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# The TIARA Array for the Study of Nucleon Transfer Reactions

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**Abstract.** The TIARA array is designed for the study of nucleon transfer reactions in inverse kinematics, using radioactive beams. Crucially, the energies of coincident gamma-rays will be used to give better energy resolution for final excited states than can be achieved by measuring the energies of particles alone. Thus, an extremely compact array of position sensitive silicon strips will fit inside an array of four segmented clover EXOGAM Ge detectors which can each be mounted as close as 50mm from the target. Approximately 90% of 4π is covered by 400μm silicon detectors manufactured using 6-inch technology. Particle ID is by the kinematical correlation between the angle and the deposited energy, measured in coincidence with the beam-like particle recorded near zero degrees. Construction will be complete early in 2003 and the array will be deployed initially at GANIL, in front of the VAMOS spectrometer. An early application will be the reaction d($^{56}$Ni,$^{55}$Ni)t.

## INTRODUCTION

The application of “traditional” nucleon transfer reactions such as (p,d), (d,p), (d,$^3$He), etc. to studies using radioactive beams represents a potentially vast field of applications using radioactive beams. Of course, the kinematics needs to be inverted, with the p or d becoming the target. This simple change has significant implications for the experimental setup, if a reasonable resolution for excited state energies in the final nucleus is to be retained.

## TRANSFER & RADIOACTIVE BEAMS

Nuclear spectroscopic studies using single-nucleon transfer reactions have recently become feasible, with the availability of beams of ~$10^4$ pps [1,2]. The experimental challenges have been assessed in some detail [3,4]. Briefly, except for some cases with light projectiles (A<20, say), it is advantageous to measure the scattered target-like particle (p, d, t, $^3$He) to obtain accurate excitation energies with the best resolution [3]. Even then, for typical realistic experimental parameters, the resolution is limited to ~300 keV. However, an interesting feature of the inverse kinematics [5] is that the energy-angle systematics of the target-like particle have very little dependence on the mass and energy of the beam, so long as the mass is large compared to the target (p or d) and the Q-value is not too large. This implies that a general purpose particle array can be constructed. Furthermore, for the study of bound states, it is possible to measure gamma-ray decay energies in order to improve the resolution. The challenge is to achieve a sufficiently high efficiency for gamma-ray detection whilst recording the target-like charged particles at all important angles.

## PHILOSOPHY OF THE DESIGN

The TIARA design is based around the use of a compact array of segmented Ge gamma-ray detectors, in coincidence with silicon-strip particle detectors. To achieve the required full-energy peak efficiency, of around 20%, requires either a very large gamma array or else a very compact array. The practicalities of mounting all the particle detectors (and beam-tracking systems) close to the target also place constraints on the arrangement. For example, the radioactivity of any scattered beam poses potential problems [6]. Thus, a compact array emerges as an attractive choice. TIARA uses EXOGAM segmented clover Ge detectors [7,8] with their front faces only 50 mm from the target. Four of these detectors can be mounted around the target, perpendicular to the beam, in a "compact cube" geometry. The electrical segmentation of the Ge clovers is sufficient to limit the Doppler broadening of peaks (due to the velocity ~0.20*c* of the emitting nucleus, and the finite solid angle of the segment) to ~30 keV at 1.332 MeV. This ultra-compact geometry places extreme constraints on the detectors that must go in between the Ge and the target. For these detectors we have chosen to use an octagonal barrel made from silicon resistive strip detectors, position sensitive along the axial direction. The "compact cube" also allows the silicons spanning forward and backward angles beyond the barrel to be placed further from the target, so that the radioactivity from scattered beam particles can be effectively shielded from the Ge detectors. A clear disadvantage to such a compact design is the difficulty of inserting and changing targets. Since the most convenient choice of target for p or d is a plastic polymer - $(CH_2)_n$ - then there will be a need to take data with a carbon target to quantify background reactions. Compounding this problem, the design was required to be compatible not only with ISOL beams but also fragmentation beams, for which a beam spot of 10mm diameter is not unusual. Finally, the beam-like particle should also be identified, at least by atomic number. This will be achieved using the VAMOS spectrometer [9]. For VAMOS, the entry quadrupole is located just 400mm from the target. Thus, the main challenges in the design were defined: to achieve an extremely compact silicon array, with position resolution better than 1° in scattering angle, with almost full solid angle coverage, but with the possibility to insert and change targets, and to fit together with the Ge detectors in front of VAMOS.

The basic principle of the TIARA approach, using the gamma-ray energy to recover good resolution, has been demonstrated to work using a weak beam that simulated radioactive beam conditions [10]. An additonal benefit of this method is that the limits placed on the target thickness by the resolution requirements (cf. [3] ) can sometimes be relaxed, thus relying entirely on the gamma-rays to identify particles with particular excited states. The thicker target can effectively compensate for the losses due to gamma-ray efficiency, so that the factor of 10 improvement in energy resolution has no net cost in statistics.

## DETAILS OF THE DESIGN

The main components of TIARA are: vacuum vessel, silicon barrel array, annular silicon arrays, target assembly, tracking detectors, electronics and data acquisition. These are now described in turn. All the silicon detectors are manufactured by Micron [11].

### Vacuum Vessel

The main vessel has an overall length of 520 mm and an outer diameter of 528 mm at each end, reducing to just 85 mm diameter along a 100 mm length in the central region around the target. Thus, it is shaped like a giant bobbin, with its axis being the beam axis. This allows the Ge detectors to be placed as close as 45 mm to the target, which is the closest possible for the EXOGAM "compact cube" with the front-most active shields removed. In the central region, the walls of the aluminium vessel are 2mm thick, increasing to 4 mm for the rest of the vessel. The vessel can be opened at either the front- or back-end flange. Opening at the front allows the vessel to be rolled back along rails and gives access to the forward-mounted silicons and the barrel array, which are all mounted off the front end-plate. For this procedure, the mounting frames for the Ge detectors are rolled away to either side, along further rails. Alternatively, opening at the back allows the vessel and the Ge array to stay in place and the backward-mounted silicons and targets can be slid out along the rails.

### Silicon Barrel Array

These silicon detectors have been designed to form an octagonal barrel of 8 detectors, each mounted on its own printed circuit board. The silicon is 400 μm thick, which is the thickest presently available in 6-inch diameter wafers. The side walls of the board are just 1.15 mm wide, to minimise the loss of azimuthal coverage, whilst the end walls are 0.5mm wide and do not protrude above the silicon. Each detector wafer is 96.8 mm long by 24.6 mm wide, and includes 4 strips arranged longitudinally with a 5.6 mm pitch (and 100 μm separation) on the junction side, which faces the target. Each strip is resistive (4 kΩ) with a signal taken from each end, and the signals from the rear end are tracked along the edge of the silicon itself, to the front end. The 8 signal pads are bonded to plated-through holes in the side walls of the board, and track to cable connections on the back of the board. The ohmic side of the wafer has a connection which goes directly to ground. All signals are taken out on 1 mm diameter micro-coaxial cables bonded to the board. The 8 detectors are mounted in a support frame using a special jig, and the barrel is mounted symmetrically around the target when in operation. It is supported from the front end-plate of the vacuum vessel. The angular range spanned is from approximately 36º to 144º, subtended at the target. The expected resolutions in position and energy are < 1 mm and < 50 keV.

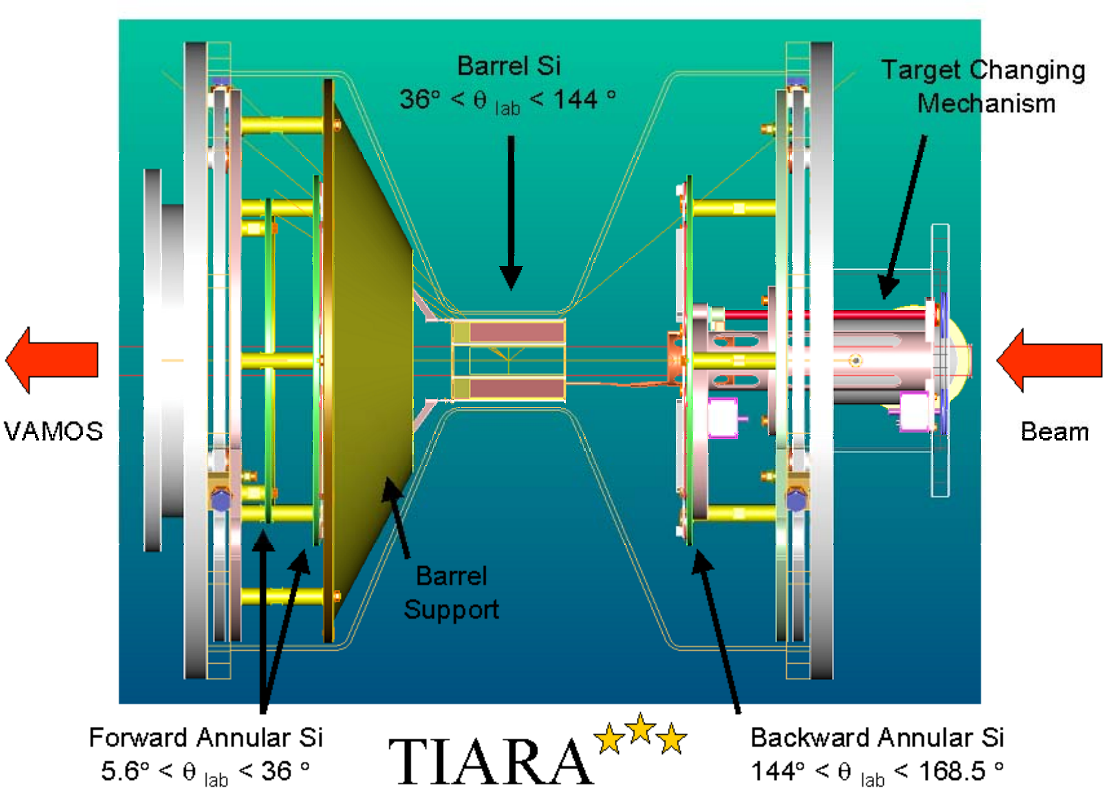


**FIGURE 1.** Side view of the TIARA chamber and array. At the barrel position, the chamber is 85 mm in diameter to allow close-placed Ge detectors. The diameter at the ends is 528 mm. The target carousel is behind the backward annular Si array.

## Annular Silicon Arrays

The forward and backward arrays each comprise 6 separate double-sided strip detectors on their own boards. The 6 detectors form a complete annulus, covering the range from 11.5º to 40.2º. These detectors were first developed at Oak Ridge for the HyBall array [12]. Their shape is roughly trapezoidal with an outer length of 130 mm, inner length 30 mm, and sloping sides of 115 mm. Once again they are made using 6-inch technology and limited to 400 μm thickness. The front of each detector is divided into 16 ring-sections, and the back into 8 azimuthal sectors. At the most forward angles, a further monolithic annular detector can be used to span the range 5.6º to 12.5º if required. The energy resolution is similar to the barrel (50 keV).

## Target Assembly and Tracking

Four targets can be mounted on a carousel that is situated behind the backward annular array. Any target can be selected and moved into the reaction position using a remotely controlled arm. The arm supports the target from below and moves longitudinally. For rigidity, it includes a cylindrical tube through which the beam must pass. Two beam-tracking detectors are included in the design: one placed immediately before the target changing assembly, one placed ~2 metres before the target. These, as well as the associated position calibration masks, can be retracted from the beam. They are gas-filled drift chambers developed by LPC Caen from an original GANIL design.

## Electronics and Data Acquisition

The decision was made, for this project, to use conventional commercial electronics in the first instance. The signals are connected via individual coaxial cables to preamplifiers mounted outside of the vacuum. The preamplifiers were developed by Paisley and Birmingham Universities, based on an original design from the CHARISSA collaboration. They have a conversion gain of 10 mV/MeV(Si) and are housed in 16-channel NIM modules. The linear amplifiers are commercial CAEN units, in 16-channel NIM modules, and are remotely controllable. Trigger logic and timing is derived using leading-edge discriminators in remotely controlled 16-channel VME modules.

The data acquisition system (DAQ) for TIARA can use either stand-alone software developed in Daresbury, or standard GANIL acquisition software. The hardware for the two is common, and is VME based. Signal amplitudes are digitized using 32-channel commercial VME ADCs, supplemented by 32-channel VXI ADCs developed by GANIL. Timing information for all channels is also recorded with VME TDCs. The system provides > 300 channels. Of course, the data from TIARA need to be combined with data from the gamma-ray detectors (EXOGAM DAQ) and the beam-like particle detector (say, VAMOS DAQ). This can be accomplished in the GANIL system using an in-house module called CENTRUM which allows time-stamping. Each of the three separate DAQs broadcasts time-stamped data which is then merged in real time by an event-building processor, and re-broadcast. The resultant, single merged data stream is written to tape for subsequent analysis and can be sampled by an on-line analysis programme. All of the signal processing and acquisition electronics is situated in the target area.

## OUTLOOK

The main components of TIARA have now been manufactured, and installation at GANIL is scheduled for January 2003. The first experiment planned to take place, after tests are completed, is a study of hole-state energies at the quasi-shell closure $^{56}$Ni via the reaction $^{56}$Ni (d,t)$^{55}$Ni (in inverse kinematics).

TIARA is optimized for the study of transfer reactions leading to bound states. For the study of unbound states, especially in light nuclei, an array such as MUST or MUST II [13] can be used. MUST has bulkier detectors but provides full identification of particles. In fact, TIARA has been designed in cooperation with the MUST collaboration, and the vessel was designed to be able to accommodate MUST II in the forward or backward hemispheres. It is worthwhile to note that the TIARA array could also be used to study fusion-evaporation reactions (with identification of evaporated particles according to deposited energy, cf. [6] ). It is also well adapted to the study of sub-barrier coulomb excitation.

## ACKNOWLEDGMENTS

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## REFERENCES

1. Rehm, K.E., *et al.*, *Phys. Rev.* **C80**, 676 (1998)
2. Winfield, J.S., *et al.*, *Nucl. Phys.* **A683**, 48 (2001).
3. Winfield, J.S., Catford, W.N. and Orr, N.A., *Nucl. Instrum. Methods* **A396**, 147 (1997)
4. Lenske, H., Schrieder, G., *Eur. Phys. J.* **A2**, 41 (1998)
5. Catford, W.N., *Nucl. Phys.* **A701**, 1 (2002); *Acta Physica Polonica* **32**, 1049 (2001)
6. Catford, W.N., *et al.*, *Nucl. Phys.* **A616**, 303c (1997)
7. Catford, W.N., *J. Phys.* **G24**, 1377 (1998)
8. Simspon, J., *et al.*, *Acta Physica Hungaria: Heavy Ions* **11**, 159 (2000)
9. Savajols, H., *et al.*, *Nucl. Phys.* **A654**, 1027c (1999)
10. Grund, C., *et al.*, *Eur. Phys. J.* **A10**, 85 (2001)
11. Micron Semiconductor Ltd., Lancing, Sussex, UK.
12. Galindo-Uribarri, A., ORNL, private communication.
13. Blumenfeld, Y., *et al.*, *Nucl. Instrum. Methods* **A421**, 471 (1999); Pollacco, E.C., these proceedings.