Luigi Cosentino
INFN - LNS
ITALY

A new Proton Recoil Telescope for the n_TOF@CERN facility

The Motivation

The role of the ^{235}U(n,f) reaction

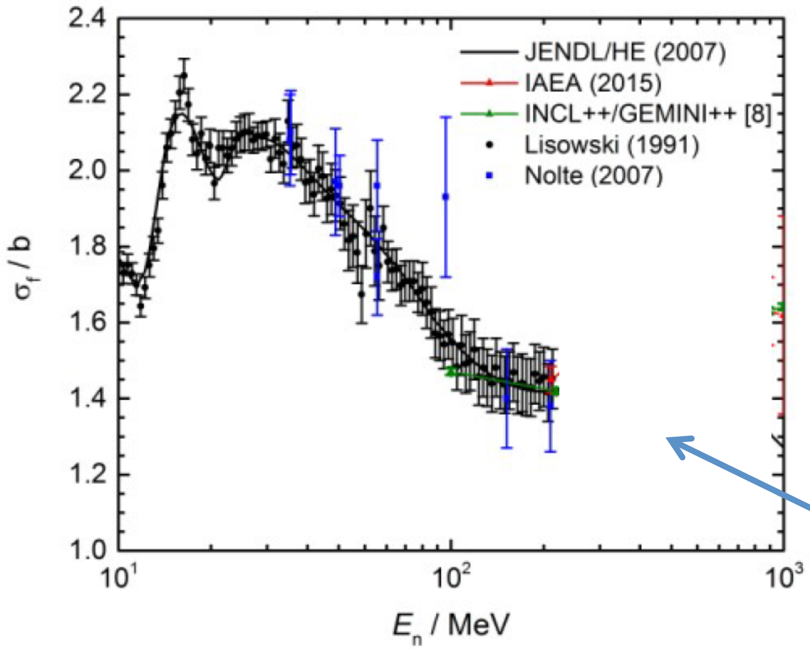
Neutron Cross Section Standards are essential for measurements and evaluations of other neutron cross sections

*The ^{235}**U(n,f)** cross section is one of the most important standards for neutron fluence measurements and for several applications, such as accelerator-driven nuclear systems, biological effectiveness of high-energy neutrons, etc..*

^{235}U(n,f) is a standard at

- ***Thermal energy: 0.025 eV***
- ***Energy range: 0.15MeV ÷ 200MeV.***

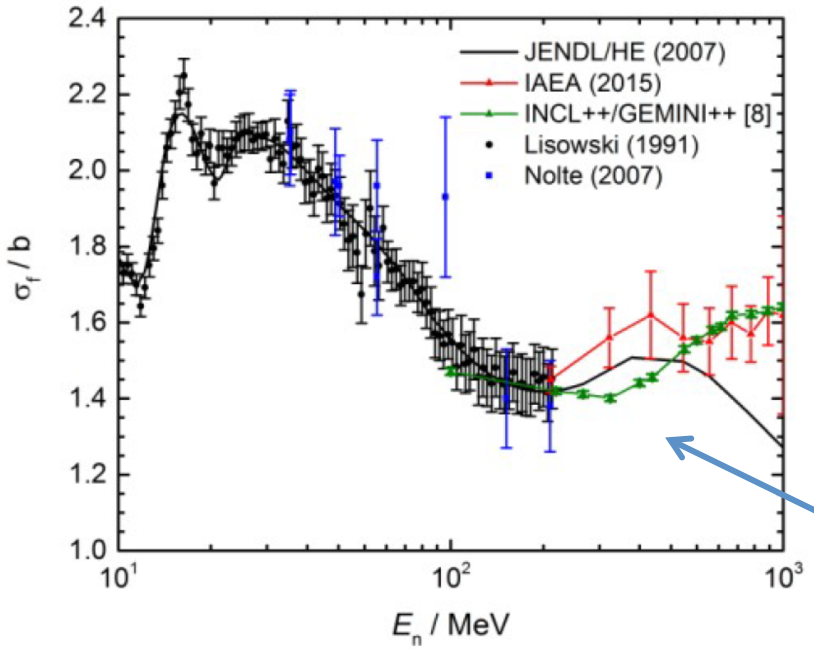
Status of the ^{235}U(n,f) cross section



No experimental data above 200MeV. Only theoretical models

Two sets of experimental data in the range 20 MeV – 200 MeV

Status of the $^{235}U(n,f)$ cross section



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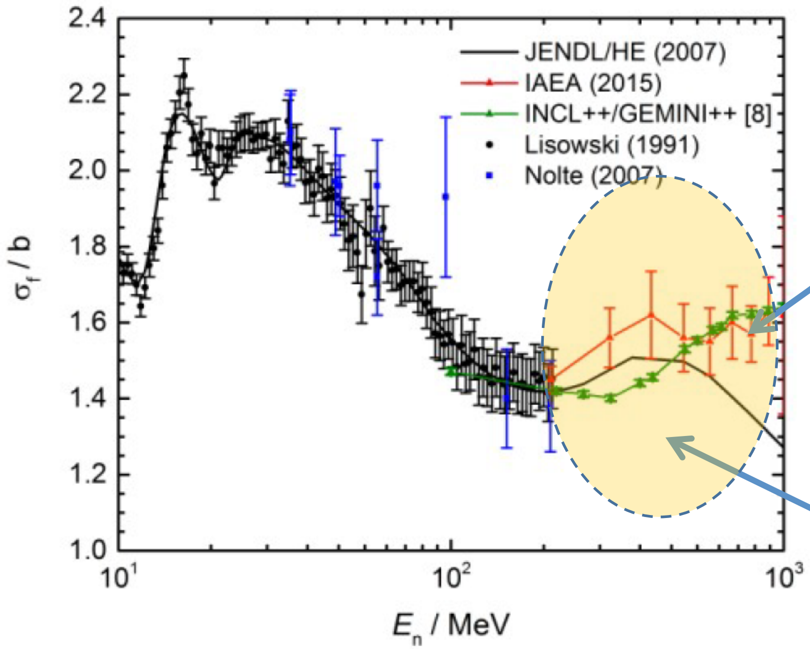

The theoretical cross section above 200MeV may be substantially different, depending on the model used for the calculations.

No experimental data above 200MeV. Only theoretical models

Two sets of experimental data in the range 20 MeV – 200 MeV

The International Atomic Energy Agency (IAEA) strongly requests new data for the $^{235}U(n,f)$ cross section up to 1GeV, with the aim to improve the uncertainty within 5%.

New measurements above 20 MeV are needed!

The experimental approach to measure the ^{235}U(n,f) cross section

The Technique: Two simultaneous measurements with a suitable neutron beam.

- **^{235}U(n,f) reaction vs neutron energy**
- **H(n,n)H reaction vs neutron energy**

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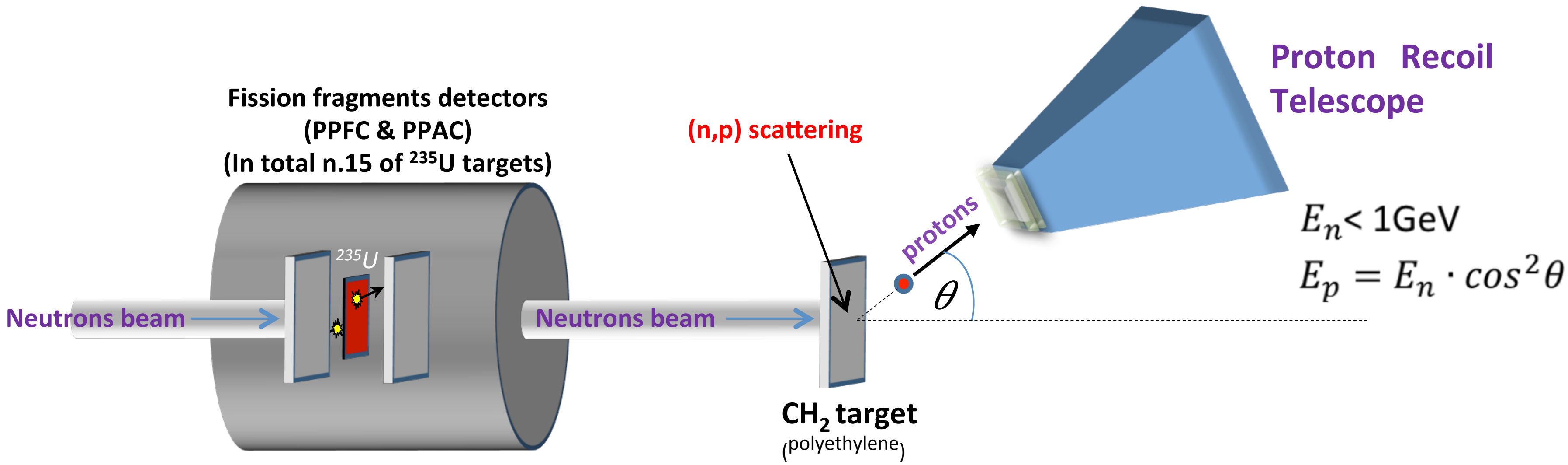

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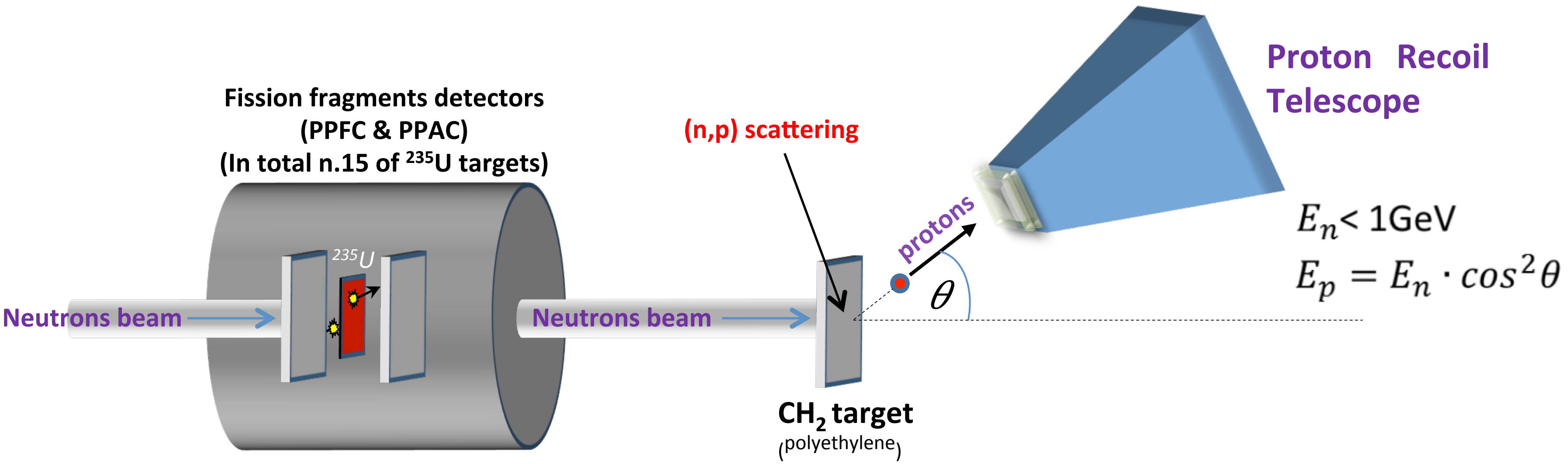

- **The (n,p) scattering is used as a reference reaction for the ^{235}U(n,f) cross section**
- **The Proton Recoil Telescope (PRT) detects recoil protons emitted by the target, to measure the neutron flux vs. neutron energy**

The experimental approach to measure the ^{235}U(n,f) cross section

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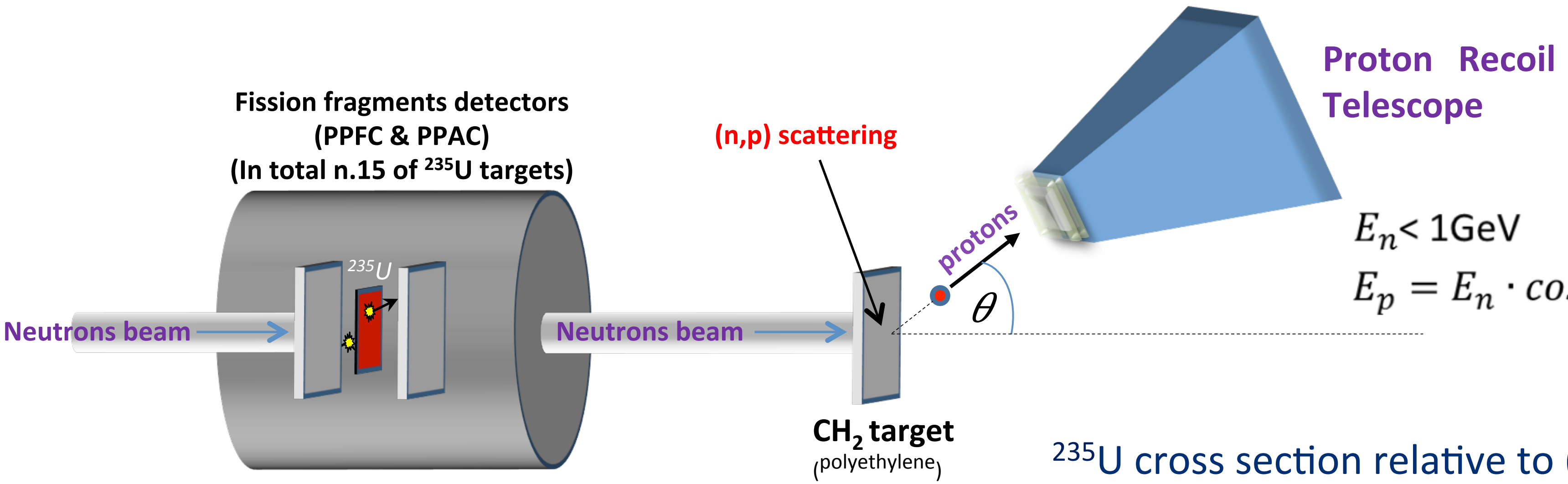

$E_n < 1\text{GeV}$

$E_p = E_n \cdot cos^2\theta$

- The (n,p) scattering is used as a reference reaction for the ^{235}U(n,f) cross section
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^{235}U cross section relative to (n,p)

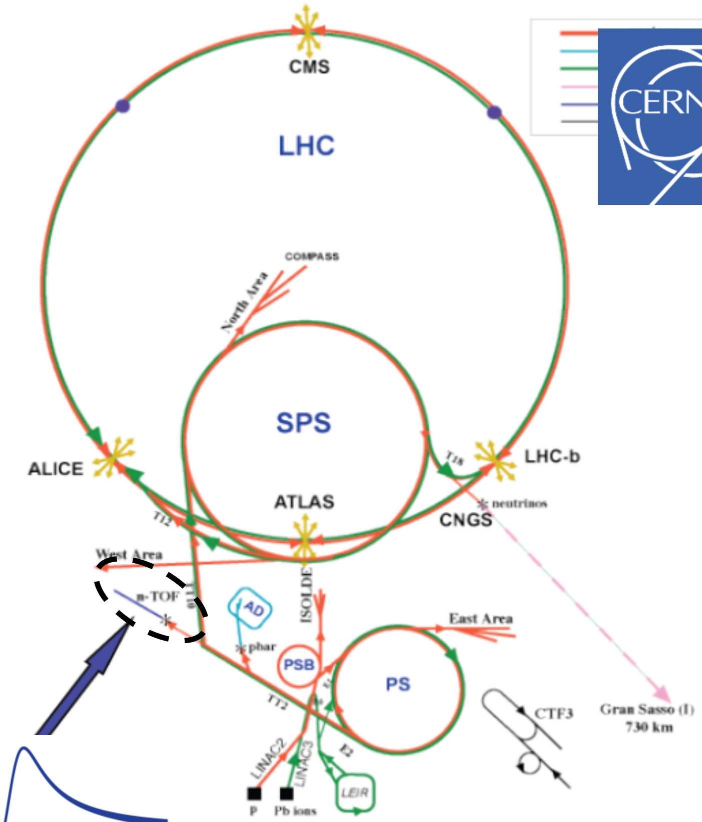
$$\frac{\sigma_{^{235}\mathrm{U(n,f)}}}{(d\sigma_{np}/d\Omega)} = \frac{n_H \varepsilon_p \Omega_{geo} N_{FF}}{n_U \varepsilon_{FF} N_p}$$

N: detected events
n: sample areal density
Ω: PRT solid angle
ε: efficiency
: cross section

Where to measure the $^{235}U(n,f)$ cross section

A neutron beam with good energy resolution in a wide energy range is needed. → *n_TOF@CERN*

Neutron_Time-Of-Flight Facility



Where to measure the ^{235}U(n,f) cross section

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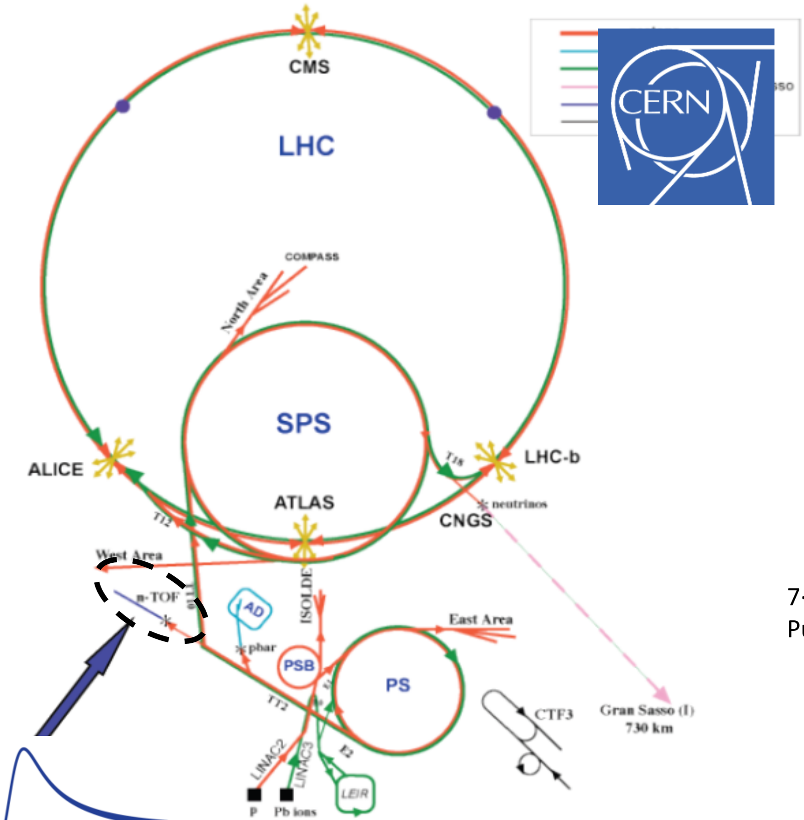
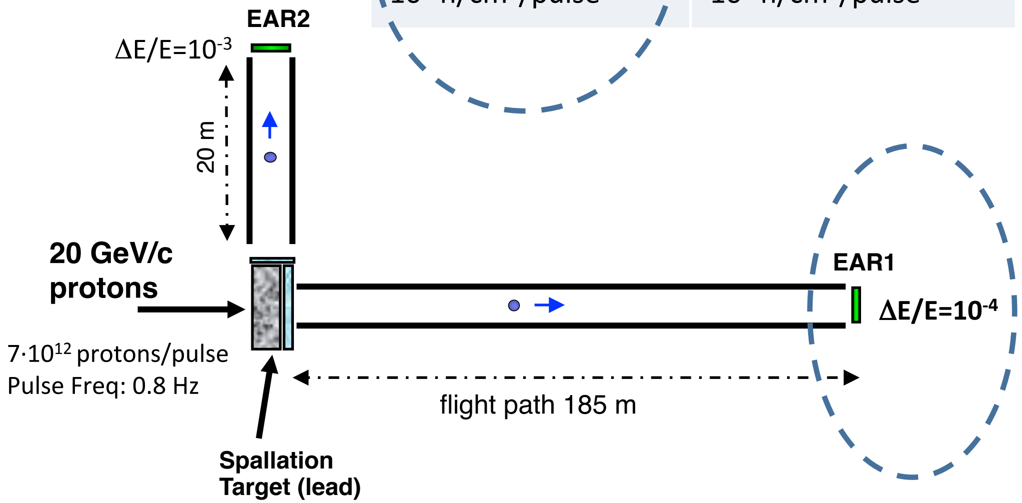
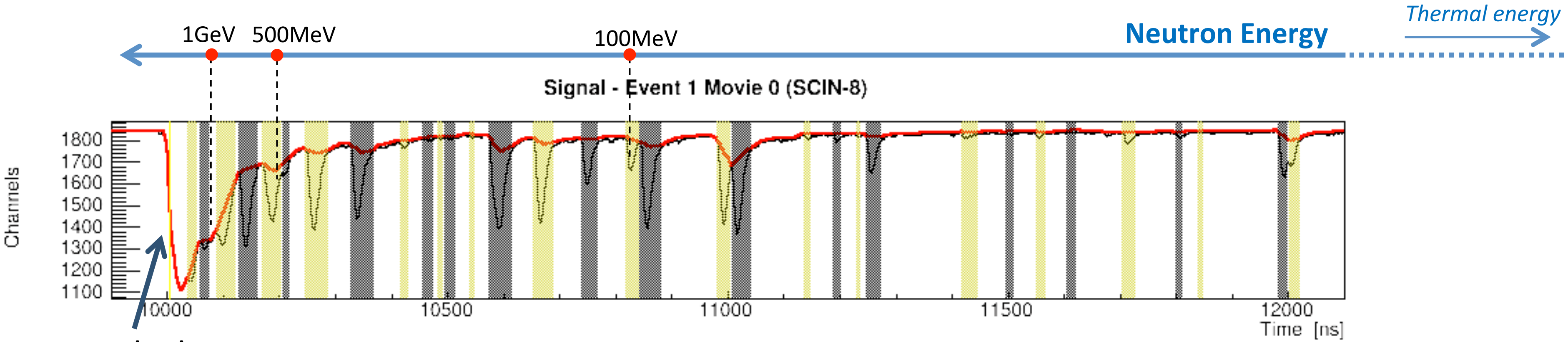


Two experimental areas

EAR-1	EAR-2
25 meV<E_n<1 GeV	25 meV<E_n<300 MeV
10^5 n/cm^2/pulse	10^6 n/cm^2/pulse



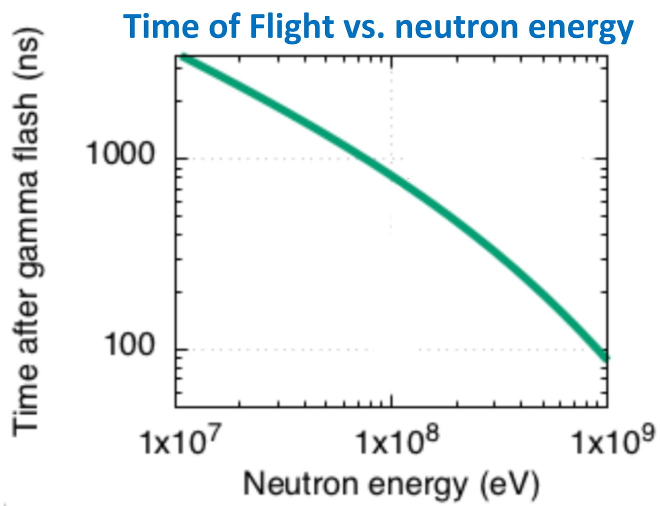
EAR1@n_TOF: The time distribution of the neutrons



A typical time distribution of neutron - induced events in EAR1.

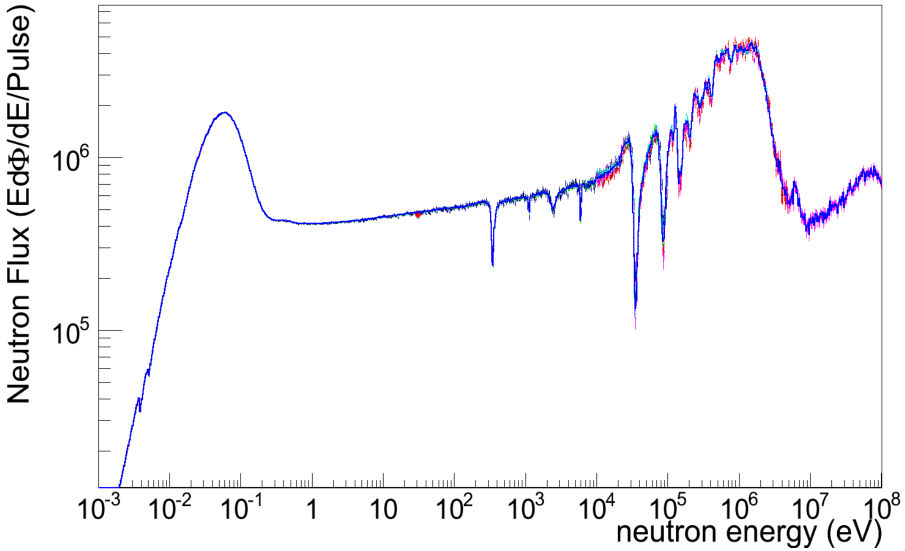
By subtracting the baseline the clean signals are extracted

- The ɣ-Flash is produced by the interaction of the protons pulse in the spallation target.
- It is the time reference to measure the time of flight of the incoming neutrons and hence their energy.
- Shorter the ɣ-Flash pulse width, higher the maximum kinetic neutron energy that can be detected



The neutron flux in EAR1

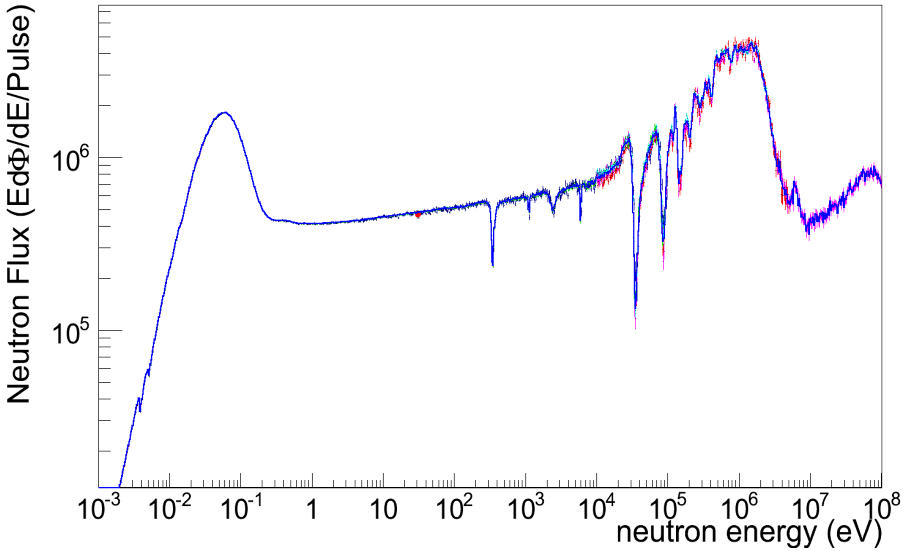
Energy distribution of the neutrons flux



n_TOF@CERN facility has all the requirements to measure the $^{235}U(n,f)$ cross section normalized to the (n,p) scattering.

The neutron flux in EAR1

Energy distribution of the neutrons flux



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The Proton Recoil Telescope

- To be used in a wide energy range: 10MeV - 1GeV
- ΔE-E particle identification to separate the recoil protons from the other light particles
- Working in coincidence mode to reject the background events
- Fast response to gamma ɣ-Flash

INFN LNS

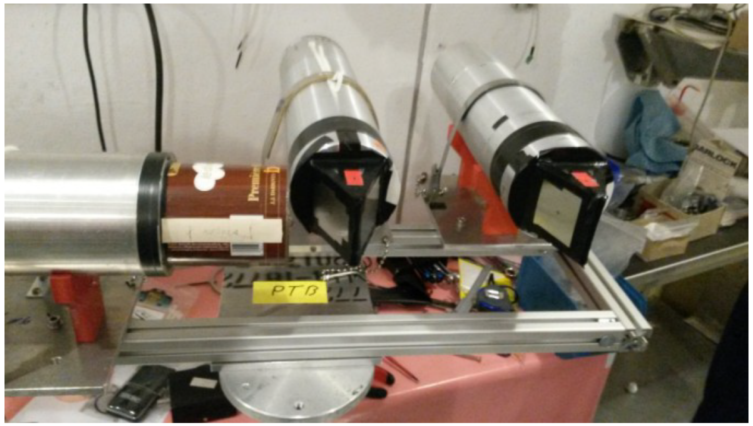
The Proton Recoil Telescope

nTOF

Two different telescopes to be developed at n_TOF

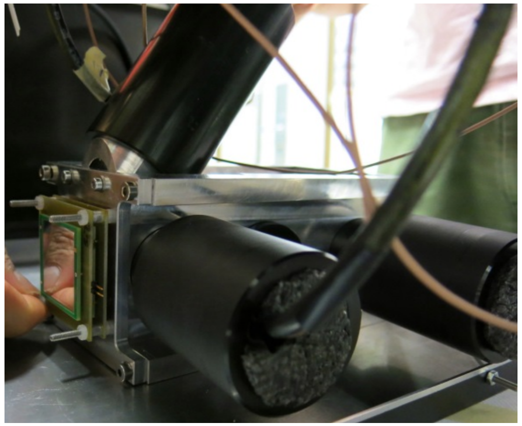
PTB - Germany

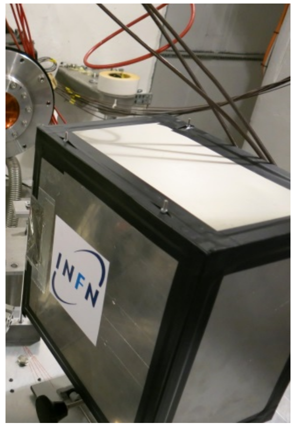
PTB Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut



INFN - Italy

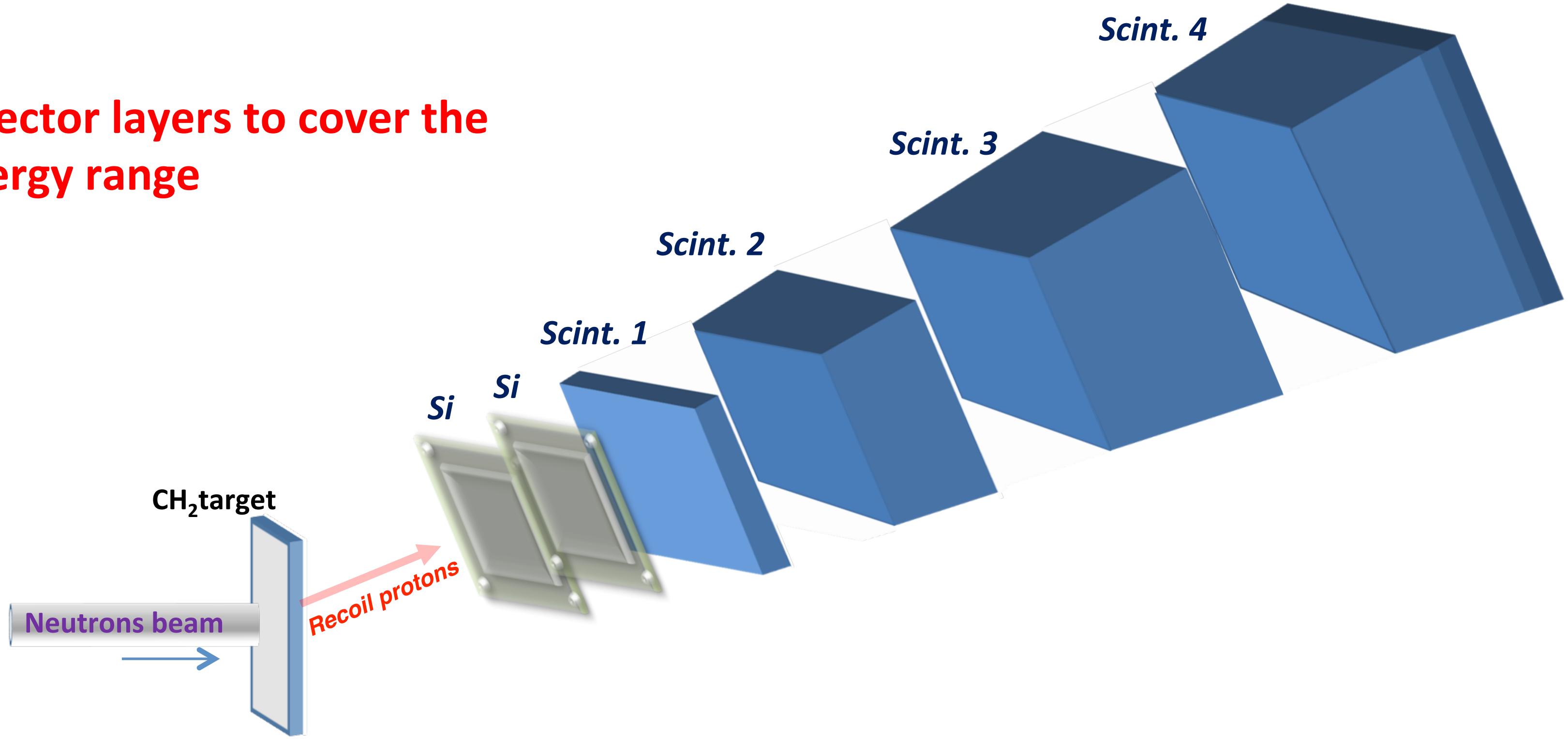
INFN Istituto Nazionale
di Fisica Nucleare





The tapered multilayer Proton Recoil Telescope

Six detector layers to cover the full energy range



- **2 Silicon detectors 300 um thick**
- **4 plastic scintillators BC408 (τ = 2.1 ns) 0.5cm, 3cm, 6cm, 6cm**
- **Fast PMT (Hamamatsu R1924A)**
- **CH_2 target (*polyethylene*): 2mm – 10mm**

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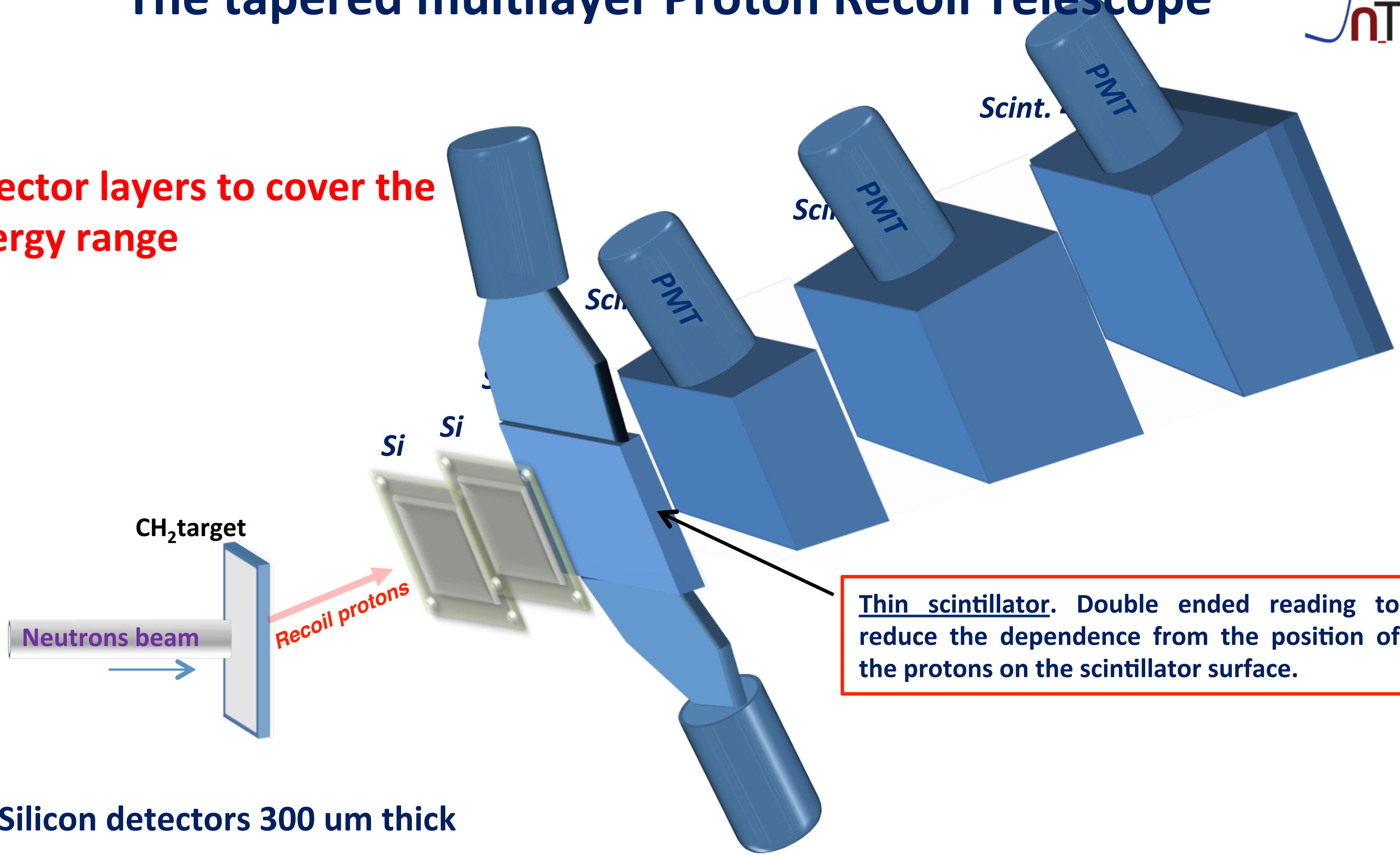

Thin scintillator. Double ended reading to reduce the dependence from the position of the protons on the scintillator surface.

- 2 Silicon detectors 300 um thick
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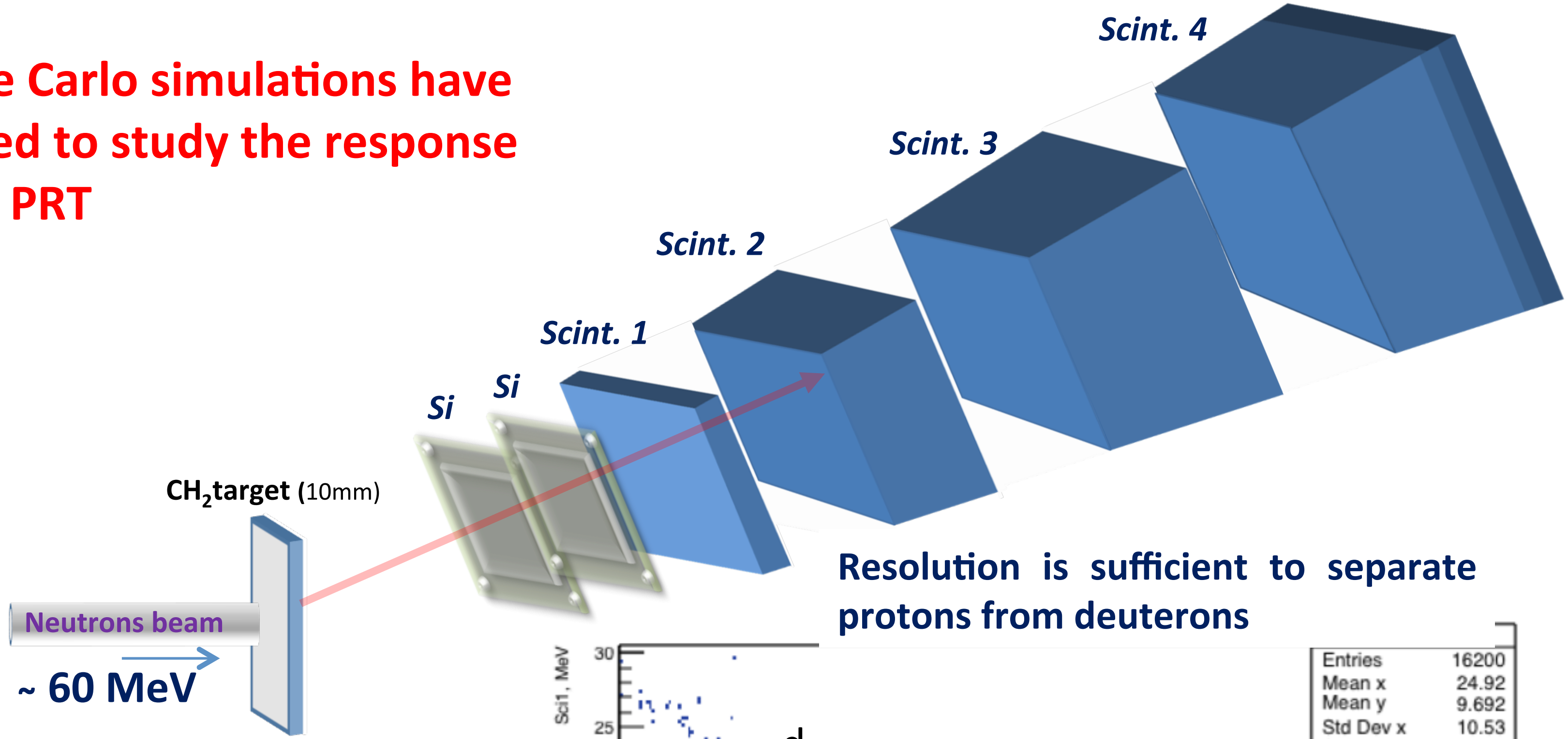
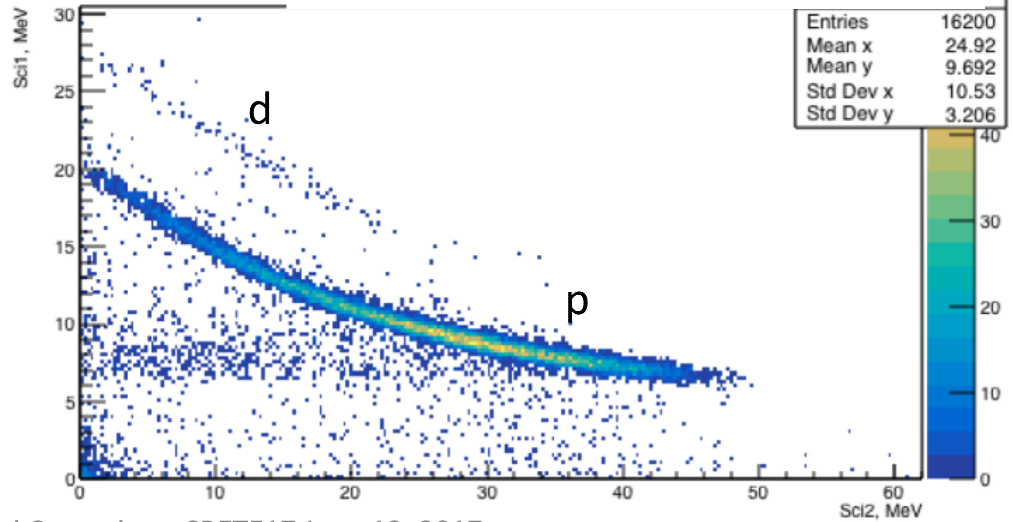
- CH_2 target (*polyethylene*): 2mm – 10mm

Monte Carlo simulations

Monte Carlo simulations have allowed to study the response of the PRT



Resolution is sufficient to separate protons from deuterons



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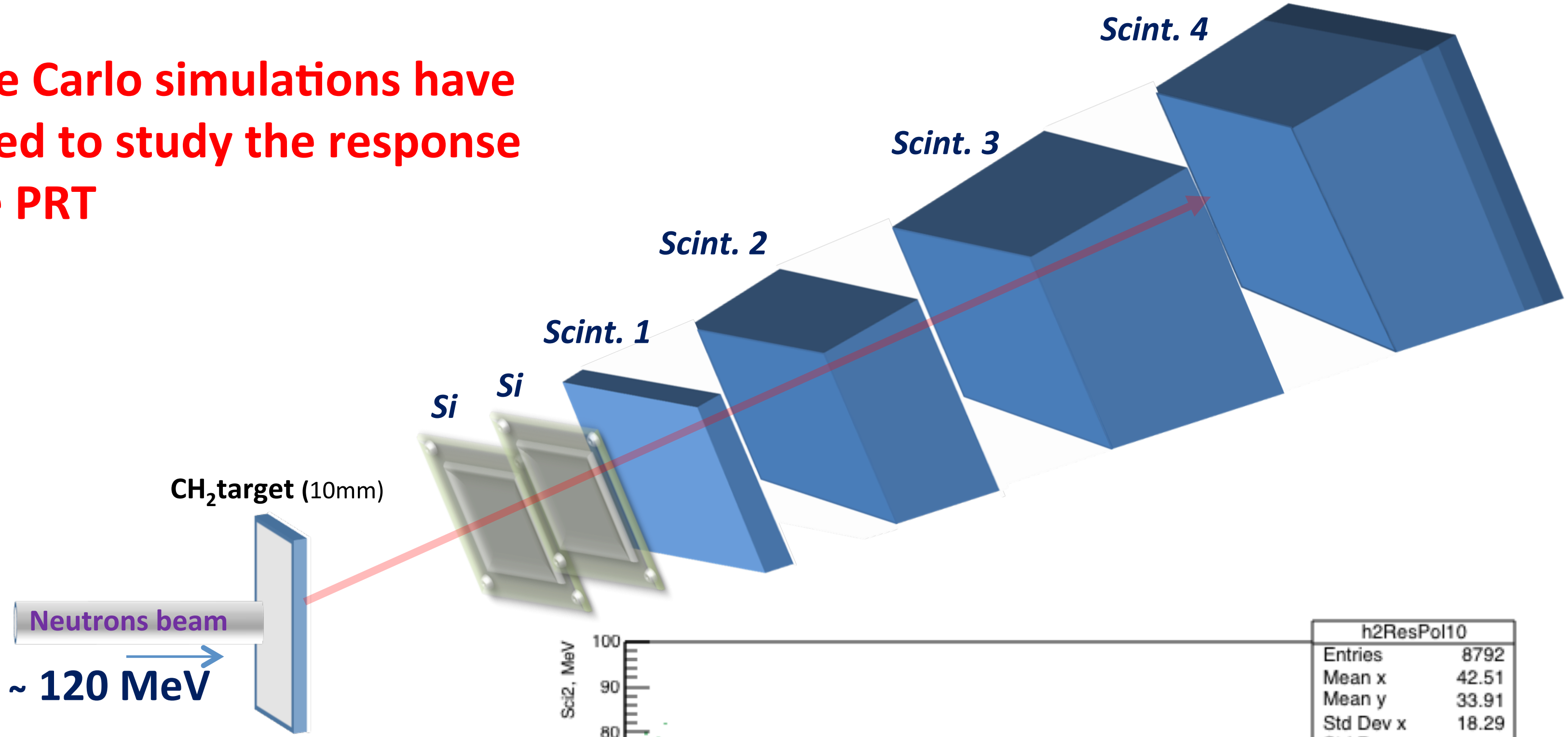

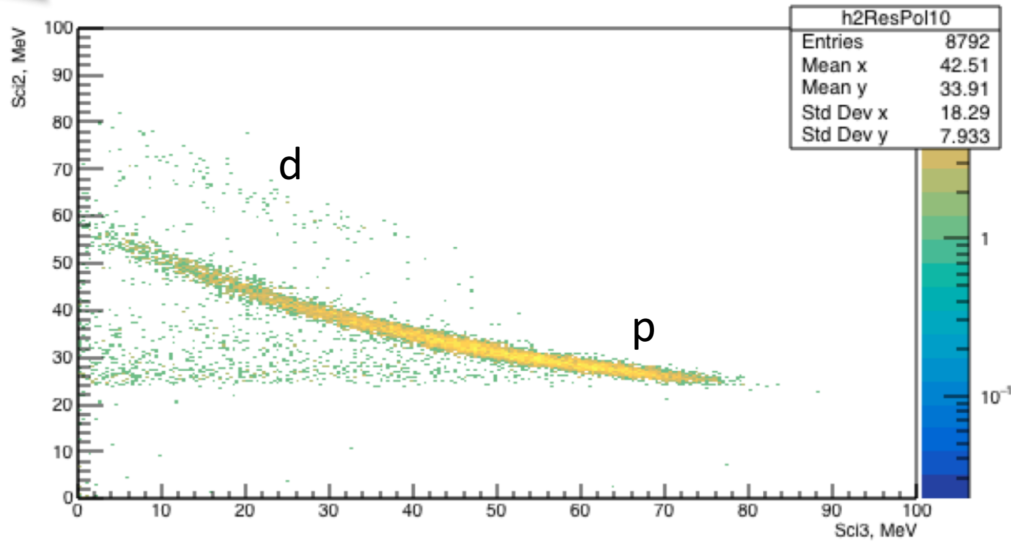

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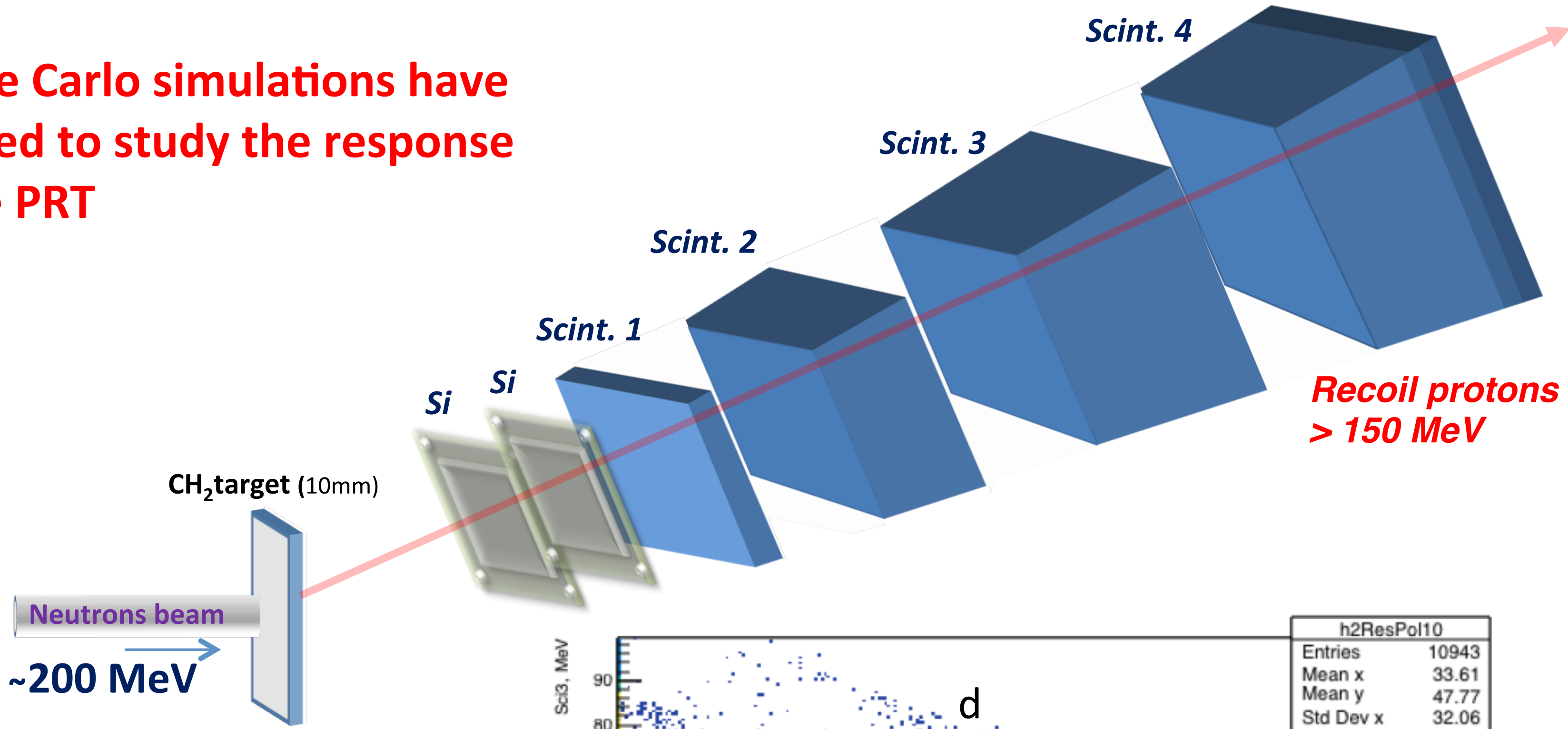
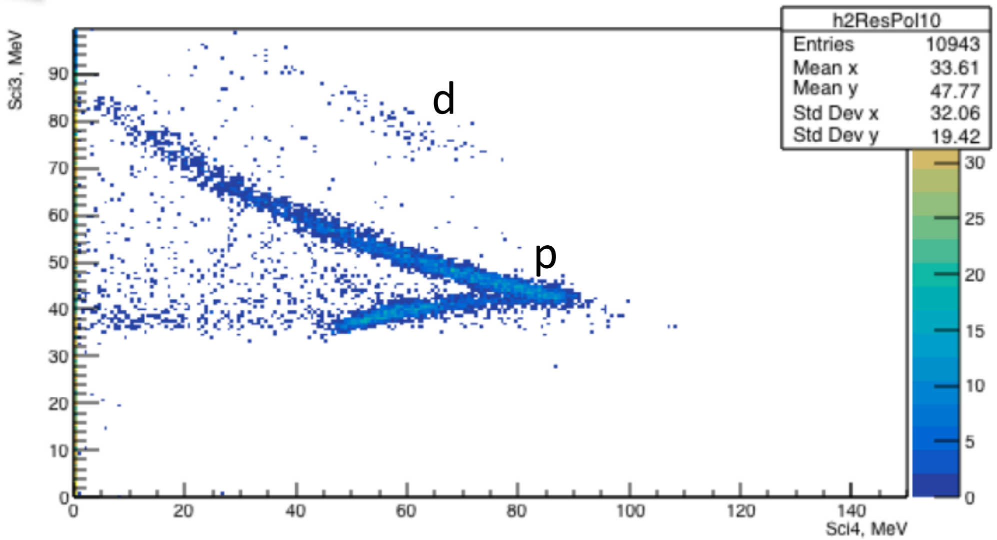
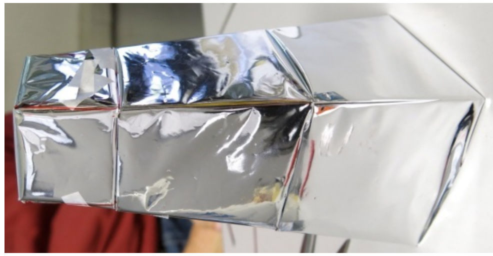
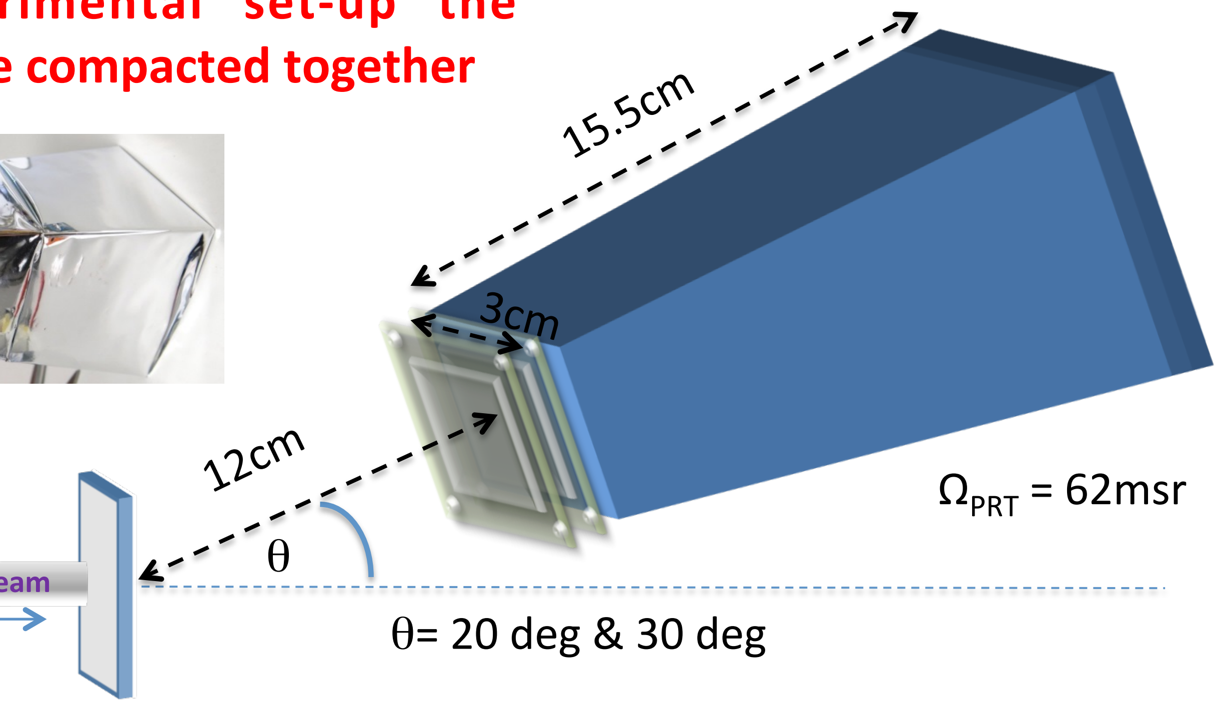




How to place the PRT

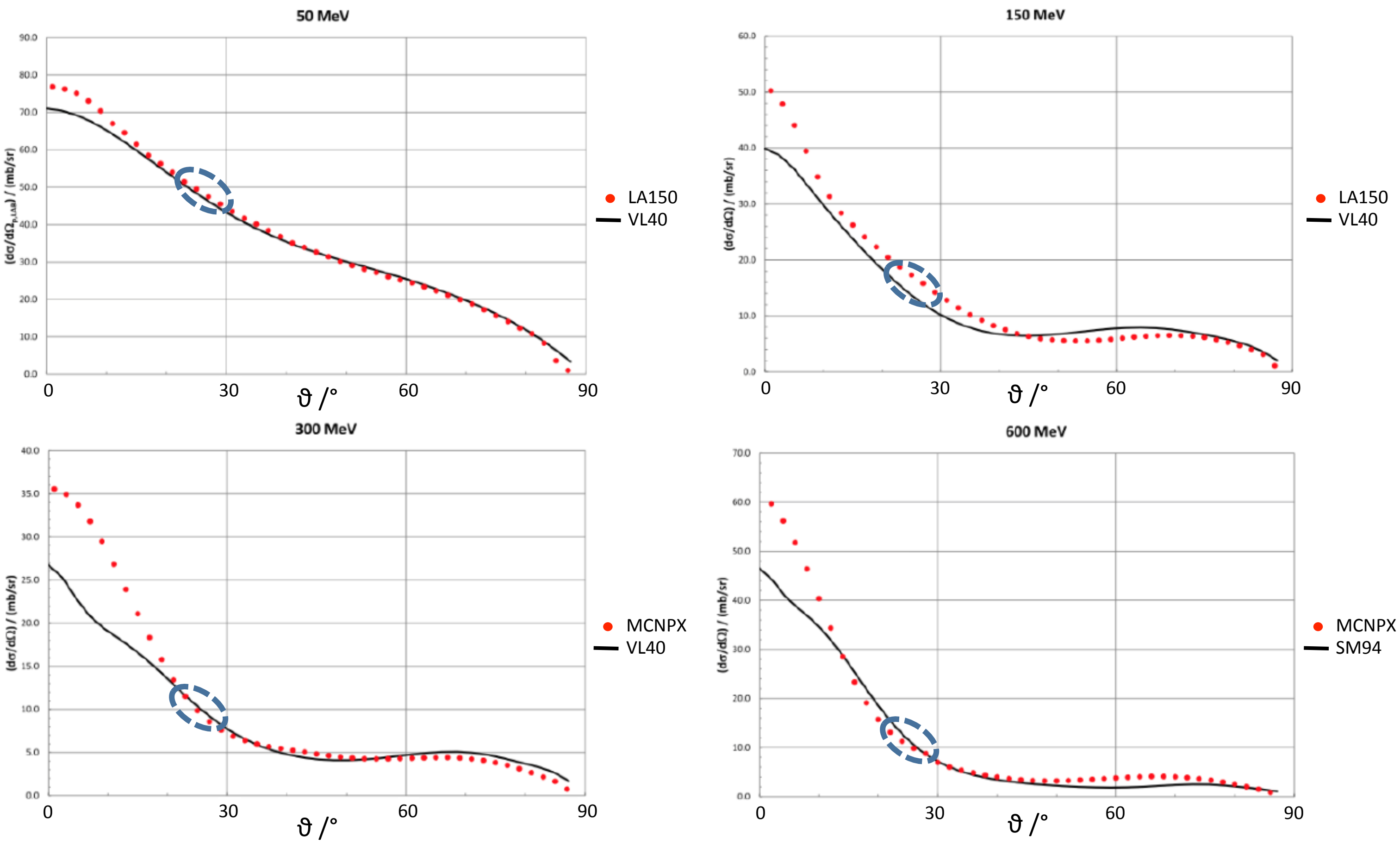
In the experimental set-up the scintillators are compacted together





The aim is to reach a statistical uncertainty around 2% within neutron energy regions of 5% relative width.

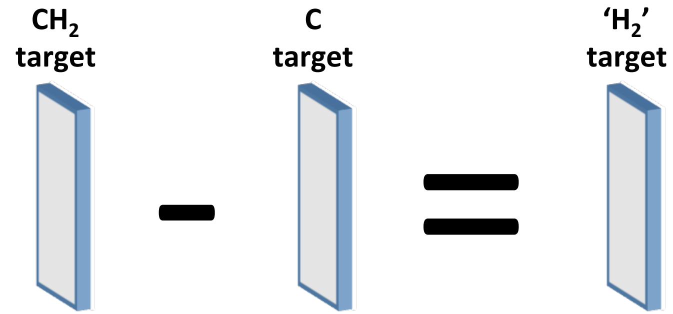
(n,p) cross section vs. angle of recoil protons



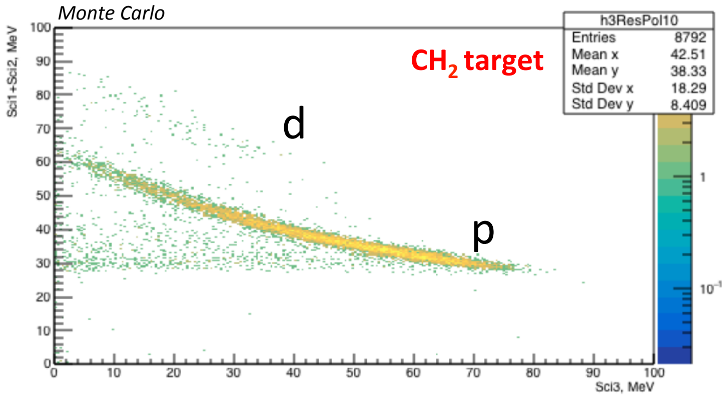
20 – 30 deg

Theoretical team is working to quantify the uncertainties

Select only the events due to hydrogen atoms in the CH_2 target



Measurements with graphite targets to subtract the contribution of the competing reaction $^{12}C(n,x)$ in the CH_2 (polyethylene) target



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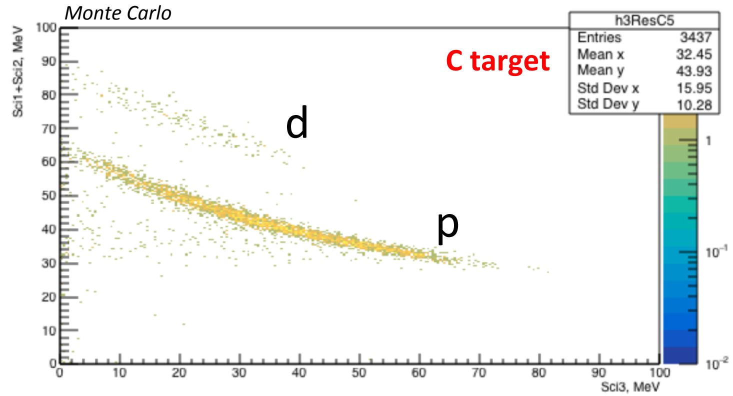
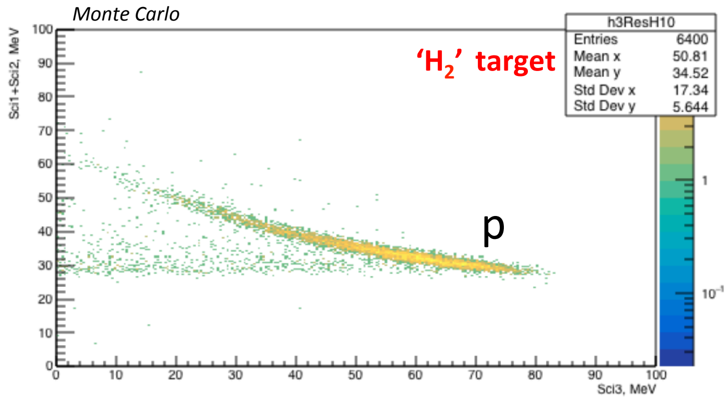
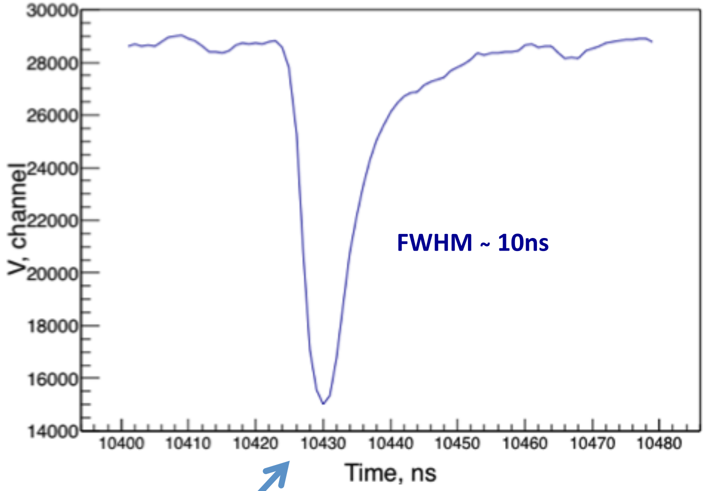
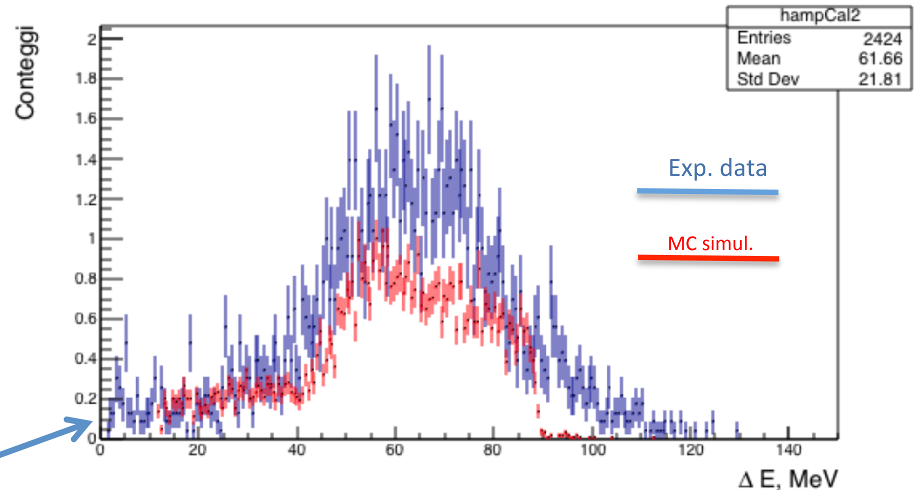
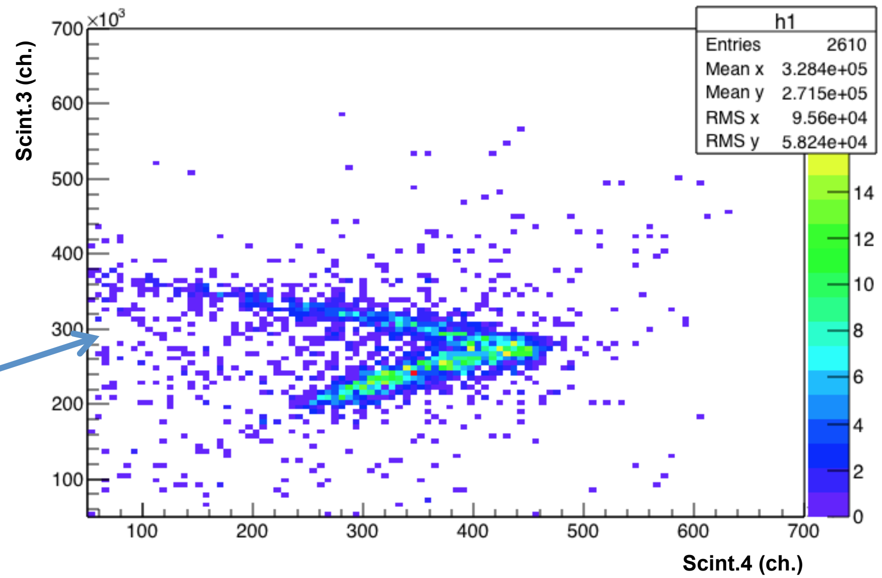




Test of the first prototype @ n_TOF







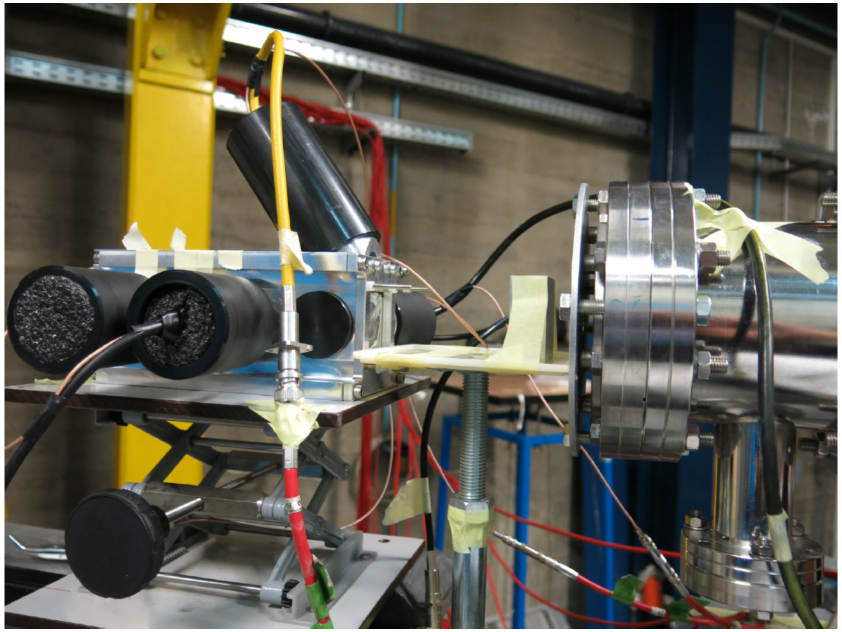
Typical pulse
PMT+scintillator

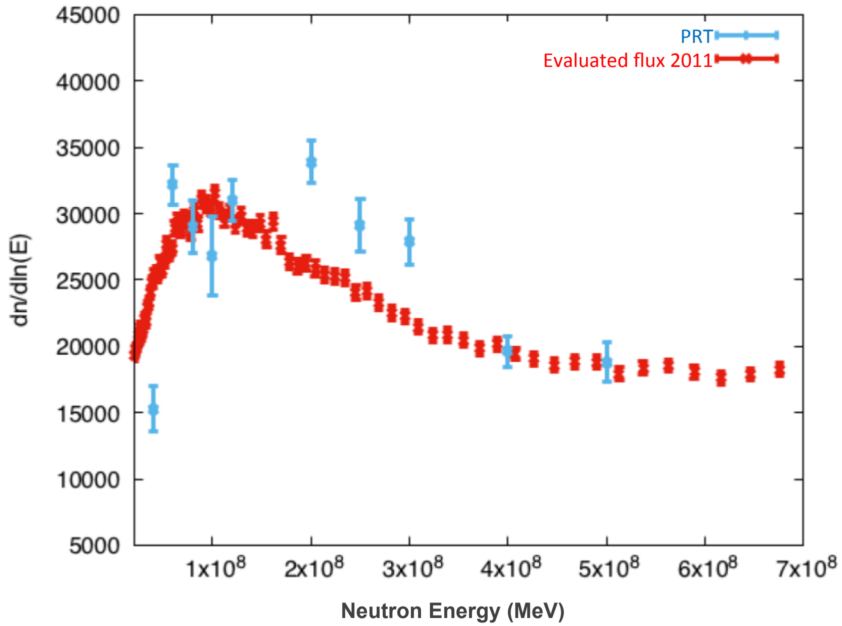
Energy spectra
Scint.4 @ En ≈ 200 MeV

ΔE – E plot
E_n= 150 – 250 MeV

A very preliminary flux reconstruction with the PRT prototype in the neutron energy range 10MeV – 500 MeV

(a few days test beam)





Alignment of the PRT to the neutron beam was not perfect

$$\varphi_n = \frac{C}{n\Omega\varepsilon\sigma}$$

C: counts
n: sample areal density
Ω: solid angle
ε: efficiency
σ: (n,p) cross section

The amount of material in the PRT mechanics must be reduced, in order to cut down the background events

Conclusions

- **The Proton Recoil Telescope allows to distinguish the recoil protons from ɣ rays and heavier particles, in a wide neutron energy range**

BUT

- **A new mechanical setup and an optimized shielding for silicon detectors are needed, in order to suppress the background events**

A final test of the PRT is foreseen at CERN in september 2017 with a renewed telescope sample, to finalize its configuration.

The measurement of the ^{235}U(n,f) cross section at n_TOF @CERN is planned for 2018.

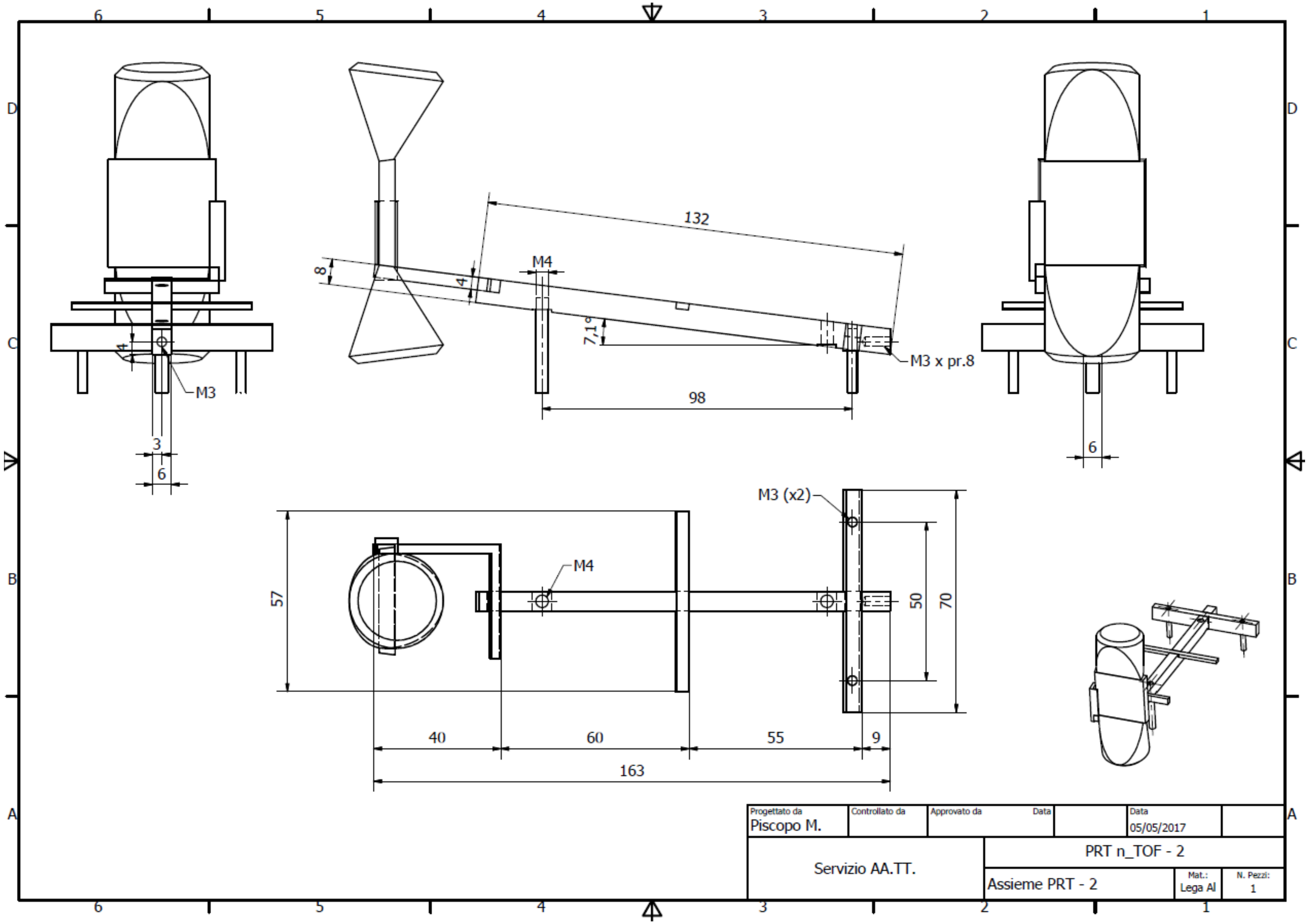
Participants to the $^{235}U(n,f)$ experiment @ n_TOF

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]

[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
[9] Dipartimento di Fisica e Astronomia, University of Catania, Italy
[10] Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Thanks for your Attention

Backup Slides


132
M4
8
4
7,1°
M3 x pr.8
98
M3
3
6
6
M3 (x2)
M4
57
50
70
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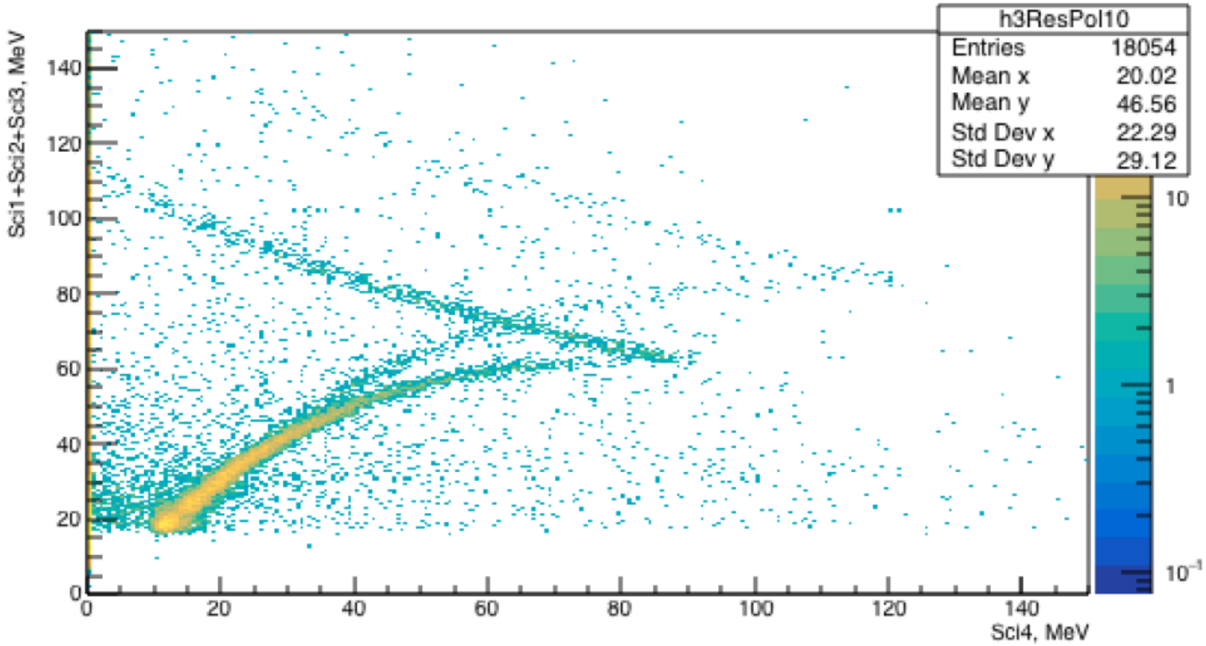
55
9
163
Progettato da
Piscopo M.
Controllato da
Approvato da
Data
Data
05/05/2017
Servizio AA.TT.
PRT n_TOF - 2
Assieme PRT - 2
Mat.:
Lega Al
N. Pezzi:
1


h3ResPol10
Entries 18054
Mean x 20.02
Mean y 46.56
Std Dev x 22.29
Std Dev y 29.12
Sci1+Sci2+Sci3, MeV
Sci4, MeV
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20
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120
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1
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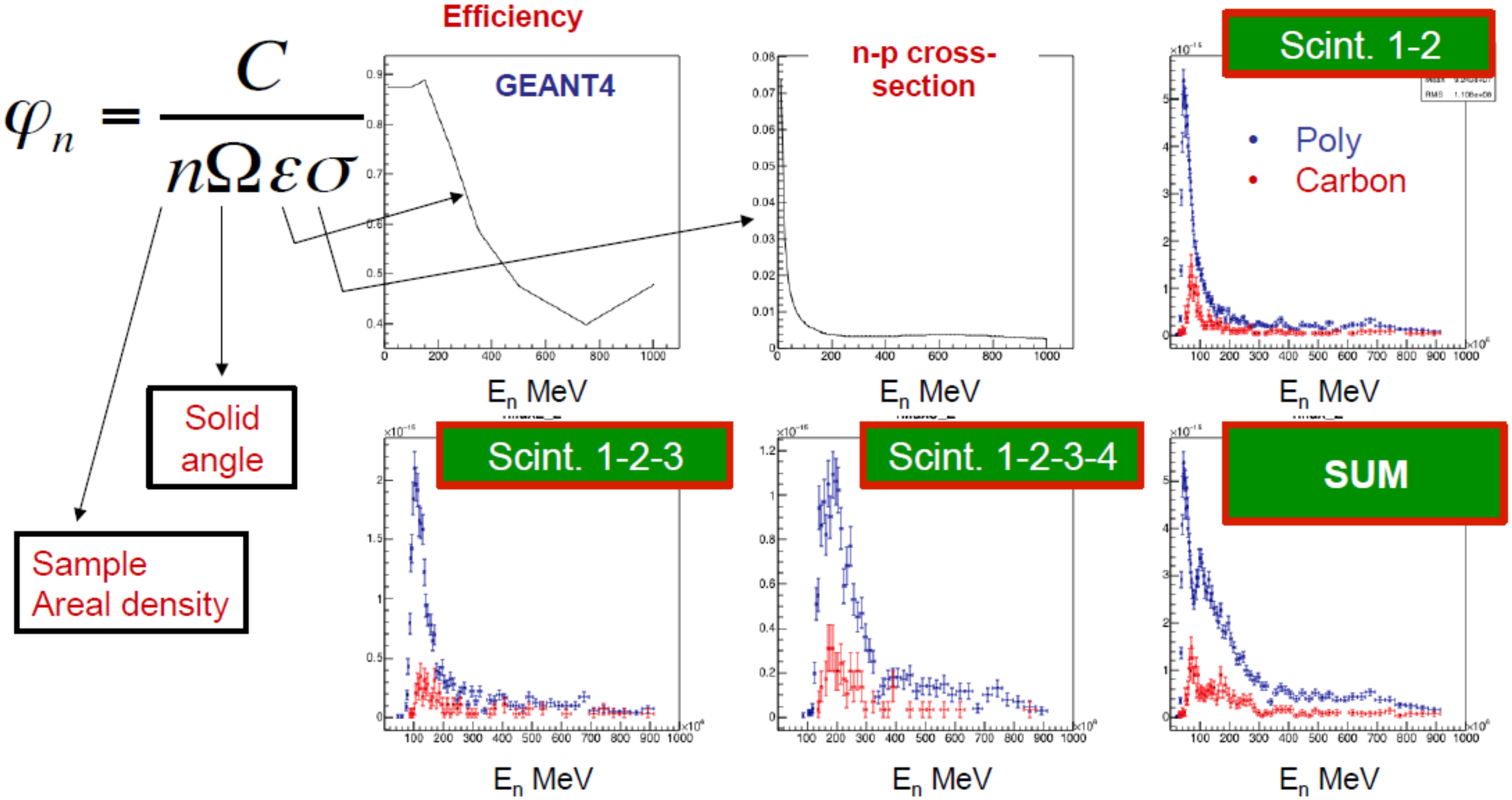
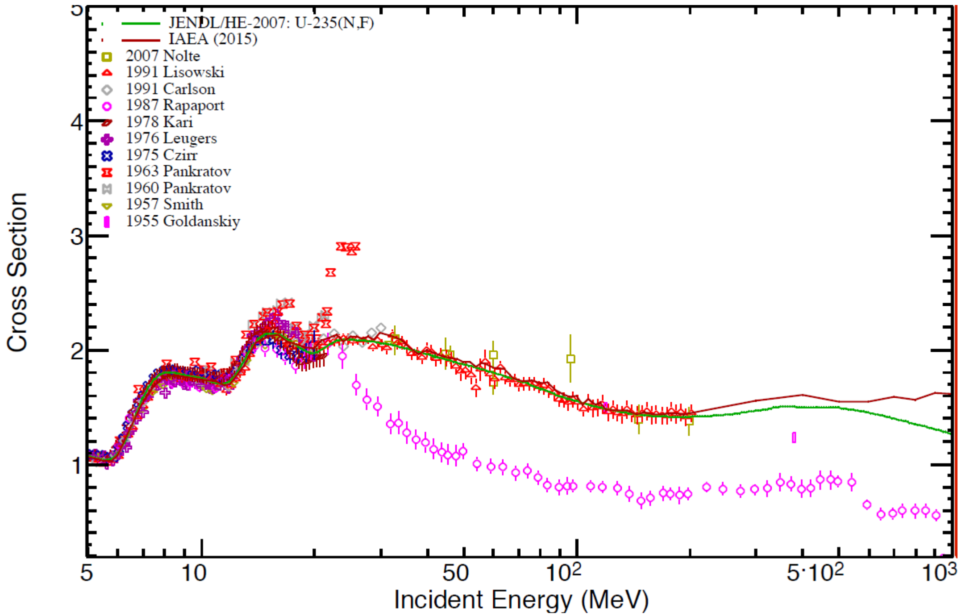
900 MeV

10-mm Polyethylene



Courtesy of Cristian Massimi



Theoretical estimates using the ^{235}U(p,f) reaction above 600 MeV as guidance.

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

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

May 06, 2017

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]

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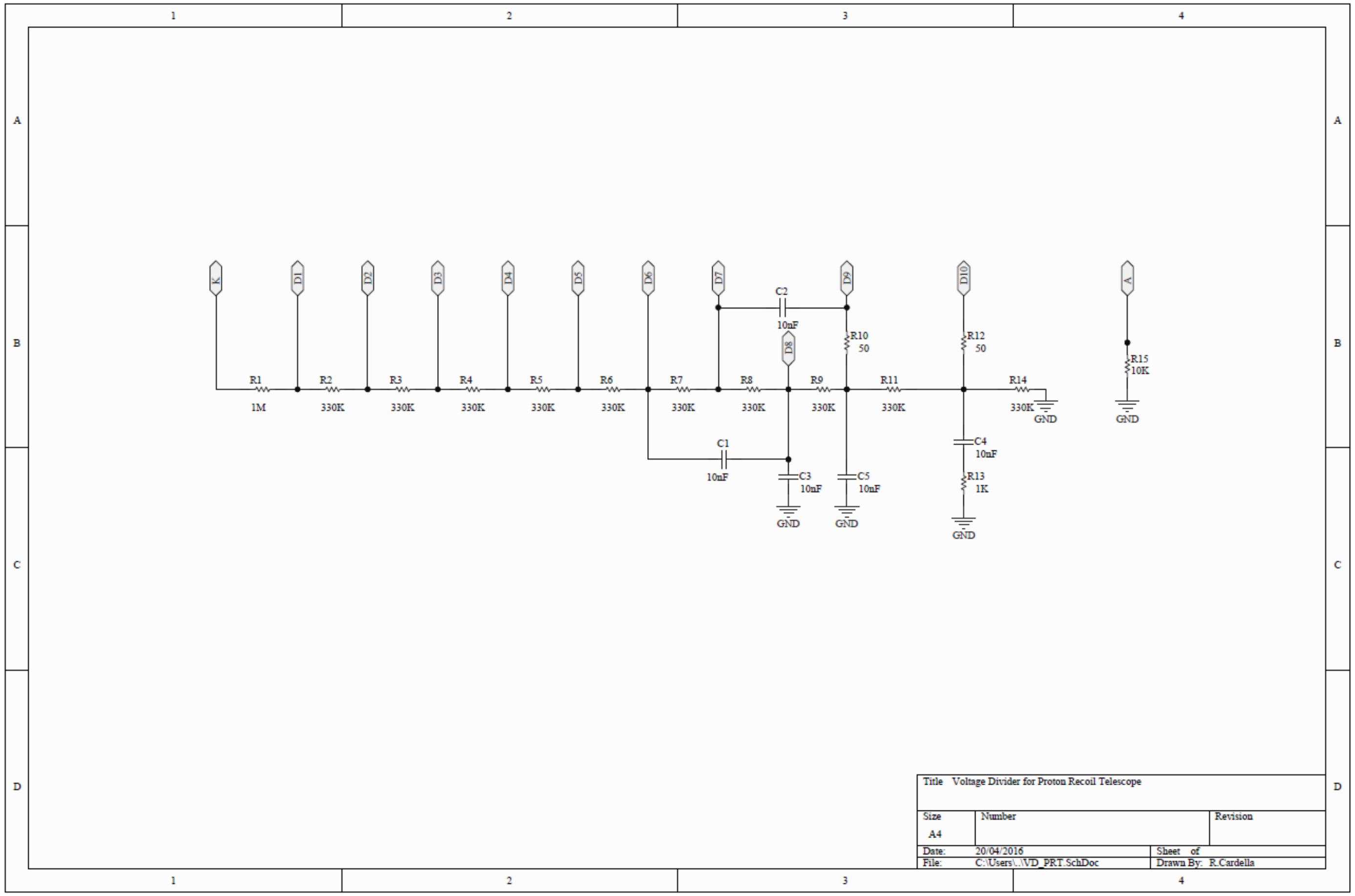
Spokespersons: C. Massimi (massimi@bo.infn.it), R. Nolte (ralf.nolte@ptb.de) and L. Cosentino (cosentino@lns.infn.it)
Technical coordinator: O. Aberle (oliver.aberle@cern.ch)


K
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
A
R1 1M
R2 330K
R3 330K
R4 330K
R5 330K
R6 330K
R7 330K
R8 330K
R9 330K
R11 330K
R14 330K
R10 50
R12 50
R13 1K
R15 10K
C1 10nF
C2 10nF
C3 10nF
C4 10nF
C5 10nF
GND
Title Voltage Divider for Proton Recoil Telescope
Size A4
Number
Revision
Date: 20/04/2016
Sheet of
File: C:\Users\..\VD_PRT.SchDoc
Drawn By: R.Cardella

Analysis

- **Experimental data:**
  - $\Theta \approx (23 \pm 2)°$
  - ΔE_1 = 2 mm, 5 mm EJ228, ΔE_2 = 5 mm EJ228, E = 80 mm EJ204
  - No particle separation

- **Comparison with MC simulations (MCNPX 2.7):**
  - E_n < 150 MeV: LA150 library for n and p
  - E_n > 150 MeV: default INC model
  - Tracking of p and d
  - Non-linear light output simulated
  - $\Delta L/L$ = 10% for E-detetector

Courtesy of Ralf Nolte