Fast neutron measurements at the nELBE time-of-flight facility

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- The nELBE neutron time-of-flight facility
- Transmission measurements of neutron total cross sections
- Inelastic neutron scattering on ^{56}Fe
- Neutron induced fission cross section of ^{235}U and ^{242}Pu

TRAKULA

DRESDEN concept

HZDR

Research Projects

ERINDA
European Research Infrastructures for Nuclear Data Applications

ERINDA 12/2010 – 12/2013

CHANDA
SOLVING CHALLENGES IN NUCLEAR DATA FOR THE SAFETY OF EUROPEAN NUCLEAR FACILITIES
SEVENTH FRAMEWORK PROGRAMME

CHANDA 12/2013- 12/2017

- Coordination of Transnational Access to neutron beam facilities for nuclear data measurements +
  Roadmap for integration of the nuclear data research in stable structure within R&D coordination tools (Eur. Energy Research Alliance, HORIZON 2020)

TRAKULA

TRAKULA 10/2009 – 12/2014

- Joint research project funded by BMBF (Energie 2020+) to study the nuclear physics of long lived actinides relevant to nuclear waste management and transmutation together with University of Mainz, University of Cologne, Technical Unversity of Munich, Technical University of Dresden, Physikalisch-Technische Bundesanstalt

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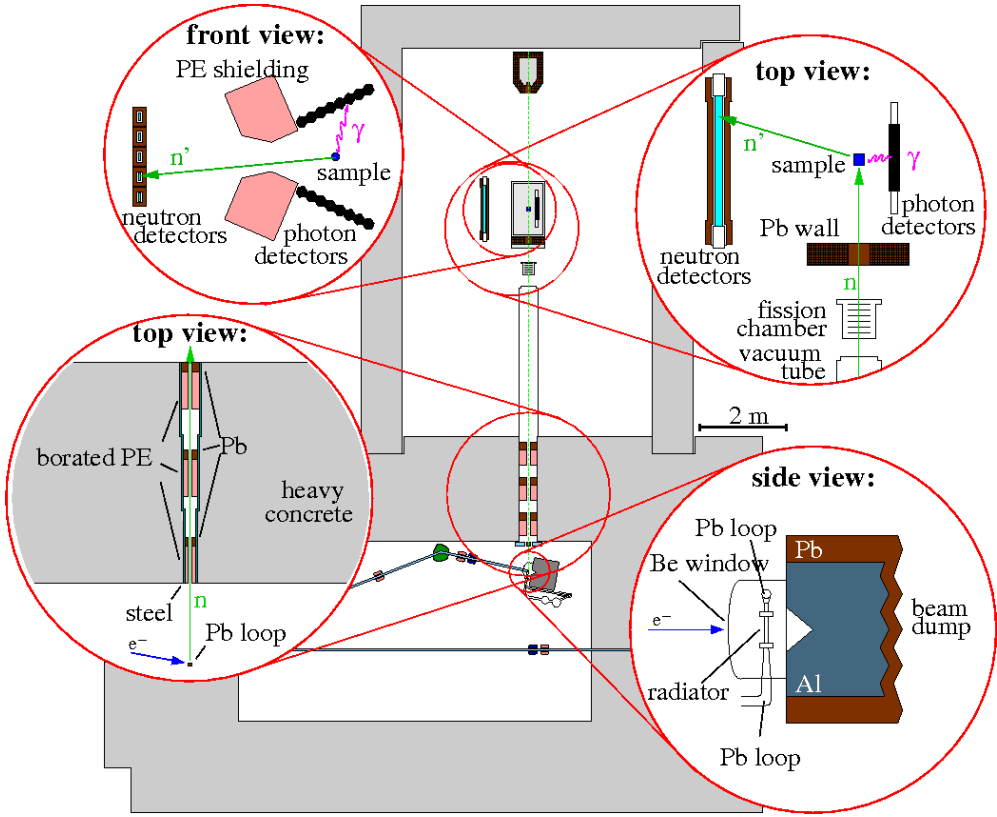
Nuclear Data Measurements at the photoneutron source nELBE

Extending the scope of accurate nuclear data

- **New Isotopes:**
  Minor actinides, New coolants, structural materials
- **New energy range:**
  Fast neutrons
- **New reactions:**
  (in)elastic scattering, (n,tot), (n,fis)
- **New neutron facilities:**
  Helmholtz-Zentrum Dreden-Rossendorf operates the world's only photoneutron source at a superconducting electron accelerator:



Characteristic parameters:

repetition rate:	101 or 202 kHz
flight path:	5 - 11 m
source strength:	ca. $1.6 \cdot 10^{11}$ n/s
intensity @ target:	ca. $2.5 \cdot 10^{4}$ n/cm^{2}s
energy range:	10 keV - 10 MeV
energy resolution:	< 1 %

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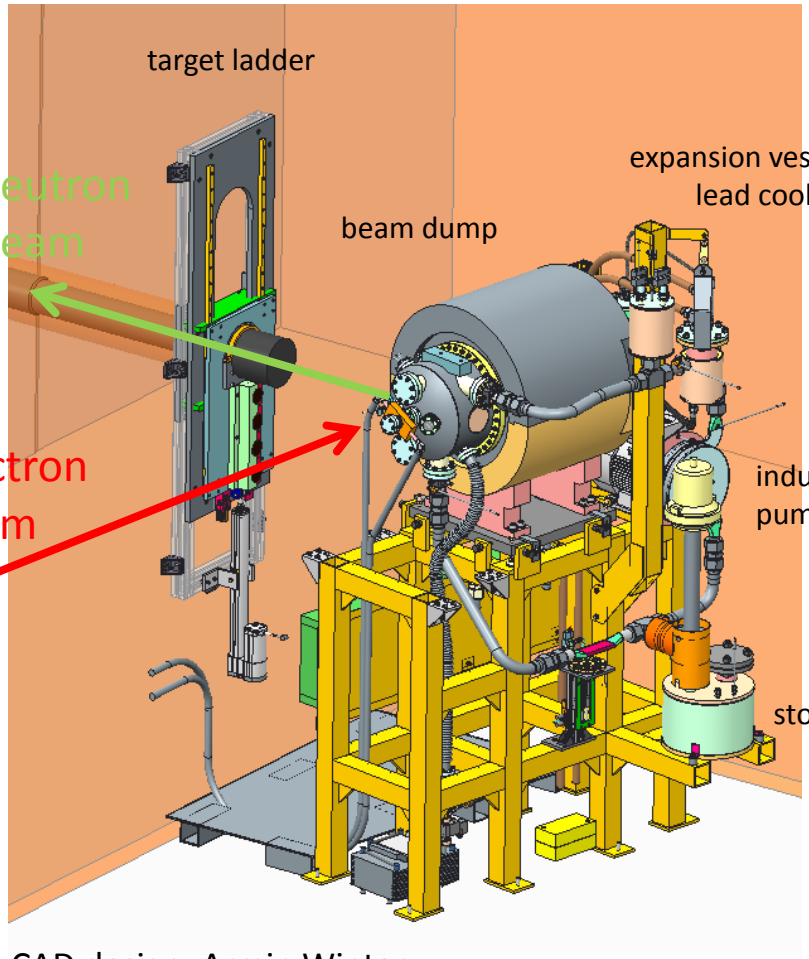
Liquid-Pb loop as neutron producing target



CAD design: Armin Winter

E. Altstadt et al., Ann. Nucl. Energy **34** (2007) 36

liquid lead circuit for heat transport

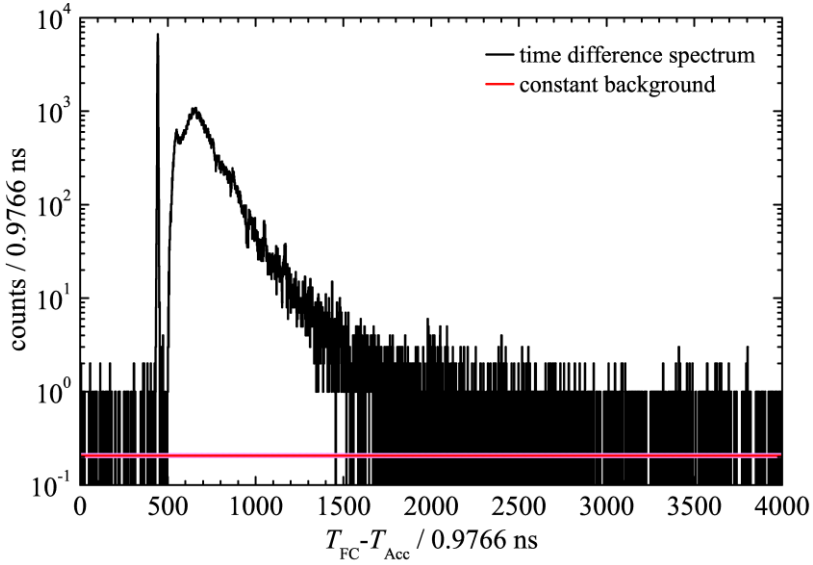
small Mo tube (11 mm diam.)
with liquid lead as neutron radiator

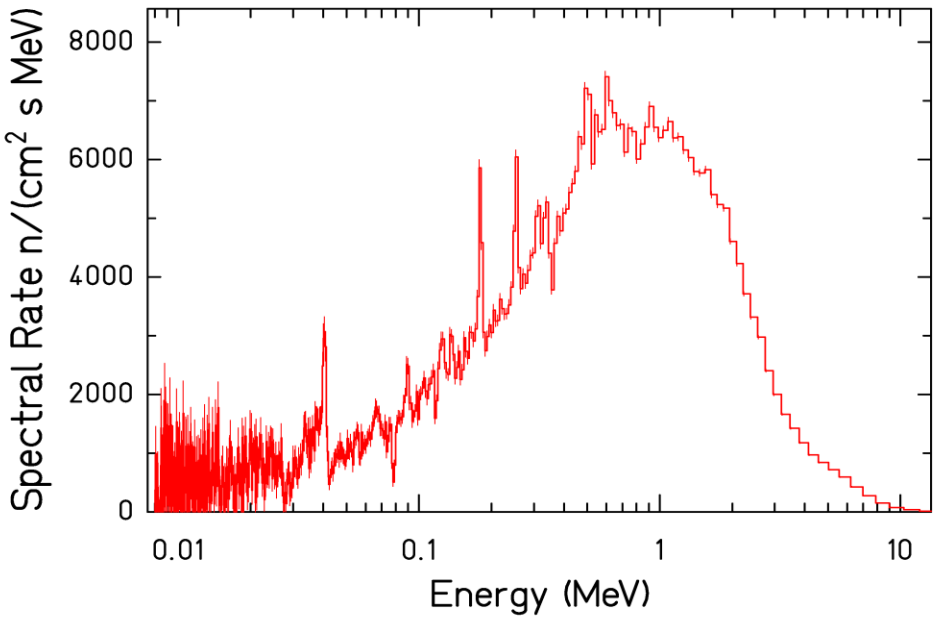
Electron beam power up to 40 kW
power density in the neutron radiator
up to 25 kW/cm^3

First beam with new Pb-loop:
August 30, 2013

nELBE neutron spectrum

^{235}U fission chamber



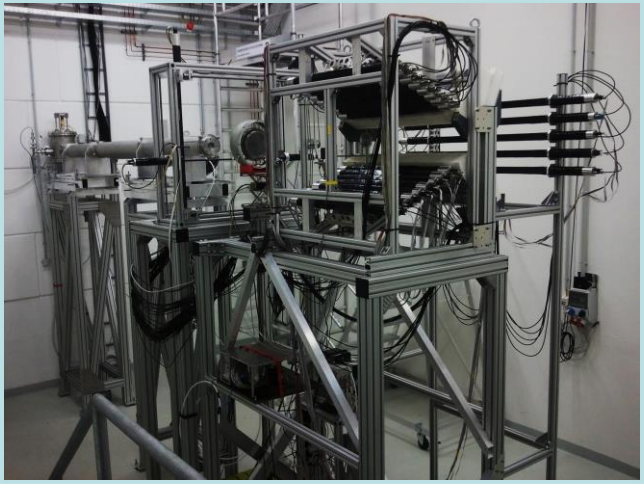


Photoneutron spectrum (measured with the PTB ^{235}U fission chamber H19)
TOF spectrum: Photofission from bremsstrahlung and neutron induced fission
Photoneutron spectrum similar to the fission neutron spectrum
Neutron time of flight range 100 ns – 2,5 µs
Neutron energy range from 100 keV – 7 MeV
Neutron spectral rate on target ca. 6*10^3 n/(cm^2 s MeV)

Measurement time : 49.4 h I_{e^-} = 15 µA, E_{e^-} = 31 MeV
Flight path 618 cm
Absorption dips : 78,117, 355, 528, 722, 820 keV ^{208}Pb scatttering resonances
Emission peaks: 40,89,179, 254, 314, 605 keV near threshold photoneutron emission
In ^{208}Pb (strong capture resonances of ^{207}Pb)
R. Beyer et al., NIM A723 (2013) 151

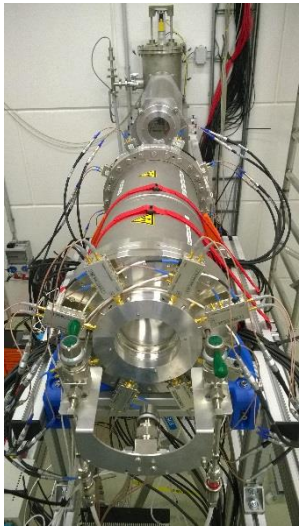
New time of flight measurements at nELBE

Transmission set-up for total cross sections



Double time of flight for inelastic neutron scattering

HPGe + $LaBr_3$ for angular distributions and
Inelastic neutron scattering



Neutron induced fission
with two fission chambers

Neutron total cross sections

- fundamental data set for the evaluation of nuclear data libraries
  large sensitivity on optical model parameters in the fast neutrons energy range
- Collaboration with IRMM and KAERI: Combination of measurements from GELINA and nELBE to cover the neutron energy range from ≈10 keV – 10 MeV.
- **^{197}Au**: on OECD NEA Nuclear Data High Priority Request list, energy range 5 – 200 keV (^{197}Au(n,γ) is activation standard in dosimetric applications)
  data with targeted uncertainty < 5 %: impact on future evaluations
  measurement from 200 keV to 2.5 MeV: consistency check
- **^{nat}Ta**: structural material in many nuclear and high-temperature applications, component in Reduced Activation Ferritic / Martensitic steels
  recent evaluation recommends careful measurement from several tens of keV to several MeV with accuracy goal of ≈ 1 %
- **^{nat}W:** structural component of divertor of fusion reactors
- **^{nat}Fe**: important structural material in reactors (^{56}Fe one of the CIELO nuclides)
- **^{238}U:** fertile component in many nuclear fuels (also one of the CIELO nuclides)

Institut for Reference Materials and Measurements

Korea Atomic Energy Research Institute

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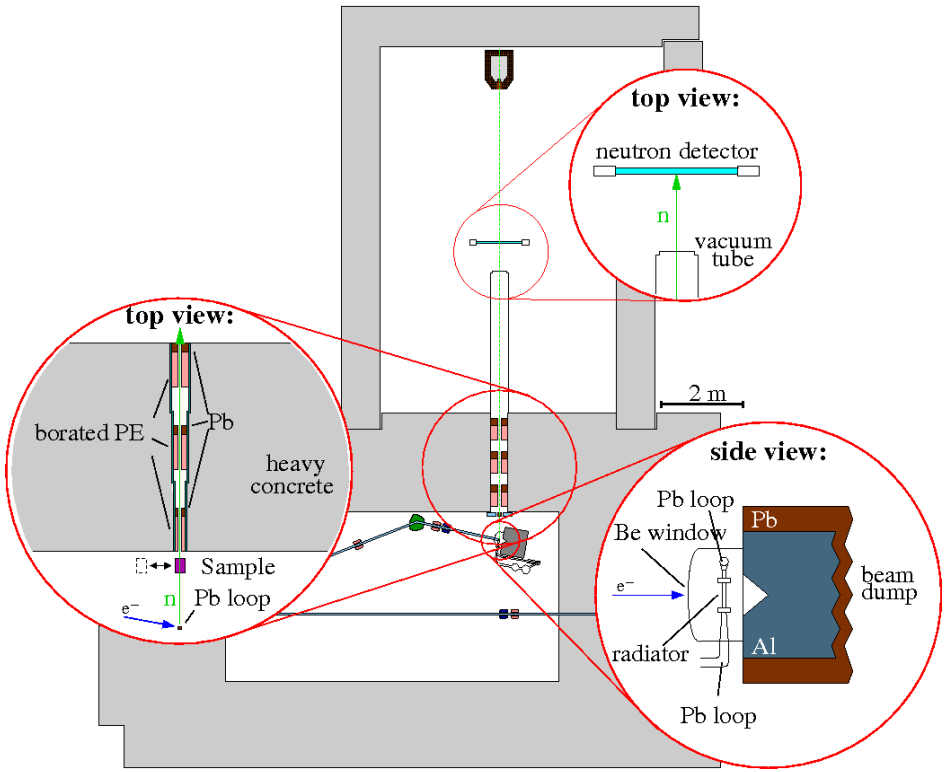
Transmission measurements

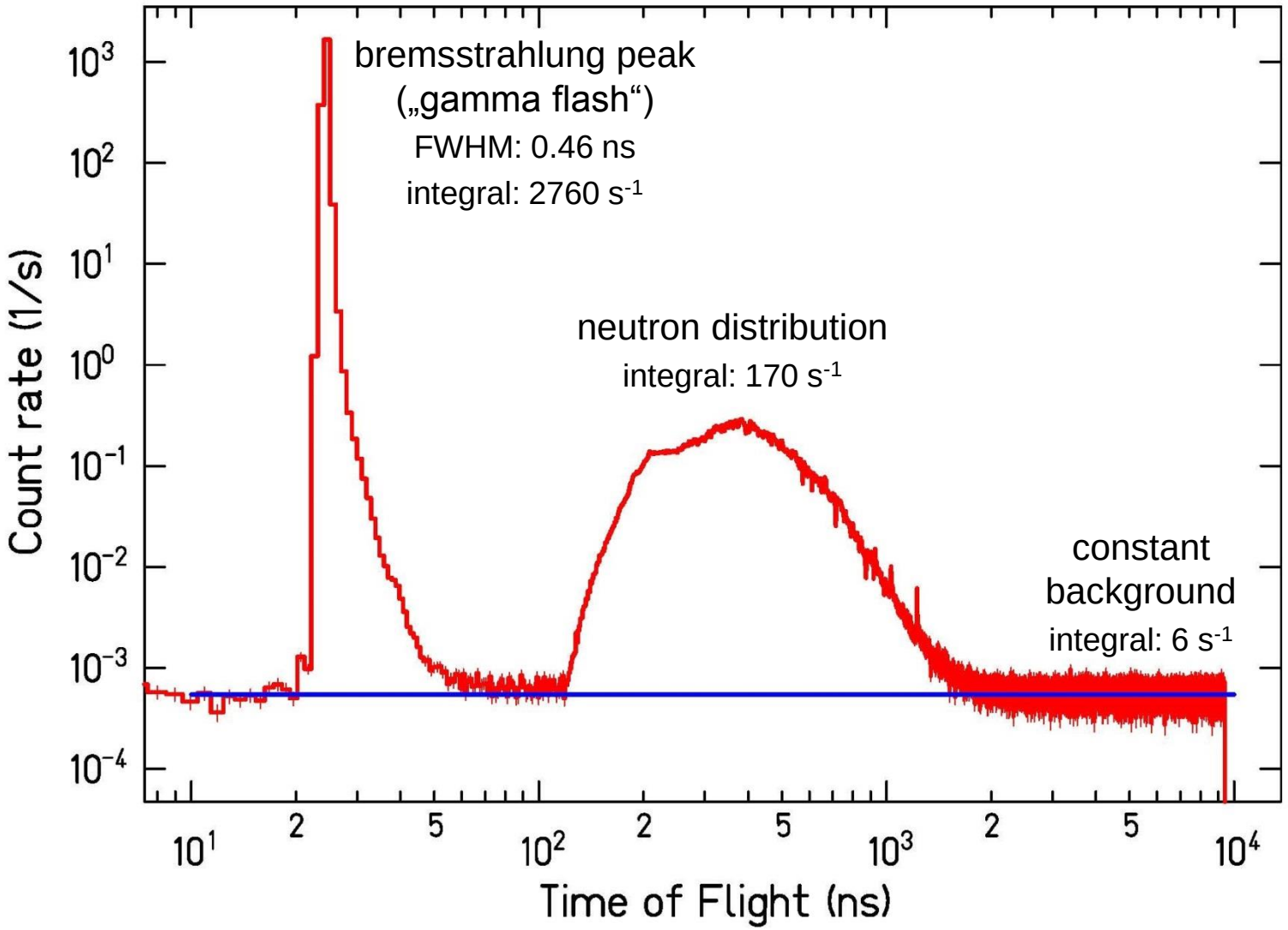


$$T = \frac{R_{in}}{R_{out}} = \exp(-nl\sigma_{tot})$$

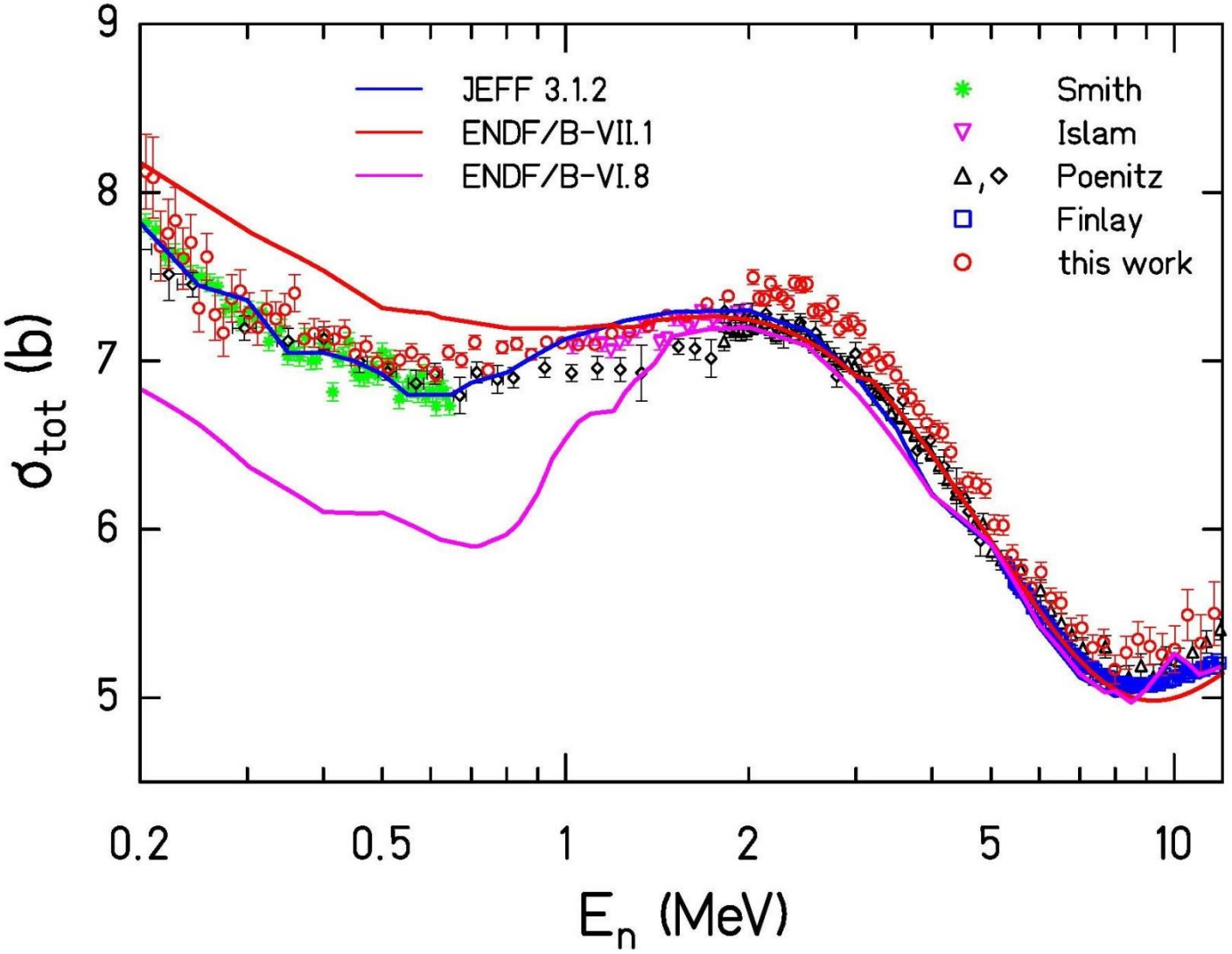
- target samples (Ø 2.5 – 2.6 cm):
  - ^{nat}Ta (0.1413(6) atoms/barn), ^{197}Au(0.0945(6) atoms/barn), ^{nat}Fe (0.1697(6) atoms/barn), ^{nat}W (0.0999(6) atoms/barn)
  - transmission $T \approx 0.3 – 0.6$
  - each with Pb absorber (l = 3 cm)
  - periodically changed (300 – 900 s)
  - Flight paths 718 cm; 852 cm
- neutron time-of-flight detector: fast plastic scintillator with low threshold
- fast QDC (6 µs busy time) + high resolution TDC (25 ps) multi-hit multi-event readout to reduce deadtime

Transmission experiment

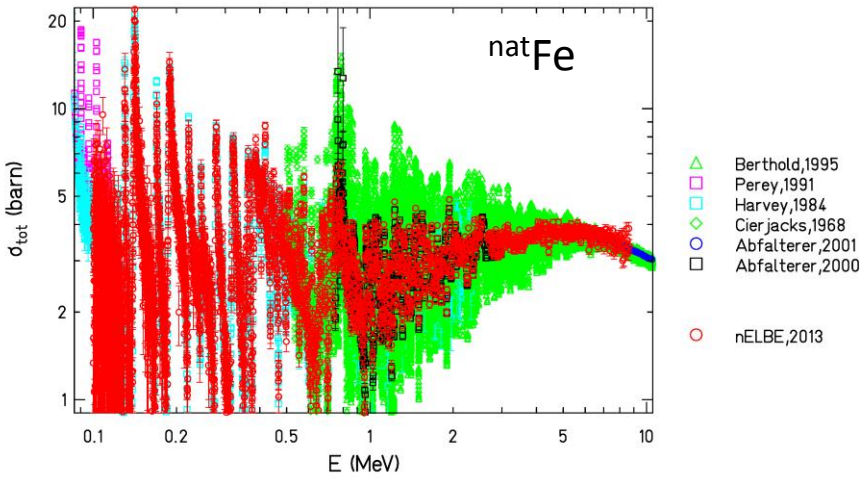
dead-time corrected count rate with ^{197}Au sample (red) and fitted background (blue)

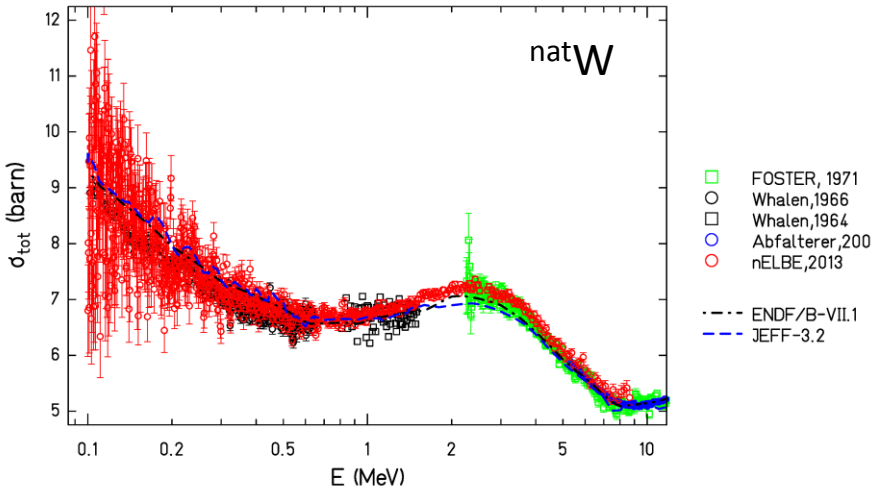


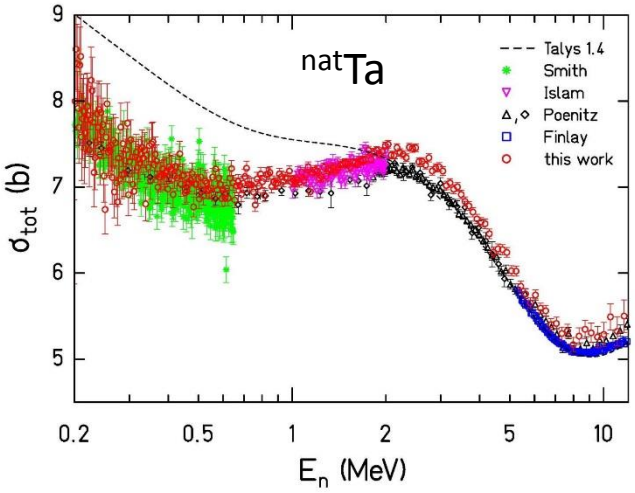
Results ^{nat}Ta: nELBE, Smith and Islam data rebinned below 2 MeV



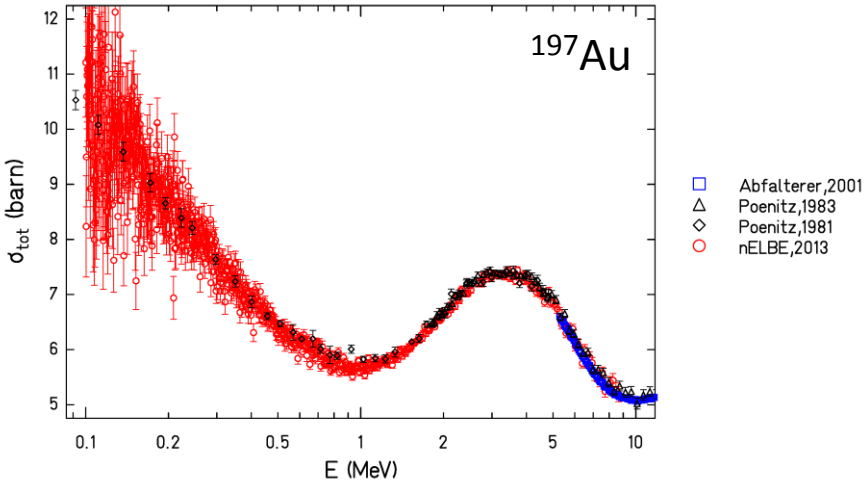
Neutron total cross sections







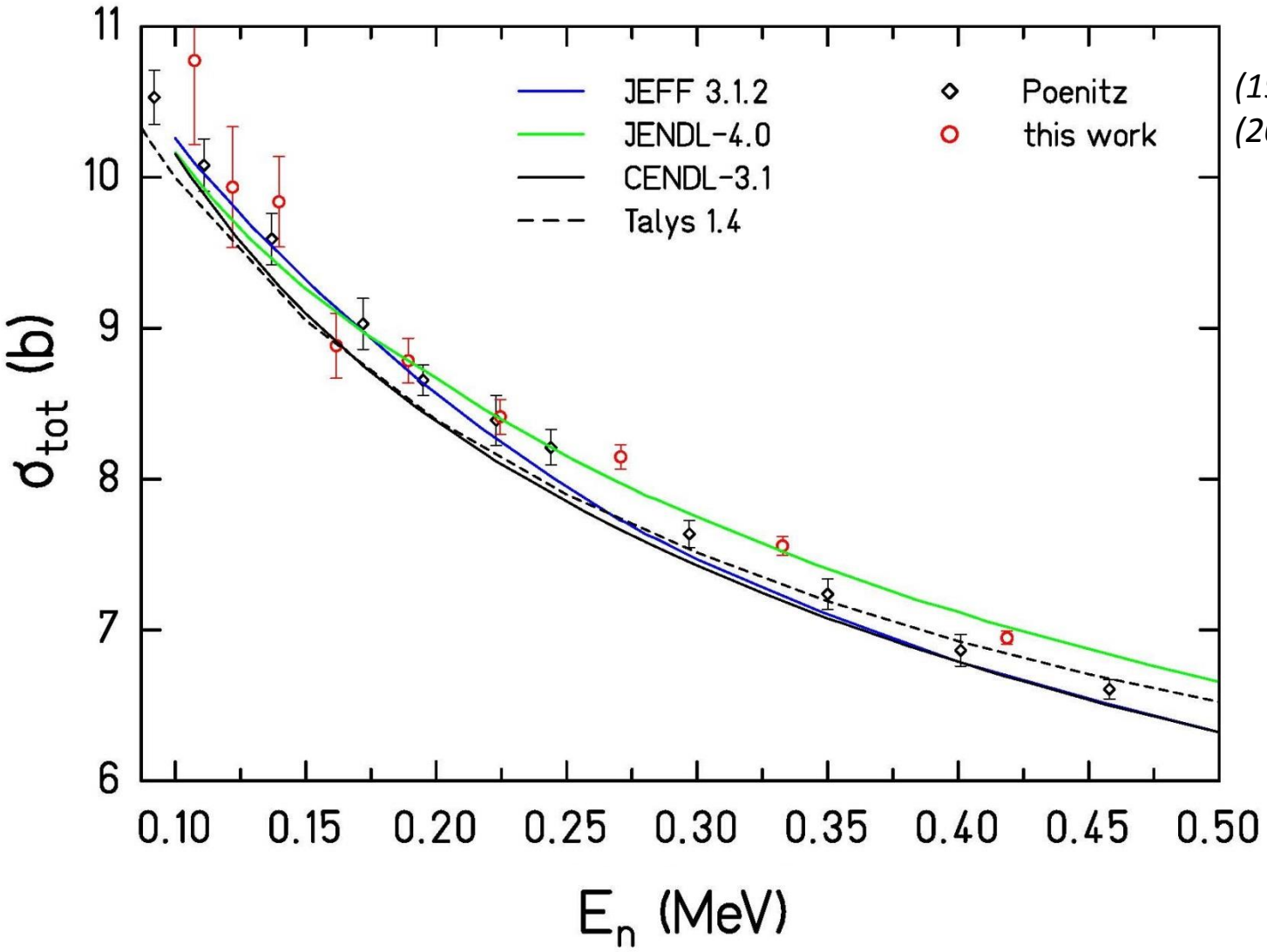
(1968 ANL)
(1973 Dacca)
(1983 ANL)
(1993 LANL)
(2013 nELBE)



DRESDEN concept

HZDR

Results ^{197}Au: from rebinned nELBE data between 100 and 500 keV



(1983 ANL)
(2013 nELBE)

Experimental uncertainties of neutron total cross section

Statistical uncertainties				
E_n (MeV)	0.2	1.0	5.0	10.0
Ta	6 % (1.0 %)*	0.9 %	0.9 %	2.6 %
Au	8 % (1.4 %)*	1.5 %	1.2 %	3.8 %
Energy resolution (source + detector)				
ΔE/E (FWHM)	1.4 %	1.4 %	3.5 %	7.4 %
Bin width (keV)	1.36 (35)*	15.1	168	465
Systematic uncertainties				
Random background subtraction	0.2 %			
Transmission normalization	0.5 %			
Areal density of the target sample	0.6 %			
Dead-time correction factor	0.8 %			
Total systematic uncertainty	1.1 %			

** rebinned data*

Au + Ta neutron total cross sections:

R. Hannaske et al., Eur. Phys. J. A (2013) 49: 137
I. Sirakov et al. Eur. Phys. J. A (2013) 49: 144

Energy resolution – simulation and measurement

- minor contribution due to geom. extension of neutron-producing target (0.2 – 0.3 %)
- major contributions from the detectors due to geom. extension, time resolution and scattering in the detector shielding (lead)

MC simulation

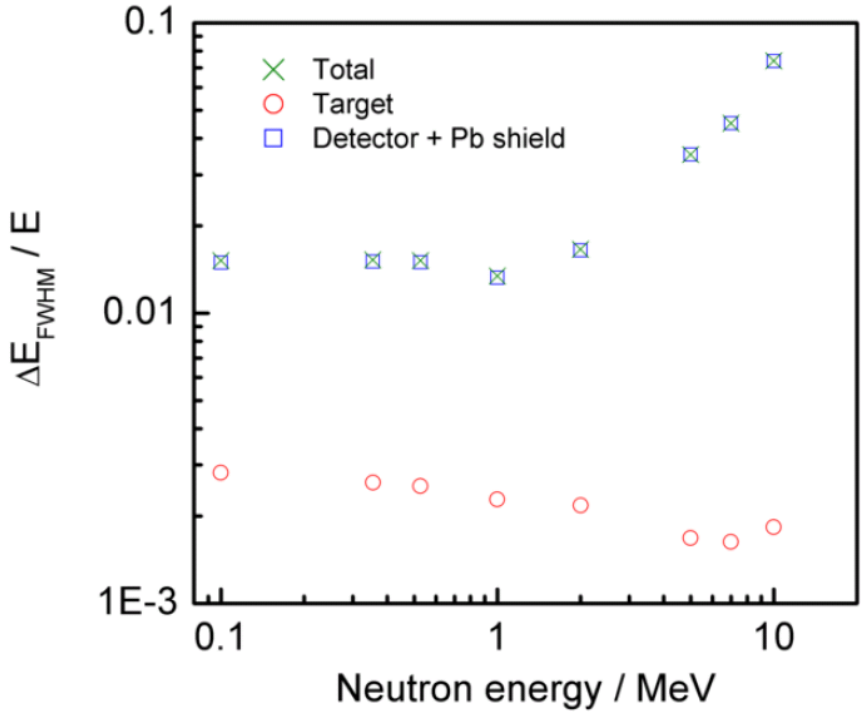
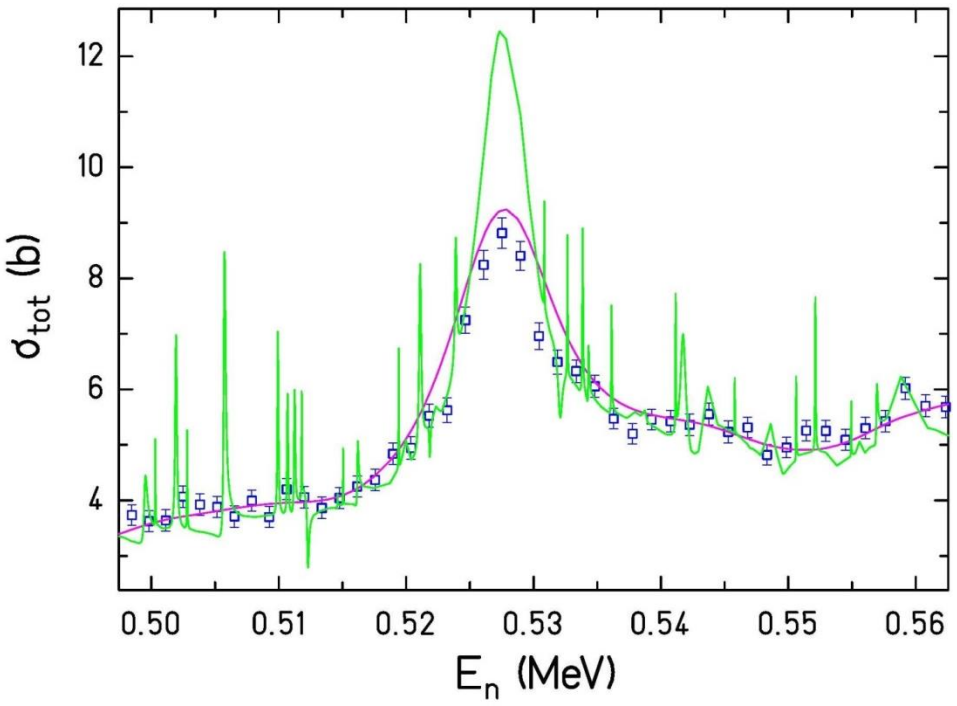
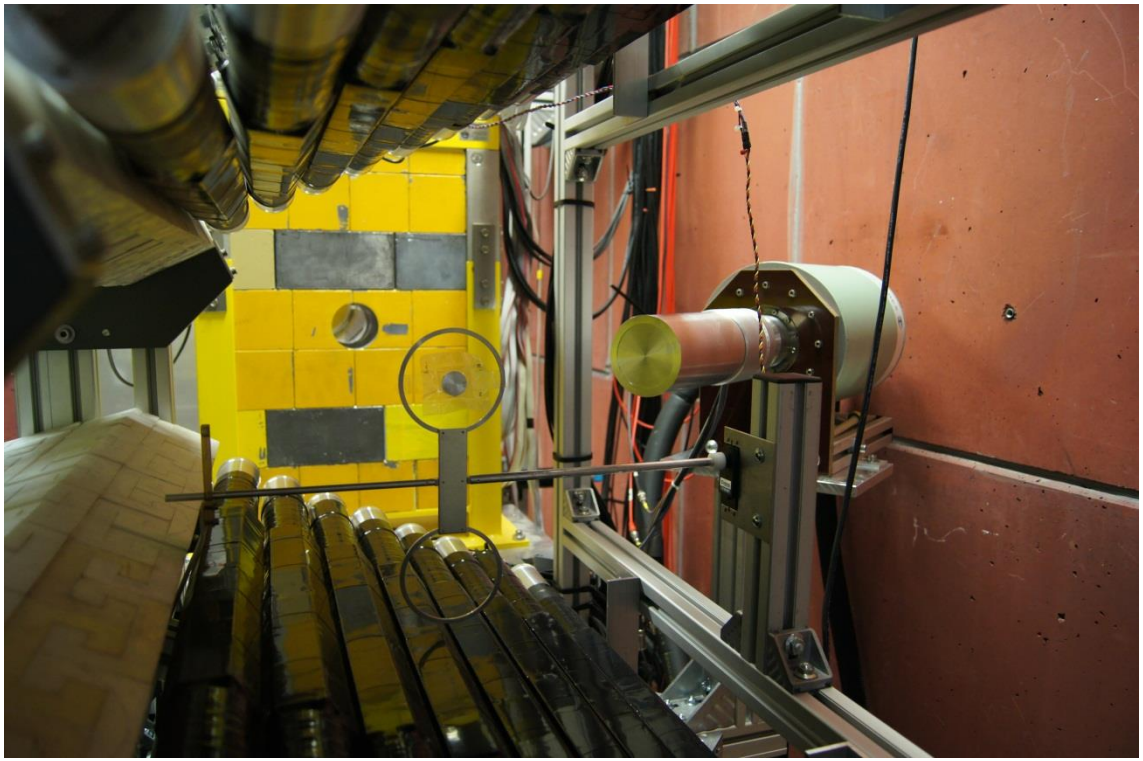


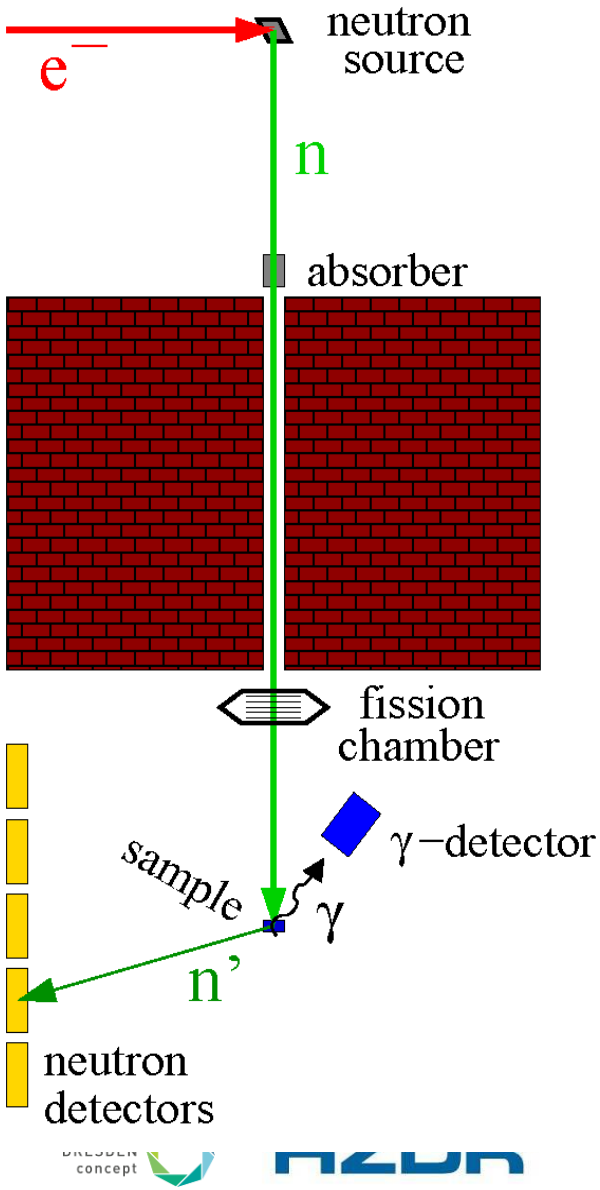
figure from Schillebeeckx et al., NDS 113 (2012) 3054

PbSb4 cross section from ENDF/B-VII.1, energy-averaged ($\Delta E_{FWHM}/E$ = 1.2 %) trans-mission based on *ENDF/B-VII.1*, and nELBE



Measurements of photon production cross section $^{56}Fe(n,n'\gamma)$





Target: cylinder of natural iron diameter 20 mm, thickness 8 mm

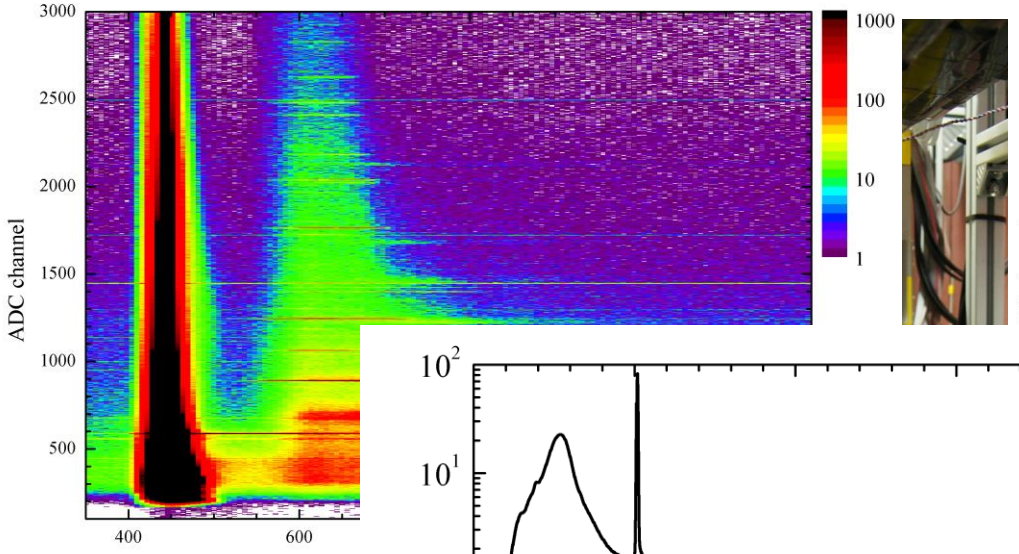
◦ HPGe detector at 125◦ to the neutron beam and a distance of 20 cm from the target

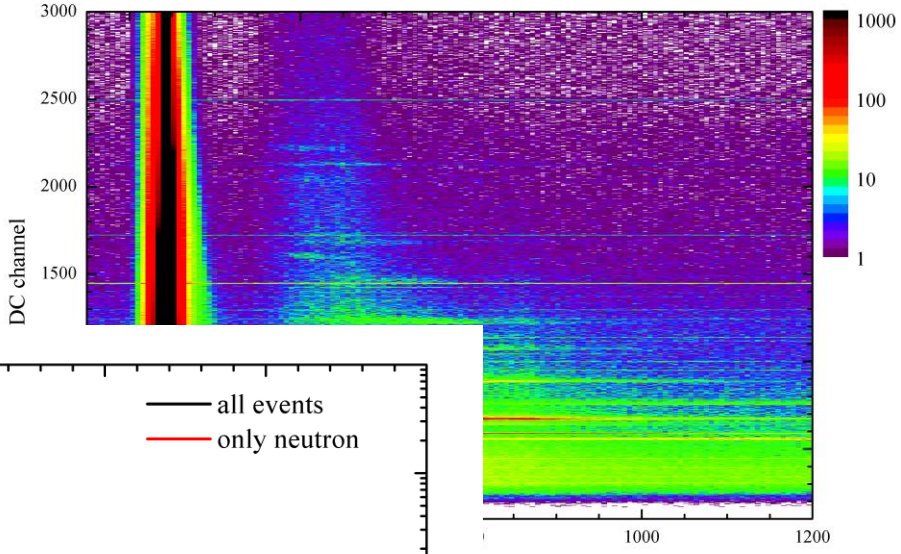
◦ Time difference between acelerator RF and signal of the HPGe detector
⇒ time-of-flight of the incident neutrons time resolution 10 ns

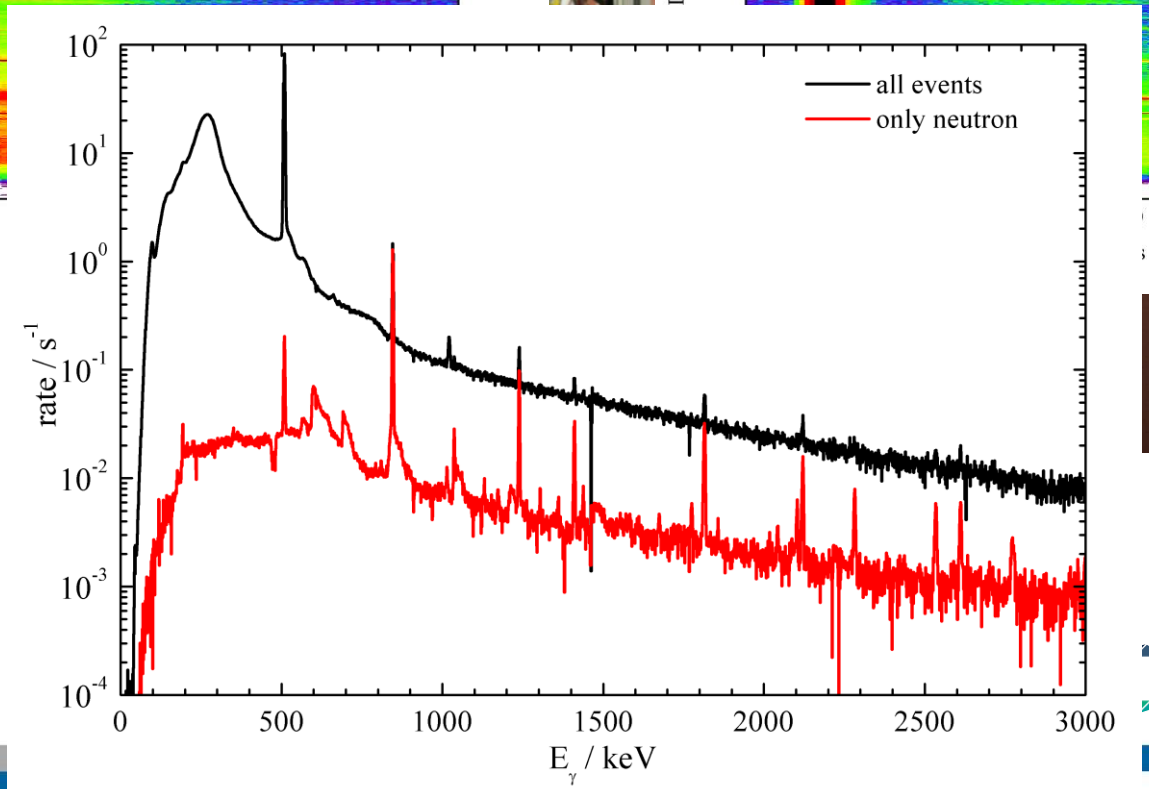
Gamma-ray energy vs. time-of-flight

with target

without target





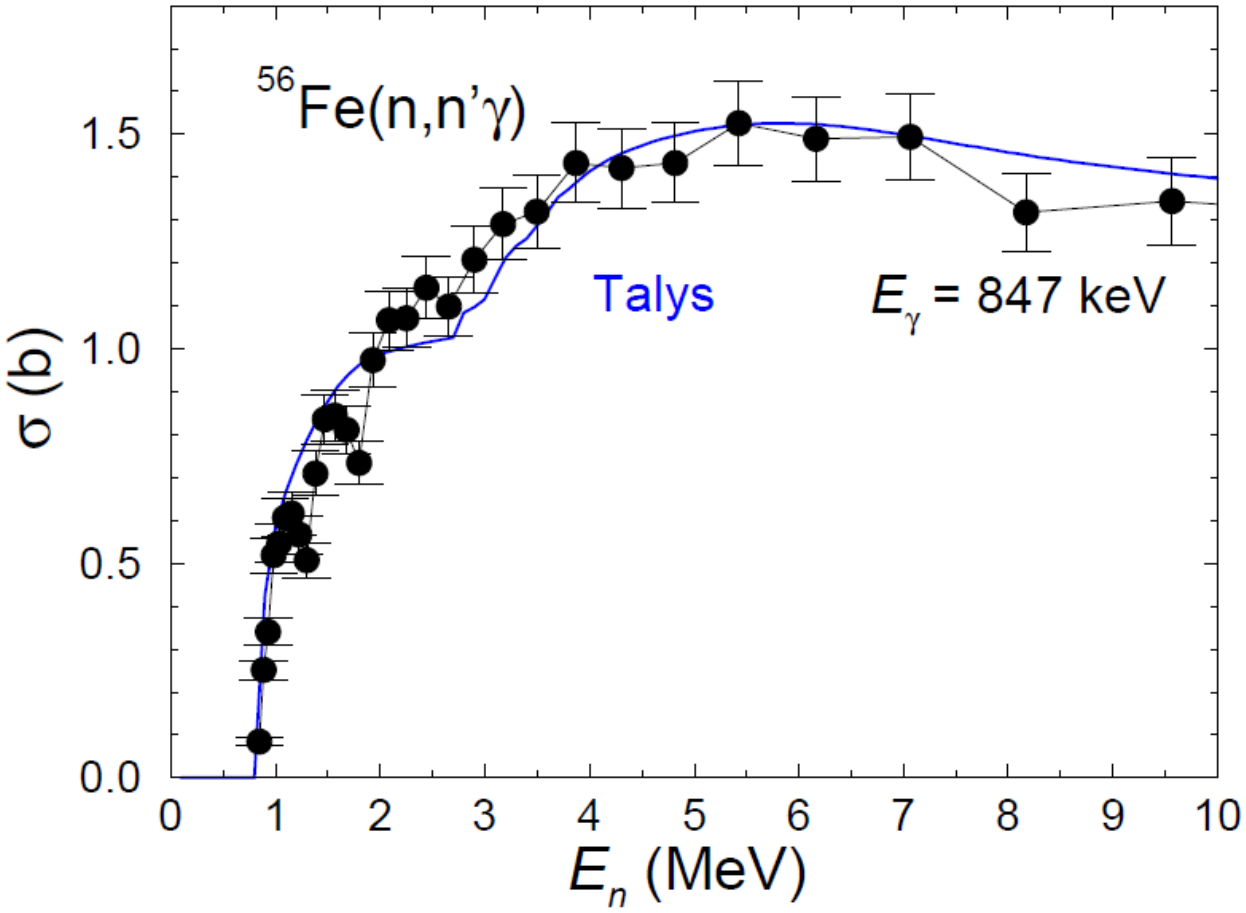


Time of flight
Interval
11.72 ns

Corrections to the inelastic cross section

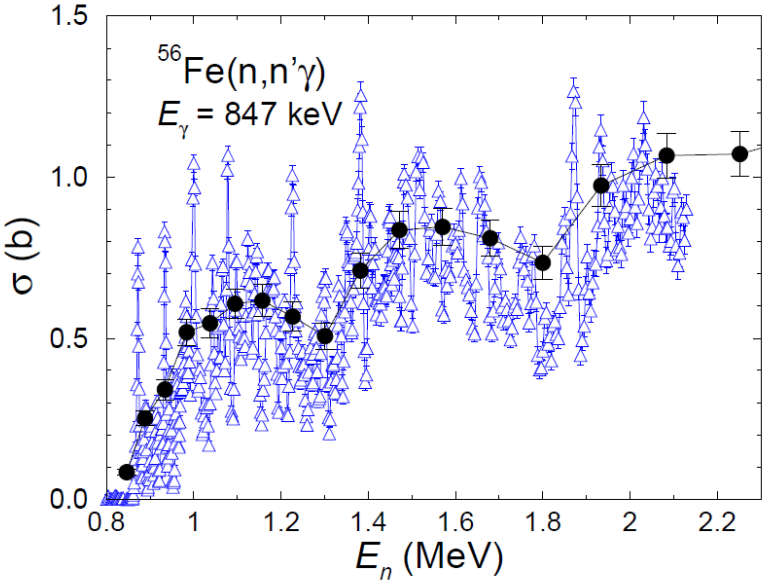
- Feeding from higher lying states
  (with observed gamma intensities)
- Probability of double scattering
  in the Fe sample 2% -10%
- Attenuation of the gamma rays in the Fe sample,
  e.g. 847 keV Factor 1.28
- Correction for angular distribution of emitted gamma-ray
  (4th order legendre polynomial) not applied

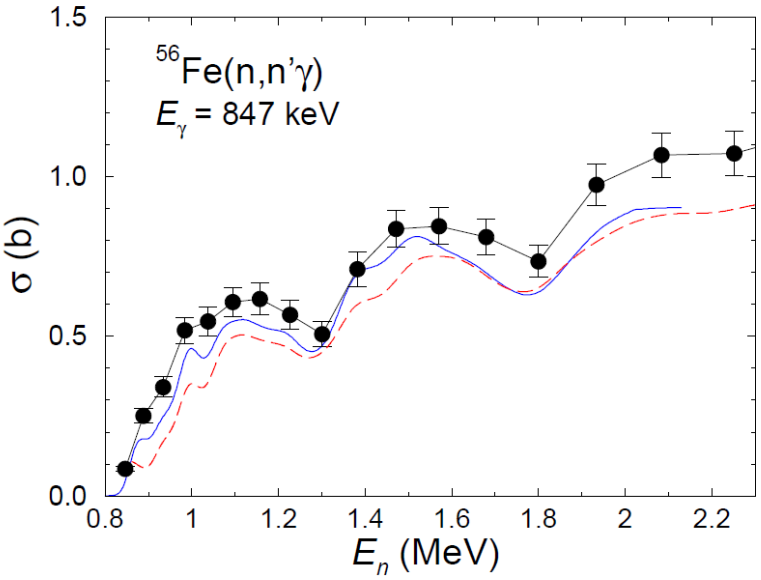
Inelastic neutron scattering cross section on ^{56}Fe



R. Beyer et al., Nucl . Phys. A. 927 (2014) 41

Inelastic scattering to the 1st excited state



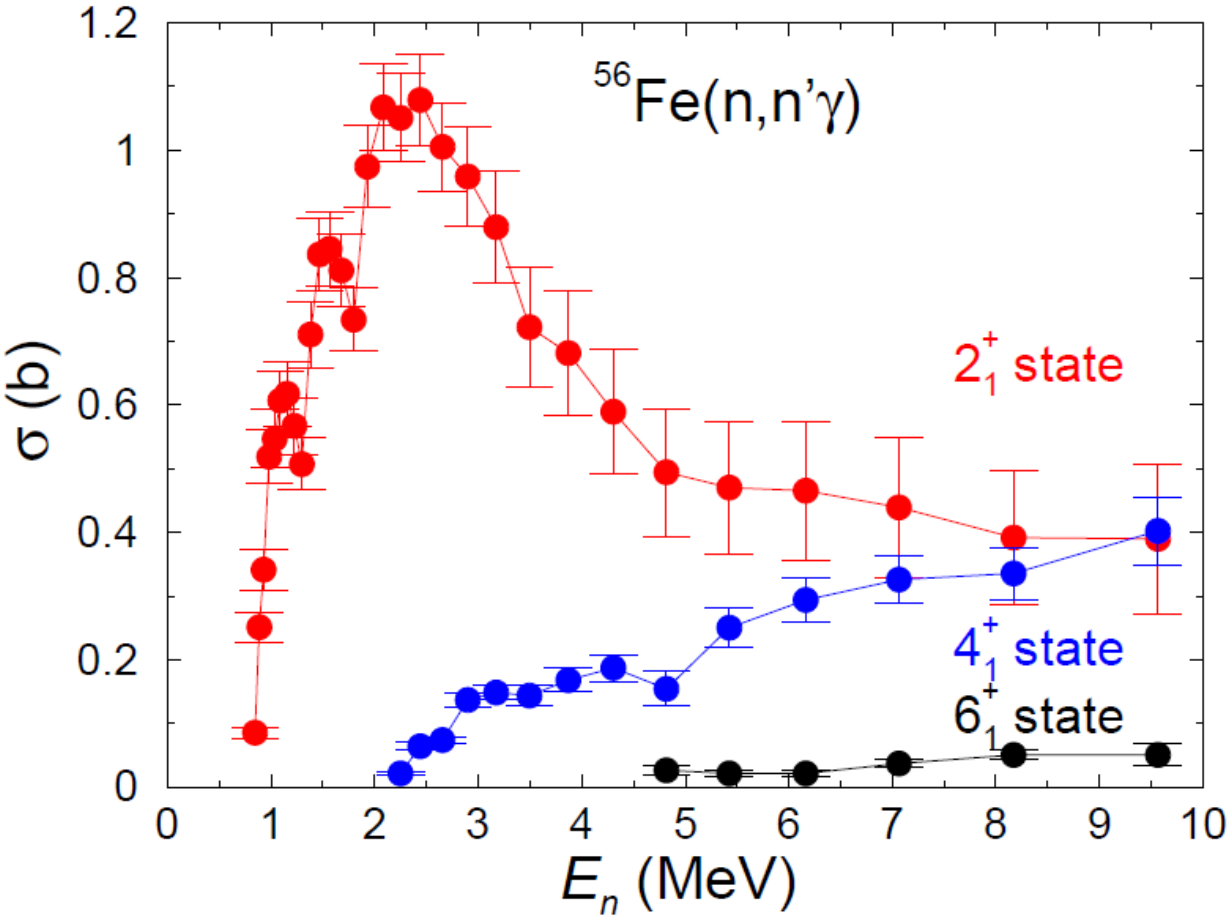


Perey et al. (1971)

JEFF-3.1.

R. Beyer et al., Nucl . Phys. A. 927 (2014) 41

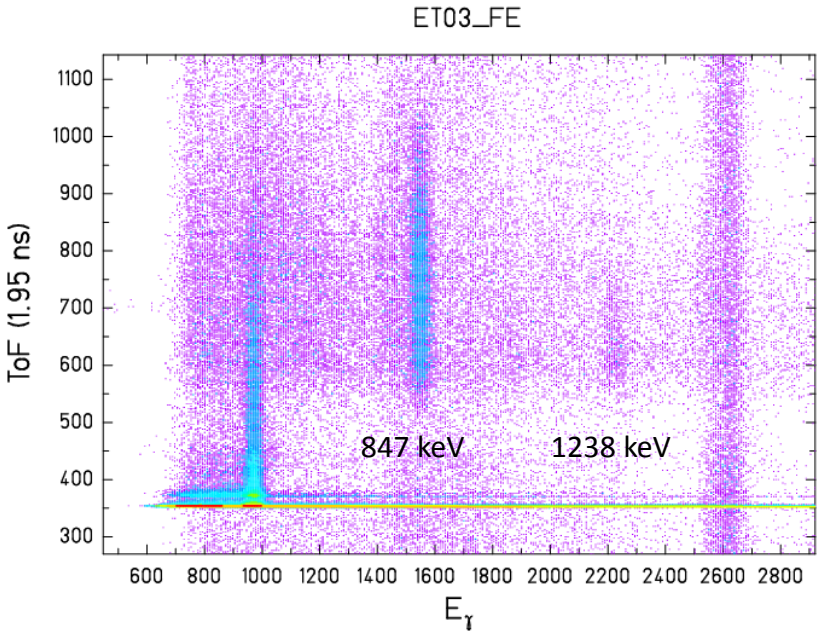
Inelastic scattering to the 2_1^+,4_1^+,6_1^+ states



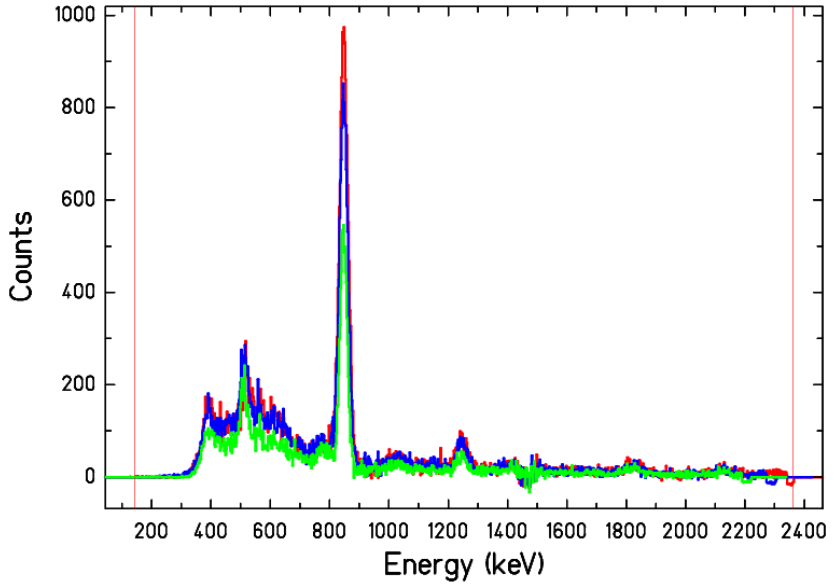
R. Beyer et al., Nucl . Phys. A. 927 (2014) 41

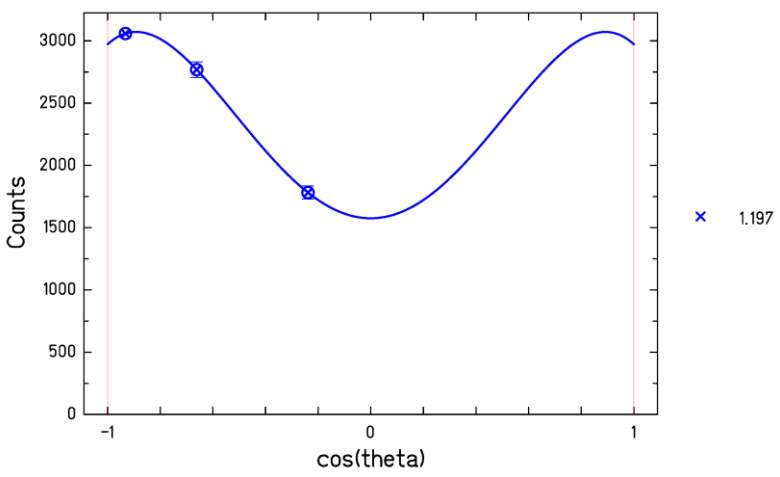
Gamma ray angular distribution setup

$^{56}Fe(n,n'\gamma)$ $LaBr_3$ spectra



Time of flight vs. energy (uncalibrated)





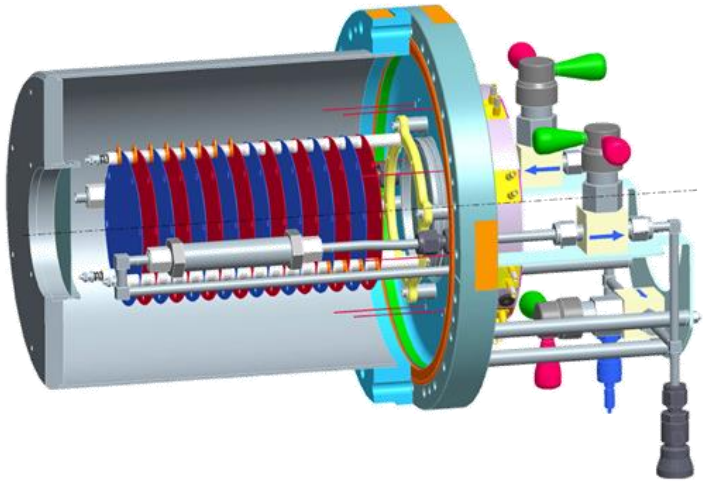
$LaBr_3$ Energy spectrum
(Target out background subtracted +
Time of flight gate for neutrons)

➔ Angular distribution measurements

Neutron induced fission experiments at nELBE

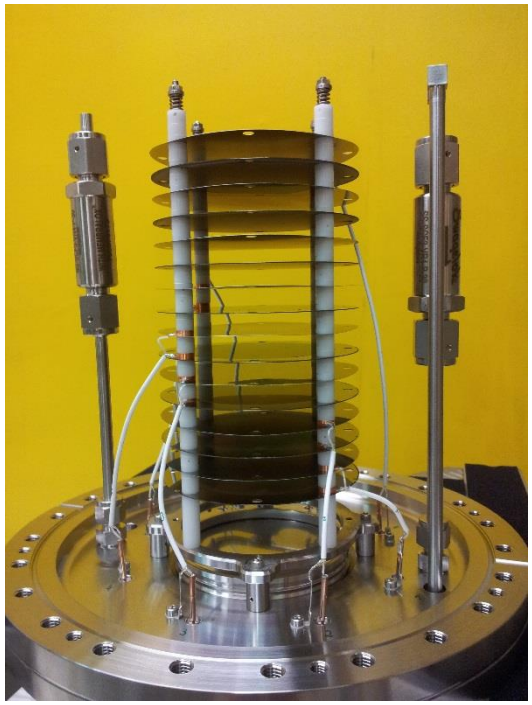
- Measurement of the ^{242}Pu neutron induced fission cross section with a parallel plate ionisation chamber relative to ^{235}U (HZDR and PTB (H19) fission chambers)

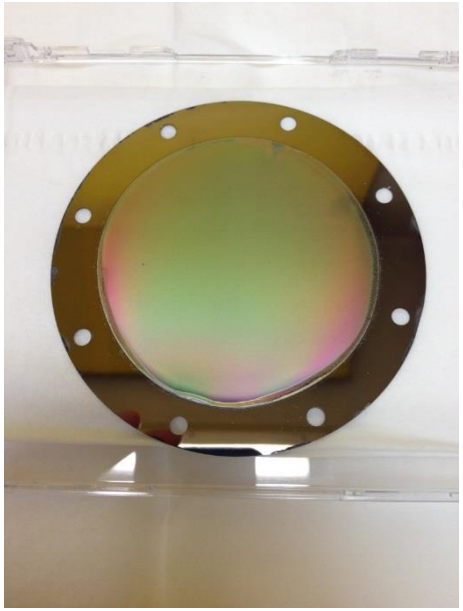
Neutron induced Fission of ^{242}Pu



- Parallel plate fission chambers high-vacuum metal sealed vessel (^{235}Uran and ^{242}Pu)
- P10 Gas flow through ultrapure gas filters

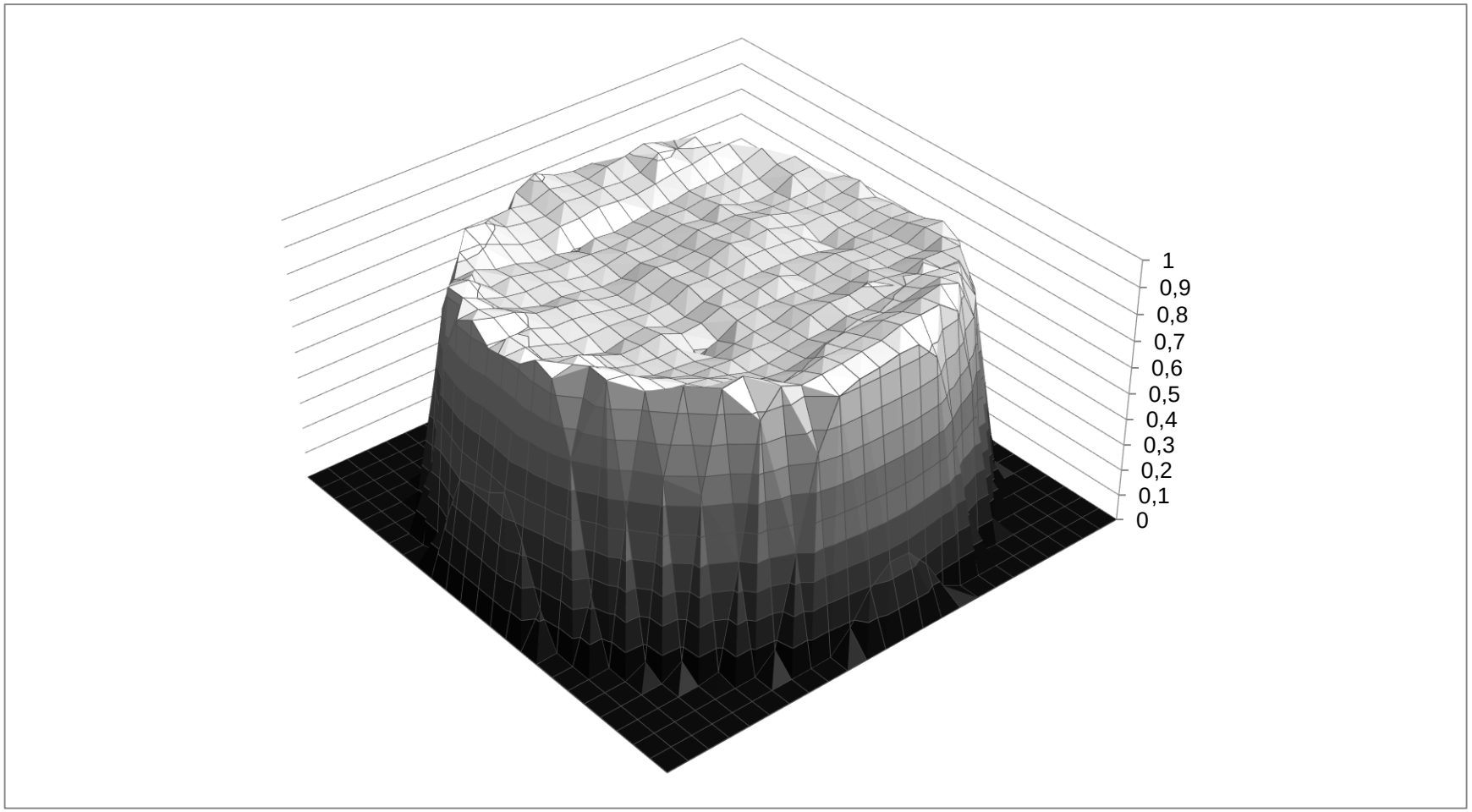
- 42.7 mg ^{242}Pu α-activity of ≈ 10 MBq distributed on 8 targets produced in Jan. 2014
→ separate readout necessary
use of fast pre-amplifiers (development of HZDR) + digital DAQ to reduce pile-up





^{242}Pu deposit 74 mm diam. Areal density ≈125 µg/cm^2
Institut für Kernchemie, Mainz

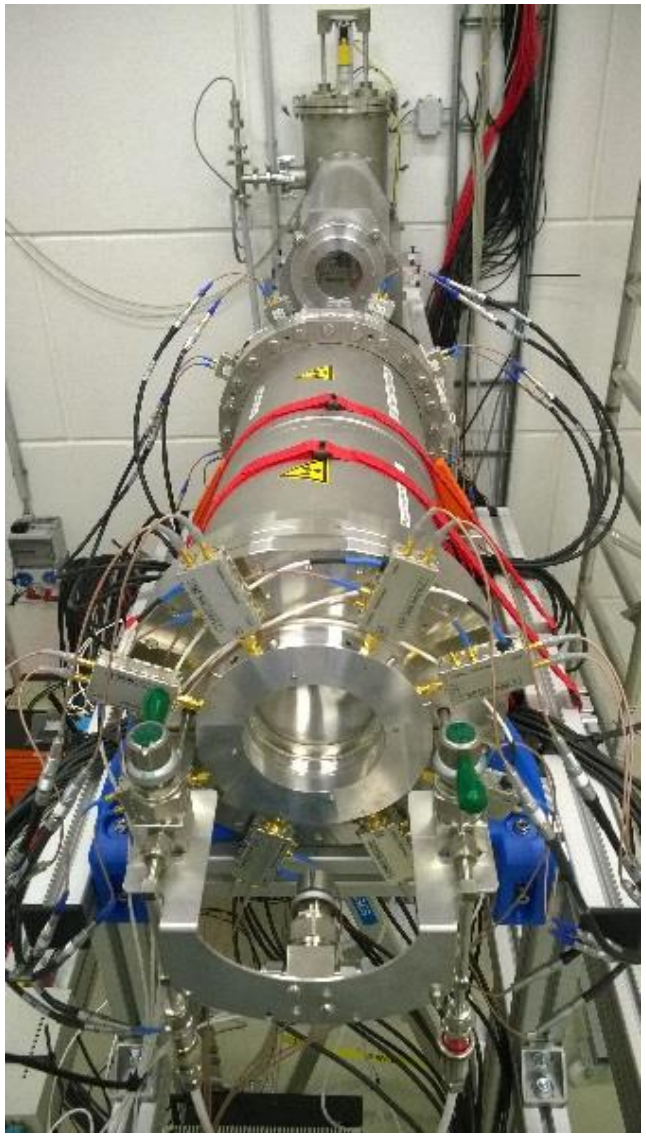
Radiographic Image ^{242}Pu deposits



Deposit #9, Diameter 74 mm, areal density ≈125 µg/cm^2

A. Vascon et al., Quantitative molecular plating of large-area 242Pu targets with improved layer properties, Submitted to Applied Radiation and Isotopes (2014)

Fission time of flight experiment

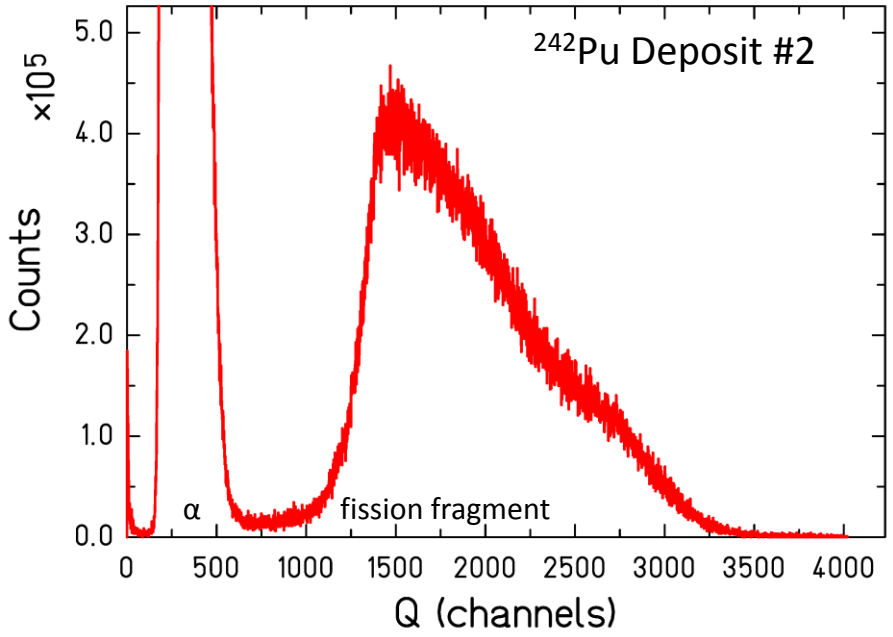


Flight path: ca. 695 cm

Listmode data acquisition for 16 channels of charge and timing information using a dual range QDC and multi-hit multi event TDC with high resolution

ELBE beam optimized for high intensity:

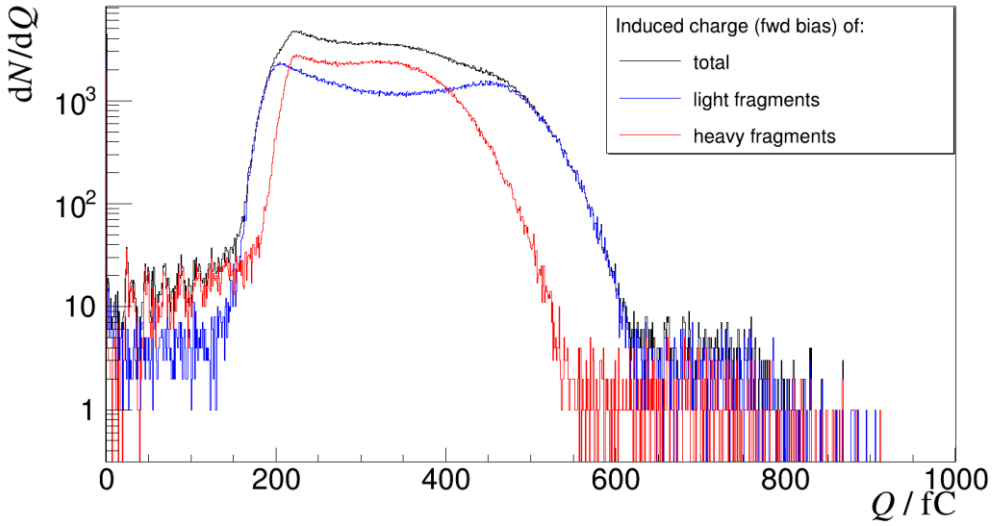
Beam energy	30 MeV
bunch charge on target	60 pC
Repetition rate	406.25 kHz

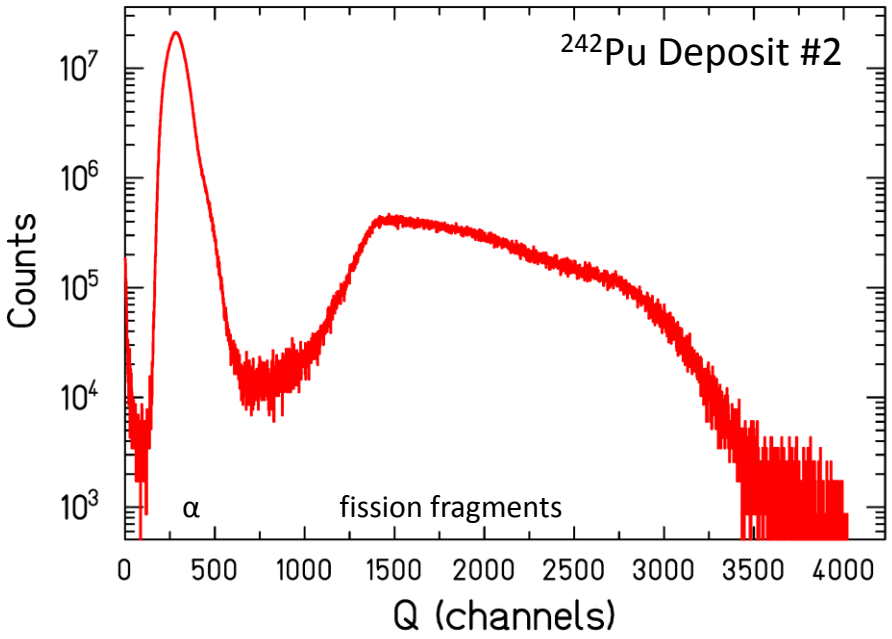


Excellent separation of fission fragment from α-signals

T. Kögler, PhD thesis in preparation

^{242}Pu Parallel-Plate Fission chamber signals





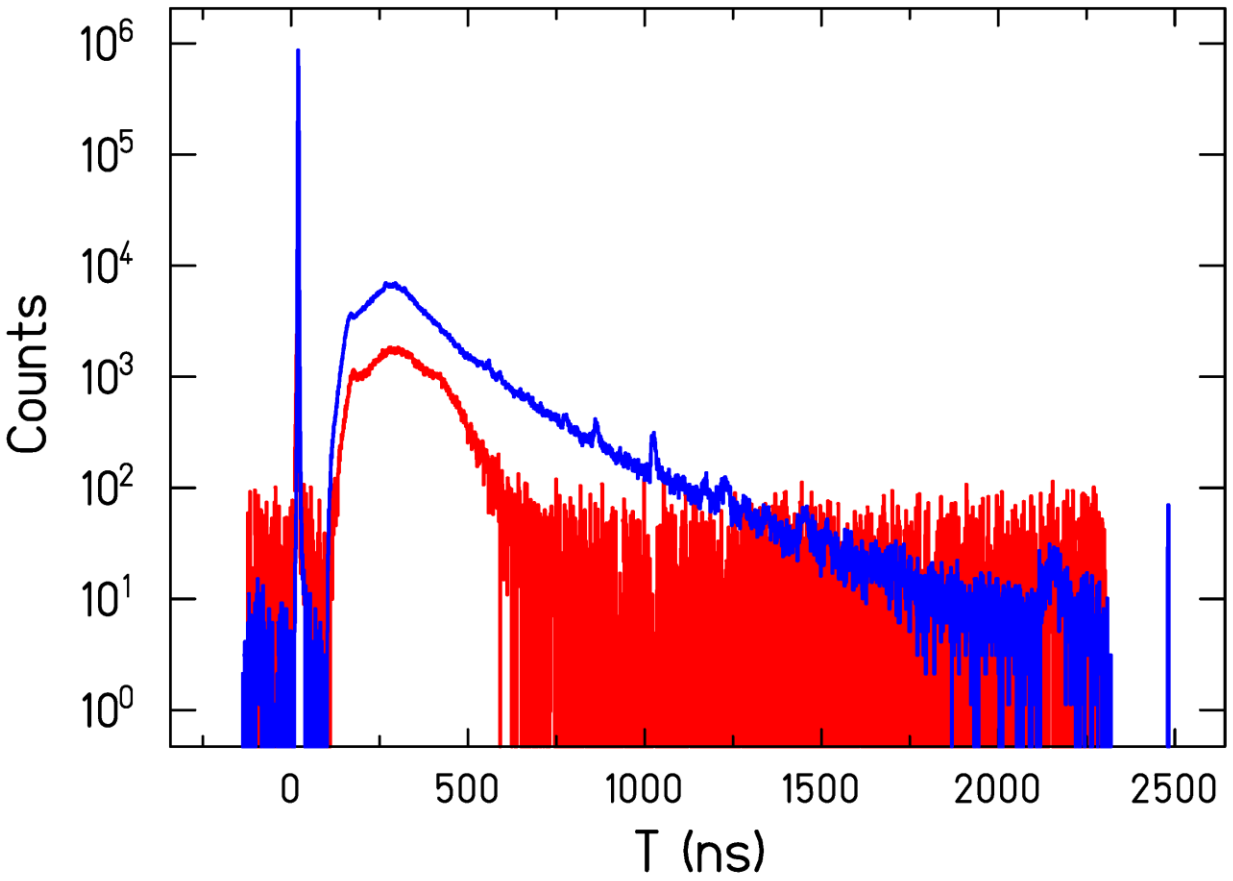
GEANT4 simulation of the induced charge on the anode

Input:

- Fission fragment (Z,A,E_{kin}) from GEF code
- Distance Anode-Cathode = 10 mm
  ➔ High energy deposit of fission fragments

- Investigation of fission fragments below detection threshold.
- Influence of deposit composition and homogeneity.

Time of flight spectra from ^{235}U and ^{242}Pu



Time resolution from photofission peak 1.7 ns (FWHM)
T. Kögler, PhD thesis in preparation

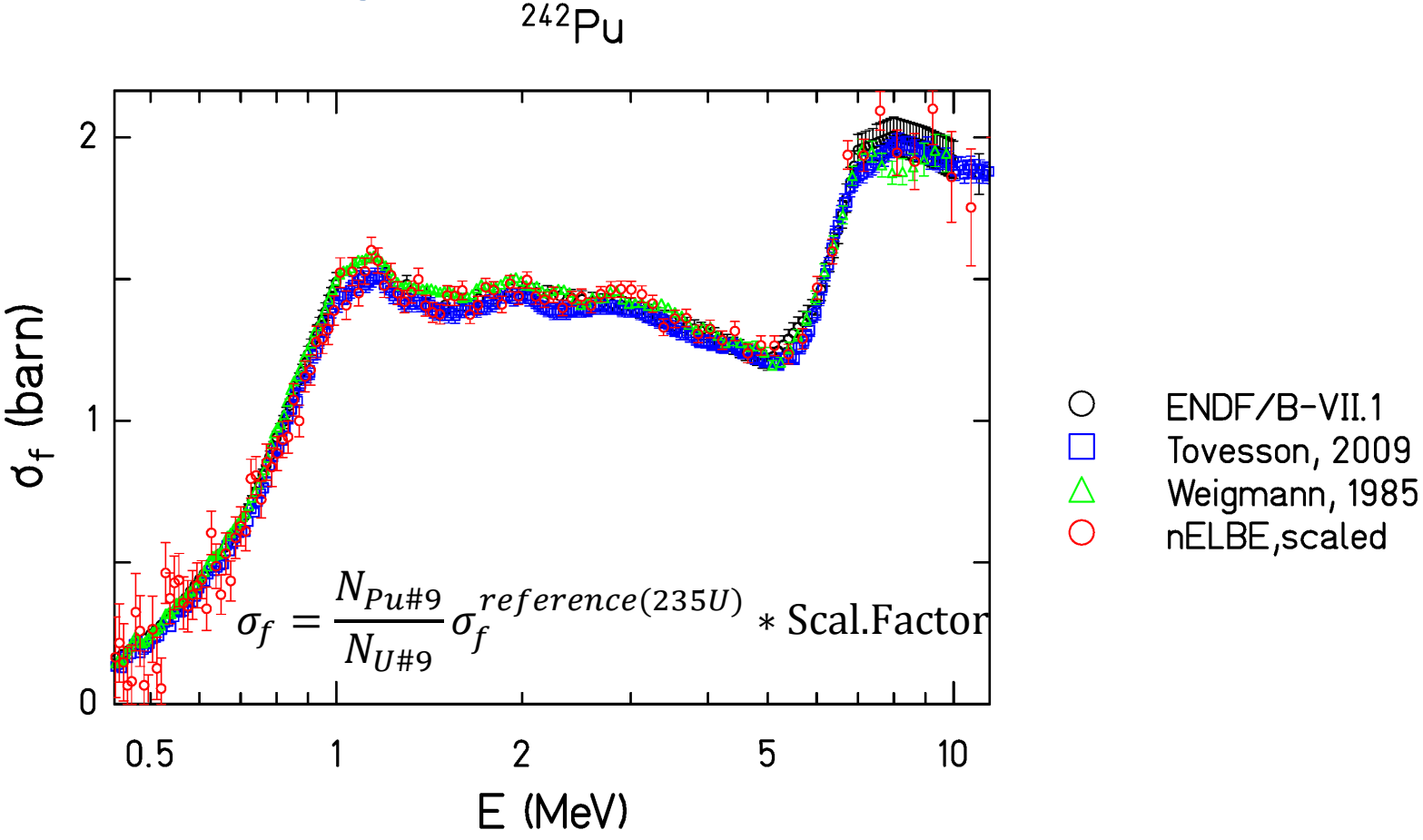
time of flight spectrum
gated on fission fragments
constant random background
subtracted (SF in ^{242}Pu)

estimated statistical
uncertainty
1.4 % for $E_n \approx 1$ MeV
with 1ns tof binning

Ongoing: Analysis of
nELBE experiment and
15 MeV n experiment at PTB

2015-16: Preparation of
Thick ^{242}Pu samples for
Neutron capture meas. at
CERN n_TOF

Preliminary relative cross section



Spectrum from ^{242}Pu deposit #9 relative to ^{235}U deposit #9 (Time-of-flight binsize 4.88 ns)
Scal. Factor to be determined by areal densities, neutron transmission.
PTB measurement at E_n=15 MeV for determination of uranium areal density

T. Kögler, PhD thesis in preparation

Summary

- Fast neutron induced reactions of relevance for nuclear transmutation and nuclear safety as well as basic nuclear physics.
  - (in)elastic scattering
  - Neutron induced fission
  - Neutron total cross sections
- nELBE is a user facility:
  External users are very welcome.

WINS 2014 Workshop on elastic and Inelastic Neutron Scattering

December 3-5, 2014

HZDR

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

WINS 2014
Helmholtz-Zentrum Dresden-Rossendorf
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Physics of Transmutation Group

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- Arnd Junghans, Daniel Bemmerer, Eckart Grosse, Klaus-Dieter Schilling, Ronald Schwengner, Andreas Wagner

- Development of the nELBE photoneutron source by Maik Partzsch, Jens Steiner, Armin Winter together with the Institute for Fluiddynamics and the Central Research Technology Group
- Mechanical construction and electronics by Manfred Sobiella, Klaus Heidel, Andreas Hartmann

1) now AREVA
2) now GSI
3) now IBA

Ende der Vortragsfolien