First Results with the Microball and Gammasphere

D.G. Sarantites⁽¹⁾, P.-F. Hua⁽¹⁾, D. LaFosse⁽¹⁾, M. Kororija⁽¹⁾, J. Elson⁽¹⁾, J.T. Hood⁽¹⁾, C. Baktash⁽²⁾, C. Gross⁽²⁾, H.-Q. Jin⁽²⁾, D.W. Stracener⁽²⁾, I.Y. Lee⁽³⁾, A. Macchiavelli⁽³⁾, B. Cederwall⁽³⁾, P. Fallon⁽³⁾, W. Rathbun⁽³⁾, F. Christando⁽⁴⁾, E. Landulfo⁽⁴⁾, J.X. Saladin⁽⁴⁾, J. Döring⁽⁵⁾, and S.L. Tabor⁽⁵⁾

⁽¹⁾ Department of Chemistry, Washington University, St. Louis, Missouri 63130

⁽²⁾ Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831

⁽³⁾ Lawrence Berkeley Laboratory, Berkeley, California 94720

⁽⁴⁾ Physics Department, University of Pittsburgh, Pittsburgh, Pensilvania 15260

⁽⁵⁾ Physics Department, Florida State University, Tallahassee, Florida 32306

The Microball, an improved 4π multi-detector array, was used recently in conjunction with Gammasphere in three experiments. Highlights of the first results are presented here. The Microball consists of 95 CsI(Tl) scintillation detectors with individual Si photodiode readout, arranged in 9 rings. In these first experiments the Microball performed as designed, but the results in new physics exceeded our expectations. We can say with certainty that by its powerful channel selection the Microball enhanced the performance of Gammasphere by *one full coincidence fold*. This was possible for all exit channels involving charged particle emission, with increasing performance benefit as one progressed to lighter reaction systems.

Below we summarize the essential characteristics of the Microball and give some performance benchmarks. A detailed description of the Microball will be given in Ref. [1]. The essential features of the signal processing has been presented in a IEEE meeting [2].

The Microball has the following design and performance characteristics :

- (1) Excellent (p , d , t , ^3He , and ^4He) particle identification (PID) resolution down to low energies.
- (2) Large solid angle coverage (geometric coverage $\simeq 98\%$ of 4π).
- (3) Low mass (540 g) that degrades the peak-to-total ratio of the Ge detectors from 54% to 49% for ^{60}Co .
- (4) Good charged particle energy resolution (2.7% for 8.78 MeV α 's).
- (5) Sufficient segmentation that increases at the forward angles. This allows angular distribution measurements to be made and helps equalize the counting rate with angle.
- (6) Good counting rate stability (much better compared to the Dwarf Ball system [3] with PMT's). No gain shift corrections were necessary for PID between protons and alphas.
- (7) It keeps up with the high rates of Gammasphere and suffers *smaller* pile-up losses than Gammasphere.
- (8) The signals are processed by 6 16-channel modules that include: pole zero correction, base line restoration, constant fraction discriminators, multiplicity counters, pile-up rejection, time-to-FERA converters, computer controlled output inspection signals, and computer controlled threshold and gain setting.
- (9) For digitization 18 FERA ADC modules are used. The entire electronics setup is very compact. It provides processing for 288 parameters and fits into 2 CAMAC crates with an additional NIM bin for the trigger gates.
- (10) For data acquisition in the experiments with the early implementation of Gammasphere we adopted the approach of the MSU 4π group. The Microball signals were

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

processed by reading the 18 FERA modules (6 for energy, 6 for PID and 6 for timing). The Gammasphere and Microball information was read via the ECL bus of the ADC's of both systems. A transputer system controlled the FERA-Faucet-Maier module and the Memory unit where the event data were buffered. Blocks of 4 kB were transferred to a Sun Spark station, which wrote the events on tape and placed them on the ethernet for two other VMS Vax stations to histogram and monitor during the run.

Beam tuning was done with an optical fiber periscope that permitted rapid focussing without removing any element from the Microball. All but one of the Microball channels performed reliably during the 2 weeks running. One detector channel was intermittent. Setting up the detector gains was possible with computer control via a PC computer. Matching of the gains was done in less than 15 minutes. The gains were set to specified α particle energies at the full ADC range for each ring by using previously determined calibration files and non-linear algorithms.

The acquisition system was reasonably robust, and the loss of data due to down time was insignificant. A software PID parameter defined as the ratio of the fast to the slow component in the CsI(Tl) was used for crude on-line channel gating and monitoring of the experiment.

Figure 1. One proton gated and ungated spectra of γ -rays from the 230 MeV $^{51}\text{V} + ^{100}\text{Mo}$ reaction. A peak to background improvement by a factor of 3.9 is clearly seen.

The systems studied were: $^{51}\text{V} + ^{100}\text{Mo} \rightarrow ^{151}\text{Tb}^*$ at 230 MeV, $^{29}\text{Si} + ^{58}\text{Ni} \rightarrow ^{87}\text{Mo}^*$ at 128 MeV, and $^{32}\text{S} + ^{58}\text{Ni} \rightarrow ^{90}\text{Ru}^*$ at 135 MeV. The event rates for the mass 150 and 90 regions were somewhat different. In the mass 150 run the total charged particle multiplicity was 0.5 per event. The Microball was operated at ≈ 1500 c/s per detector, with all detectors counting approximately at the same singles rate, while in the Gammasphere we had the maximum rate of $\approx 10,000$ c/s per detector. For the mass 90 region experiments the average charged-particle multiplicity was 3.0 and the Microball detectors were operated at a rate of 2500-3000 c/s, again with similar rates in each detector. Under these

conditions the Ge detectors were counting between 6000-7000 c/s close to the maximum. It is possible to run the Microball in this lighter system with rates commensurate with the maximum rates in the Gammasphere without compromising the particle identification. However, this reaches the rate limit for CsI(Tl) scintillation. At counting rates above 4000 c/s some loss in PID resolution occurs only for protons and deuterons. The proton to alpha separation is maintained in all the detectors, except for the most backward angles where the proton and alpha energies come down to a few MeV. For heavier systems and for normal kinematics reactions the proton alpha separation is good at all energies.

It is important to protect the particle detectors from elastic scattering at the forward angles and from target electrons for the remaining angles. In the present experiments we had 25 to 15 mg/cm² Sn-Pb absorbers in the forward 4 rings, and 5 mg/cm² Sn-Pb for the remaining rings. We found that for the mass 90 reactions with ^{28,29}Si and ³²S beams these absorbers were satisfactory. However, for the 230 MeV ⁵¹V + ¹⁰⁰Mo → ¹⁵¹Tb* reaction we observed a sudden loss of PID resolution from ring 4 to ring 5 (5mg/cm² absorber). This indicates that for the heavier beams at least 10 mg/cm² of Sn-Pb may be necessary.

Figure 2. Spectra of γ -rays from the $\alpha 3p$, $\alpha 2p$, $4p$, $3p$, and $2p$ gates from the reactions of 128 MeV ²⁹Si + ⁵⁸Ni, as indicated for the panels (a) - (e), respectively. The prominent peaks are labelled in keV. Each spectrum shows γ -rays mainly from two nuclei. The scales for the counts shown on the right of the spectra reflect the relative cross sections for the gates. Five additional gates, not shown, namely α , $2\alpha p$, $2\alpha 2p$, $3\alpha p$, $3\alpha 2p$ carry about 20% of the total yield.

The channel selection performance of the Microball is determined by the overall efficiency for detection of each particle that enters with the power of its multiplicity. Thus

for the $^{100}\text{Mo}(^{51}\text{V}, p_{xn})$ reaction with a measured a 90% proton efficiency, the peak to background improvement, or the Resolving Power (RP) of the Microball is given by the $0.90/f_{pxn}$, where f_{pxn} is the fraction of the pxn channels to the total. In the $^{151}\text{Tb}^*$ system we found a Microball RP of $0.90/0.23 = 3.9$ as seen in Fig. 1. For the $^{58}\text{Ni}(^{29}\text{Si}, 4p)$ channel the selection efficiency was $0.87^4 = 0.57$, while the Microball RP was $0.87^4/f_{4p} = 0.87^4/0.08 = 7.2$. This RP is close to the Resolving Power of Gammasphere, which is given by $\frac{P}{T} \times \frac{\Delta E_\gamma}{FWHM} \approx 0.5 \times \frac{60}{4} = 7.5$, where $\frac{P}{T}$ is the peak to total ratio of the Ge detectors. While the RP of Gammasphere may be independent of the reaction used, the Microball RP depends on the channel cross section fraction f_{chan} . Therefore the Microball RP can exceed that of Gammasphere if $\epsilon^{M_{part}}/f_{chan} > \frac{P}{T} \times \frac{\Delta E_\gamma}{FWHM}$, where ϵ is the particle detection efficiency and M_{part} is the particle multiplicity. We conclude that for charged particle channels the Microball can enhance Gammasphere by a full coincidence fold or more, without significant loss of efficiency. This benefit is true for all mass regions and it becomes more pronounced for the lighter systems and for low cross section channels.

In all cases studied in the mass 90 reactions we found that in each particle gate mainly 2 exit channels were present in the spectra (see Fig. 2 for five indicated particle gates). This means that the low spin background radiation originates from the channel with the larger number of emitted particles in each gate.

The high selectivity of the Microball allowed us to assign a recently reported superdeformed band in the mass 80 region to ^{83}Sr (4p channel), and to observe new SD bands in ^{81}Sr ($\alpha 2p$ channel) and ^{84}Zr (2pn channel). In the $^{87}\text{Mo}^*$ system had ~ 3 times less total statistics compared to a similar Eurogam I experiment in which the reaction $128 \text{ MeV } ^{30}\text{Si} + ^{56}\text{Fe}$ was employed without particle selection. Here we obtained a 4p-gated cube containing only $4 \cdot 10^7$ events compared to $1.5 \cdot 10^9$ from the Eurogam I experiment. Despite the low statistics from a $\approx 25 \text{ mb}$ channel we easily identified a SD band with 1.7% yield of the 4p channel. Without the Microball one has to look for an $\approx 0.05\%$ population of the SD band in the presence of all the reaction channels. Not only we were able to see the SD bands, but we could easily identify the nuclei where these SD bands are, a totally impossible task from the same data without the channel selection. As an illustration, we note that the most intense γ -ray of the ^{83}Sr SD band has an intensity of 1.7% of the 874 keV transition in Fig. 2(c).

We should mention that because the detection efficiency for charged particles is less than 100%, some of the yield of each channel is transferred to gates containing a subset of detected particles (e.g. part of the 4p channel yield appears in the 3p gate, etc.). Since the efficiency can be measured quantitatively, it is possible, for example, to subtract the appropriate fraction of the 4p matrix or spectra from the 3p-gated matrix or spectra. This procedure has been employed extensively in our data analysis. This made it possible to study a weak 2pn channel in the presence of large $3p_{xn}$ or 4p cross sections. In fact we identified the properties of the SD band in ^{84}Zr in this way.

Finally, we have found that charged particle emission widens the ER recoil angle and thus decreases the energy resolution compared to the channels emitting only neutrons. Since in the lighter reaction systems there is very little neutron emission, most of the channels of interest emit only protons or α particles. The contribution to broadening of a proton and an α particle are in the ratio of 1.7 and 3.0 compared to neutrons. Since we

measured nearly all the particles we can reconstruct on an event by event basis the recoil correction and completely remove the loss of resolution due to the recoil angle. In fact we should obtain better resolution than that for the xn exit channels. Preliminary analysis indicates that this is feasible and in fact it is absolutely essential for channels involving α particles, where before correction the FWHM is about 2 times larger than in the xn channels at the same γ -ray energy.

In the $^{151}\text{Tb}^*$ system we searched for evidence of hyperdeformation (HD) in ^{147}Gd produced by the (^{51}V , $p3n$) reaction. In this data set we identified clearly known SD bands in ^{146}Gd ($p4n$ channel), ^{147}Gd ($p3n$ channel) and ^{143}Eu ($\alpha3n$ channel). A search for a HD ridge structure was made. From the proton gated 4+higher fold Ge data, a background subtracted $E_\gamma-E_\gamma$ matrix was constructed that exhibited a ridge with a 32 ± 1 keV spacing in the energy interval 1.0–1.35 MeV. In addition, from the p -gated 3+higher fold Ge data a cube was constructed. Background subtracted [4] cuts perpendicular to the cube diagonal ("snow flakes") were constructed and carefully examined. Evidence for a weak hexagonal snow flake was found primarily in the 1.05–1.10 MeV cut. Its spacing is 35 ± 1 keV. In this way the probability of accidentally obtaining a cascade of three extraneous γ -rays with the 35 keV spacing is reduced substantially. Unfortunately this is achieved by substantial loss of statistics. However, if this is indeed a ridge from HD then assuming $\mathfrak{S}^{(1)} = \mathfrak{S}^{(2)}$ and an upper energy of 1.3 MeV we estimate the maximum spin to be $2\cdot E_\gamma/\Delta E_\gamma \approx 74 \hbar$. This is a much more comfortable estimate than $\approx 95 \hbar$ from Ref. [5].

References

- [1] P.-F. Hua, D.G. Sarantites, J. Elson, J.T. Hood, M.R. Maier, and A. Vander Mollen, to be published.
- [2] J. Elson, P.-F. Hua, J.T. Hood, D.G. Sarantites, L.G. Sobotka, and M.R. Maier, IEEE (in press).
- [3] D.W. Stracener, *et al.* Nucl. Instr. Meth. **A294**, 485 (1990).
- [4] G. Hackman and J.C. Waddington, *This conference* LBL-35687 Rep. p. 141.
- [5] A. Galindo-Uribarri *et al.*, Phys. Rev. Lett., **71**, 231 (1993).

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.