Gamma Detection for ISOL Beams

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Outline:

- **RIBS: Experimental challenges**
- **Examples**
    - Fusion-evaporation
    - RIB Coulomb Excitation
    - Single-nucleon transfer reactions
- **Conclusions for RIA detector requirements**

Physics Opportunities

Reaccelerated RIBs at RIA will provide an incredible opportunity for whole classes of experiments:

- Fusion-evaporation -- for example (among many others):
  - band structure in n-rich nuclei
  - new K-isomers in Hf region, *etc.*
- Coulomb excitation
  - B(E2) values, transition moments
  - static quadrupole moments by reorientation
- Single-nucleon transfer reactions
  - *e.g.* (d,p), (^{3}He,d) in inverse kinematics
  - spectroscopic factors, shell-model wavefunctions

Experimental Challenges

- Beams are **radioactive**
  - Stopped/scattered beam can give huge background
  - Good beam quality & careful tuning essential
- Beams are generally isobar cocktails, *i.e.* **contaminated**

  e.g. HRIBF A=132 beam: 87%Te, 12% Sb, 1% Sn

  $\Rightarrow$ Need good γ-ray *energy resolution*
- Beams are **weak** (or the *interesting part* is)
  - γ, $\gamma\gamma$ rates of interest generally ≤ 1 /s
  - Background rate from stopped beam may be $\geq \sim 10^4$ /s $(10^8 \times 10^{-3})$

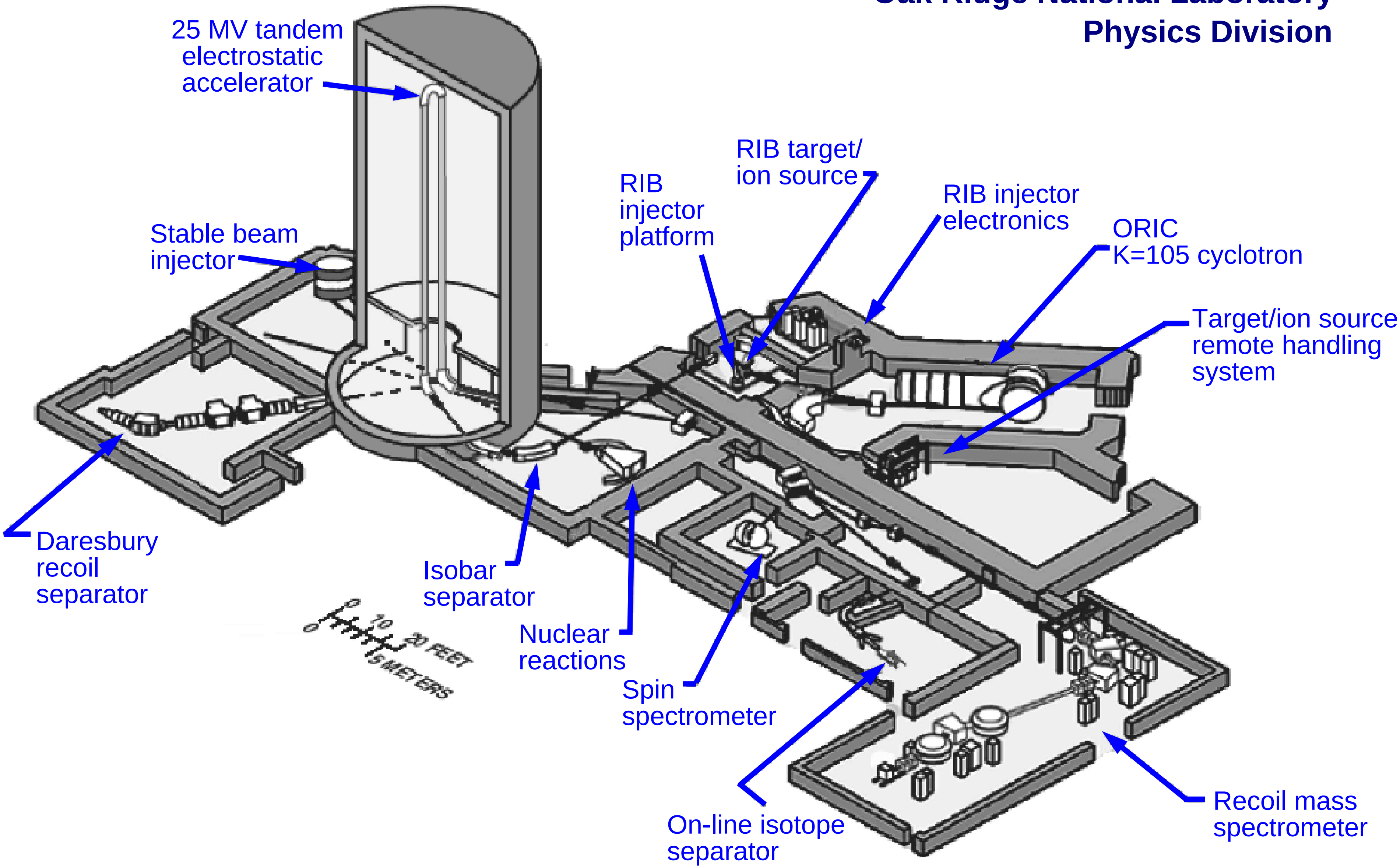
  $\Rightarrow$ Need best possible *efficiency*

  $\Rightarrow$ Need *clean trigger* and *good timing* (to reduce randoms)
- Usually require light targets, inverse kinematics
  - Large recoil velocity, Doppler broadening

  $\Rightarrow$ Need excellent *angular resolution*

The Holifield Radioactive Ion Beam Facility

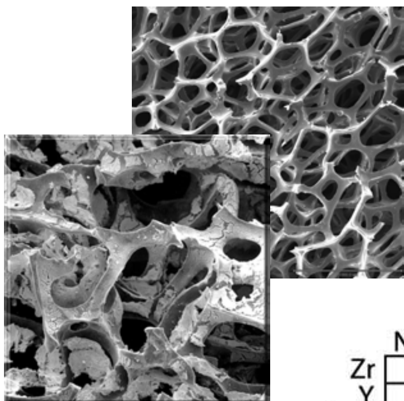
Oak Ridge National Laboratory
Physics Division

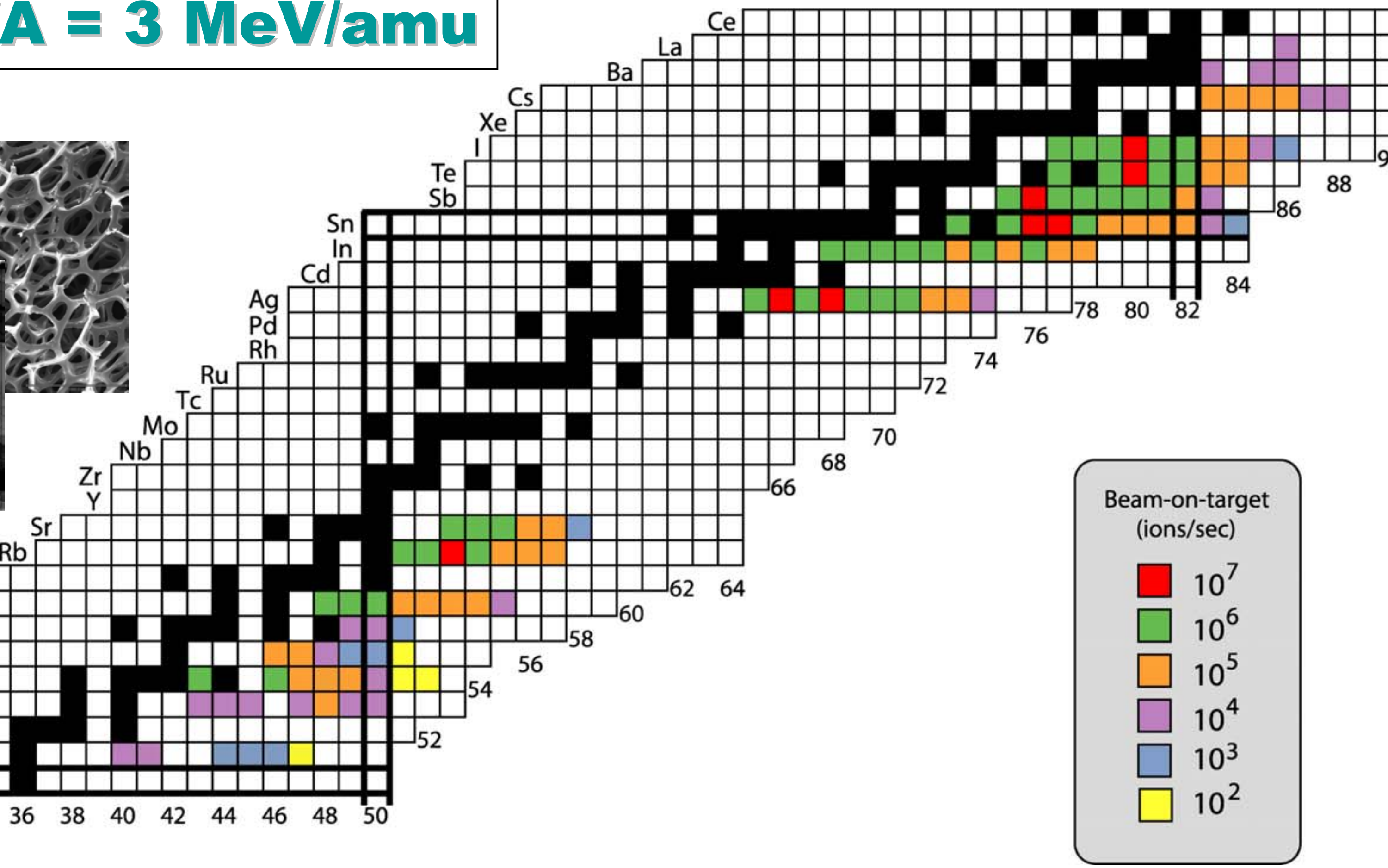


Available Neutron-rich Radioactive Ion Beams

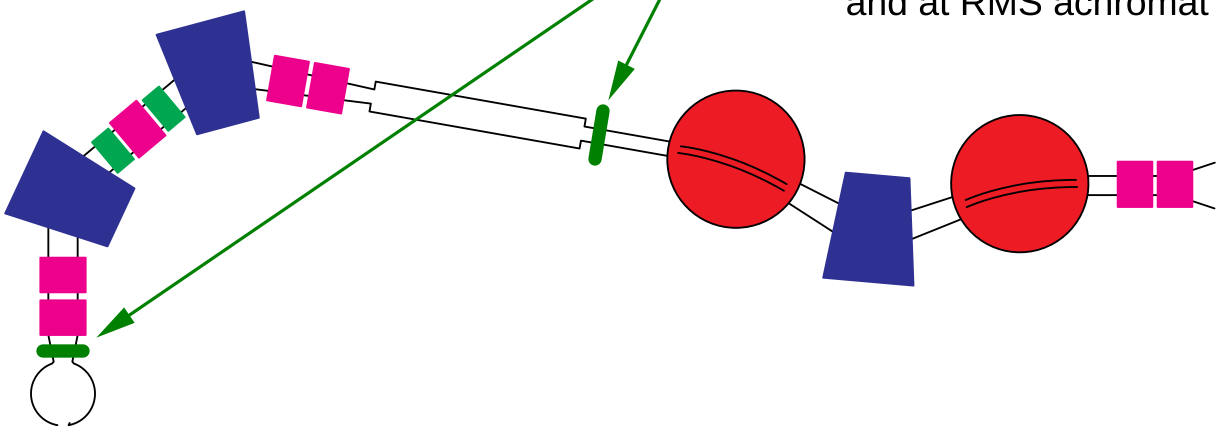
(over 100 beams with intensities $\geq 10^3$ ions/sec)

E/A = 3 MeV/amu





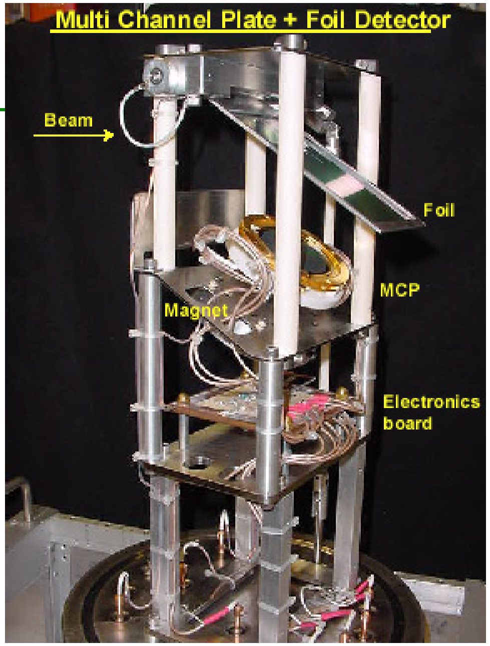
Setup for experiments with neutron-rich RIBS



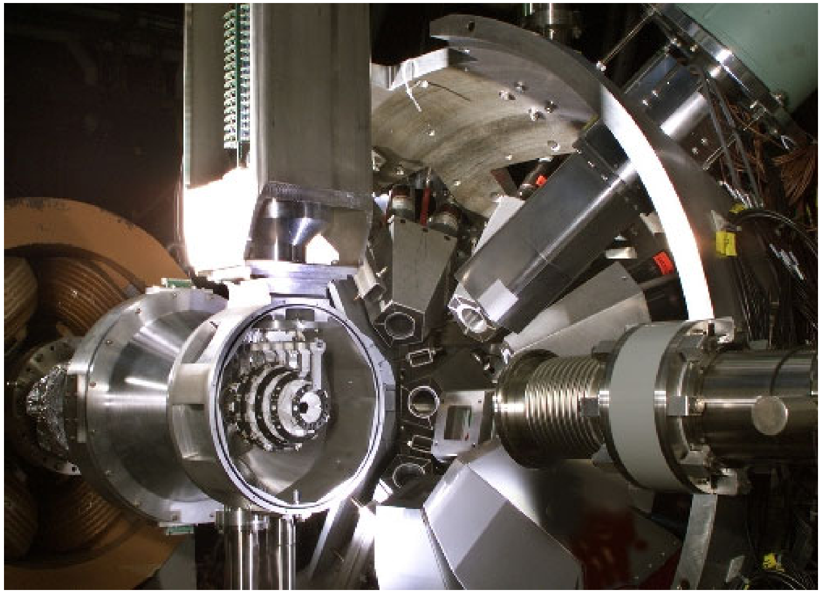
Recoil Detectors

50 cm downstream from target
and at RMS achromat

Target



Foil plus multichannel plate



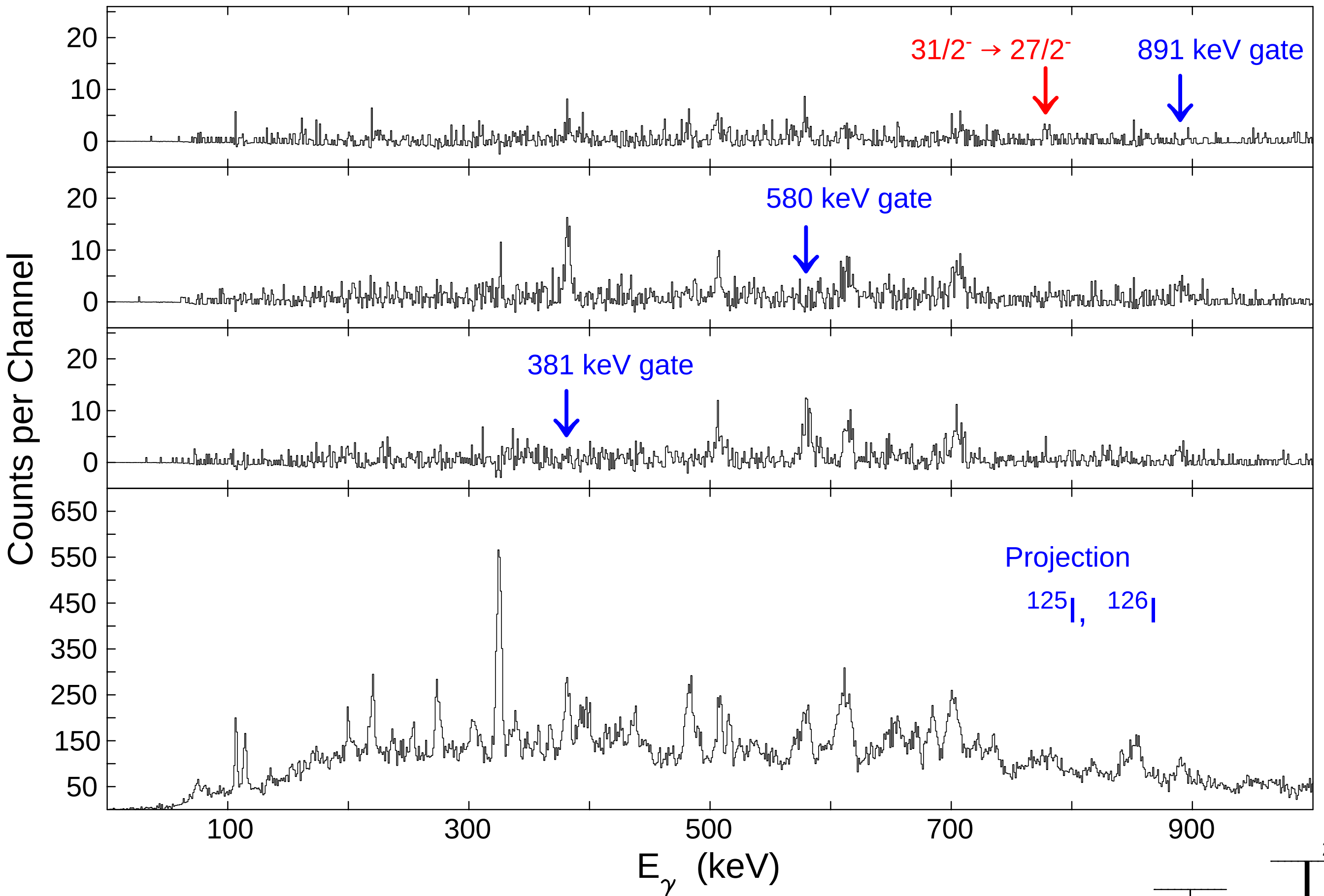
CLARION

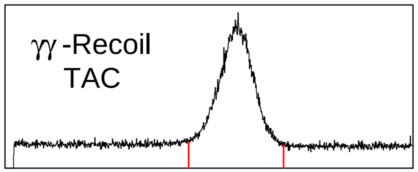
11 segmented clover Ge detectors

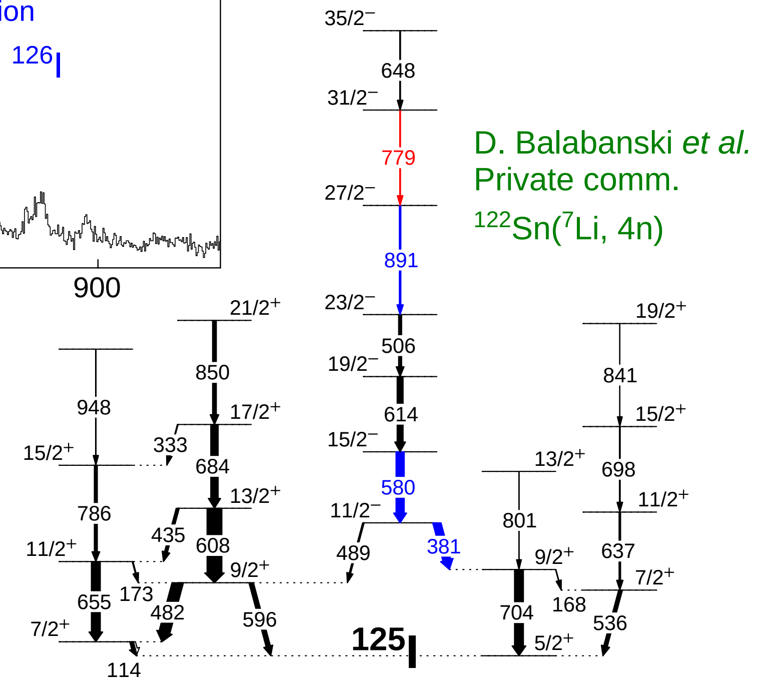
HyBall

95 CsI detectors with photodiodes

Fusion-Evaporation Reactions





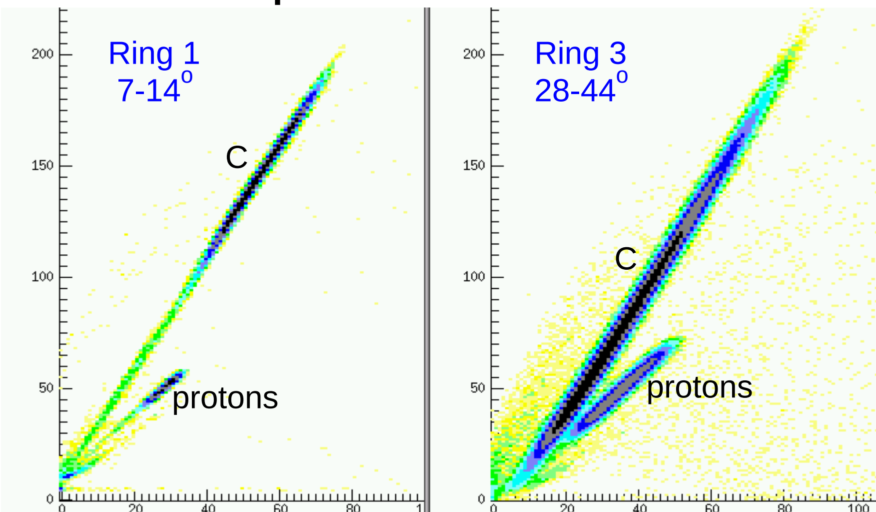


^{12}C(^{118}Ag,5n)^{125}I γγ gates

~10^6 ^{118}Ag /s for 33 hours

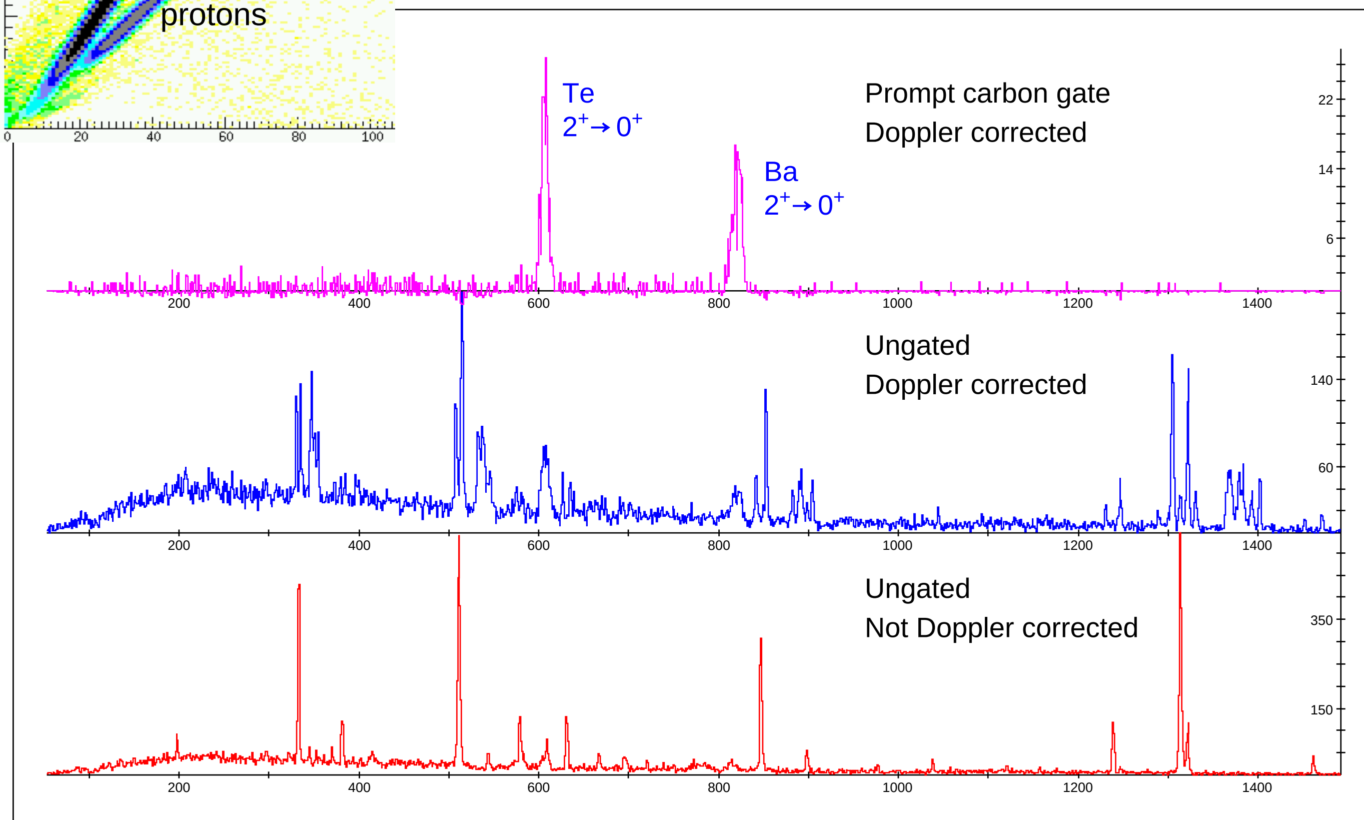
Example: A = 136 Coulex

Particle ID Spectra:

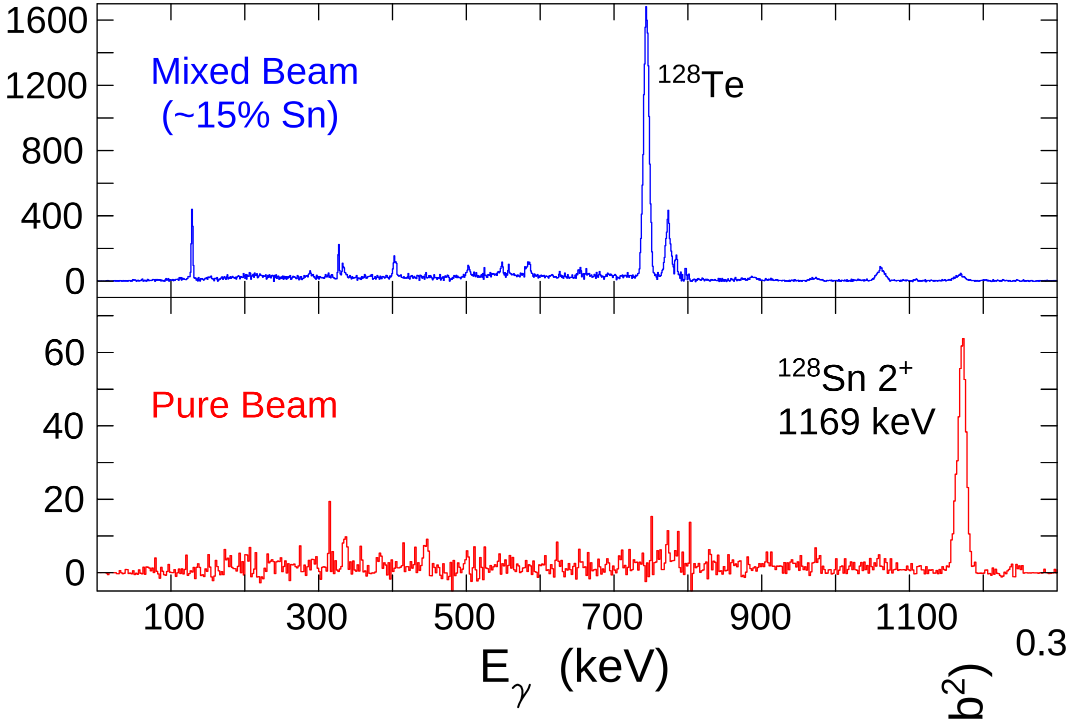


$396\ \text{MeV}\ ^{136}\text{Te} + {}^{136}\text{Ba}$

on $0.83\ \text{mg/cm}^2$ C target



Coulomb Excitation of Pure ^{128}Sn RIB

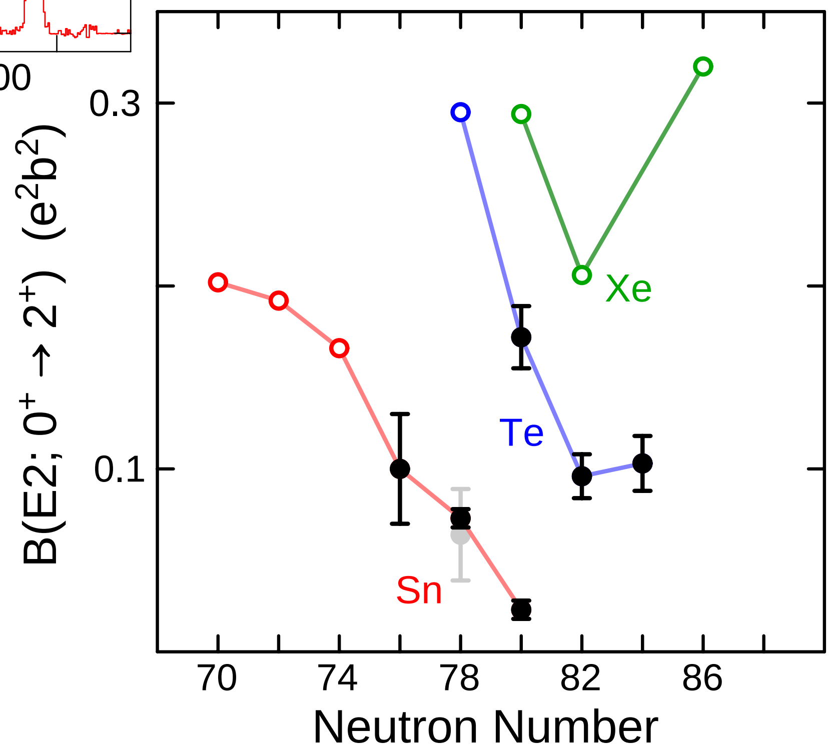


3×10^6 Pure ^{128}Sn s^{-1}

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

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

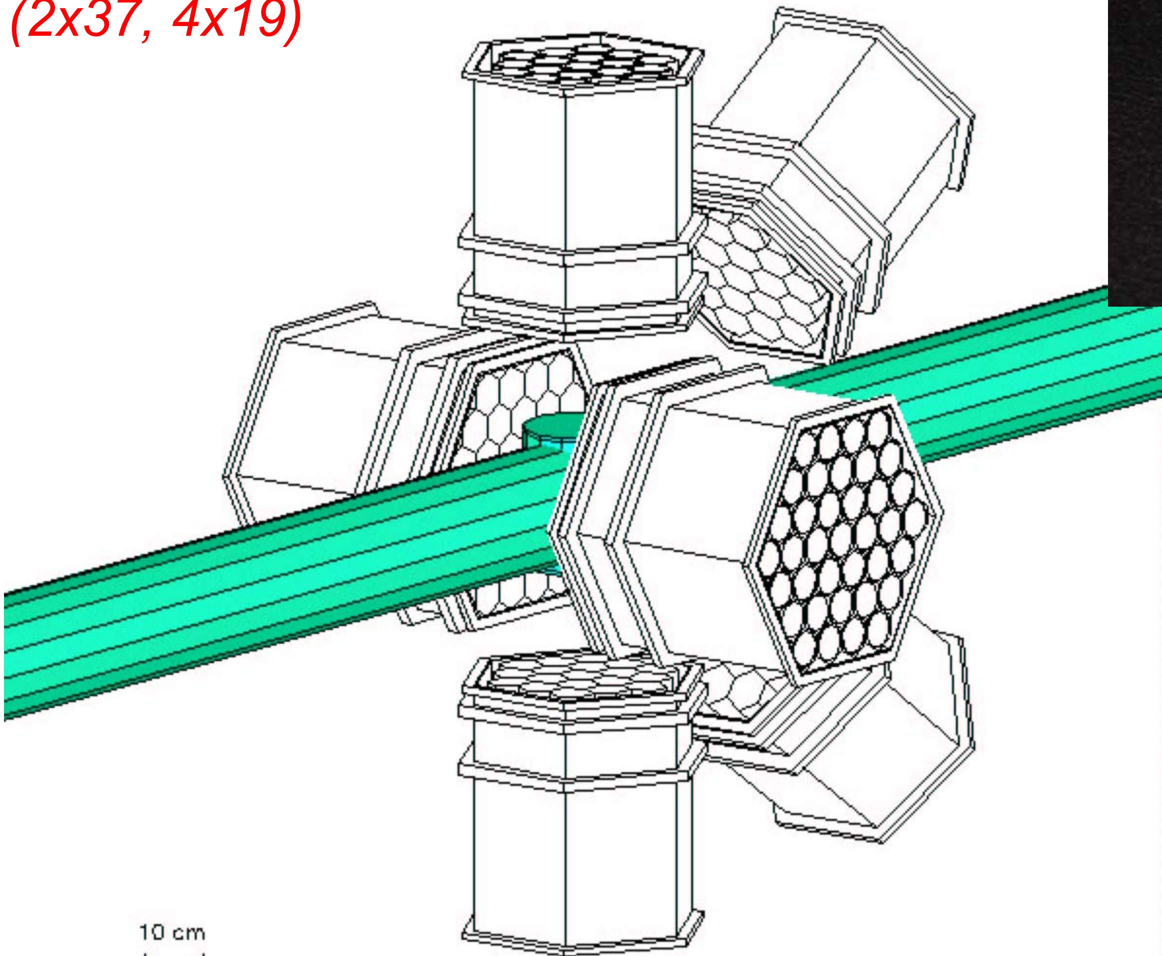
(preliminary!)

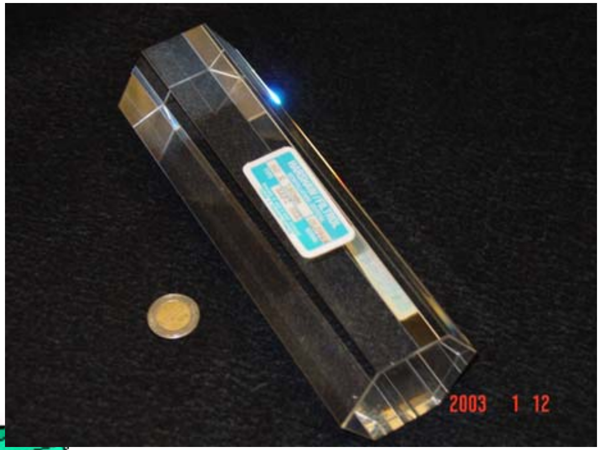


^{132}Sn Coulomb Excitation Measurement

- Jim Beene, Robert Varner *et al.*

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



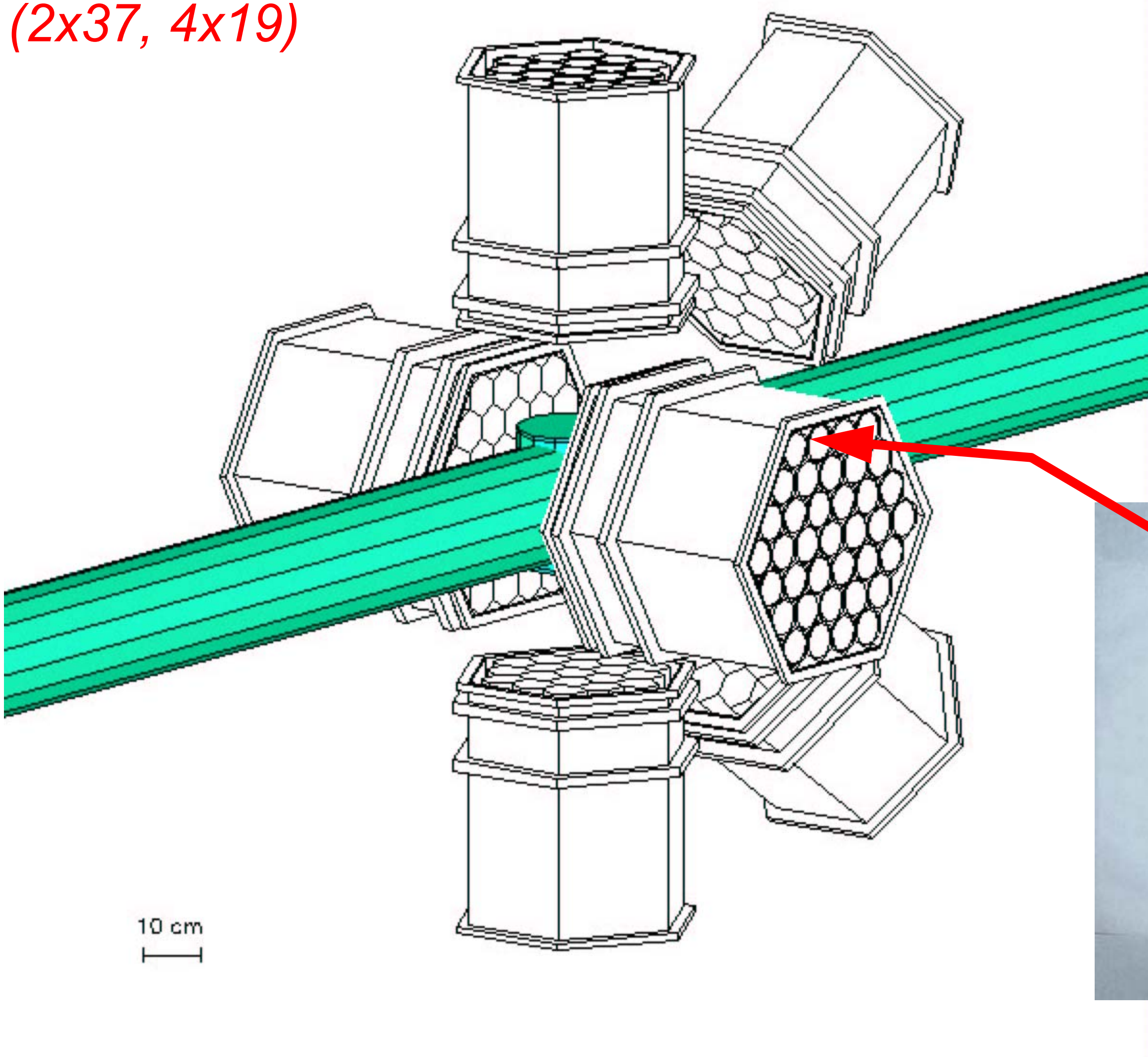


- BaF_2 single crystals, 6.5cm dia., 20cm long
- ΔE = 10% at 1 MeV
- $\Delta\Omega = 0.65(4\pi)$
- Detection eff. = 60%
- Total eff. = 40%

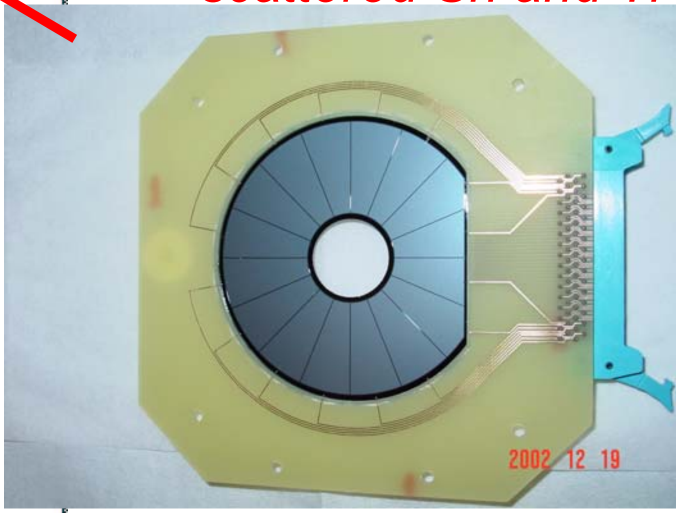
^{132}Sn Coulomb Excitation Measurement

- Jim Beene, Robert Varner *et al.*

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



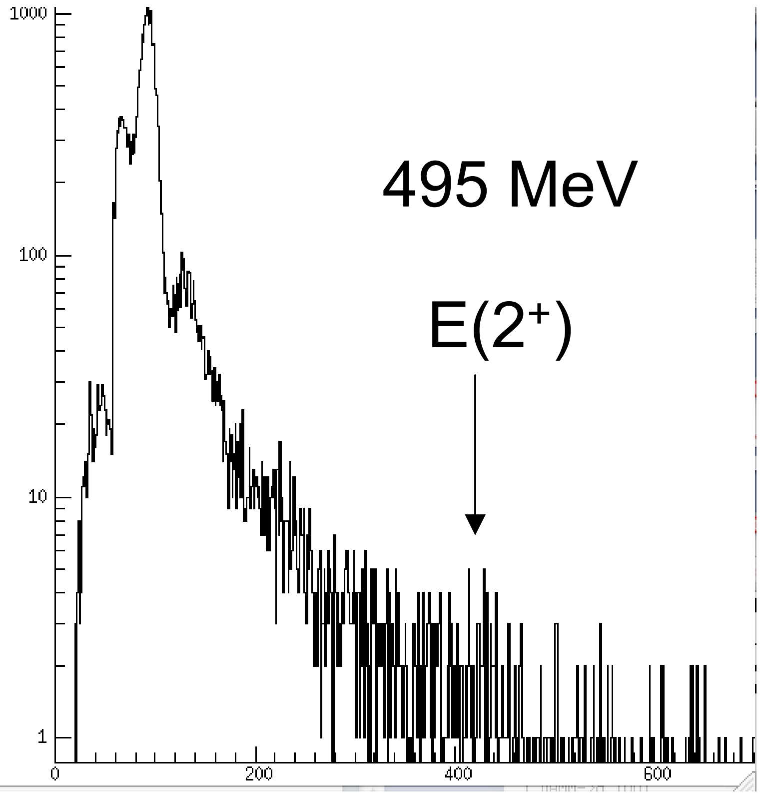
"CD" detector for scattered Sn and Ti

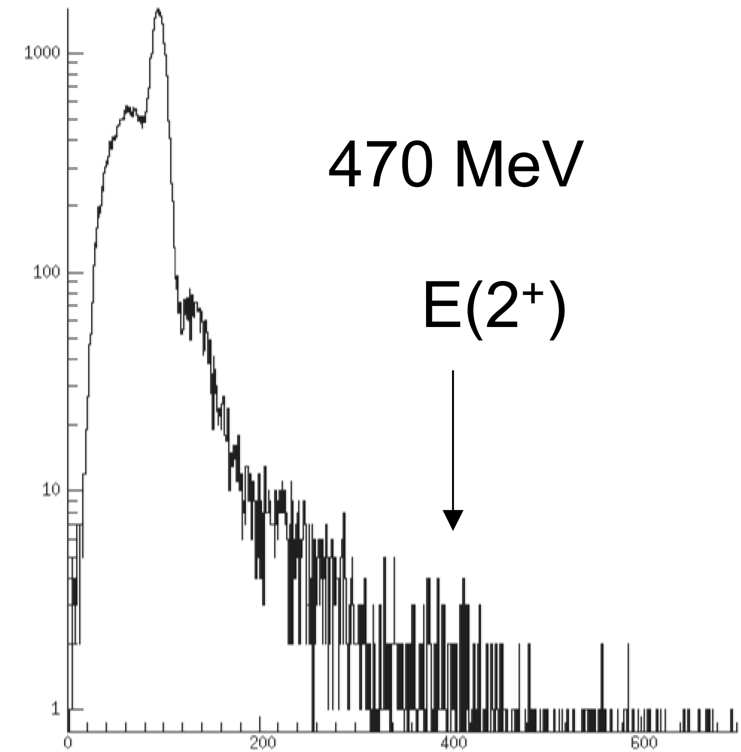


^{132}Sn γ-yields

- BaF_2
  - γ-particle Coincidence gate
  - γ-identification in BaF_2
  - pack multiplicity
  - Array multiplicity
  - Calibrations approximate

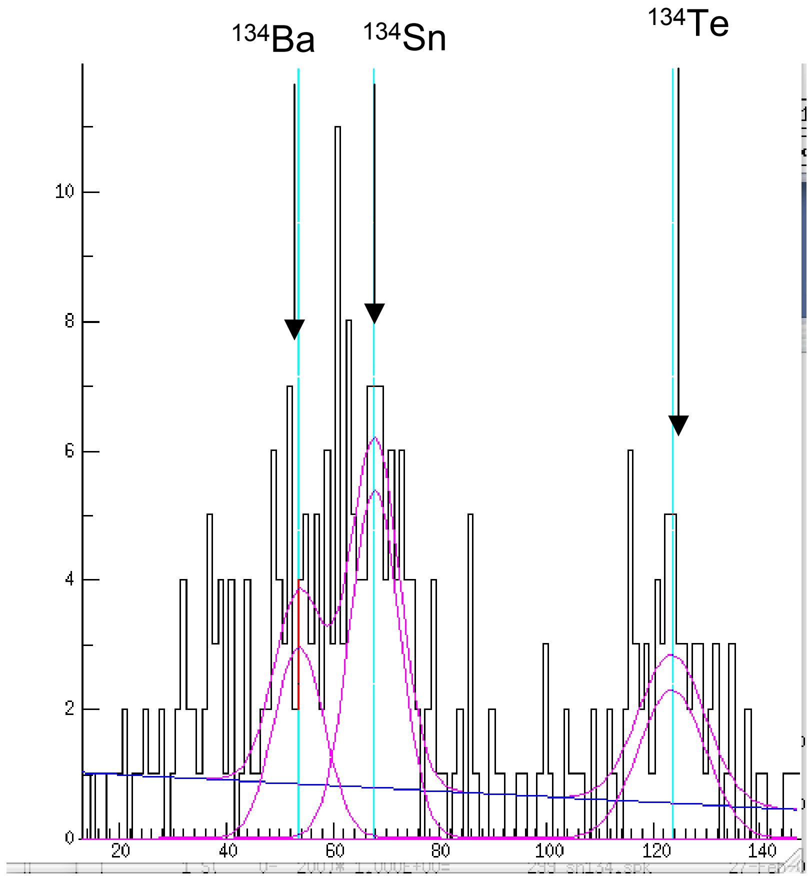
- CD
  - Good strip
  - Good wedge E
  - Good wedge T



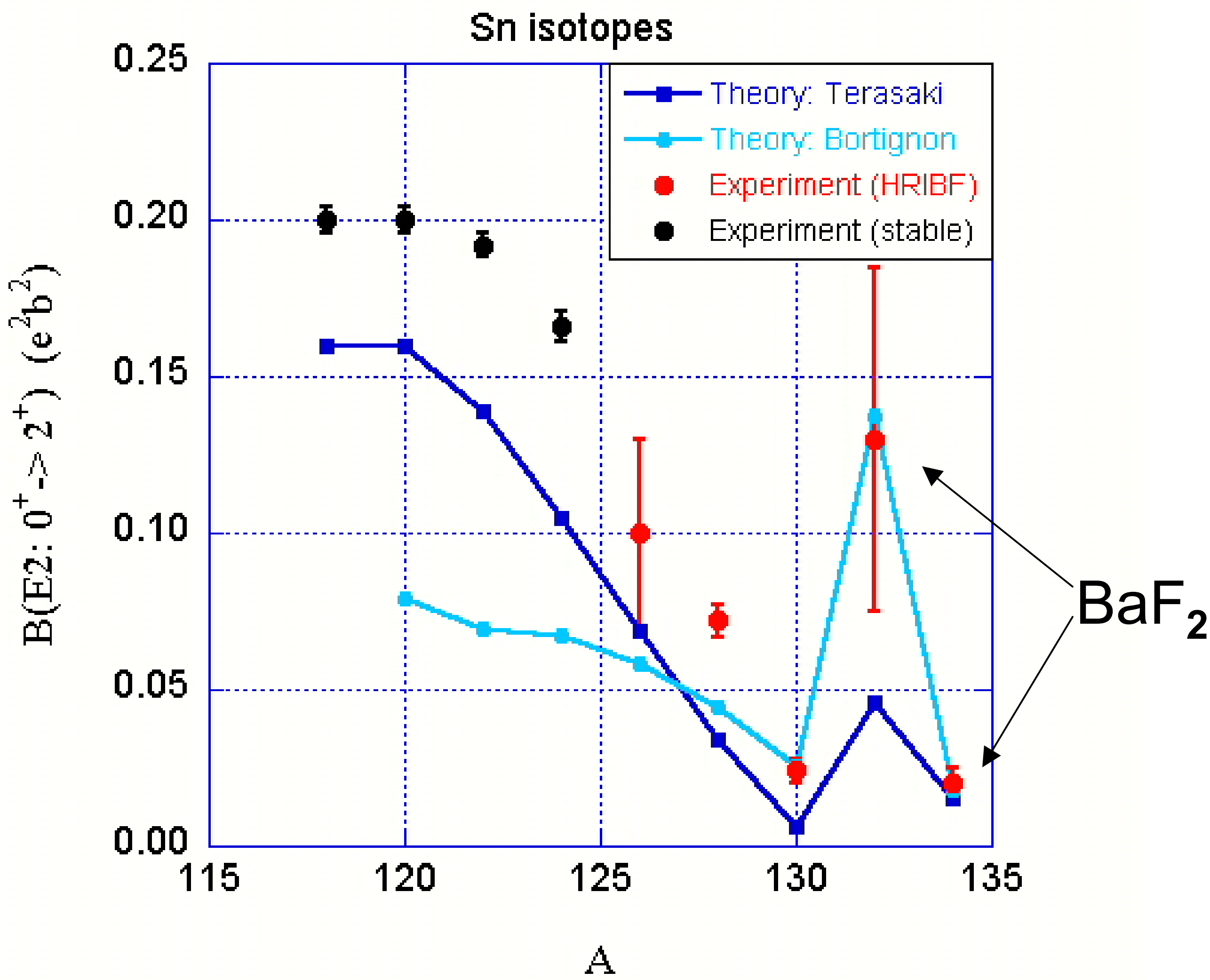


^{134}Sn at 400 MeV

- Success with ^{132}Sn ->
  - Measured ^{134}Sn rate of 2000/s (out of 10k/s total)
- $E(2^+)=0.725$, near ^{48}Ti $E(2^+)$
- Choose ^{90}Zr target $E(2^+)=2.186$
- Same detector array
- Bragg counter



Our results in context



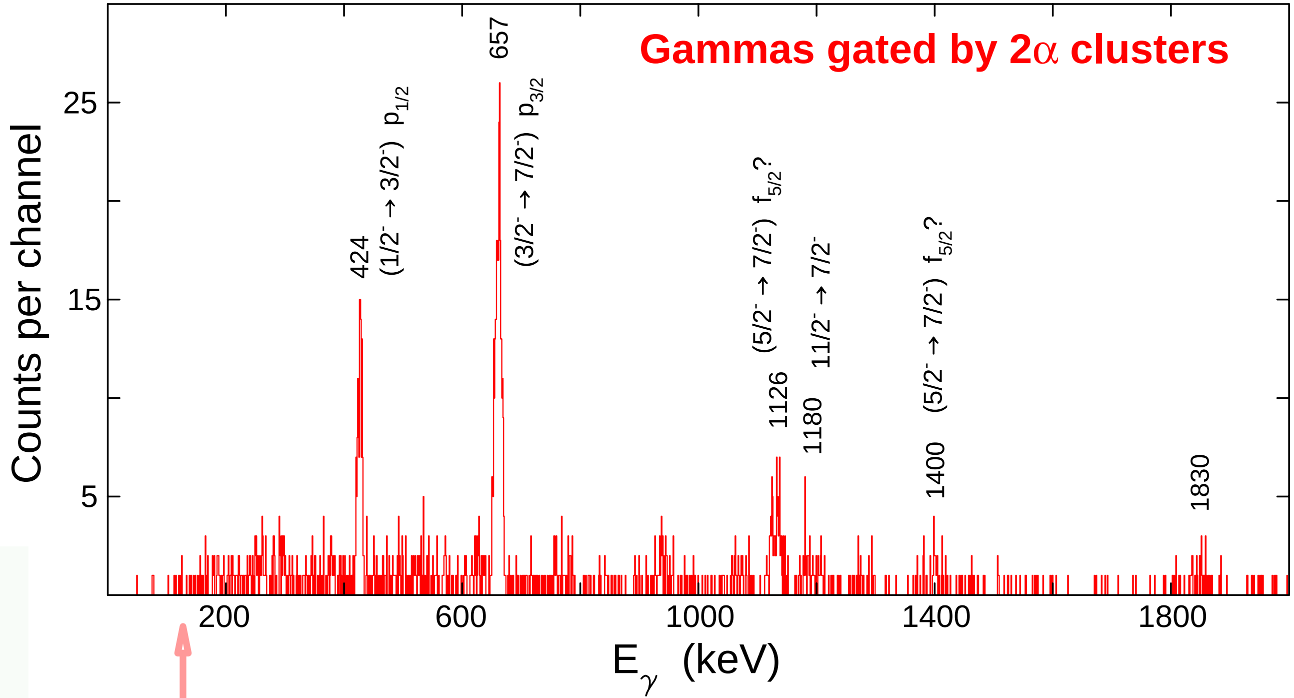
Results for 132 and 134 are very preliminary. The 132 analysis is based on a single BaF2 block. The final 132 uncertainty will be about 20% - compared to 50% on this plot.

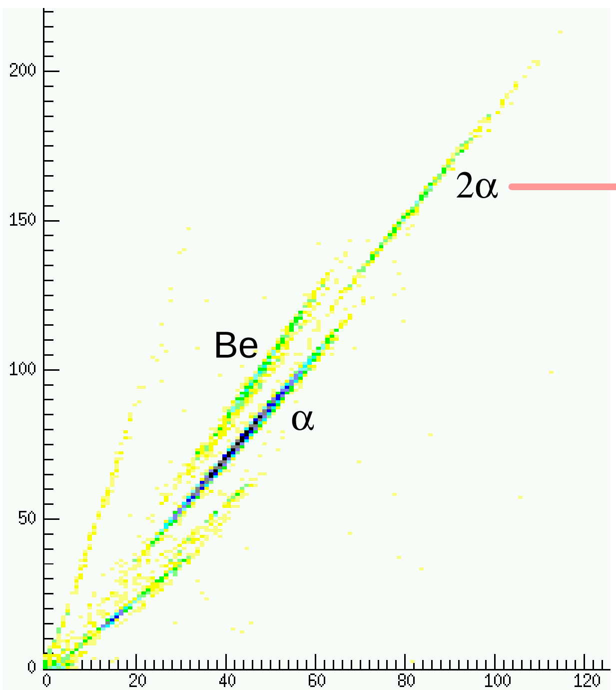
Transfer Reactions with Neutron-Rich RIBS

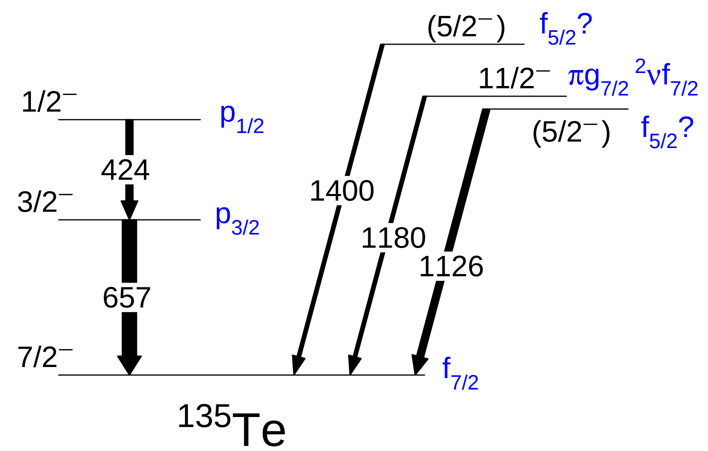
^{9}Be(^{134}Te,^{8}Be)^{135}Te

$\hookrightarrow 2\alpha$

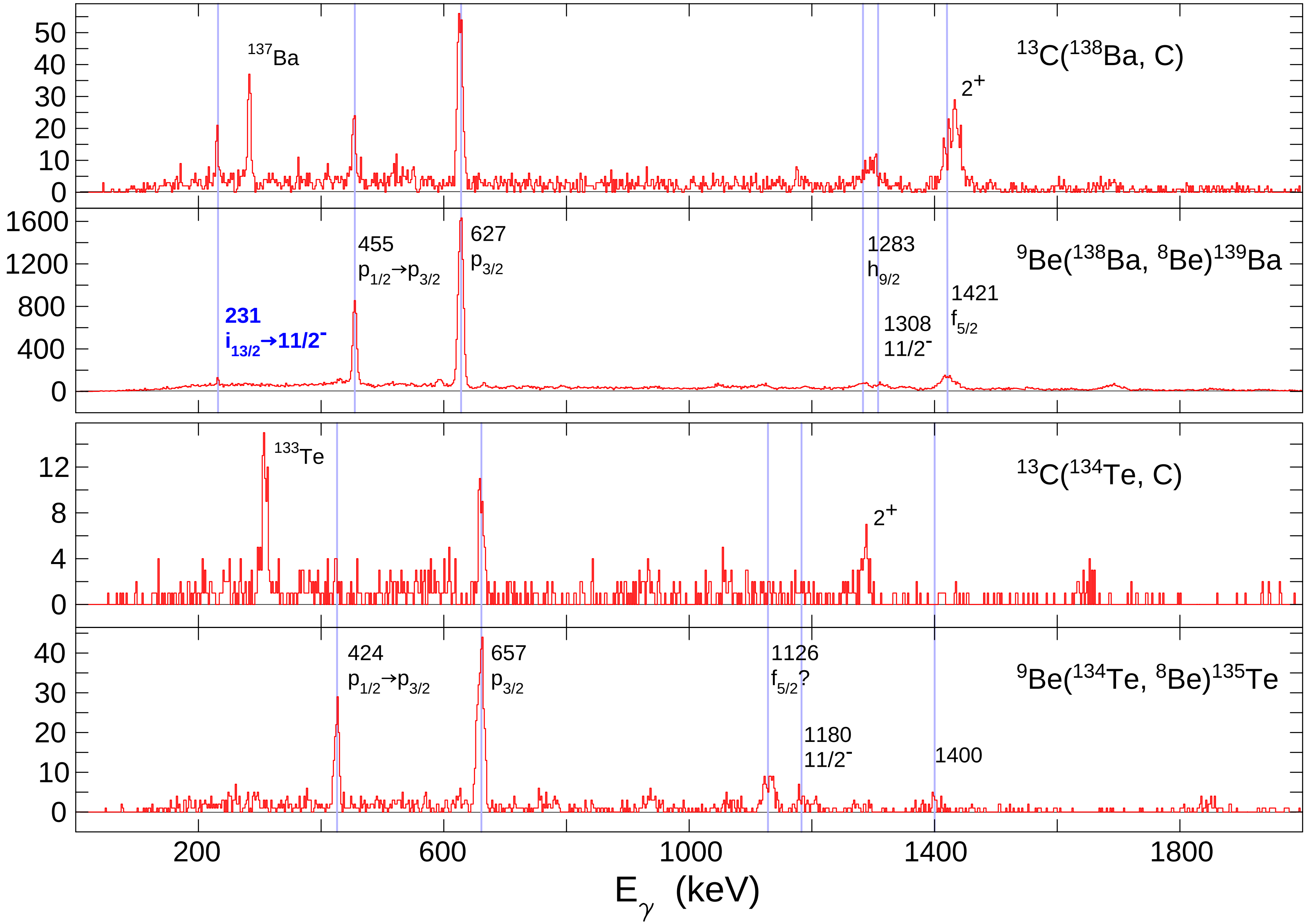
~4 MeV per nucleon





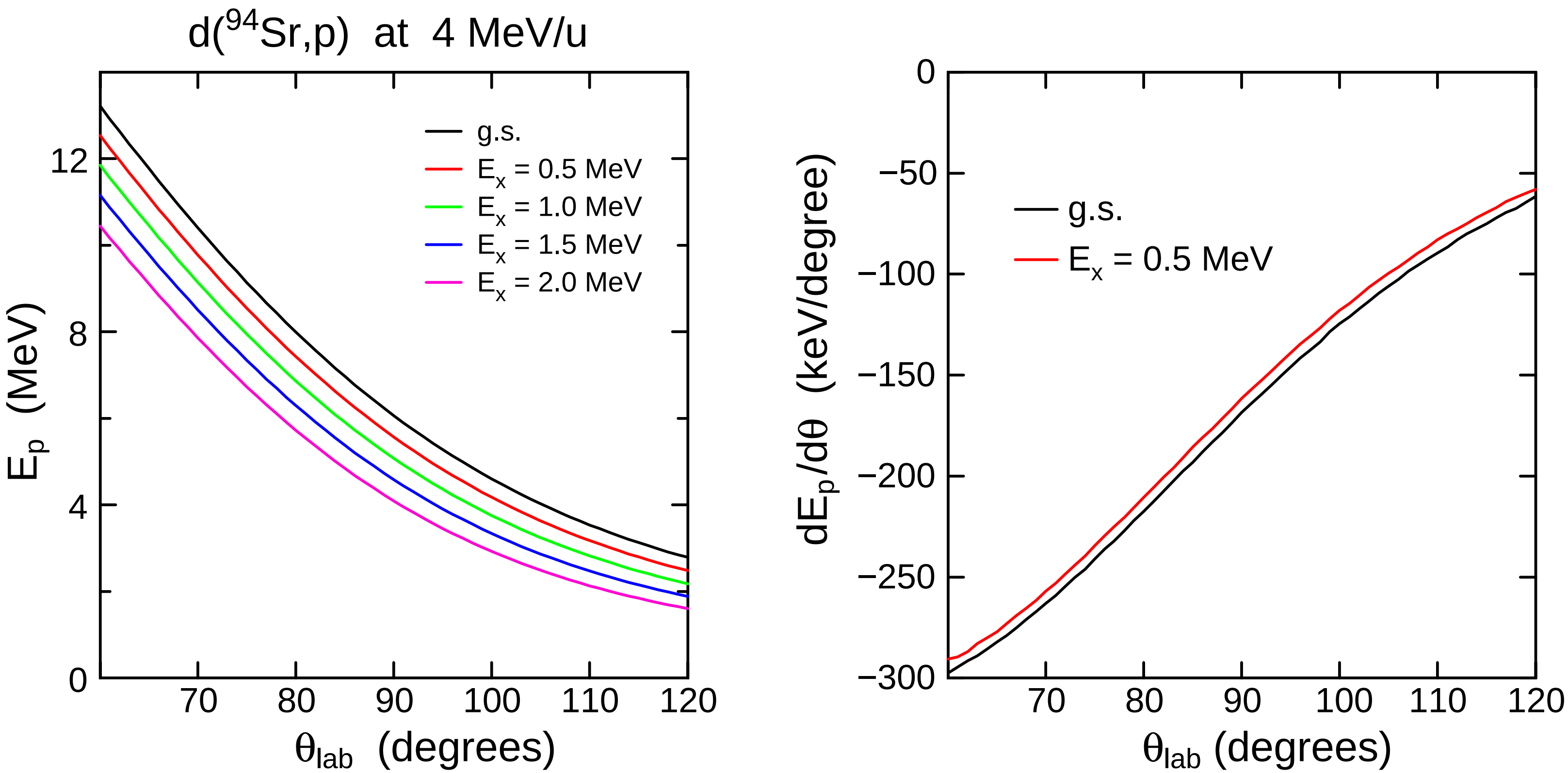


Neutron transfer with ^{134}Te and ^{138}Ba



(d,p) Reactions - *e.g.* d(^{132}Sn, p)^{133}Sn

- **Inverse kinematics leads to large kinematic broadening of proton energy**
  - Even with ~mm proton position resolution, beam spot gives large E_p spread
  - Energy loss of heavy beam in target also spreads proton energy
- **These effects lead to poor resolution in Q-value**
  - Cannot resolve states that are closer than ~300 keV



New Idea: Use Gamma-ray Calorimetry

- **Have seen that gamma detection can be used to identify excited states**
  - CLARION efficiency is too small for angular correlation measurements
  - ~ 10% energy resolution would be sufficient to resolve most levels
  - For moderate resolution but high efficiency, can select levels using the sum energy as well as individual cascades

- **Spin Spectrometer: a good gamma calorimeter for these experiments?**
  - 70 large NaI crystals
  - Energy resolution ~ 10-12%, efficiency ~ 85%

Plan to try using the Spin Spectrometer to select levels of interest, and measuring proton cross-sections and angular correlations in coincidence.

- **The ultimate tool will be GRETA**

Conclusions -- Gamma detection for ISOL

⇒ Gamma detection will be used in almost all experiments with reaccelerated beams at RIA

⇒ Need best possible *efficiency,* even at high energies (~ 4 MeV)
- The weakest beams will be the most interesting
- Many experiments will require $\gamma\gamma$ coincidences (or higher)
- May want to use array as a calorimeter and/or gamma-veto

⇒ Need clean trigger and *good timing*
- Real-to-random ratio can be crucial
- Gammas of interest may also be generated by beam decay

⇒ Need good *energy resolution*
- Helps in bypassing problems from isobaric contamination
- Improves signal-to-noise

⇒ Need good *angular resolution*
- Avoids Doppler broadening at high recoil velocity

⇒ Need as much *space* as possible inside the array
- Will need to be be used with a wide variety of auxiliary detectors

Conclusions -- Gamma detection for ISOL

⇒ **GRETA:** the ideal detector for ISOL experiments?

- Excellent efficiency, ~ 50% for low multiplicity
- Good efficiency even at high energies
- Best possible energy and angular resolution
- Good calorimeter

⇒ I predict that GRETA will be requested for the vast majority of experiments using reaccelerated (& fragmentation?) beams at RIA!

- RIB experiments will be expensive, beam time in great demand
- Will always want as complete information as possible – e.g transfer

⇒ Must be “portable”

⇒ Must be kept as flexible as possible

→ inner space / diameter

→ trigger and readout

Conclusions -- Gamma detection for ISOL

⇒ Will also want a few other smaller systems for dedicated applications

- Close-packed clover array for decay studies *etc.*
- BaF_2 array or similar for very high energy gammas
- Perhaps another ball with even better calorimetric properties

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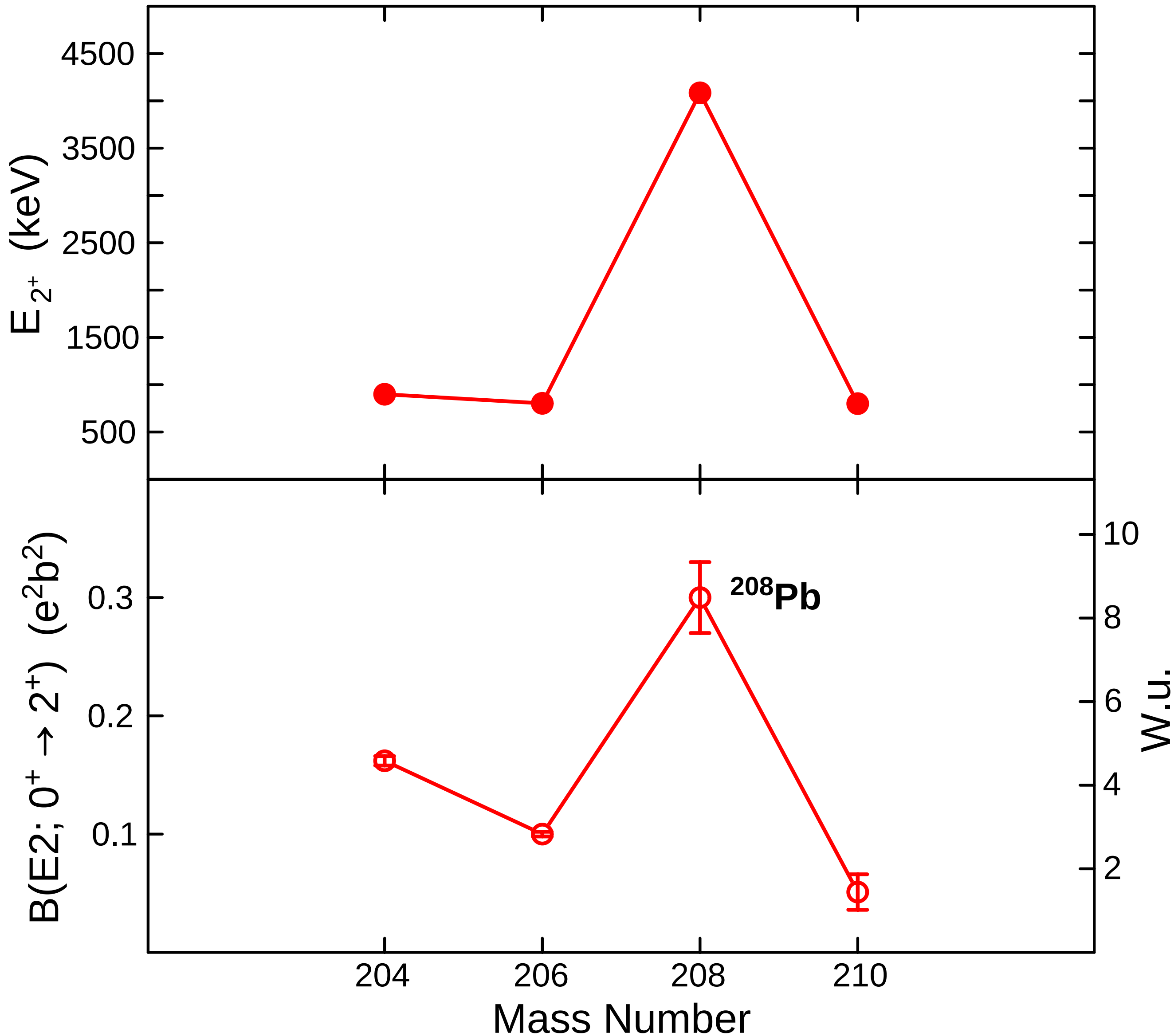
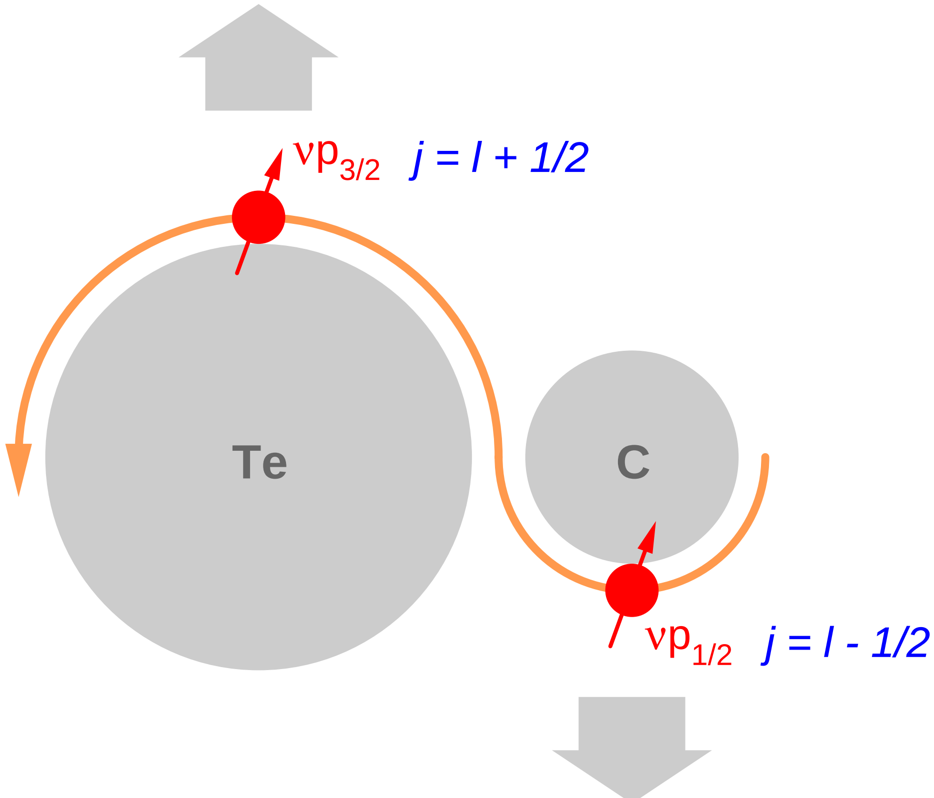
Lead B(E2) Systematics

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



Neutron Transfer: different targets

Are $j = l - 1/2 \longleftrightarrow j = l + 1/2$ transitions preferred?



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)**

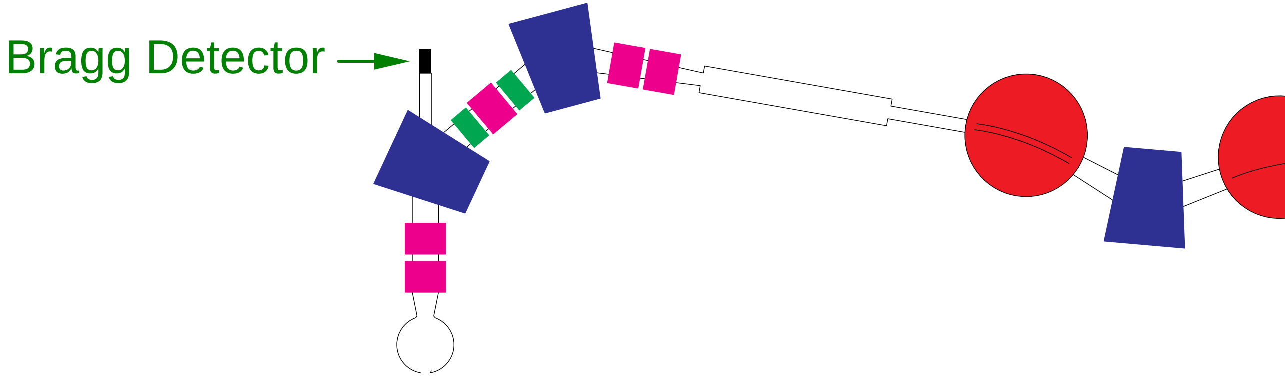
- **Integrate** σ **over the first three rings of HyBall**

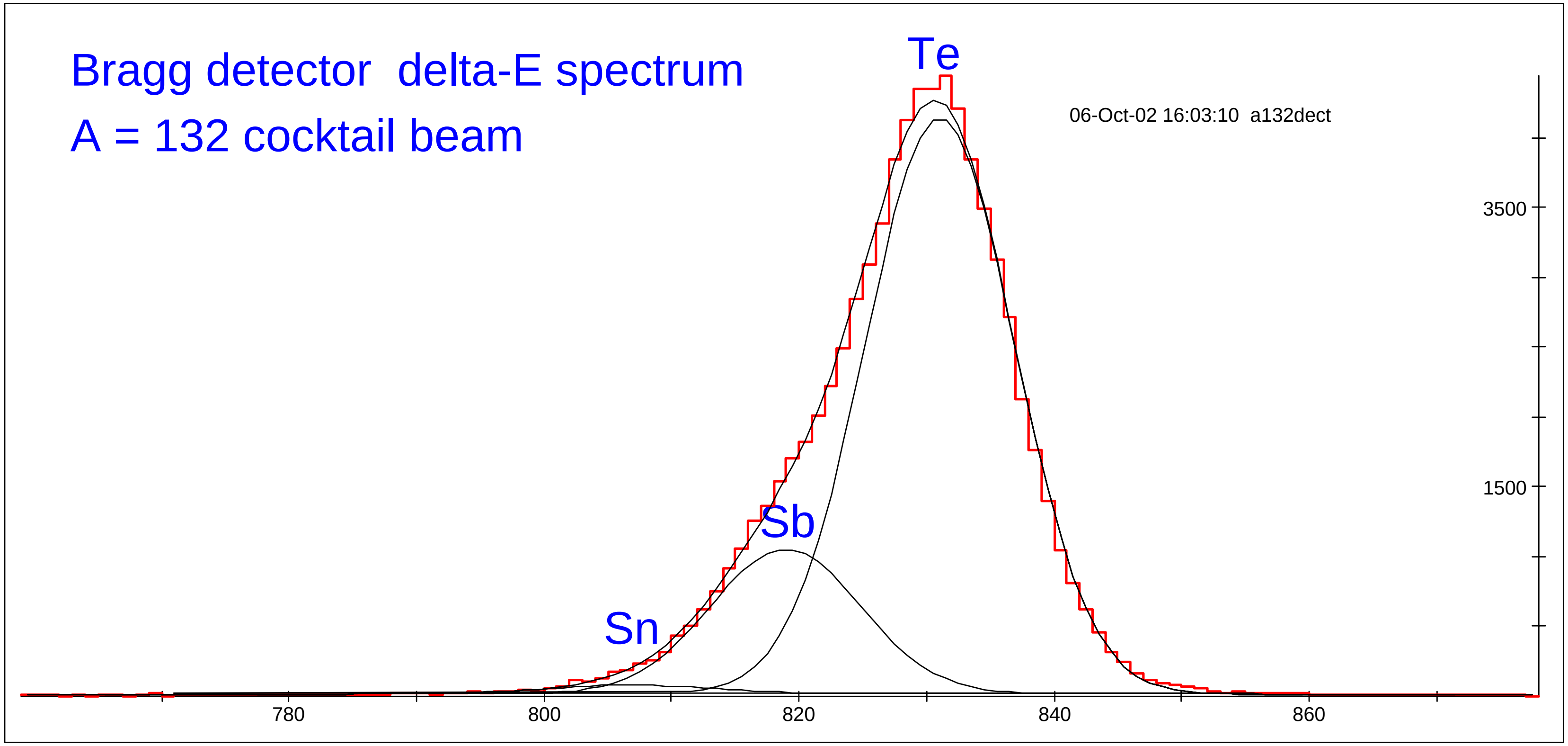
- **Compare calculated** $\dfrac{\sigma_C}{\sigma_R}\,\varepsilon_\gamma$ **with observed** $\dfrac{\gamma H}{H}$ **to get B(E2)**

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

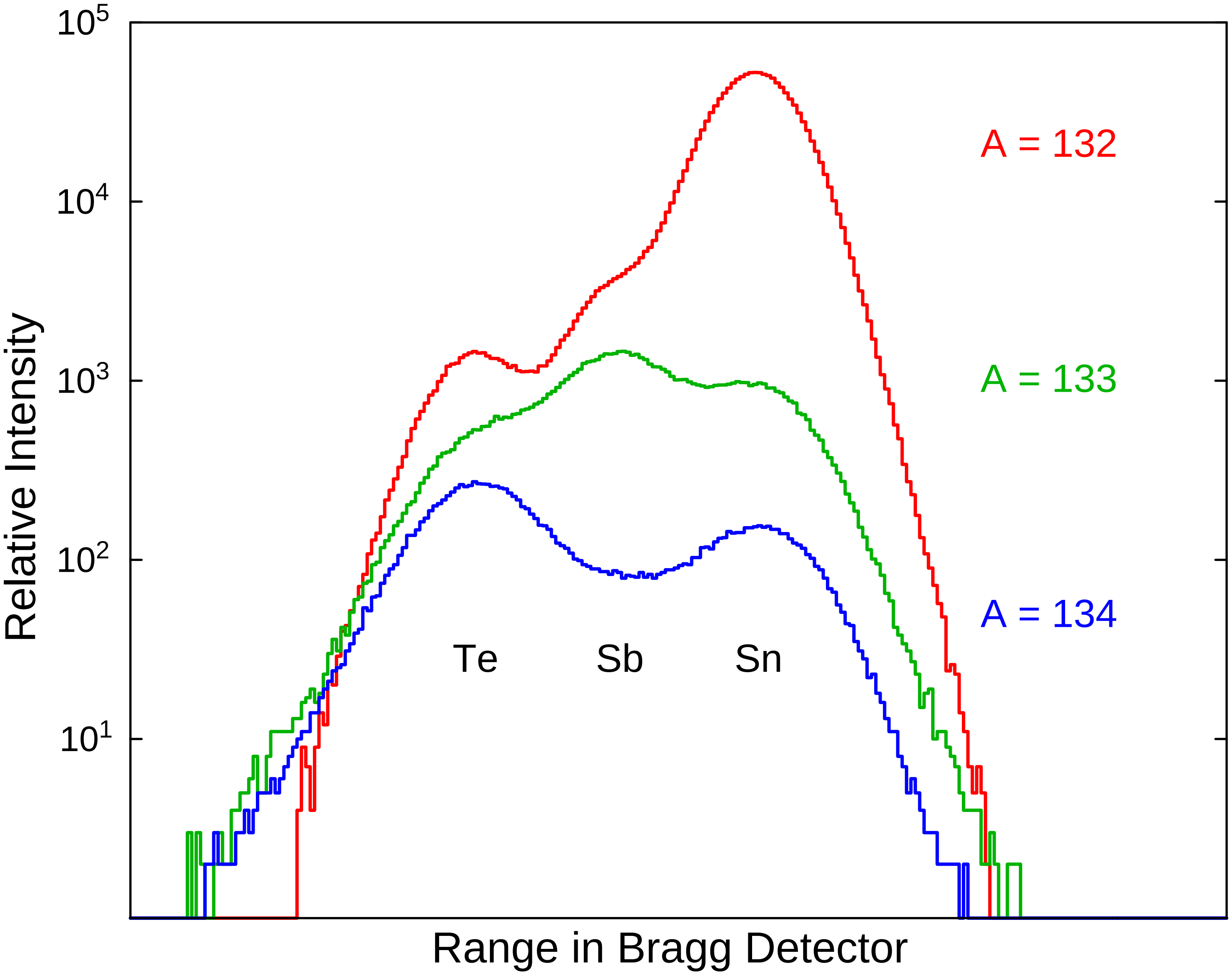
  - determined from Coulex of stable contaminants, decay counting and X-ray spectra

Beam Composition from Bragg-Curve Detector

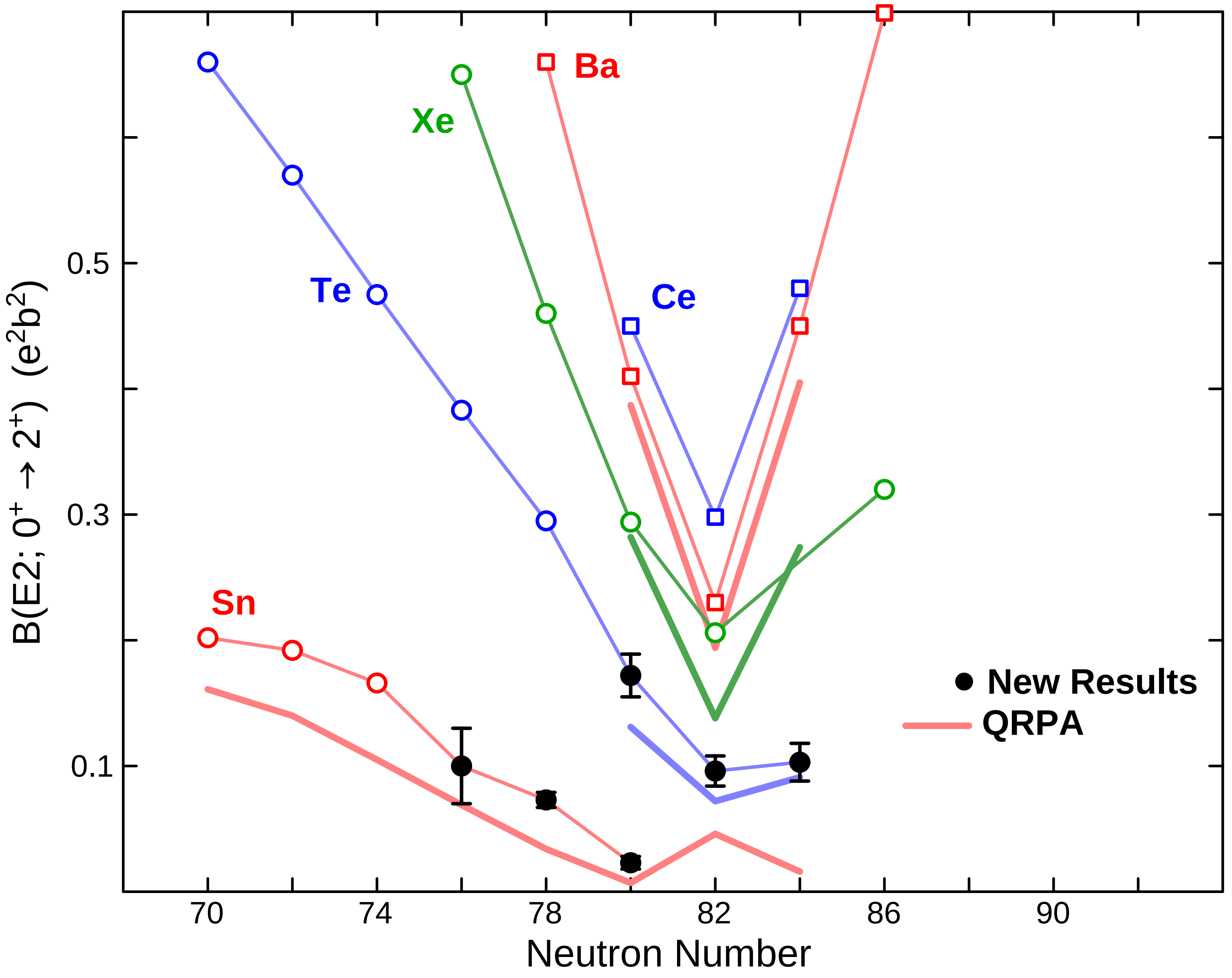




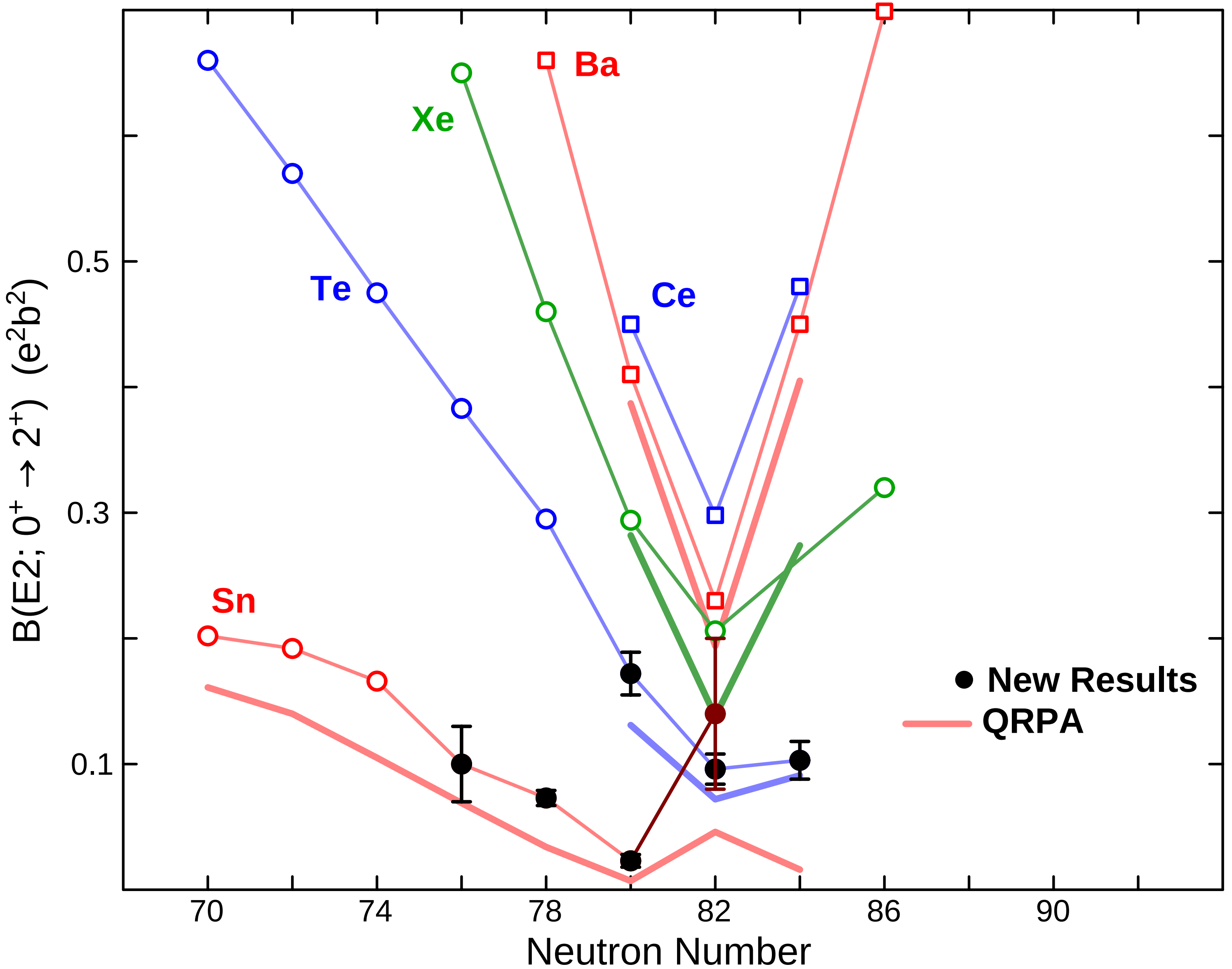
Intensity and Purity of $^{132,133,134}Sn$ Beams from SnS



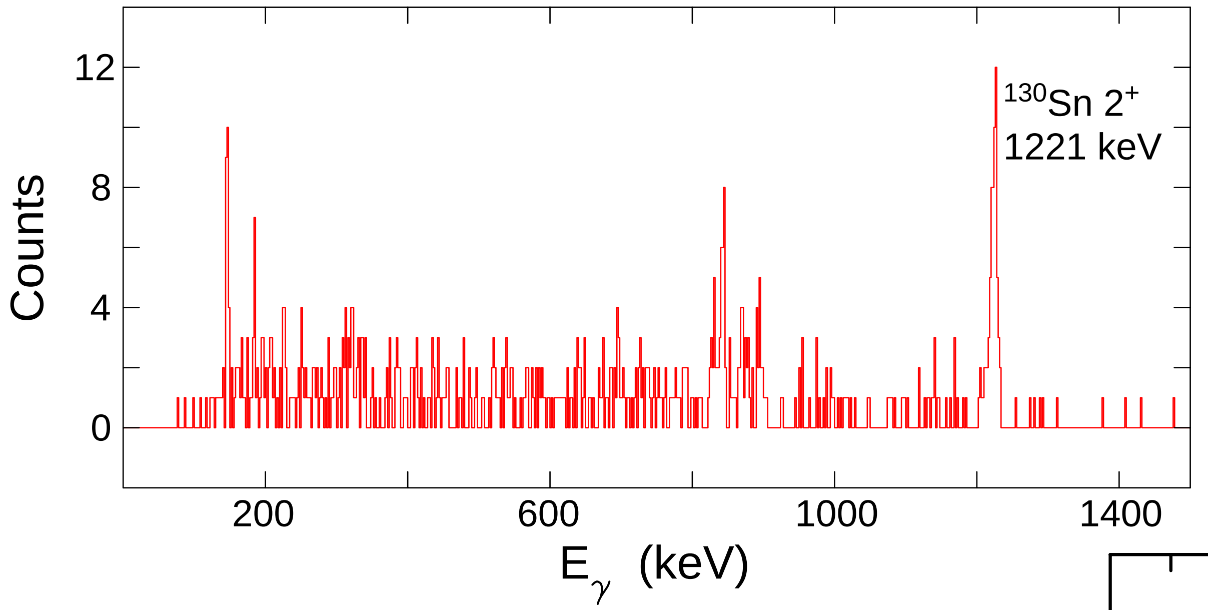
B(E2) Results with QRPA Calculations (Terasaki *et al.*)



B(E2) Results with new ^{132}Sn and QRPA Calculations



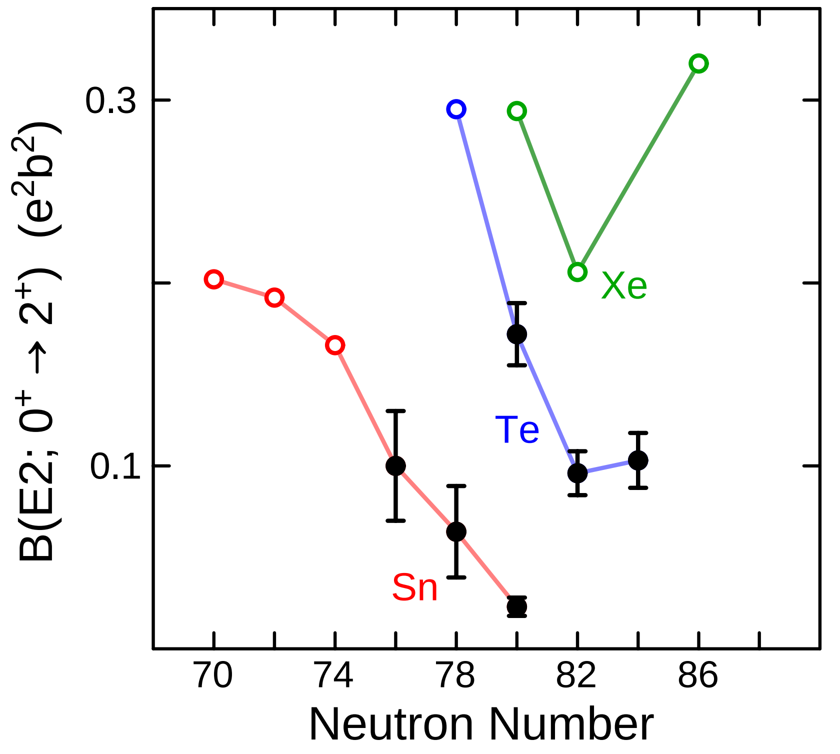
Coulomb Excitation of Pure ^{130}Sn RIB



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



^{132,134}Sn Coulomb Excitation

- Collectivity of doubly magic ^{132}Sn
- Systematics of collectivity in nearby nuclei - ^{134}Sn
- Unique opportunity
  - pure Sn beams (10^4-10^5/s)
  - BaF_2 array (large ε)

- ^{132}Sn + ^{48}Ti 495 MeV
- ^{132}Sn + ^{48}Tl 470 MeV
- ^{134}Sn + ^{90}Zr 400 MeV

^{132}Sn Results (Preliminary)

- ^{132}Sn beam, doubly stripped

  ~96% pure

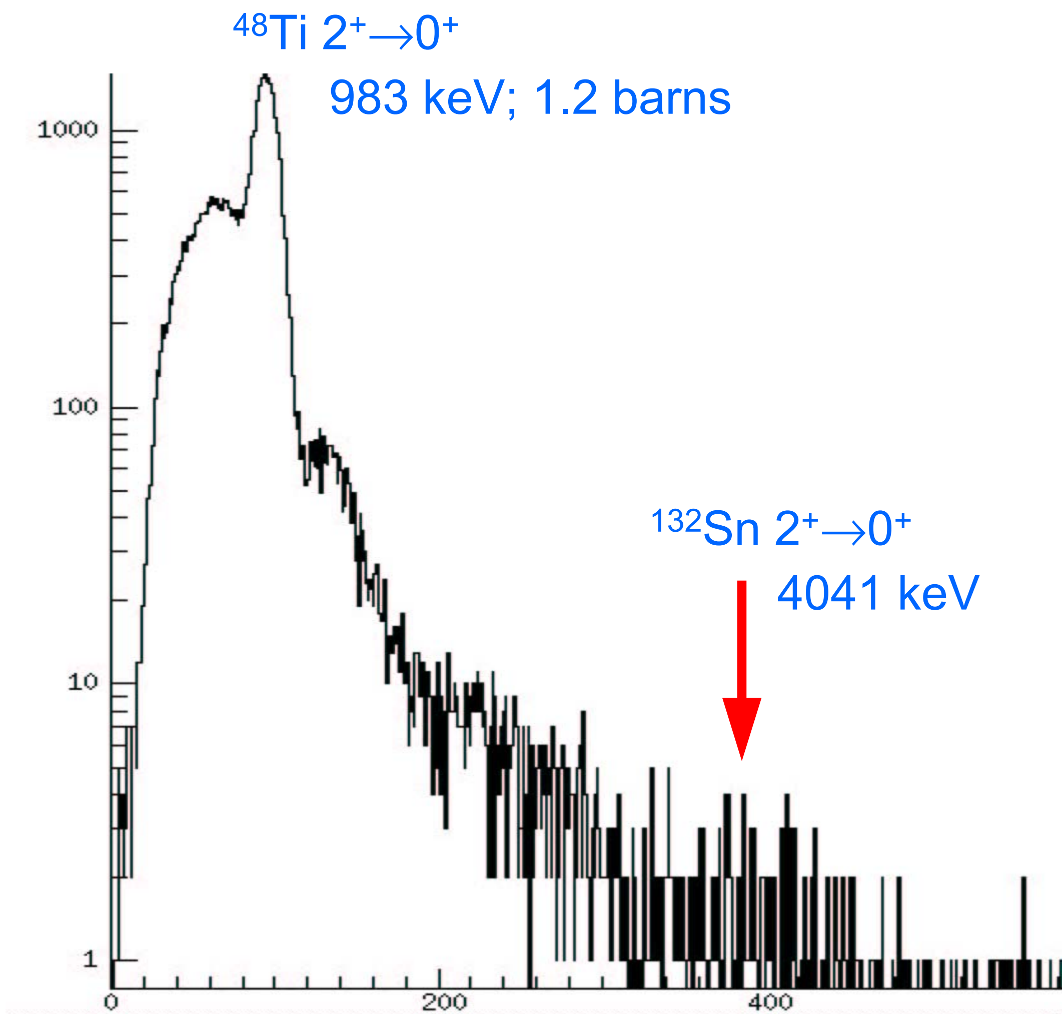
  1.3 x 10^5 ions/s!

  3.56 MeV/u
- ^{48}Ti target
- High γ efficiency (~ 40%)
- Two-week experiment
- Fast γ–ion coincidences

  to suppress background

B(E2; $0^+ \rightarrow 2^+$) ~ 0.14(6) e^2b^2

Sample gamma-ray spectrum:



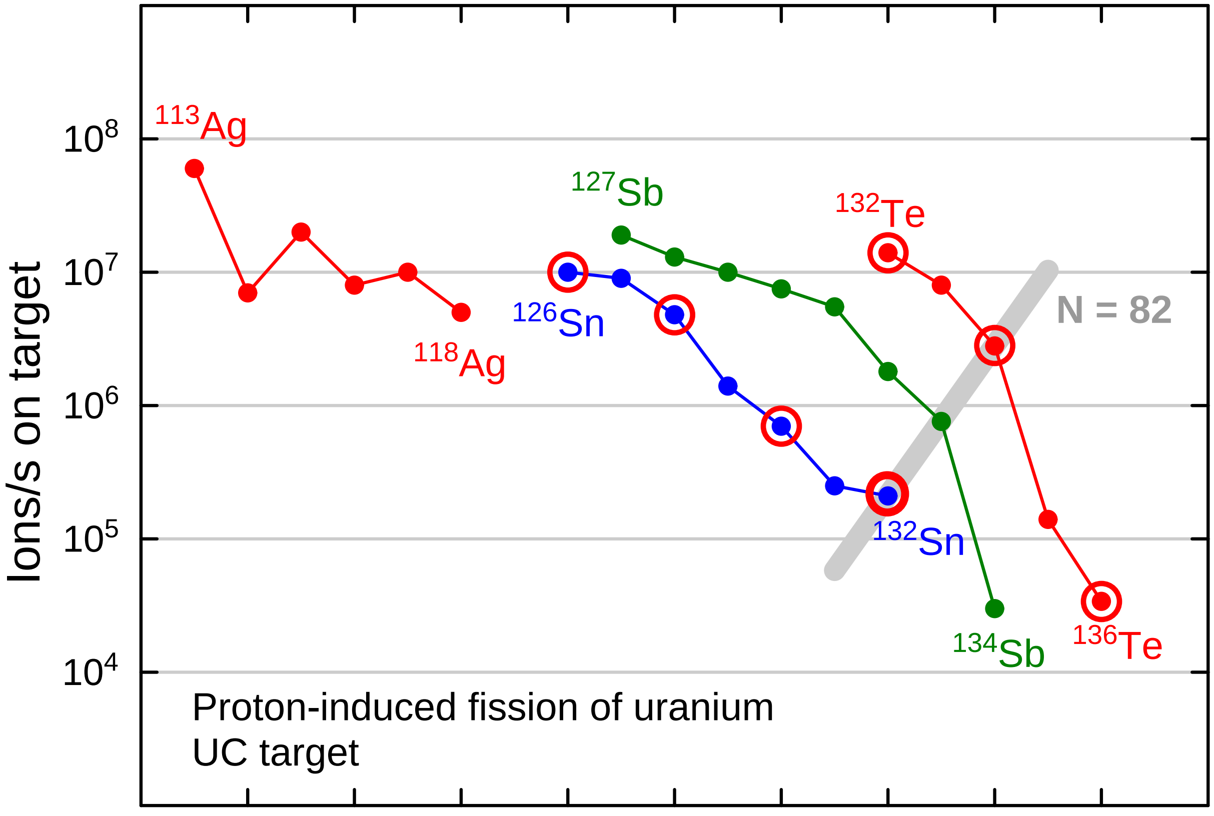
Present Status of the Spin Spectrometer

- **Spin Spectrometer has not been used for about 10 years**
  - New electronics and data acquisition system being assembled
  - Washington University (St. Louis) helping with support and electronics
  - HV has been applied to all 70 detectors;
    all detectors are giving output pulses
  - Next step: resolution and efficiency tests for all detectors
  - Tests of subset gave promising results; 8-14% resolution for ^{137}Cs

- **Spectrometer will need to be moved to a new beam line**
  - Present target room needed for second RIB platform

Some HRIBF beam currents

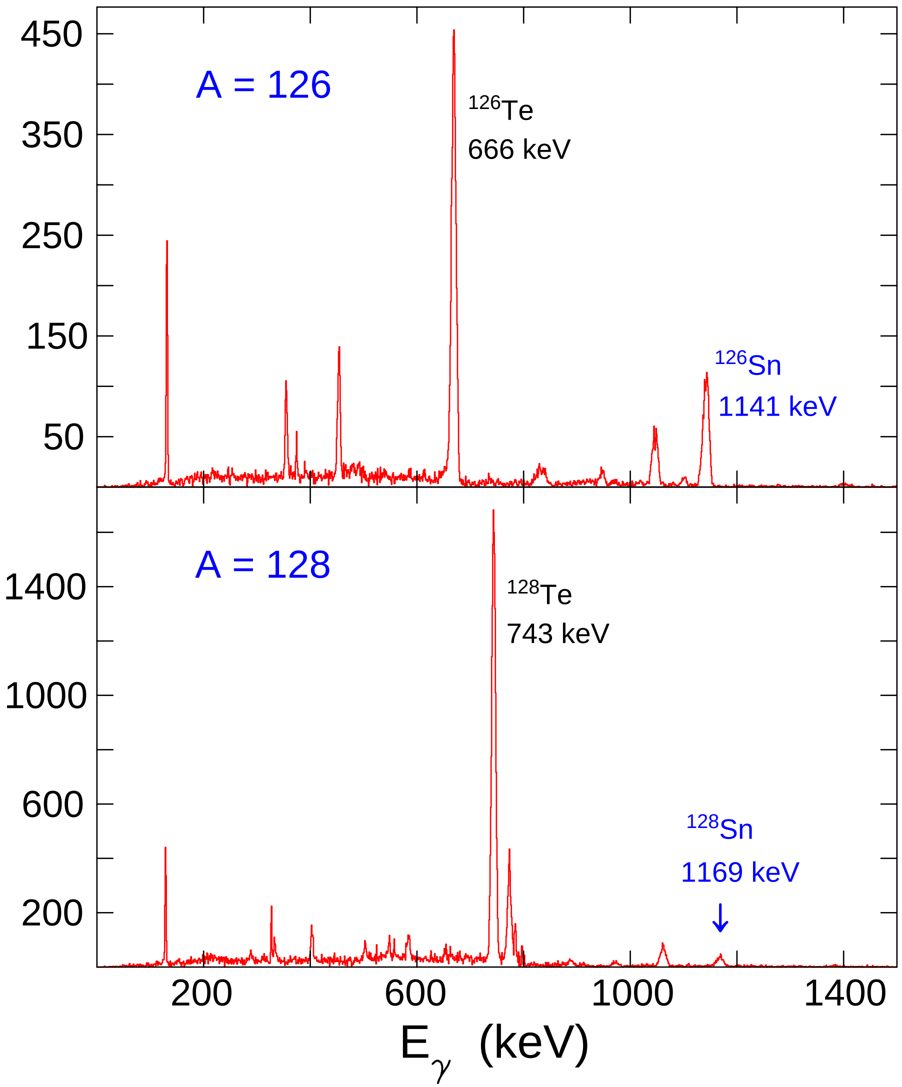
Singly stripped - suitable for Coulex
For doubly stripped, divide by five

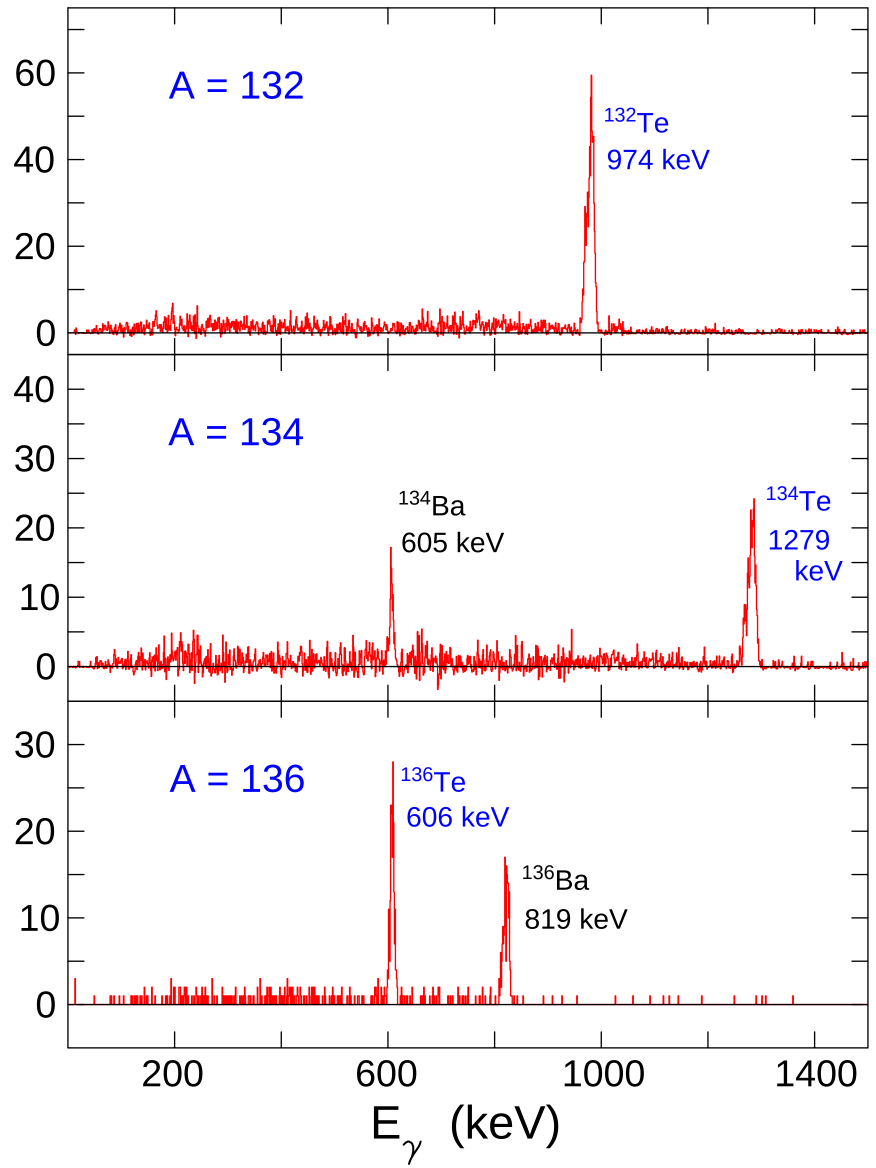


HRIBF will be the only facility that can accelerate these beams above the Coulomb barrier for at least 4 - 5 years.

Total of over 100 beams with at least 10^3 ions/s.

Coulex Results: Sn & Te Spectra





Note multiple beam components

Pure Ge and Sn Beams

- Neutron-rich RIBs are “cocktail” beams;
  Sn can be a small component
  A=132 beam: 87%Te, 12% Sb, 1% Sn
- Solution: Extract from ion source as SnS^+ and mass analyze for molecular ion
- Sulfur is added to the UC target via H_2S
- Convert SnS^+ to Sn^- in a Cs-vapor cell and mass analyze again for Sn mass
- Selection process against Te, Sb is unknown
  - TeS^+ SbS^+ unstable?
- Similar purification for Ge beams