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Neutron induced reactions at the n_TOF facility at CERN

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on behalf of the n_TOF Collaboration

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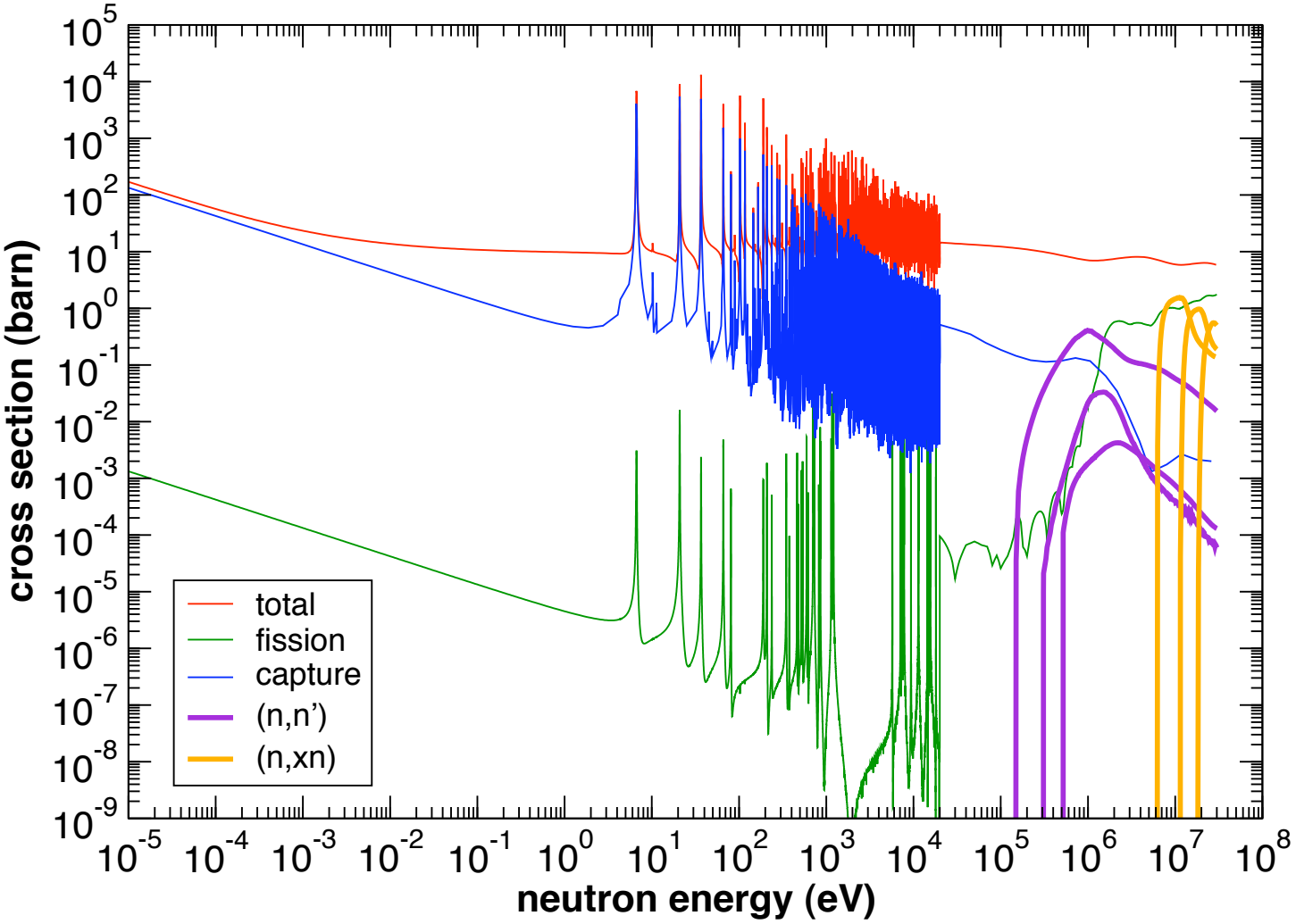
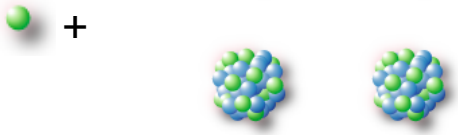
Neutron induced reaction cross sections

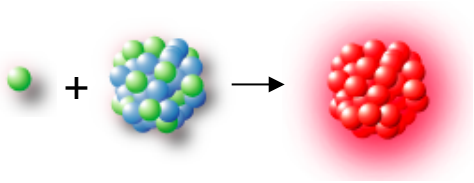


Neutron induced reactions

solid state



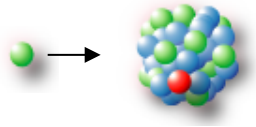
compound nucleus reactions



$\tau \sim 10^{-16}$

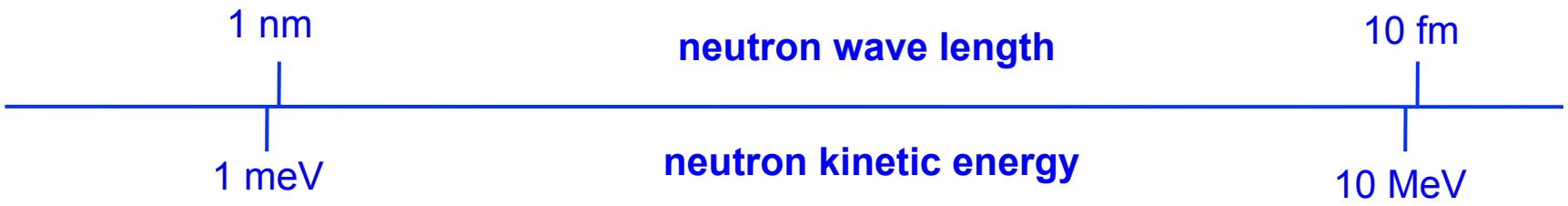
$E_n < 10$ MeV

direct reactions



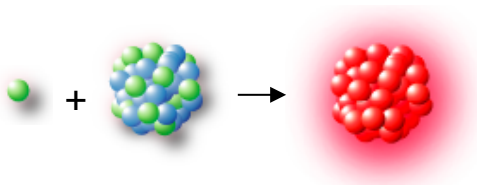
$\tau \sim 10^{-22}$

$E_n > 10$ MeV



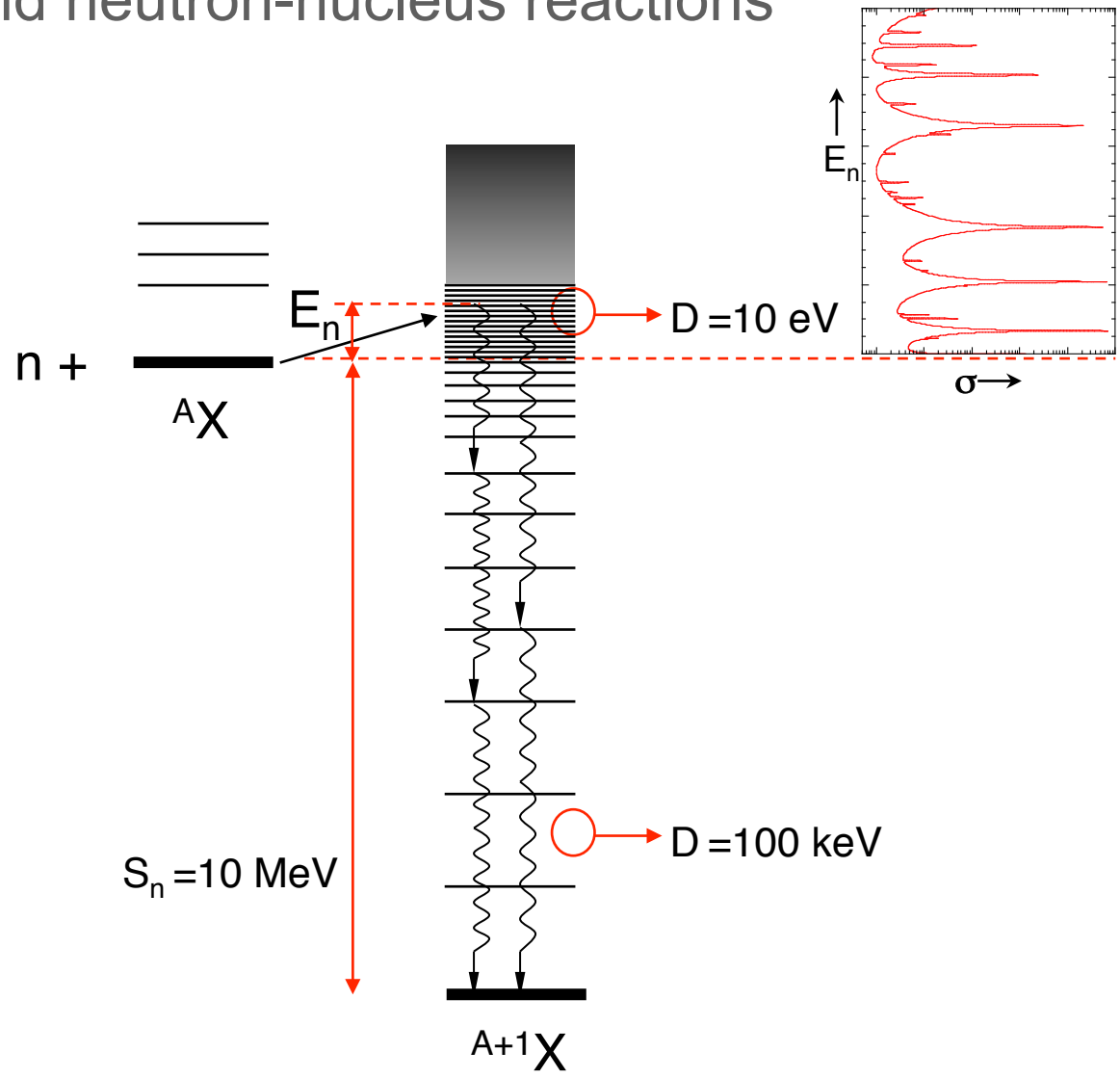
Compound neutron-nucleus reactions

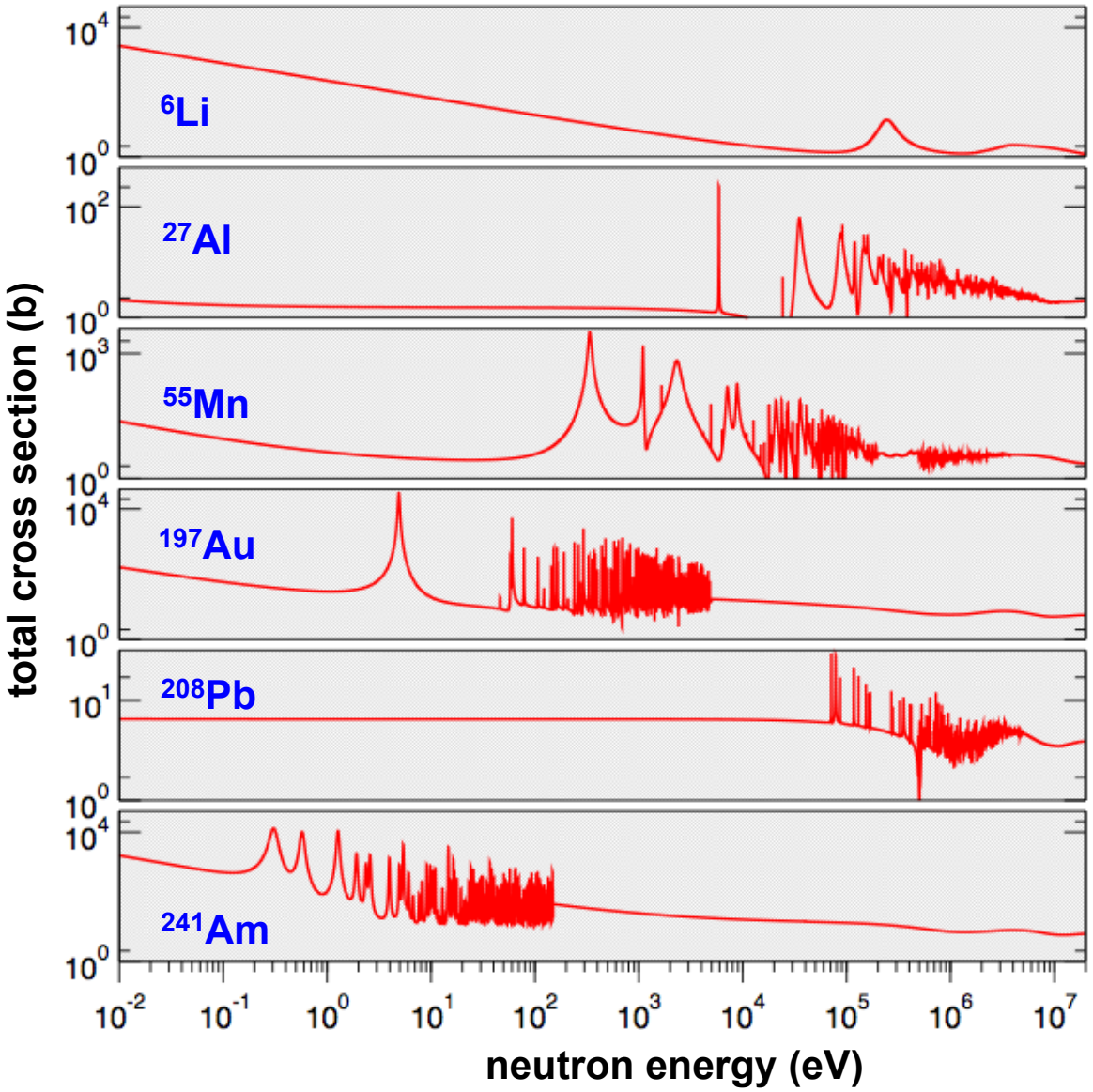
compound nucleus reaction



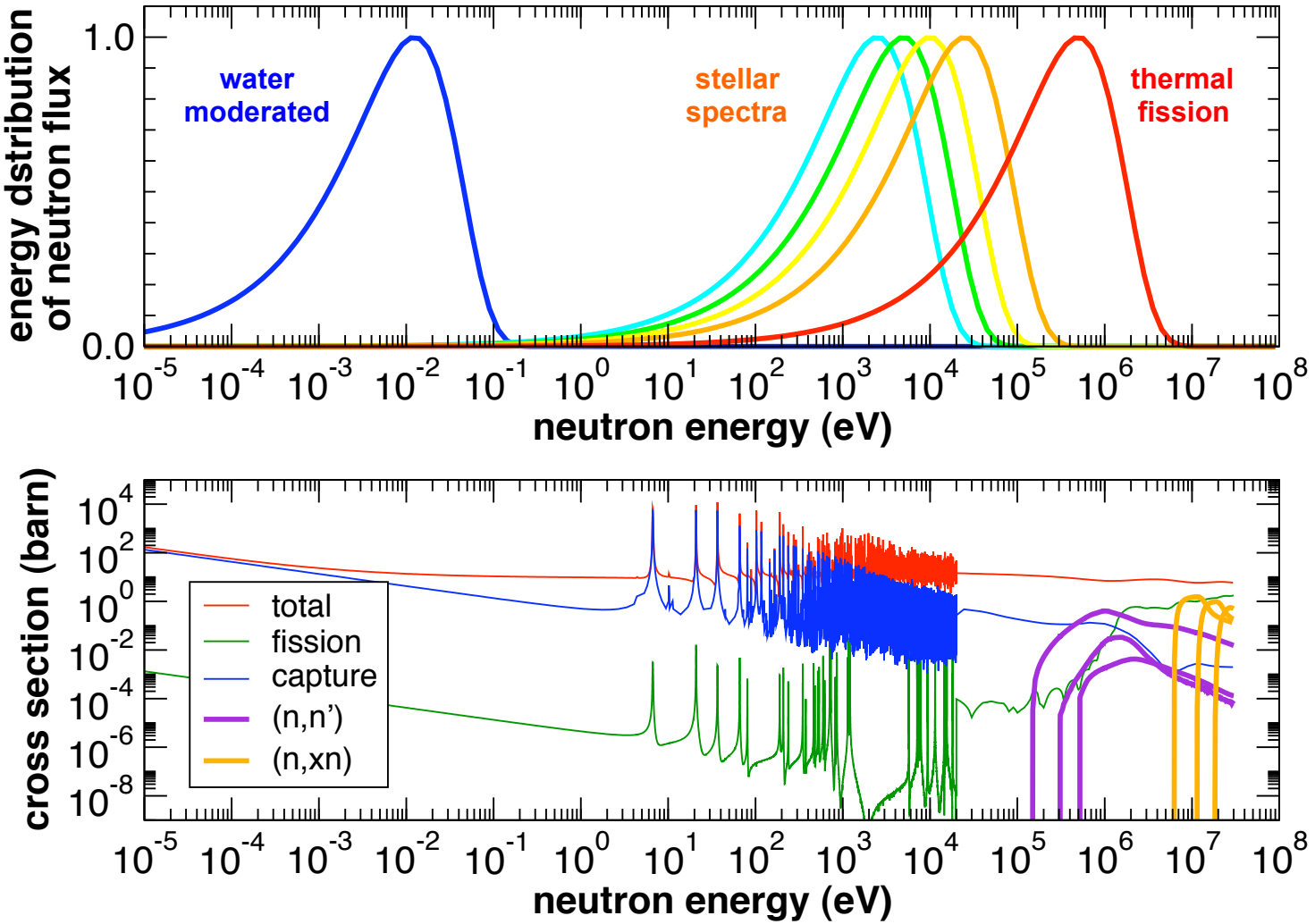
$\tau \sim 10^{-16}$

$E_n < 10$ MeV

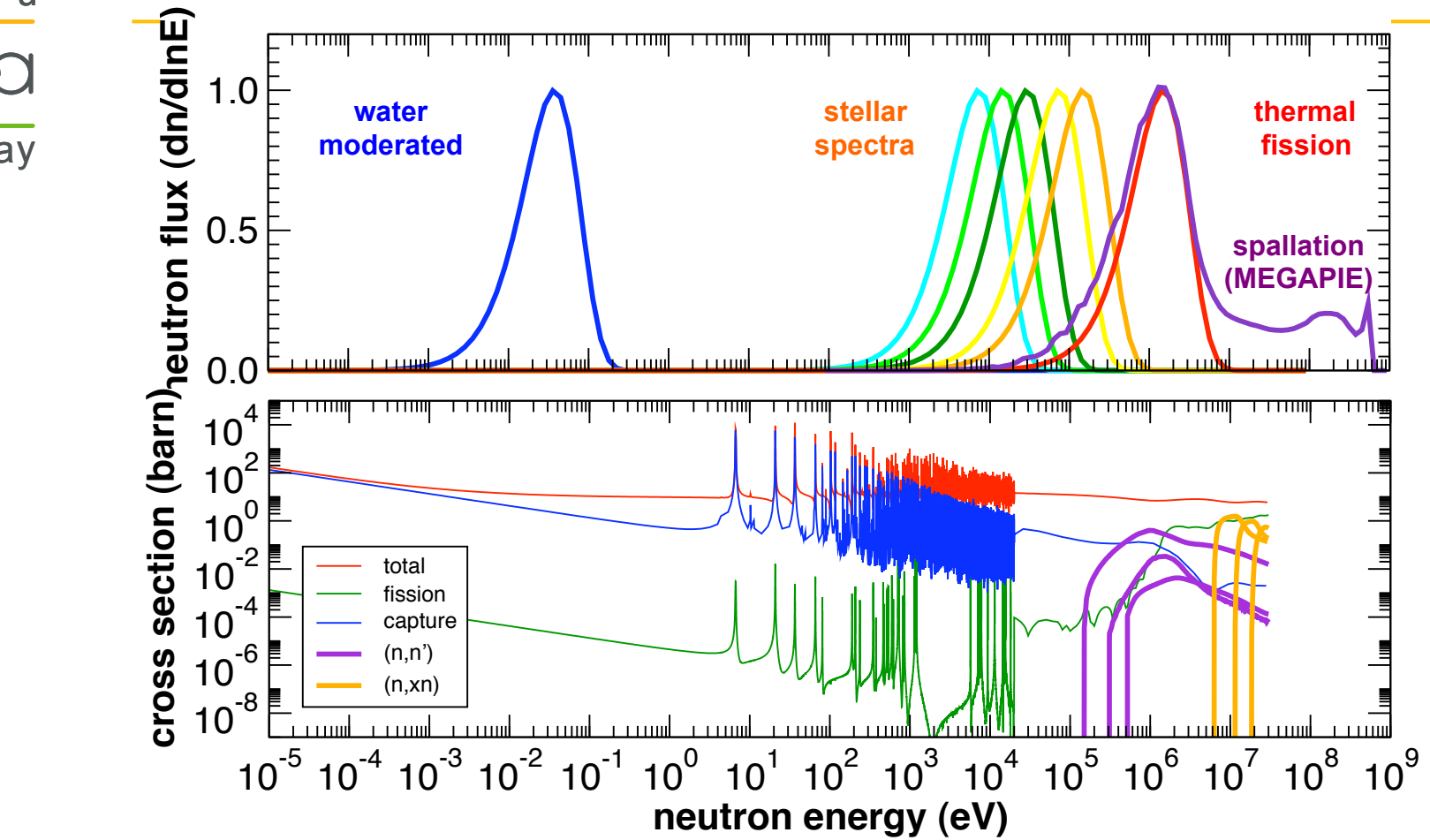


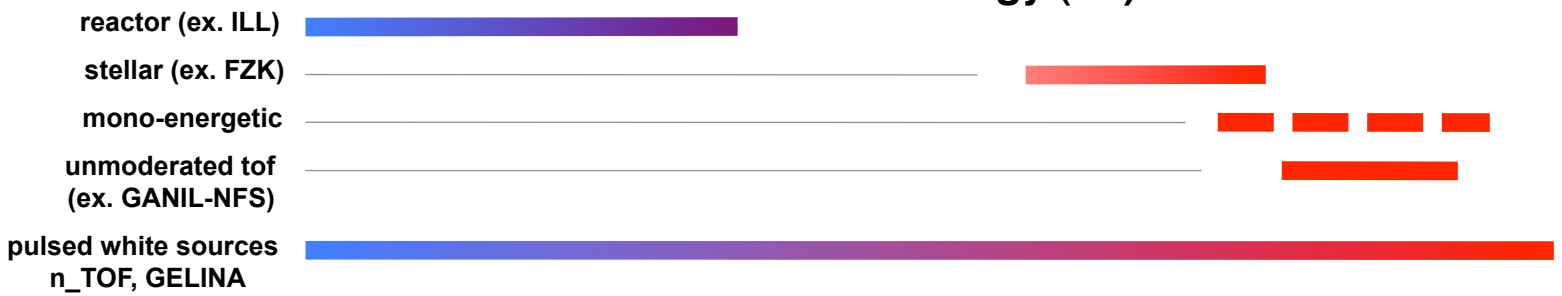

total cross section (b)
neutron energy (eV)
6Li
27Al
55Mn
197Au
208Pb
241Am

Neutron fluxes and cross sections

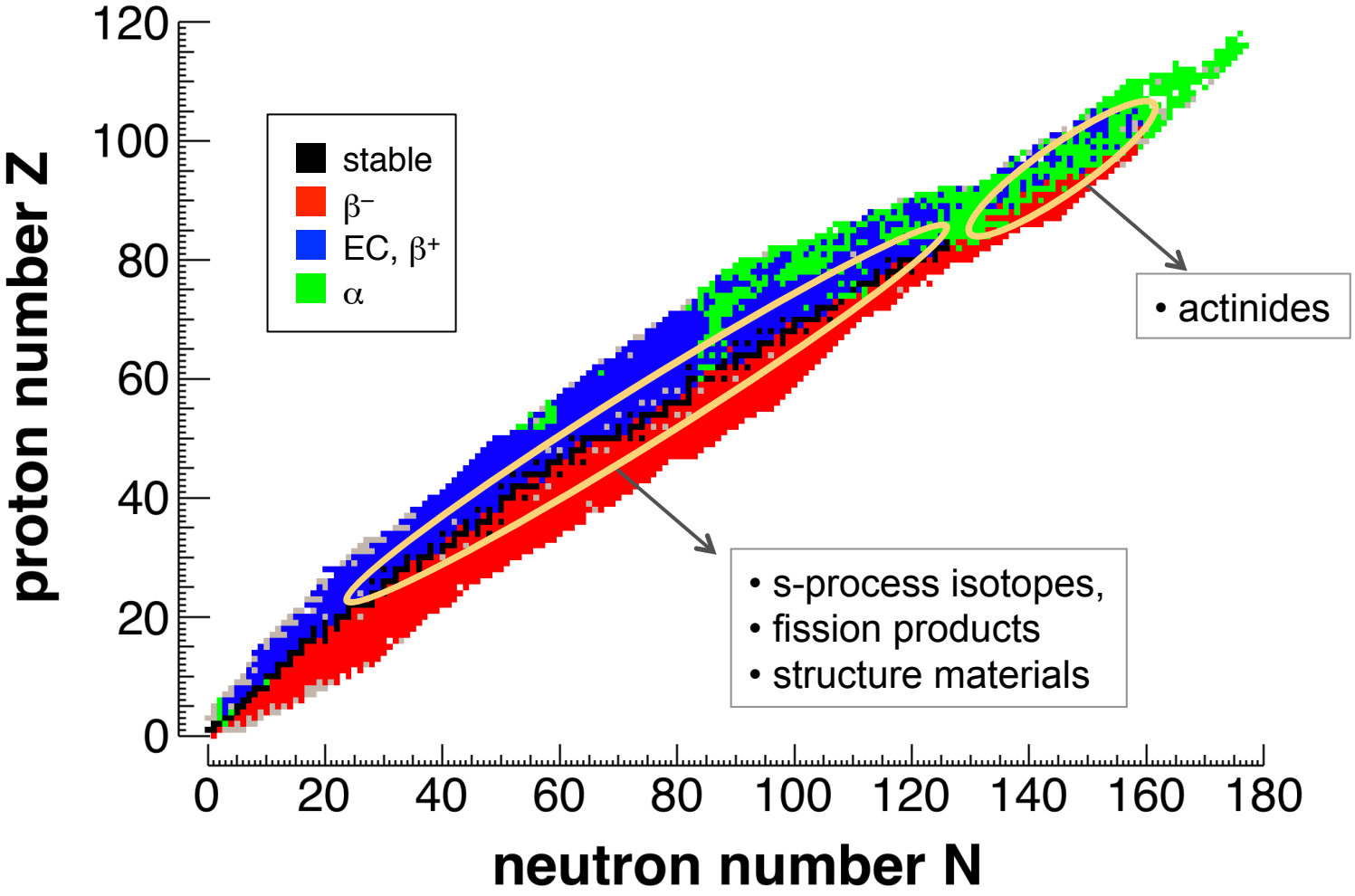


Neutron fluxes and cross sections

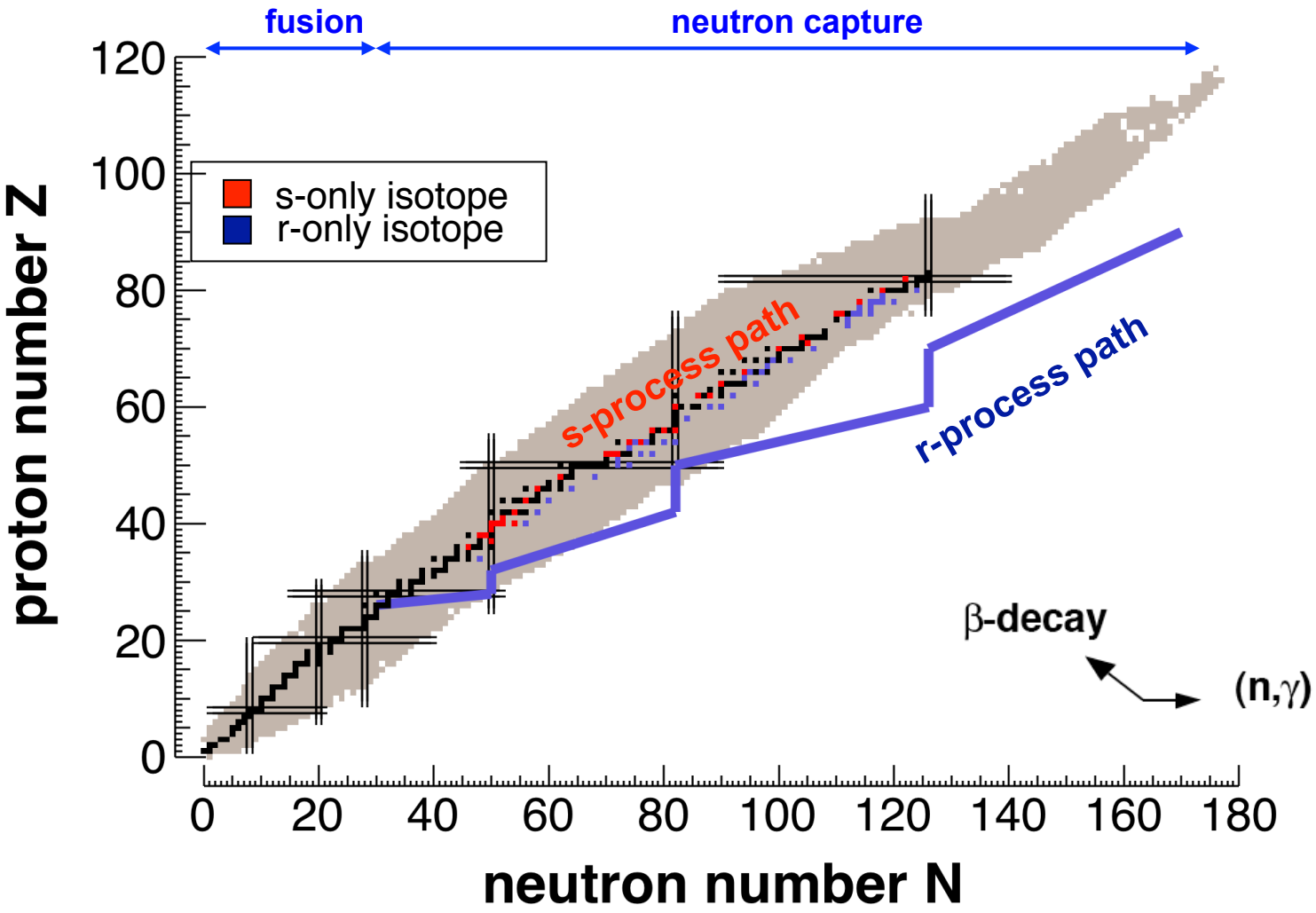




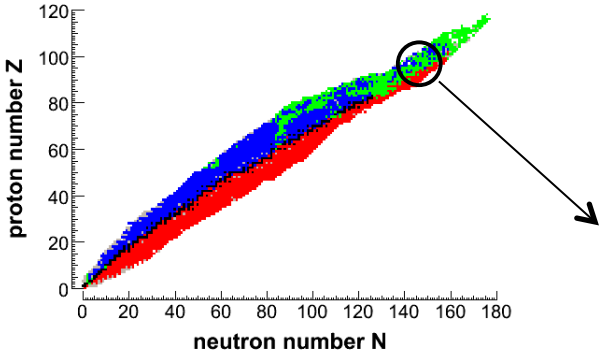
Nuclei for neutron induced reactions



Stellar nucleosynthesis (s-, r-process)



Actinide build-up in reactors (w-process)



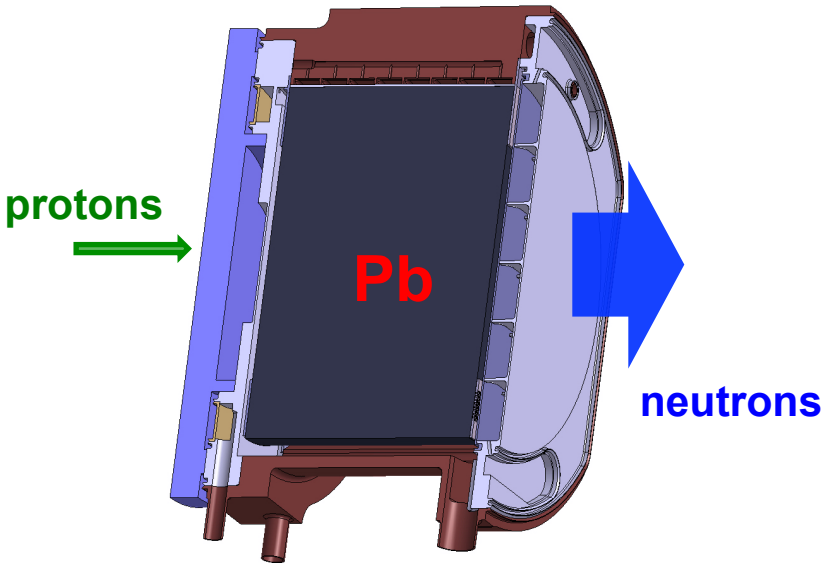
$$^{238}\mathrm{U} + \mathrm{n} \longrightarrow {}^{239}\mathrm{U} \xrightarrow{\beta^-\ (23\ min)} {}^{239}\mathrm{Np} \xrightarrow{\beta^-\ (2.4\ d)} {}^{239}\mathrm{Pu}$$

$$^{232}\mathrm{Th} + \mathrm{n} \longrightarrow {}^{233}\mathrm{Th} \xrightarrow{\beta^-\ (22\ min)} {}^{233}\mathrm{Pa} \xrightarrow{\beta^-\ (27\ d)} {}^{233}\mathrm{U}$$

The n_TOF facility at CERN

Pulsed white neutron source:

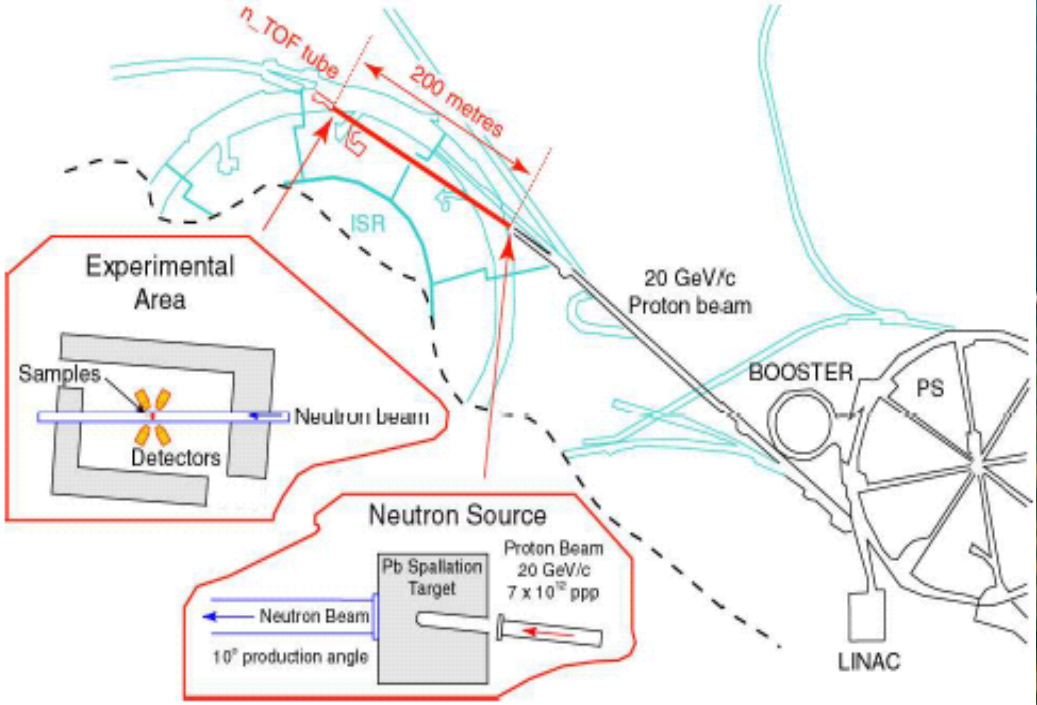
- 20 GeV/c protons
- neutrons from spallation
- 6 ns rms pulse width
- frequency 1 pulse/2.4 seconds
- separate cooling and moderation
- flight path length 185 m
- 7×10^{12} protons/pulse
- 2×10^{15} neutrons/pulse



Main advantages:

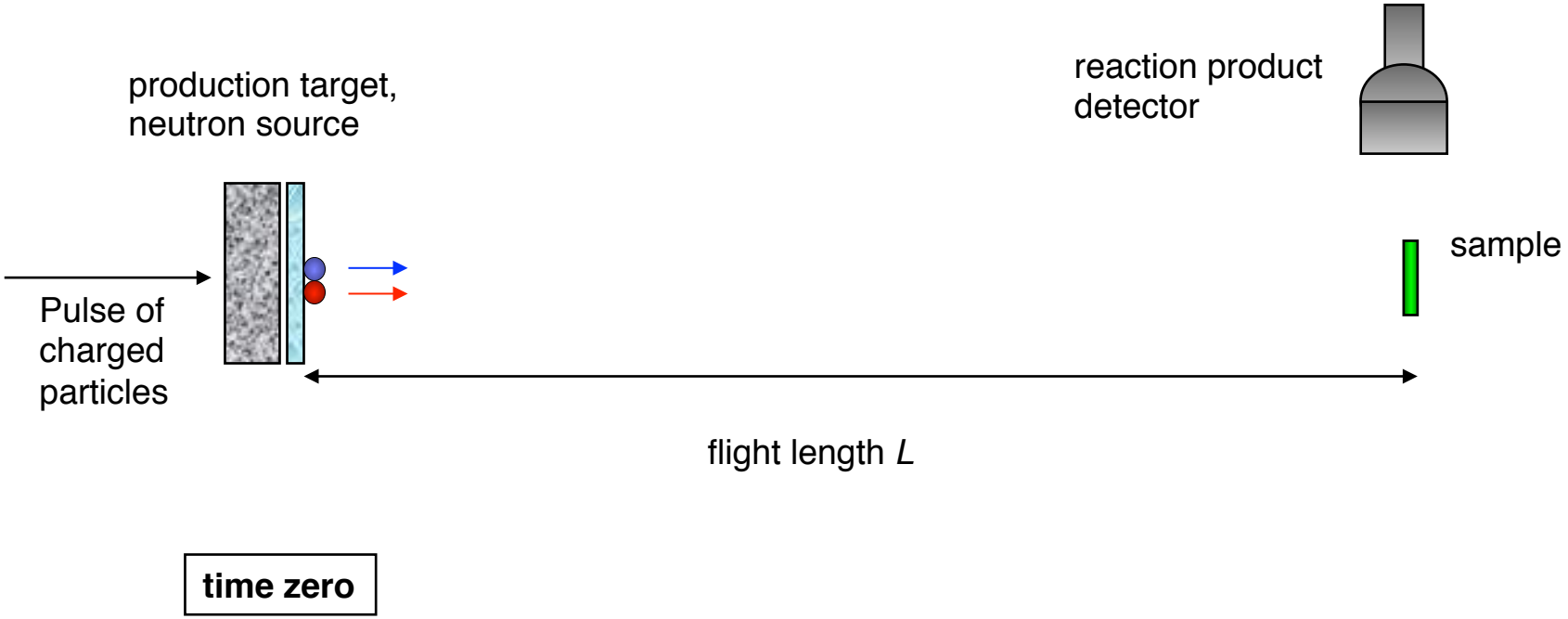
- Large energy range in one experiment (0.1 eV - 250 MeV)
- Favorable signal to noise ratio for capture on radioactive isotopes (actinides, fission products)

n_TOF at CERN


n_TOF tube
200 metres
ISR
Experimental Area
Samples
Detectors
Neutron Beam
Neutron Source
Pb Spallation Target
Proton Beam
20 GeV/c
7 x 10^12 ppp
Neutron Beam
10° production angle
20 GeV/c
Proton beam
BOOSTER
PS
LINAC


Lake of Geneva
9 km
CERN

Measuring a reaction yield using the time-of-flight technique



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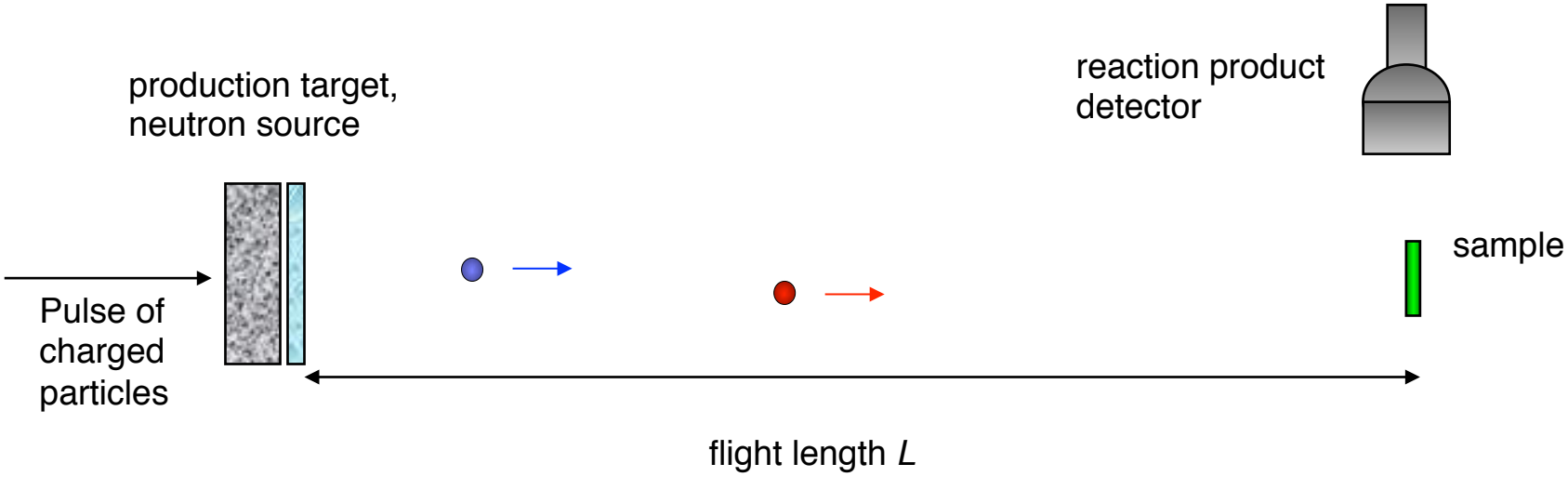
Measuring a reaction yield using the time-of-flight technique



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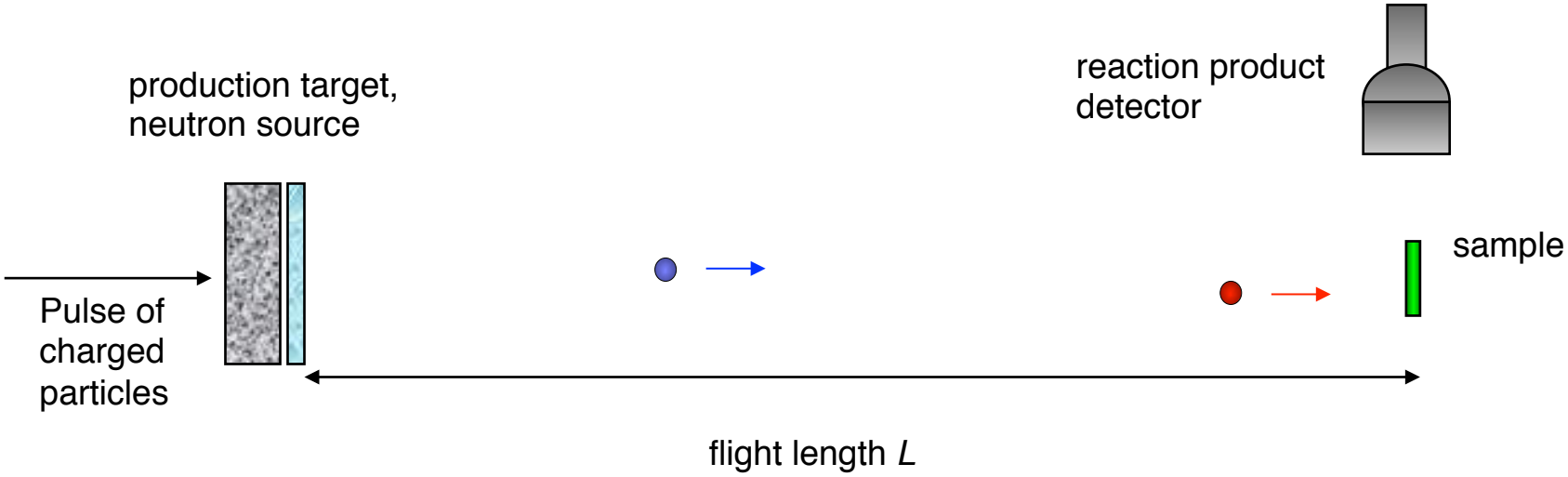
Measuring a reaction yield using the time-of-flight technique



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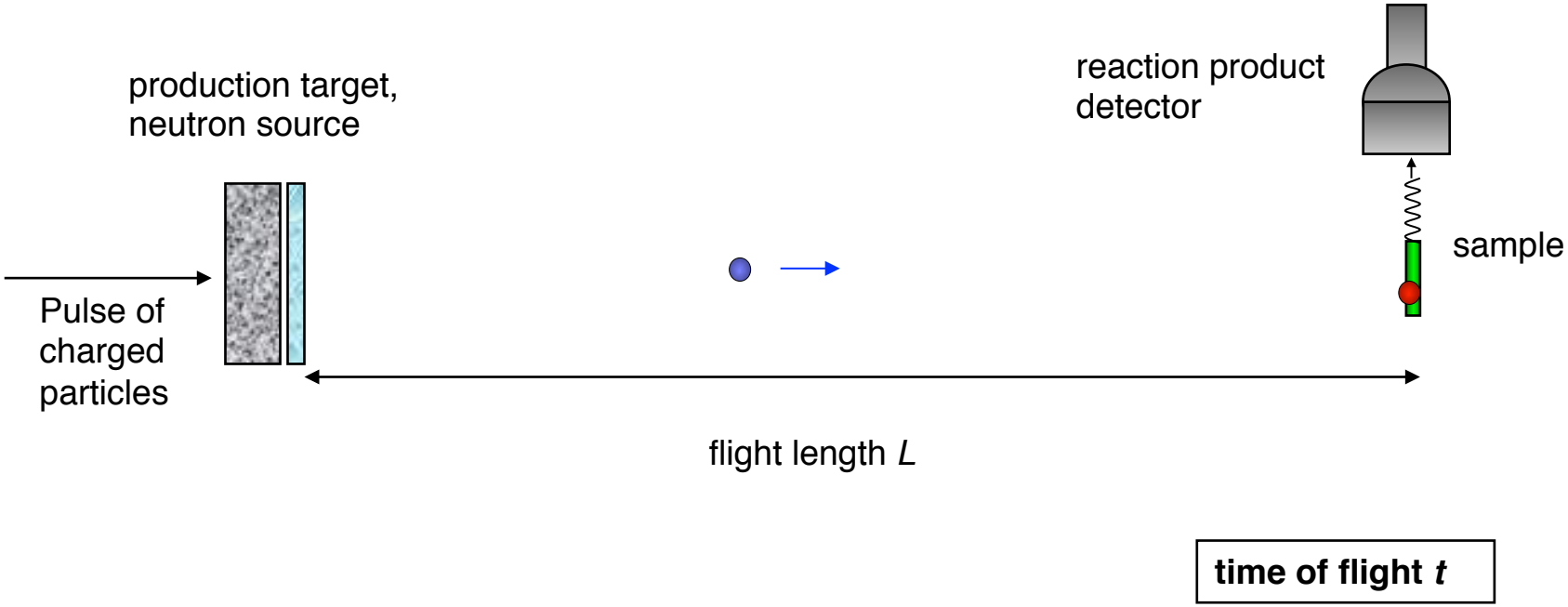
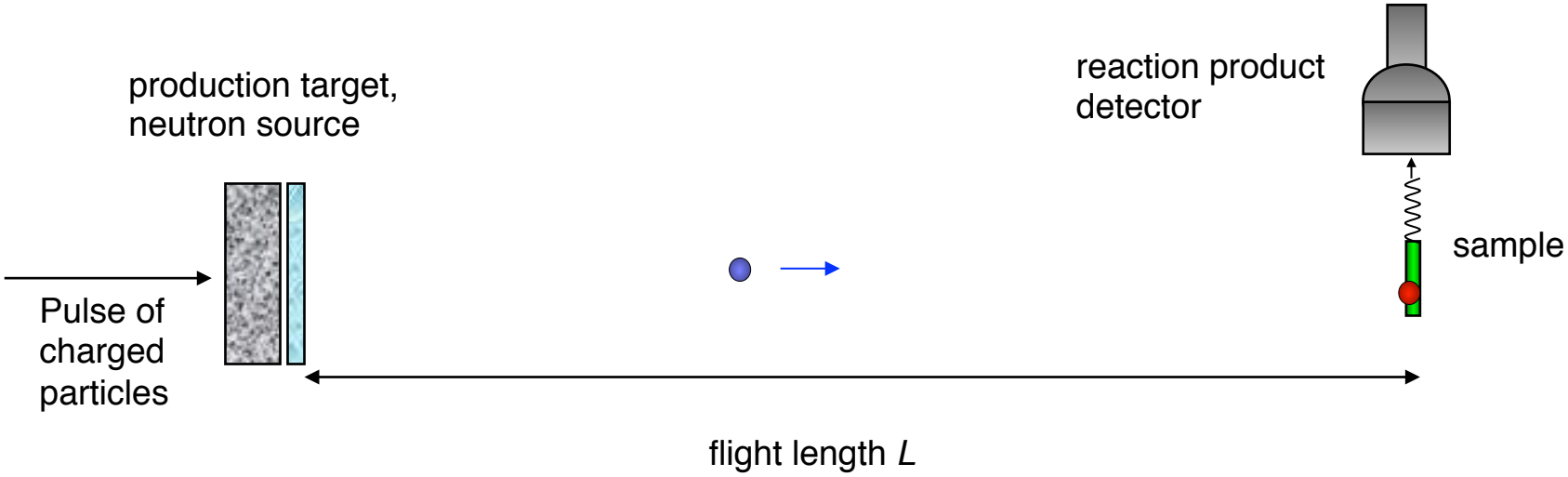
Measuring a reaction yield using the time-of-flight technique



time of flight *t*

Measuring a reaction yield using the time-of-flight technique



time of flight *t*

Kinetic energy of the neutron by time-of-flight

$$E_n = E_{tot} - mc^2 = c^2p^2 + m^2c^4 - mc^2 = mc^2(\gamma - 1) \qquad \gamma = (1 - v^2/c^2)^{-1/2}$$

$$E_n = \frac{1}{2}mv^2 = \alpha^2 \cdot \frac{L^2}{t^2}$$

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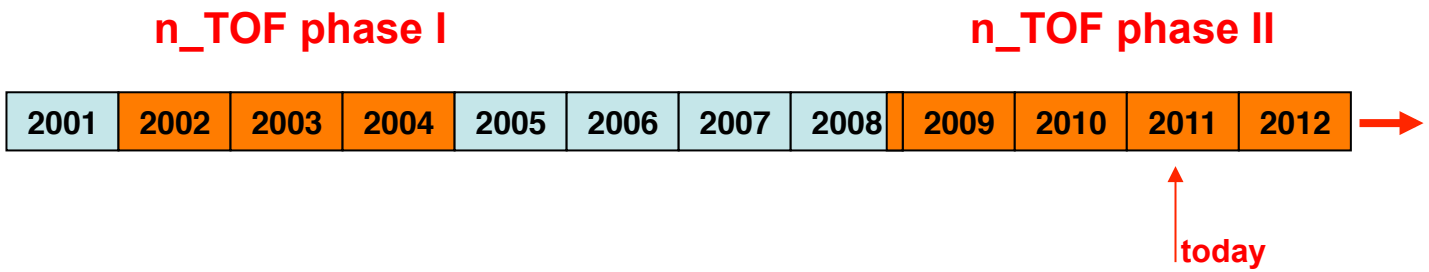
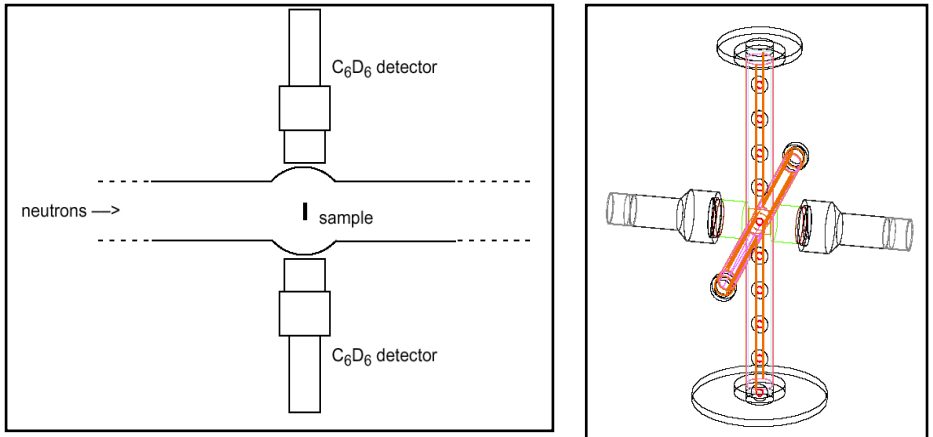
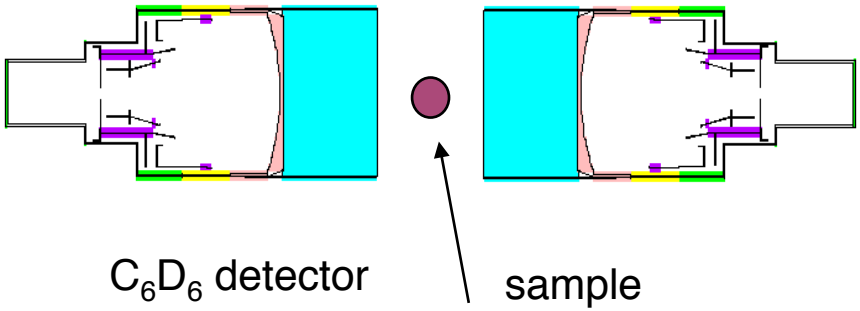
Status of n_TOF at CERN today

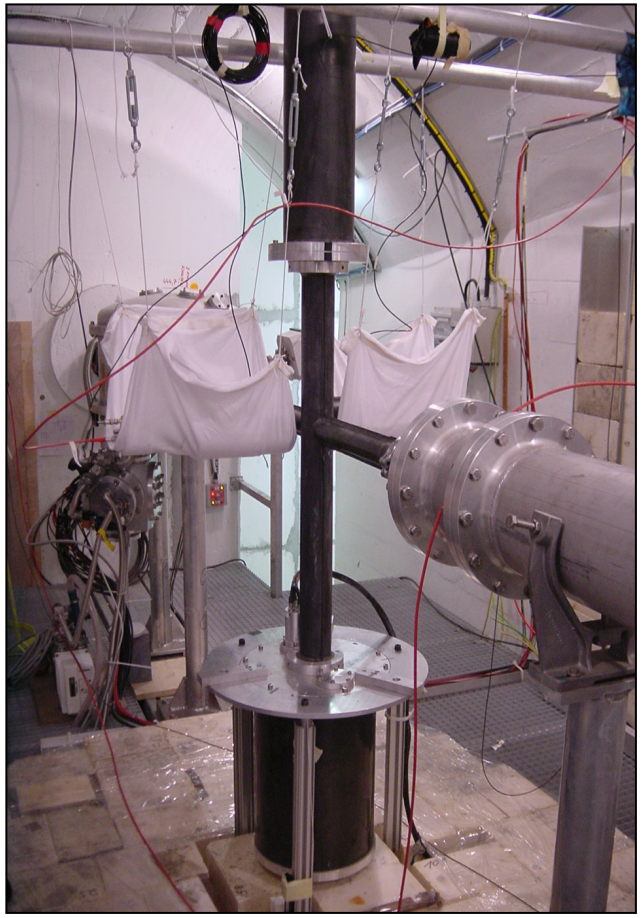


- 1998 - 2001 preparation and commissioning
- 2002 - 2004 phase I data taking
- 2005 - 2007 spallation target upgrade
- 2008 first protons on target
- 2009 - phase II data taking

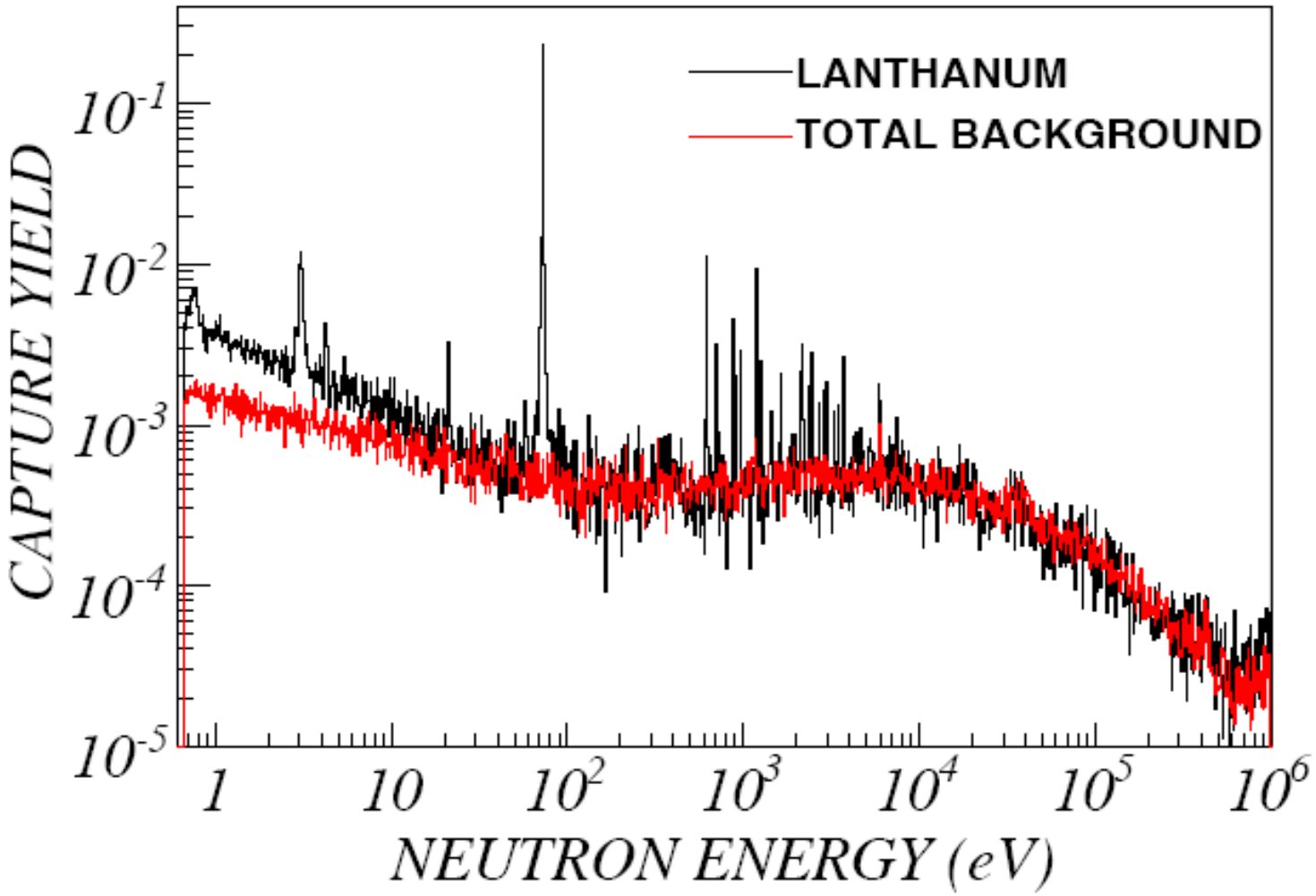
Capture measurement setup







Example: ^{139}La(n,γ)



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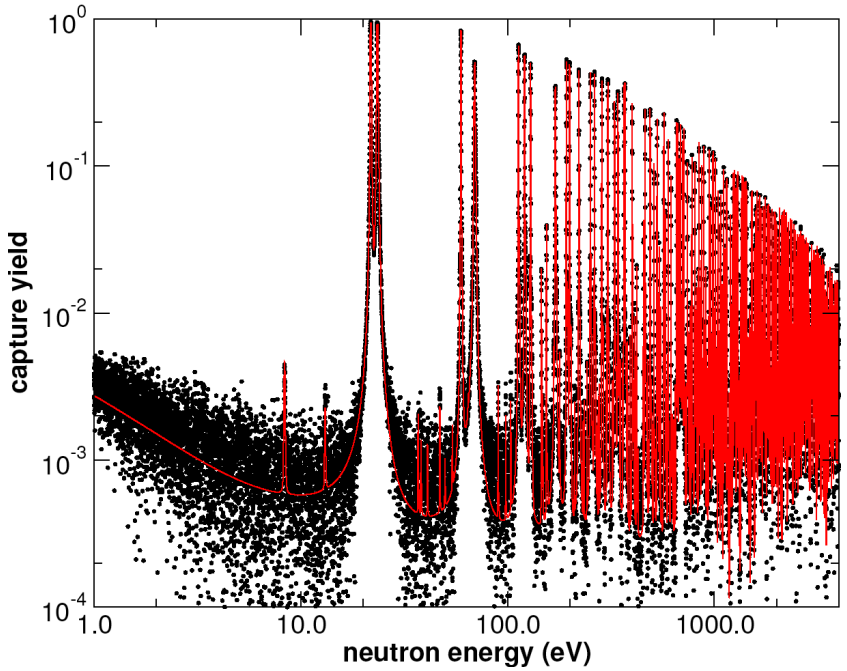
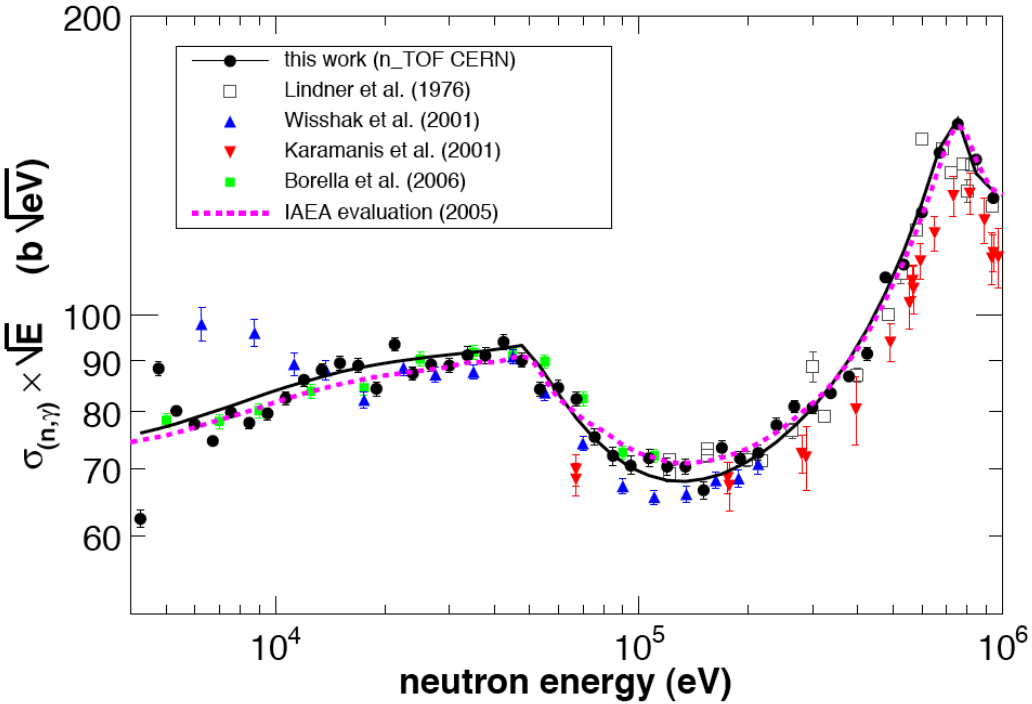
Example: ^{232}Th(n,γ)

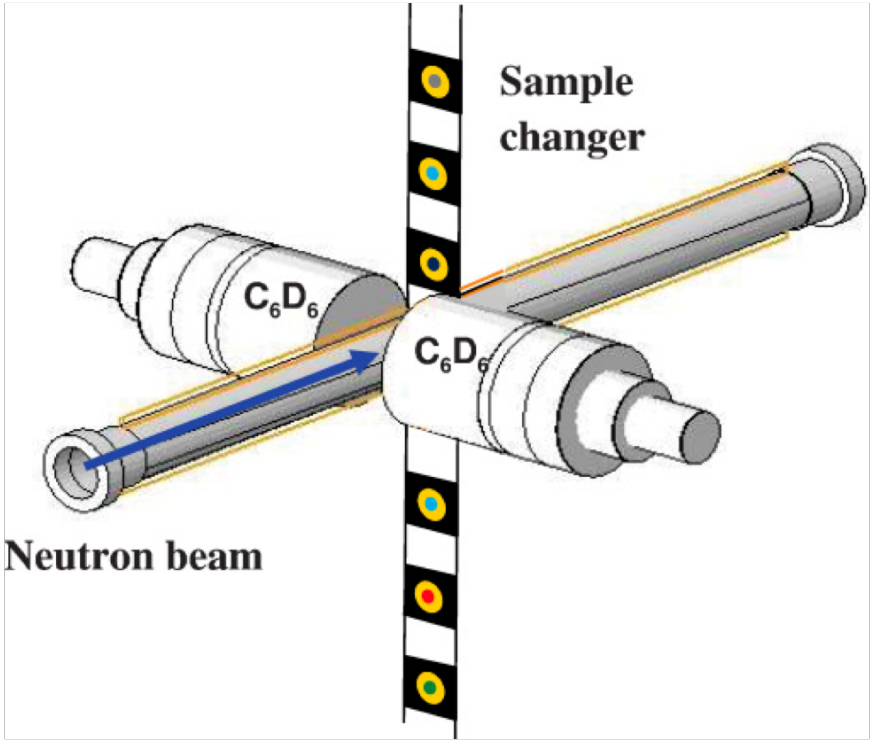
Resolved resonances

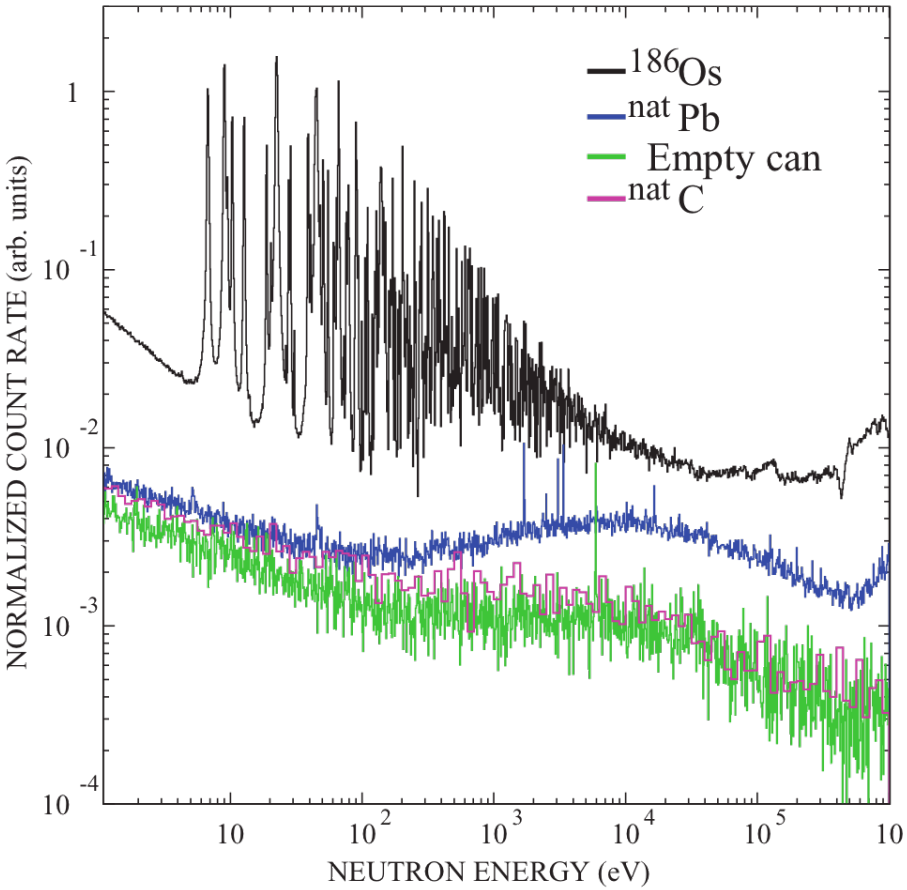


Unesolved resonances



$^{186, 187, 188}$Os(n,γ) at n_TOF





Experimental setup

measured spectra

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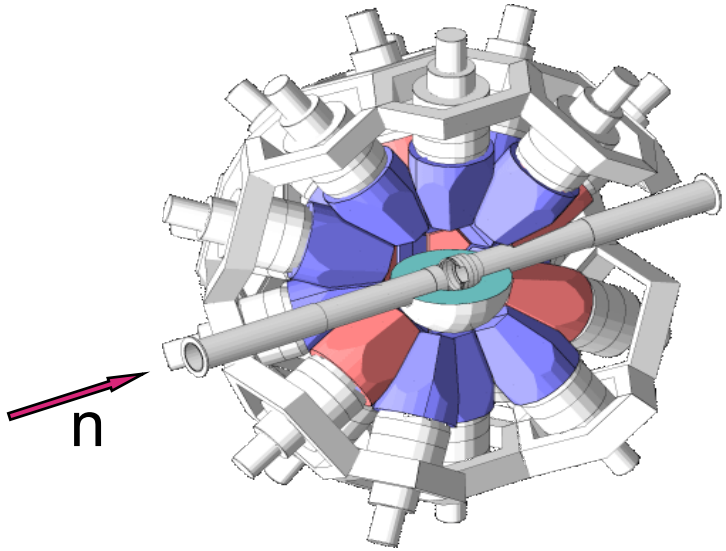
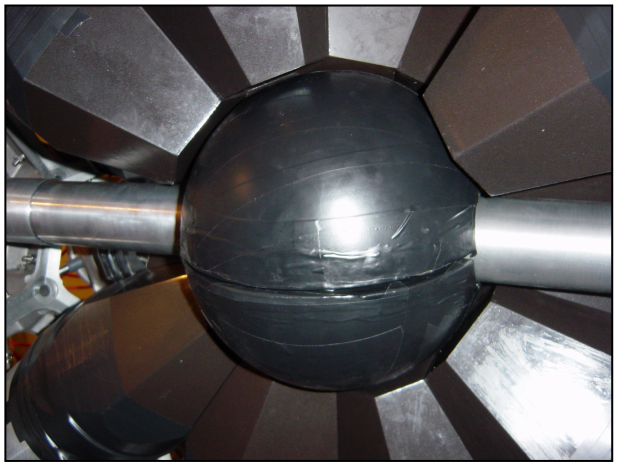
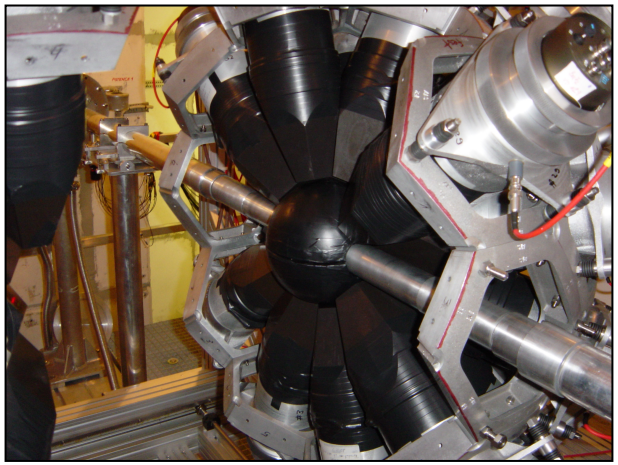
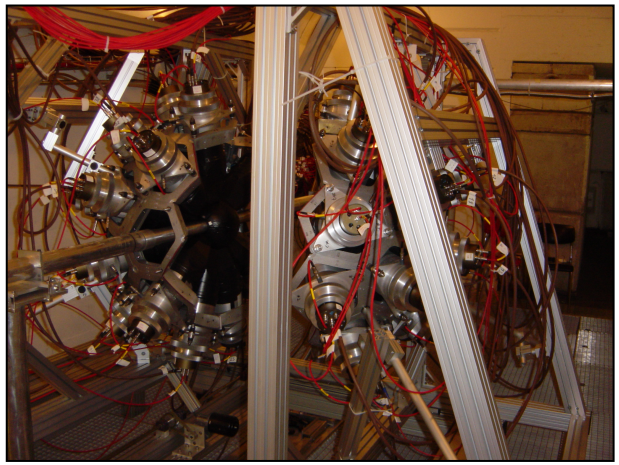
Measurements at n_TOF-CERN with BaF_2 detector

- calorimeter with 40 BaF_2 crystals
- 4π solid angle
- 100% efficiency for gamma rays
- operating since 2004









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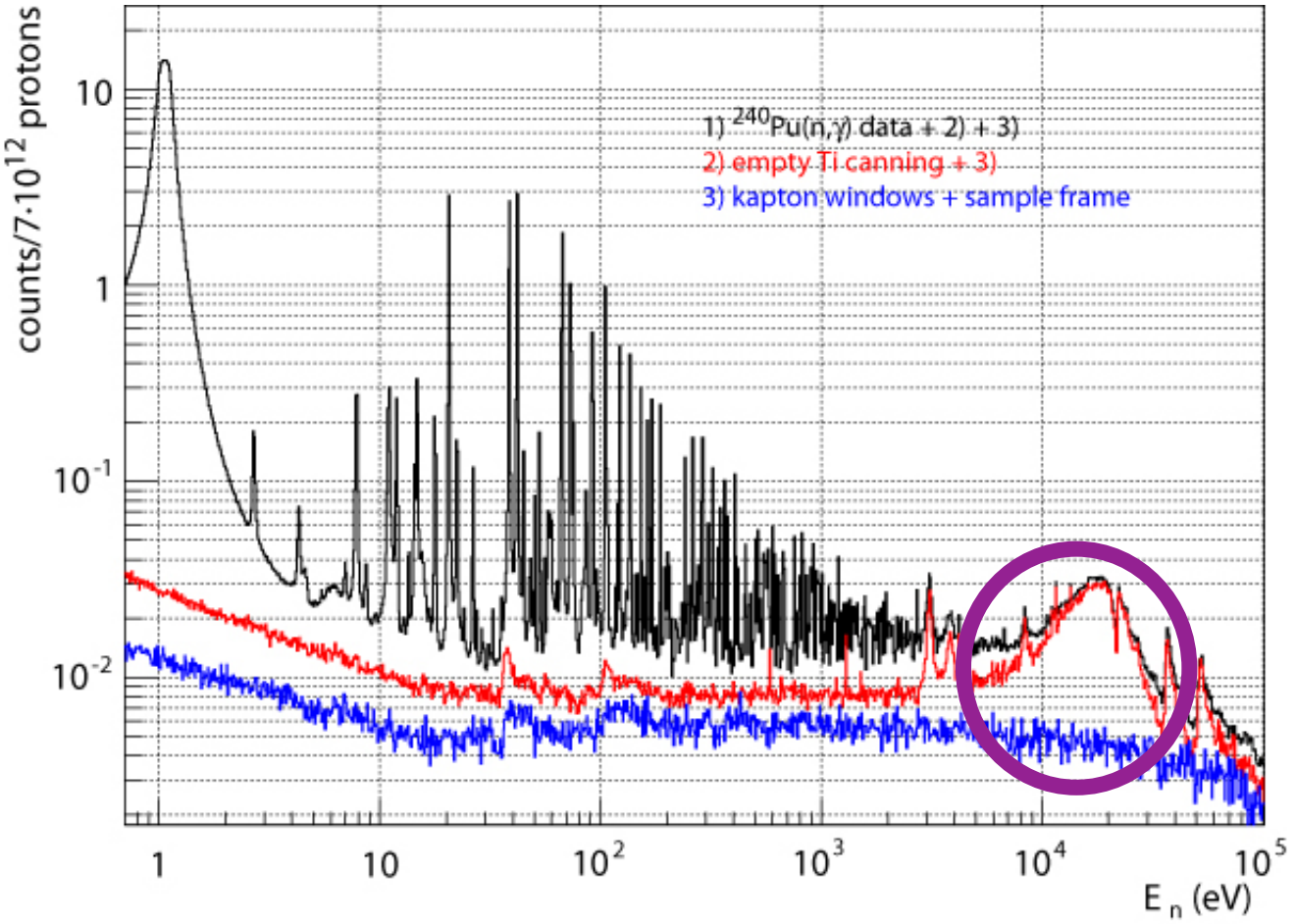
Example: ^{240}Pu(n,γ)



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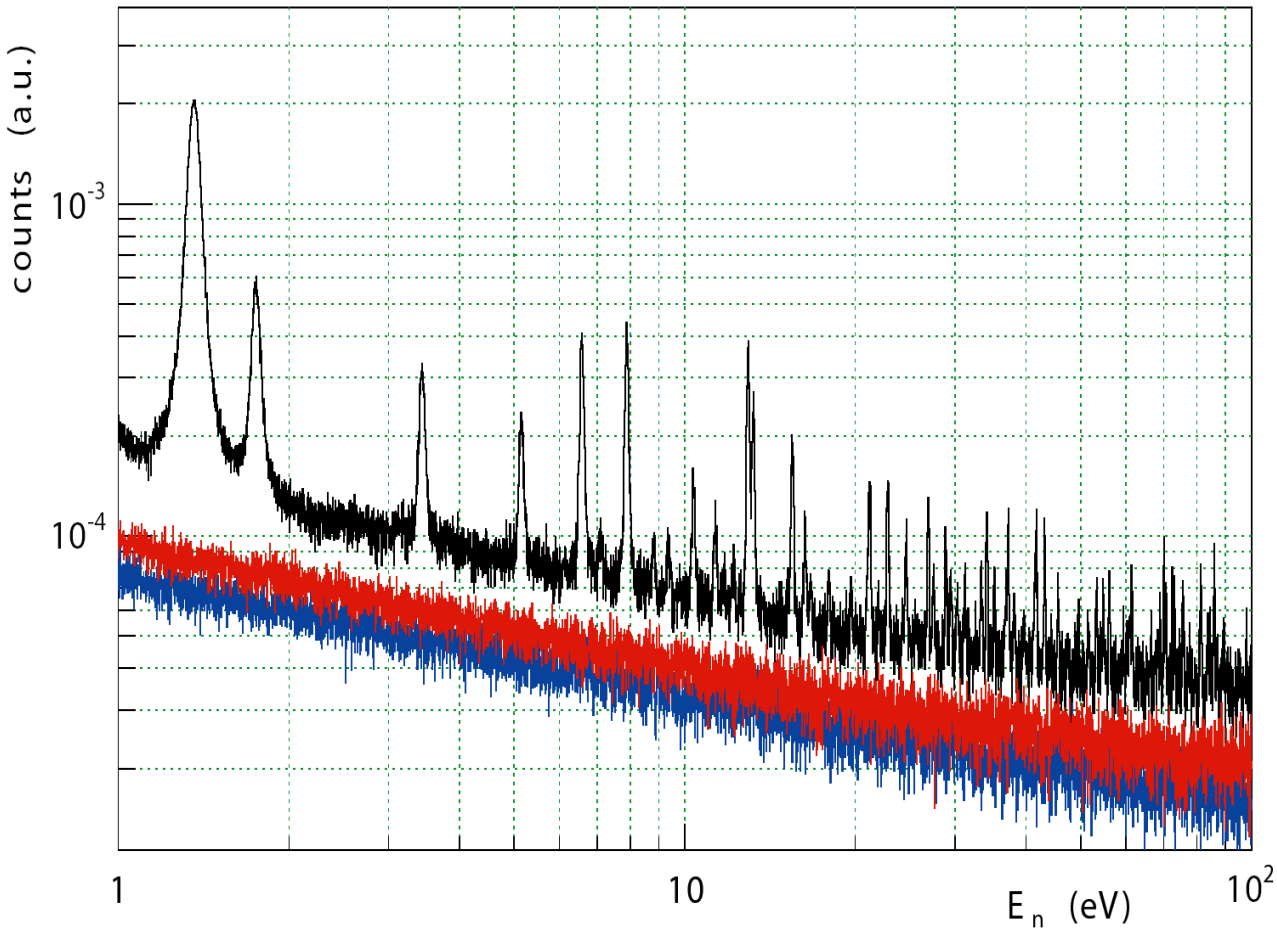
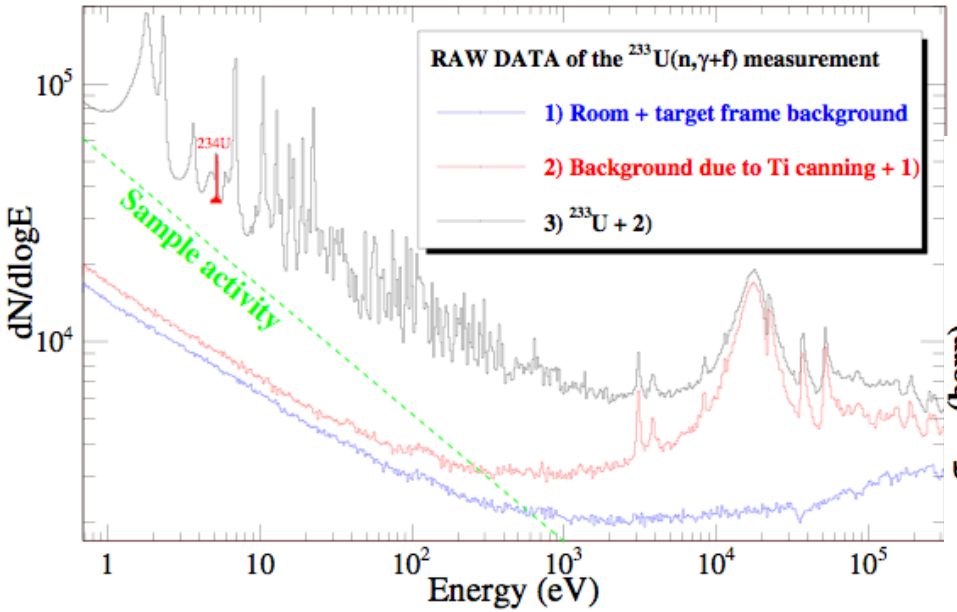
Example: ^{243}Am(n,γ)
10 mg sample

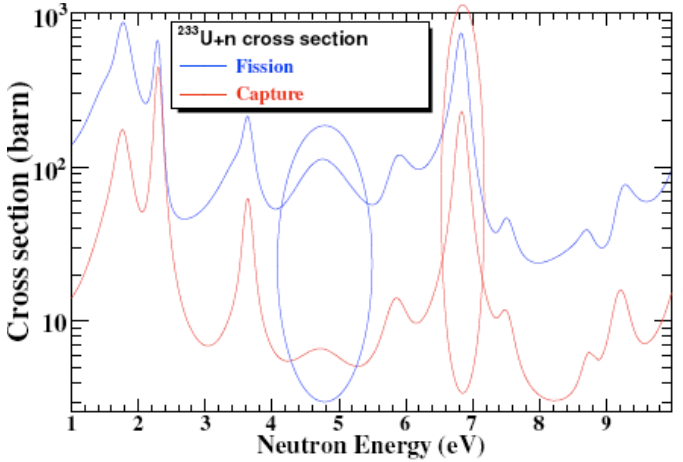


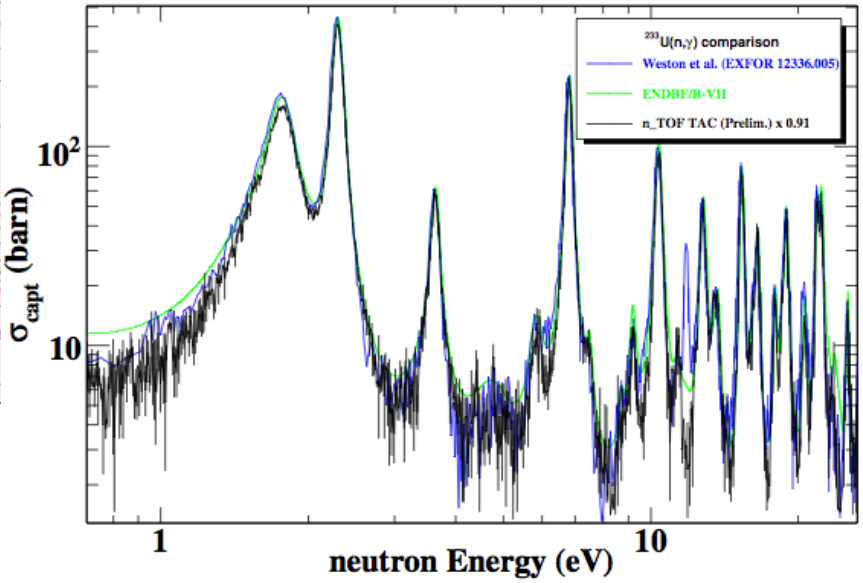
Example: ^{233}U(n,γ)

Fission background in capture spectrum deduced from fission-only resonance

91 mg ^{233}U







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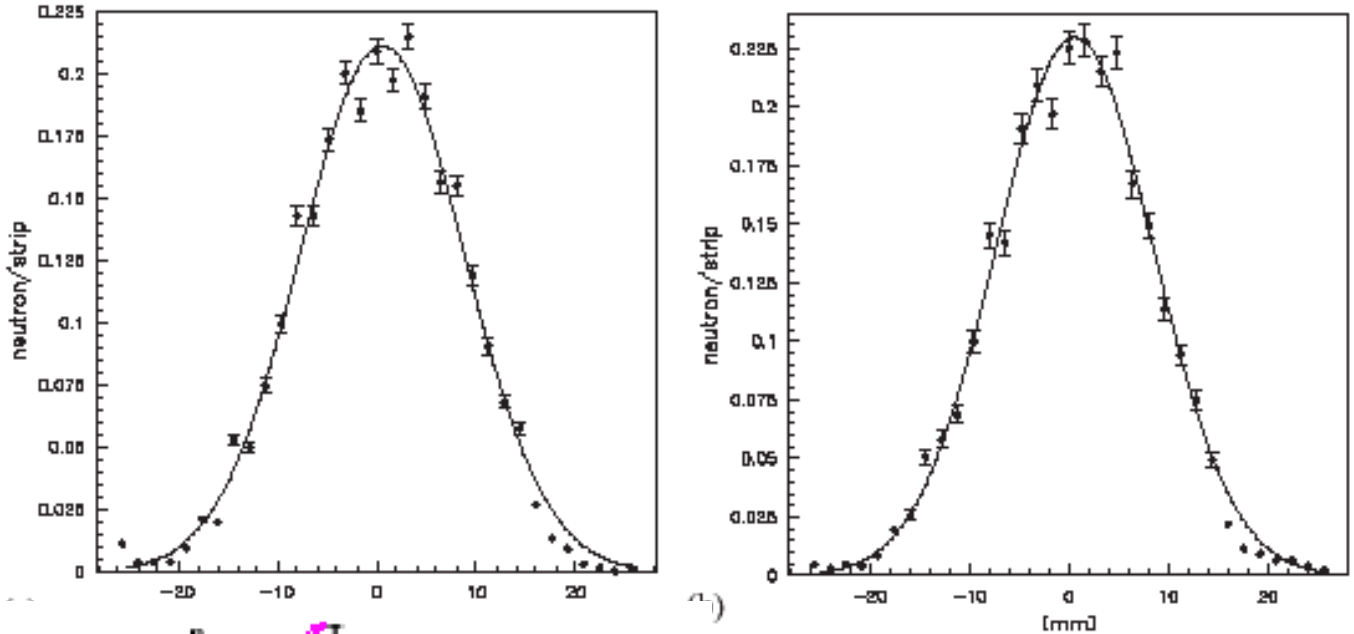
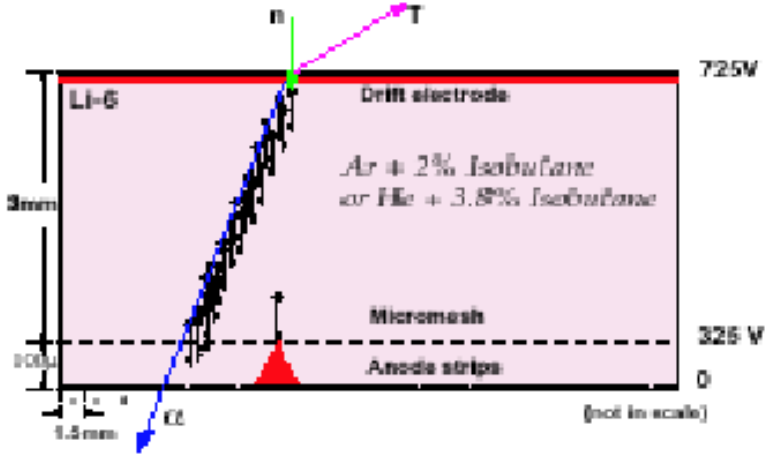
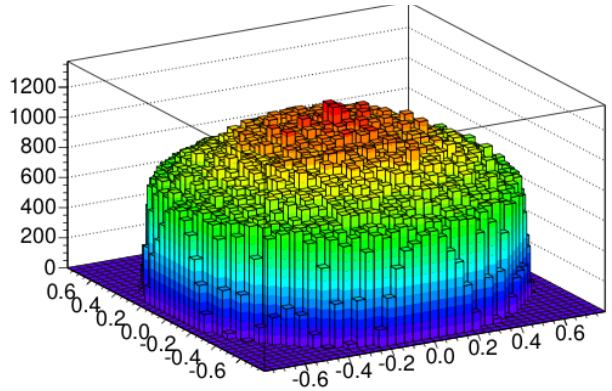
Beam profile using MicroMegas

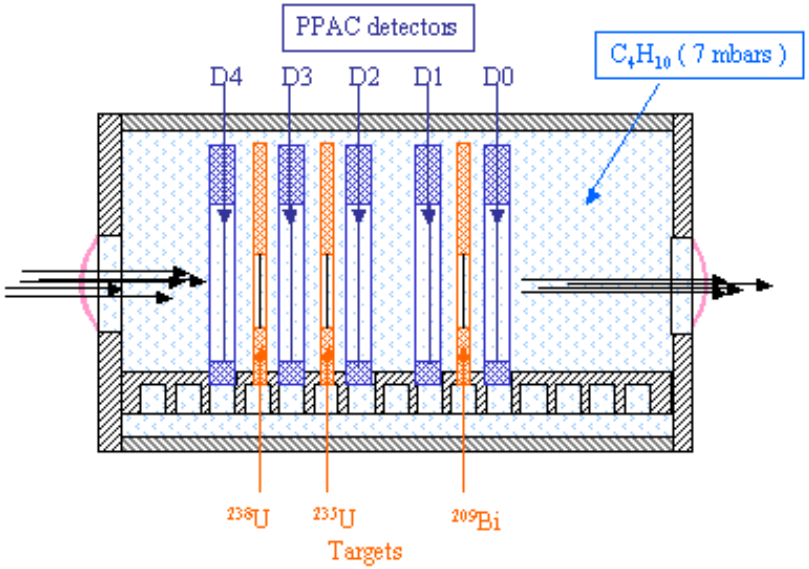




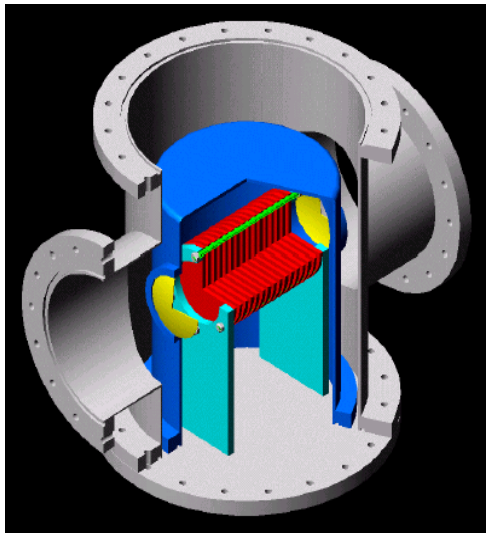


Fission detectors

- Parallel plate avalance counters chamber detectors.
(PPACS) fission detectors



- Fission ionization



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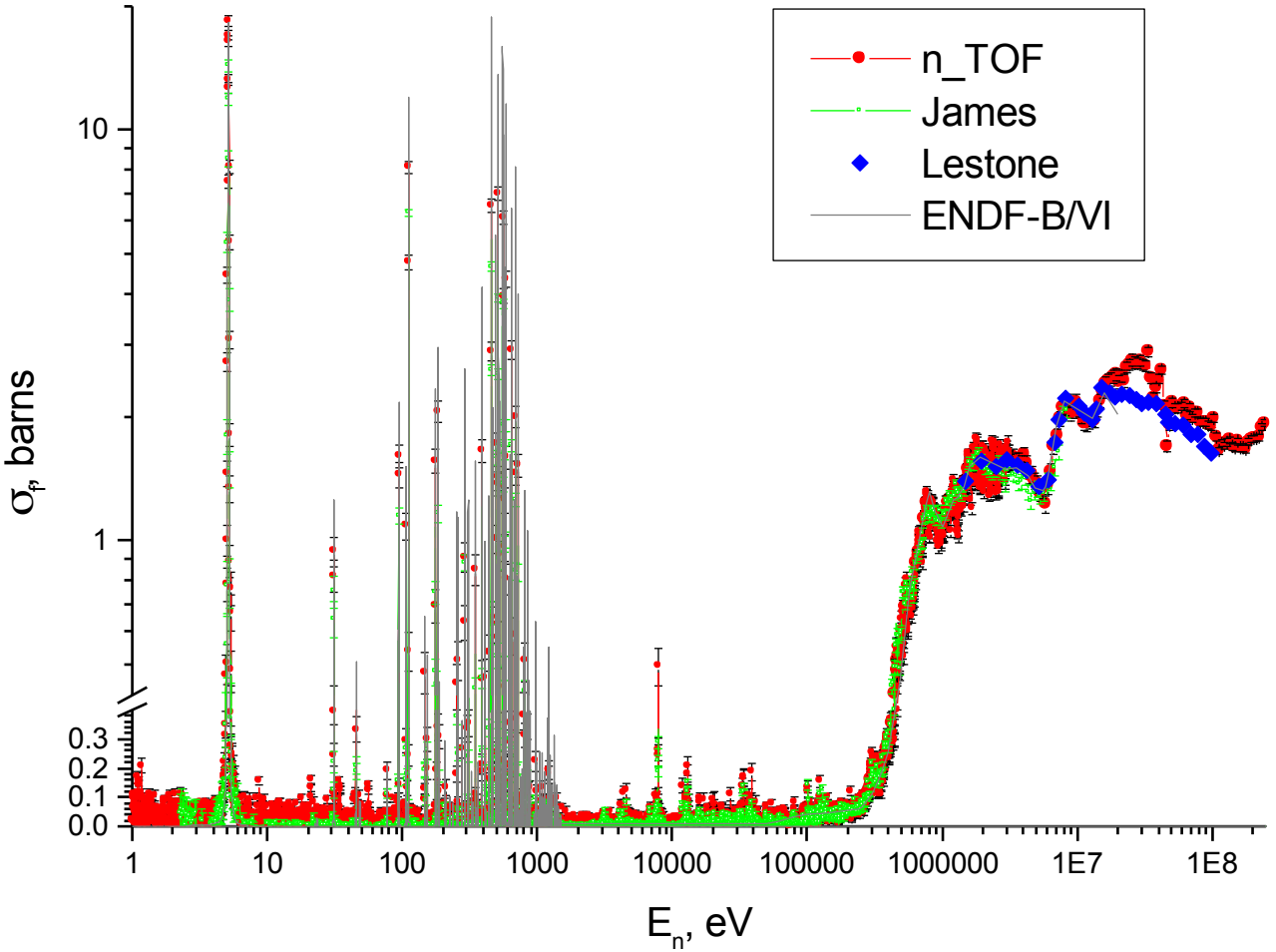
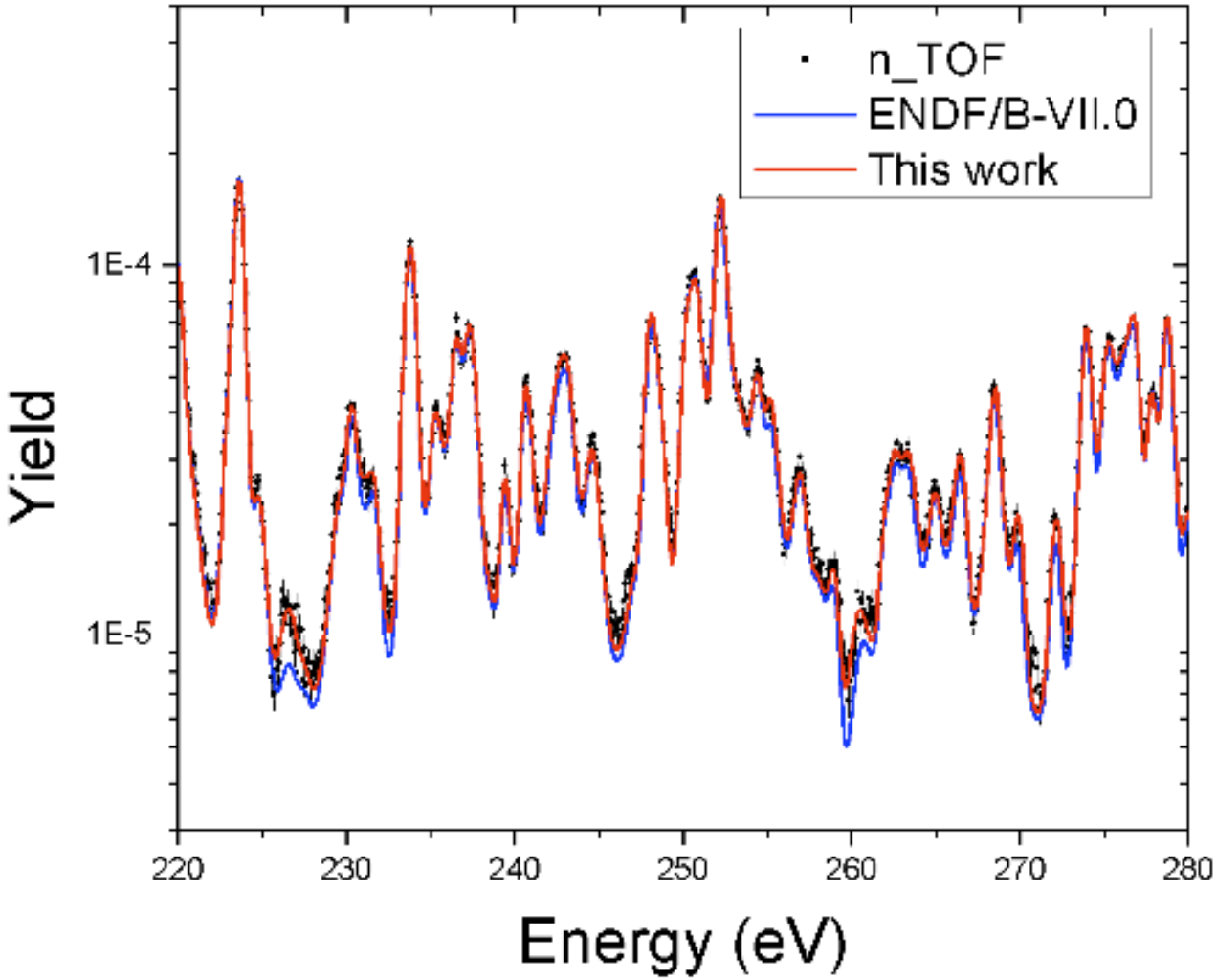
Example: PPAC ^{234}U(n,f)



Example: FIC ^{233}U(n,f)



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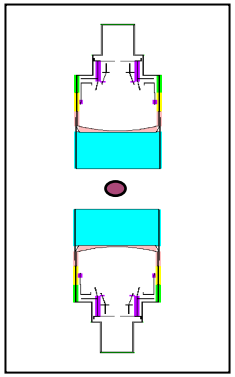
n_TOF CERN phase I (2001-2004)
Summary of measurements

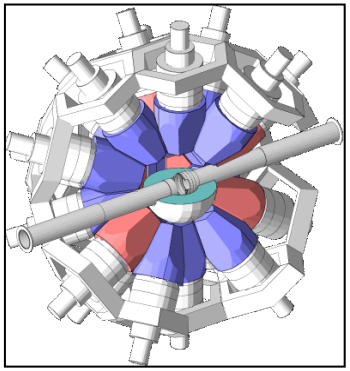
capture C_6D_6
- $^{24,25,26}Mg$
- ^{56}Fe
- $^{90,91,92,93,94,96}Zr$
- ^{139}La
- ^{151}Sm
- $^{186,187,188}Os$
- ^{197}Au
- $^{204, 206, 207,208}Pb$
- ^{209}Bi
- ^{232}Th

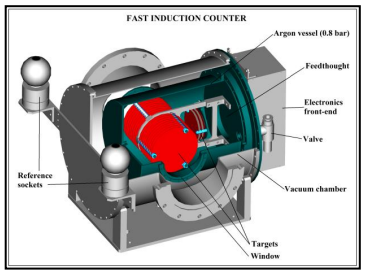
capture BaF_2
- ^{197}Au
- $^{233,234}U$
- ^{237}Np
- ^{240}Pu
- ^{243}Am

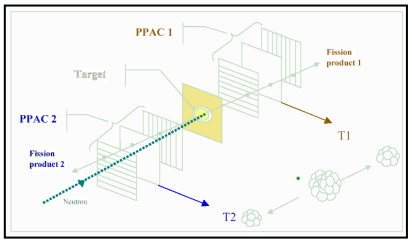
fission FIC
- ^{232}Th
- ^{237}Np
- $^{233,234,235,236,238}U$
- $^{241,243}Am$
- ^{245}Cm

fission PPAC
- ^{nat}Pb
- ^{209}Bi
- ^{232}Th
- ^{237}Np
- $^{233,234,235,238}U$









New Spallation Target

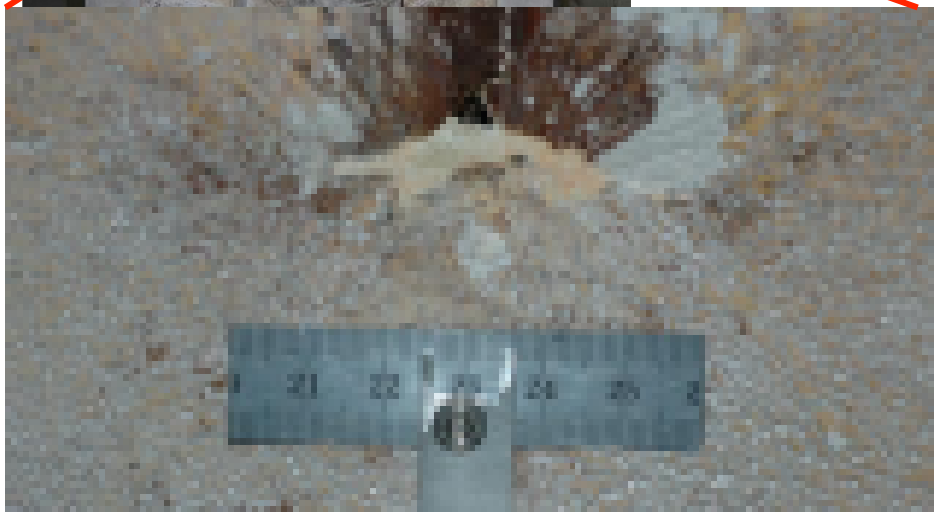
- At the end of 2004 an increased radioactivity was observed in the filters of the cooling water circuit: stop of n_TOF beam.

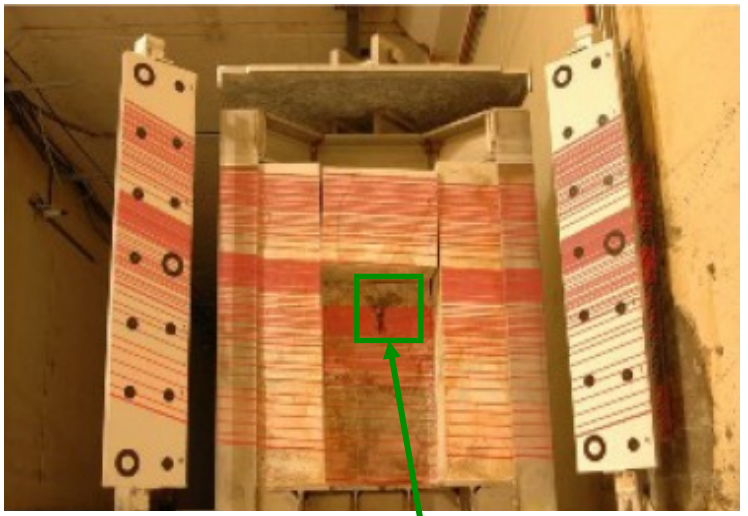
- In 2007 the target has been thoroughly investigated and a new design was made.
  - new lead spallation target
  - separated cooling and moderation water circuit
  - cooling system with monitoring of pH, O_2, T etc.
  - new ventilation station

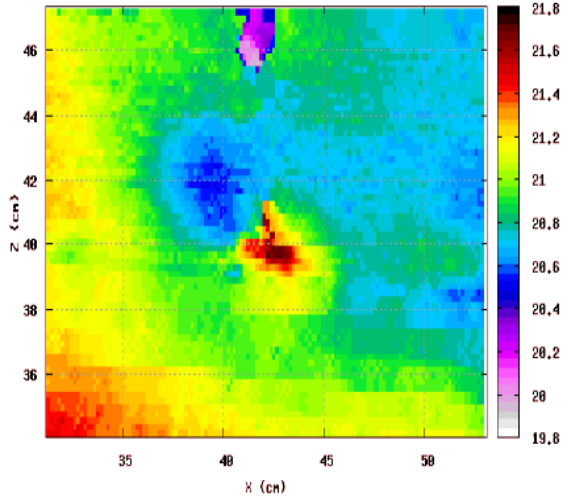
- upgraded facility was ready by the end of 2008

- measurement programme started in 2009

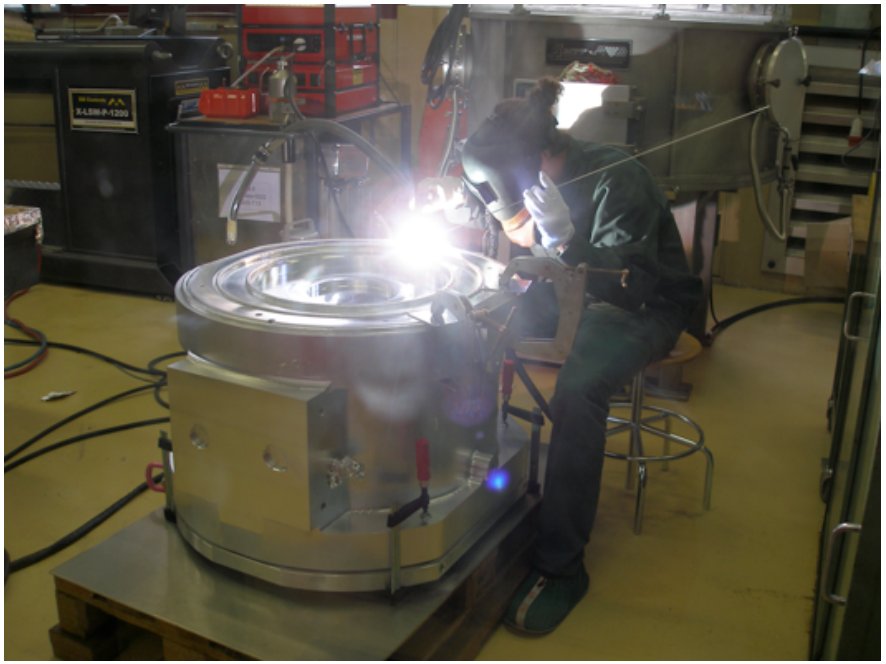
Old Spallation Target



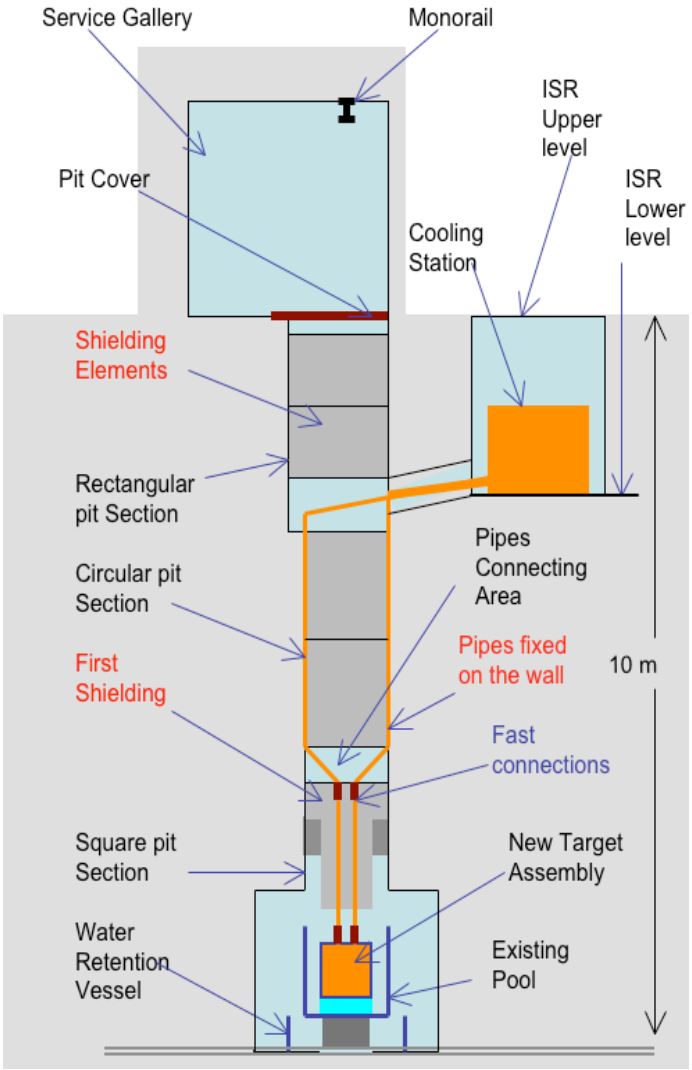


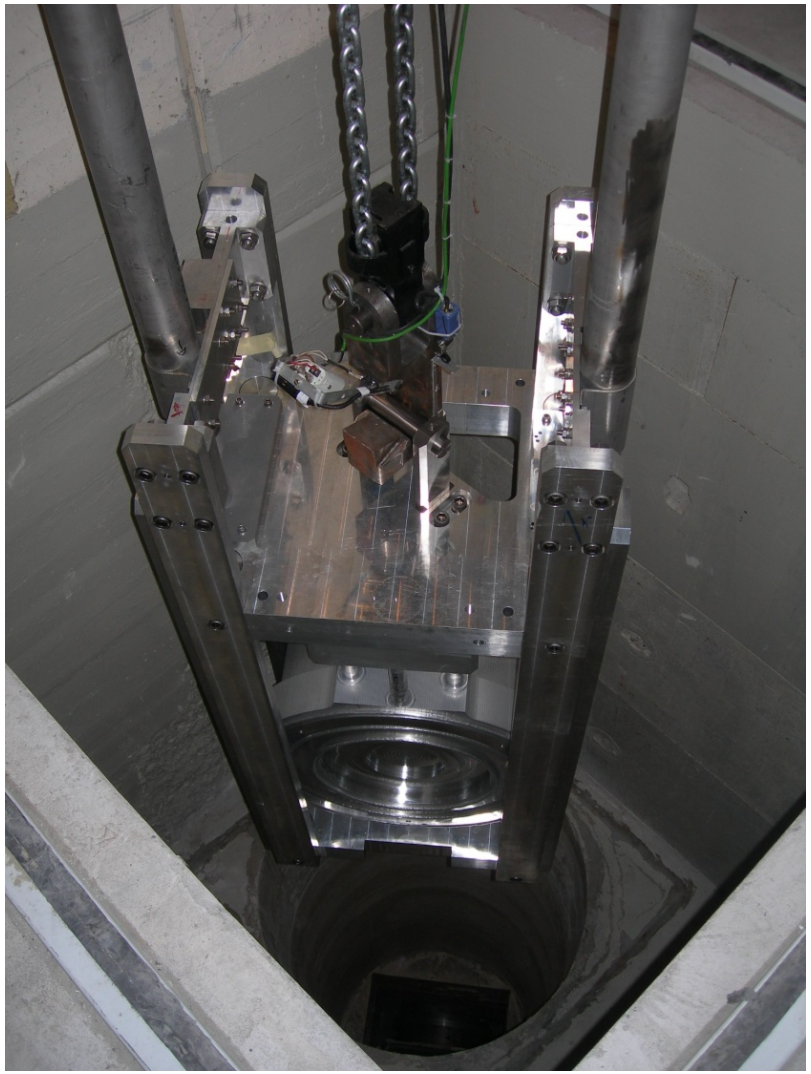


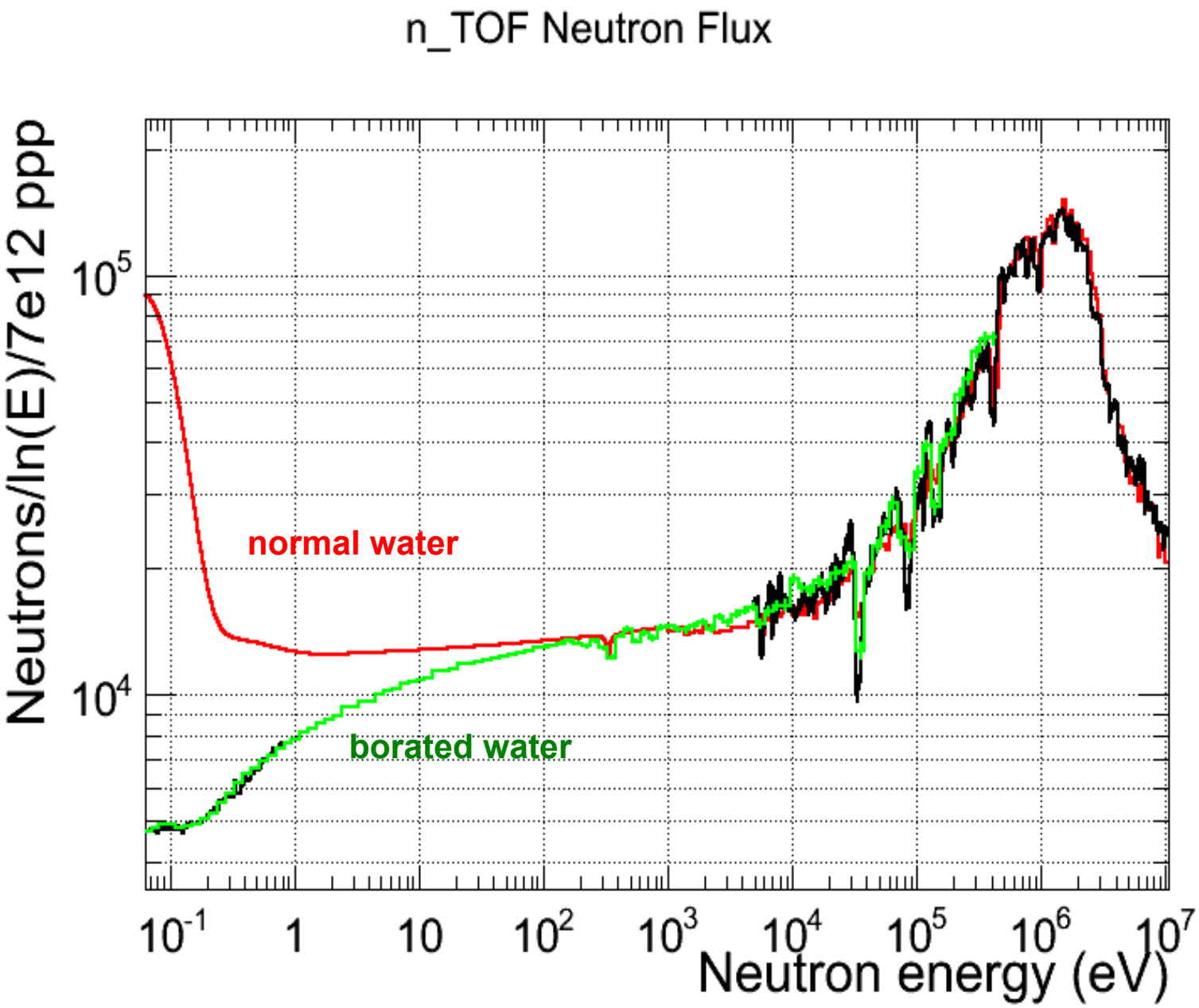
New Spallation Target



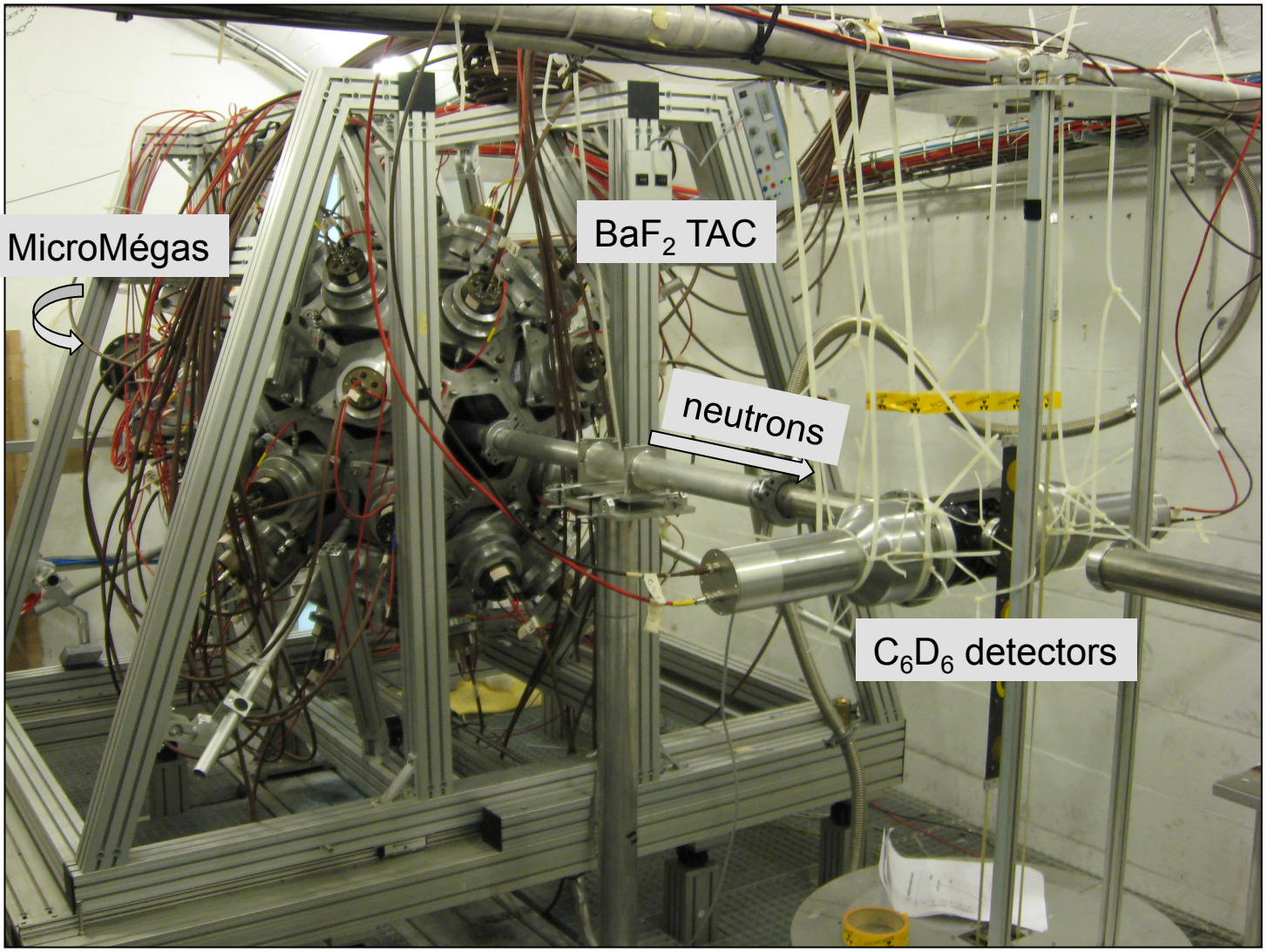
New Spallation Target



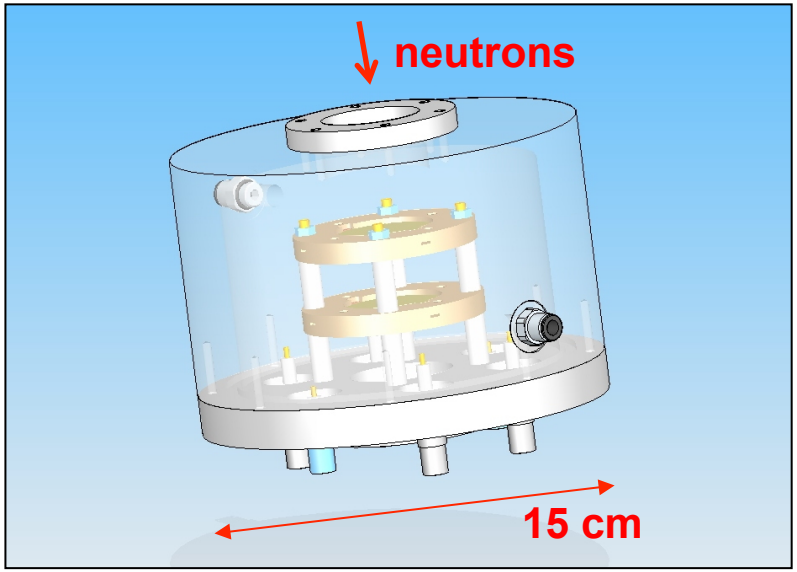


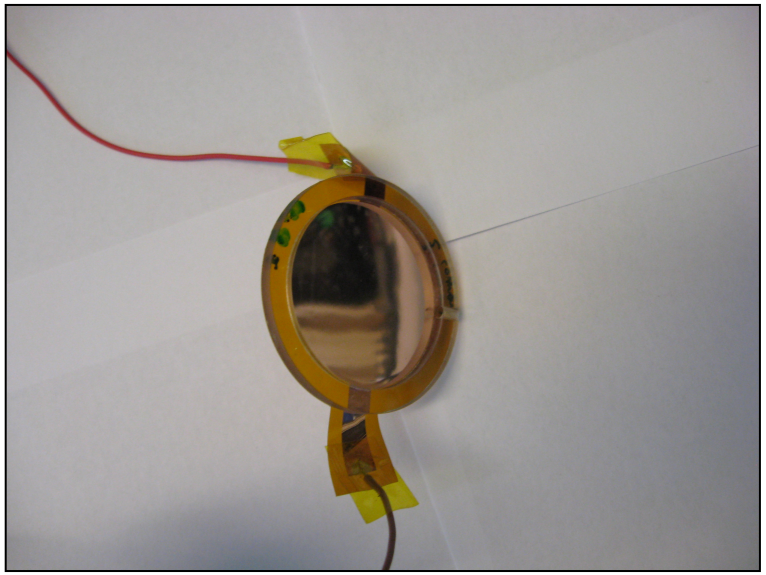

n_TOF Neutron Flux
Neutrons/ln(E)/7e12 ppp
10^5
10^4
normal water
borated water
10^{-1}
1
10
10^2
10^3
10^4
10^5
10^6
10^7
Neutron energy (eV)

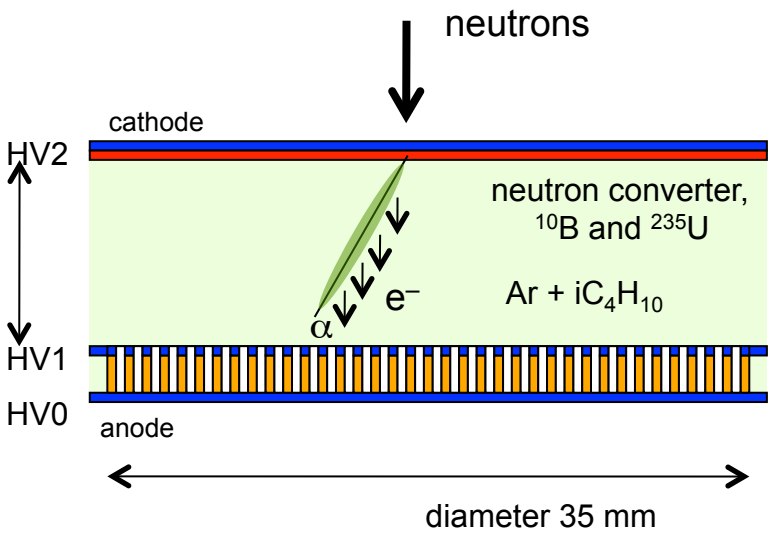
n_TOF at CERN experimental area



MicroMegas-based neutron flux monitor

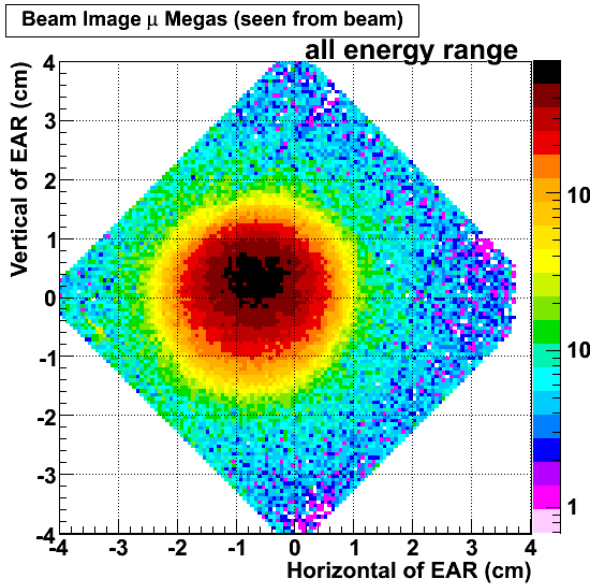




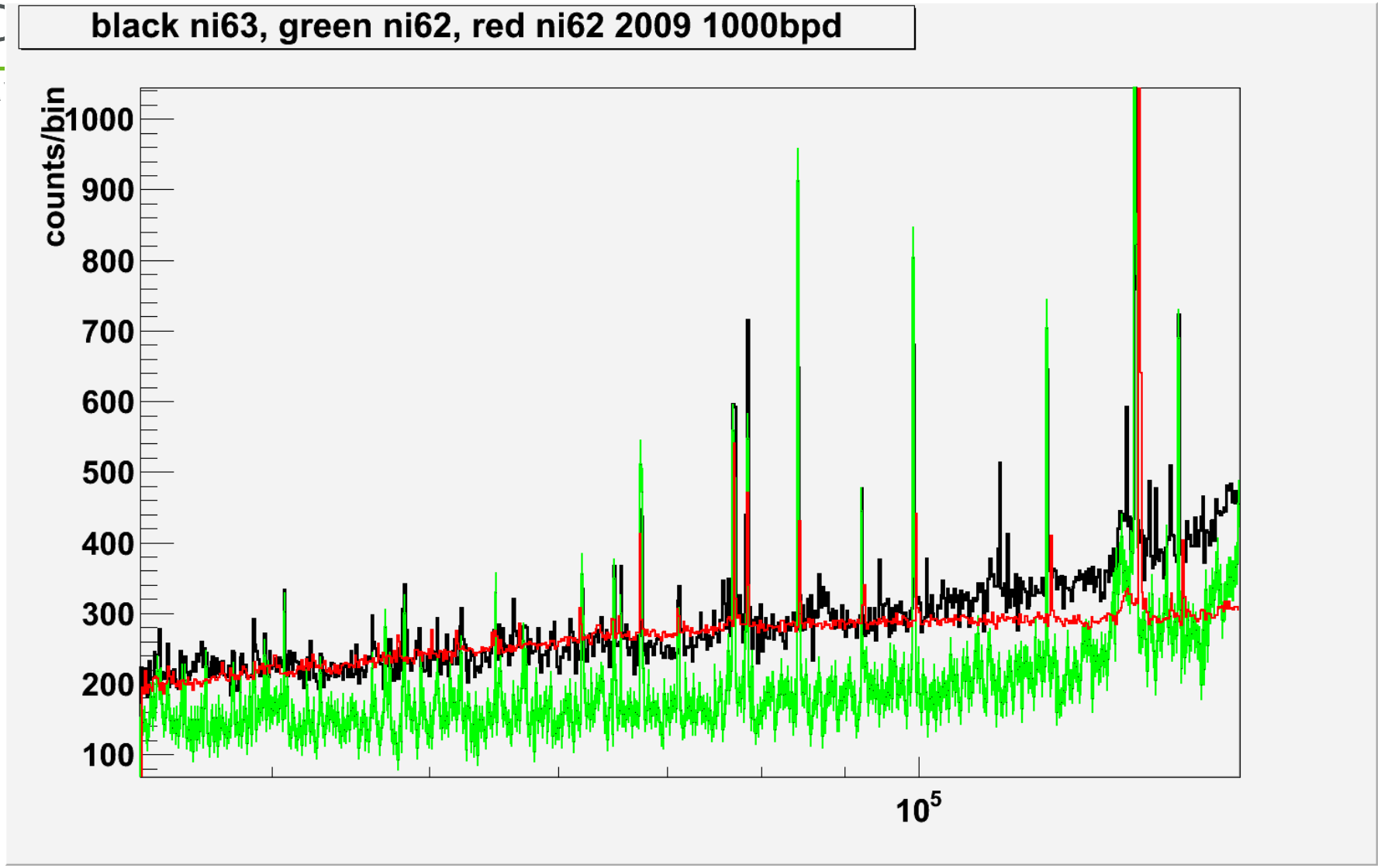


aluminized mylar
(1.5 µm + 1 nm)

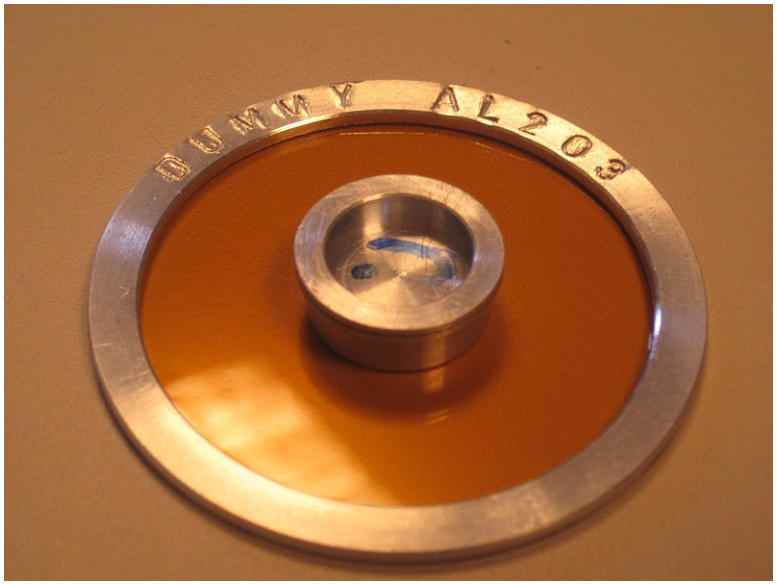
Mircobulk:
Cu + kapton
(50 µm kapton +
2 x 5 µm Cu)

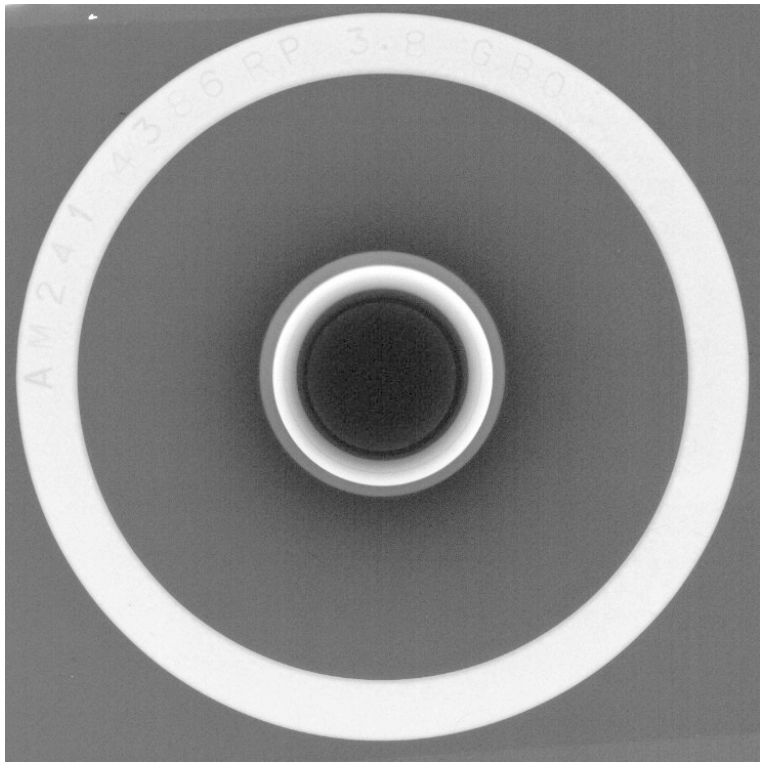


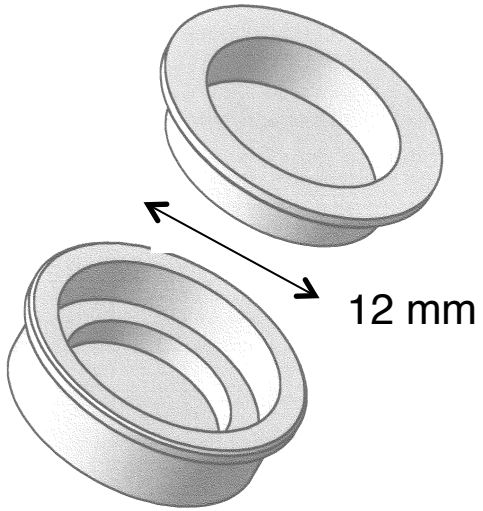
^{63}Ni(n,γ) measurement

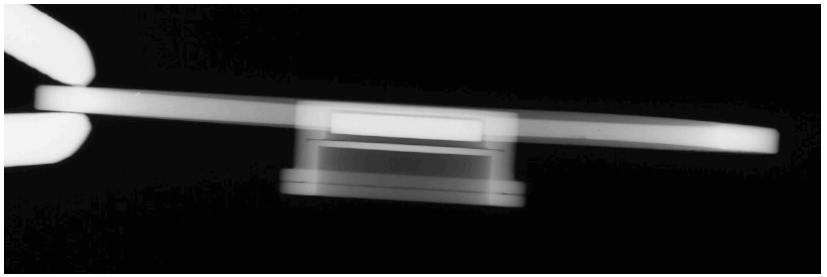


^{241}Am sample









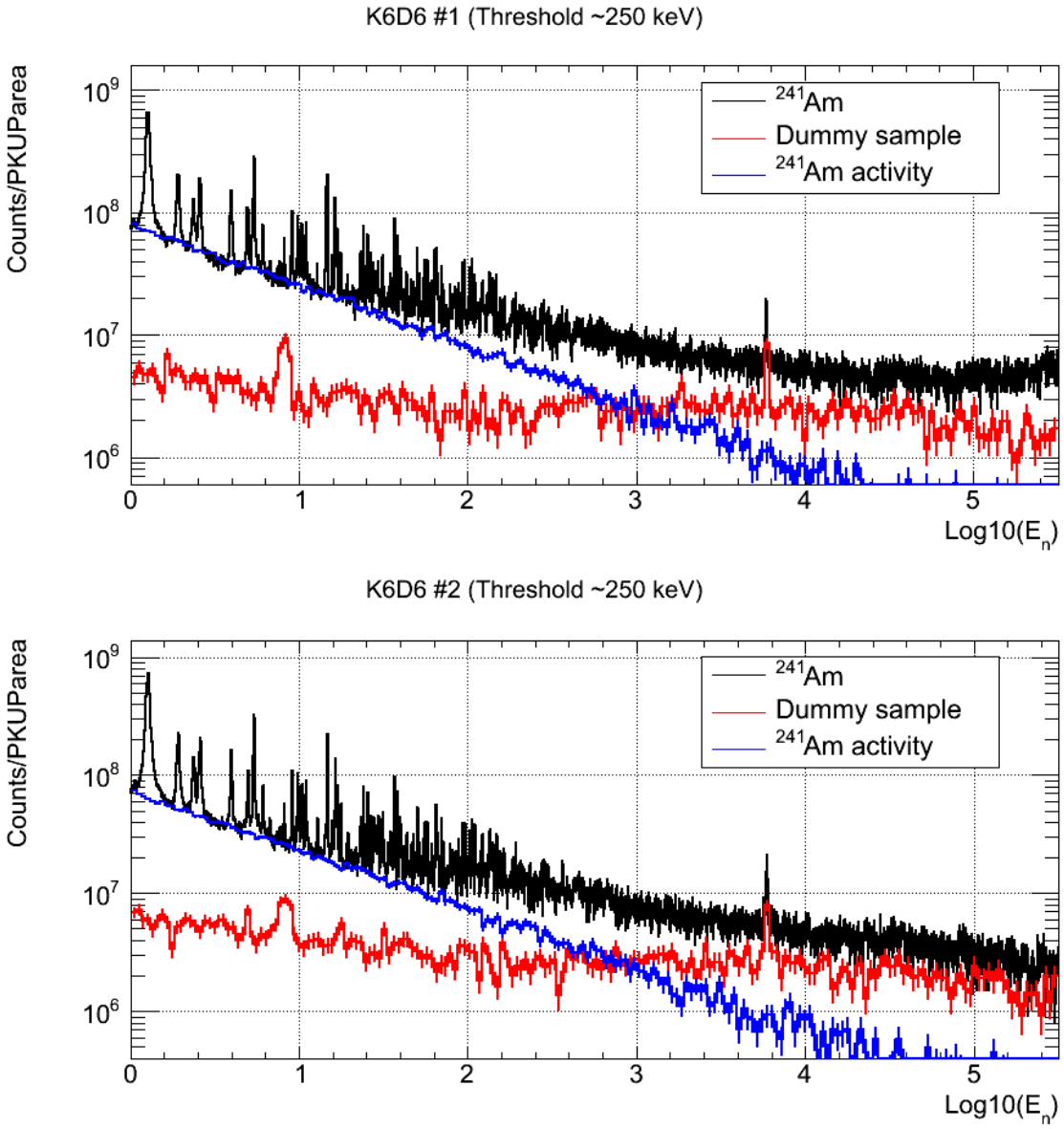
irfu

cea

saclay

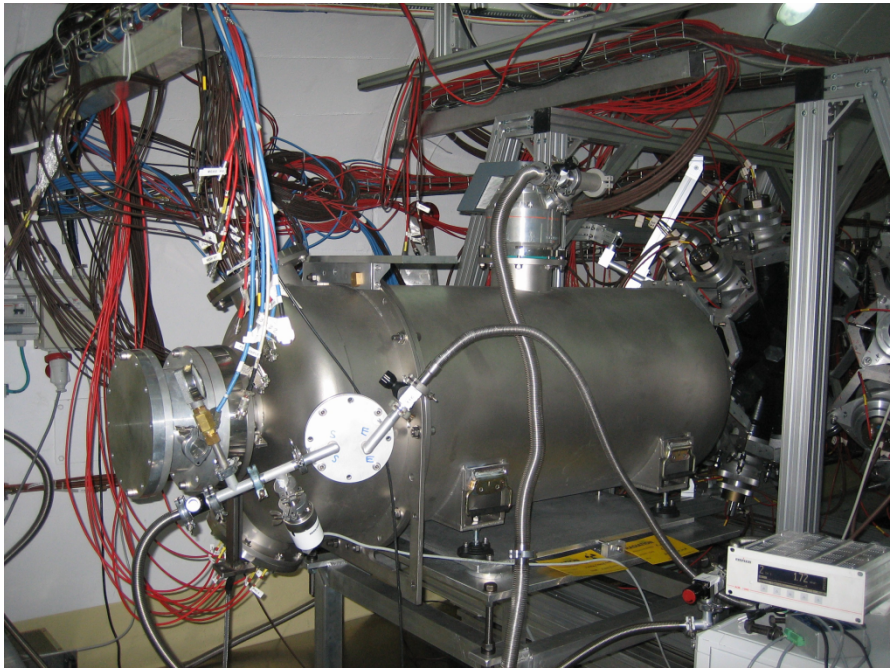
Transport ^{241}Am à l'intérieur du CERN

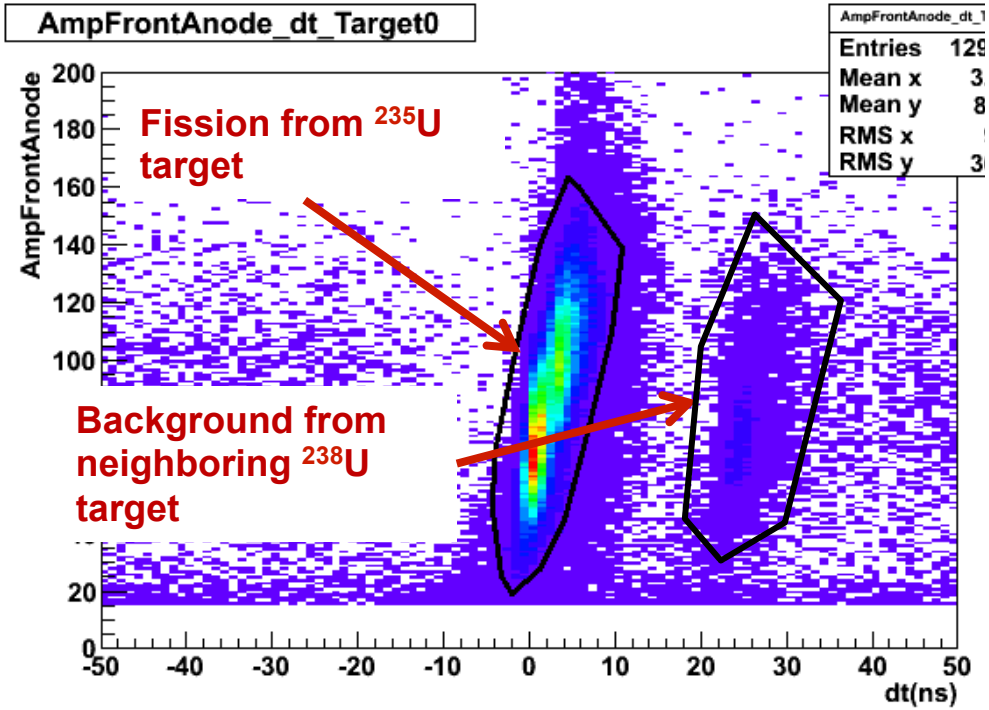
^{241}Am (n,γ) data



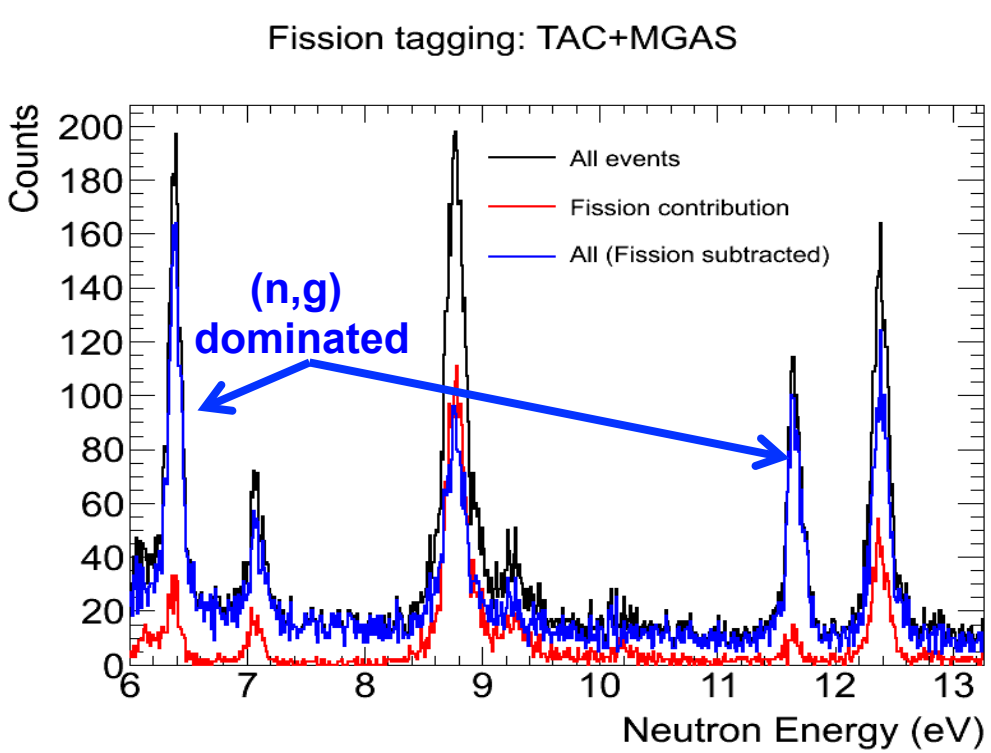
Angular distribution of fission fragments

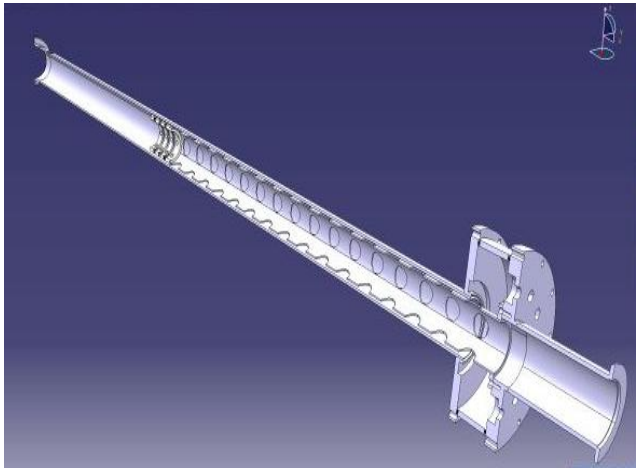
- PPAC with 10 parallel plate detectors tilted 45 degrees with respect to the beam.
- 9 samples: ^{235}U, ^{238}U, ^{237}Np and 6x^{232}Th.

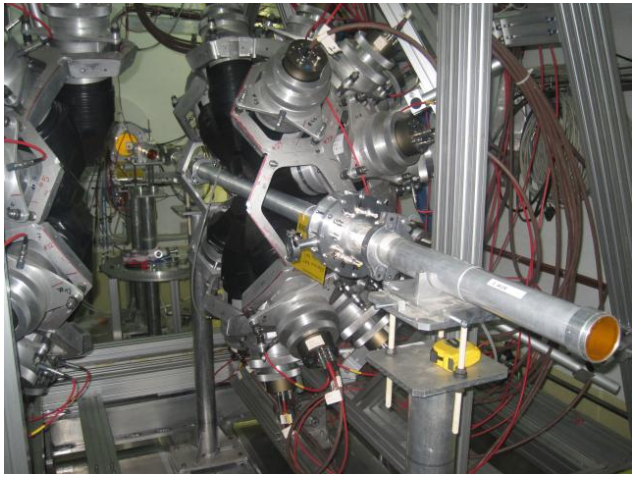




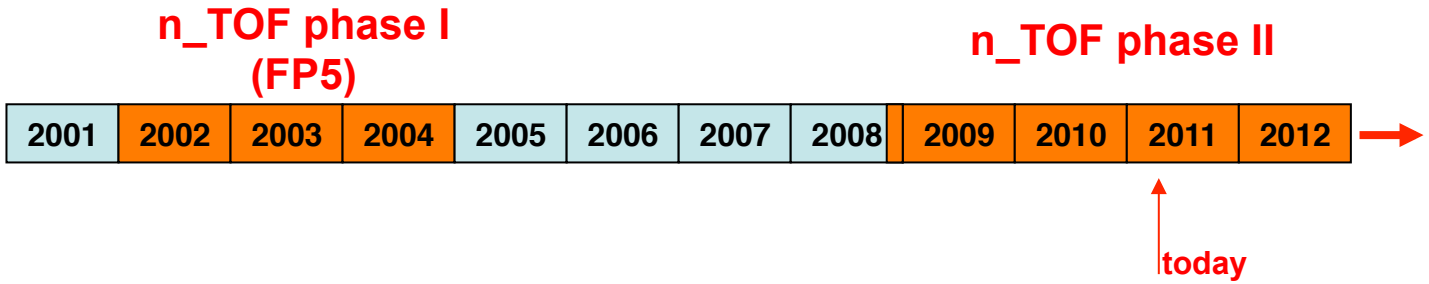
Simultaneous capture and fission







Outlook n_TOF at CERN



- 1998 - 2001 preparation and commissioning
- 2002 - 2004 **phase I** data taking
- 2005 - 2007 spallation target upgrade
- 2008 first protons on target
- 2009 **phase II** data taking
- 2010 class A lab. borated water
- **future** **second, short flight path (20 m)**

The n_TOF Collaboration

irfu

cea

saclay

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More information: www.cern.ch/ntof