Gamma Ray Detection at RIA

Summary Report:
Physics & Functional Requirements

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Physics goals

Experimental tools:
Techniques & Reactions

Functional
Requirements

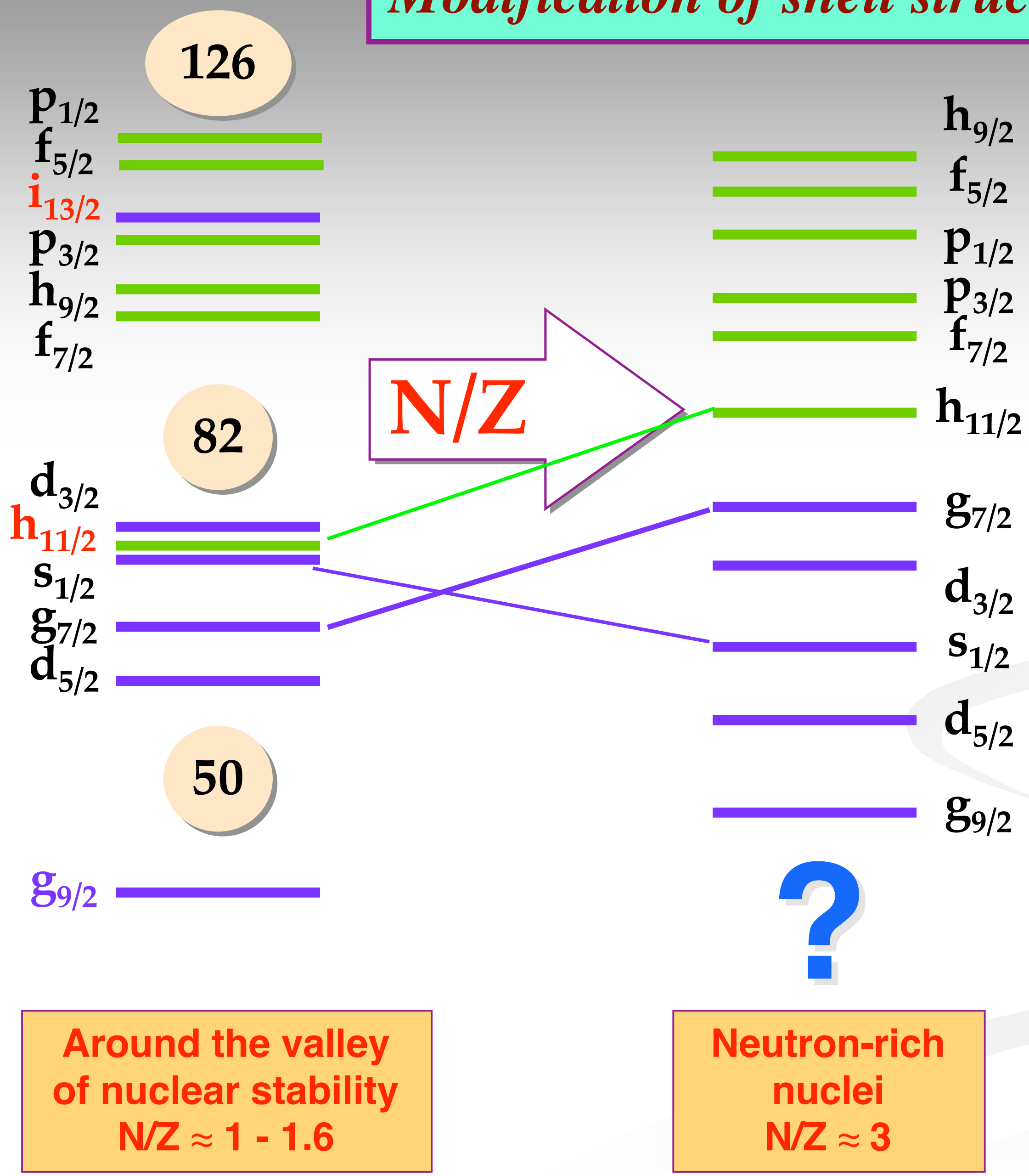
Physics Questions (Discussed extensively in RIA reports)

1. Nature of the nucleonic matter
    - Gross properties
    - Collective properties
    - Microscopic structure: Properties at the limits
    (To amplify terms most sensitive to interaction)

2. Origin of the elements

3. Fundamental interactions & symmetries

Modification of shell structure near n drip line



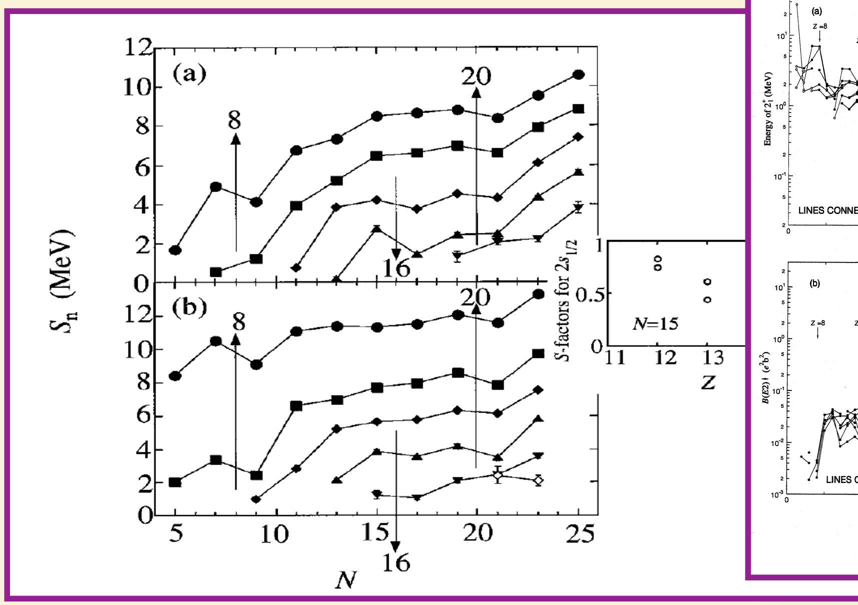
Questions:

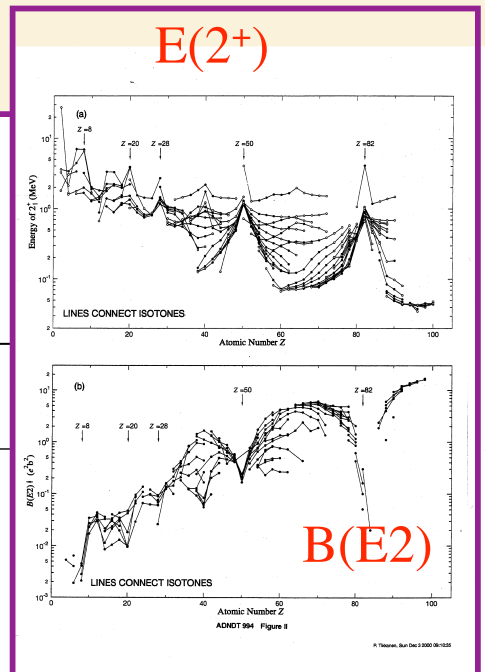
- **What is the shell structure near neutron drip line?**
- **What are the features of the new shell structure?**
- **How to experimentally determine the new magic numbers?**

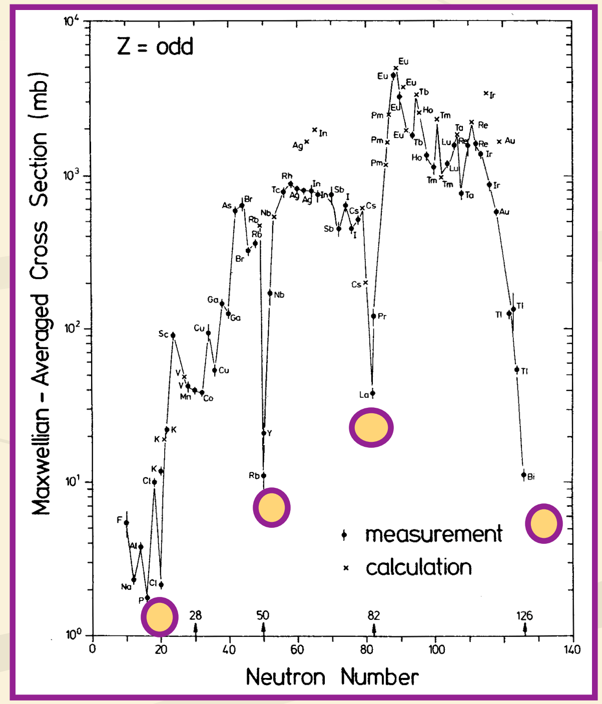
Signatures of large shell gaps & magic numbers

Combinations of:

- **Kinks in *1n* and *2n* separation energies**
- **Large E(2$^+$) and small B(E2) -- signature of rigid spheres**
- **Small σ(n,γ) (peaks in element abundances)**
- **Kinks in single-particle energies**







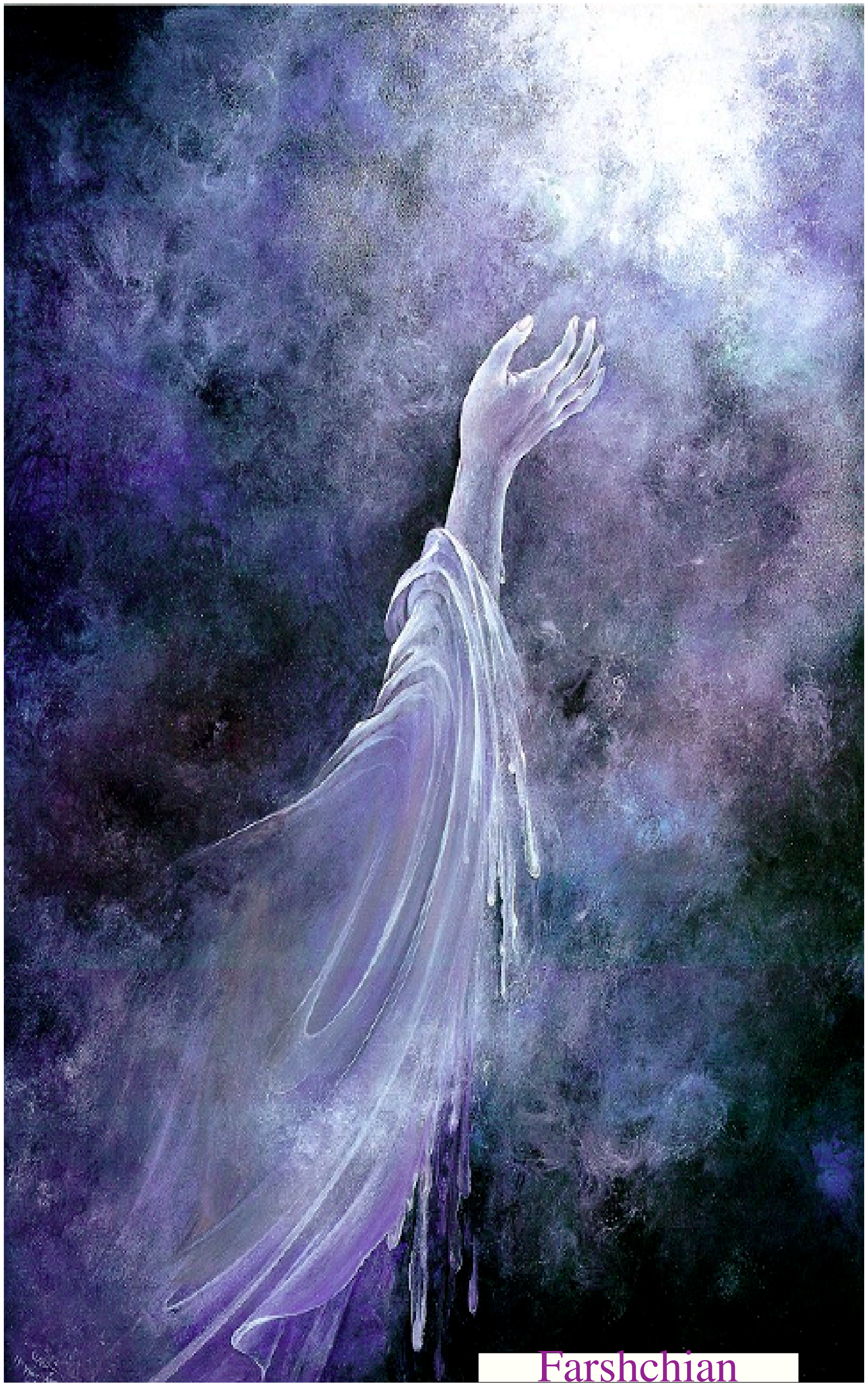
Ozawa *et al.*, Phys. Rev. Lett. 84 (2000) 5493

Physics Questions

1. Nature of the nucleonic matter
   - Gross properties
   - Collective properties
   - Microscopic structure: Properties at the limits

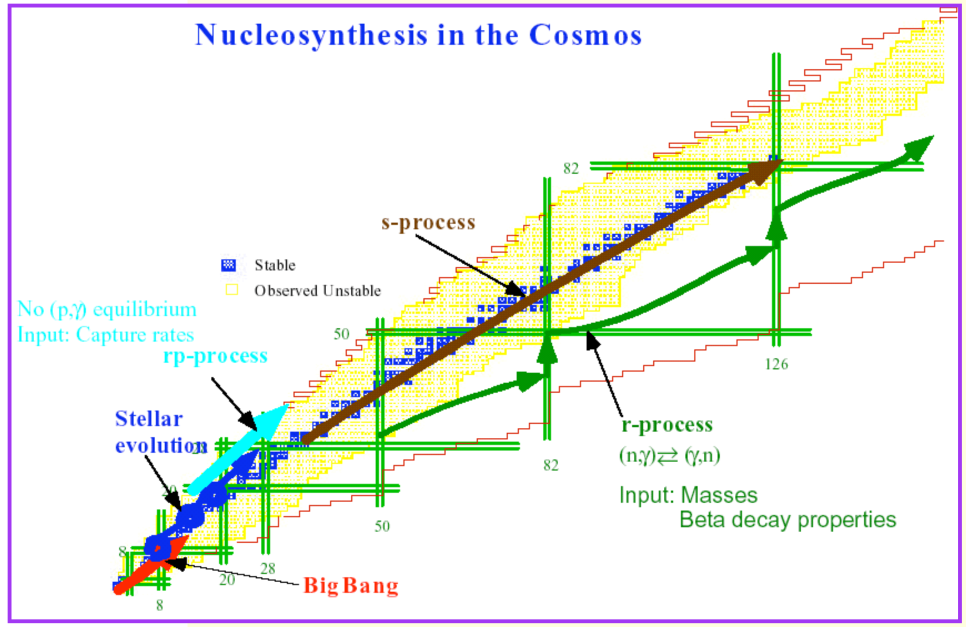
2. Origin of the elements
   - reactions and structure studies related to
     rp (p rich) & r processes (n-rich);
     many are similar to the above

3. Fundamental interactions & symmetries



Origin of the Elements:
A Long Journey From Heavens to Earth

Heavens: Primarily H (~3/4) & He (~1/4)



Earth: Heavy Elements (Fe, Si, . . .)

Physics Questions

1. Nature of the nucleonic matter
    - Gross properties
    - Collective properties
    - Microscopic structure: Properties at the limits

2. Origin of the elements
    - rp & r process

3. Fundamental interactions & symmetries
    - For example, superallowed beta decay

Tools to address the 2nd & 3rd questions are similar to those used for the first one.

What, where, how?

Gross Properties	Masses, radii shapes, lifetimes	Traps, lasers, inelastic scattering, decay spectroscopy
Collective Properties	Modes (Vib'n, Rot'n, . . .) Multipolarity (□) Strength functions	Decay, capture, scattering, Coulex, transfer, fusion, DIC, . . .
Microscopic properties at the limits	-p & n drip lines -Superheavy elements -High spin, Temperature	Same as above Knock out reactions . . .
Reaction Dynamics		Break up Fusion & fission, etc.

□detection is needed or desired for majority of these experiments!

Important factors in gamma detection

I. Physics

- *Energy range*. Examples:
  - Gamma ray spectroscopy ~100 keV to few MeV
  - Giant resonances ~10-30 MeV

- Complexity of spectra (level spacing, intrinsic width) define the *energy resolution* requirements:
  - Spectroscopy ~ 0.2%
  - Giant resonance ~10%

- Angular distribution defines *angular coverage*

Important factors in gamma detection

II. Reaction parameters

(applies to both stable and radioactive ion beams)

- Total cross section
  - impacts efficiency
- Partial cross section or background
  - impacts peak/total, energy resolution, & auxiliary detectors
- Maximum spin or gamma multiplicity
  - impacts peak/total, energy resolution
- Recoil velocity (Doppler correction)
  - impacts energy resolution

Reactions	Physics	Energy (MeV/u)	v/c %	γ Mult.	Eγ (MeV)	Energy Resolution	(H,K)	RIB Back G.	γ Vector	Auxiliary Detectors
Fragmentation beams	Coulex, knock out, soft dipole	>70	>25	few	<5	0.5-1%	-	-	y	Tracking, particle detectors
Capture, inverse	Astrophysics	1-4	<10	low	<3	~0.5%	-	-	y	Micro-channel plate (MCP), separator
Coulomb Excittaion:										
Inverse Kinematics	Collective properties	~4	7-10	1-15	<5	~0.3%	-	-	y	Particle detectors, MCP
Normal Kinematics	Collective properties	~4	2-4	1-15	<5	few keV	-	y	y	Particle detectors
Transfer Reactions:										
Inverse, heavy target	Single & multi-particle transfer	4-6	<10	<15	<3	~0.3%	y	-	y	Gas & Si det., MCP, separator
Inverse, light target	Single-particle transfer	<15	<20	<5	<3	~0.3%	y	-	y	Position sensitive Si, MCP, separator
Normal, light ion	Single-particle transfer	4-15	<3	<5	<3	few keV	-	y	-	Particle detectors
Normal, heavy ion	Single & multi-particle transfer	4-6	<7	<15	<3	few keV	y	y	y	Particle detectors
Fusion:										
Inverse Kinematics	Hi spin, decay tagging, p-rich	4-5	<10	<25	<4	~0.3%	y	-	y	Particle and neutron det., separators, plunger
Normal Kinematics	Hi spin, decay tagging, p-rich	4-5	<6	<25	<4	few keV	y	y	y	Mini-orange
Deep Inelastic Collisions:										
Inverse Kinematics	Hi spin, n-rich,	>5	<10	<25	<5	~0.3%	y	-	y	Particle detectors
Normal Kinematics	Hi spin, n-rich,	>5	<5	<25	<3	few keV	y	y	y	Particle detectors
Hot GDR	Giant Resonances	4-5	<6	<25	<25	-	y	-	-	Particle detectors
Decay Tagging	Particle unbound, isomerism	4-5	<6	<25	<3	few keV	y	y	y	Separator, variety of focal plane detectors

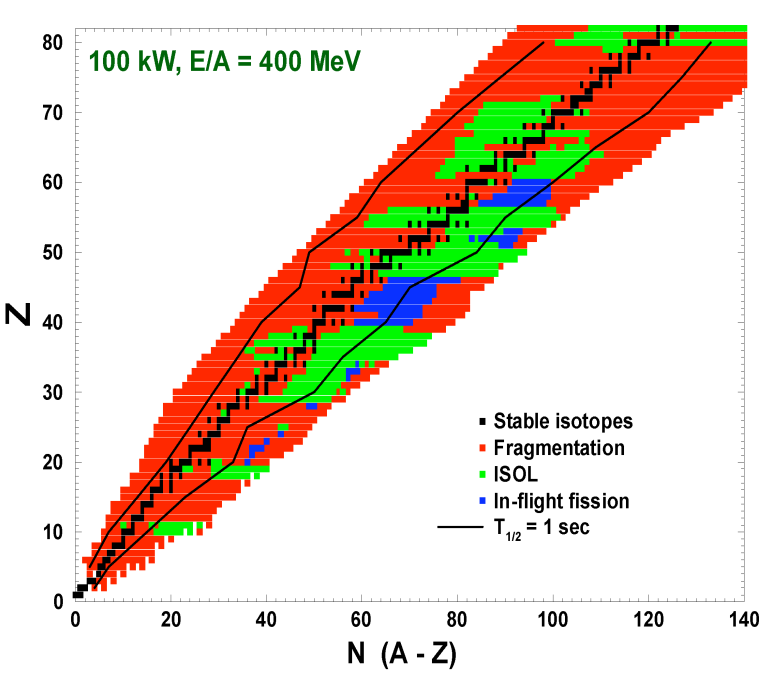
Important factors in gamma detection

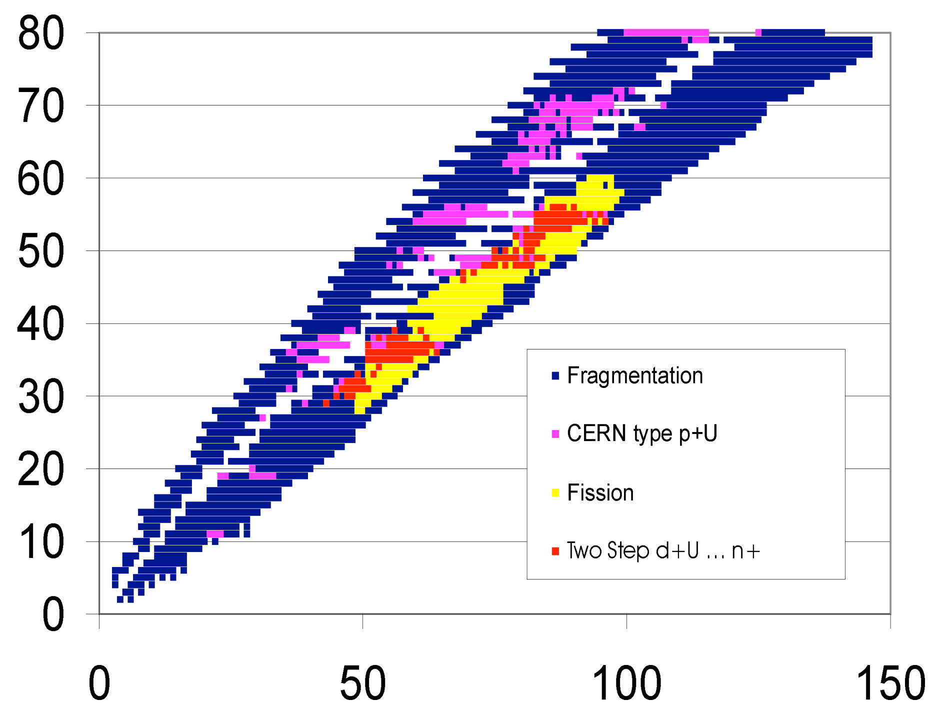
III. Special considerations for radioactive ion beams

- Beam intensity (2 to 8 orders of magnitude less than stable beams
    - impacts efficiency
- Isobaric impurity
    - Auxiliary detectors for Z-ID or beam assay
- Background (beta and gamma) due to decay of the stopped or scattered beams - worse for slow beams
    - Good beam quality and tune
    - Attention to kinematics & geometry
    - Good timing (coincidence) & hi count rate capability
- Usually inverse kinematics , v/c ~ 5-50%
    - Correct Doppler effects - worse for fast beams

Optimum production mechanism of beams @RIA includes both fragmentation and ISOL techniques.

Therefore, detectors should handle both beams even for the same physics.





ISOL Task Force Report: http://srfsrv.jlab.org/isol/

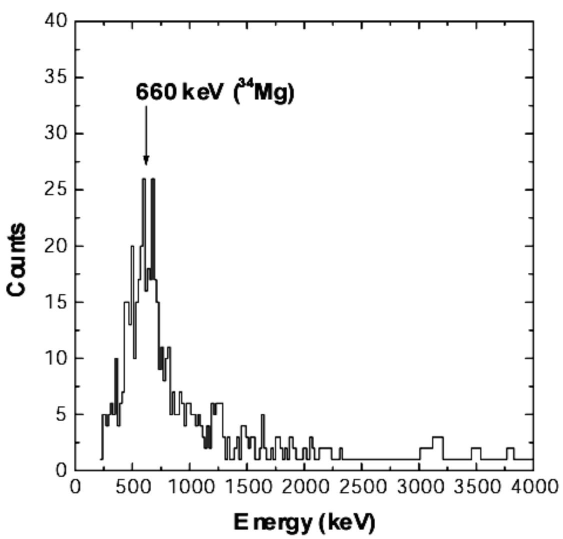
Coulomb excitation of radioactive ion beams
Two complementary methods:

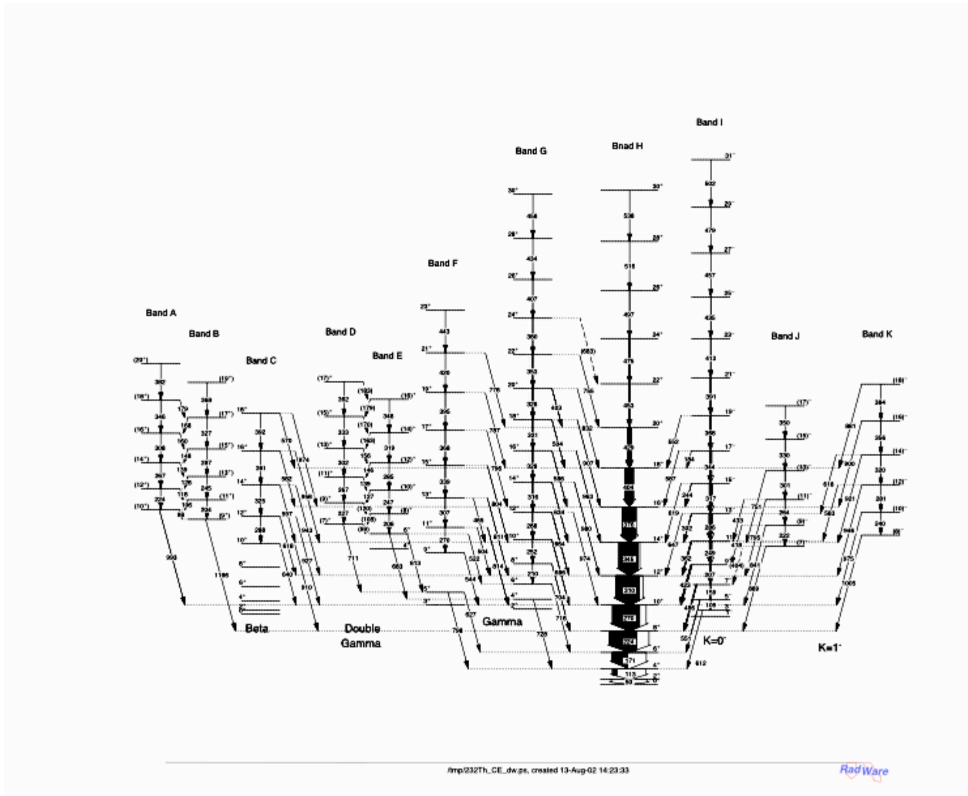
At intermediate energies:

- Uses thick targets, better yields
- One step process; Useful for excited levels connected to the ground state by an E2
- Extensively used at RIKEN, NSCL, & GANIL (^{32}Mg by Motobayashi *et al.*)

At Coulomb barrier:

- Uses "thin" targets (20-40 thinner)
- Multi-step process; can populate 4^+ & high-spin states
- Used at ORNL





Summary of important factors in gamma detection

Requirements are different depending on the physic, reactions & beams.

Therefore, a *general-purpose* detector should have:

- High efficiency
- High energy resolution
- Large dynamic range
- Large angular coverage (~ 4π)
- Good peak/total
- large pixellation to correct for severe Doppler effects in inverse kinematics
- Good timing
- Ability to accommodate different auxiliary detectors (modular, portable, large cavity)

Solution

- A ~ 4 Tracking Detector satisfies nearly all of above requirements
(See report of the Gamma Ray Tracking Coordinating Committee)

- GRETA design meets these needs

GRETA Staged Performance

Type of Reaction	<E > (MeV)	v/c	M_	Resolving Power	Staging Relative Factor (Relative to Gammasphere)					
				_x = 2 mm _=80%	1/4		1/2		3/4	
1) Stopped 2)	5.0 1.5	0.0 0.0	4 4	2.1×10^7 4.4×10^7	.02 .02	4 1.5	.10 .11	20 9	.35 .34	70 28
3) High-spin Normal Kinematics	1.0	0.04	20	2.4×10^6	.015	0.8	.08	4.5	.31	17
4) High-spin Inverse Kinematics	1.0	0.07	20	2.2×10^6	015	1.8	.08	10	.30	36
5) Coulex/transfer	1.5	0.1	15	3.7×10^6	.015	8	.09	47	.31	160
6) Fragmentation	1.5	0.5	6	5.9×10^6	.008	100	.06	730	.25	3080
7) In beam Coulex 8)	5.0 1.5	0.5 0.5	2 2	$2.7 \text{ X } 10^3$ 4.1×10^3	.41 .62	45 30	.60 .75	66 38	.77 .85	85 43

- However, the full research program at RIA needs more than just one general purpose detector.

- At the HRIBF, nearly 2/3 of the beam time is used for experiments that require gamma detection.

- Improving gamma detection capabilities of RIA is the most cost effective way to increase the number of experiments and total physics output of the facility.

Therefore, we also need several other *specialized* and *less expensive* detectors.

Two examples:

1. Medium-resolution, highly efficient arrays for, e.g., giant resonance studies. (BaF2, new scintillators?)

2. High-resolution, compact arrays for decay spectroscopy:
   □-□, □-charged particle, □-n
   Hybrid detectors offer a good solution.
   - Segmented planar Ge + segmented Clover (GREAT), or
   - Segmented Si(Li)+ segmented Clover in one cryostat to detect x-ray, beta and gamma in one package.