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

L. Audouin[1], M. Barbagallo[2], N. Colonna[2], L. Cosentino[2], M. Diakaki[3,4], I. Duran[5], P. Finelli[6,2], P. Finocchiaro[2], J. Heyse[7], S. Lo Meo[8,2], C. Massimi[2,6], P.F. Mastinu[2], P.M. Milazzo[2], F. Mingrone[3], A. Musumarra[2,9], R. Nolte[10], C. Paradela[7], D. Radeck[10] , P. Schillebeeckx[7], L. Tassan-Got[1], G. Vannini[2,6], A. Ventura[2]

and the n_TOF Collaboration

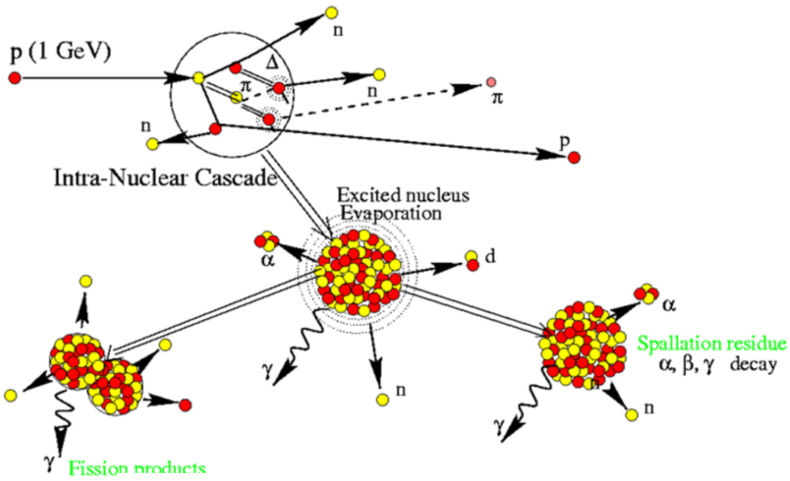
[1] CNRS-IN2P3, Univ. Paris-Sud, Univ. Paris-Saclay, Orsay, France
[2] INFN - sezioni di Bari, Bologna, LNL, LNS and Trieste, Italy
[3] CERN, Switzerland
[4] National Technical University of Athens, Greece
[5] Universidad de Santiago de Compostela, Spain
[6] Dipartimento di Fisica e Astronomia, University of Bologna, Italy
[7] European Commission, Joint Research Centre - Geel, Belgium
[8] ENEA – Bologna, Italy
[9] Dipartimento di Fisica e Astronomia, University of Catania, Italy
[10] Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Outline

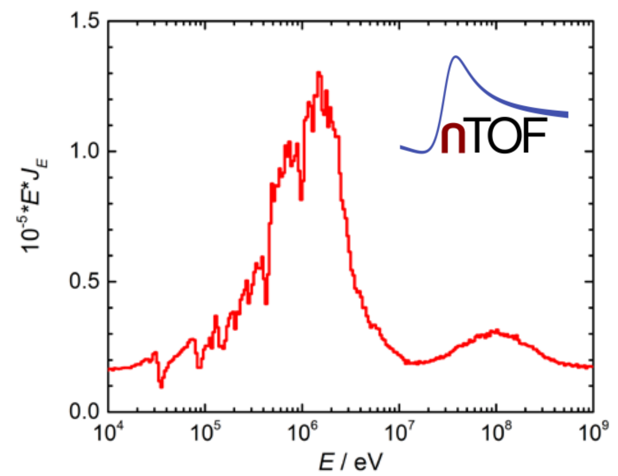
- Scientific Motivation
- Present Status of the Data for ^{235}U(n,f) at E_n > 20 MeV
- Proposed Experimental Setup
- Results from Test Runs
- Beam Time Request

Interest in Neutron-Induced Fission at High Energies

- **Physics Interest:**
  - **Coupling of INC and fission models**
  - **Role of pre-equilibrium processes**
  - **Isospin effects: (p,f) / (n,f) ratio**
  - **Level densities, fission barriers**
  - **…**

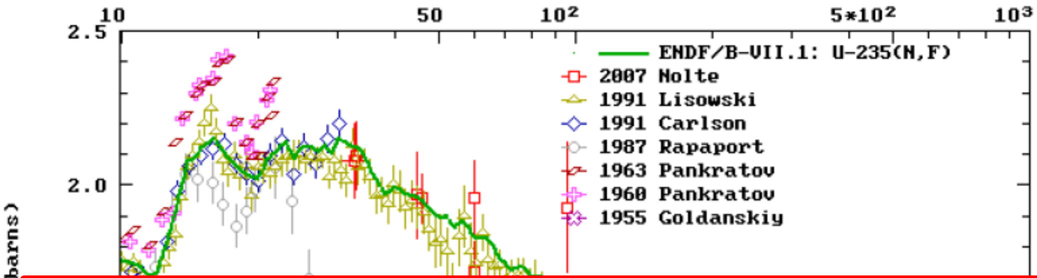


- **Technological Interest:**
  - **Design of targets for spallation sources**
  - **Accelerator Driven Systems**
  - **Reference XS for neutron measurements**
    secondary neutrons in hadron therapy,
    dosimetry at flight altitude and in space,
    shielding of high-energy accelerators,
  - **^{235}U(n,f) used to measure n_TOF flux, normalization rel. to ^{1}H(n,n)p still missing**



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

- **^{235}U(n,f): most important secondary standard for neutron flux measurements up to 200 MeV**



PTB
Eing. – 5. NOV. 2007

IAEA
Atoms for Peace
International Atomic Energy Agency
Agence internationale de l'énergie atomique
Международное агентство по атомной энергии
Organismo Internacional de Energía Atómica

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

Wagramer Strasse 5, PO Box 100, 1400 Wien, Austria
Phone: (+43 1) 2600 • Fax: (+43 1) 26007
Email: Official.Mail@iaea.org • Internet: http://www.iaea.org

In reply please refer to:
Dial directly to extension: (+431) 2600-

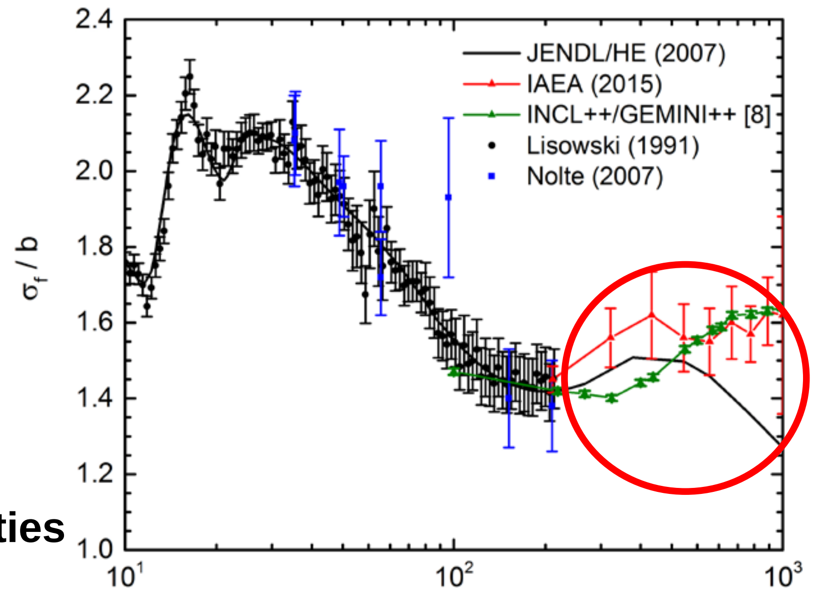
2007-10-29

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.

- **Only one ‚complete' dataset relative to ^{1}H(n,n)p: Lisowski/LANL (1991)**
- **Some additional scattered data with larger uncertainties**

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

- **Data base of high-energy fission cross section:**
  - **no 'absolute' (n,f) data above 200 MeV**
  - **(n,f) cross section ratios: n_TOF!**
  - **(p,f) data (Kotov 2006)**



- **Evaluation procedure uses**
  - **(p,f) data, (n,f) data where available**
  - **nuclear event generators: $\sigma_{(n,f)} / \sigma_{(p,f)}$**
  - **$\sigma_{(n,f)} / \sigma_{(p,f)} \approx 1$ around 1 GeV**
  - **adjust fission barriers and level densities**

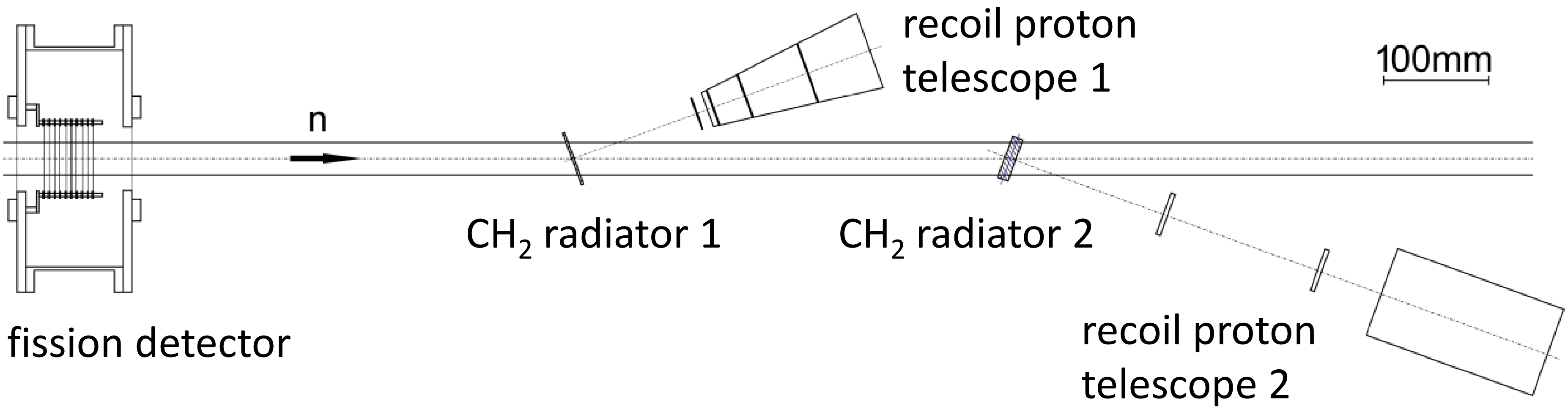
IAEA
International Atomic Energy Agency

INDC(NDS)-0681
Distr. ST/J/G/NM

INDC International Nuclear Data Committee

Our analysis indicates that the new absolute measurements of the neutron induced fission cross sections (e.g. relative to n-p scattering) on uranium, bismuth, lead and plutonium have the highest priority in establishing neutron induced fission reaction standards above 200 MeV.

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



Simultaneous detection of fission fragments and recoil protons:

- **Detection efficiencies do not cancel!**
- **Experiment at EAR1:**
  high neutron energies,
  good time resolution
- **Capture collimator:**
  small kinematical energy spread in RPTs,
  less distortions from γ-flash
- **Challenge: E_n = 1 GeV ⇒ $t_n - t_\gamma$ = 90 ns**

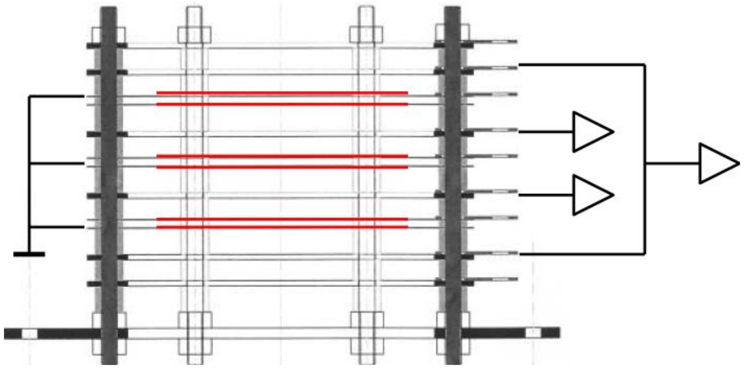
$$\frac{\sigma_{^{235}\mathrm{U(n,f)}}}{(\mathrm{d}\sigma_{\mathrm{np}}/\mathrm{d}\Omega)} = \frac{k_{\mathrm{p}} n_{\mathrm{H}} \varepsilon_{\mathrm{p}} \Omega_{\mathrm{geo}} N_{\mathrm{FF}}}{k_{\mathrm{f}} n_{\mathrm{U}} \varepsilon_{\mathrm{FF}} N_{\mathrm{p}}}$$

Detection of Fission Fragments

- **Main challenge:**
  - **Distortions induced by the γ flash**
  - **Separation of fission events and background from fragments**

- **PPAC:**

  low pressure: not sensitive to γ-flash
  FF detection efficiency $\varepsilon_{FF} \approx 60$ %
  operation up to 1 GeV demonstrated
  limited number of transparent ^{235}U samples



- **PPFC:**

  atmospheric pressure: sensitive to γ-flash
  $\varepsilon_{FF} \approx 95$ %, uncertainty about 1 %
  operation up to 200 MeV demonstrated (FIC, H19)

⇒ Strategy:

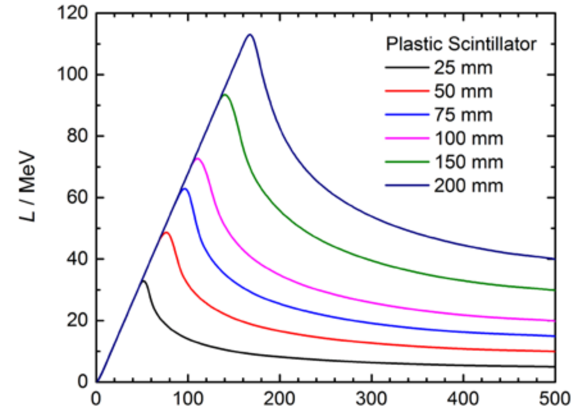
- **use dedicated low-mass PPFC at 'lower' neutron energies**
- **calibrate PPAC for higher energies**

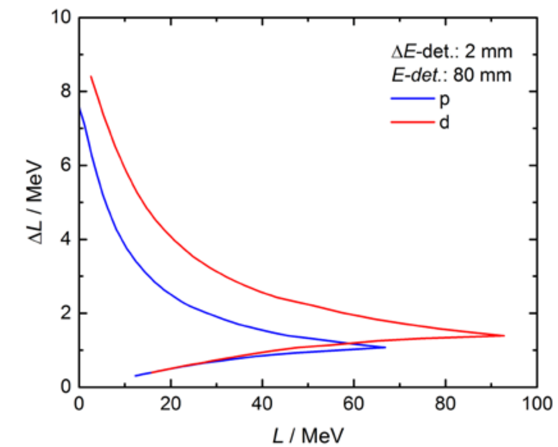
Detection of Recoil Protons

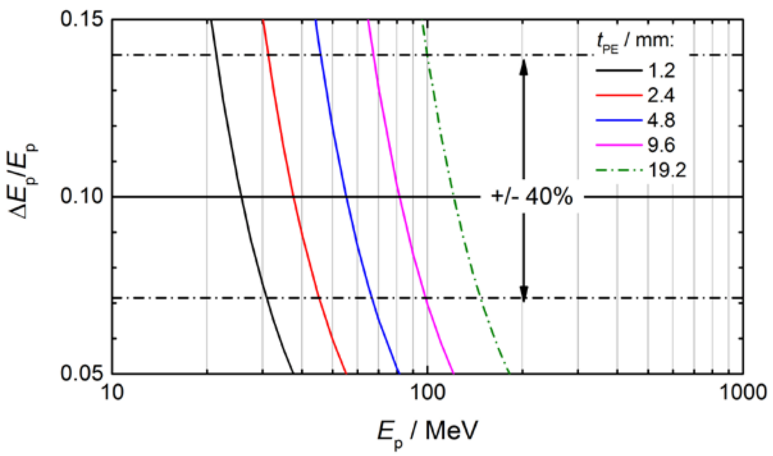
CH_2 radiators + fast plastic scintillator telescopes

- $E_p \approx E_n \cos^2(\Theta_p)$: distinct recoil peak
- ^{12}C(n, lcp x): ΔE-E particle identification
- ^{12}C(n, p x): graphite sample
- Energy loss limits sample thickness

⇒ **Several telescopes and samples required to cover full energy range!**







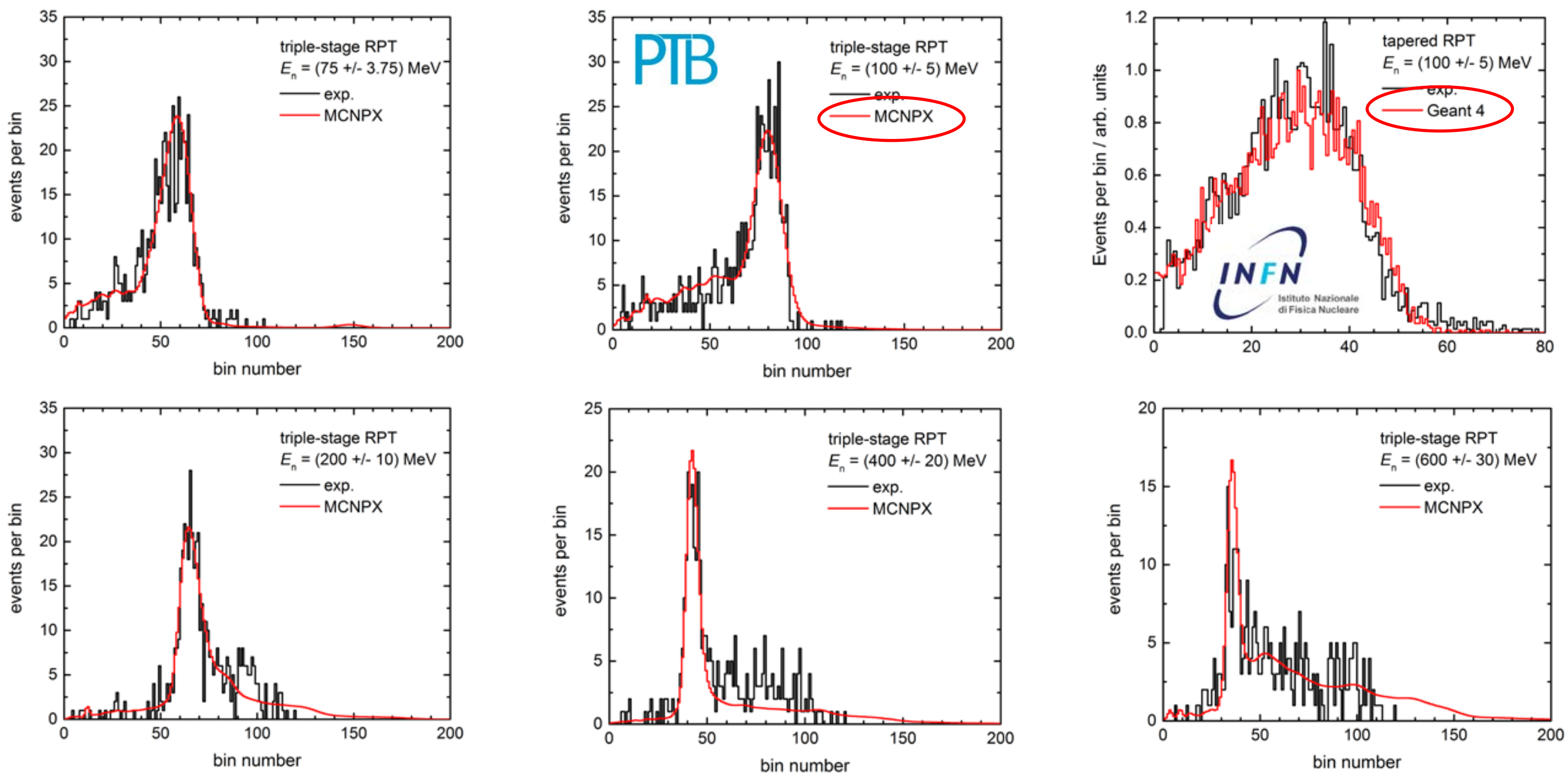
⇒ **Particle identification requires full energy deposition!**

1^{st} Test Run: Performance of the RPTs

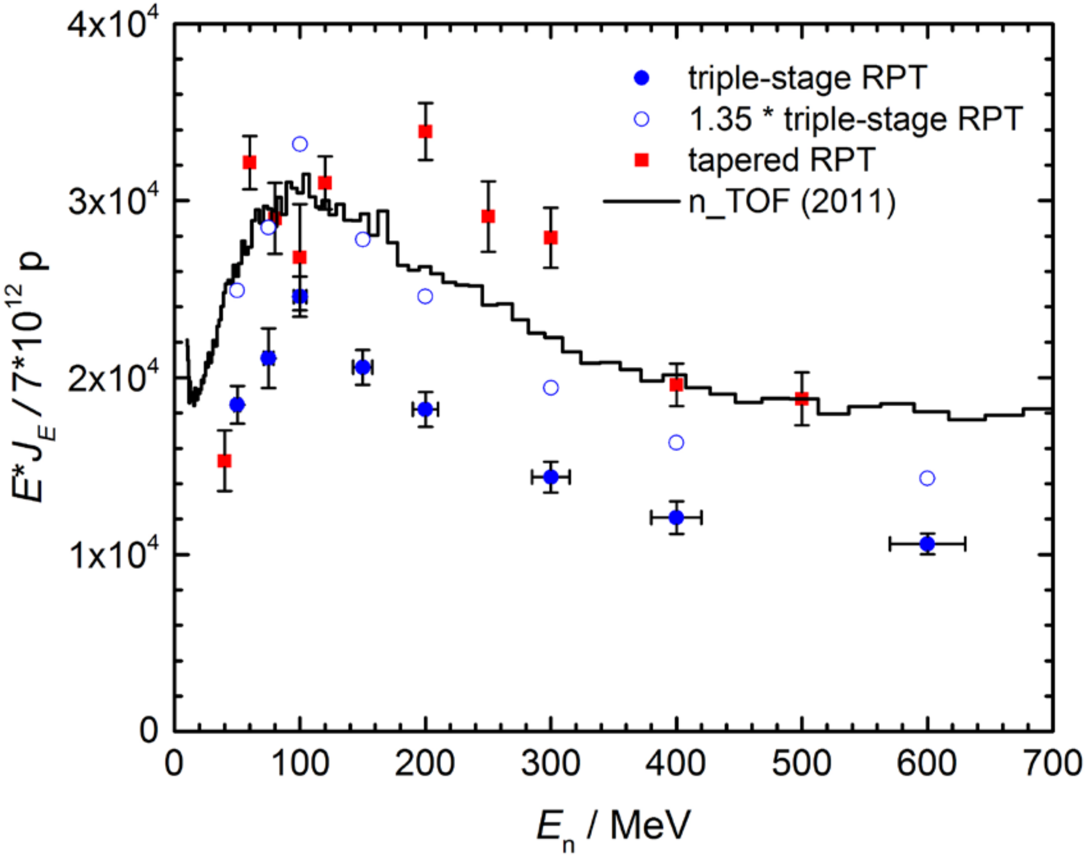
Focus: Test of two slightly different RPT designs

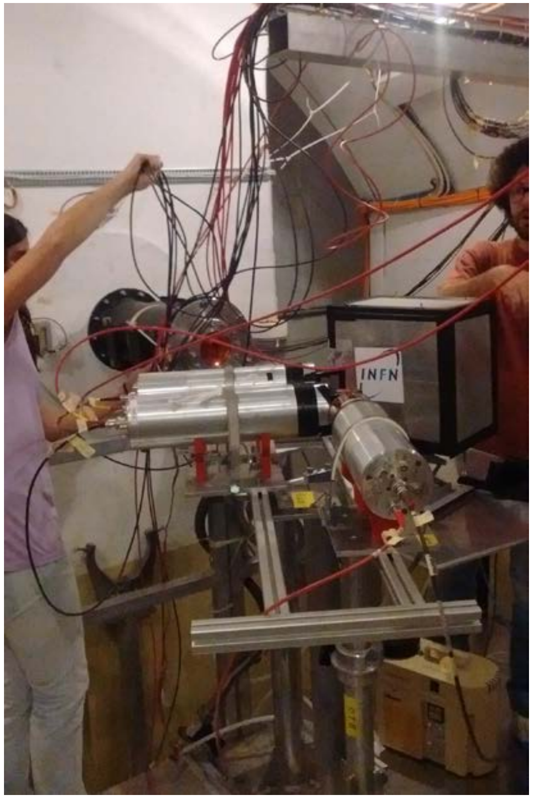
- both RPTs work up two 600 MeV
- γ-flash is no major problem!
- foreground / background ratio $\leq 10^{-2}$

Sample: 10 mm CH_2
Protons: 4.5×10^{16}



1st Test Run: Reconstructed n_TOF Flux





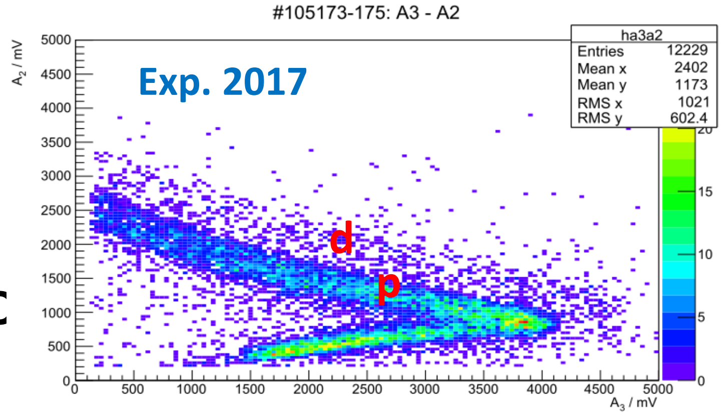
NB: **Alignment of RPTs to the neutron beam was not perfect**

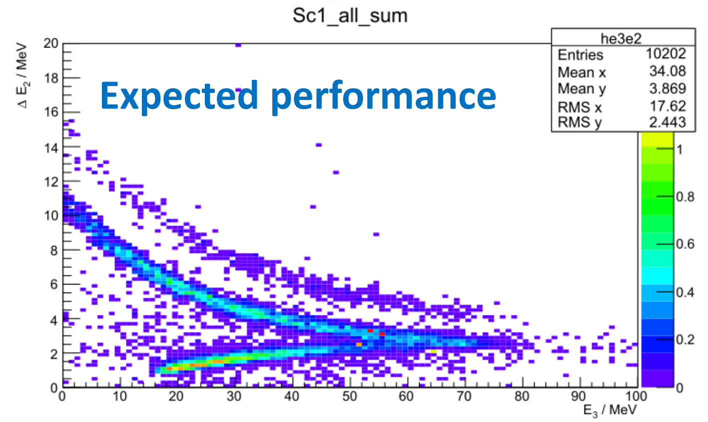
2^{nd} Test Run: Expected Results

Second Test in September 2017: 5×10^17 p

- **Test of fission test detector:**
  - dedicated simplified PPAC + low-mass PPFC
  - existing PPAC monitor + low-mass PPFC

- **Quantitative RPT test:**
  - Improved mechanical alignment and support structure!
  - Verification of improved particle separation
  - Full energy deposition at higher neutron energies: BaF_2 + optical filter as stop detector





Expected Event Rate

RPTs: Θ_p = 20°, Ω_{geo} = 18 msr (4 × 4 cm^2 @ 300 mm)
30 % overhead protons for graphite radiator

PPAC: 10 ^{235}U samples, 300 μg cm^{-2}

PPFC: 5 ^{235}U samples, 300 μg cm^{-2}

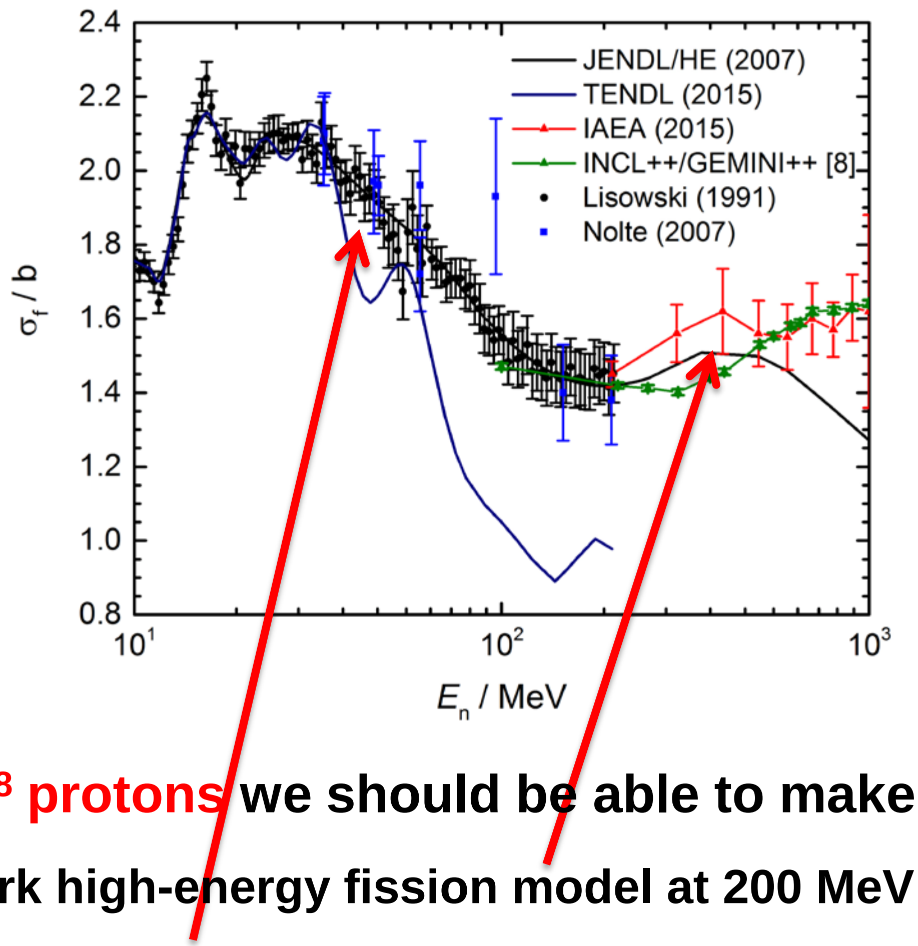
energy res.: $\Delta E_n / E_n$ = 0.05

stat. uncertainty: $\Delta N / N$ = 2 % for FFs and protons

E_n / MeV	23	30	40	60	100	150	230	300	400	600
J_E / MeV^{-1}	861	720	628	466	310	193	110	73	49	30
	RPT									
t_{PE} / mm	1	2	5	5	10	10	10	10	10	10
N_p / 10^{18}	0.64	0.78	036	0.50	0.39	0.62	0.94	1.10	1.09	0.95
	PPFC									
N_p / 10^{18}	3.0	2.8	2.5	2.5	2.6	3.0	3.4	3.6	3.9	4.5
	PPAC									
N_p / 10^{18}	2.4	2.2	2.0	2.0	2.1	2.4	2.7	2.9	3.2	3.6

NB: RPTs four times more efficient than PPFC/PPAC

Requested Number of Protons



With 4×10[18] protons we should be able to make a difference!

- **Benchmark high-energy fission model at 200 MeV – 600MeV**
- **Improve reference data below 200 MeV**

Thank you
for your attention!