Inelastic neutron scattering at nELBE

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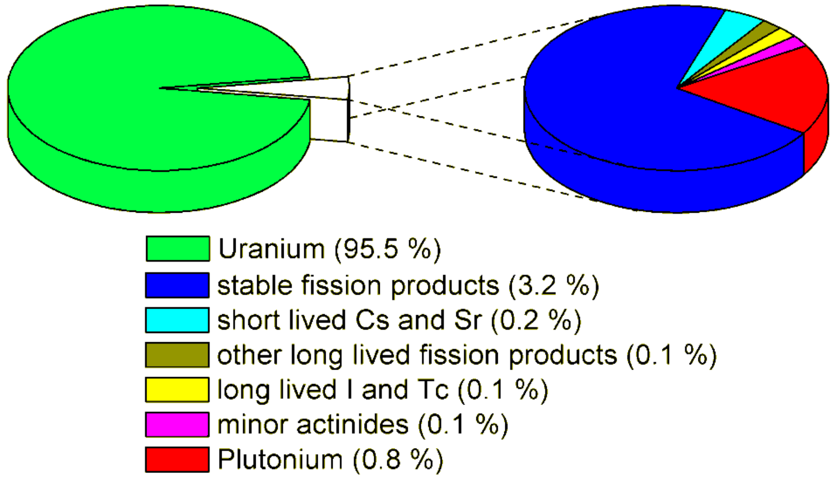
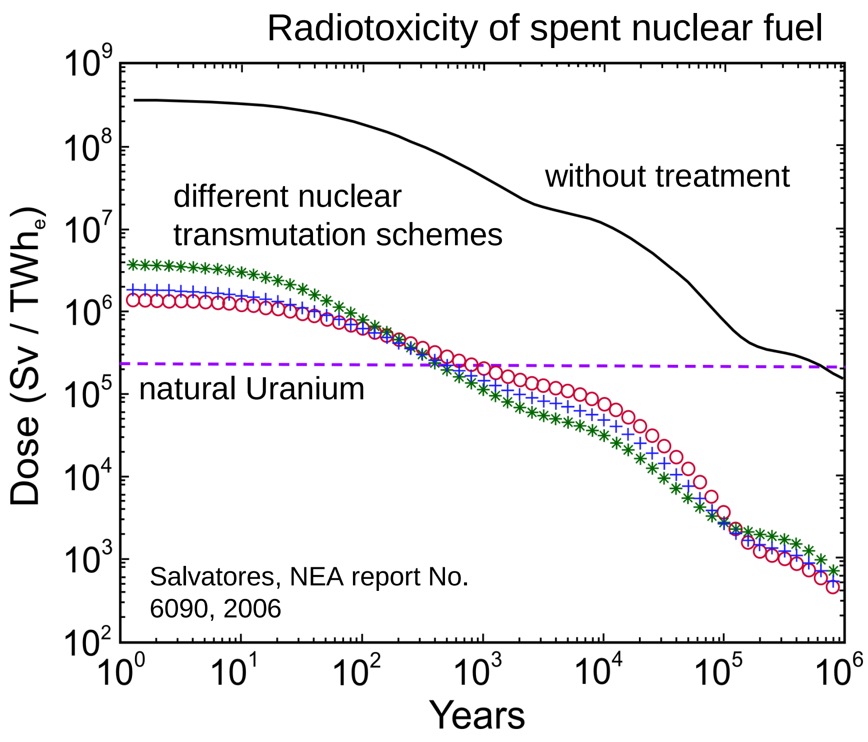
The nuclear waste problem

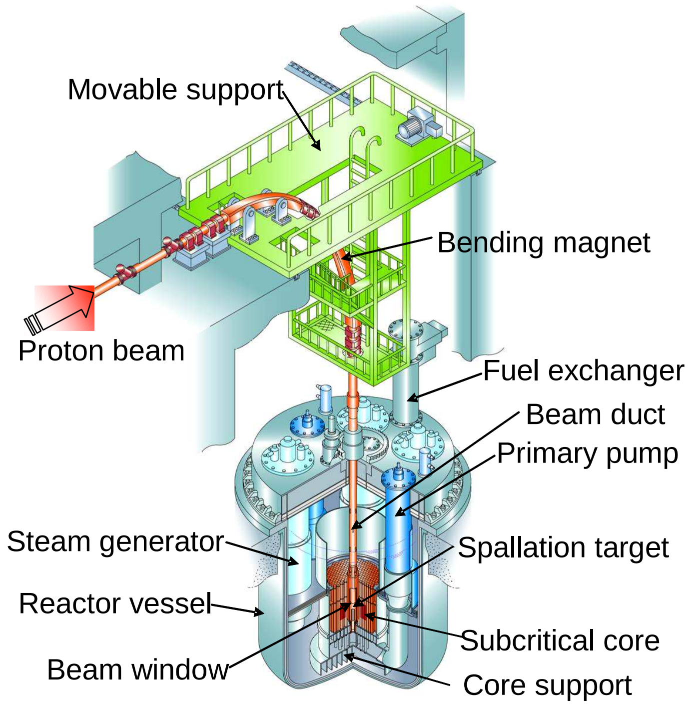


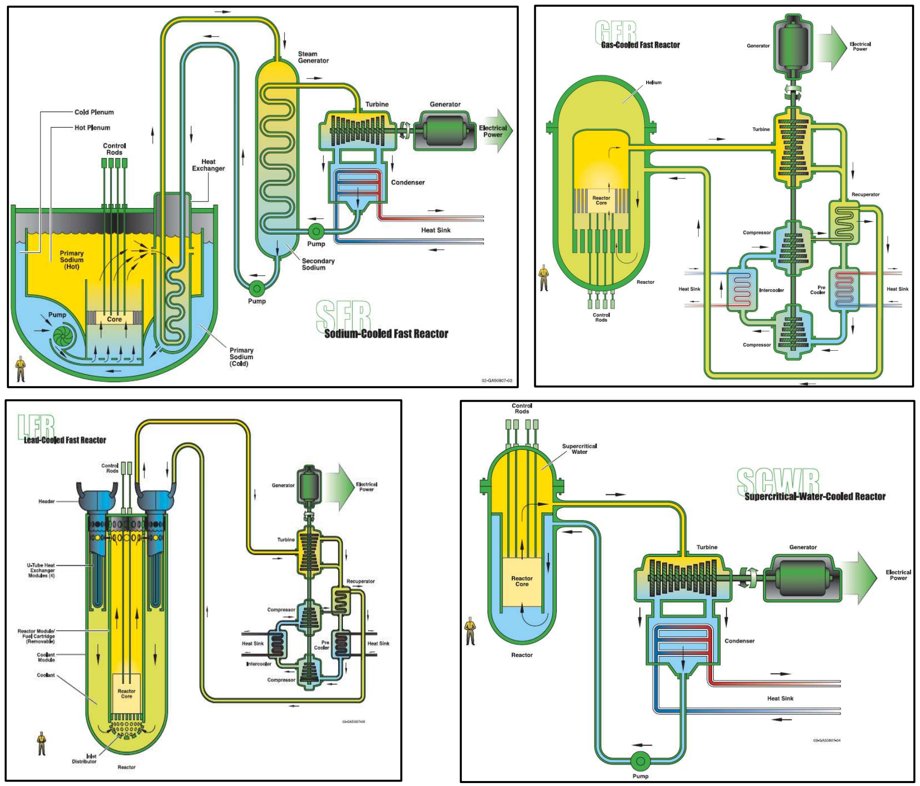


long lived isotopes cause main part of long term radiotoxicity
➔ **safe disposal is necessary for more 500,000 years**

➔ treatment of nuclear waste can **reduce disposal time by several orders of magnitude**
➔ **Partitioning:** separate actinides from the rest
➔ **Transmutation:** convert long lived isotopes into short lived ones

Accelerator driven systems / Generation IV nuclear reactors





➔ **fast neutron** induced fission is used to produce electrical power and to **burn up long lived actinides**

Hiroyuki OIGAWA
Presentation at Euratom PARTRA Cluster Meeting at FZK, Feb. 2008

http://www.gen-4.org/Technology/roadmap.htm

Data needs

Table 32. Summary of Highest Priority Target Accuracies for Fast Reactors

		Energy Range	Current Accuracy (%)	Target Accuracy (%)
U238	σ_{inel}	6.07 ÷ 0.498 MeV	10 ÷ 20	2 ÷ 3
	σ_{capt}	24.8 ÷ 2.04 keV	3 ÷ 9	1.5 ÷ 2
Pu241	σ_{fiss}	1.35MeV ÷ 454 eV	8 ÷ 20	2 ÷ 3 (SFR,GFR, LFR) 5 ÷ 8 (ABTR, EFR)
Pu239	σ_{capt}	498 ÷ 2.04 keV	7 ÷ 15	4 ÷ 7
Pu240	σ_{fiss}	1.35 ÷ 0.498 MeV	6	1.5 ÷ 2
	ν	1.35 ÷ 0.498 MeV	4	1 ÷ 3
Pu242	σ_{fiss}	2.23 ÷ 0.498 MeV	19 ÷ 21	3 ÷ 5
Pu238	σ_{fiss}	1.35 ÷ 0.183 MeV	17	3 ÷ 5
Am242m	σ_{fiss}	1.35MeV ÷ 67.4keV	17	3 ÷ 4
Am241	σ_{fiss}	6.07 ÷ 2.23 MeV	12	3
Cm244	σ_{fiss}	1.35 ÷ 0.498 MeV	50	5
Cm245	σ_{fiss}	183 ÷ 67.4 keV	47	7
Fe56	σ_{inel}	2.23 ÷ 0.498 MeV	16 ÷ 25	3 ÷ 6
Na23	σ_{inel}	1.35 ÷ 0.498 MeV	28	4 ÷ 10
Pb206	σ_{inel}	2.23 ÷ 1.35 MeV	14	3
Pb207	σ_{inel}	1.35 ÷ 0.498 MeV	11	3
Si28	σ_{inel}	6.07 ÷ 1.35 MeV	14 ÷ 50	3 ÷ 6
	σ_{capt}	19.6 ÷ 6.07 MeV	53	6

- for simulations and calculations to design such facilities **detailed knowledge about the neutron interactions in the relevant energy region are necessary**

➔ for nuclei to be transmuted as well as for structural materials

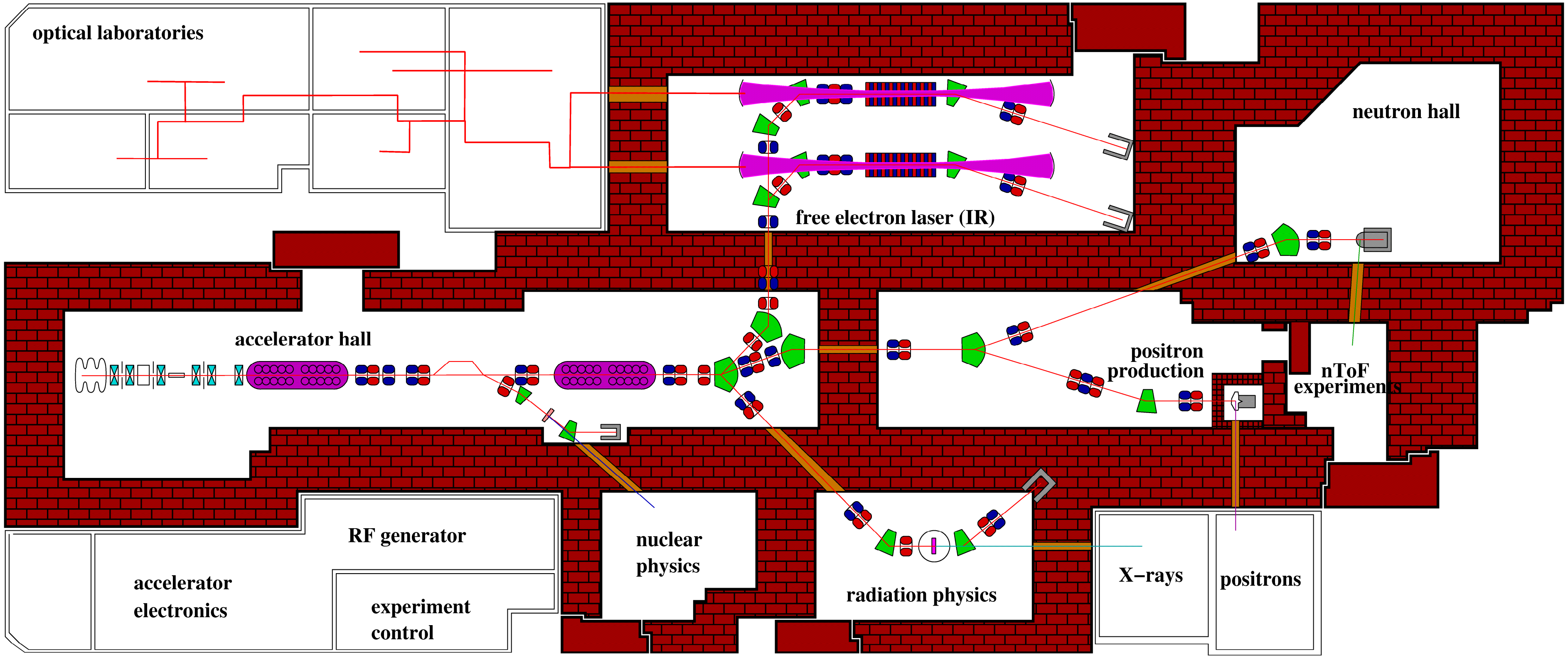
➔ fast neutron spectrum

- neutron capture
- neutron induced fission
- neutron inelastic scattering

➔ ^{56}Fe (n,n'γ) ^{56}Fe

http://www.nea.fr/html/science/wpec/volume26/volume26.pdf

nELBE – neutron facility at ELBE



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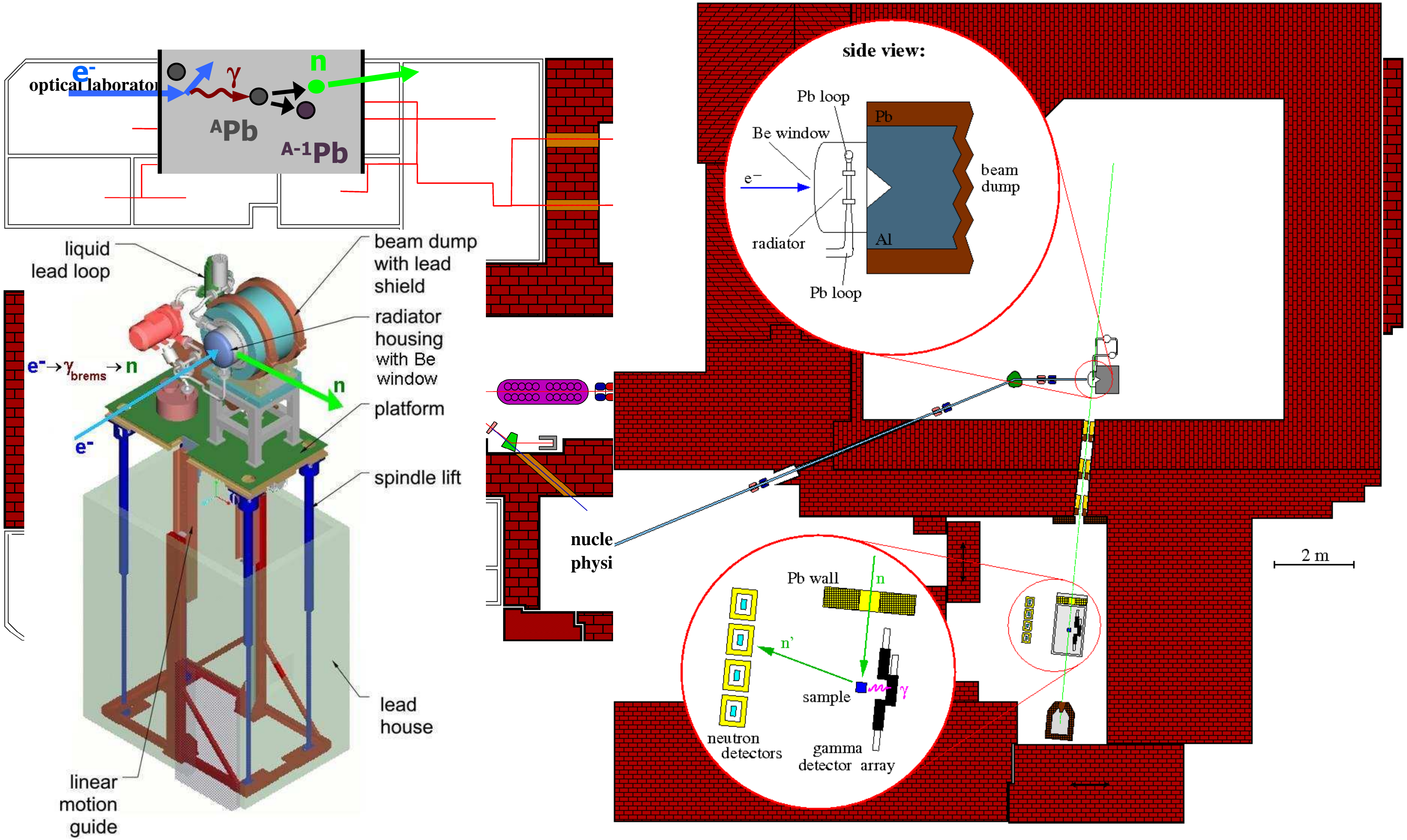
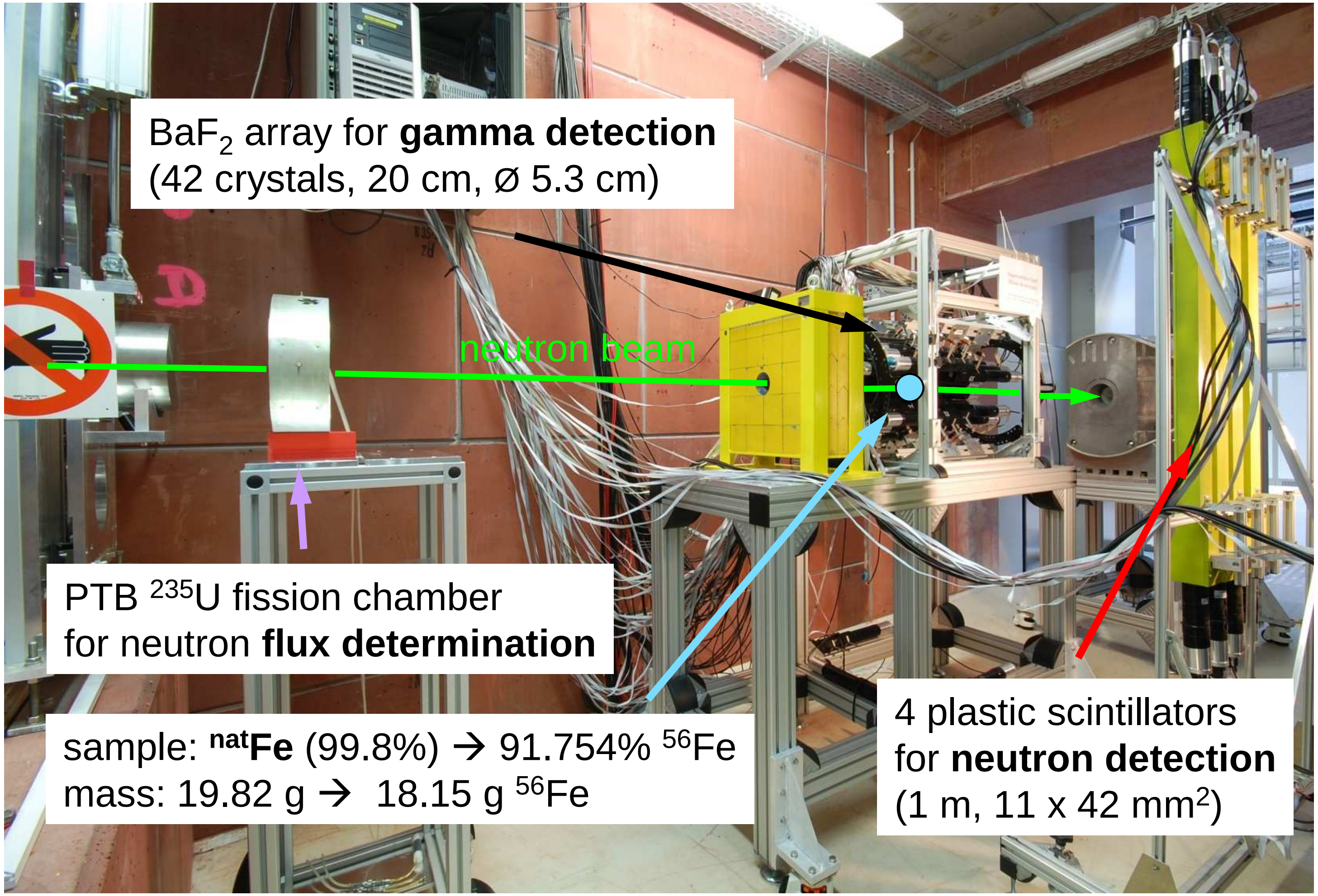
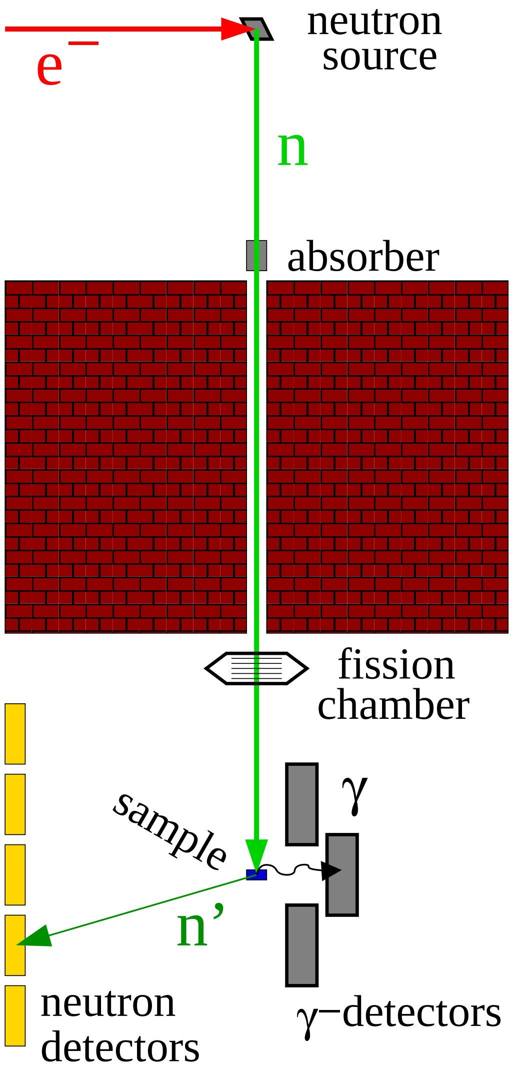
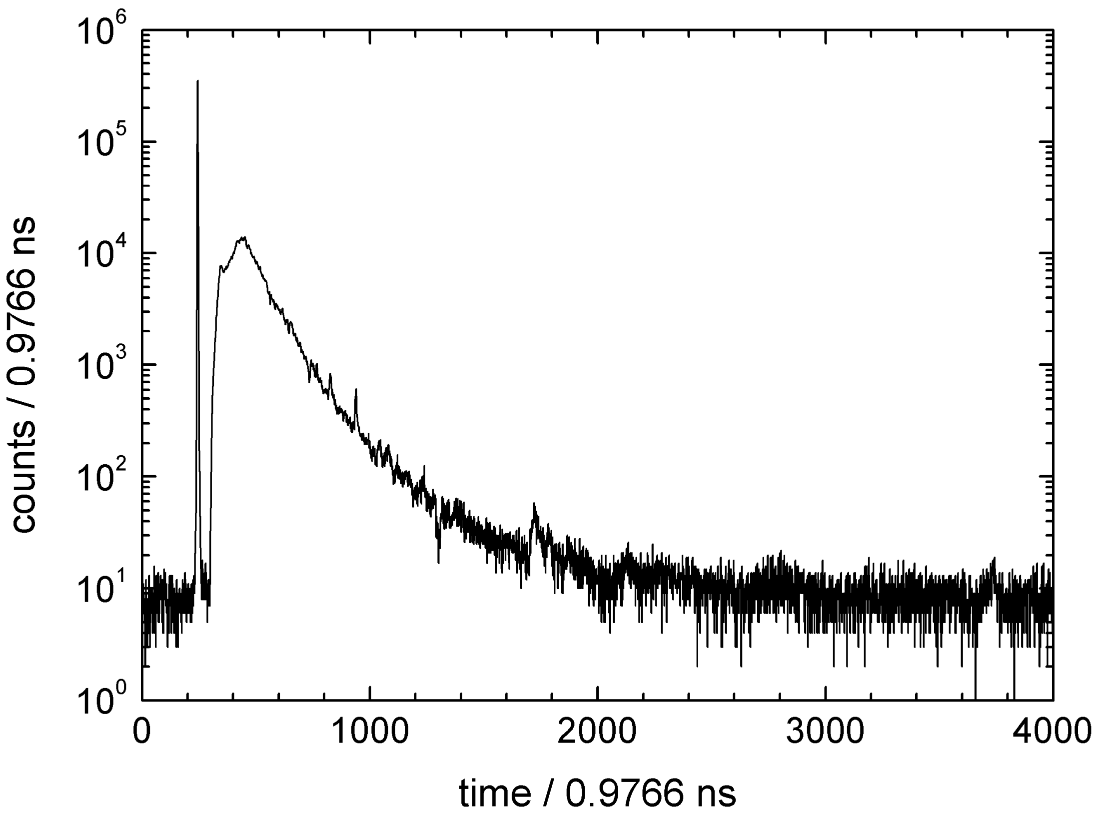


nELBE – detector setup



Experimental methods and results – Inelastic scattering





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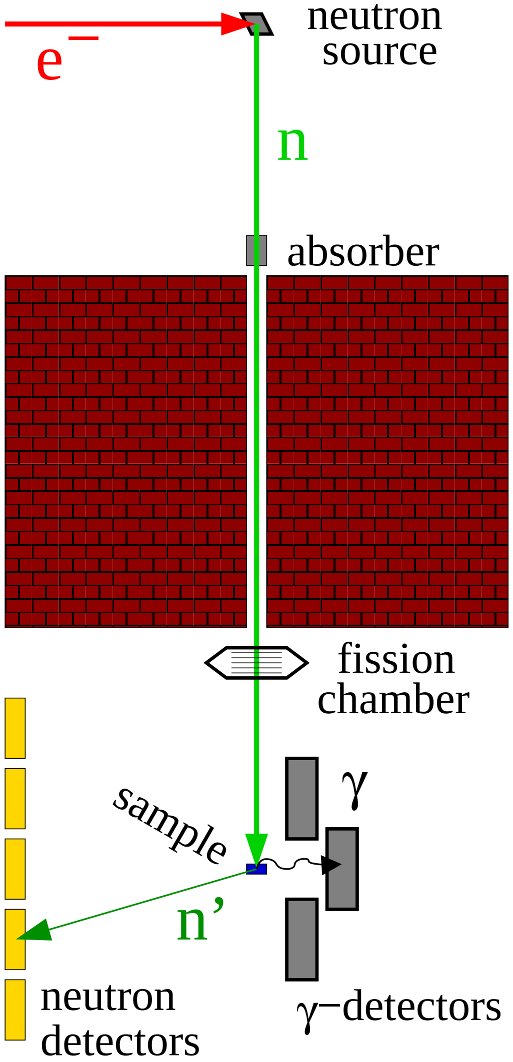

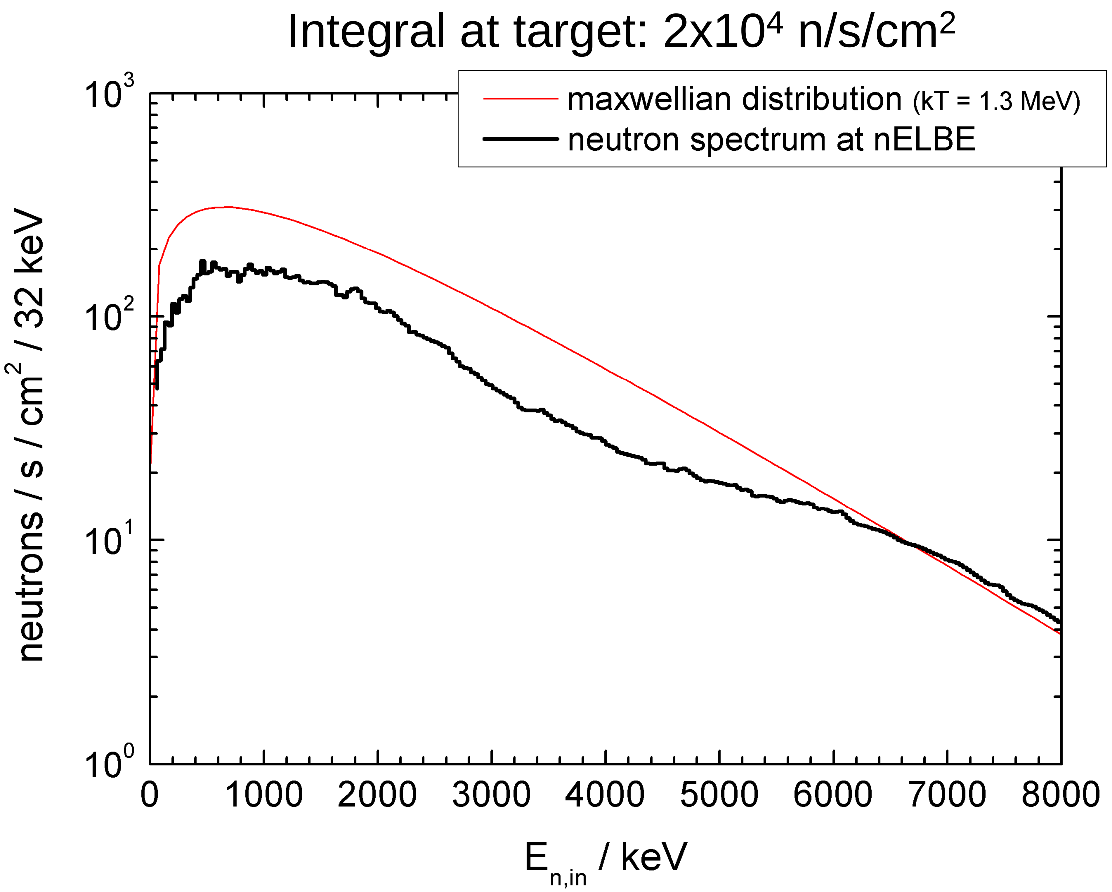

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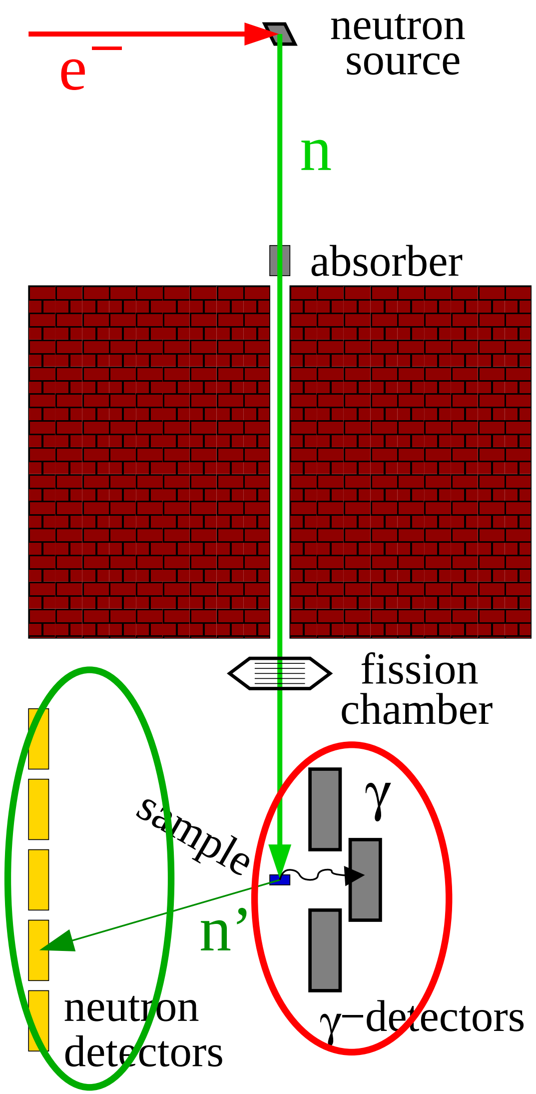
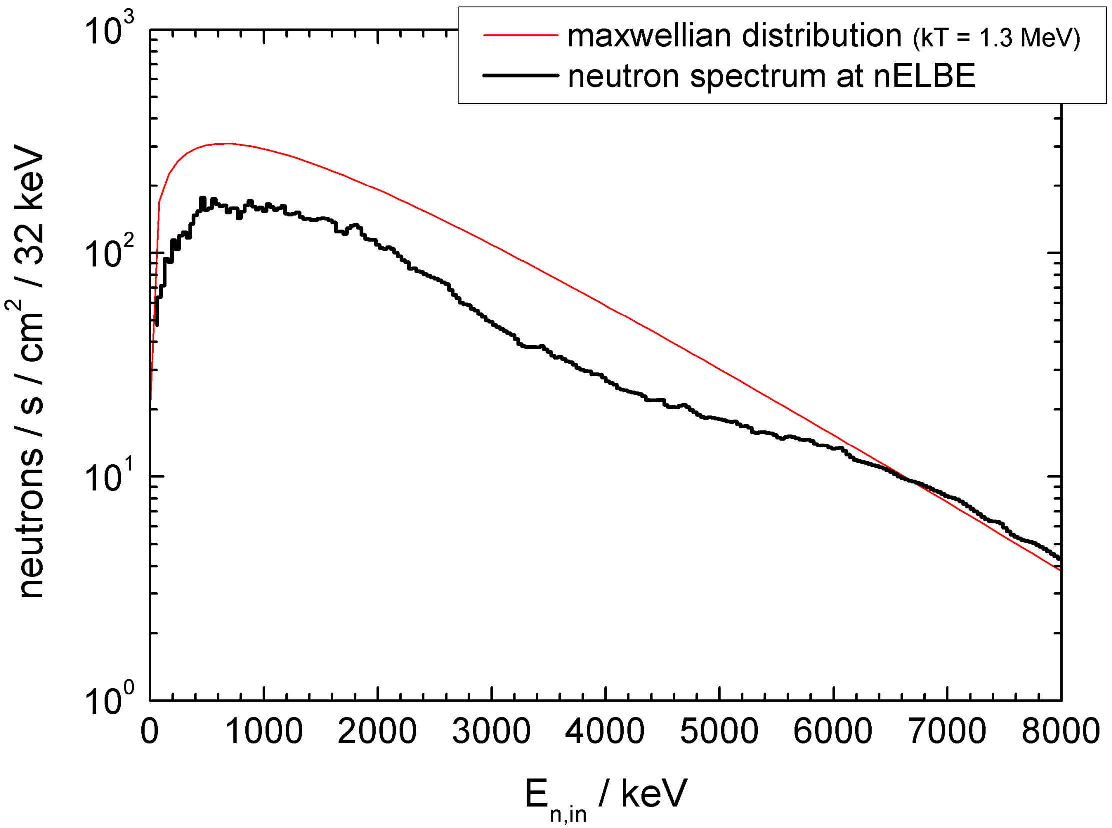


$$^{56}\mathrm{Fe}(n,n'\gamma)^{56}\mathrm{Fe} \left\{ \begin{array}{l} ^{56}\mathrm{Fe}+n \rightarrow {}^{56}\mathrm{Fe}^{*}+n' \\ ^{56}\mathrm{Fe}^{*} \rightarrow {}^{56}\mathrm{Fe}+\gamma \end{array} \right.$$



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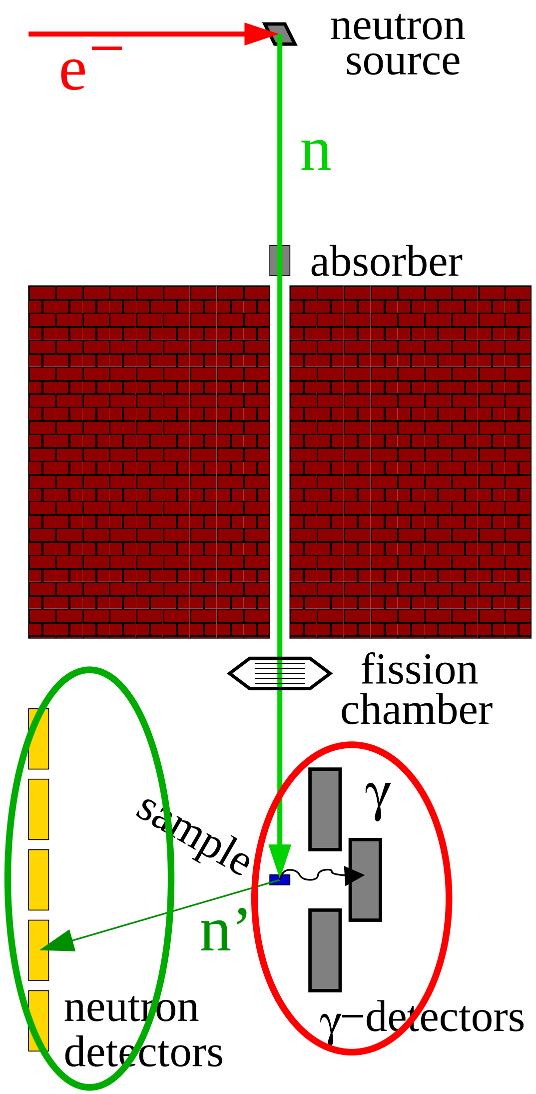

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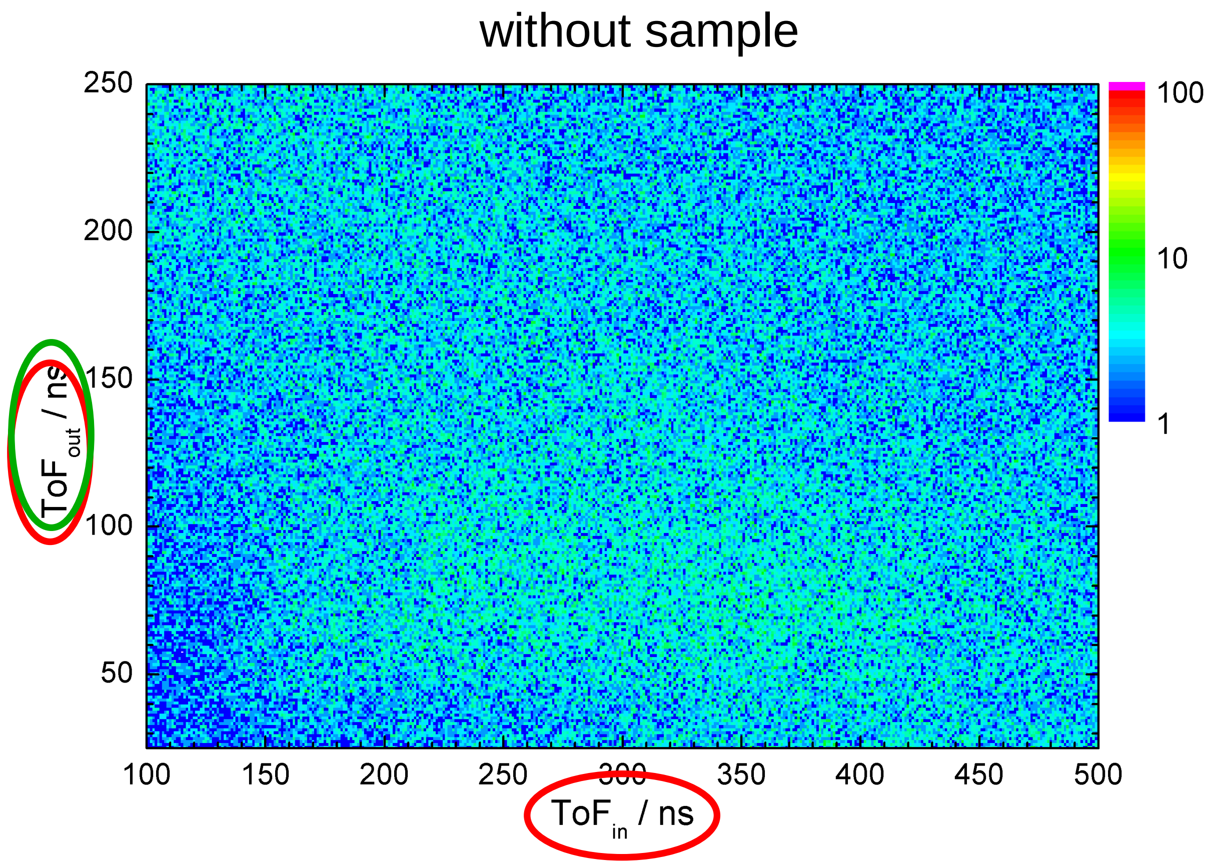

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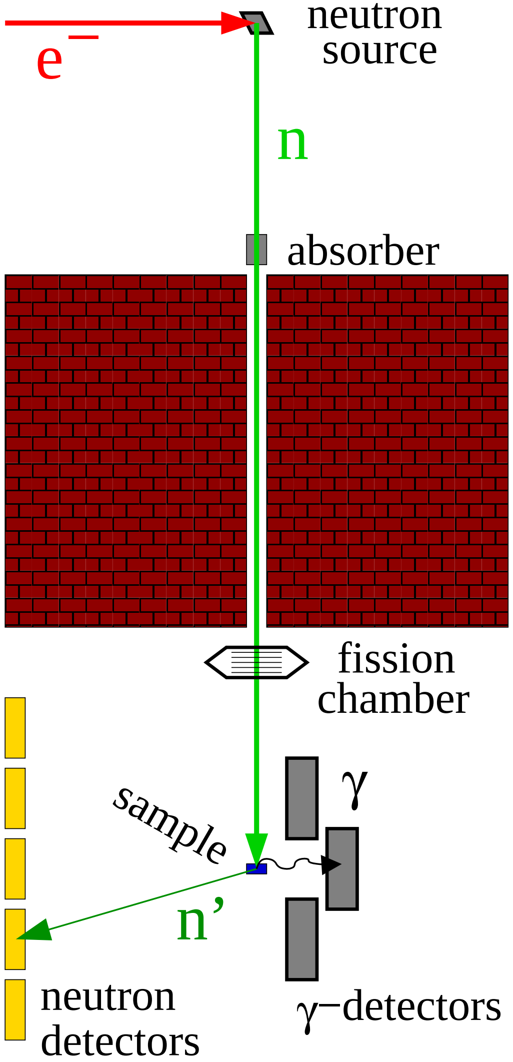

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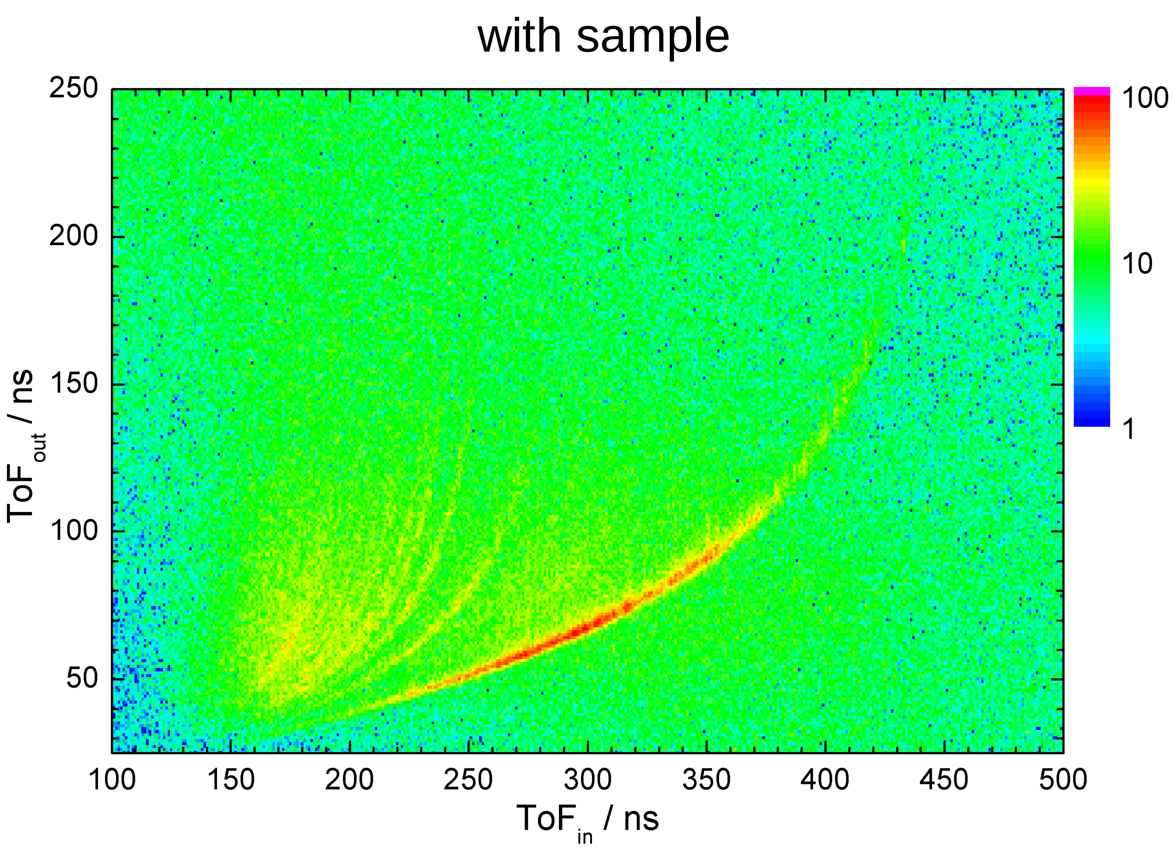

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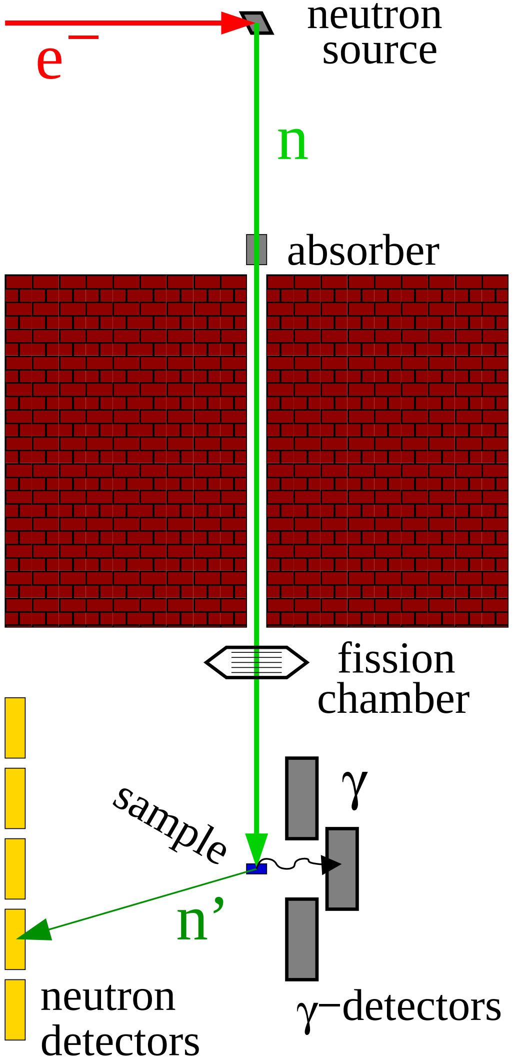

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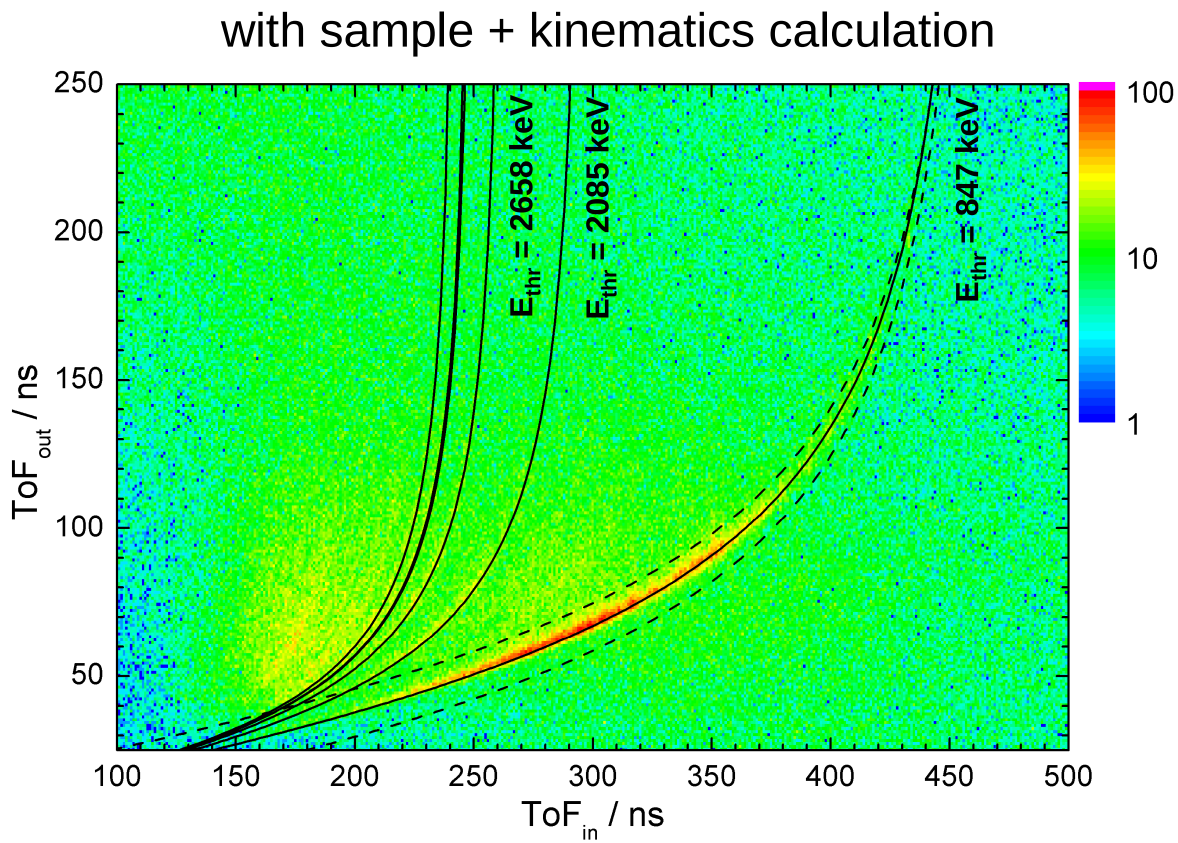
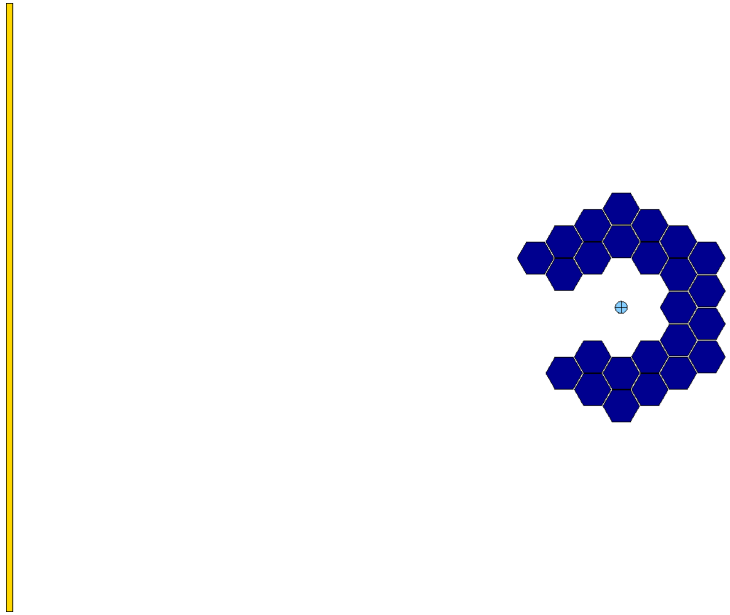


Investigations of background sources



"good event": inelastic scattering in target

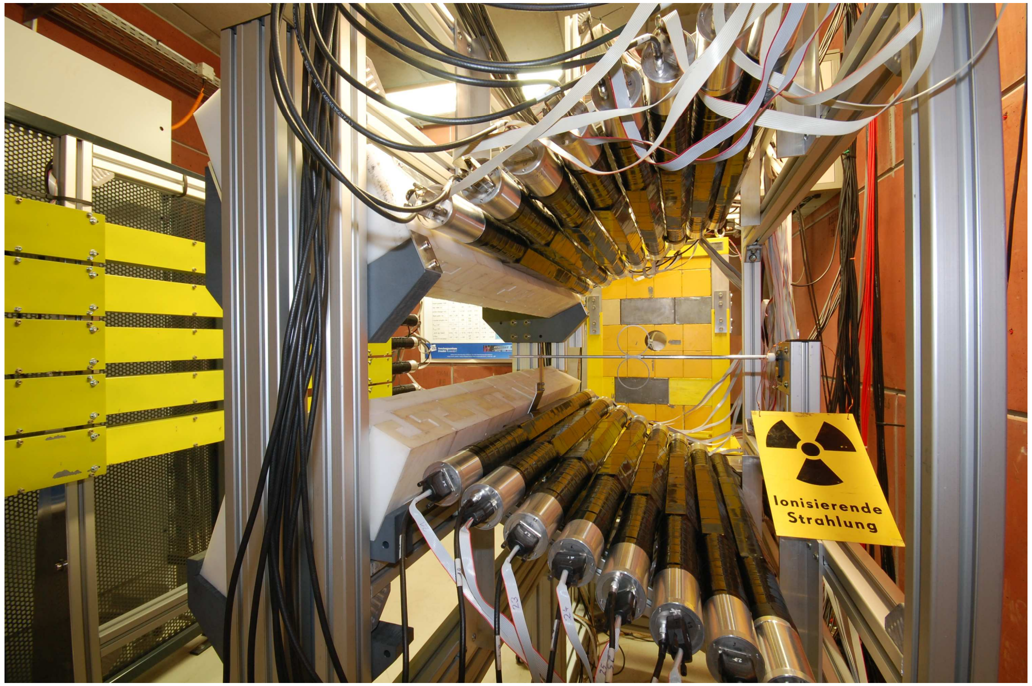
➔ gamma detected in BaF2, neutron detected in plastic

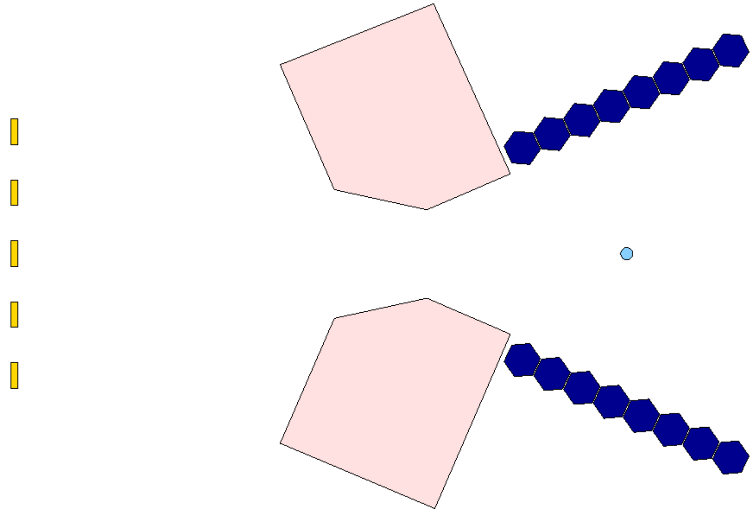
"bad event": elastic scattering in target/air and inelastic scattering in BaF2

➔ neutron detected in plastic

➔ prevent neutrons flying from BaF_2 to plastic

Investigations of background sources





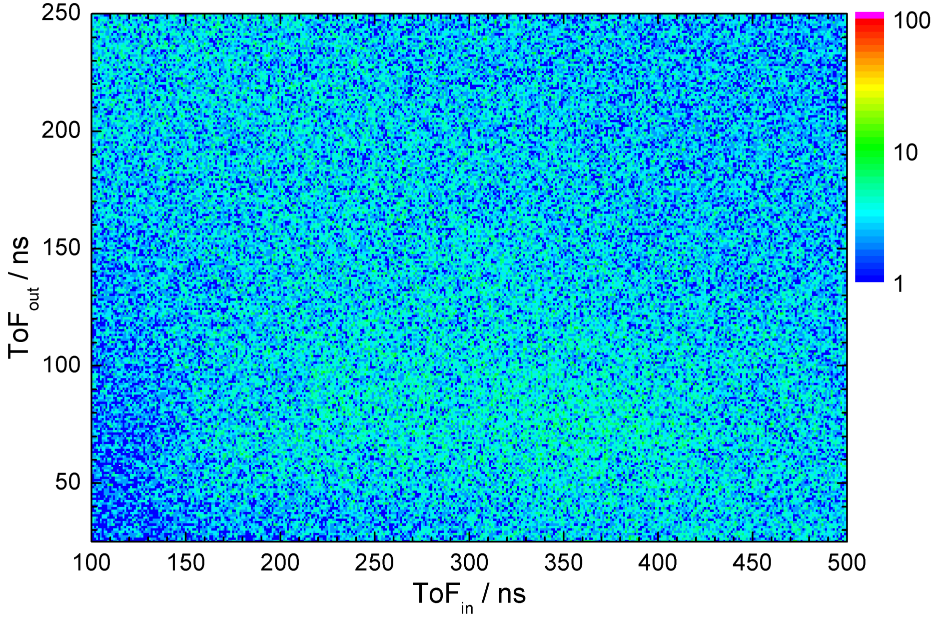
Plastics

BaF_2-Setup

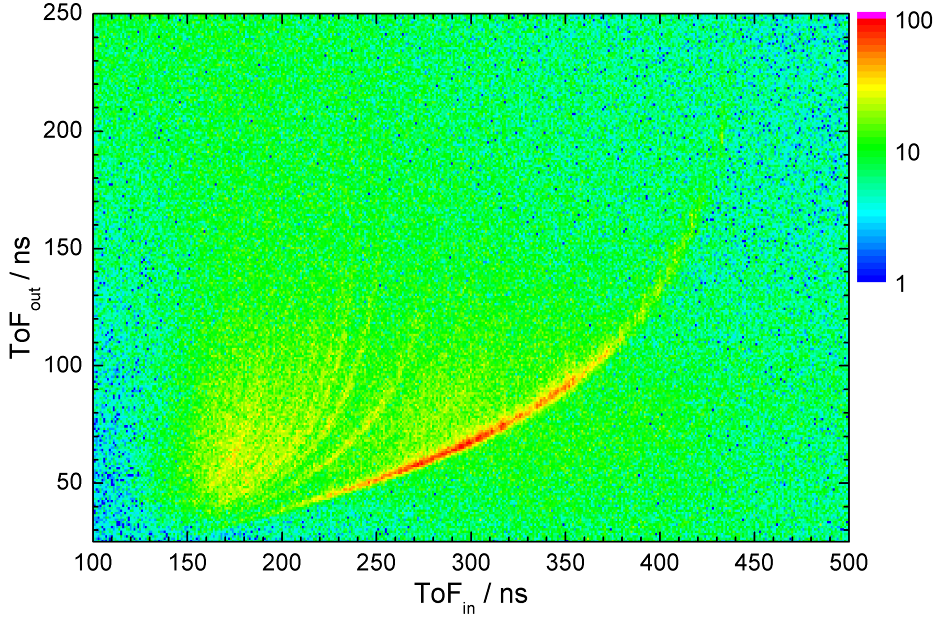
- ➔ borated polyethylene block between BaF_2 and plastics
- ➔ change in geometry
- ➔ combination of two single sided readout 20 cm long crystals to one double sided readout 40 cm long detector

2D ToF spectra from Feb'09 beamtime

empty target t_{live} = 79 604 s

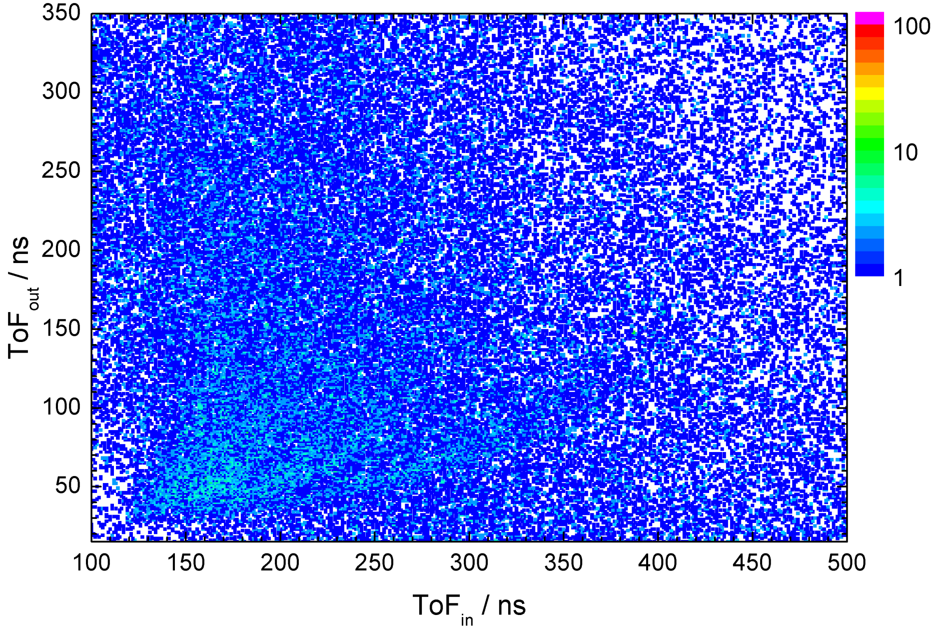


Fe-nat t_{live} = 84 251 s (68 %)

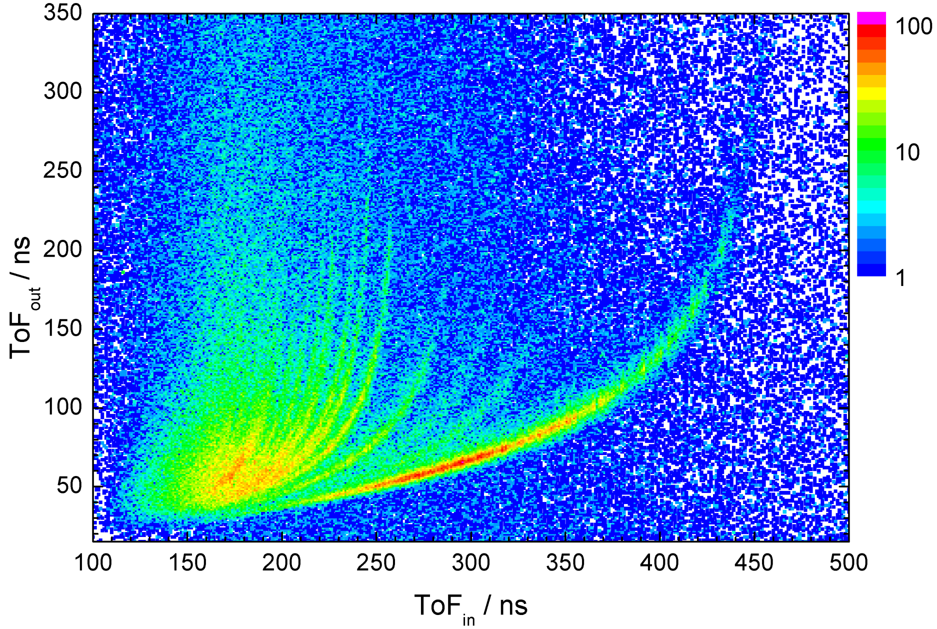


2D ToF spectra from May'10 beamtime

empty target t_{live} = 294 515 s

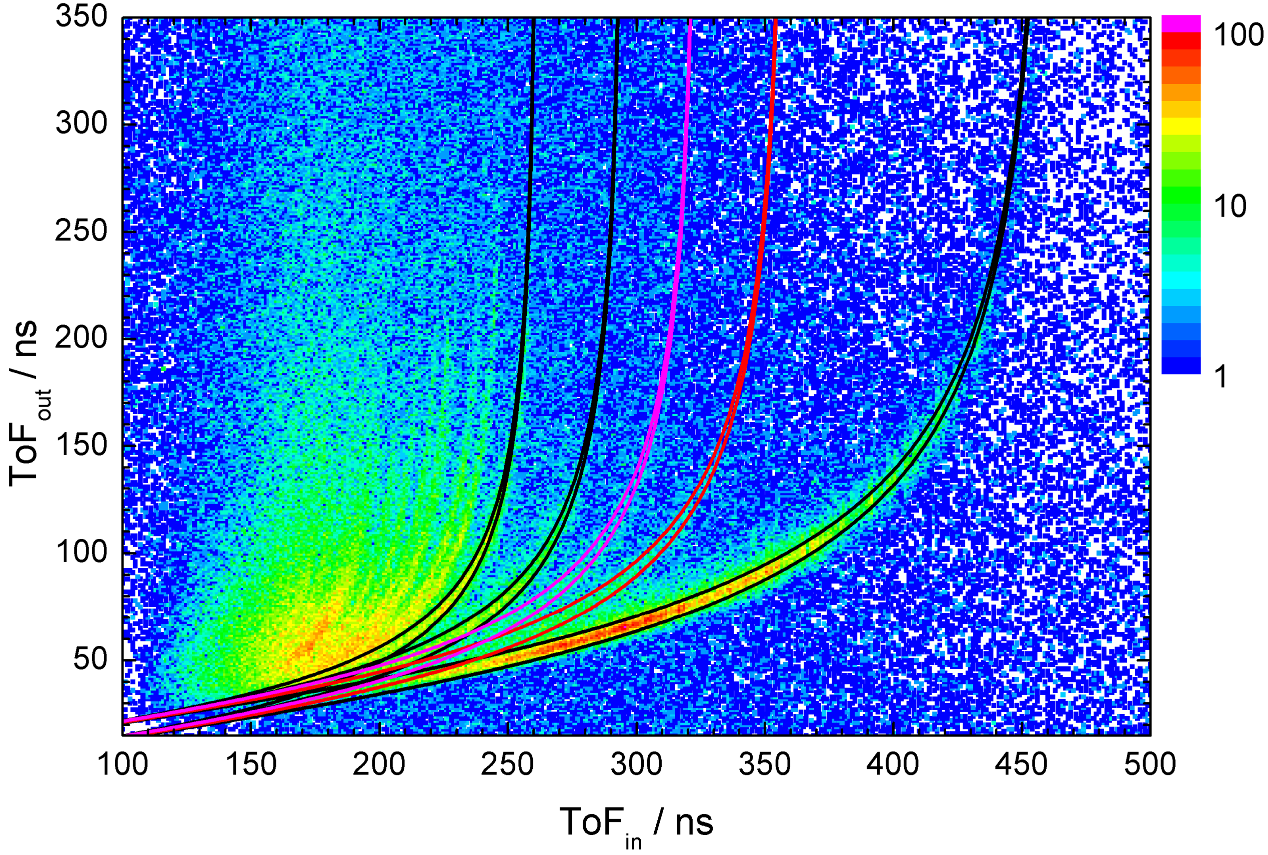


Fe-nat t_{live} = 280 567 s (83 %)



→ lower background (5x in empty, 10x in target run)
→ 10x better signal to background ratio
→ target structures also visible in in empty spectrum
(due to too small distance of target out position)

2D ToF spectra from May’10 beamtime



- Fe-56 (1.,2.,3. Level)

- Fe-54 (1. Level)

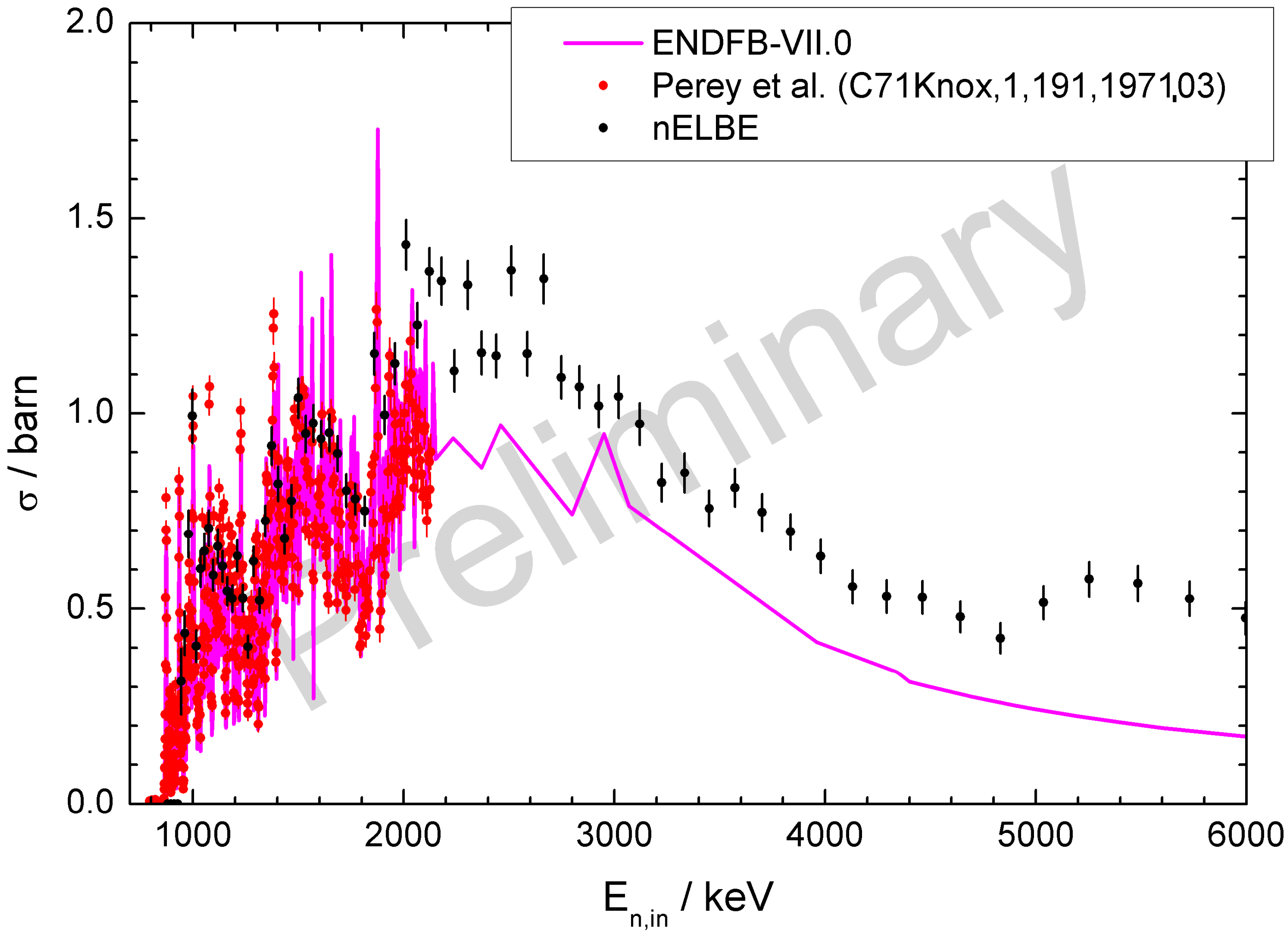
- ? 1700 keV

→is not:

- Al-27
- C-14
- Fe-57
- Mn-55
- N-14
- O-16
- Pb-207
- Pb-208
- …

➔ double-scattering on Fe-56 1st level (847 keV)

The $^{56}Fe(n,n'\gamma)$ cross section for the 1st excited state



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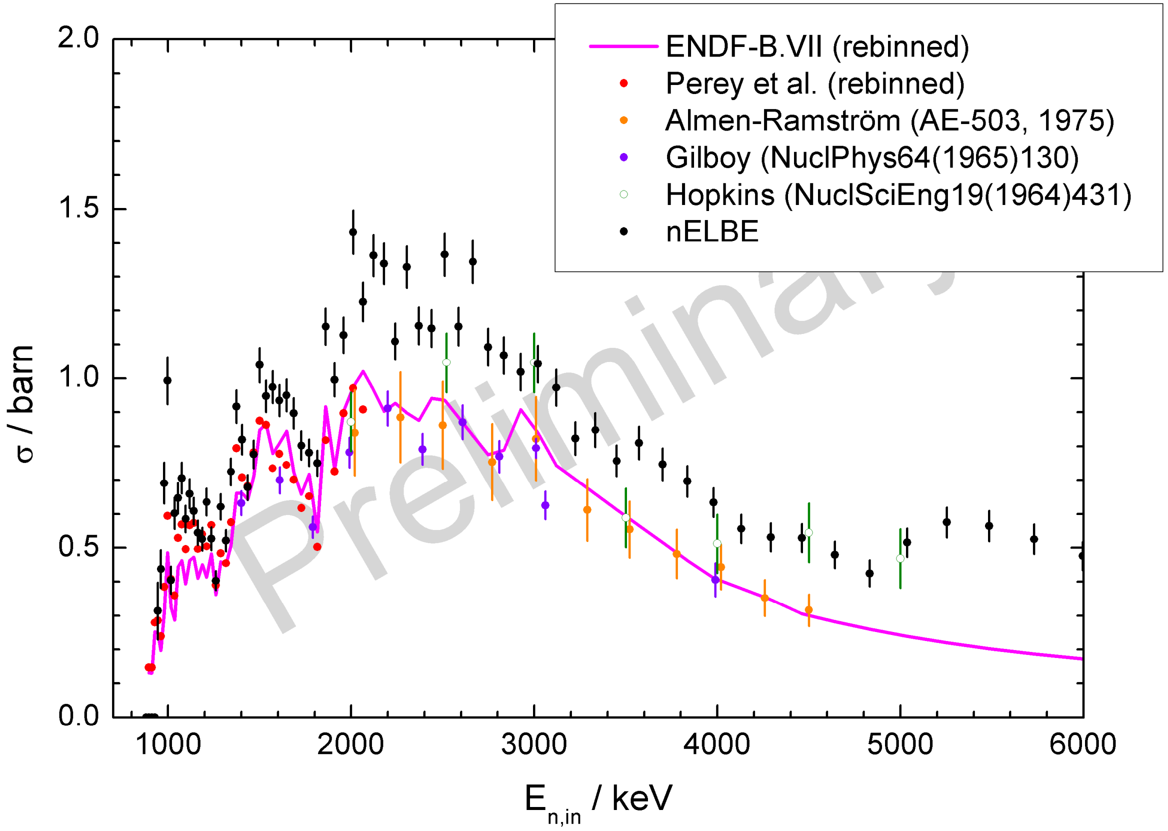
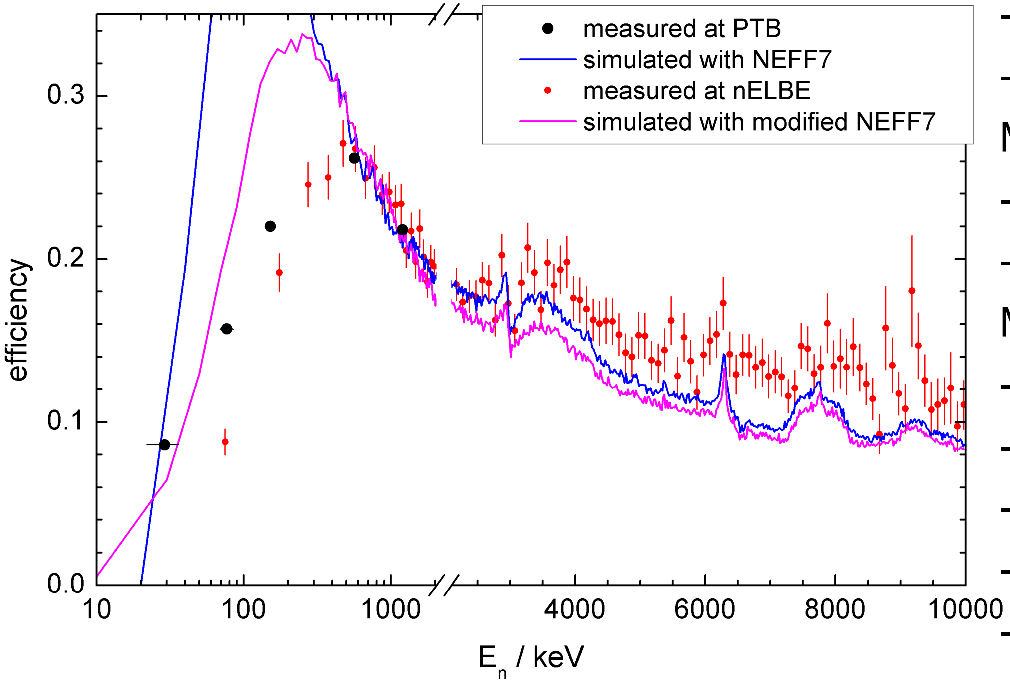


Uncertainties:	@ 2 MeV
Fission chamber efficiency	2.2 %
Fission chamber counts	0.7 %
Fission chamber background	1.8 %
Loss due to ADC range	0.1 %
Scaling factor FC<->Target	0.9 %
→ Neutron flux	2.5 %
Sample in counts	2.3 %
Sample out counts	15.1 %
Normalization factor	1.7 %
BaF_2 efficiency	1.8 %
Plastic efficiency	5.1 %
→ Reaction rate	5.9 %
→ Cross section	**6.4 %**

Plastics Efficiency



Measurement at PTB:

- Monoenergetic neutrons
- Beyer et al., NIMA 575 (2007) 449

Measurement at FZD:

- nELBE spectrum
- Relative to ^{235}U fission chamber

Modified NEFF7:

- Cuboid detector geometry
- Double sided readout
- Scintillation light propagation/attenuation
- PMT Quantum efficiency
- Threshold = one photo electron per PMT

Problems:

In simulation:

- Unknown light output function at low energy transfer

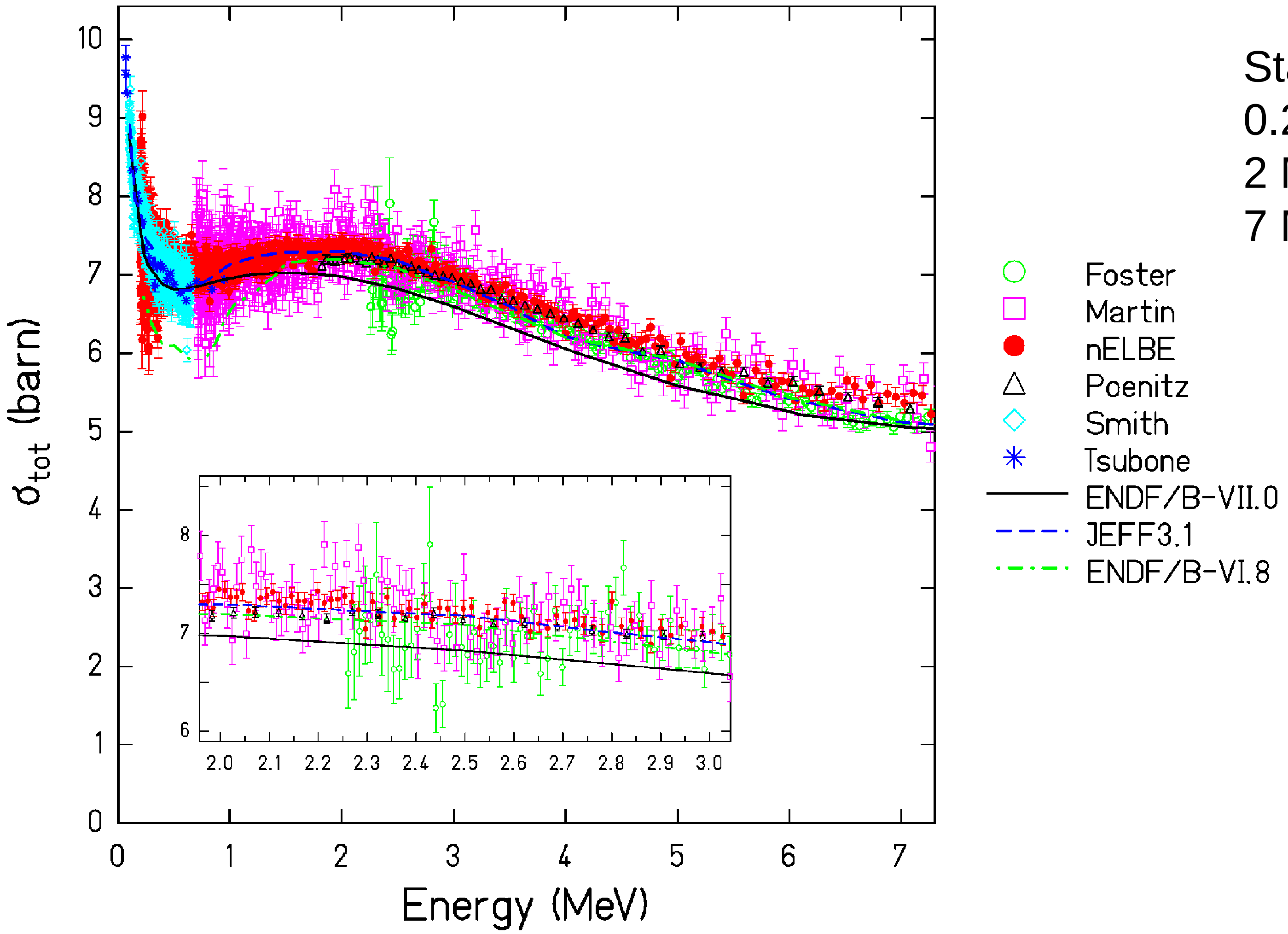
In measurement:

- Collimated beam at nELBE
- Influence of lead shielding

Summary and outlook

- nELBE is intended to deliver data on fast neutron induced reactions
- the ELBE electron beam delivers a high neutron flux
  (new injector will deliver ~60 times more)
- nELBE is the only photoneutron source at a superconducting cw linac
- total cross section measurements were performed on ^{nat}Ta

Total neutron cross section of ^{nat}Ta



Statistical uncertainty:
0.2 MeV – 5 %
2 MeV – 1.2 %
7 MeV – 2.3 %

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- total cross section measurements were performed on Ta

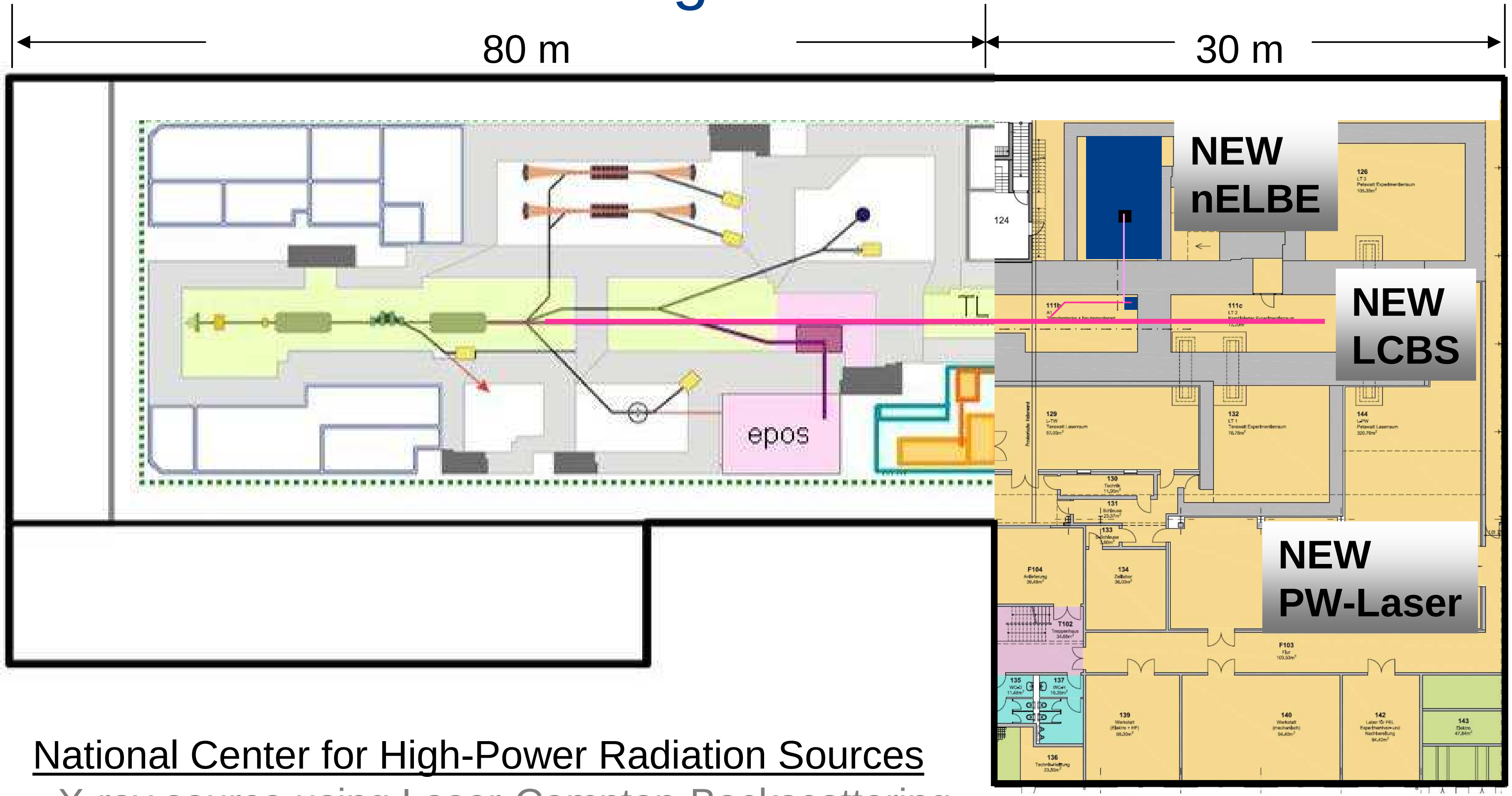
- first experiments were performed on inelastic neutron scattering using a double time of flight setup
- further investigations have to be done to:
  - ➢ re-measure plastics efficiency
  - ➢ determine influence of double scattering
  - ➢ correct for angular effects → neutron-gamma-angular correlation
- analyze data for higher levels of Fe-56 and 1st level of Fe-54

- measurement of Na-23(n,n'γ)

- prepare measurements of neutron fission cross sections

- new bigger experimental area within extension of ELBE facility

National Center for High-Power Radiation sources



National Center for High-Power Radiation Sources

- X-ray source using Laser-Compton-Backscattering
- High-Power Laser (PW) for Ion Acceleration
- New Neutron Time-of-Flight Facility for Transmutation Studies

ground breaking started April 2010

Thanks to all collaborators

FZD, Institute of Radiation Physics:

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FZD, Department Radiation Protection and Safety:

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FZD, Department Research Technology:

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Physikalisch Technische Bundesanstalt Braunschweig:

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Others:

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