Highlights at HRIBF

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ORNL

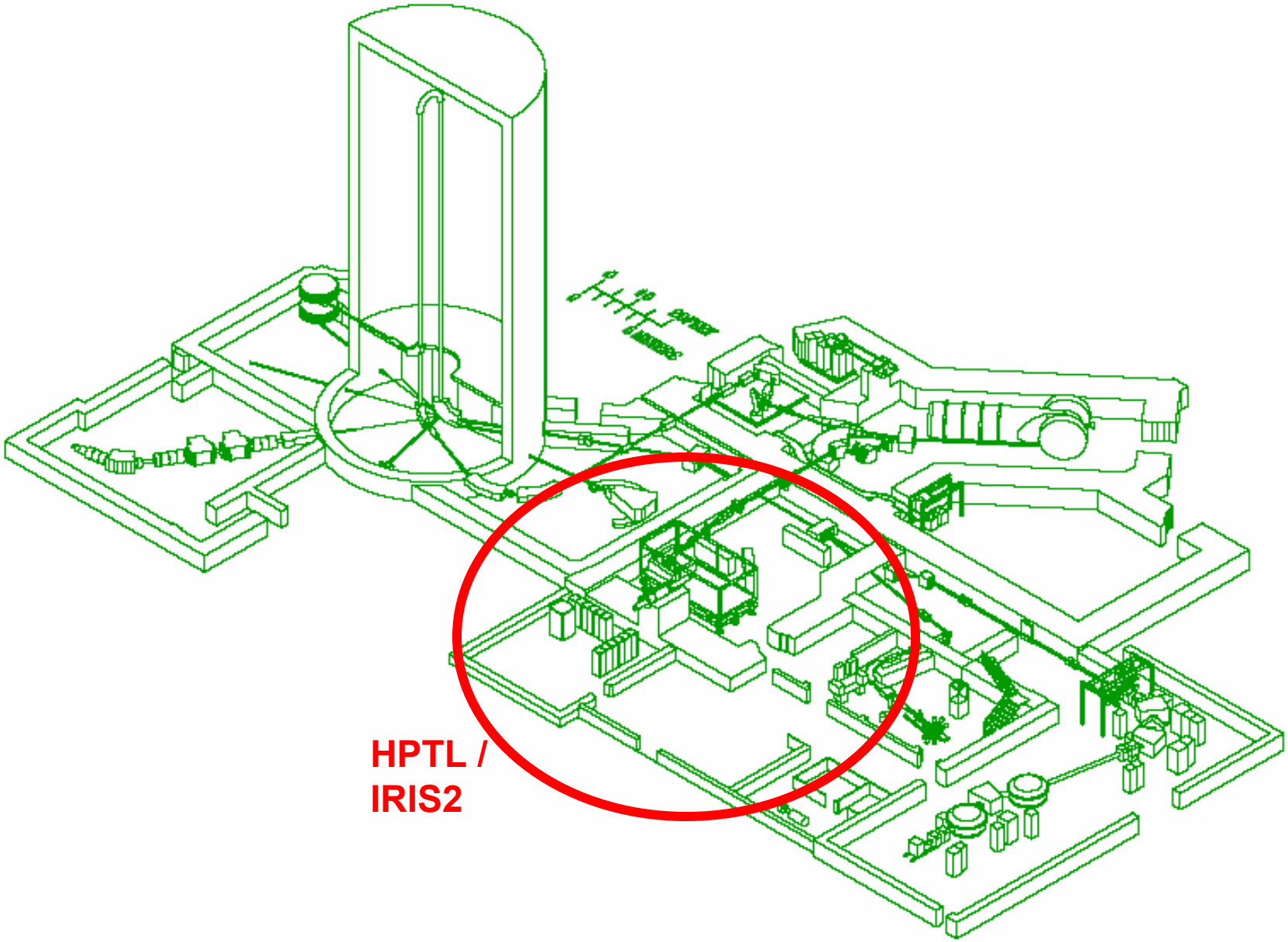
NSAC

March 3, 2005

HRIBF

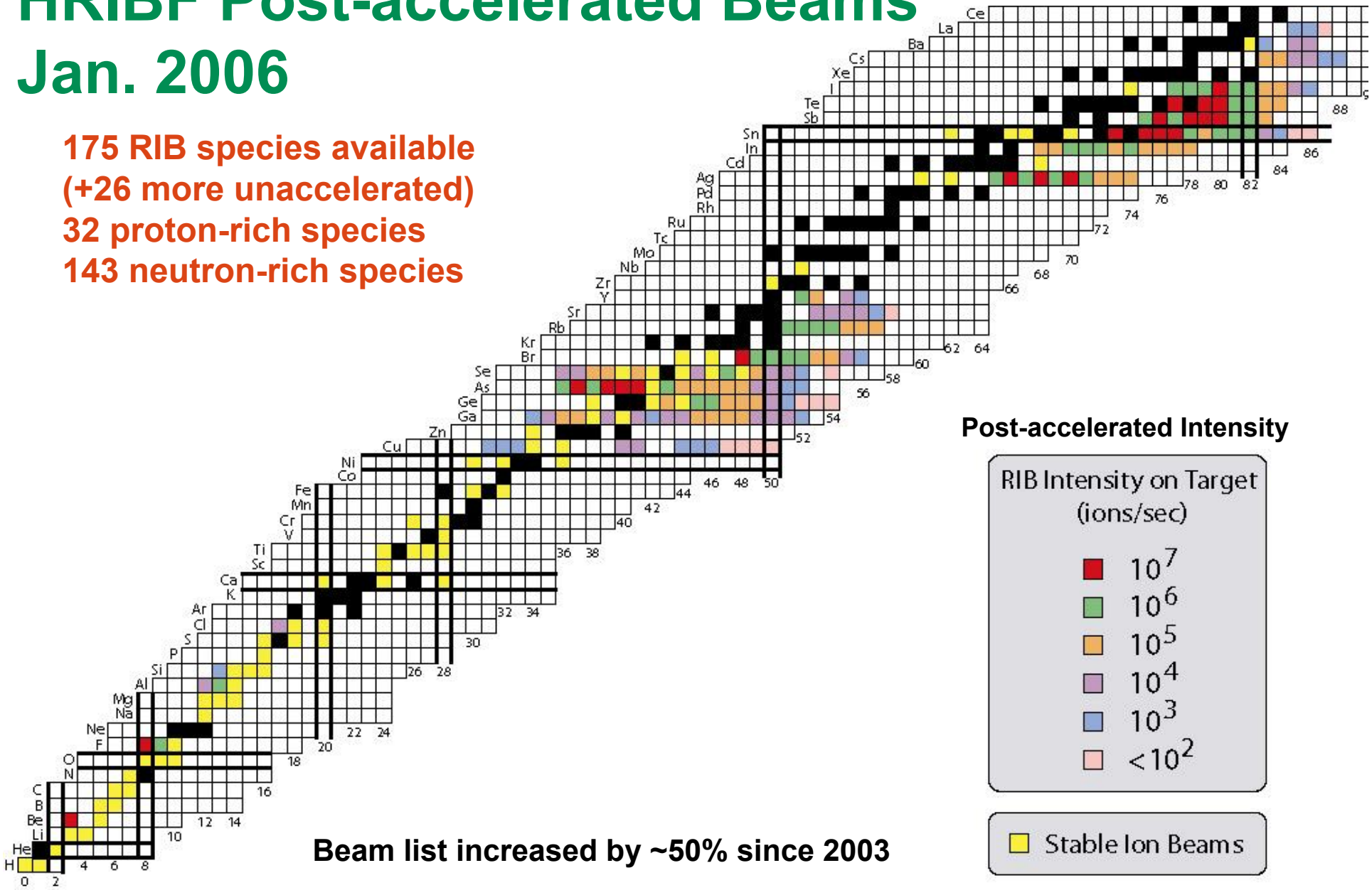
- Produces high-quality post-accelerated beams of unstable nuclei
  - Radioactive ion beams (RIBs)
- A national user facility for RIB science
  - Developed at low cost out of an existing accelerator complex
  - Approx. 350 users
  - Research programs in two primary areas
    - Nuclear structure & reactions
    - Nuclear astrophysics
  - Operates 5+ day 24 hour schedule
    - ~4000 total research hours per year
    - 1500 to 2000 hours RIB on target in present configuration
    - Up to 3000 hours RIB (5day ops) with new production target area
- Only facility of its type in the US
- Has capabilities that are unique worldwide
- Helping to develop ISOL RIB science
  - Pioneering techniques, developing technology
  - Helping to develop, maintain a user base for next generation facility

HRIBF Schematic



HRIBF Post-accelerated Beams Jan. 2006

175 RIB species available
(+26 more unaccelerated)
32 proton-rich species
143 neutron-rich species



Beam list increased by ~50% since 2003

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Radioactive Beam Development

- The success of HRIBF as a radioactive beam facility depends on the development of physically interesting beams.
- In general development of each beam is a research project in itself.
- Each new beam can require development of a new target system.
- In some cases optimized ion sources must be developed for particular RIB species.

ISOL R&D

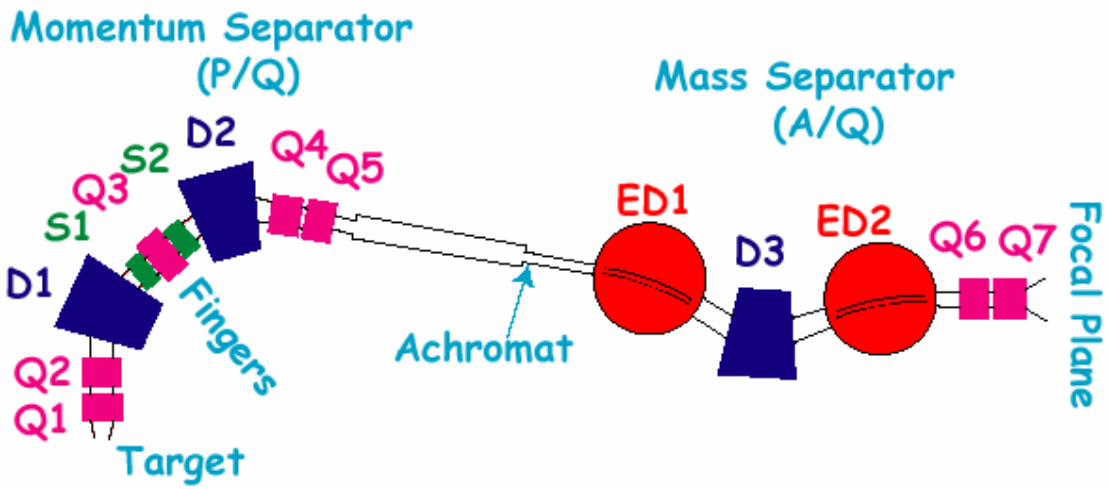
- Ion source system development and optimization
- Target material and format development
- Target thermal performance
- Beam purification and manipulation
  - Chemistry, IS, resonant laser, non-resonant laser, ion-guide…
    - Examples:
      - Sn, Ge purified via sulfide chemistry
        - Mass 132 from 2% Sn → 96% Sn
      - Ni purified via laser photodetachment
      - Br, I purified via IS specificity
- RLIS development
- Target release studies

HRIBF Core Science Programs

- Astrophysics
  - Reactions relevant to explosive nucleosynthesis
    - Direct and indirect studies
    - Surrogate reaction studies
    - Level properties of n-rich systems
  - Solar physics
- Nuclear structure and reactions
  - Coulex, transfer, static moment measurements
  - Reactions in very neutron-rich systems
    - Relevance to superheavies?
  - Reactions with weakly bound probes
  - Decay spectroscopy
- Theory
  - Close and fertile collaboration in major experimental prorrams
- ISOL science and technology
- Applications
  - NNSA Center of Excellence in Stockpile Stewardship (Rutgers U.)
  - AMS

Nuclear Structure Endstation

Recoil Mass Spectrometer



Mentors:
Carl Gross
Kris Rykaczewski
David Radford
Alfredo Galindo-Uribarri
Chang-Hong Yu

Performance Numbers

Energy acceptance +/-10%
A/Q acceptance +/-4.9%
Mass resolution (M/ΔM) ~400
Efficiency: Reaction dependent
(typically around 5%)
Length - 25 m
Time-of-flight - 1.5-3 us
Gross et al., NIM 450A, 12 (2000)

Detectors

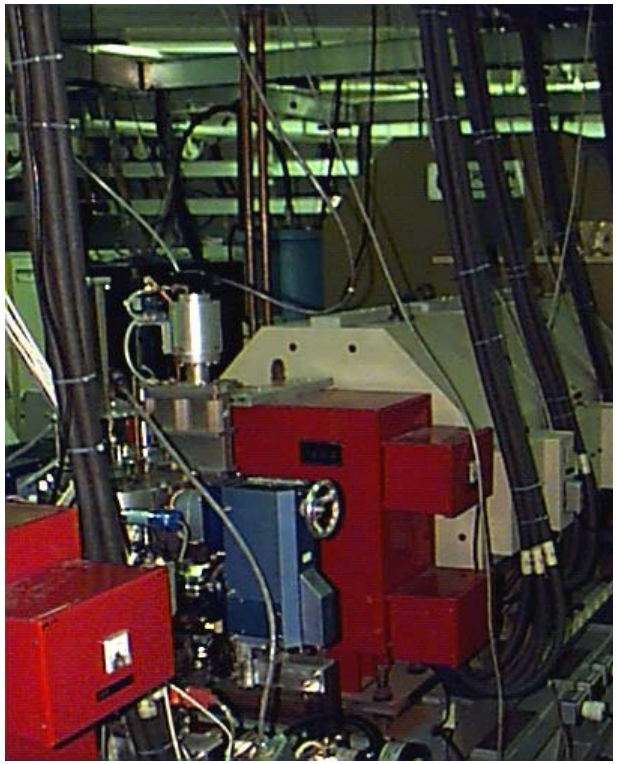
Clarion - 11 Clover Ge (2.2% eff)
HyBall - 95-element CsI
Neutron array - 19-element NE-213
Forward array - Si E-ΔE (~7º-~30º)
MCPs and PSAC @ focal plane
Double-sided Si strip detectors
Moving Tape Collector
CARDS - Ge detectors @ focal plane
Beta & electron (BESCA) detectors

The HRIBF Recoil Mass Separator (RMS)

C.J.Gross et al., NIM Phys.Res. A450 (2000) 12

Daresbury Recoil Separator (DRS)

Astrophysics Endstation

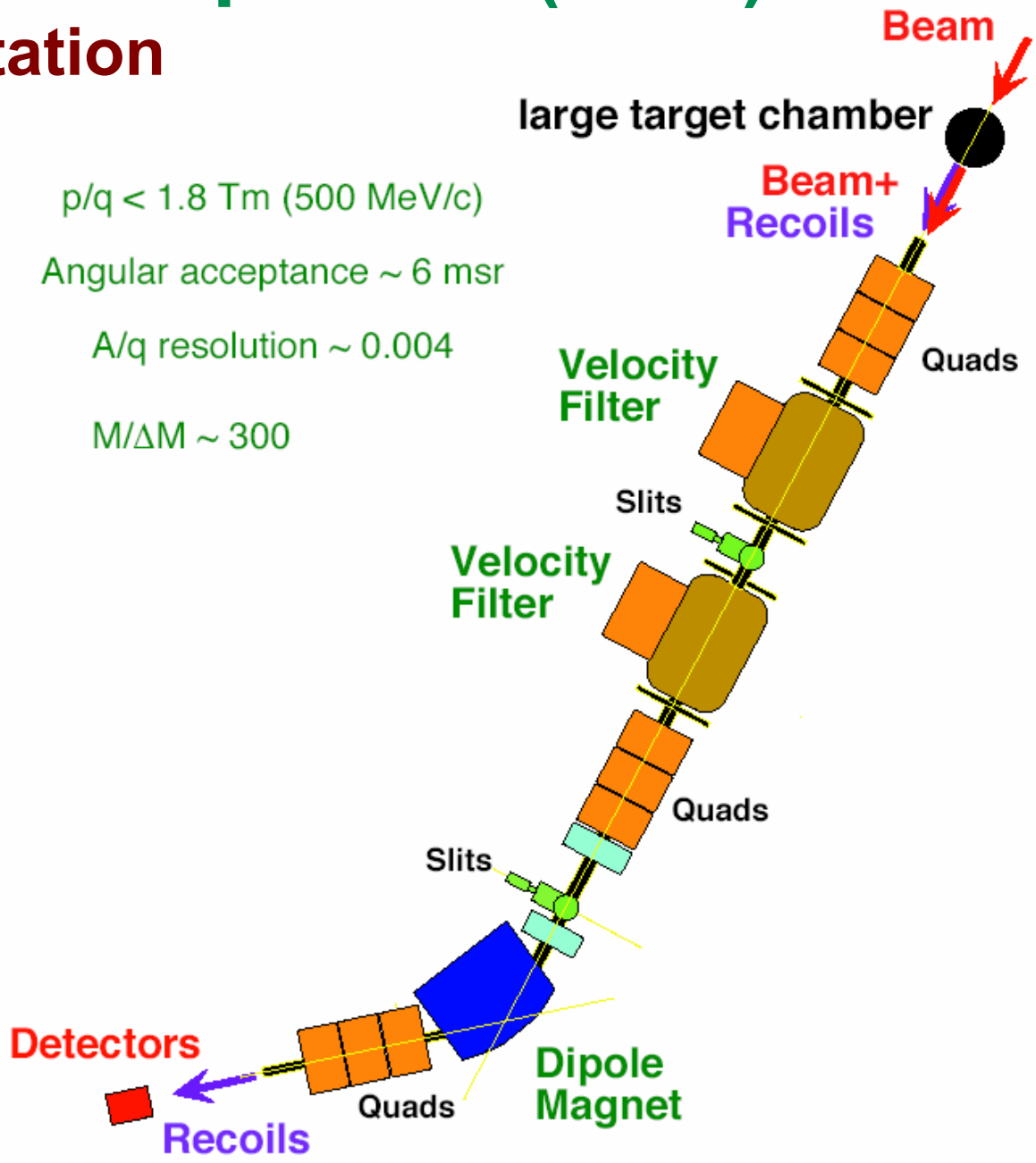


p/q < 1.8 Tm (500 MeV/c)

Angular acceptance ~ 6 msr

A/q resolution ~ 0.004

M/ΔM ~ 300



SIDAR
Ion Chamber
Windowless gas cell

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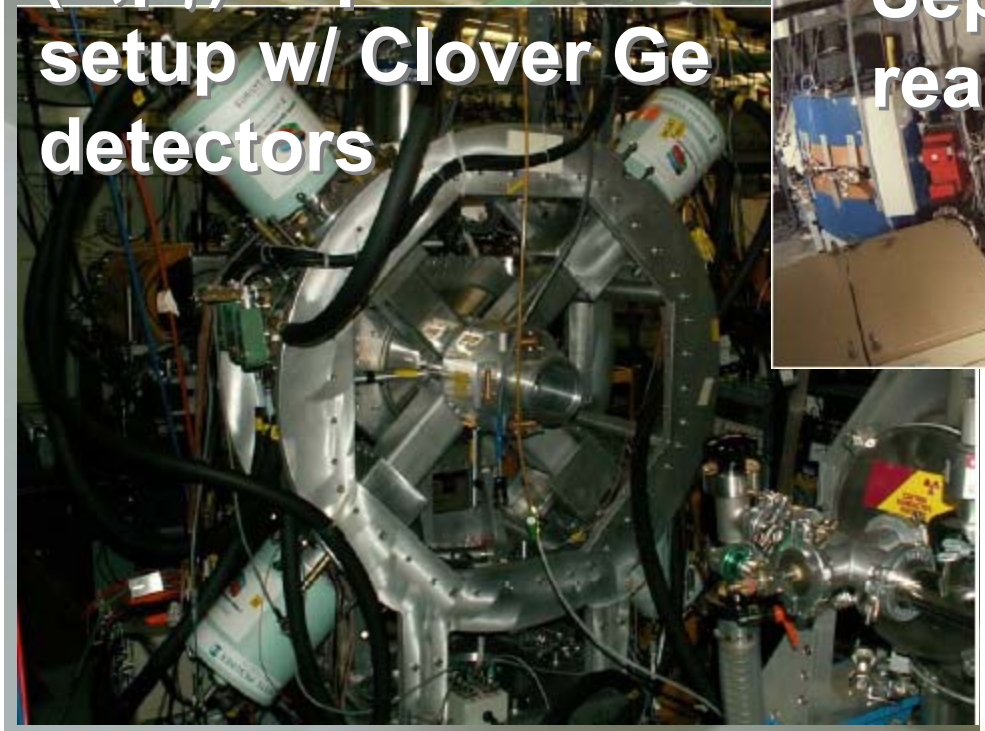
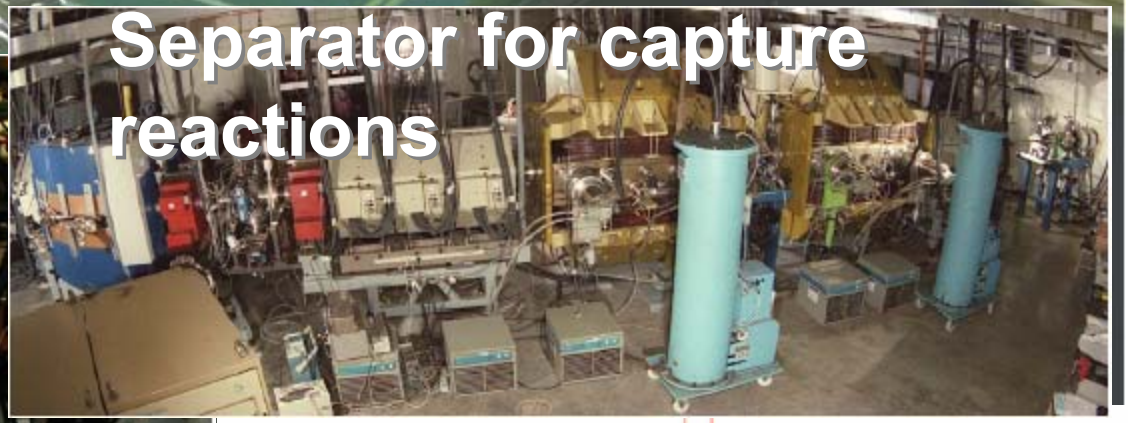
HRIBF Nuclear Astrophysics Detector Systems

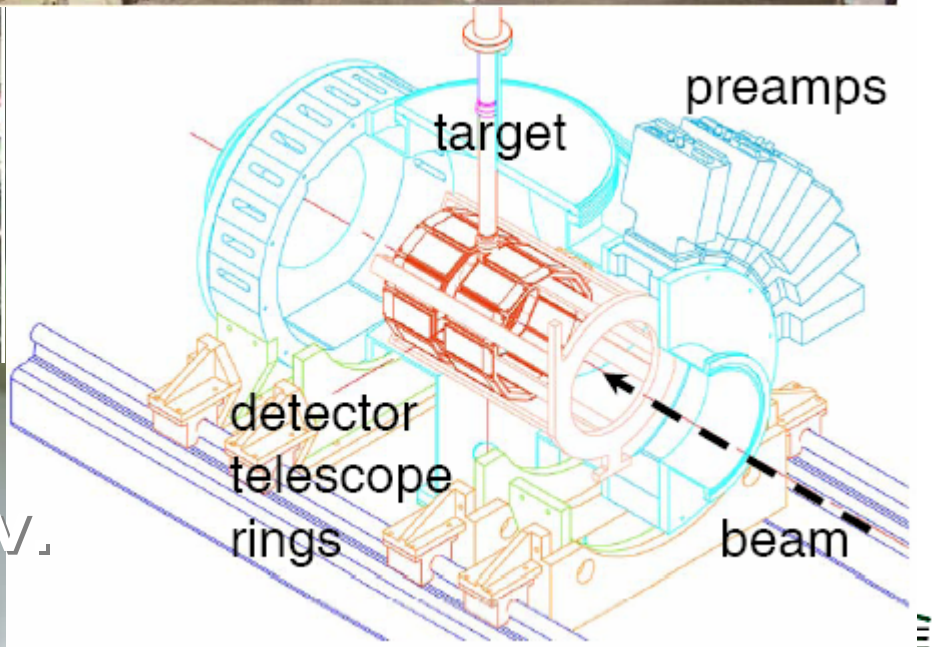
(d,pγ) experimental setup w/ Clover Ge detectors



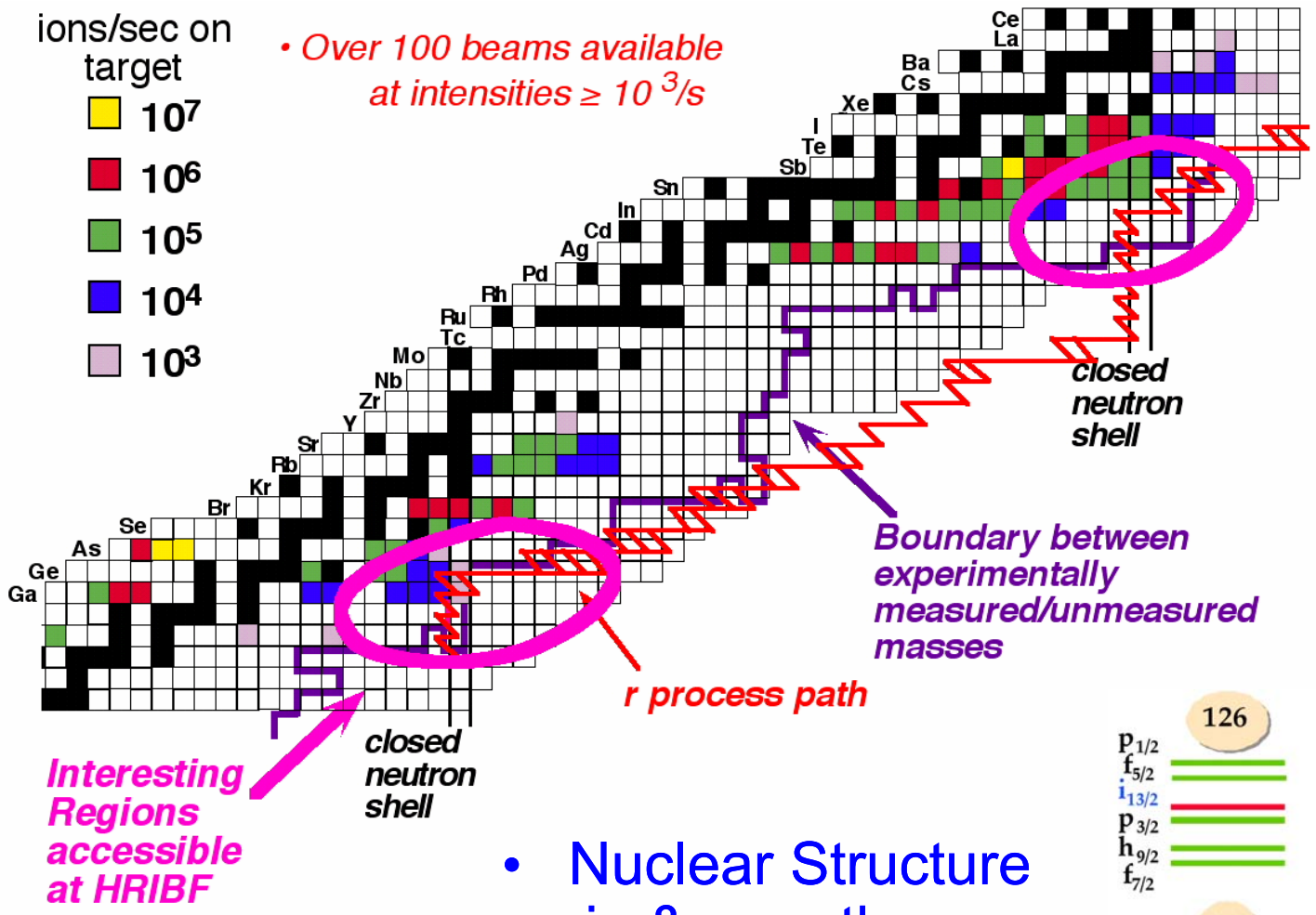
Daresbury Recoil Separator for capture reactions



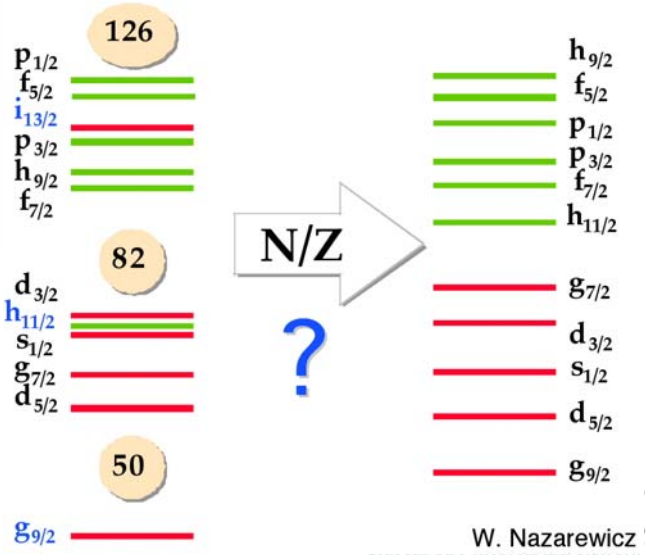
ORRUBA - Oak Ridge Rutgers Univ. Barrel Array



Nuclear Structure Studies at Large Neutron Excess



- Nuclear Structure in & near the r-process path



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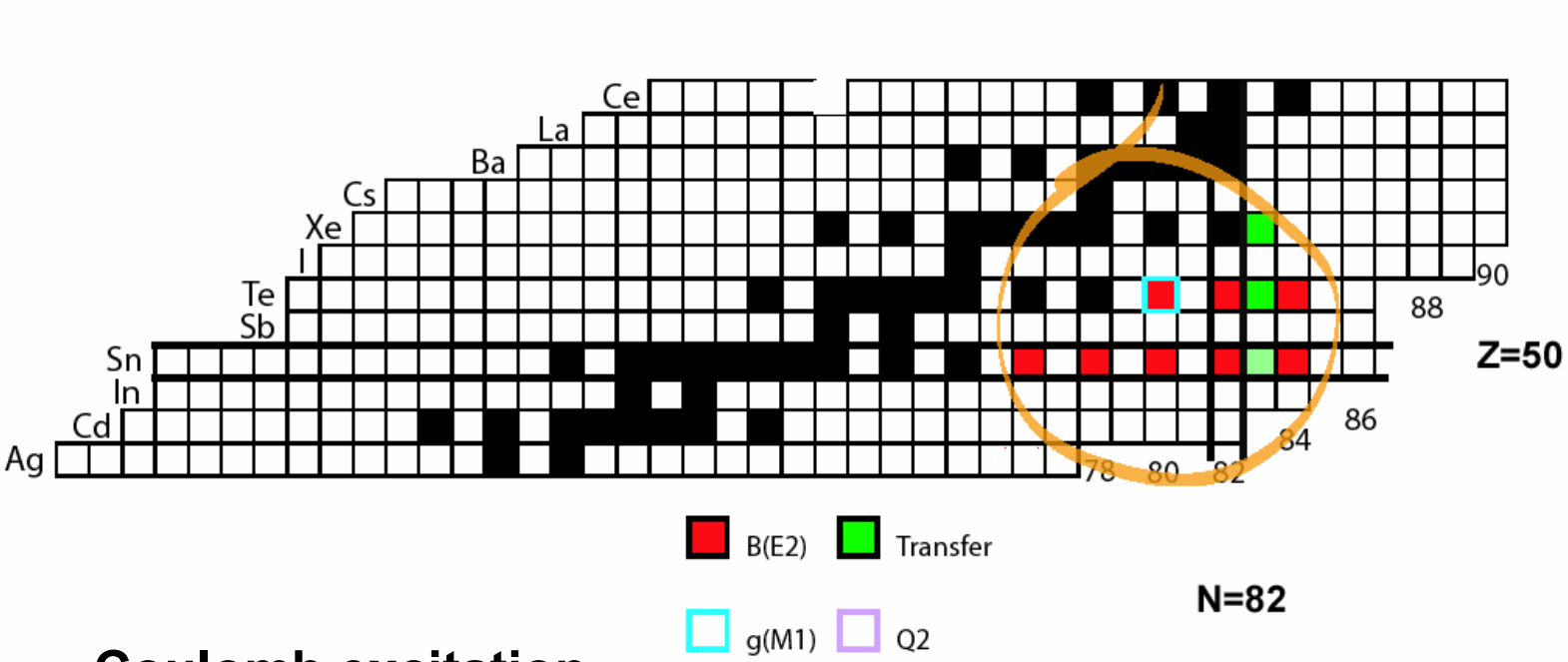
Measurements near ^{132}Sn

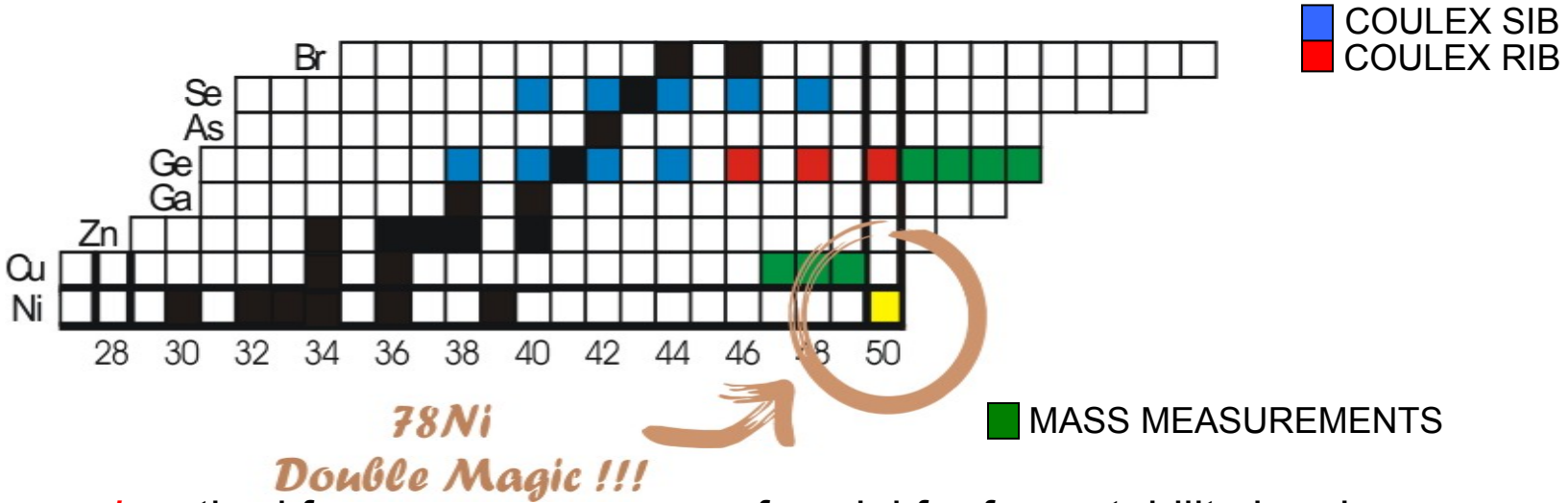


- **Coulomb excitation**
  - **B(E2) values → transition matrix elements**
  - **Magnetic moments (transient field, recoil-in-vacuum)**
  - **Static quadrupole moments by reorientation → nuclear shape**
- **Transfer reactions**
  - ***e.g.* (d,p), (3He,d)**
- **Fusion-evaporation; $\gamma\gamma$ spectroscopy**
  - **→ band structure, *etc.***

Measurements near N=50

A research program focused in studying the evolution of the nuclear structure as we approach N=50 has been established at HRIBF

1. B(E2) values have been measured using the same technique for both *RIB*s and *SIB*s along the Ge and Se isotopic chains.



2. A *novel* method for measure masses of nuclei far from stability has been demonstrated with very low beam intensities
3. Quadrupole Moments for ^{78}Ge
4. B(E2) of ^{84}Se
5. *g*-factor for ^{80}Ge

Future measurements

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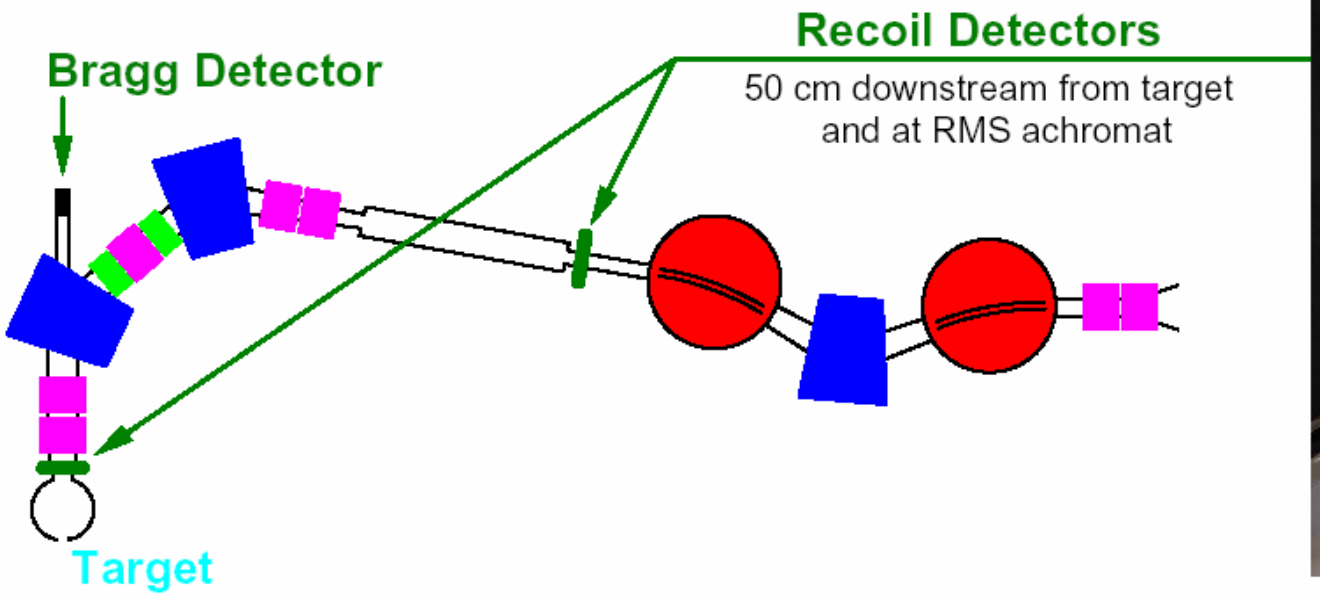
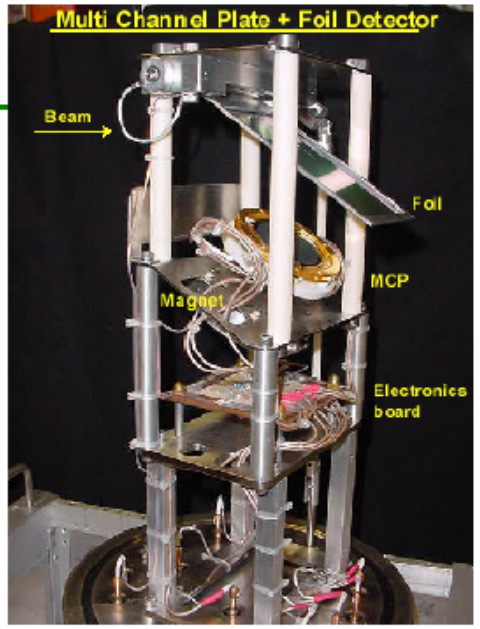
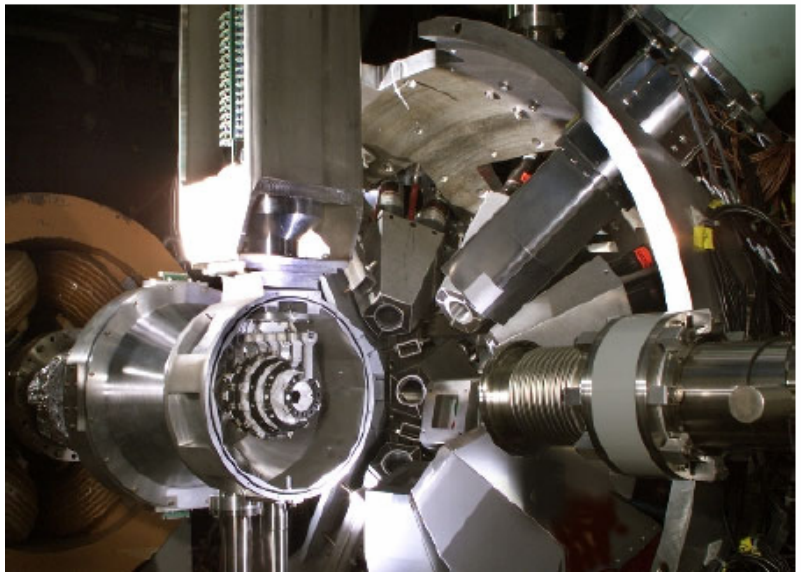
Set-up for n-rich Coulex / transfer studies





Foil plus multichannel plate



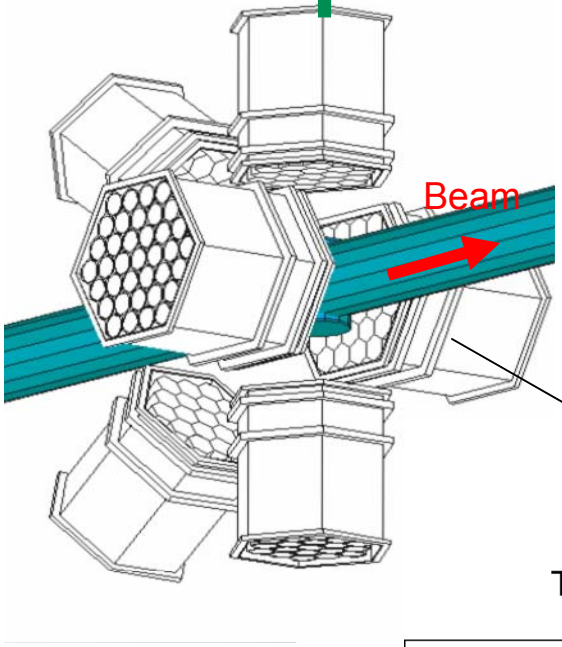
CLARION

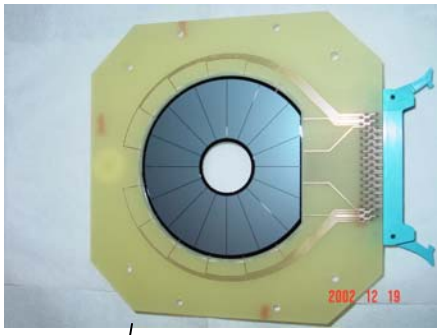
11 segmented clover Ge detectors

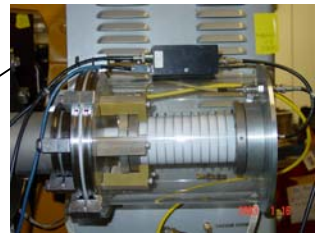
HyBall

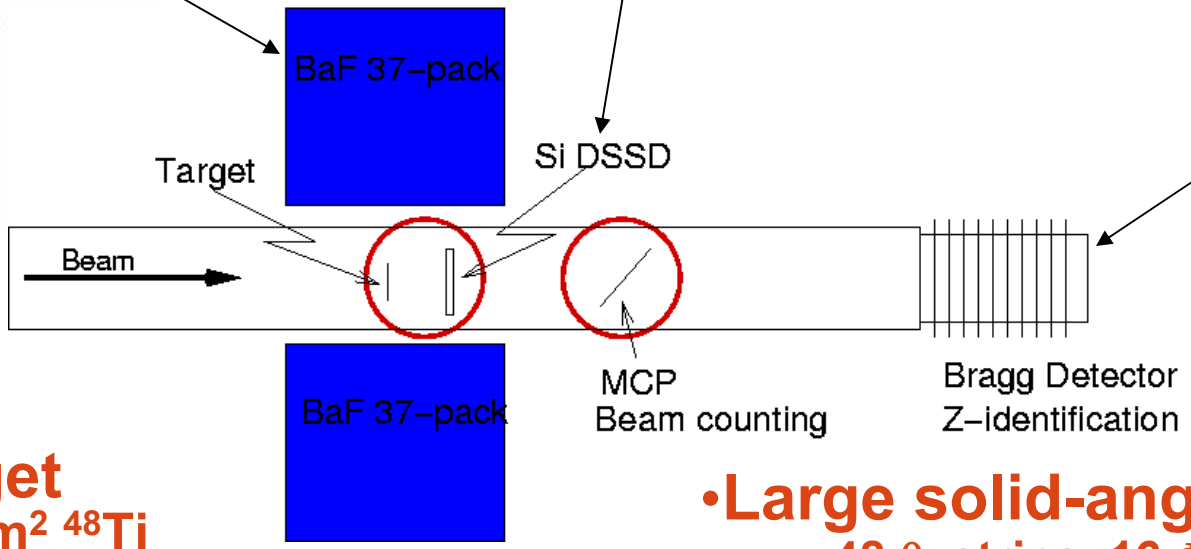
95 CsI detectors with photodiodes

Setup for ^{132,134}Sn









- **Thick target**
  - 1.3mg/cm^2 ^{48}Ti
- **BaF$_2$ array**
  - $\Delta\Omega$=65%
  - $\varepsilon \sim 40\%$ full-energy efficiency

- **Large solid-angle DSSD**
  - 48 θ–strips, 16 Φ-sectors
  - θ_{lab} ~8.5^0 – 24^0
- **Beam counting detector**
- **Beam composition monitor**

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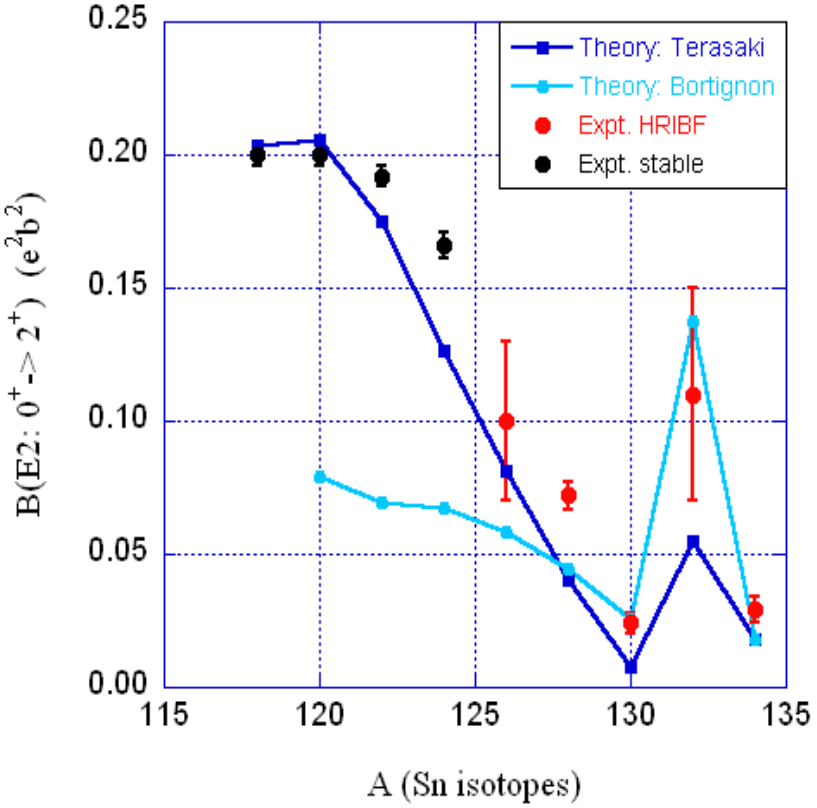
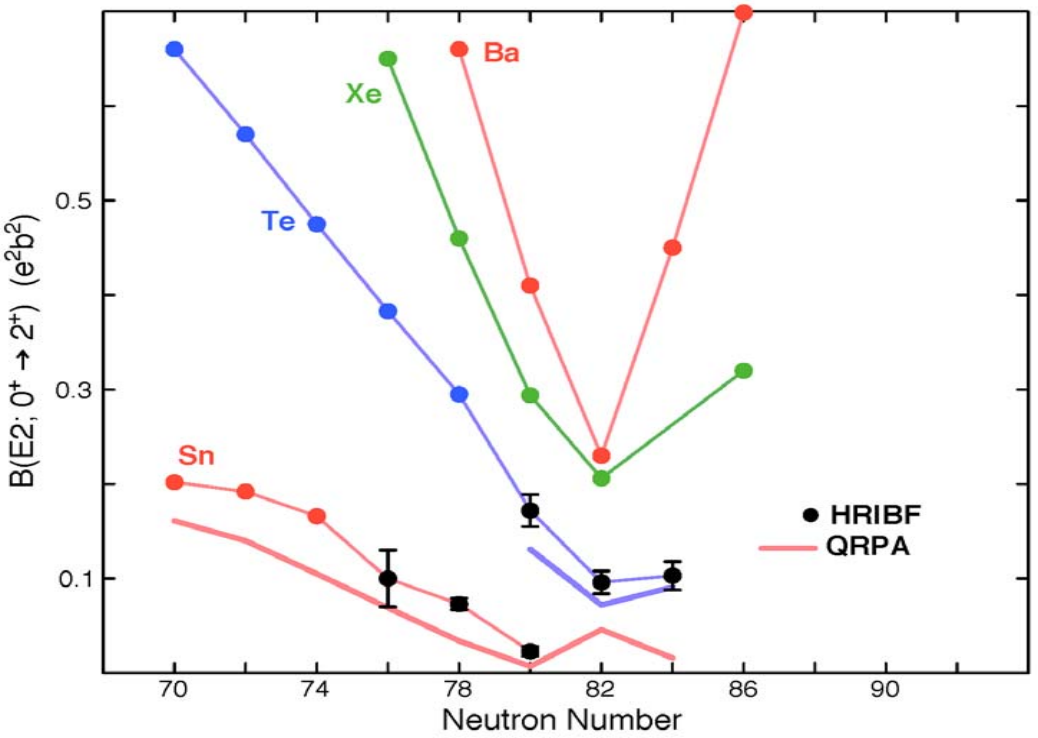
Coulex measurements near ^{132}Sn

Sn Coulex



Te Coulex



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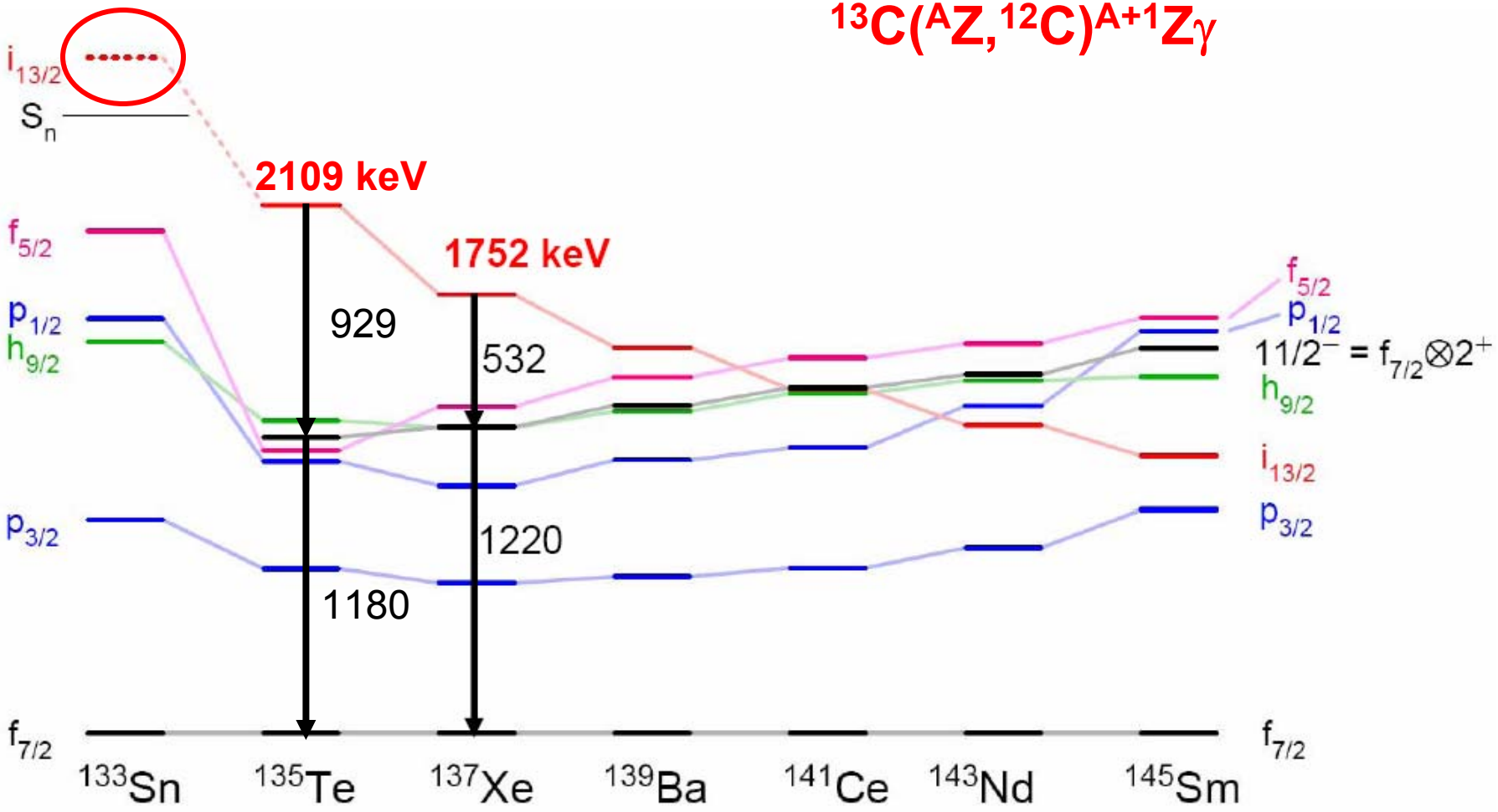
N = 83 level energy systematics

$^{13}C(^{A}Z,^{12}C)^{A+1}Z\gamma$



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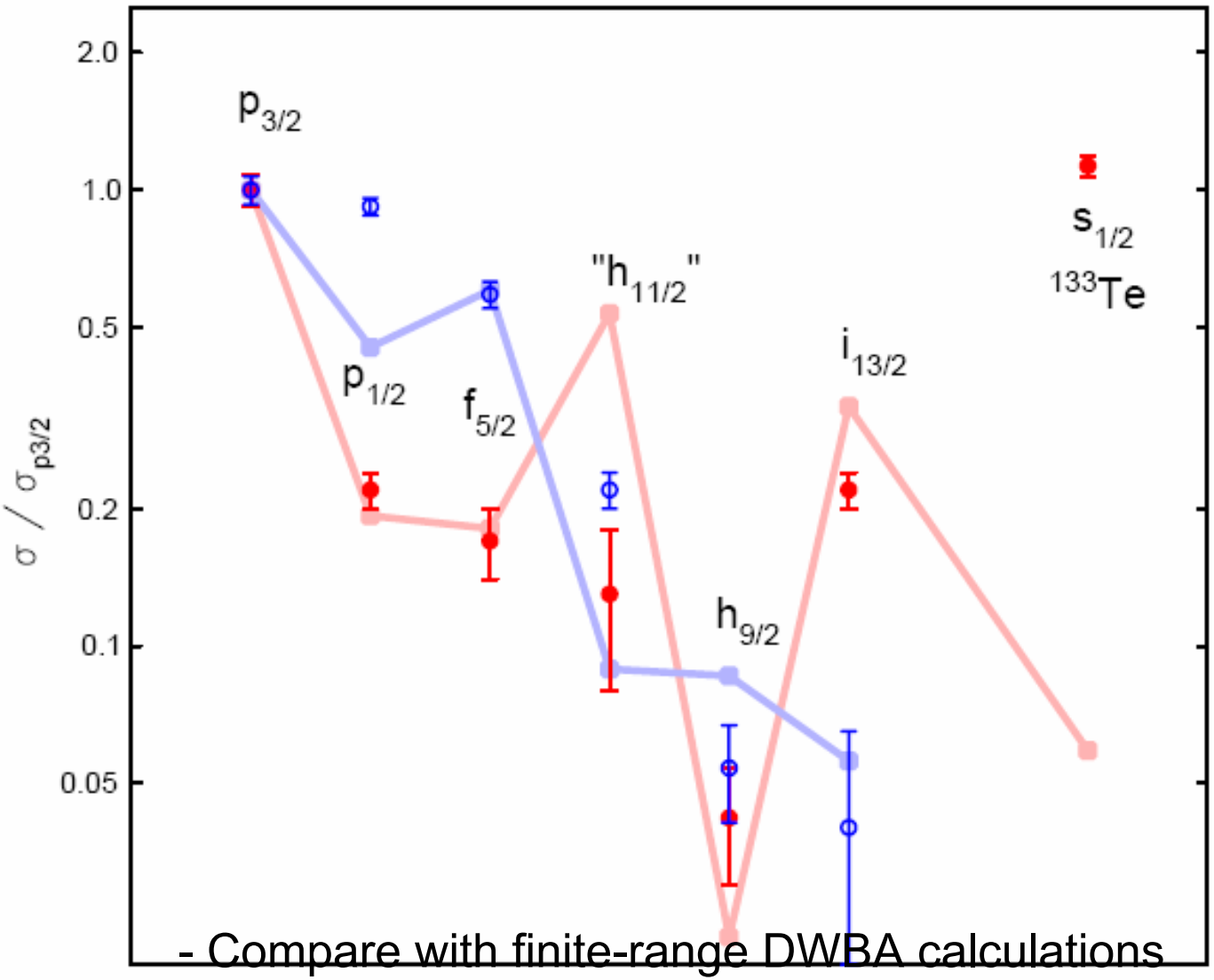
Relative transfer cross sections

$^{13}C(^{A}Z,^{12}C)^{A+1}Z$ $^{9}Be(^{A}Z,^{8}Be\rightarrow\alpha\alpha)^{A+1}Z$

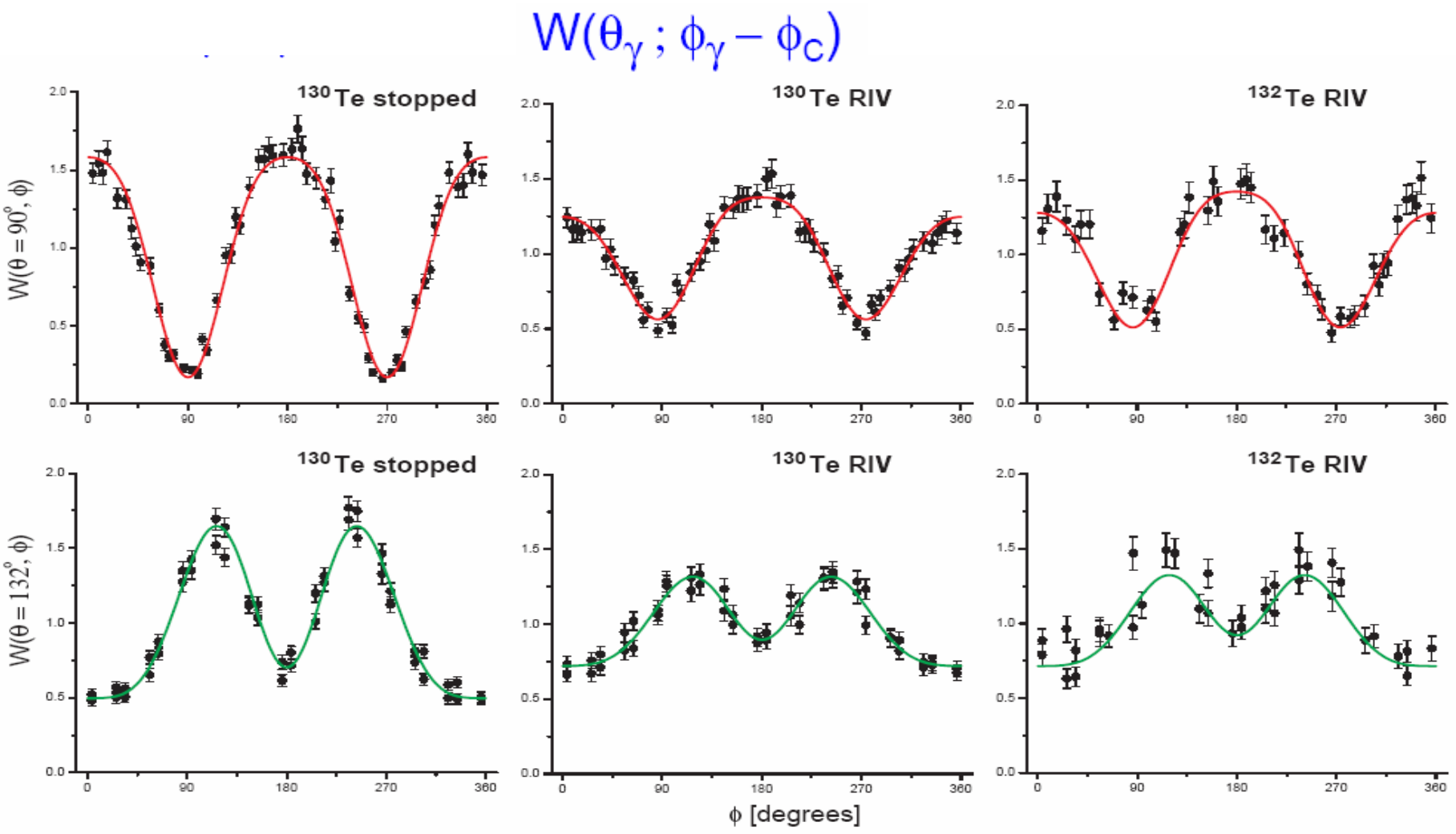


Red: ^{13}C target

Blue: ^{9}Be target

- Compare with finite-range DWBA calculations

Attenuated angular correlations: g-factor by RIV



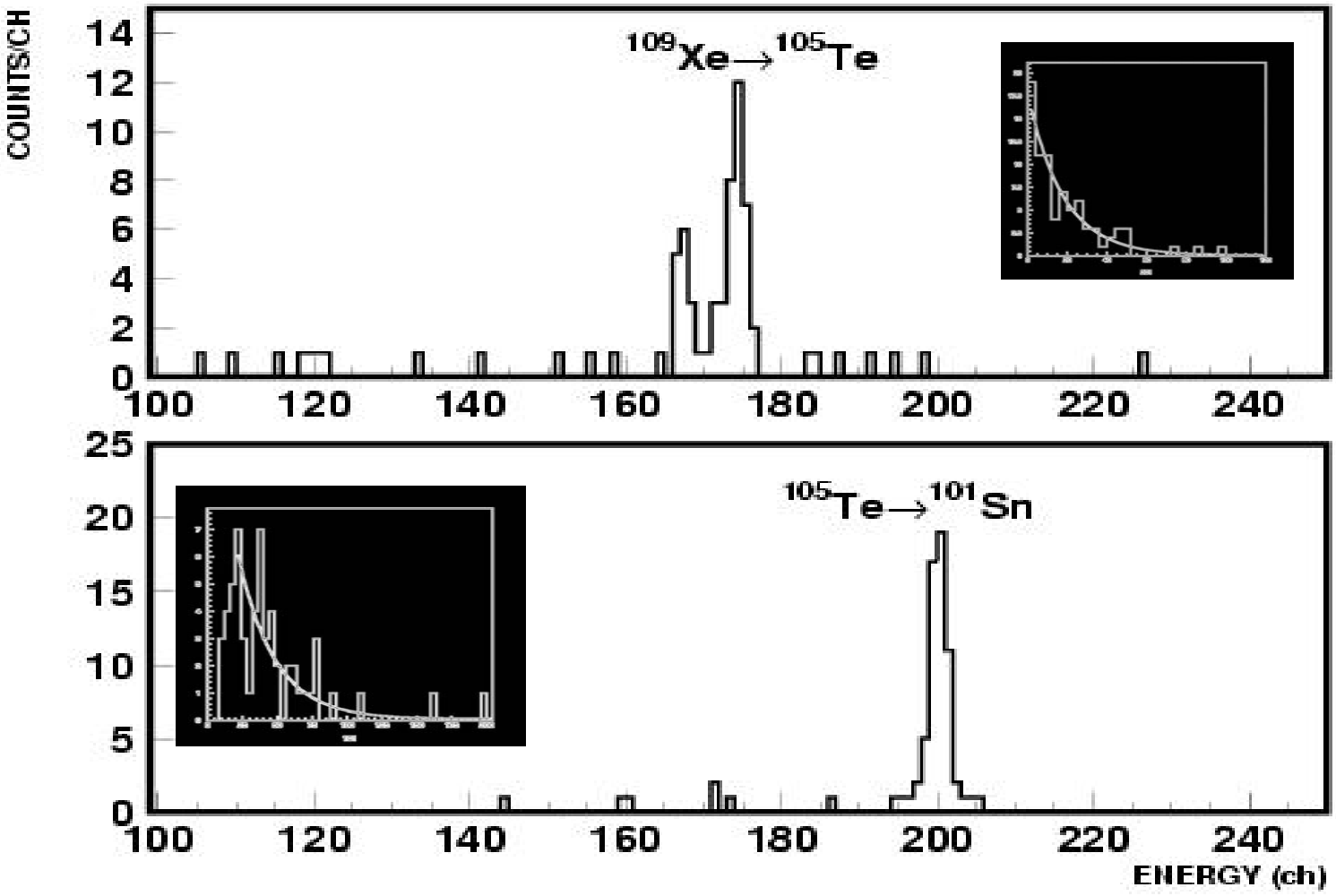
Stone et al. PRL 2005

Exotic nuclei via decay spectroscopy

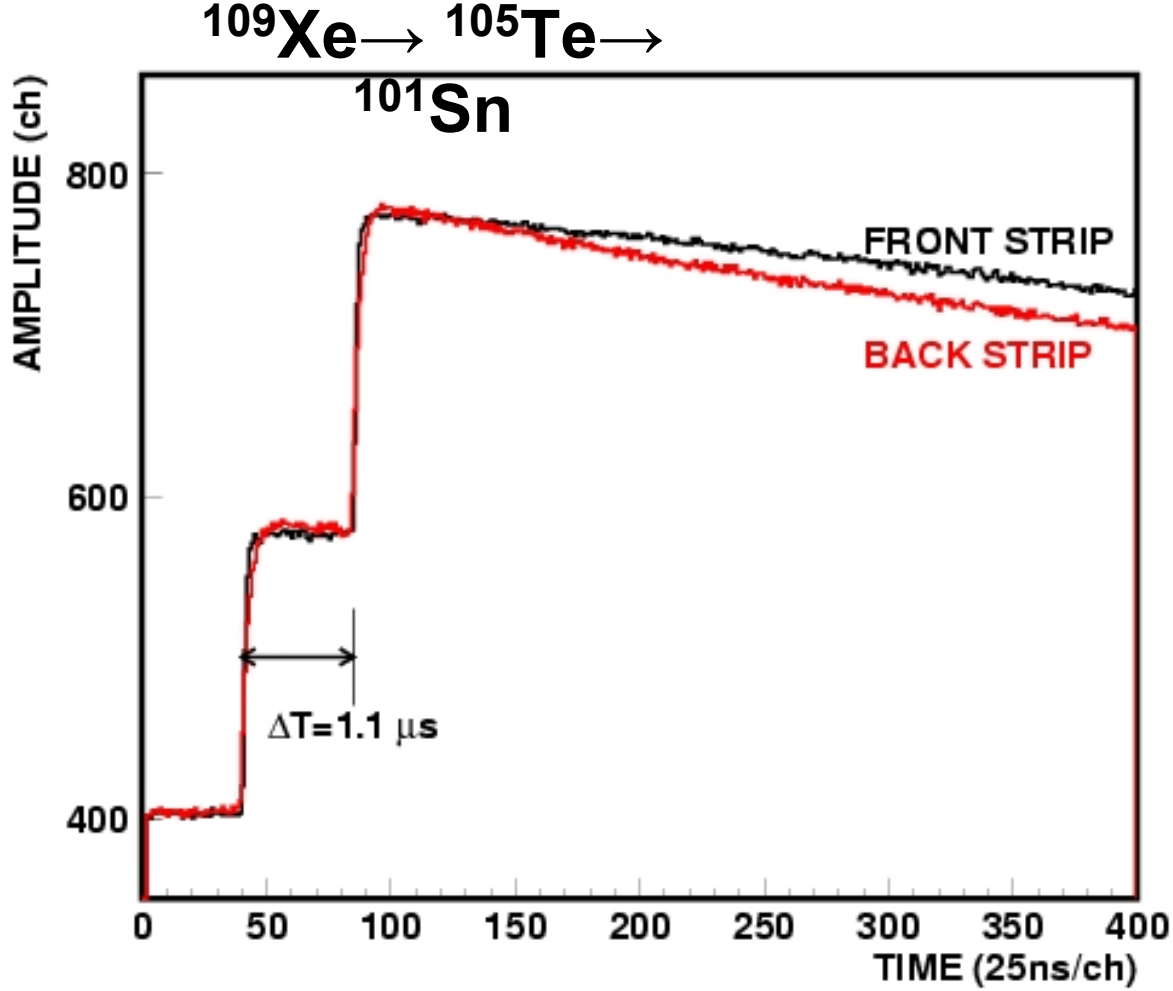
- **Probe spectroscopy at and beyond the proton drip line.**
- **Nuclear structure relevant to rp process**
- **Approach ^{100}Sn**
- **Use new experimenal tools and unique HRIBF beams to explore β-n**

$^{109}Xe \rightarrow {}^{105}Te \rightarrow {}^{101}Sn$

~70 counts in 5 days



Example of the alpha decay chain pulse



one ^{109}Xe ion per 6x10^{6} A=109 implants

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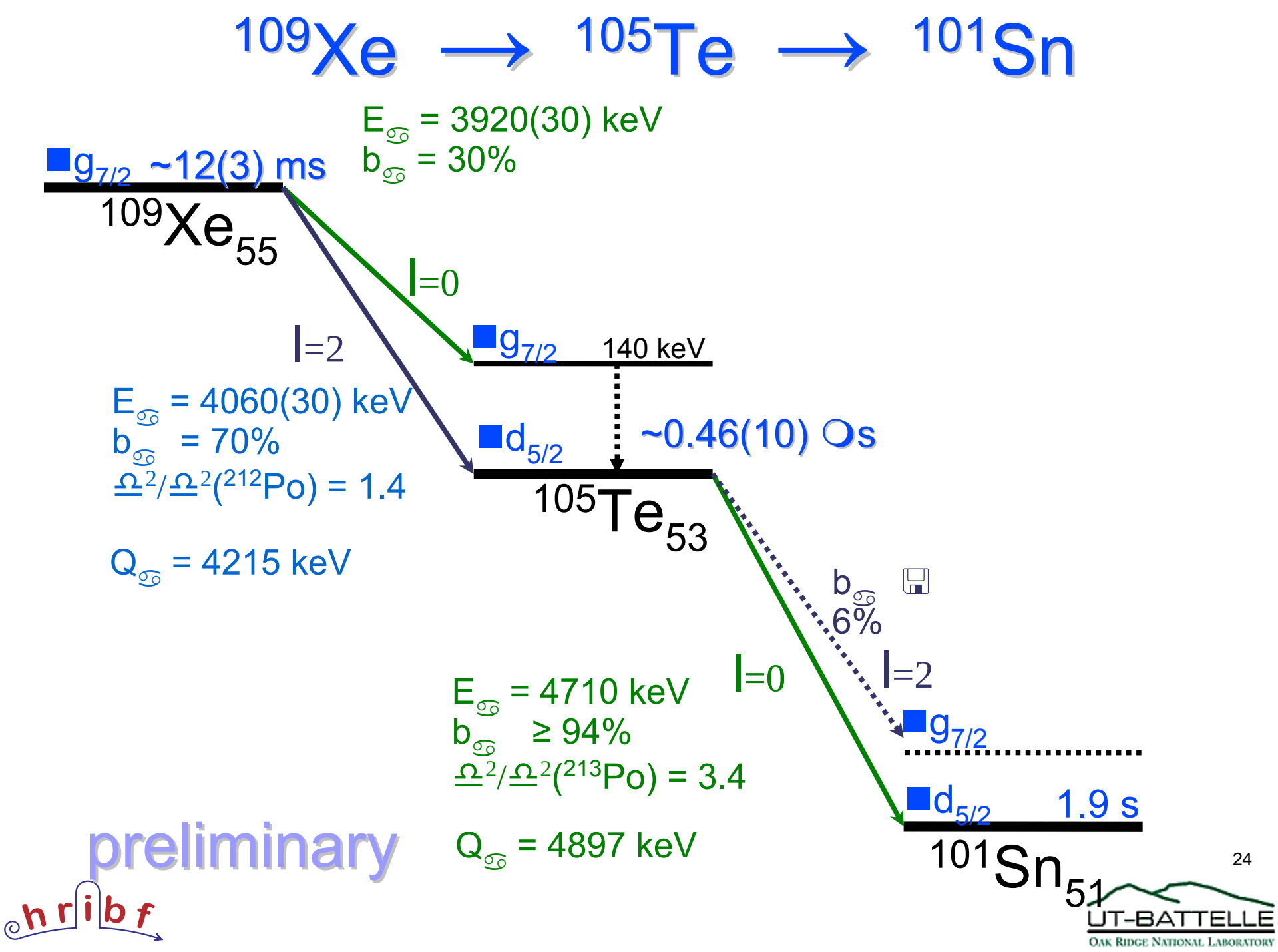
109Xe → 105Te → 101Sn
Eβ = 3920(30) keV
bβ = 30%
g7/2 ~12(3) ms
109Xe55
l=0
l=2
g7/2 140 keV
Eβ = 4060(30) keV
bβ = 70%
Ω2/Ω2(212Po) = 1.4
d5/2
~0.46(10) μs
105Te53
Qβ = 4215 keV
bβ 6%
l=0
l=2
Eβ = 4710 keV
bβ ≥ 94%
Ω2/Ω2(213Po) = 3.4
g7/2
d5/2 1.9 s
Qβ = 4897 keV
101Sn51
preliminary
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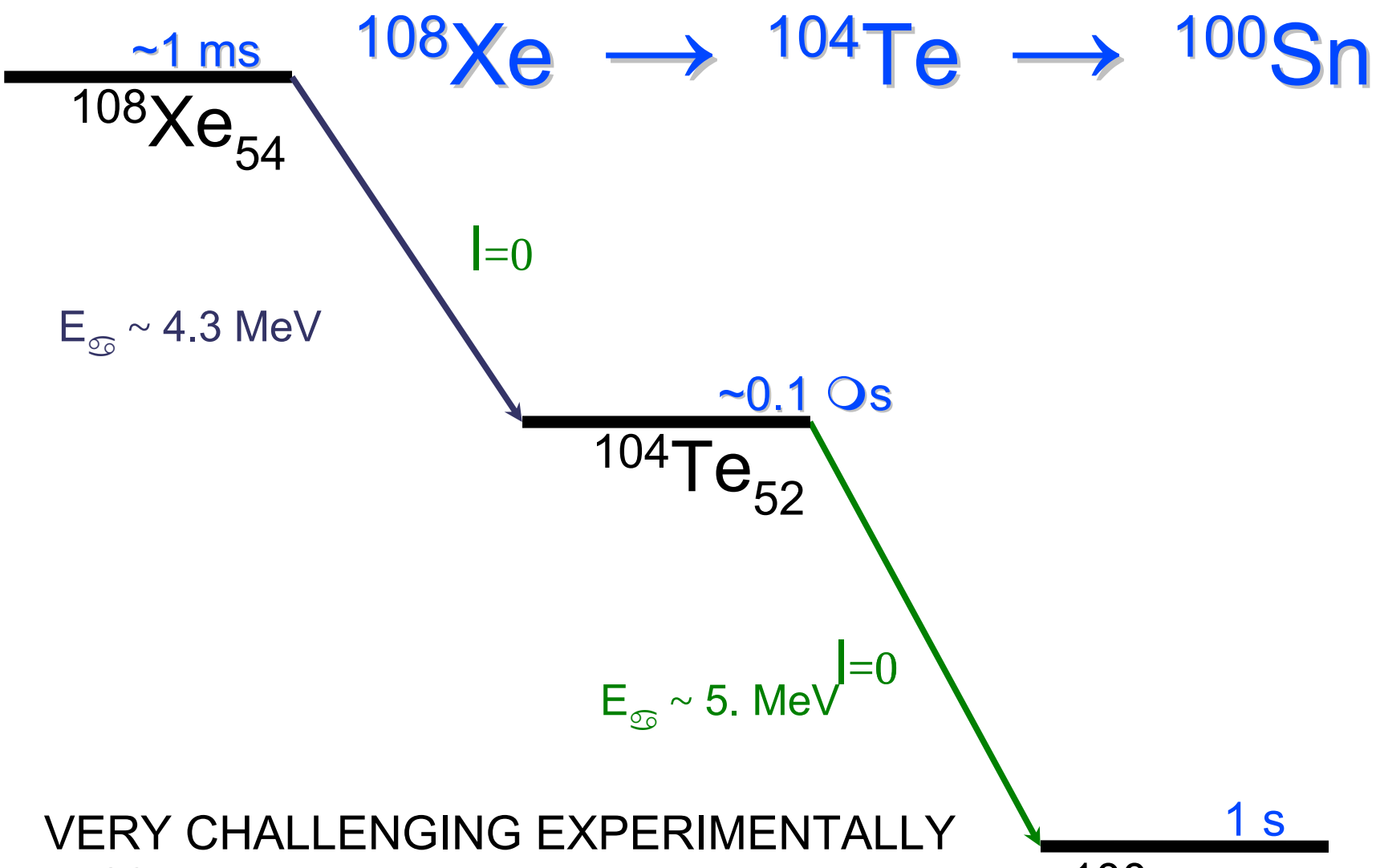
NEXT:

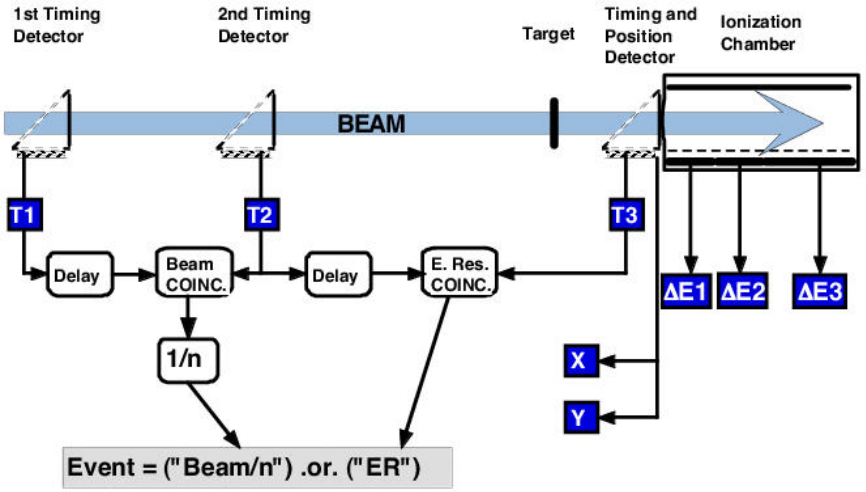


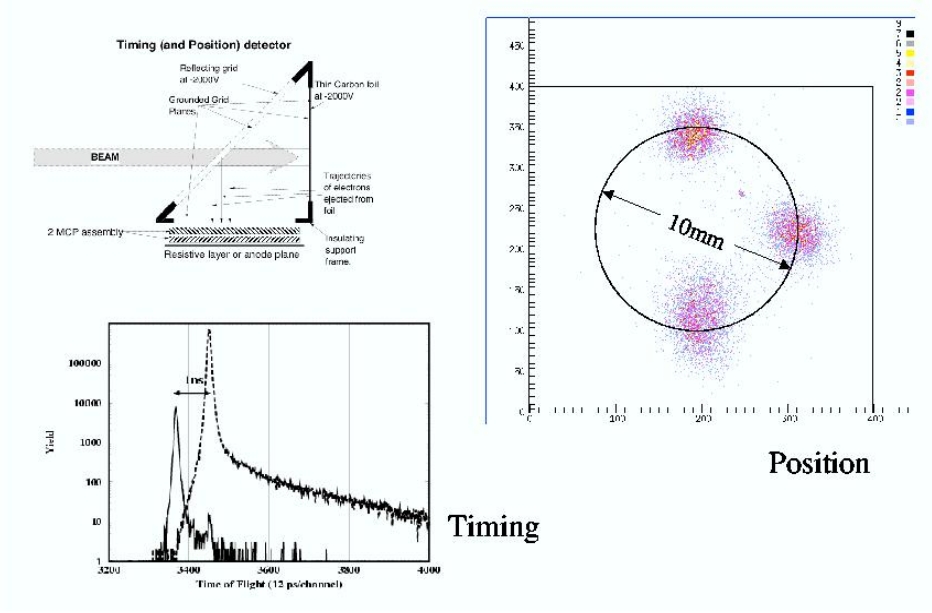
VERY CHALLENGING EXPERIMENTALLY
~ 20 decays in 5 days experiment

Fusion like reactions in very n-rich systems

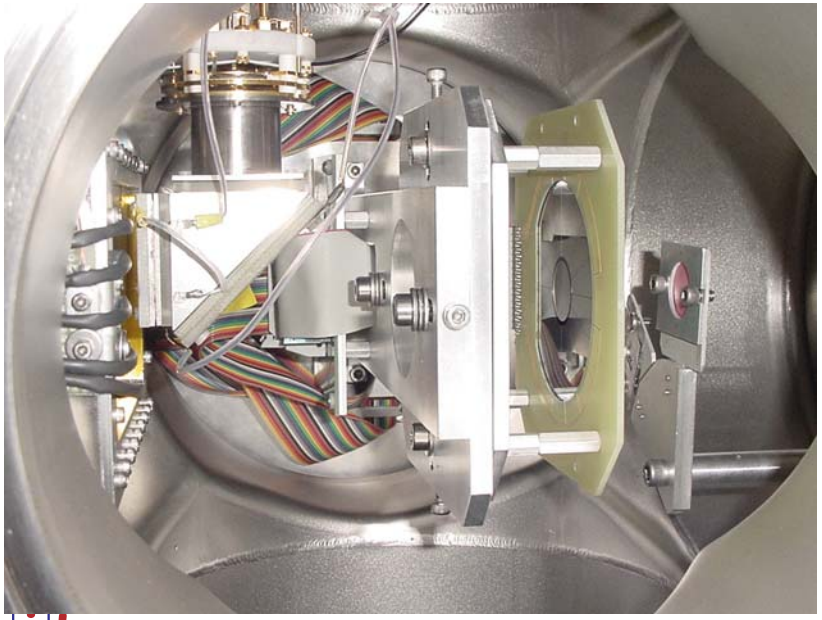
- Look at the influence of extreme isospin on formation and decay of composite system
- Evaporation residue measurements with ^{132}Sn, ^{134}Sn + Ni isotopes
- Fission studies in heavier systems

Evaporation Residues

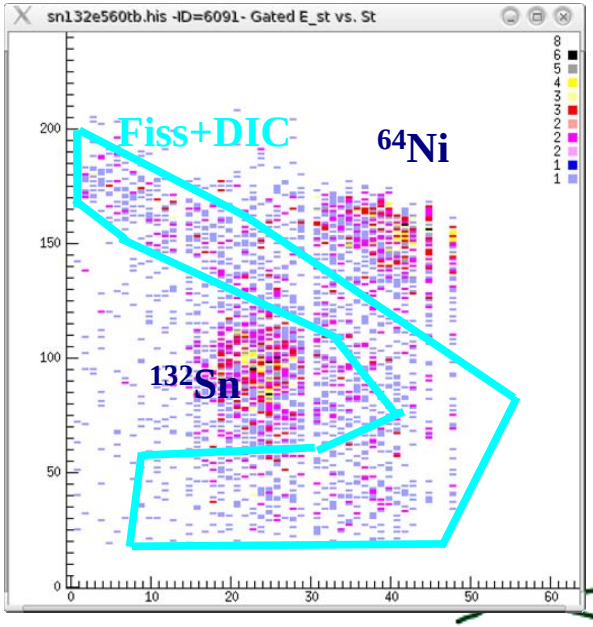


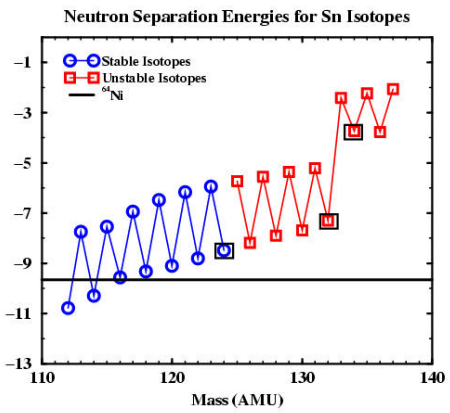


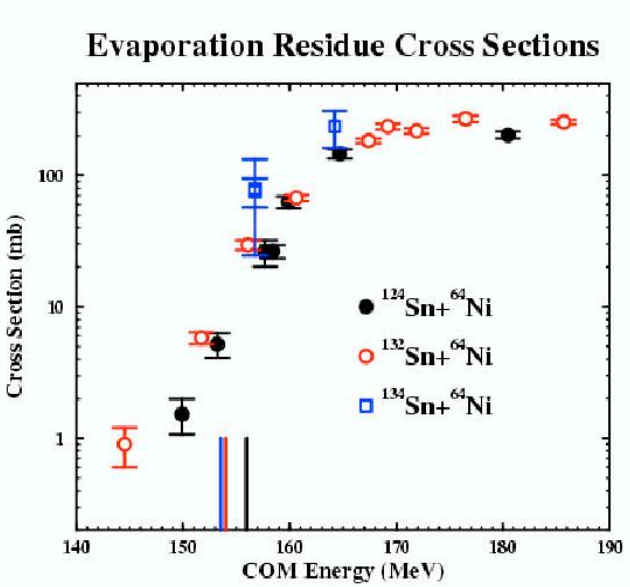
Fission



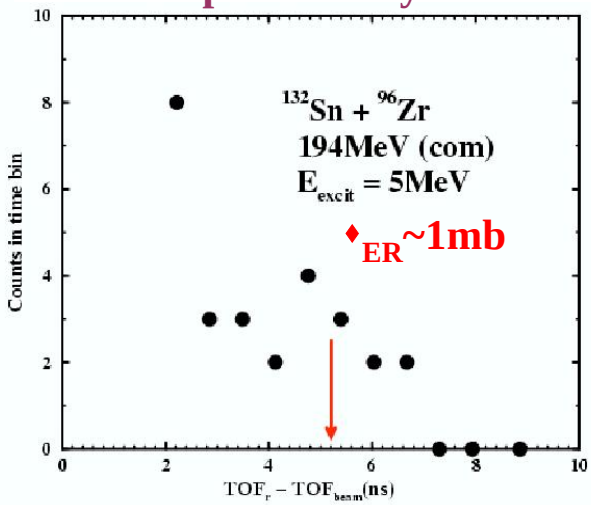
560MeV ^{132}Sn+^{64}Ni coinc. data

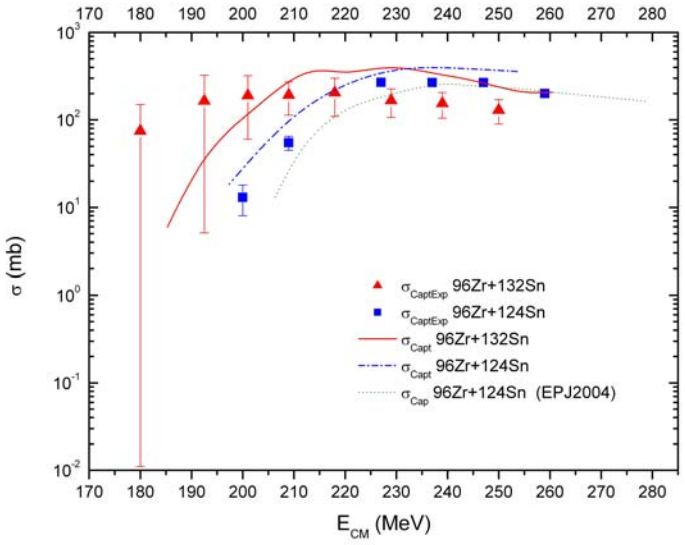


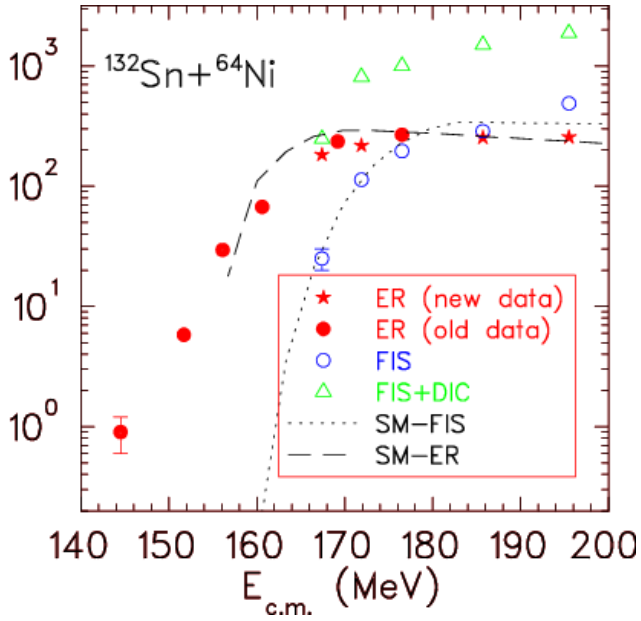




preliminary







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Nuclear Astrophysics at HRIBF

- Fundamental Questions:

  How do the stars evolve -- and die catastrophically ?

  What is the origin of the elements making up our bodies & our world?

- unique multi-disciplinary approach

  HRIBF measurements with proton-rich & neutron-rich radioactive beams

  nuclear data evaluations, processing, & disseminations

  simulations of element synthesis in stellar explosions

- recent results with ^{18}F, ^{82}Ge, ^{84}Se, ^{7}Be unstable beams, as well as integrated data & theoretical work

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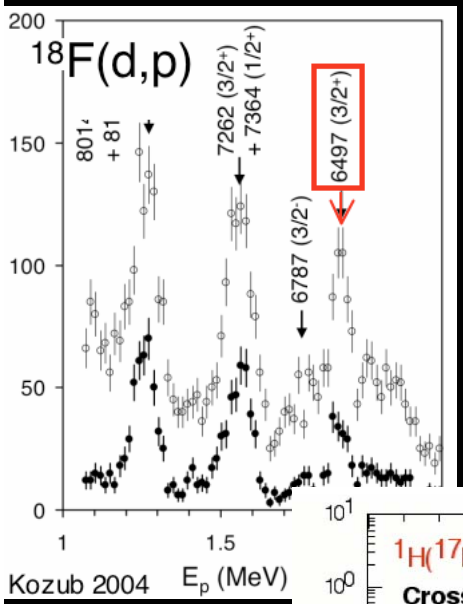
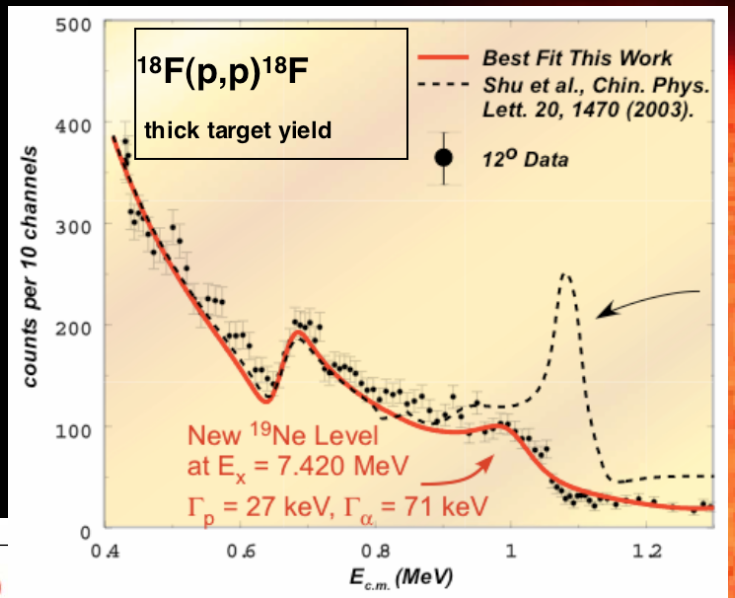
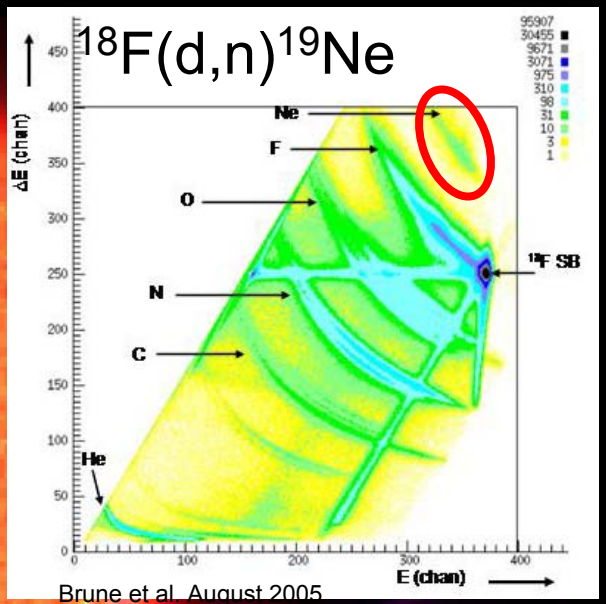
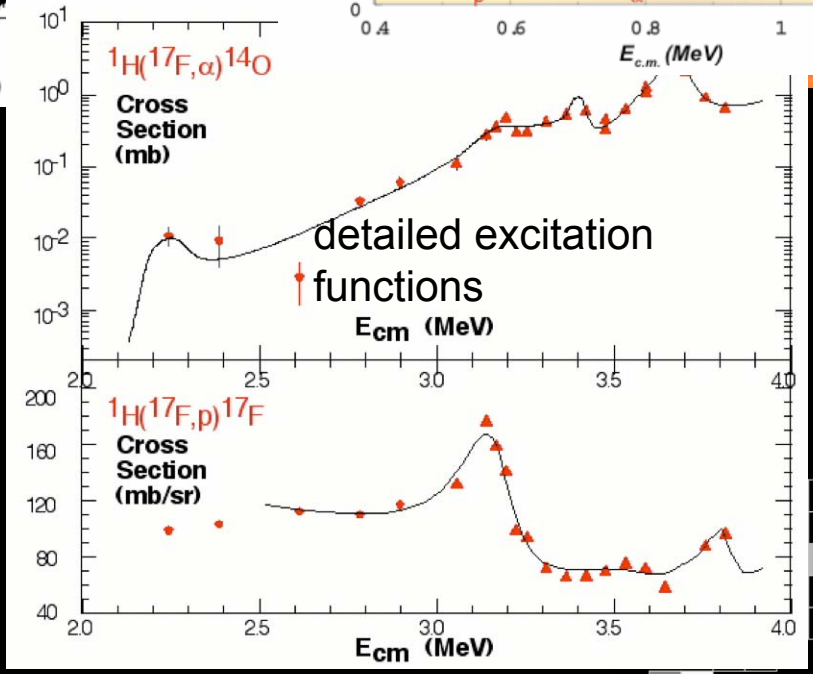
Precision HRIBF Measurements with p-rich ^{17,18}F beams

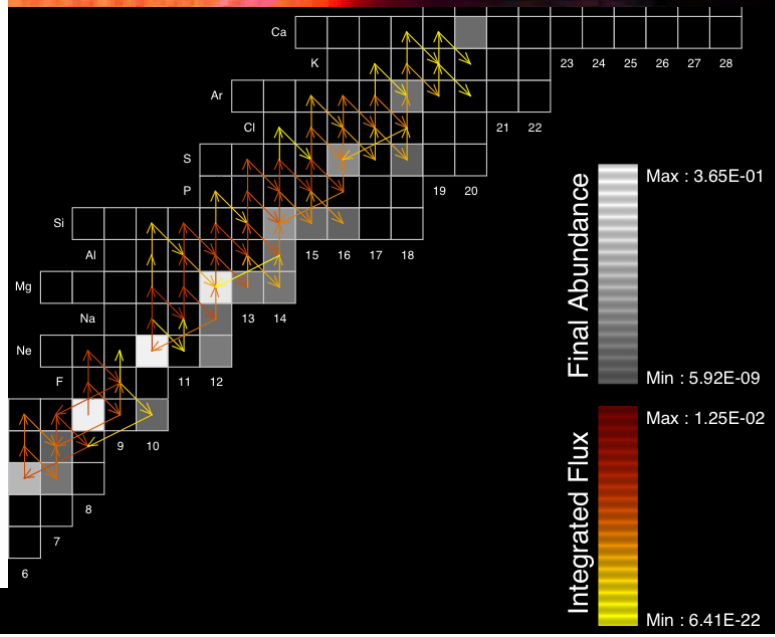
Helping diagnose nova explosions





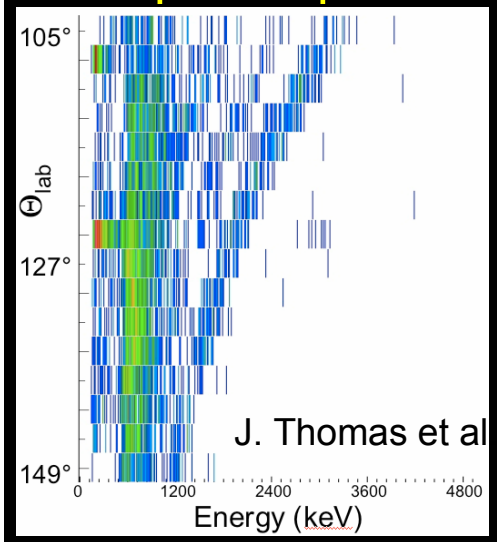




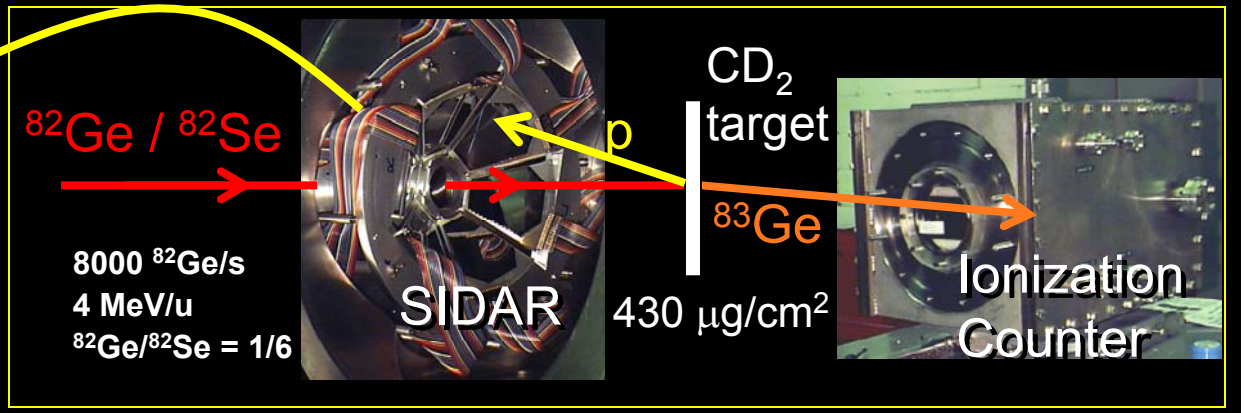


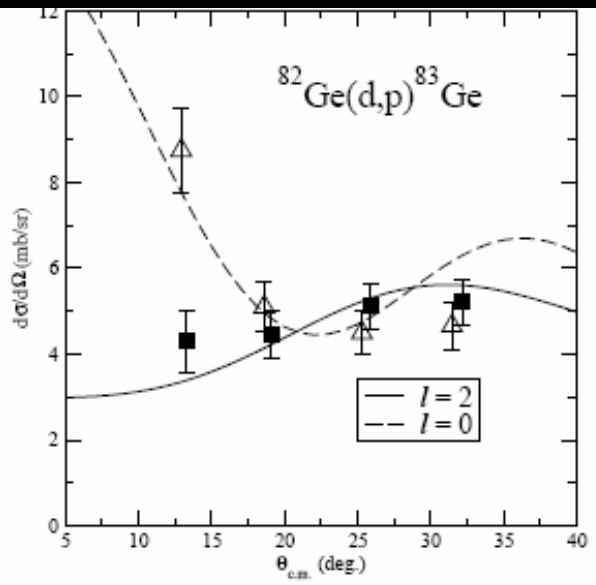
First (d,p) study on an r-process nucleus: ^{82}Ge(d,p)^{83}Ge

- (d,p) reaction transfers a neutron from ^{2}H target to beam particle
- can use to determine mass (Q-value), levels, single particle strengths, spins & parities (angular momentum transfer) …



- technique has been discussed for years to probe r-process reactions using unstable beams





- **our results**:

Q-value (MeV)	E_x (keV)	ℓ	J^π	$S_{\ell j}$
1.47 ± 0.02 (stat.) ± 0.07 (sys.)	0	2	$5/2^+$	0.48 ± 0.14
1.19 ± 0.02 (stat.) ± 0.07 (sys.)	280 ± 20 (stat.)	0	$1/2^+$	0.50 ± 0.15

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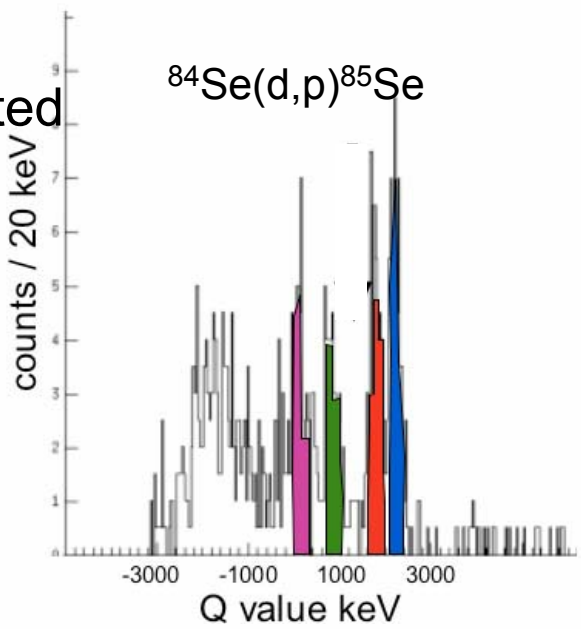
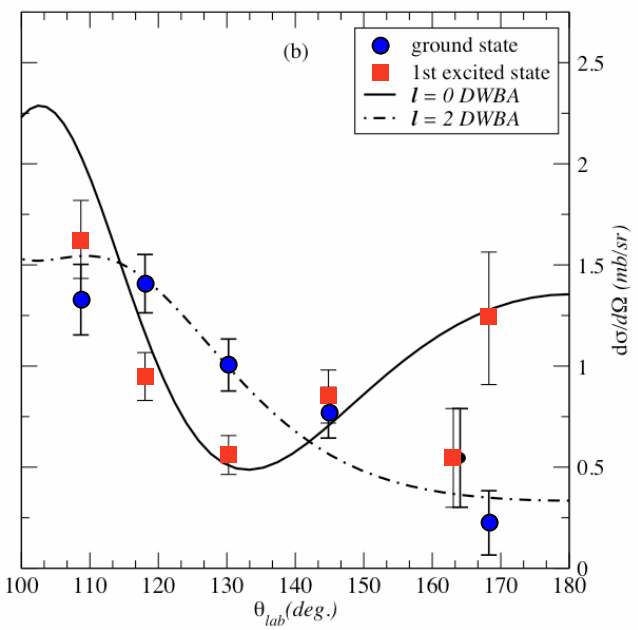
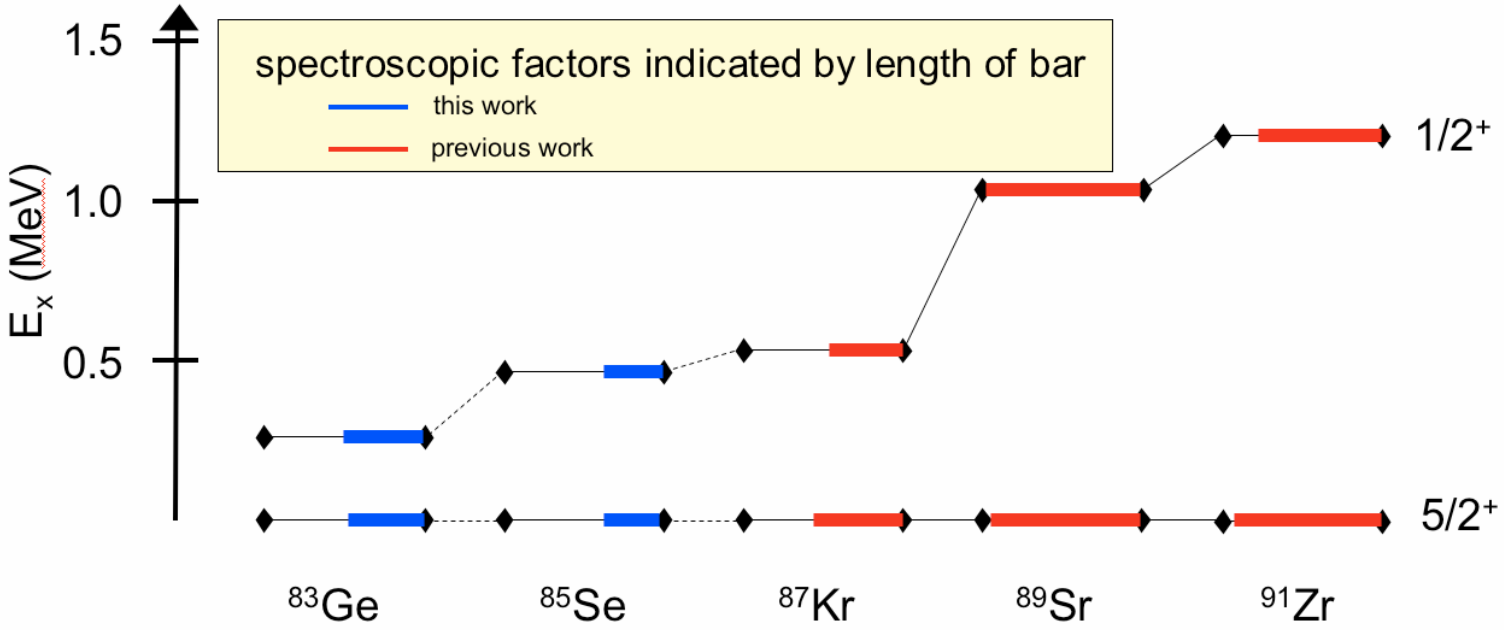
Using (d,p) reactions to study N=51 isotones

- ^{84}Se(d,p)^{85}Se measured, four strong groups populated
- energies & spectroscopic factors extracted
- combined with ^{83}Ge data to better understand N=51 isotones



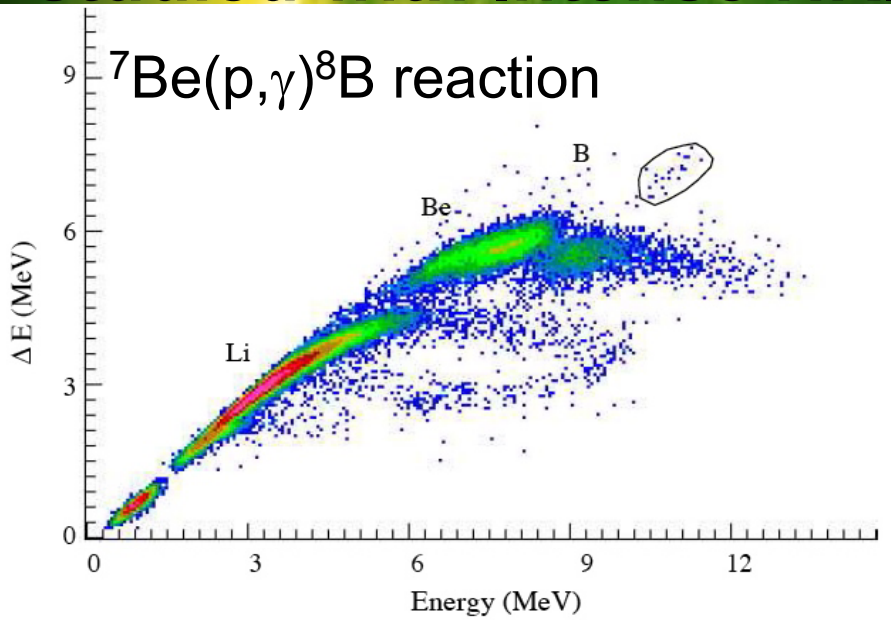




- **Impact: demonstrated viability of inverse-kinematics (d,p) measurements**

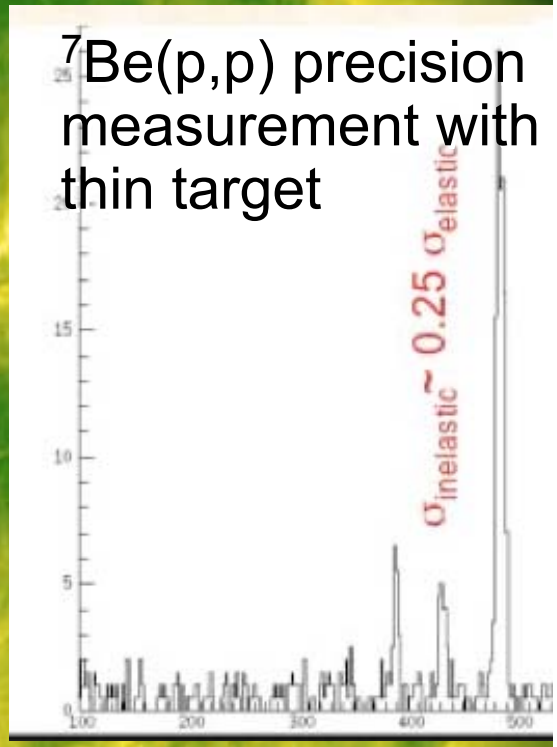
Thermonuclear Burning in our Sun
studied with Intense HRIBF Radioactive ^{7}Be beams

^{7}Be(p,γ)^{8}B reaction

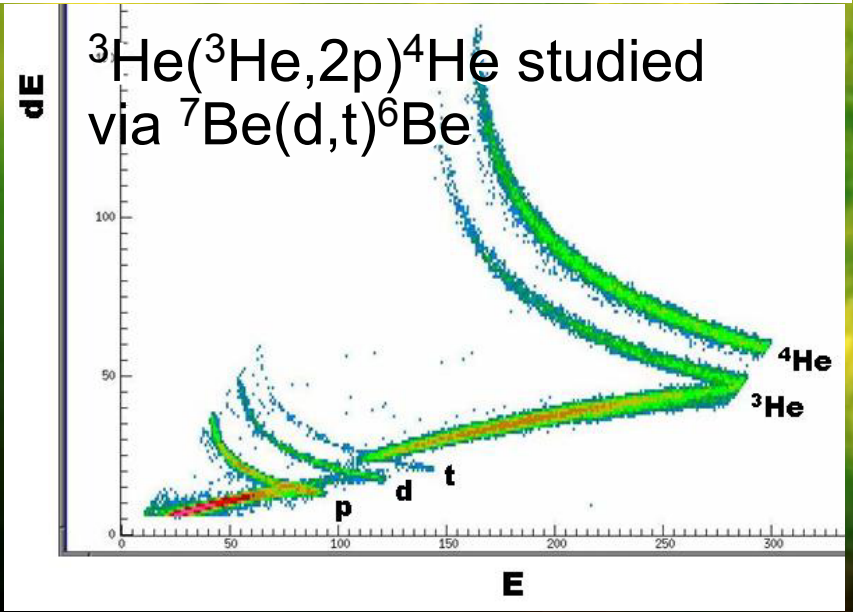


Help determine flux of high-energy neutrinos from the sun

^{7}Be(p,p) precision measurement with thin target

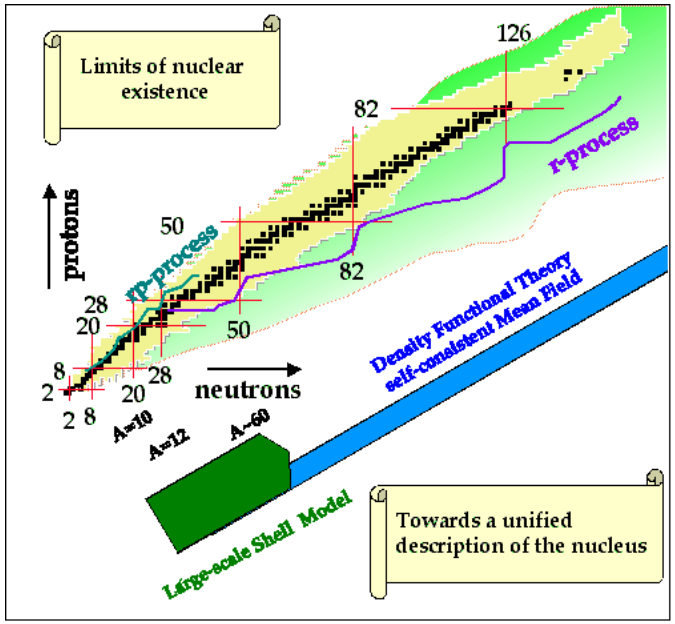


^{3}He(^{3}He,2p)^{4}He studied via ^{7}Be(d,t)^{6}Be



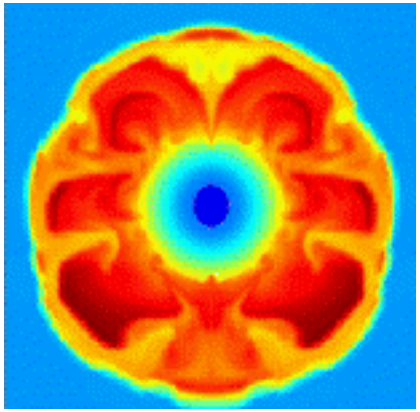
Explain anomalous cross section at low energies using transfer reaction to search for missing ^{6}Be resonance

Theory effort



Computational nuclear Many-body problem

Astrophysics



Nuclear Structure

- QRPA description of the low-energy multipole strength. Interpretation of collective excitations in neutron-rich nuclei (**Coulex data from HRIBF**)
- Theory of weakly-bound and unbound nuclear states. Deformed proton emitters (**Decay spectroscopy data from HRIBF**) and drip-line neutron-rich nuclei within the Continuum Shell Model
- Shell-Model and Mean-Field description of single-particle states in nearly-spherical nuclei (**Transfer reactions data from HRIBF**)
- Ab-initio (coupled cluster) theory of light nuclei; Shell-Model description of medium-mass nuclei; Density-Functional-Theory of complex nuclei, superdeformed nuclei

Nuclear Reactions

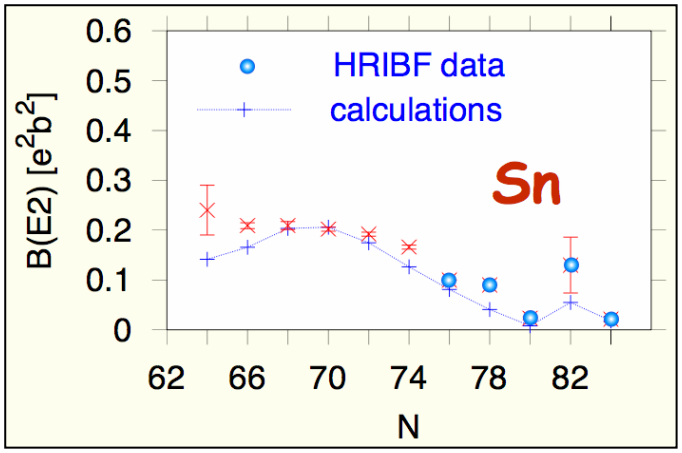
- Self-consistent description of heavy-ion reactions (**Subbarrier fusion studies with neutron-rich beams at HRIBF**)
- Gamow-shell-model description of direct reactions (**Transfer studies at HRIBF**)

Nuclear Astrophysics

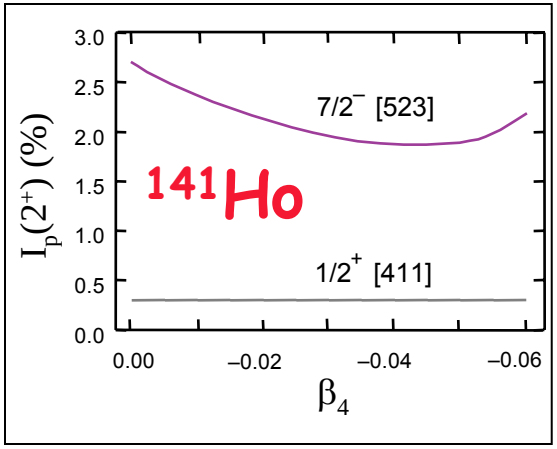
- Examine the astrophysical impact of HRIBF measurements (**^{25}Al(p,γ)^{26}Si, ^{17}F(p,γ)^{18}Ne, ^{18}F(p,α)^{15}O, ^{14}O(α,p)^{17}F**)
- Conduct sensitivity studies to determine measurement needs (Nova, X-ray burst, r-process)
- Supernova Program

Quantum Many-Body Problem

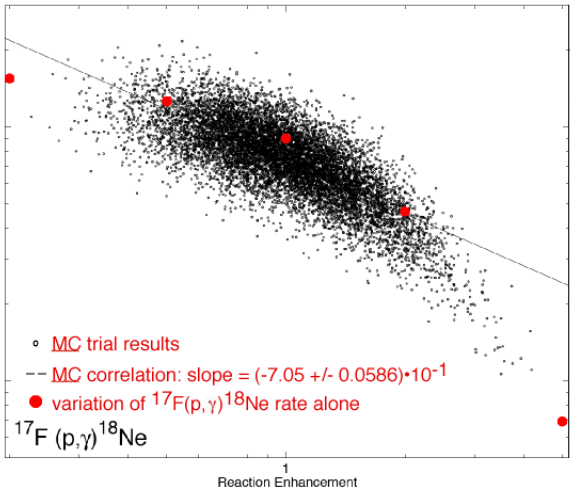
- Interdisciplinary research on many-body systems on various scales



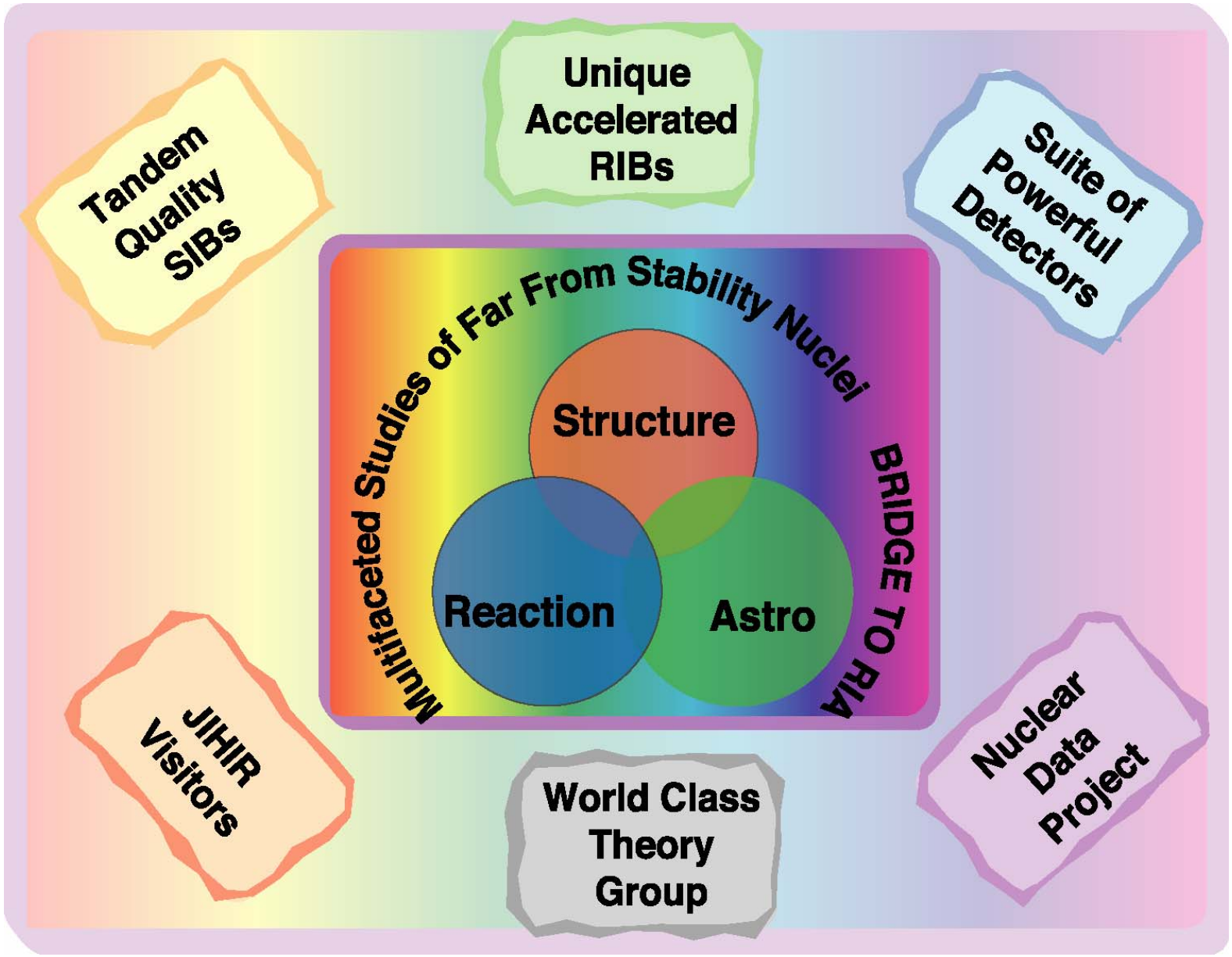
QRPA studies of quadrupole collectivity in the Sn isotopes



Continuum Shell Model studies of fine structure in proton emission



Monte-Carlo sensitivity studies for the ^{17}F(p,γ)^{18}Ne reaction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Multifaceted Studies of Far From Stability Nuclei
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