Summary of in-beam spectroscopy session

HRIBF Workshop

Lee Riedinger, Mark Riley,
David Radford, Chang Hong Yu

November 14, 2009

Discussion topic "initiators"

1. I-Yang Lee - Update on GRETINA at HRIBF
2. David Radford - Transfer Reactions
3. Chang Hong - Coulex in Odd-A Nuclei
4. Robert Varner – Coulex using the BaF array
5. Magda Zielinska - Collectivity in the vicinity of the N=50 shell closure
6. Cyrus Baktash – Physics with ^{56}Ni beam: N = Z
7. Mike Carpenter – Fusion evaporation reaction opportunities
8. Mark Riley – Deep inelastic reactions and exotic fusion evaporation reactions
9. Wojtek Krolas - Physics from DIC studies of sub-microsecond neutron-rich isomers
10. Mustafa Rajabali - DI-isomer scope
11. Demetrios Sarantites - Nanosecond isomers with SuperHercules and Gretina
12. Gerfried Kumbartzki - g factor Opportunities at HRIBF (part 1)
13. Nick Stone - g factor opportunities at HRIBF (part 2)
14. David Kulp – Disentangling Mixed Coexisting Shapes

Status and plan of GRETINA - I. Y. Lee

γ−ray tracking is essential

Especially for a Radioactive Beam Facility

GRETINA capabilities

- High position resolution
  Doppler correction
- High efficiency
- High P/T
- High counting rate
- Background rejection

Experimental conditions

Large recoil velocity

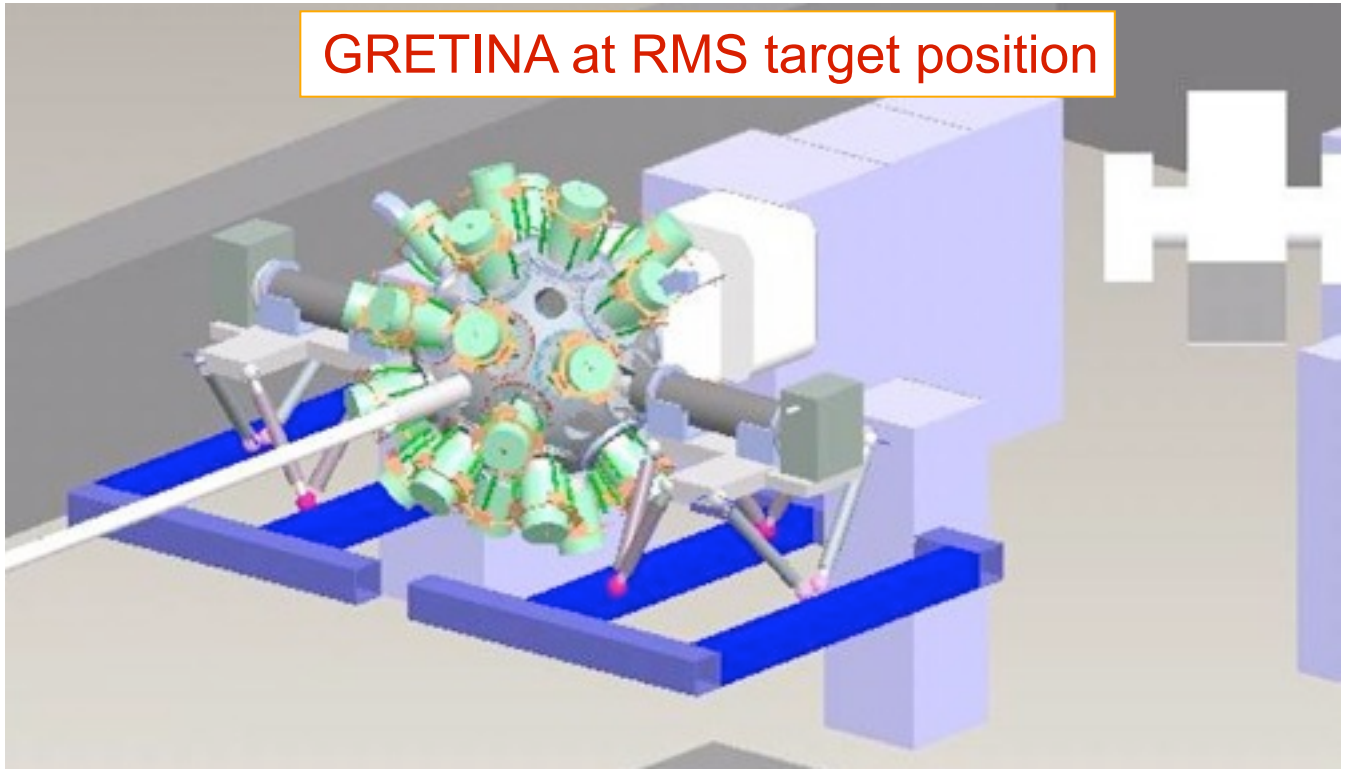
- Inverse reaction

Low beam intensity

High background rate

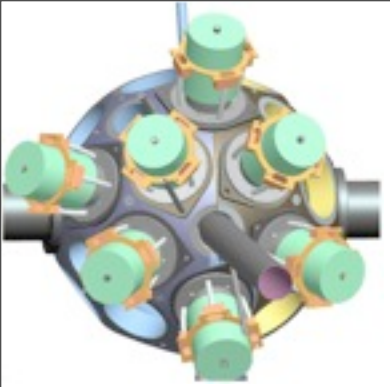
- Beam decay
- Beam impurity

Installation at HRIBF



- **Project is within budget and on schedule.**
- **Expect to complete on scheduled date: Monday 2/14/2011.**
- **Physics campaign schedule proposed which extends through 2013.**

  September-October 2012, move to HRIBF
  November 2012 –April 2013, operation at HRIBF



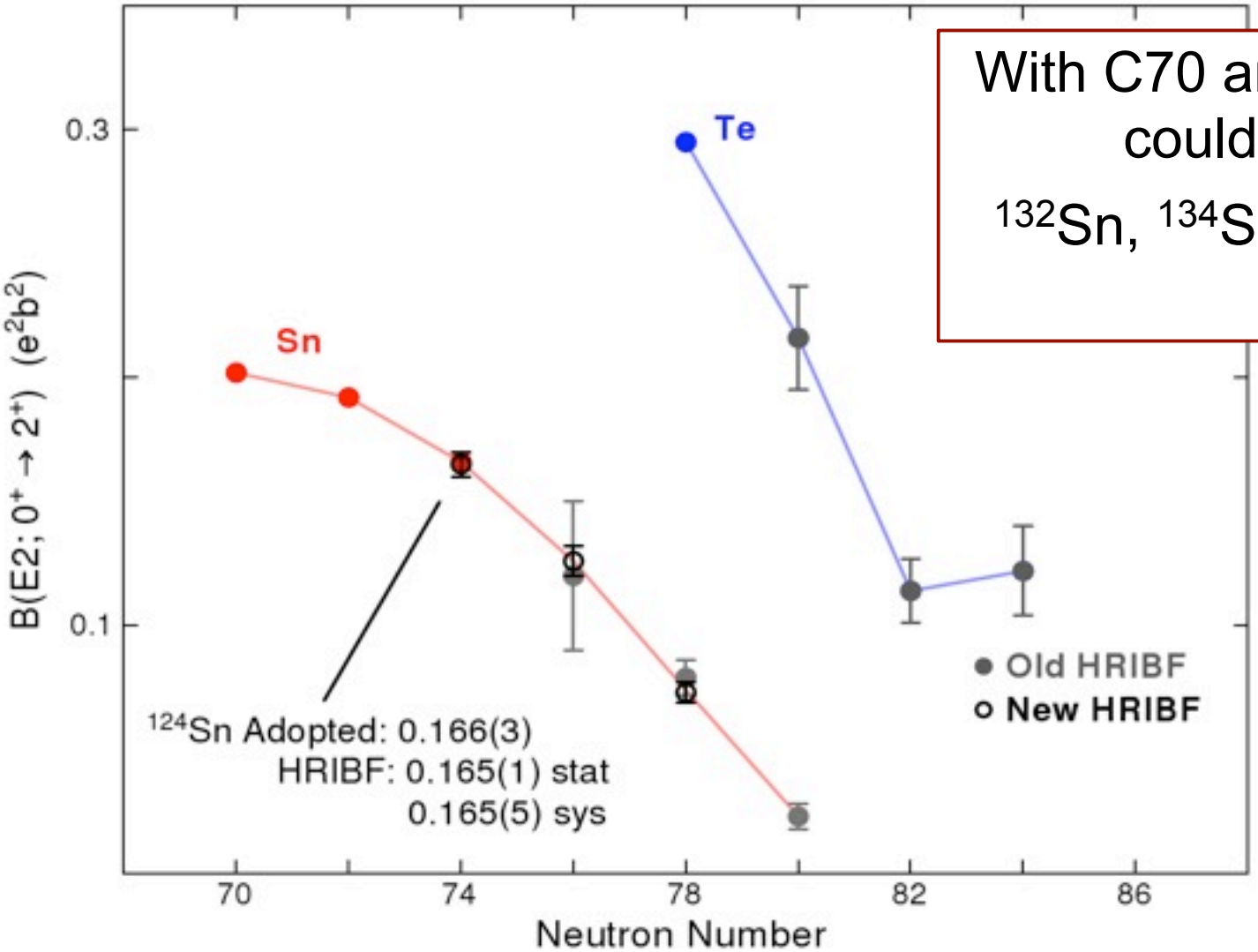
Transfer Reaction Studies and Coulomb Excitation of Neutron-Rich Nuclei

David Radford and Chang Hong Yu

Physics Division, ORNL

Precision RIB Coulomb Excitation in Sn

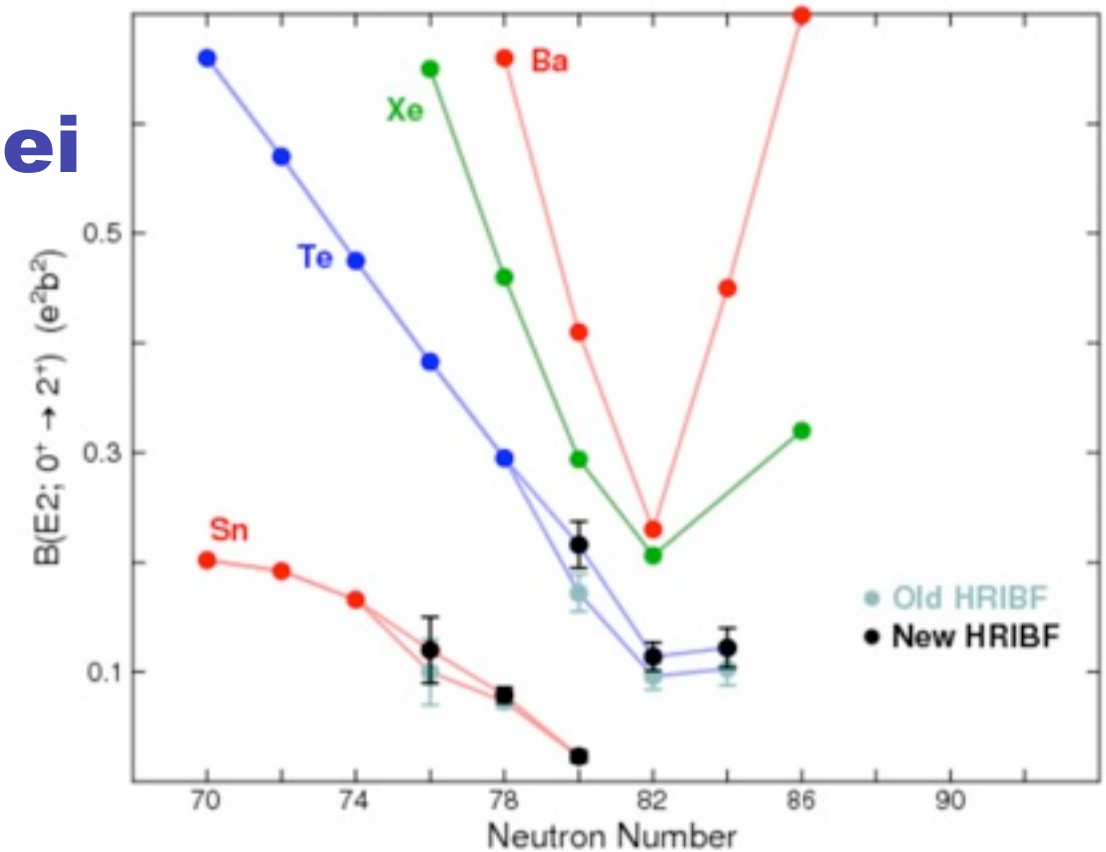
Measurements of B(E2) values for ^{124}Sn, ^{126}Sn, ^{128}Sn, ^{130}Sn with CLARION at HRIBF



With C70 and GRETINA, could extend to

^{132}Sn, ^{134}Sn, ^{138}Te, ^{140}Te

B(E2)s of Even-Even Nuclei



Asymmetry of Te B(E2) values around N=82 remains

Future Plans:

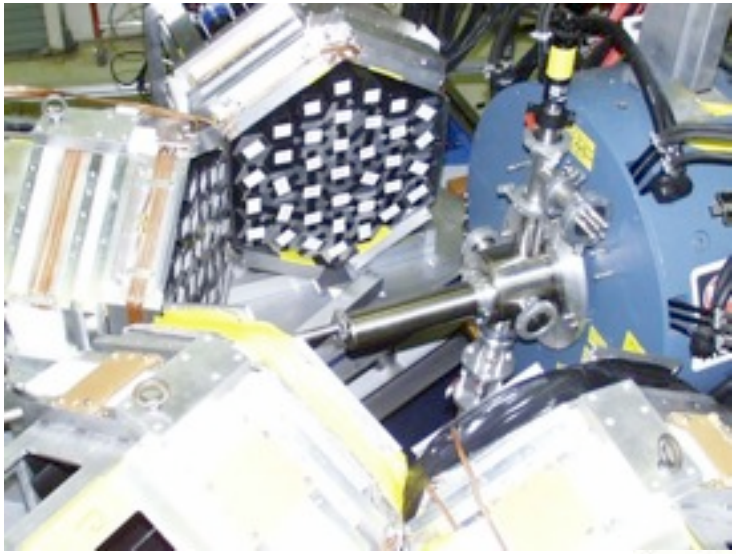
Expand the odd-A study toward ^{132}Sn

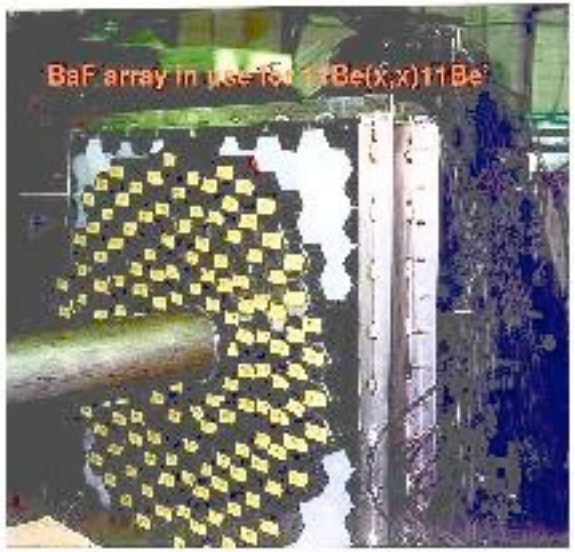
^{127,129,131,133}Sn, ^{131,133,135}Sb, ^{131,133,135,137}Te, ^{133,135}I

Summary of David and Chang Hong

- C70 upgrade opens many exciting avenues for detailed structure studies of exotic neutron-rich nuclei
- ^{132}Sn region is of special interest
- For both Coulex and transfer, the upgrade expands the physics reach of the HRIBF by ~ 4 additional neutrons
- (^{9}Be,^{8}Be) & (^{13}C,^{12}C) reactions with GRETINA will be excellent tools to identify new levels, and for detailed study of selected states
- Higher intensities will allow proton transfer studies as well as neutron transfer, e.g., single-proton states in ^{133}Sb
- Light-ion transfer will provide good complementary information
- Full capabilities of GRETINA require new auxiliary detector(s) for charged particles and/or recoils
  - 2π CsI array with higher granularity
  - Fine-pitch Si DSSD array (deltaE-E ?)
  - Recoil detector (gas? HERCULES-style?) at ~1m, with ~1° resolution
- Should develop plunger apparatus that interfaces properly with GRETINA and auxiliary particle detectors

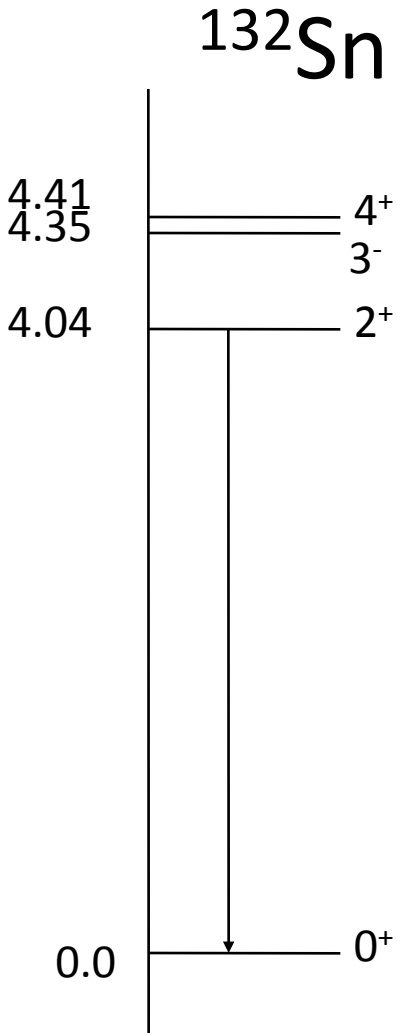
High efficiency γ spectroscopy
Robert Varner, ORNL





Experimental challenges

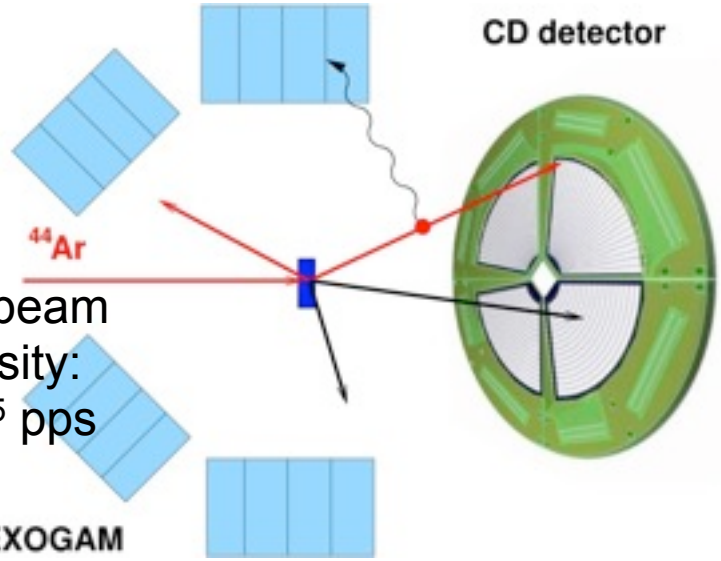
- High-energy excitation
  - Coulex σ is small; lots of BaF_2
- High energy photon
  - Low Ge efficiency; use BaF_2
- Beams have low intensity
  - planned intensity = 5×10^4 (^{132}Sn)
  - γ rates less than background
    - Employ very efficient detector systems, e.g., BaF Array
    - Highly selective trigger needed, e.g., γ-particle coincidence



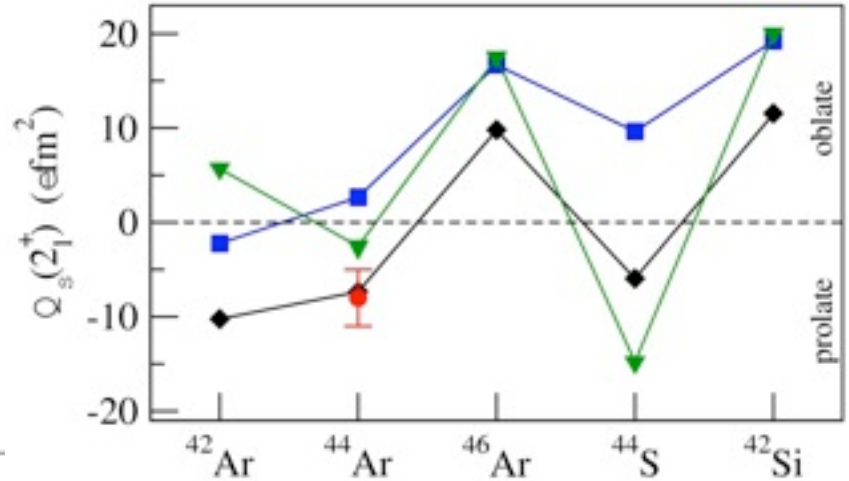
Collectivity in the vicinity of the N = 50 shell closure

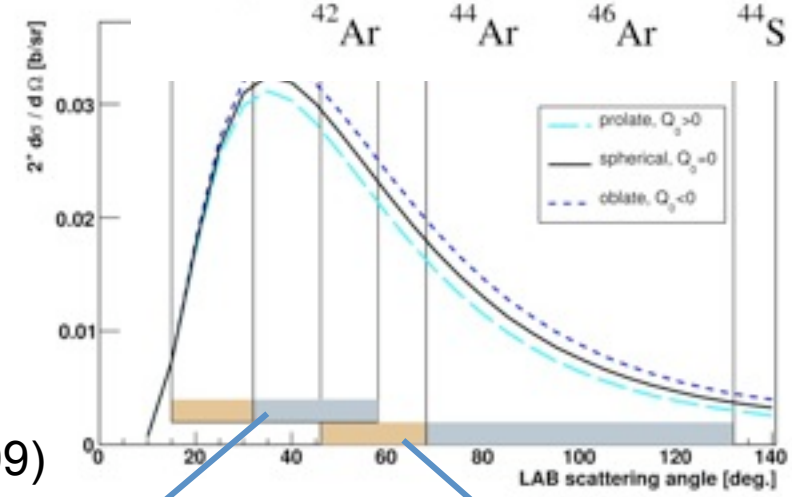
M. Zielińska and P. Napiorkowski
Heavy Ion Laboratory
University of Warsaw

Successful example: ^{44}Ar @ GANIL

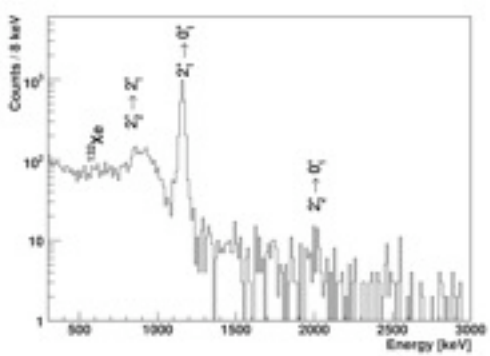


^{44}Ar beam intensity: 2×10^5 pps

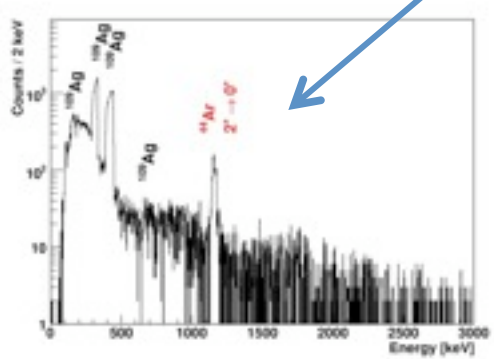




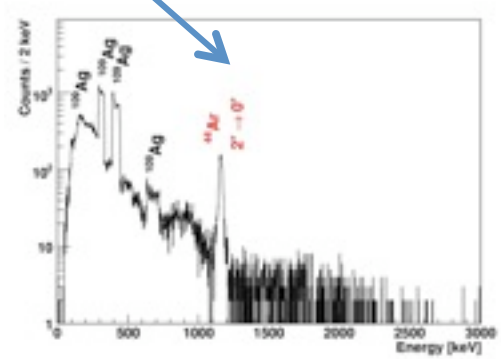
M. Zielińska *et al.* PRC 80, 014317 (2009)



4.4 MeV on ^{208}Pb



2.7 MeV ·A on ^{109}Ag



2.7 MeV ·A on ^{109}Ag

^{70}Ge: M.Sugawara, *et al.* Eur.Phys.J. A16, 409 (2003)

^{72}Ge: B.Kotlinski, *et al.* Nucl.Phys. A519, 646 (1990)

^{74}Ge: Y.Toh, *et al.* Eur.Phys.J. A 9, 353 (2000)

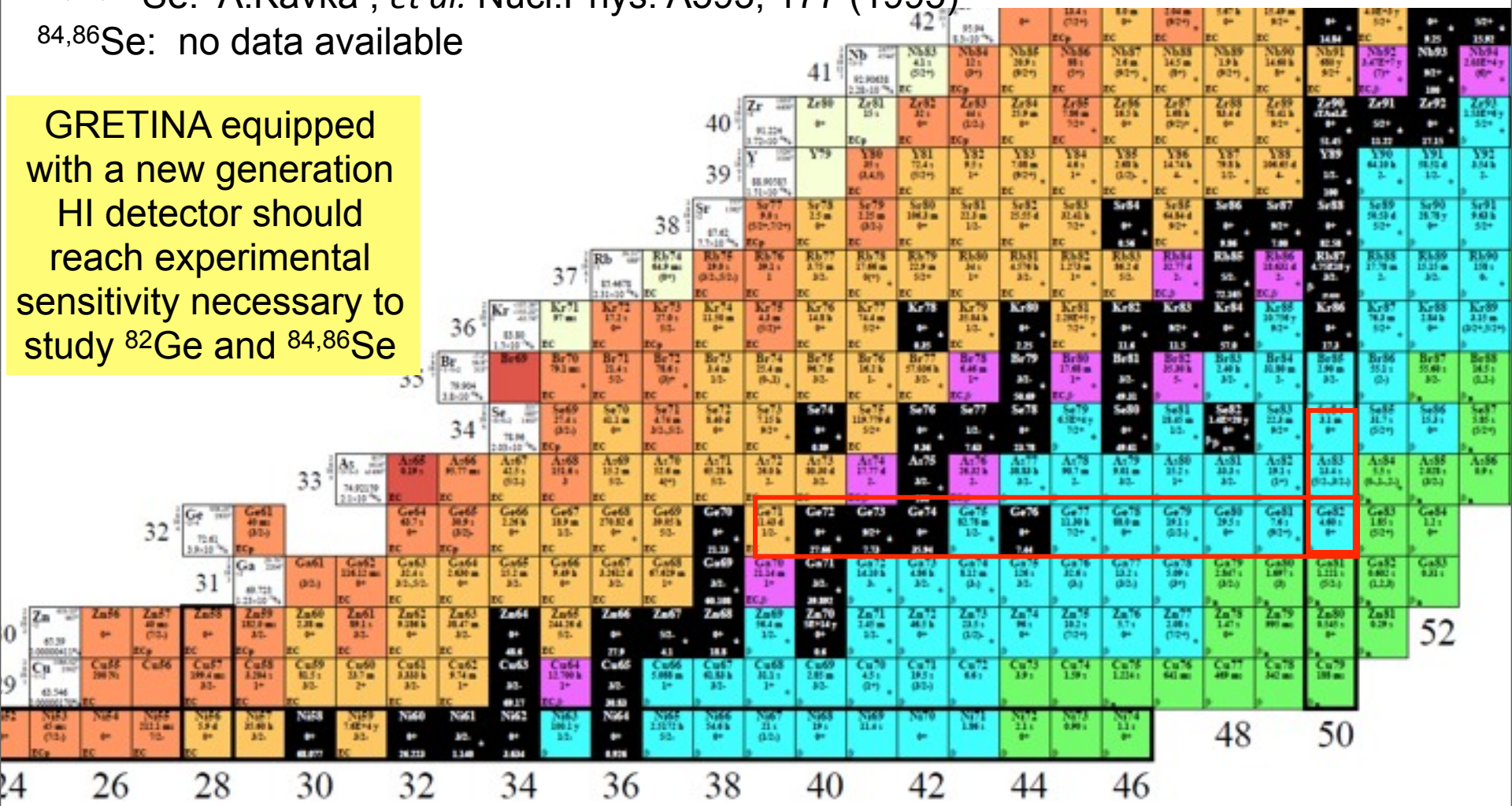
^{76}Ge: Y.Toh, *et al.* J. Phys. G: 27, 1475 (2001)

^{78,80,82}Ge: E. Padilla-Rodal, *et al.* PRL 94, 122501 (2005)

^{78,80,82}Se: A.Kavka , *et al.* Nucl.Phys. A593, 177 (1995)

^{84,86}Se: no data available

GRETINA equipped with a new generation HI detector should reach experimental sensitivity necessary to study ^{82}Ge and ^{84,86}Se



Studying high spins with fusion evaporation reactions in inverse kinematics using RIB's

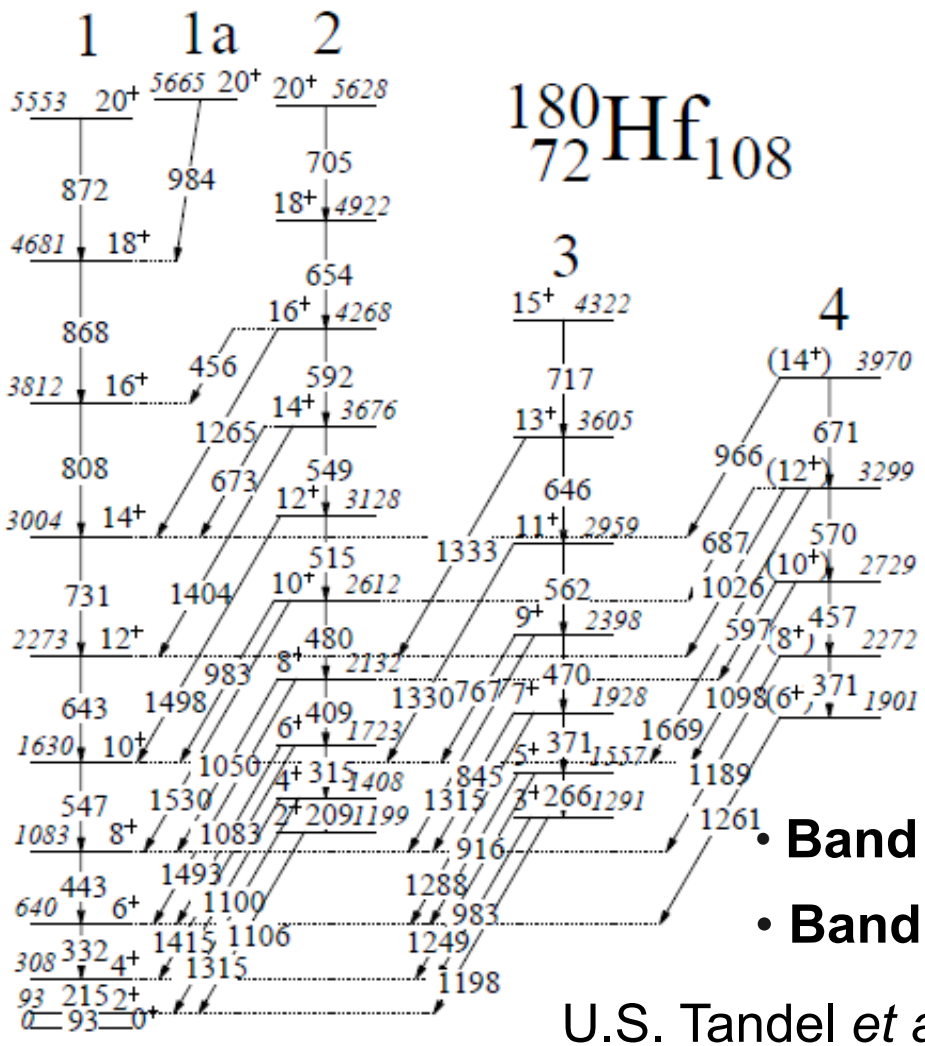
Mike Carpenter – ANL

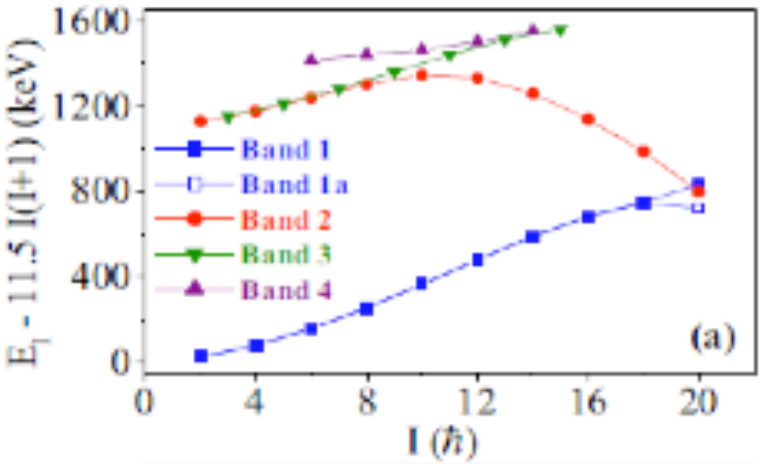
ORNL workshop

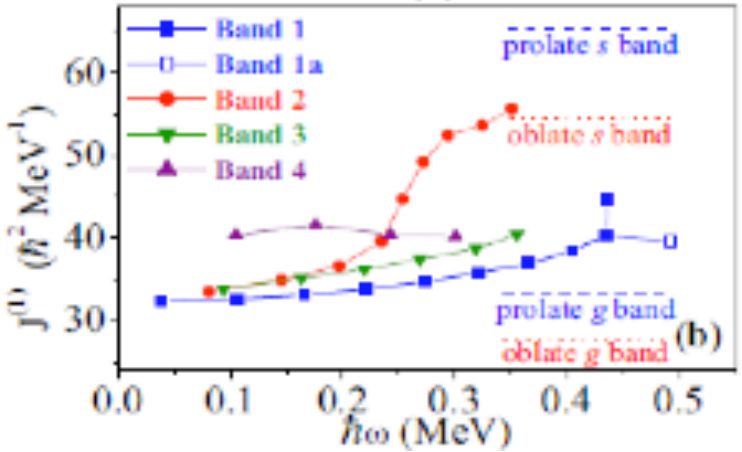
Nov. 13, 2009

Unsafe Coulomb Excitation of ^{180}Hf Beam on ^{232}Th target

Gammasphere + Chico







- **Band 1 – prolate gsb**
- **Band 2 – suggested to be oblate gsb**

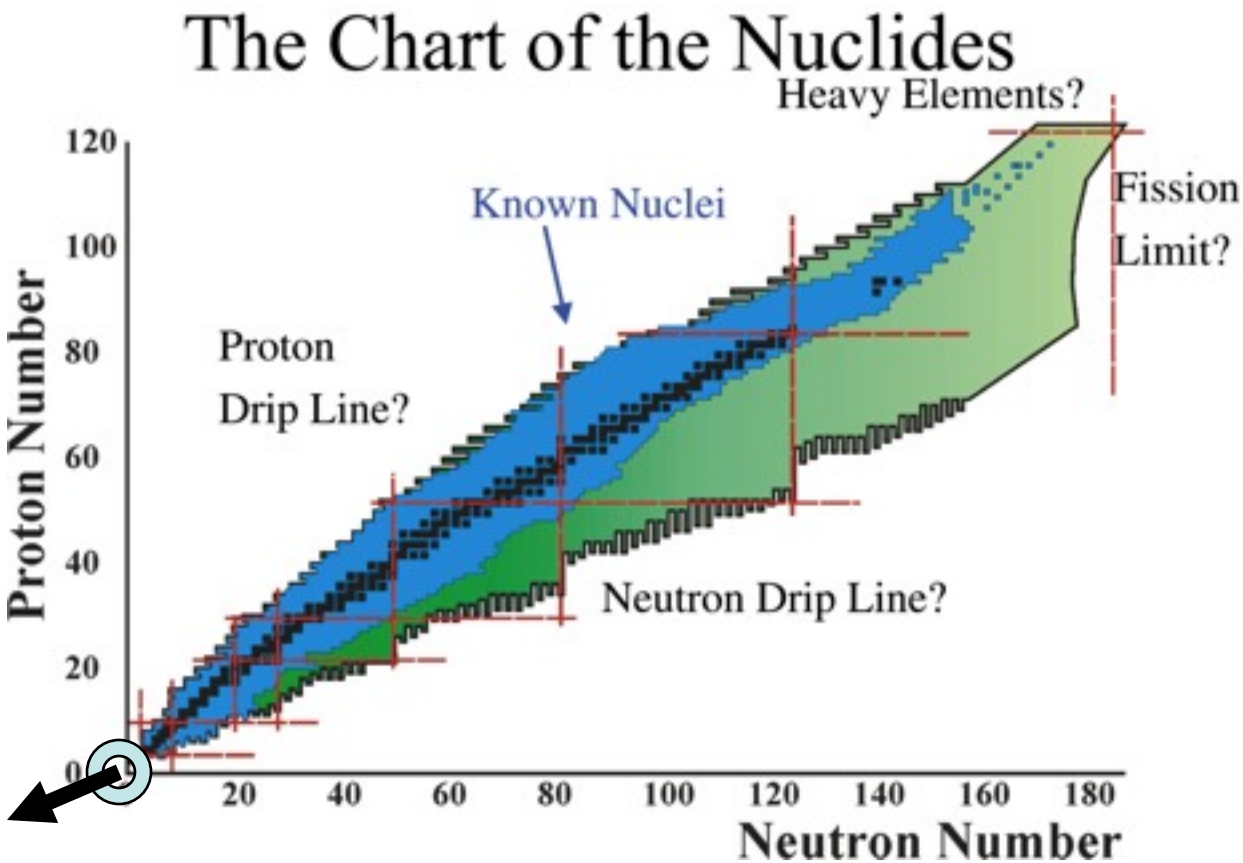
U.S. Tandel *et al.*, Phys. Rev. Lett

Could we do better with RIB beams available with HRIBF upgrade?

- Possible reactions to populate N = 108 isotopes at high spins:
  - $^{48}Ca(^{132}Sn,2n)^{178}Yb$ ($2x10^8$)
  - $^{48}Ca(^{134}Te,2n)^{180}Hf$ ($4x10^8$) or $^{50}Ti(^{132}Sn,2n)^{180}Hf$ ($2x10^8$)
  - $^{50}Ti(^{134}Te,2n)^{182}W$ ($4x10^8$)
- Experimental Equipment: GRETINA
  - similar efficiency to Gammasphere (~5.5%)
  - Also provides superior doppler reconstruction for inverse kinematics. Set limit for fusion evaporation at $1x10^6$ part/sec for 100 mb cross-section in favorable Q value cases
- Possible reactions to populate N > 108 isotopes at high spins:
  - $^{48}Ca(^{134}Sn,2n)^{180}Yb$ ($3x10^6$)
  - $^{48}Ca(^{136}Te,2n)^{182}Hf$ ($4x10^7$)
  - $^{48}Ca(^{138}Te,2n)^{184}Hf$ ($1x10^6$)
  - $^{50}Ti(^{136}Te,2n)^{184}W$ ($4x10^7$)
  - $^{50}Ti(^{136}Te,2n)^{186}W$ ($1x10^6$)

Looking at excited states in exotic nuclei allows us to extrapolate how single particle levels are changing farther from stability

Mark Riley



Increasing Angular Momentum and Excitation Energy:

An excellent way to investigate nuclear structure. Remember these studies are ultra-sensitive to what the intruder shells are doing!

Also don't let us forget

A mantra of Mark's for many years!

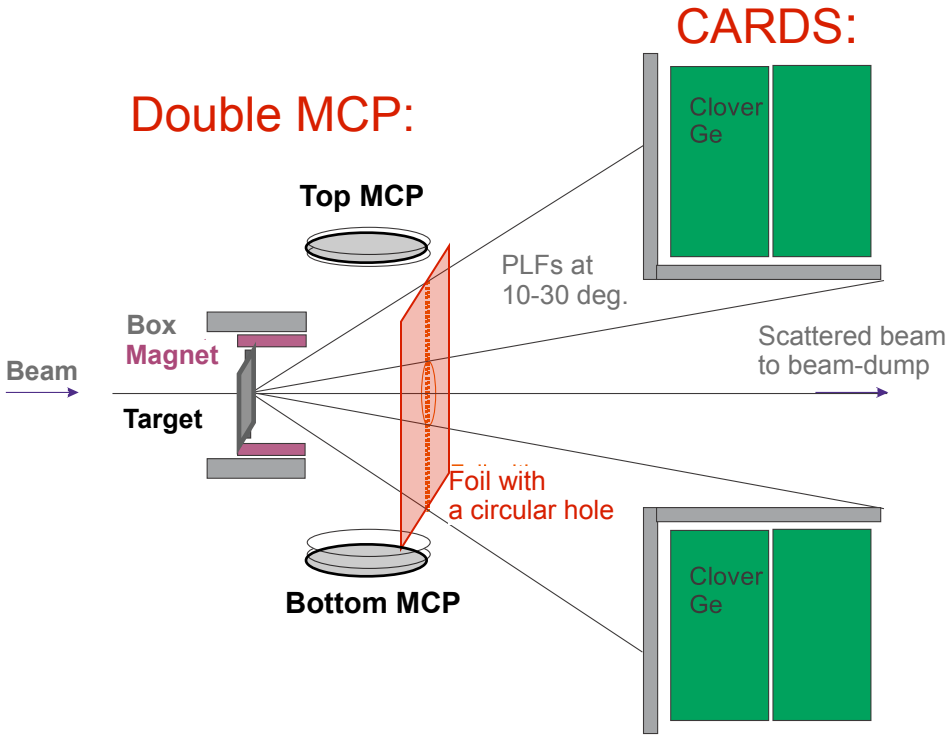
TARGETS – TARGETS – TARGETS

After going to so much trouble with creating the right beam and getting all the detector instrumentation ready to catch those "precious" signals we MUST NOT forget how important a role TARGETS (and **target makers**) play!

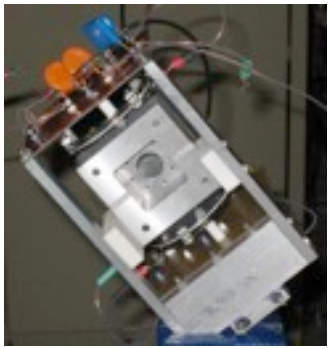
We should ALL be very concerned about this for the future!

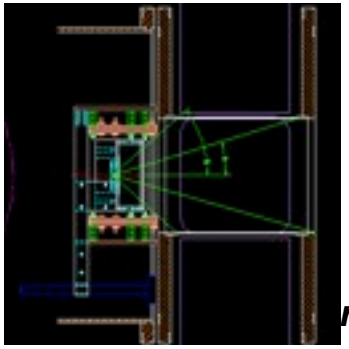
UT/Kraków Isomer-scope for experiments with RIBs

W. Królas, IFJ PAN Kraków



- radioactive beams of A ≈ 80 on ^{124}Sn or ^{130}Te target (~2 mg/cm^2)
- MCP tagging on PLFs emitted at and around the grazing angle, 10-30 deg. – MCP efficiency ≥ 90%
- scattered beam ions produce no signal
- CARDS: 4 Clover Ge detectors in a close geometry to measure time stamped γ(-γ) isomeric decay events in 10-1000 ns range



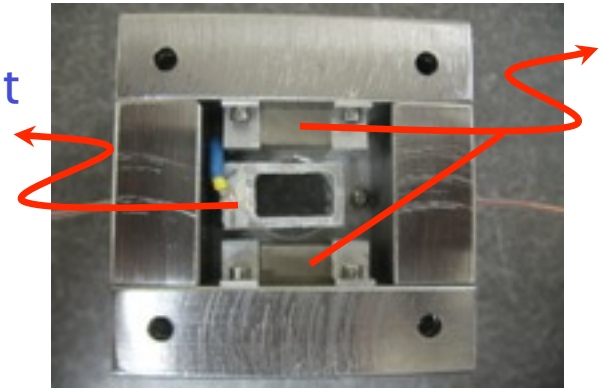


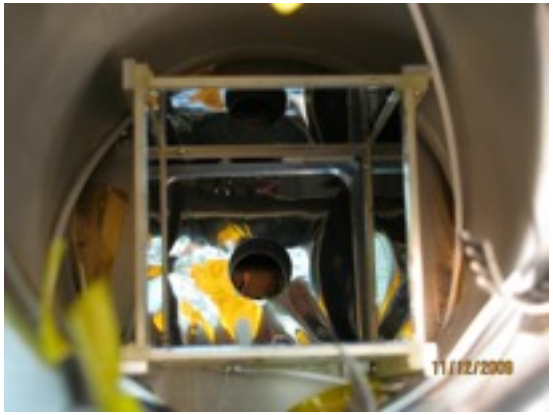
Dual micro channel plate detector system

Mustafa Rajabali, University of Tennessee

magnets

New target holder



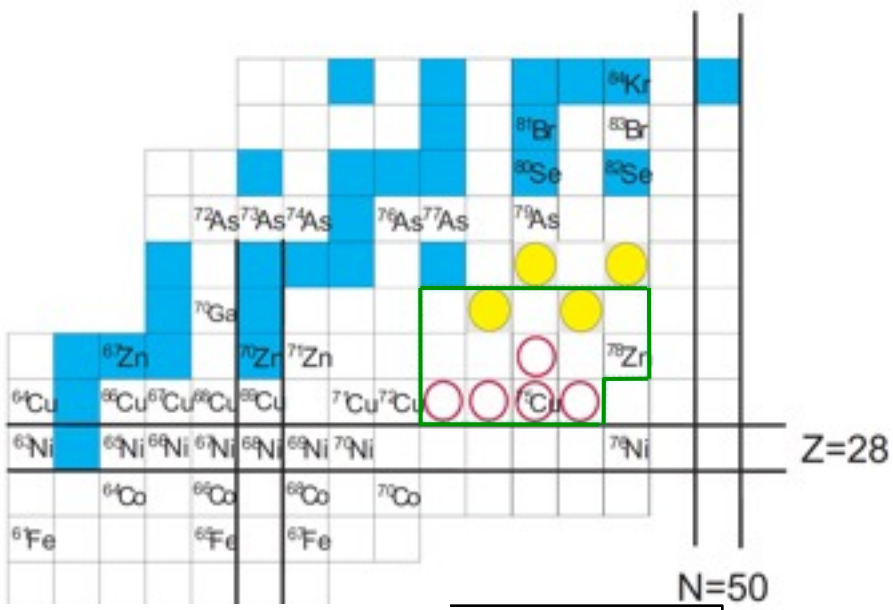


- **80%** efficiency for detecting events on the foil – this is excellent!
- Second verification of efficiency to be done on Monday 11/16/09
- Detector is **ready to search for ns isomers**

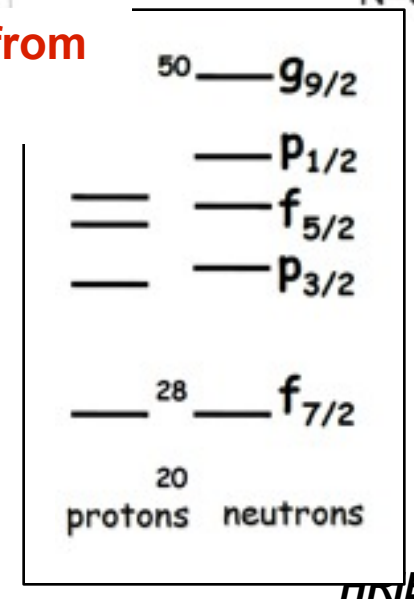
Future and other uses

- Reaction studies – limiting factors?
- Coulomb excitation measurements – position/angle sensitive DMCP !!

Isomer-scope experiments: ORIC beams



Isomers arise from $\nu g_{9/2}$ orbitals



Isomers in neutron-rich Cu and Zn isotopes:

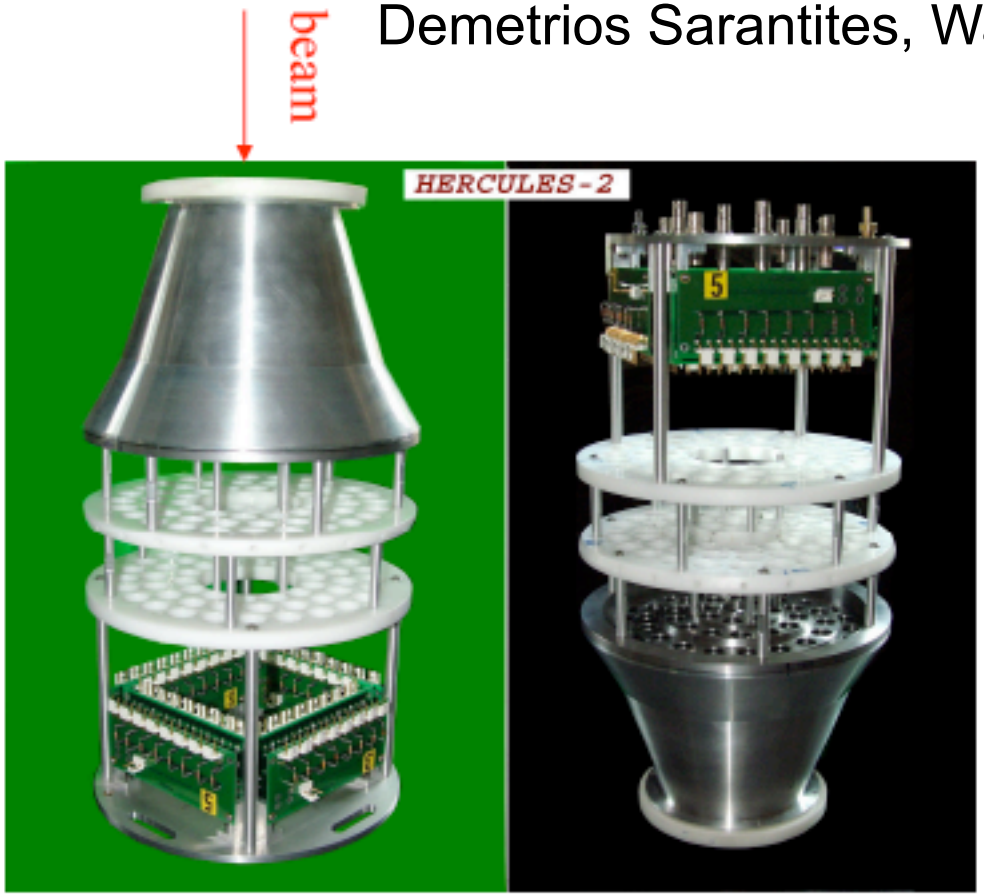
- In Cu isotopes - find yrast configurations dominated by $\nu g_{9/2}$ similar to the known $\nu g_{9/2}^2$ configurations of Ni isotopes
- Investigate the role of proton-neutron residual interactions, between $f_{5/2}$, $p_{3/2}$ protons and $g_{9/2}$ neutrons

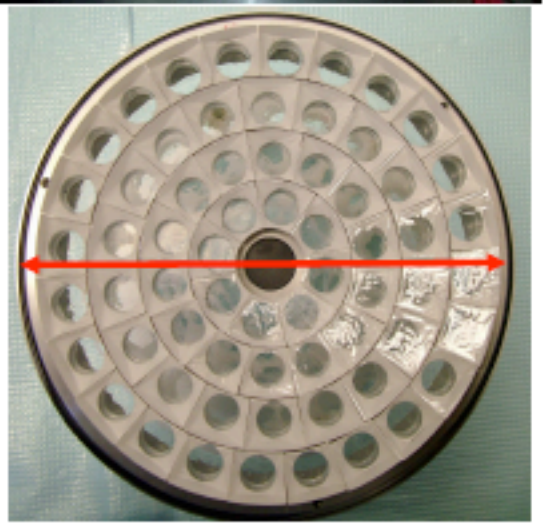
Original RIB-152 plan based on ORIC beams:

- ^{76,78}Ga and ^{78,80}Ge post-accelerated beams at 2 x 10^5 – 10^6 ions/sec
- Isomers in $^{73\text{-}76}$Cu, ^{76,78}Zn
- a 5 days experiment, from all rate estimates enough to observe isomeric decays

II. INSTRUMENTATION: (HERCULES–2)

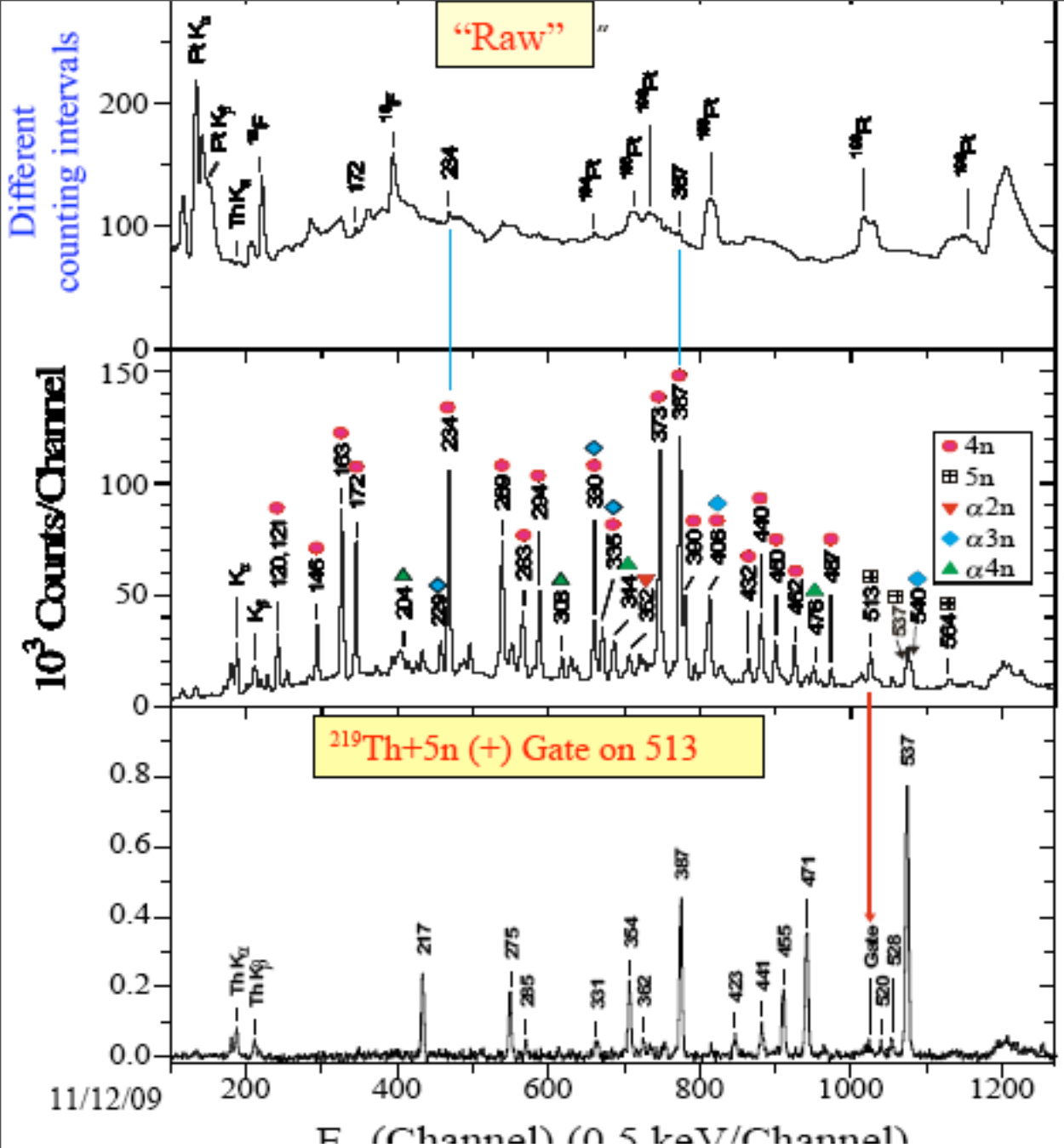
Demetrios Sarantites, Washington University





64 detectors in 4 rings

$\theta = 4.1^{o}\text{-}26.8^{o}$, $D_{target} = 23.2$ cm



$^{26}Mg + ^{198}Pt = ^{224}Th^*$

E_{lab}=128 MeV

$\pi \lambda^2$ relatively large a (++)

E_{ER} = 4.7-11 MeV

ER gated, **ε = 59(4) %**

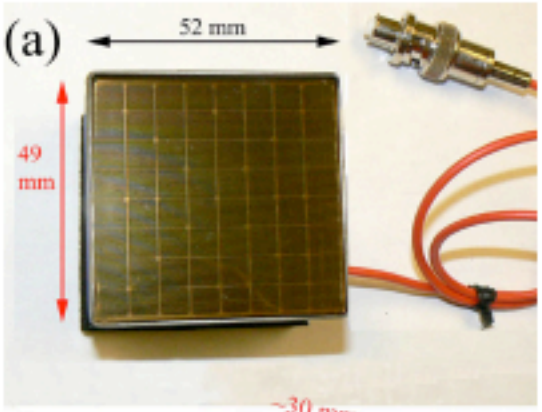
- ^{220}Th+4n
- ^{217}Ra+α3n
- ^{216}Ra+α4n
- ^{219}Th+5n
- ^{218}Ra+a2n

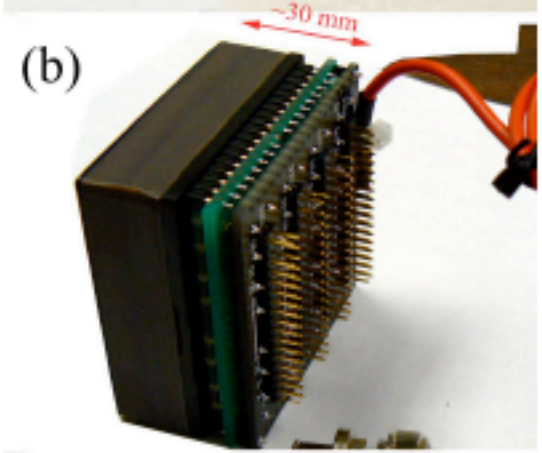
Decreasing σ

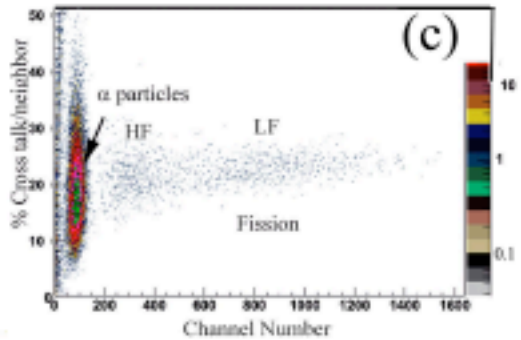
ER and γ gating

SuperHERCULES: an Array with 8x8 pixel Multianode PMT (H8500)

- Pixel size 6.0 x 6.0 mm^2
- Active packing faction 89%
- Use common light-guide 0.15 mm thick plastic (50x50 mm^2)
- 1.0 mg/cm^2 fast scintillator on top. Counting rate up to 100 kHz per pixel.
- Prototype module tested in beam at ATLAS (electron suppression+individual channel gating easily detected: ER, target recoils and Fission fragments (by ToF + Pulse height)
- Planned Readout with Sobotka's PSD Chip (216-channel array available now, 512 under construction).
- Subpixel-Position Determination (SPD) analysis in progress Uses PH ratio of central hit to neighbor. It gives 1-2 mm position resolution.







11/12/09

Magnetic moments: "Why, how, and what is possible at this time"

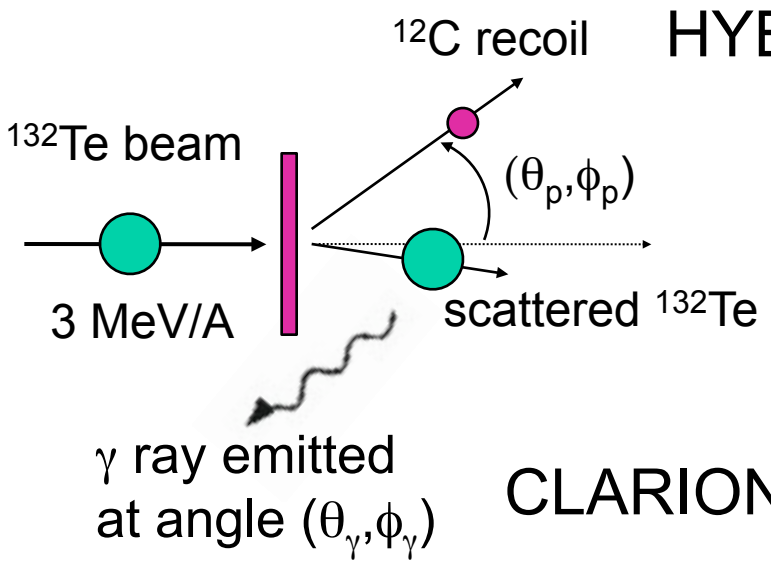
Gerfried Kumbartzki

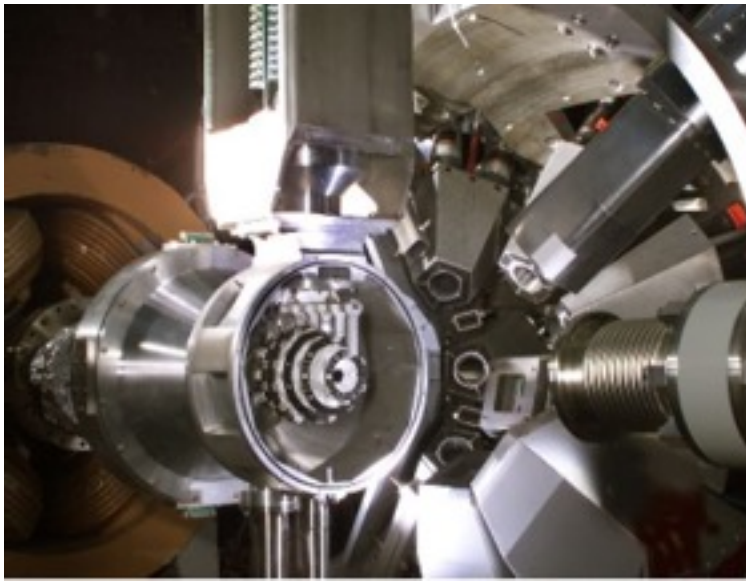
What is possible

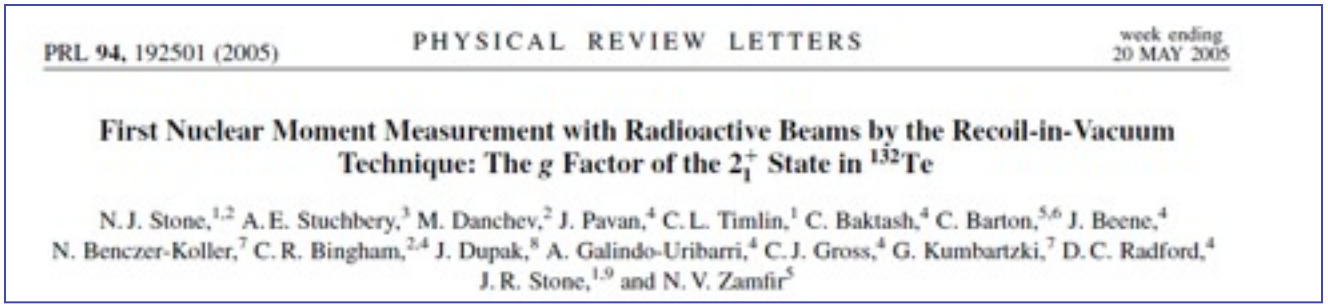
- The interesting physics for now is limited by available beams
- Both methods rely on statistics
- Minimum of 10^6 particle/sec
- Minimize radioactivity buildup near target
- Recoil in Vacuum
  - Simple (thin) target
  - Larger available detector arrays
- Transient fields
  - Relatively thick ferromagnetic foil
  - Detector arrays can be used
  - Need magnet at target
  - Cool Gd to LN temperatures

RIV example: ^{132}Te CLARION+HYBALL at HRIBF Nick Stone

Slow beams: v/c < ~ 6%



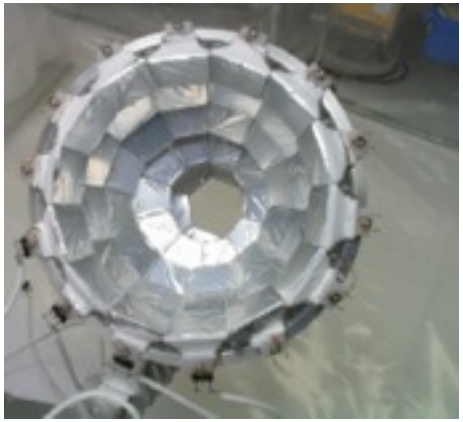




PRL 94, 192501 (2005) PHYSICAL REVIEW LETTERS week ending 20 MAY 2005

First Nuclear Moment Measurement with Radioactive Beams by the Recoil-in-Vacuum Technique: The g Factor of the 2_1^+ State in ^{132}Te

N. J. Stone,[1,2] A. E. Stuchbery,[3] M. Danchev,[2] J. Pavan,[4] C. L. Timlin,[1] C. Baktash,[4] C. Barton,[5,6] J. Beene,[4] N. Benczer-Koller,[7] C. R. Bingham,[2,4] J. Dupak,[8] A. Galindo-Uribarri,[4] C. J. Gross,[4] G. Kumbartzki,[7] D. C. Radford,[4] J. R. Stone,[1,9] and N. V. Zamfir[5]



Multiple-step Coulomb excitation
David Kulp, Georgia Tech

- Few-step Coulex studies with the upgrade are possible.
- GRETINA will extend reach to shapes with less mixing, as well as to nuclei farther from stability.
- Mapping quadrupole and triaxiality parameters will provide key insight into coexisting shapes near subshell gaps that may otherwise be unrecognized.
- Multiple spectroscopy programs (e.g., with decay and transfer studies) and systematic studies will yield a more complete picture.
- HRIBF will not be alone - focus on selectivity and work with neighbors up North.

Conclusions from session

1. GRETINA is on track; community needs and supports GRETINA followed by GRETA; GRETINA is 16x better than Clarion for measurements at Holifield
2. C70 and GRETINA give an expansion of physics around ^{132}Sn; use GRETINA for Coulexc and transfer reactions of lowest cross section; need increased focus on auxiliary detectors
3. BaF_2 array can be used for niche experiments that need highest efficiency where energy resolution is not so important, e.g., ^{132}Sn; but, need an upgrade
4. Coulexc could be done on heavy Ge with C70, and farther out with GRETINA
5. ^{56}Ni beam is very important for N = Z physics; low cross section is a problem, but C70 with laser ion source would enable new N = Z physics by getting rid of ^{56}Co contaminant

Conclusions from session

6. Should be able to do (HI,2n) for high-spin spectroscopy with C70 RIBs as low as 10^6 particle/sec level in favorable cases, e.g., using ^{134}Sn or ^{136,138}Te beams - explore a variety of physics questions in uncharted areas of high spin and high excitation energy in nuclei that cannot be reached with stable beams
7. Our community needs to have a plan for the future for making targets of isotopes that we need for our experiments
8. Probe yrast structure in region of ^{78}Ni using enhanced RIBs from C70 using study of isomers, giving sensitive single-particle information; work is progressing on the dual micro-plate detector system for study of ns isomers
9. SuperHercules holds great potential for study of transfer reactions coupled to GRETINA
10. g factor measurements give vital information on composition of state and are being done with RIBs, and will have a wider possibility with C70; understanding the theory of RIV is important
11. Few step Coulexc studies with C70 possible to explore shape coexistence around N = 50, e.g.; but need to cooperate with ISAC