Delayed neutron measurements for ^{232}Th neutron-induced fission

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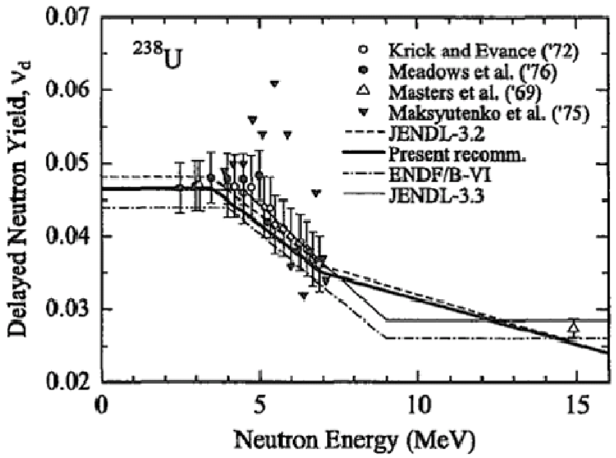
Contents

Motivations

- Fission process study
- Key role in the reactors
- Active interrogation



Example of U 238 :

Data between 2 and 7 MeV and above 14 MeV

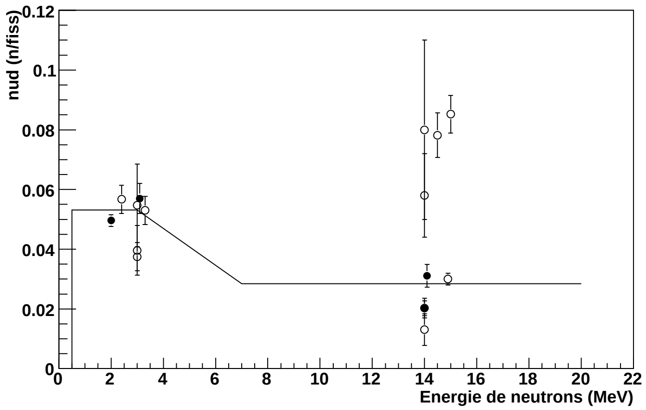
ν_d decreases above 3 MeV

Th 232 :

No data between 3 and 14 MeV

Data very scattered

Interest for Thorium fuel cycle



Goal of the experiment :

Accurate measurements

Fill the energy range between 2 and 16 MeV

The delayed neutrons

Delayed neutrons are emitted by fission fragments after β de-excitation

More than 200 precursors

Definition of 6 groups characterized by a_i, λ_i

100 keV < E < 1 MeV

$$Y_d(t) = \nu_d \sum_{i=1,6} a_i \exp(-\lambda_i t)(1-\exp(-\lambda_i t_{irr}))$$

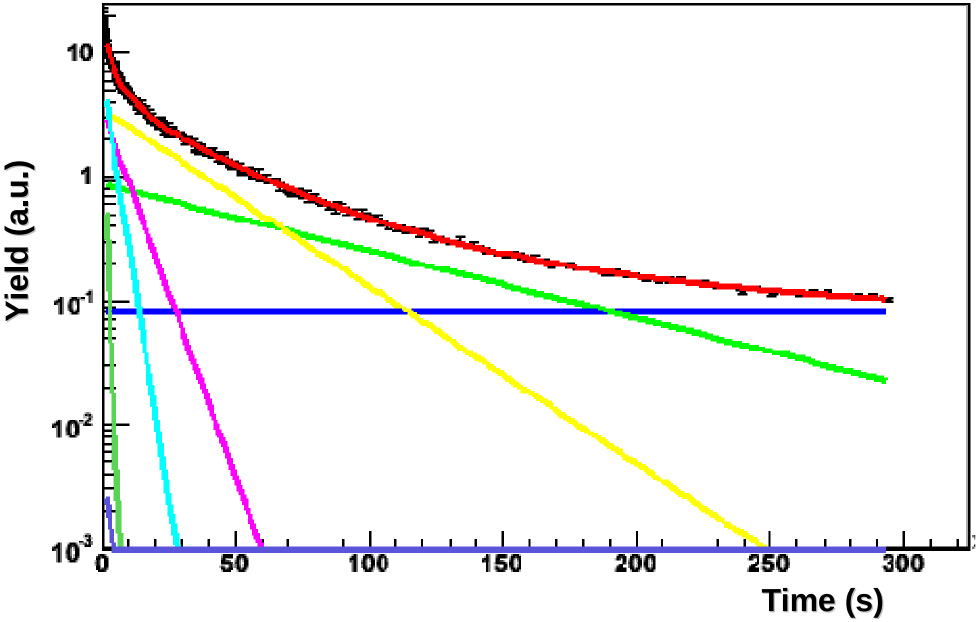
$$\sum_i a_i = 1$$

$Y_d(t)$ Delayed neutrons

ν_d Nb of delayed neutrons per fission

t_{irr} Irradiation time

$\lambda_i = Ln(2)/T_i$ with T_i period of group i



Delayed-neutron data in n+^{232}Th with fission spectrum (Keepin et al.)

Groupe	T_i (s)	a_i (%)
1	56.03 ± 0.95	3.4 ± 0.2
2	20.75 ± 0.66	15.0 ± 0.5
3	5.74 ± 0.24	15.5 ± 2.1
4	2.16 ± 0.08	44.6 ± 1.5
5	0.571 ± 0.042	17.2 ± 1.3
6	0.211 ± 0.019	4.3 ± 0.6

Principle of the measurement

Delayed neutrons decay time distribution after irradiation time t_{irr}:

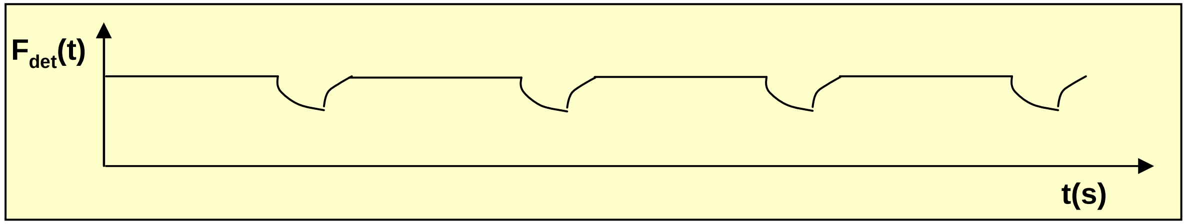
$$Y_d(t) = \upsilon_d \sum_{i=1,6} a_i \exp(-\lambda_i t)(1-\exp(-\lambda_i t_{irr}))$$

When $t_{irr} >> T_1$

$$Y_d(t) = \upsilon_d \sum_{i=1,6} a_i \exp(-\lambda_i t)$$

At t=0 $\quad Y_d(0) = \upsilon_d$

Irradiation 5 min to reach equilibrium
and
Succession of cycles:
- irradiation 7 s
- delayed neutrons detection 1s

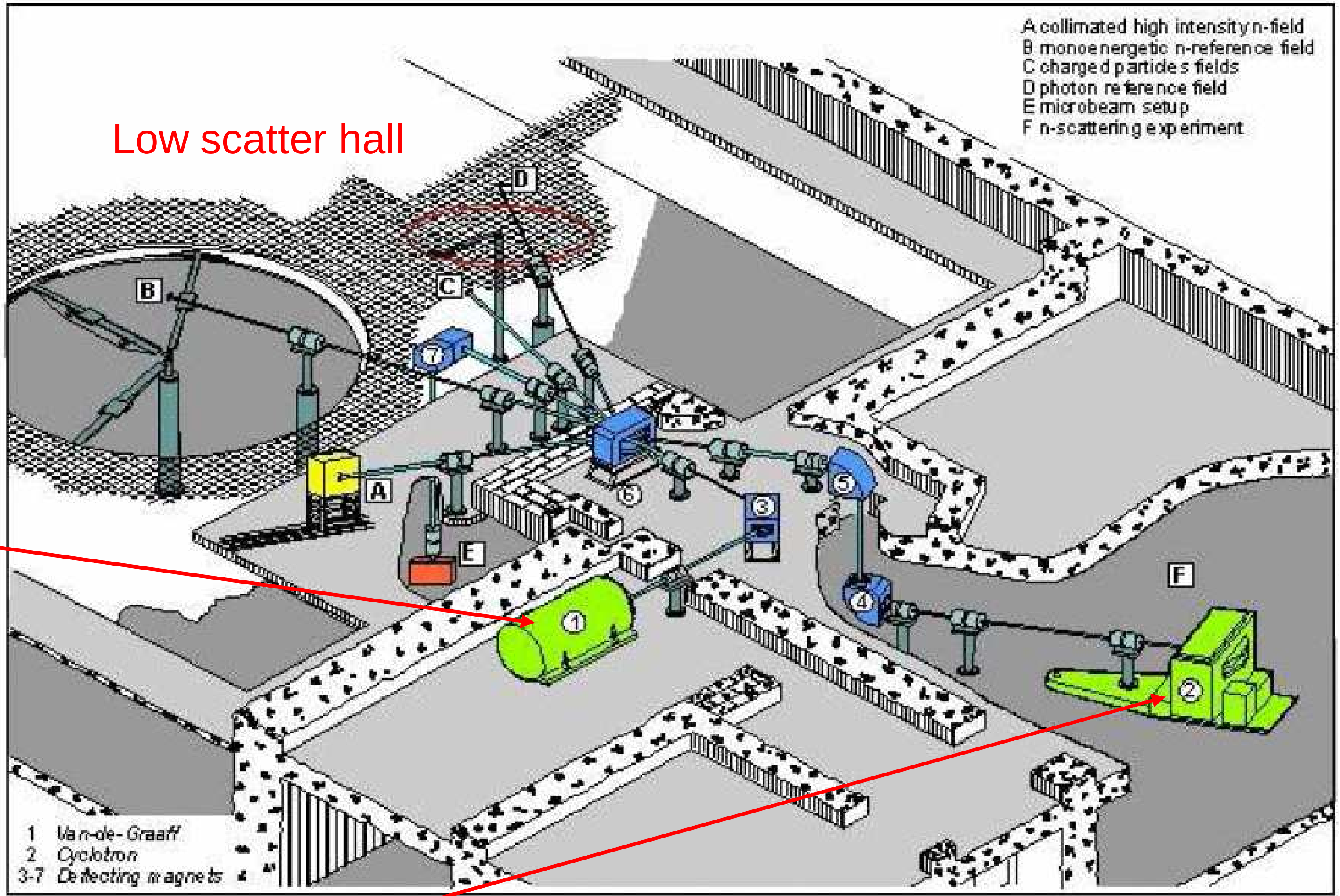


$$F_{\text{det}}(t) = N_{fissions}\ \varepsilon\ Y_d(t)$$

$$\upsilon_d = \frac{F_{\text{det}}(0)}{N_{fissions}\ \varepsilon}$$

$F_{det}(0)$	Delayed neutrons detected at t=0
$N_{fissions}$	Nb of fissions par second
ε	Global detection efficiency
ν_d	Nb of delayed neutrons per fission

PTB Facility



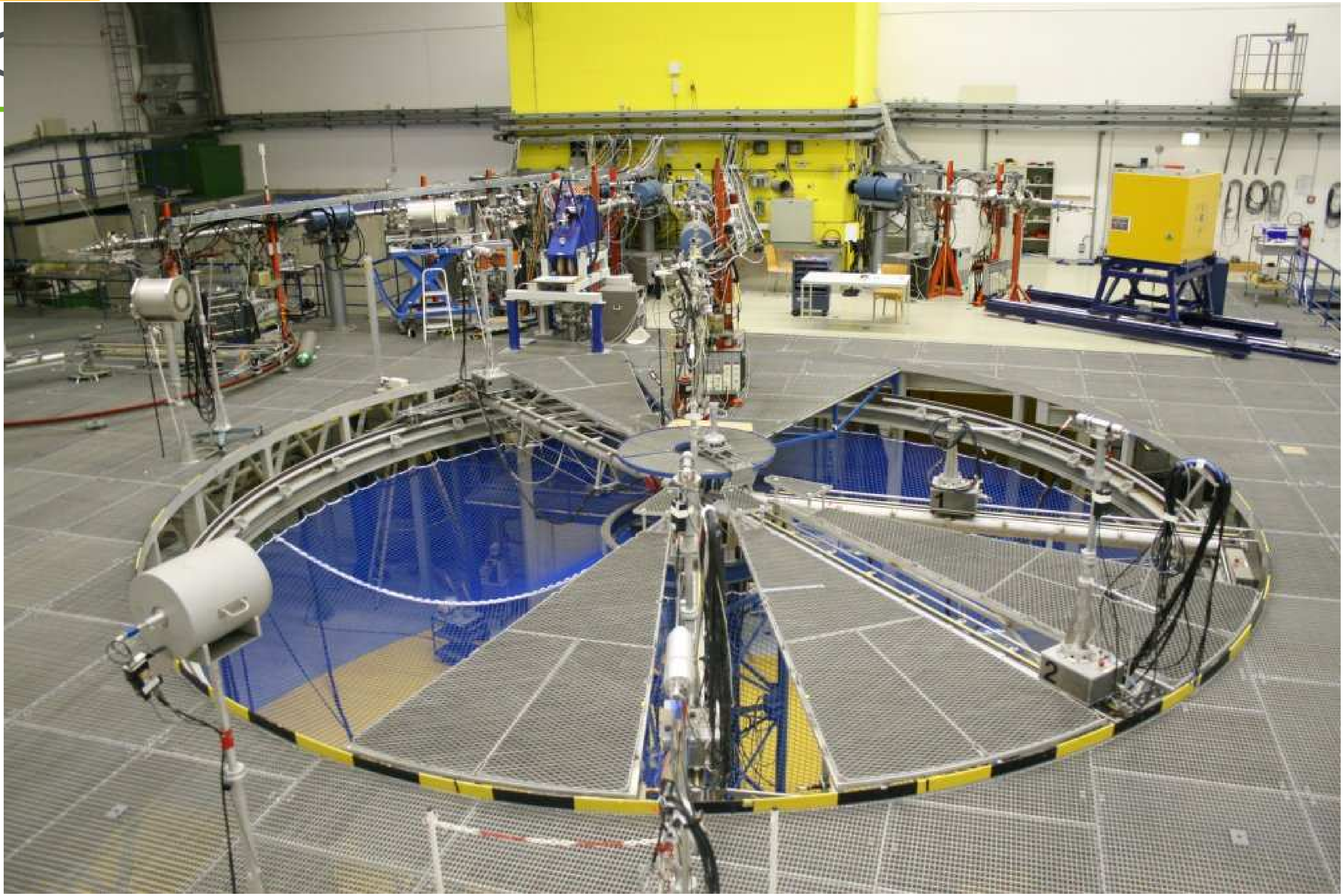
Accelerator facility of PTB in Braunschweig

Van de Graaff
2 MeV T(p,n)
6 MeV D(d,n)
16 MeV T(d,n)

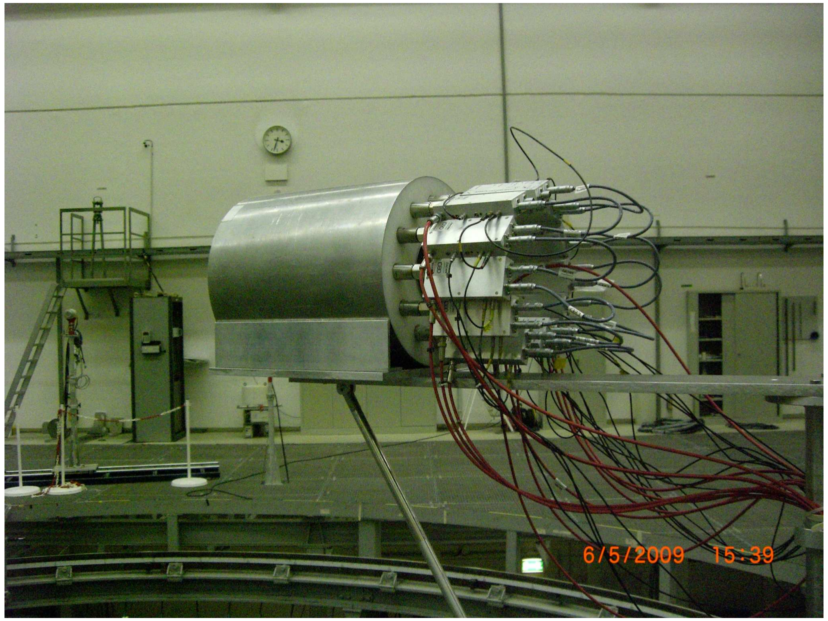
Cyclotron CV28
3 MeV T(p,n)
4 MeV T(p,n)
7 MeV   D(d,n)
10 MeV D(d,n)

Beam switching by fast steering magnet

The Low Scatter Hall



The neutron detector



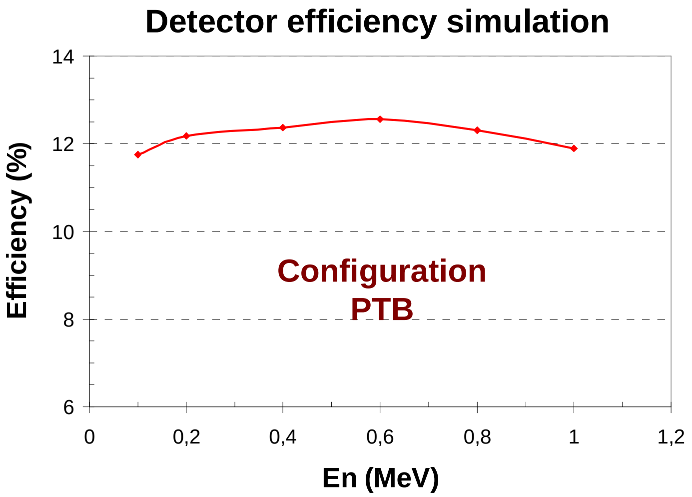
Characteristics :

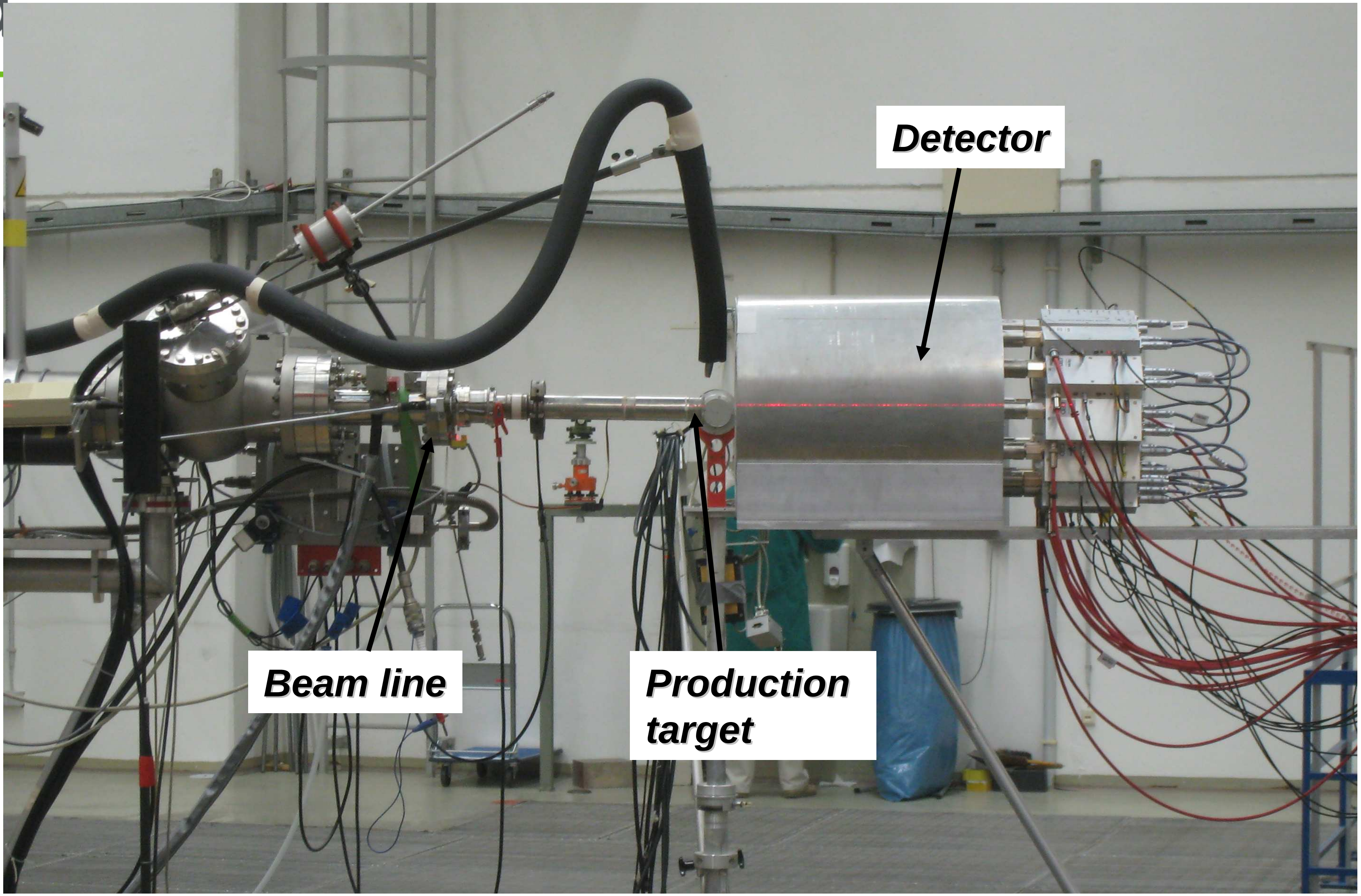
- Cylinder of CH2 (Φint=12 cm, Φext=32 cm, L=37cm)
- 12 tubes 3He
- Efficiency ε > 20% (sample in centre)
- Constant efficiency between 0.1 and 1 MeV
- Not sensitive to gamma
- Also used for photofission studies

Efficiency :

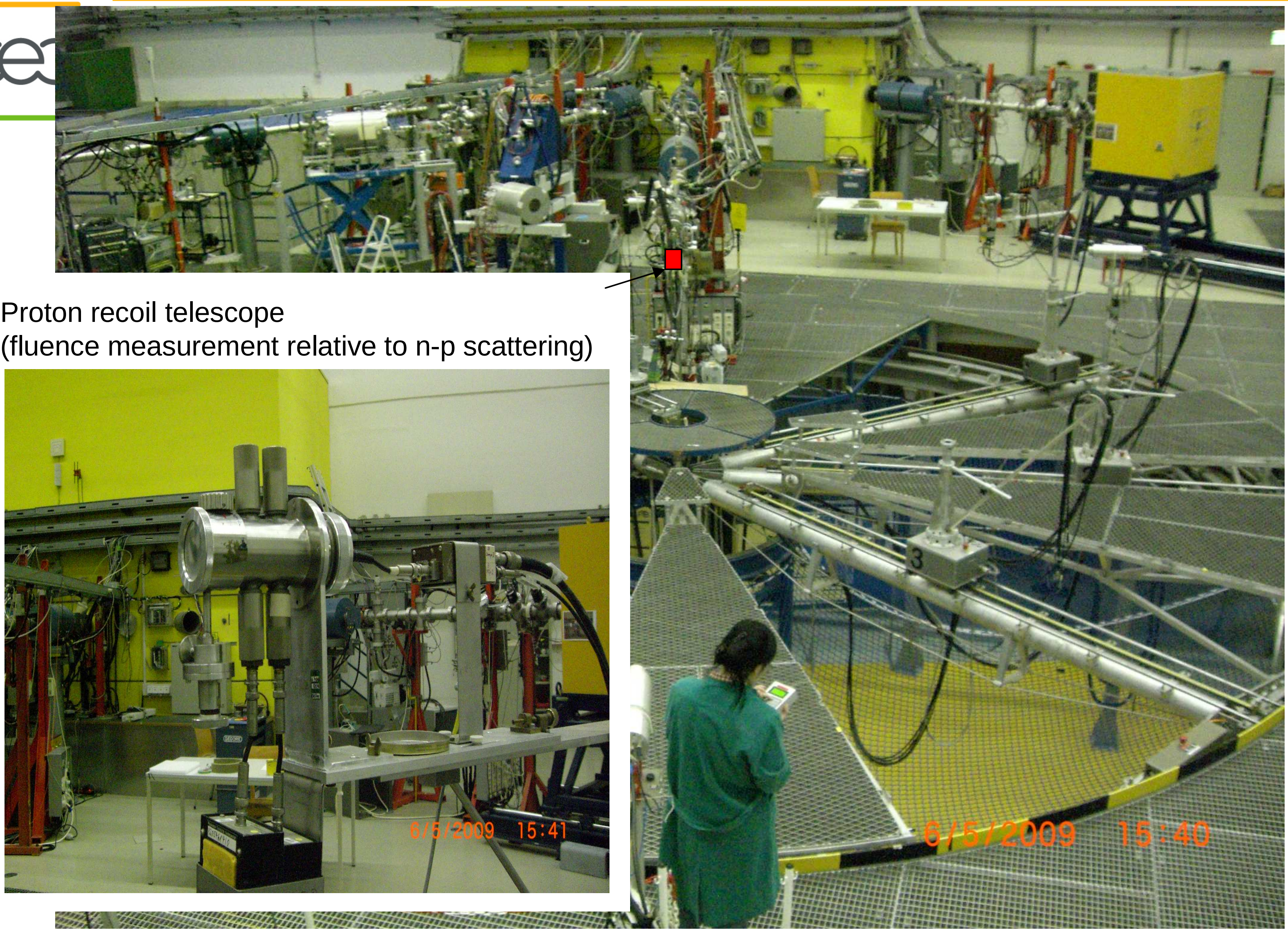
- MCNPX simulations
- Measurements with Cf-252 sources

During this experiment the sample was not placed in the centre of the detector → Lower Efficiency →




Detector
Beam line
Production target

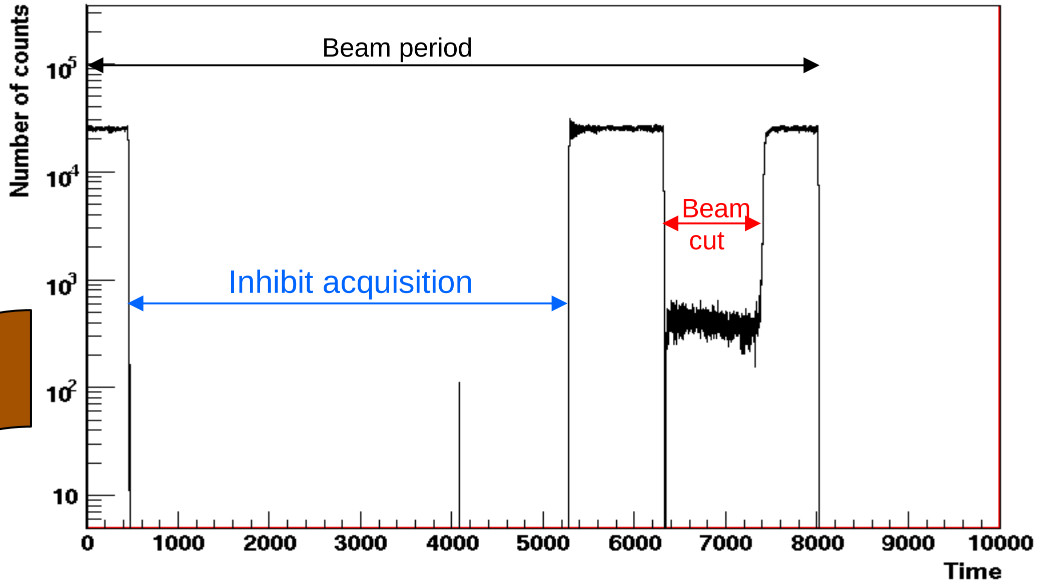
Neutron flux measurement



Proton recoil telescope
(fluence measurement relative to n-p scattering)

Data analysis

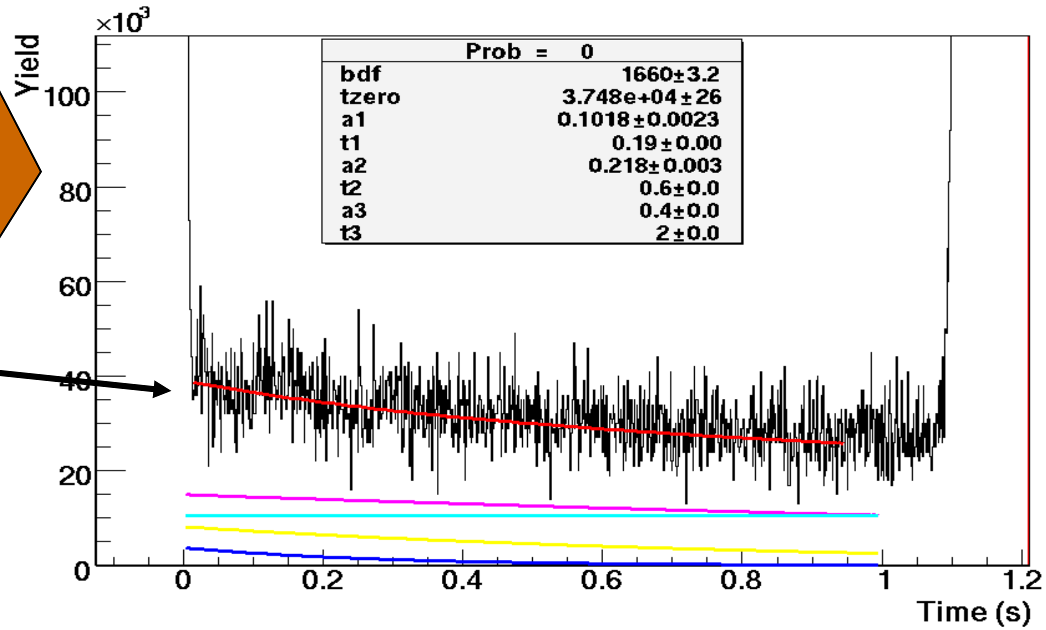
Raw data



- Neutron selection
- Time rescaling
- Cycle summation
- Background subtraction (runs without sample)

Low background

$F_{det}(t=0)$



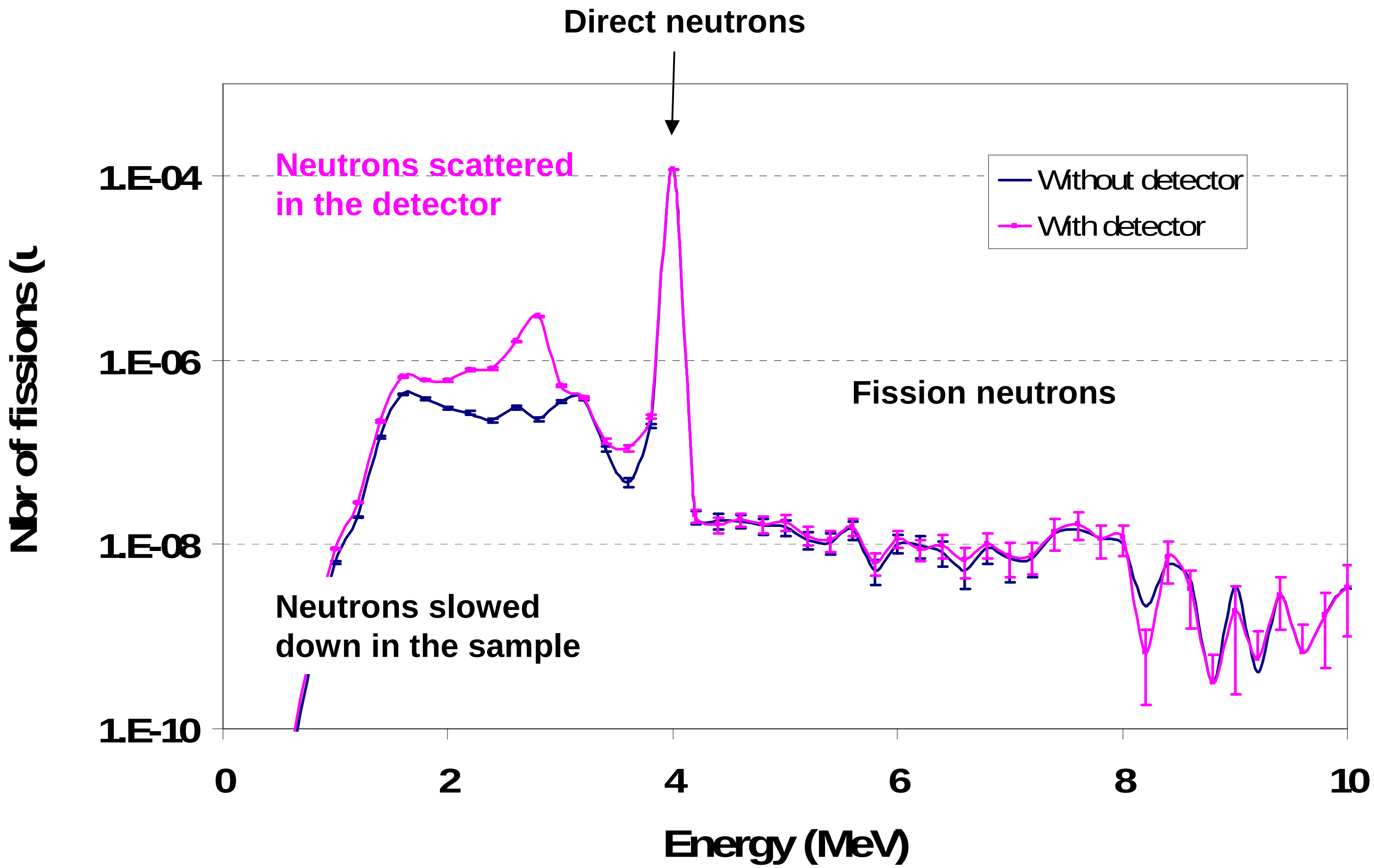
$$\upsilon_d = \frac{F_{\text{det}}(0)}{N_{fissions}\ \varepsilon}$$

Number of fissions

Delayed neutrons are emitted by all the fissions in the sample :

Thick thorium sample : 180g

Fissions are induced by :



+ Break-up component for 10 MeV neutrons

ν_d determination

The number of fissions are calculated for 3 energy domains

N_{fiss}^{mono} for $E=E_{beam}$

N_{fiss}^{up} for $E>E_{beam}$

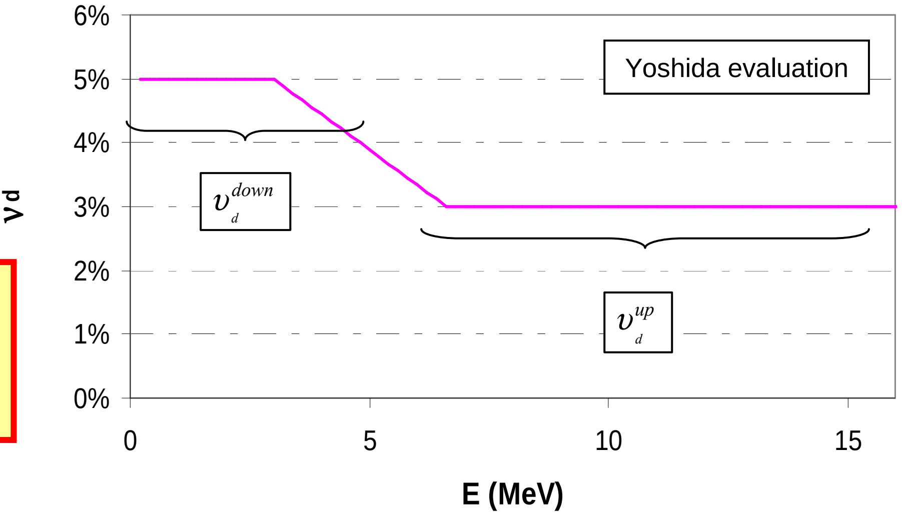
N_{fiss}^{down} for $E<E_{beam}$

N_{fiss} obtained from simulations and fluence measurement

The number of delayed neutrons at t=0 :

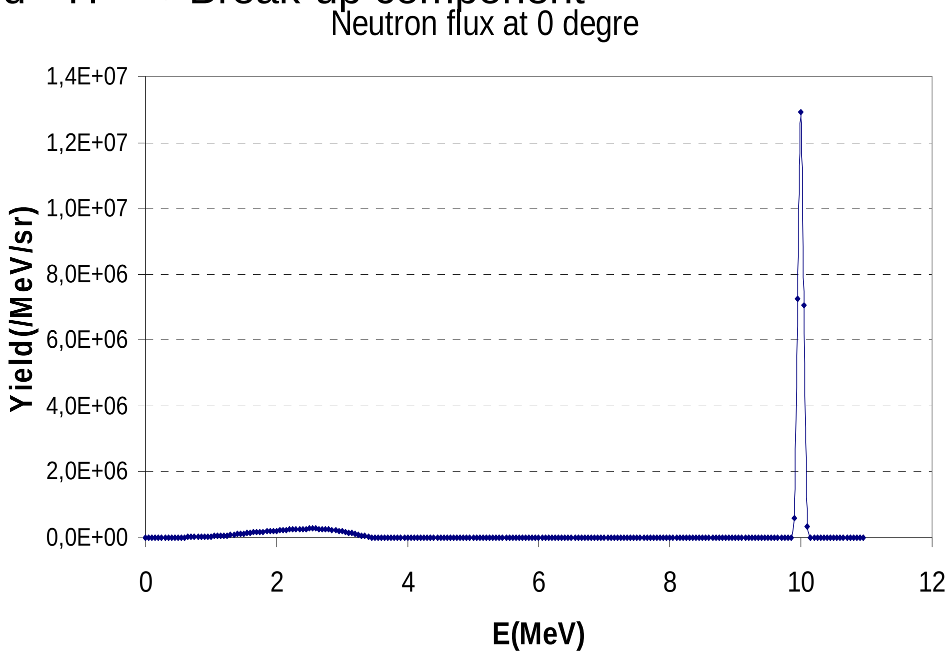
$$Y_d(0)=\upsilon_d^{mono}\,N_{fiss}^{mono} + \upsilon_d^{up}\,N_{fiss}^{up} + \upsilon_d^{dowm}\,N_{fiss}^{down}$$

$$\upsilon_d^{mono} = \frac{F_{\det}(0)/\varepsilon - (\upsilon_d^{up}\,N_{fiss}^{up} + \upsilon_d^{dowm}\,N_{fiss}^{down})}{N_{fiss}^{mono}}$$



Case of 10 MeV

- Neutrons produced by 7 MeV d+^{2}H → Break-up component

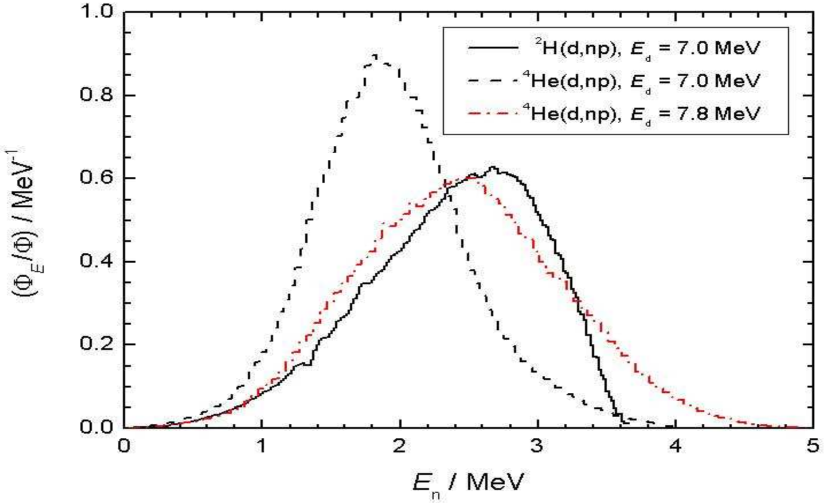


Preliminary analysis :

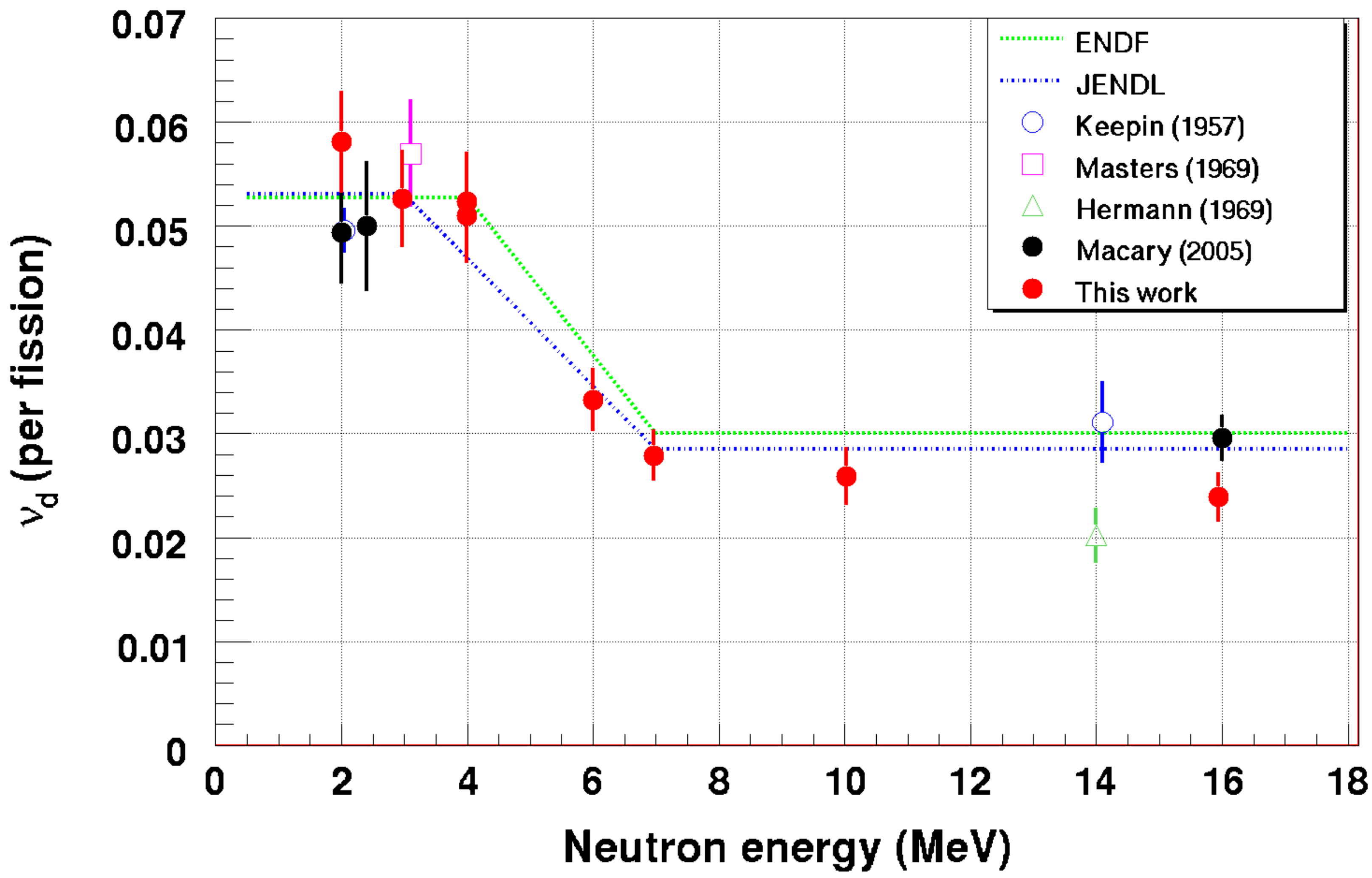
- Corrections of additional fissions due to break-up are evaluated by simulation
- MCNPX simulation
- Assumption: Isotropic distribution of the break-up component

Additional measurement :

- Neutrons produced by 7.8 MeV d+^{4}He reaction
- Spectrum similar to 7.0 MeV ^{3}He(d,np)
- *Not yet analyzed*



Preliminary results



Conclusions

- Experiment performed at **P**TB **I**on **A**ccelerator **F**acility (EFNUDAT funding)
- Measurement of ν_d of Thorium at 2, 3, 4, 6, 7, 10 and 16 MeV
  - Consistent measurements on a wide energy range
  - Measurement at 10 MeV particularly interesting
- Very good experimental conditions (very low background)
- Flux normalized with σ(n,p)
- Work still to do :
  - Uncertainties estimation
  - Analysis of d+^{4}He measurement for 10 MeV break-up component correction

Preliminary results