CERN

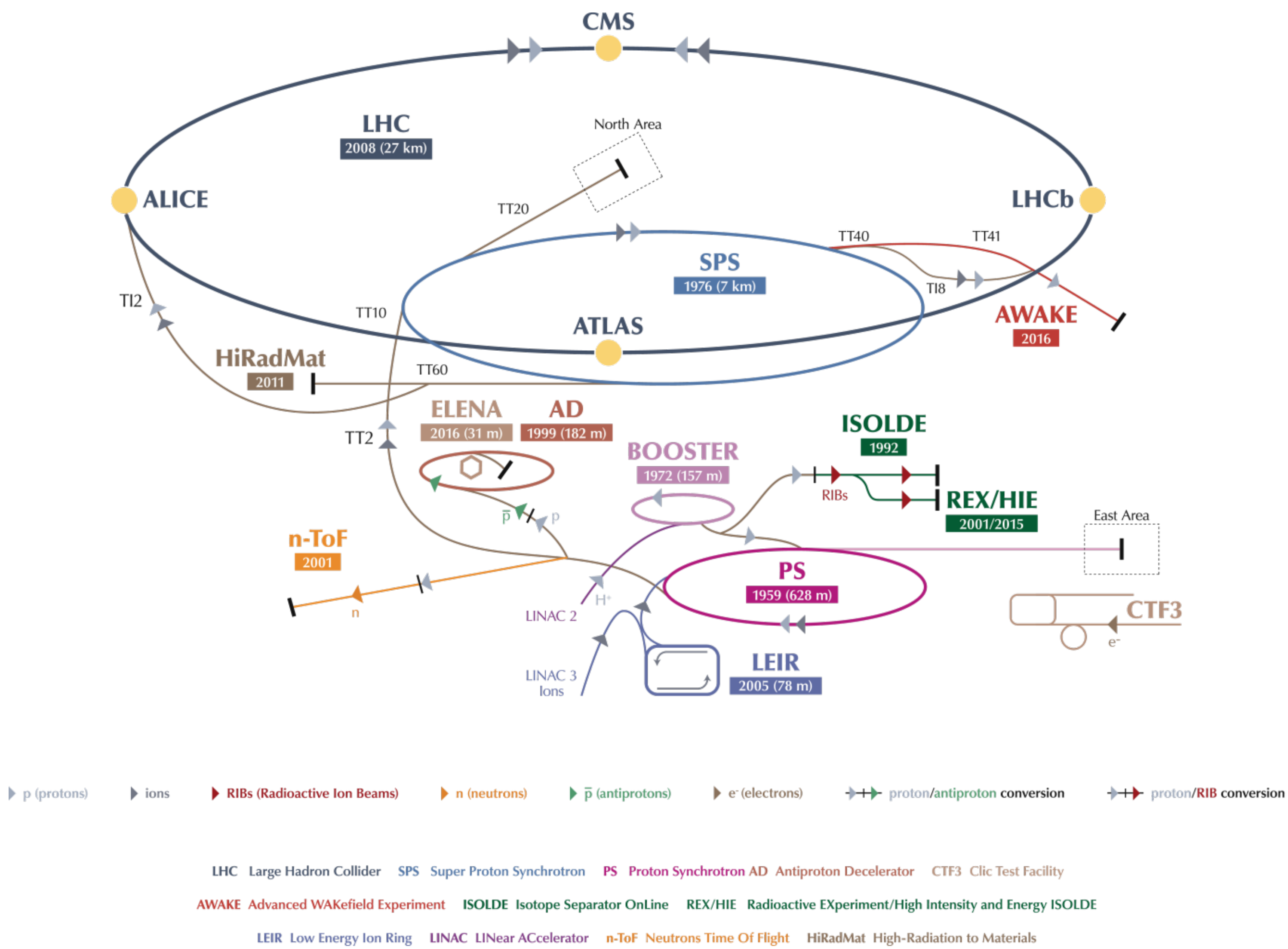
Neutron-induced fission measurements at the CERN n_TOF facility

A. Tsinganis (European Organisation for Nuclear Research, CERN)
on behalf of the n_TOF Collaboration

FIESTA 2017, September 17-22, Santa Fe


LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km
CERN

The CERN accelerator complex



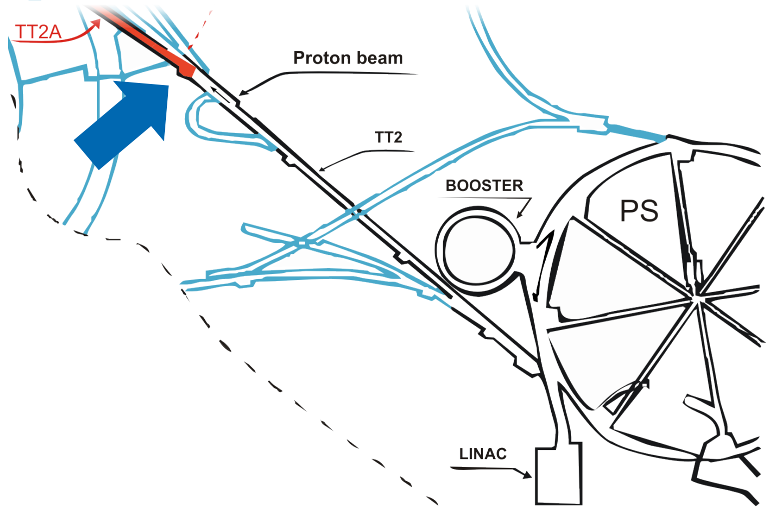
Outline

- The n_TOF facility
  - Neutron production
  - Experimental areas
- Detectors for fission
- Recent activities and the near future
  - Recent results
  - Some interesting problems
  - Planned measurements

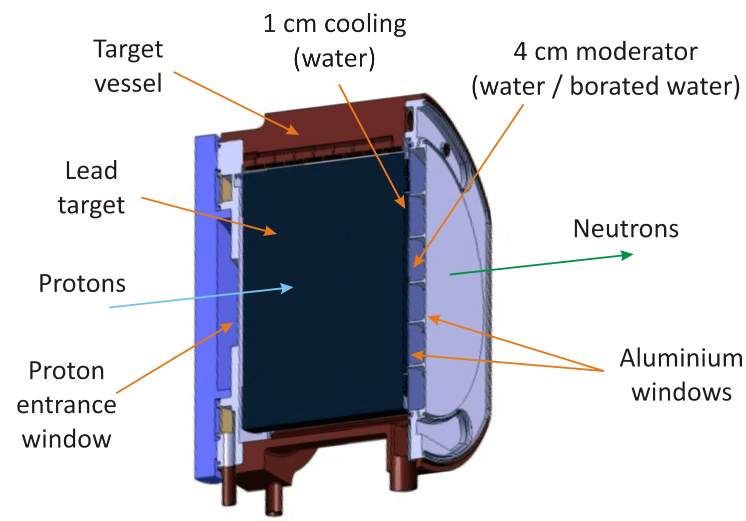
The n_TOF facility

n_TOF: a spallation neutron source

- Pulsed 20 GeV proton beam provided by the CERN PS
  - 7-8x10^{12} protons per bunch
  - 7 ns r.m.s.
  - Low repetition rate (<0.8 Hz)
  - No neutron bunch overlap

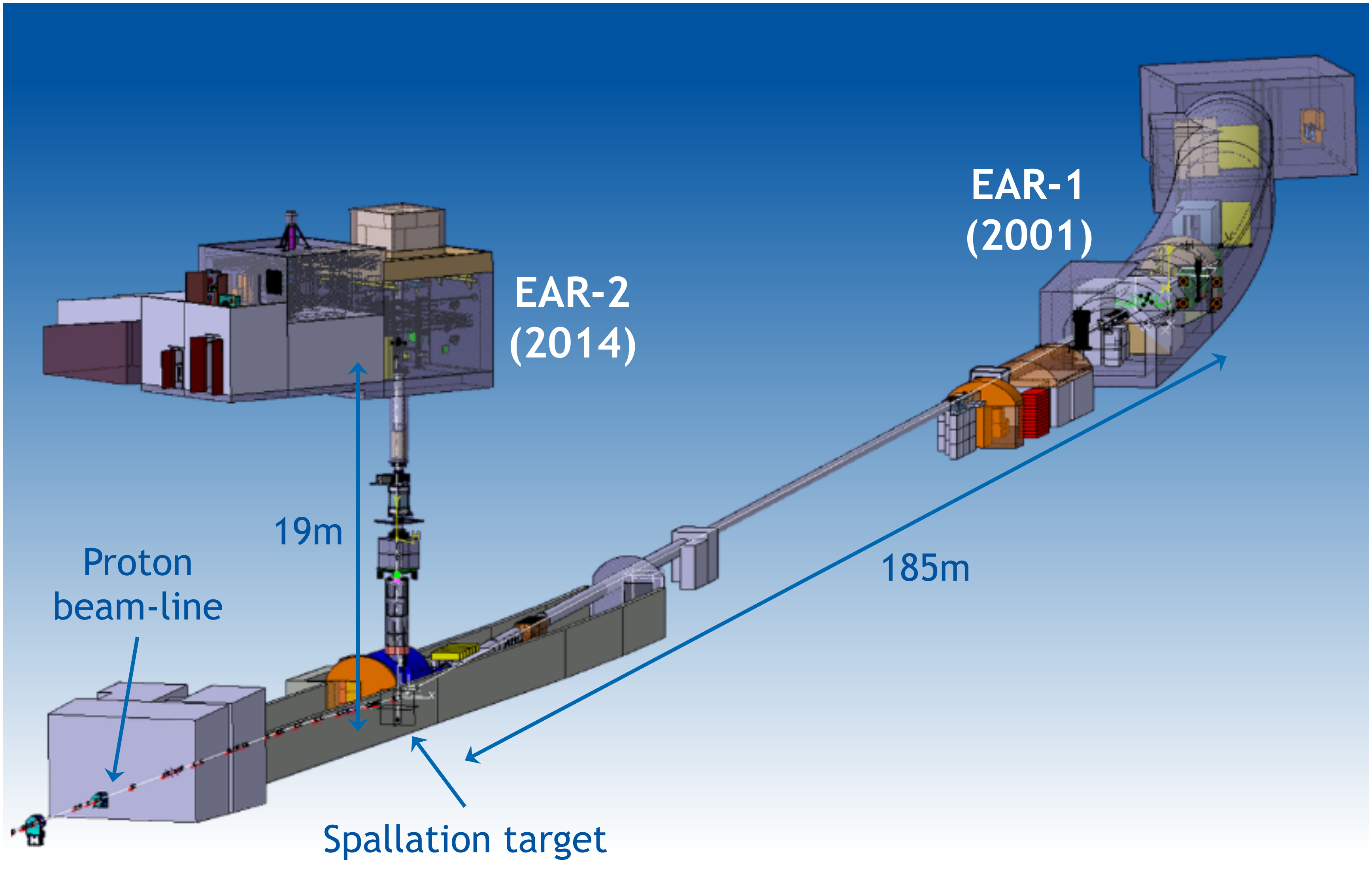


- Water-cooled lead target (40 cm length, 60 cm diameter)
  - Cooling layer (1 cm)
  - Moderator layer (4 cm)
    - H_2O (demineralised water)
    - H_2O + H_3BO_3 (boric acid, enriched in ^{10}B)

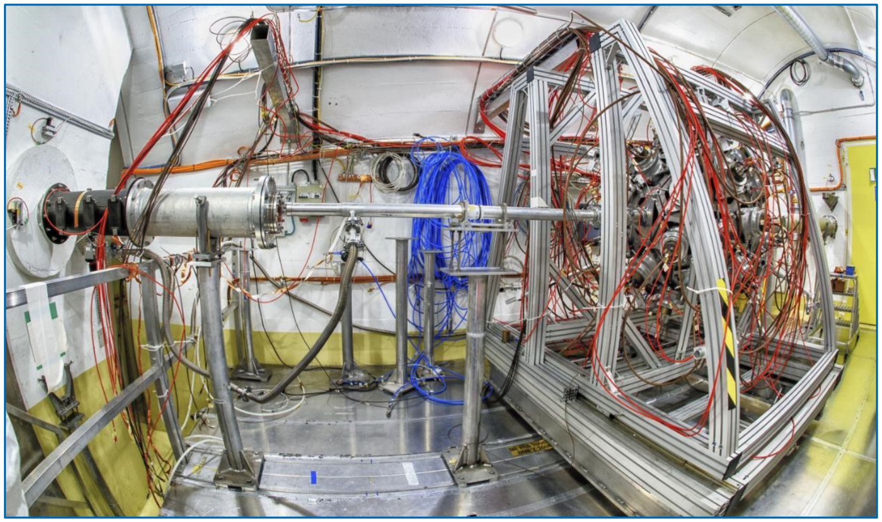


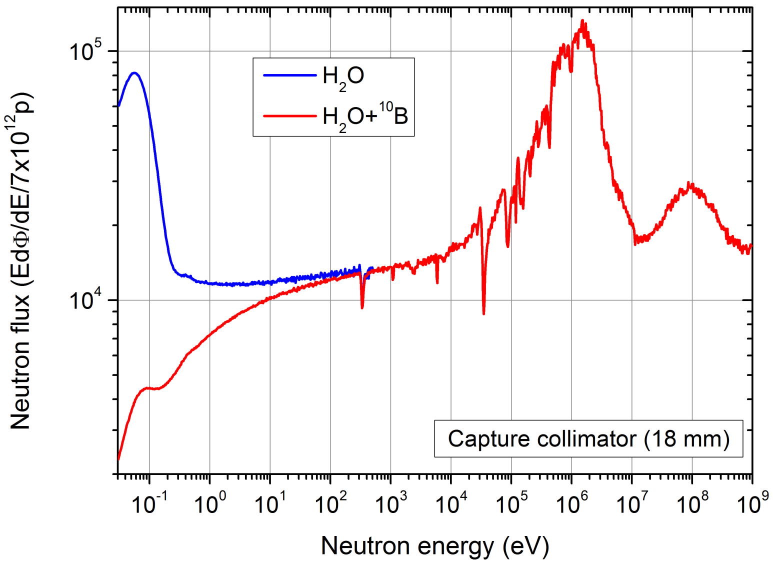
- High instantaneous flux
- Wide energy range (thermal to GeV)

n_TOF: global view

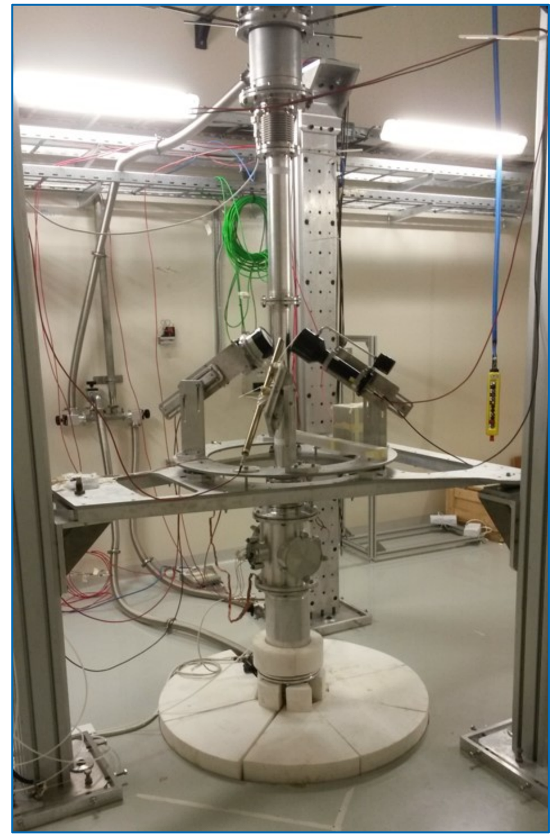


Experimental Area I (EAR-1)

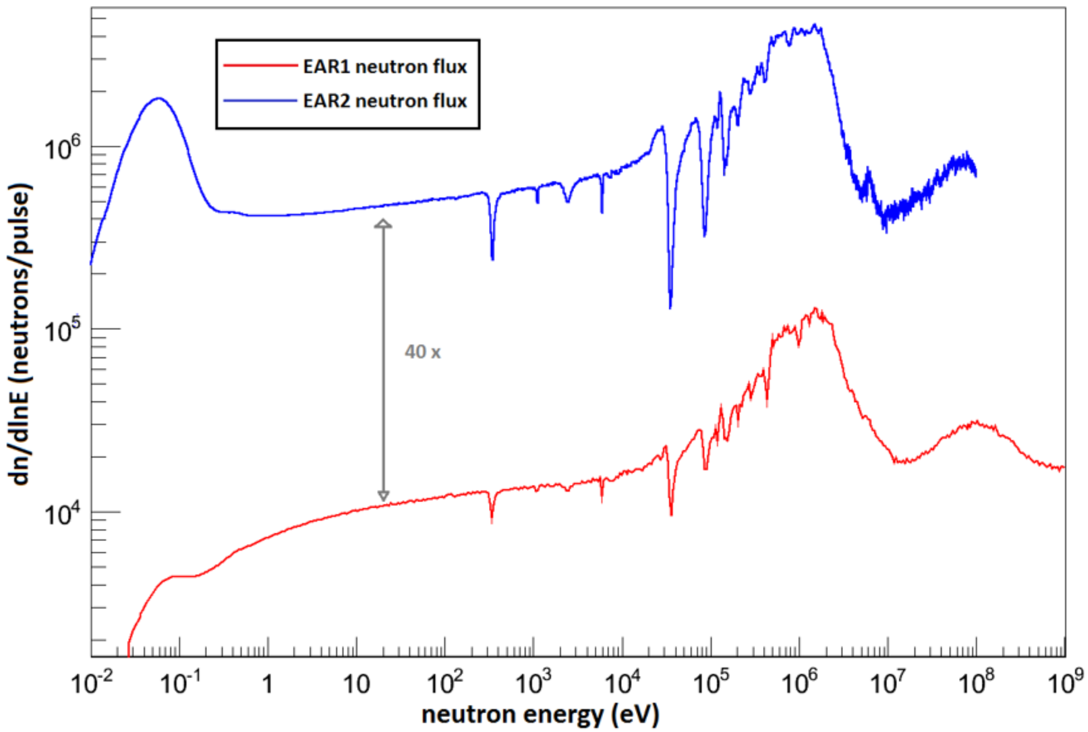




Experimental Area II (EAR-2)



Experimental Area II (EAR-2)

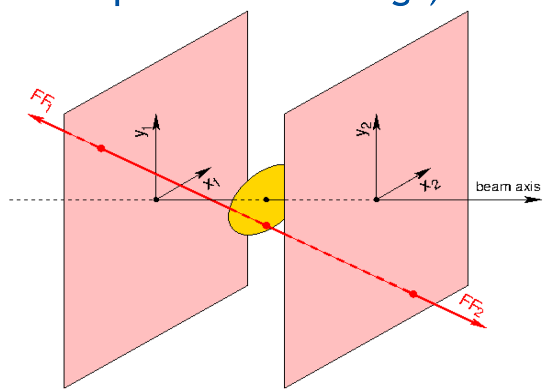


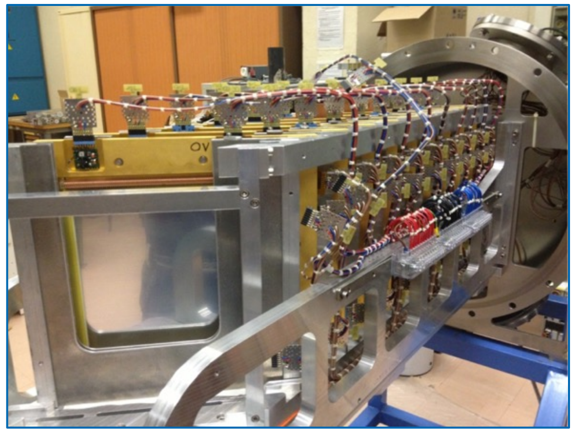
- ~40 times higher flux, ~10 times shorter bunch
  - 400 times higher instantaneous flux
  - Stronger background suppression!
- Few neutrons above 100 MeV (90^o wrt proton beam)

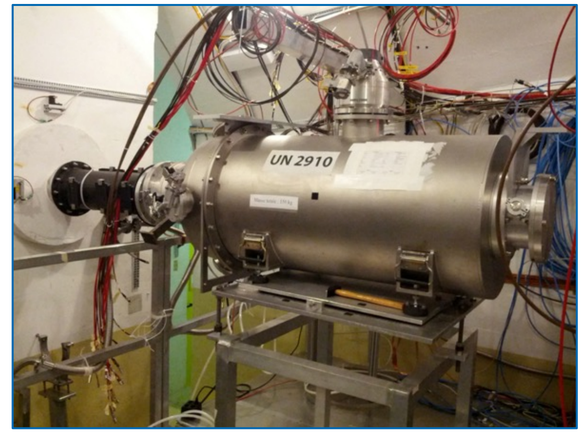
Detectors for fission

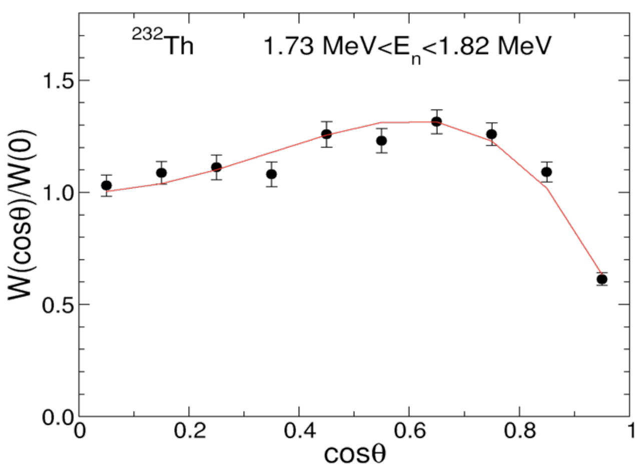
Parallel Plate Avalanche Counters (PPAC)

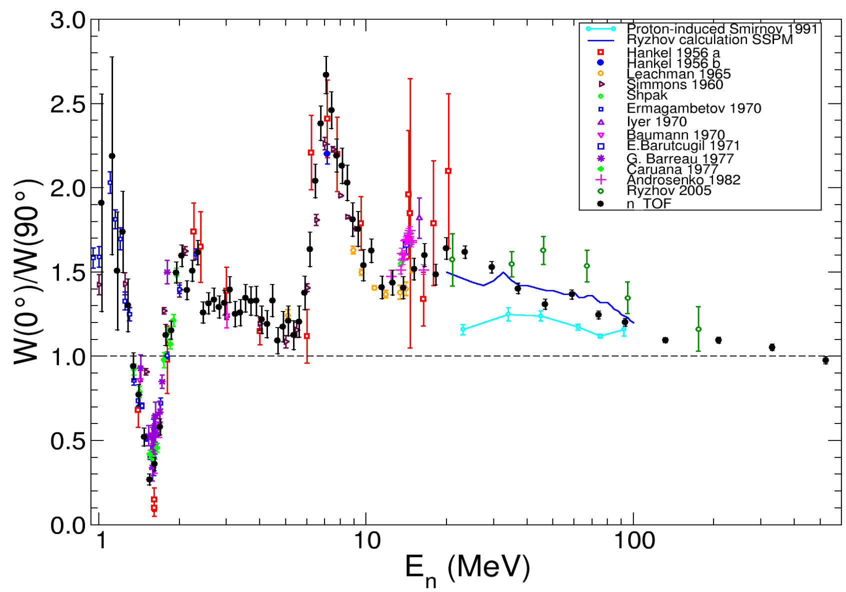
- Fission fragments detected in coincidence (very thin samples and backings)





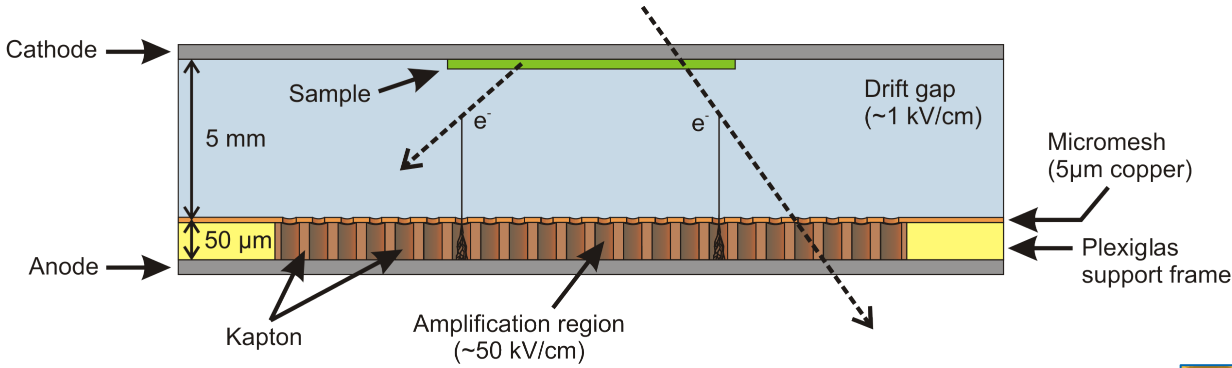


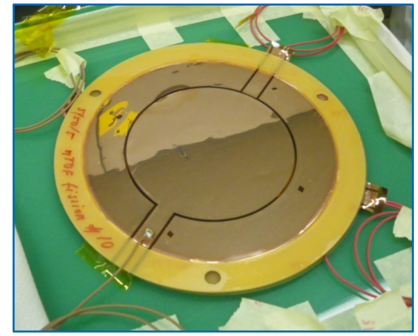


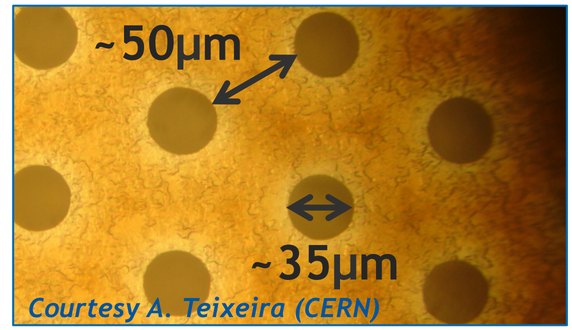


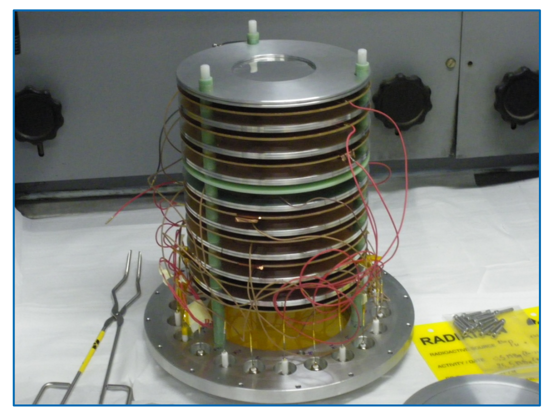
See talk by E. Leal-Cidoncha

Micromegas detectors





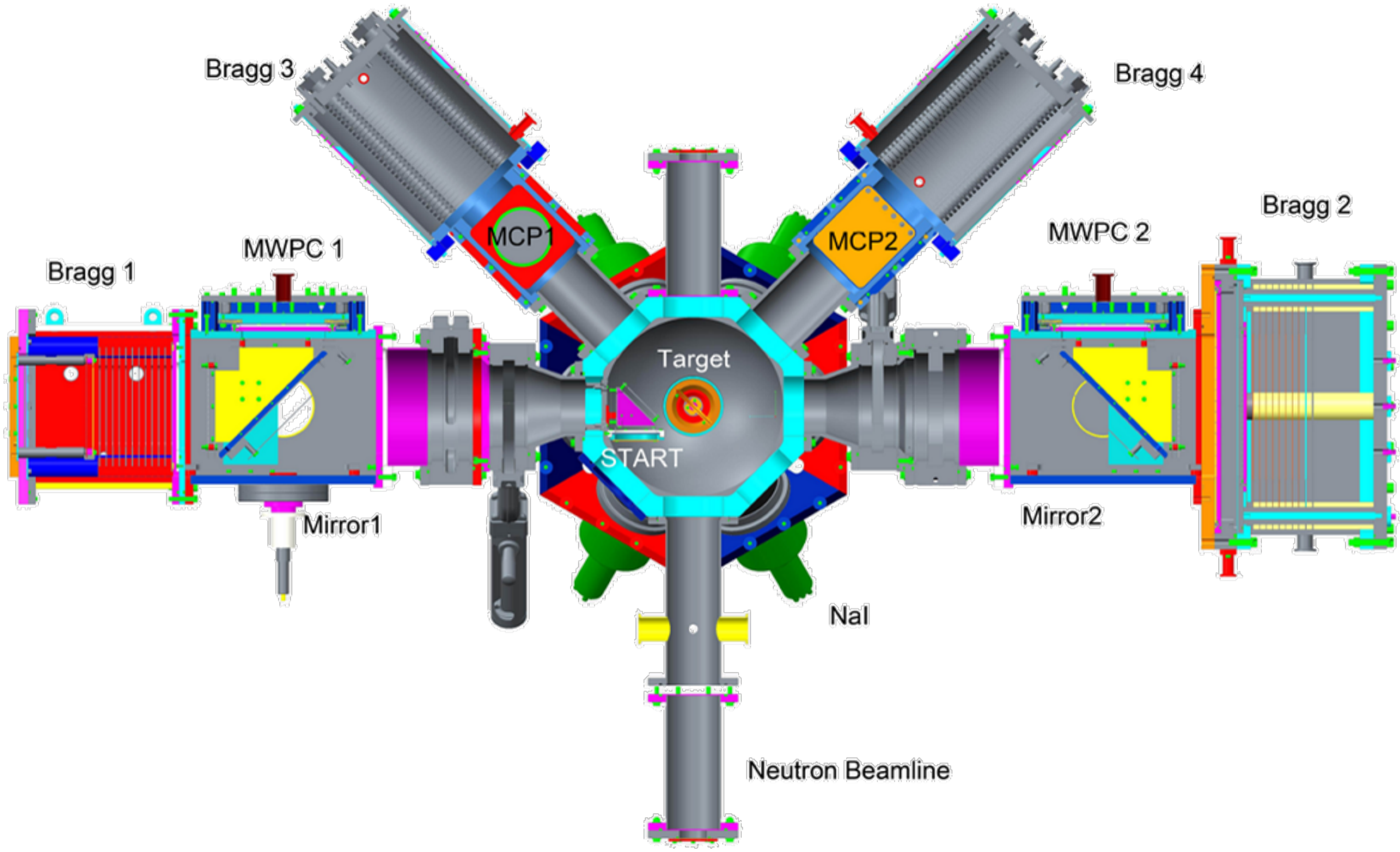




- **MICRO-MEsh GAseous Structure**
- "Microbulk" variant
  - Low amount of material to minimise neutron interactions
- Drift space
  - Primary ionisation and charge drift
- Micromesh
- Amplification region
  - Charge multiplication and read-out

STEFF: Spectrometer for Exotic Fission Fragments

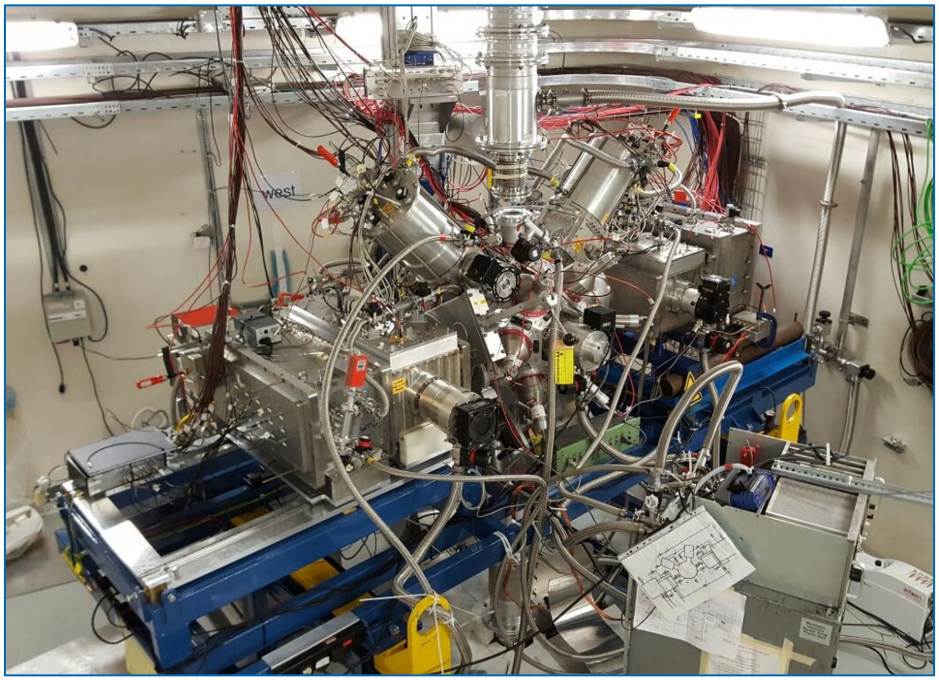
- Detection & characterisation of FFs in coincidence with γ-rays

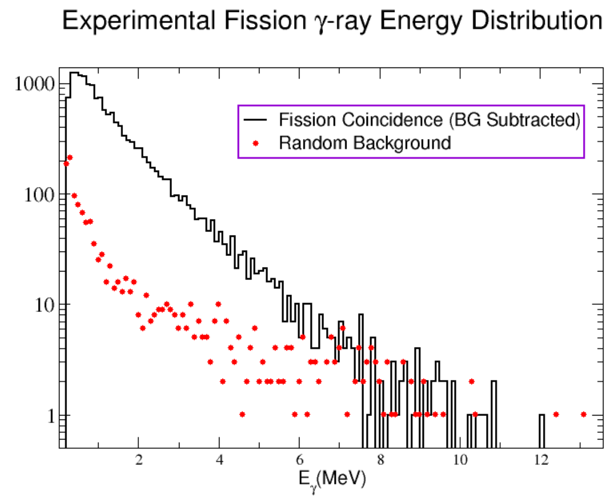


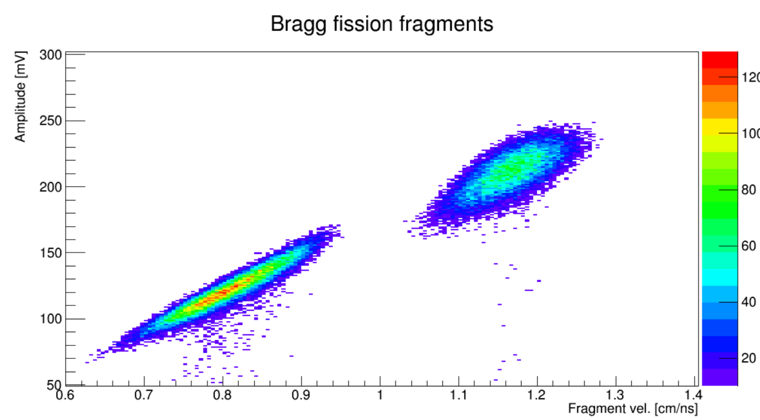
Courtesy: G. Smith

STEFF: Spectrometer for Exotic Fission Fragments

- Installed in EAR-2 (2015): measurement of ^{235}U prompt fission γ-ray spectra
- Very strong background rejection capabilities (S/B~0.001)



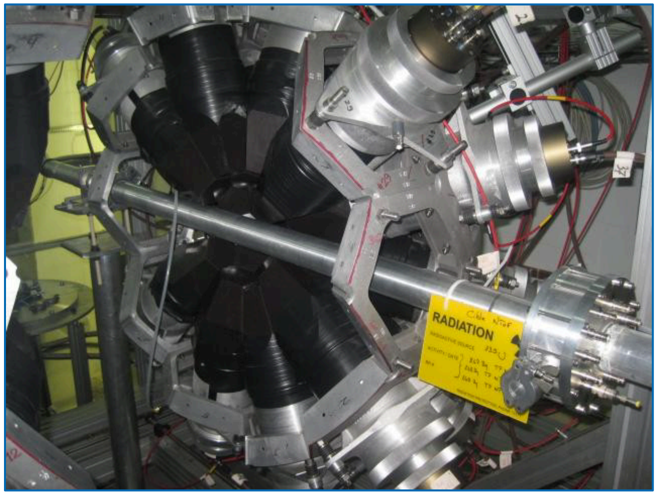


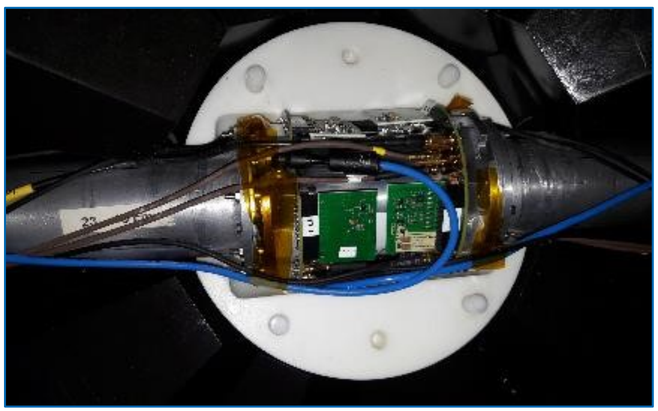


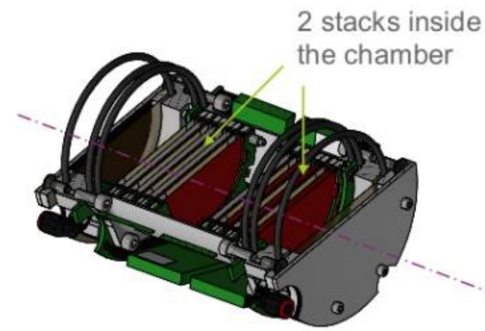
Courtesy: G. Smith

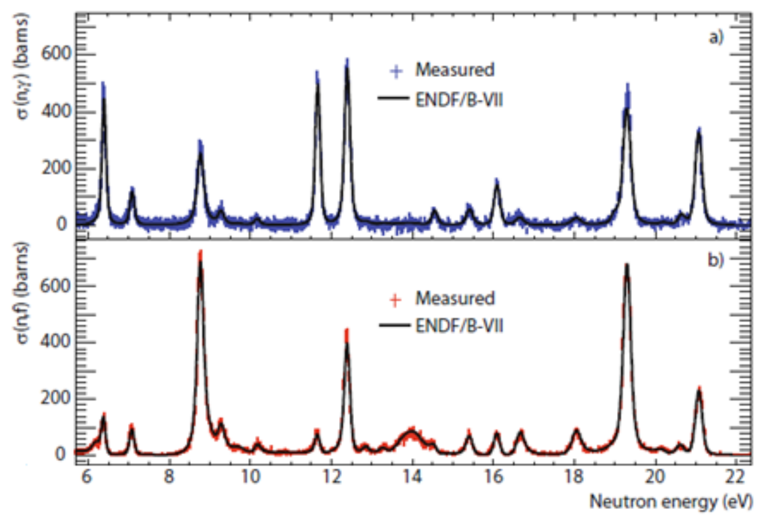
Simultaneous measurement of (n,γ), (n,f) cross-section

- Capture of fissile isotopes (^{235}U, ^{233}U, ^{239}Pu, ^{241}Pu…)
- Fission chamber placed inside Total Absorption Calorimeter (TAC)







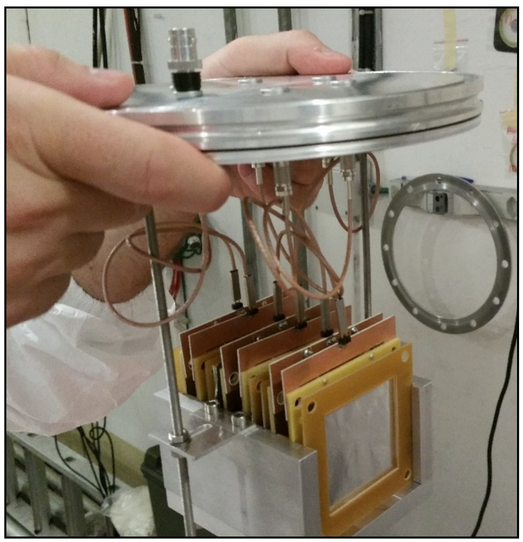


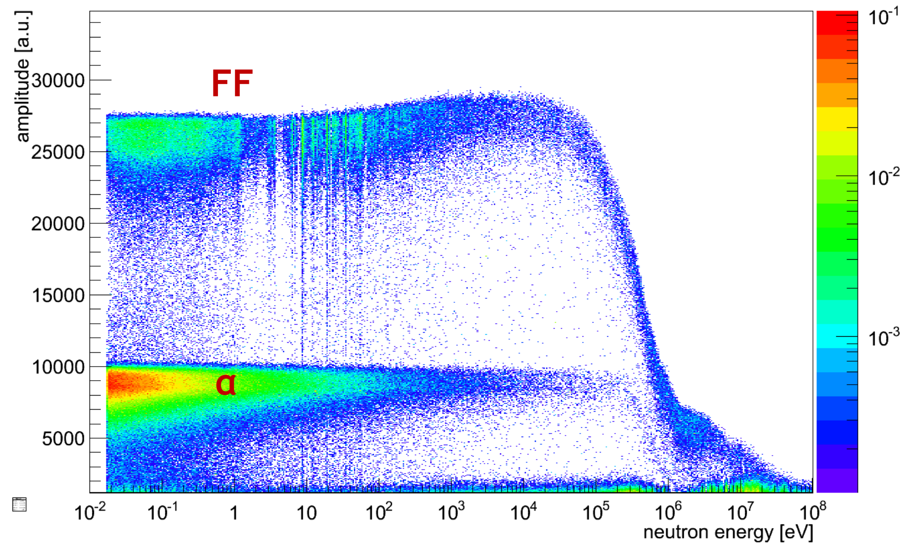
Courtesy: M. Bacak, M. Diakaki

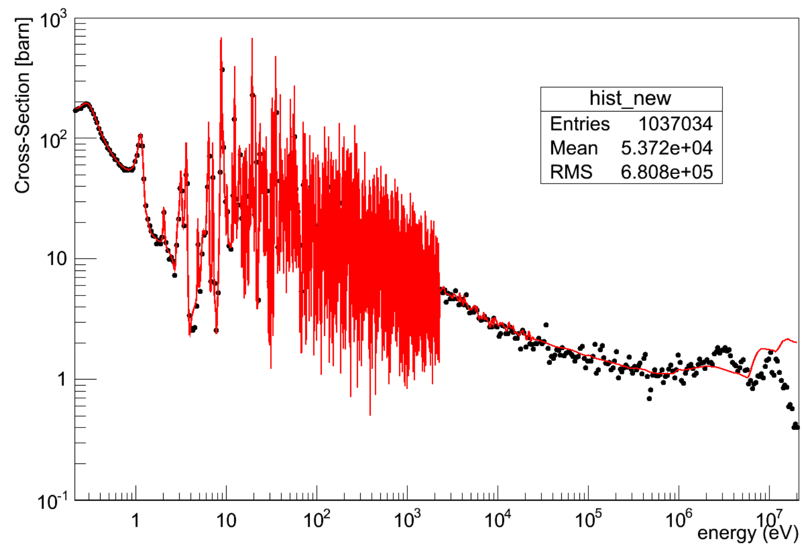
C. Guerrero et al., Eur. Phys. J. A (2012) 48:29

Si detectors for fission

- In-beam Si detector stack (5x5 cm^2 and 200 μm thickness)
- New measurement of $^{235}U(n,f)$ with respect to $^{6}Li(n,t)$ and $^{10}B(n,a)$ (focus on 10-30keV region)
- OK up to ~1MeV, further analysis ongoing



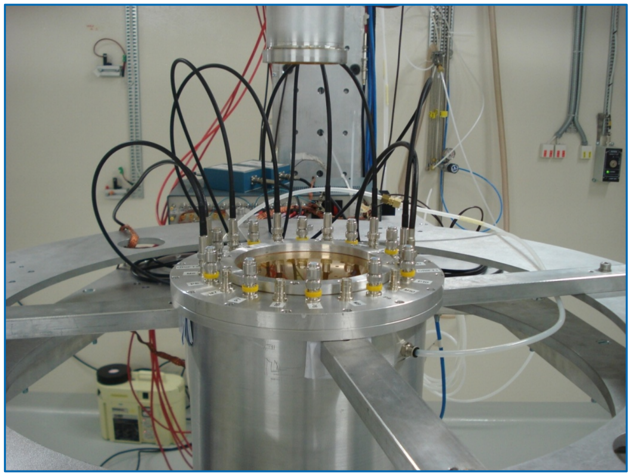




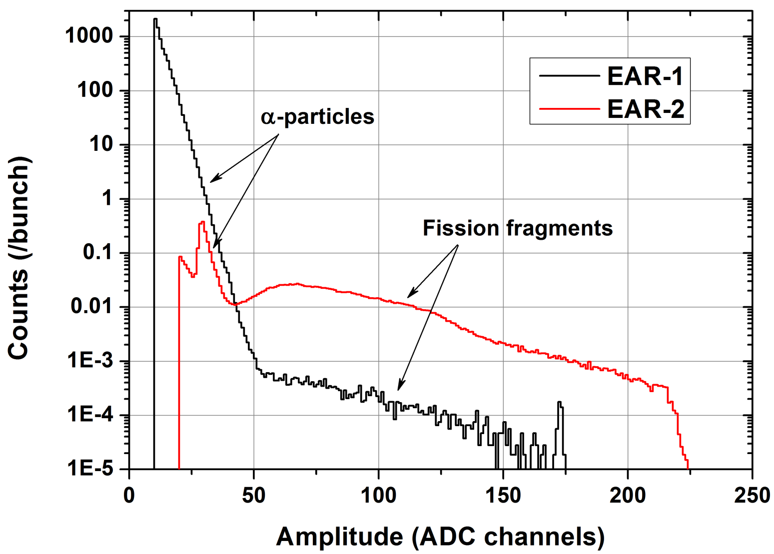
Courtesy: M. Barbagallo

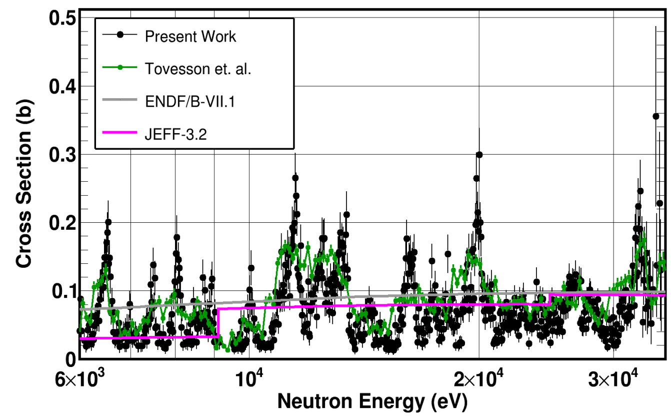
Recent activities and the near future

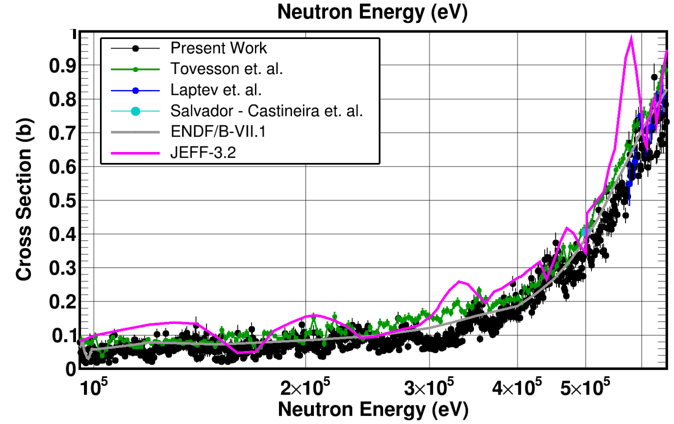
$^{240}Pu(n,f)$: making use if EAR-2



- First measurement performed in EAR-2
- Previously attempted in EAR-1
  - Comparison shows the benefits of the higher flux and better background suppression



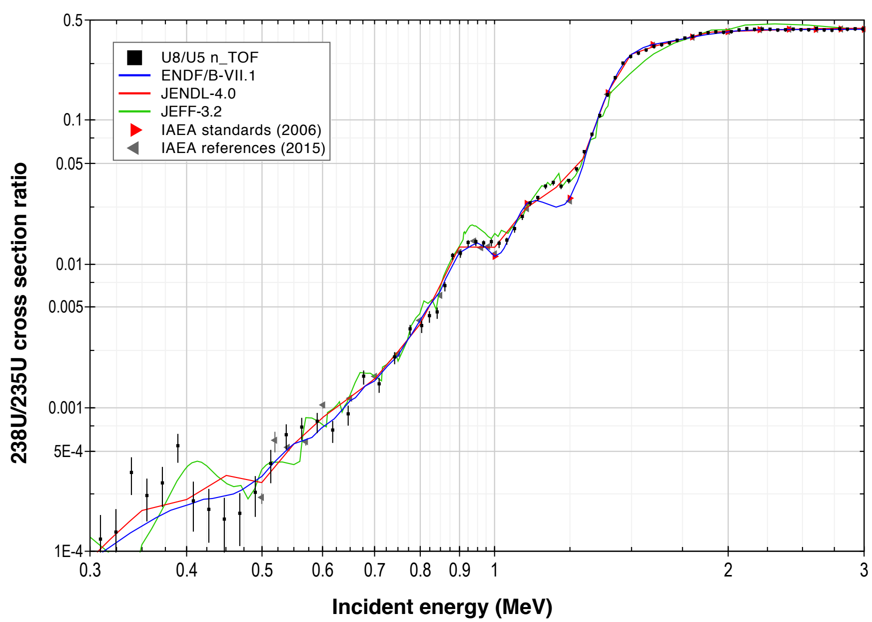




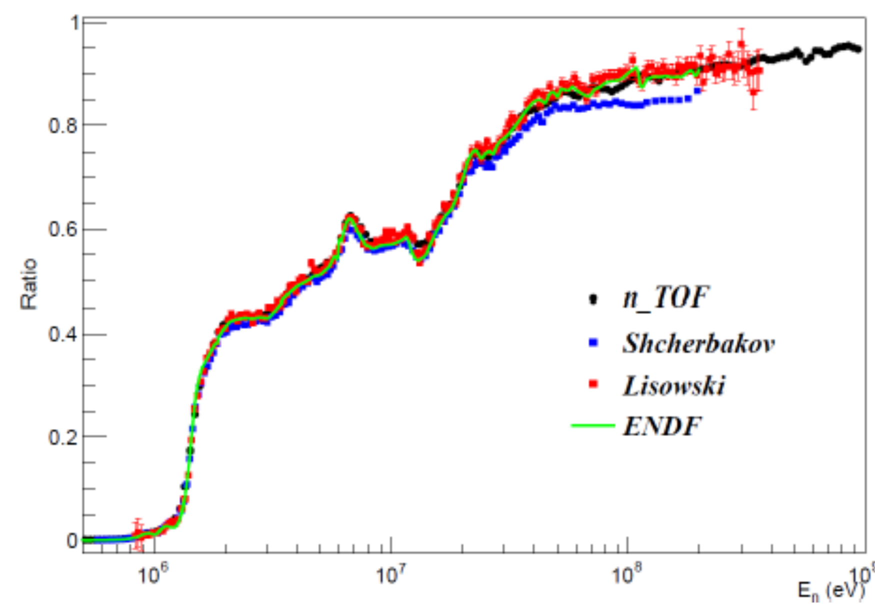
Courtesy: A. Stamatopoulos

The $^{238}U(n,f)/^{235}U(n,f)$ ratio up to 1 GeV

- Five datasets collected and compared (different detectors and techniques)
- Ratio extended to 1 GeV
- Some deviations from major libraries observed
- Statistics will be increased with EAR-2 data

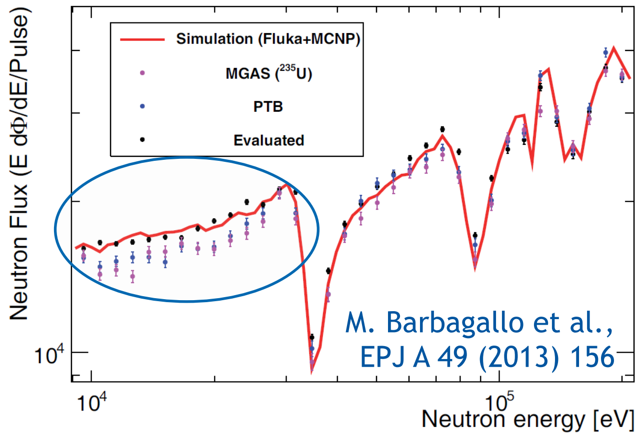


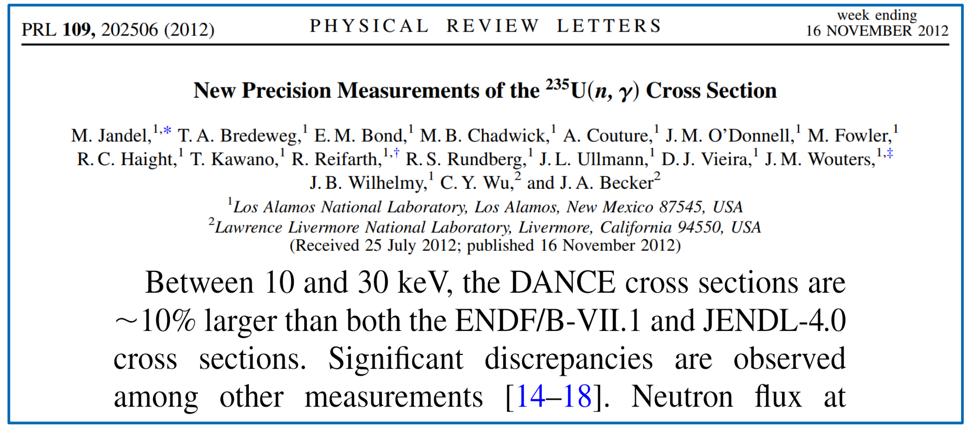
*M. Diakaki et al., EPJ Web of Conferences **111**, 02002 (2016)*



C. Paradela et al., Phys. Rev C 024602 (2015)

The ^{235}U(n,f) cross-section at 10-30 keV





PRL 109, 202506 (2012) PHYSICAL REVIEW LETTERS week ending 16 NOVEMBER 2012

New Precision Measurements of the ^{235}U(n, γ) Cross Section

M. Jandel,[1,*] T. A. Bredeweg,[1] E. M. Bond,[1] M. B. Chadwick,[1] A. Couture,[1] J. M. O'Donnell,[1] M. Fowler,[1] R. C. Haight,[1] T. Kawano,[1] R. Reifarth,[1,†] R. S. Rundberg,[1] J. L. Ullmann,[1] D. J. Vieira,[1] J. M. Wouters,[1,‡] J. B. Wilhelmy,[1] C. Y. Wu,[2] and J. A. Becker[2]

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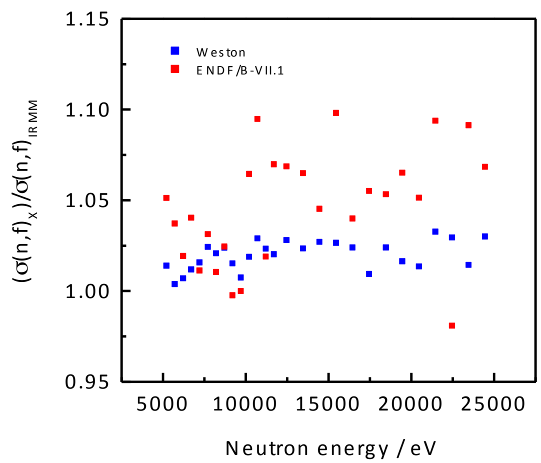
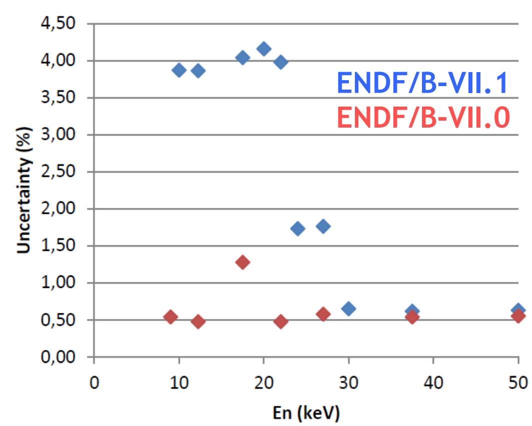
(Received 25 July 2012; published 16 November 2012)

Between 10 and 30 keV, the DANCE cross sections are ~10% larger than both the ENDF/B-VII.1 and JENDL-4.0 cross sections. Significant discrepancies are observed among other measurements [14–18]. Neutron flux at

- Flux obtained with ^{235}U(n,f) systematically lower than expected in the 10-30 keV range (independently of detection system used)
- **Hypothesis: the fission cross-section in this range could be overestimated by 6-8%**
- 10% difference attributed to ^{235}U(n,γ) cross-section in LANL measurement could instead be explained by overestimation of fission cross-section
- Additional evidence from IRMM
- Uncertainty in ENDF increased between versions VII.0 and VII.1

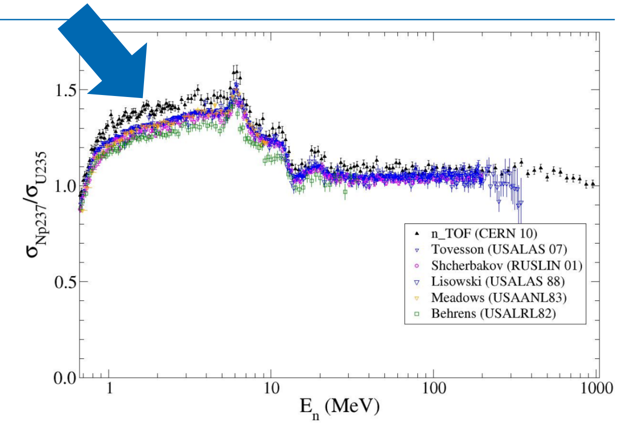


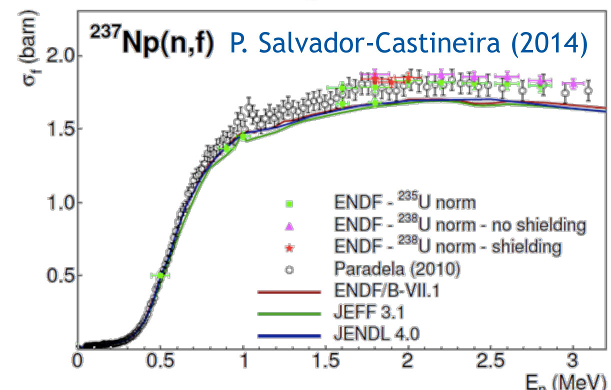


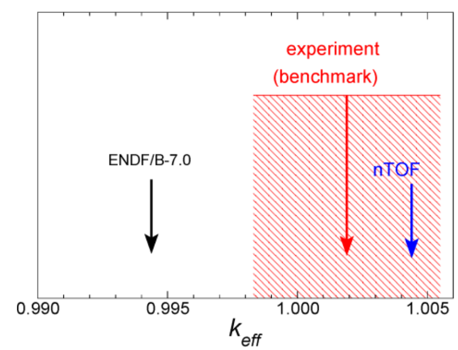
Courtesy P. Schillebeeckx, IRMM

The case of ^{237}Np(n,f)

- Significant discrepancies ~6-8% exist in data above the fission threshold
- n_TOF results obtained with PPACs (EAR-1) (Paradela et al., 2010) systematically higher than other measurements in fission plateau
- Apparent agreement between previous measurements partly due to arbitrary normalisations
- Recent experiments with monoenergetic neutron beams have not resolved this discrepancy
  - Results with Micromegas detectors at 4.5-5.3 MeV (Athens) lie between evaluations and n_TOF data
  - Better reproduction of Pu evaluations using n_TOF data between 0.5-3 MeV at IRMM van de Graaf
- LANL benchmark experiment (enriched Np sphere inside enriched ^{235}U shells)
- Two measurements performed at n_TOF (PPAC in EAR-1, Micromegas in EAR-2), analysis in progress

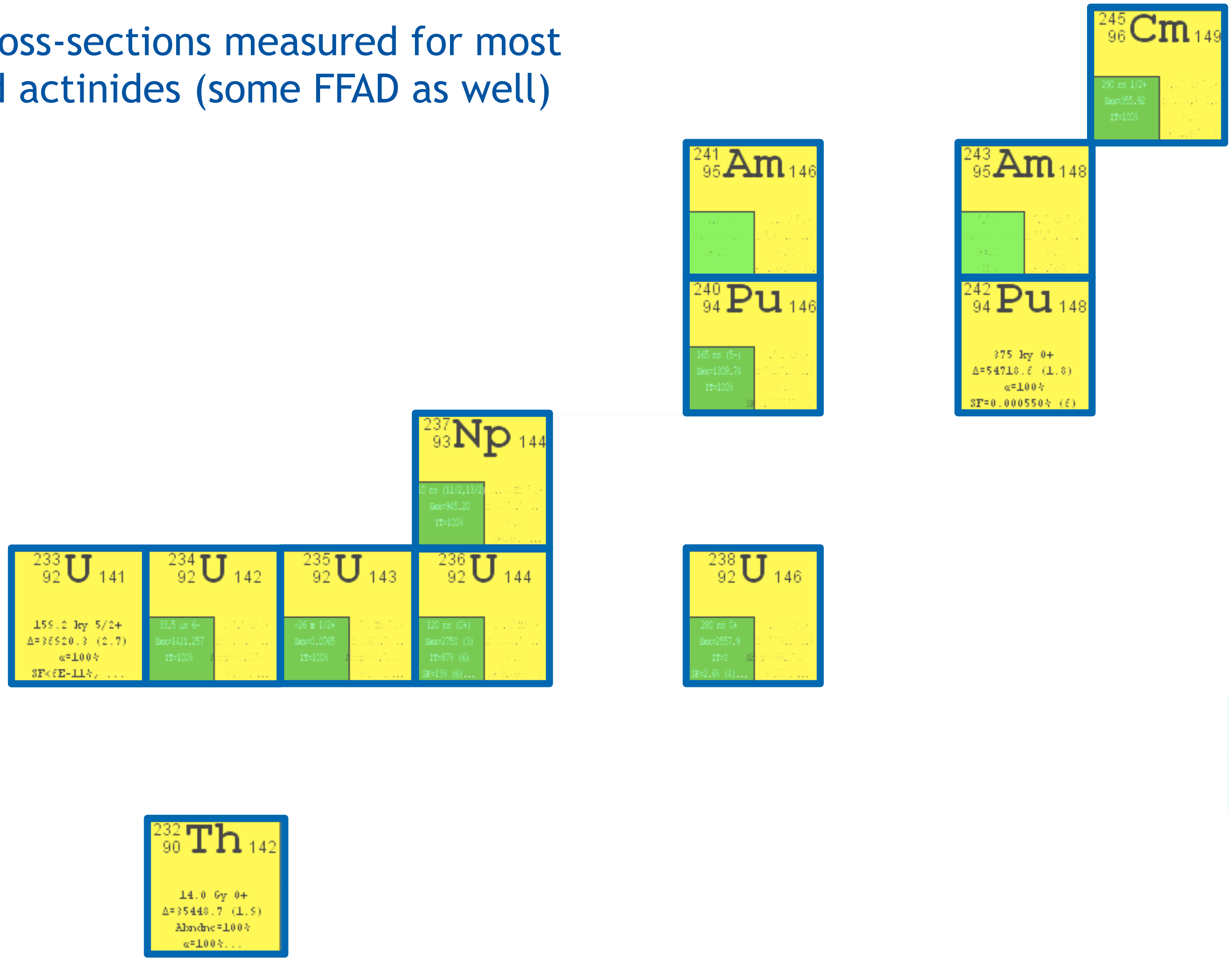






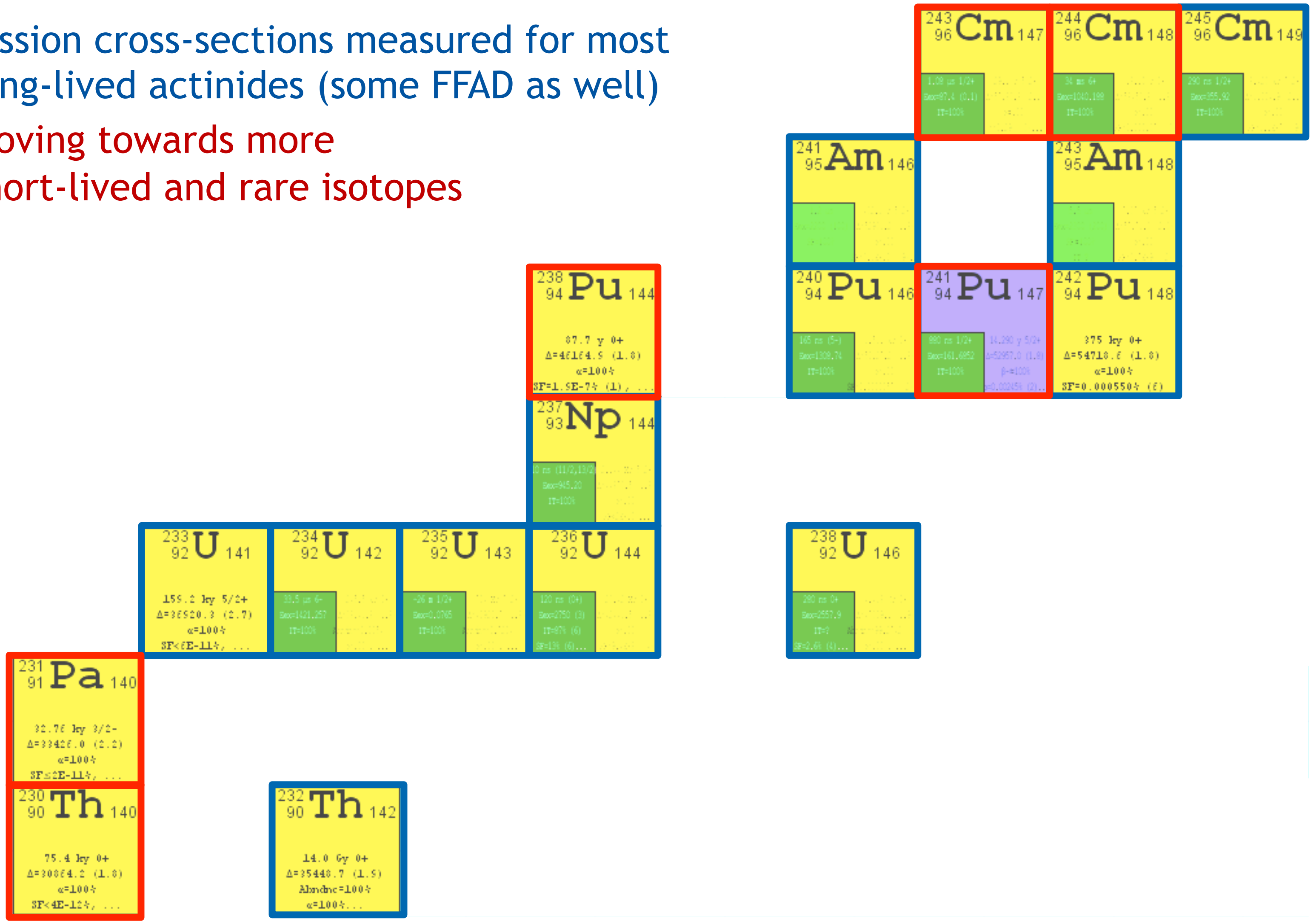
Ideas for the future

- Fission cross-sections measured for most long-lived actinides (some FFAD as well)

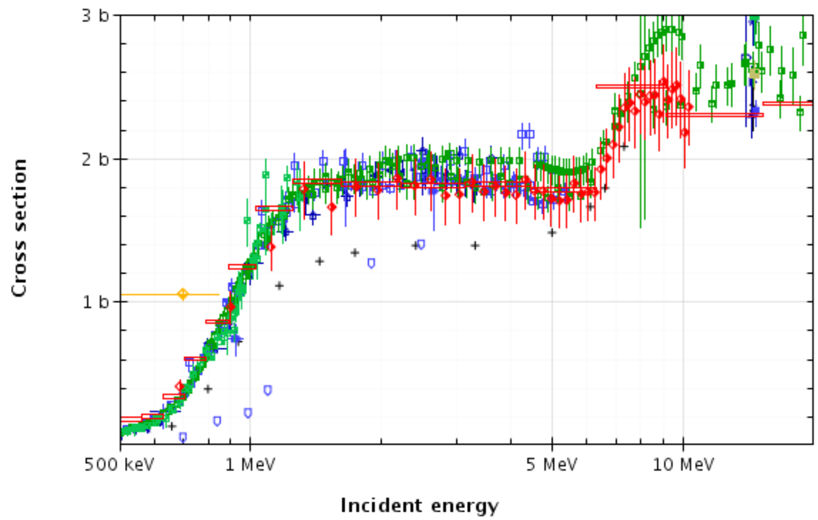


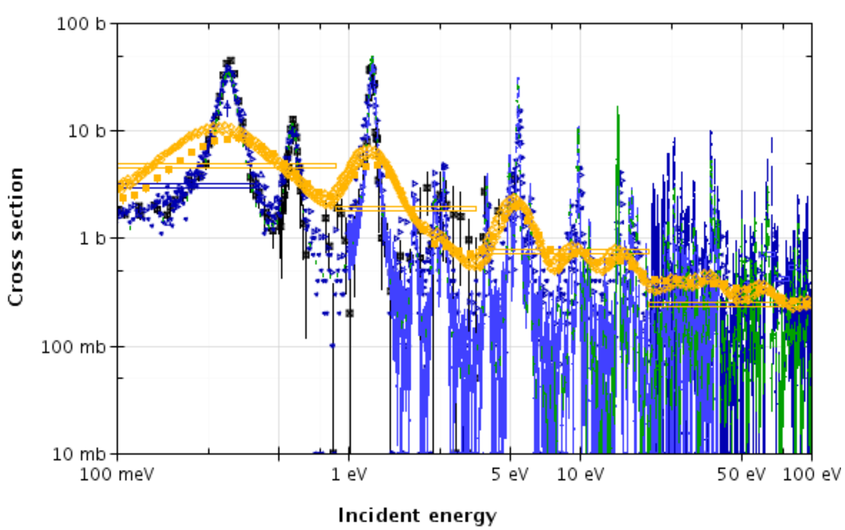
Ideas for the future

- Fission cross-sections measured for most long-lived actinides (some FFAD as well)
- Moving towards more short-lived and rare isotopes



Upcoming measurement: $^{241}Am(n,f)$

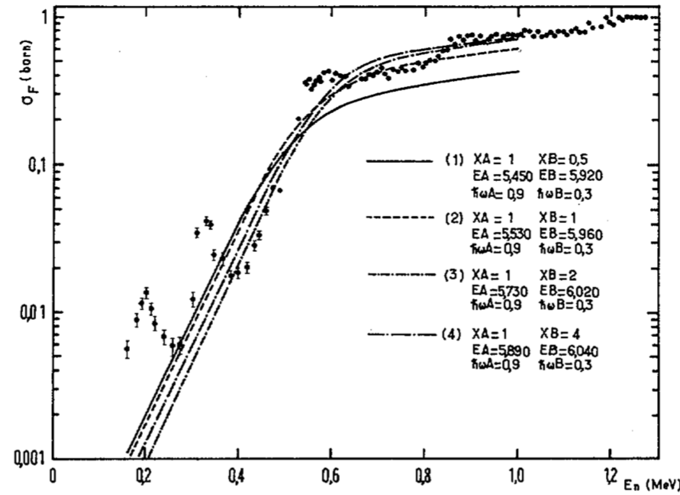




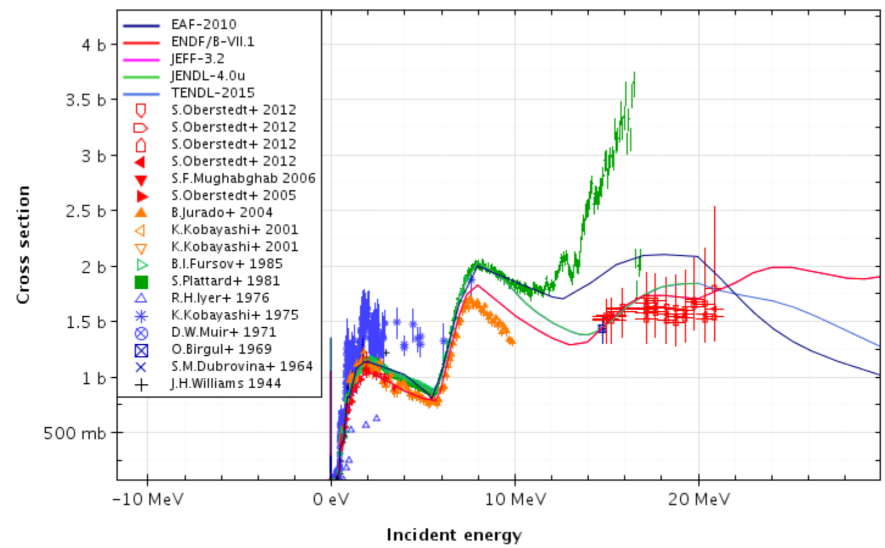
- A challenging measurement
  - 127 MBq/mg, 100% α
  - Steep fission threshold, xs decreasing rapidly below 1 MeV
- Previous n_TOF measurement
  - High amplitude threshold applied, data normalized to 3rd resonance in Dabbs data
  - Low statistics at and above fission threshold
- New measurement in EAR-2
  - Maximization of the flux with the large collimator (more than x20 wrt previous measurement)

Upcoming measurement: $^{231}Pa(n,f)$

- Relevant for Th cycle
  - Produced through $^{232}Th(n,2n)$ and $^{230}Th(n,\gamma)$
- Strong vibrational resonances at threshold
- Scarce measurements with large discrepancies
  - Only one dataset with poor resolution is available at low energies
  - Only two measurements of the FFAD are reported
- New measurement to be performed with PPAC setup in EAR-2

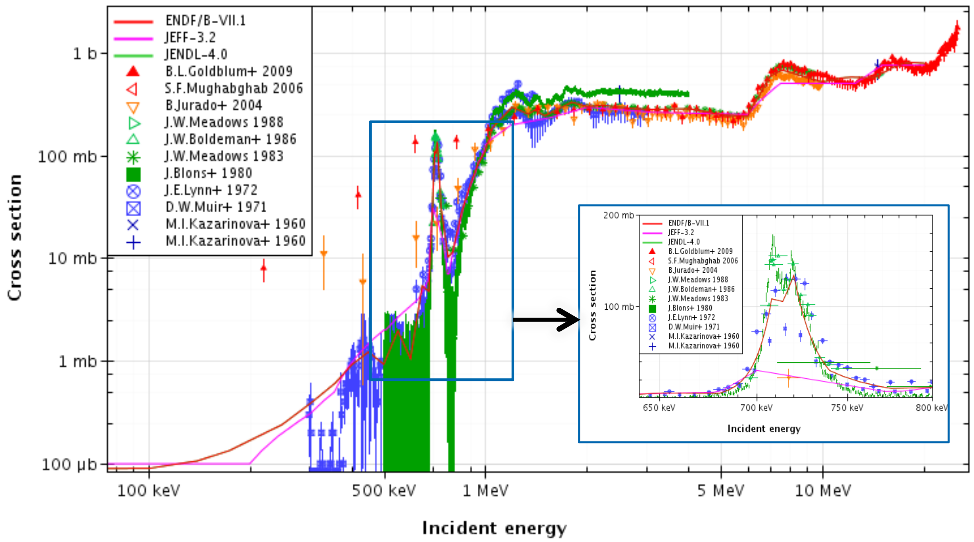


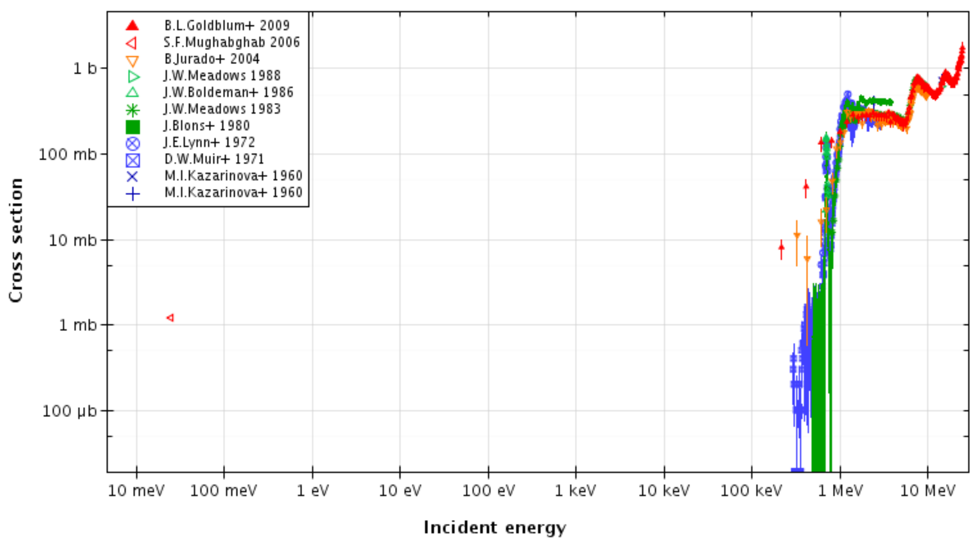
A. Sicre et al. IEAE-SM-174/40 (1973)



Upcoming measurement: ^{230}Th(n,f)

- Rare isotope (0.02% of nat. Th), low cross section
- Discrepant data at and above threshold
- Only one point at thermal below threshold
- Combination of both EARs
  - EAR-1: excellent resolution to study features at threshold and major resonances
  - EAR-2: high flux to populate sub-threshold and low energy region

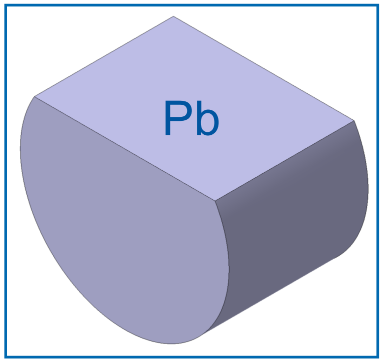


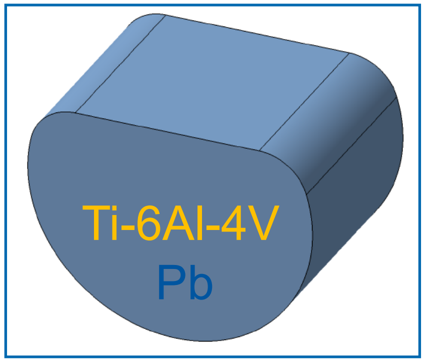


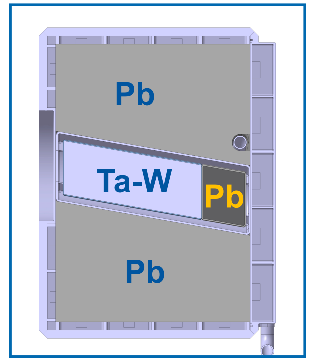
The new spallation target

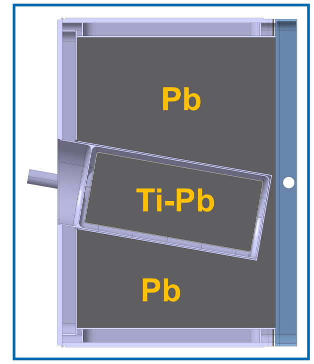
New spallation target

- The Pb target will be replaced during the next long shutdown (2019-20)
- Optimisation of vertical beam-line (increased flux in EAR-2)
- Several solutions are being investigated, decision to be taken in 2018

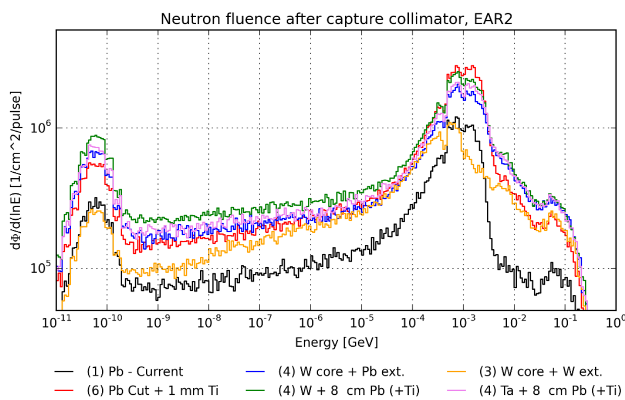


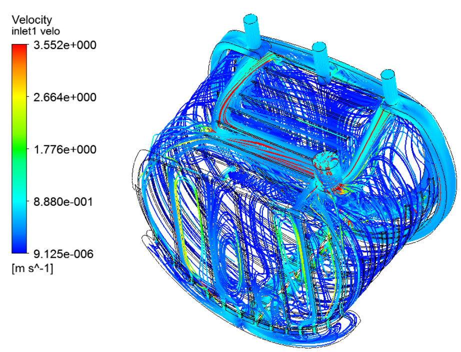


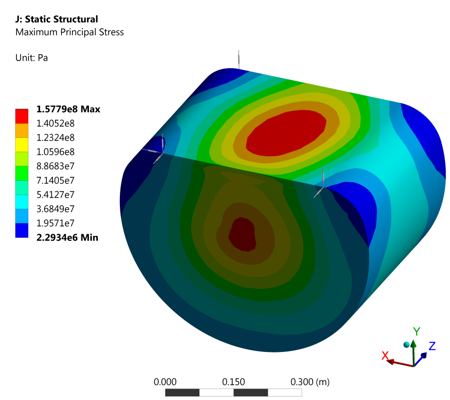




- Intensive MC simulations, prototyping, validation of manufacturing processes (e.g. Ti cladding of Pb core)







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