

CENTER OF EXCELLENCE FOR
RADIOACTIVE ION BEAM STUDIES
FOR STEWARDSHIP SCIENCE



The Center of Excellence for Radioactive Ion Beam Studies for Stewardship Science

Dan Bardayan
University of Notre Dame
for

Jolie A. Cizewski
Rutgers University



- Use RIBS to investigate structure of exotic atomic nuclei and nucleosynthesis through decays and reactions. Develop tools (experiment and theory) and train early career scientists for the future of fundamental and applied nuclear science.
- Do good science.
- Train and educate future generation of nuclear scientists.
- Educate and expose these next generation scientists to the opportunities available at the National Security Laboratories (LANL, LLNL).



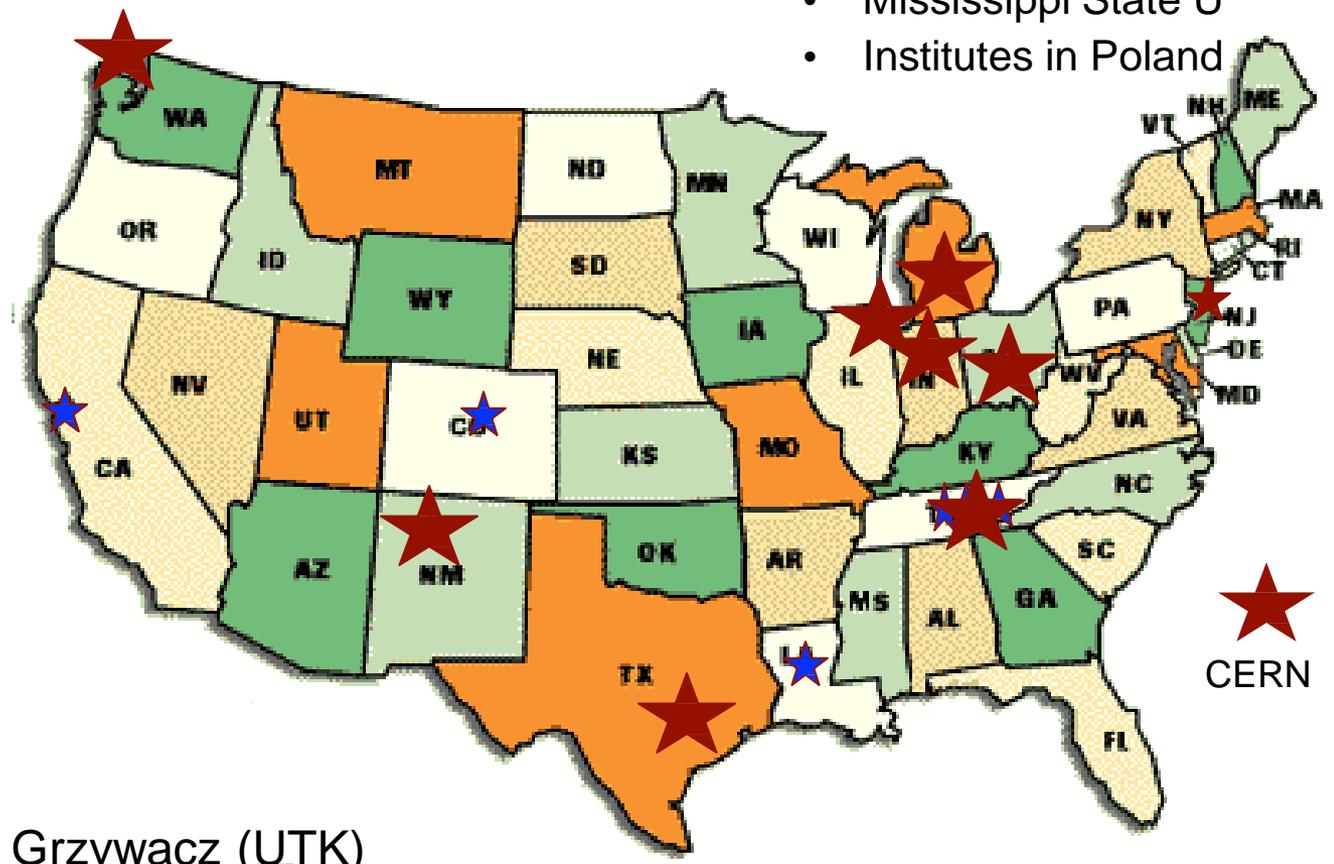
Center of Excellence for Radioactive Ion Beam Studies for Stewardship Science 2003-present

Collaborators

- ORNL
- NSCL
- Notre Dame
- ANL
- CERN
- Mississippi State U
- Institutes in Poland

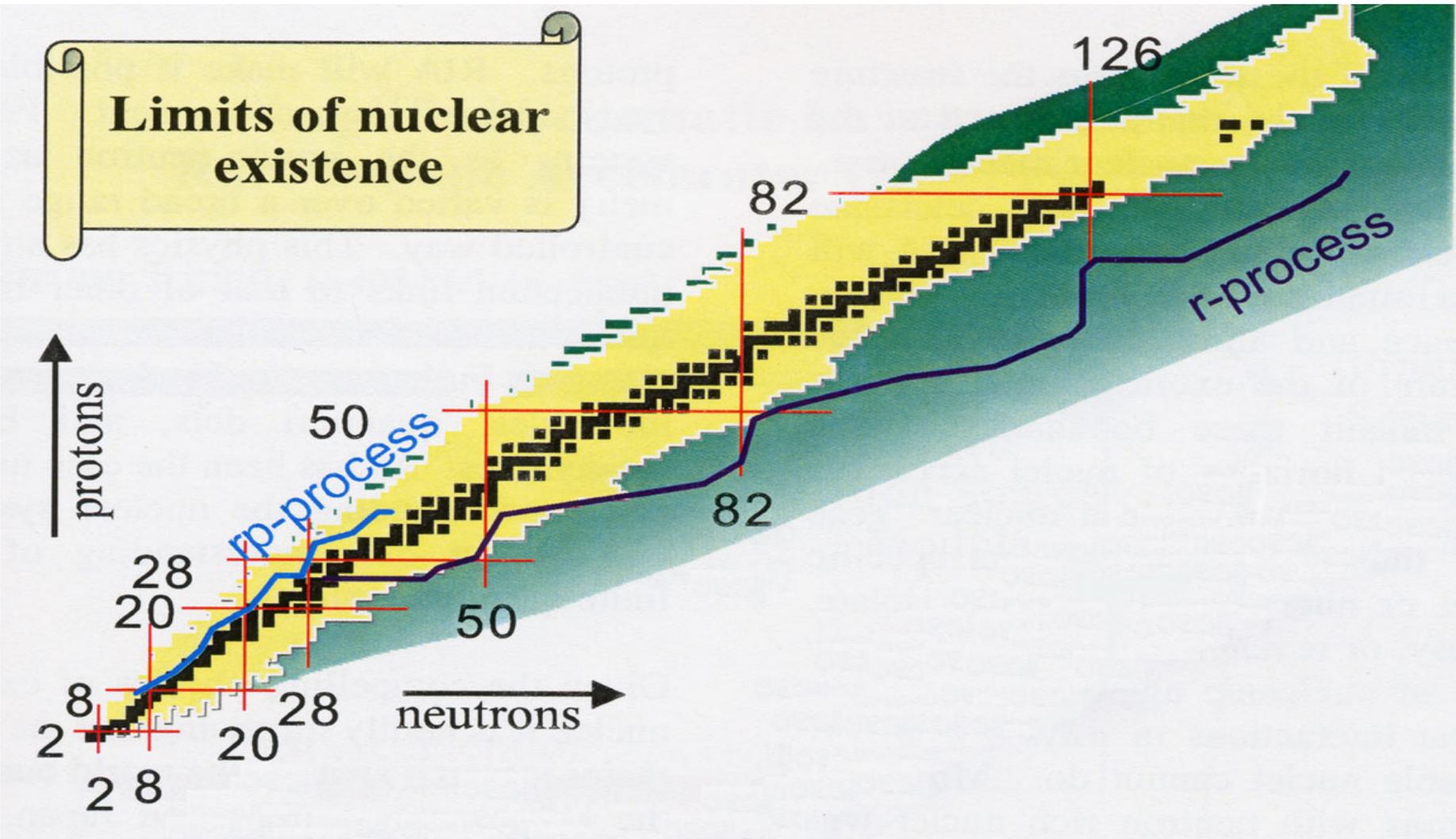
- ★ Rutgers
- ★ Exp research labs
- ★ Co-PIs
 - U Tenn (2)
 - Oak Ridge Nat Lab
 - Michigan State U (2)
 - CO School Mines
 - LLNL
 - Louisiana State U
 - Tenn Tech
 - Notre Dame
- ★ NNSA Partners:
LANL, LLNL

Robert Grzywacz (UTK)
Associate Director



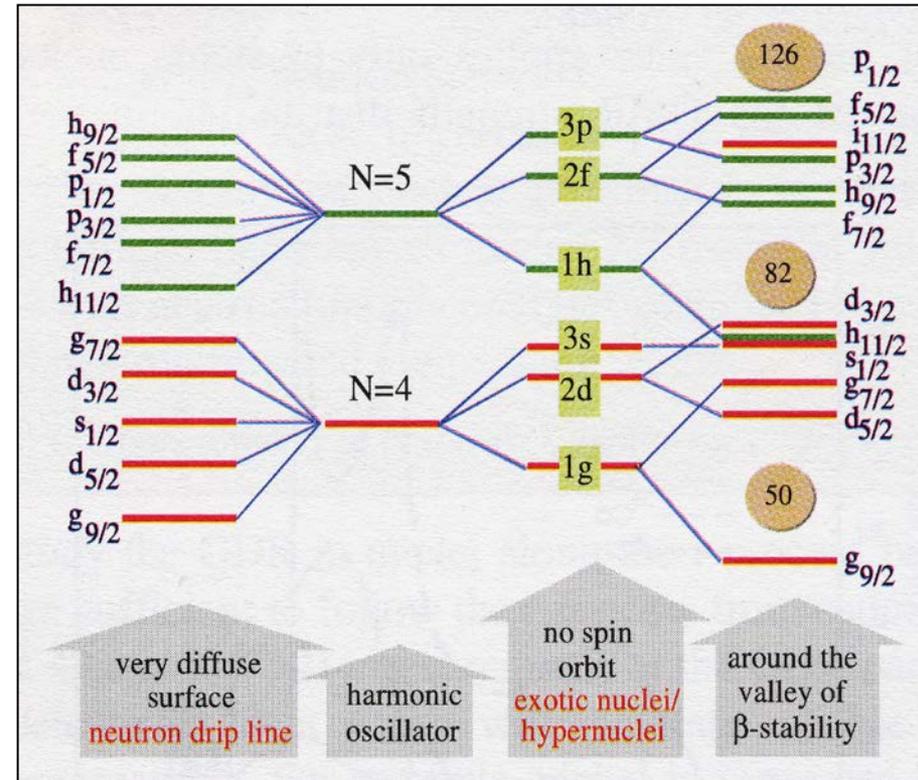
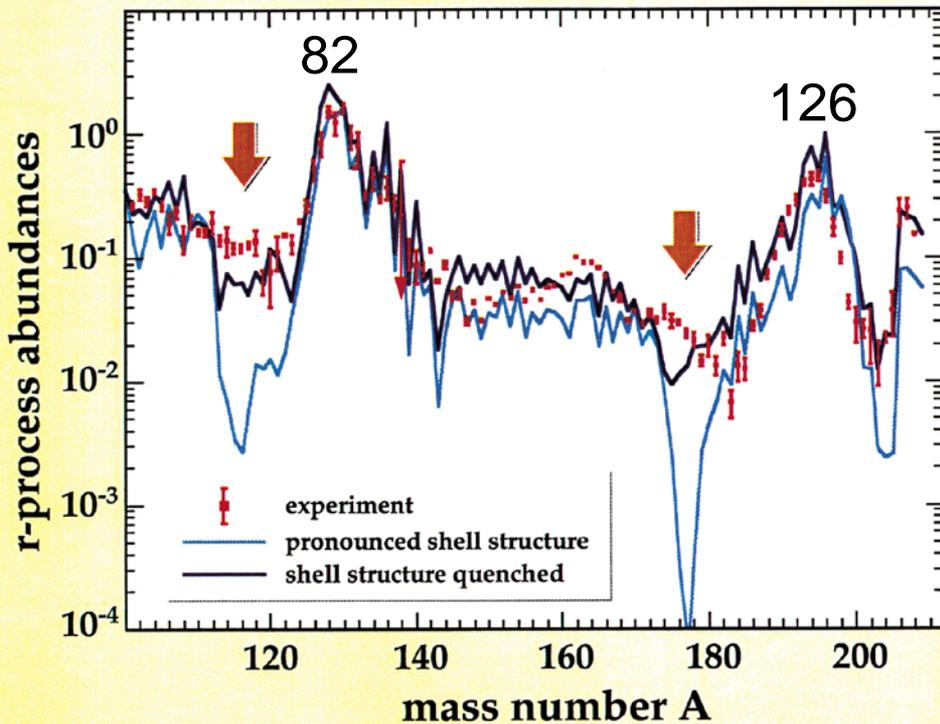


What is the origin of the chemical elements that make up our world?





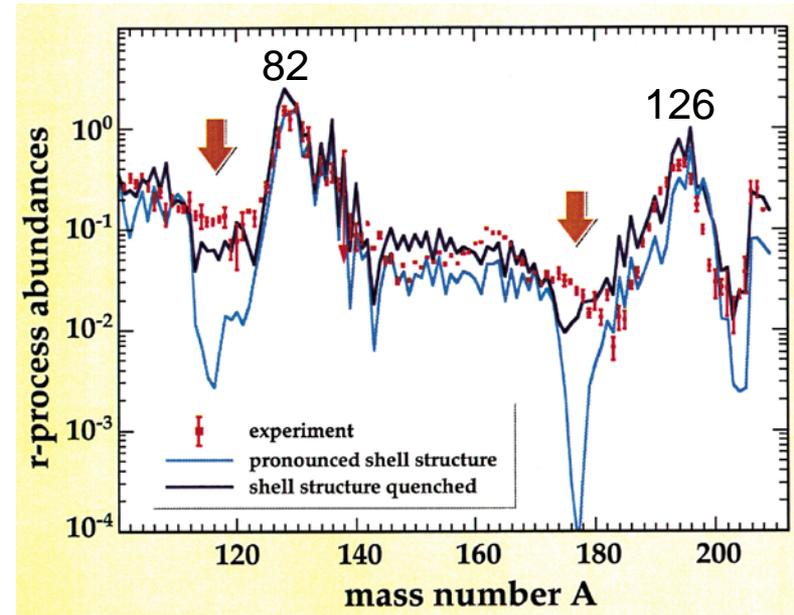
r process abundances



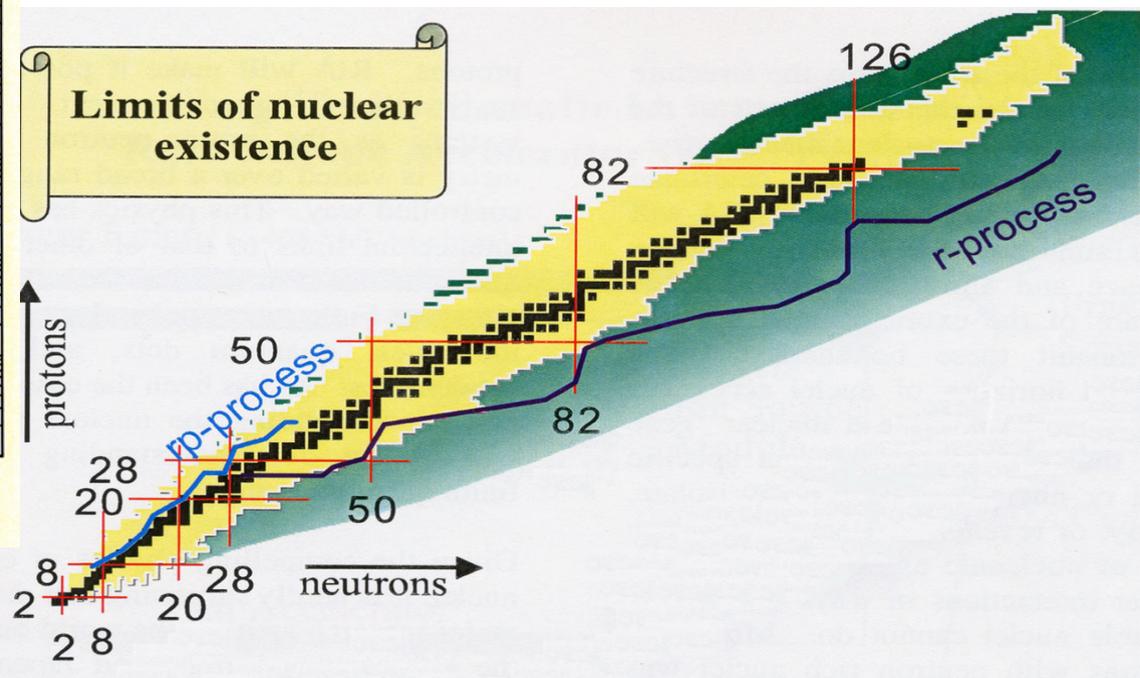
Stars telling us that shell model that has worked for over 65 years may not be valid far from stability.



Informing nucleosynthesis in stars and explosions



Limits of nuclear existence

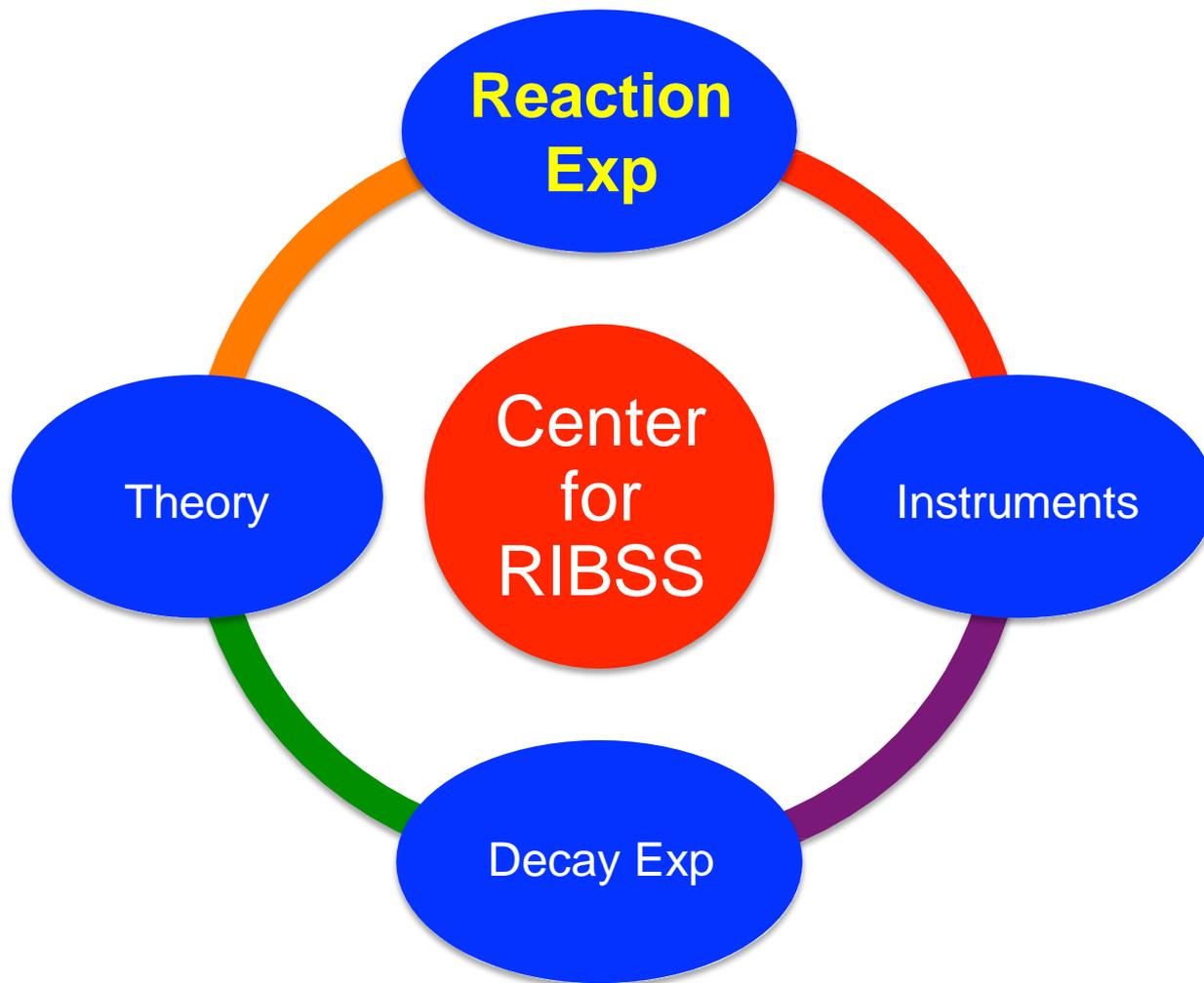


Need nuclear data

- Masses
 - Reaction & decay studies
- Beta-decay half lives
- Beta-delayed neutron probabilities
- (n,γ) , (p,γ) rates ← reaction exp & theory studies
- Nuclear structure ← reaction, decay & theory

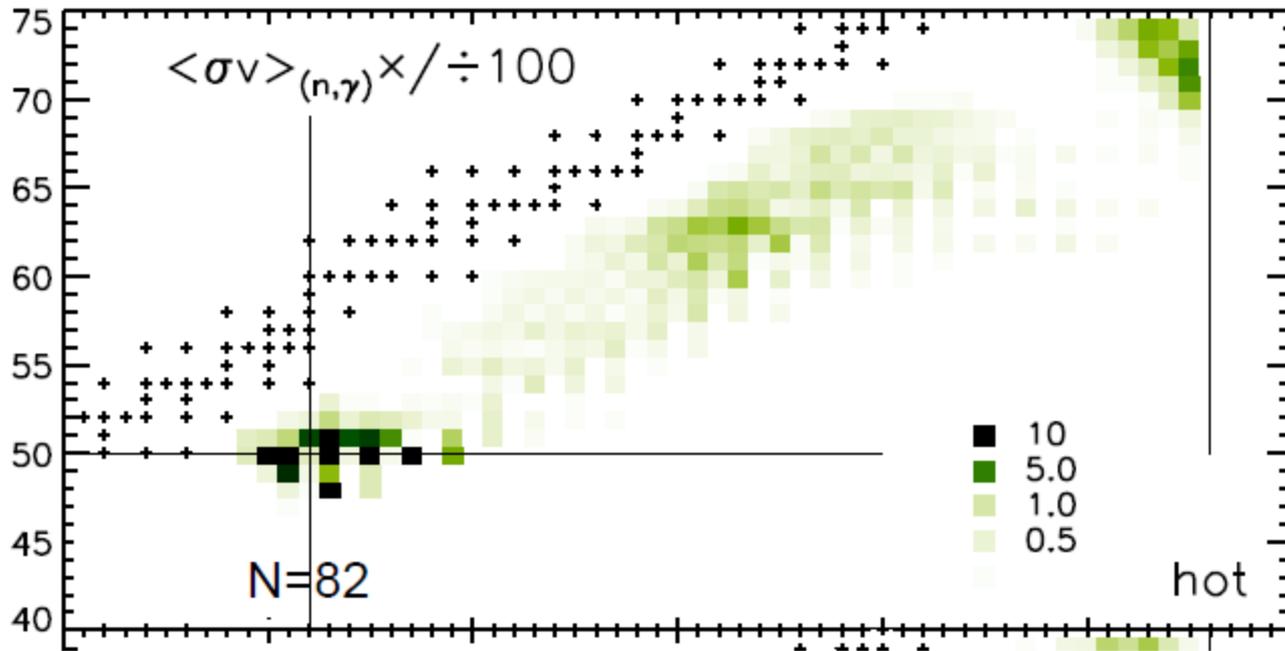


Addressing compelling questions nuclear structure, decay, reactions & astrophysics





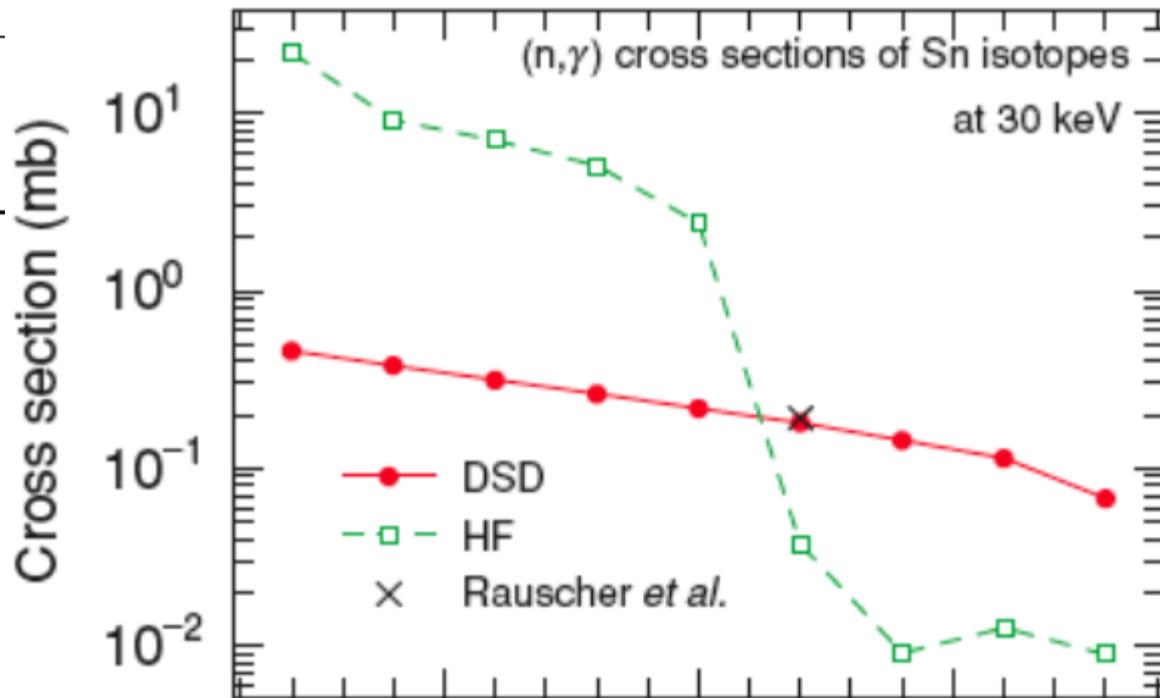
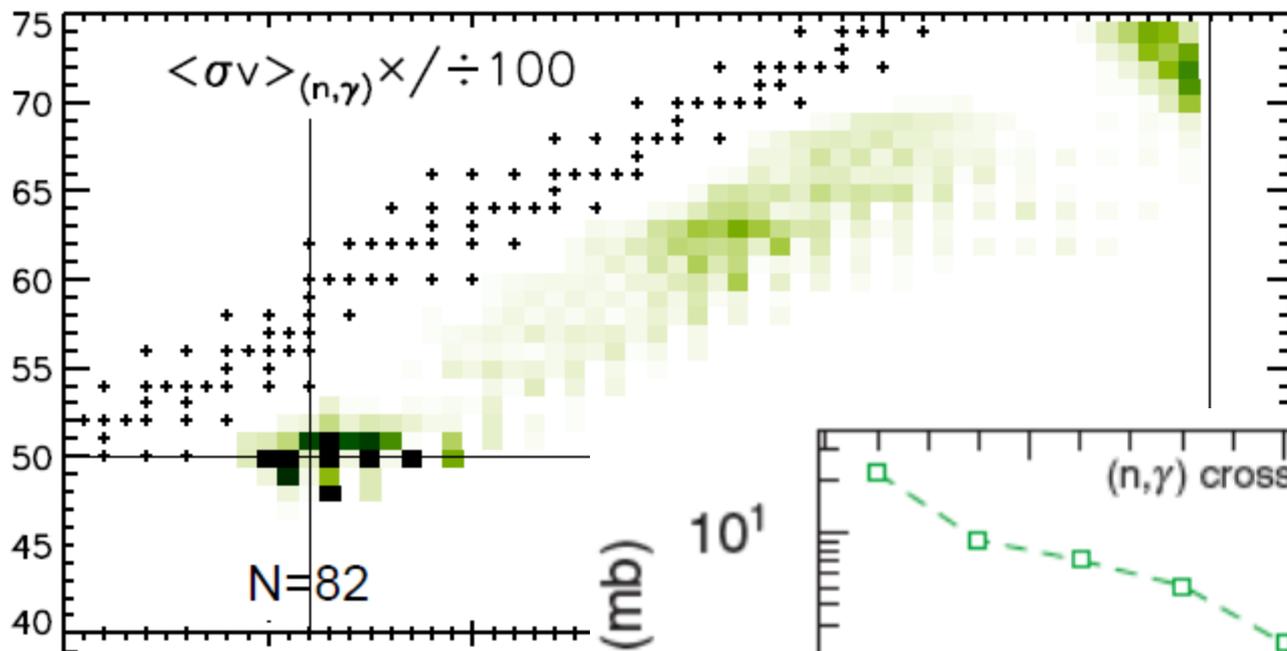
(d,p) reactions and the r-process



- Neutron capture on r-process path cannot be measured directly
- Accelerated RIBs + neutron target not currently possible
- Necessary to study structure and validate surrogate for (n,γ)



(d,p) reactions and the r-process



125

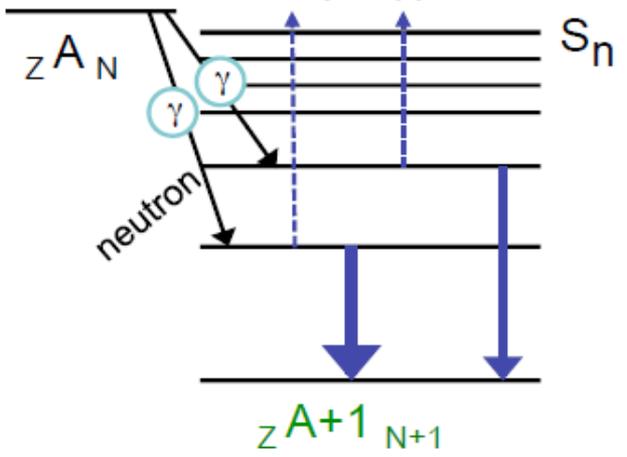
Sn(n,γ) vs A
Chiba, et al. PRC **77**, 015809 (2008)



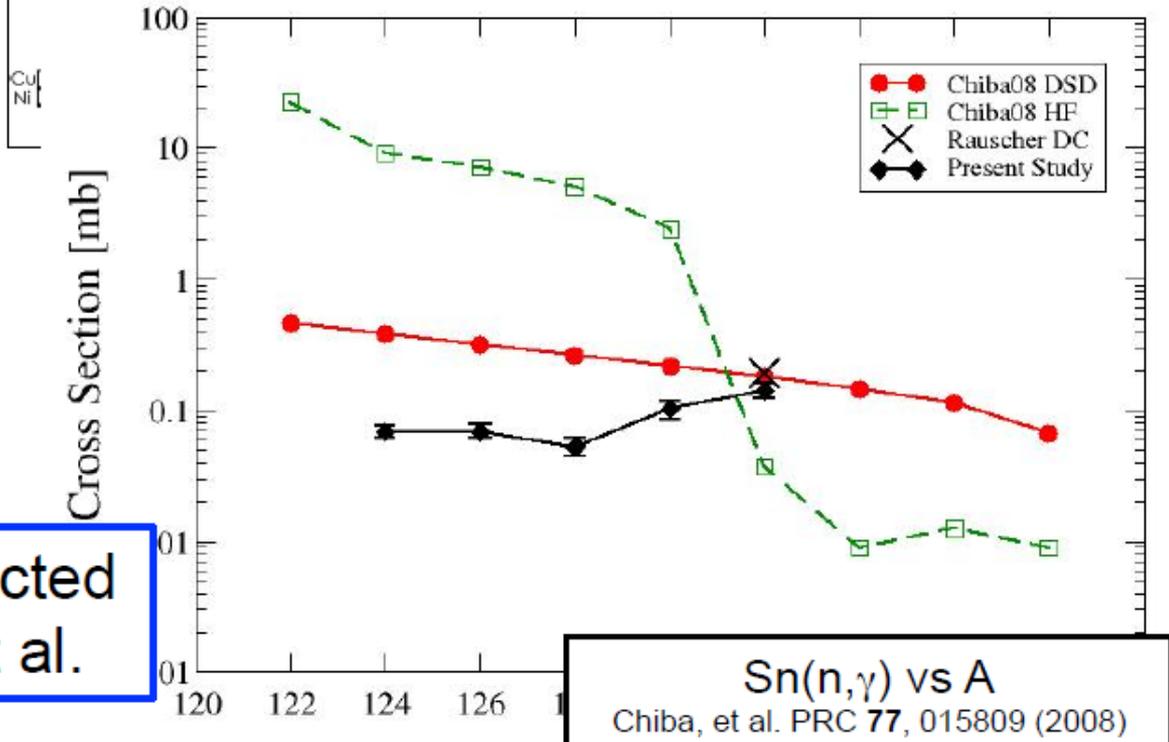
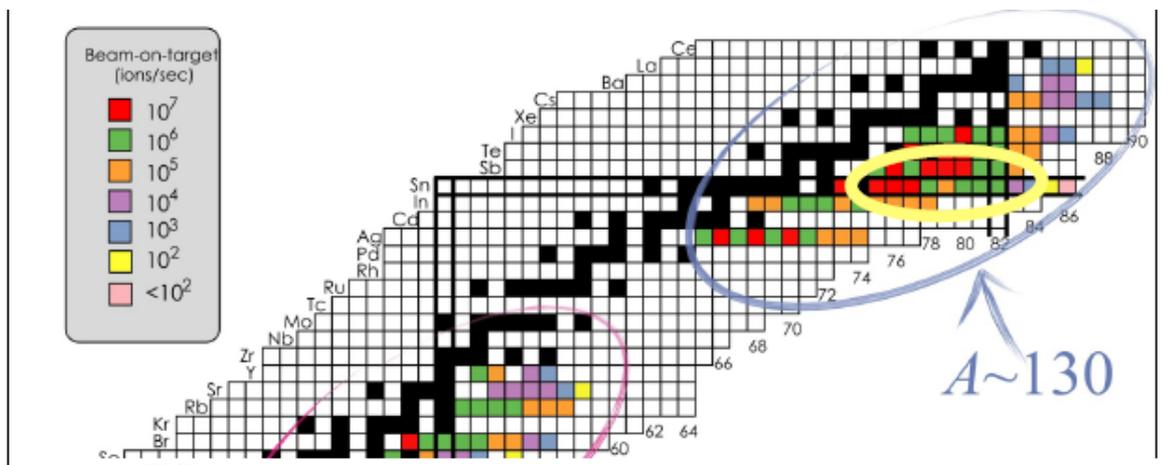
(d,p) reactions and the r-process

Direct-semi-direct
Near waiting points

(n, γ)



124-132Sn DSD (n, γ) extracted
from (d,p) B. Manning et al.

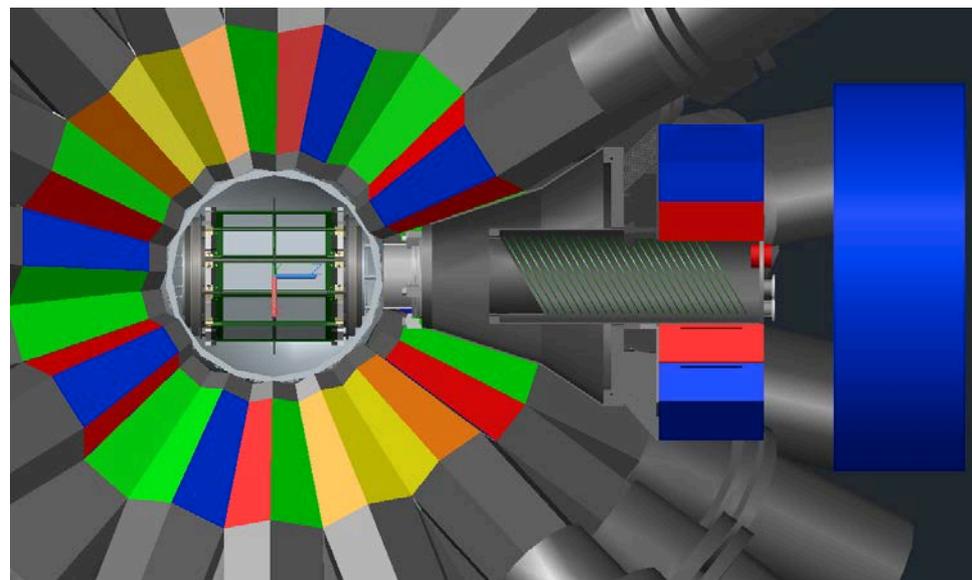
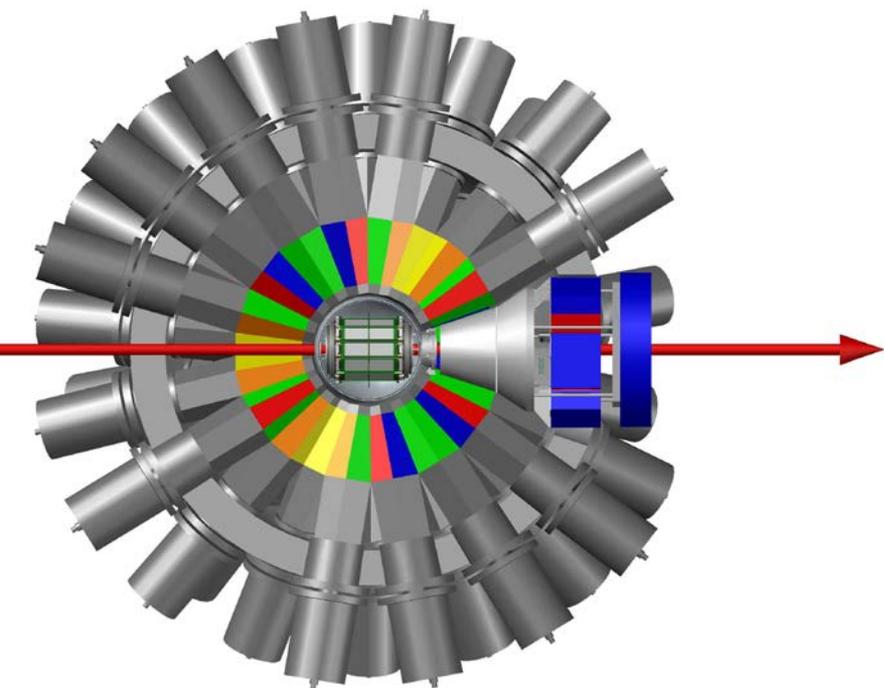


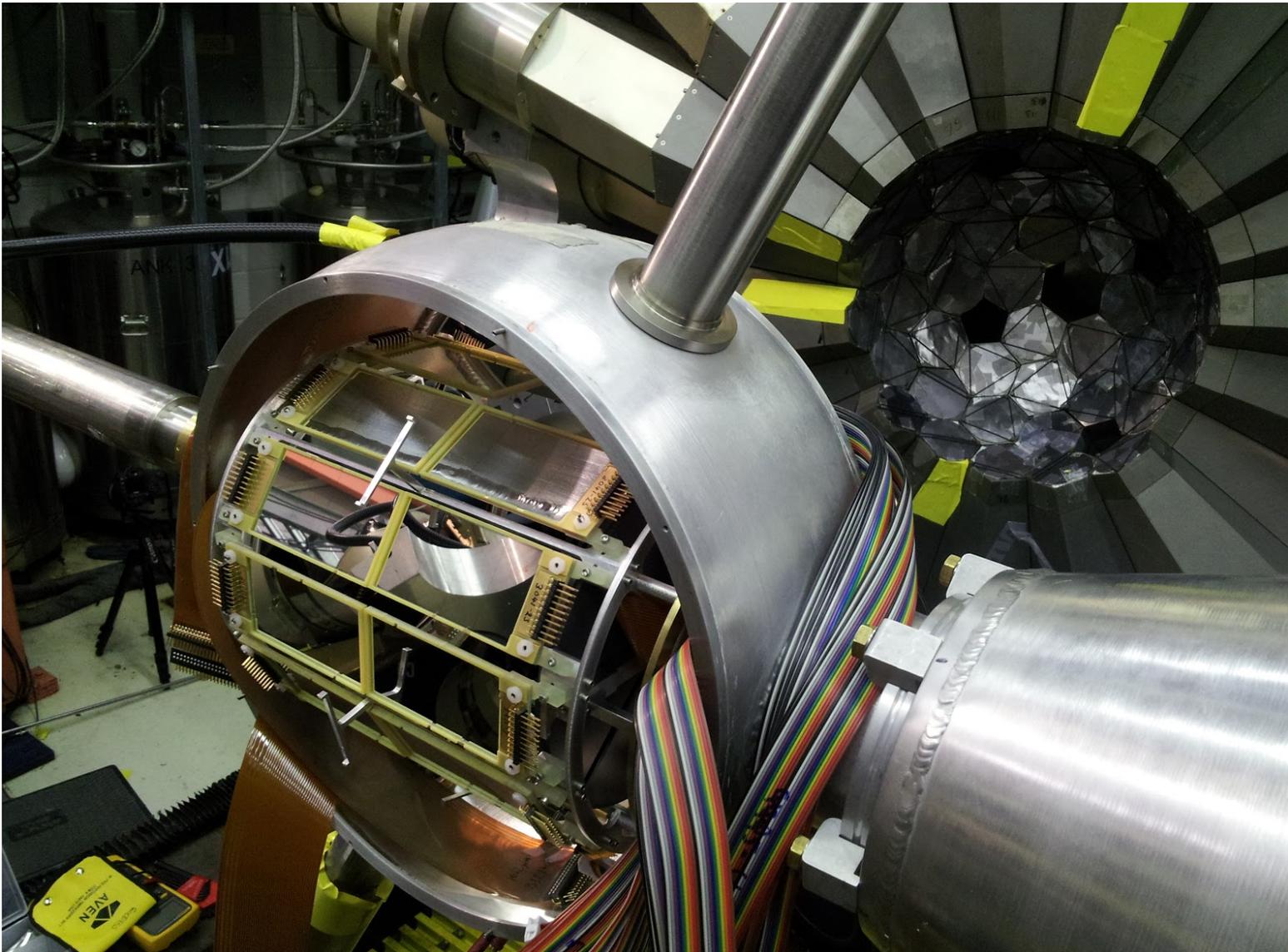
Sn(n,γ) vs A
Chiba, et al. PRC 77, 015809 (2008)



GODDESS (Gammasphere ORRUBA: Dual Detectors for Experimental Structure Studies)

- Development of $(d,p\gamma)$ in inverse kinematics (with RIBs)
 - Coupling Si strip detector array ORRUBA + endcap to Gammasphere



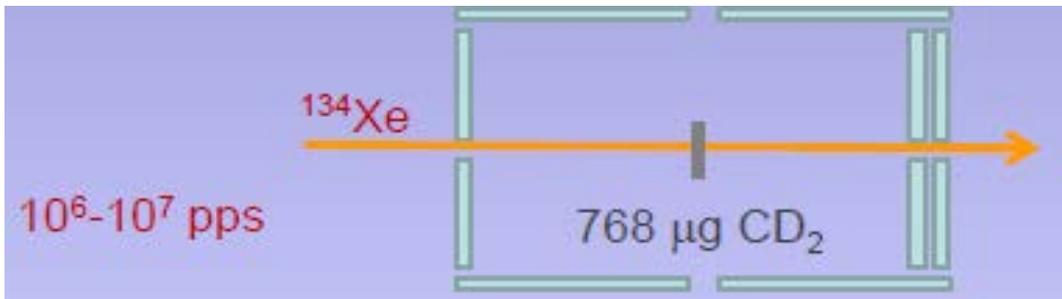
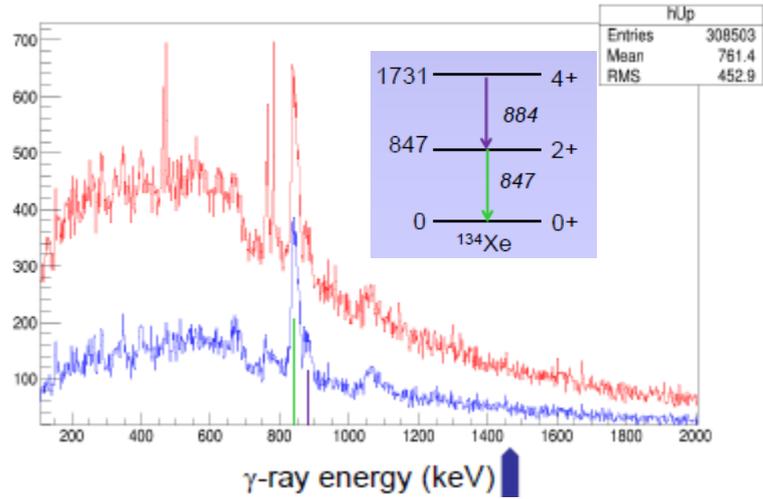
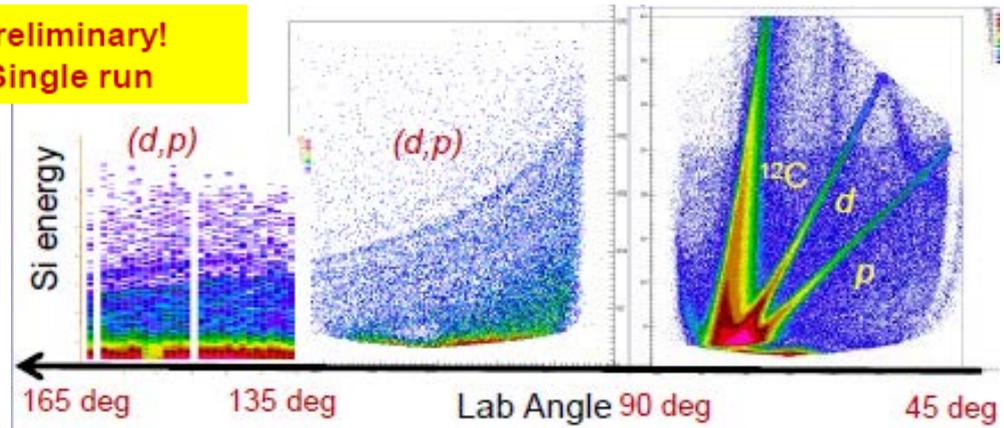




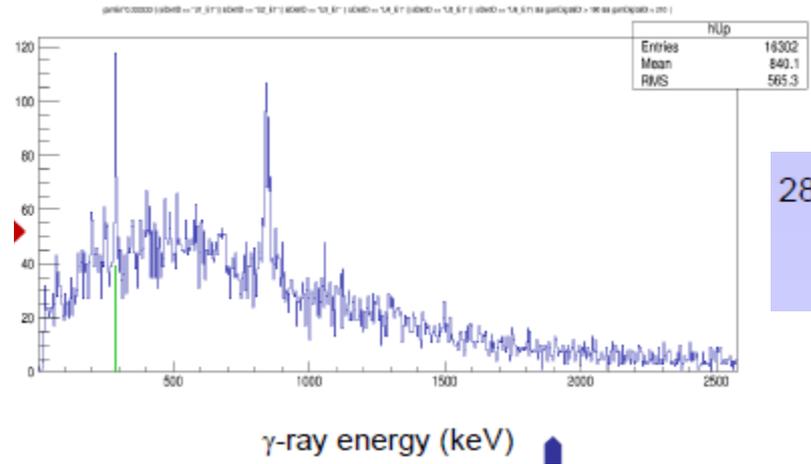
N=80 ^{134}Xe beam - $^2\text{H}(^{134}\text{Xe}, p\gamma)$ – S. D. Pain

See strong Coulex lines
when gating on forward-
angle detectors

Preliminary!
Single run

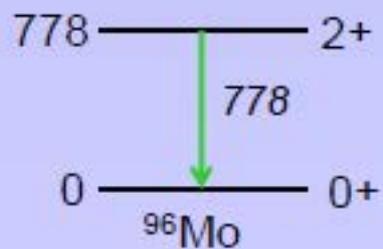
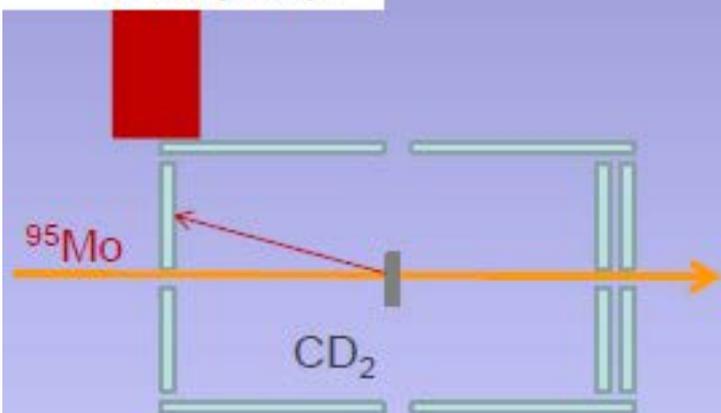
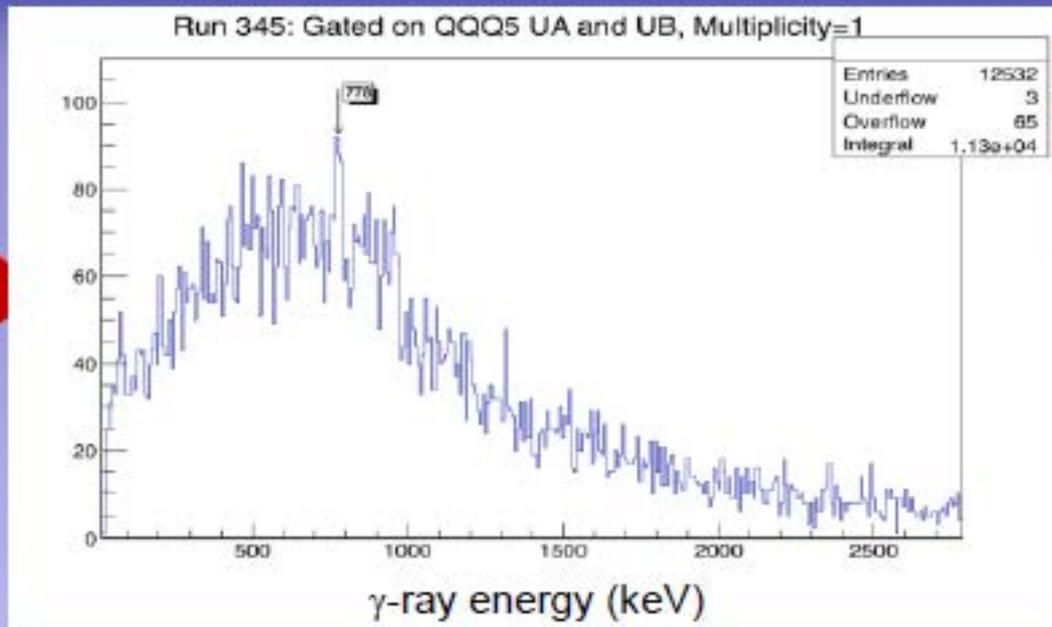
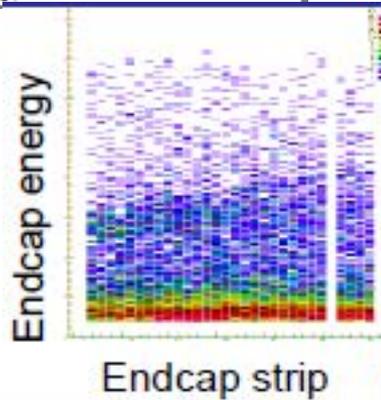


See (d,p) events
when gate on
backward-angle
detectors





Surrogate Study ${}^2\text{H}({}^{95}\text{Mo}, p\gamma)$ – J. A. Cizewski

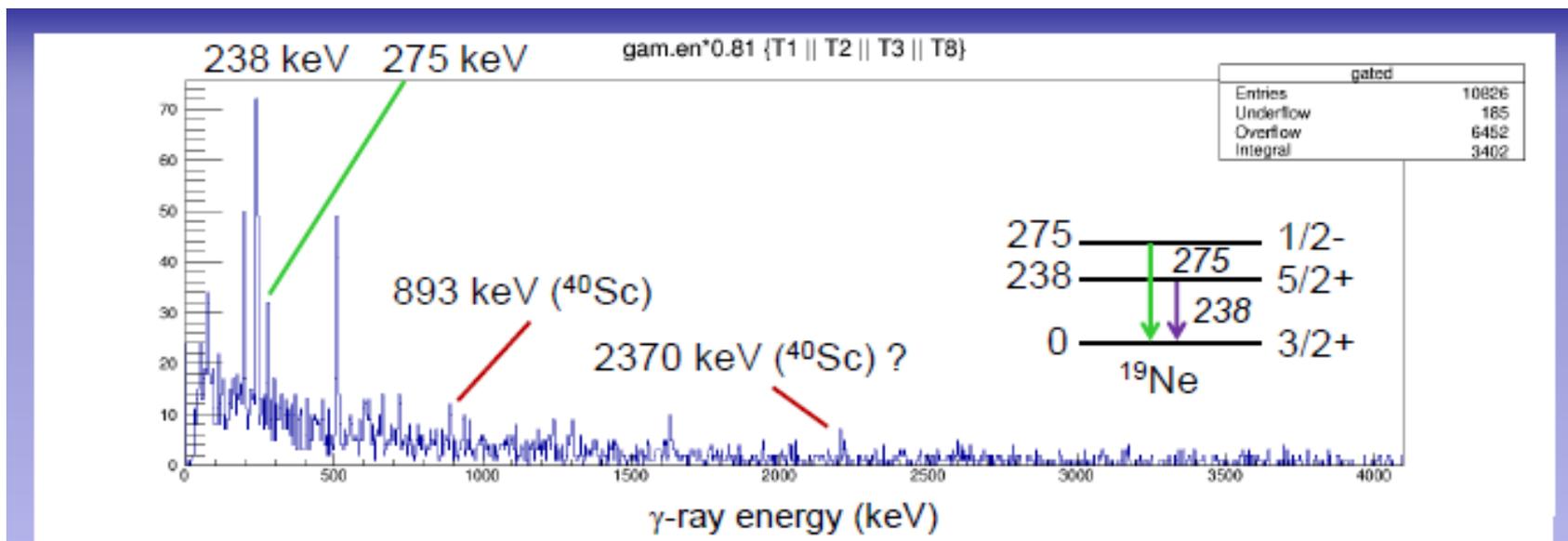


Preliminary!
Single run

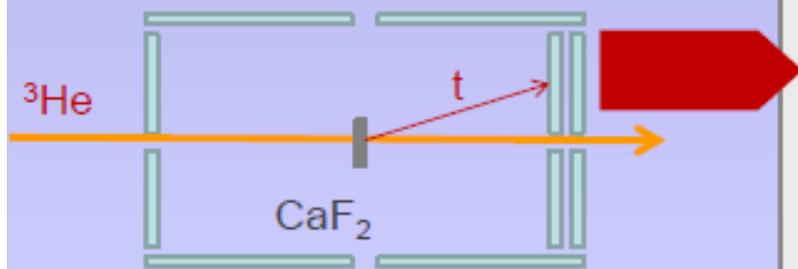




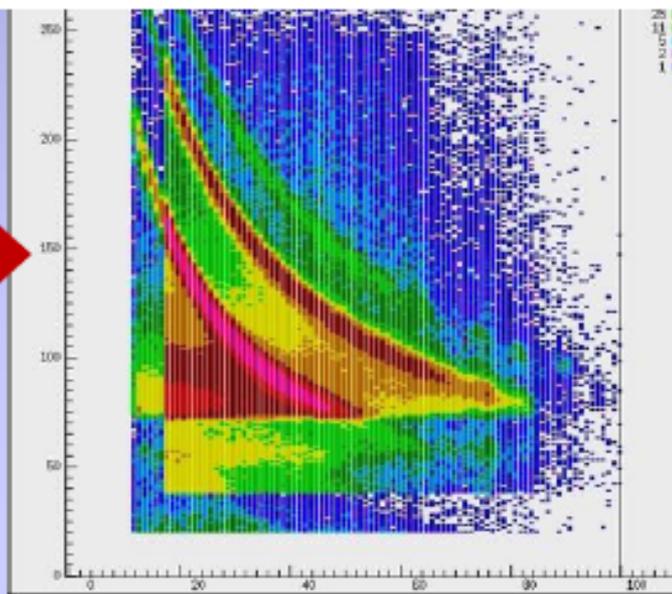
Properties of ^{19}Ne determine astrophysical $^{18}\text{F}(p,\alpha)^{15}\text{O}$ rate.



Matt Hall
University of Notre Dame (PhD)

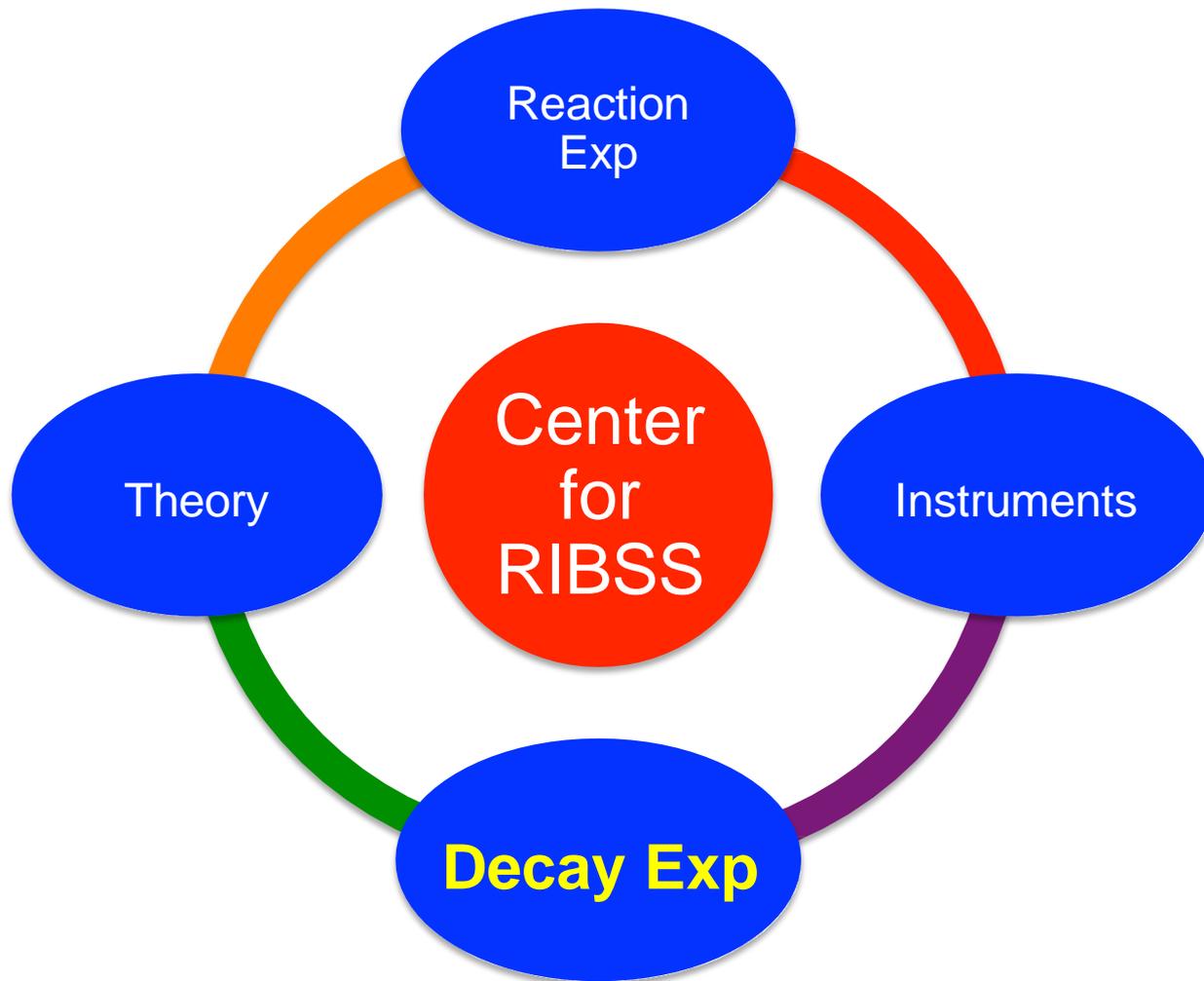


Preliminary!



tritons
deuterons
protons

Addressing compelling questions nuclear structure, decay, reactions & astrophysics

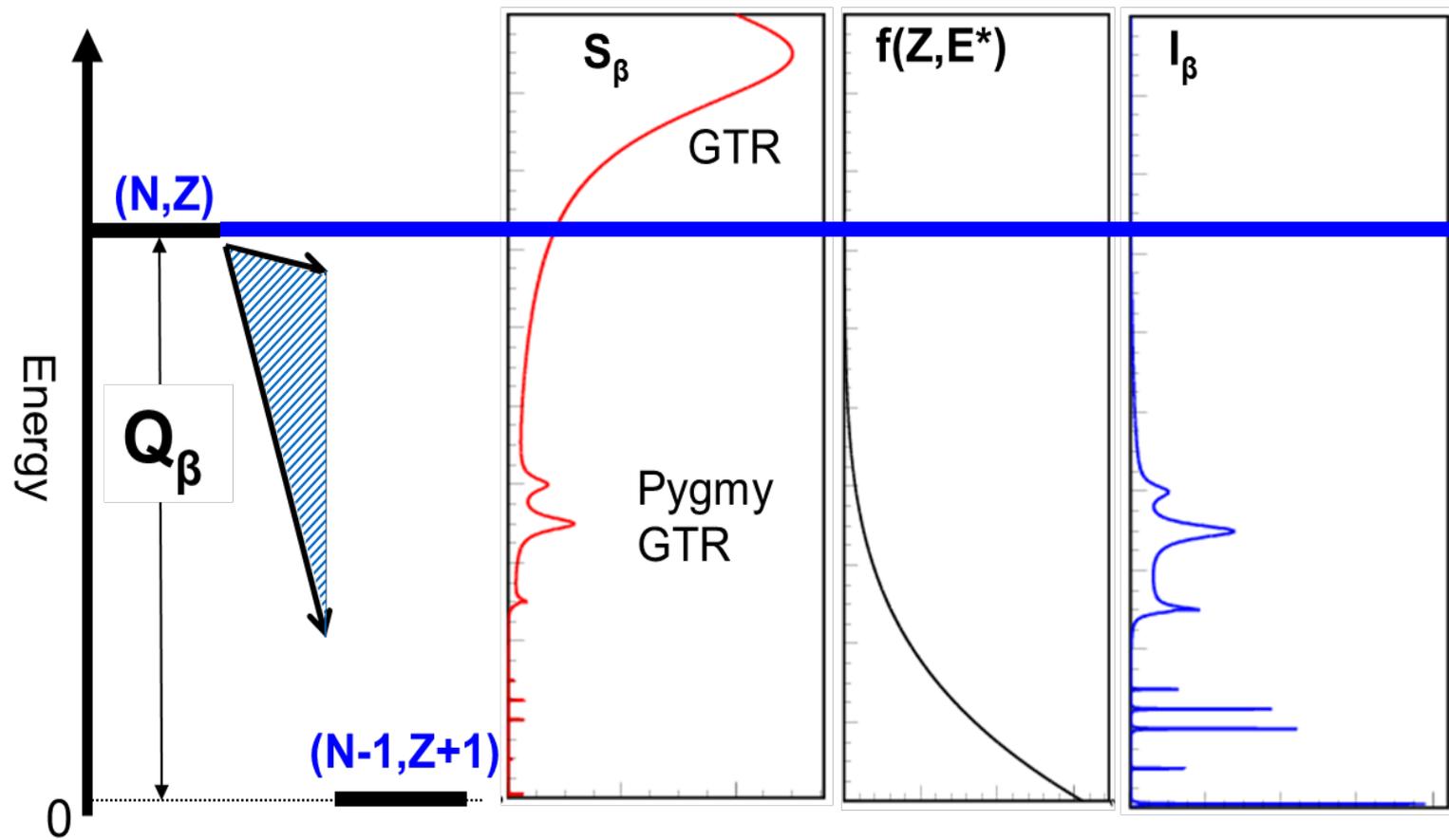




Beta strength, nuclear lifetimes & branching ratios

$$\frac{1}{T_{1/2}} = \sum_{E_i \geq 0}^{E_i \leq Q_\beta} S_\beta(E_i) \times f(Z, Q_\beta - E_i)$$

$$S_\beta(E_i) = \langle \psi_f | \hat{O}_\beta | \psi_{mother} \rangle$$

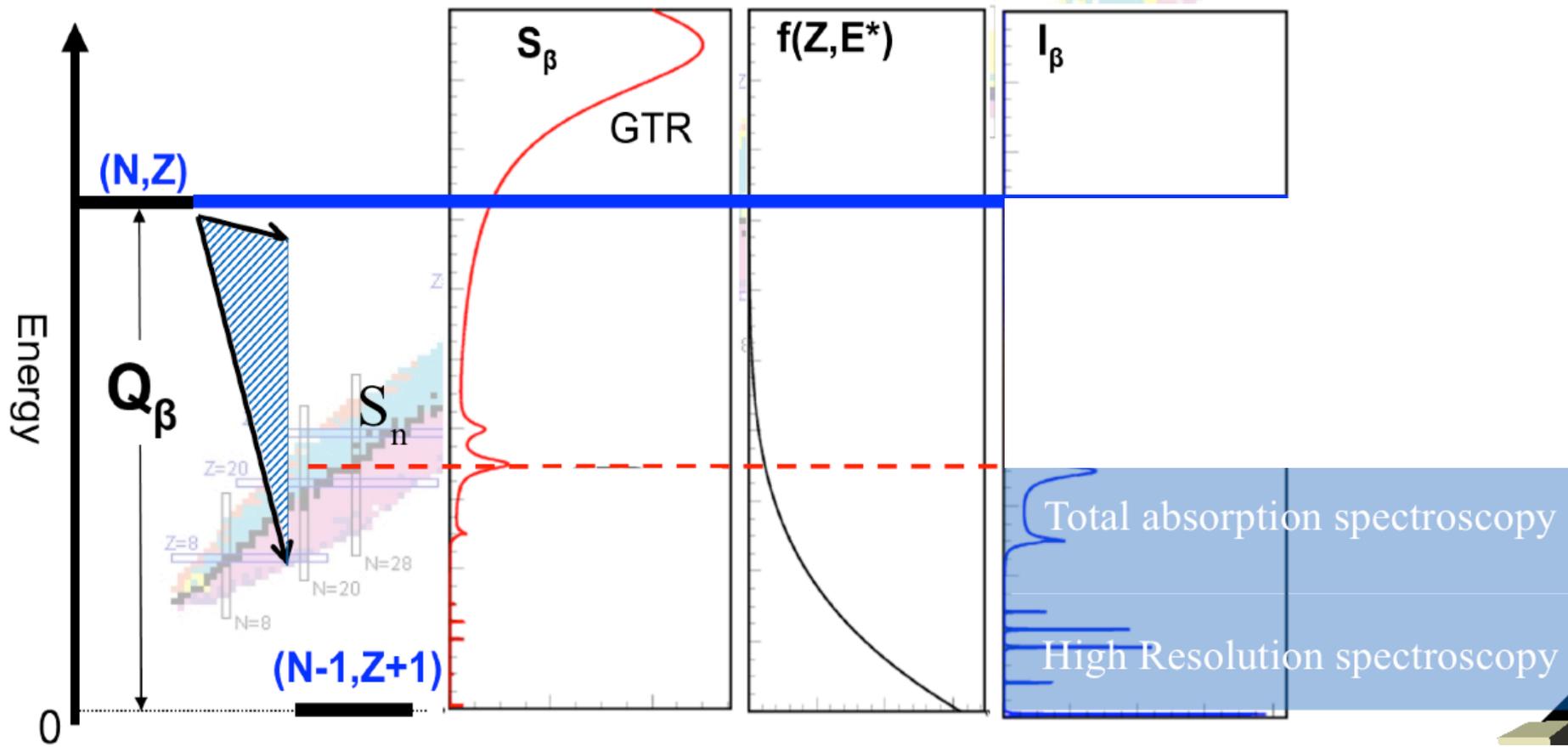




Beta strength, nuclear lifetimes & branching ratios

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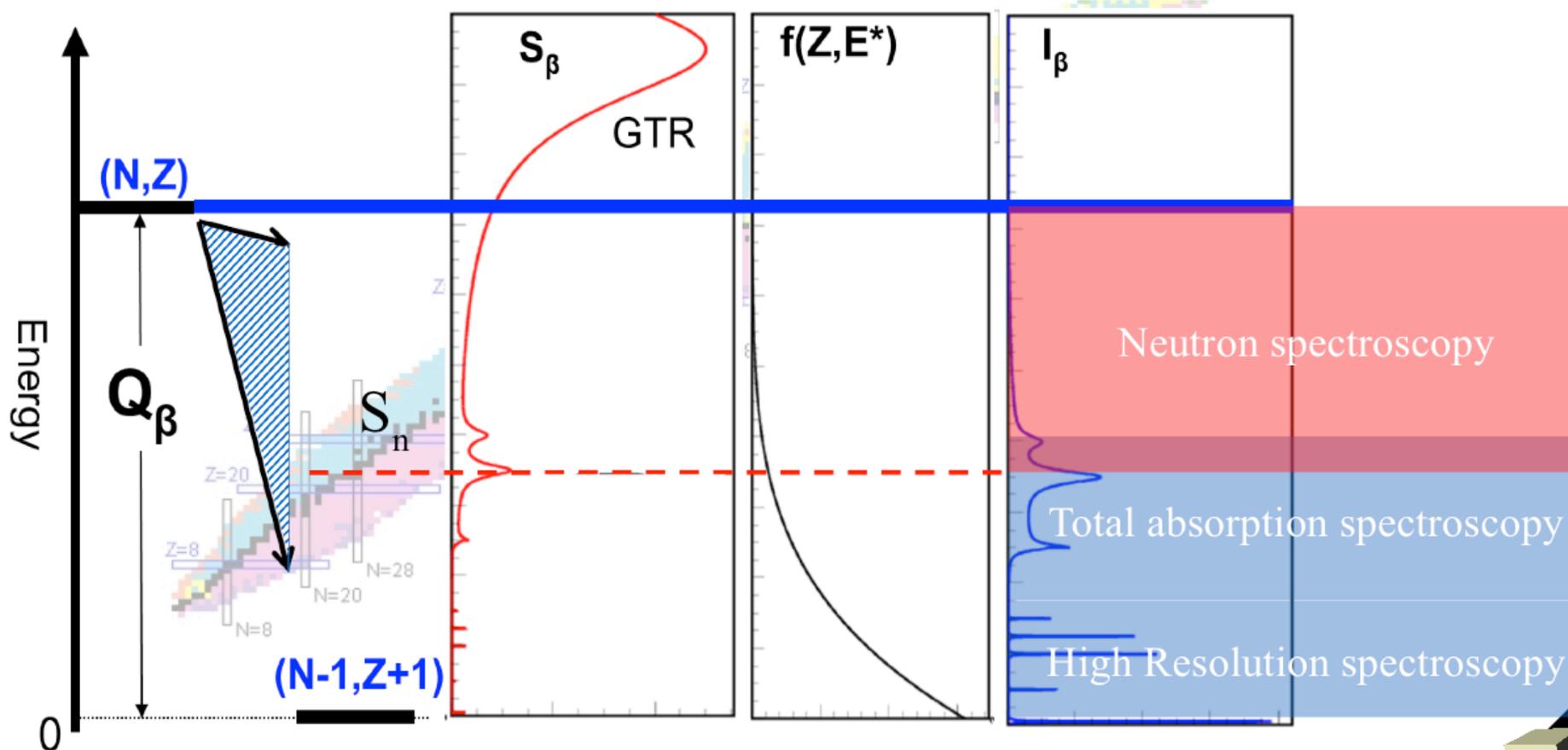




$Q_\beta > S_n \Rightarrow$ beta-delayed neutron emission

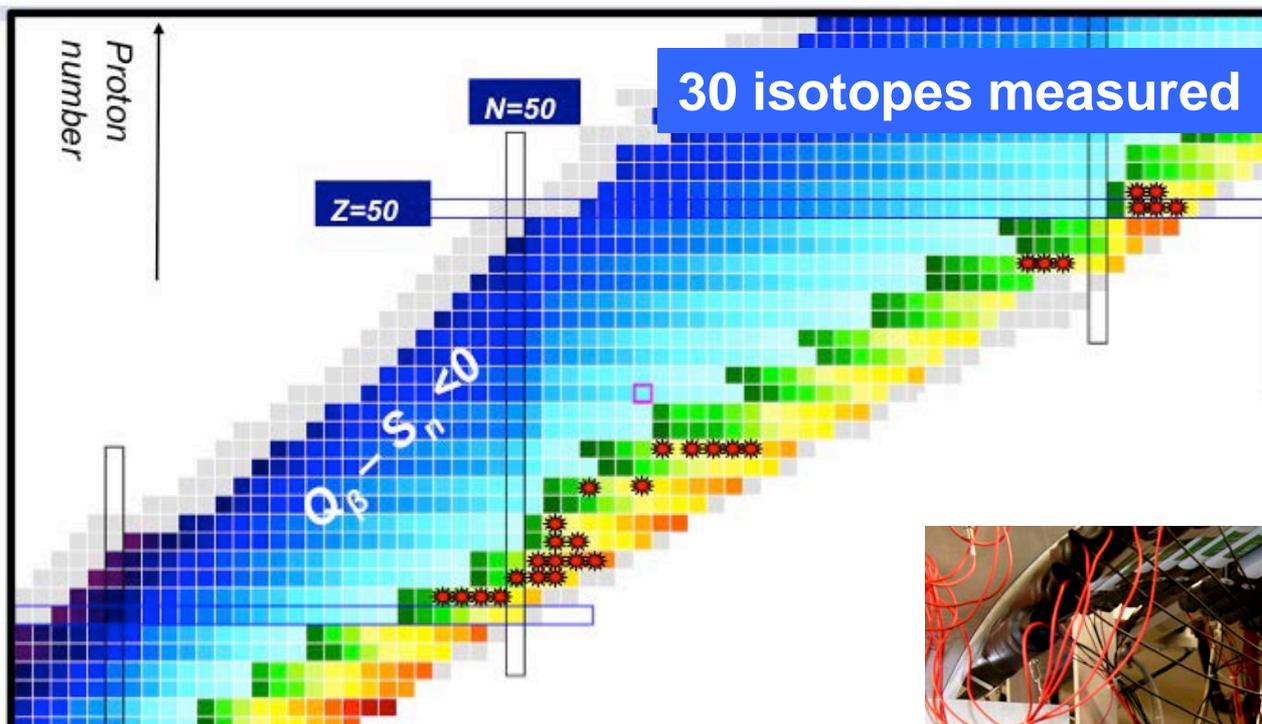
$$\frac{1}{T_{1/2}} = \sum_{\substack{E_i \leq Q_\beta \\ E_i \geq 0}} S_\beta(E_i) \times f(Z, Q_\beta - E_i)$$

$$S_\beta(E_i) = \langle \psi_f | \hat{O}_\beta | \psi_{mother} \rangle$$





Versatile Array of Neutron Detectors at Low Energy

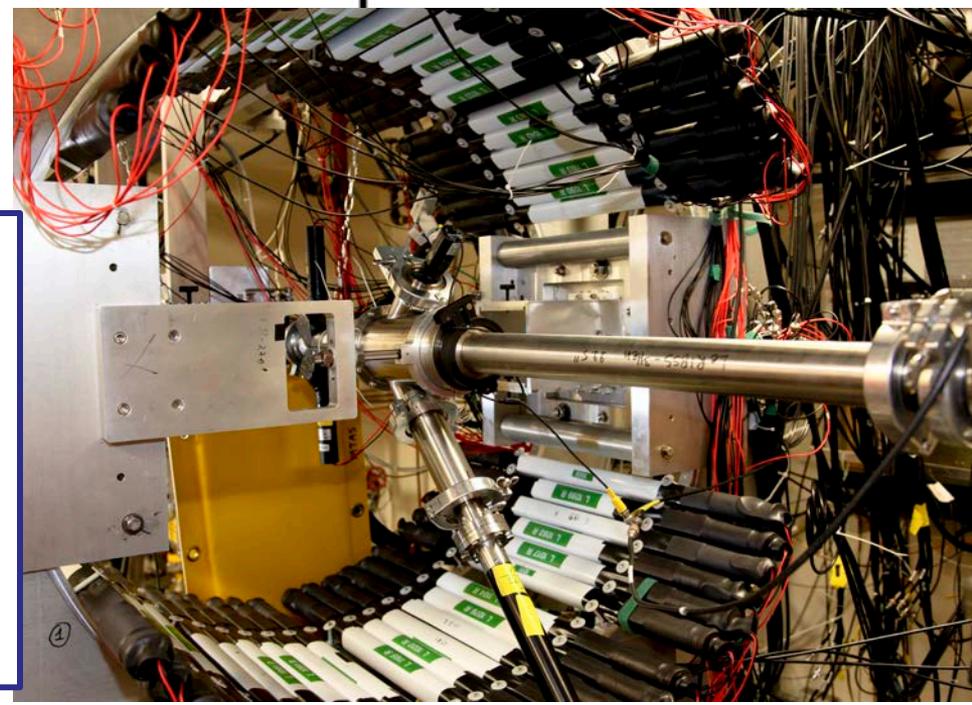


VANDLE

- 48 60-cm long plastic scintillator bars
- PMT both ends
- Digital signal processing

S.V. Paulauskas, et al., NIM (2014)

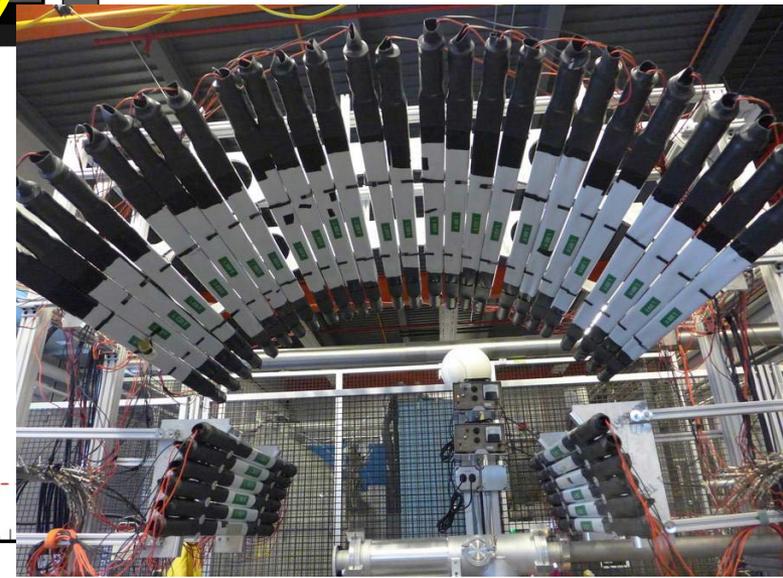
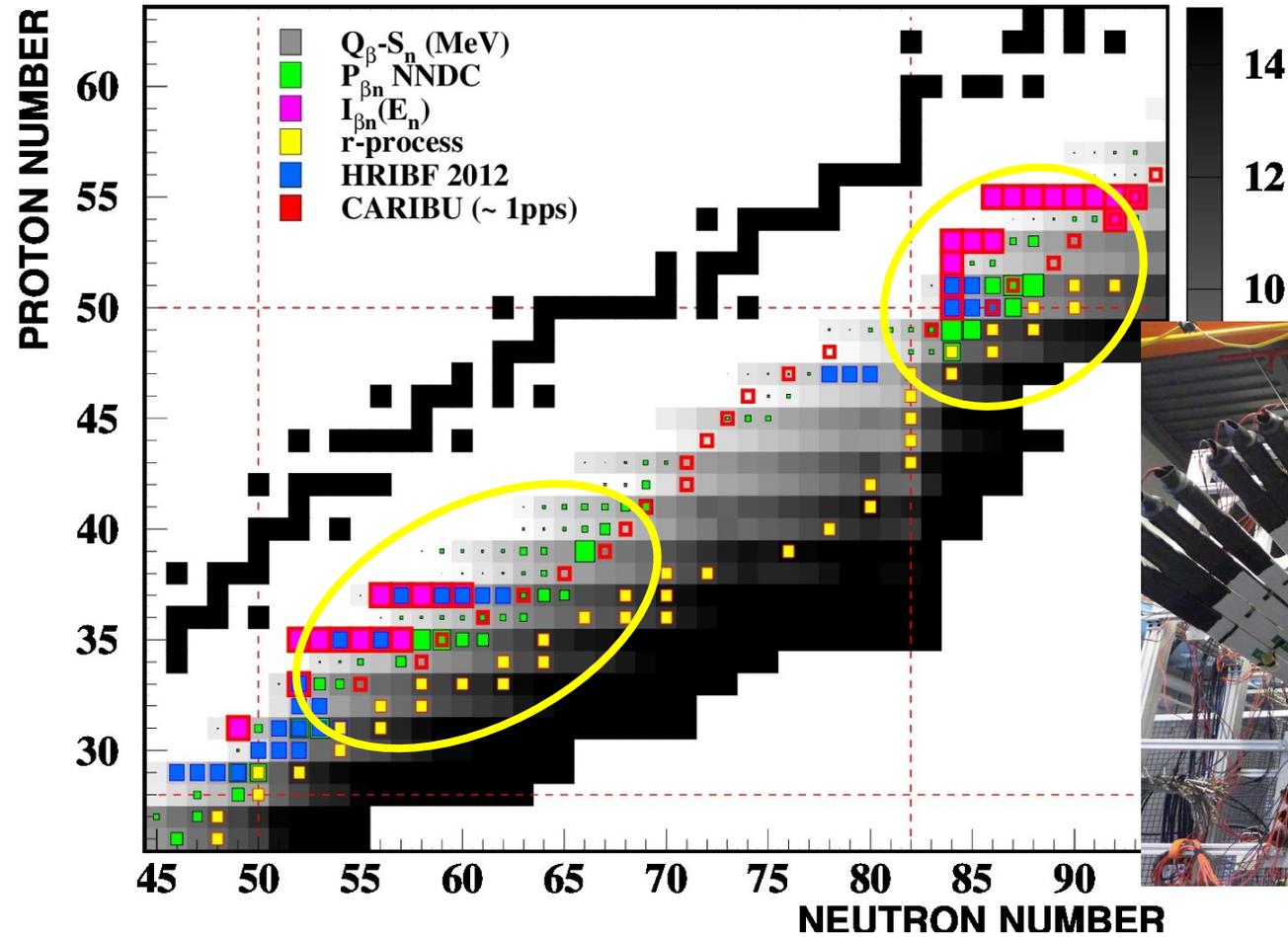
W.A. Peters et al., NIM (submitted)





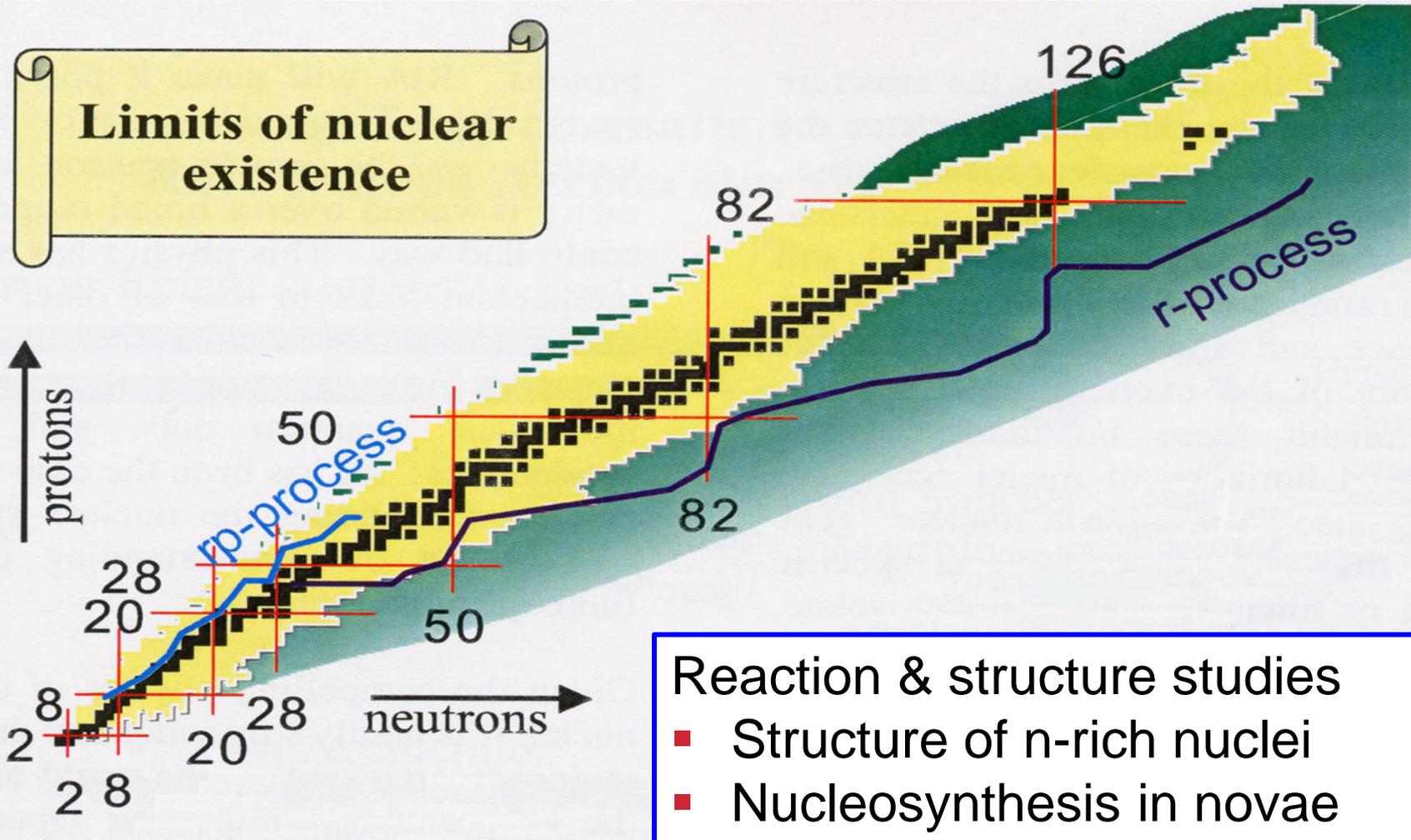
β -delayed neutrons and the r process: CARIBU and VANDLE

CARIBU and VANDLE



Early 2015 campaigns with new VANDLE configuration

Limits of nuclear existence



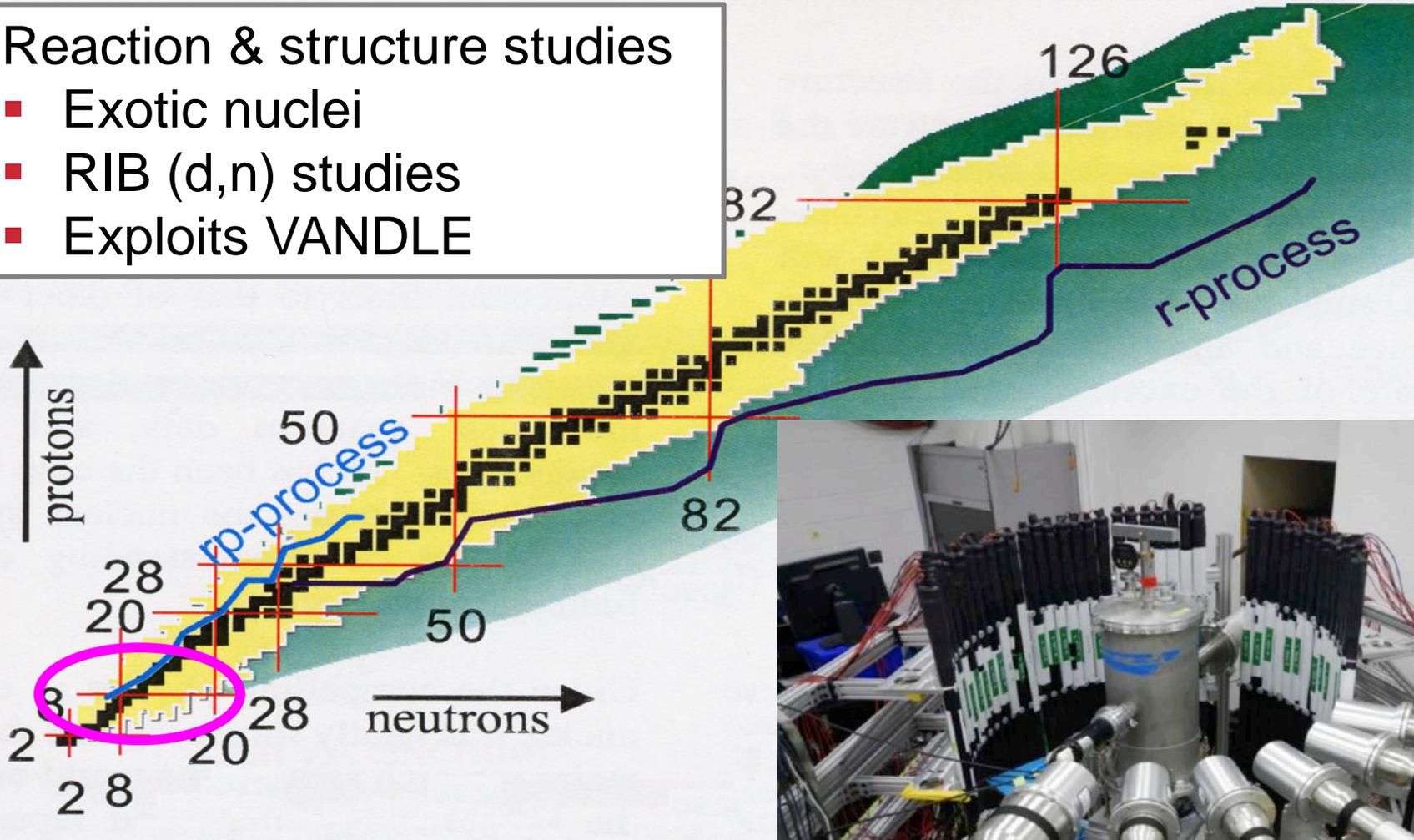
Reaction & structure studies

- Structure of n-rich nuclei
- Nucleosynthesis in novae
- Reactions with weakly bound beams & targets

Nuclear reaction studies beyond r process

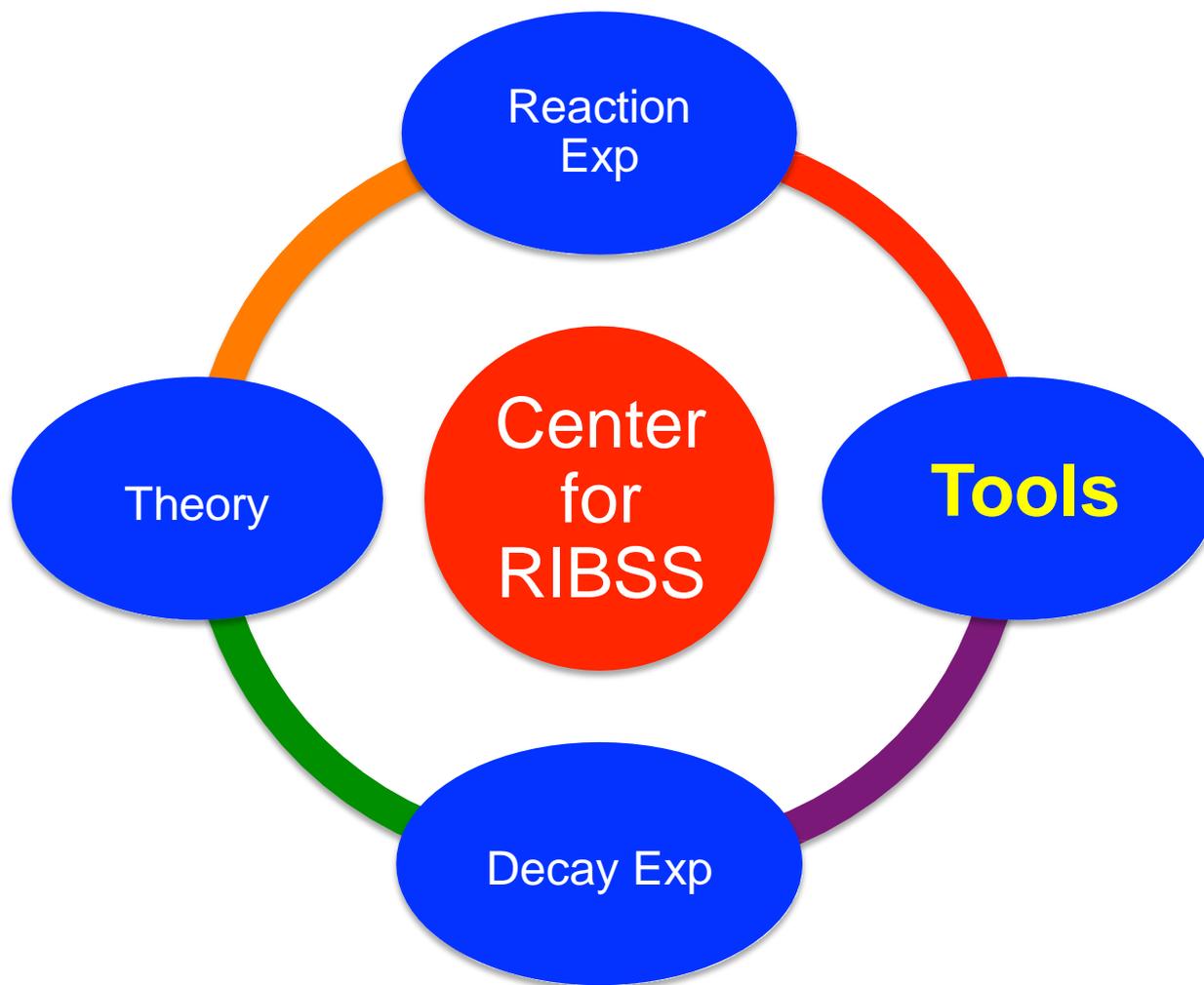
Reaction & structure studies

- Exotic nuclei
- RIB (d,n) studies
- Exploits VANDLE



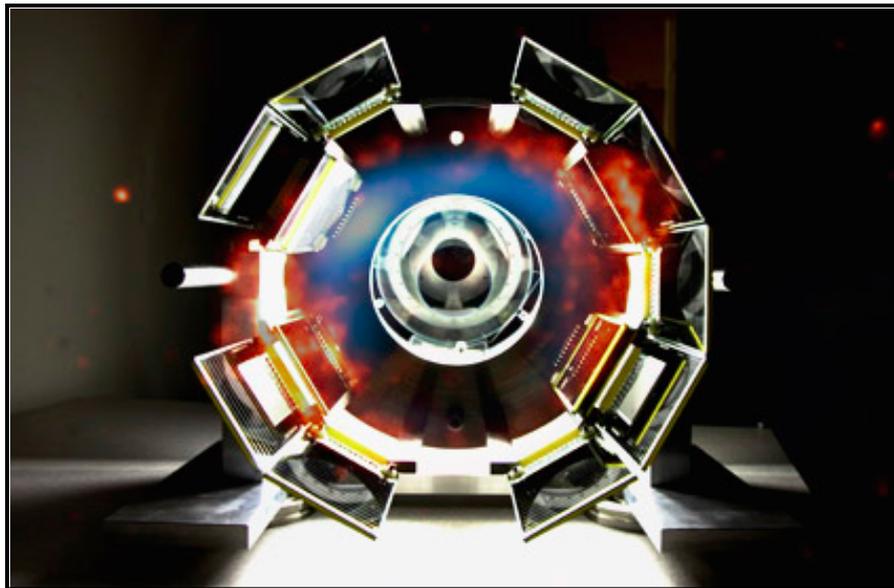


Tools to address compelling questions

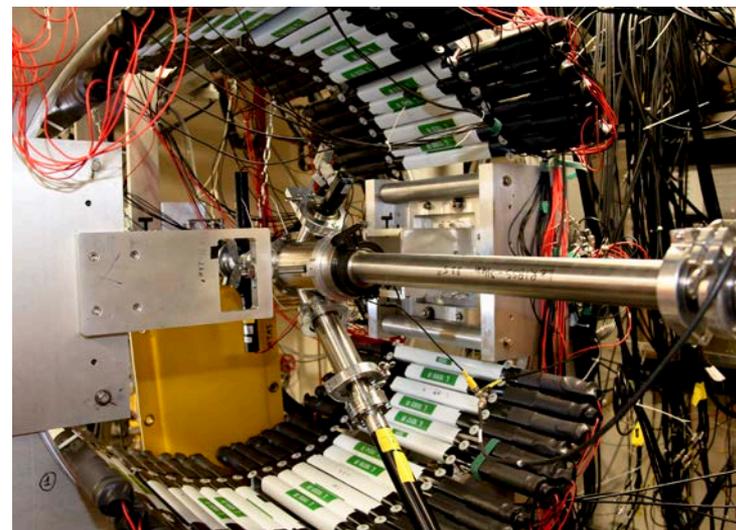




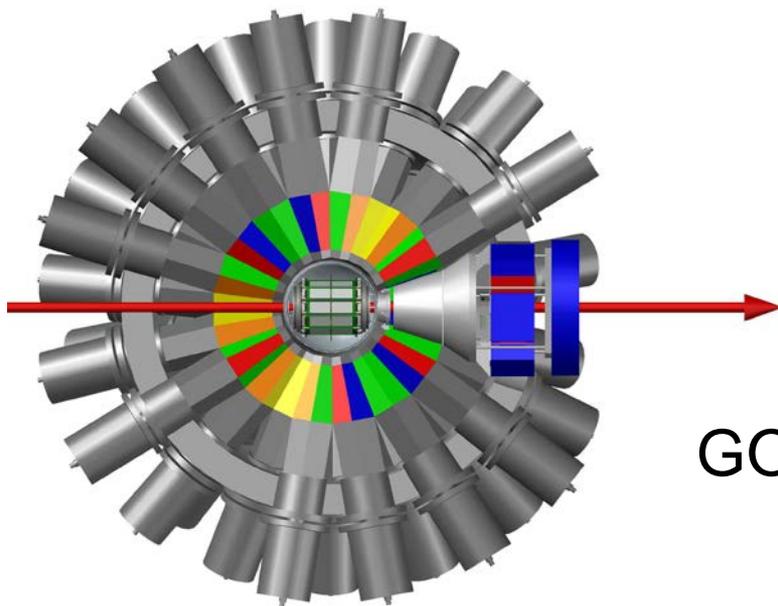
ORRUBA, VANDLE, GODDESS



ORRUBA



VANDLE



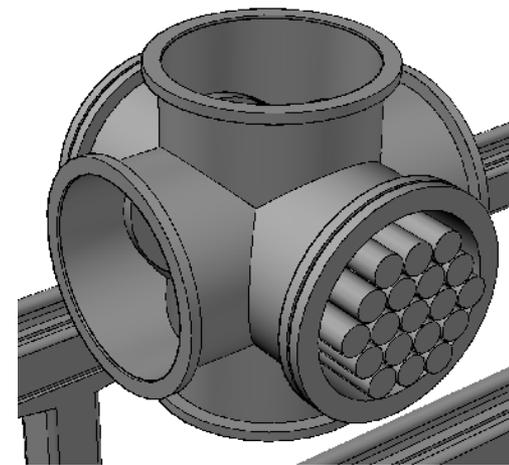
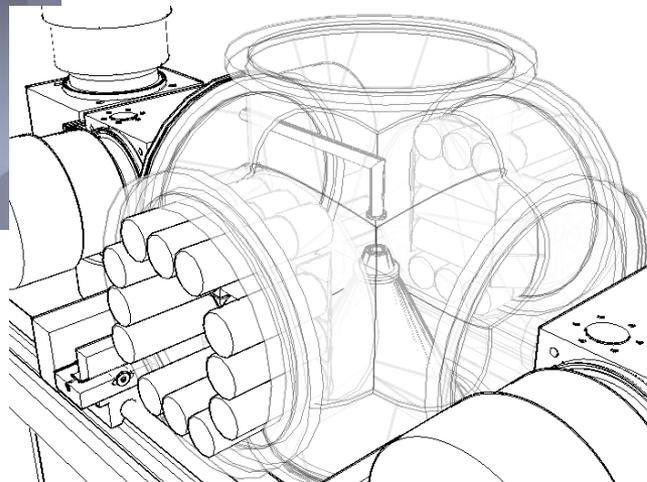
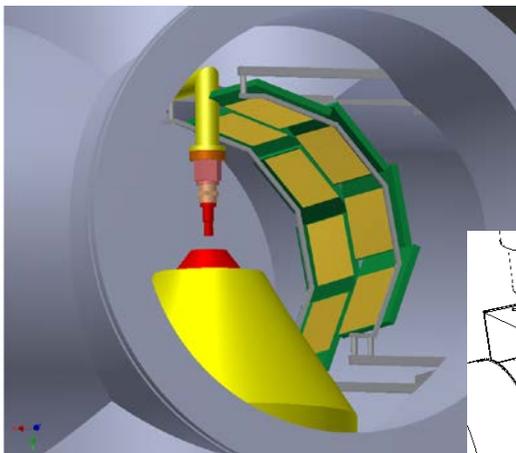
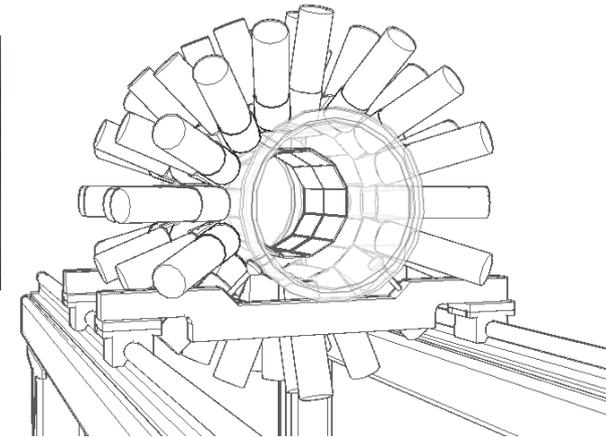
GODDESS



Hybrid Array of Gamma-Ray Detectors

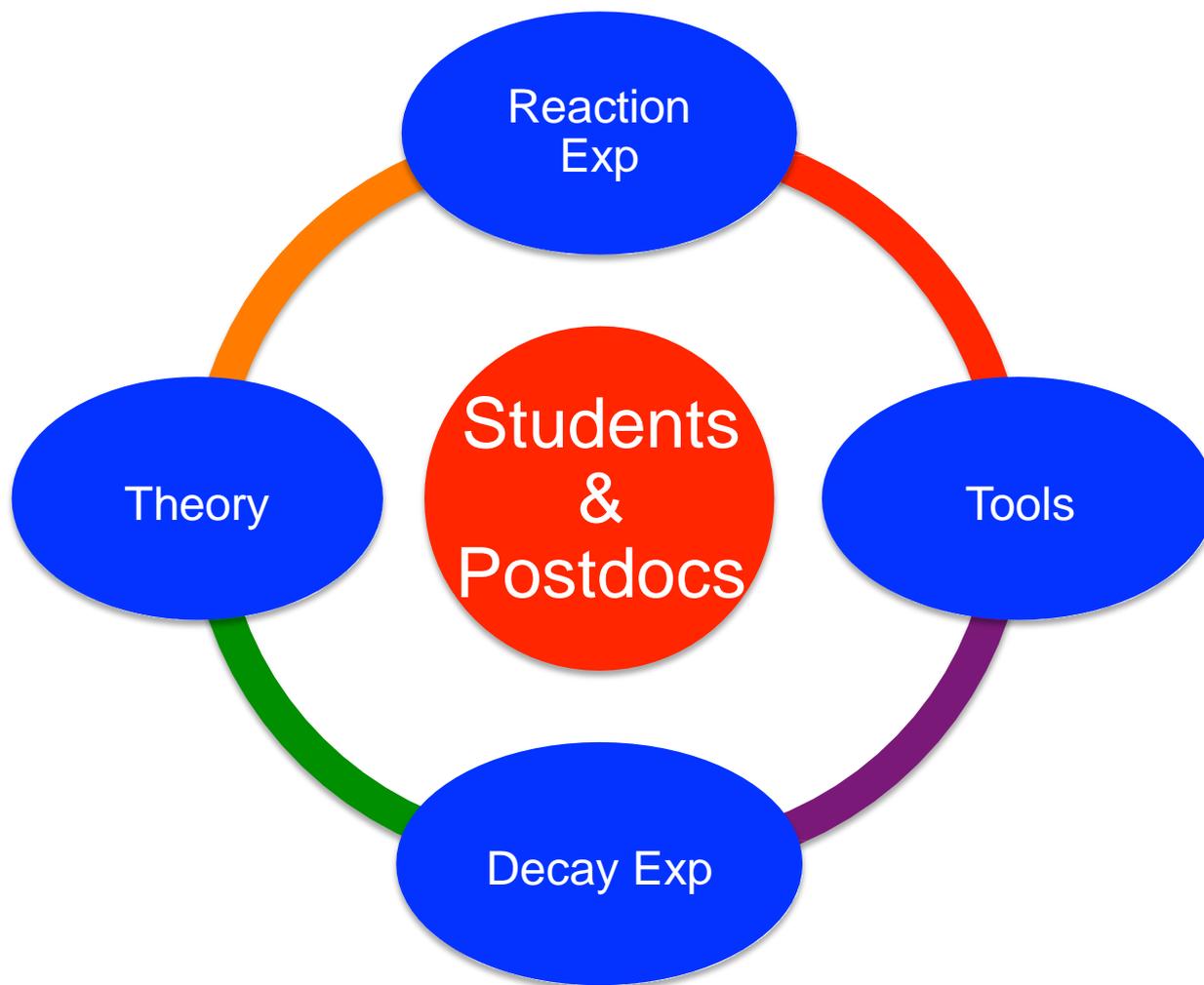
Developing HAGRiD over 5-year project

- Array of LaBr Detectors
- First large order Fall 2015
- Experiments:
 - ORRUBA and solid targets
 - JENSA gas-jet target at ReA3





Addressing compelling questions: need people





Workshops at LANL & LLNL

- Students & postdocs make oral and poster presentations
- Local speaker topics
 - Applied and fundamental research
- Tours of LANSCE facilities (& NIF)

SSAA meetings DC & LANL hosts

- Students & postdocs make oral and poster presentations

8-week practicum –

Kevin Macon (LANL, spring 2014)

- DANCE technical & experiment

Chris Prokop (LLNL, summer 2014)

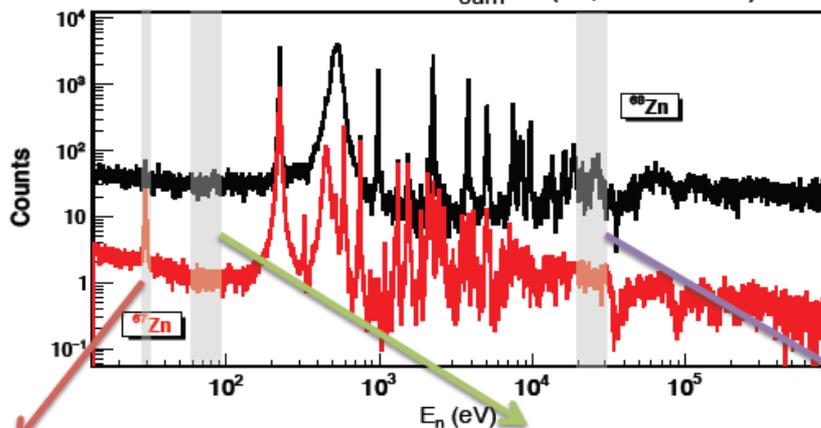
- Production and Spectroscopy of Tb Isotopes for Nuclear Forensics

David Walter (LANL, winter 2015-16)

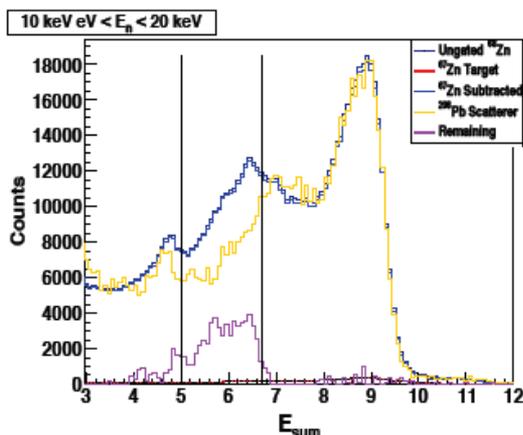
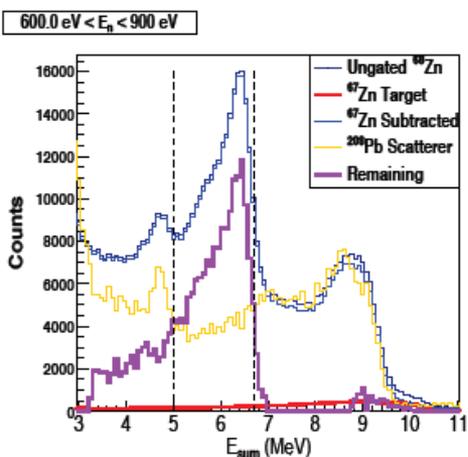
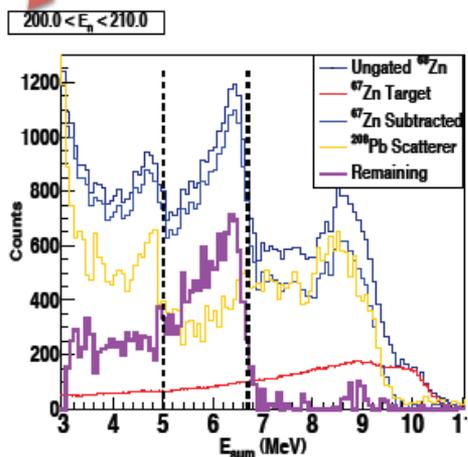
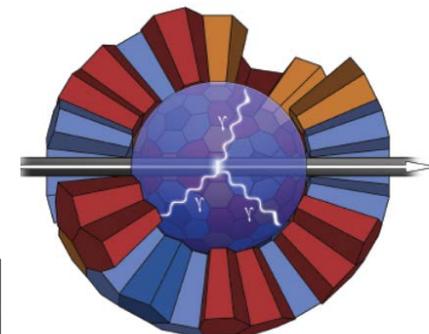
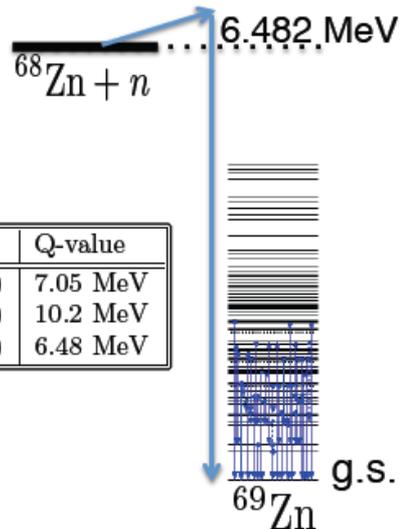


$^{67,68}\text{Zn}(n, \gamma)$ DANCE Data

Events Selected $E_{\text{sum}} = (5, 6.7 \text{ MeV})$



	Q-value
$^{66}\text{Zn}(n, \gamma)$	7.05 MeV
$^{67}\text{Zn}(n, \gamma)$	10.2 MeV
$^{68}\text{Zn}(n, \gamma)$	6.48 MeV

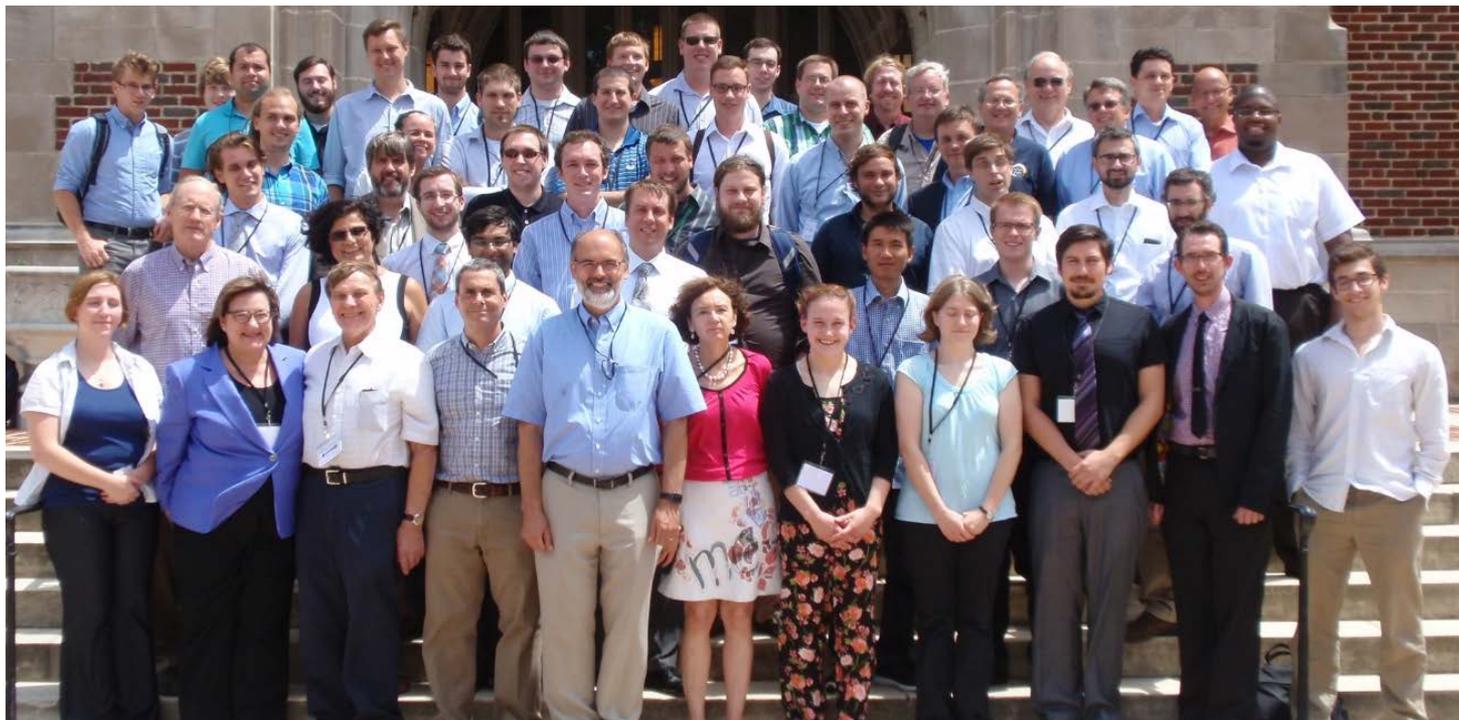




Recent Placements

- Brett Manning (LANL, PD)
- Karolina Kolos (LLNL, PD)
- Andrew Ratkiewicz (LLNL, PD)

Scientific Advisory Committee Meeting (July 2015)



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FOR STEWARDSHIP SCIENCE



Thank you

Overview of the

Center for Radioactive Ion Beam Studies for Stewardship Science

Supported in part by the U.S. Department of Energy
National Nuclear Security Administration under the
Stewardship Science Academic Alliances program