European Commission

OECD-NEA DB Experiments Europe

Arjan Plompen

Joint Research Centre

the European Commission's
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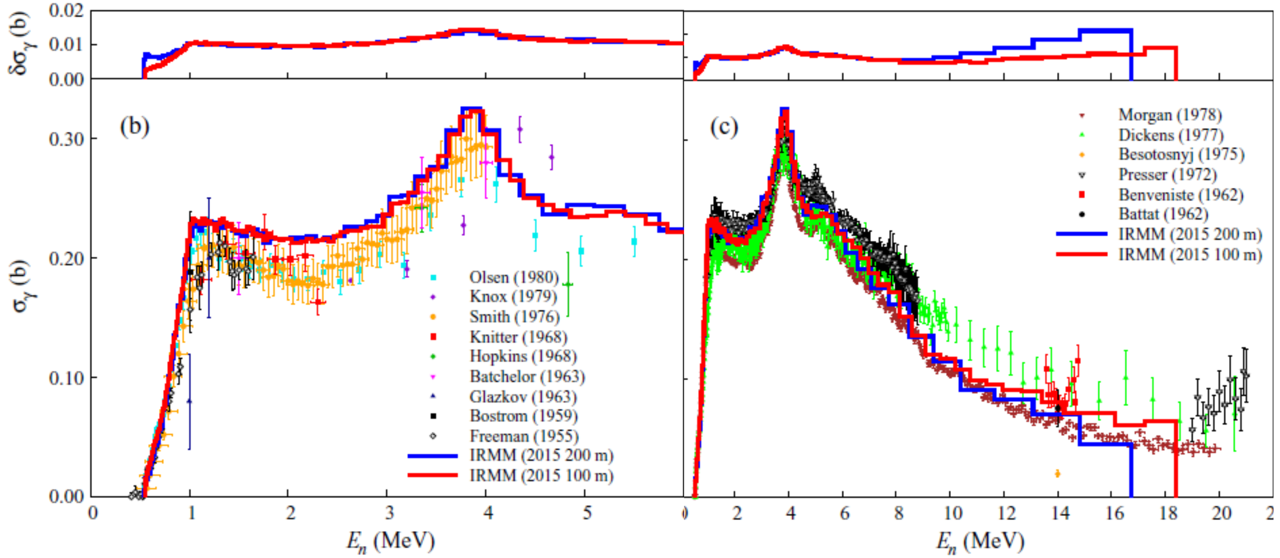
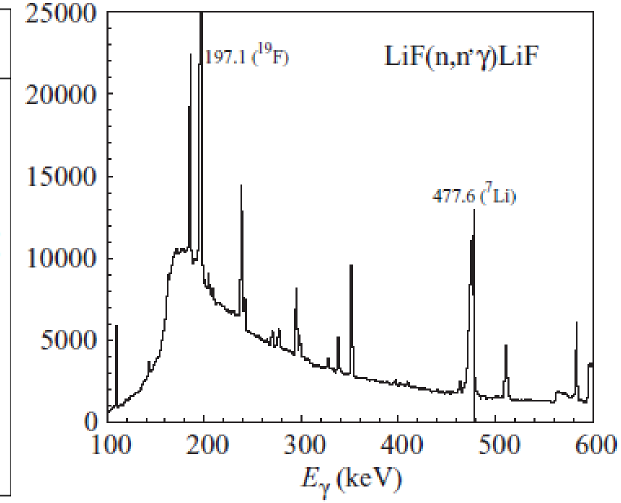
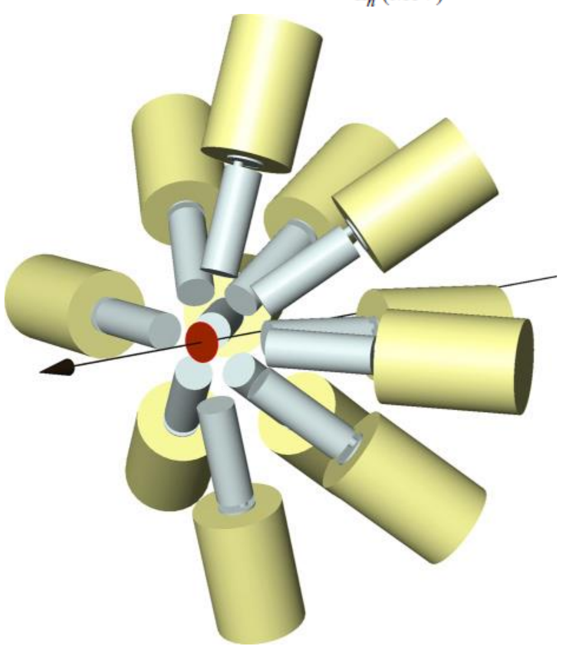
Nuclear Research Facilities at JRC Geel

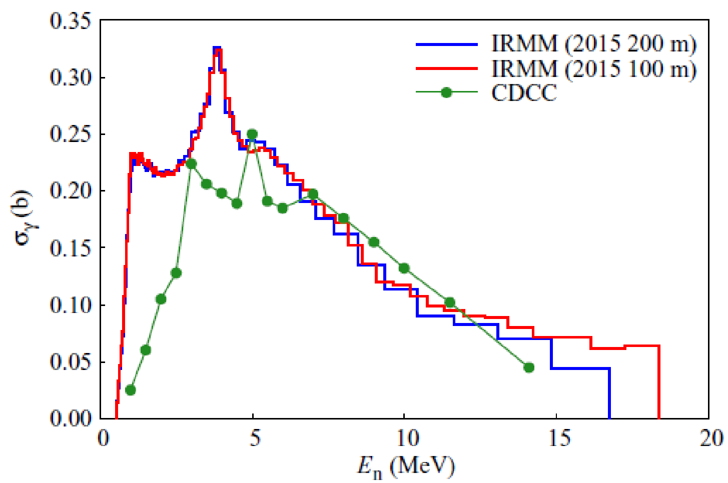
$^{7}Li(n,n'g)$

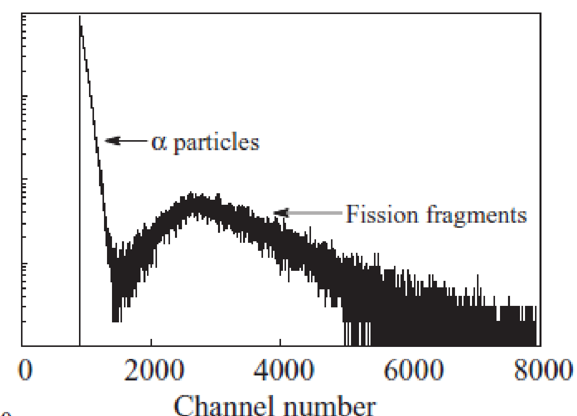
M. Nyman et al. PRC93(2016)024610











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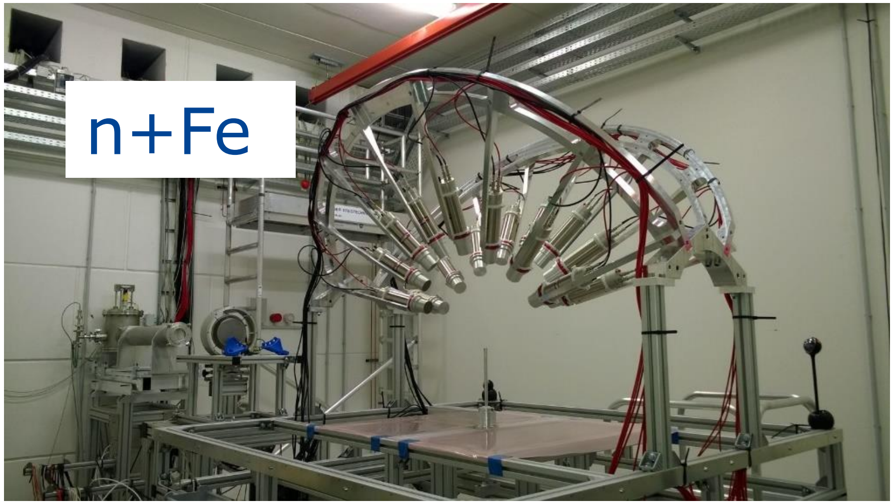
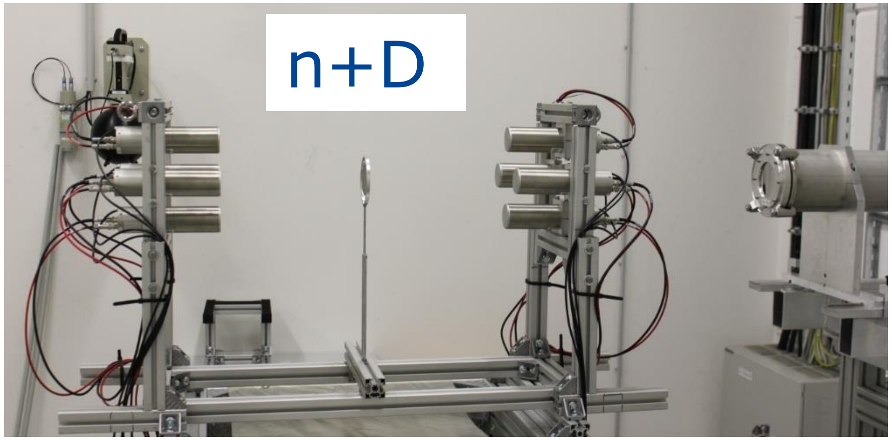
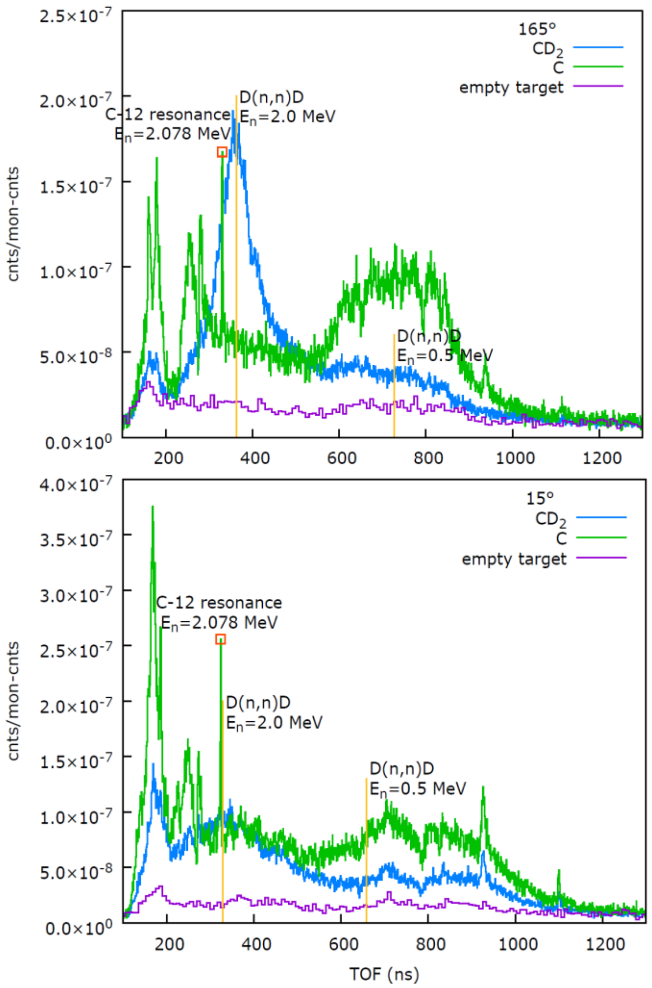
nELBE, example of TAA experiments







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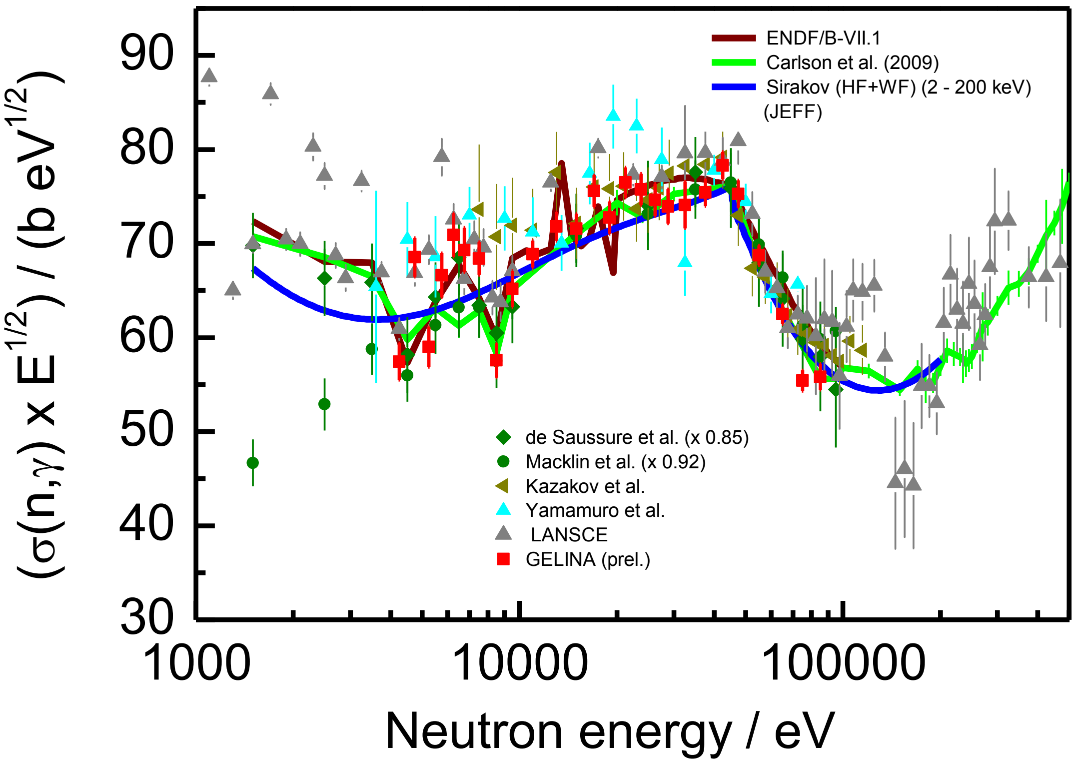
$^{238}U(n,\gamma)$ in URR



Scattering radius RRR

- ENDF-B/VII.1 : R' = 9.48 fm
- REFIT : R' = 9.65 fm

Scattering radius URR

- at 0 eV : R' = 9.6 fm

$S_0 = 1.06\ 10^{-4}$

$S_1 = 1.64\ 10^{-4}$

$S_2 = 1.38\ 10^{-4}$

$T_{\gamma,1/2+} = 6.48\ 10^{-3}$

$T_{\gamma,1/2-} = 6.46\ 10^{-3}$

Mass and kinetic energy distributions

Double velocity – double energy (2v-2E) spectrometer

VERDI

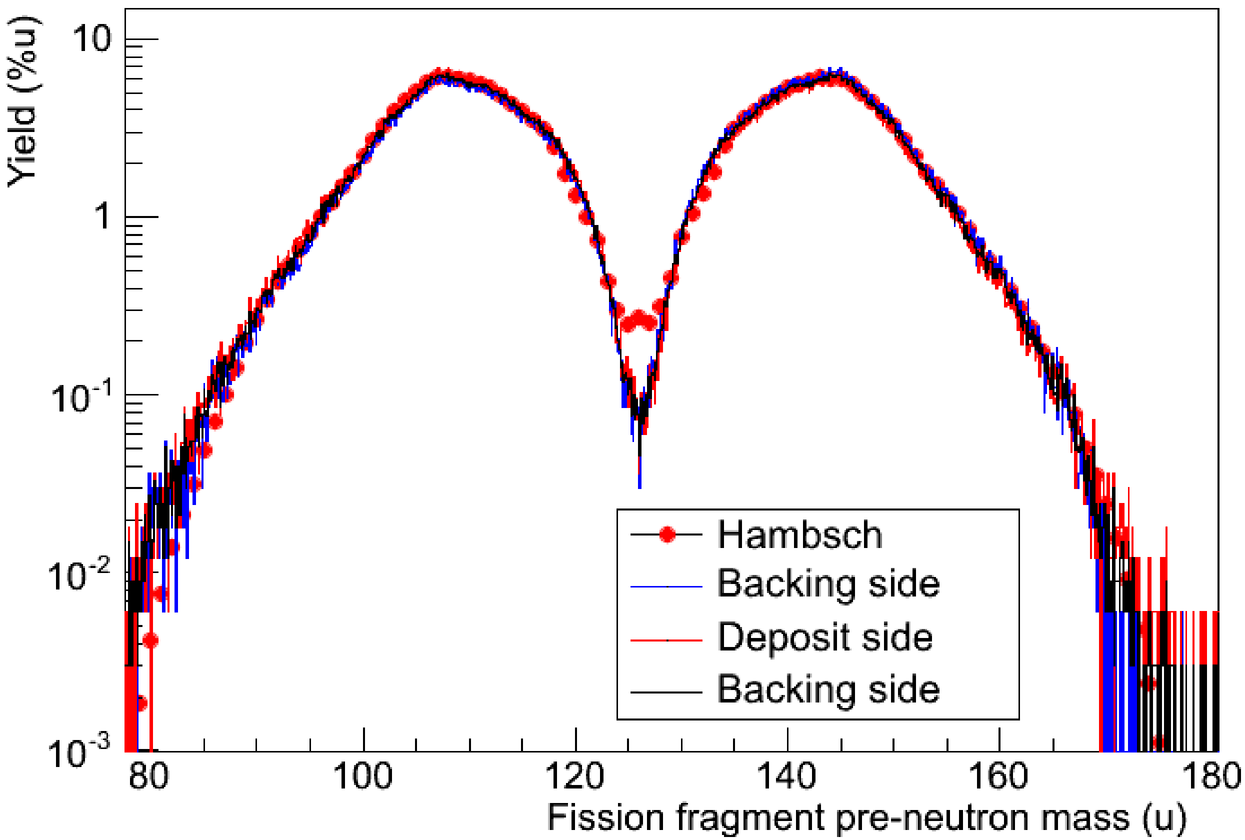
full 2v-2E version operational

pre-neutron mass resolution $\Delta A \approx 1.5$ u

geometrical efficiency, $\mathcal{O}(10^{-2})$

First Y(A*,A; ν) results

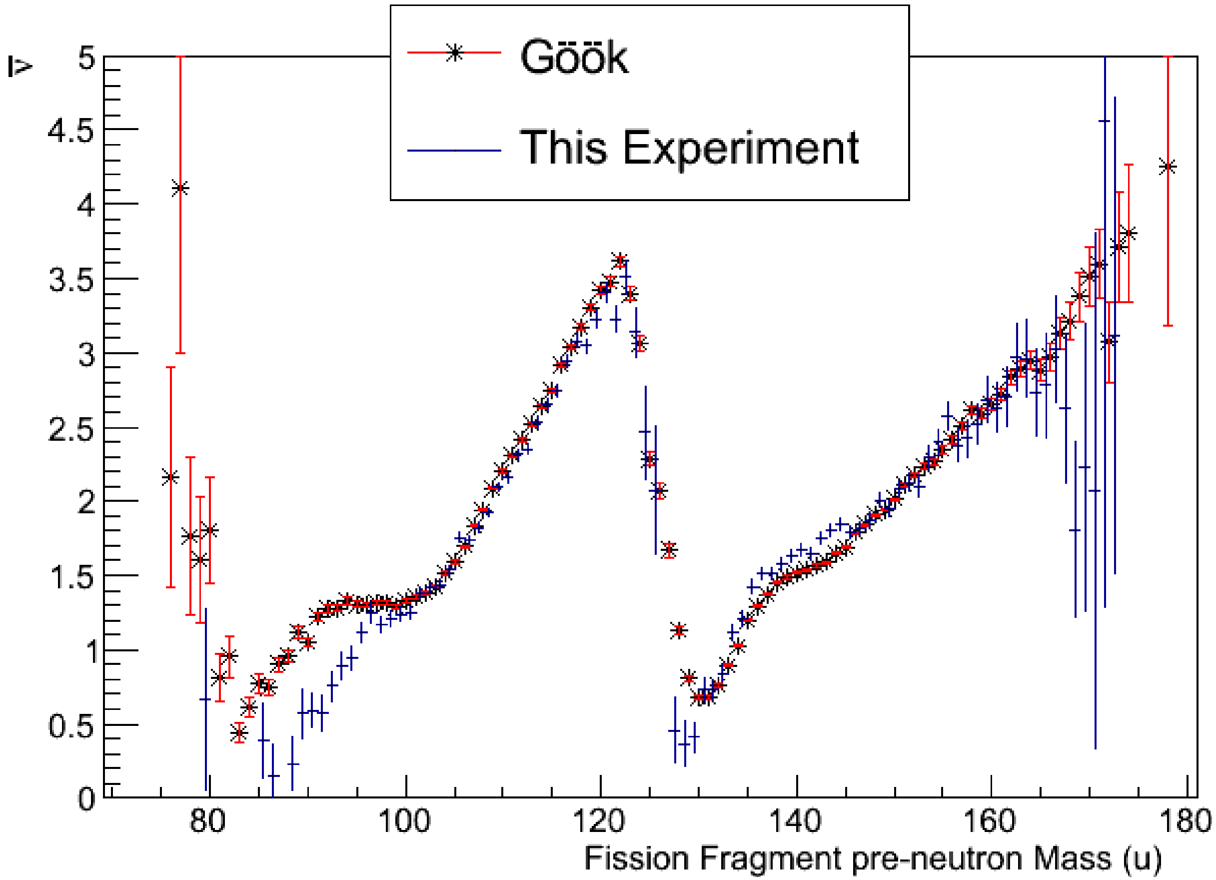
VERDI $^{252}Cf(SF)$ pre-neutron yield



Comparison to high resolution 2E measurement
(Hambsch, Oberstedt, Nucl. Phys A617 (1997))

VERDI shows better resolution especially in symmetry (lower yields)

VERDI ν(A) ^{252}Cf(SF)



Very good agreement in shape with neutron detector and ionisation chamber measurement (Göök et al., Phys. Rev. C90 (2014))

VERDI post and pre-neutron data subtraction needs still scaling of 15%

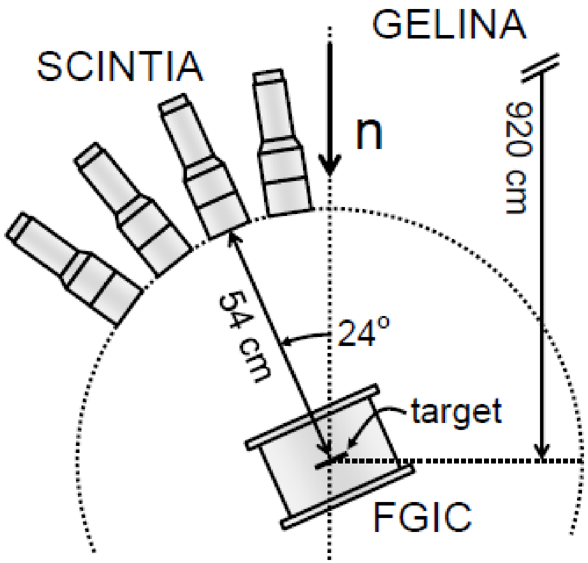
To be improved in next step by adding a 2nd start detector (in preparation)

Collaboration started with Uppsala University (PhD thesis), CEA, Saclay and GANIL, Caen

European Commission

SCINTIA array

- Array of 12 neutron detectors
  - 7 SCIONIX LS301 (Φ=13 cm, h=7 cm)
  - 5 P-therphenyl (Φ=8.5 cm, h=6.8 cm)
- Twin Frisch grid ionisation chamber
- GELINA TOF 8 m station
- Double TOF setup
- Digital signal processing



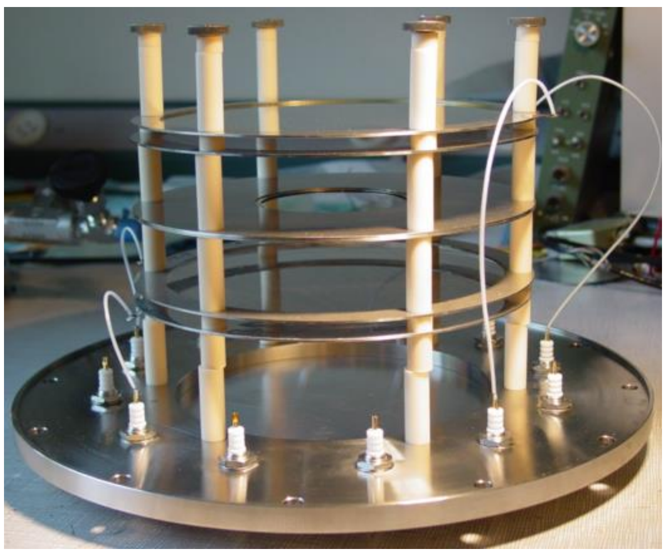
Request of better $\nu(E_n)$ and ν (A) by evaluations for ^{235}U and ^{239}Pu

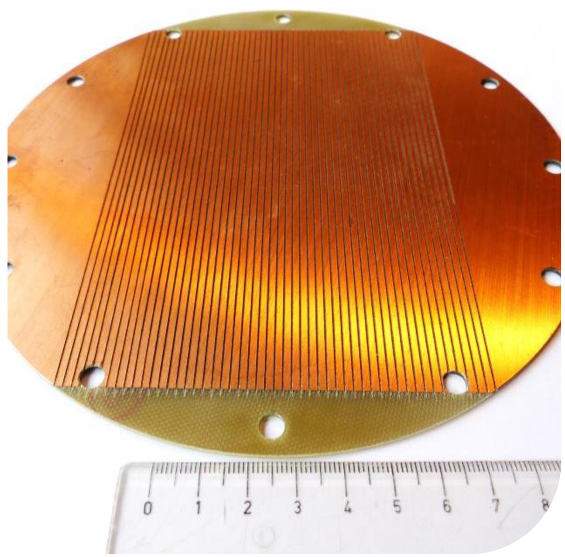
Fission Fragment Detector

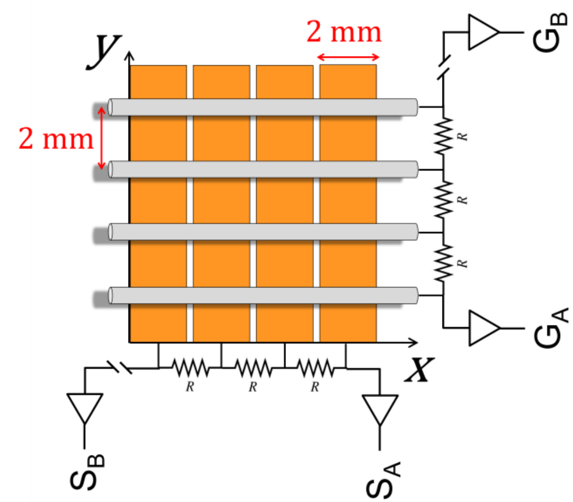
Position Sensitivity is required

- Electron collector in ionization chamber replaced by position sensitive electrode
- Charge-division readout

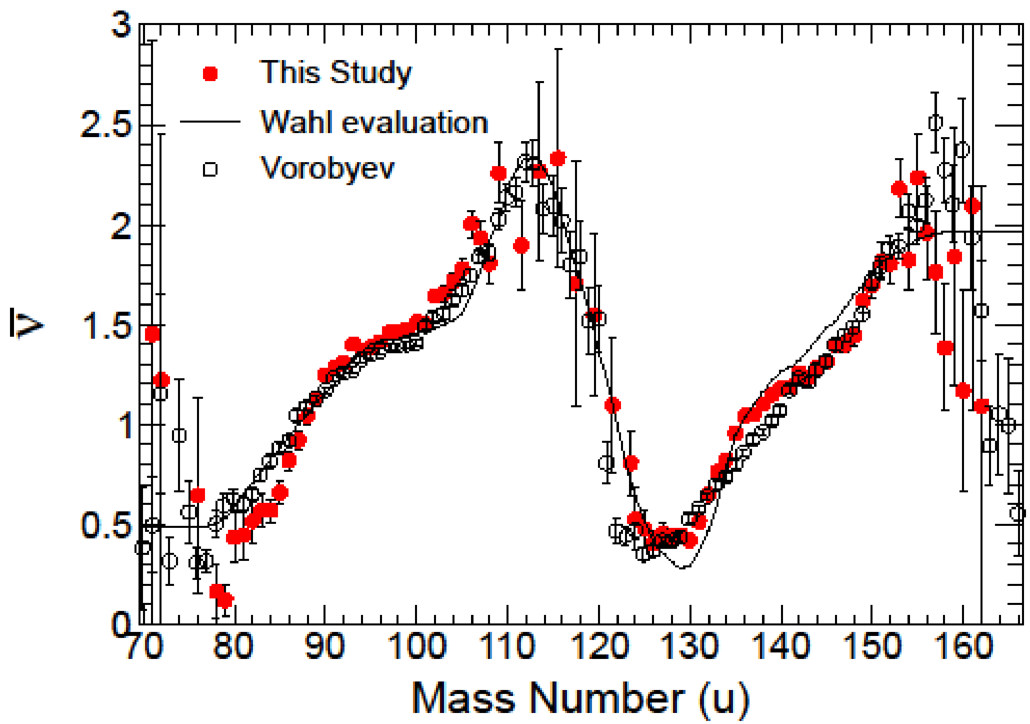
Orientation of fission-axis in 3D-space







Prompt neutron emission as a function of mass



- Continuation with ^{235}U (first half 2016)
- Extension of the SCINTIA array with another 12 neutron detectors and digital channels (order placed)
- Resonance neutron induced fission of ^{239}Pu (2nd half 2016 or towards end 2016)

Collaboration started with Uppsala University

European Commission

Prompt γ-ray emission

Prediction of γ-heating for design of Gen-IV reactors

about 10 % of total energy released in the core of a standard nuclear reactor by fission γ-rays
about 40 % of those due to prompt γ-decay of fission products

Modelling requires uncertainty not larger than 7.5 % (1σ)

present γ-ray emission data determined in early 1970's,
underestimating γ-heating with 10 - 28 % for ^{235}U and ^{239}Pu

OECD/NEA Nuclear Data HPRL (H:3,H:4):

measurement of prompt γ-ray emission from ^{235}U(n,f) and ^{239}Pu(n,f)

European Commission

Measurement method

active sample on polyimide backing

backing only 30 $\mu g/cm^2$ thick

Vacuum deposition, molecular plating

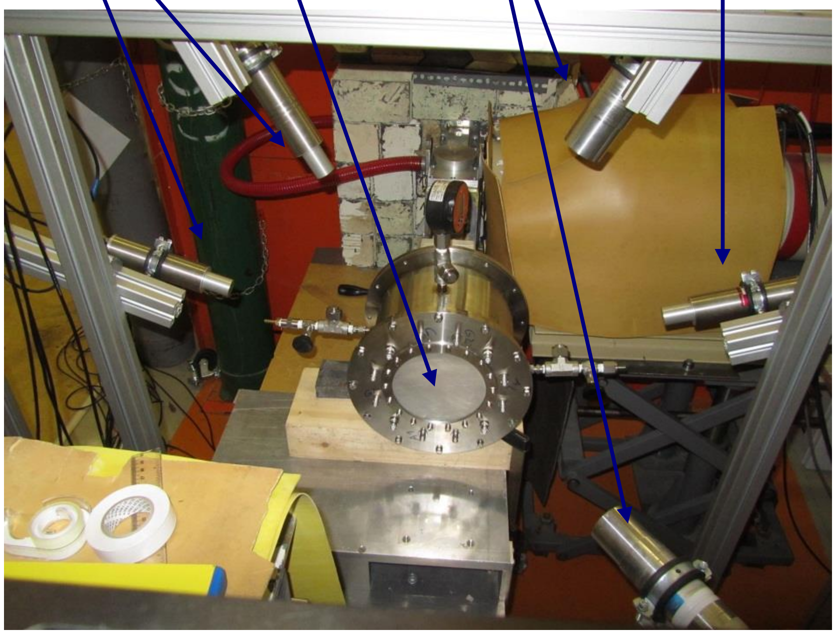
^{232}Th, $^{233-238}U$, $^{239,241}Pu$ (IRMM SP group)

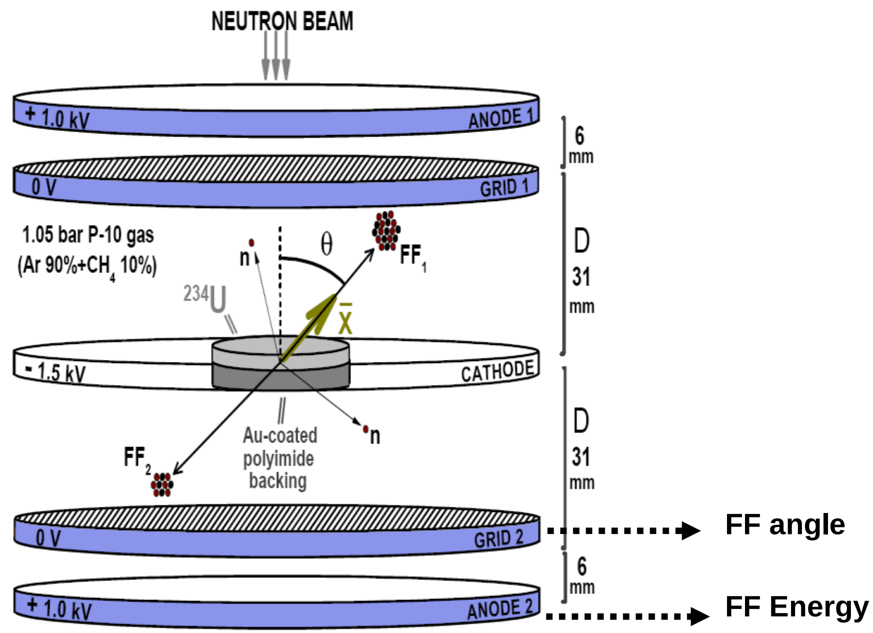
Twin Frisch-grid ionization chamber

$LaBr_3$ 2”× 2”

$CeBr_3$ 1”× 2”

$CeBr_3$ 1”× 2”





support by the ERINDA and CHANDA FP7 programmes

Present situation

- Investigated fissioning systems
  - Thermal n-induced fission of ^{241}Pu, ^{239}Pu (Nov 2015), ^{235}U
  - Spontaneous fission of ^{252}Cf (method development)
  - Difference to evaluation (ENDF/B-VII)
    - $^{252}Cf(SF)$ ~ 3.5 %
    - $^{235}U(n_{th},f)$ ~ 5 %
    - $^{241}Pu(n_{th},f)$ ~ 3.4 %
    - $^{239}Pu(n_{th},f)$ to be analysed

Collaboration with IPN, Orsay on fast neutron induced fission on $^{235,238}U$ (shape data published in PRC92, spectral data on U8 submitted) ^{239}Pu (starting Feb. 2016)

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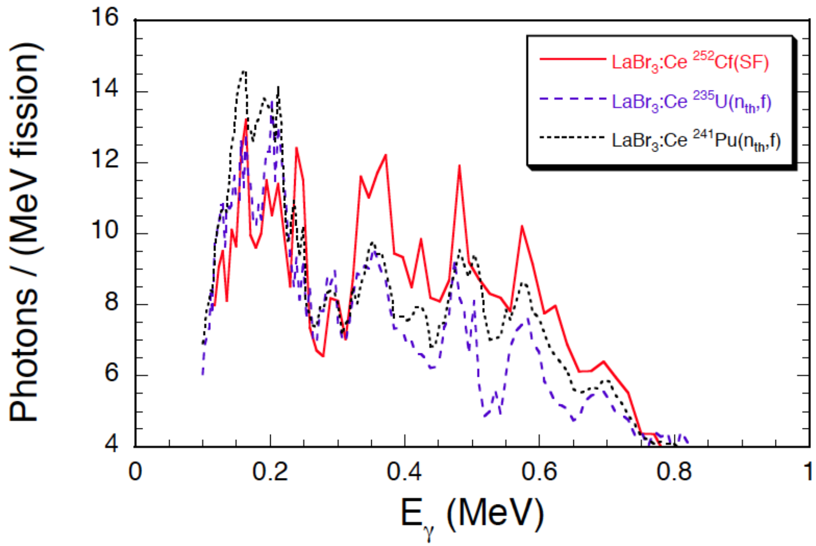
Prompt fission γ-rays $^{241}Pu(n_{th},f)$ TAA, Budapest

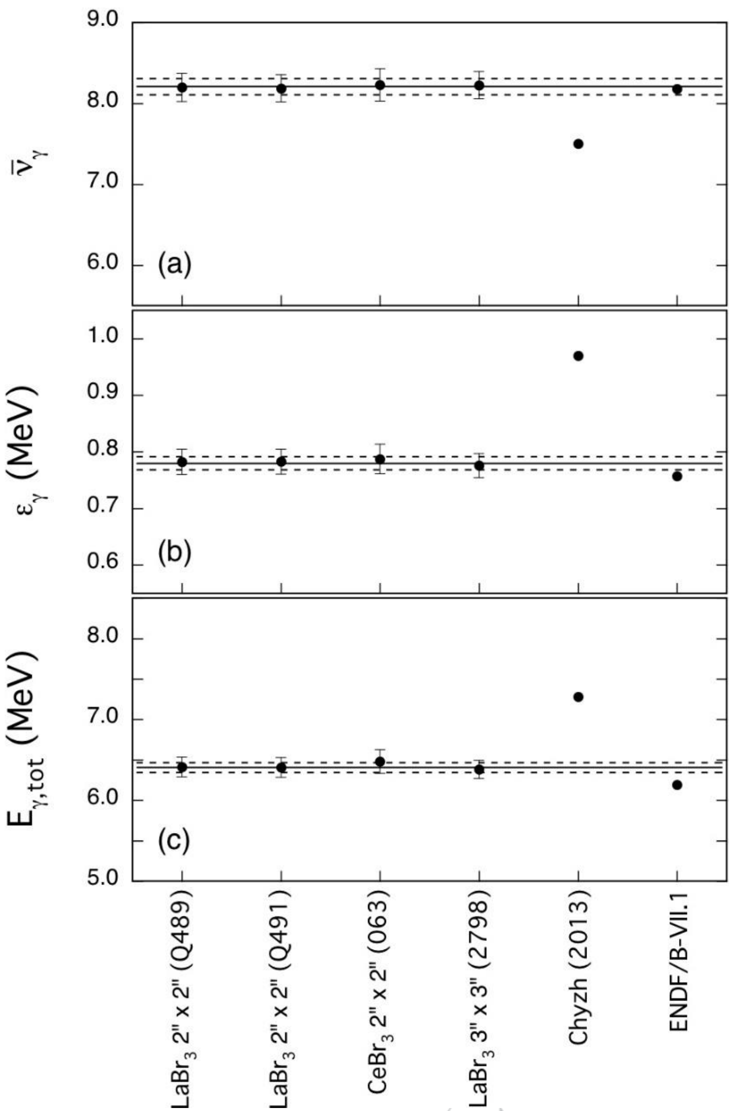
In response to an OECD/NEA high-priority data request

Relevant for γ heating

Data for benchmarking nuclear models

High-precision prompt γ-ray spectral data





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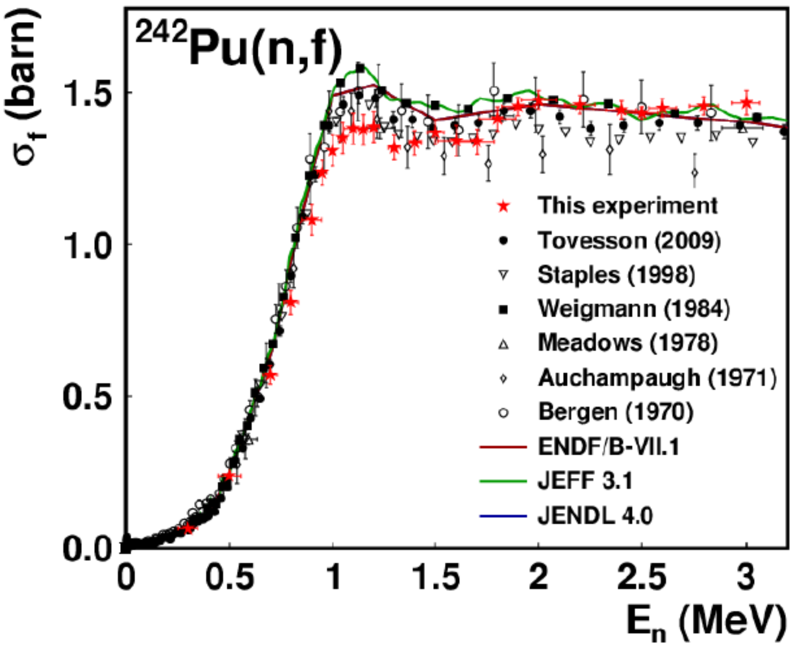
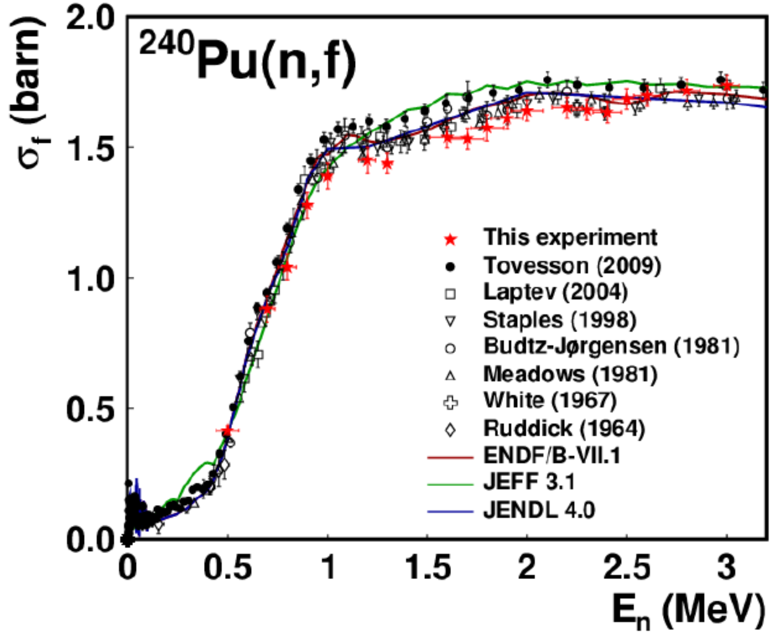
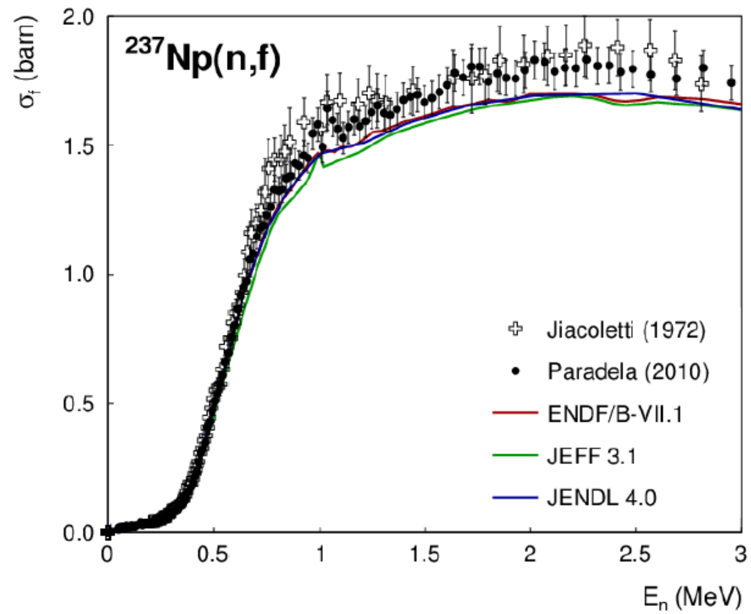






Collab with UPC Barcelona

MCNP modeling of setup

Thin ^{242}Pu target

Reference Targets:

^{235}U, ^{237}Np, ^{238}U

P. Salvador Castineira et al.
Phys. Rev. C 92, 044606 (2015)
Phys. Rev. C 92, 014620 (2015)
Phys. Rev. C 88, 064611 (2013)

Activities status
05-2016

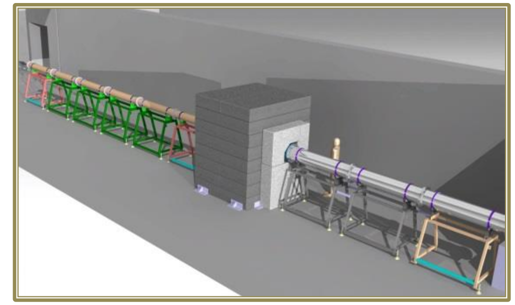
Inelastic scattering @ GELINA

- Reassembly of the set-up after refresh works in the cabin (02/2016)
- ^{233}U measurement campaign started with the segmented HPGe detector

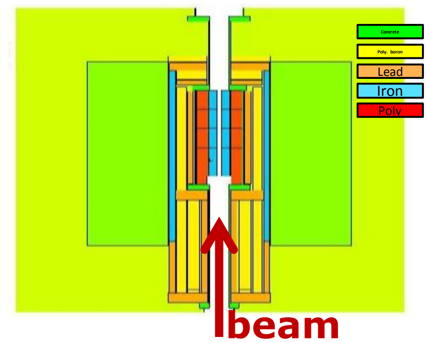
- ^{238}U completion of analysis & theoretical progresses of the description of (n,n' γ) cross sections (tests of the influence of structure parameters)
- $^{nat,182}W$ and ^{232}Th analysis in progress

NFS : time of flight facility

- Vacuum pipe under construction



- Design of the second collimator



e^- conversion measurements

- Bibliography and review of the technics have been done (IPHC)
- Simulations (IPHC) and tests of Si detector with alpha source under vacuum are in progress (IFIN)

Towards measuring neutron-induced independent fission yields at IGISOL

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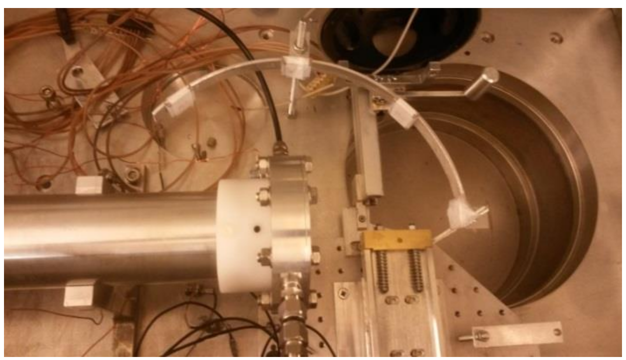
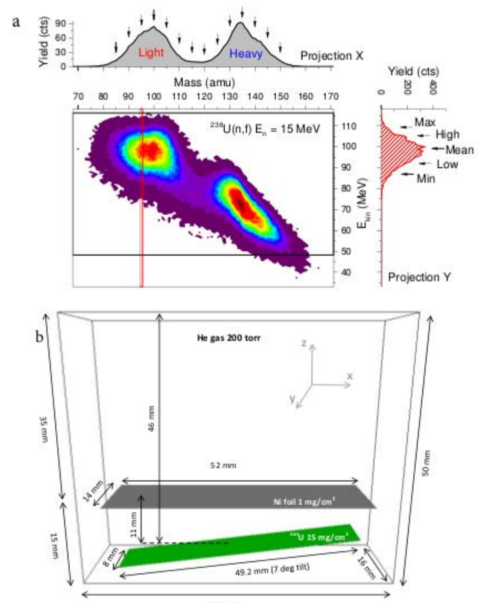
M. Lantz, A. Mattera, V. Rakopoulos, A. Solders , A. Al Adili, S. Pomp, A. Prokofiev, and the JYFL IGISOL team

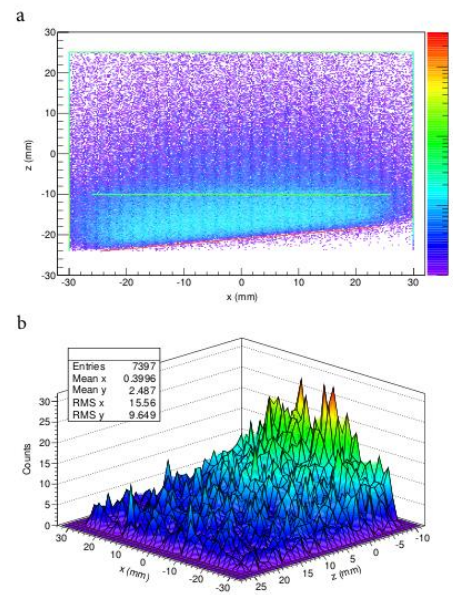
Goal: Obtain high quality data for better understanding of the fission process and for better use of resources in present and future nuclear systems.

Method: Measurements of neutron-induced independent fission yields from different fissile isotopes (^{235,238}U, ^{239,240}Pu, ^{241,243}Am) with fast and thermal neutrons.



Characterization of Be(p,xn) neutron field with activation plates.





Simulations of mass- and energy dependence of fission product extraction efficiencies.

A. Solders et al., NDS 119 (2014) 338
A. Smirnov et al., NIM A 687 (2012) 14
A. Al Adili et al., EPJA (2015) 51:59

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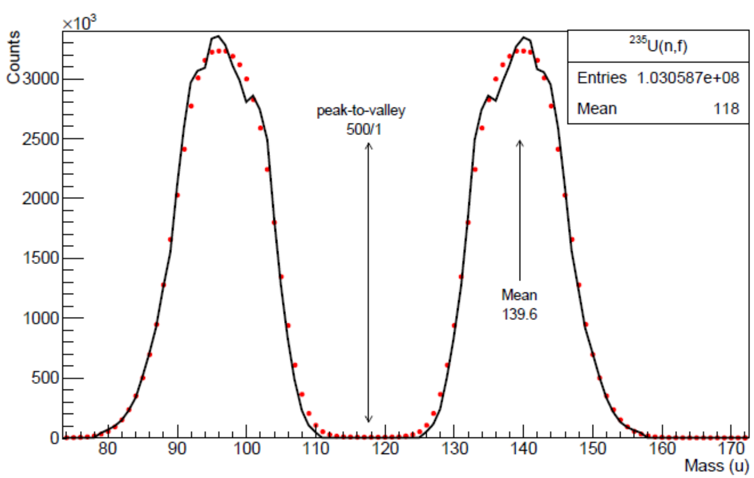
Measurement of $^{234}U(n,f)$ at sub-thermal energies at ILL

SEE CNR15 conference proceedings, A. Al-Adili et al. (2016) - In print

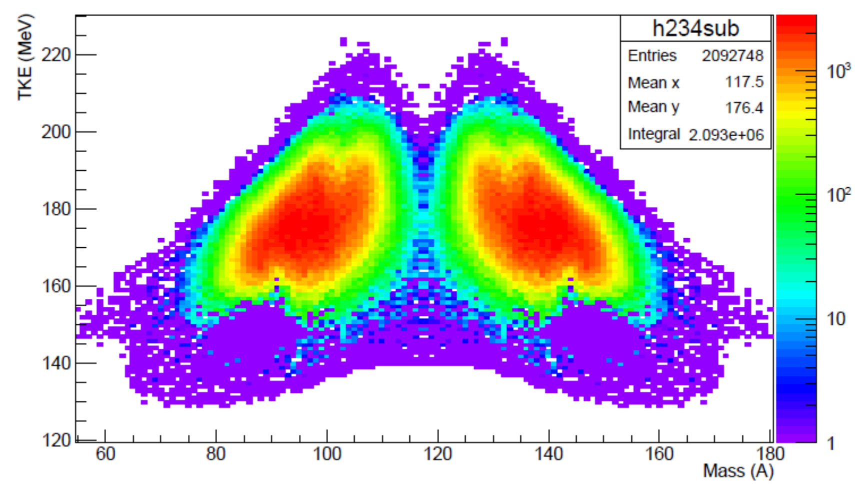
A. Al Adili[1], F.-J. Hambsch[2], S. Oberstedt[2], A. Göök[2], D. Tarrio[1], S. Pomp[1]

[1]Uppsala University, Sweden [2]JRC-IRMM, Belgium

Aim:	Measure, for the first time, the fission mass yield, angular- and energy distributions of 234U(n,f) at sub-thermal energy
Data:	Obtained in 1999. Problem: large U-235 background.
Method:	Frisch-Grid Ionization Chamber with CF_4 as counting gas.
Targets:	U-234 target: 92.677 µg/cm^2; U-234: 99.08%, U-235: 0.077%
	U-235 target: 86 µg/cm^2; U-238: 99.3%, U-235: 0.7%



Preliminary result for mass distribution from U-235 target (red dots).
Solid line: Simon et al. NIM A286 (1990) 220



Preliminary results for U-234 (background subtracted)
"Trick": analyze U-235 as U-234 and subtract

Measurement of nubar(A,E) and PFNS for ^{235}U and ^{237}Np at IRMM

A. Al Adili[1], A. Göök[2], K. Jansson[1], F.-J. Hambsch[2], S. Oberstedt[2], V. Rakopoulos[1], A. Solders[1], D. Tarrio[1], S. Pomp[1]

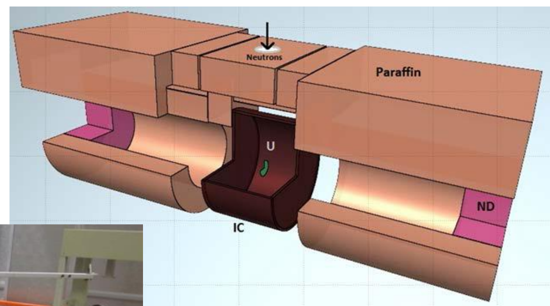
[1]Uppsala University, Sweden [2]JRC-IRMM, Belgium

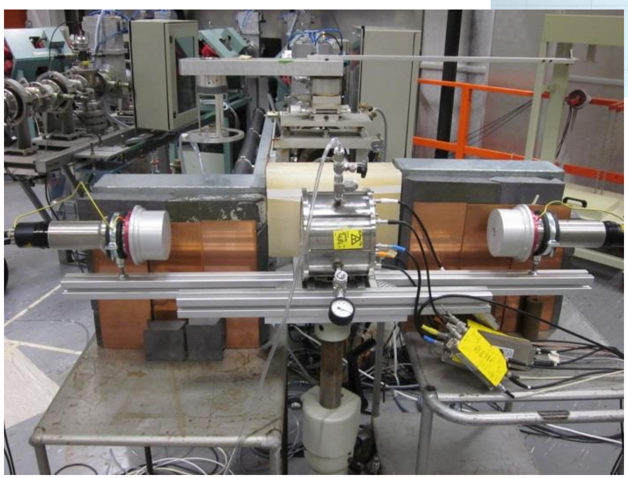
Aim: Measure nubar and PFNS as function of energy and mass for various targets

Method: Frisch-Grid Ionization Chamber + neutron detectors from SCINTIA setup

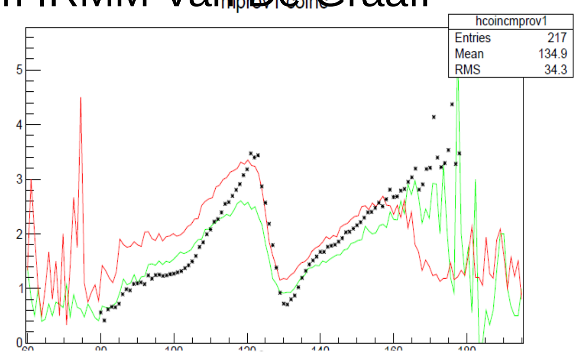
Data: First measurements with thermalized neutrons from IRMM Van De Graaff
New run at higher energy (5.5 MeV) planned.

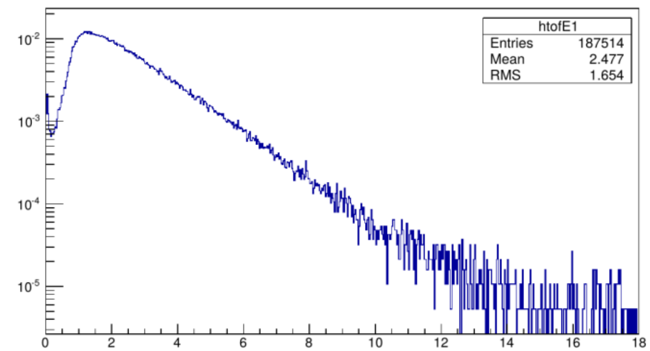
Drawing for FLUKA simulations





Setup with FGIC, 2 neutron detectors, moderator and shielding





SEE CNR15 conference proceedings, A. Al-Adili et al. (2016) - In print

VERY preliminary result for Cf252 Nubar and PFNS

Measuring FF properties with the VERDI (2E-2v) spectrometer at GELINA

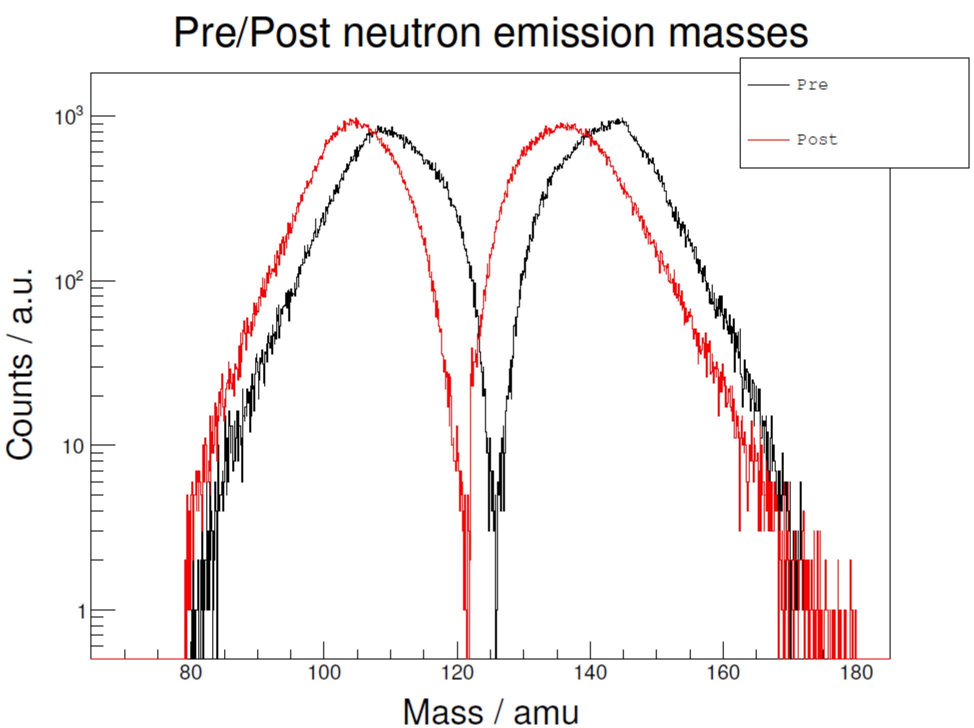
K. Jansson[1], S. Oberstedt[2] , M.-O. Fregeau[2,3], A. Al Adili[1], C. Gustavsson[1], F.-J. Hambsch[2], D. Tarrio[1], S. Pomp[1] , et al.

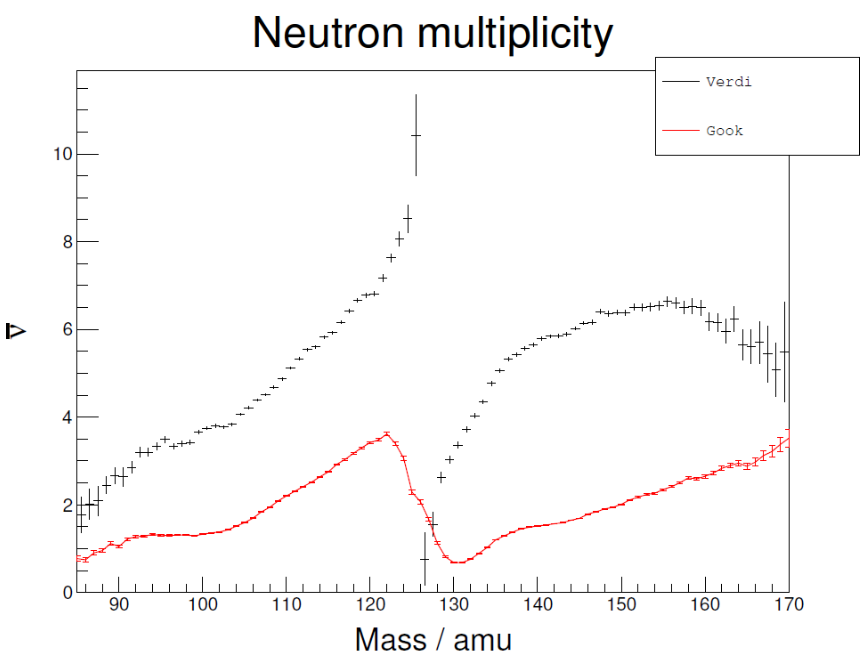
[1]Uppsala University, Sweden [2]JRC-IRMM, Belgium [3]GANIL, France

Aim: Develop VERDI and measure FF properties via the 2E-2v method.

Method: VERDI spectrometer at GELINA facility.

Status: Proof of principle using both arms (individual timing information). Test case: Cf(sf).





Part of PhD project of Kaj Jansson

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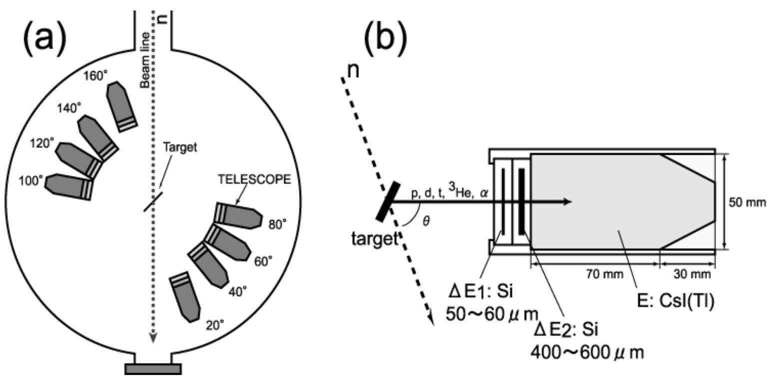
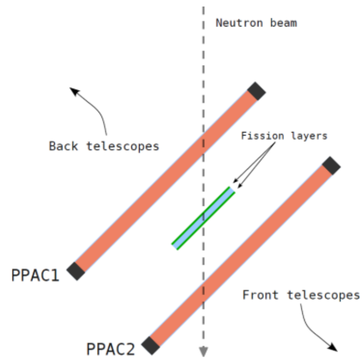
Fission fragment angular distribution and fission cross section measurements relative to elastic np scattering with Medley@NFS

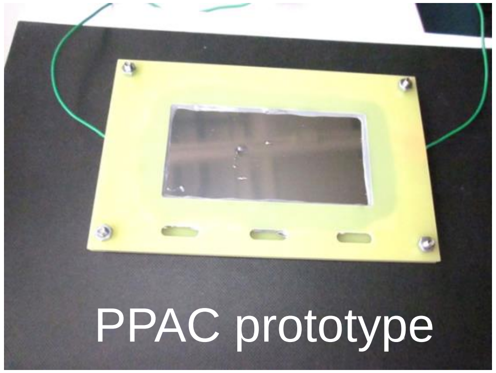
D. Tarrío, A.V. Prokofiev, S. Pomp, C. Gustavsson, K. Jansson, E. Andersson Sundén

Aim: Simultaneous measurement of cross sections for H(n,n), ^{235}U(n,f), and ^{238}U(n,f) over the energy range of the future ”white” neutron beam at NFS (1–40 MeV).
Goal: High-quality data (uncertainties below 2%) on neutron standard cross sections.

K. Jansson et al., NDS 119 (2014) 395
K. Jansson et al., NIM A794 (2015) 141







The existing Medley setup is being upgraded with PPACs to allow neutron ToF measurements. A gas system for the chamber is operational. The targets are under development within the CHANDA project. The beam time at NFS is expected in 2017.

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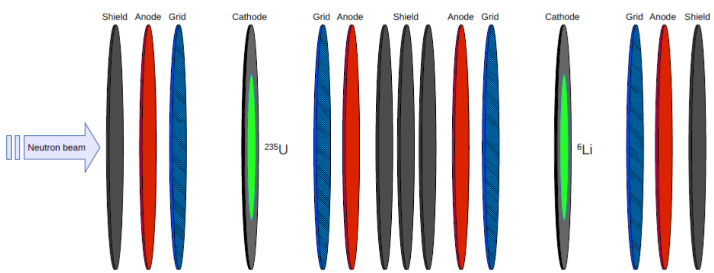
Measuring ^{6}Li (n,α) at IRMM with the GELINA white spectrum neutron source

K. Jansson[1], A. Al Adili[1], C. Gustavsson[1], F.-J. Hambsch[2], S. Oberstedt[2], D. Tarrio[1], S. Pomp[1] , et al.

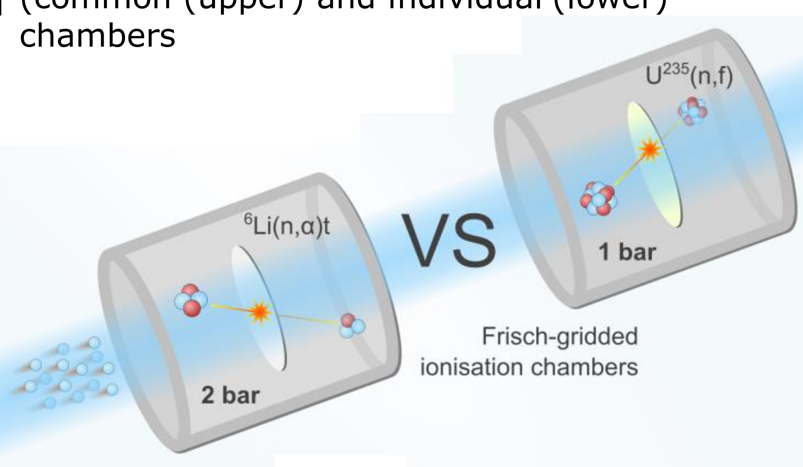
[1]Uppsala University, Sweden [2]JRC-IRMM, Belgium

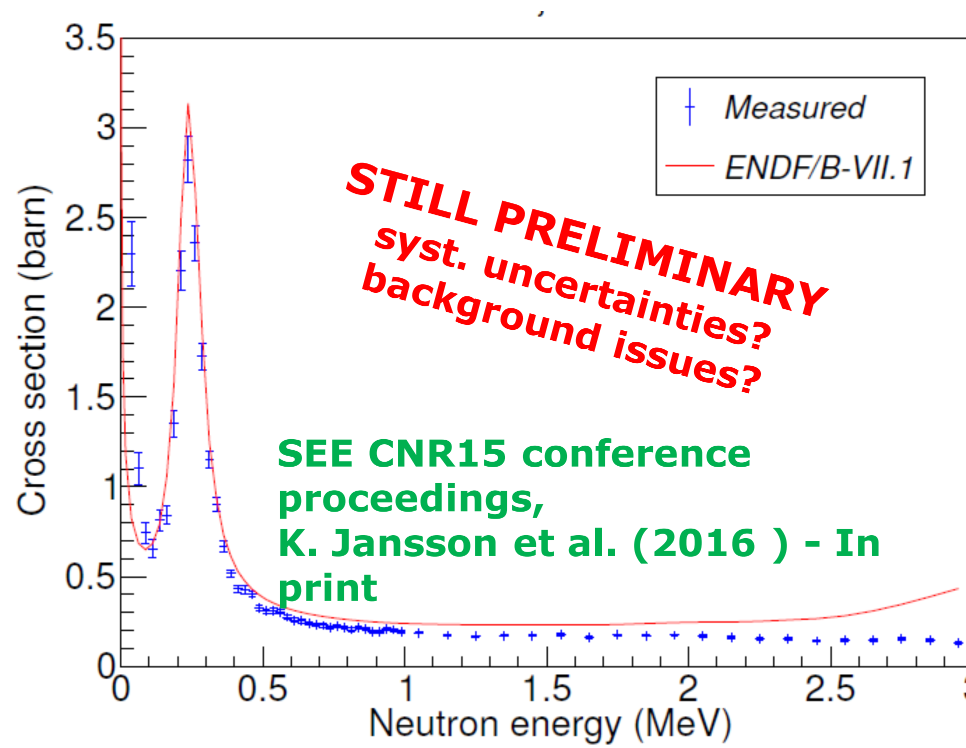
Aim: Measure ^{6}Li(n,α) cross section up to several MeV for extension of neutron standard

Method: Twin Frisch-Grid Ionization Chamber (with P-10) at GELINA facility using LiF targets and U-235 as reference; digital DAQ



TFGIC with U-235 and LiF target (common (upper) and individual (lower) chambers





Part of the PhD project of of Kaj Jansson

The SOFIA collaboration

CEA

GSI

IPN
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

CENBG

GANIL spiral2
laboratoire commun CEA/DSM CNRS/IN2P3

USC
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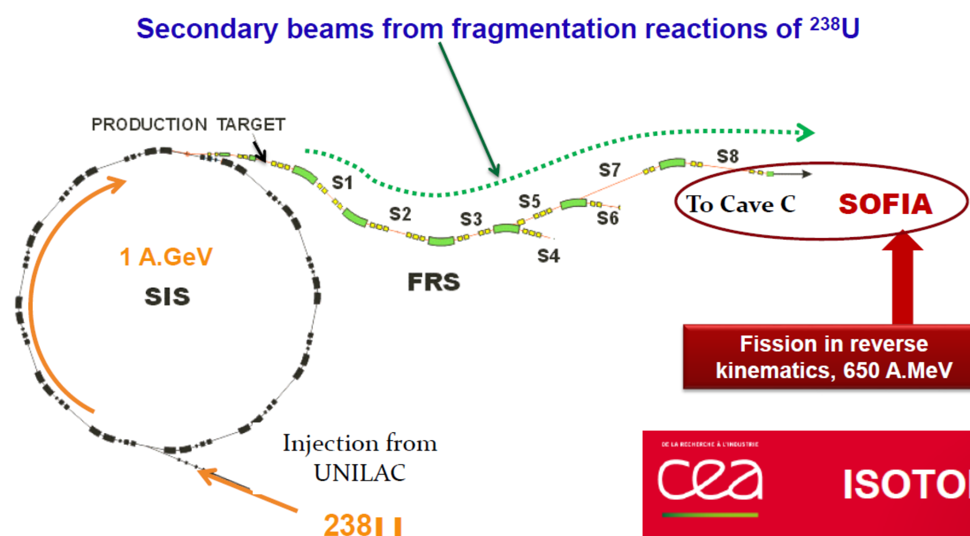
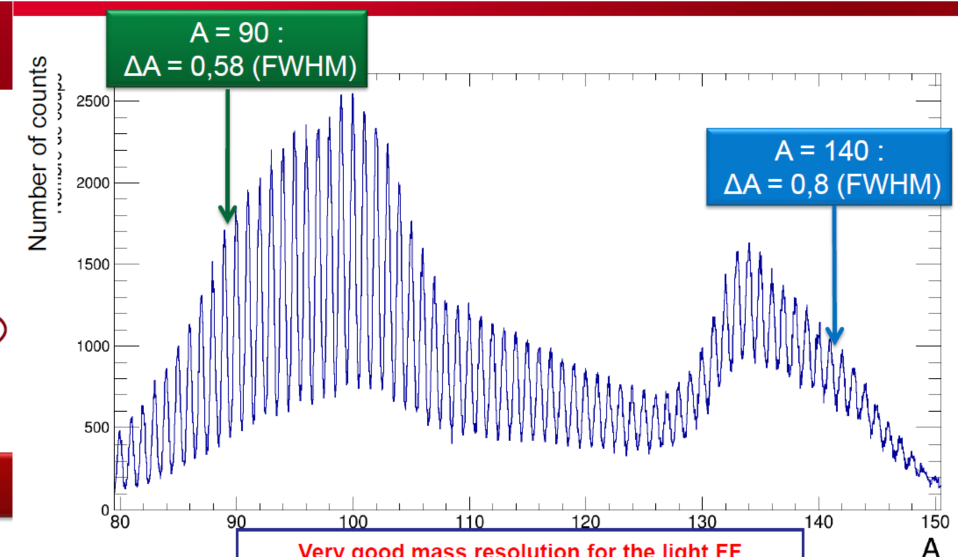
DE SANTIAGO
DE COMPOSTELA

UNIVERSIDADE
DE VIGO

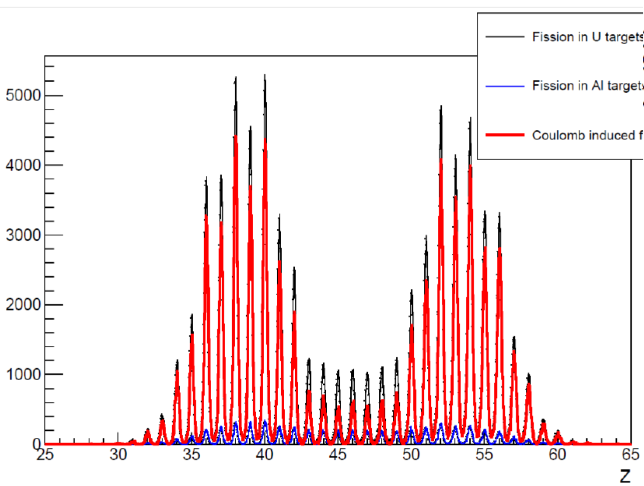
AVANCEZ
1829
CHALMERS
UNIVERSITY OF TECHNOLOGY

GSI (DARMSTADT)



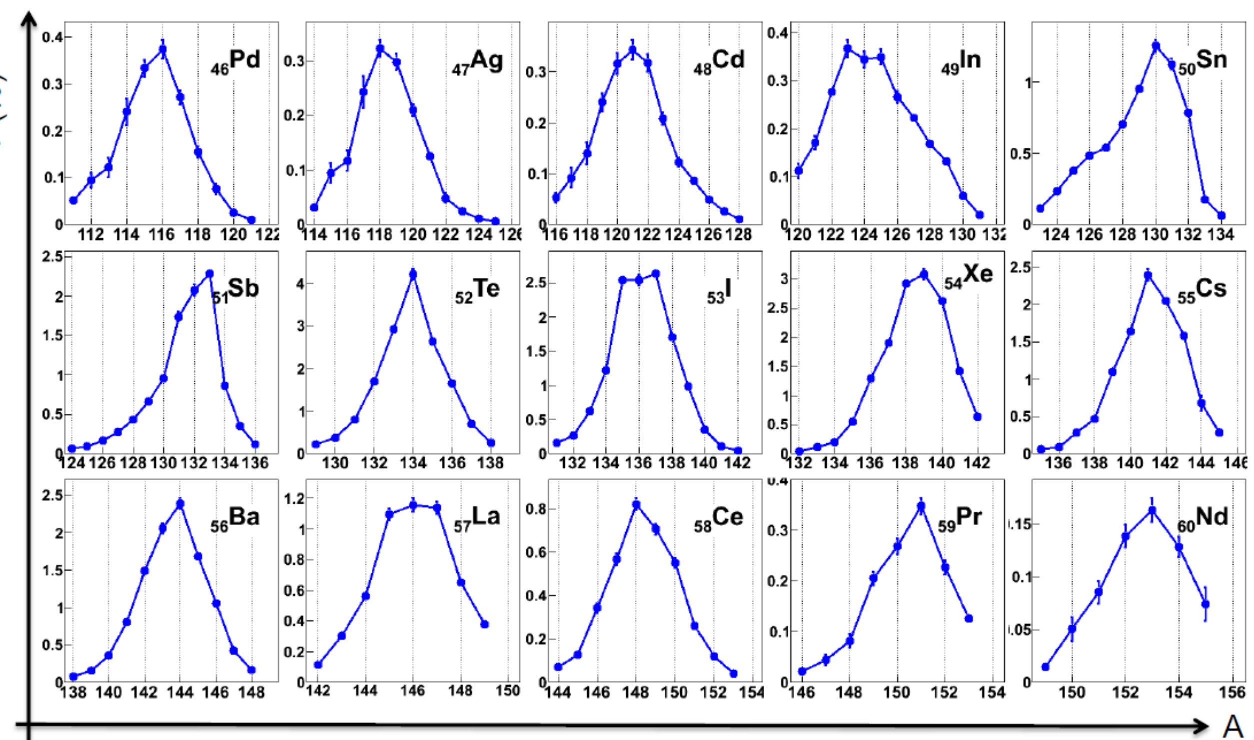


^{236}U CHARGE COULEX INDUCED FISSION



- 2.3 Million events…

ISOTOPIC YIELDS (HEAVY FF)

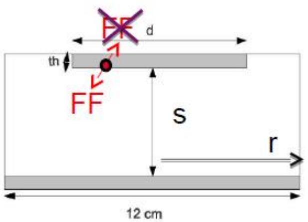


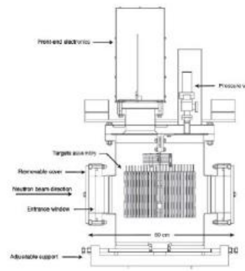
Recent results of fission measurements at n_TOF on ^{235}U, ^{238}U and ^{237}Np

Laurent Audouin (IPN Orsay / univ. Paris-Saclay)
Maria Diakaki (CEA/Irfu Saclay)
Esther Leal-Cidoncha (univ. Santiago de Compostella)
Carlos Paradela (IRMM)
and the n_TOF collaboration

Fission measurements setup: FIC

- Fast Ionization Chamber
- No multiplication: no gas circulation, a discrimination by amplitude
- Developed by JINR (Dubna), IPPE (Obninsk), EET group (CERN)
- Detection of 1 FF, solid angle ~2π
  - Efficiency ~95% (FLUKA simulations)

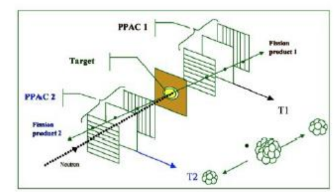


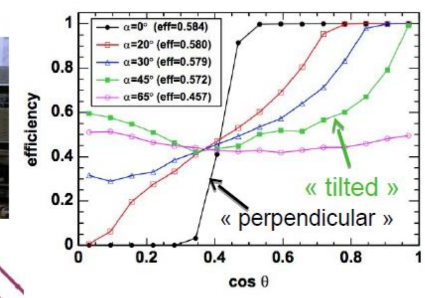


- Targets :
  - painting on 100 μm Al
  - 8 cm diameter, up to 450 μg/cm²
  - characterized by RBS and a spectro

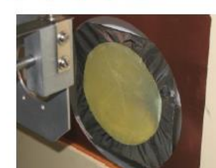
Fission measurements setup: PPAC

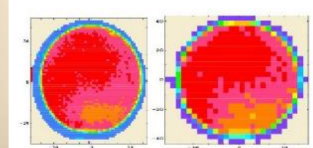
- Parallel Plates Avalanche Chamber
- Proportional counters : gas circulation
- Developed by IPN Orsay
- Detection of both FF
- Position measurement of each FF : fission angle
- 2 geometries : 90° and 45° / neutrons direction





- Targets :
  - electrodeposition on 2 and 0.7 μm Al
  - 8 cm diameter, 75 μg/cm²
  - characterized by RBS and a spectro





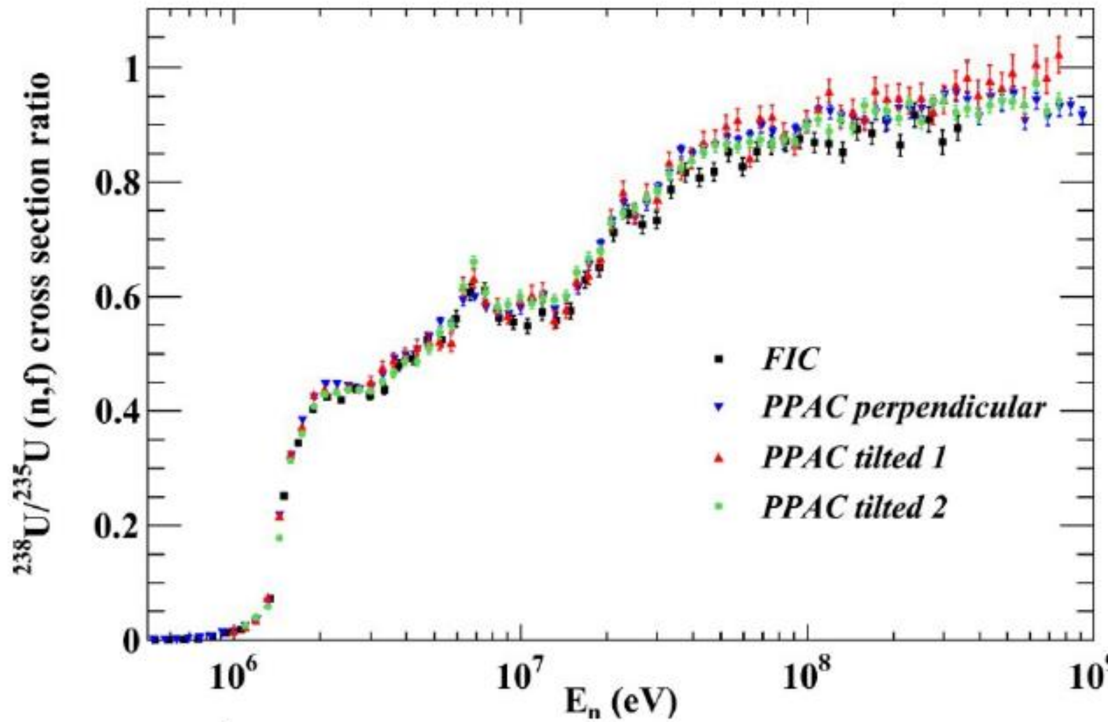
$^{238}U/^{235}U$ ratio

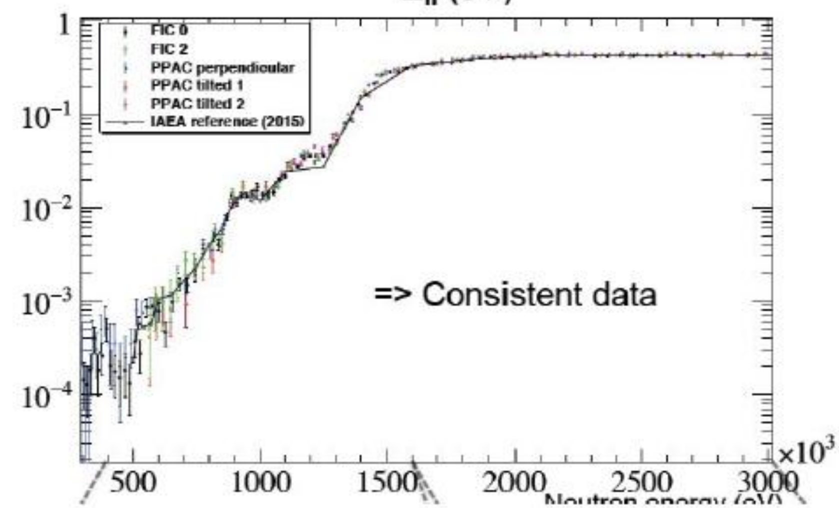
- 5 data sets : 2 FIC, 3 PPAC
- Years 2002 to 2012

$$\frac{\sigma_{U8}(En)}{\sigma_{U5}(En)} = \frac{C_{U8}(En)}{C_{U5}(En)} \times \frac{N_{U5}}{N_{U8}} \times \frac{\varepsilon_{U5}}{\varepsilon_{U8}}$$

- Same diameter of targets
  - Independant of flux profile
- Systematic uncertainties ~3%

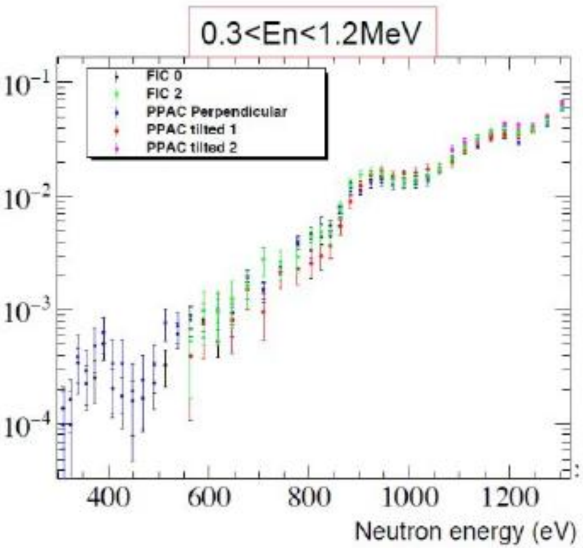
Setup	Sample mass	efficiency	Dead time	Total
FIC0	2	1-2	<0.5	**2.5**
FIC 2	1.5	1	<3	**3.5**
PPAC perpendicular	1.1	3	<1	**≥3**
PPAC tilted 1	1.1	2	<1	**≥3**
PPAC tilted 2	(~1)	1	<1	**2.5**

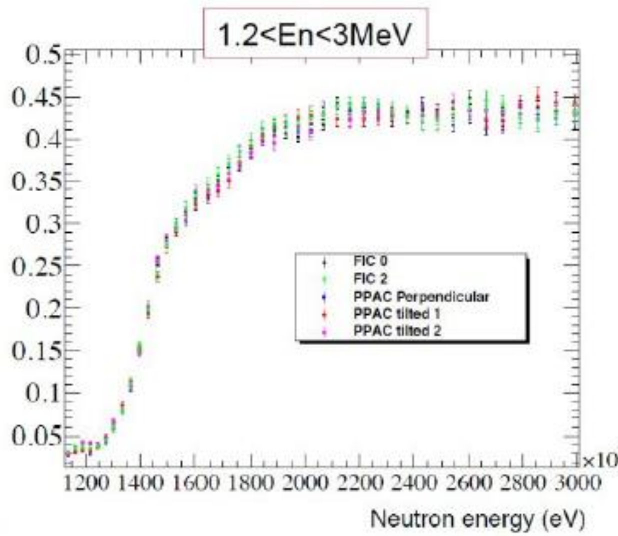


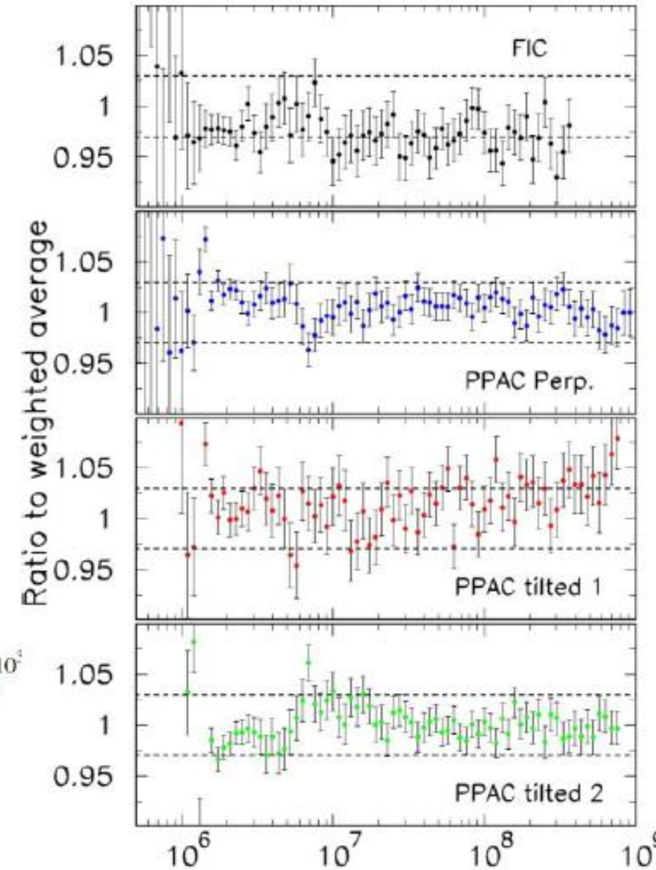


$^{238}U/^{235}U$ ratio : a common nTOF data set

- Renormalization of the various data sets to IAEA standard (2.2 - 2.6 MeV) : < 3%
- Energy shift in the 1.34-1.48 MeV range : < 0.5%
- Linear interpolation for a common binning

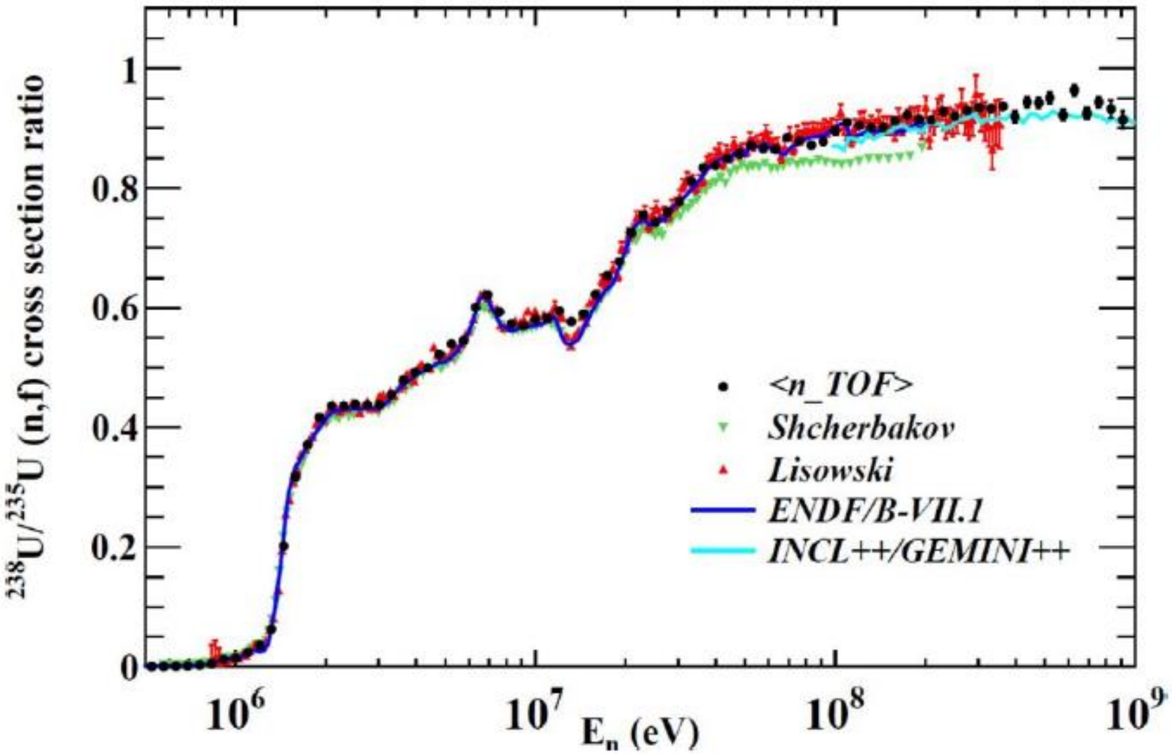


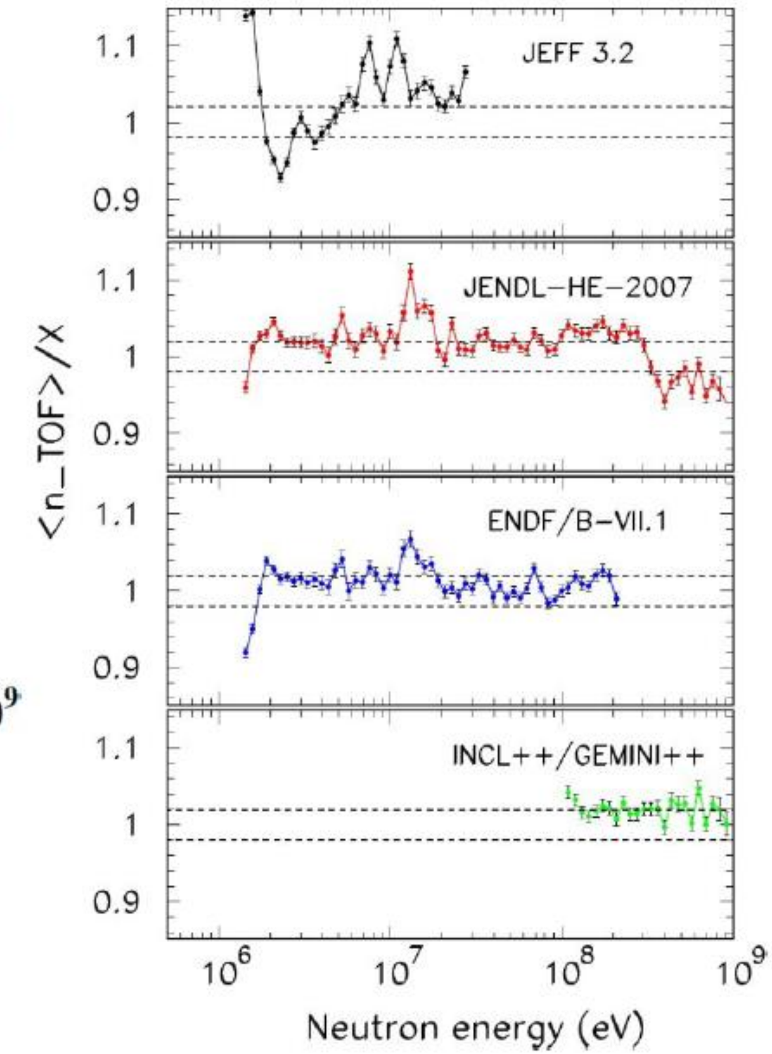




- Creation of a common "nTOF" data set (weighted average)
- Uncertainties : systematic ~3%, statistical from weighted average error

Comparison to evaluations : high energy



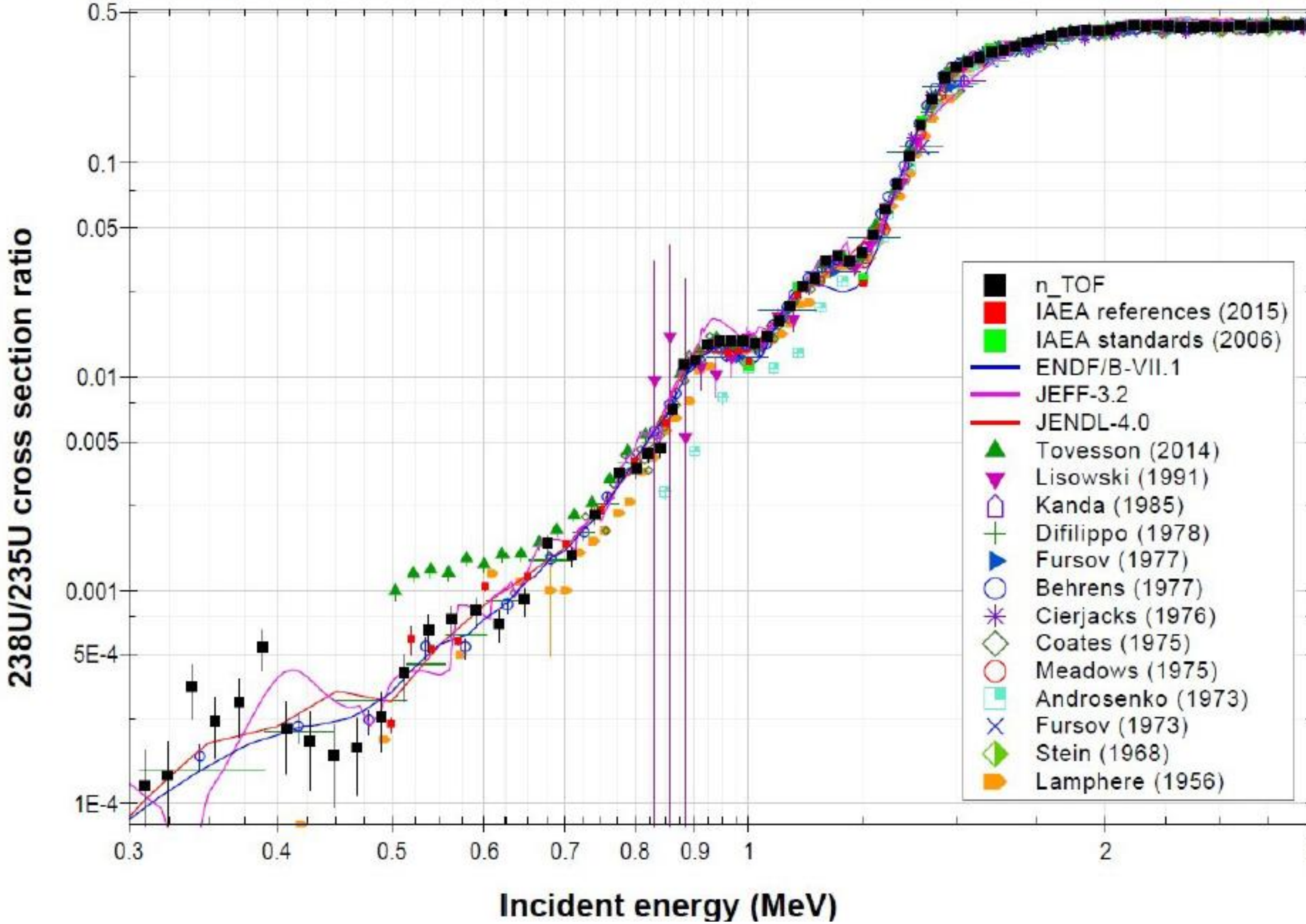


- Very good agreement with Lisowski and ENDF
- Systematic 2% shift compared to JENDL-HE
- Significant discrepancies with JEFF 3.2

- Obvious issue around 14 MeV (or 3rd chance fission opening?)

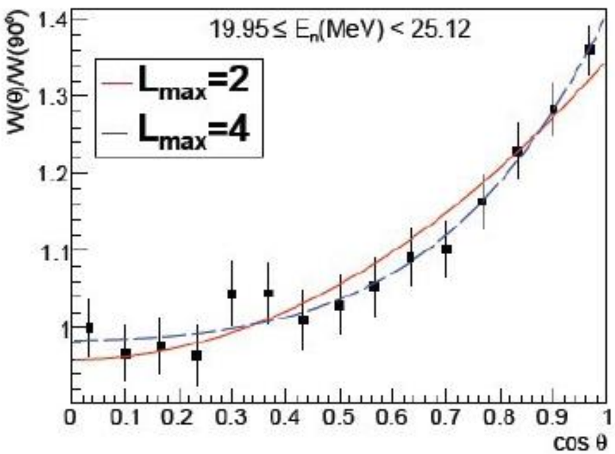
Comparison to low-energy experimental sets

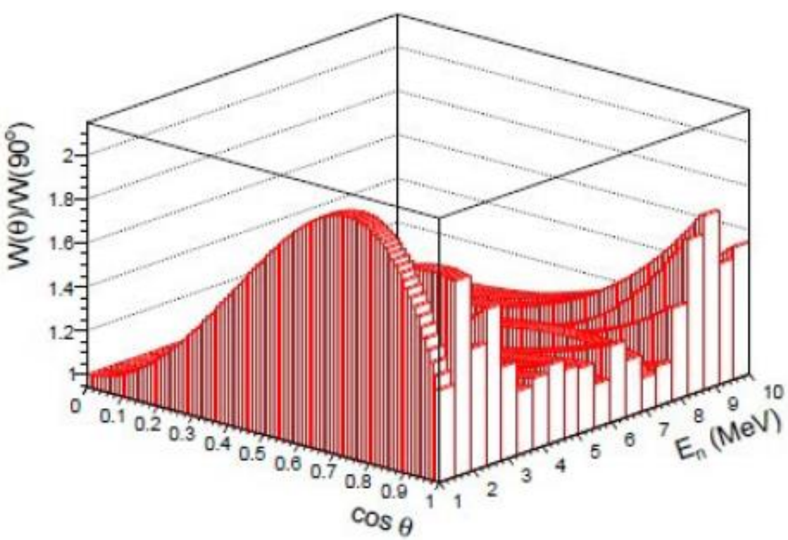
- Very good agreement beyond 0.8 MeV, lack of measurement below this
  - Surprisingly the agreement is much better with Behrens (1977) than Tovesson (2014)

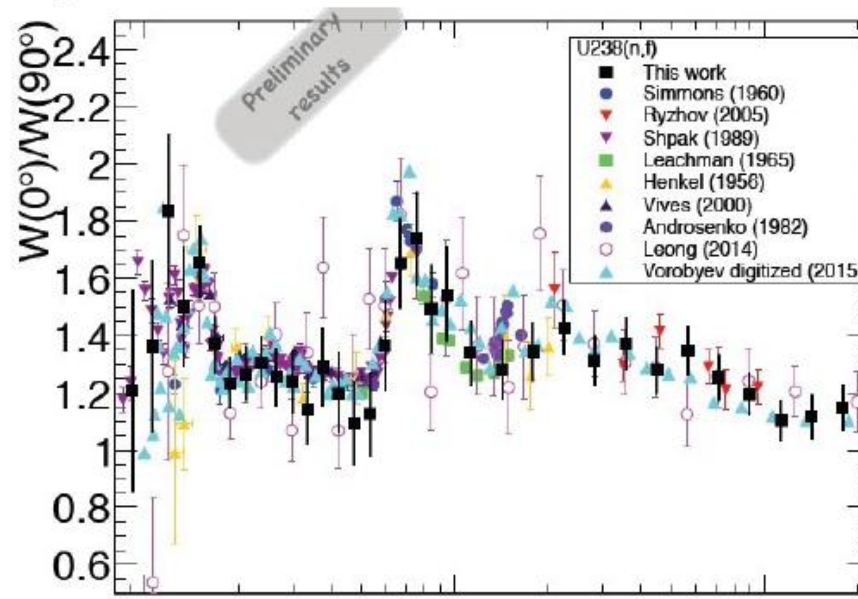


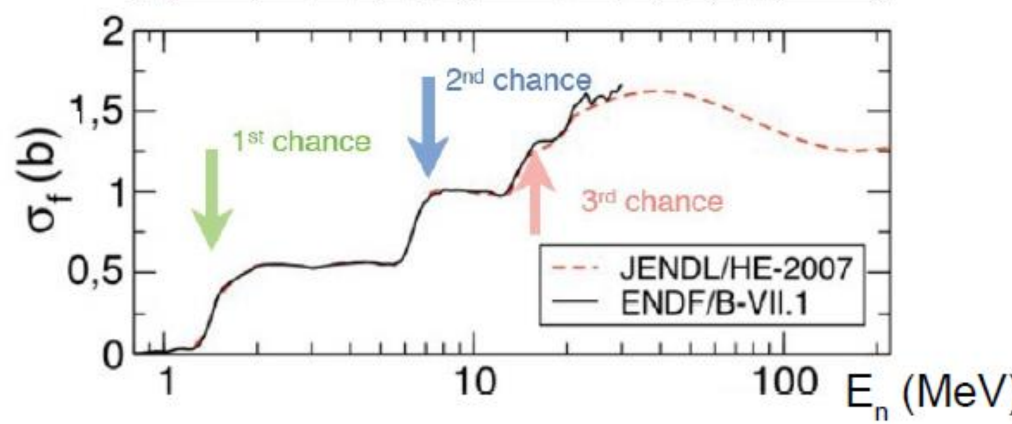
Fission Fragment Angular Distributions : ^{238}U

- Angular distributions fitted by Legendre polynomials: $W(\theta) = A_0 \left[1 + \sum_{L=2}^{L_{max}} A_L P_L(\cos\theta) \right]$
- Anisotropy parameter $A = \frac{W(0^\circ)}{W(90^\circ)} = \frac{1 + A_2 + A_4}{1 - \frac{1}{2}A_2 + \frac{3}{8}A_4}$ (simplified description)



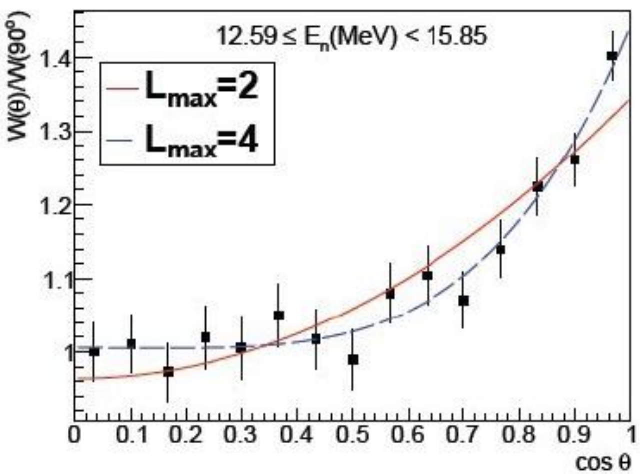


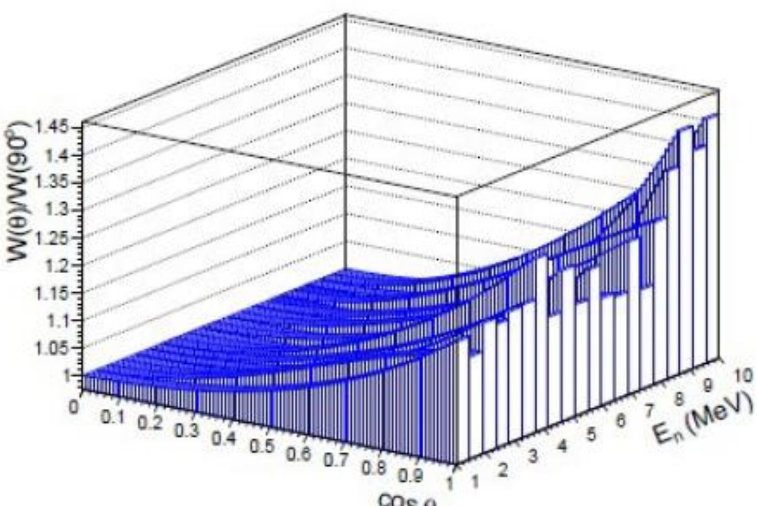


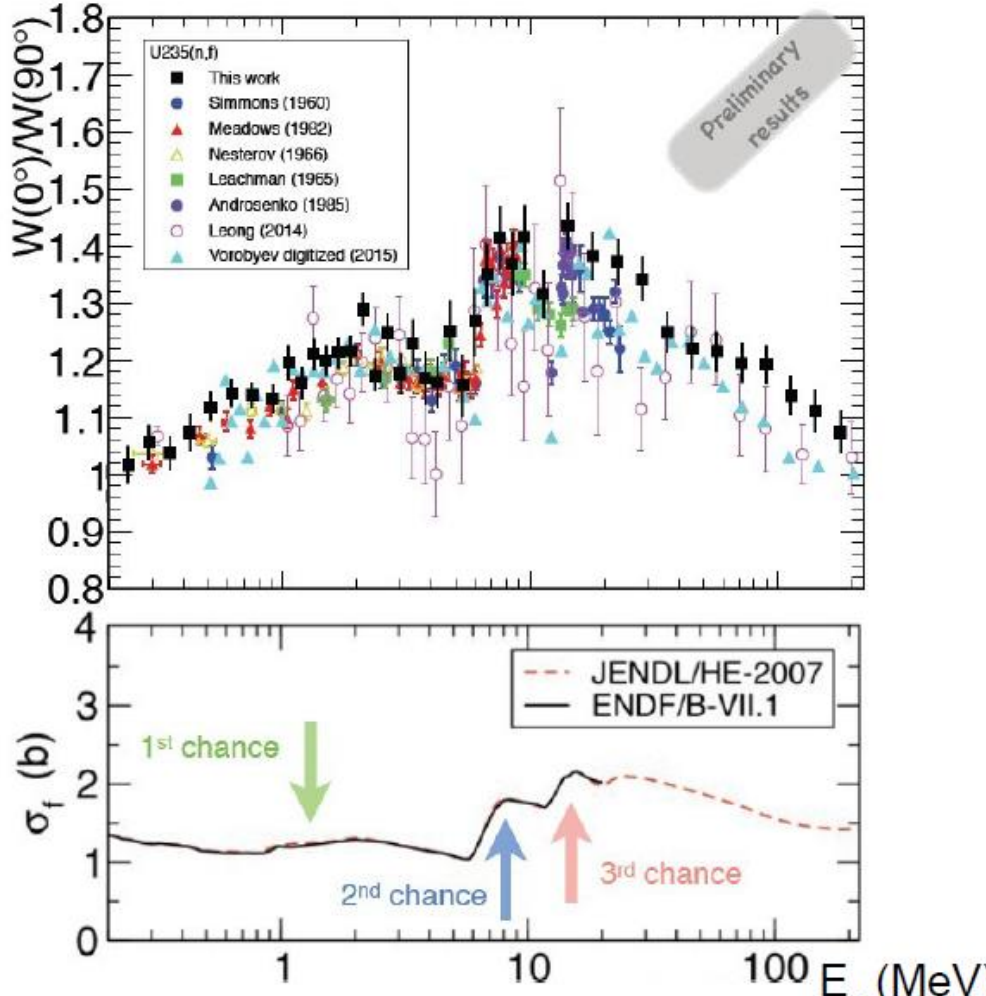


Fission Fragment Angular Distributions : ^{235}U

- Angular distributions fitted by Legendre polynomials: $W(\theta) = A_0\left[1 + \sum_{L=2}^{L_{max}} A_L P_L(\cos\theta)\right]$
- Anisotropy parameter $A = \frac{W(0^\circ)}{W(90^\circ)} = \frac{1 + A_2 + A_4}{1 - \frac{1}{2}A_2 + \frac{3}{8}A_4}$ (simplified description)

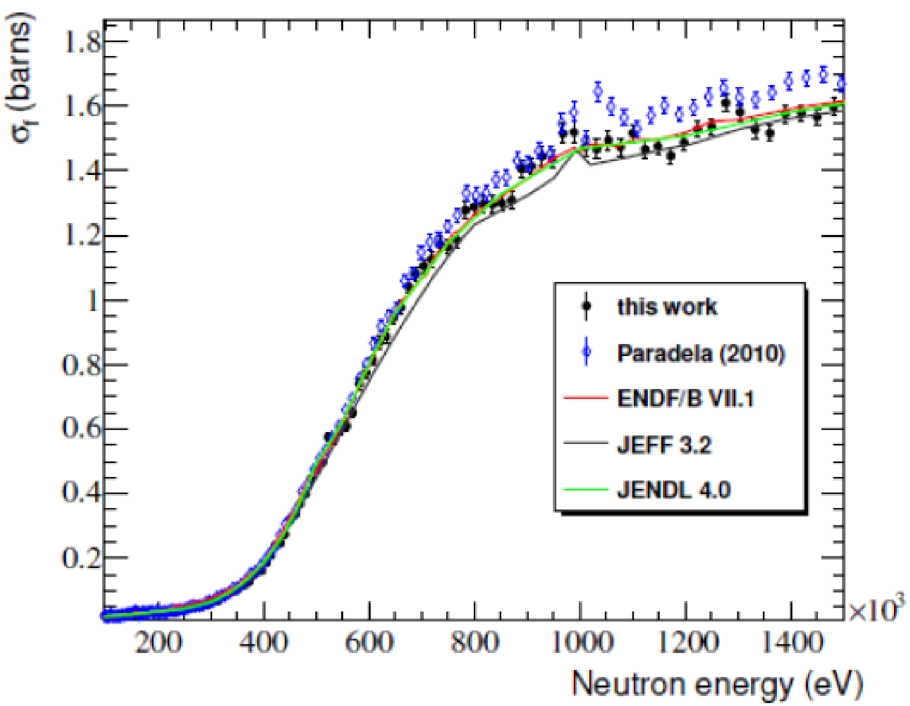


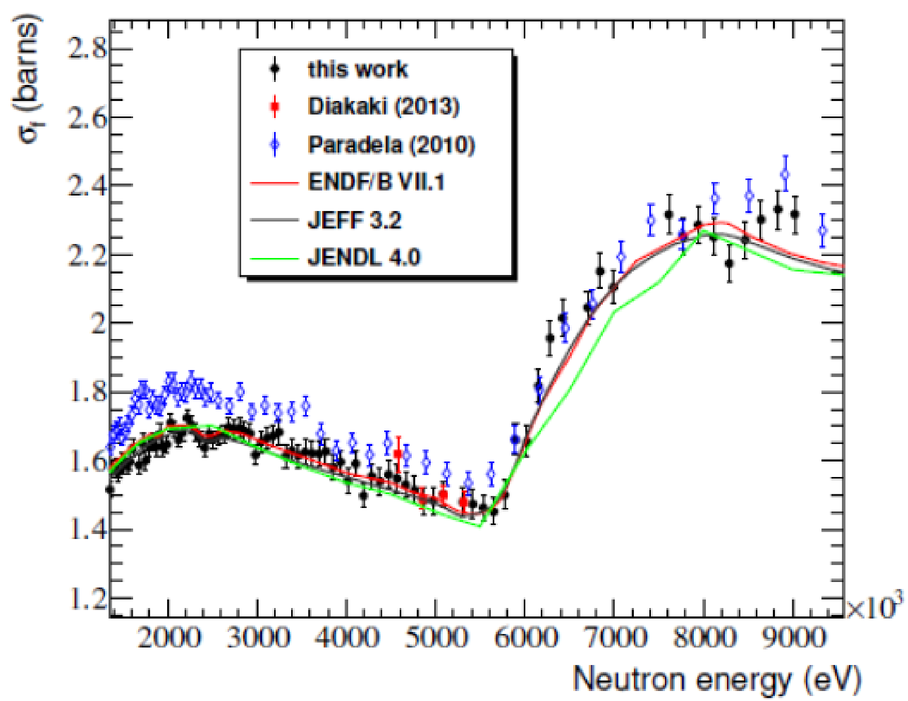




"New" $^{237}Np(n,f)$ data from n_TOF

- Data taken by the FIC-0 chamber in 2002 finally analyzed
  - Very delicate analysis due to gamma-flash saturation in the electronics
  - Pulse-shape analysis, normalization to different targets according to the energy range





- Discrepancy with PPAC data and agreement with evaluations

Fission measurements data sets

Detector	Measurement	Reference	EXFOR
FIC	^{233}U: σ (thermal – 1 MeV) σ (0.5 – 20 MeV)	M. Calviani, Phys.Rev.C 80 (2009) 044604 F. Belloni, Eur. Phys. J. A 47 (2011) 2	**23072**
	^{236}U: σ (up to 2 MeV)	R. Sarmento, Phys. Rev. C 84 (2011) 044618	23131
	^{243}Am: σ (0.5 – 20 MeV)	F. Belloni, Eur. Phys. J. A 47 (2011) 160	23148
	^{245}Cm: σ (thermal – 1 MeV)	M. Calviani, Phys. Rev. C 85 (2012) 034616	**23168**
	^{234}U : σ (20 keV – 200 MeV)	D. Karadimos, Phys. Rev. C 89 (2014) 044606	**23231**
	^{241}Am: σ (0.5 - 20 MeV)	F. Belloni, Eur. Phys. J. A 49 (2013) 2	23148
PPAC	^{234}U, ^{237}Np: σ (1eV - 1 GeV)	C. Paradela, Phys. Rev. C 82 (2010) 034601	**23126**
	^{209}Bi/^{nat}Pb: σ (thr – 1 GeV)	D. Tarrio, Phys. Rev. C 83 (2011) 044620	23151
	^{232}Th: FFAD (thr – 3 MeV)	D. Tarrio, NIMA 743 (2014) 79-85	23209
	^{233}U: σ	L. Tassan-Got – to be published	
	^{235}U & ^{238}U: σ + FFAD	C. Paradela, Phys. Rev. C 91 (2015) 024602	**23269**
MGAS	^{235}U: fission tagging	C. Guerrero, Eur. Phys. J. A 48 (2012) 29	23162
	^{240,242}Pu	A. Tsinganis – work ongoing	

High accuracy $^{235}U(n,f)$ data in the resonance energy region

Ignacio DURAN
GENP-USC

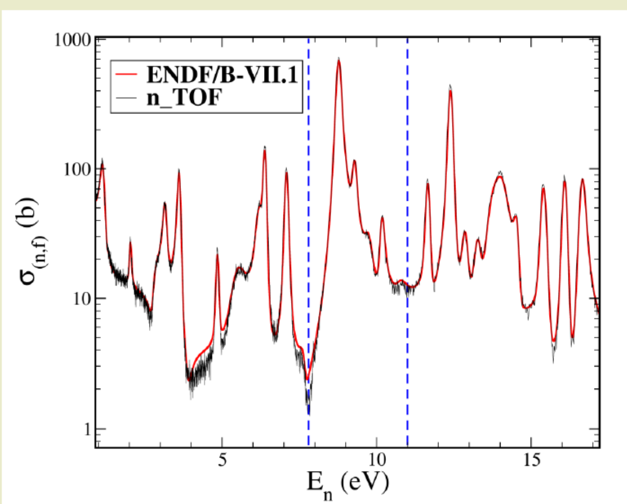
Carlos PARADELA
EC-JRC-IRMM

On behalf of
n_TOF Coll. CERN

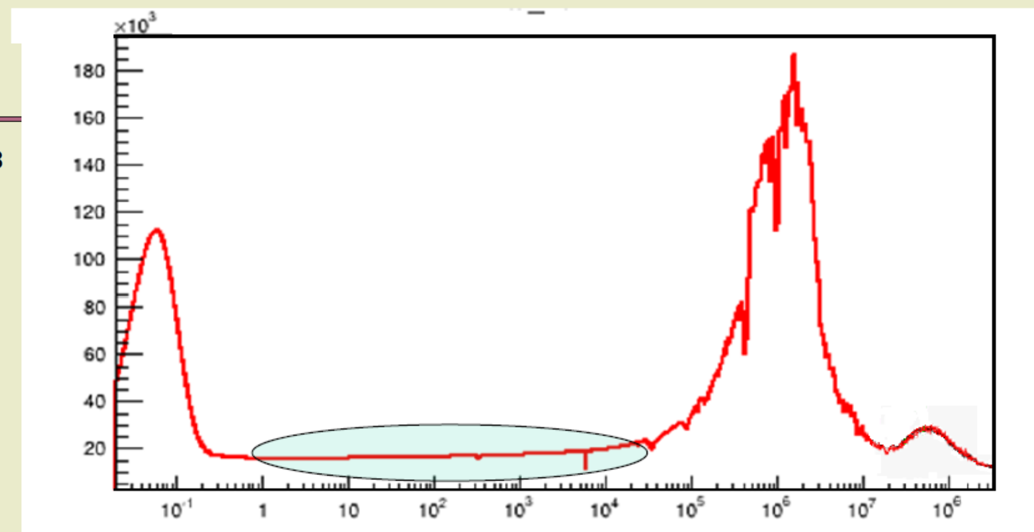
JEFF-NEEDS Workshop on Nuclear Data Measuremen

U5(n,f) XS from 1 eV to 10 keV

To normalise we used the secondary reference interval between 7.8 and 11 eV recommended by IAEA (246.4±1.2 b eV) while ENDF/B-VII.1 and JEFF-3.2 provide a 2% lower value (241.6)



The neutron flux



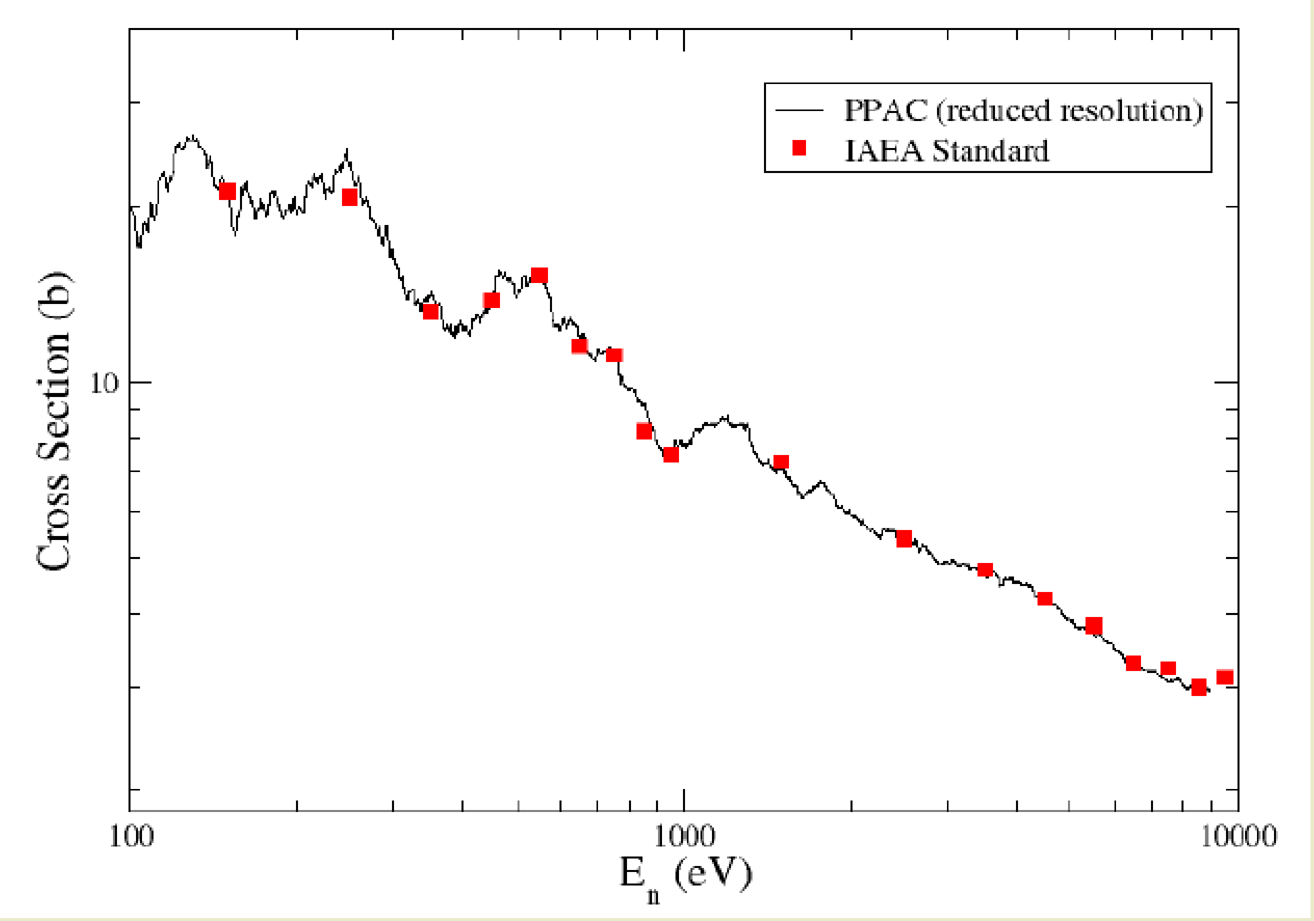
Based on $^6Li(n,t)$ standard (SiMon)
Capture collimator
Smooth: 100 bins/decade

F. Gunsing *et al.*, Nucl. Instrum. Meth. B 261 (2007) 925

U5(n,f) XS from 1 eV to 10 keV

The IAEA maintains the standards and recommendations.

The U5 in this energy range is not standard but recommended



PPACs data apparently reproduces well the IAEA values up to 10 keV. But let´s check the numbers.

Close Criticism

E_n (eV)	n_TOF	IAEA	ENDF/B-VII
100-200	21.054(22)	21.17(11) ↔	20.321
200-300	20.726(28)	20.69(11)	20.601
300-400	12.891(26)	13.135(72)	12.806
400-500	13.575(30)	13.781(76)	13.288
500-600	15.055(35)	15.174(86)	14.870
600-700	11.463(33)	11.513(65)	11.238
700-800	10.912(35)	11.101(64)	10.880
800-900	8.137(32)	8.213(48)	7.977
900-1000	7.356(30)	7.502(44)	7.240
1000-2000	7.291(12)	7.303(40)	7.138
2000-3000	5.211(14)	5.386(33)	5.290
3000-4000	4.721(15)	4.784(30)	4.778
4000-5000	4.193(16)	4.261(25)	4.207
5000-6000	3.766(17)	3.838(24)	3.905
6000-7000	3.185(17)	3.291(21)	3.287
7000-8000	3.115(18)	3.236(19)	3.158
8000-9000	2.906(18)	3.009(18)	2.940
9000-10000	3.058(29)	3.120(19)	3.043

Even though a very good general agreement, some evident discrepancies arose when comparing the integral values:

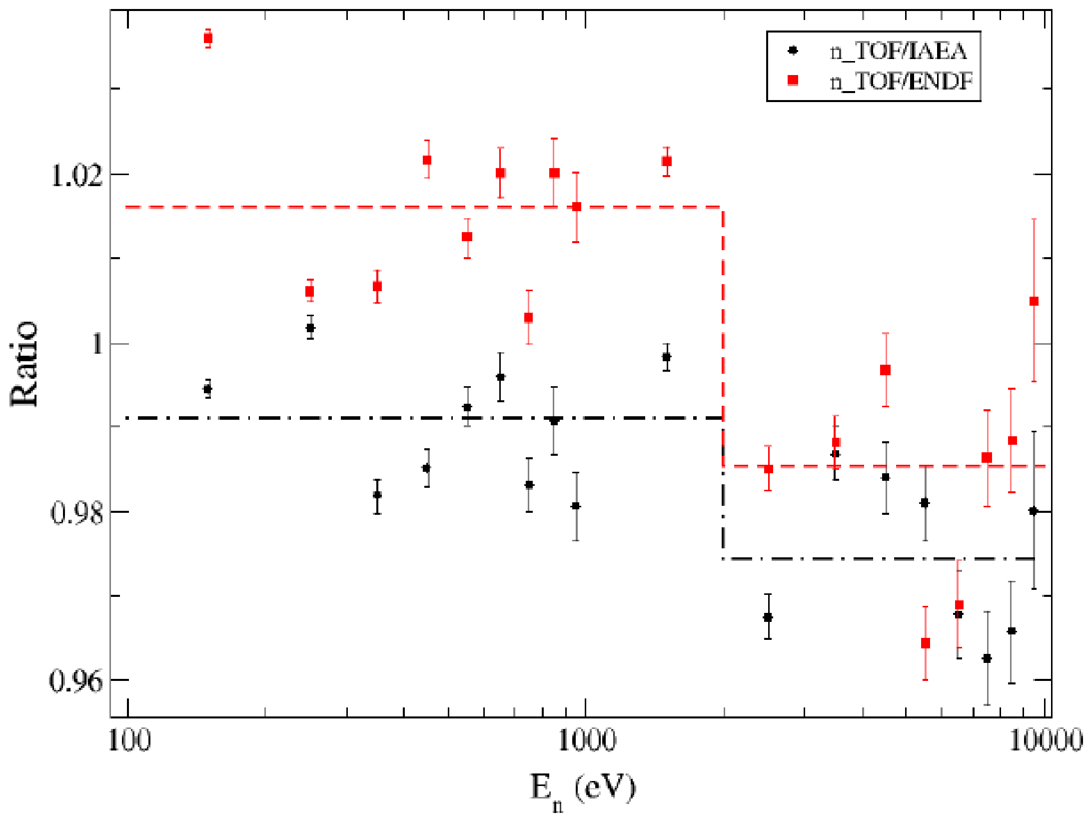
- First, the notable discrepancy at 100 eV inherit from the 2% discrepancy at 7.8-11 eV.

- Second, these lower values of ENDF up to 2 keV, that becomes systematically higher above the transition from RRR to URR;

- Third is a systematic small shift between IAEA and both nTOF and ENDF.

Close Criticism

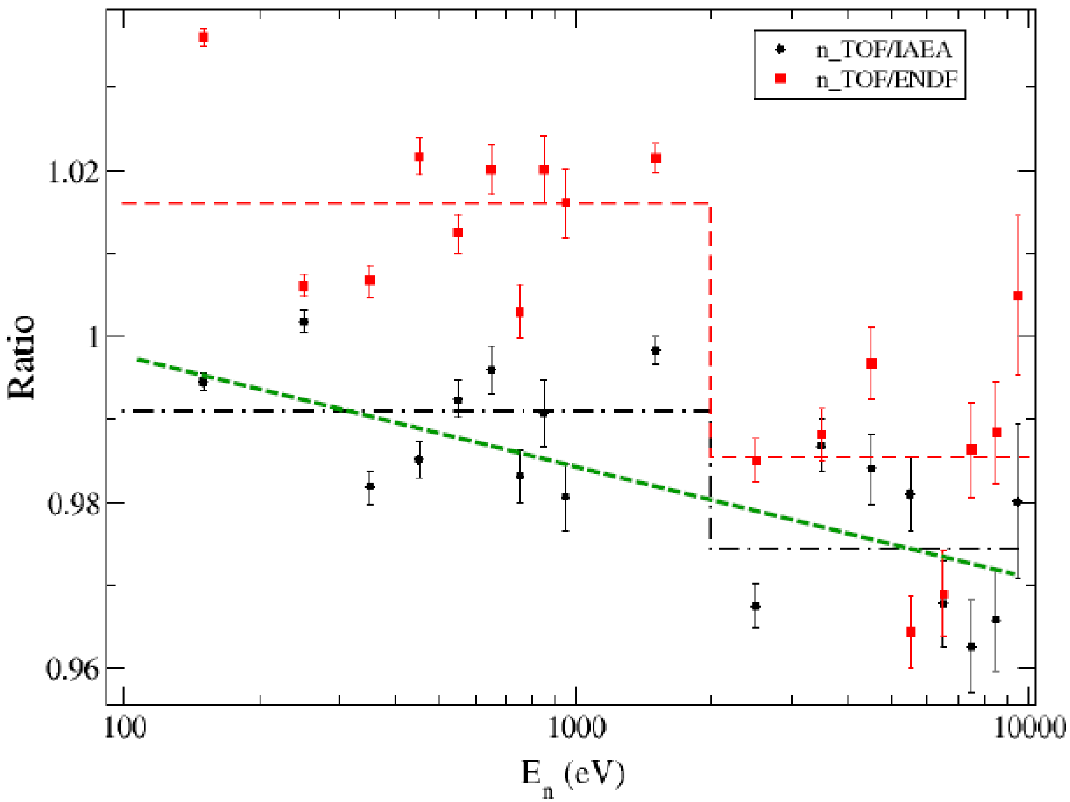
Ratios of n_TOF over ENDF and IAEA



- ENDF shows an abrupt step at 2.25 keV (3%) not compatible with neither statistical nor systematic uncertainties.

Close Criticism

Ratios of nTOF over ENDF and IAEA



- ENDF shows an abrupt step at 2.25 keV (3%) not compatible with neither statistical nor systematic uncertainties.

-The IAEA trend is compatible with an small offset, going from 0.06 to 3% because the XS values becomes more and more lower.

CONCLUSIONS & PERSPECTIVES

1. Very good agreement with the shape of both Weston data in the RRR, comparable resolution and broader E range.

2. The PPACs data show a very low background, specially around eV.

3. ENDF/JEFF integral values, apart from the 2% shift at 7.8 – 11.0 eV, show, compared to both n_TOF and IAEA, an abrupt step at 2.25 keV (RRR to URR transition).

4. Present n_TOF data show a quite good agreement with the IAEA reference data set, provided that an small offset of 0.09 b is applied in the whole energy range or a linear E-dependent correction. Flux shape cross-check needed.

Measurement of fission fragment beta decay properties through Total Absorption Spectroscopy.

A. Porta, M. Fallot and A.A. Zakari-Issofou

Subatech, CNRS/IN2P3, Univ. Nantes, EMN, Nantes, France

for the TAS Collaboration

Many thanks to A. Algora and J.L. Tain for the inputs provided

Decay heat

Fission process : n + ^{235}U -> ^{236}U* -> PF$_1$ + PF$_2$ + neutrons (200 MeV)

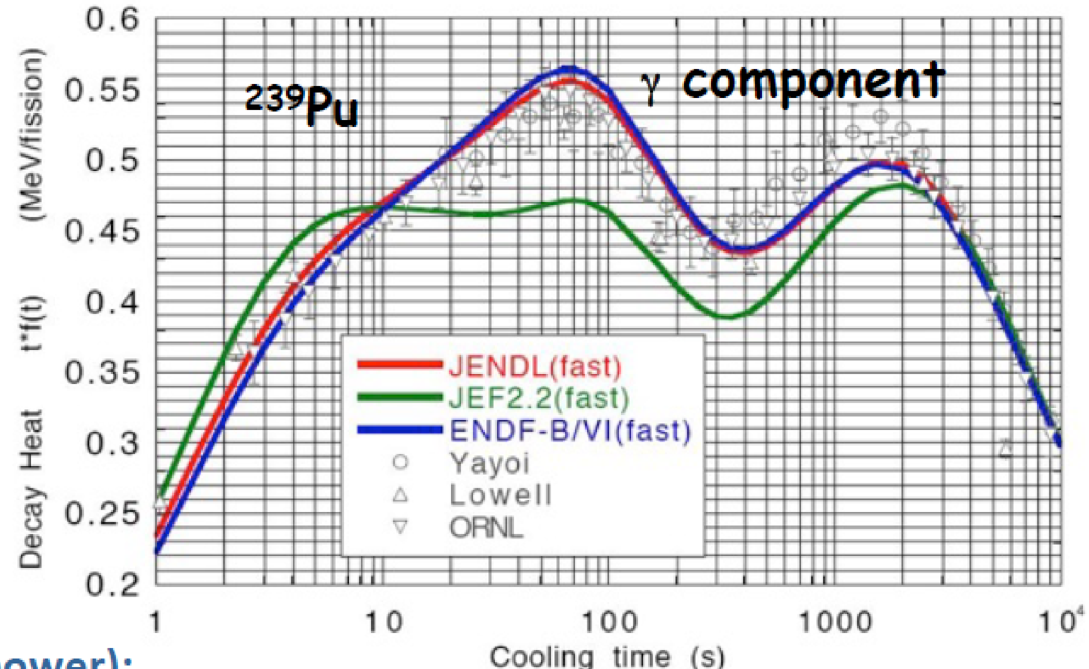
Beta decay of fission products: $^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y^{*} + e^{-} + \bar{\nu}_e$

Estimate through the « summation method »: summation of all the fission product contributions

$$\mathbf{f}(t) = \sum_i (\bar{E}_{\beta,i} + \bar{E}_{\gamma,i})\lambda_i \mathbf{N}_i(t)$$

- ⇒ The only predictive method for future reactors
- ⇒ Usually cross-checked through comparison with integral experiments
- ⇒ Important discrepancies observed
- ⇒ JEFF is the only one containing only data (no models)

T. Yoshida et al., Journal of Nucl. Science and technology 36 (1999) 135



Interests:

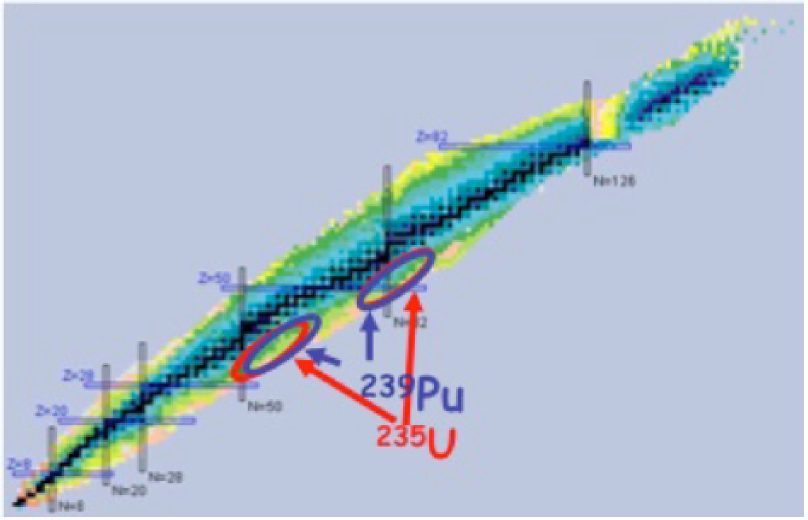
- Residual power (~8% of nominal power):
- Safety and economical reasons

→ We need to improve our knowledge about beta decay properties of FP

→ One reason of the discrepancies: the Pandemonium Effect

Assessment of Fission Product Decay Data for Decay Heat Calculations, Nuclear Science NEA/WPEC-25 (2007)
Decay Heat Calculation: Assessment of Fission Product Decay Data Requirements for Th/U Fuel INDC(NDS)-0577
Total Absorption Gamma-ray Spectroscopy (TAGS), Current Status of Measurement Programmes for Decay Heat Calculations and Other Applications (INDC(NDS-0551), 15th-17th december 2014 @ IAEA

Reactor Antineutrinos

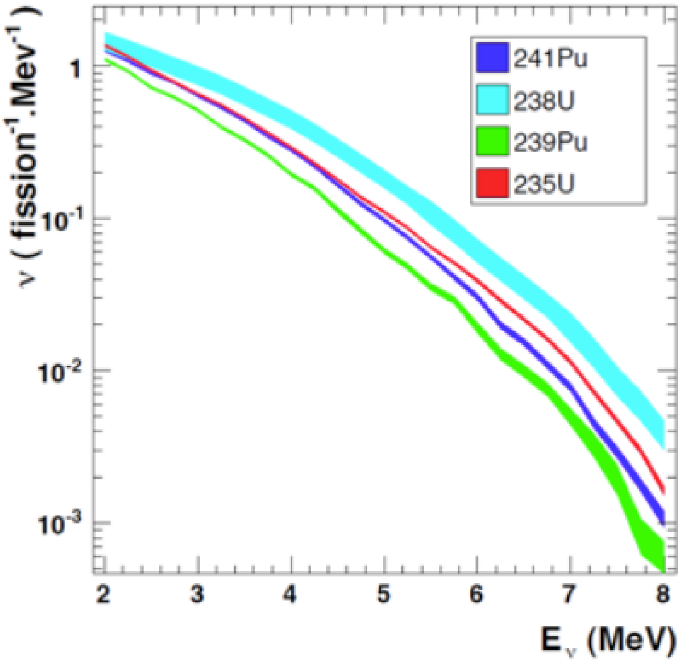


$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^{-} + \overline{\nu}_e$$

ν flux characteristics depend on fuel composition

Spectra calculation through Summation Method:

$$N(E_\nu) = \sum_n Y_n(Z,A,t) \cdot \sum_i b_{n,i}(E_0^i) P_\nu(E_\nu, E_0^i, Z)$$



	^{235}U	^{239}Pu
E_f (MeV)	201.9	210.0
$\langle E_\nu \rangle$ (MeV)	1.46	1.32
$\langle N_\nu \rangle$ (E>1.8MeV)	5.58 (1.92)	5.09 (1.45)

About 6 antineutrinos emitted per fission

→ About 10^{21} antineutrinos/s emitted by a 1 GW_{el} reactor

→ Reactors are copious antineutrino emitters

→ Can be used for **reactor and fuel composition monitoring (non-proliferation)**

The result for ^{92}Rb

Calculation of level energy feeding through the resolution of the inverse problem* (See A.Algora's talk for more details)

$$d_i=\Sigma R_{ij}*f_j$$

Clean data

Response matrix

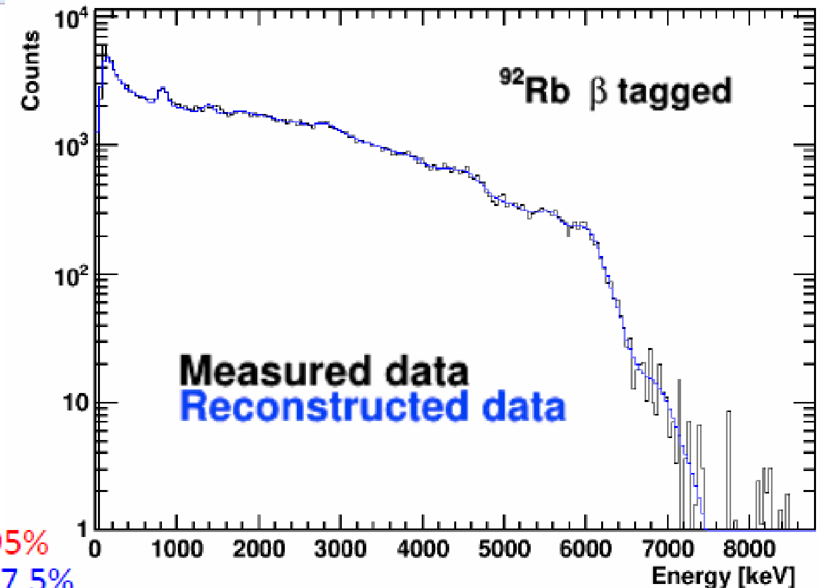
Level feeding

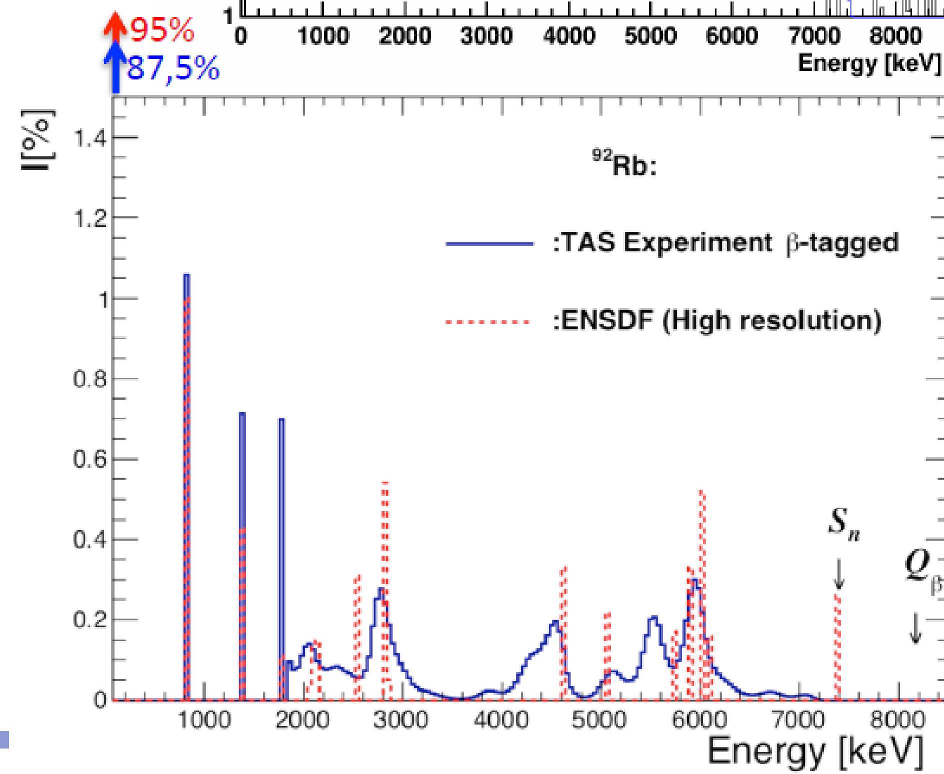
* Tain et al. NIM A571 (2007) 719,728

PhD Thesis work:
A.-A. Zakari-Issoufou (Subatech, Nantes)

A.-A. Zakari-Issoufou et al., Phys. Rev. Lett. 115, 102503 (2015)

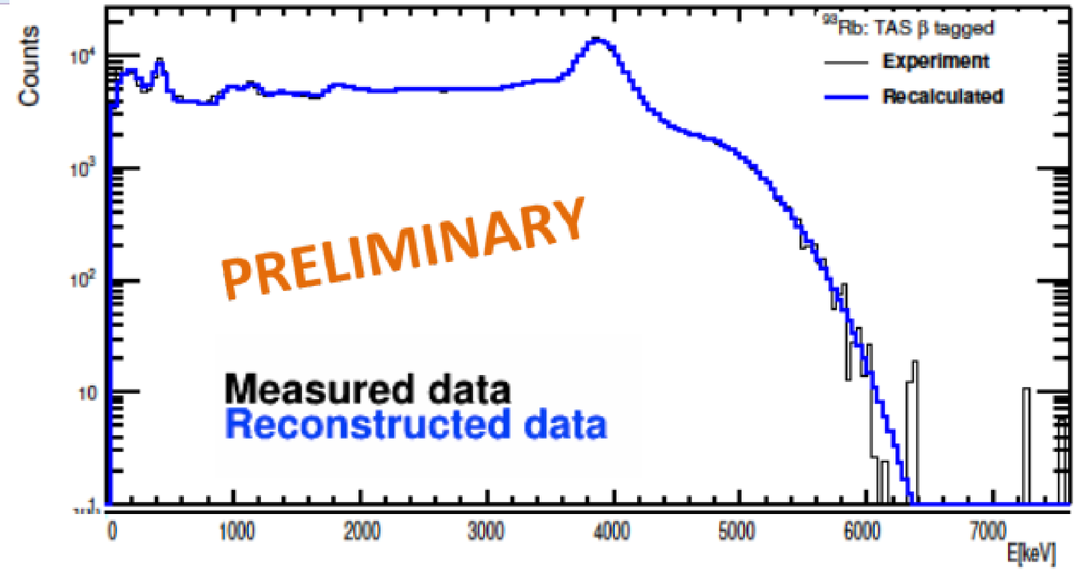
arXiv:1504.05812 [nucl-ex]

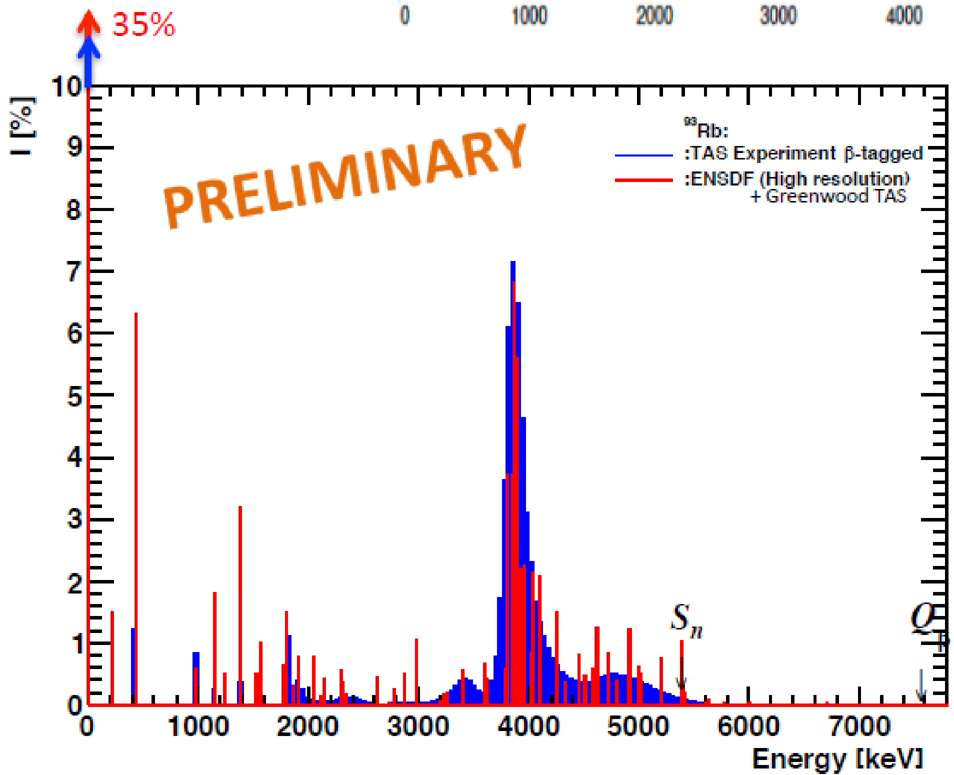




The result for ^{93}Rb

PhD Thesis work:
A.-A. Zakari-Issoufou
(Subatech, Nantes)

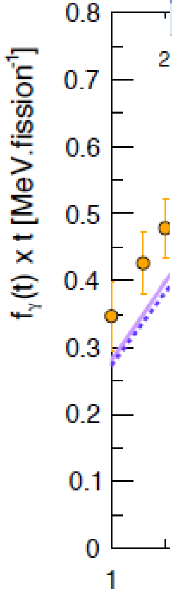


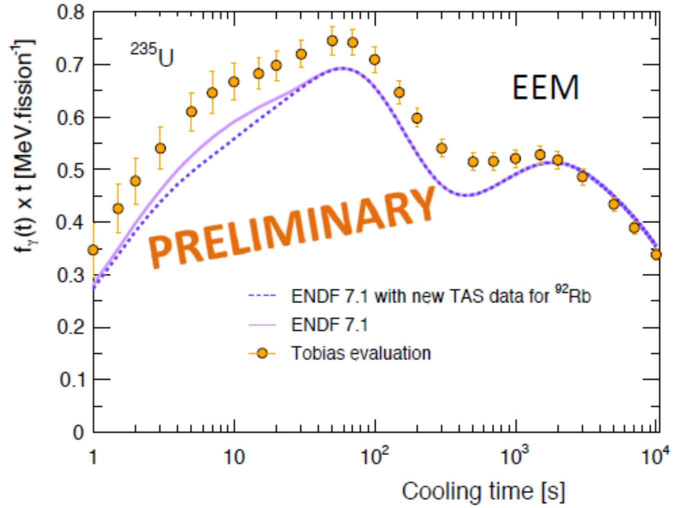


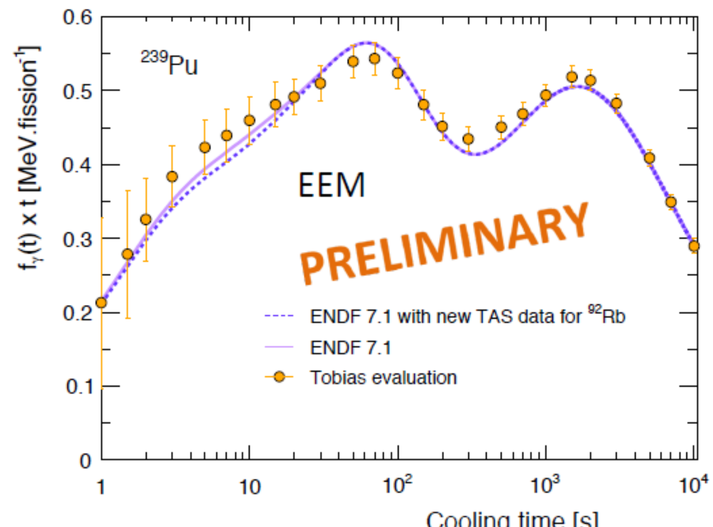
And Decay Heat

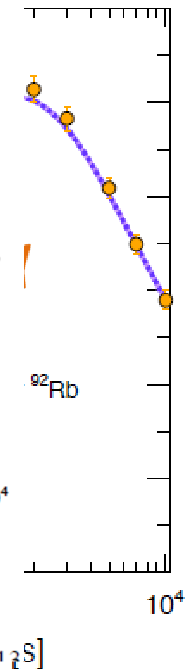
And Decay Heat

Decay heat computation done by A. Sonzogni (BNL):









New EEM mean value: 459.5keV, New ELP value: 3.49MeV

Compared with ENDF7.1 (G.S. to G.S. feeding 51%): EEM 2.15MeV ELP 2.87MeV

Compared with ENDF7.1.1 (G.S. to G.S. feeding 95.2%): EEM 170keV ELP 3.63MeV

New EEM mean value: 459.5keV, New ELP value: 3.49MeV

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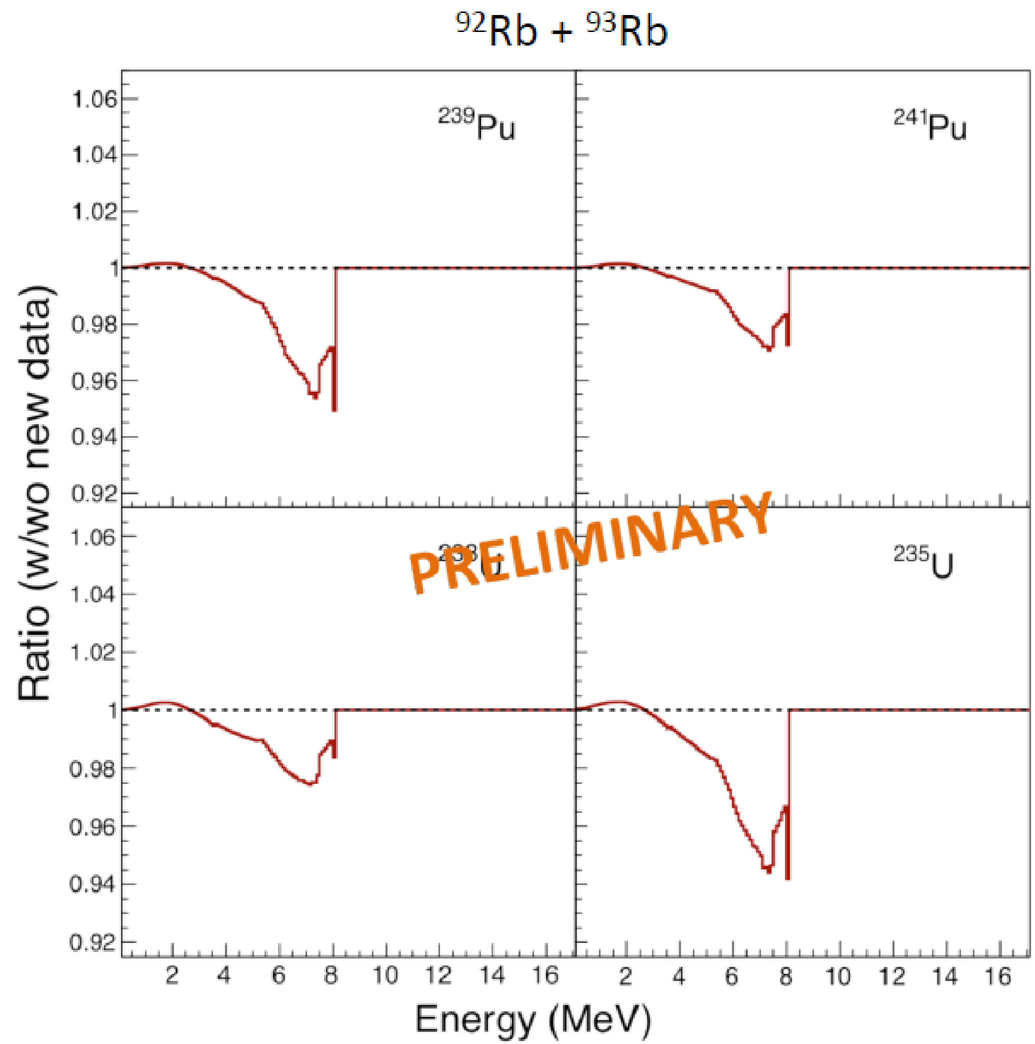
Compared with ENDF7.1.1 (G.S. to G.S. feeding 95.2%): EEM 170keV ELP 3.63MeV

Impact of these measurements on antineutrino spectra calculation

- Main effect in 4 to 8MeV energy range and it is about 6% for 235U, 5% for 239Pu, 3% for 241Pu and 2.5% for 238U.

- Sharp drop of the ratio at high energy is because of a different Q value between Rudstam et al. and ENSDF.

- We have compared these new energy spectra with converted spectra from P.Huber**. The overall agreement is improved in the 4 to 8 MeV range except in the case of 235U for which the summation method spectrum is always below the converted spectrum.



For ^{92}Rb results: A.-A. Zakari-Issoufou et al., Phys. Rev. Lett. 115, 102503 (2015) , arXiv:1504.05812 [nucl-ex]

*G.Rudstam et al., Atomic Data and Nuclear Data Tables 45.2 (1990), p. 239 –320)

**P. Huber, Phys. Rev. C 84, 024617 (2011).

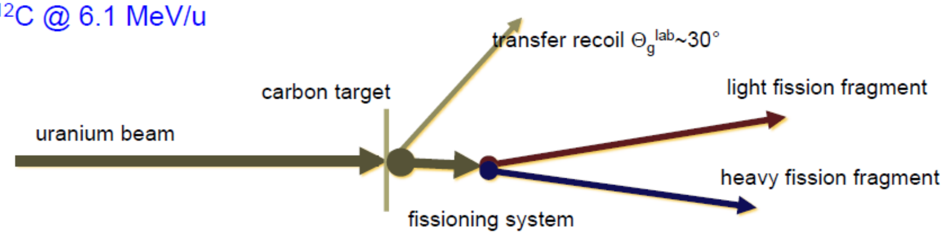
Isotopic fission yields in inverse kinematics: towards an integration in fission yields evaluation ?

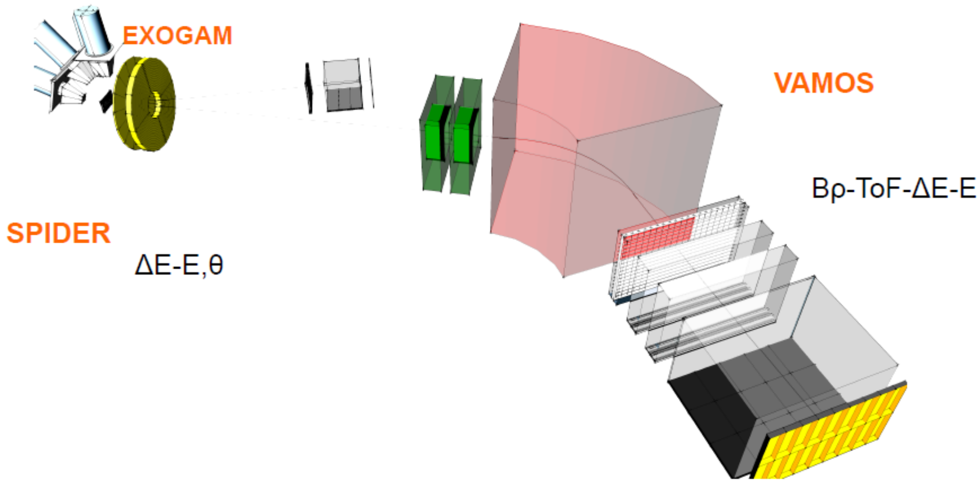
F. Farget, O. Delaune, X. Derkx, C. Golabek,
T. Roger, A. Navin, M. Rejmund, C. Rodriguez-Tajes, C. Schmitt — GANIL, France
K.-H. Schmidt, B. Jurado — CENBG, France
D. Doré, M. Delphine de Salsac — SPhN, France
J. Benlliure, M. Caamaño, E. Casarejos, D. Cortina,
B. Fernandez-Dominguez, D. Ramos — USC, Spain
L. Audouin, C.-O. Bacri, — IPNO, France
L. Gaudefroy, J. Taieb — CEA DIF, France
A. Heinz — Chalmers U., Sweden

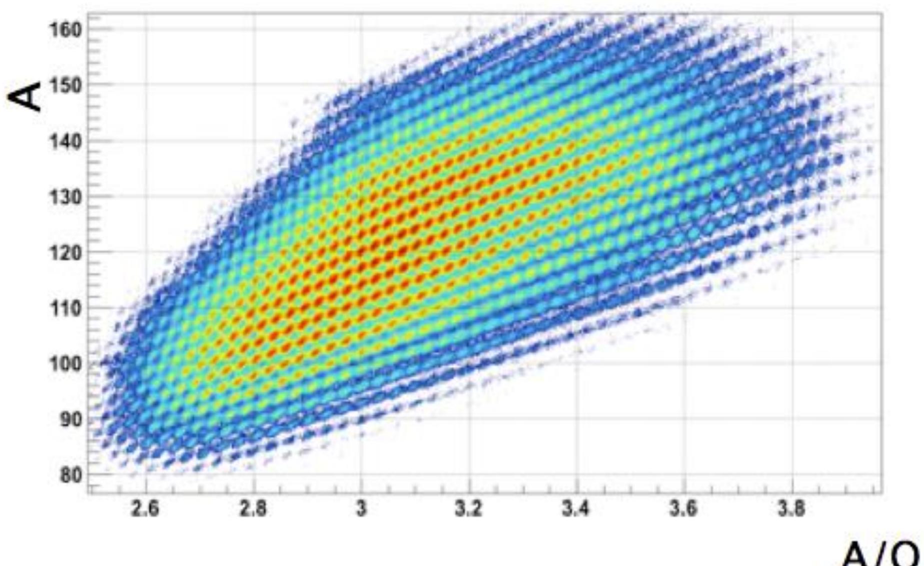
2 years fellowship EURATOM
1 year fellowship ANDES
3 calls NEEDS
4 years fellowship of the spanish minister

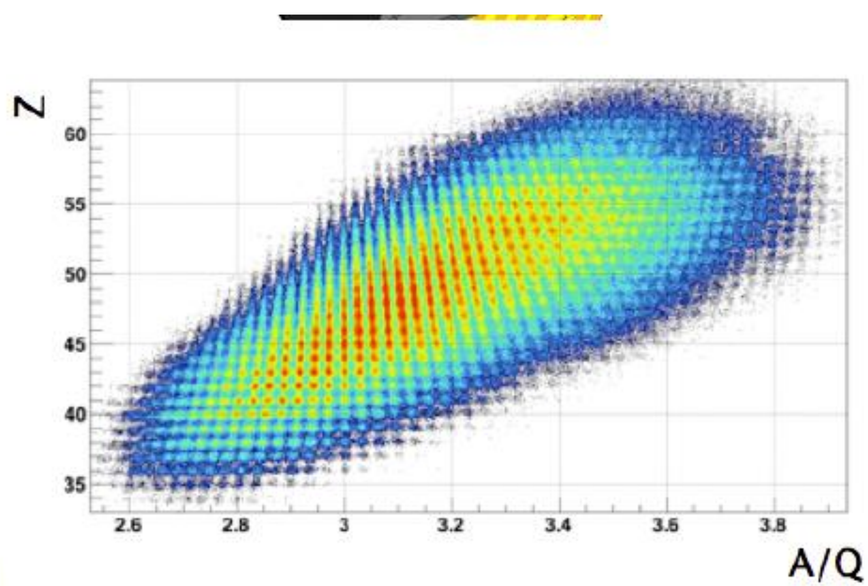
Research infrastructure of IN2P3: 2 PhD fellowships + VAMOS@GANIL

$^{238}U + ^{12}C$ @ 6.1 MeV/u

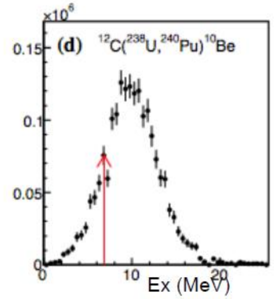




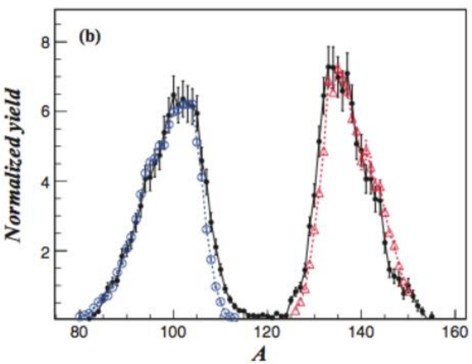




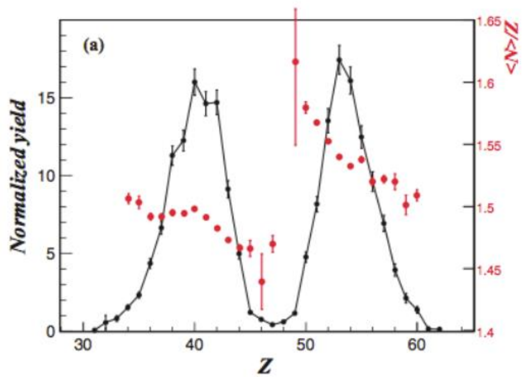
Fission Yields of ^{240}Pu E*~ 10 MeV



Mass distribution,
Element distribution
Neutron excess of fragments



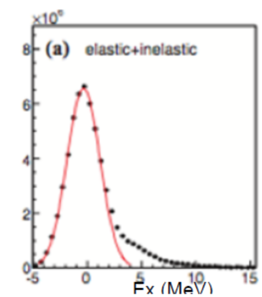
C. Schmitt et al, NPA430 (1984) A. Bail, PRC84 (2011)

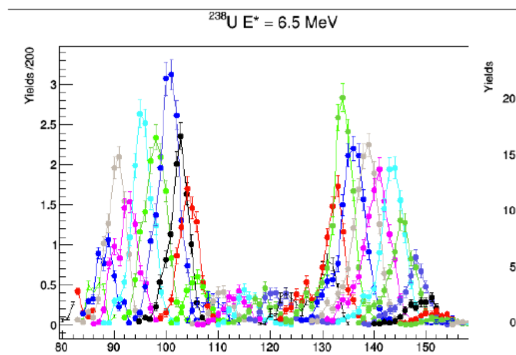


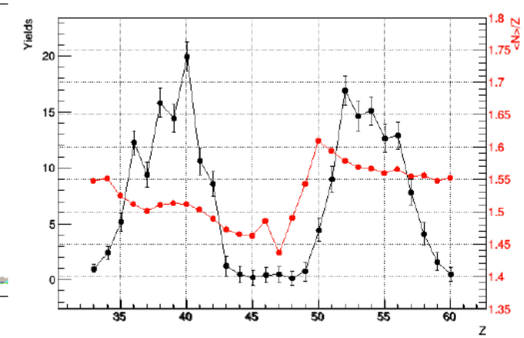
M. Caamaño et al., PRC 88 (2013) 024605

Fission Yields of ^{238}U E*~ 6.5 MeV

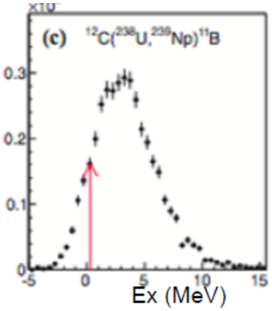
Preliminary data from D. Ramos (USC)

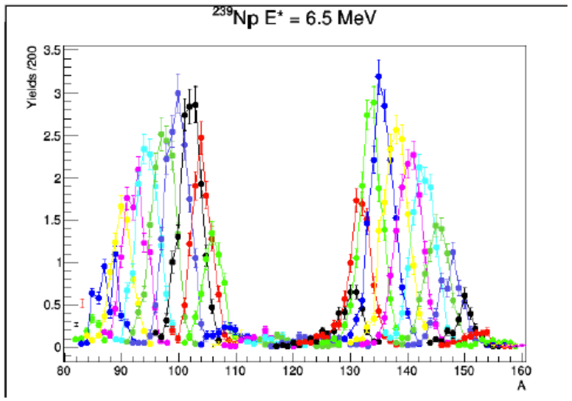


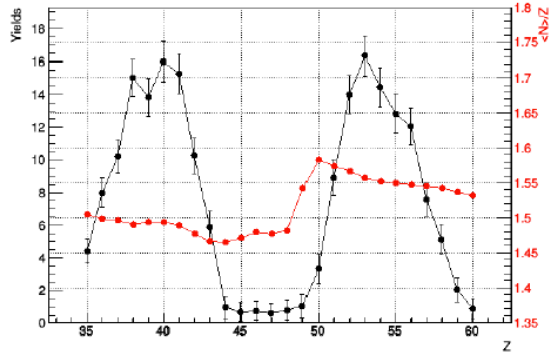




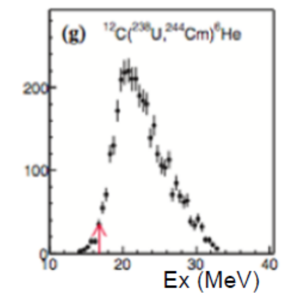
Fission Yields of ^{239}Np E*~ 6.5 MeV

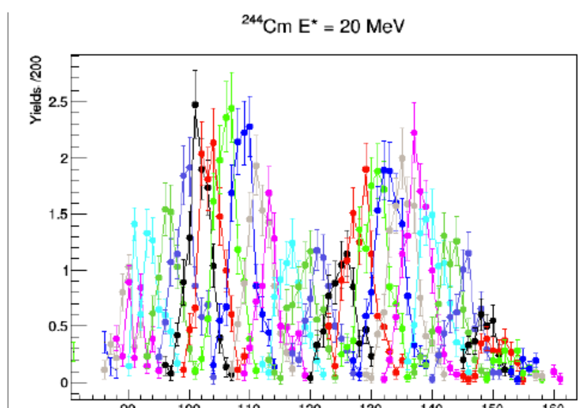


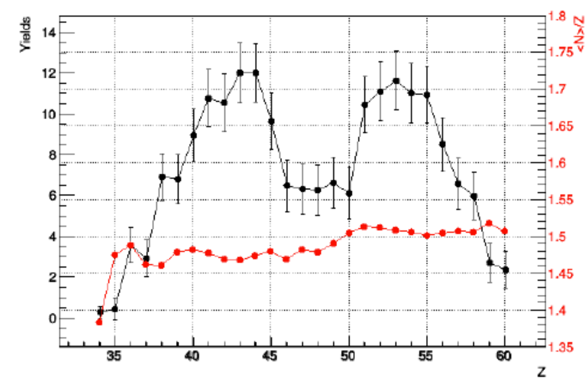




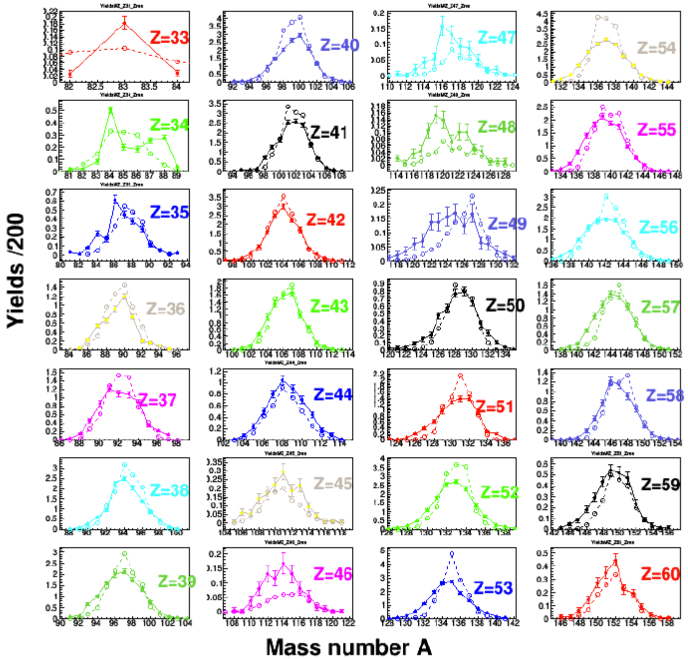
Fission Yields of ^{244}Cm E*~ 20 MeV





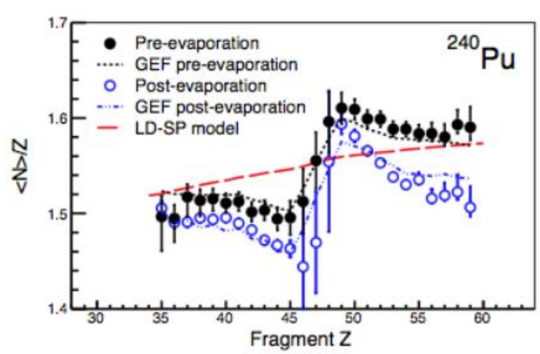


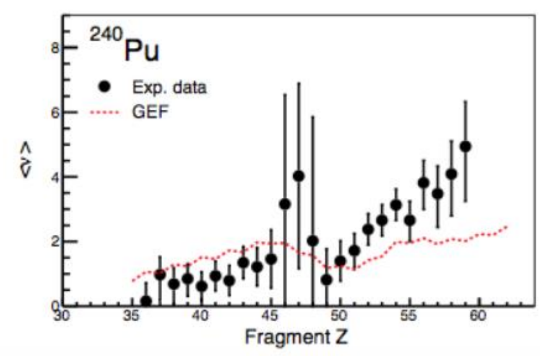
Fission Yields of ^{240}Pu E*~ 10 MeVIsotopic Yields compared to GEF



From Velocity Measurement:
Scission fragment characterization !!

$$\langle V \rangle (Z) = \frac{\sum_A Y(A,Z)V(Z,A)}{\sum_A Y(A,Z)} \qquad \frac{V_1}{V_2} = \frac{A_2^*}{A_1^*} \qquad \langle A_1^* \rangle = A_{FS}\frac{\langle V_2 \rangle}{\langle V_1 \rangle} \qquad \langle A_2^* \rangle = A_{FS} - \langle A_1^* \rangle$$





DE LA RECHERCHE À L'INDUSTRIE

ONGOING EXPERIMENTAL ACTIVITIES AT CEA ON NUCLEAR DATA

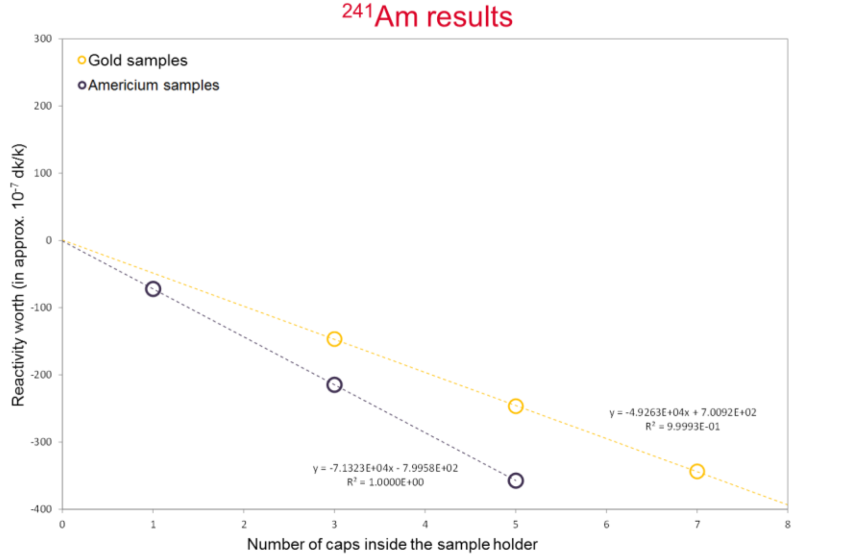
P. Leconte (DER/SPRC)

www.cea.fr

❑ Samples transported from IRMM to Cadarache

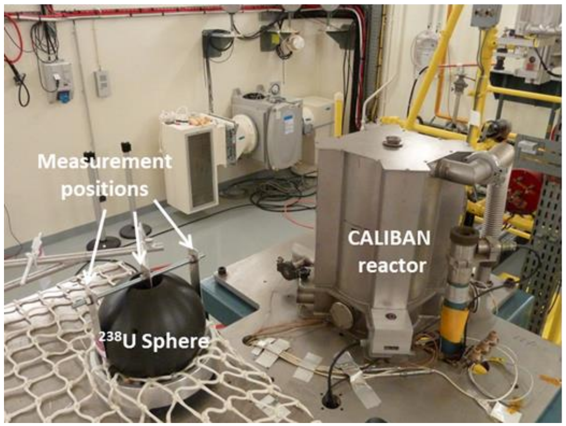
- 7 americium oxide in Al_2O_3 matrix
- 10 technetium oxide (pure material)

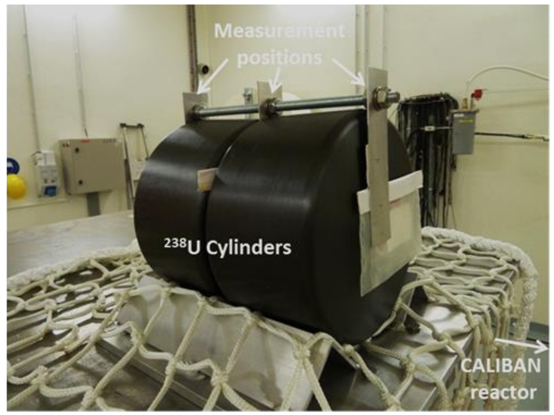
❑ Oscillation measurements in MINERVE

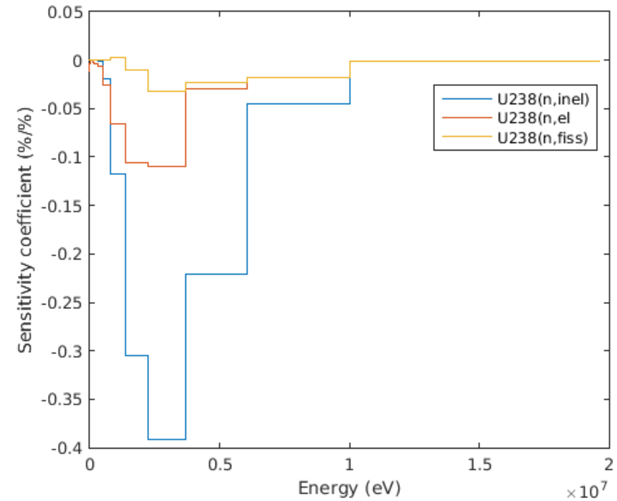


INTEGRAL TRANSMISSION EXPERIMENT ON U238 FOR INELASTIC SCATTERING VALIDATION

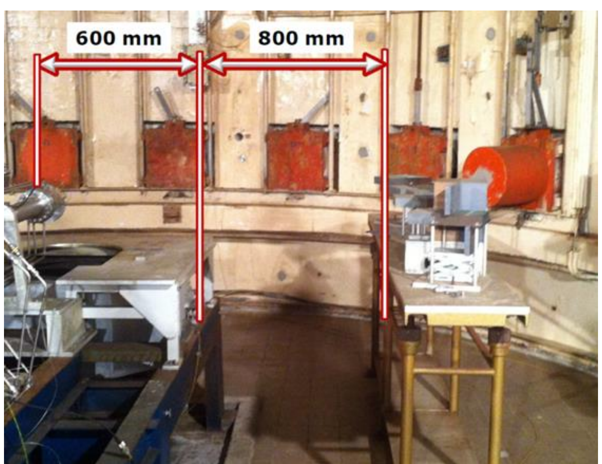
- **EXCALIBUR: Integral transmission through large blocks of U238 (sphere and cylinder) using fast neutrons from the CALIBAN facility**

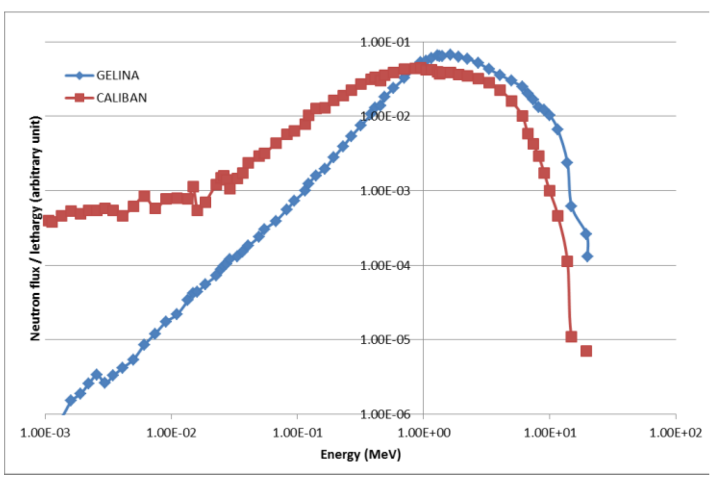






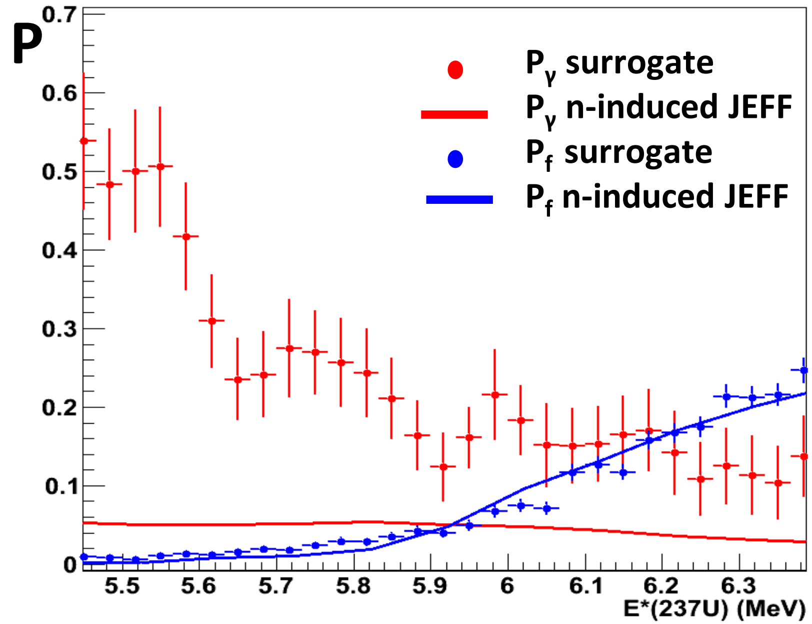
- **Ongoing studies to evaluate the feasibility of such experiments in the GELINA target hall**



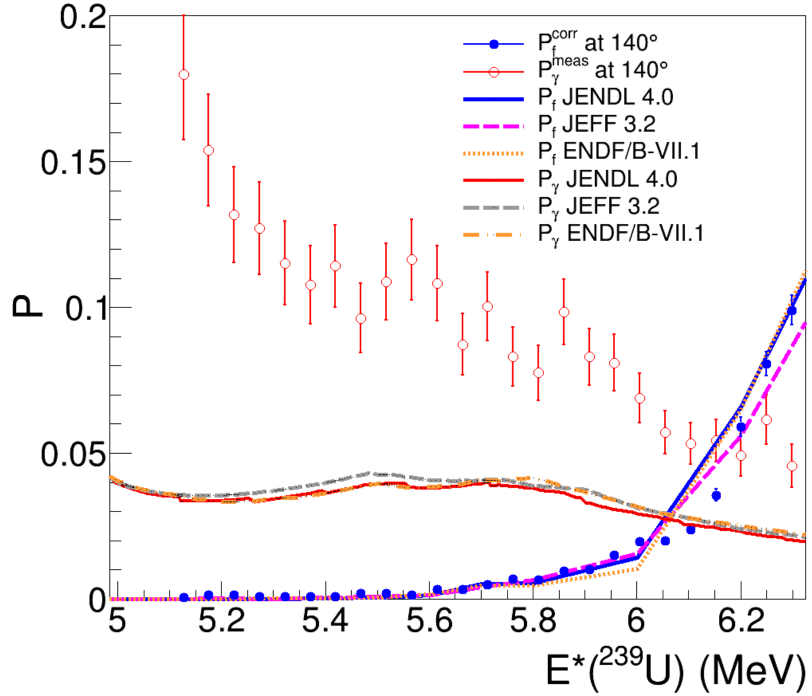


First simultaneous measurement of fission and gamma-emission probabilities for the understanding of the surrogate-reaction method

3He + 238U-> 4He + 237U ↔ n + 236U



d + 238U-> p + 239U ↔ n + 239U



Fission is much less sensitive to the entrance channel than gamma-decay!
This result cannot be explained with the performed statistical-model calculations, further theoretical efforts are needed!

Study of the surrogate-reaction method via the simultaneous measurement of gamma-emission and fission probabilities

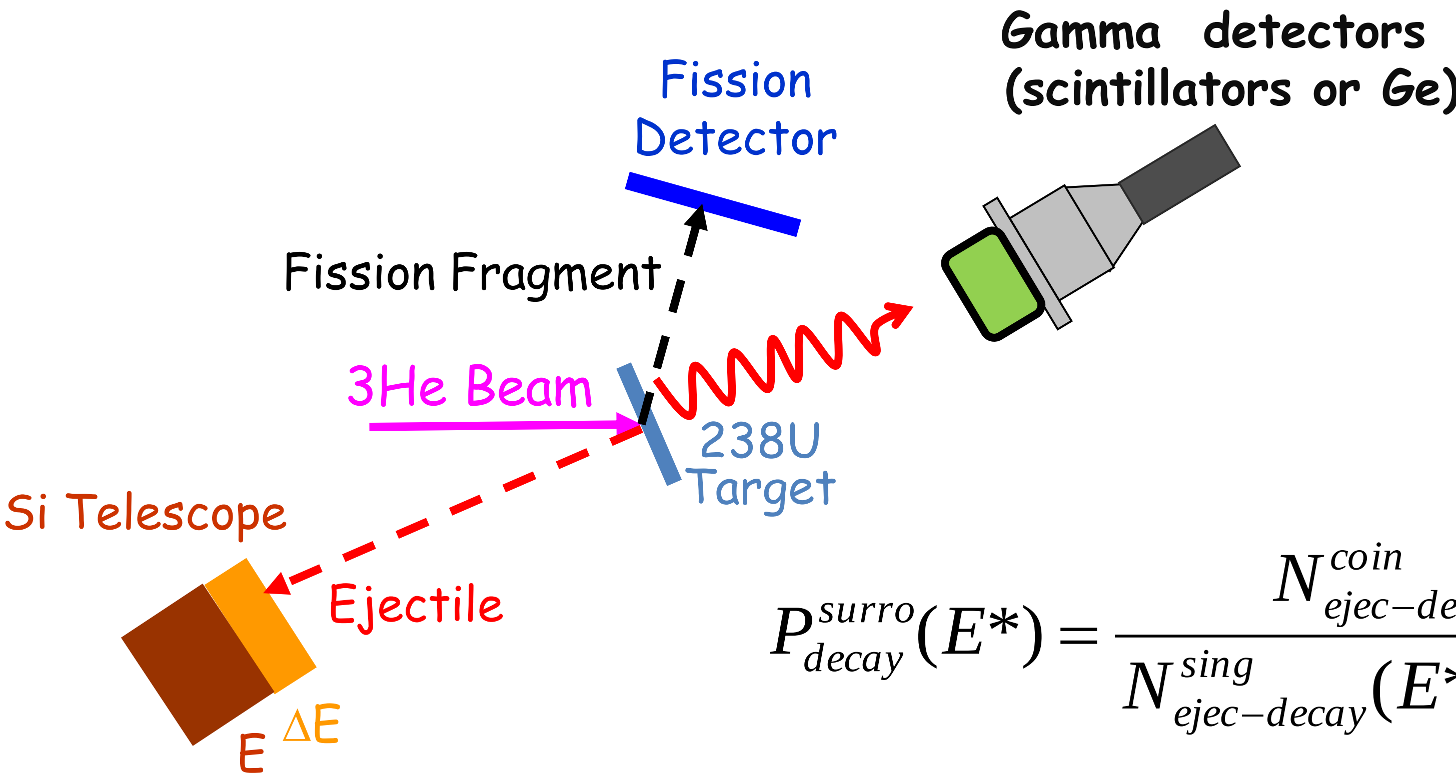
Q. Ducasse, P. Marini, B. Jurado, L. Mathieu, M. Aiche, G. Barreau, S. Czajkowski, I. Tsekhanovich, **CENBG, Bordeaux, France**

L. Audouin, M. Lebois, L. Tassan-Got, J. Wilson, **IPN-Orsay, France**

G. Boutoux, D. Denis-Petit, V. Méot, O. Roig, O. Sérot, **CEA-DAM & CEA-DEN, France**

S. Oberstedt, **IRMM, Belgium**
A. Oberstedt, **Chalmers University, Sweden**
M. Guttormsen, **University of Oslo, Norway**
G. Kessedjian, **LPSC, Grenoble, France**

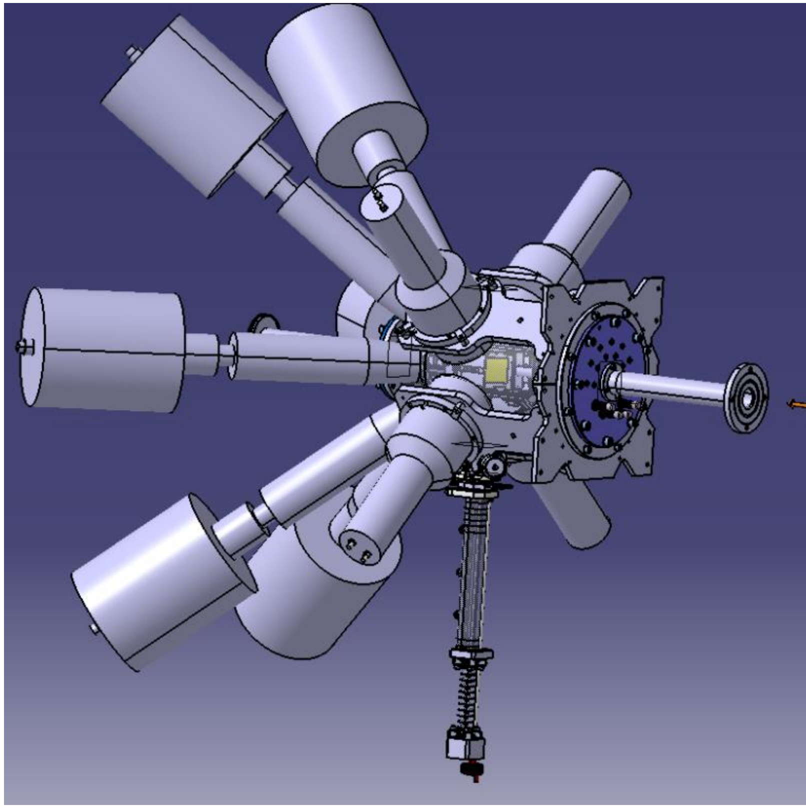
Setup for simultaneous measurement of fission and gamma-decay probabilities

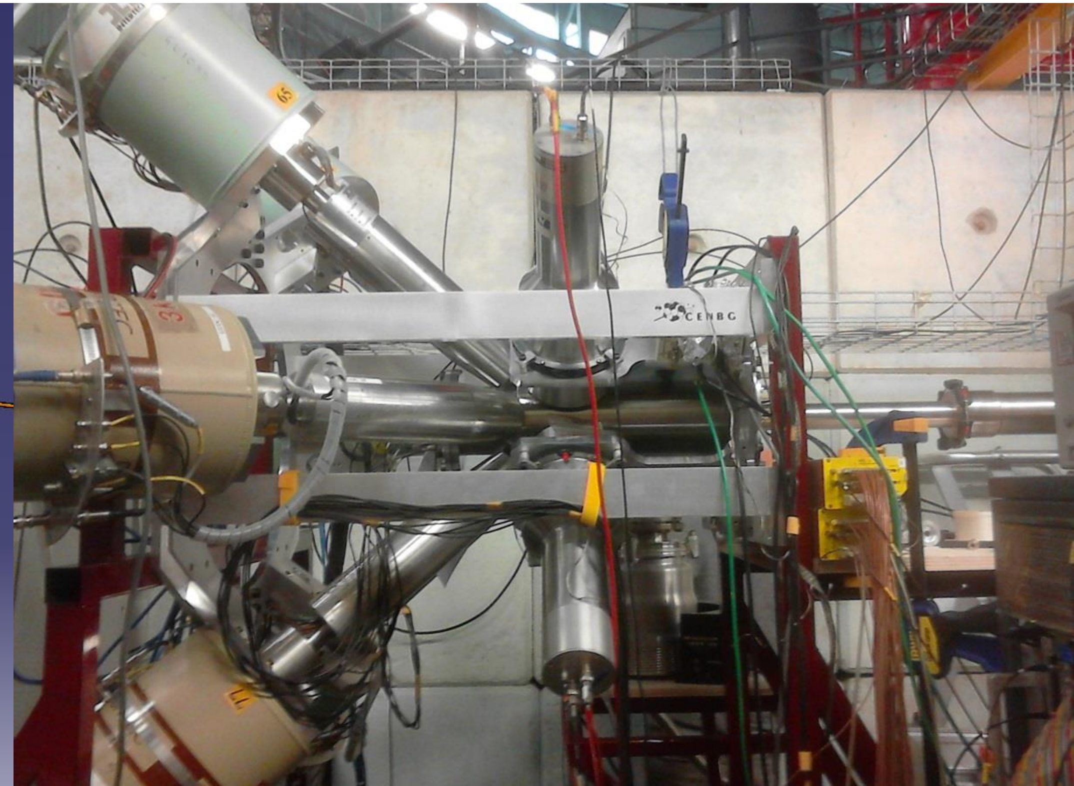


$$P^{surro}_{decay}(E^*) = \frac{N^{coin}_{ejec-decay}(E^*)}{N^{sing}_{ejec-decay}(E^*) \cdot \varepsilon_{decay}(E^*)}$$

Challenge: removal of gamma rays emitted by the fission fragments !

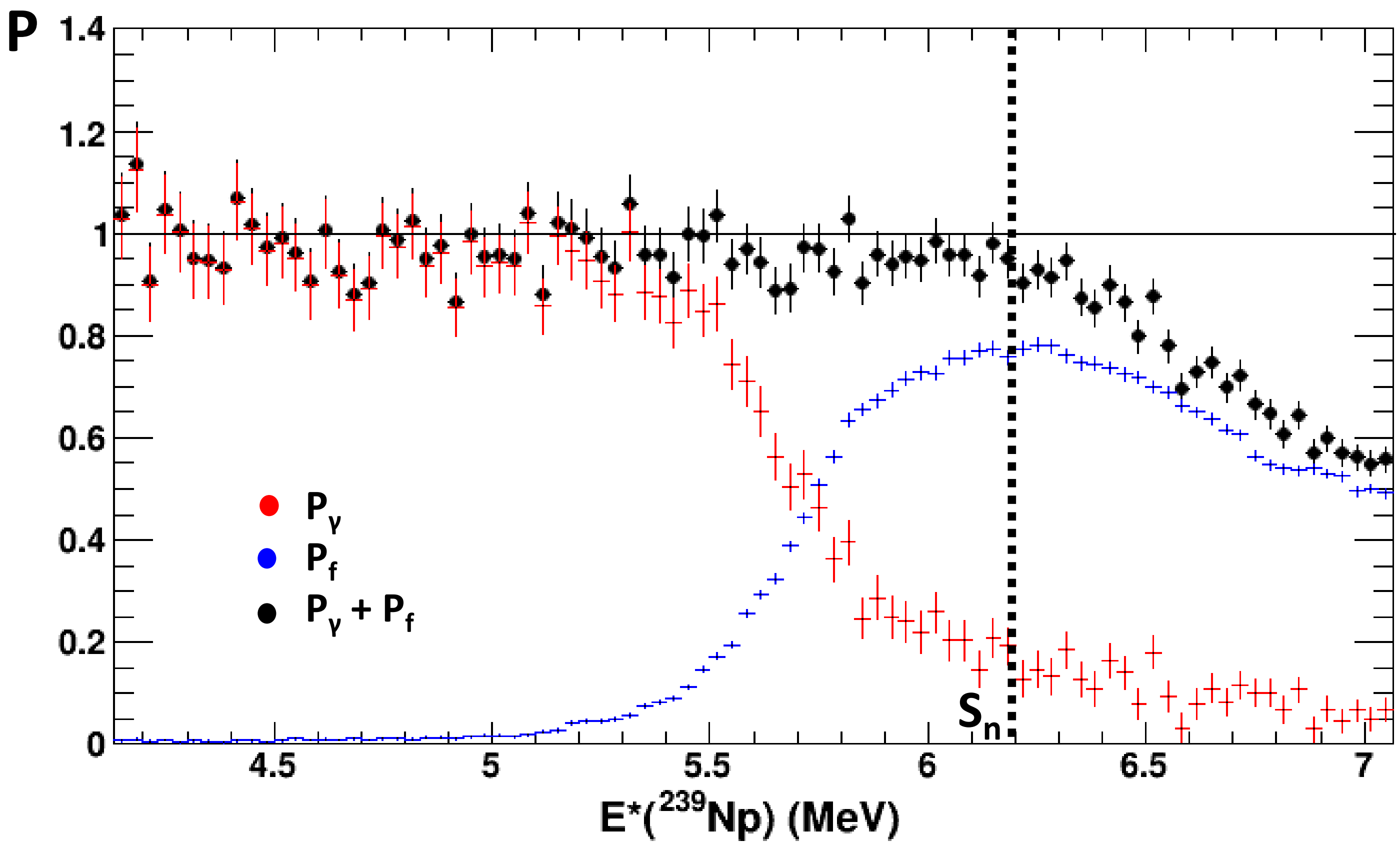
Setup used for experiment at the Orsay tandem in April 2015





Preliminary results!

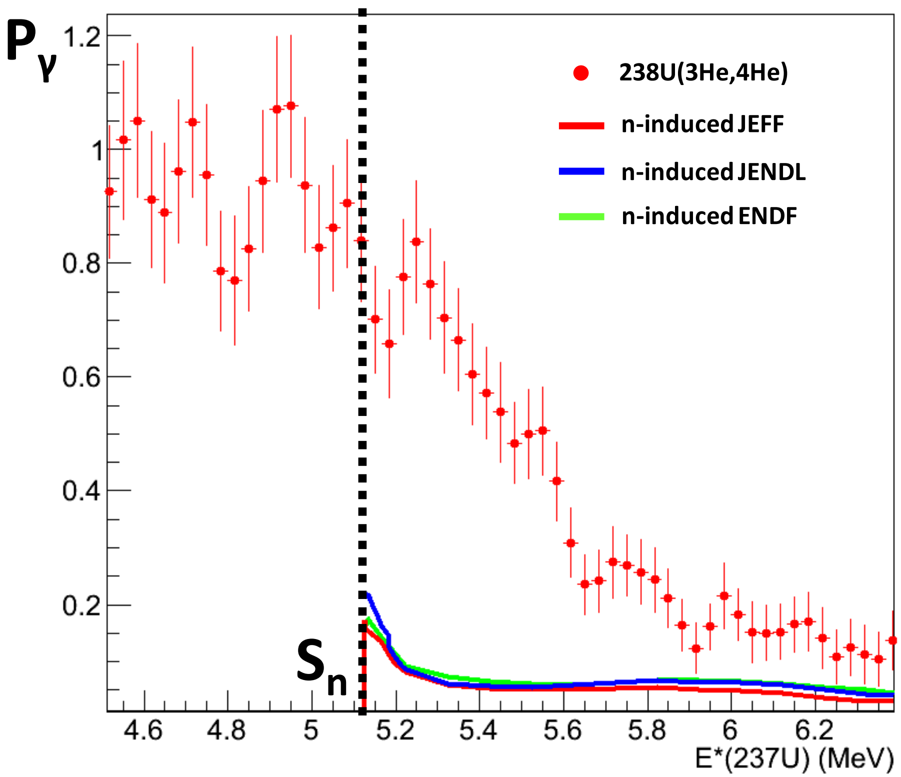
3He + 238U-> d + 239Np ↔ n + 238Np (2,1d)

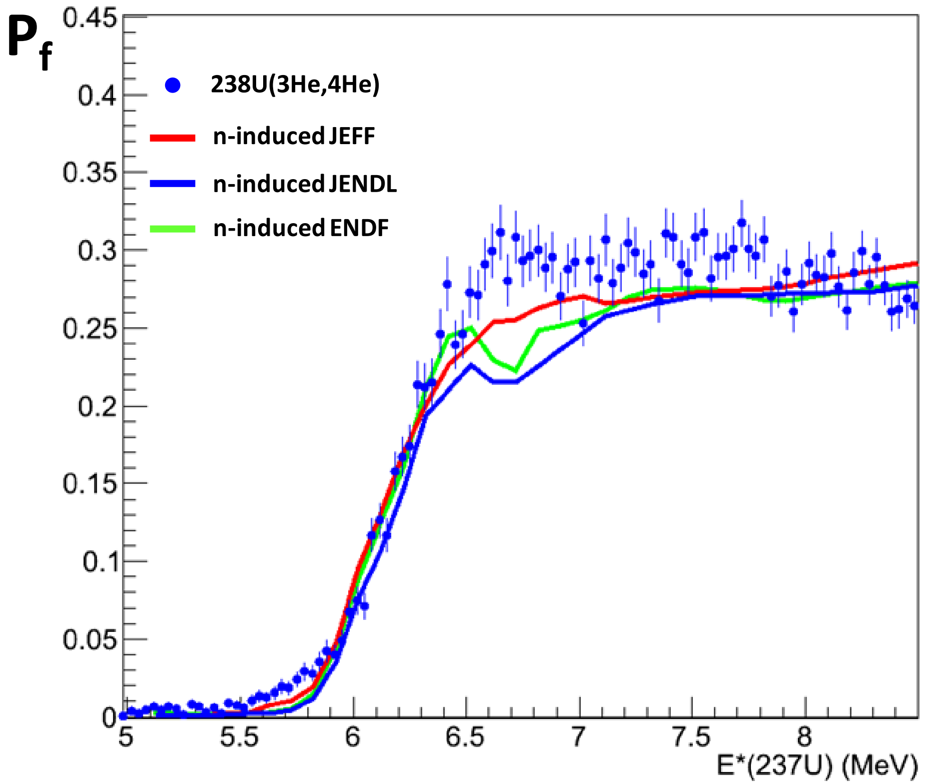


$P_f + P_\gamma = 1$ at $E^* < S_n$:
Validation of analysis procedure!

Preliminary results!

3He + 238U-> 4He + 237U ↔ n + 236U

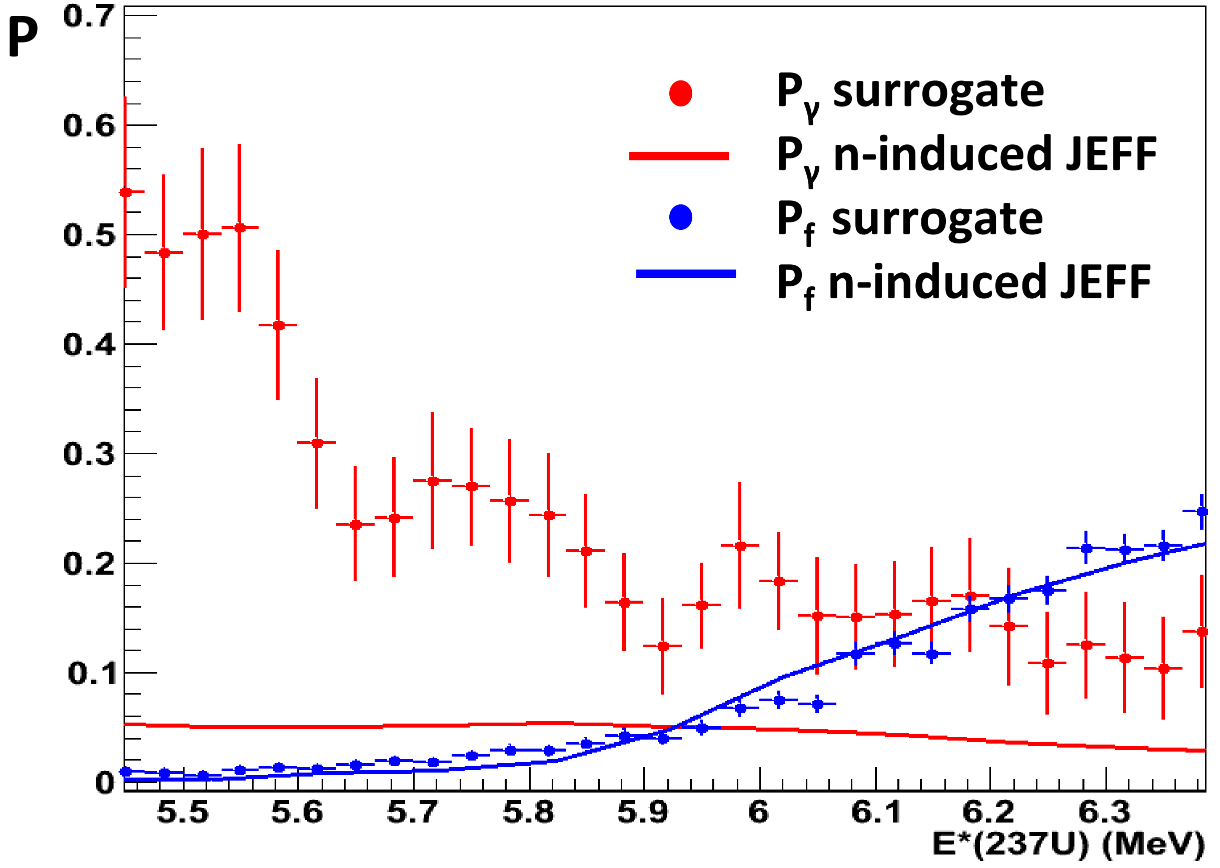




Focus on the overlap region

Preliminary results!

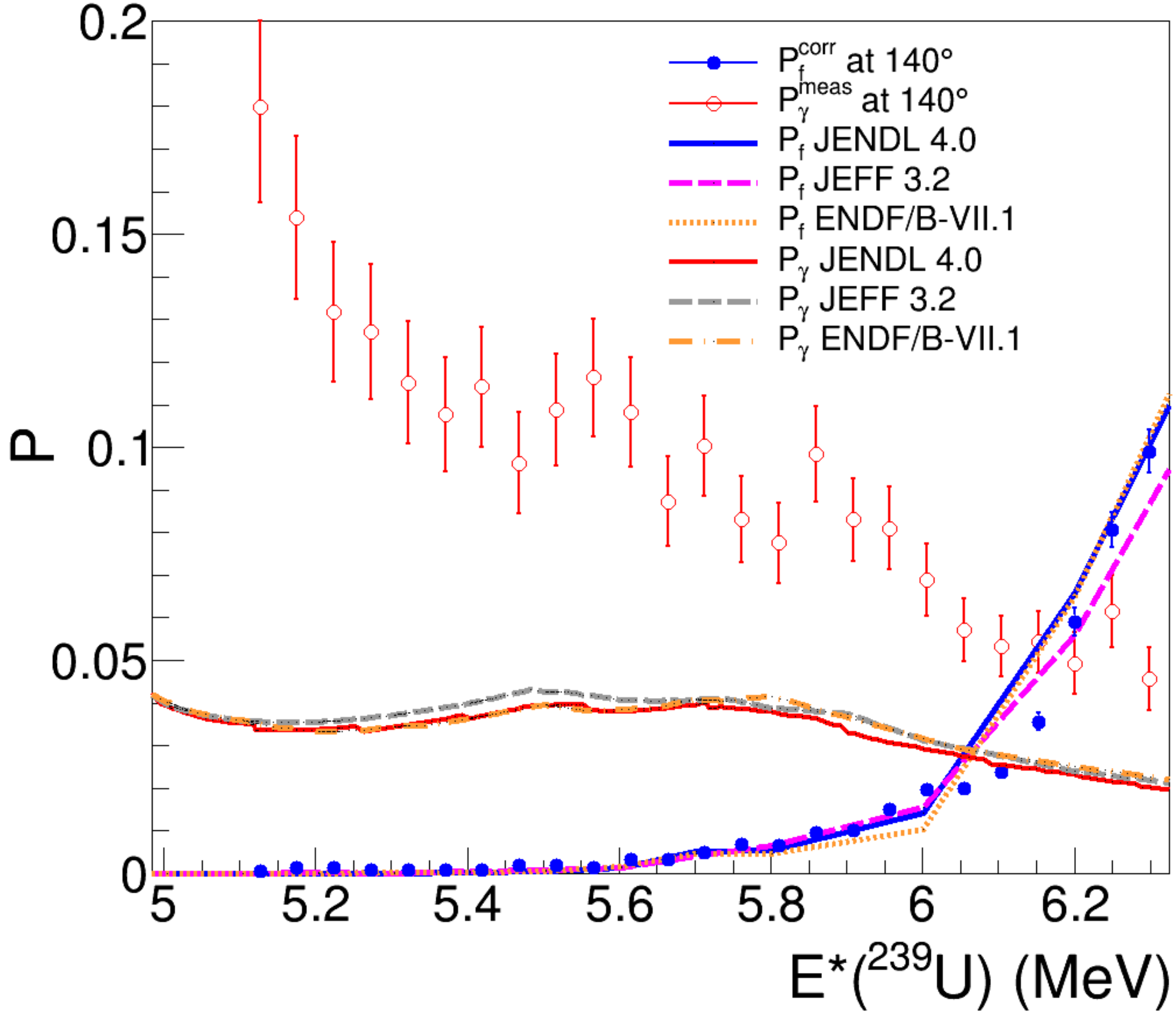
3He + 238U-> 4He + 237U ↔ n + 236U



Fission is much less sensitive to the entrance channel than gamma-decay!

Focus on the overlap region

d + 238U-> p + 239U ↔ n + 238U



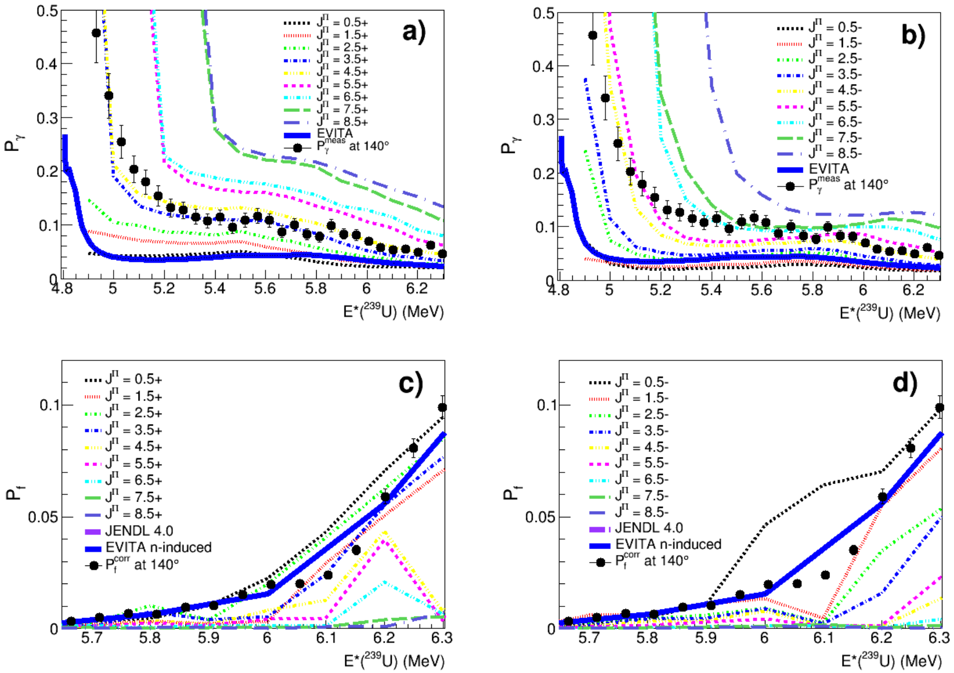
Q. Ducasse et al., Nucl. Instrum. Meth. A 826 (2016) 60

Q. Ducasse et al., submitted to Phys. Rev. C (http://arxiv.org/abs/1512.06334)

Can we understand these results within the frame of the statistical model?

238U(d,p)

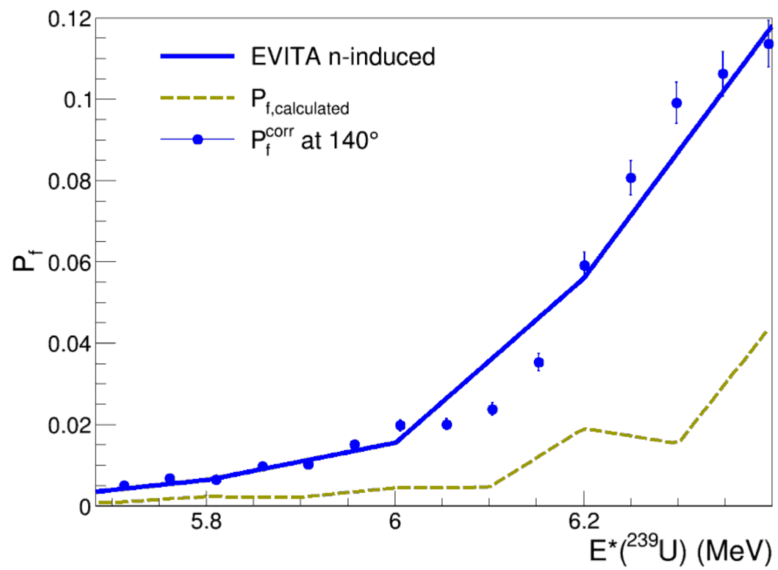
Calculations performed with the Hauser-Feshbach code EVITA developped by the CEA/DAM



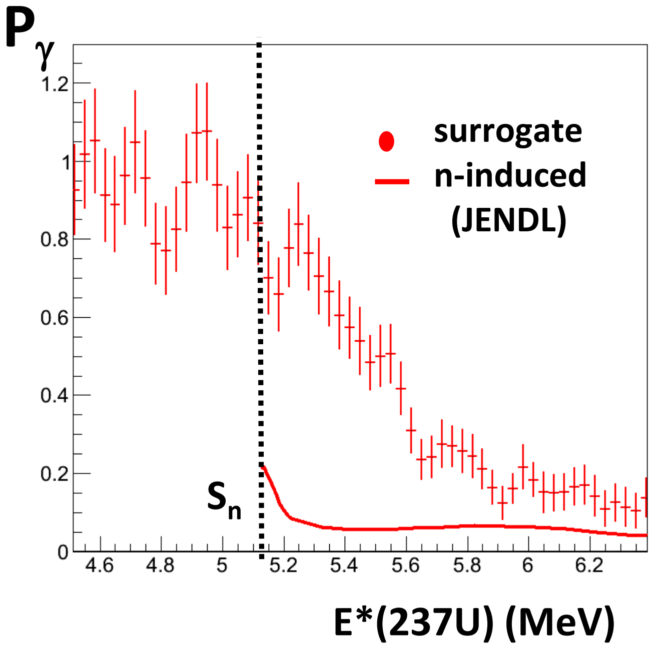
	$\bar{J}$	σ
$P_f^{EVITA,n}$	1.3	1.1
$P_\gamma^{EVITA,n}$	1.5	1.2
P_f^{corr}	1.4	0.8
P_γ^{meas}	4.5	1.4

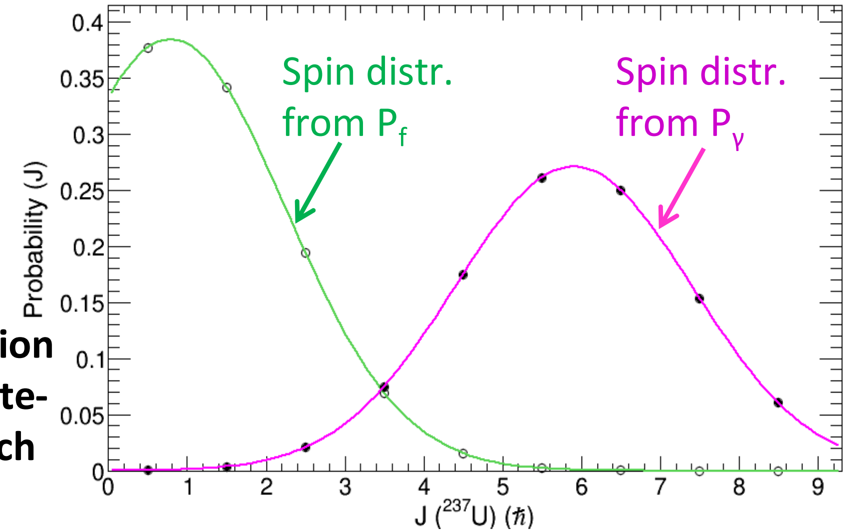
For the surrogate data, the spin distribution deduced with the gamma-emission probability is very different from the one deduced with the fission probability

If we use the spin distribution deduced with the gamma-decay probability as input of the Hauser-Feshbach calculations we obtain the dashed curve which does not reproduce the experimental data represented by the blue dots.

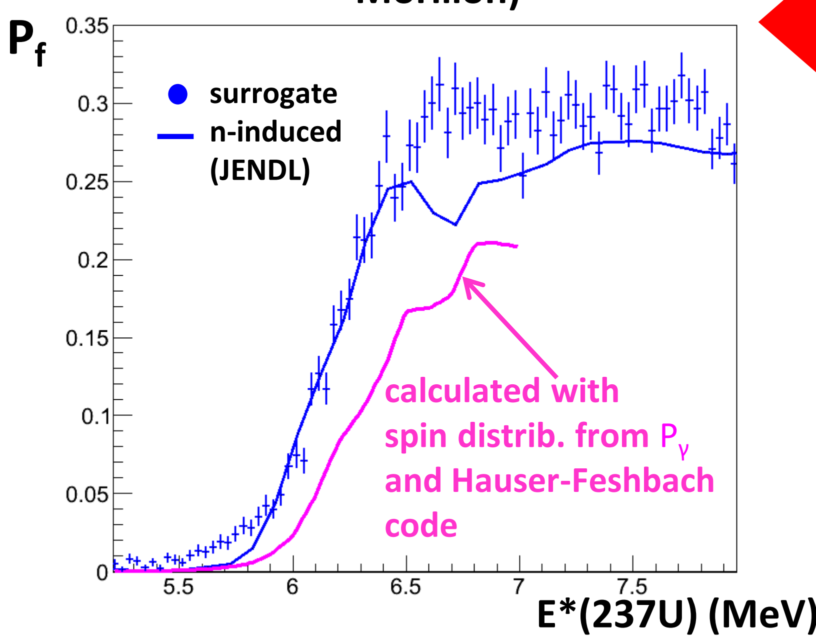


238U(3He,4He)





Deduce spin distribution with the help of monte-carlo Hauser Feshbach code EVITA (Based on TALYS and run by CEA evaluator B. Morillon)



The calculations predict a strong sensitivity of the fission probability to angular momentum in contradiction with our results!

Conclusions…

- **First simultaneous measurement of gamma-decay and fission probabilities for surrogate reactions**

- **The fission probability is much less sensitive than the gamma-decay probability to the differences in the entrance channel.**

- **This finding cannot be explained by statistical model calculations based on TALYS with the parameters of the JEFF 3.2 evaluation**

… Perspectives

- **Pursue theoretical efforts to understand our results**
- **Measurement P_f and $P\gamma$ for even-even 240Pu**
- **Perform systematic studies in other regions of the chart of nuclei, isomeric beams**

→Experiments in inverse kinematics inside storage rings with the RIBs of GSI and HIE-ISOLDE