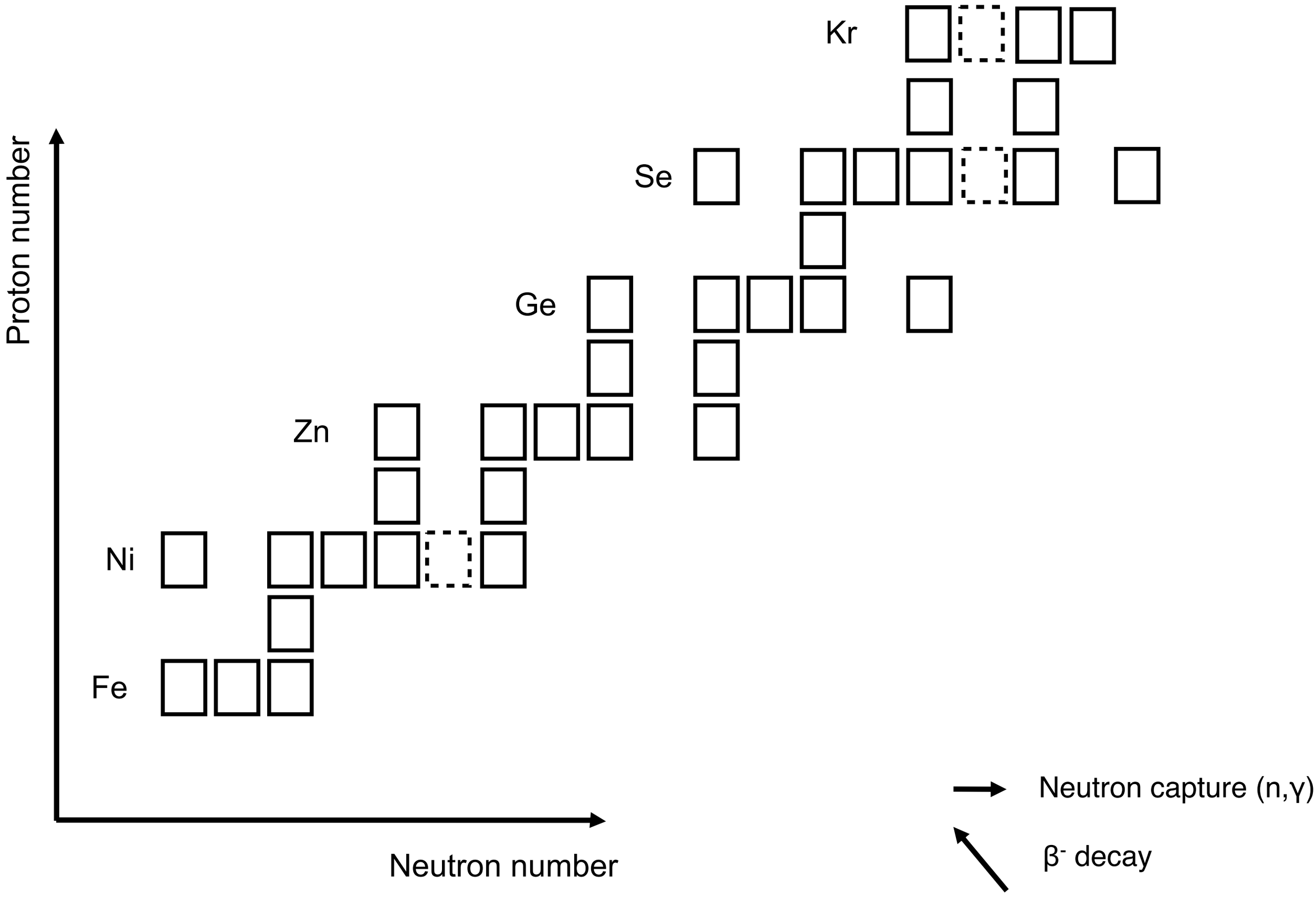
Neutron Induced Reactions in Astrophysics

Claudia Lederer-Woods
University of Edinburgh

Nuclei in the Cosmos XV
24-29 June 2018, Assergi, Italy

Nucleosynthesis of the heavy elements



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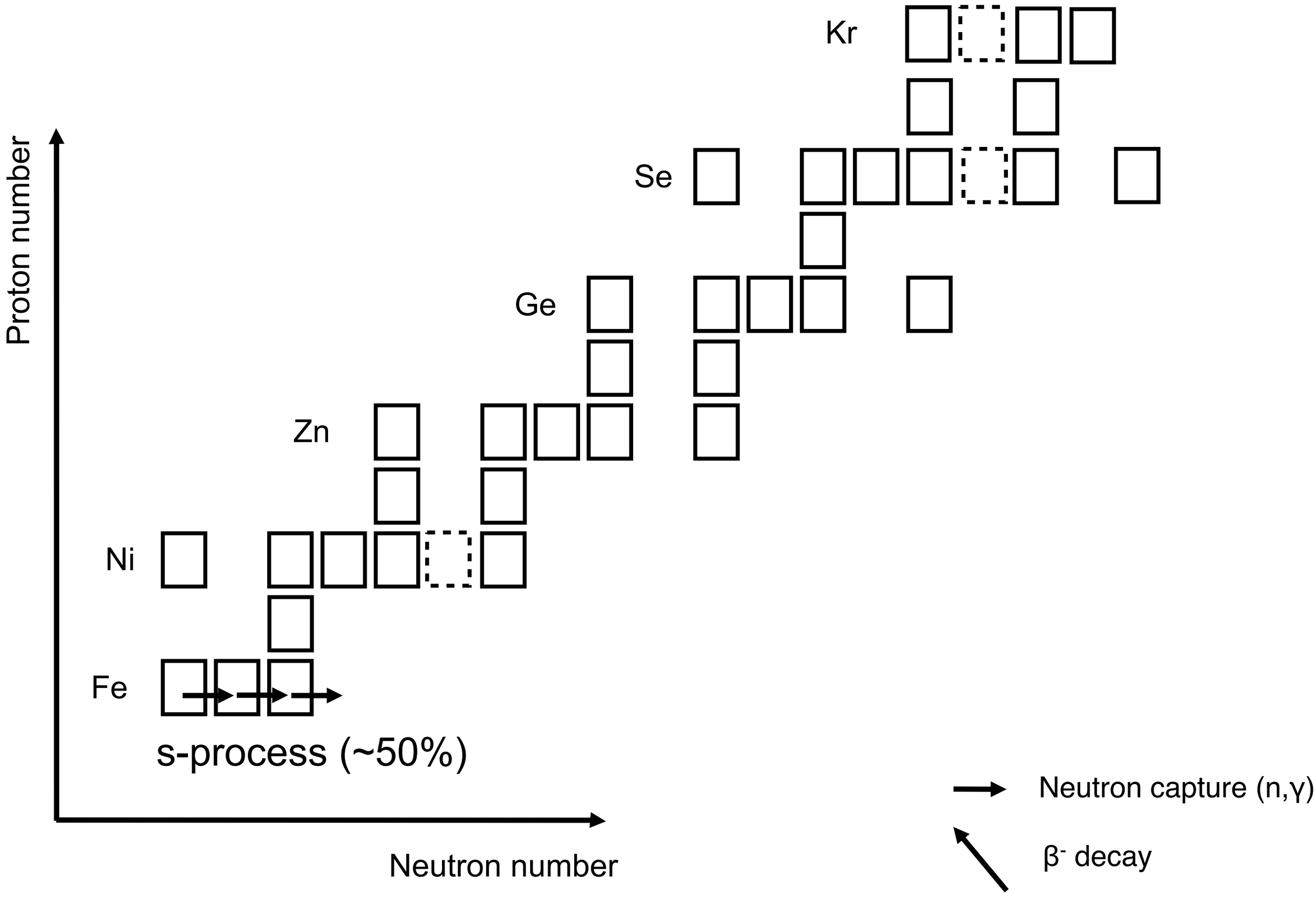

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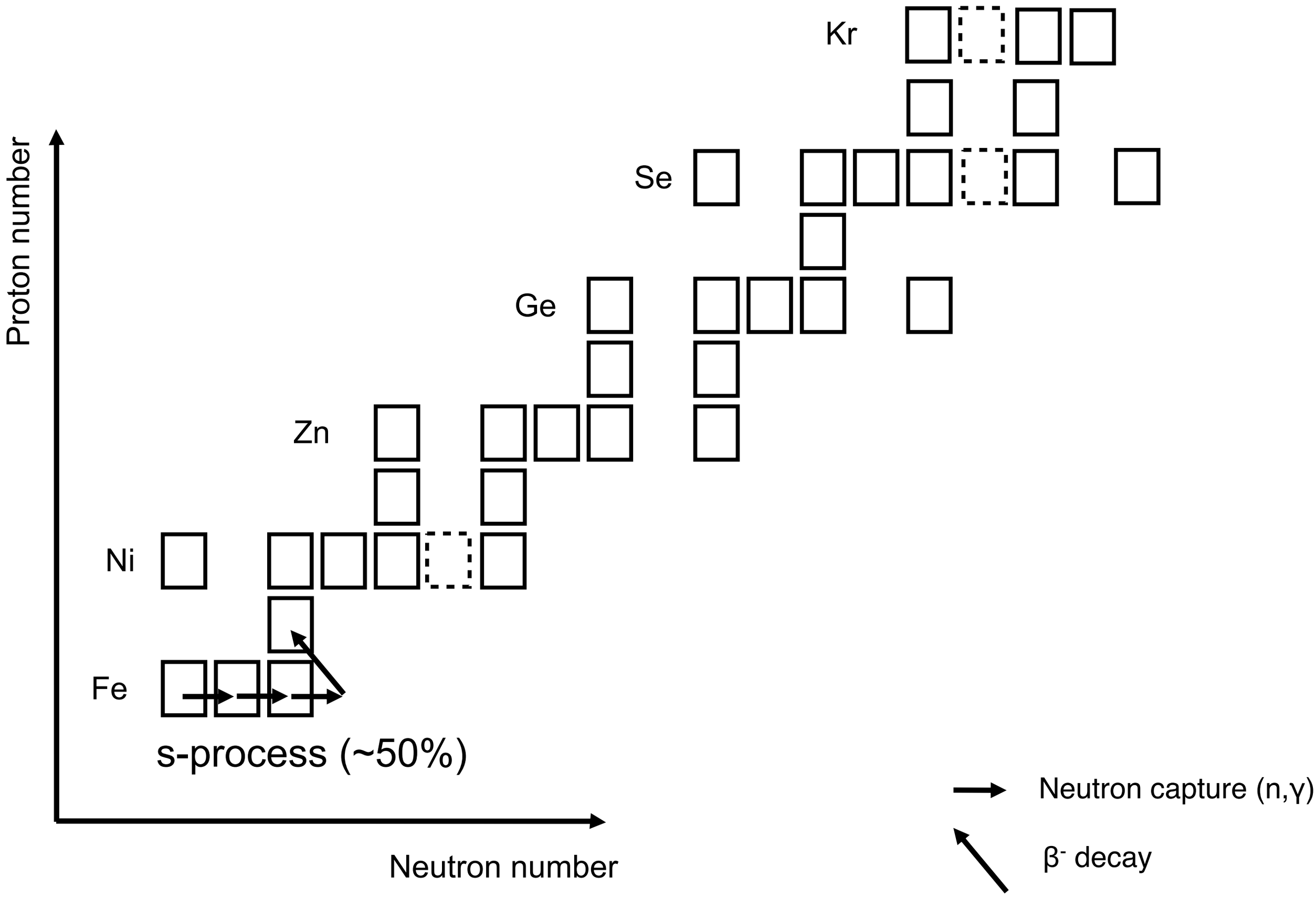

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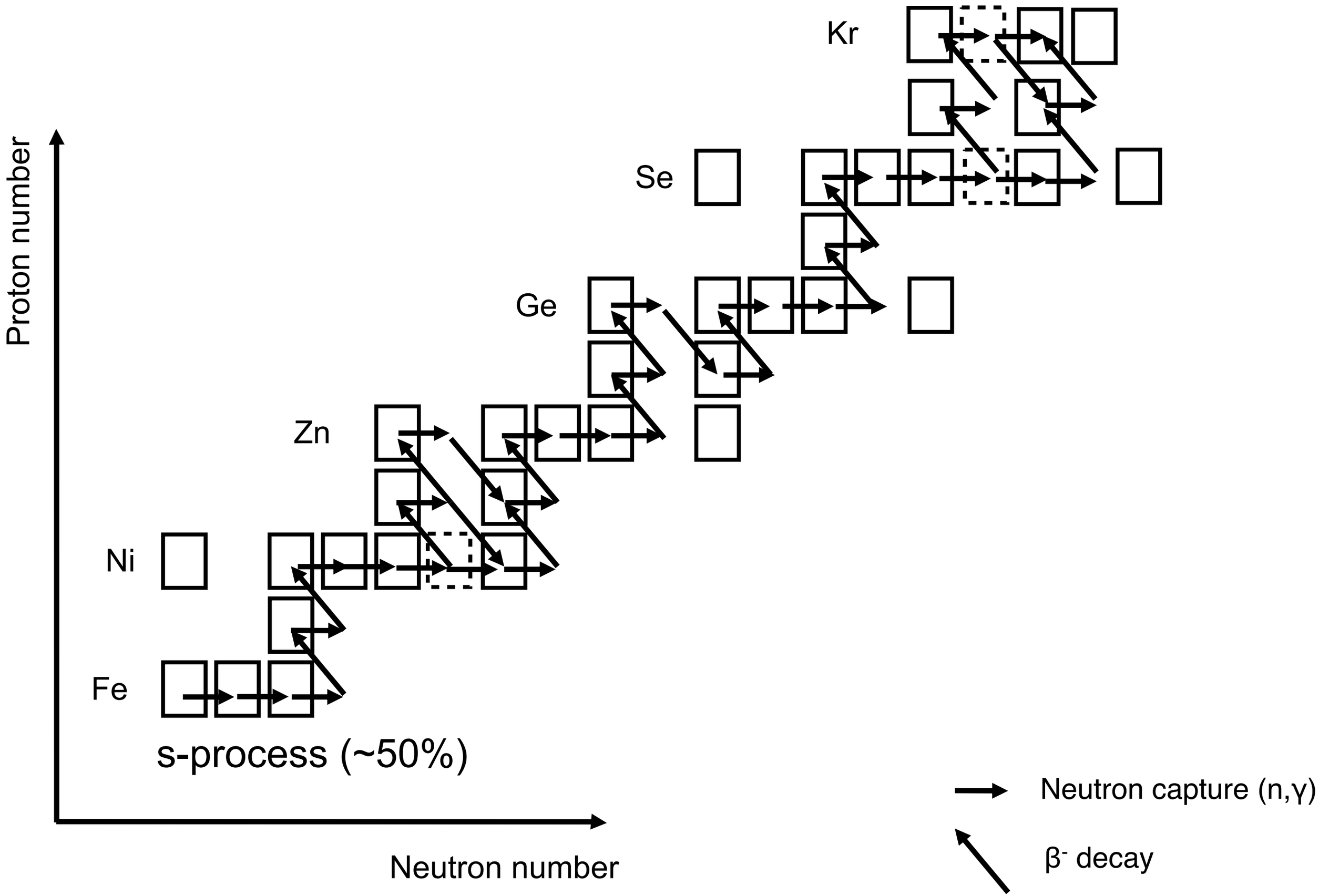

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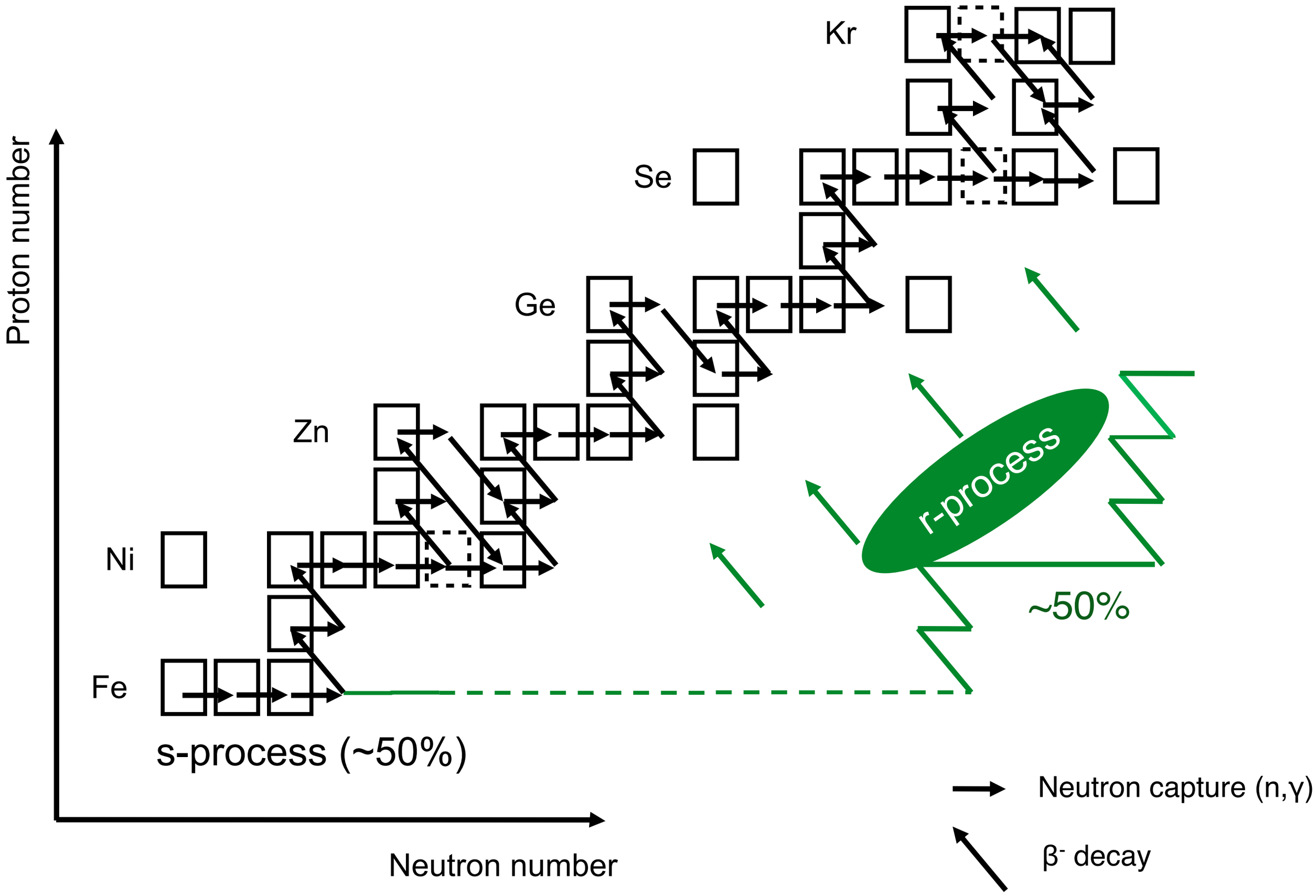

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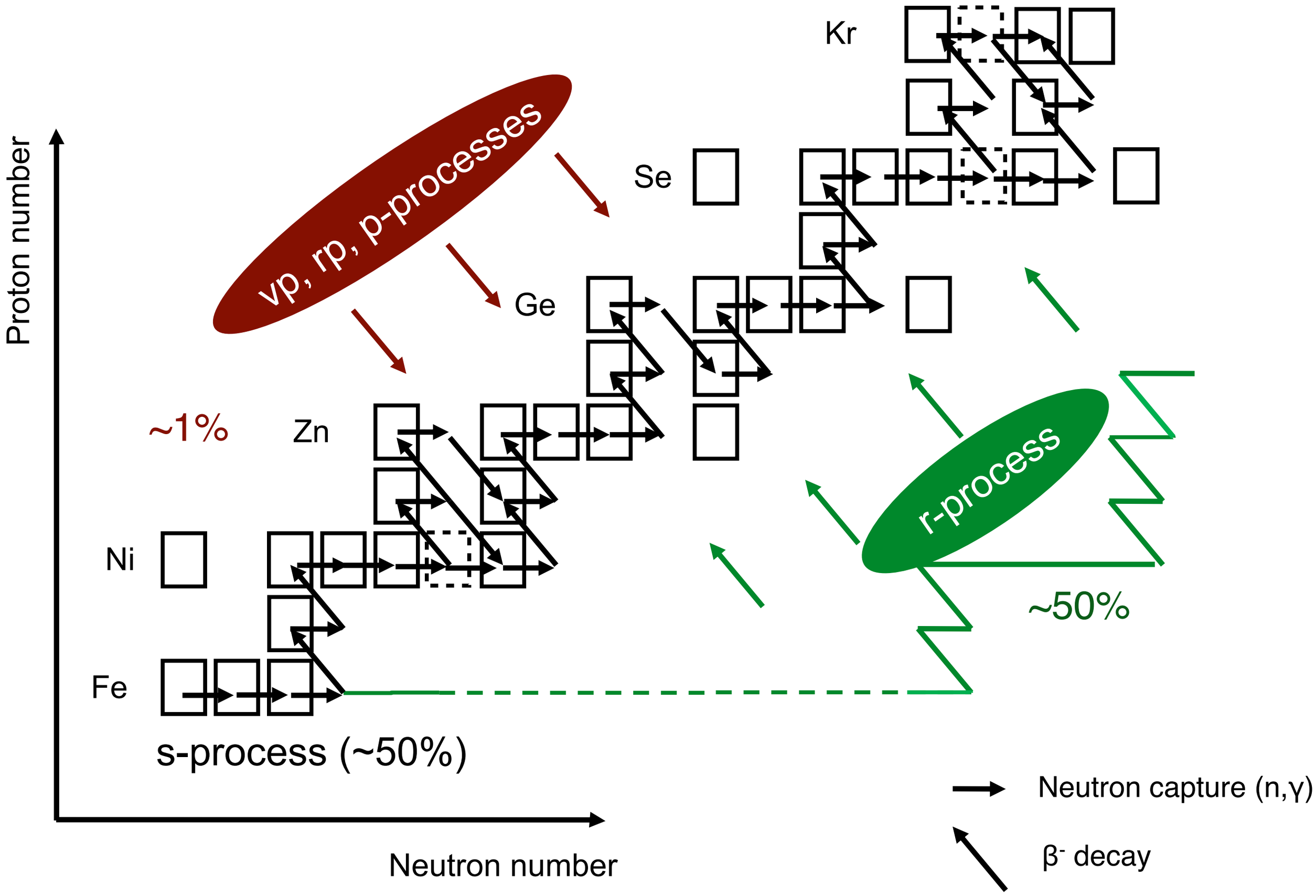
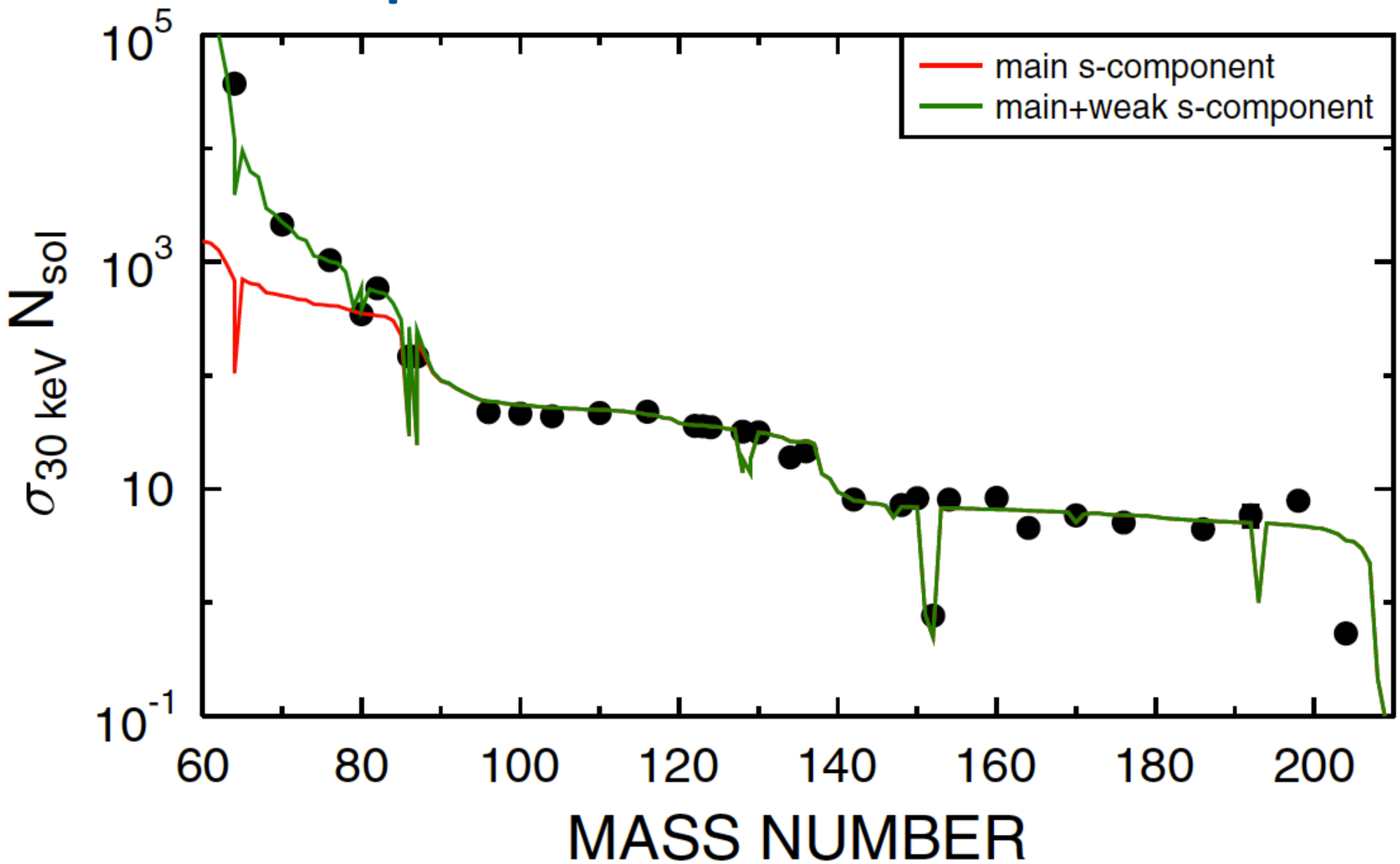


s-process abundances x MACS



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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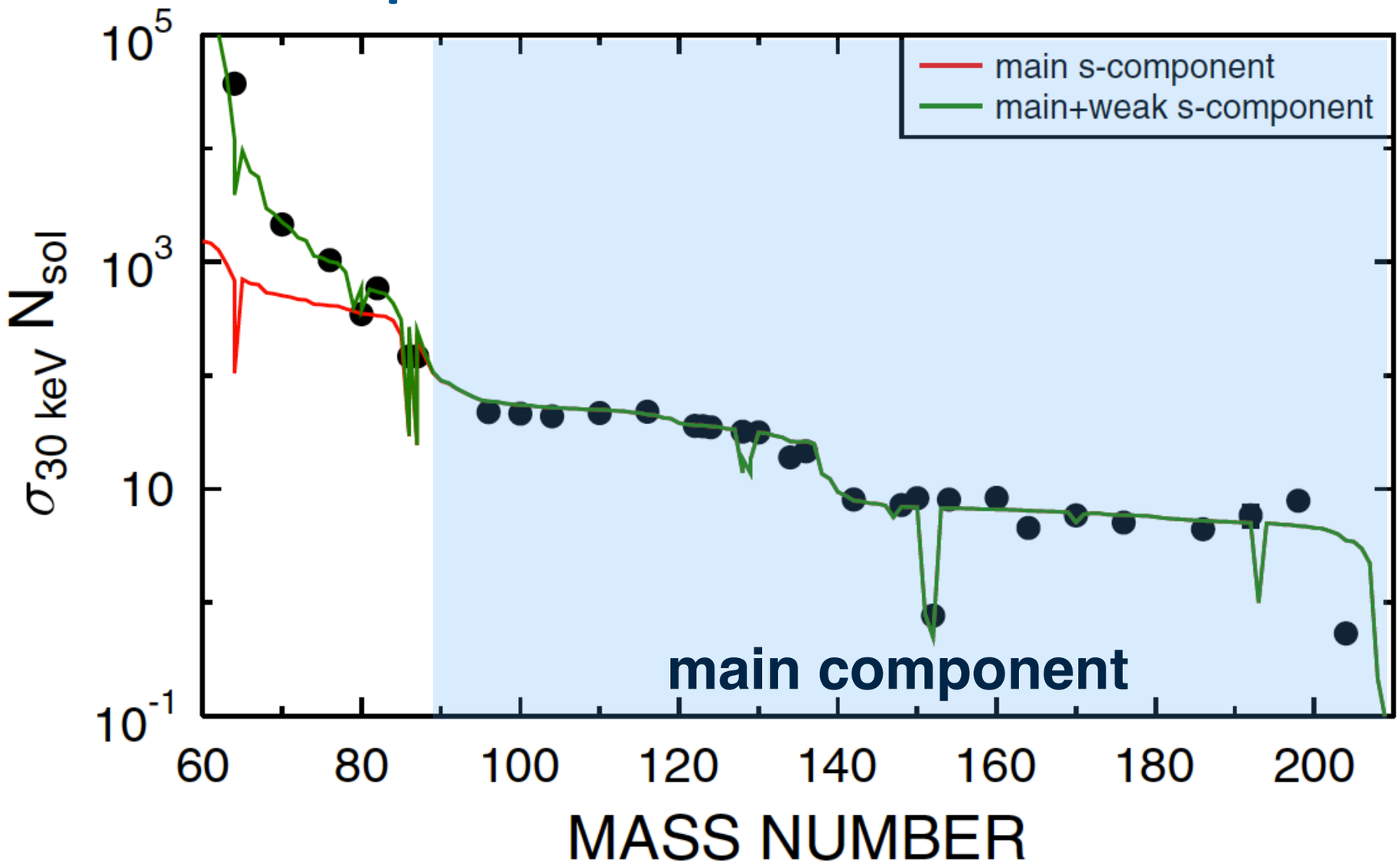

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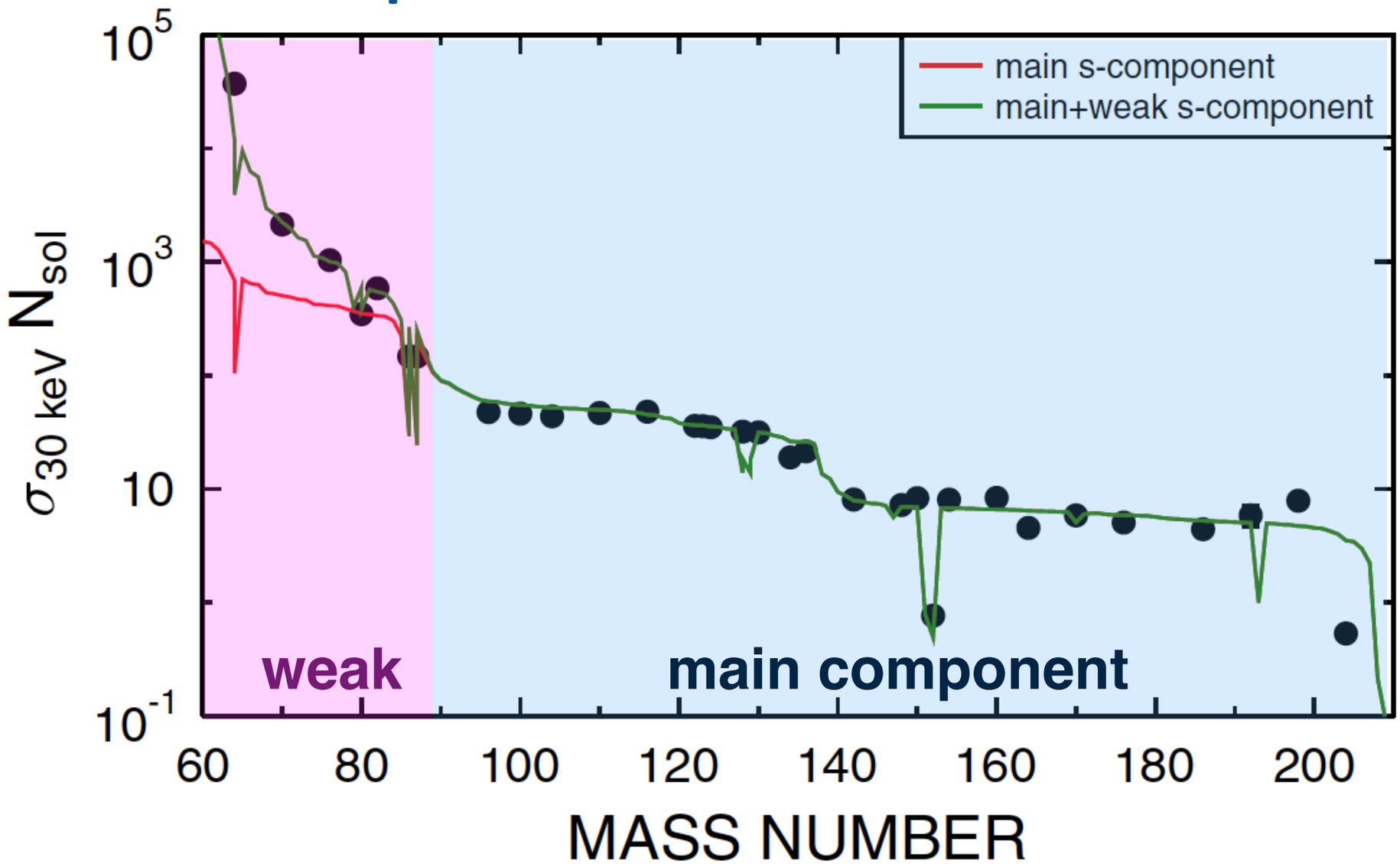

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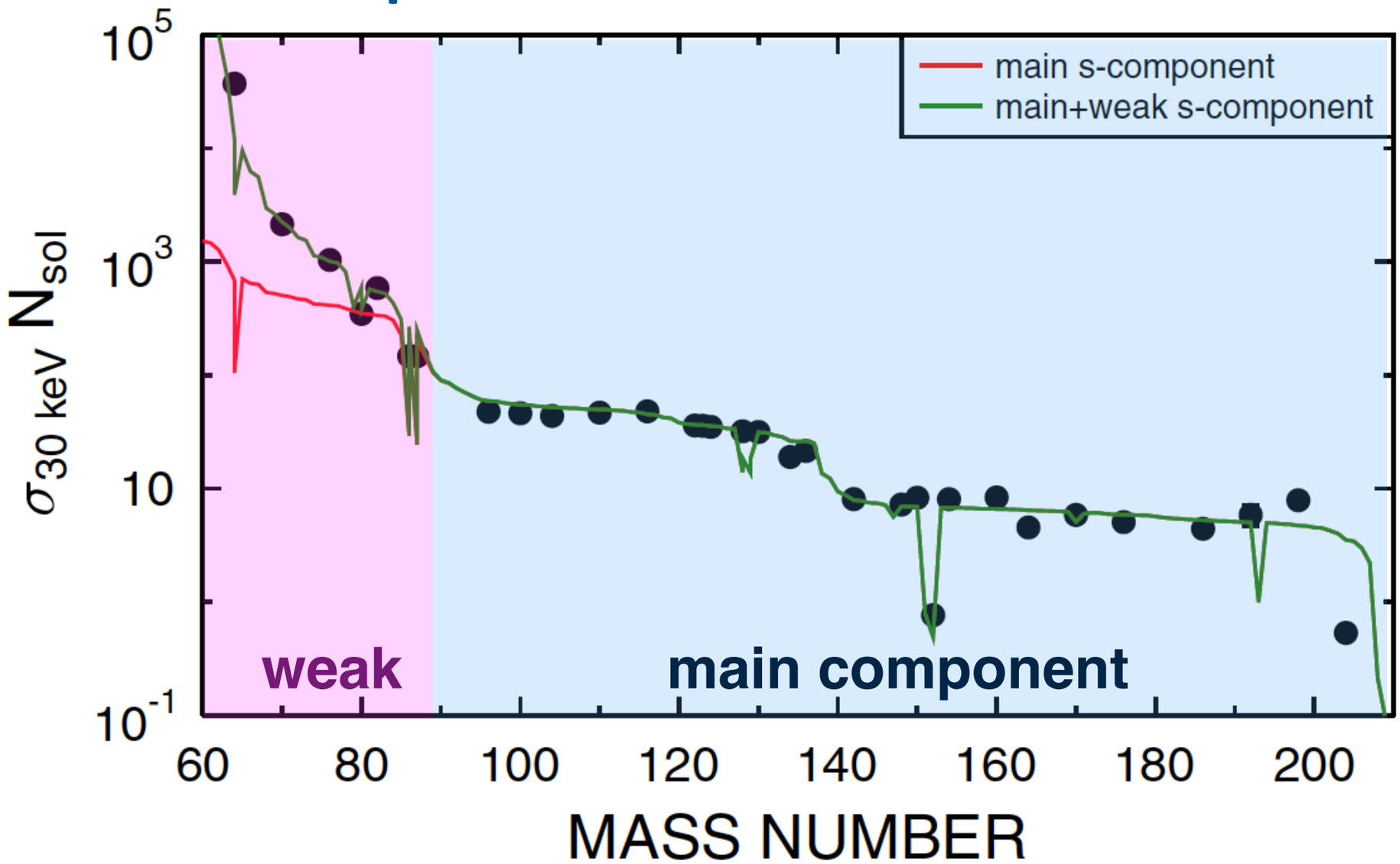
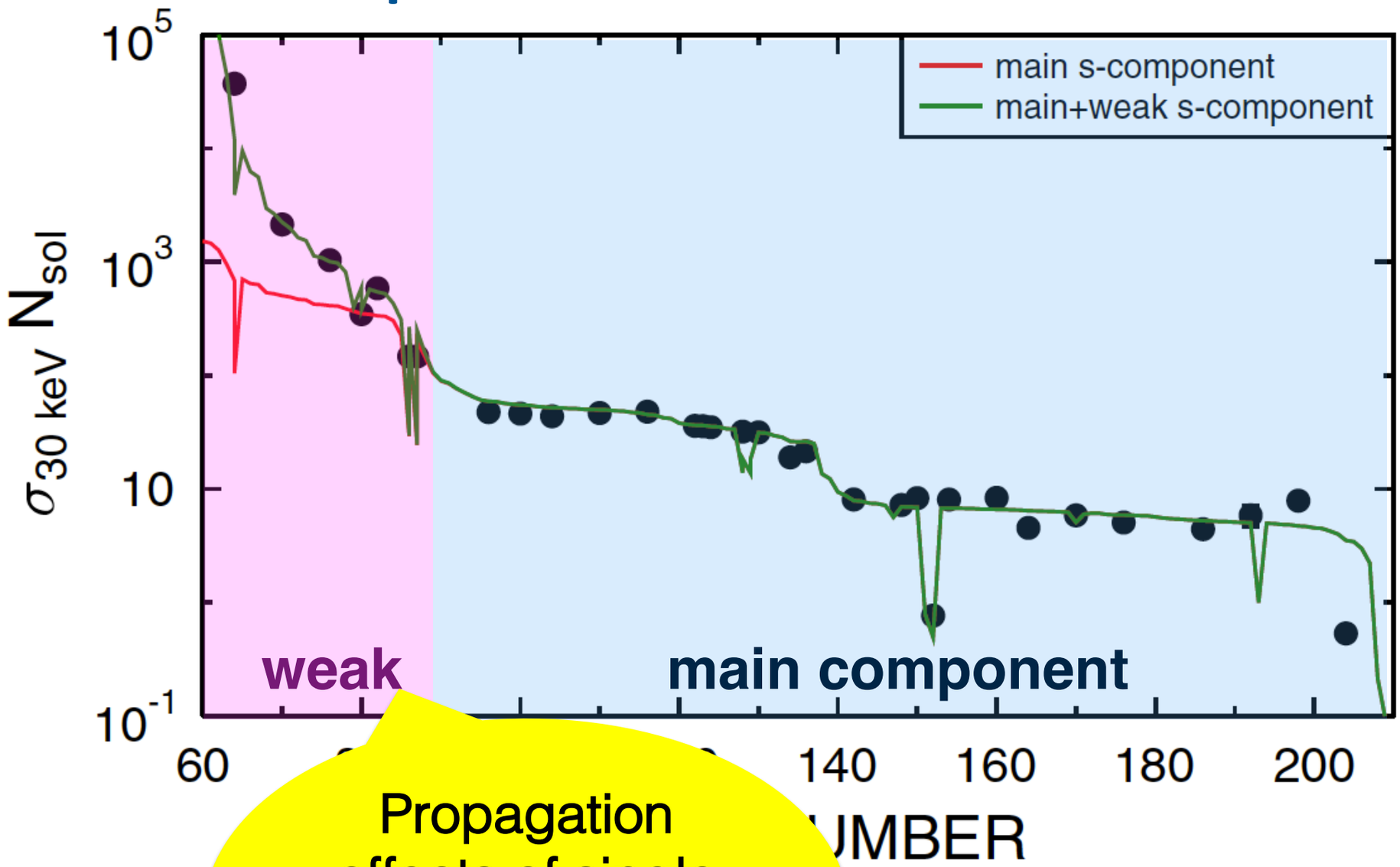


→ Two astrophysical sites

Massive stars: He core (kT~26 keV), C shell burning (kT~90 keV)

AGB stars: H shell (kT~ 8 keV), He flash (kT~26 keV)

s-process abundances x MACS



Propagation effects of single MACS on abundances

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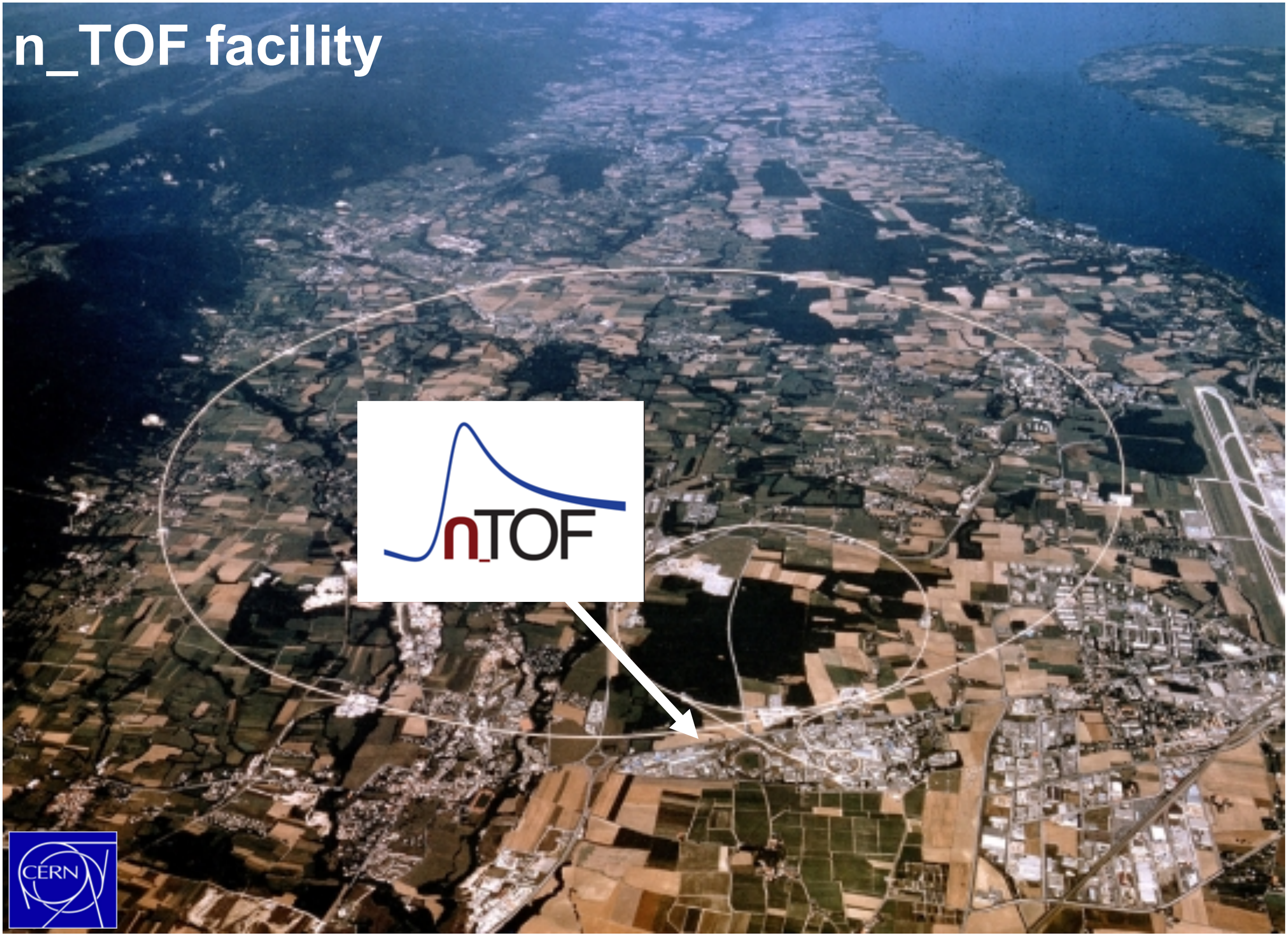
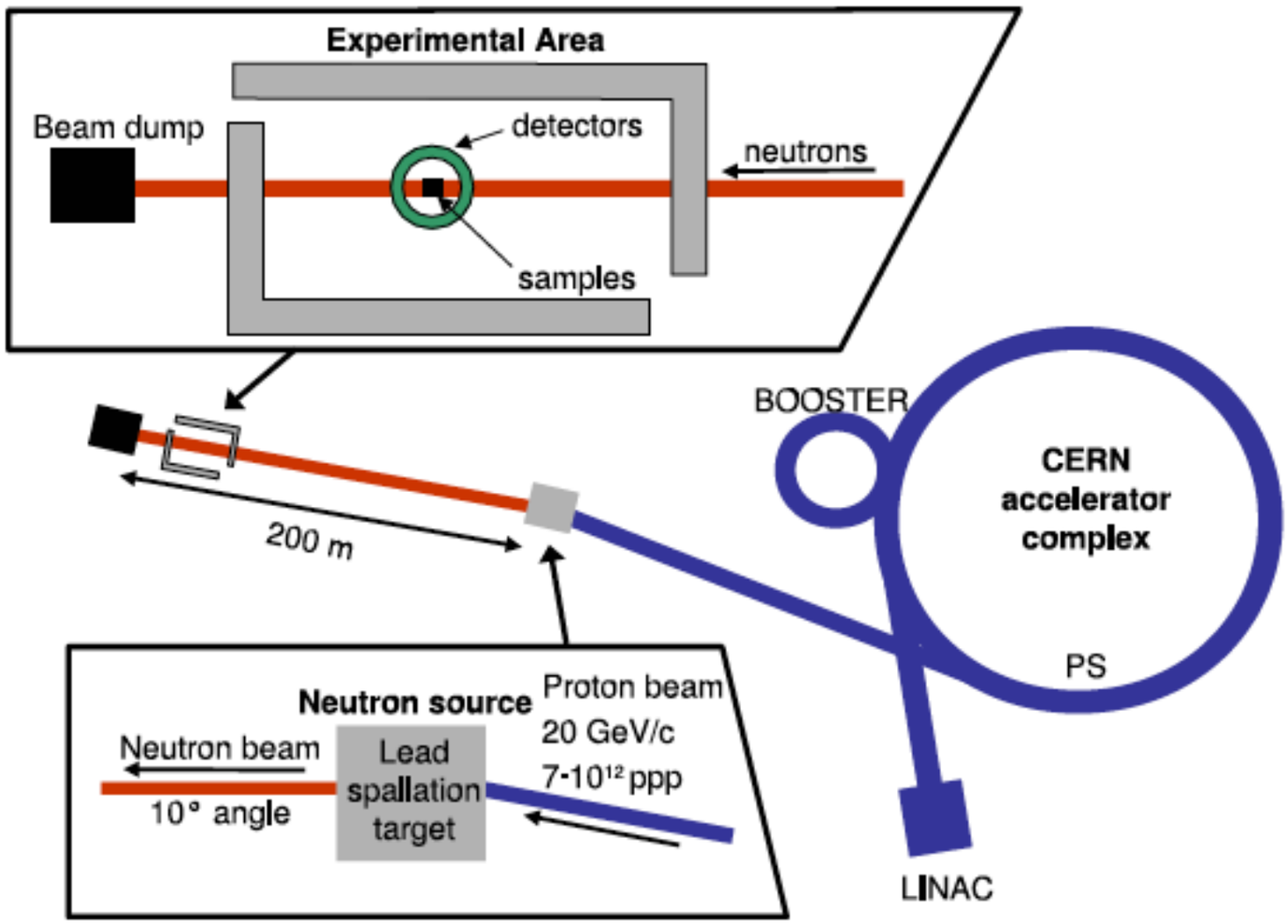
n_TOF facility



The n_TOF facility at CERN

www.cern.ch/ntof



Eur. Phys. J. A (2013) 49: 27

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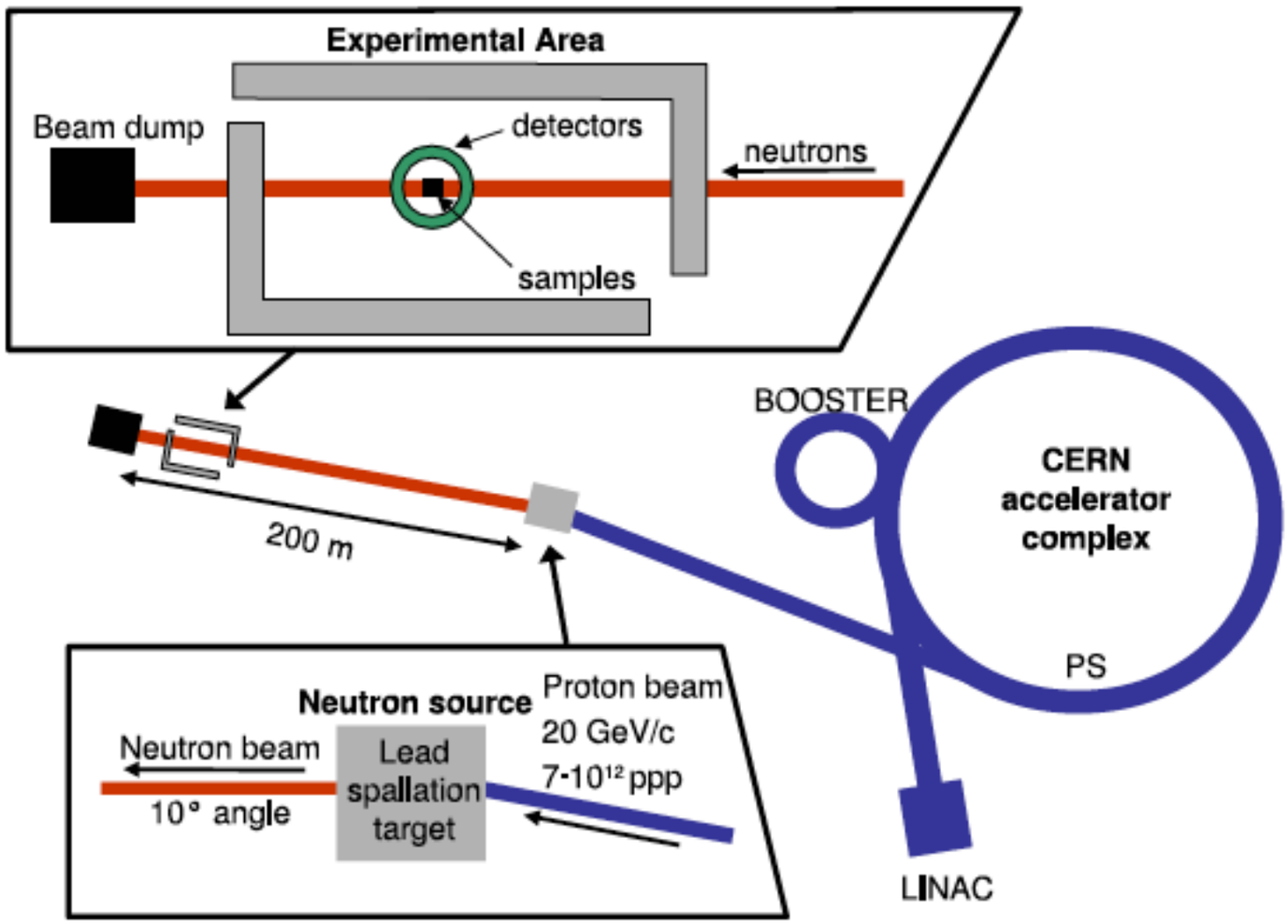

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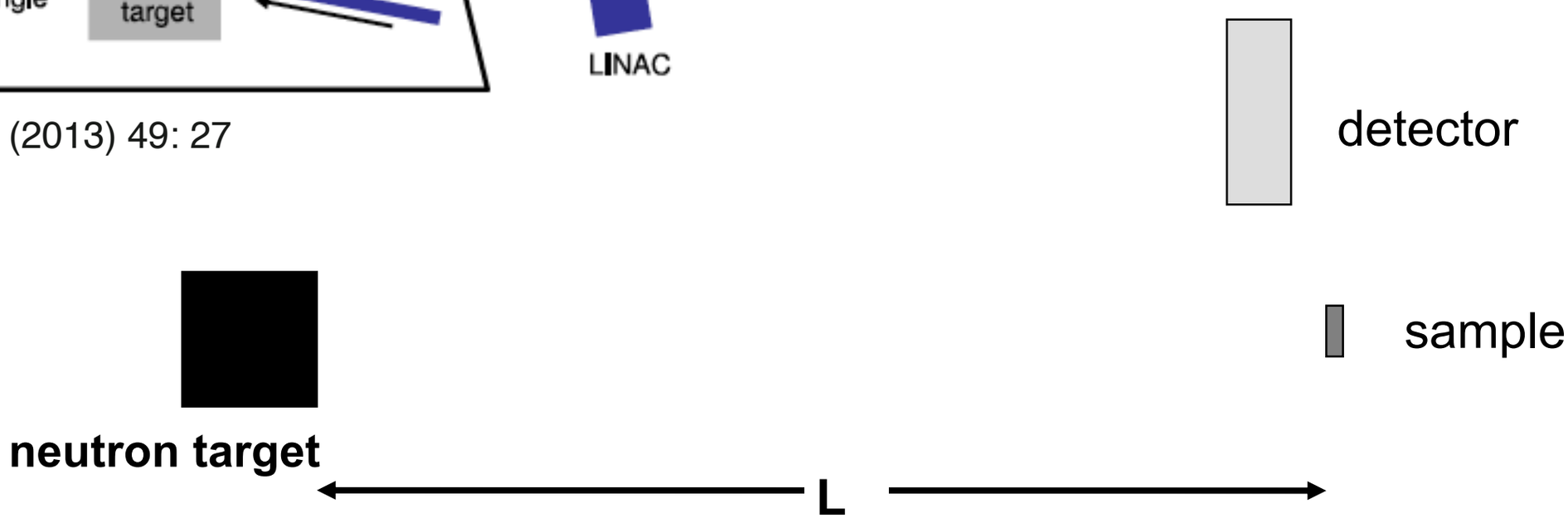

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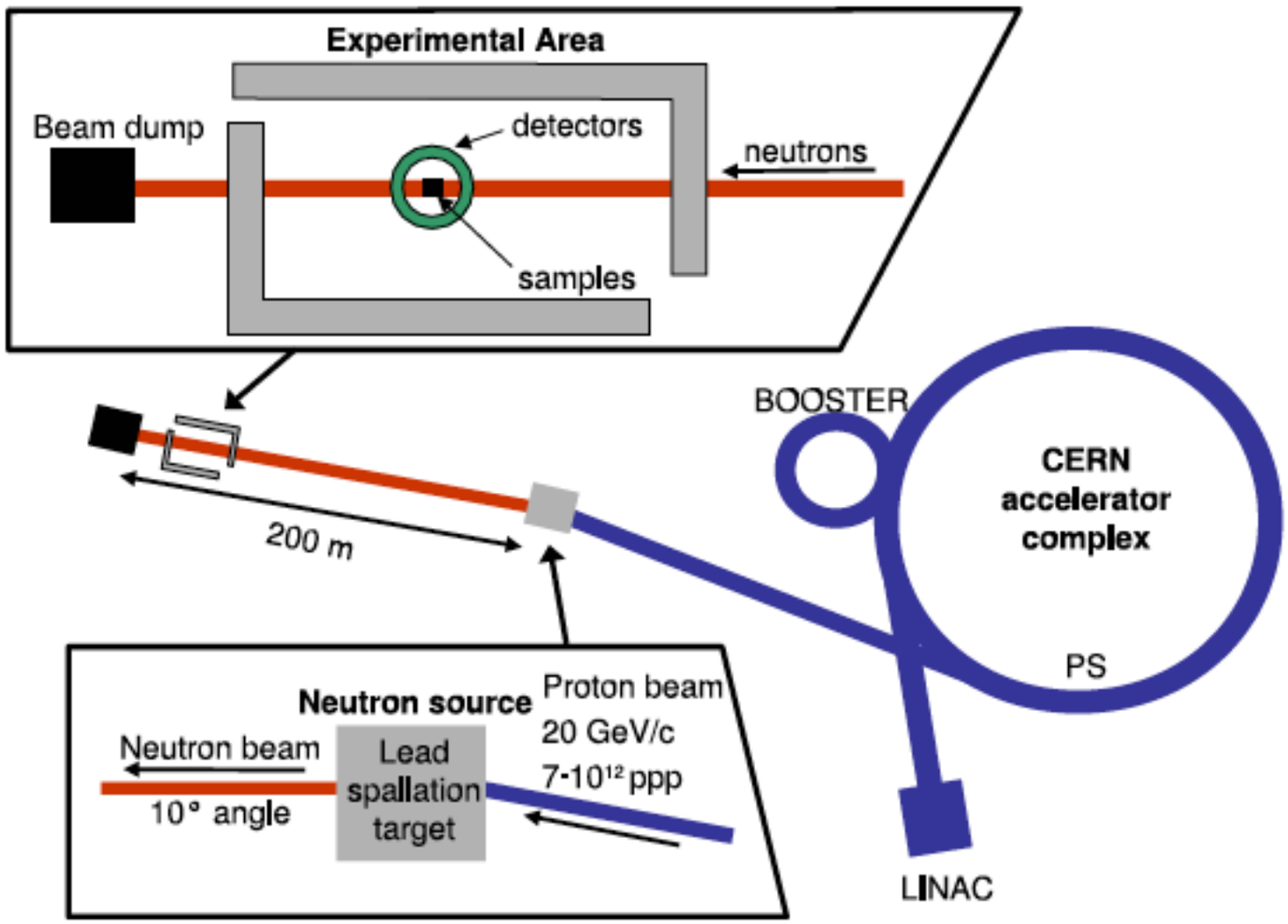

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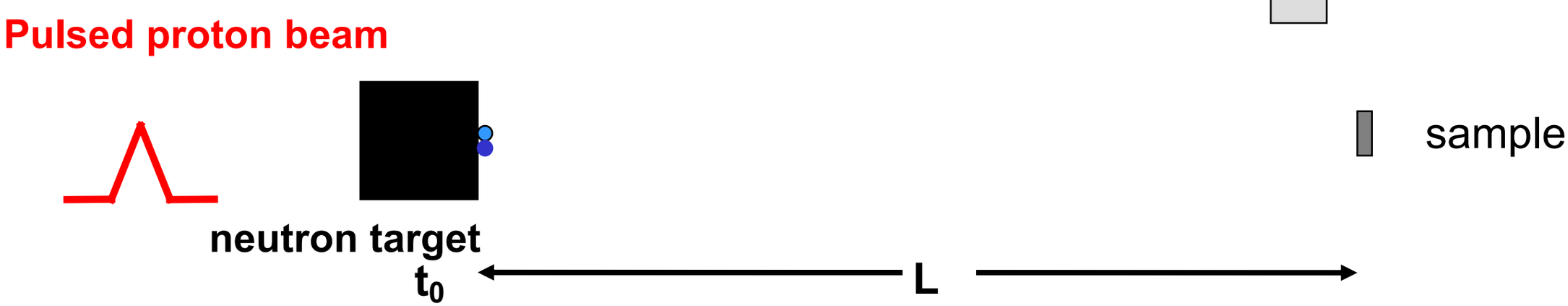

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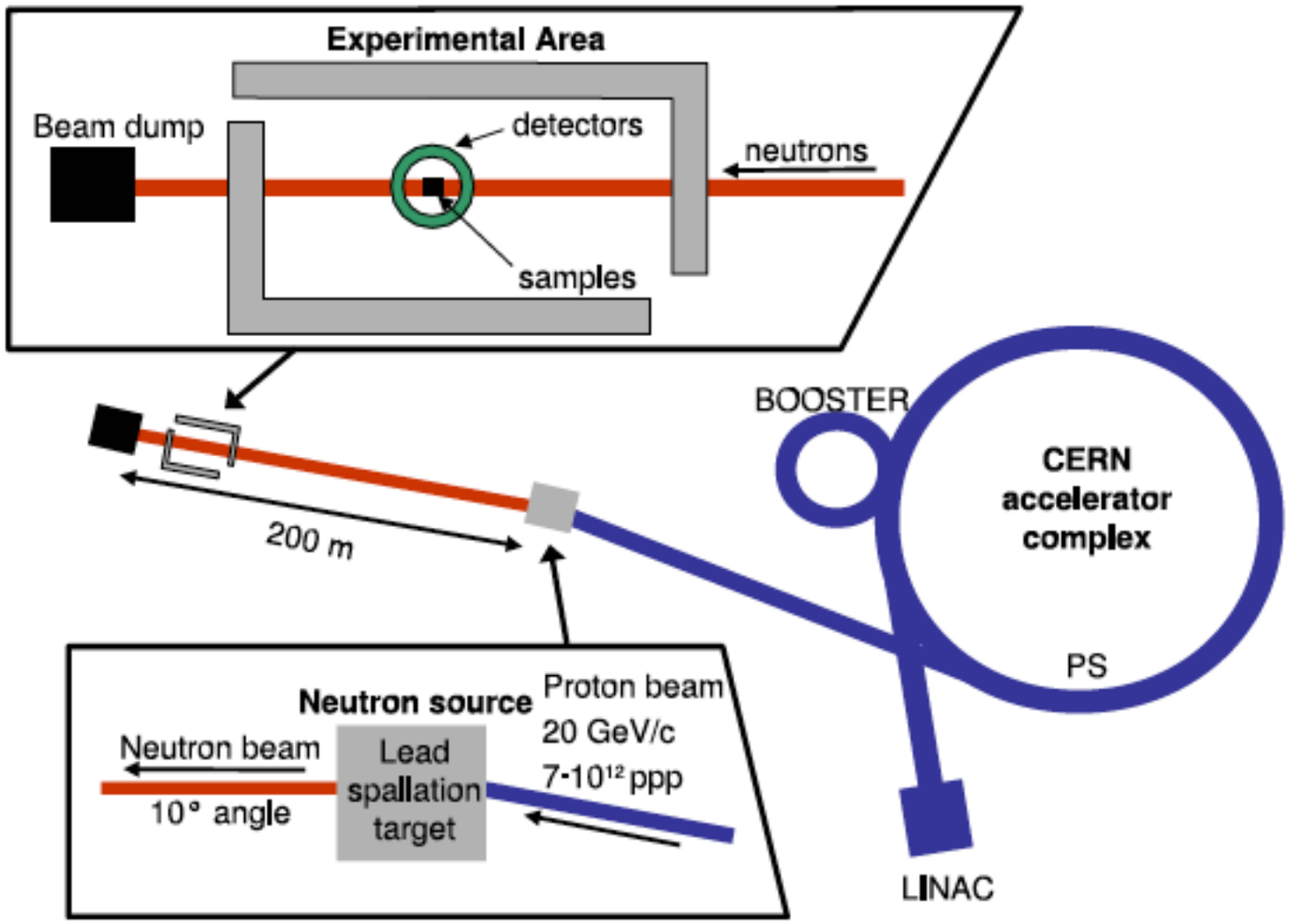

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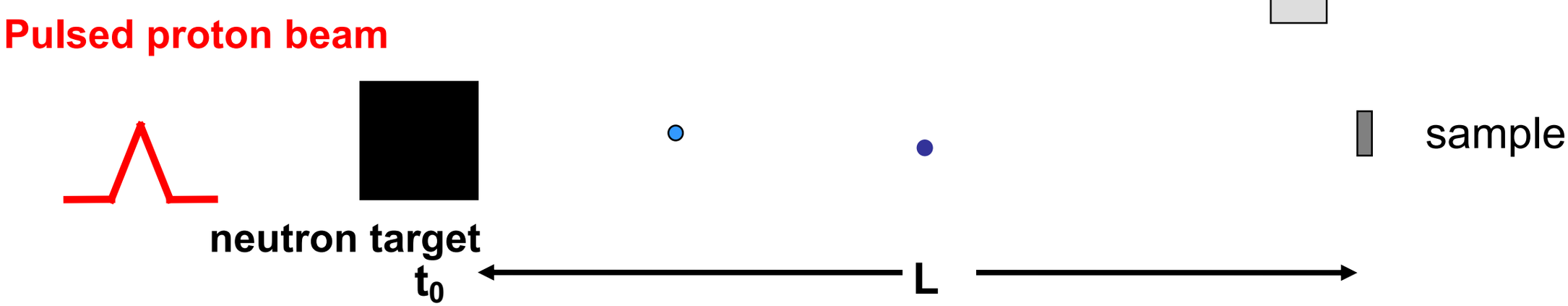

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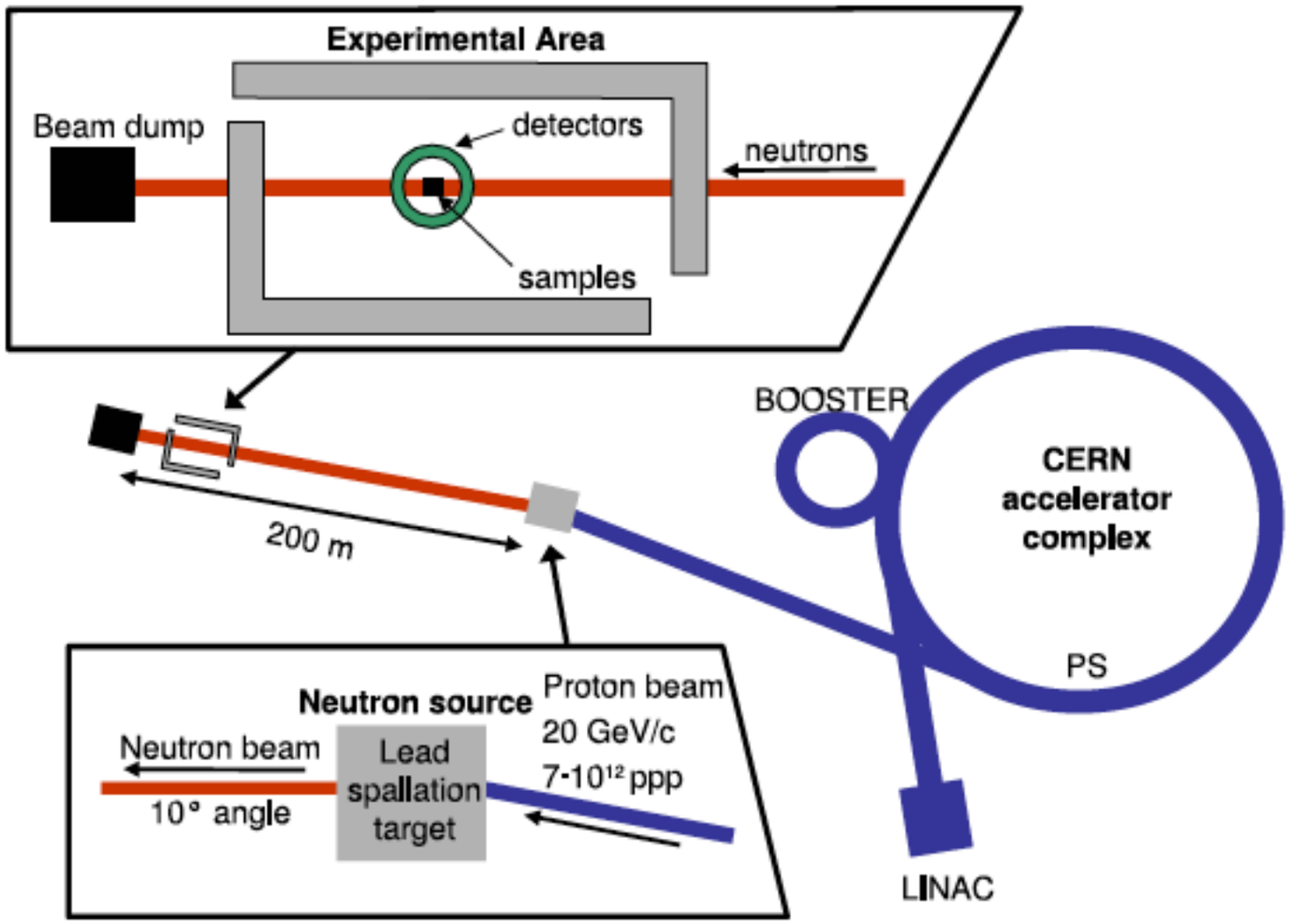

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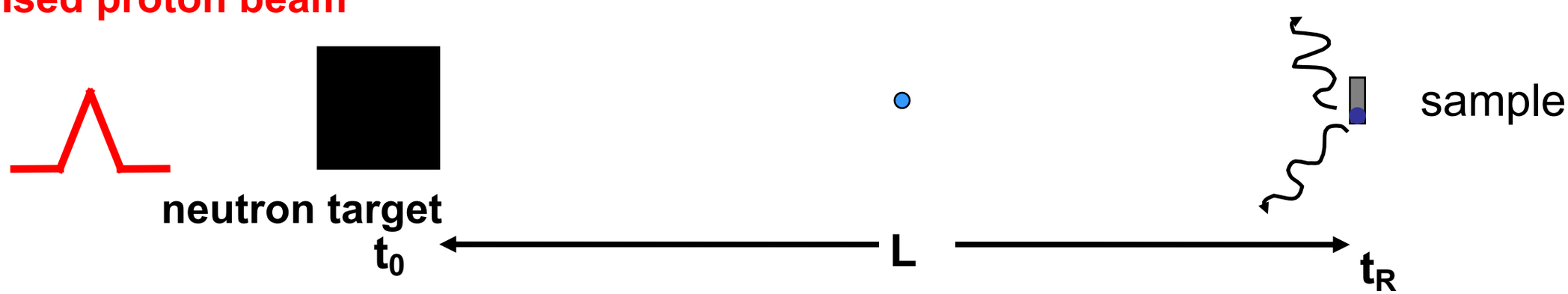
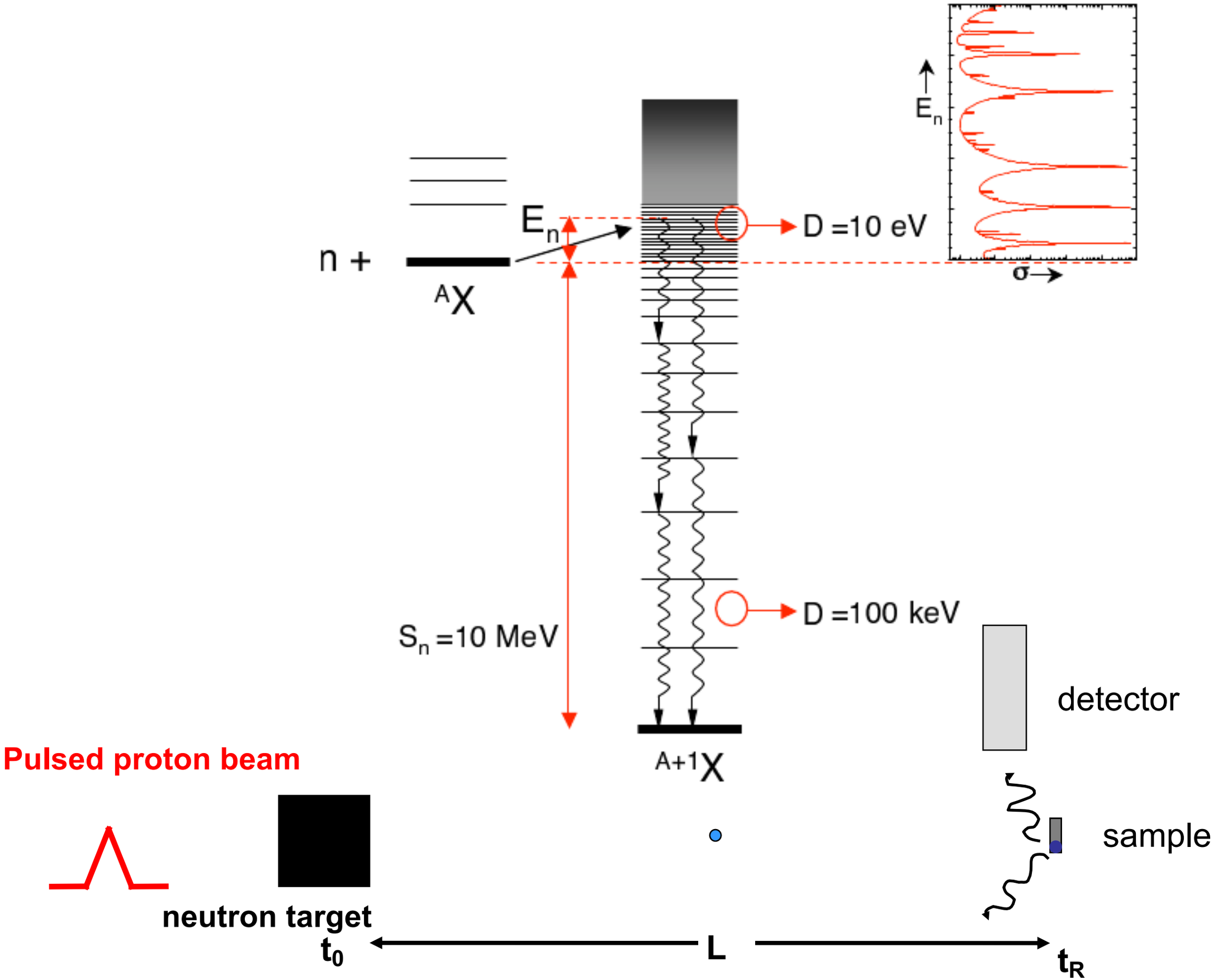
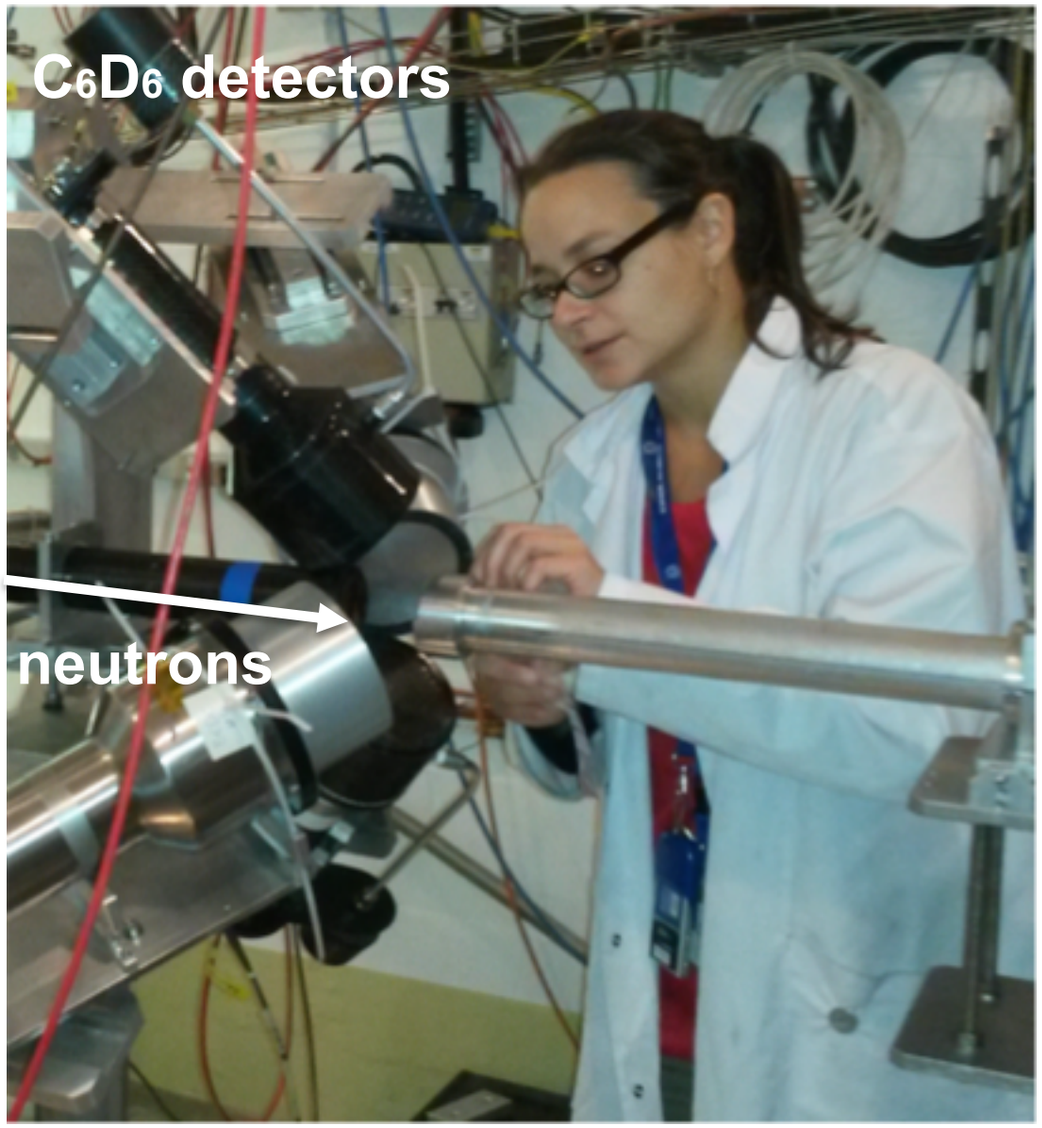
Pulsed proton beam



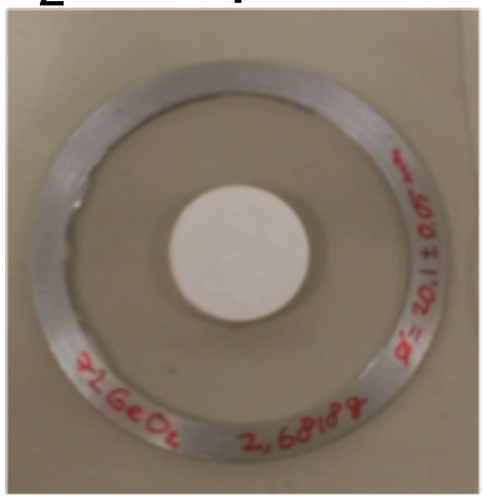


Courtesy F. Gunsing

Neutron Capture Measurements at n_TOF: stable Ge isotopes



Isotopically enriched GeO_2 sample



Experimental campaign 2014-16

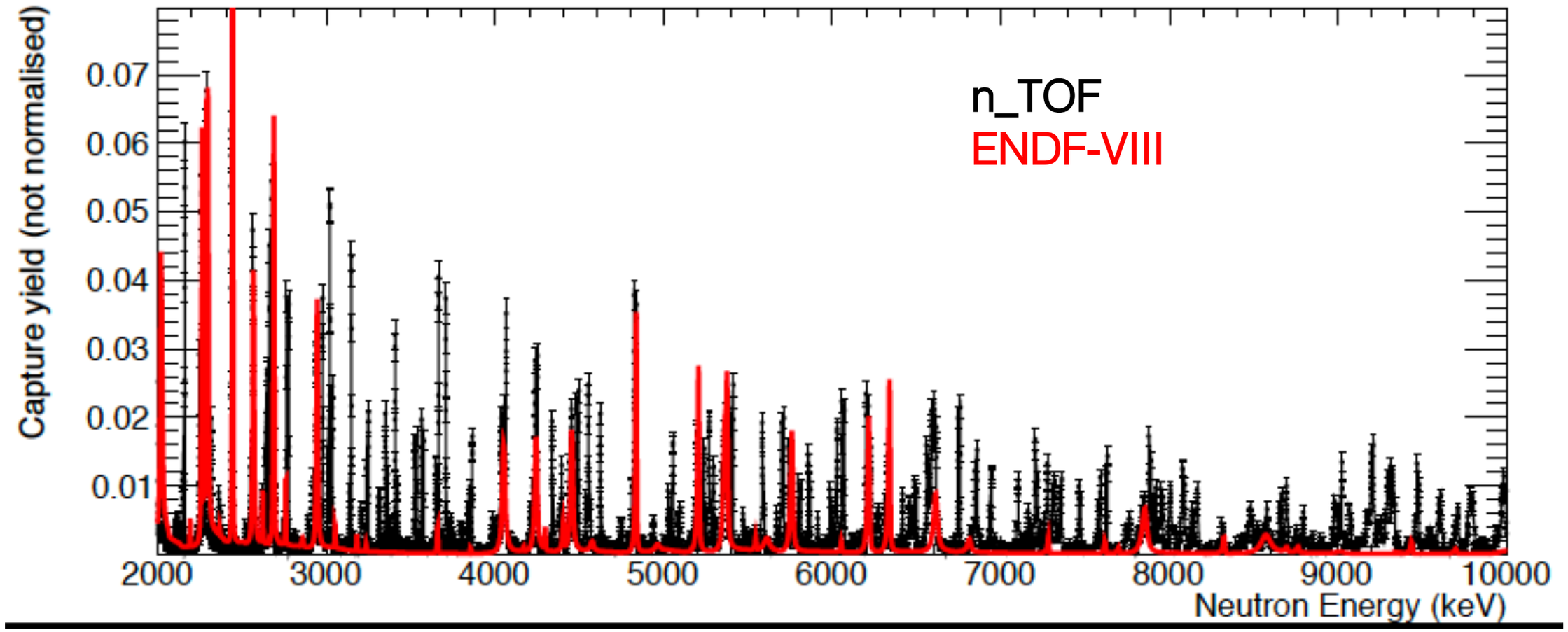
No exp. data for ^{72}Ge and ^{73}Ge>10 keV

Measurement from E_n~eV to E_n~300 keV

nTOF

Adolf Messer Stiftung

Stellar ^{73}Ge(n,γ) cross section



- Results suggest significantly higher cross section than previous recommendation
- Final uncertainty ~5%

Lederer-Woods et al., in preparation

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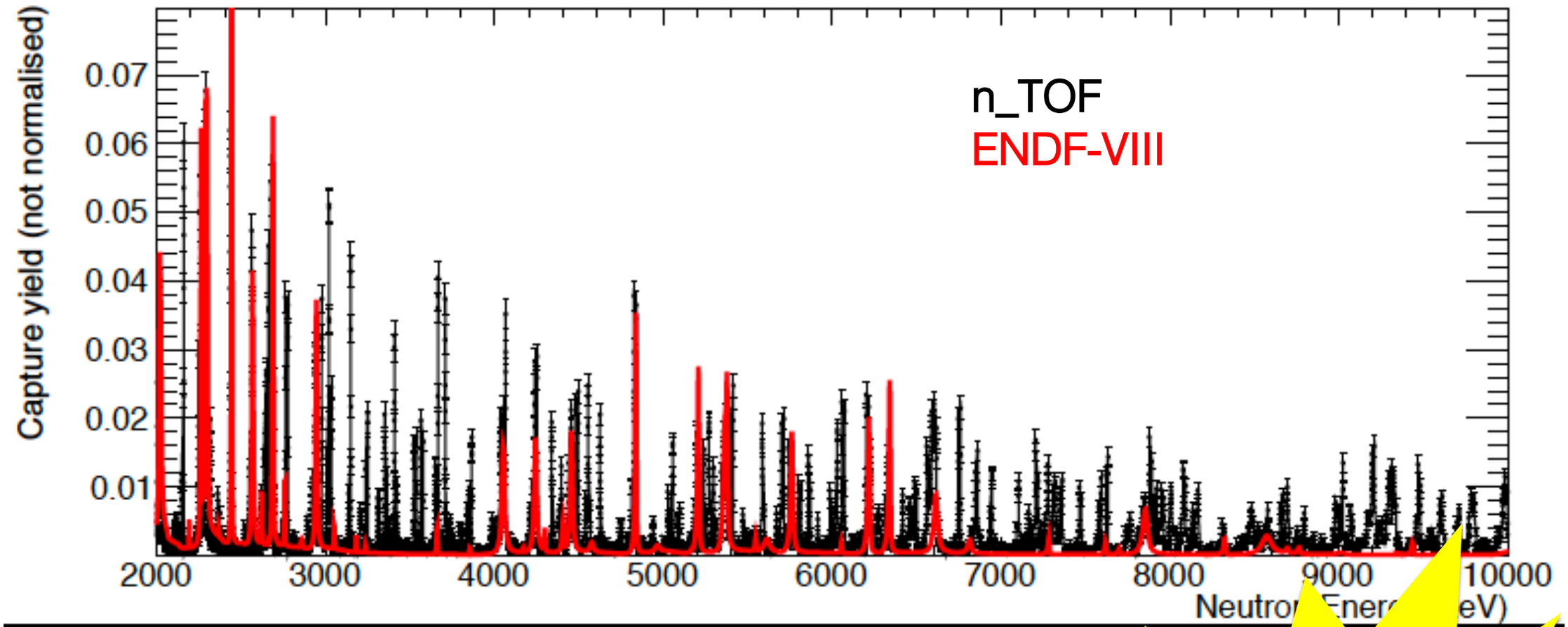

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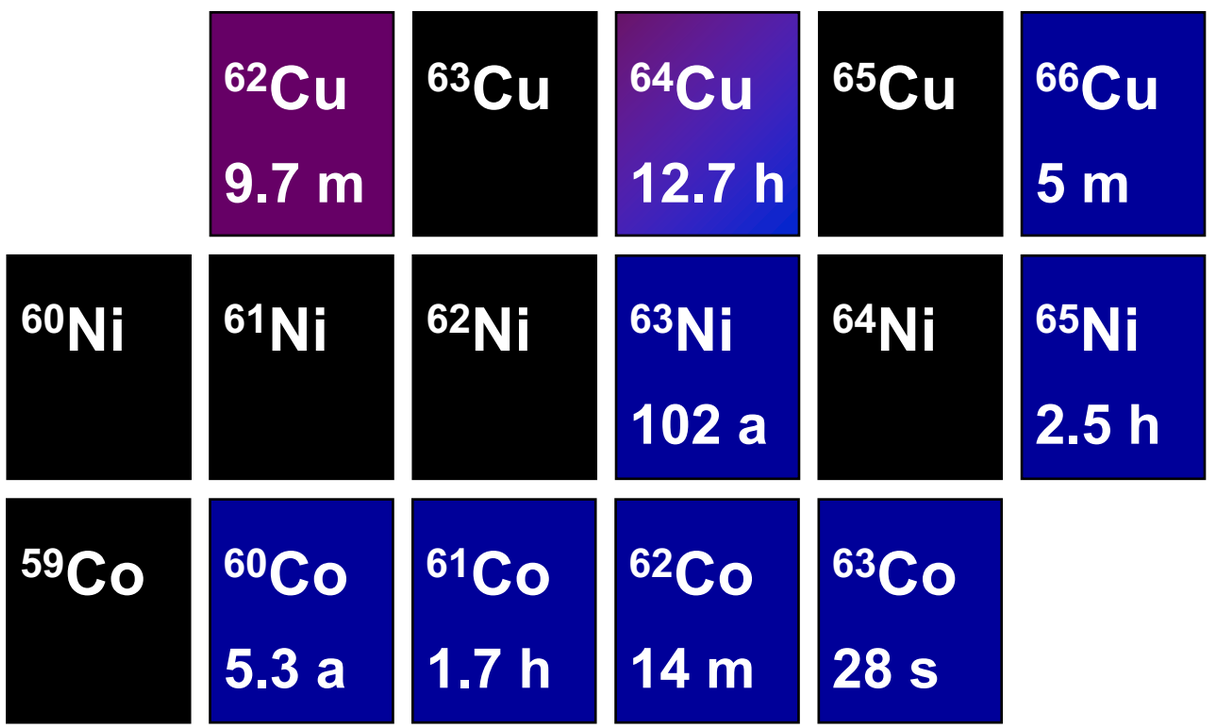
Poster by Mirco Dietz about ^{72}Ge(n,γ)

Lederer-Woods et al., in preparation

^{62,63}Ni(n,γ) n_TOF data for s process studies

Radioactive ^{63}Ni (~100mg), half life ~100 years

Sample produced by irradiation of ^{62}Ni in thermal reactor
(ILL/TU Munich ~1990, purified for n_TOF at PSI)



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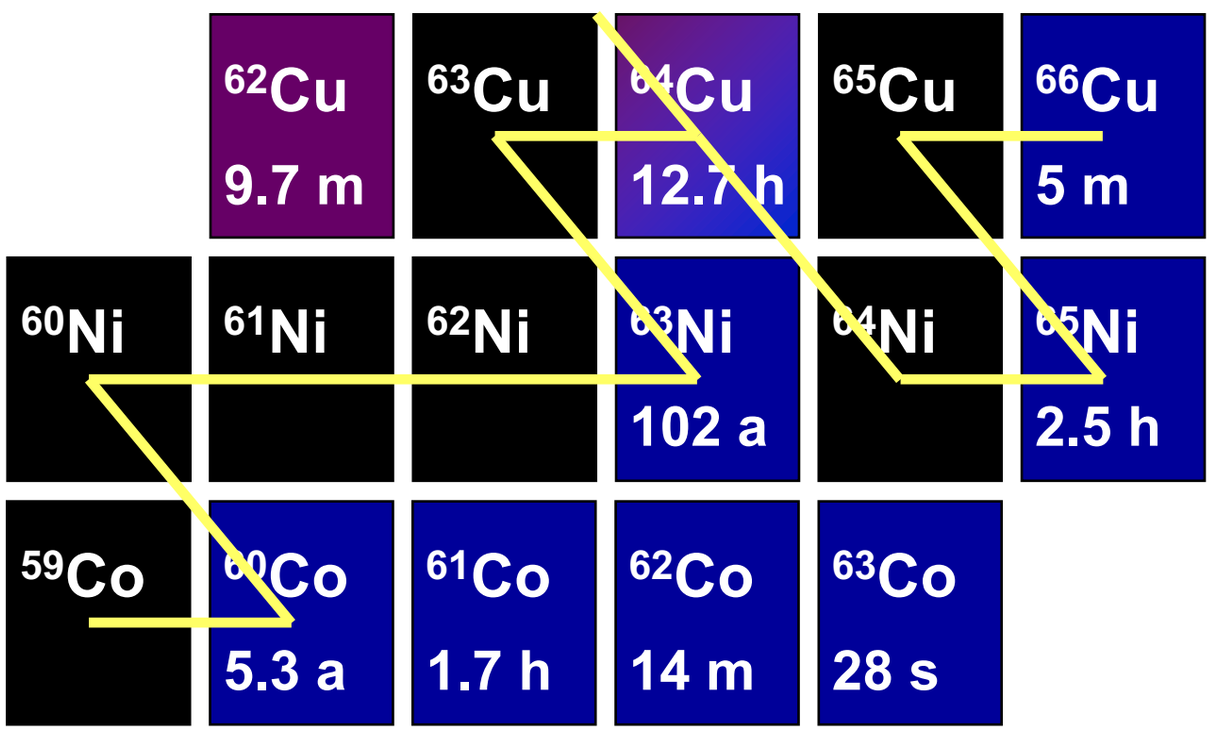

He core burning: N_n~10^6 cm^{-3}

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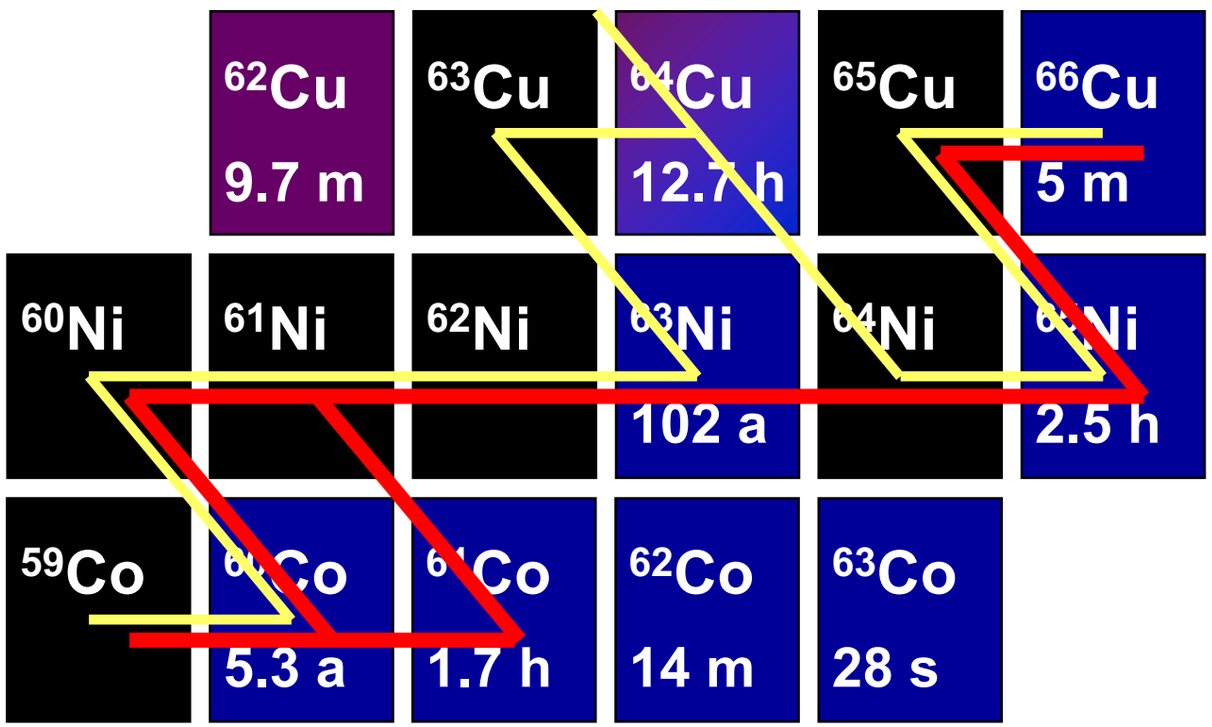

He core burning: N_n~10^6 cm^{-3}

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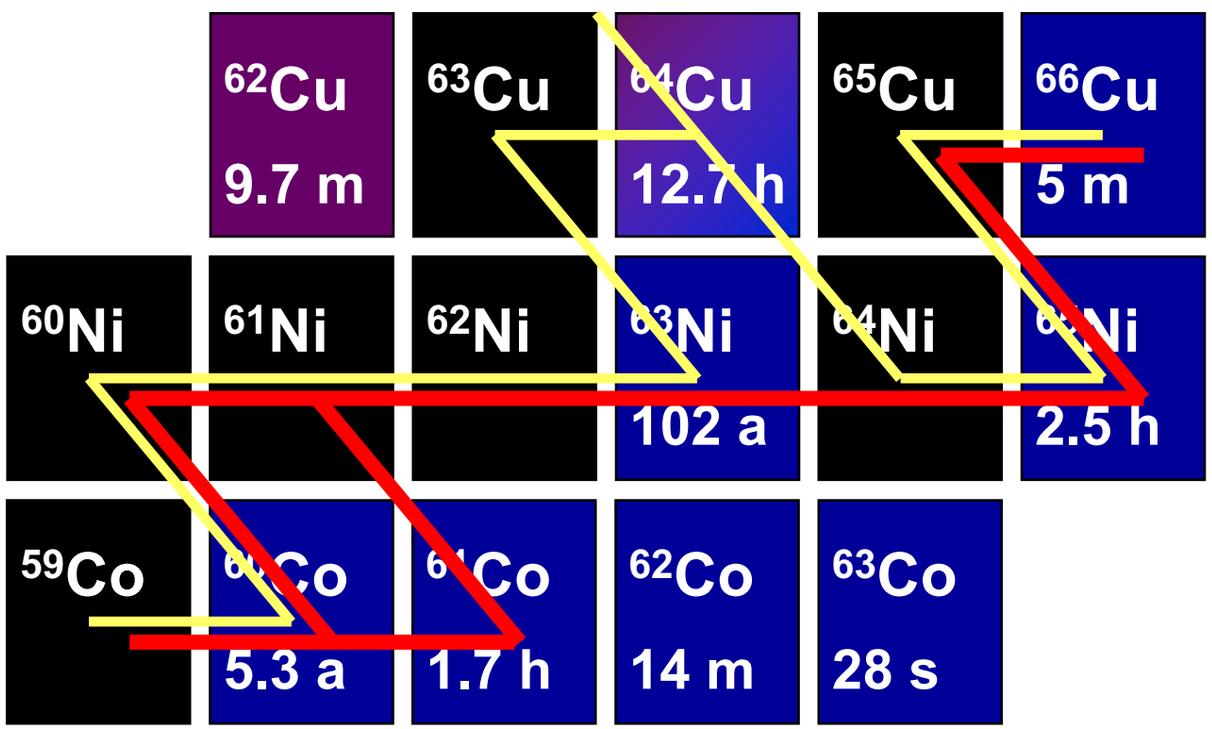
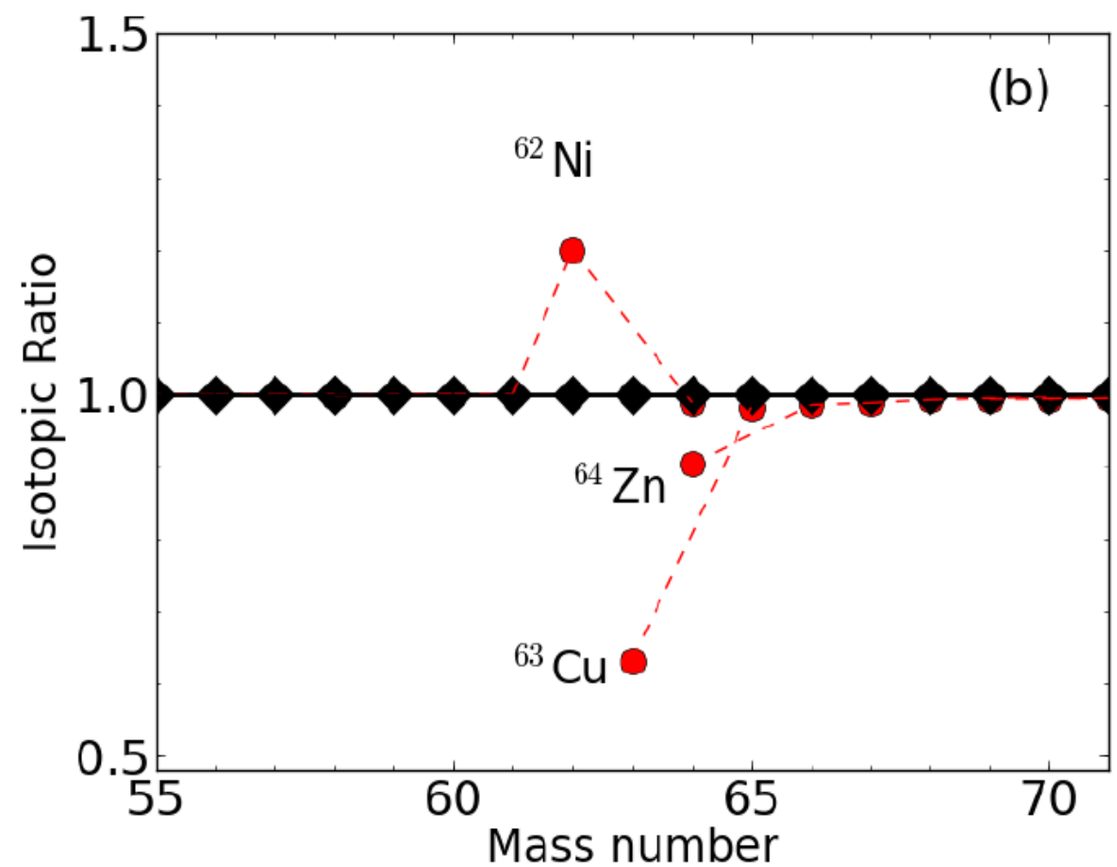
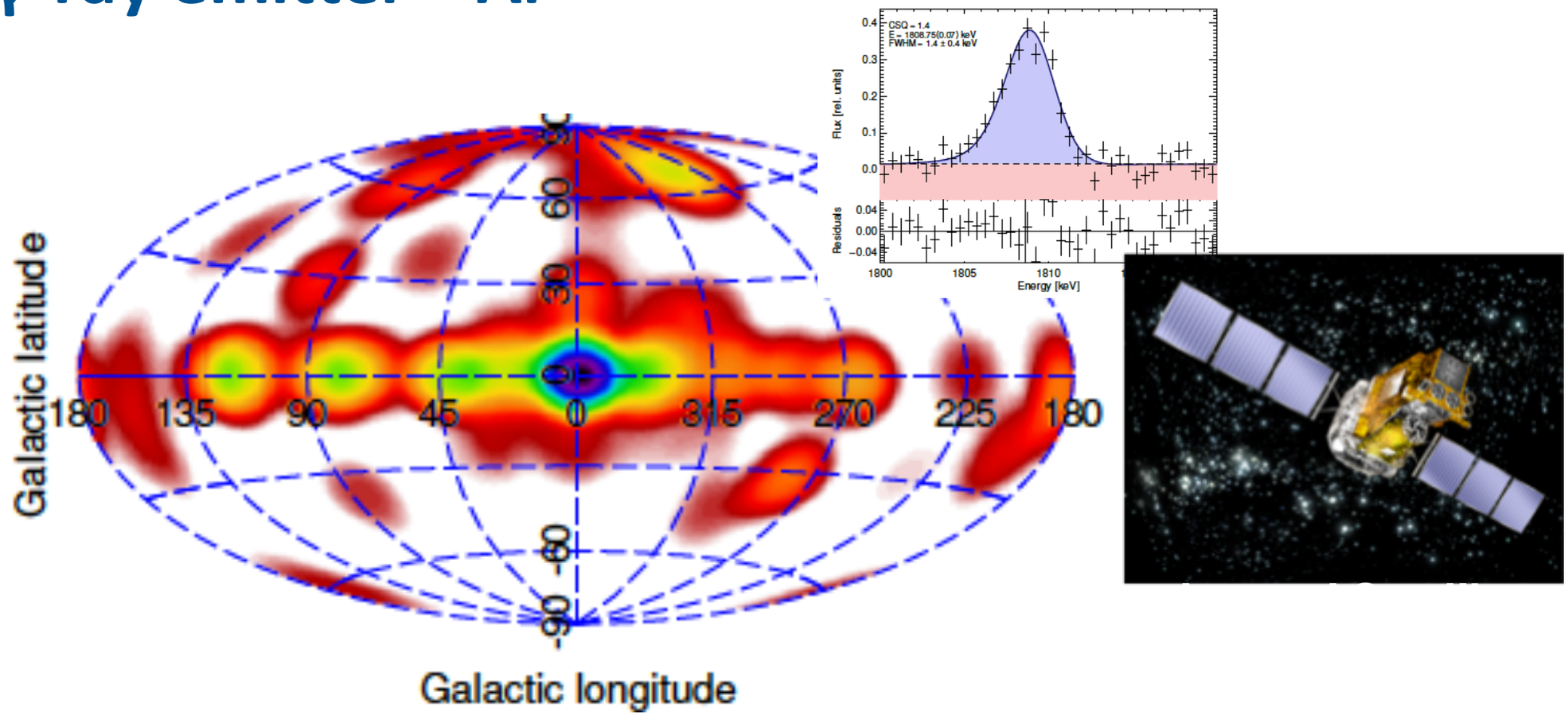


Isotopic Abundance Change



C. Lederer et al., PRL 110, 022501 (2013)
C. Lederer et al., PRC 89, 025810 (2014)

Cosmic γ-ray emitter ^{26}Al



Main Origin of ^{26}Al in massive stars (Diehl et al, Nature 439 (2006))

Mainly produced in

- convective hydrogen burning in Wolf-Rayet stars followed by ejection by stellar wind
- convective Carbon shell burning followed by ejection from core collapse supernova
- explosive Ne/C burning in core collapse phase of supernova

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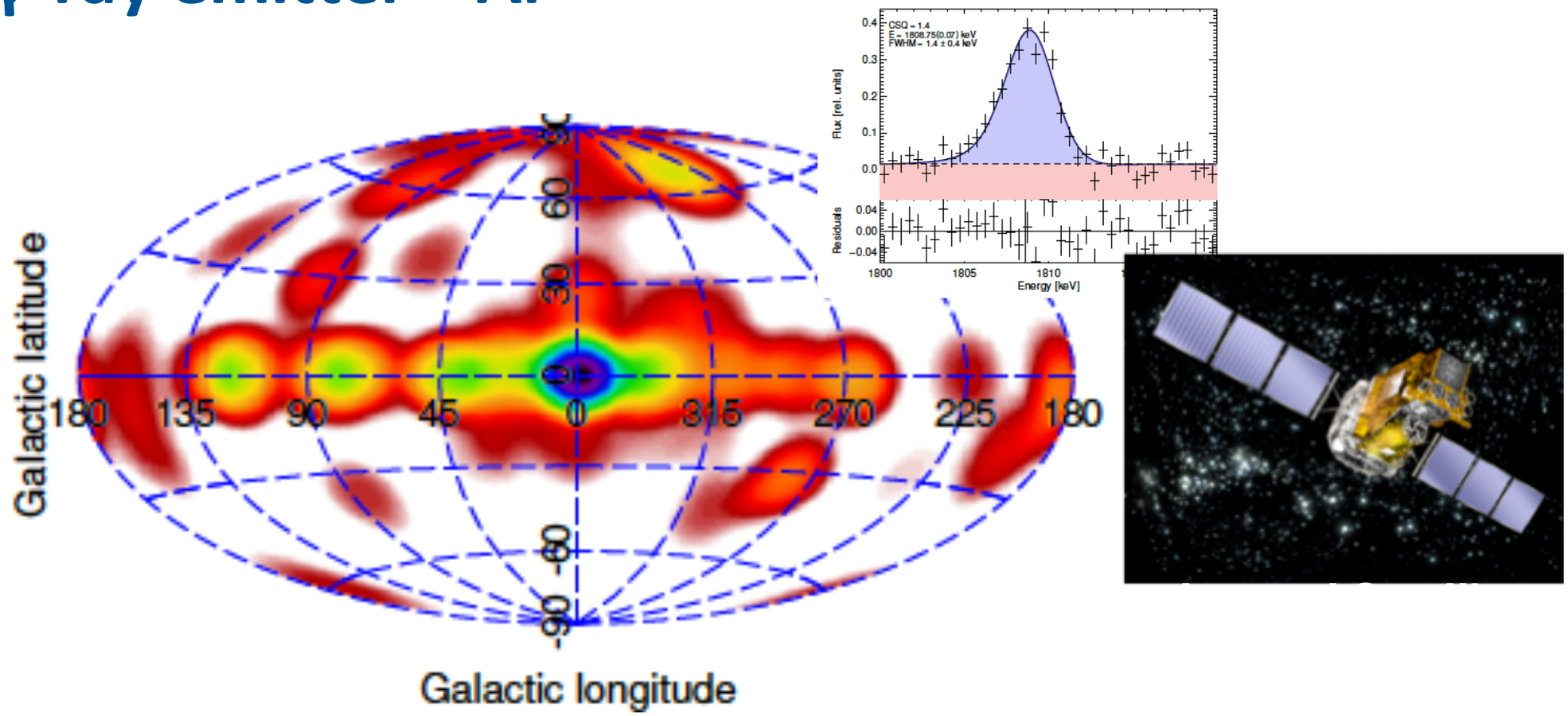

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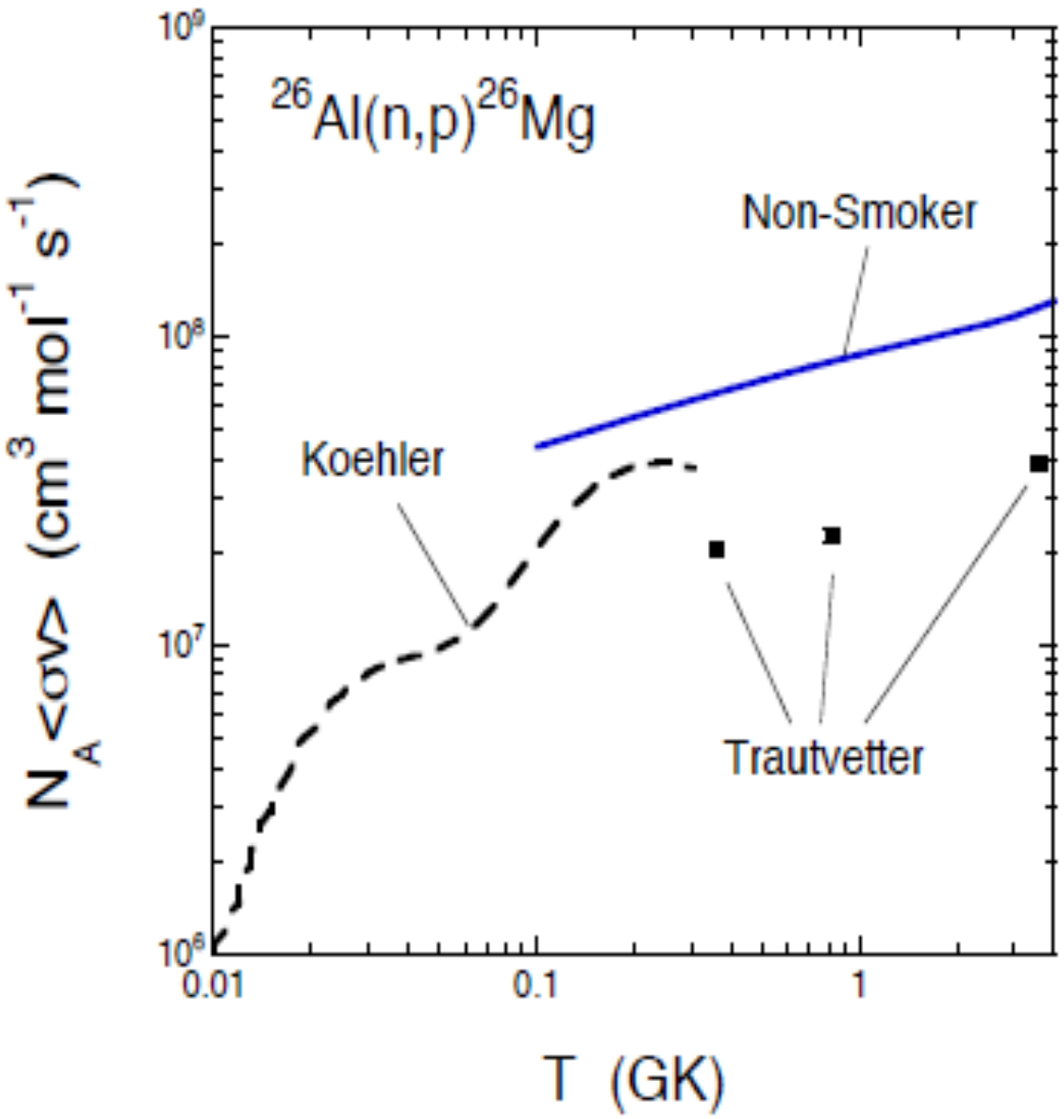
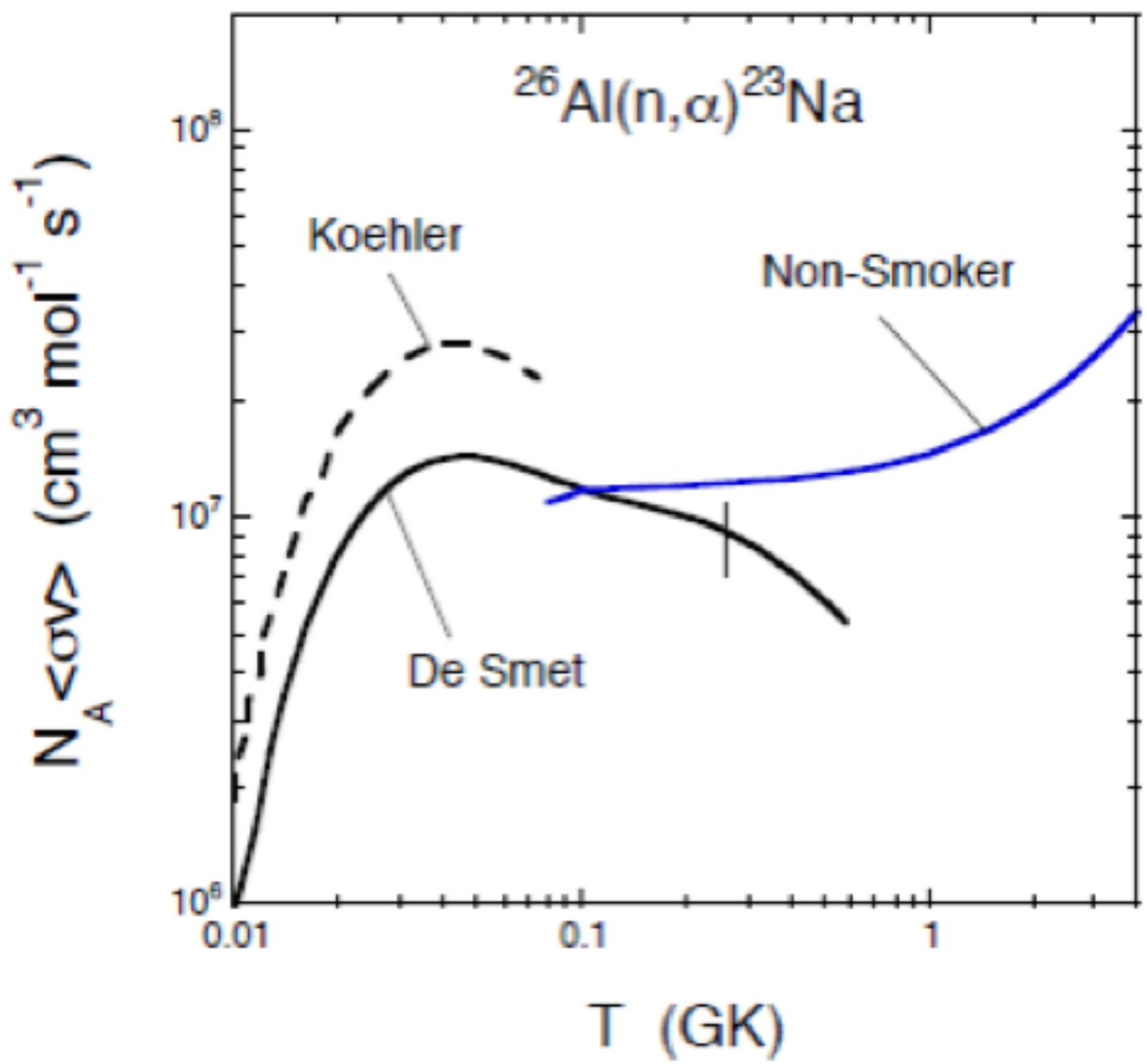
Key uncertainties for theoretical predictions of abundances: **^{26}Al(n,p)** and **^{26}Al(n,α)** reaction rates [Iliadis et al., Astrophys. J. Supp. 193, 16 (2011)]

^{26}Al +n reaction rates from previous measurements



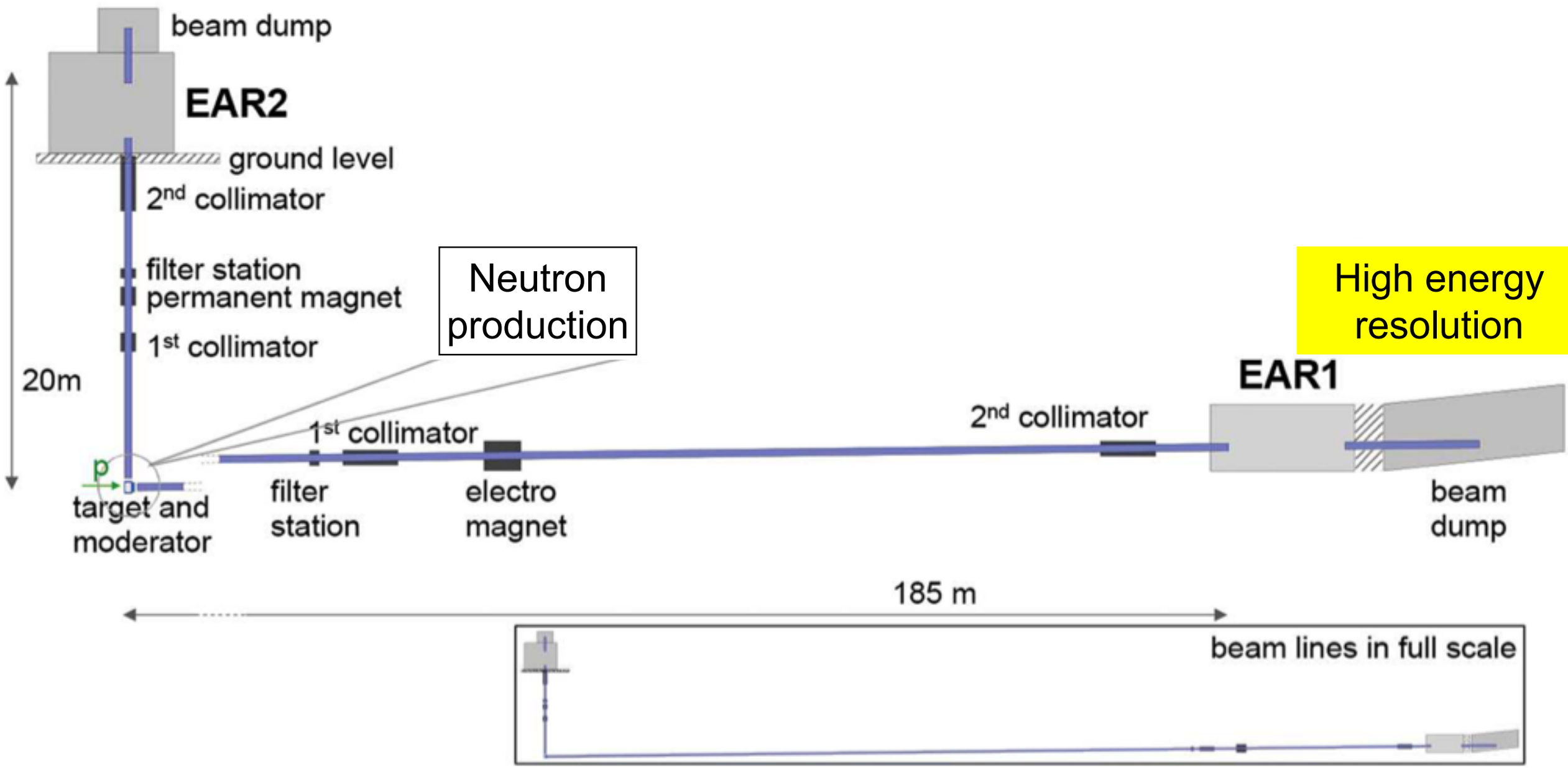


C Iliadis et al., Ast. J. Supp. 193, 16 (2011)

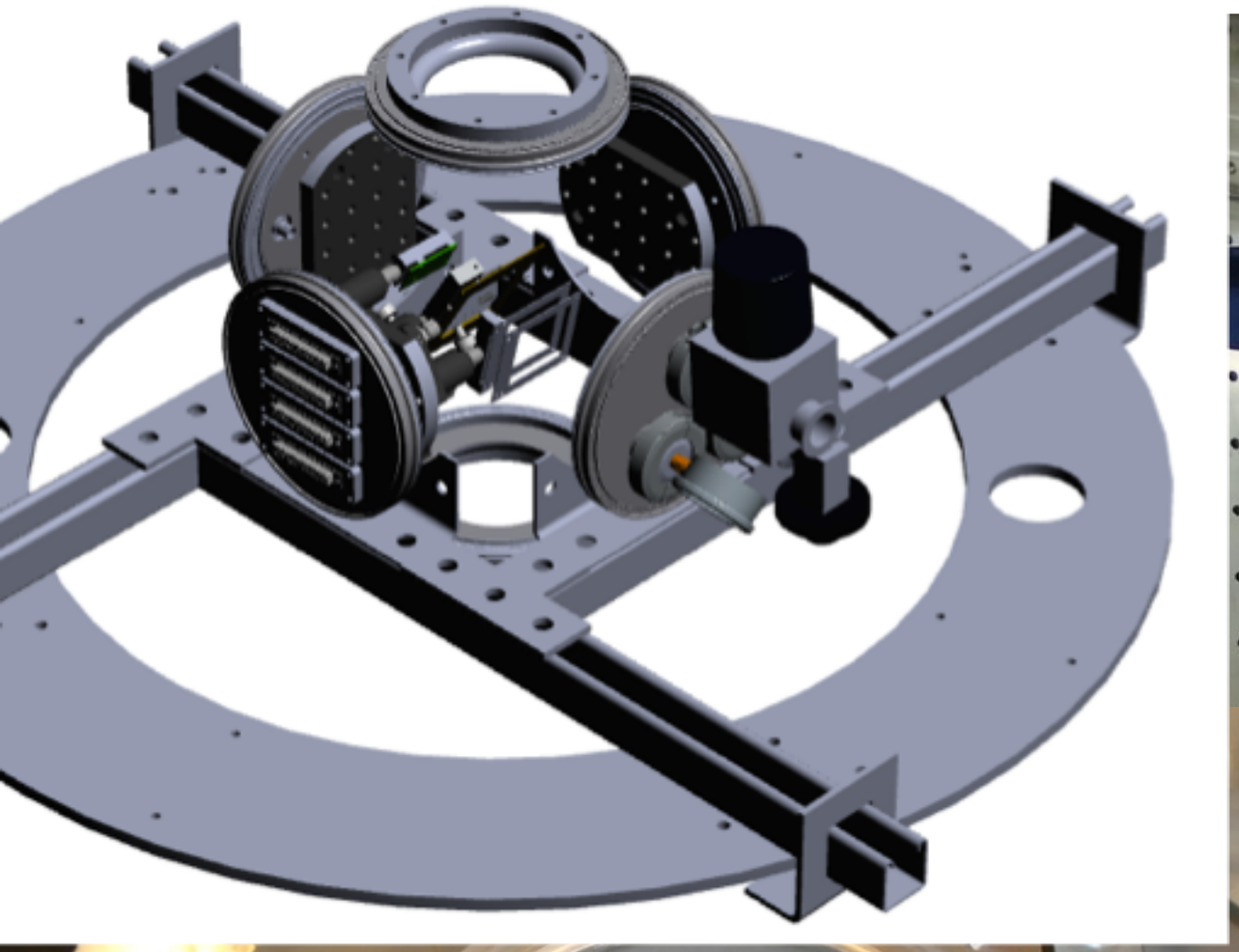
The n_TOF Facility @ CERN

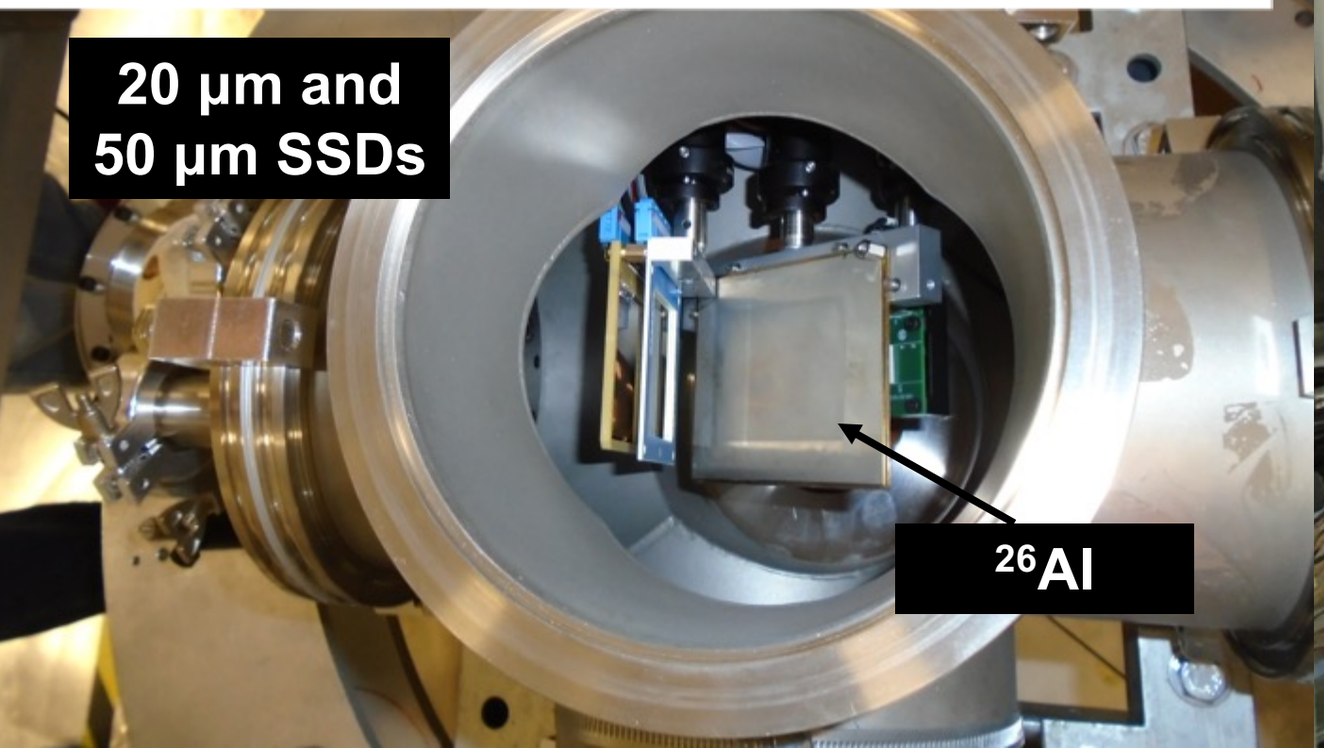
High neutron flux

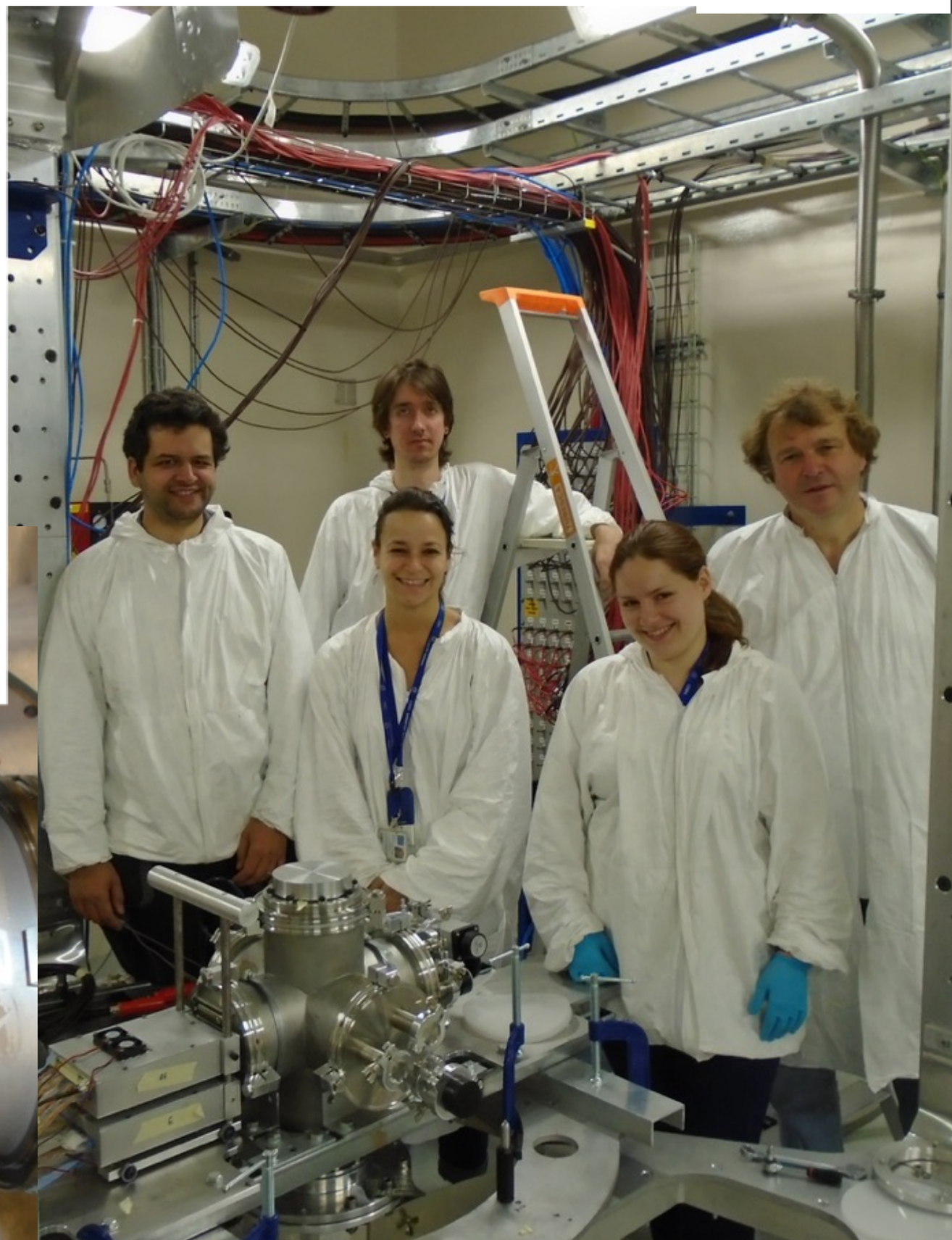
High energy resolution



^{26}Al(n,α/p) at n_TOF EAR-2: New Silicon detection setup

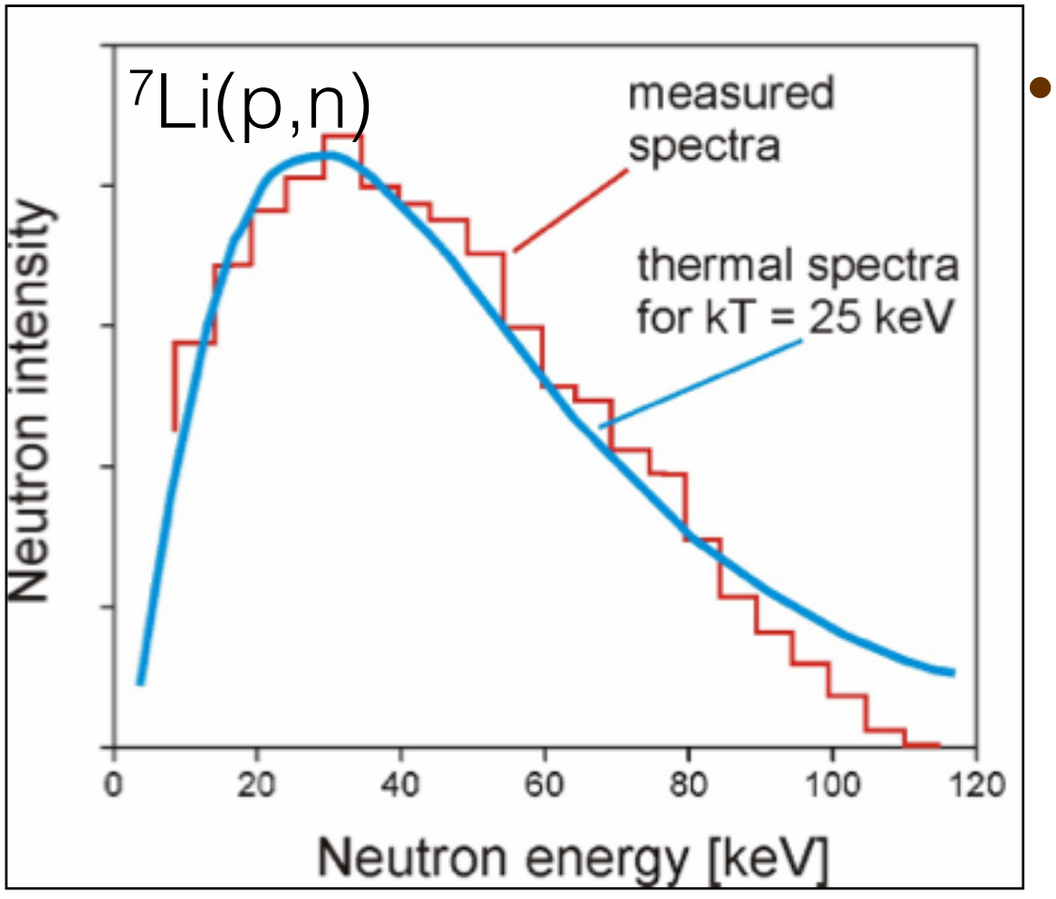






(n,γ) cross sections with activation

- continuous neutron beam → higher flux
- create quasi Maxwellian spectrum in laboratory
- detect radioactive decay of product or count product with accelerator mass spectrometry
- needs radioactive reaction product



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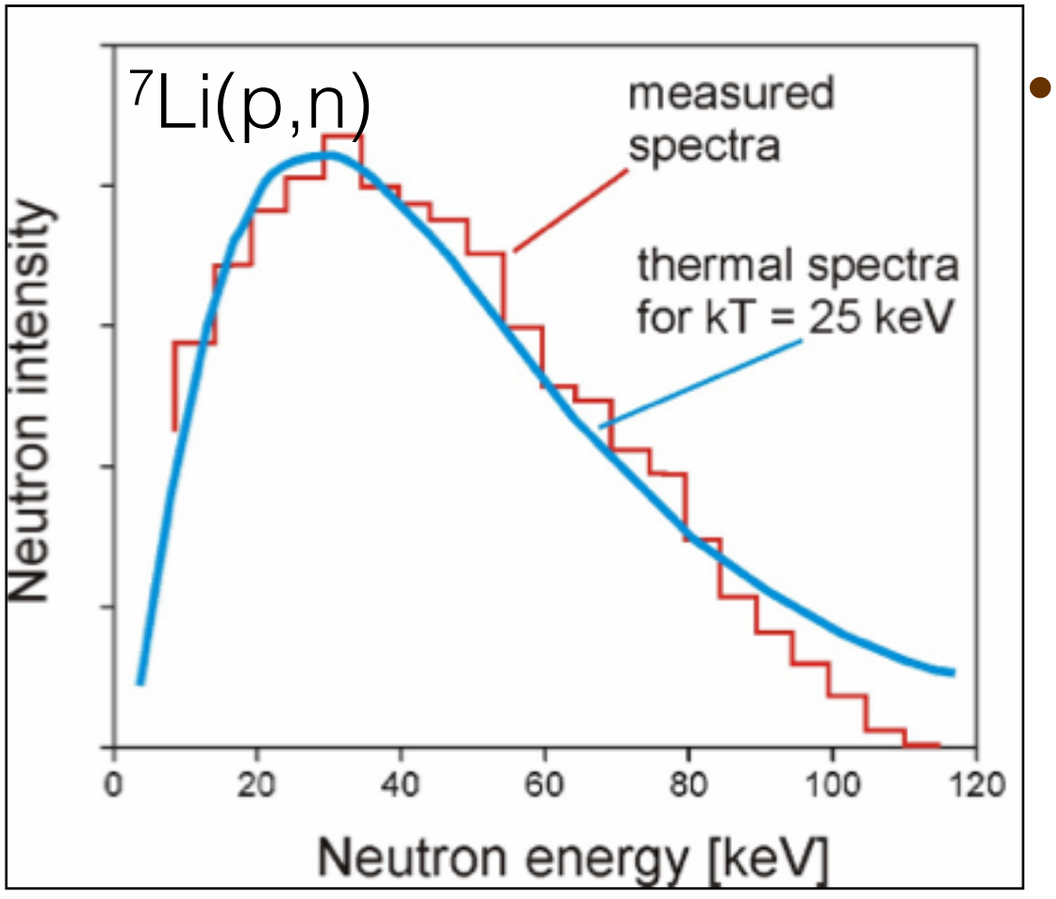

New ultra high flux facilities recently in operation (LiLiT@SARAF) or under construction (FRANZ, Goethe University)

Outlook

- New ultra high neutron flux facilities provide exciting opportunities for cross section measurements on radioactive species
- There is, however, still a need for high precision measurements on stable isotopes – new data are on the way, e.g. Se, Zn,…..
- For very short lived isotopes (i-, r-process) alternative methods need to be applied (suggestion to use storage rings, Reifarth & Litvinov, Phys. Rev. ST Accel. Beams 17, 014701 (2014))