Measurement of the $^{62,63}Ni(n,\gamma)$ cross section at n_TOF/CERN

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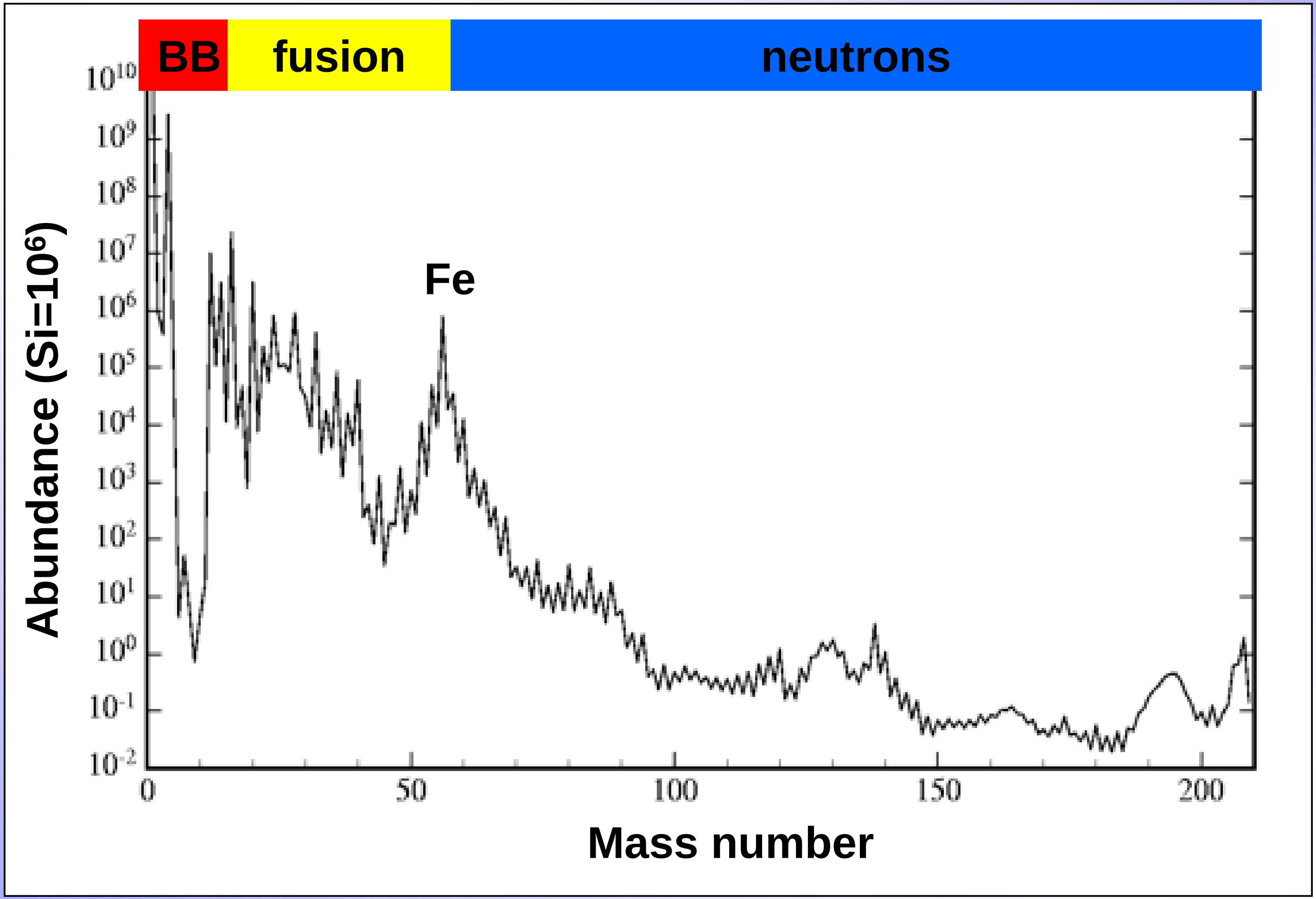
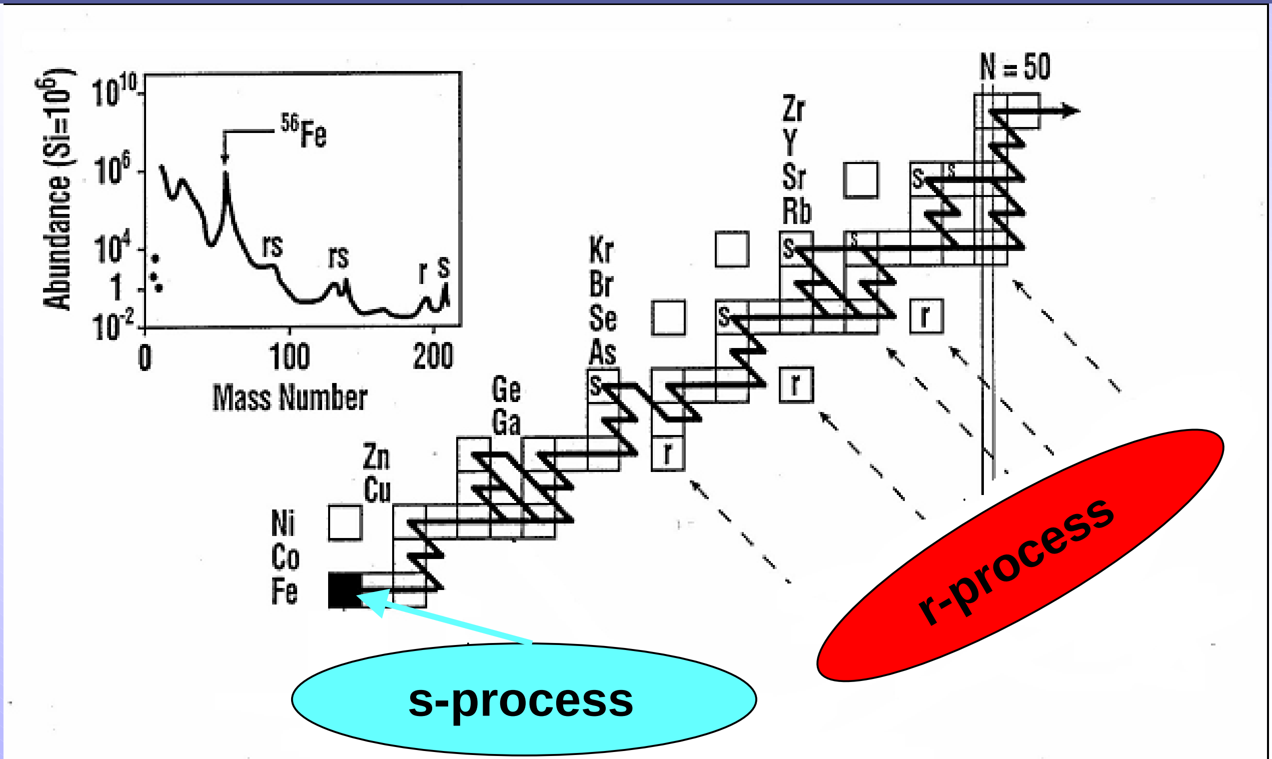
ERAWAST II, Zürich

Nucleosynthesis of heavy elements



Nucleosynthesis of heavy elements



rapid neutron capture

- explosive scenarios (supernovae)
- $\tau_{n,\gamma}$ (10^{-3}s) < $t_{1/2}$
- $N_n \sim 10^{21}$ cm^{-3}

slow neutron capture

- AGB stars, massive stars
- $\tau_{n,\gamma}$ (~100 yr) > $t_{1/2}$
- $N_n \sim 10^{8}$ cm^{-3}

s-process: Local approximation

- repeated neutron bursts
- temperature and neutron density constant

s-process abundance x cross section = $\mathbf{N_s<\sigma>}$ = constant

Maxwellian averaged cross section (MACS):

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

s-process: Local approximation

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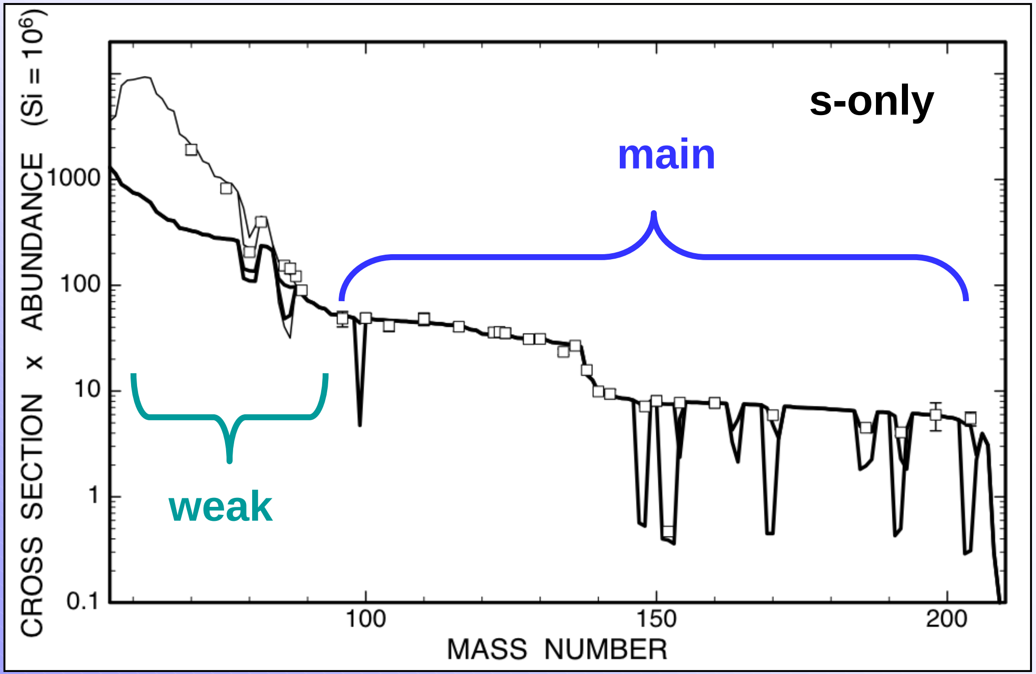


A<90 weak s-process

A>90 main s-process

F. Käppeler, Prog. Part. Nucl. Phys. 43 (1999)

s-process: stellar sites

weak component: Massive stars (>8$M_\odot$)		**main component:** AGB stars (1-3$M_\odot$)	
He core burning ^{22}Ne(α,n)	C shell burning ^{22}Ne(α,n)	H shell burning ^{13}C(α,n)	He flash ^{22}Ne(α,n)
kT~25 keV	**kT~90 keV**	**kT~8 keV**	**kT~25 keV**
T~3-3.5x10^8 K N_n= 10^6 cm^{-3}	T~10^9 K N_n=10^{11}- 10^{12} cm^{-3}	T~0.9x10^8 K N_n= 10^7-10^8 cm^{-3}	T~3-3.5x10^8 K N_n= 10^{10}-10^{11} cm^{-3}
Nσ not const → Propagation effects !!			

How to measure MACS?

- **activation technique**

create quasi Maxwellian spectrum in laboratory

measure spectrum averaged CS:

$$<\sigma>_{EXP} = \frac{N_P}{N_T}\frac{1}{\Phi}$$

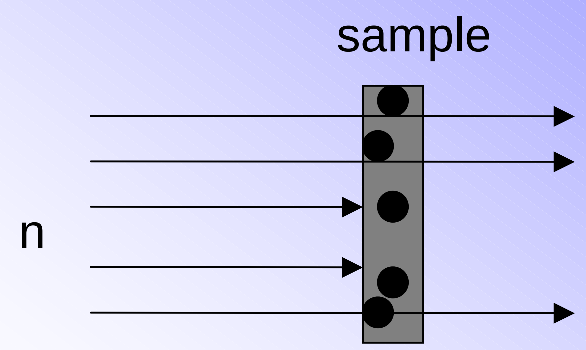
needs radioactive reaction product

include direct component

need to know: CS dependence and neutron spectrum

- **time of flight technique**

1)



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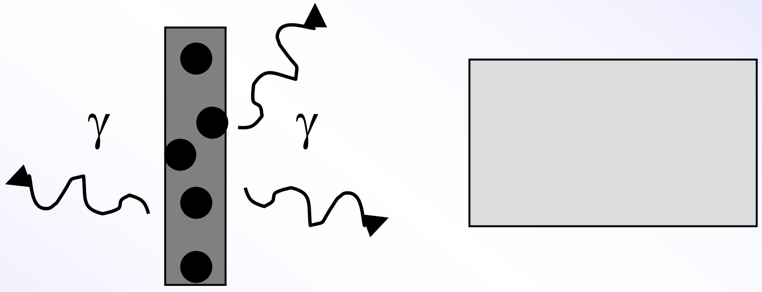
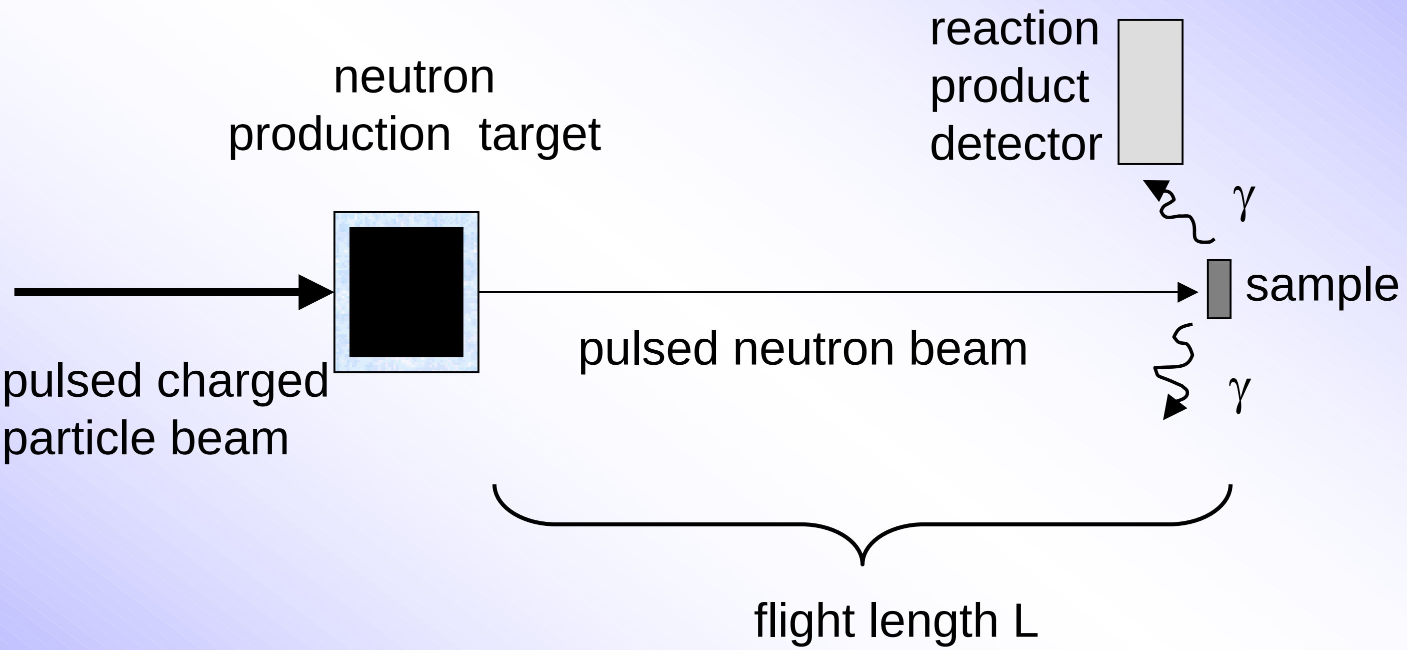


The time-of-flight technique

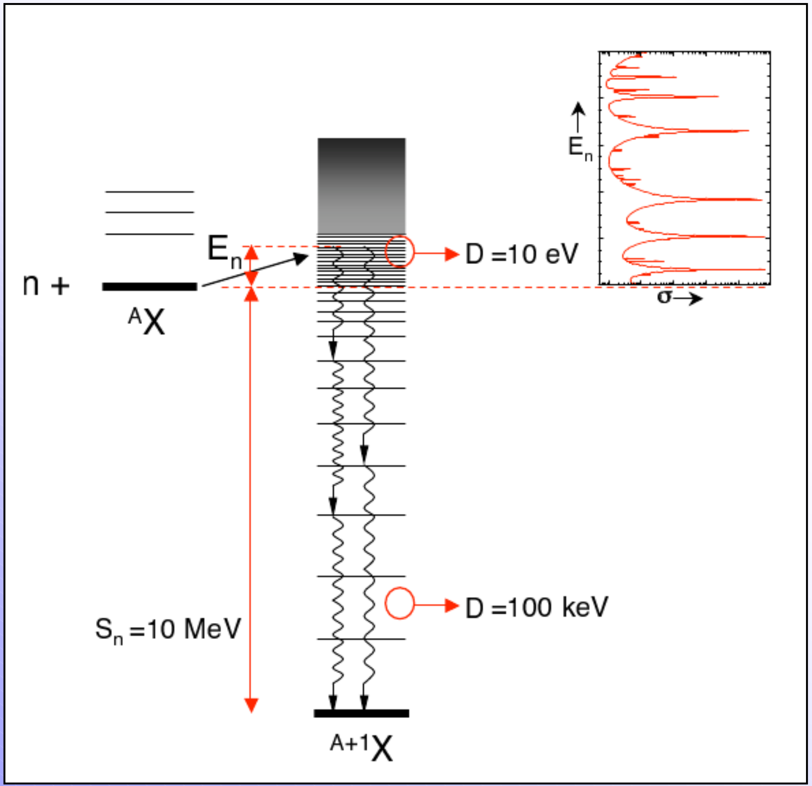


$$tof = t_{reaction} - t_{production} \longrightarrow v = L / tof$$

$$E_n = mc^2(\gamma - 1) \quad \text{with} \quad \gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

The time-of-flight technique

- Extract cross-section by determining **reaction-yield Y_R (E_n)**:



$$Y_R = \frac{C - B}{\varepsilon \cdot f \cdot \phi}$$

C....count rate

B....background

ε.....efficiency

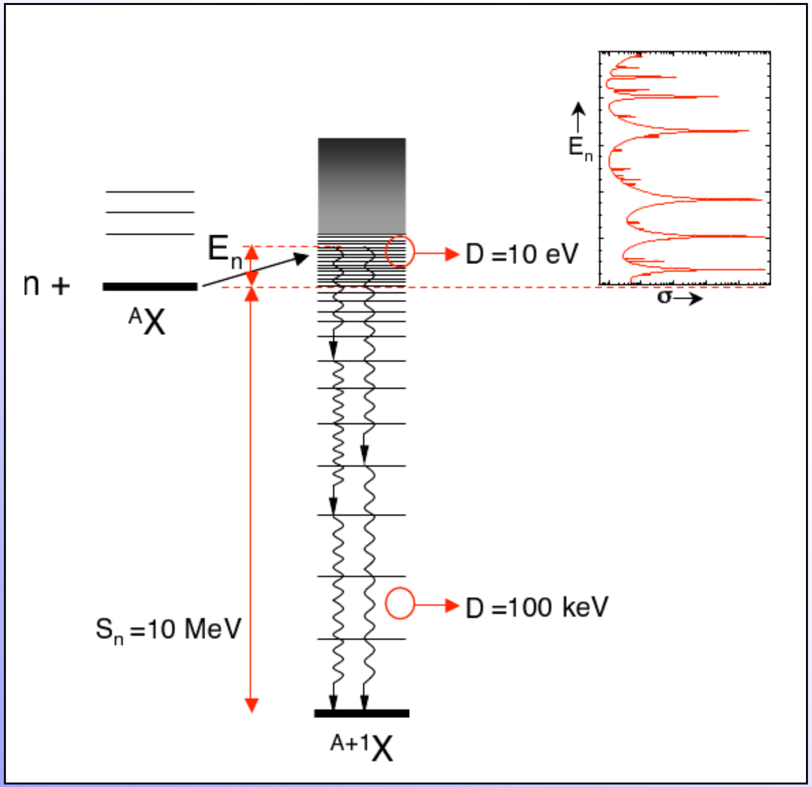
f.....corrections for sample size

ϕ....neutron flux

Courtesy F. Gunsing

The time-of-flight technique

- Excitation Energy: $E_c = \Sigma E_\gamma = E_n + S_n$



Courtesy F. Gunsing

- **detection of full γ cascade**

ε_c~ 100 %

4π detector array

- **detection of single γ's**

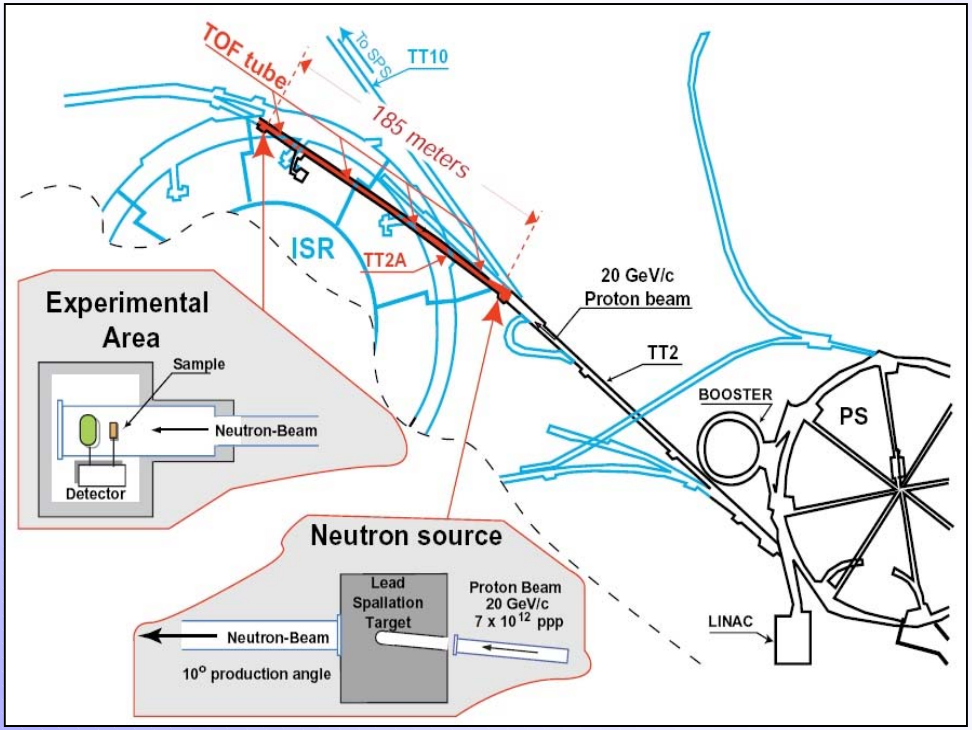
e.g. apply pulse height weighting technique:

pulse height dependent weight on signals to achieve

$\varepsilon_\gamma = k * E_\gamma$

so that: $\varepsilon_c = k * (E_n + S_n)$

The n_TOF/CERN facility



spallation neutron source

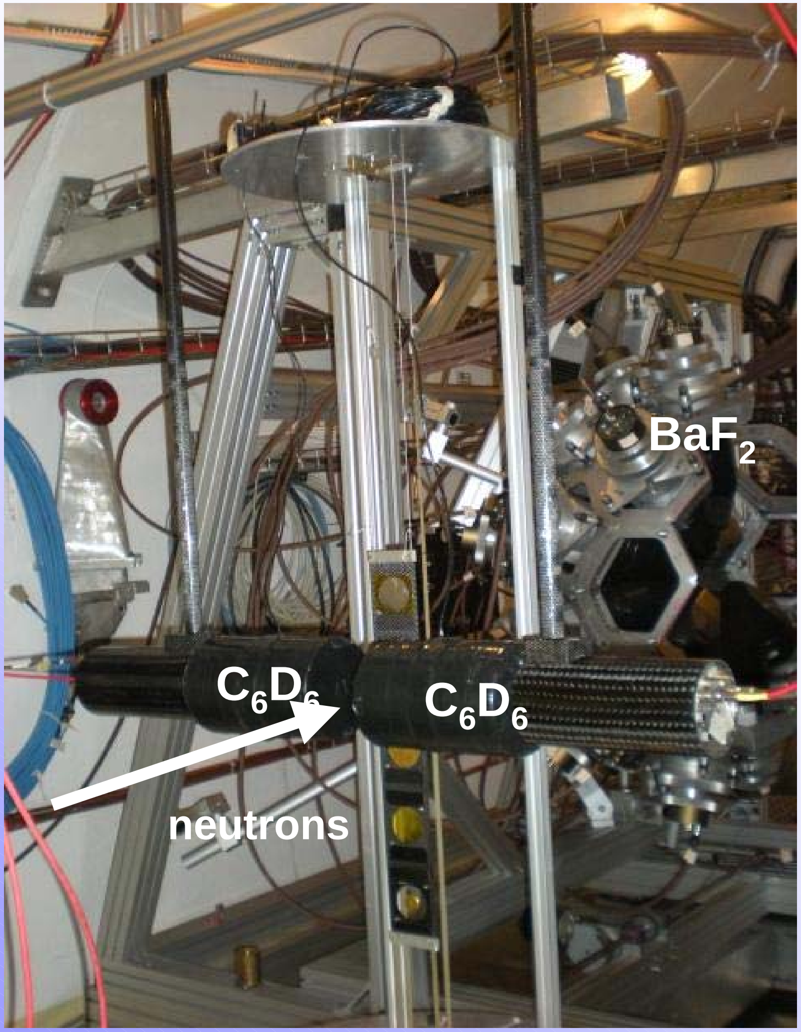
- 20 GeV/c protons on Pb-target
- water as moderator and coolant
- pulse width: 7 ns
- intensity: $7 \cdot 10^{12}$ protons per pulse

→ 1.2×10^{6} neutrons/pulse @ 185 m

- flight path: 185 m
- neutron energy: 10^{-3}-10^{10} eV
- beam size at capture setup: Ø~4 cm
- energy resolution $\Delta E/E$: 3×10^{-4} @ 1 eV – 4.2×10^{-3} @ 1 MeV

www.cern.ch/ntof

The n_TOF/CERN facility



2 setups for capture measurements:

• BaF_2 total absorption calorimeter
40 crystals in 4π geometry

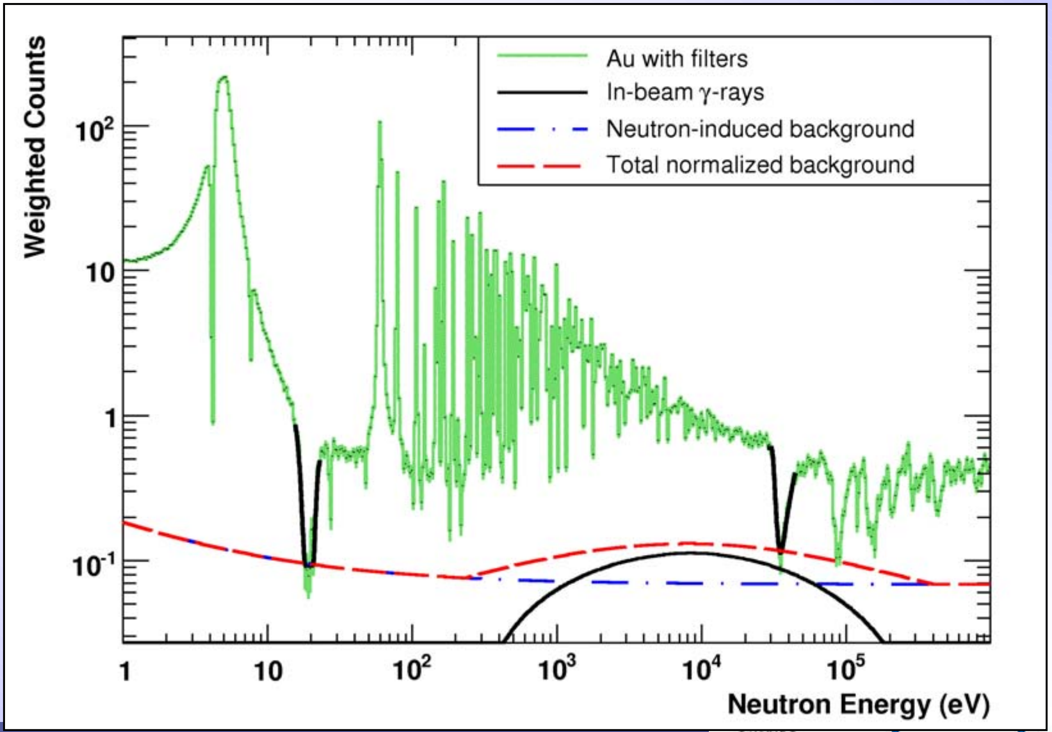
• **two C_6D_6 detectors**
optimized for low neutron sensitivity ($\varepsilon_n/\varepsilon_\gamma<4\cdot10^{-5}$)
detection of at most one γ ray per cascade
→ PHWT

Backgrounds at n_TOF

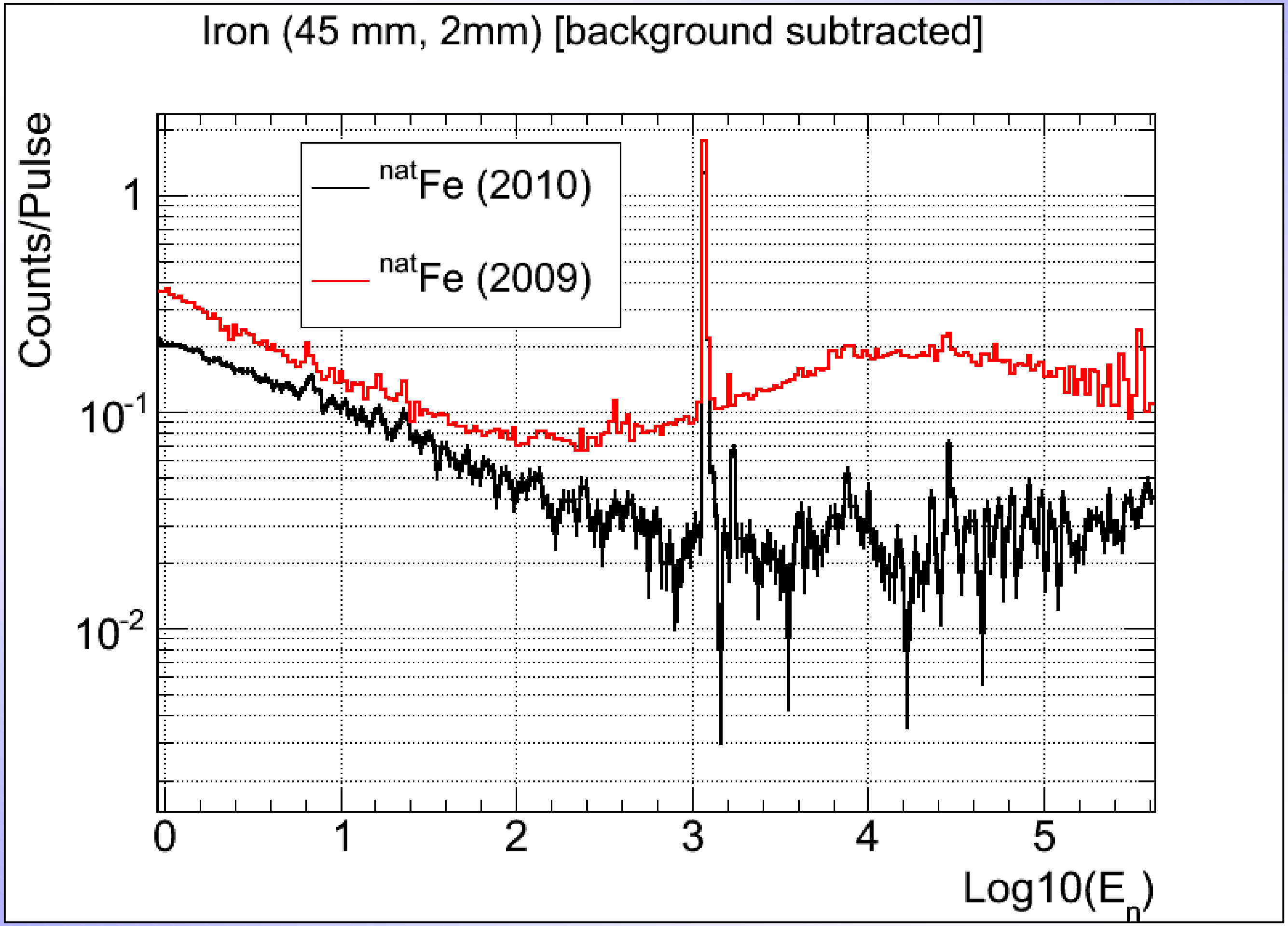
- sample independent background → measurement of empty holder
- neutron induced background → measurement of dummy sample (e.g. Carbon)
- γ-induced background (200 eV – 300 keV) → measurement of dummy sample (e.g. Pb)
- measurement with neutron filters

Borated water as moderator: significant reduction of γ background!!!

Au(n,γ)



Borated water: 2009 vs. 2010



universität wien

^{62}Ni(n,γ): Motivation

Observation of old halo star CS22892-052:

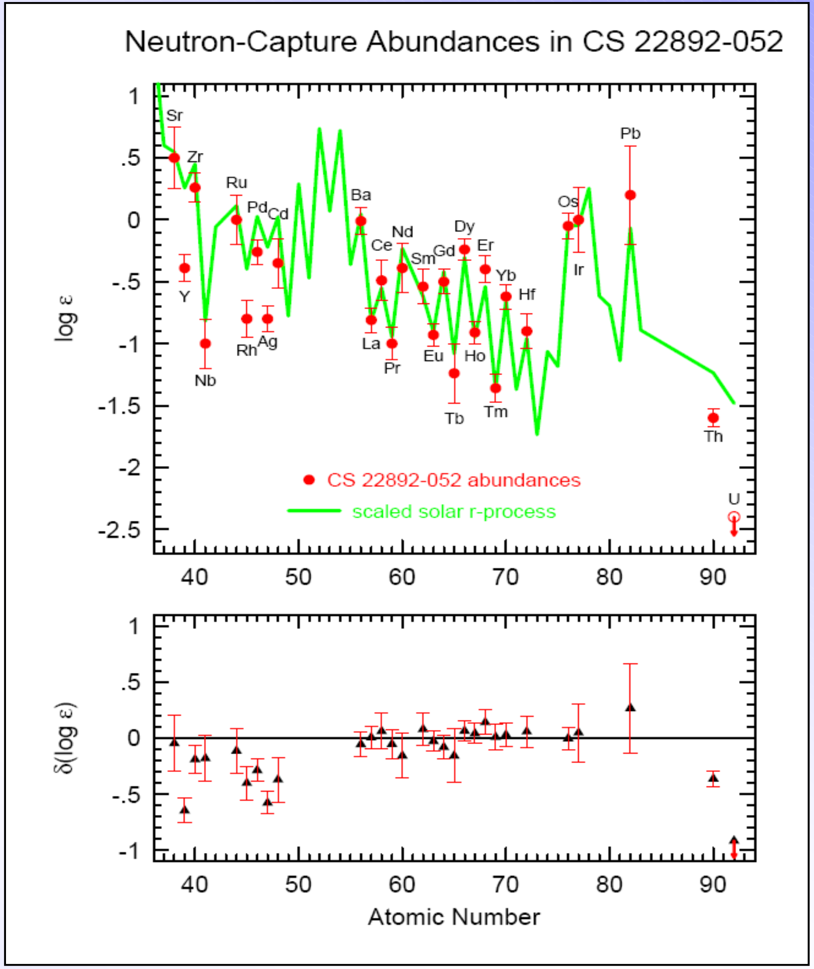
- A>120: scales with solar **r-process component**
- A<120: abundances systematically lower

(Sneden et al.)

solar r-component:

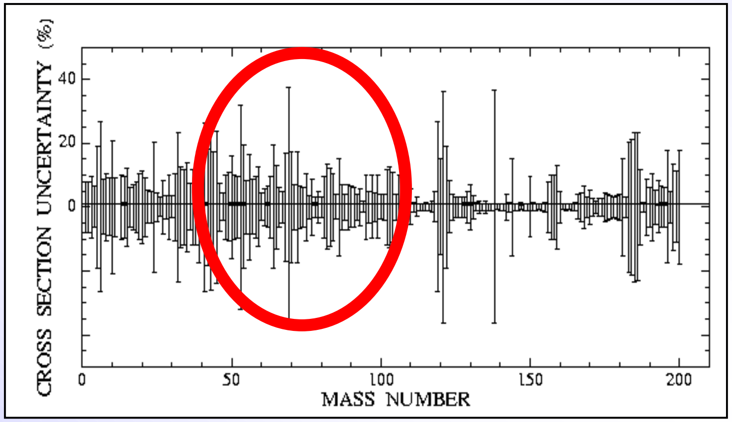
$$N_r = N_{\odot} - N_s$$

$\propto 1/\langle\sigma\rangle_{n,\gamma}$



Sneden at al. APJ533 (2000)

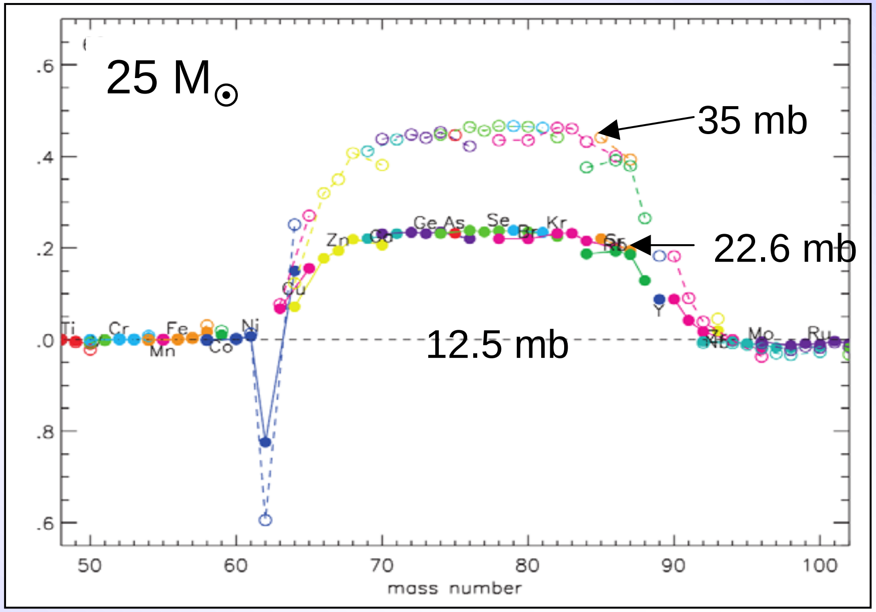
^{62}Ni(n,γ): Motivation



Bao et al. (2000)

High uncertainties of (n,γ) cross-sections in medium mass region directly enter into r-process calculations.

^{62}Ni(n,γ) MACS at 30 keV

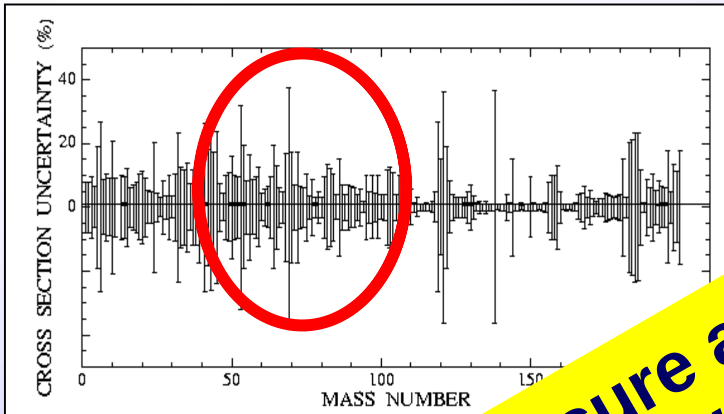


Nassar et al. (2005)

Neutron capture cross-section of ^{62}Ni influences abundance of following isotopes up to A=90 !

universität wien

^{62}Ni(n,γ): Motivation



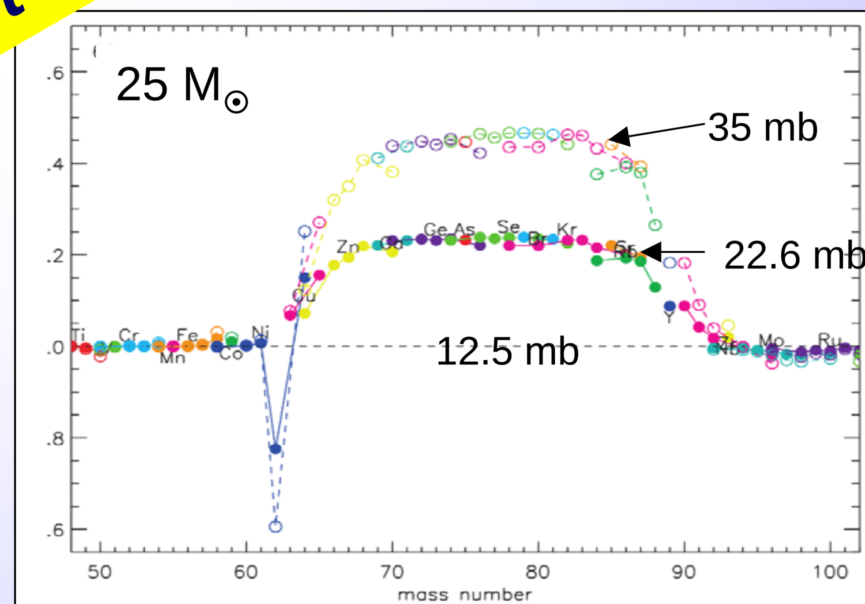
Bao et al. (2000)

High uncertain...
cross-sect...
mass ... nter
i... culations.

Campaign to measure all stable Fe and Ni isotopes!
(J.L. Tain, M. Heil et al, INTC/P-208, 2006)

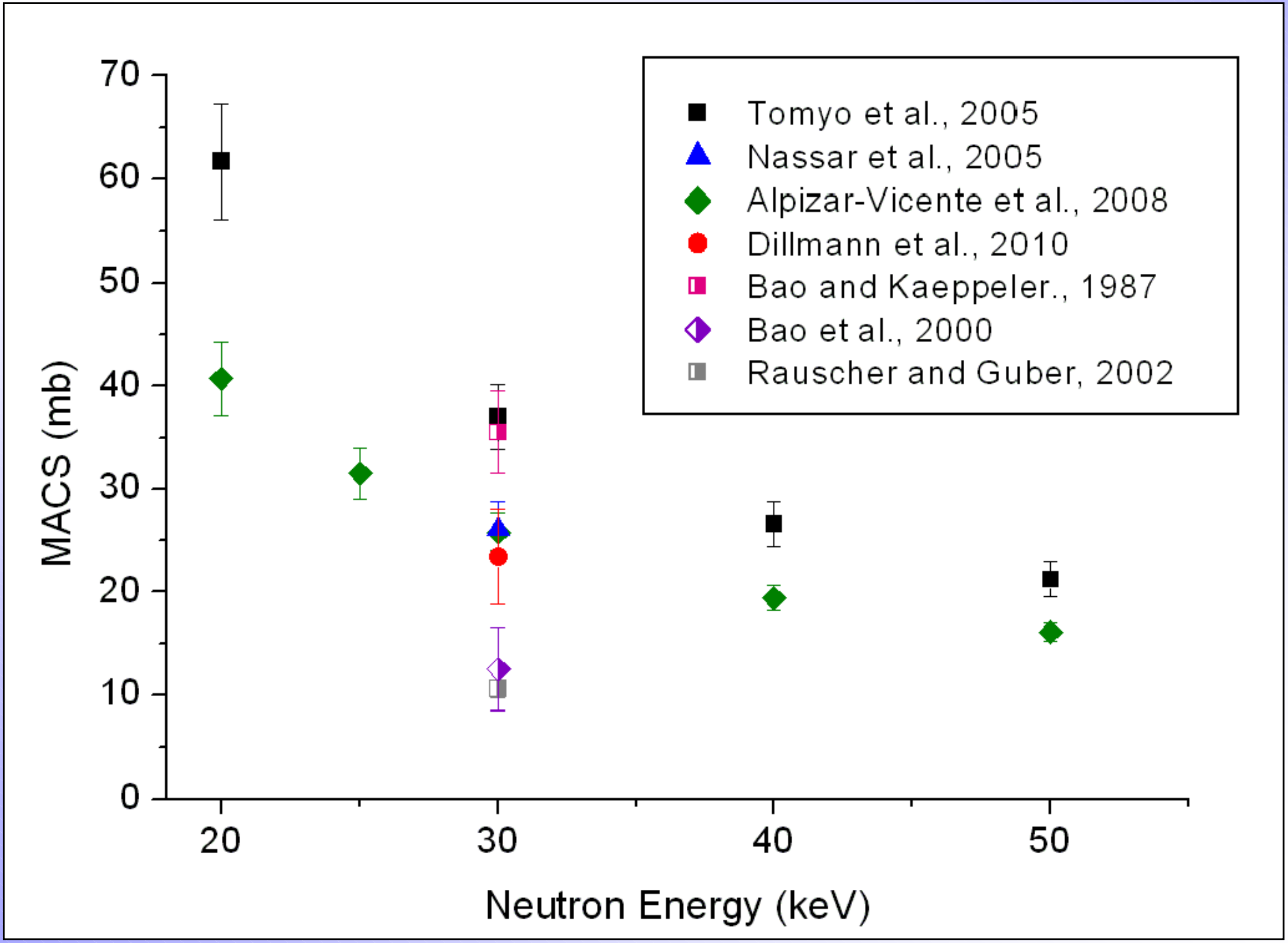
...apture
...section of ^{62}Ni
...nfluences abundance
of following isotopes
up to A=90 !

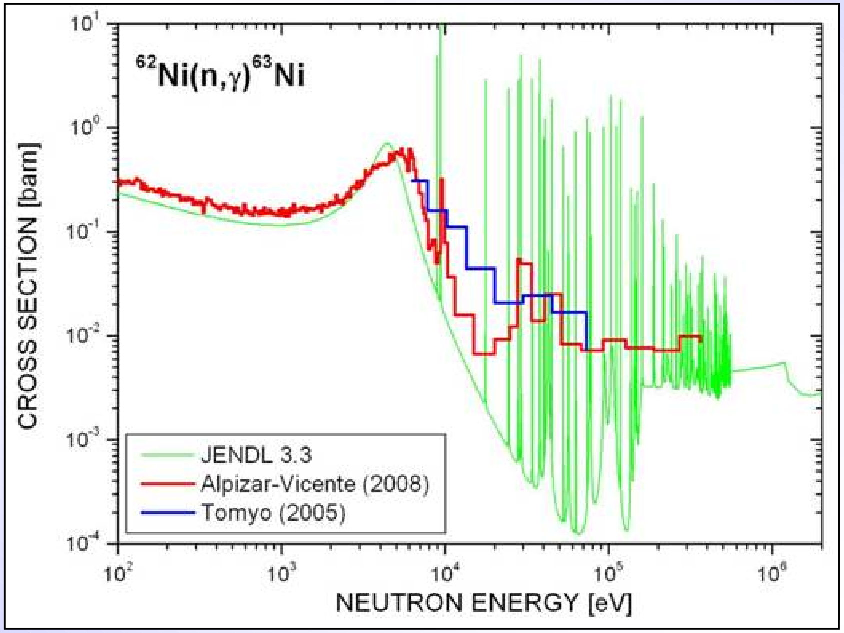
^{62}Ni(n,γ) MACS at 30 keV



Nassar et al. (2005)

$^{62}Ni(n,\gamma)$: available data

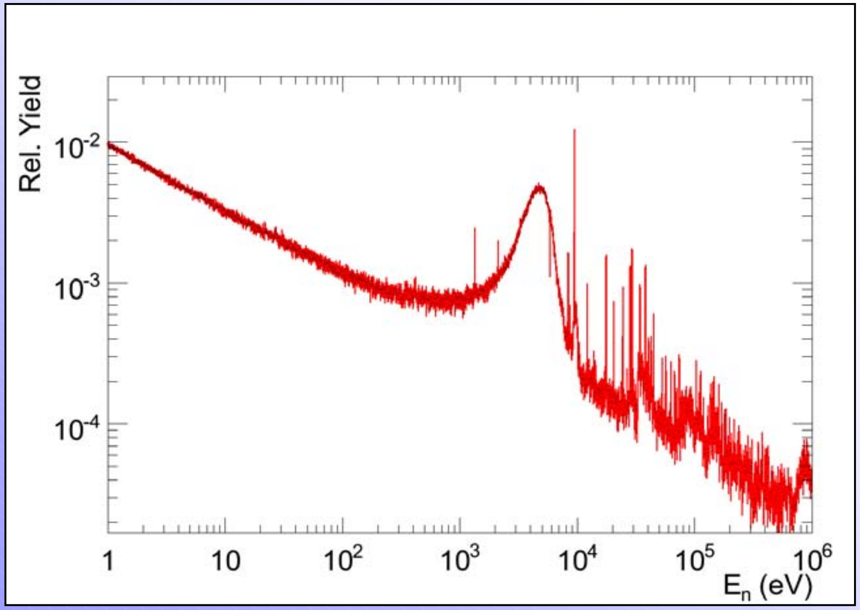


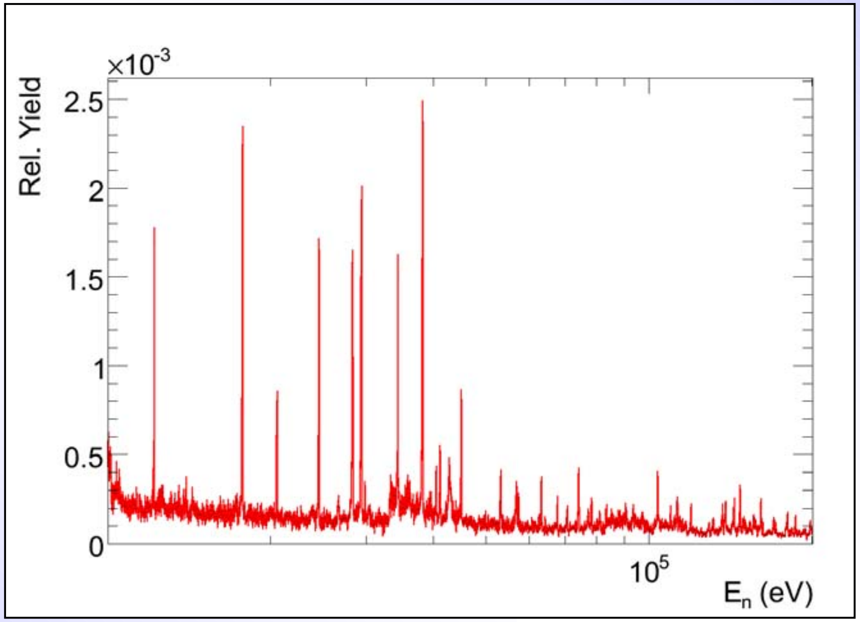


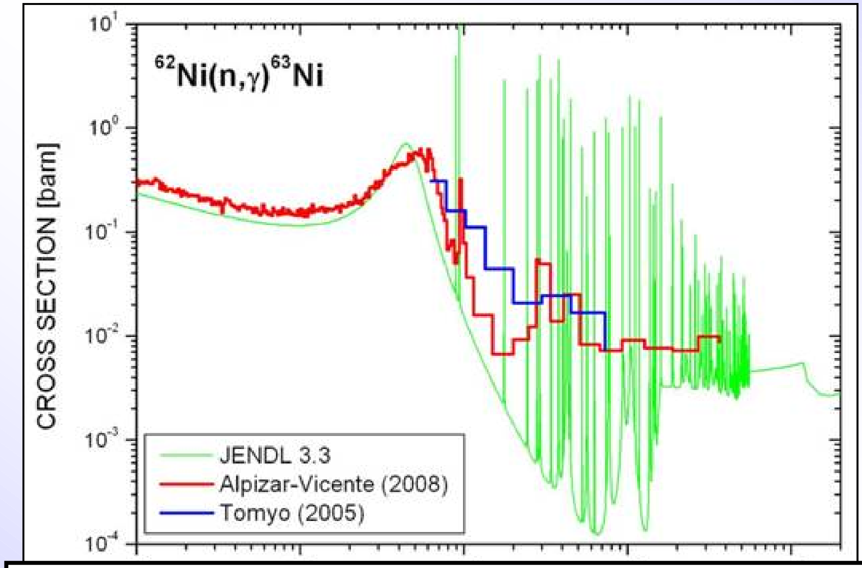
previous measurements compared to JENDL evaluation

(Courtesy I. Dillmann)

new data from n_TOF







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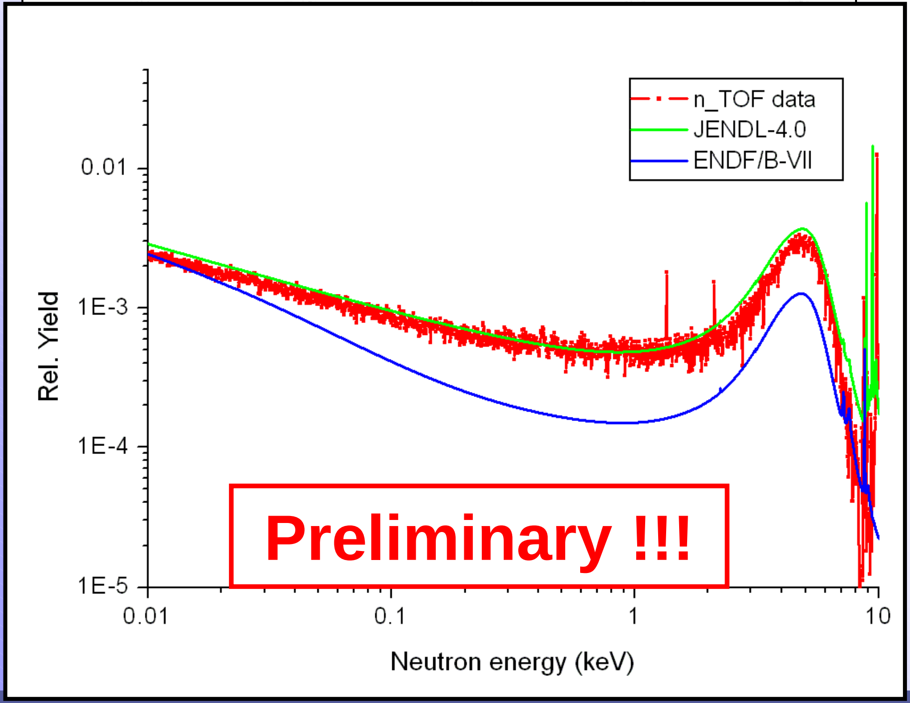
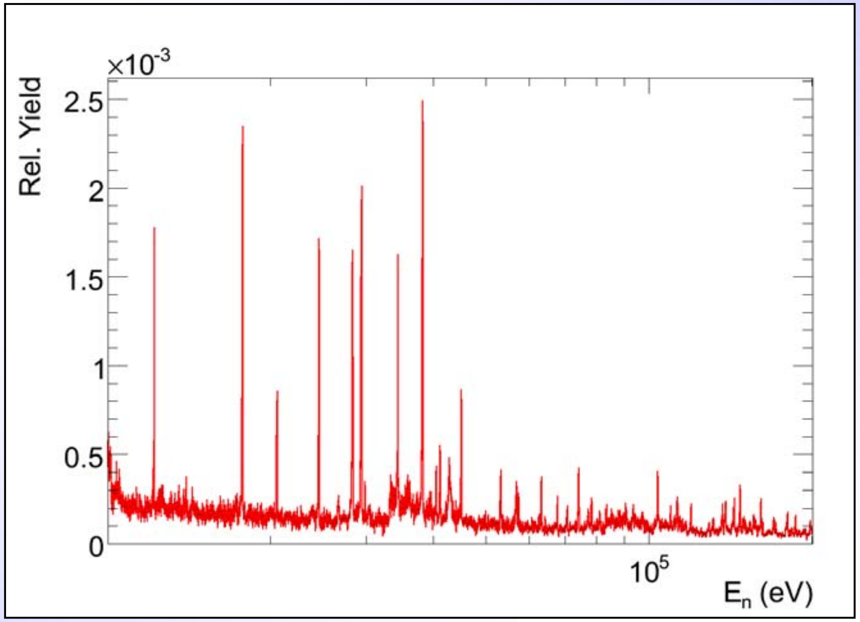
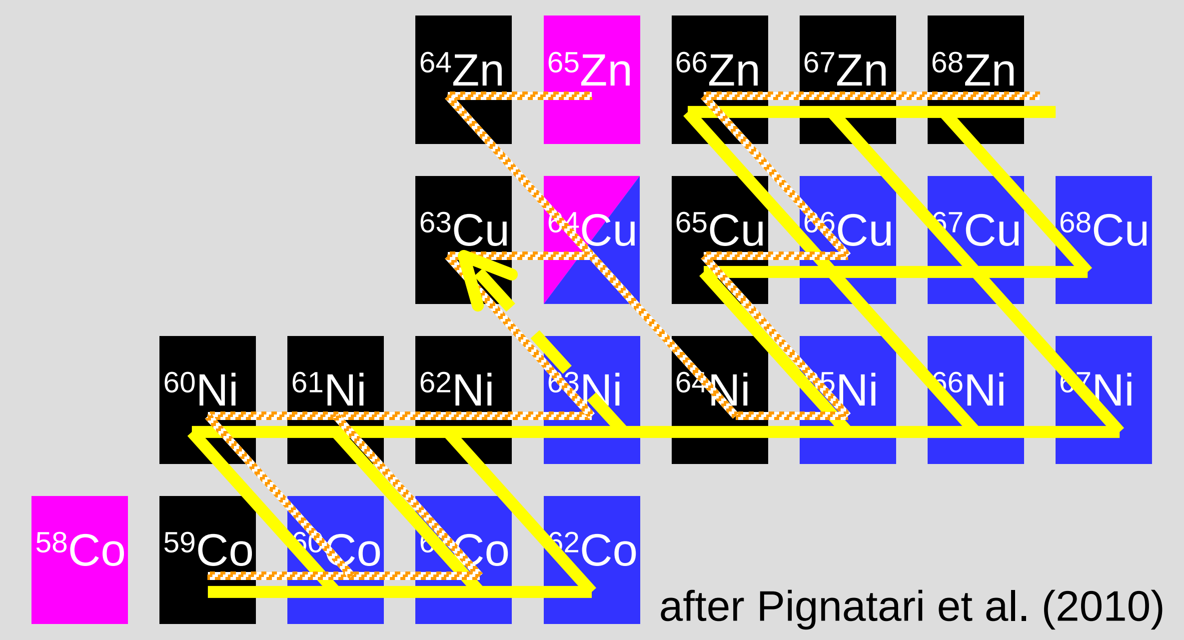




^{63}Ni(n,γ): Motivation

- $t_{1/2}$(terr)=100.1 y, **$t_{1/2}$(90 keV)= 0.4 y**

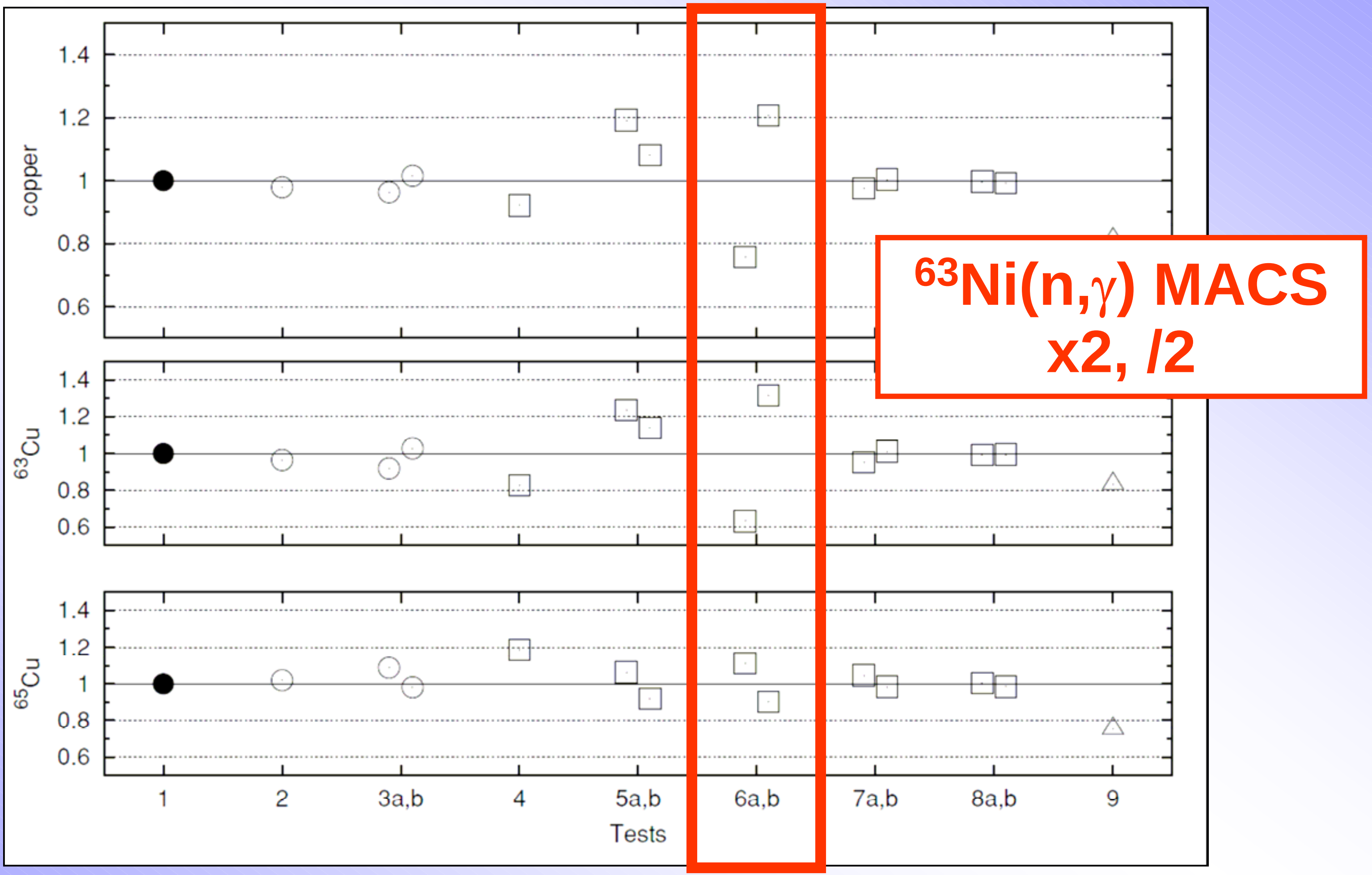


after Pignatari et al. (2010)

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

C shell burning, kT=90 keV, $N_n \sim 10^{11}$ cm^{-3}

^{63}Ni(n,γ): Motivation



Pignatari et al., ApJ 710 (2010)

^{63}Ni(n,γ) at n_TOF

- $t_{1/2}$=100.1 yr
- no cross section data above thermal energies
- MACS at stellar energies relies on extrapolations or calculations
- MACS at 30 keV:

KADoNiS: 31± 6 mb
TENDL(2009): 68.9 mb

- **Measurement of ^{63}Ni(n,γ) at n_TOF (C. Lederer, C. Massimi, et al., INTC/P-283, 2010)**

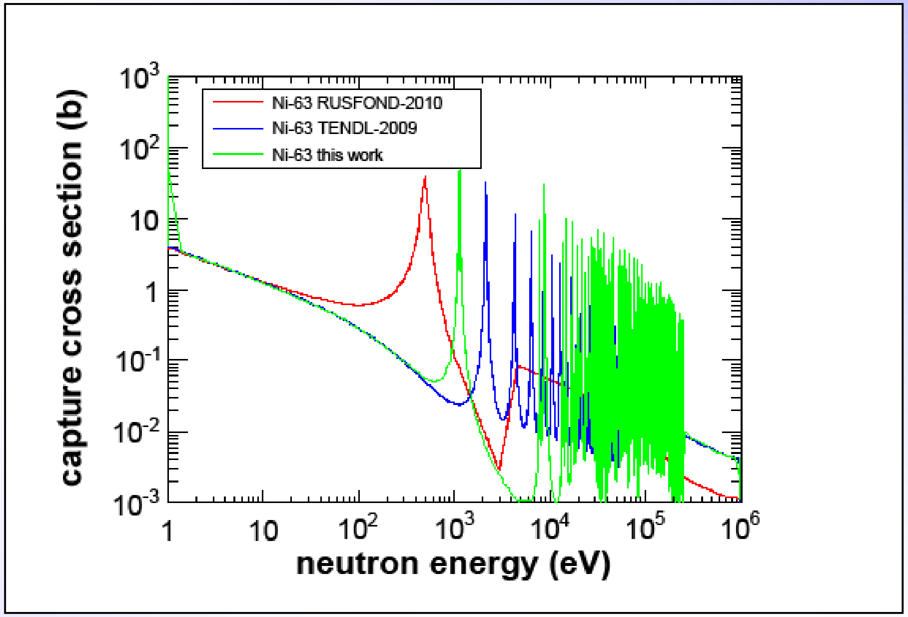
^{63}Ni(n,γ) at n_TOF

- $t_{1/2}$=100.1 yr
- no cross section data above thermal energies
- MACS at stellar energies relies on extrapolations or calculations

- MACS at 30 keV:

  KADoNiS: 31± 6 mb
  TENDL(2009): 68.9 mb
  this work: 90.8 mb

- this work: generation of artificial set resonances with fixed statistical properties



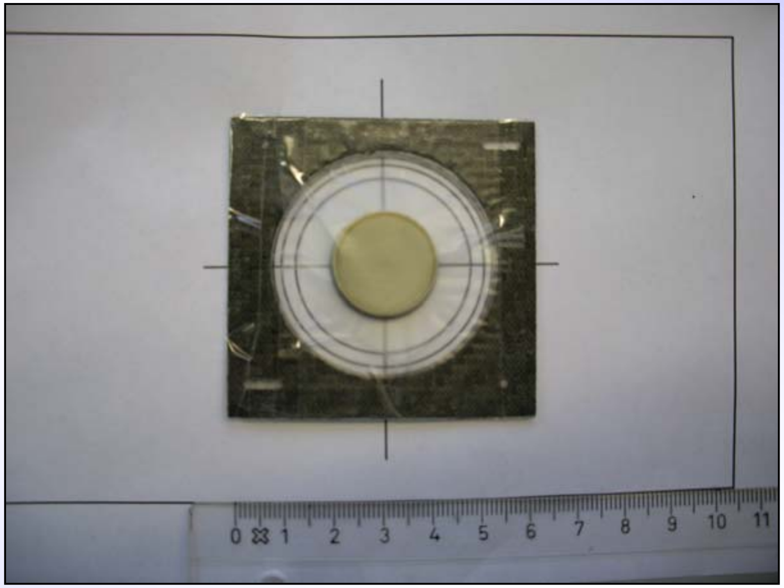
^{63}Ni sample

Original material (TU Munich, *G. Korschinek, T. Faestermann*):

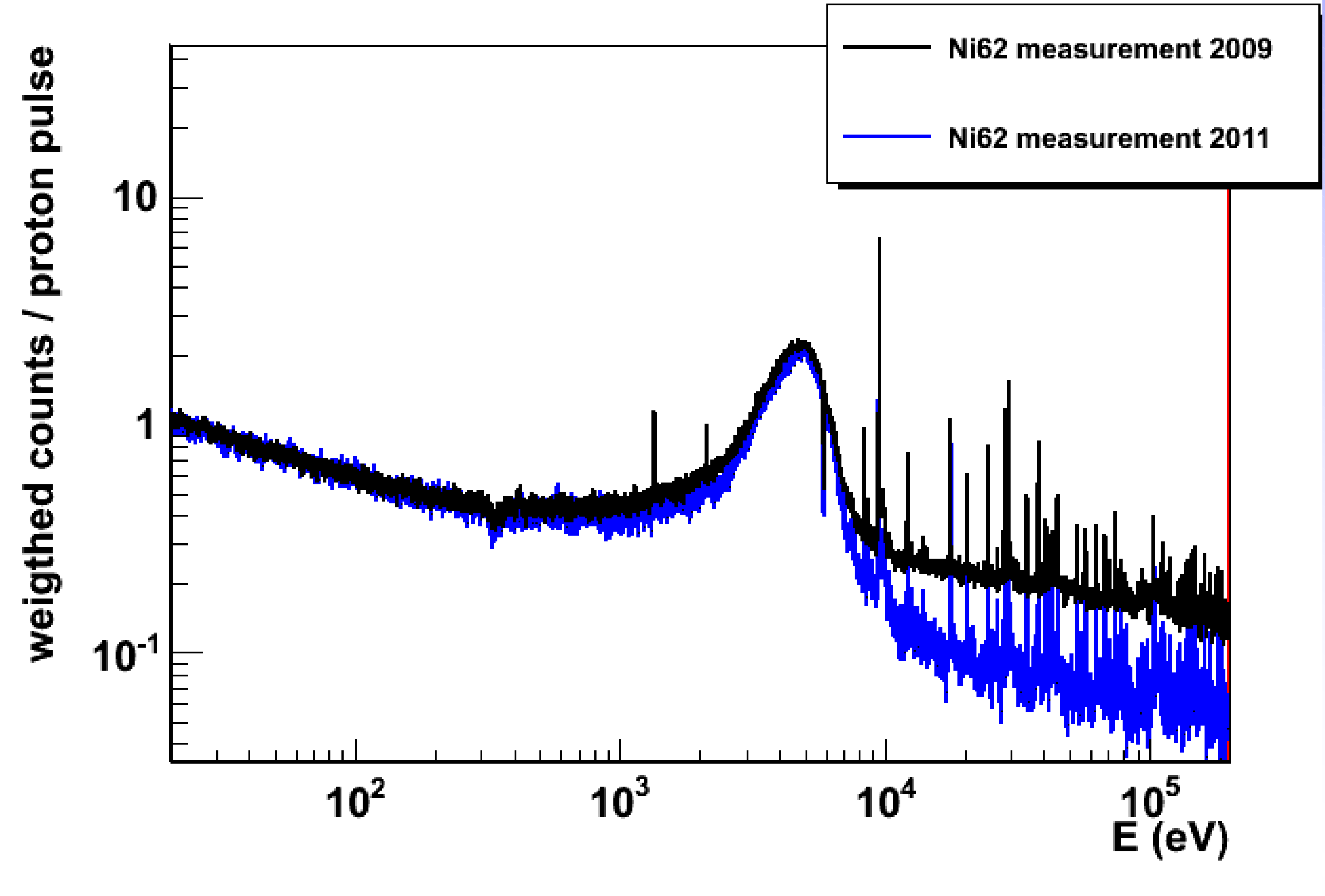
- ^{62}Ni sample irradiated in thermal reactor (in 1984 and 1992)
- total mass: 1002 mg
- enrichment in ^{63}Ni: ~13 % (= 131.8 mg)
- contaminants: ~15.4 mg ^{63}Cu

After chemical separation at PSI (*D. Schumann*):

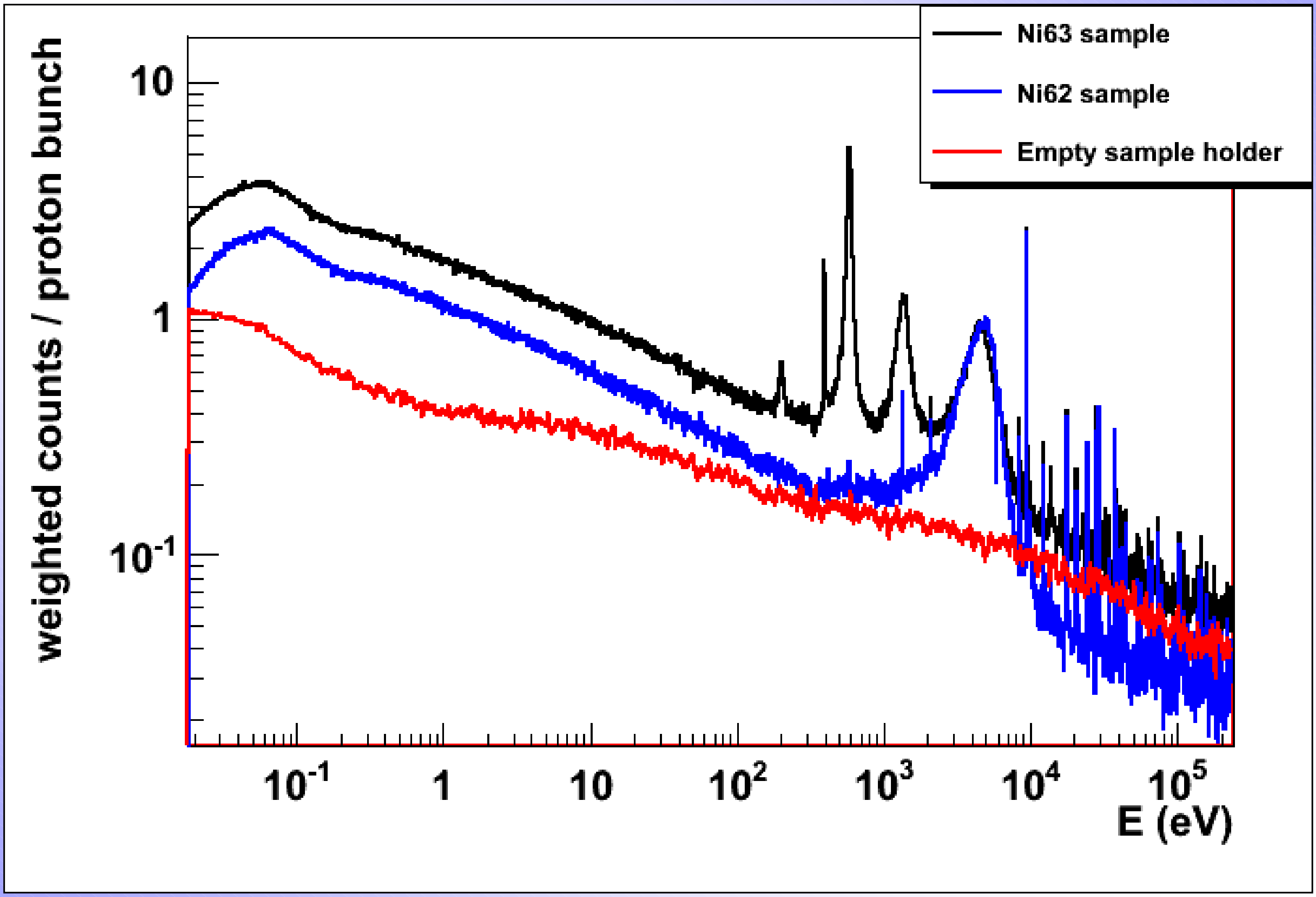
- NiO powder, 1156 mg
- ^{63}Ni/^{62}Ni=0.134 (=108.4 mg)
- Container: PEEK ($C_{20}H_{12}O_3$)
- <0.01 mg ^{63}Cu



Borated water: 2009 vs. 2011



$^{63}Ni(n,\gamma)$ – first results from n_TOF (2011)



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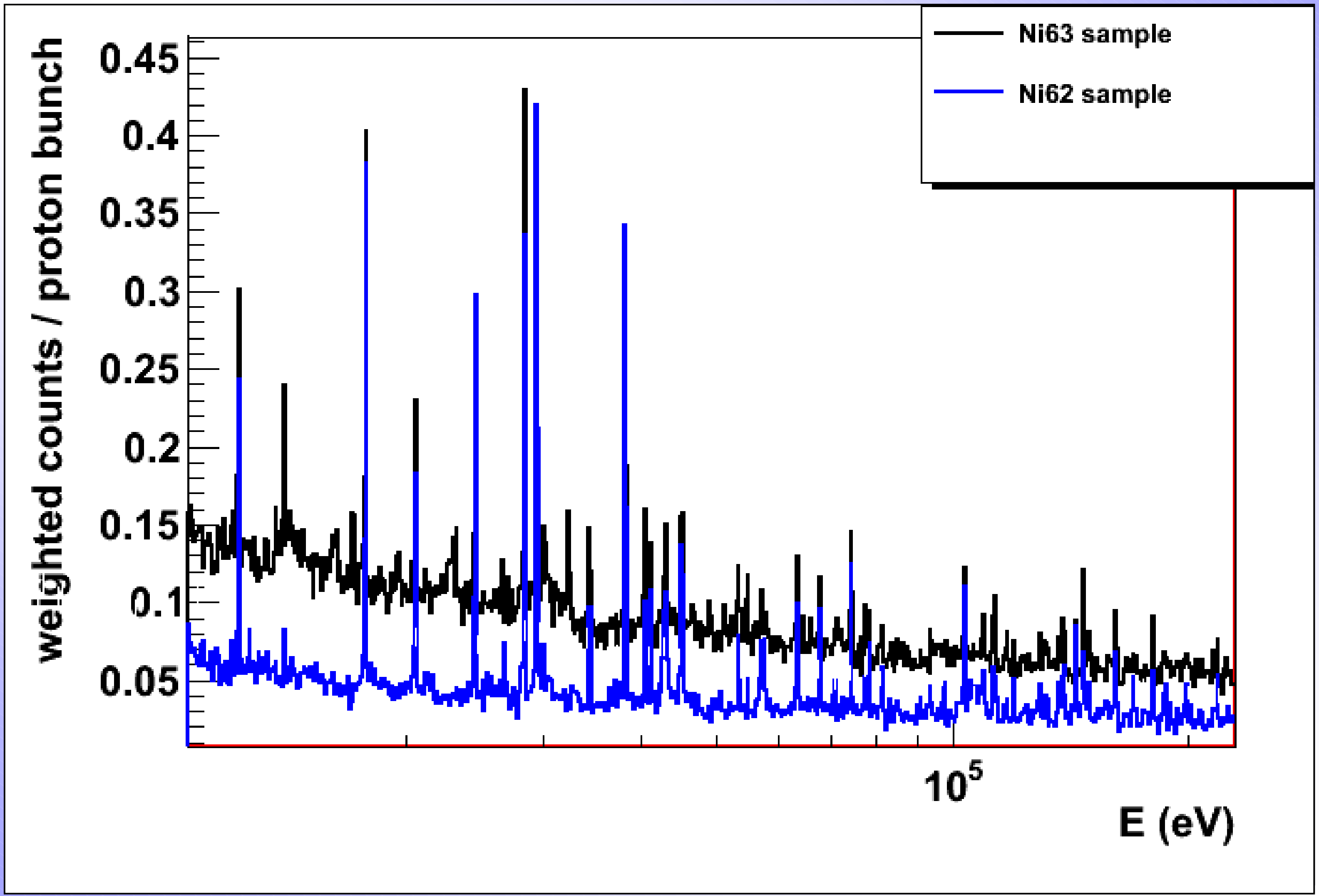

Summary

• (n,γ) cross sections over wide energy range (few – hundreds keV) are needed as input for s-process studies

• measurement campaign at n_TOF for improving data on Fe/Ni cross sections (^{54,56,57}Fe, ^{62}Ni finished, ^{58}Ni underway)

• measurement of unstable ^{63}Ni(n,γ) at n_TOF sucessfully finished 2011, data analysis underway

• new n_TOF programmes of astrophysical interest coming forward, e.g. (n,p) reactions (see talk by P.J. Woods)

THANK YOU FOR YOUR ATTENTION