INTC-P-283

The neutron capture cross section of the s-process branch point ^{63}Ni

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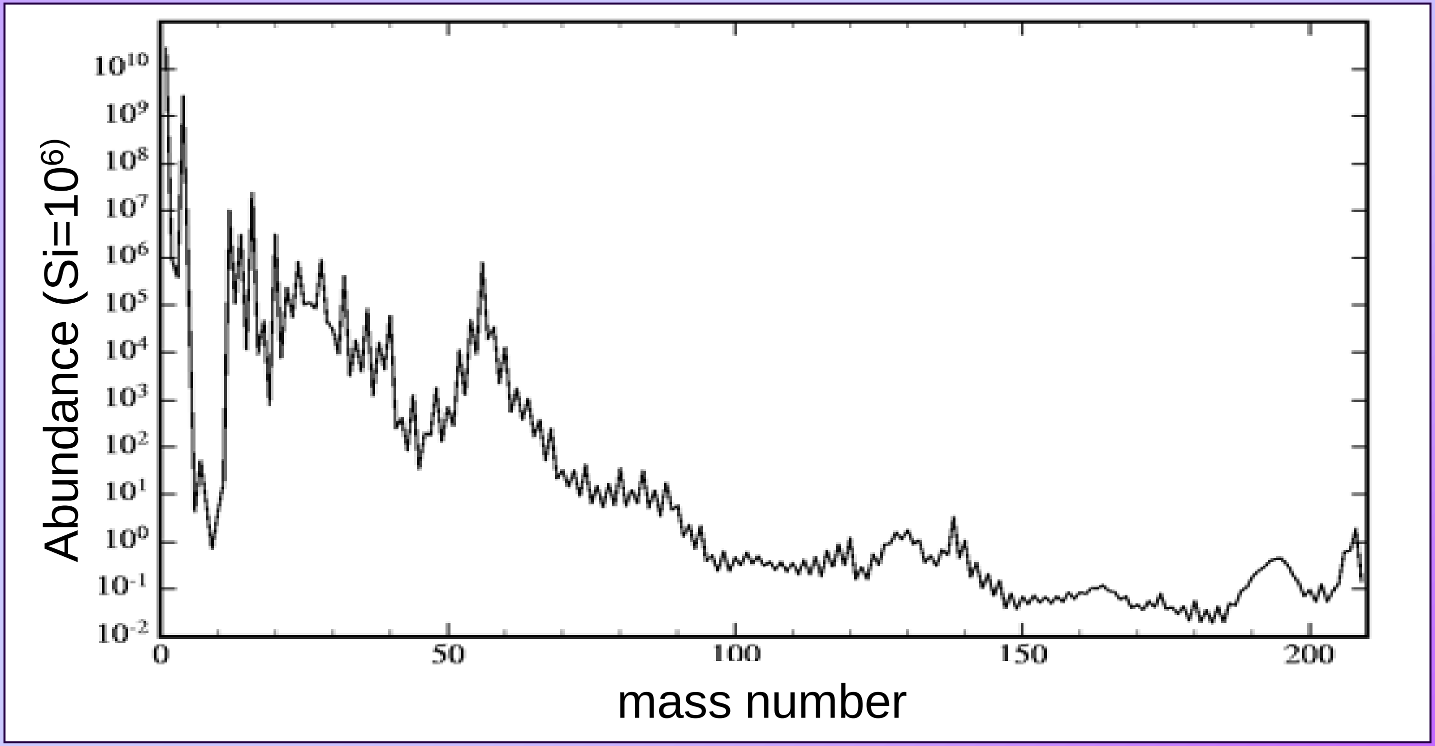
MOTIVATION

Motivation

- How are heavy elements formed (>Fe) ?



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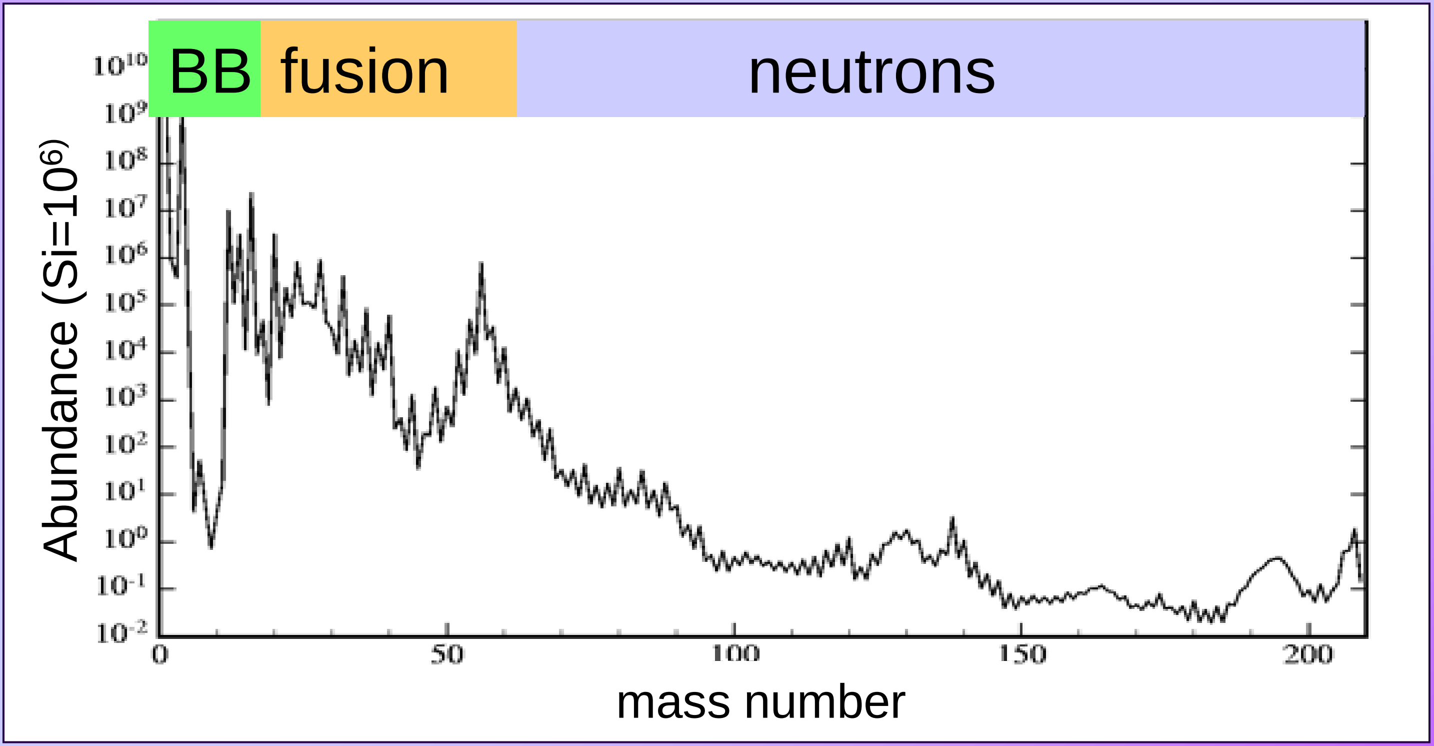

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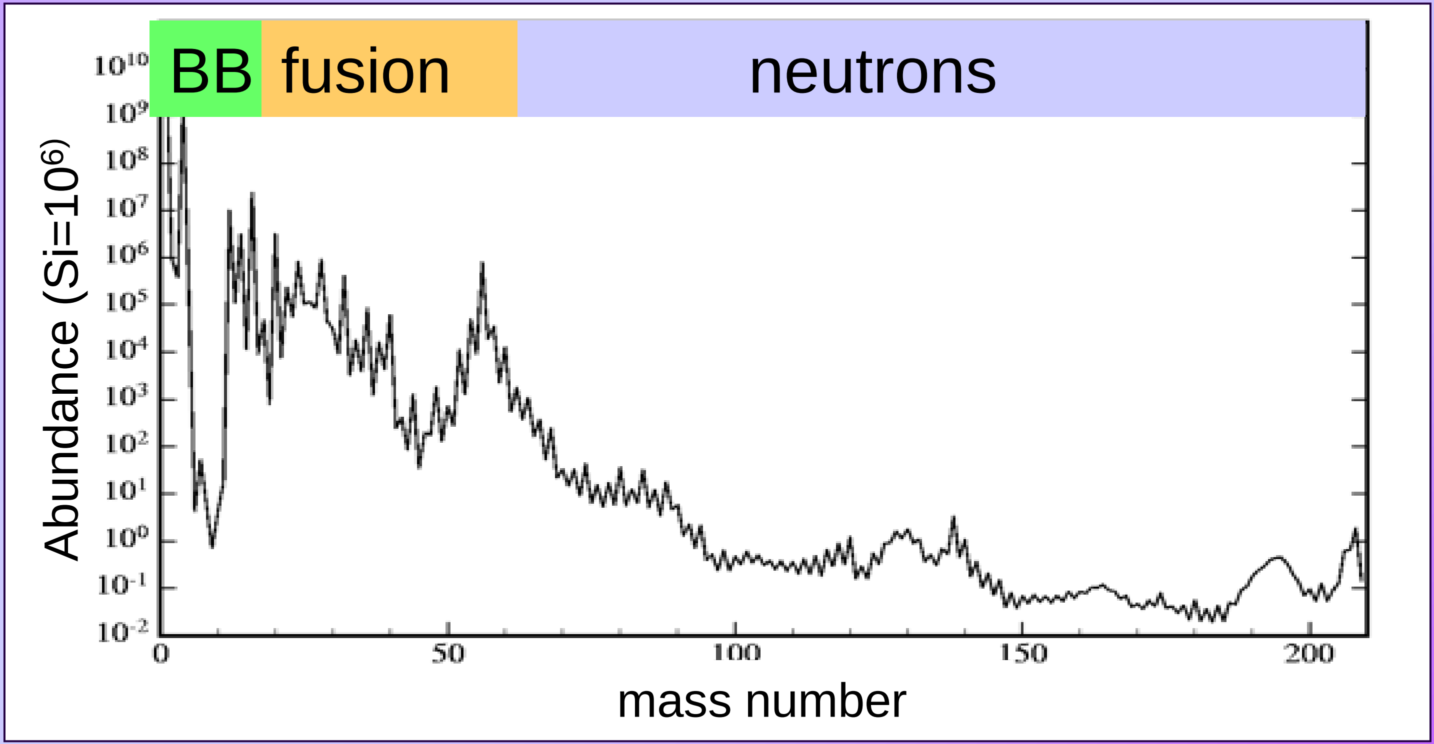
slow neutron capture (s-process)

rapid neutron capture (r-process)



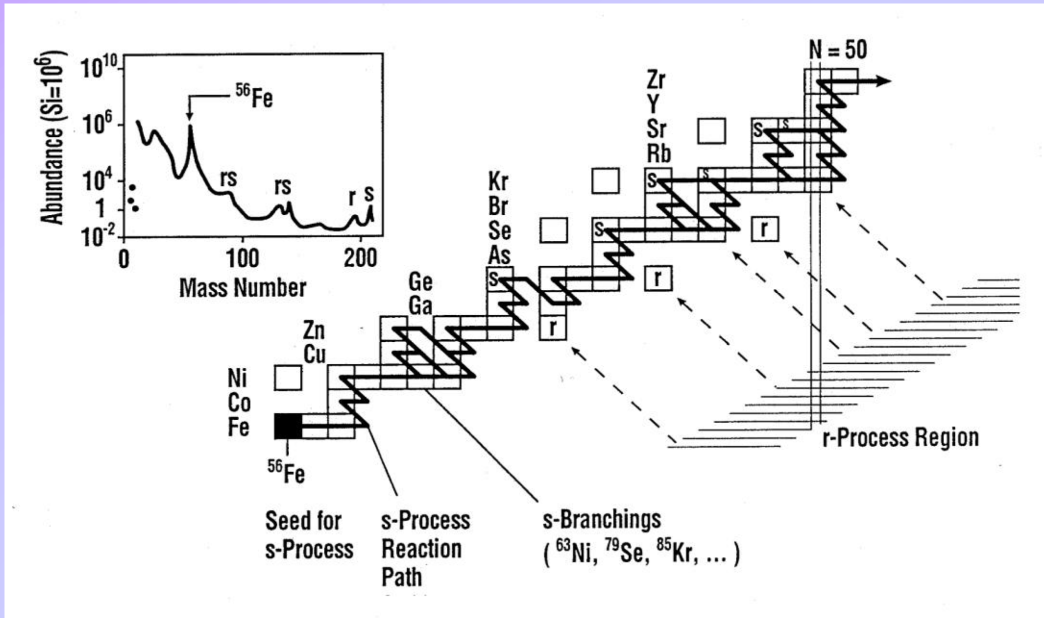
Neutron capture processes

slow neutron capture (s-process)

- AGB stars, massive stars
- $\tau_{n,\gamma}$ (~1 yr) > $t_{1/2}$
- N_n~10^8 cm^{-3}
- close to valley of stability
- nuclear physics input: $<\sigma_{n,\gamma}>$, $t_{1/2}$

rapid neutron capture (r-process)

- explosive scenarios
- $\tau_{n,\gamma}$ (10^{-4}s) < $t_{1/2}$
- N_n~10^{21} cm^{-3}
- far from valley of stability



these 2 processes can explain almost all isotopic signatures !!

F. Käppeler, A. Mengoni, Nucl. Phys. A **777** (2006)

Neutron capture processes

slow neutron capture (s-process)

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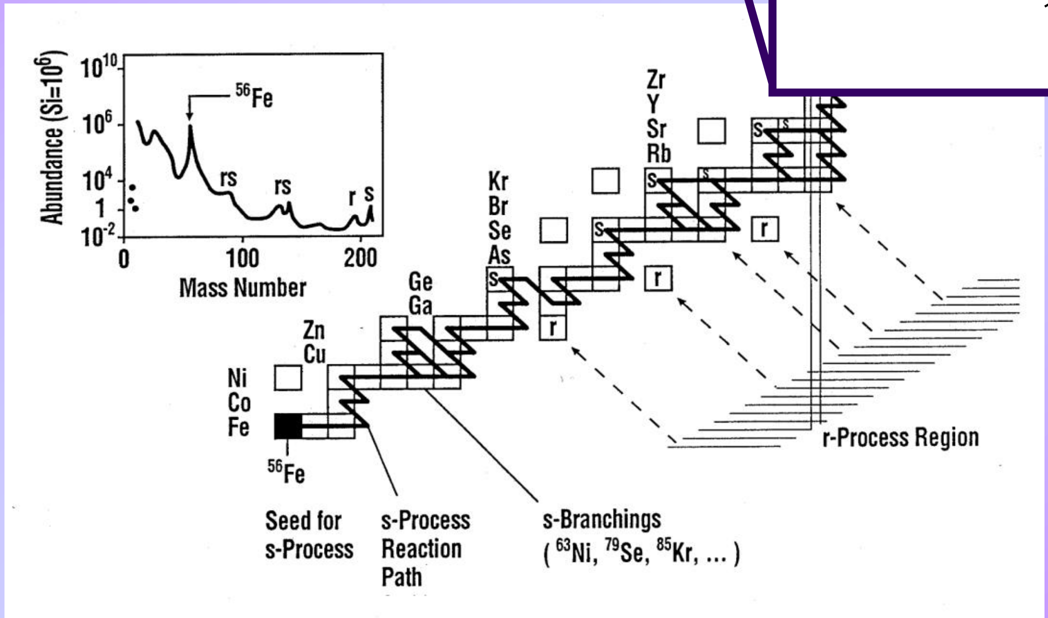
- $\tau_{n,\gamma}$ (~1 yr) > $t_{1/2}$
- $N_n \sim 10^8$ cm^{-3}
- close to valley of stability
- nuclear physics input: $<\sigma_{n,\gamma}>$,

Maxwellian Averaged Cross Section (MACS)

$$<\sigma>_{kT} = \frac{2}{\sqrt{\pi}} \frac{\int \sigma(E_n) E_n \exp(-E_n / kT) dE_n}{\int E_n \exp(-E_n / kT) dE_n}$$



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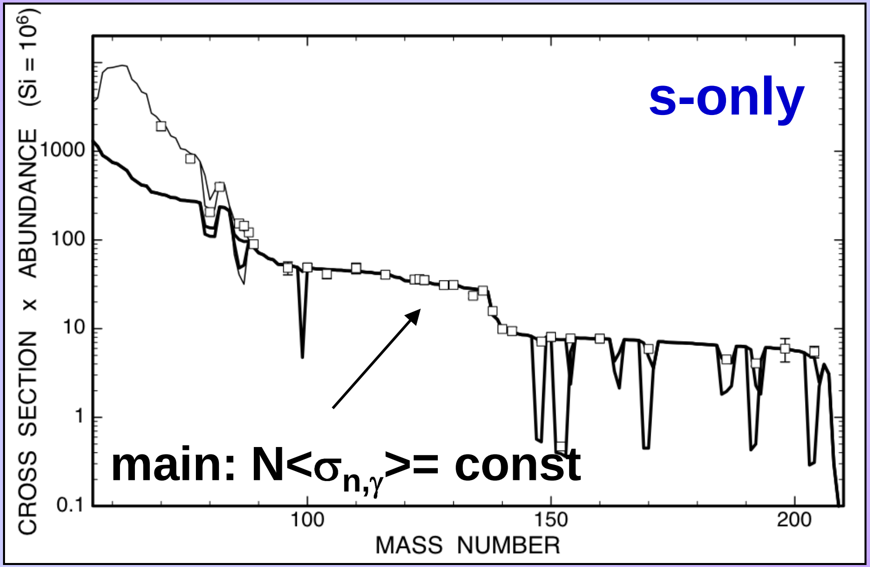
s-process

- **main s-process**: Zr < A < Bi
- in thermally pulsing AGB stars after He core burning (1-3 $M_\odot$); kT= 8 keV, 23 keV
- Local equilibrium $N\langle\sigma_{n,\gamma}\rangle$=const. between neutron shell closures



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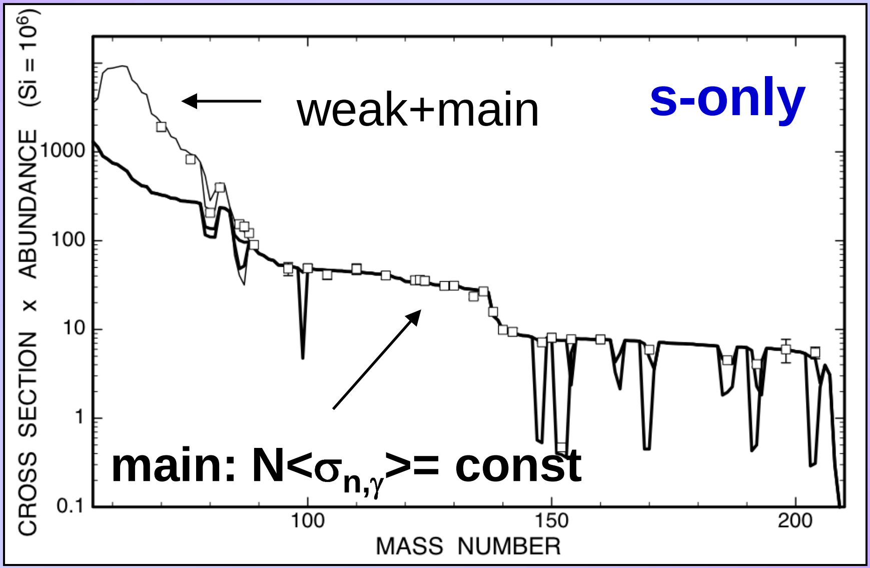

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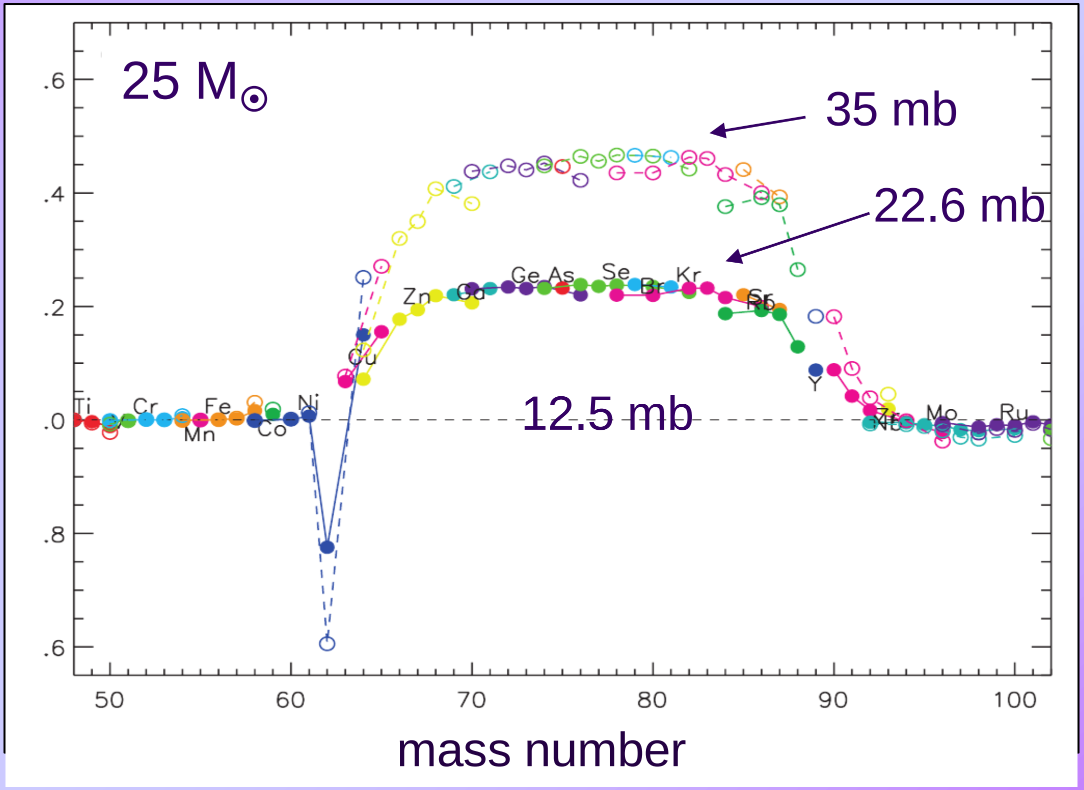
- **weak s-process:** additional component for Fe < A < Zr
- in massive stars (> 8 $M_\odot$); kT= 25 keV, 91 keV
- neutron fluence too small for equilibrium

Propagation effect of cross section: ^{62}Ni(n,γ)

MACS at 30 keV



Nassar et al. (2005)

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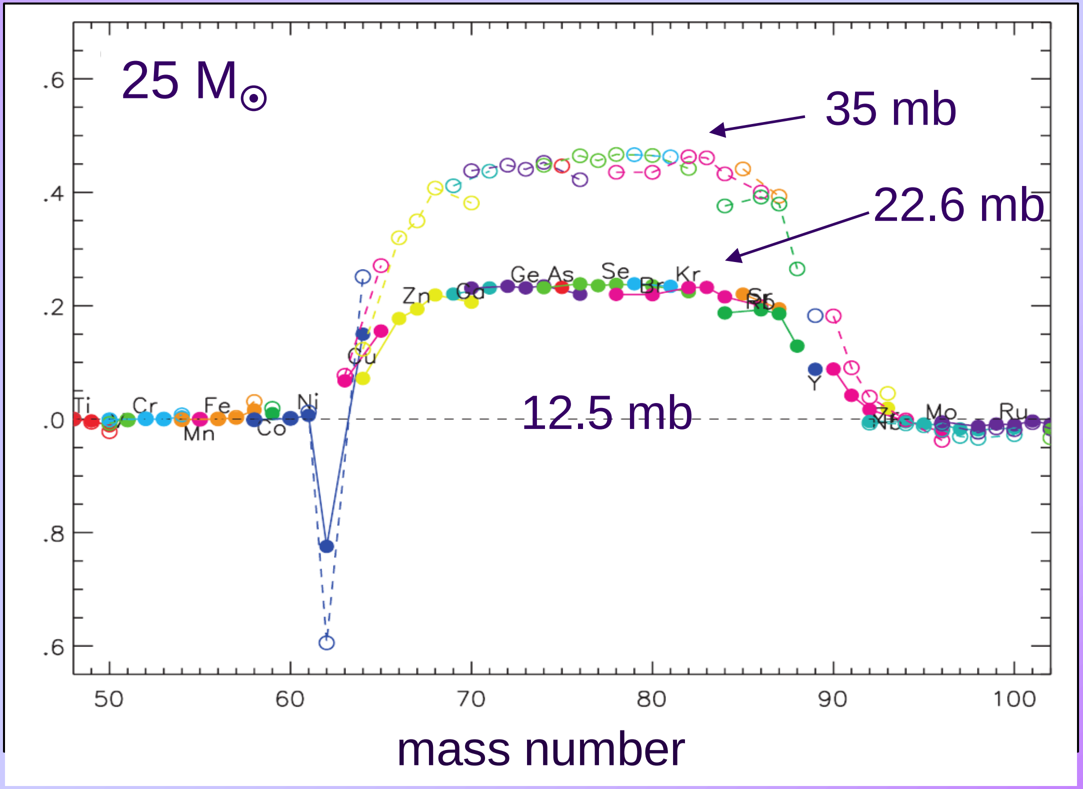

Nassar et al. (2005)

- capture cross section influences abundances of all following isotopes up to A~90 !
- MACS needed up to ~100 keV !

The case of ^{63}Ni

- $t_{1/2}$=100.1 yr
- decay: β^- to ^{63}Cu (no γ-emission → no radioactive background)
- $t_{1/2}$ reduced under stellar conditions → for kT=91 keV, $t_{1/2}$= 0.4 yr ! (Pignatari et al. Ap.J. **710** (2010))

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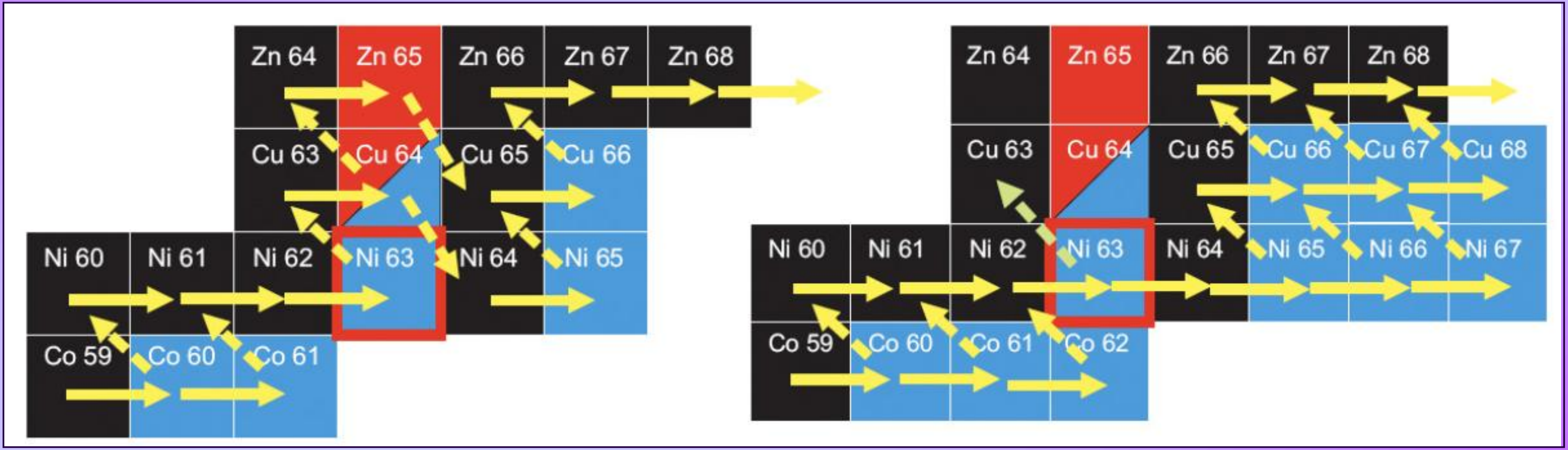

core He burning, kT=25 keV, $N_n \sim 10^6\ \mathrm{cm}^{-3}$

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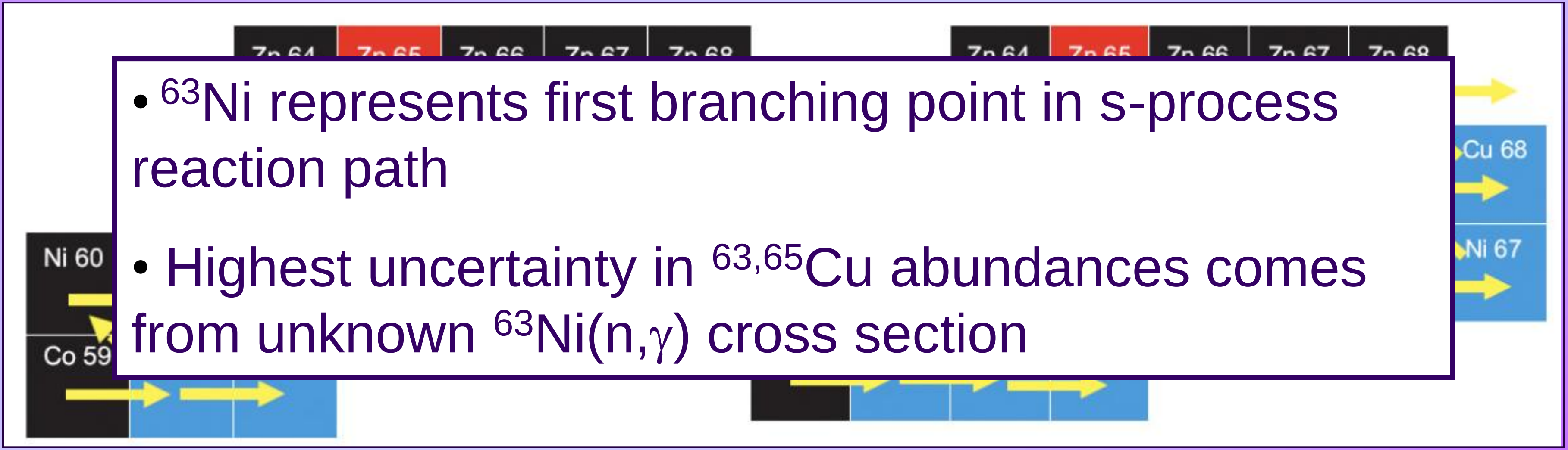


- ^{63}Ni represents first branching point in s-process reaction path
- Highest uncertainty in ^{63,65}Cu abundances comes from unknown ^{63}Ni(n,γ) cross section

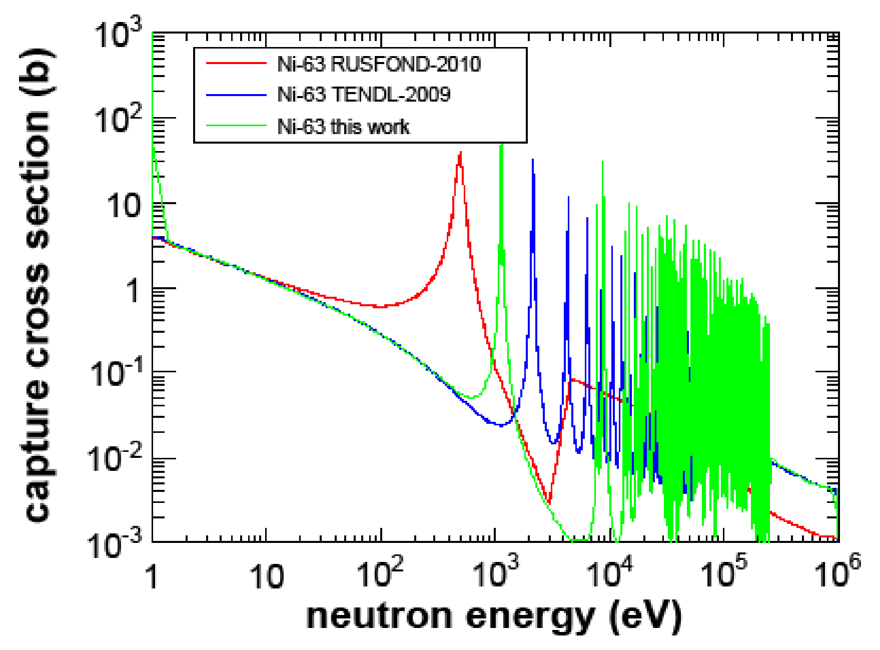
core He burning, kT=25 keV,
N_n~10^6 cm^{-3}

C shell burning, kT=91 keV,
N_n~10^{11} cm^{-3}

Present situation on ^{63}Ni(n,γ)

- measurements so far ONLY at thermal energies
- MACS are based on extrapolation of these cross sections → theoretical assumptions could be affected by big uncertainties

- ^{63}Ni cross section according to calculations:



This work: estimate of cross section by generating artificial set of resonances:

- fixed statistical properties of level spacing, neutron widths and gamma widths
- neutron strength functions and reaction widths close to exp. values of ^{62}Ni (small variations for different Ni isotopes)
- procedure tested on stable Ni isotopes

Present situation on ^{63}Ni(n,γ)

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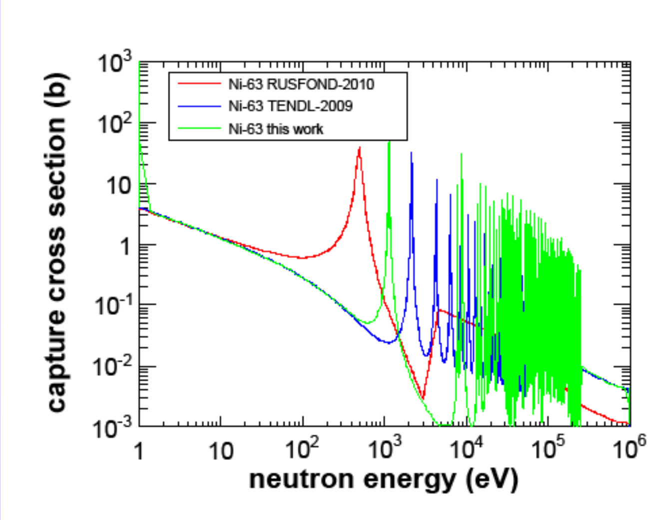
- MACS at 30 keV:

  KADoNiS: 31± 6 mb

  TENDL(2009): 68.9 mb

  this work: 90.8 mb



MEASUREMENT
&
BEAM TIME REQUEST

^{63}Ni sample

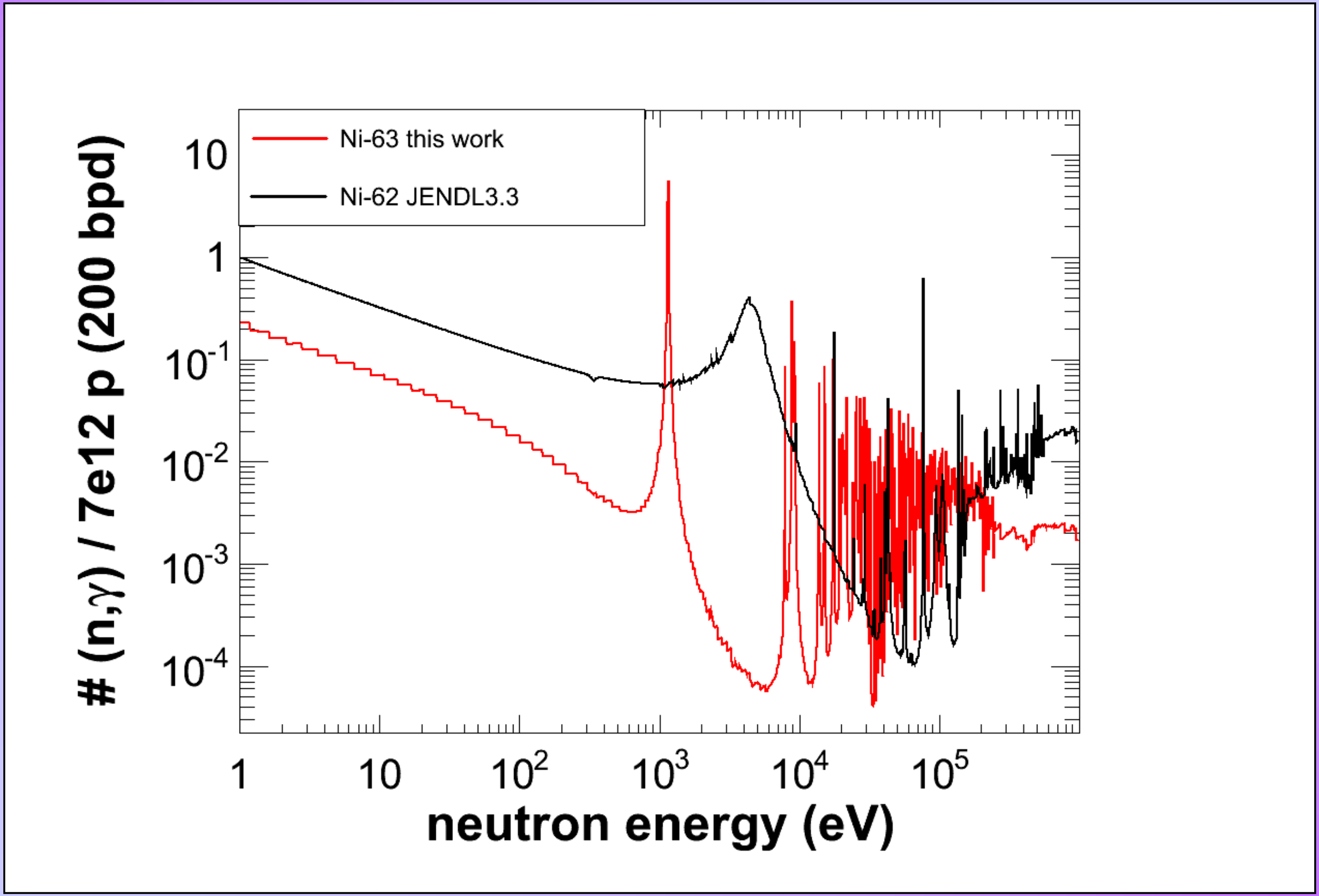
- 3 metal discs (2 foils produced 1984, 1 foil produced 1992)
- total mass: 955 mg
- diameter: 10 mm
- enrichment in ^{63}Ni: 11.7 % (= 112 mg)
- contaminants: 18.3 mg ^{63}Cu → will be removed chemically at PSI

Special suitability of n_TOF because of.....

- high intensity neutron pulses → background uncorrelated with neutron beam very small
- 185 m flight path → good energy resolution also at high neutron energies
- C_6D_6 detector setup optimized for low neutron efficiency → minimized background due to neutron scattering
- upgrade in DAQ allows measuring thermal point
- ^{62}Ni capture yield already measured at n_TOF in 2009

Count rate estimate

- based on calculated cross section described before



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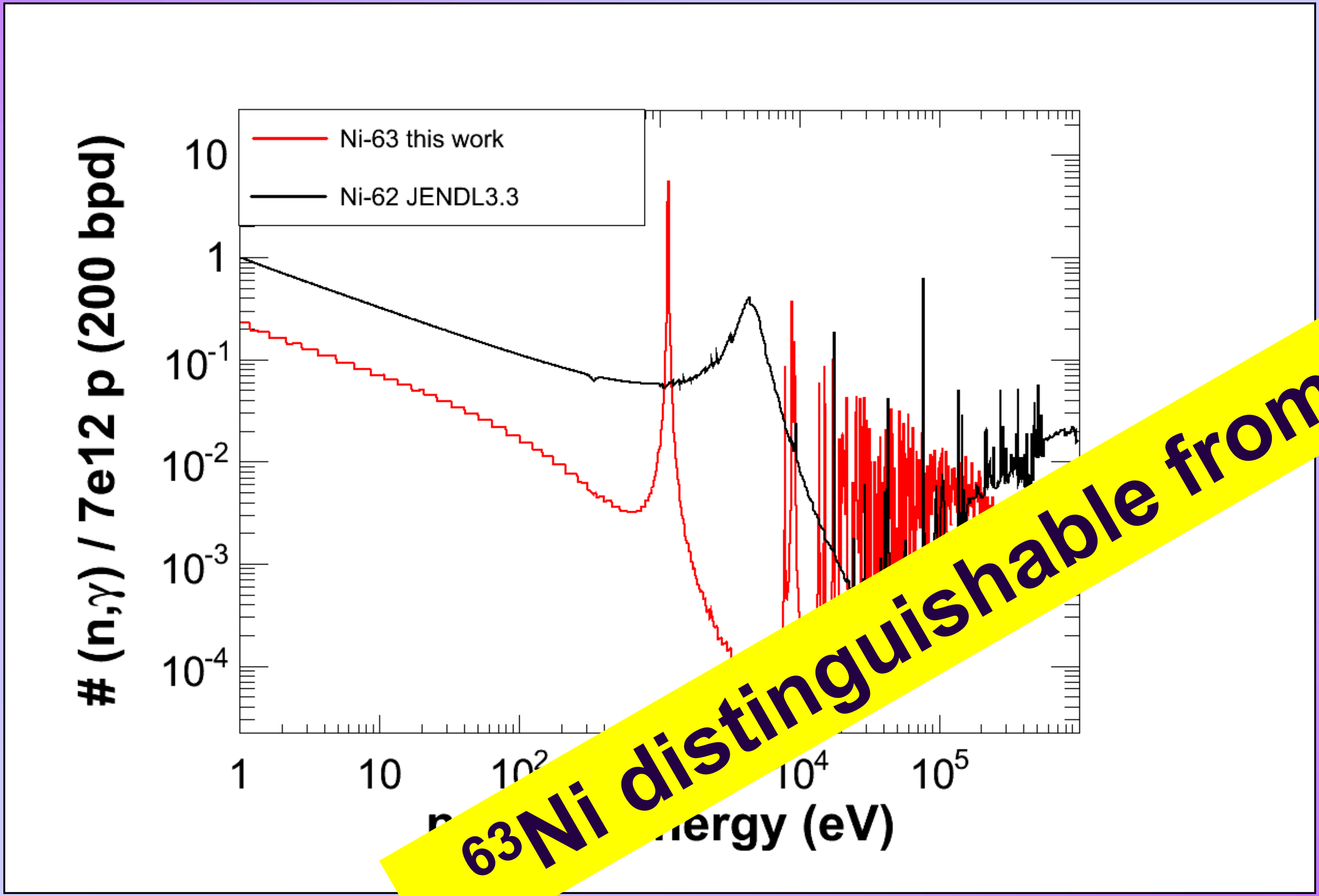

^{63}Ni distinguishable from ^{62}Ni

Beam Time Request

- 112 mg ^{63}Ni in sample
- 2009 campaign → 2 g of ^{62}Ni and $2x10^{18}$ protons
- ^{63}Ni mass 20 times smaller BUT cross section higher according to calculations + reduced resolution acceptable
- less background at high neutron energies due to borated water → remeasurement of ^{62}Ni for background determination
- runs with Au (normalization) and C (neutron scattering background) necessary

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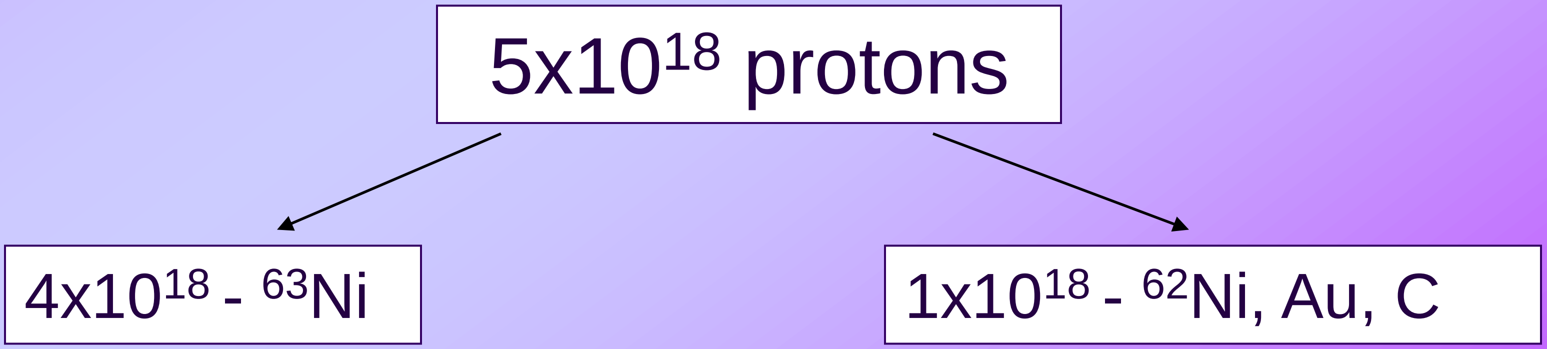
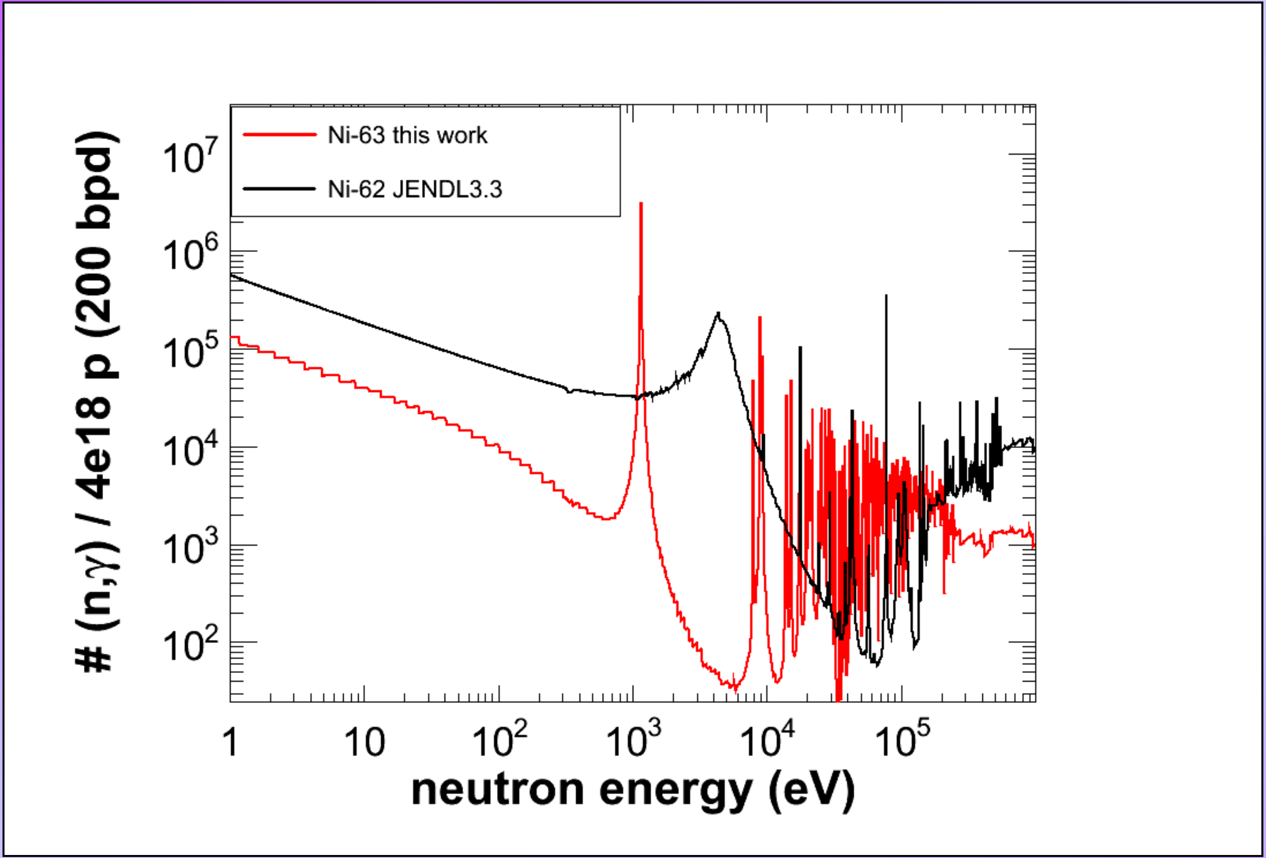
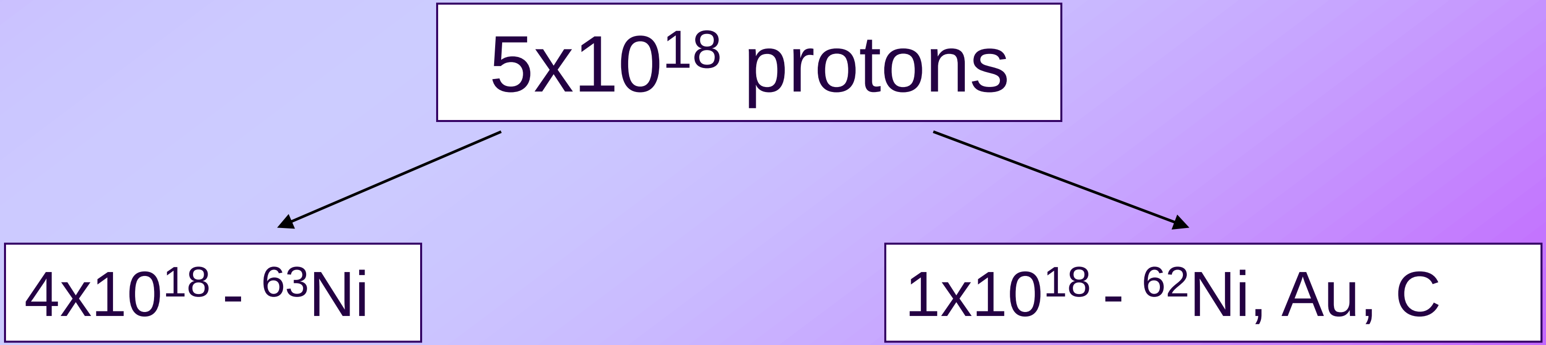


5×10^{18} protons

4×10^{18} - ^{63}Ni

1×10^{18} - ^{62}Ni, Au, C





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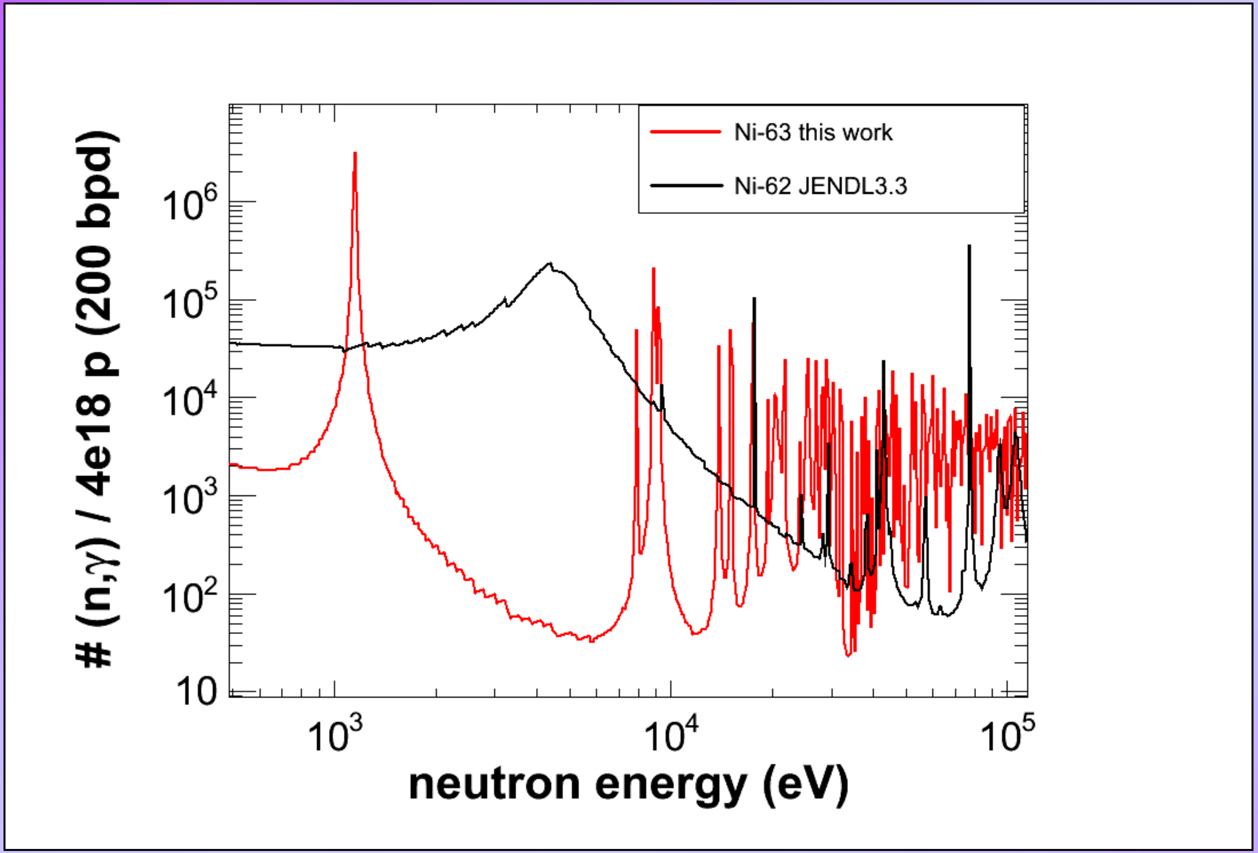

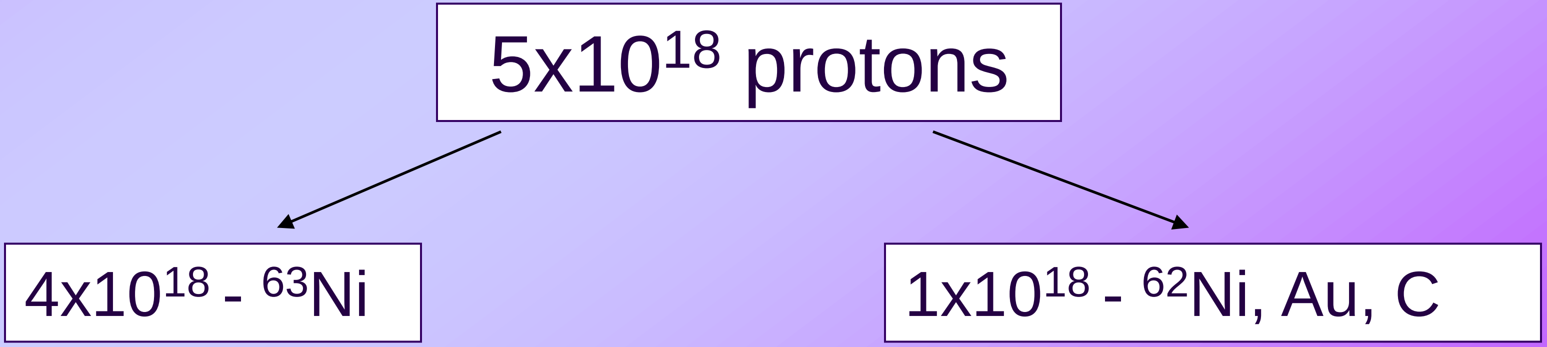

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Summary

- ^{63}Ni represents the first branching point of the s-process path and knowledge of its (n,γ) cross section is of great importance for nuclear astrophysics
- there are no experimental data of the ^{63}Ni(n,γ) cross section above thermal
- unique ^{63}Ni sample suitable for a time-of-flight measurement is available
- combining a high neutron flux with a long flight path and an optimized detection setup, n_TOF is perfectly suited for performing this important measurement
- we propose 5×10^{18} protons for this measurement

Thank you for your attention !