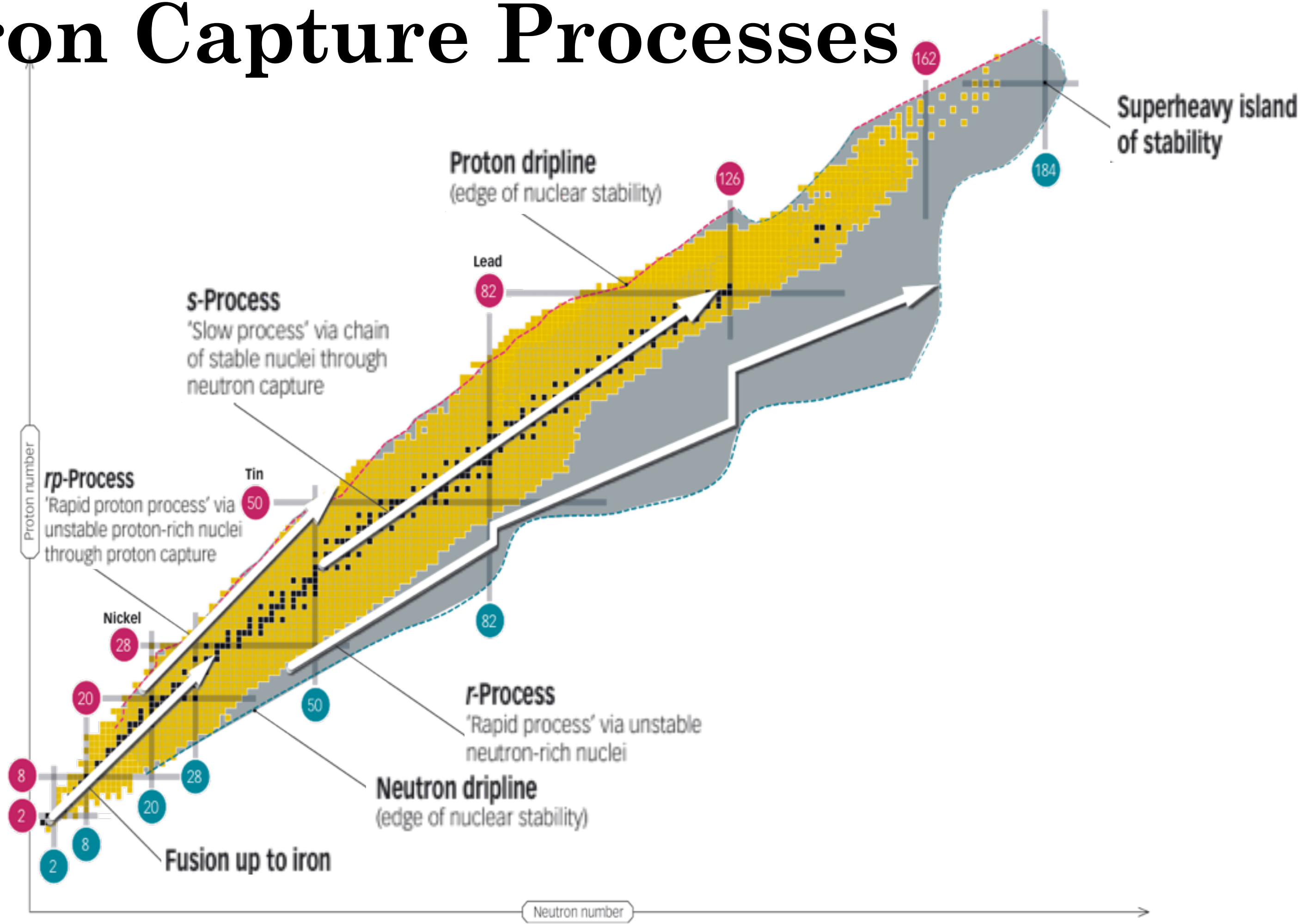
Constraining the Neutron Capture Rate for ^{90}Sr through beta-Decay into the Short-Lived ^{91}Sr Nucleus

WNPPC, Feb. 19 2023

Beau Greaves

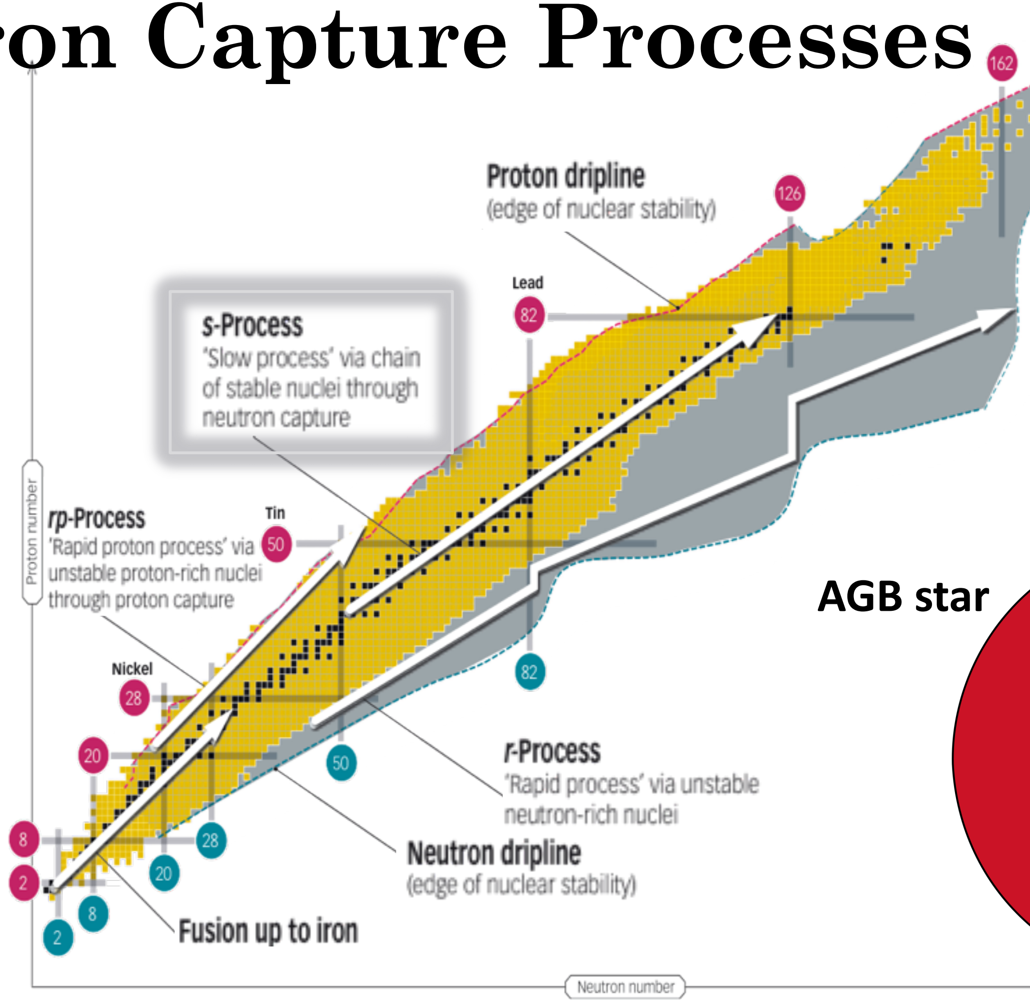
University of Guelph

Neutron Capture Processes



UNIVERSITY of GUELPH

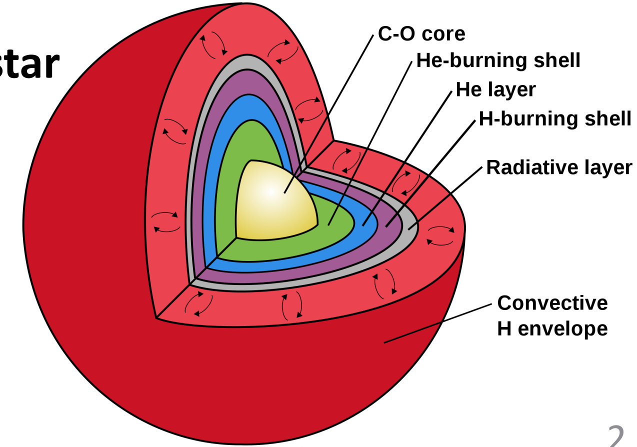
Neutron Capture Processes



time scale: 100+ years

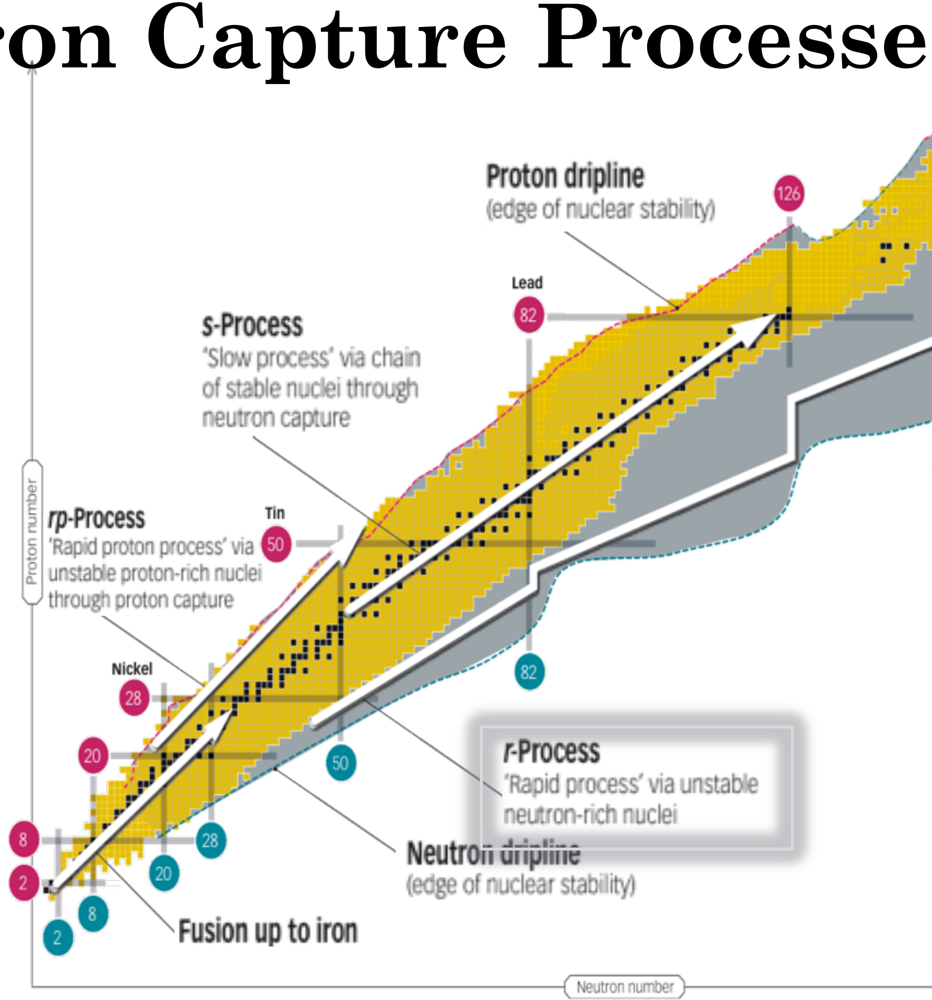
~10^8 neutrons/cm^3

AGB star



UNIVERSITY of GUELPH

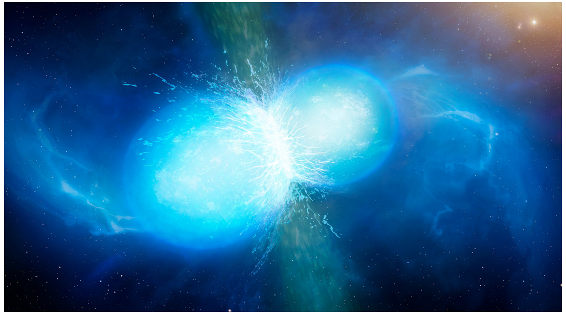
Neutron Capture Processes



time scale: 10 seconds

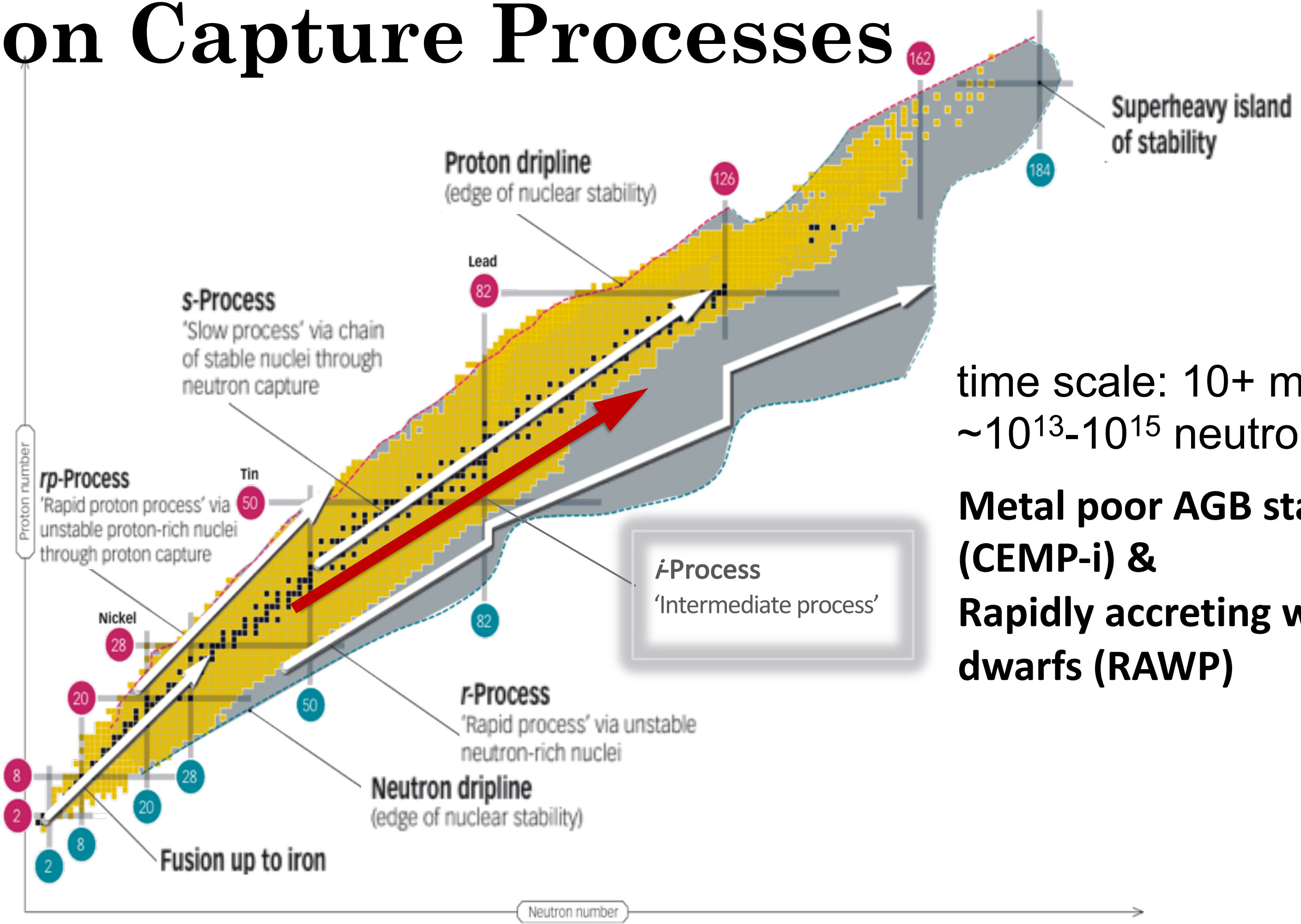
~10^{22} neutrons/cm^3

Neutron star mergers & core collapse supernova



UNIVERSITY of GUELPH

Neutron Capture Processes



time scale: 10+ minutes

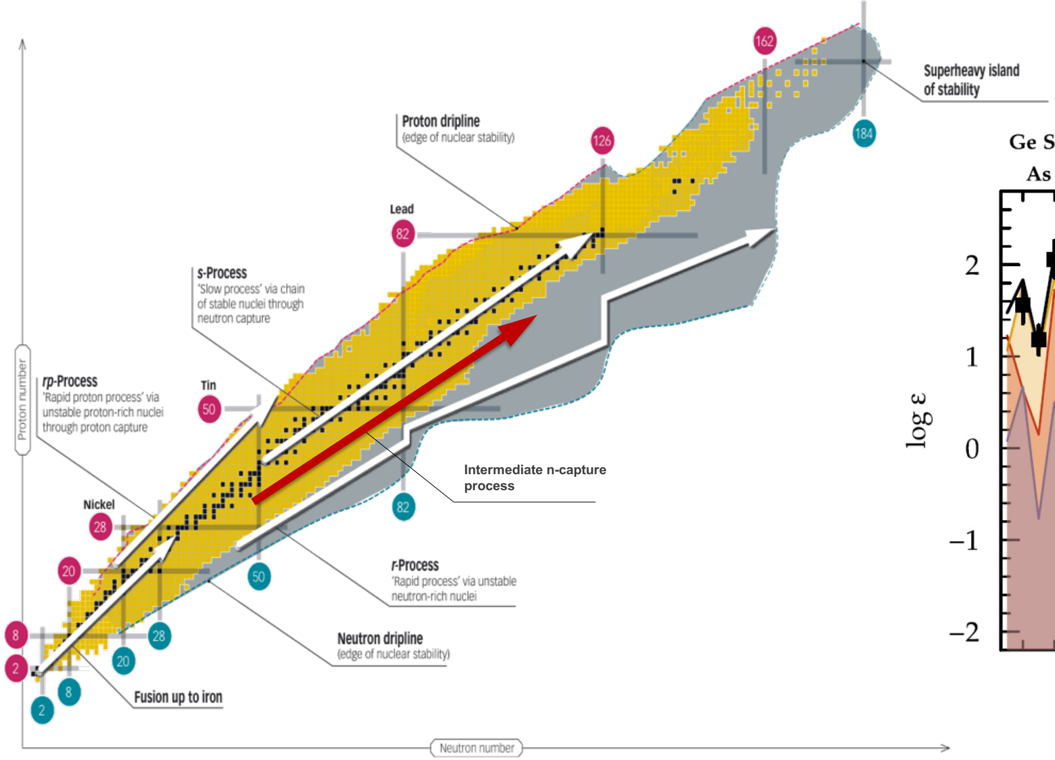
~10^{13}-10^{15} neutrons/cm^3

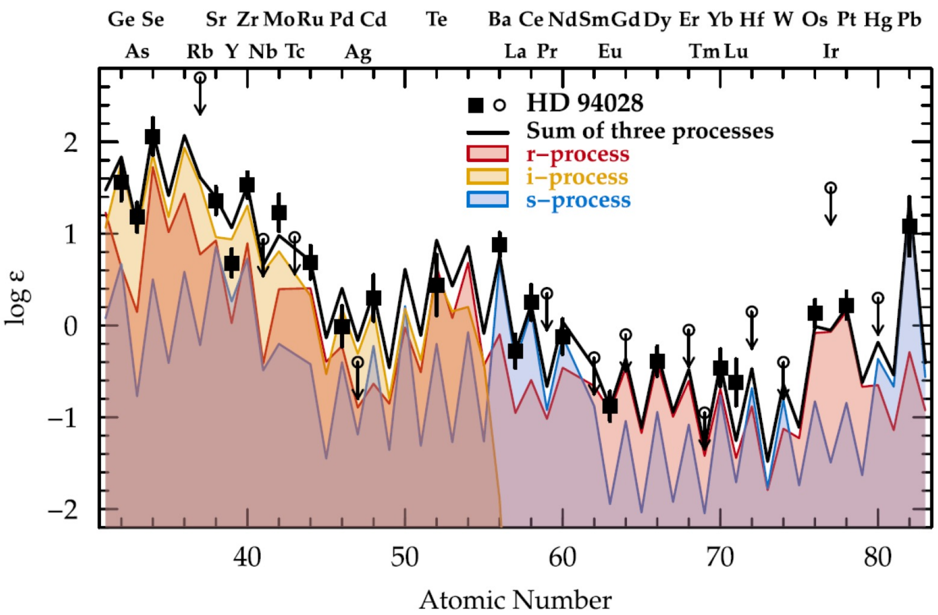
Metal poor AGB stars (CEMP-i) &

Rapidly accreting white dwarfs (RAWP)

UNIVERSITY of GUELPH

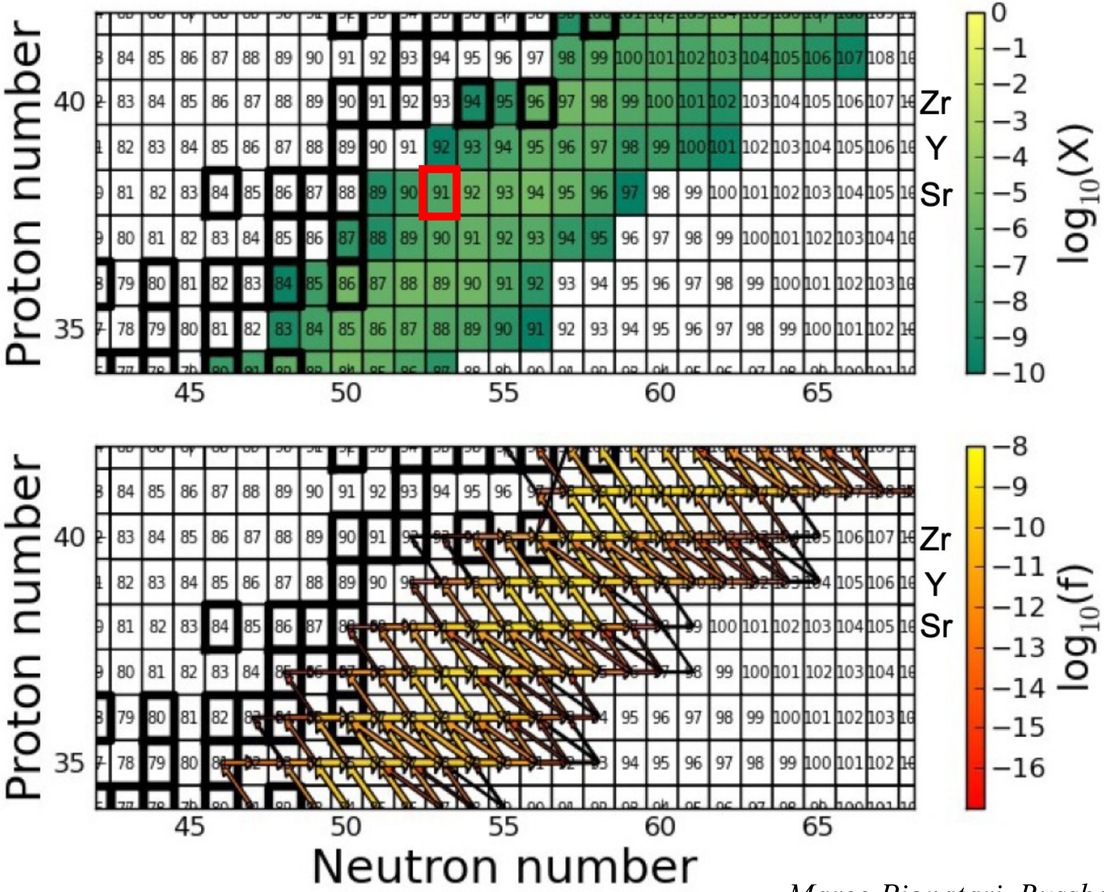
Neutron Capture Processes





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

i -process



UNIVERSITY of GUELPH

Marco Pignatari, Russbach school 2014

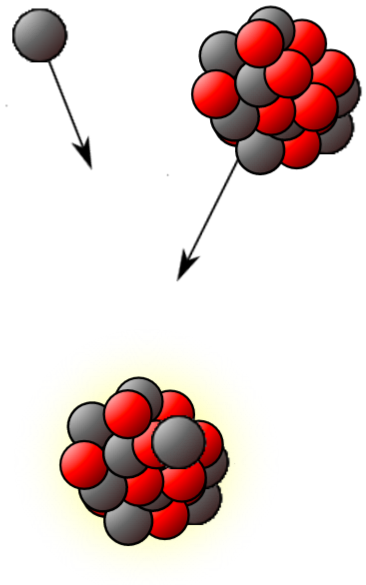
Constraining Neutron Capture Rates

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

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

  →**The Oslo Method**

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



UNIVERSITY of GUELPH

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

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

- 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**

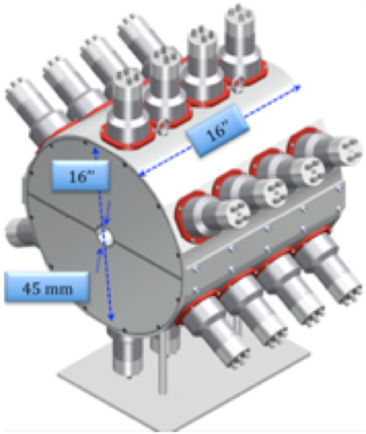
$$\mathcal{T}_\gamma = \sum_\nu \mathcal{T}_\gamma^\nu + \int_{E^\nu}^{E} \sum_{J,\pi} \mathcal{T}_\gamma^\nu \cdot \boldsymbol{\rho}\, dE$$

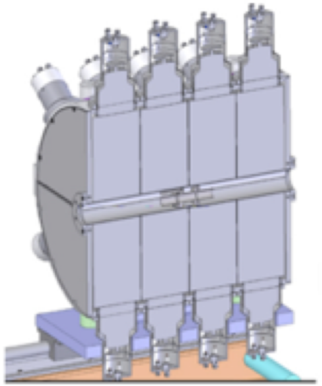
$$\mathcal{T}_{XL}(E_\gamma) = 2\pi E_\gamma^{(2L+1)} \boldsymbol{f_{XL}(E_\gamma)}$$

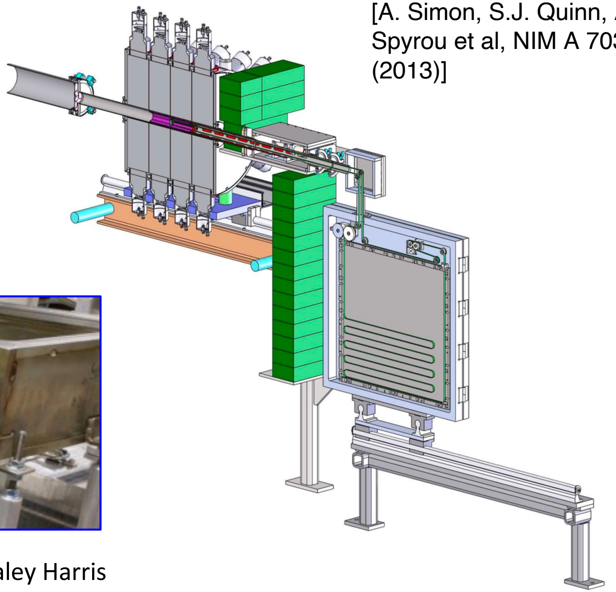
UNIVERSITY of GUELPH

β-Decay with SuN

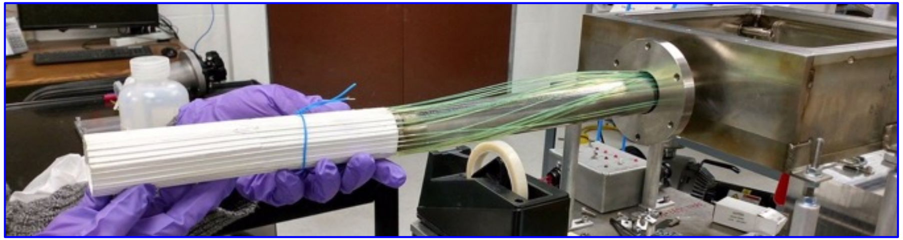
- **SuN** – Total Absorption Spectrometer composed of 8 large volume NaI crystals, each with 3 PMTs
- **SuNTAN** – Tape Transport System
- **Fiber Detector** - ß-detection via scintillating barrel coupled to PMTs





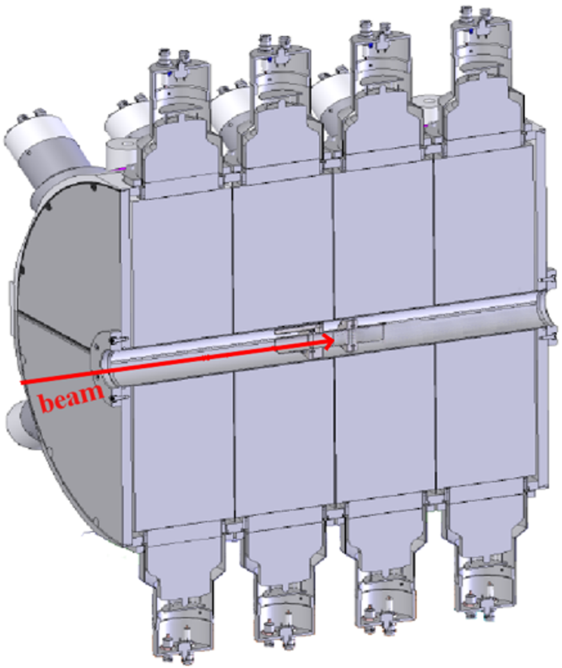


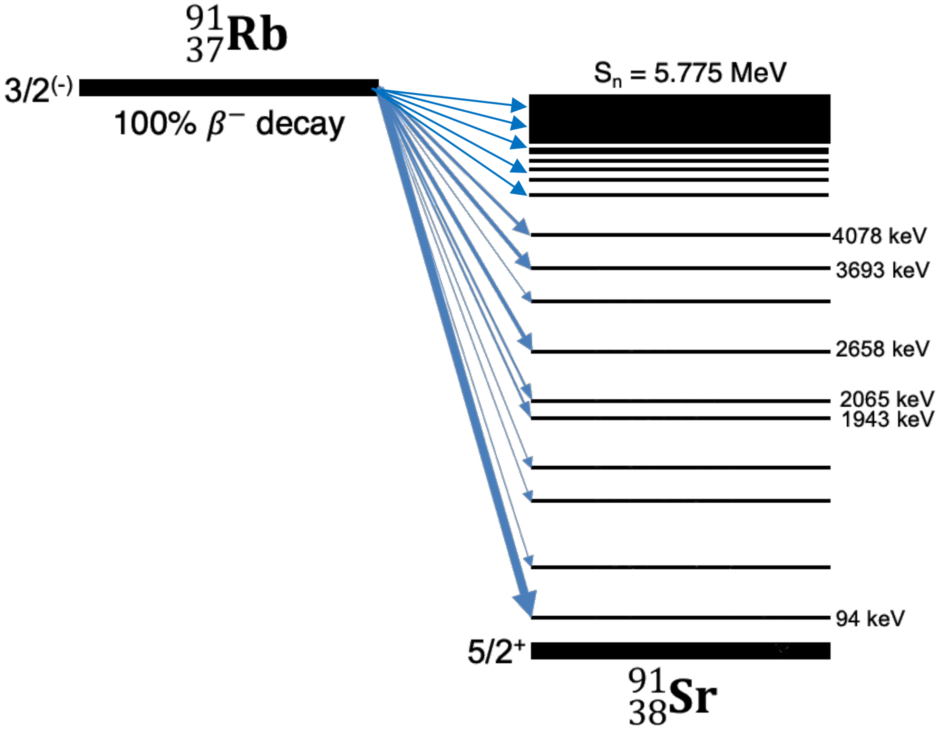
[A. Simon, S.J. Quinn, A. Spyrou et al, NIM A 703, 16 (2013)]



UNIVERSITY of GUELPH

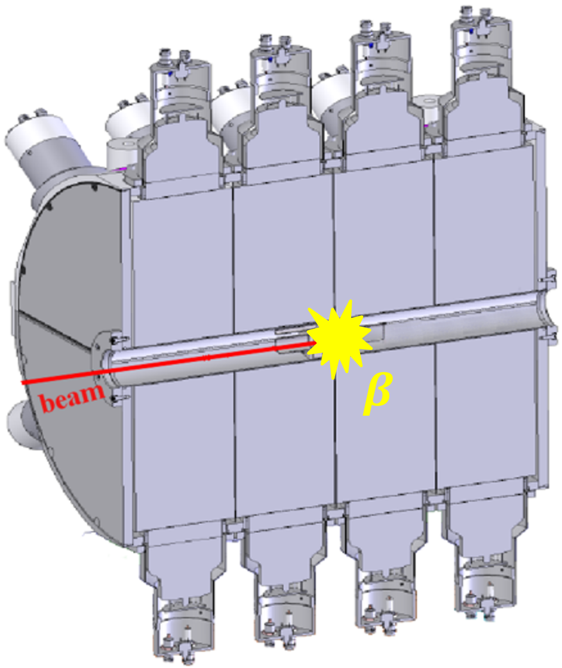
Total Absorption Spectrometry

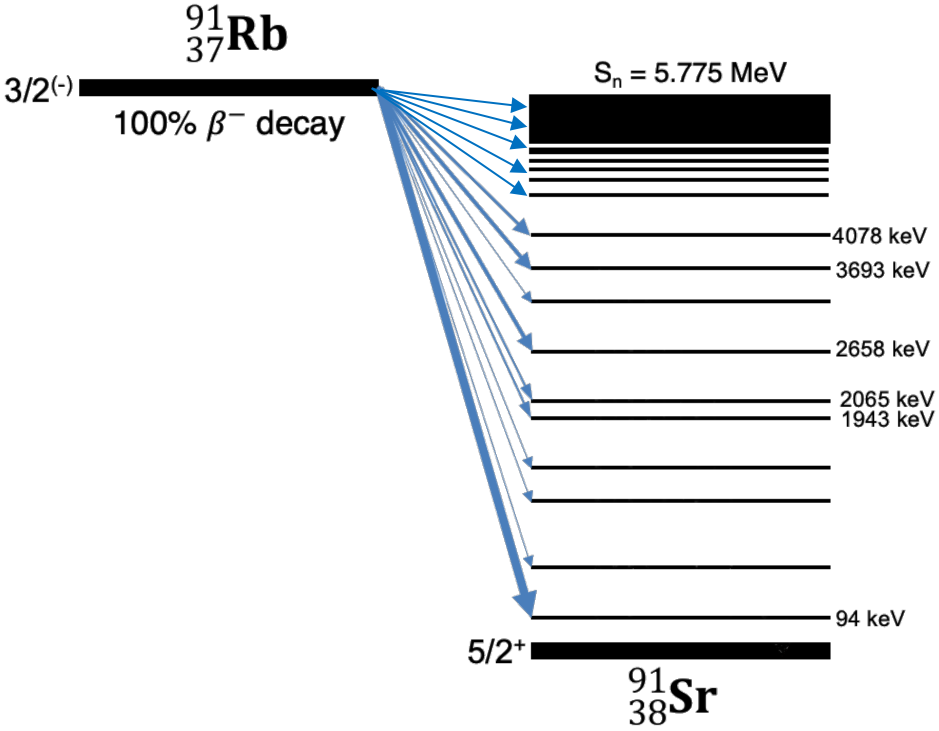




UNIVERSITY of GUELPH

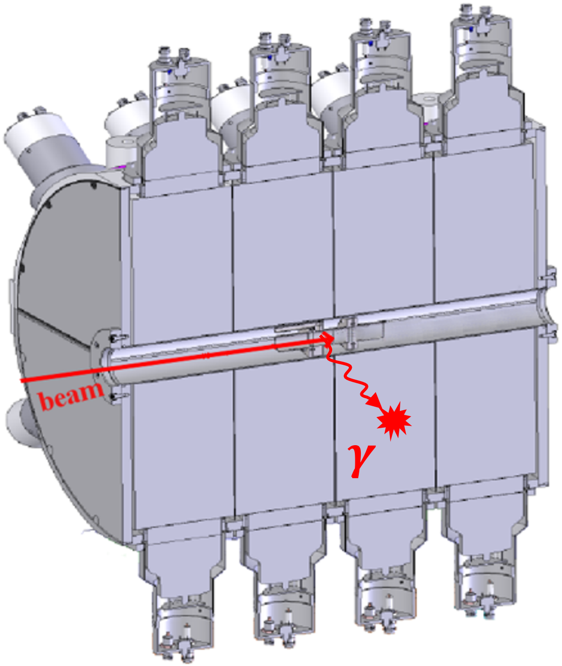
Total Absorption Spectrometry

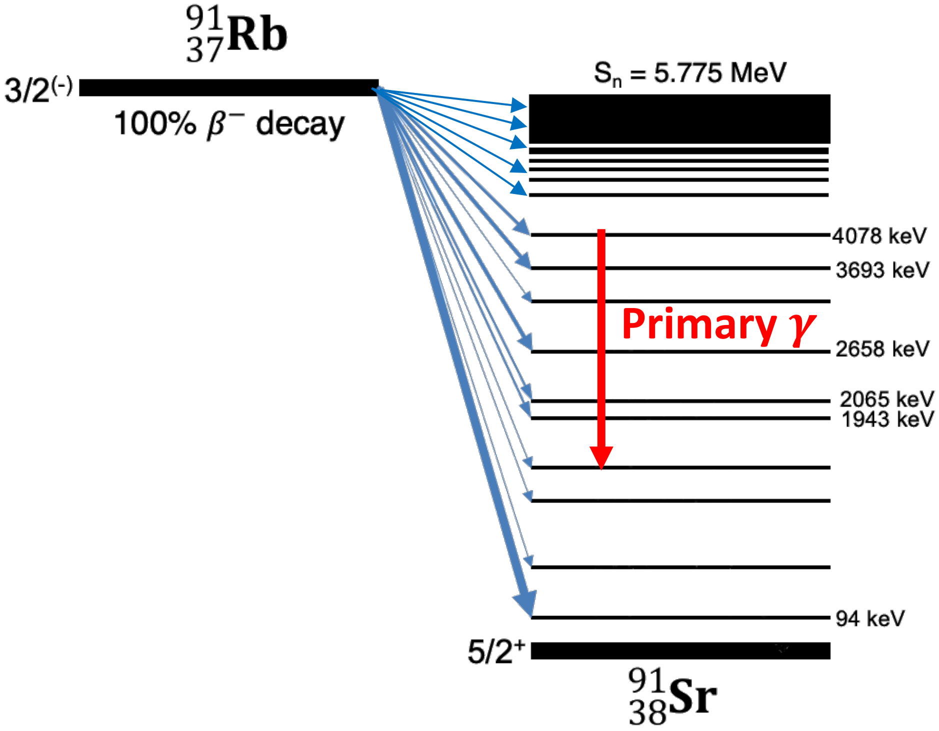




UNIVERSITY of GUELPH

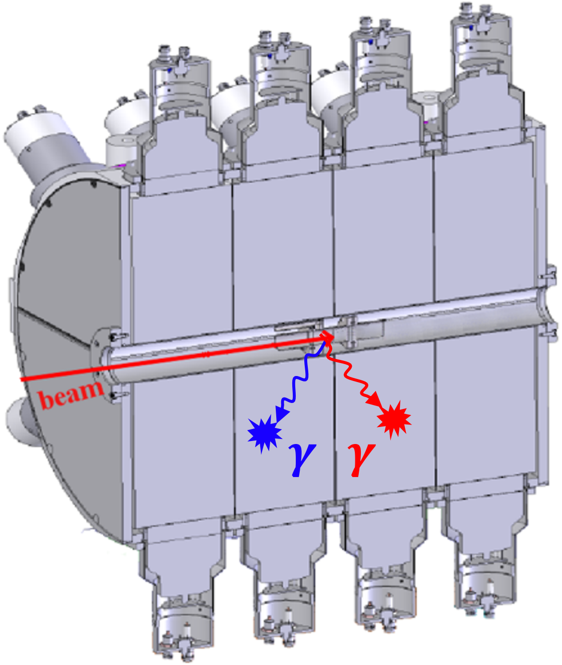
Total Absorption Spectrometry

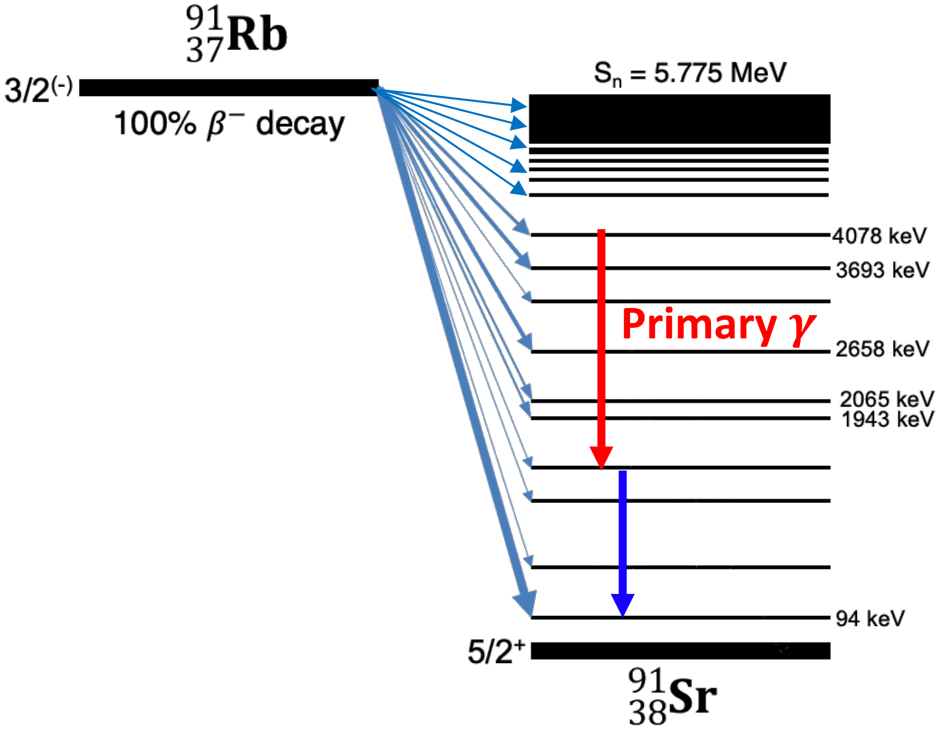




UNIVERSITY of GUELPH

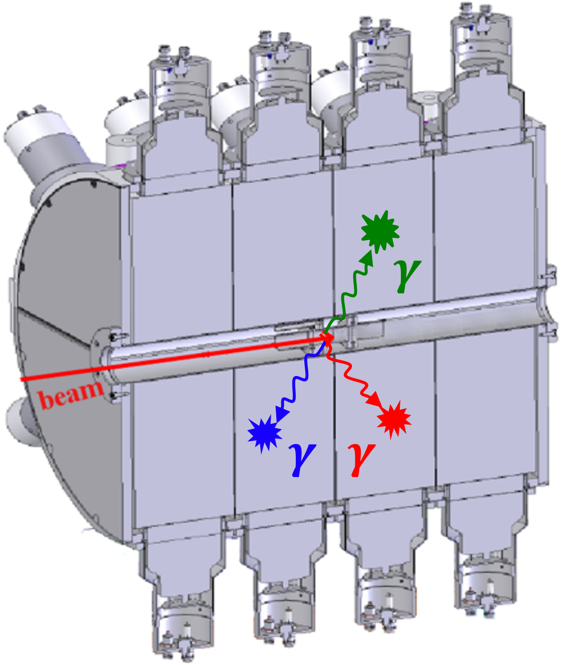
Total Absorption Spectrometry

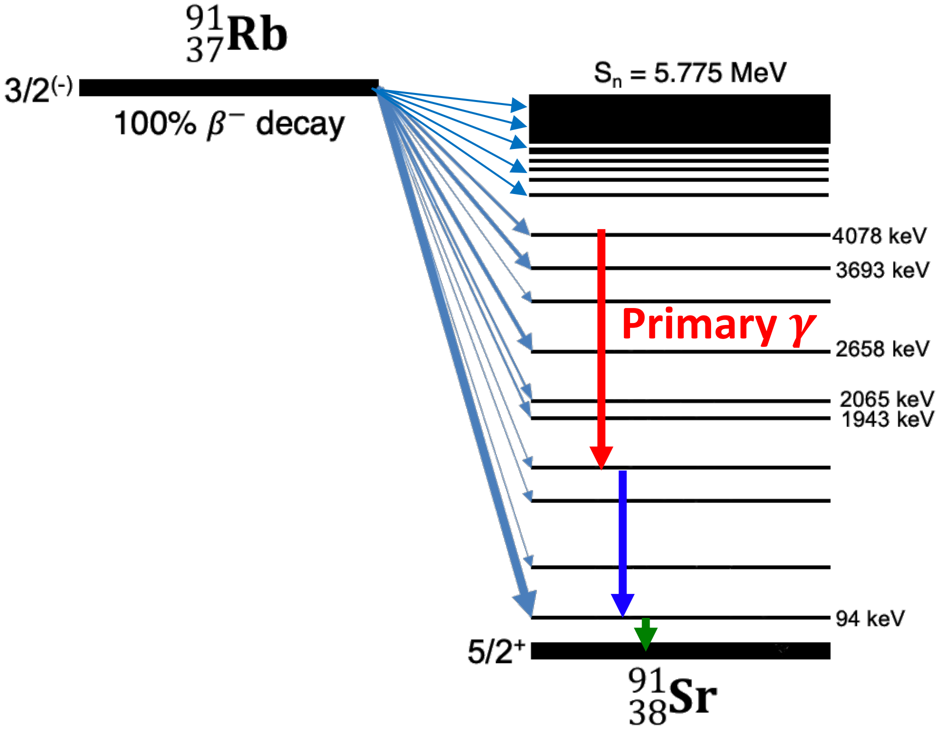




UNIVERSITY of GUELPH

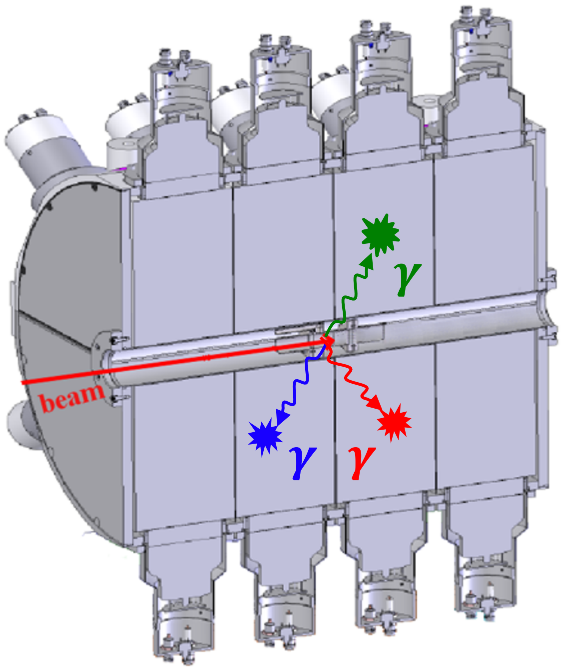
Total Absorption Spectrometry

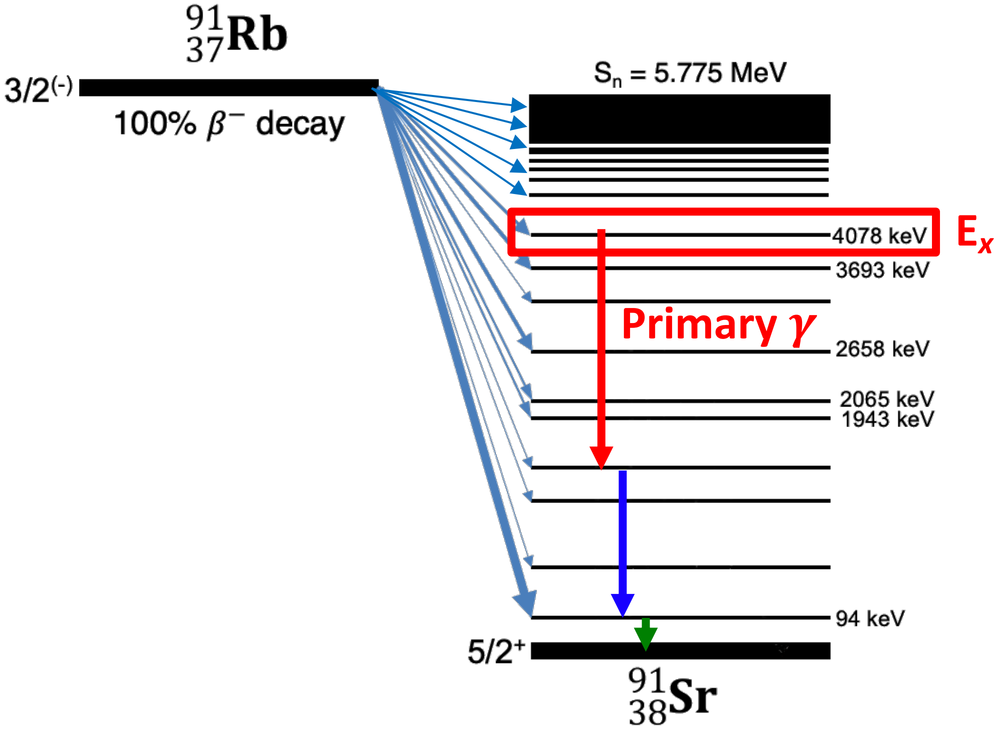




UNIVERSITY of GUELPH

Total Absorption Spectrometry

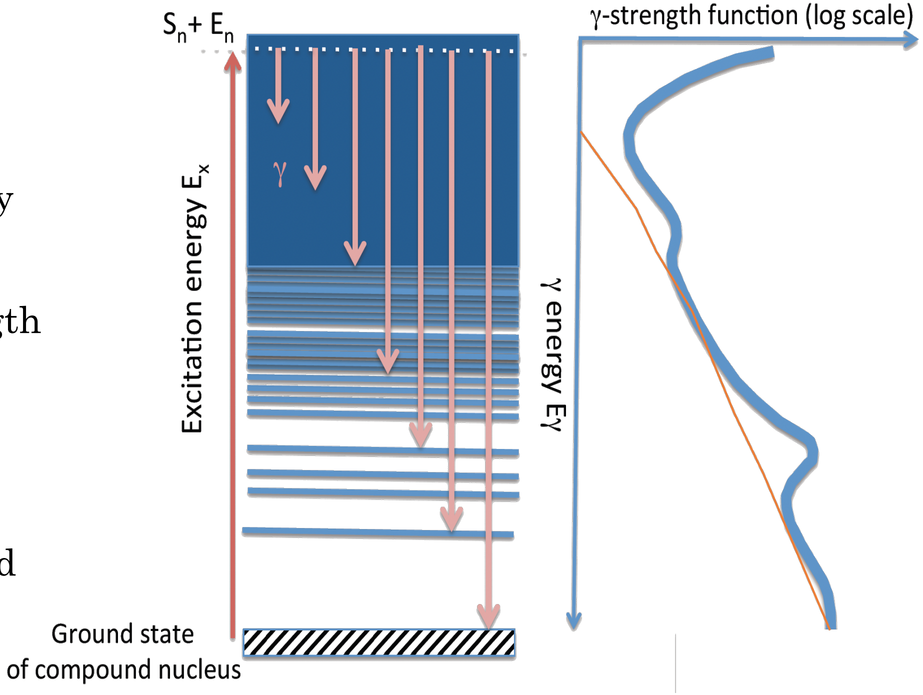




UNIVERSITY of GUELPH

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

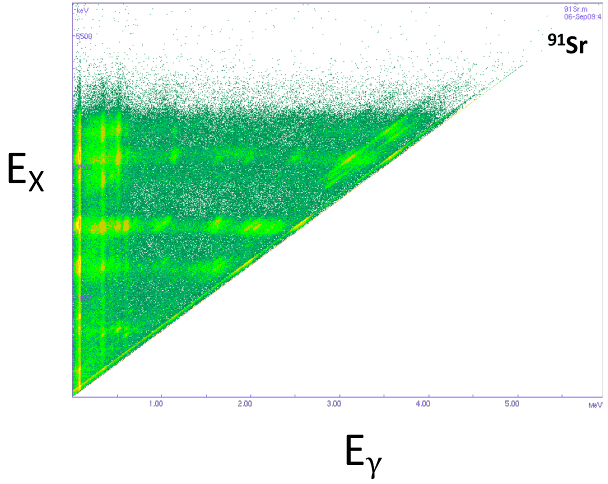


UNIVERSITY of GUELPH

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

Producing Primary Matrix

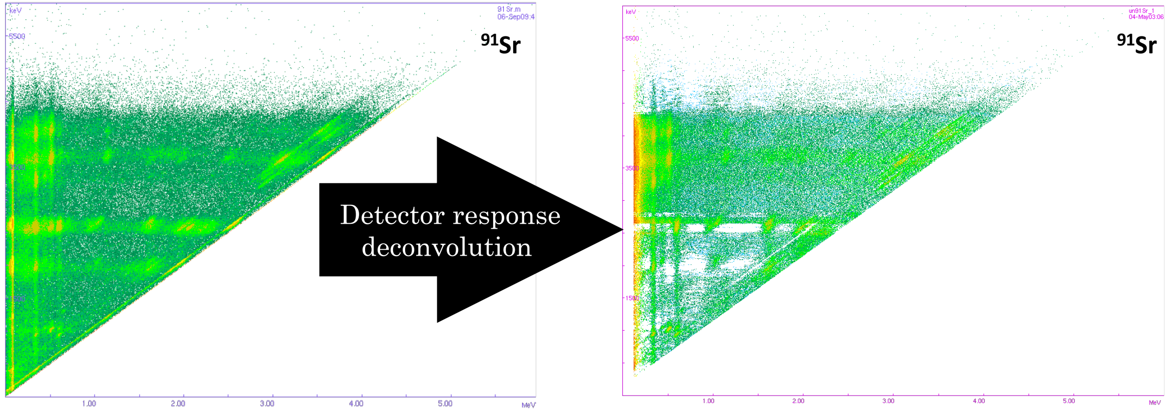
Raw matrix



Producing Primary Matrix

Raw matrix **“Unfolded” matrix**

E_X

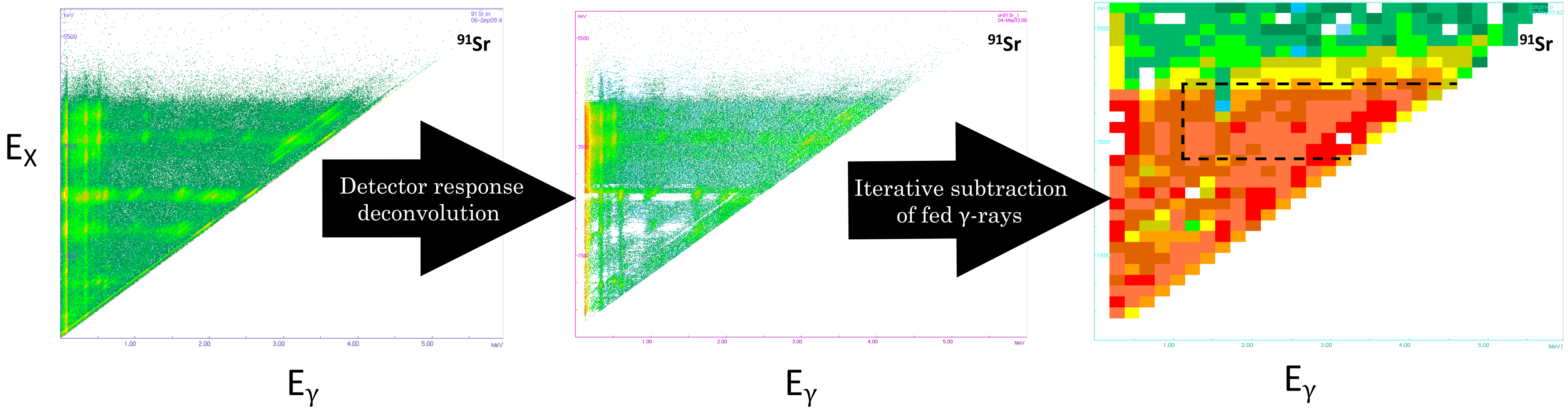


E_γ E_γ

UNIVERSITY of GUELPH

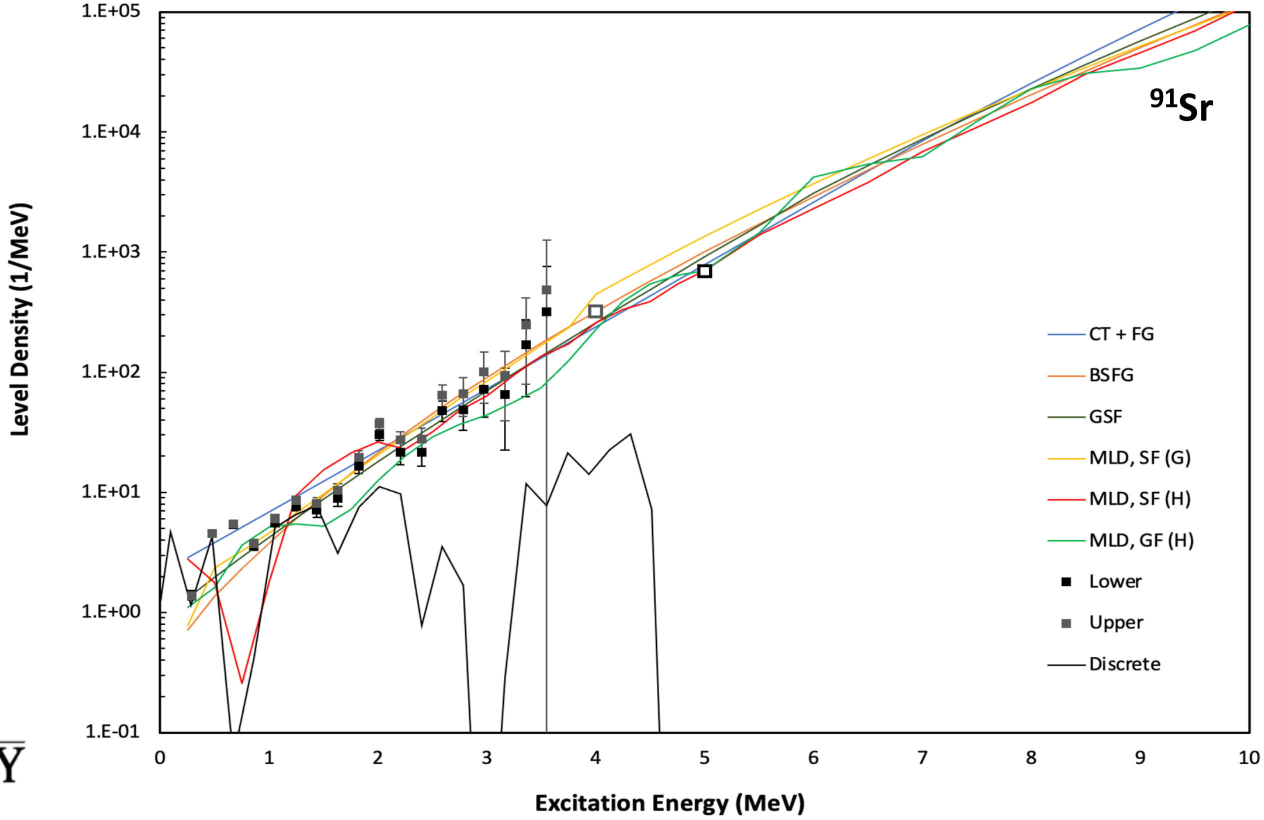
Producing Primary Matrix

Raw matrix | **"Unfolded" matrix** | **Primary γ coincidences**

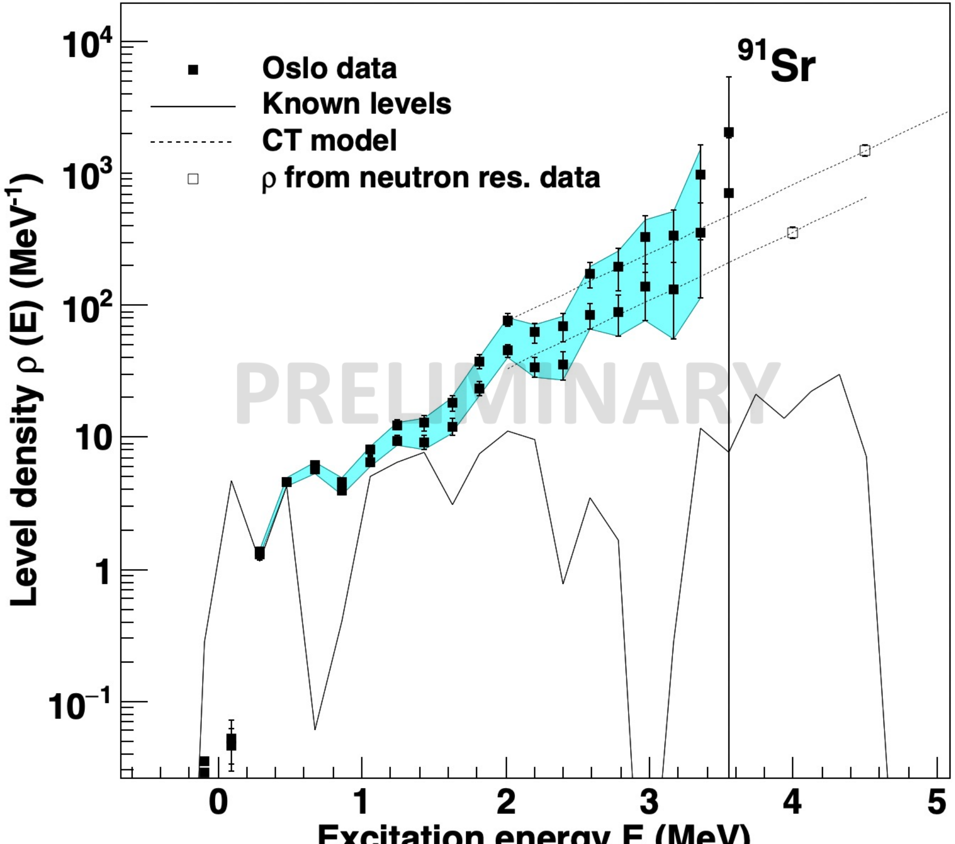


UNIVERSITY of GUELPH

Constraining Nuclear Level Density

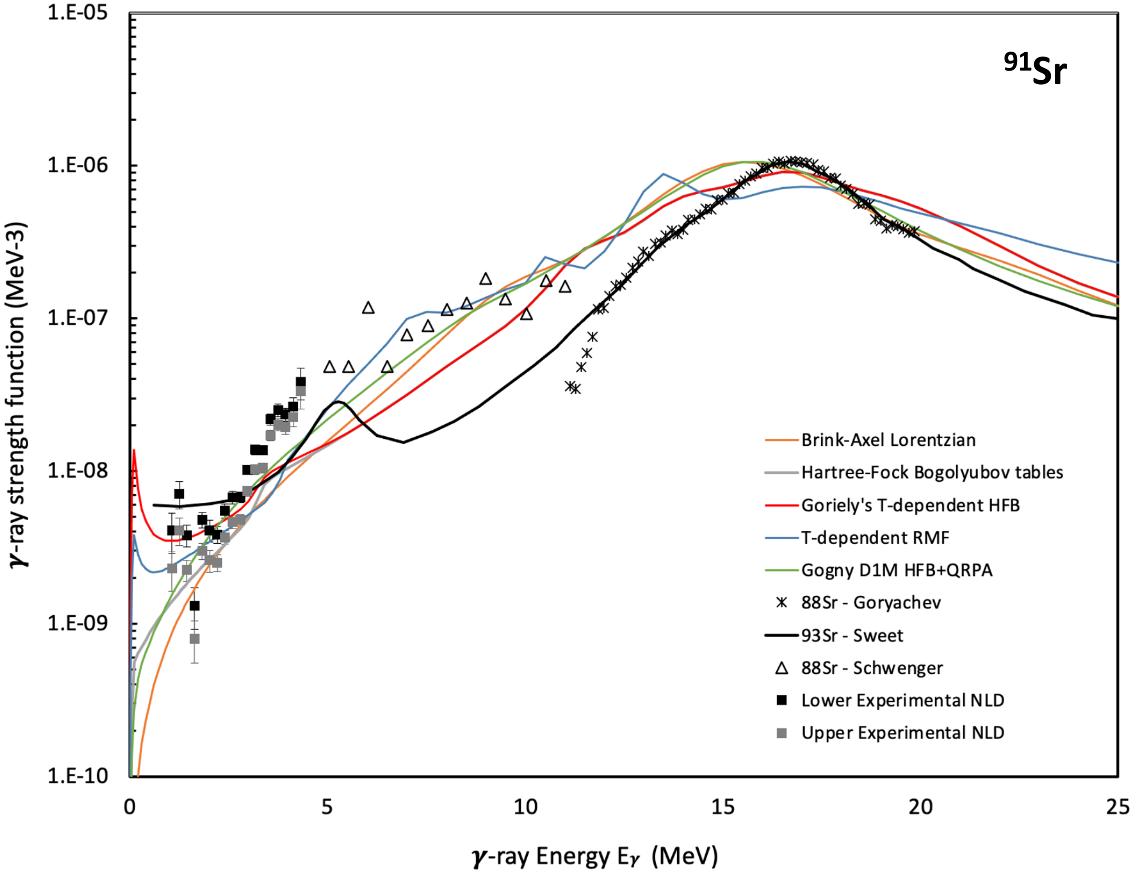


Constraining Nuclear Level Density



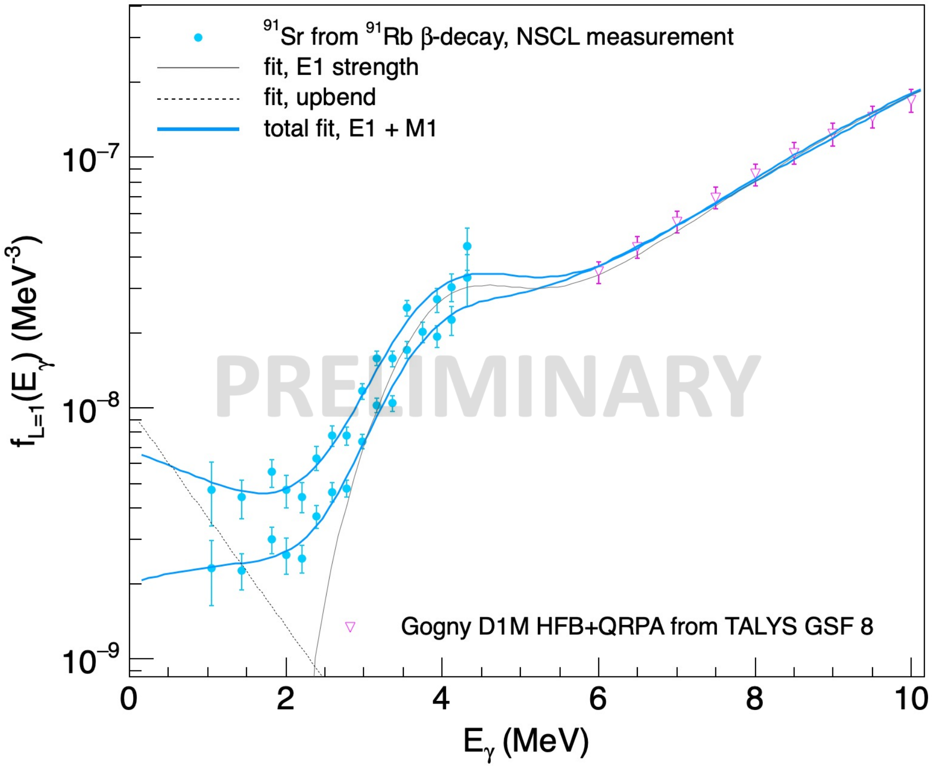
UNIVERSITY of GUELPH

Constraining γ-ray Strength Function



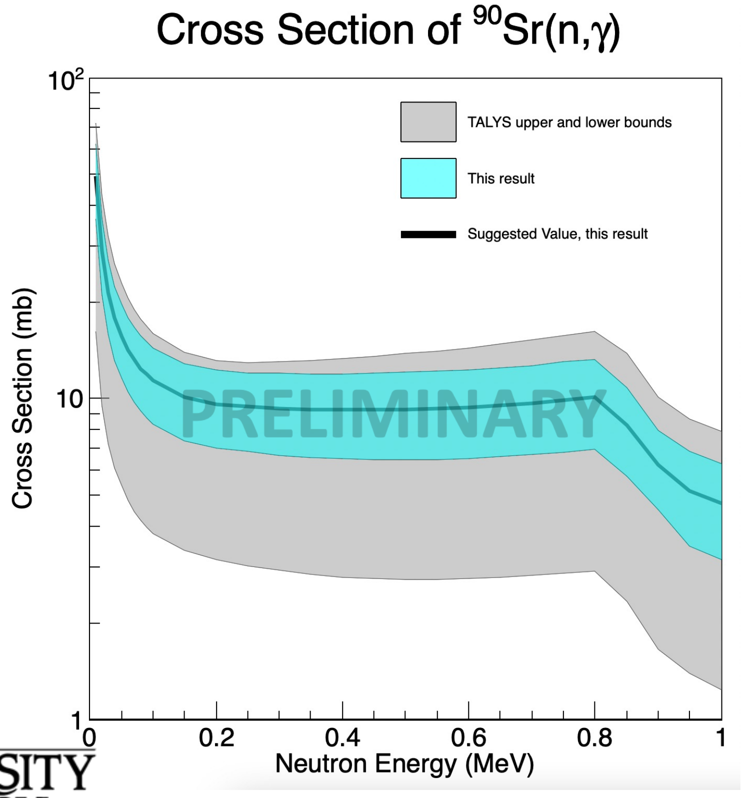
UNIVERSITY of GUELPH

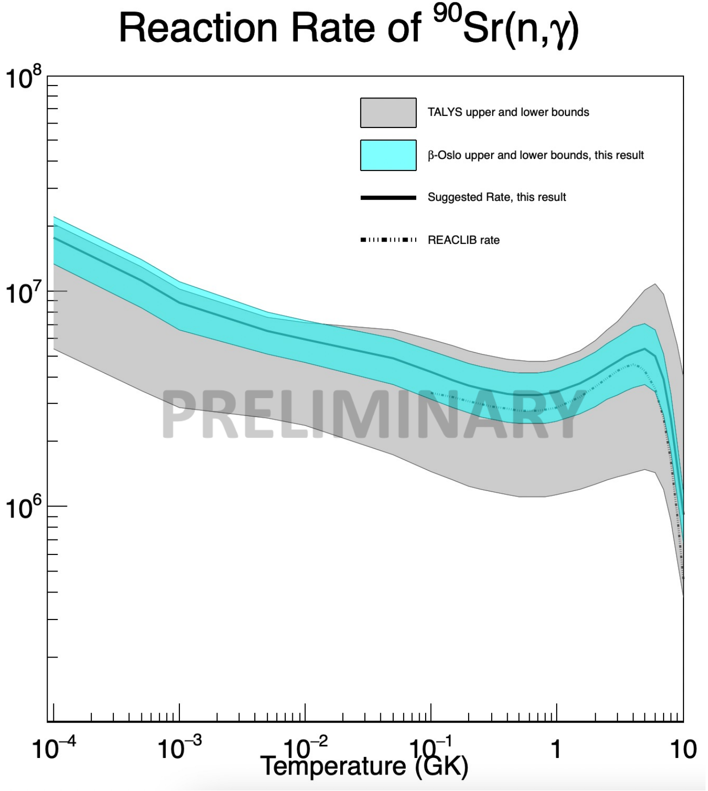
Constraining γ-ray Strength Function



UNIVERSITY of GUELPH

Experimental Results





UNIVERSITY of GUELPH

Summary

- Populated ^{91}Sr via β-decay at NSCL in 2018 and measured with with SuN total absorption spectrometer
- Performed TAS on data to limit it to only β-decay events from ^{91}Rb
- Performed the Oslo method to produce the primary matrix and extract the NLD and γ-SF
- Bound the NLD and γ-SF normalization to theory in order to set final uncertainty on the neutron capture cross section
- Currently in collaboration with modelers to determine the final impact on i-process abundances

UNIVERSITY of GUELPH

Acknowledgements

University of Guelph / TRIUMF - D. Mücher
FRIB / Michigan State University - A. Spyrou, C. Harris, B. Lewis, S.N. Liddick, F. Naqvi, A. Palmisano, N. Scielzo, L. Selensky, M.K. Smith, A. Torode, W. VonSeeger, M. Watts
Lawrence Livermore National Lab - D.L. Bleuel, A. Richard, A. Sweet
University of Oslo - P. DeYoung, M. Guttormson, A.C. Larsen, F. Zeiser
University of Notre Dame - A. Drombos
Hope College - J. Gombas, C. Persch
Pacific Northwest National Lab - S. Lyons
iThemba LABS / University of the Witwatersrand - M. Wiedeking
University of Kentucky - Y. Xiao

UNIVERSITY of GUELPH
INNOVATION.CA
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION
NSERC CRSNG
NSCL