Nuclear data measurements at white and quasi-monoenergetic sources of high-energy neutrons:

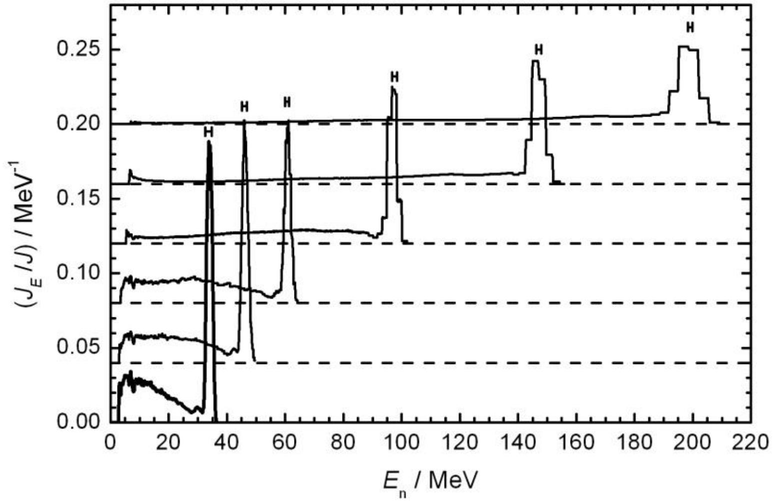
The example $^{235}U(n,f)$ / $^{1}H(n,n)p$.

R. Nolte, **n_TOF collaboration, TLABS neutron beam collaboration**

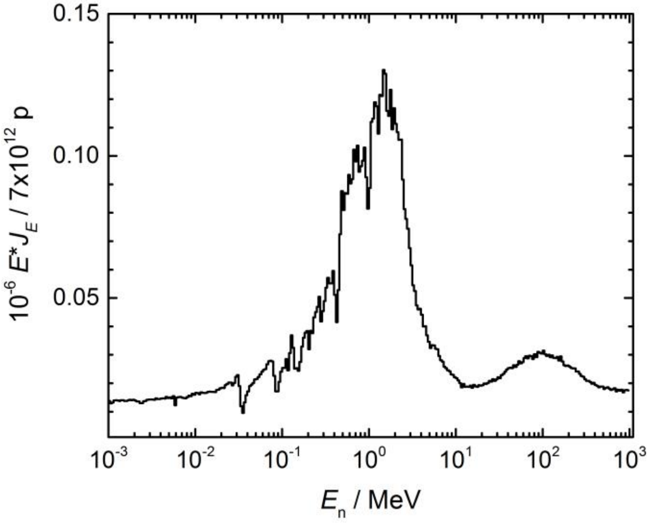
PTB Department 6.4 ‘Neutron Radiation’

Overview

iThemba LABS: $^{7}Li + p$



CERN: n_TOF



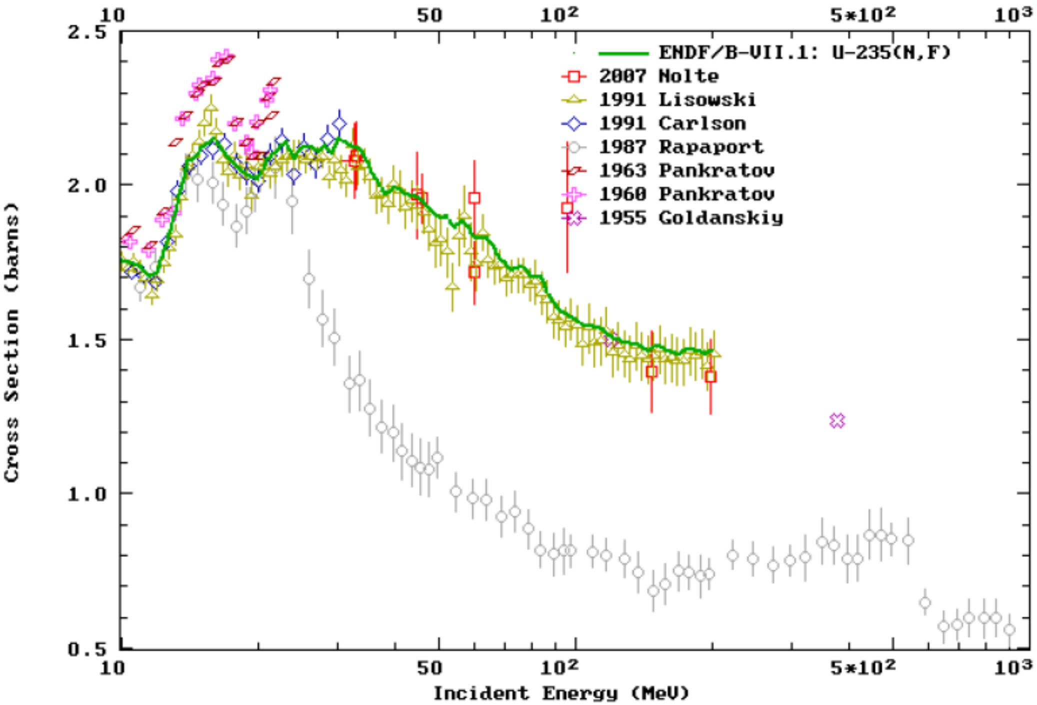
Measurement of ^{235}U fission cross section rel. to np scattering:

^{235}U(n,f) / ^{1}H(n,n)p

- **Continuous ('white') neutron source:** **n_TOF**
- **Quasi-monoenergetic neutron source:** **iThemba LABS**

^{235}U(n,f): Experimental Data for E_n > 20 MeV

- **^{235}U(n,f): most important secondary standard for neutron flux measurements above 20 MeV**



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PTB Eing. – 5. NOV. 2007

Prof. Dr. Ernst Otto Göbel
Physikalisch-Technische Bundesanstalt
Präsidiale Stabsstelle
Bundesallee 100
38116 Braunschweig
Germany

2007-10-29

Dear Professor Göbel,

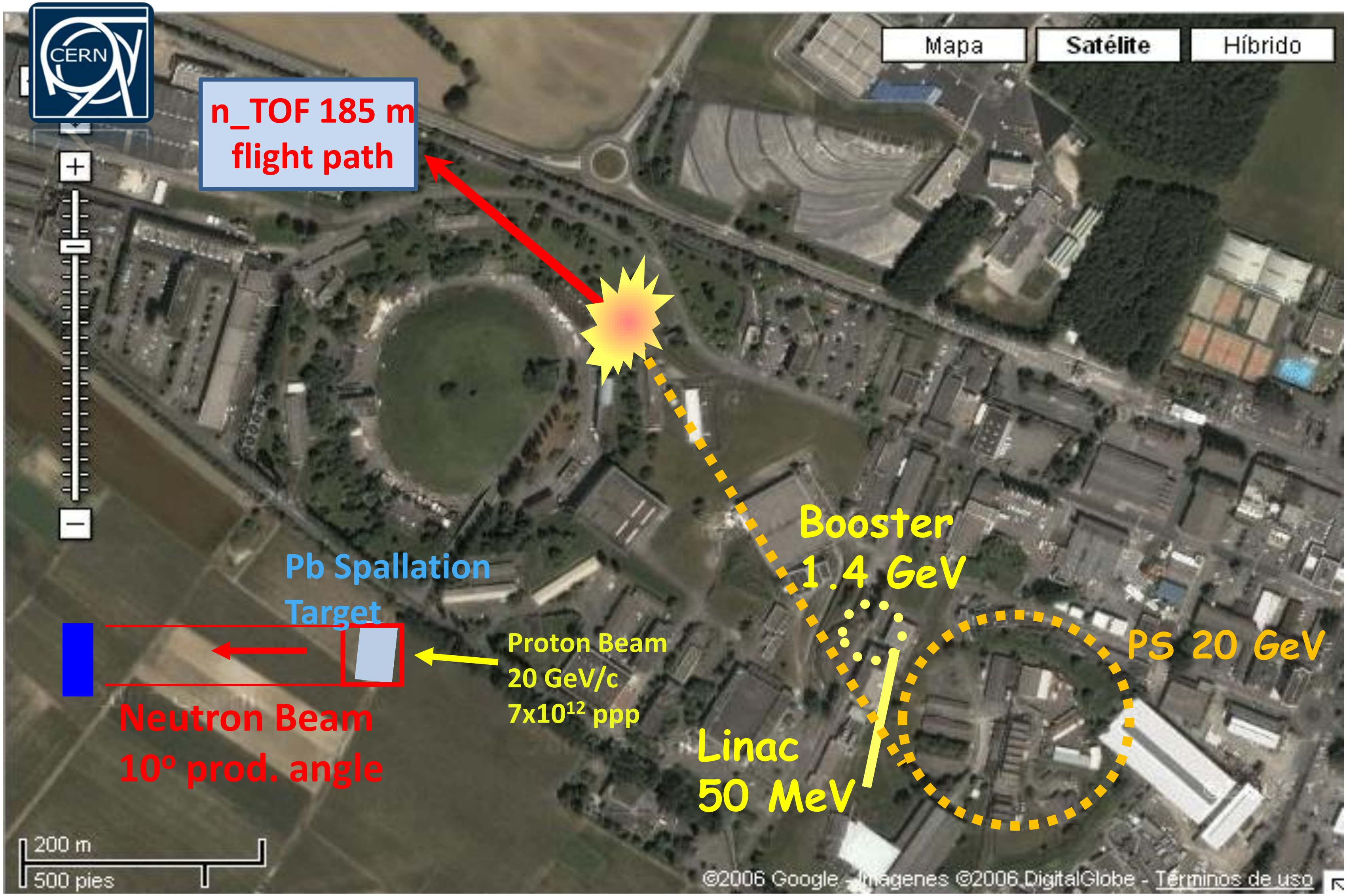
The Nuclear Data Section of the International Atomic Energy Agency has finalized work on the Co-ordinated Research Project (CRP) "International Evaluation of Neutron Cross Section Standards". These standards are essential for subsequent measurements and evaluations of other neutron cross sections for nuclei included in international and national nuclear data libraries. Standards for ^{235}U(n,f) and ^{238}U(n,f) cover the energy range from thermal to 200 MeV. Unfortunately, there are not many measurements in the high-energy region (above 20 MeV), and most are not absolute measurements. Thus, the absolute cross section measurements made by Dr. Nolte in 2004 (Nucl. Sci. Eng., **156**, 197 (2007)) were a very valuable contribution to the standard work within the CRP.

We understand that the accuracy reached in these measurements can be improved further (currently between 5 – 10%), and there is no physical limitations as to the choice of the energies studied. We would be very interested in such a measurement programme, especially in the energy range from 50 to 60 MeV, where some experimental data and model calculations exhibit significant irregulations in the cross-section behaviour. Data points for absolute cross sections with a uncertainty of 5% in the energy range from 60 to 150 MeV will assist considerably with resolution of the existing discrepancy between two sets of shape cross section measurements carried out independently at Los Alamos National Laboratory, USA and V. G. Khlopin Radium Institute, Russia.

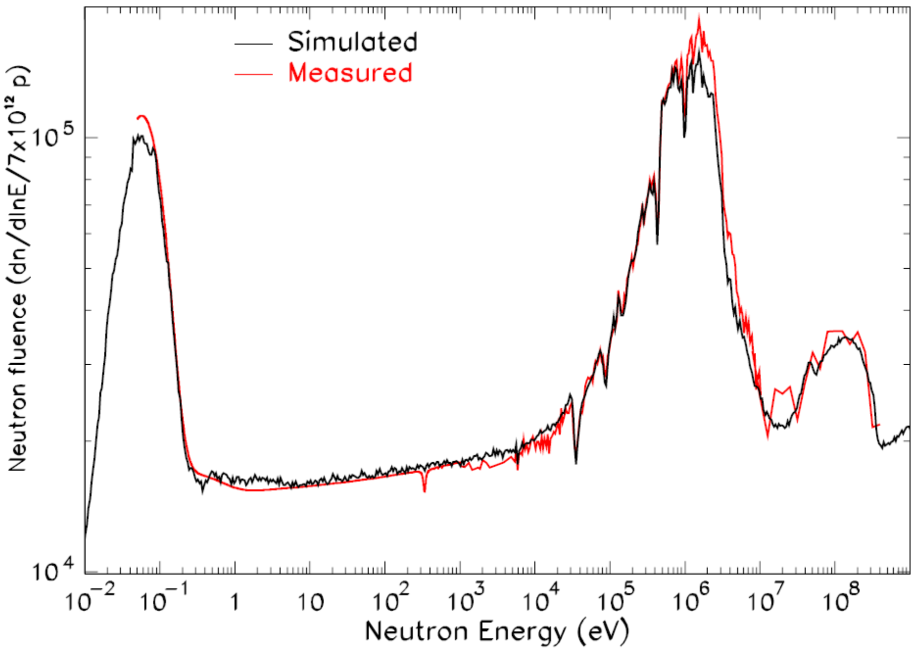
Yours sincerely,

- **Only one 'complete' dataset relative to Lisowski/LANL (1991)**
- **Some additional scattered data with larger uncertainties**

The n_TOF Facility at CERN: a Google view



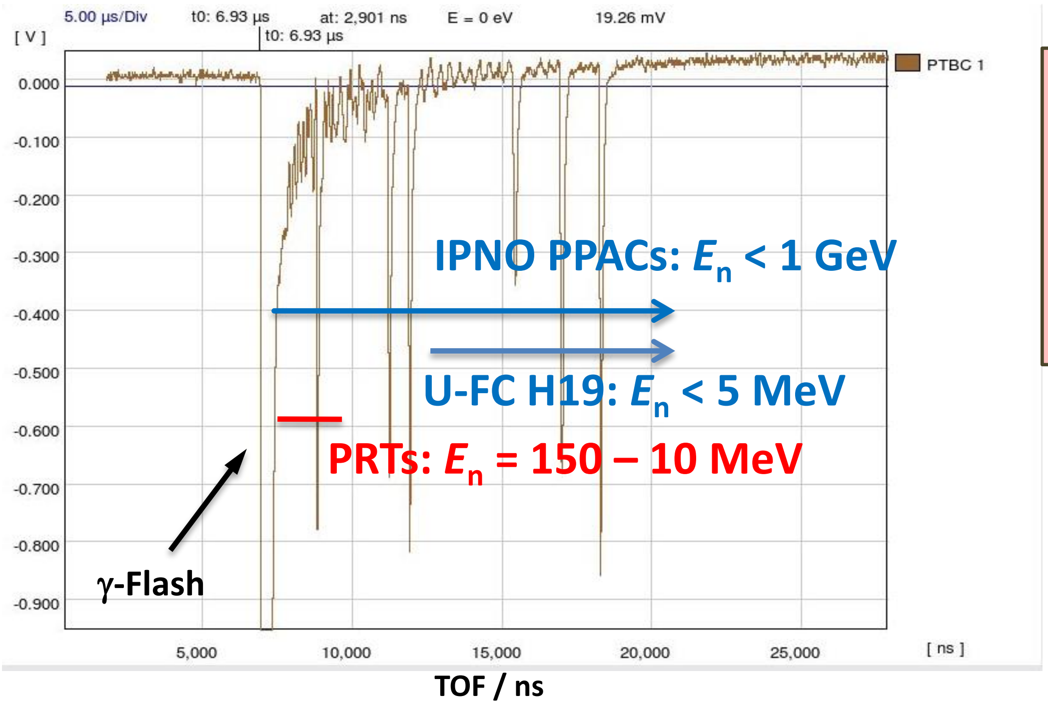
The n_TOF Neutron Beam



- Main feature of n_TOF is the extremely high instantaneous neutron flux (10^5 n/cm^2/pulse)
- Unique facility for measurements of radioactive isotopes (maximize S/N)
  - Branch point isotopes (astrophysics)
  - Actinides (nuclear technology)

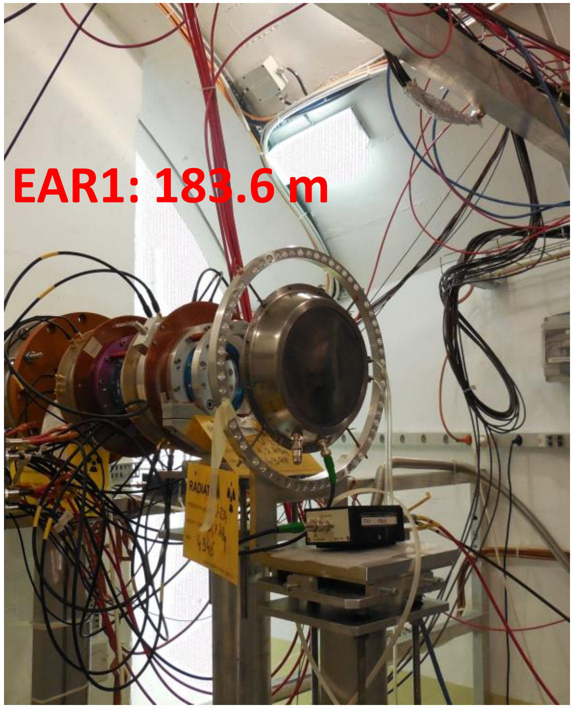
- Other features of the neutron beam:
  - High resolution in energy ($\Delta E/E=10^{-4}$) → study resonances
  - Large energy range (25 meV<E_n<1 GeV) → measure fission up to 1 GeV
  - Low repetition rate (<0.8 Hz) → no wrap-around

Experimental Challenges at n_TOF



n_TOF source:

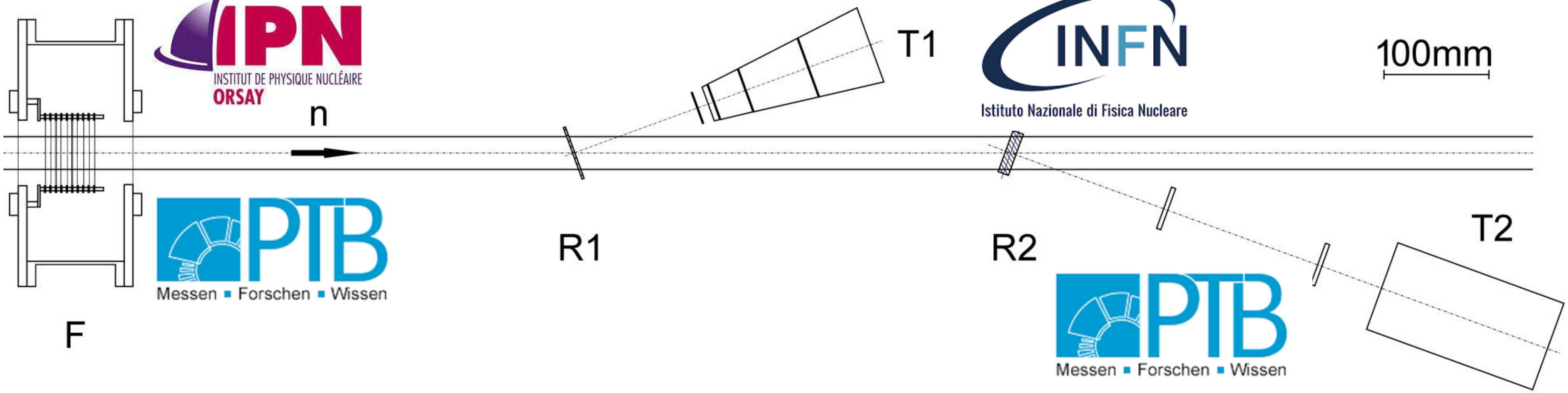
- high instantaneous flux
- low average flux
- intense γ-flash



Requirements:

- Fast detectors
- Fast, EMI-proof frontend electronics
- High efficiency and/or high granularity
- Many DAQ-channels

The ^{235}U(n,f) / ^{1}H(n,n)p Experiment

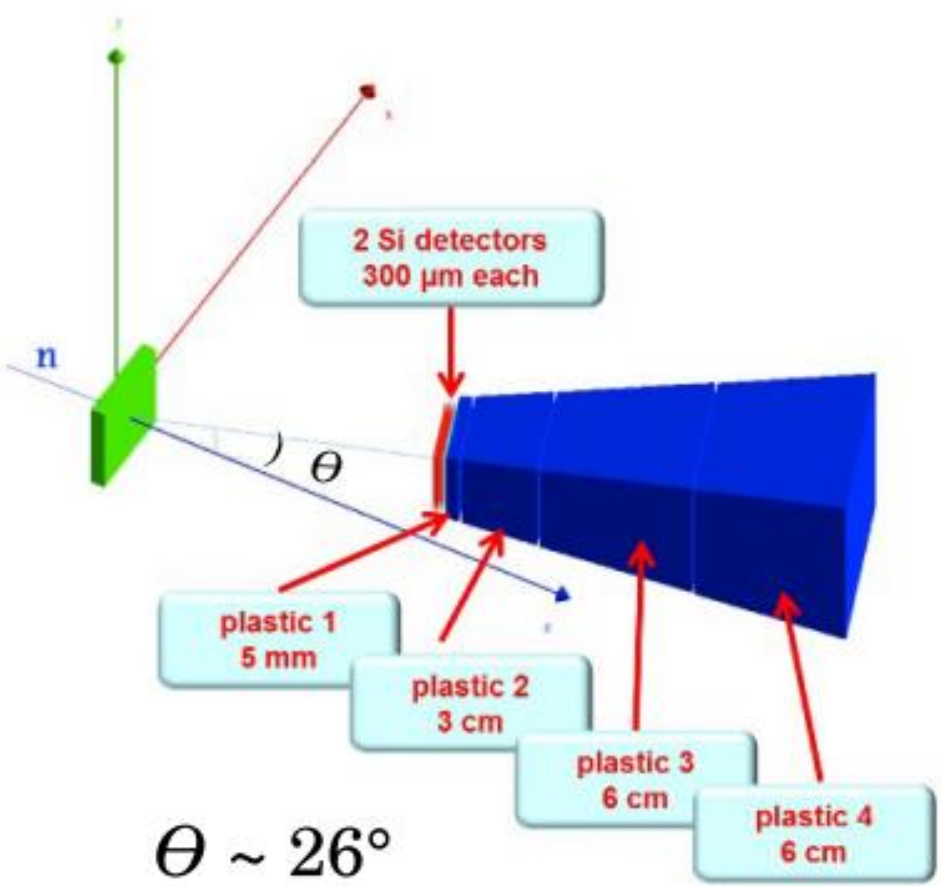


Simultaneous detection of recoil protons and fission fragments:

- **Experiment at EAR1:**
  high neutron energies, good time resolution
- **Capture collimator:**
  small kinematical energy spread,
  red. neutron flux
- **Challenge: intense γ flash**
- **Detection efficiencies do not cancel!**

$$\frac{\sigma_{^{235}\mathrm{U(n,f)}}}{(\mathrm{d}\sigma_{\mathrm{np}}/\mathrm{d}\Omega)} = \frac{n_{\mathrm{H}}\varepsilon_{\mathrm{p}}\Omega_{\mathrm{geo}}N_{\mathrm{FF}}}{n_{\mathrm{U}}\varepsilon_{\mathrm{FF}}N_{\mathrm{p}}}$$

Experimental set-up

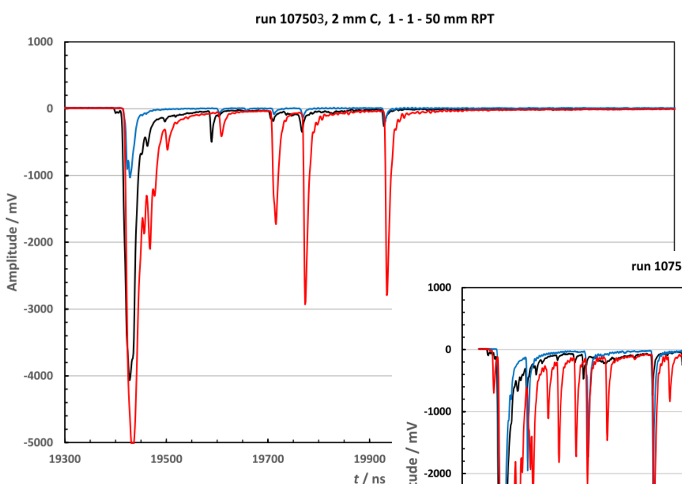


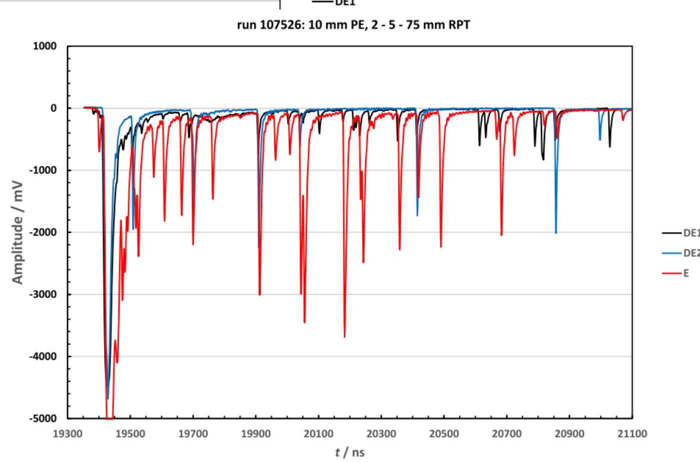
Triple-Stage RPT

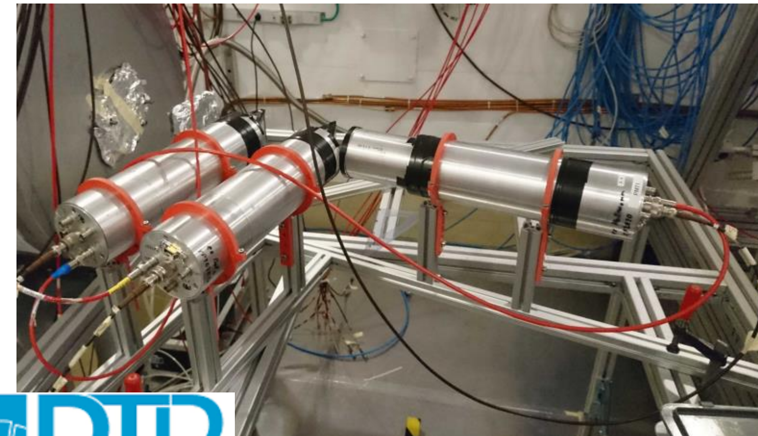
Several ΔE_1-ΔE_2-E RPT configurations:

- **solid angle defined by ΔE_2**
- **1, 2, 5 mm ΔE scintillators (EJ204)**
- **50, 100 mm E scintillators (EJ204)**

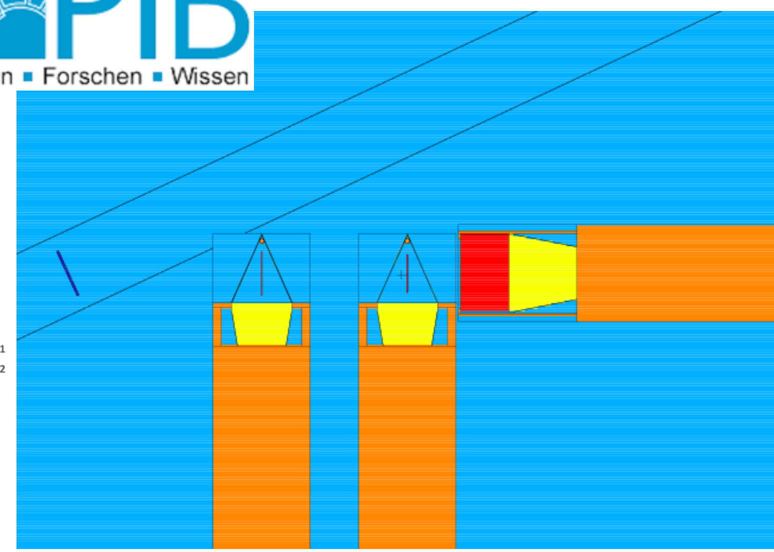
⇒ low Z: reduced sensitivity to γ flash!





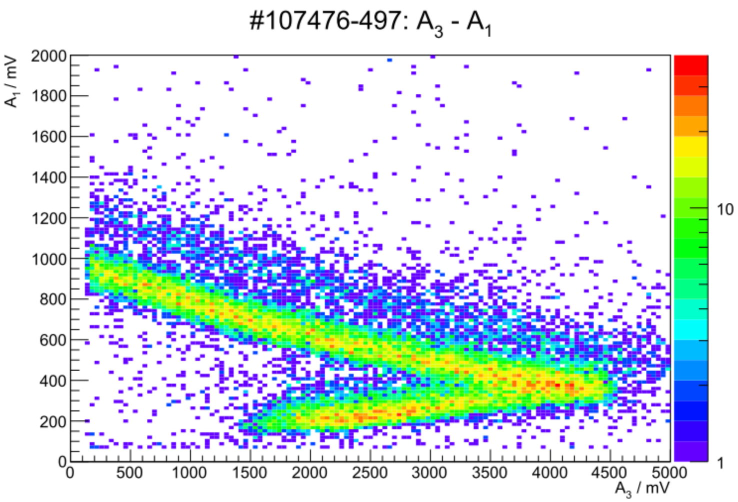


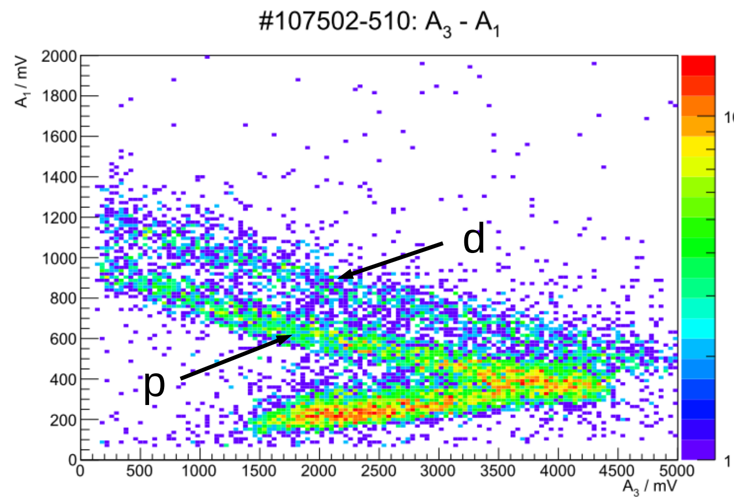
Messen ■ Forschen ■ Wissen



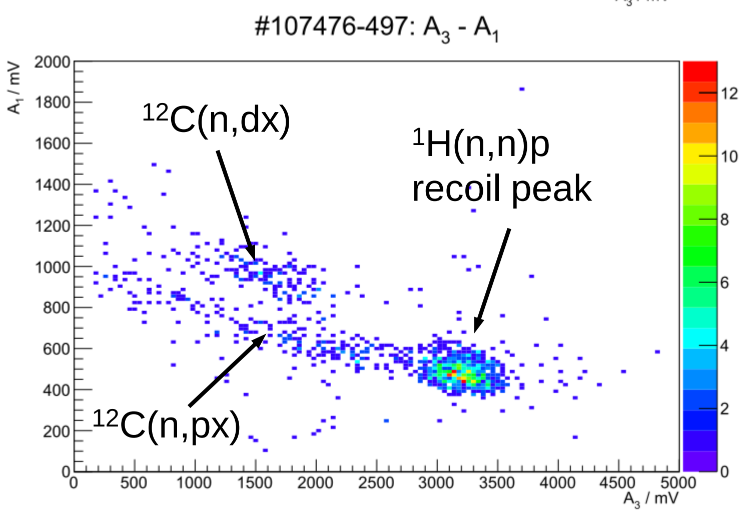
Particle separation: 1 mm - 1 mm - 50 mm EJ204

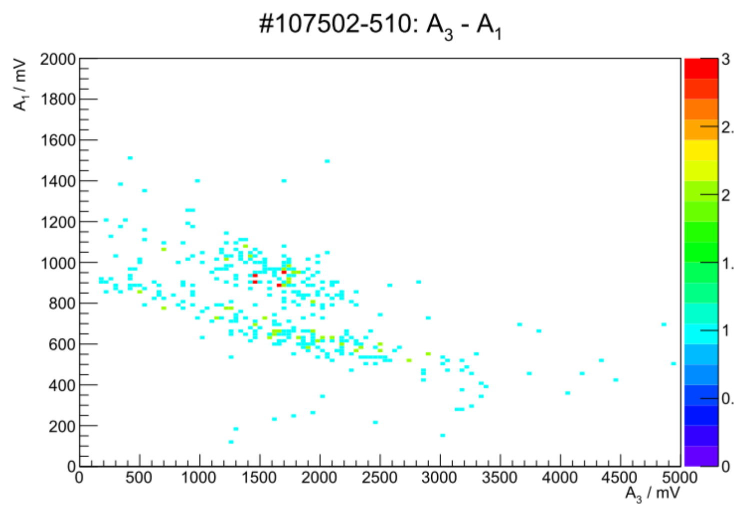
2 mm PE, 1.80×10^{17} p | **2 mm C, 1.31×10^{17} p**





all energies

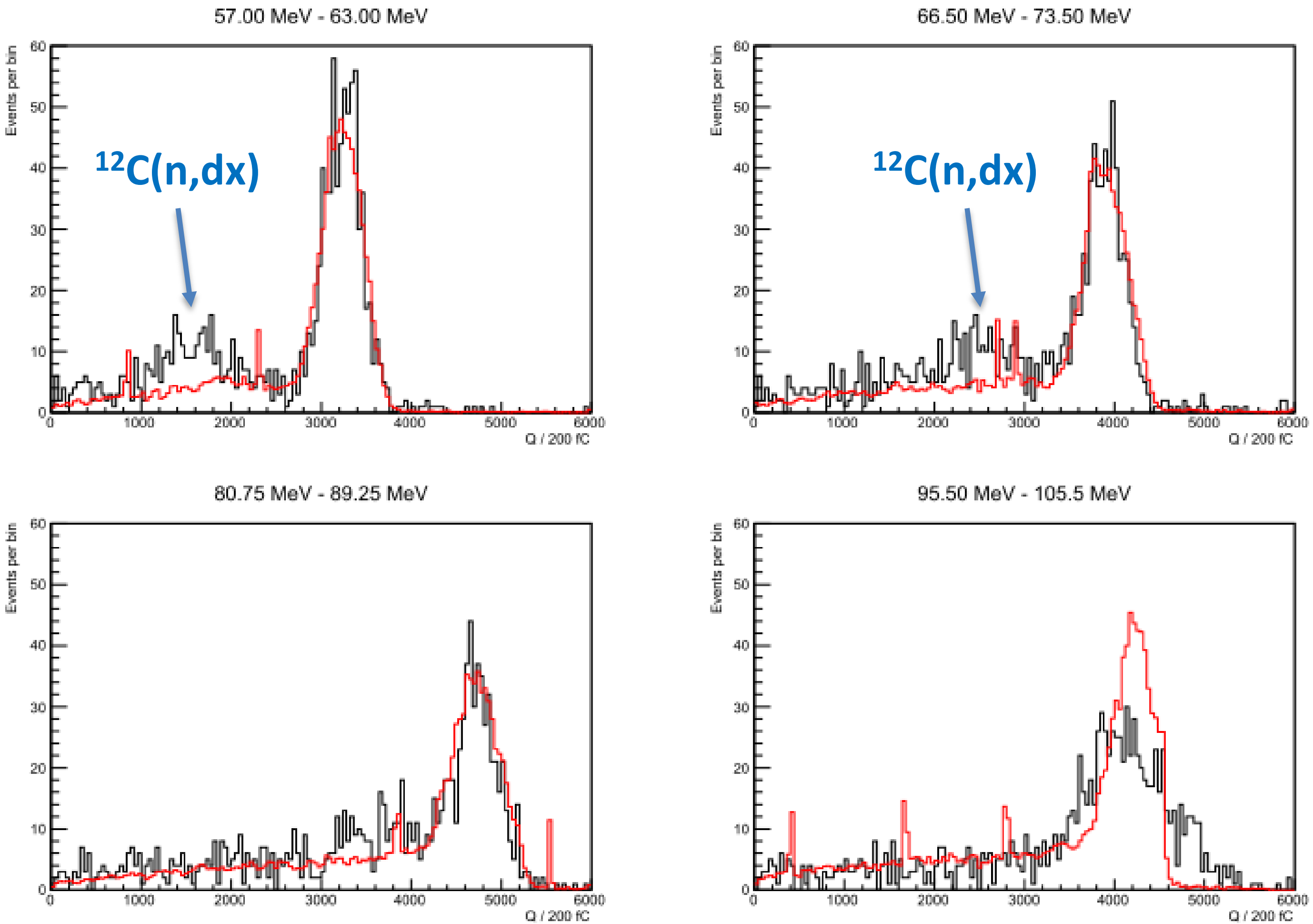




57 MeV – 63 MeV

Full MCNPX Simulation : 1 mm – 1 mm – 50 mm RPT, 2 mm PE

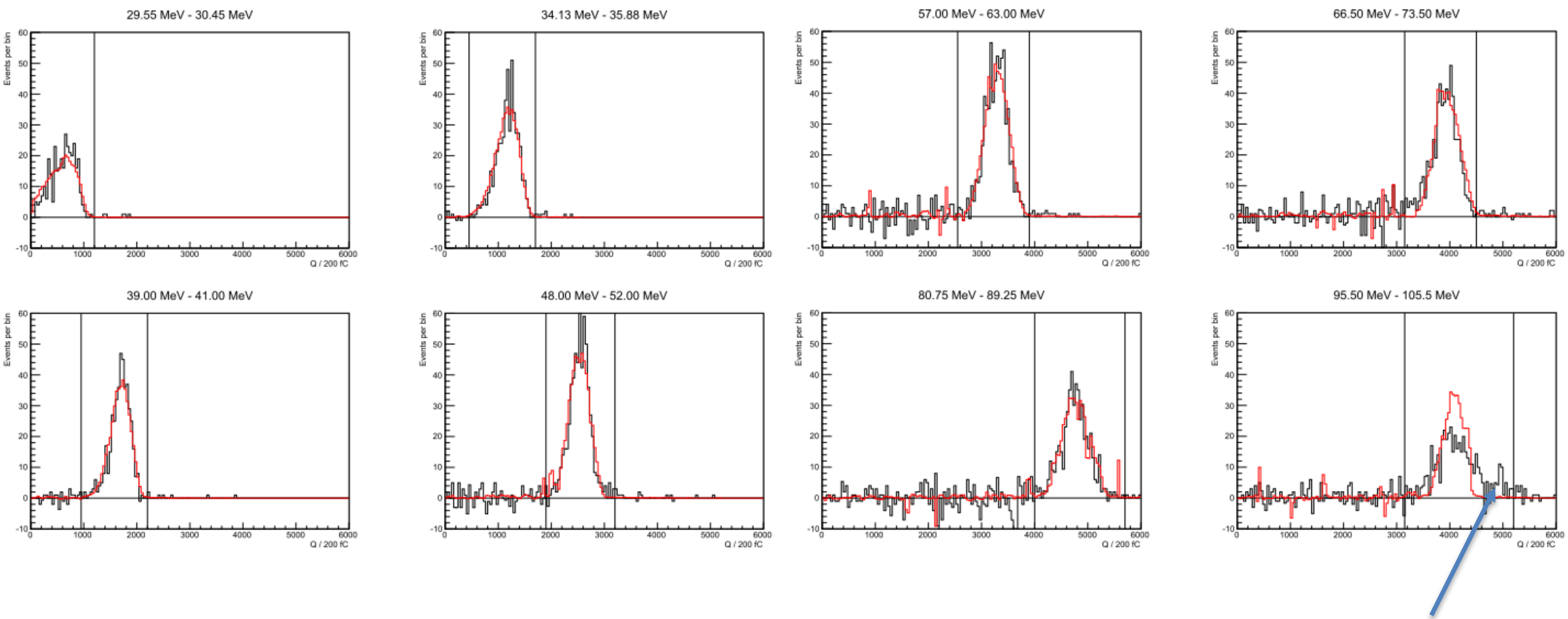
Pulse-height distributions in the *E* detector



Transported particles: n, p, d

R. Nolte

MCNPX Simulation : 1 mm – 1 mm – 50 mm RPT, 2 mm PE



proton escape!

^{12}C(n,x) background subtracted in sim. and exp. data using matched graphite samples

Detection of Fission Fragments

- **PPAC:**

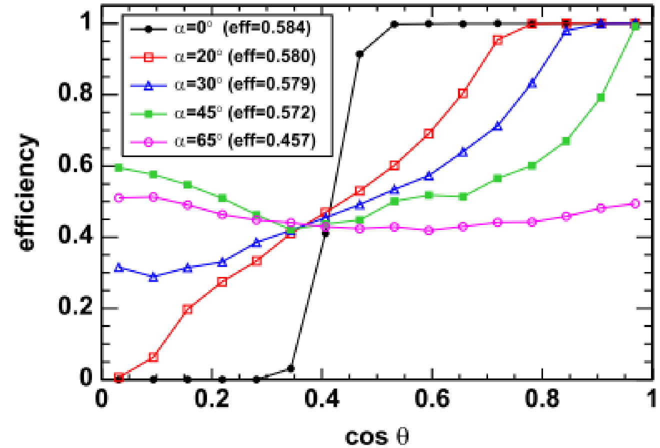
  low pressure: not sensitive to γ-flash
  FF detection efficiency $\varepsilon_{FF} \approx 60\%$
  good identification of fission events

- **PPFC:**

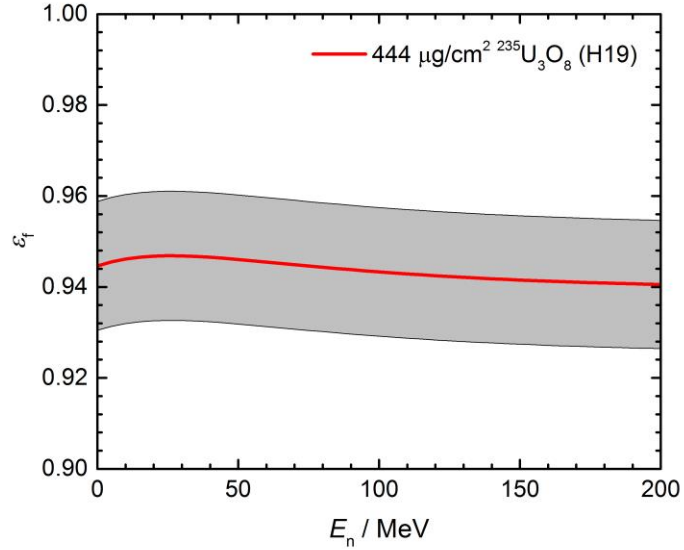
  ambient pressure: sensitive to γ-flash
  no gain: sensitive to EM interference
  calculable efficiency: $\varepsilon_{FF} \approx 94\% - 97\%$

⇒ Strategy:

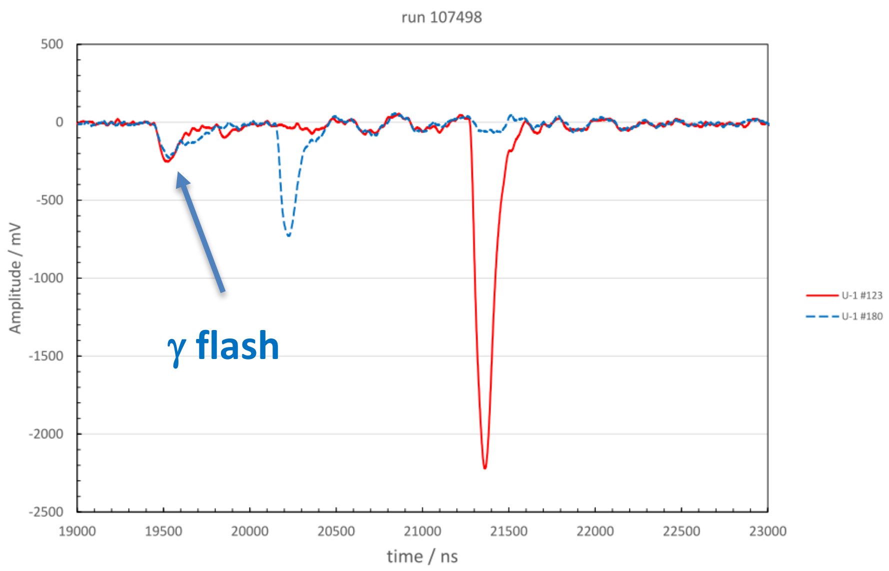
- **use PPFC at 'lower' neutron energies**
- **calibrate PPAC for higher energies**

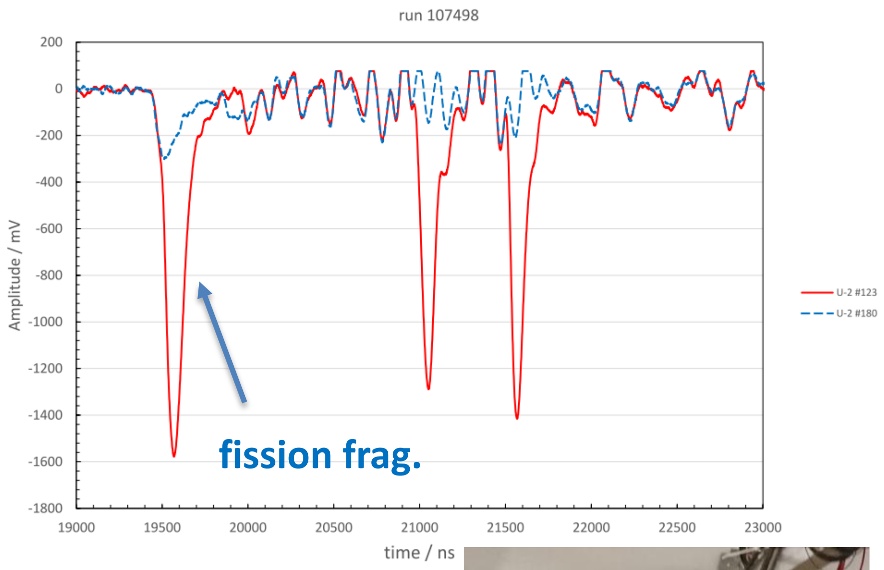


D. Tarrio et al., NIMA743 (2014) 78-85

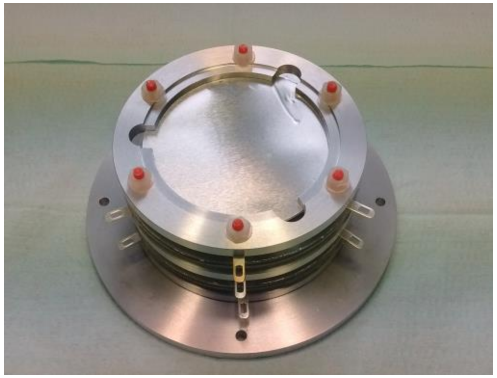


Fission Chamber: Waveforms

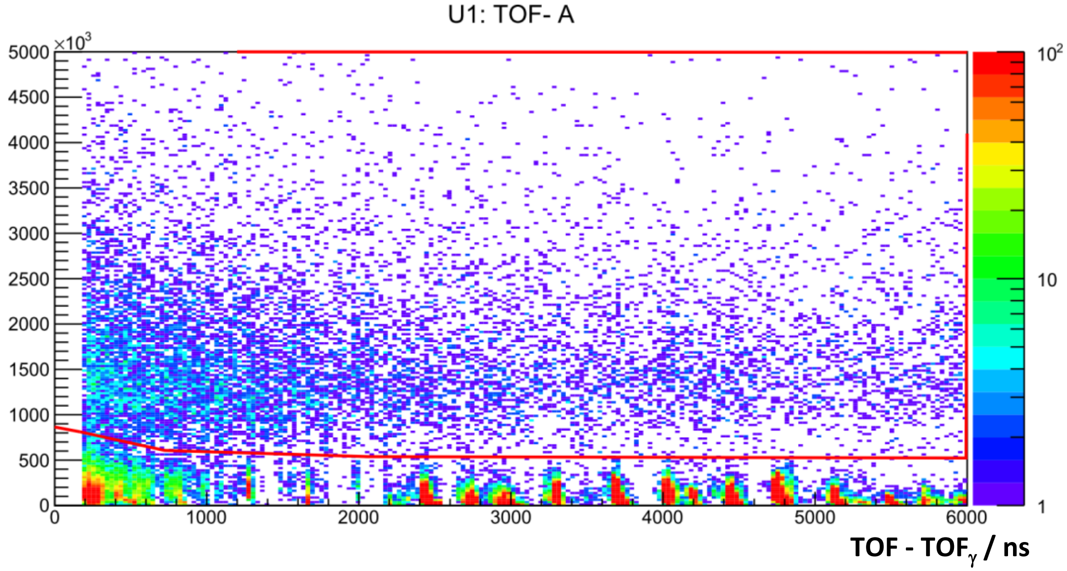


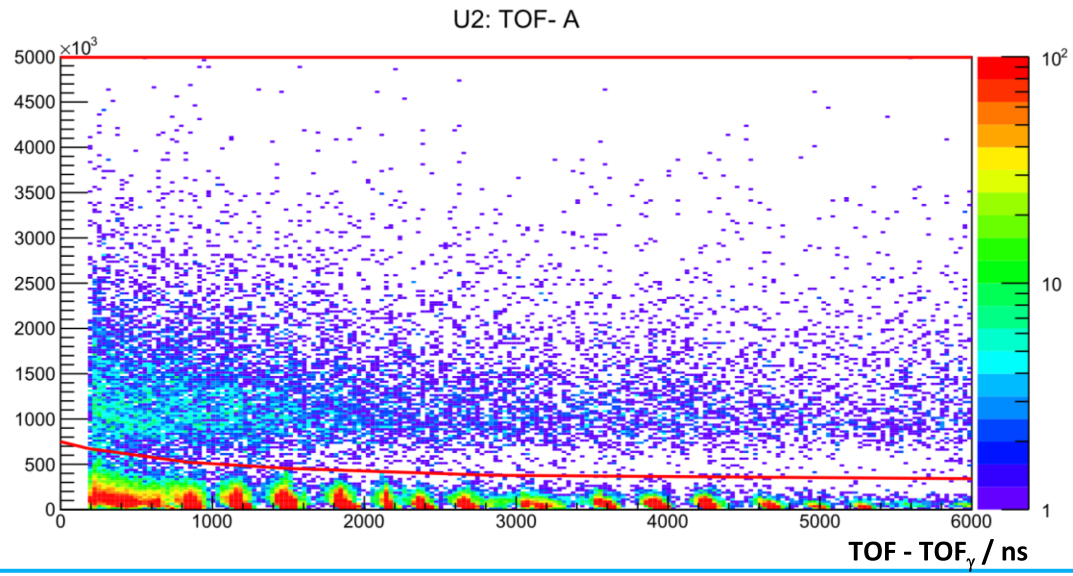


- **Weak γ flash!**
- **EM interference: 'ringing'!**
- **Waveforms from blank and U samples are different**
- **Proper pulse shape analysis: tbd!**



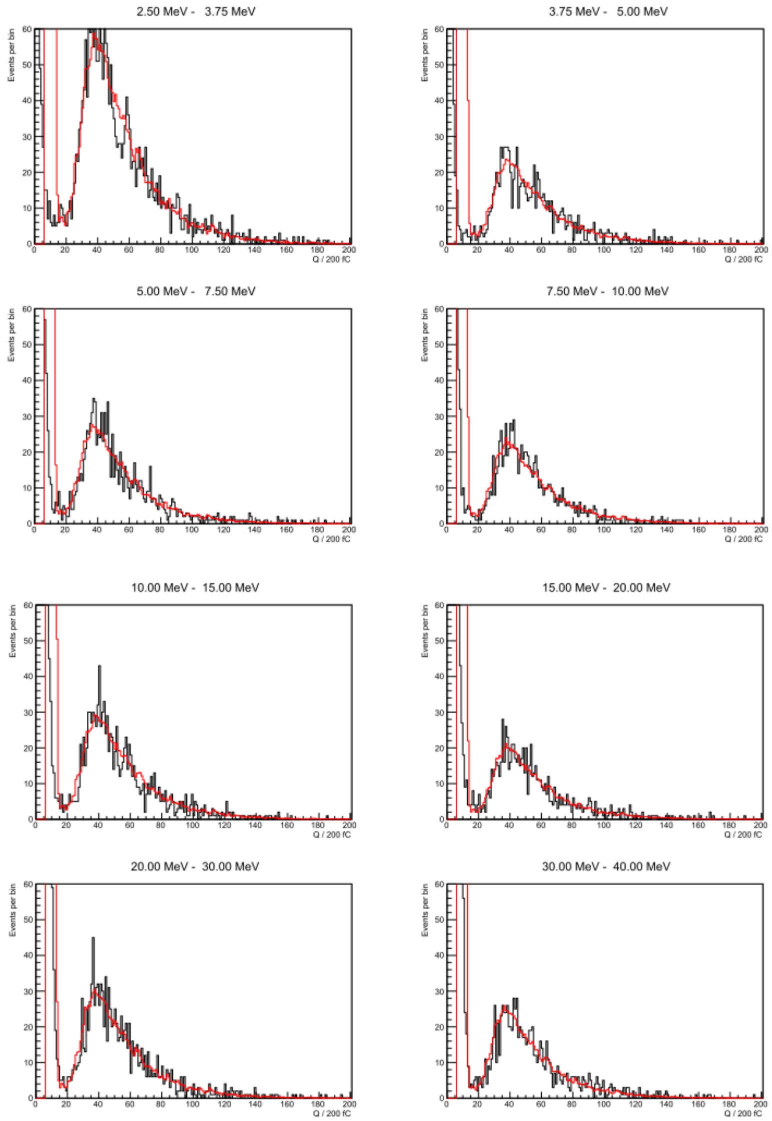
Fission Chamber: Amplitude - TOF

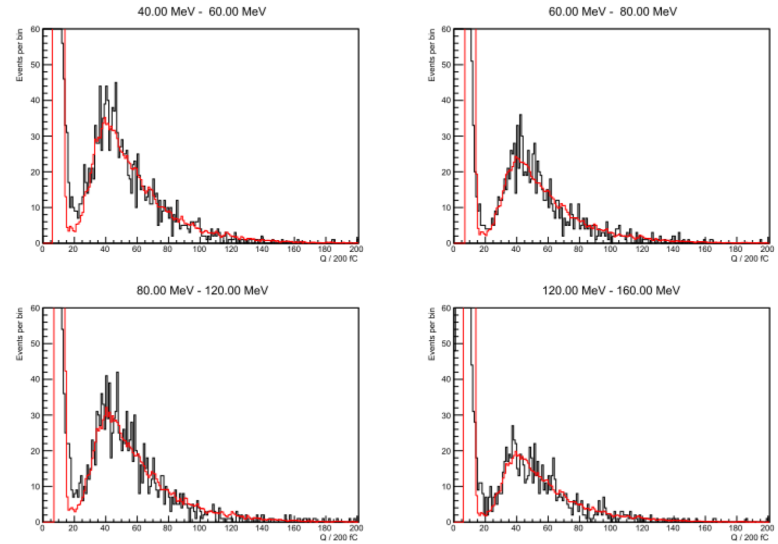




- **Parasitic and dedicated pulses**
- **5.02×10^{17} protons**
- **Charge-sensitive PreAmps + Fast Filter**

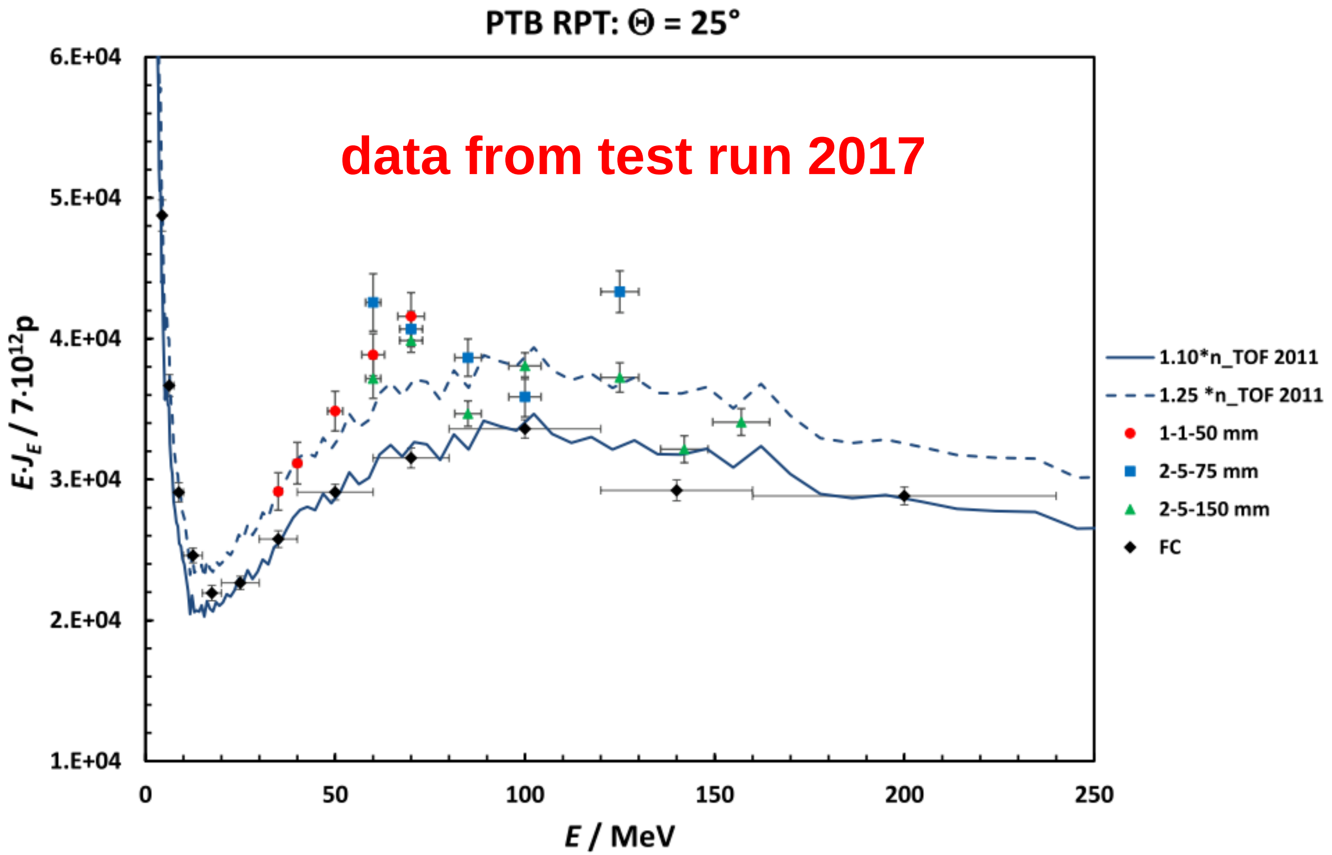
Fission Chamber: Amplitude Distributions





- **Reference distribution $\langle E_n \rangle$ = 25.4 meV:**
  Zero bias correction $k_0 \approx 1.05$
- **FC works at intermediate energies:**
  $E_n \leq 150$ MeV
- **PPAC required for higher energies**

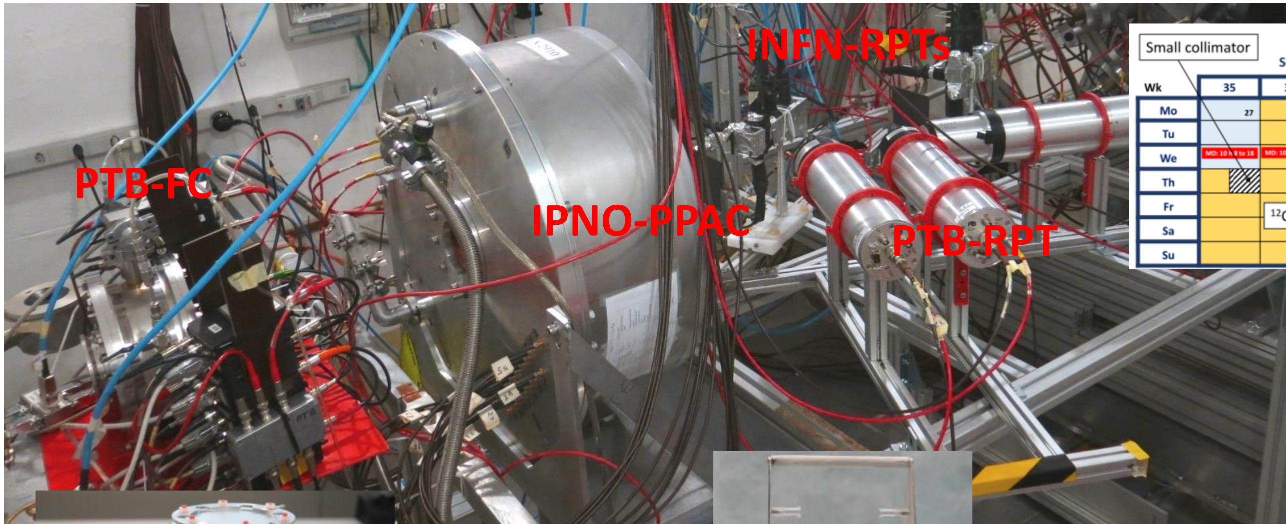
Preliminary Reconstructed Flux

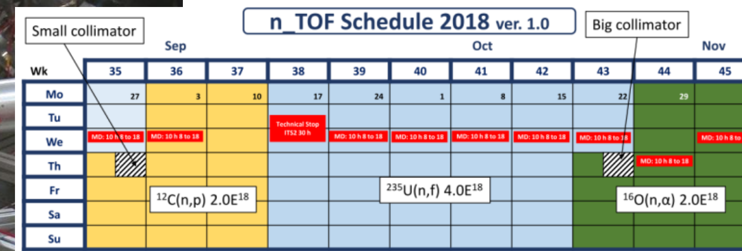


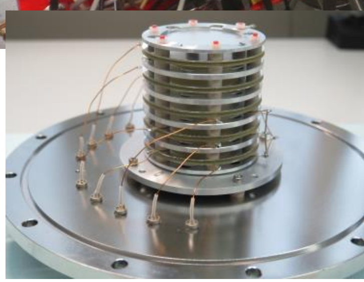
- **Still considerable scatter in the RPT data**
- **Systematic difference between RPT and FC: 15 %**

⇒ Cross check using quasi-mon. neutrons at TLABS!

Final Experiment 2018







Final run 2018:

- **35 days**
- **$3.4{\cdot}10^{18}$ protons**

PTB detectors:

Energy range: 30 MeV – 130 MeV

FC: 8 ^{235}U layers, m_{tot} = 2.4 mg/cm^2

RPT: 0.5 mm – 0.5 mm – 50 mm EJ204
1 mm – 1 mm – 50 mm
2 mm – 2 mm – 100 mm

PE-Samples:
1 mm, 2 mm, 5 mm

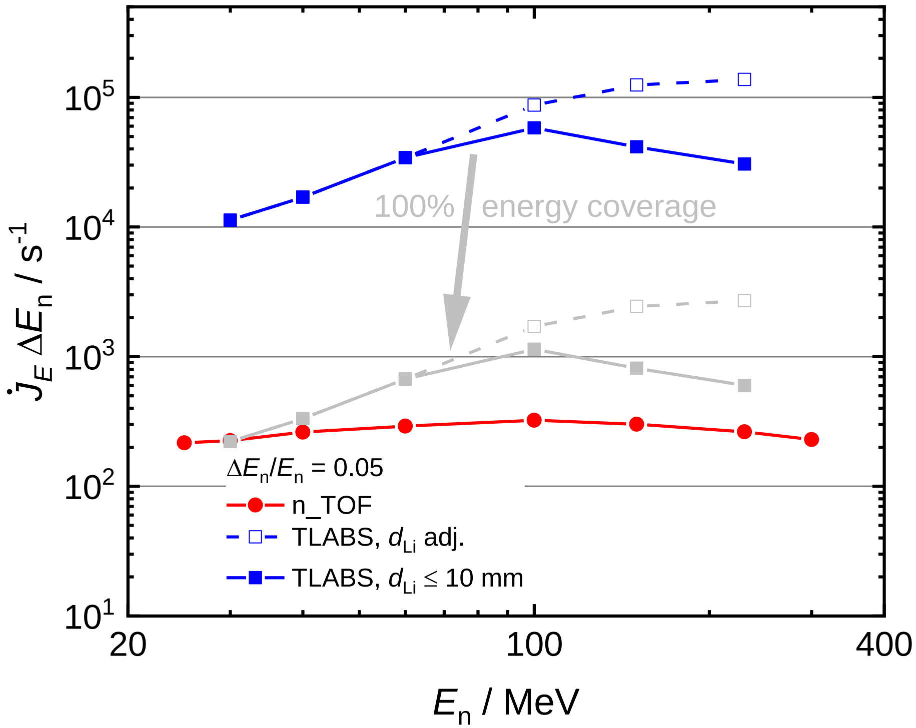
Analysis in progress!

- E. Pirovano, Q. Ducasse (PTB)
- A. Manna (INFN / U Bologna)

n_TOF - iThemba LABS

Compare white and qmn beams for finite energy groups: $\Delta E_n/E_n = 0.05$

- **n_TOF:**
  - d = 182 m (EAR1)
  - Capture collimator
  - $9{\cdot}10^{16}$ protons per day
- **iThemba LABS QMN Facility:**
  - d = 5.5 m
  - Collimator: ∅18 mm
  - Li target thickness: $\Delta E_n/E_n \leq 0.05$
  - no pulse selection



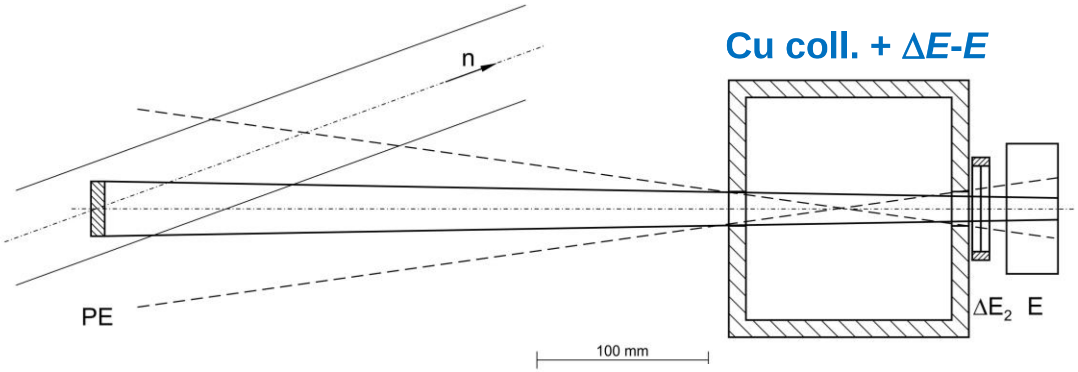
iThemba LABS:

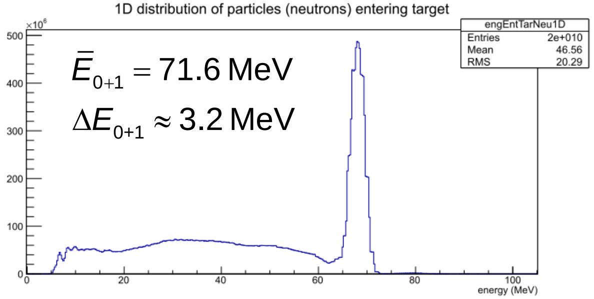
- **higher brilliance**
- **quasi-DC beam: rep. rate = 11 – 26 MHz**
- **⇒ well suited for cross checking n_TOF measurements !**

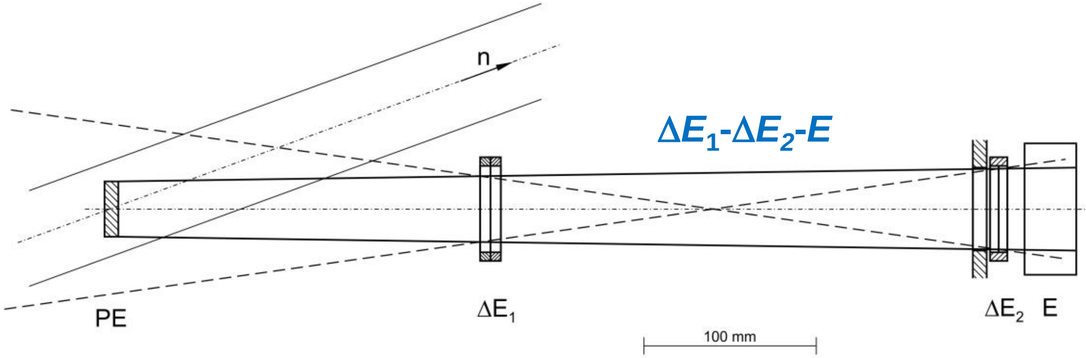
RPT Design Exercise at iThemba LABS

Test of a recoil proton telescopes in 2013:

- **Neutron Source: ^{nat}Li (8 mm) + p (75 MeV):**
- **Collimated beam (50×50 mm^2)**
- **Two RPT designs**

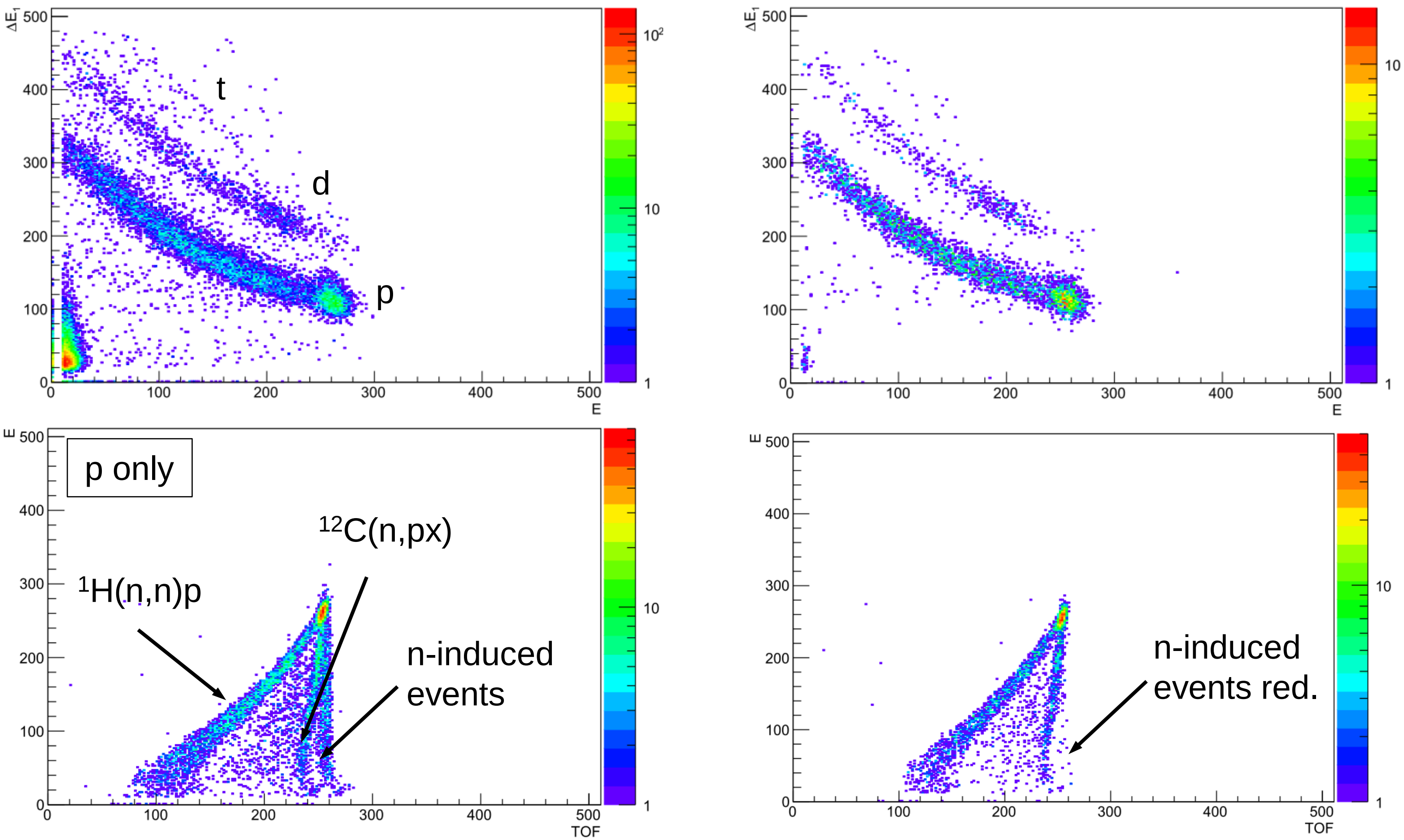






RPT Design Exercise: Results

Double stage RPT: Cu-coll. + ΔE-E | **Triple stage RPT: ΔE_1-ΔE_2-E**

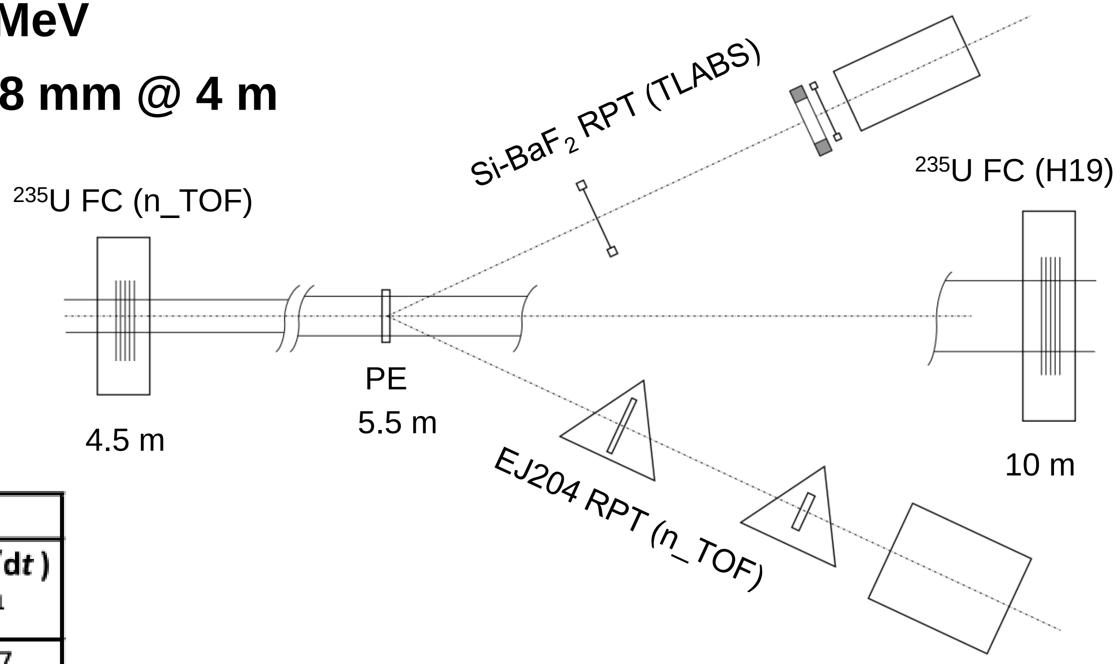


- **Good particle discrimination with 500 µm Si-PIPS**
- **Less neutron-induced coupling with ΔE_1-ΔE_2-E RPT**

^{235}U(n,f) / ^{1}H(n,n)p Benchmark Experiment for TLABS

Direct comparison: fission chambers - recoil telescopes:

- **Reference: H19 (PTB ref. instrument)**
- **E_n = 30 MeV, 60 MeV, 150 MeV**
- **Optimized collimation: ∅18 mm @ 4 m**
- **no pulse selection**



Expected count rates:

E_n MeV	RPT (dN_p/dt) h^{-1}	PPFC m_U mg/cm^2	PPFC (dN_f/dt) h^{-1}
30	396	2.32	367
40	500	2.32	524
60	1064	2.32	972
100	2640	2.32	2112
150	1395	2.32	2838
200	1597	2.32	3131

⇒ **stat. uncertainties of 1-2% can be achieved!**

Summary

- **First fission cross section measurement at n_TOF relative to the n-p scattering cross section**
- **Two fission and recoil proton detectors.**
- **Useful data at least up to 150 MeV (600 ns after γ-flash) for all detectors**

- **An experiment with qmn neutrons at TLABS would be a very useful cross check of the RPT efficiencies!**
- **This would also provide the metrological infrastructure for the upgraded TLABS facility**

Thank you for your attention!

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