Measurement of the (n,γ) cross section of the fissile isotope ^{235}U with the CERN n_TOF Total Absorption Calorimeter and a fission tagging based on micromegas detectors

[1]J. Balibrea, [1]E. Mendoza, [1]D. Cano Ott, [2]C. Guerrero,
[2]E. Berthoumieux, [3]M. Sabaté

*and the **n_TOF collaboration***

[1]CIEMAT – Spain
[2]CERN – Switzerland
[3]University of Sevilla – Spain

Accurate nuclear data on neutron-induced capture and fission cross-sections are essential for the design of innovative nuclear systems such as Gen-IV reactors and Accelerator Driven Systems.

The actual nuclear data priorities are summarized reasonably well in the High Priority Request List of the Nuclear Energy Agency.

http://www.nea.fr/dbdata/hprl/index.html

The following capture cross sections of fissile isotopes are part of the prioritized data requests: ^{233,235}U and ^{239,241}Pu.

Home | About Us | Work Areas | Data Bank | Publications | Delegates' Area | Press Room

NEA
Nuclear Energy Agency

NEA search engine Go

OECD

Nuclear Data Services

NEA Nuclear Data High Priority Request List, HPRL

HPRL-Main | Search | New request template | New request guidelines | Related references

Request ID	12		Status of the request	High Priority request	
Target	Reaction and process	Incident Energy	Secondary energy or angle	Target uncertainty	Covariance
92-U-235	(n,g) SIG, RP	100 eV-1 MeV		3	Y
Field	Subfield	Date Request created	Date Request accepted	Ongoing action	
Fission	FBR, Thermal reactors	29-AUG-07	06-NOV-07		

Send a comment on this request to NEA.

Requester: Dr Yasunobu NAGAYA at JAEA, JPN
Email: nagaya.yasunobu@jaea.go.jp

Project (context): JENDL, NEA WPEC Subgroup 29

Impact:
U-235 cross sections are very important not only for major thermal reactors but for FBRs beca
have been performed at critical assemblies where UO2 fuels are used as driver fuels. Experim
assemblies have a great impact on design work for FBRs. Recent studies show that calculated
experiments underestimate the experimental results by 30-50% [1].
The significant discrepancies not only exceed the target accuracy of 20% for a FBR design but
estimated with the cross-section adjustment and bias factor techniques. Thus such experimenta
techniques.

Requested accuracies:
100 eV – 500 eV: 5%
500 eV – 1 keV: 5%
1 keV – 2.25 keV: 8%
5 keV – 10 keV: 8%
10 keV – 30 keV: 8%
30 keV – 1 MeV: 3%

NEA
Nuclear Energy Agency

NEA search engine Go

OECD

Nuclear Data Services

NEA Nuclear Data High Priority Request List, HPRL

HPRL-Main | Search | New request template | New request guidelines | Related references

Request ID	4		Status of the request	High Priority request	
Target	Reaction and process	Incident Energy	Secondary energy or angle	Target uncertainty	Covariance
92-U-235	(n,f) prompt g-prod	Thermal-Fast	Eg=0-10MeV	7.5	Y
Field	Subfield	Date Request created	Date Request accepted	Ongoing action	
Fission	LWR, Gen-IV	10-MAY-06	12-MAY-06	N	

Send a comment on this request to NEA.

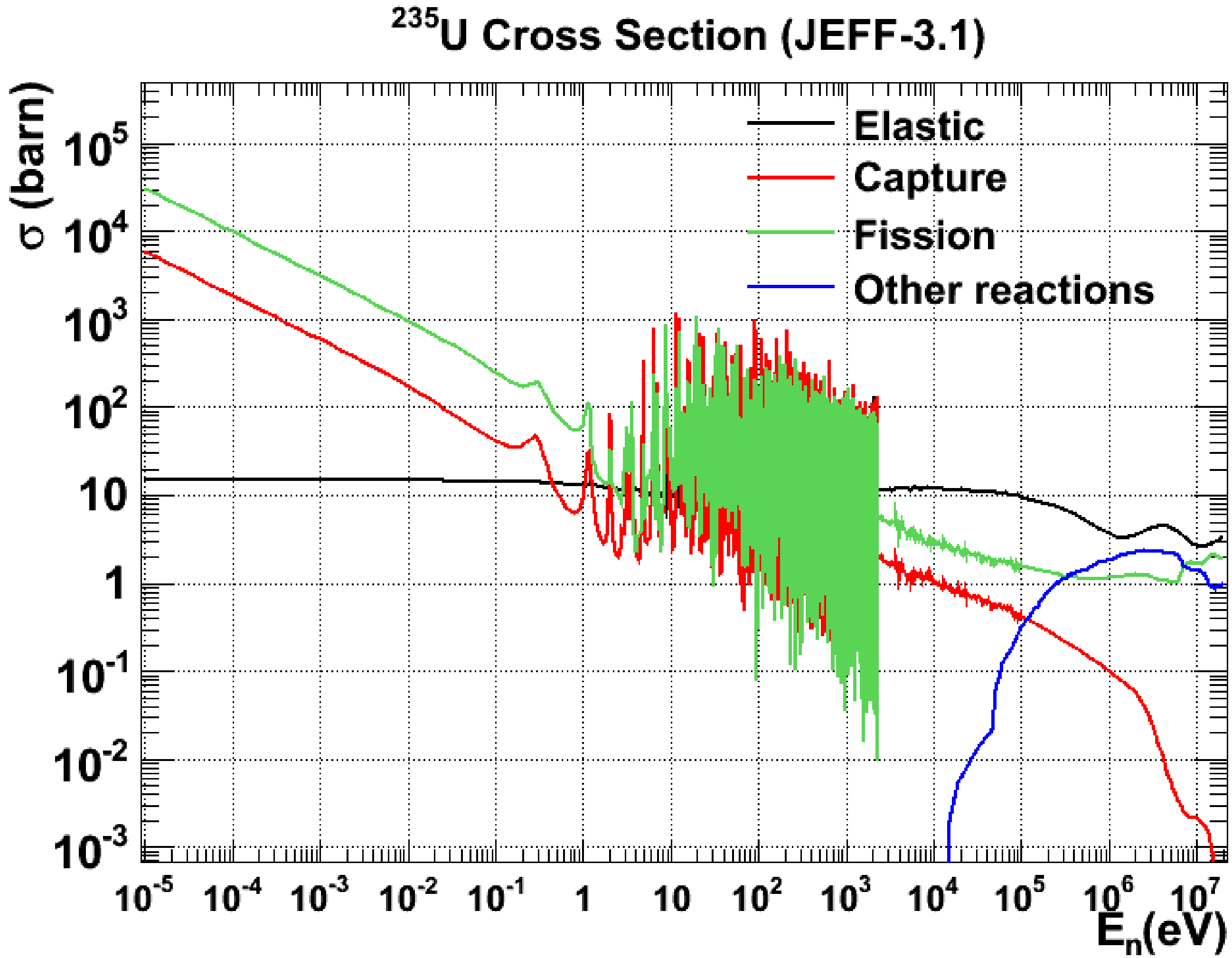
Requester: Dr. Gerald RIMPAULT at CADARACHE, FR
Email: gerald.rimpault@cea.fr

Project (context): JEFF, NEA WPEC Subgroup 27

Impact:
The four fast reactor systems of GenIV feature innovative core characteristics for which gamma-ray heating estimates for non-fuel zones require an uncertainty of 7.5% [1]. For the experimental Jules Horowitz Reactor (RJH) at Cadarache a similar requirement appears [2]. Recent studies show evidence of discrepancies on integral measurement in MASURCA, EOLE and MINERVE, from which it is clear that the expectations for GenIV systems and the RJH thermal reactor are not met [3]. Gamma-ray energy release is dominated by Pu-239 and U-235.

Accuracy:
7.5% on the total gamma energy
7.5% on multiplicity
Best accuracy achievable for the gamma spectrum shape

Why to measure again the $^{235}U(n,\gamma)$ cross section



$\langle m_\gamma \rangle$ in (n,γ) reactions 3 – 4
$\langle m_\gamma \rangle$ in (n,f) reactions 6 – 7

About 10 times larger γ-ray background from fission!

The ^{235}U(n,γ) measurement

2010 – test experiment for proving the principle

2012 (Aug – Nov) Measurement of the ^{235}U(n,γ) cross section

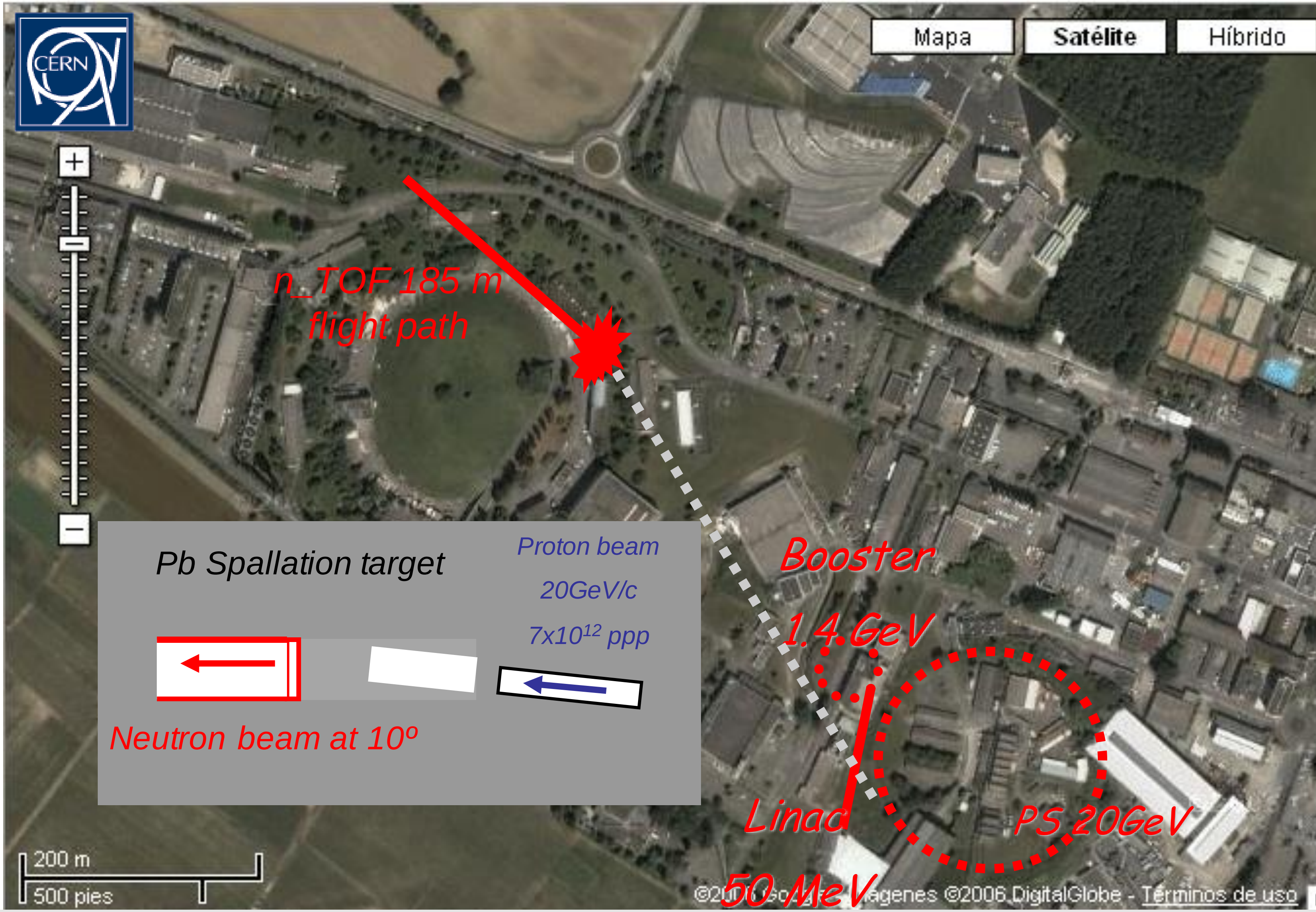
Goals of the measurement (PhD theses of J. Balibrea – CIEMAT)

1. Measurement of the ^{235}U(n,γ) cross section and control of the systematic uncertainties associated to the technique:
- Experimental and Monte Carlo determination of the detection efficiencies vs normalization to evaluated data.

2. Measurement of the α-ratios in the 1 to few hundred eV region.
3. Measurement of the EM cascades from capture (Photon Strength Functions) and from the prompt fission.
4. Acquire experience for the realization of more challenging measurements at EAR-2.

Work supported by the EC FP7 ERINDA project and part of the scientific programme of the FP7 project CHANDA .

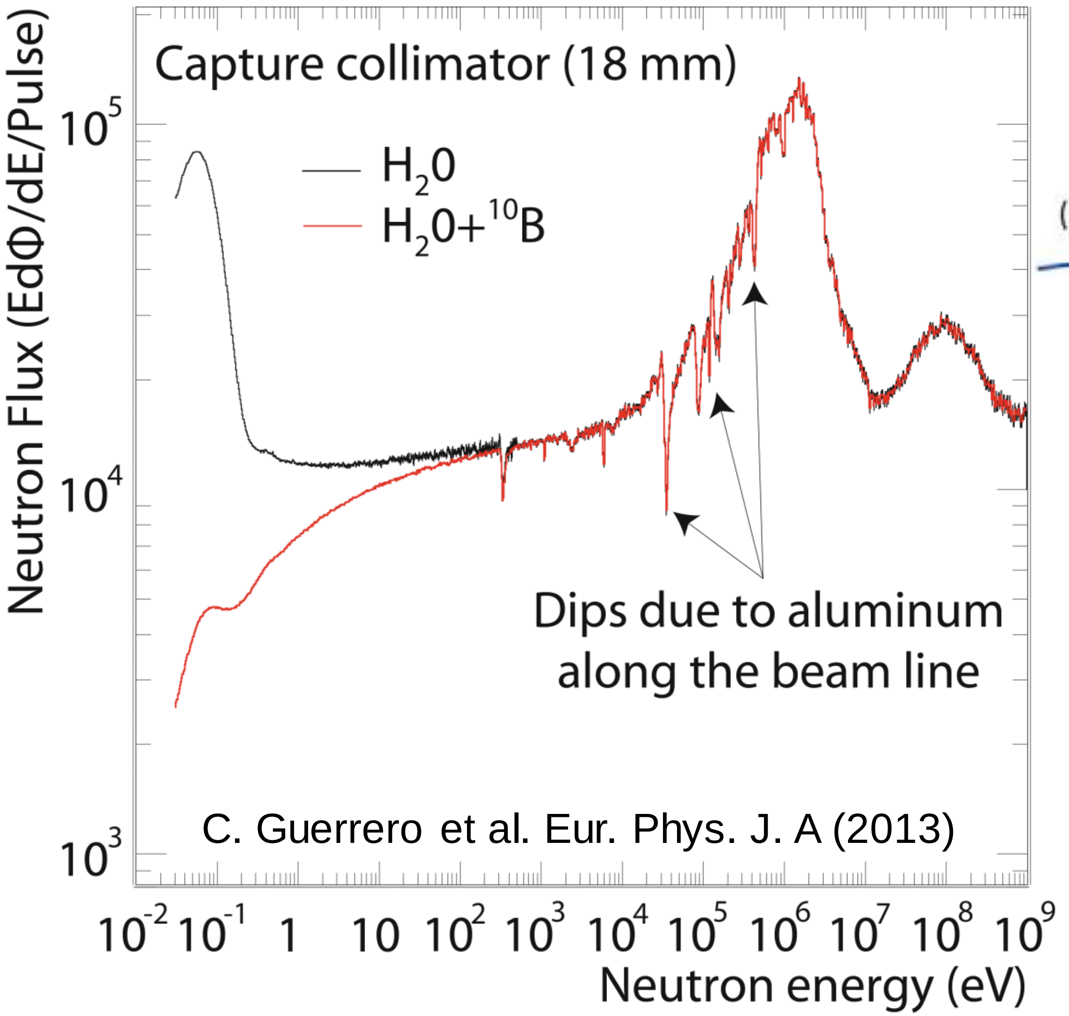
The n_TOF facility

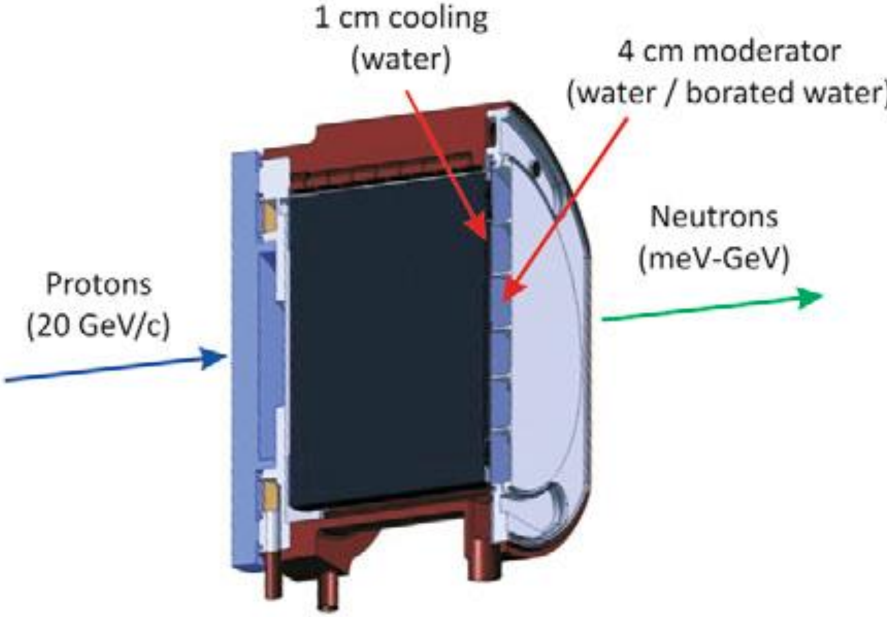


GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

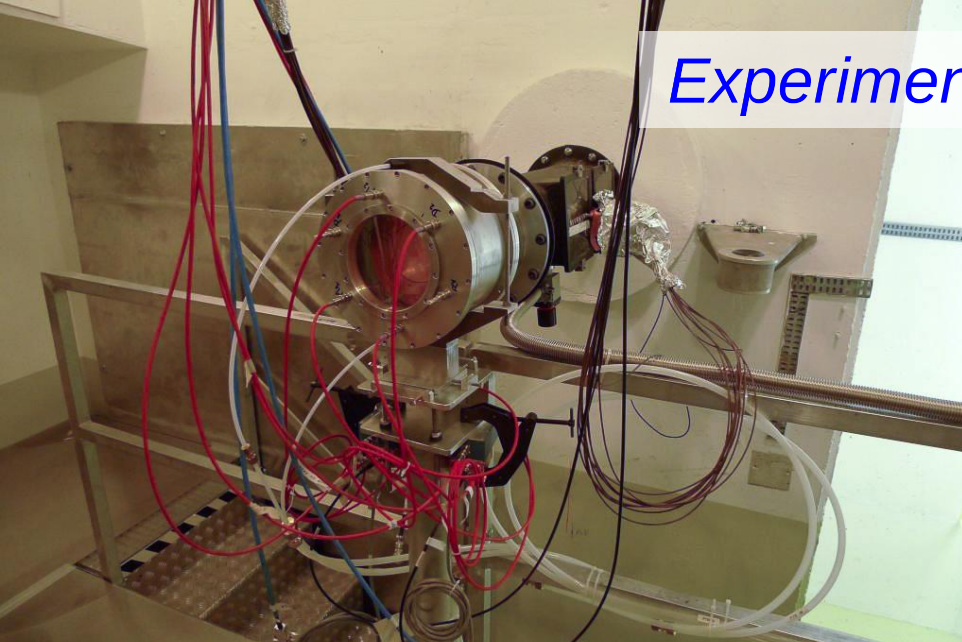
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

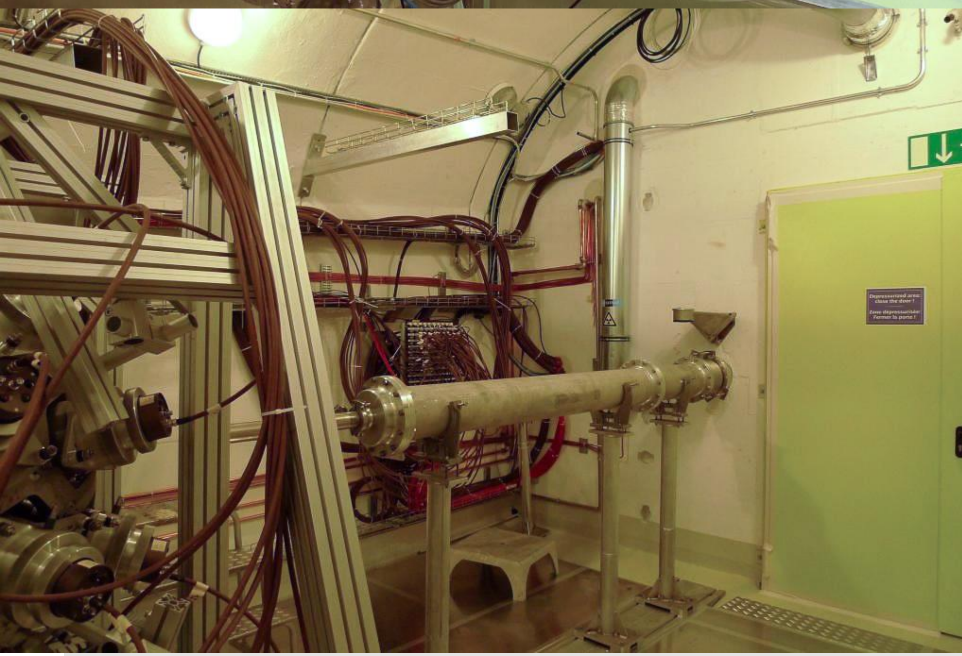
Characteristics of the neutron beam

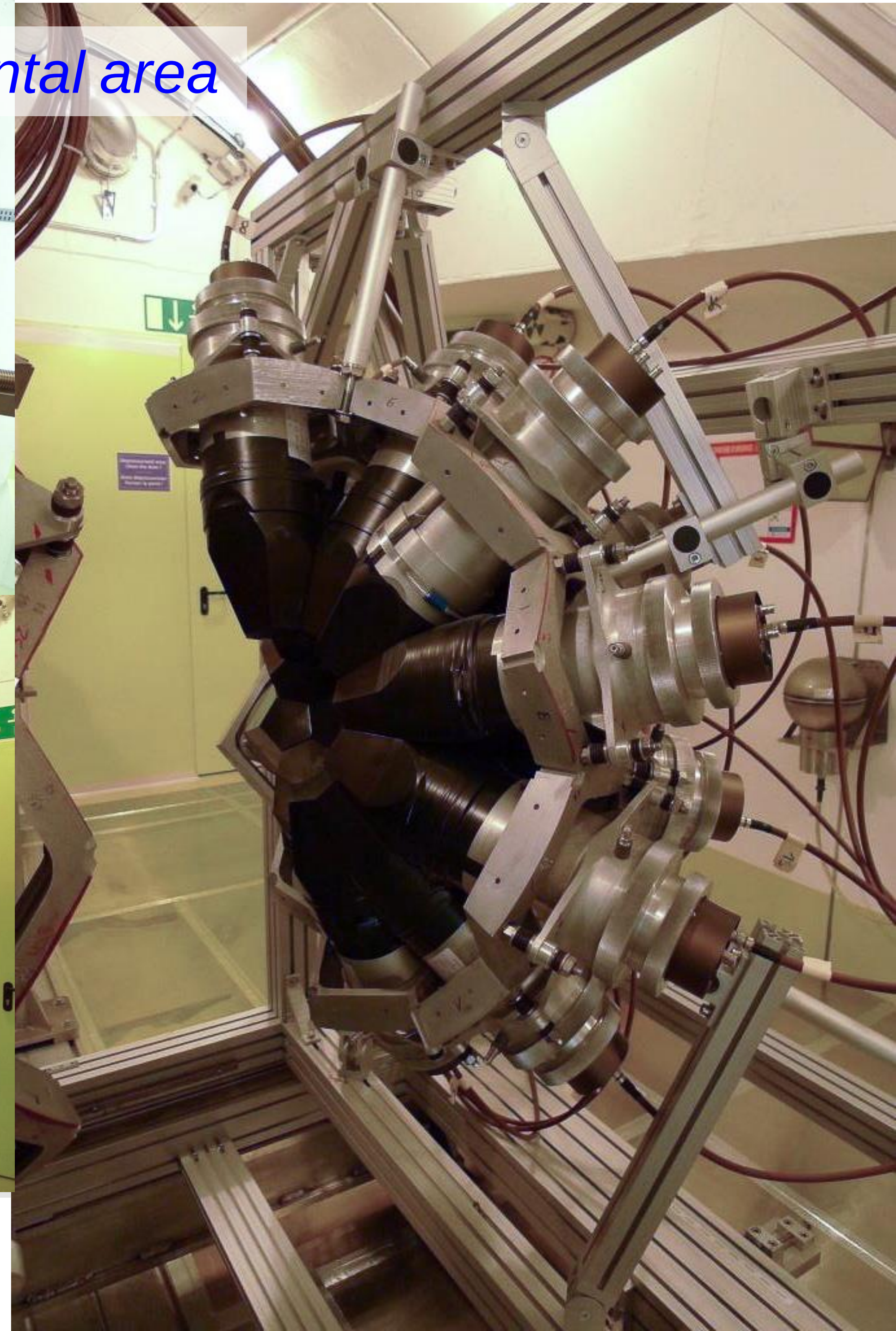




Experimental area







GOBIERNO
DE ESPAÑA

MINISTERIO
DE ECONOMÍA
Y COMPETITIVIDAD

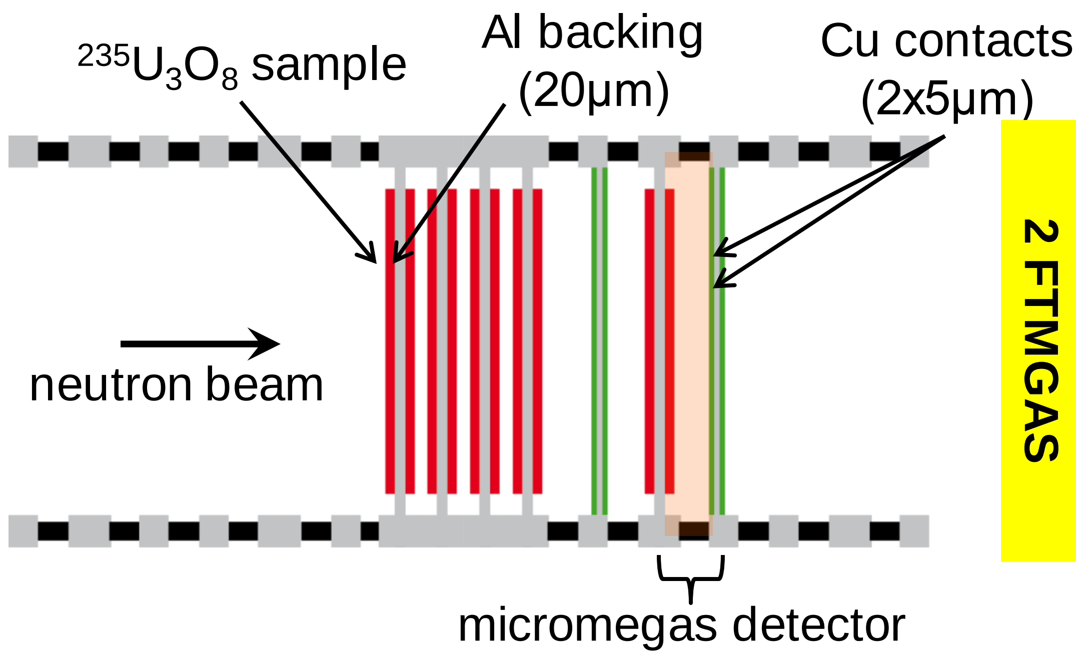
Ciemat

Centro de Investigaciones
Energéticas, Medioambientales
y Tecnológicas

The two complementary experimental setups

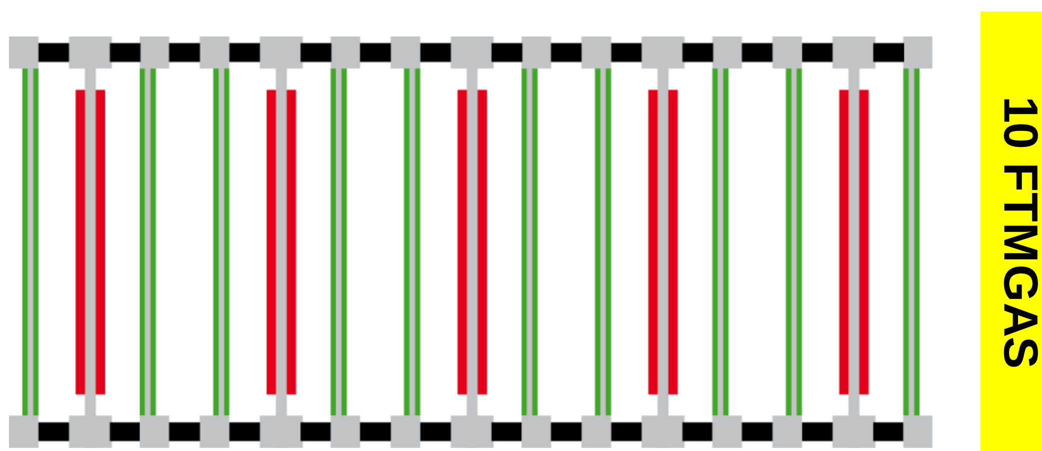
8 samples + 2FTMGAS

Low tagging efficiency (~20%)
Less dead material in the neutron beam, i.e. lower background.
Data for (n,γ) cross section.



10FTMGAS

High tagging efficiency (~90%)
More dead material in the neutron beam, i.e. lower background.
Data for α-ratio measurements.



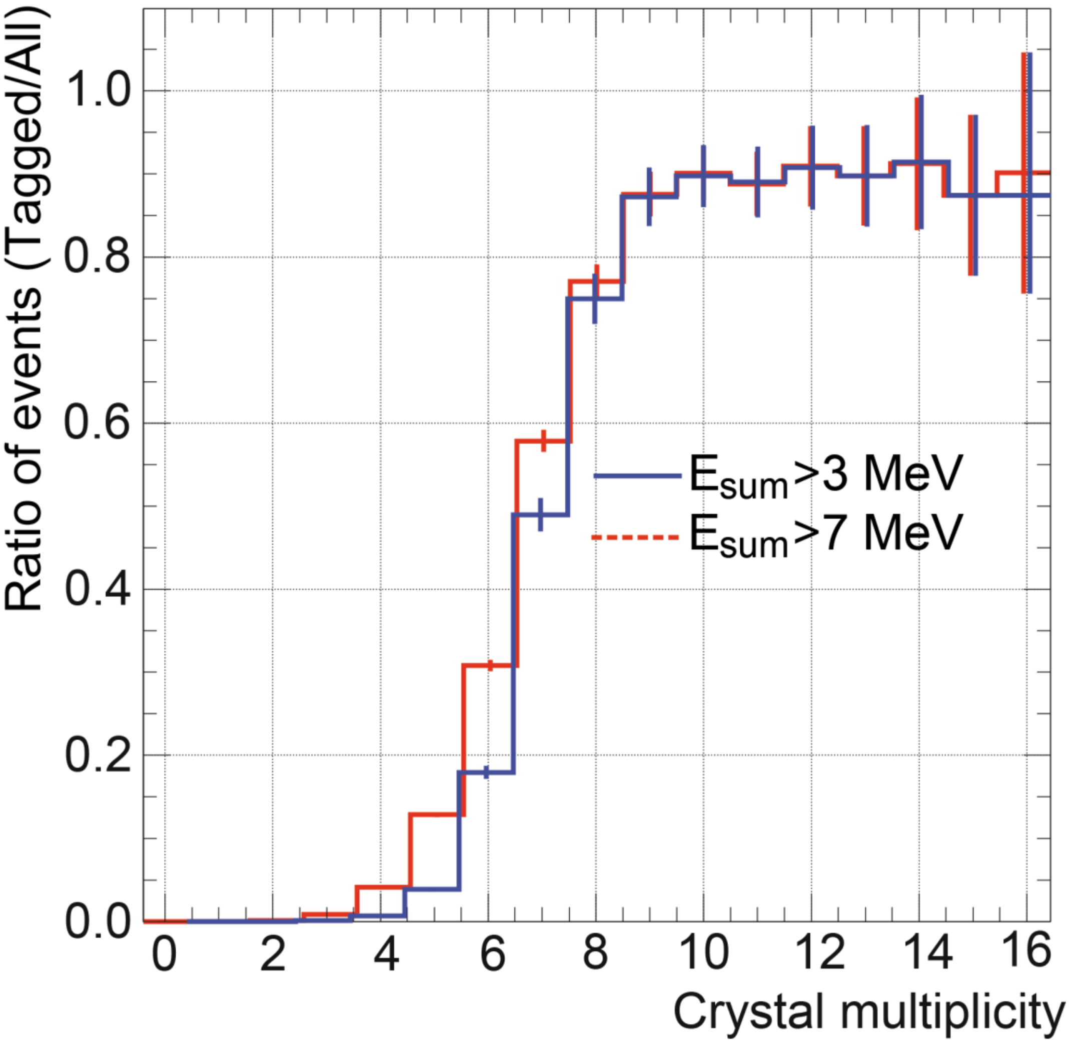
The fission tagging efficiency

It is possible to determine the tagging efficiency with great accuracy.

-High m_γ only due to fission
-ε_{TAC} ~100% for high m_γ events

$$\varepsilon_{tagging} = \frac{\text{tagged events (high } m_\gamma)}{\text{untagged events (high } m_\gamma)}$$

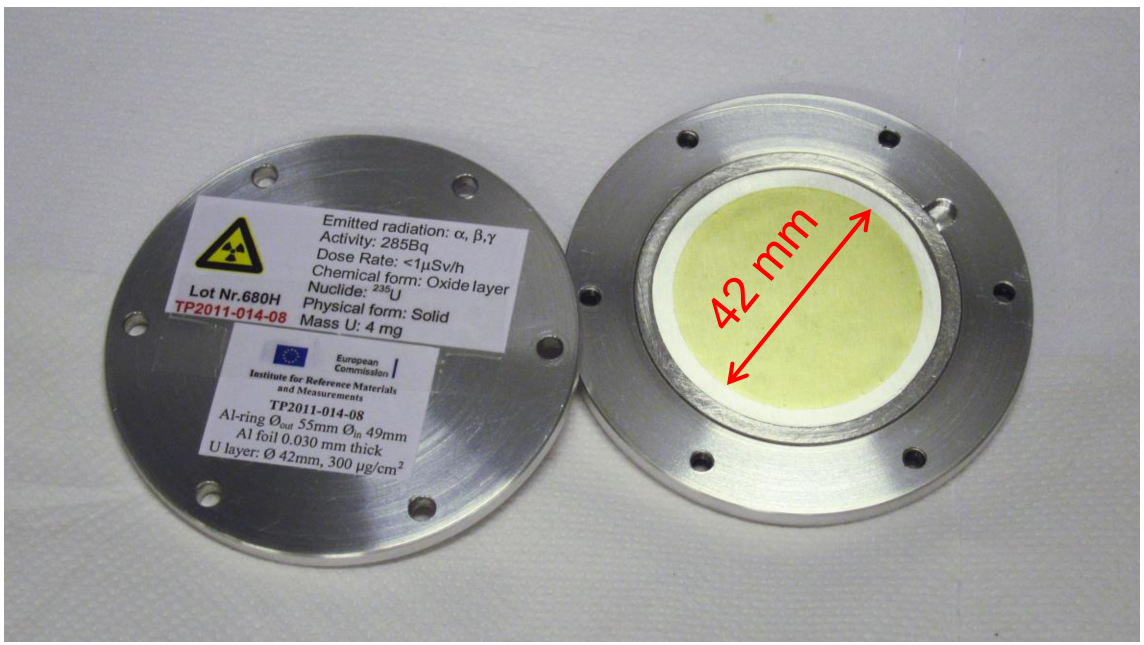
C. Guerrero et al. Eur. Phys. J. A (2012)

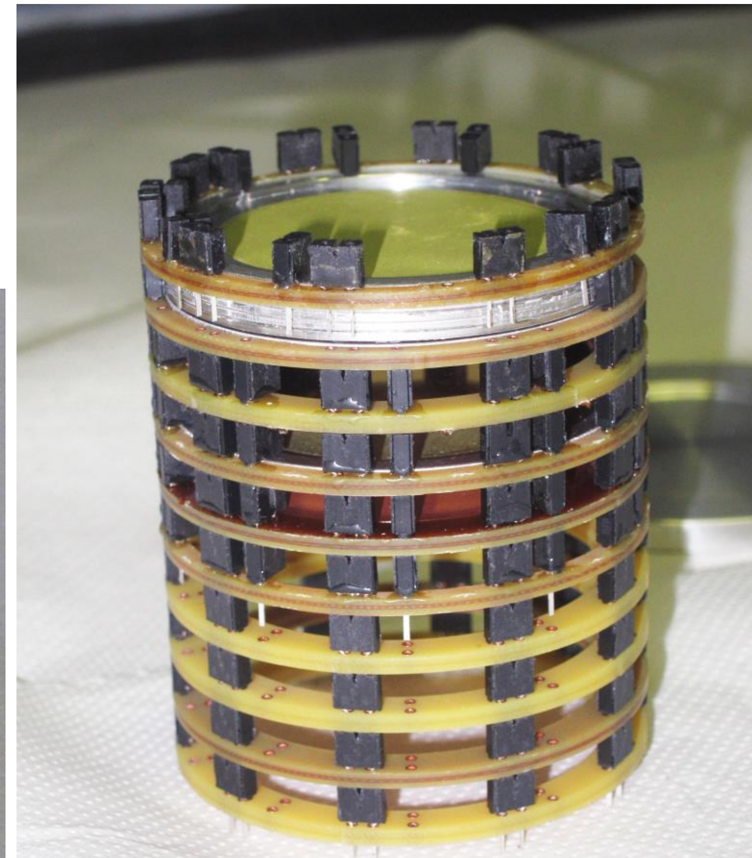


The ^{235}U samples

The samples U_3O_8 have a surface density of 300 μg/cm^2 , are deposited on a 20 μm thick aluminum backing and have diameter of 42 mm, thus covering the entire neutron beam profile. Manufactured at IRRM – Geel.

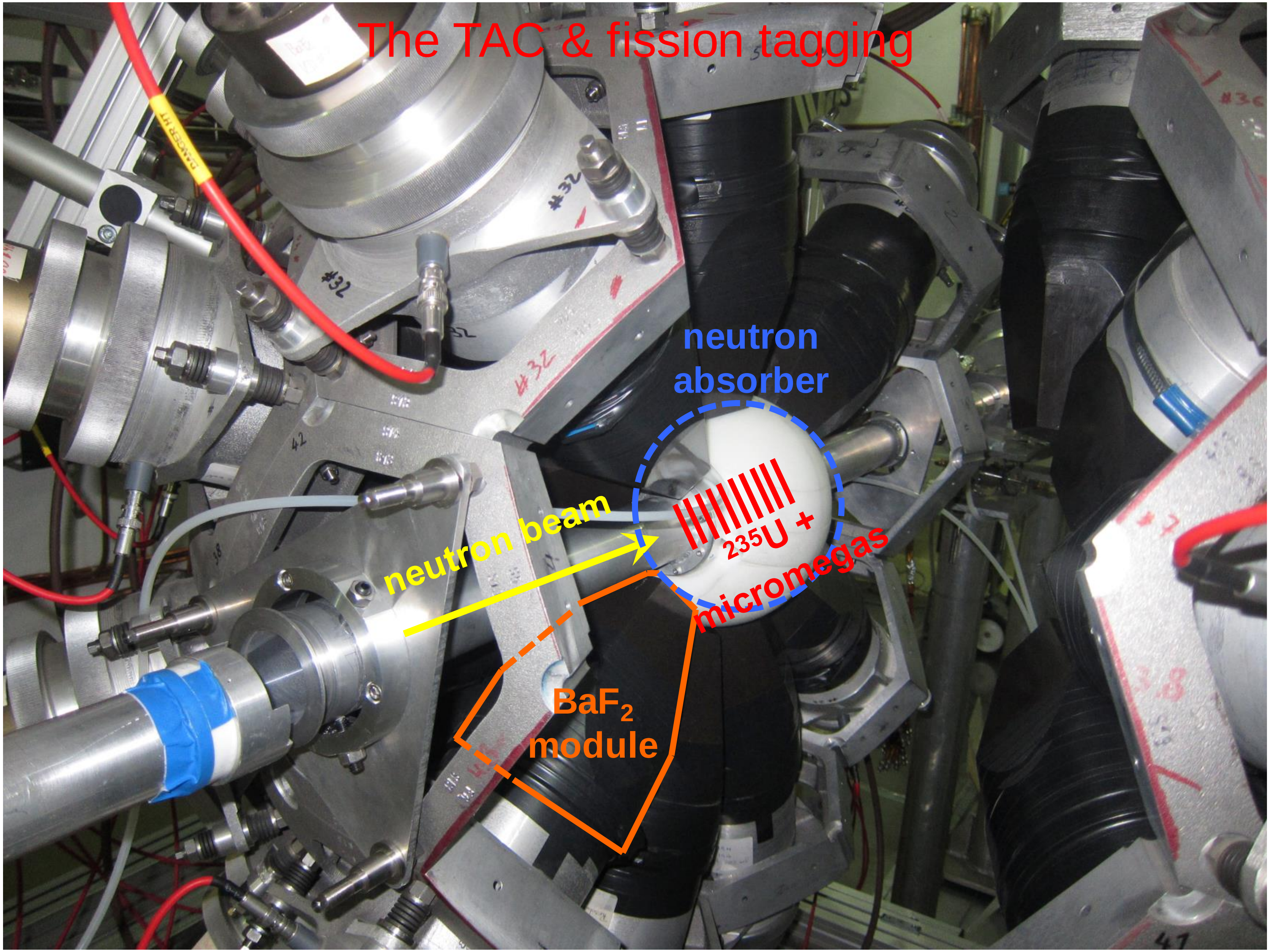
The uranium isotopic content is as follows:
$^{233}U <$ 0.001%, ^{234}U=0.036%, **^{235}U=99.94%**,
^{236}U=0.011%, ^{238}U=0.013%.



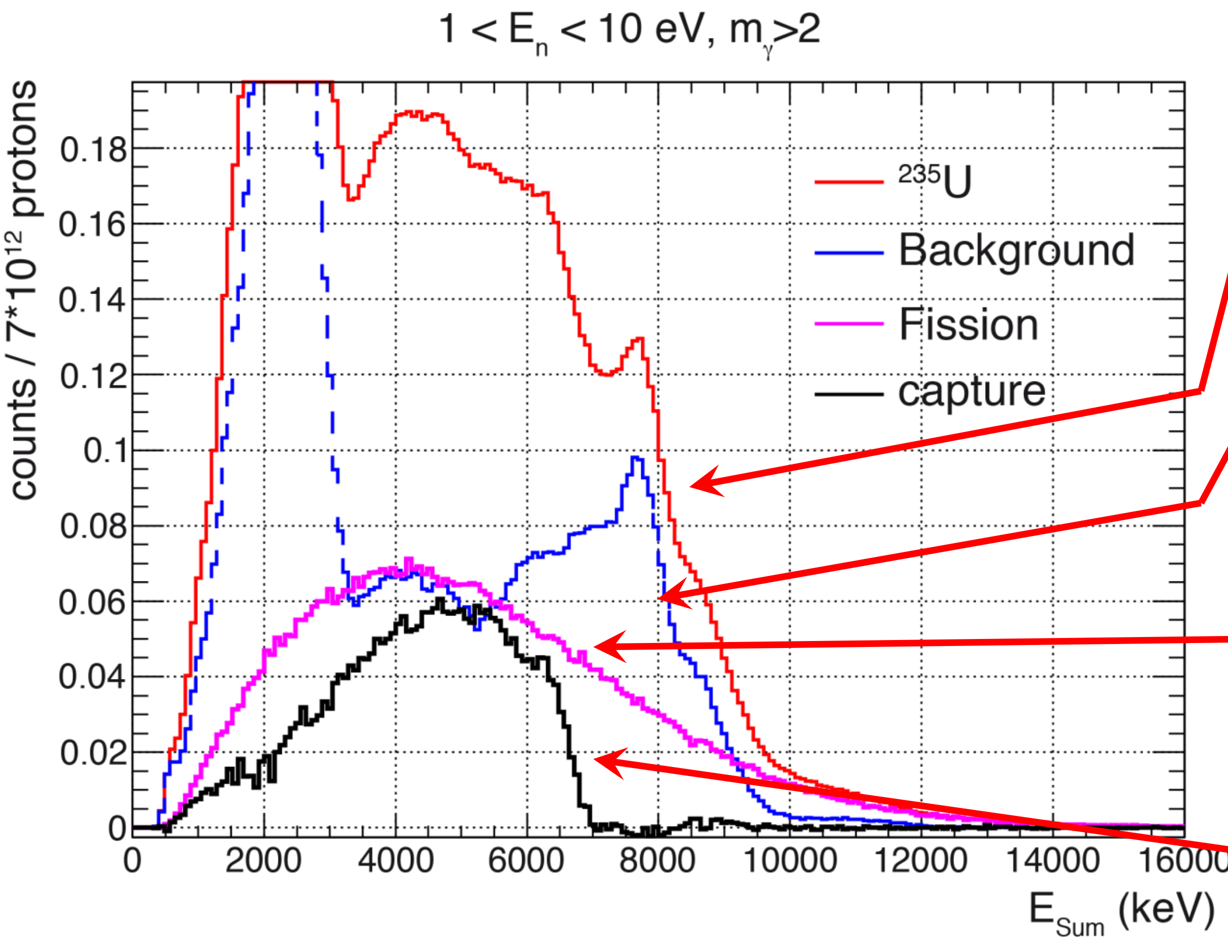


Operated with a gas mixture of Ar-88%, CF_4-10% and isobutane - 2% at 1 atm.

The TAC & fission tagging



2 Fission tagging micromegas (2FTMGAS)



Total energy deposition in the TAC.

Background measured with a dummy sample (everything but ^{235}U foils). Components: $^{nat}Cu(n, \gamma)$, $^{27}Al(n, \gamma)$ and elastic scattering

TAC response to fission events (fission tagging)

TAC response to capture events (after background subtraction)

The cross section in the thin target approximation

Counting rate in the detector
(TAC or micromegas)

Background in the detector

$$s(n,x) = \frac{1}{n_{at}} \frac{C_x(E_n) - B_x(E_n)}{e_x f(E_n)}$$

$$x = g, f$$

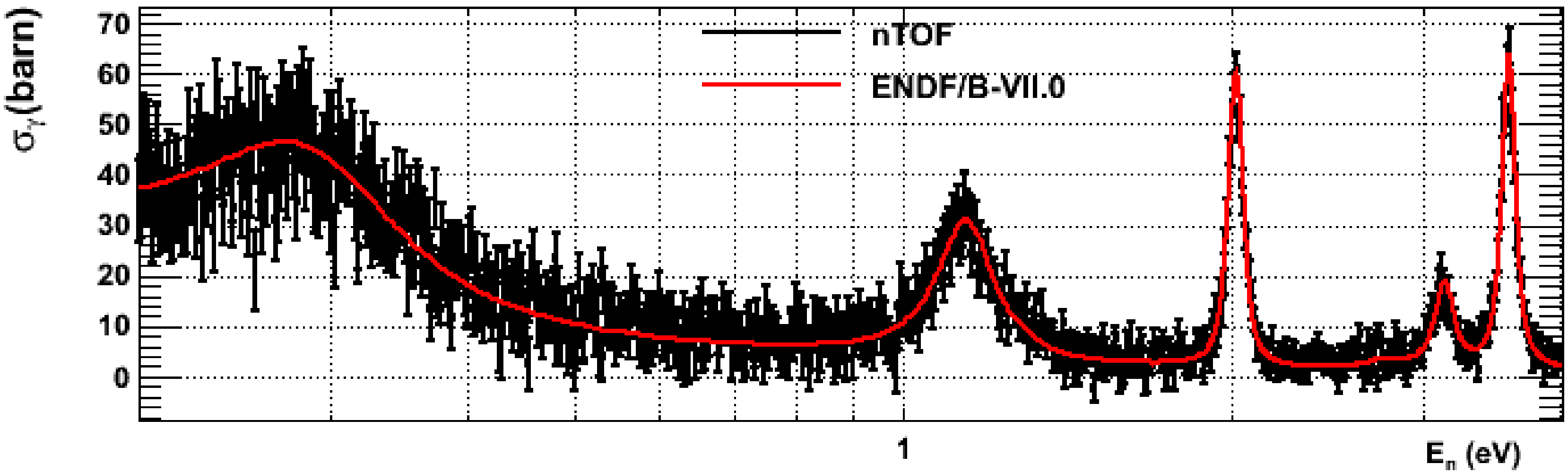
Detection efficiency
Can be determined:
-experimentally
-by Monte Carlo simulation
-Normalization to evaluated cross section data

Neutron energy fluence
-Determined experimentally
-Removed in a relative measurement – ^{235}U(n,f)

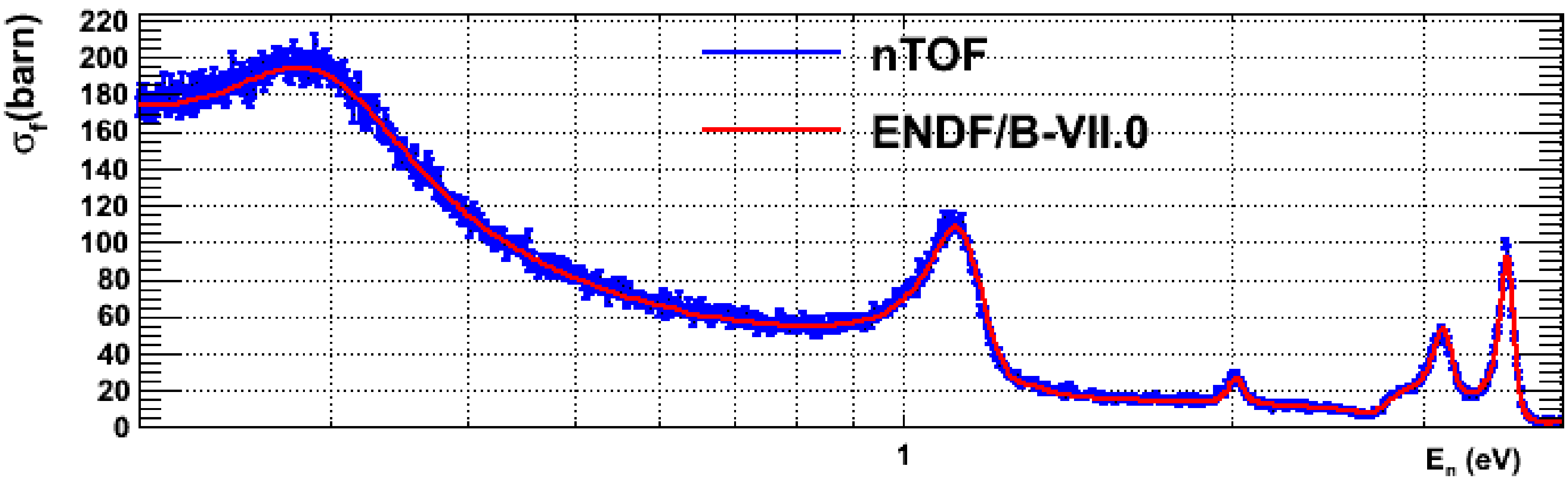
Preliminary analysis

- (n,f) – no background in the micromegas.
- (n,γ) – subtraction of the dummy sample and the target activity background.
- ε_x has been obtained from the normalisation to ENDFB/VII.1 in the 1 to 10 eV range.

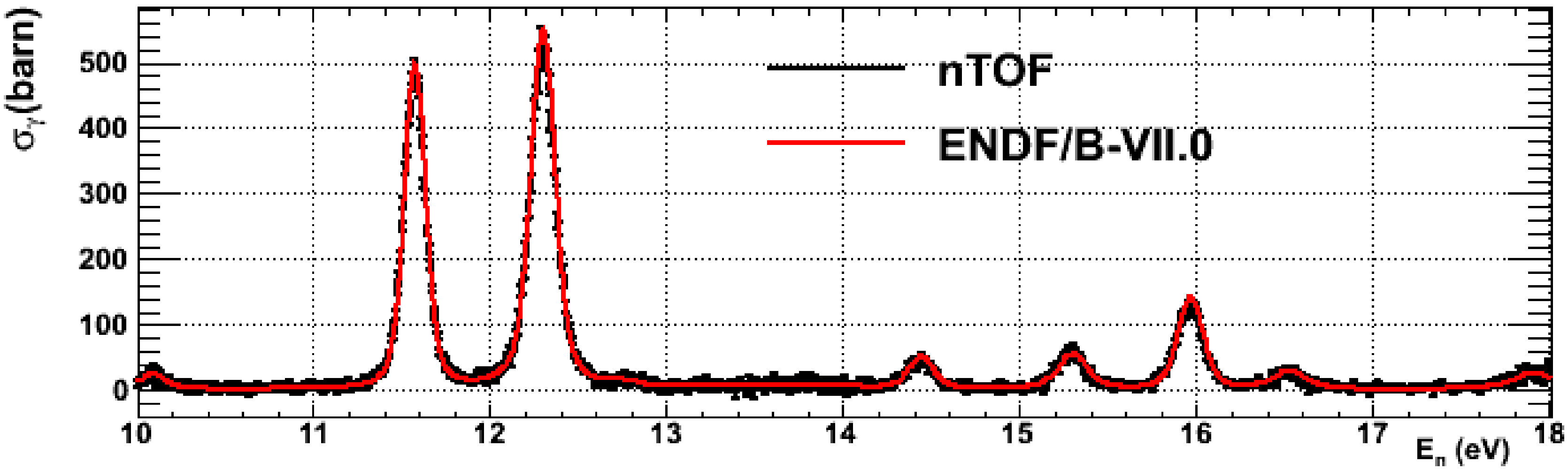
2FTMGAS (i)



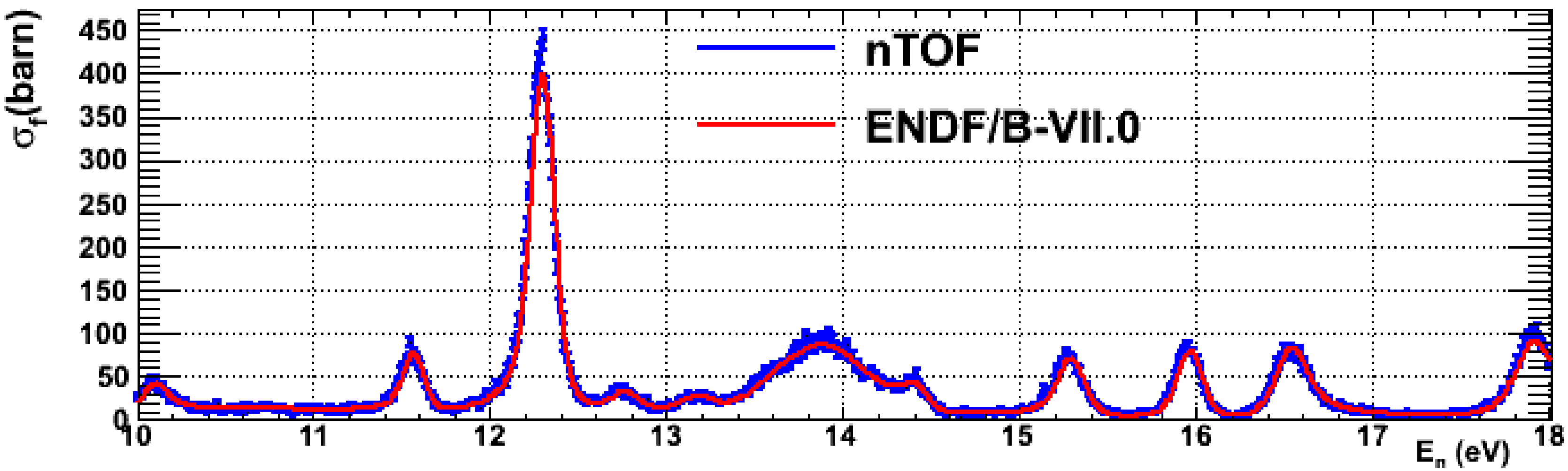
MORE THAN PRELIMINARY



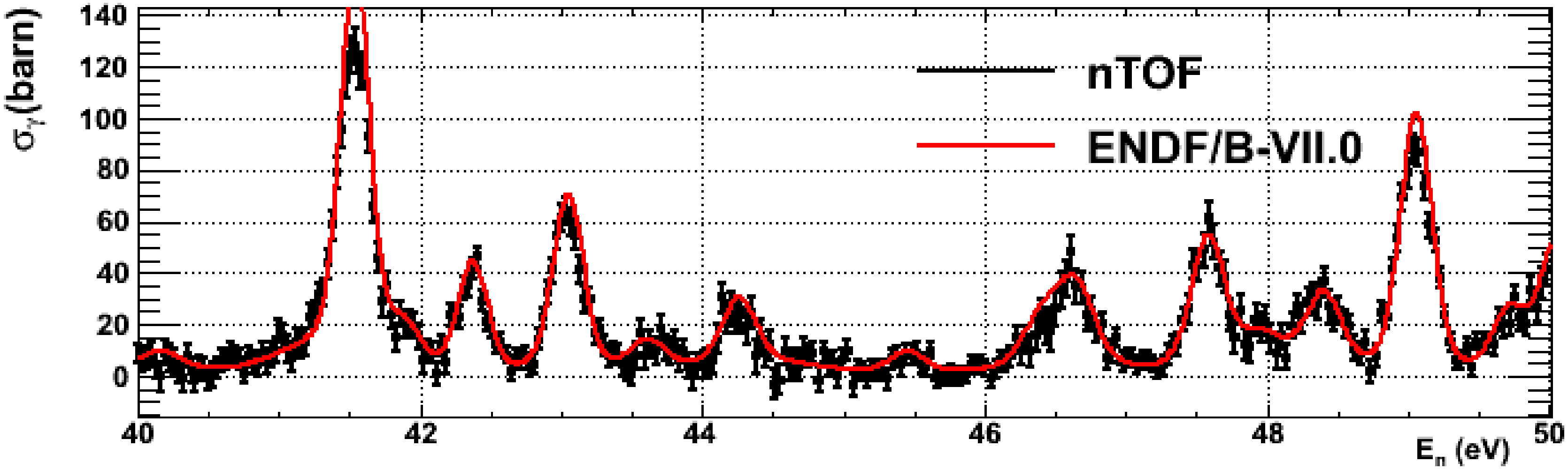
2FTMGAS (ii)



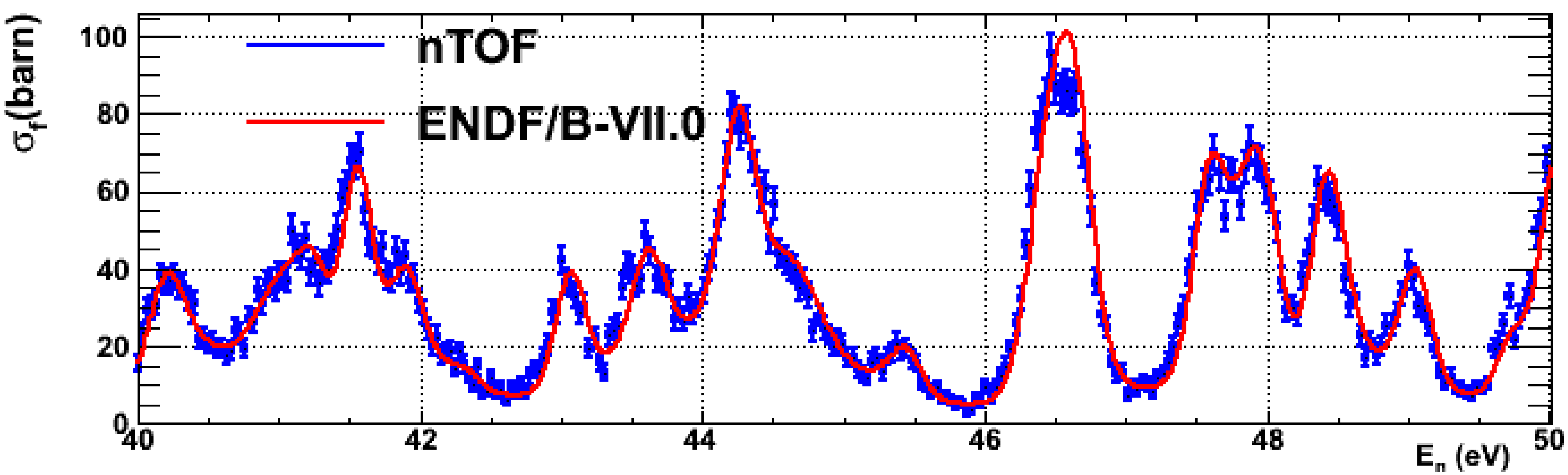
MORE THAN PRELIMINARY



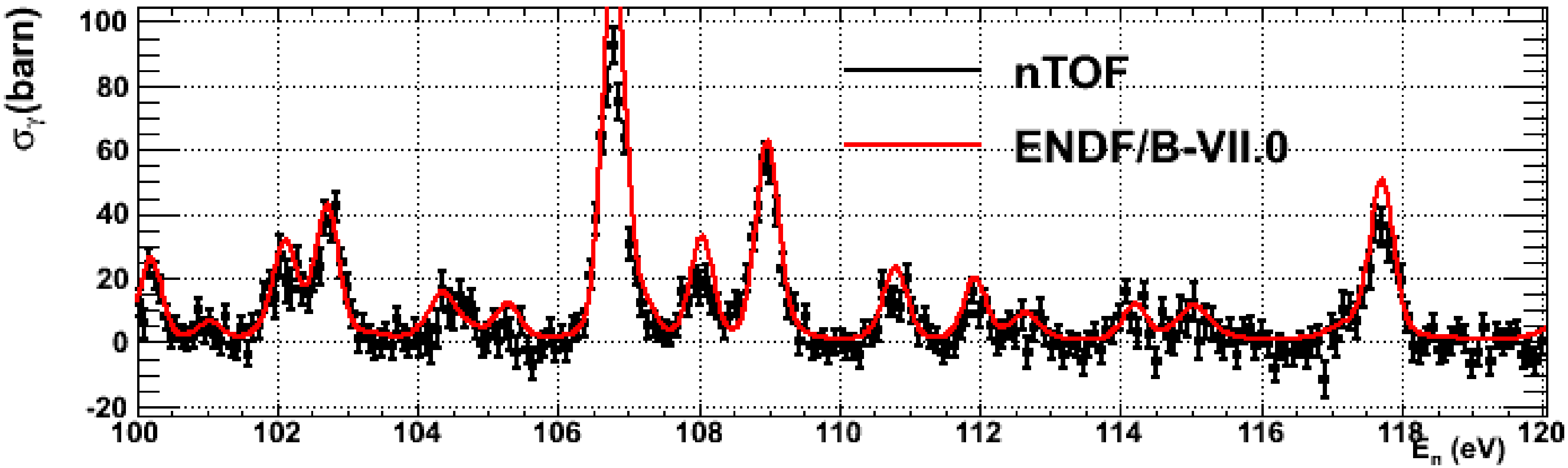
2FTMGAS (iii)



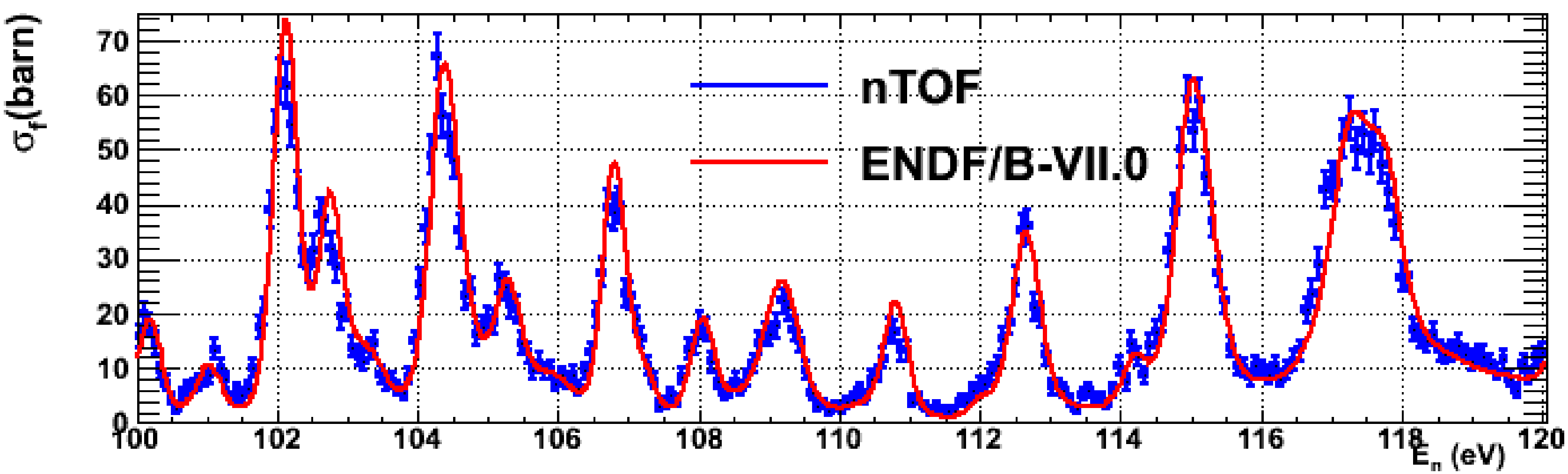
MORE THAN PRELIMINARY



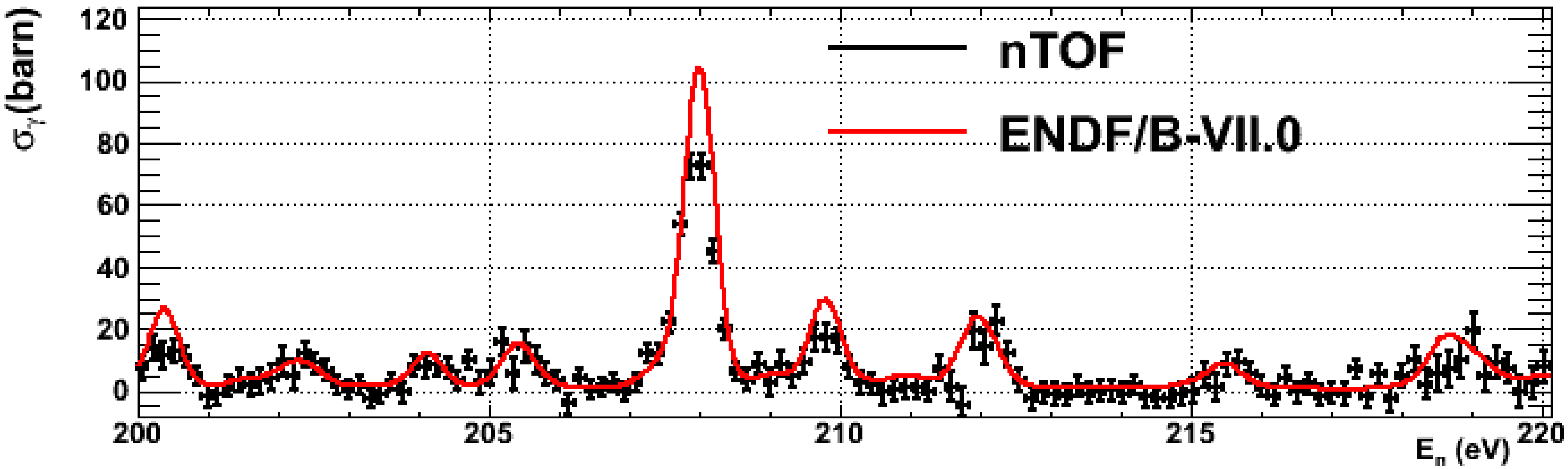
2FTMGAS (iv)



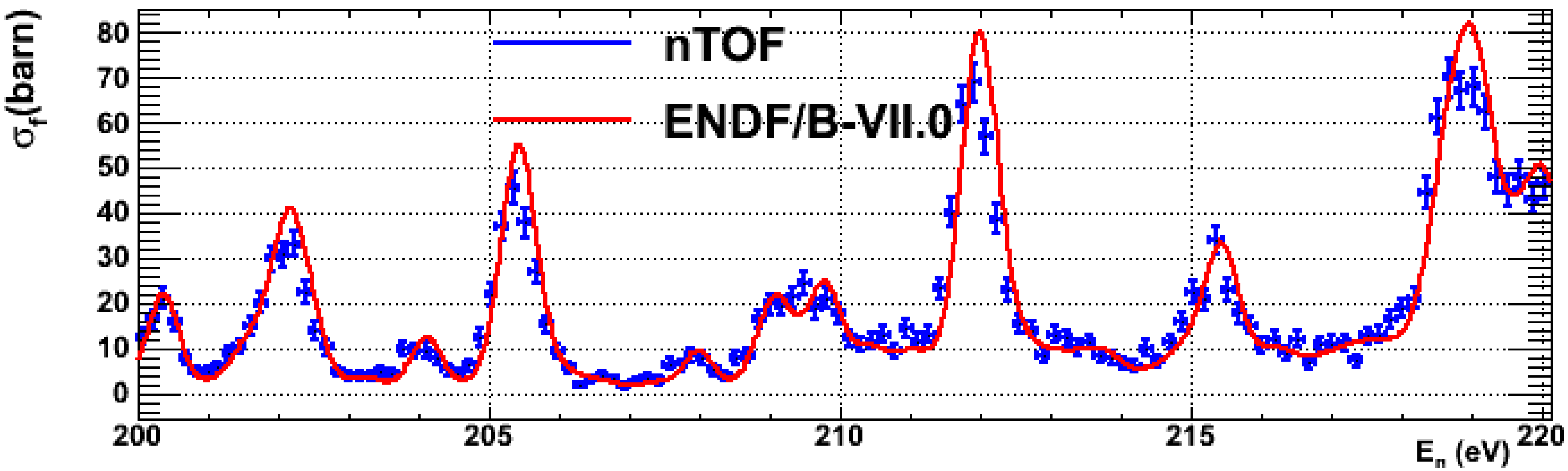
<u>MORE</u> THAN PRELIMINARY



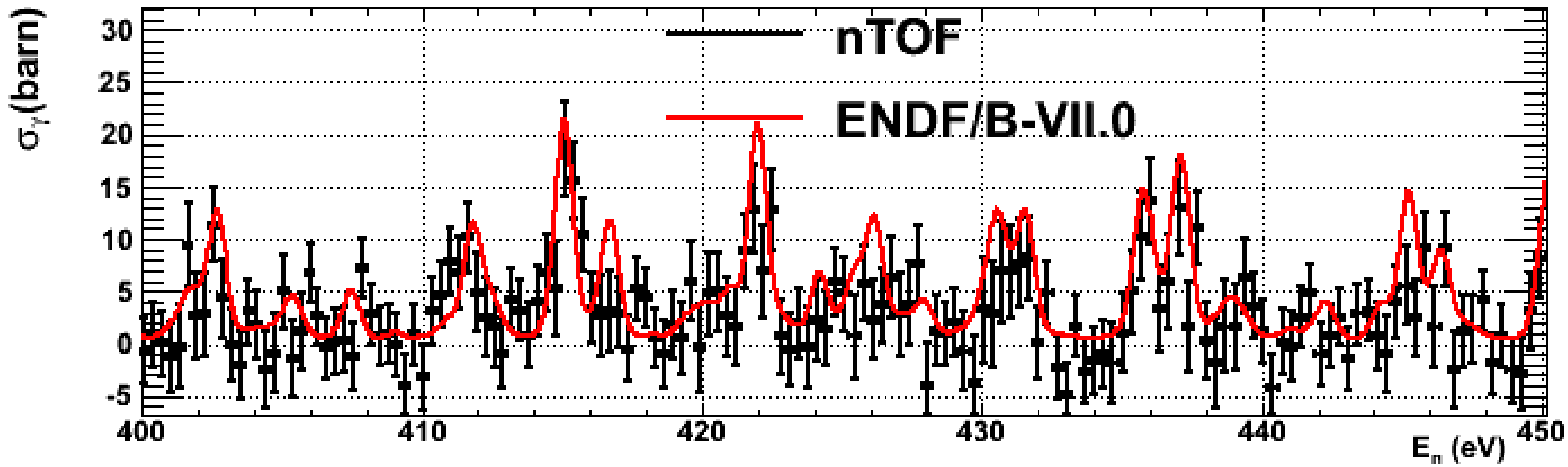
2FTMGAS (v)



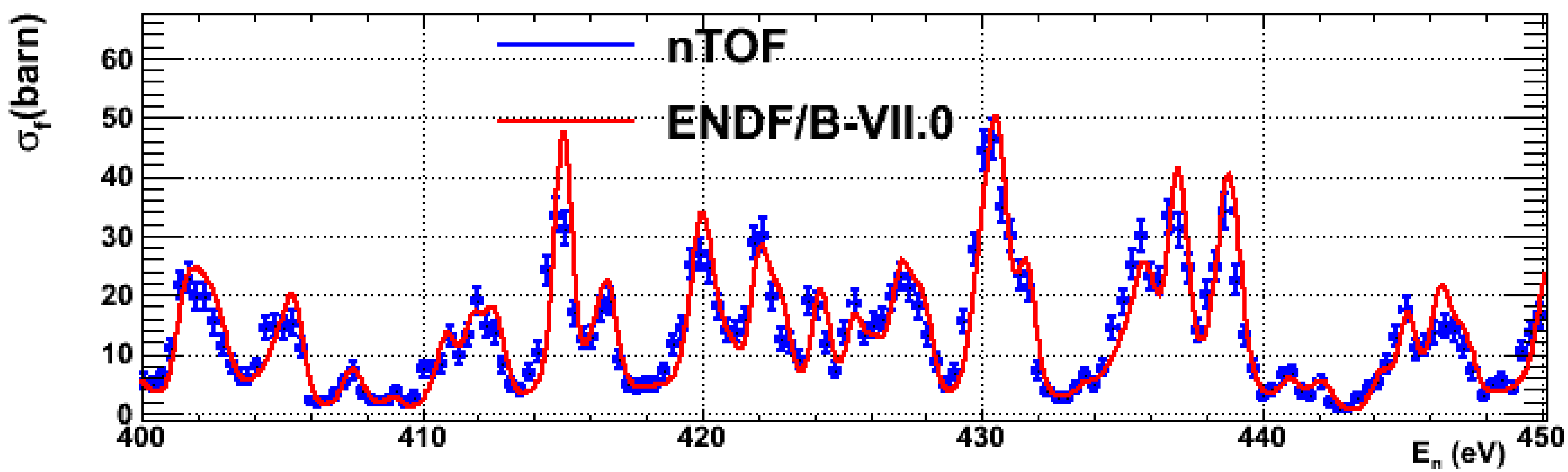
<u>MORE</u> THAN PRELIMINARY



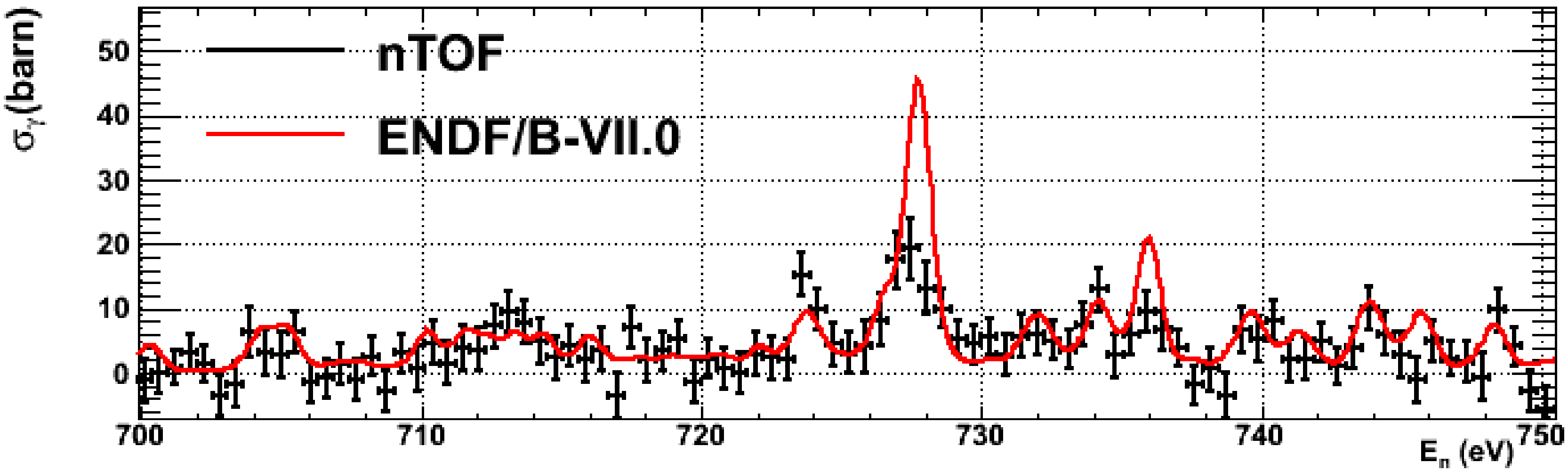
2FTMGAS (vi)



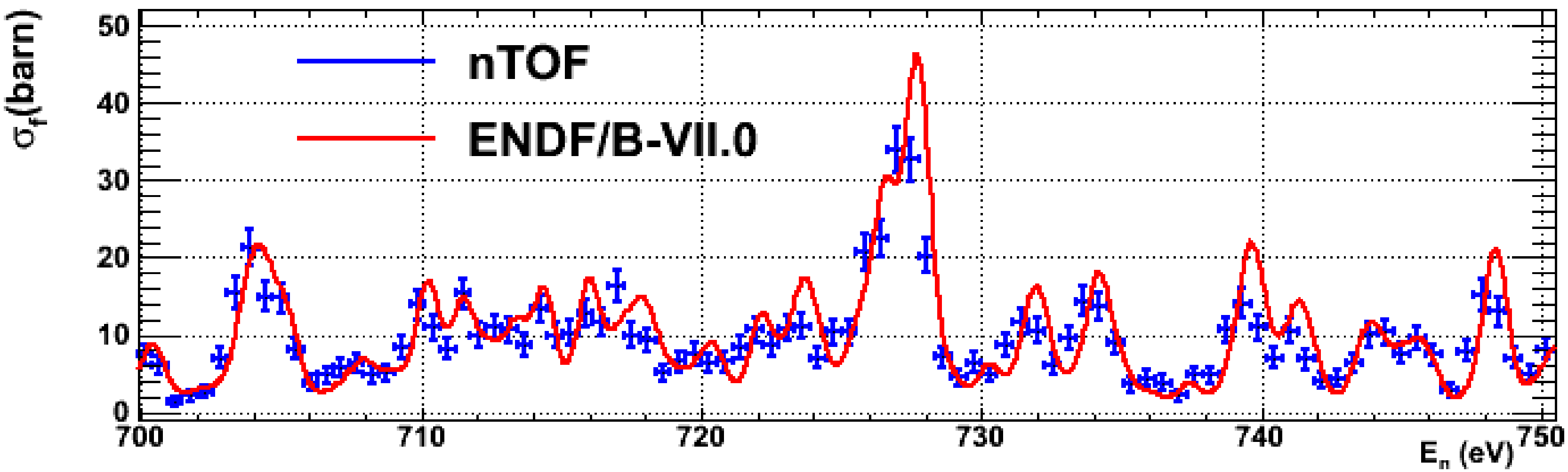
MORE THAN PRELIMINARY



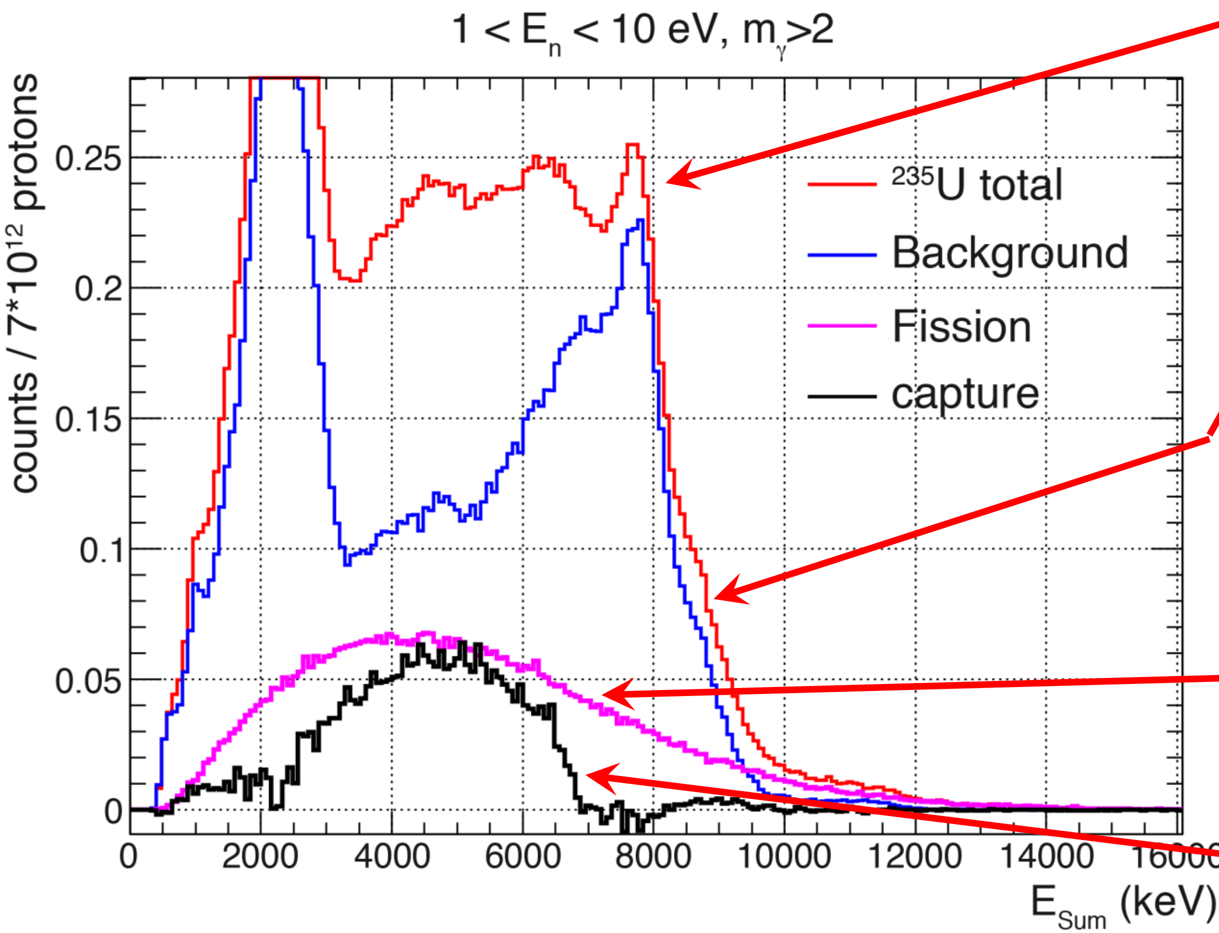
2FTMGAS (vii)



<u>MORE</u> THAN PRELIMINARY



10 Fission tagging micromegas (10FTMGAS)



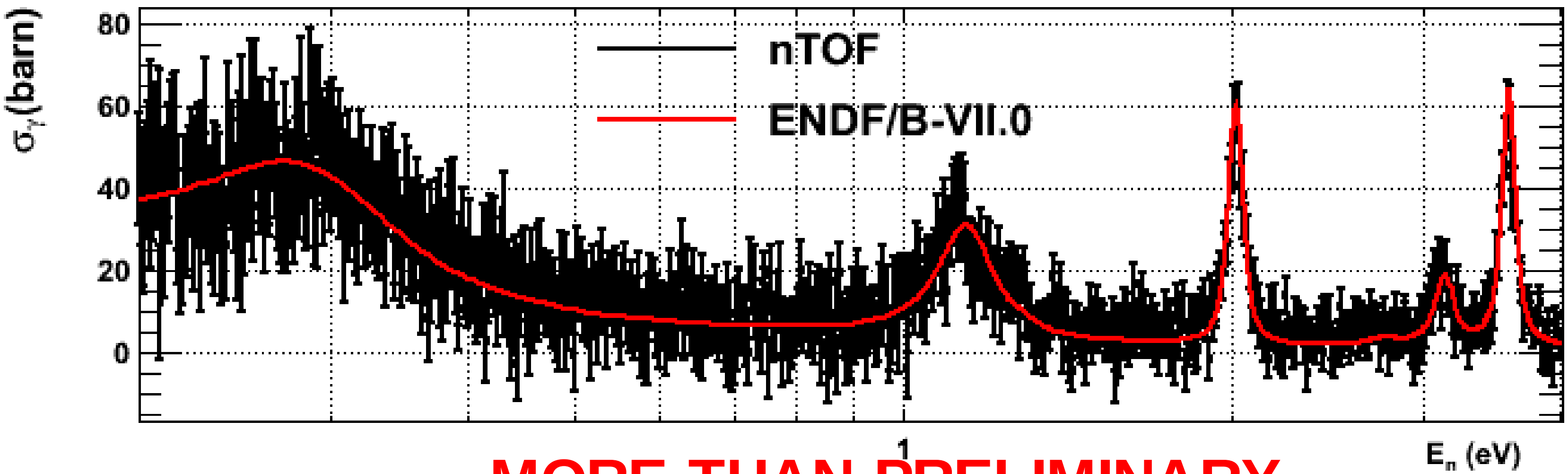
Total energy deposition in the TAC.

Background measured with a dummy sample (everything but ^{235}U foils). Components: $^{nat}Cu(n,\gamma)$, $^{27}Al(n,\gamma)$ and elastic scattering. Larger than for the 2FMTGAS case.

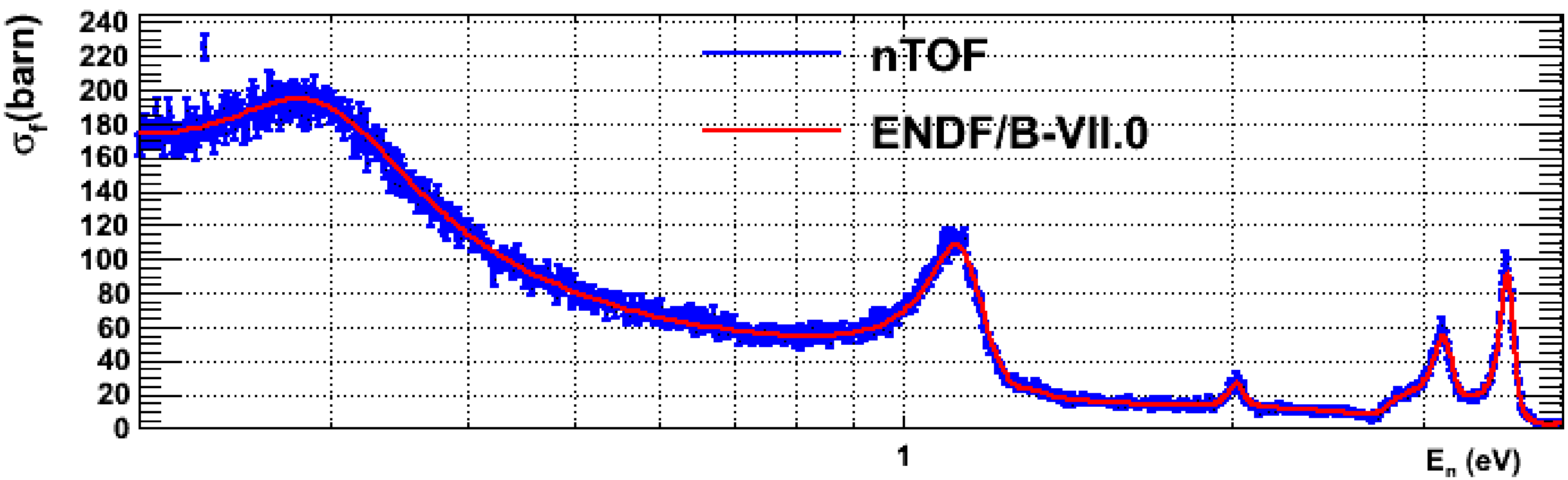
TAC response to fission events (fission tagging)

TAC response to capture events (after background subtraction)

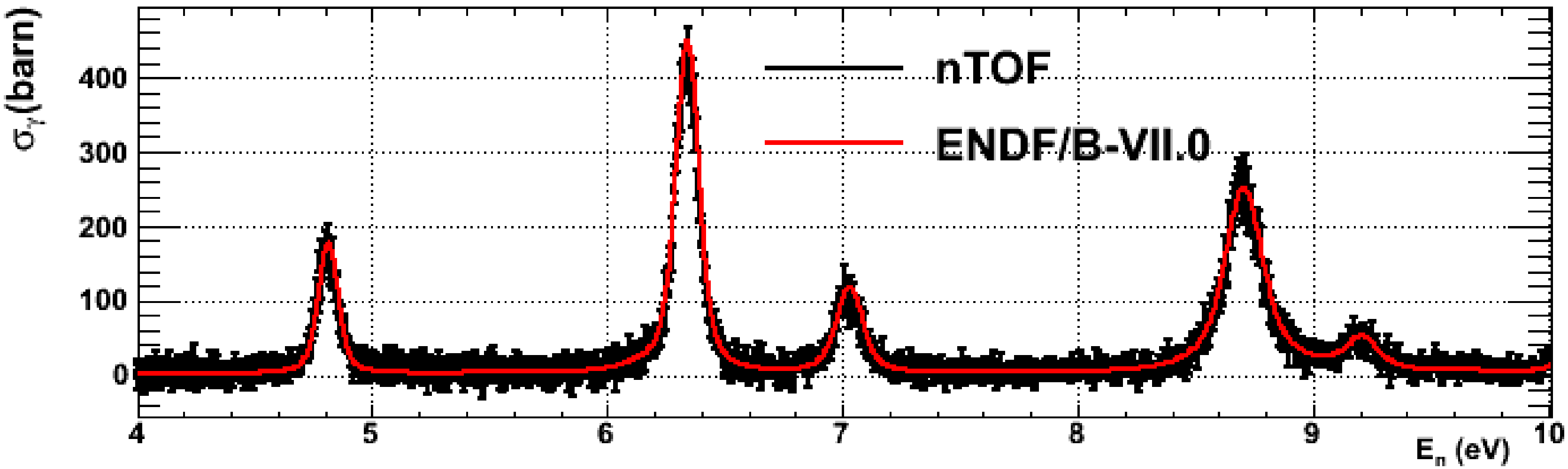
10FTMGAS (i)



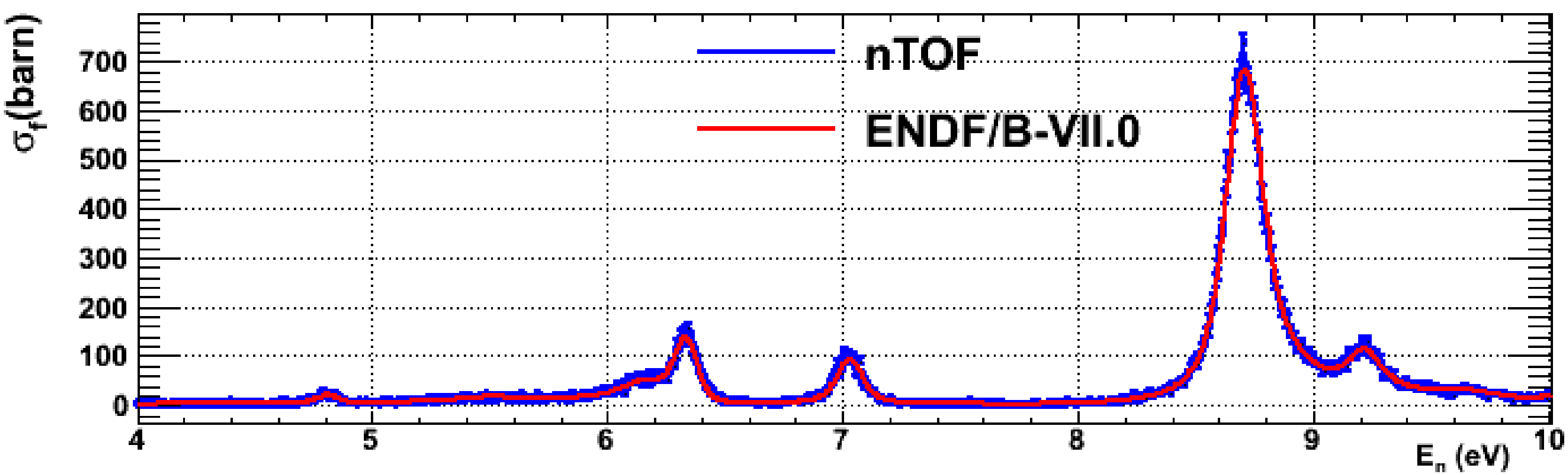
<u>MORE</u> THAN PRELIMINARY



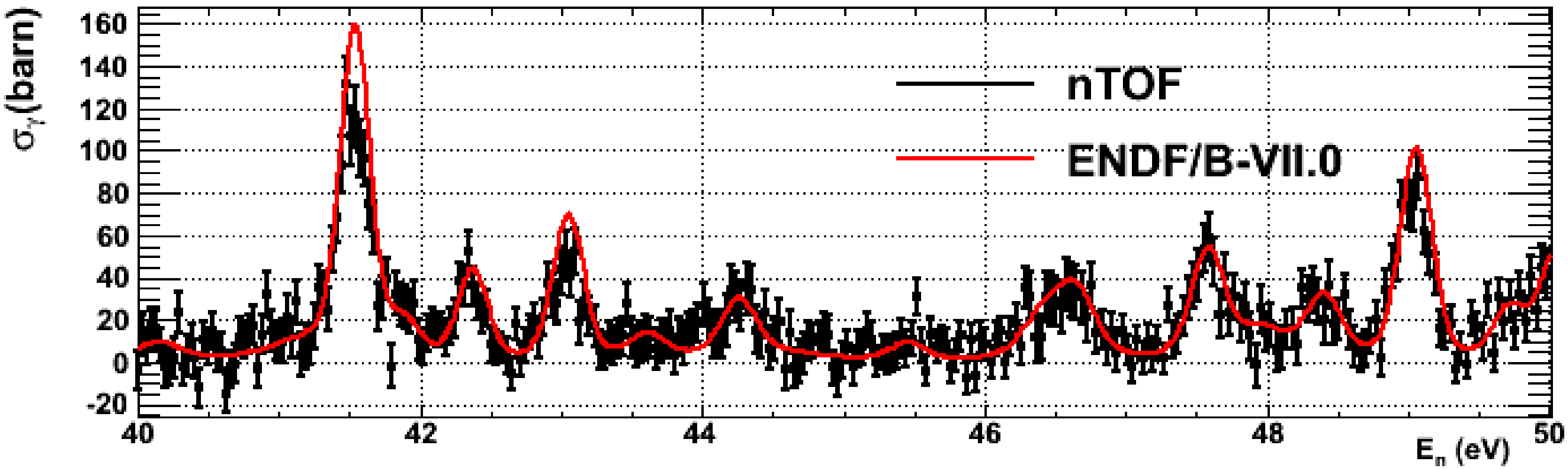
10FTMGAS (ii)



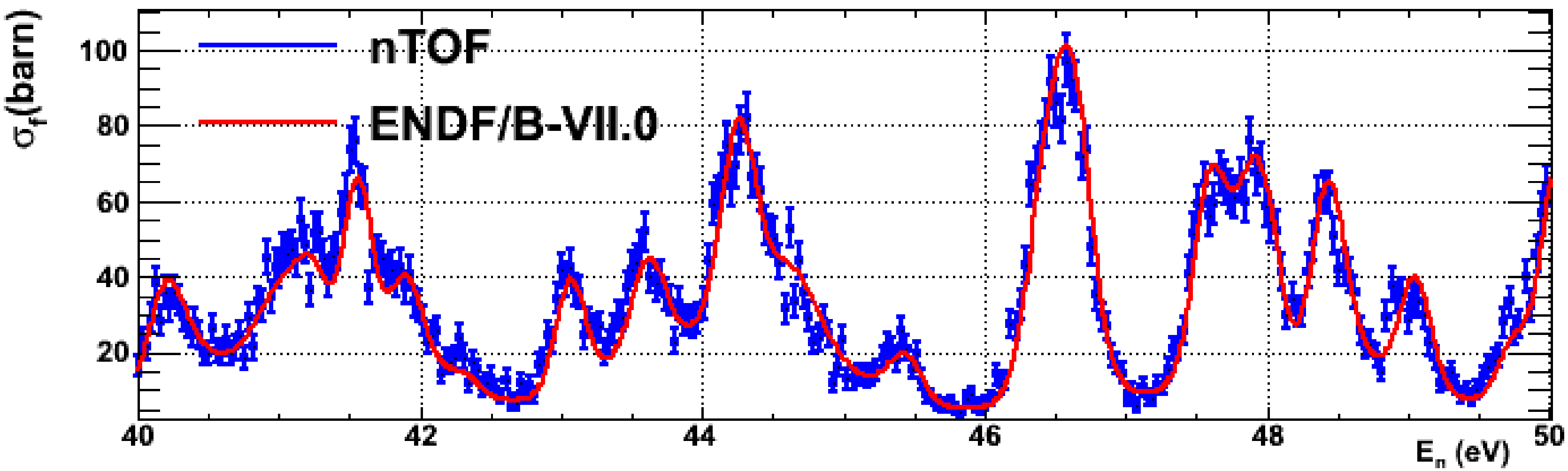
<u>MORE</u> THAN PRELIMINARY



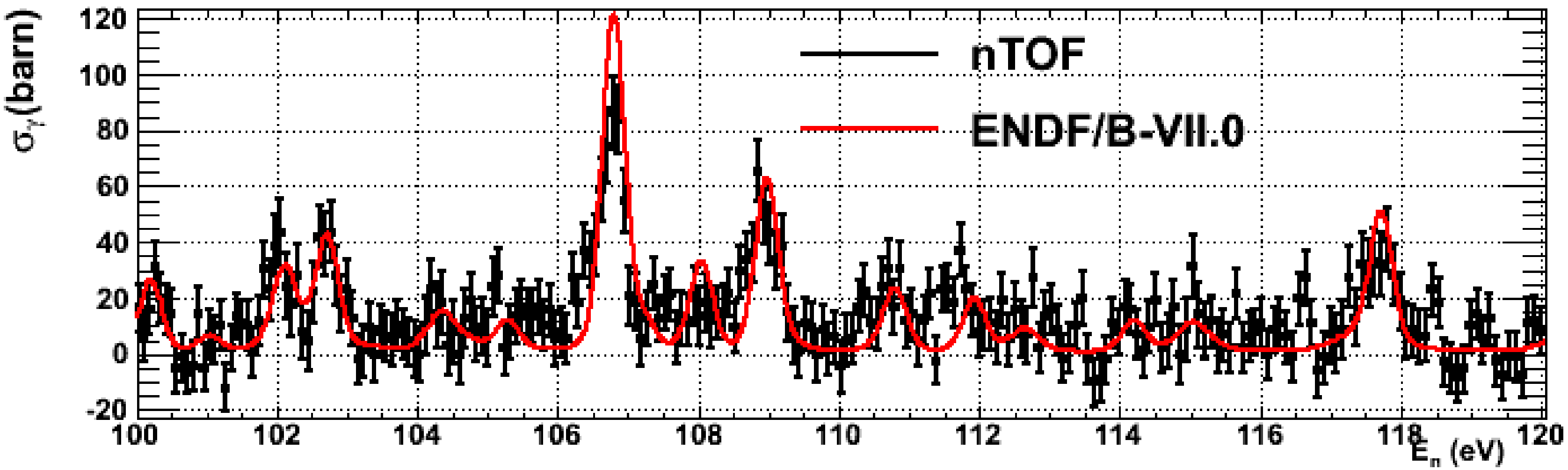
10FTMGAS (iii)



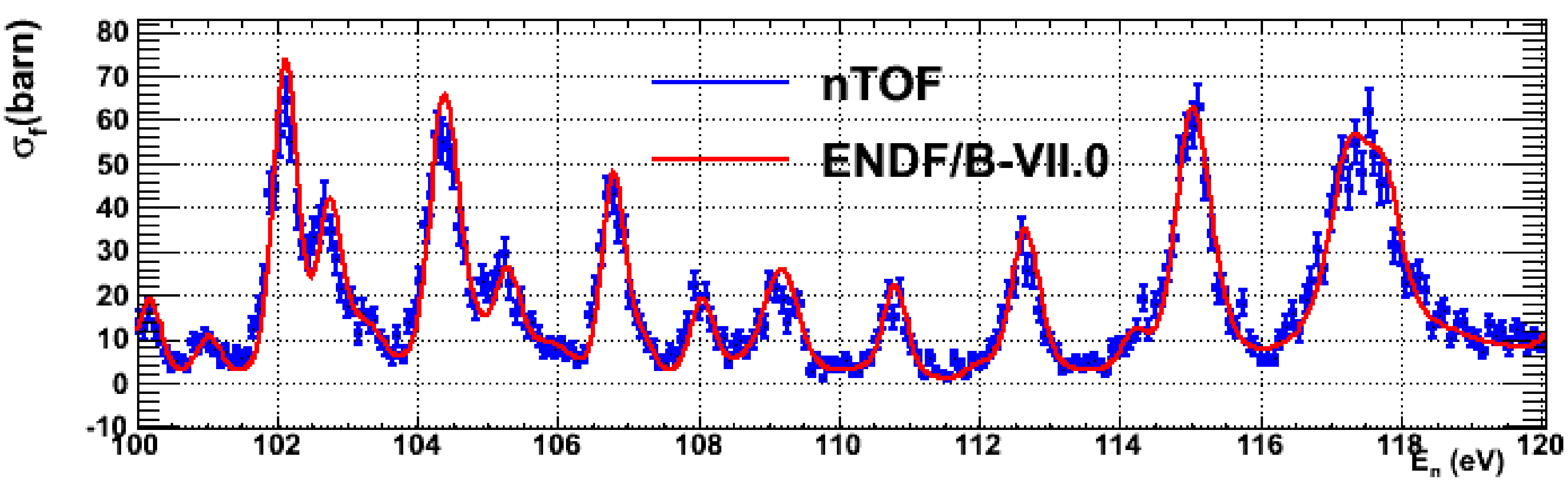
MORE THAN PRELIMINARY



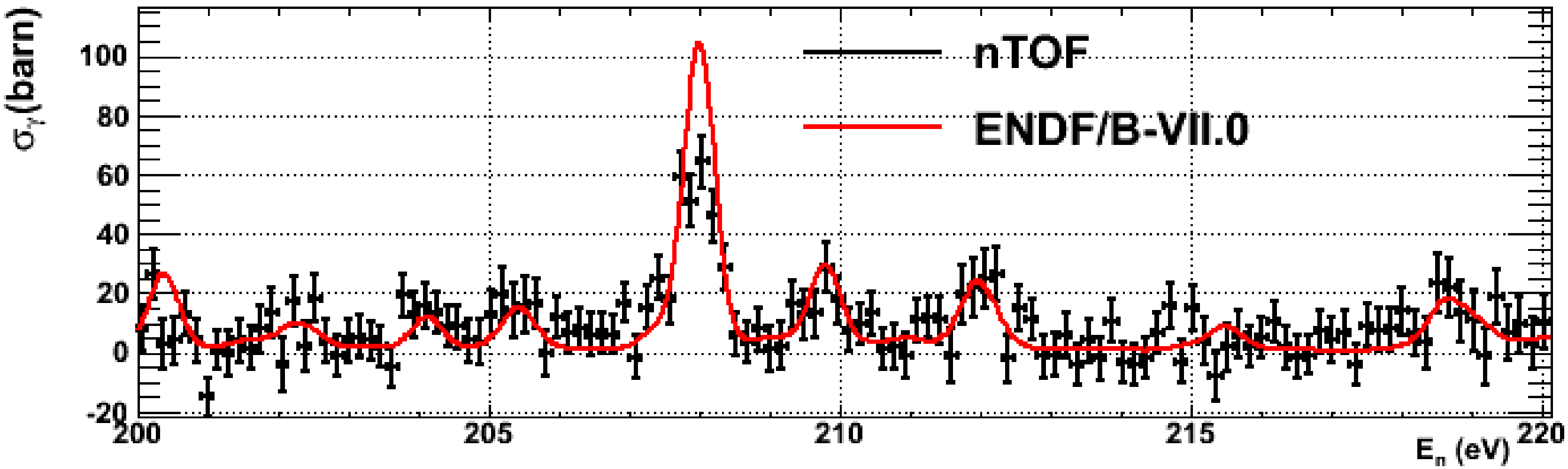
10FTMGAS (iv)



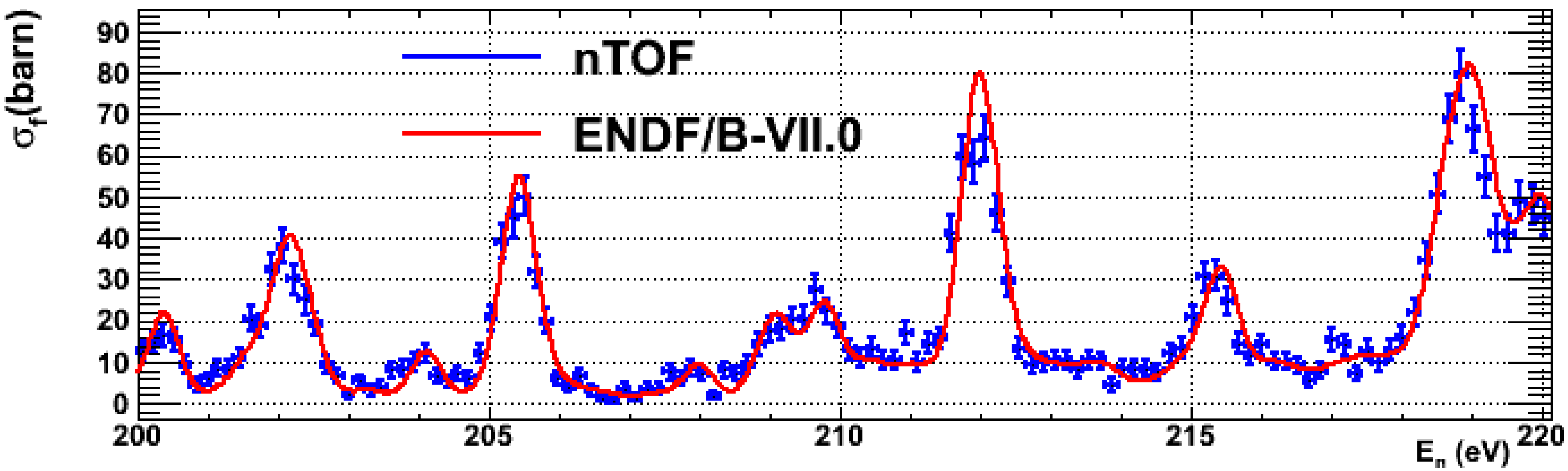
<u>MORE</u> THAN PRELIMINARY



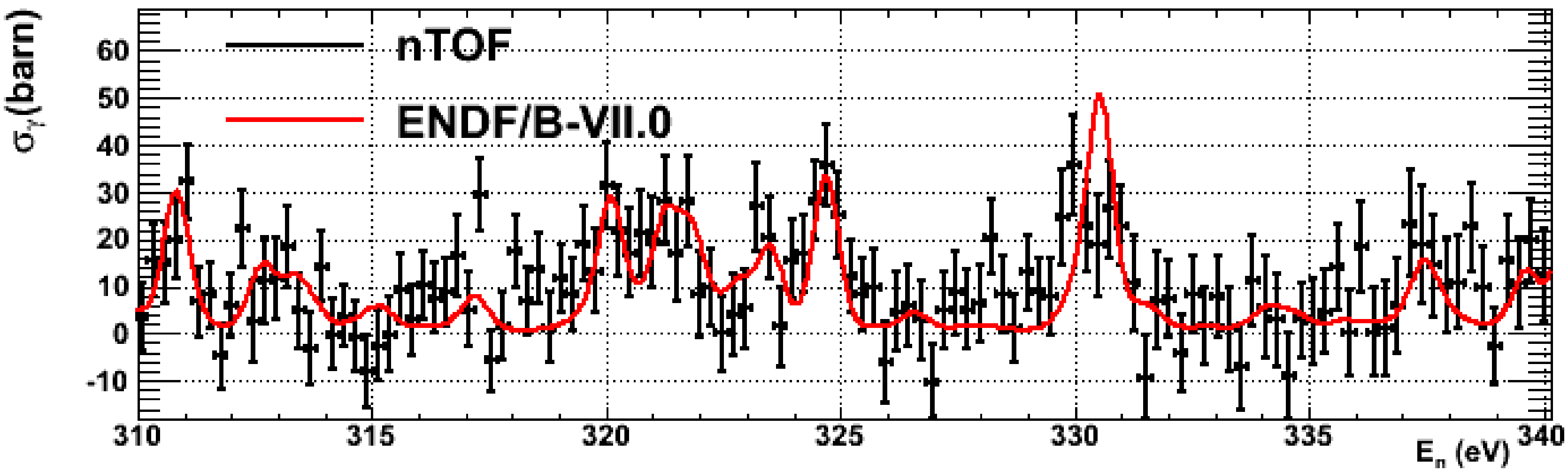
10FTMGAS (v)



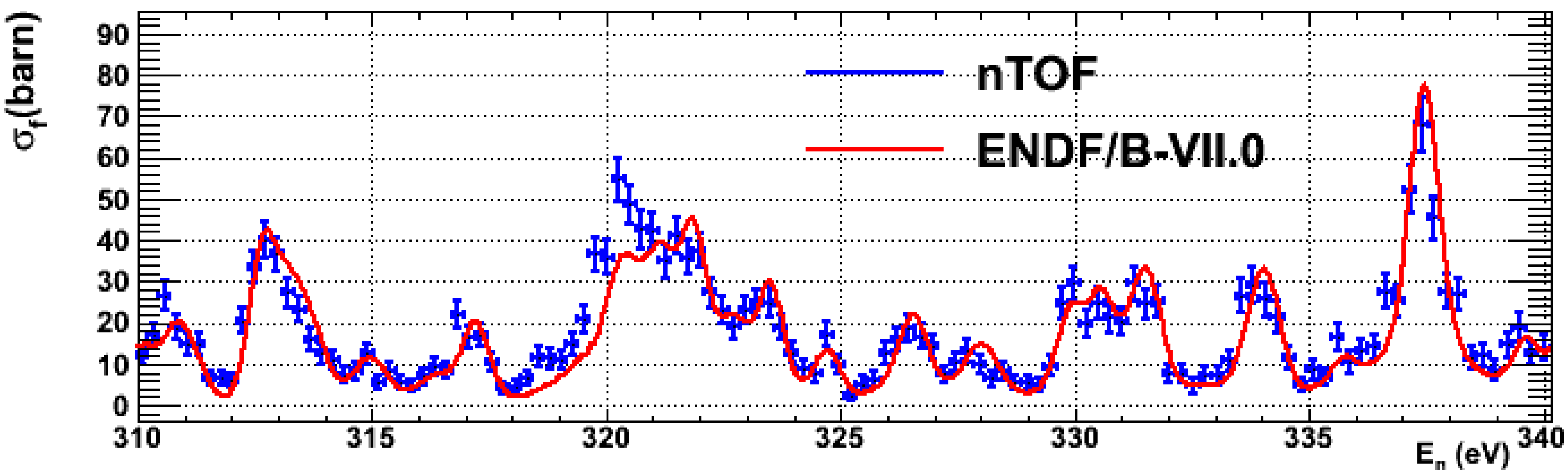
MORE THAN PRELIMINARY



10FTMGAS (v)

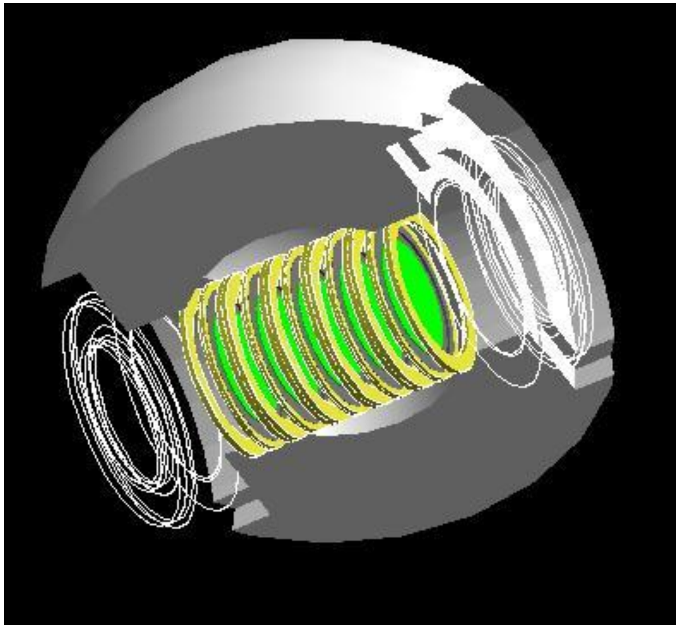


MORE THAN PRELIMINARY



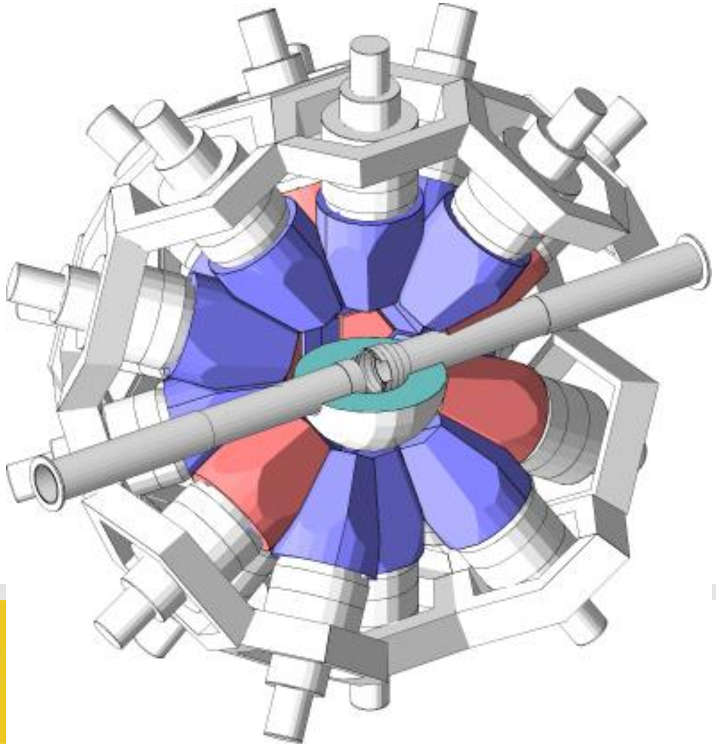
Monte Carlo simulations

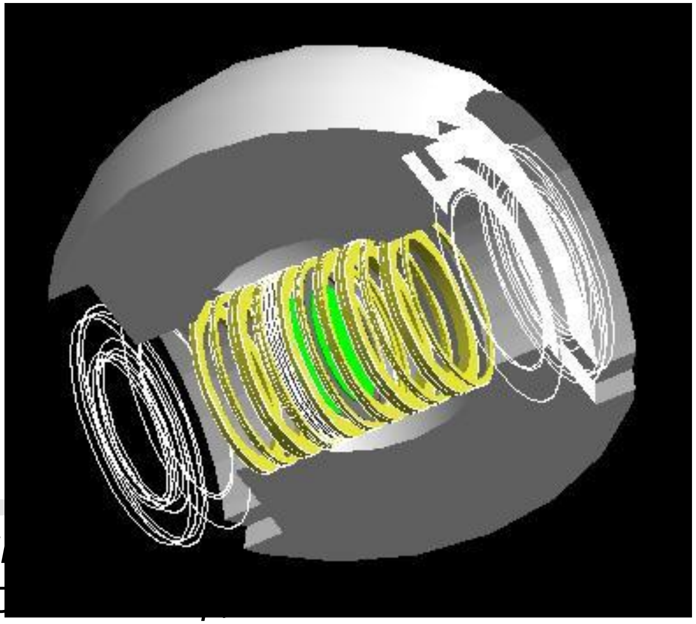
The response of the TAC can be simulated with high accuracy (<3%) by Monte Carlo simulation.



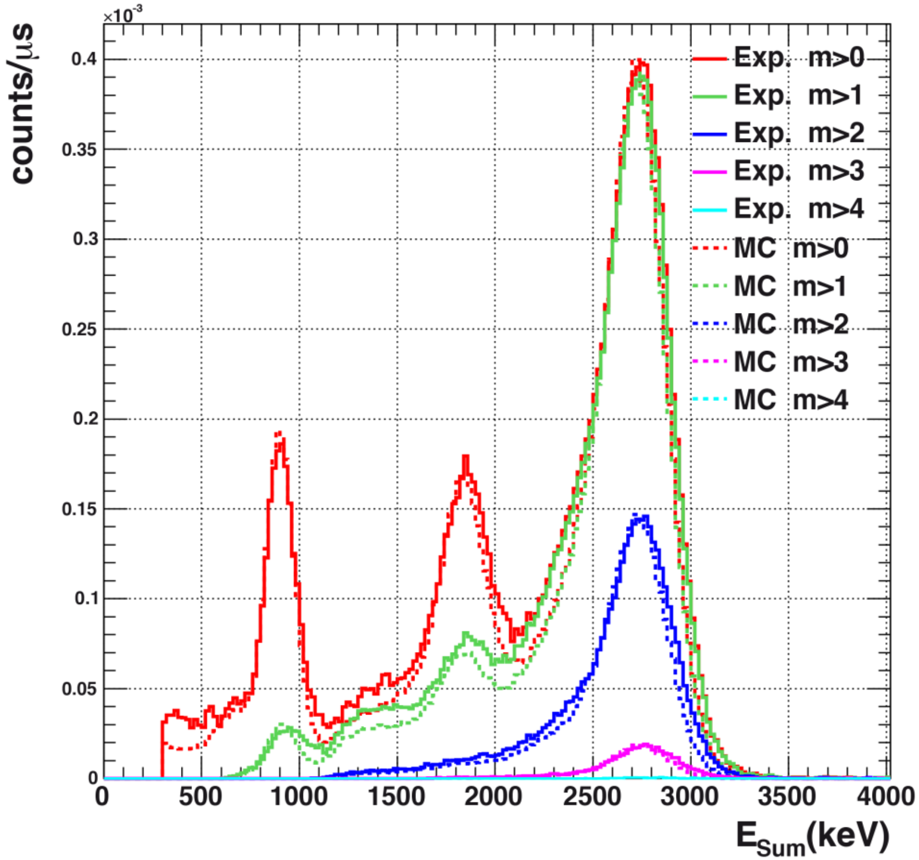
-Detailed modeling and validation of the geometry with known decay schemes (^{137}Cs, ^{88}Y, ^{24}Na…)
-Use of the DECAYGEN code for the simulation of complex (n,γ) EM cascades

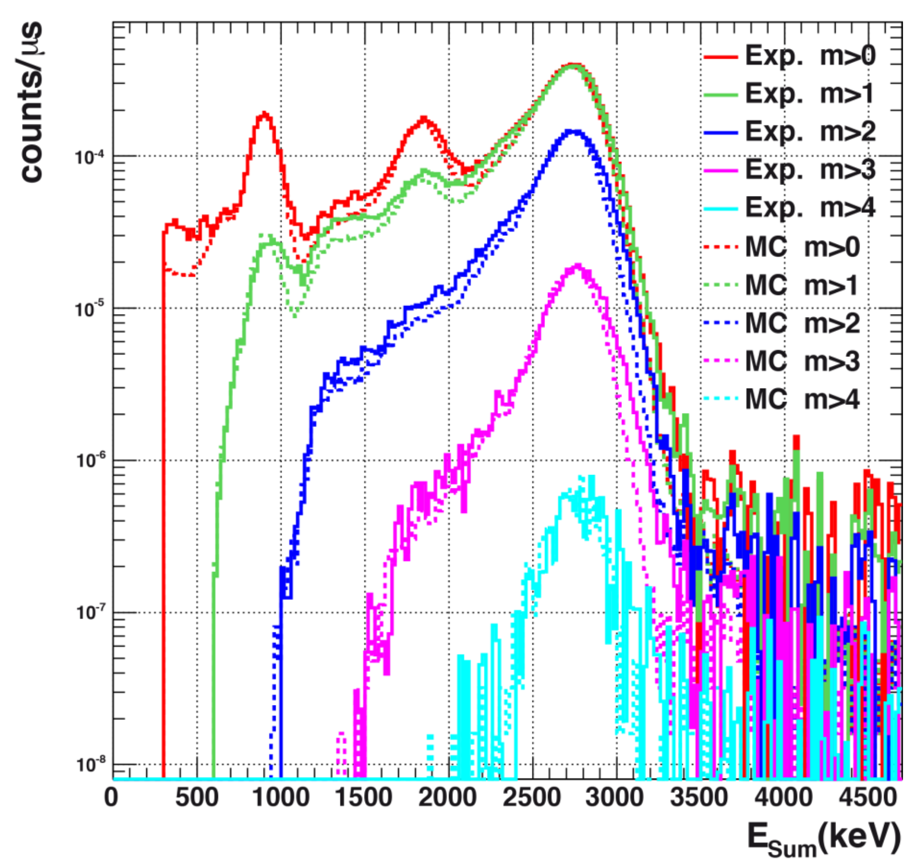
C. Guerrero et al., Nucl. Instr. Meth. A 671 (2012)
J.L.Tain, D.Cano-Ott, Nucl. Instr. Meth. A 571 (2007)





1st validation of the geometry: ^{88}Y decay



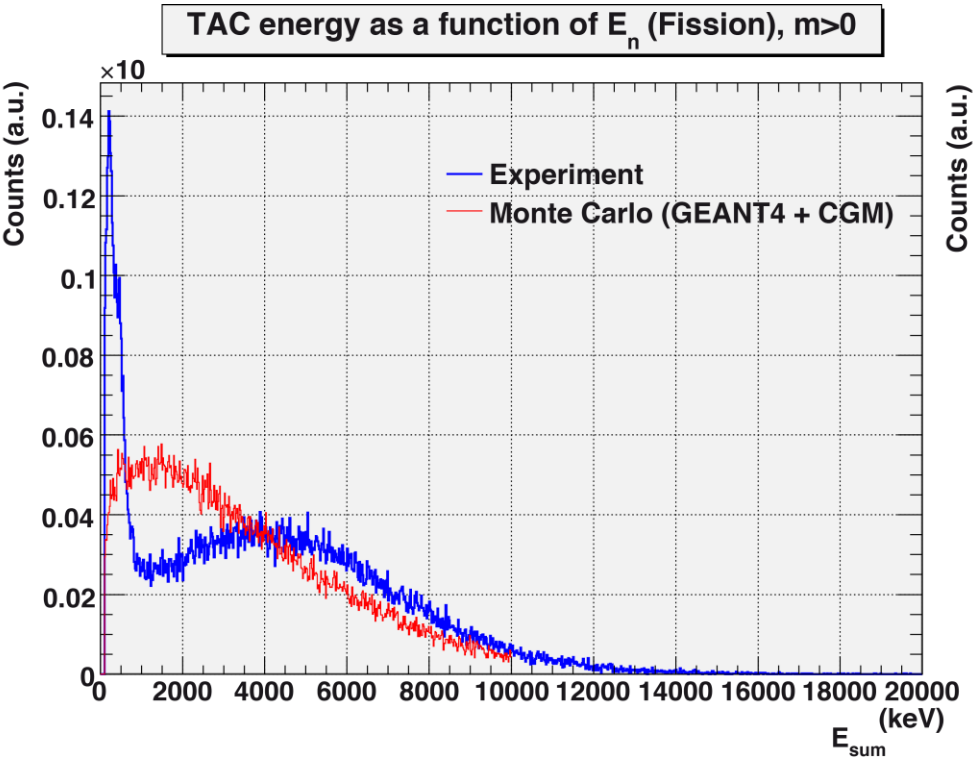


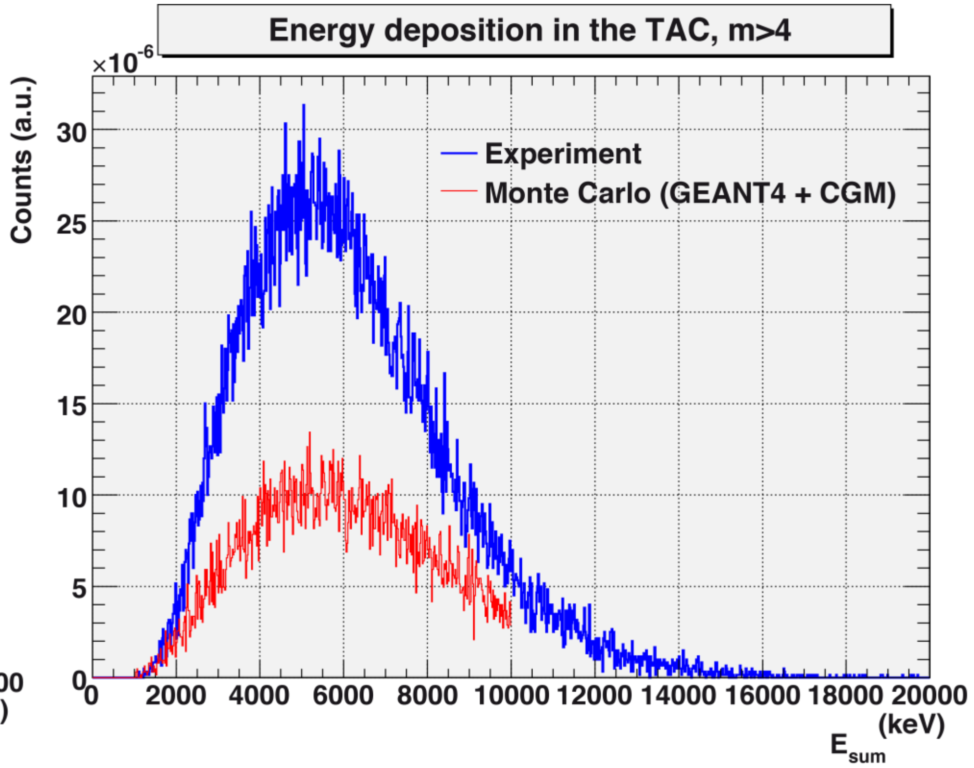
Next:

- Model the capture cascades
- Simulate the response to fission cascades provided by I. Stetcu and T. Kawano (CGM code)

Very preliminary results for the (n,f) EM cascades

A first simulation with the realistic geometry (10FTMGAS) has been performed with the cascades provided by I. Stetcu and T. Kawano (CGM code).





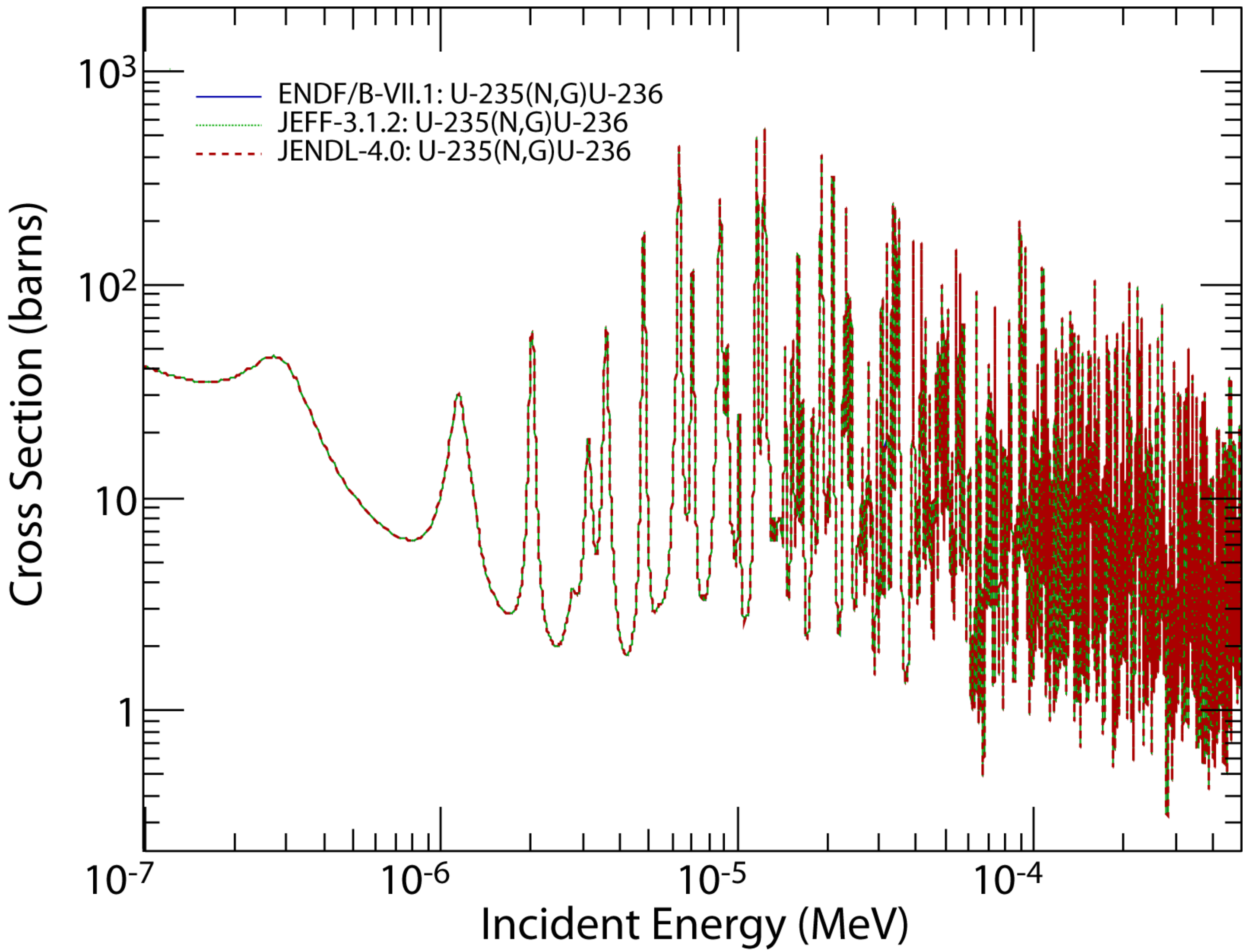
Summary and conclusions

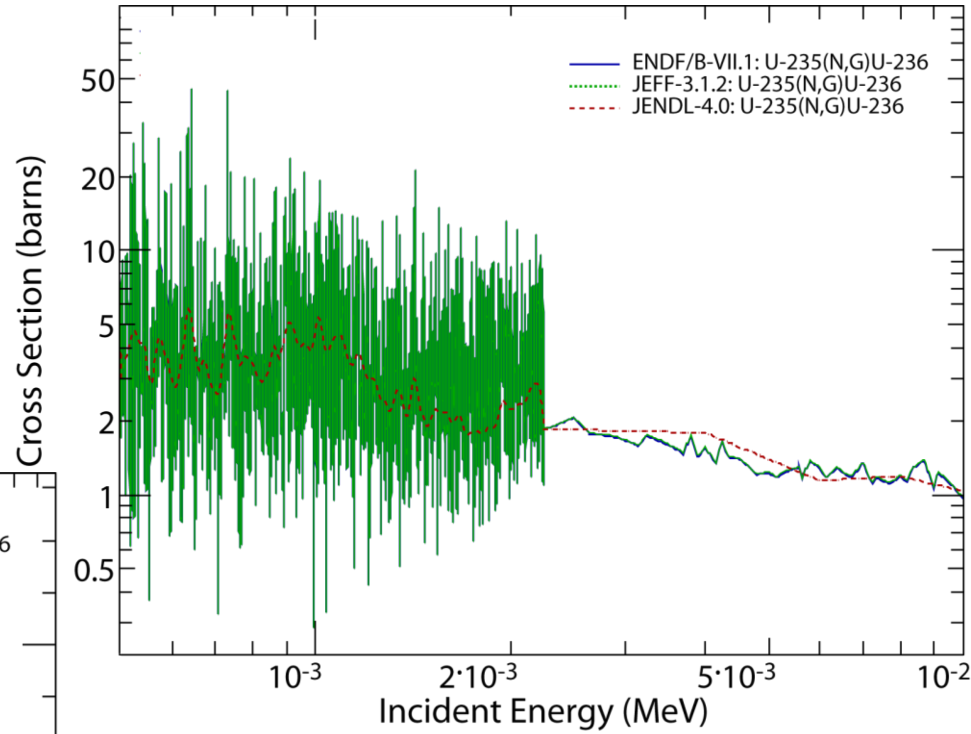
We have measured at n_TOF the $^{235}U(n,\gamma)$ cross section (ERINDA PAC3/1) with two different setups:

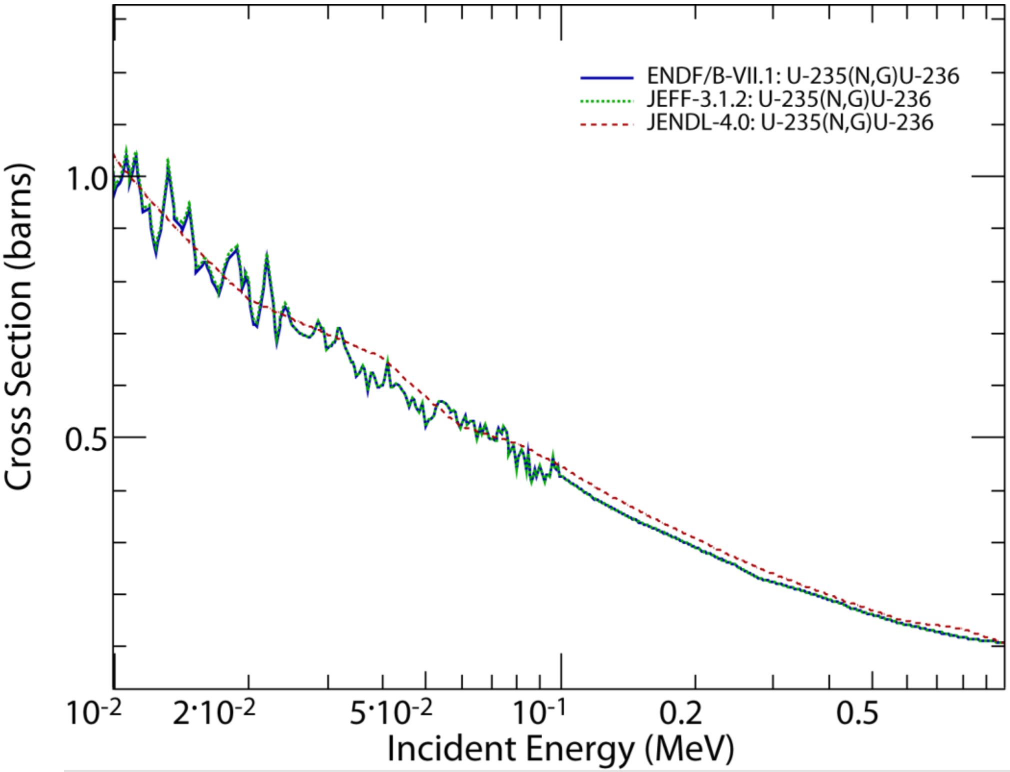
•10 Fission tagging micromegas (90% efficiency)
•2 Fission tagging micromegas (20% efficiency)

The sources of systematic uncertainties will be evaluated by performing various independent analyses:
-normalization relying on pure experimental & Monte Carlo numbers: ε_{TAC}, ε_{FTMGAS}, $\Phi(E_n)$.
-Comparison to evaluated files in different energy ranges
-Comparison of the 2 and 10 FTMGAS data sets

The measurement has produced as well low resolution data on the prompt fission γ-rays that will be compared to Monte Carlo simulations (γ-ray distributions from the CGM code).


ENDF/B-VII.1: U-235(N,G)U-236
JEFF-3.1.2: U-235(N,G)U-236
JENDL-4.0: U-235(N,G)U-236
Cross Section (barns)
10^3
10^2
10
1
10^-7
10^-6
10^-5
10^-4
Incident Energy (MeV)





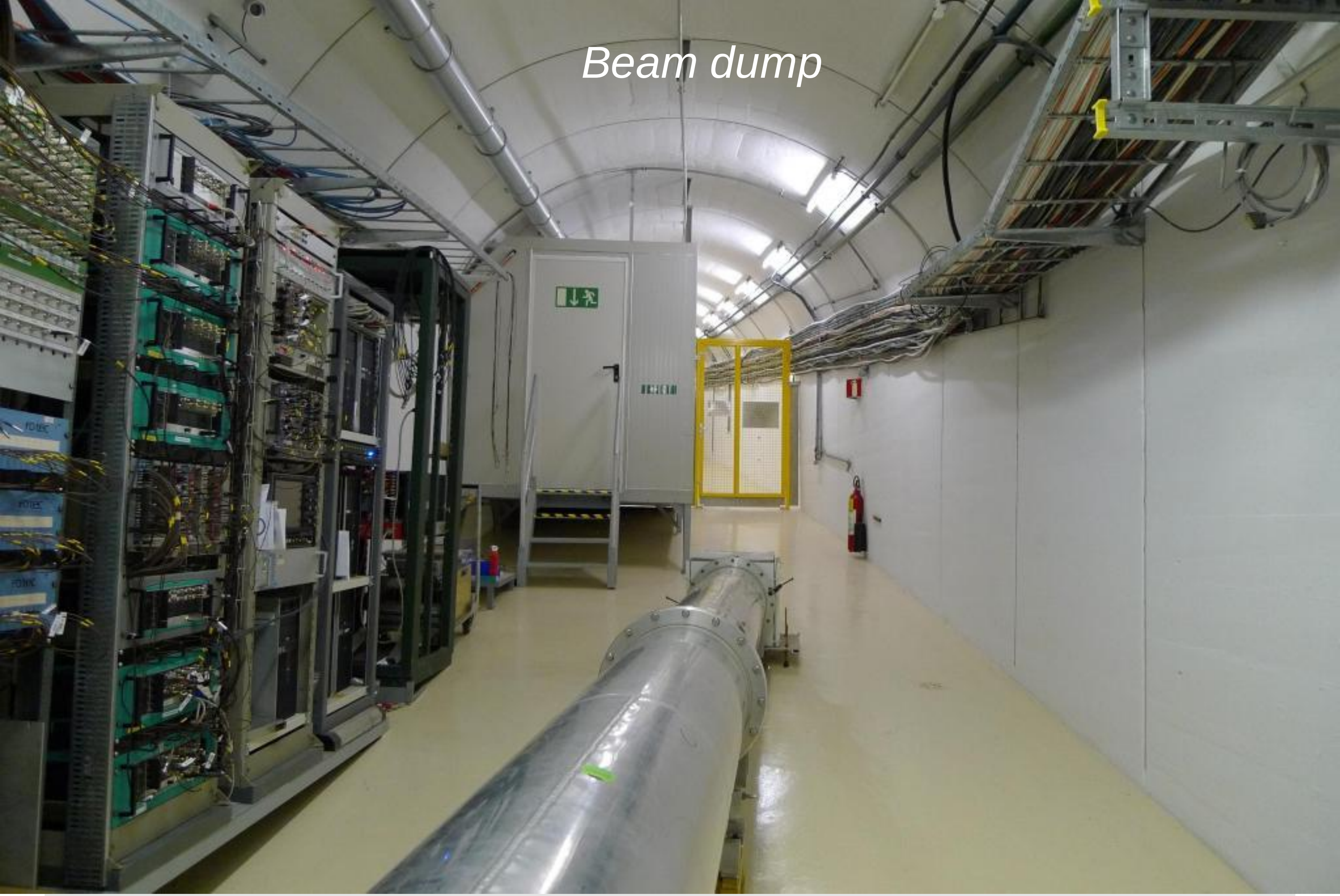
Enrique M. Gonzalez
ERINDA Workshop, Oct. 2013

Type A experimental area (non-certified radiactive samples)


RADIATION
ZONE CONTRÔLÉE
CONTROLLED AREA
LIMITED STAY
SEJOUR LIMITE
Material entrance
Entrée matériel
Changing room
Vestiaire

Dressing room

Beam dump



GOBIERNO DE ESPAÑA

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Ciemat

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Enrique M. Gonzalez

Fully digital DAQ