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The Region of High-Level Density in ^{95}Mo

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Outline

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i. NIF and high-level density nuclear science (Lee).

ii. Experimental approach to study the region of high-level density in ^{95}Mo.
   i. STARS-LIBERACE
   ii. Reaction selection
   iii. Gating technique

iii. Experimental results.
   i. Proton and Gamma spectrum
   ii. Feeding

iv. Examining the nuclear structure of ^{95}Mo.

v. Discrete level structure of ^{95}Mo.

Quasi-Continuum and NIF

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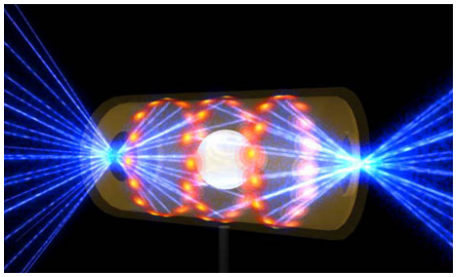
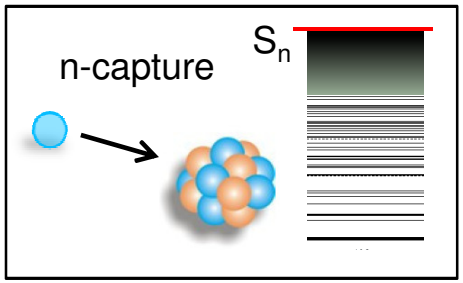


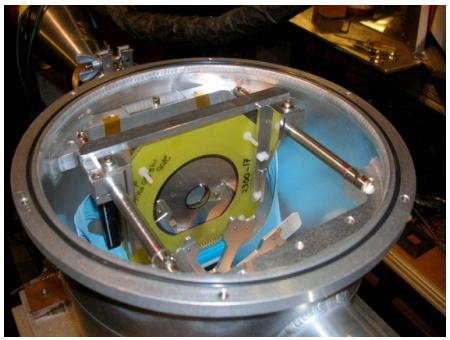
NIF exposes nuclei to astrophysical environments.

Great opportunity but to understand data we need to know some nuclear properties.

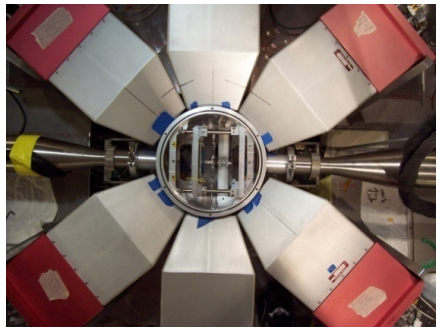
We need statistical decay, statistical model calculations, and discrete level structure.



- Studying the region of high-level density (decay/ lifetimes) as an integral part to understanding NIF data and astrophysical processes.
- Use STARS-LIBERACE array to measure feeding of discrete states from continuum by varying spin and excitation energy.



Charged particle detection with large area segmented silicon detectors.



γ-radiation detected with Clover HPGe detectors.

Experimental Approach

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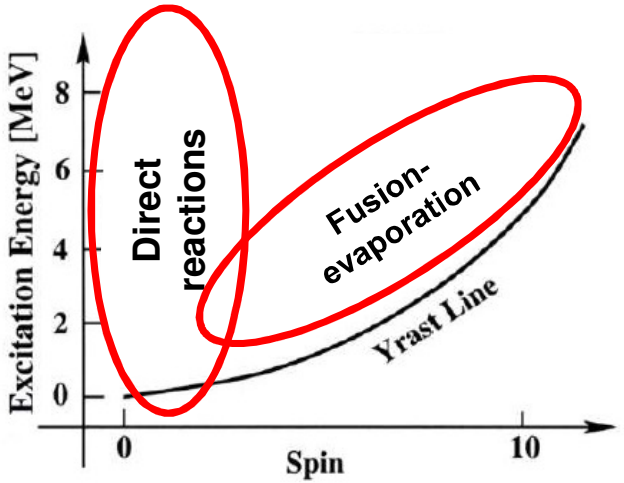
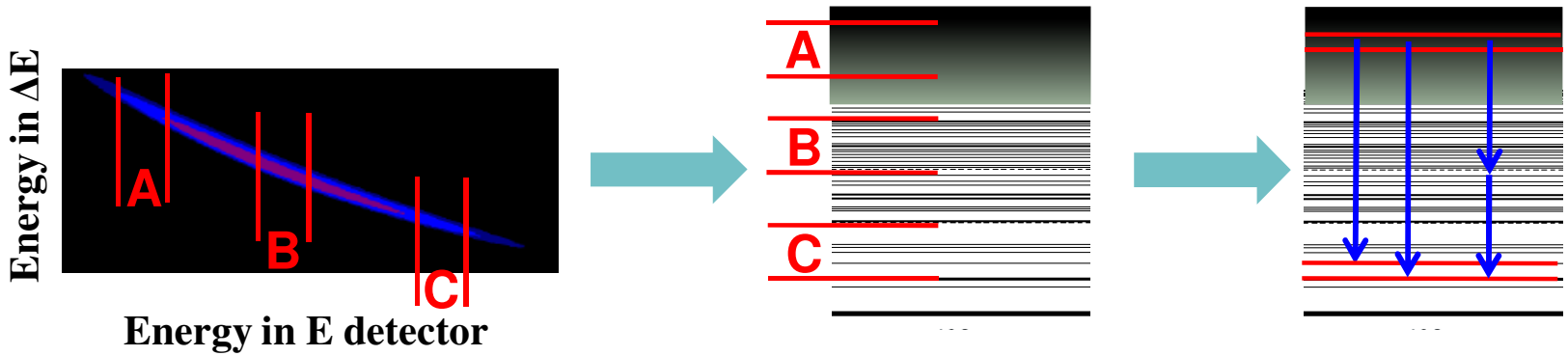
Use direct reactions to populate states with high excitation energy away from yrast line rather than fusion-evaporation which follows along the yrast line.



Charged particles will be used to specify entrance excitation energy into the system and γ -rays in coincidence are studied e.g feeding, lifetime.



Experimental setup

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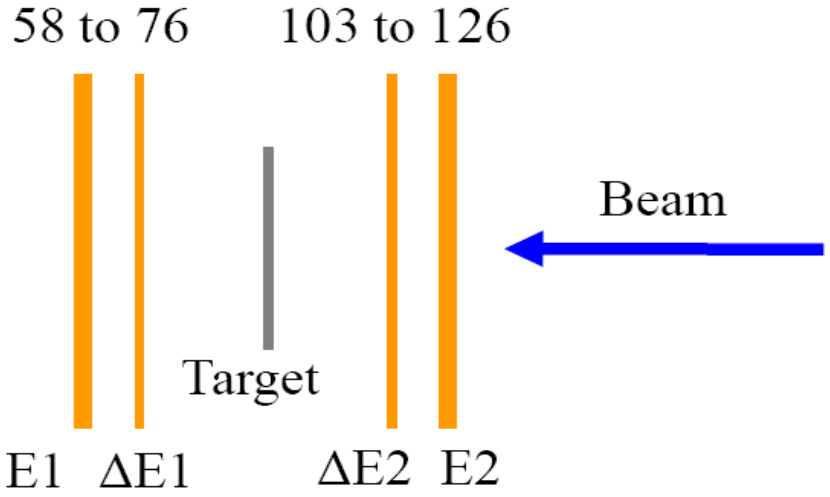
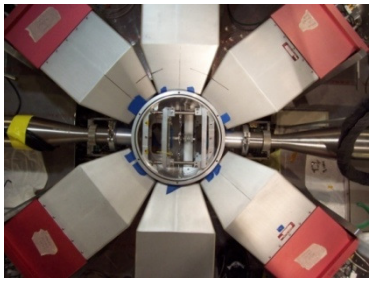
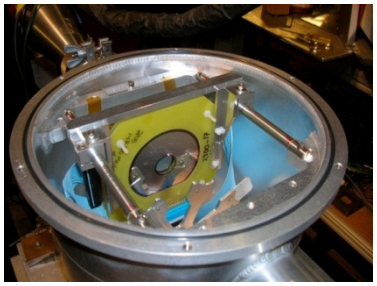
- $^{94}Mo(d,p)^{95}Mo$ at 11 MeV.
- Thin target ^{94}Mo ~100 µg/cm^2.
- 5 Clovers: at 140, 90, and 40 degrees.
  → high resolution spectra.
- 2 particle telescopes with an angular coverage of 28° to 56° and 118° to 145°.
- Gamma energy between 0 to ~8 MeV.
- For efficiency calibration use $^{12}C(d,p)$ with 3.7 and 3.9 MeV and $^{13}C(d,p)$ with 6.1 and 6.6 MeV transitions.
- Gamma-gamma, particle-gamma, particle-gamma-gamma, and particle singles.







$^{94}Mo(d,p)^{95}Mo$: protons

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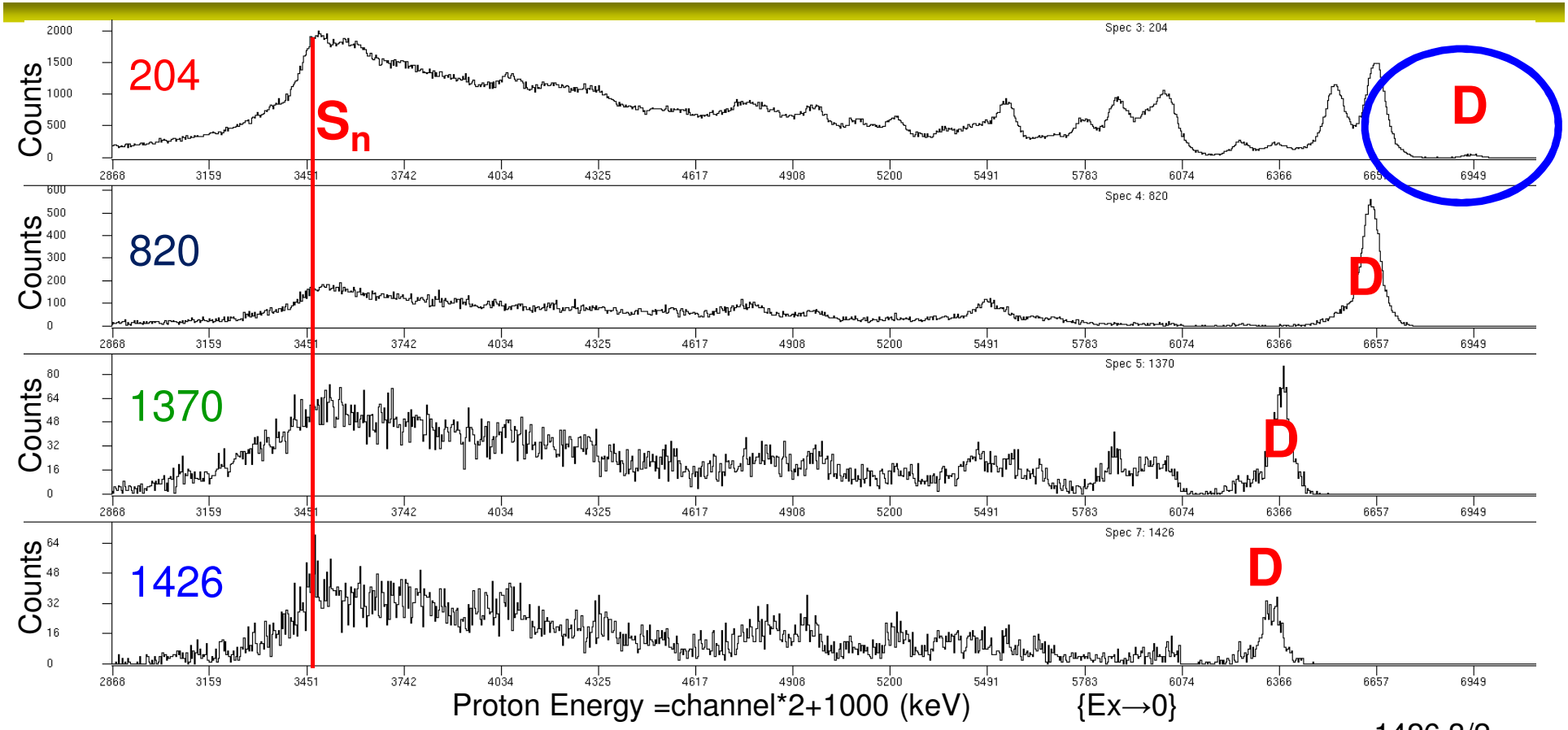
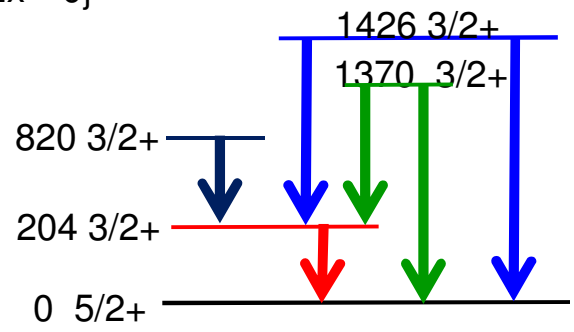


Gamma gated proton spectrum.
All are gated on 3/2⁺ levels.
Note reduced direct populated to the 204 level.



S_n and Spin

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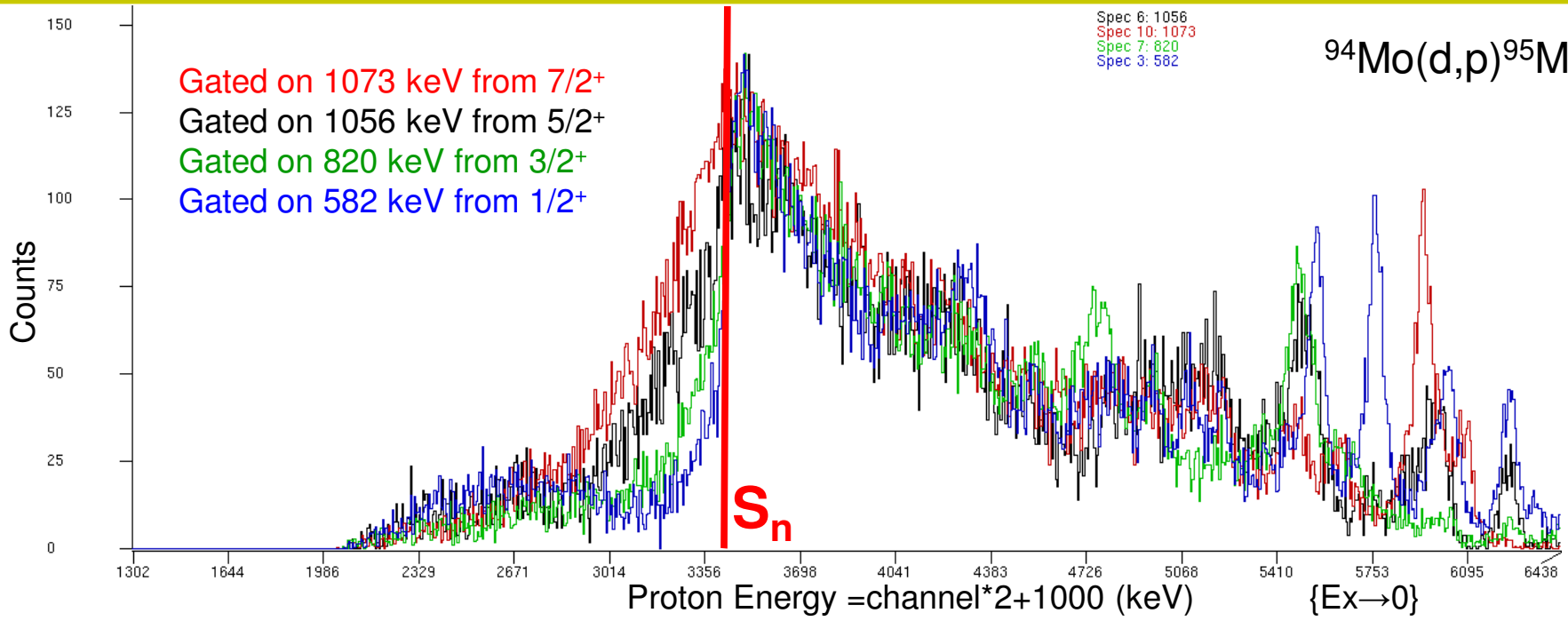

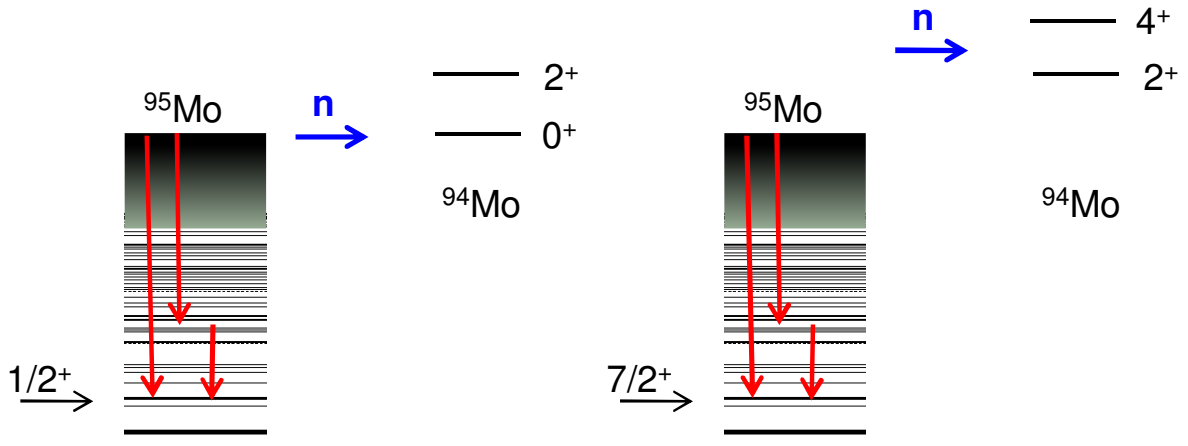

Need to find appropriate spin to release neutron.
Most decays are E1
Average multiplicity 2-3
S.A. Sheets PRC 76, 064317 (2007).

Used this to determine spins of some discrete states.

Feeding information

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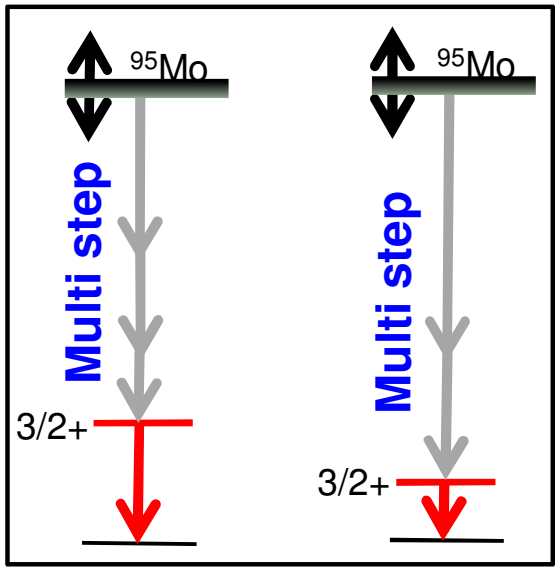
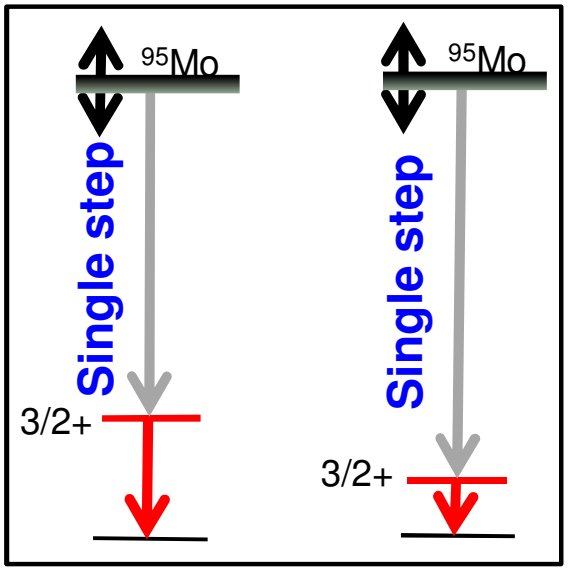
- Study feeding to different discrete states by gating on discrete gamma transitions
- Originate from same excitation energy region → from the same level density.
- Study the feeing by varying the entrance excitation energy and discrete level i.e. spin.
- Scanning is accomplished event by event. 800 keV binning is performed afterwards.
- Correct for efficiencies, $(Ex\text{-}E_\gamma)^3$
- Take ratios: These are independent of cross section, spin distribution, level density…
- Have $4x3/2^+$, $2x9/2^+$, $2x7/2^+$, $2x1/2^+$, $2x5/2^+$ states to take ratios in ^{95}Mo.

Multi/Multi: different states



Single/Single: different states



$^{94}Mo(d,p)^{95}Mo$: G.S. gammas

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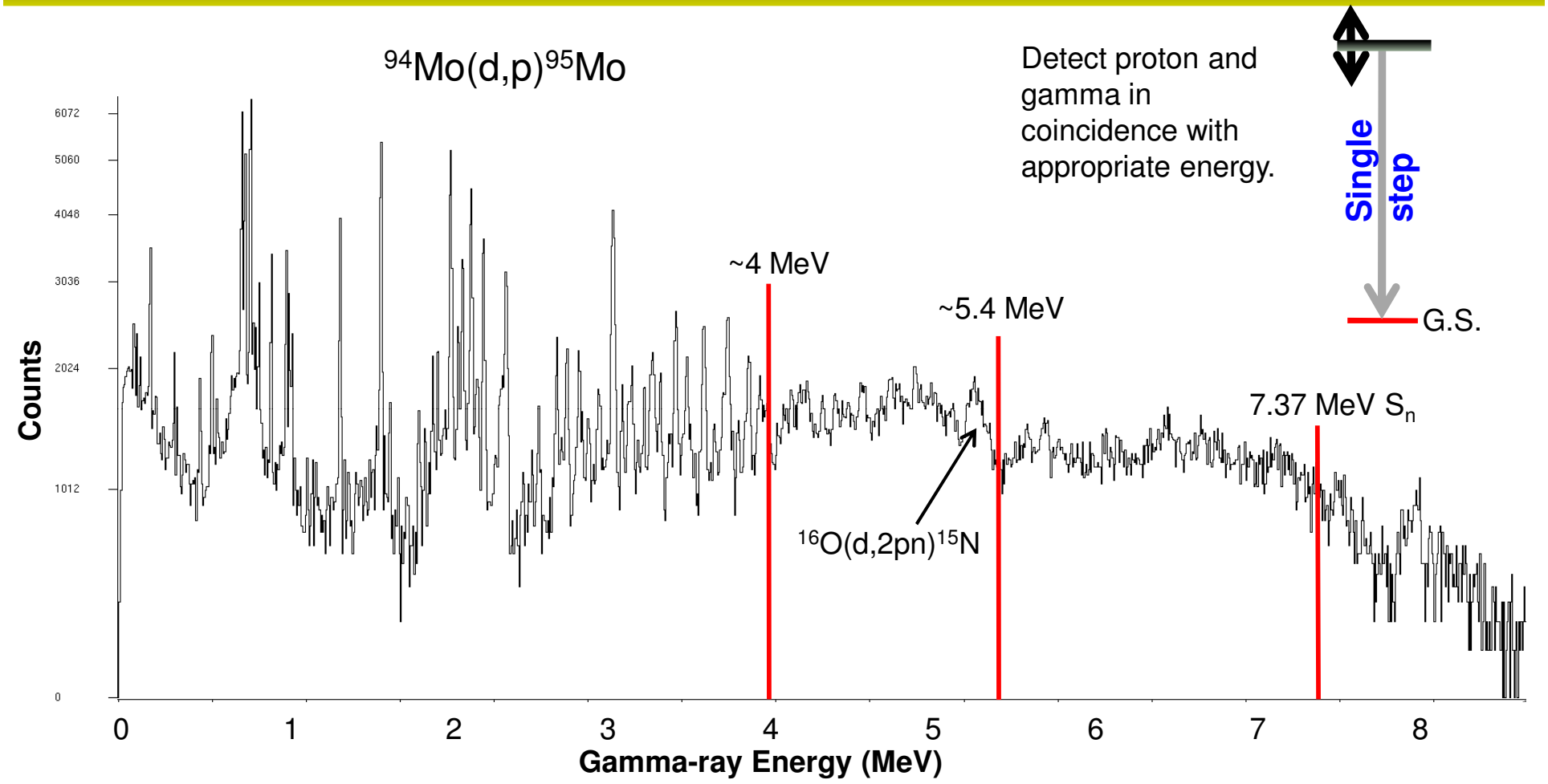

Focus on excitation energy region between 4 and 7.37 MeV (S_n) to study feeding to discrete levels.

Multi step feeding: ^{95}Mo

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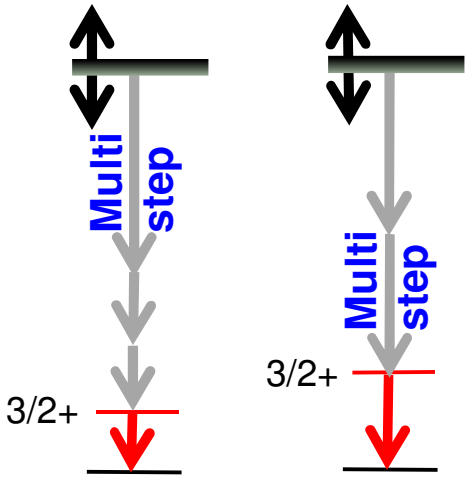

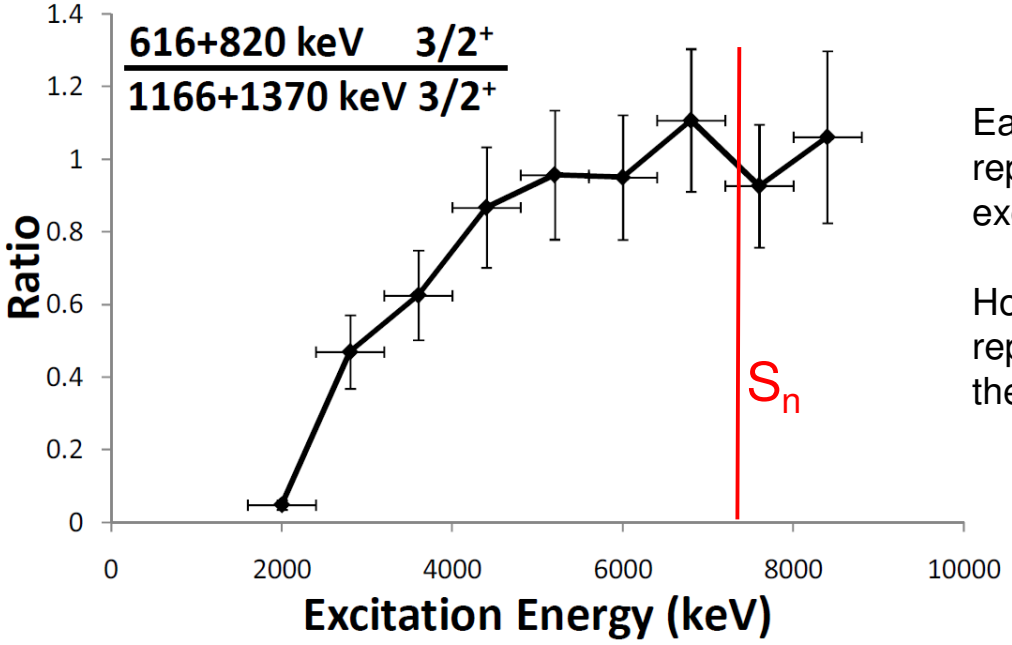

Each ratio point represents an excitation energy bin.

Horizontal error bars represent the width of the bins.

Level1	Level2	Spin	Ratio >4MeV
820	1370	3/2	~1

Multi step feeding: ^{95}Mo

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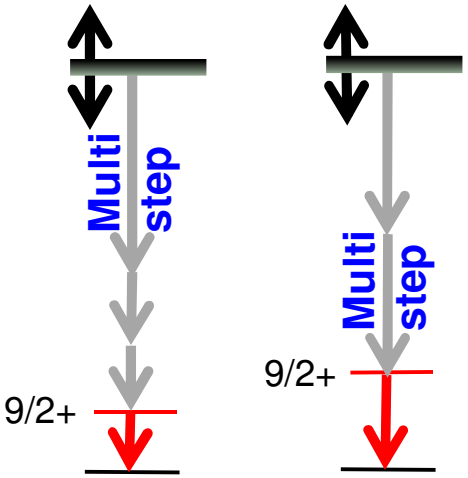
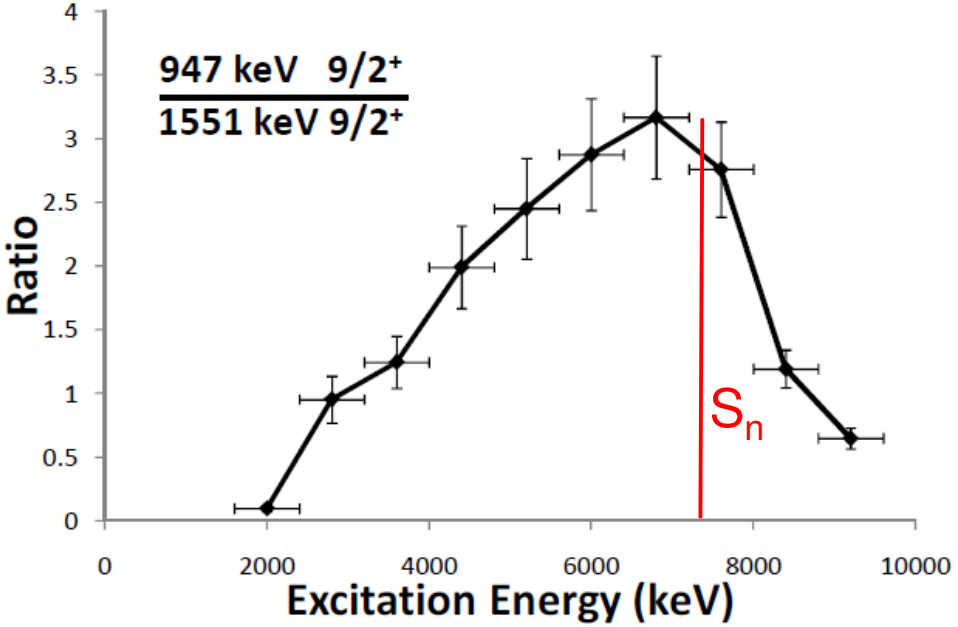
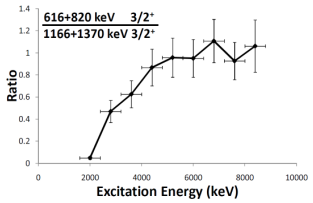
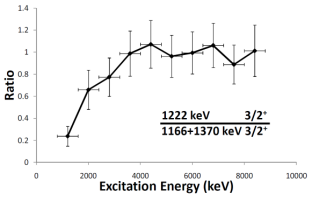
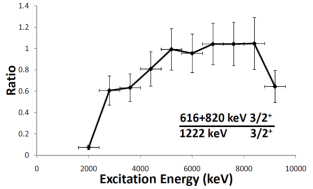
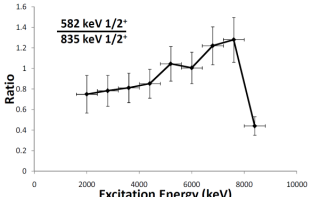




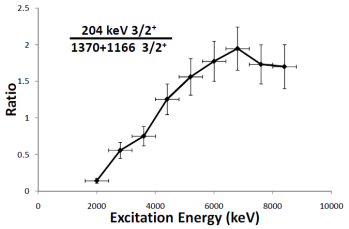


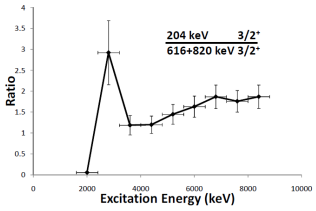


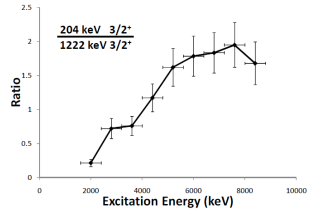




Level1	Level2	Spin	Ratio >4MeV
820	1370	3/2	~1
1426	1370	3/2	~1
820	1426	3/2	~1
786	1039	1/2	~1
204	1426	3/2	~1.7
204	820	3/2	~1.7
204	1370	3/2	~1.7
947	**1551**	**9/2**	**~2.5**







Single step feeding

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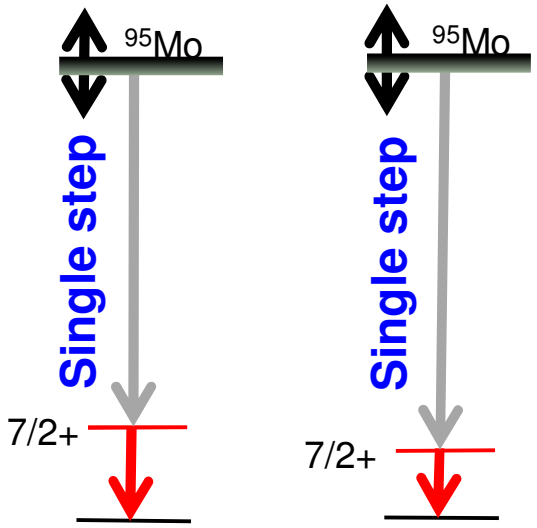

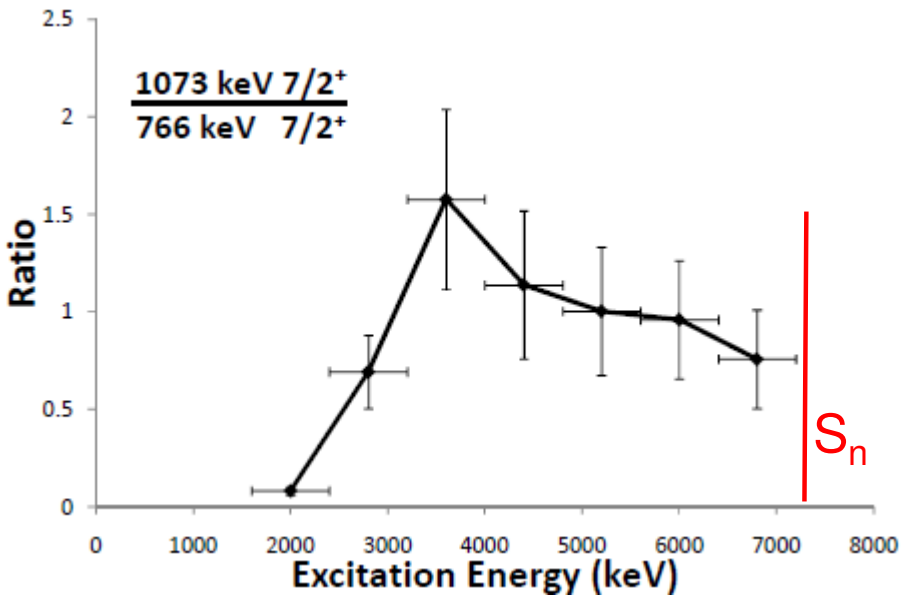

Level1	Level2	Spin	Ratio ~1
1073	766	7/2	>4 MeV

Single step feeding

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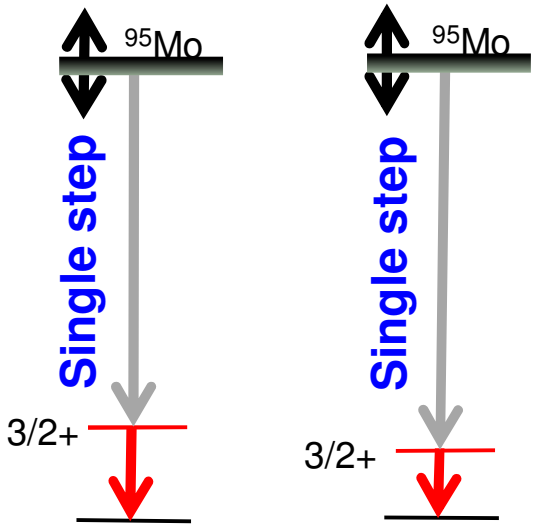

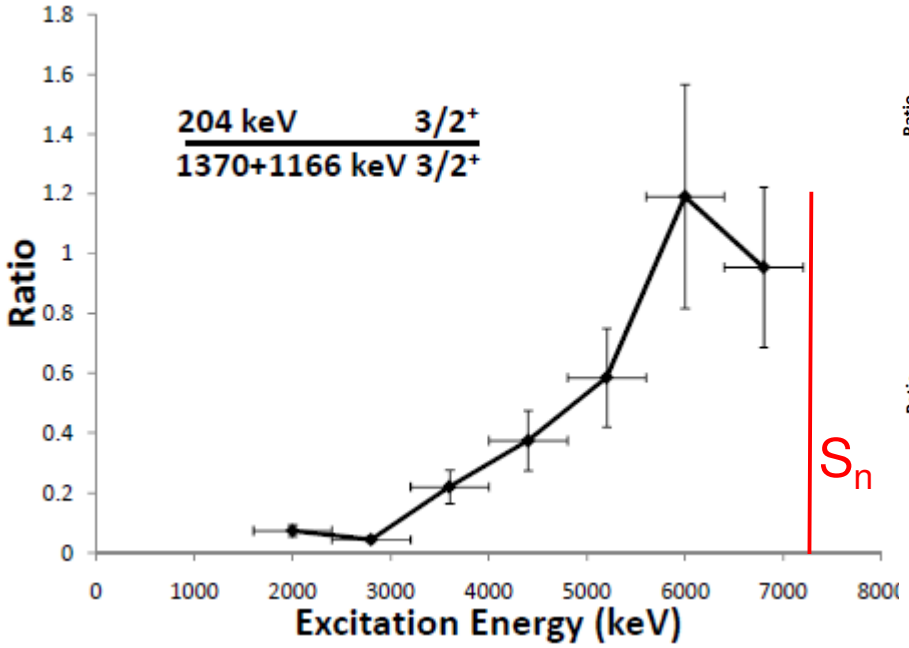

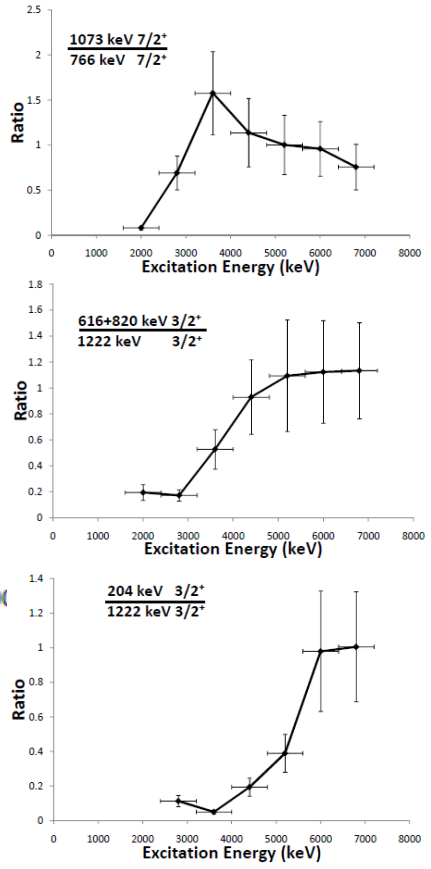

Level1	Level2	Spins	Ratio ~1
1073	766	7/2	>4 MeV
820	1426	3/2	>4 MeV
820	1370	3/2	>4 MeV
1426	1370	3/2	>4 MeV
1039	786	1/2	>4 MeV
947	1551	9/2	>4 MeV
204	1426	3/2	>6 MeV
204	**1370**	**3/2**	**>6 MeV**

^{95}Mo: Structure details

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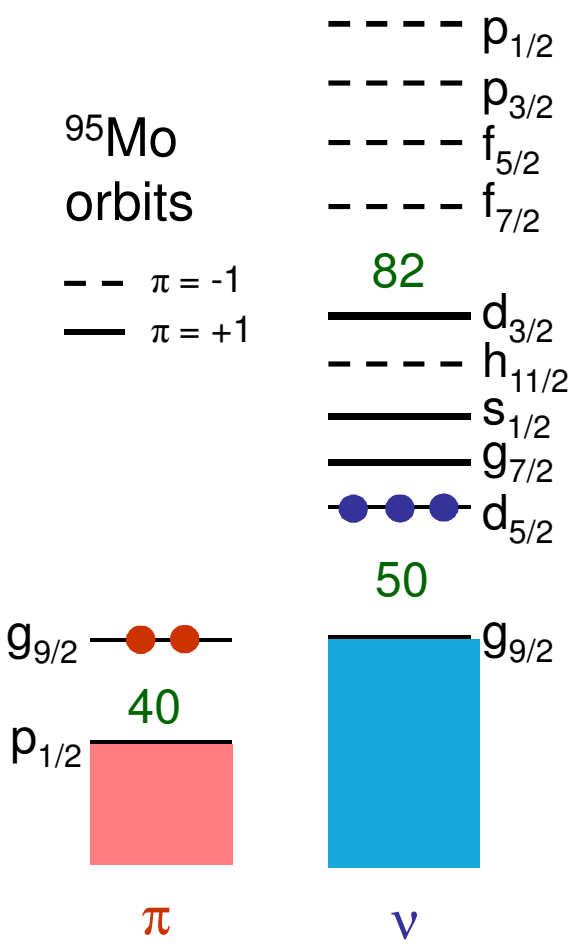
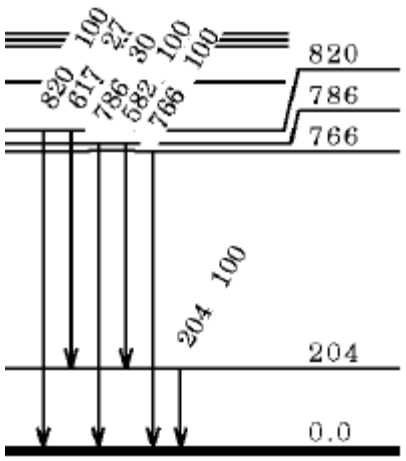


- Assumption: The region of high-level density decays by E1 transitions only.
- Only gated positive-parity discrete levels are used.
- Single step feeding sensitive to negative-parity levels populated in the (d,p) reaction only i.e. the neutron enters the ^{95}Mo system via the negative-parity orbits $p_{1/2,3/2}$, $f_{7/2,5/2}$, $h_{11/2}$
- Also the spin window is defined by the gated discrete level.
- For multi step feeding these statements cannot be made.

Spin construction from $d_{5/2}$ neutrons: $5/2^+$,$3/2^+$, and $9/2^+$
G.s., first-excited state at 204 keV, and the first $9/2^+$ level at 947 keV are pure $d_{5/2}$ neutron configurations [1].
Other levels involve higher-lying orbits and have mixed configurations.



Does the feeding from high-level density differentiate between mixed versus pure discrete configurations?
(J. Escher, M. Krtička)

[1] P. Da R. Andrade et al, Nucl. Phys. 77, 298 (1966).

DICEBOX

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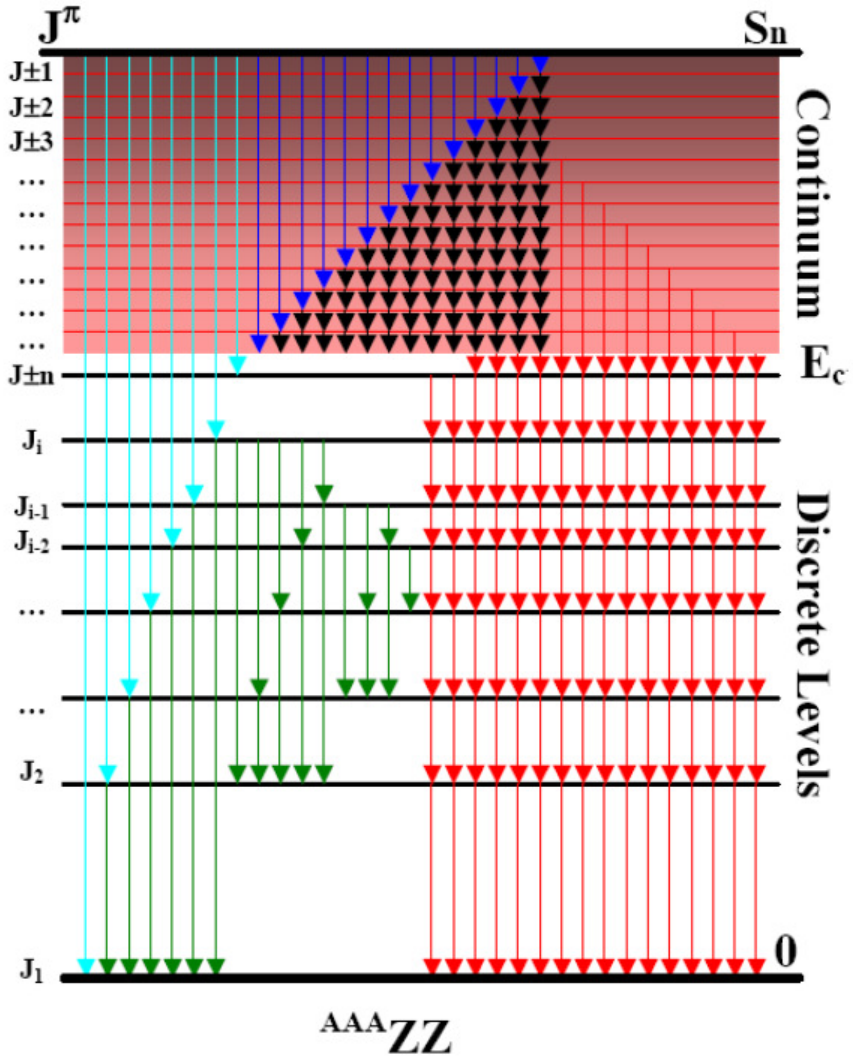
- Feeding results are currently compared to DICEBOX model calculations (M. Krtička).
- Monte Carlo Statistical gamma decay code
- Levels and gammas above cutoff energy are randomly generated (statistically) based on level density (CT,BSF) and photon strength function (BA,KMF,GLO,SP,SF) models.
- Input of lower levels below a cutoff energy.
- For calculations a complete knowledge below cutoff energy necessary:

→ Discrete level energy, spin, parity.

→ Decay properties of level

- We need good knowledge of lower levels from experiments.
- Mo seems great – has been studied in detail

→ double check.



R.B. Firestone, Isotope Project, LBNL

^{95}Mo Level Scheme

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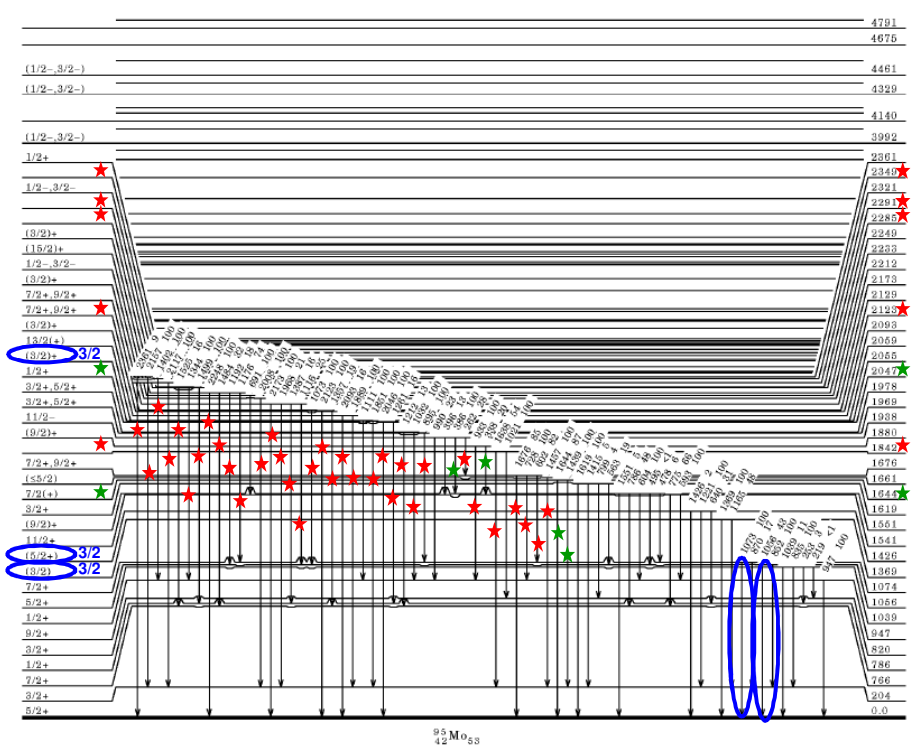

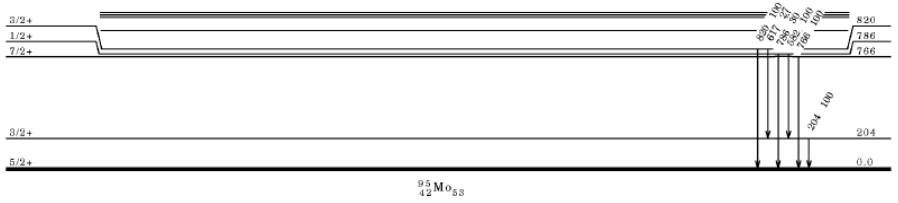

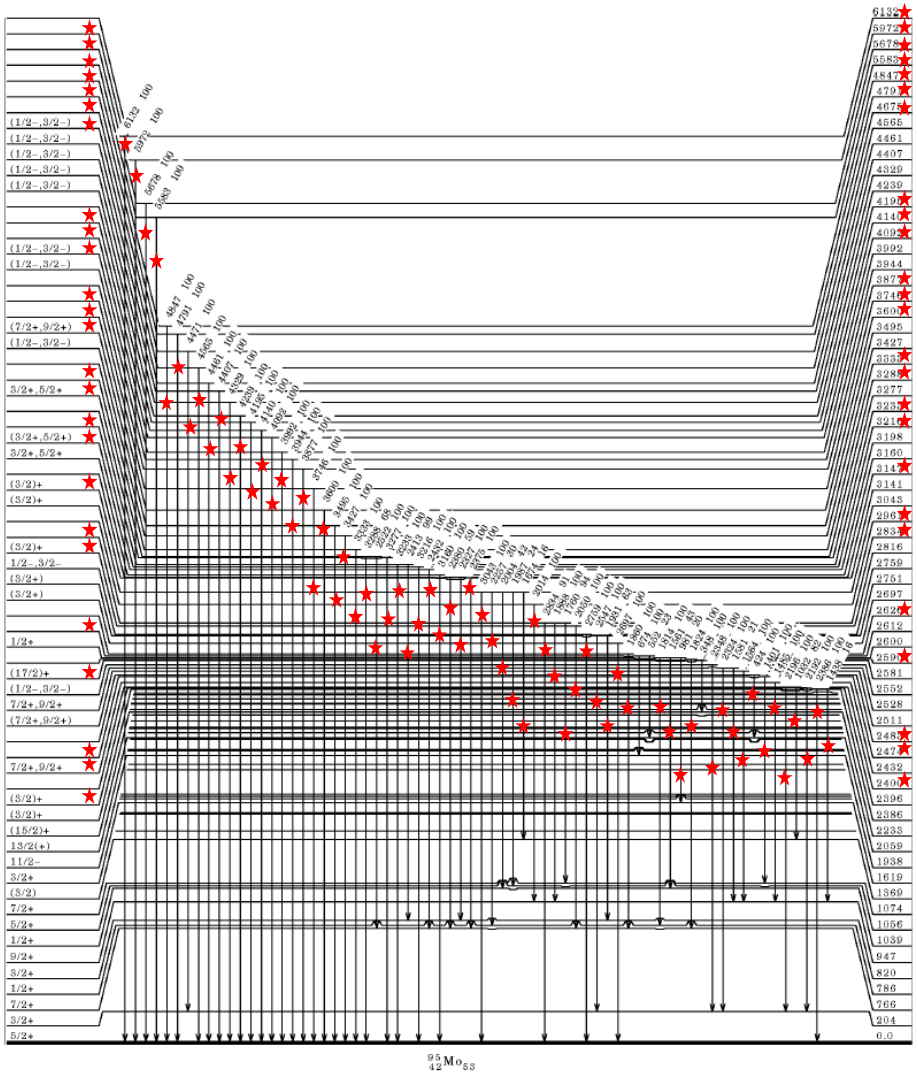

28 new states, 99 new transitions, 2 states confirmed, 4 transitions confirmed,
3 spins confirmed/corrected, 2 low energy decay properties significantly different.

Summary

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i. The quasi-continuum and how it is explored experimentally using the STARS LIBERACE array and gating technique.

ii. Characterization of feeding from the quasi-continuum to discrete states in ^{95}Mo by looking at ratios of M/M, and S/S.

iii. Generally, the relative feeding to discrete levels indicates feeding of the same strength without fluctuations.

iv. Exceptions are the 204 keV (947 keV) state which exhibits different feeding strengths compared to other levels of the same spin.

v. The feeding from the region of high-level density to a discrete level seems to depend on the mixing/purity of the discrete configuration.

vi. Be cautious when using data bases for the discrete level structure.

Collaborators

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