EFNUDAT synergies in astrophysics

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- astrophysics ⟺ EFNUDAT
- weak *s* process in massive stars
- examples: ^{62}Ni, ^{64}Ni, and ^{22}Ne

mutual benefits

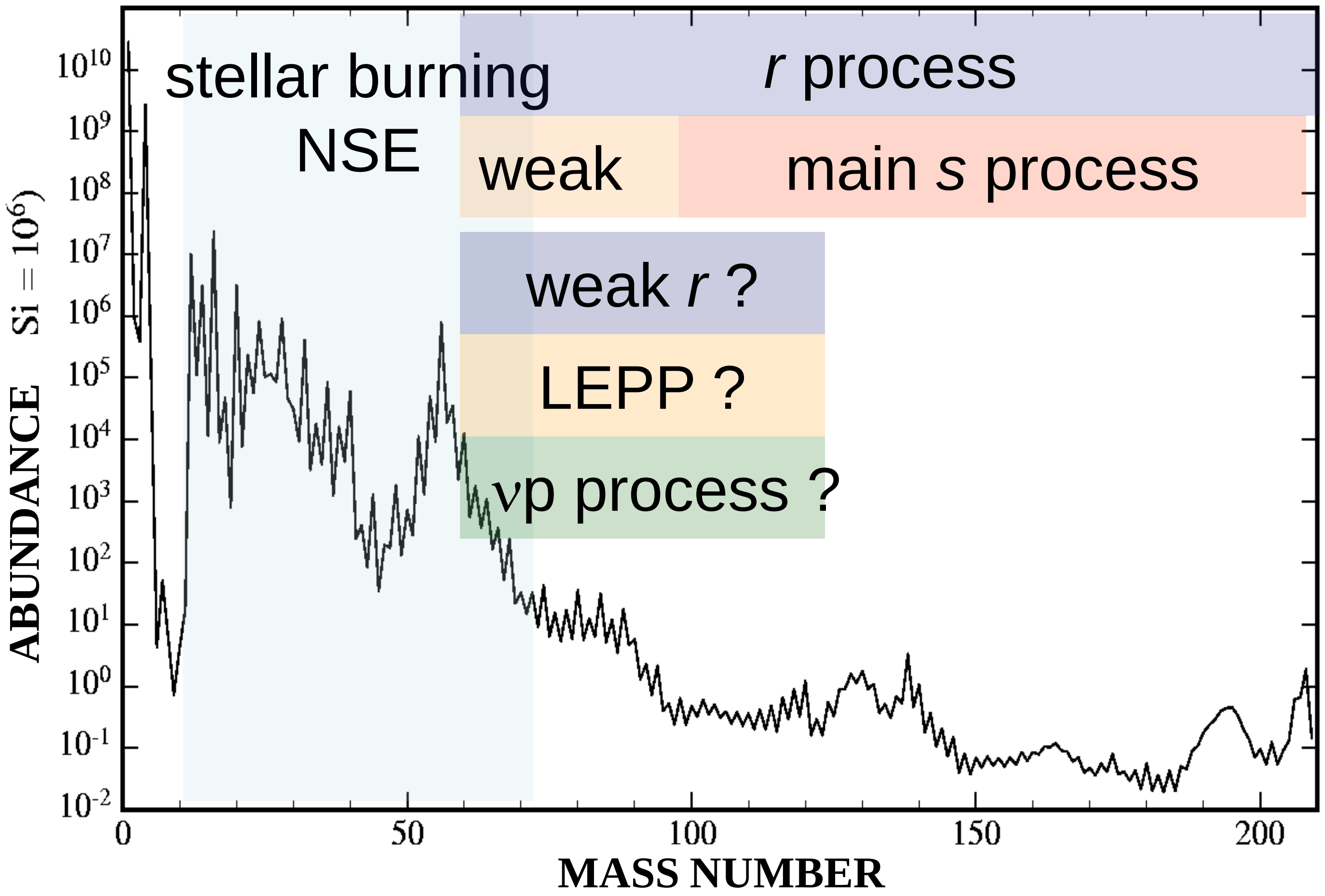
- astrophysical techniques and applications:
  - high power target for ^{7}Li(p,n), DAQ with flash ADC
  - (n, γ) measurements on ^{231}Pa, ^{235,238}U by activation
- EFNUDAT activities of relevance for astrophysics:
  - improved data for weak *s* process in massive stars
  - examples: ^{62}Ni(n,γ), ^{64}Ni, and ^{22}Ne

in addition to ^{24,25,26}Mg by Cristian Massimi
and the ^{7}Li spectrum definition by Claudia Lederer

origin of the elements

Nuclear Astrophysics: **how** and **where** are the chemical elements produced?

solar abundance distribution



current GCE models find deficit in the mass region of the weak s process

s abundances are determined by (n, γ) cross sections

important to improve cross sections

weak s process – conditions at stellar site

stellar site: massive stars with $M > 8M_{\odot}$

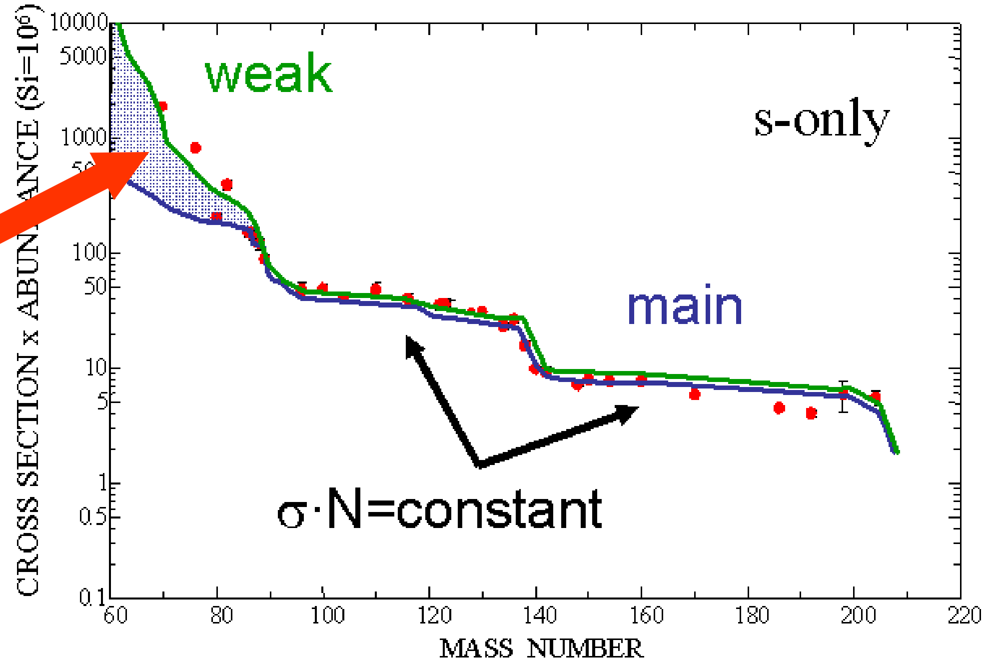
	core He-burning	shell C-burning
temperature	$3\text{-}3.5 \cdot 10^{8}$ K	$\sim 1 \cdot 10^{9}$ K
neutron density	10^{6} cm^{-3}	$10^{11}\text{-}10^{12}$ cm^{-3}
neutron source	$^{22}Ne(\alpha,n)$	**$^{22}Ne(\alpha,n)$**, $^{13}C(\alpha,n)^{16}O$

- neutron exposure in the C shell comparable with core He-burning
- material from core He-burning is reprocessed during shell C-burning
- **important:** weak *s* component goes together with *r* process

nuclear data needs

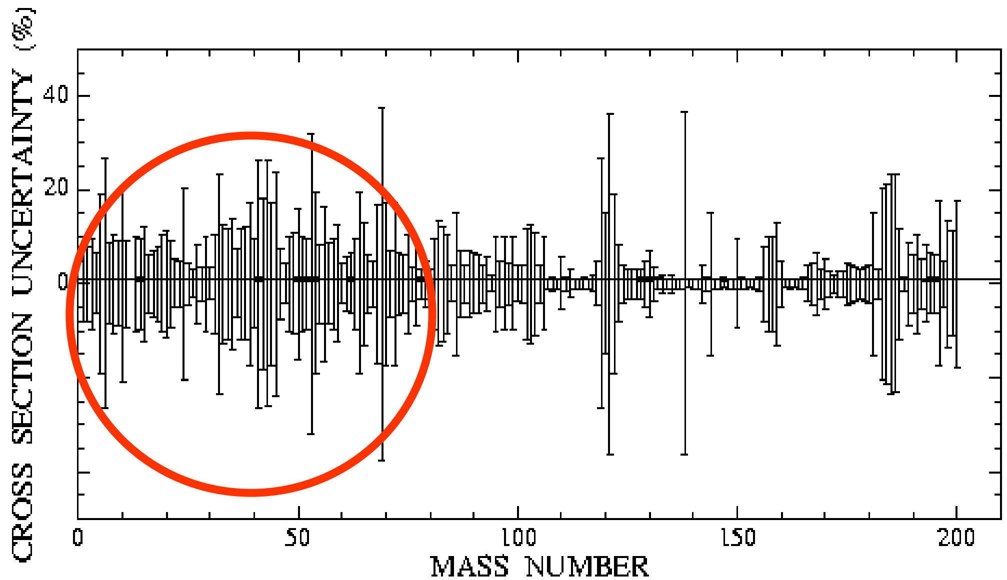
s-process abundances are determined mainly by **Maxwellian averaged neutron capture cross sections** for thermal energies of kT=25 – 90 keV.

weak s process NOT in flow equilibrium



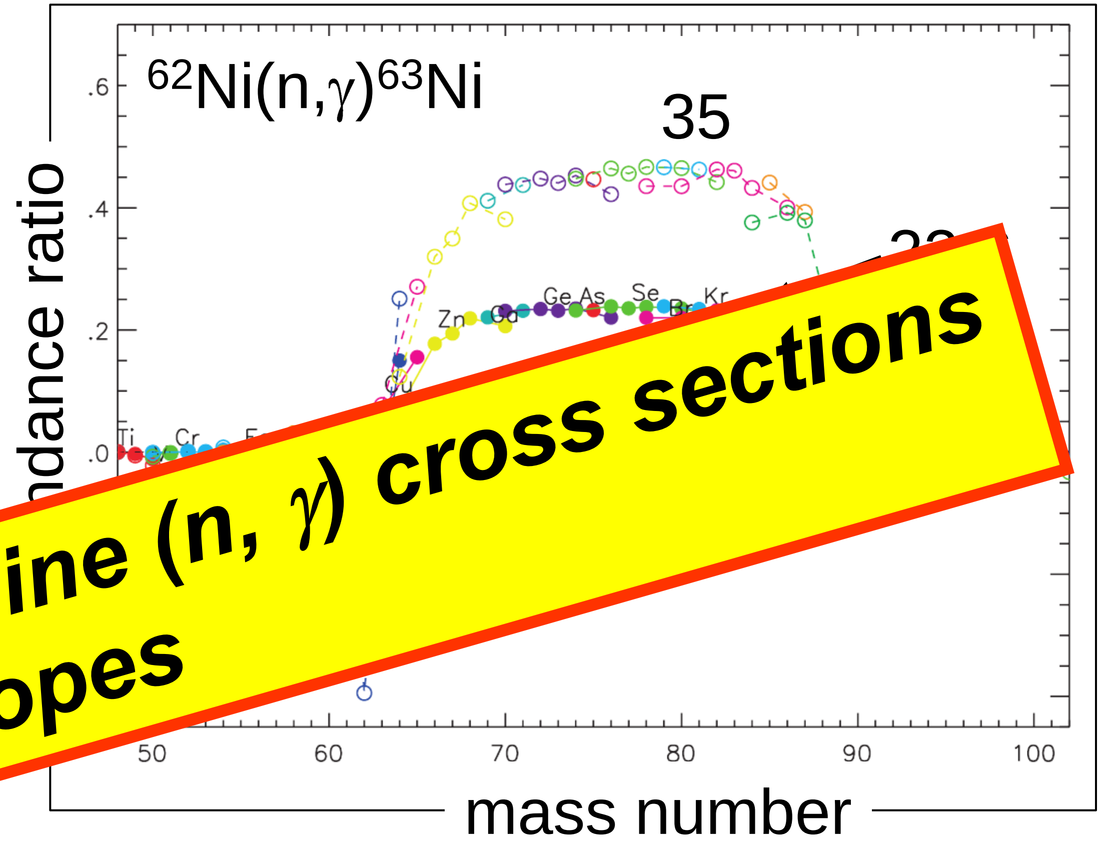
persisting experimental problems:

- small cross sections
- resonance dominated
- contributions from direct capture



the case of ^{62}Ni

- strong propagation effect for abundances of weak *s* process

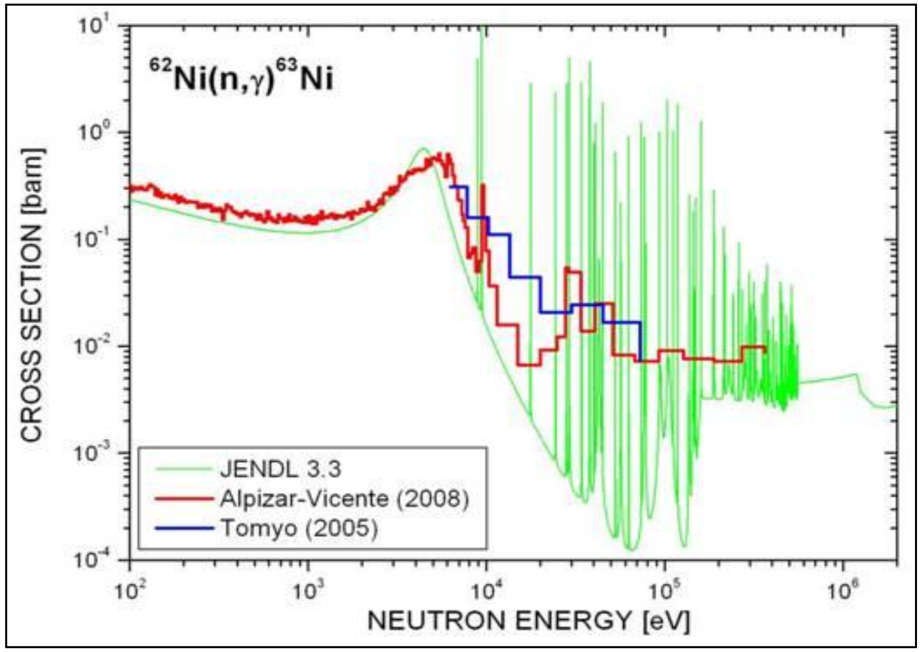


stellar 62N

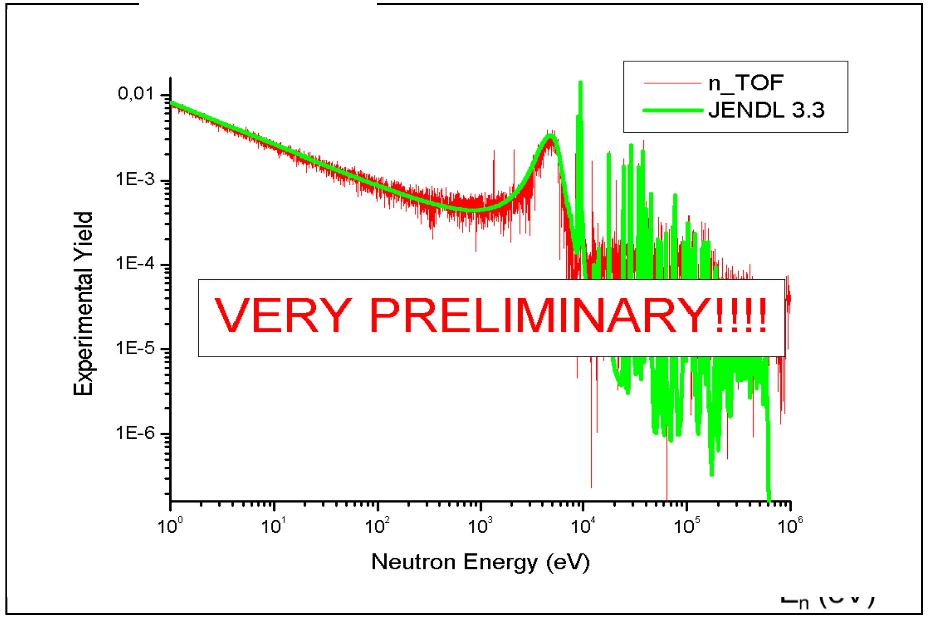
n_TOF campaign to determine (n, γ) cross sections of all stable Fe and Ni isotopes

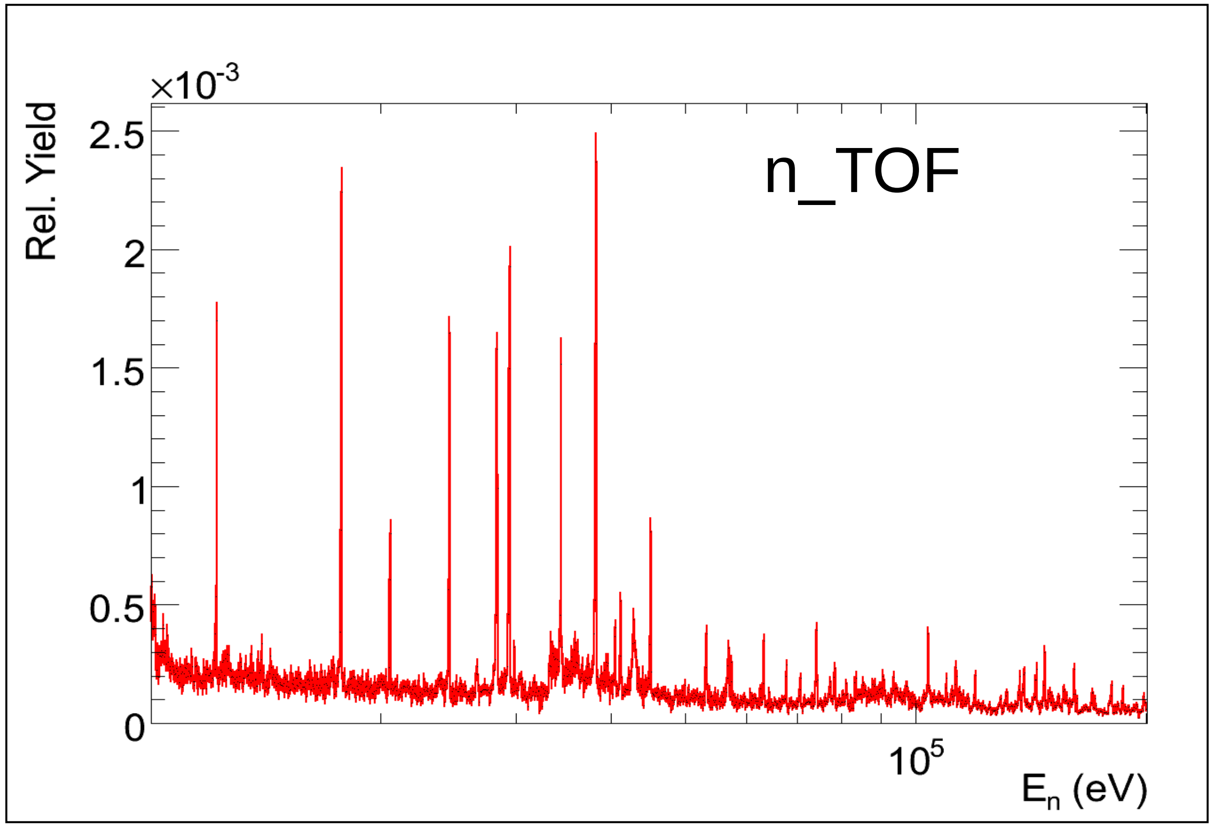
	activation
(2008)	20.2 ± 2.1 (2009)
?7.0 ± 3.2 (2005)	23.4 ± 4.6 (2008)
12.5 ± 4.0 (1983)	26.1 ± 2.6 (2005)
26.8 ± 5.0 (1975)	

first results for ^{62}Ni:
C. Lederer & n_TOF collaboration, NIC-XI, 2010



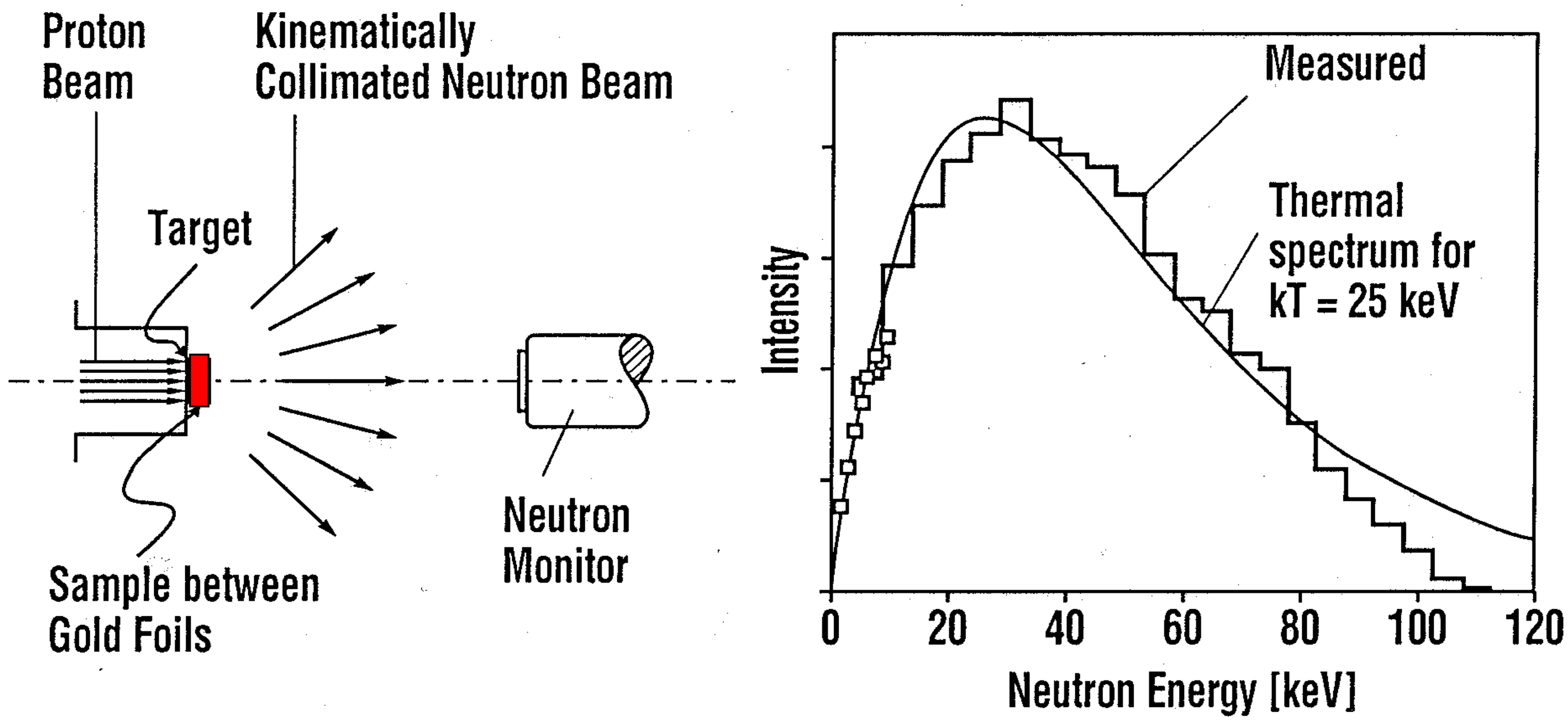
recent TOF measurements
(courtesy I. Dillmann)





activation technique at kT=25 keV

- neutron production via $^7Li(p,n)^7Be$ reaction at E_p = 1912 keV.
- induced activity measured after irradiation with HPGe detectors.



- possible if product nucleus is radioactive

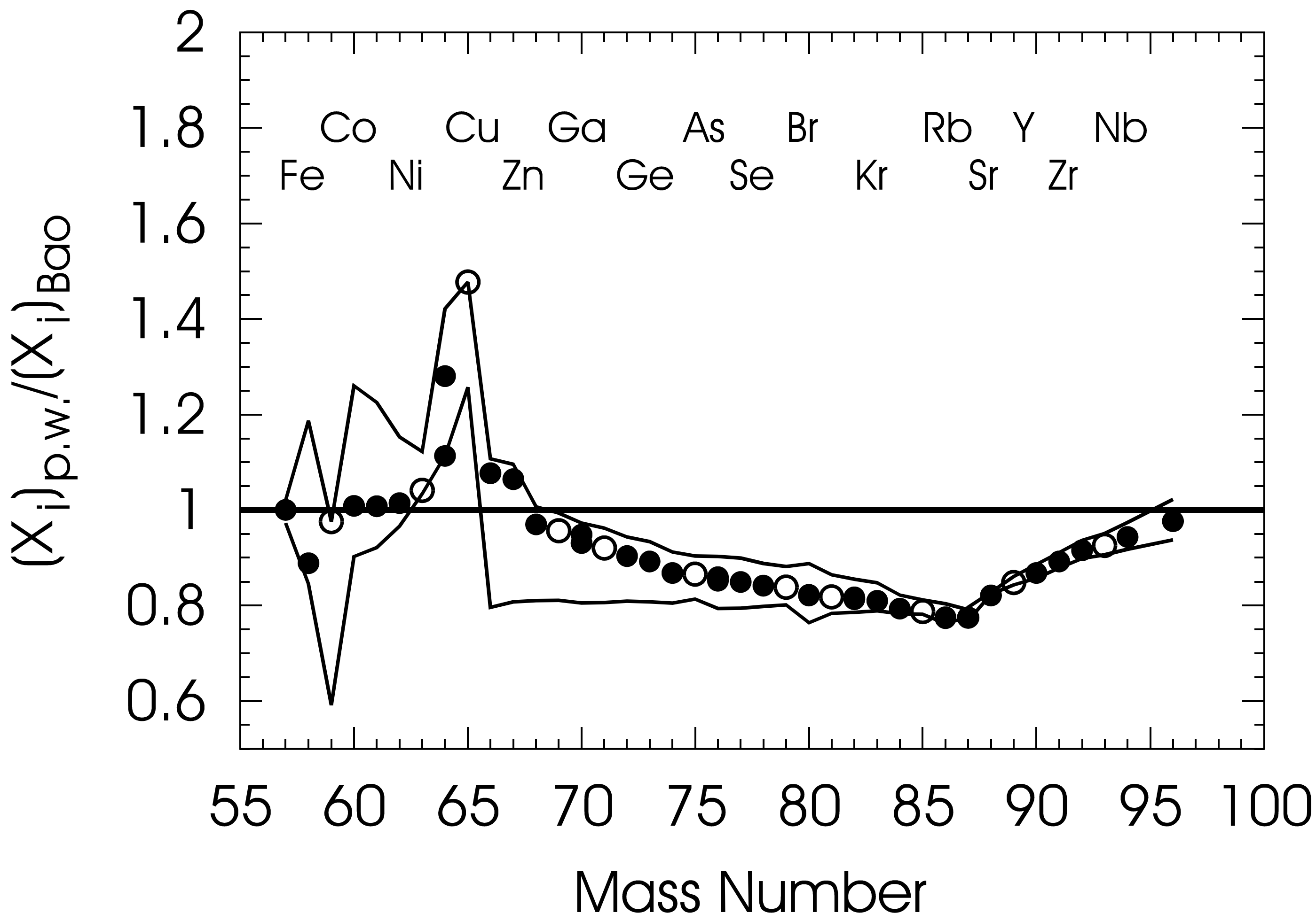
✓ high sensitivity ➡ small sample masses or small cross sections

✓ natural samples possible, isotopic enrichment not required

✓ Direct Capture component included

Karlsruhe activations for weak *s* process

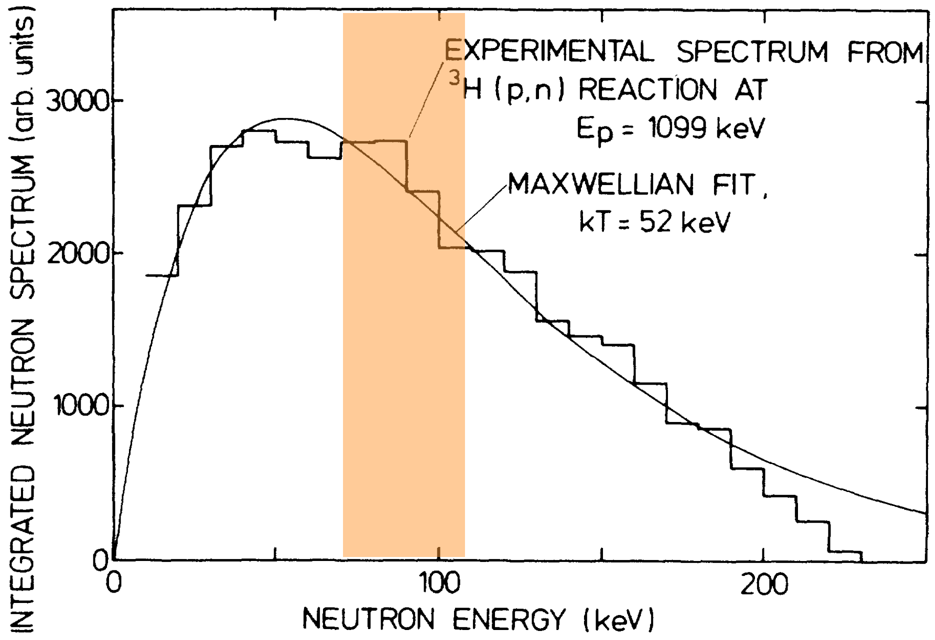
The propagation effect of cross section uncertainties into the abundance distribution of the weak *s* process was confirmed by a series of activation measurements at 25 keV [e.g. PRC **77 (**2008**)** 015808; **78** (2008) 025802; **79 (**2008**)** 065802]



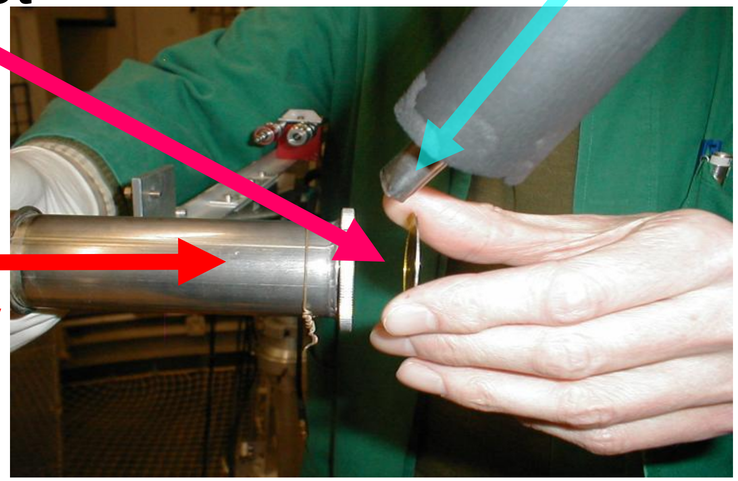
limited to kT=25 keV,
but
data also needed for kT=90 keV

PTB - EFNUDAT activations at kT=52 keV

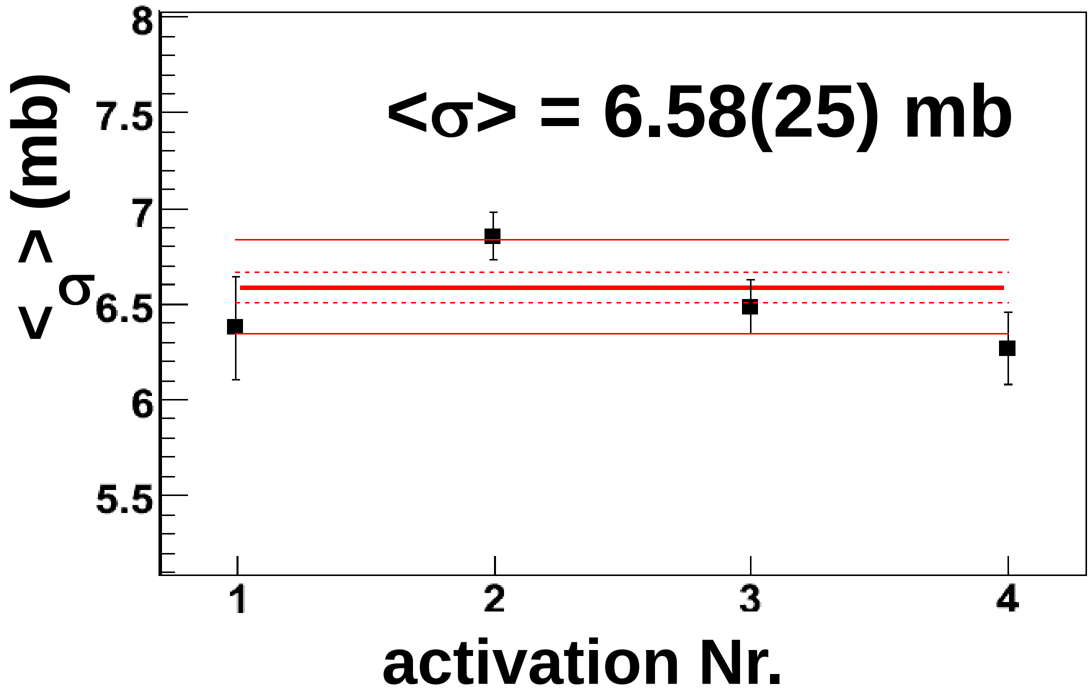
$^3H(p,n)^3He$

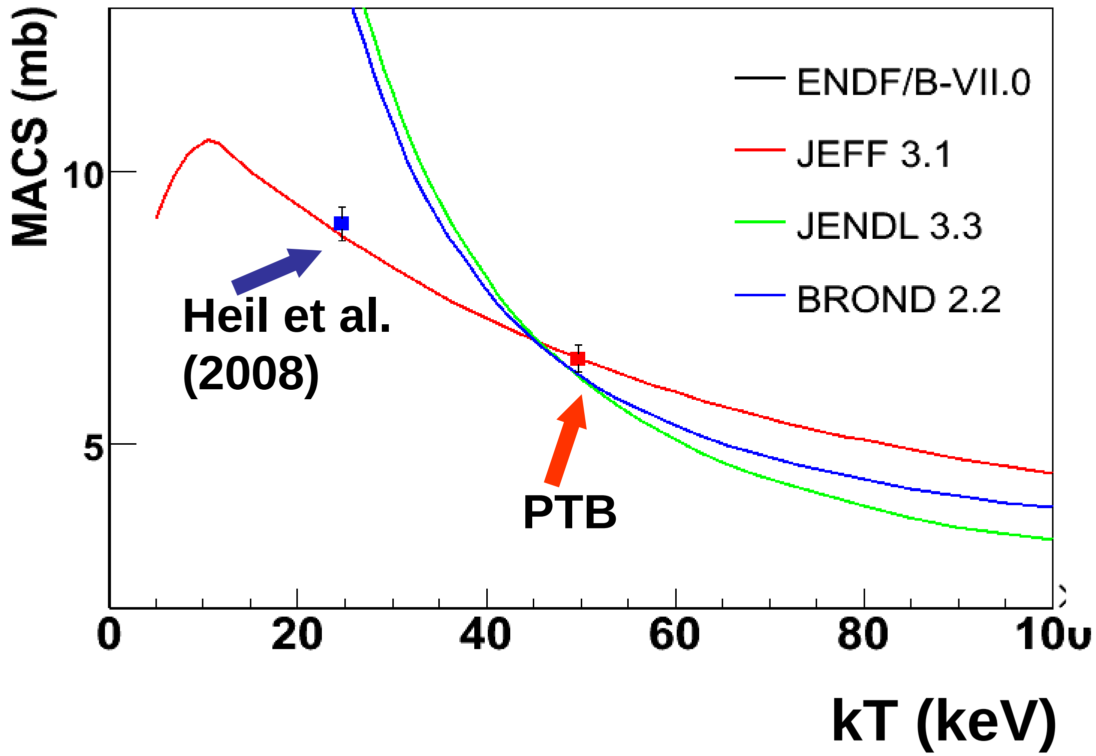


kT = 52 keV



^{64}Ni(n, γ) @ kT=52 keV





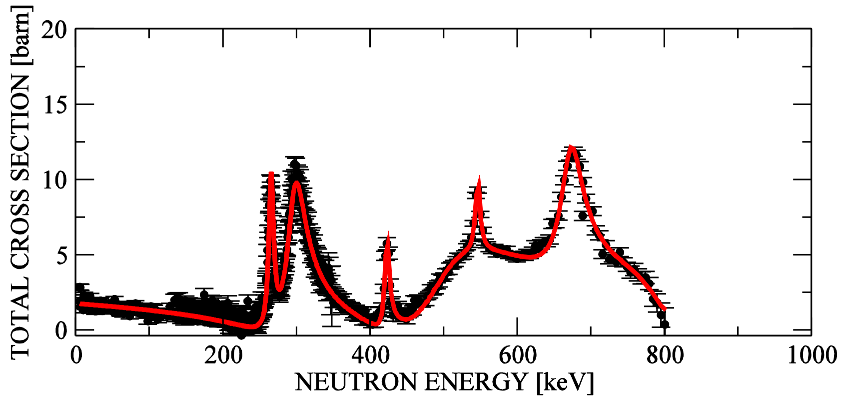
will be complemented over full energy range by n_TOF measurements

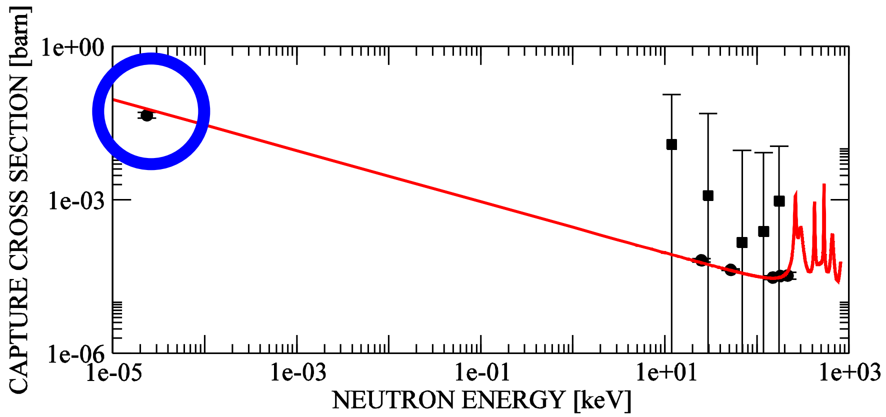
- consistent with previous measurement at 25 keV,
- confirming the correct energy dependence of the cross section

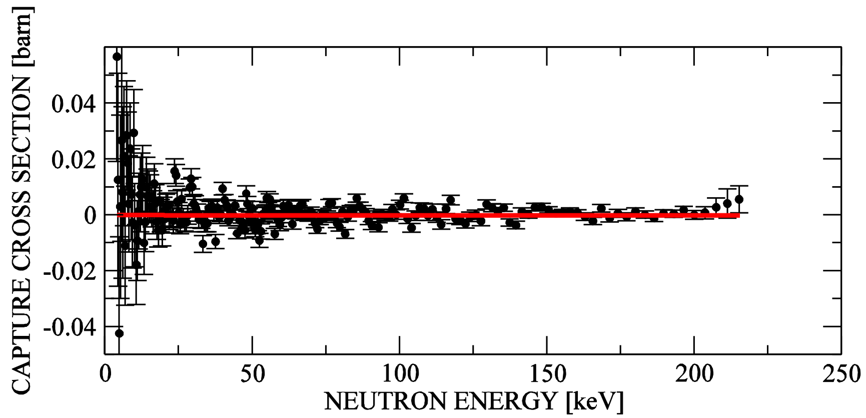
the case of $^{22}Ne(n,\gamma)$

- at the onset of He burning ^{22}Ne is the most abundant “heavy” isotope.
- it represents the major neutron source in massive stars
- at the same time it is an important neutron poison for the *s* process
- the analysis of TOF data from the keV region exhibits a clear mismatch for the thermal value

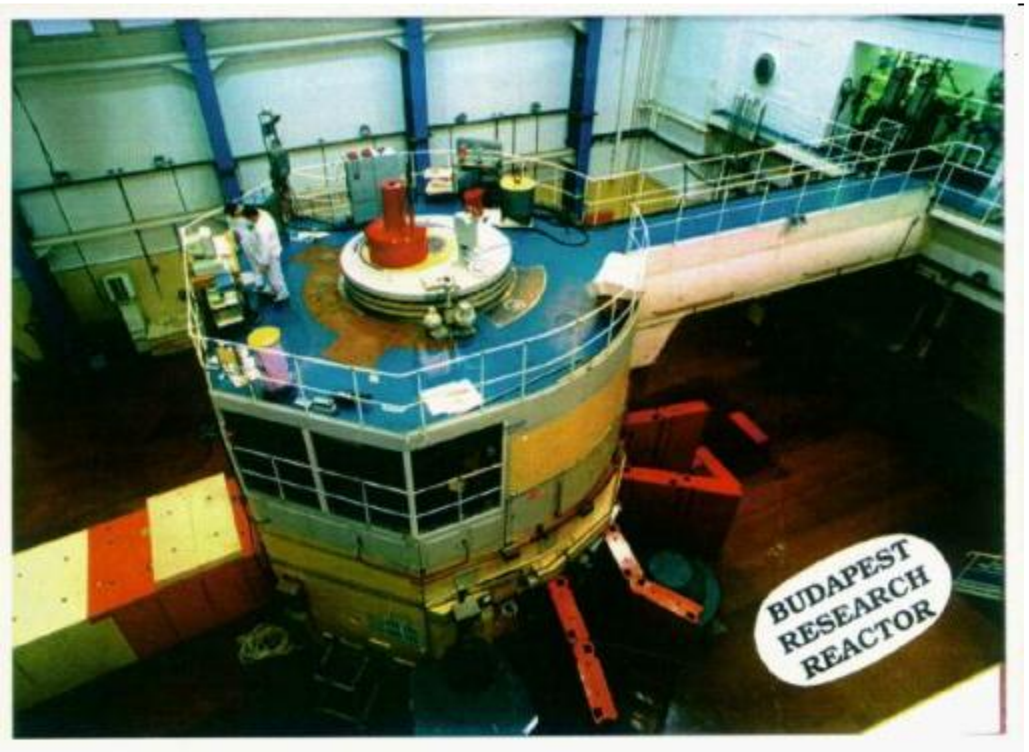
$\sigma_{th} = 44.5 \quad 2.8$ mb (literature)
$\sigma_{pred} \sim 54$ mb







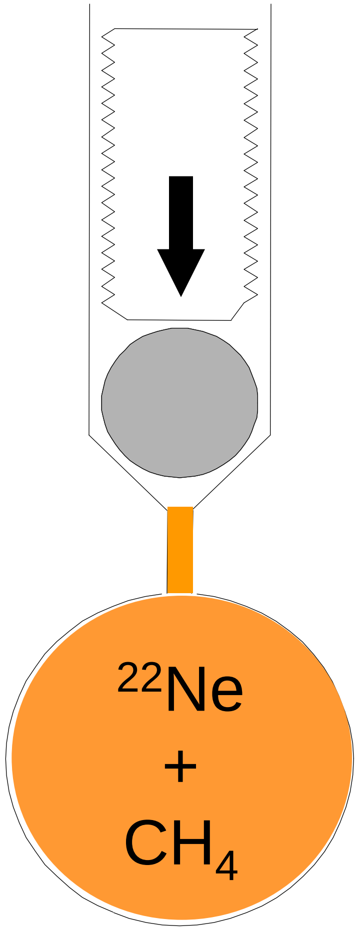
EFNUDAT measurement at IKI Budapest

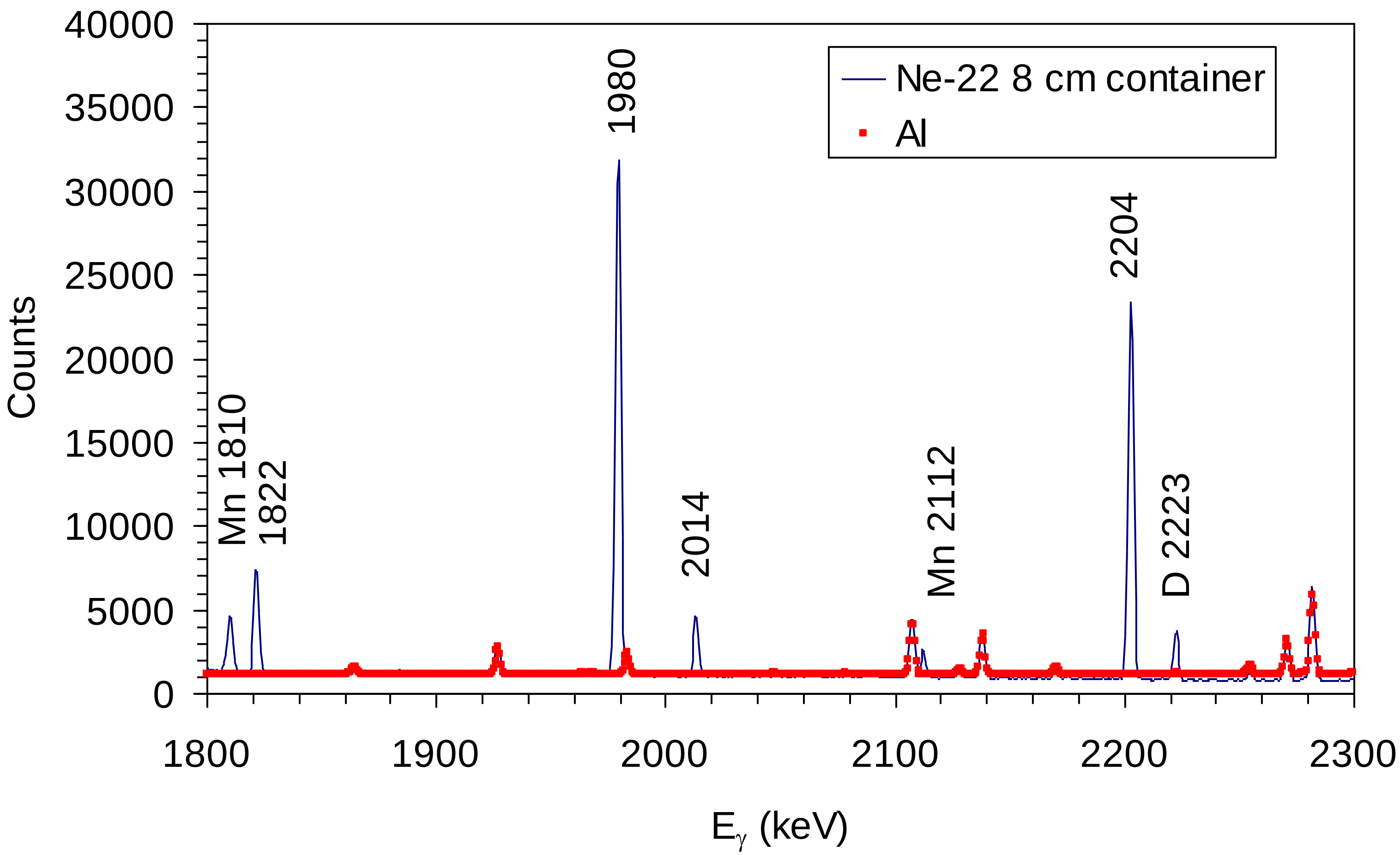


- 10 MW Research Reactor
- thermal flux $2.2 \cdot 10^{14}$ $cm^{-2}s^{-1}$
- guided cold neutron beam ($7 \cdot 10^{7}$ $cm^{-2}s^{-1}$)

- high pressure gas cells (loaded with 30 to 100 bar)
- enriched ^{22}Ne gas (98.87%) with CH_4 admixture
- measurement relative to H cross section standard
- PGAA analysis using BGO guarded HPGe detector

EFNUDAT measurement at IKI Budapest





$\sigma_{th} = 44.5 \quad 2.8$ mb (literature)

$\sigma_{pred} \sim 54$ mb

this work:

$\sigma_{th} = 52.7 \quad 0.7$ mb

summary

EFNUDAT synergies for astrophysics:

- supported access to other facilities,
- new and intensified collaborations,
- innovative approaches (AMS),
- full solutions: TOF studies on Fe and Ni isotopes for high *kT*