Spectroscopy with Heavy Neutron-Rich RIBS at the HRIBF

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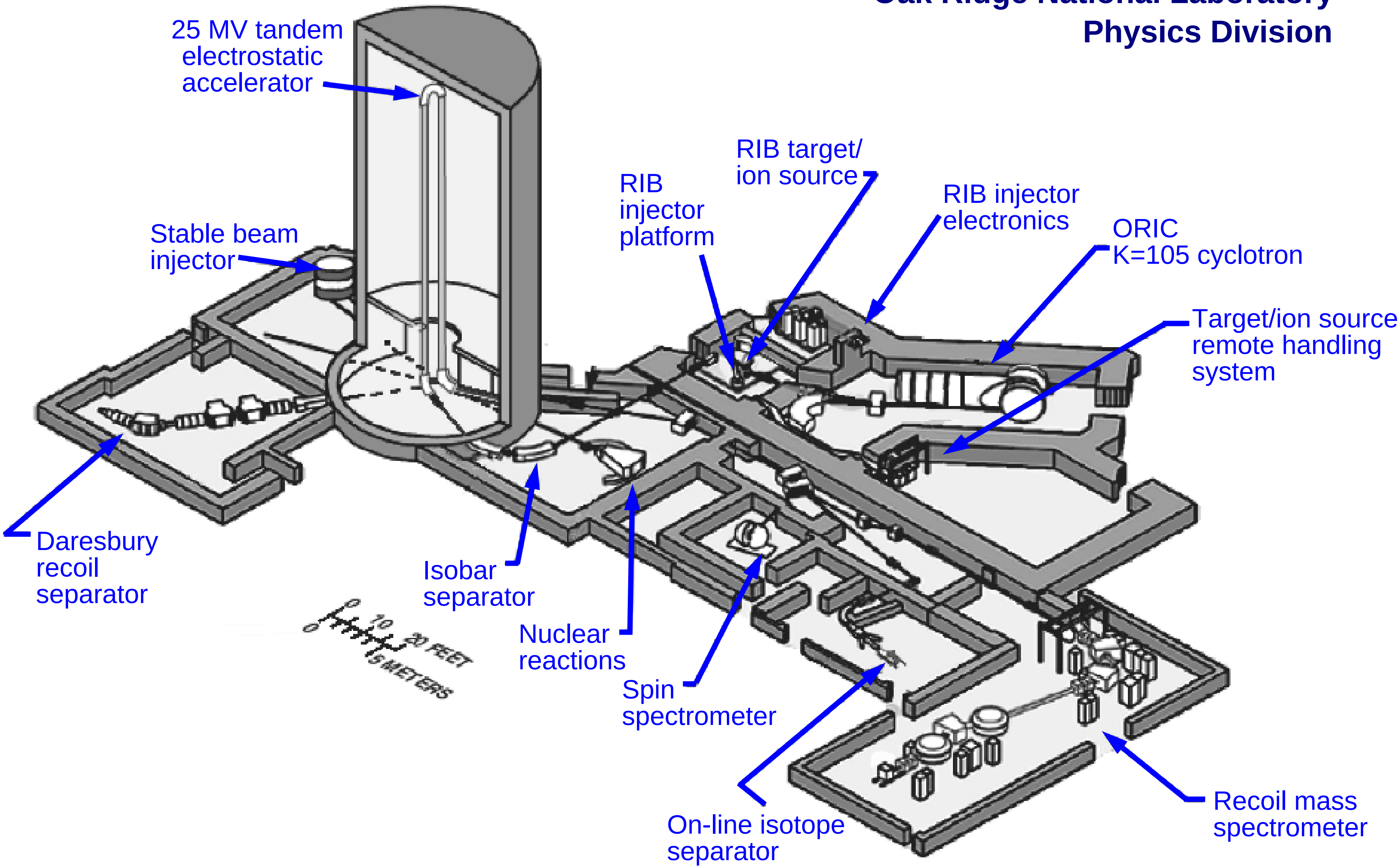
RNB6 Sept. 2003

Outline:

- RIB Coulomb Excitation using CLARION
- RIB Coulomb Excitation using BaF_2 array
- (^{9}Be, ^{8}Be) and (^{13}C, ^{12}C) neutron transfer
- Plans and conclusion

The Holifield Radioactive Ion Beam Facility

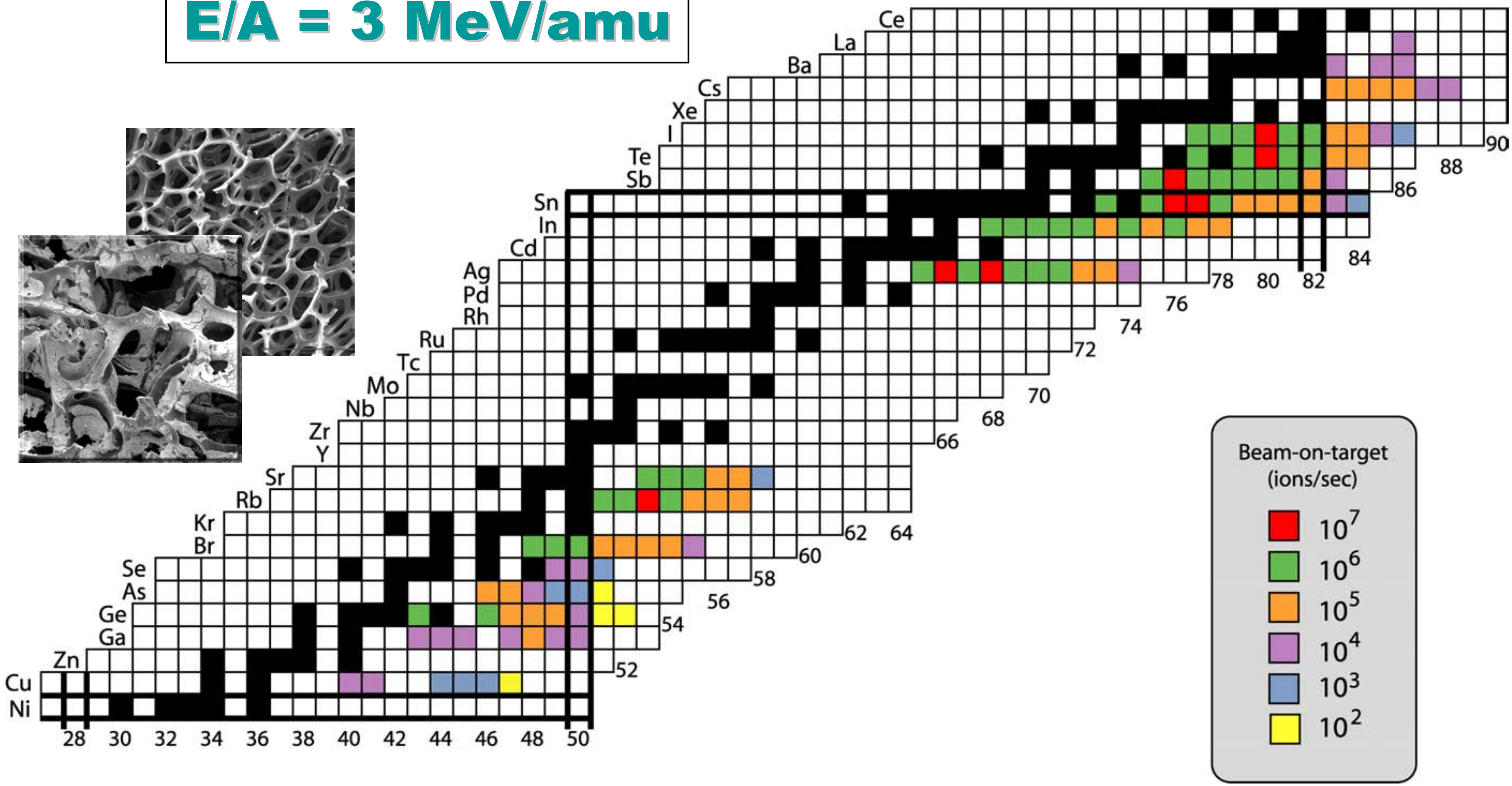
Oak Ridge National Laboratory
Physics Division



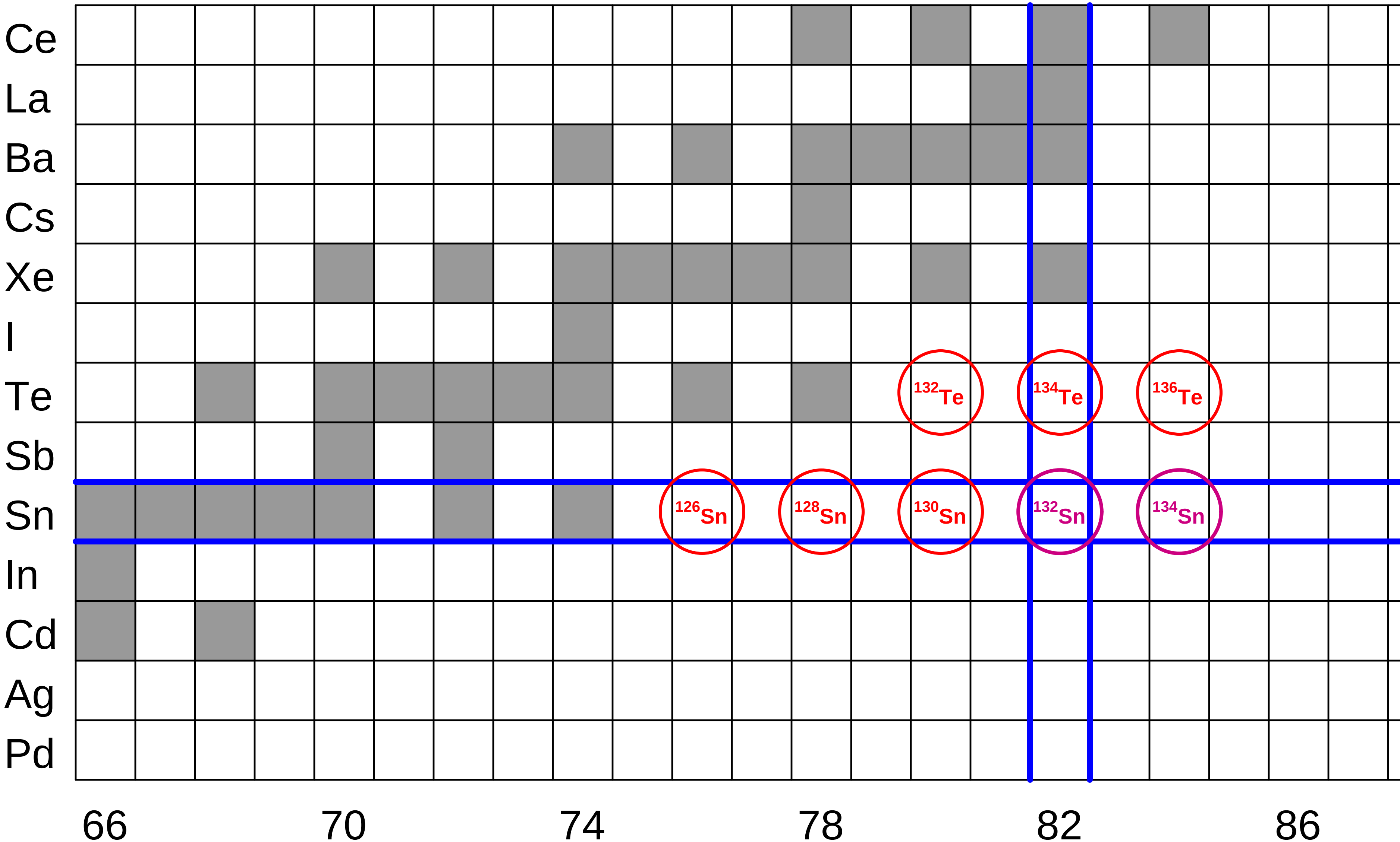
Available Neutron-rich Radioactive Ion Beams

(over 100 beams with intensities ≥10^3 ions/sec)

E/A = 3 MeV/amu



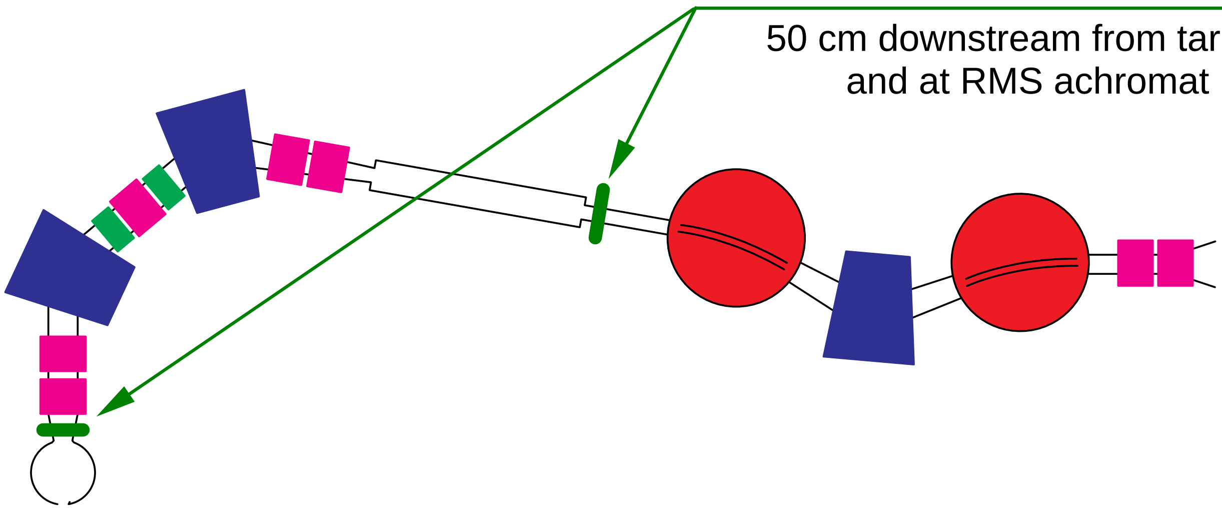
Coulomb Excitation Measurements Near ^{132}Sn

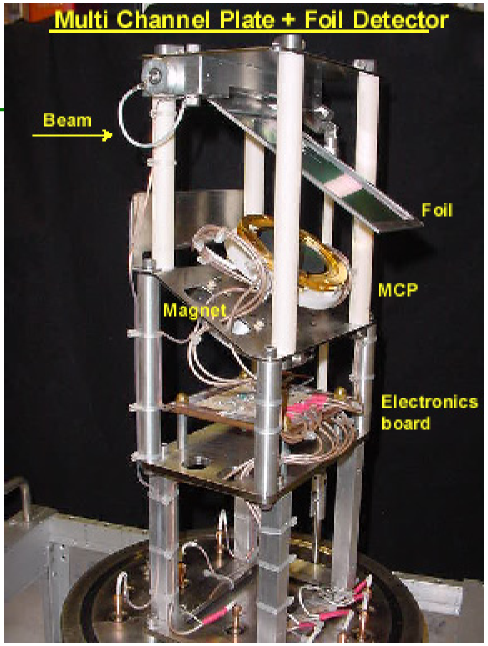


Setup for experiments with neutron-rich RIBS at the RMS

Recoil Detectors

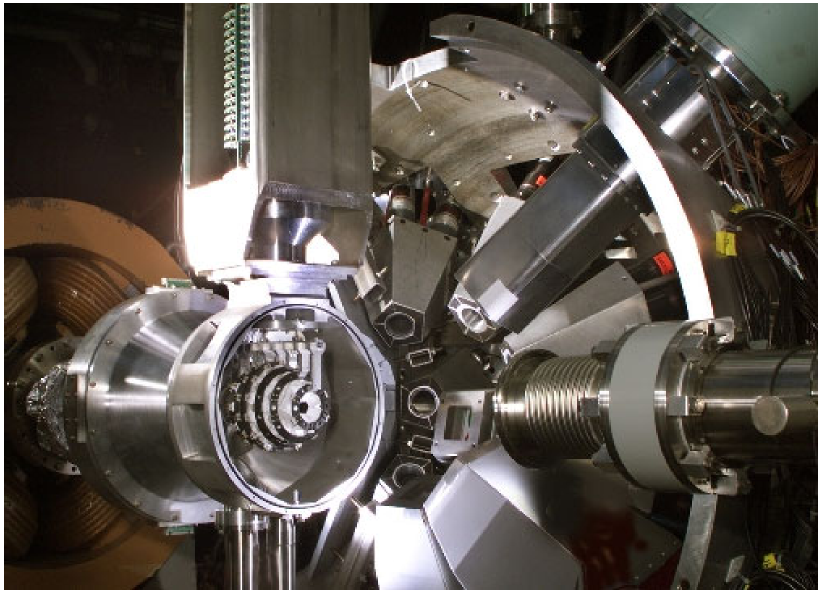
50 cm downstream from target
and at RMS achromat





Foil plus multichannel plate

Target



CLARION

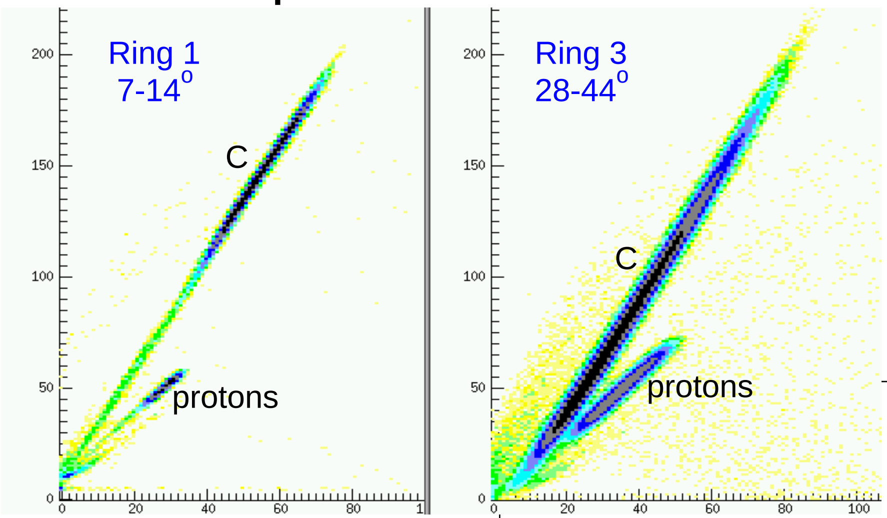
11 segmented clover Ge detectors

HyBall

95 CsI detectors with photodiodes

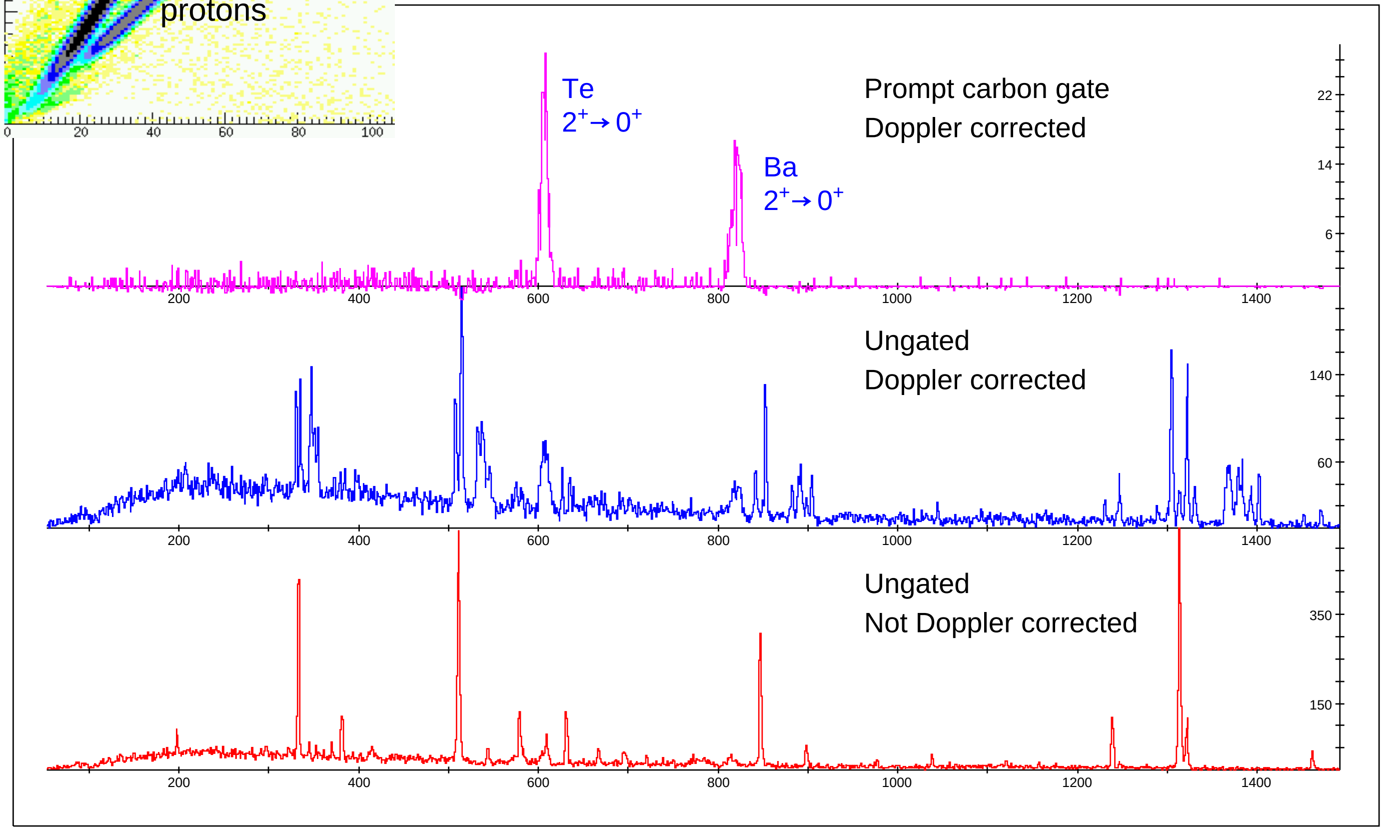
Example: A = 136 Coulex

Particle ID Spectra:



396 MeV A = 136 (^{136}Te + ^{136}Ba)

on 0.83 mg/cm^2 C target



RIB Coulex Analysis

- **Measure** $\dfrac{\gamma\text{-HyBall coincidences}}{\text{HyBall singles}} = \dfrac{\sigma_C}{\sigma_R}\,\varepsilon_\gamma$

- **Calculate** $\dfrac{d\sigma}{d\Omega}$ **for Coulex and Rutherford as a function of B(E2)**

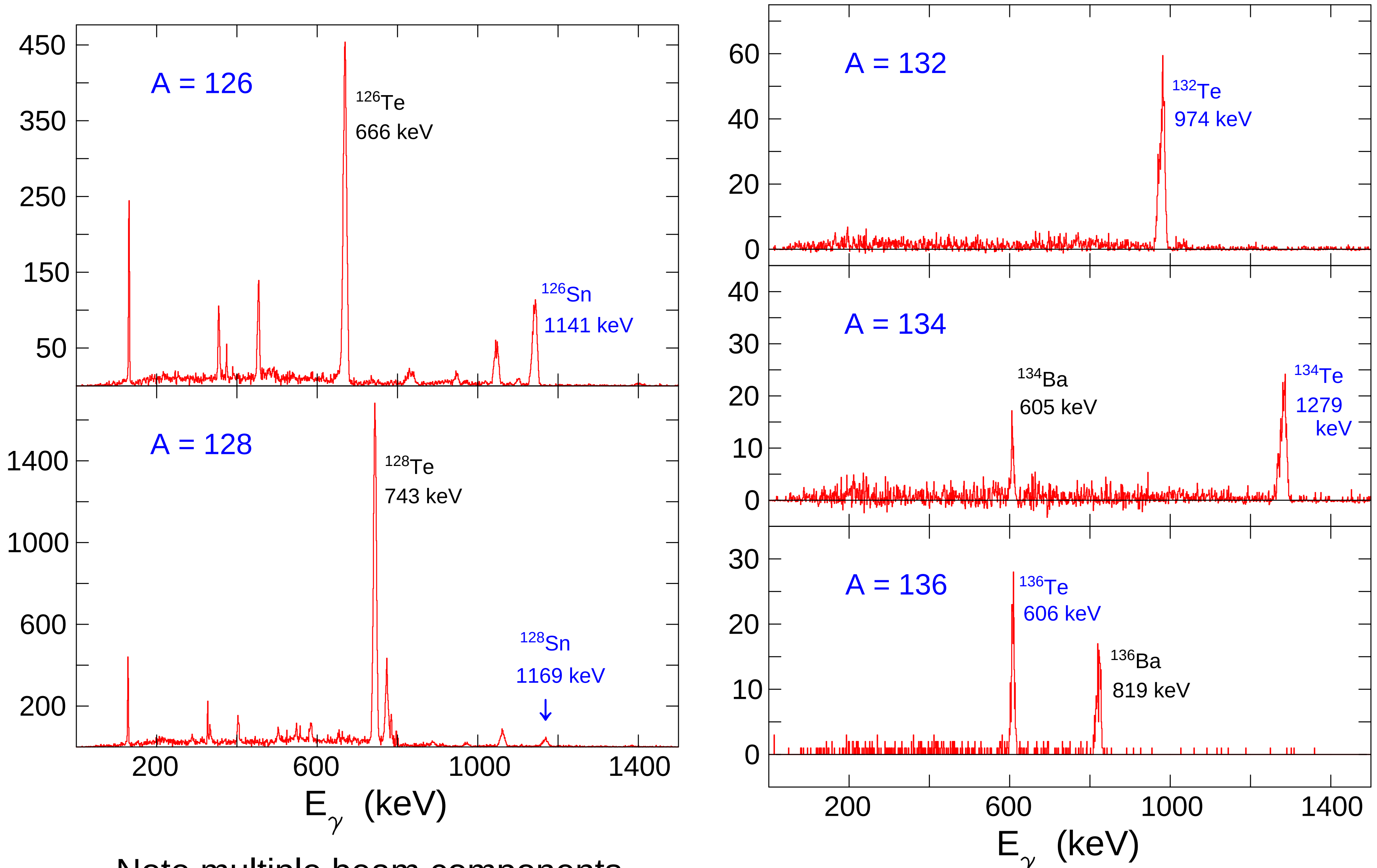
- **Integrate** σ **over the first three rings of HyBall**

- **Compare calculated** $\dfrac{\sigma_C}{\sigma_R}\,\varepsilon_\gamma$ **with observed** $\dfrac{\gamma H}{H}$ **to get B(E2)**

- **Correct for isobaric content of the beam**

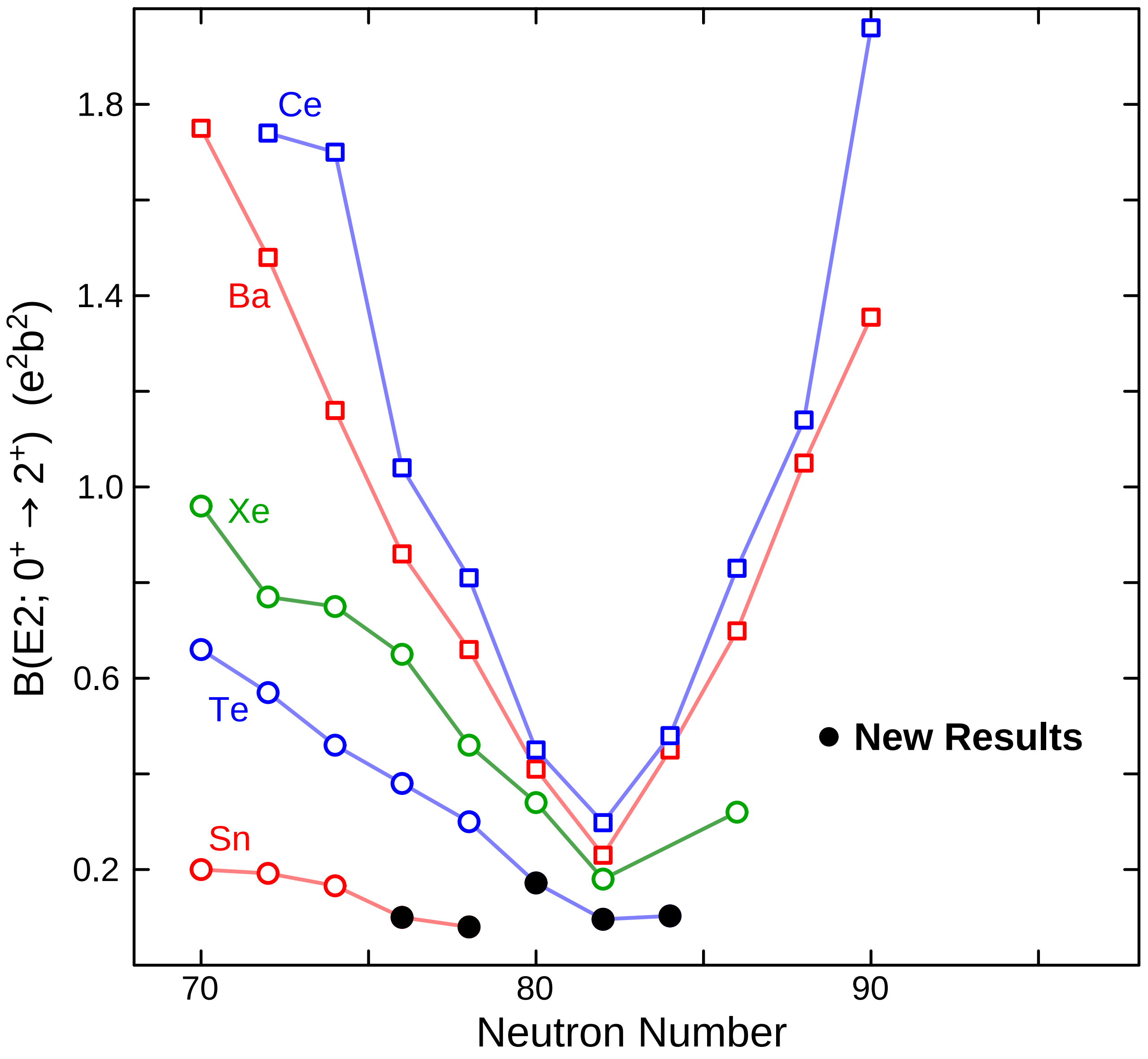
  - determined from Coulex of stable contaminants,
    decay counting, and X-ray or Bragg detector spectra

Coulex Results: Sn & Te Spectra



Note multiple beam components

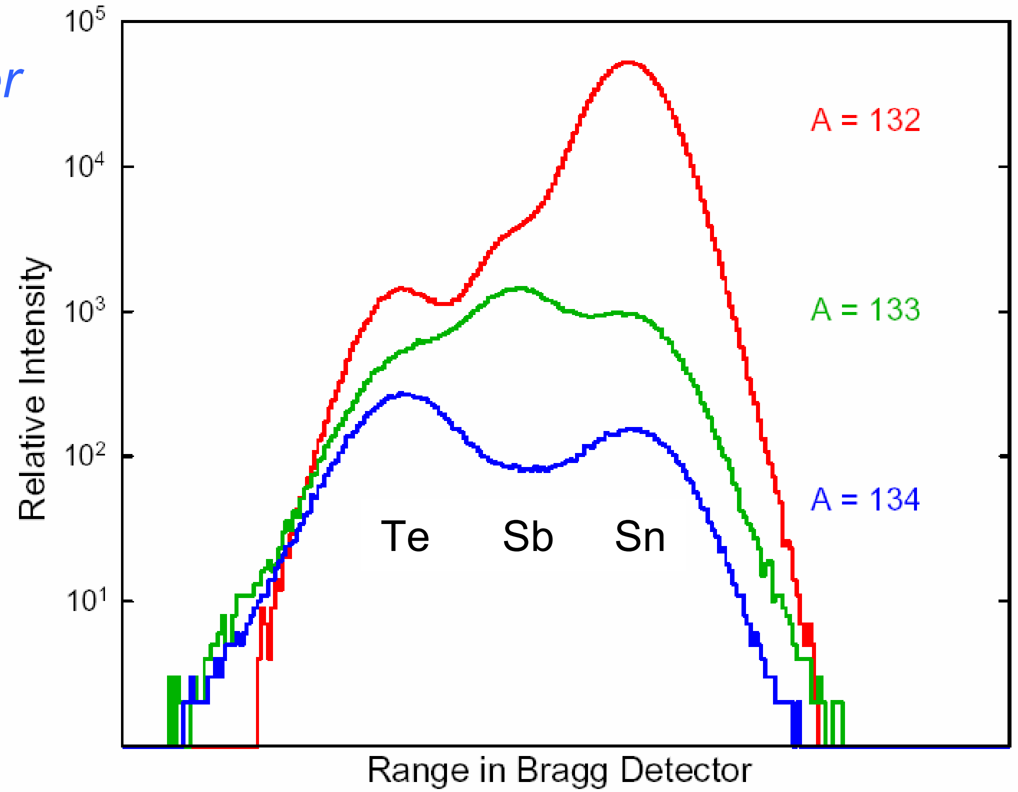
B(E2) Results and Systematics

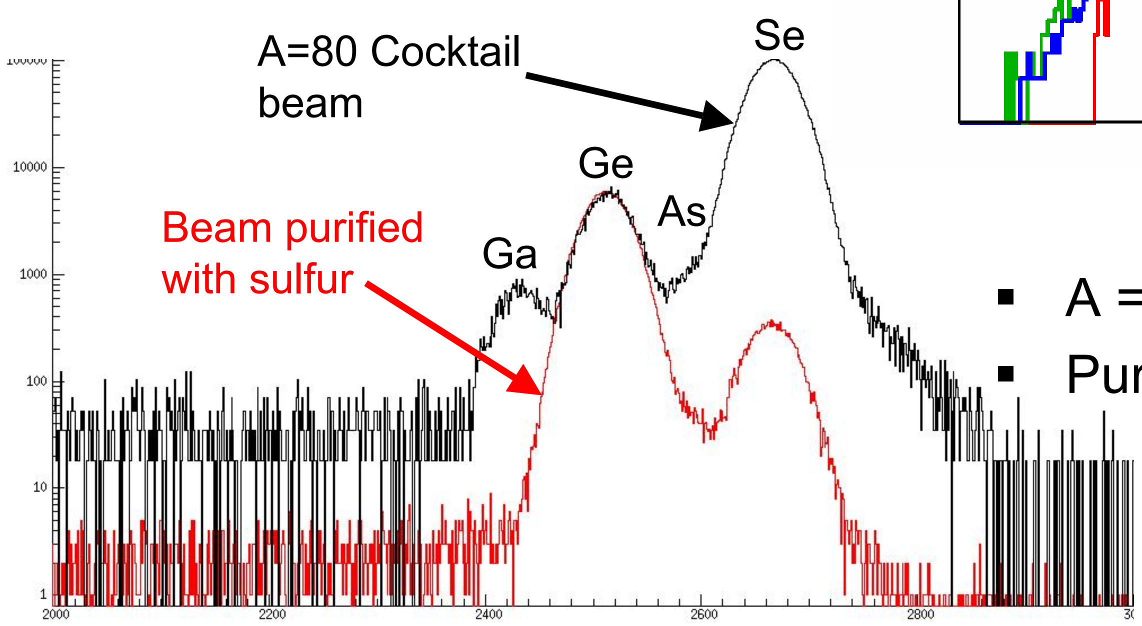


Beam Purification with Sulfide Molecular Ions

-Yesterday's talk by Dan Stracener

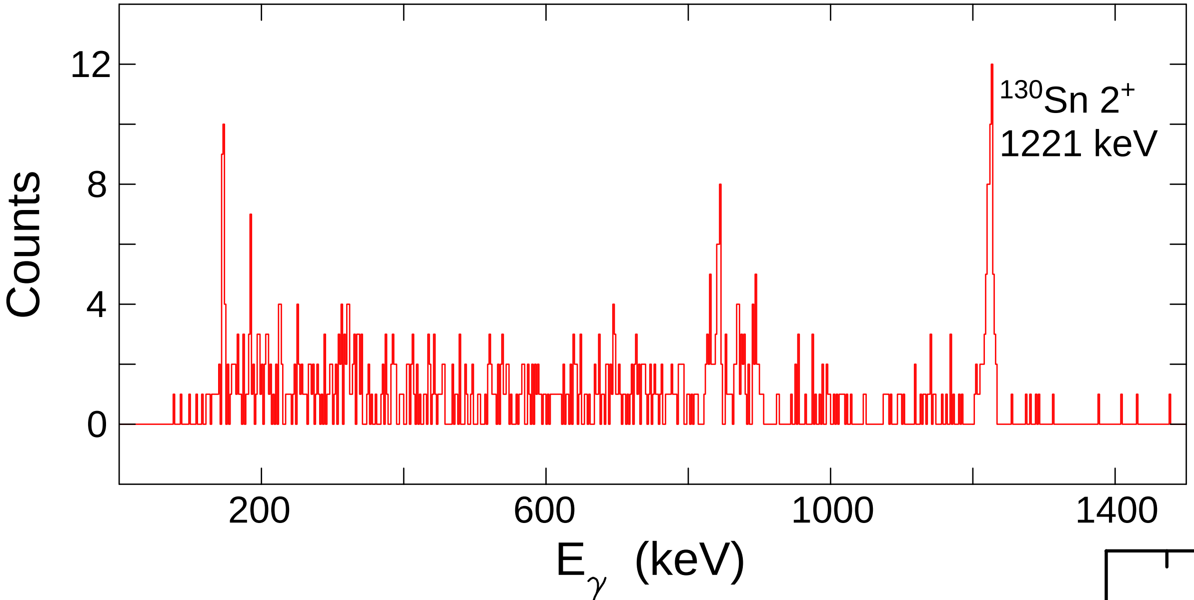
- A = 132 cocktail is
  ~ 85% Te, ~ 1% Sn
- Purified A = 132 beam is
  < 1% Te, > 95% Sn





- A = 80 cocktail is > 90% Se
- Purified A = 80 beam is 95% Ge

Coulomb Excitation of Pure ^{130}Sn RIB



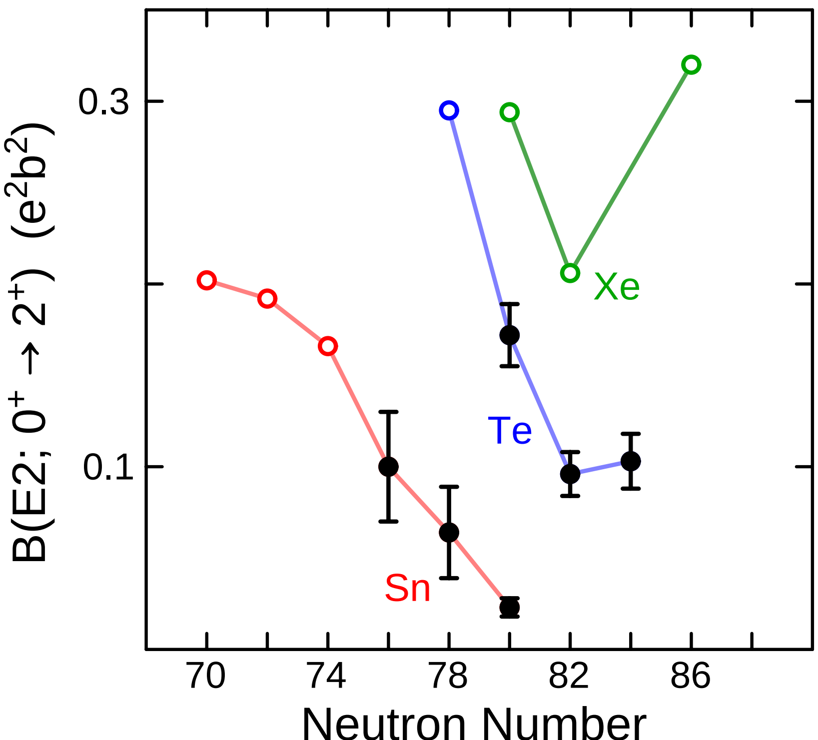
5×10^5 Pure ^{130}Sn s^{-1}

89% g.s., 11% 7^- isomer

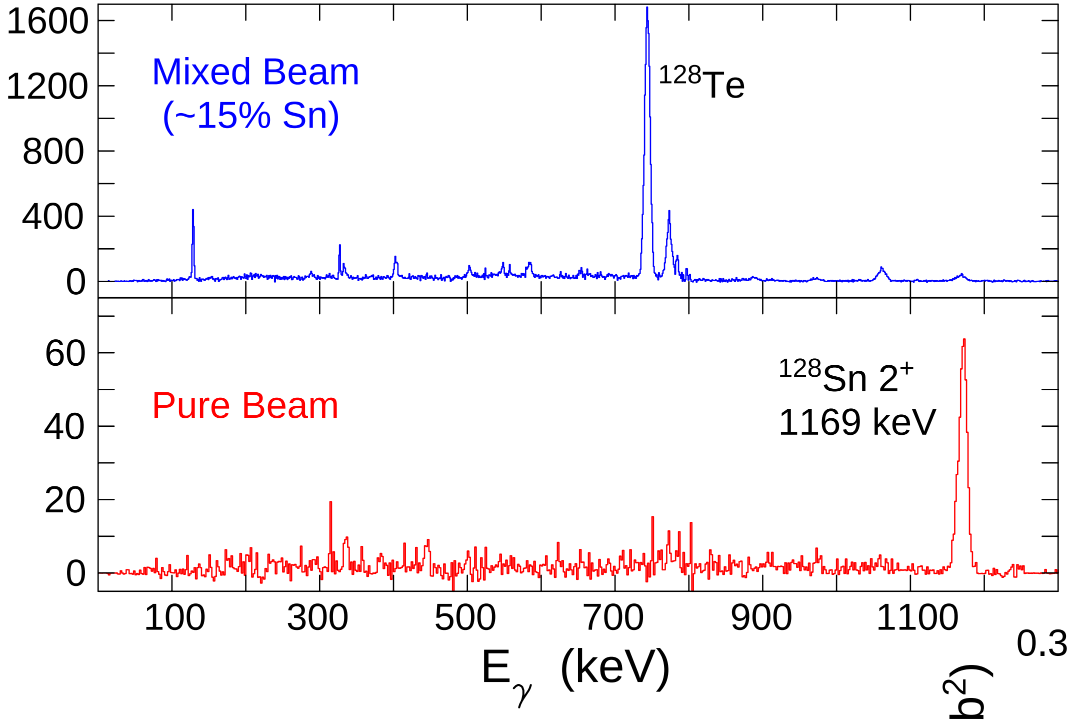
$B(E2; 0^+ \rightarrow 2^+) = 0.023(4)\ e^2b^2$

$= 1.2$ s.p.u.

$\sigma_C = 1$ mb



Coulomb Excitation of Pure ^{128}Sn RIB

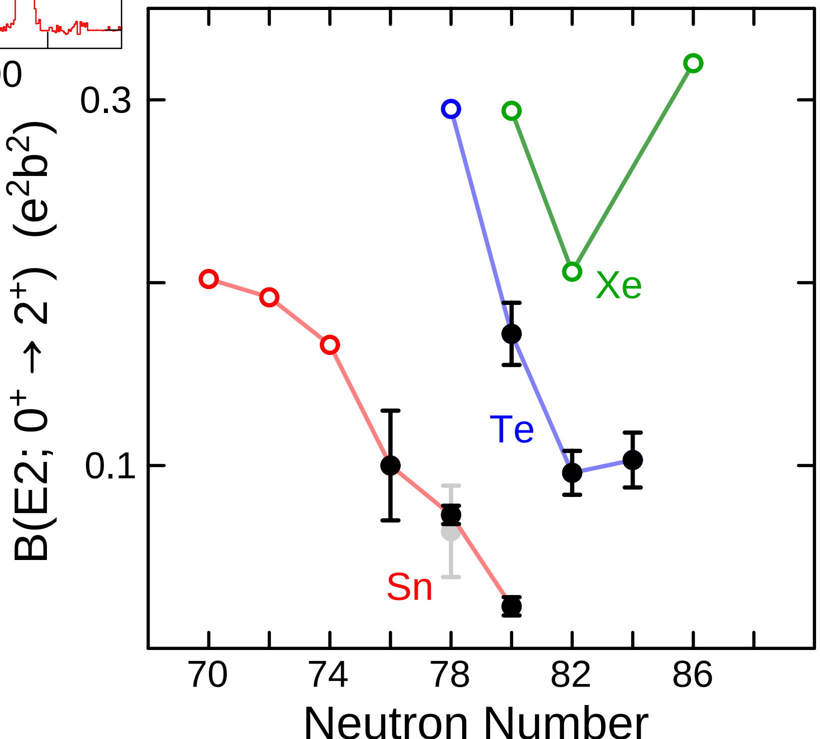


3×10^6 Pure ^{128}Sn s^{-1}

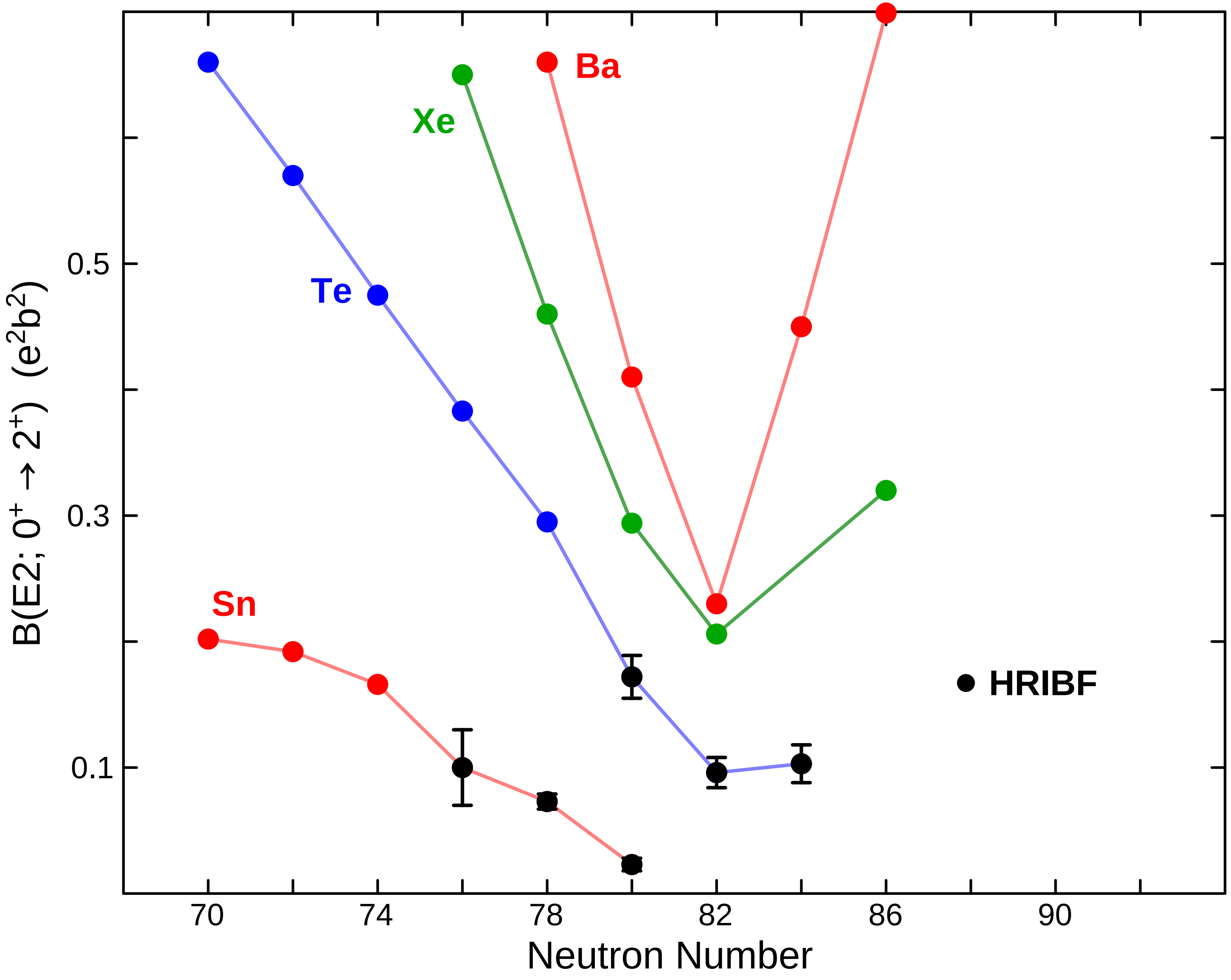
91.5% g.s., 8.5% 7^- isomer

$B(E2; 0^+ \rightarrow 2^+) = 0.073(5)\ e^2b^2$

(preliminary!)



B(E2) Results

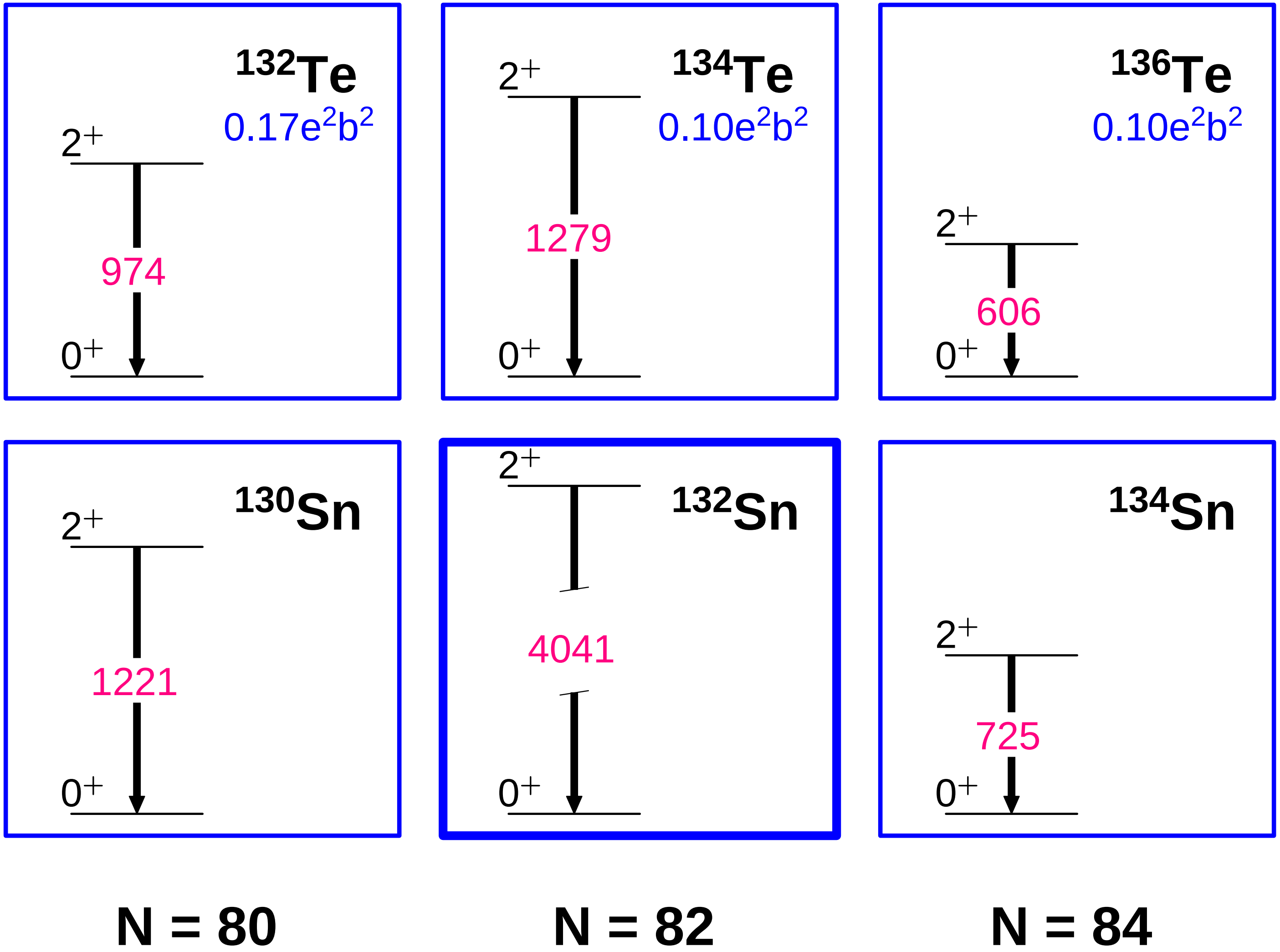


Ba
Xe
Te
Sn
HRIBF
0.5
0.3
0.1
70
74
78
82
86
90
Neutron Number
B(E2; 0+ → 2+) (e2b2)

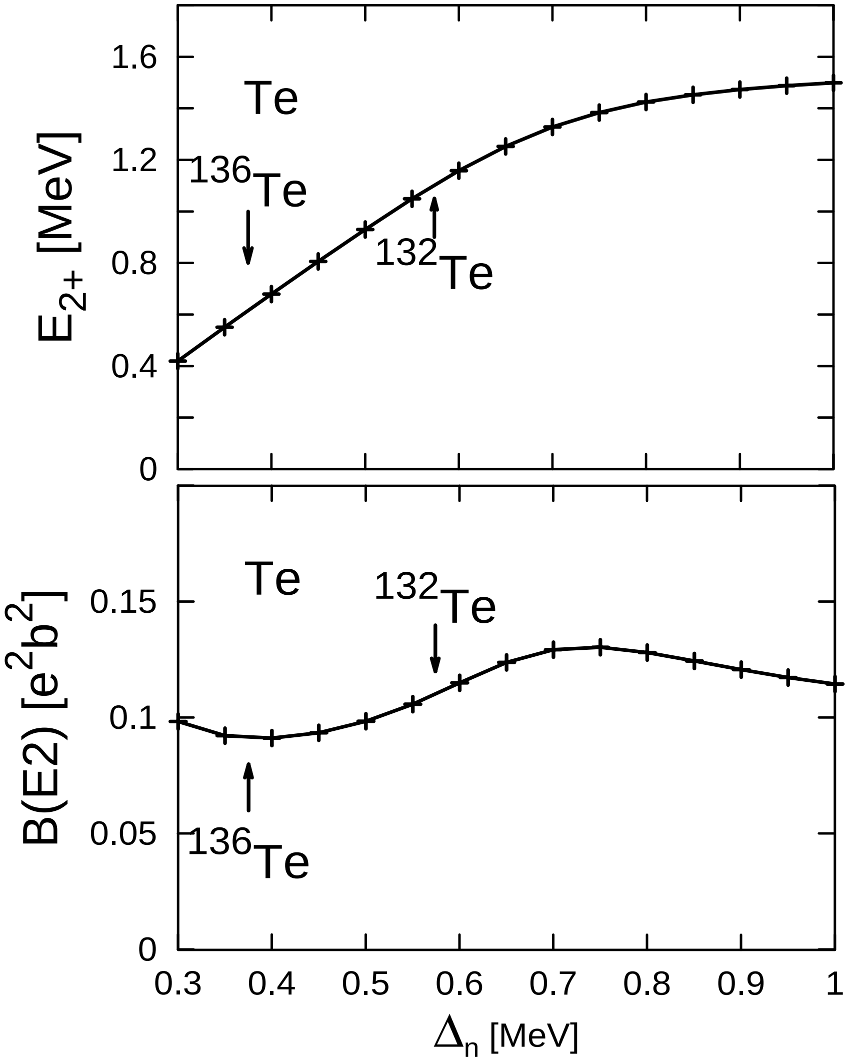
^{136}Te: Low B(E2) Value

The low value for the B(E2) in ^{136}Te is (was) very surprising

- Energy of 2^+ levels is also low

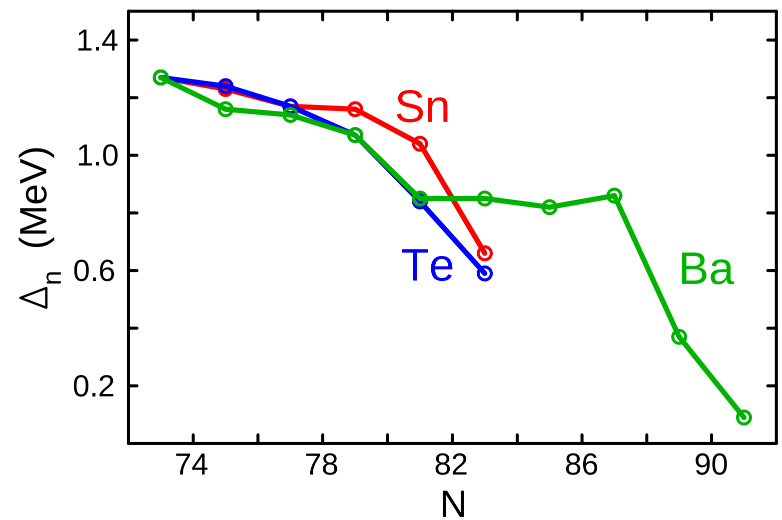


Quasiparticle RPA Calculations - J. Terasaki *et al.*

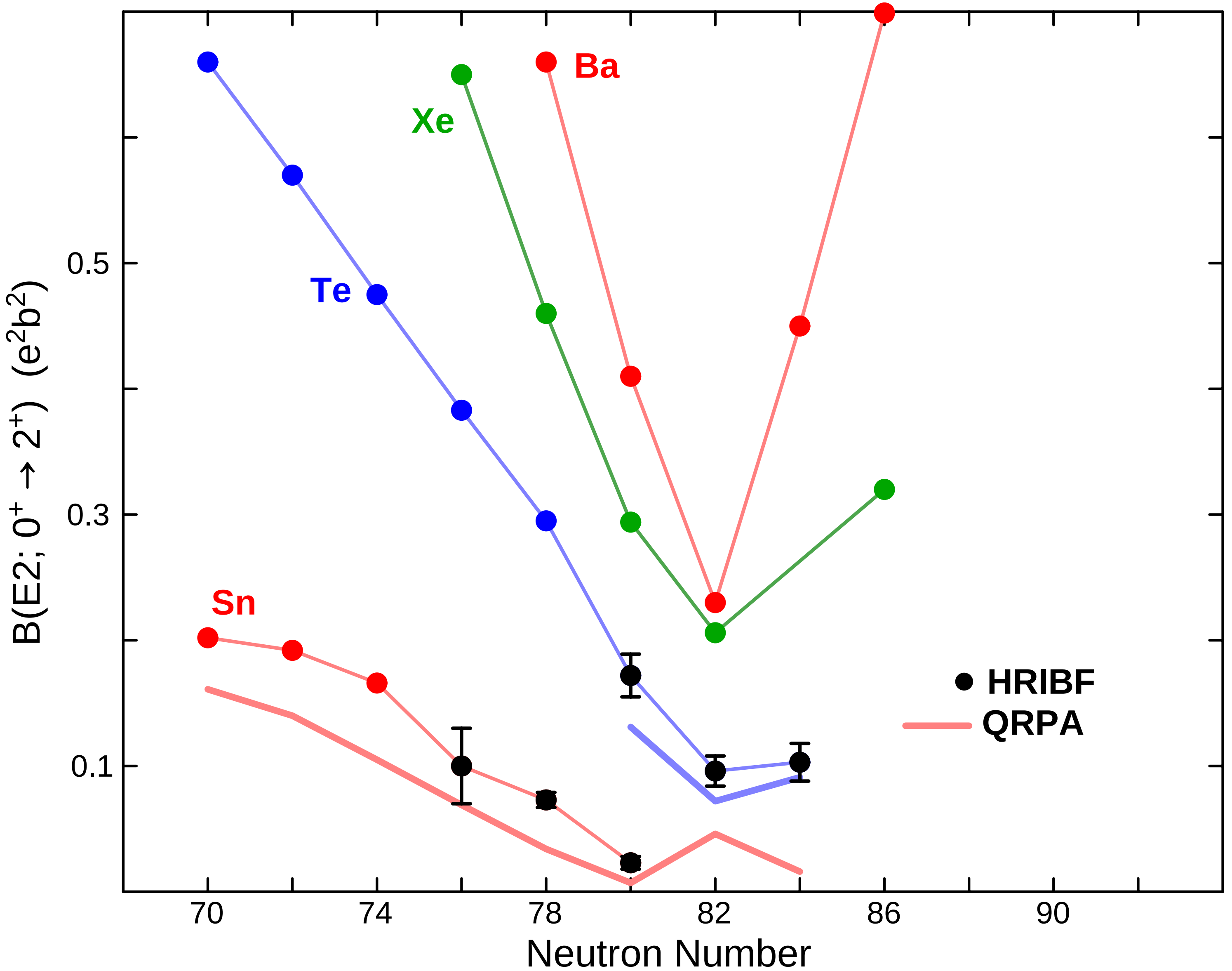


Energy and B(E2) both **decrease**
for small values of neutron pairing gap

Neutron pairing strength from
experimental odd-even mass differences:



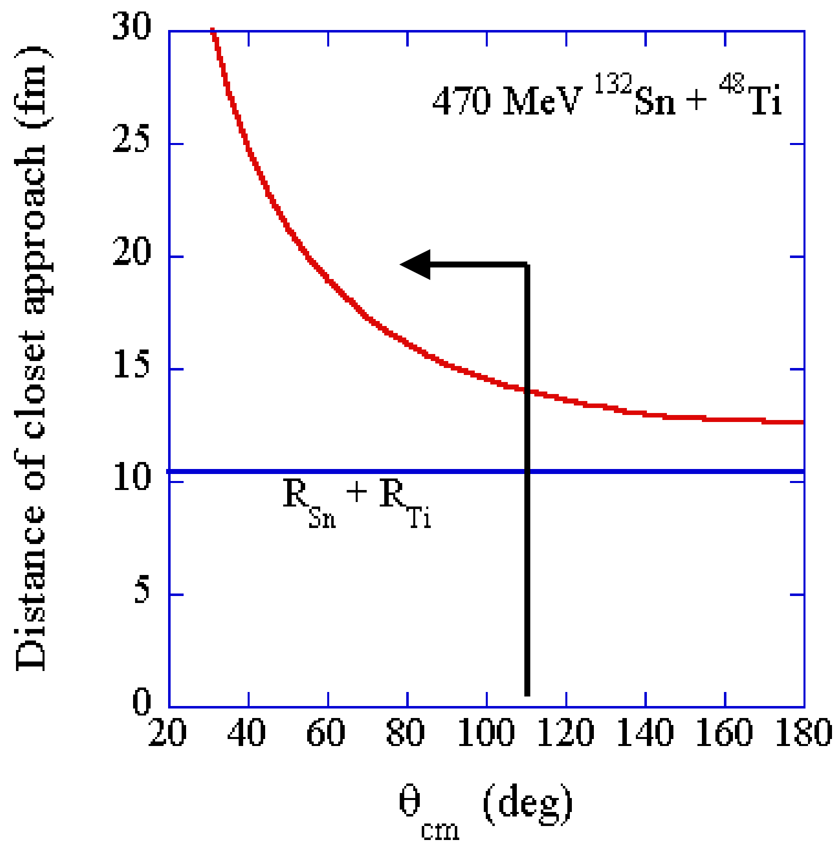
B(E2) Results with QRPA Calculations (Terasaki *et al.*)



^{132}Sn Coulomb Excitation - Jim Beene, Robert Varner *et al.*

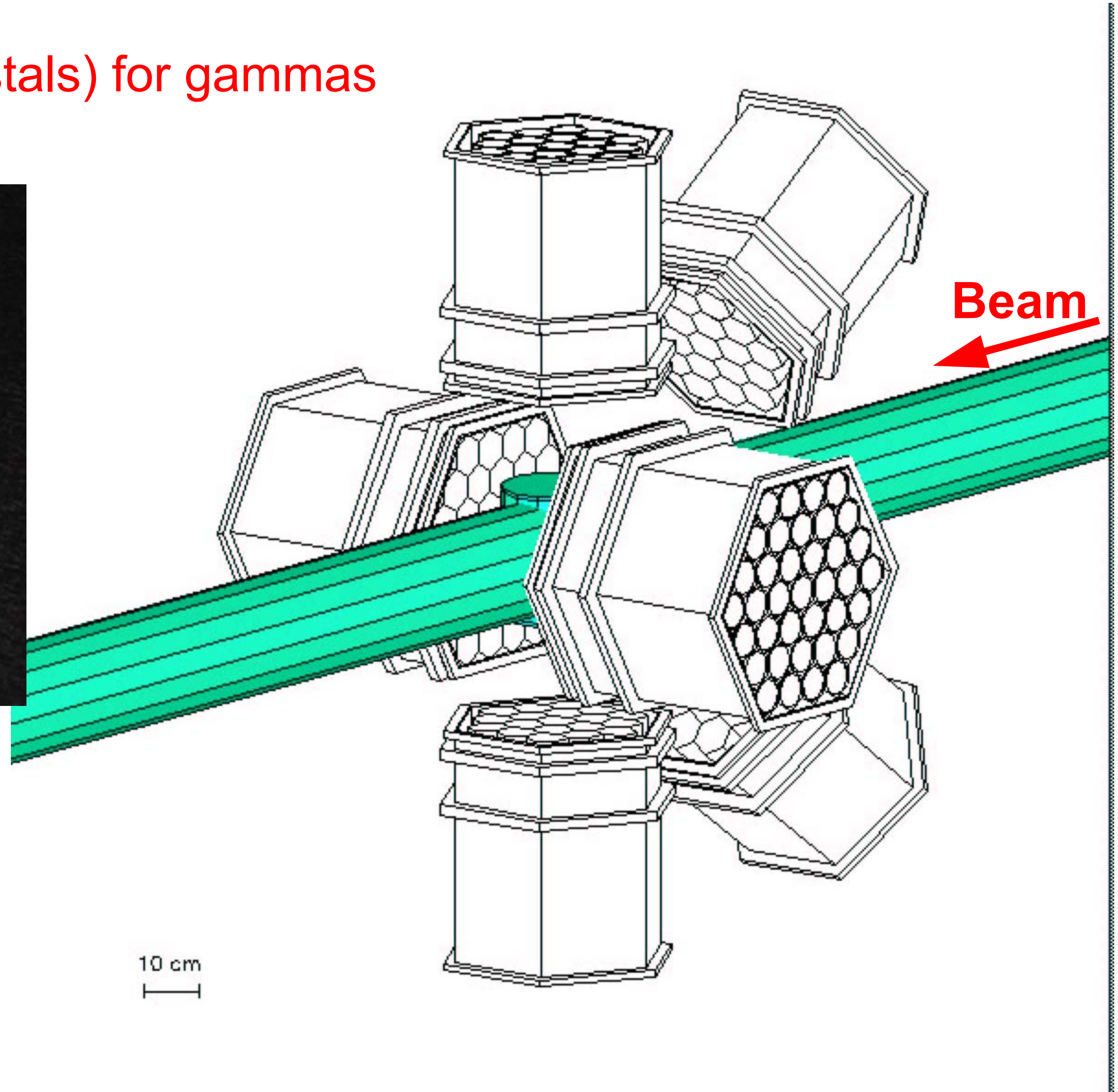
- Opportunity to study a new doubly magic nucleus
- Study collectivity of N=82, Z=50 core excitation
- High E(2^+) + small B(E2) + weak beam
  ⇒ very low event rate

- Employ high efficiency BaF_2 γ-array
  - ~ 40% full-energy at 4 MeV
- Use high-Z target (^{48}Ti)
- Run at higher (“unsafe”) energies (495 MeV and 470 MeV)
- Limit distance of closest approach by looking only at forward angles in center of mass



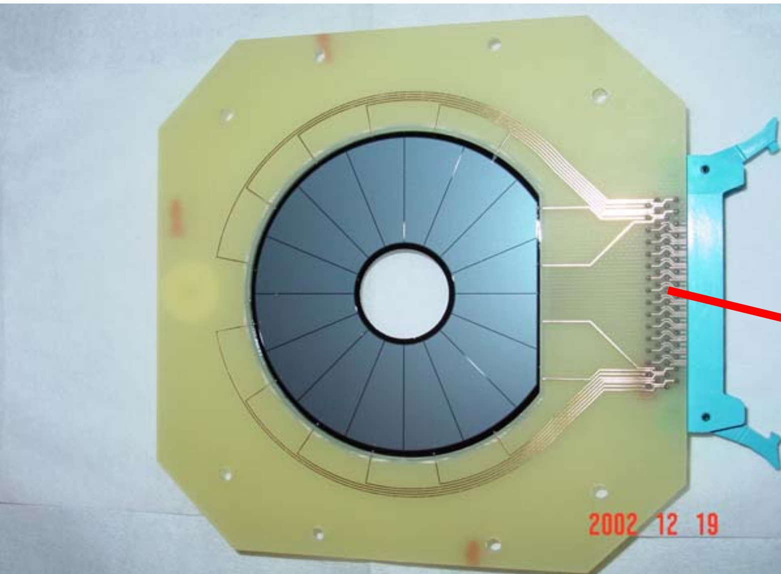
Setup for ^{132,134}Sn Coulomb Excitation

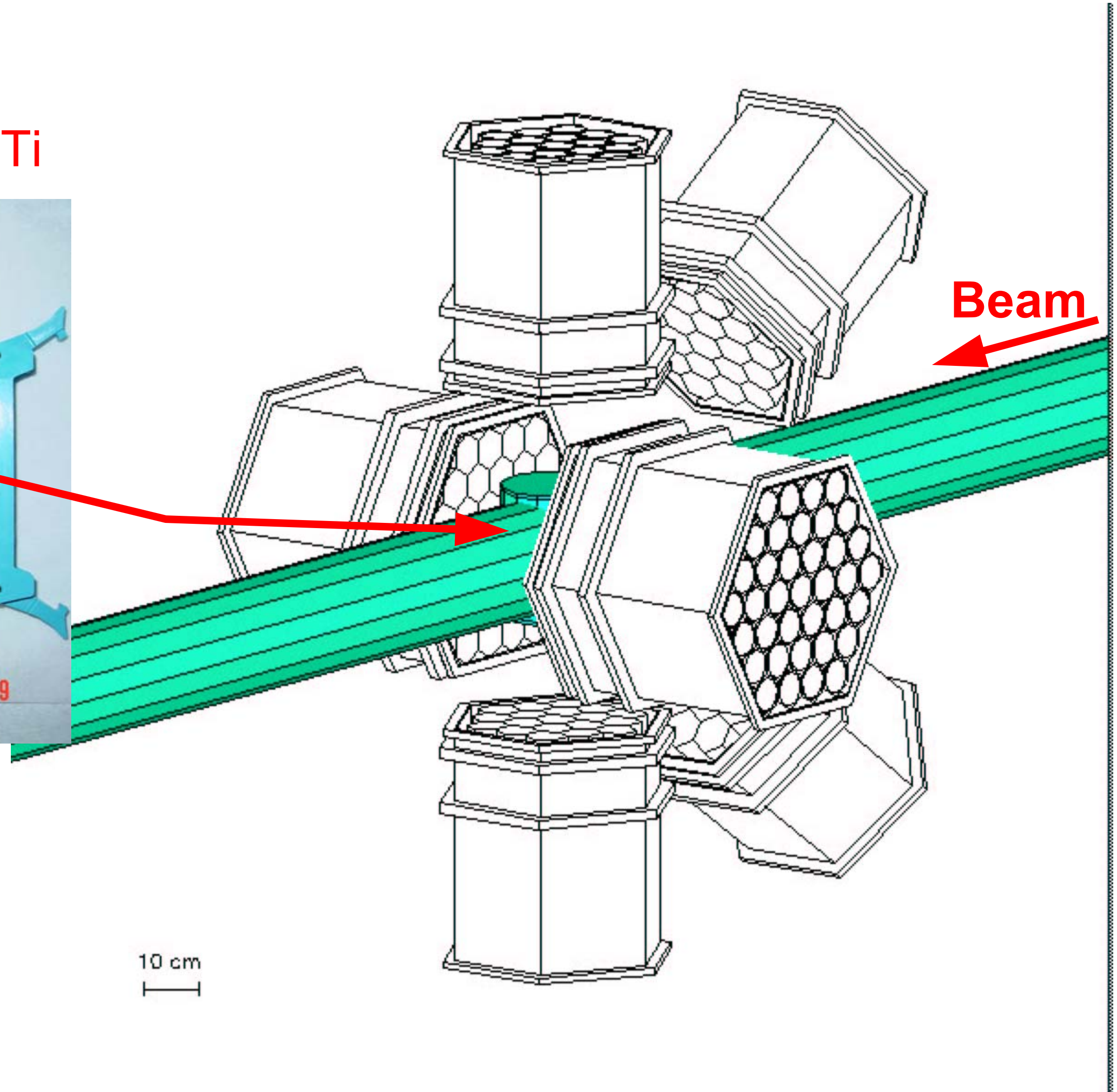
BaF_2 array (150 crystals) for gammas
(2x37, 4x19)



Setup for ^{132,134}Sn Coulomb Excitation

"CD"-type Si detector for scattered Sn and Ti



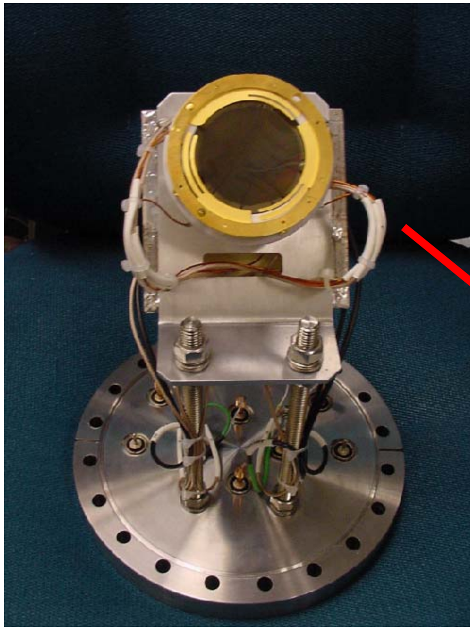


- 7 cm diameter
- 48 radial strips
- 16 sectors

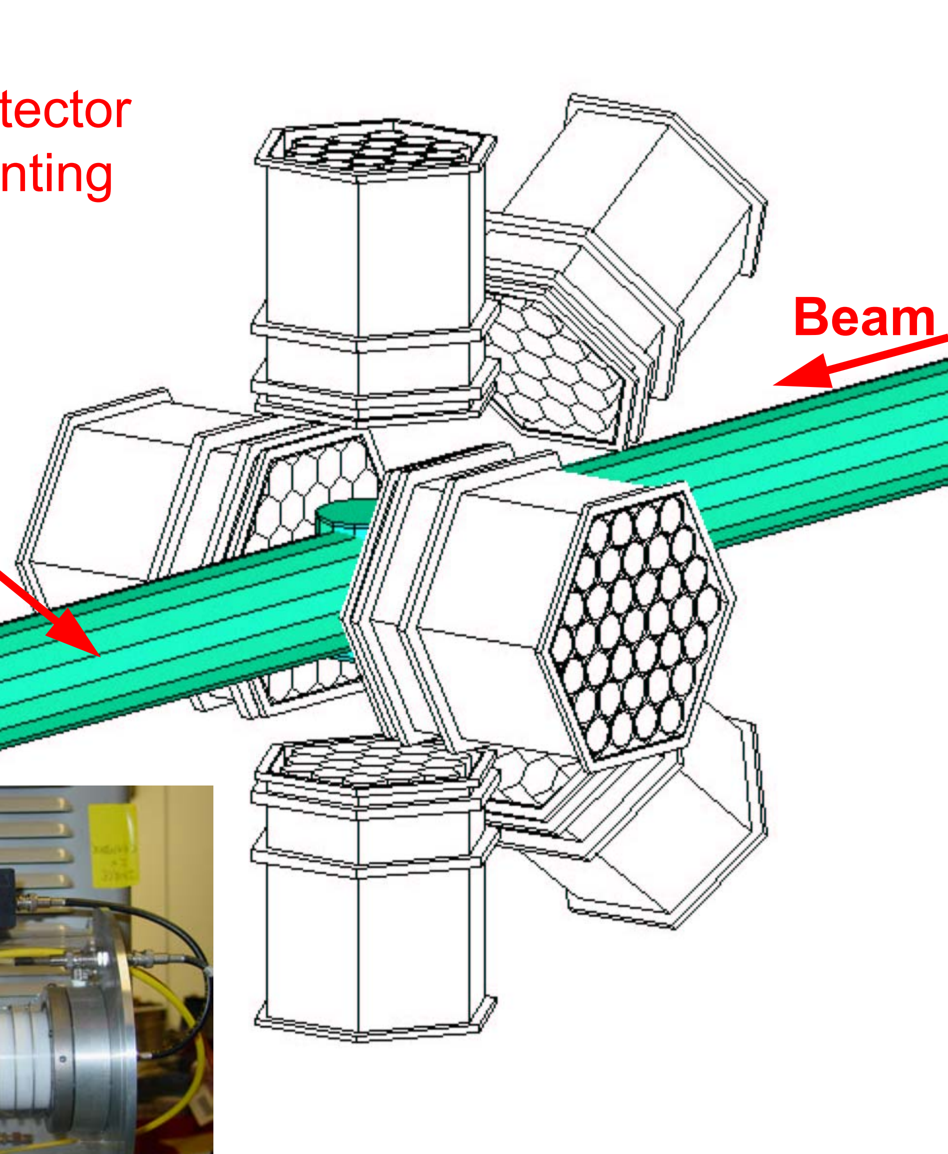
$\theta_{LAB} \sim 7° – 25°$

$\theta_{CM} \sim 30° - 160°$

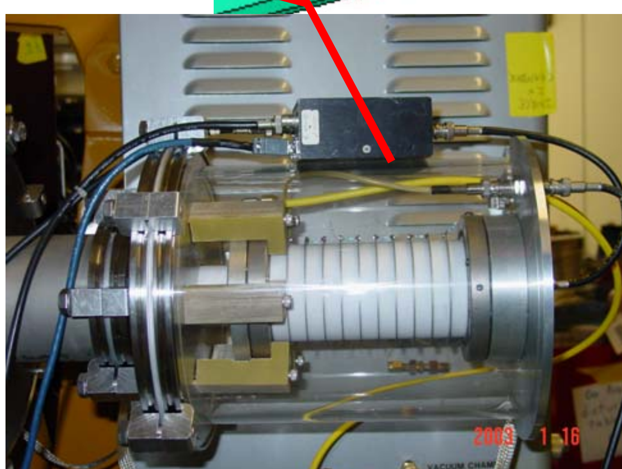
Setup for ^{132,134}Sn Coulomb Excitation



Foil+MCP detector
for beam counting
and imaging



Bragg detector
for beam assay



^{132}Sn Results (Preliminary!)

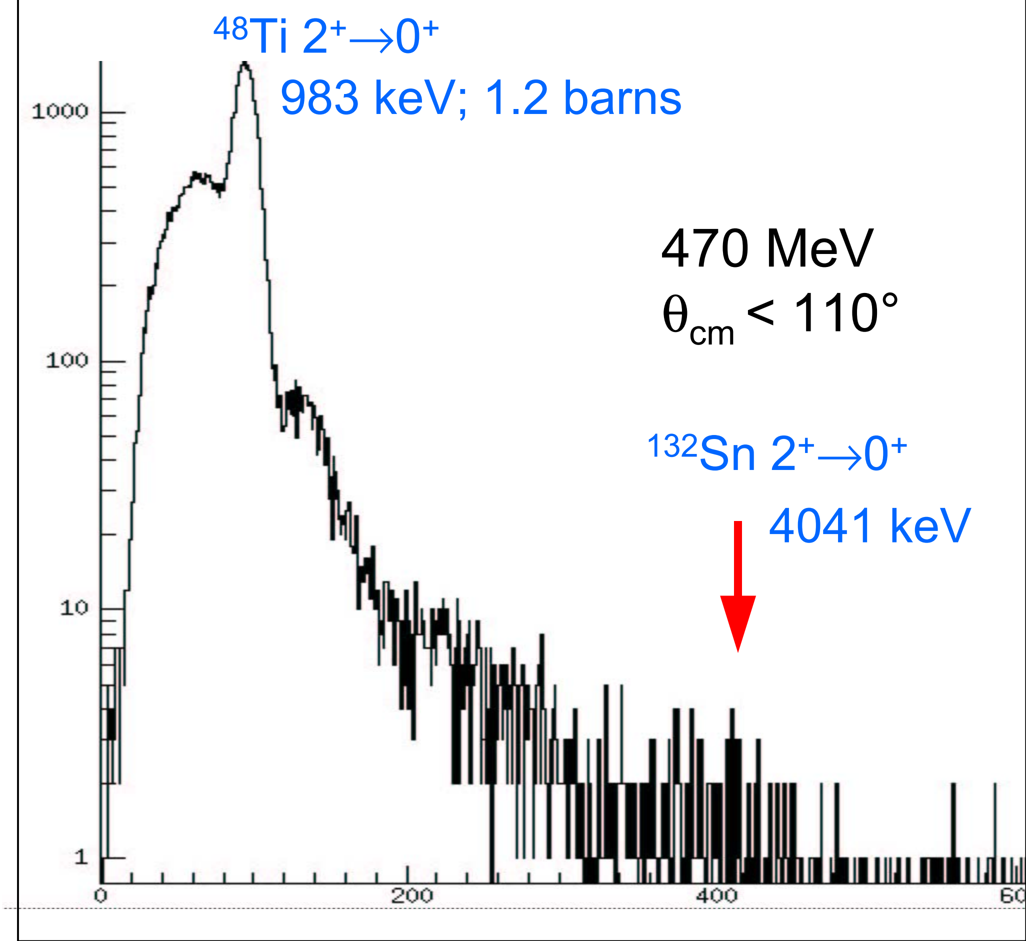
- ^{132}Sn beam, doubly stripped
  - 96% pure
  - 1.3 x 10^5 ions/s
  - 3.75 & 3.56 MeV/nucleon
- ^{48}Ti target
- High γ efficiency (~ 40%)
- Two-week experiment
- Fast γ–ion coincidences to suppress background

B(E2; $0^+ \rightarrow 2^+$) ~ 0.14(5) e^2b^2

(preliminary)

Sample gamma-ray spectrum:

- *~30% of data, one energy*
- *Crystal gain matching & background suppression not yet optimum*



^{134}Sn Coulomb Excitation - Jim Beene, Robert Varner *et al.*

- Push knowledge of nuclear structure further from stability
- Probe two-neutron wavefunction beyond ^{132}Sn under simplest conditions
- Neutron pairing effects – related to small B(E2) in ^{136}Te?

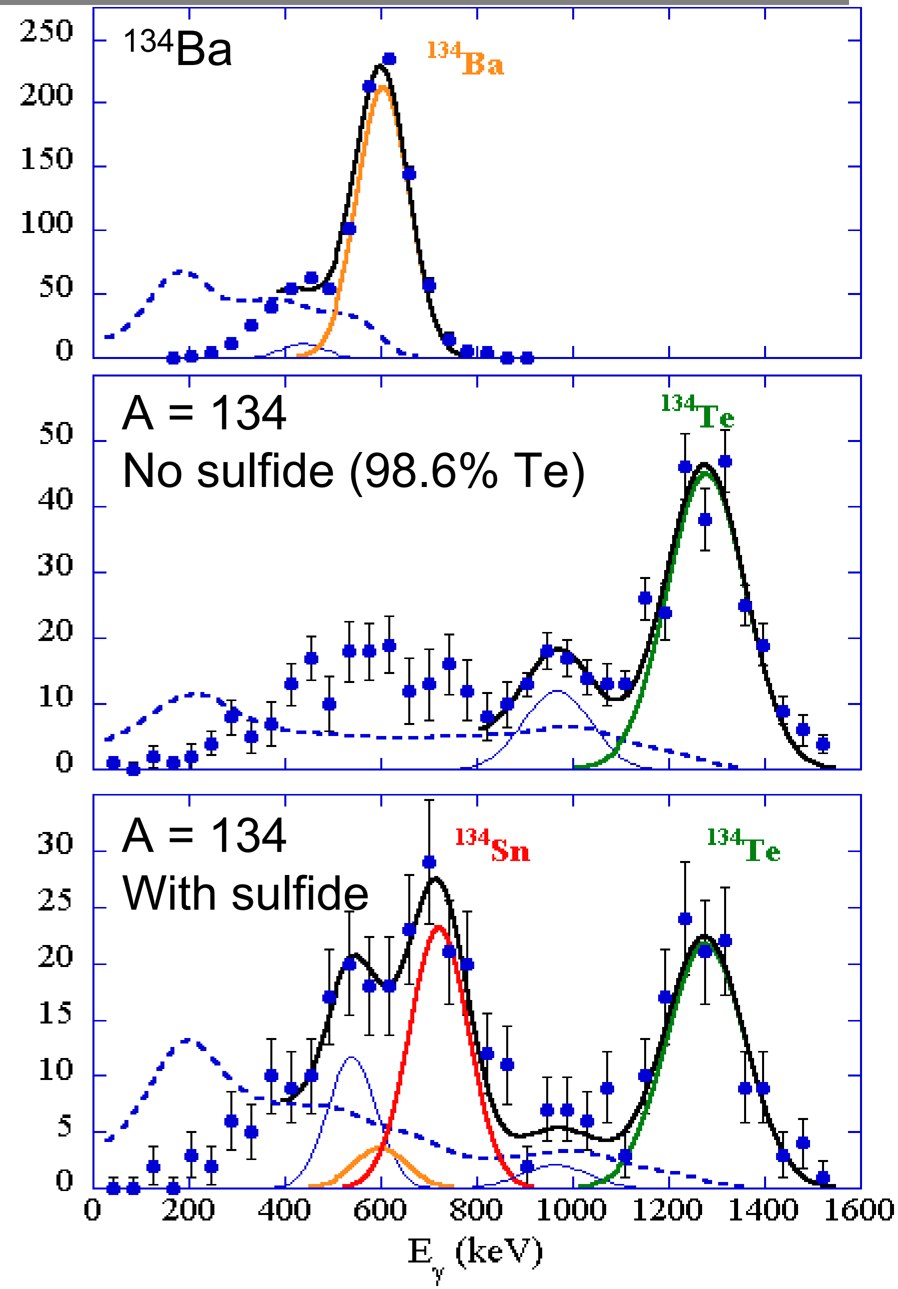
- Experimental problems very different:
  - $E(2^+) = 725$ keV
    - Unsafe bombarding energy unnecessary
  - ^{134}Sn beam intensity only ~3000 pps
    - Still need very good detection efficiencies

- But similar experimental setup still works well
  - BaF_2 array gives large geometrical efficiency
  - CD detector gives almost 4π coverage for Coulomb scattering
  - Change to ^{90}Zr target; large cross section, no interfering γ rays

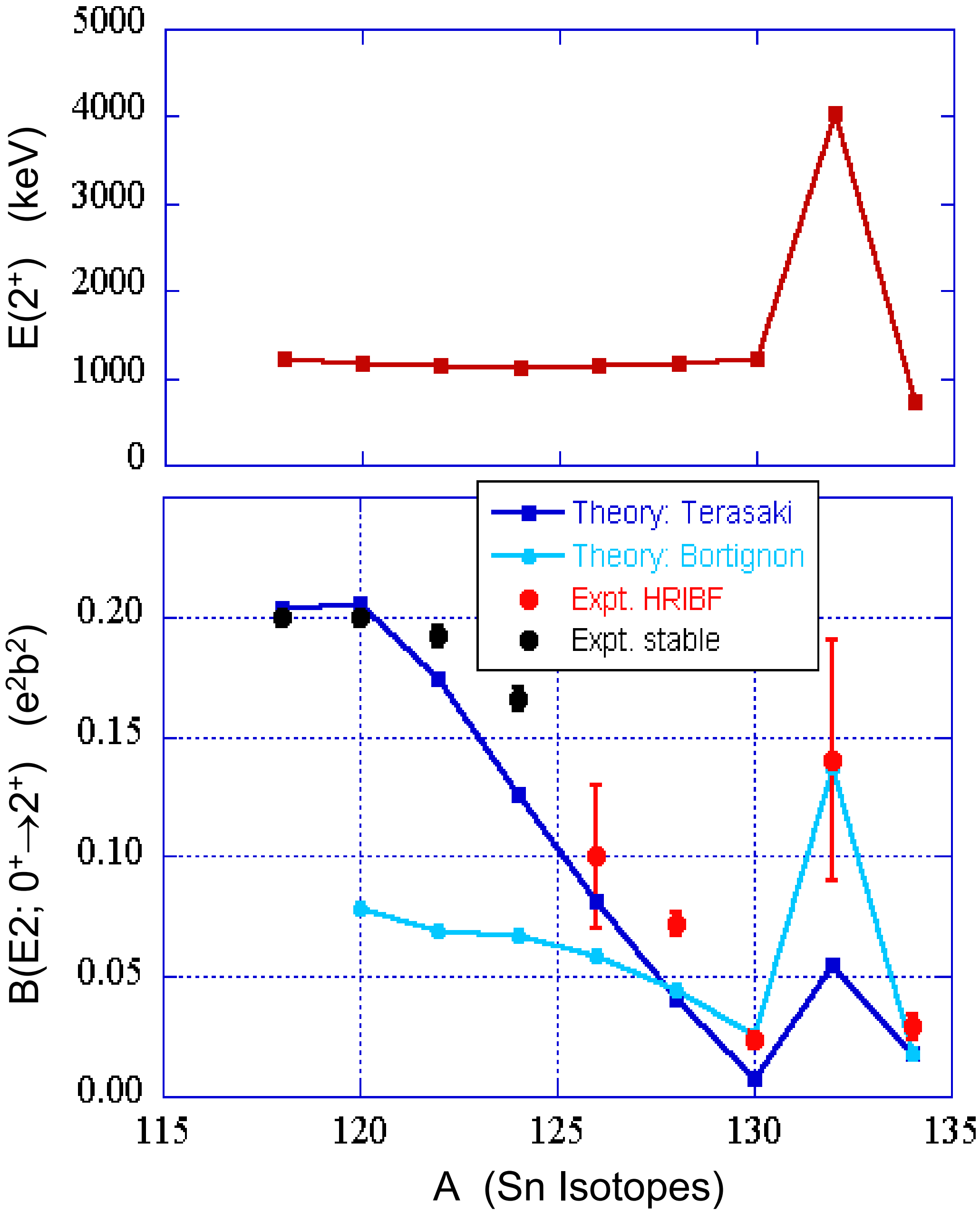
^{134}Sn Results

- ^{90}Zr target
- A = 134 RIB (purified with sulfide)
  Total beam ~10^4 pps
  - 25.6% ^{134}Sn (~3000 pps)
  - 12.2% ^{134}Sb
  - 61.6% ^{134}Te
  - 0.56% ^{134}Ba
- 3 MeV/nucleon: safe Coulex at all θ

Nucleus	B(E2) (e^{2}b^2) This expt.	B(E2) (e^{2}b^2) Prev. expt.
^{134}Sn	**0.029(5)**	
^{134}Te	0.104(10)	0.096(12)
^{134}Ba	0.63(4)	0.658(7)



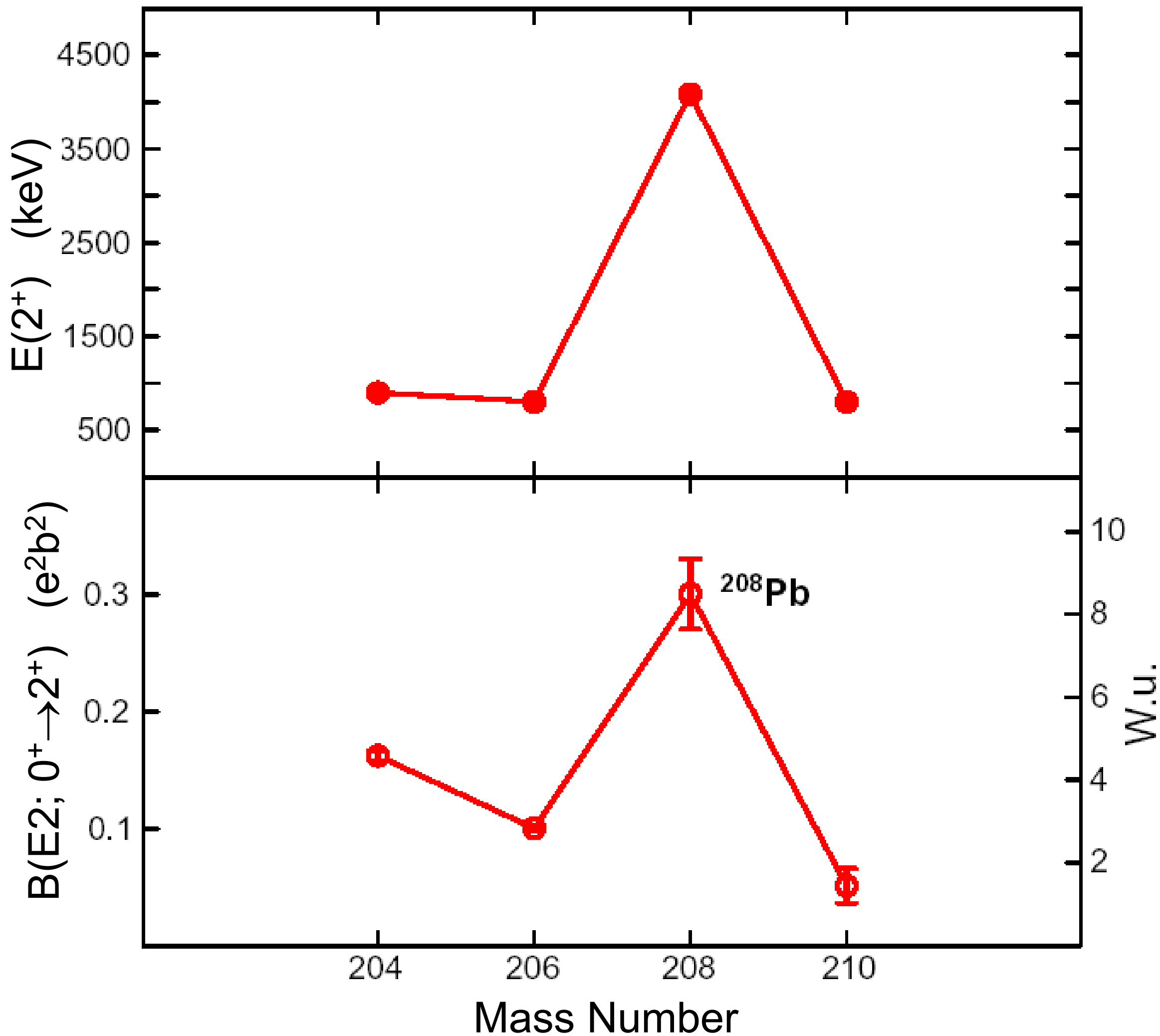
Sn Coulomb Excitation Results



- ^{132}Sn: **B(E2) ~ 0.14(5) e^{2}b^2**
  - 14% Isoscalar E2 EWSR
  - Very preliminary!
  - Final uncertainty will be ~25%
- ^{134}Sn: **B(E2) = 0.029(4) e^{2}b^2**

Lead B(E2) Systematics

^{208}Pb B(E2) = 8.5 W.u.; 19% of Isoscalar E2 EWSR

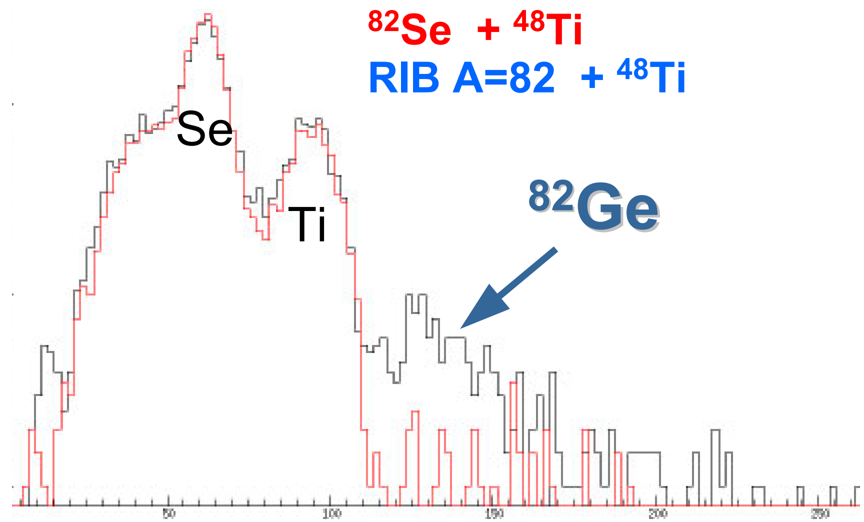


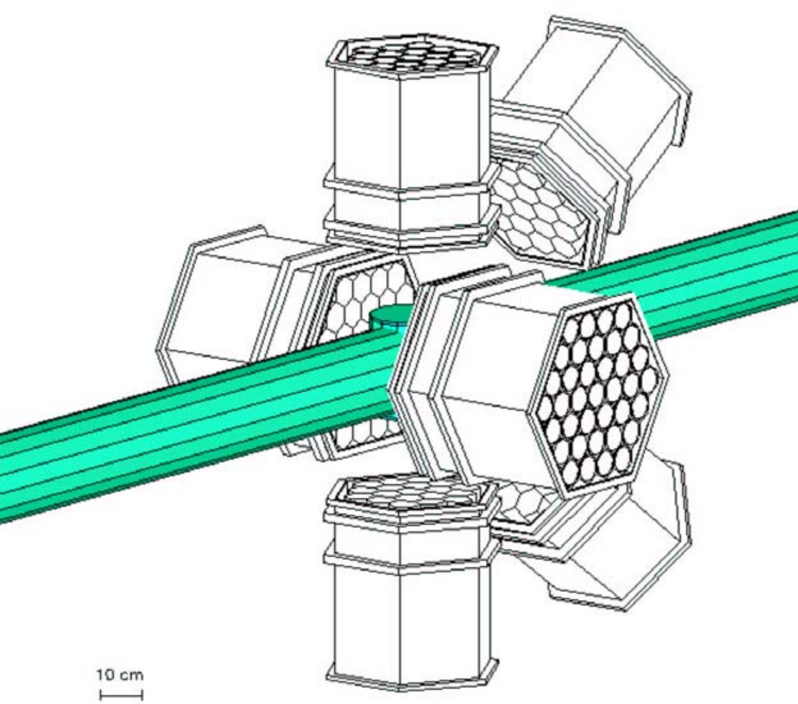
B(E2) for semi-magic ^{82}Ge with BaF_2 array

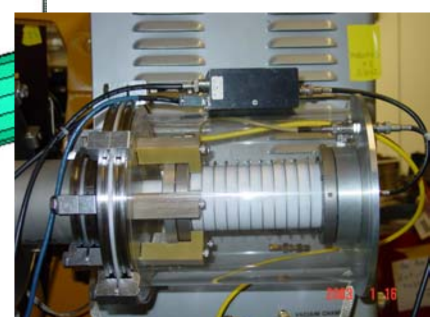
A=82 + ^{48}Ti at 220 MeV

E. Padilla et al.

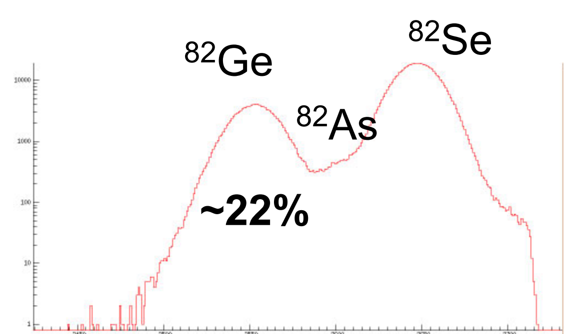
B(E2)=0.035(5) e^2b^2
(Preliminary)







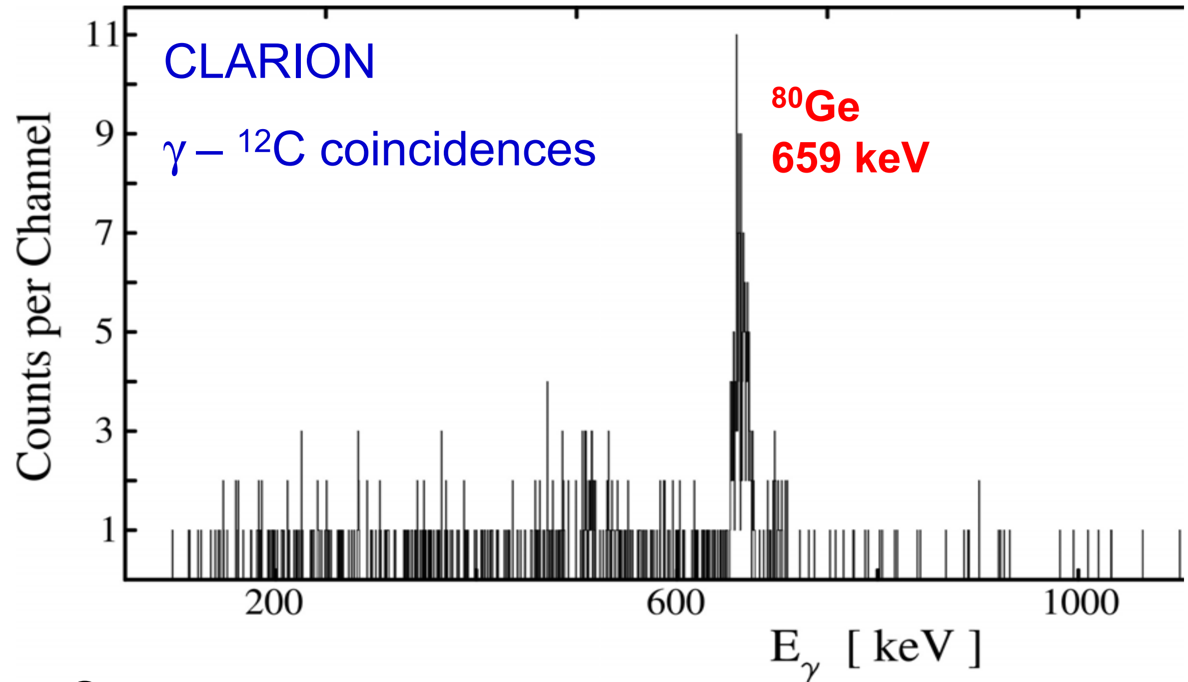
Bragg curve detector



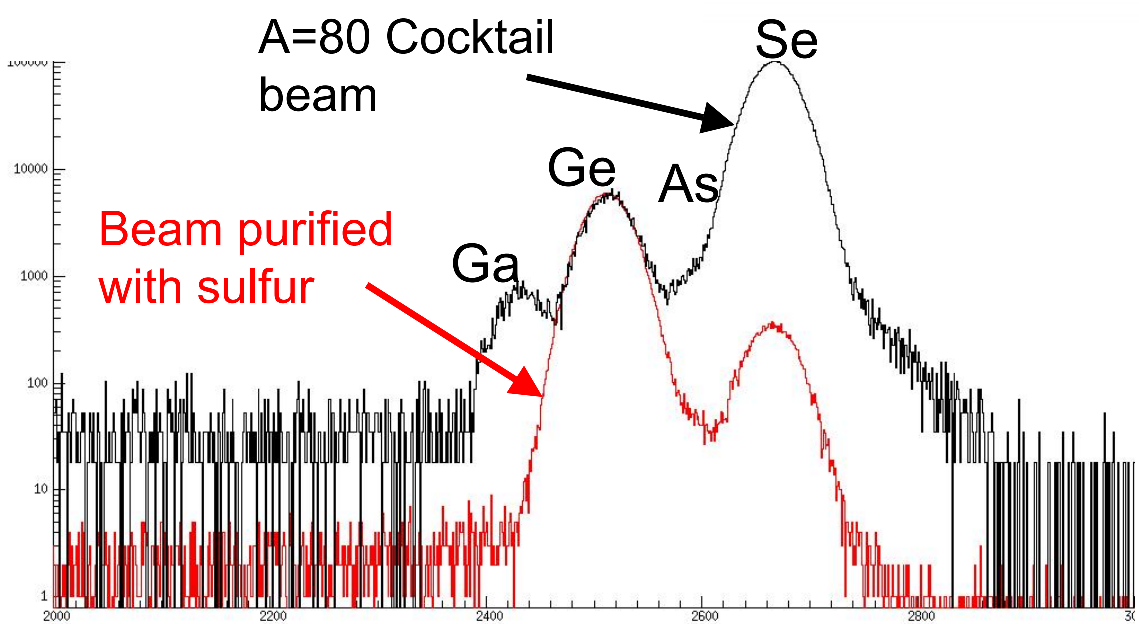
^{80}Ge Coulex with GeS^+ pure RIB

E. Padilla *et al.*

A=80 + ^{12}C at 178 MeV



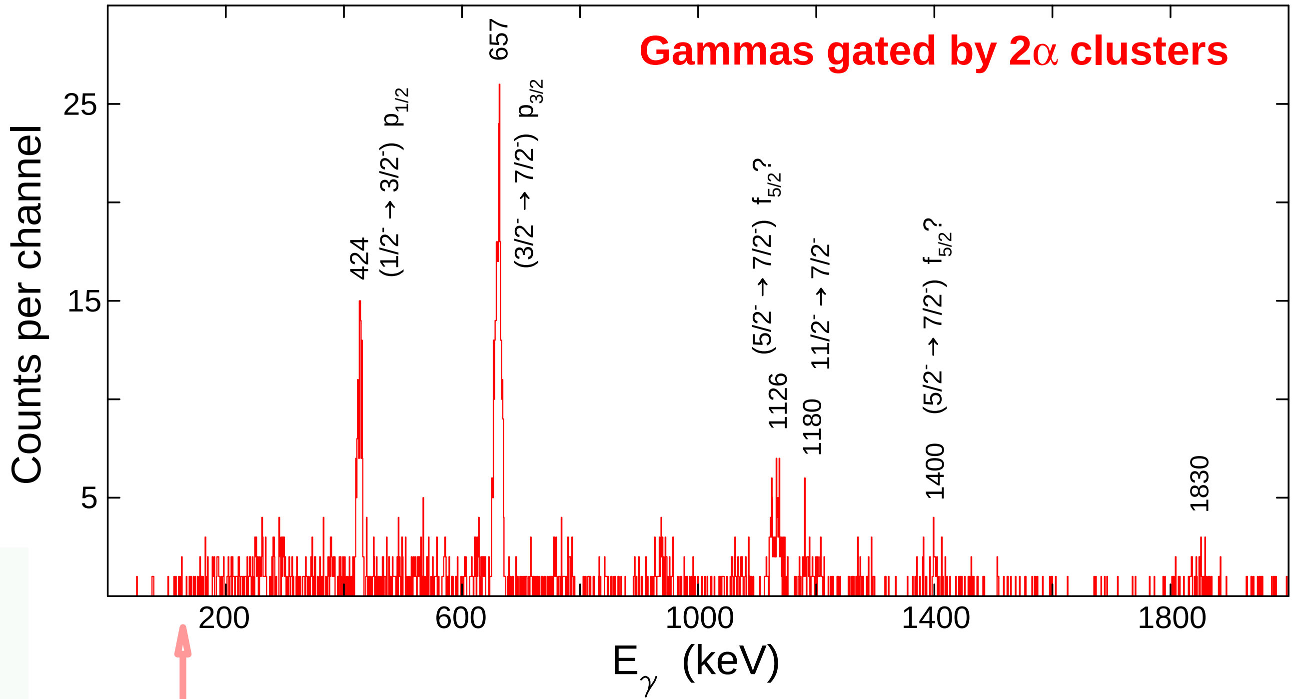
Bragg detector:

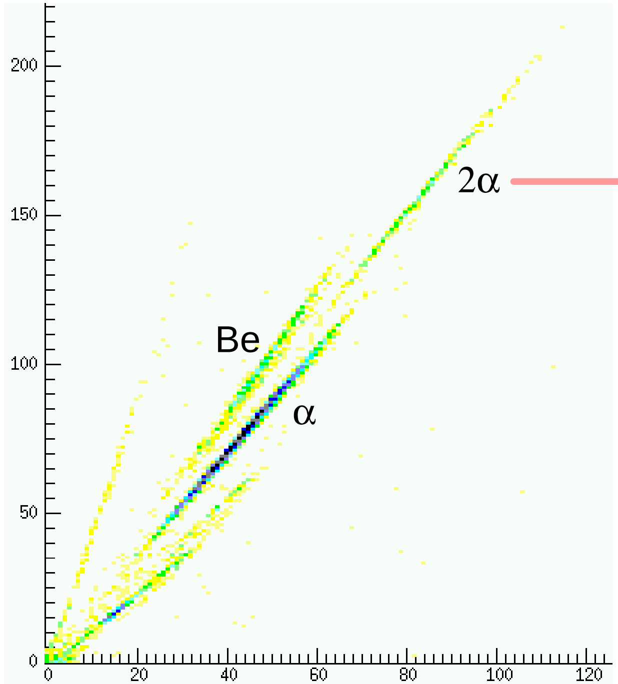


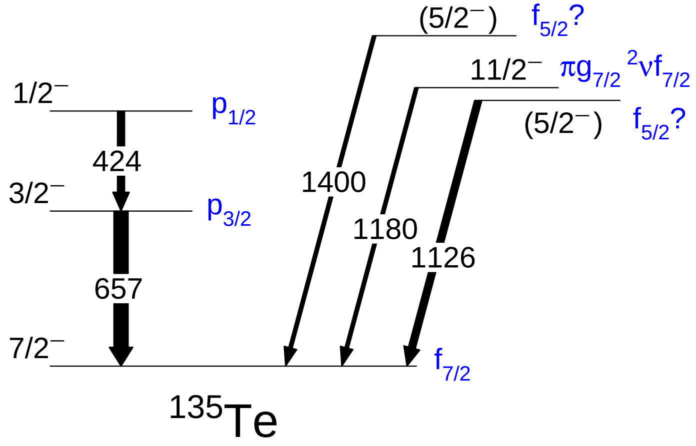
Transfer Reactions with Neutron-Rich RIBS

^{9}Be(^{134}Te,^{8}Be)^{135}Te
↳ 2α

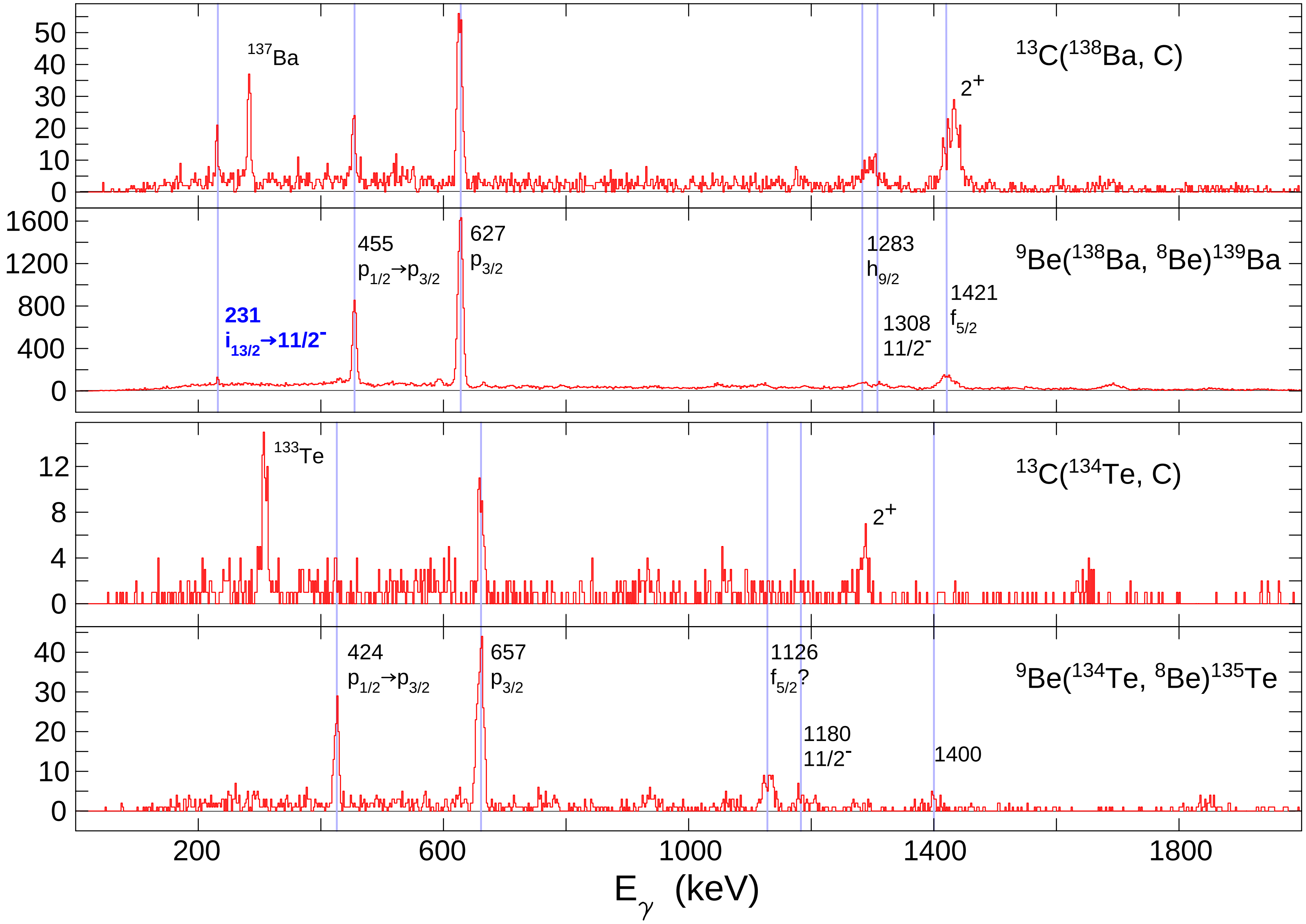
~4 MeV per nucleon







Neutron transfer with ^{134}Te and ^{138}Ba



Future Plans: Coulomb Excitation

- Static quadrupole moment Q_{2+} in ^{126}Sn by reorientation
- Odd-even and odd-odd nuclei
  - Could populate many levels not observed in β-decay
- Higher excited states in even-even nuclei

Future Plans: Transfer

- Search for $\nu i_{13/2}$ state in ^{135}Te, and $\pi s_{1/2}$ state in ^{133}Sb
- Long-term goal: (d,p), (^{3}He,d) *etc.* spectroscopic factors
  - Major difficulty: kinematic broadening of proton energy
    - gives ~ 300 keV resolution for level energies, at best
    - beam energies limited to ~ 5 MeV/nucleon
  - Try using the Spin Spectrometer to identify populated levels by γ-ray calorimetry
    - 70 NaI detectors, efficiency ~ 80%, resolution ~ 10%

See also poster by A. Piechaczek et al. - abstract p.133

"Proton transfer spectroscopy in the ^{132}Sn region"

Conclusions

- Accelerated n-rich RIBS at HRIBF have tremendous physics potential
- ^{132}Sn beams with excellent purity and intensity (>10^5) are now available
- Coulex and fusion-evaporation experiments are feasible and exciting
  - Require clean trigger, good beam quality
- $B(E2; 0^+ \rightarrow 2^+)$ in ^{132,134}Sn recently measured with BaF_2 array
  - Value for ^{132}Sn is large, similar to ^{208}Pb
  - Values for semi-magic ^{130,134}Sn are small
- Transfer reactions are more difficult, but we are beginning to develop appropriate techniques
  - Plan to look for $\nu i_{13/2}$ state in ^{135}Te, $\pi s_{1/2}$ state in ^{133}Sb

Participants

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