G. EQUIPMENT DEVELOPMENT

One strength of the heavy-ion group program is continuing excellence in developing new equipment. During the last year, considerable progress was made in many areas. A new data-acquisition system was developed and is now almost ready to be deployed in experiments. The FMA is being upgraded and its focal plane detectors enhanced. The production, separation, capture and transport of ions to the CPT was greatly improved, and our development of large area planar detectors for gamma-ray tracking reached sufficient maturity to start a full program of measurements. Finally, intense planning for the return of Gammasphere to ATLAS is underway, including "two-beam line" operation, and numerous small modifications to the electronics designed to reduce deadtime and enhance the quality of the data collected.

g.1. Data-Acquisition Development (B. Nardi, K. Teh, and A. H. Wuosmaa)

A new data acquisition and analysis system is under development for experiments at ATLAS. The end goal of the project is to introduce both new hardware for data acquisition, and software tools for the analysis and visualization of data. These will become necessary with the phasing out of the existing DAPHNE system and the VMS/Alpha computers on which it runs. Hardware development includes work on a system based upon a commercially available CAMAC-PC interface built by Wiener Systems (the CC32), as well as a system designed and developed primarily within the Physics Division, called PICA (see below). The CC32 system was tested and used in an experimental environment in an experiment conducted at Lawrence Berkeley National Laboratory (see Secs. a.2 and a.3 in this chapter). The data acquisition and control software package (called SCARLET) was produced in the Physics Division, and can be used with either the CC32 or PICA systems.

For data analysis and visualization, there exists an interface between SCARLET and the ROOT system developed at CERN. ROOT possesses the advantages that it is readily available, widely used, well supported and continually upgraded. A ROOT-based analysis package provides easier portability for data, and runs on a wide variety of platforms, freeing the user from the VMS operating system currently in use.

PICA

The PICA system is currently in the final prototype construction stage. PICA is built around an intelligent CAMAC crate controller module containing an embedded Intel x86 microprocessor running the RealTime Linux (RTLinux) operating system. Within the CAMAC controller, a CAMAC logic sequencer communicates directly with the x86 processor via the embedded processor's PCI bus. Data from the PICA controller in each CAMAC crate in an experiment are sent via a private Ethernet link to a separate event builder that consolidates the data for each event, fills them into event buffers, which are then sent via Ethernet to data-consumer processes. Proof-of-principal prototype versions of the CAMAC logic sequencer and PCI communication hardware were built and tested. Based upon the results of these tests the design was refined, and the first full prototypes were designed and are being constructed by the ANL Division of Electronics and Computing Technologies. It is planned to deploy the first production modules in mid-2002.

g.2. New Double-Sided Si Strip Detector (D. Seweryniak, C. N. Davids, A. Heinz, P. J. Woods,* T. Davinson,* H. Mahmud,* P. Munro,* J. Shergur,† A. Woehr,† and W. B. Walters†)

In order to improve the α and proton decay implantation station behind the focal plane of the FMA a new Double-sided Si Strip detector was installed and instrumented. The new detector is more versatile than its predecessors and offers both high granularity and large area. The front and the back face of the new detector is divided into 80 400-μm wide strips. The picture of the detector mounted on the flange is shown in Figure I-71. The detector was used for the first time in a successful search for the new proton emitter ^{135}Tb. The estimated cross section for populating ^{135}Tb is about 2 nb, and is the weakest proton emitter ever observed. Presently, the new detector is routinely available for experiments.

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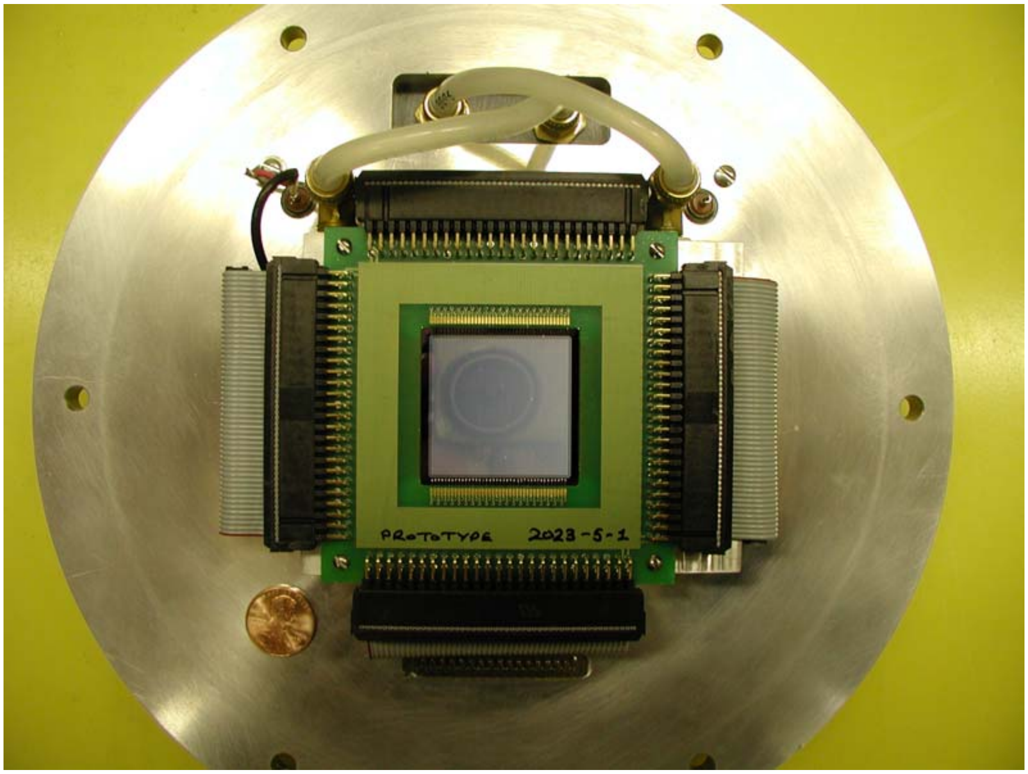

Fig. I-71. New 80 × 80 DSSD.

g.3. Delay-Line Shaping Amplifiers for a Double-Sided Silicon Strip Detector
(C. N. Davids, P. Wilt, and D. Seweryniak)

The prototype delay-line shaping amplifier mentioned in the previous report was tested in-beam with heavy recoils from a reaction, and found to perform as expected. It should be possible to observe decay protons with energies of only a few hundred keV, and starting ~1.5 microsecond after the beginning of the implant pulse. The printed circuit boards for the amplifiers and the associated motherboards were obtained, and construction of the 160 amplifiers needed began. A test run of the system has been approved by the ATLAS PAC, and this should take place in the coming year.

g.4. Split Anode for the First FMA Electric Dipole (C. N. Davids and J. Falout)

A new anode was designed for the first electric dipole of the FMA. In the current situation, the unreacted primary beam is stopped on this anode. Some particles can scatter out of the anode and make their way to the focal plane, where they induce a background signal. The new anode is split vertically, leaving a 1-cm gap, and the unreacted primary beam particles enter the anode structure and are stopped near the end on a tantalum plate. This should considerably reduce the flux of scattered beam that is detected at the focal plane.

The new anode was delivered, and has been installed and tested during the Spring of 2002.

g.5. Design of a Recoil Separator for Superheavy Element Chemistry (C. N. Davids)

A recoil separator to be used in studies of superheavy element chemistry was designed. The main goal was to obtain a high efficiency for transporting recoils from the $^{244}Pu(^{48}Ca,4n)^{288}114$ reaction. Other design goals include small transmission efficiencies for the primary beam and transfer products ($<10^{-3}$), as well as providing as small an image size as possible.

The design evolved out of the ion-optical configuration of the Fragment Mass Analyzer. To achieve high transmission, the M/Q acceptance was broadened by increasing the interior sizes of all ion-optical elements. The resulting fields are all within the range of those achieved with the FMA. In addition, the target was placed closer to the input quadrupole, and the tuning of all elements was adjusted for zero mass dispersion at the focal plane. In order to better match the properties of the resulting beam inside the separator, the focusing of the last two quadrupoles in the horizontal direction was made converging-diverging instead of diverging-converging.

Preliminary transmission calculations for $^{288}114$ have been made, using rectangular distributions for angle, energy, and charge state. Using an angular range of ±105 mr (±6° both horizontal and vertical), an energy range of ±5%, and a charge state distribution range of ±15% (7 charge states around Q = 20), an overall transmission of 30% was obtained. The use of rectangular distributions means that this transmission figure represents a lower limit, since the actual distributions tend to be more peaked around their central values. The image size obtained was 1 (horiz.) x 4 (vert.) cm^2.

The presence of an electric dipole at the front of the separator means that transfer products and primary beam particles lie outside the energy/charge acceptance of the separator. Unwanted particles will be dumped in a shielded Faraday cup after passing through the split anode of the electric dipole. An additional feature of the separator is the fact that the ion-optical configuration of the FMA can be recovered by reversing the polarities of the last two quadrupoles. This means that the device can be used to obtain M/Q information if desired, with somewhat lower transmission.

Figure I-72 shows the horizontal (x) and vertical (y) optics for 38-MeV beams of $^{288}114$ having input angles between ±80 mr (horiz.) and ±50 mr (vert.), and charge states 19 -21 (charge state 20 not shown).

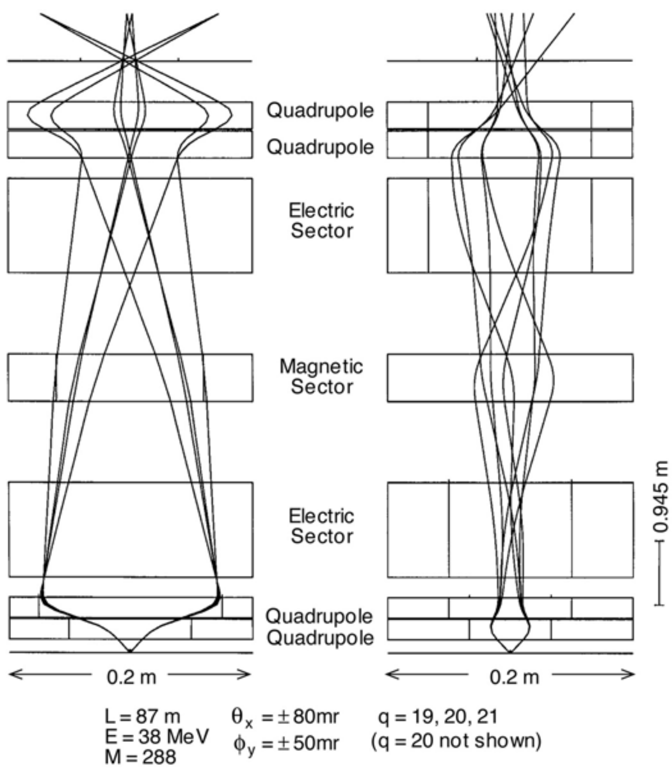

Fig. I-72. Vertical and horizontal optics for a recoil separator designed for use with superheavy elements chemistry.

g.6. Test of Upgraded MWPC for High Count Rate Applications (T. Pennington, D. J. Henderson, C. N. Davids, D. Seweryniak, J. P. Greene, C. J. Lister, A. M. Heinz, G. Mukherjee, A. Woehr,* and B. J. Truett†)

With ten years of exceptional service from the Fragment Mass Analyzer (FMA) using the Multi-Wire Proportional Counter (MWPC) as a focal plane detector, many experiments were completed successfully. The present design of the MWPC is limited in count rate to 5 kHz, for lengthy (five days or longer) experiments. This count rate restriction is a direct result of the cracking of the isobutane in the MWPC by both scattered beam and by the heavy ion recoils. The recombination of dissociated organic molecules results in the formation of solid or liquid polymers, which accumulate on the cathode and anode of the detector. Ions reaching the cathode and anode must then slowly diffuse through this polymer layer to be neutralized. This reduction in the diffusion rate of the ions in the detector causes a decrease in the efficiency, gain and resolution of the detector. This process occurs until a continuous discharge takes place in the detector, which continues even after the scattered beam and heavy ion recoils are removed. Only a complete cleaning of the wire planes can restore the detector. The MWPC can be cleaned with the use of ethanol and the physical rubbing of the wires with a cotton swab. This style of cleaning only works for a limited number of times. If the wires are too "dirty" the entire wire plane has to be replaced.

UPGRADE OF THE MWPC

We substituted the cathode and anode wire planes with three metallized mylar foils (two cathodes and one anode). The new anode and cathodes were constructed as follows; a 70 $\mu g/cm^2$ mylar foil was stretched and attached to an OFHC copper frame. Then a layer of gold 17 $\mu g/cm^2$ thick was evaporated onto both sides of the mylar foil. Figure I-73 is a cutaway view of the MWPC with the new anode and cathodes. The brown frames are the location of the anode and cathodes. The internal electrical connections are not shown in the figure for clarity. The gas pressure used in the upgrade was the same as the gas pressure used in the original arrangement 3 Torr of isobutane. The operating voltage used in the upgrade was -250 V for the cathodes and +250 V for the anode. This is different from the bias scheme used in the original MWPC, which was -200 V for the cathode and +350 for the anode. The spacing of the planes in the upgrade is the same as the original, 0.125 inches. Energy loss and multiple scattering calculations show that this upgrade would not adversely affect the detector due to the extra material that has been introduced, except for very heavy, slow-moving ionsl. We believe that the shape of the electric field near a planar electrode will eliminate some of the problems produced by the 1/r dependence of the electric field near a wire. The upgrade was tested offline using a ^{240}Pu-^{244}Cm alpha source at the rear of the FMA. The detector was then tested with heavy ion recoils under experimental conditions. In most there are usually one or two mass strong peaks in the MWPC. This means that there are one or two localized regions in the detector that receive most of the heavy ion flux. This localized flux also contributes to a lower maximum count rate for the detector, since the recombination of the dissociated organic molecules and the formation of the solid and liquid polymers occur at an increased rate in these localized regions.

HEAVY ION RECOIL TESTS

We tested the upgraded MWPC at high count rates (above 20 kHz) with heavy ions. The reaction that was used for the first test was a ^{92}Mo beam on a ^{58}Ni target. The use of this beam target combination produced the needed high count rate of both scattered beam and heavy ion recoils. Once the response to scattered beam was observed, the scattered beam component was removed by the use of slits at the FMA focal plane. Due to beam current limitations, the average limit rate during a two-day run did not exceed 13 kHz. In a second test, a ^{58}Ni beam was used to bombard a ^{56}Fe target. This average count rate achieved during this one-day run was 20 kHz, again using slits at its focal plane to remove the scattered beam component. No degradation of the MWPC was observed during these tests. At present the maximum count rate for the upgrade is unknown. Work continues on the analysis of the data from the two tests.

Work is continuing to improve the MWPC by reducing the added material from the metallized foil planes. One improvement will be to use aluminum instead of gold for the metallization and have metal on only one side of the cathodes. An other possible improvement is the used of thin freestanding aluminum foils instead of the metallized mylar.

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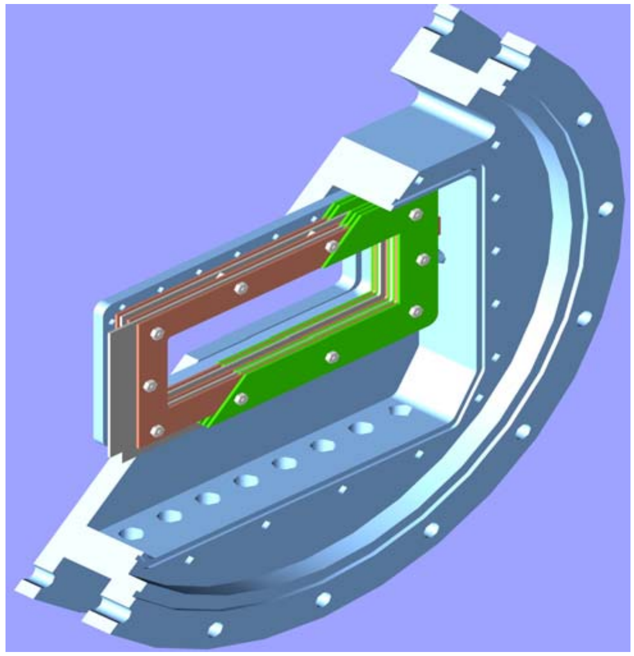
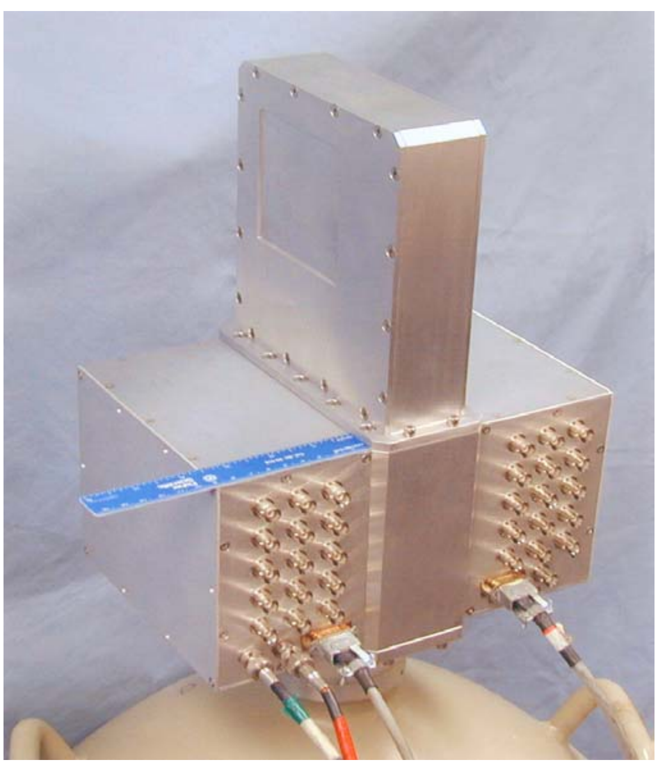


Fig. I-73. Cutaway view of the MWPC with the new anode and cathodes.

g.7. Development of Large Area Planar Germanium Detectors (HpGeDSSDs) for Future Tracking Arrays (C. J. Lister, M. P. Carpenter, R. V. F. Janssens, T. L. Khoo, G. Mukherjee, S. M. Fischer, E. F. Moore, T. Lauritsen, D. Seweryniak, J. Ammann,* B. J. Truett,† P. Chowdhury,‡ P. Sangsingkeow,§ T. A. Underwood,§ R. Kroeger,¶ and B. Phlips¶)



"Next Generation" gamma-ray detectors will combine excellent energy and time response normally associated with germanium counters with very high efficiency and the ability to "track" incident radiation and determine the "hit position" and direction of incoming photons. Considerable progress was made in developing and exploiting position sensitive planar germanium detectors. The "Mark 3" detector was delivered in February 2002, and shows considerably improved performance, compared to earlier prototypes. The germanium wafer is 90 mm × 90 mm × 20 mm, still the largest operating planar in the world. The big improvements appear to arise from the use of a "guardring" around the perimeter of the counter. All of the orthogonal 16 × 16 (85 mm × 5.3 mm strips) are functional, with a mean resolution of 2.8 keV for 122 keV photons. The detector package was tidied up, reducing noise. Figure I-74 shows the latest detector. The uniformity of efficiency is also improved.

Fig. I-74. The "Mark 3" planar germanium HpGeDSSD detector, now ready for physics applications.

We implemented a "fine positioning" system which enables a source to be moved by computer control and is reproducible at the few micron level. In addition, we built a slit collimator, which allows restricted regions of each strip of the detector to be illuminated. Collimation as tight as 25 microns was achieved. To exploit this, and make measurements of position sensitivity, "line" calibration sources of ^{57}Co and ^{137}Cs were fabricated.

Investigation of the pulse shapes started. Capturing digital pulses using a 1 GHz oscilloscope clearly reveals strong image charge pulses developing on strips adjacent to the ones which collect real charge created by the incoming photons. These signals clearly show that full position characterization of the first interaction (x,y,z,E,t) is possible in many cases. The lateral strip-to-strip interpolation appears straightforward, with a resolution which is a function of incident energy and depth, but can be as good as 0.5 mm and seldom is worse than 2.5 mm. Depth profiling seems straightforward at the <1 mm level.

The Mark 2 detector is to return to Ortec for an upgrade, developed in the light of progress with the present detector. A guardring will be implanted. It will be fitted with cold-FET preamps, which will further improve the resolution significantly. The two detectors will then be used for construction of a Compton Camera, in collaboration with the ANL Technology Division.

Test experiments are continuing. We are pursuing the precision and linearity of digital pulse processing. A full compliment of analog electronics is being installed, and parallel digital readout of interesting events is being planned. Full 2D uniformity can be then investigated, including the absolute efficiency of the wafer. An "in-beam" experiment is scheduled for May, in which precise Doppler reconstruction will be demonstrated. The detectors are being used for an SBIR project, with Bio-Imaging Company, a local business interested in imaging objects with x-rays and gamma rays. First publication of our results is being prepared.

*DePaul University, †Purdue University Calumet, ‡University of Massachusetts-Lowell, §Ortec, ¶Navel Research Laboratory

g.8. Design of the X-Array, an Efficient Gamma-Ray Detector for the Focal Plane of the FMA (C. J. Lister, E. F. Moore, R. V. F. Janssens, M. P. Carpenter, D. Seweryniak, and T. L. Khoo)

A very productive line of research in the last few years is the exploitation of charged particle groundstate radioactivities to infer spectroscopic information. At ATLAS these decays are usually studied after mass separation using the Fragment Mass Analyzer. The decays, proton emission in very neutron deficient nuclei, and alpha decay in heavy nuclei, can provide a wealth of data on relative binding energies, shapes and single particle states. Of particular interest, especially in heavy nuclei, are particle decays which proceed to excited states (so called "fine structure"). The states thus populated then usually decay by gamma emission. The correlations between particles and subsequent gammas can often provide extremely clean and unique information on the location of the single particle states, can strongly restrict spins and parities, and can remove ambiguities over level positions which can arise from particle (or gamma) spectroscopy alone. One recent example is rigorously establishing the location of the first excited state in ^{103}Sn following the α-decay of ^{107}Te (see Sec. b.1.4 in this chapter).

In addition to charged-particle radioactivities, beta-decay continues to provide important information on nuclear structure across the nuclear landscape. The decay selection rules tend to favor low spin and often non-yrast states, so act as a natural compliment to "in-beam" spectroscopy . Technically, the continuous beta spectrum and the relatively long halflives make ultra-selective, low cross-section, beta decay experiments difficult, so many of the most interesting β-decays from near the proton dripline have yet to be studied. However, β-decay is frequently followed by γ-deexcitation, so efficient detection of gamma-rays, and correlation of their spatial position of emitter and γ-decay, can provide a means of achieving enhanced sensitivity.

The current generation of decay experiments can be made much more efficient by improving the γ-detection part of the experiments, which, using small single germanium detectors are, at present, only a few percent efficient. This increase in efficiency directly maps into a commensurate improvement in sensitivity. We performed MCNP Monte Carlo calculations to examine how to build an efficient experiment for these decay studies. It would appear than an array can be built which has an efficiency about twice that of Gammasphere (~20%) for 1.332 MeV γ-rays and ~50% for low energy radiation.

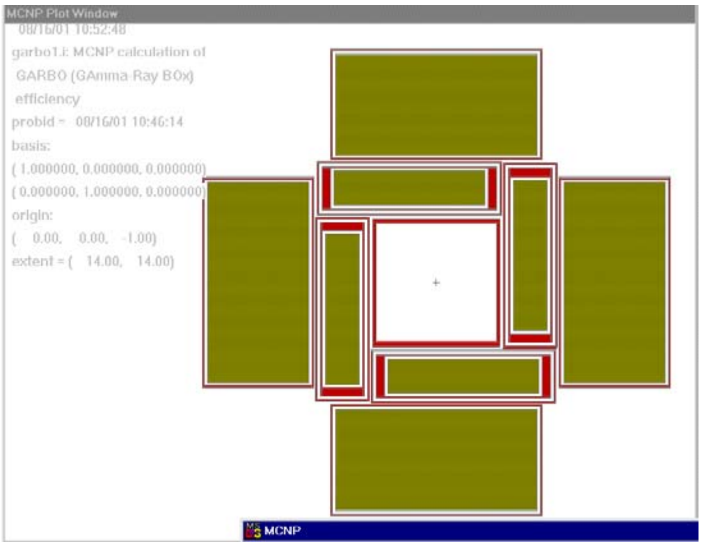


Fig. I-75. A possible schematic layout of the X-Array, a spectrometer for studying radioactive decays, viewed from the FMA. It consists of a five-sided box of gamma detectors.

The array is designed to surround our existing silicon detector system which is deployed inside the focal plane vacuum system and detects implanted ions, and their subsequent α– β– electron- or proton decays. It consists of a five-sided cubic box: the sixth side is open to admit recoil ions from the FMA. The gamma spectrometer is in two layers: a planar layer optimized for detecting low energy radiation, at high countrates, with excellent timing, good energy resolution, and excellent spatial information. The detectors are ultra-large germanium planar wafers. This array is backed by a second layer of large conventional "clover" detectors to enhance efficiency for higher energy radiation. The array appears to have many attractive features. In particular, for some events it will allow "gamma tracking" to ensure the detected radiation originates from the implant site. The array will also be very efficient for x-rays, from which the atomic number (Z) of the decaying parent can be inferred. Z-tagging, when combined with the mass separation of the FMA, can provide unique isotopic identification. In addition, the high efficiency will be ideal for γ–γ and α–γ angular correlations which help constrain spin and parity both of the parent and daughter states.

The design of the array is being finalized and the specification of the detectors refined. The first two "clover" detectors will be used with our existing planars to conduct first experiments with a "two-wall" box in FY2003, and we project the entire array can be complete by 2005.

g.9. Participation in the GRETA Project (C. J. Lister, M. P. Carpenter, T. L. Khoo, and R. V. F. Janssens)

Considerable effort is being dedicated to planning a "next generation" gamma ray spectrometer to replace Gammasphere in the future. Ideally, the detector would consist of a contiguous 4-π shell of germanium, and would allow "tracking" of all interactions, that is the ability to infer the sites of all the interactions as the radiation is absorbed. This information should allow full event reconstruction, thus improving the "peak-to-total" ratio (through identifying "background" events where radiation leaked form the detector), allowing excellent Doppler reconstruction even for the swiftest moving ions (through inferring the exact angle of the first interaction), and allowing polarization measurements (through measuring the asymmetry of scattering).

Much of the pioneering R&D into this concept, known as GRETA, was done at Lawrence Berkeley National

Laboratory. However, as the project gains momentum and the financial and manpower scope of the project becomes clearer, involvement of other national laboratories and universities is increasing. At ANL several direction are being pursued.

1) The development of "tracking" in planar detectors at ANL offers a complimentary challenge with a huge overlap in necessary R&D. All the downstream digitization, event building, reconstruction, storage and analysis are very similar. The technology of "tracking" is new and requires considerable effort, but may have great spin-off into other fields, especially where gamma-ray imaging is needed. These areas include space science, medical physics, environmental clean-up, and national security. In these applied areas, the planar germanium wafer technology will probably have many applications. Parallel development of tracking in the large segmented detectors needed for GRETA, and in planar germanium wafers, will allow efficient utilization of the developing "tracking" technologies, to the benefit of all applications.
2 We are involved in the GRETA steering committee, and in the National Gamma Ray Tracking Co-Coordinating Committee.
3 We have been involved in specialized workshops to sharpen the GRETA concept: a digital electronics workshop held at ANL, and a GRETA workshop which was organized at U. Massachusetts, Lowell.

We anticipate these efforts will increase during the next few years as the project moves from a concept to a full design.

g.10. The Science and Operation of Gammasphere at ATLAS: Phase 2 (C. J. Lister, M. P. Carpenter, R. V. F. Janssens, T. L. Khoo, and D. Seweryniak)

The scientific case for moving Gammasphere from Berkeley to Argonne in 1996 was to re-direct the power of the device towards the spectroscopy of nuclei far from stability, especially along the proton drip line and in heavy nuclei (the original proposal can be found at http://www.phy.anl.gov/gammasphere/science/index.html). It allowed us to investigate a key issue in contemporary nuclear physics: the extent to which we can extrapolate the well known physics of near-stability out to the limits of nuclear binding. This campaign, which lasted from January 1998 until March 2000, 27 months, was successful in all respects. The device achieved unprecedented performance and reliability. The project broadened the base of gamma-ray spectroscopy in our community, especially exploring nuclei far from stability, a new direction that is a natural match to the physics goals of the NSAC Long Range Plan, the RIA project and to the program of the NSCL at MSU. In addition, the ATLAS accelerator reliably provided a very wide range of beams, with excellent emittance, energy reach and timing characteristics, which allowed the Gammasphere project to diversify in many other directions.

In February 2002 we proposed to return Gammasphere to ATLAS for a second campaign, with the move being initiated in October 2002 so that operations at ANL can start early in 2003. Two years of operation are anticipated, based on past experience showing this period of time to be optimal for maximal science output and efficient operation of the device. This proposal is aimed at building the momentum of the overall national program to understand the physics of nuclei far from stability. The first campaign was an exploratory sortie into new territory. 100 different experiments were performed, involving over 300 users (of which more than 100 were students) from 71 institutions in 17 countries. The data are undergoing intensive analysis, and to date the research already produced more than 15 Physical Review Letters and 50 papers (a full bibliography can be found at (http://www.phy.anl.gov/gammasphere/pub/index.html)

During the campaign, experiments of increasing complexity and sensitivity were achieved, until in some of the later studies technical obstacles were identified which hampered further progress. In the last two years we worked hard on improvements to ATLAS and our equipment to overcome many of these barriers and allow the projects to make major advances once more. In addition, we developed a cost-effective plan to allow Gammasphere to operate on two adjacent beam lines and to run either free-standing or coupled to the Argonne Fragment Mass Analyzer (FMA), a plan which will further enhance our flexibility. In the following pages we will review the progress in the first cycle of operation at ANL and discuss the exciting opportunities that lie ahead.

By now it is clear that re-siting Gammasphere on a two-year cycle has many advantages, for new physics ideas, for efficient manpower commitment, for analysis and publication, and for equipment regeneration and upgrades. The present LBNL cycle will end in the summer of 2002. We feel it fits into the natural cycle of RIA buildup; as the RIA project grows it will demand more and more effort from the ANL heavy-ion group, so a further move away from ANL after 2004 may then be optimal.

g.11. **Support for Gammasphere Operations at LBNL** (M. P. Carpenter, J. P Greene, R. V. F. Janssens, T. Lauritsen, C. J. Lister, and P. Wilt)

The Gammasphere array is currently located at the 88-inch cyclotron facility of the Lawrence Berkeley National Laboratory. As part of the Physics Division's commitment to the successful operation of the device, several activities continue at Argonne on an "as needed" basis. These include: repairs of Germanium detectors, development and modifications of data-acquisition and analysis software, repair and modifications to electronics modules, fabrication of targets, and preparation of special calibration sources. It is worth noting that, during the past year, three germanium detectors were shipped to Argonne for repair. In all cases, problems with electronics components located inside the cryostats were diagnosed. Thus, the repairs involved breaking the cryostat's vacuum and replacing components (mostly FET's). Following such operations, "pump and bake" annealing cycles took place. The three detectors were subsequently found to function satisfactorily with resolutions equal or even better than those reported at the time of original delivery from the manufacturer.

g.12. **High-Intensity Beam Tests at ATLAS** (A. Heinz, R. V. F. Janssens, D. Seweryniak, K. Abu Saleem, I. Ahmad, B. Back, J. Caggiano, M. P. Carpenter, C. N. Davids, J. P. Greene, D. J. Henderson, C.-L. Jiang, T. L. Khoo, F. G. Kondev, T. Lauritsen, C. J. Lister, E. F. Moore, R. C. Pardo, T. Pennington, G. Savard, J. P. Schiffer, R. H. Scott, R. C. Vondrasek, A. Woehr,* and J. Shergur*)

In preparation for a program to study heavy-elements at ATLAS, experiments with high-intensity ^{86}Kr beam impinging on $^{nat.}$Pb targets were performed. The goal of those experiments was to improve techniques to monitor targets exposed to high beam currents and to enhance the survival of low melting-point targets under such conditions. This program also allowed testing the accelerator reliability at high beam intensities. A test setup using the standard FMA scattering chamber and a target wheel with a radius of 8.8 cm was used in the general purpose area. The targets were made of $^{nat.}$Pa with a thickness of about 500 μg/cm^2 with an upstream backing of 40-μg/cm^2 carbon. To reduce sputtering, a 5-μg/cm^2 layer of carbon covered the downstream side of the target. The wheel was operated at about 1000 RPM. In addition to the target rotation, the beam was defocussed. The maximum beam intensity on target was 190 pnA according to a reading on the last Faraday cup in the beamline. The targets were able to stand this intensity without any problems after careful conditioning with lower beam intensities.

To monitor the targets, a silicon monitor detector was used. In addition the transmission through the target was monitored using a IR sensor and a light source. A second silicon detector and an alpha-source were employed to determine continuously the energy-loss inside the target.

The experience gained in this experiment will be used to improve future experiments at high beam intensities.

*University of Maryland

g.13. A New Dedicated Chamber for Super-Heavy Element Research (A. Heinz, R. V. F. Janssens, J. Falout, J. P. Greene, C. J. Lister, D. Seweryniak, B. Back, T. Pennington, D. Henderson, B. Nardi, and G. Savard)

The production cross sections for the heaviest known nuclei are in the order of pb[1] and are thus among the lowest cross sections measured in nuclear physics. In order to cope with such low cross sections, it is necessary to optimize the event rates as much as possible. One important factor is the beam intensity. But while the increase of the beam intensity requires optimizing the ion-source output and the transmission of the accelerator, the experimental setup has to be able to cope with large beam currents. Especially for targets with a low melting point this becomes a non-trivial problem. A dedicated target chamber for this kind of experiment has been designed and is nearing completion.

In this chamber three different mechanisms are used in order to prevent the target from melting: rotation, wobbling and gas-cooling. Mounting several targets on a wheel allows to spread the heat deposited by the beam over a larger area and allows the target material to cool until the beam hits the same target spot again.[2] It is possible to use the available target area further by implementing a periodic deflection of the beam in the vertical direction by using a steering magnet. This is referred to as wobbling. In vacuum, targets will cool by emission of radiation and by heat conduction of the target material. If the target is surrounded by a gas-filled volume the cooling will be enhanced.

In the new target chamber, a wheel with an active radius of 15.5 cm was installed. It is possible to spin this target wheel with a design speed of 1000 rpm, even though higher rotational speeds are possible. The chamber itself is 30.5-cm long and has a diameter of 36.8 cm. At the entrance and the exit of that chamber rotating windows made of carbon will be installed. These widows will allow containing a gas (such as N_2, for example) at pressures of 1-3 torr. The provision for rotation is intended to reduce the possibility of breaking the windows under high beam intensities.

Even with those techniques the lifetime of a target wheel might be shorter than the duration of an experiment. Thus, it becomes necessary to monitor the condition of the target continuously. The chamber provides several methods to achieve this. First, two types of monitor detectors can be used; a standard silicon monitor detector, which is mounted on a rotating arm, and an ionization chamber at a fixed angle of 44º. The latter detector might prove to be superior to the silicon detector due to the fact that it does not suffer from radiation damage. The target wheel supports frames for 16 targets. An infrared sensor/source will sweep the beam at the spoke positions. A second infrared sensor/source combination measures the target transmission. Also, a strong alpha source and a silicon detector are used to detect any change in energy-loss of the target material. The chamber provides also viewing ports for optical inspection of the target wheel and a faraday cup for beam tuning.

[1]S. Hofmann, G. Münzenberg, Rev. Mod. Phys. **72**, 733 (2000).
[2]J. P. Greene, R. Gabor, and J. Neubauer, *Applications of Accelerators in Research and Industry*, CAARI 2000, AIP **576**, 1152 (2001)

g.14. Design of a Large Area Window for the GSI Gas Cell (T. Pennington, G. Savard, B. Zabransky, J. P. Greene, and J. Falout)

A large area Havar window (~77 cm^2) was designed for the GSI Gas Cell tests being conducted at ATLAS. The window is 2 mg/cm^2 (~2.4 µm) thick and is supported by 28 - 250 µm diameter beryllium copper wires. The wires are laid out in a rectangular pattern with a spacing of 0.635 cm on center. The wires will be soldered into grooves cut into a 0.635-cm thick OFHC copper plate. The window will be mounted to this support structure. The completed window will then be mounted to a specially machined double-sided knife-edge flange with an indium vacuum seal between the flange and the window support structure. The window is designed for a differential pressure of ~103 kPa (15 psia). At this differential pressure the stress on the Havar is approximately 8% of the tensile strength of Havar and the stress on the support wires is approximately 74% of the yield strength and 58% of the tensile strength of beryllium copper. At present the flange and window support structure is being machined and will be tested in the near future.

g.15. Nuclear Target Development (J. P. Greene and G. E. Thomas)

The Physics Division operates a target development laboratory that produces targets and foils of various thicknesses and substrates, depending on the requirements, for experiments performed at the ATLAS and Dynamitron accelerators. The targets are prepared from both naturally occurring materials and stable isotopes that are supplied either in pure, elemental form or as stable compounds. Although typically, the responsibilities of the target laboratory were constrained to providing targets for experiments at ATLAS, in reality it has become much more far ranging. In addition to ATLAS experiments, targets and foils are provided for all staff members whether working within the Physics Division or undertaking experiments at other facilities, for instance, the Advance Photon Source (APS). Also, wherever possible, support is provided to other ANL Divisions, and in particular to requests from researchers at the University of Chicago. Collaborations have grown out of efforts between the Physics Division and target laboratory staff with outside groups in order to provide targets. Many of these, unfortunately, cannot be accepted due to the limited resources of, and time constraints placed on the target laboratory staff.

In the past year, numerous targets were fabricated either as self-supporting foils, on various substrates or as "sandwich" targets. Targets produced included Al, Al_2O_3, Ag, Au, ^{10}B, Be, ^{12}C, ^{40}Ca, CaO, $^{106,116}Cd$, CD_2, ^{52}Cr, Cu, $^{54,56}Fe$, formvar, Havar, ^{180}Hf, ^{7}LiH, ^{24}Mg, $^{92,94,96,97,98,100}Mo$, mylar, $^{142,150}Nd$, $^{58,61}Ni$, $^{207,208}Pb$, PbF_2, ^{110}Pd, phosphor, polypropylene, ^{96}Ru, Si, $^{28,30}SiO_2$, $^{144,149,154}Sm$, Ta, ^{126}Te, Th, $^{46,48,50}Ti$, Y, ^{172}Yb, and $^{90,92,96}Zr$. Many of these target foils were fabricated via mechanical rolling using our small rolling mill. During the 2001 calendar year, approximately 700 targets were prepared for various experiments.

The Argonne/MSU/ORNL BaF_2 array concluded a successful research program with a great majority of the experiments requiring a rotating target wheel so as to increase target lifetimes and allow for higher beam currents. The Gammasphere style target wheel found routine use within the LEPPEX array target chamber. The target laboratory fabricated approximately 40 targets (mainly as target wheels) for the LEPPEX research effort during this time period. Gammasphere, although relocated to LBL, still demands many targets prepared by the target laboratory. For the year, 186 targets were prepared for experiments at Gammasphere.

Experiments were undertaken to explore and increase the production of the heaviest elements. Intense beams, by necessity, must be employed, requiring new demands upon target performance. Target wheels of isotopic lead on carbon backings were prepared for these initial experimental runs using the existing large FMA target wheel. The goal of this present work was the production of Rf, element 104 and look at detection limits and beam rejection using the FMA. Beam intensities up to 250 pnA were put on target. An online target monitoring system was developed to anticipate target degradation. Calculations were performed in an effort to model the target behavior. The next step is to increase the target wheel diameter in a new chamber set-up at the FMA, which will also allow for gas cooling of the target. A larger wheel of similar design is already in use within a new target chamber at the front end of the CPT experiment using the SPS in Area II. By employing a target wheel station, increased beam currents will be available for the production of low cross-section reaction products for measurement.

Outside of target development, support is being provided for the production of thin plastic films and foils for use in various detector systems developed for experiments at ATLAS as well as energy degraders needed for astrophysics research using radioactive beams at SPS III. Several variations of metallized plastic foils were prepared for use in the gas counter and channel plate detectors used at the FMA.

As part of ATLAS support, the target lab routinely produces carbon stripper foils of 2 $\mu g/cm^2$ for use in the Tandem as well as other thickness for additional stripping throughout the accelerator. Over 800 carbon stripper and gold foils of various types were prepared for ATLAS during this past year. There continues to be an increase in the preparation of various dilutions of isotopic source material into a form and shape suitable for introduction into PIIECR and SNICS sources for the production of enriched beams at ATLAS. These included ^{54}Fe, $Li^{6}F$, Mn, ^{61}Ni, and ^{50}Ti. The continuing procurement of stable and enriched material for ATLAS consumption and maintenance of isotope inventories for enriched beam production is being provided by the target laboratory staff.

The target development laboratory includes state-of-the-art equipment used for thin-film fabrication. The available techniques consist of multiple resistive heating, focused ion beam sputtering, glow-discharge plasma deposition, electron beam and electron bombardment evaporation, electrodeposition and mechanical rolling. The evaporators are maintained under high vacuum and each vessel contains a quartz-crystal film-thickness monitor with deposition rate indicators. Also included are movable shutters, quartz-lamp substrate heaters and thermocouple temperature sensors, allowing for complete process monitoring during target deposition.

Other auxiliary equipment used for target development includes electrodeposition equipment, a small rolling mill, an alpha particle counting chamber, inert atmosphere glove box, laminar flow clean bench, pellet press, a reduction furnace, and a variety of precision balances. A turbo-pumped target storage facility is in operation for maintaining, under high vacuum, those targets that readily oxidize in air. This system utilizes computer-controlled circuitry to prevent targets from exposure to atmosphere during power interruptions. A second storage system employing a bank of vacuum desiccators and connected to a mechanically pumped manifold is available for use by individual experimenters. Similar systems are in operation at ATLAS just inside the entrance to Target Area II. A new additional set-up, consisting of two large glass desiccators evacuated using a small turbo-pump system, is in operation for long-term material storage. This allows a separation of material storage from target storage, hence eliminating repeated exposure when transferring and retrieving targets.

A low-level radioactive source and target preparation laboratory exists at a separate location within the division that is dedicated to the production of these sources and targets. Available preparation techniques include multiple resistive heating, employing a diffusion-pumped vacuum evaporator. A second, smaller evaporator system was constructed for close proximity evaporations of higher activity materials, to be used as targets as well as radioactive sources. The small size of this system allows for installation within a hood. Preparation and handling of fission targets (mainly ^{252}Cf) by electrodeposition was done for experimental studies at ATLAS.

Another area of increased research effort is development of radioactive beams for the RIA proposal and involves neutron producing targets which in turn induce fission in uranium or a uranium compound production target. Toward this end, direct measurements of the thermal conductivity of uranium carbide were made using the method of heating by electron bombardment and measuring the surface temperature of thin UC_2 disks by optical pyrometry. The uranium carbide sample disks are first prepared by the reduction of uranium oxide using carbon in a resistively heated source in the Radioactive Target Laboratory. Next, the samples are heated by a 10-kV electron beam provided by a mortar source in a vacuum evaporator in the target lab and the temperature measured as a function of beam current using a two-color pyrometer. This work is still in progress.

Finally, the selection and procurement of a new, general purpose, high-vacuum deposition system is becoming necessary to insure the reliable and continued availability of high-purity targets. The recommended specifications for this system should include an automated, high-vacuum pumping station (cryopump) with a large volume chamber (box-coater) capable of handling large area foils or installation of a substrate planetary system for uniform coating capabilities. The state-of-the-art in coating technology points toward ion beam and plasma assisted deposition. Although not directly applicable to isotopic evaporations, there has always been a need for sputtered films of many kinds from the target laboratory. Any new deposition system procured should include the most advanced coating technology. If possible this equipment should be sought together as an integrated system, for ease of operation. Selection of a suitable system is being investigated and new funding sought.

g.16. Developments at the Canadian Penning Trap Mass Spectrometer and Its Injection System (G. Savard, J. A. Caggiano, J. P. Greene, A. Heinz, D. Seweryniak, J. A. Clark,* R. C. Barber,* C. Boudreau,† F. Buchinger,† J. E. Crawford,† S. Gulick,† J. C. Hardy,‡ J. K. P. Lee,† R. B. Moore,† K. S. Sharma,* G. Sprouse,§ J. Vaz,* and J. C. Wang*)

The Canadian Penning Trap (CPT) mass spectrometer is designed to make precise mass measurements on nuclides with half-lives longer than 50 ms. The radioactive nuclides are produced through fusion evaporation reactions using heavy-ion beams from the Argonne Tandem Linac Accelerator System (ATLAS). Once created, the nuclides of interest are separated from the beam in an Enge magnetic spectrometer operated in the gas-filled mode. They are then stopped in a gas catcher filled with 150 Torr of helium, extracted and subsequently guided to a radio-frequency quadrupole ion trap where they are accumulated before being transferred to a high-precision Penning trap. Activities at the CPT spectrometer have continued to improve the transfer efficiency of ions from the target to the Penning trap, decreasing the number of contaminants and performing mass measurements on short-lived isotopes. The most significant improvements in the last year involved the installation of a large diameter rotating target, a magnetic triplet situated after the target chamber to increase the acceptance of the Enge spectrometer, a velocity filter to more effectively separate the beam from the reaction products and the replacement of the Paul trap with a linear trap resulting in more efficient capture and accumulation of ions from the ion cooler. These improvements will be described in details below.

The production target has been moved approximately 3 metres upstream to accommodate the insertion of a magnetic triplet and velocity filter in front of the Enge spectrograph. The single rotating target has been replaced by a rotating target wheel (see Fig. I-76) which can hold 16 individual targets at the edge of the wheel's 6" radius. The position of the wheel is continually monitored by a CAMAC module, which can be programmed to issue a signal to deflect the beam at prescribed positions of the wheel. This prevents the beam from hitting the 'spokes' between targets or specific targets themselves. On-line tests of this target wheel have shown that 1 mg/cm^2 ^{12}C targets can easily withstand 100 pnA of ^{58}Ni for the duration of a run, typically four days.

Fig. I-76. Picture of the large rotating target wheel installed at the Enge spectrograph. The beam hits the targets at 6 inch radius with the target rotating at about 1000 rpm.

Downstream immediately following the new target wheel lies a magnetic triplet to focus the recoil products into the Enge spectrometer. This combination of three magnetic quadrupoles has increased the number of recoil products entering the Enge by about a factor of three. Following the magnetic triplet (see Fig. I-77) is a velocity filter whose purpose is to separate the recoil product of interest from the primary beam. The electric field of the velocity filter is provided by two 70-cm long parallel plate electrodes separated by 5 cm. A potential difference of 100 kV can be applied across the plates. The perpendicular magnetic field of the velocity filter is provided by a box type magnet with 40 turns of hollow copper tubing. Fields of up to 1500 Gauss can be obtained by applying up to 300 A through the water-cooled coils. The appropriate balance of electric, E, and magnetic, B, field strengths allows ions of a particular velocity, v, to traverse the 70-cm length of the filter unhindered as v = E/B. The rejection of ions of other velocities is determined by the dispersion which can be augmented by increasing the strengths of the two fields while maintaining the ratio.

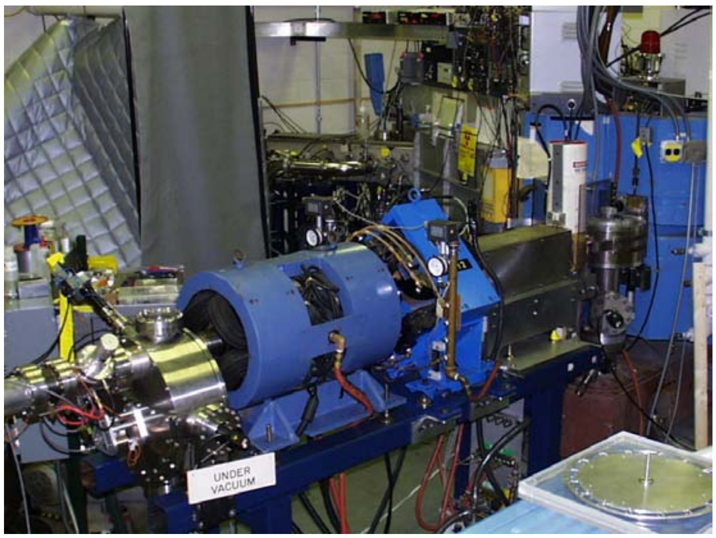


Fig. I-77. View of the new target chamber, magnetic triplet and velocity filter leading to the "old" target chamber and entrance to the Enge spectrograph.

For our purpose, a deflection of the primary beam by 1 cm over the 70-cm length of the filter is sufficient to prevent the beam from entering the Enge spectrometer. Through on-line tests of the velocity filter, we successfully suppressed the primary beam by five orders of magnitude while accepting the reaction products.

On the CPT side, the standard three-electrode structure of the Paul trap (two endcap electrodes with an intermediate ring electrode) was replaced by a linear Paul trap (see Fig. I-78). Essentially, the ring electrode of the Paul trap was replaced by two pairs of segmented parallel rods. The linear Paul trap has a greater phase-space acceptance and is much easier to operate. For example, the RF applied to the ring electrode of the original Paul trap results in a time-varying force along the longitudinal axis, or the axis in which the ions are injected and subsequently ejected. Ions must then be injected carefully into the Paul trap by synchronizing the injection with the RF applied. However, the RF applied to the rods of the new linear trap creates no such time-varying force along the longitudinal axis, and therefore the RF-phase criterion is not as critical. Recall that the Paul trap is used to collect, accumulate, and cool the ions before transport to the Penning trap. The typical efficiency of this process with the original Paul trap was about 15%, whereas, we routinely get 80% or better with the new linear Paul trap.

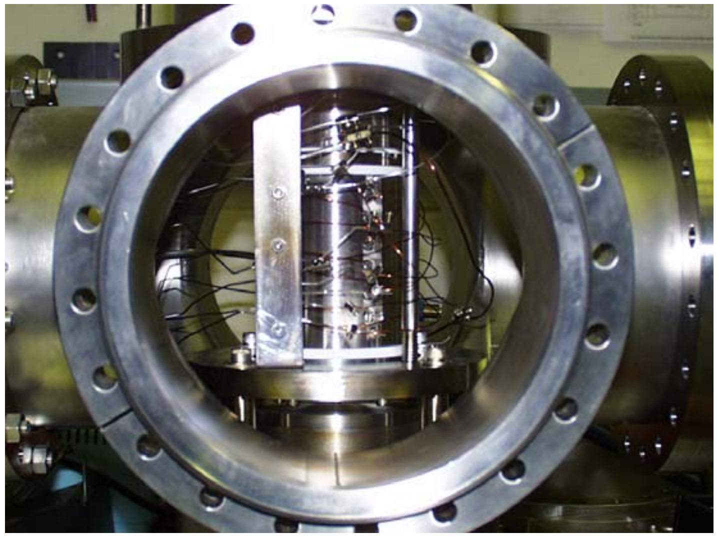


Fig. I-78. New linear Paul trap used for ion accumulation and cooling.

The CPT penning trap itself saw no changes this year except for a retuning of the magnetic field shims in the spring which yielded much improved resonance shape and better cleaning in the precision trap.

The overall efficiency of the injection system of the mass spectrometer improved by a factor of 5 after the gas cooler and a factor of 3 to 5 in the Enge spectrograph as seen on-line with detected yields of ^{68}Ge and ^{68}As. At the same time, the contaminant ions were reduced by a factor of about 3. This not only made new measurements of ^{68}Ge and ^{68}As much easier, but more importantly, more weakly-produced isotopes of importance to the astrophysical rp-process, such as ^{68}Se, are now within our reach. This efficiency improvement also allowed us to study neutron-rich radioactive ions produced by a fission source as reported in Sec. b.2.10. of this chapter.

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g.17. **Progress in the Construction of the Advanced Penning Trap System** (G. Savard, A. Heinz, D. Seweryniak, J. A. Clark,* C. Boudreau,† F. Buchinger,† J. E. Crawford,† S. Gulick,† J. K. P. Lee,† R. B. Moore,† K. S. Sharma,* J. Vaz,* and J. C. Wang*)

The technical developments in ion trapping of radioactive isotopes demonstrated at the CPT mass spectrometer open new venues to probe fundamental aspects of the electroweak sector of the standard model of particle physics. This can be done through the observation of angular correlations in the beta-decay of specific radioactive isotopes stored selectively in an open geometry ion trap surrounded by a detector array. This approach could lead to significantly improved limits on the presence of interactions outside the standard V-A form in the charged weak interaction.

Stringent constraints on extension of the Standard Model come from high-precision measurements of angular correlations in the beta-decay of short-lived isotopes. These short-lived isotopes are available with increasing intensity but the present measurement methods are limited by interaction of the particles emitted in the decay with the source holder. With the recent developments mentioned above, it is now possible for essentially all species of short-lived isotopes to be captured efficiently in ion traps where these radioactive ions are confined, floating at rest in vacuum. This effectively removes the need for a source holder and opens up the possibilities of experiments with much improved accuracy. We therefore started building a new ion trap system, the Advanced Penning Trap (APT) system, suited to angular correlation measurements in nuclear beta-decay.

The APT system will consist of two ion traps, an open geometry linear RFQ trap and a Penning trap sitting in a large bore 7 Tesla magnet, which are injected by the gas cell/gas cooler system developed for the CPT. The APT will be located besides the CPT in the triangular room adjacent to experimental area II.

The isotopes that will be studied at the APT will, in general, be short-lived superallowed emitters. The extraction of such light ions from the gas cooler and transfer to the APT was simulated in details and minor modifications to the gas cooler implemented to avoid losses. Monte Carlo simulations for the first experiment to be performed at the APT, a prototypical experiment to look for possible scalar interactions, to be conducted with trapped radioactive isotopes of ^{14}O, are completed. The computer simulations determined the optimum ion trap and detector array geometry. This was completed with a simulation for the trap geometry and ion transport based on the SIMION software to which a number of subroutines were added (and are being upgraded) over the years to take into account the effects of buffer gas collisions for cooling of the ions in the trap. The detector geometry was simulated using GEANT and the response of different beta detectors compared. The response of the full system was then simulated incorporating a proper Fermi distribution for the positrons and the recoil distribution calculated with the theoretical electron-neutrino correlation. The design of the injection system and first trap of the APT was optimized for this first experiment.

The second trap of the APT, a Penning trap, will be used for experiments that required polarization of the radioactive sample. The superconducting magnet (see Fig. I-79) was received in Dec. 2001. It will be installed on a non-magnetic frame to avoid perturbing the magnetic field.

Fig. I-79. Picture of the 5 inch warm bore, 7 Tesla, superconducting solenoid that will be used to host the Penning trap of the APT.

The additional services required in area II to host the APT were identified and are being installed. Most large components (vacuum, electronics, control system) are either received or ordered. Assembly of the 2 traps is expected to proceed in FY2002.

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