Spectroscopy of Light Lead and Actinde Nuclei using an Evaporation Residue Detector

W. Reviol, D.G. Sarantites, C.J. Chiara, J. Elson, O. Pechenaya, and L.G. Sobotka
Washington University, St. Louis, Missouri, USA

"Nuclei at the Limits" Argonne, July, 2004

Detailed spectroscopy in actinide and light lead nuclei

Problems:

- > 100 mb fusion cross section but > 95 % fission; ~ 500mb Coulex and transfer.
- No selectivity from evaporated particle multiplicity (inner ball gating) and no possibility for Z-identification of residues by $\Delta E - E$ (ion. chamber).

*A **"tag"** is needed!*

Solutions (plural!):

1. **Recoil mass separation and Recoil Decay Tagging.**
   - ❖ Clean spectra – very low cross sections – superb identification capabilities!
   - ➢ Restrictions due to small spectrograph angular acceptance:
     - Limited choice of beam and target (nearly symmetric reactions)
     - Requirement of thin target and high current
     - Exclusion of important reaction channel: axn
   - ➢ Limited applicability of RDT (500 ns $\leq t_{1/2}(\alpha) \leq$ 500 μs)

2. **Direct residue detection by ToF and Pulse Height. (HERCULES)**
   - ➢ Limitations due to presence of elastic scattering:
     - Somewhat dirty γ-spectra (no very low cross sections)
     - Limited beam intensity (≤ 2 pnA) but thick target
   - ➢ Almost no identification capability

3. **Isomer Tagging near the target.**
   - ➢ No identification capability

Residue detectors - previous attempts

Ward et al.
NPA 406 (1983)

- Secondary electrons, one detector

Heese et al.
Acta Phys. Pol.
B 24 (1993)

- Secondary electrons, 18 detectors, long flight path, beam sweeping (RFD)

Ajintanand et al.
NIM A 316 (1992)

- Direct detection with fast plastic scintill., one detector, thin target and short exposure to beam

Design Considerations for HERCULES

- Plastic foils thin (1.0 mg/cm^2) and uniform : *Stop only the residues.*

- Response of scintillators to heavy evaporation residues: *Ensure high trigger efficiency at low E_{kin} and high Z.*
- Radiation damage from elastics: *Control loss in pulse height, compensate for it.*

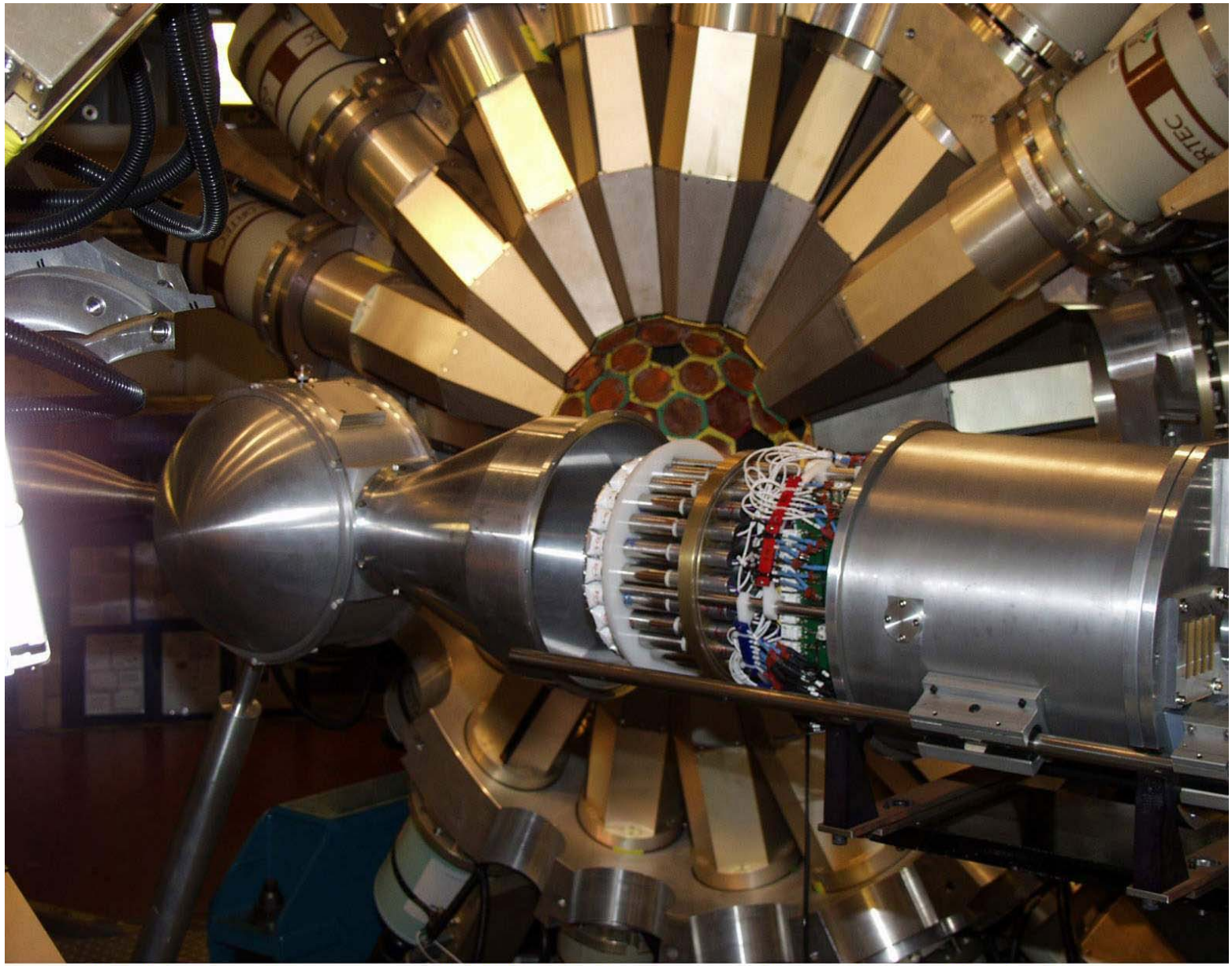
- Fast electronics: *Achieve full recovery in 10 ns.*

- High segmentation in the array: *Reduce rate in each detector.*

- Geometry: *Have residues reach the detector before next beam burst.*

64 Detectors in 4 Rings →

Ring	# Dets	Angular Range
1	8	3.2^o – 7.1^o
2	14	7.1^o – 11.2^o
3	18	11.2^o – 15.2^o
4	24	15.2^o – 19.1^o



Washington University: HERCULES in Gammasphere, August 20, 2002

Commissioning run for HERCULES at Gammasphere

Series of experiments in a 6 day run:

(1) 215-MeV $^{48}Ti+^{126}Te$ (0.74 mg/cm^2 on 0.3 mg/cm^2 Au).
(2) 230-MeV $^{48}Ti+^{142}Nd$ (1.1 mg/cm^2 ; 0.16, 0.48 mg/cm^2 Au).
(3) 230-MeV $^{48}Ti+^{142}Nd$ (0.46 mg/cm^2 ; 0.1, 0.37 mg/cm^2 Au).
(4) 238-MeV $^{48}Ti+^{142}Nd$ (same target as [3]).
(5) 238-MeV $^{48}Ti+^{142}Nd$ (1.0 mg/cm^2 ; 0.84 mg/cm^2 Au **target stack).**
(6) 238-MeV $^{48}Ti+^{126}Te$ (same target as [1]).

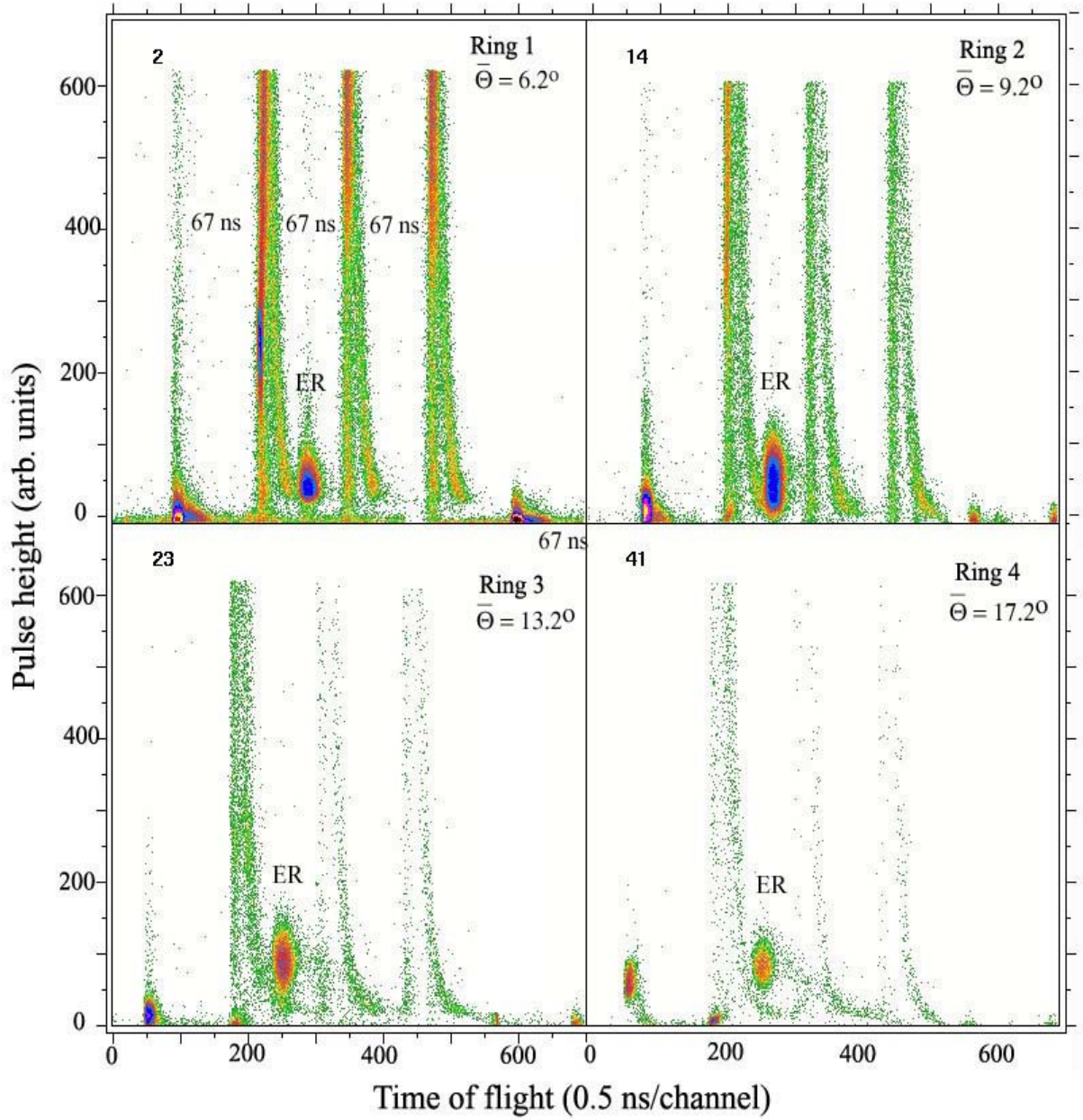
88-Inch Cyclotron at LBNL

Setup:

HERCULES at 31 cm from the target ; 5.6 ^{o} - 19.1^o coverage.
Gammasphere with 102 detectors.
Trigger: γ^4 .
Nuclei of interest: $^{186}Pb+4n$ and $^{186}Tl+p3n$.

$^{48}Ti+^{126}Te$ at 238 MeV

(0.74 mg/cm^2 Au backing)

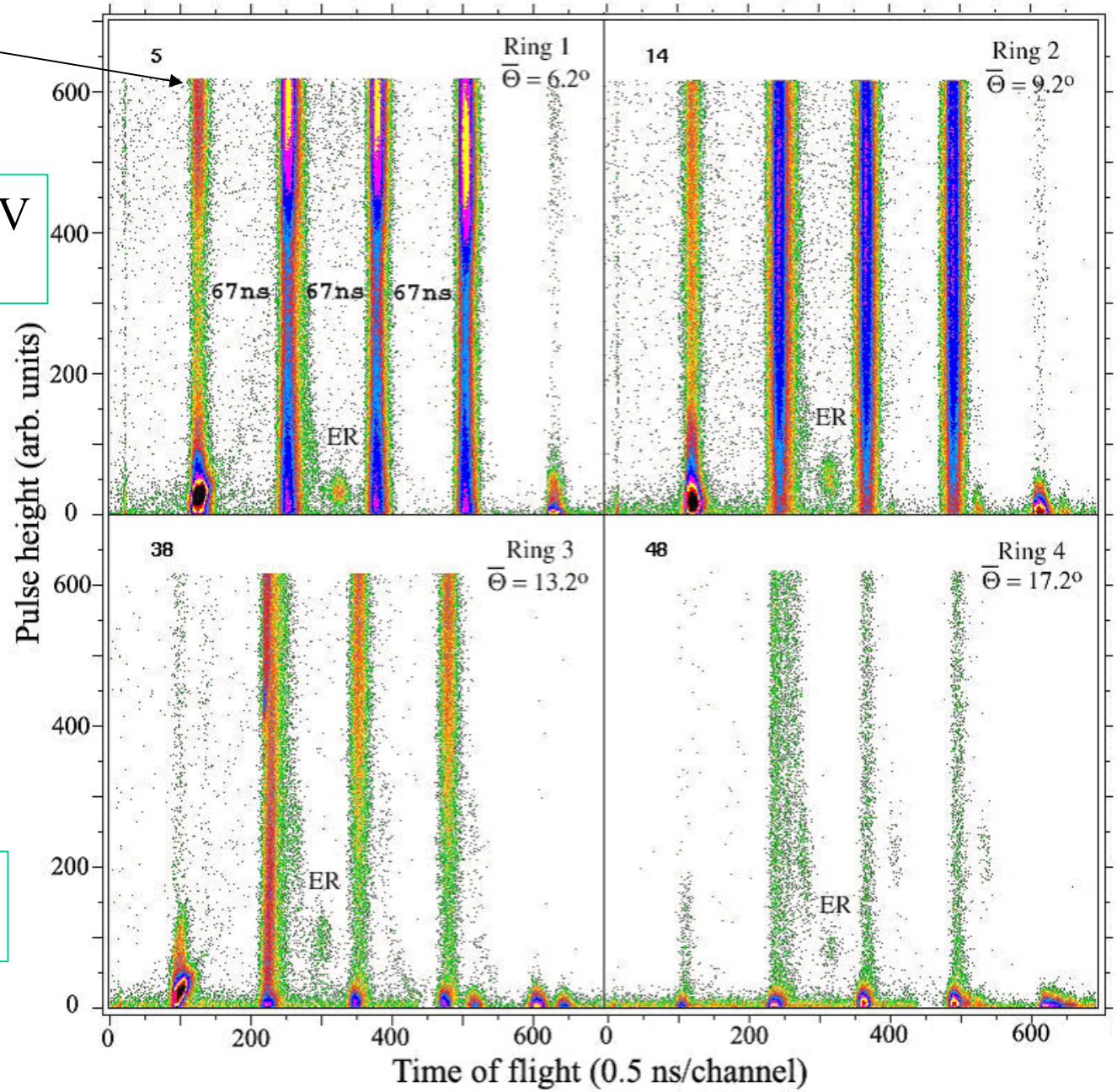


ER cross section ~100 mb

07/30/04

~ 1 MHz/detector

$^{48}Ti+^{142}Nd$ at 230 MeV
(0.46 mg/cm^2 Au backing)

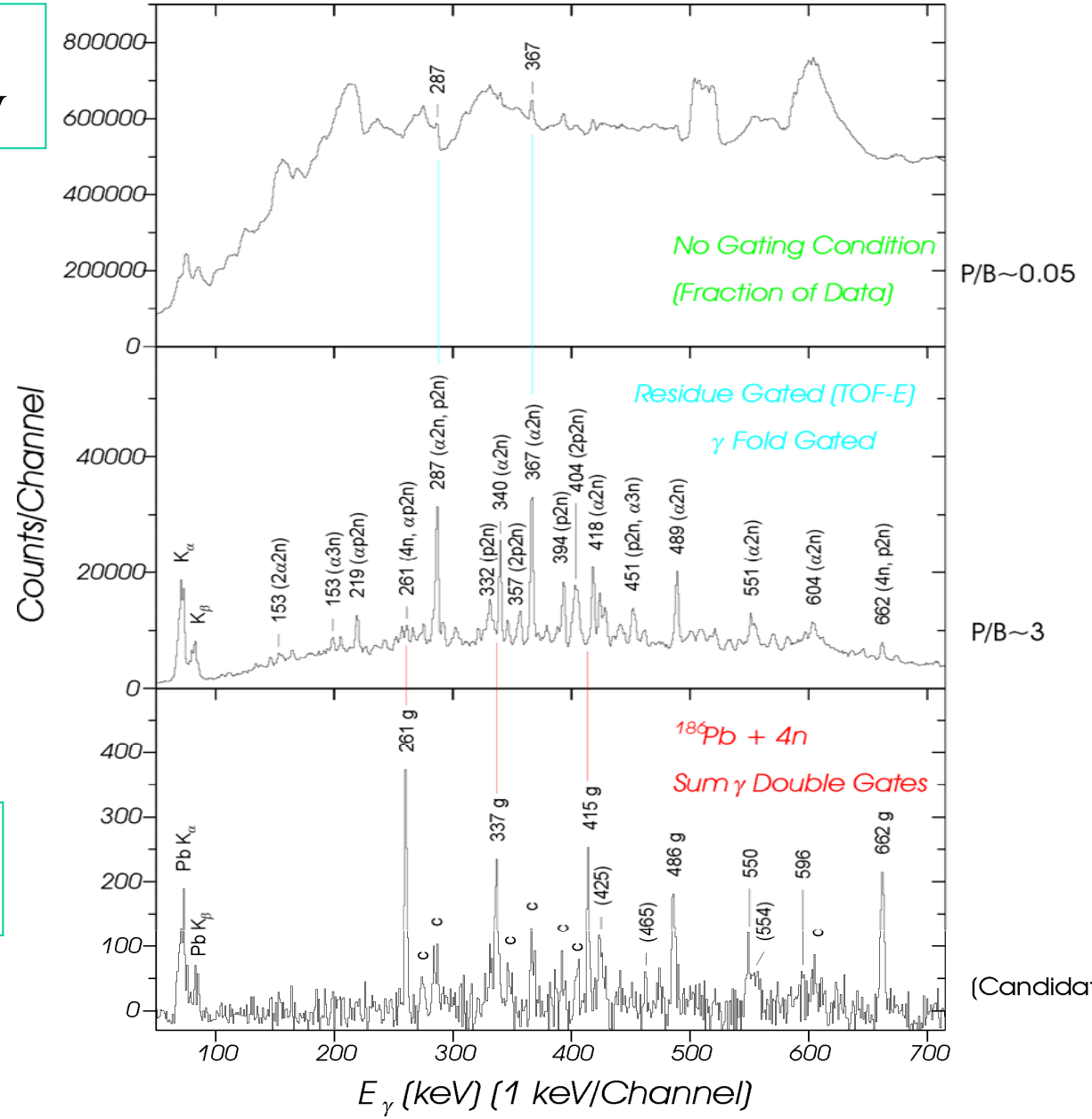


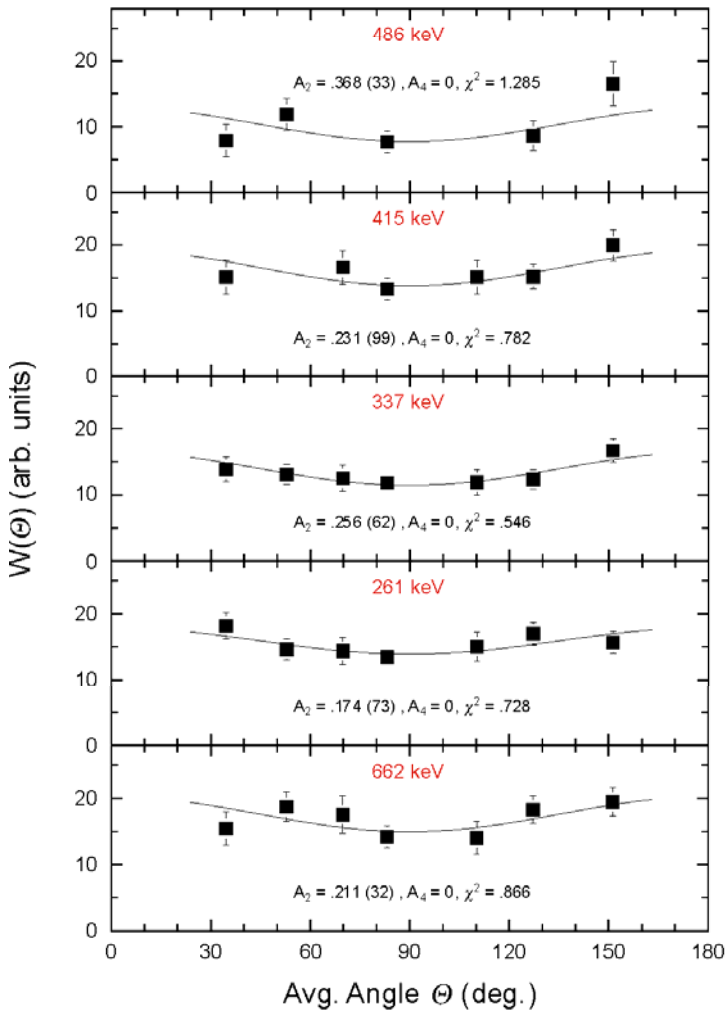
ER cross section ~1 mb
Fus. cross section ~ 180 mb

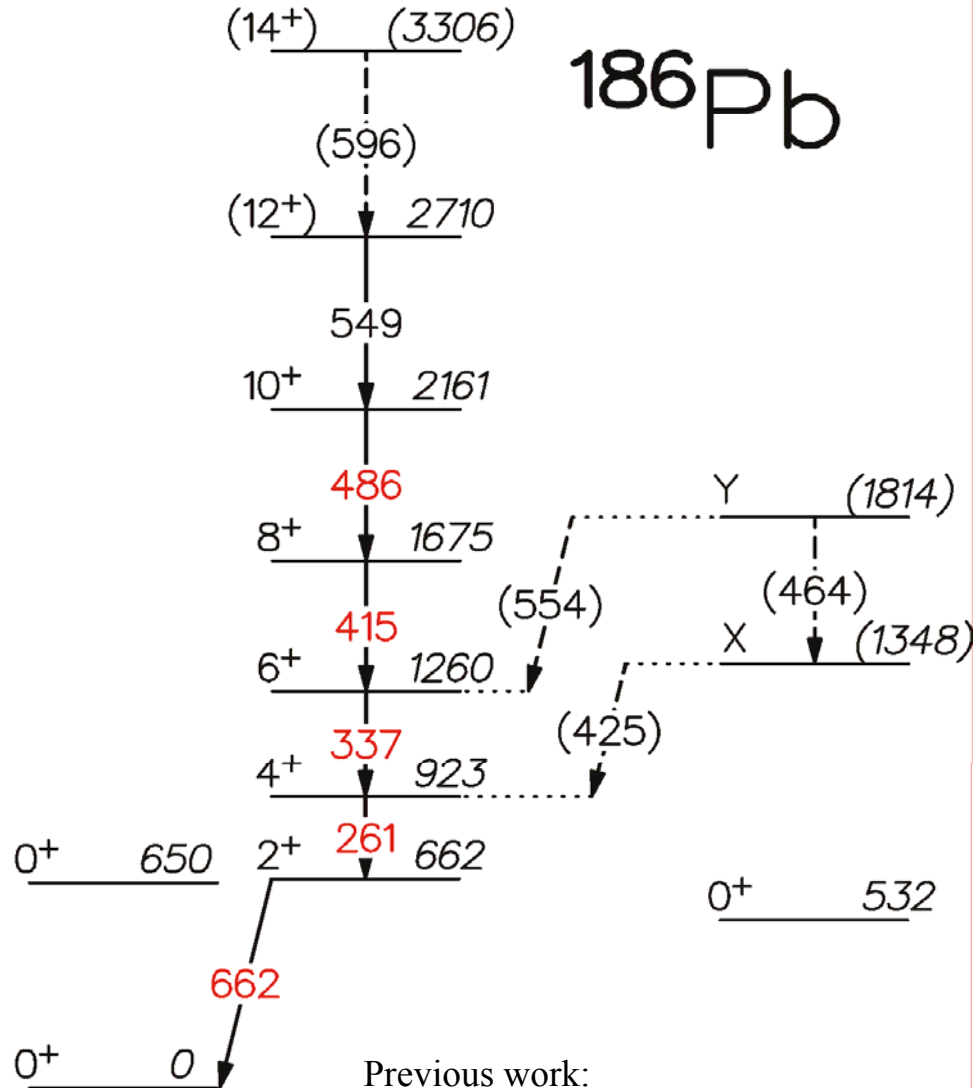
$^{48}Ti + ^{142}Nd$
@ 230, 238 MeV

The Power of HERCULES

The Power of Gammasphere







Previous work:
Baxter et al. PRC 48 (1993)

Efficiencies for the present reactions

Reaction	Int. (pnA)	Target	% Eff. xn or pxn	% Eff. αxn	Eff / Eff geo αxn
$^{48}Ti + ^{126}Te \rightarrow ^{174}W$	0.25	0.74 mg/cm^2 + Au	16.8	28.7	0.82
$^{48}Ti + ^{126}Te \rightarrow ^{174}W$	1.0	0.74 mg/cm^2 + Au	9.1	15.6	0.44
^{48}Ti * + $^{142}Nd \rightarrow ^{190}Pb$	1.5	1.1 mg/cm^2 + Au	13.2	19.5	0.45
^{48}Ti * + $^{142}Nd \rightarrow ^{190}Pb$	1.5	0.46 mg/cm^2 + Au	10.2	14.2	0.33

* 230 MeV

Efficiency depends on:

Beam Current (always recovery?)

→ Angular Distribution (**xn or pxn** vs. **αxn**)

→ Target Thickness (lateral straggling)

(Target Layers [Rutherford scattering])

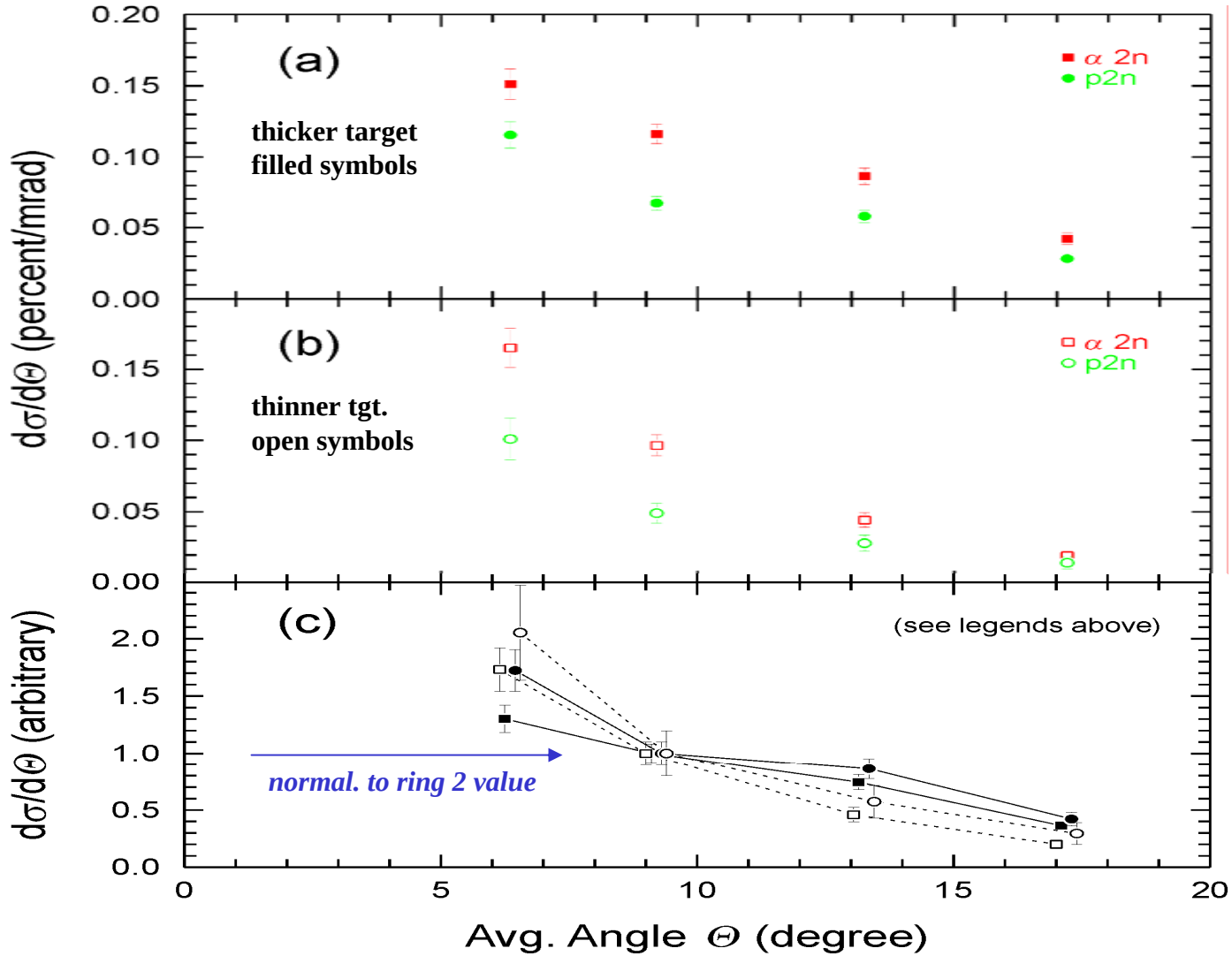
Example for residue angular distribution: $^{48}Ti + ^{142}Nd$ @ 230 MeV

For e.g. Ring 2:

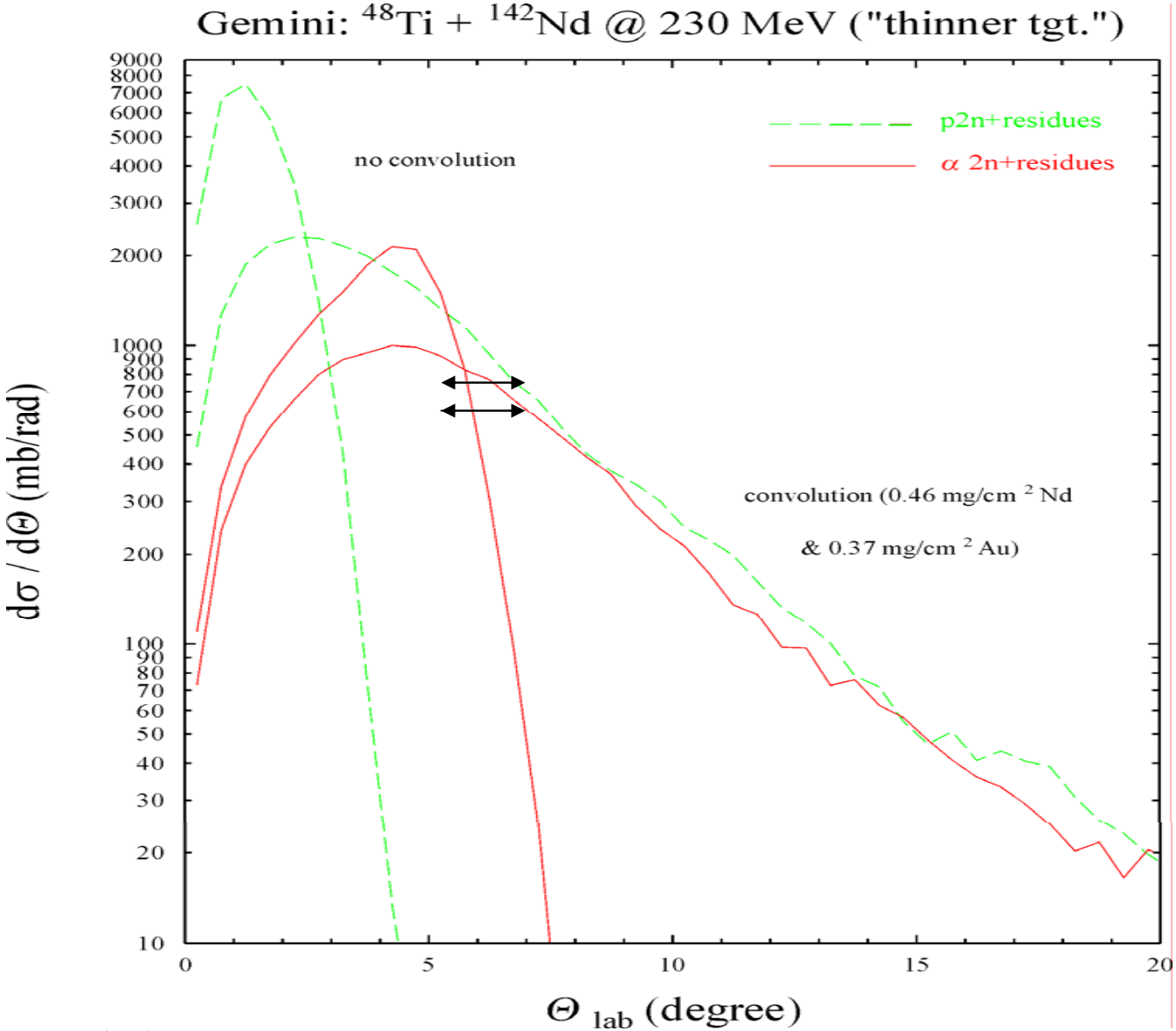
7.2 ^{o} – 11.2 ^{o}

70 mrad

$\theta_{Avg.} = 9.2\ ^{o}$



Simulation of residue angular distributions



Ring 1 = 5.6° – 7.1°

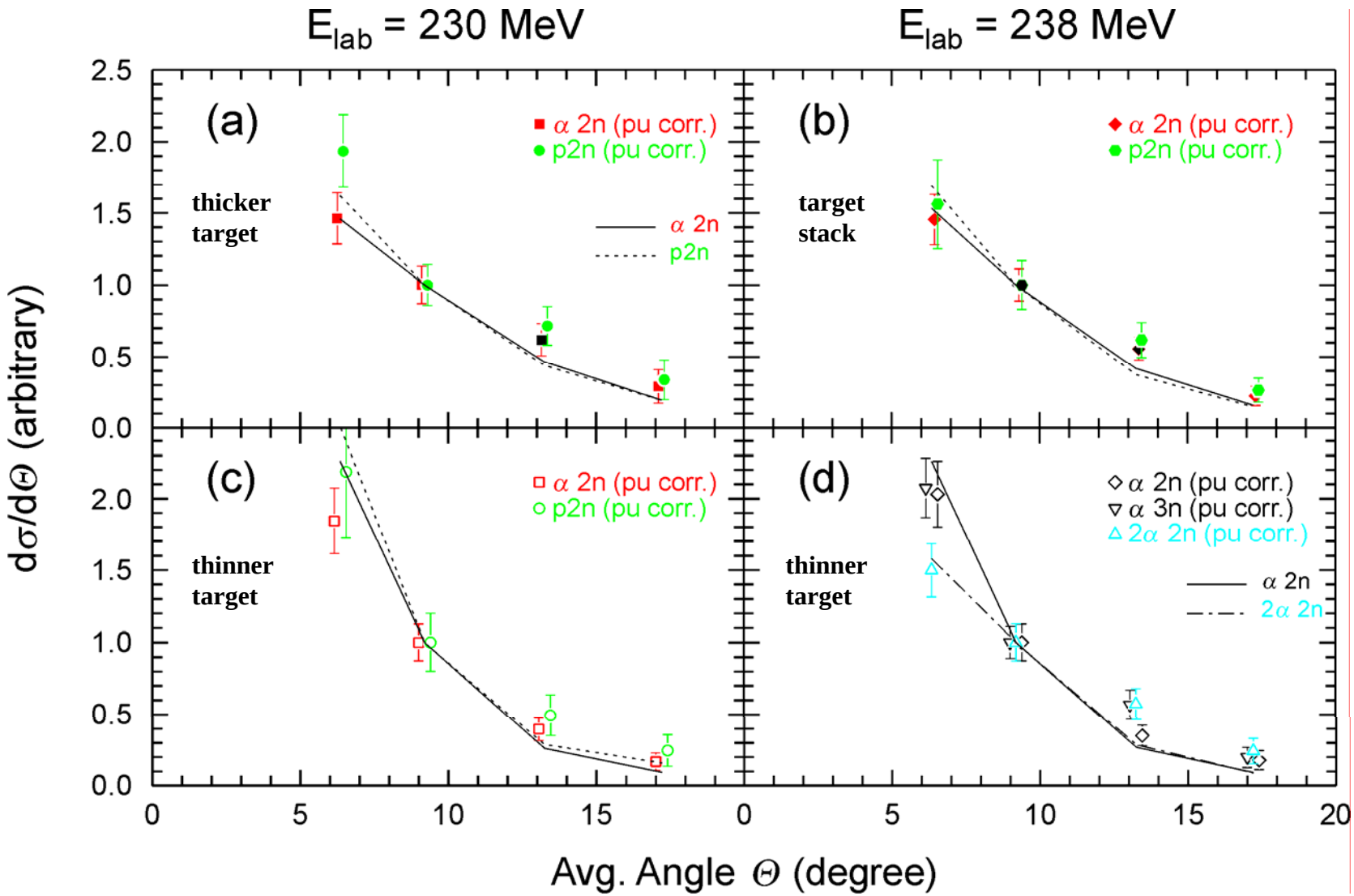
Ring 1 to 4 = 5.6° – 19.1°
(expected geometric efficiency = 0.5)

For convolution:

"Slicing" target in portions (0.15 mg/cm^2)

Lateral straggling (direction cosines) from TRIM

Comparison of data and simulations



Data corrected for pileup

PHYSICAL REVIEW C, VOLUME 60, 044602

Fission hindrance in hot ^{216}Th: Evaporation residue measurements

B. B. Back, D. J. Blumenthal, C. N. Davids, D. J. Henderson, R. Hermann, D. J. Hofman, C. L. Jiang, H. T. Penttilä, and A. H. Wuosmaa
Argonne National Laboratory, Argonne, Illinois 60439
(Received 8 April 1999; published 25 August 1999)

The fusion evaporation-residue cross sections for $^{32}S+^{184}W$ have been measured at beam energies of E_{beam}= 165, 174, 185, 196, 205, 215, 225, 236, 246, and 257 MeV using the ATLAS Fragment Mass Analyzer. The data are compared with statistical model calculations and it is found that a nuclear dissipation strength, which increases with the excitation energy, is required to reproduce the excitation function. A comparison with previously published data shows that the dissipation strength depends strongly on the shell structure of the nuclear system. [S0556-2813(99)02709-0]

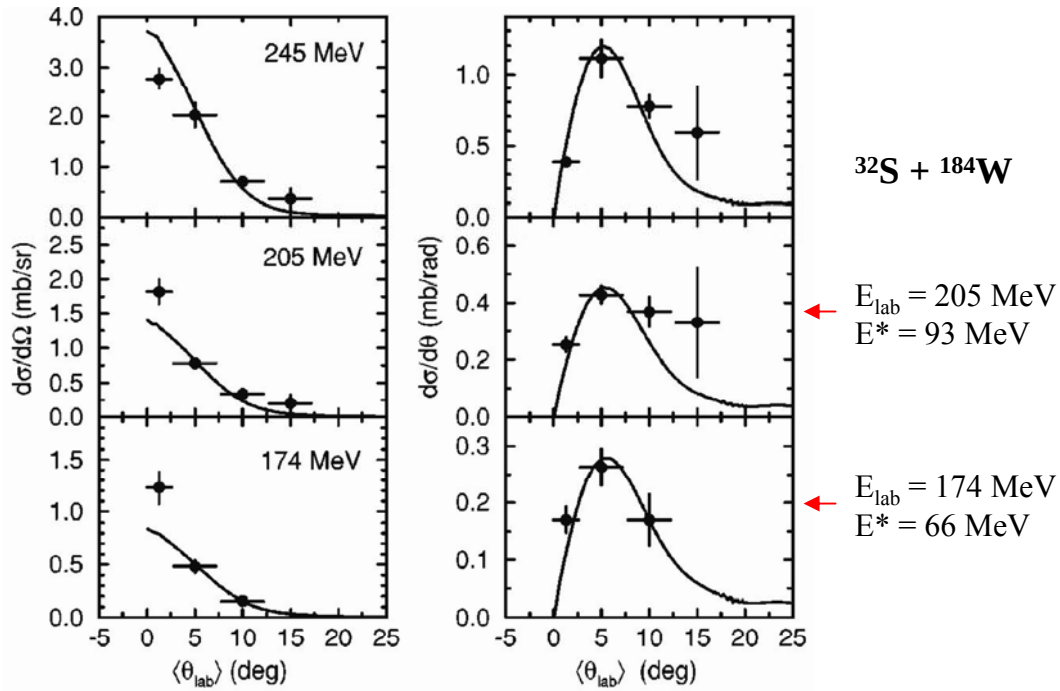
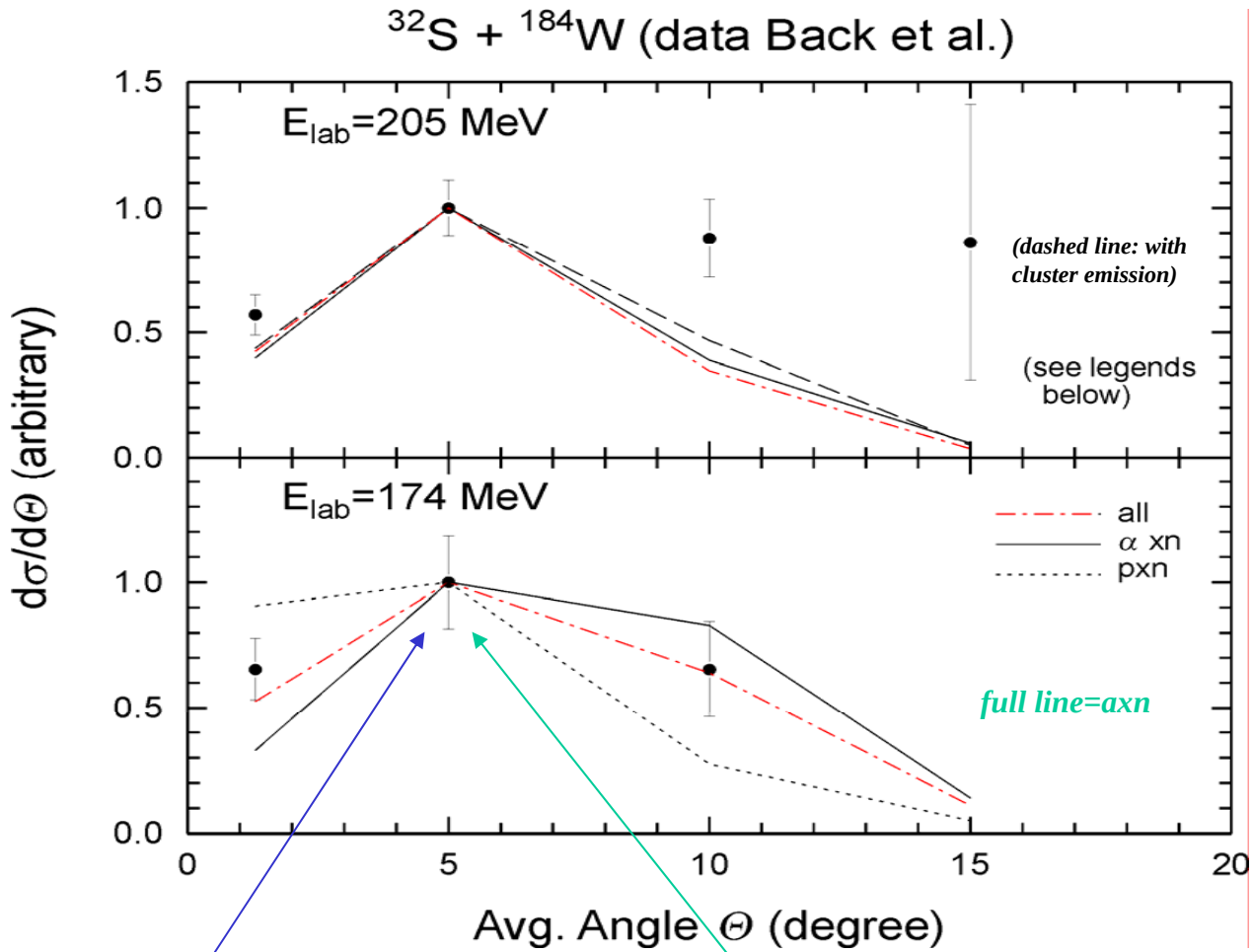


FIG. 7. Right panels: Experimental angular distributions $d\sigma/d\theta_{lab}$ are compared with calculations (solid curves), see text, at three beam energies. Left panels: the same data and curves are shown in a $d\sigma/d\Omega$ representation.



normal. to segment 2.9° – 7.1°
($\Theta_{Avg.}$ = 5°)

axn:pxn=1.9:1
(at $\Theta_{Avg.}$ = 5°)

Summary and Conclusion

- Described the **HERCULES** detector system, presented the **^{186}Pb+4n** result from its commissioning run (^{186}Tl not covered), and discussed various aspects of residue angular distributions.
- HERCULES plus Gammasphere works as a spectroscopy tool!
- At present, the best use of HERCULES is for **αxn** reactions: achievable is 30 % efficiency at 2 pnA.
- Other good spectroscopy applications are reactions induced by rather light ions down to Ne (any channel) and source measurements.
- For **detailed** in-beam spectroscopy of heavy nuclei are various, complimentary methods/setups needed (more than in other regions).

Acknowledgement

ANL

R.V.F. Janssens, D. Seweryniak, C.J. Lister

LBNL

A.O. Macchiavelli, P. Fallon, M. Cromaz

Washington Univ.

R.J. Charity

HMI Berlin

K.H. Maier