Experiments for the astrophysical s-process

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Workshop on Nuclear Astrophysics at the Dresden Felsenkeller
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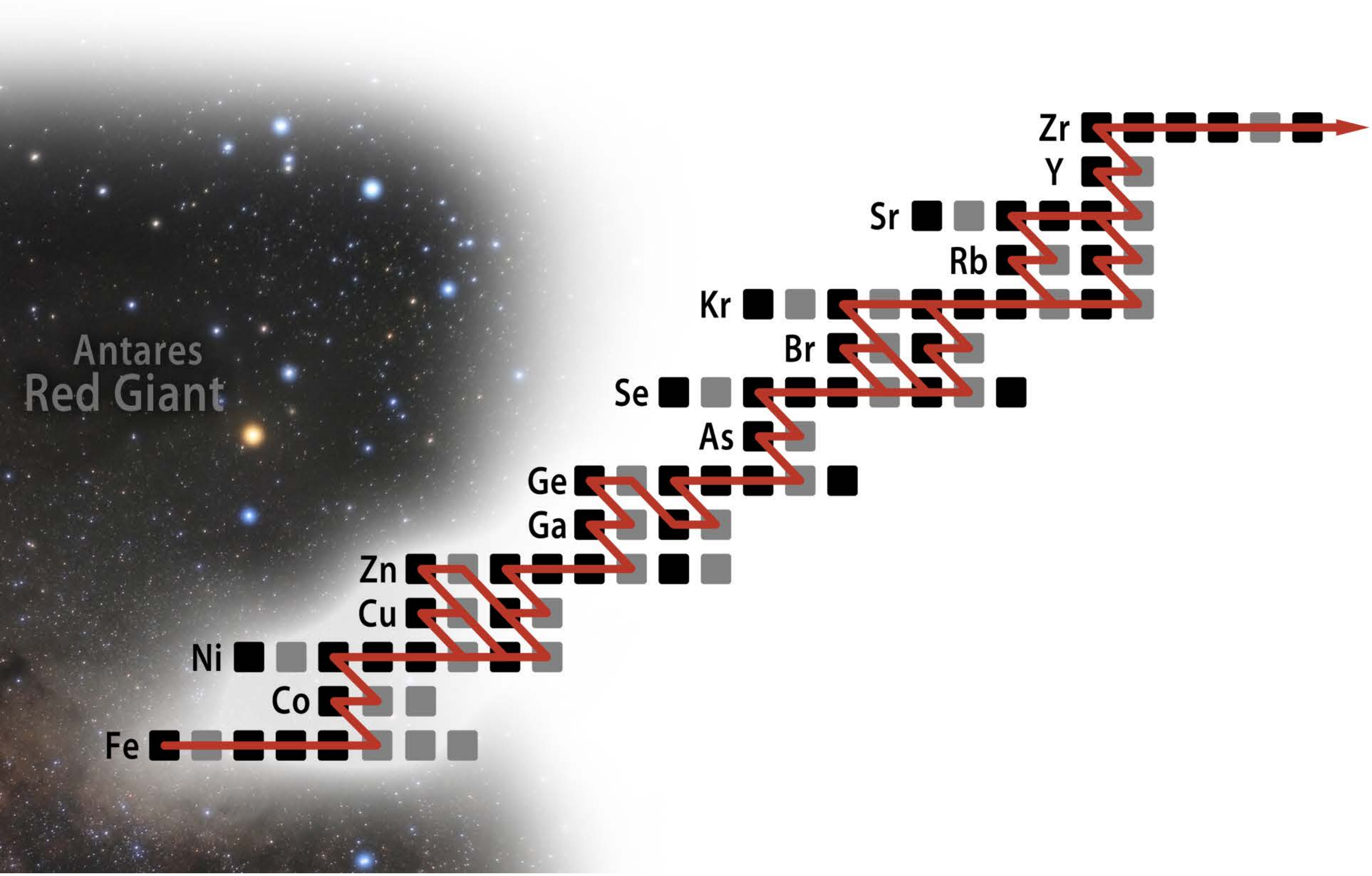
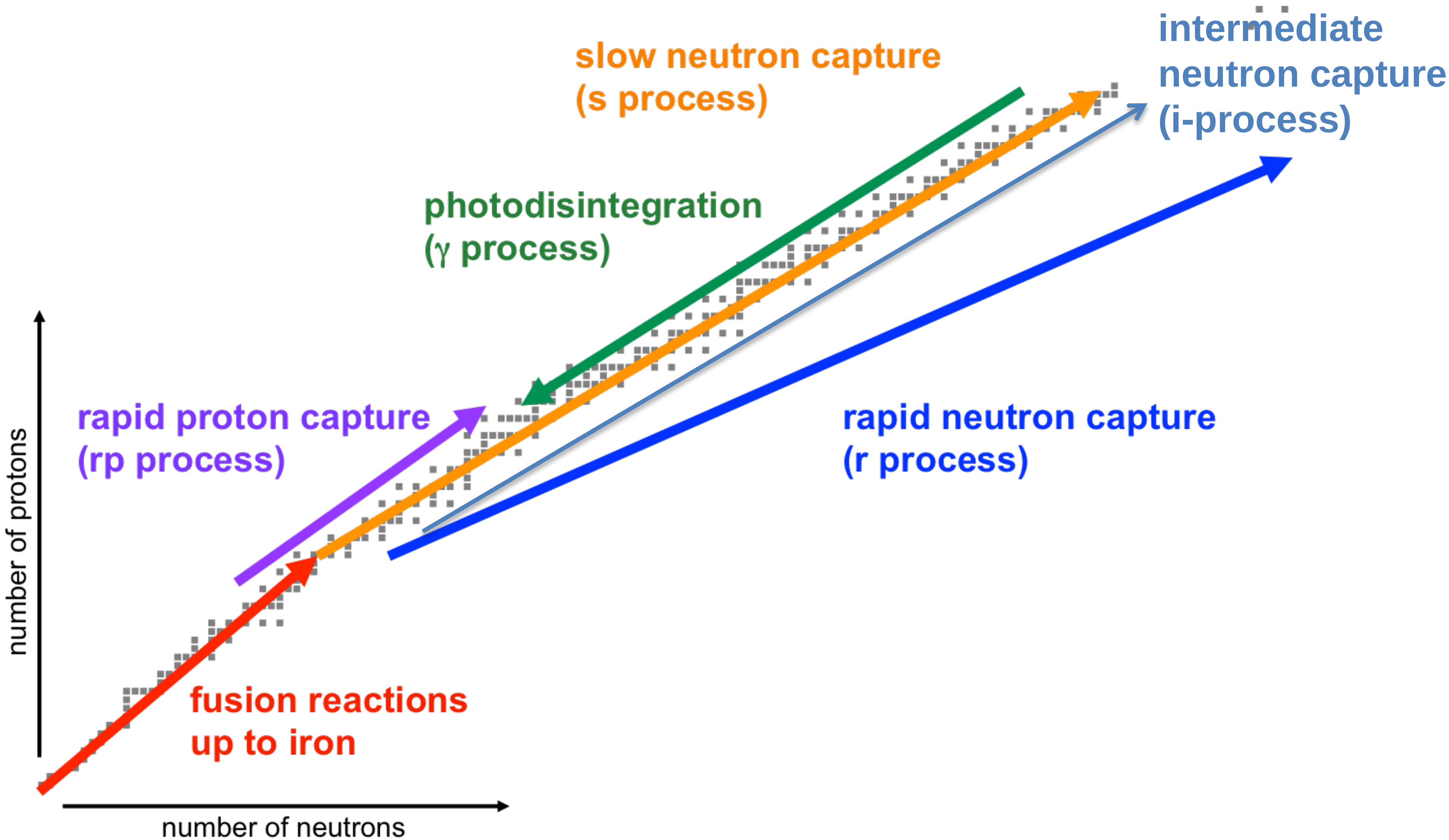
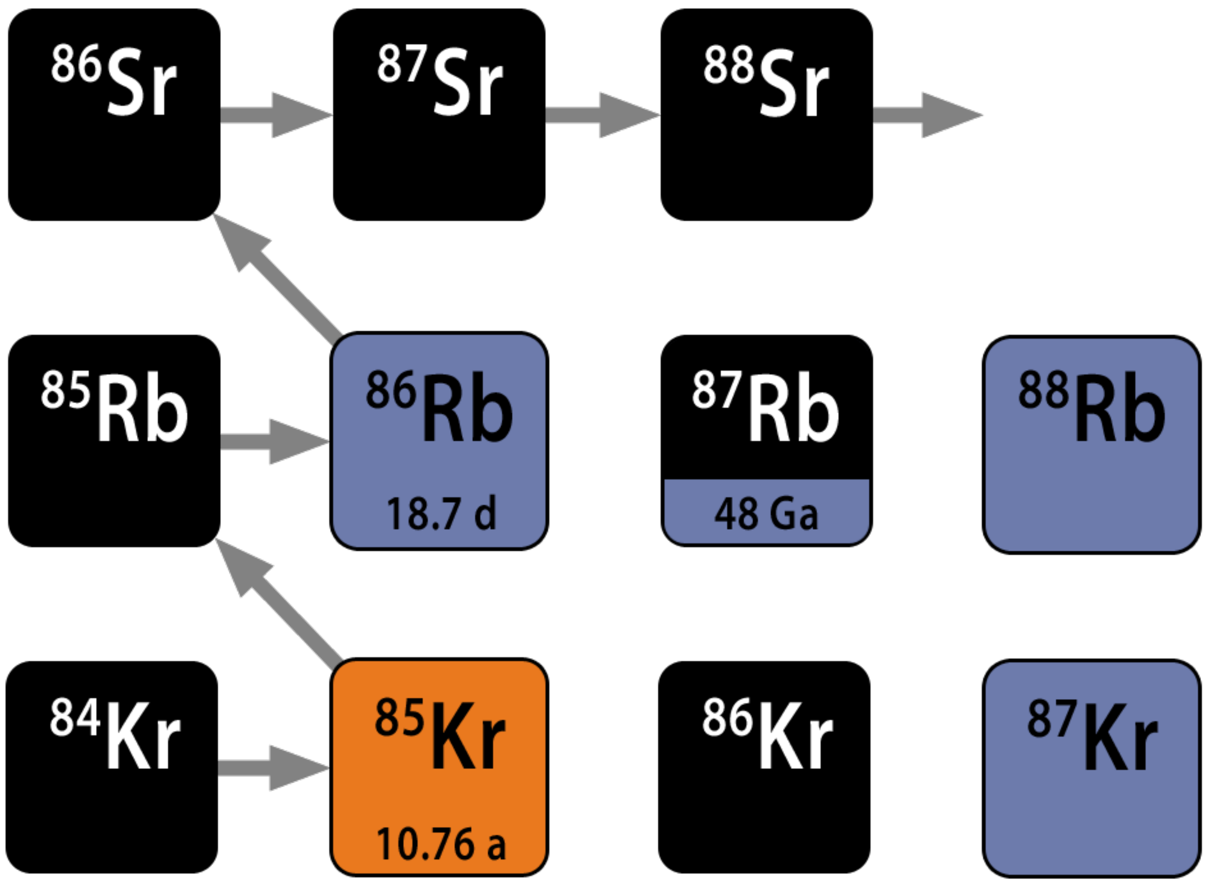
Nucleosynthesis – tales from the past



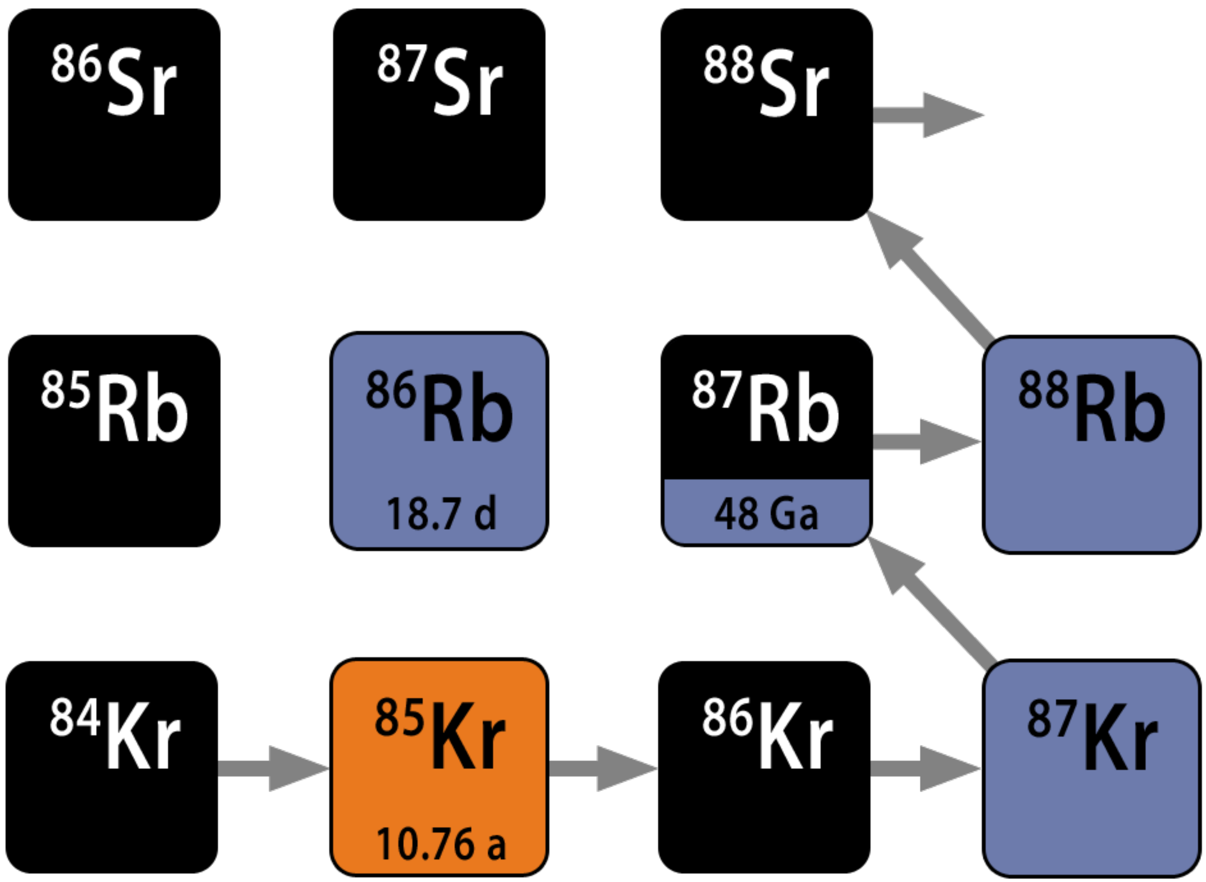
The nucleosynthesis of the elements



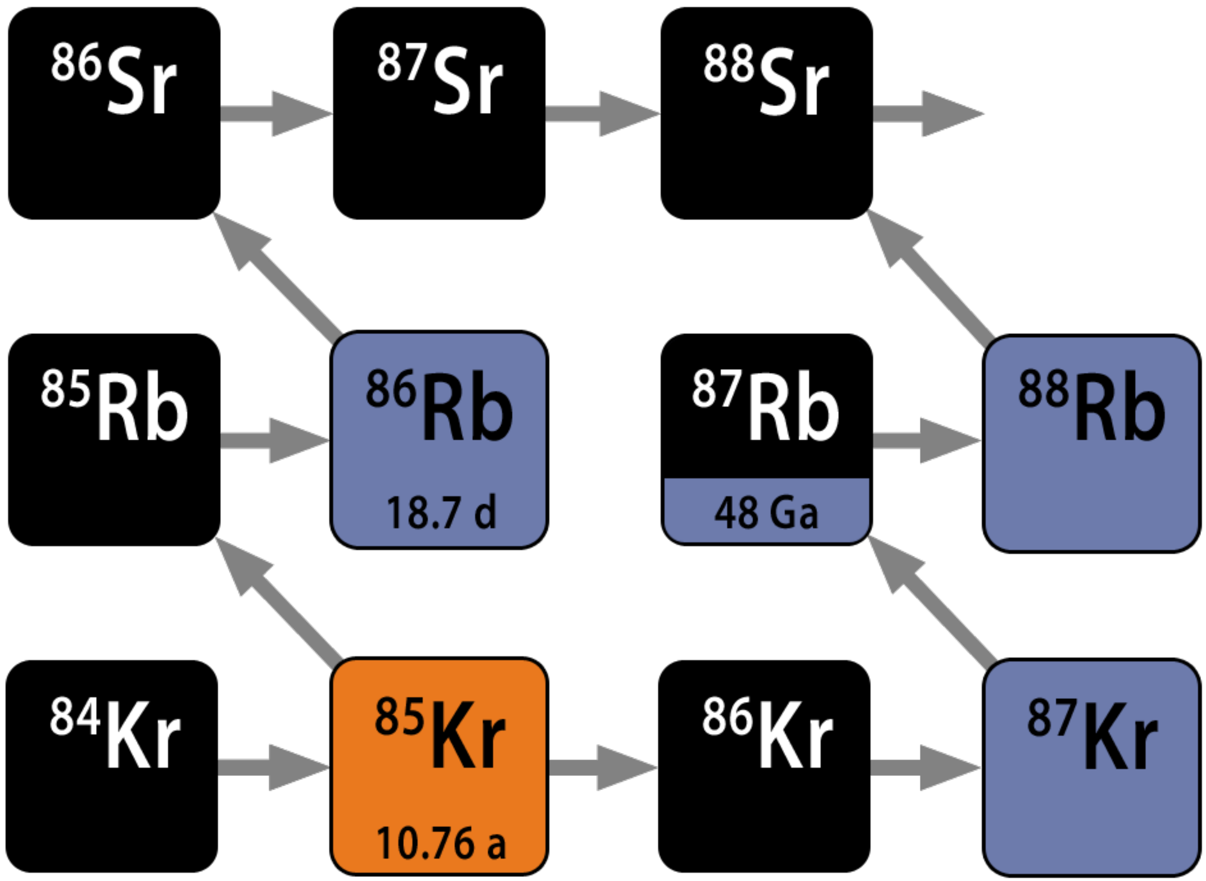
Radioactive isotopes in the s-process



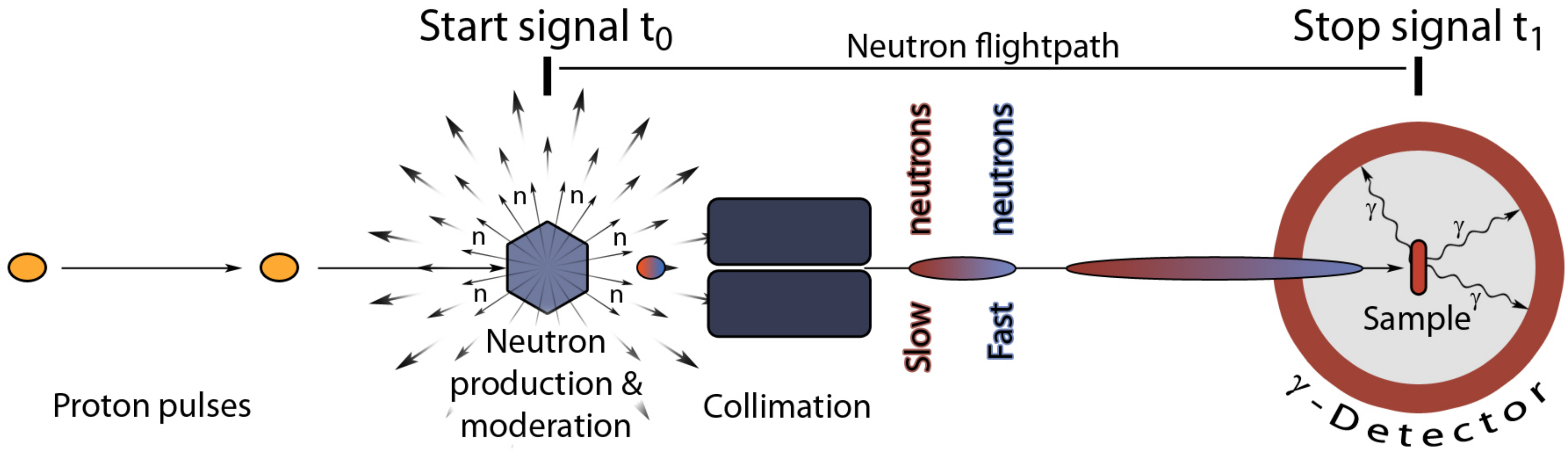
Radioactive isotopes in the s-process



Radioactive isotopes in the s-process



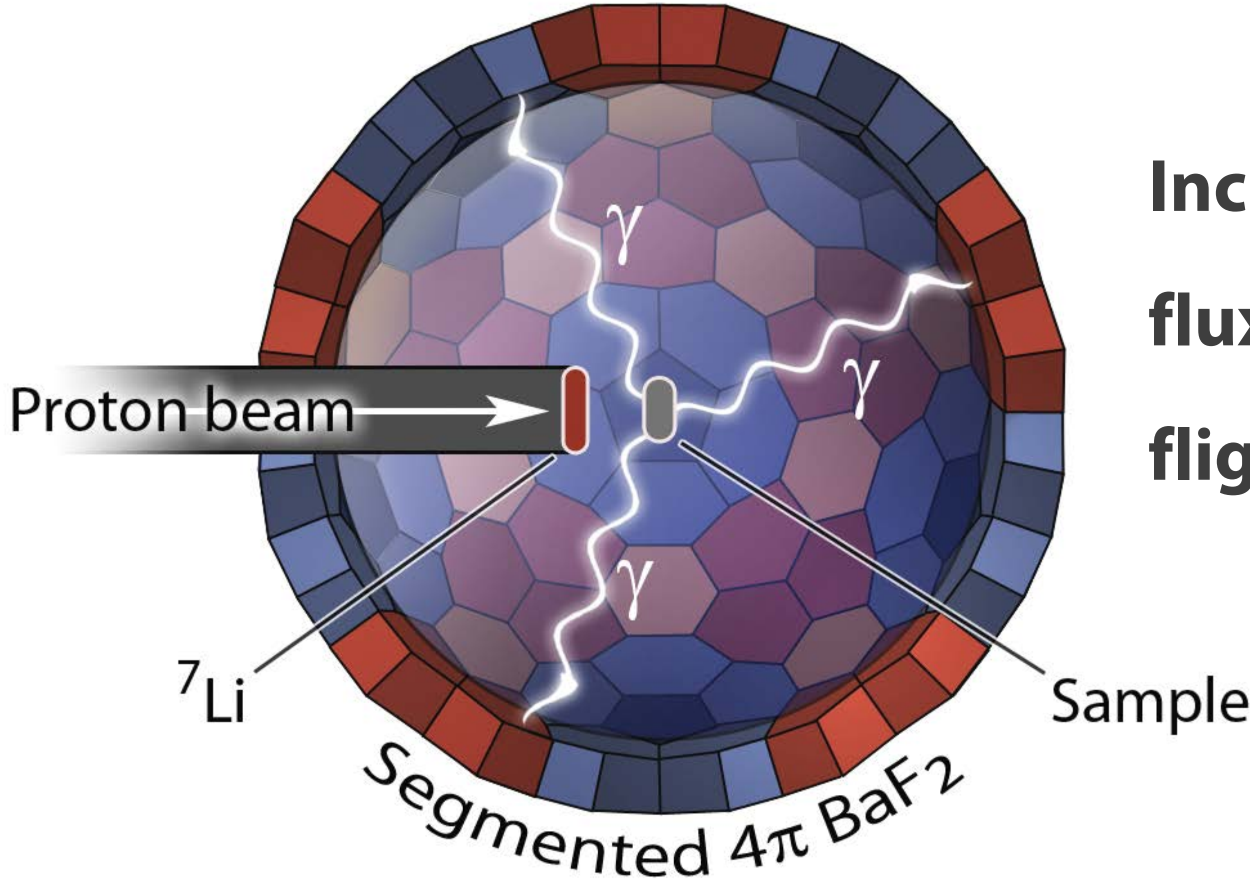
Neutron Captures – time-of-flight technique



- the TOF-technique is the only generally applicable method the determine energy-dependent neutron capture cross sections
- beam pulsing & distance to the neutron production site significantly reduce the number of neutrons available on the sample

Reifarth et al. J. Phys. G: Nucl. Part. Phys. 41 (2014) 053101

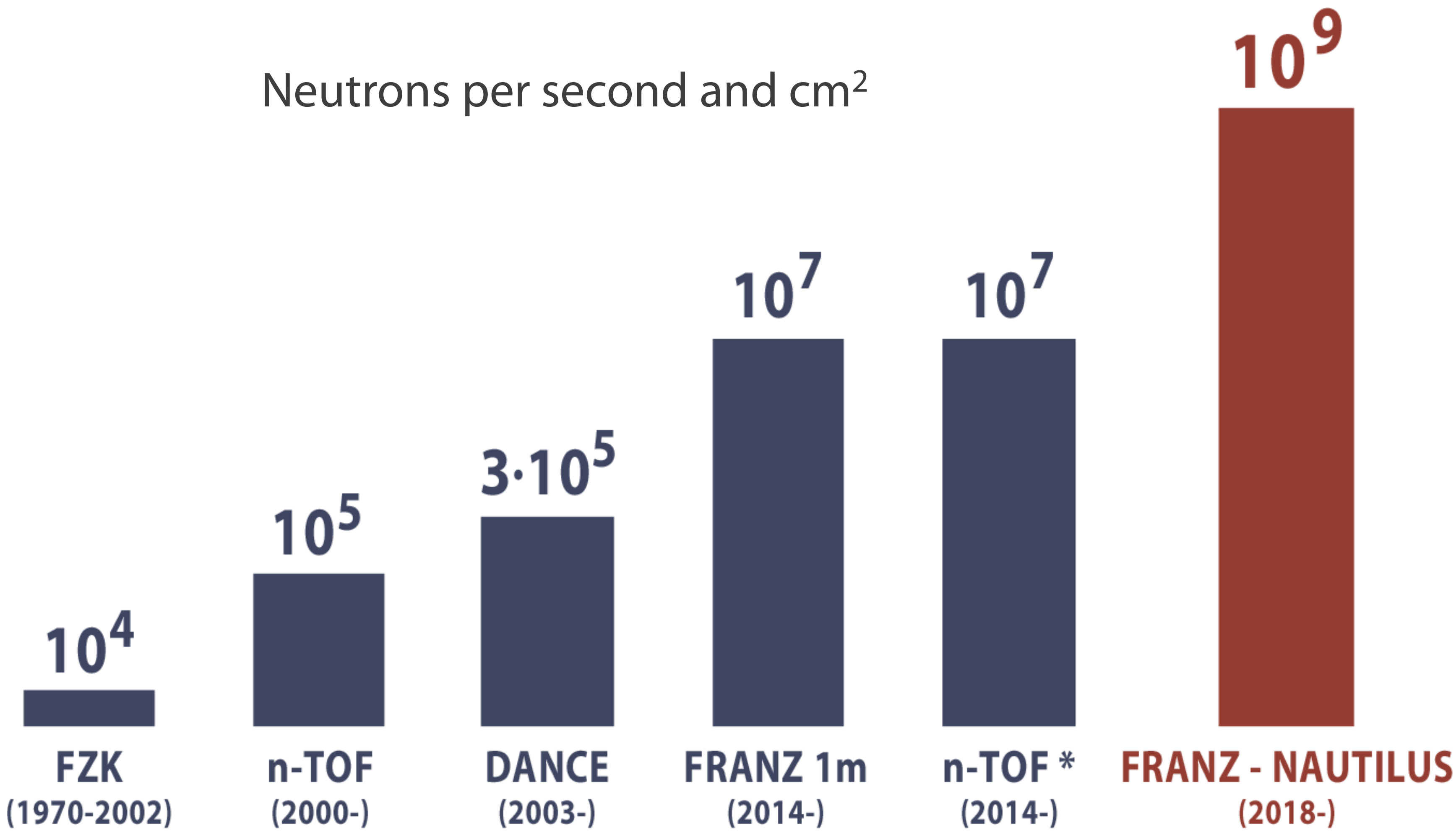
NAUTILUS –
Neutron capture with short flightpath

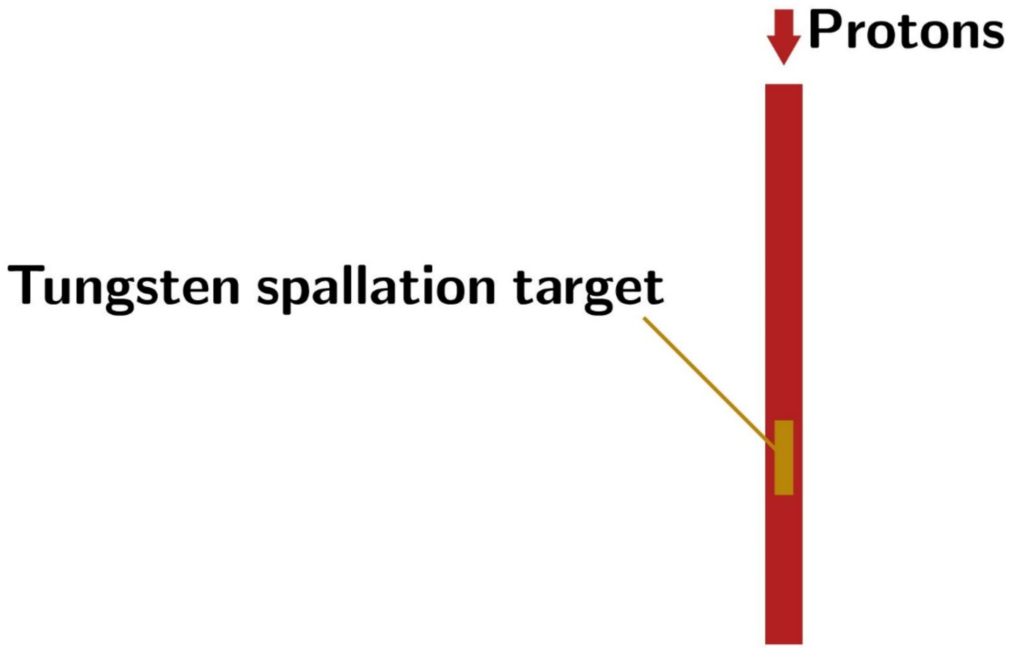


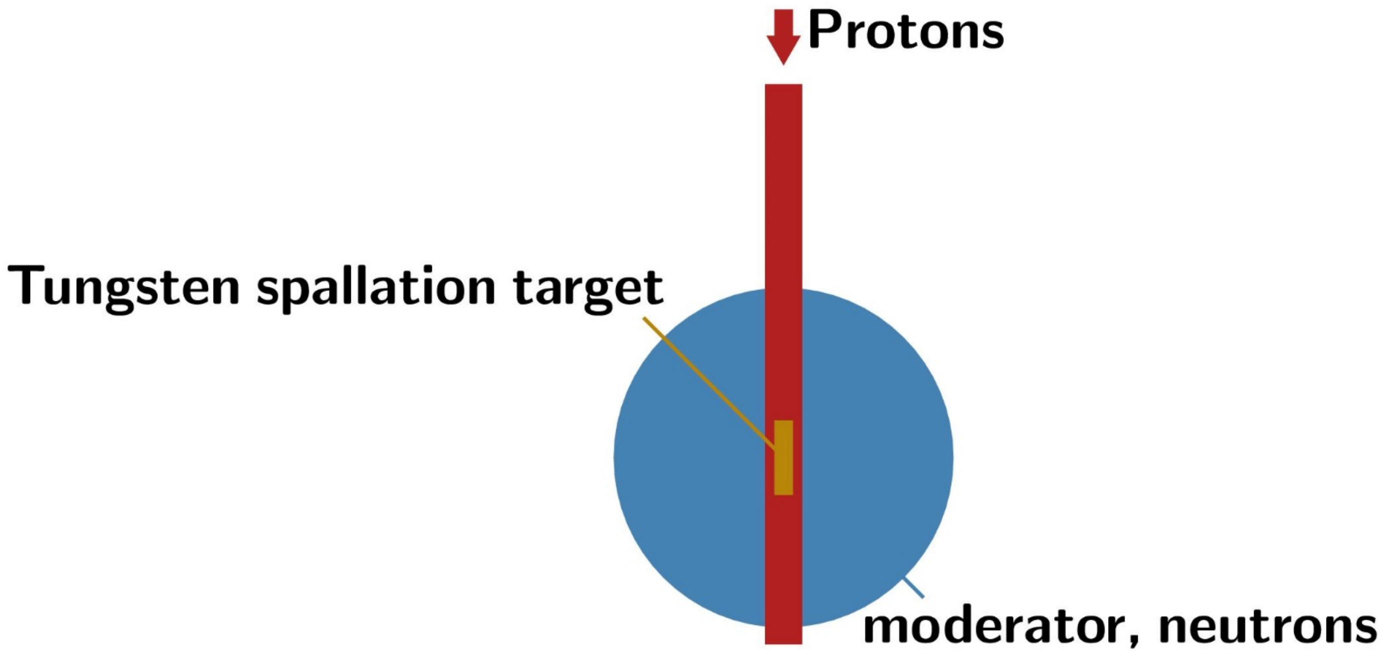
Increase neutron flux with ultra-short flightpath

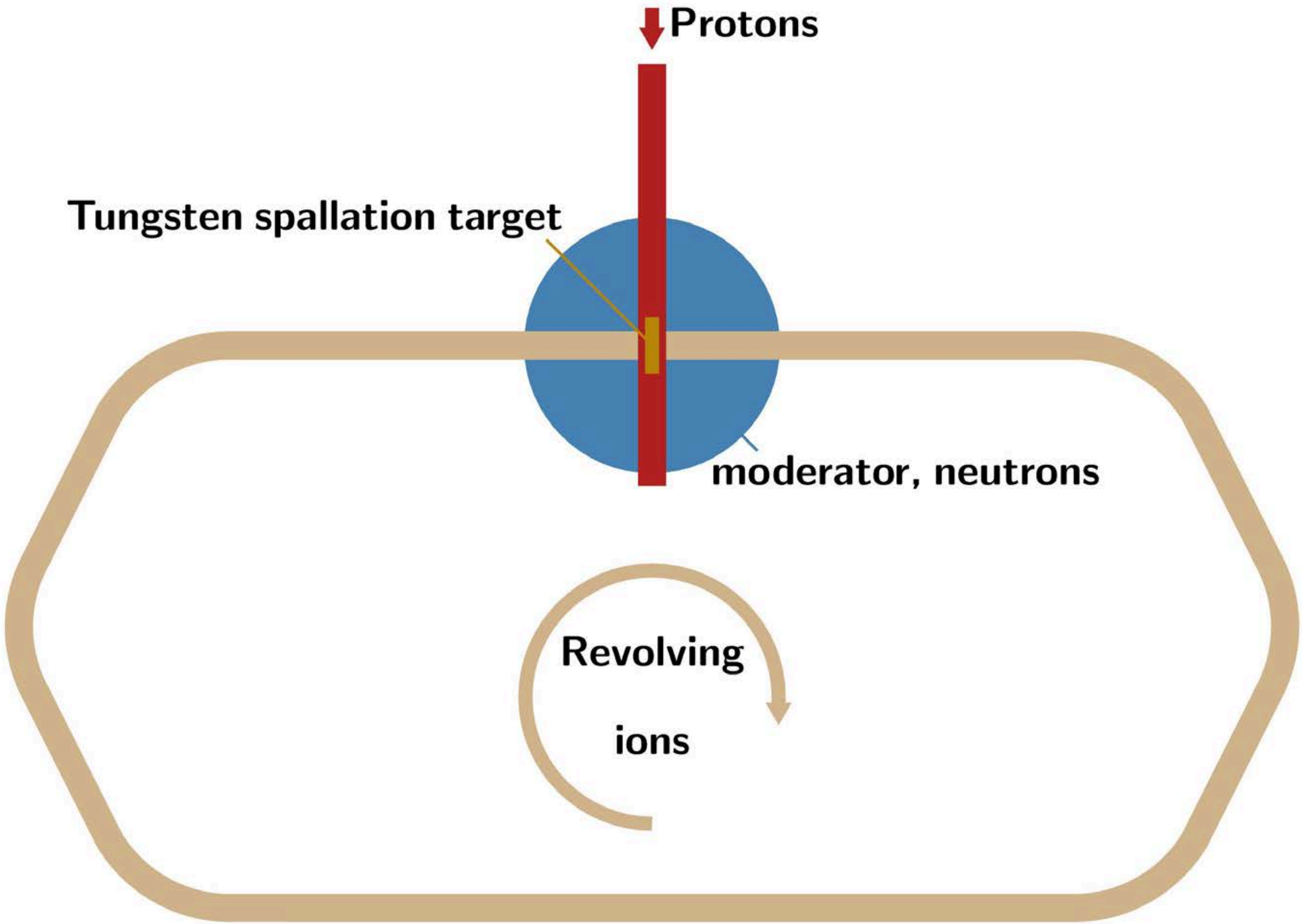
Reifarth et al. NIM A 524 (2004) 215–226

Neutron flux in astrophysical region



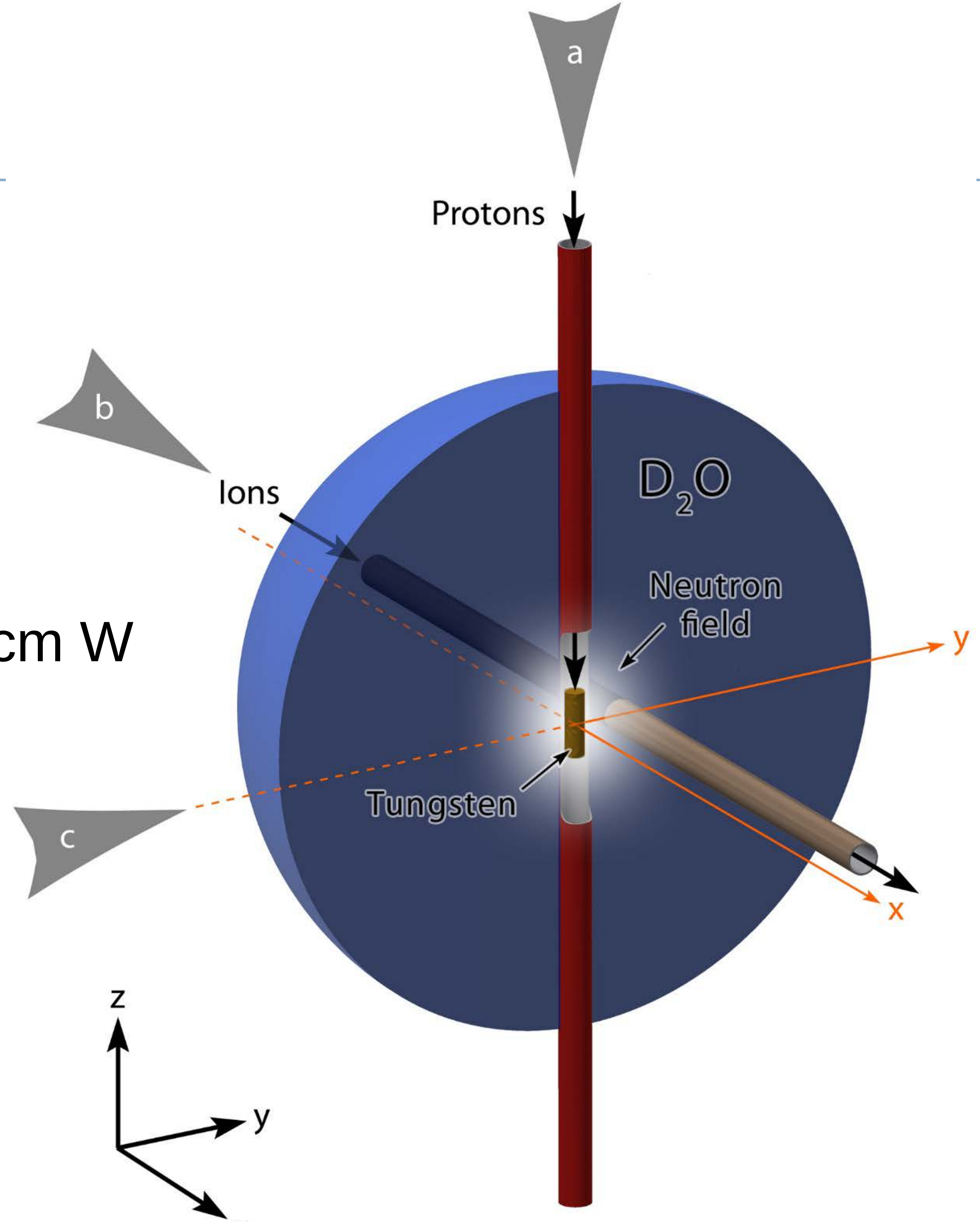

Protons
Tungsten spallation target


Protons
Tungsten spallation target
moderator, neutrons


Protons
Tungsten spallation target
moderator, neutrons
Revolving
ions

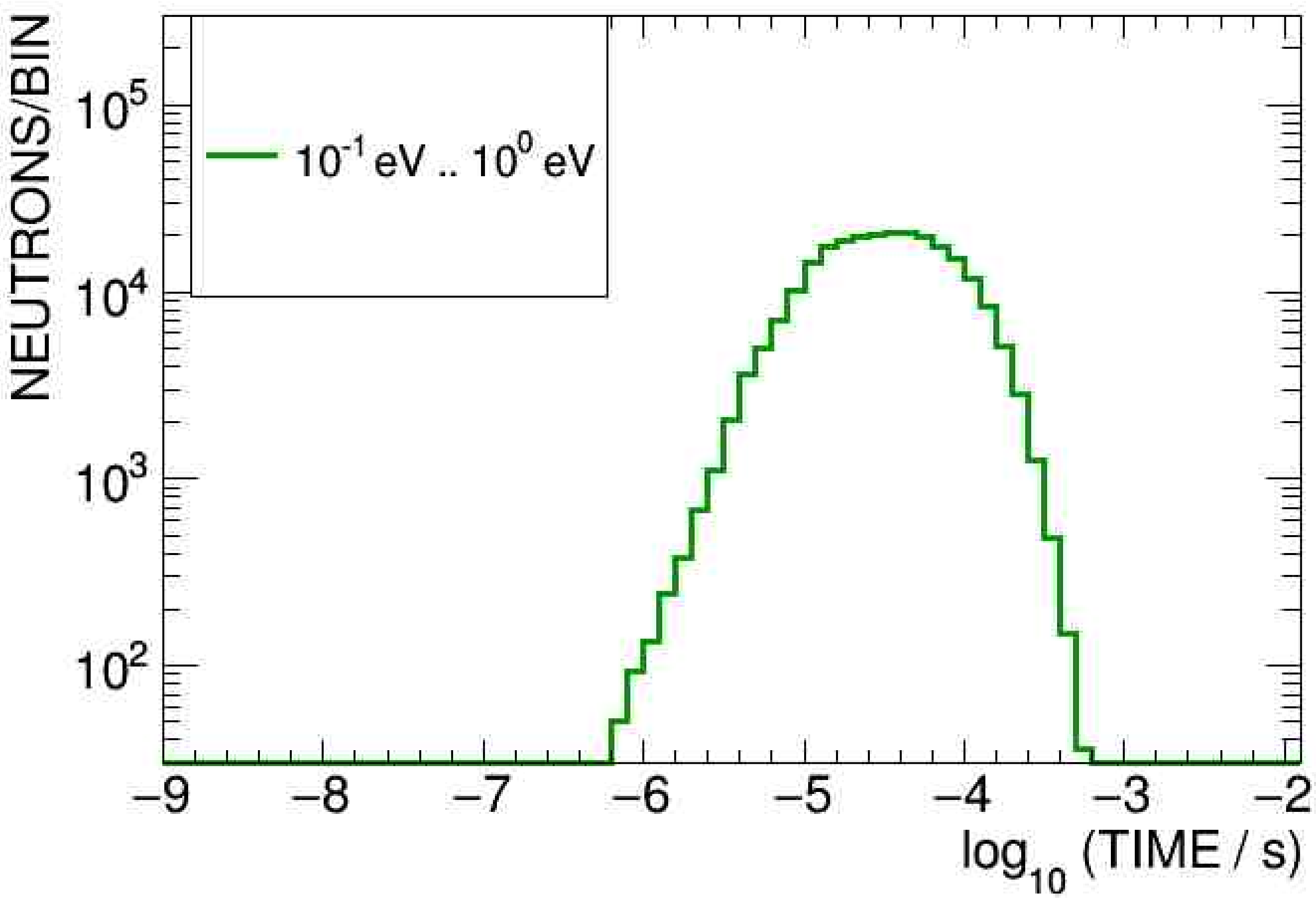
Proposed setup

- Moderator: 0.5-2m D_2O
- Spallation target: 10-50 cm W
- Protons: 0.5 – 50 GeV



Reifarth et al, Phys. Rev ST Accelerator and Beams, 20, 044701 (2017)

1m D_2O, neutron time in ion pipe



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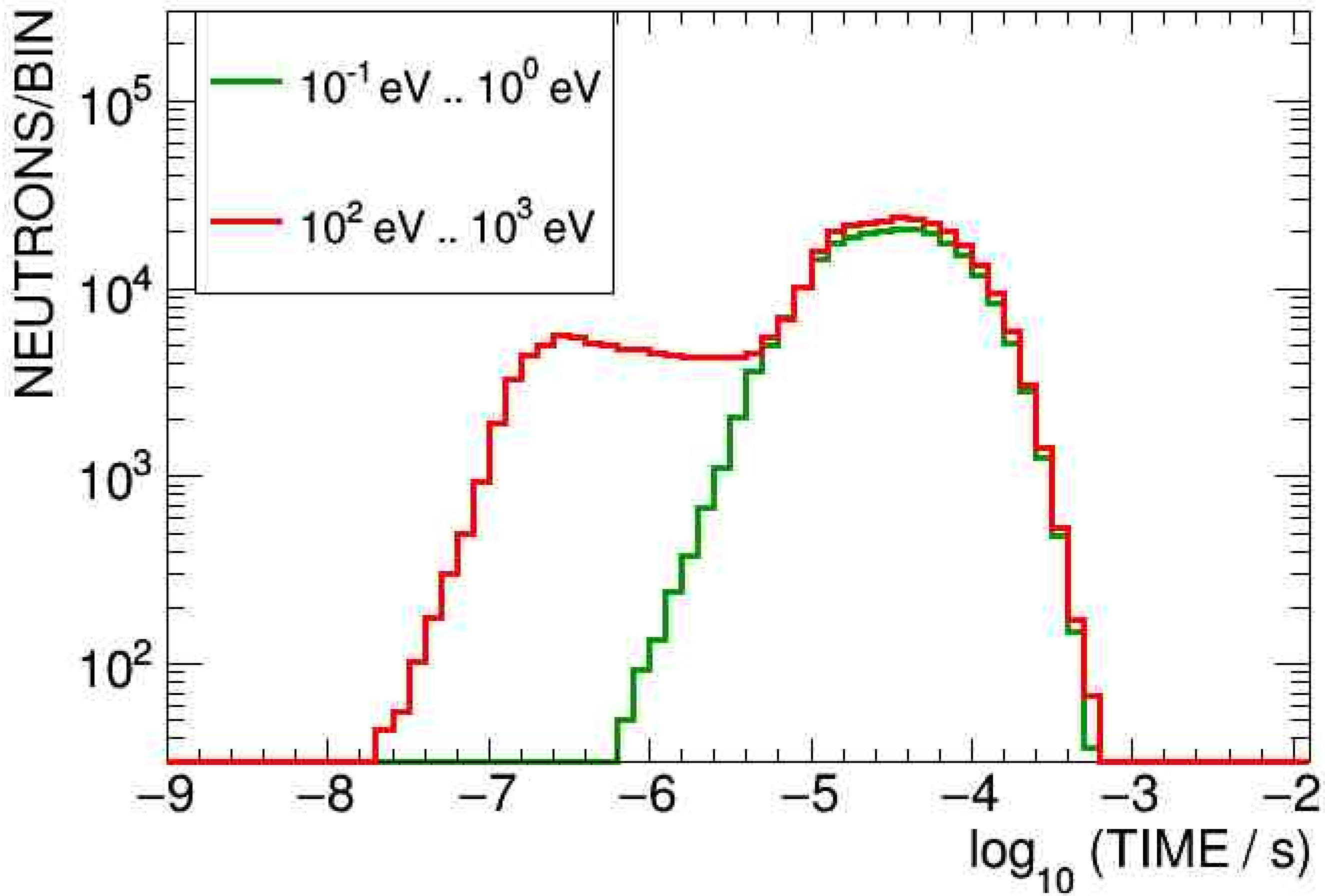

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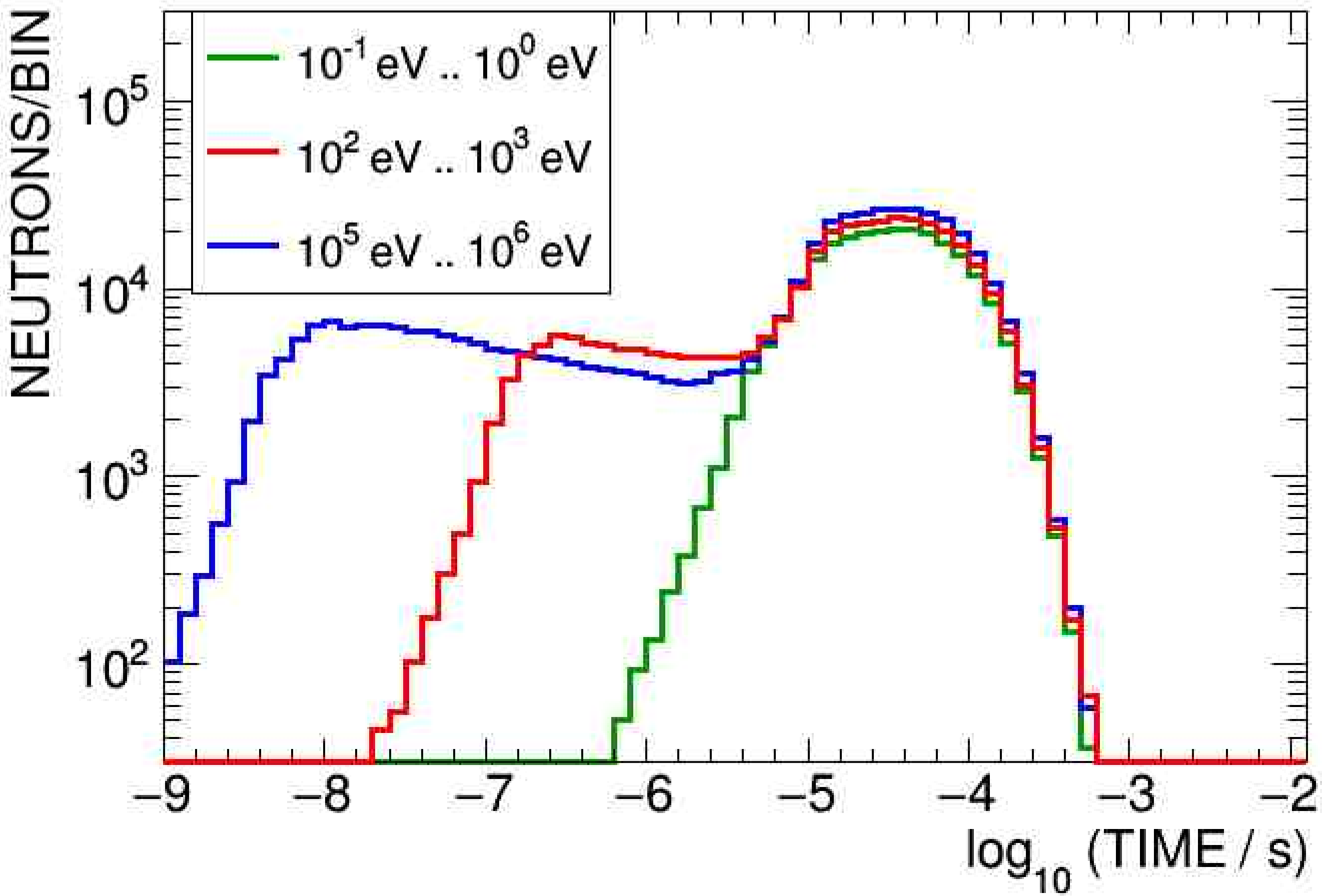

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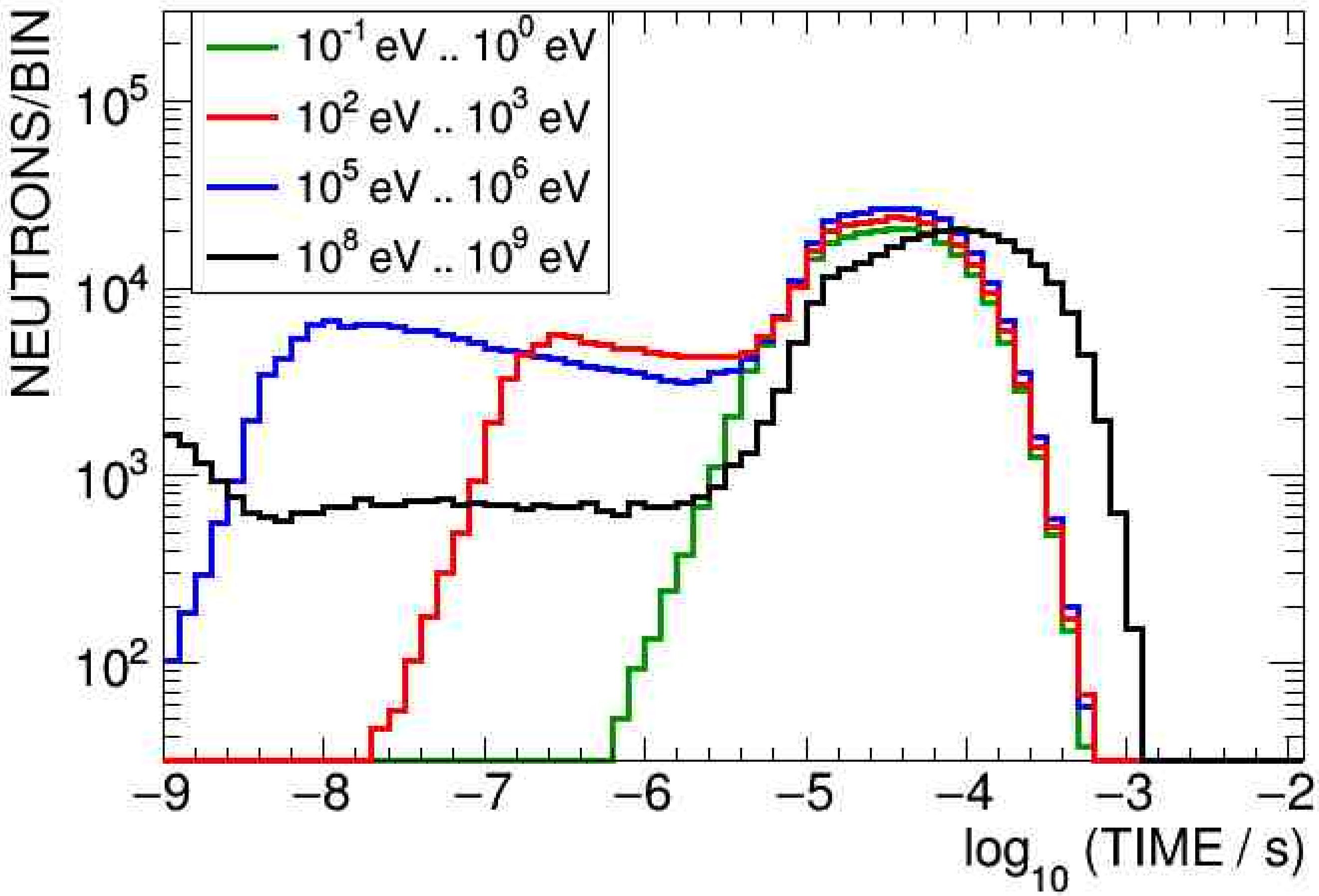

Energy distribution of target neutrons

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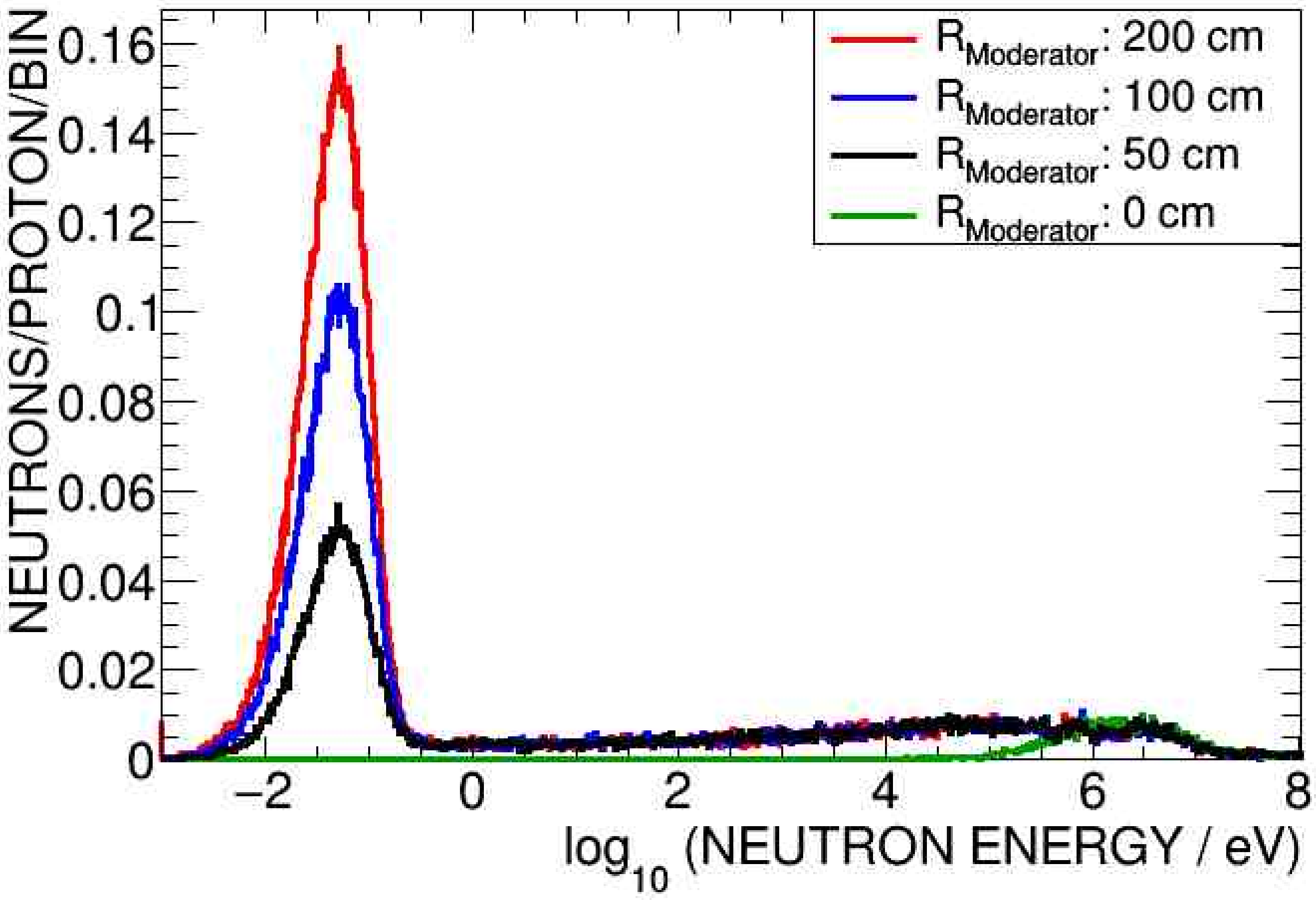

Neutron target density

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- **800 MeV, 100 µA, 10 cm W, 2 m D_2O:**

$8\ 10^9\ n/cm^2$

- **20 GeV, 0.5 µA ($3\ 10^{12}$ protons/s), 50 cm W, 2 m D_2O:**

$5\ 10^8\ n/cm^2$

New estimate

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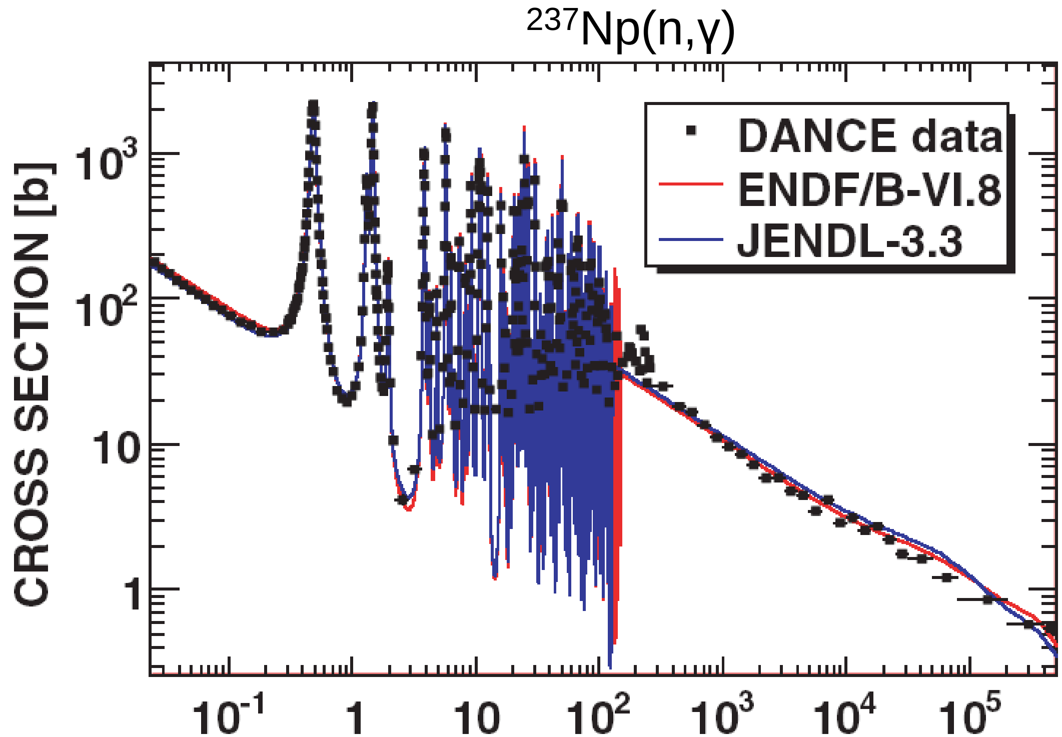
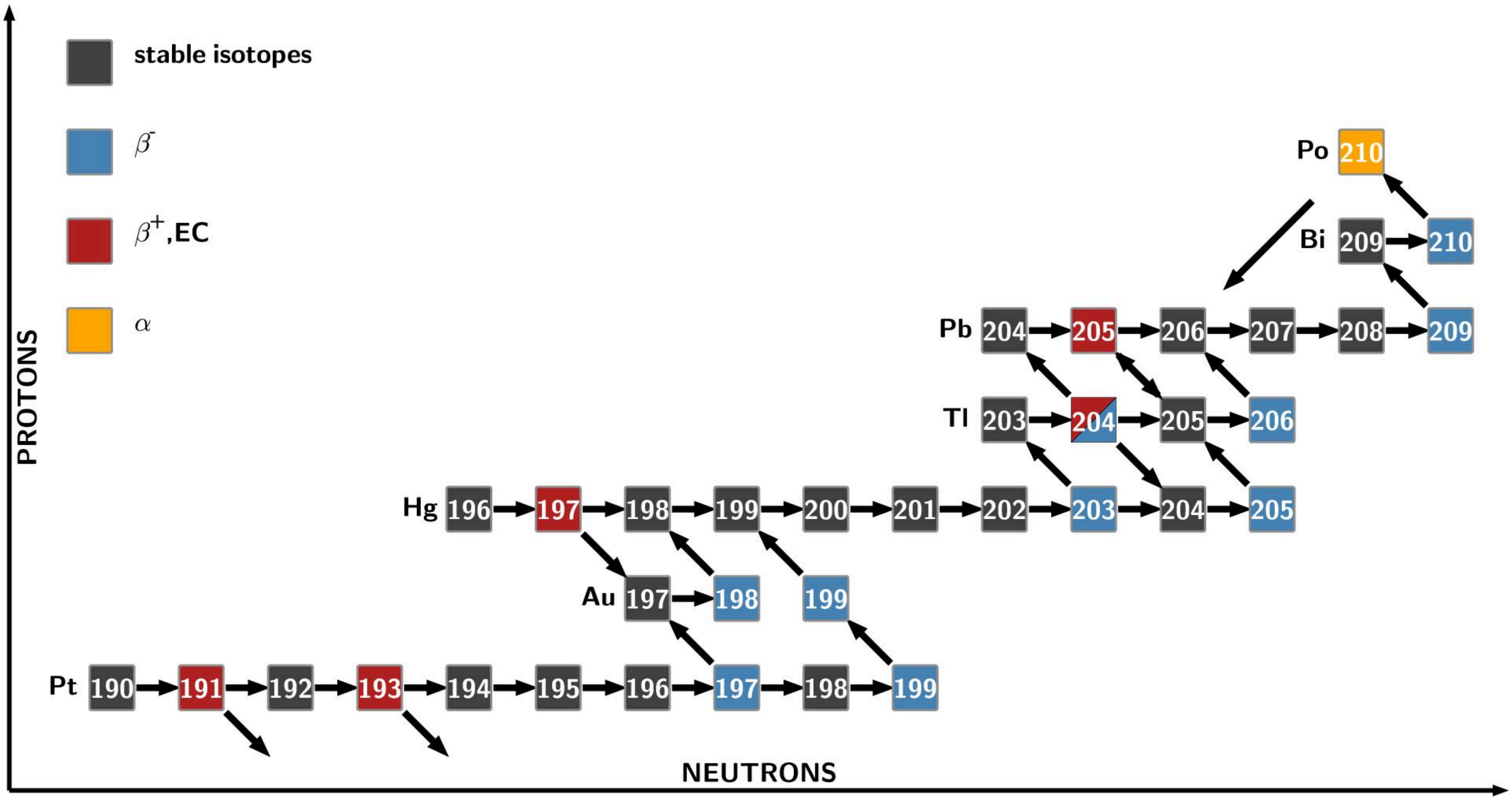
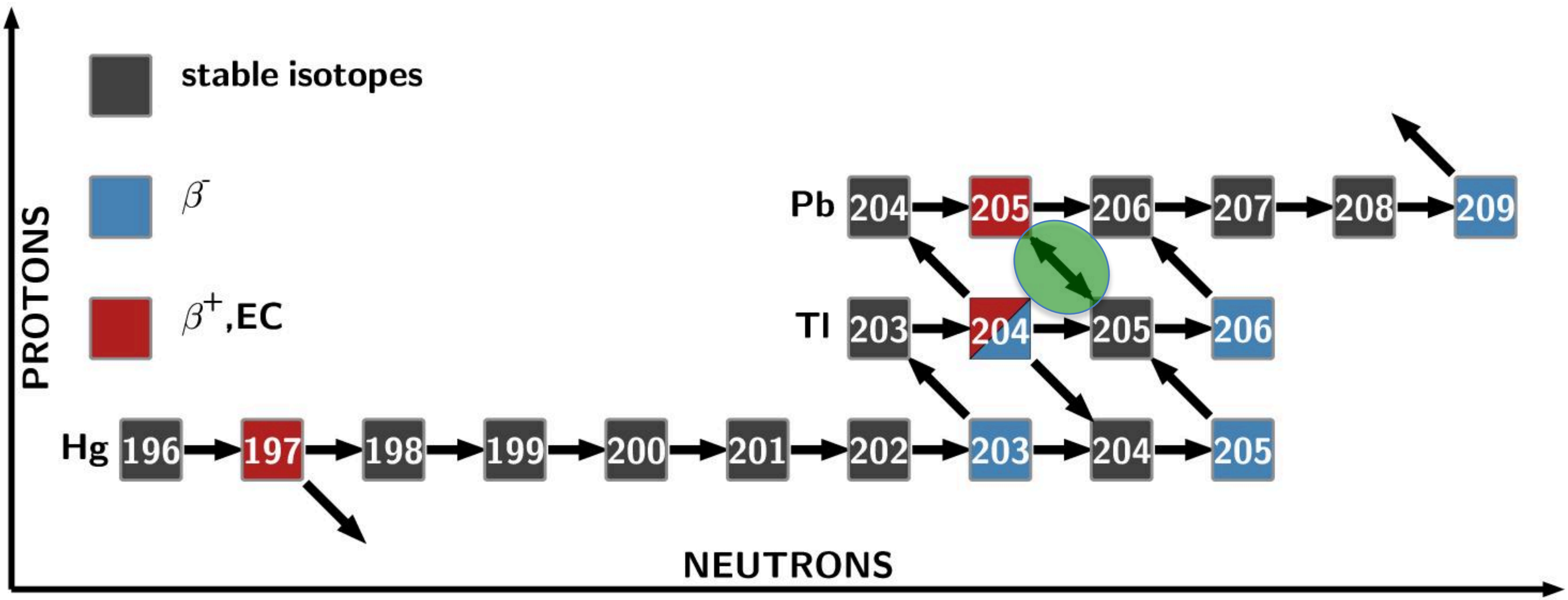
- Protons: 100 µA @ 1 GeV
- **D_2O moderator radius: 2 m**
- Neutron target: 10^{10} n/cm^2
- **Counts per day: 10 σ / mb**



The termination point of the s-process



EC and β⁻ - decay in ecquilibrium



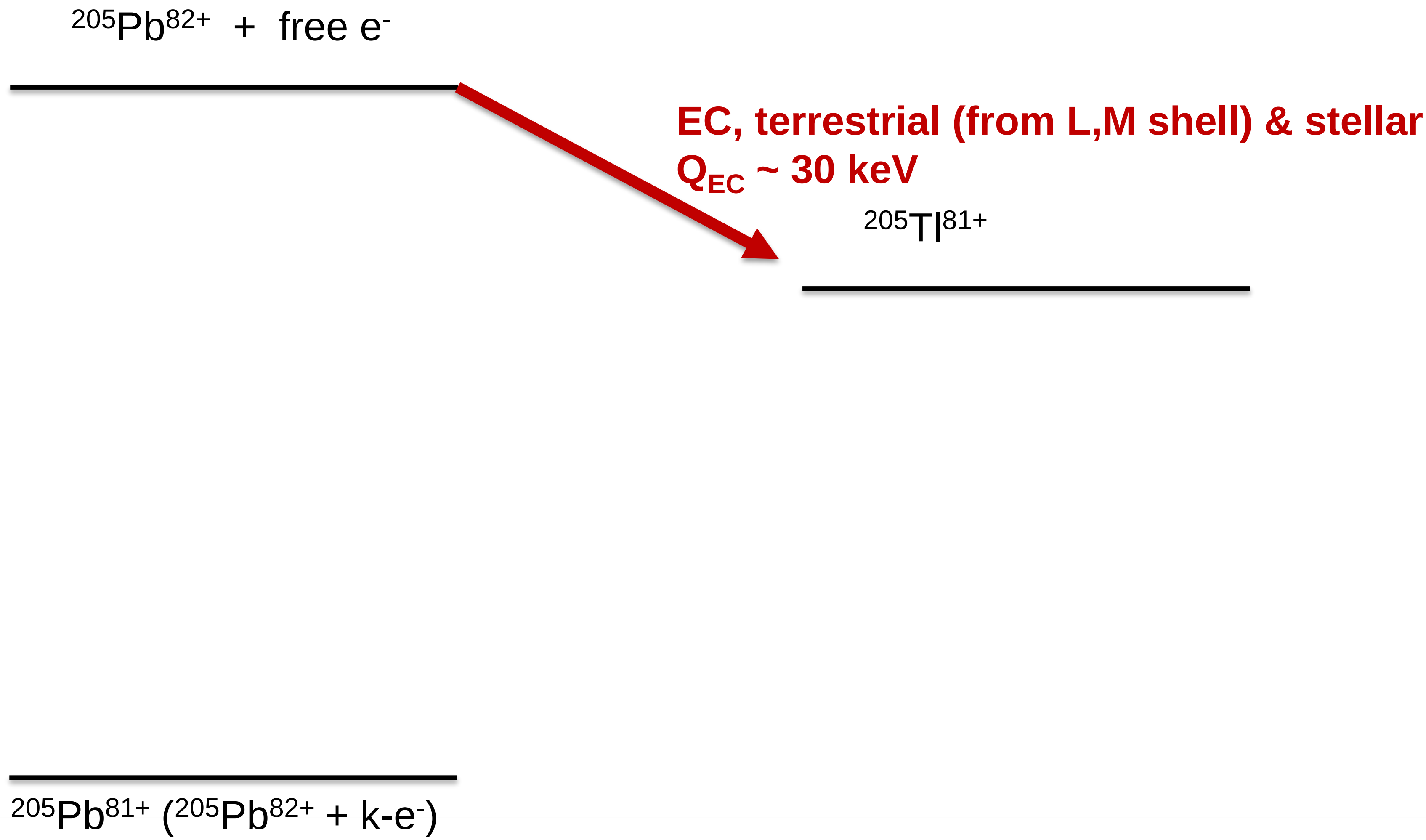
Nuclear and atomic physics at work

$^{205}Pb^{82+}$ + free e^{-}

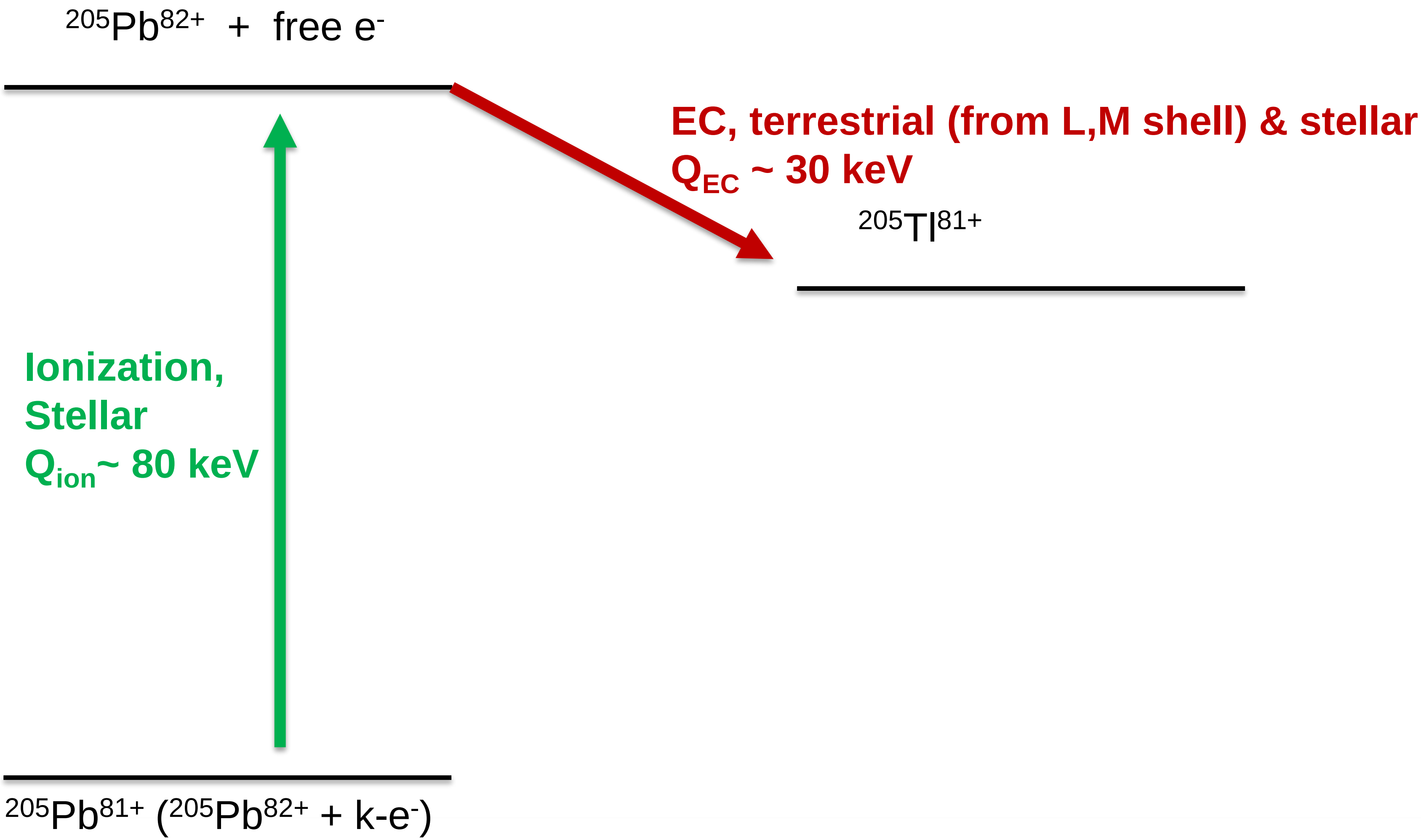
$^{205}Tl^{81+}$

$^{205}Pb^{81+}$ ($^{205}Pb^{82+}$ + k-e^{-})

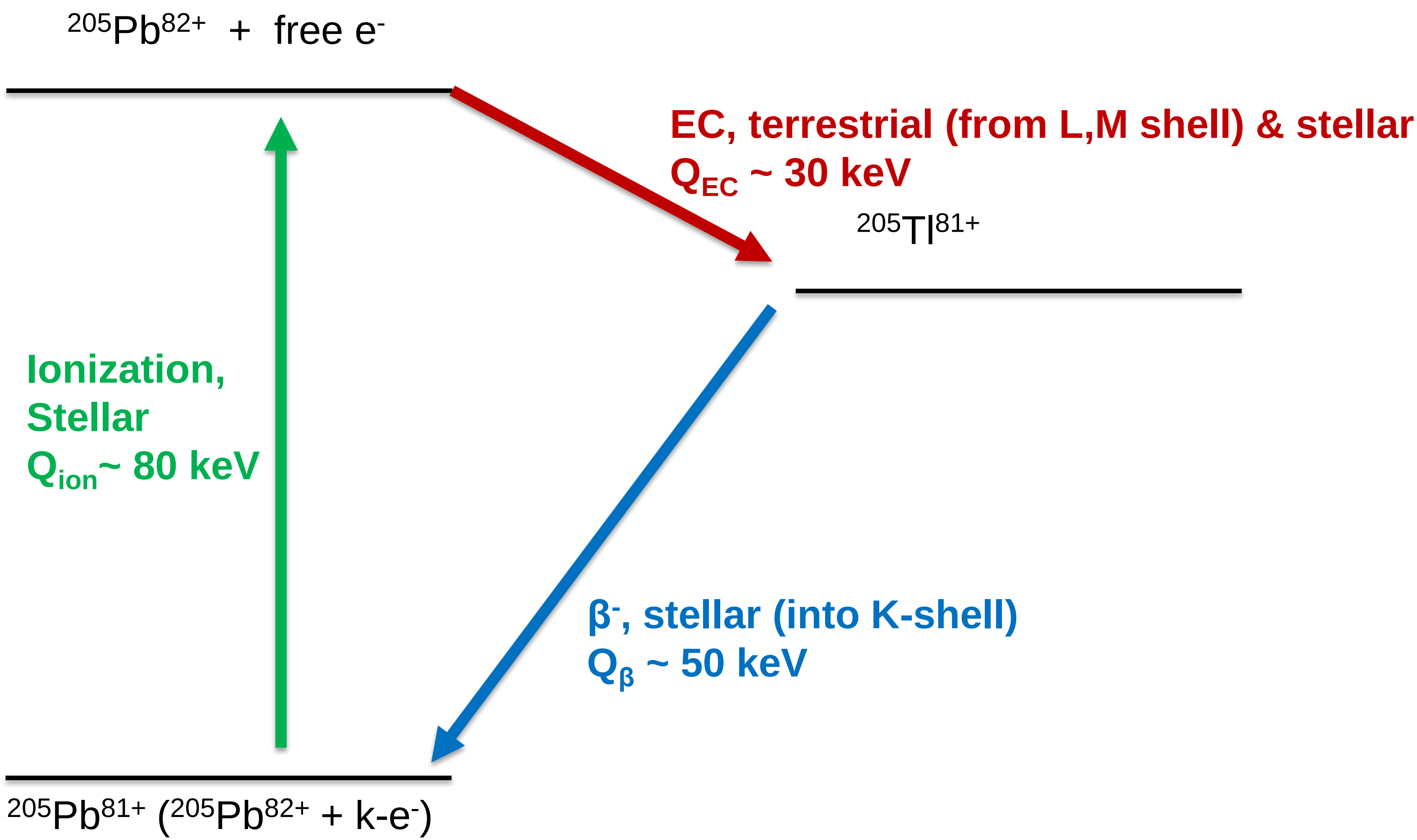
Nuclear and atomic physics at work



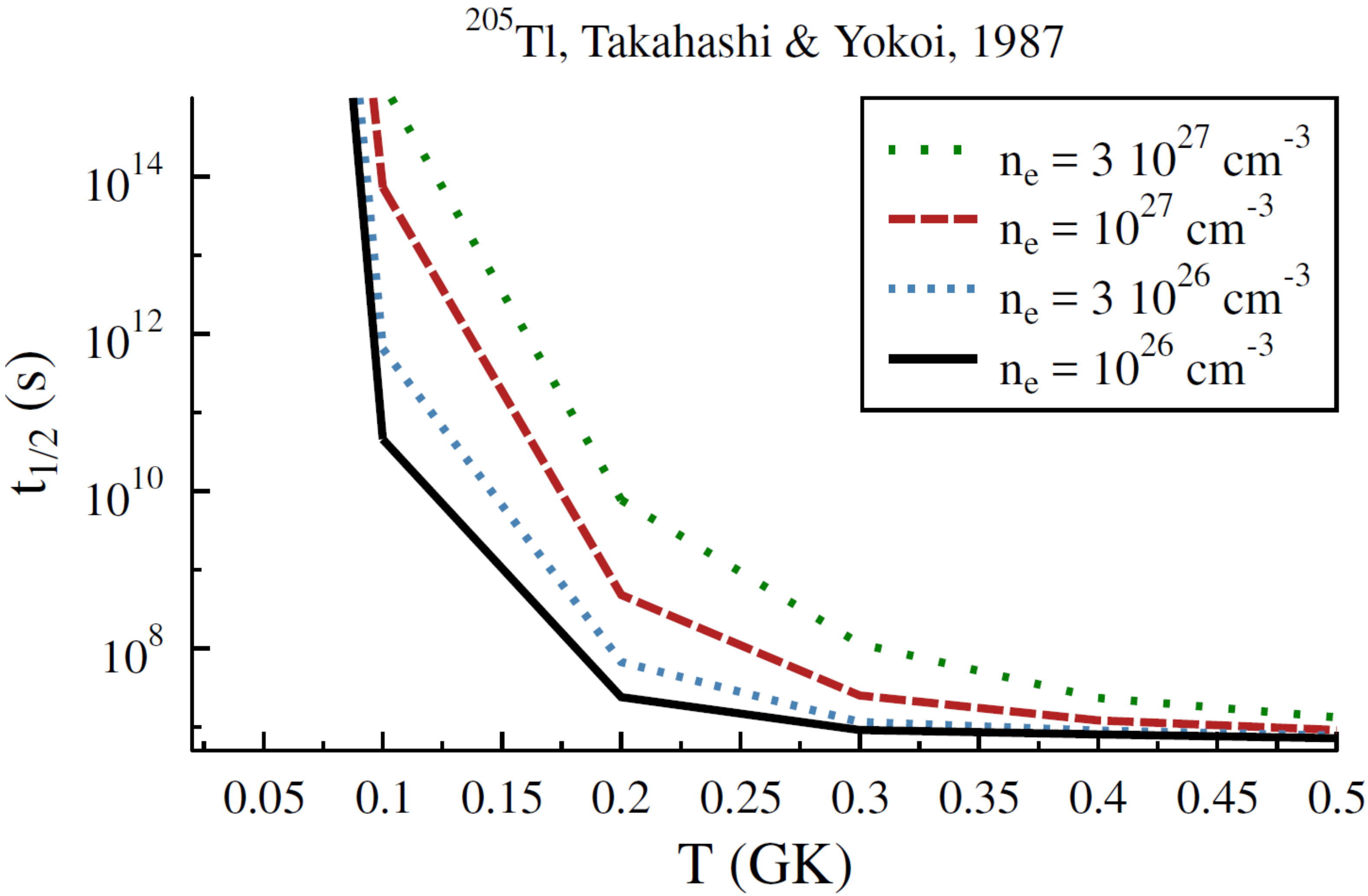
Nuclear and atomic physics at work



Nuclear and atomic physics at work



β^- - decay of ^{205}Tl



Equilibrium abundance of ^{205}Pb

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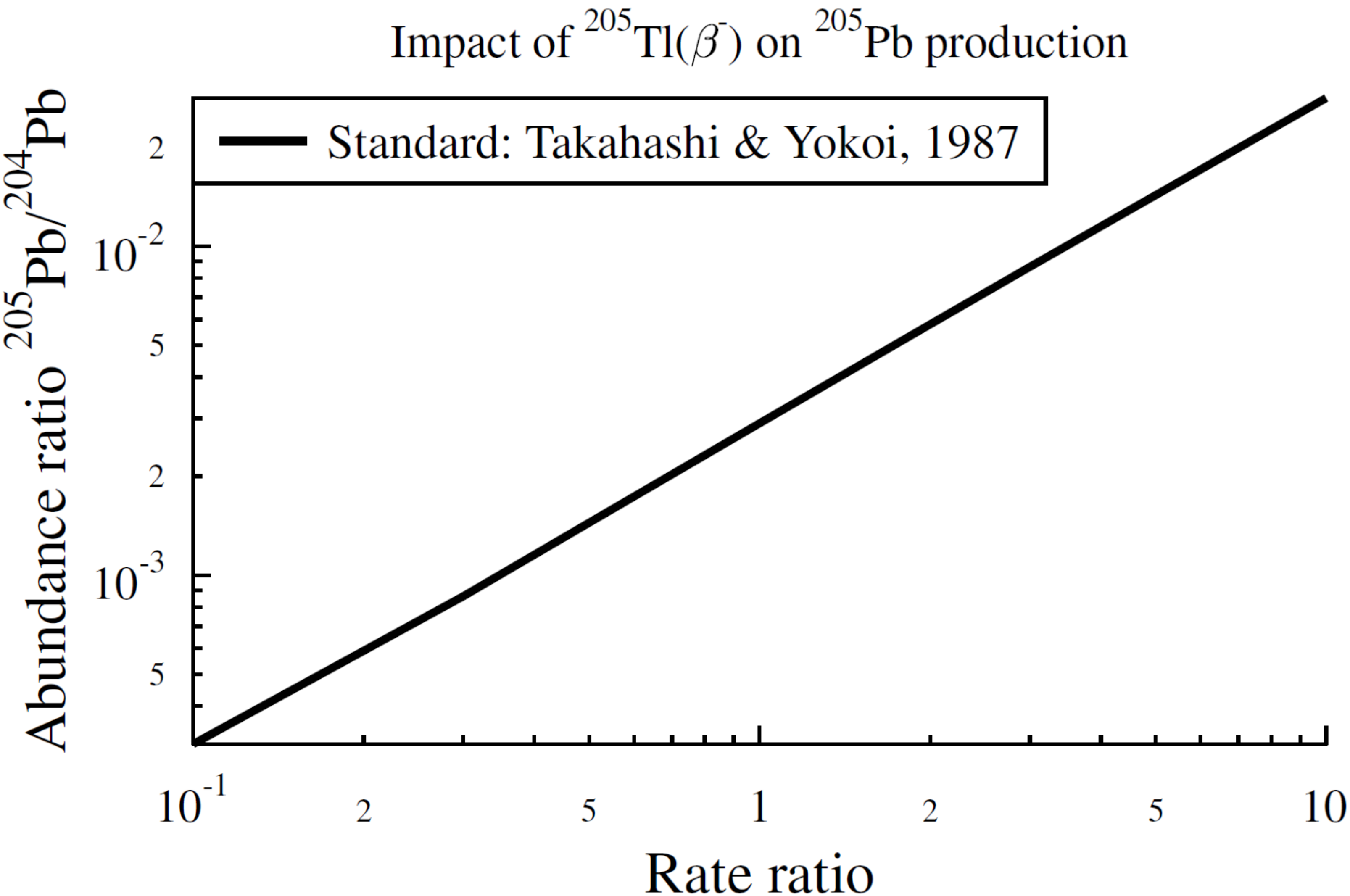
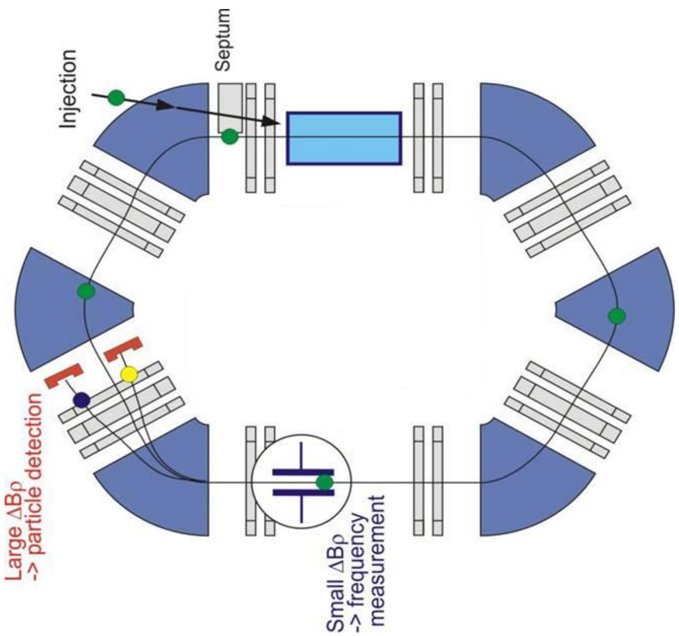


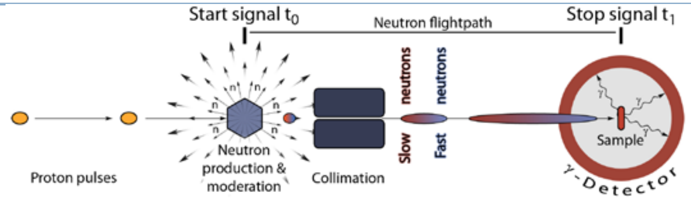
Measurement of the bound-state beta decay of bare ^{205}Tl ions

- **Proposed at the ESR@GSI/FAIR**
- **Original idea: Fritz Bosch, now Yuri Litvinov**
- **Challenge: Tl is a poison**
  - U-beam
  - Fragmentation
  - Fragment separation
  - Injection into ESR
- **Challenge: detection of decays**
  - Storage, decays: $^{205}Tl^{81+} \rightarrow {}^{205}Pb^{81+}$
  - Stripping with Ar-jet: $^{205}Pb^{81+} \rightarrow {}^{205}Pb^{82+}$
  - Detection via revolution frequency

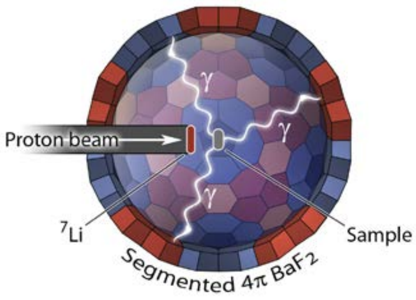


Summary

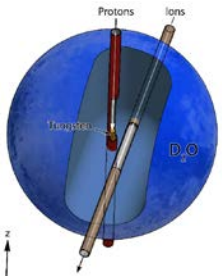
- **Neutron induced reaction studies are very difficult on unstable nuclei**



- **FRANZ & NAUTILUS will push the limit**



- **A combination of a neutron target and a ion storage ring might open a new era**



- **Stellar beta-decay rates are very important to investigate**