Constraining the Neutron Capture Rate for ^{90}Sr through β-Decay into the Short-Lived ^{91}Sr Nucleus

WNPPC, Feb. 15 2024

Beau Greaves

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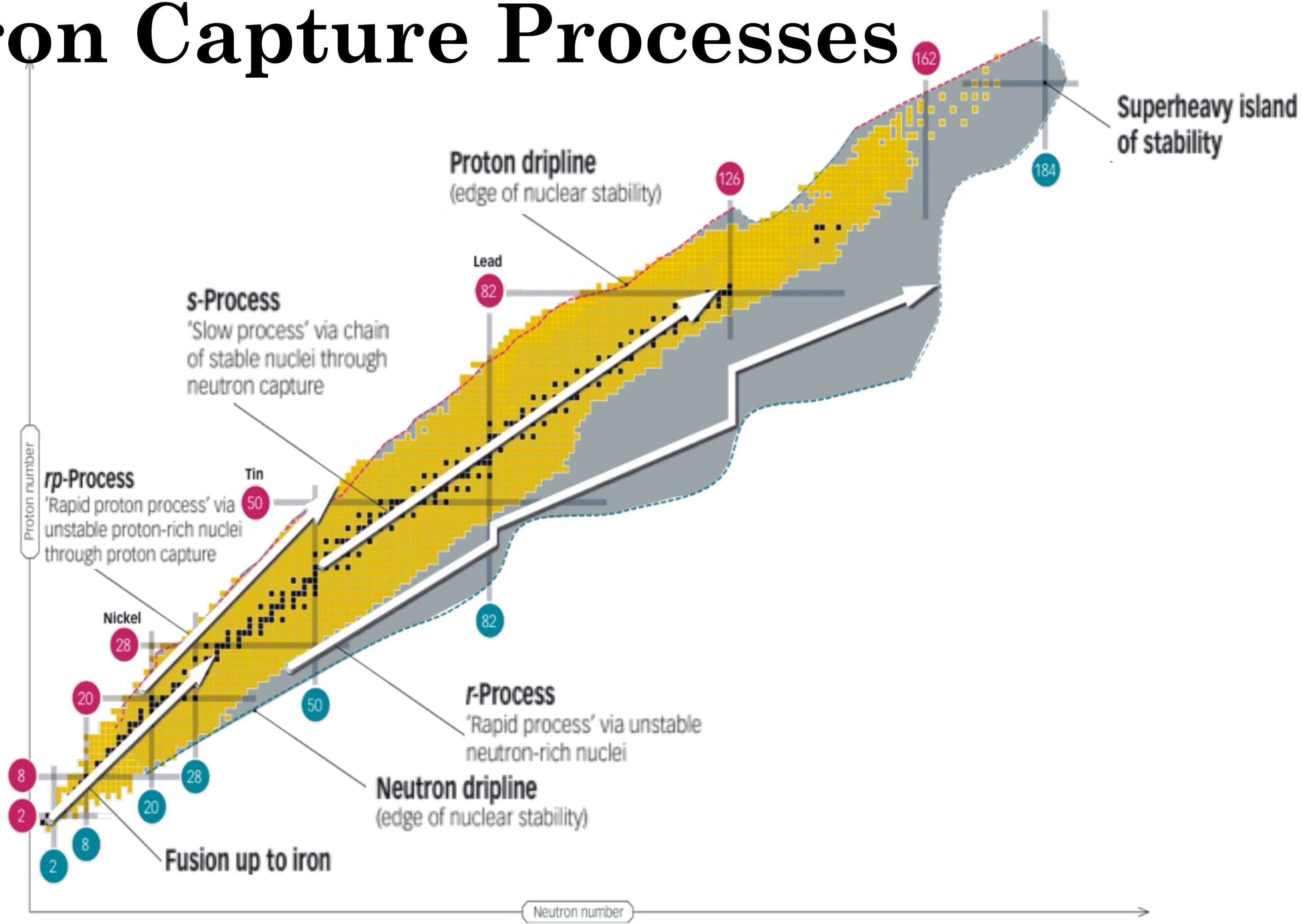
Neutron Capture Processes



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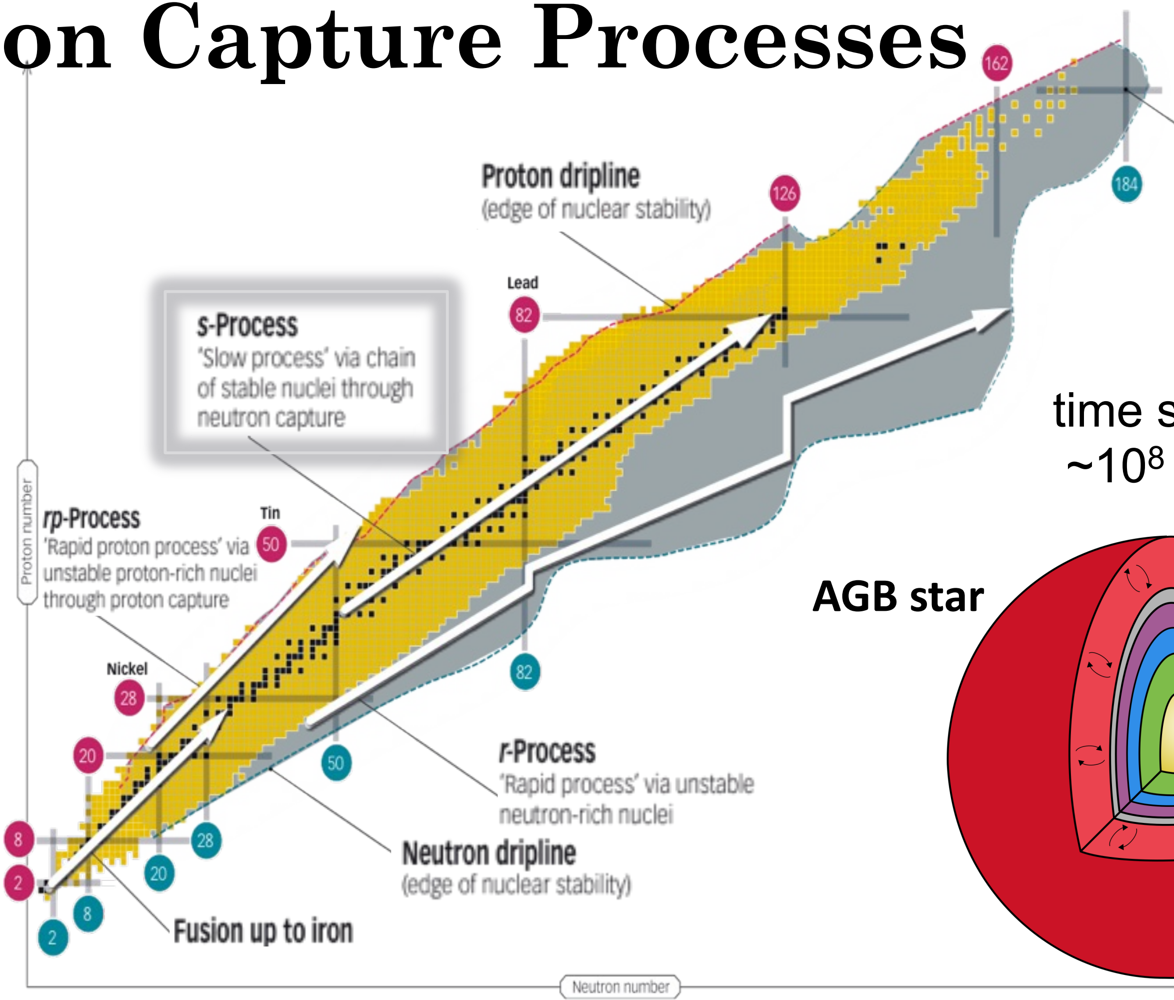
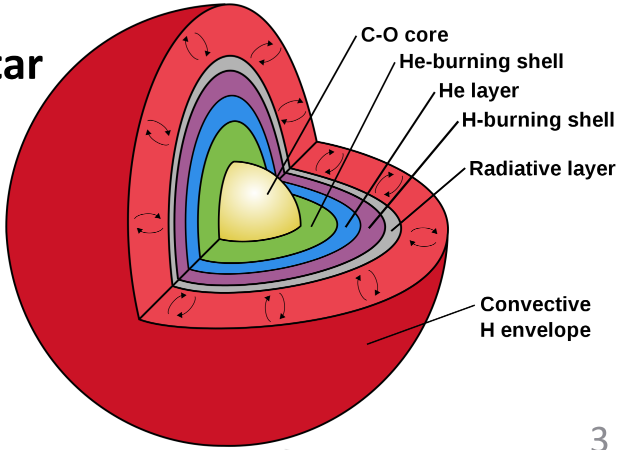


time scale: 100+ years

$\sim 10^8$ neutrons/cm^3

AGB star



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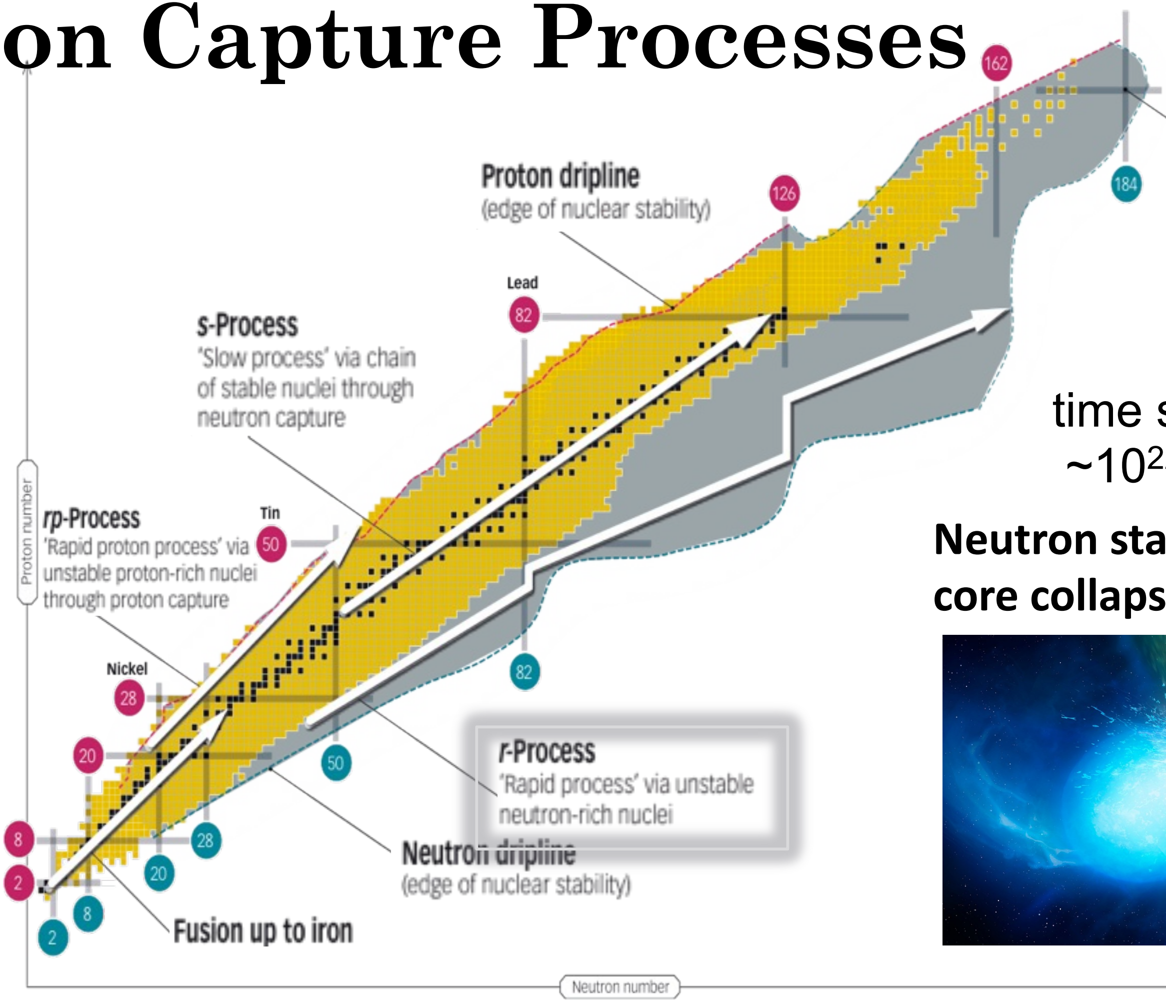
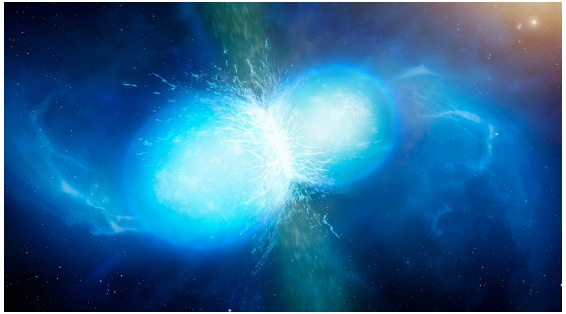


time scale: 10 seconds

~10^{22} neutrons/cm^3

Neutron star mergers & core collapse supernova



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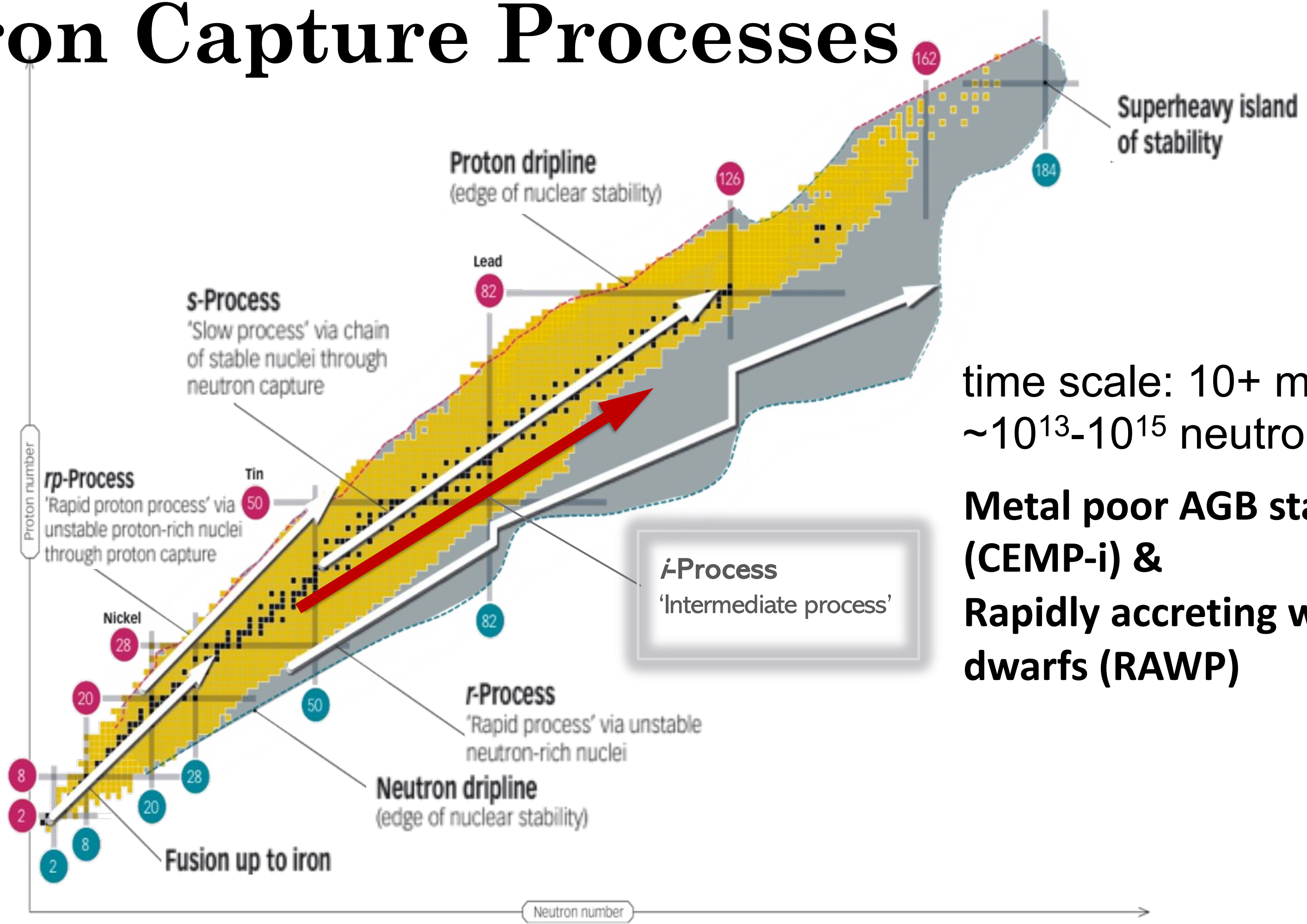

time scale: 10+ minutes
~10^{13}-10^{15} neutrons/cm^3

Metal poor AGB stars (CEMP-i) &
Rapidly accreting white dwarfs (RAWP)

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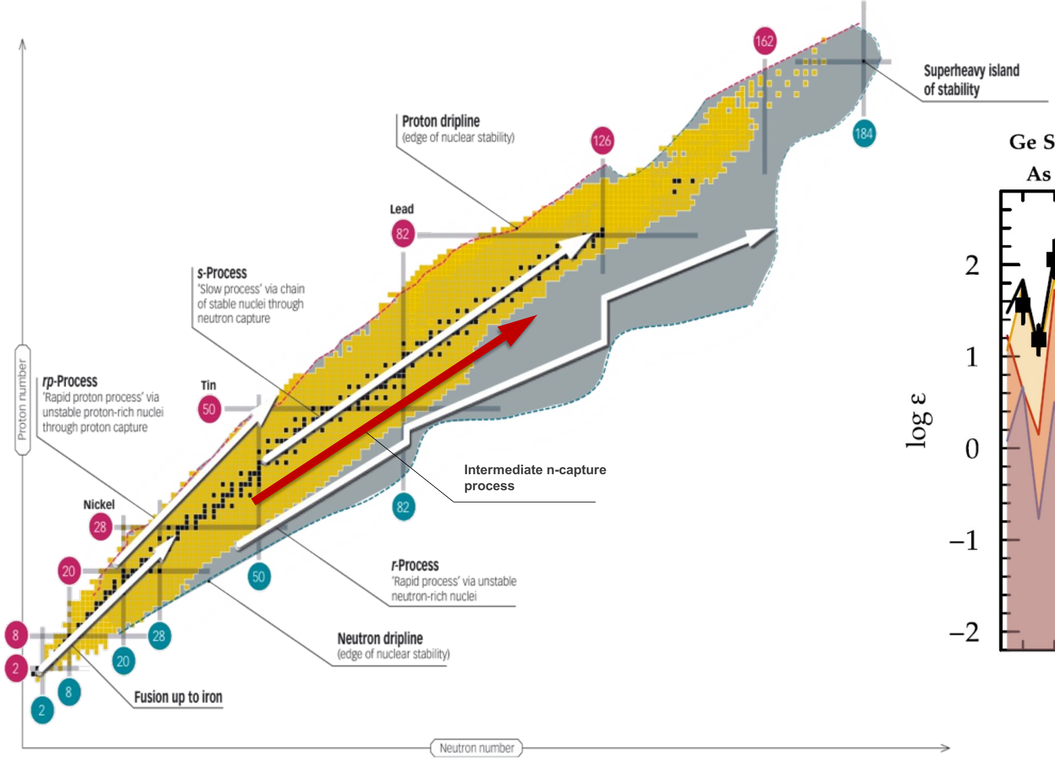
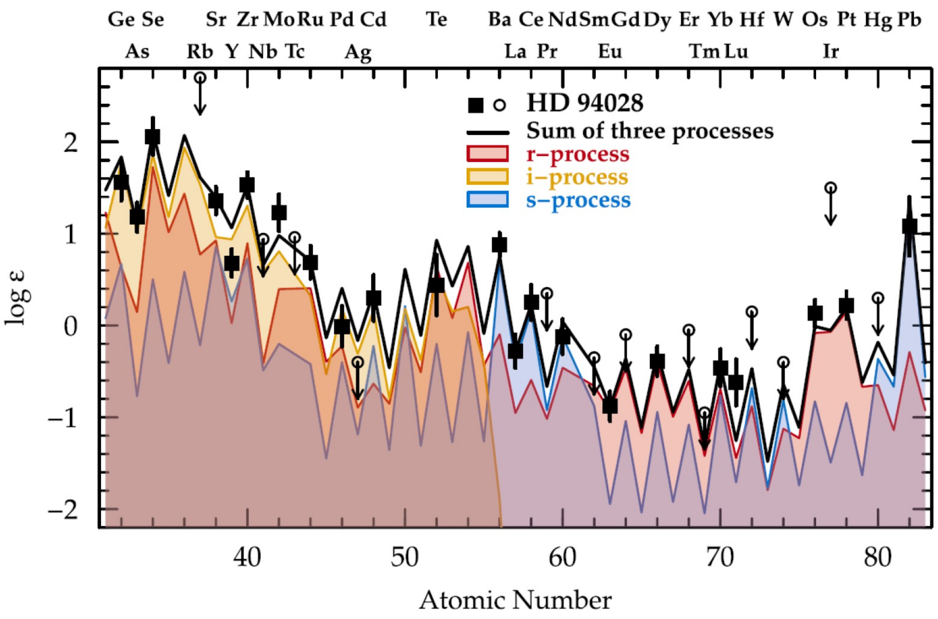
Neutron Capture Processes





Roederer et al Astroph. J. 821 (2016) 37

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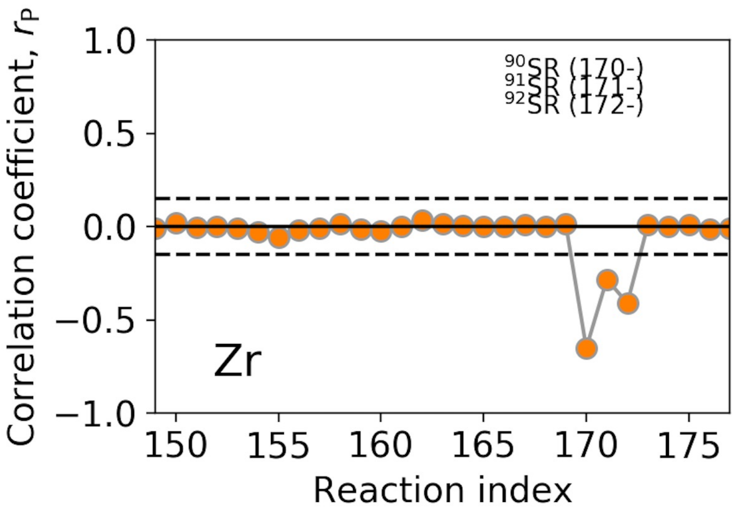
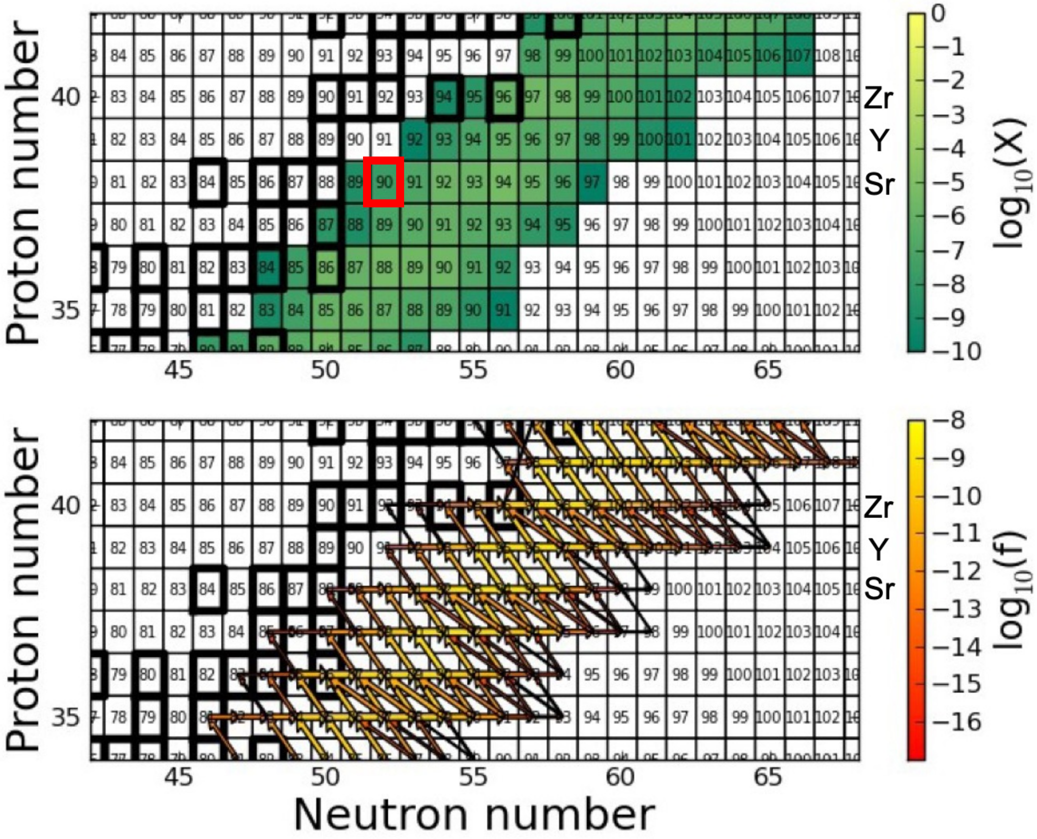
i –process Relevance





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Pavel Denisenkov

Marco Pignatari, Russbach school 2014

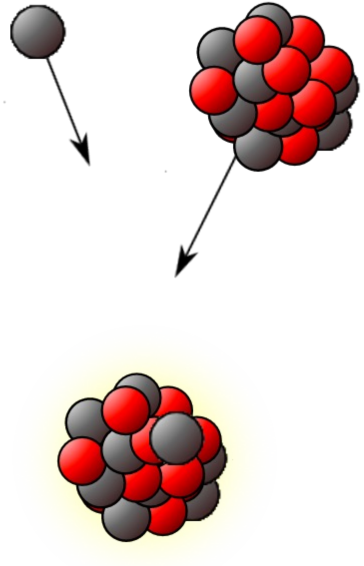
Constraining Neutron Capture Rates

- Since direct measurements of neutron capture are very difficult with radioactive isotopes, we require an alternative

- Instead, we can calculate it using data taken from indirect measurements

→**The Oslo Method**

- Using Brink-Axel hypothesis with spin corrections, decay properties can be measured with population by **β-decay**



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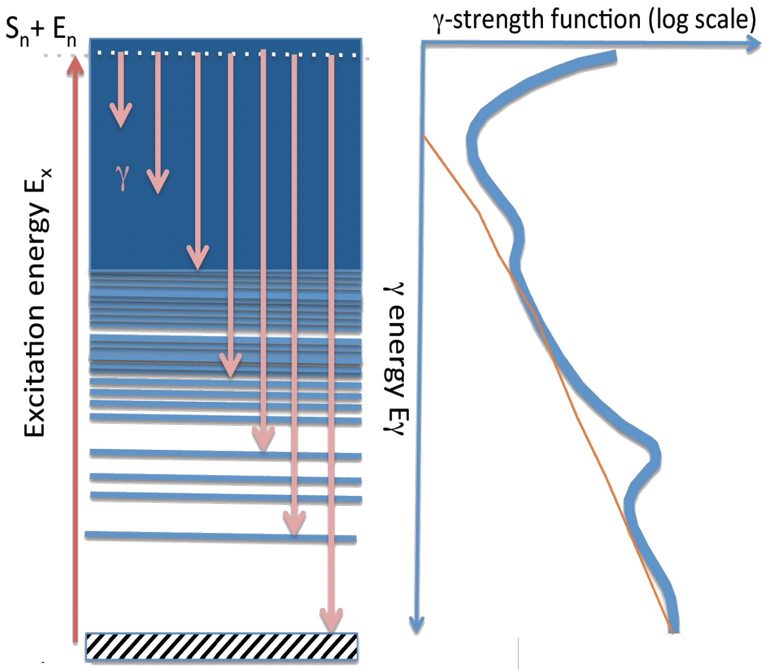
Intro to the Oslo Method

- The Hauser-Feshbach neutron-capture cross-section is dependent on the Nuclear Level Density (NLD) and γ-Strength Function (γ-SF)
  - **NLD:** Density of excitation as a function of energy
  - **γ-SF:** Strength of decay for a given γ- ray energy
- What data do we need?
  - Nuclear level structure information
  - The ratio of γ-decay intensities as a function of γ-ray energy per parent level

  → **Experimentally measure shell structure and γ-decays of yield nucleus**



Larsen, Spyrou, Liddick, Guttormsen
PPNP,Vol 107, 69-108 (2019)

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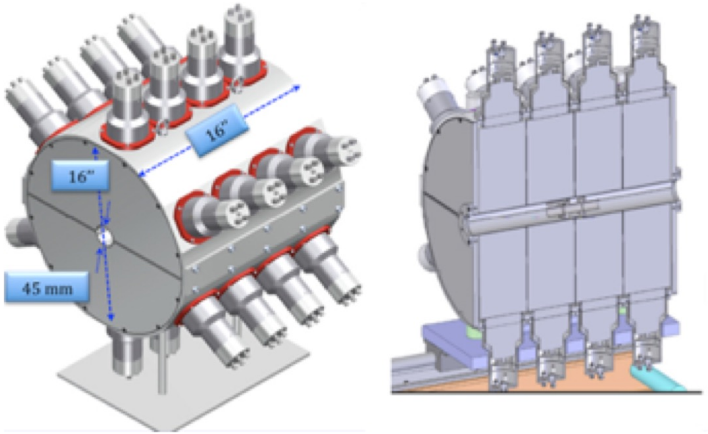
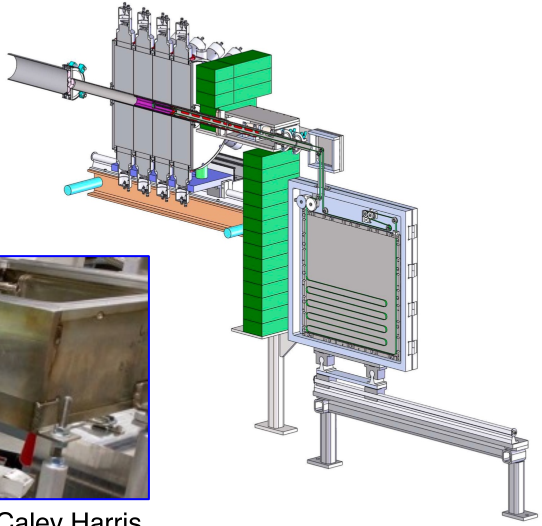
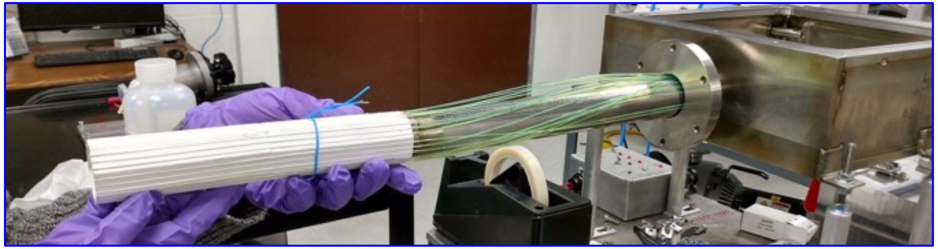
β-Decay with SuN

- **SuN** – Total Absorption Spectrometer composed of 8 large volume NaI crystals, each with 3 PMTs
- **SuNTAN** – Tape Transport System
- **Fiber Detector** - ß-detection via paneled scintillating barrel



[A. Simon, S.J. Quinn, A. Spyrou et al, NIM A 703, 16 (2013)]





Caley Harris

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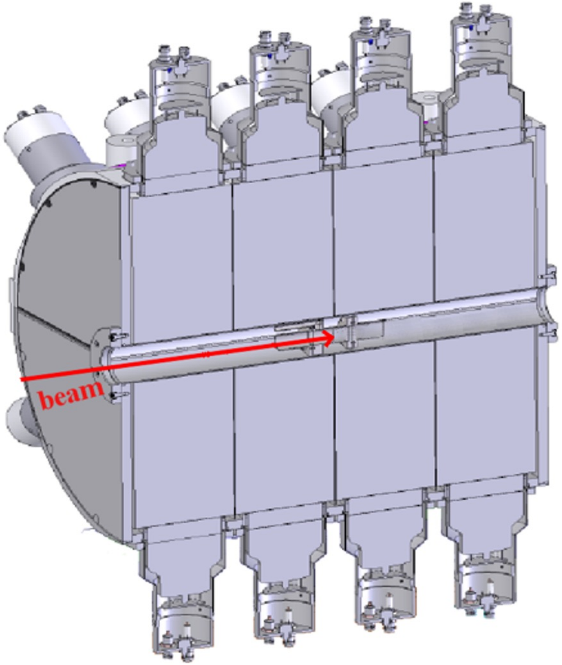
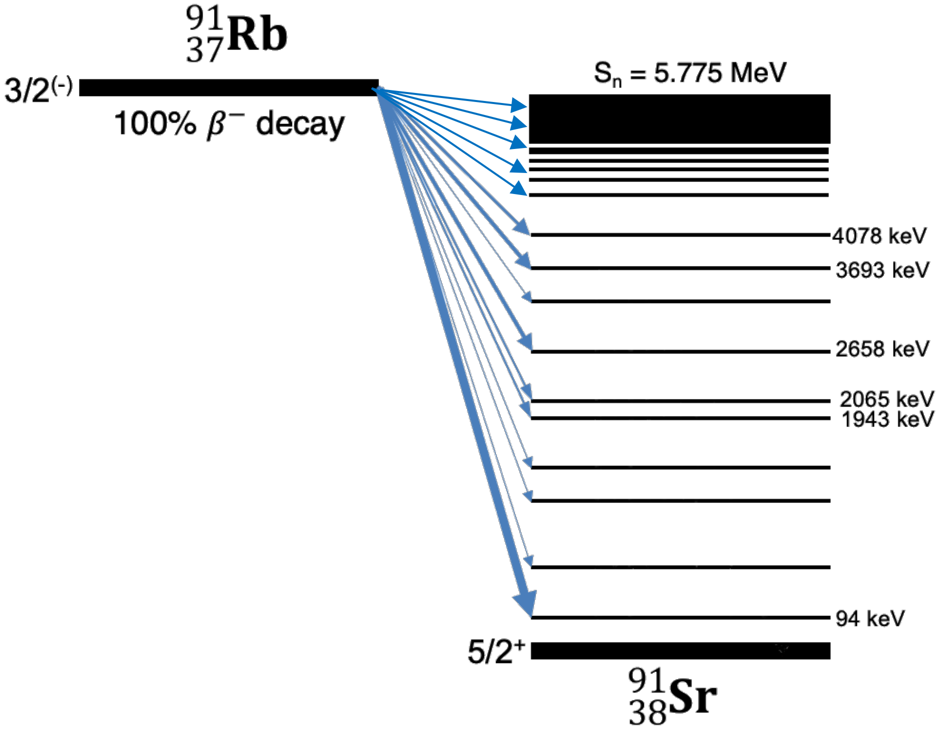
Total Absorption Spectrometry





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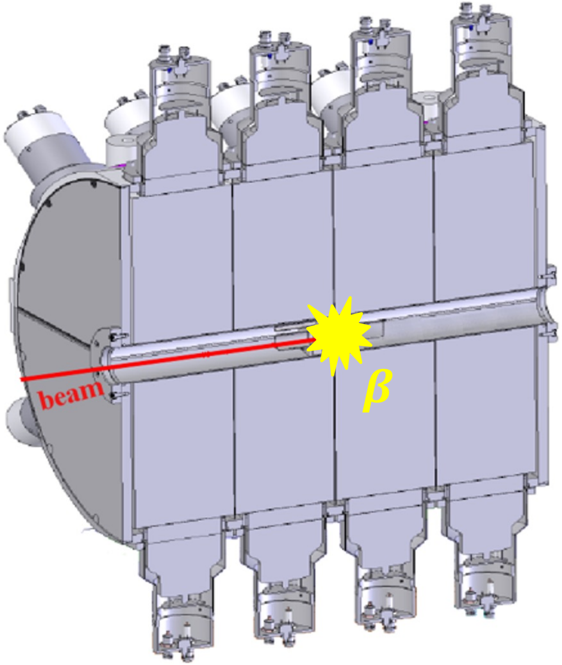

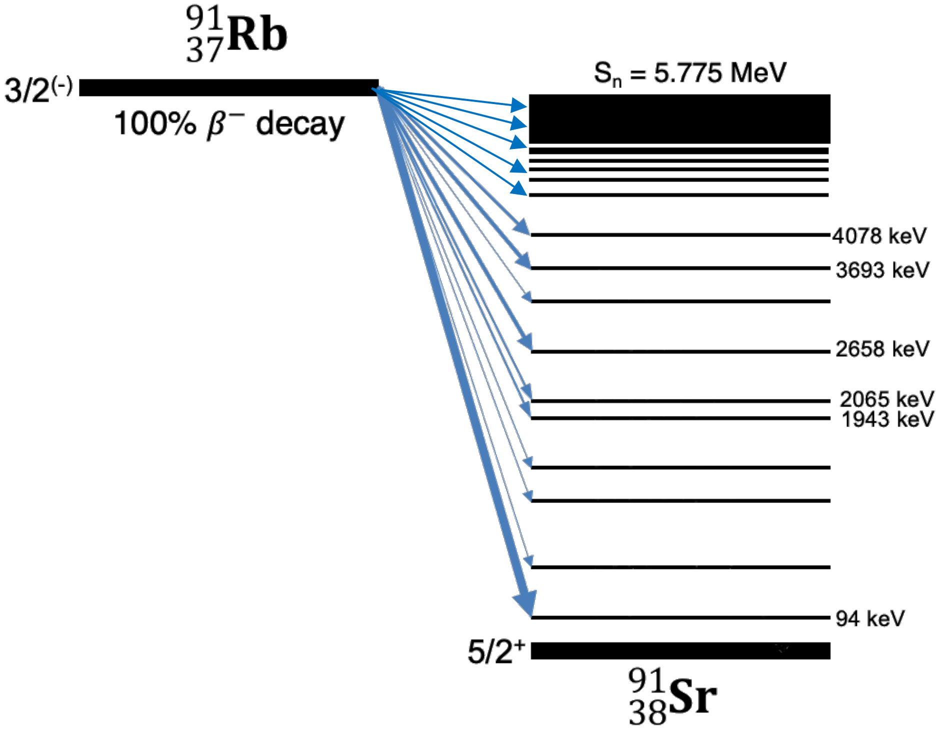

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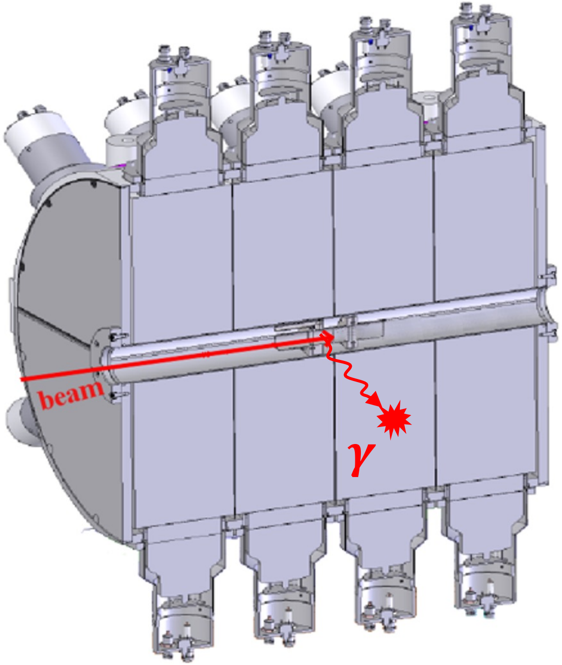
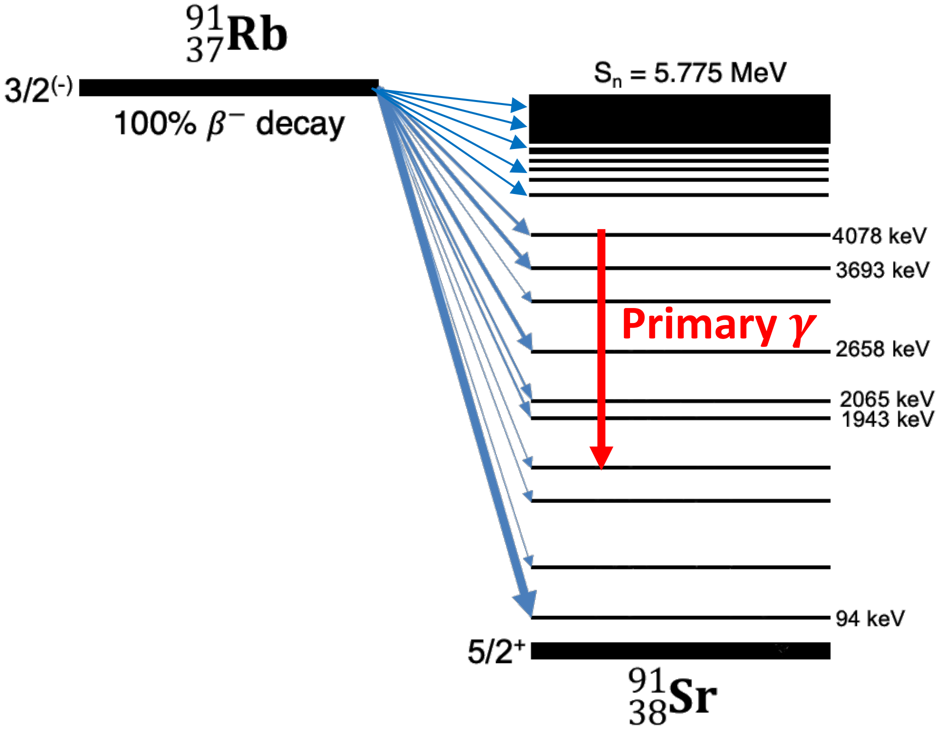
Total Absorption Spectrometry





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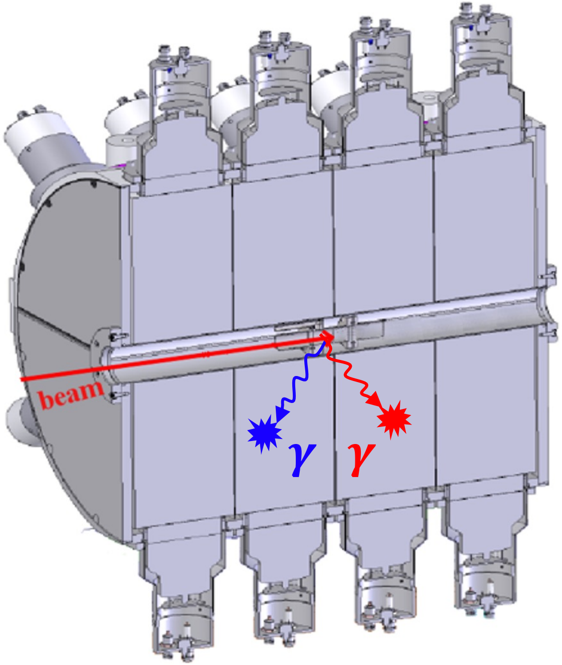

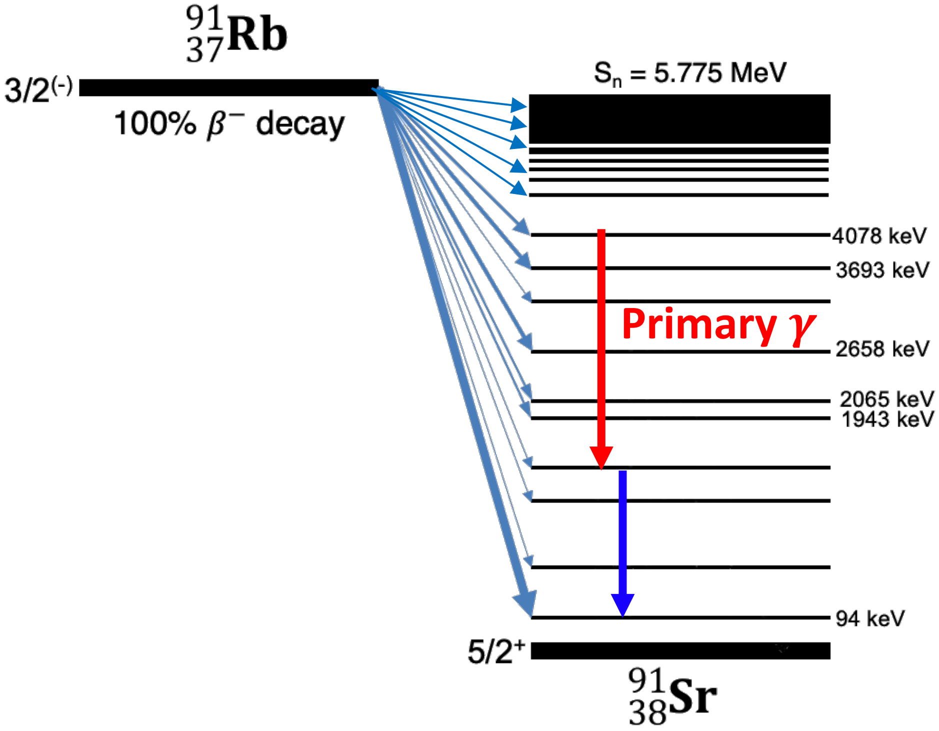

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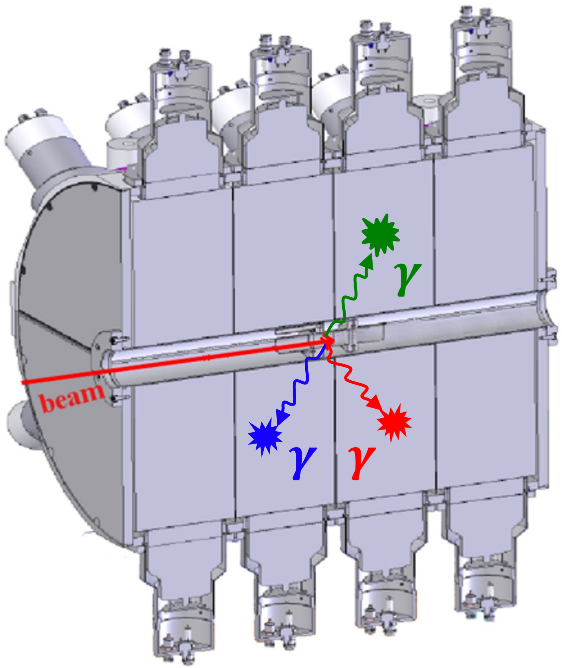

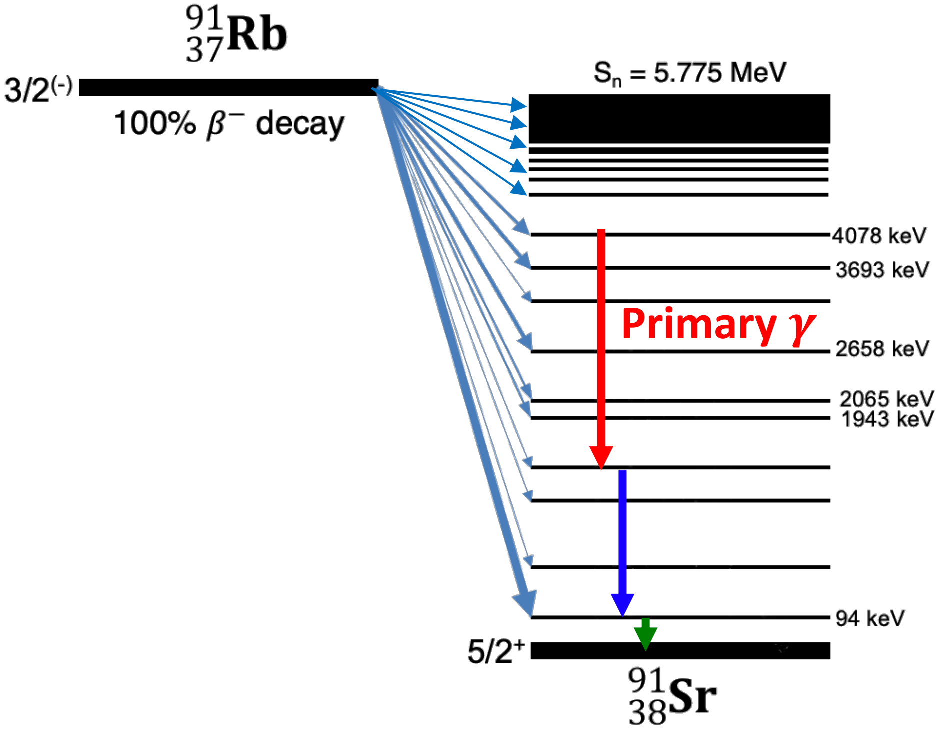

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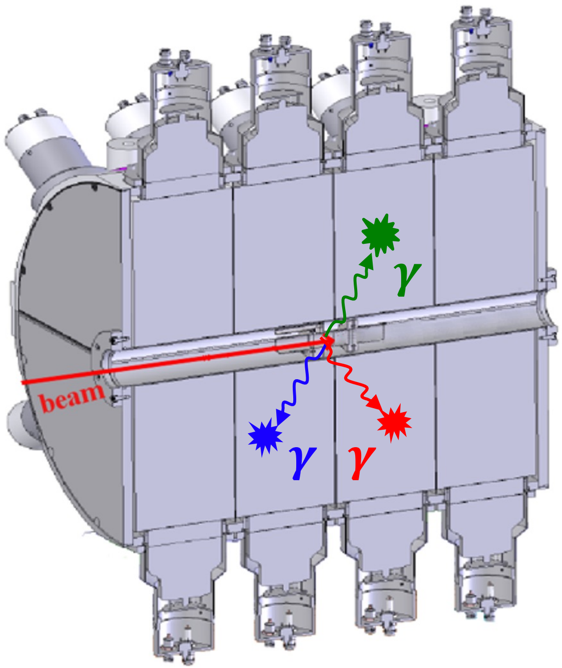

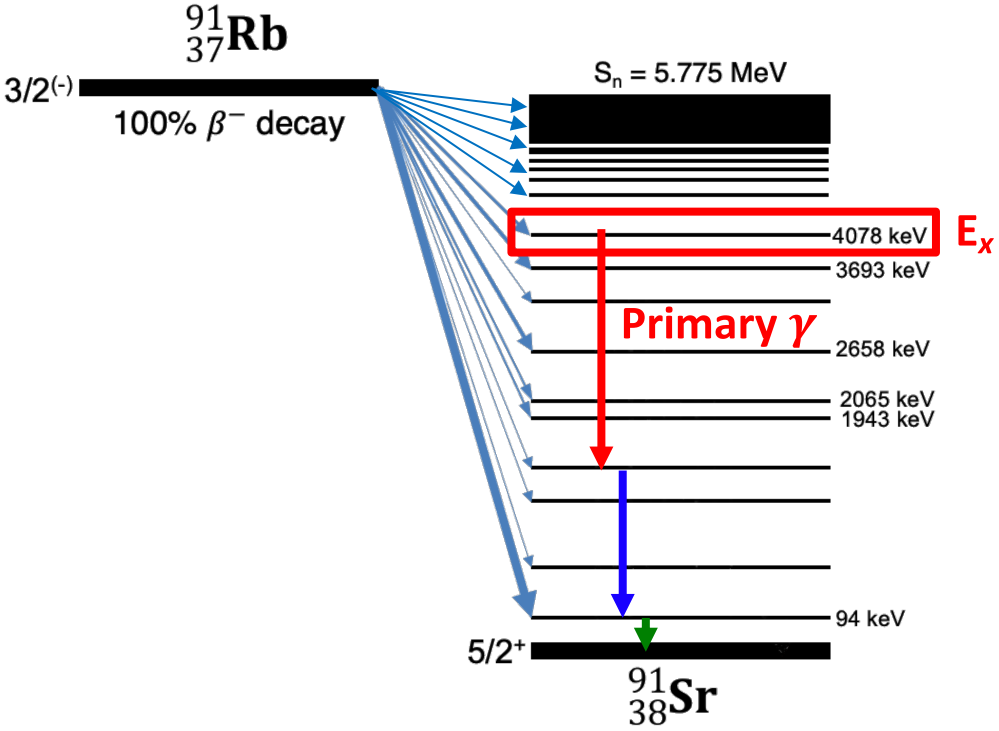

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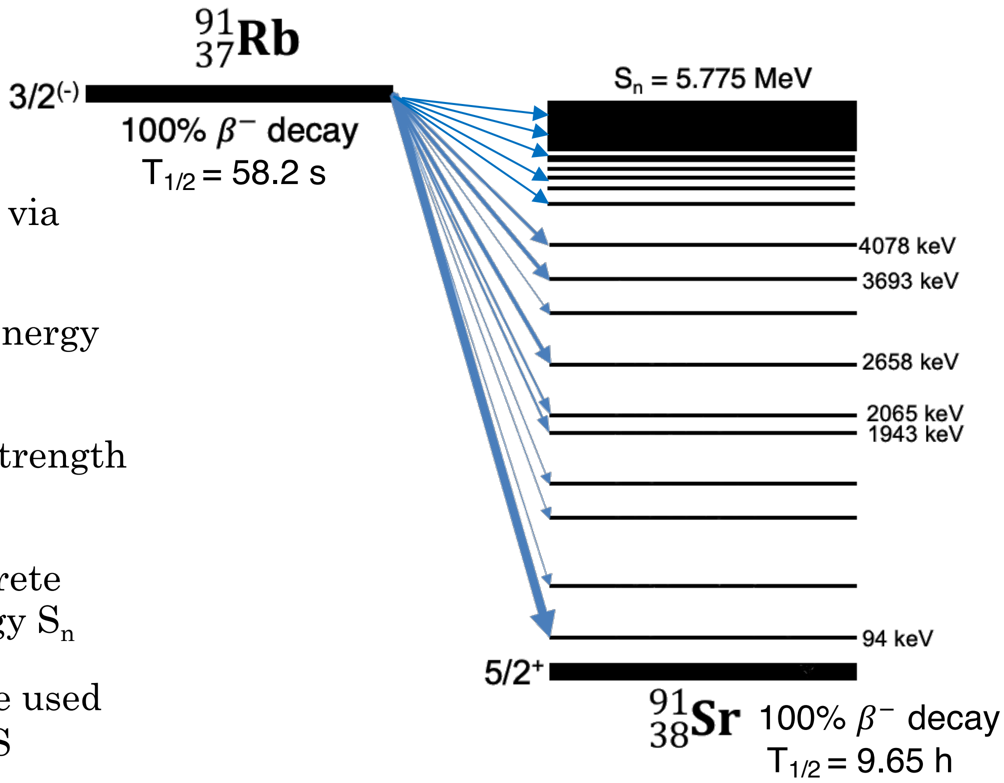
β-Oslo Method

- Correct (E_γ,E_x) matrix for detector response via "unfolding"
- Extract primary γ-rays for each excitation-energy bin
- Extract nuclear level density (NLD) and γ-strength function (γ-SF) from primary γ-ray matrix
- Normalize NLD and γ-SF using known discrete levels and NLD at neutron separation energy S_n
- Use the NLD and γ-SF to guide models to be used as input in the nuclear reaction code TALYS



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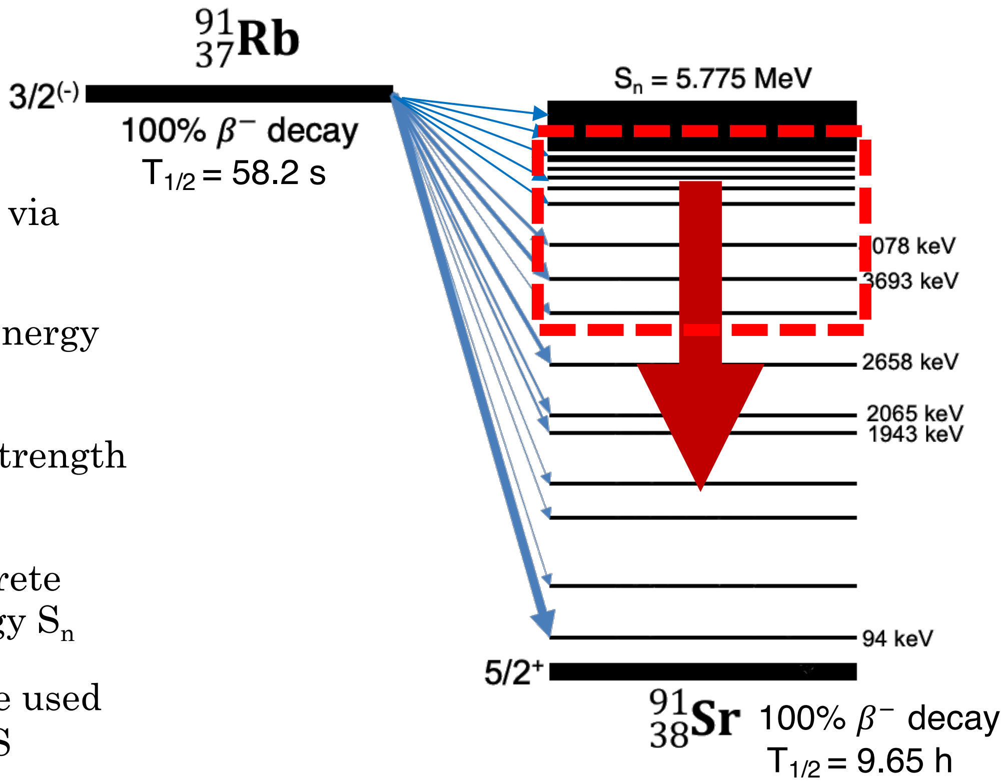

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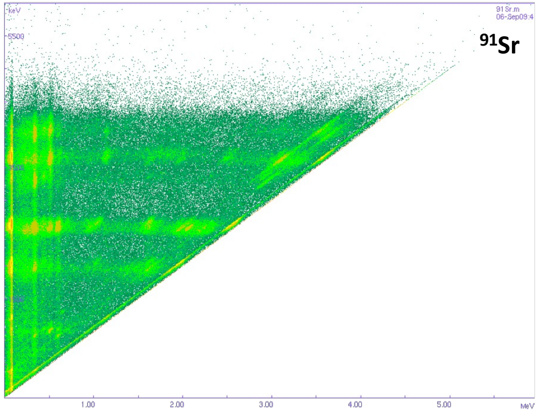
Producing Primary Matrix

Raw matrix



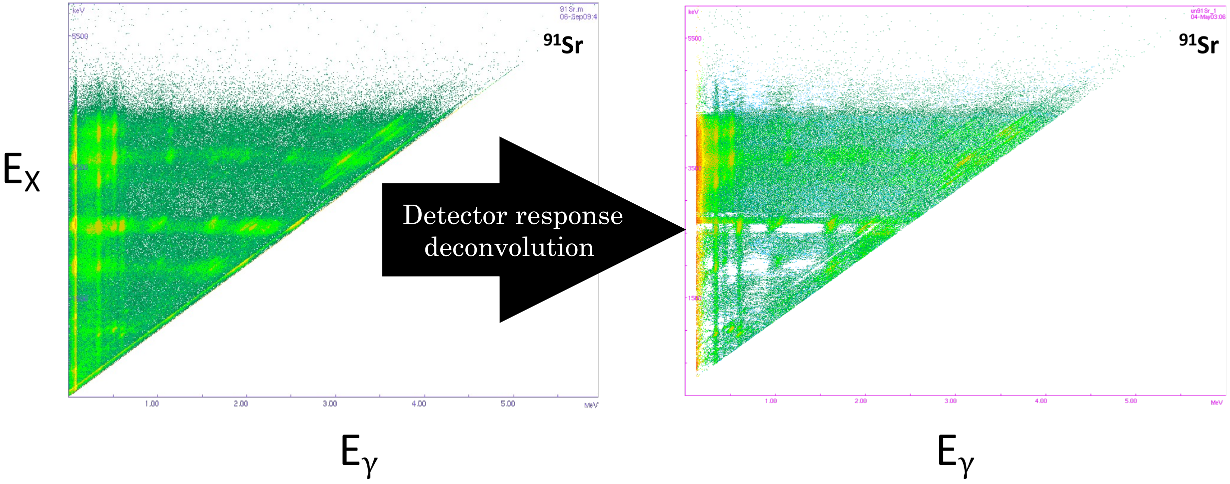
E_X

E_γ

Producing Primary Matrix

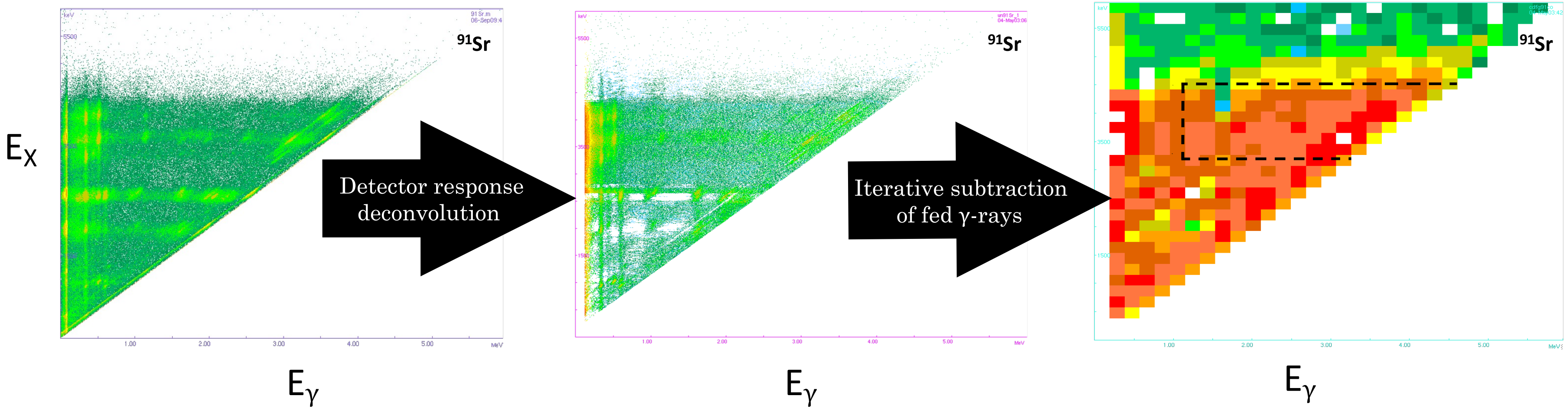
Raw matrix

"Unfolded" matrix



Producing Primary Matrix

Raw matrix | **“Unfolded” matrix** | **Primary γ coincidences**



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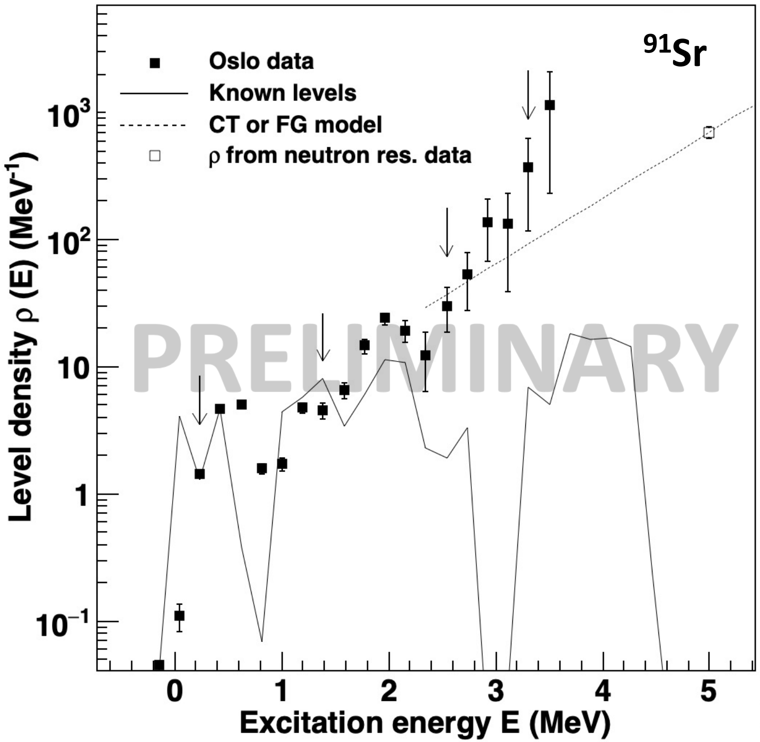
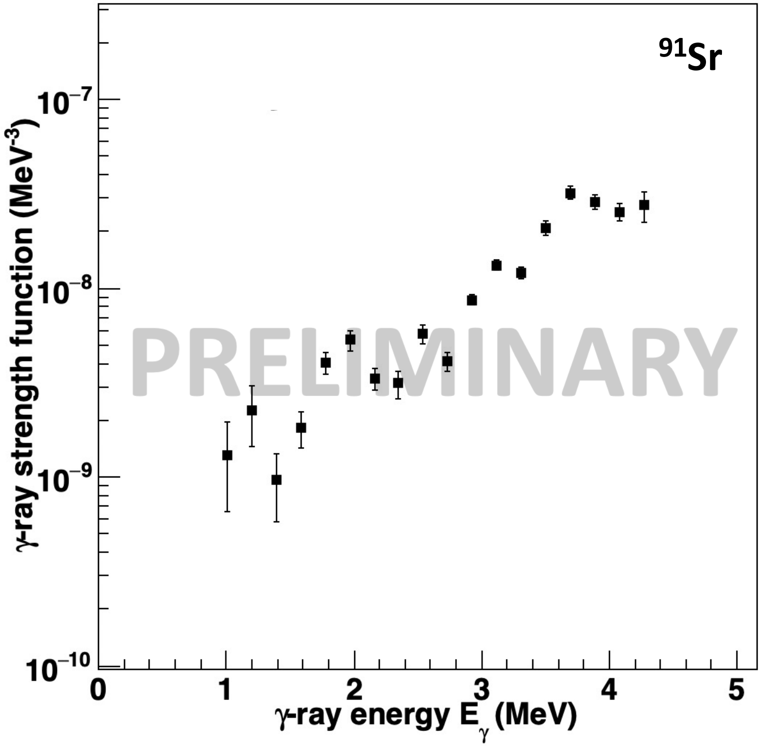
First Results





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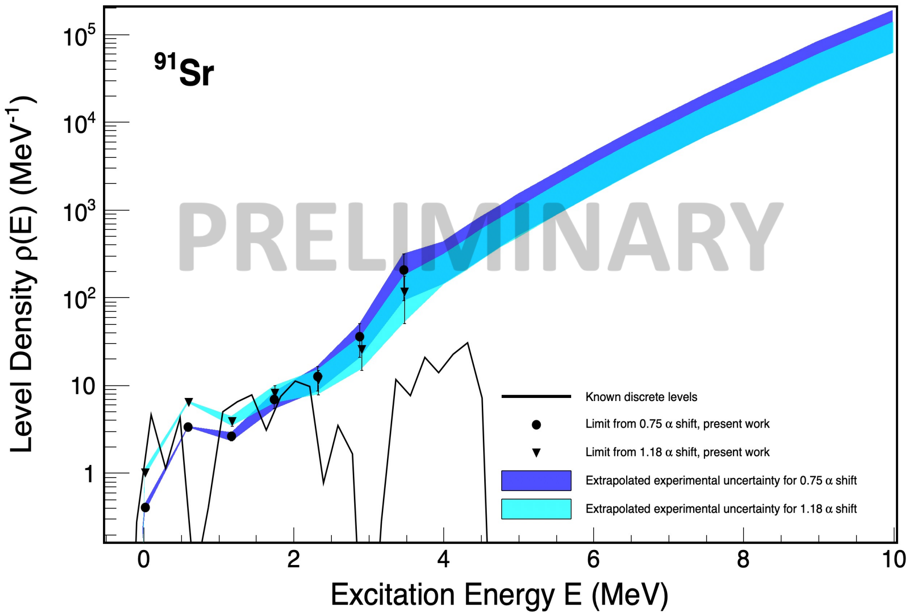
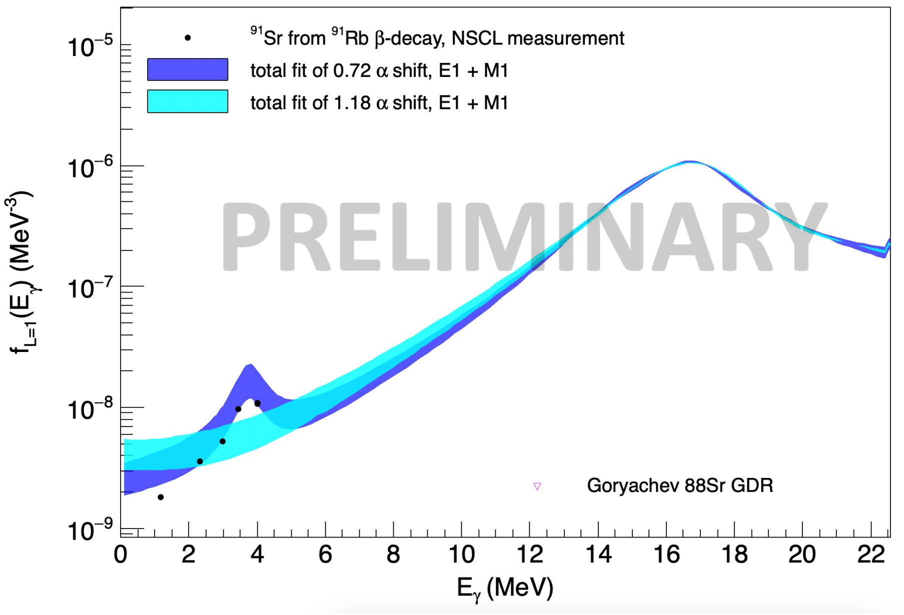
Resulting NLD & γ-SF





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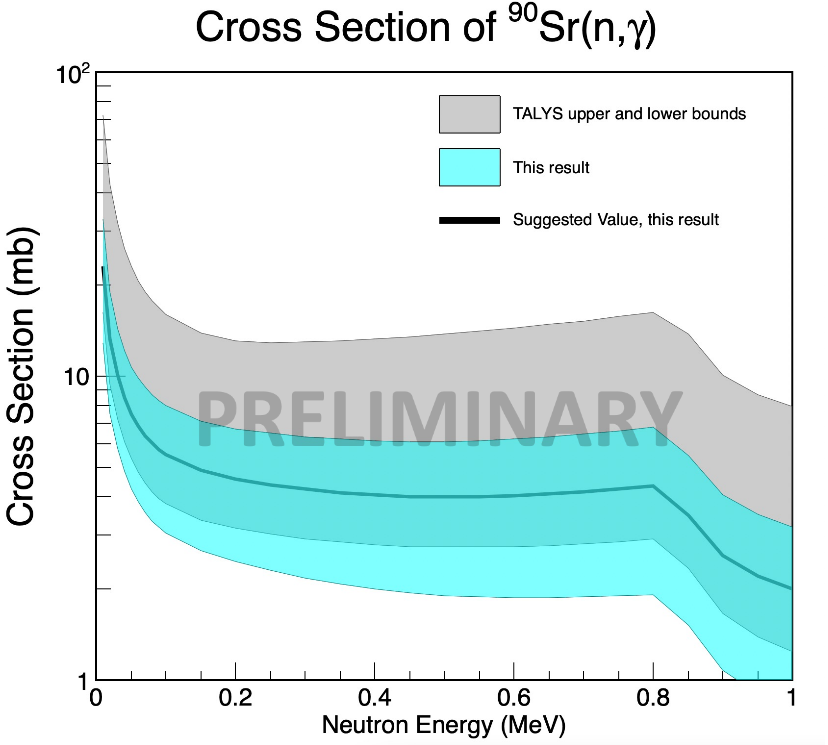
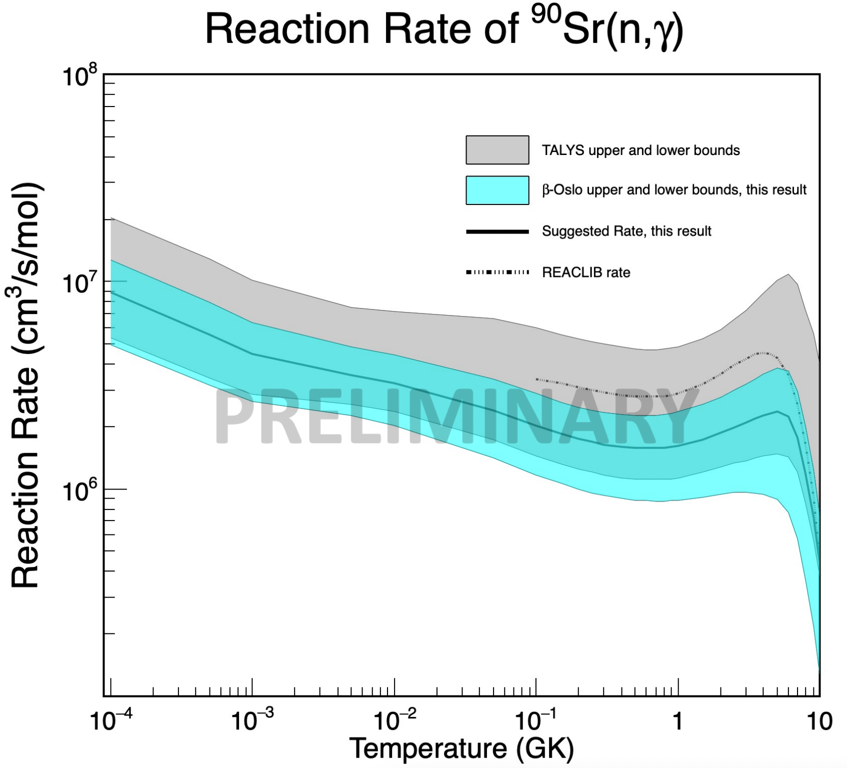
Experimental Results





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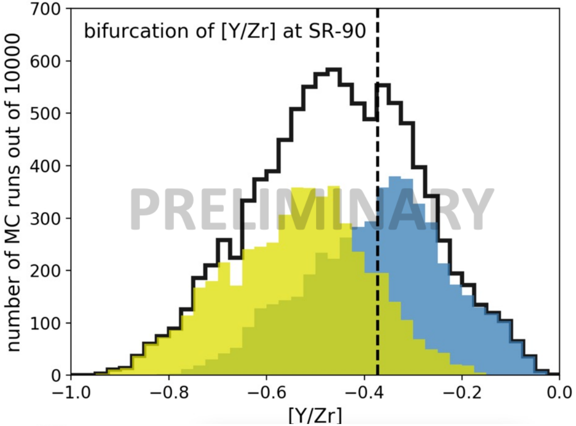
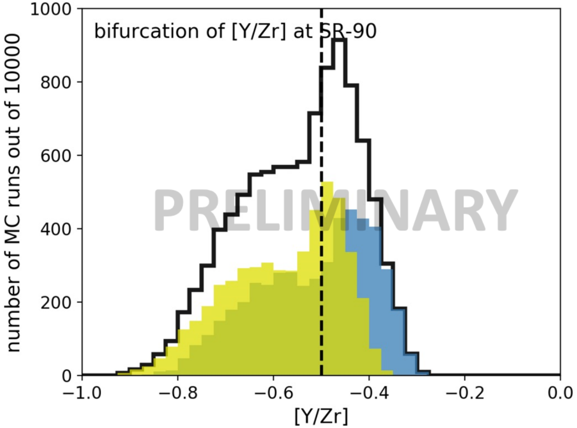
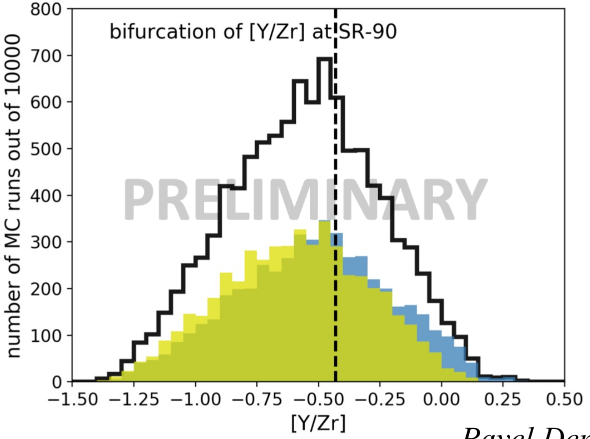
Experimental Results

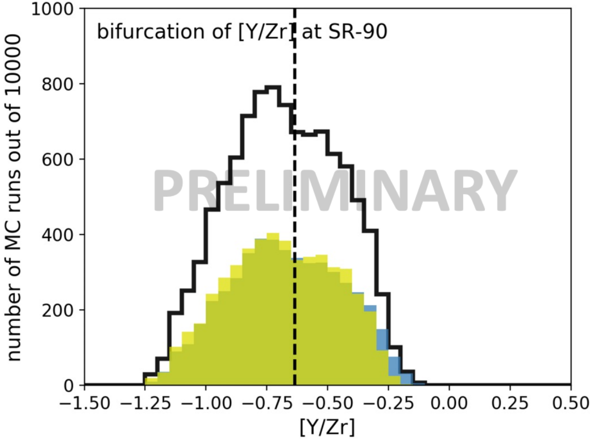
10^{13} n/cm^3





10^{14} n/cm^3





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Pavel Denisenkov

Summary

- Populated ^{91}Sr via ß-decay at NSCL in 2018 and measured with with SuN total absorption spectrometer
- Performed the Oslo method to produce the primary matrix and extract the NLD and γ-SF
- Used NLD and γ-SF constraints to reduce uncertainty on the neutron-capture rate of ^{90}Sr
- First experimental constraint of ^{90}Sr(n,γ)^{91}Sr used in one-zone i-process nucleosynthesis simulation to model impact on peak element abundances
- Paper coming soon

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University of Oslo - M. Guttormsen, A.C. Larsen, F. Zeiser
University of Notre Dame - A. Drombos
Hope College - P. DeYoung, J. Gombas
Pacific Northwest National Lab - S. Lyons
University of Colorado Boulder - C. Persch
iThemba LABS / University of the Witwatersrand - M. Wiedeking
University of Kentucky - Y. Xiao

Intro to the Oslo Method

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  - **NLD:** Density of excitation as a function of energy
  - **γ-SF:** Strength of decay for a given γ- ray energy

- What data do we need?
  - Nuclear level structure information
  - The ratio of γ-decay intensities as a function of γ-ray energy per parent level

  → **Experimentally measure shell structure and γ-decays of yield nucleus**

$$\sigma_{n\gamma} = \frac{\pi\hbar^2}{2\tilde{m}_{tn}E_{tn}} \frac{1}{(2J_t+1)(2J_n+1)} \sum_{J,\pi}(2J+1)\frac{\mathcal{T}_n\mathcal{T}_\gamma}{\mathcal{T}_{tot}}$$

$$\mathcal{T}_\gamma = \sum_{\nu}\mathcal{T}_\gamma^\nu + \int_{E^\nu}^{E}\sum_{J,\pi}\mathcal{T}_\gamma^\nu \cdot \boldsymbol{\rho}\, dE$$

$$\mathcal{T}_{XL}(E_\gamma) = 2\pi E_\gamma^{(2L+1)} \boldsymbol{f_{XL}(E_\gamma)}$$

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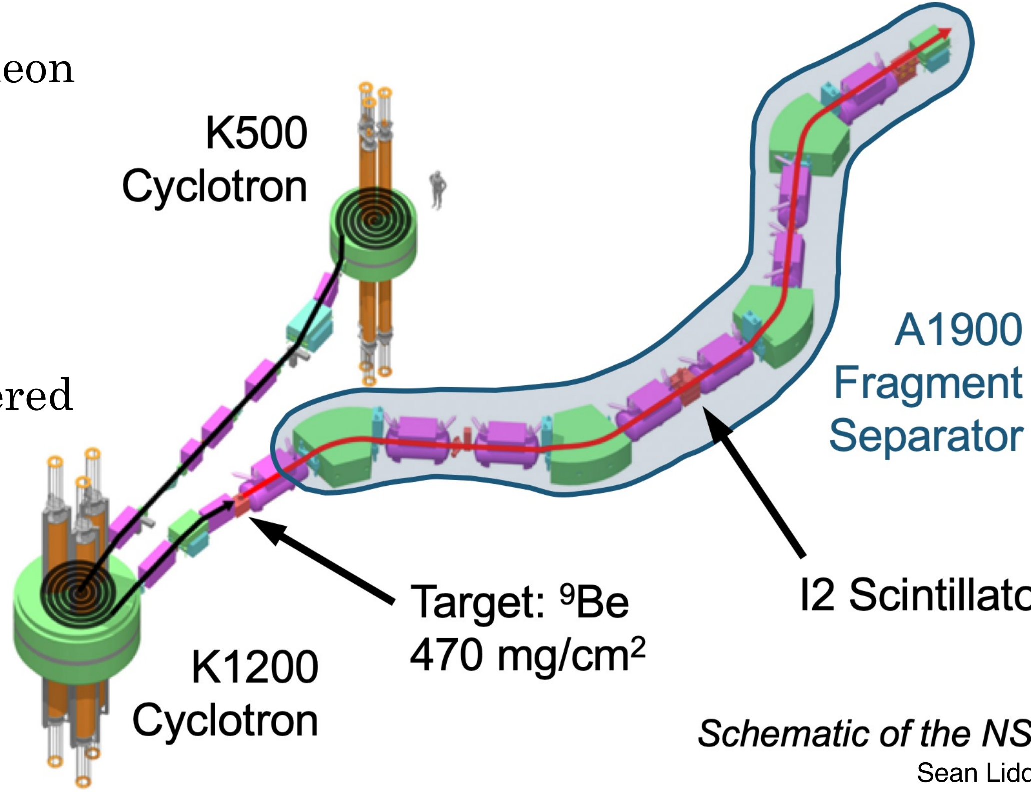
β-Decay with SuN

- Primary beam of 120 MeV/nucleon ^{96}Zr on ^{9}Be target
- Secondary beam separated in A1900 fragment separator, delivered to N4 gas cell
- ^{91}Rb beam extracted and delivered to SuN setup at 245 particles/s
- 5 min on / 5 min off beam between tape cycle



Schematic of the NSCL

Sean Liddick

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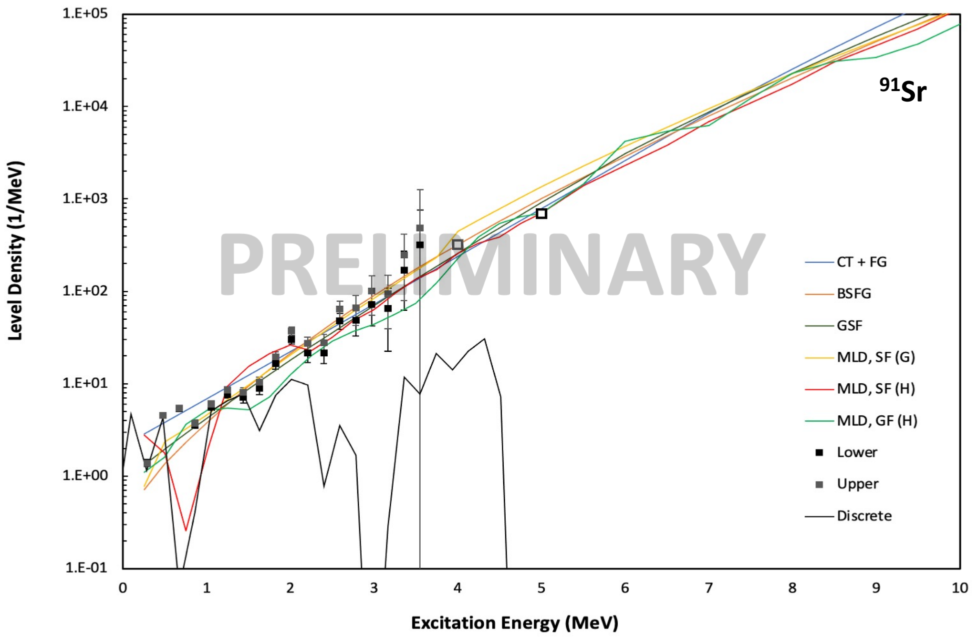
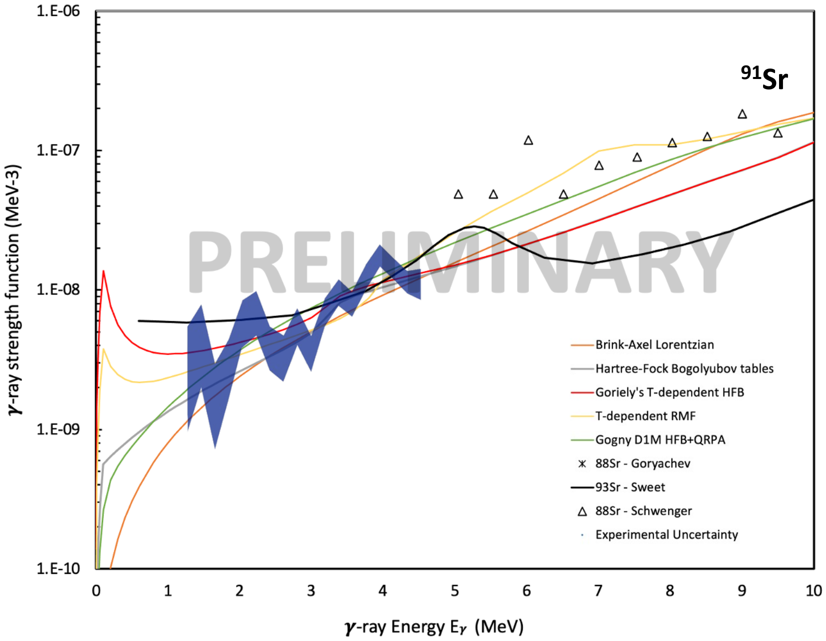
Constraints on NLD & γSF





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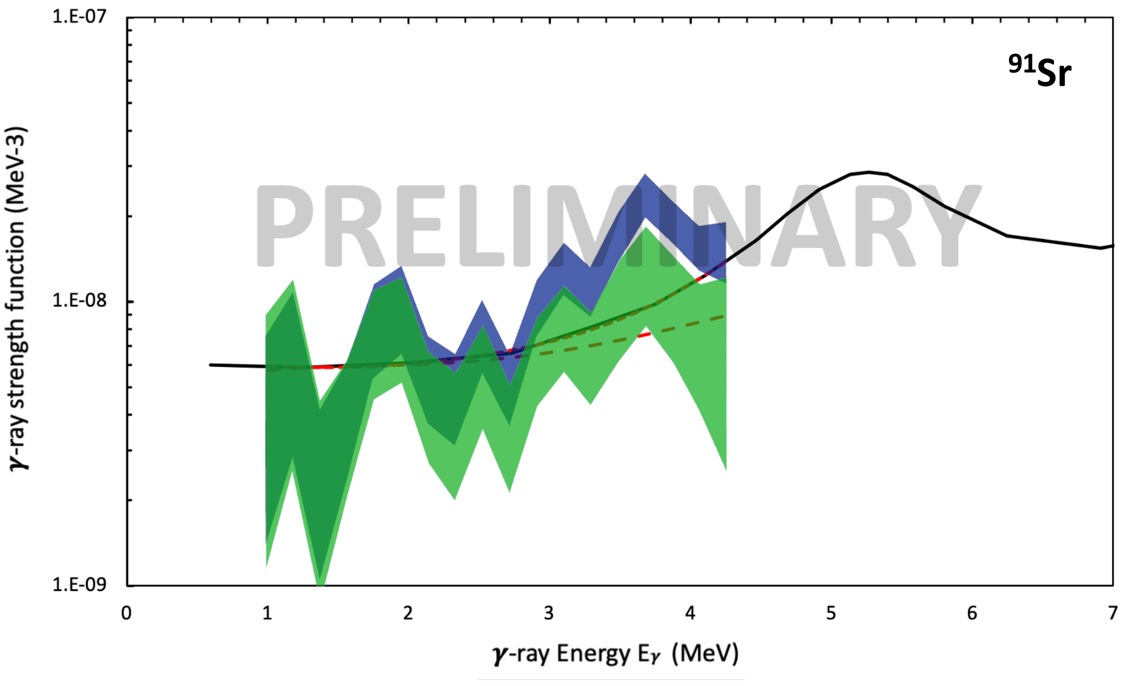
Constraining γ-ray Strength Function

$$\tilde{\rho}(E - E_\gamma) = A\exp[\alpha(E - E_\gamma)]\,\rho(E - E_\gamma)$$

$$\tilde{f}(E_\gamma) = B\,\exp(\alpha E_\gamma)\,f(E_\gamma)$$



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