Perspectives on Measurements of Prompt Fission Neutron Spectra for Fission Induced by Fast Neutrons

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Perspectives on measurements of prompt fission neutron spectra

- Spontaneous fission (^{252}Cf)
- Neutron-induced fission
  - Thermal neutron-induced fission
  - **Fast neutron-induced fission**

Components for neutron-induced PFNS measurements

- Experiments
  - Neutron source – **intense, low background neededs**
  - Detectors – **good neutron identification (psd or ?), good efficiency, "modelable" in MCNP, GEANT, …**
  - Data acquisition – implementation of new hardware, firmware, software – **good resolution, good timing, programmable, capable of handling high counting rates**
- Modeling neutron transport as corrections to literature data, and design and analysis of new experiments

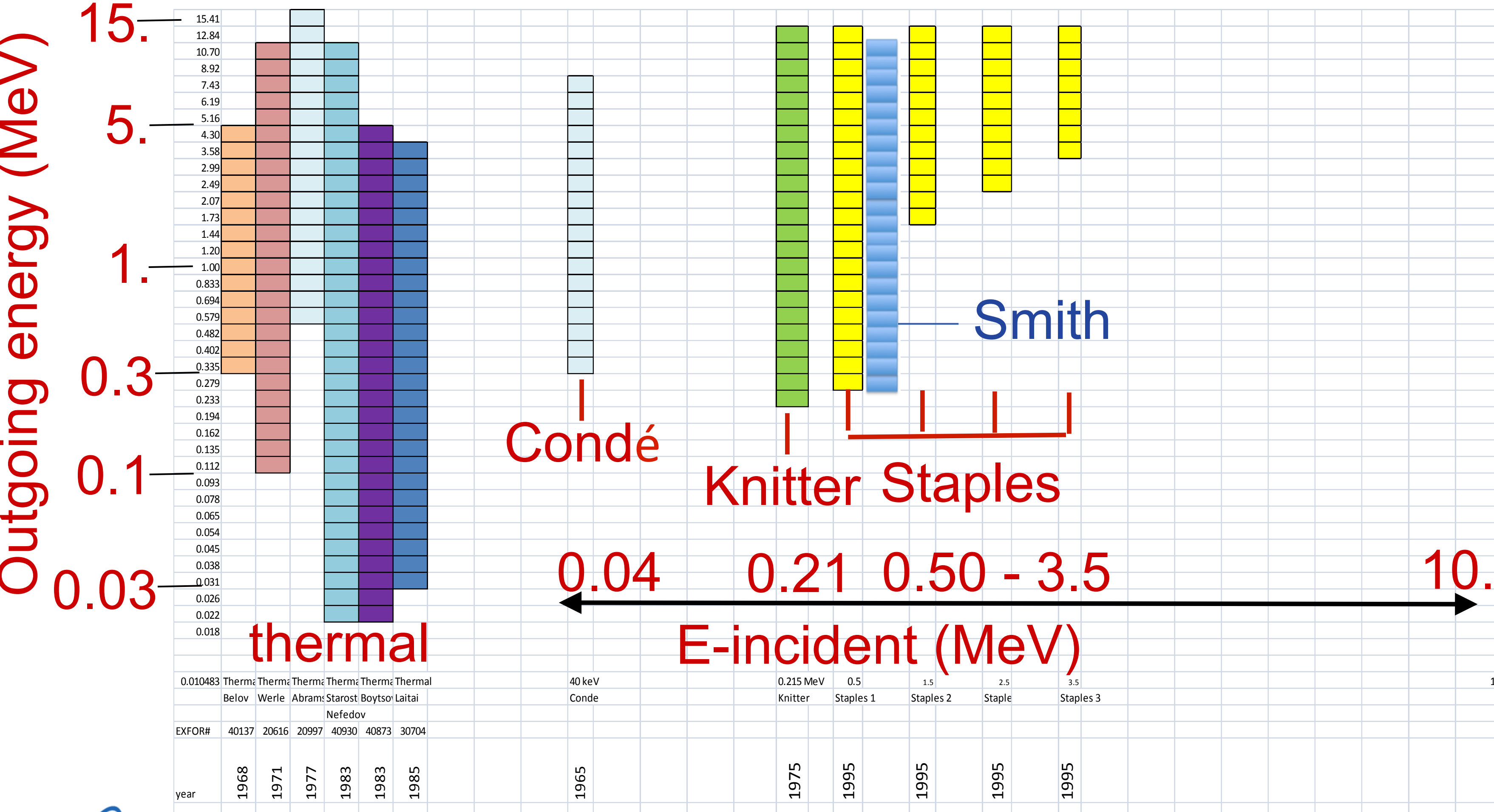
Predictions for PFNS measurement technologies

- Experiments
  - Neutron source – **intense, low background needed** -- **no new facilities for this type of measurement (?) :- (**
  - Detectors – **good neutron identification (psd or ?), good efficiency, "modelable" in MCNP, GEANT …** -- **nothing for greatly advanced capabilities :- (,:-)**
  - Data acquisition – implementation of new hardware, firmware, software – **good resolution, good timing, programmable, capable of handling high counting rates** -- **In progress :-)**
- Modeling neutron transport as corrections to literature data, and design and analysis of new experiments-- **NOW and continuing :-)** ★ ★ ★ ★

Predictions for PFNS measurements – work to be done

- ^{239}Pu(n,f) – for incident neutron energies > 0.5 MeV and to requested accuracy
  - Resolve discrepancies for PFNS > 0.5 MeV – probable in 2-3 years
  - Produce new data for PFNS in range 0.05 to 0.50 MeV -- maybe in 3-4 years
- ^{235}U(n,f) – for incident neutron energies > 0.5 MeV
  - Data for PFNS > 0.5 MeV – probable in 3-4 years
  - Produce new data for PFNS in range 0.05 to 0.50 MeV -- maybe in 4-5 years

Data in the literature: PFNS for $^{239}Pu(n,f)$ – incident monoenergetic sources



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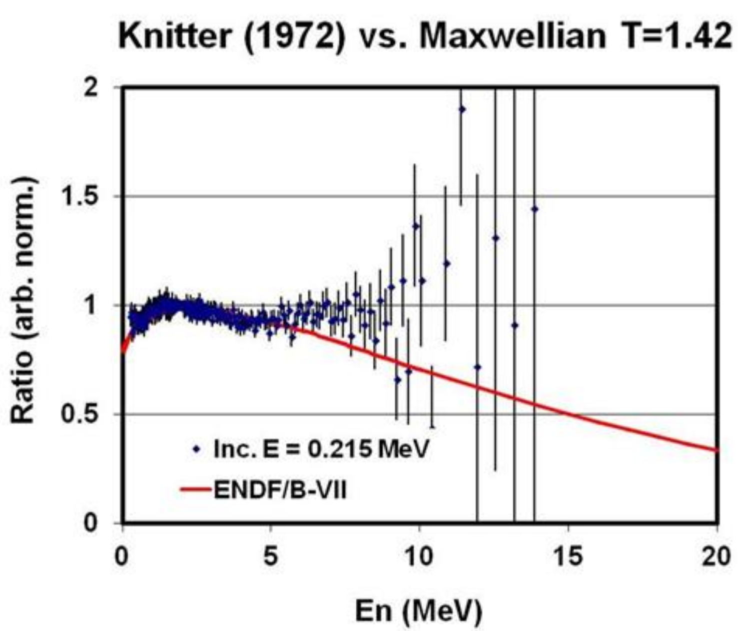
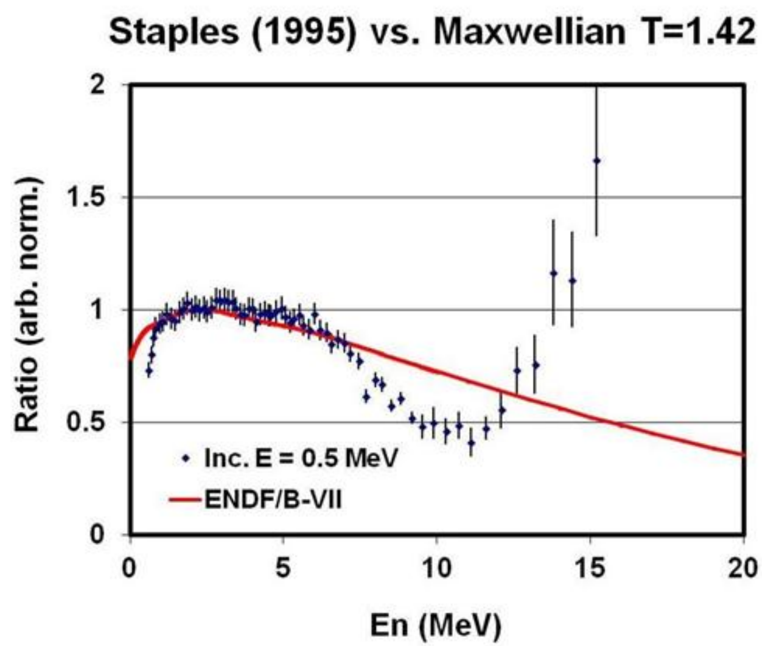
Discrepancy in monoenergetic data for high-energy end of PFNS



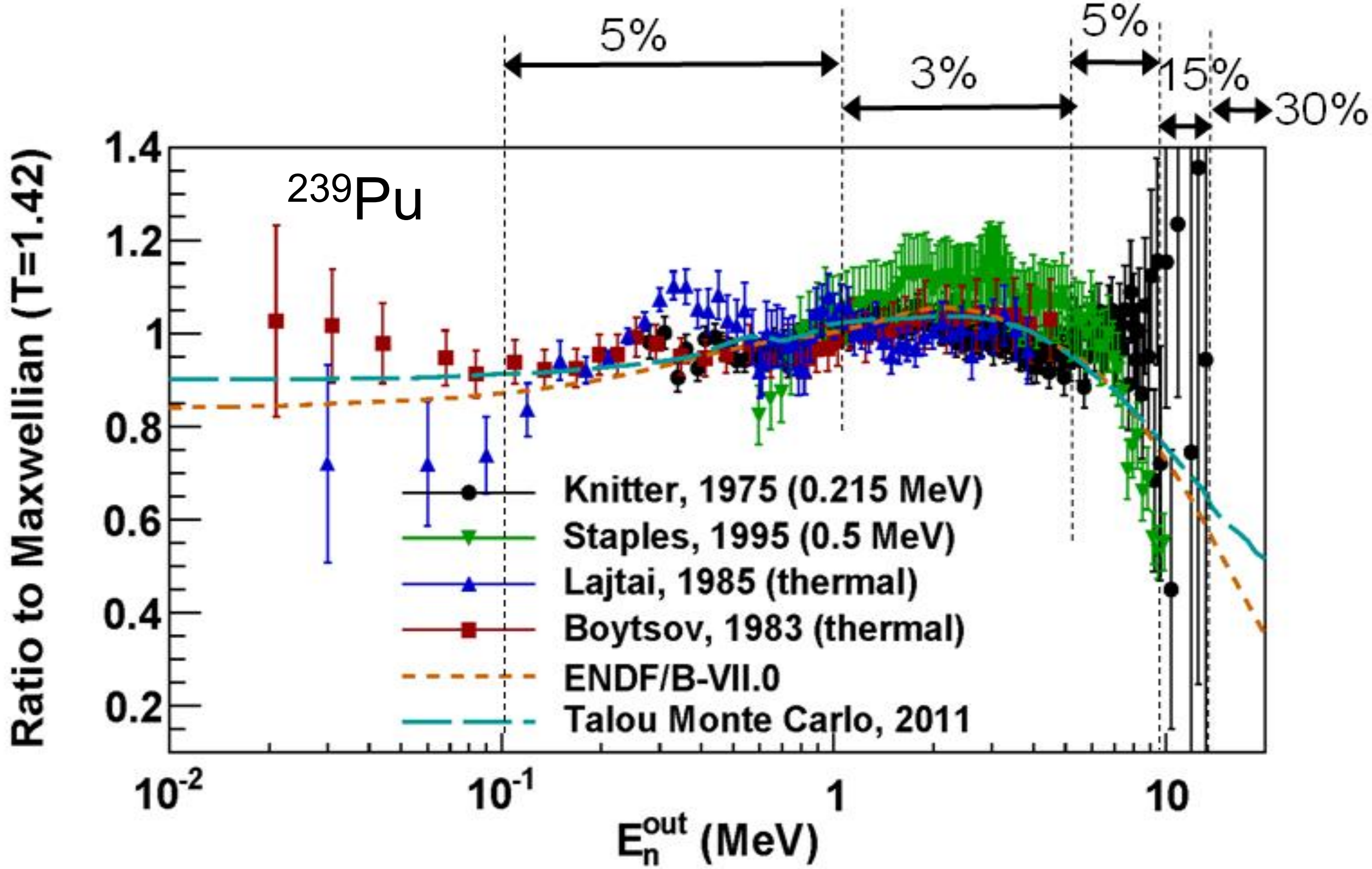


Data > ENDF for Eout > 7 MeV

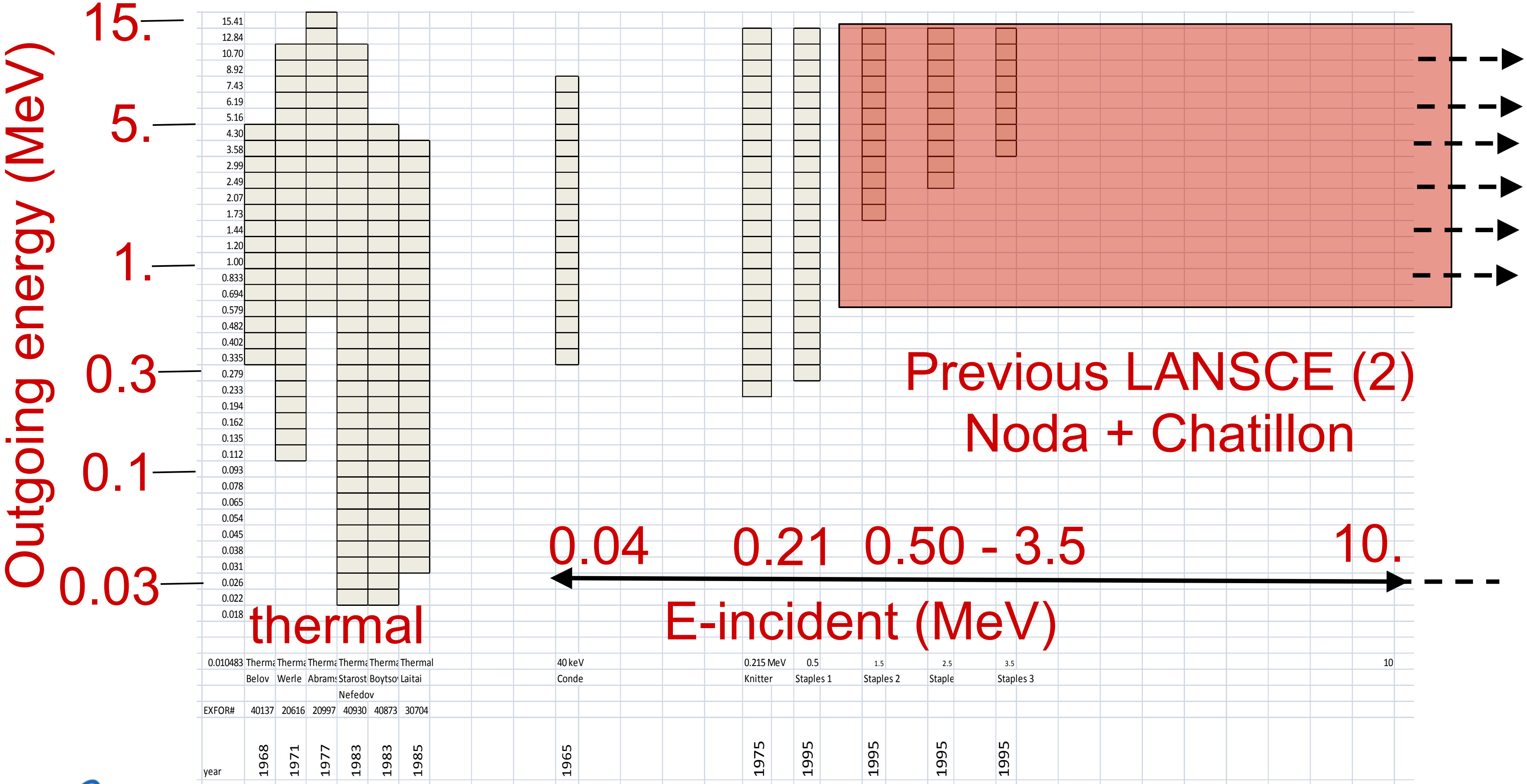
Data < ENDF for Eout 7 to 12 MeV

Note: Staples also for Einc = 1.5, 2.5, 3.5 MeV

Literature data, discrepancies and target accuracies

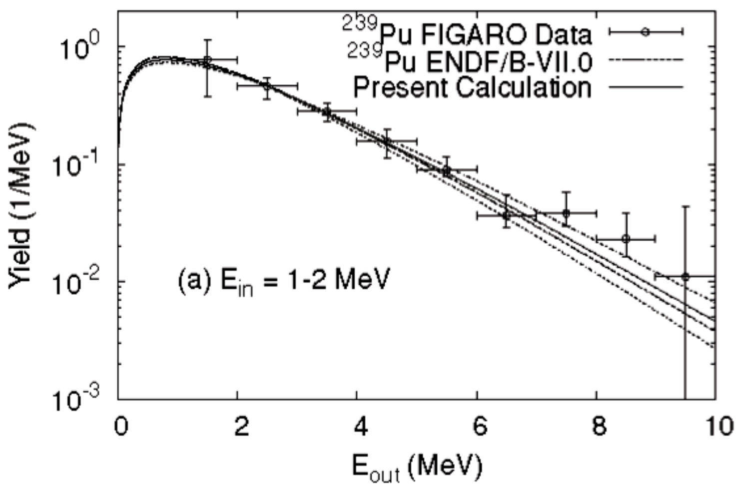


Data in the literature: PFNS for ^{239}Pu(n,f) – incident continuous sources



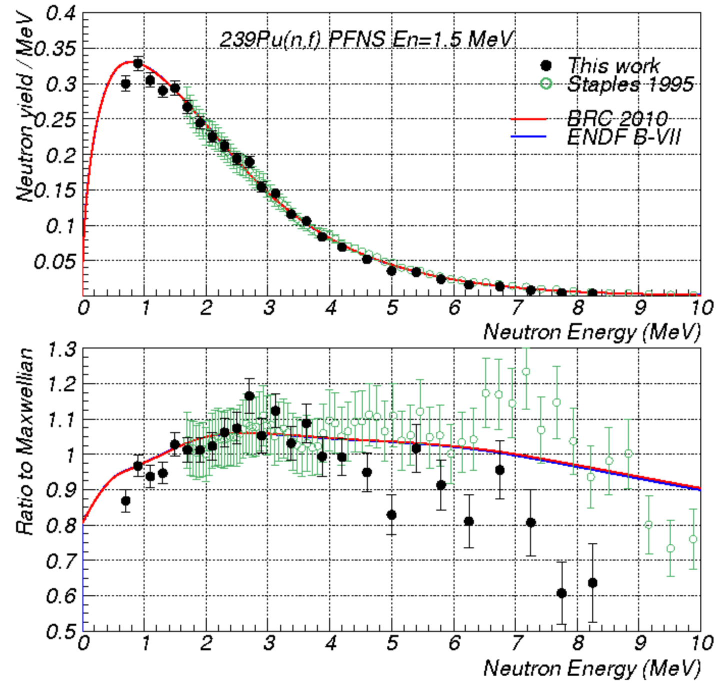
Measurements made with "white" neutron source at LANSCE for ^{239}Pu(n,f): CEA-LANL collaboration

S. Noda et al., Phys. Rev. C 83, 034604 (2011)



Data > ENDF for Eout > 7 MeV

A. Chatillon et al., Phys. Rev. C 89, 014611 (2014)



Data < ENDF for Eout > 7 MeV

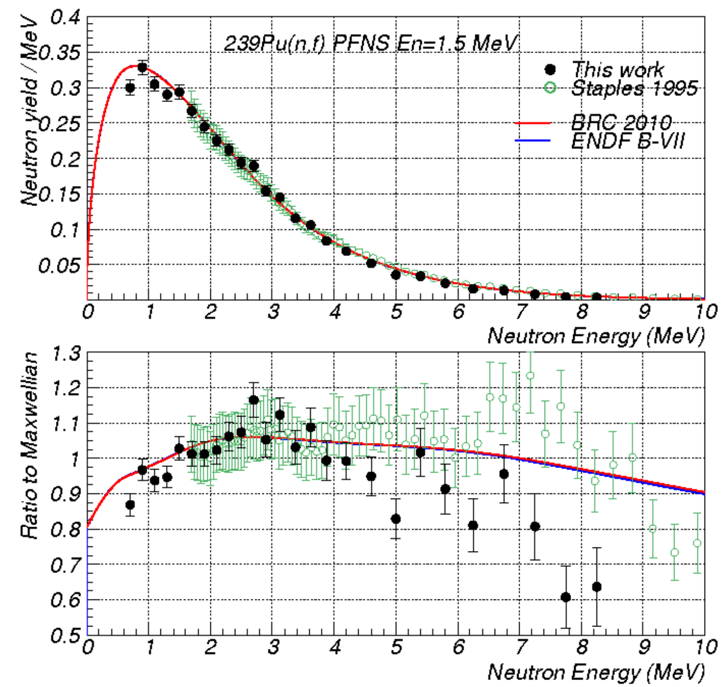
Note: Data for both also for Einc = 1.0 to > 20 MeV

Chatillon data will also be reduced due to time resolution. Detector calibration difference needs to be included also.

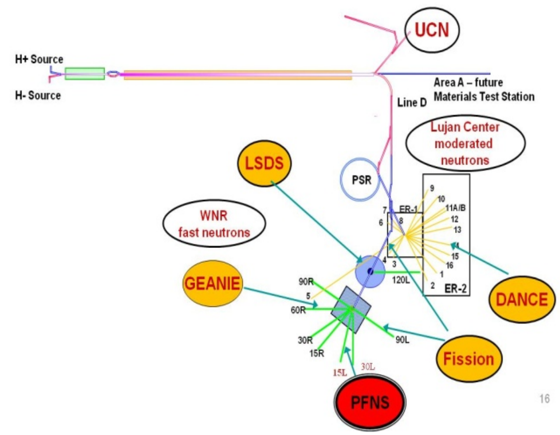
- Correction will reduce data points above 7 MeV but not so much as Noda data because of better time resolution by Chatillon fission chamber

- Major difference with Noda is in calibration of neutron detector efficiency, which explains why Chatillon < Noda above 7 MeV.

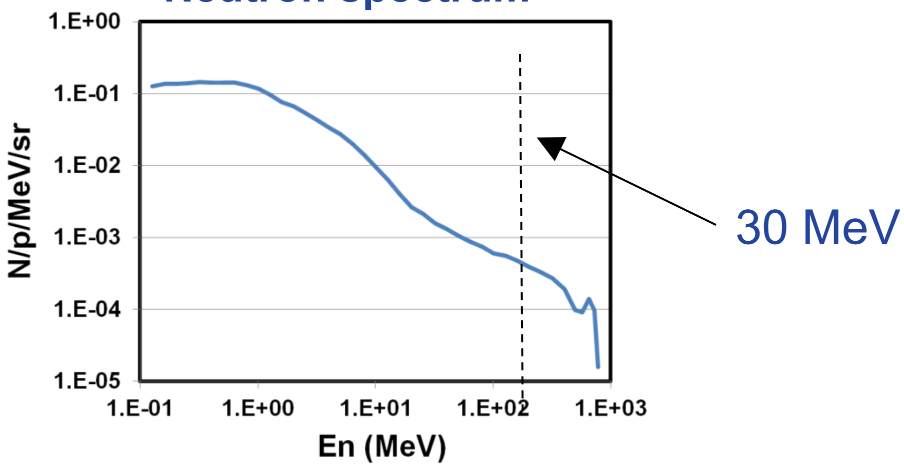
A. Chatillon et al.,Phys. Rev. C89, 014611 (2014)



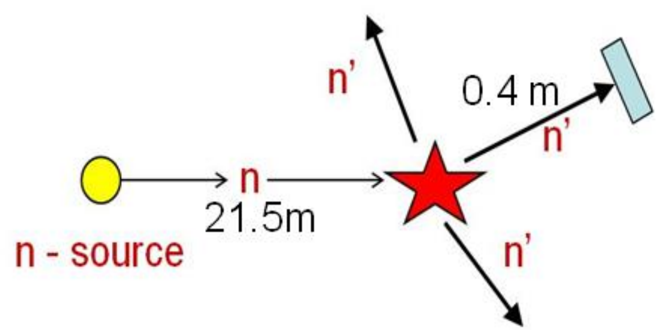
WNR/LANSCE provides neutrons from 100 keV to 200 MeV for PFNS Studies



Neutron spectrum



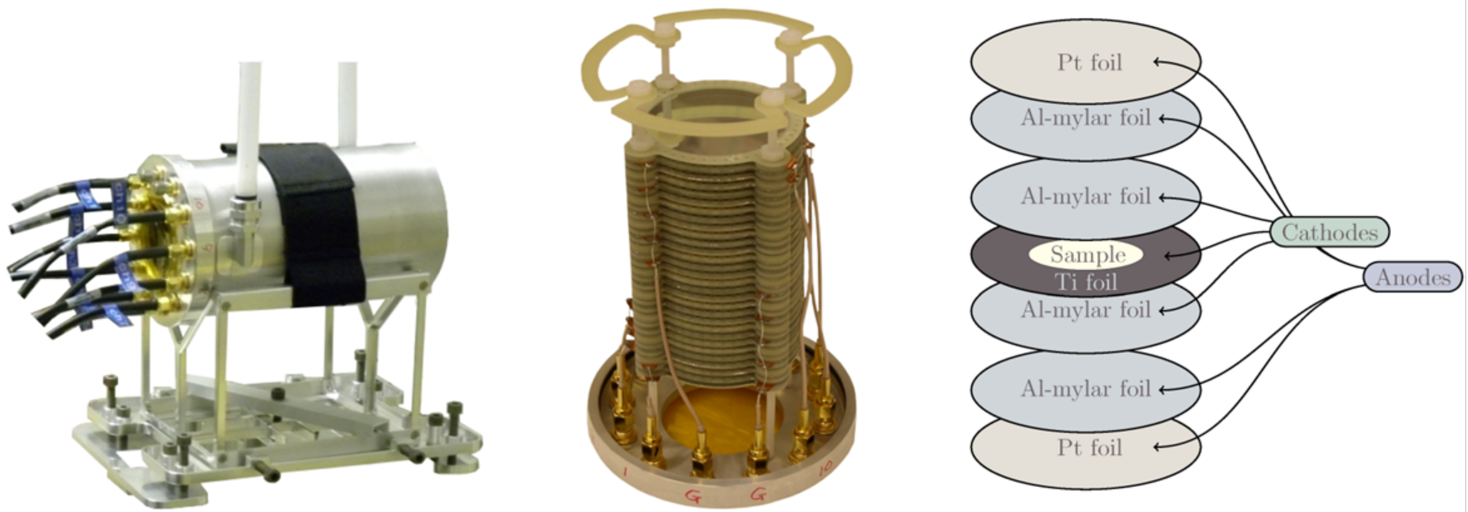
Double time-of-flight experiment



Fission sample and fission counter (LLNL) to contain ~ 100 mg of ^{239}Pu

- **Parallel-Plate Avalanche Counter (PPAC)**

In Beam | Cover Off | One Foil Stack (of 10)



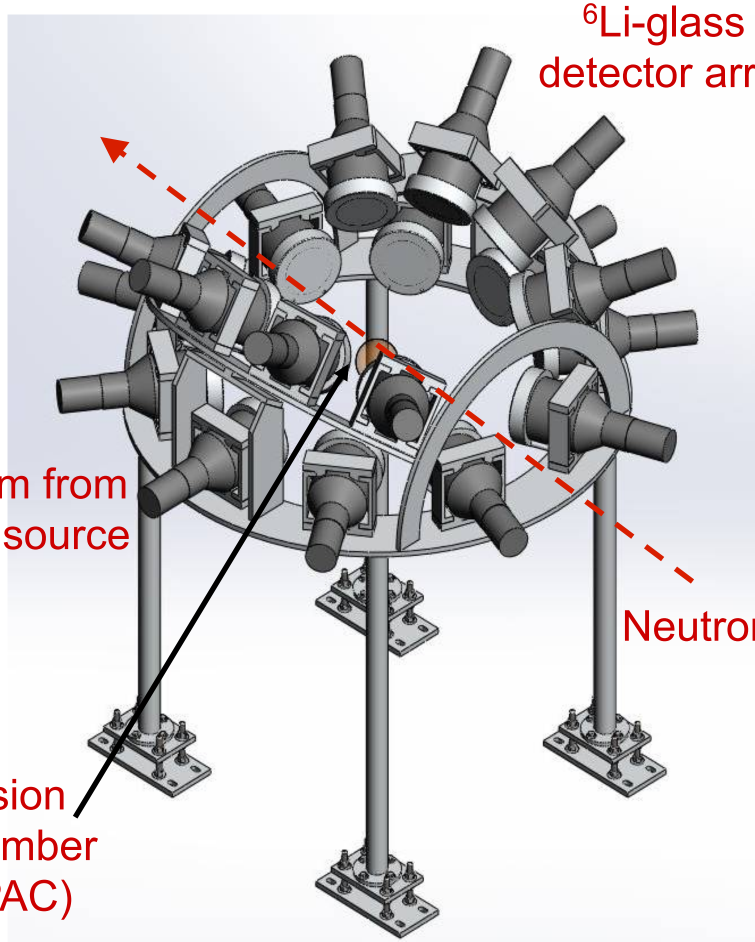
10 cm diam. × 17 cm

Foil: 5 cm diam.
Sample: 4 cm diam.

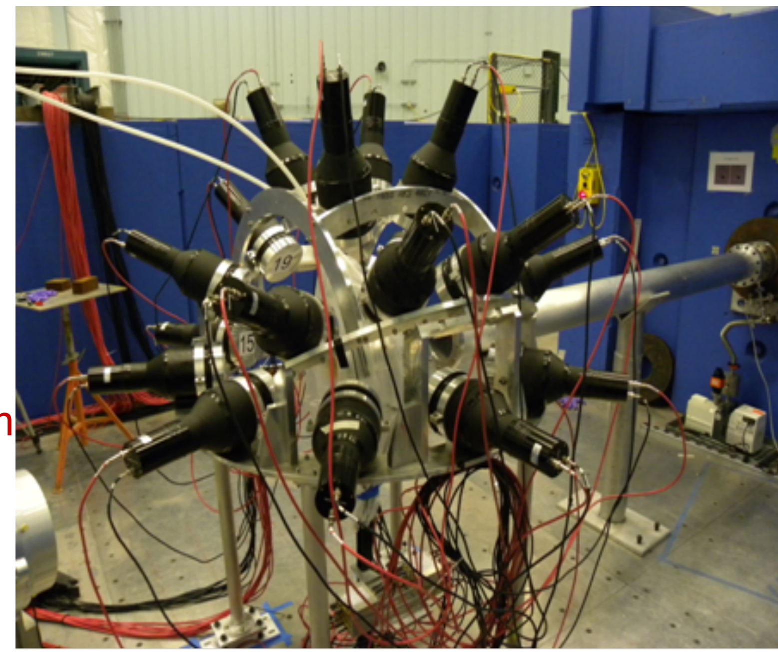
t = 400 μg/cm^2
Timing res.: 1–1.5 ns

Source – PPAC → Time of flight (1)
→ Energy of incident neutron

Chi-Nu array of fast neutron detectors measures prompt neutron spectra emitted in fission

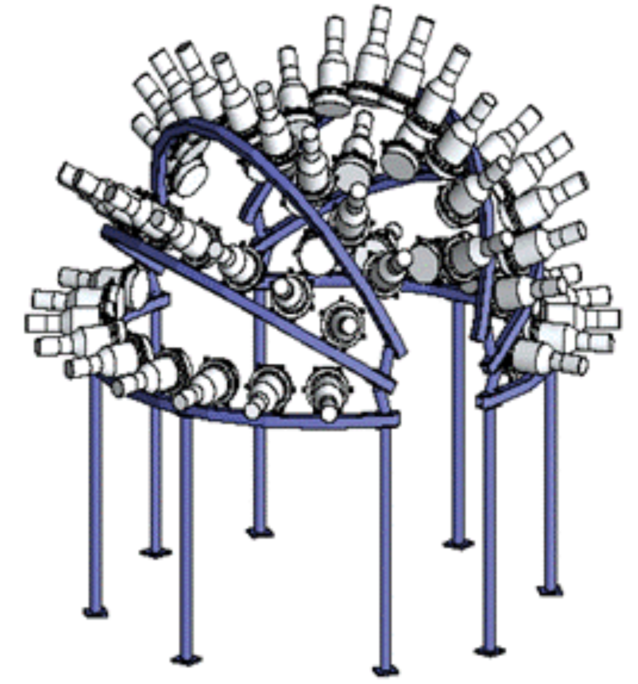


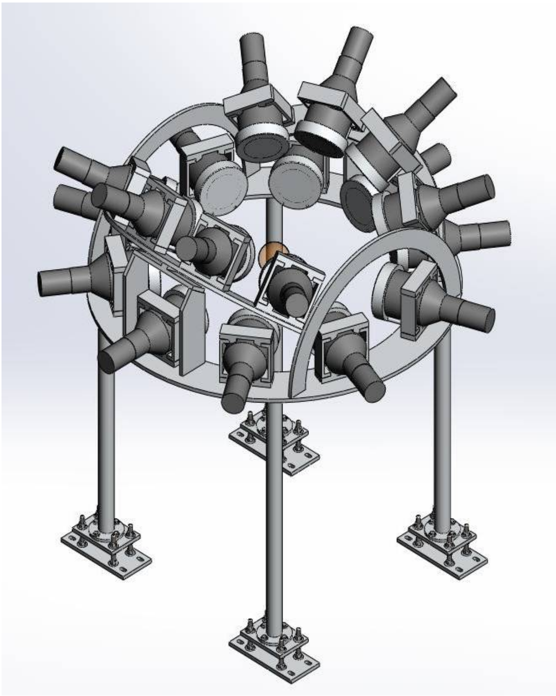
- 22 ^{6}Li-glass scintillation detectors - - or
- 54 liquid scintillation neutron detectors



Double time-of-flight experiment

Neutron detectors – two types





54 Liquid scintillators – 1.0 m flight path

22 ^{6}Li-glass scintillators – 0.4 m flight path

PPAC – neutron detector → Time of flight (2)
→ Energy of outgoing neutron

Modeling Neutron Transport in PFNS Experiments

Terry Taddeucci

MCNP simulations have been used to investigate some previous measurements of the PFNS

Two standard papers for ^{239}Pu:

- P. Staples et al., Nucl. Phys. A591, 41 (1995)
- H.H. Knitter, Atomkernenergie 26, 76 (1975)

Some possible sources of systematic error:

- multiple scattering in the target
- multiple scattering in the collimation
- detector efficiency

(these are not necessarily decoupled)

- background subtraction
- Calibrations (TOF, PH, flight path, etc)

Experimental layout for the measurements by Staples et al.

P. Staples et al. / Nuclear Physics A 591 (1995) 41–60 45

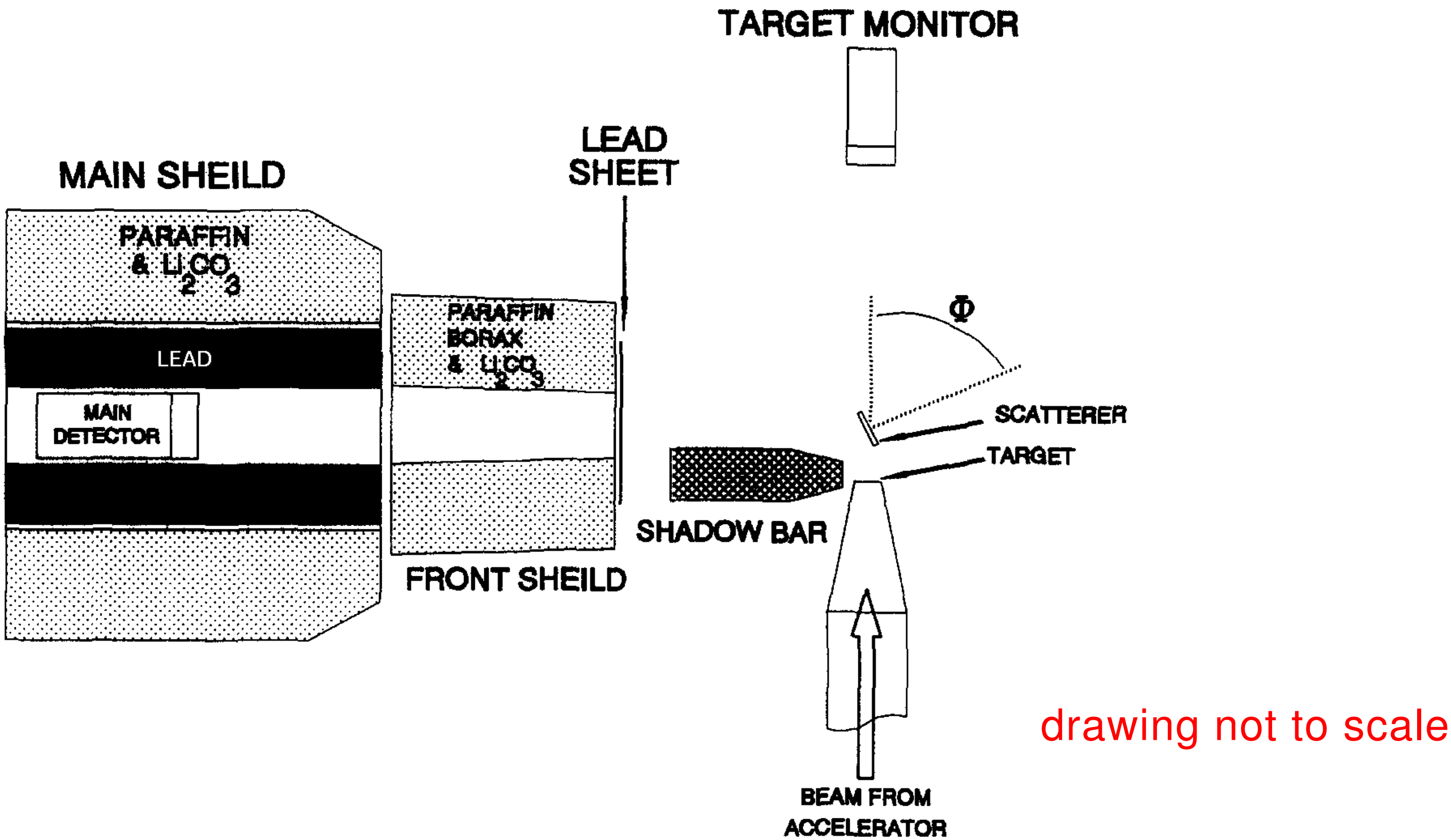


Fig. 1. Experimental arrangement in the target room.

Experimental layout for the measurements by Knitter

M. Coppola and H.H. Knitter, Z. Physik 232, 286 (1970)

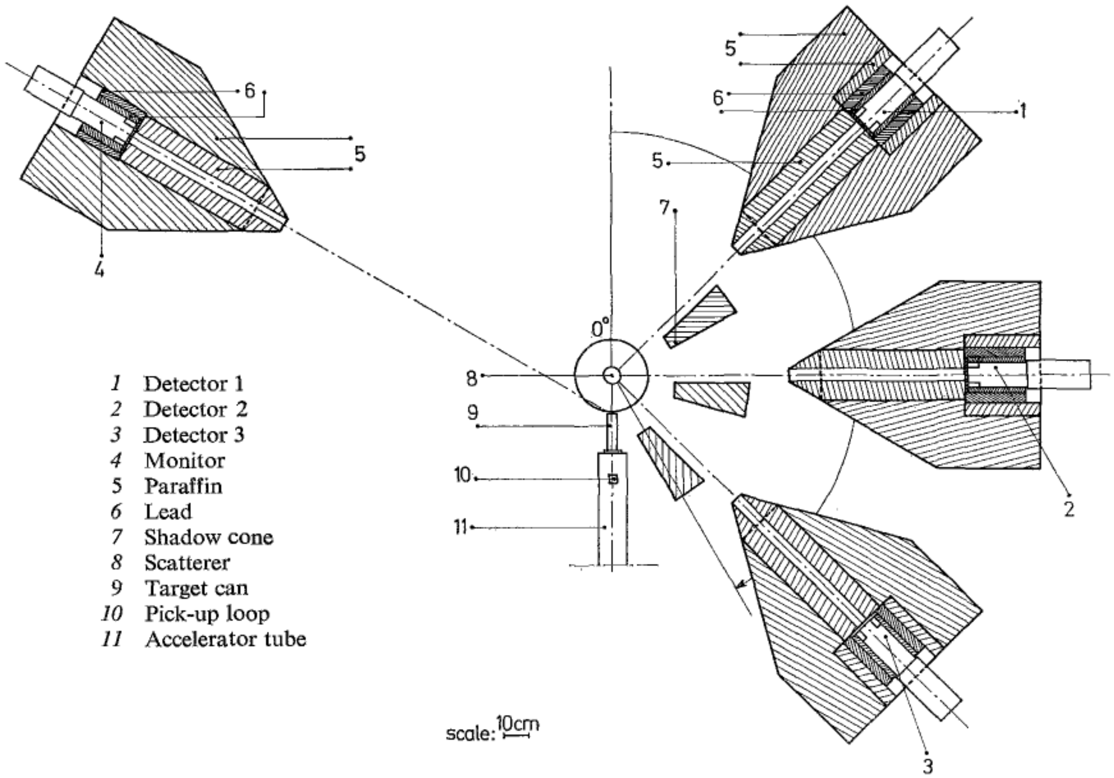


Fig. 1. Lay-out of the detecting system

typical for this facility (CBNM, Geel)

How did Knitter and Staples handle target corrections?

Staples:

"Multiple scattering corrections and neutron attenuation corrections have not been performed because the samples are so small that these effects can be neglected."

Knitter:

"The result of the fit gave an average fission neutron energy of

$$\langle E \rangle = 3/2T = 2.12 \pm 0.01 \text{ MeV}$$

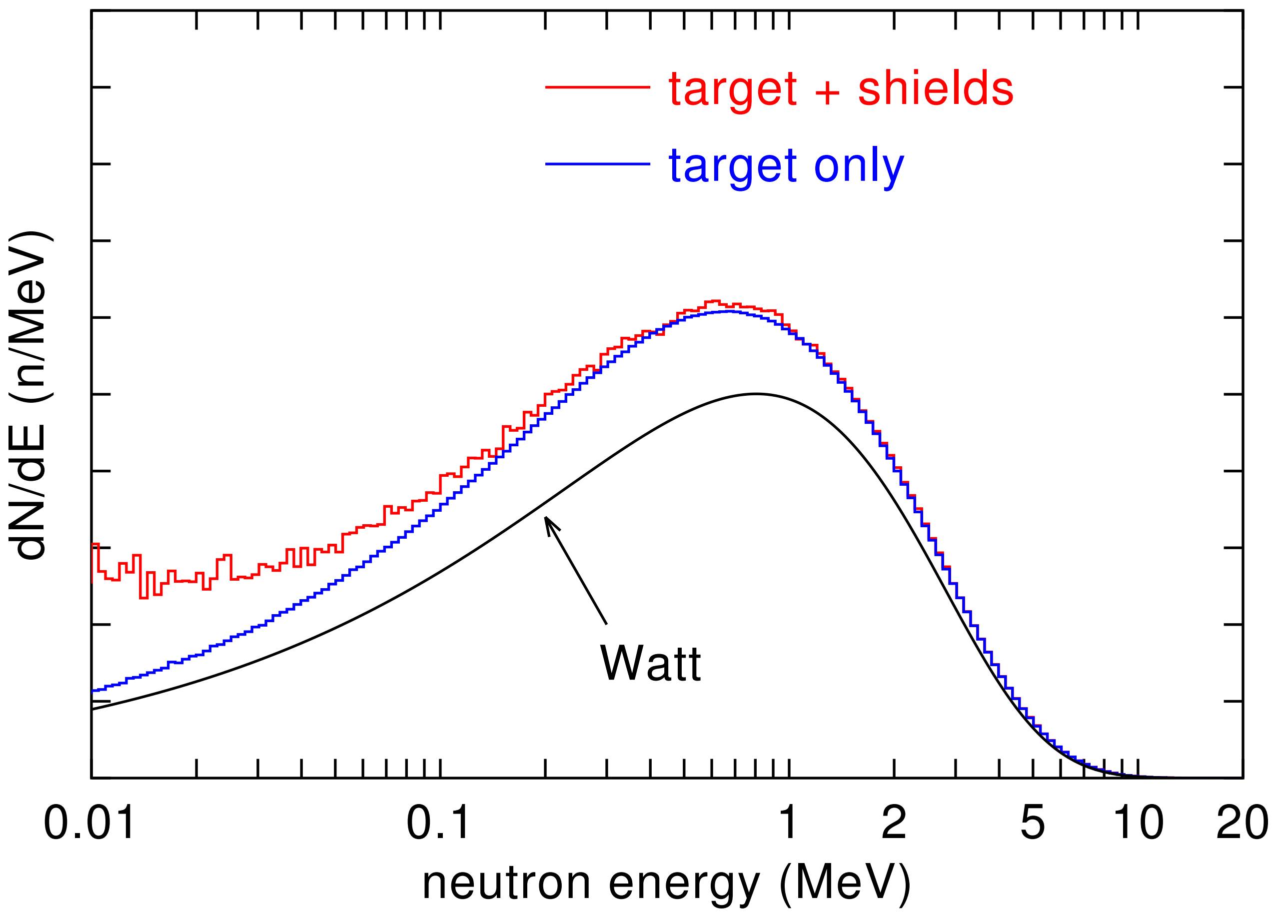
This result contains a small calculable systematic error, since the fission neutrons produced in the sample can make secondary interactions with the sample material. Correction calculations were done in the manner described in a previous paper [1]."

[1] Kiefhaber,E., D. Thiem: Panel Proceedings Series, p127, IAEA Vienna (1972)

→ cf. Islam and Knitter, Nucl. Sci. Eng. 50, 108 (1973)

Multiple scattering plays a significant role in the ^{239}Pu measurements of Knitter

MCNP flux at the detector position



two effects:

n-multiplication

in-scattering

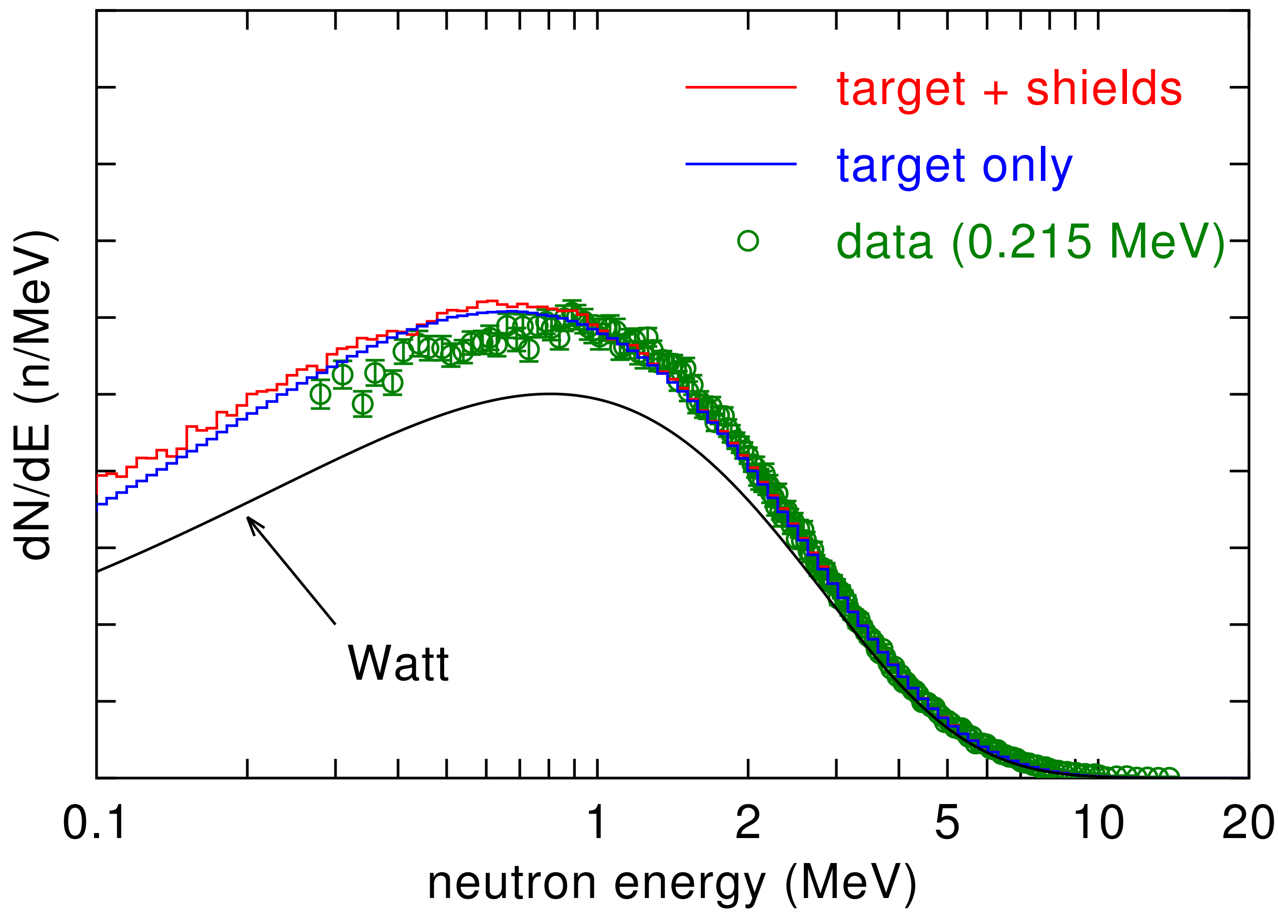
calculations for

^{239}Pu target

knitter-Pu-mcnp.plt: 23 Apr 2013 21:57:26

Comparison of MCNP calculations to the ^{239}Pu measurements of Knitter

MCNP flux at the detector position



two effects:

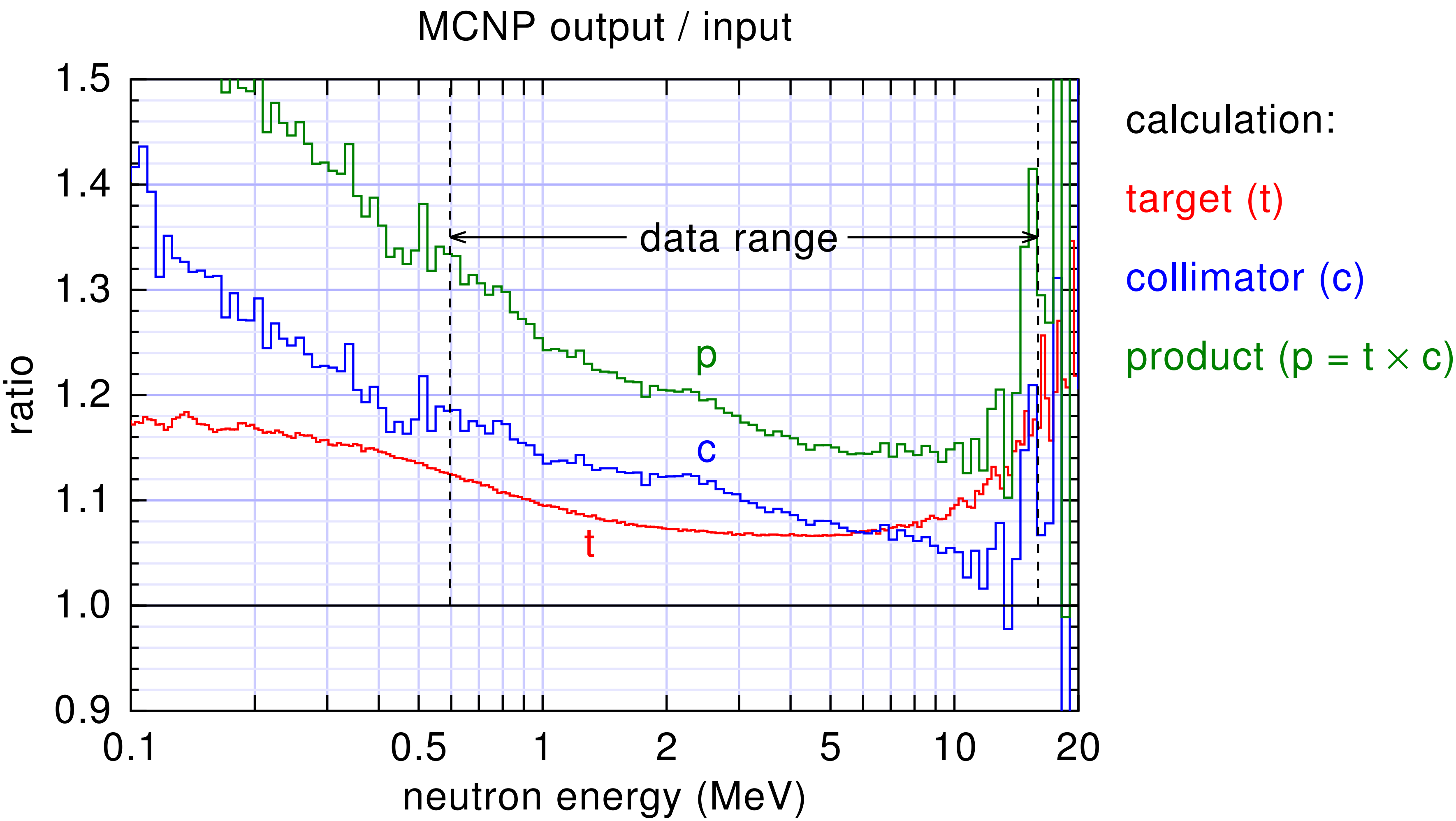
n-multiplication

in-scattering

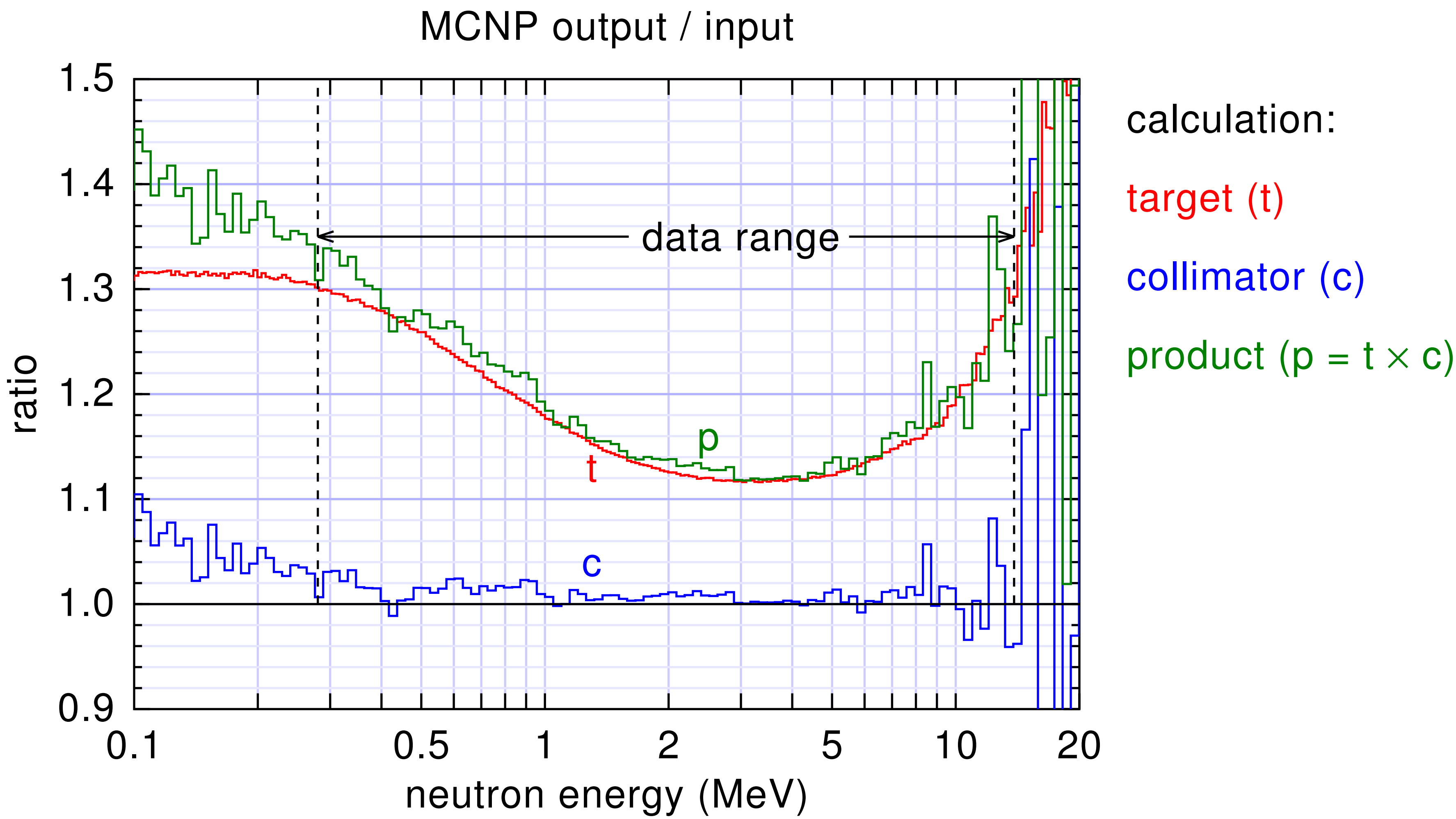
calculations for

^{239}Pu target

Target and collimator effects in the ^{239}Pu data of Staples *et al.*



Target and collimator effects in the ^{239}Pu data of Knitter



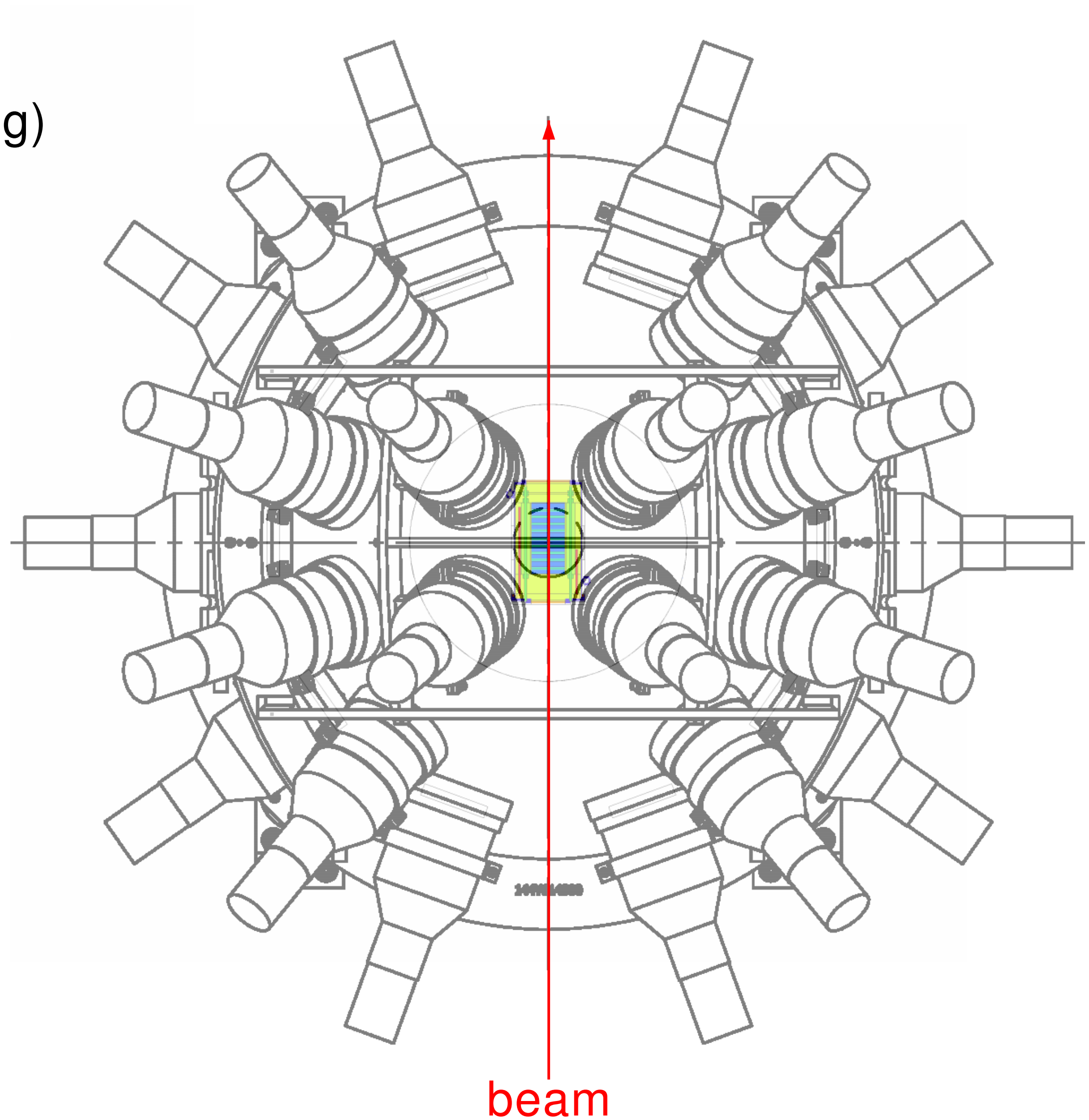
Modeling of Our Present Experiments

Terry Taddeucci

The low-energy part of the PFNS is being measured with an array of ^{6}Li-glass detectors

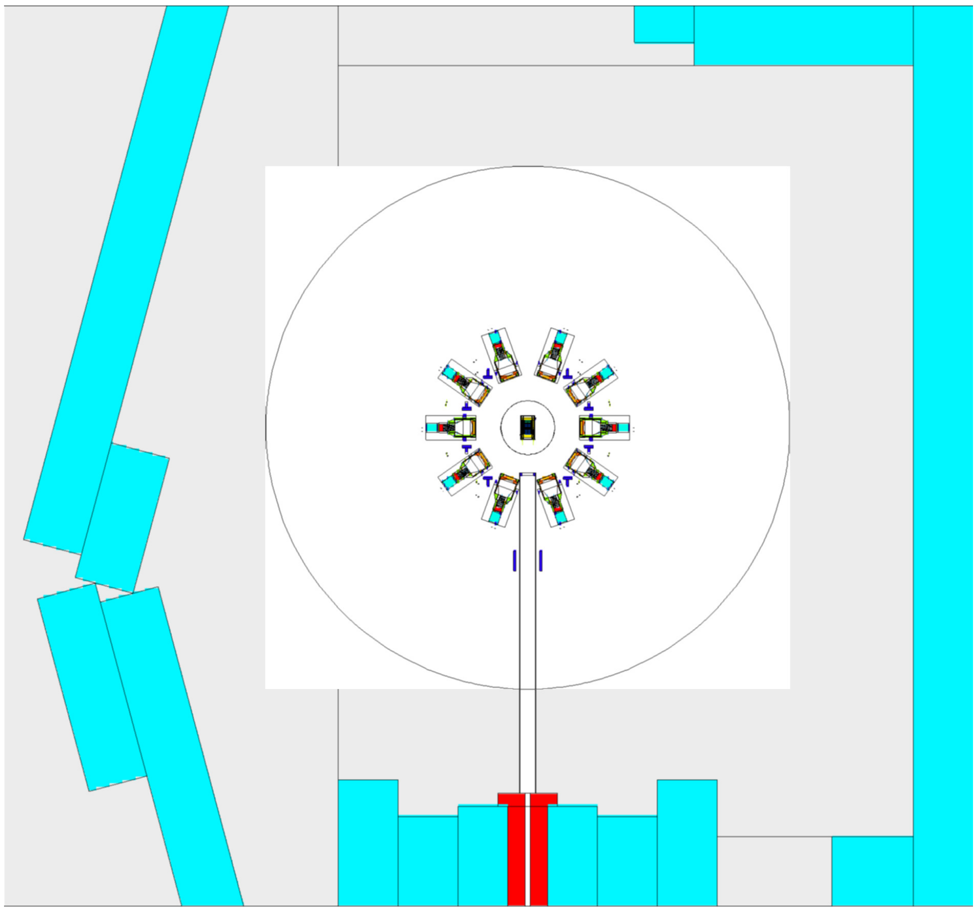
- active thin target (~100 mg)
- many detectors (22)
- open geometry

  (no shielding)

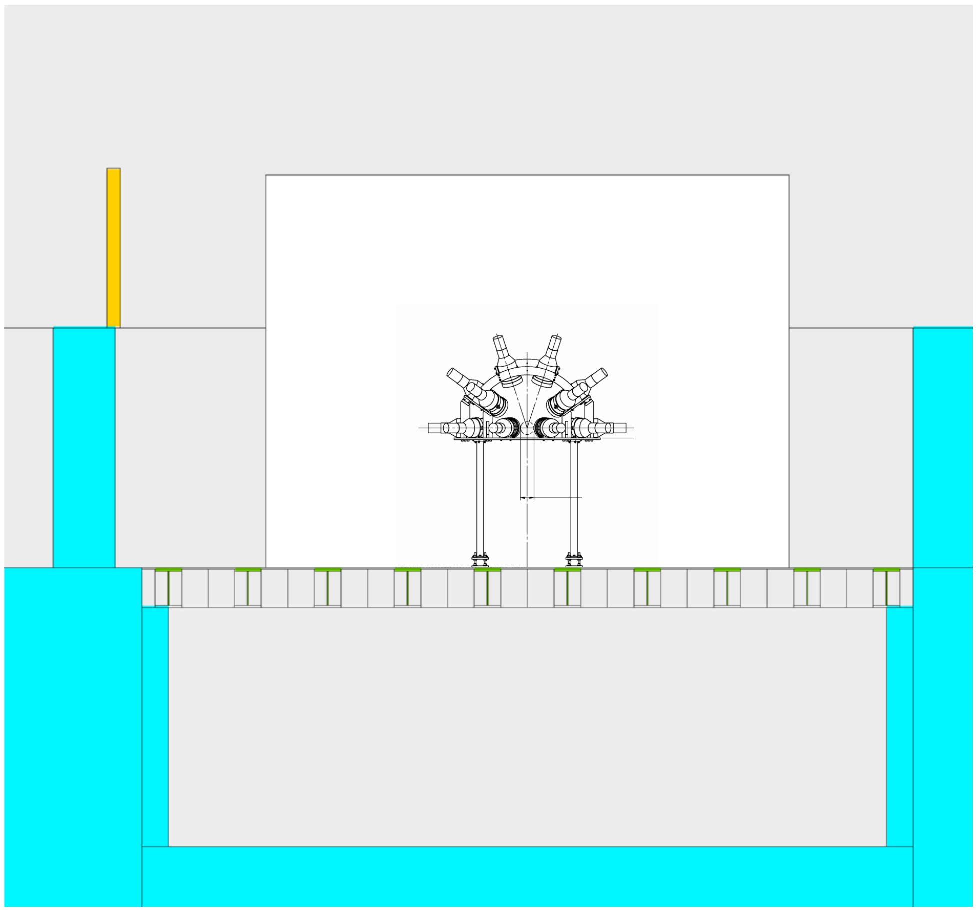


The Chi-Nu MCNP model accounts for neutron scattering from all nearby objects

top view

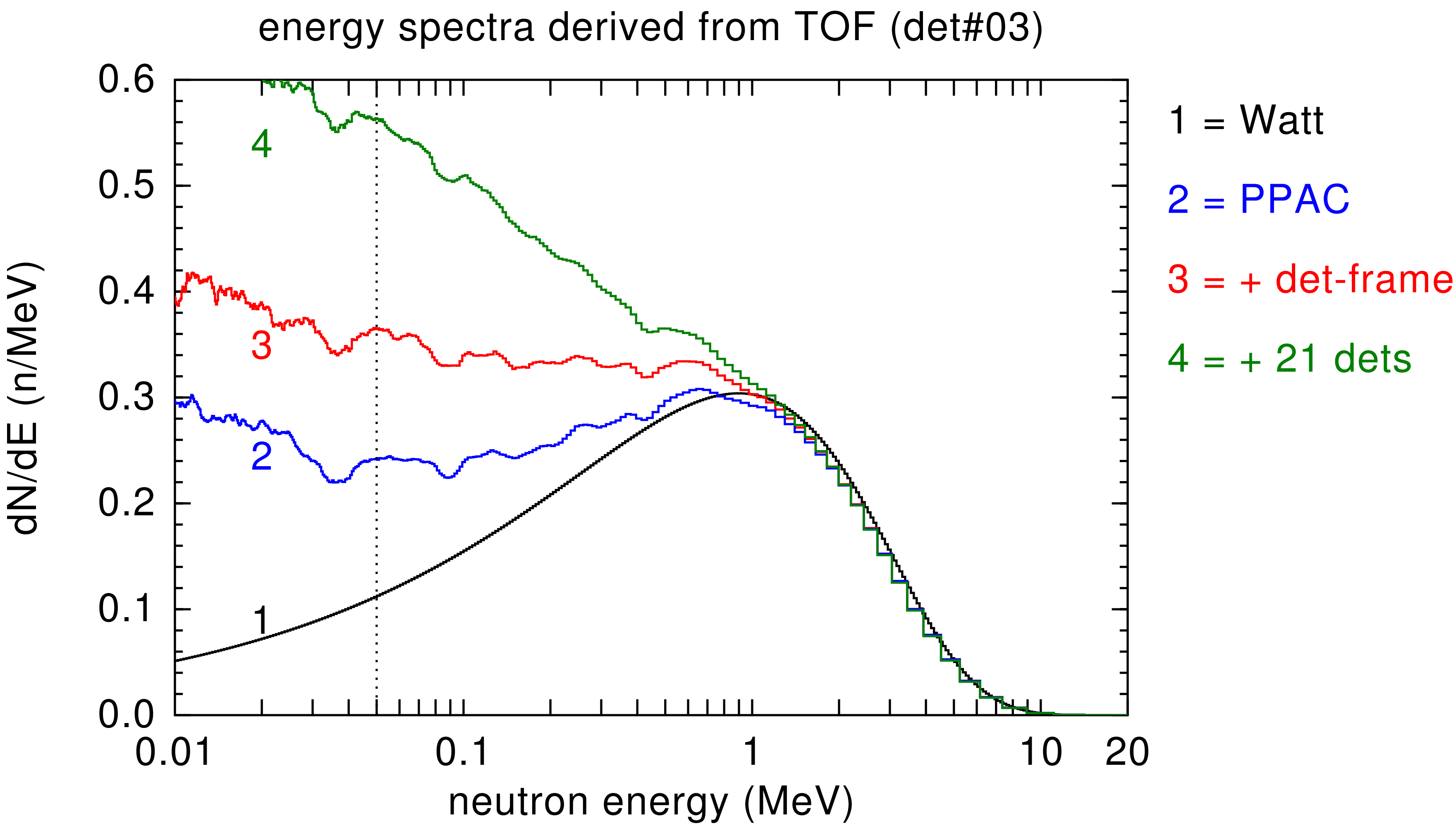


front view

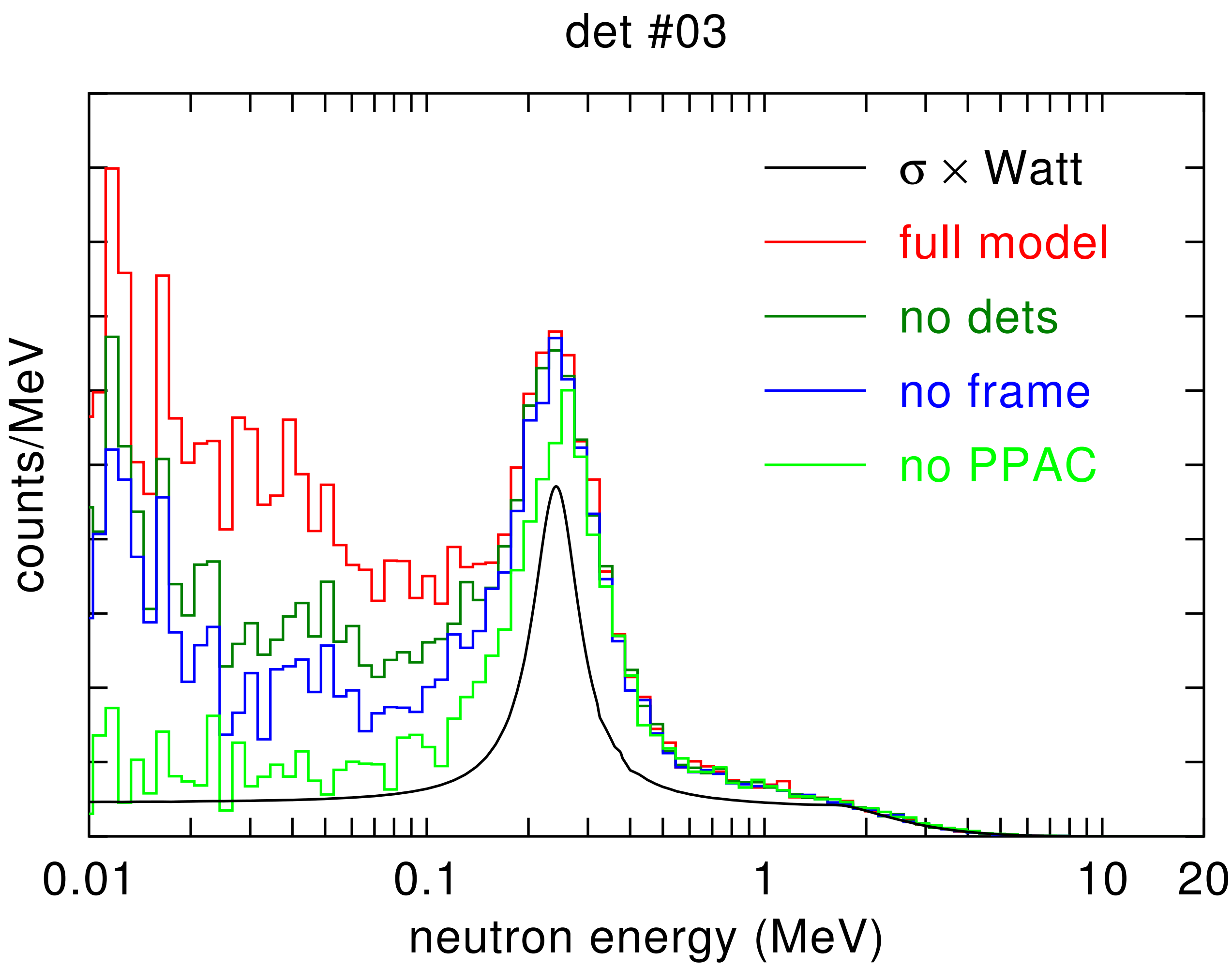


model space $(\Delta x, \Delta y, \Delta z) = 7.5 \times 7.6 \times 6.9\ m^3 = 393.3\ m^3$

Multiple scattering is a significant problem for energies < 1 MeV

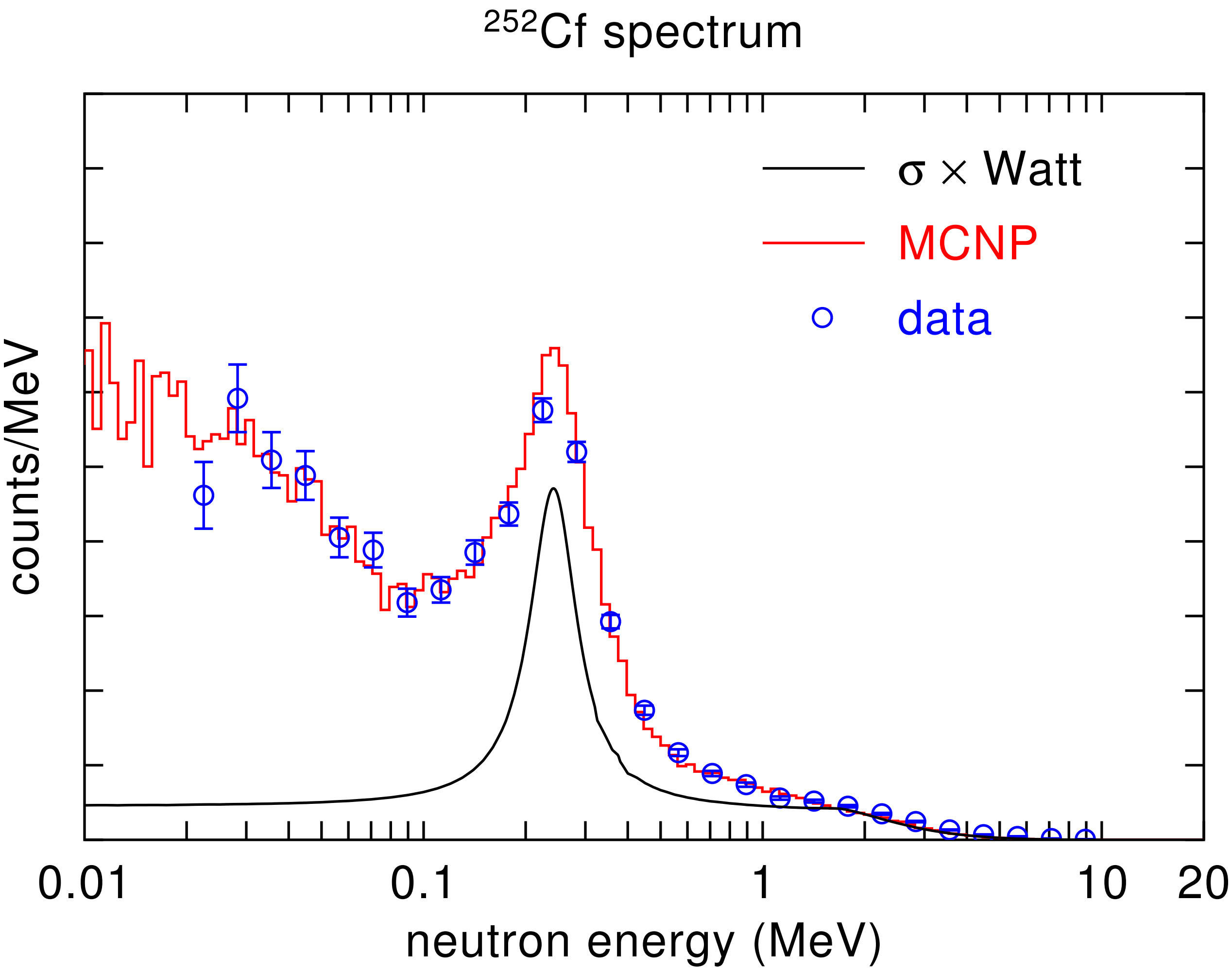


Multiple scattering effects are more accurately represented by including the detector response



1 calculation =
46 cpu-h
(MCNP-PoliMi)

A preliminary comparison of simulation and data shows good agreement



239 cpu-h

dnde-det2.plt: 23 Apr 2014 10:00:16

PFNS for $^{239}Pu(n_{th},f)$ –

Is it a good guide for PFNS in fast-neutron-induced fission?

PFNS for $^{239}Pu(n_{th},f)$ – is it a good guide for PFNS in fast-neutron-induced fission?

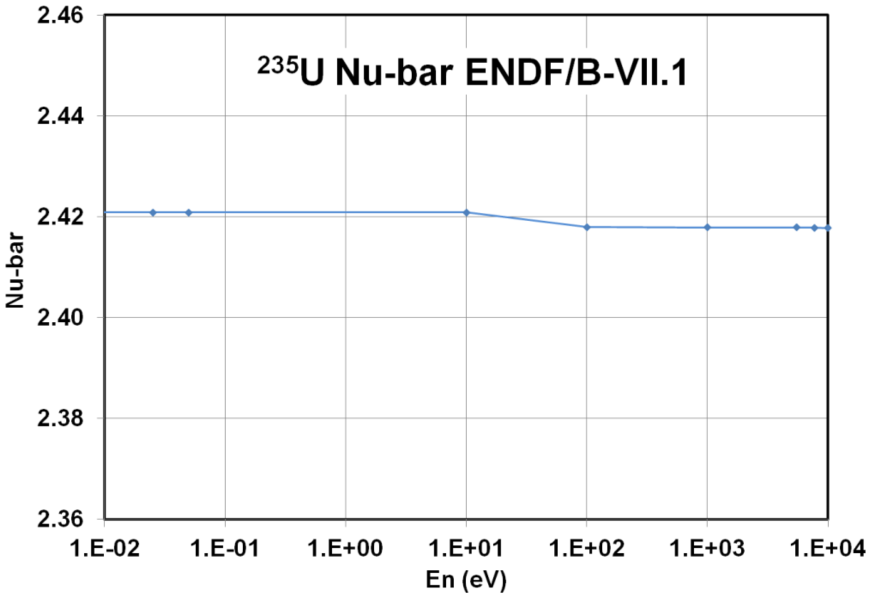
- **Prompt fission neutron spectra have been measured at thermal for ^{235}U and ^{235}Pu. Reactions at thermal can be dominated by one or only a few resonances**

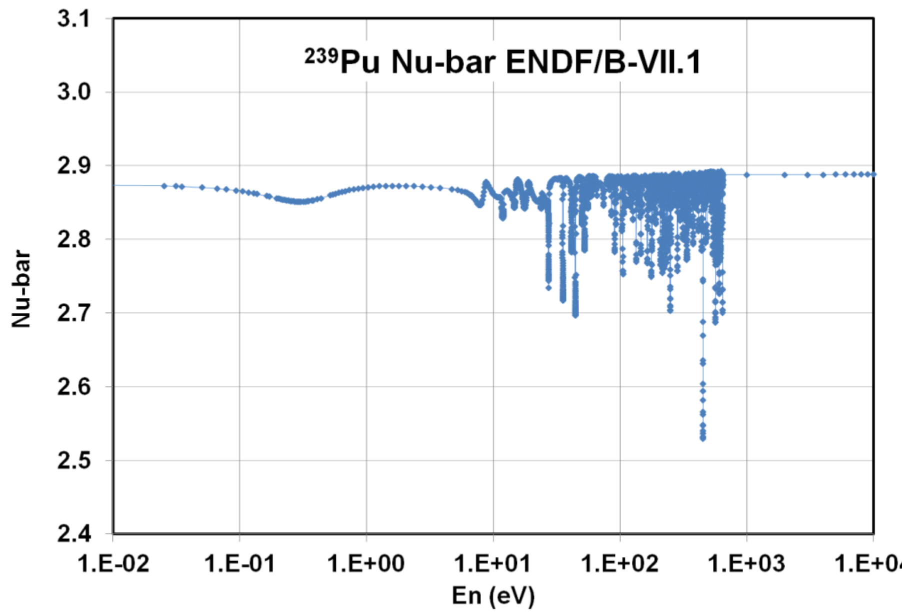
- **Do the data at thermal have any relevance to PFNS for fission induced by higher energy neutrons?**

- **Zero order analysis – look at average number of neutrons emitted in fission. If they vary with incident neutron energy, then there could well be a change in the spectra of emitted neutrons**

Are PFNS measured at thermal relevant for higher incident neutrons?

- Nu-bar for $^{235}U(n,f)$ has no structure
- Nu-bar for ^{239}Pu has a lot of structure

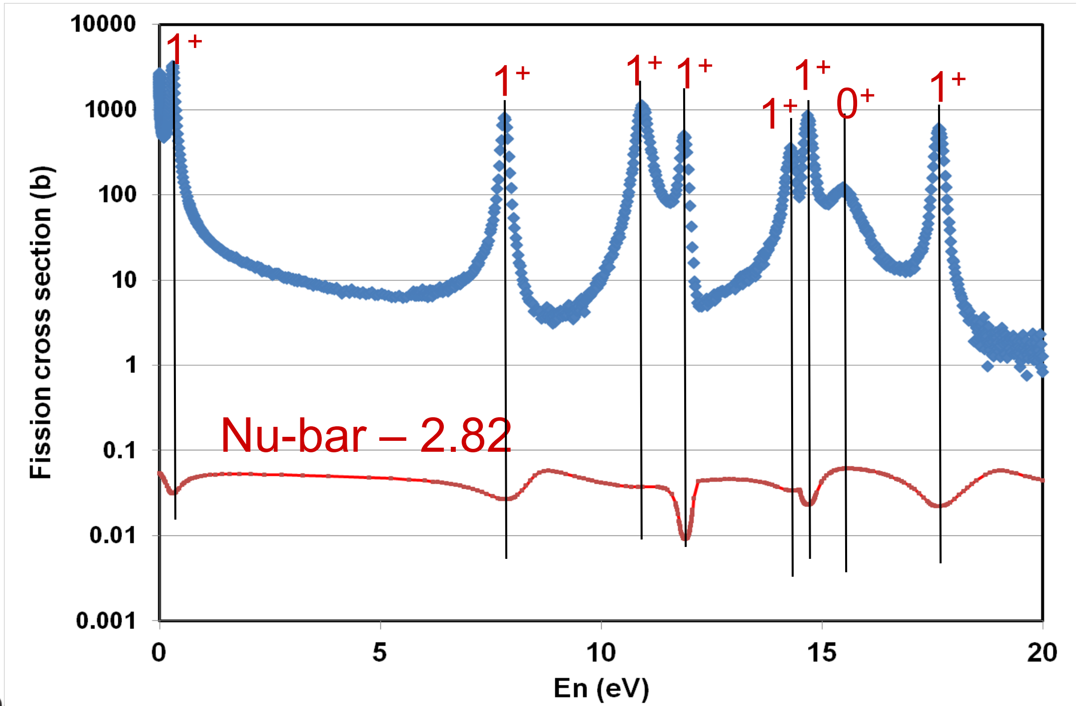




Note also the scale: <<1% for ^{235}U; up to 12 % for ^{239}Pu

Correlate structure in nu-bar for ^{239}Pu(n,f) with fission cross section

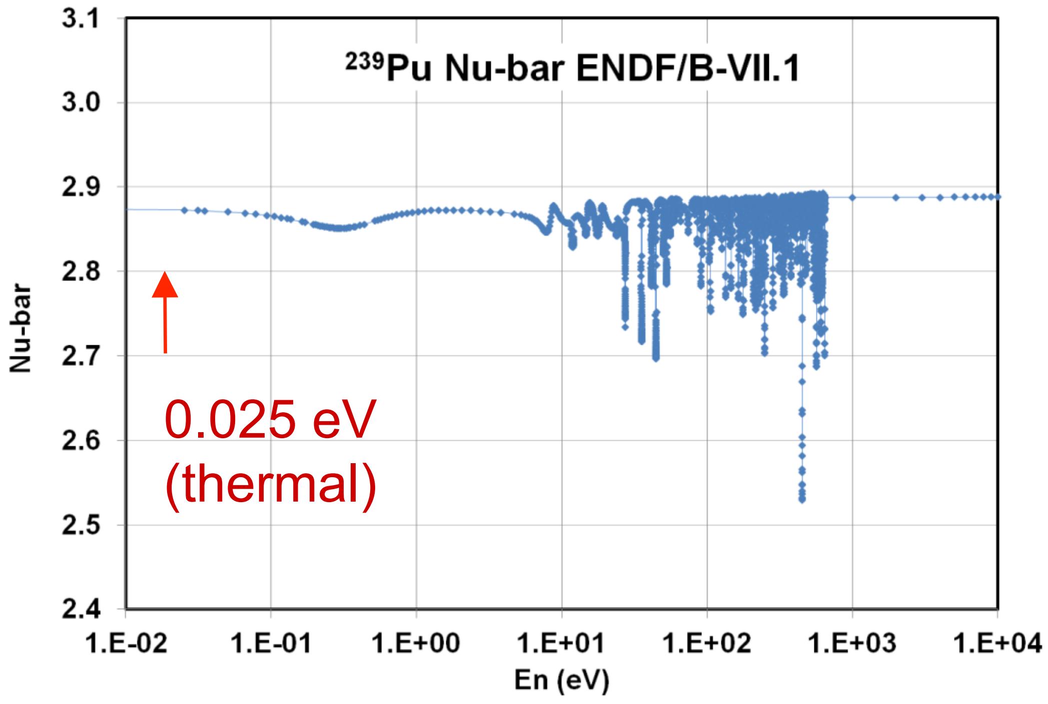
- Fission cross section from Weston [NSE 115,164 (1993)]
- Subtract a constant (2.82) from nu-bar for clarity of display
- Add spins and parities (all positive) from Mughabghab
  - 0+ resonance shows no effect in nu-bar
  - 1+ resonances show varying effects



Probably (n,γ f) process

Now the good news (maybe)

- Nu-bar at thermal for ^{239}Pu(n,f) is almost the same as for 1-10 keV. Maybe the thermal neutron PFNS is relevant to higher energies
- Q: Is nu-bar at thermal dominated by the 1^+ resonance at 0.3 eV ?

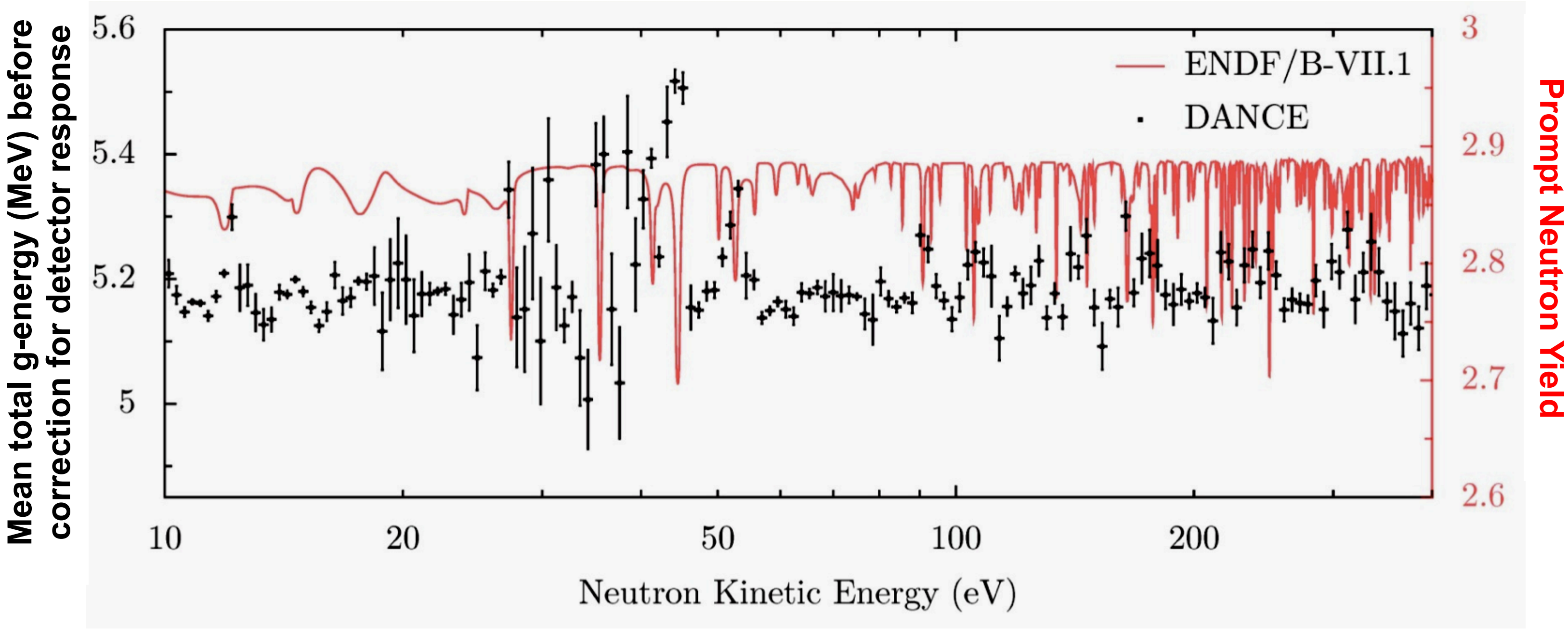


Prospects for PFNS measurements with fission induced by epithermal neutrons

- $^{239}Pu(n,f)$ – for incident neutron energies in resonance region – not planned but would be interesting physics!
  - Note: gamma production from fission in resonance region has been studied. Yes, spectra do depend on incident neutron energy and correlate with variations in nu-bar!

    Ref: S. Mosby et al., DANCE collaborations

Fission total γ-ray energy vs. incident neutron energy for ^{239}Pu(n,f)



- Fluctuations in prompt fission gamma energy anti-correlated with neutron emission
- More detailed information on ^{239}Pu(n,γf) process (Lynn, 1965)
- Qualitative behavior reported by Shackleton in 1972

Advanced PFNS measurements

- Correlate PFNS with fission products (Z,A) – difficult – could improve models of fission physics

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- LANL: H. Y. Lee, T. N. Taddeucci, J. M. O'Donnell, N. Fotiades, M. Devlin, J. L. Ullmann, T. Bredeweg, M. Jandel, R. O. Nelson, S. A. Wender, D. Neudecker, M. Rising, S. Mosby, S. Sjue, M. White; R. C. Haight
- LLNL: C.-Y. Wu, B. Bucher, R. Henderson
- CEA: T. Ethvignot, T. Granier, A. Chatillon, J. Taieb, B. Laurent, Alix Sardet