The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA

**1930-7**

# Joint ICTP-IAEA Advanced Workshop on Model Codes for Spallation Reactions

*4 - 8 February 2008*

## Spallation Data and Applications

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*Vienna*
*Austria*

# Nuclear Physics, Astrophysics, and Advanced Technologies with Neutrons

Alberto Mengoni
IAEA , Vienna

- Generalities
- Example of experimental activity: n_TOF at CERN
- From experimental data to evaluated data libraries

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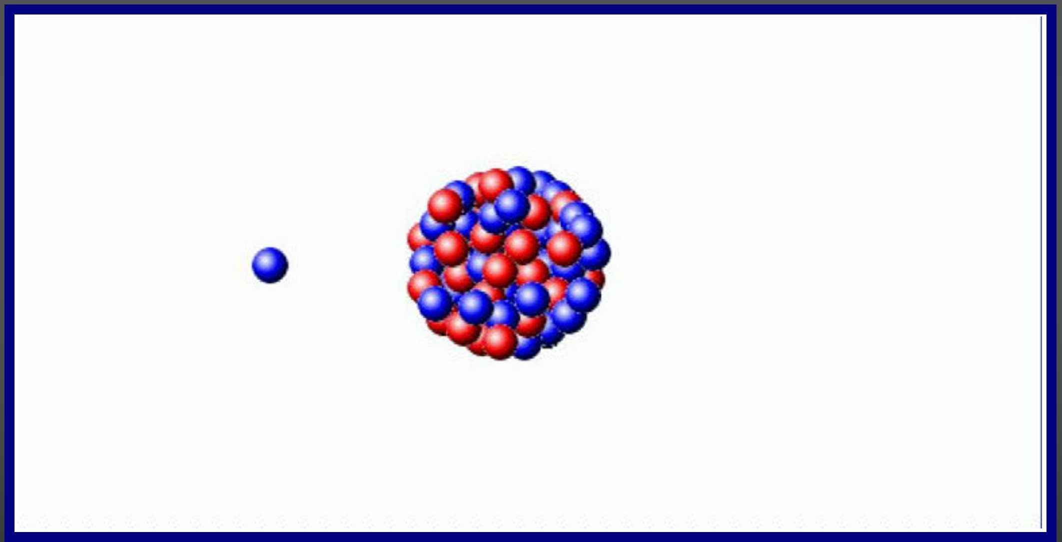
# Nuclear Reaction Experiments

Neutron induced reactions



Source: the web

movie

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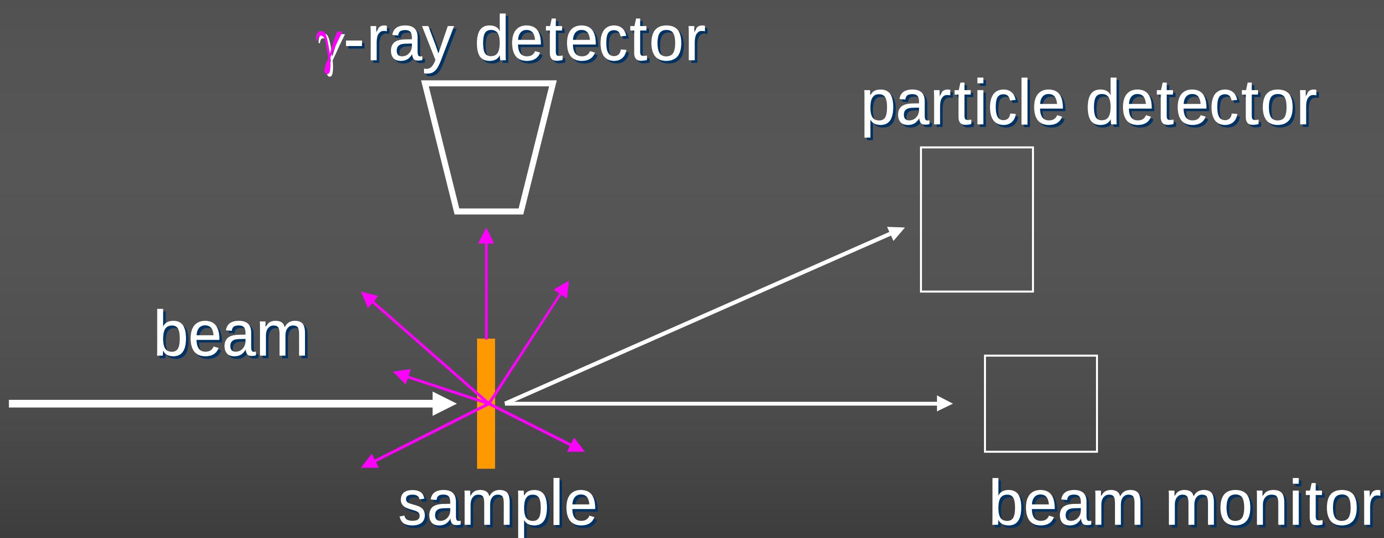
# Nuclear Reaction Experiments

Neutron induced reactions




$$r = \Phi \sigma \rho_A$$

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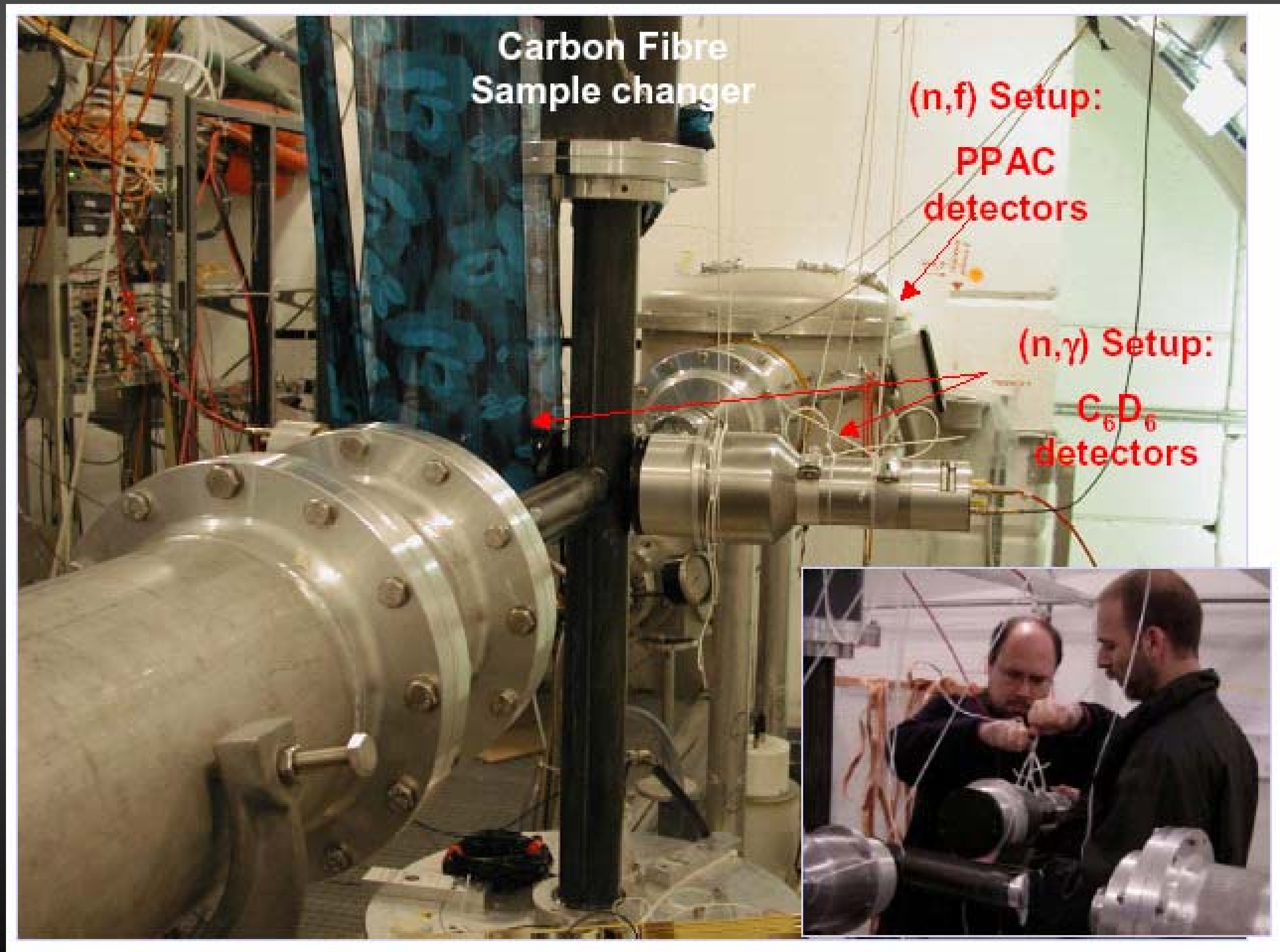
# Nuclear Reaction Experiments

Neutron induced reactions



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# Objectives

- Nuclear Astrophysics
- Nuclear Technologies
  advanced reactors, nuclear waste transmutation, etc.
- Neutrons as probes for fundamental Nuclear Physics

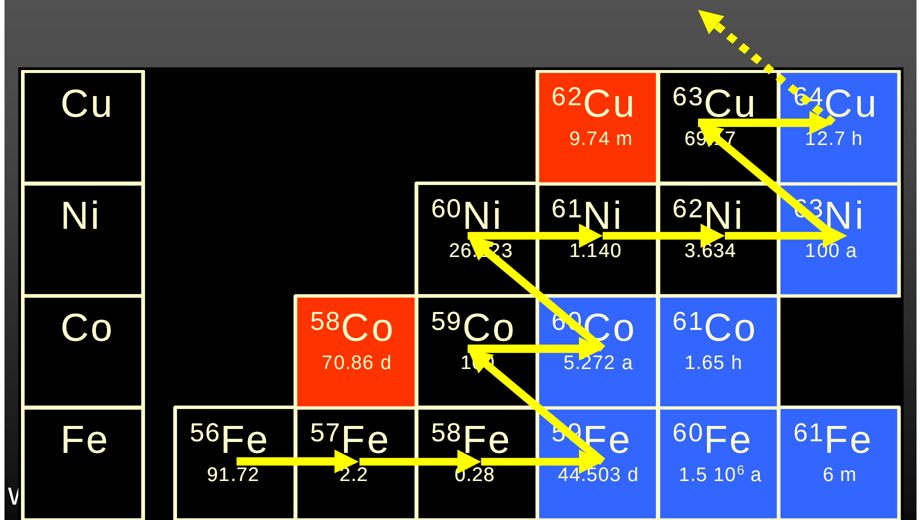
# Nucleosynthesis: the s-process

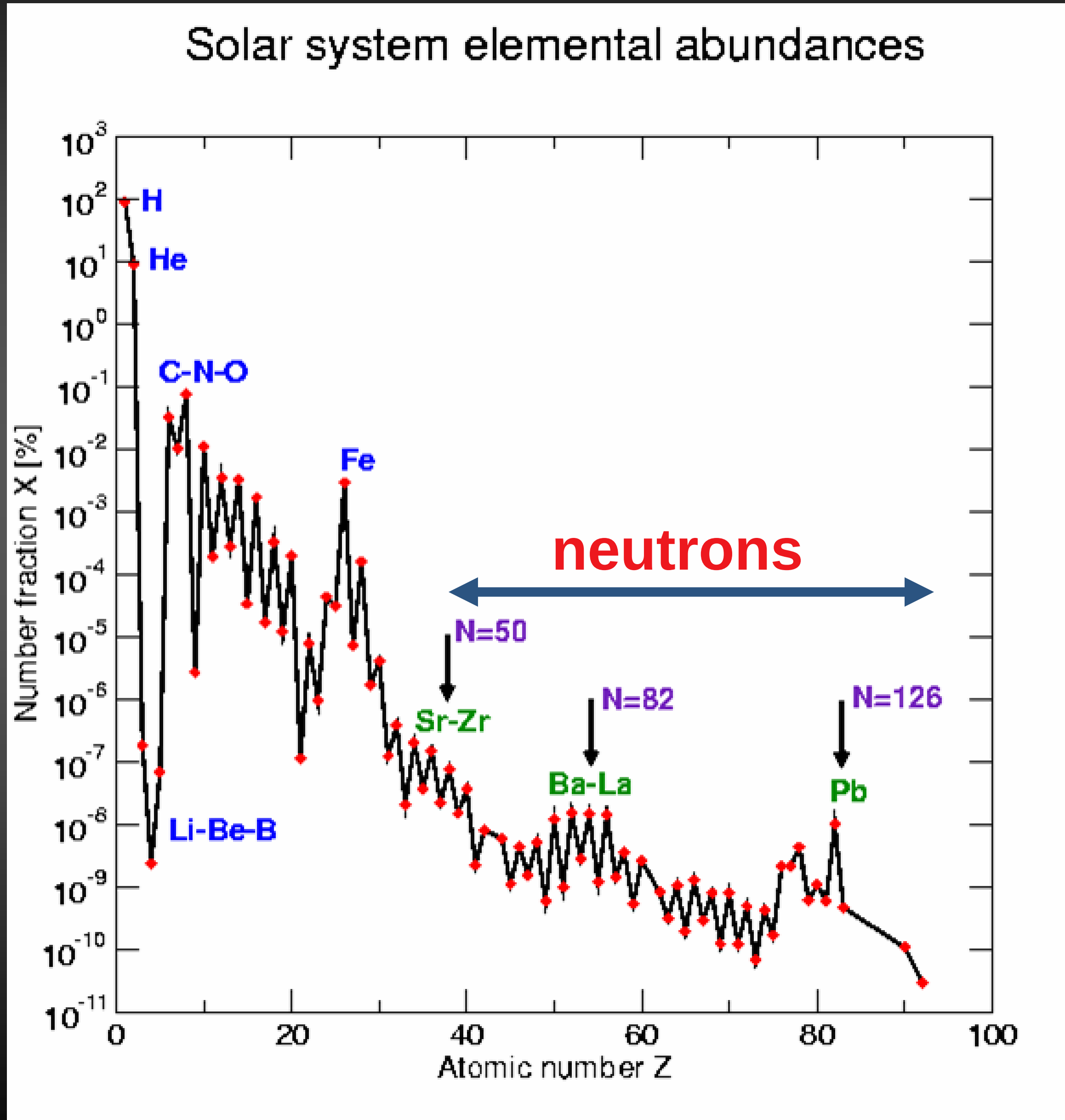
direct correlation between neutron capture cross section and abundance:

$$\sigma(n,\gamma) \cdot N = const.$$

>>

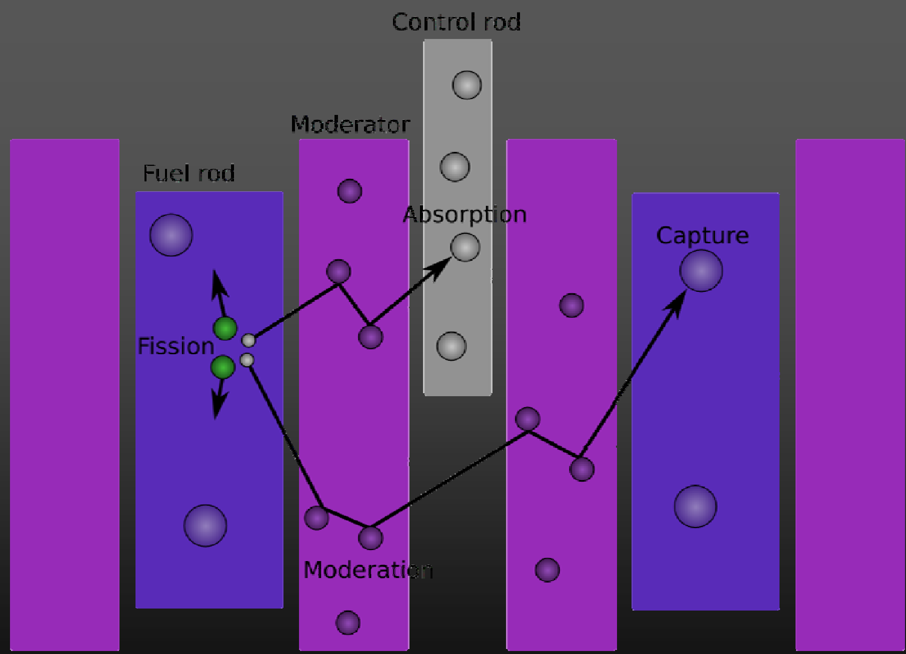
**The canonical s-process**



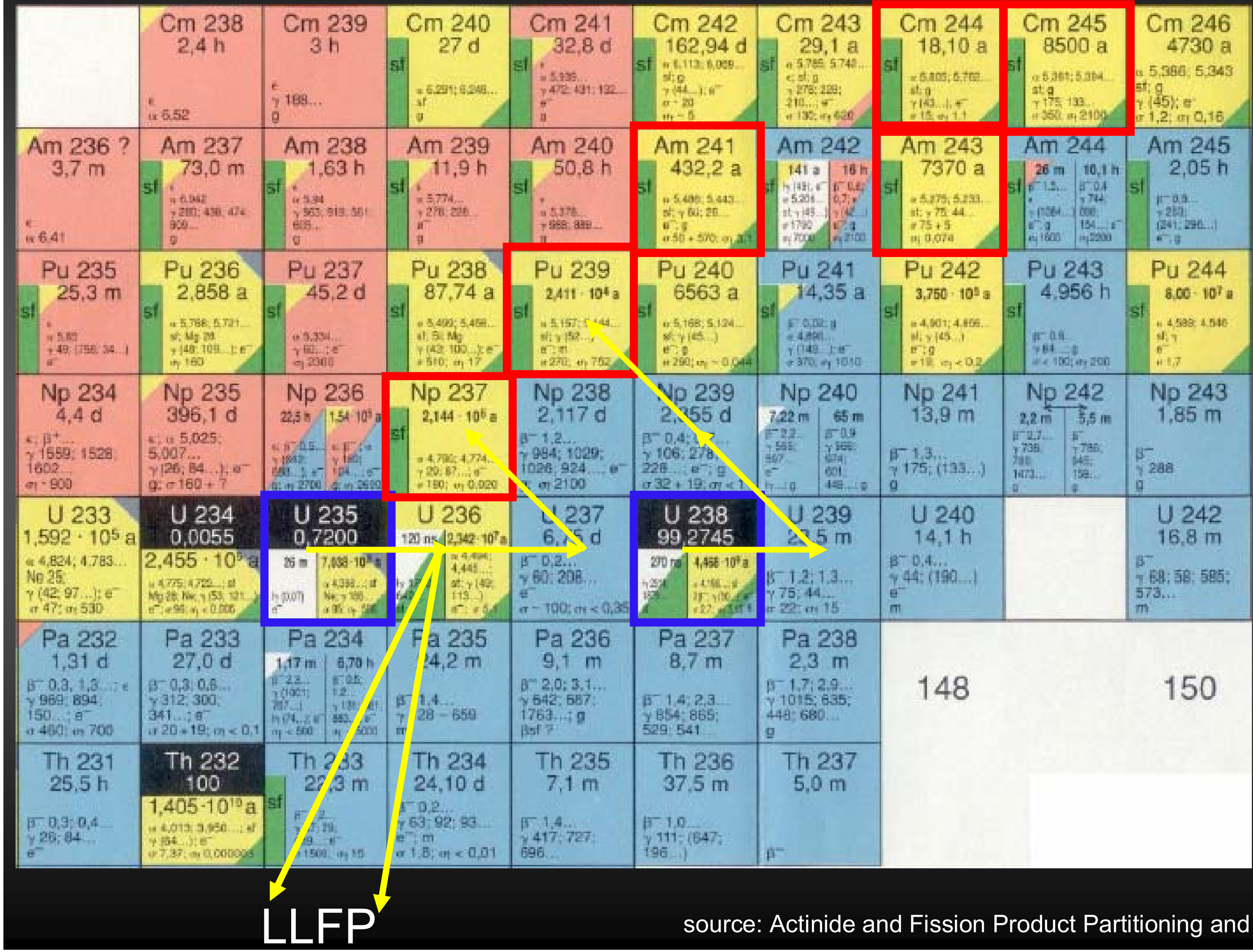



# Energy generation and Nucleosynthesis: not only in stars!

The Candu Qinshan Nuclear Power Plant



# Nucleosynthesis: TRU (1000 $MW_e$ LWR)




$^{244}Cm$ 1.5 Kg/yr

$^{241}Am$: 11.6 Kg/yr
$^{243}Am$: 4.8 Kg/yr

$^{239}Pu$: 125 Kg/yr

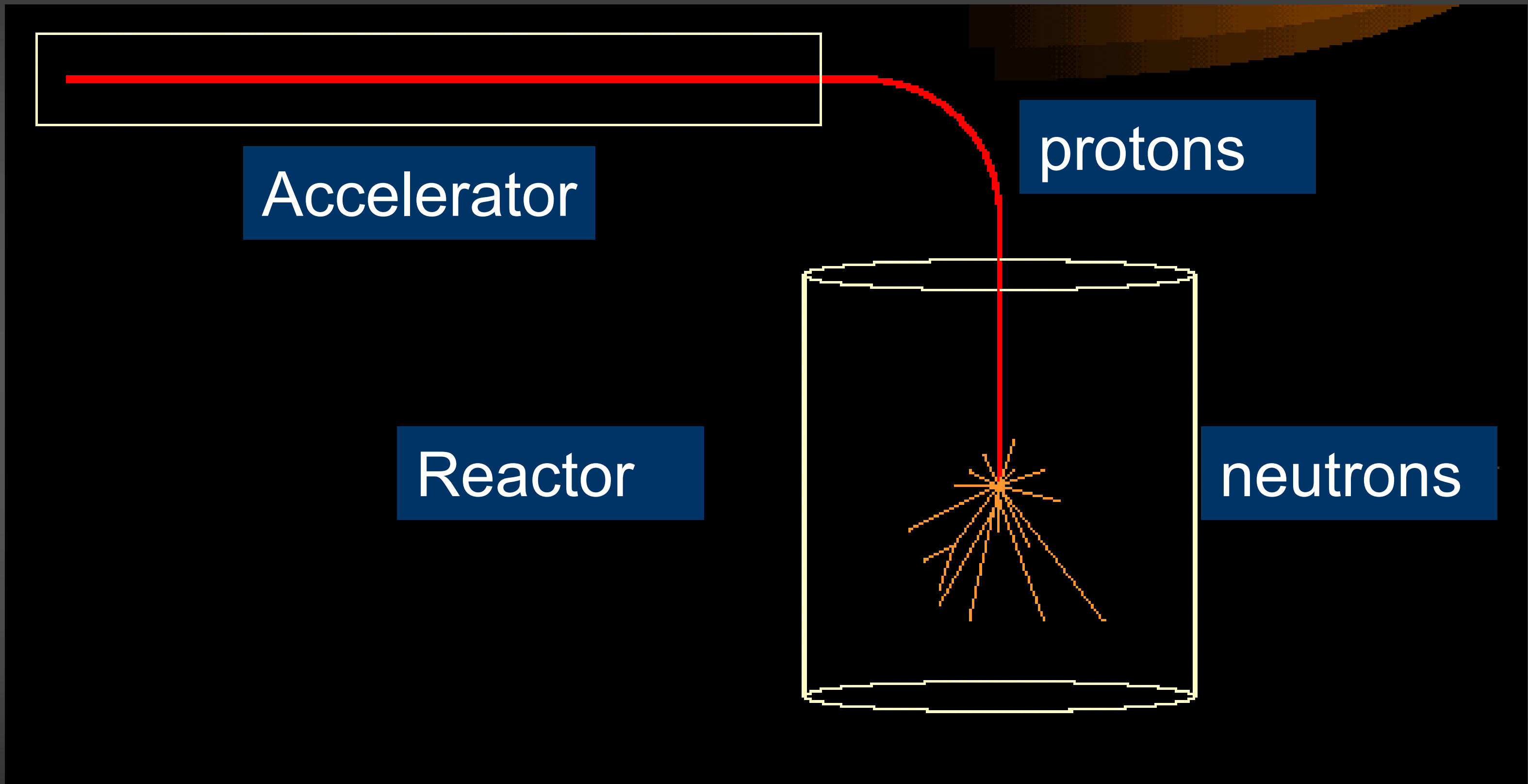
$^{237}Np$: 16 Kg/yr

LLFP 76.2 Kg/yr

source: Actinide and Fission Product Partitioning and Transmutation – NEA (1999)

# Th/U fuel cycle

# ADS (Accelerator Driven Systems)

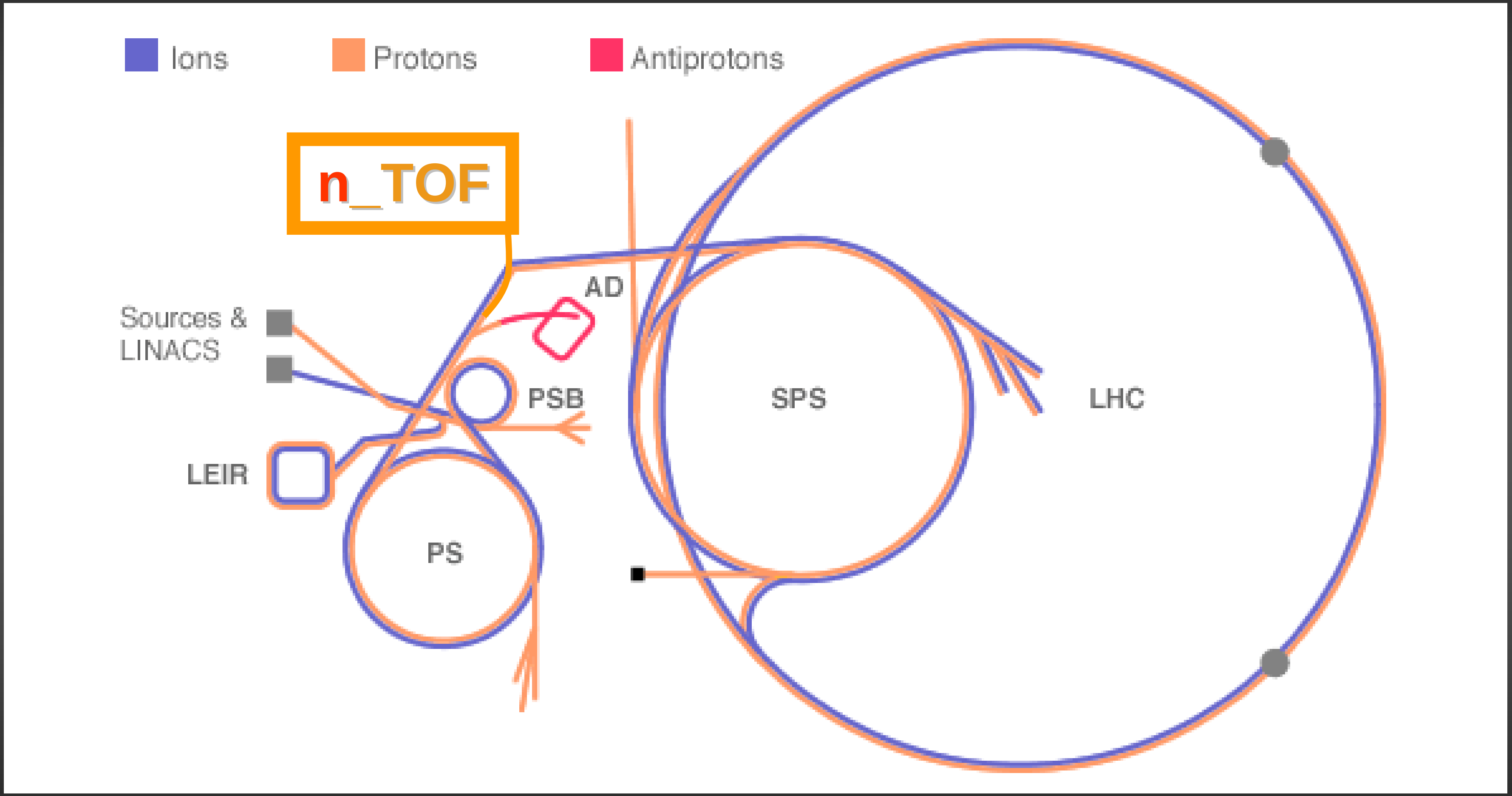



Zen-ADS

# World scene for tof measurements

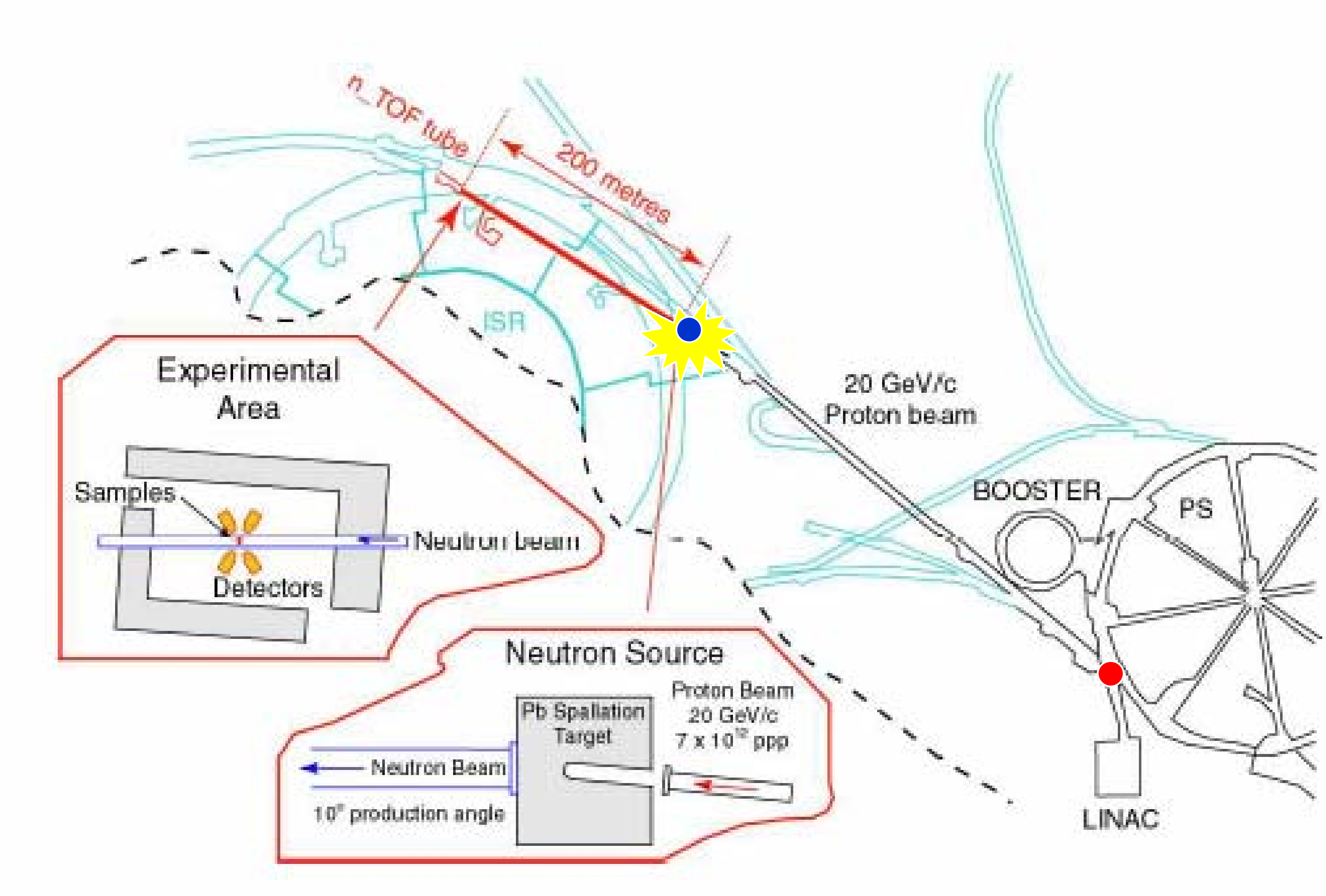
| facility | | driver and energy | repetition rate | n source | n energy range | flight path length |
|---|---|---|---|---|---|---|
| FZK<br>TIT<br>... | Karlsruhe<br>Tokyo<br>... | varii in the MeV range | MHz | $^{7}Li(p,n)$<br>& others | few keV up to 1 MeV<br>monoE above | 10s cm |
| GELINA | EC-JRC<br>Geel | electron linac<br>150 MeV | 800 Hz | photo-n<br>photo-f | 10 meV –<br>20 MeV | 10m<br>to<br>400m |
| LANSCE | Los Alamos National Laboratory | proton linac<br>800 MeV | 20 Hz | spallation | < 500 keV<br>(DANCE) | 20m |
| n_TOF | CERN | PS<br>20 GeV | 0.4 Hz<br>(average) | spallation | 10 meV –<br>250 MeV<br>(or wider) | 200m |

# CERN accelerator Complex




Linac(s): up to 50 MeV   PSB: up to 1 GeV   PS: up to 24 GeV

# The n_TOF facility at CERN

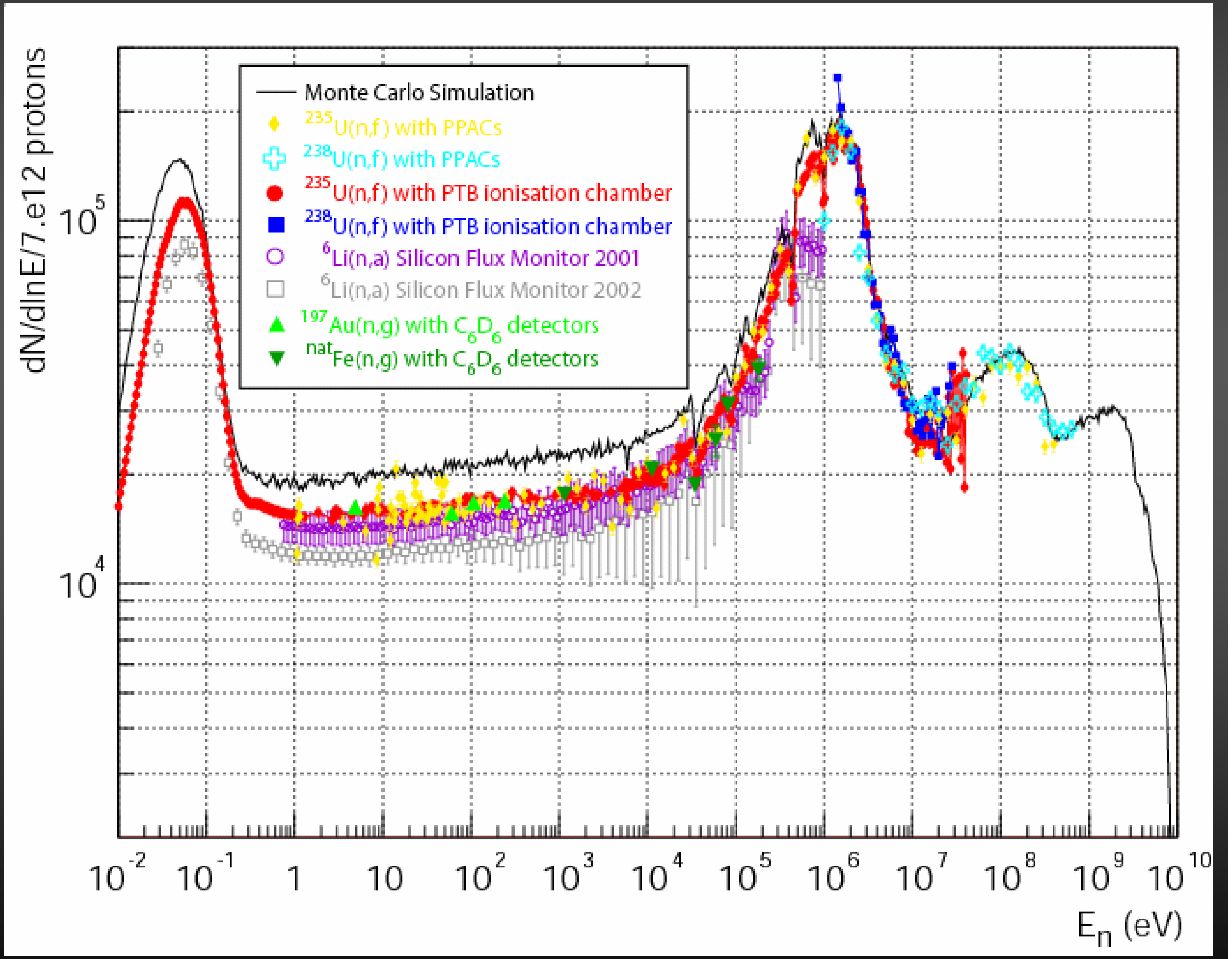


# n_TOF basic parameters

| | |
|---|---|
| proton beam momentum | 20 GeV/c |
| intensity (dedicated mode) | 7 x $10^{12}$ protons/pulse |
| repetition frequency | 1 pulse/2.4s |
| pulse width | 6 ns (rms) |
| n/p | 300 |
| lead target dimensions | 80x80x60 $cm^3$ |
| cooling & moderation material | $H_2O$ |
| moderator thickness in the exit face | 5 cm |
| neutron beam dimension in EAR-1 (capture mode) | 2 cm (FWHM) |

# Basic characteristics of experiments at n_TOF

- wide energy range

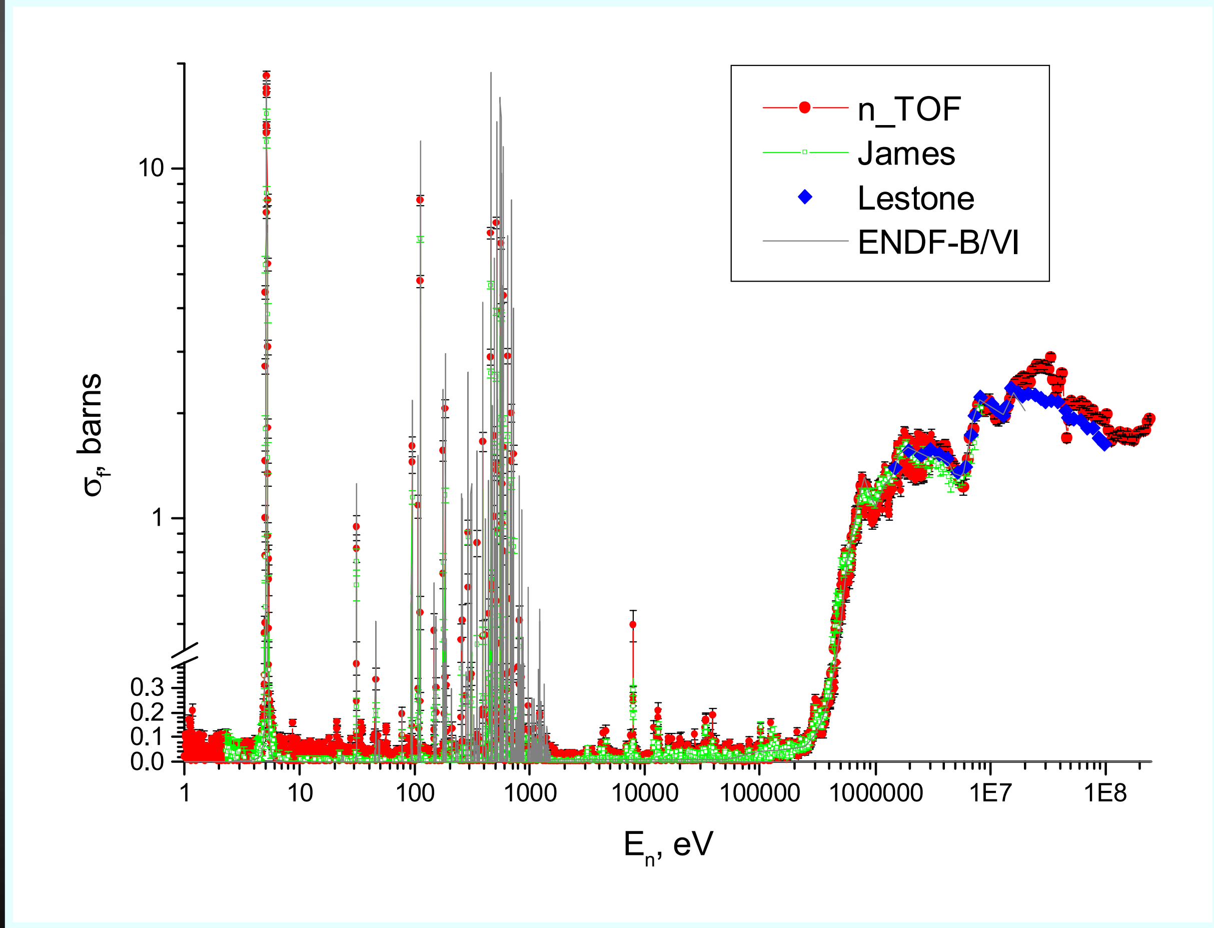


# Basic characteristics of experiments at n_TOF

- wide energy range

PPACs & FIC-0 (2003)

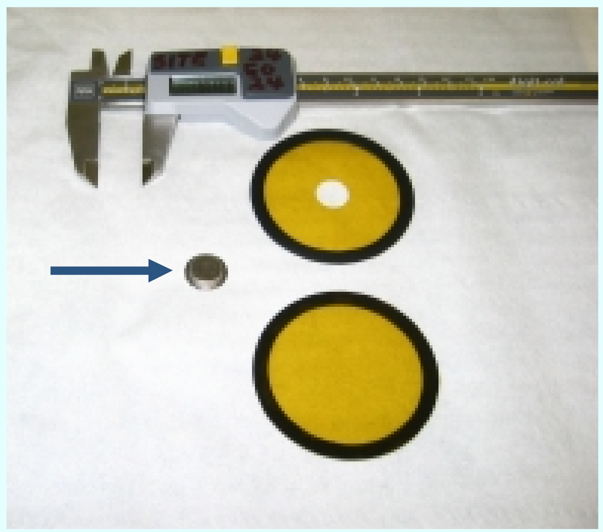
$^{234}U(n,f)$



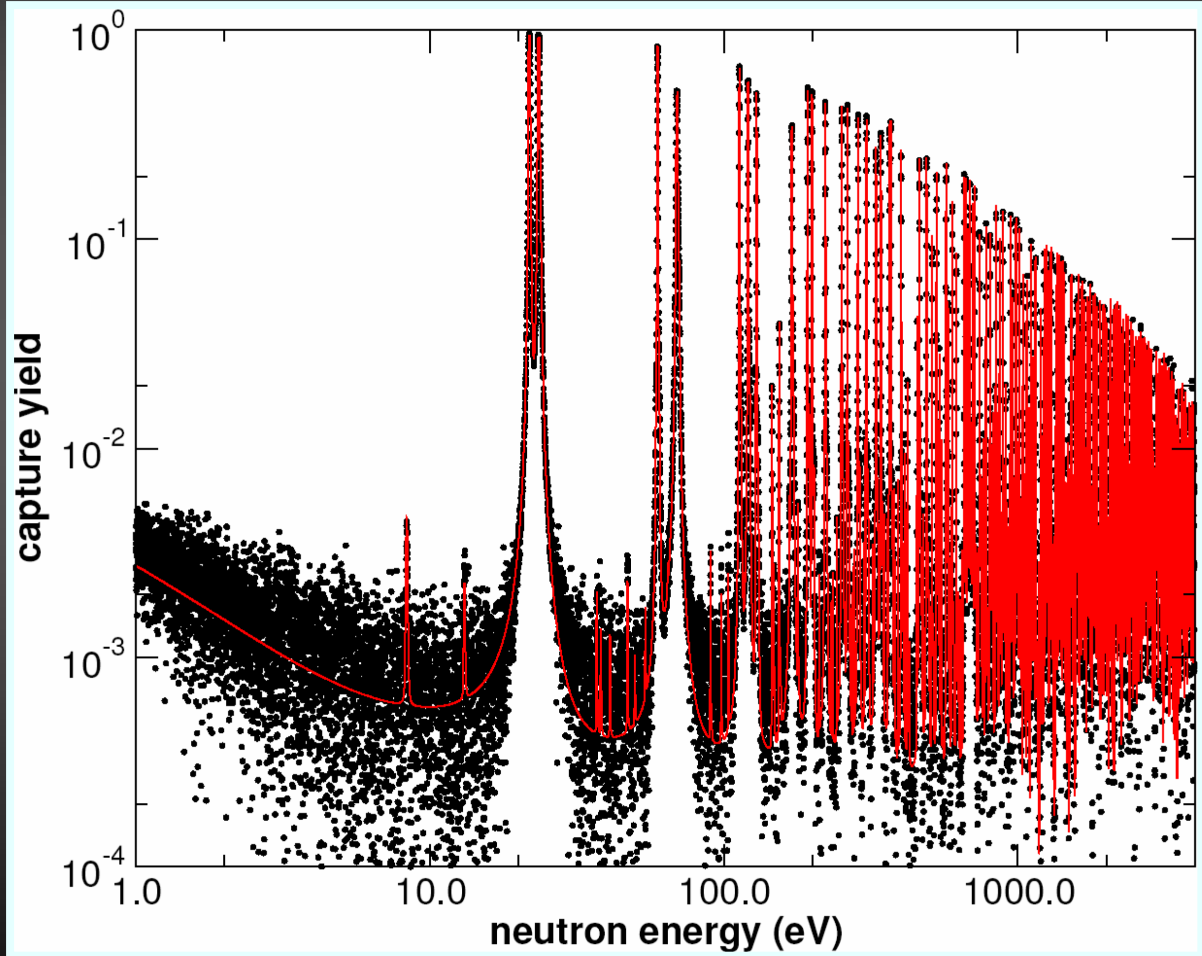
# Basic characteristics of experiments at n_TOF

- wide energy range
- high neutron flux & high energy resolution

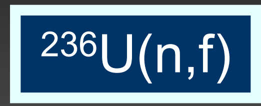
small samples



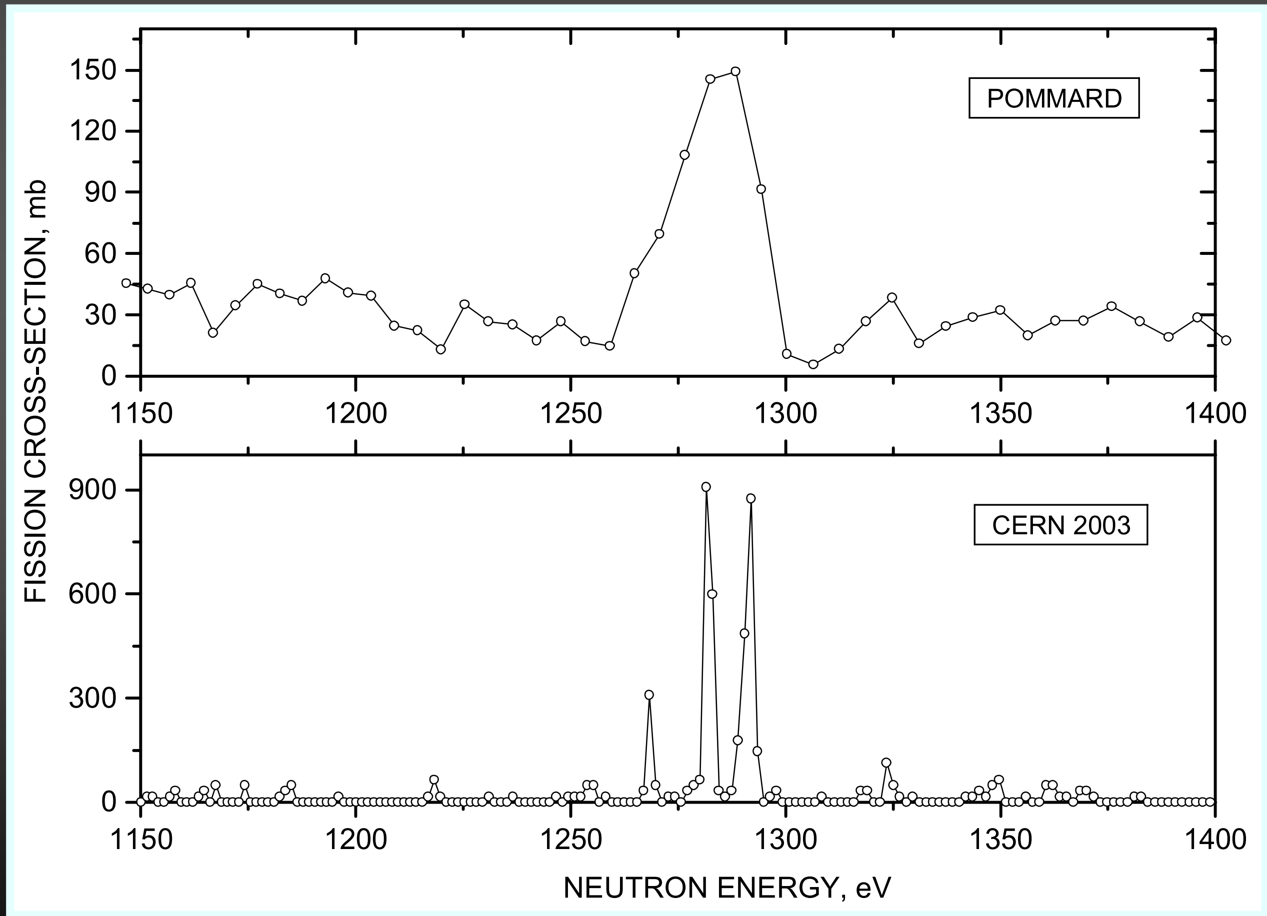
$^{232}Th(n,\gamma)$



# Basic characteristics of experiments at n_TOF



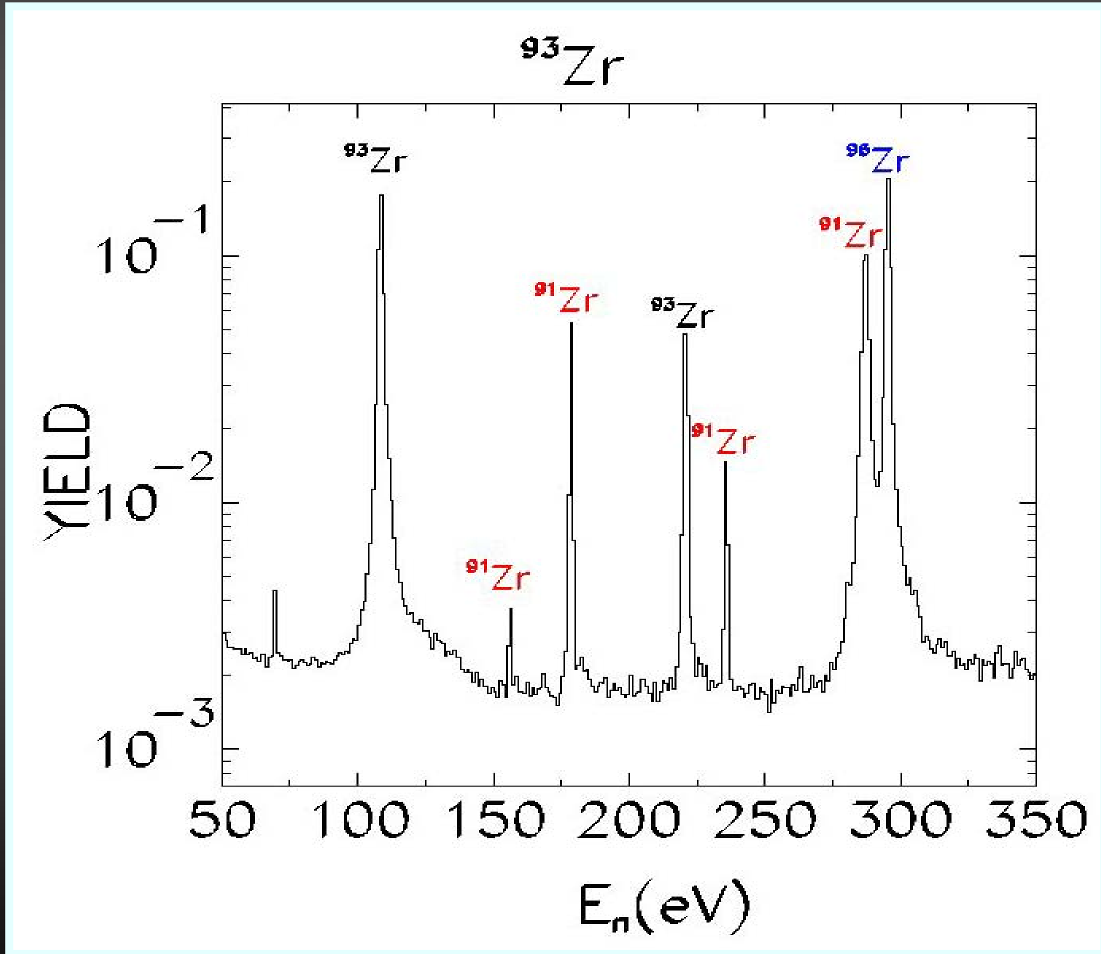

- wide energy range
- high neutron flux & high energy resolution



# Basic characteristics of experiments at n_TOF

$^{93}Zr(n,\gamma)$

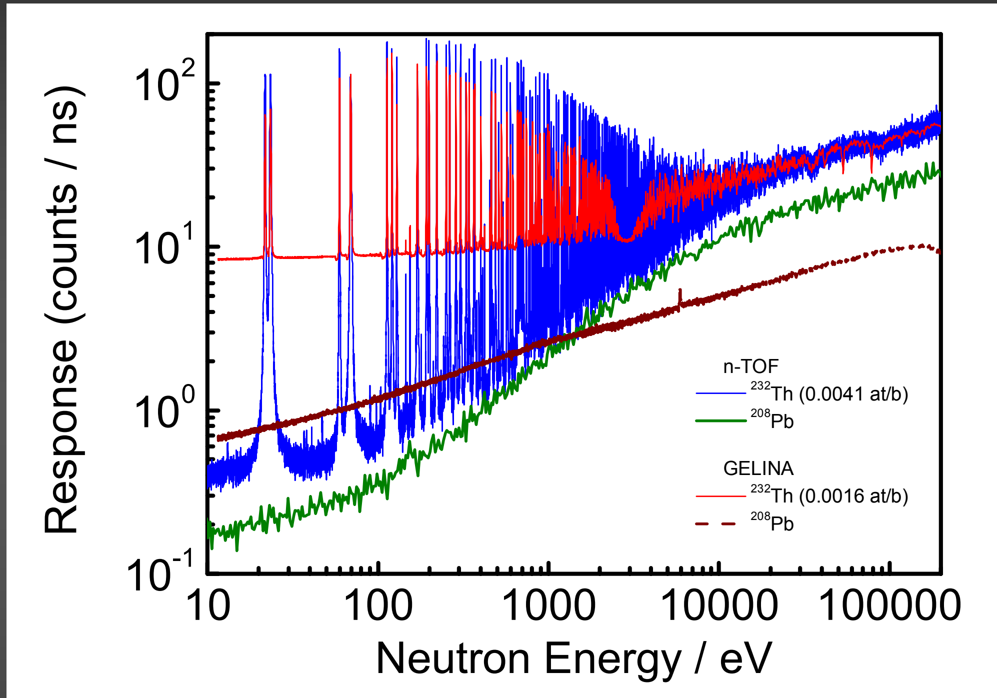
- wide energy range
- high neutron flux & high energy resolution



# Basic characteristics of experiments at n_TOF

$^{232}Th(n,\gamma)$

- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver




source: P Rullhusen (GELINA)

$$\frac{f_1}{f_2} \times \frac{L_1}{L_2} = \frac{0.28\,[1/s]}{800\,[1/s]} \times \frac{187.5\,[m]}{30\,[m]} = \frac{1}{457}$$

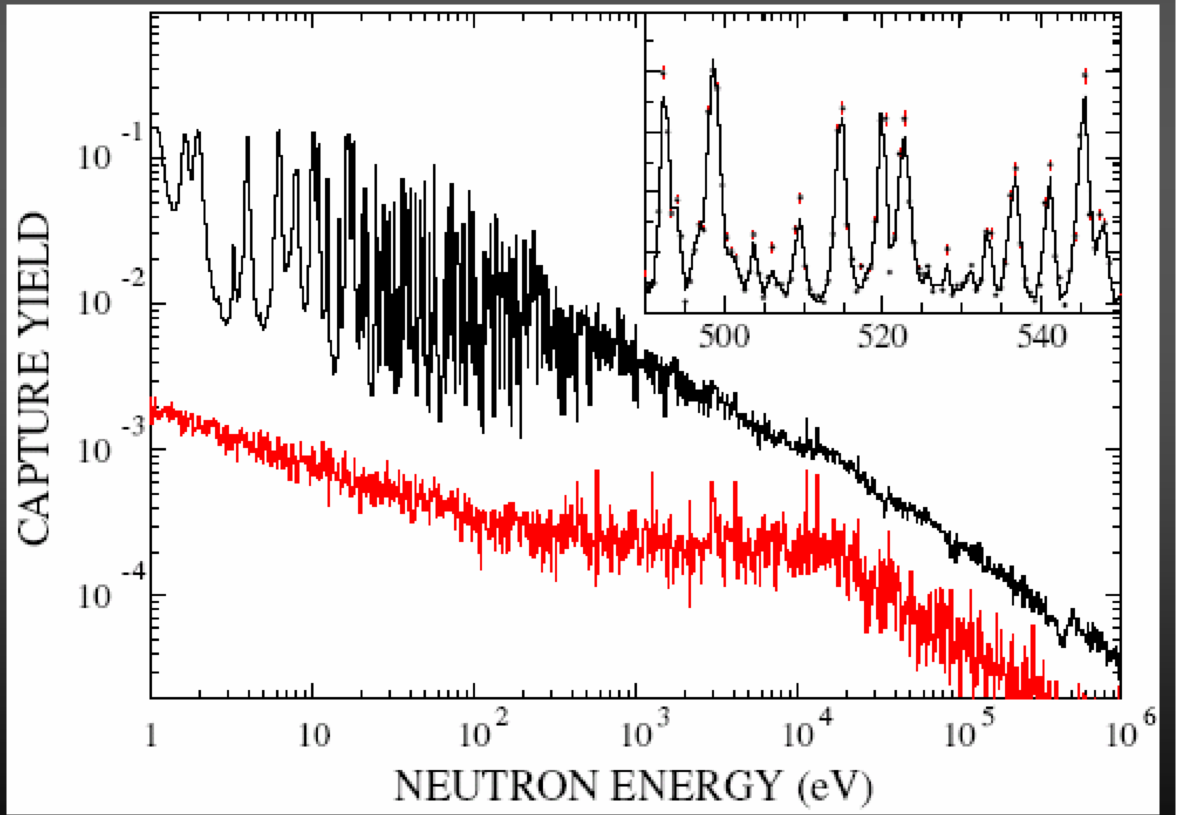
comparison with GELINA (~ same average flux at 30m)

# Basic characteristics of experiments at n_TOF

- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver
- low background conditions

U Abbondanno et al. (The n_TOF Collaboration)
Phys. Rev. Lett. **93** (2004), 161103
&
S Marrone et al. (The n_TOF Collaboration)
Phys. Rev. C **73** 03604 (2006)

$^{151}$Sm(n,γ)

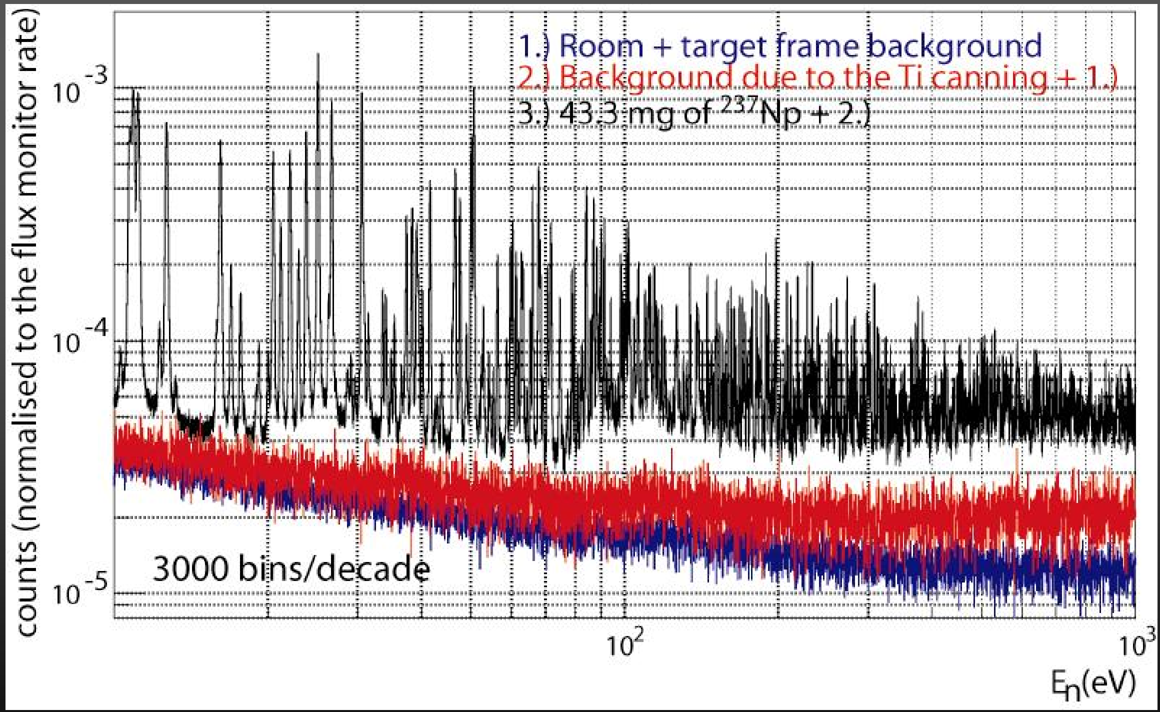


# Basic characteristics of experiments at n_TOF

- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver
- low background conditions

$^{237}Np(n,\gamma)$

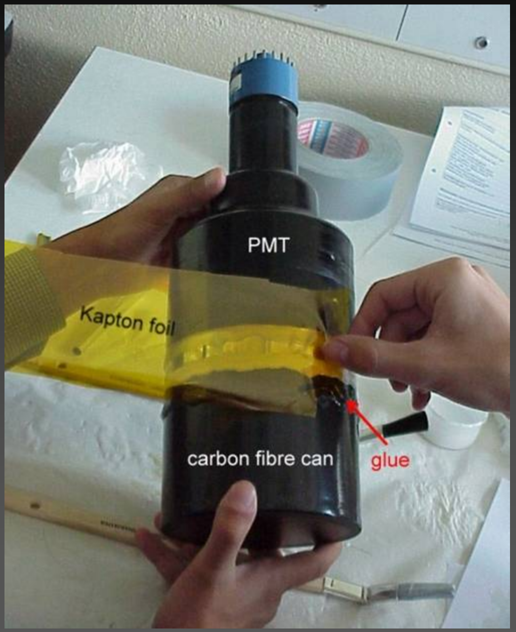
D Cano-Ott, *et al.* (The n_TOF Collaboration)
ND2004 Conference, Santa Fe, NM – Sept. 2004

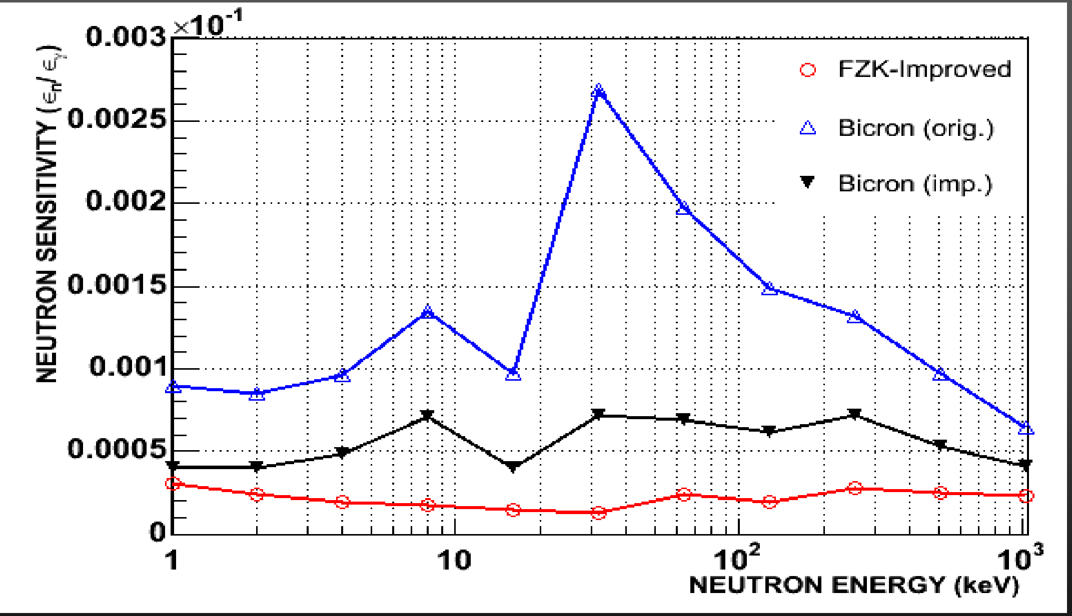


# Basic characteristics of experiments at n_TOF

- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver
- low background conditions

- detectors with extremely low neutron sensitivity



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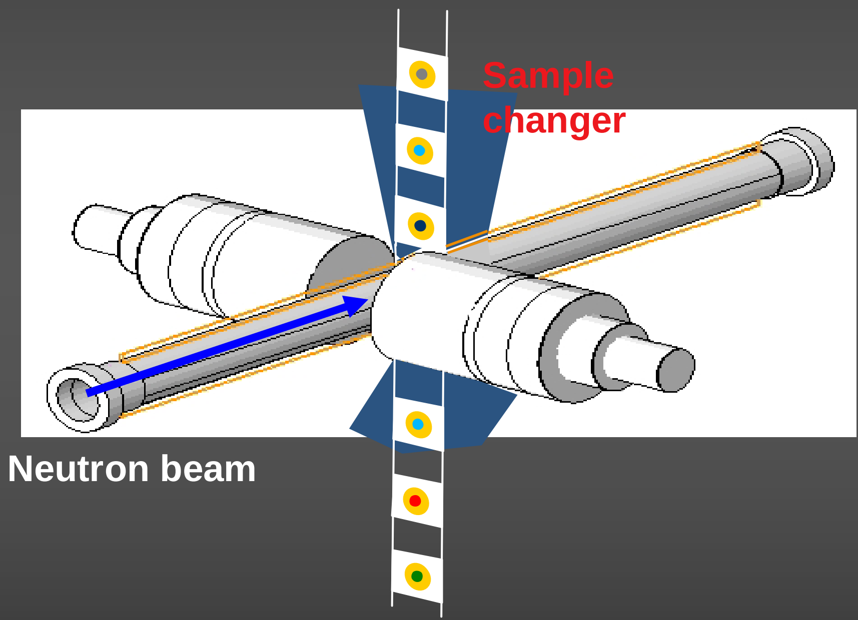
- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver
- low background conditions

- detectors with extremely low neutron sensitivity



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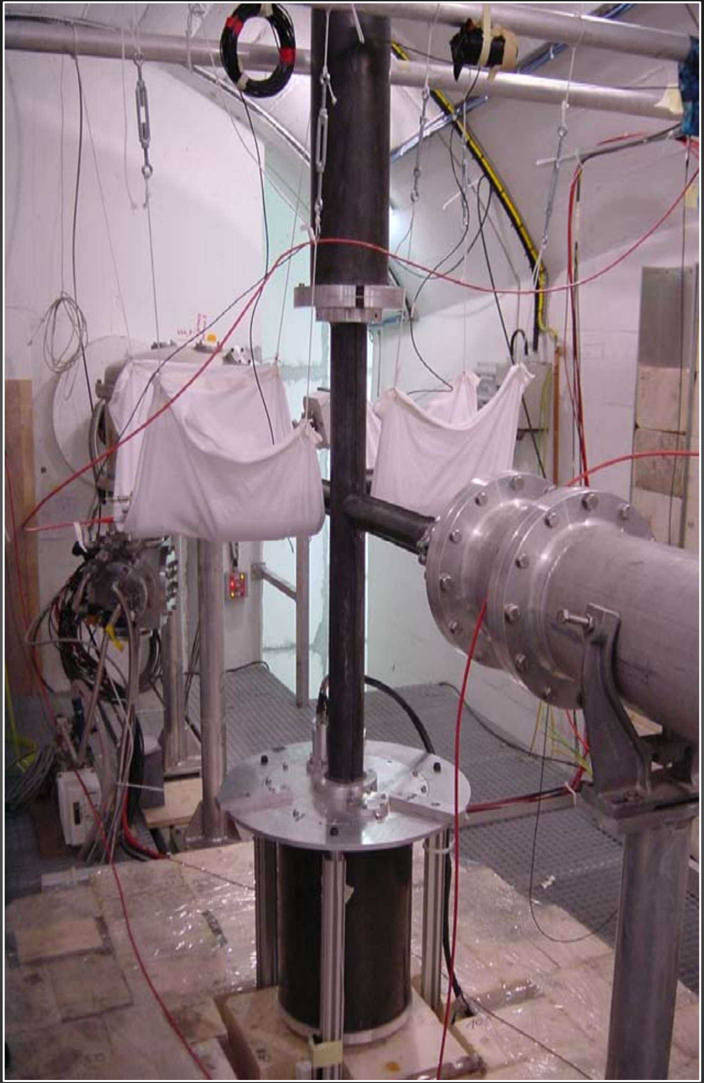
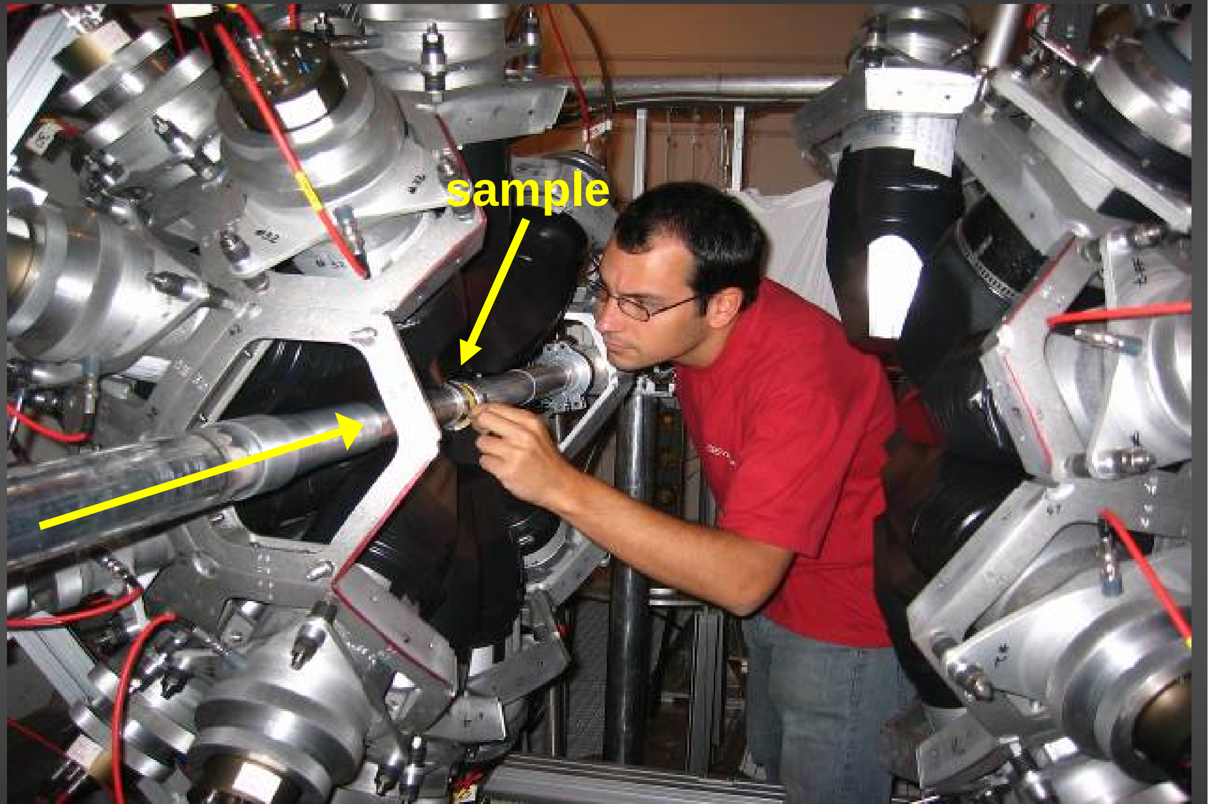


sample changer and beam pipe made out of carbon fiber

# Basic characteristics of experiments at n_TOF

- 40 $BaF_2$ crystals
- high detection efficiency ≈100%
- good energy resolution




- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver
- low background conditions
- detectors with extremely low neutron sensitivity
- high-efficiency detectors (TAC)

more >>

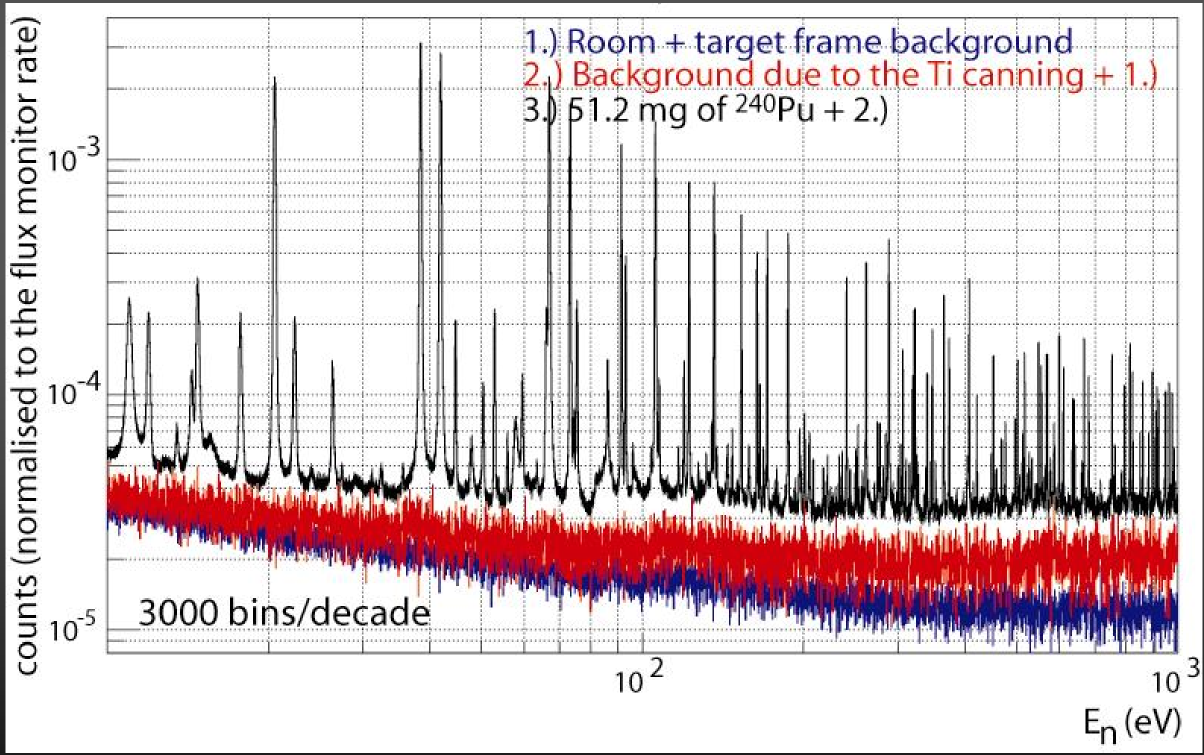
# Basic characteristics of experiments at n_TOF

- wide energy range
- high neutron flux & high energy resolution
- low repetition rate of the proton driver
- low background conditions

- detectors with extremely low neutron sensitivity
- high-efficiency detectors (TAC)

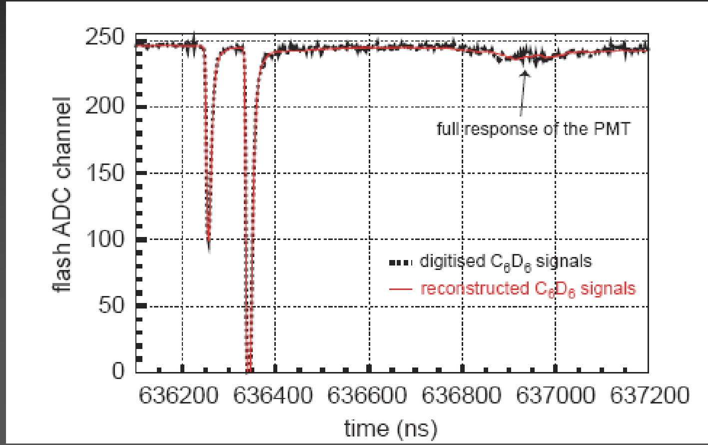
$^{240}Pu(n,\gamma)$

C Guerrero *et al.* (The n_TOF Collaboration)
ND2007 Conference, Nice, France, April 2007



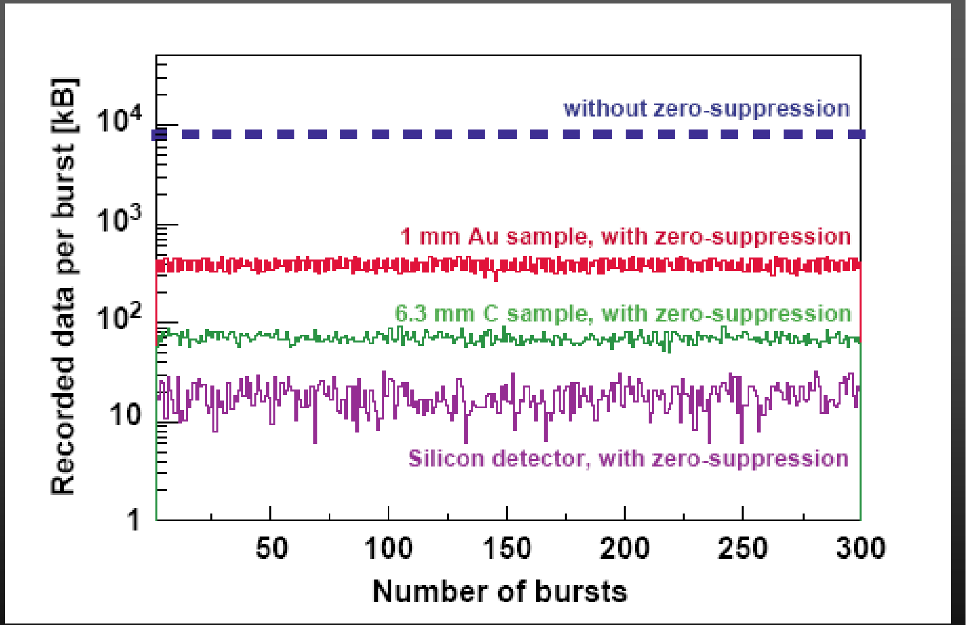
# Basic characteristics of experiments at n_TOF

R Plag et al. (The n_TOF Collaboration)
NIMA 538 (2005) 693




- wide energy range
- high neutron flux &
  high energy resolution
- low repetition rate
  of the proton driver
- low background conditions

- detectors with extremely
  low neutron sensitivity
- high-efficiency detectors (TAC)
- advanced daq system



# Basic characteristics of experiments at n_TOF

- wide energy range
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- low repetition rate of the proton driver
- low background conditions

- detectors with extremely low neutron sensitivity
- high-efficiency detectors (TAC)
- advanced daq system

**n_TOF beam characteristics and experimental setup proved to be a unique combination for high accuracy measurements**

# n_TOF experiments

## Capture

$^{151}$Sm

$^{204,206,207,208}$Pb, $^{209}$Bi

$^{232}$Th

$^{24,25,26}$Mg

$^{90,91,92,94,96}$Zr, $^{93}$Zr

$^{139}$La

$^{186,187,188}$Os

$^{233,234}$U

$^{237}$Np, $^{240}$Pu, $^{243}$Am

## Fission

$^{233,234,235,236,238}$U

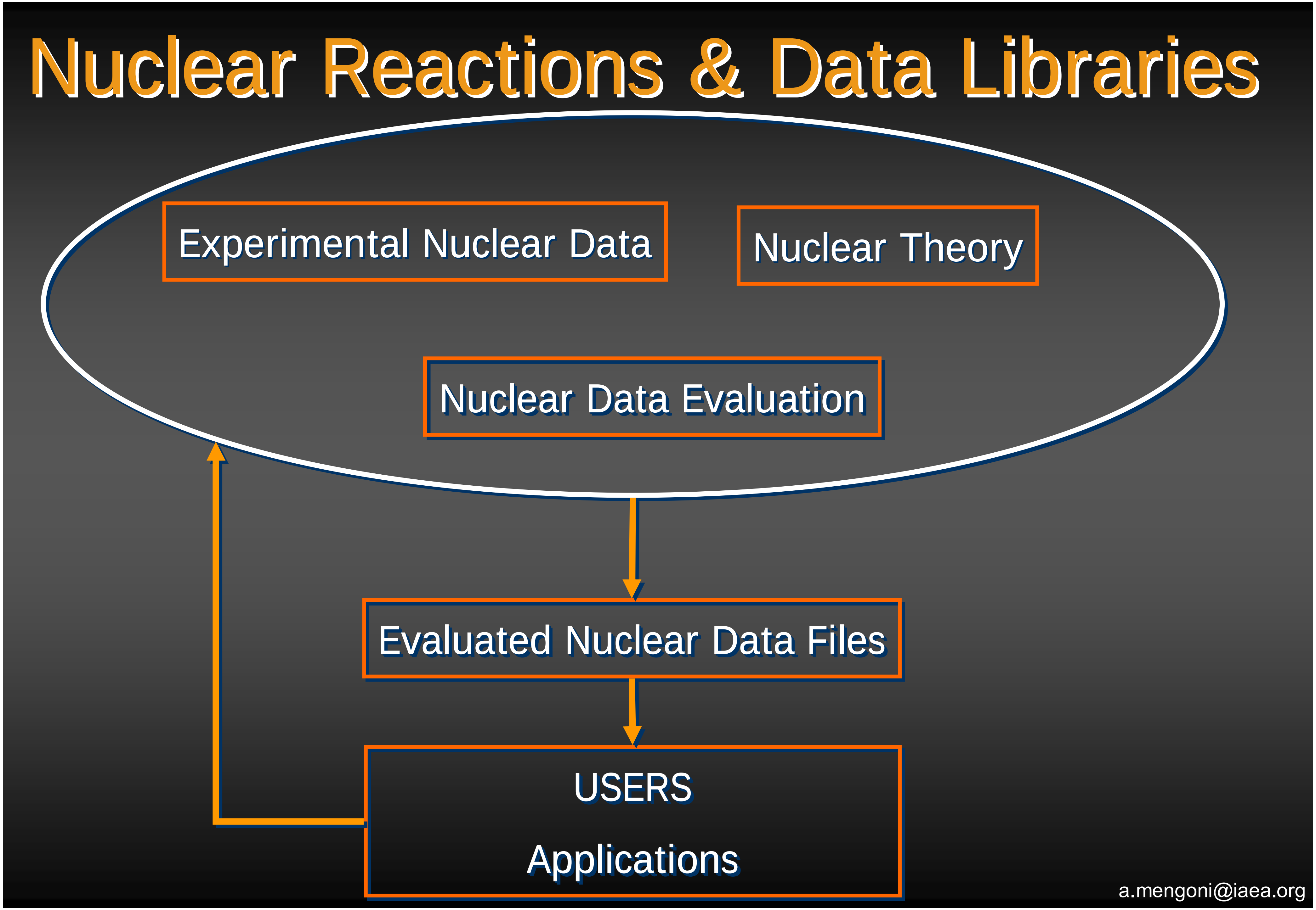
$^{232}$Th

$^{209}$Bi

$^{237}$Np

$^{241,243}$Am, $^{245}$Cm

- Measurements of neutron cross sections relevant for Nuclear Waste Transmutation and related Nuclear Technologies
  - Th/U fuel cycle (capture & fission)
  - Transmutation of MA (capture & fission)
  - Transmutation of FP (capture)
- Cross sections relevant for Nuclear Astrophysics
  - s-process: branchings
  - s-process: presolar grains
- Neutrons as probes for fundamental Nuclear Physics
  - Nuclear level density & n-nucleus interaction



Nuclear Reactions & Data Libraries
Experimental Nuclear Data
Nuclear Theory
Nuclear Data Evaluation
Evaluated Nuclear Data Files
USERS
Applications
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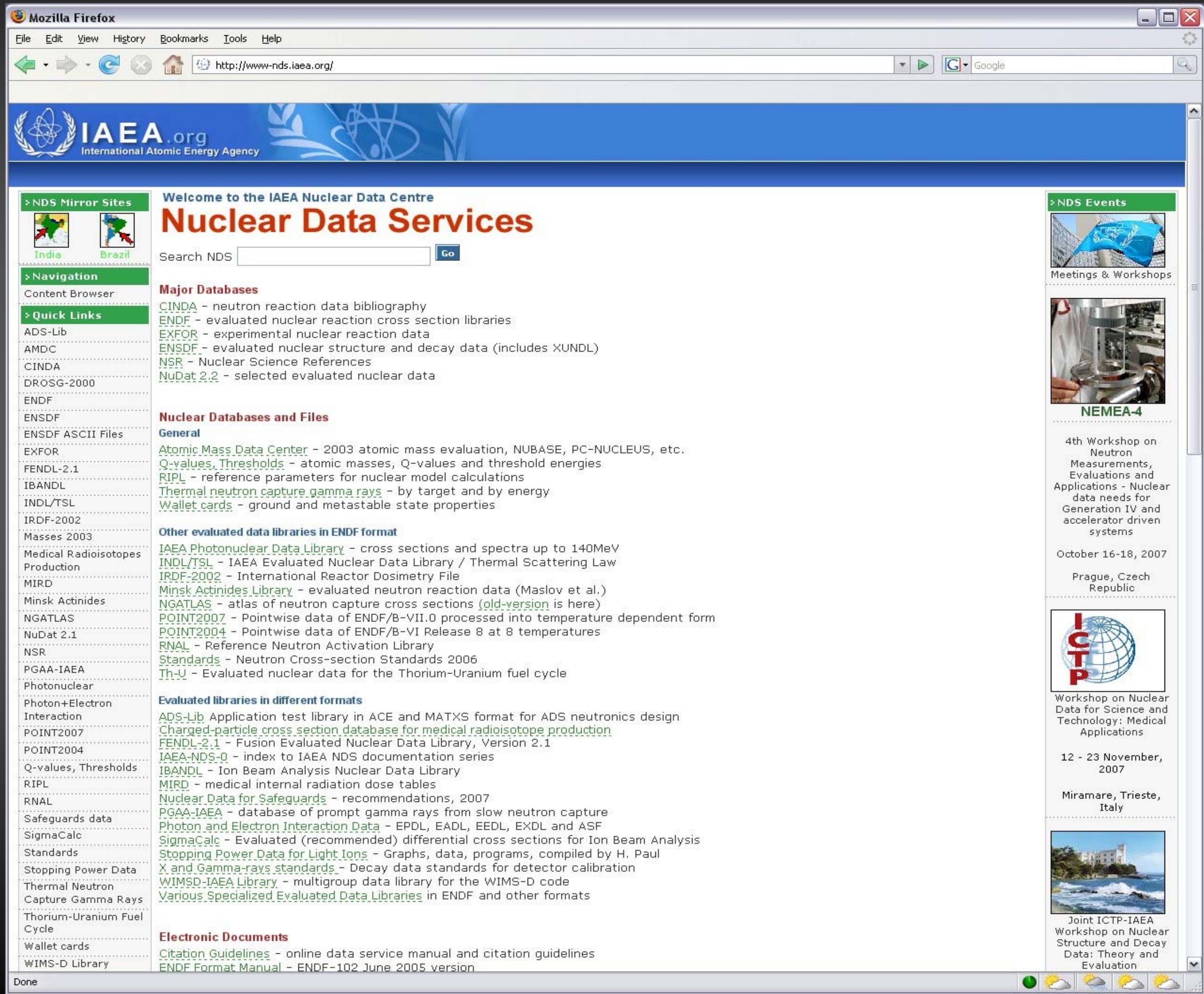
# Evaluated Data Libraries

Evaluated data sets are produced through the process of critical comparison, selection renormalization and averaging of the available experimental data, normally complemented by nuclear model calculations.

Evaluated Libraries are computer files of evaluated data which, appropriately processed, form the input data to computations for a wide variety of nuclear science and technology applications. Each of these evaluated libraries may consist of individual evaluated data sets for several hundred isotopes or elements (commonly referred to as 'materials').

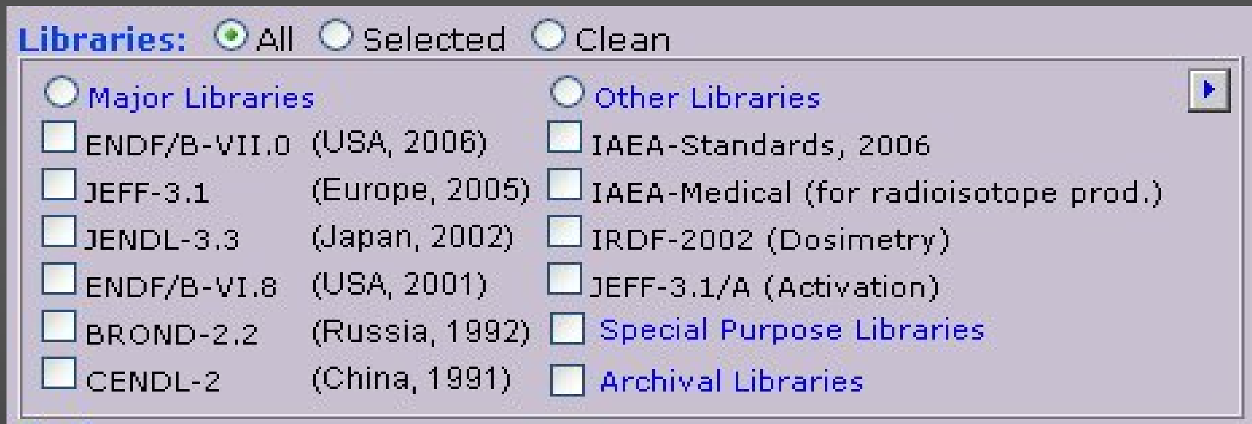
# Data Libraries




www-nds.iaea.org

# Data Libraries

Major Evaluated Nuclear Data libraries available for display & retrieval:



# The End

a.mengoni@iaea.org

# n_TOF experiments

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$^{232}$Th(n,γ)

Th/U nuclear fuel cycle


The n_TOF Collaboration

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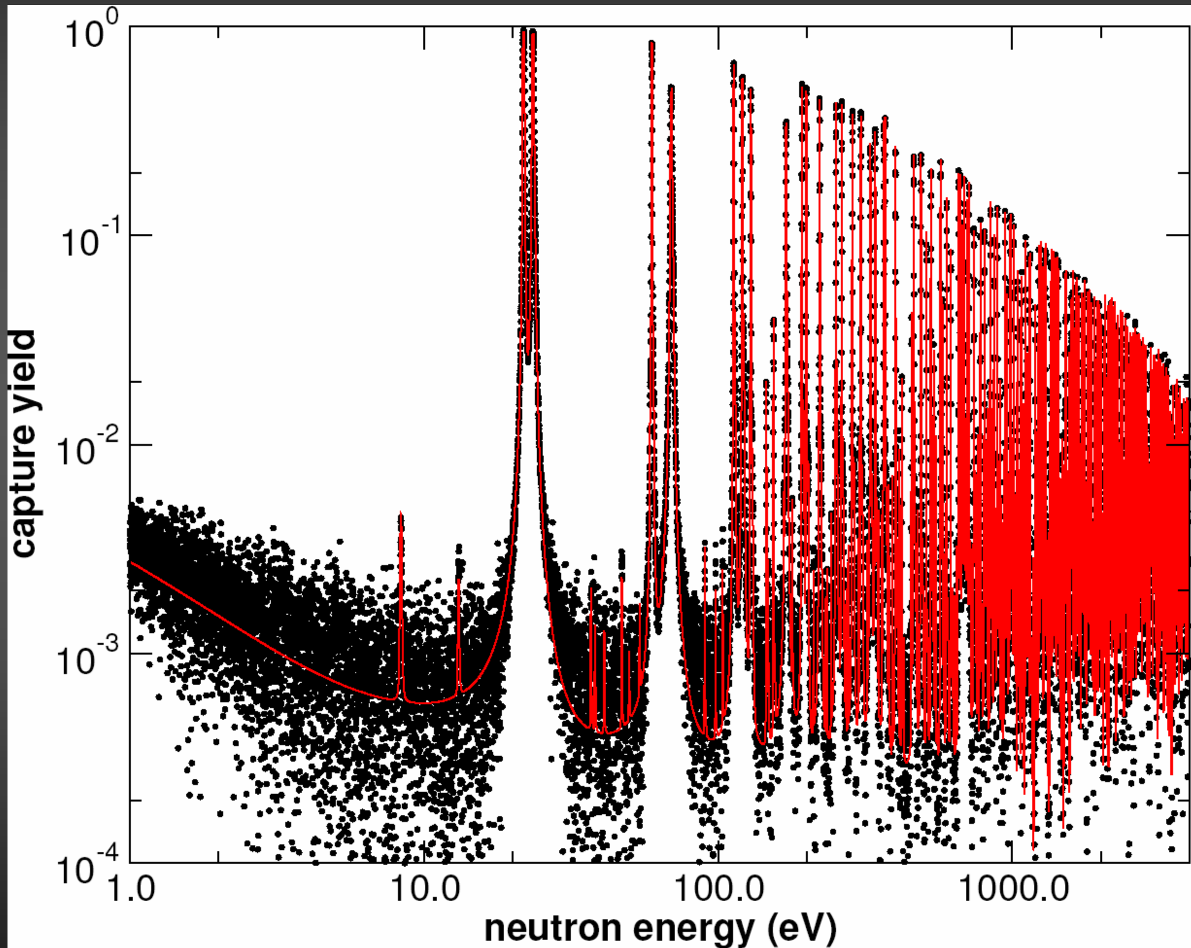
F Gunsing, et al. - The n_TOF Collaboration
ND2004 Conference, Santa Fe, NM – Sept. 2004




extremely high-resolution data!

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$^{232}Th(n,\gamma)$

F Gunsing, et al. - The n_TOF Collaboration
ND2004 Conference, Santa Fe, NM – Sept. 2004
&
G Aerts et al. (The n_TOF Collaboration)
Phys. Rev. C 73, 054610 (2006)

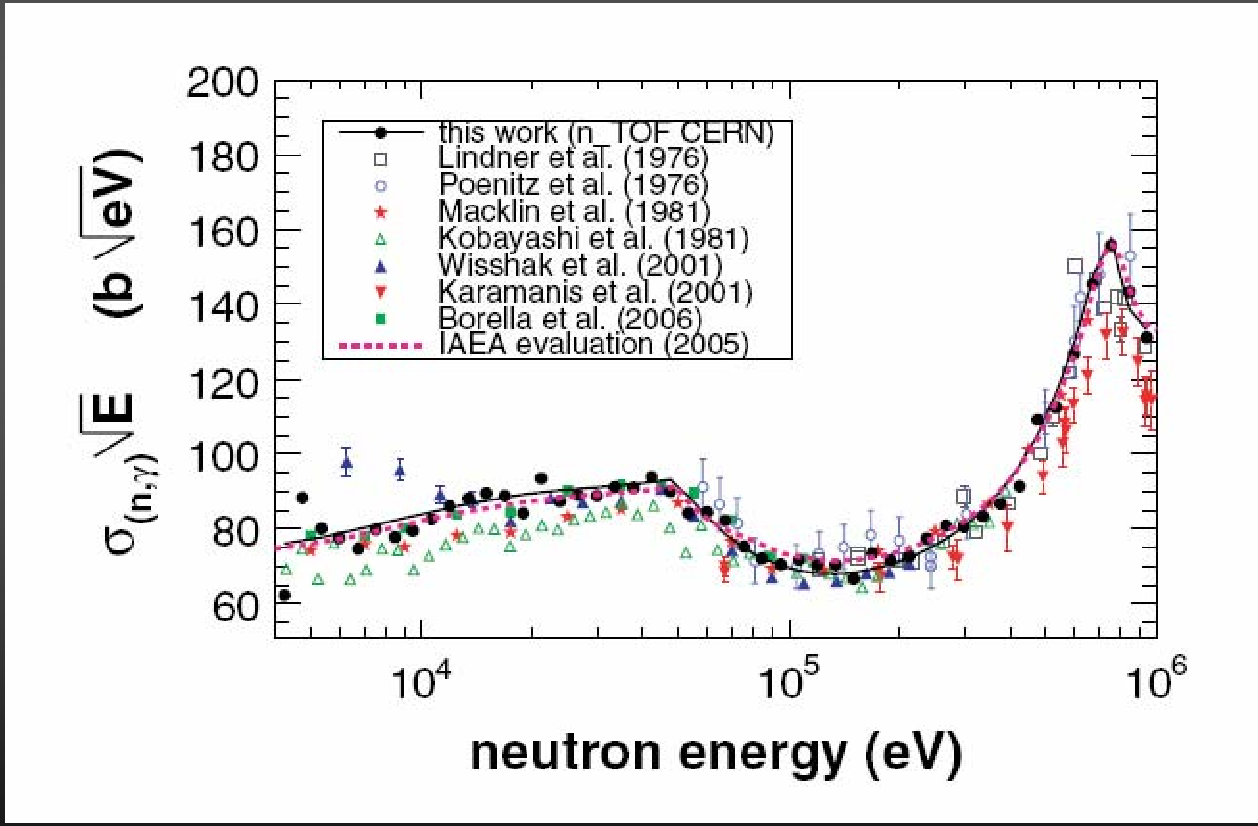

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TABLE II. Different components of estimated systematic or correlated uncertainty in the measured cross section.

| Component | Uncertainty (%) |
|---|---|
| PHWT | 0.5 |
| Normalization | 0.5 |
| Background | 2.5 |
| Flux shape | 2.0 |
| Total | 3.3 |

| $E_{low}$ (keV) | $E_{high}$ (keV) | Cross section (b) | Uncertainty (b) |
|---|---|---|---|
| 3.994 | 4.482 | 0.958 | 0.020 |
| 4.482 | 5.028 | 1.281 | 0.021 |
| 5.028 | 5.642 | 1.097 | 0.016 |
| 5.642 | 6.331 | 1.004 | 0.014 |
| 6.331 | 7.103 | 0.912 | 0.013 |
| 7.103 | 7.970 | 0.919 | 0.013 |
| 7.970 | 8.942 | 0.848 | 0.013 |
| 8.942 | 10.033 | 0.817 | 0.012 |
| 10.033 | 11.257 | 0.800 | 0.012 |
| 11.257 | 12.631 | 0.787 | 0.012 |
| 12.631 | 14.172 | 0.761 | 0.012 |
| 14.172 | 15.902 | 0.729 | 0.011 |
| 15.902 | 17.842 | 0.685 | 0.011 |
| 17.842 | 20.019 | 0.613 | 0.010 |
| 20.019 | 22.461 | 0.641 | 0.010 |
| 22.461 | 25.202 | 0.566 | 0.009 |
| 25.202 | 28.277 | 0.545 | 0.009 |
| 28.277 | 31.728 | 0.513 | 0.008 |
| 31.728 | 35.599 | 0.497 | 0.009 |
| 35.599 | 39.943 | 0.468 | 0.009 |
| 39.943 | 44.816 | 0.456 | 0.008 |
| 44.816 | 50.285 | 0.413 | 0.007 |
| 50.285 | 56.421 | 0.365 | 0.006 |
| 56.421 | 63.305 | 0.346 | 0.006 |
| 63.305 | 71.029 | 0.318 | 0.006 |
| 71.029 | 79.696 | 0.275 | 0.005 |
| 79.696 | 89.421 | 0.248 | 0.005 |
| 89.421 | 100.332 | 0.229 | 0.005 |
| 100.332 | 112.574 | 0.220 | 0.004 |
| 112.574 | 126.310 | 0.204 | 0.004 |
| 126.310 | 141.722 | 0.192 | 0.004 |

For $E_n$ = 4 keV up to 1 MeV full dataset is available on the PRC publication

# n_TOF experiments

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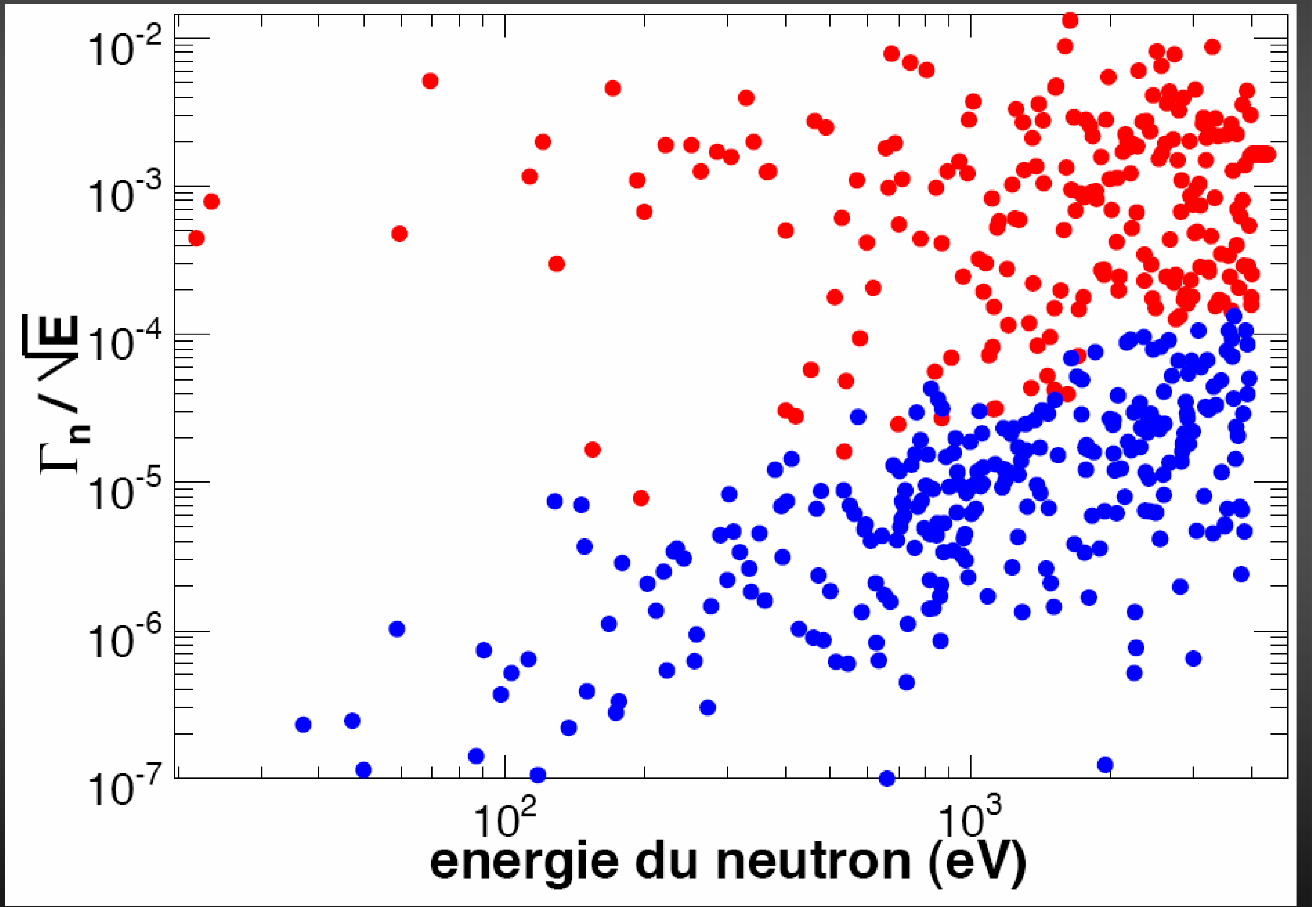
$^{232}Th(n,\gamma)$

F Gunsing, et al. - The n_TOF Collaboration
analysis in progress



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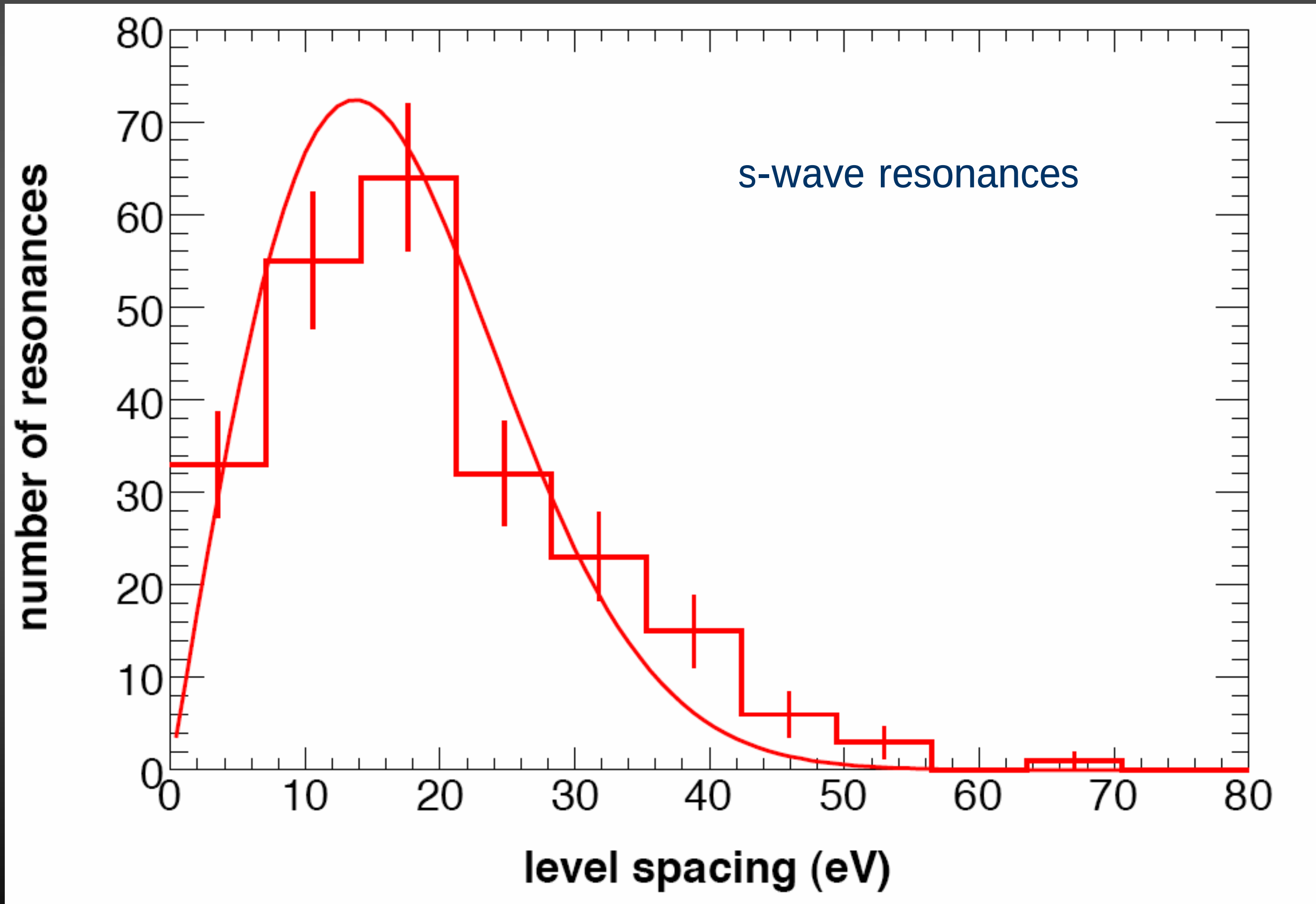
F Gunsing, et al. - The n_TOF Collaboration
analysis in progress



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