Neutron total cross section measurements of gold and tantalum at the nELBE photoneutron source

R. Hannaske[1,2], Z. Elekes[1], R. Beyer[1], A.R. Junghans[1], D. Bemmerer[1], E. Birgersson[1], A. Ferrari[1], E. Grosse[1,2], M. Kempe[1,2], T. Kögler[1,2], M. Marta[1], R. Massarczyk[1,2], A. Matic[1], G. Schramm[1,2], R. Schwengner[1], and A. Wagner[1]

[1] Institute of Radiation Physics, Helmholtz-Zentrum Dresden - Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany

[2] Technische Universität Dresden, 01062 Dresden, Germany

Supported by the European Commission in the projects ERINDA (FP7-269499) and EFNUDAT (FP6-036434), and by the German Federal Ministry for Education and Science (TRAKULA project, 02NUK13A).

ERINDA
European Research Infrastructures for Nuclear Data Applications

TRAKULA

Bundesministerium für Bildung und Forschung

EFNUDAT
European Facilities for Nuclear Data Measurements

Partner von DRESDEN concept exzellenz-dresden.de

HZDR
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Neutron total cross section

- fundamental data set for the evaluation of nuclear data libraries
- large sensitivity on optical model parameters in the fast neutrons energy range
- important for innovative nuclear applications

- **^{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 %

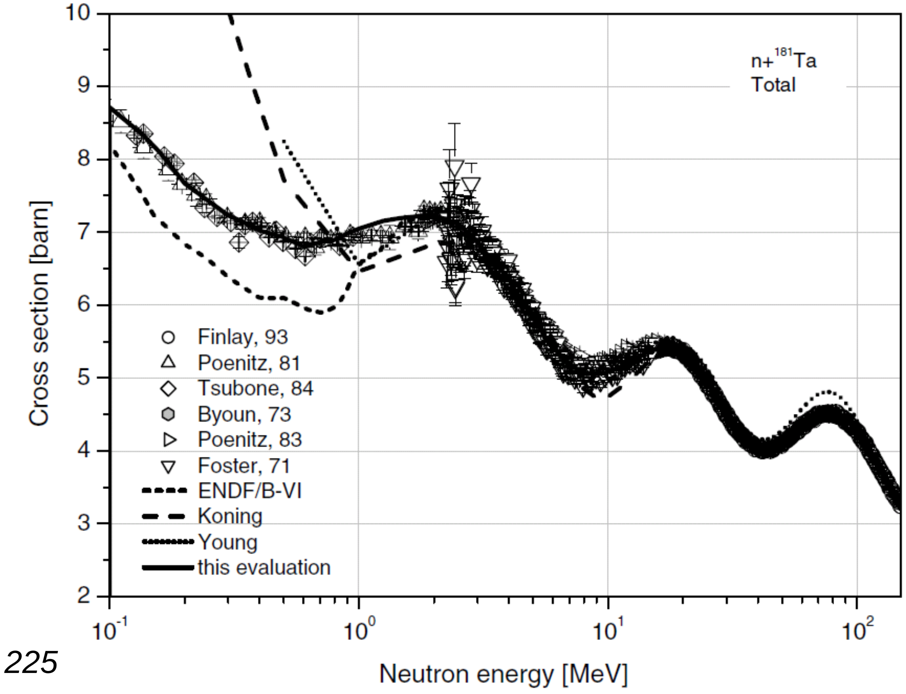
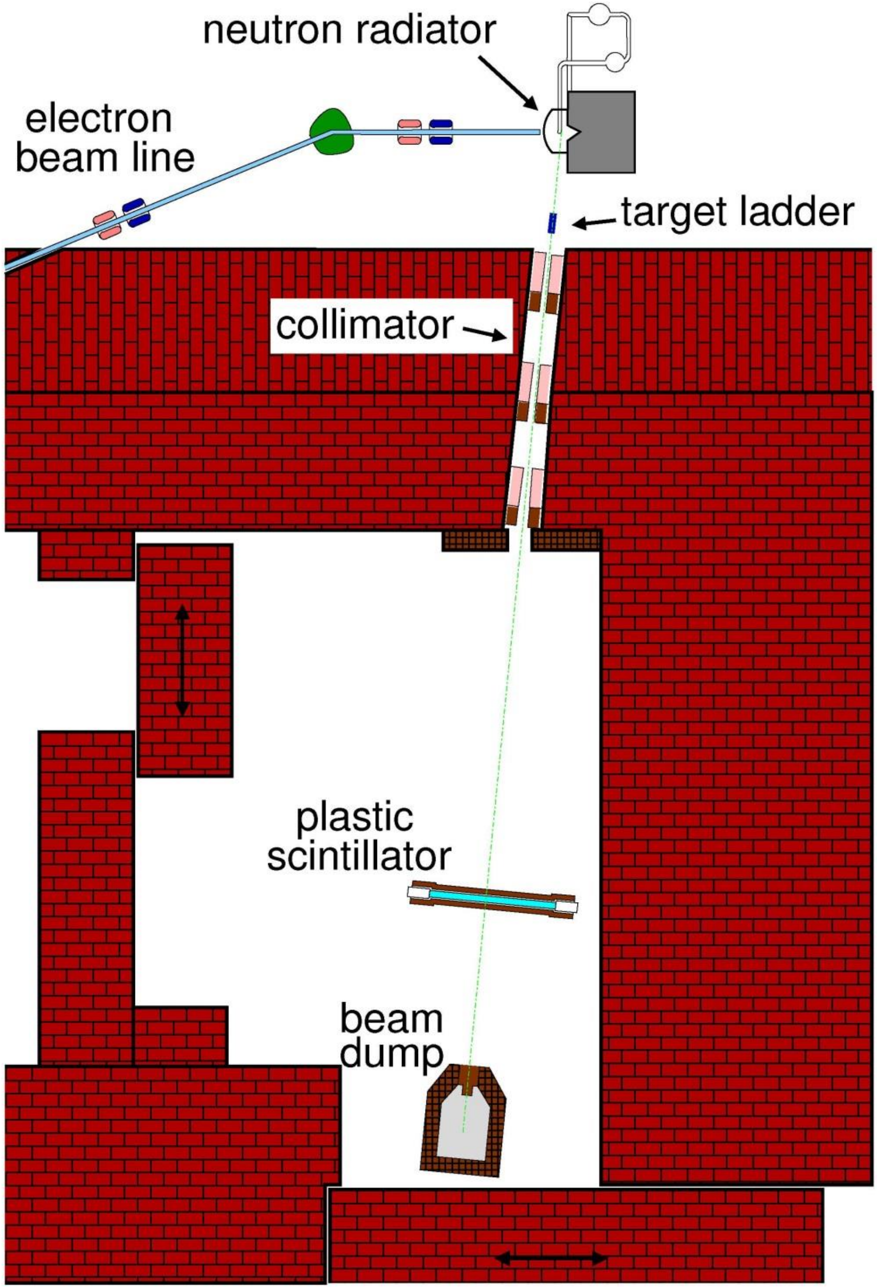


figure from Pereslavtsev and Fischer, NIM B 248 (2006) 225

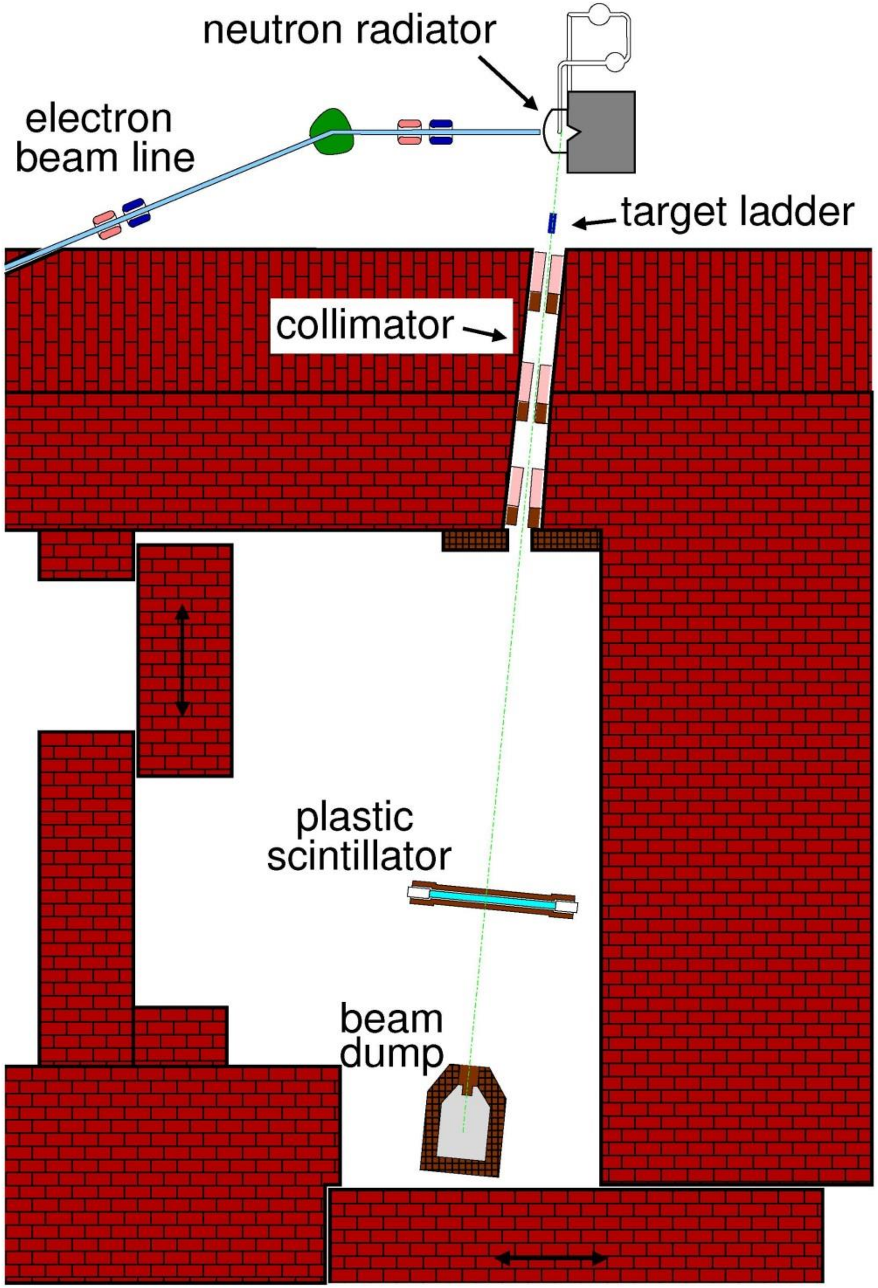


nELBE at HZDR

- world's only neutron time-of-flight facility driven by superconducting electron acc.
- compact photoneutron source (liquid lead circuit)
- experiments:
  - inelastic scattering (talk R. Schwengner)
  - fission (at new facility, talk T. Kögler)
  - transmission

electron bunch length	5 ps
repetition rate	101.6 kHz (cw)
flight path	7.175 m
neutron energy range	10 keV to 10 MeV
neutron source strength	10^{11} s^{-1}

reference ELBE & nELBE:
Gabriel et al., NIM B 161 (2000) 1143
Altstadt et al., Ann. Nucl. Ene. 34 (2007) 36
Klug et al., NIM A 577 (2007) 641
Beyer et al., NIM A 575 (2007) 449
Beyer et al., NIM A 723 (2013) 151



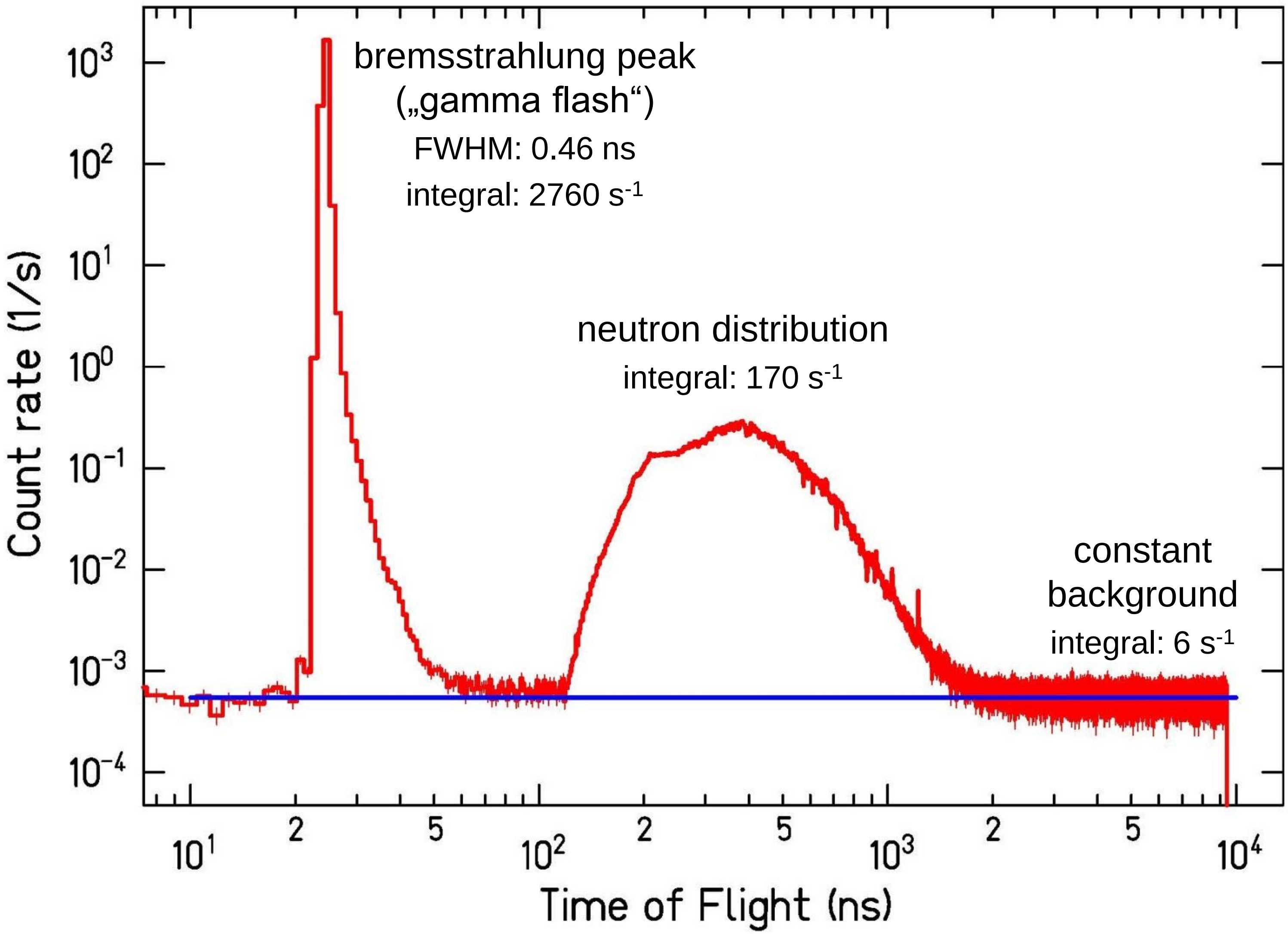
Transmission experiment

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

- target samples (Ø 2.5 – 2.6 cm):
  - ^{nat}Ta (210 g, l = 2.6 cm),
    ^{197}Au (164 g, l =1.6 cm),
    PbSb4,
    empty
  - transmission $T \approx$ 0.3 – 0.6
  - each with PbSb4 absorber (l = 3 cm)
  - periodically changed (300 – 900 s)
- neutron time-of-flight detector:
  fast plastic scintillator with low threshold
- relative measurement:
  efficiency / neutron flux not needed
- “effective” cross section from trans-
  mission averaged over energy resolution

Transmission experiment

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



Data analysis

- subtraction of constant random background
  - ➔ dominated by beam-off background
  - ➔ reduced by using position information
  - ➔ only very small dependence on fitting time interval
  - ➔ contributes with 0.2 % to the systematic uncertainty of the cross section

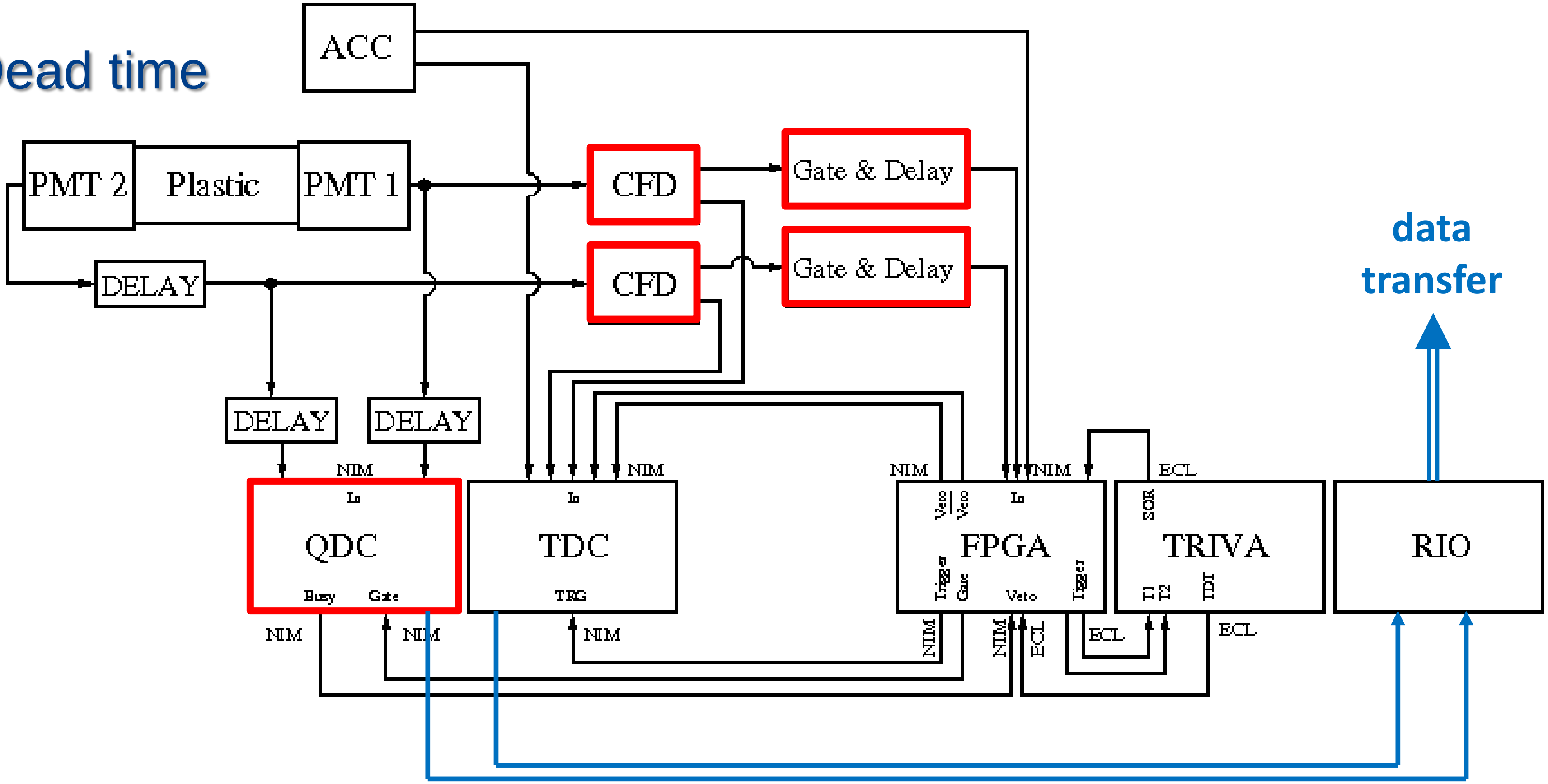
- inscattering of neutrons
  - ➔ negligible (minimized by geometry of setup)

- resonant self shielding
  - ➔ negligible above 100 keV (overlapping resonances)

- correction for a time-of-flight dependent dead time
- neutron beam intensity fluctuations

Member of the Helmholtz Association
Roland Hannaske | Institute of Radiation Physics | www.hzdr.de

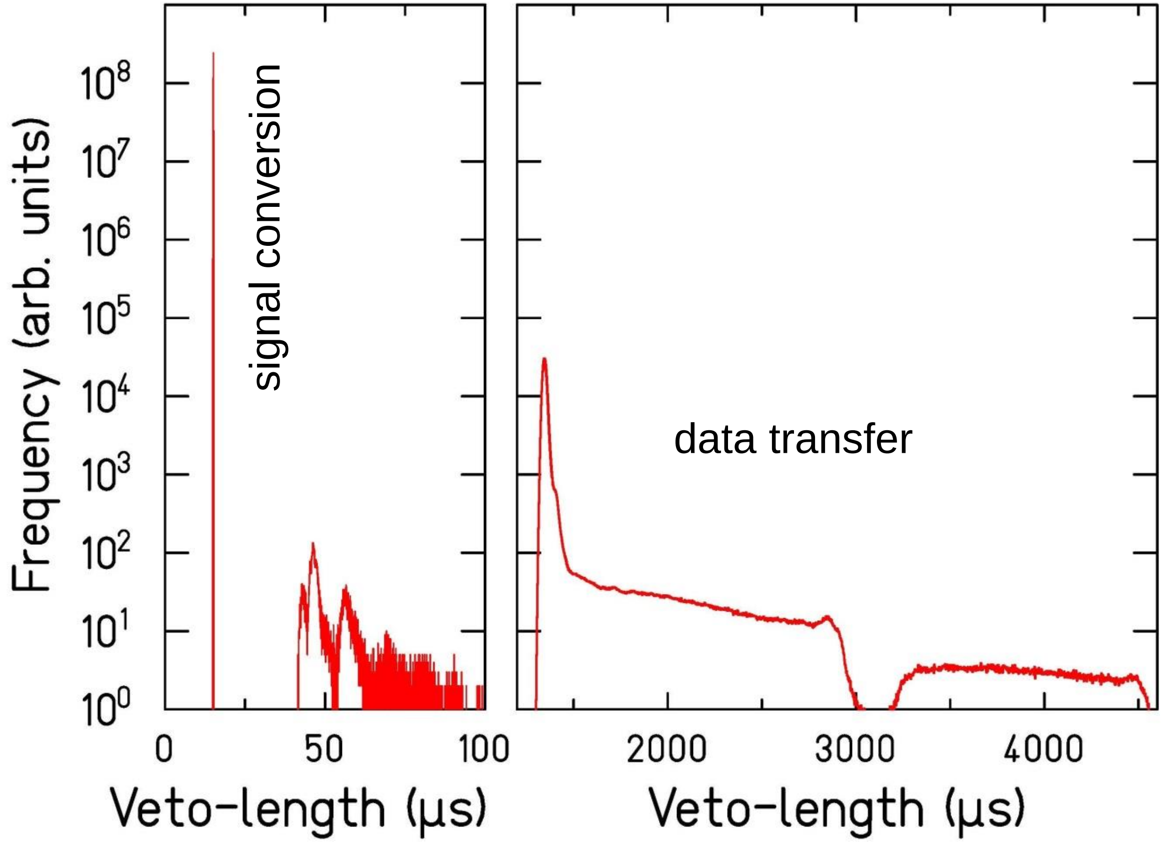
Dead time



(veto) length	module	purpose	frequency
30 – 60 ns	Gate & Delay	trigger generation	coincidence PMT 1 and 2
2.7 µs	CFD	afterpulse suppression	PMT signal (up to $2x10^4$ s^{-1})
15 µs	QDC	signal conversion	trigger (up to 10^4 s^{-1})
0.8 – 5 ms		data transfer	after 31 triggers

Dead time

- veto length measured for each event with 25 ns resolution

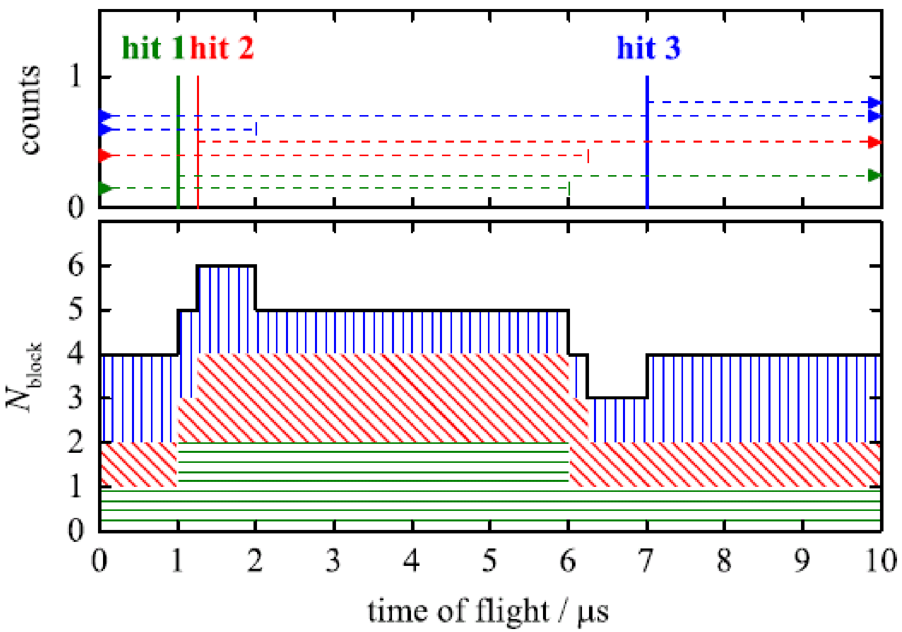


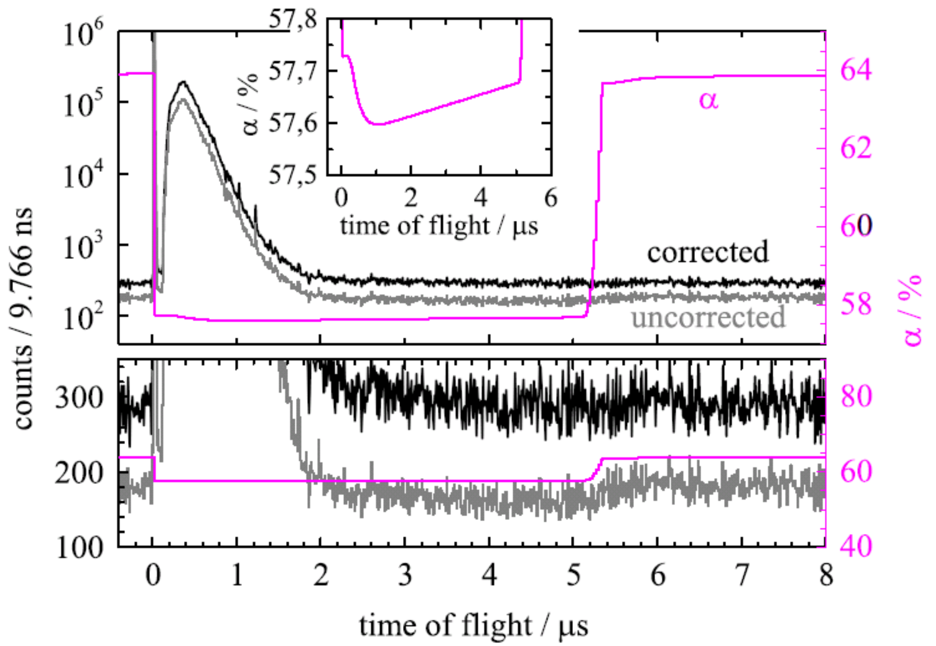
(veto) length	module	purpose	frequency
30 – 60 ns	Gate & Delay	trigger generation	coincidence PMT 1 and 2
2.7 µs	CFD	afterpulse suppression	PMT signal (up to $2x10^4$ s^{-1})
15 µs	QDC	signal conversion	trigger (up to 10^4 s^{-1})
0.8 – 5 ms		data transfer	after 31 triggers

Time-of-flight dependent dead-time correction

figures from Beyer et al., NIM A 723 (2013) 151

- veto start and duration measured
- How often (N_{block}) a time-of-flight channel (i) was blocked relative to all accelerator pulses (N_{acc})?
- truly happened events (N_{real}) as function of number of registered events (N_{live}), α and variation of beam intensity (σ)

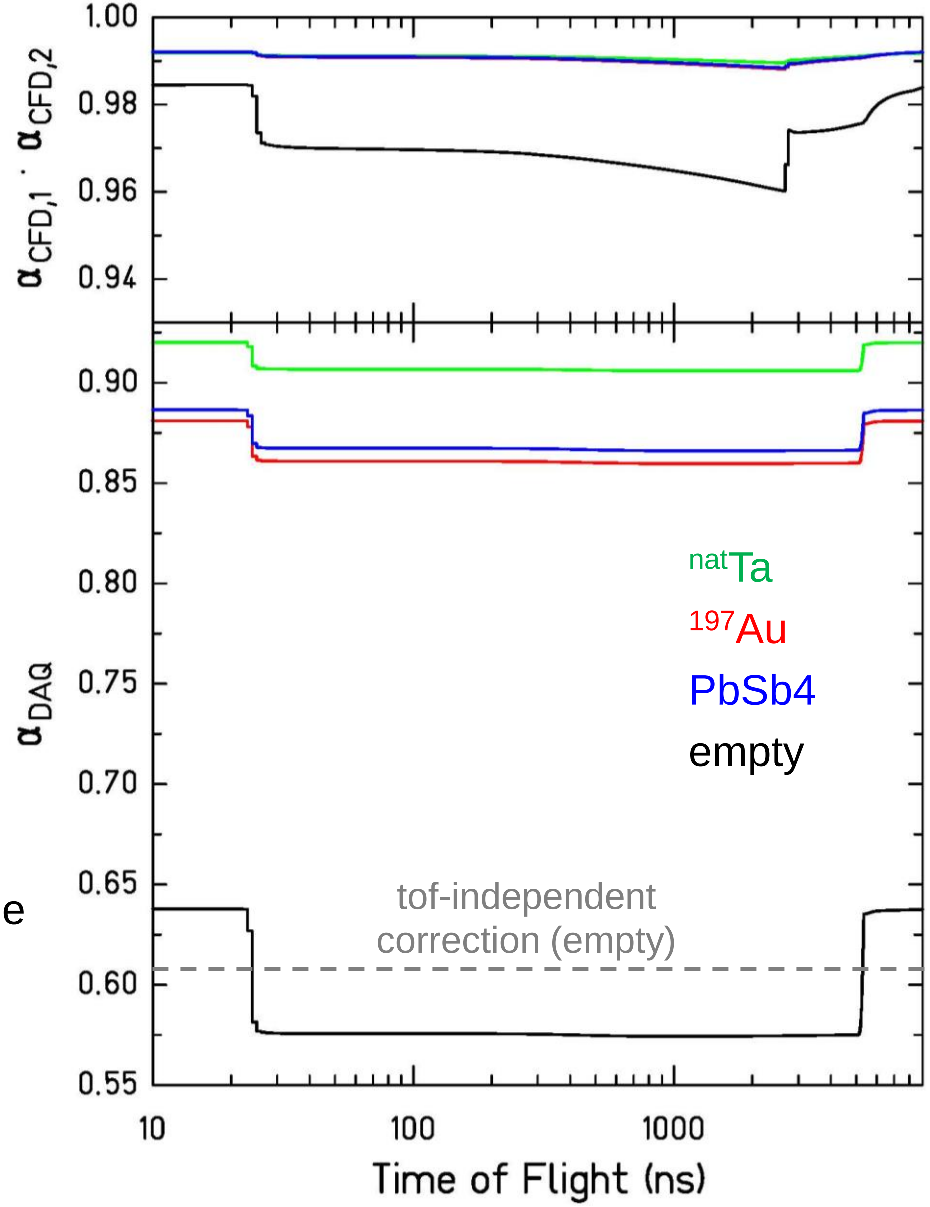




$$\alpha(i) = 1 - \frac{N_{block}(i)}{N_{acc}} \qquad N_{real}(i) = \frac{N_{live}(i)}{\alpha_{CFD,1}(i) \cdot \alpha_{CFD,2}(i) \cdot \alpha_{DAQ}(i) \cdot \{1 - \sigma \tanh(\sigma[1 - \alpha_{DAQ}(i)])\}}$$

Time-of-flight dependent dead-time correction

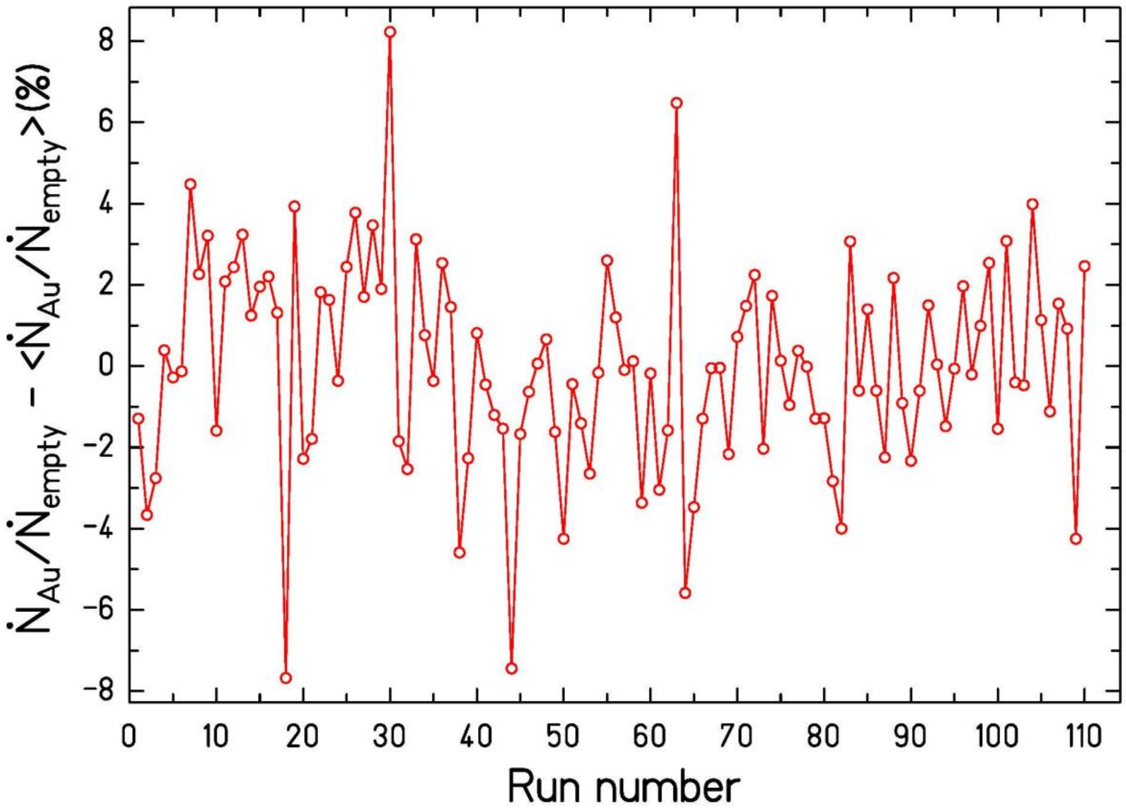
- significant deviation from tof-independent correction
- $\sigma \tanh(\sigma[1-\alpha_{DAQ}(i)])$ < 0.3 % corrects beam intensity variation (σ = 0.075) *[Moore, NIM 169 (1980) 245]*
- α_{DAQ} calculated from all events: negligible contribution to uncertainty of cross section
- $\alpha_{CFD,1} \cdot \alpha_{CFD,2}$ of empty sample contributes with 0.8 % to uncertainty of cross section due to extrapolations
- new electronic setup with less dead time (see outlook)



$$\alpha(i) = 1 - \frac{N_{block}(i)}{N_{acc}} \qquad N_{real}(i) = \frac{N_{live}(i)}{\alpha_{CFD,1}(i) \cdot \alpha_{CFD,2}(i) \cdot \alpha_{DAQ}(i) \cdot \{1-\sigma \tanh(\sigma[1-\alpha_{DAQ}(i)])\}}$$

Neutron beam intensity fluctuations

- transmission measurements need stable beam
- periodic target changes (300 – 900 s)
- fluctuations of count rate ratios have rel. standard deviation of 2.6 %



- different accumulation modes (all runs, average of groups of 5 runs): cross sections agree to < 0.5 %

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

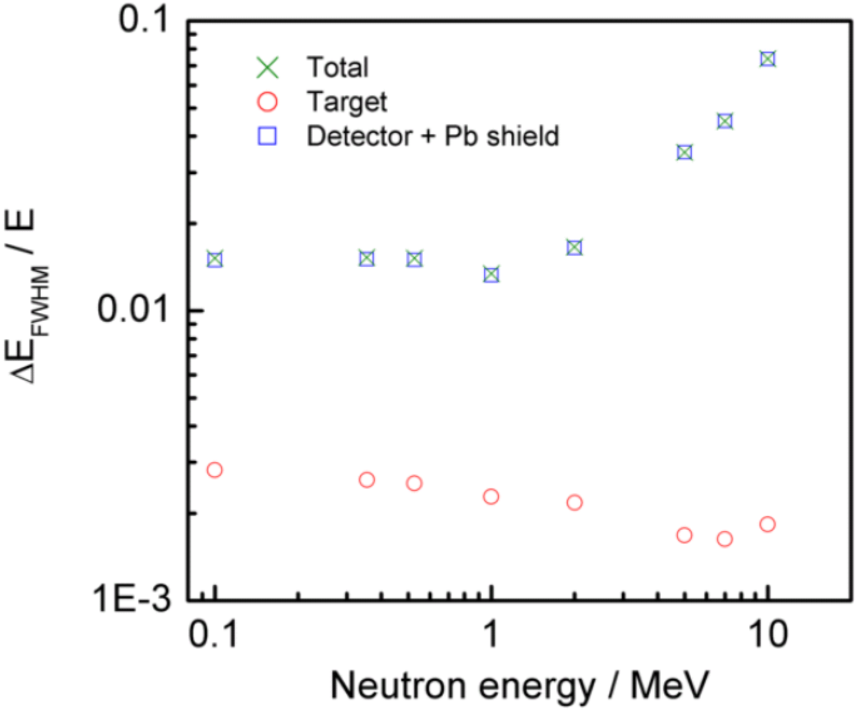
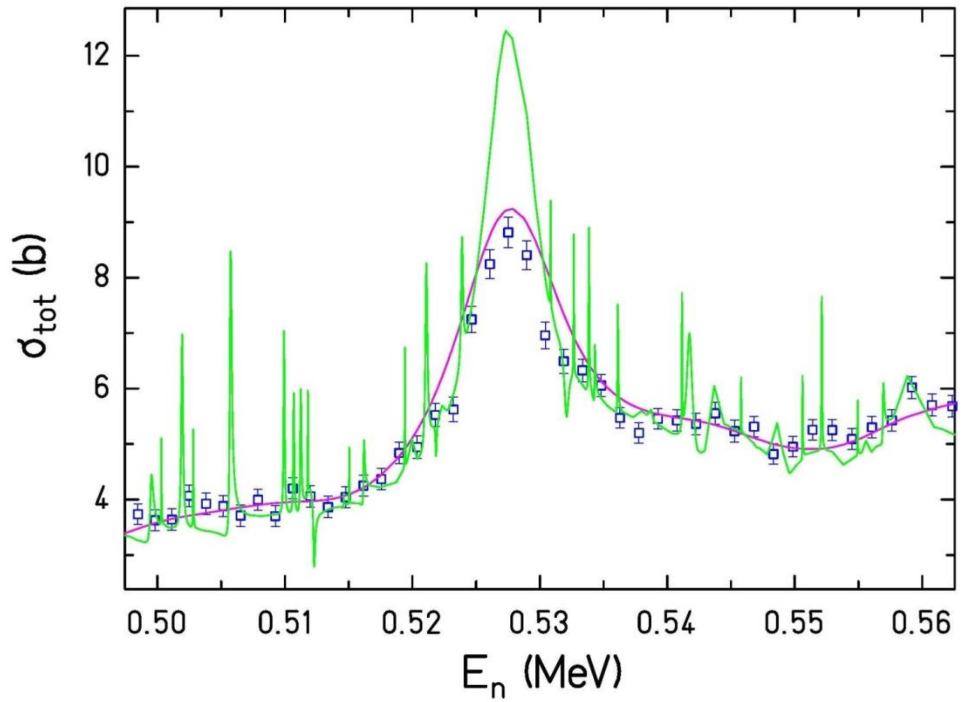


figure from Schillebeeckx et al., NDS 113 (2012) 3054

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

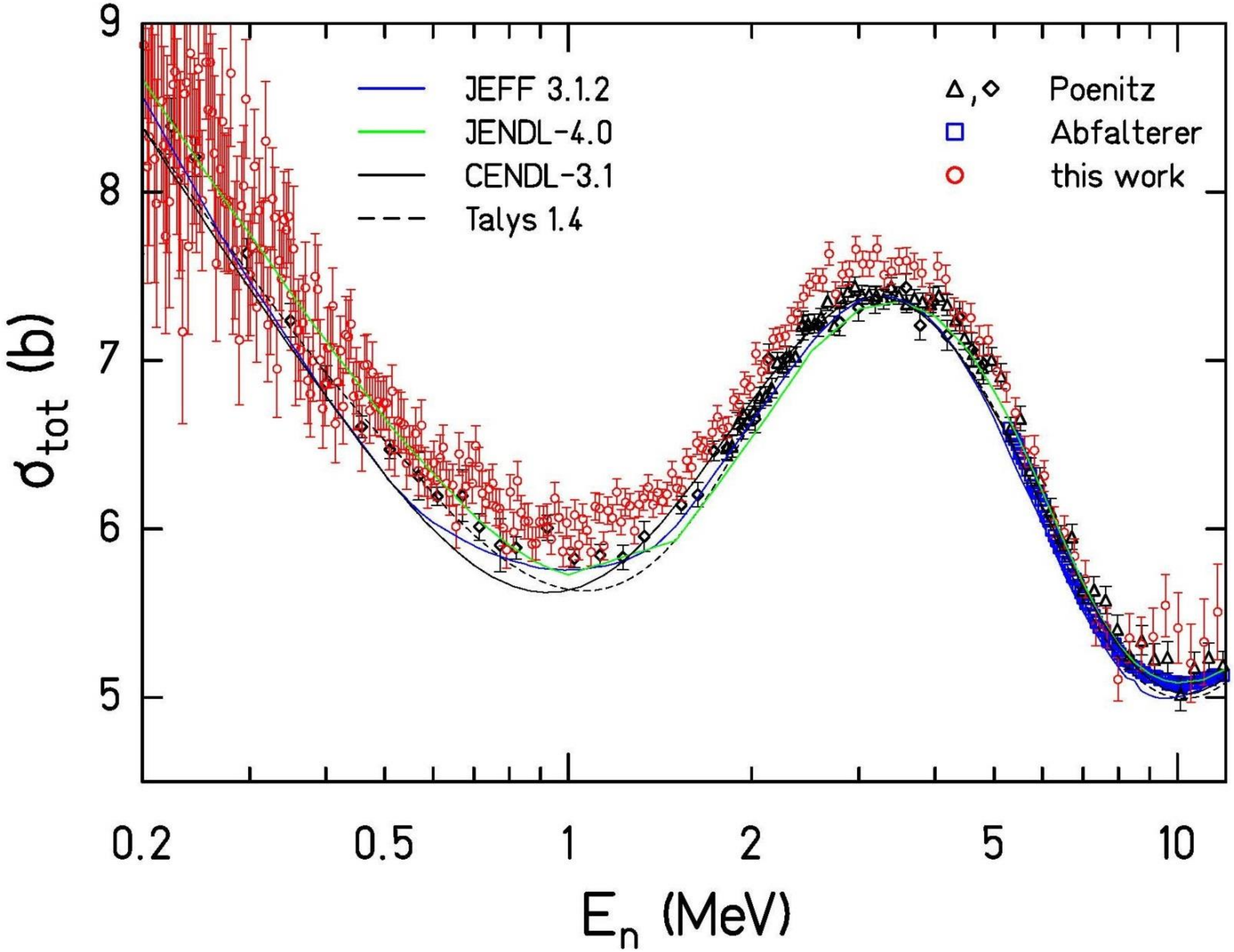


Experimental uncertainties of neutron total cross section

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 %			

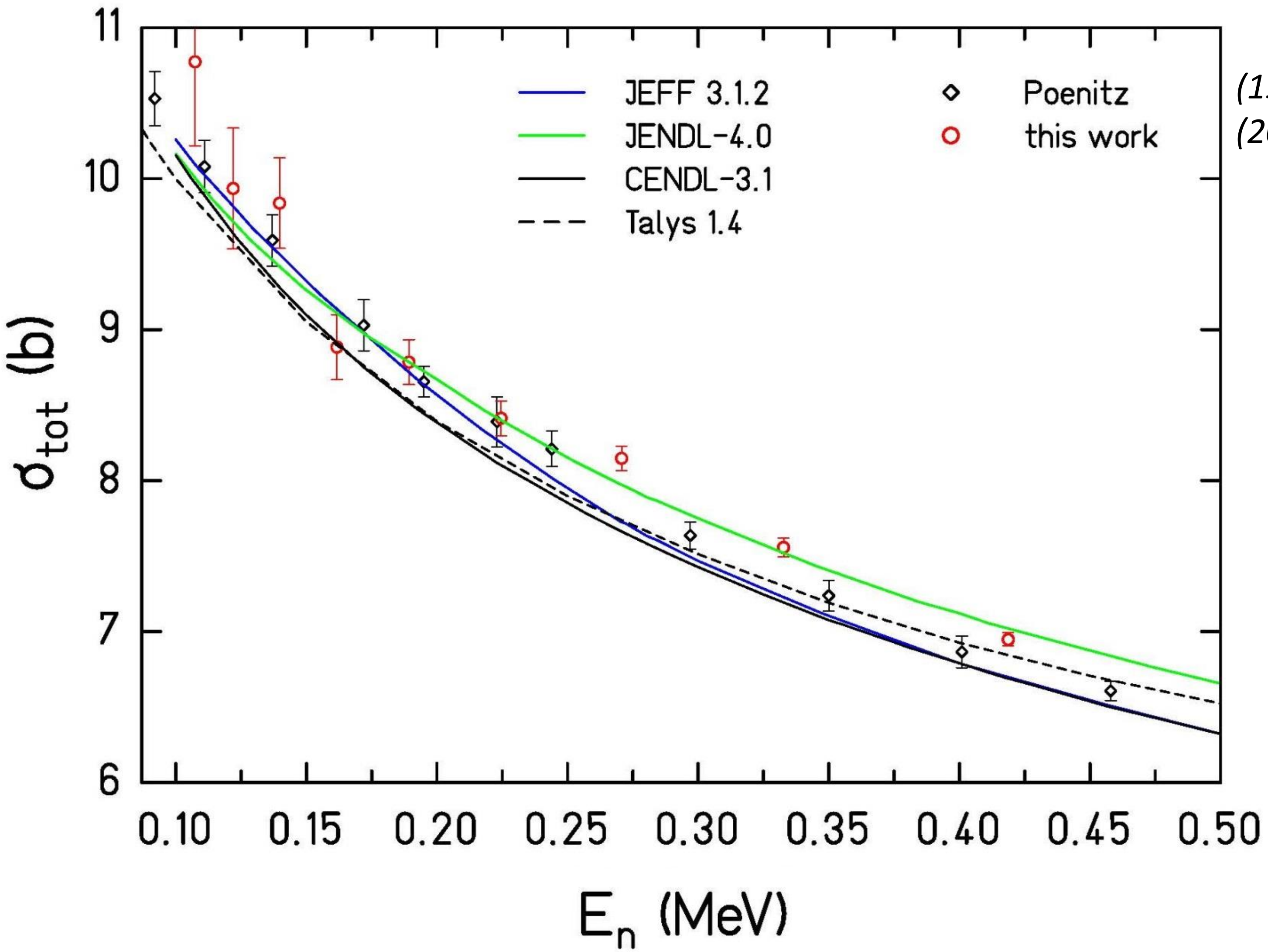
** rebinned data*

Results ^{197}Au



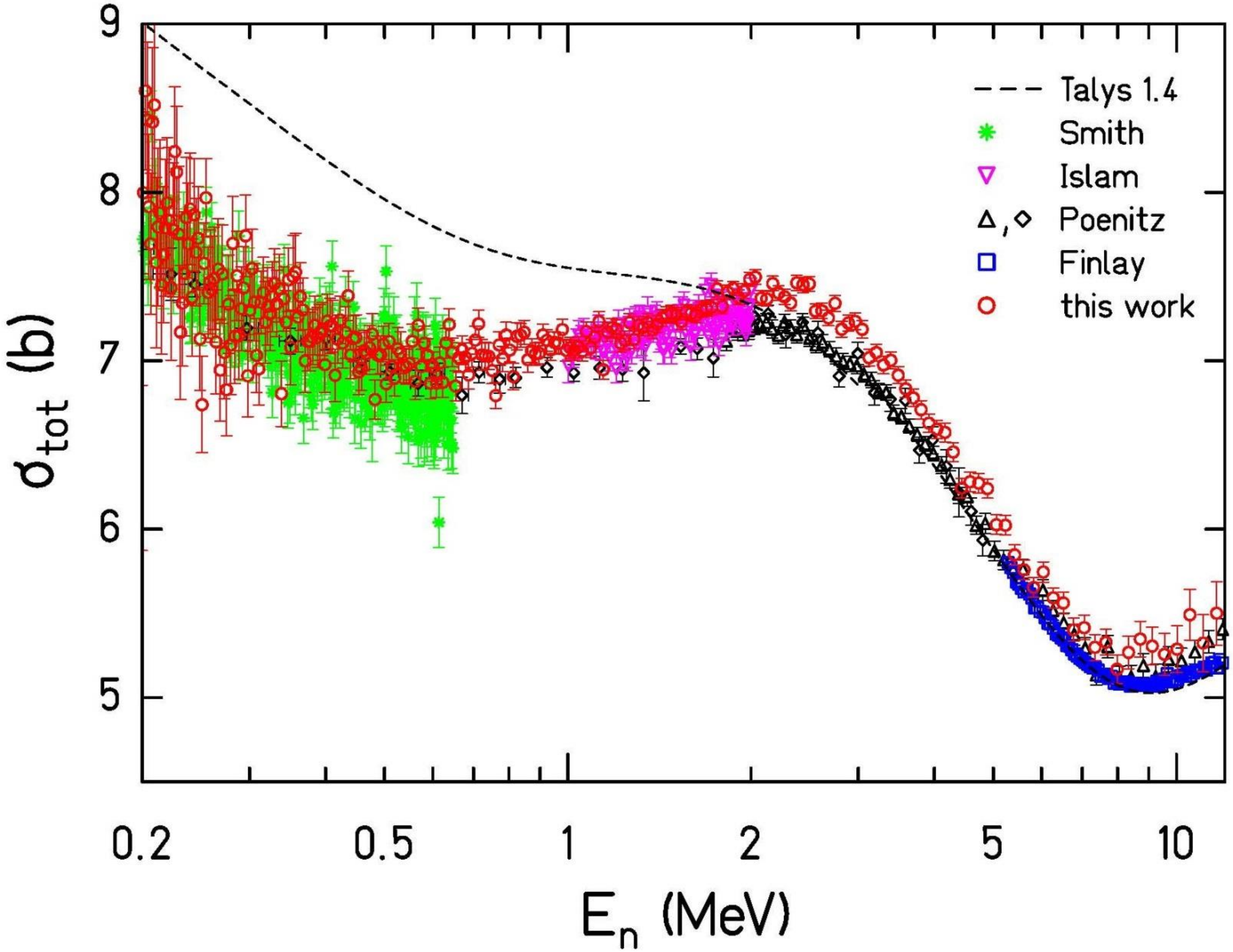
(1983 ANL)
(2001 LANL)
(2013 nELBE)

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



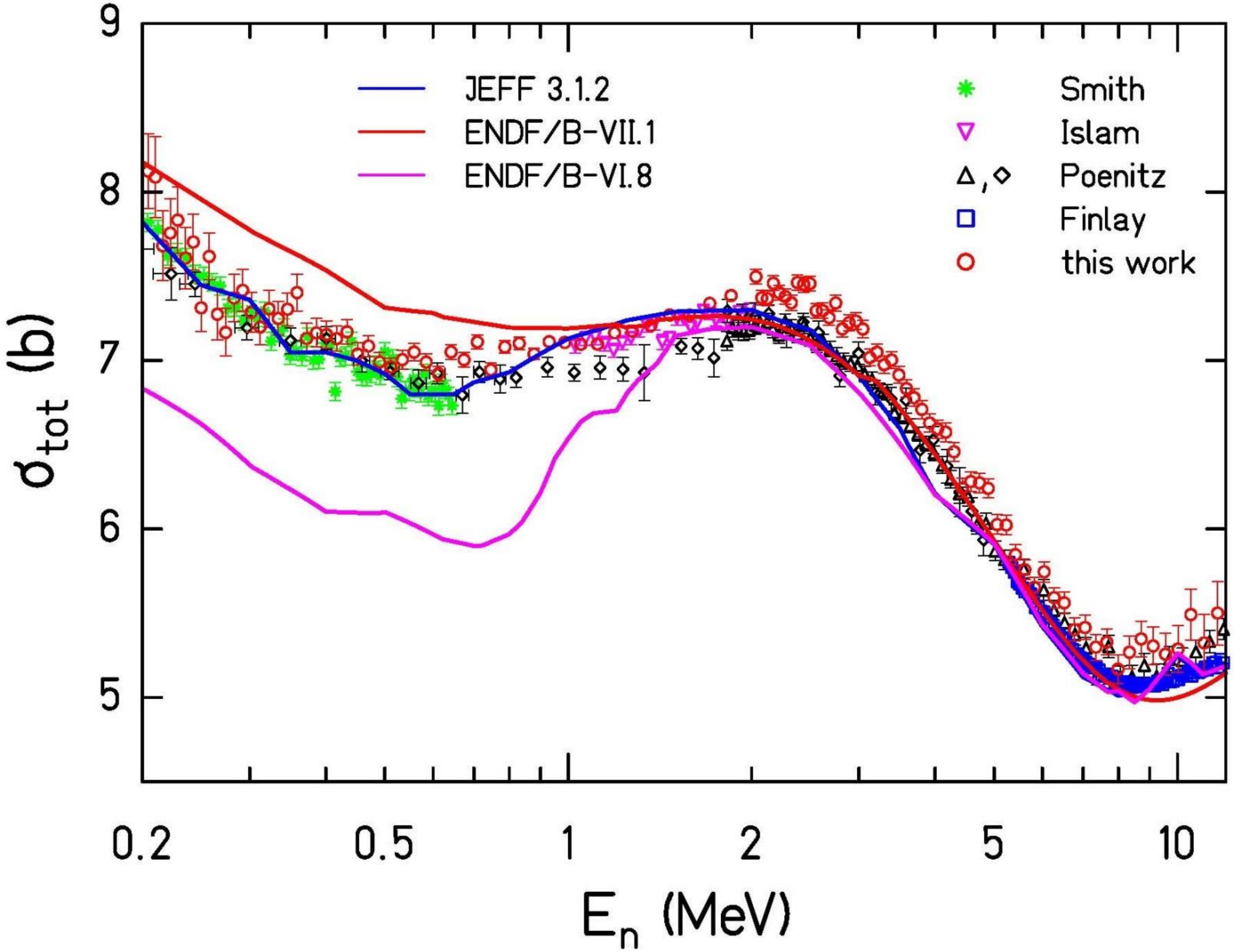
(1983 ANL)
(2013 nELBE)

Results ^{nat}Ta



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

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



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

Summary

- neutron total cross sections of ^{197}Au and ^{nat}Ta have been measured at nELBE
    - energy range from 0.1 – 10 MeV
    - statistical uncertainty of up to 2 %
    - total systematic uncertainty of 1 %
    - very different beam and background conditions than found at other facilities
- nELBE data systematically higher than most other experiments
    - ^{197}Au: ≈ 2 %
    - ^{nat}Ta: ≈ 3 %
- submitted to Eur. Phys. J. A

Outlook: new electronic setup

- inputs: two PMTs of one single plastic scintillator and the accelerator reference
- fast QDC (6 µs busy time instead of 15 µs) and high resolution TDC (25 ps)
- dedicated FPGA trigger and veto logic

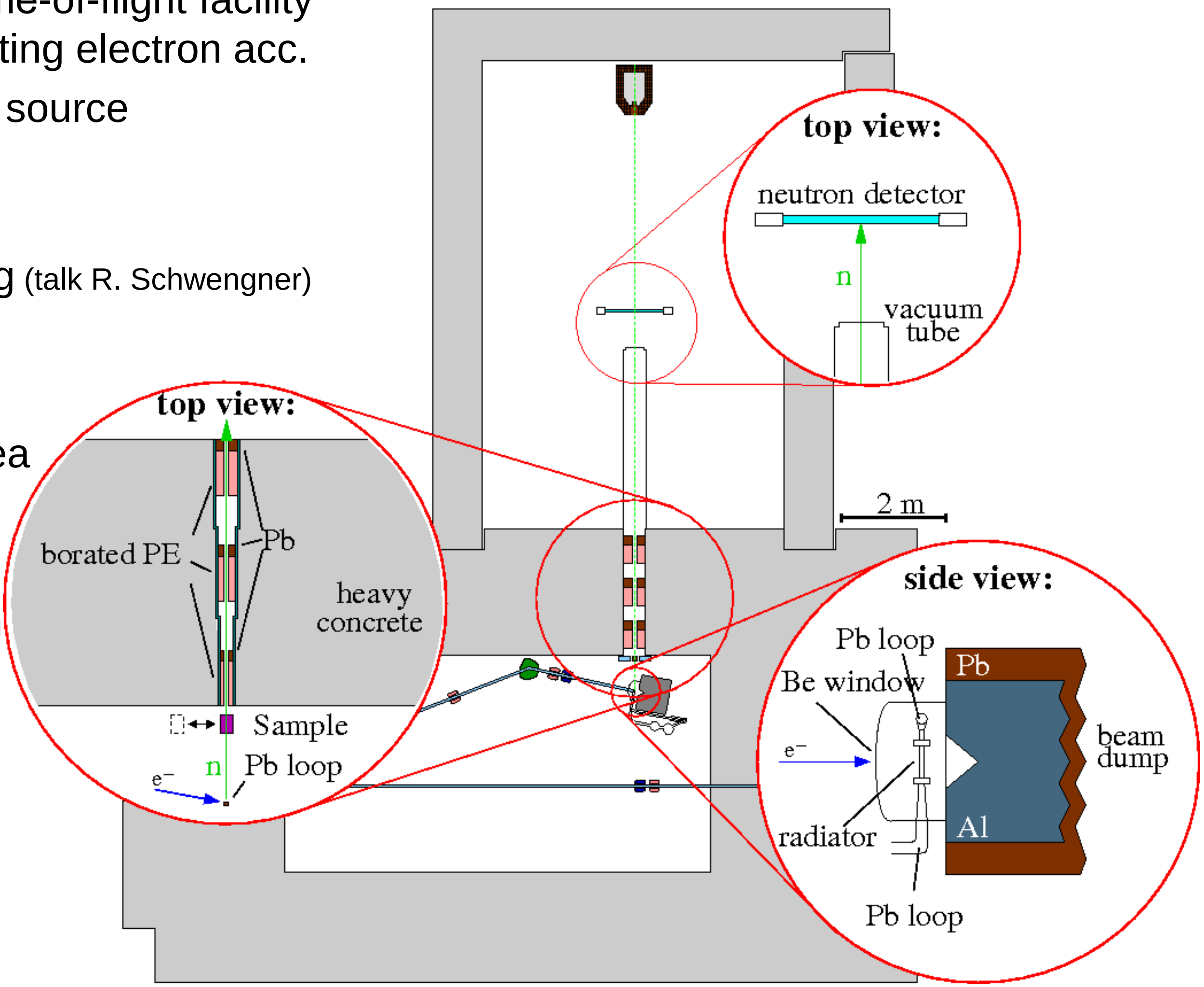
- different acquisition modes possible:
  1. keep correlation between QDC and TDC events,
     veto length = QDC busy & readout time & trigger width
  2. ignore QDC-TDC-correlation, veto length = readout time & trigger width
  3. measure during readout, veto length = trigger width
  4. continuous storage mode, no veto

- first tests at new nELBE facility with detector coincidence rate of 22000 s^{-1}

mode	events / readout	TDC words / readout	trigger rate in 1000 s^{-1}	readout rate in s^{-1}	data rate in kbit/s	t_{live}/t_{real}
1	31	580	8.5	277	7580	0.616
2	1024	19800	10.4	10	7860	0.738
3	1024	19800	13.5	13	10120	0.959
4		24100		19	14580	1

Outlook: new nELBE facility

- world's only neutron time-of-flight facility driven by superconducting electron acc.
- compact photoneutron source (liquid lead circuit)
- experiments:
  - inelastic scattering (talk R. Schwengner)
  - fission (talk T. Kögler)
  - transmission
- larger experimental area
- first beam in August 2013
- plans for sharing beam with low-frequency experiments



Outlook: new nELBE facility

Thank you for your attention!