The European Commission's science and knowledge service

Joint Research Centre

European Commission

Summary of experimental activities reported to JEFF

Arjan Plompen

OECD-NEA, 17 May 2018

European Commission

Source

- Two JEFF meetings with EU CHANDA project
- November 2017
- April 2018
- Detailed information is/will be available at NEA website

elastic scattering measurements at GELINA

new setup at GELINA

- for elastic scattering
- potentially inelastic scattering too. . .

to measure

- neutron angular distributions/ differential cross sections
- total elastic cross section via numerical integration
- in the fast neutron energy range

experiments:

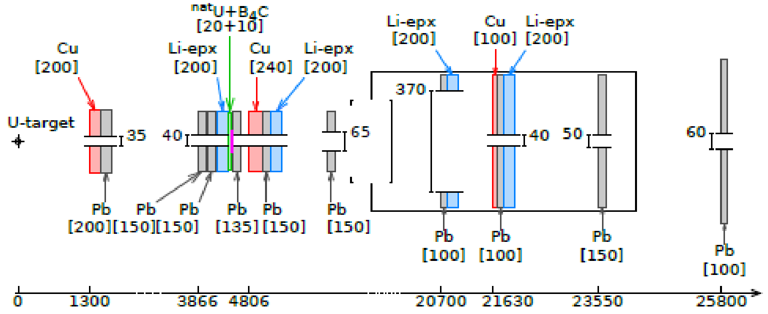
- C-nat, as reference
- Fe-56

Flight path 27.037(5) m, 108° with respect to the primary electron beam

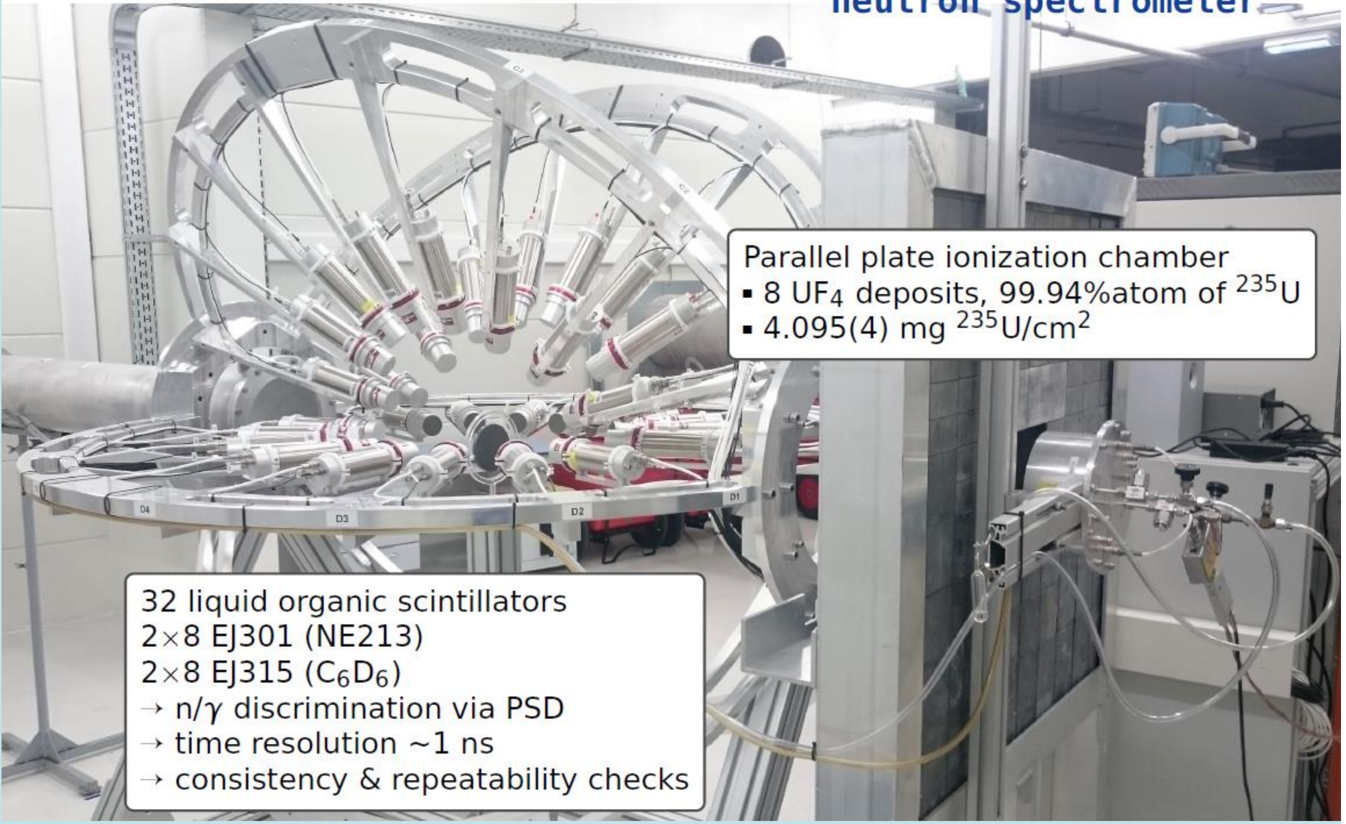
➠ lower target self-absorption, higher neutron flux

TOF resolution 5 ns

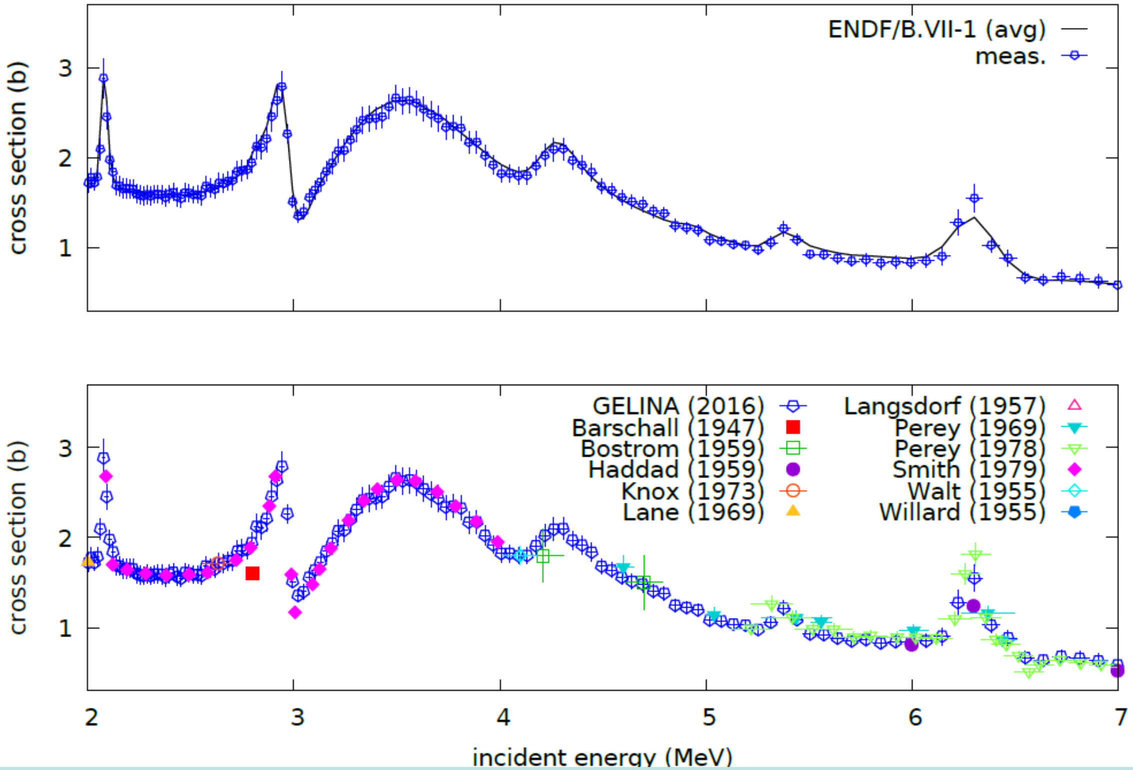
Energy resolution 5 keV @1 MeV



neutron spectrometer



total elastic cross section



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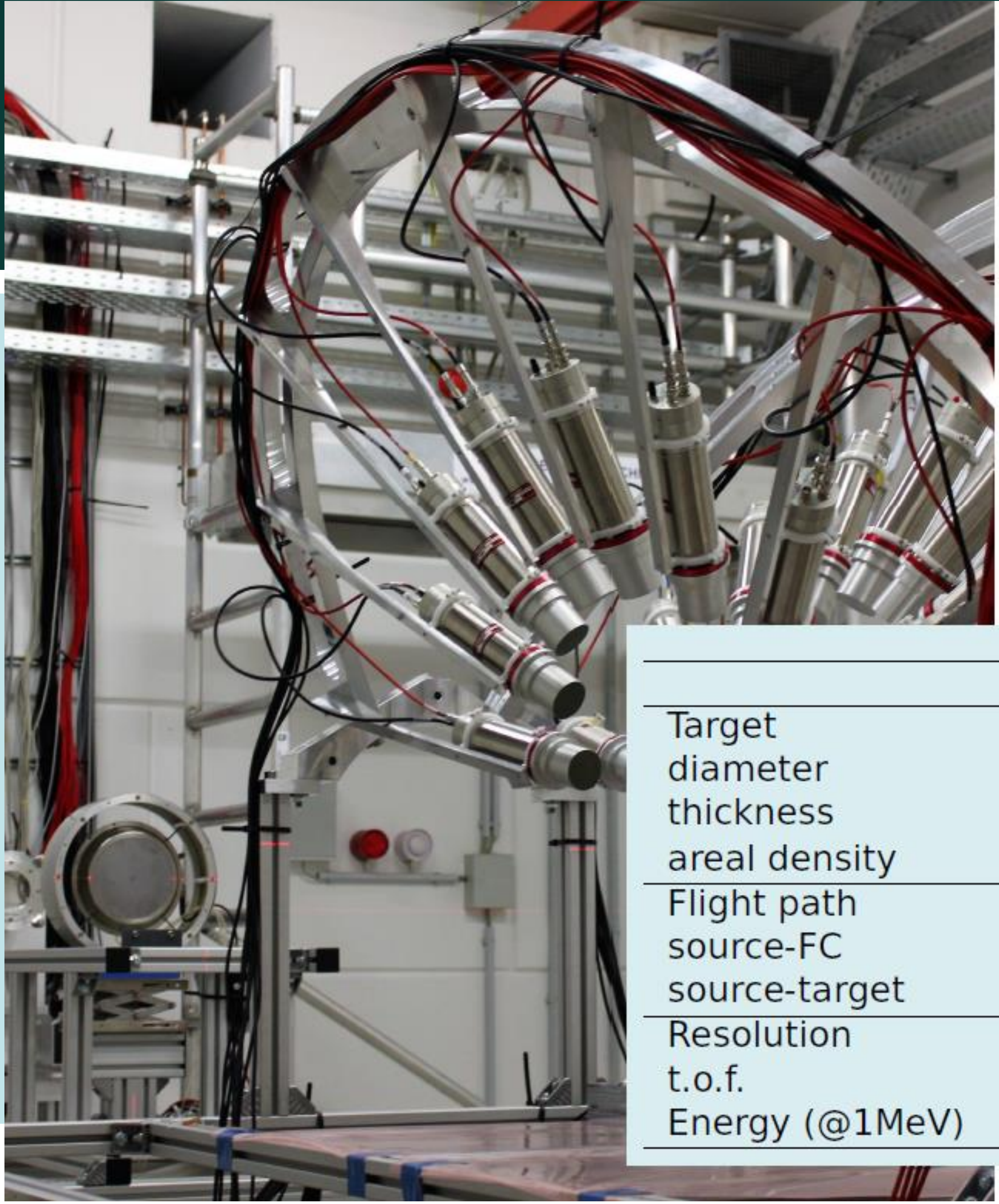


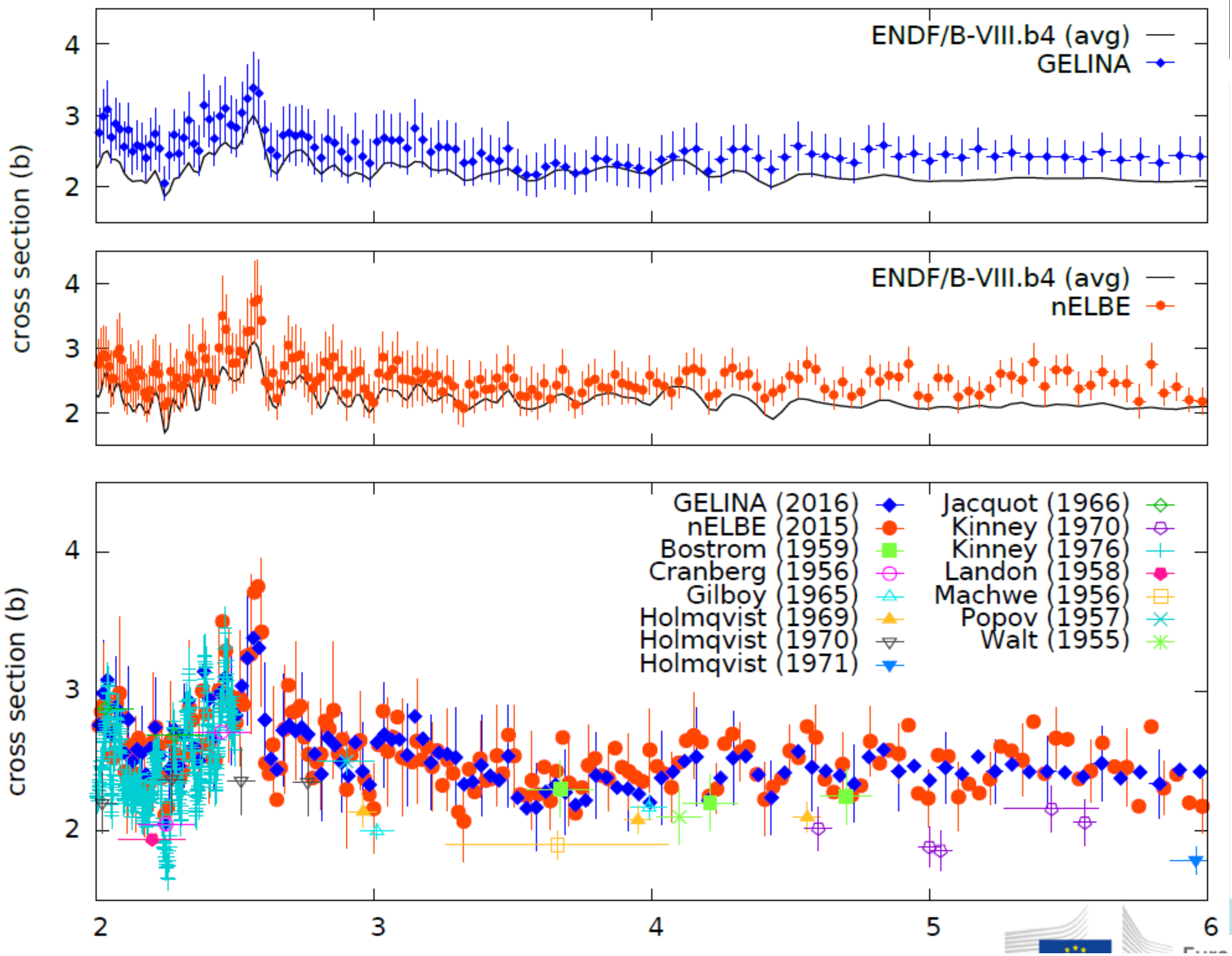
n-^{nat}Fe scattering

natural iron

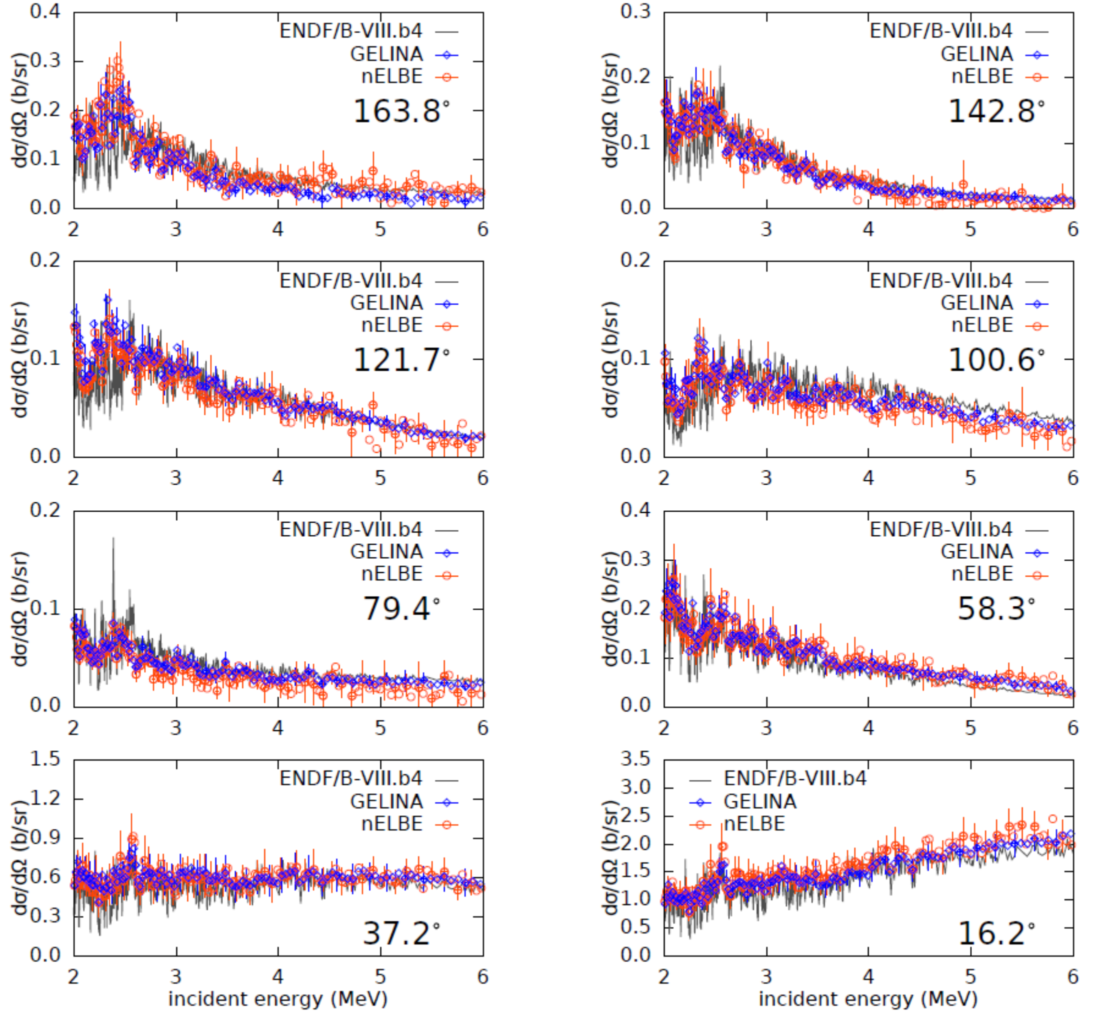
- ^{54}Fe → 5.845%(atom)
- ^{56}Fe → 91.754%
- ^{57}Fe → 2.119%
- ^{58}Fe → 0.282%

	GELINA	nELBE
Target		
diameter	7.103(1) cm	7.90(1) cm
thickness	0.30(1) cm	0.31(1) cm
areal density	2.4283(7) g/cm^2	2.442(6) g/cm^2
Flight path		
source-FC	25.667(5) m	6.044(5) m
source-target	27.037(5) m	8.300(5) m
Resolution		
t.o.f.	5 ns	1 ns
Energy (@1MeV)	5 keV	3 keV

total elastic cross sectio

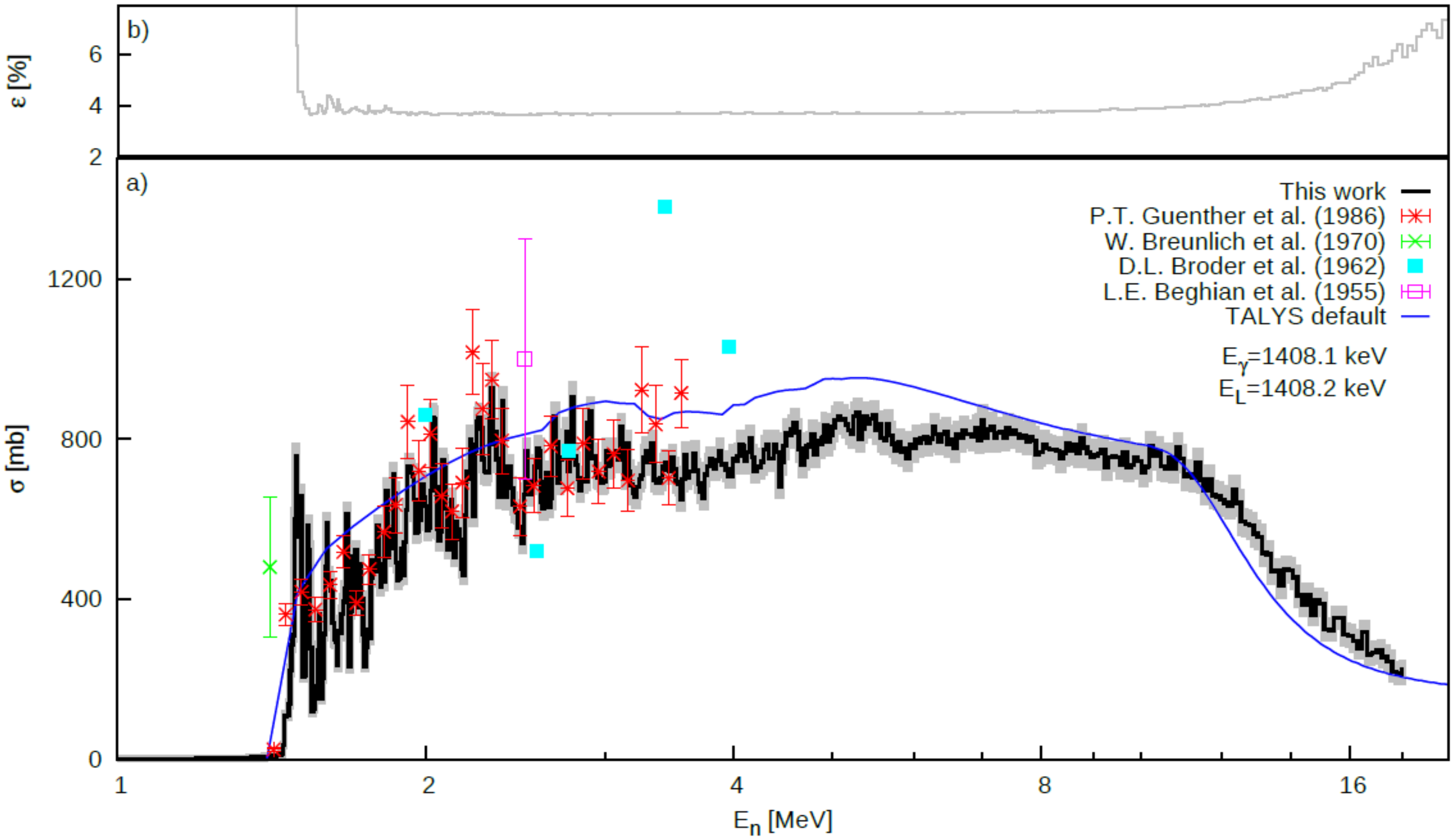


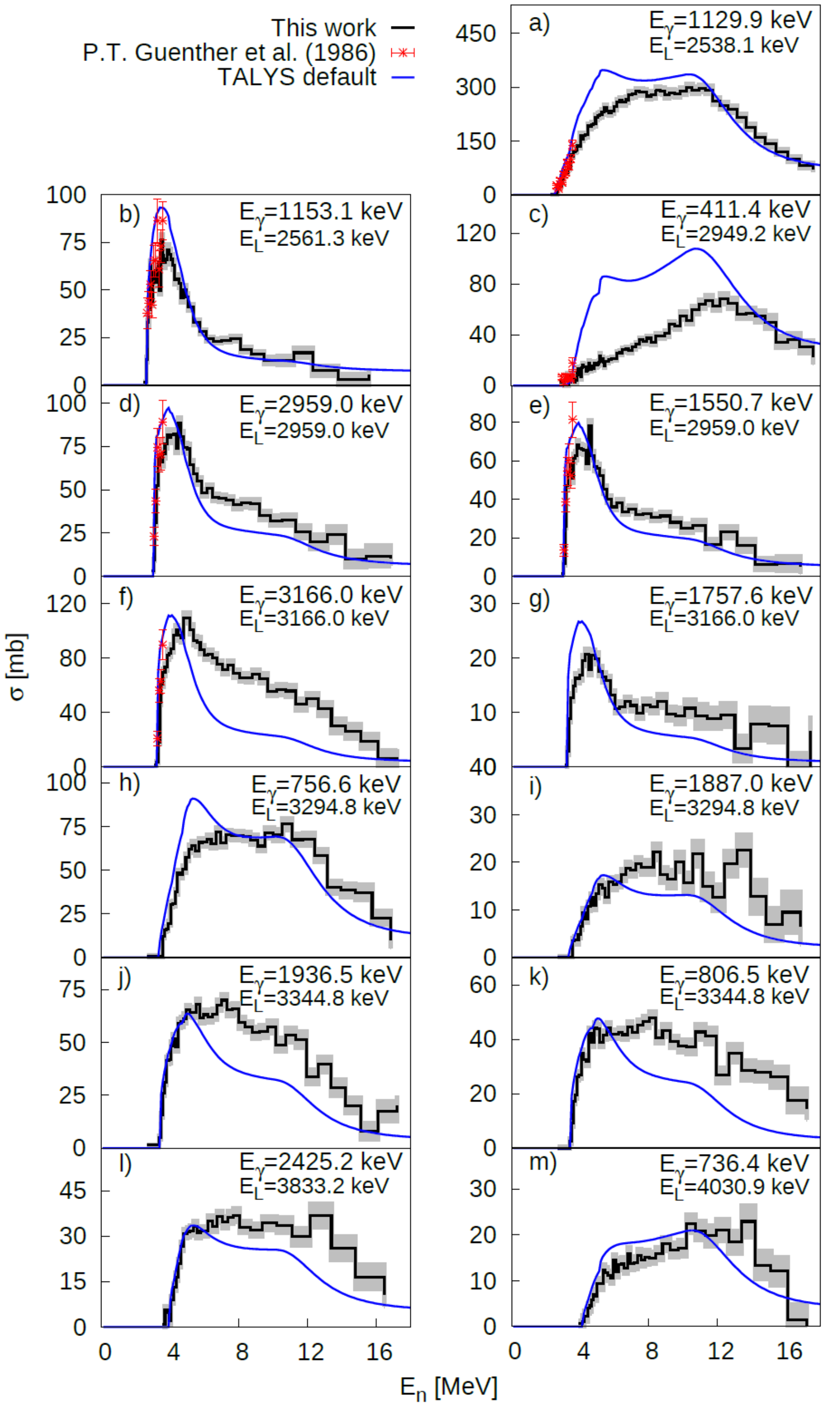
differential elastic cross section

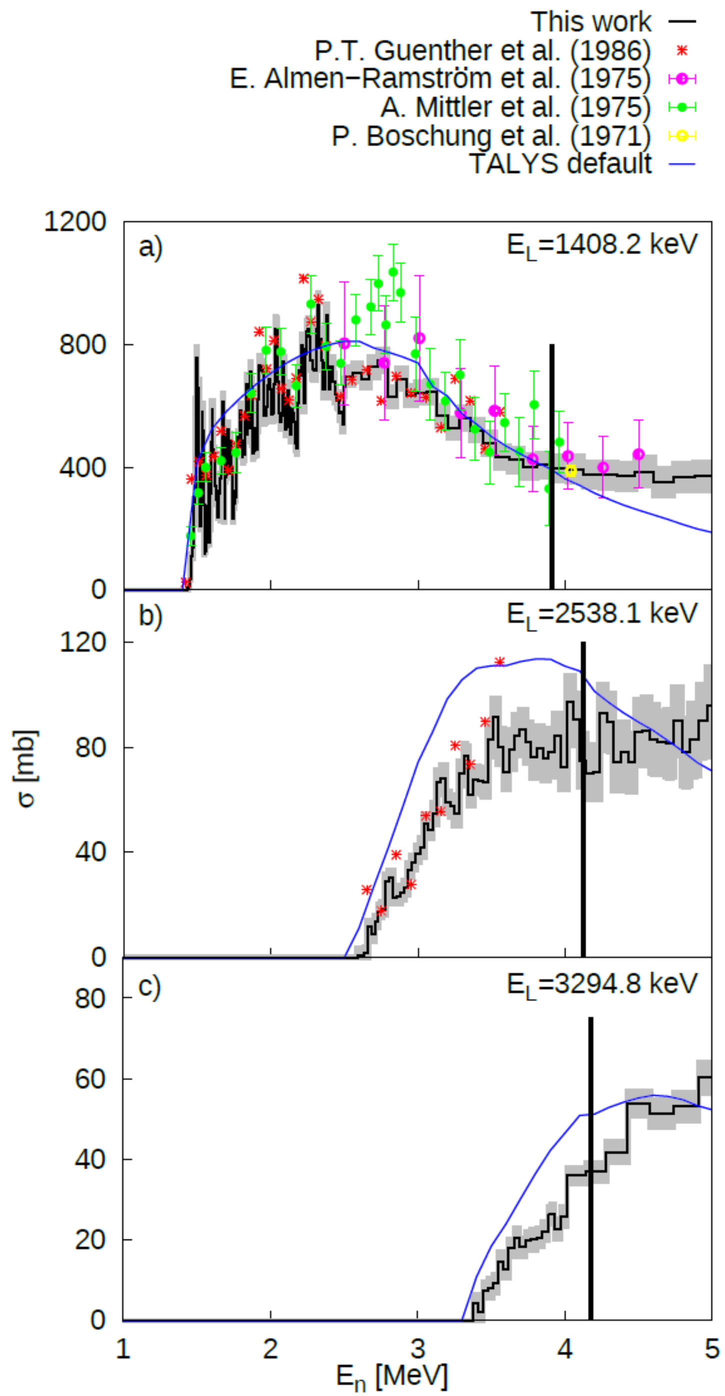


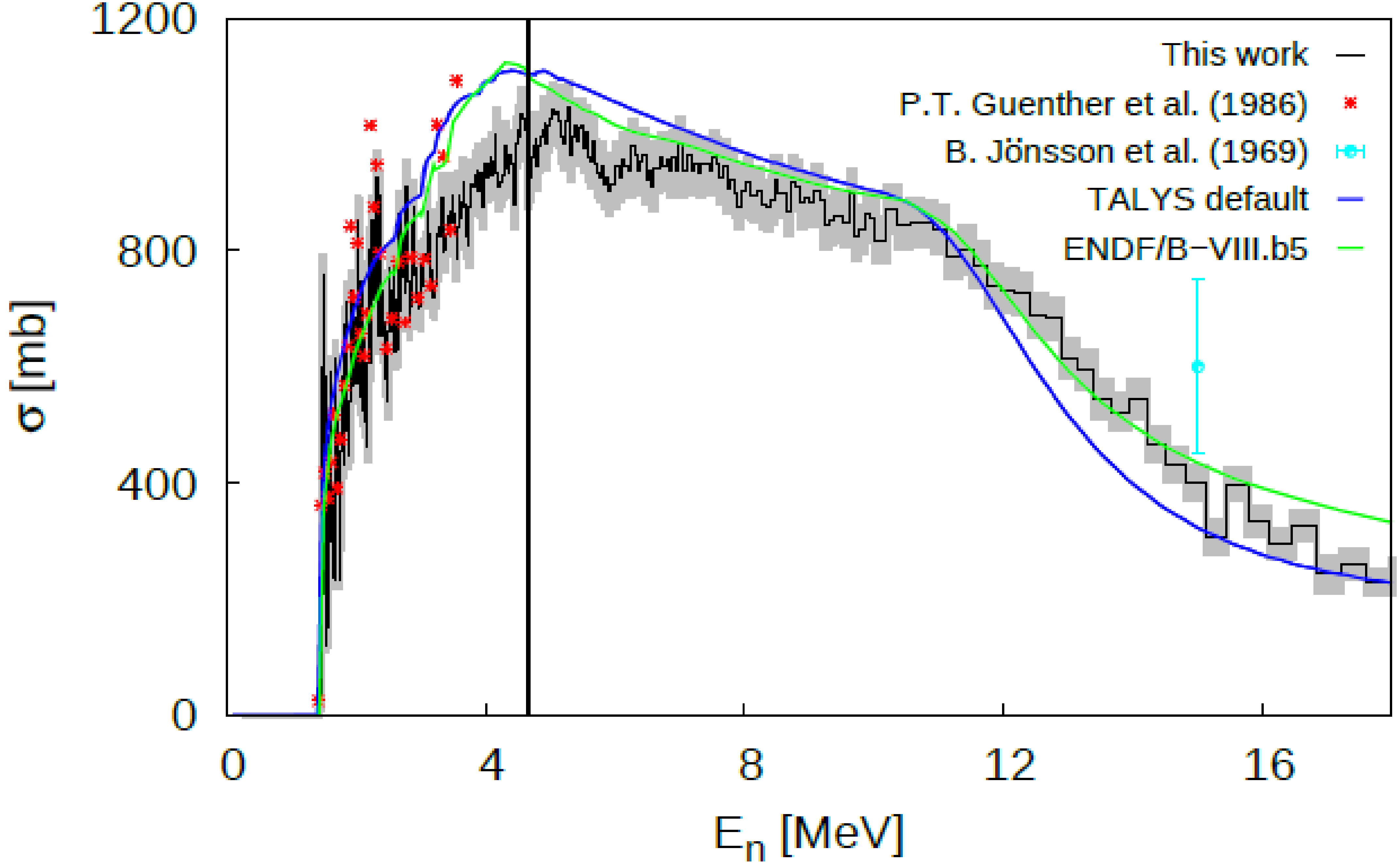
$^{54}Fe(n,n'g)$, A. Olacel et al., IFIN-HH, JRC, IPHC, IRSN

- 97.68(7)% ^{54}Fe




This work
P.T. Guenther et al. (1986)
TALYS default
a) Eγ=1129.9 keV EL=2538.1 keV
b) Eγ=1153.1 keV EL=2561.3 keV
c) Eγ=411.4 keV EL=2949.2 keV
d) Eγ=2959.0 keV EL=2959.0 keV
e) Eγ=1550.7 keV EL=2959.0 keV
f) Eγ=3166.0 keV EL=3166.0 keV
g) Eγ=1757.6 keV EL=3166.0 keV
h) Eγ=756.6 keV EL=3294.8 keV
i) Eγ=1887.0 keV EL=3294.8 keV
j) Eγ=1936.5 keV EL=3344.8 keV
k) Eγ=806.5 keV EL=3344.8 keV
l) Eγ=2425.2 keV EL=3833.2 keV
m) Eγ=736.4 keV EL=4030.9 keV
σ [mb]
En [MeV]


This work
P.T. Guenther et al. (1986)
E. Almen−Ramström et al. (1975)
A. Mittler et al. (1975)
P. Boschung et al. (1971)
TALYS default
a) EL=1408.2 keV
b) EL=2538.1 keV
c) EL=3294.8 keV
σ [mb]
En [MeV]



This work
P.T. Guenther et al. (1986)
B. Jönsson et al. (1969)
TALYS default
ENDF/B−VIII.b5
σ [mb]
1200
800
400
0
0
4
8
12
16
E_n [MeV]

Investigations of fission neutrons

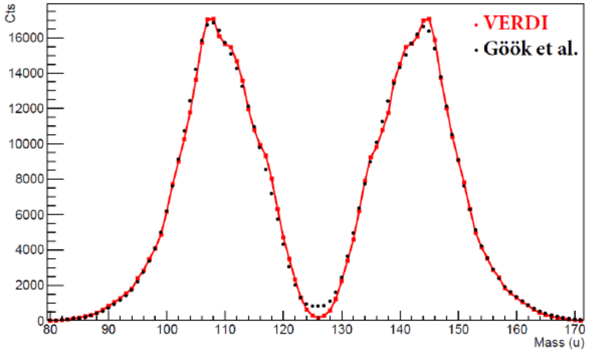
A. Al-Adili [1,*], K. Jansson [1], D. Tarrío [1], F.-J. Hambsch [2], A. Göök [2], S. Oberstedt [2], V. Rakopoulos [1], A. Solders [1], S.Pomp [1]

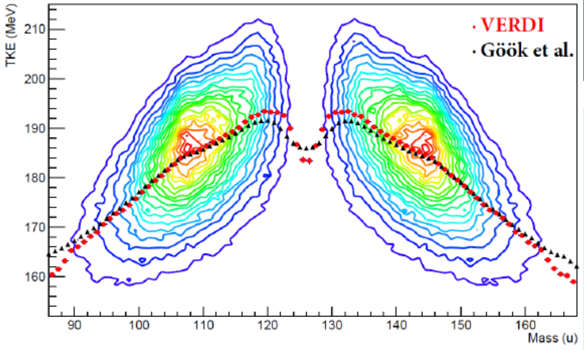
1 Department of Physics and Astronomy, Uppsala University, Sweden

2 European Commission, Joint Research Centre, Directorate G-2, Geel, Belgium

Results from Cf-252

The data look promising !

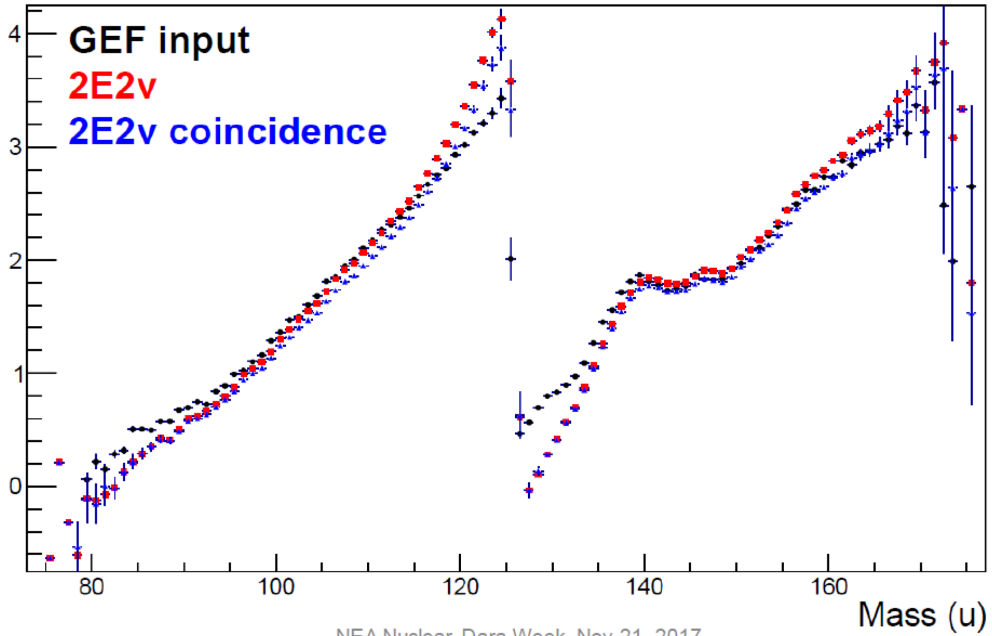




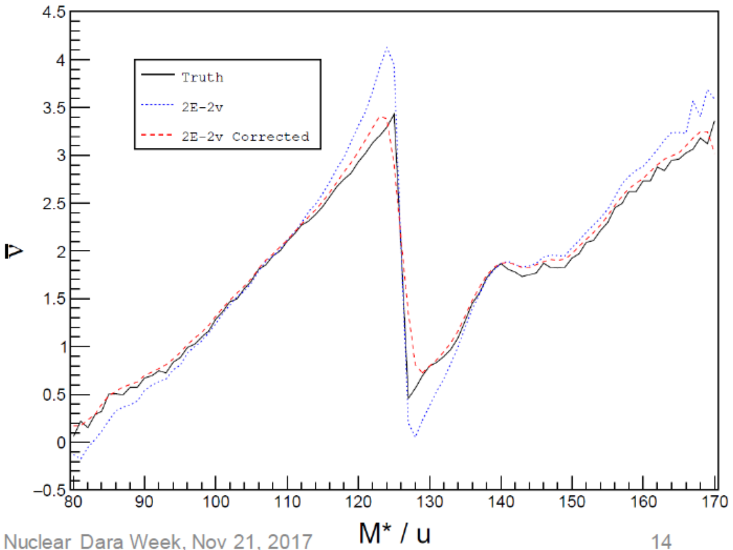
NOTE: In both distributions we can observe improved mass resolution compared to 2E.

GEF simulations - Nubar (A)

Slight changes of nubar.
Note overshoot/undershoot effects!

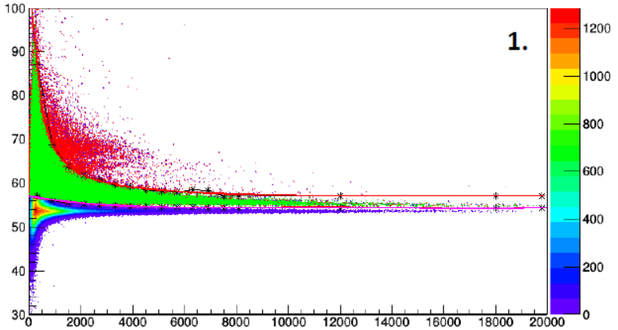


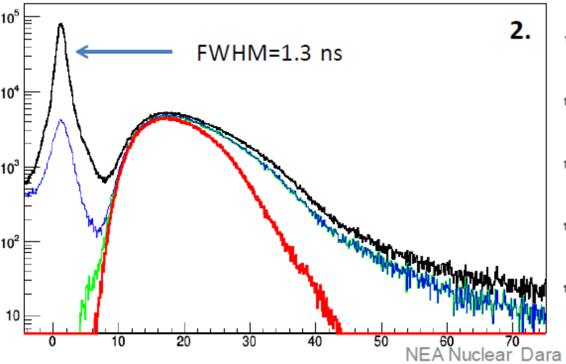
- Fundamental problem with the central assumption of unchanged fragment velocity, on average!
- Introduced a mass smearing of 0.8 amu in Cf-252
- Correction possible by deconvolution!

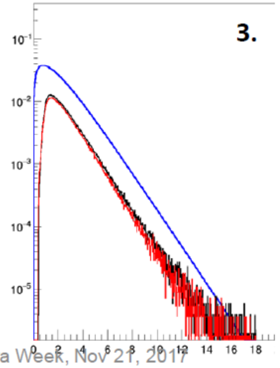


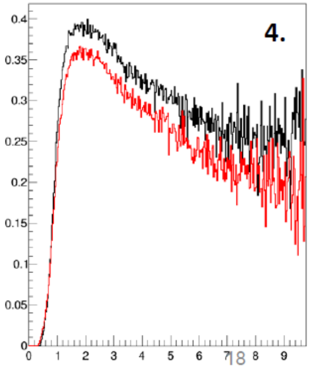
Neutron data (Cf-252)

1. Pulse shape discrimination.
2. TOF and cuts.
3. Neutron energy.
4. Detector efficiency



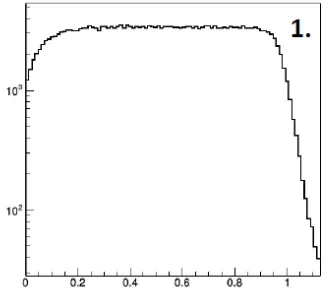


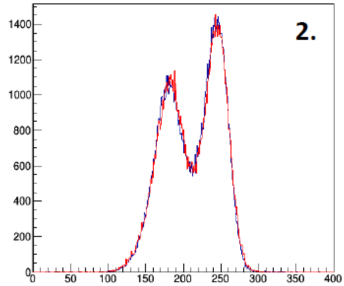


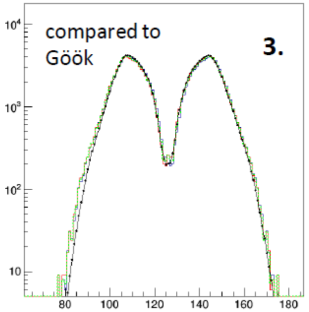


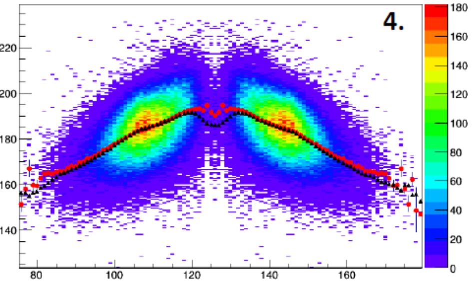
Results Cf-252

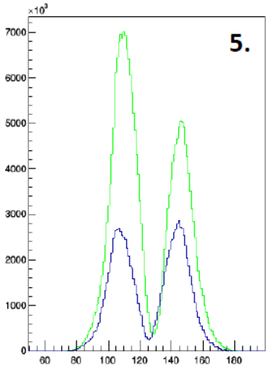
1. Cosine(θ)
2. FF Pulse Heights
3. Mass distribution
4. Mass vs TKE
5. Coincidence mass distribution



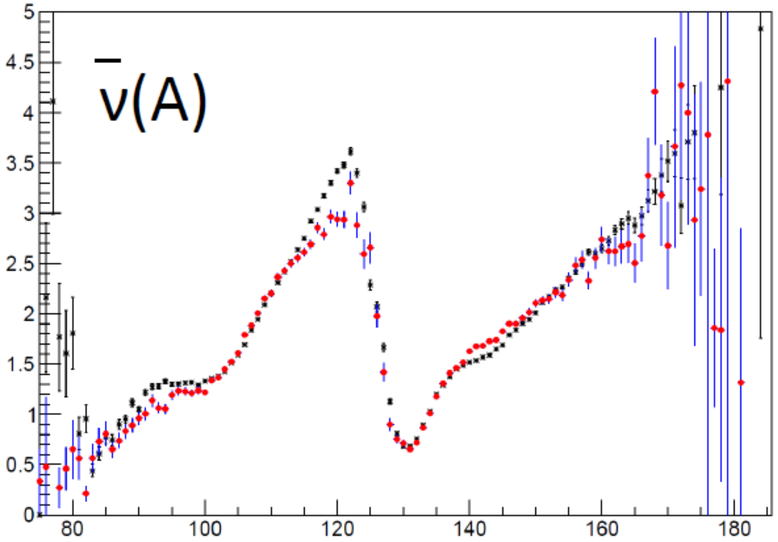


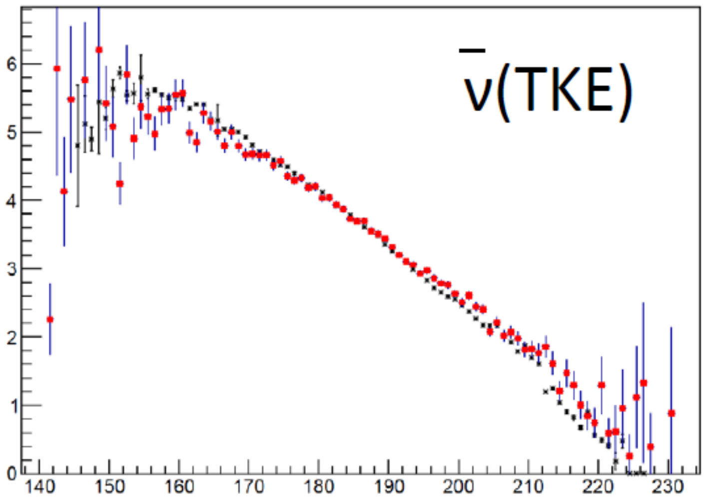






- We confirm the data of Göök et al.





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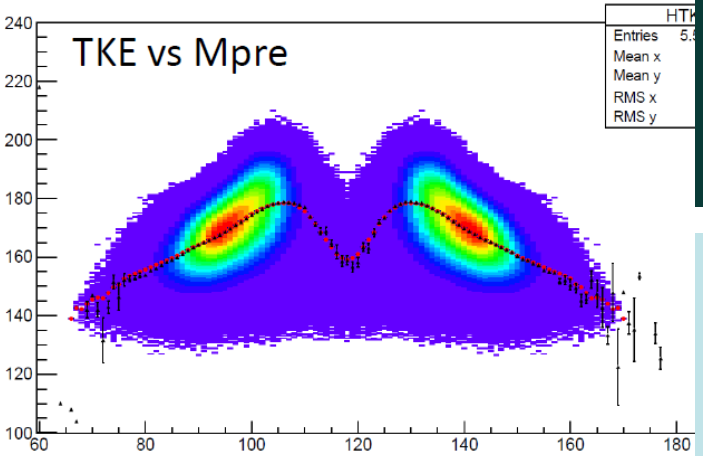
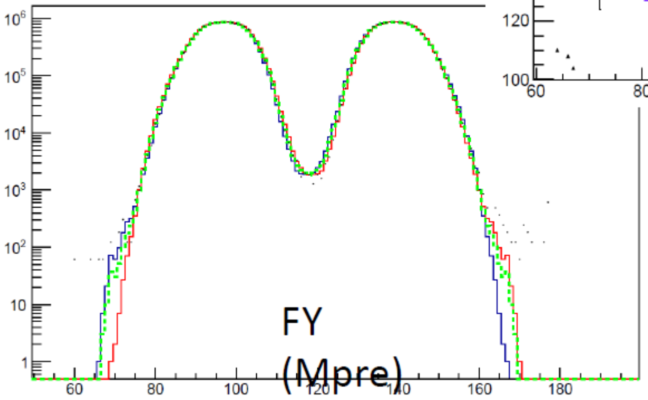
Results U-235 thermal data

- Good agreement with FF data from Göök et al. (plotted in black)

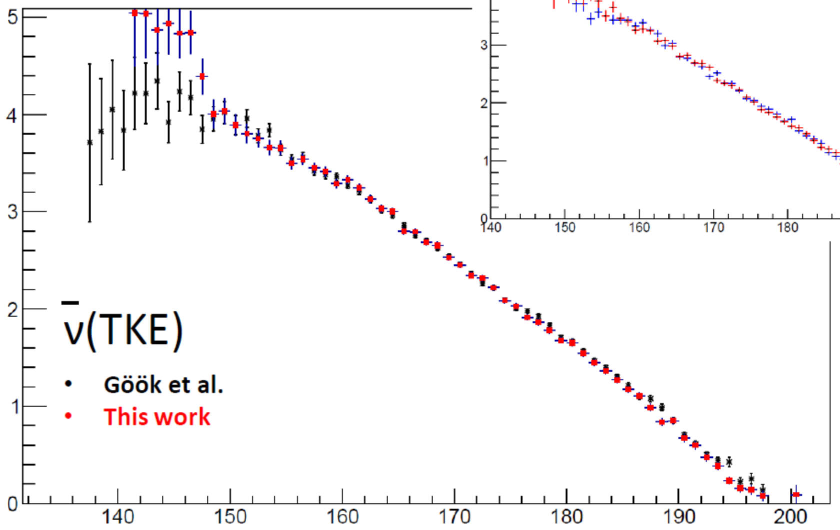


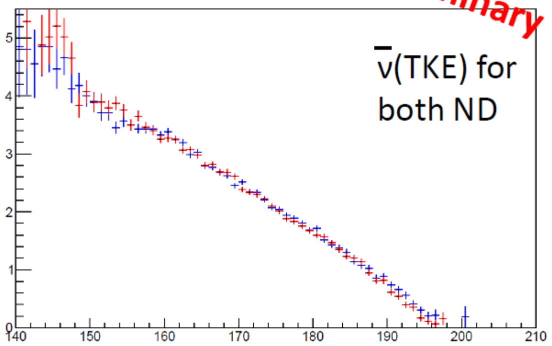


Preliminary

Results U-235 thermal data

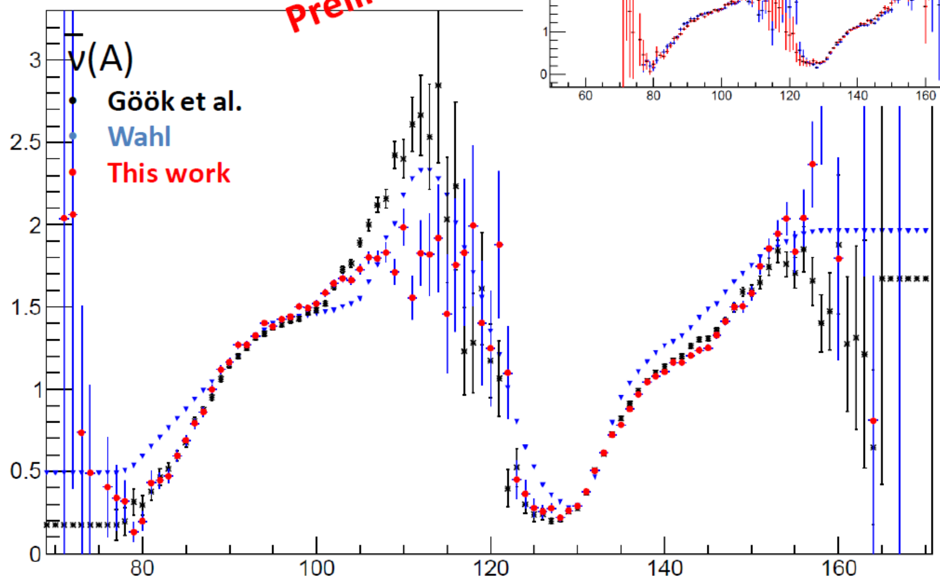
Preliminary

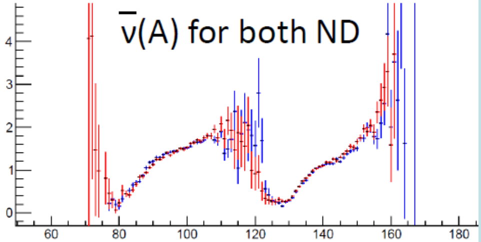




Results U-235

Preliminary





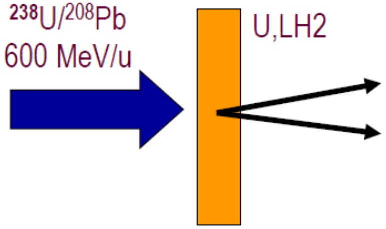
Advanced experimental techniques providing more complete and accurate data on spallation and fission reactions

CHANDA meeting Task 11.4

Paris November 20-21, 2017

José Benlliure

Complete kinematic of FF in inverse kinamatics



Advantages:

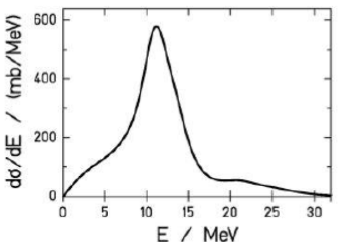
- Fission cross sections
- A, Z and TKE of both fission fragments
- neutrons and l.c.p. in coincidence
- non stable fissioning nuclei

Limitations:

- Initial configuration (A, Z, E*, J)
- Minor actinides

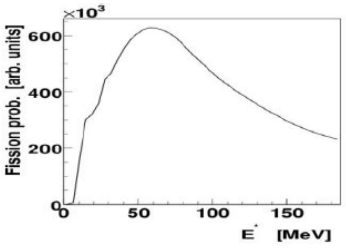
Static properties of fission:

- Coulex



Dynamics of fission:

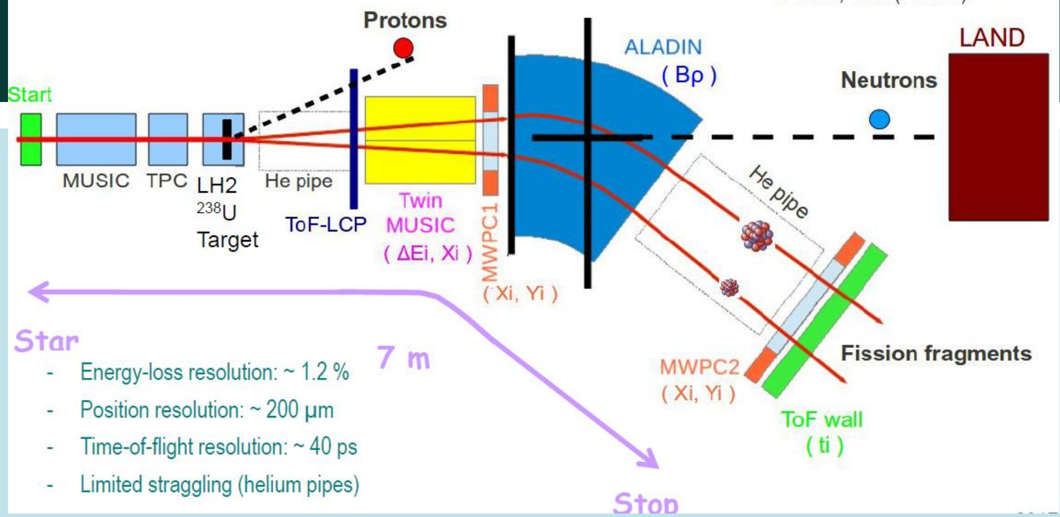
- Fission induced by relativistic protons



The SOFIA experiment at GSI

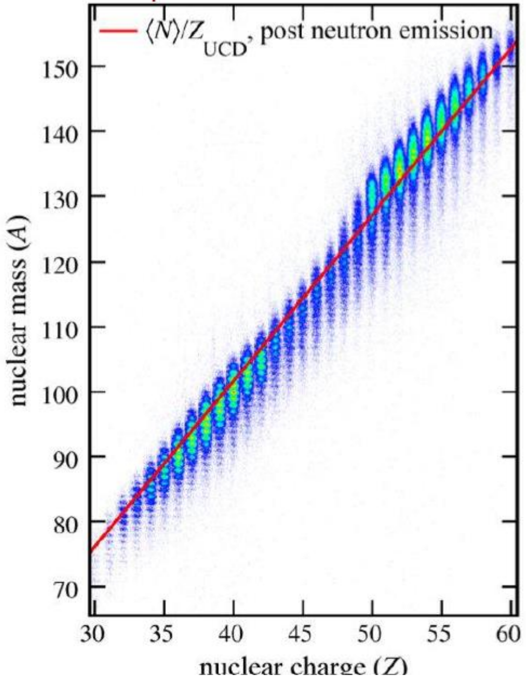
Compete identification in A, Z of both fission fragments together with light-charged particles

J. Taieb, CEA (France)

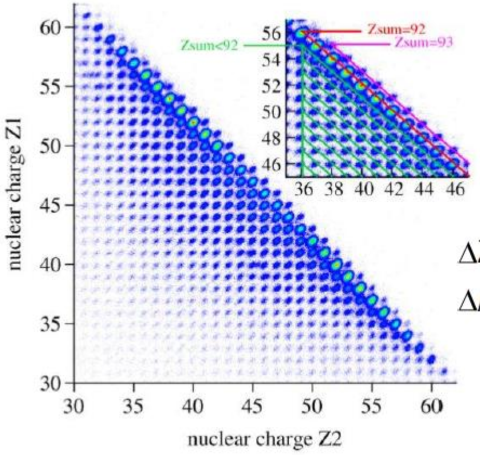


- Energy-loss resolution: ~ 1.2 %
- Position resolution: ~ 200 μm
- Time-of-flight resolution: ~ 40 ps
- Limited straggling (helium pipes)

Complete identification of both fission fragments



For the first time both fission fragments were identified in atomic and mass number and their velocities were determined with good accuracy.

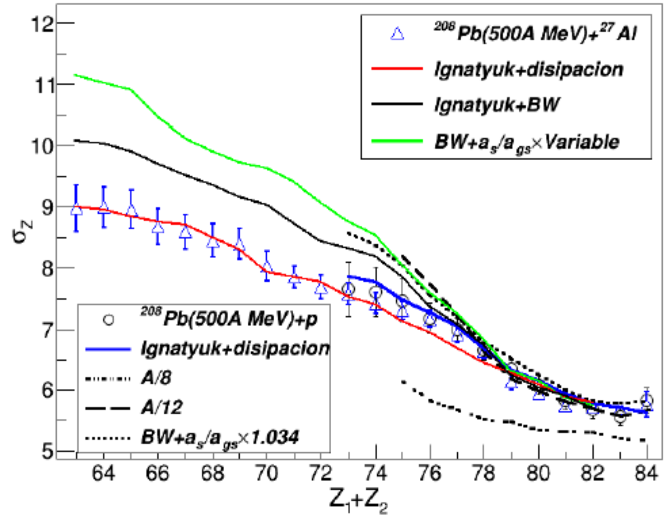


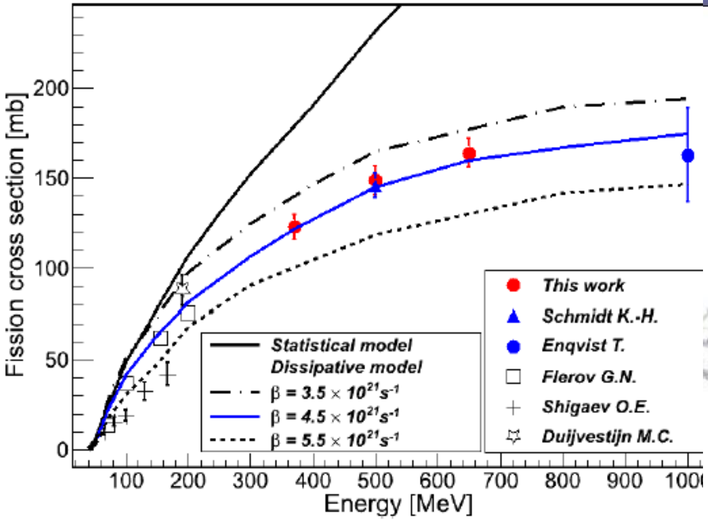
ΔZ~0.4

ΔA~0.6

E. Pellereau et al., Phys. Rev. C 95, 054603 (2017)
J.L. Rodriguez et al., Phys. Rev. C 91, 064616 (2015)

Charge distribution of fission fragments: saddle point configuration

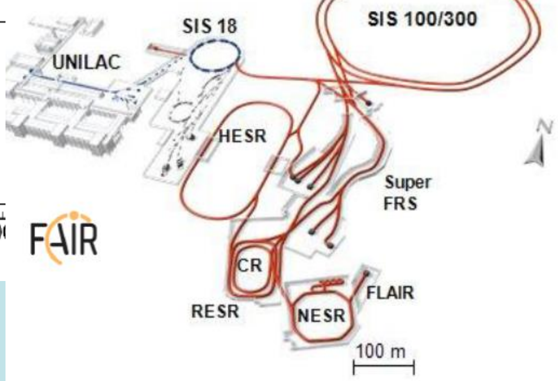


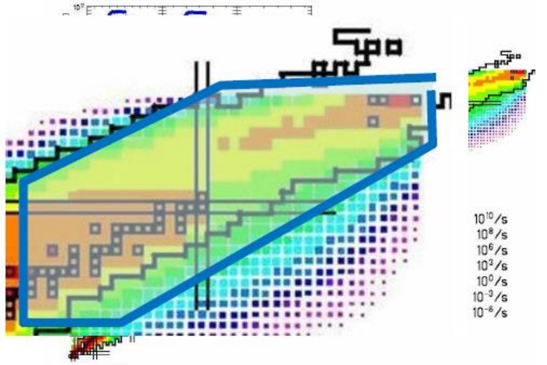


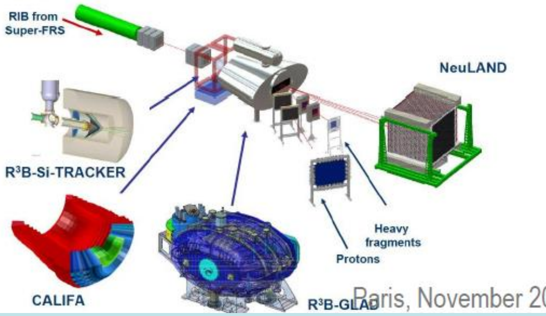
New experimental approaches

(p,2p) and (p,pn) quasi-free scattering: experimental requirements

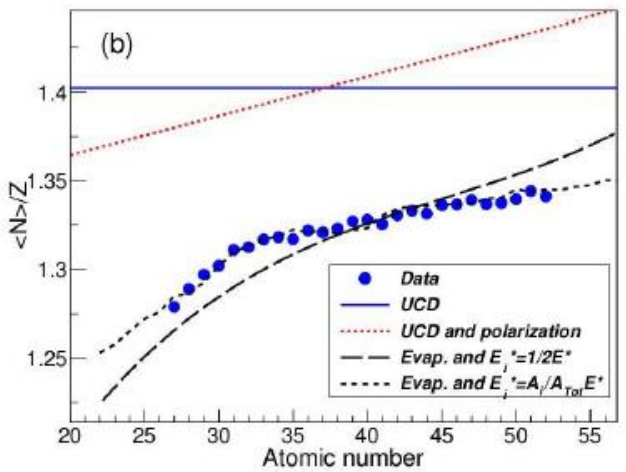
- Secondary beams
- Inverse kinematics

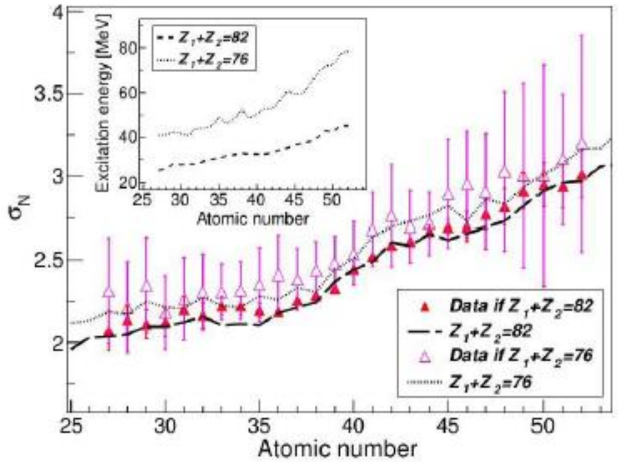


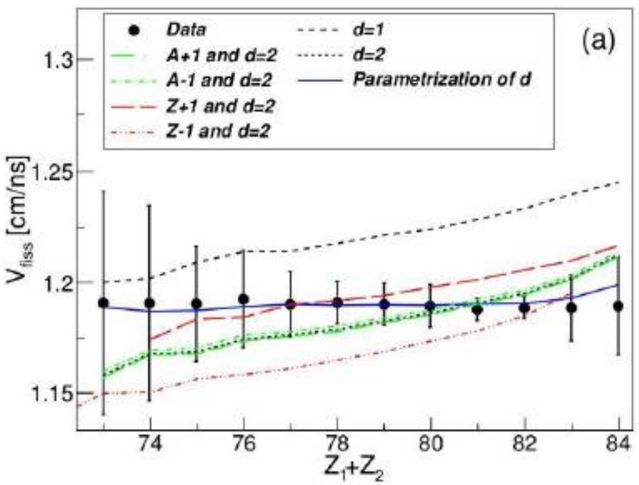




Isotopic and TKE distributions of fission fragments: scission point configuration







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DE LA RECHERCHE À L'INDUSTRIE

G. Belier et al.

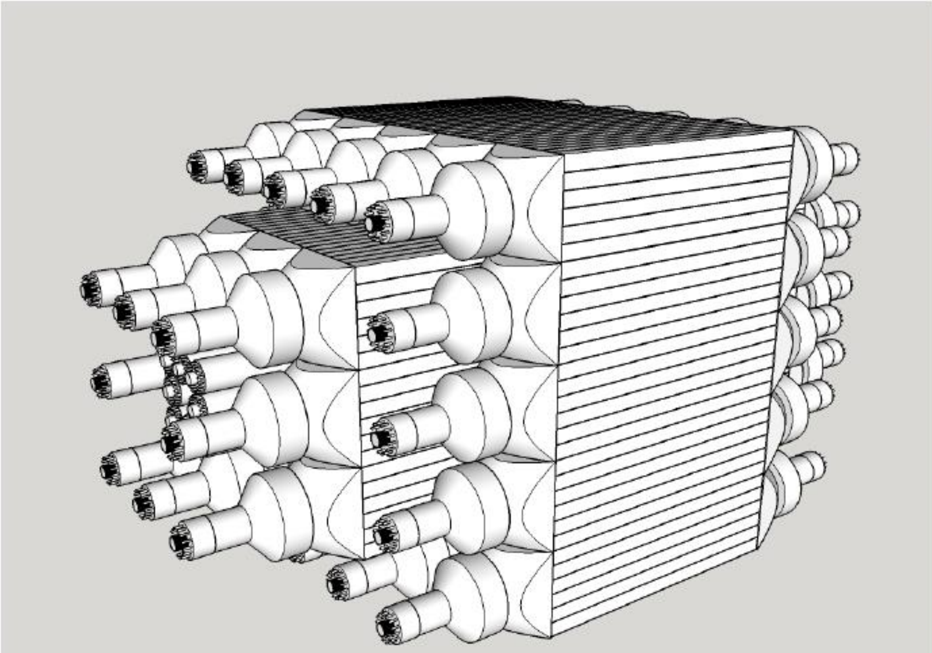
Measurement of (n,xn) reactions on actinides @GANIL/NFS

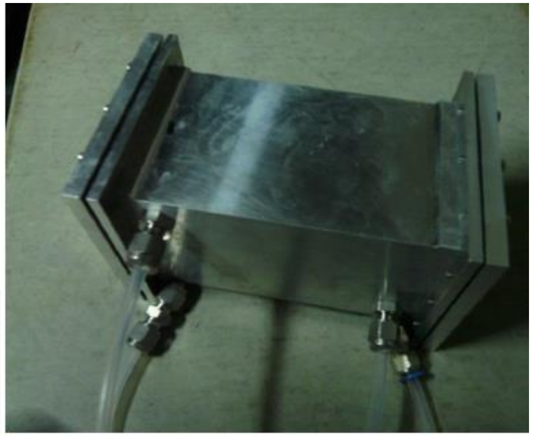
Multiplate fission chamber: **360 mg of ^{238}U** →

72 deposits, CF_4 gas, homemade dedicated preamps

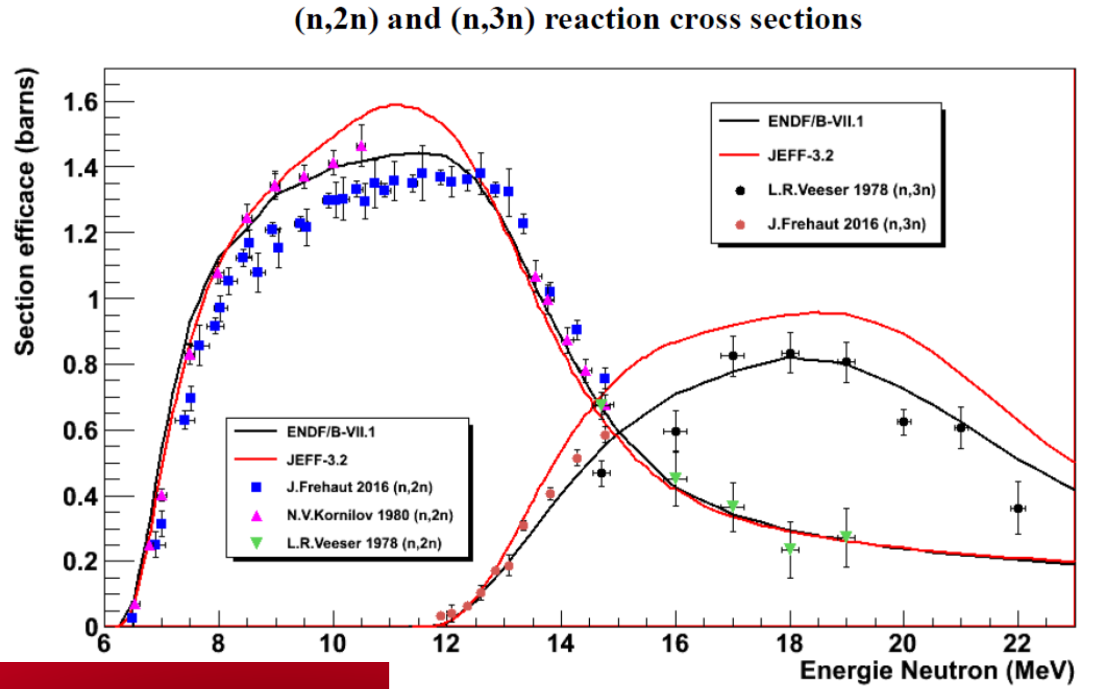
→ Fission veto

SCONE (Solid COunter for NEutron)

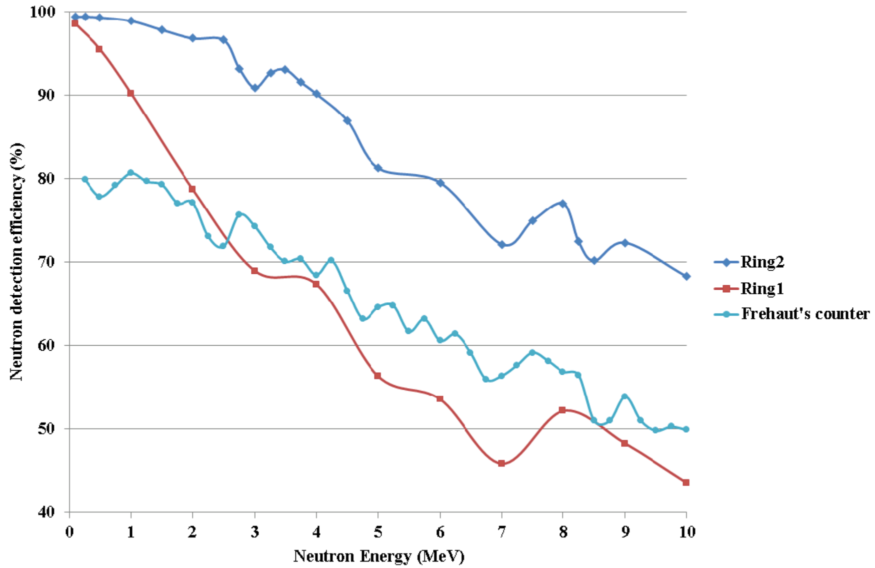




Accepted experiment @NFS on ^{238}U



Simulated detection efficiency



European Commission

TAGS measurements of fission products with the new DTAS detector

Víctor Guadilla

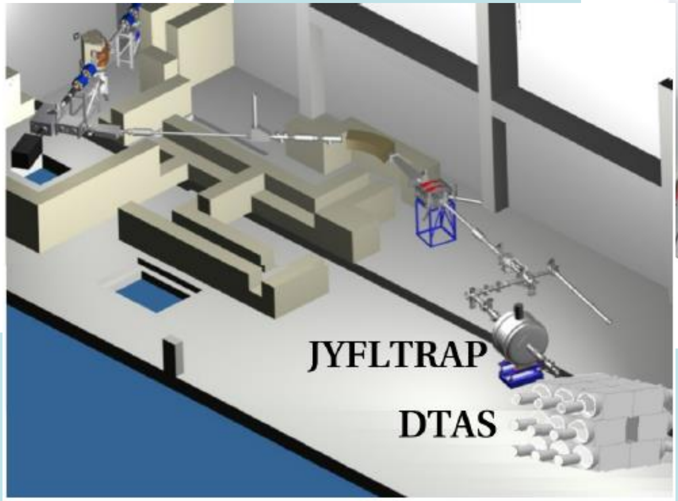
Subatech, IMT-Atlantique, Université de Nantes, CNRS-IN2P3

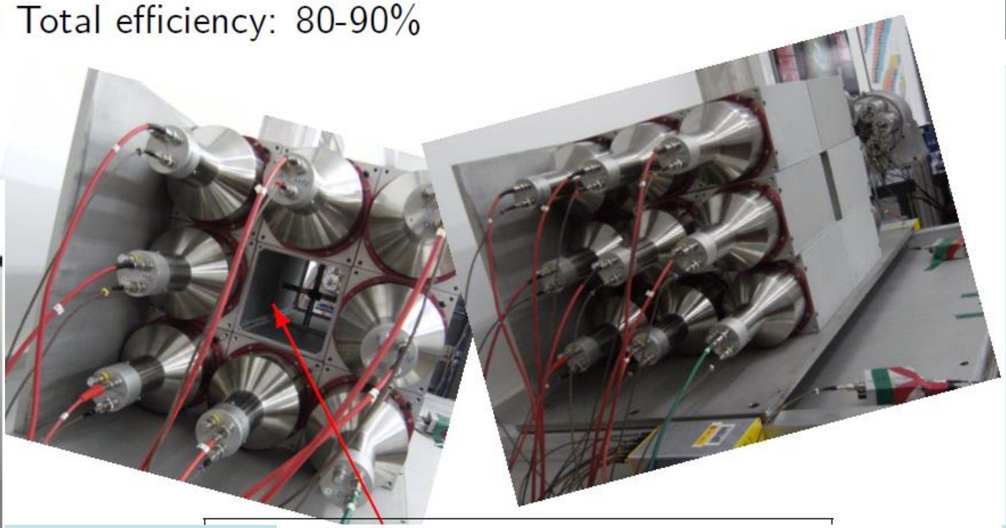
on behalf of the
IFIC-Subatech TAGS collaboration

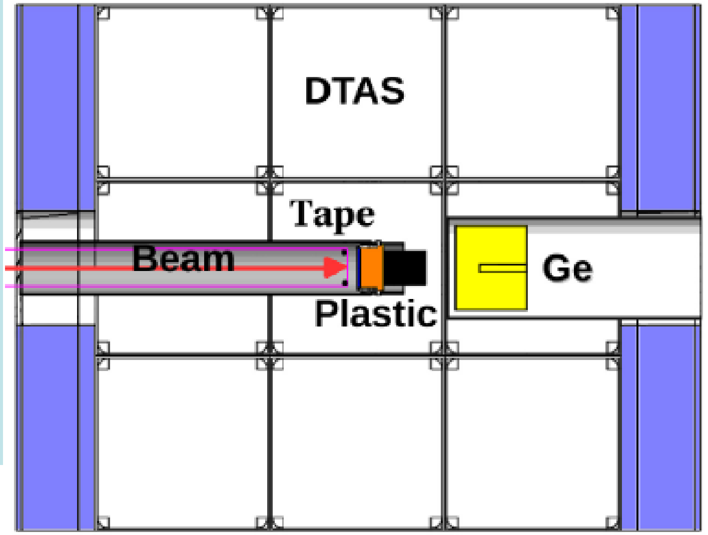
The **new** segmented DTAS detector

J.L. Tain et al., NIMA 803 (2015) 36

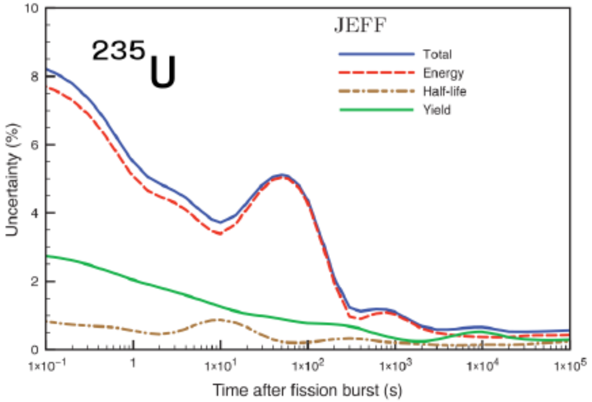
- 16-18 NaI(Tl) crystals of 150 mm × 150 mm × 250 mm
- Individual crystal resolutions: 7-8%
- Total efficiency: 80-90%

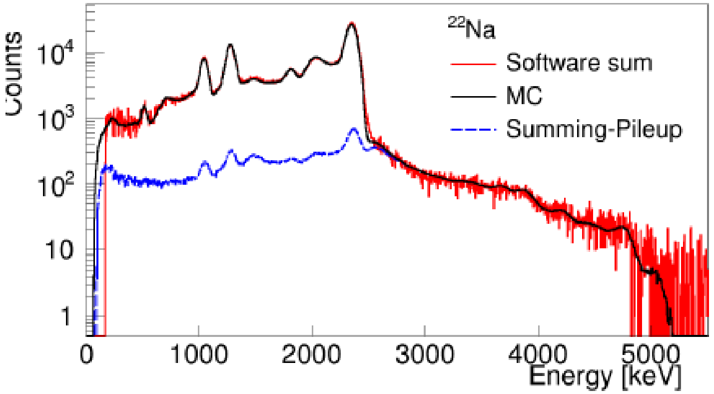






Decay energy: main uncertainty at cooling times < 1000 s





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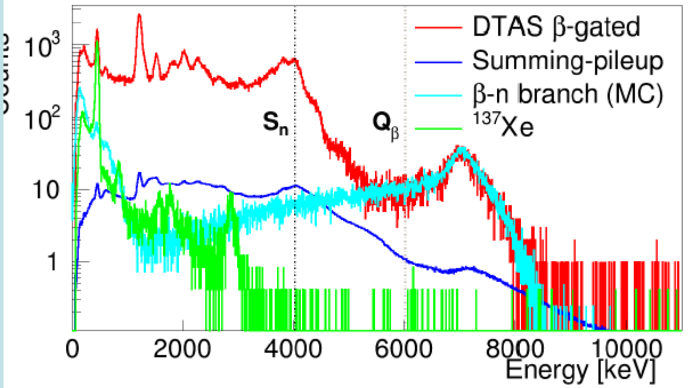
Example: ^{137}I

Q_β=6.027 MeV and S_n=4.025 MeV with P_n=7.33%



Normalization:

- β-n branch: P_n value
- Daughter: peak at 455.5 keV
- Summing-pileup: counting rate and ADC gate-length

V.Guadilla Ph.D. Thesis

Campaign DTAS 2014

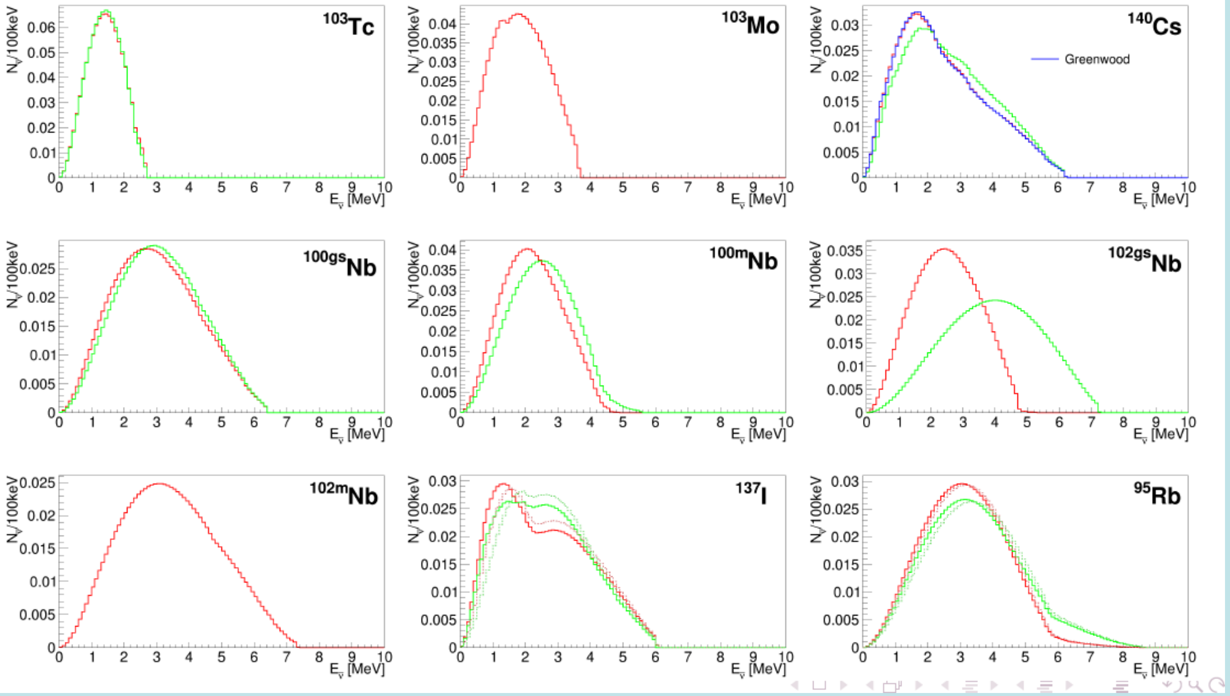
Nuclide	Priority U/Pu	Priority Th/U	Priority $\overline{\nu}_e$	Nuclide	Priority U/Pu	Priority Th/U	Priority $\overline{\nu}_e$
^{95}Rb	1	2		^{102m}Nb	-	1	-
^{95}Sr	-	-	1	^{103}Tc	1	2	-
^{95}Y	-	-	1	^{103}Mo	1	2	-
^{96gs}Y	2	2	1	^{108}Tc	-	-	-
^{96m}Y	-	1	-	^{108}Mo	-	-	-
^{99}Y	-	-	1	^{137}Xe	1	3	-
^{99}Zr	2	1	-	^{138}Xe	-	1	-
^{98gs}Nb	1	1	1	^{137}I	1	2	1
^{98m}Nb	-	-	-	^{138}I	-	-	2
^{100gs}Nb	1	1	1	^{140}Cs	-	-	1
^{100m}Nb	-	1	-	^{142}Cs	3	-	1
^{102gs}Nb	2	2	1				

V.Guadilla Ph.D. Thesis

European Commission

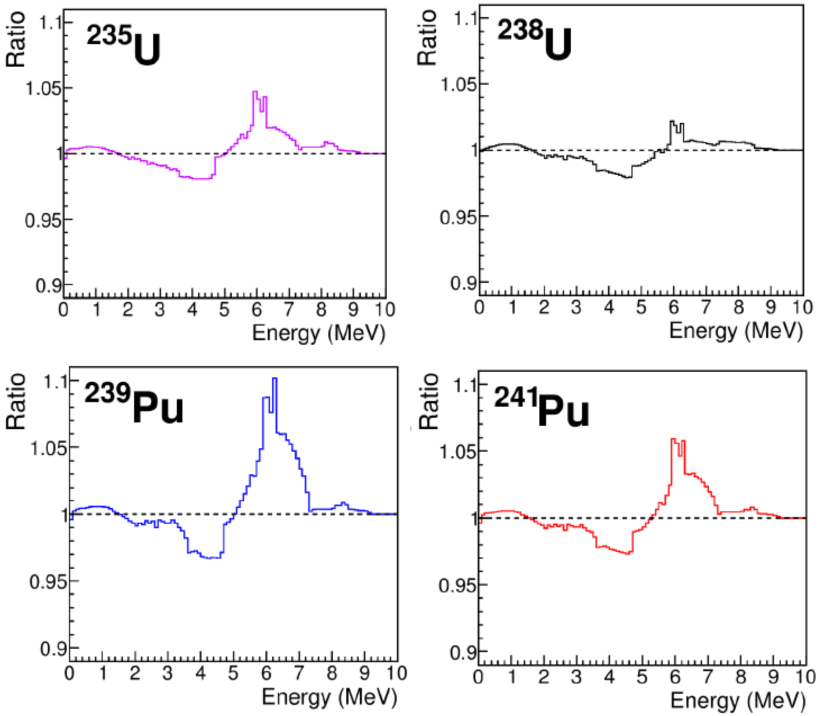
Antineutrino spectra: DTAS vs. ENSDF

$$S_{\overline{\nu}}(E_{\overline{\nu}}) = \int_0^{Q_\beta} I_\beta(E_x) s_{\overline{\nu}}(Q_\beta - E_x, E_{\overline{\nu}}) dEx$$



Reactor antineutrino summation calculations

- **Subatech** group
- **PWR**
- **MURE** MCNP code
- **JEFF** fission yields
- **With/Without**

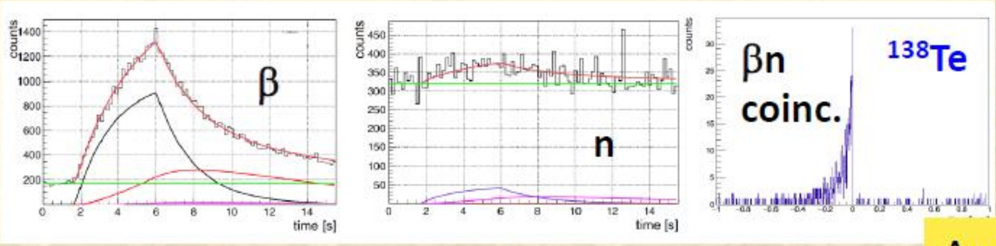


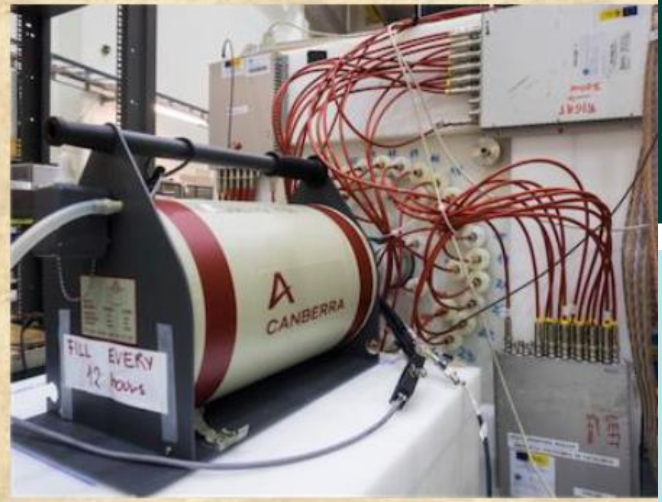
European Commission

Commissioning of BELEN-48 at IGISOL IV (JYFL) - *November 2014*

Study systematic errors of two ways to obtain P_n:

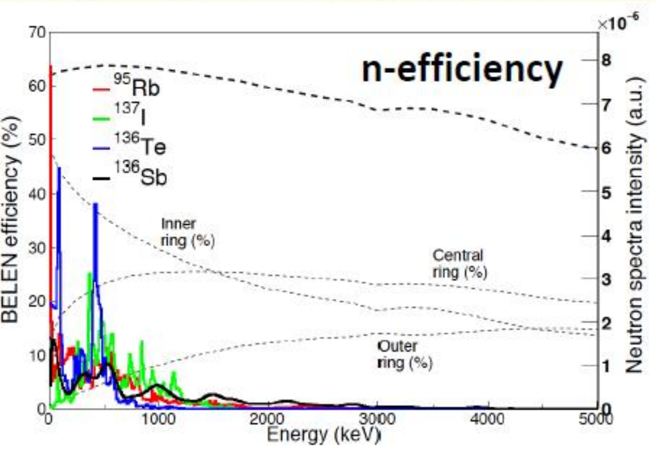
$$P_n = \frac{\varepsilon_\beta}{\varepsilon_n}\frac{N_n}{N_\beta} \quad (2a); \quad P_n = \frac{\varepsilon_\beta}{\varepsilon_\beta \varepsilon_n}\frac{N_{\beta n}}{N_\beta} \quad (2b)$$

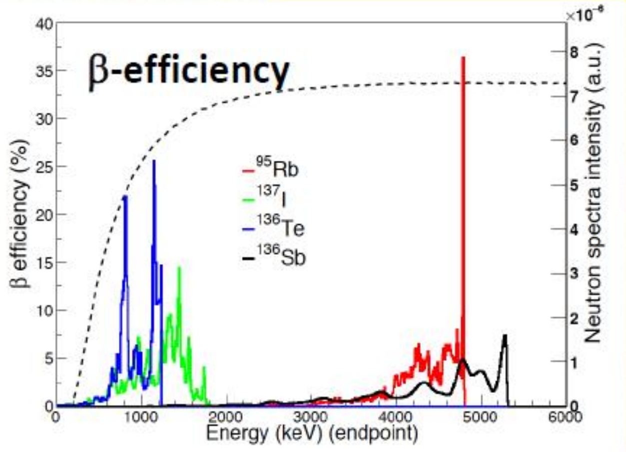




Agramunt+, EPJWoC146(2017)01001
Caballero-Folch+, arXiv:1803.07205

Dependence on isotope:

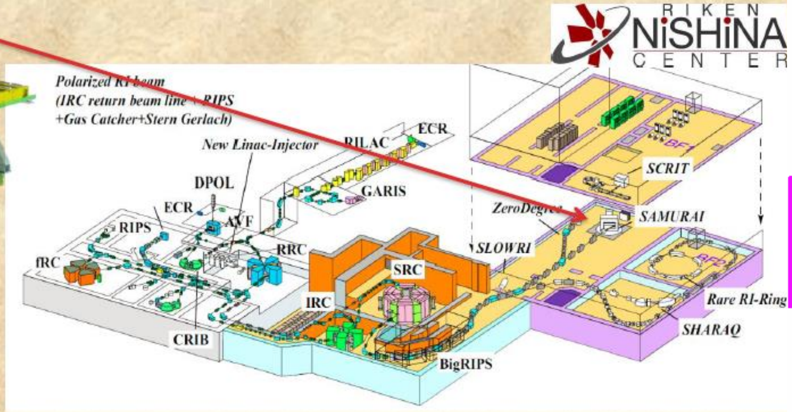




European Commission

The BRIKEN project

- The largest ^{3}He moderated n counter
- The AIDA implant/decay detector
- The RIBF high intensity radioactive beams
- The BigRIPS+ZeroDegree spectrometer

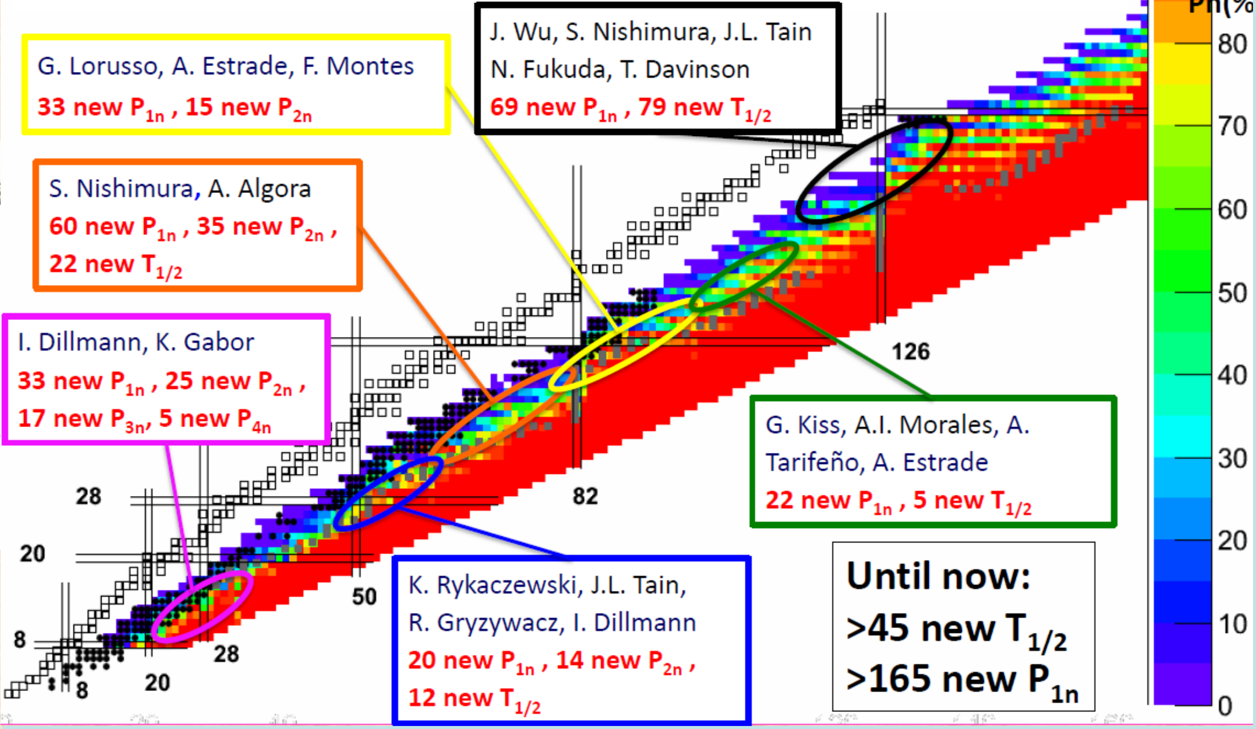


- 20 institutions
- 60 participants
- 6 experiments approved

Tain+, ActPhysPolB49(2018)417
Dillman+, NucPhysNews28(2018)28

BRIKEN goal: astrophysics (r-process) and nuclear structure

Six proposals accepted until now to measure $T_{1/2}$, P_{1n}, P_{2n} of nuclei around A~20, 80, 110, 130, 150 and 200



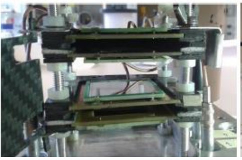
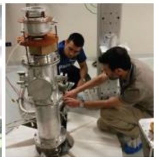
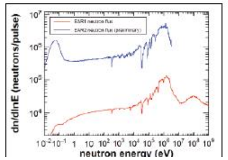
The n_TOF Collaboration, www.cern.ch/n_TOF

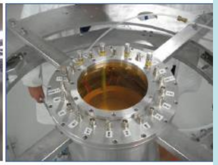
CHANDA meeting

The experimental program on fission reactions at n_TOF (CERN)

Nicola Colonna

Istituto Nazionale Fisica Nucleare, Sezione di Bari, Italy

MicroMegas detector (EAR1 & EAR2)
CEA-IRFU, CERN, INFN, NTUA

Parallel Plate Avalance Counters (EAR1 & EAR2)
IPN-Orsay, Universite Paris-Sud

Silicon detectors (EAR1)
INFN Bari/LNS/Bologna

Fission Tagging setup (EAR1)
CEA-IRFU, CEA-DAM, TUW

SpecTrometer for Exotic Fission Fragments (EAR2)
Univ. of Manchester

Proton Recoil Telescope (EAR1)
PTB and INFN

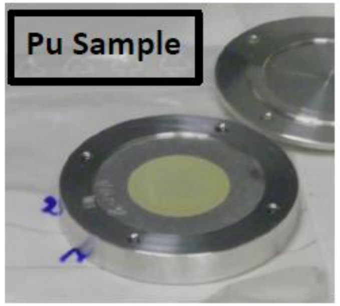
The ^{240}Pu(n,f) measurement in EAR2

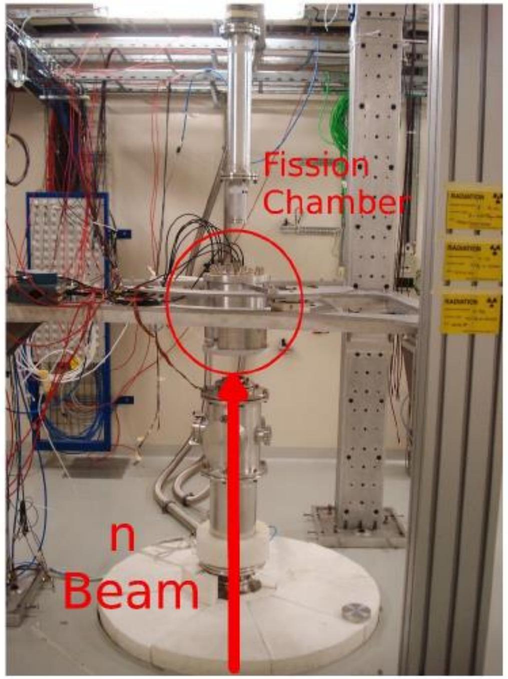
Set of 6 MicroMegas detectors

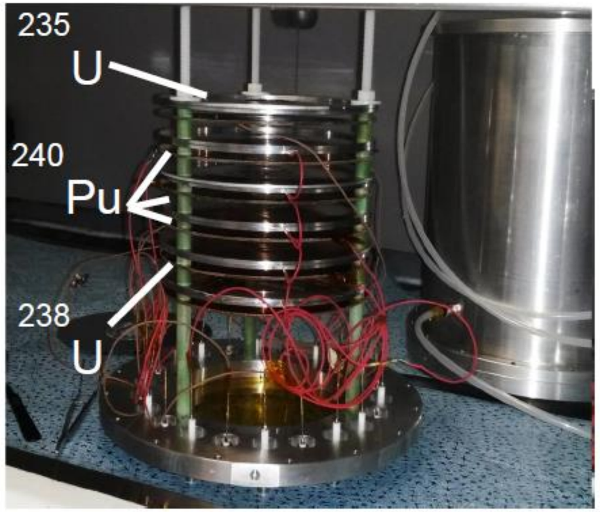
3 ^{240}Pu samples prepared at the IRMM
Total Mass : 2.288 mg (0.3248 mg/cm^2)
Total Activity : 19.219 MBq

2 ^{235}U, and ^{238}U for reference

1 Empty position for background check





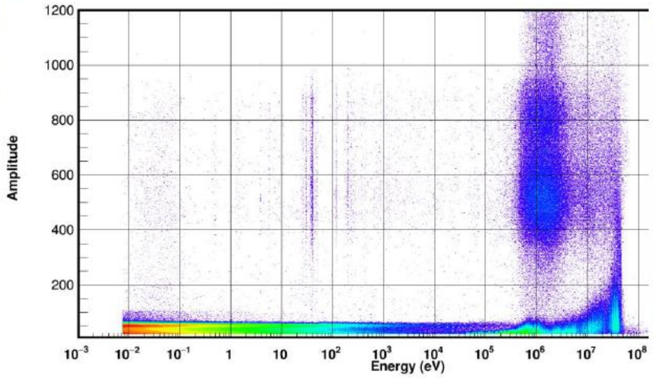


Other Fission Cross Section Measurements

^{237}Np, ^{242}Pu (Accepted: ^{230}Th, ^{241}Am)

European Commission

Measurement of $^{237}Np(n,f)$ reactions in EAR2



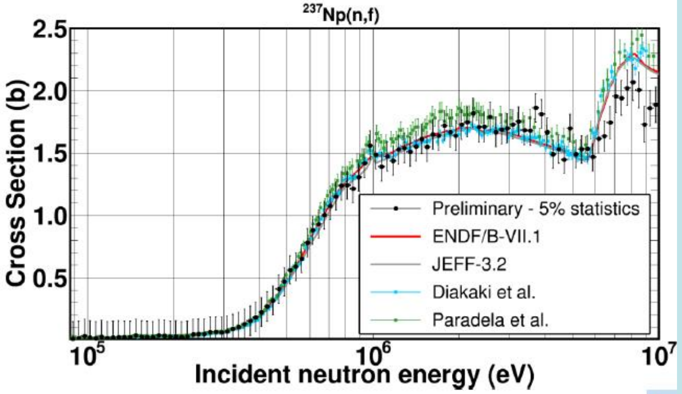
4 ^{237}Np samples from JRC-Geel
- Total Mass : ~1.6 mg
- Total Activity : ~44 kBq

1 ^{237}Np from INP-Orsay
- Mass : ~1.5 mg
- Activity : ~40 kBq

^{235}U, ^{238}U and Empty

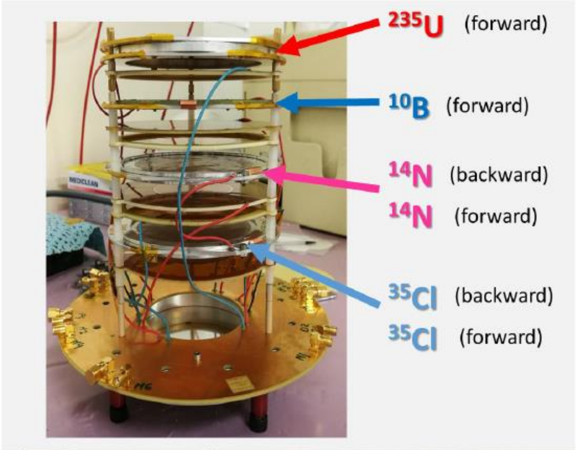
Measured in EAR2 with Micromegas detector, from thermal to >10 MeV.

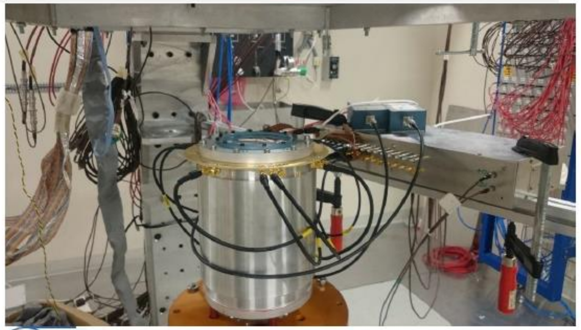
Preliminary results show agreement with ENDF/B-VII.1.

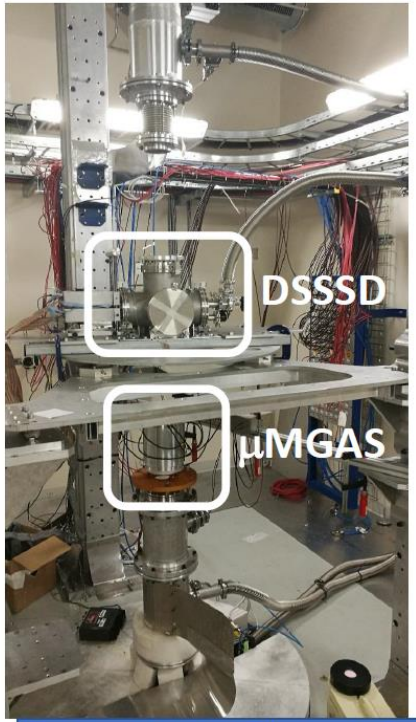


M. Diakaki *(CEA, Cadarache)*

Measurements of (n,cp) reactions in EAR2

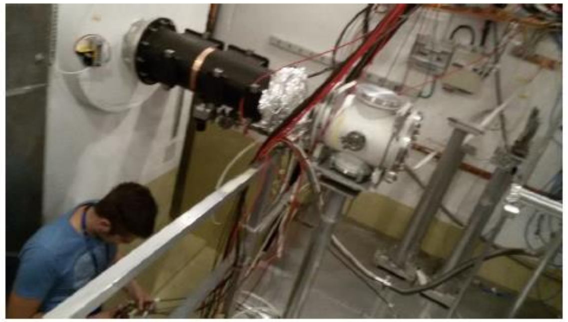


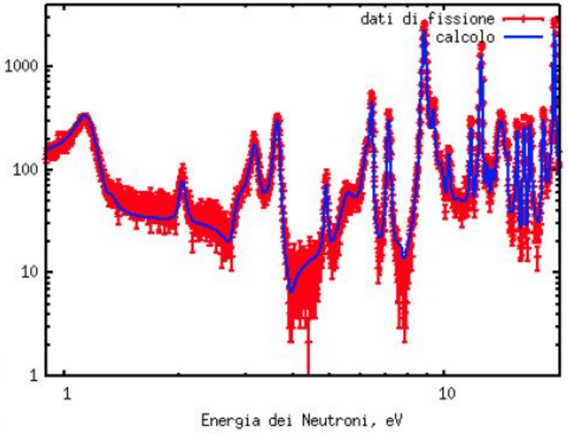




Courtesy of M. Sabaté-Gilarte and J. Praena

Measurement of the $^{235}U(n,f)$ (EAR1)



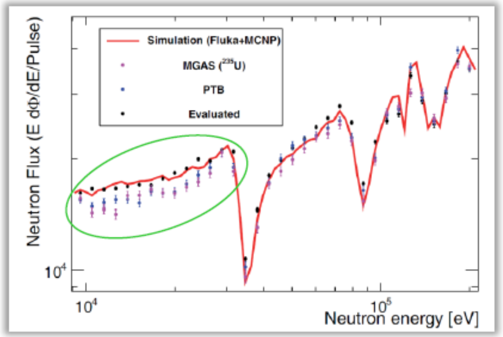


Expected results (soon)

- Ratios $^{235}U(n,f)/^{6}Li(n,t)$ and $^{235}U(n,f)/^{10}B(n,\alpha)$ from **thermal to 1 MeV**
- **Forward/backward** anisotropy for ^{6}Li and ^{10}B
- Provide high-resolution, high-accuracy data for **improving ^{235}U standard** (or reference)

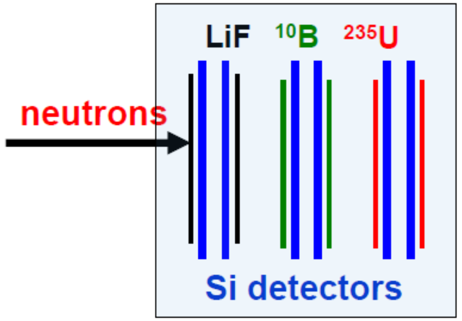
M. Barbagallo, S. Amaducci *(INFN Bari, Bologna, LNS, Italy)*

Si-based fission setup (EAR1)



Triggered by anomaly in the $^{235}U(n,f)$ cross section between 10 and 30 keV

$^{235}U(n,f)$ relative to **$^{6}Li(n,t)$ and $^{10}B(n,\alpha)$** from thermal to 1 MeV



Detection at forward and backward directions, with high energy resolution

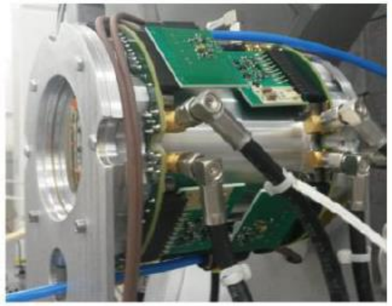
Stack of silicon detectors 5x5 cm^2 and 200 μm thickness **in the beam**

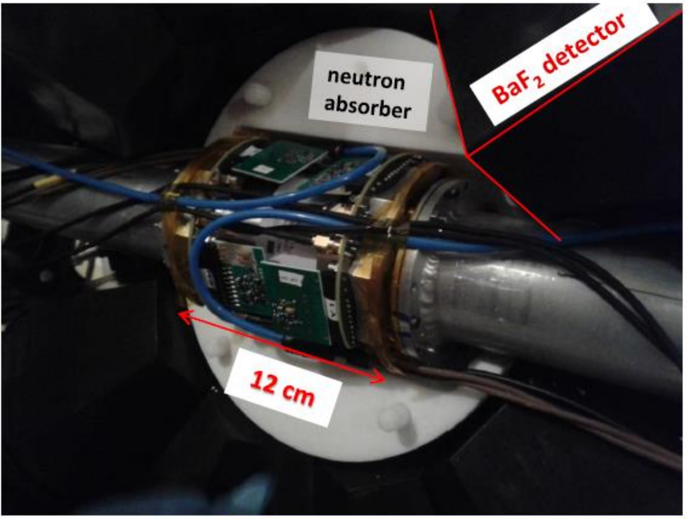
Samples		
^{6}LiF	500 μg/cm^2 on 50 μm Al backing	*(Laboratori Nazionali del Sud)*
$^{10}BC_4$	80 nm on 18 μm Al backing	*(ESS, Linkoping- Chewbacca)*
^{235}U	275 μg/cm^2 , 250 μm Al backing	*(JRC- IRMM)*

M. Barbagallo, S. Amaducci *(INFN Bari, Bologna, LNS, Italy)*

European Commission

Fission tagging chamber (EAR1)





Measurements of **capture cross sections** of actinides with **fission tagging**:

small fission chamber **to fit inside the** n_TOF Total Absorptioin Calorimeter **(TAC)**.

Novel Fission Chamber (FICH)

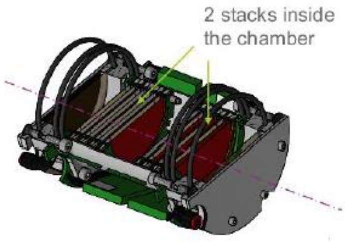
Developed by CEA-DAM/IRFU

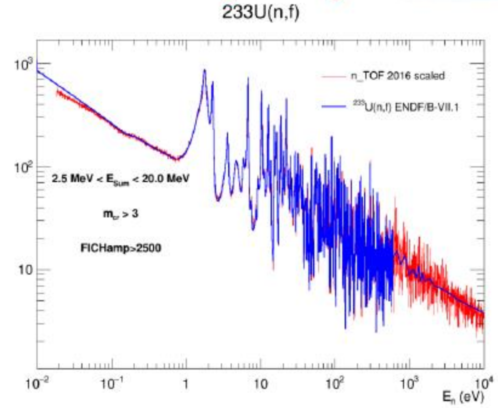
- **Compact** cylindrical chamber
  Ø 9 cm × 12 cm
- **Multi-plate** ionization cells
  14 samples
- **Fast** signals: 34 ns FWHM
  - ✓ Fast ionizing gas CF_4 @ 1.1 bar
  - ✓ Dedicated fast preamplifiers plugged on (CEA/DAM/DIF)
  - ✓ Gap width: 3 mm @ 1.4 kV/cm

Can **sustain high a-particle** count rates (>1 MBq per anode).

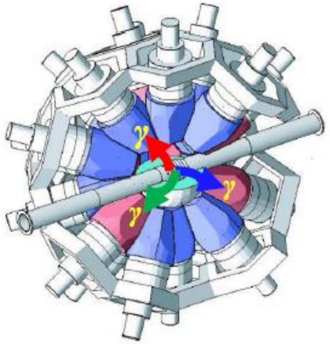
E. Berthoumieux, E. Dupont, F. Gunsing, J. Taieb, B. Laurent *(CEA-IRFU/DAM)*

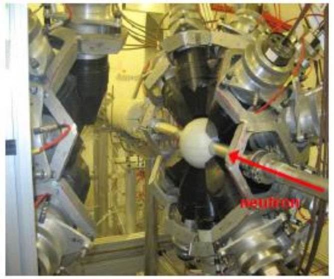
The $^{233}U(n,\gamma/f)$ measurement (EAR1)

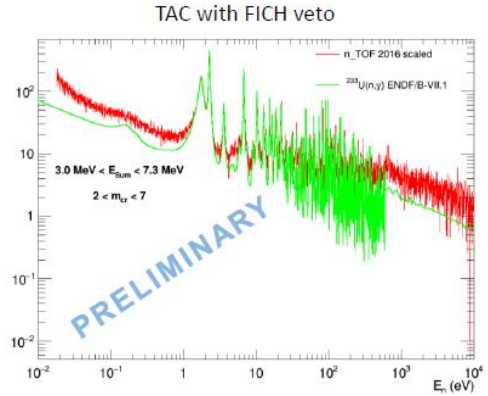




Half-life: 1.6×10^5 y
Mass: ~46.7 mg (14 samples)
Activity: 1.5 MBq (per sample)







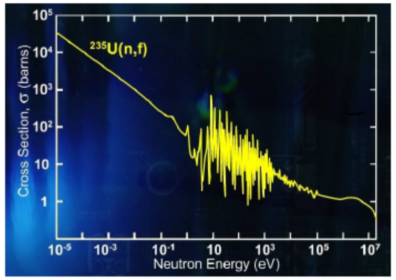
E. Bartoumieux, M. Bacak *(CEA-IRFU & Tech.. Univ. Wien)*

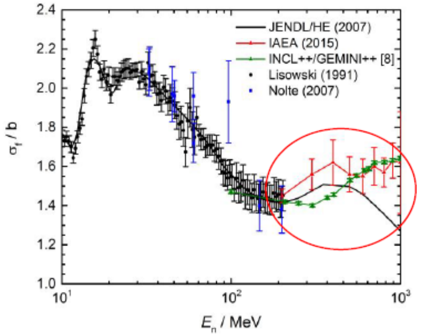
European Commission

To be continued

The Proton Recoil Telescope

What | **Why** | **How**

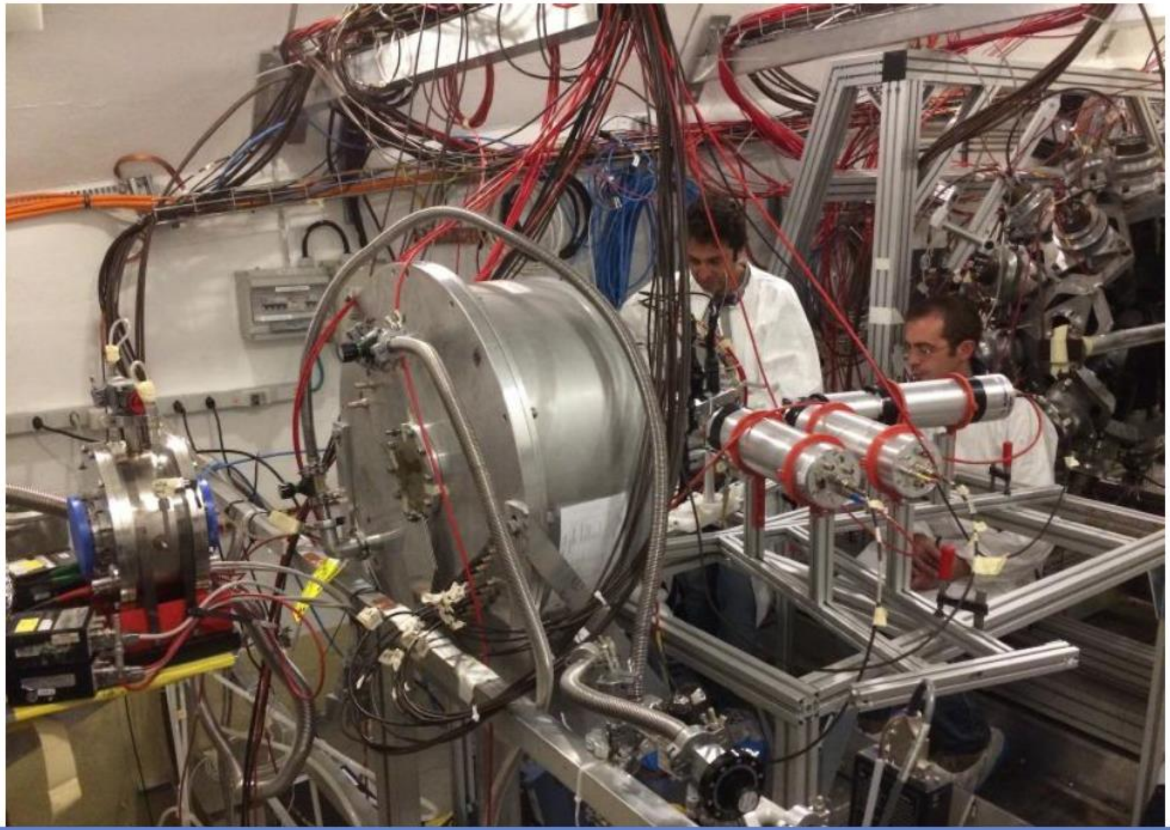




- fission chamber
- PPAC
- Proton Recoil Telescope

Measure the ^{235}U(n,f) cross section relative to the n-p scattering up to 1 GeV

P. Finocchiaro *(INFN-LNS, Catania, Italy)*

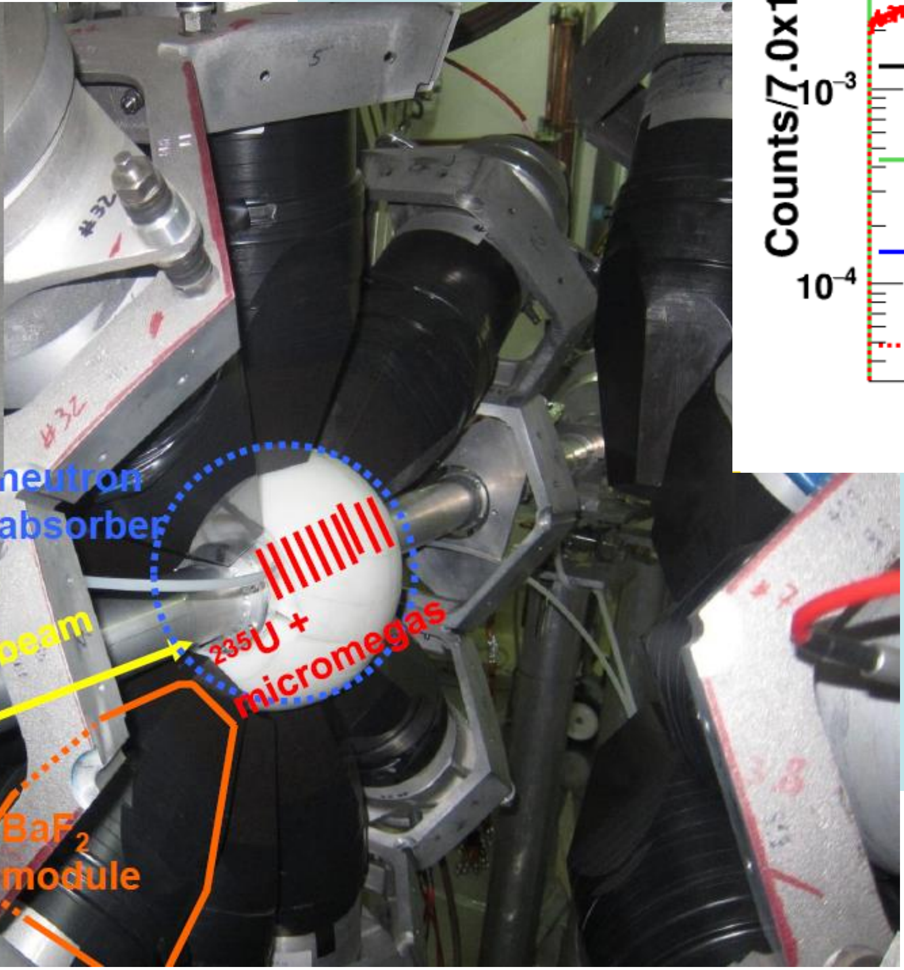


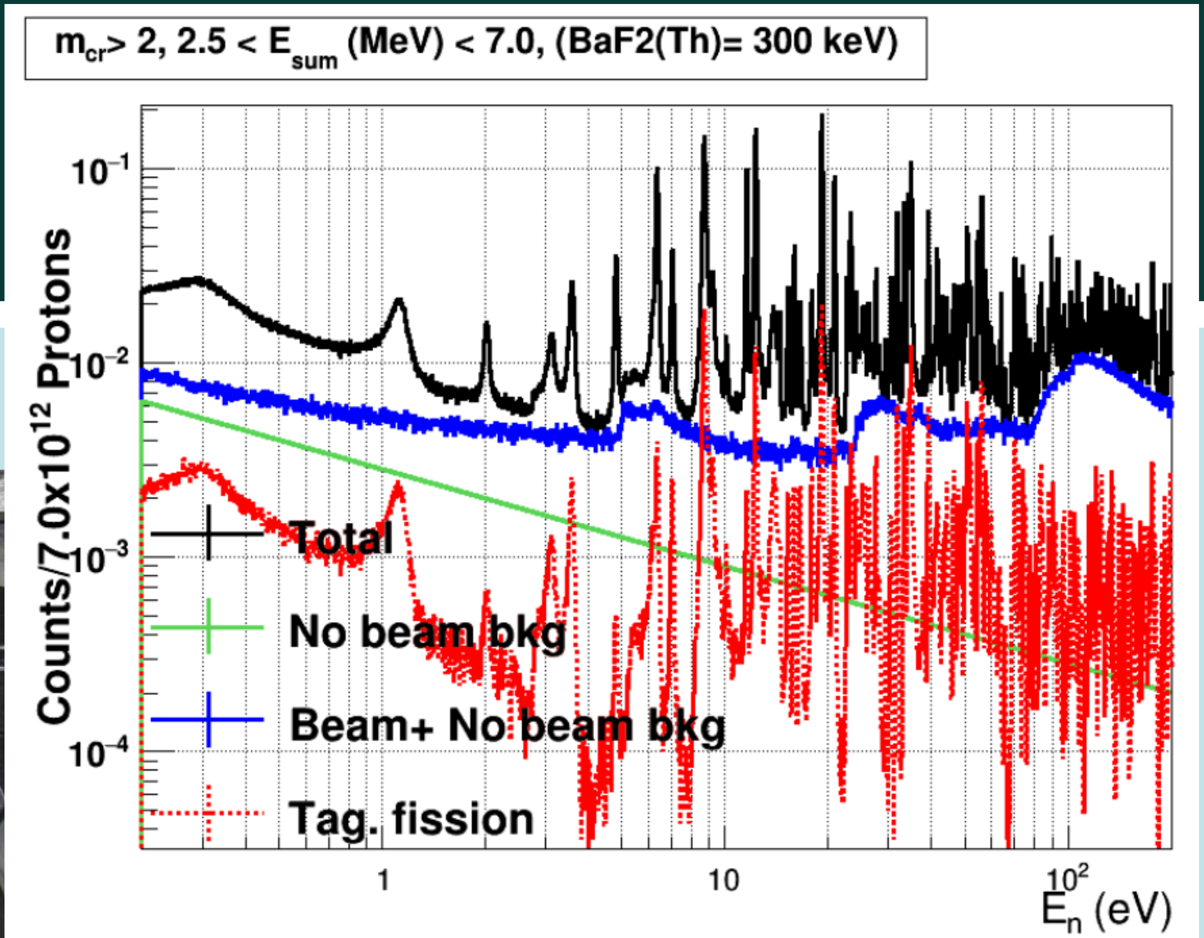
R. Nolte, L. Cosentino, D. Ramos, D. Radek, C. Massimi, L. Auduin, P. Finocchiaro *(PTB, INFN and IPN)*

European Commission

Measurement of the of $^{235}U(n,\gamma)$ cross-section with fission tagging

PhD Thesis of J. Balibrea, D. Cano-Ott, E. Mendoza
and the **n_TOF collaboratio**
- Spain

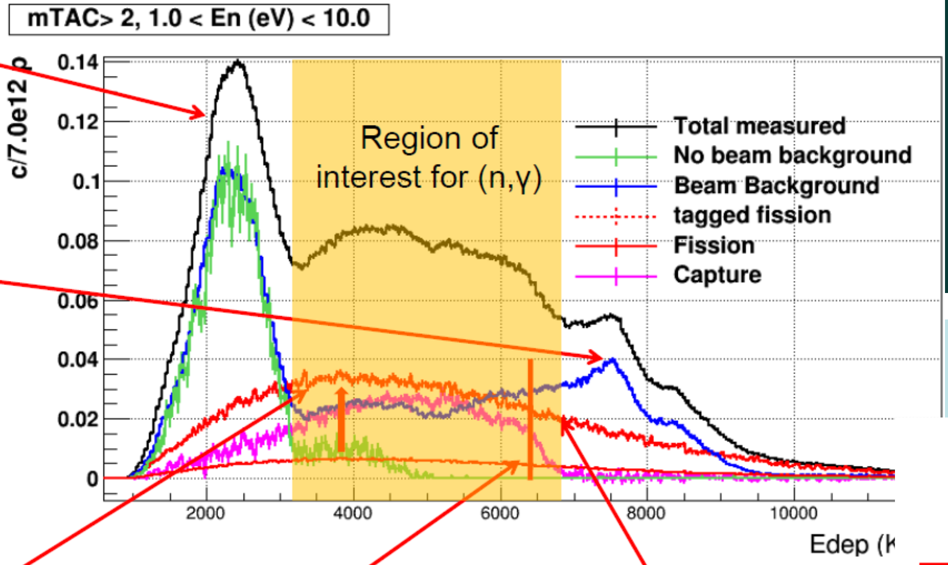




Total energy deposited in TAC

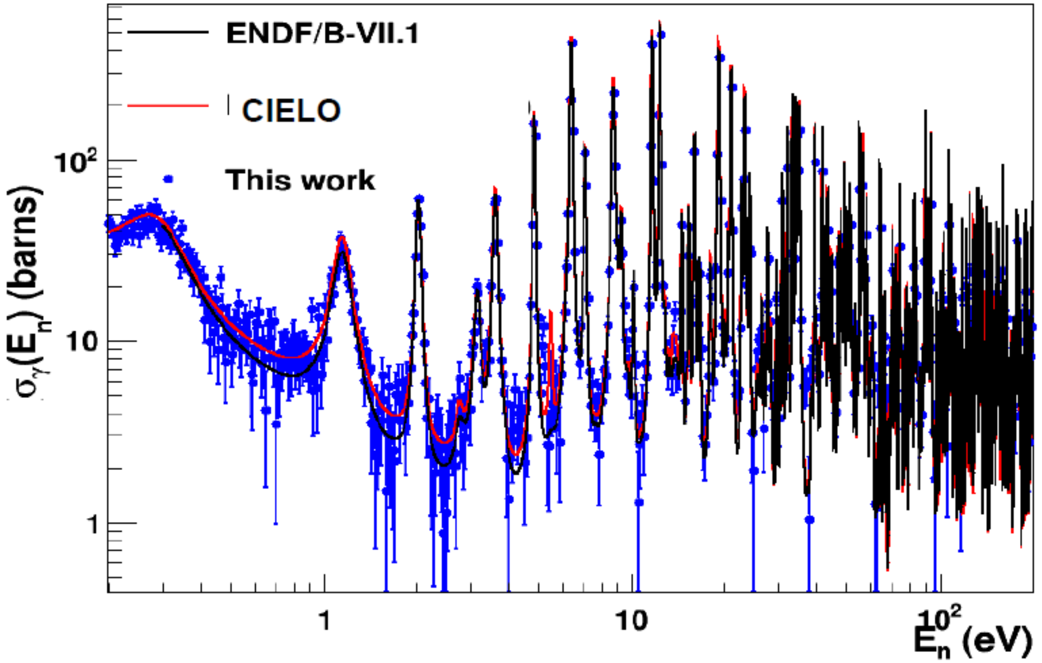
Background measured with a dummy sample. Components: ${}^{nat}Cu(n,\gamma)$, ${}^{27}Al(n,\gamma)$ and elastic scattering from the gas

TAC response to capture reactions (after the background subtraction)

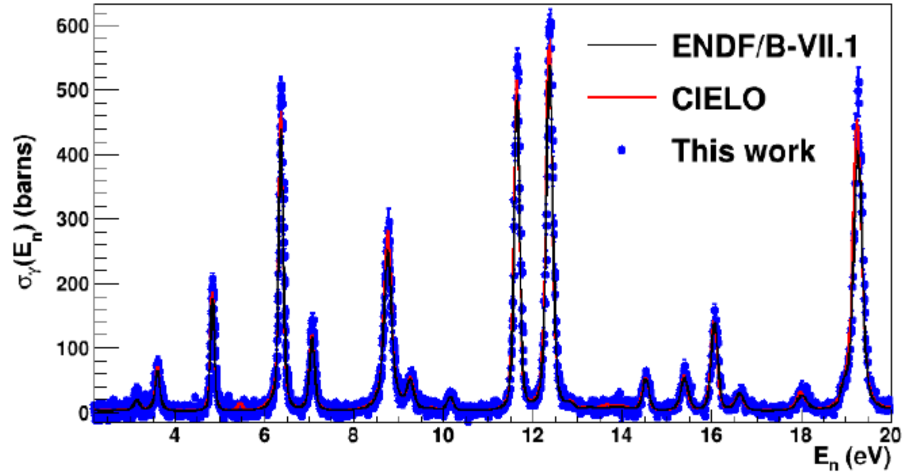


Neutron separation energy of ${}^{236}U$

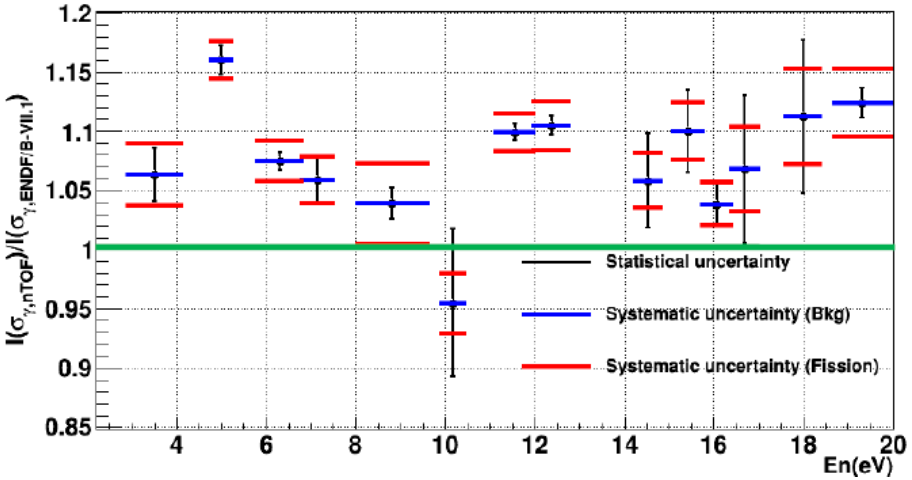
The fission background has to be corrected by the tagging efficiency



Neutron energy range: 2.2-20.0 eV



Neutron resonance integrals (ENDF/B-VII.1 JEFF-3.2)



Summary and conclusions

- The $^{235}U(n,\gamma)$ **cross-section** was **measured at the n_TOF** facility at CERN using the **fission tagging technique** in the neutron **energy range from 0.2 to 200 eV**.

- We have improved/developed a new methodology for measuring the **absolute α-ratio:**

  - Accurate determination of the **ε_f and subtraction of the prompt fission γ-ray background $\Delta\varepsilon_f$=2.2%.**

    We have observed a **correlation observed detecting prompt fission γ-ray** events which **wasn't reported** in **previous experiments** with **similar experimental** setups.

  - Accurate determination of the (n,γ) **TAC detection efficiency. $\Delta\varepsilon_\gamma$=1.7%**.

- **Our data** has contributed mainly to the **IAEA-CIELO evaluated library** for the neutron **resonances between 2.2 and 20.0 eV**. The ^{235}U capture **cross-section** has been **increased by ~8%.**

- **Ready for exciting stuff: ^{239}Pu** (we need samples and a copper free fission detector)

Summary

- There is no substitute for the real thing: full presentations are on the JEFF webpage.
- I acknowledge the high level presentations presented at JEFF.