Constraining the γ process

Cross section measurements of (p,γ) reactions in inverse kinematics

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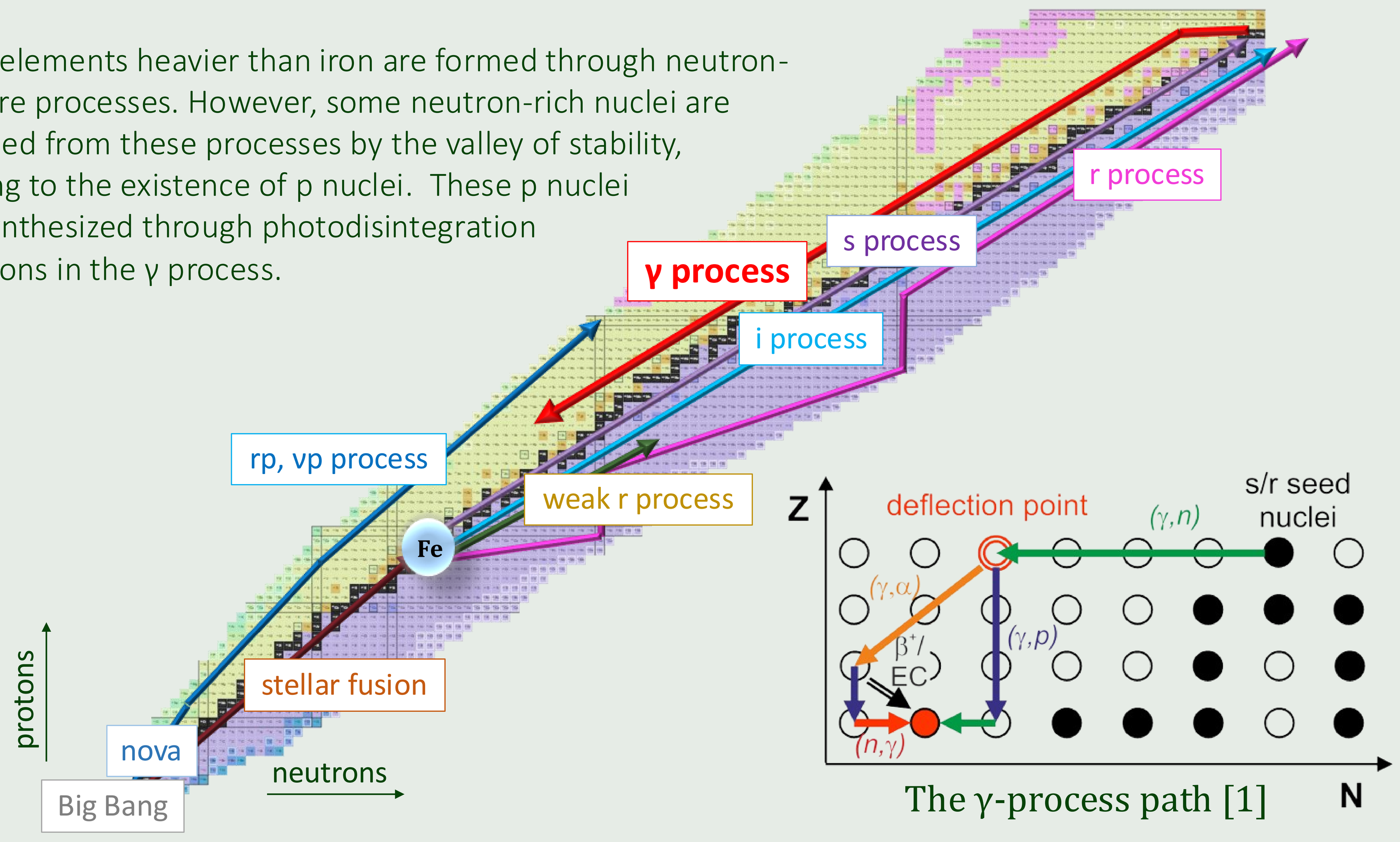
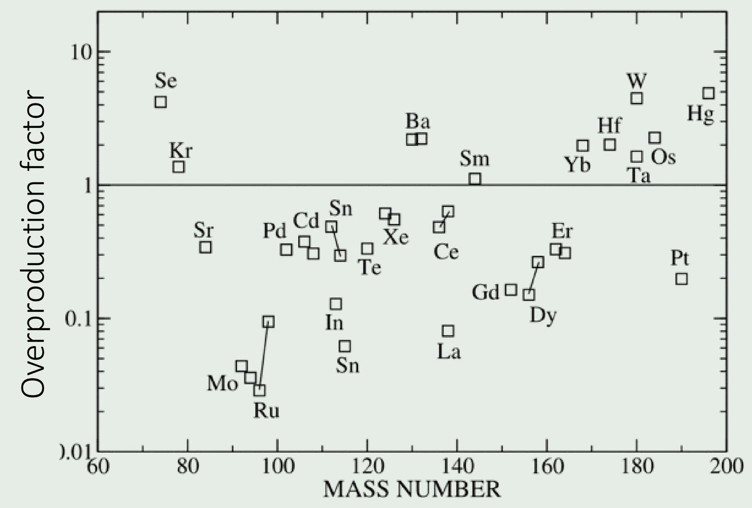
Introduction

Most elements heavier than iron are formed through neutron-capture processes. However, some neutron-rich nuclei are shielded from these processes by the valley of stability, leading to the existence of p nuclei. These p nuclei are synthesized through photodisintegration reactions in the γ process.



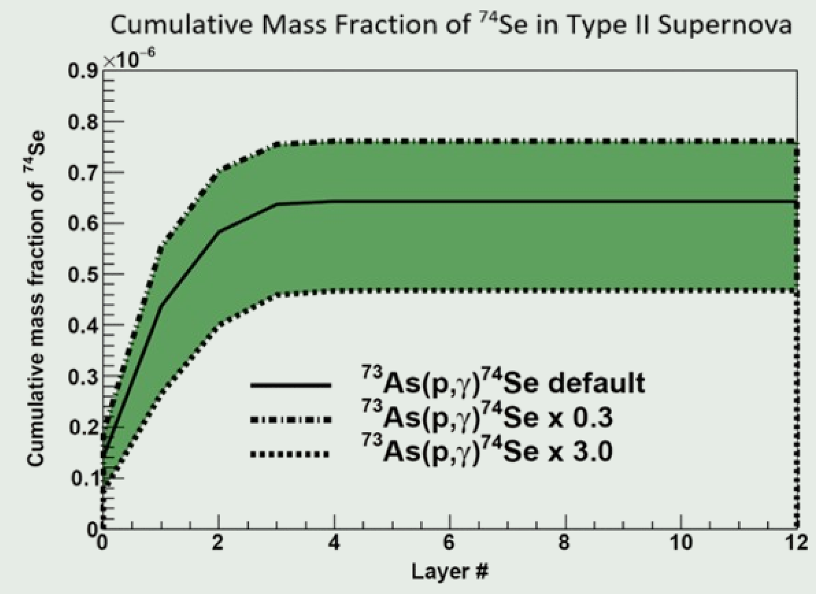
The γ-process path [1]

Calculated p-nuclei abundances [2]

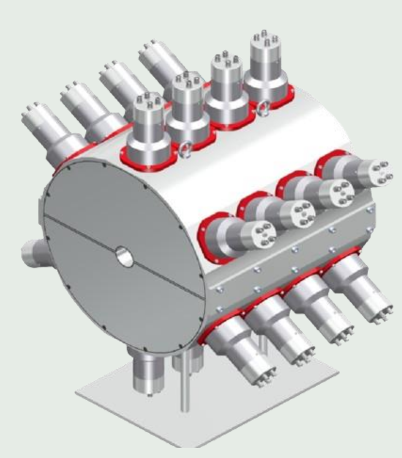


The path of the γ process begins by a series of (γ,n) reactions, followed by a (γ,p) or (γ,α) reaction. This network of reactions involves more than 2000 nuclei, most of which are radioactive. Therefore the study of those (γ,p) and (γ,α) reactions on radioactive elements is important for the accurate reproduction of the p nuclei.

The ^{74}Se(γ,p)^{73}As reaction has been identified as one with high impact on the final abundance of the lightest p-nucleus ^{74}Se, as it is one of its main destruction mechanisms. In this work we focus on the measurement of the inverse reaction ^{73}As(p,γ)^{74}Se, with a radioactive ^{73}As beam.



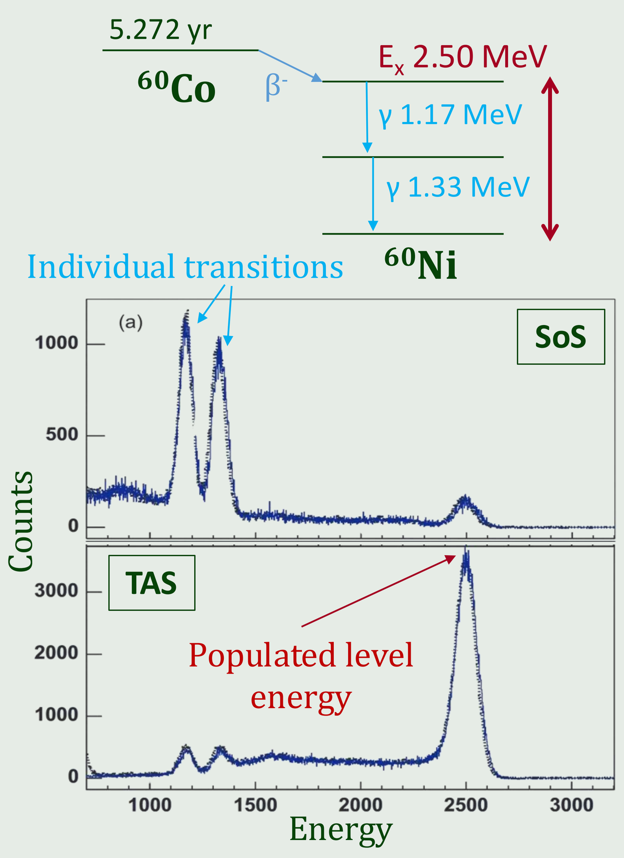
Methods

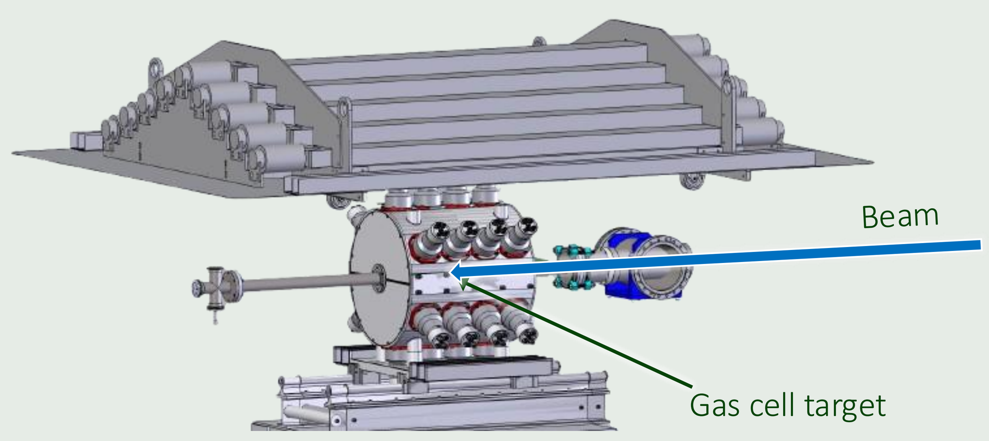


Summing NaI(Tl) SuN

- Large size, high efficiency γ-ray calorimeter
- 8 optically isolated segments, 24 PMTs
- Sum of Segments (SoS) → Information about individual γ-rays
- Total Absorption Spectrum (TAS) → Information about total excitation energy Ex

Total Absorption Spectroscopy





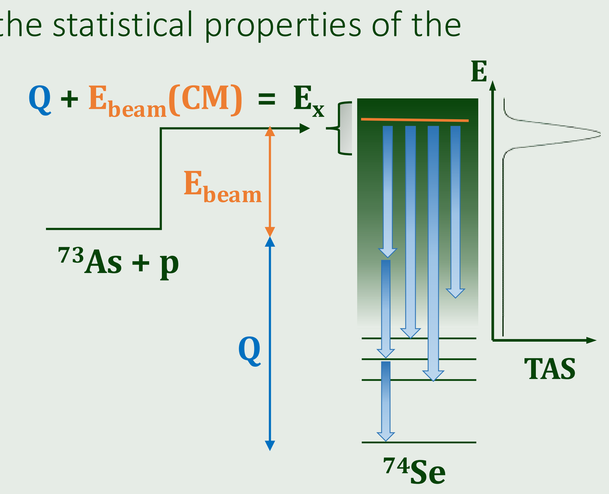
Experiments

- Cross section measurements in inverse kinematics at the Facility for Rare Isotope Beams
  - Proof-of-principle experiment with a stable beam for the ^{82}Kr(p,γ)^{83}Rb reaction (2017)
  - Radioactive beam experiment for the ^{73}As(p,γ)^{74}Se reaction (2023)
- Hydrogen gas cell target located in the center of SuN
- SuN + SuNSCREEN [3] detectors for γ-ray detection and cosmic background rejection

Analysis Overview

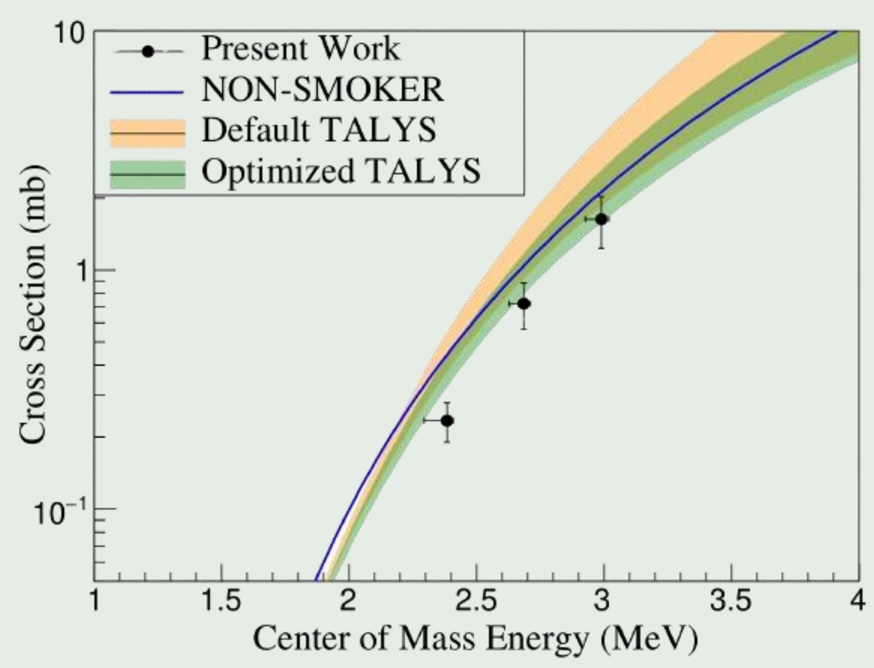
- After background subtraction, the measured yield corresponds to the integral of the total absorption peak (sum peak)
- Due to energy straggling within the gas target and Doppler shift, the sum peak was widened significantly
  → The detection efficiency needs to be calculated as a function of all contributing energies within the sum peak
- The de-excitation of the compound nucleus was simulated using Hauser-Feshbach theory in order to calculate the function of energies that contribute in the sum peak
  → Obtained constraints on the statistical properties of the compound nucleus

$$\sigma = \frac{Yield}{\Phi \cdot N_t \cdot \varepsilon_{eff}(E)}$$



Results

^{82}Kr(p,γ)^{83}Rb

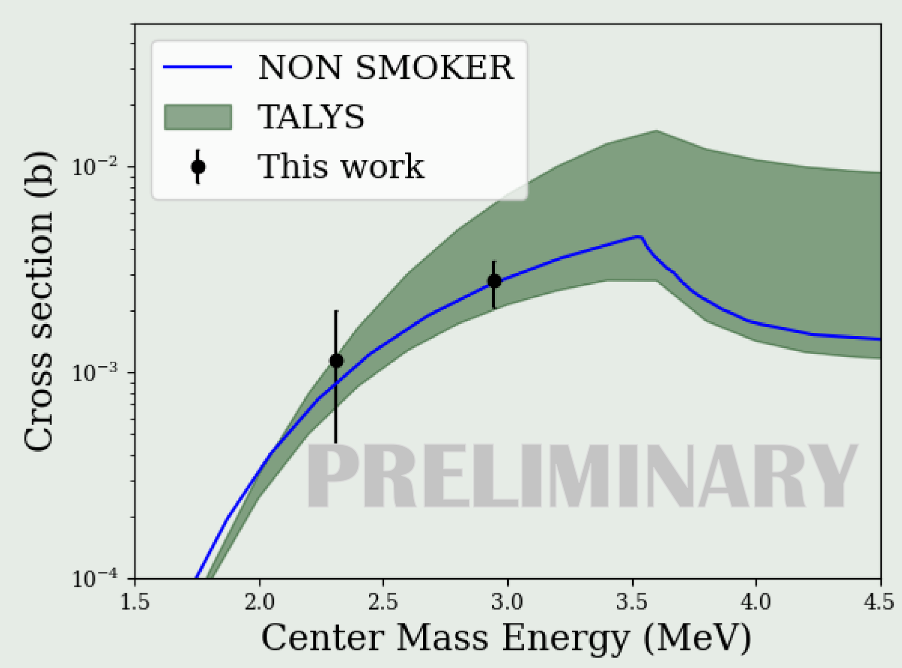


The ^{82}Kr(p,γ)^{83}Rb cross section was measured in three energies within the Gamow window for the γ process [4].

The results indicate that standard statistical model calculations using NON-SMOKER and TALYS tend to overestimate the cross section. Based on experimental data in neighboring nuclei [5,6], there appears to be a consistent trend in this mass region.

The constraints on the statistical properties of the ^{83}Rb nucleus allow for a better description of the experimental data with TALYS, as well as a constrain on the cross section on broader energy range

^{73}As(p,γ)^{74}Se



The ^{73}As(p,γ)^{74}Se cross section was measured for the first time within the Gamow window for the γ process.

There is good agreement between the measured cross section and statistical model calculations using NON-SMOKER. This may suggest that the overproduction of Se in network calculations is not due to uncertainty in this reaction.

Future Work

1. Finalize analysis of the ^{73}As(p,γ)^{74}Se data
2. Provide broader cross section constraint from statistical properties
3. Study the effect of the extracted ^{73}As(p,γ)^{74}Se cross section on the ^{74}Se final abundance for a SNII scenario

References

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