crystal.

crystallographic axis where the drift velocities are best known and are parallel to the electric field axis. The agreement is best near the outer edge of the crystal. Sources of error near the core continue to be investigated. Work in 2005 will include full implementation of the anistropic drift velocities, including lateral deflection of charge carriers when the electric field is not along a crystallographic axis, improved treatment of edge effects, and improved modelling of the impurity distribution in the crystals.

This work earned undergraduate student Nick Cowan the award for Best Student Talk and an opportunity to present his results at the 2005 Western Regional Nuclear and Particle Physics Conference. Nick is currently a graduate student at the University of Washington.

Collaboration

The TIGRESS family grew with the addition of three NSERC grant-eligible collaborators: Prof. Roby Austin (St. Mary's), Prof. Paul Garrett (Guelph), and Prof. Jo Ressler (SFU). Of the three research associates who were part of the TRIUMF-based TIGRESS team last year, Prof. Fred Sarazin (Colorado School of Mines) remains an active member of the collaboration. Andrei Andreyev, Colin Morton and Chris Pearson have joined TIGRESS as research scientists, working with staff scientists Gordon Ball and Greg Hackman. A workshop is planned for University of Guelph in early 2005 to invite and encourage American and European involvement in TIGRESS auxiliary detectors.

Status of the TITAN System

(J. Dilling, TRIUMF, for the TITAN Collaboration)

TITAN (TRIUMF's ion trap for atomic and nuclear science) is a facility for a variety of high precision experiments. The main goal is accurate atomic mass measurements on short-lived radioactive isotopes. In order to achieve this the nuclei, produced at ISAC, undergo various preparations, before the actual mass measurement in a Penning trap. What sets this facility apart from all other Penning trap mass spectrometers for radionuclei is the fact that we boost the charge state of the ions. The atomic mass of the ions is determined by measuring the cyclotron frequency $\nu_c = q/m \cdot B$ of the ions with q/m being the mass-to-charge ratio and B the magnetic field strength of the Penning trap. The precision of this determination is limited by the observation or preparation time available, and is proportional to $\approx T \cdot q$. To overcome this limitation of observation time for short-lived isotopes, one can make use of charge bred highly charged ions. The charge breeding is done employing a high current EBIT (electron beam ion trap). In order to achieve a high efficient charge breeding process, the beam has to be converted from a dc beam to a bunched beam, and an additional reduction of the phase space or emittance is desired. These two important steps are carried out by a gas-filled linear Pauli trap or radio frequency quadrupole (RFQ).

After the charge breeding additional cooling is required. A dedicated cooler Penning trap is foreseen for this task. The TITAN system comprises in total 4 main components: the RFQ cooler and buncher, the EBIT charge breeder, a Penning trap for cooling of highly charged ions, and the Penning trap for high precision mass measurements. The sub-systems can be tested independently using the off-line ion source and will be installed on a platform in the low energy area of the ISAC-I experimental hall. Figure 157 shows a rendered drawing outlining the location of the different components with respect to the ground-level ISAC beam line. Figure 158 shows a recent photograph of the TITAN platform.

In the following, the various components will be described in more detail.

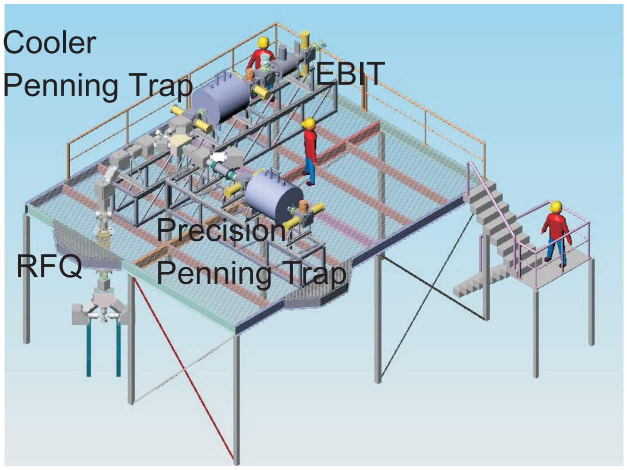


Fig. 157. Rendered drawing of the TITAN system located on, or just below, the platform in the ISAC-I experimental hall. The four main components are identified.

Fig. 158. Photograph of the recently installed TITAN platform in the low-energy ISAC area.

The TITAN RFQ beam cooler and buncher

The motivations for beam handling arise from the need to manipulate the beam properties for a variety of post processes, in our case charge breeding in the TITAN EBIT. Cooling and bunching of beams are of most interest. In this method, the incoming radioactive ion beam is cooled and subsequently delivered in bunches at a prescribed repetition rate, adjusted to the breeding cycle of the EBIT. Cooling the incoming beam reduces the energy spread both in the longitudinal and transverse directions. This improves the quality of the beam which allows us to match the emittance of it to the acceptance of the EBIT, and hence achieve an increased efficiency. The RFQ beam cooler is the first beam processing device in the TITAN experimental set-up as it processes and delivers the ISAC beam to a variety of experimental end stations, both on and off the TITAN beam line. The TITAN RFQ beam cooler is currently undergoing operational tests in the TITAN test stand (see Fig. 159). The initial tests are designed to characterize the system prior to the final coupling of the beam cooler to the ISAC beam line. The TITAN beam cooler is a radio-frequency quadrupole device that is driven by an oscillating square waveform as opposed to traditional sinusoidal driven devices. The RFQ driver developed (in collaboration with the Kicker group) for the TITAN system is capable of generating a rectangular voltage waveform of peak to peak amplitudes up to 600 V with a variable duty cycle and pulse repetition rates up to 3 MHz. This system is frequency agile as it has a flat frequency response over the entire operational range. This allows for frequency scanning without the tedium of changing circuit components as required in traditional tuned circuit systems.

Fig. 159. The RFQ off-line test stand. Composed of an off-line source, the RFQ inside the high voltage cage, and a Faraday cup diagnosis system behind the exit, on ground potential.

Initial injection tests, comparing the beam on a Faraday cup straight up from the ion source, compared to a cup on the high voltage platform, behind the final retardation electrode, have shown that around 70% of the incident beam has been successfully decelerated into the RFQ confines. Of this, 20% has been transmitted through the length of the RFQ with the RFQ operated in continuous (transmission) mode, without buffer gas. For the latter measurements a Faraday cup was mounted on ground potential behind the extraction system of the RFQ. The first test using buffer gas at a pressure of $p_{\mathrm{Ne}} \approx 4 \times 10^{-3}$ mbar showed a rise in transmission efficiency, indicating cooling of the beam. Proper optimization of the parameters, like dc gradient, buffer gas pressure and rf parameters, are under way. Trapping and subsequent ejection of a cooled bunched beam will follow shortly. Transverse and longitudinal emittance measurements will be performed to measure the extent of beam cooling and to assess the quality of the extracted bunched beam. A specially engineered support structure will hold the RFQ beam cooler in the vertical position above the ISAC-I experimental floor in the final set-up. In this position, the beam cooler will couple the TITAN beam line, situated on the recently constructed platform, to the ISAC beam line. In addition to delivering the beam to the TITAN EBIT, the beam bunches can be extracted at the bottom end. This allows the experiments along the ISAC beam line to be provided with cooled bunched beams. Experiments that would benefit from this include the collinear laser spectroscopy and the β-NMR system. Detailed ion transport calculations based on the standard ISAC matrix code were carried out to insure that a proper injection and extraction from and into the ISAC beam line are possible. The same code was used to determine the ion optical needs for the beam transfer to the upper level of the TITAN platform. Further simulations for the complete beam line will follow.

Figure 160 shows details of how the RFQ will be mounted in the vertical position, and how the removal could be done. The concept is based on a rails system, that will allow a careful extraction of the RFQ structure from the vacuum tank, and a precise insertion, reproducing the position on a sub-millimetre level.

The TITAN high-current EBIT progress

The TITAN electron beam ion trap (EBIT) for charge breeding of radionuclides is currently under construction in the EBIT group at the MPI for nuclear physics in Heidelberg. An electron beam is produced with a thermionic cathode and then electrostatically accelerated and injected into a strong magnetic field. Here the electrons are radially confined by the Lorentz

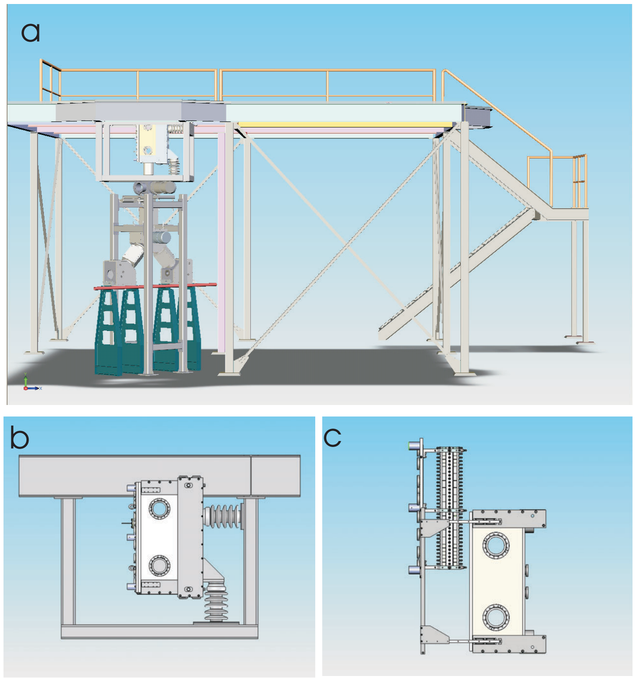


Fig. 160. Rendered drawings of the side view of the TITAN beam line, connecting the upper level (on the TITAN platform) to the ISAC beam line. Picture a) shows the RFQ in the planned location, together with the high-voltage cage frame, and support for the beam line. The lower pictures (b and c) show details of the support system for the RFQ, based on high-voltage insulators and the concept of removing the system from the vacuum tank for servicing purposes.

force, and the beam is compressed as the electrons enter the region of high magnetic field. A field of 6 T is generated by a cryogen-free superconducting magnet operating at a temperature of 3.5 K. The electron beam acceleration voltage will be variable up to 80 kV, and a beam current of 5 A is envisaged. With these parameters a compression of the electron beam down to 150 μm is expected. The confinement of such an amount of negative electric charge provides a space charge potential, which is more than 5 kV deep. This space charge potential traps the ions radially. Axial confinement is accomplished by applying appropriate potentials to cylindrical electrodes, which are lined up coaxially in the bore of the magnet. While trapped in the dense electron beam, the ions undergo further ionization through successive electron impact processes. To obtain highly charged ions in charge states such as Xe^{44+}, typical ionization times are in the order of 10 to 50 ms.

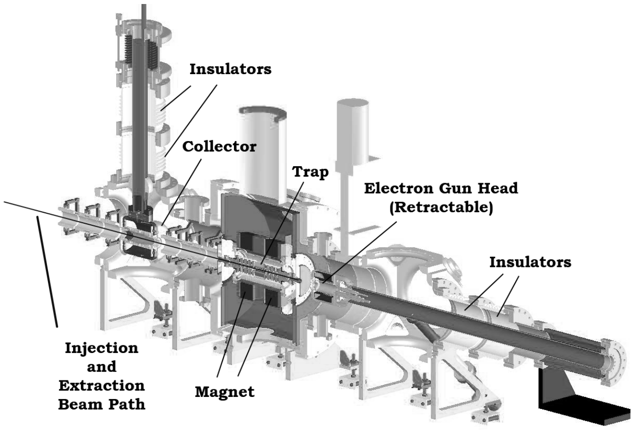


Fig. 161. Schematic overview of the TITAN EBIT. A superconducting 6 T magnet with cold bore houses the actual trap set-up. Both the electron gun head and the electron collector unit are adjustable with respect to the magnetic field and relative to each other to provide an optimal electron beam performance. The electron gun and the collector are floating on negative high voltage whereas the trap is held at ground potential.

Figure 161 shows a schematic overview of the TITAN EBIT. The radionuclides enter the EBIT as cooled bunches of singly charged ions (in the figure, from the left side through the collector). The extraction after charge breeding takes place along the same path in the opposite direction. The extraction and the transport to the precision Penning trap will be accomplished by means of floatable drift tubes and pulsed cavities.

Recently the TITAN EBIT assembly was completed (see Fig. 162). Some last components are expected shortly, including the final version of the trap electrodes. Using a prototype trap assembly in the first test, an electron beam current of more than 180 mA and a kinetic energy of 14 keV was achieved. Besides trapping and ionizing, the electron beam gives rise to excitation of the trapped ions and recombination. A germanium detector was placed on one of the seven radial ports to observe X-rays from the trap region through a beryllium vacuum-window. A sample X-ray spectrum taken during the first week of operation is shown in Fig. 163. Barium (and tungsten) which is

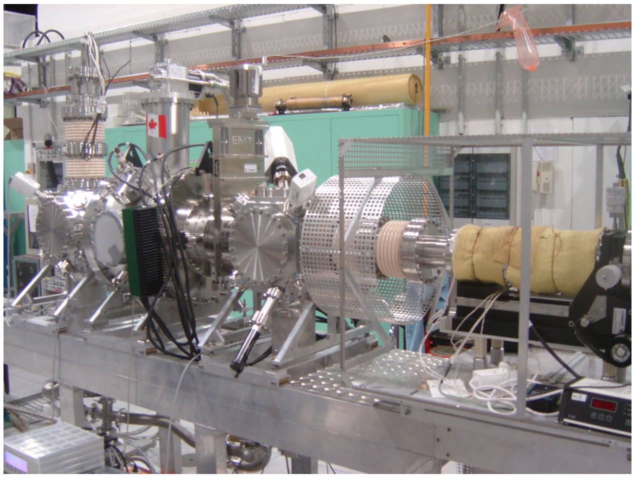


Fig. 162. Photo of the TITAN EBIT set-up.

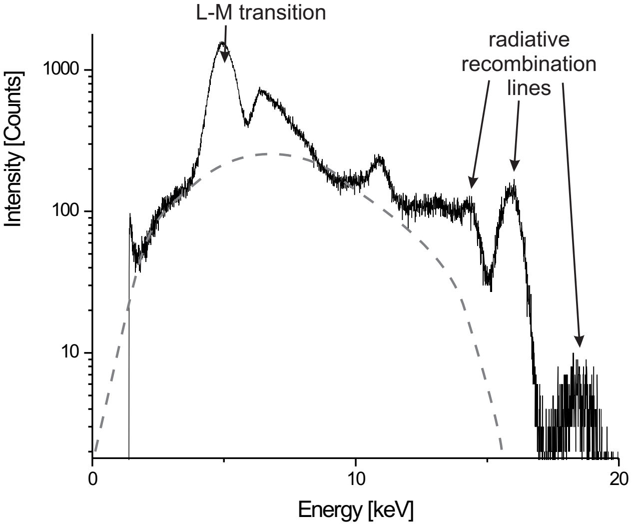


Fig. 163. X-ray spectrum from trapped highly charged Ba ions. On top of the bremsstrahlung-continuum (dashed line) spectral lines can be seen. Besides direct transitions, of which the L-M transition is the most prominent one, resonances at energies much higher than the kinetic energy (16.5 keV) of the electrons are observed. They are emitted by electrons which are captured in radiative recombination processes from the continuum into the $n = 4$, 3 and 2 shell of Ba.

evaporated from the cathode surface makes its way as neutral atoms into the trapping region where it gets ionized to high charge states. The spectrum gives clear evidence for trapping and ionizing of Ba. The most prominent excitation and recombination lines were observed.

In the near future the TITAN EBIT will be equipped with a gas injection system to increase the variety of elements to test with and to allow for insertion of cooling gas such as argon or neon. Furthermore a test ion source, a position sensitive particle detector and a charge-to-mass ratio analyzing magnet, all of them being operational already, will be attached to the set-up. Charge breeding and extraction of externally produced ions will be proven in the fall of 2005 and quantitative values for breeding times, temperature and beam emittance of extracted highly charged ions will become available. Shipping of the TITAN EBIT and its incorporation into the TITAN set-up is foreseen to occur in early 2006.

TITAN cooler Penning trap

The energy spread of highly charged ions (HCI) extracted from the EBIT has not been measured yet. In fact, it is rather difficult to estimate since experience with such high electron charge densities doesn't exist. However, it will most likely be too high for direct injection into the mass measurement trap. Typically, energies of <1 eV$/q$ are required for the cyclotron resonance technique (q is the charge of the ion). Current experience with EBITs indicates that energy spreads of >10 eV$/q$ must be expected. In addition, the TITAN EBIT is designed to provide currents up to 5 A, leading to significantly higher electron densities and collisional heating rates compared to current devices. To remedy this, we plan to insert a cooler Penning trap between the charge breeding and the mass measurement. The proven method of buffer gas cooling is ruled out by the unacceptably large charge transfer; resistive cooling requires a cryogenic environment and is highly q/m specific. We are currently exploring two promising routes towards cooled HCI – sympathetic cooling with electrons and light, cold ions such as protons or He^{2+}. Electron cooling is attractive as electrons are easily produced and self-cool to the temperature of the environment via the emission of synchrotron radiation with a time constant of $\approx$100 ms in a 6 T field. A complication is the possibility of electron-ion recombination. For typical parameters such as an electron temperature of 300 K, an electron density of 10^7 cm^{-3}, and $q = 50$, the radiative recombination rate amounts to $\approx$0.1 s^{-1}. This would be tolerable; however, higher electron densities, effects of dielectronic recombination and three-body recombination could shorten the lifetime significantly. In addition, the opposite charge of electrons and ions requires the use of a nested trap, where electrons are trapped in one or multiple inverted wells inside a larger ion trap. At ion energies corresponding to the height of the inverted well, the two species start to decouple spatially, halting the cooling process. As an alternative, we are looking into light-ion cooling of HCI. In this scheme, sub-eV protons from an ion source are injected into the trap. Preliminary calculations show (see Fig. 164) that this method can cool HCI at time scales much shorter than 1 s.

The Manitoba group has recently received a CFI grant to build the cooler trap. The set-up will be flexible to explore electron-ion and ion-ion cooling. For effective synchrotron radiation cooling, the magnet needs to produce at least a 6 T field. Efficient capture

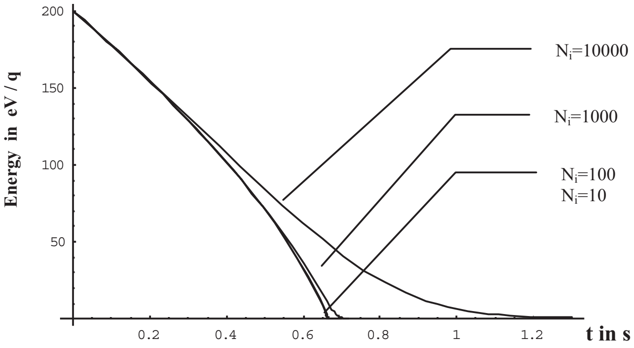


Fig. 164. U^{90+} with an initial energy of 200 eV$/q$ and different numbers of injected ions. Cooled by 10^7 protons with a density of $n = 10^7$ cm^{-3}.

of HCI bunches from the TITAN EBIT requires a long trap (≈50 cm). A cylindrical electrode structure with about a dozen separately controllable electrodes can produce various geometries for a nested trap potential. Construction will start in 2005.

TITAN mass measurement Penning trap

Penning trap design Mass measurements in a Penning trap are carried out by determining the cyclotron frequency of the charged particles in the magnetic field of a strong homogeneous magnet. Naturally, special care has to be taken in selecting the magnet, since deviations from the homogeneous field couple directly to the uncertainty in the mass determination. One of the first things for the precision Penning trap project was to establish the specifications of the Penning trap magnet. In the first round of negotiations with magnet manufacturers it was determined that the desired parameters would put the price of the magnet outside the budget goal. Since the highly charged ions used for mass measurements at TITAN would not require as high a field to achieve the desired accuracy, the decision was made to acquire a magnet with magnetic field strength of 4 T. The magnet is scheduled for delivery in December, 2005. Measurements on the highly charged ions require UHV to XHV ($10^{-9}-10^{-12}$ mbar) vacuum conditions in the vacuum chamber. Additional stringent requirements from the magnetic field homogeneity restrict the choice of materials for the Penning trap vacuum system. The main vacuum chamber that will contain the measurement trap has been designed from pure titanium and is currently being manufactured. To achieve the required vacuum conditions, a vacuum system concept was developed that consists of two pumping stations with the ion getter pumps and NEG pumps. A support structure design for the Penning trap and the ion optics electrodes has been finalized.

Figure 165 shows the rendered overview drawing of the Penning trap, including the magnet, the titanium vacuum chamber, with feedthrough vessel and vacuum pumps (a). Figures 165b and c show details of the vacuum chamber and the Penning trap electrode structure support.

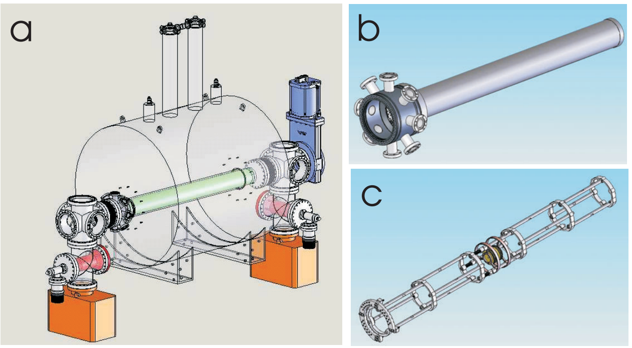


Fig. 165. Mechanical and vacuum design of the Penning trap: a) vacuum system concept; b) main vacuum chamber; c) Penning trap support structure.

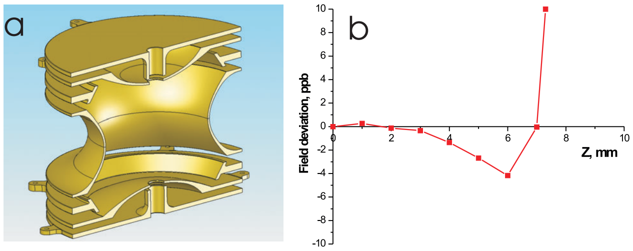


Fig. 166. a) Section view of the electrode design of the precision Penning trap; b) disturbance to the magnetic field homogeneity by the Penning trap electrodes.

The electric and magnetic field homogeneity in the mass measurement Penning trap is crucial for achieving the target accuracy. Therefore, a series of electrostatic calculations was performed to achieve the best electric field parameters. The material along the trap electrodes was then redistributed by successive optimizations to obtain the best possible magnetic field homogeneity. The magnetic field calculations were incorporated into a CAD design program (SolidWorks). The produced trap geometry and the corresponding magnetic field inhomogeneity are shown in Fig. 166. The calculations indicate that the required field homogeneity of ≈10 ppb can be reached or surpassed.

Ion injection and extraction simulations Careful ion transport into the precision Penning trap through the fringe field of the superconducting magnet is very important for the mass measurement. The magnetic field gradient can produce a magnet mirror, reflecting the incoming ions, and leading to substantial losses of the radioactive isotopes. Hence, extensive simulations of the ion injection into the trap to optimize the ion optical parameters and to determine the position of the optical elements were performed. Under the conservative assumption of a beam of charge bred ions with an emittance of $100\,\pi$ mm mrad (beam without cooling), it is impossible to achieve the necessary initial ion distribution in the Penning trap. Similar calculations were carried out with a beam emittance of $10\,\pi$ mm mrad (employing the cooler Penning trap). The results of the simulations for the $100\,\pi$ mm mrad beam are shown in Figs. 167 and 168.

Test ion source and emittance meter For the calibration of the Penning trap during the mass measurements, an off-line ion source is desired. It should supply the reference ions with a mass-to-charge ratio close to that of a highly charged ion, hence probing the same phase space inside the Penning trap. Ions that could be used as reference ions are the hydrogen molecular ions H^{2+} and H^{3+}, and helium ion He^{+} with mass to charge

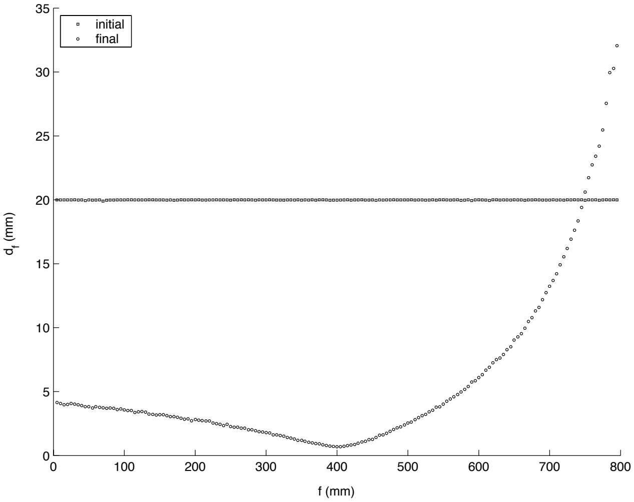


Fig. 167. Ion injection into the precision Penning trap as a function of final focal point before the Penning trap. Graph: size of the injected beam inside the trap (initial size top dots).

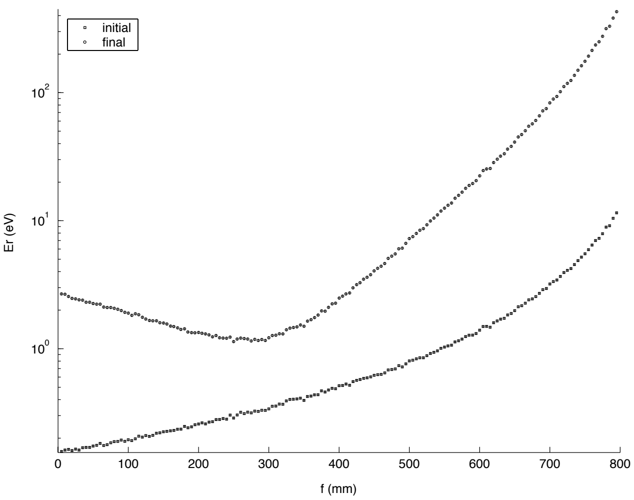


Fig. 168. Cyclotron energy of the ions inside the magnetic field as a function of final focal point (initial energy bottom dots).

ratios of 2, 3, and 4 respectively. A cooler Penning trap based on protons as a coolant would, of course, also require a source of protons. We have pursued a dc plasma discharge ion source based on a commercial design. The initial version of the ion source was quickly put together and successfully tested for Xe ion beam delivery. The design was then modified to conform with UHV requirements of the TITAN transfer beam line and ability to be used as a multi-purpose unit with differential pumping station and built-in Faraday cup diagnostics. The source is now undergoing tests and delivering 3 μA of Xe ion beam. It can be used for all four traps at various locations in the TITAN set-up.

A device to measure the emittance of a charged particle beam was designed and built, in order to characterize the ion beam from the test ion source, the RFQ cooler and buncher, and the EBIT. It is based on the ISAC emittance meter rig design. The original design was modified in the following way: the materials used in the device are UHV compatible, the design was lightened, and made significantly more compact (it fits into the standard 8 in. conflat 4-way cross). First measurements of the emittance of the Xe beam from the plasma ion source have been carried out. Figure 169 shows a photograph of the test set-up with the ion source (inside the high voltage cage), extraction optics, a Wien-filter and the emittance meter on a linear feedthrough.

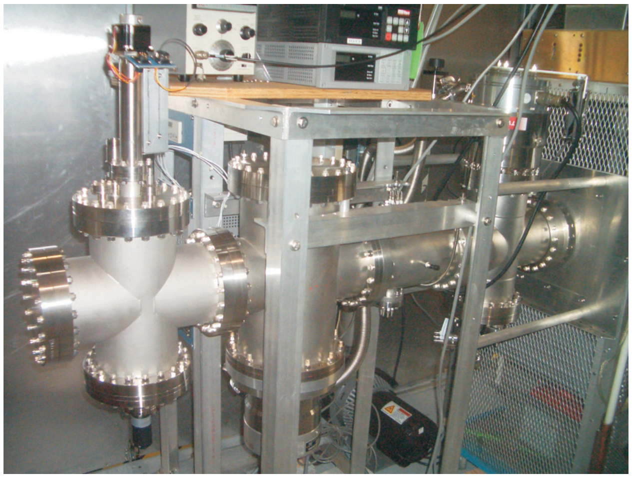


Fig. 169. Photo of the ion source test stand, with Wien-filter and emittance meter.

Summary and conclusion

The TITAN facility set-up and construction is well under way. Some of the main components, the gas-filled RFQ cooler and buncher, and the charge breeder EBIT are already in the test or operational phase. The progress on the Penning trap project allows a projection to first tests in early 2006, after the mass measurement Penning trap magnet is received in December, 2005. The key infrastructure component, the TITAN platform, is already erected. The move of the RFQ system to the ISAC hall is foreseen for later in 2005. First laser spectroscopy experiments are possible at this stage. The advantage of having an off-line ion source built into the system will become evident during the set-up and commissioning phase of the individual components and the test of the transfer of beam from one subsystem to the next. This is planned for the coming year.

Linear Collider TPC Development

(D. Karlen, Victoria/TRIUMF)

The Victoria time projection chamber (TPC) prototype, designed for use in magnetic fields at TRIUMF and DESY, had a successful data-taking run at

DESY in the summer. The prototype was operated with GEMs and micromegas gas amplification and its performance was investigated with cosmic and laser tracks. This work was performed in order to demonstrate the capabilities of such a device as a large volume gaseous central tracking system for a linear collider experiment. As a result of the success of this program, the long baseline neutrino experiment, T2K, now includes these types of devices in the design of the near detector tracker, and the Victoria/TRIUMF groups are leading the T2K TPC project.

Introduction

Given the precise three dimensional information it provides, a large volume TPC is a leading candidate for the central tracker for an experiment at the International Linear Collider. Starting in 2003, the Victoria prototype TPC has demonstrated the performance of TPCs with micropattern gas detectors operated in magnetic fields. The TPC is of modest scale, with an active drift volume of about 300 mm × 85 mm × 64 mm, read out with 256 channels of modified STAR prototype electronics. From data taken in 2003, it was shown that up to the full drift distance, 30 cm, the prototype had a space point resolution of approximately 100 μm for a 7 mm sample in P5 gas at magnetic fields above about 1.5 T.

This year, the TPC was modified to allow UV laser pulses to enter the drift volume, which would produce a straight line of ionization, in a repeatable fashion. A laser delivery system was designed and built at the University of Victoria in order to control the beams sent to the TPC during operation in the DESY magnet. For personnel safety reasons, the system was designed for remote control. Pictures of the laser delivery system are shown in Fig. 170. The YAG laser, provided by DESY, produced a 266 nm wavelength beam.

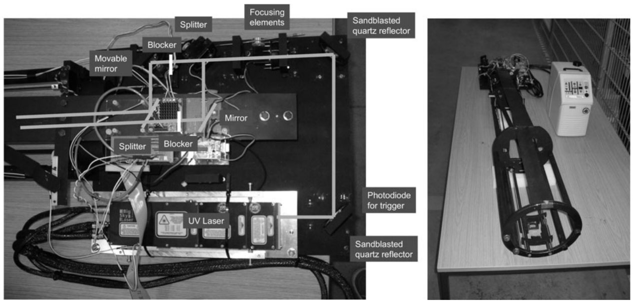


Fig. 170. Photographs of the laser delivery system designed for TPC operation in the DESY magnet. The left image shows the optical components, with movable mirrors and blockers to produce one or two beams of variable separation. The right image shows the TPC holder that includes movable mirrors to direct the laser beams through the TPC at different drift distances.

Results from 2004 DESY run

The prototype was operated with laser and cosmic triggers in P5 (Ar:CH_4 95:10) and the so-called TDR (Ar:CH_4:CO_2 93:5:2) gas mixtures. The laser intensity was adjusted to give mean ionization density similar to that of minimum ionizing particles. Primarily it was operated using a double GEM; only a short test using micromegas with a resistive anode was performed.

The laser track position in the TPC was very stable, typically drifting less than 10 μm over a period of 24 hours. The laser was found to be very useful to quickly measure the drift velocity, and thereby monitor the equilibrium time after gas changes or after periods of opening the TPC.

Since the laser tracks were stable in location from pulse to pulse, they provide an excellent control sample to demonstrate the techniques used to estimate the tracking resolution for cosmic ray tracks. By using 8 rows of 2 mm × 7 mm pads, the standard deviation of the horizontal track parameters of the track fits to the laser pulses was typically 28 μm, corresponding to a single row resolution of 79 μm. The technique used for cosmic ray tracks (comparing single row fits with all row fits) gives 77 μm, in good agreement.

By bringing two parallel laser beams close together at the same drift distance, the two track resolution capability of the device was investigated. The two remote control blockers allowed one or the other laser beam to pass through the TPC, or both. Single fits of the individual tracks were compared to a simultaneous fit to the two tracks. For 2 mm wide pads, the resolution of the two track fits was found to only degrade significantly for track separations less than 2 mm, as shown in Fig. 171.

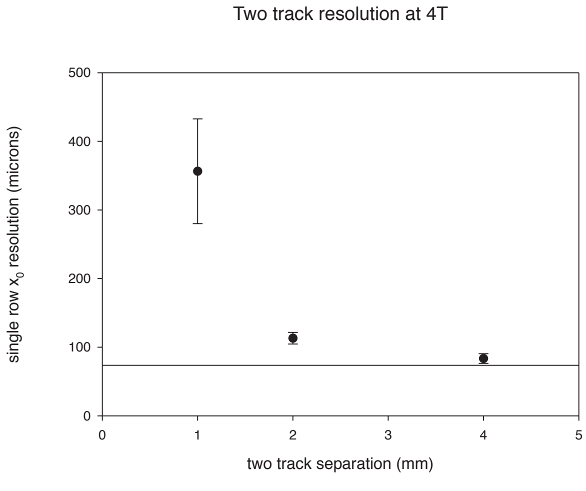


Fig. 171. The two track resolution capability of the TPC is shown for 2 mm wide pads. The horizontal line shows the single pad row resolution for single tracks. The points show the single pad row resolution for two parallel tracks at different separation distances. This represents the first measurement of this property for GEM-TPCs.

To better understand the results from cosmic ray samples, a full GEANT3 simulation of the cosmic events was developed. The energy loss of charged particles as they pass through the gas is simulated by GEANT, and the values are passed to the jtpc TPC simulation package. The simulated events are analyzed with the same program as the real data. The resolution measured in the simulated samples is in good agreement with the real data. The momentum distribution of the muons as estimated by the radius of curvature is in good agreement.

The ionization energy loss, dE/dx, was also examined, and the relativistic rise with momentum is clearly visible. The dE/dx resolution was measured to be 17% for the 85 mm track length, consistent with the expectation from an extrapolation of traditional large gaseous tracking systems.

A set of narrower readout pads, 1.2 mm pitch instead of 2 mm pitch, were also tested. This was done because the defocusing of the GEMs for P5 gas at high fields provides less than optimal charge sharing for the larger pads. For P10, the defocusing is larger, but the use of this gas was not allowed in the DESY set-up.

An initial study showed biases in the data, as if pad rows were offset from their nominal locations by various amounts of order 100 μm. The original gerber file for the PCB layout was reviewed, and it was found that the pads were, in fact, not correctly placed. After correcting for this in the analysis, the biases were found to be less than 5 μm.

The single row resolution for the narrow pad cosmic data is shown in Fig. 172, and compared to the result from the GEANT-jtpc simulation. Single row resolution of approximately 60–80 μm is found. It appears that systematic effects, not included in the simulation, are not influencing the resolution at this level.

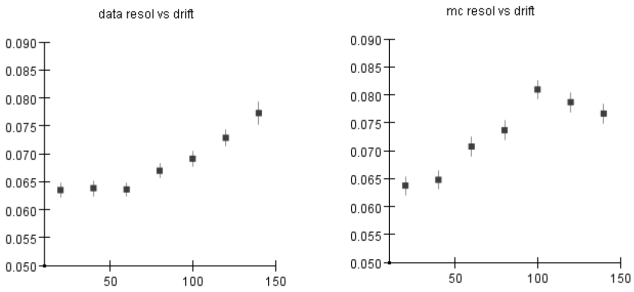


Fig. 172. The single row resolution (mm) of cosmic tracks is shown for 1.2 mm wide pads for 7 mm samples in P5 gas as a function of drift distance (time bins – range from 0 to 300 mm). The figure on the left shows the result from data, and the figure on the right is from the full simulation.

Future work

A full analysis of these data is under way for publication. The results and experience gained with the Victoria prototype will be very helpful in designing a large Linear Collider prototype TPC, in collaboration with physicists from Europe and the US, and in designing the T2K TPC modules over the coming year.

University of Victoria LC TPC group in 2004: Dean Karlen, Mark Lenkowski, Chris Nell, Paul Poffenberger, Gabe Rosenbaum.

TPC R&D for the International Linear Collider

(M. Dixit, Carleton/TRIUMF)

Introduction

The time projection chamber (TPC) for the future international linear collider will need to measure about 200 track points with a resolution of better than 100 μm. The resolution goal, close to the fundamental limit from ionization electron statistics and transverse diffusion in gas, is nearly two times better than has been achieved by conventional wire/pad TPCs. A TPC with a micro pattern gas detector (MPGD) readout could, in principle, reach the target resolution. However, it may require sub-millimetre width pads resulting in a large increase in the number of electronics channels and detector cost and complexity over conventional TPCs.

In the recent past, the R&D at Carleton has focused on exploring new ideas to improve TPC resolution (see Fig. 173). We have recently developed a new readout concept based on the phenomenon of charge dispersion in MPGDs with a resistive anode. With charge dispersion, wide pads similar in width to the ones used with wire/pad TPCs can be used without sacrificing resolution.

We have proven the concept of charge dispersion for a collimated X-ray source earlier. We have recently

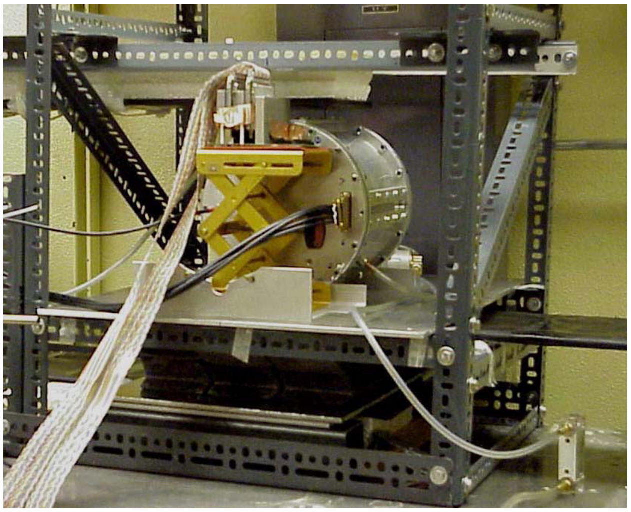


Fig. 173. Cosmic ray GEM-TPC set-up at Carleton.

measured the spatial resolution of a small prototype TPC using the charge dispersion readout as proof of principle. In cosmic ray tests with no magnetic field, we have measured the resolution for a number of gases with different diffusion. The dependence of measured resolution on drift distance was consistent with diffusion in all cases. This is the first time a TPC has achieved a spatial resolution close to the fundamental limit from diffusion. The resistive anode GEM in the TPC endcap was recently replaced with a resistive anode micromegas. Preliminary results from the micromegas TPC with the charge dispersion readout are quite encouraging. These activities are described below.

GEM-TPC resolution from charge dispersion

A small cosmic ray test TPC used earlier with a conventional direct charge GEM readout was modified for charge dispersion studies. The GEM endcap was altered to accommodate a resistive anode. Signals on 60 pads, 2 mm × 6 mm each, were read out using Aleph TPC wire preamplifiers and digitized by 200 MHz FADCs.

Figure 174 shows TPC pulses for two pads. Both the pulse rise time and the decay time depend on the position of the charge with respect to the pad. The charge collecting pad has a fast signal. The signal on the adjacent pad has a slower rise and decay time. Figure 175 shows track signals for all the pads for a cosmic ray track.

Since the risetime and the pulse height both depend on the charge position, there are many possible ways to define and use the pad response function (PRF). For the present analysis, we have used only the pulse height information. We used part of the cosmic ray data to determine the PRFs (see Fig. 176). The remaining data were used for resolution studies.

The charge dispersion signals are affected by non-uniformities in the anode resistivity and the capacitance per unit area. Positions measured from PRF need to be corrected for local RC distortions. The bias corrections were also determined from the calibration data set.

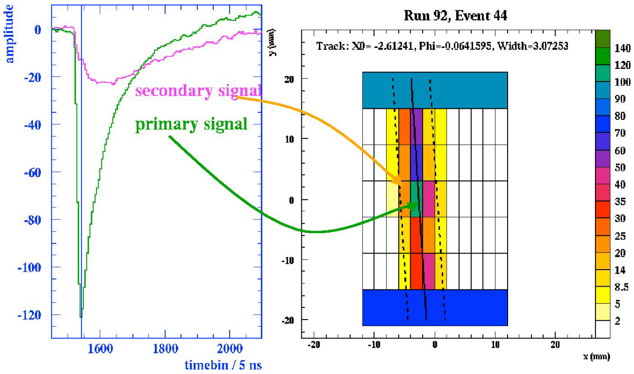


Fig. 174. Charge dispersion signal on a charge collecting pad and its neighbour for a cosmic ray track in the TPC. Ar:CO_2/90:10.

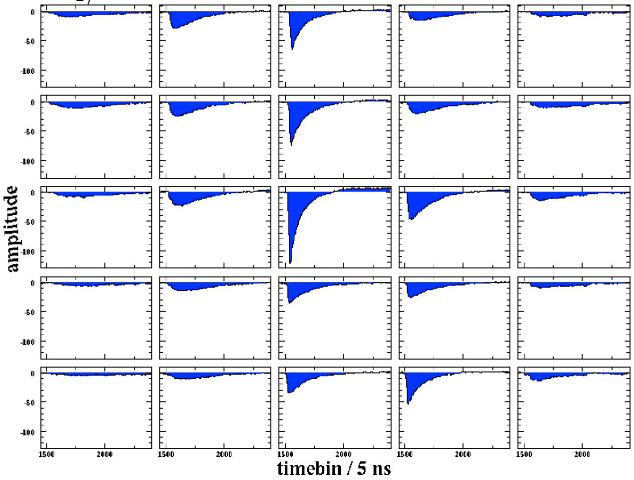


Fig. 175. FADC charge dispersion signals on 2 × 6 mm^2 readout pads for a cosmic ray track. The TPC fill gas was Ar:CO_2/90:10.

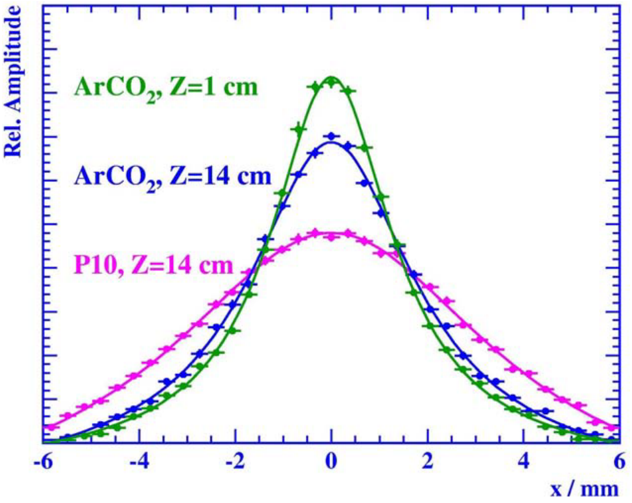
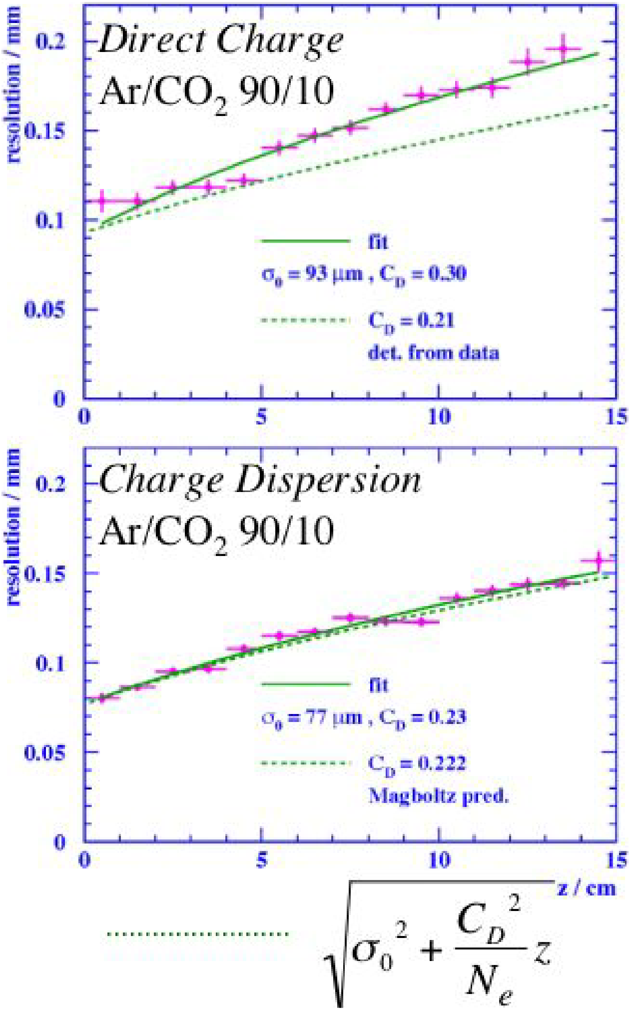


Fig. 176. Example pad response functions (PRF). The PRFs were determined from a subset of the cosmic ray data set.

Figure 177 shows the resolution measurements for Ar:CO_2 with and without charge dispersion. P10 results are shown in Fig. 178. The resolution from charge dispersion is significantly better than for the direct charge readout for both gases. Apart from a constant term, the dependence of resolution on drift distance is consistent with diffusion.

A detailed simulation has been done to understand the characteristics of charge dispersion signals. Initial ionization clustering, electron drift, diffusion effects, the MPGD gain, the intrinsic detector pulse-shape and electronics effects have been included. All aspects of



$$\sqrt{\sigma_0^{\;2} + \frac{C_D^{\;2}}{N_e} z}$$

Fig. 177. Charge dispersion improves TPC resolution over that from direct charge for low diffusion gases like Ar:CO$_2$ with limited charge sharing between pads.

charge dispersion phenomena can be simulated including pulse shapes (see Fig. 179) and the PRF. The simulation is in good agreement with the experiment and can be used to optimize the charge dispersion readout for the TPC.

In summary, the charge dispersion on a resistive anode improves the GEM-TPC resolution significantly over that achievable with conventional direct charge readout. Bias errors due to RC inhomogeneities can be corrected. With no magnetic field, the measured dependence of resolution on drift distance is consistent with diffusion and electron statistics. Charge dispersion resolution studies with a micromegas TPC are in progress. Preliminary results are are quite encouraging and are similar to those with the GEM readout.

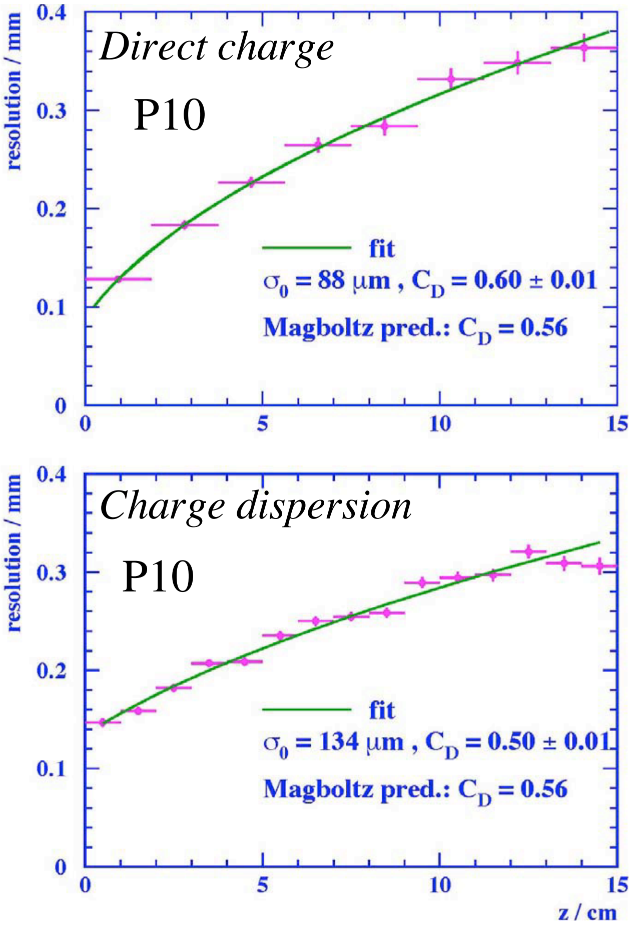


Fig. 178. Charge dispersion improves TPC resolution even if the track charge is spread over several pads due to transverse diffusion, as is the case for P10.

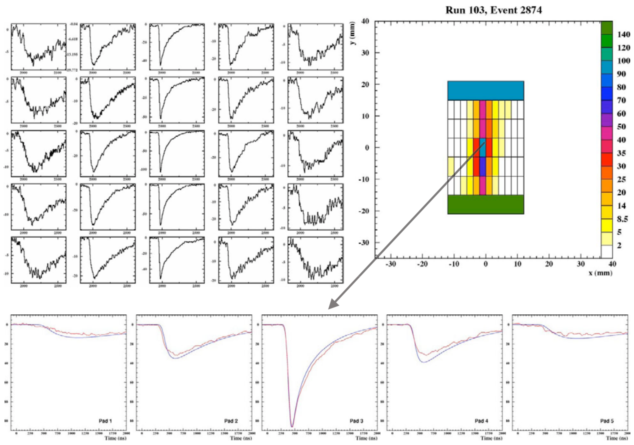


Fig. 179. Simulated and experimental cosmic ray charge dispersion signals on a row of cosmic ray TPC readout pads.

Future plans

TPC resolution studies for a micromegas TPC with a resistive anode readout will be completed. Beam tests in a magnet are planned for the summer of 2005 in a KEK test beam. With the announcement of the choice of superconducting rf structures for the ILC last summer, the TPC R&D effort worldwide is gaining momentum. The time scale is driven by the expectation that the ILC will be operational by 2015. A major ILC-TPC goal is to choose the readout technology and build and test a large prototype by 2007. If a TPC resolution of less than 100 μm for all drift distances (diffusion limit in a magnet) can be reached, it will have a major impact on the ILC detector design. We expect to contribute significantly to this effort.

IILC TPC R&D group in Canada: A. Bellerive, K. Boudjemline, R. Carnegie, H. Mes, J. Miyamoto, K. Sachs (Carleton), M. Dixit (Carleton/TRIUMF), J.-P. Martin (Montreal), and D. Karlen (Victoria).