Gamma-Ray Experiments at RIA with Slow Beams

Mark Riley

With special help from

David Radford, Filip Kondev, Mike Carpenter, Kim Lister, IY Lee, and Paul Fallon

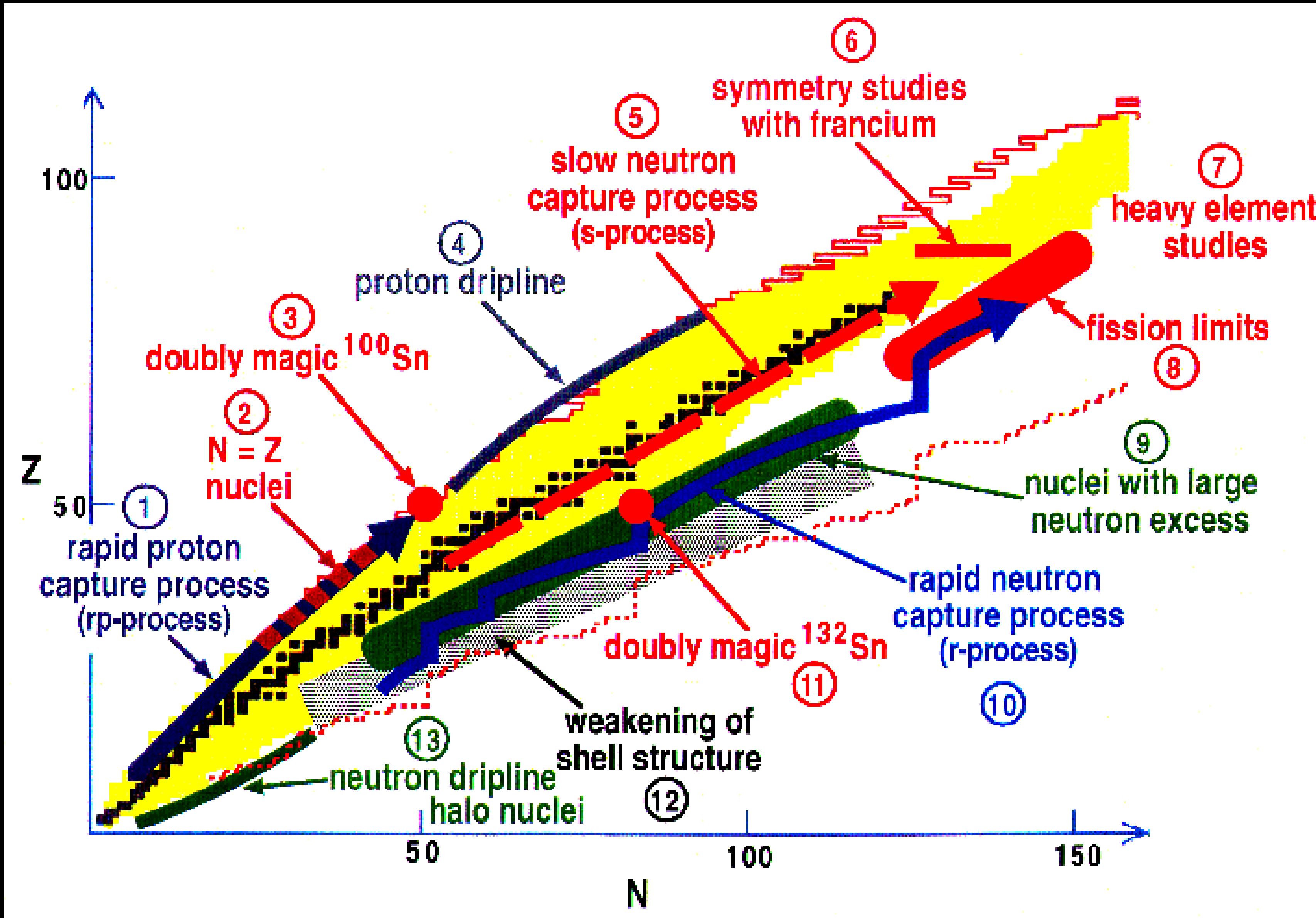
Some Experimental Problems for Gamma-Ray Experiments

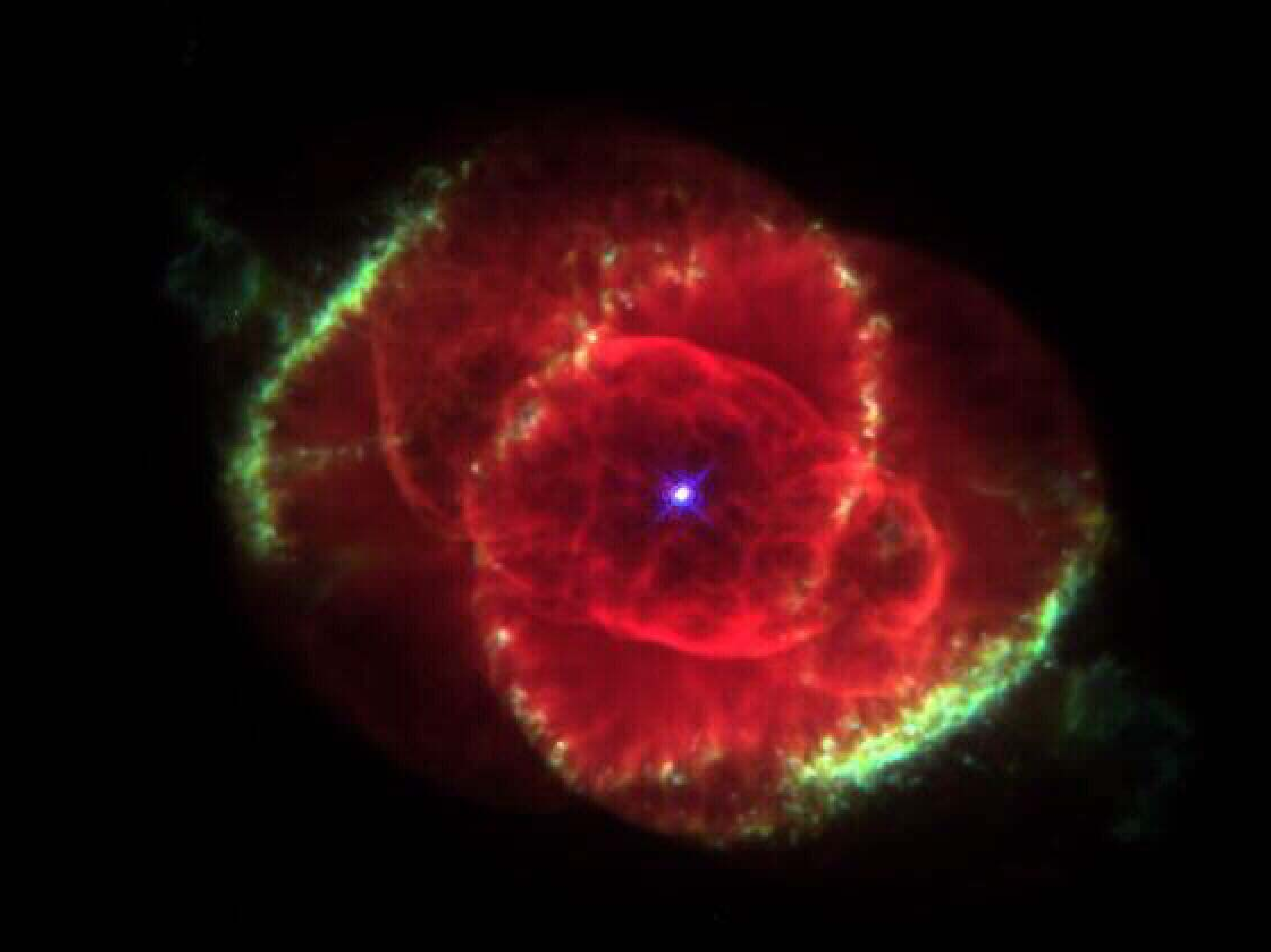
- **Beam is radioactive - high background**
- **Many beams will be low intensity**
- **Most interesting cross-sections are usually small**
- **Many experiments in Inverse-Kinematics – Doppler broadening**

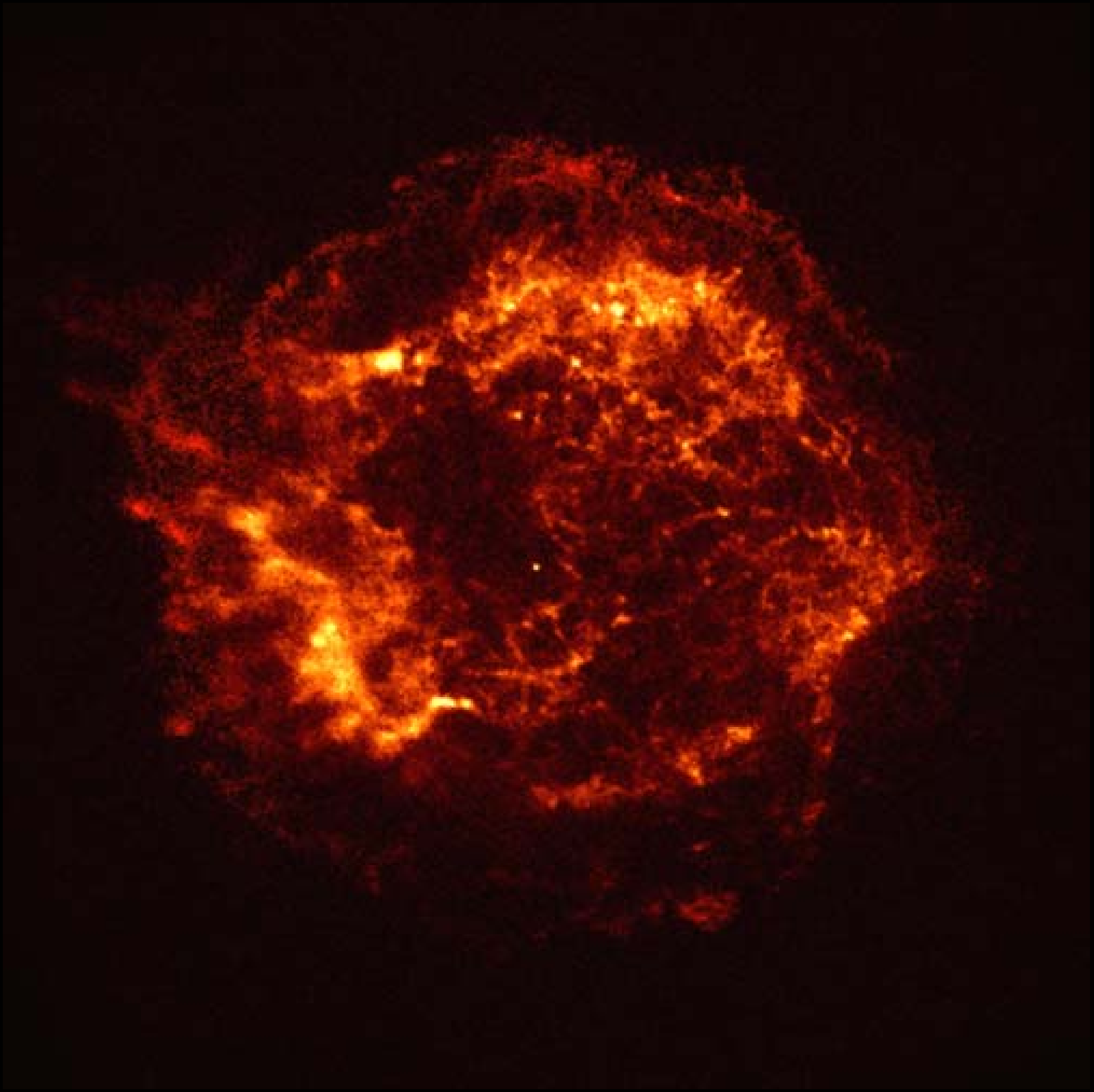
So gamma-ray detector(s) need

- **High Resolution**
- **High Efficiency**
- **High Peak-to-Total**
- **High Count Rate capability**
- **High Selectivity (good coincidence efficiency and also use triggers with aux. dets.,),**
- **High Granularity to minimize Doppler broadening, for high multiplicity and high count rates, also directional info to reduce room background (tracking)**
- **Be modular + easily movable for use with a range of aux. dets.**

Some Research Opportunities at RIA





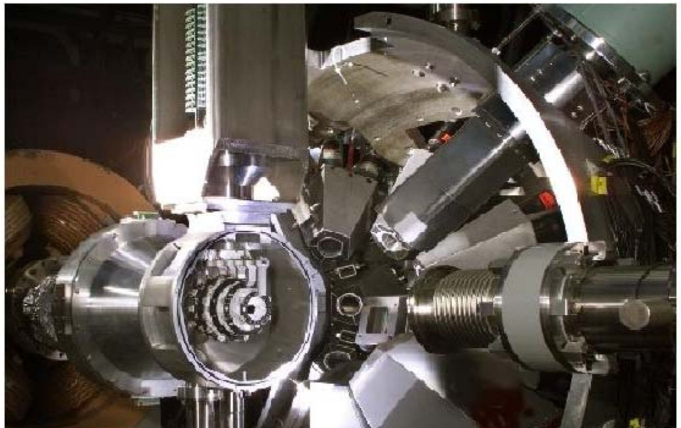


Apologies to non-US friends and visitors for my lack of experimental examples from non-US Labs

Neutron Rich

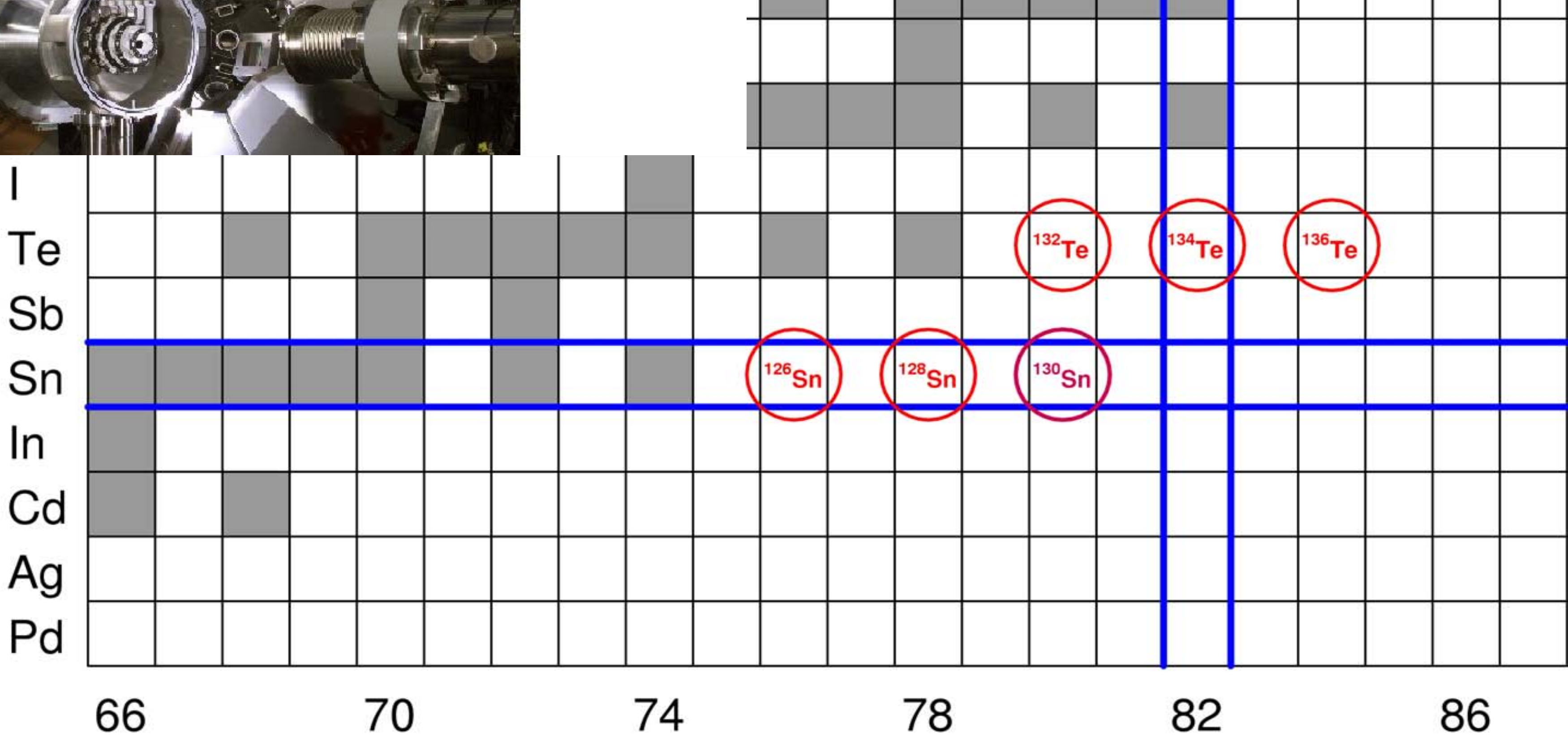
David Radford

Coulomb Excitation Measurements Near ^{132}Sn



CLARION:
11 segmented clover Ge detectors
10 small Ge detectors

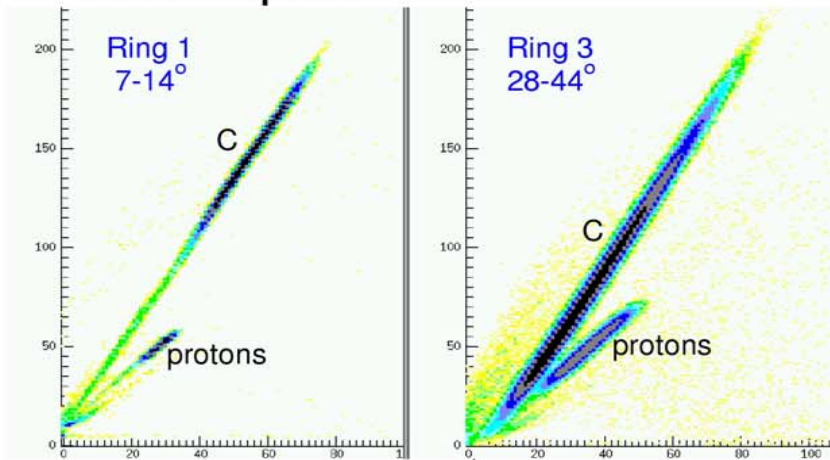
Hyball:
95 CsI detectors with photodiodes



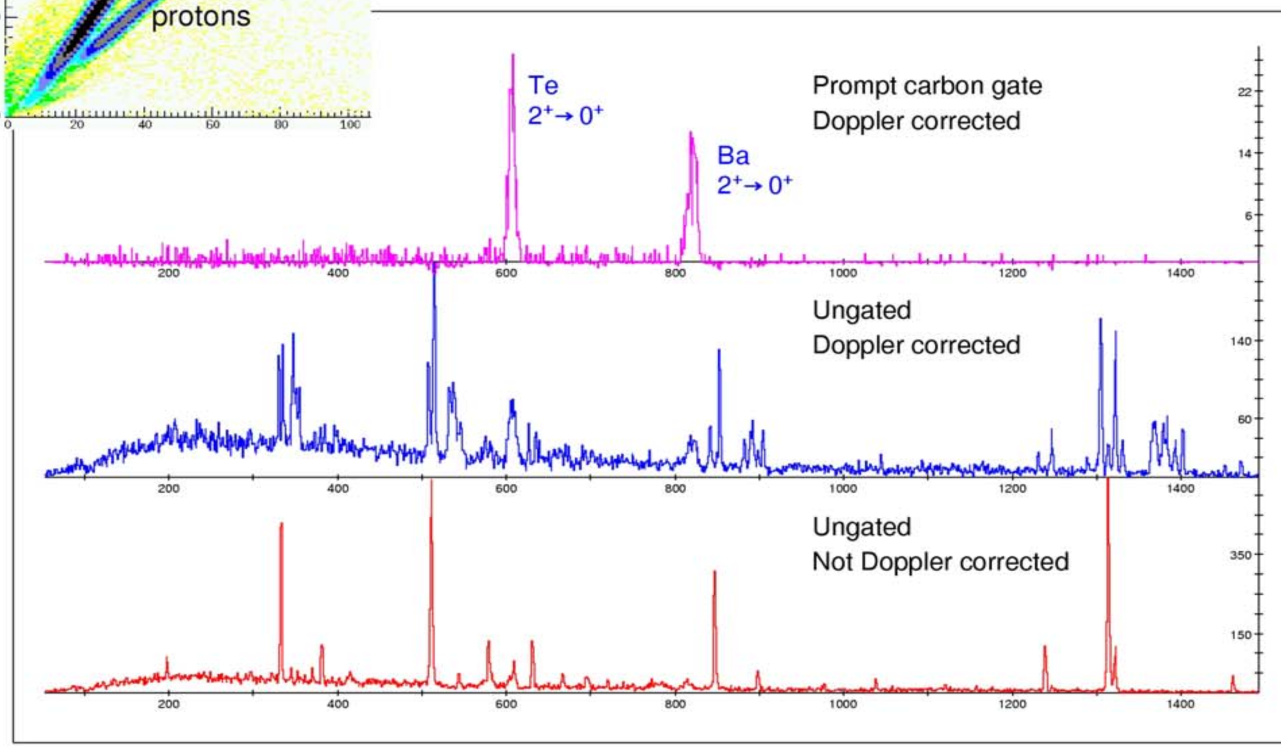
David Radford

Example: A = 136 Coulex

Particle ID Spectra:

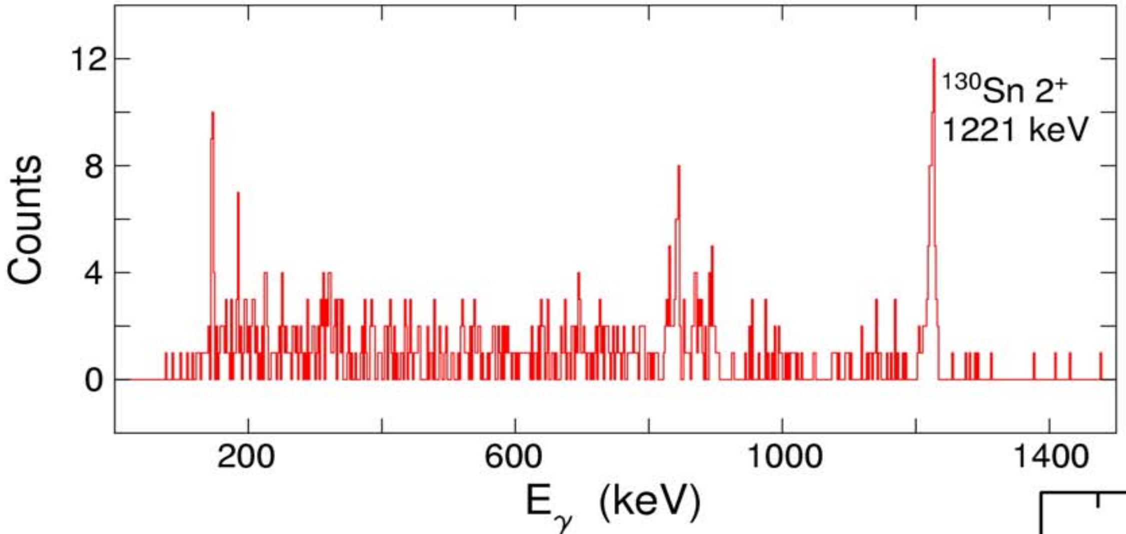


396 MeV ^{136}Te + ^{136}Ba
on 0.83 mg/cm^2 C target



David Radford

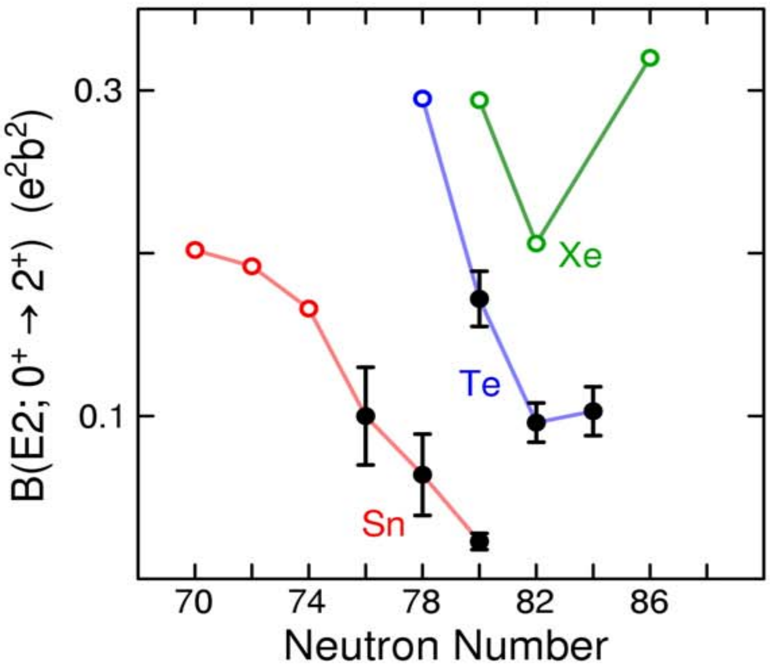
Coulomb Excitation of Pure ^{130}Sn RIB



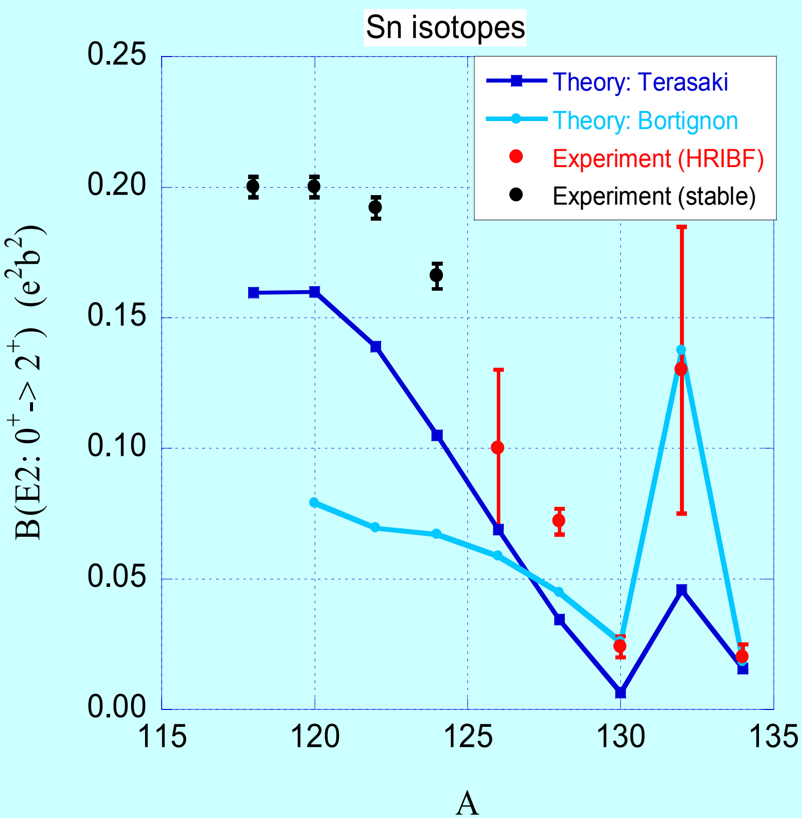
5×10^5 Pure ^{130}Sn s^{-1}
89% g.s., 11% 7^- isomer

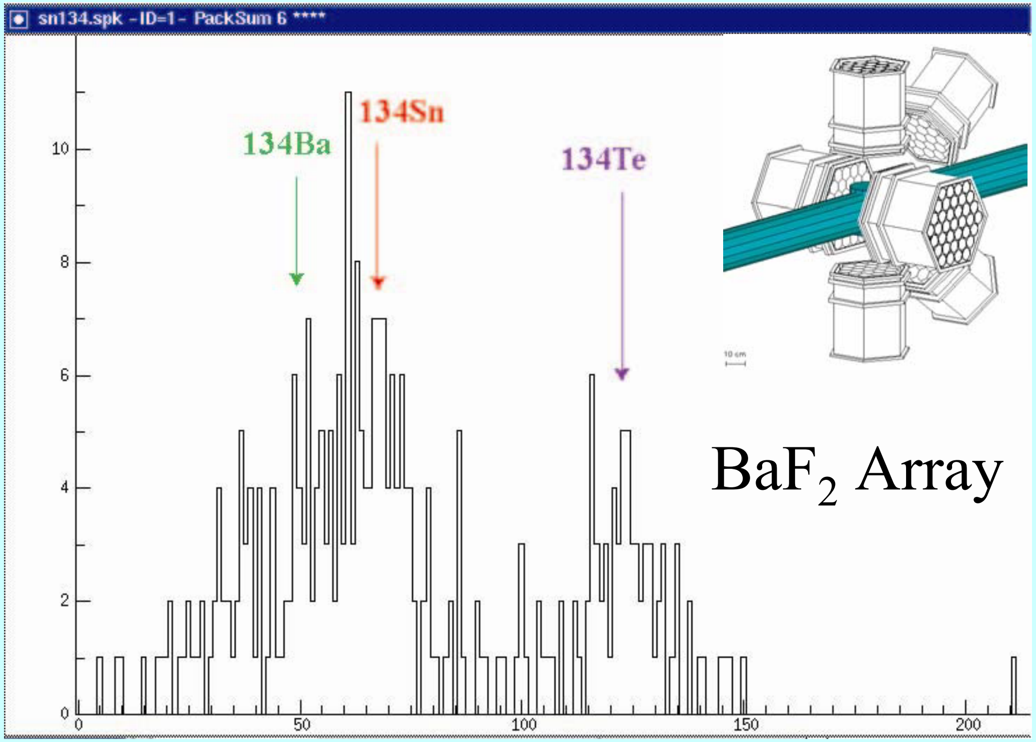
$B(E2; 0^+ \rightarrow 2^+) = 0.023(4)\ e^2b^2$
$= 1.2$ s.p.u.

$\sigma_C = 1$ mb



Hot off the press (very preliminary! Beene, Varner et al)





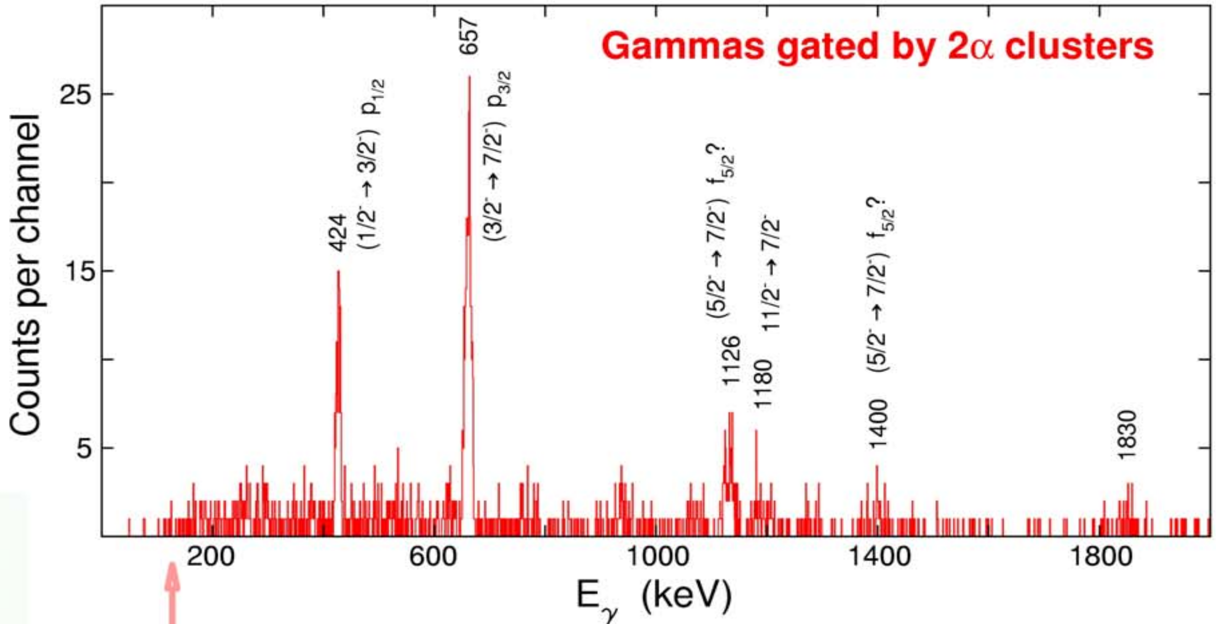
- We've taken B(E2) measurements past the ^{132}Sn double closed shell!

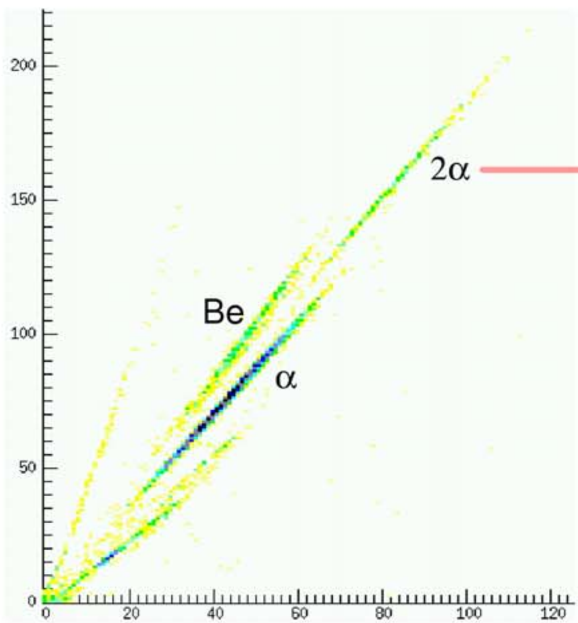
David Radford

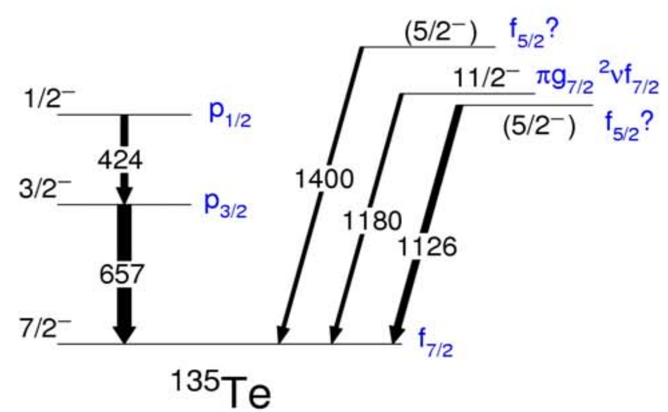
Transfer Reactions with Neutron-Rich RIBS

$^{9}Be(^{134}Te,^{8}Be)^{135}Te$
└→ 2α

~4 MeV per nucleon

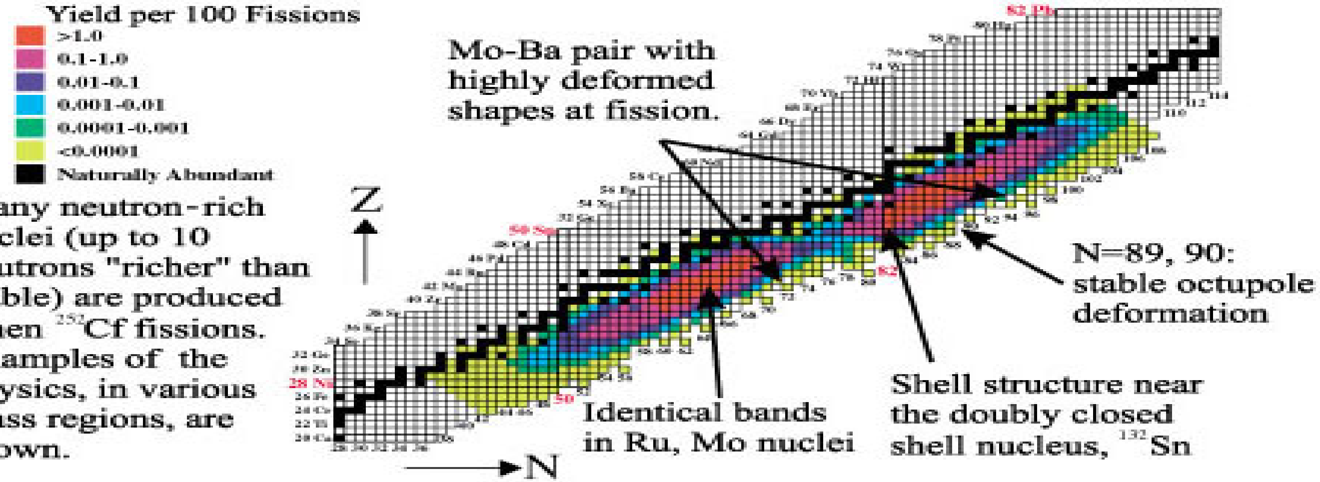






Studying Neutron Rich Nuclei with GAMMASPHERE

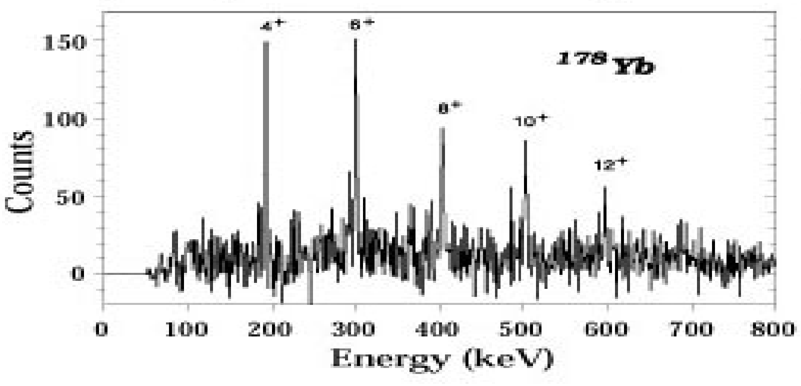
Nuclides Produced by ²⁵²Cf Spontaneous Fission

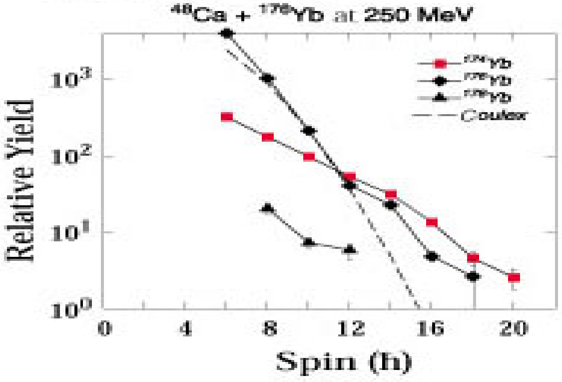


Many neutron-rich nuclei (up to 10 neutrons "richer" than stable) are produced when ²⁵²Cf fissions. Examples of the physics, in various mass regions, are shown.

Neutron rich nuclei from deep-inelastic and transfer reactions

Triple gamma-gated spectra, in coincidence with the scattered nucleus, allow one to study weakly populated (0.3 mb) neutron-rich nuclei e.g. ¹⁷⁸Yb.

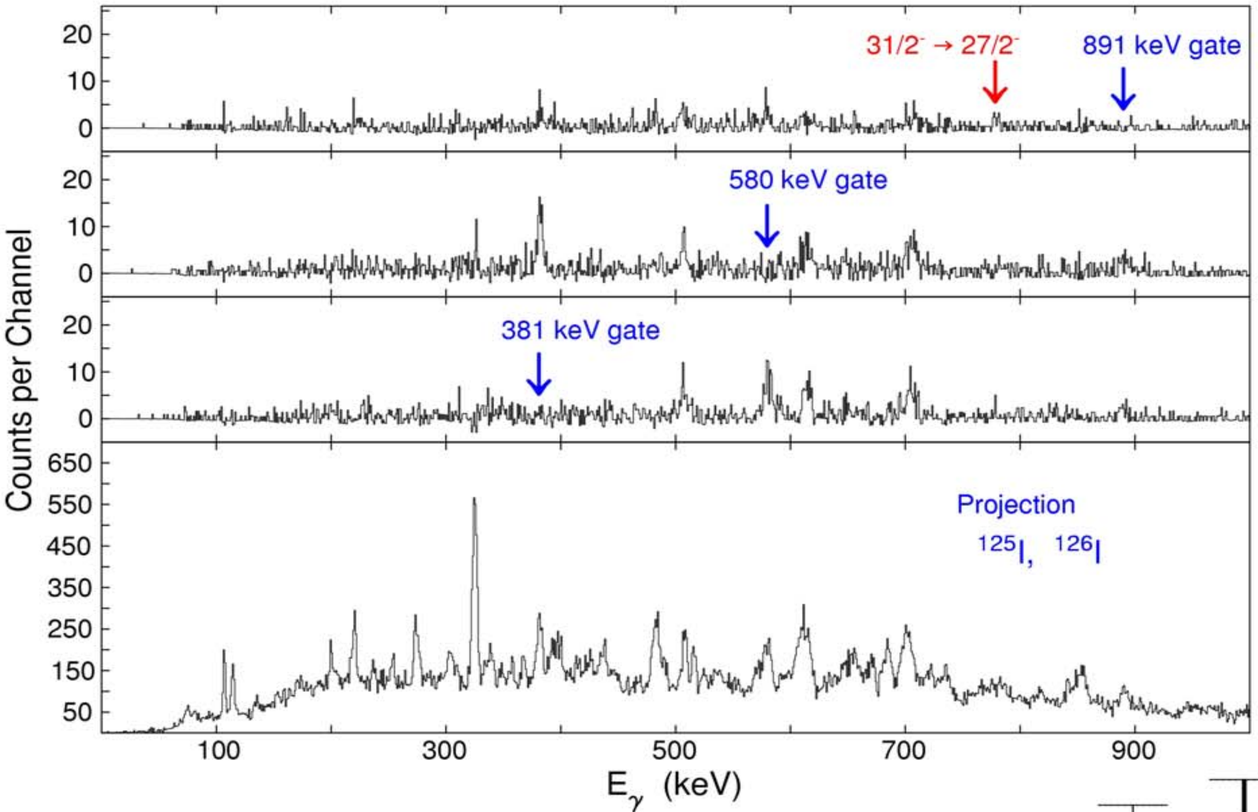


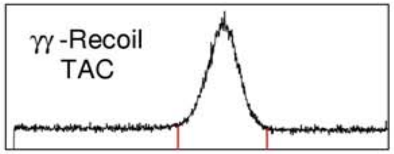


Yield versus spin curves show that inelastic/transfer channels lead to higher spins compared with Coulomb excitation.

David Radford

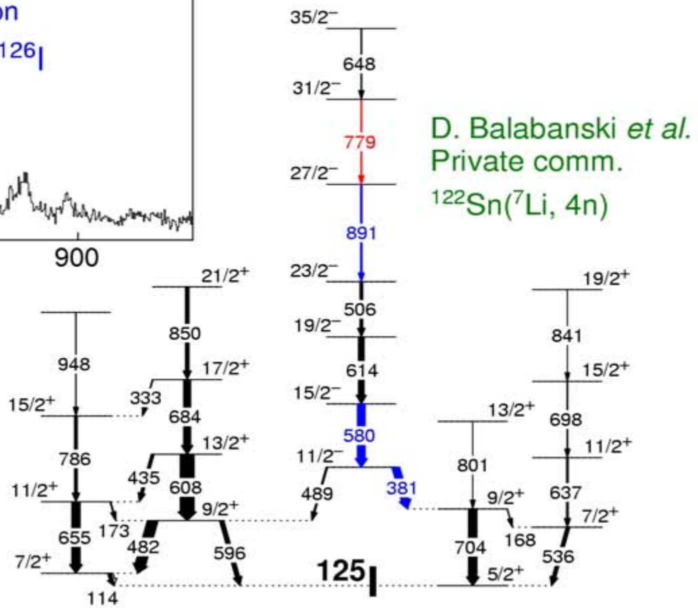
Fusion-Evaporation Reactions



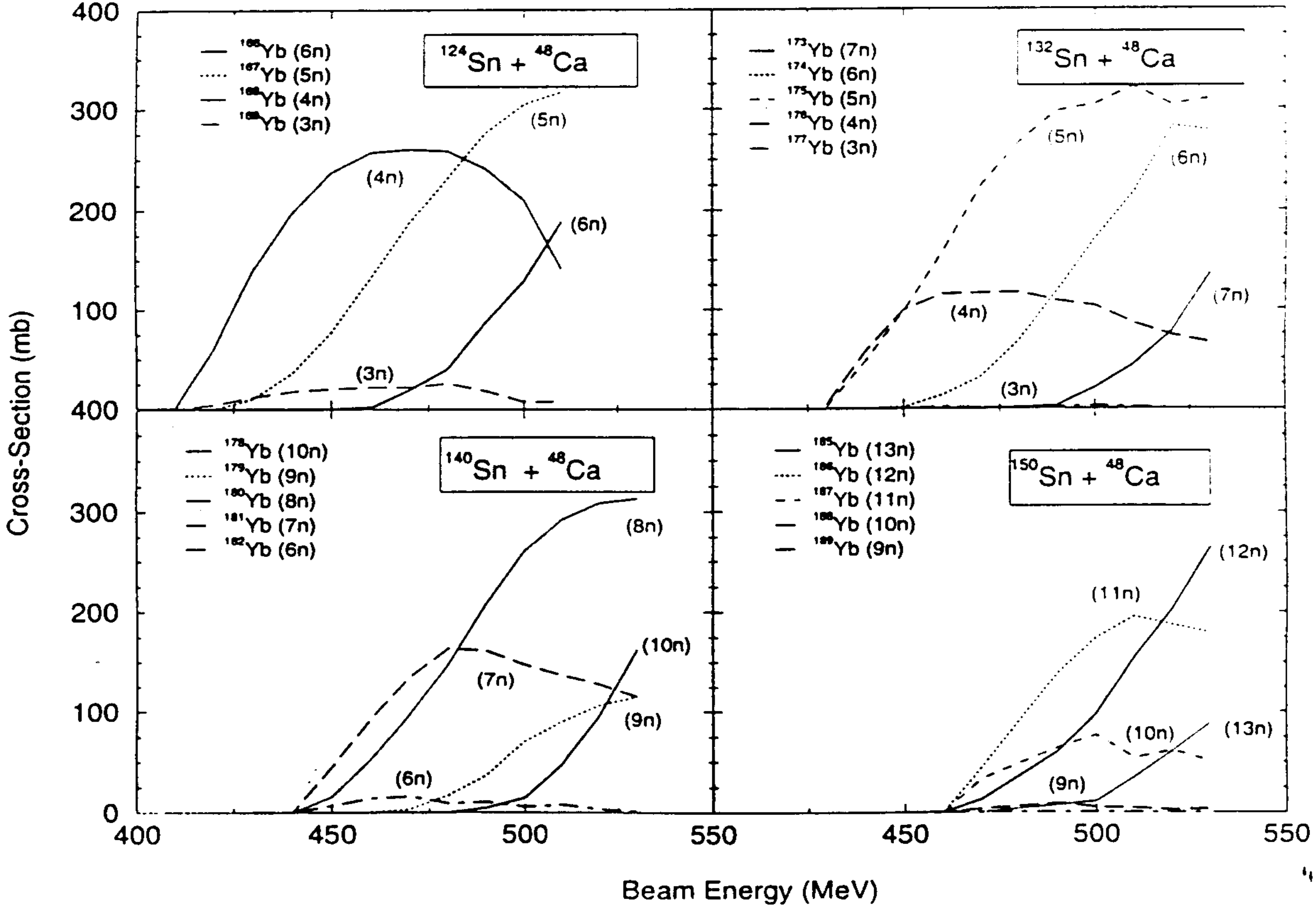


$^{12}C(^{118}Ag,5n)^{125}I$ γγ gates

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

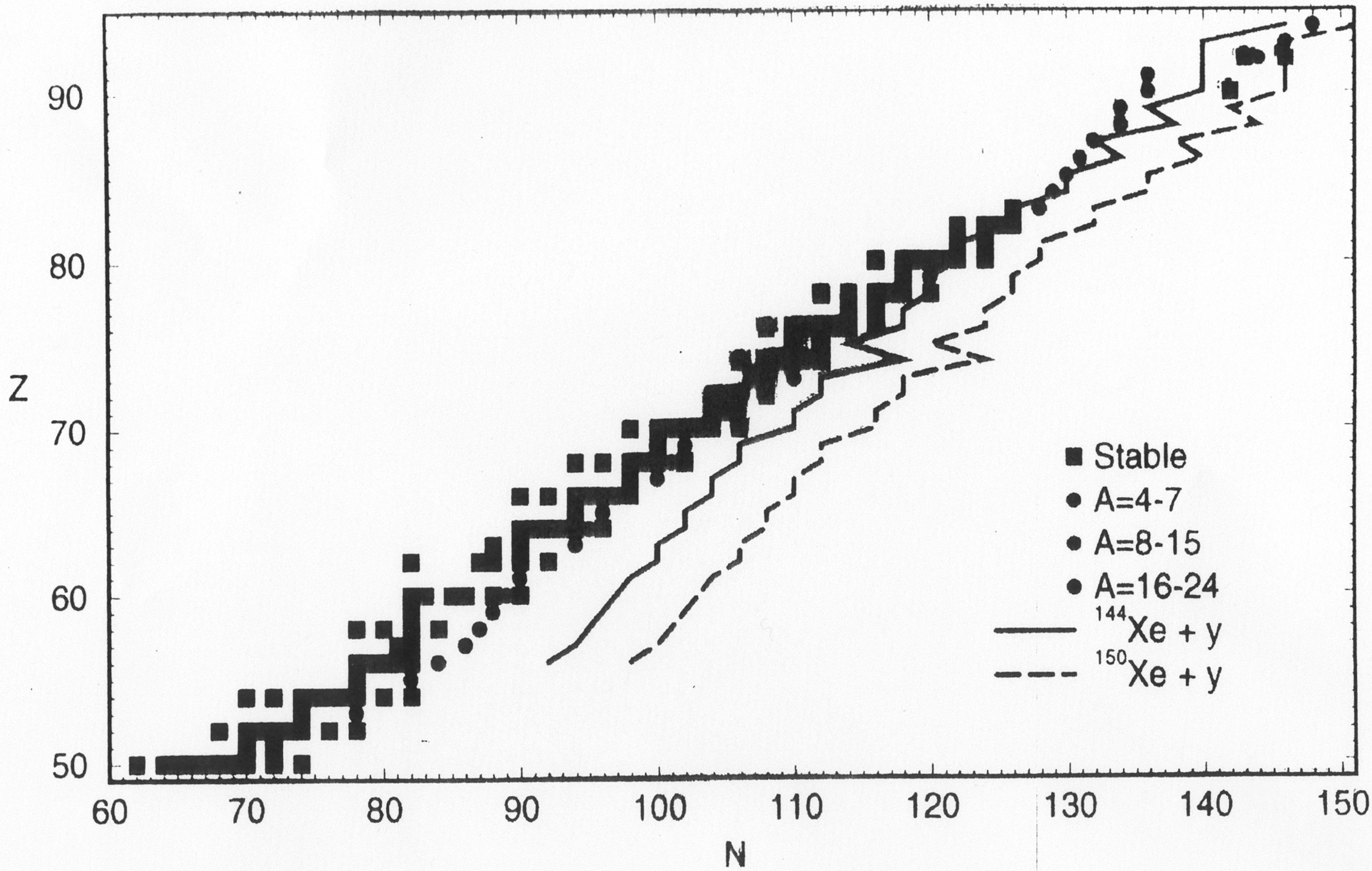


Calculated Residue Cross Sections for the Yb Chain



Mike Carpenter

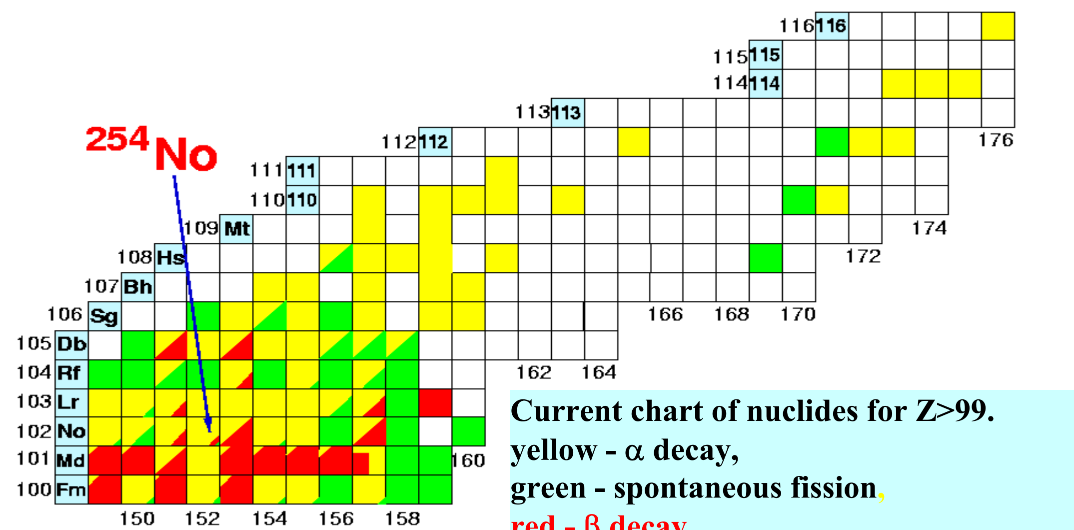
Where some useful beams can take us



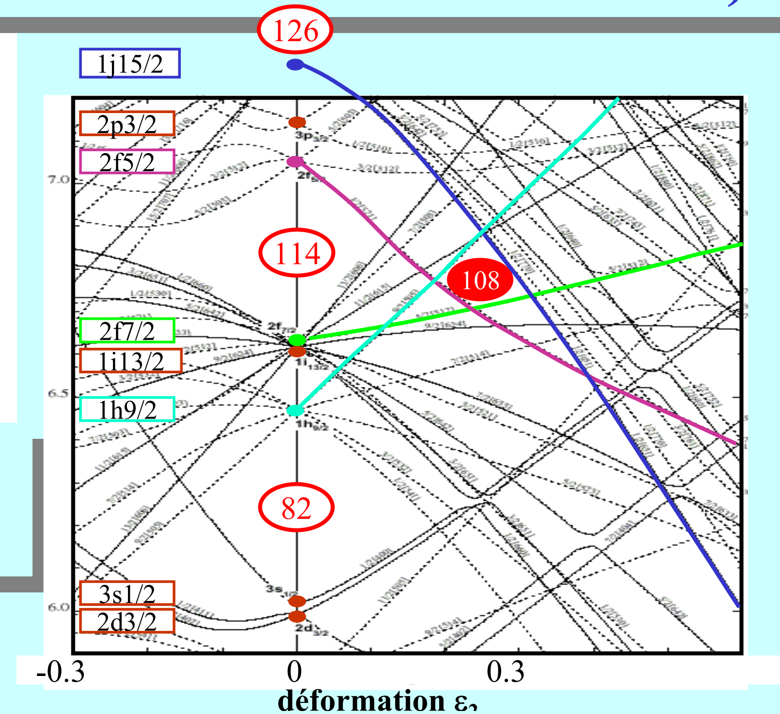
Mike Carpenter

High-A,
High-K,
High-I,
High-Def,
Hi-Mom!

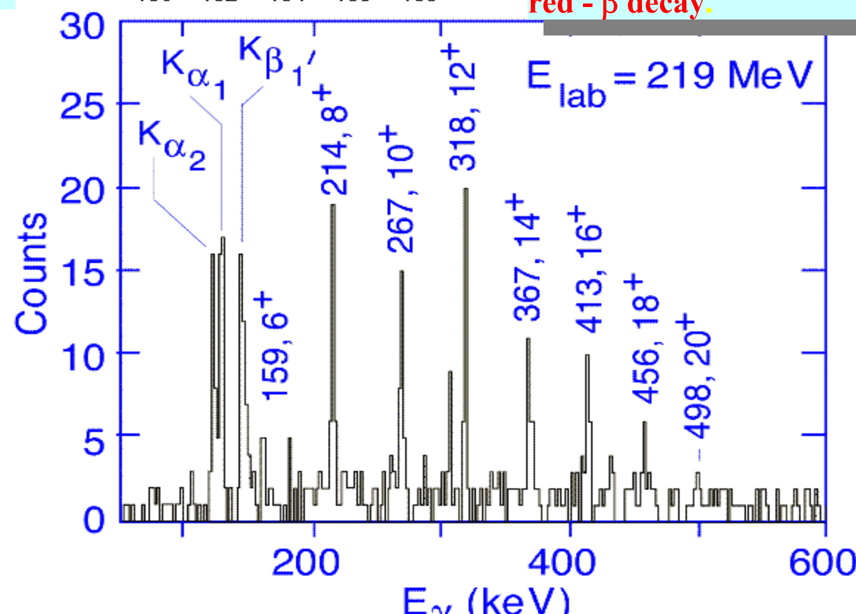
Spectroscopy of the Heaviest Elements : Surprises in the survival of the species. (Complementary studies with stable and RIA beams.)



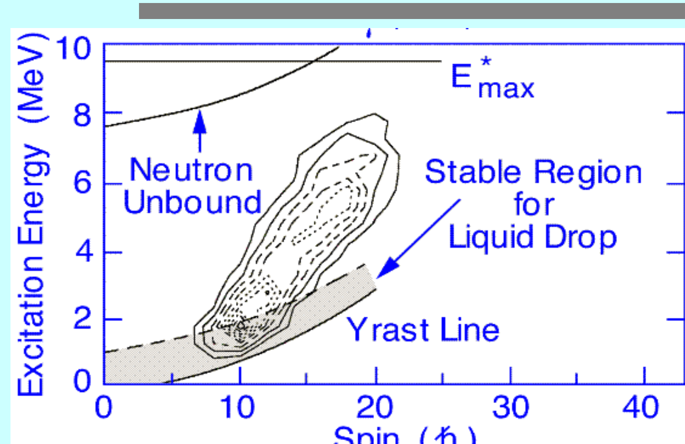
Current chart of nuclides for Z>99.
yellow - α decay,
green - spontaneous fission,
red - β decay.



Spectroscopy will tell us about s.p. spectrum

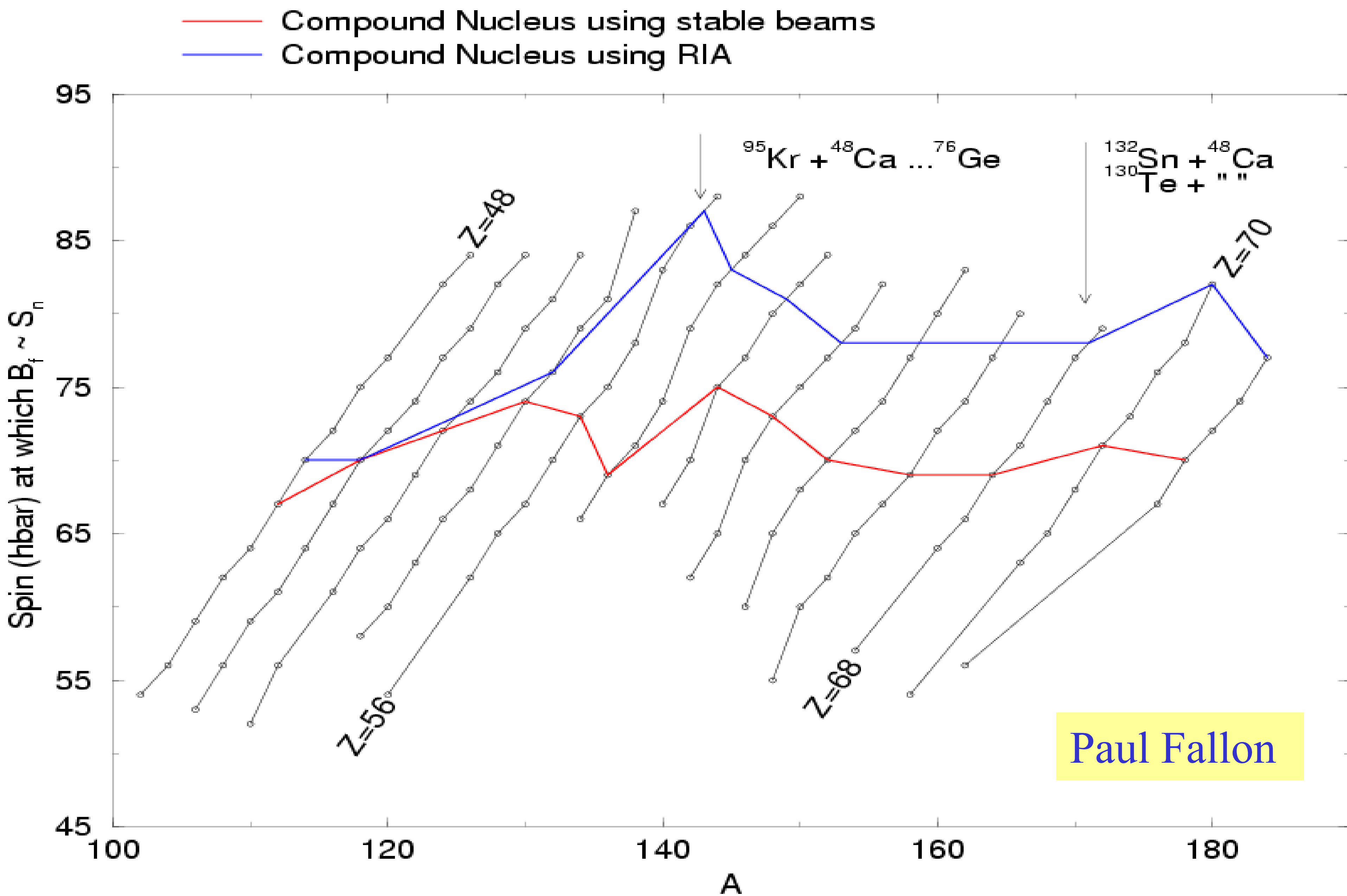


Rotational transitions in deformed ^{254}No



Entry distribution in spin and excitation energy for ^{254}No – Plenty of room to study structure

RIA can enable us to create certain nuclei at higher spin

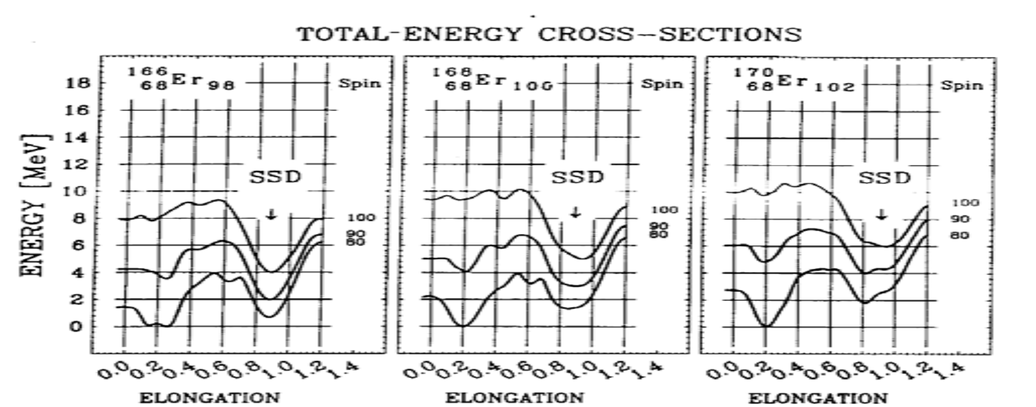


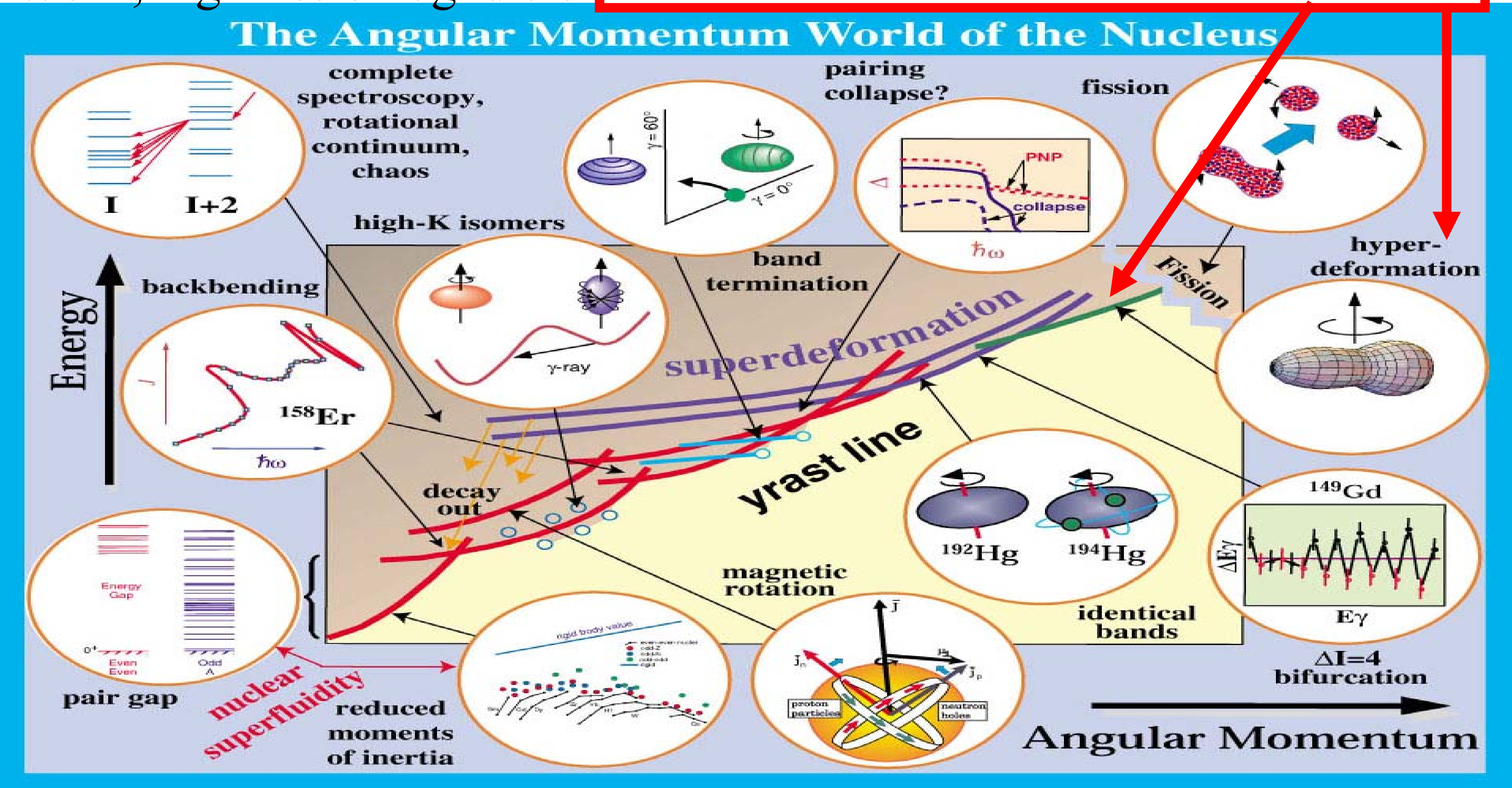
Paul Fallon

The Quest to observe Hyperdeformation at Ultra-High Spins

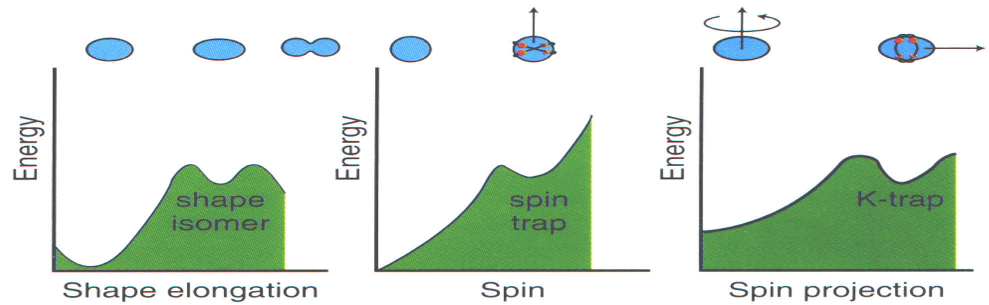
Dudek, Werner and Riedinger, P.L.B.211(88)252

Weak, high fission bgnd etc

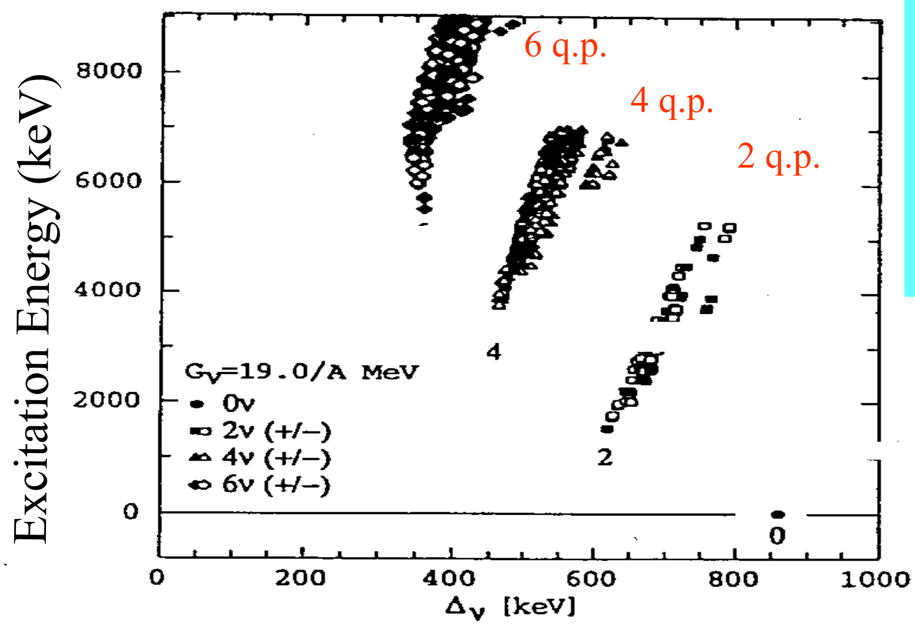




Energy traps in Nuclei (Isomers)

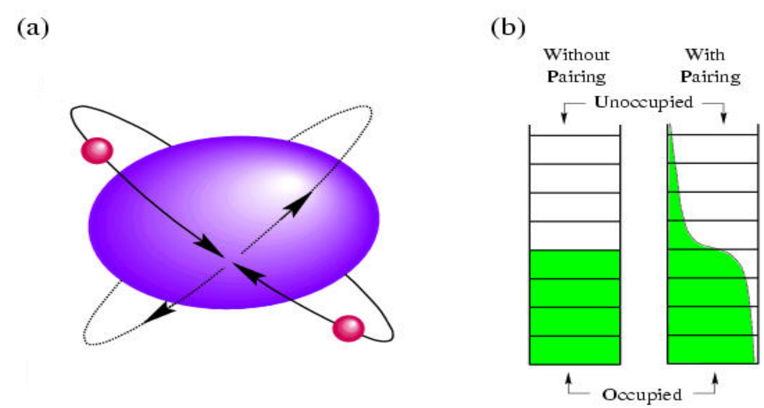


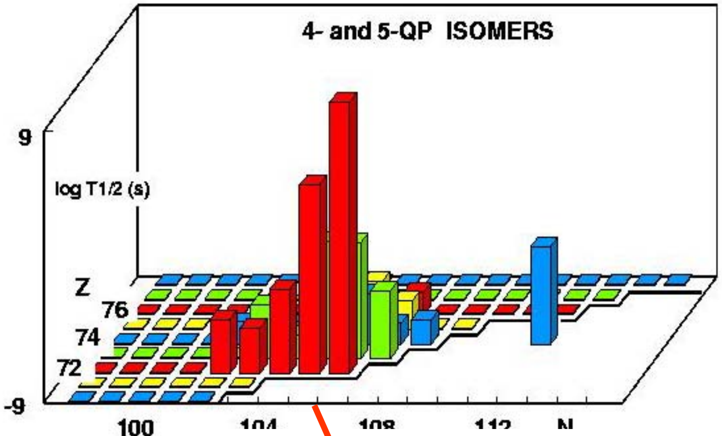
These metastable states occur in a small proportion of nuclei and have been found to display some remarkable properties, properties that are far from being understood.



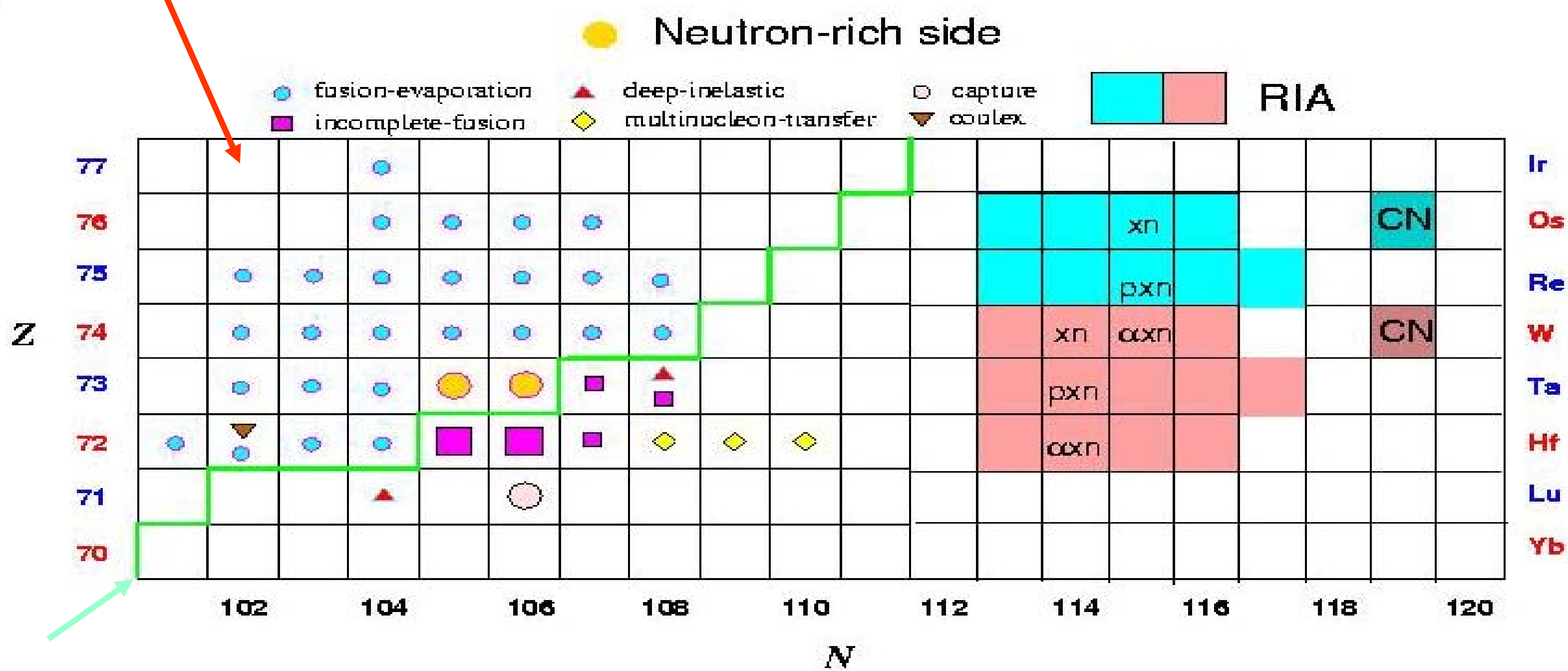
Pairing Strength Δ (keV)

These special states have told us a lot about nuclear structure and the reduction of pairing correlations with seniority in recent years, e.g. Dracoulis, Kondev and Walker, PLB 419 (98) 7.





RIA will allow us into new regions for study, e.g. n-rich A=180 and p-rich A=130 and to populate higher seniority quasi-particle states.



Stable beam limit

$^{145}Xe + ^{50}Ti \rightarrow ^{195}Os$

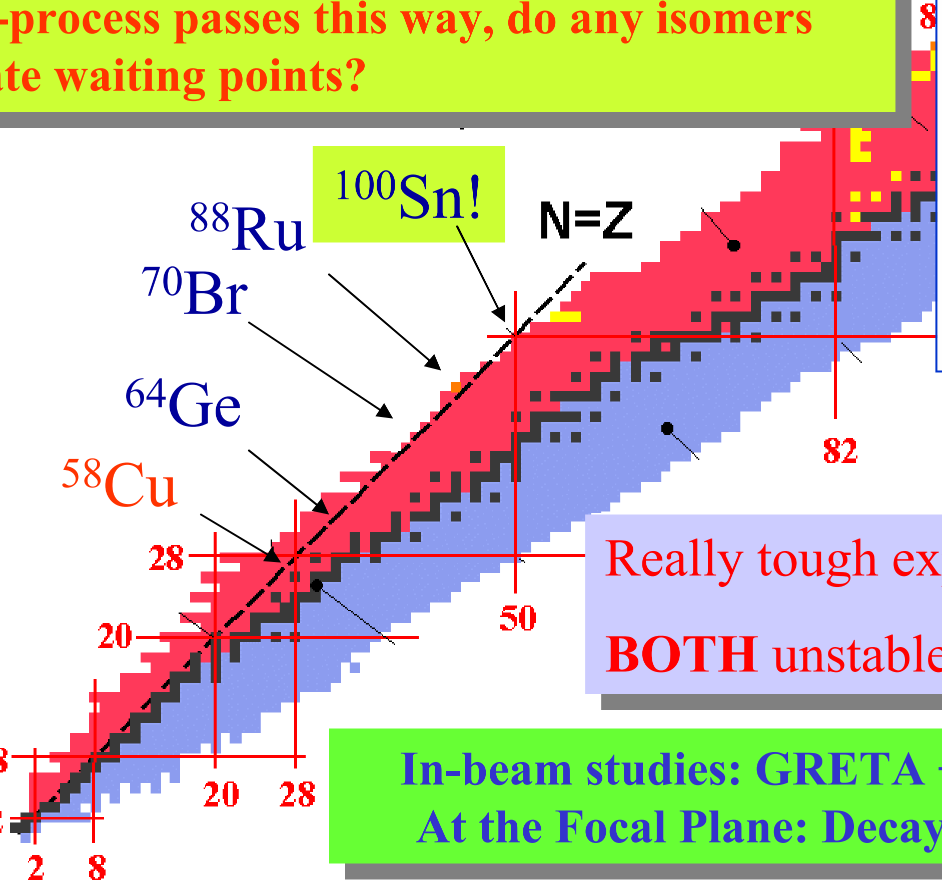
$^{145}Xe + ^{48}Ca \rightarrow ^{193}W$

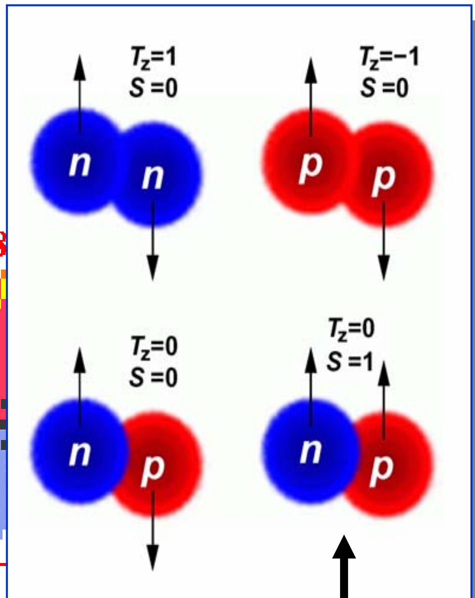
Filip Kondev

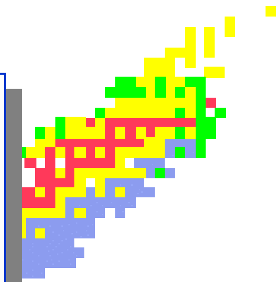
Proton Rich

Physics at the Proton Drip Line

- Spectroscopy at and beyond the dripline
- Isospin symmetries and mirror pairs
- pn pairing correlations, new pairing phase?
- ^{100}Sn and surrounding area
- rp-process passes this way, do any isomers create waiting points?







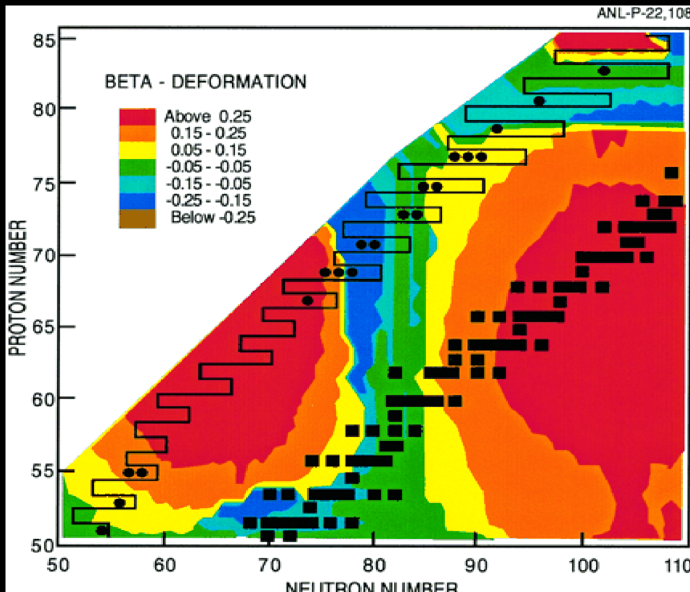
Resistant to Coriolis force!

Really tough expts due to small cross-sections

BOTH unstable and stable beams will play a role

In-beam studies: GRETA + nano-ball + recoil spectrometer
At the Focal Plane: Decay studies and Coulomb excitation

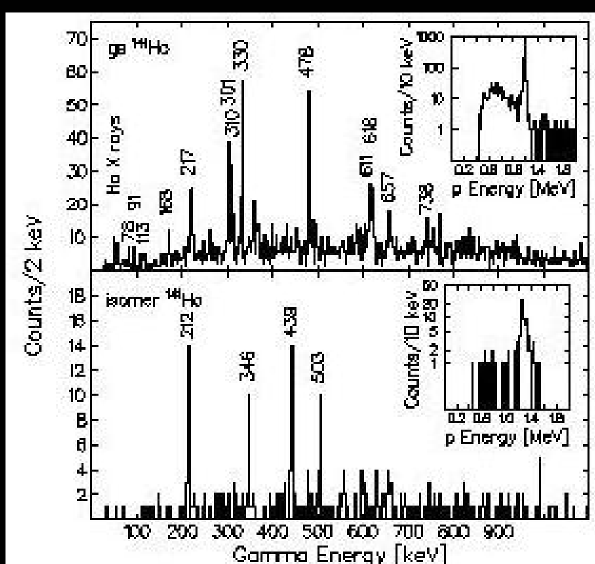
Spectroscopy at the Proton Drip Line: Excited States in ^{141}Ho. Proton decay in a deformed potential.



Contour plot of quadrupole, β_2, deformation as a function of neutron and proton number.

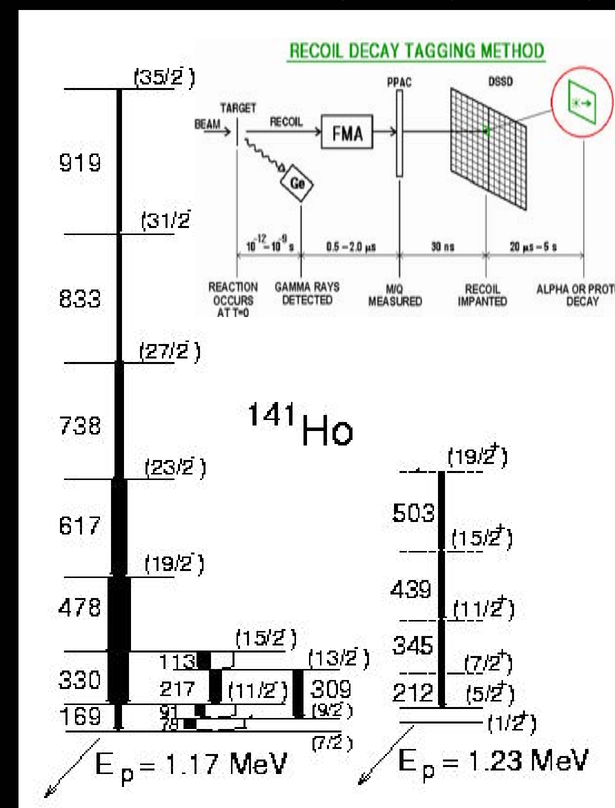
^{141}Ho created once in every 5 million reactions! GS + FMA + RDT make it worthwhile.

(Seweryniak et al., PRL 86 (2001) 1458)



The γ-ray spectrum tagged with protons

The level scheme deduced that shows that the protons are emitted from a deformed nucleus.

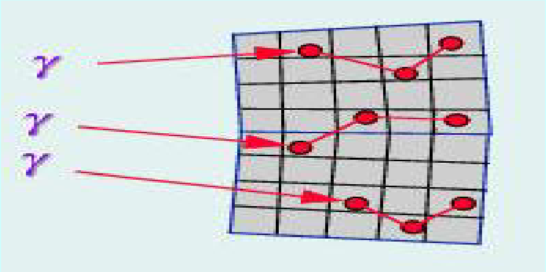


Gamma-Ray Detectors

A key to all this wonderful new science is not only RIA but RIA + New Instrumentation. (plus dastardly cunning on our part!)

Report from workshop
at LBNL July 98.

"…, after going through so much effort to create rare and exotic nuclear species, it only makes sense to have the best and most efficient detector systems to catch their "precious signals". It is therefore extremely exciting that, ….. revolutionary breakthroughs in gamma-ray technology seem possible."



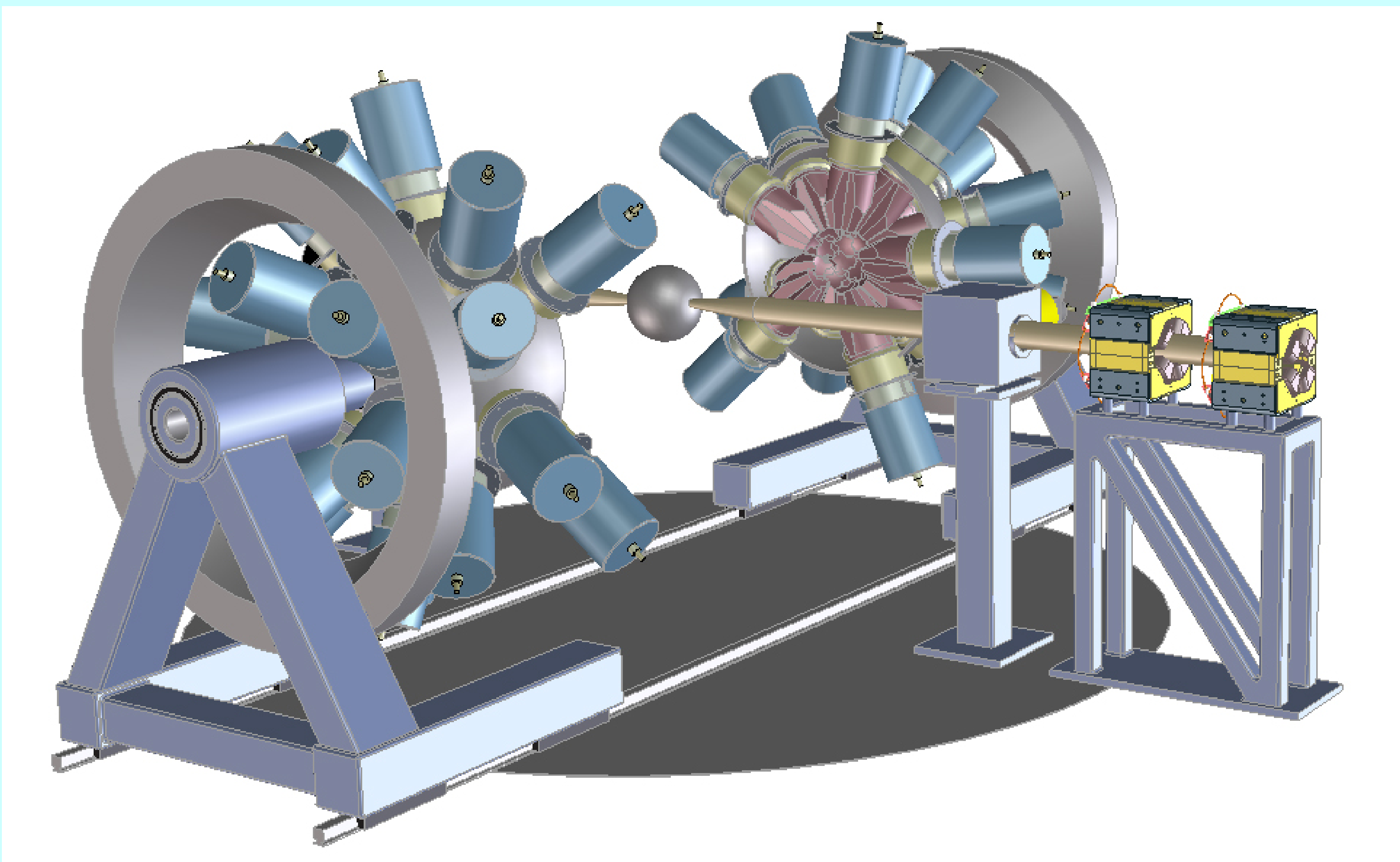
Gamma-Ray Tracking is the future of Gamma-Ray Spectroscopy!

H. Spieler (LBNL) "Novel technology turns into discovery potential."

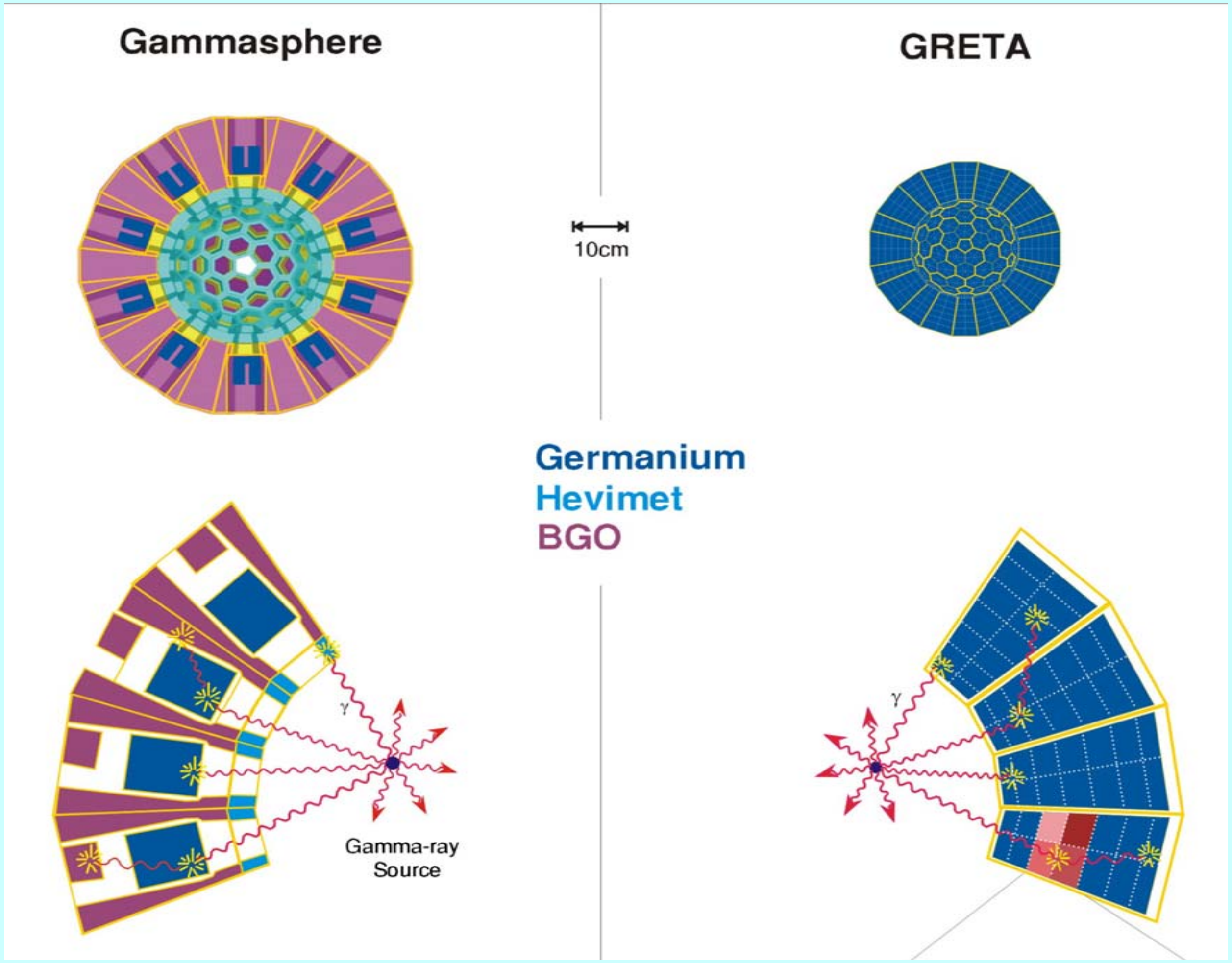
To extract the best science and to unlock new physics one must create the right environment. I think we will have the right ingredients.

RIA + Tracking Dets. + Aux. Dets = Discovery Potential

A New Opportunity in Gamma-Ray Physics



Compare Gammasphere with GRETA



	Gammasphere	GRETA
Efficiency (1 MeV)	8%	55%
Efficiency (15 MeV)	0.5%	12%
Peak/Total (1 MeV)	55%	85%
Position resolution	20mm	1 mm

IY Lee

GRETA Capabilities

Broad physics opportunities

- Resolving power: 10^7 vs. 10^4
  - Cross sections down to ~1 nb
    - Most exotic nuclei
    - Heavy elements (e.g. ^{253,254}No)
    - Drip-line physics
    - High level densities (e.g. chaos)
- Efficiency (12% vs. 0.5% at E_γ=15 MeV)
  - Shape of GDR
  - Studies of hypernuclei
- Efficiency (slow beams) (55% vs. 9% at E_γ =1.3 MeV)
  - Fusion evaporation reactions
- Efficiency (fast beams) (55% vs. 0.5% at E_γ =1.3 MeV)
  - Fast-beam spectroscopy with low rates -> RIA
- Angular resolution (0.2° vs. 8°)
  - N-rich exotic beams
    - Coulomb excitation
  - Fragmentation-beam spectroscopy
    - Halos
    - Evolution of shell structure
    - Transfer reactions
- Count rate per crystal (50 kHz vs. 10 kHz)
  - More efficient use of available beam intensity
- Linear polarization
- Background rejection by direction

IY Lee

Gamma-Ray Tracking Coordinating Committee Report, July 02

Table 5.1.2: The calculated resolving power of GRETA for a variety of different reaction types ranging from β-decay (low multiplicity and v/c = 0) to fragmentation of fast beams, to very high spin fusion evaporation reactions. The final three columns list the improvement in the resolving power of GRETA, relative to Gammasphere, for three different assumptions about the total solid angle coverage and position resolution of GRETA.

Type of Reaction	$\langle E_\gamma \rangle$ (MeV)	v/c	M_γ	Resolving Power	Improvement Factor (Relative to Gammasphere)		
				Δx = 2 mm Ω=80%	Δx = 0 mm Ω=100%	Δx = 1 mm Ω=90%	Δx = 2 mm Ω=80%
Stopped	5.0	0.0	4	2.1×10^7	370	290	200
	1.5	0.0	4	4.4×10^7	170	120	77
High-spin Normal Kinematics	1.0	0.04	20	2.4×10^6	240	140	55
High-spin Inverse Kinematics	1.0	0.07	20	2.2×10^6	600	340	120
Coulex/transfer	1.5	0.1	15	3.7×10^6	2200	1320	510
Fragmentation	1.5	0.5	6	5.9×10^6	137600	46570	12490
In beam Coulex	5.0	0.5	2	2.7×10^3	1510	440	110
	1.5	0.5	2	4.1×10^3	1800	180	50

www.pas.rochester.edu/~cline/GRTCC-report.pdf

The Nuclear Physics Scientific Horizon:

Projects for the Next Twenty Years

Report of the Ad-hoc Facilities Subcommittee of the Nuclear Science Advisory Committee

K. Lesko
B. Jacak
K. de Jager
R. Janssens
R. G. H. Robertson
B. Sherrill
W. Zajc
C. Glashausser (Chair)

MARCH 3, 2003

PROJECT	SCIENCE	READINESS
Rare Isotope Accelerator (RIA)	1	1
CEBAF 12 GeV Upgrade	1	1
GRETA	1	1
RHIC II/eRHIC	1/1	2
Underground Detector I	1	2/3
CEBAF II/ELIC upgrade	1	3
Upgrade Stable Beam Facility	3	3
RIA II	3	3
Underground Detector II	1	3

PROJECT TITLE: Gamma Ray Energy Tracking Array (GRETA)
First Estimate : ☒ $50M -$99M ☐ $100M-499M ☐ $500M-$1B ☐ >$1B

SCIENCE (Category 1)

- understanding interplay of single-particle and collective modes
- exploring (Z, N) limits for bound nuclei
- unraveling properties of exotic nuclei
- investigating density oscillations in nuclear matter

Unique?
Absolutely—this is a much improved version of Gammasphere, itself perhaps without peer.

Different areas, synergies?
Since it is an essential complement of RIA, it ha s applications in nuclear structure and astrophysics, homeland security and medical physics.

Demand
A significant fraction of the expected users of RIA have already organized to develop GRETA. A device like this would be very useful soon, and essential at RIA.

Reviewed?
LRP 2002 noted: "*The physics justification for a [new] 4π tracking array is extremely compelling, spanning a wide range of fundamental questions…*"

READINESS (Category 1)

Formally studied? Reviewed?
Engineering designs have been generated for all critical components of the project. A national gamma-ray tracking coordination committee (GRTCC) has reviewed all aspects of the device including the R&D plan, the mechanical design, the specifications for detectors and electronics, the time line for construction, the cost and contingency estimates, etc.

Confident that technical challenges can be met? Sufficient R&D?
Over the last 5 years, major R&D efforts at several universities and national laboratories have validated the GRETA concept and demonstrated proof of principle. The major upcoming milestone will be the testing of the three-crystal detector module. No high-risk technical challenges were identified in the GRTCC review and GRETA was found to be ready to initiate construction.

Cost understood?
A total cost and cost profile has been generated by Jay Marx, Bill Edwards, Bob Minor and others. The cost depends critically on the price of the germanium crystals, which has increased significantly recently.

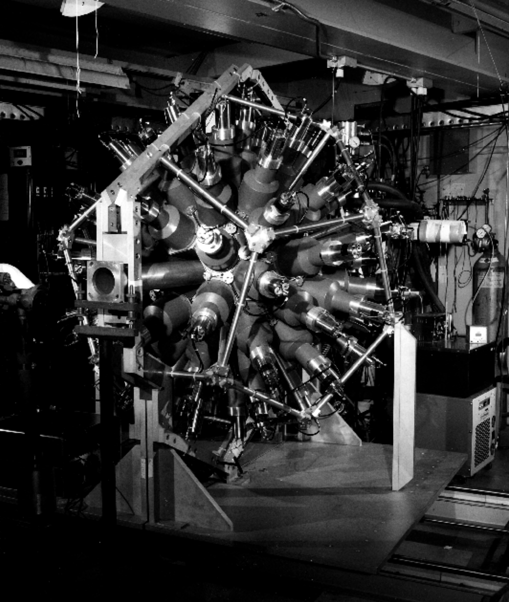
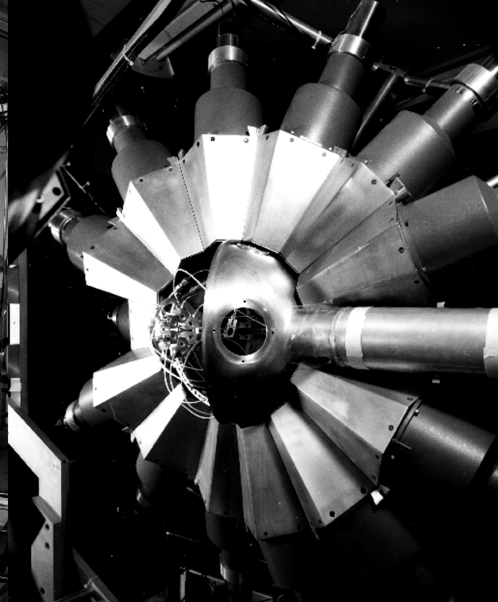
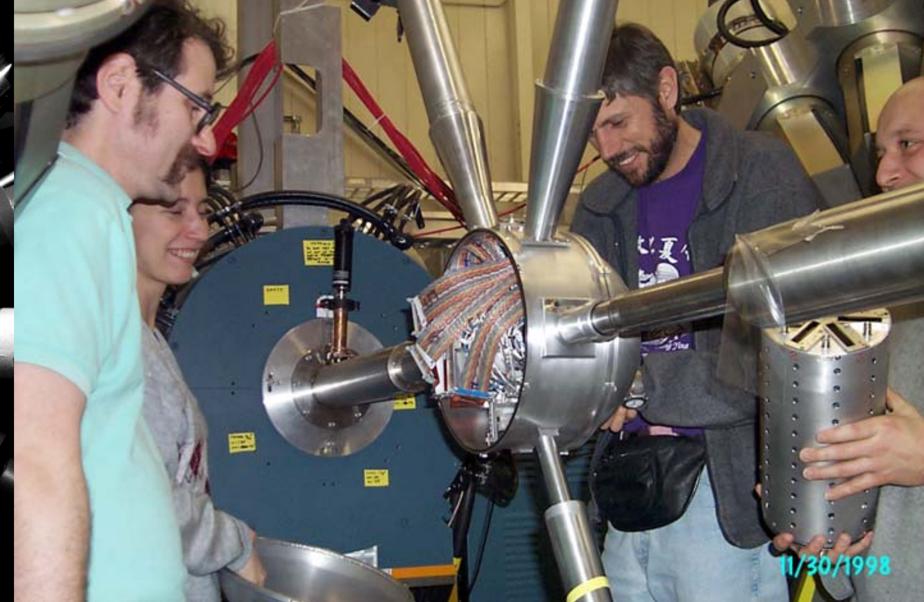
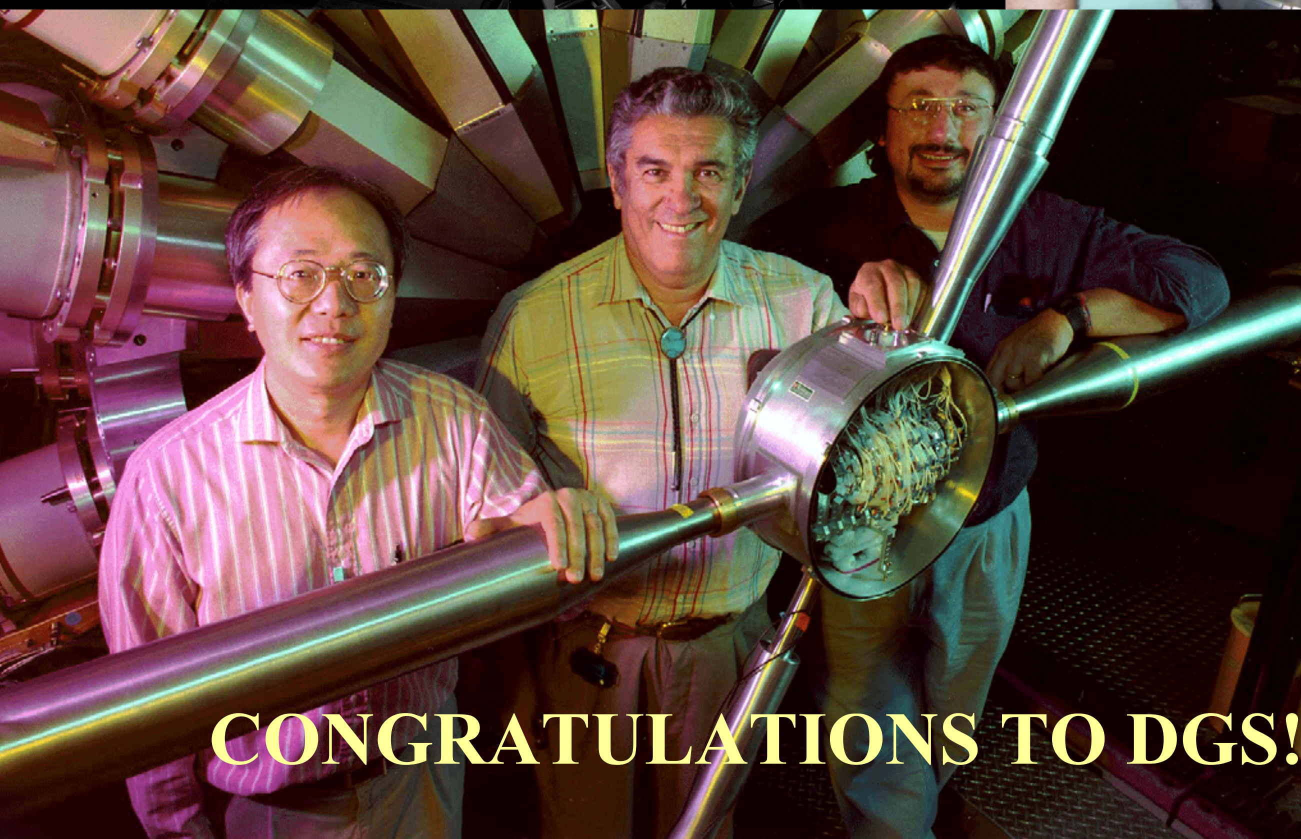
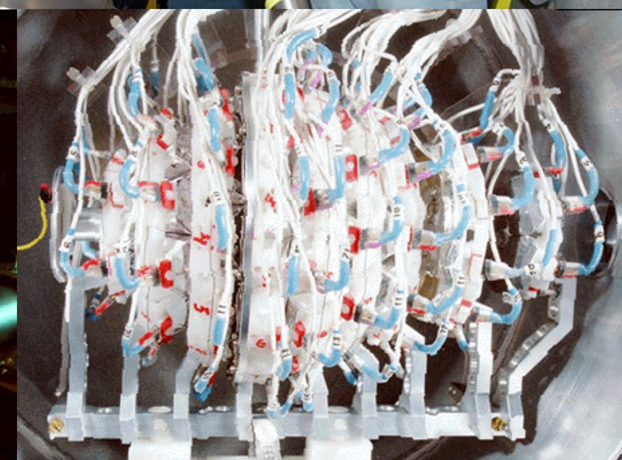
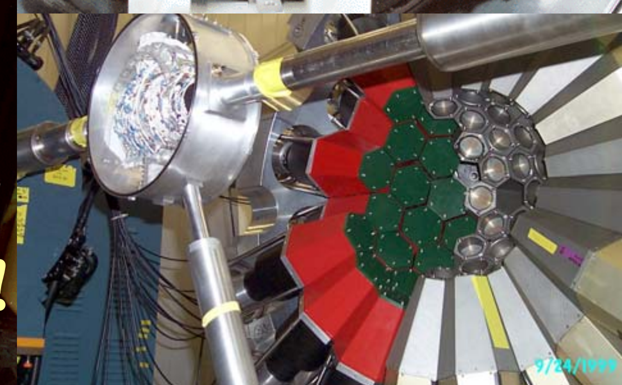
Other Detector Needs and Very Slow Beams ………. Including Stopped!

For example, Decay spectroscopy and other physics at the focal plane.

See Kim and others later this week

The recent move of Gammasphere, thanks again to certain SUPER-HEROES, has gone very well.

See Gammasphere at your local theater on June 20, 2003




11/30/1998

CONGRATULATIONS TO DGS!


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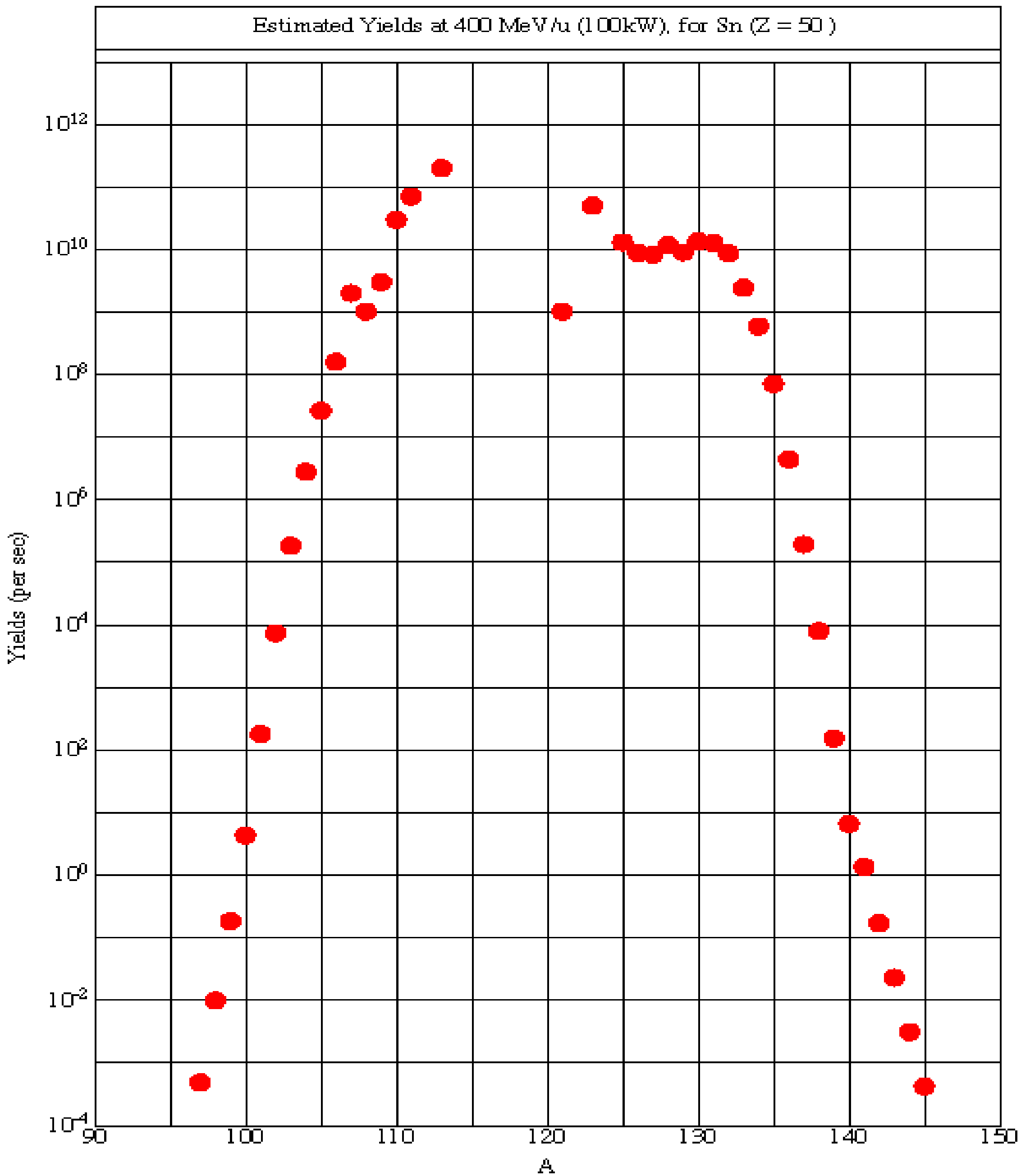
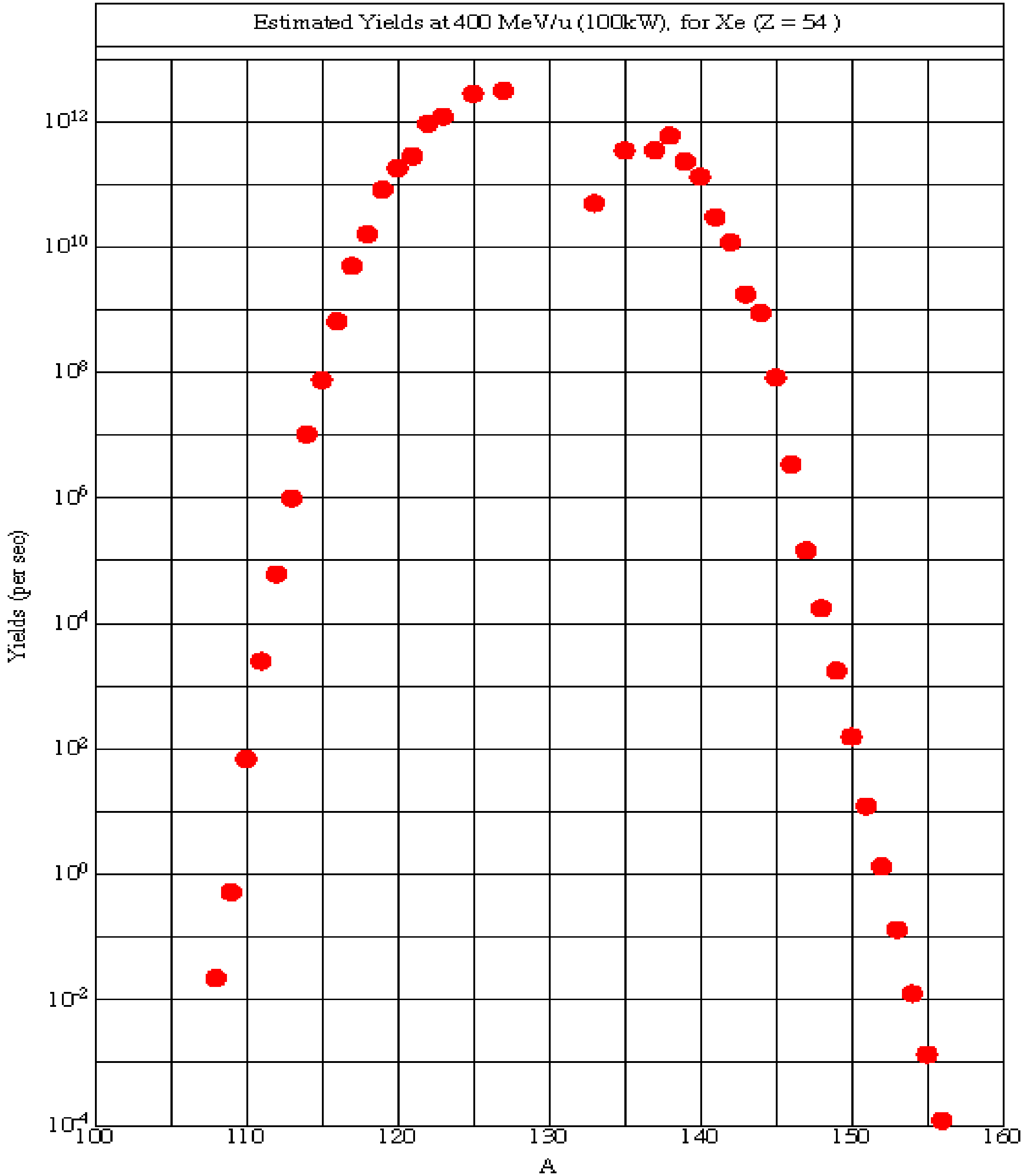

Estimated Yields at 400 MeV/u (100kW), for Sn (Z = 50)
Yields (per sec)
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
90
100
110
120
130
140
150
A



Estimated Yields at 400 MeV/u (100kW), for Xe (Z = 54)
Yields (per sec)
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
100
110
120
130
140
150
160
A