

## H. DEVELOPMENT OF NEW EXPERIMENTAL EQUIPMENT

New techniques and new approaches drive the field of nuclear physics forward. It is encouraging that the current year has been very rich in equipment developments. In almost all our experimental areas new projects are emerging that offer unparalleled opportunities for the next generation of nuclear science.

### h.1. Nuclear Target Development (J. P. Greene)

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. 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. Numerous 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, Au,  $^{10}\text{B}$ , Be,  $^{12,13}\text{C}$ ,  $^{40}\text{Ca}$ , CaO,  $^{106}\text{Cd}$ ,  $\text{CD}_2$ ,  $\text{CH}_2$ , Cu,  $^{57}\text{Fe}$ , Formvar, Graphite, Havar,  $^{180}\text{Hf}$ , In, Kapton,  $^7\text{LiF}$ , Lu, Melamine,  $^{92,98}\text{Mo}$ , Mylar,  $^{58,64}\text{Ni}$ ,  $^{\text{nat}}\text{NiO}$ ,  $^{208}\text{Pb}$ ,  $\text{PbO}$ , Phosphor, Polypropylene, Pt,  $^{121}\text{Sb}$ ,  $\text{SiO}$ ,  $\text{SiO}_2$ ,  $^{112,114,116,118,120,122,124}\text{Sn}$ , Ta,  $^{130}\text{Te}$ ,  $^{50}\text{Ti}$ , TiN, U,  $\text{UC}_2$ , Valine,  $\text{WO}_3$ , Y,  $^{172,174,176}\text{Yb}$ , and  $^{68,70}\text{Zn}$ . Many of these target foils were fabricated via mechanical rolling using our small rolling mill. During 2003, approximately 656 targets were prepared for various experiments.

Gammasphere returned to ATLAS and an increase in demand for various targets prepared by the target laboratory is expected. For the past calendar year, 369 targets were prepared for experiments using Gammasphere.

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 the CPT and for astrophysics research using radioactive beams at SPS III and the FMA. Several variations of metallized plastic foils were prepared for use in the gas counter detector used at the FMA focal plane.

As part of ATLAS support, the target lab routinely produces carbon stripper foils of  $2\ \mu\text{g}/\text{cm}^2$  for use in the Tandem as well as other thickness for additional stripping throughout the accelerator. Over 305 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 the ion sources for the production of enriched beams at ATLAS. These have included  $^7\text{Li}$  and  $^{64}\text{Ni}$ . 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 apparatus, 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. An 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  $^{14}\text{C}$  targets as well as fission sources (mainly  $^{252}\text{Cf}$ ) by electrodeposition has been done in this lab for experimental studies at ATLAS as well as routine rolling of natural U and Th foils.

Another area of increased research effort is toward 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 electron beam heating provided by a 10 kV mortar source in vacuum with the temperature measured as a function of beam current using a two-color pyrometer. Sample uranium carbide material of small grain size is being prepared in-house in collaboration with The ES Division in Building 212. This work is still in progress.

The culmination of the 21<sup>st</sup> World Conference of the International Nuclear Target Development Society (INTDS) held at ANL, November 2002 was the preparation of the Conference Proceedings. These are now published, both in print and electronic media and include thirty-six contributions in 8 sections representing a wide range of target topics. Highlights include high power targets and stripper foil applications for the development of the next generation RIB facilities.

DOE Office of Nuclear Physics made available substantial funds for improvements and upgrades to the target laboratory. To this end, the selection and procurement of a new, general purpose, high-vacuum deposition system was made in order to insure a continued availability of high-purity targets. The specifications for this system include an automated, high-vacuum cryopump system coupled to a large volume cylindrical chamber capable of handling large area foils or installation of a rotating substrate holder for uniform coating capabilities. The state-of-the-art in coating technology points toward ion beam and plasma assisted deposition and is included. The entire system and target process will be under computer control. These new and innovative techniques deserve a place in the methods available for target preparation in the Physics Division. Delivery is expected in Spring 2004.

## h.2. Production of New Radioactive Beams with the In-Flight Technique (R. C. Pardo, K. E. Rehm, A. Wuosmaa, J. Greene, D. Henderson, R. V. F. Janssens, C. L. Jiang, F. Moore, G. Mukherjee, G. Savard, J. P. Schiffer, S. Sinha, X. D. Tang, L. Jissona,\* and R. E. Segel\*)

Production tests for new radioactive beams were performed that will be used in several planned experiments. These include  ${}^6\text{He}$ ,  ${}^8\text{Li}$ ,  ${}^{14}\text{O}$  and  ${}^{16}\text{N}$  beams that are produced using the in-flight technique.

${}^6\text{He}, {}^8\text{Li}$ : Studies of (d,p) reactions in inverse kinematics require beams with energies of about 5 - 10 MeV/u. Under these conditions the backward-emitted protons have high enough energies to permit their detection, however the production cross sections for the secondary beams (via the  $d({}^7\text{Li}, {}^8\text{Li})$  and  $d({}^7\text{Li}, {}^6\text{He})$  reactions) are smaller than their maximum yields which are typically obtained at 1 - 2 MeV/u. In test runs we produced  ${}^8\text{Li}$  and  ${}^6\text{He}$  beams with energies of 76 and 72 MeV, respectively. The maximum beam intensities measured on target so far were: 2000 particles/sec/(pnA of  ${}^7\text{Li}$ ) for  ${}^8\text{Li}$  and 150 particles/sec/(pnA of  ${}^7\text{Li}$ ) for  ${}^6\text{He}$ . These beams are exceptionally pure with very good energy resolution (see Fig. I-61). With a 100 pnA primary  ${}^7\text{Li}$  beam, (limited by the radiation safety system) secondary beam

beam intensities of  $10^4 - 10^5$  on target can be achieved for these beams. Since the HAVAR windows in the gas cells used for the in-flight production can withstand even higher primary beam intensities we are presently trying to improve the shielding of critical beam line components.

${}^{14}\text{O}$ : Beams of  ${}^{14}\text{O}$  are interesting for a number of astrophysical and nuclear-structure investigations. In production tests,  ${}^{14}\text{O}$  was produced via the  $p({}^{14}\text{N}, {}^{14}\text{O})n$  reaction using a 170 MeV primary  ${}^{14}\text{N}$  beam. The observed production rate on target was 1100  ${}^{14}\text{O}/\text{sec}/(\text{pnA of } {}^{14}\text{N})$  with an  ${}^{14}\text{O}$  energy of 155 MeV.

${}^{16}\text{N}$ : For a measurement of the E1-component of the S factor of the  ${}^{12}\text{C}(\alpha, \gamma){}^{16}\text{O}$  reaction a  ${}^{16}\text{N}$  beam was developed. The beam was produced via the  $d({}^{15}\text{N}, {}^{16}\text{N})p$  reaction. With a 70 MeV primary  ${}^{15}\text{N}$  beam a specific rate of 18,000  ${}^{16}\text{N}/\text{sec}/(\text{pnA of } {}^{15}\text{N})$  at  $E({}^{16}\text{N}) = 60$  MeV was obtained.

\*Northwestern University.

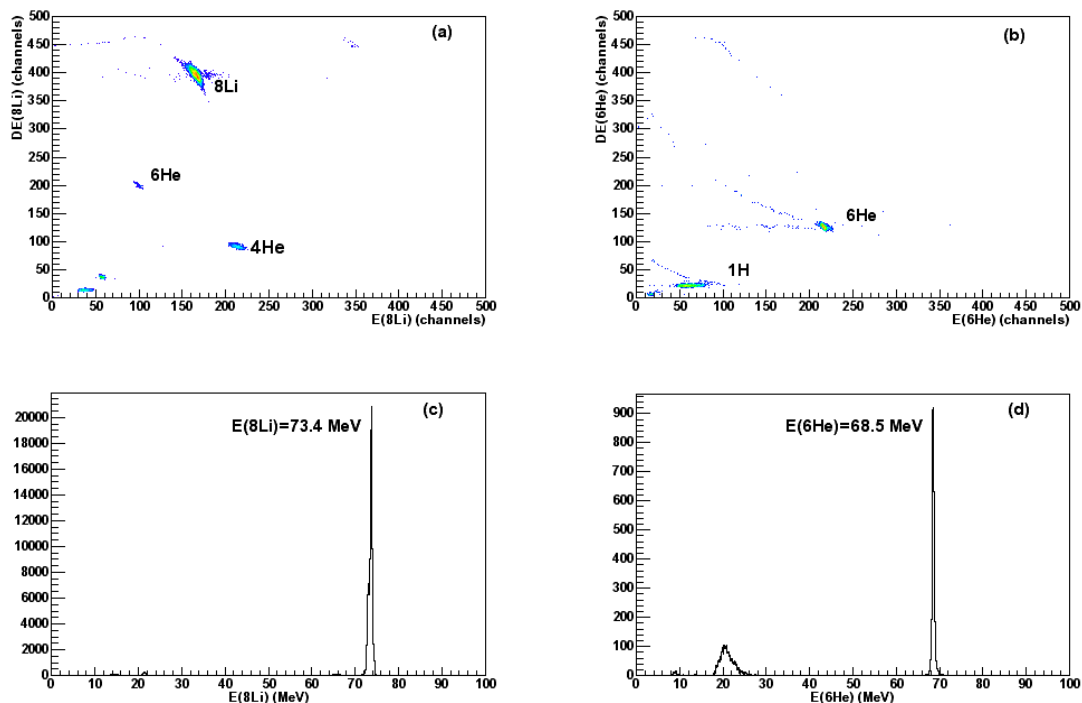


Fig. I-61. Measured particle identification (a), (b) and energy (c), (d) for  ${}^8\text{Li}$  and  ${}^6\text{He}$  beams.

### h.3. A Solenoid for Particle Detection from Reactions in Inverse Kinematics

(J. P. Schiffer, B. B. Back, K. E. Rehm, and A. H. Wuosmaa\*)

Reactions with short-lived beams must usually be studied in 'inverse kinematics' and this poses a number of experimental problems. The reaction products of most interest are usually in the 'forward' direction in the center of mass, which in many such cases is in the direction opposite to that of the beam. For example, the study of the  $^{132}\text{Sn}(d,p)$  reaction with a beam of  $^{132}\text{Sn}$ , requires the detection of low-energy protons in the backward hemisphere. This has several disadvantages.

- a) The particles have a kinetic energy a factor of  $\sim 10$  lower than in the forward direction, making particle identification difficult;
- b) They are spread out in angle so that the solid angle of a given detector covers only about 1/5 of what it would cover in the center of mass;
- c) The proton energy scale is compressed by a factor of  $\sim 4$  and proton groups corresponding to final states with different energies are compressed, separated by much less in laboratory energy than in excitation energy.

A collection device that is a uniform-field solenoid would largely overcome these problems. With a target placed on the axis of the solenoid, and the beam incident along the solenoid axis,

- a) The particles will be transported back to the axis of the solenoid. Thus  $2\pi$  of solid angle will be covered by a small cylindrical detector, instead of a large umbrella array.
- b) The energy separation between groups corresponding to different final states, at one location along the solenoid axis, will be separated by their separations in excitation energy.
- c) Particle identification can be made by time-of-flight, since all particles of a given type have the same cyclotron period (return to the axis in the same time), independent of their energies or angles of emission.
- d) The center-of-mass angles and energies can be reconstructed simply from the observed energies on axis and the position along the axis.

The scheme is illustrated in Fig. I-62 and the energy spectra to be expected in Fig. I-63. Table I-5 gives an example of flight times for different particle types.

\*Western Michigan University.

Table I-5. Cyclotron period for various particles ( $B = 2T$ ).

Particle	$T_{\text{cyclotron}}$ (ns)
p	32.8
d, $\alpha$	65.6
t	98.4
$^3\text{He}$	49.2

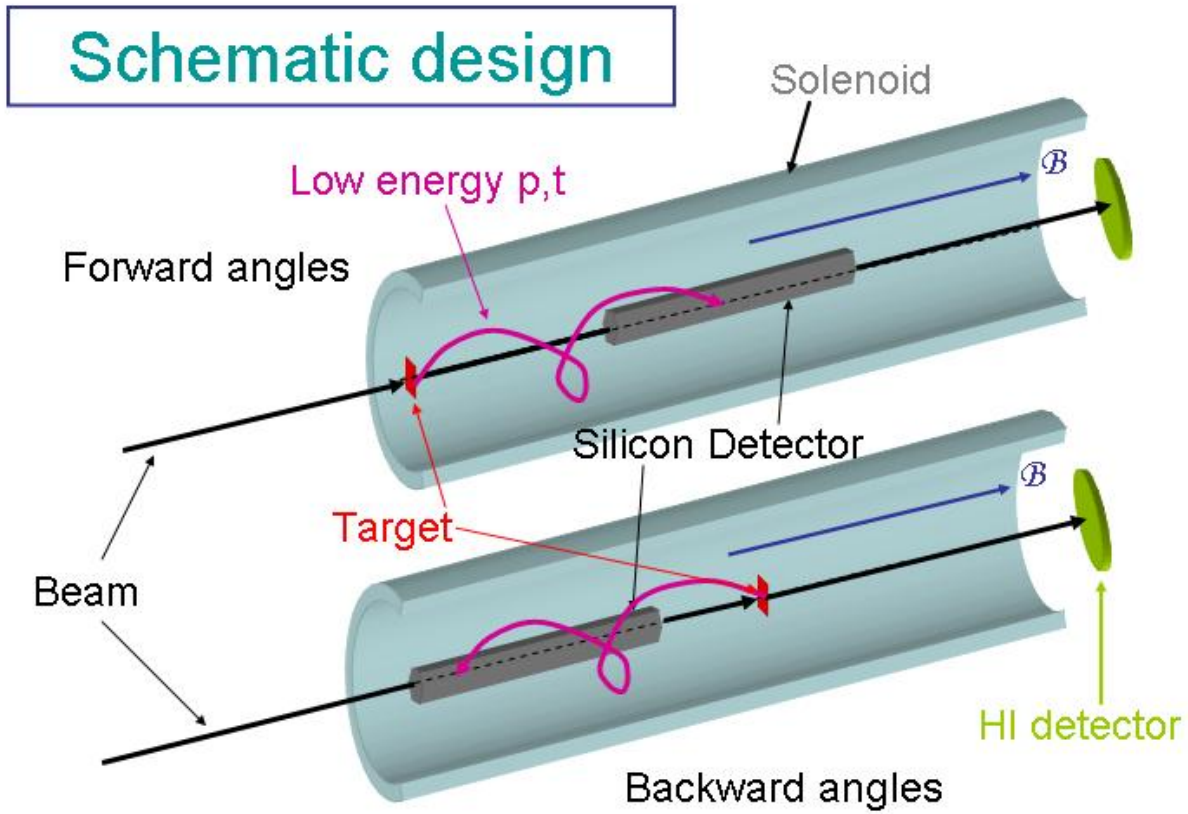


Fig. I-62. Outline of a solenoid, shown for detection in the forward or backward hemisphere. The grey block represents the detector for the light reaction products: it is position sensitive in the axial direction. The green disk represents the detector for the beam-like particle from the reaction.

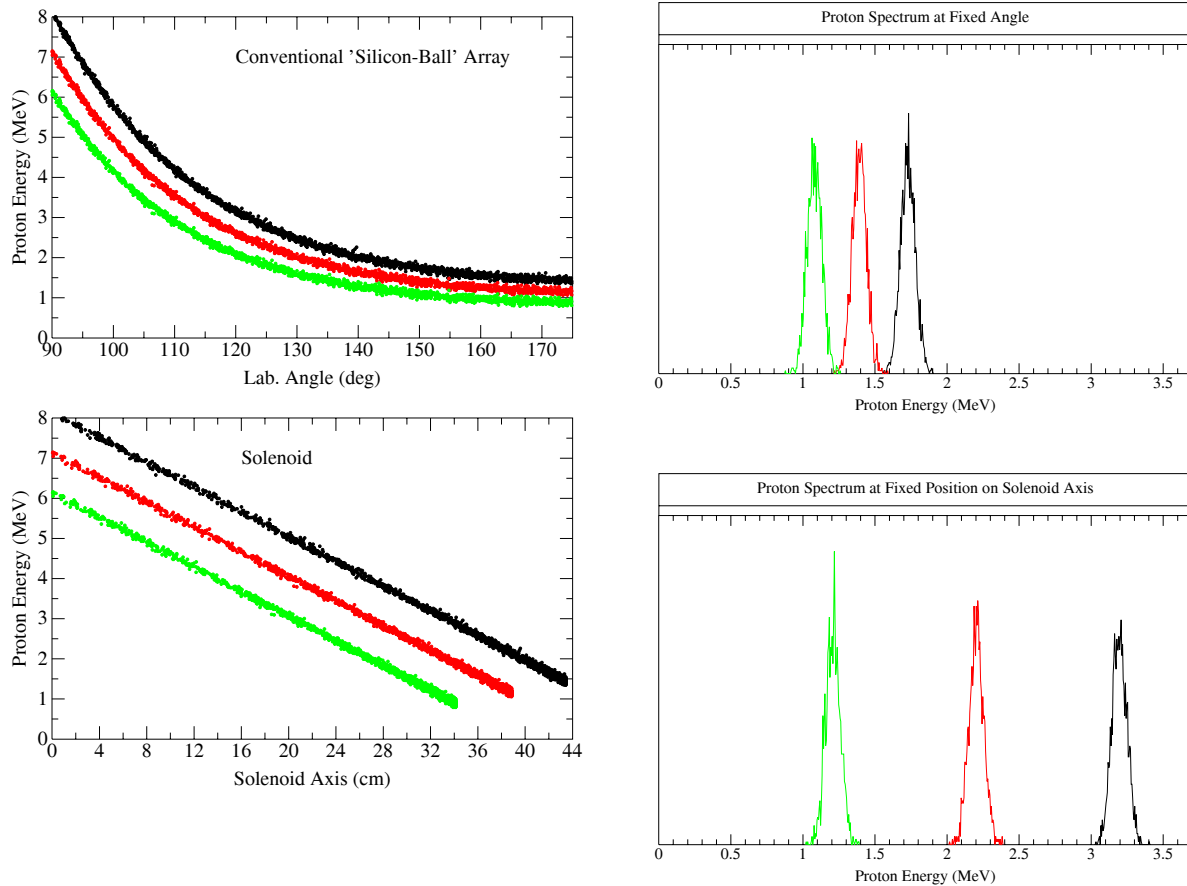


Fig. I-63. Proton energies expected from three hypothetical states at 0, 1 and 2-MeV excitation energy from the  $^{132}\text{Sn}(d,p)$  reaction as a with finite resolution folded in. On the top left are the energies as a function of laboratory angle in the backward hemisphere, corresponding to forward (in the center-of-mass system) on the bottom as a function of distance along the solenoid axis. On the right are pulse height spectra at a fixed angle, on top, and at a fixed distance along the solenoid axis on the bottom.

#### h.4. Progress at the Advanced Penning Trap System (N. D. Scielzo, G. Savard, B. J. Zabransky, J. A. Clark\*, A. Levand, K. S. Sharma\*, J. Wang\*, Y. Wang, and Z. Zhou)

The use of radioactive ions held in an ion trap for nuclear  $\beta$ -decay experiments should allow improved measurements of angular correlations. Constraints on interactions beyond the dominant  $V$ - $A$  terms were placed by  $\beta$ - $\nu$  correlation measurements in a few nuclei. However, contributions from scalar and tensor interactions as large as 10% of the vector and axial-vector terms are not excluded. Radioactive ions held in an ion trap are a nearly ideal source of activity for the next generation of  $\beta$ -decay experiments. Following  $\beta$ -

decay, the recoiling daughter nuclei (with energy  $\sim 100$  eV) emerge from the source without scattering so their momentum can be studied unperturbed. The loading of the ion trap is efficient and selective, and the ions can be confined in a volume of  $\sim 1$  mm.<sup>3</sup> The techniques are applicable to ions of any element, allowing isotopes with the optimal decay properties to be selected for study.

The Advanced Penning Trap (APT) will make use of the existing Canadian Penning Trap (CPT) injection system that can produce low-energy beams of any isotope produced by ATLAS. A schematic of the APT system is shown in Fig. I-64. A quadrupole deflector will soon be installed to direct ions into the isobar separator Penning trap of the APT line. With a magnetic field of 7 Tesla, this Penning trap should have a mass resolution exceeding  $10^5$ , allowing effective cleaning of contaminants. Ions collected in the Penning trap can then either be loaded into the linear RFQ trap

or returned to the existing CPT transfer line for injection into the CPT. The bi-directional ion flow requires diagnostic systems that consist of additional quadrupole deflectors that can direct ions into MCP and Si detectors that are off to the side. The ion optics and loading parameters to be used were determined through simulations of the apparatus using SIMION.

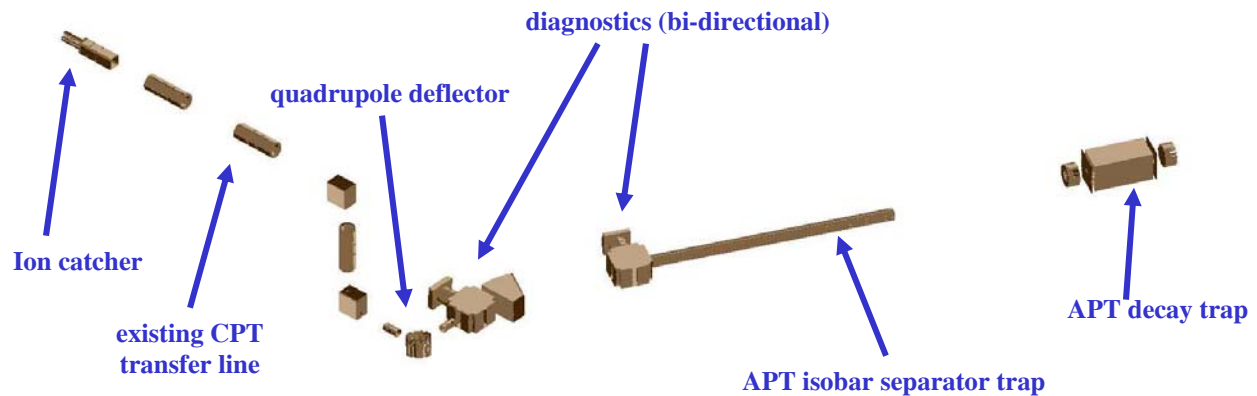


Fig. I-64. Elements used for ion transport. Using SIMION, the optimal settings to load ions from the ion catcher into the APT decay trap were determined.

The APT decay trap is an open geometry RFQ trap that allows four sets of charged particle and  $\gamma$ -ray detectors to be brought close to the trapped ions. Each set of detectors will have a total solid angle of  $\sim 20\%$  of  $4\pi$ . Figure I-65 shows a cross section of the center of the linear RFQ trap. The trap will be cooled with  $\text{LN}_2$  so that the trapped ions can be cooled to 77 K by  $^4\text{He}$  buffer gas at a pressure of  $10^{-6}$  torr. Only UHV compatible materials are being used so that contaminants in the gas will be minimized. This measure should limit ion loss from the trap. The

electrode support structure and detector mounts were designed so that the detectors and electrodes can be positioned to a precision of  $\sim 0.1$  mm. All four Si detector telescopes (consisting of one 300  $\mu\text{m}$  thick DSSD and three 1-mm thick planar detectors) were constructed with ceramic mounts and were tested at 77 K. Two 80% p-type HPGe detectors with excellent resolution (FWHM  $\sim 1.7$  keV at 1.33 MeV) were purchased. The RFQ trap is designed and assembly will begin shortly.

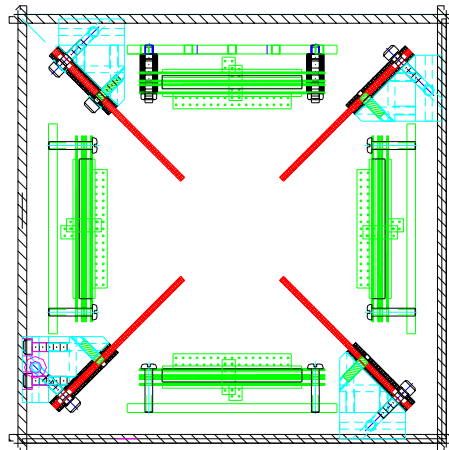


Fig. I-65. Cross-section of center of trap. In red are the electrodes that provide radial confinement through RF fields. Axial confinement is obtained by having two other sets of electrodes (one set above the page and one below the page) that have a positive DC voltage relative to the center set. An HPGe detector (not shown) will be placed behind each silicon detector telescope (shown in green).

The first experiment with the APT system will be a measurement of the  $\beta$ - $\nu$  correlation coefficient,  $a$ , in  $^{14}\text{O}$ . In superallowed  $0^+ \rightarrow 0^+$  Fermi decays, deviations of  $a$  from the Standard Model prediction would be indicative of a scalar component of the weak interaction. By detecting  $\beta$ - $\gamma$  coincidences, the momentum of the recoil nucleus can be inferred from the Doppler shift of the  $\gamma$ -rays. Figure I-66 shows a

Monte Carlo simulation of the different Doppler shift signatures for  $a = 1$  and  $a = -1$  when the  $\beta$  and  $\gamma$ -ray strike detector pairs separated by  $180^\circ$  (red) and  $0^\circ$  (blue). The superallowed  $0^+ \rightarrow 0^+$  Fermi decay best suited for this experiment is that of  $^{14}\text{O}$  because of the nucleus' low mass, half-life of 70.6 s, and large branching ratio (99.3%) to a 2.3 MeV  $\gamma$ -ray.

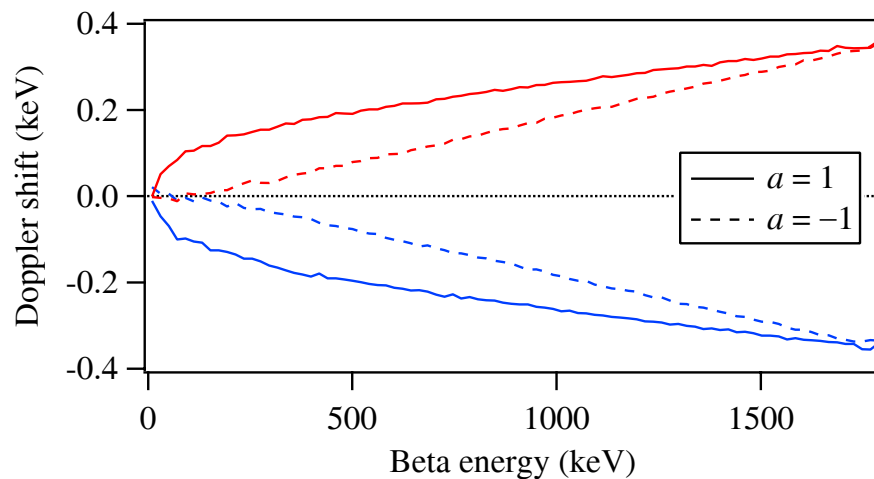


Fig. I-66. Monte Carlo simulation of the Doppler shift of 2.313 MeV  $\gamma$ -rays from  $^{14}\text{O}$   $\beta$ -decay assuming realistic detector geometries and ideal detector resolutions. The red curves are for when the  $\beta$  and  $\gamma$ -rays hit detectors  $180^\circ$  apart and the blue curves are for when the detectors are  $0^\circ$  apart. For detector pairs separated by  $90^\circ$ , the Doppler shift is zero.



We estimate that  $10^5 - 10^6$   $^{14}\text{O}^{1+}$  ions can be loaded into the trap. The efficiency for  $\beta$ - $\gamma$  coincidences is  $\sim 0.2\%$ , allowing a statistical uncertainty of  $0.5\%$  to be obtained in 0.5 - 5 days of beam time. Potential systematic effects are being investigated using a Monte Carlo simulation that includes the full  $\beta$ -decay kinematics and the source and detector geometry. Detailed GEANT4

simulations of the system and detectors are underway. We believe the systematic uncertainty can be limited to less than  $0.5\%$  with careful determination of the Si telescope and HPGe detector response and positioning, as well as trapped ion distribution.

We anticipate the first  $^{14}\text{O}^{1+}$  ions to be loaded into the APT at end of 2004.

\*University of Manitoba, Winnipeg, Manitoba.

### **h.5. Developments of the Wiener-Based “Scarlet” Data Acquisition System (K. M. Teh)**

For some time there has been a need for a new, flexible, inexpensive data-acquisition system for both “online” and “offline” experimental applications. We are developing a system with a compact PC embedded in a CAMAC module (the PICA system), and in parallel built a system using small rack mount PCs and a commercial PCI-CAMAC interface from Wiener Systems. The advantage of the latter arrangement is that it can be immediately deployed, it allows full development of the front-end acquisition software, its interface with the ROOT sorting and visualization software, and the design and deployment of the “onenet” network in the experimental areas.

Software development of the SCARLET data acquisition system was completed last year. At present, there are three SCARLET systems deployed, primarily for off-line work, in the G-wing germanium strip detector laboratory, in the F-wing APT development

laboratory and at ATSCAT where new gas detectors are being tested for Notre Dame. A fourth system is being assembled. Progress is being made in extending the system to allow multiple CAMAC crates and to generalize the system to allow the use of VME crates. Effort is now underway to deploy the SCARLET system in production mode. Production deployment of a new data acquisition offers us the opportunity to rethink various aspects of data acquisition and analysis as it is practiced at ATLAS. For example, experimental data are traditionally stored on tape media. Disk storage is an obvious alternative given the availability of relatively inexpensive large disk arrays. Furthermore, it may be more convenient for outside users to retrieve their data via the network. These and other issues are being discussed at the moment so that we can meet the needs of in-house and outside users. Input from ATLAS users will be solicited at upcoming workshops.

### **h.6. Design and Construction of a New Target Wheel for the Planned $^{16}\text{N}$ Experiment**

(X. D. Tang, B. Zabransky, J. Greene, D. Henderson, B. Nardi, K. E. Rehm, I. Ahmad, A. Hecht, C. L. Jiang, E. F. Moore, R. C. Pardo, G. Savard, J. P. Schiffer, S. Sinha, M. Paul, R. E. Segel,\* L. Jisonna,\* C. Brune,† and A. Wuosmaa†)

For a planned experiment to study the beta-delayed alpha decay of  $^{16}\text{N}$  using a new technique a dedicated target chamber was installed at ATLAS (see section I.a.2 of this document). It consists of 2 pairs of back-to-back ion chambers with a target wheel in the middle acting as a common cathode. The  $^{16}\text{N}$  particles produced via the in-flight technique via the  $d(^{15}\text{N}, ^{16}\text{N})p$  reaction enter the new chamber through an absorber cell filled with P10 gas. The pressure in the cell is adjusted so that the  $^{16}\text{N}$  ions are stopped in the vicinity of a  $10\text{-}\mu\text{g}/\text{cm}^2$  thick capture foil. After an irradiation lasting about 15 s the foil is then rotated into the middle of an

ion chamber pair. Extensive measurements with alphas from a  $^{148}\text{Gd}$  source and with  $^{16}\text{N}$  beams were performed. From these tests it became clear that the shape of the alpha spectrum at low energies depends critically on the detailed geometry in the immediate vicinity of the alpha source. For this reason a modified target wheel was designed (see Fig.I-67) which eliminates as much as possible all mechanical obstacles (e.g. screws, collimators, ..) in the vicinity of the capture foil. A first test run is scheduled for later this year.

\*Northwestern University, †Western Michigan University.

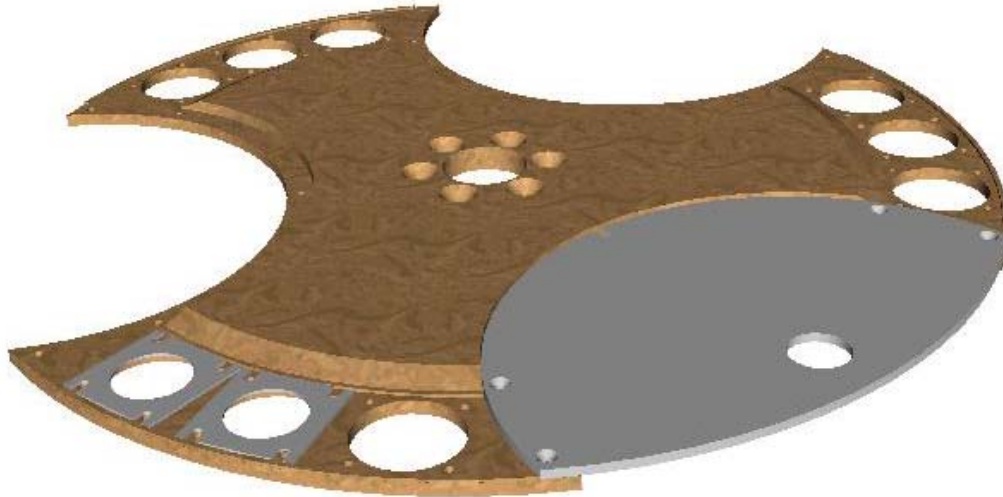


Fig. I-67. New target wheel for the planned  $^{16}\text{N}$  experiment. The  $^{12}\text{C}$  foils will be mounted on the circular opening in the oval-shaped target holders (only one is shown).

**h.7. Transmission Ion Chamber: Design and Application** (B. Shumard, T. Pennington, D. J. Henderson, D. Seweryniak, K. E. Rehm, C. L. Jiang, C. N. Davids, C. J. Lister, B. J. Zabransky, and B. Blank\*)

The Argonne Fragment Mass Analyzer (FMA) proved to be a powerful tool for heavy ion reaction studies and nuclear spectroscopy. A vast range of applications were pursued, from astrophysics research, through radioactive beam preparation, decay spectroscopy, to measurement of reaction cross sections. The device is vital for triggering Gammasphere in the studies of nuclei beyond the proton dripline and in the heaviest systems ever investigated “in-beam”. One of the keys to the FMA success is the development of a modular set of detectors which encompass PPACs, channel plate counters, silicon detector arrays, ion chambers, PIN-diodes and moving tape systems. Frequently, it turned out that combinations of these devices provide the most sensitive measurements. Their construction, based on a common shared mechanical format, allowed considerable flexibility of operation.

For many experiments, the energy loss of ions in gas is critical for measuring the nuclear charge,  $Z$ , both to allow separation of residues and reject scattered beam. This is traditionally done in an ion chamber. However, on occasions the energy loss needs to be measured and then the ions need to be free to pass on to a further detector system. For example, the ions may have an energy loss measurement followed by implantation into silicon, or collection on a tape. To this end a transmission ion chamber was developed that will allow energy loss data to be added to information from other detector systems (Fig. I-68). Two systems are being assembled.

The body of the ion chamber resembles the current “Daresbury” style counter in use at the FMA for some time. Attention was paid to removing all material that is slow to out-gas. To maximize modularity, considerable

thought was dedicated to window design. The counter can be operated without windows, perhaps sharing a common gas volume with a series of PPACs at low pressure. It can also operate with its own entrance and exit windows, both designed to allow the pressure gradient to be positive or negative.

Three projects will immediately use the Transmission Ion Chambers (TICs). One involves seeking the beta decay of  $^{69}\text{Kr}$  in order to investigate the proton unbound daughter  $^{69}\text{Br}$ . A second investigation is to cleanly

identify  $^{101}\text{Sn}$  in order to perform “in-beam” gamma ray spectroscopy. Finally, a program was initiated to investigate far sub-barrier heavy-ion fusion mechanisms. For this latter study a PPAC-TIC-PPAC-TIC-PPAC-IC arrangement was assembled. This sophisticated arrangement allows fusion cross-sections below 1 nb to be investigated. The key to such high sensitivity is overdefinition: measuring both the time of flight of ions and their energy loss cleanly remove all ambiguities.

\*University of Bordeaux, France.

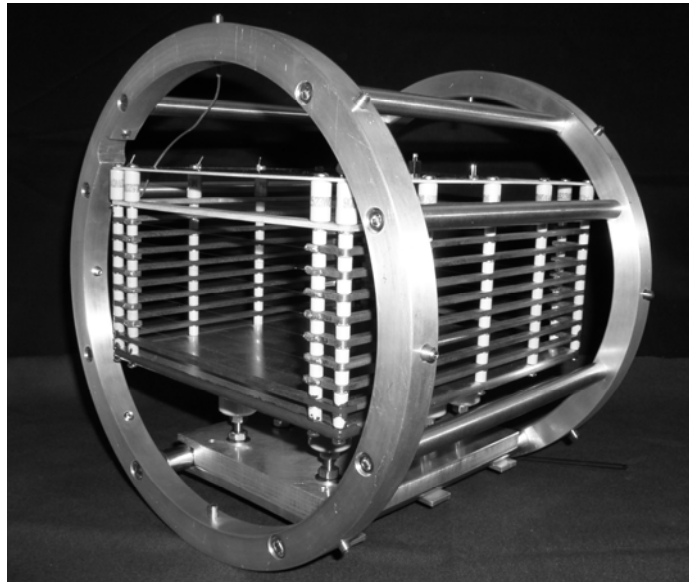


Fig. I-68. The first Transmission Ion Chamber (TIC) dismantled from its vacuum envelope.

#### **h.8. Test Experiment of a Hybrid Detector System at FMA (C. L. Jiang, K. E. Rehm, D. J. Henderson, G. Mukherjee, T. O. Pennington, and D. Seweryniak)**

In a study of heavy-ion fusion evaporation reactions at extremely sub-barrier energies<sup>1,2</sup>, a Fragmentation Mass Analyzer (FMA)<sup>3</sup>, and its focal-plane detector system were used to detect the evaporation residues. The background, due to the scattering of beam particles, restricts the lowest cross sections, that can be measured. Recently, the anode in the first electric dipole of the FMA was replaced by a split anode<sup>4</sup>, and as a result, the background induced by scattered beam particles was greatly reduced. But measurements at even lower background levels are planned in the future.

The focal-plane detector used in the experiment consisted of a parallel plate avalanche counter (PPAC), an ionization chamber (IC) and a surface barrier Si detector. In order to measure even lower cross sections, higher beam currents need to be used, resulting in rather high count rates. Besides the increased background, radiation damage of the Si detector can also become a serious problem. We plan to develop a hybrid gas detector system to avoid the radiation damage problem and to further reduce the background.

The pile-up effects constitute the main part of the background. The character of pile up in the timing signal is very different from the pile up of the E (or  $\Delta E$ ) signals. We plan to build a detector system consisting of three PPAC's and three ionization chambers, arranged as PPAC-TIC-PPAC-TIC-PPAC-IC. The first two ionization chambers are of transmission type (TIC)<sup>5</sup>, working at low gas pressure. The last ionization chamber will work at an adjustable higher gas pressure to stop the ions of interest. Each ionization chamber has three anodes. All evaporation

residues will stop before entering the electric field region of the third anode of the last ionization chamber. There are three position signals, four time-of-flight signals, and  $\Delta E$  signals, which can be used to identify the evaporation residues and reduce the background.

A short test experiment with a PPAC-TIC-TIC-PPAC-IC system was recently performed at ATLAS with <sup>64</sup>Ni beam. The remaining component is presently under construction.

<sup>1</sup>C. L. Jiang *et al.*, Phys. Rev. Lett. **89**, 052701 (2002).

<sup>2</sup>C. L. Jiang *et al.*, Physics Division Annual Report 2002, Argonne National Laboratory, p. 85 (2002).

<sup>3</sup>C. N. Davids *et al.*, Nucl. Instrum. Methods **B70**, 358 (1992).

<sup>4</sup>C. N. Davids, Physics Division Annual Report 2002, Argonne National Laboratory, p. 104 (2002).

<sup>5</sup>T. Pennington *et al.*, Physics Division Annual Report 2002, Argonne National Laboratory, p. 105 (2002).

### **h.9. Preparations for the Move of Gammasphere to the APEX Beam Line**

(M. P. Carpenter, C. J. Lister, R. V. F. Janssens, J. E. Rohrer, B. J. Zabransky, and B. G. Nardi)

To maximize the physics potential of Gammasphere at ATLAS we are planning to make Gammasphere movable, so it can either operate with the FMA (as it did during the 1997-2000) campaign), or in "standalone" mode (as it was during the 1995-1997 and 2000-2002 Berkeley campaigns). This move is planned for ATLAS target hall 4 and involves a move of about 4 meters....between the FMA beam line and the beam line where the APEX experiment was constructed.

trench areas needed stiffening to permit the move of the device. A test move of the Gammasphere platform was successfully conducted using a test load of 15 tons of shielding blocks. The biggest challenge appears to be maintenance of the signal infrastructure. The detectors need to be kept cold and with high voltage applied during the move. This essentially demands the physical transition must be complete in less than 8 hours. Detailed plans for the re-routing of LN2 and signal cables were made, and stocks of the needed equipment have been purchased. A safety review of the operation has been done. The move is anticipated for early summer 2004.

Many issues needed to be resolved. We investigated movement by crane, airpads and rollers. Rollers were finally selected on the grounds of cost. The floor and

### **h.10. VME Interface for Gammasphere**

(T. Lauritsen, M. P. Carpenter, and J. Weizeorick\*)

When Gammasphere was first constructed the only auxiliary data (i.e. extra information beyond that from the gamma array) that could be added was entered through a fast ANL-built interface which only supported reading ECL-format data from CAMAC devices. By far the most commonly used devices were LeCroy FERA QDCs. This auxiliary data was then built into the normal data stream, being appended, event-by-event, to the information about gamma rays.

auxiliary data, the approach has limitations. The FERAs have limited resolution and each 16-channel bank can only have one gate. In order to improve the quality of auxiliary data, and specifically to allow new high resolution, high-density, high-speed ADCs to be used a new approach is being developed. This involves building an interface to support VME crates and read VME format modules.

While this system is successful, with some experiments adding hundreds of extra parameters, and nearly 2/3 of all the ANL Gammasphere experiments involving some

Several alternative methods were evaluated for incorporating VME data into the Gammasphere stream. A solution was adopted in which the VME crate(s) will be added to the existing highway that collects all the

gamma-ray data from the existing six VXI crates. An interface module was designed, built, and is being

tested. It is hoped to incorporate this capability into Gammasphere in late calendar year 2004.

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\*Computing and Information Sciences Division, Argonne National Laboratory.

### **h.11. New Data Acquisition System for Gammasphere**

(T. Lauritsen, J. Weizeorick,\* and M. Chromaz†)

The current VME-Based Gammasphere front-end data acquisition system is based on Motorola microprocessors that are no longer manufactured. Consequently, with the future in mind, the Gammasphere community started to develop a new system that will eventually replace the existing front end. The new system was constructed by Mario Chromaz at LBNL and delivered to ANL in November 2003. The new system is based on a PowerPC from CES in a VME crate with one of John Weizeorick's event builders (EB) and two CES memories. The DAQ program running on the PowerPC will read one CES memory over the VME backplane, process the data and write it to an NFS mounted disk, while the EB stores data in the other CES memory. Thus, as opposed to the old DAQ, the new system only has one fast processor that does everything.

The DAQ was somewhat rudimentary at the time of delivery and prone to crashes. The output data format was inconsistent and needed rewriting. The DAQ failed quite often, a fault originally ascribed to do with the data format problem. However, after the format problem was fixed, it soon became clear that there were

more fundamental problems with the new DAQ. The DAQ would fail after 10-50 minutes and it would fail without leaving useful diagnostics to help locate the problem. This started a period of debugging the system. One of the event builders (EB) had a hardware problem which disguised underlying issues. The problem was finally resolved by adding two dummy interrupt-vector-handler routines. Now the system will stay up and running for days – at least with sources in the array.

The current Gammasphere DAQ is controlled via graphical EPICS screens. At present the new DAQ is menu driven from a program that has to be run from the Console of the PowerPC in the VME crate. This is less elegant, and eventually the new system will need to be incorporated into the existing graphics interface. For now, the key functions are driven by have the following menu options. However, the existing system allows the functionality to be expanded to include features like calibrations, histogramming and eventually data storage on disk. These developments are continuing with the goal of switching systems in calendar year 2005.

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\*Computing and Information Sciences Division, Argonne National Laboratory, †Lawrence Berkeley National Laboratory.

### **h.12. Refinements of the FMA Focal Plane Counter: The X-Array** (E. F. Moore, C. J. Lister, R. V. F. Janssens, T. L. Khoo, D. Seweryniak, and C. N. Davids)

In nuclei very far from stability, and in very heavy nuclei, radioactive decay spectroscopy plays a vital role in nuclear structure studies. The substantial decay Q-values and strict decay selection rules often provide access to states that cannot be reached by other means. Detection of the subsequent gamma decay of these states, in  $\alpha$ - $\gamma$ ,  $\beta$ - $\gamma$  and  $p$ - $\gamma$  experiments is often crucial to interpreting the decays and extracting quantum numbers. Unfortunately, the isotopes of greatest interest are usually produced with very low cross-section, so the station for particle-gamma decay studies must be very efficient to be useful. This need for efficiency, plus the fact the nuclei of interest are stopped (so have no Doppler shift) and usually the

decays are of low multiplicity, means the ideal detector system is very different in geometry from current “in-beam” arrays like Gammasphere, Euroball and GASP. It is a multi-layered system, consisting of a fast separator with particle identification, followed by a highly pixilated detector for measuring the decay particles, surrounded by a gamma-array. This outer array must be very compact, in order to achieve the greatest possible efficiency.

At ATLAS, many components are in place for constructing a world-class system. The FMA still leads in proton radioactivity studies and is very useful for heavy-nuclear spectroscopy. Its suite of focal plane

counters allows a variety of decay studies. We are planning a design for the chamber and outer array. For raw efficiency, a close-packed setup using large clover-type detectors is difficult to beat, certainly as a cost-effective arrangement. A MCNP Monte-Carlo simulation of a box arrangement with five counters is more than twice as efficient as Gammasphere for radiation up to 1 MeV. We purchased two clover counters, based on 6 cm crystals (Exogam

configuration) that were delivered, and a third counter is being procured. The crystals are unsegmented, in order to give the best possible resolution, and to reduce the cost. When assembled, this arrangement will be competitive with the GREAT array at Jyväskylä; our enhanced gamma-efficiency offsetting against the efficiency of their gas-filled separator. We anticipate a competitive system will be operational early in calendar year 2005.

### **h.13. Polarization of Gamma Rays Following $^{227,228}\text{Th}$ $\alpha$ -Decay (N. J. Hammond, C. J. Lister, and G. D. Jones\*)**

An offline experiment was set up to calibrate the “Mark IV” detector for measuring the linear polarization of gamma rays. The calibration exploited the high alignment that can occur following alpha decay. The standard case is for even-even  $^{228}\text{Th}$ , a 0-2-0 correlation which leads to maximally polarized photons. Figure I-69 shows the calibration setup. It involved two alpha particle counters mounted at  $90^\circ$ , so two orthogonal reaction planes could be defined. Further, the whole chamber could be rotated  $90^\circ$ , allowing further tests of systematic effects.

Extensive analysis was performed. Using the ring of “second neighbor” pixels to define the azimuthal scattering angle and energy sharing to define the Compton angle, a beautiful correlation could be observed, that is shown in Fig. I-70. This asymmetry is more than 70% of that predicted for point detectors. Polarimeters have a “figure of merit” combining their

efficiency with their polarization sensitivity. Our planar polarimeter has the best figure of merit ever reported, as it has sensitivity as good as any previous device combined with an efficiency that is an order of magnitude higher than previous single crystal polarimeters. A NIM paper is being finalized describing this calibration.

We are in process of analyzing the decays from odd-A  $^{229}\text{Th}$ . Here, the analysis is more complex as most transitions have mixed multiple ratios. Further, the large solid angle of the detector averages over many scattering angles, so detailed analysis is needed. This work is in progress, though considerable asymmetries are observed. Qualitatively, the observations agree with many assignments suggested in the literature. The challenge is to make these polarization determinations absolute and use them to eliminate existing spin and mixing ratio hypotheses.

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\*University of Liverpool, United Kingdom.

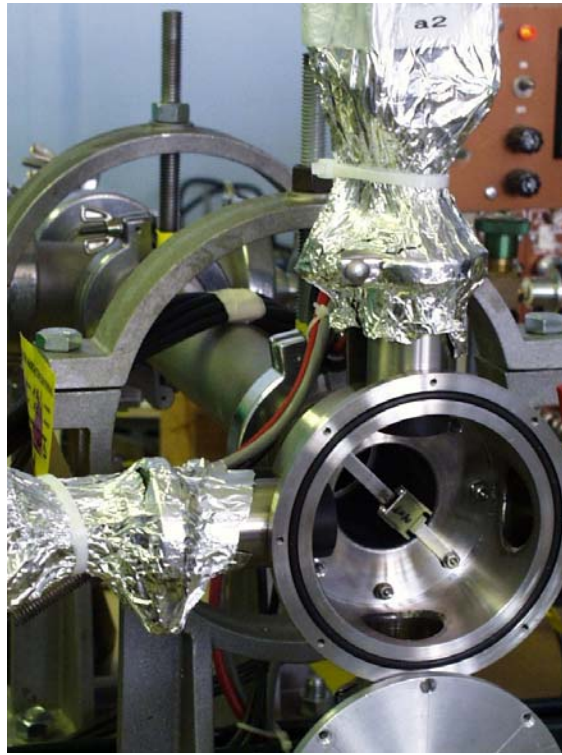


Fig. I-69. The chamber used for polarimeter calibration. An  $^{228}\text{Th}$  source was placed in the center of the circular chamber, and alpha particles detected in silicon surface barrier detectors when emitted vertically or horizontally. The chamber was then sealed and evacuated. Gamma rays emitted out of the plane of the photograph were detected in an  $85 \times 85$  mm planar position sensitive HpGeDSSD that was mounted immediately behind the cover plate.

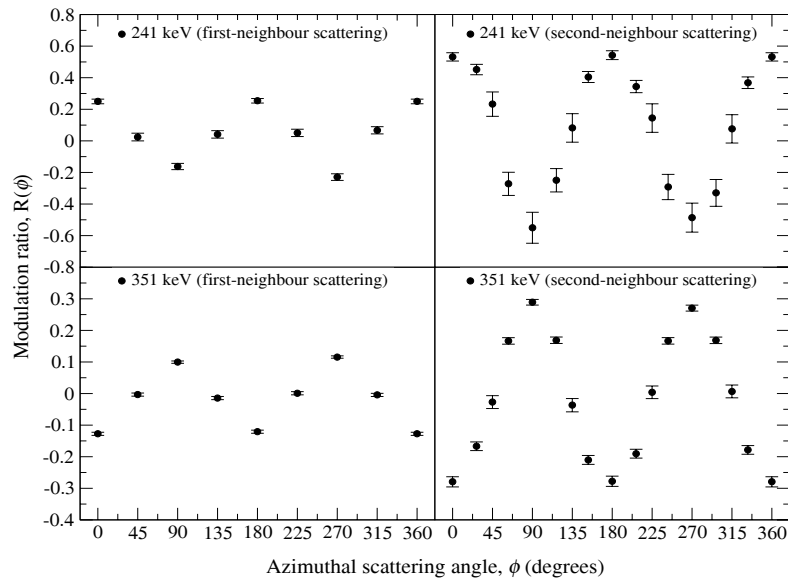


Fig. I-70. Measured gamma ray asymmetries measured using the HpGeDSSD. The data are for 241keV and 351keV radiation (top and bottom) and using “nearest neighbor” and “second neighbor” analysis (left and right, respectively).

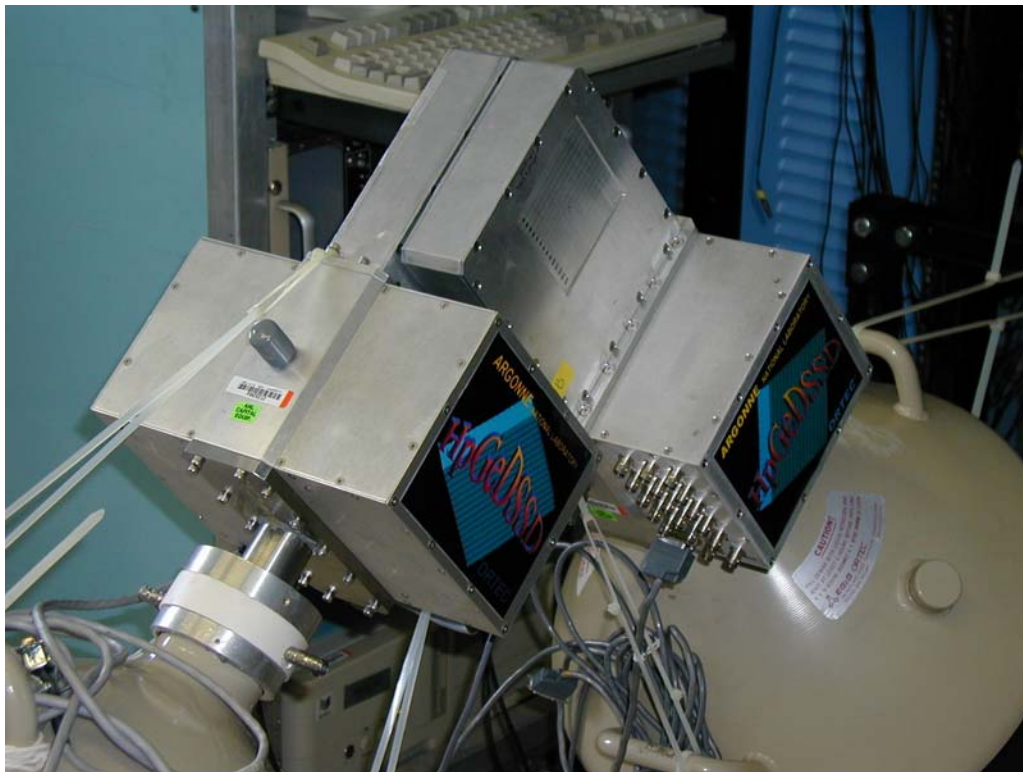
**h.14. Construction of a Compton Camera** (F. G. Kondev\* and C. J. Lister)

Hyperpure planar wafer gamma ray detectors have many applications in nuclear structure physics, especially in correcting for high Doppler shifts and in measuring the linear polarization of gamma rays. However, in addition, these detectors are very useful in “spin-off” applications.

We leveraged our investment in planar germanium detectors to investigate gamma ray imaging and to construct a Digital Compton Camera (Fig. I-71) to

search for sources of radioactivity in the environment. To this end we applied for and have been granted an Argonne LDRD grant to develop Camera Technology. We also worked in collaboration with the Naval Research Laboratory (NRL) in Washington, DC to develop digital algorithms to improve spatial resolution. These projects are in their infancy, but should lead to new research directions and collaborations in calendar year 2004.

\*Nuclear Engineering Division, ANL.



*Fig. I-71. A prototype Compton Camera employing two 90 × 90 × 20 mm germanium wafers.*

**h.15. Development of HpGeDSSDs** (N. Hammond, C. J. Lister, P. Wilt, S. J. Freeman,\* and P. Chowdhury†)

We are continuing to investigate the properties of large area planar detectors and identify definitive tests to characterize their performance. This is much more difficult than for normal germanium detectors, as there are strong correlations between the signals, both

between neighboring strips on each side of the counters, and between the front and back electrodes. The large data sets collected for measuring gamma-ray polarization (see section I. h.13.) have allowed new insights to be gained. For example, use of single



gamma rays can allow tests of charge collection. For the boron contacts of our Mark IV detector, selection of “two-strip” events reveal almost perfect charge sharing following Compton scattering, whereas for the lithium contacts the energy sharing correlation shows three distinct components; one due to true Compton scattering between strips, a second that corresponds to artificial energy sharing that turns “one-strip” interactions into apparent “two-strip” events, and a third type that involves inducing false double firing and loss of total charge. The latter events involving loss of charge cause tails in the “add-back” energy peaks. They arise from inside the detector crystal itself, apparently from interactions near the lithium strips.

We are investigating procuring a detector which is free of these shortcomings. One possibility is a detector with amorphous germanium contacts, both of p- and n-type. Detectors of this type are manufactured commercially, but do not seem to have sufficient longevity for practical use; after some months the

contacts fail. An alternative, using very thin lithium contacts, without intervening sawcut grooves between strips, may also remedy some of the shortcomings found in our current detectors but retain the problems of lithium migration and sensitivity to vacuum contamination. We are trying to procure detectors of modest size and strip pitch of both types to investigate the relative merits. We are also collaborating with some SBIR-funded groups to try to develop new technologies.

An electrical accident led to damage to the Mark IV detector with all 28 preamplifiers blowing their front-end FETs. The 14 “warm-side” preamps were quickly repaired, as the critical components lie outside the vacuum envelope. However, the replacement of the 14 “cold-side” FETs involved extensive in-cryostat work. This repair was successful. It allowed us to start developing mechanical designs for our own cryostat that is much more compact than the setup we currently use.

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\*University of Manchester, United Kingdom, †University of Massachusetts-Lowell.

