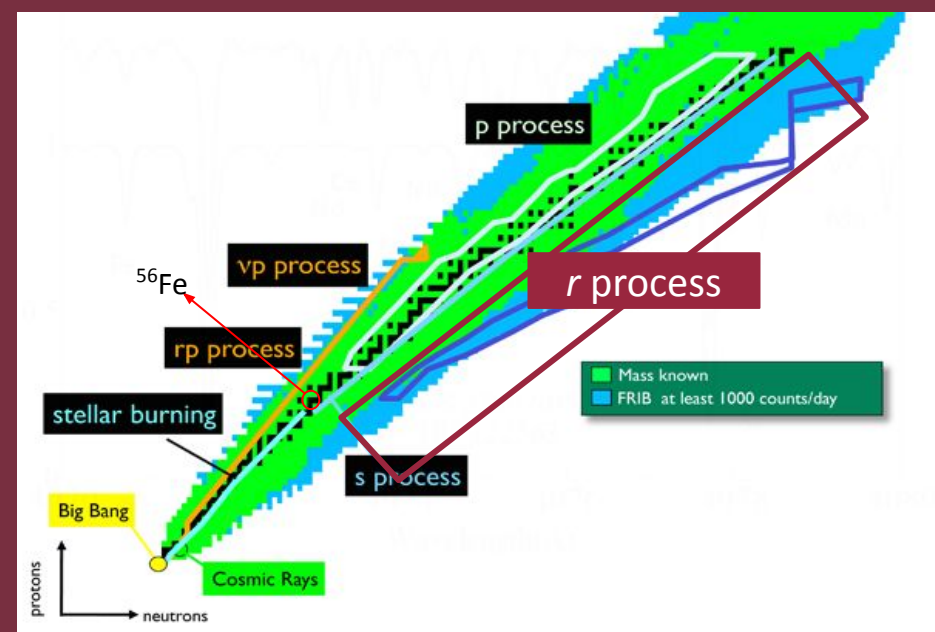


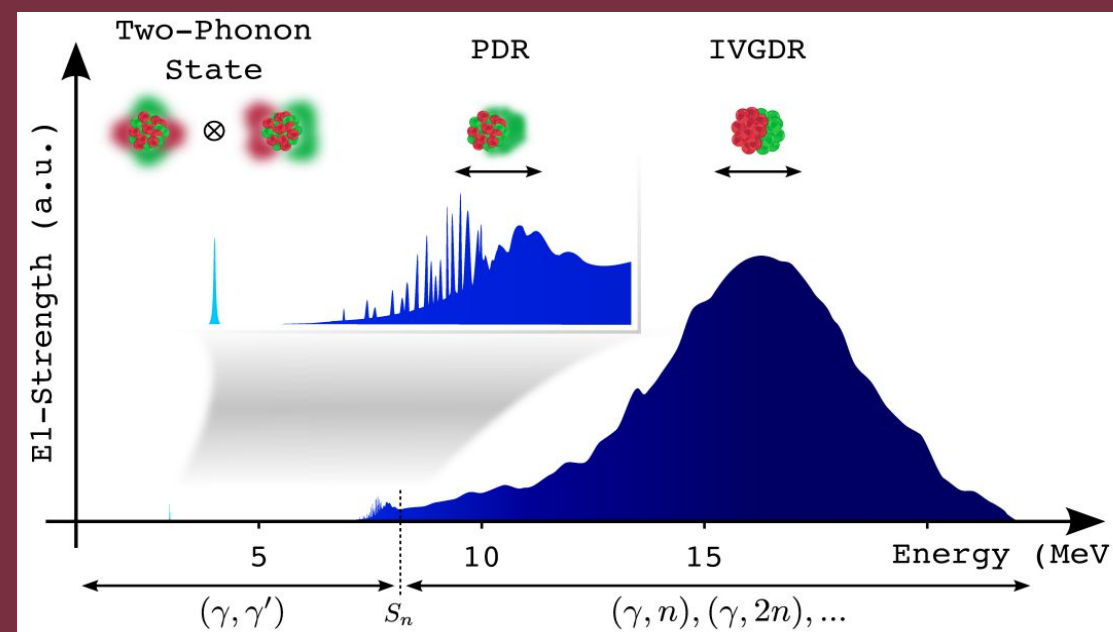
Studying Low-Lying E1 Strength & Neutron Capture Rates in $A \approx 50$ Nuclei via Surrogate Reactions

Bryan Kelly, Scott Baker, Alex Conley, Dennis Houlihan, Ramiro Renom, Mark-Christoph Spieker

I. Role of E1 strength in nucleosynthesis

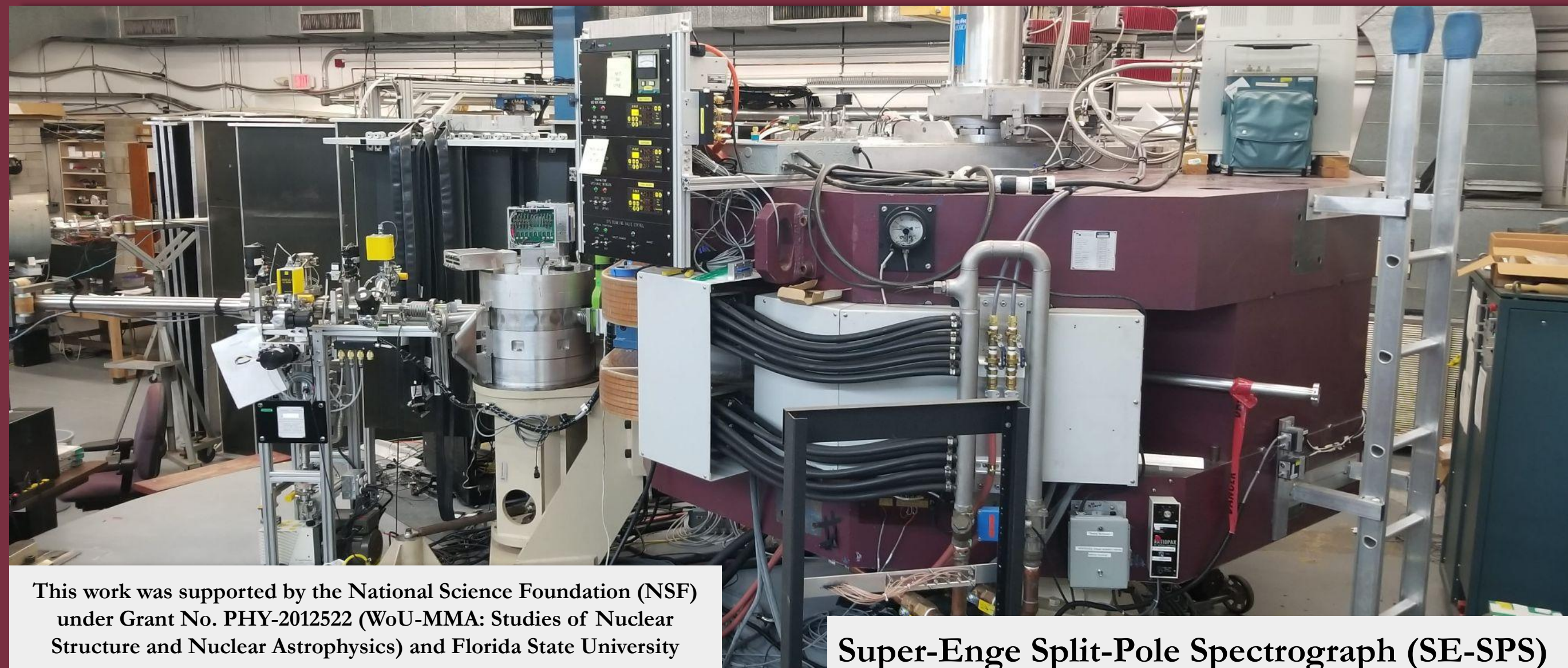


Astrophysical processes on nuclear chart [1].



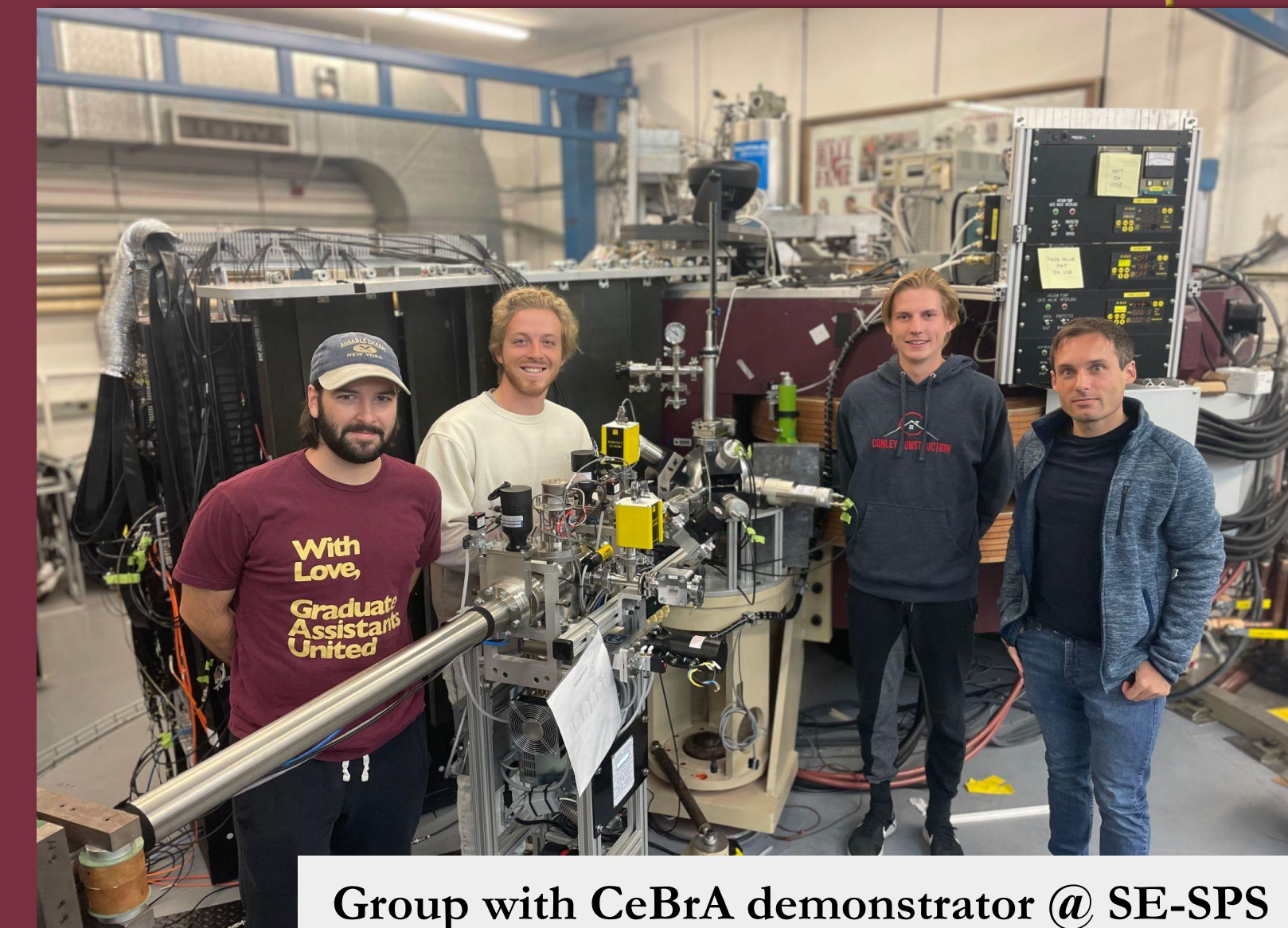
Electric dipole (E1) response in atomic nuclei [2].

- E1 strength impacts (n, γ) capture rates in s and r process, influencing the abundance pattern of heavy elements.
- As part of E1 response, the Pygmy Dipole Resonance (PDR) is observed around neutron-separation energy, S_n .



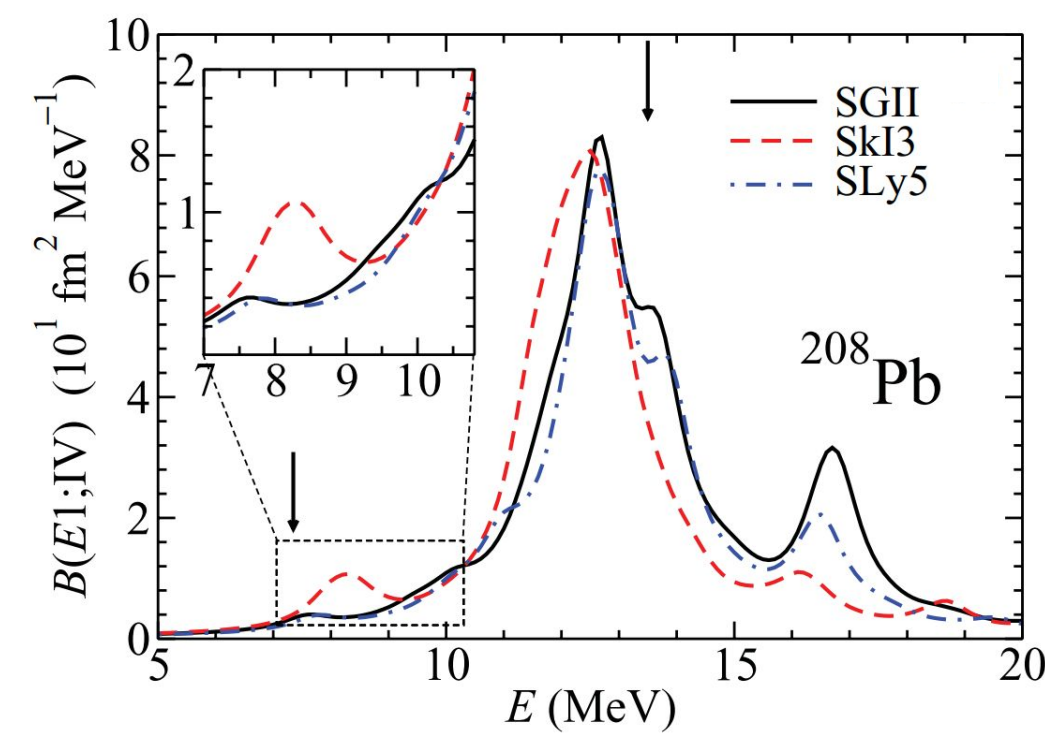
This work was supported by the National Science Foundation (NSF) under Grant No. PHY-2012522 (WoU-MMA: Studies of Nuclear Structure and Nuclear Astrophysics) and Florida State University

Super-Engel Split-Pole Spectrograph (SE-SPS)



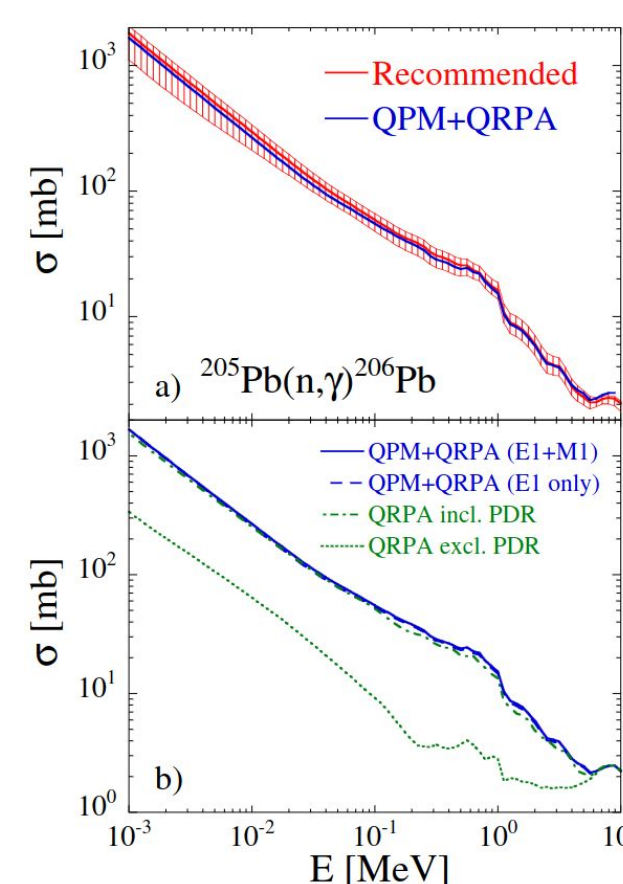
Group with CeBrA demonstrator @ SE-SPS

II. Influence of the PDR on capture rates



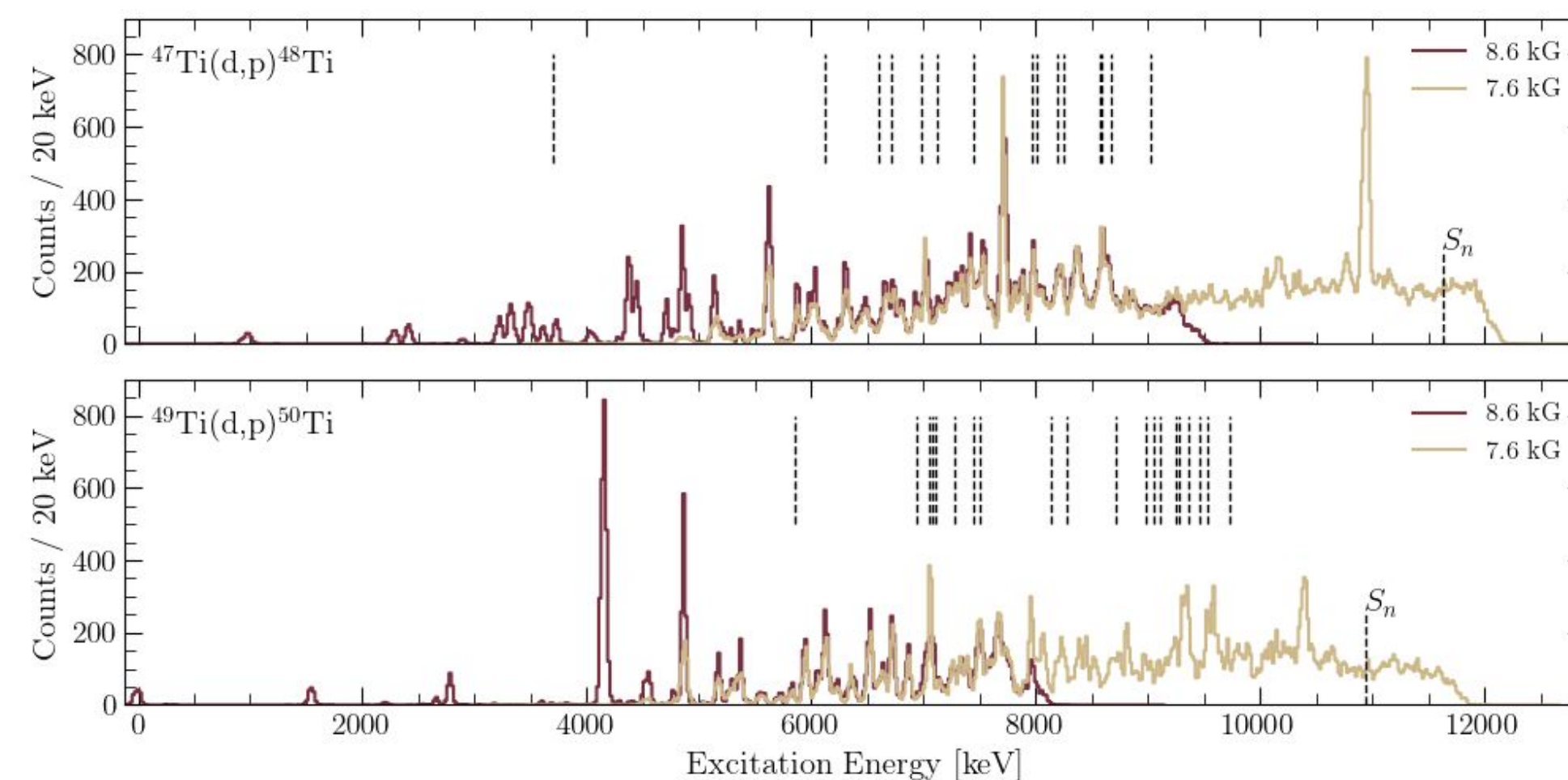
Isovector electric dipole response for ^{208}Pb predicted by different models [4].

- Strong model dependency observed.
- Can we reliably predict influence of E1 response on (n, γ) rates.



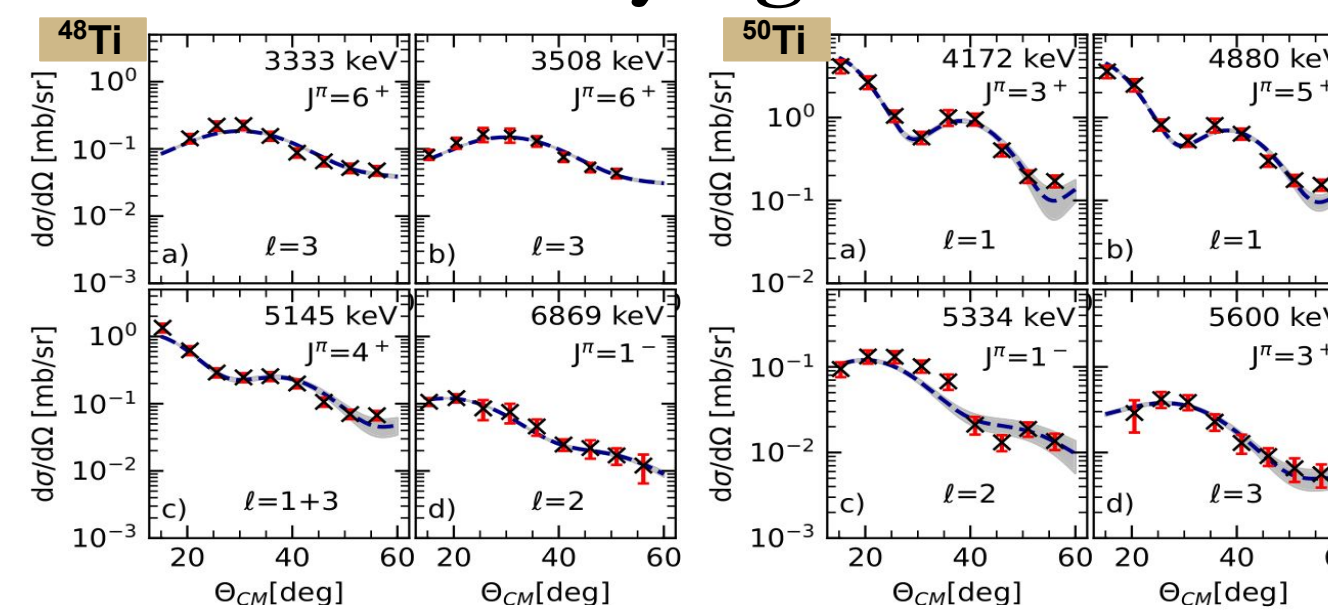
a) Comparison of (n, γ) cross sections (red-hatched) with QPM+QRPA predictions (blue). b) Contributions of E1+M1, E1 only, and PDR contributions to the overall (n, γ) cross section [3].

IV. Studying the $A \approx 50$ region @ John D. Fox Lab

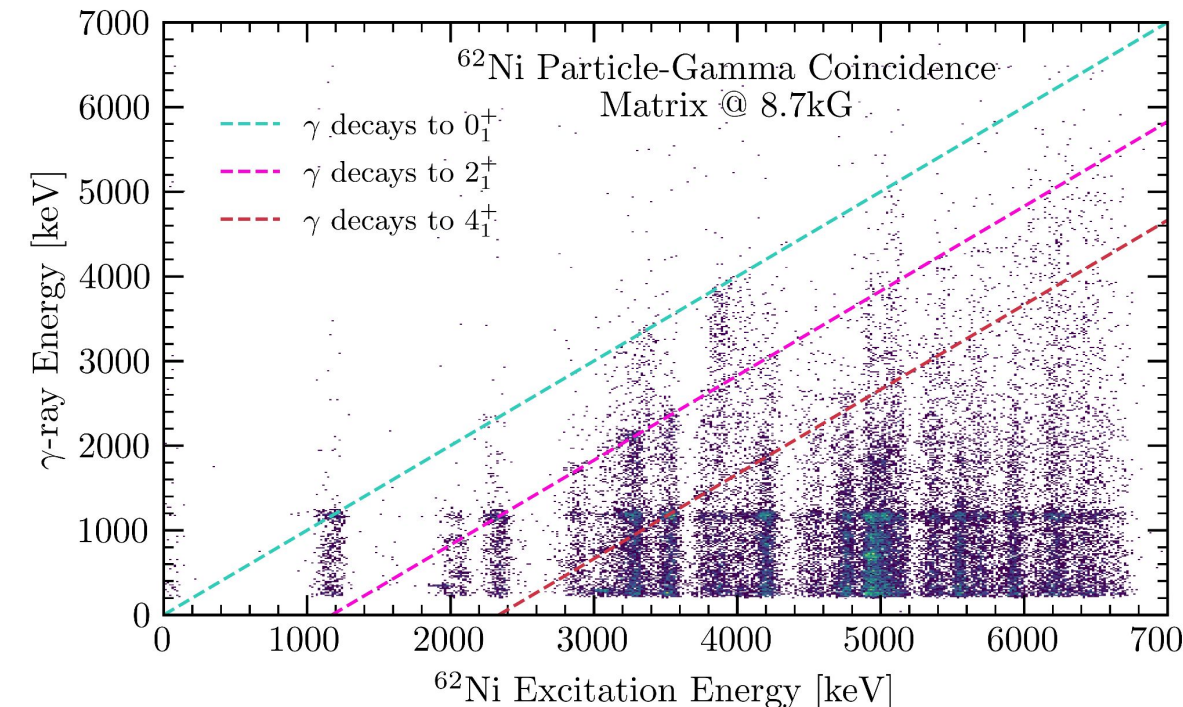


Proton-energy spectra for $^{48,50}\text{Ti}$ using the Super-Engel Split-Pole Spectrograph (SE-SPS) @ $\theta_{\text{SPS}} = 25^\circ$, measured for two different magnetic field settings. Potential PDR states seen in $^{48,50}\text{Ti}(d, p)^{A+1}\text{Ti}(\gamma, \gamma')$ are shown with vertical dashed lines [7]. Neutron-separation energies are also shown.

V. Identifying PDR states Experimentally



Angular distributions (symbols) measured for $^{47,49}\text{Ti}(d, p)^{48,50}\text{Ti}$ with the SE-SPS. ADWA calculations (lines) are scaled to data. The orbital angular momentum transfer is determined by comparison. This comparison also determines the parity quantum number for the populated excited state.

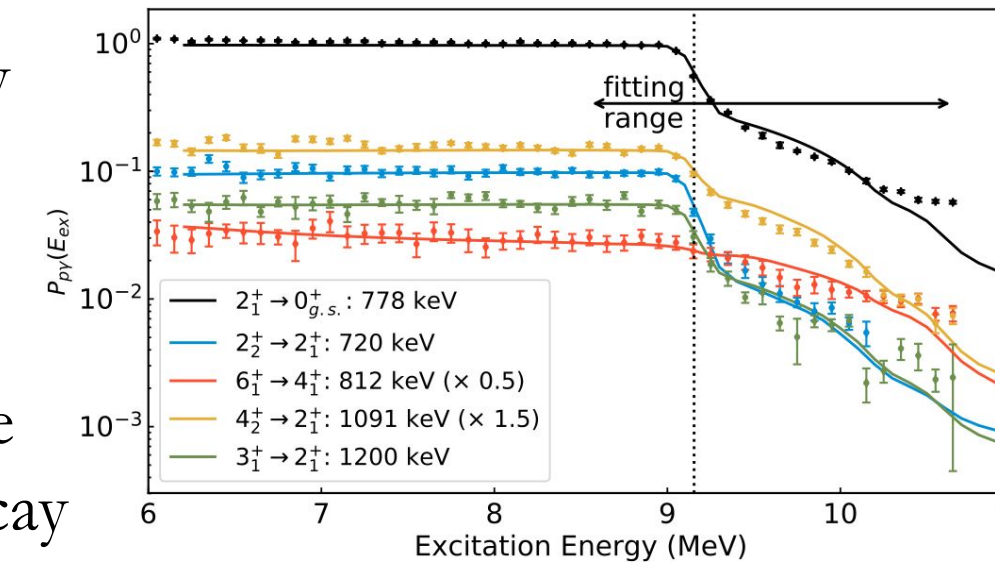


$^{61}\text{Ni}(d, p)^{62}\text{Ni}$ p- γ coincidence matrix. Diagonal lines correspond to $E_x = E_\gamma + E_f$ where transitions along each corresponding line full energy decay to the final state, E_f , at which the line intercepts the x-axis.

- Use diagonal bands as selective spin filters in identifying PDR states and for studying γ SF

VI. The use of γ coincidences to study structure

- Coupling of the SE-SPS with a newly commissioned γ -ray array, CeBrA.
- Particle- γ coincidences guide spin-parity assignments.
- Gain insight into nuclear structure (e.g. multipole mixing ratios, γ -decay intensities, etc.)
- Single-particle structure can be further investigated via γ decay of PDR states.
- γ -ray emission probabilities, P_γ , will provide further constraints on γ SF and thus (n, γ) cross sections.

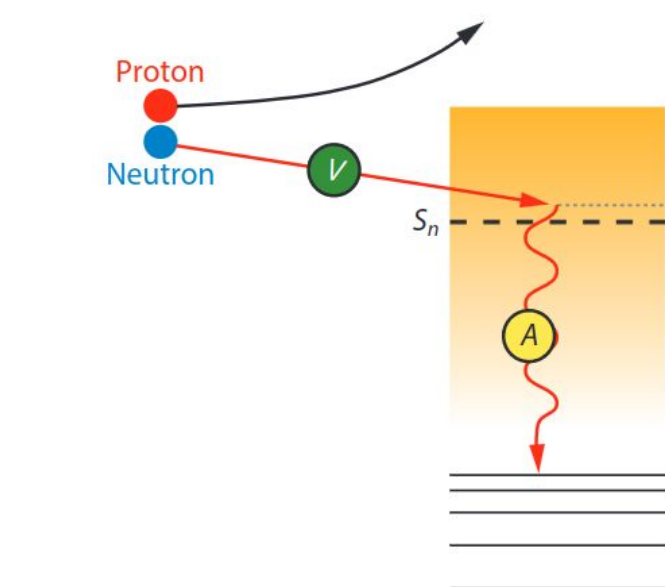


γ -ray emission probabilities for the $^{95}\text{Mo}(d, p)^{96}\text{Mo}$ reaction [8]. Similar work will be performed for $^{61}\text{Ni}(d, p)^{62}\text{Ni}$.

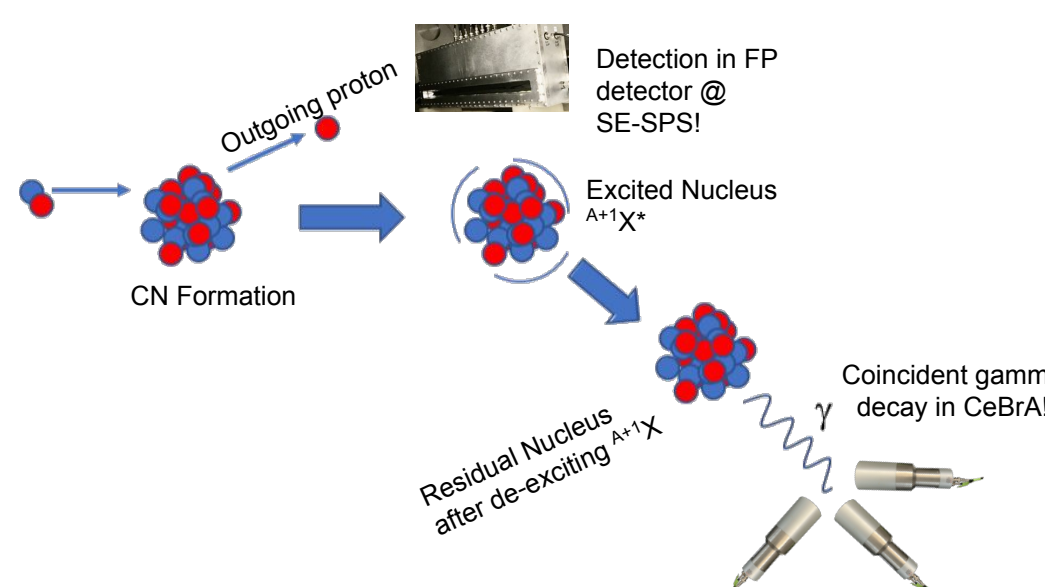
- Constrain γ SF by statistical fitting to replicate observed γ -ray emission probabilities

III. Indirect (Surrogate) Reaction Mechanisms

- r process nuclei are unstable, making direct (n, γ) measurements extremely difficult. Thus, surrogate transfer reactions as (d, p) need to be used to constrain (n, γ) rates off stability.
- In surrogate reactions, the same intermediate $A+1X^*$ nucleus is formed. The subsequent decay is believed to be independent of its formation.



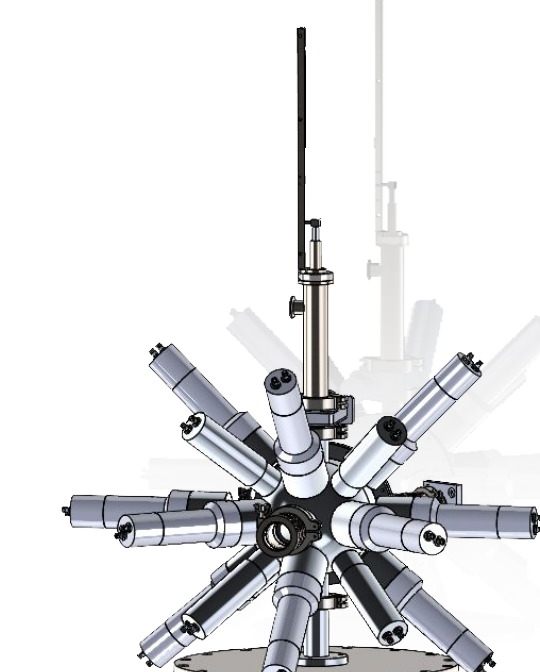
Schematic of (d, p) reaction, populating the same entrance state as (n, γ) [5].



Schematic of experimental approach using FSU's SE-SPS & γ -ray array CeBrA. Figure adapted from [6].

VII. Conclusion & Future Work

- Additional detectors added to CeBrA will allow greater efficiency in detecting high energy γ rays.
- Further benchmarking of surrogate reactions in stable nuclei needed to test applicability far off stability.
- Further experiments needed to understand the single-particle structure of the PDR and its influence on the γ SF.



Planned CeBrA γ -ray array, with 14 CeBr₃ detectors.

References

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