

# Measurements with neutrons at wELBE

Roland Beyer, Helmholtz-Zentrum Dresden-Rossendorf, Germany

HZDR

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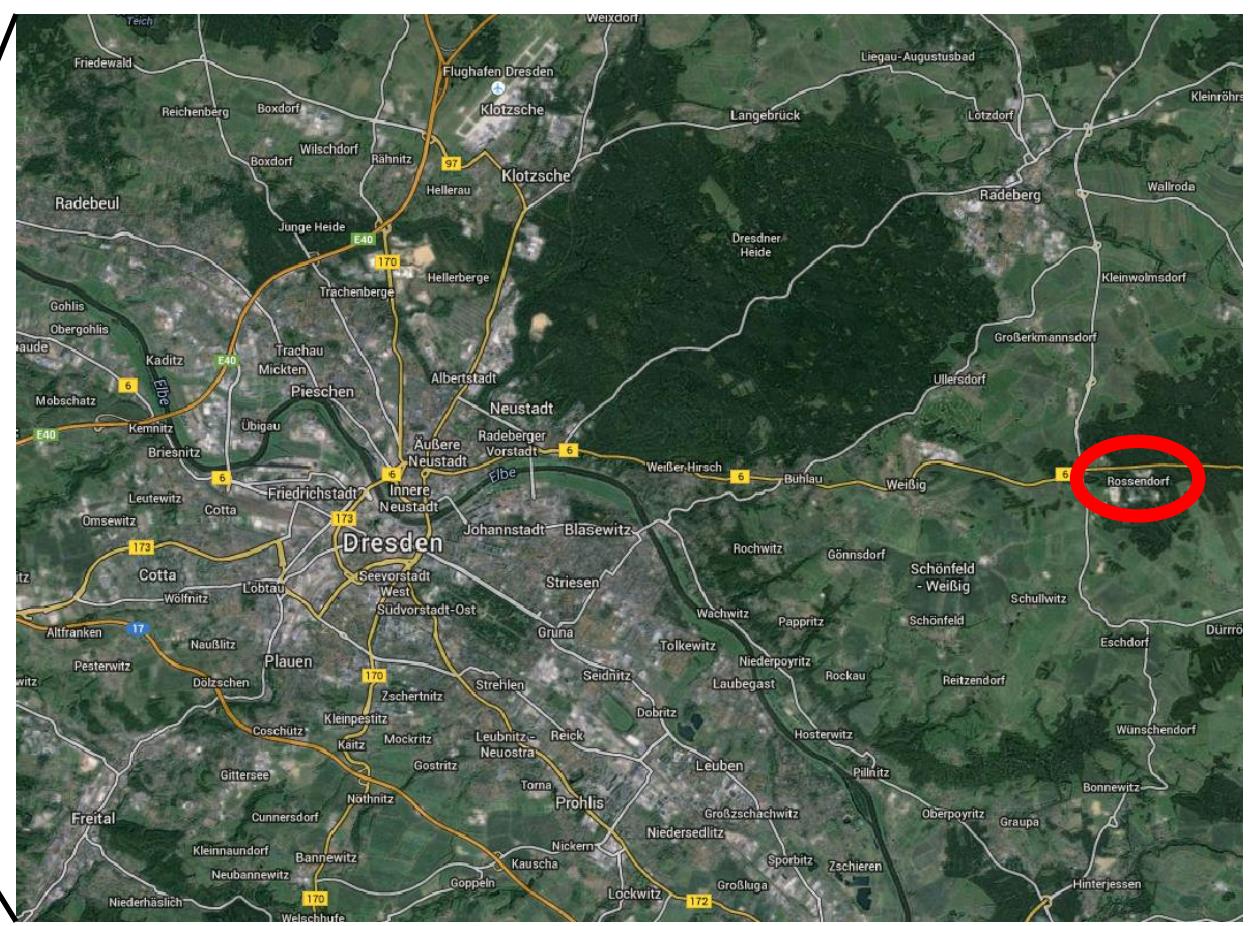
# Outline

- The  $\nu$ ELBE - neutron time-of-flight facility
- Transmission of thick iron samples
- $^{19}\text{F}/^{16}\text{O}(\text{n},\alpha)$  with SCALP
- Summary

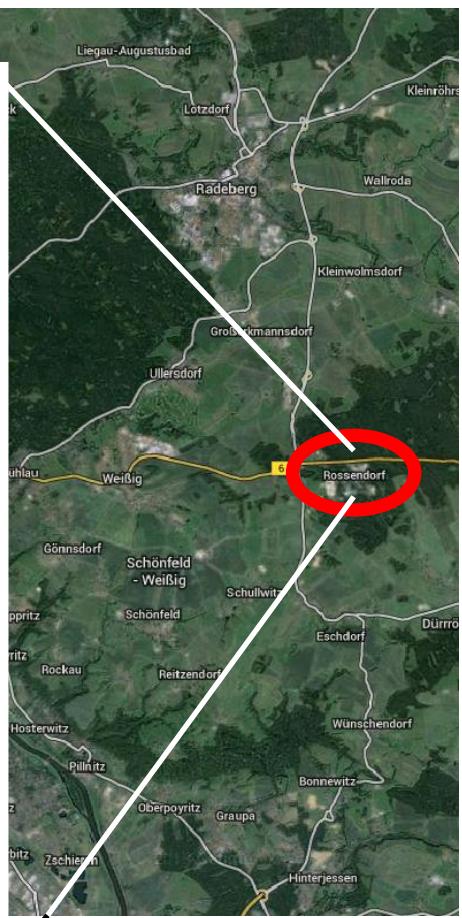
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# nELBE – The neutron time-of-flight facility at ELBE

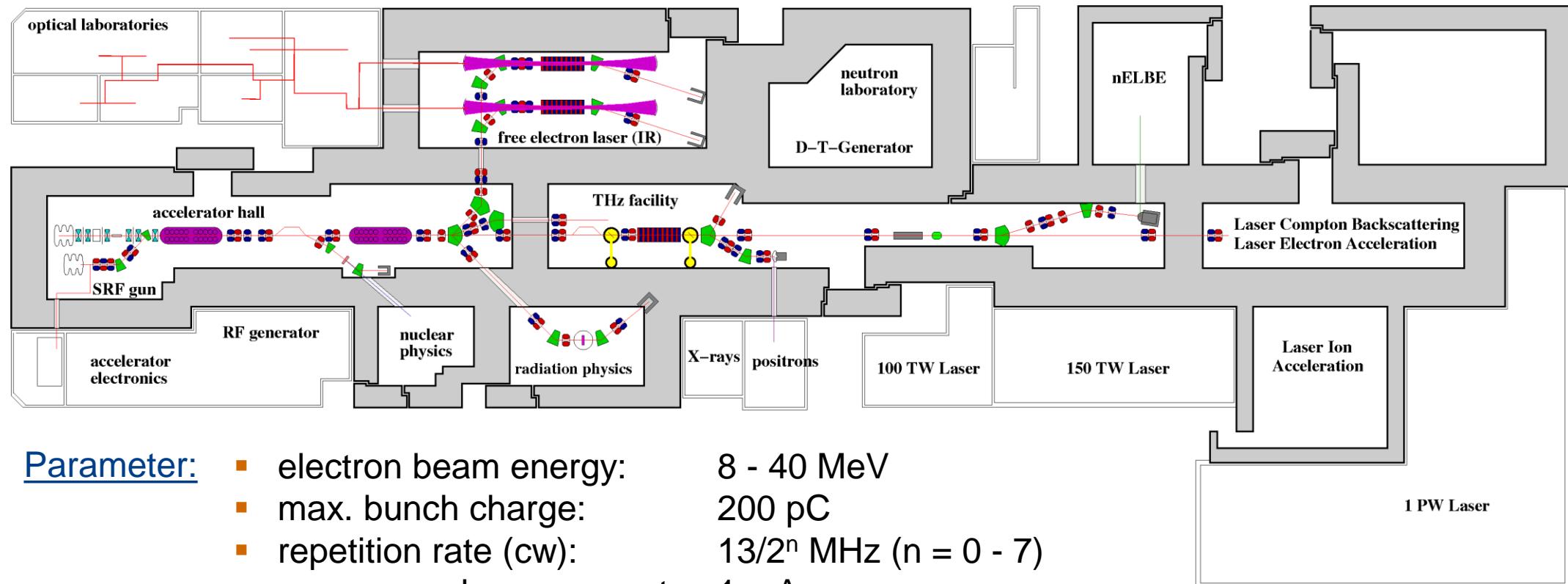


## nELBE – The neutron time-of-flight facility at ELBE



# nELBE – The neutron time-of-flight facility at ELBE

ELBE - Center for high-power radiation sources (Electron Linac for beams with high **B**rilliance and low **E**mittance)



## Parameter:

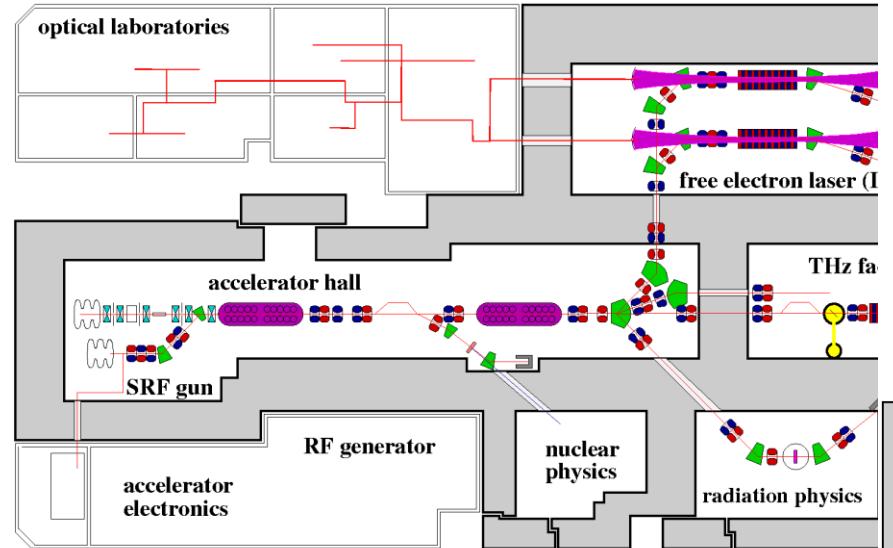
- electron beam energy: 8 - 40 MeV
- max. bunch charge: 200 pC
- repetition rate (cw):  $13/2^n$  MHz ( $n = 0 - 7$ )
- max. mean beam current: 1 mA
- micro pulse length: ca. 5 ps

<http://www.hzdr.de/elbe>



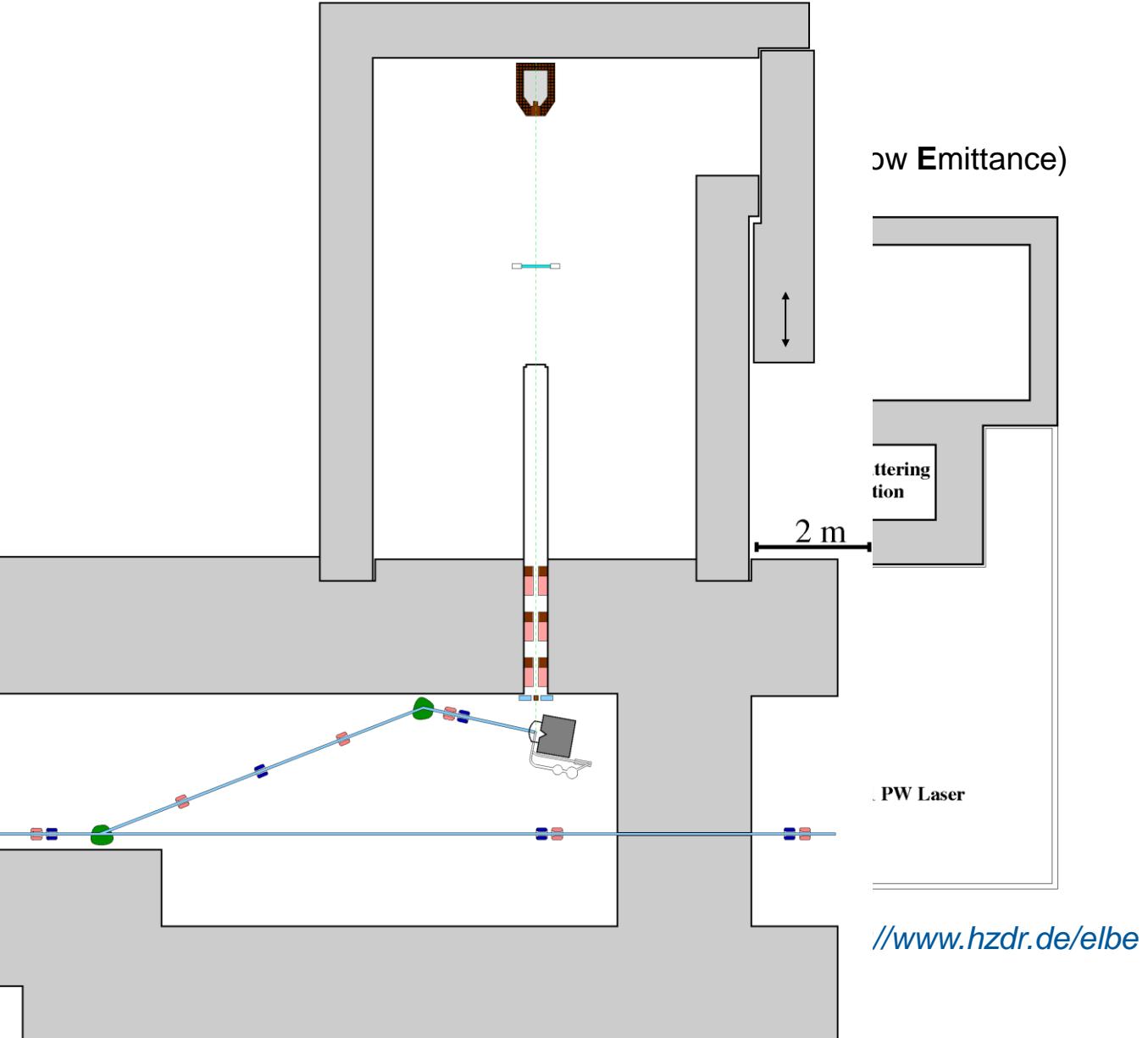
# nELBE – The neutron time-of-flight

ELBE - Center for high-power radiation sources



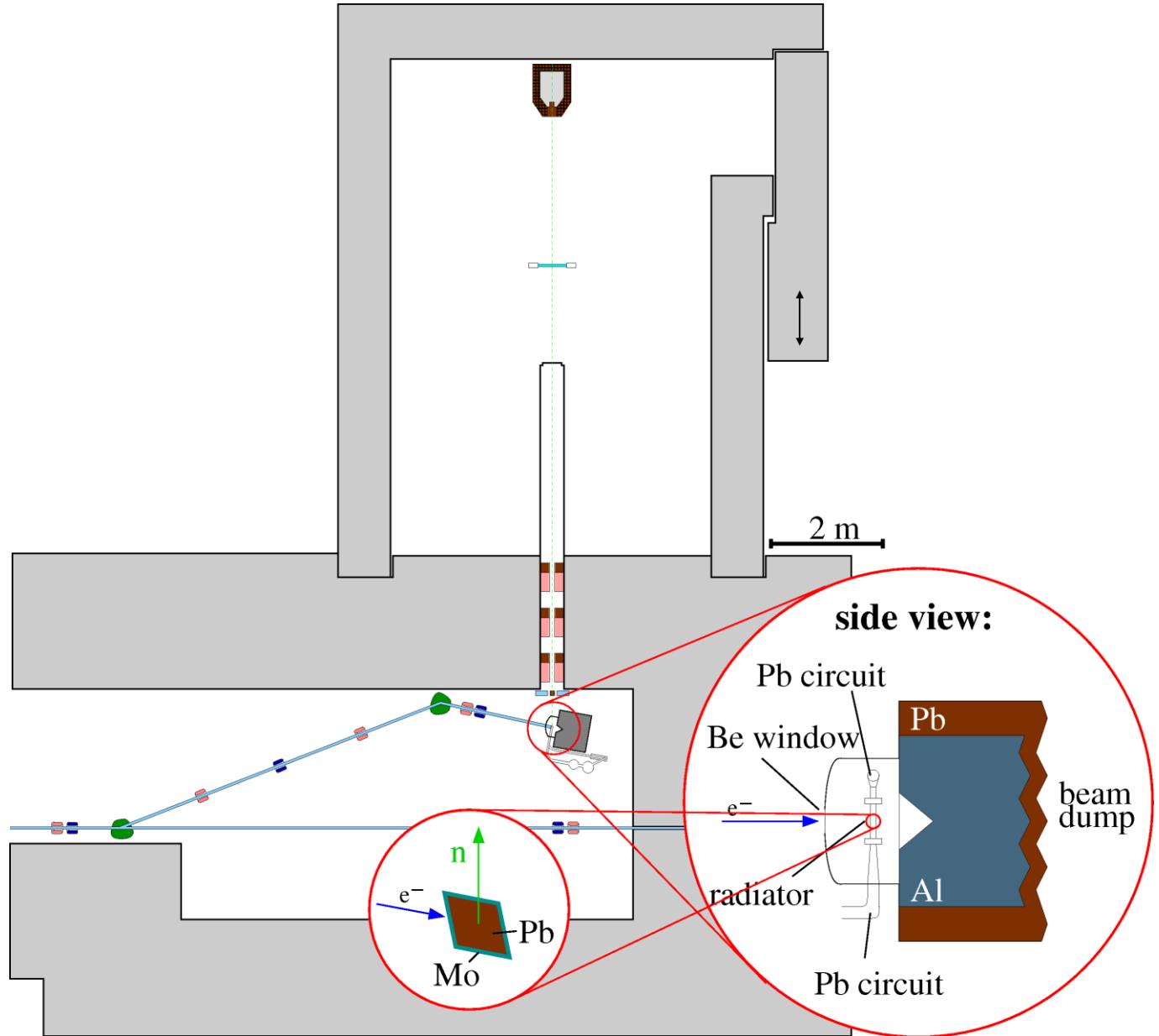
## Parameter:

- electron beam energy:
- max. bunch charge:
- repetition rate (cw):
- max. mean beam current:
- micro pulse length:

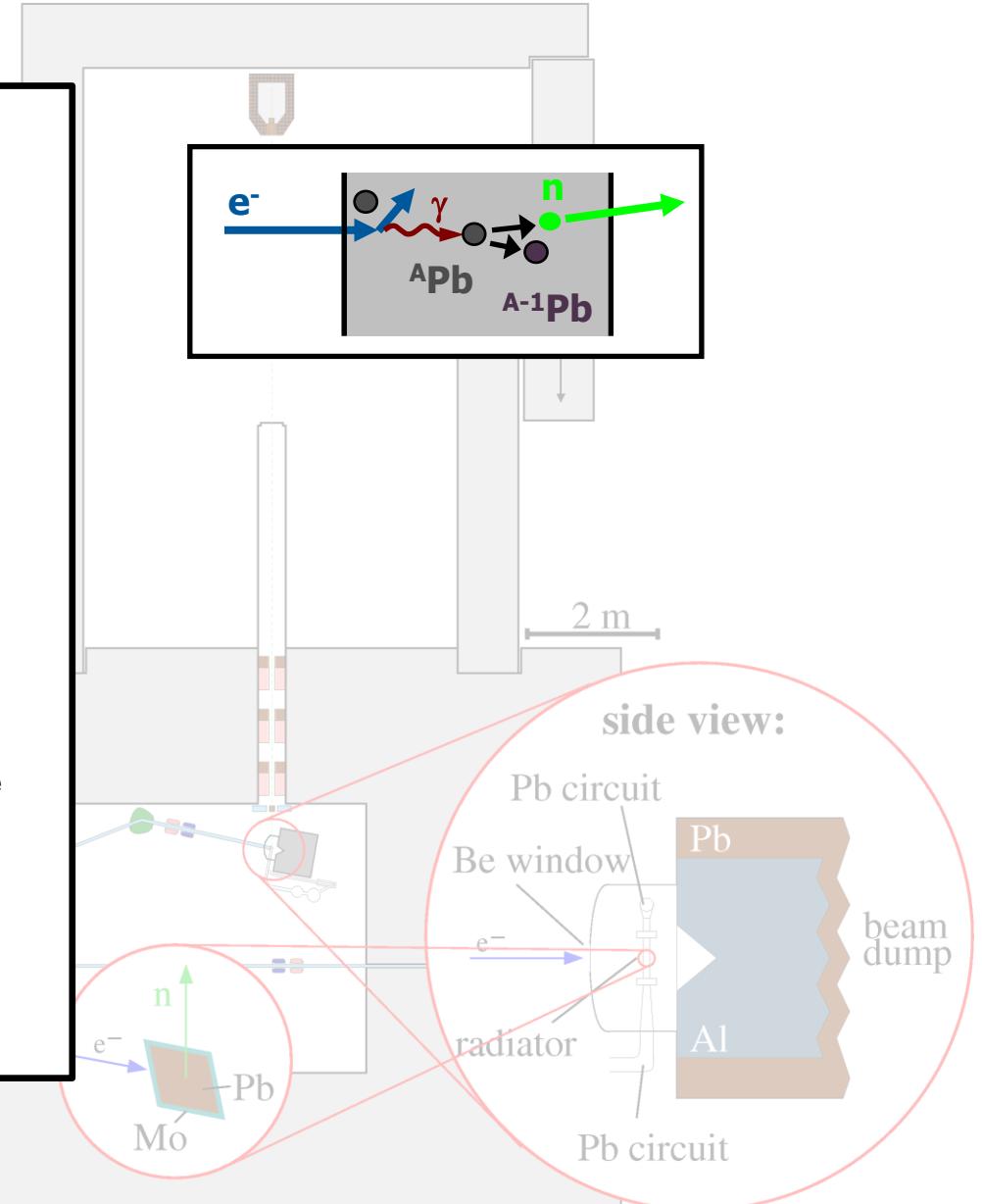
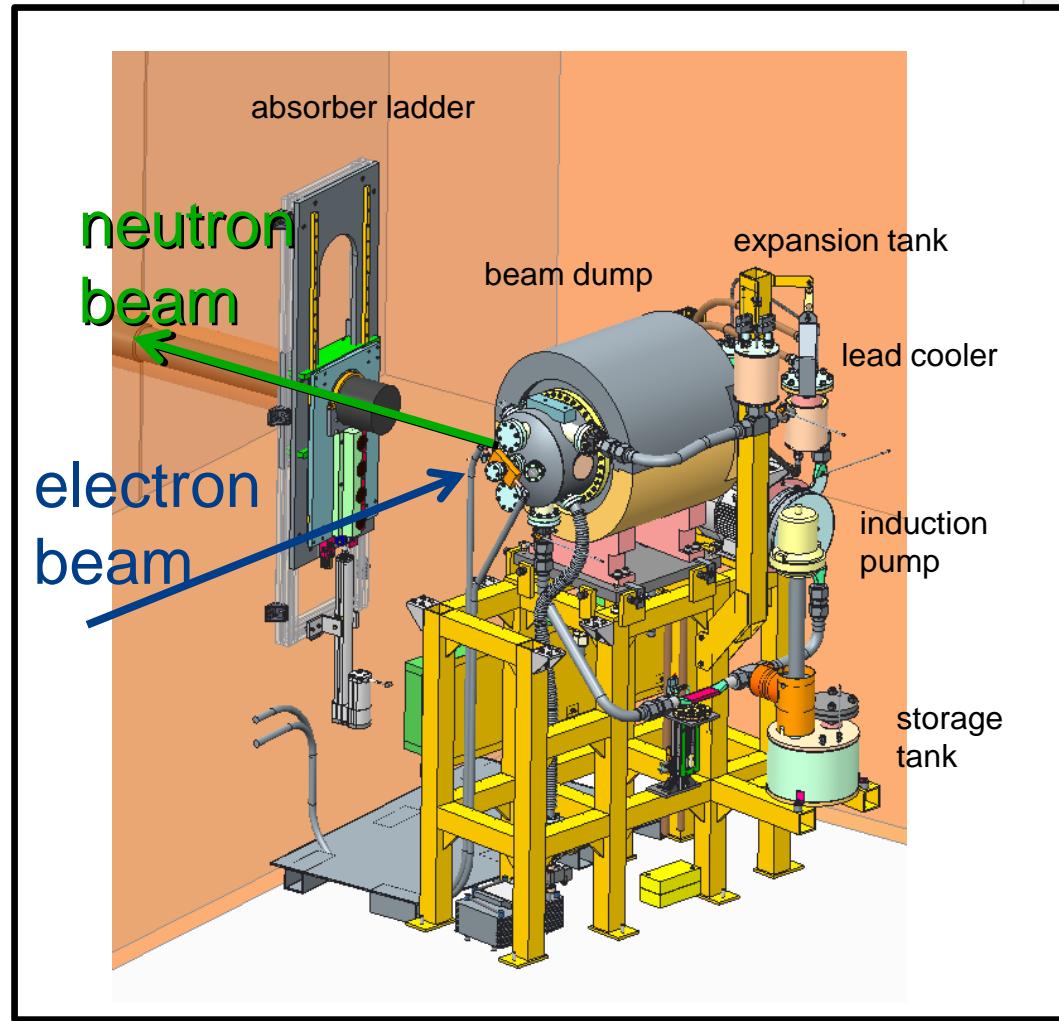


Gabriel et al., Nucl.Inst.Meth.B 161 (2000) 1143; Teichert et al.

# Neutron production



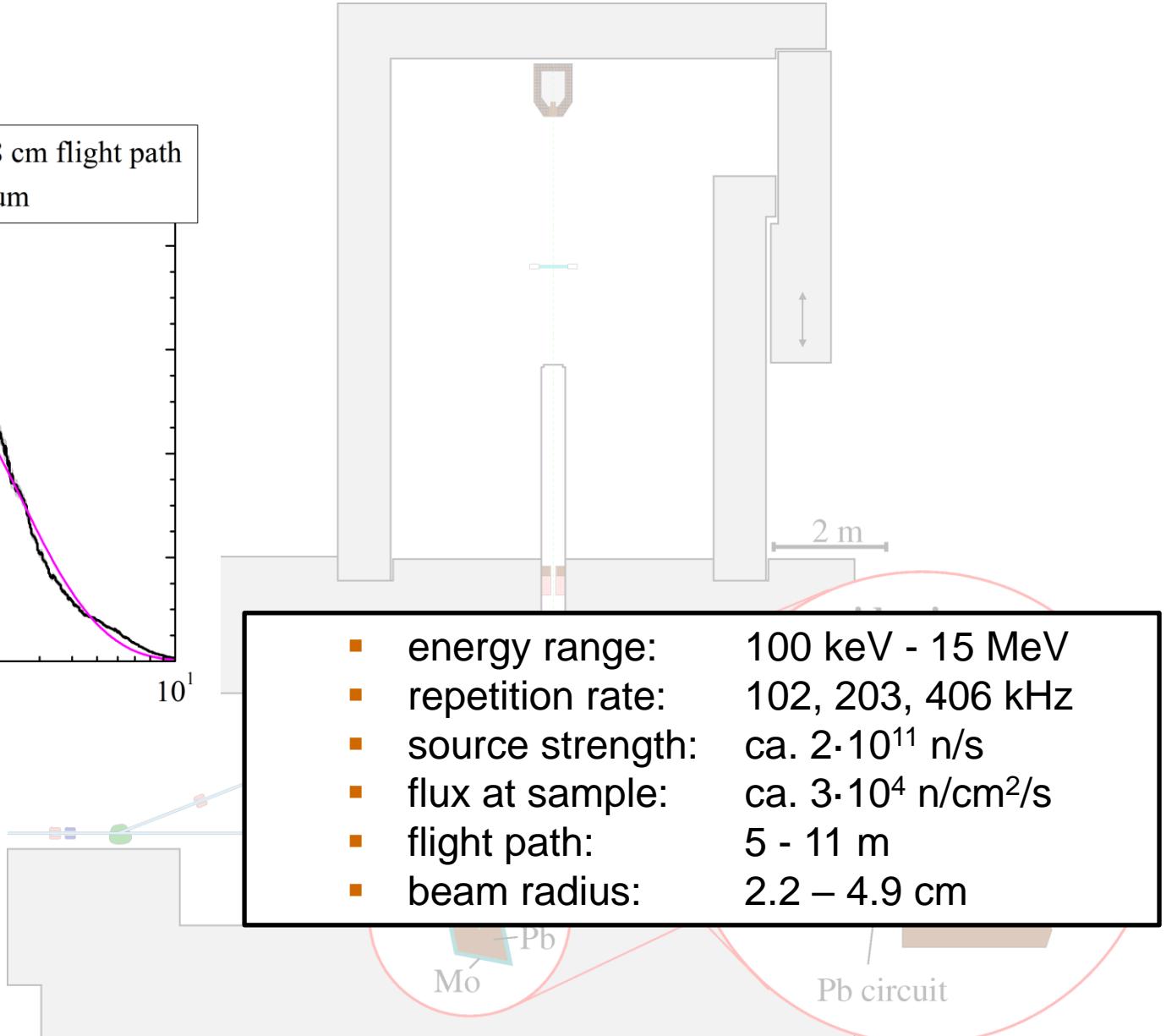
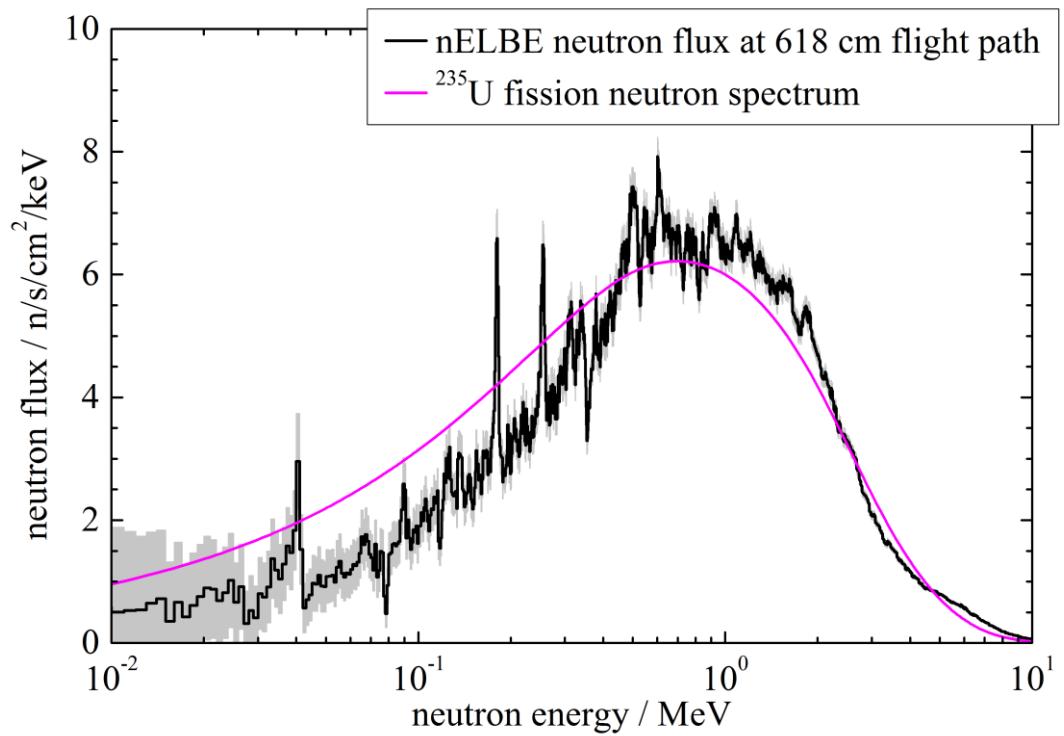
# Neutron production



Altstadt et al., Ann.Nucl.Ene. 34 (2007) 36

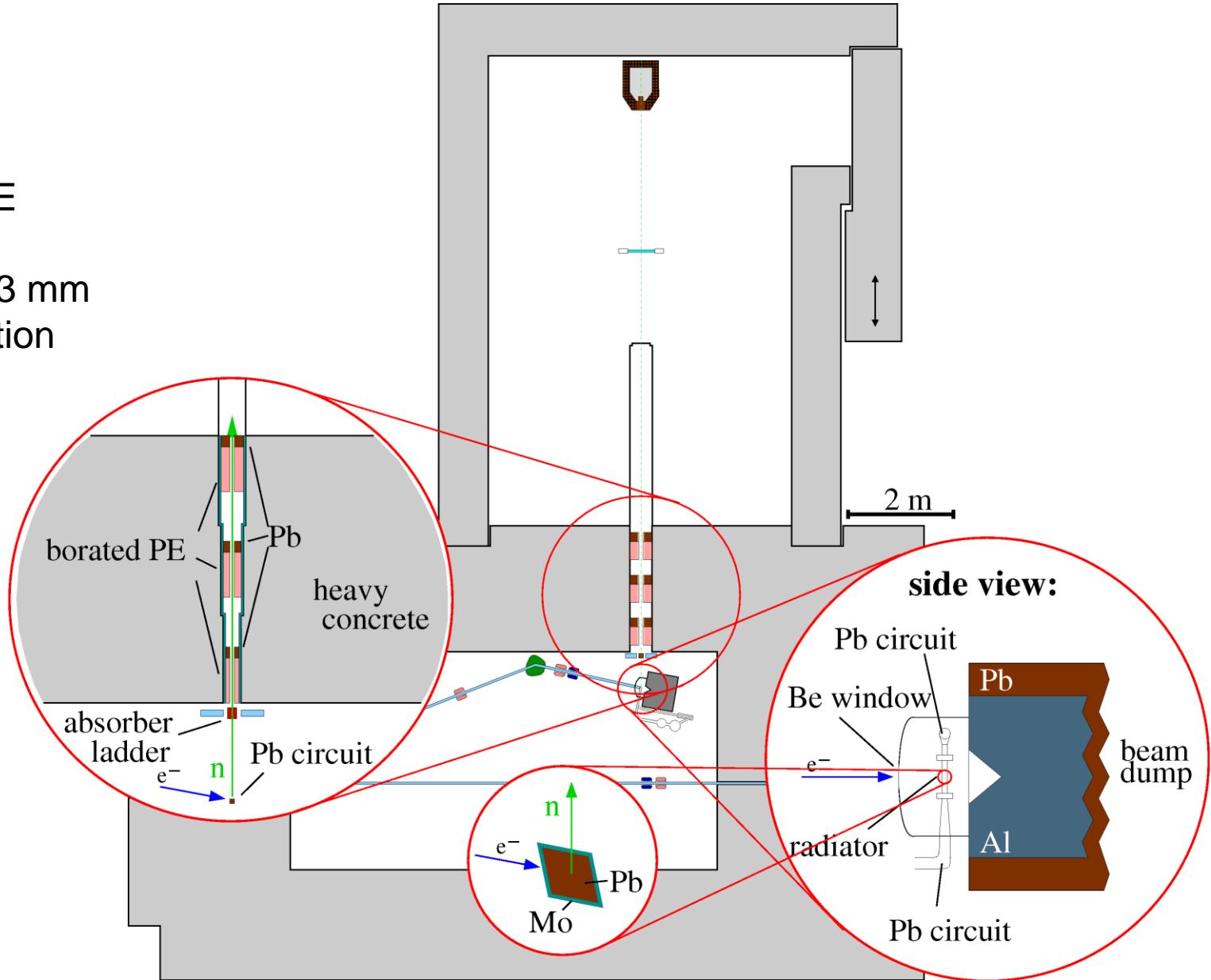
Klug et al., Nucl.Inst.Meth.A 577 (2007) 641

# Neutron production

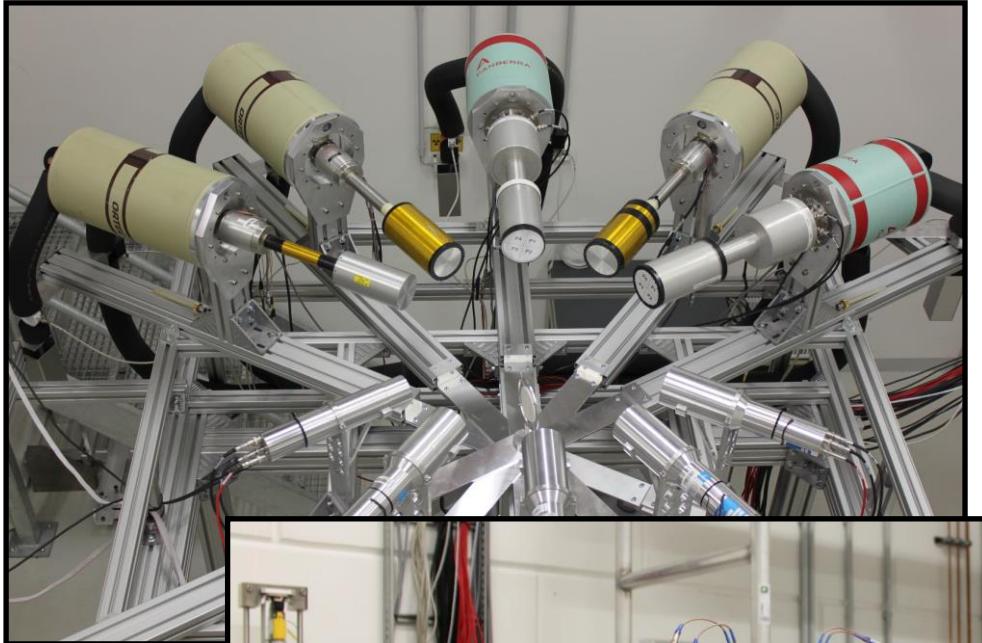


# Collimator

- evacuated steel tube
- insets of Pb and borated PE
- conical borehole
- entrance/exit diameter = 2/3 mm
- cylindrical intensity distribution  
(diam. 5 - 10 cm)

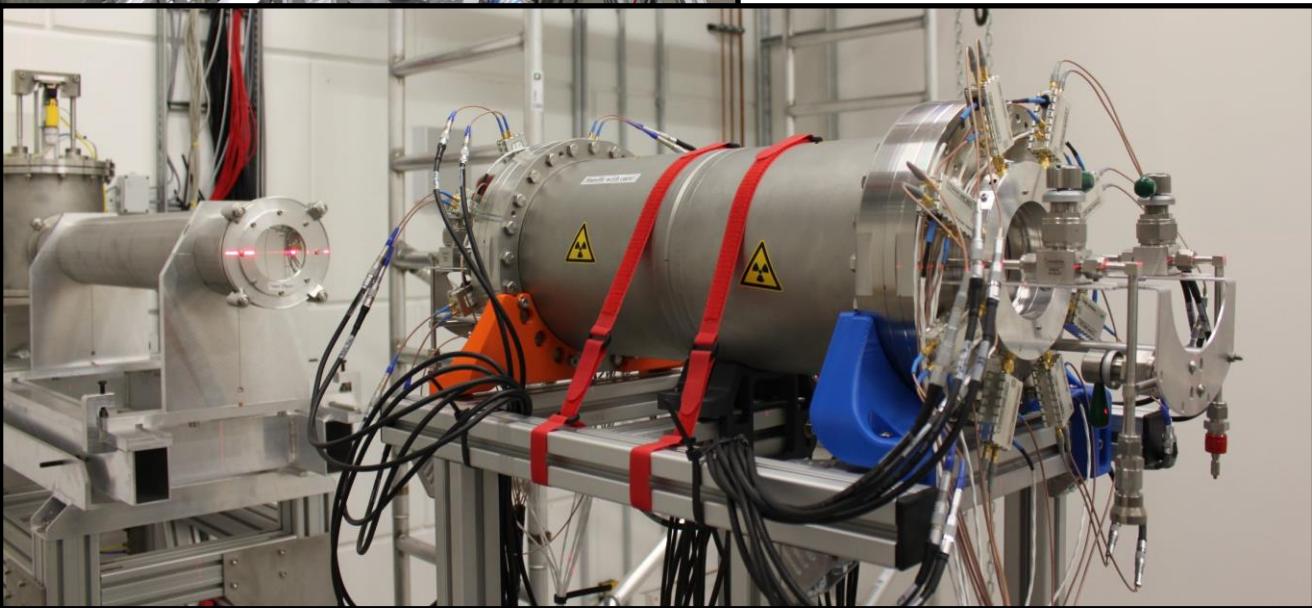


## Examples of experiments

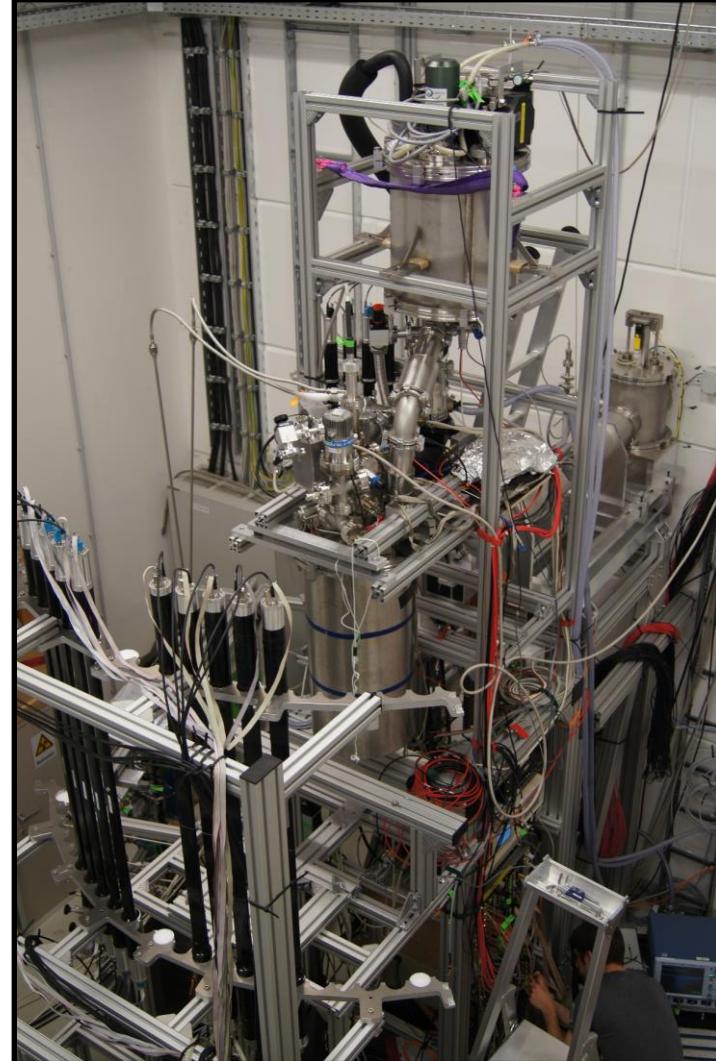


$(n,n'\gamma)$ ,  $(n,\text{el})$

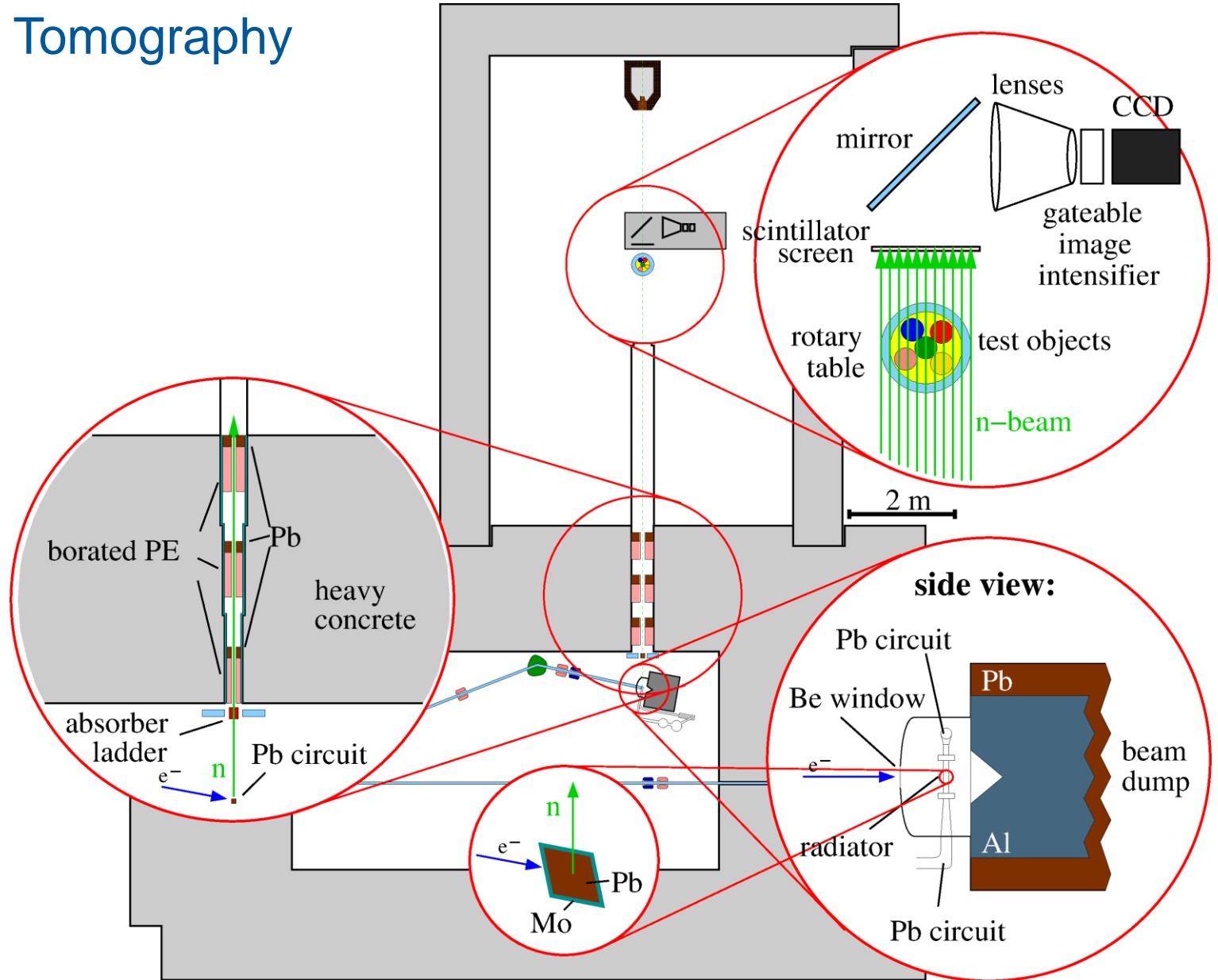
detector response



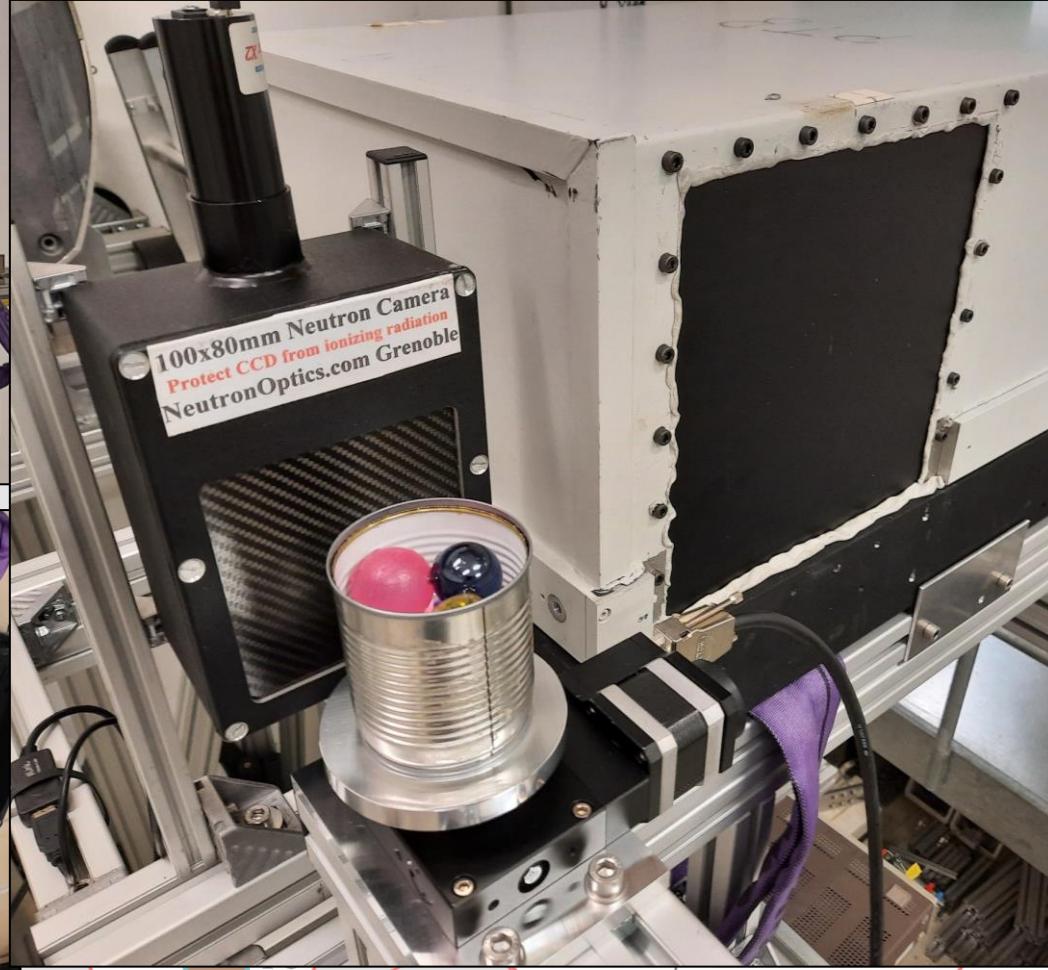
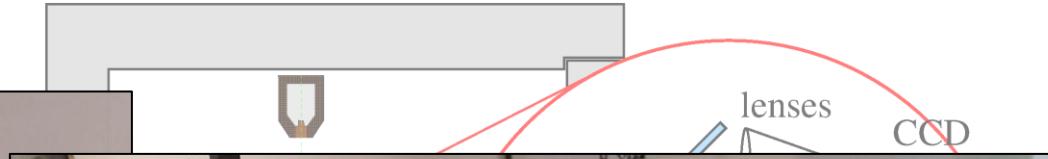
$(n,\text{fis})$



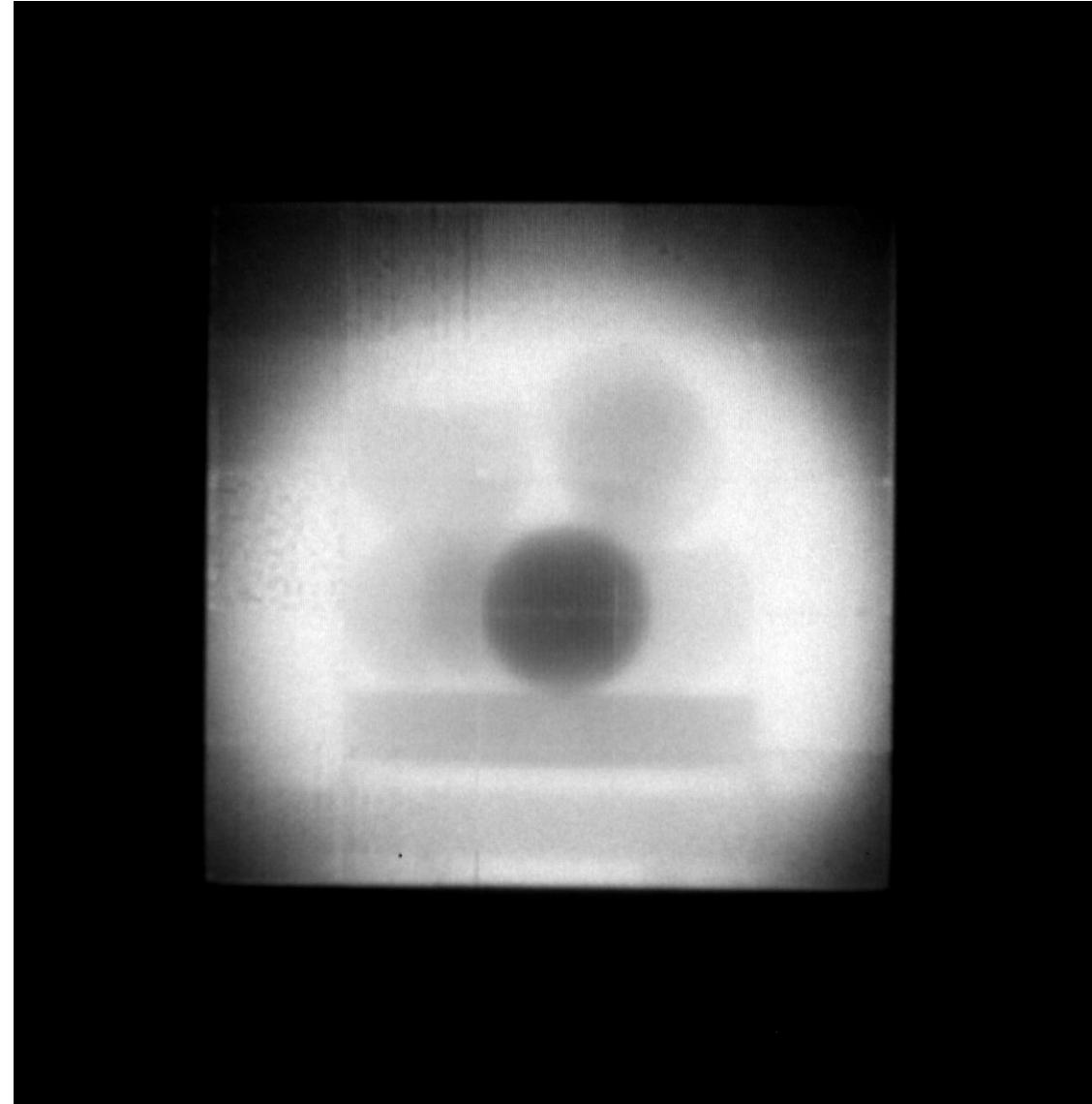
# Neutron Radiography + Tomography



# Neutron Radiography + Tomography



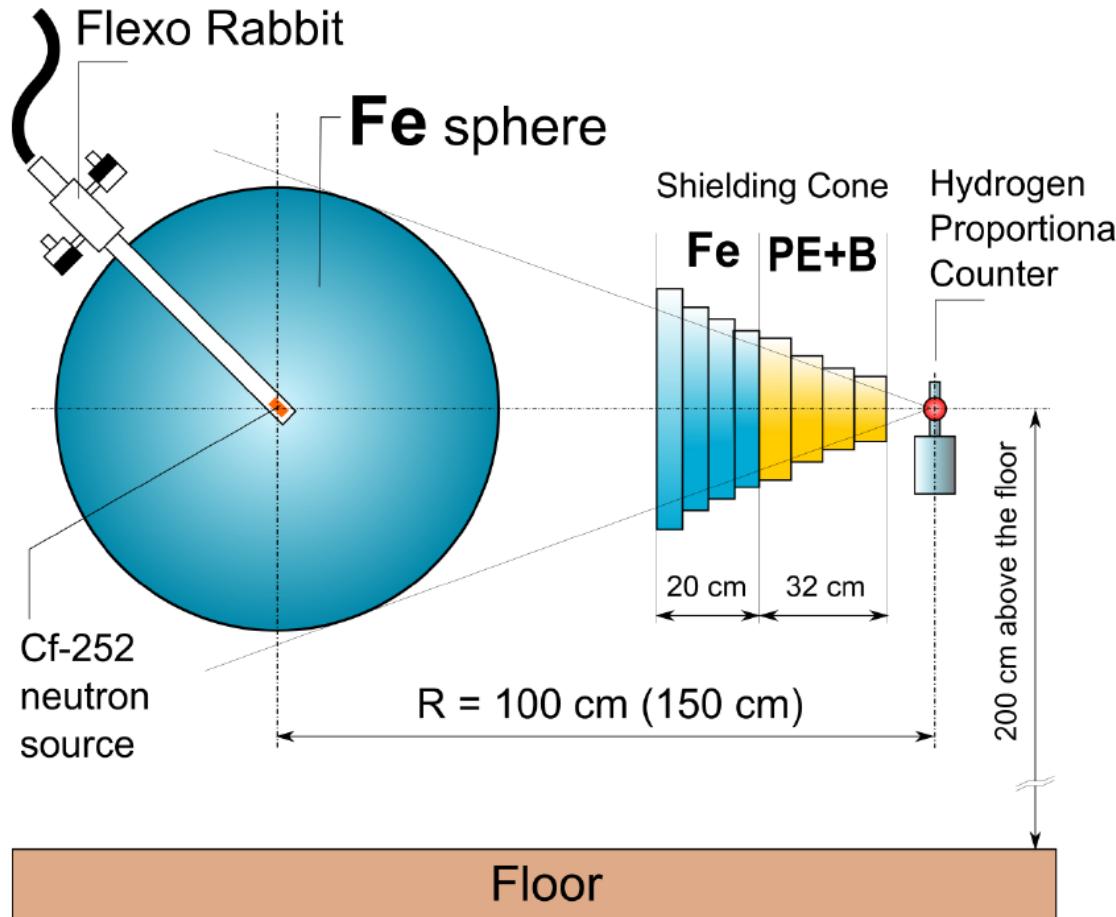
# Neutron Radiography + Tomography



# Outline

- The  $\text{\textmu ELBE}$  - neutron time-of-flight facility
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# Transmission on thick iron samples - Motivation



## Thick iron sphere leakage measurements at Rez

- Fe sphere radius 50 cm
- Hydrogen proportional counter with good energy resolution
- Detect transmitted neutrons in the regions of the  ${}^{\text{nat}}\text{Fe}$  cross section minima
- Resolution to resolve peak structure 200-500 keV

M. Schulc ARI 130, 224, Fig. 1, and JEFFDOC-1918

# Transmission on thick iron samples - Motivation

Tab.1 Assembly FE DIA100, R53; 200gpd, integral values, C/E

( Jansky, ND 2013, New York, [1] )

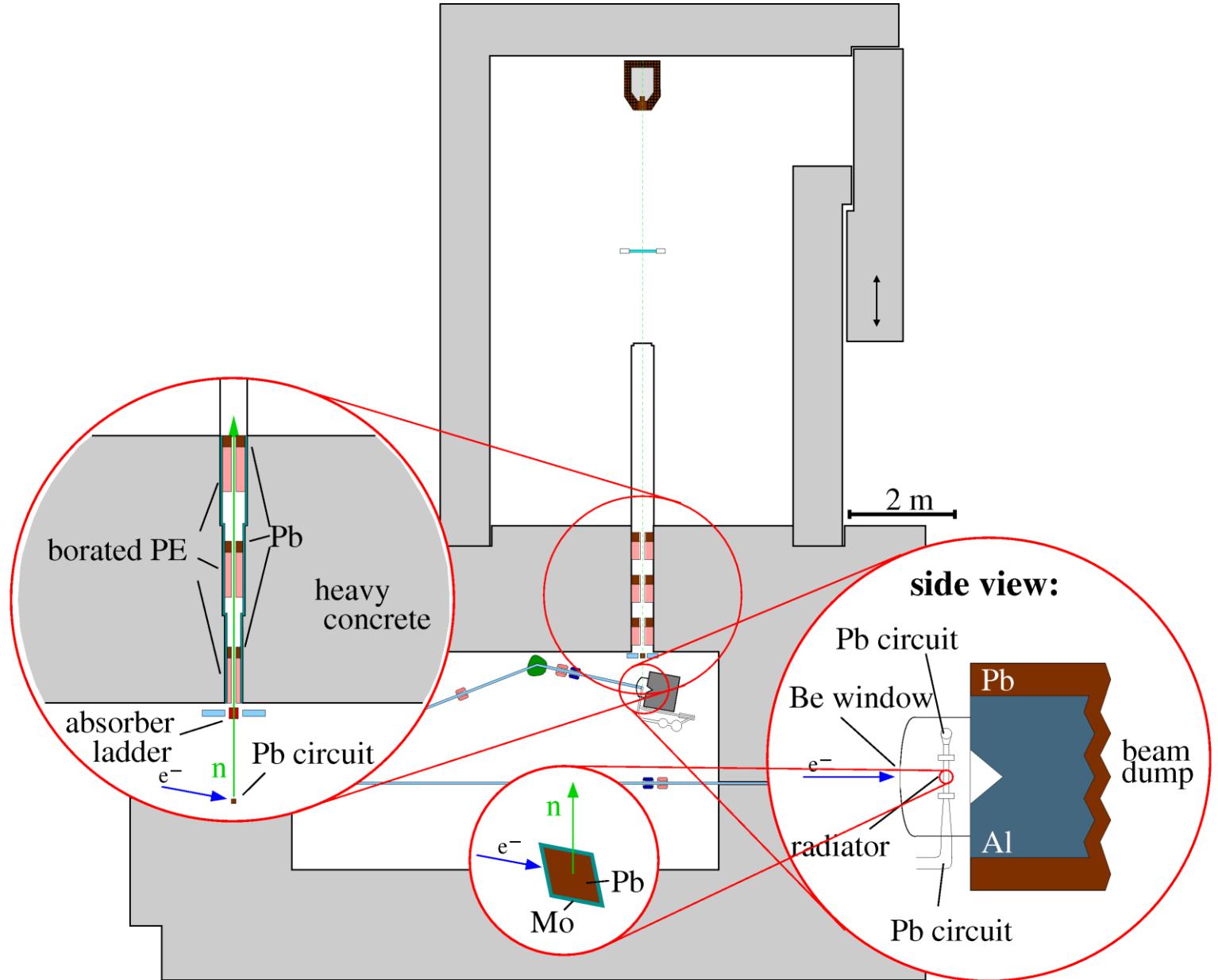
No.	En.range[MeV]		main peak [keV]	Library used for MCNP Calculation					
	from	to		ENDF/B-VII.1	BROND-3	JENDL-4.0	JEFF-3.2T2	TENDL-2012	CENDL-3.1
0	0.013	1.290	total range	1.031	1.036	1.049	1.053	1.031	1.040
1	0.013	0.030	24.4	0.918	0.836	1.029	0.989	1.221	0.891
2	0.030	0.075		0.909	0.835	0.903	0.967	0.858	1.146
3	0.075	0.090	82	1.008	0.912	0.999	1.017	1.119	1.402
4	0.090	0.150	137	0.845	0.828	0.920	1.004	0.970	0.732
5	0.150	0.200	167+183	0.907	0.898	0.974	1.015	1.012	0.909
6	0.200	0.250		1.012	1.051	1.024	1.018	0.872	1.196
7	0.250	0.289	272	1.075	1.097	1.011	1.015	0.948	1.115
8	0.289	0.333	309	1.423	1.366	1.338	1.245	1.317	1.129
9	0.333	0.410	350	1.269	1.256	1.278	1.235	1.335	1.474
10	0.410	0.520		1.044	1.177	1.046	1.085	0.779	1.036
11	0.520	0.780	610+650+703	1.147	1.366	1.122	1.064	0.835	1.152
12	0.780	1.060		0.946	1.017	0.863	1.050	0.730	0.681
13	1.060	1.290		0.910	0.710	0.834	0.866	0.826	0.777



- shortcomings found in several cross section minima between 50 and 700 keV

M. Schulc ARI 130, 224, Fig. 4, and JEFFDOC-1918

# Absorber ladder



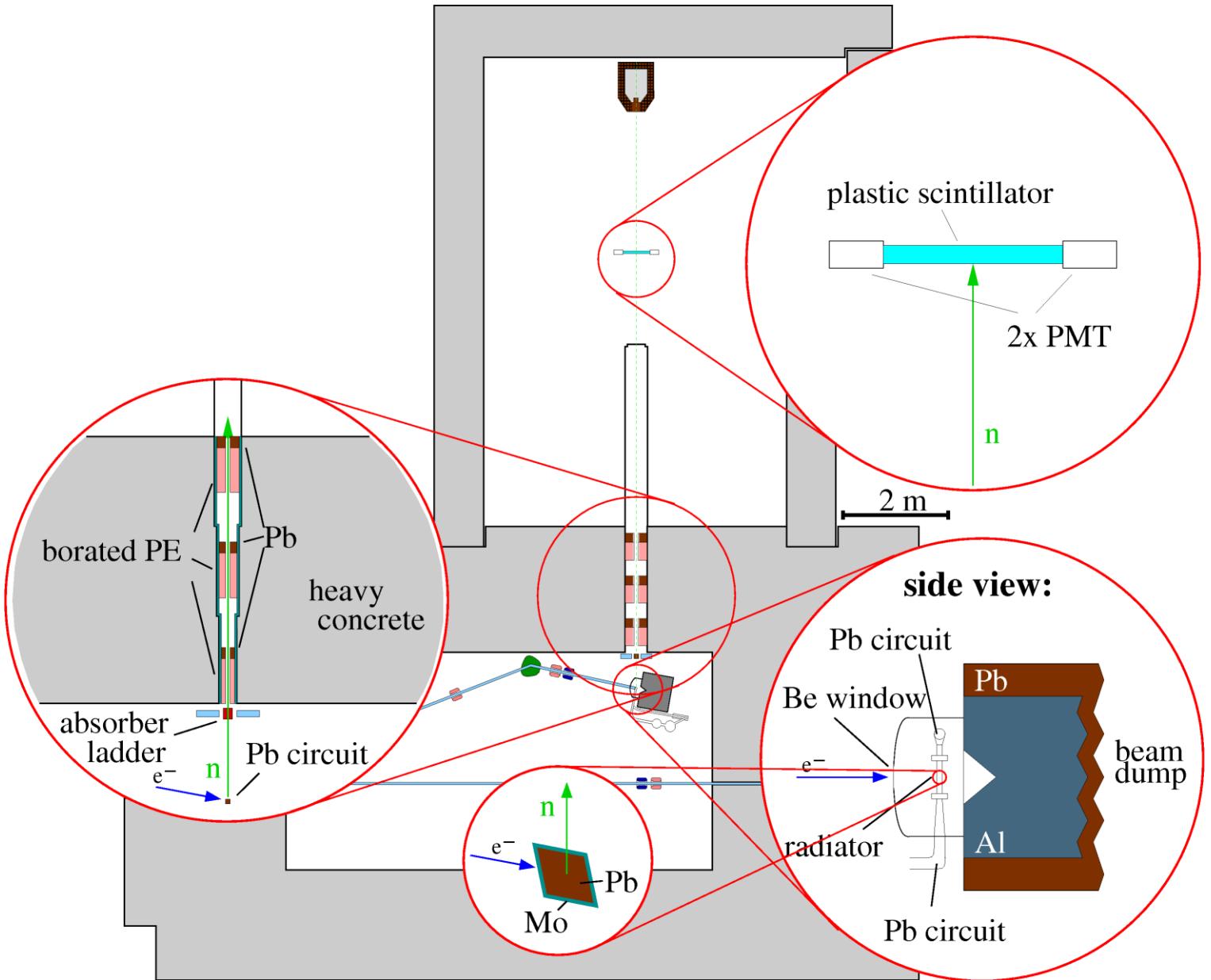
## Absorber ladder



- tungsten shutter
- 3 positions for transmission samples + empty
  - Puron pure iron samples (99.9226%)
  - 20, 50, 90 mm thickness
  - 0.16948, 0.42495, 0.76445 at/barn
- automatic movement every 5 – 40 minutes



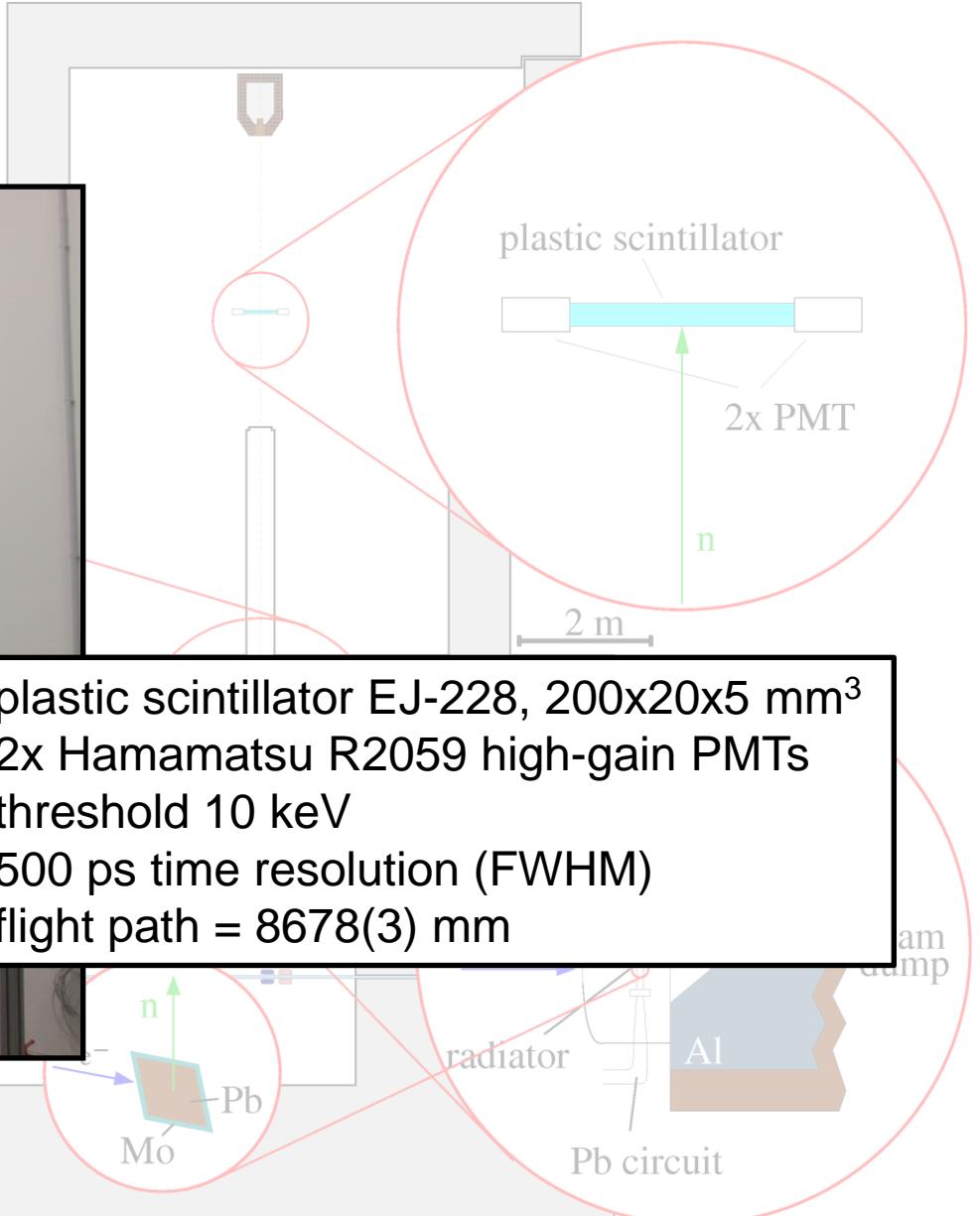
# Transmission

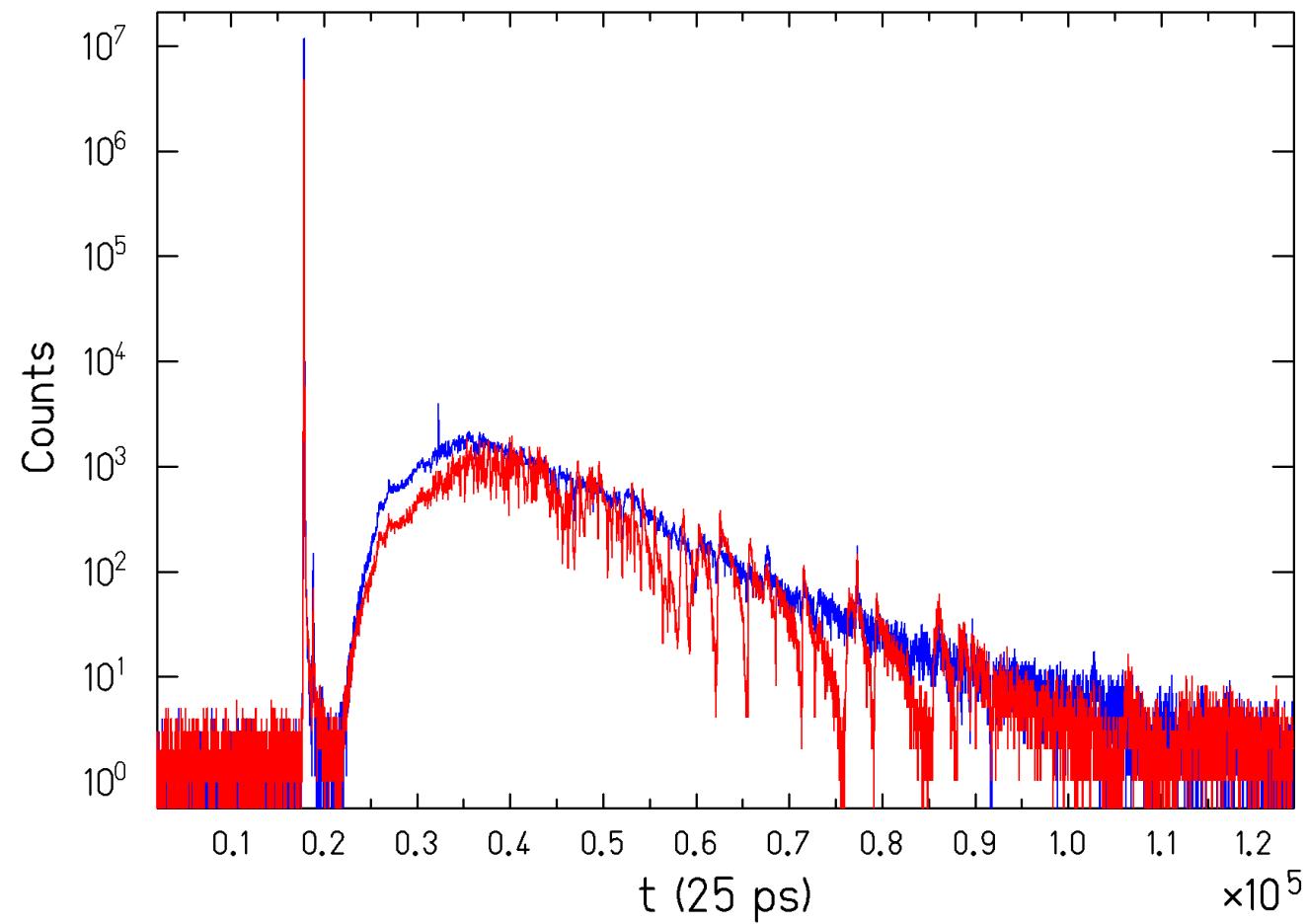


# Transmission



- plastic scintillator EJ-228,  $200 \times 20 \times 5 \text{ mm}^3$
- 2x Hamamatsu R2059 high-gain PMTs
- threshold 10 keV
- 500 ps time resolution (FWHM)
- flight path =  $8678(3) \text{ mm}$



$\text{natFe(n,tot)}$ 

$$T_{exp} = \frac{R_{in}}{R_{out}} = \frac{\frac{N_{in}}{\alpha_{in}} - B_{in}}{\frac{N_{out}}{\alpha_{out}} - B_{out}} \cdot f_{norm}$$

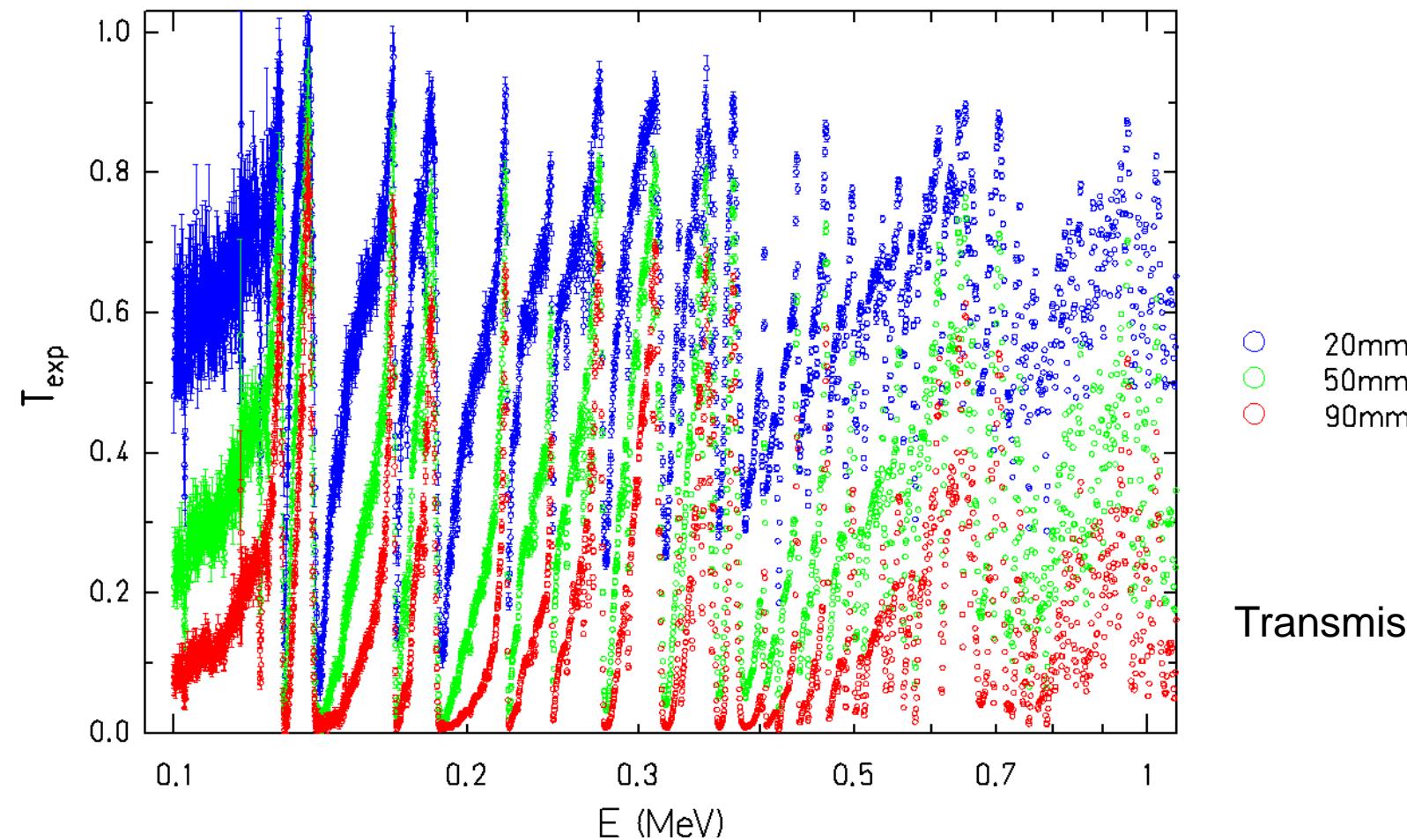
- neutron rate ca.  $200\text{-}500 \text{ s}^{-1}$
- random background mostly beam off background
- cross section maxima saturated at 90 mm thickness
- time resolution of 500 ps from  $\gamma$ -flash width

## $\text{natFe(n,tot)}$

$$T_{exp} = \frac{R_{in}}{R_{out}} = \frac{\frac{N_{in}}{\alpha_{in}} - B_{in}}{\frac{N_{out}}{\alpha_{out}} - B_{out}} \cdot f_{norm}$$

- **time-of-flight dependent dead time**  
fraction of blocked tof channels accumulated for all accelerator periods  $\alpha_{in}, \alpha_{out}$
- **constant random background  $B_{in}$ ,**  
dominated by beam-off background, nearly t.o.f. independent  
reduced by using position information (gate on  $\Delta t$  from PMT signals)
- **neutron beam intensity fluctuations  $f_{norm}$**   
frequent absorber changes (target in / target out)  
normalisation factor  $f_{norm}$  from target out neutron rate and  
spectrum averaged neutron transmission
- **in scattering of neutrons negligible (< 0.1 %)**  
target sample in front of a small solid angle collimator.
- $T_{exp}$  is larger than would be estimated on point-wise cross sections due to  
**resonant self shielding** in the **unresolved resonance range** at  $E_n < 150 \text{ keV}$   
MCNP simulation with probability tables method →  $F_T$

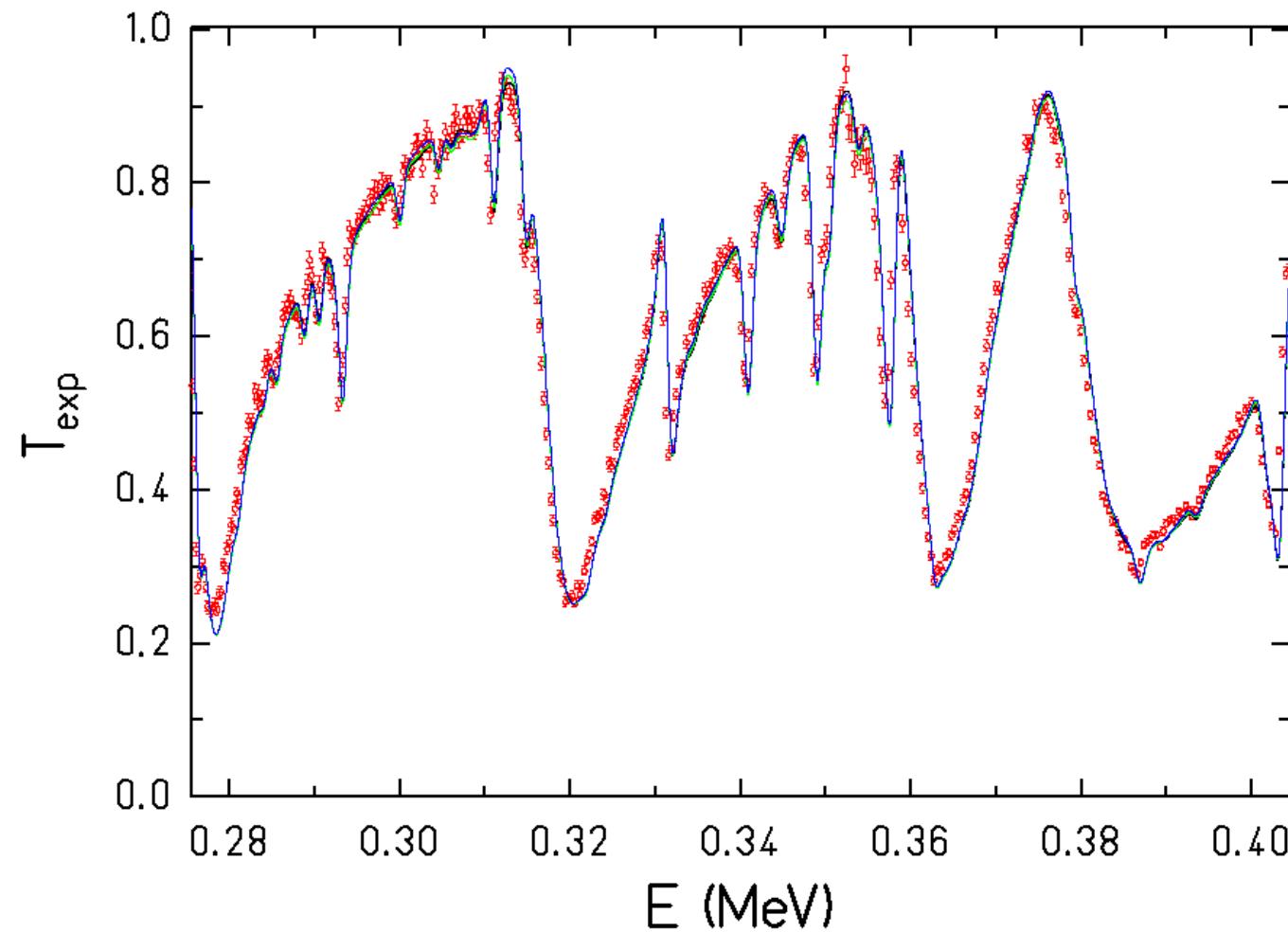
$$\langle T_{exp} \rangle = F_T \cdot e^{-n\langle \sigma_{tot} \rangle}$$

$\text{natFe(n,tot)}$ 

Transmission measured from 0.10 to 12 MeV

$\text{natFe}(n, \text{tot})$ 

Fe (20 mm)



Gaussian resolution function

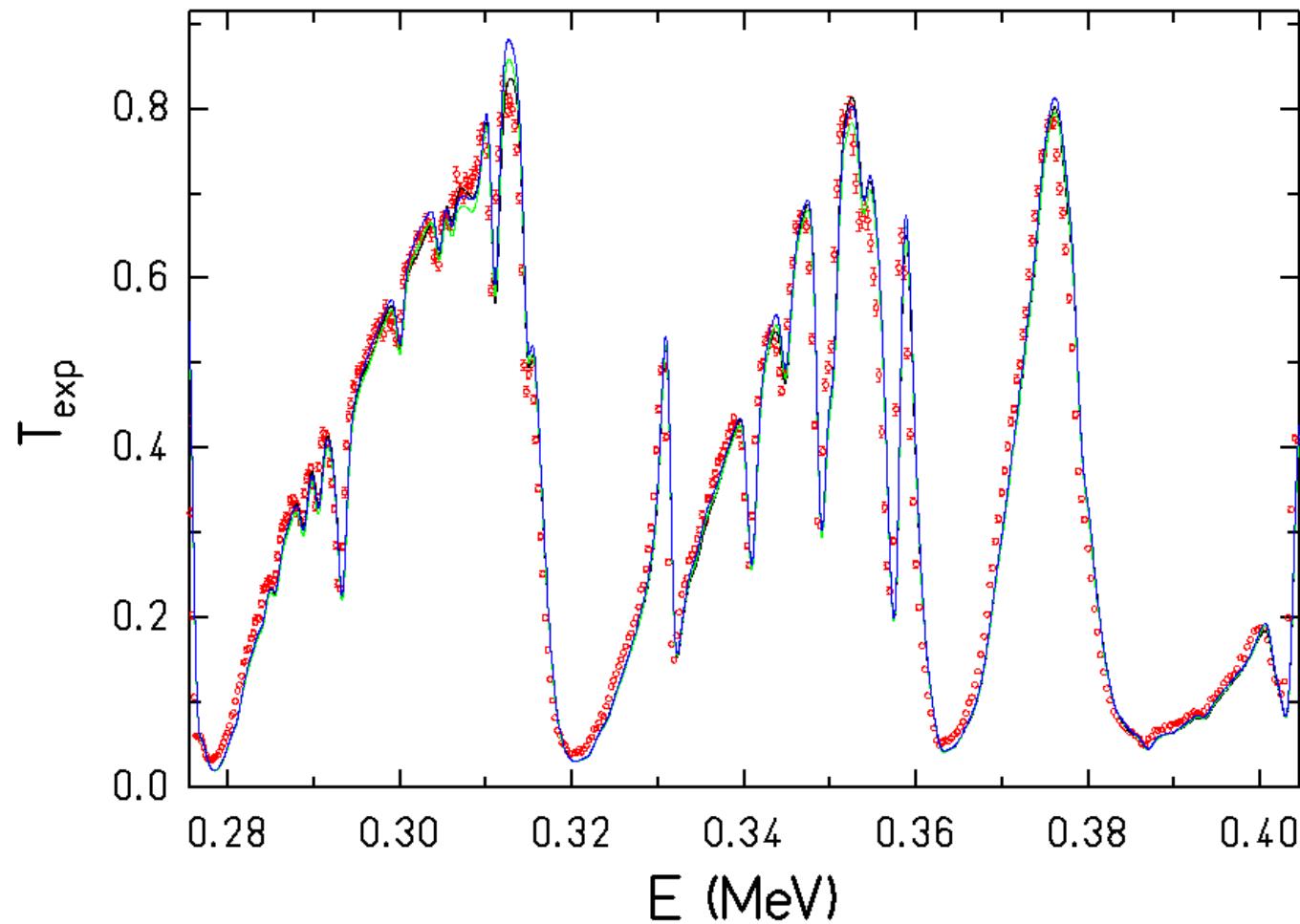
 $\Delta t = 0.21 \text{ ns}, \Delta L = 0.55 \text{ cm} (1 \sigma)$ 

$$T(E) = \int R(E - E') \exp \left[ -n\sigma_{\Delta(E')} \right] dE'$$

- 20mm
- INDEN\_new
- JEFF
- ENDF VIII

$\text{natFe(n,tot)}$ 

Fe (50mm)



Gaussian resolution function

 $\Delta t = 0.21 \text{ ns}, \Delta L = 0.55 \text{ cm} (1 \sigma)$ 

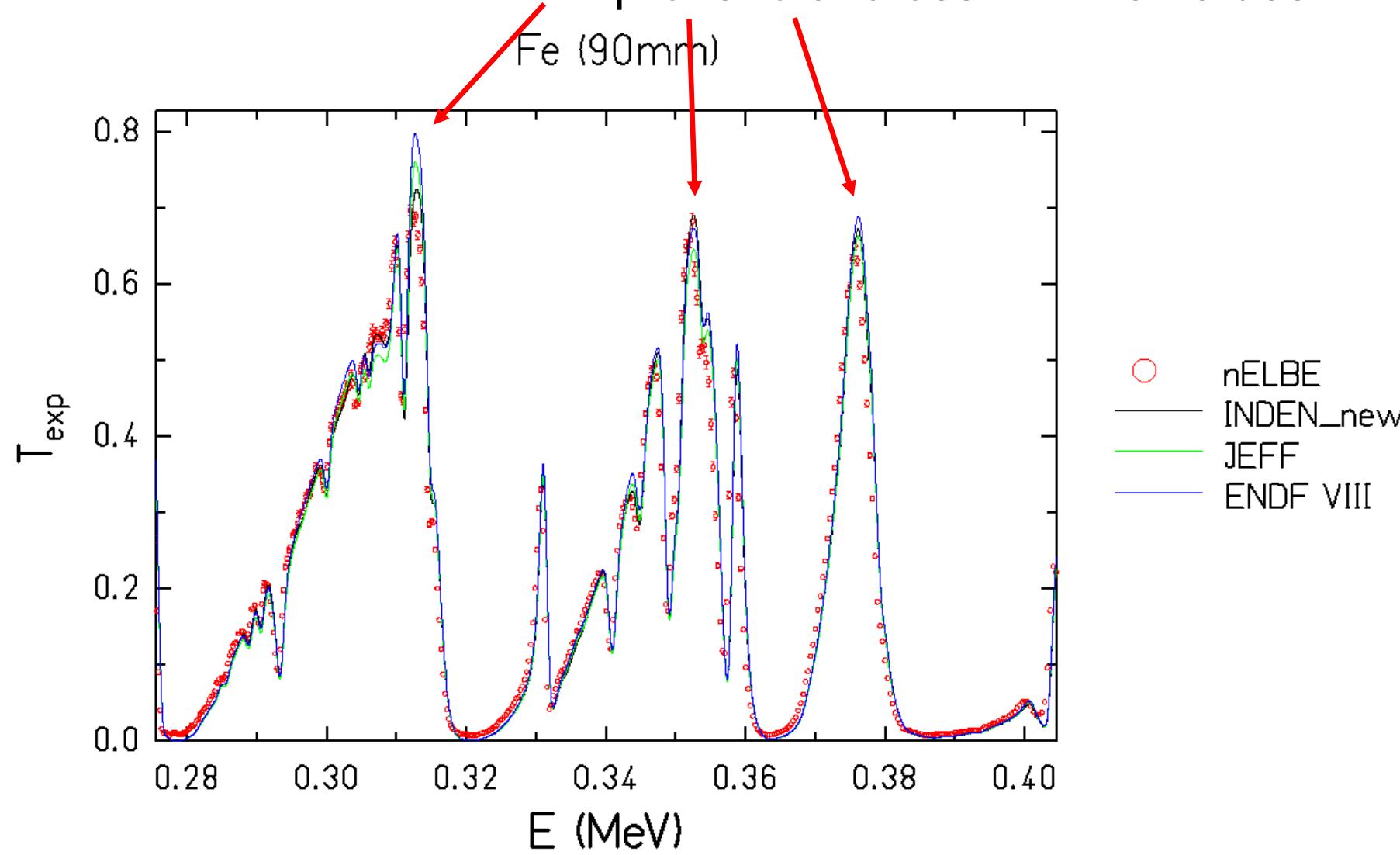
$$T(E) = \int R(E - E') \exp \left[ -n\sigma_{\Delta(E')} \right] dE'$$

- nELBE
- INDEN\_new
- JEFF
- ENDF VIII

Sensitivity increases at cross section minima (max. transmission)

${}^{\text{nat}}\text{Fe}(\text{n,tot})$ 

Improve total cross minima values



# Outline

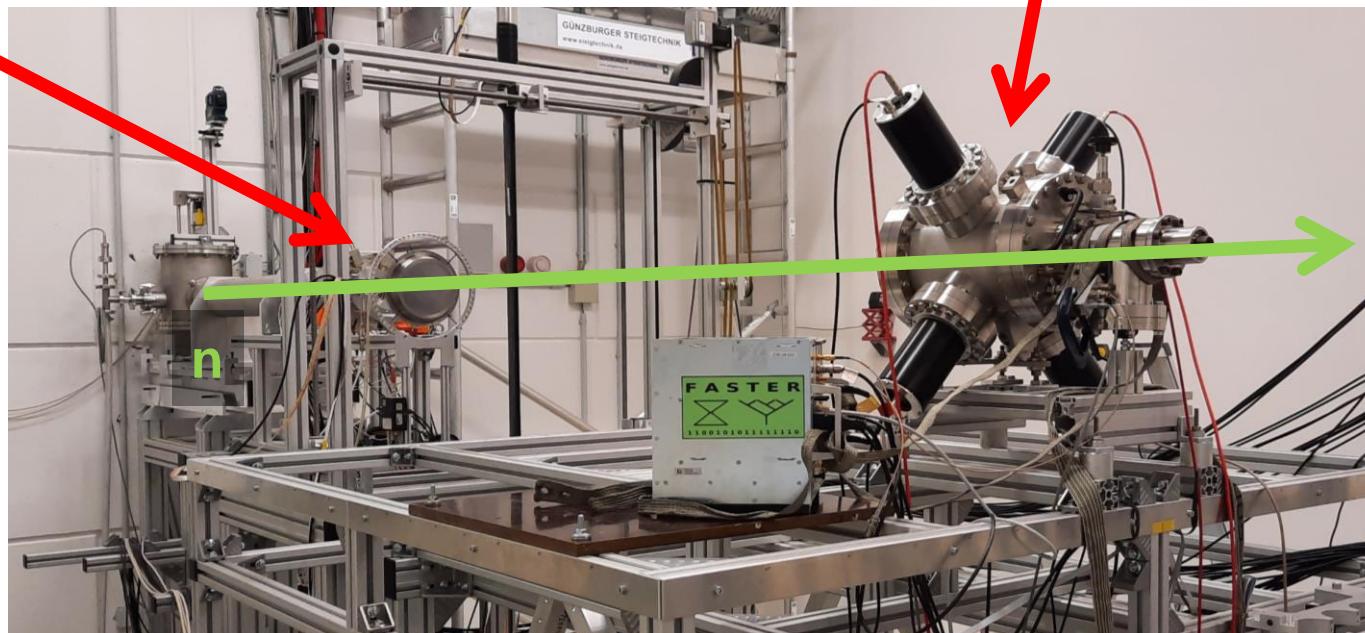
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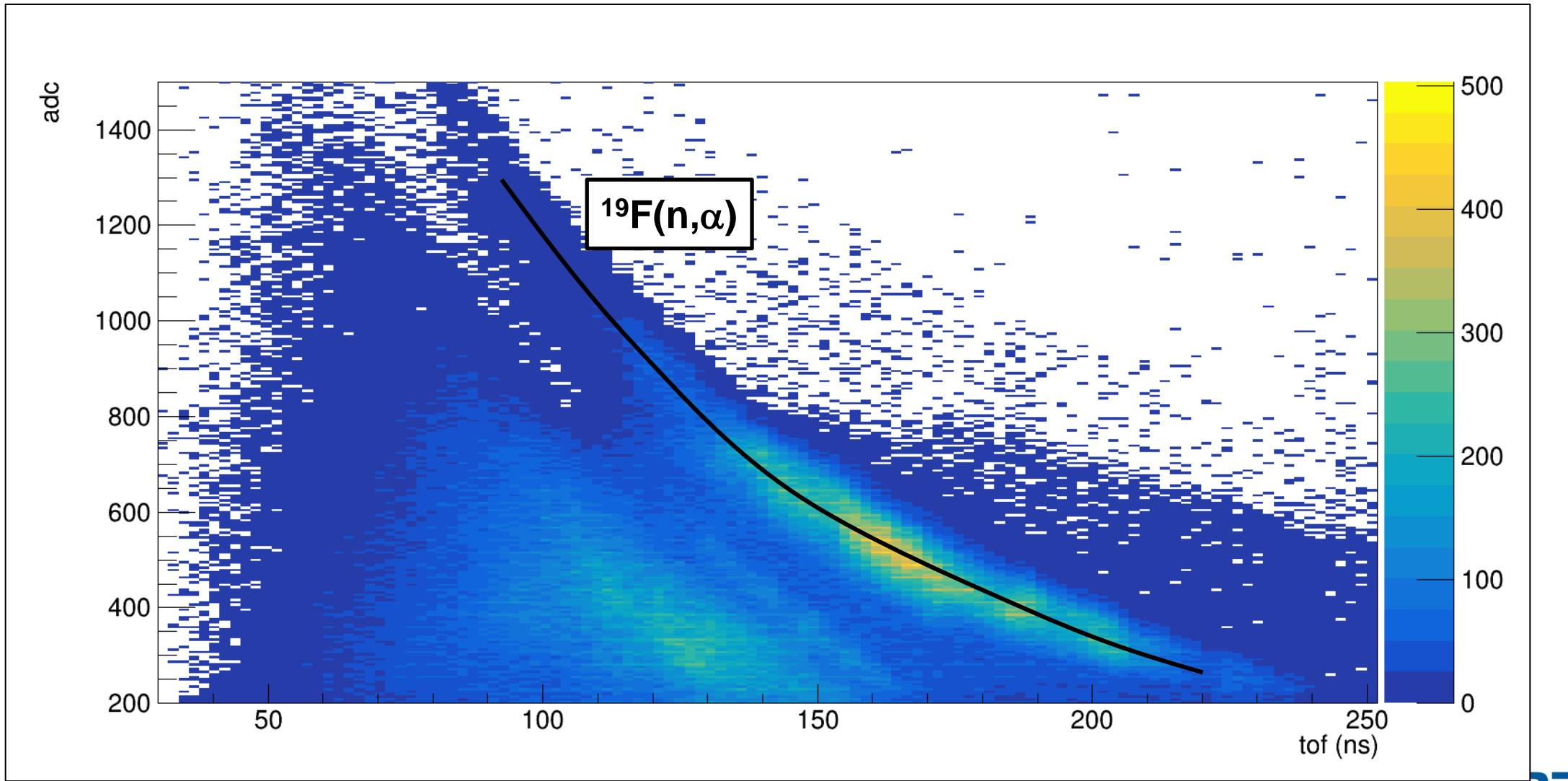
## $^{19}\text{F}/^{16}\text{O}(\text{n},\alpha)$ with SCALP

- ARIEL Proposal TAA\_1\_3 by Gregory Lehaut / Francois-René, LPC Caen
- Done in three blocks:
  - 01.-05.09.22  $^{19}\text{F}(\text{n},\alpha)$
  - 08.-15.12.22 + 16.-20.02.23  $^{16}\text{O}(\text{n},\alpha)$

SCALP – “Scintillating ionization Chamber for ALPha particle production in neutron induced reaction” = Ionization chamber filled with  $\text{CF}_4$  or  $\text{CF}_4+\text{CO}_2$  + 4 PMTs

PTB  $^{235}\text{U}$  fission chamber H19 for flux determination



$^{19}\text{F}/^{16}\text{O}(\text{n},\text{a})$  with SCALP

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847594 (ARIEL).

## Summary

The ***n*ELBE** neutron time-of-flight facility provides

- ... neutrons in the energy range from about 100 keV to 10 MeV
- ... a flux of  $10^4$  n/cm<sup>2</sup>/s at a repetition rate of 100 kHz
- ... a very defined time structure for time-of-flight measurements
- ... a broad pool of neutron and photon detectors
- ... flexible conditions for many kinds of experiments

External users are very welcome!

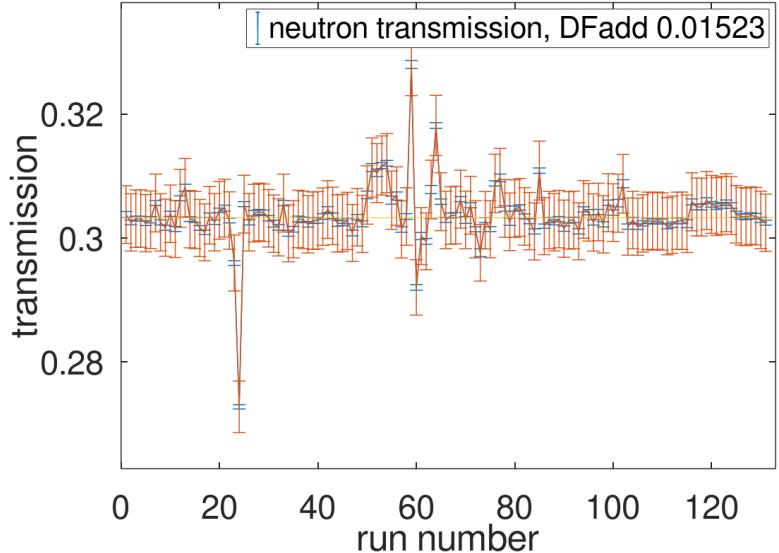
(Proposal dead line for beam time in the second half of 2023 is March 20<sup>th</sup>)

The end!

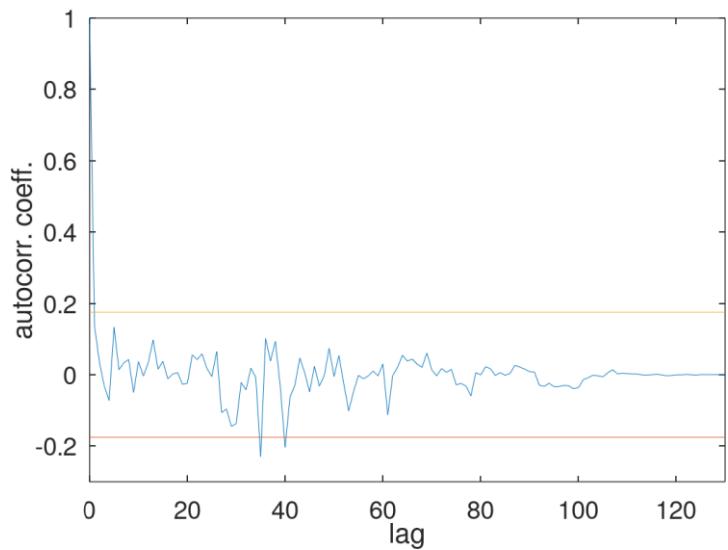


# Beam stability analysis

spectrum averaged iron50 transmission for each run

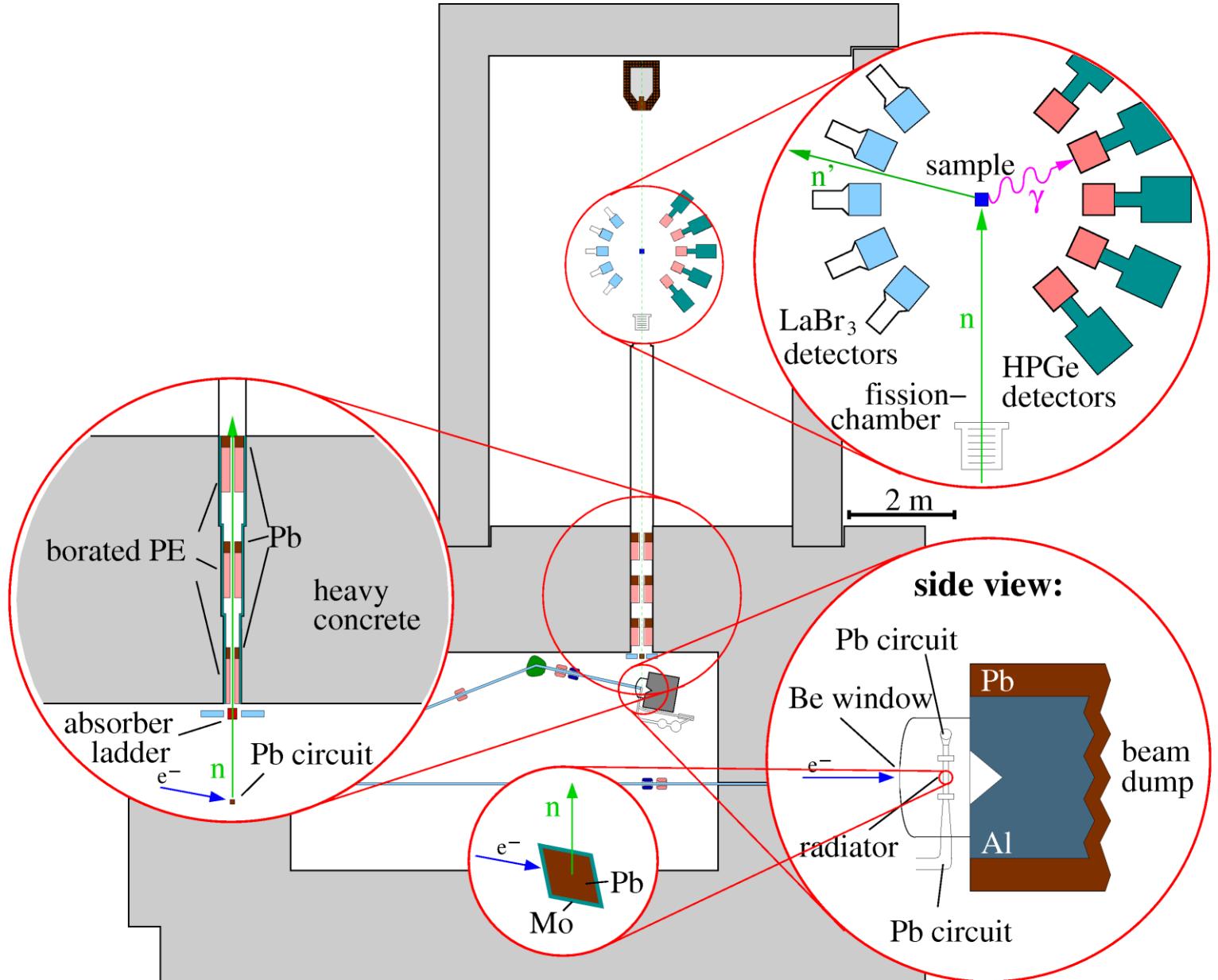


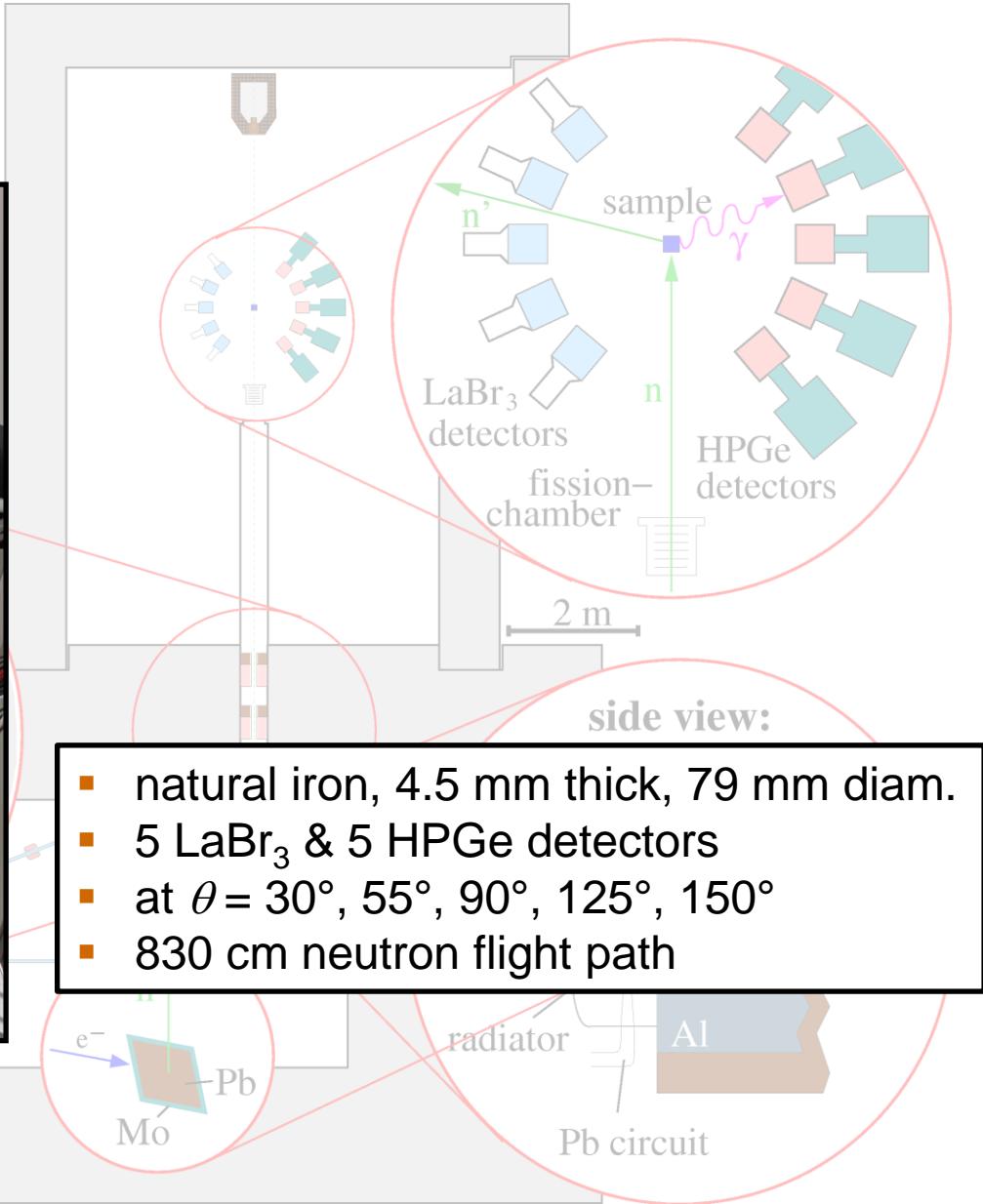
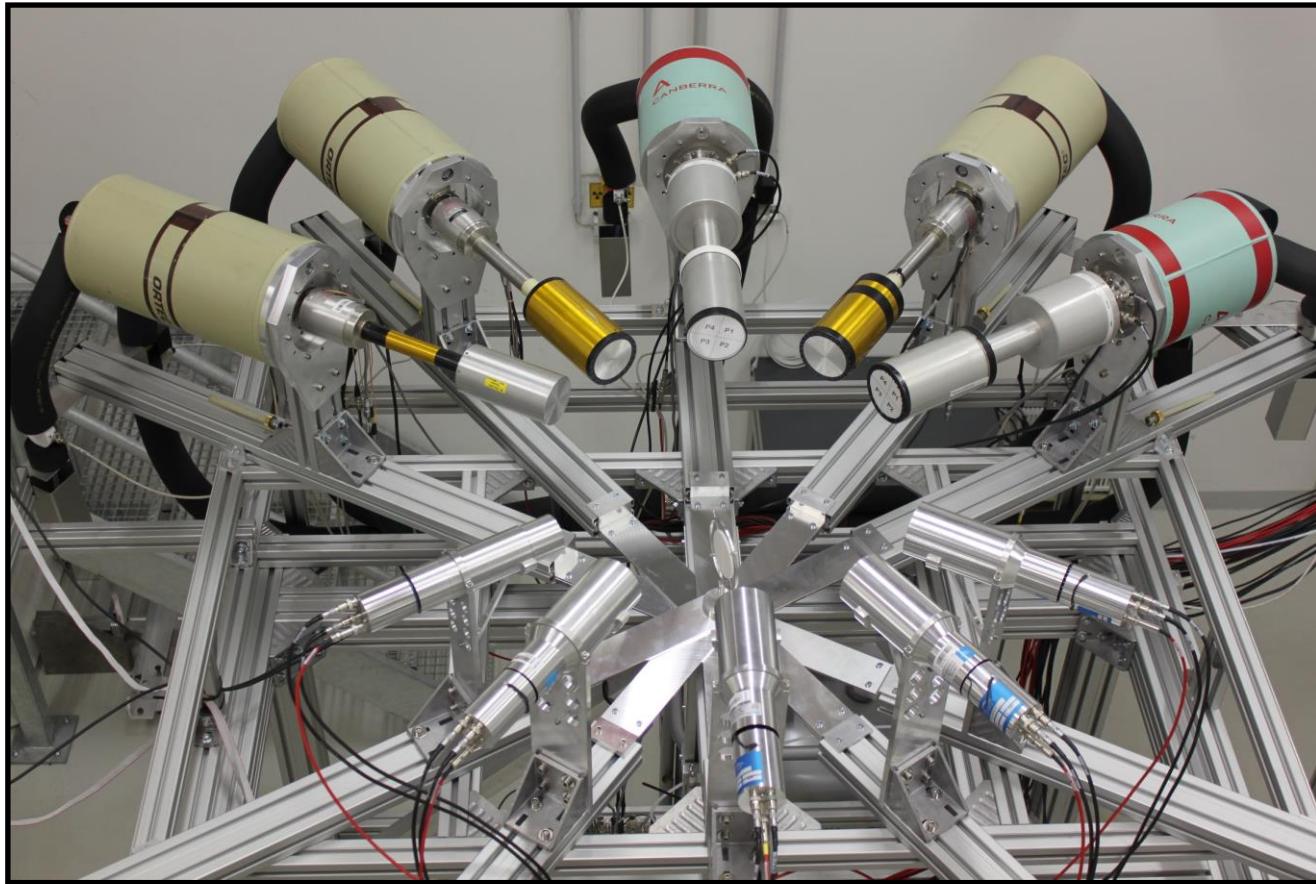
Transmission data divided into 130 runs with several absorber changes typical duration 2-3 hours beam time



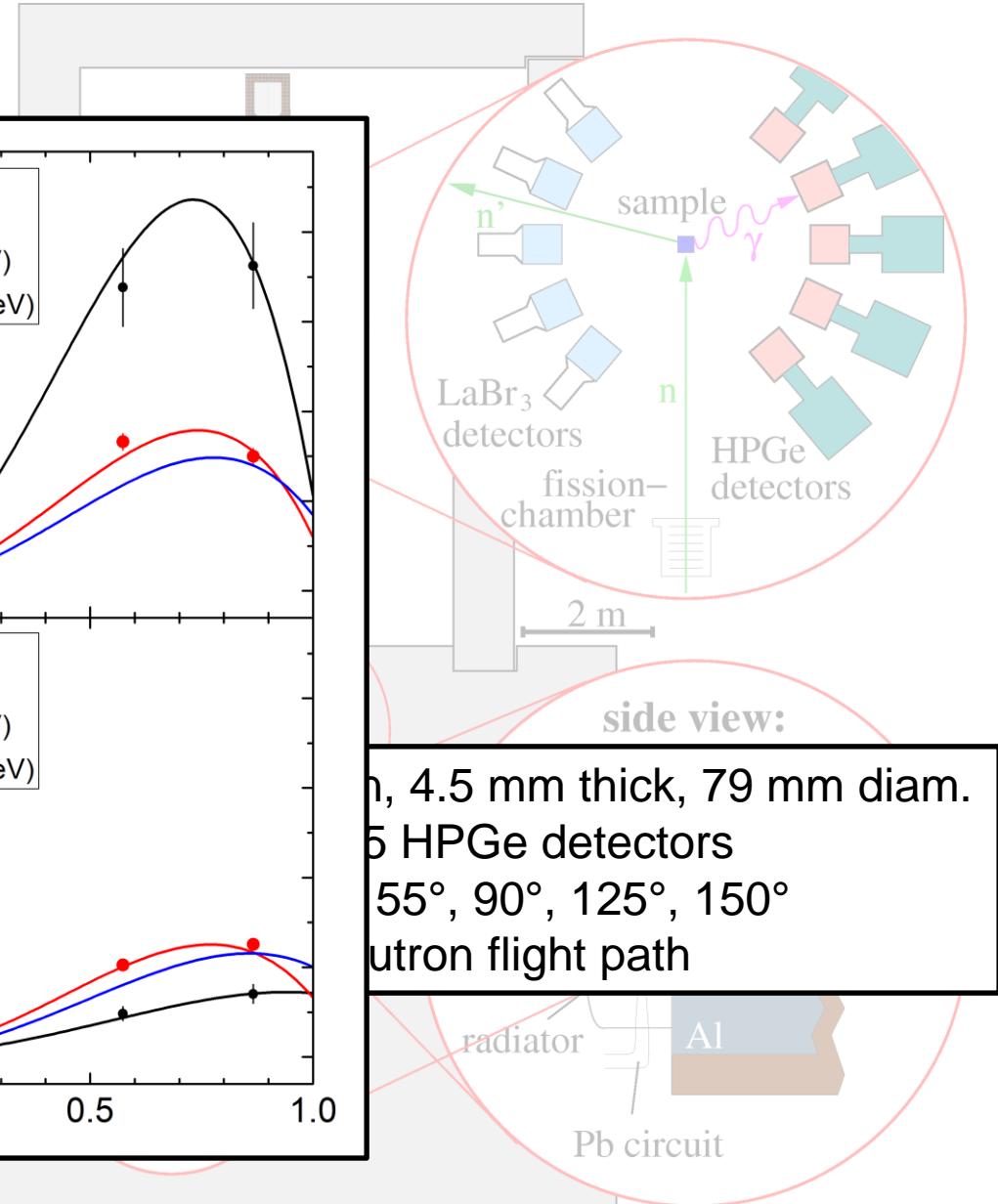
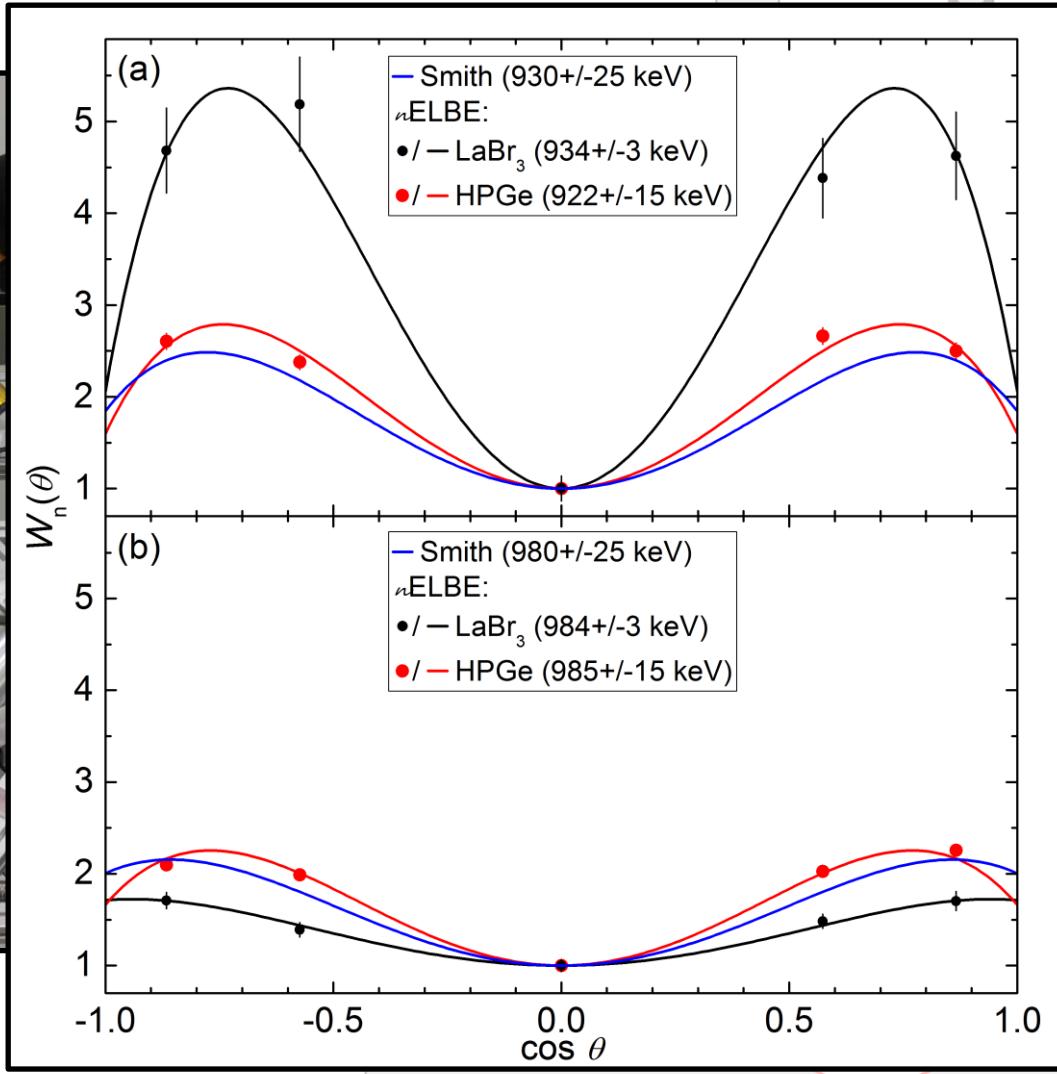
Statistical distribution of the residuals with the time-of-flight spectrum averaged transmission checked with autocorrelation coefficient.

# Inelastic scattering

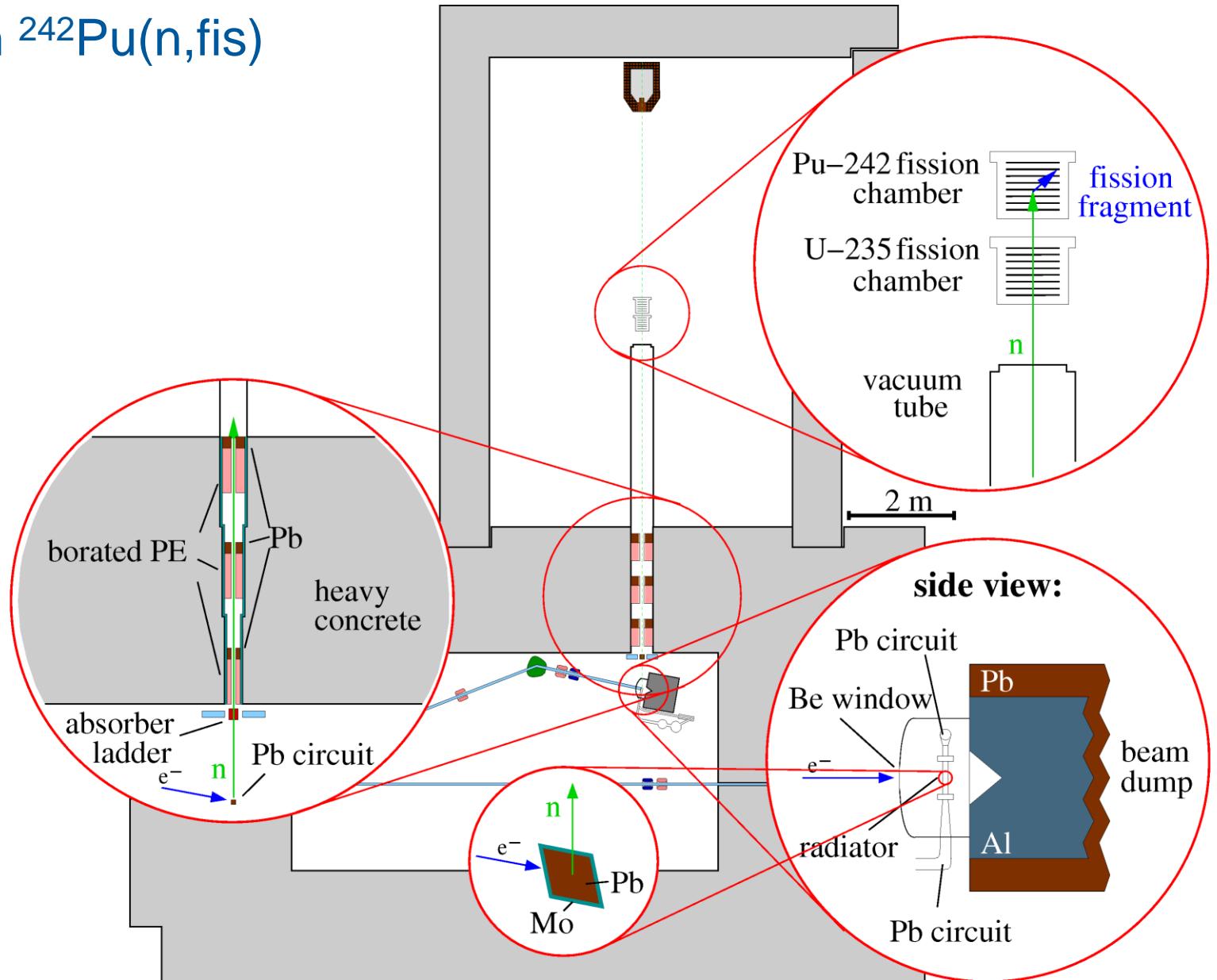


Inelastic scattering  $^{56}\text{Fe}(\text{n},\text{n}'\gamma)$ 

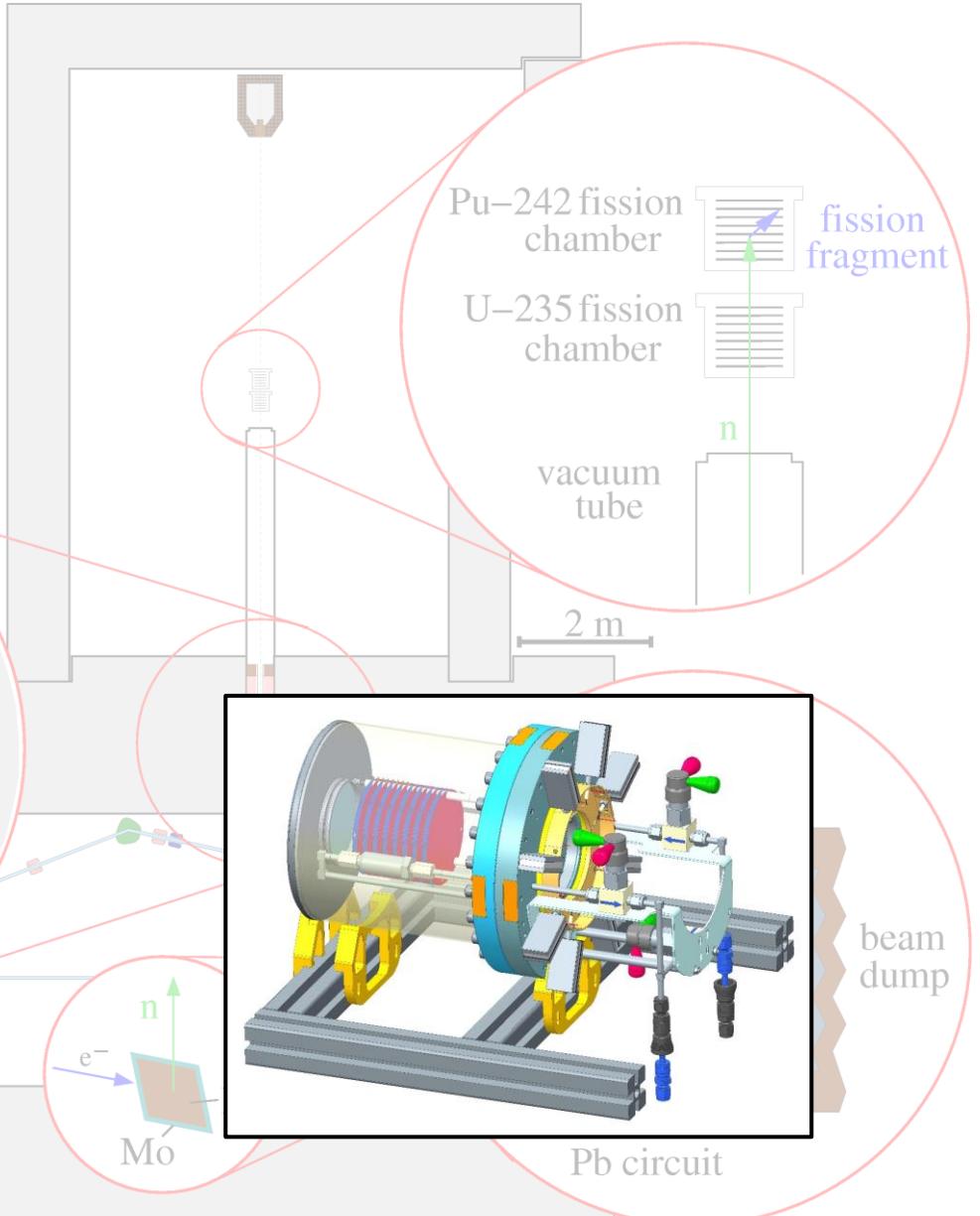
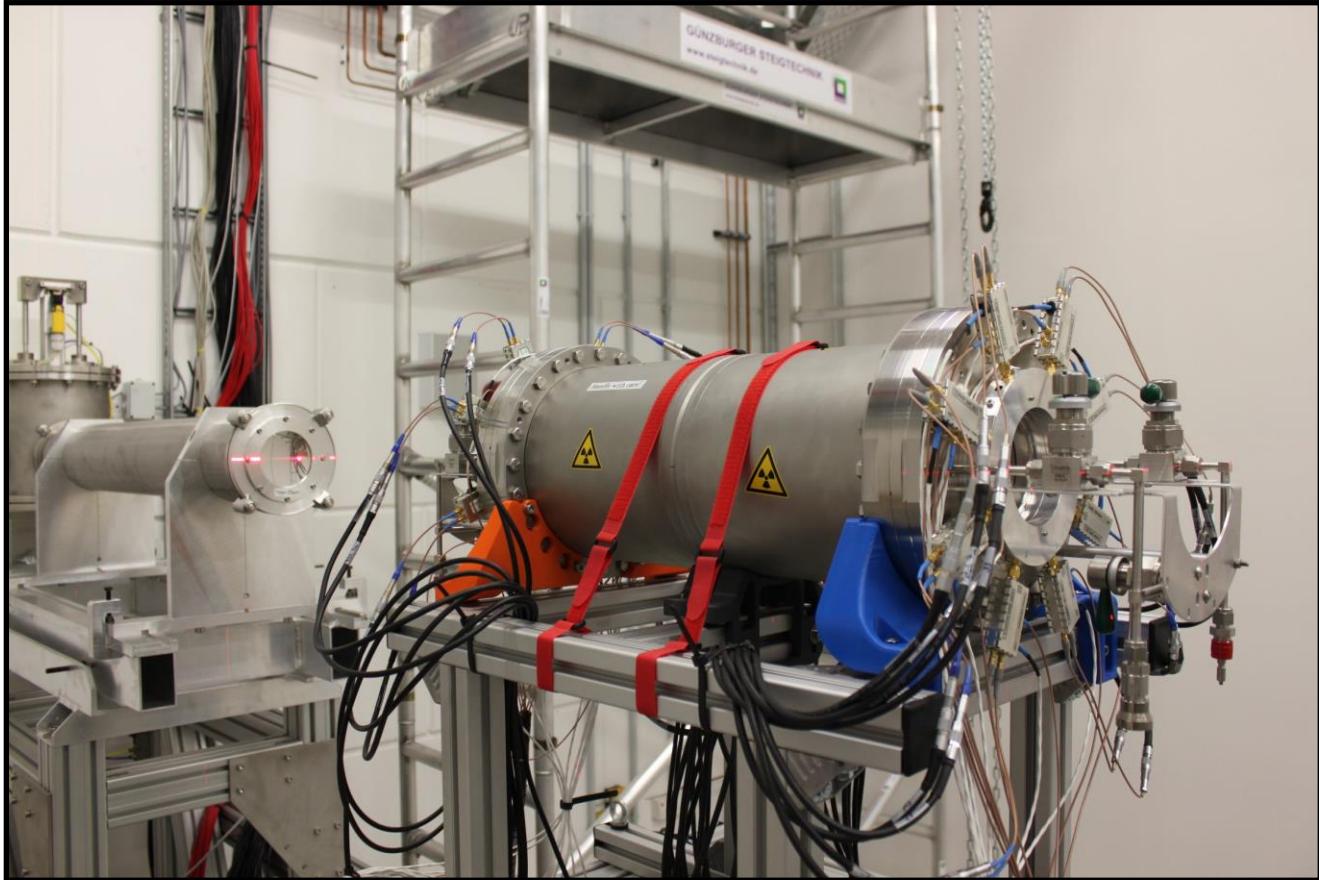
# Inelastic scattering $^{56}\text{Fe}(\text{n},\text{n}'\gamma)$

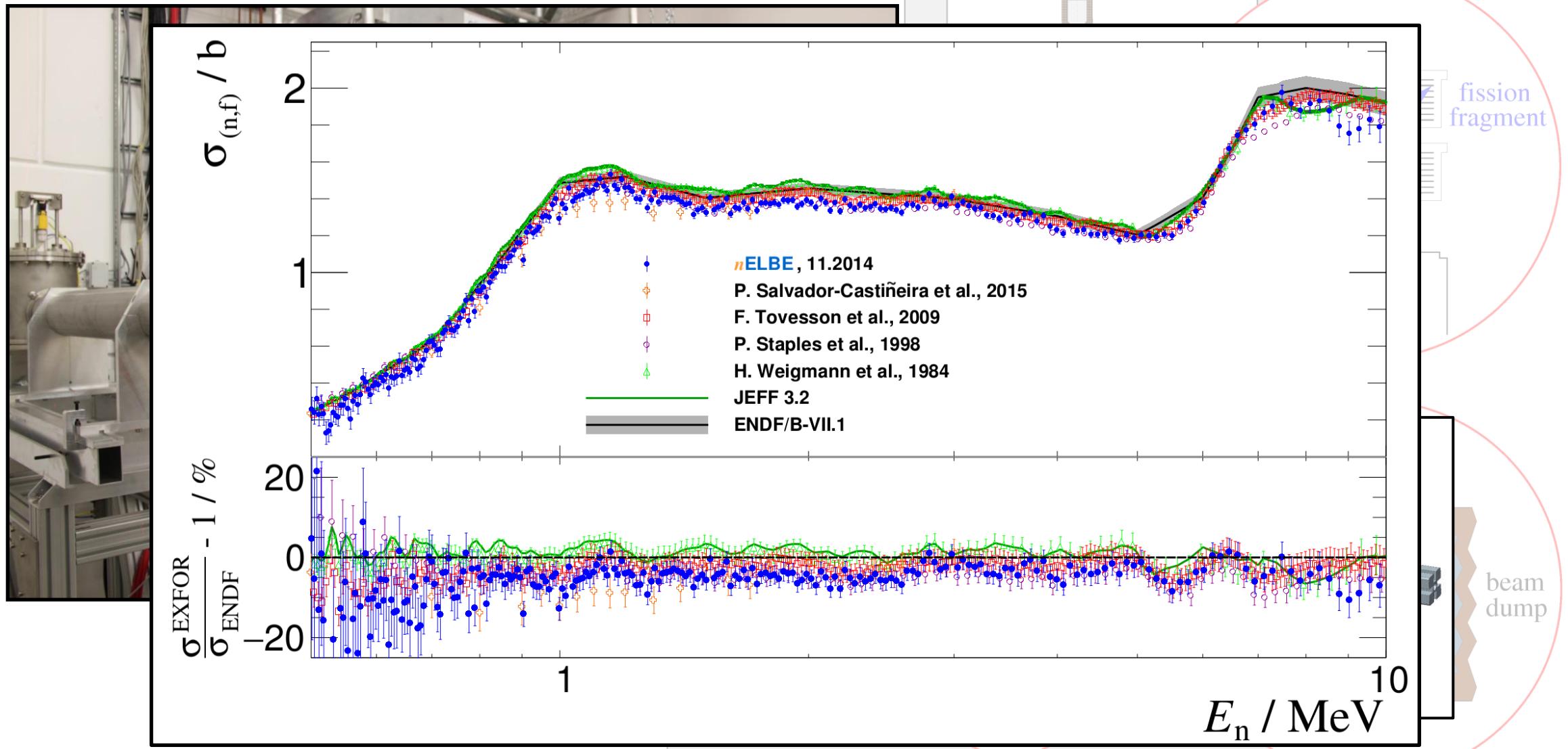


# Neutron induced fission $^{242}\text{Pu}(n,\text{fis})$

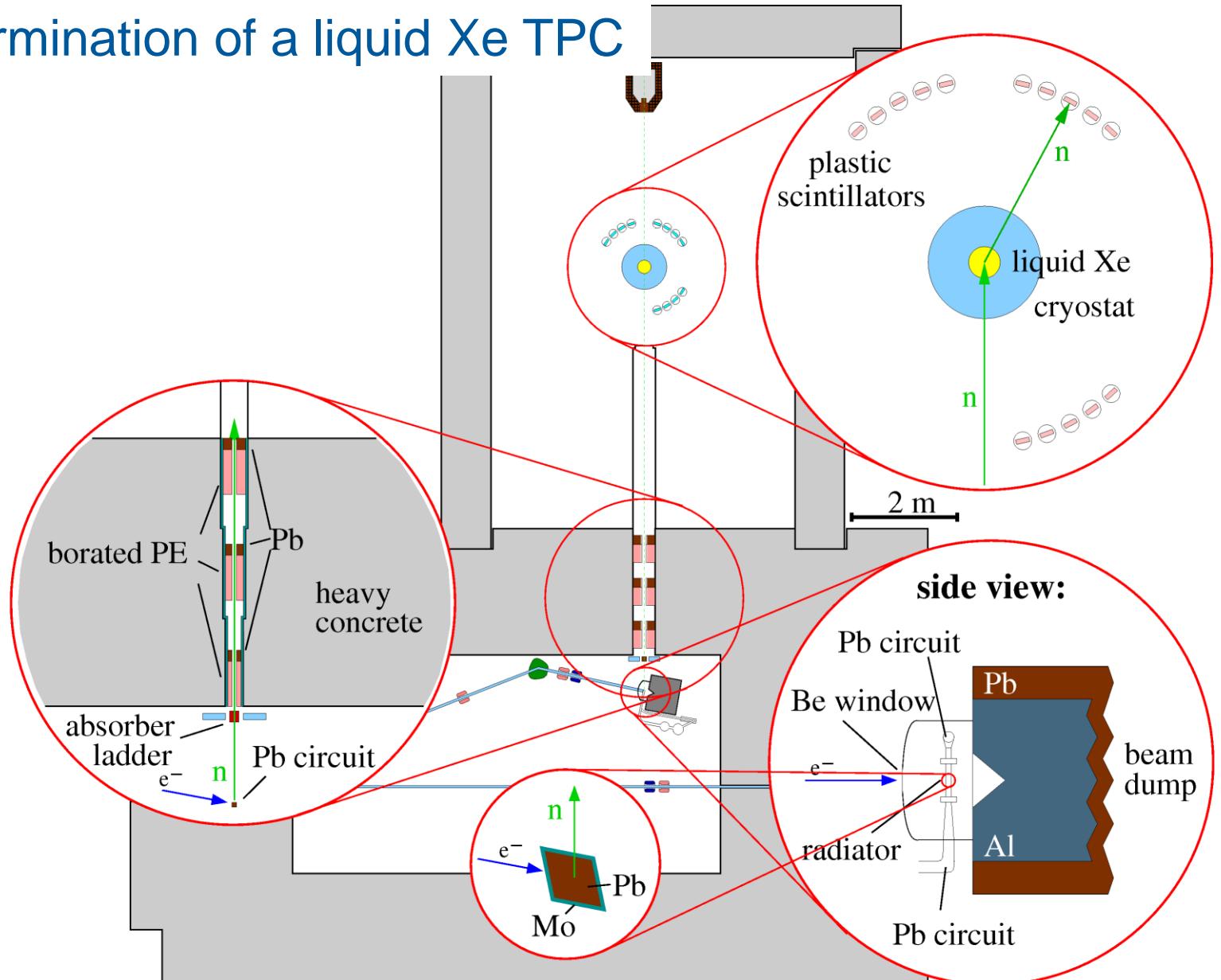


# Neutron induced fission $^{242}\text{Pu}(\text{n},\text{fis})$



Neutron induced fission  $^{242}\text{Pu}(\text{n,fis})$ 

# Neutron response determination of a liquid Xe TPC



# Neutron response determination of a liquid Xe TPC

