Constraining ^{135}Xe(n,γ) through β-Oslo Measurements of ^{136}I decay

NDIAWG Project Update

Workshop for Applied Nuclear Data Activities (WANDA) 2026

February 10, 2026

Darren Bleuel, Sean Liddick, Stephanie Lyons, Andrea Richard, Artemis Spyrou, Adriana Sweet, and Mathis Wiedeking

This work was supported by the Office of Defense Nuclear Nonproliferation Research and Development within the U.S. Department of Energy's National Nuclear Security Administration and performed under the auspices the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and Berkeley Lab under Contract AC02-05CH11231.

The Collaboration

Subcontract

Lead Institution

Lawrence Livermore National Laboratory

Darren Bleuel
Lead PI

Adriana Sweet
β-Oslo expert

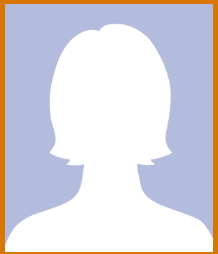
OHIO UNIVERSITY 1804

Andrea Richard
Student Advisor

Austin Rambo
Student

Pacific Northwest NATIONAL LABORATORY

Stephanie Lyons
Postdoc Advisor



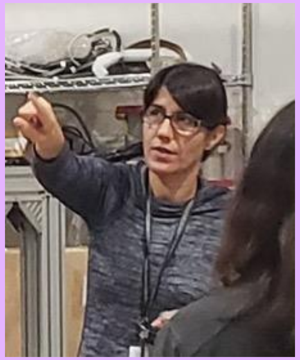
TBD (TAS)
Postdoc

BERKELEY LAB

Mathis Wiedeking Inventor of Shape Method

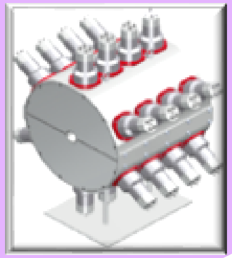
Unfunded partner

FACILITY FOR RARE ISOTOPE BEAMS at Michigan State University



Artemis Spyrou
Inventor of β-Oslo

Sean Liddick

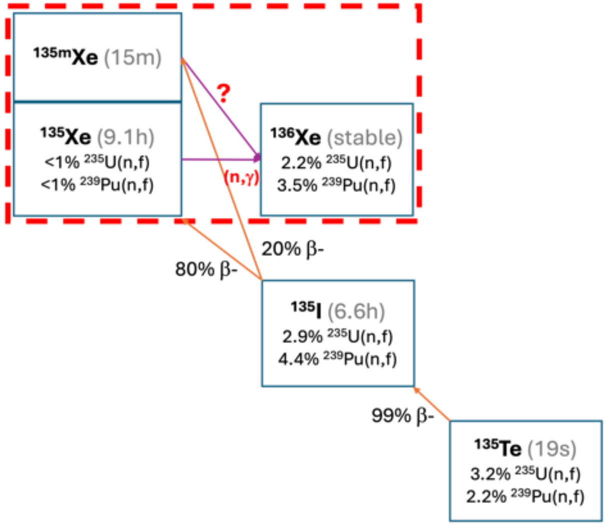


Equipment: SuN Total Absorption Spectrometer

Thanks to the whole team for their hard work!

Motivation

- ^{135}Xe is a well-known neutron poison in nuclear reactors due to its unusually-large absorption cross section.
- Knowledge of its burnup rate is critical (ha!) to reactor operation as well as atmospheric monitoring for nuclear safeguards [1].
- However, the ^{135}Xe(n,γ) cross section is famously unknown at energies higher than thermal.



[2] Yang, W. S. *Nuclear Engineering and Technology*, 44(2), 722 (2012).

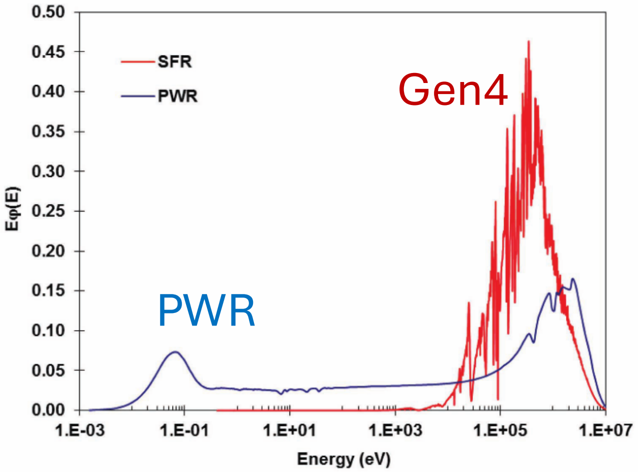
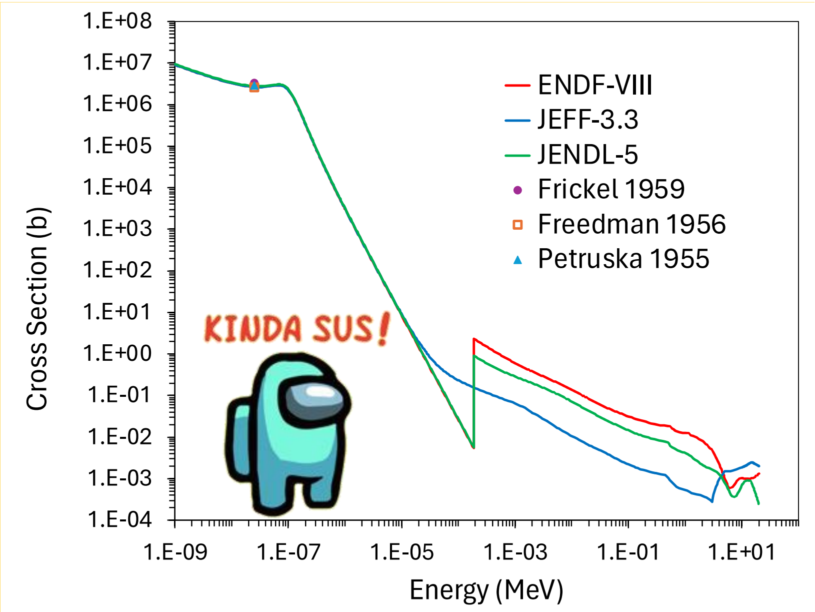


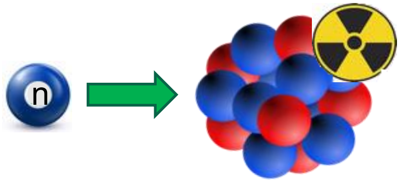
Fig. 7. Neutron Flux Spectra of Thermal (PWR) and Fast (SFR) Reactors



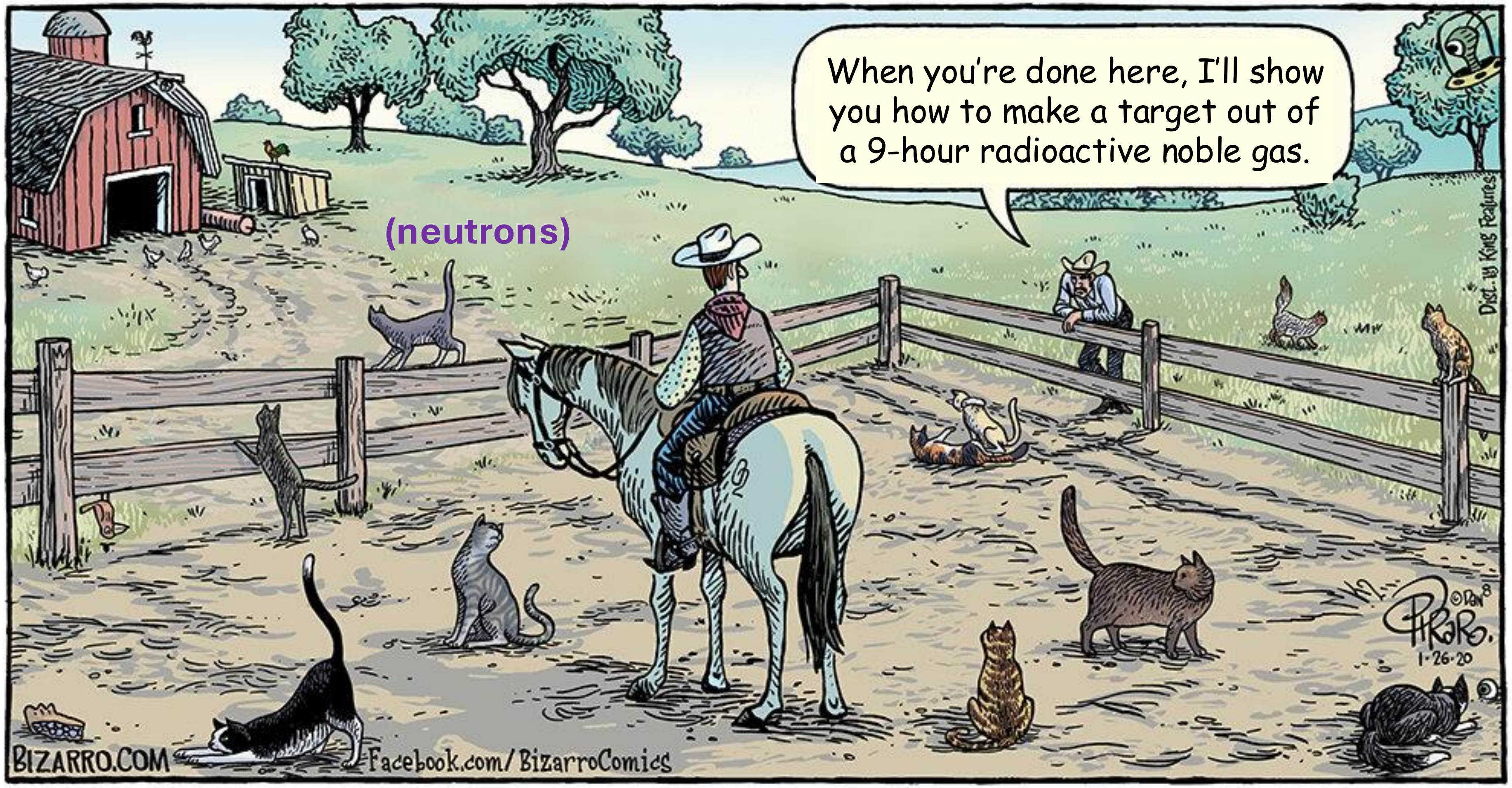
But how do we measure neutron reactions on a gaseous, radioactive target?

[1] J. Carlson,, *et al.*, Progress in Particle and Nuclear Physics 94, 68 (2017)

The problem



^{135}Xe

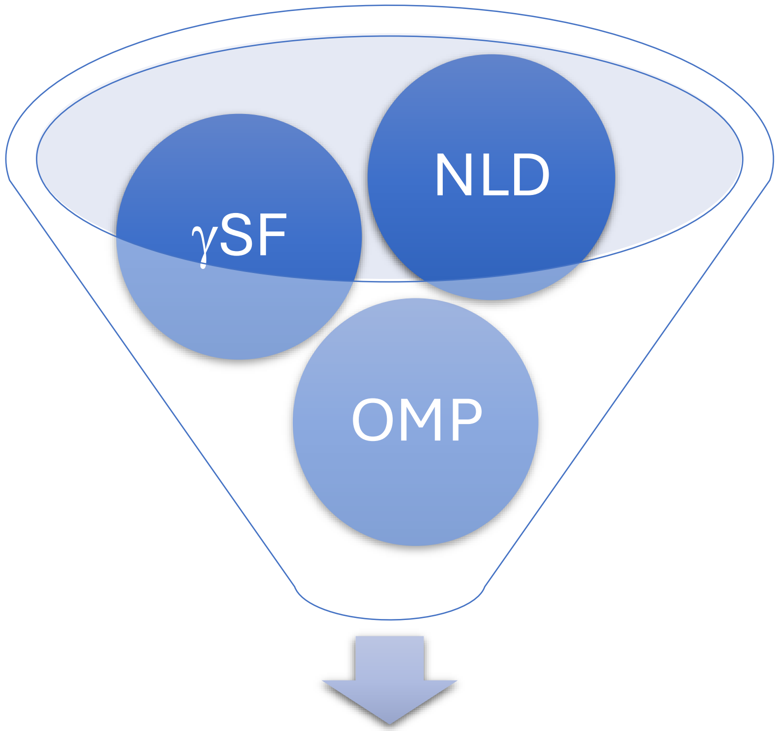


Thank you Dan Piraro!

The solution – Indirect methods to measure fundamental nuclear properties as inputs to predictive theory codes

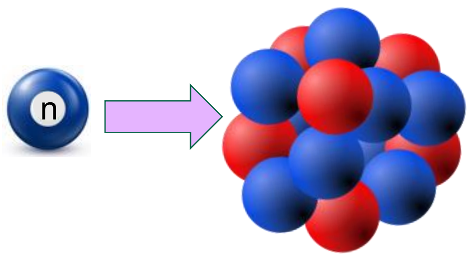
Hauser-Feshbach codes such as **TALYS** use **three** fundamental nuclear properties to predict **cross sections**:

- Optical Model Potential (**OMP**)
- Nuclear Level Density (**NLD**)
- Gamma-ray Strength Function (***γ*SF**)



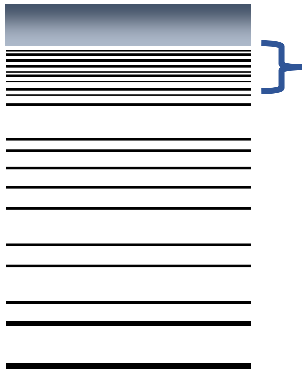
(n,γ) cross section

OMP



i.e: “Will it neutron?”

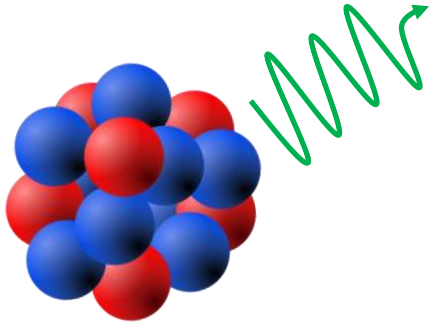
NLD



^{136}Xe

How many ways?

***γ*SF**



“Will it gamma?”

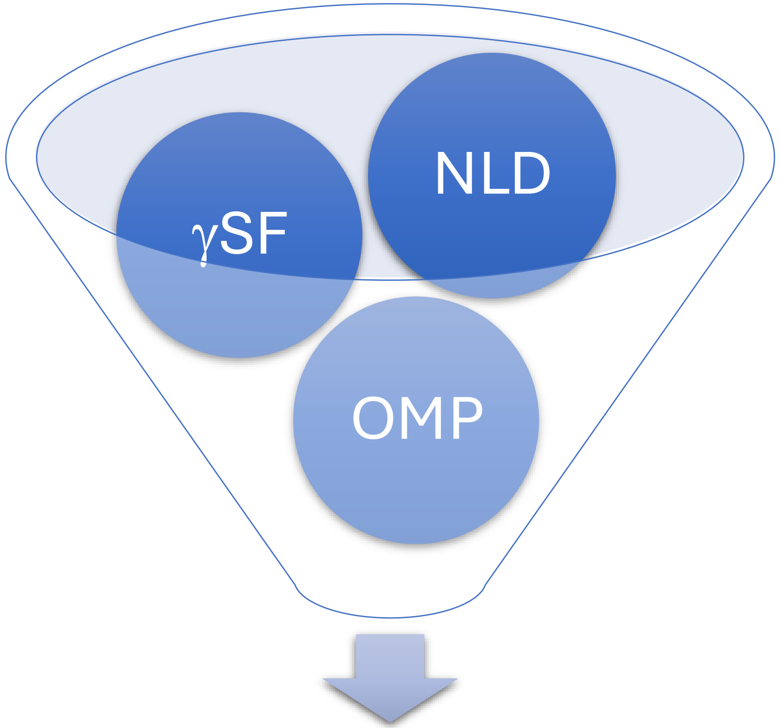
NLD and γSF measurements provide constraints on (n,γ) cross sections

[1] M. Guttormsen, et. al, Phys. Rev. C **90**, 044309 (2014). [2] Wiedeking et al., PRL **108**, 162503 (2012)

The solution – Indirect methods to measure fundamental nuclear properties as inputs to predictive theory codes

Hauser-Feshbach codes such as **TALYS** use **three** fundamental nuclear properties to predict **cross sections**:

- Optical Model Potential (**OMP**)
- Nuclear Level Density (**NLD**)
- Gamma-ray Strength Function (***γ*SF**)



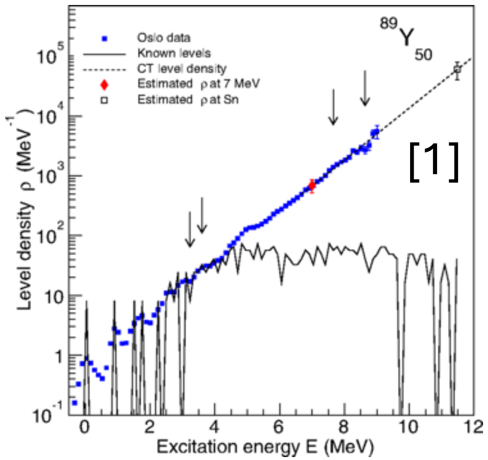
(n,γ) cross section

OMP

"Generally predictable by theory"

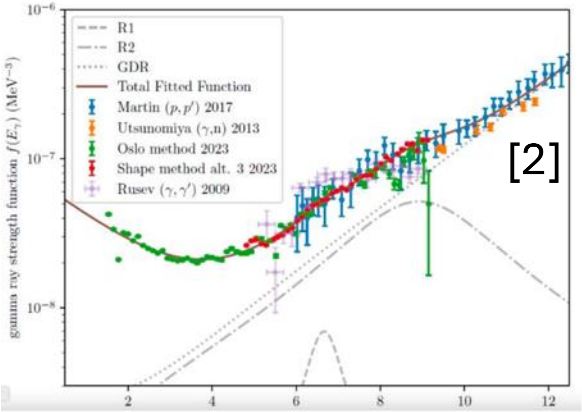
i.e: "Will it neutron?"

NLD



How many ways?

***γ*SF**



"Will it gamma?"

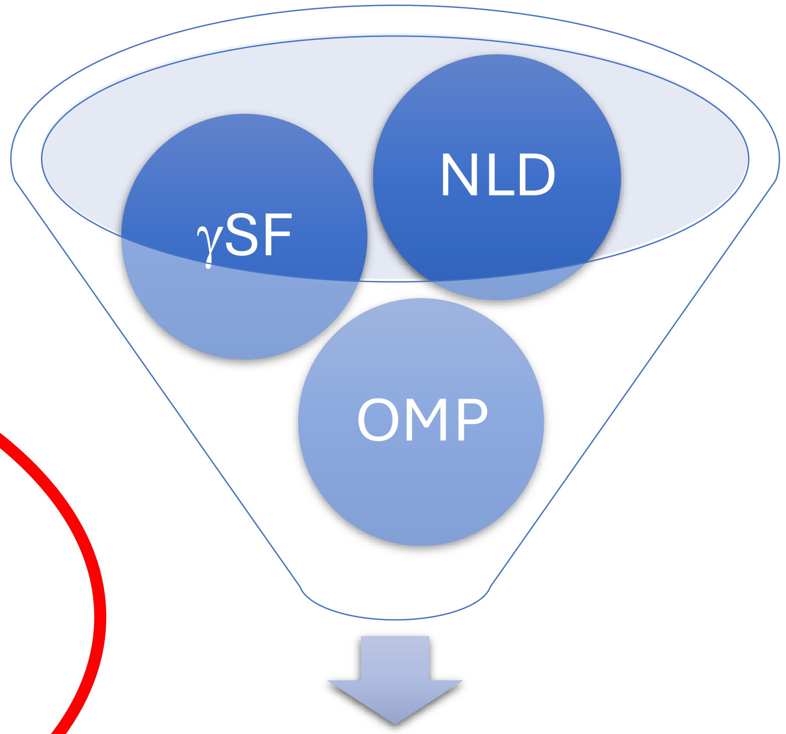
NLD and γSF measurements provide constraints on (n,γ) cross sections

[1] M. Guttormsen, et. al, Phys. Rev. C **90**, 044309 (2014). [2] Wiedeking et al., PRL **108**, 162503 (2012)

The solution – Indirect methods to measure fundamental nuclear properties as inputs to predictive theory codes

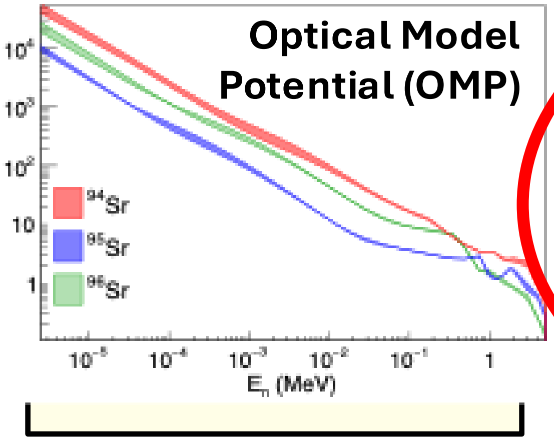
Hauser-Feshbach codes such as **TALYS** use **three** fundamental nuclear properties to predict **cross sections**:

- Optical Model Potential (**OMP**)
- Nuclear Level Density (**NLD**)
- Gamma-ray Strength Function (**γSF**)



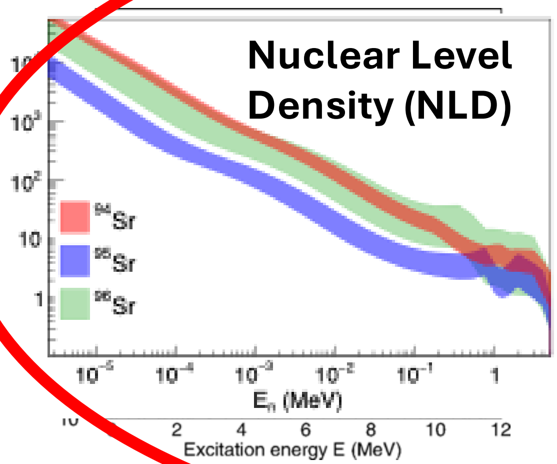
(n,γ) cross section

OMP



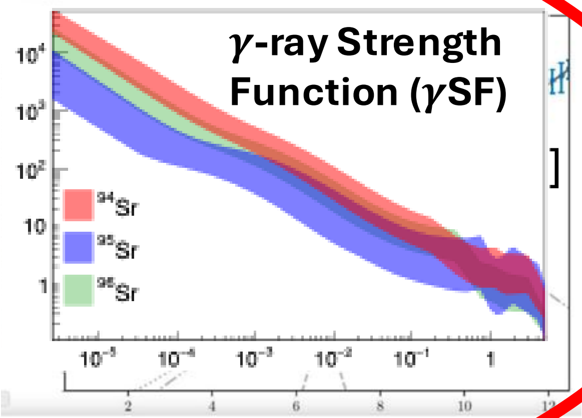
i.e: "Will it neutron?"

NLD



How many ways?

γSF

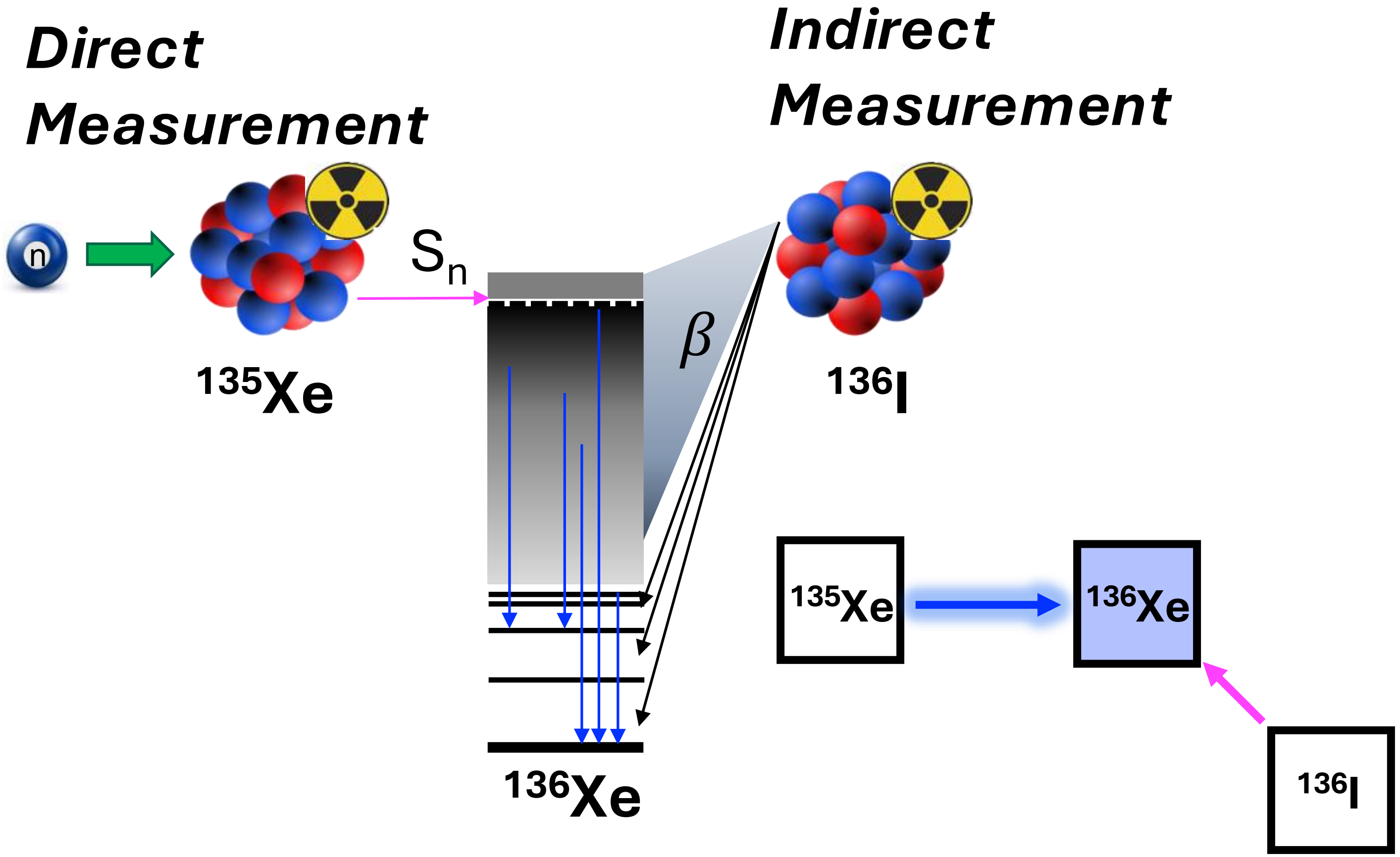


"Will it gamma?"

NLD and γSF measurements provide constraints on (n,γ) cross sections

[1] M. Guttormsen, et. al, Phys. Rev. C **90**, 044309 (2014). [2] Wiedeking et al., PRL **108**, 162503 (2012)

The β-Oslo method



The *Oslo Method* is an iterative procedure to obtain the **NLD** and **γSF** from a matrix of gamma-rays emitted vs excitation energy.

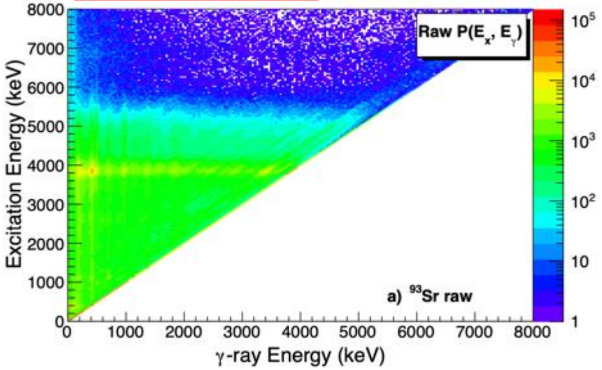
1. Measure E_x & E_γ
2. Extract **NLD** & **γSF**
3. **Normalize** using auxiliary nuclear data and/or estimates
4. Constrain the **σ(n,γ)**

But where do we measure this data?

Analysis (example of ^{93}Sr)

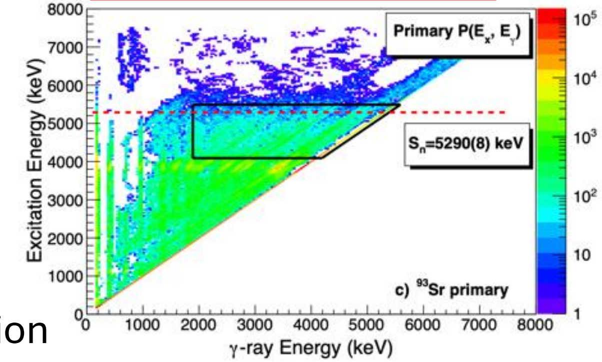
A. Sweet, *et al.*, Phys. Rev. C **109**, 054305 (2024).

Raw data



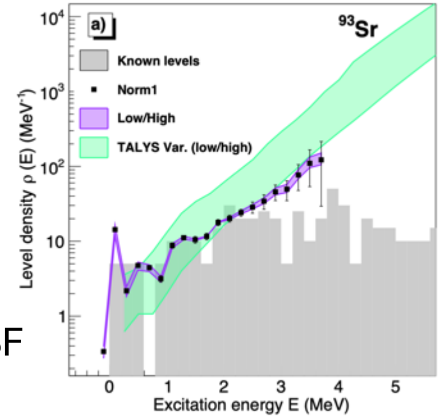
Unfold +
Oslo Iteration

Primary gammas

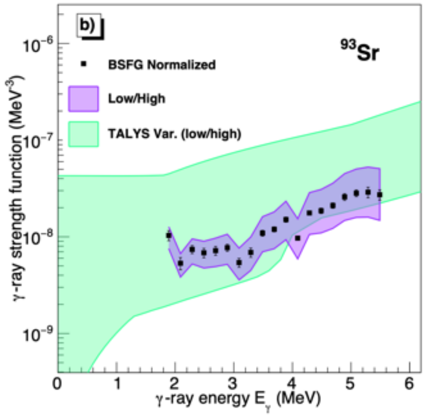


Extract
NLD/γSF

NLD

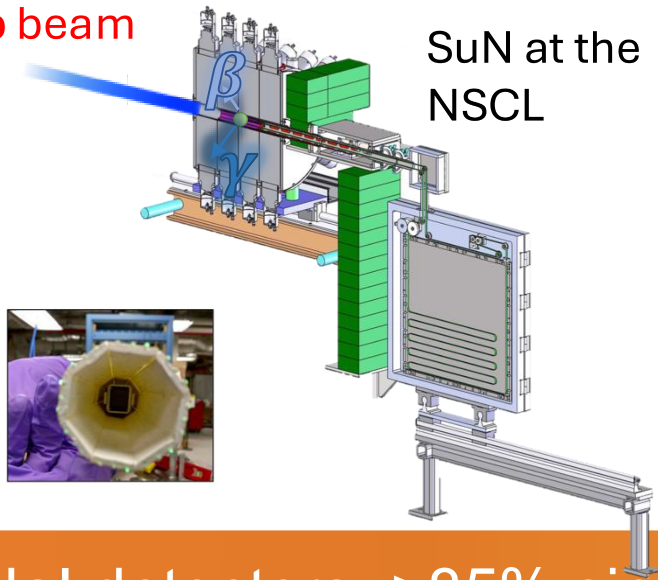


γSF



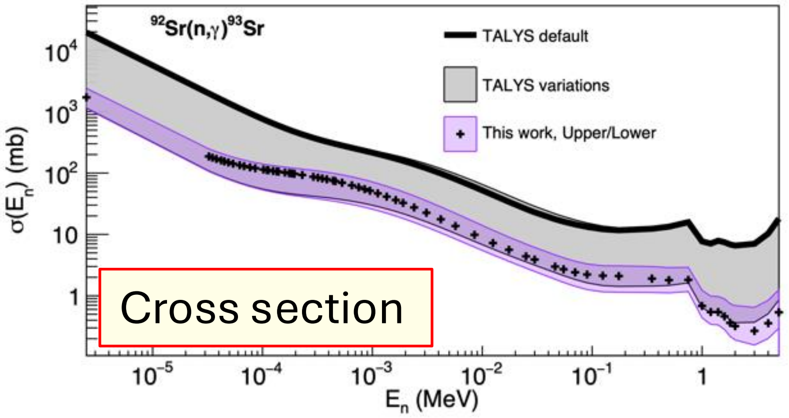
1. Measure E_x & E_γ
2. Extract **NLD** & γ**SF**
3. **Normalize** using auxiliary nuclear data and/or estimates
4. Constrain the σ**(n,**γ**)**

^{93}**Rb** beam



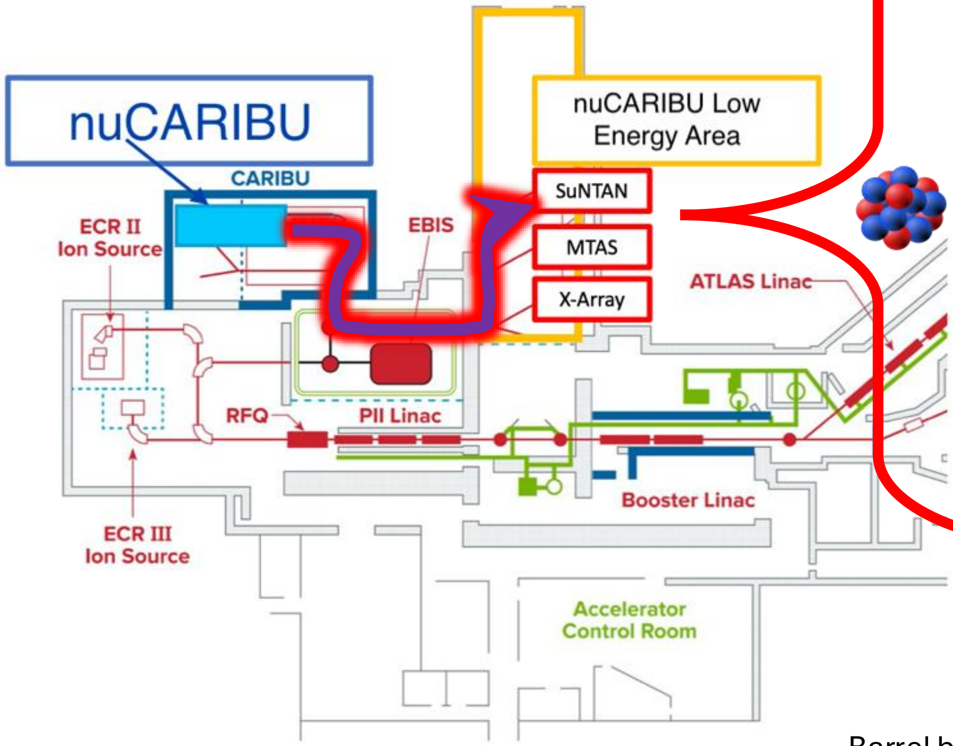
SuN at the NSCL

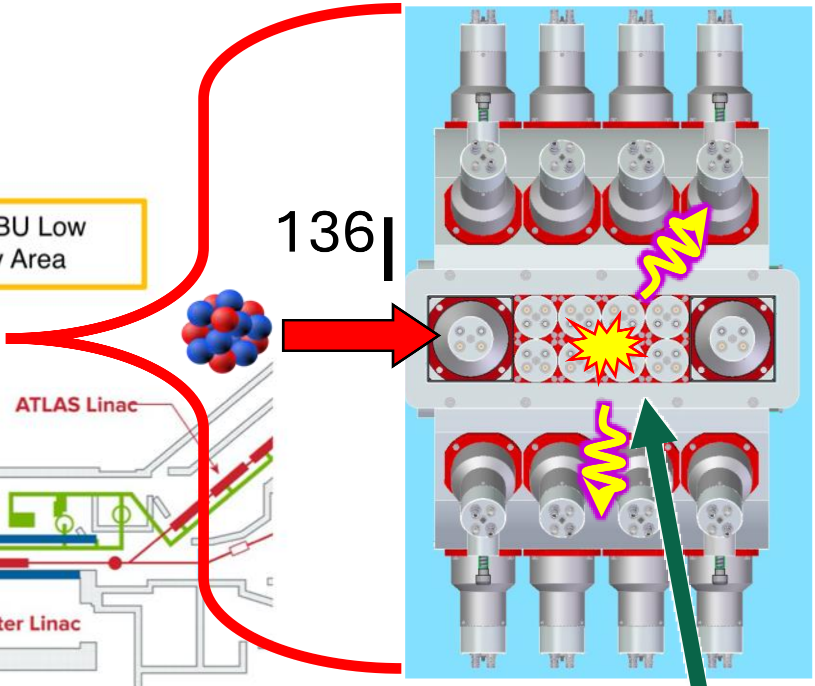
Apply normalization factors + Hauser-Feshbach code

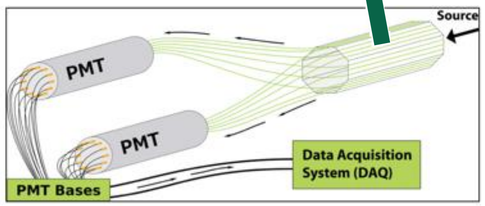


SuN consists of 8 NaI detectors, >85% single-γ efficiency @ 1 MeV

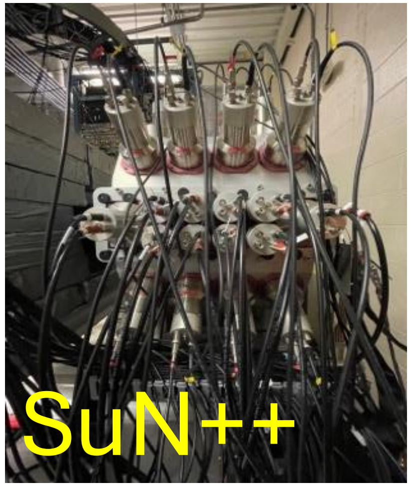
Total Absorption Spectrometry (TAS) with the Summing Sodium Iodine Spectrometer at the nuCARIBU Facility (ANL)



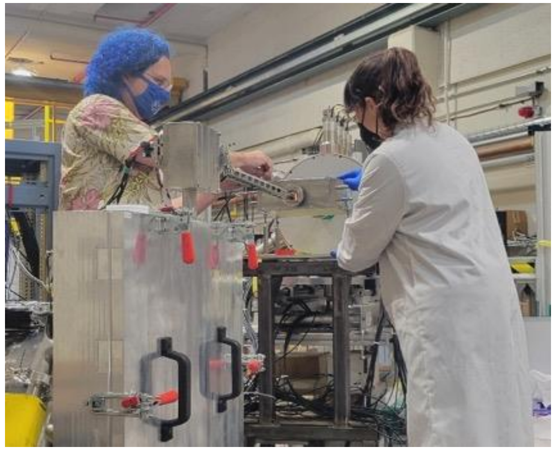




Barrel beta detector



Dr. Darren Bleuel (left) & Dr. Adriana Sweet (right)



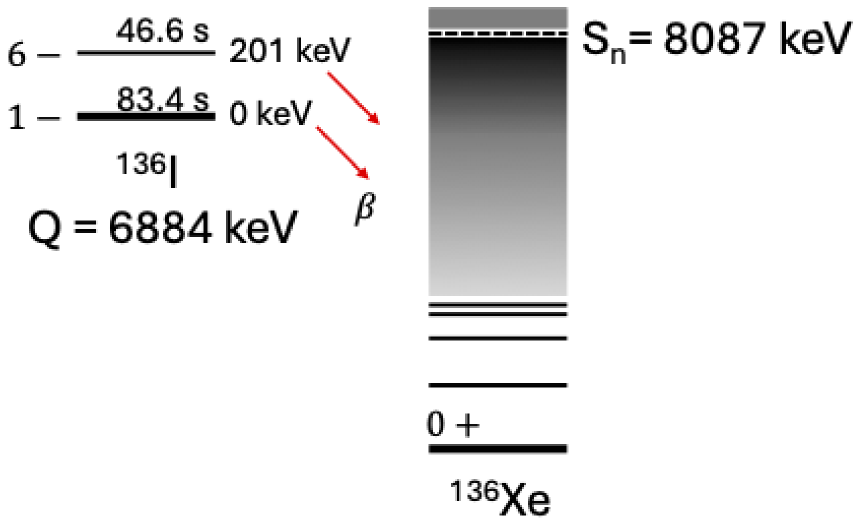
^{136}I atoms from n+U fission are transported to and implanted in the SuN++ TAS detector, where gamma rays are detected in coincidence with beta particles. The sum of all gammas determines the excitation energy.

nuCARIBU is finalizing commissioning and scheduled our experiment: <u>May 4-9, 2026!</u>

Two nuCARIBU experiments planned to probe spin selectivity

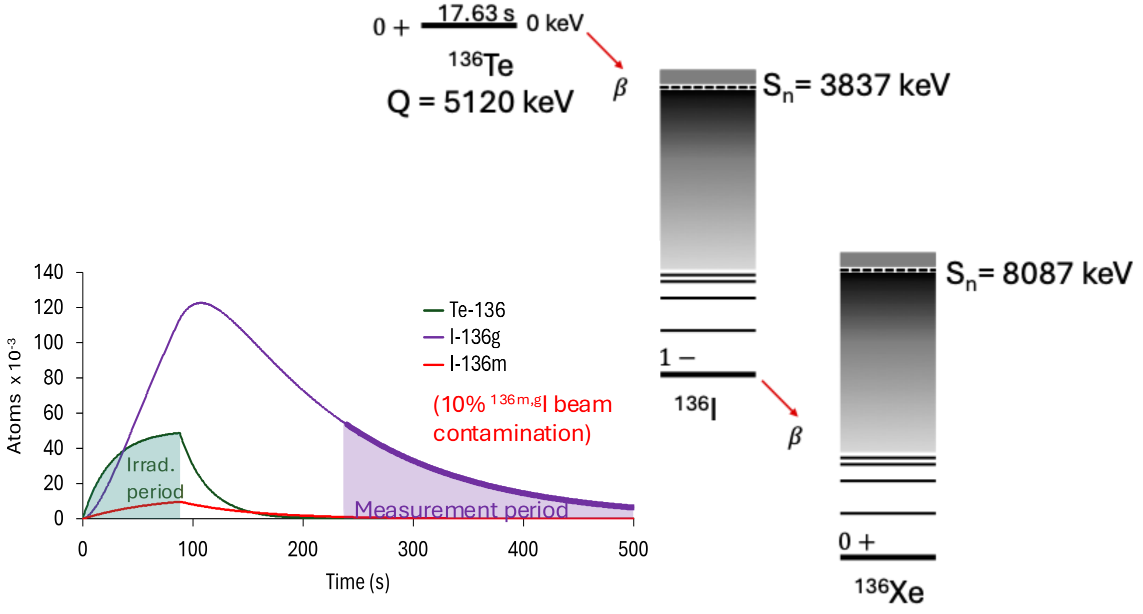
Exp **#1**: ^{136}I beam, Mixed iso./g.s.

Spins populated in ^{136}Xe: L = 0^-, 1^-, 2^-, 5^-, 6^-, 7^-



Exp **#2**: ^{136}Te beam—^{136}I g.s. only

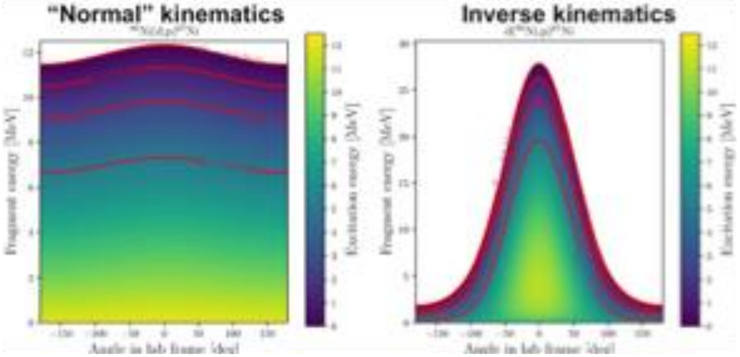
Spins populated in ^{136}Xe: L = 0^-, 1^-, 2^-



Not expected to work, but we will also try to separate iso from g.s. with MRTOF

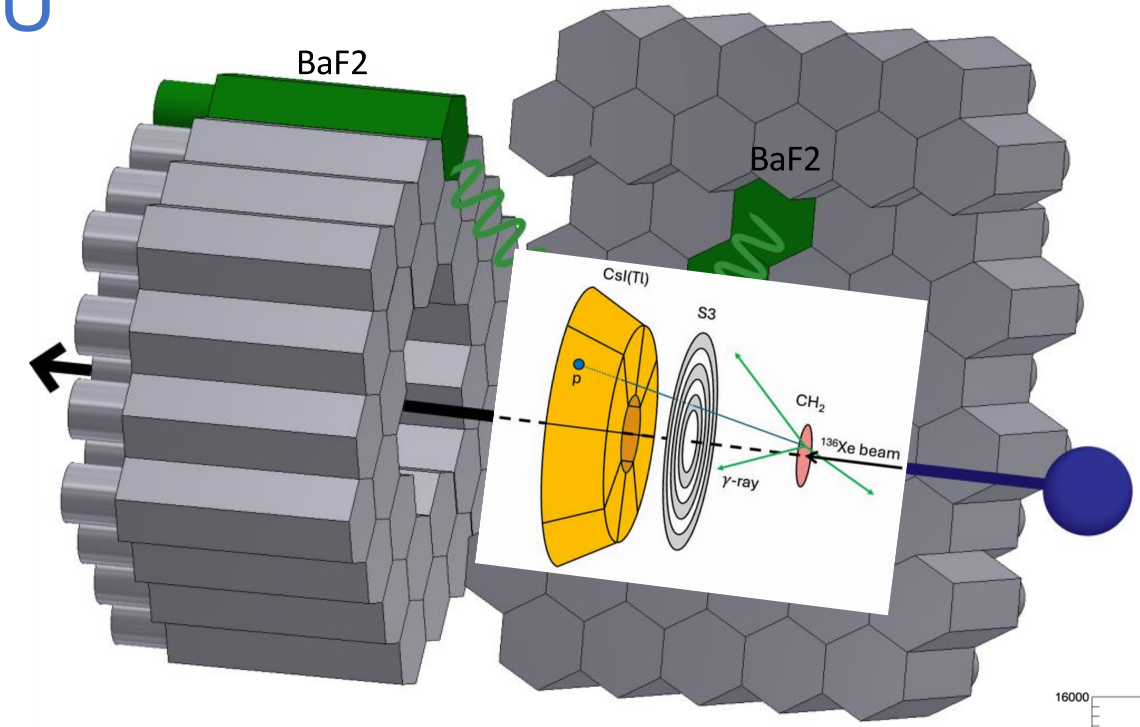
Stretch goal!: Inverse Oslo at TAMU

We are adapting the **DAPPER** capability at Texas A&M to perform the same measurement using the ***inverse Oslo method***.



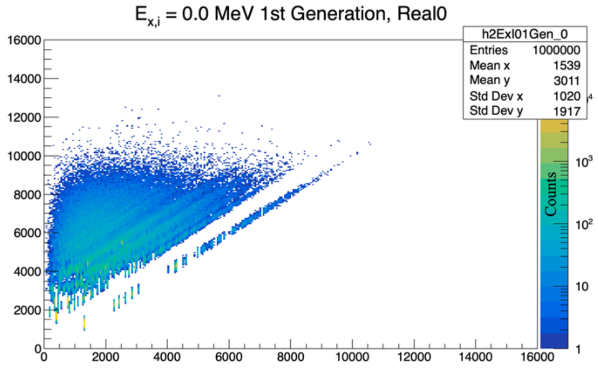
Ingeberg, Neutron Capture Workshop, Huizhou China 2023

Measuring the same quantity with multiple methods lends confidence in the results!*



Currently upgrading the target chamber and detectors to enable forward angle proton detection.

See Austin Rambo's poster yesterday for more details on modeling both these experiments!

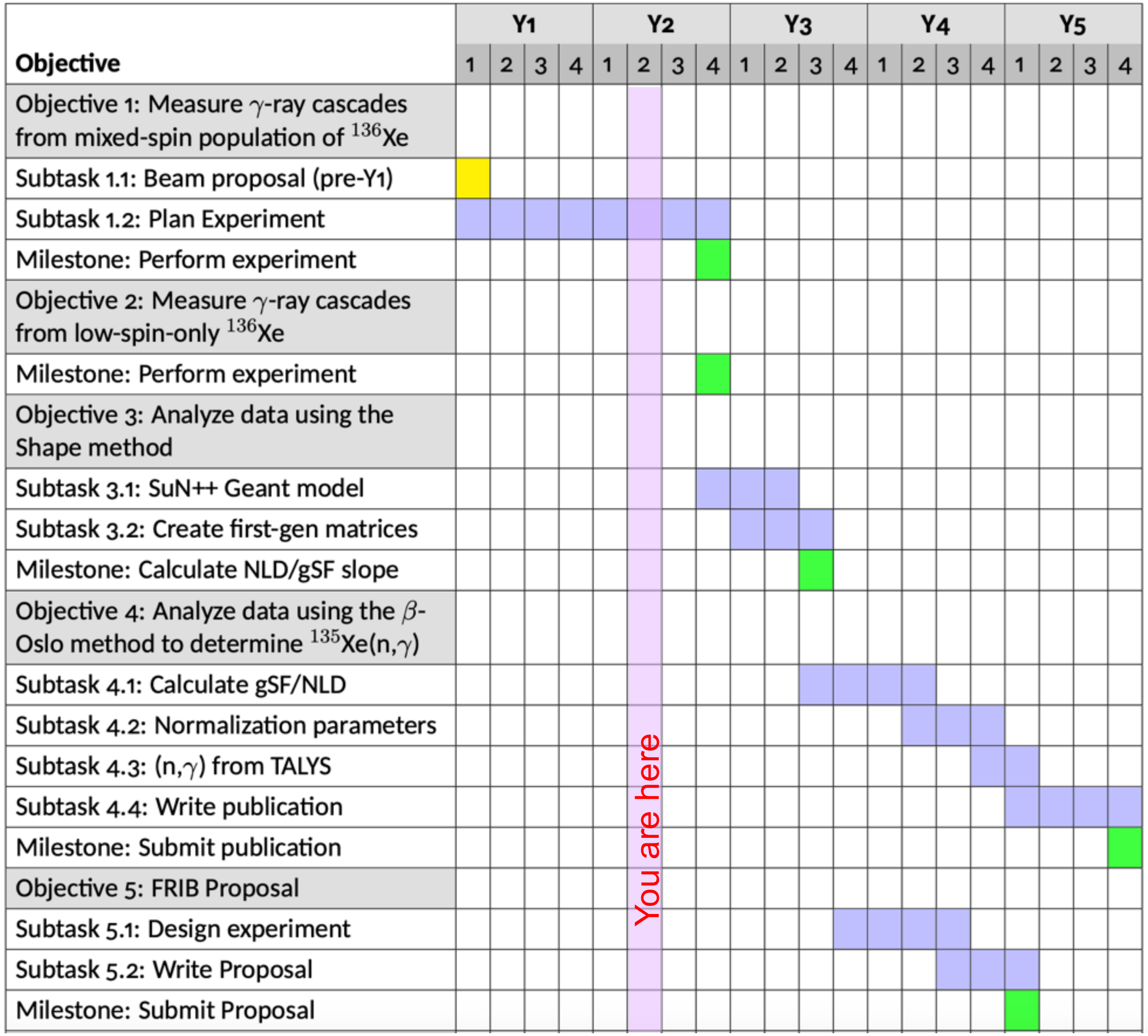


***or not**

Timeline

Select Deliverables/Milestones:

- Y1: Beam time proposal ✓
- Y2: Perform experiment
- Y3/4: Calculate NLD/γSF
- Y4: Student presentation
- Y4: FRIB experiment designed
- Y5: Cross section publication written



FRIB proposal submission dependent on assessed need

Summary

- The $^{135}Xe(n,\gamma)$ has been identified as a top priority for both Gen 4 reactor design and nuclear safeguards.
- We have the method, the expert team, and the beam time to provide not only this measurement, but a robustness test of the method itself.
- To mitigate risk (and train our student), we are now pursuing *two* complementary experiments. Beta-Oslo at nuCARIBU is currently winning the race (May 2026).
- Thank you for this opportunity! Risks low! Spirits high!

Thank you!

Main risk _was_ commissioning of nuCARIBU. Stay tuned for Facilities/Instrumentation!

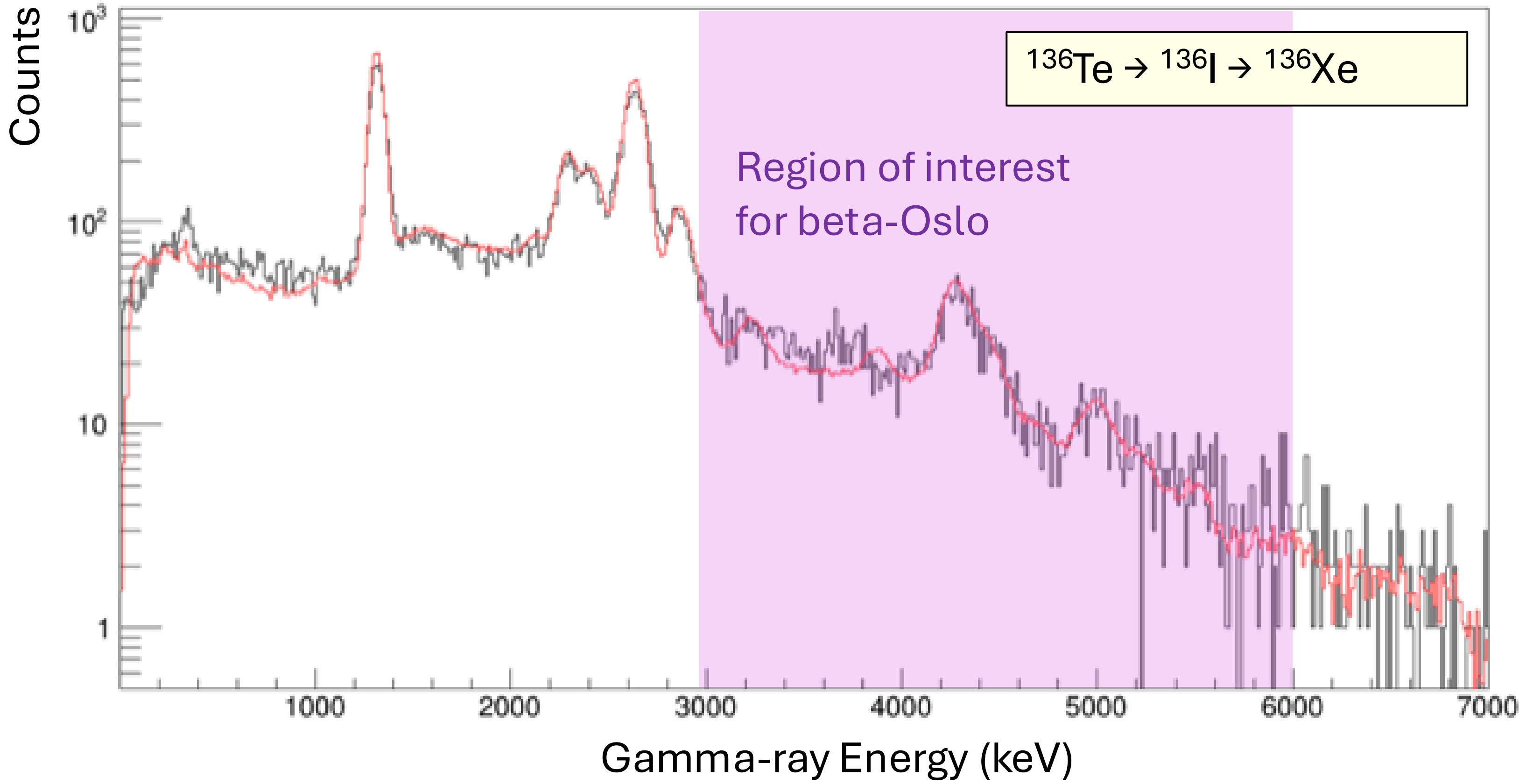
Extra Slides

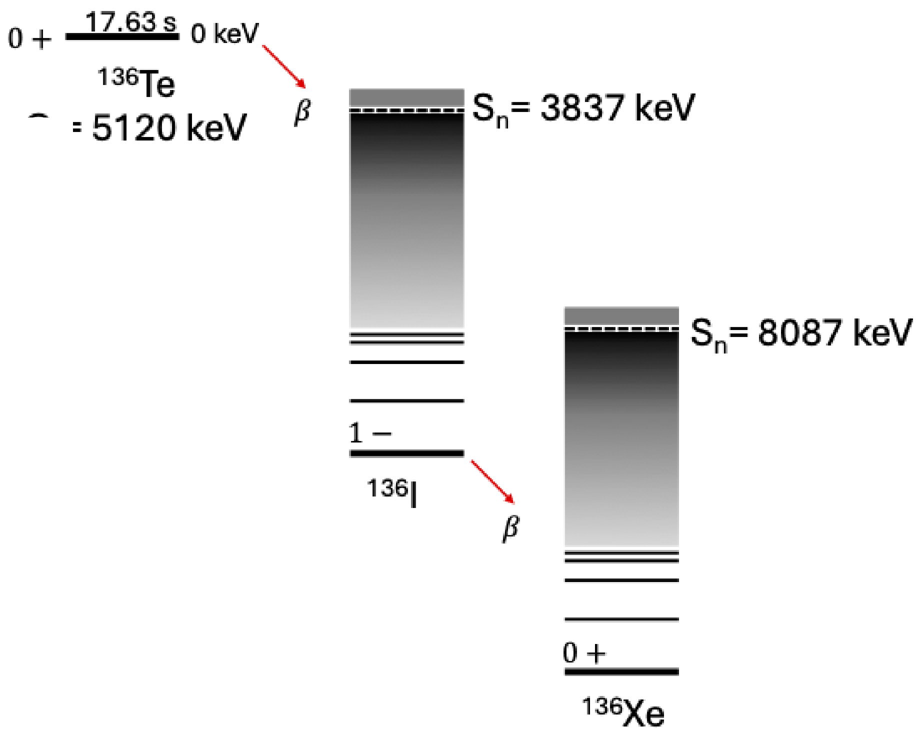
Improvements to previous beta-Oslo measurements

- Unlike neutron-rich isotopes, ^{136}Xe is stable and normalization parameters (**$<\Gamma_\gamma>$** and **D_0**) in this region are better known and measured.
- The stability of ^{136}Xe also means **no background** from its subsequent decay.
- Available beam rates are extremely high compared to neutron-rich isotopes, allowing not just **improved statistics**, but the freedom to test aspects of the method itself.
- Beta decay is a spin-restricted process. We will conduct a campaign to populate a **range of spin states** in ^{136}Xe to probe the effect of spin.

Tell me more about these spin-selection experiments!

Proven success?





Members of our team have observed ^{136}Xe once before—adequate gamma rate