16th ASRC International Workshop
" Nuclear Fission and Structure of Exotic Nuclei "

Present and Future of Fission at n_TOF

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Outline

- The n_TOF Facility @ CERN
- n_TOF Parameters
- Fission Measurements in Phase 1 & 2
- n_TOF Phase 3 & Conclusions

THE n_TOF FACILITY @ CERN

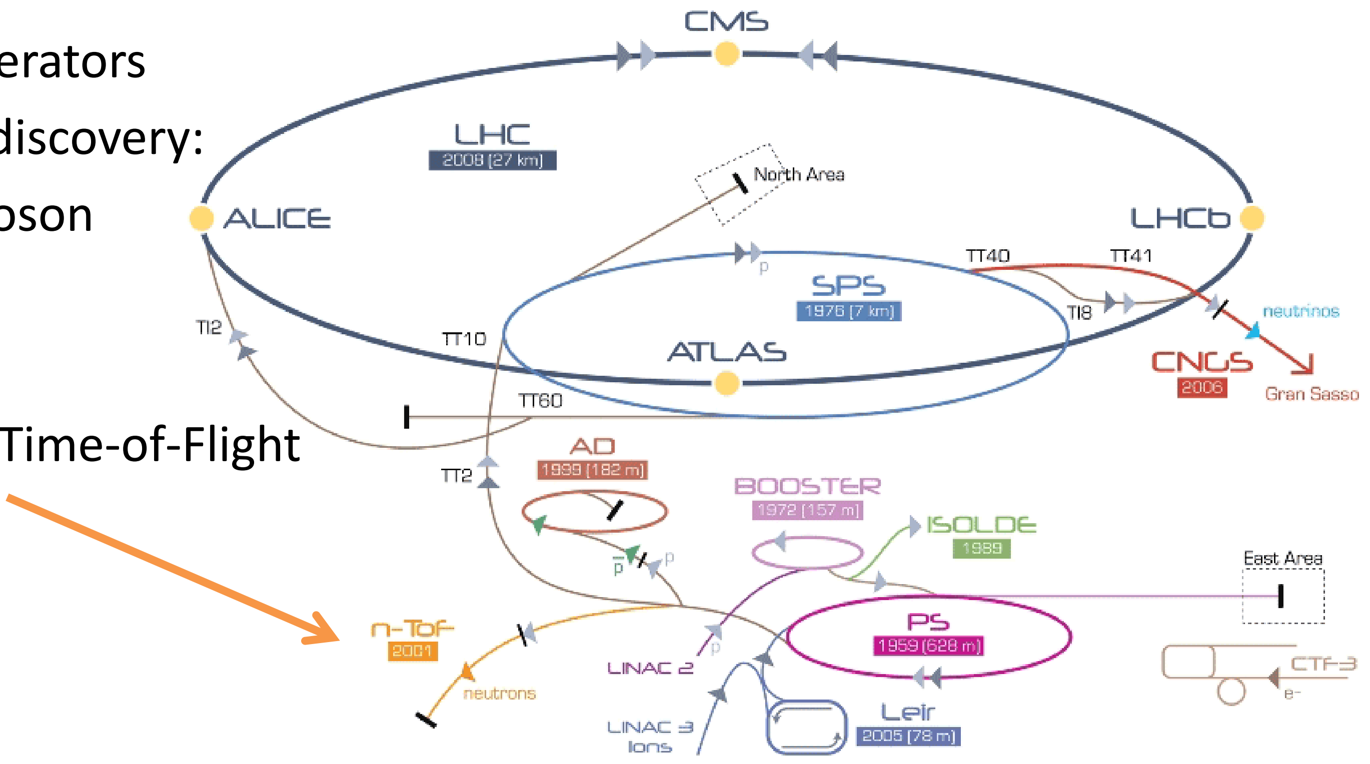
CERN Accelerator Complex

CERN: European Organization for Nuclear Research (Geneva / Switzerland)

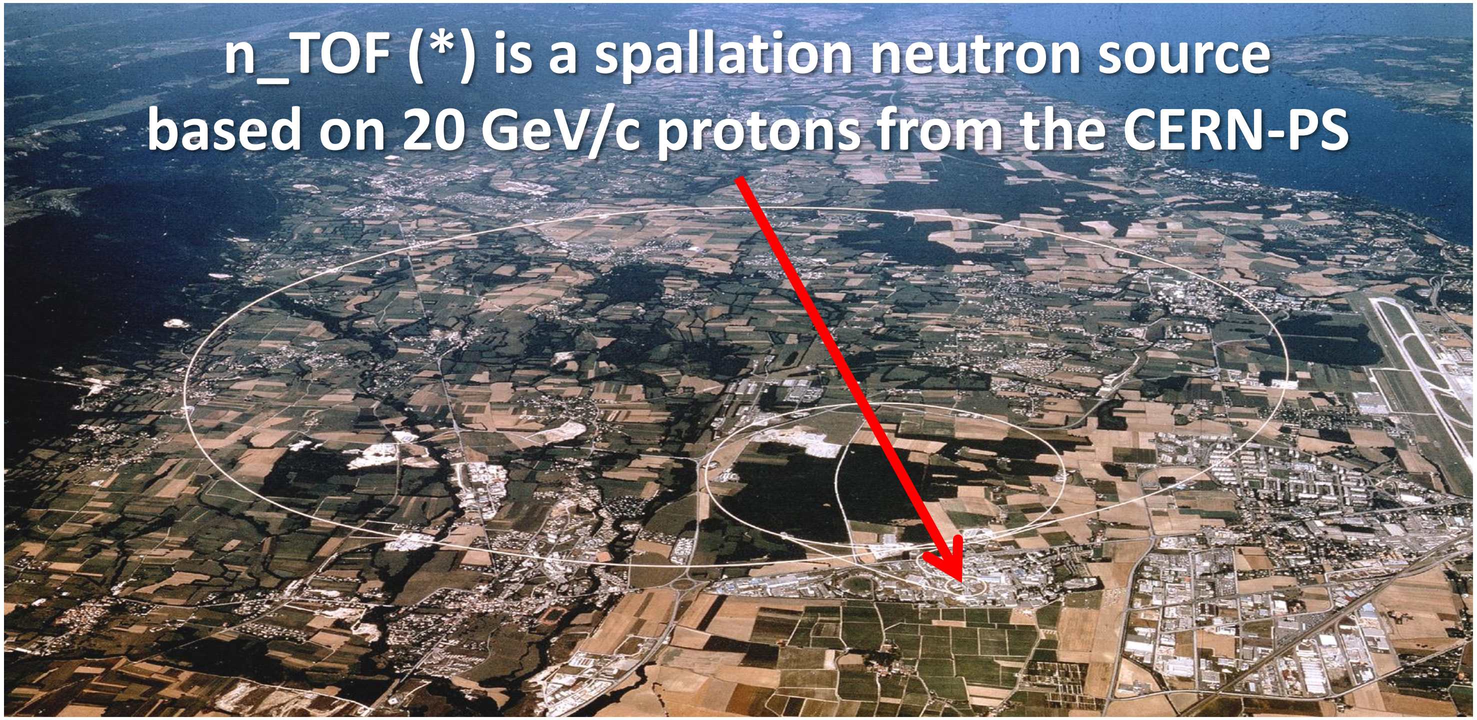
- Since 1954
- Various accelerators
- Most recent discovery:

  2012 Higgs Boson

n_TOF: Neutron Time-of-Flight



The n_TOF Facility @ CERN



(*) C Rubbia et al., A High Resolution Spallation Driven Facility at the CERN-PS to measure Neutron Cross Sections in the Interval from 1 eV to 250 MeV, CERN/LHC/98-02(EET) 1998.

The n_TOF Collaboration

The n_TOF Collaboration
30 Research Institutions from Europe, Asia and USA.
16 PhD students

NUCLEAR ASTROPHYSICS: stellar nucleosynthesis

Neutron capture and (n,α) cross section of stable & unstable isotopes playing a role in the *s*- and *r*-processes (0.1-500 keV).

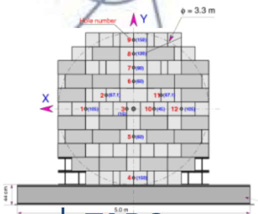
NUCLEAR TECHNOLOGIES: ADS, Gen-IV and Th/U fuel cycle

Neutron capture and fission cross sections of Actinides in the thermal (meV), epithermal (eV-keV) and fast (MeV) energy regions.

BASIC NUCLEAR PHYSICS: levels densities, γ-ray strength functions and ang. Distributions

Time-of-Flight measurements with dedicated detectors providing valuable information on basic nuclear physics quantities.

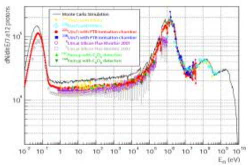
n_TOF Timeline



1995-1997 **TARC** experiment

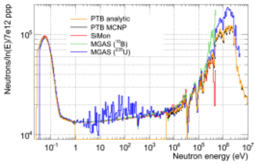
May 1998 **Feasibility** CERN/LHC/98-02+Add

2000 **Commissioning**



2004-2007 **Problem** Investigation

May 2009 **Commissioning**



2010 **Upgrades:** Borated-H_2O Second Line Class-A

July 2014 **Commissioning**

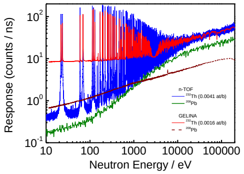
1996 — 2014

1997 **Concept** by C.Rubbia CERN/ET/Int. Note 97-19

Aug 1998 **Proposal** submitted

1999 **Construction** started

2001-2004



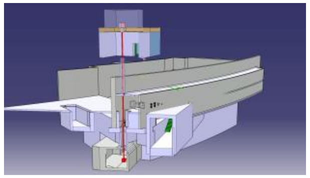
Phase I Isotopes Capture: 25 Fission: 11

2008

New Target construction

2009 - 2012 **Phase II** Isotopes Capture: 14 Fission: 3 (n,cp): 2

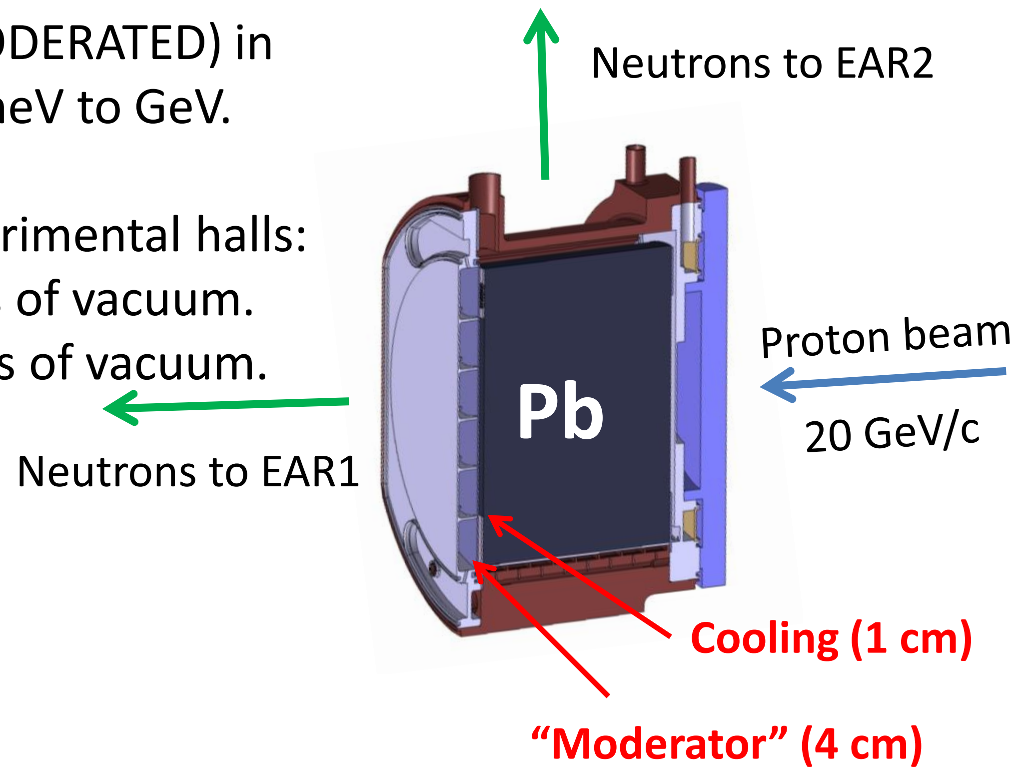
2011



EAR2 Design and Construction

The Pb Spallation Target

- Approx. 400 FAST (MeV-GeV) neutrons/proton (20 GeV/c) are generated @ target.
- They are slowed-down (MODERATED) in 5 cm of water+^{10}B-water: meV to GeV.
- A fraction reaches the experimental halls:
  1. EAR1: after 185 meters of vacuum.
  2. EAR2: after 18.5 meters of vacuum.



The n_TOF Facility (2014)

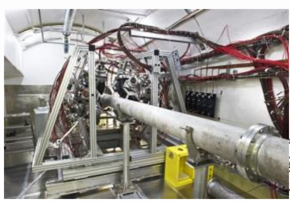
Two experimental areas (EAR):

- Horizontal flight path:
  EAR1 at **182.5 m**
- Vertical flight path:
  EAR2 at **18.2 m**

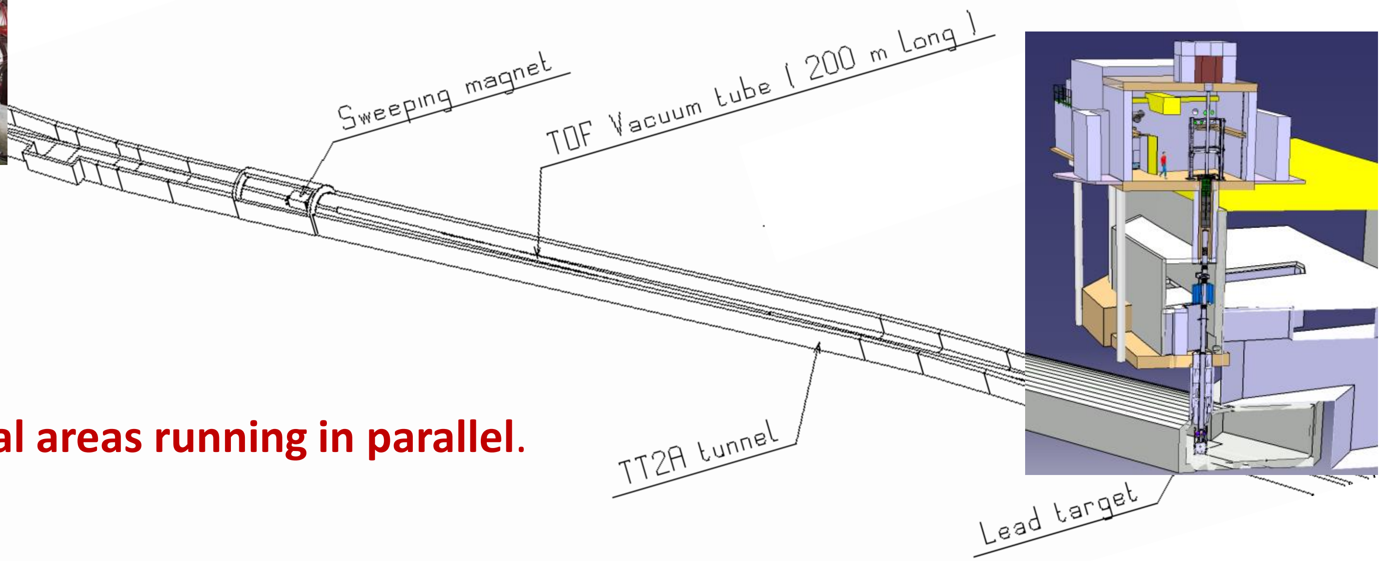
Both beam lines have:

- 1st collimator:
  halo cleaning + first beam shaping.
- Filter station.
- Sweeping magnet.
- 2nd collimator: beam shaping.

EAR1



EAR2

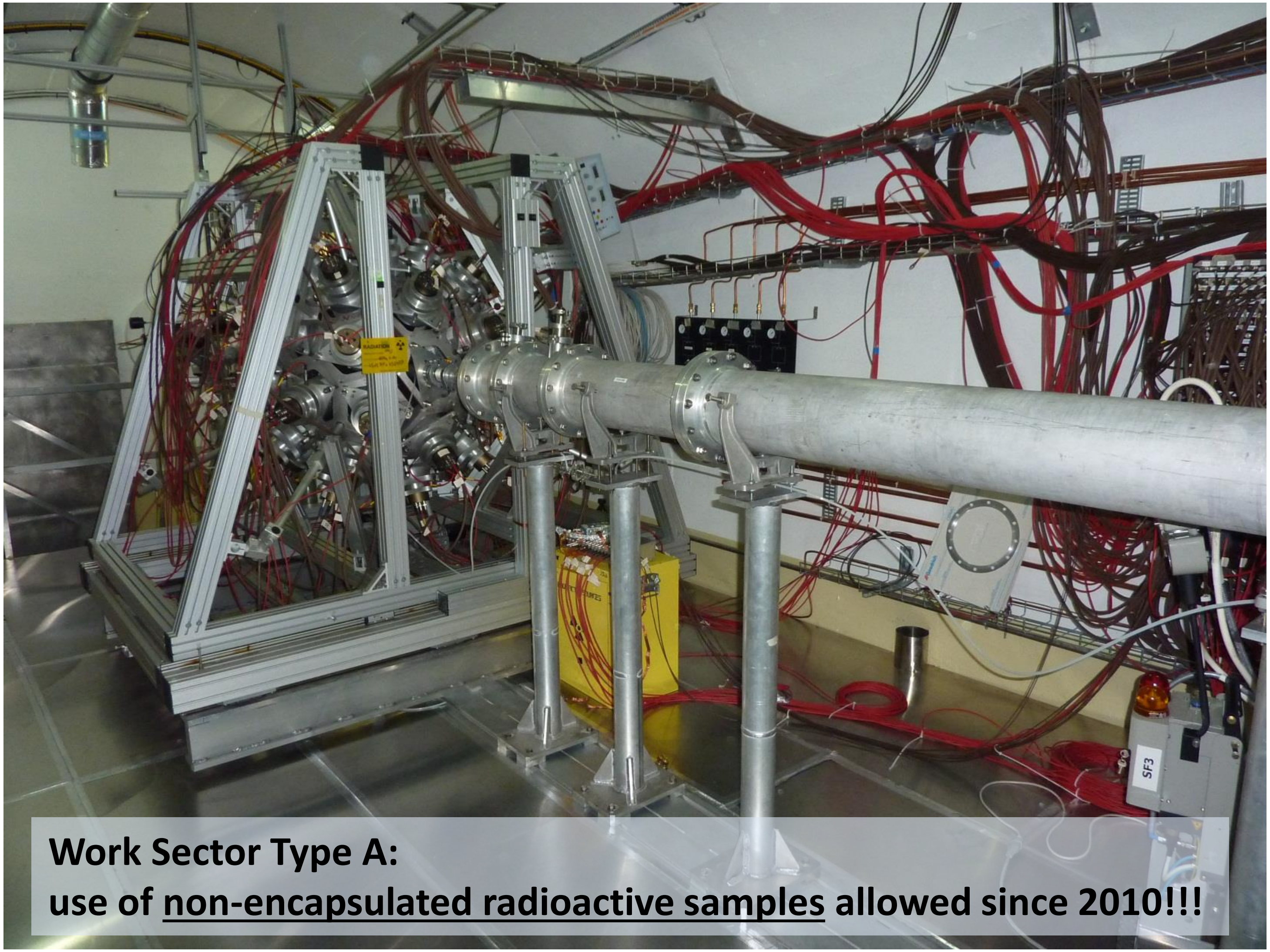


Two experimental areas running in parallel.

Main Features of n_TOF

- Extremely high instantaneous neutron flux:
  1. EAR1: 10^5 n/cm^2/pulse
  2. EAR2: 10^6 n/cm^2/pulse
- Unique facility for measurements on radioactive isotopes (maximize S/N)
  - Branch point isotopes (astrophysics)
  - Actinides (nuclear technology)
- Large energy range:
  1. EAR1: 25 meV<E_n<1 GeV → measure fission up to 1 GeV
  2. EAR2: 25 meV<E_n<300 MeV
- Low repetition rate (<0.8 Hz) → no wrap-around
- High resolution in energy:
  1. EAR1 $\Delta E/E=10^{-4}$ → study resonances
  2. EAR2 $\Delta E/E=10^{-3}$

Class-A Laboratory

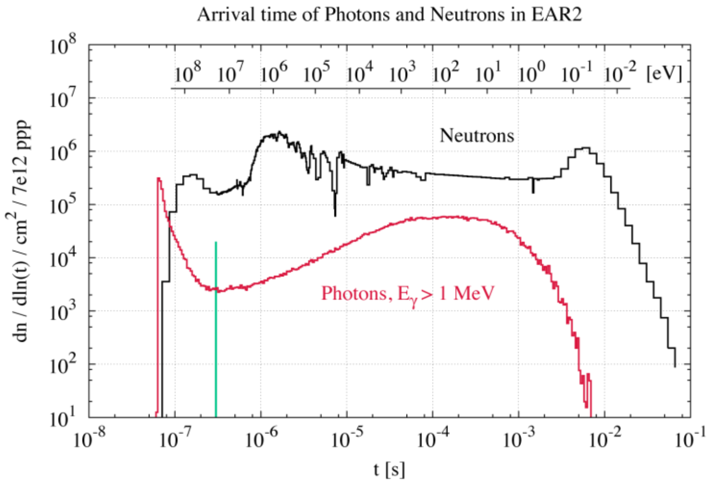


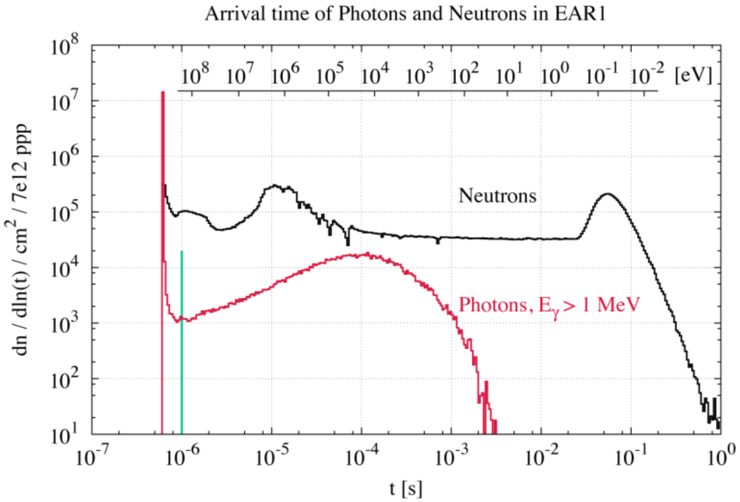
Work Sector Type A:
use of <u>non-encapsulated radioactive samples</u> allowed since 2010!!!

n_TOF PARAMETERS

n_TOF Beam: TOF - E_n

- Neutrons over wide E_n range.
- Photons:
  1. γ-flash: photons from spallation.
  2. In-beam γ: photons from moderation of neutrons.



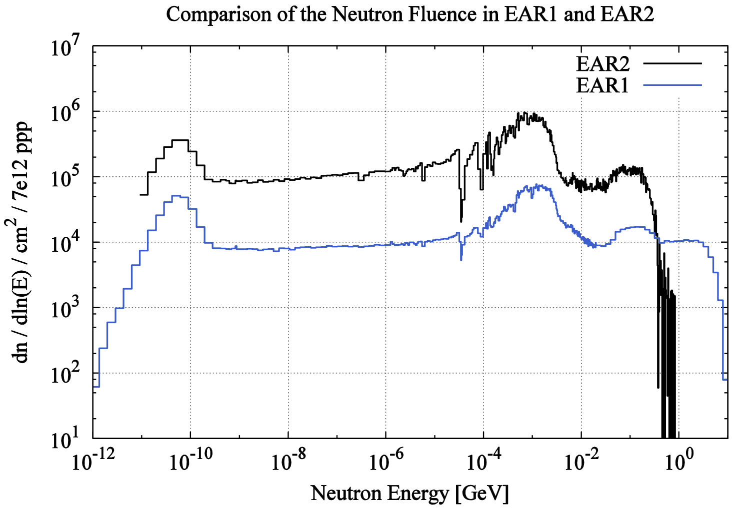


E_n	TOF EAR I: 185m	TOF EAR II: 20 m
γ - Flash	620 ns	70 ns
1 GeV	710 ns	80 ns
1 MeV	13 µs	1.5 µs
1 keV	423 µs	46 µs
1 eV	13 ms	1.5 ms
1e-2 eV	134 ms	15 ms

Neutron Fluence

- High-gain spallation source + moderation:

  -> high instantaneous flux.
  -> large energy range.



Results from FLUKA simulations:

Energy Interval	EAR2 n / cm² / pulse	EAR1 n / cm² / pulse	Gain EAR2 / EAR1
0.02 – 10 eV	1.64e6	1.07e5	15.4
10 eV – 1 keV	1.07e6	3.98e4	26.8
1 keV – 100 keV	1.36e6	5.02e4	27.0
0.1 – 10 MeV	3.00e6	1.76e5	17.1
10 – 200 MeV	4.78e5	4.15e4	11.5
Total range	7.54e6	4.14e5	18.2

EAR2 especially suited for measurements on radioactive samples, as the neutron rate is a factor ~ 250 higher than in EAR1
=> Better signal to background ratio for radioactive samples.

Beam Profile

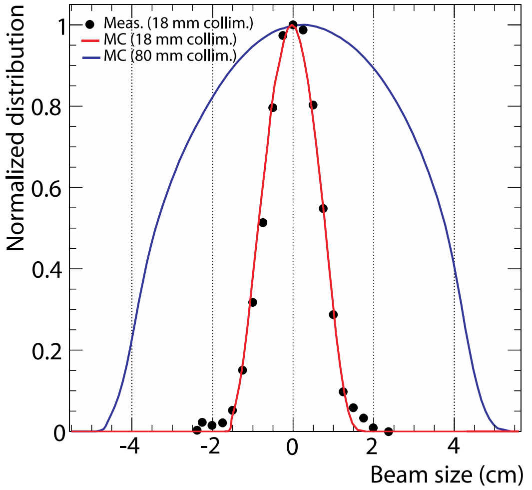
- EAR1:

1. Capture collimator:

   ø 18 mm, straight geometry of collimator, Gaussian beam.

1. Fission collimator:

   ø 80 mm, straight geometry of collimator, Gaussian beam.



- EAR2: Collimators under study. Most likely 2 conical configurations:

1. Small collimator with ø 20 mm at the exit:

   -> same number of neutrons in 10 mm diameter, as the total fission beam in EAR1.

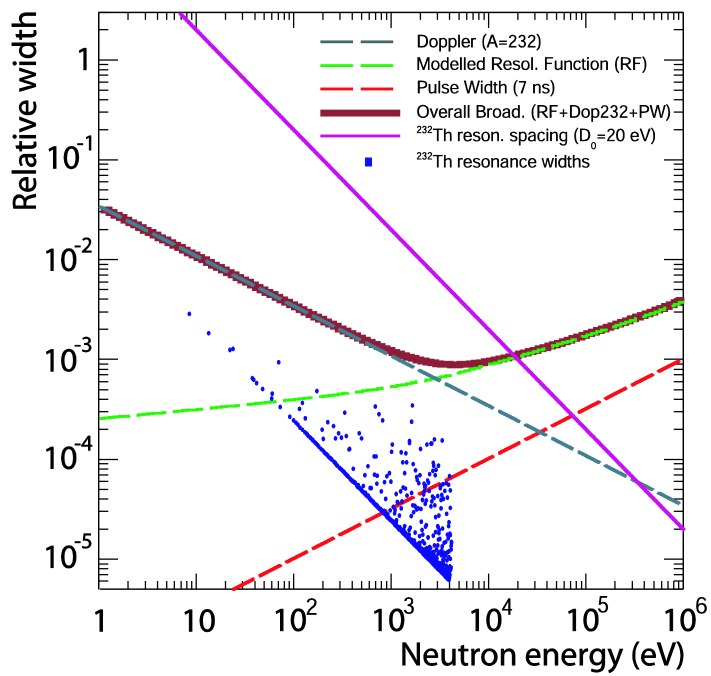
1. Big collimator with ø 80 mm: for very small cross-sections and thin samples.

Resolution Function

- Neutron energy resolution dictated by:
  - Proton beam width.
  - Spallation process in extended Pb target.
  - Moderation process.
  - Flight path.

Neutron Energy	EAR2: L_0 = 18.9 m	EAR1: L_0 = 187.5 m
	ΔE/E	ΔE/E
1 eV	4.3e-3	3.0e-4
1 keV	8.5e-3	5.4e-4
1 MeV	4.1e-2	3.6e-3

EAR1



FISSION @ n_TOF: PHASE 1 & 2

Fission Measurements @ n_TOF

Detector	Fission Measurements	Reference
FIC	233U: 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
	236U: σ (up to 2 MeV)	R. Sarmento, Phys. Rev. C 84 (2011) 044618
	243Am: σ (0.5 – 20 MeV)	F. Belloni, Eur. Phys. J. A 47 (2011) 160
	245Cm: σ (thermal – 1 MeV)	M. Calviani, Phys. Rev. C 85 (2012) 034616
	241Am: σ (0.5 - 20 MeV)	F. Belloni, Eur. Phys. J. A 49 (2013) 2
PPAC	234U/237Np: σ (1eV - 1 GeV)	C. Paradela, Phys. Rev. C 82 (2010) 034601
	209Bi/natPb: σ (thr – 1 GeV)	D. Tarrio, Phys. Rev. C 83 (2011) 044620
	232Th: FFAD (thr – 3 MeV)	D. Tarrio, NIMA 743 (2014) 79-85
	233U: σ	L. Tassan-Got – to be published
	235U & 238 U: σ + FFAD	Analysis pending
MGAS	235U: fission tagging	C. Guerrero, Eur. Phys. J. A 48 (2012) 29
	240,242Pu	A. Tsinganis – work ongoing

Measuring Fission up to 1 GeV

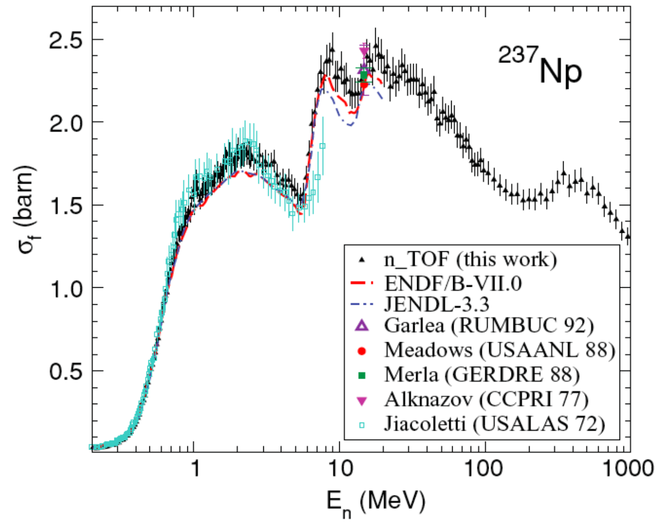
C. Paradela et al., *Neutron-induced fission cross section of ^{234}U and ^{237}Np measured at the CERN Neutron Time-of-Flight (n_TOF) facility*, Phys. Rev. C 82, 034601 (2010)

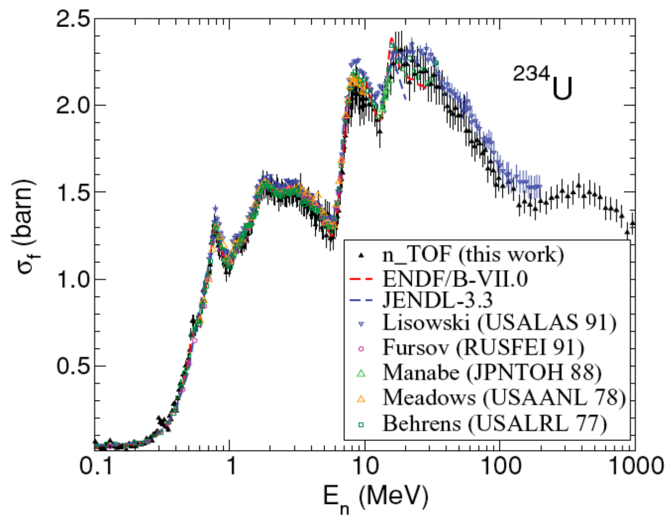
Measurement with parallel plate avalanche counters (PPAC):

- Highly transparent detector: less than 1% neutron fluence loss with assembly of 10 PPACs.
- Coincidence measurement -> excellent background rejection.
- Fast anode signal (9 ns FWHM): measurement up to 1 GeV possible.

Measurement at n_TOF:

- High E_n-resolution: Measurement of sub-threshold resonances.
- Wide E_n spectrum: Measurement of cross-section up to 1 GeV.





Angular Distribution of FF

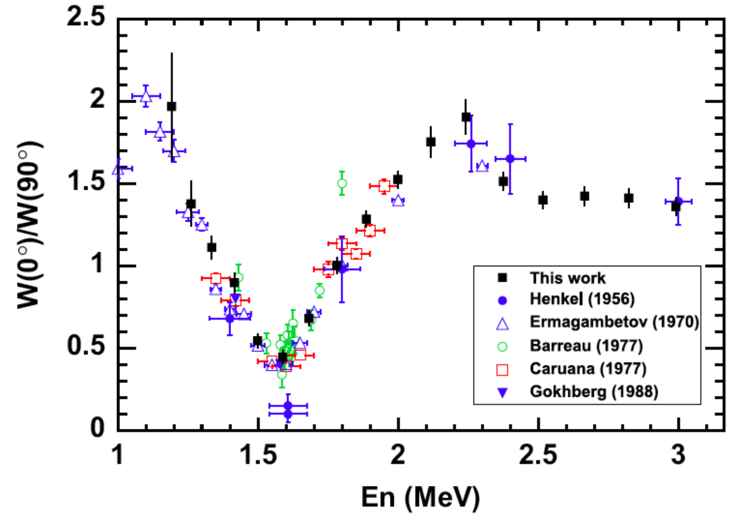
D. Tarrio et al., *Measurement of the angular distribution of fission fragments using a PPAC assembly at CERN n_TOF*, NIMA 743, 79-85 (2014)

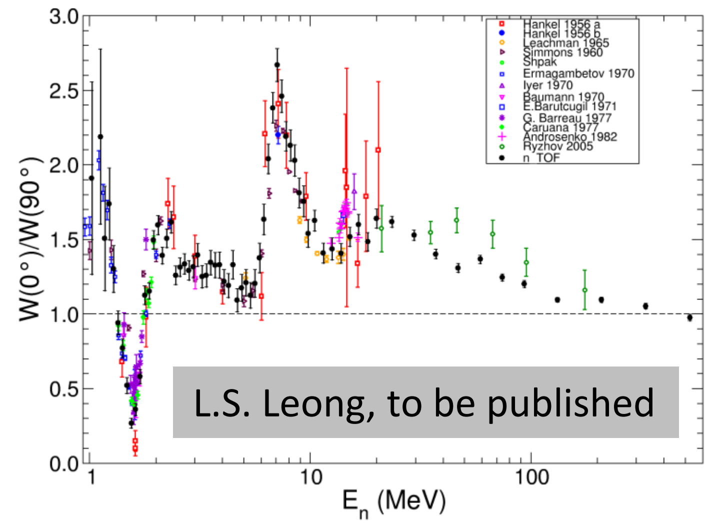
Measurement with PPACs:

- Detectors tilted by 45°-> FFAD measurement possible for 0 < cosΘ < 1. Continuous angular range with a resolution of +/- 4.5°.
- Segmented Cathodes (100 strips 1.9 mm wide with 100 μm spacing in between), perpendicular to each other: Information on angular distribution of fission fragments is obtained.

Measurement at n_TOF:

- Study of energy dependence with high resolution.





Measuring high Activity Samples

A. Tsinganis et al., *Measurement of the 242Pu(n,f) Cross Section at the CERN n TOF Facility*, Nuclear Data Conference, New York 2013

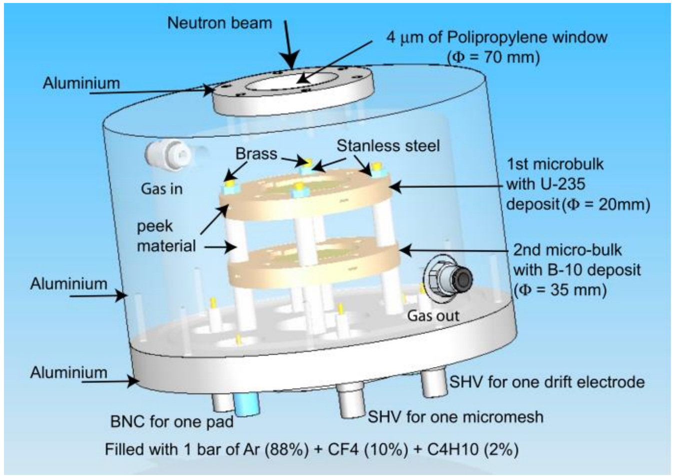
Measurement with **MICRO**-**ME**sh **GA**seous **S**tructure (μMGAS) detectors:

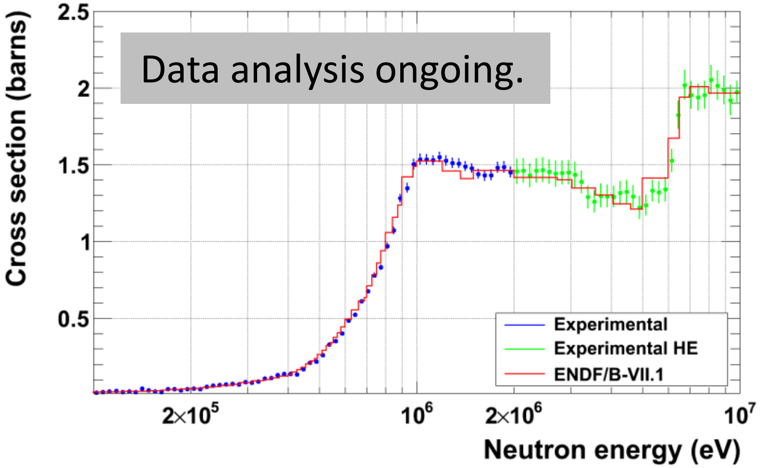
- Fast, Low background, radiation hard.

Measurement at n_TOF:

- High instantaneous flux -> Measurement of high activity samples possible.

^{240}Pu		^{242}Pu	
^{240}Pu	99.8915%	^{242}Pu	99.96518%
Mass	3.1 mg	Mass	3.6 mg
Activity	25.7 MBq	Activity	0.53 MBq
Surface density		0.10 – 0.13 mg/cm^2	



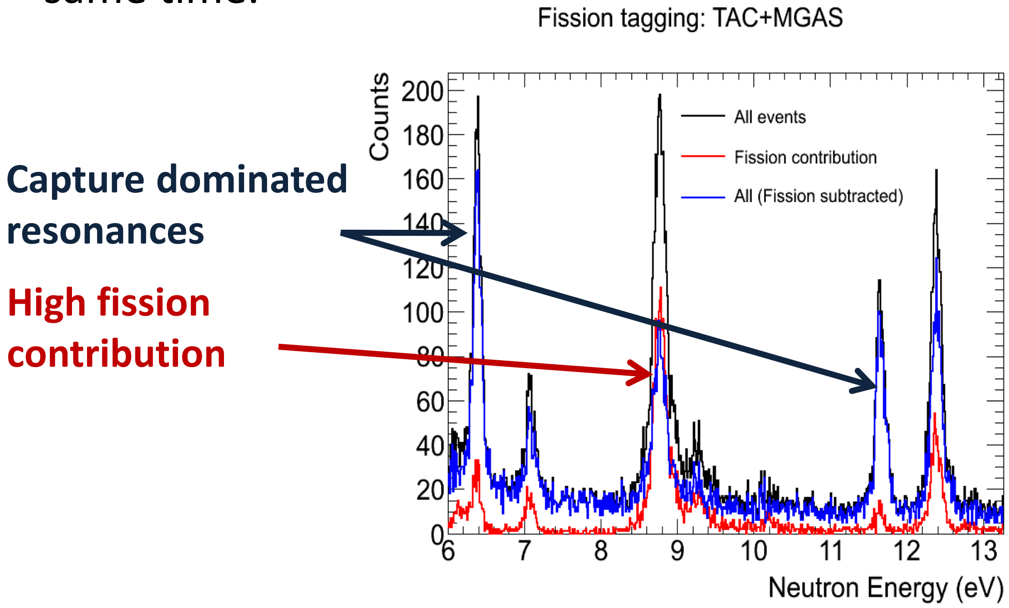


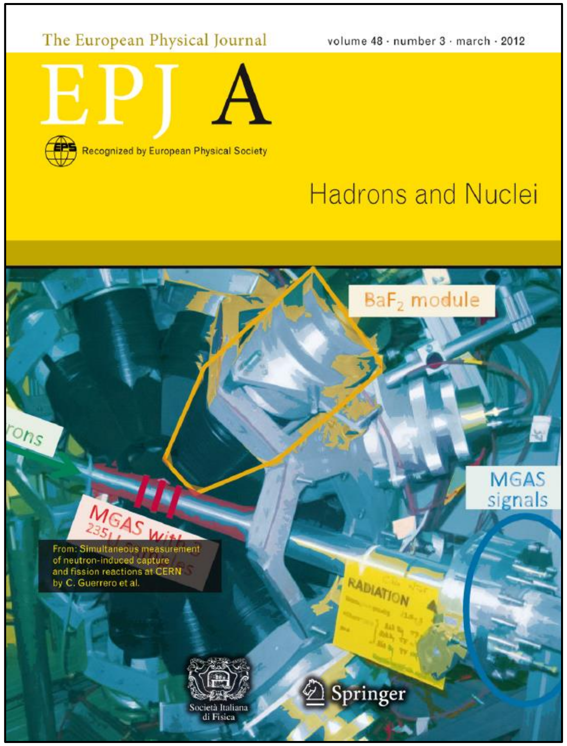
Fission in Anti-Coincidence

C. Guerrero et al., Simultaneous *measurement of neutron-induced capture and fission reactions at CERN,* Eur. Phys. J. A 48:29 (2012)

Measurement with µMGAS in combination with Total Absorption Calorimeter (TAC):

- Capture and fission can be measured at the same time.





n_TOF PHASE 3

Proposals and Outlook

The experimental areas will be ready for new measurements after the commissioning phase 2014:

- EAR1: Physics start September 2014.
- EAR2: Physics start November 2014.

Phase 3 period: 2014 – 2018 (next long shutdown at CERN).

Fission measurements planned for Phase 3:

- 233U fission tagging.
- 235U with STEFF detector, first measurement of γ-rays in coincidence with FF mass distribution and atomic number Z at n_TOF.
- 231Pa with PPAC.
- 244Cm fission tagging.
- More to come!

Conclusions

- The n_TOF facility at CERN offers the possibility to measure neutron-induced fission over a wide neutron energy range.
- The fission cross-sections of 14 different isotopes were measured so far at n_TOF during Phase 1 & 2.
- Two experimental facilities will be operational in parallel from July 2014 onwards:
  - 200 m flight path for high resolution measurements.
  - 20 m flight path for:
    1. Low mass samples.
    2. Low cross-sections.
    3. High activity radioactive samples.

THANK YOU FOR YOUR ATTENTION!