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OPERATED AS A JOINT VENTURE

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UNDER A CONTRIBUTION FROM THE
NATIONAL RESEARCH COUNCIL OF CANADA

DECEMBER 2006

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)

During this year 58 users from 24 different companies or institutions made use of the proton and neutron testing facilities at TRIUMF. Of the companies, 8 were Canadian although some of these companies had several testing sessions throughout the year. As for previous years, the Canadian users are mostly space-related companies and make use of protons, while the neutrons are used primarily by foreign companies for avionics and microelectronics testing. However, a few more US aerospace companies are starting to use protons for single event effect testing to compare the results to neutron measurements for terrestrial applications.

Proton irradiation facility

During the year there were seven scheduled periods for proton testing on the low energy beam line BL2C and during the two periods in September and December the high energy beam line BL1B was also available. Unfortunately a failure of the BL1 extraction probe reduced the high energy beam availability in December.

There have been a number of requests for a low flux neutron beam (10^3 to 10^4 neutrons cm^{-2} s^{-1}) that can irradiate large devices or systems modules with a uniform beam over dimensions of 50 cm by 50 cm. The September and December periods were used to develop such a beam on BL2C at 116 MeV proton energy and on BL1B at 500 MeV. Neutrons are produced by stopping the protons in a lead or iron beam stop and then placing the test equipment 1.4 to 3.5 m downstream of the beam stop, depending on the desired size of the neutron beam. The neutron flux is measured using activation of carbon and aluminum foils and the uniformity can be measured by scanning a moderated BF3 counter across the beam. FLUKA calculations have been made to compare against the measured results. In December a group from Honeywell Canada used this neutron beam on BL2C for testing an aircraft electronic module. Figure 215 shows the neutron spectrum. About 5 hours of beam operation at 5 nA proton current corresponds to 10 years at 40,000 ft.

The Sandia/CEA/TRIUMF collaboration continued its work on Expt. 1021, Proton Radiation Effects in Advanced Semiconductor Technologies, in two beam periods – one on BL2C at lower energies in May, and then again on BL2C in December. Unfortunately BL1B was not operational for the December run. This experiment had a number of studies, including investigating the effect of proton angle-of-incidence on single-event latchup as a function of proton energy. The paper on the 2004 work presented at the 2005 Nuclear and Space Radiation Effects Conference, "Effects of proton energy on proton-induced single-event latchup", was given the best paper award at the conference. The Sandia group also used some commercial time for single-event testing of various devices.

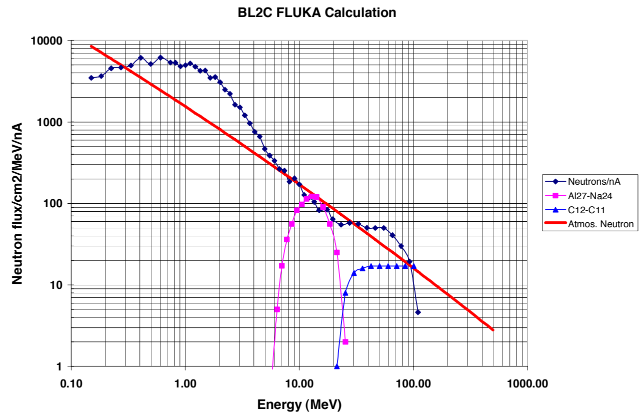


Fig. 215. Calculated neutron energy spectrum for BL2C at 110 MeV proton energy compared with the atmospheric spectrum. The activation cross sections used for flux normalization are also shown.

Canadian groups from MDA (previously MD Robotics), Routes Astro Engineering, and UTIAS/Dynacon visited the facility on several occasions during the year. Tests of radiation effects on optical equipment were carried out for the University of Calgary and ABB-Bomem. A group from JPL and Seagate irradiated a number of disk drives for total dose effects at fluences up to 5×10^{12} protons cm^{-2}. This required a uniform beam over a 10 cm diameter spot at high flux so that double scattering was used and optimized for 100 MeV. The reason for the inability to extract protons with energies above 103 MeV on BL2C was eventually traced to a faulty polarity switch on a dipole and now 116 MeV is again available.

Neutron irradiation facility

The high flux neutron beam at the final beam dump on BL1A has an energy spectrum that is similar to the atmospheric spectrum from below 1 MeV to the highest neutron energies around 400 MeV. The neutron rate above 10 MeV is about 2×10^6 neutrons cm^{-2} s^{-1} at BL1A currents of 100 μA. A substantial flux of thermal neutrons is also present. The only other similar facility is at LANSCE in Los Alamos but it does not have thermal neutrons.

The users in 2005 were similar to those in 2004. They included avionics testing by a Swedish/UK collaboration called SPAESRANE, a US company Smiths Aerospace, along with two microelectronics testing companies, HIREX from France and IROC Technologies from US/France, and a FPGA manufacturing company Lattice Semiconductor Corp.

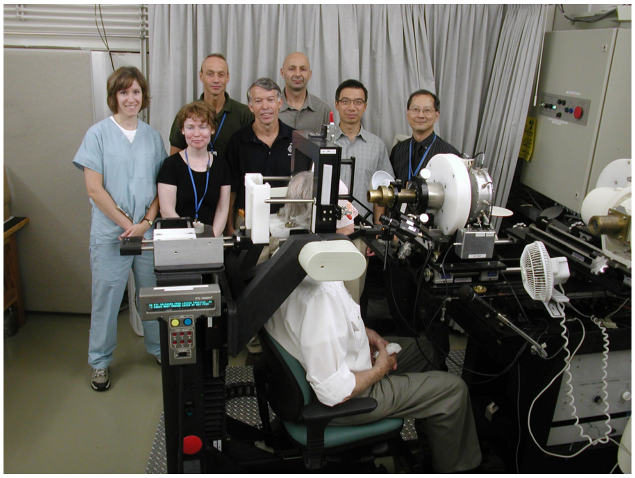


Fig. 216. The proton eye treatment team together with the 100th patient.

Proton Therapy Facility
(E.W. Blackmore, TRIUMF)

In 2005 there were 10 patients treated with protons during five scheduled treatment sessions. This brings the total number of patients treated at TRIUMF to 104. A significant milestone was reached in the August treatment period with the treatment of the 100th patient and this month also marked the 10th anniversary of proton therapy at TRIUMF. One of the treatment sessions for the 100th patient was televised and, together with interviews of the patient and members of the proton therapy team, appeared later on the "Your Health with Dr. Rhonda Low" segment of the CTV news.

Of the 10 patients treated, nine were for choroidal melanoma and one for an iris tumour.

There were no significant changes made to the treatment system or the treatment planning software during 2005. As a result of extended beam running for proton irradiation of electronics on BL2C, the plastic range shifter is becoming radiation damaged. A second range shifter was NC machined at TRIUMF and calibrated for range vs. position. The second range shifter is within 0.1 mm of the original range shifter in thickness for 74 MeV protons. This new range shifter will be used only for patient treatments.

Centre for Molecular and Materials Science (μSR + β-NMQR) User Facility
(S. Kreitzman, TRIUMF)

Facility overview

Proposals and funding In 2005 the Centre for Molecular and Materials Science (CMMS) personnel funding from its NSREC Major Facilities Access Grant (MFAG) was once again (for the third year in a row) in place for only one year. As in the previous two years, the NSERC committee was, at the time of the allocation, unable to know if the proposals in TRIUMF's Five-Year plan regarding the installation of new μSR facilities would in fact be funded. Subsequent to this "holding pattern" for the CMMS facility MFAG, TRIUMF has, in the spring of 2005, been advised of the status of funding for its own 5-Year plan. Within those funding guidelines TRIUMF has decided to allocate \$2.7 million to add one of the two proposed new beam lines, M9A. This will provide a new high luminosity surface muon beam line fitted with an achromatic spin rotator/separator. Complementing the beam line will be a state of the art turnkey spectrometer suitable for the broad range of general condensed matter and physical chemistry researchers who wish to utilize μSR as a relevant research tool. The funding (and physical preparation) for this new muon beam line is set to begin in fiscal 2006–07. With these TRIUMF plans in place and committed, the CMMS had again submitted an expanded MFAG application to support the new planned infrastructure.

In addition to this, the CMMS is engaged in a major multi-university Canadian Foundation for Innovation (CFI) proposal to secure funding for the M20 beam line upgrade which could not proceed under the financial restrictions of TRIUMF's 2005–10 funding. This proposal foresees rebuilding M20 into a dual-leg beam line with MORE (Muons on Request) capabilities and an high efficiency achromatic spin rotator/separator, identical to the M9 beam line mentioned above. CFI funding decisions will be known in the fall of 2006, with funds becoming available in the 2007–08 fiscal year if successful.

Support for the facility has also been bolstered by a three year TRIUMF resident post-doctoral position funded by Toyota Research Laboratories.

Beam utilization An overall indicator of beam utilization can be found by consulting the links tcmms.ca/sched/sch106a.html and tcmms.ca/sched/sch107a.html. Beam delivery in the fall was without incident but that in the spring/summer was impacted over a period of two weeks by cyclotron issues and also by an overlap with the μSR conference (held every four years) which took place in the UK during this time. A summary of the schedules shows experiments taking 927 twelve hour shifts or 76 beam weeks on four beam lines. The breakdown for the major spectrometers was (in weeks): OMNI′ – 9; HiTime – 9; DR – 11; LAMPF/SFUMU – 16; Helios – 23; β-NMR/QR – 9.

Facility developments

Facility developments are categorized into two broad components: i) evolutions in beam line operation and modes of operation and ii) technical progress on specific instruments or inserts.

Operational evolutions The M9B channel at TRIUMF has, over the past few years, been known to generate significant quantities of transversely polarized muons at momenta from 60–95 Mev/c. This phenomena has been tracked down to a malfunctioning triplet located just after the superconducting solenoid. This triplet has now been repaired with the feature that the left and right quadrupole pairs can be powered independently, and asymmetrically, hence incorporating a dipole component into the triplet. This feature allows us to experimentally optimize the transverse polarization production of any given decay mode tune. To more fully understand how the transverse spin polarization comes about, we have modelled the channel with Geant. With the assistance of Peter Gumplinger, the code has been substantially supplemented to track the all important muon polarization. A diagram of the simulated transport results using this code is shown in Fig. 217. The muon envelope at the end of the M9B beam line is also shown.

The β-NMR/β-NQR line shape experiment now utilizes pulsed frequency selective excitation with the line scanning algorithm implemented through a random frequency sweep through the spectrum. This method of line shape determination has two critical experimental features: i) it removes all the systematic error associated with more traditional sweep methods which have well defined time frequency correlations (i.e. a linear frequency sweep as shown in Fig. 218); ii) the pulsed method, with its millisecond measurement time, removes effects of random beam instabilities that occur on the time scale of seconds.

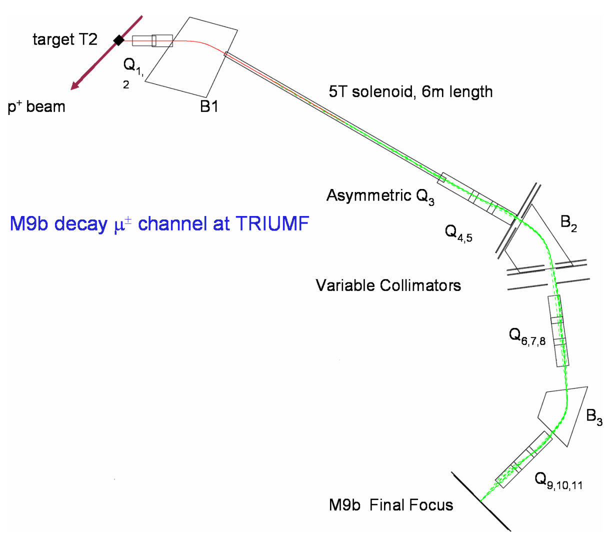


Fig. 217. A Geant simulation of the pion transport and decay (red), with the subsequent muon transport (green) into the experimental area of the M9B decay channel. The simulation is for 90 MeV/c muons.

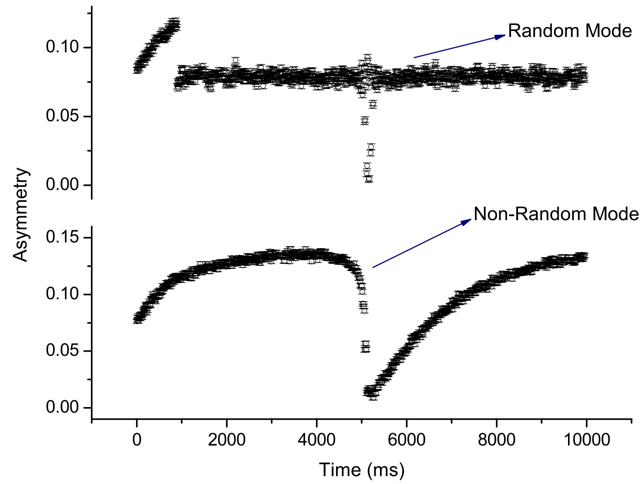


Fig. 218. The β-NMR line shape in gold foil using random vs. sequential frequency excitation.

Scheduled maintenance and all pertinent maintenance records are now being tracked on a Web based in-house database application, allowing us to implement increased quality control in the MRO operations of the facility.

Technical progress and developments The new high field, high timing front end for our dilution refrigerator (DR) has been fabricated. To balance the magnetic forces that the pmt shields exert on the magnet, a mirror image shielding array has been manufactured for the opposite side of the DR. Two of the shields in this array in fact house pmts which utilize the same wave shifting technology found in the front end, i.e. the back and active collimator detectors, to implement the forward/veto counter. A schematic can be found in Fig. 219.

Design and development of the high pressure cell system that we plan to implement continues. A non-yielding version of the stress strain calculation is shown

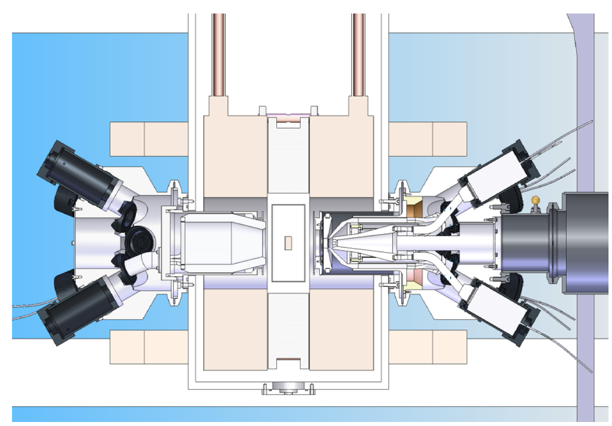


Fig. 219. A cut away view of the DR's high timing resolution front end (containing back, muon and active collimators) and the magnetic balance which houses the forward/veto counter.

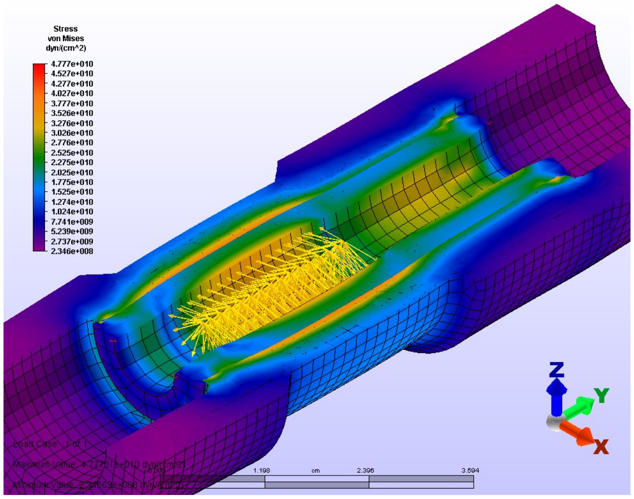


Fig. 220. Pressure cell design calculation, with 2.5 GPa of hydrostatic stress applied in the central region of a double walled NiCrAl cell. The strain shown represents an (idealized) elastic response of the system.

in Fig. 220 for a double walled cell made up of the very high strength NiCrAl alloy that has been supplied by R&D Support in Japan.

A third generation temperature stable variable frequency microwave (0.8–2.5 GHz) transmitter/cavity system has now received its experimental commissioning.

A new (mark II) β-NQR broad band (500 Hz–1 MHz) power amplifier has been designed and commissioned to supply up to 3 A rms of current across the entire frequency range.

Facility future perspectives

To date the operation of the β-NMR/β-NQR experiment has required the dedication of specialists, i.e. researchers very well versed in the field and its technicalities. With the ongoing standardization of the experiment we foresee that this research technique will slowly become more available to a broader range of investigators who are not directly connected with its development.

On the μSR front, with the impending design and construction of the new M9A surface muon beam line, the facility has embarked on a path (CFI funding through its multi-university facilities) which may allow its vision for an upgraded M20 to be realized. The theme of both of these developments is increased research throughput coincident with a high level of user friendliness to promote enhanced access to the broader research community.

Facility 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

Overall, 2005 was another year of consolidation and laying the network foundation to participate in the ATLAS experiment which is to begin in 2007.

The UBC-TRIUMF component of WestGrid, called Glacier, offering 14 TB of network attached disk and 80 TB of tape storage and running the Torque resource manager with the Moab job scheduler, was upgraded from 1008 (504 dual) to a 1680 (840 dual) 3.06 GHz Xeon CPU cluster.

Network

Through the generous loan of equipment from Foundry we conducted 10 GbE lightpath tests to CERN using the configuration illustrated in Fig. 221.

Figure 222 shows the configuration of the 10 Gb link between TRIUMF and CERN to be used for the support of ATLAS Tier 1 at TRIUMF. Completion of the final parts (TRIUMF to BCNET and Amsterdam to CERN) are expected to take place early in 2006.

Locally, the separation of the single flat class B IP address space has been delayed till February, 2006. At that time, the secure wireless LAN (WLAN) router from Colubris will finally be put into service. This device will be used to automate IP assignments to the TRIUMF users in general and visitors in particular.

Commodity traffic continued to be serviced via the 1 Gbit link to UBC (which is supported by 3 redundant service providers) as the bandwidth manager effectively maintains this at an acceptable low rate.

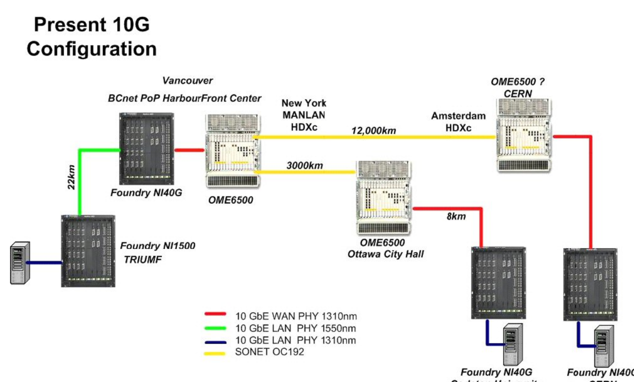


Fig. 221. Equipment used for 10 GbE lightpath tests to CERN.

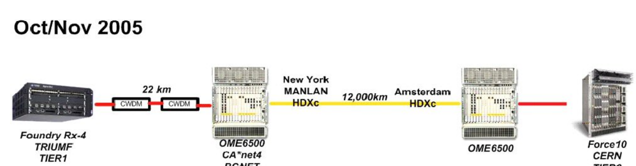


Fig. 222. Equipment to be used for Tier 1 support.

Computer security

Administrative computing reliability was enhanced by supplementing its UPS with diesel generated power backup.

The unforeseen re-routing of the UPS feed to the main computing room in ISAC-II had a minimal impact on the user community since all public servers, being connected to dual power supplies, were able to be transferred from UPS to/from regular building power without interrupting these critical services.

The reliability and regulation of the air-conditioners cooling the main compute server room in ISAC-II continues to be questionable and plans are under way for early 2006 to address this with improved monitoring, ducting modifications, and supplementary heating to further reduce temperature excursions and improve reliability.

All computing accounts went through a renewal process this year. About 30% of the ∼1000 accounts were eliminated through non-renewal. The complete phase-out of X-terminal use at TRIUMF is still ongoing.

The mandatory move to Windows SP2 took place in 2005.

An Amanda system based on a 2.2 GHz Dual Opteron computer, with 2 GB memory and 16 400 GB WD disks connected to 2 LSI Megaraid disk controllers, provides daily incremental backup to about 150 Linux machines over a cycle period of about 1 month. At least 2 full backups (at about 1/month) are retained on disk. A 26 slot Overland DLT tape library system (using SDLT 600 drive with 300 GB native capacity tapes) provides long term backup.

E-mail

Aggressive and improved e-mail filtering, as well as an overall slight decline in the spam volume has resulted in noticeable improvement in handling unwanted e-mails.

Plans are in place to further improve e-mail responsiveness by using a Dell 2850 to perform the anti-virus, anti-spam, and sendmail functions while the existing Dell 2650 would handle the imap and webmail (actual reception of e-mail) functions. A third machine may also be designated to further expedite the handling of outgoing mail.

Servers

We installed and configured a new Linux based print server for Linux computers on site. As an upgrade to tnt2k we installed and configured tnt2k3, a new Windows 2003 based terminal server, for users who do not have access to a personal Windows system, to run the latest available MS Windows based programs regardless of the Operating System on their own computers. InDiCo, a new Linux based conference hosting product developed at CERN, was installed. The source code was extensively modified, and scripts written tailored to meet TRIUMF's needs. InDiCo will eventually replace the existing Agenda. A new Web based HelpDesk was created which incorporated LDAP to allow anybody with an e-mail account at TRIUMF to log on and use its services. Over a dozen next generation Wireless Access Points (AP) were installed and configured to extend the wireless coverage onsite and to replace some of the old APs.

Documentation details for much of the work are available as tutorials on TRIUMF Web pages at http://www.triumf.ca/internal/tutorial/tutorial.html and https://helpdesk.triumf.ca.

Storage for the public cluster ibm00 was made more reliable by attaching 7 146 GB SCSI disks in a raid5 configuration. This will be expanded to its full capacity of 14 146 GB disks in early 2006. This released ∼1 TB from the Brownie unit (total 2 TB) for use of user files that will not be backed-up.

Figure 223 shows the current status of the main components of the Computing Services facility. A number of 20 A UPS circuits were added to support the added hardware.

CERN/ATLAS service challenges / IGT and 10 GbE developments

The essential element which allowed TRIUMF to participate in the CERN/ATLAS service challenges was the use of the CAnet 4 International Grid Test Bed. With special software developed by CANARIE, individual users can now directly control routing of a lightpath, that is, the interconnection and switching of a user assigned lightpath across the network. Essentially, User Controlled Lighpath (UCLP) software is used to create a layer 1 Virtual Private Network (VPN). It is important to note that UCLP allows a user to reconfigure the topology of VPNs and change their shape, size, and path – hence the term "Articulated" Private Network (APN). For details refer to http://www.canarie.ca/canet4/uclp/UCLP_Roadmap.doc.

In July TRIUMF signed a Memorandum of Understanding with HEPnet, ATLAS Canada, and

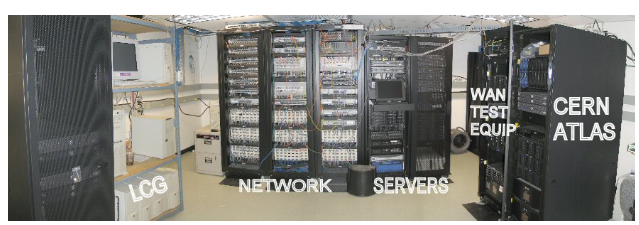


Fig. 223. Status of main components of the Computing Services hardware facilities.

CANARIE to provide the high energy physics community with dedicated Articulated Private Network (APN) across Canada as well as to CERN to support the data requirements of the ATLAS Tier 1 site at TRIUMF.

The CAnet International Grid Testbed (IGT) was used by TRIUMF in the past year to continue 10 GbE experiments on robust data transfers between a Tier 1 ATLAS site at TRIUMF and CERN. Foundry Networks was very generous in the loan of the multiple NI40G switches, with 10 GbE WAN PHY, as well as an NI1400 switch to solve the "last mile" problem between TRIUMF and the BCNET PoP in Vancouver, which permitted the direct connectivity to OC-192/STM-64 interfaces of the optical transport equipment. The loan of these NI40Gs in Ottawa and the NI1400 switch at TRIUMF/BCNET were extended to the end of 2005.

ATLAS service challenge tests were conducted throughout the year. They successfully met the target goals. Figure 224 shows some results of disk-to-disk transfers using the 10 Gb link (subsequently replaced by two permanent 1 Gb links). Disk-to-disk transfers of 275 MB/s (∼1 TB/hr) were sustained for a period of days.

Most of the hardware to establish a permanent 10 Gb link between TRIUMF and CERN arrived in late 2005. Figure 225 shows the installed Foundry BigIron RX-4 switch to be used to consolidate transfers on the TRIUMF-CERN 10 Gb link. Completion is awaiting the 1550 nm DWDM optics from MRV which will be used down one of the 4 channels of TRIUMF's existing CWDM linking TRIUMF to BCNET.

Software developments

The Extrema program, successor to Physica, was released as an Open Source project. Extrema was accepted by SourceForge.net in 2005 (see http://sourceforge.net/projects/extrema). Extrema was also chosen by UBC Physics as the preferred data analysis program for use by undergraduate students (replacing Mathematica). Work is now in progress converting Extrema to the wxWidgets cross-platform API with the goal of having a consistent Extrema for Linux, MS Windows, and Mac OS X.

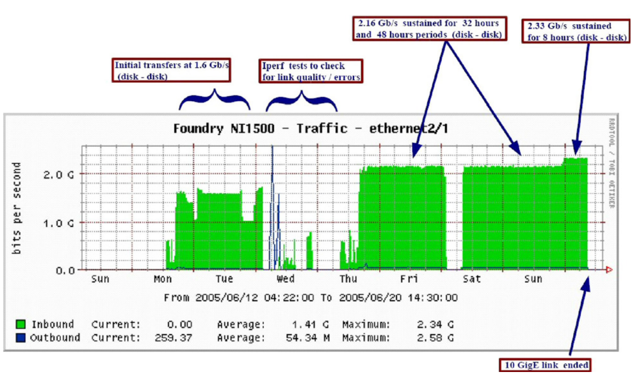


Fig. 224. Some results of TRIUMF-CERN disk-to-disk transfers using the 10 Gb link.

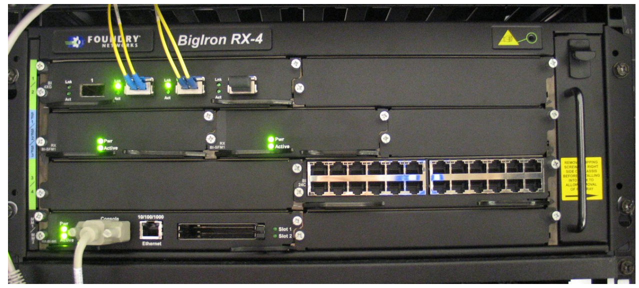


Fig. 225. Foundry RX-4 to be used to consolidate transfers on TRIUMF-CERN 10 Gb link.

Many enhancements were made to ROODY, (see http://midas.triumf.ca/roody/html/) which is a program based solely on CERN-ROOT for histogram display and is meant for display of .root files. ROODY can be run with either the MIDAS analyzer or the ROME (Root based object oriented MIDAS extension) analyzer to visualize on-line data received through a socket port.

As a summer student project, PHP scripts were developed which automated the generation of thumbnail images for high resolution images placed in appropriate directories of a shared space of the Web page server trshare.triumf.ca.

Linux at TRIUMF continues its migration to Scientific Linux (generously supported by the efforts at FNAL and CERN), with Redhat 7.3 and Fedora Core (3 recommended) versions still being supported (albeit without updates). The update/install scripts run from the server trsev.triumf.ca while the actual installations take place from server mirror.triumf.ca.

Numerical computing

FEMLAB → COMSOL As of release 3.2, FEMLAB, the multi-physics PDE solver, is now named COMSOL. The community of TRIUMF users continues to grow although the 3 floating licences appear to match current use requirements. COMSOL runs on Windows XP and Linux (32 and 64 bit).

Videoconferencing

The videoconferencing facilities in the auditorium were upgraded with a new sound system, the permanent mounting of the main digital projector, and the dedication of a computer supporting VRVS, AccessGrid, and local presentations.

A Web application was written to monitor activity on the ESnet H.323 gatekeeper. This system is used for conferencing on the US research networks and the application was used to justify the purchase of additional equipment at ESnet.

Miscellaneous

The substandard CAT6 cabling in the ISAC-II switching rooms was redone to improve reliability of optional gigabit cabling to the desktop.

To support better searching of documents stored at TRIUMF a "Google Mini" was installed at TRIUMF. This low cost ($3 k US) hardware/software solution, allows up to 100,000 documents to be indexed and Web searched (with double that on the same hardware for double the price).

The migration of TRIUMF web pages to the new format continued in 2005 and is not expected to be completed until sometime in 2006.

The structural re-organization of TRIUMF, initiated mid-2005, is expected to be completed in 2006. No significant changes are anticipated to Computing Services, although the installation of a Tier 1 ATLAS/CERN facility at TRIUMF, currently undergoing various service challenge tests and projected for full implementation starting in 2006, will significantly impact TRIUMF infrastructure. The proposed 5 sections in Computing are:

- ATLAS Tier 1
- Core Computing and Networking Services
- PC Hardware and Windows Support
- DAQ
- Management Information Support.

Detector Facility
(R.S. Henderson, TRIUMF)

This year has been a busy one for the detector facility. The KOPIO experiment has now been cancelled. This was a disappointment to the KOPIO people who have spent years in design and prototyping effort. With the cancellation of KOPIO, the detector facility has only one major project, the T2K experiment planned for JPARC in Japan. Several KOPIO people have since moved to T2K. Some of the KOPIO expertise and R&D will be applicable to T2K. For example, the KOPIO development of extruded scintillator by the local company (Celco) is already proving useful for the T2K fine grain detector (FGD). Chapman Lim and Naimat Kahn have done two developmental runs to produce 10 mm × 10 mm scintillator rod with a single central hole and a co-extruded TiO_2 outer coating. The test pieces have already been tested in beam and produce more light than expected. This effort should soon lead to a small production run in early 2006.

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 Jefferson Lab). The small Bridgeport 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 Jefferson Lab. More KOPIO prototype detectors were also fabricated. A major effort was made to complete the large amount of G10 machining for the T2K prototype TPC. This was made more difficult because of the small machining area of the Bridgeport mill and the fact that this machine is almost worn out.

The TRIUMF T2K group and the detector facility are responsible for two of the major detector components. The first is the three large tracking TPCs (2 m × 2 m × 1 m). A small prototype of this TPC (∼1 m × 2 m × 0.6 m) has been designed and built at TRIUMF. It was shipped to Victoria on December 20, 2005 for installation of the two GEM modules (three GEMS each), the readout electronics and for testing with cosmic rays. Early results look very good and will be reported to the NSERC committee during their T2K review on January 11–12, 2006 and to the T2K collaboration meeting in Japan the following week. Figure 226 shows a side-view drawing of the prototype TPC and Fig. 227 shows some photographs taken during construction. Figure 228 shows the prototype during initial gas and HV studies in the facility.

The second of the T2K detectors is the two fine grain detectors (FGDs) that are between the three double-ended TPC gasboxes. These FGDs are ∼2 m × 2 m × 0.3 m and there are two types. The first type is made from fifteen XY-layers bolted into a 30-layer module. Each XY-layer consists of two layers of 10 mm × 10 mm scintillator (single hole, co-extruded TiO_2 outer coating). These ∼6,000 scintillator pieces would be read out with WLS fibres and SPMs. The second type of FGD is called "passive water" and consists of six XY-layers alternating with six 30 mm thick water layers. Each water layer consists of three 10 mm thick extruded polystyrene panels (commercially available) that have the ends sealed and are filled with water. A full-size prototype of each of these FGDs is planned for 2006.

A third type of FGD called "active water" is still in the R&D stage. It would use fifteen XY-layers (like the first FGD), but instead of extruded solid scintillator, these layers would be made from the extruded polystyrene panels filled with a liquid scintillator and readout just like the solid scintillator (WLS fibres and SPMs). Unfortunately, the liquid scintillator attacks many materials and becomes discoloured. Considerable progress had been made, but it is not ready for use yet.

CFI funding for LADD has been approved and much money has already been spent 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. A precision 5-ton crane has been added to our large cleanroom in the meson hall and a 2-ton crane will be installed in the MESA in February, 2006. Half of the magnet development area in the proton hall extension has been re-allocated to the facility for a large (3 m × 3 m) router that will be used for both inspection and fabrication of the pieces for the T2K detectors. AC and dust-extraction systems have been purchased and are being installed, the router delivery is late but expected before the end of January, 2006.

A major redevelopment of the scintillator shop is proposed for 2006. If this budget change is approved by CFI, we plan to replace the worn-out Bridgeport mill with a Haas VF5/40XT. This new high quality 5-axis machine will greatly improve the machining ability of the scintillator shop (the milling volume will increase from 30 in. × 12 in. × 5 in. to 60 in. × 26 in. × 25 in.). In addition, a new NC lathe will replace our small lathe. An AC system will be installed on the roof, giving the shop a controlled temperature for precise machining in plastic. The existing dust-extraction system will be replaced. With these changes, the scintillator shop will be capable of machining larger items to higher accuracy. For example, the G10 machining for the TPC prototype could have been machined in a single set-up, instead of four set-ups for each of the many pieces.

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 17 broken wires, in 15 wire-planes, from 12 different detector modules. The cradle and detector stack were brought back to the facility for several months of module repair and bench testing. This involved five people and a total of ∼7.5 man-months of labour. This has been completed and TWIST is again taking data. During the January–March, 2006 shutdown, a broken wire in one of the dense stack modules will be replaced.

From the above, it is clear that with full-scale preproduction versions of the TPC and FGD detectors scheduled before the end of 2006, and LADD upgrades to the facility, the coming year will be a very busy one for the TRIUMF detector facility.

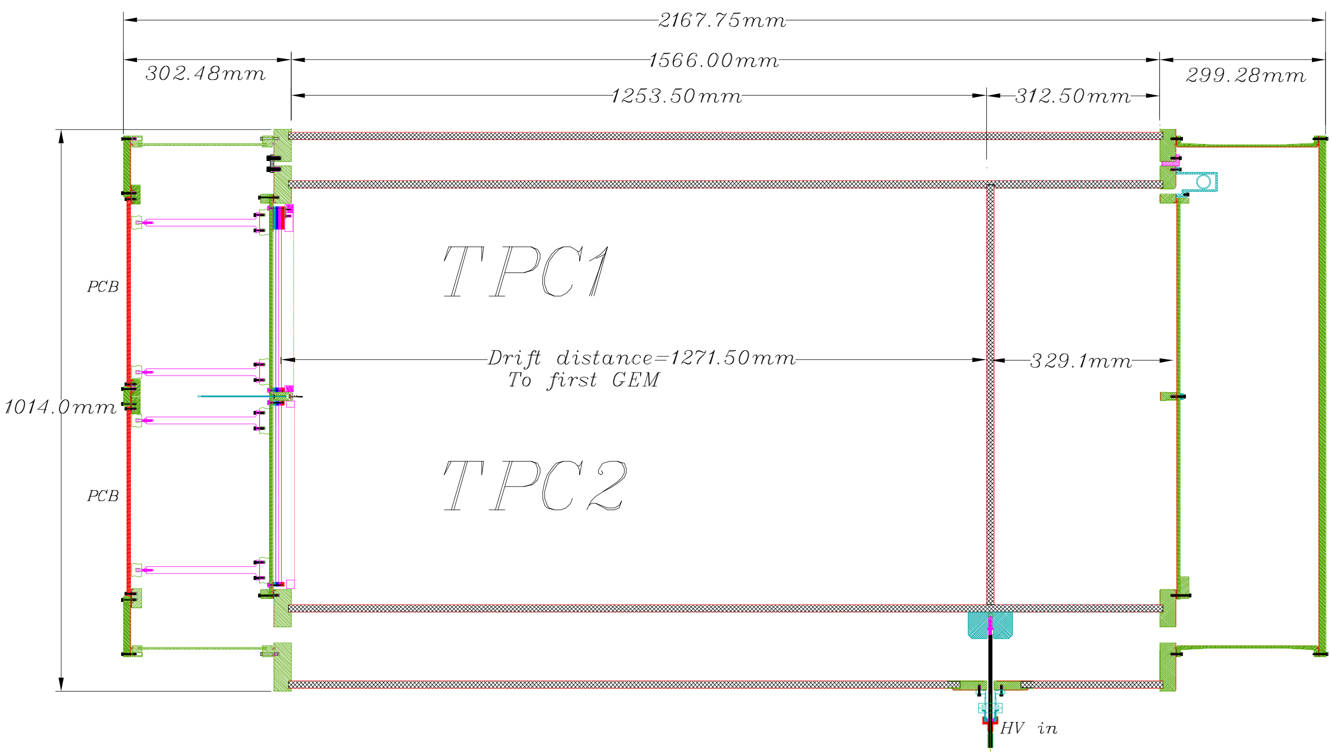


Fig. 226. Side view of T2K prototype TPC.

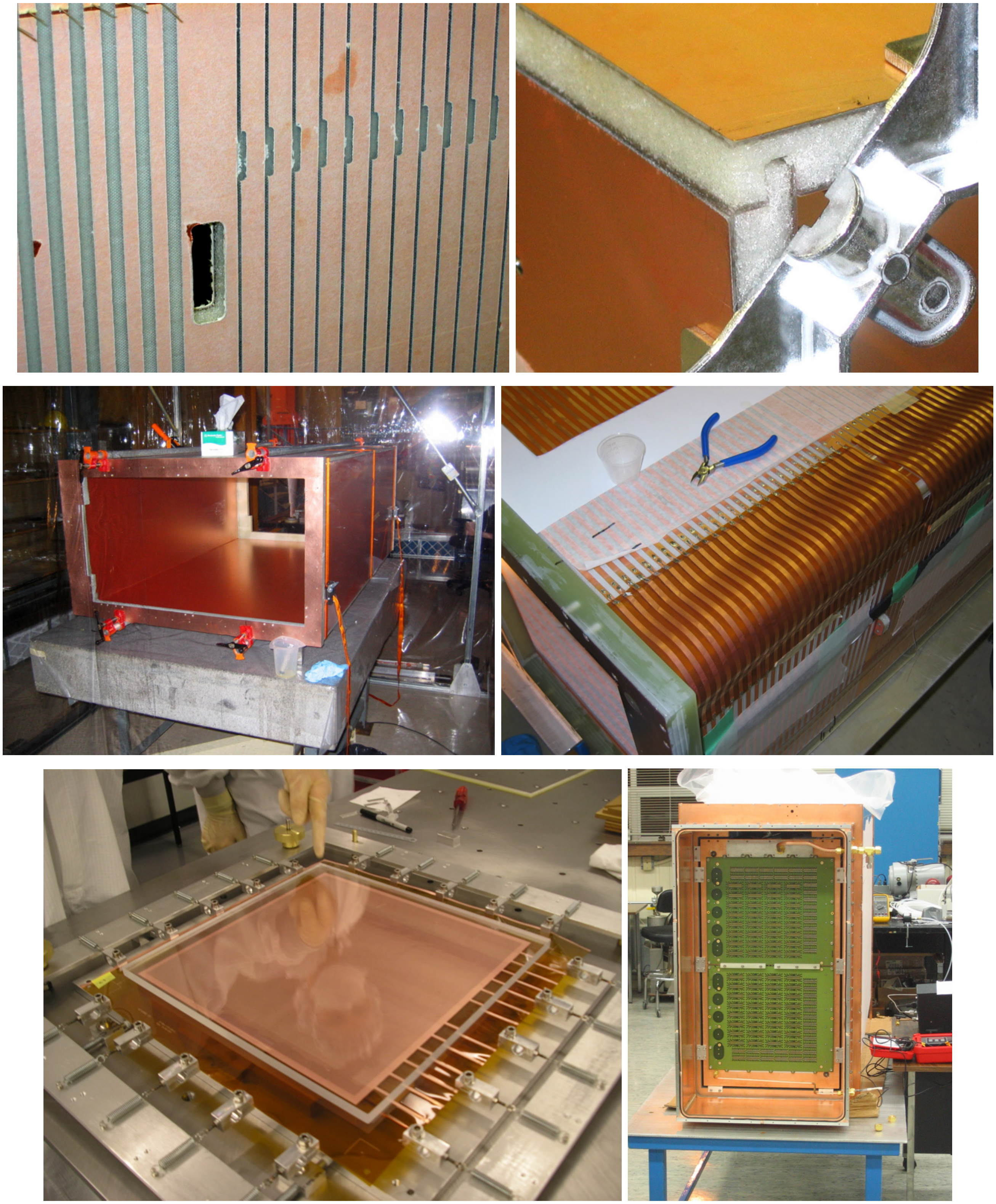


Fig. 227. Photographs of TPC prototype during construction. Top-left: Machined Cu/G10/Rohacell/G10/Cu inner wall panel (paper still on). Top-right: Outer box panels held with clamp for initial assembly check. Middle-left: Outer box in hot tent during gluing. Middle-right: Rounded corners being added to inner box. Bottom-left: Readout end of prototype TPC, shows two GEM pad boards. Bottom-right: Stretched GEM foil being glued to G10 frame at Victoria.

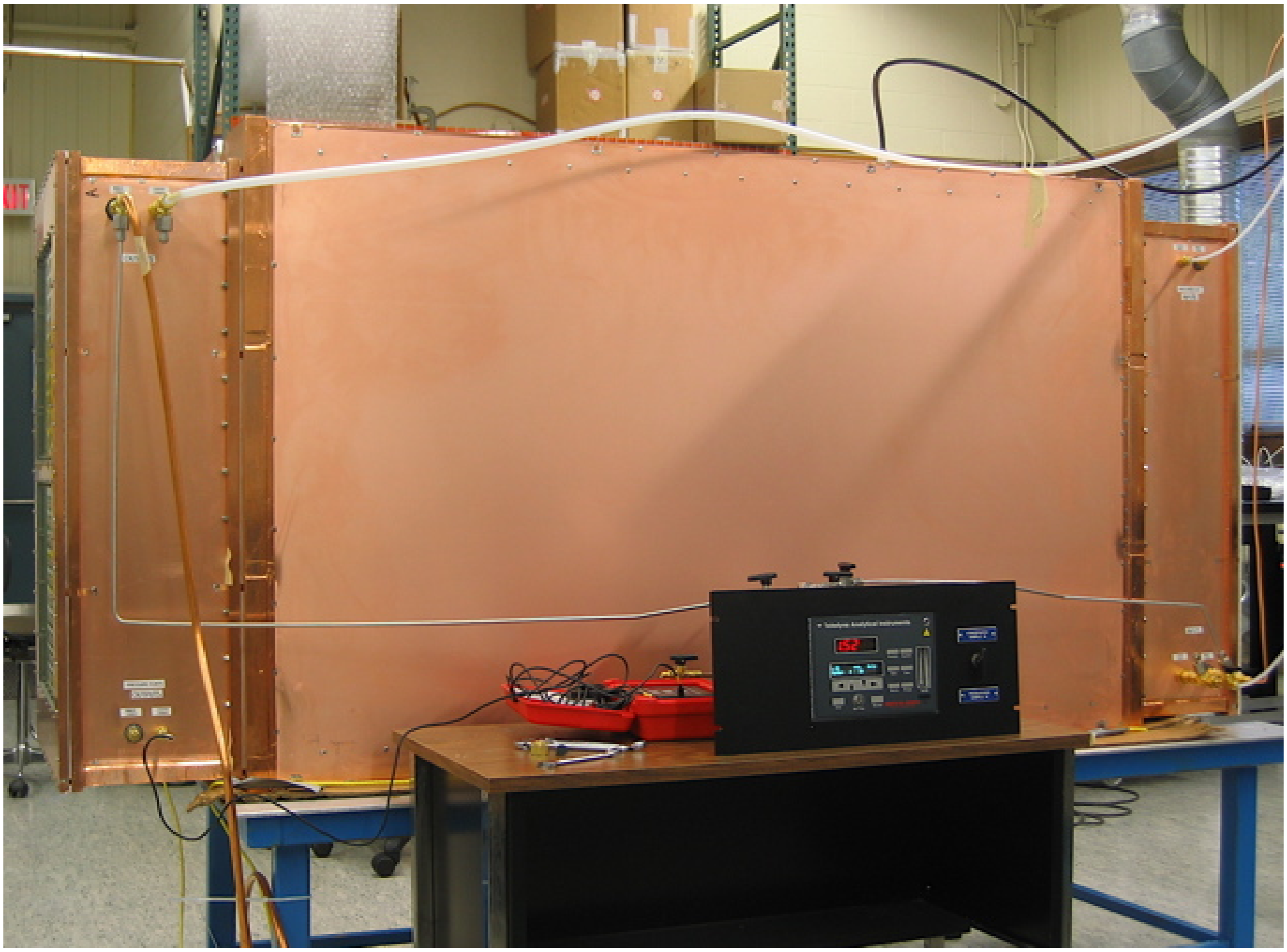


Fig. 228. TPC prototype during initial gas and HV testing in the facility.

Geant4

(P. Gumplinger, F.W. Jones, TRIUMF)

Geant4 is a software toolkit for the simulation of the passage of particles through matter. It is used by a large number of experiments and projects in a variety of application domains, including high energy physics, astrophysics and space science, medical physics and radiation protection. Geant4 provides comprehensive detector and physics modelling capabilities embedded in a flexible structure. The kernel encompasses tracking, geometry description and navigation, material specification, abstract interfaces to physics processes, management of events, run configuration, stacking for track prioritization, tools for handling the detector response, and interfaces to external frameworks, graphics and user interface systems. Geant4 physics processes cover diverse interactions over an extended energy range, from optical photon and thermal neutrons to the high energy reactions at the Large Hadron Collider (LHC) and in cosmic ray experiments. Particles tracked include leptons, photons, hadrons and ions. Various implementations of physics processes are offered, providing complementary or alternative modelling approaches. Moreover, Geant4 provides interfaces to enable its users to interact with their application and save their results. Visualization drivers, graphical user interfaces and a flexible framework for persistence are also included in the toolkit.

Geant4 was the first large scale software project to pioneer the adoption of object-oriented technology in particle physics. Geant4 follows an iterative-incremental software process. This approach facilitates the extension and refinement of the toolkit without affecting the existing code already used in production mode by many experiments. New developments in the Geant4 kernel provide a number of improvements to enhance stability for production and new tools to identify infrequent problems. The Run Manager module was also redesigned, separating its mandatory kernel functionality into a new class. This refinement enables a user to create a customized run-manager, which more easily fits into even more general software frameworks, such as those used by the large LHC experiments. One of the most significant enhancements of Geant4 capabilities is the possibility to define regions in the experimental set-up, and to set a different particle production threshold in each of these regions. In early versions of Geant4, the same threshold for producing secondary particles was enforced throughout the set-up for each particle type. While this feature ensured consistency of the simulation accuracy, it did not reflect the real-life design of most experiments, which are characterized by detectors of very different precision, e.g. an inner micro-vertex detector and an outer coarse-grained muon detector. This new ability allows the accuracy and performance to be optimized; detailed and accurate for the region of high resolution detectors, while saving computing time where the coarser detector resolution does not justify tracking the lowest energy particles. To facilitate the usage of variance reduction techniques, general-purpose biasing methods have been introduced into the toolkit. Radiation shielding studies can profit from this functionality to achieve large gains in time efficiency. Geant4 now provides importance biasing with splitting and Russian roulette where an importance value is associated with each volume.

A significant new feature in Geant4 geometry is the abstraction of the navigator class G4Navigator. This enables a user to replace or change the Geant4 navigator, or to add functionality to it. Models to describe twisted solids were added to the already extensive list of Construed Solid Geometry (CSG) volumes. Twisted trapezoids are important components in the liquid argon end-cap calorimeter of the ATLAS detector. Another new solid for the use case of a full sphere, the G4Orb, allows for much faster performance when tracking in large spheres.

Saving the description of a geometrical set-up is a typical requirement of many experiments, which makes it possible to share the same geometry model across various software domains, such as simulation and reconstruction. The geometry description markup language (GDML) and its module for interfacing with Geant4 have been extended to facilitate a geometrical description based on common tools and standards. A new module enables a user to save a Geant4 geometry description, which is in memory, by writing it into a text file by extensible markup language (XML).

A number of developments and improvements have been made in the electromagnetic processes in recent Geant4 releases. The new cuts-per-region functionality affected the implementation of the electromagnetic processes, which evolved to deal with different particle production thresholds in different regions. The standard EM package has been completely redesigned. The new implementation encompasses a model-based design, concentrating the treatment of physics modelling in smaller, dedicated classes. This simplifies maintenance and facilitates extensions and refinements. Performance has been improved, in particular for low production thresholds. Refinements include the option to save and retrieve physics tables. This speeds up the startup in execution when several simulation programs run under the same physics configurations, aiding in particular the interactive use in set-ups with many materials. Improvements in multiple scattering, muon and ion ionization and in simulation of electron-positron pair production by muons were implemented. The new multiple scattering model provides improved sampling of the tail of the angular distribution and less dependence on the step size. All the electromagnetic models provided by Geant4 for electrons, photons, protons and alpha particles have been compared to the National Institute of Standards and Technology (NIST) database, which represents a well known, authoritative reference in the field; this database is also adopted in the definition of medical physics protocols. This systematic test involved quantitative comparisons between simulation and reference data using statistical methods. It confirmed good agreement of all Geant4 electromagnetic models with the NIST reference. Other comprehensive validation studies addressed transmission and backscattering distributions.

The hadronic physics simulation in more recent Geant4 versions includes the first release of the Binary Cascade model and an implementation of the Bertini Cascade. Also available is the chiral invariant phase space model (CHIPS), which is the quark-level event generator for the fragmentation of hadronic systems into hadrons. Making an optimal selection of a set of models among those available can present a daunting learning curve, especially for hadronic interactions. For the same combination of projectile and target at a given energy, there can be several models applicable with different accuracy, strengths and computational cost. By using a consistent, tailored set of models it is possible to address the requirements of a particular use case. Choosing among the Geant4 hadronic models is made easier by a number of "Physics Lists" which are now included in the release. Each Physics List is a complete and consistent collection of models chosen to be appropriate for a given use case. Hadronic use cases relevant to high energy physics applications include calorimeters, trackers and typical general-purpose detectors. At low energy the use cases of neutron dosimetry and nuclear penetration shielding are covered. Results already obtained with these Physics Lists are available and provide invaluable reference points and benchmarks.

The Geant4 toolkit is complemented by a set of examples which illustrate not only the basic usage of the software but also demonstrate realistic experimental configurations. They include the simulation of calorimeters, a ring imaging Čerenkov detector, space telescopes for X-ray and γ-ray astronomy, an underground detector for dark matter searches, electrostatic charging of isolated test masses by galactic cosmic rays, and a cosmic ray experiment. Two examples deal with neutron shielding and protection from radioactivity for interplanetary manned missions. Other examples cover various radiotherapy techniques, including brachytherapy, hadron therapy and intensity modulated radiotherapy.

There is no use for a simulation without analysis of the results. Geant4 is amendable to the user's choice of analysis system. An example recently added to the distribution shows a recommended design to integrate simulation analysis into a user application: a layer of abstract interfaces decouples the user's code and the Geant4 toolkit from the implementations of the analysis subsystems. To achieve this, the Abstract Interfaces for Data Analysis (AIDA) package was chosen.

Simulations often involve the generation of large numbers of events and require significant computing resources. Execution in a parallel mode allows for adequate statistics in a reduced time frame. The use of job-level parallelism, using independent jobs on farms of computers, is well established but requires experience in distributing jobs and gathering the results. Other types of parallelism provide an alternative with simpler ways to launch jobs and obtain results. A new extended example shows how to use the task oriented parallel package TOP-C to parallelize Geant4 using event-level parallelism. Even though the application actually runs in parallel on distributed computers, it appears to run as a single process storing and analyzing a single collection of hits. The master process transparently generates events that are processed on slave processors, and whose hits are brought back to the master.

The development of the Geant4 toolkit will continue to be pursued in the future by the Geant4 Collaboration in response to the evolving requirements of the wide experimental community using it. The work on Geant4's physics capabilities represents a continuous effort to improve the simulation accuracy, while a significant effort is also invested in the validation of its physics models.

Laboratory for Advanced Detector Development (LADD)

(D. Bryman, UBC; L. Kurchaninov, F. Retière, TRIUMF)

The Laboratory for Advanced Detector Development (LADD) is being established at TRIUMF and the University of Montreal with support from the Canada Foundation for Innovation, the Provinces of BC and Quebec, the University of Montreal (UM), TRIUMF and UBC. In 2005, LADD has continued setting up infrastructure for detector development and testing at TRIUMF, UBC, and UM. LADD has also begun to support detector development projects at UBC, TRIUMF, UVic and UM by providing expertise and equipment for nuclear and particle physics, condensed matter physics and medical imaging research. In the following, we describe progress on development and use of LADD infrastructure at TRIUMF.

LADD infrastructure

LADD infrastructure encompasses 4 different components: an electronics laboratory, a general purpose detector testing facility, a detector construction facility and a noble liquid detector development facility.

The microstructure electronics laboratory underwent a complete refurbishing in 2005. It has been remodelled and most pieces of equipment have been upgraded. The emphasis has been put on enhancing PC board design, fabrication and testing capabilities. The design and simulation tools have been upgraded by purchasing new software and new computers. We have acquired equipment required for small scale board repair and patching. The test equipment has been considerably upgraded by acquiring state of the art high speed oscilloscopes. LADD has considerably enhanced the electronics laboratory capabilities at TRIUMF.

LADD has also devoted significant resources to upgrade the detector testing facility. We have focused on upgrading outdated equipment, acquiring equipment that was in short supply, and purchasing new pieces of equipment to enable new developments. The data acquisition capabilities have been upgraded by building four complete VME based systems, including crates, controllers, ADCs, TDCs, waveform digitizers and scaler modules. Each system interfaces directly to a central server for data storage, also acquired by LADD. Ancillary pieces of equipment such as high voltage power supplies and pulsers complement the data acquisition set-ups. LADD now provides complete state of the art set-ups for detector development at TRIUMF.

Detector construction at TRIUMF has been enhanced by upgrading the clean rooms and purchasing granite tables, an inspection table, and various other pieces of equipment for precision detector construction. In addition a large CNC router has been ordered. It will allow building large scale detectors. The T2K time projection chambers will be built with the router at relatively low cost, for example. Thus, LADD equipment also significantly enhances TRIUMF detector construction capabilities.

Detector development supported by LADD

LADD has contributed to the development of the nuclear physics experiments TIGRESS and TACTIC by providing pieces of equipment. TIGRESS used LADD's planar motion table to characterize the spatial response of their germanium detectors. TACTIC has relied on one of the LADD test set-ups to study the performances of gas electron multipliers (GEM) in low pressure gas. Both experiments have performed finite element simulation with the software FEMLAB, provided in part by LADD.

The μSR experiments have used a laser system provided by LADD to investigate the timing resolution of their detector. The laser provides a very short pulse (500 ps) with a very low jitter. An attenuator system was also purchased to control the light intensity. The laser wavelength was chosen to look like the light emitted by charged particles going through a plastic scintillator. We foresee using this set-up in the testing phase for T2K equipment as well for investigating the response of silicon photomultipliers.

With the cancellation of the KOPIO experiment in September, some LADD resources have been redirected to the T2K experiment. Nevertheless, the detector development for KOPIO supported by LADD has been very fruitful: design and fabrication of a 48 channel VME TDC board, development of a scintillation extrusion technique in collaboration with Celco (Surrey, BC) and development of large area flat panel scintillators, and development of large area FR4 (G-10) panels by Profile Industries (Sydney, BC).

The T2K experiment is capitalizing on the KOPIO developments to produce its own scintillator bars at Celco. Furthermore, T2K scintillator development has received a lot of support from LADD, providing silicon photomultipliers and phototubes, a test set-up and a high voltage power supply. The development of the T2K fine grain detector will continue to be supported by LADD until it becomes a construction project. LADD supports the development of silicon photomultipliers that have the potential of replacing standard vacuum based photomutipliers. Hence the scope of this R&D goes beyond T2K.

The T2K TPC development has also relied heavily on LADD for constructing and equipping its first prototype. LADD provided a high voltage power supply for the cathode, readout electronics, and an oxygen monitor. As the T2K TPC will soon shift from R&D to fabrication stage, LADD equipment will be returned to a pool and become available to future detector R&D projects. T2K will then rely on the LADD detector fabrication facility to build both the FGD and TPC. The CNC router will be used to machine all the Rohacell/G10 walls of the T2K TPC. Thus, T2K is the first experiment benefiting heavily from the support of LADD, which has enabled the Canadian group to take a leadership position in developing the tracker components of the T2K ND280 detector.

Detector development within LADD

While LADD supports detector development for physics experiments at the R&D stage, the group is also involved in developing detectors for medical imaging applications. The focus is on developing a detector for positron emission tomography (PET) based on liquid xenon technology. PET relies on the measurement of both 511 keV photons from positron annihilation within the sample being studied. In the current PET detector technology, the photons are measured in an array of scintillating crystals. This suffers from some drawbacks: depth of interaction uncertainties, and limited energy and timing resolution. While these issues can be addressed by improving the scintillating crystal array, the liquid xenon technology promises to provide far superior performance: 3-dimensional reconstruction of the photon interaction points and superior energy and timing resolutions. The key advantage of the liquid xenon technology is to allow measuring the ionization signal in addition to the scintillation light. Indeed, a 511 keV photon photoelectric interaction in the xenon releases roughly 20,000 scintillation photons and 20,000 electron-ion pairs. Since the xenon scintillation decay time is on the order of a few nanoseconds, a timing resolution of 1 ns can be achieved with a modest photon collection efficiency. The 3-dimensional position is reconstructed by drifting the electrons within the xenon to a segmented anode, which provides a 2-dimensional position, and then reconstructing the third dimension from the electrons' drift time. Very good energy resolution is then achieved by using low noise electronics and combining both charge and light measurements.

We have designed a liquid xenon based micro-PET detector. We foresee building a cylindrical vessel of 10 cm inner radius, 22 cm outer radius, and 16 cm in length. 511 keV photons are reconstructed in eight separated sectors inserted within the vessel. Ionization electrons drift towards the outer radius where they are measured on cross wires and anode strips. The pitch of the wires and strips is chosen in order to overlap to minimize pileup, i.e. overlapping ionization signal from two different photons. The same constraint applies when choosing the shaping time of the readout electronics, as the position along the drift length is obtained from the drift time, which is itself deconvoluted from the signal waveform. Hence, short shaping time minimizes the overlap between independent waveforms. The scintillation light will be collected on both cylinder endcaps by an array of avalanche photodiodes.

Coarse position information needs to be extracted from the scintillation light in order to identify the matching ionization signal. This concept relies on measuring both scintillation light and ionization signal in order to achieve optimum position and energy resolution. The solutions that we have chosen have all been demonstrated by other groups, but they have not been combined within the same design. Thus, we are developing prototypes aimed at demonstrating our concepts.

In order to test the liquid xenon PET concept we built a test set-up in 2005. Our first milestone was to demonstrate that electronegative impurities (e.g. water or oxygen) could be kept at the part per billion level. Such a purity level must be achieved in order to keep the electron absorption to a level that allows measuring electrons drifting several centimeters through the liquid xenon. A very clean vessel was designed to house a variety of test chambers. The chamber that was used in 2005 is a small time projection chamber, with a 3 cm drift volume defined by a cathode foil, whose voltage is set to 4–8 kV and a grid at ground potential. The electrons drift through the grid and are collected on two anode surfaces. Photons from positron anihilation were measured in the chamber over the full 3 cm drift length, which shows that we achieved the targeted impurity level. Following this success, the test chamber was dismantled and equipped with avalanche photodiodes in order to measure both light and ionization signals simultaneously. The chamber will be operated in this configuration in 2006.

We are also investigating the issues associated with reconstructing 511 keV photons in liquid xenon. Indeed, only 22% of the 511 keV photons entering the liquid xenon release all their energy in one photoelectric conversion. The other 78% undergo at least one Compton scattering before a photo-electric interaction. Thus, a single photon is likely to lose energy at several locations along its path through the xenon. This information can be used to constrain the photon trajectory as the Compton scattering is directly related to the scattering photon energy. Simulations have been performed in order to define Compton reconstruction algorithms. An efficiency of 70% has been achieved for reconstructing the right sequence of photon interactions. The set of simulations performed in 2005 demonstrates the feasibility of using Compton scattering information to reject background. In 2006, we will tie up the simulations to the prototype results in order to obtain accurate extrapolations of the performances to the full scale micro-PET detector. Hence, the simulation and prototype efforts will now go hand in hand towards our goal of producing a micro-PET detector.

Scientific Services

(M. Comyn, TRIUMF)

The Scientific Services group encompasses the Publications Office, Library, Information Office, and Conferences. Its activities during 2005 included: producing the 2004 Annual Report, conference proceedings, and the TRIUMF preprints; maintaining the Library; coordinating TRIUMF tours and assisting with the production of public relations materials; and supporting seventeen past, present and future conferences and workshops.

Publications Office

The TRIUMF Annual Report Scientific Activities has been truly electronic since 1998. Electronic files have been used throughout, from initial contributor submission, through editing, transmission to the printer, and subsequent direct printing on a Xerox Docutech system. The same files are used for the WWW versions of the report which are available at http://www.triumf.ca/annrep in both Portable Document Format and PostScript file formats. Unlike the monochrome paper version, the electronic versions allow those figures which were submitted in colour to be both viewed and printed in colour. The WWW version of the 2004 report was available to readers four weeks before the printed version. The Annual Report mailing list has been reduced and the trend is expected to continue as people and libraries 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 2004 submissions, and the continued processing of the manuscripts for the refereed conference proceedings of the Eighth International Symposium on Nuclei in the Cosmos (NIC8), which was held in Vancouver, July 19–23, 2004. Producing refereed proceedings is a complex, time-consuming procedure which requires multiple communications between author, referee and editor for each manuscript. All communications were tracked on a database, and nearly all were via e-mail with original source files or scanned manuscripts and referee information sheets being sent as PDF attachments. By avoiding the use of conventional mail, communications were much faster than those experienced with previous conferences. A complete set of manuscripts were couriered to the publisher, Elsevier, on a CD-ROM in late April. The next two months were spent finalizing the front material, reviewing and correcting proofs, and specifying the cover design. The electronic version of the July, 2005 volume of Nuclear Physics **A758** went on-line in late June, and the 900 page hard copy versions were mailed to the delegates in mid-July – less than a year after the conference.

Advice was given regarding the publication of the FPCP 2006 conference proceedings, and requests for quotations were prepared for the TCP'06 conference.

Web site and other support was provided for the TRIUMF Summer Institute, held July 11–22.

Activities for the Joint Accelerator Conference Website (JACoW) committee included attending the Scientific Programme Management System (SPMS) meeting and then serving as a proceedings editor for the Particle Accelerator Conference, PAC'05, held in Knoxville, TN during May. In November, two talks were presented at the JACoW Team Meeting held at LNF in Frascati, Italy.

Library

The Library saw a major reorganization during 2005 as new shelving was added to accommodate the ever-growing journal collection. All journal subscriptions were retained. A Committee on Library and Publications at TRIUMF was struck in August, chaired by L. Buchmann with representatives from TRIUMF's different scientific disciplines and divisions. 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 225 tours for 3131 people during 2005. The general public tours were conducted by a summer student during the June to August period when tours were offered twice a day. 137 people attended one of the 40 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 XXII shows the number of people taking tours, the number of tours, and the number of tour guides required to conduct them (groups of more than 15 require multiple tour guides) for each of the years 2000–2005. 2005 saw increased or similar numbers in all categories when compared to recent years, even after subtracting the 950 people who attended the Open House held June 4. This extremely successful event, organized in collaboration with the UBC Department of Physics and Astronomy, was staged in conjunction with the Canadian Association of Physicists Congress which started the following day and marked the World Year of Physics. The tour numbers are divided into four categories which are defined as follows:

Table XXII. Breakdown of TRIUMF tour numbers for the period 2000–2005.

Category	2000	2001	2002	2003	2004	2005
General Public						
# people	368	421	499	482	399	1342
# tours	107	110	131	126	109	111
# guides	107	111	134	126	111	139
Science						
# people	294	383	592	651	729	860
# tours	20	30	23	34	36	51
# guides	26	43	57	59	70	82
Students						
# people	612	839	894	626	440	831
# tours	40	30	40	38	23	33
# guides	53	60	70	50	35	66
VIP						
# people	171	258	193	260	95	98
# tours	37	59	53	63	26	30
# guides	40	65	55	71	26	31
Total						
# people	1445	1901	2178	2019	1663	3131
# tours	204	229	247	261	194	225
# guides	226	279	316	306	242	318

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

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

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

Conferences

Support was provided for seven conferences and workshops, along with preparations for nine conferences and workshops in 2006 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 2005:

- ICFA Workshop, TRIUMF, February 10–11 (20 delegates).
- Western Regional Nuclear and Particle Physics Conference (WRNPPC'05), Banff, AB, February 18–20 (45 delegates).
- 2005 CAP Congress, UBC, June 5–9 (600 delegates).
- TITAN 2005 Workshop, TRIUMF, June 10–11 (55 delegates).
- TRIUMF Summer Institute 2005, TRIUMF, July 11–22 (46 delegates plus 9 lecturers).
- T2K 280 m Near Detector Meeting, TRIUMF, August 29–31 (56 delegates).
- TRIUMF Users' Group Annual General Meeting, TRIUMF, December 7 (55 delegates).

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

- Winter Nuclear and Particle Physics Conference (WNPPC'06), Banff, AB, February 17–19, 2006.
- Flavor Physics & CP Violation (FPCP2006), Vancouver, April 9–12, 2006.
- 1st Workshop on Actinide Target Development (WATD'06), TRIUMF, April 26–29, 2006.
- TRIUMF Summer Institute 2006, TRIUMF, July 10–21, 2006.
- Vancouver Linear Collider Workshop (VLCW06), UBC, July 19–22, 2006.
- International Conference on Trapped Charged Particles and Fundamental Physics (TCP'06), Parksville, BC, September 3–8, 2006.
- International Conference on Computing in High Energy and Nuclear Physics (CHEP2007), Victoria, BC, September 2–7, 2007.
- International Linear Accelerator Conference (LINAC08), Victoria, BC, September 29 – October 5, 2008.
- Particle Accelerator Conference (PAC'09), Vancouver, May 4–8, 2009.

ATLAS Computing
(R. Tafirout, TRIUMF)

TRIUMF is planning to host Canada's Tier-1 centre for the ATLAS experiment at CERN's Large Hadron Collider (LHC). This will be achieved within the context of the LHC Computing Grid (LCG). Eleven such centres are currently being developed and deployed worldwide to serve all four LHC experiments. These Tier-1 centres are primarily located at the national laboratories of countries participating in the project. By the year 2010, the computing resources of the Tier-1 centre at TRIUMF will consist of about 5000 processors, 2.5 PB of disk storage, and 2 PB of tape storage.

The ATLAS experiment at the LHC will collect nominally about 3.2 PB of raw data for each year of its operation. Secondary data sets by means of reconstruction, reprocessing and calibration will produce an additional 2.5 PB for each year of data-taking. This requires significant computing resources in both CPU and storage (disk and tape media) that cannot be aggregated into a single centre, and therefore will be distributed worldwide. The ATLAS computing model is based on a Tier structure, where CERN (Tier-0) will collect and store the primary raw data that pass the high level trigger (HLT). The Tier-0 will also produce first pass reprocessing data. Primary and reprocessed data will be distributed to the Tier-1 centres around the world. Each Tier-1 will only be a custodian of its share of this data, and is expected to provide a collaboration wide access around the clock. The Tier-1 centres will perform further reprocessing of the primary data when better calibration constants of the ATLAS detector are made available, therefore producing better quality data for physics analyses. Each Tier-1 centre will be associated with a set of Tier-2 centres. Tier-2 centres will be based primarily at the universities and will be producing the simulated data sets needed for the experiment. The simulated data sets will be uploaded to the Tier-1. ATLAS wide user analysis will be done at the Tier-2 centres.

The Tier-1 centre needs to provide a reliable level of services to the ATLAS collaboration as a whole. The centre will be operated around the clock and any downtime shall be kept to a strict minimum. In the last year or so, a modest Tier-1 was developed and maintained essentially from scratch. It all started initially as a small LCG cluster (basically providing only a Tier-2 type of functionality) and was gradually expanded to a fully functional Tier-1 with all the required LCG baseline services deployed. At the moment it has a relatively limited processing and storage capacity: 18 processors, about 5 TB of disk and 7 TB of tape. As part of the Tier-1 functionalities, database services need also to be deployed and maintained in the near future. The current TRIUMF funding for the period 2005–2010 will not fully cover the total costs of the Tier-1 centre (capital and operating), therefore a proposal was submitted to the Canada Foundation for Innovation (CFI) under the Exceptional Opportunities Fund program.

Grid solutions

In 2005, various solutions within the context of LCG were developed and maintained at TRIUMF:

- a modest, fully fledged local LCG cluster with conventional grid services (computing element, storage element, information system and monitoring). This cluster is used in various data challenges, which consist of the production of large Monte Carlo data sets on LCG, and coordinated by ATLAS;
- a gateway that unites resources at Canadian universities and makes them accessible to LCG as one site, via a computing element that uses CondorG technology (this is a unique Canadian initiative, see www.gridX1.ca);
- a development cluster that is dedicated to the service challenges on which LCG baseline services are deployed and tested. The main focus at TRIUMF last year was to set up the components to participate in all aspects of LCG service challenge 3, such as disk-to-disk and disk-to-tape transfers between CERN and TRIUMF, and disk-to-disk transfers between TRIUMF and several Canadian universities that were acting as Tier-2 centres;
- a distinct LCG executor based on CondorG (and hosted by TRIUMF and Simon Fraser University), which has doubled ATLAS's overall capacity for production and job submission on the Grid. This was crucial to complete the Monte Carlo samples that were needed for last year's ATLAS Physics Workshop, held in Rome.

Networking

Since the spring, two dedicated 1 Gb/s lightpath links between TRIUMF and CERN were made available and used for the service challenges. The links were provided by CANARIE. For the longer term a 10 GigE link will be established. To this end a Memorandum of Understanding was signed between HEPNET, CANARIE and TRIUMF to establish UCLP (user controlled light paths): a 10 GigE from TRIUMF to New York, 5 GigE from New York to CERN via Amsterdam, 1 GigE to each of the Canadian Tier-2s, and X Gig to other Tier-1s (X to be determined, depending on the peering/pairing model of the various the Tier-1s). TRIUMF Network and Computing Services bought a Foundry Rx-4 that will act as 10 GigE network backbone for the ATLAS Tier-1 centre. The 10 GigE link between TRIUMF and CERN is expected to be commissioned in 2006. TRIUMF has strong expertise in high speed data transfers over long distances. In June a temporary 10 Gb/s lightpath between CERN and TRIUMF was made available for a few days and was used to do various transfer tests and to check for quality/errors on the link; a sustained transfer rate of 2.33 Gb/s was achieved as shown in Fig. 229. To achieve this, several machines were used at both the sending and receiving ends, a somewhat realistic use case.

Service challenges

To test the LHC experiment's computing models, several service challenges phases have been planned. The service challenges are meant to test the robustness of grid middleware services, storage access and networking at several sites in order to ensure readiness for LHC start-up. In the summer, service challenge phase 3 was conducted, which consisted of transfers between CERN and several Tier-1 sites (disk → disk and disk → tape) as shown in Fig. 230. Disk transfers between TRIUMF and several Canadian universities acting as Tier-2 centres were also conducted. The universities involved were Simon Fraser University, University of Alberta, University of Toronto, and University of Victoria. All the transfers were done using the file transfer service (FTS) which was deployed at TRIUMF.

Cluster design: infrastructure and hardware

The Tier-1 centre will be housed in the new ISAC-II building, and the available floor space is about 900 sq. ft. The design of the cluster should be optimized and space constraints taken into account. Hardware components up to and including year 2009 should fit in the available space. For 2010 and beyond, a larger computing room will be necessary. With respect to power consumption, the current estimates are 175 kW for the computing nodes (CPU), 95 kW for the disk storage and 30 kW for the remaining components (tape library and drives, network switches, grid services and database nodes). The air conditioning/cooling system will use about 130 kW. Its design will be critical for the centre. Hardware will be acquired in a gradual way in order to meet the demand of the ATLAS experiment, therefore the system should be highly scalable for smooth growth/expansion for the coming years and downtimes should be minimized as much as possible. Various hardware solutions with respect to CPU, disk and tape storage have been explored.

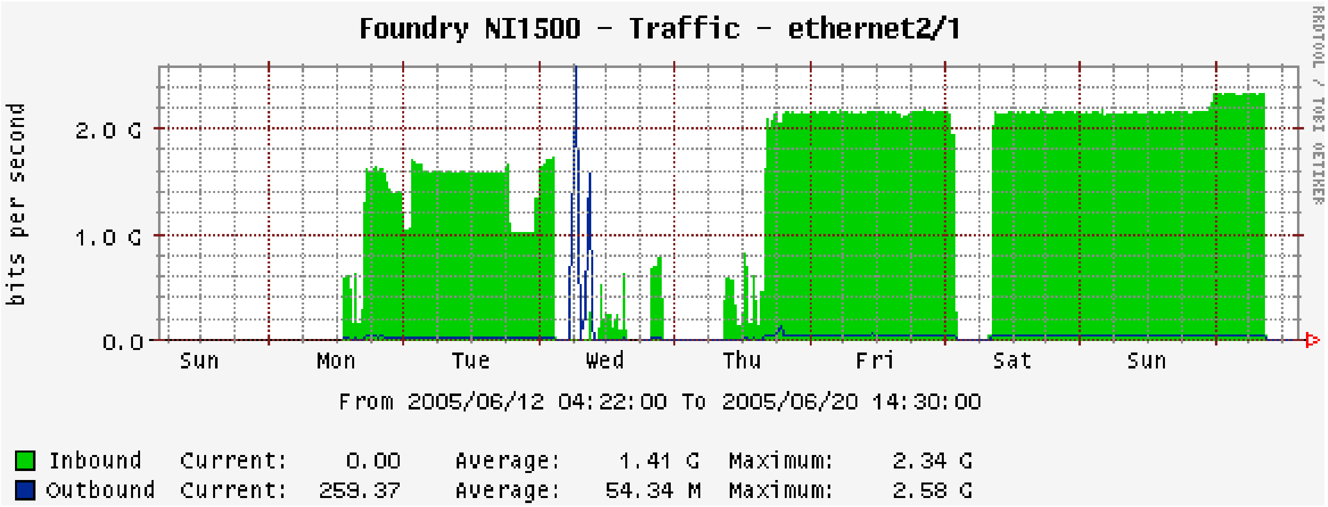
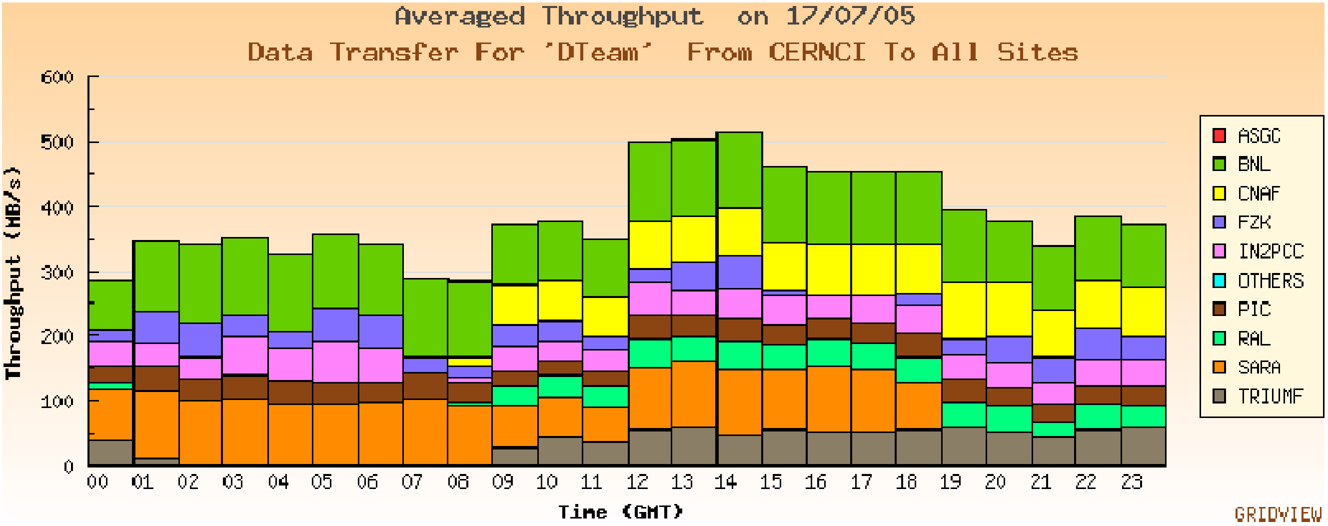


Fig. 229. CERN–TRIUMF transfers on a temporary 10 Gb/s link.



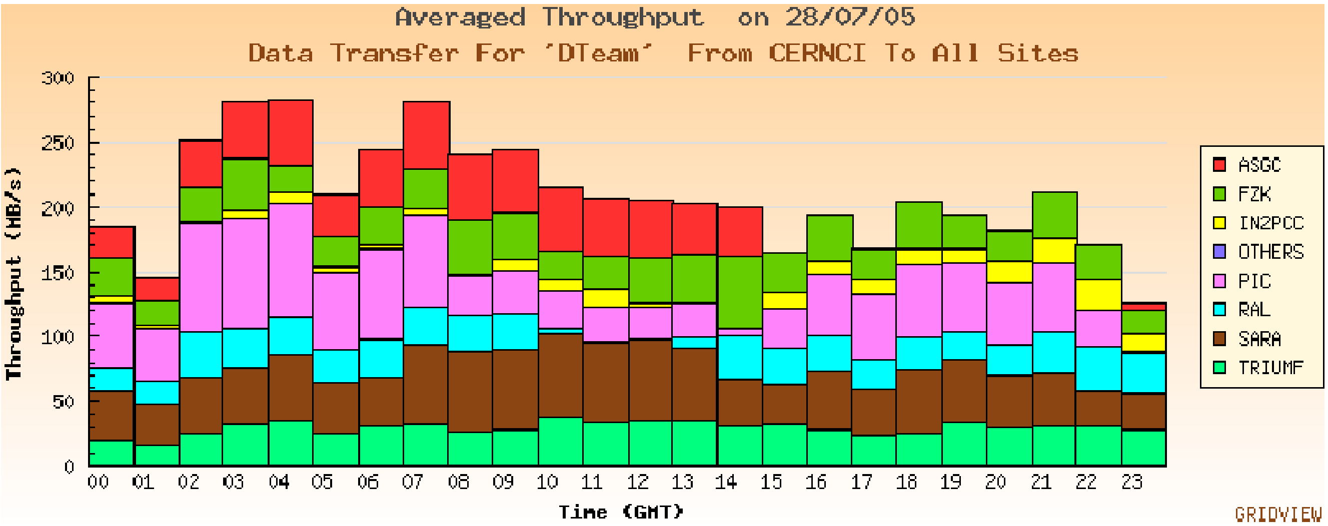


Fig. 230. Service challenge 3 (CERN–TRIUMF transfers).

The DRAGON Facility

(D.H. Hutcheon, TRIUMF)

DRAGON is a facility 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 the study is to measure reaction strengths of relevance in nuclear astrophysics, but the facility has been used for nuclear structure experiments as well.

The year 2005 saw new upper and lower limits in the masses of accelerated beams delivered to DRAGON. At the high end, a ^{40}Ca beam for Expt. 1024 evaded the A/q limit of 30 in the RFQ accelerator after ion source development produced a clean beam of Ca^{2+} ions. The lightest beam, protons for Expt. 1027, was accelerated as triatomic hydrogen molecules in order to satisfy $A/q \geq 3$ in the DTL accelerator. Intermediate masses produced were ^{16}O for Expt. 1022, ^{20,21}Ne for development studies, and ^{26g}Al and ^{28}Si for Expt. 989. Experimental results are described in more detail elsewhere in this Annual Report. These new experiments required several improvements or additions to DRAGON, as described below.

Charge state booster foil

Recoil Ti ions from the ^{40}Ca$(\alpha,\gamma)^{44}$Ti experiment (Expt. 1024) emerge from the windowless gas target in a range of charge states, but the ions in the most-populated states have magnetic or electric rigidities higher than the maximum values allowed by the electromagnetic elements of the separator. Ions emerge from a solid foil in higher average charge state than after passage through a gas, prompting investigation of using a post-target foil as a charge state booster.

Thin amorphous silicon nitride (SiN) membranes were studied because of their high degree of uniformity. A foil mounted downstream of the gas target cell gave the expected boost in charge of beam ions when there was no helium gas in the target, but when target gas was present the charges were reset to lower values by gas in pumping tubes downstream of the SiN foil. A foil that blocked the end of the pumping tube would have prevented the charge resetting problem, but also would have interfered with measurement of beam transmission which is a standard part of the beam tuning procedure. The solution was to mount the SiN foil on a guillotine-like sliding mechanism which allowed insertion or retraction of the foil without having to break vacuum (Fig. 231). The extremely tight geometry of the gas target box required that the mechanism be driven by a long push-rod actuated by a miniature motor designed for control surfaces of model airplanes.

Recoil ion detection

As indicated in the DRAGON contribution to last year's Annual Report, an ionization chamber has several advantages for particle identification of low-energy heavy ions. The main drawback of the usually used silicon detectors (like the double-sided-silicon-strip-detector, DSSSD) is the significant energy loss in the dead layer. Unavoidable energy-loss straggling deteriorates the final energy resolution of the detector. In addition, low-energy tails from inter-strip events provide significant background in the region of the expected recoils, which usually have slightly lower energy than leaky beam in proton capture reactions.

During Expt. 989 we could make a comparison between the DSSSD and the ionization chamber with Al and Si ions of 200 keV/u. Figure 232 shows energy spectra of attenuated ^{26g}Al beam measured with the DSSSD front strips and ^{28}Si measured with the ionization chamber equipped with a thin 50 nm SiN window. Besides the improved energy resolution by a factor of 2, a significant reduction (about factor 10) in the low energy tail is visible. The reason for this is mainly the thinness and high homogeneity of the SiN foils.

However, there are still drawbacks to ionization chambers. First, the window size of 5×5 mm^2 is too small for a real application in an experiment at the moment, but this can be improved using a larger foil or an array of SiN foils. Second, no position information is possible with the current set-up. A position-sensitive detector in front of the ionization chamber (like a PGAC) would add an additional dead layer and thus reduce the advantage of thin entrance window.

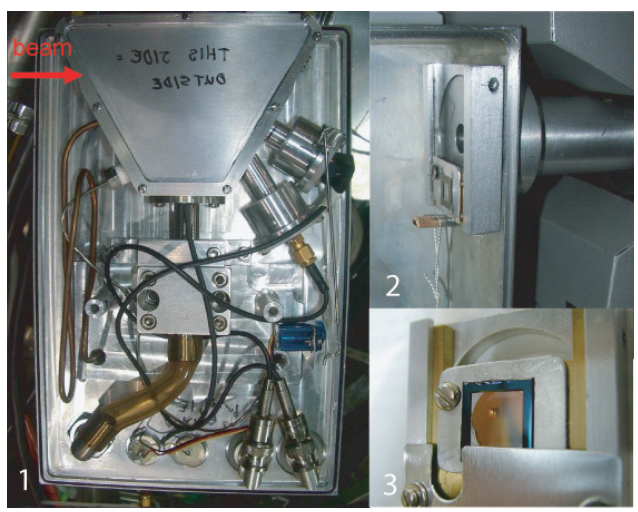


Fig. 231. Pictures of the charge state booster set-up inside the DRAGON windowless gas target. (1) cover plate with inner gas cell and miniature motor on the lower right side (in blue). (2) guillotine-like sliding mechanism mounted on the exit tube, SiN foil in position out. (3) used SiN foil, position in.

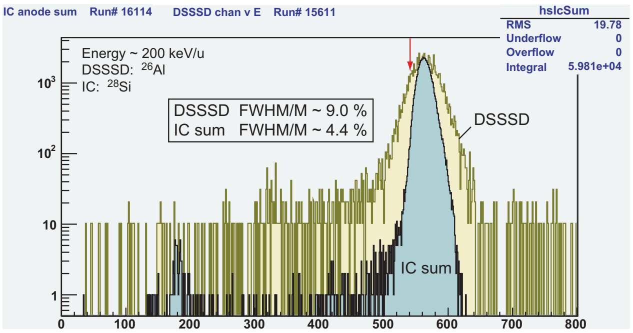


Fig. 232. Comparison of the energy spectra of the DSSSD and the ionization chamber equipped with 50 nm SiN entrance window. The energy channels are scaled to result in the same peak position. The arrow indicates the expected position of recoils.

Solid target scanning facility

As a test of Expt. 1027's plan to implant ^{22}Na ions in Cu or Ni foils, a series of implantations were done with stable ^{23}Na. The 3D density profiles of ^{23}Na ions were then mapped using DRAGON's BGO array to detect γ-rays from the strong resonance of the ^{23}Na$(p,\gamma)^{24}$Mg reaction at 309 keV.

The depth (z) profile could be measured by adjusting the energy of the incident proton beam to cause the resonance energy condition to occur at a desired depth within the target. The desired $x-y$ resolution was somewhat smaller than the beam spotsize, so the beam size was limited by a collimator and the target was moved in $x-y$ relative to the collimated beam.

The standard vacuum box for the gas target was replaced by a larger one (left over from an early design for a less compact gamma array) to allow room for an $x-y$ translation stage. Vacuum feedthroughs allowed manual adjustment of the $x-y$ position of the target and for changing of the collimator to a Faraday cup.

Halo-blocker iris

The ^{26g}Al beam of Expt. 989 was accompanied by small contaminations of metastable ^{26m}Al and of ^{26}Na. Although all but $\approx$0.1% of the beam was transmitted through the gas target, the small ^{26}Na component of the small fraction of beam stopping at the target constituted the dominant accidental coincidence background of the experiment. The decay of ^{26}Na is by energetic betas followed by 1809 keV γ-rays plus weak branches producing γ-rays of higher energy. These radiations cover the energy range of γ-rays from the ^{26g}Al(p,γ) reaction of interest, so the ^{26}Na background could not be suppressed by absorbers or high trigger thresholds.

The chosen solution was to install a mechanical iris approximately 30 cm upstream of the target cell, close enough to intercept the halo and cast a sharp "shadow" at the target, yet far enough that it could be shielded from the gamma-detector array. Via vacuum feedthroughs it was possible to make small adjustments in the $x-y$ position of the iris and to vary the opening of the iris. In the October campaign with ^{26g}Al beam, the iris provided a 4-fold reduction in background rate in the BGO counters at the cost of a 10% reduction in transmitted beam (but a compensating reduction in DAQ system deadtime).

Interceptor diagnostic device

In order to learn more about the trajectories of leaky beam (beam particles which are transmitted by the separator), an intercepting probe was added to the diagnostic equipment. Located just after a momentum-dispersed focus in the second stage of the separator, it consisted of a "picture frame" which could be driven horizontally across the optic axis. When centred on the optic axis, the inner edges of the frame defined an area somewhat larger than the recoil-ion envelope calculated for a standard tune of the separator. As the frame was withdrawn, the vertical bar of the frame intercepted particles at varying x positions.

For a beam and tune typical of proton capture experiments in the mass region A = 20–26, the leaky beam transmission was measured as a function of x-position of the interceptor. When the frame was centred on the optic axis, the leaky beam rate was essentially the same as when the frame was fully retracted. It was concluded that fully-adjustable slits at this location would not be effective in suppressing leaky beam while allowing full transmission of desired recoil ions.

Data acquisition and analysis

Continued improvements to DAQ software have been made. Software controlling the EPICS data readout has been improved and all hardware devices connected to the DRAGON separator via EPICS can be viewed in on-line histograms. Planned upgrades to hardware have begun with the purchase of several VME modules including two CAEN V785 peak-sensing ADCs and one CAEN V1190B TDC.

Electrostatic dipoles

The recoil ions from the ^{40}Ca$(\alpha,\gamma)^{44}$Ti experiment (Expt. 1024) had higher electric rigidity than the recoils from previous experiments. Even with the use of a charge-boosting SiN foil (described above), operation of the first-stage electrostatic dipole, ED1, often was required to be near 175 kV.

During high-voltage conditioning before the final running period of Expt. 1024, the cathode HV supply suddenly began drawing excess current at voltages above $\approx$140 kV. The problem was traced to tracking inside the nylon tube which houses the HV stack of the cathode. The ED1 tank was vented and the stack assembly was re-mounted in a spare tube made of polyethylene. HV conditioning proceeded normally (i.e. micro-discharges causing simultaneous, brief excursions in anode current, tank vacuum and X-ray rate) and desired high voltage was reached just at the beginning of beam time. A similar problem had occurred for the ED1 anode supply earlier in the year, except that the excess current apparently was flowing through a film deposited on the outside (i.e. the high vacuum side) of the insulating tube.

8π Spectrometer
(G.C. Ball, TRIUMF)

In spring, a safety interlock system for the 8π electronics shack was fabricated, installed and commissioned. The system contains smoke alarm, fan flow and over temperature detectors. The system provides equipment protection and fire detection in two different modes (fast response to smoke, and warning/slower response to fan failure and over-temperature). The unit also has a power shutoff feature for all electronics racks and the air conditioner.

Once again, the 8π data acquisition system (see 2002–04 Annual Reports for details) was upgraded to increase the data throughput by installing single channel AD114 16k channel ADCs for readout of the HPGe detectors. Following the successful tests of the performance of BaF_2 detectors integrated into the 8π array (see Expt. 984, 2004 Annual Report for details), the components for the full 10 element detector array DANTE (dipentagonal array for nuclear timing experiments) are being acquired and commissioning of the array is expected in fall, 2006.

The use of the 8π γ-ray spectrometer for high-precision β-decay lifetime measurements has been reported previously (see Expt. 909, 2002–04 Annual Reports). In May, 2005, the second attempt to obtain a ^{34}Ar beam from the TRIUMF ECR ion-source for a high-precision lifetime measurement of this superallowed β-emitter failed to produce the beam intensity required. As a result, this experiment must wait for the development of the FEBIAD ion source.

In July an upgraded version of PACES (pentagonal array for conversion electron spectroscopy) (see 2004 Annual Report for details) was installed and commissioned. In particular, by redesigning the liquid nitrogen cooling system it was possible to provide sufficient cooling for all five SiLi detectors (see Fig. 233).

Two experiments used PACES in August. In the first experiment, by observing the K, L and M conversion electrons from the decay of the previously observed 2.3 s isomer in ^{174}Tm it was possible to determine the spin and parity of this isomer to be 0^+ (see Expt. 921, 2004–05 Annual Reports for more details). In the second experiment the study of coexisting collective phases in ^{158}Er was made possible by a detailed measurement of the β-decay of ^{158}Tm. The results of this experiment led by D. Kulp are reported separately (see Expt. 973, this Annual Report).

Yield measurements were carried out with the 8π spectrometer in September to determine the feasibility of using a high-powered Ta target to produce ^{38m}K for Expt. 823 and heavy $^{(51-53)}$K isotopes for a proposed study of excited states in Ca isotopes near the "doubly magic" ^{54}Ca. The results led to Expt. 1064 that was approved by the TRIUMF EEC in December.

One other 8π experiment received beam in 2005, namely, a high-precision measurement of the branching ratio for the superallowed β-emitter ^{62}Ga (Expt. 823). In this experiment the purity and intensity of the laser-ionized ^{62}Ga beam was improved substantially from that obtained in the first development run in December, 2004. As a result, it was possible to obtain three times the data obtained previously. This experiment is reported in more detail elsewhere in this Annual Report.

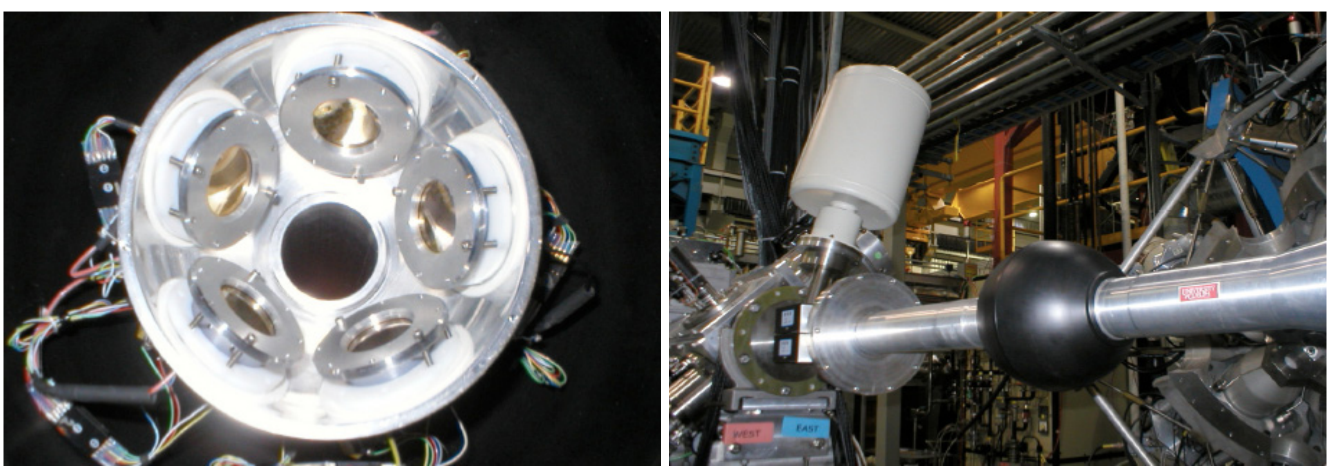


Fig. 233. Photos (left) of PACES SiLi detector array and (right) of PACES vacuum chamber mounted on 8π beam line.

There are currently 19 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, 1054, 1059, 1064, 1068) including four which were approved by the TRIUMF EEC in 2005. During the past year a total of 42 collaborators from 13 institutions actively participated in the development and/or use of the 8π spectrometer, including: 4 undergraduate students, 10 graduate students and 11 post-doctoral fellows.

EMMA – The Electromagnetic Mass Analyser
(B. Davids, TRIUMF)

EMMA is a proposed recoil separator for ISAC-II. Starting in 2007, ISAC-II will provide intense, low-emittance beams of unstable nuclei with masses up to 150 u and eventual maximum energies of at least 6.5 A MeV. With the imminent completion of the accelerator, it is essential that ISAC-II be instrumented with experimental equipment that will allow the exploitation of what will be the world's most intense radioactive beams at Coulomb barrier energies. The advanced γ-ray spectrometer TIGRESS is fully funded and will be the first apparatus available for experiments. TIGRESS will be used in many different types of experiments with radioactive beams, especially those involving fusion-evaporation and transfer reactions. However, the detection of γ-rays alone is seldom sufficient for a successful measurement. Background radiation from more probable reactions usually obscures the signal of interest, and additional measurements are required to isolate the γ-rays emitted by the recoil nucleus being studied. The same problem occurs when using charged particle detectors to investigate transfer reactions. In both cases, direct detection and unique identification of the recoil nucleus results in tremendous background reduction, allowing experiments that otherwise would be impossible to be performed. Therefore, an efficient and selective recoil spectrometer, possessing large acceptances in angle, mass, and energy without sacrificing the necessary beam suppression and mass resolution, is urgently needed for the ISAC-II science program.

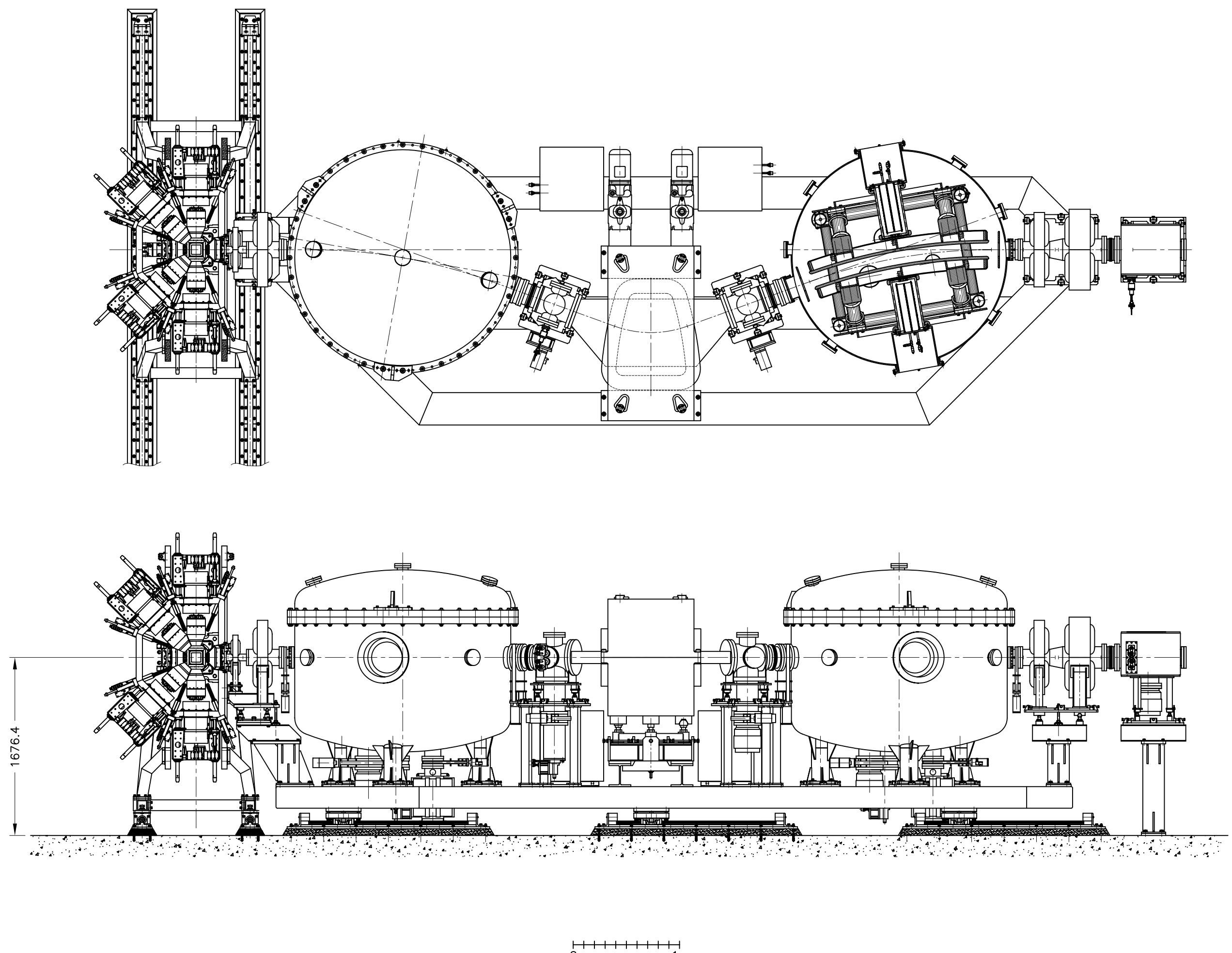


Fig. 234. EMMA coupled with TIGRESS.

An ion optical design study has been completed. The design for EMMA is based on a symmetric configuration of electric and magnetic dipoles, a proven design that provides for energy dispersion cancellation. However, our new design represents a significant improvement over existing instruments of this type. In particular, EMMA will have the largest energy and angular acceptances of any recoil mass spectrometer, while simultaneously providing high mass resolving power due to the design of its quadrupole lenses and the curvature of its magnetic dipole field boundaries. This combination of large acceptance and high resolution will make EMMA the most advanced instrument of its kind. It will be an indispensable part of the ISAC-II experimental facility. Figure 234 depicts EMMA with TIGRESS surrounding the target position.

The design of EMMA underwent both internal (TRIUMF) and external (NSERC) technical reviews in 2004 in order to ascertain the soundness of its ion optics as well as its suitability for the anticipated experimental needs. Both reviews found the design to be of very high quality. In 2005, a paper describing the design was published in Nuclear Instruments and Methods in Physics Research **A544**, 565.

TRIUMF management has deemed the project so essential to the future of the laboratory that it has pledged \$1 M toward its construction. Moreover, in a long-range planning exercise completed in 2005, the Canadian nuclear physics community ranked EMMA as its highest priority for new capital investment. EMMA is the subject of a \$2.1 M NSERC RTI grant proposal in the 2006 competition.

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. The key features of TIGRESS have been described in last year's Annual Report.

In 2005 the collaboration has built on the prior year's accomplishments. The main highlight was the first end-to-end in-beam test with the prototype clover. This test involved the first use of the TIG-10 Rev.1 modules, improved waveform simulations, and a first implementation of signal decomposition. Other highlights included preliminary acceptance of two production clover units, receipt of one set of production suppressors, design and strength analysis of the full array superstructure, conceptual design of a beam dump, and a science roadmap meeting. Further details of the year's progress, including developments pertaining to auxilliary detectors, may be found at the University of Guelph TIGRESS Web site [TIGRESS Collaboration, *TIGRESS technical progress report* (unpublished) available at http://www.physics.uoguelph.ca/~ggrinyer/Nucweb/files/TigressProgRep05.pdf; TIGRESS Collaboration, *TIGRESS scientific road map* (unpublished) available at *ibid.* TigressRoadmap05.pdf].

In-beam test

An in-beam test was performed to simulate experimental conditions. A beam of ^{16}O at 20 MeV was directed upon two 50 μg/cm^2 carbon foils. This populated γ-emitting excited states in ^{27}Al by fusion evaporation; the recoiling residual nucleus had a velocity of 3% the speed of light. The prototype detector was installed with the cryostat centre line perpendicular to the beam line and with the front face 11 cm from the target (Fig. 235). This was well suited to testing all aspects of the incident-angle reconstruction algorithms. A silicon detector was installed at zero degrees, with a gold foil absorber that would stop beam and recoil ions but would allow the evaporated protons to pass. Events were read out with 5 TIG-10 Rev.1 waveform digitizers and one TIG-C collector card also acting as a master card (Fig. 236).

A key outcome of this in-beam test was to demonstrate sub-segment position sensitivity. The event waveforms collected by the TIG-10 Rev.1 cards were analyzed by a least-squares minimization in comparison to a calculated database. Based on the resulting measurement of the first-interaction position, the measured energies were Doppler-corrected. For this first attempt at interaction-location reconstruction, it was simply assumed that all events corresponded to single interactions. Figure 237 shows the original spectrum, without Doppler correction, having a FWHM width of

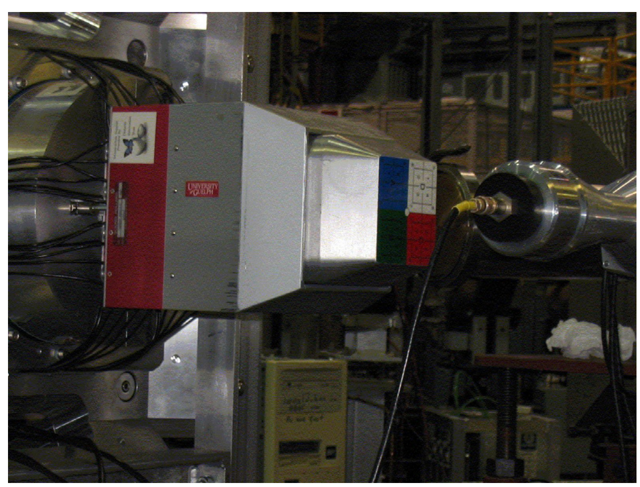


Fig. 235. TIGRESS prototype clover viewing scattering chamber for in-beam test.

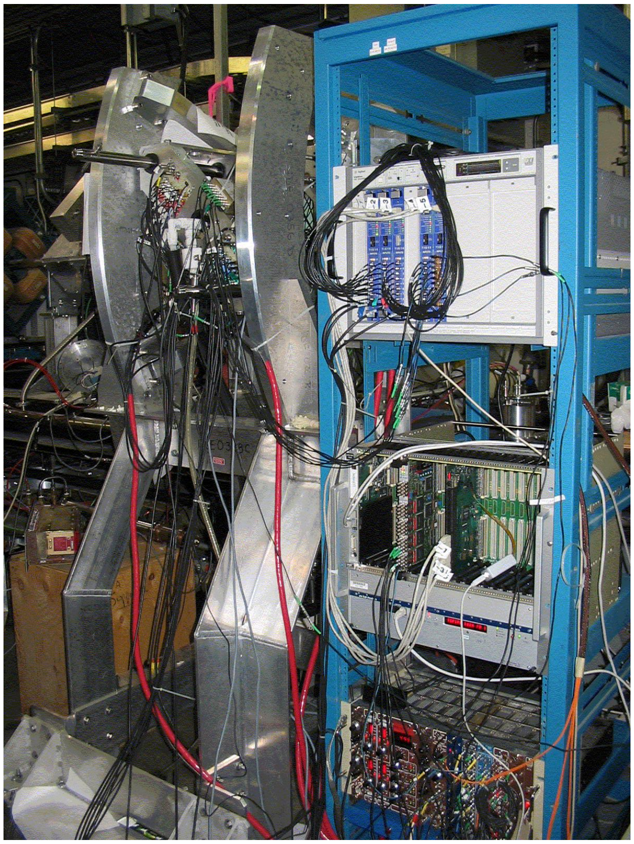


Fig. 236. TIGRESS prototype clover, single-detector prototype stand, and TIG-10-based acquisition system for in-beam test.

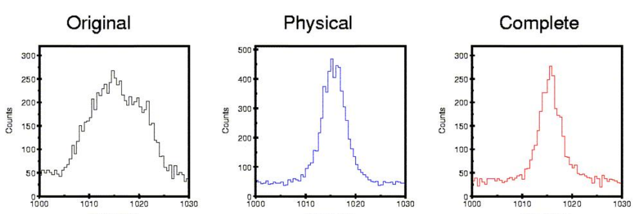


Fig. 237. Doppler reconstruction of the 1014 keV γ-ray from ^{27}Al.

12 keV. Physical reconstruction based on segment hit information alone, without waveform analysis, reduces this to 6 keV. Complete reconstruction based on waveforms reduces this still further to 4.7 keV. Given the intrinsic resolution of the detector readout for stopped lines and broadening due to kinematics, the difference from physical to complete reconstruction shows that the single-interaction reconstruction approximation is equivalent to halving the angular uncertainty of the spectrometer.

TIG-10 Rev.1

The in-beam test required five functioning TIG-10 cards (Fig. 238) and one TIG-C collector card. Various directions for improvement of the TIG-10 Rev.1 were identified. Most of them required small modifications

Fig. 238. TIG-10 Rev. 1 module.

to board components or firmware. The most troubling was a poor energy resolution measured with sources. Problems with card initialization, triggering, event synchronization, and spontaneous hardware hang-ups were traced down to a problem with the termination of the high-speed serial link between the TIG-10 cards and the TIG-C. This was corrected with a small field repair to the TIG-10 cards.

The TIG-10 cards also measure the energy deposition in a segment by onboard waveform analysis. In initial tests with a complete set of TIG-10 cards, the 1332 keV line of a stationary ^{60}Co source had a full-width at half-maximum of 3.0 keV. The intrinsic resolution of these clovers is specified as 2.3 keV or better, which was confirmed with traditional analogue amplifiers and commerical multi-channel scalers. The discrepancy was initially attributed to ground loops. Further work to optimize the pole-zero correction and the integration time parameters has resulted in resolutions for the production clovers that are now 0.2 keV higher than those measured with analogue equipment. The source of the remaining discrepancy is still under investigation. Initially the poor resolution was attributed to ground loops. Collaborators at Université de Montréal are designing and testing a new front-end network that will reduce sensitivity to common-mode noise, thus reducing any future sensitivity to ground loops. If successful this will be applied to Revision 2 modules.

Waveform simulations

Work on the simulation of position-dependent waveforms focused on proper inclusion of crystal anisotropy effects and quantification of systematic position errors. At the electric fields typical of an operational germanium detector it is well known (but not fully understood) that the charge carriers' velocity magnitude and direction are non-trivial functions of the electric field vector. In the case of the electrons, this effect is fairly well described in terms of the electronic band structure and effective masses. We have adopted the algebraic formalism described in Mihailescu *et al.* [Nucl. Instrum. Methods **A447**, 350 (2000)] to evaluate the electron drift velocity vectors. Depending on the orientation of the electric field to the crystal lattice, the magnitude of the electron drift velocity can vary by up to 20%, and the drift direction by up to 16° different than the electric field direction. No similar formalism exists for hole drift velocities. For the hole velocities we are implementing a "magnitude matching" algorithm where the hole drift speed is a weighted average of speeds along primary cyrstallographic axis and the drift direction is forced parallel to the electric field. When this algorithm is applied to electrons, it underestimates the drift velocity by up to 10% for fields applied off-axis. A systematic error of up to a similar size could be expected for the holes, but there is no algebraic form to describe the hole behaviour.

The systematic position reconstruction error arising from using simulated waveforms, as opposed to measured ones, was evaluated. Owing to the coaxial geometry of the germanium crystals, the waveforms are better described as separable functions in a cylindrical coordinate system with the coaxial core contact concentric with the z axis. Systematic errors were evaluated in terms of a radial position error δr and an azimuthal position error $\delta s = r\delta\phi$. The position dependencies of derived parameters – rise times of net-charge signals, amplitudes of induced signals – were determined from the simulations. The differences between simulated derived parameters and measured parameters for a given, well-defined position in the coincidence-scan data [Svensson *et al.*, Nucl. Instrum. Methods **A540**, 348 (2005)] were then scaled by the position dependency. This effectively gives an estimate of the systematic error in determining the location of a measured interaction based on comparison to a simulated database. In the radial direction these errors were small: $\delta r \sim 0.1$ mm. The azimuthal error of $\delta s \sim 1.8$ mm arises due a consistent, systematic over-estimation in the simulations of the amplitude of induced signals.

Further details of this work may be found in the B.Sc. honours thesis of Robin Prest [Simon Fraser University (2005); see also Web site *op. cit.*].

Signal decomposition

While the pulse-shape simulations described in the previous section allow for the calculation of signal waveforms for energy deposition at a given (x, y, z) location in a TIGRESS detector, γ-rays with energies above 100 keV typically Compton scatter one or more times in a bulk HPGe detector, and thus generally deposit energy at more than one location. Algorithms to reconstruct the locations of multiple γ-ray interactions based on measured waveforms are thus essential to determine the first interaction location.

The first algorithm applied to TIGRESS data invokes a least-squares minimization of up to two interactions in a single crystal against a grid of calculated waveforms. The realization of these algorithms is based on code developed for the GRETINA project [Radford, private communication; codes available at ftp://radware.phy.ornl.gov/pub/misc/decomp]. The latter involves crystals with a much higher symmetry, so the search space is an order of magnitude larger. The double-interaction version of this code has been tested by superposing the waveforms from two distinct locations, adding 1% noise, and fitting the resulting sum. The error in best-fit interaction (for example, Fig. 239) locations in the plane perpendicular to the core is typically 1 mm in most of the crystal. Errors become larger and approach the 3 mm size of the search grid when the interaction is near a segment boundary.

The single-interaction version of this fitting routine was used in the analysis of the in-beam test data.

Production clover delivery

Two production-model clover detectors were delivered to TRIUMF in the first half of the year. Although they exceeded specifications for γ-ray photopeak efficiency and core-contact energy resolution, they did not meet outer-contact energy resolution specifications that are part of preliminary acceptance. The problem was traced to abnormally high sensitivity to room noise (microphony). The detectors were returned to the factory and retrofitted to reduce the microphonic sensitivity. Both detectors showed an acceptably low microphonic sensitivity and passed preliminary acceptance.

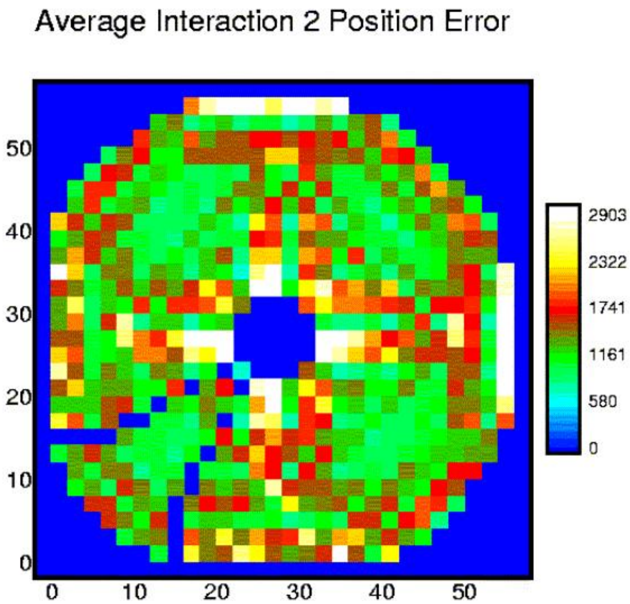


Fig. 239. Error in second interaction, in μm, for a given first-interaction location, in mm. Two-interaction events were generated for all possible pairs of (x, y) coordinates ($z = 46$ mm) in the crystal. The plot coordinate represents the coordinate of the first interaction. The value is the average of the discrepancy between the simulated and best-fit location of the second interaction, for all possibilites of the latter.

The coincidence scanning of these detectors is now under way.

Production suppressors

Late in 2005, the first set of production suppressors was received. Acceptance testing will continue into 2006.

Mechanical superstructure

In 2004 and 2005, the mechanisms for holding and adjusting individual detector elements were refined, and attention was focused on the overall superstructure. Two design modifications in particular were identified to simplify access to the beam line target location. The corona (ring) and lampshade (front and back) components of the superstructure will be fabricated as six semi-monolithic pieces, to improve ease of use and overall mechanical stability (Fig. 240). New support pieces for individual suppressor plates have been designed, so that in cases where the suppressor plates lie along a split in the array, the suppressor will remain with its nearest germanium unit when the array is opened. This will greatly simplify cabling and alignment. A mounting machine for the safe insertion and removal of the germanium units has also been designed. Finally, a finite element analysis of the superstructure verified a safety factor of 15 for failure and >1000 for buckling modes, and calculated that the maximum deflection of a detector unit under load was under

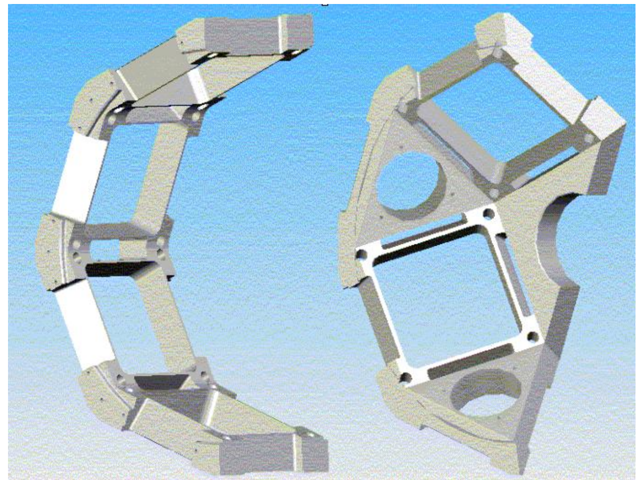


Fig. 240. Semi-monolithic inner structure design.

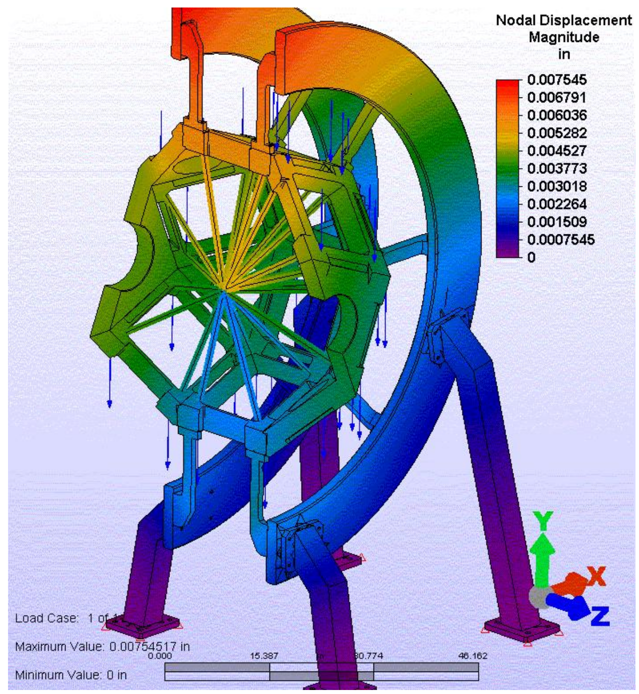


Fig. 241. Sample finite element analysis for superstructure.

0.2 mm (Fig. 241). Further details can be found at the TIGRESS Web site.

Beam dump

In γ-ray spectroscopy studies with radioactive beams, special attention should be paid to the beam optics and the beam dump to avoid backgrounds from the decay of misdirected ions. Indeed, radioactive beam particles that do not interact with the target need to be stopped in a dedicated beam dump. Detailed optics simulations have been carried out, based on the characteristics of different radioactive beams at different energies through different targets. The challenge of the beam dump design comes from the broad charge state distributions of the outgoing particles, as the target plays the role of a stripper.

A conceptual design for a beam dump has been adopted. It is based on two large acceptance Q-pole magnetic elements (Q1 and Q2) to refocus most of the radioactive beam particles into a shielded area. The two quadrupoles have been repurposed from the BL2A beam dump in the proton hall. The quadrupoles were re-mapped and it was verified that, with the fringe, fields would be below the 15 G for which the TIGRESS suppressor phototubes have been magnetically shielded. With these quadrupoles it will be possible to refocus the beam from one of the most challenging cases, ^{132}Sn at the minimum ISAC-II design energy, to ± 3 cm in both directions (Fig. 242). In this configuration, the beam envelope reaches the maximum aperture at the second quadrupole. The conceptual design includes a removeable beam line and an instrumented, shielded beam dump for diagnostics (Fig. 243).

Science roadmap

In early 2005, the collaboration held a "Science Roadmap" meeting to identify science priorities and auxilliary detectors needed to accomplish those goals. Proceedings from this meeting can be found at the TIGRESS Web site.

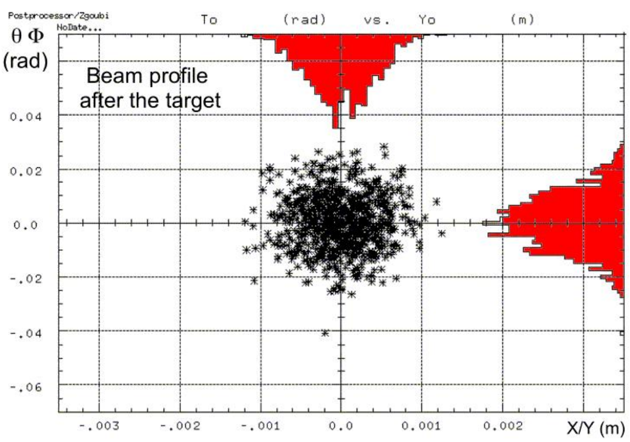


Fig. 242. Optics simulation for beam dump.

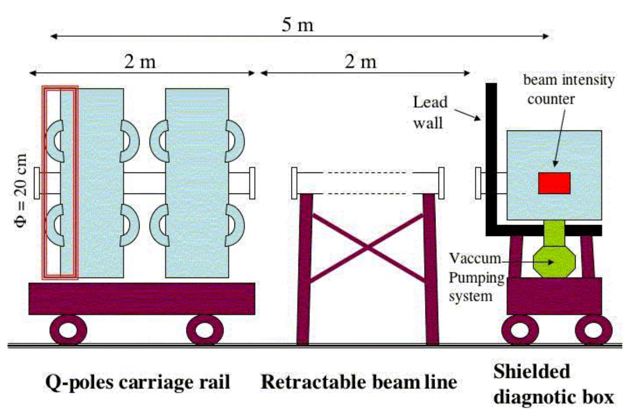


Fig. 243. Beam dump concept.

TPC R&D for the International Linear Collider

(M. Dixit, Carleton/TRIUMF)

Introduction

The micro pattern gas detector (MPGD) readout time projection chamber for the International Linear Collider (ILC) will have to measure ∼200 track points with a resolution close to 100 μm for all drift distances. It will be difficult to meet the resolution goal with standard MPGD readout techniques if ∼2 mm wide pads were used as is presently envisioned. Reducing the pad width to improve resolution could add significantly to the TPC detector cost and complexity. The new MPGD readout concept of charge dispersion developed at Carleton could be an attractive alternative for the ILC TPC. In cosmic ray studies with no magnetic field, our prototype MPGD-TPC has achieved excellent resolution without resorting to narrower pads.

Our major milestone for the year last fall was to study the performance of MPGD-TPCs with charge dispersion in a 1 T superconducting magnet in a 4 GeV/c test beam at KEK. ILC-TPC R&D groups from MPI (Munich), Saclay and Orsay groups from France, and KEK and several university groups from Japan participated in the beam test during which two TPCs were tested. The Carleton TPC was outfitted with a Micromegas endplate. The second TPC, provided by MPI was tested with both a GEM and a Micromegas endplate.

The two TPCs were in the beam at the same time, one in the superconducting Jacee magnet and one outside – see Fig. 244. Data were recorded both in and

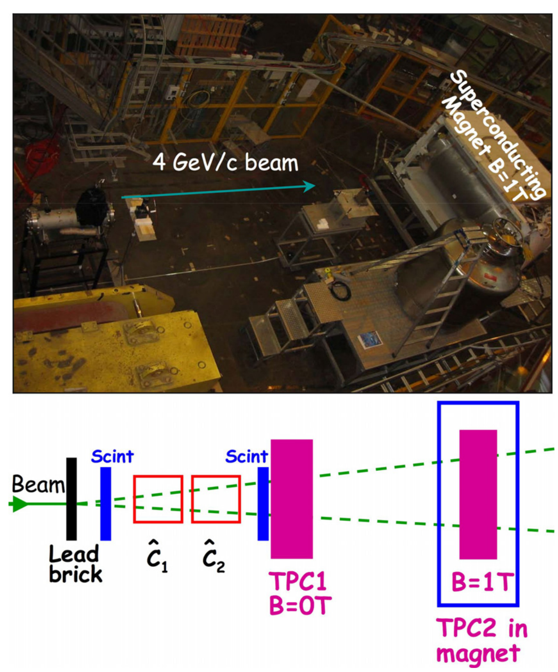


Fig. 244. Experimental set-up for TPC beam test at KEK.

outside the magnet for the two TPCs for several different gas mixtures. Carleton TPC recorded close to 500,000 events, and the MPI-TPC about 100,000 events. Data analysis is in progress. Preliminary results, described below, are quite encouraging. Transverse resolution close to 50 μm was achieved with 2 mm wide pads at 1 T for short drift distances. The dependence of resolution on drift distance was as expected from diffusion. With a much stronger suppression of transverse diffusion at $\sim$4 T, the resolution goal of 100 μm appears feasible for the ILC TPC.

Cosmic ray tests and beam tests in a magnet of MPGD-TPCs with charge dispersion

For cosmic rays tests, the small 15 cm drift length Carleton TPC tested earlier with a double GEM readout system was modified to accommodate a Micromegas endplate. Similar to our studies with the GEM endplate, signals from 60 pads, 2 mm $\times$ 6 mm each, were read out using Aleph wire TPC preamplifiers and digitized directly using 200 MHz 8 bit FADCs built by the University of Montreal. The TPC and the readout electronics were upgraded for the KEK beam test. For improved track reconstruction in a magnetic field, the number of pad rows was increased from 5 rows with a total of 64 pads to 9 rows with a total of 128 pads. The DAQ and the readout system were upgraded to increase the number of FADC readout channels and the speed of the data acquisition system.

The second TPC for the beam test was provided by the MPI group. It had been tested previously at KEK with normal proportional wire, GEM and Micromegas readout endplates, where the GEM endplate was built by the Saga University group in Japan and the Micromegas endplate by the Saclay group. The Micromegas and the GEM endplates were modified by the Carleton group for charge dispersion readout studies. The data were recorded using the 11 MHz Aleph TPC digitizers. For comparison, part of the MPI-TPC data were also recorded using Canadian 200 MHz FADCs.

The gas used, $Ar{:}CO_2$/90:10 for the initial Micromegas-TPC tests with no magnetic field, was chosen to simulate reduced transverse diffusion conditions for a TPC in a magnetic field. Figure 245 shows the TPC transverse resolution measured at Carleton for cosmic rays and in the test beam at KEK. The resolution for the 4 GeV/c π beam is better because of better geometry and higher dE/dx for the beam particles.

We used $Ar{:}C_4H_{10}$/95:5, P5 ($Ar{:}CH_4$/95:5) and $Ar{:}CF_4$/95:5 gases for TPC beam tests in the magnet. P5 and $Ar{:}CF_4$ are possible candidate gases for the ILC TPC. The TPC drift fields for different gases were adjusted to maximize the Lorentz suppression of transverse diffusion for TPC operation in the 1 T magnet available for the tests. The analysis is in progress. Some of the preliminary results for P5 and $Ar{:}C_4H_{10}$ are described below.

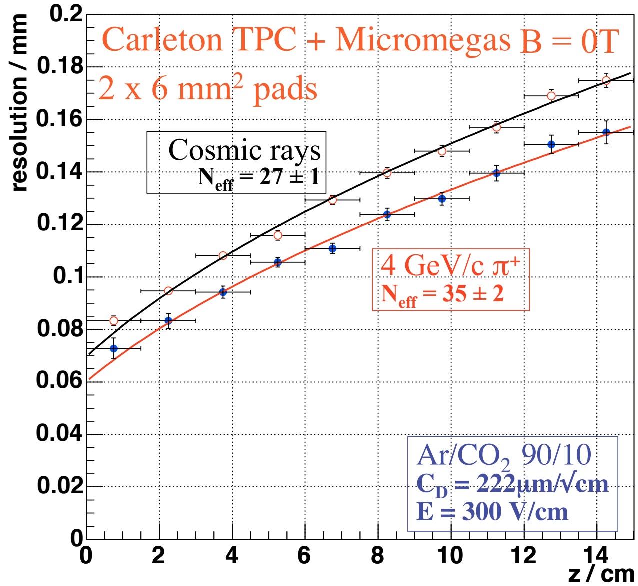


Fig. 245. Transverse resolution for $Ar{:}CO_2$ for Carleton TPC with a Micromegas charge dispersion readout for cosmic rays and for beam particles.

Most of the data for the MPI-TPC for the triple GEM and the Micromegas endplate were collected with the 11 MHz Aleph Time Projection Digitizers (TPD). These data sets are presently being analyzed at Saclay, at DESY and in Japan. For the triple GEM endplate with 2.3 mm $\times$ 6 mm pads, part of the MPI-TPC data for the P5 gas were recorded using Canadian 200 MHz FADCs. Figure 246 shows preliminary results from this measurement for 4 GeV/c pions. Due to beam

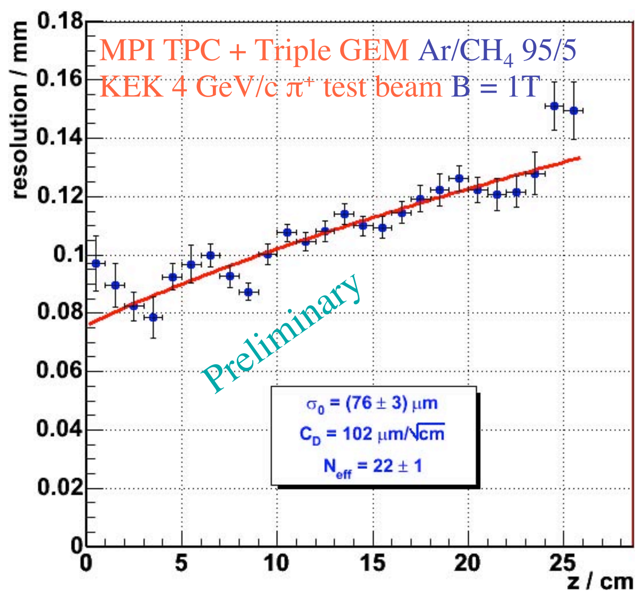


Fig. 246. Triple-GEM MPI TPC resolution with charge dispersion in the test beam with data collected for P5 gas with 200 MHz FADCs.

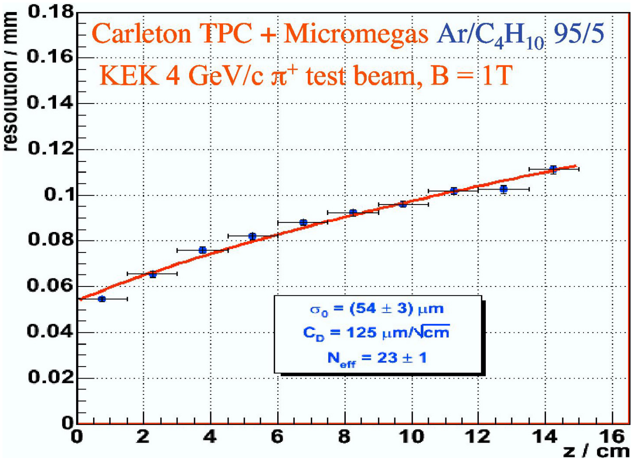


Fig. 247. Transverse resolution for beam particles for $Ar:C_4H_{10}$ for Carleton TPC in a 1 T magnetic field.

geometry and local TPC field distortions, there were very few events for the 25 cm long TPC near its extremities where there are large measurement errors. Nevertheless, the resolution measured with the charge dispersion is better than has been achieved previously under similar conditions with conventional GEM readout techniques.

Figure 247 shows the measured transverse resolution at 1 T in the beam for $Ar:C_4H_{10}$ for the Carleton TPC with the Micromegas endplate. For 2 mm wide pads, the 50 μm resolution for short drift distances is impressive for 105 $\mu m/\sqrt{cm}$ transverse diffusion.

The dependence of resolution on drift distance was as expected from diffusion. To date, no MPGD-TPC read out with conventional techniques has achieved as good resolution, whether it is in or outside a magnetic field. With a much stronger suppression of transverse diffusion at $\sim$4 T, the resolution goal of 100 μm appears feasible for the ILC TPC. Hence a charge dispersion MPGD endplate is a serious candidate for the ILC TPC readout.

Future plans

A large amount of data was taken during the KEK beam test and it will take a significant effort to analyze this data fully.

Our measurements to date have demonstrated the feasibility of achieving resolution limited only by diffusion in a 1 T magnetic field. With a much stronger suppression of transverse diffusion at $\sim$4 T magnetic field for the ILC TPC, the resolution should get much better – close to the ILC TPC goal of 100 μm. We plan to demonstrate this in cosmic ray tests this summer in a 4 T magnet at DESY.

The international effort to construct a large prototype for the ILC-TPC is just starting. The large prototype (LP) is needed to demonstrate that performance of relatively small prototypes can be achieved in a large-scale device. The LP is essential to provide input to designing the ILC TPC. The Carleton group plans to develop the charge dispersion readout option for the LP-TPC endplate. We have built up valuable experience in producing the first generation prototypes and are well positioned to effectively contribute to LP-TPC effort.

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