

Measurement of the neutron-induced fission cross section of ^{239}Pu at n_TOF

L. Audouin[Ⓢ], M. Caamaño, D. Cano-Ott, I. Duran, J. Heyse, C. Le Naour, A. Manna[Ⓢ],
C. Massimi, M. Mastromarco, A. Mengoni, C. Paradela, P. Schillebeeckx,
M. Spelta, D. Tarrio, L. Tassan-Got, G. Vannini, A. Ventura, R. Zarrella and
the n_TOF Collaboration

May 22nd, 2024 – 76th INTC



new generation of nuclear reactors, ADS and Generation IV Fast Neutron Reactors, high-accuracy data of neutron-induced reactions **at least up to 20 MeV** neutron energy

Aliberti et al., Annals of Nuclear Energy 33.8 (2006)

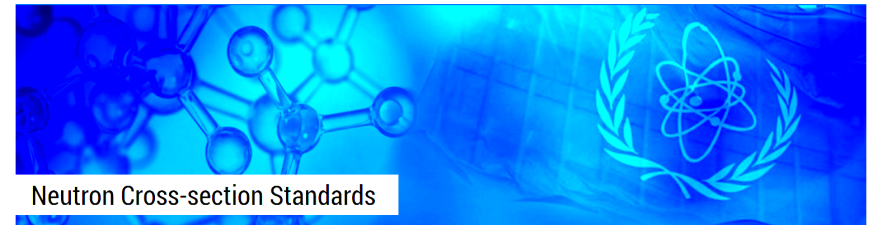
Looking for integral references for the fission cross sections in actinides above 1 MeV

Ignacio Durán^{1,3}, Roberto Capote², and Georg Schnabel²*

...integral reference values in the 8 to 10 MeV interval for a set of actinide isotopes of relevance for the study of fast fission reactors: ^{232}Th , $^{233-235-238}\text{U}$, ^{237}Np , $^{239-241-242}\text{Pu}$, and $^{241-242\text{m}}\text{Am}$, which will be well suited to renormalize the experimental datasets of actinide nuclei of interest...

EPJ Web of Conferences 294, 04001 (2024)

“...Our analysis indicates that the new absolute measurements of the neutron induced fission cross sections on uranium, bismuth, lead and **plutonium** have the highest priority in establishing neutron induced fission reaction standards above 200 MeV...”



Neutron Cross-section Standards

The last data sets in literature...

Lisowski, 1991	Los Alamos – 20 m FP	[0.5 – 260] MeV	fast PPIC + 2 RPTs
Staples, 1998	Los Alamos – 20 m FP	[0.85 – 62] MeV	2 PPIC
Shcherbakov, 2002	GNEIS – 48.5 m FP	[1 – 200] MeV	2 fast PPIC
Tovesson, 2010	Los Alamos – 10.5 m + 7.93 m	[0.01 eV – 200 MeV]	PPIC
Snyder, 2021	Los Alamos – 7–15 m	[0.1 – 100] MeV	TPC

The last data sets in literature...

Lisowski, 1991	Los Alamos – 20 m FP	[0.5 – 260] MeV	fast PPIC + 2 RPTs	Unc. Stat 1–1.5%
Staples, 1998	Los Alamos – 20 m FP	[0.85 – 62] MeV	2 PPIC	Unc. Stat <1% + Unc. Sys ~1%
Shcherbakov, 2002	GNEIS – 48.5 m FP	[1 – 200] MeV	2 fast PPIC	Unc. Stat [2–1]% + Unc. Sys ~1.5%
Tovesson, 2010	Los Alamos – 10.5 m + 7.93 m	[0.01 eV – 200 MeV]	PPIC	Unc. Stat <1% (up to 140 MeV), up to 1.5% at 200 MeV Unc. Sys <1% (up to 140 MeV), up to 1.7% at 200 MeV
Snyder, 2021	Los Alamos – 7–15 m	[0.1 – 100] MeV	TPC	Unc. Stat <1% + Unc. Sys <1%

The last data sets in literature...

Lisowski, 1991

Unc. Stat 1–1.5%

Staples, 1998

Unc. <1% + ~1%

Shcherbakov, 2002

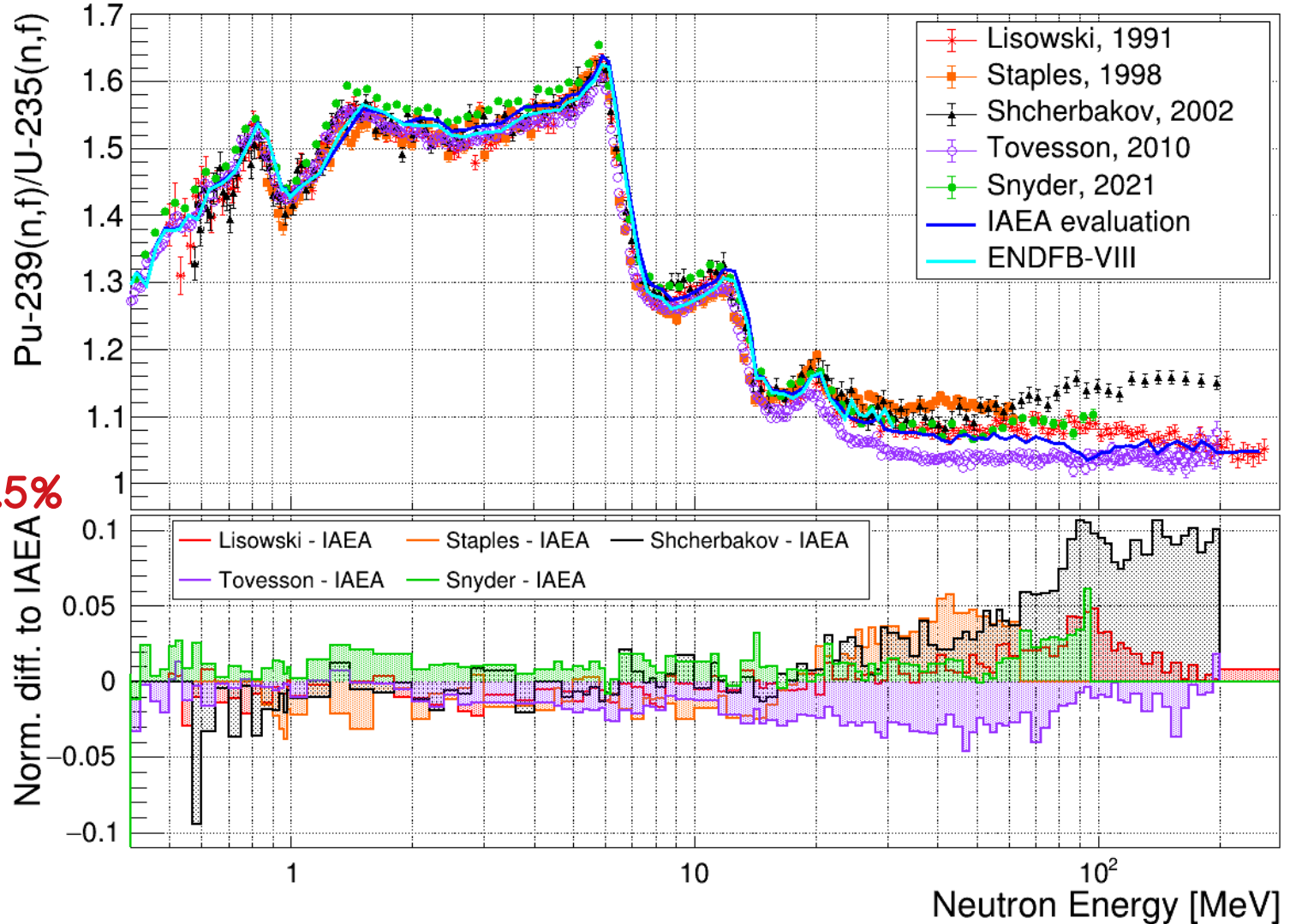
Unc. [2–1]% + ~1.5%

Tovesson, 2010

Unc. Stat <1% – 1.5%
+ <1% – 1.7%

Snyder, 2021

Unc. <1% + <1%



The last data sets in literature...

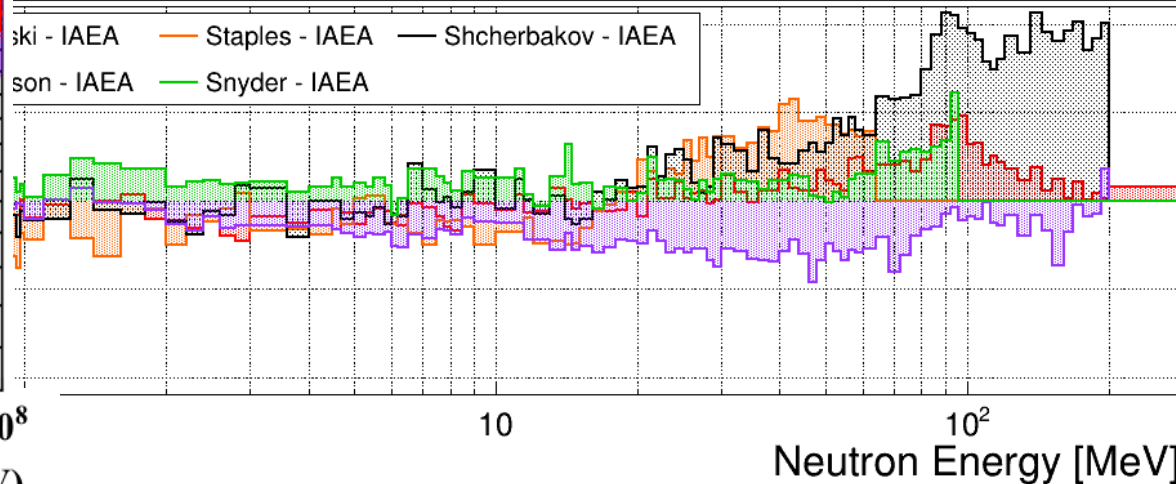
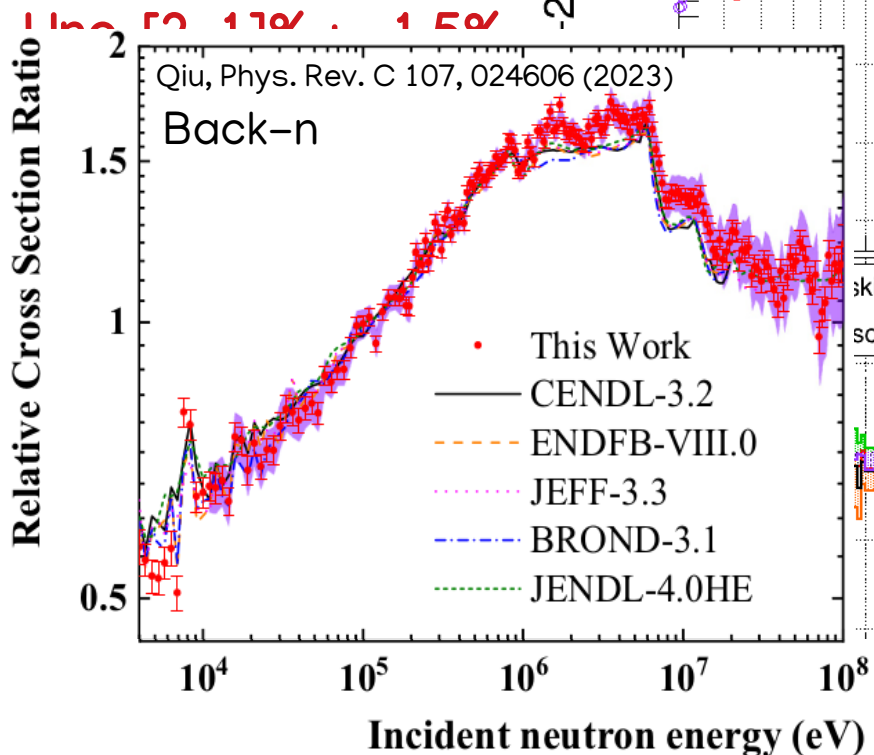
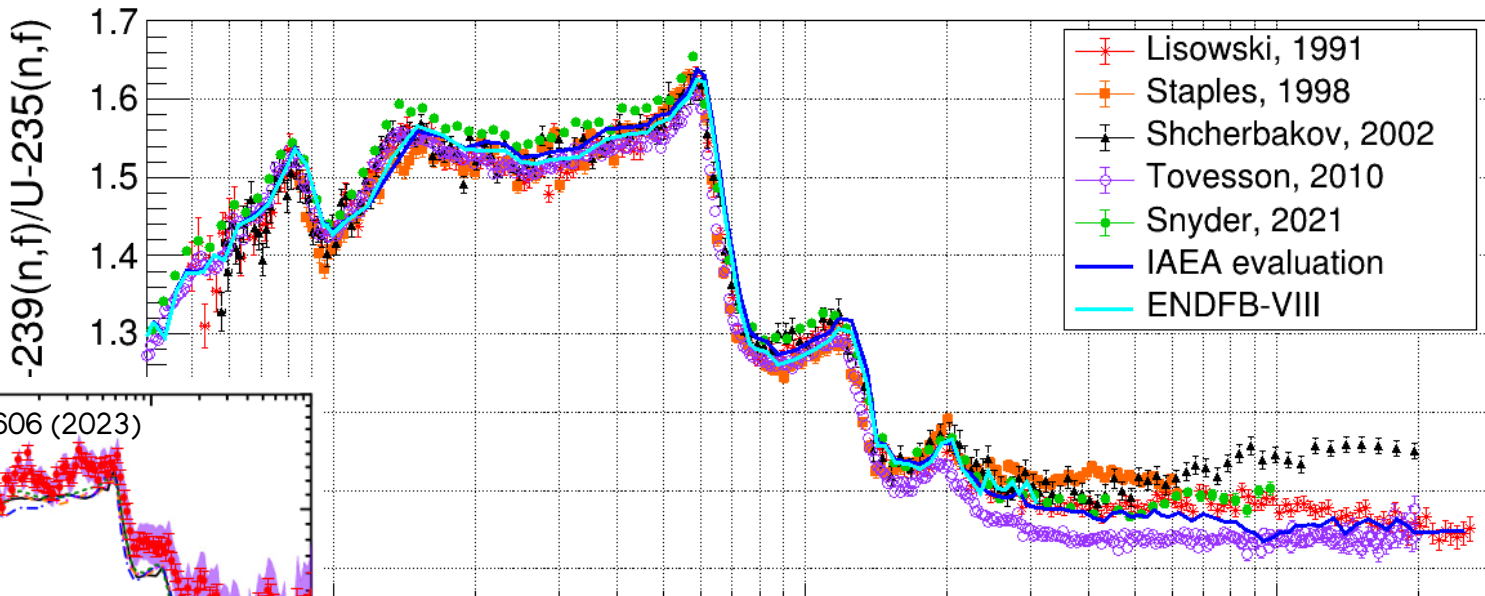
Lisowski, 1991

Unc. Stat 1-1.5%

Staples, 1998

Unc. <1% + ~1%

Shcherbakov, 2002



Experimental setup

Identify the fission induced by neutrons with an energy of up to 1 GeV.

General Requirements:

 Very good time resolution




 Low sensitivity to the γ -flash

 Good discrimination between α particles and FFs
(^{239}Pu activity ~ 2 MBq/mg).

Experimental setup

Identify the fission induced by neutrons with an energy of up to 1 GeV.

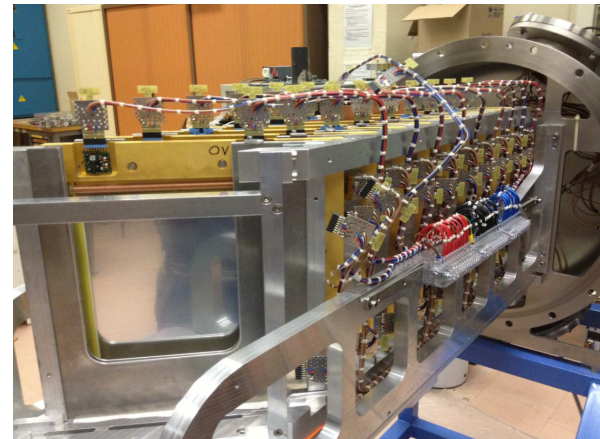
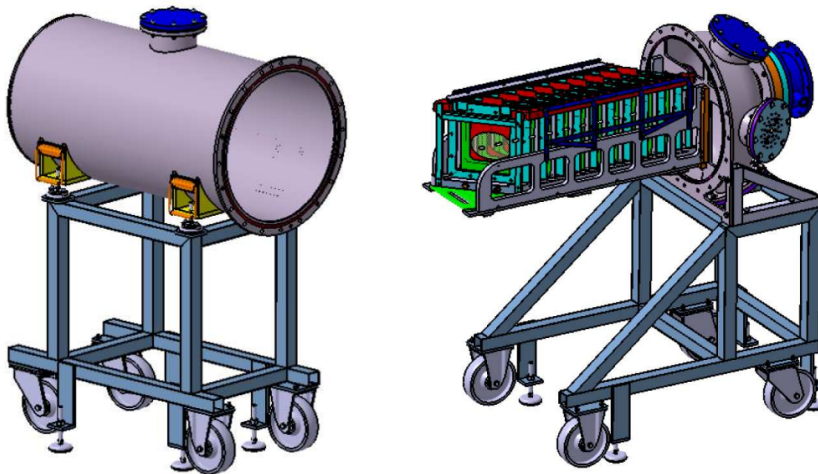
General Requirements:

-  Very good time resolution
-  Low sensitivity to the γ -flash
-  Good discrimination between α particles and FFs
(^{239}Pu activity ~ 2 MBq/mg).



PPAC ensemble:

9 target slots and 10 PPACs tilted by 45° with respect to the neutron beam direction.



Experimental setup

Identify the fission induced by neutrons with an energy of up to 1 GeV.

General Requirements:

WE NEED THIS! Very good time resolution **200 ps**

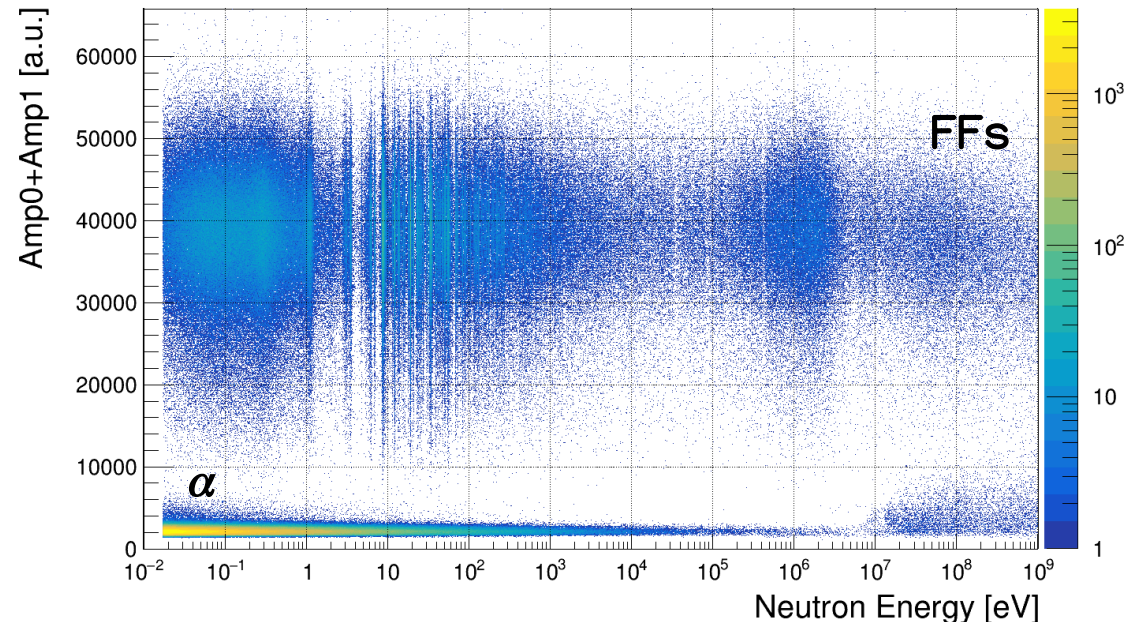
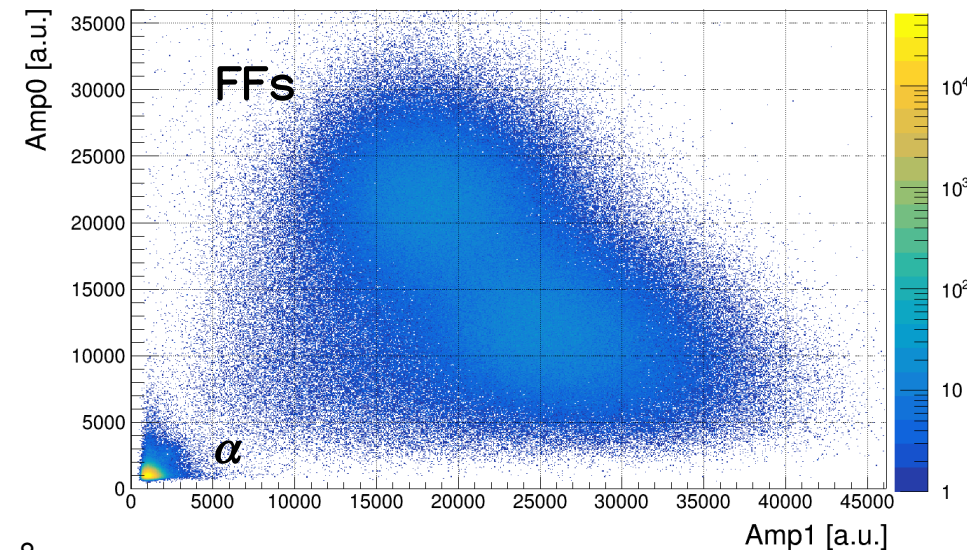
WE NEED THIS! Low sensitivity to the γ -flash

WE NEED THIS! Good discrimination between α particles and FFs
(^{239}Pu activity ~ 2 MBq/mg).



PPAC ensemble

Detector already used in cross section measurement from **thermal energy to GeV**



Samples



^{239}Pu Material already @JRC-Geel from
the $^{239}\text{Pu}(n,\gamma)$ experimental campaign

Purity 99.90 wt.%, **May, 2017**,
0.10 wt.% Pu-240-241-242

@ SCK CEN:

Purification $^{241}\text{Am}/^{239}\text{Pu}$
of the order 1 ppm

proposed for end of this year

sck cen

Samples



^{239}Pu Material already @JRC–Geel from the $^{239}\text{Pu}(n,\gamma)$ experimental campaign

Purity 99.90 wt.%, **May, 2017**,
0.10 wt.% Pu–240–241–242

@IJCLab, Orsay
samples preparation



^{239}Pu will be deposited on ultra-thin aluminum foils (2 μm thick) by electroplating

→ layers of 40 mm diameter and $\sim 160 \mu\text{g}/\text{cm}^2$ density

@ SCK CEN:

Purification $^{241}\text{Am}/^{239}\text{Pu}$
of the order 1 ppm

proposed for end of this year

sck cen

Experimental setup

Samples



^{239}Pu Material already @JRC-Geel from the $^{239}\text{Pu}(n,\gamma)$ experimental campaign

Purity 99.90 wt.%, **May, 2017**,
0.10 wt.% Pu-240-241-242

@ SCK CEN:

Purification $^{241}\text{Am}/^{239}\text{Pu}$
of the order 1 ppm

proposed for end of this year

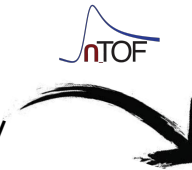
sck cen

@IJCLab, Orsay
samples preparation



^{239}Pu will be deposited on ultra-thin aluminum foils (2 μm thick) by electroplating

→ layers of 40 mm diameter and $\sim 160 \mu\text{g}/\text{cm}^2$ density



Fission Collimator

beam profile > samples diameter

Measurement relative to $^{235}\text{U}(n,f)^*$

→ ^{235}U samples with the same dimension

* $^{235}\text{U}(n,f)$ relative to n-p @n_TOF up to 450 MeV (INTC-P-507 – paper submitted)

Proton request

The $^{239}\text{Pu}(n,f)$ cross section will be measured as ratio with respect to the $^{235}\text{U}(n,f)$

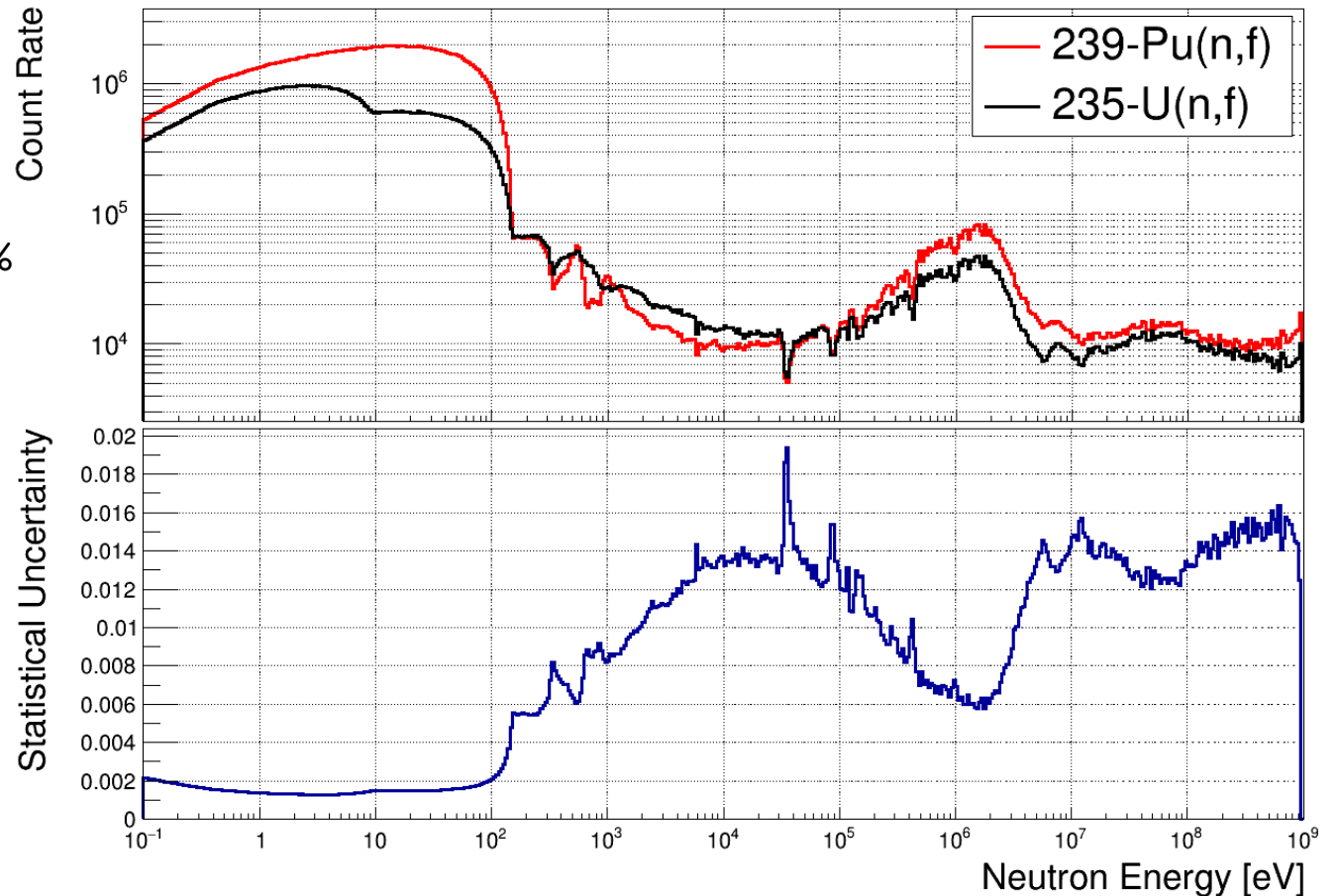
First measurement from thermal neutron energy to GeV

Considering:

EAR1 – fission collimator
 effective BIF of 0.35
 the typical FFs detection
 efficiency for the PPAC of 55%

the total number of fission
 reactions with **50 bpd** from
 6 ^{239}Pu and
 3 ^{235}U samples

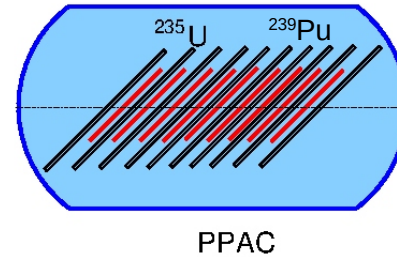
With
 4.5×10^{18} protons on target



INTC-P-705 + INTC-P-507-ADD-1

We propose to measure the $^{239}\text{Pu}(n,f)$ cross section as ratio with respect to the $^{235}\text{U}(n,f)$ cross section

4.5×10^{18} protons on target – EAR1 fission collimator



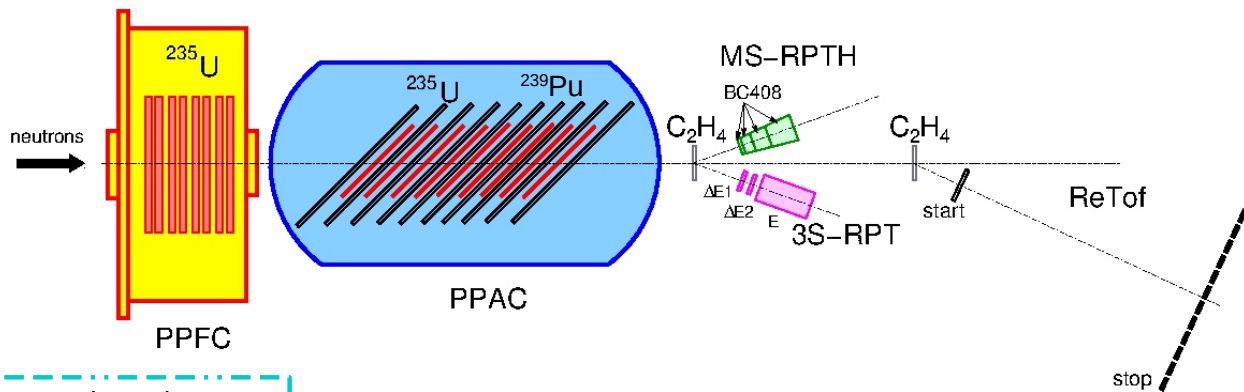
“...Our analysis indicates that the new absolute measurements of the neutron induced fission cross sections on uranium, bismuth, lead and **plutonium** have the highest priority in establishing neutron induced fission reaction standards above 200 MeV...”

INTC-P-705 + INTC-P-507-ADD-1

We propose to measure the $^{239}\text{Pu}(n,f)$ cross section as ratio with respect to the $^{235}\text{U}(n,f)$ cross section

4.5×10^{18} protons on target – EAR1 fission collimator

4.0×10^{18} protons on target – EAR1 capture collimator



“...Our analysis indicates that the new absolute measurements of the neutron induced fission cross sections on uranium, bismuth, lead and **plutonium** have the highest priority in establishing neutron induced fission reaction standards above 200 MeV...”

Conclusion

We propose to measure the $^{239}\text{Pu}(n,f)$ cross section as ratio with respect to the $^{235}\text{U}(n,f)$ cross section

The tilted PPAC ensemble is suitable for cross section measurement **from thermal energy to GeV**

The detector will be loaded with
6 ^{239}Pu samples and
3 ^{235}U samples

4.5×10^{18} protons on target – EAR1 fission collimator

^{239}Pu material already available

sck:cen proposed to perform the purification $^{239}\text{Pu}/^{241}\text{Am}$ by the end of this year
→ if approved, measurement could be performed in 2025

Conclusion

We propose to measure the $^{239}\text{Pu}(n,f)$ cross section as ratio with respect to the $^{235}\text{U}(n,f)$ cross section

The tilted PPAC ensemble is suitable for cross section measurement **from thermal energy to GeV**

The detector will be loaded with
6 ^{239}Pu samples and
3 ^{235}U samples

4.5×10^{18} protons on target – EAR1 fission collimator

^{239}Pu material already available

sck cen proposed to perform the purification $^{239}\text{Pu}/^{241}\text{Am}$ by the end of this year
→ if approved, measurement could be performed in 2025

Thank you for your attention

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Measurement of the neutron-induced fission cross section of ^{239}Pu at n_TOF

L. Audouin¹, M. Caamaño², D. Cano-Ott³, I. Duran², J. Heyse⁴, C. Le Naour¹,
A. Manna^{5,6}, C. Massimi^{5,6}, A. Mengoni^{5,7,8}, C. Paradela⁴, P. Schillebeeckx⁴, M. Spelta⁵,
D. Tarrío⁹, L. Tassan-Got¹, G. Vannini^{5,6}, A. Ventura⁵, R. Zarrella^{5,6}, and the n_TOF
Collaboration⁸

¹Université Paris-Saclay, CNRS, IJCLab, Orsay, France

²Universidad de Santiago de Compostela, Spain

³Centro de Investigaciones Energéticas Medioambientales y Tecnológicas, Spain

⁴European Commission, Joint Research Centre, Geel, Belgium

⁵INFN, Sezioni di Bologna and Trieste, Italy

⁶Dipartimento di Fisica e Astronomia, University of Bologna, Italy

⁷ENEA, Bologna, Italy

⁸CERN, Geneva, Switzerland

⁹Department of Physics and Astronomy, Uppsala University, Box 516, Uppsala, Sweden

April 9, 2024
Backup

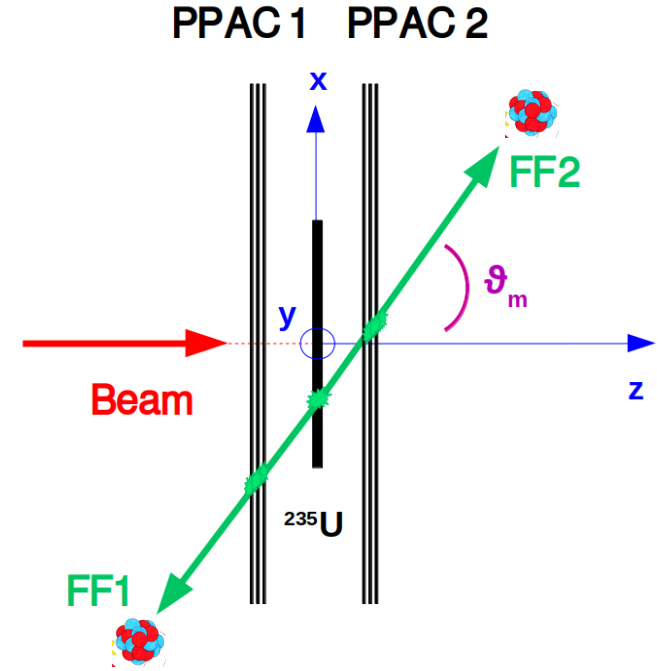
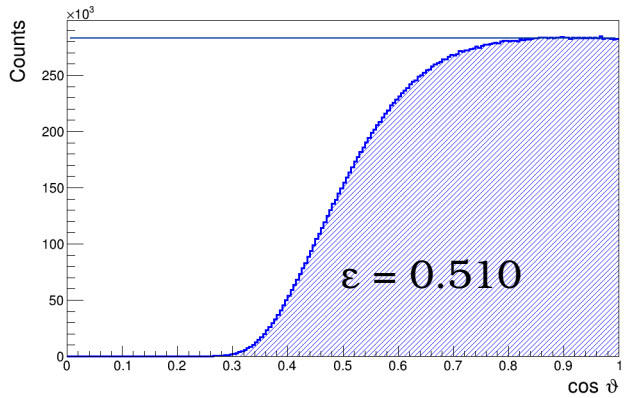
Spokespersons: Alice Manna (alice.manna@bo.infn.it), Laurent Audouin
(laurent.audouin@ijclab.in2p3.fr)

Technical coordinator: Oliver Aberle (oliver.aberle@cern.ch)

Systematics uncertainties

- ✿ ^{235}U and ^{239}Pu areal density
- ✿ Detector Efficiency
 - ~1.5% from thermal energy to ~100 keV
 - ~2% > 100 keV

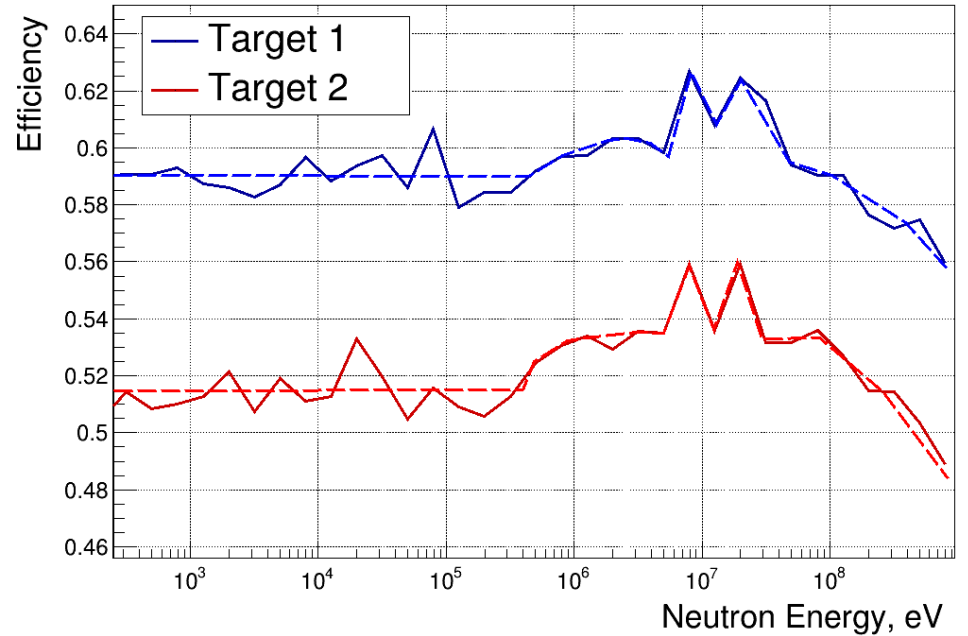
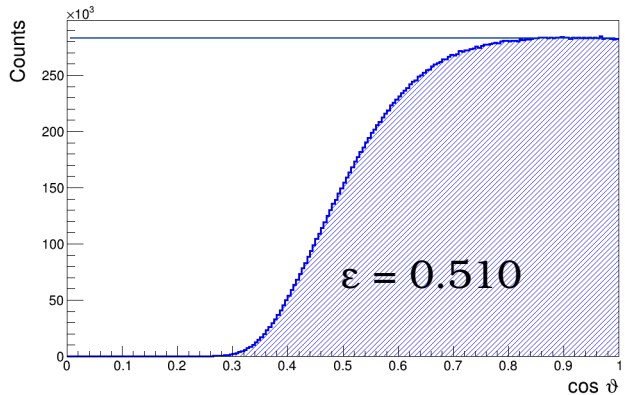
Can be determined experimentally



Systematics uncertainties

- ✿ ^{235}U and ^{239}Pu areal density
- ✿ Detector Efficiency
 - ~1.5% from thermal energy to ~100 keV
 - ~2% > 100 keV

Can be determined experimentally



geometrical efficiency geometrical efficiency

angular distribution

linear momentum transfer

With the tilted PPAC can be measured accurately so it is not part of the uncertainty assessment

