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Advantage of Usage of Neutron Signals from Opposite Directions for Reconstruction of Neutron Energy Spectra

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CZECH TECHNICAL UNIVERSITY IN PRAGUE

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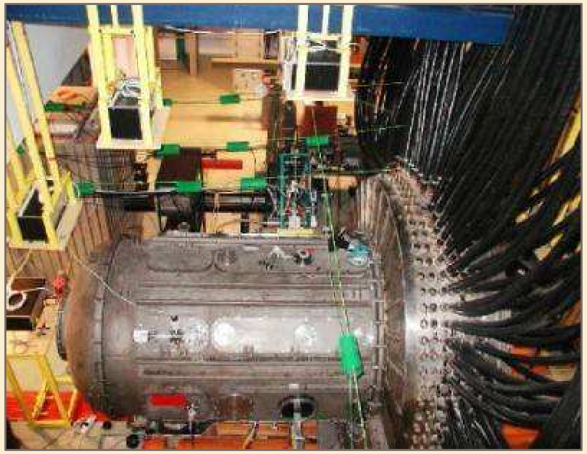
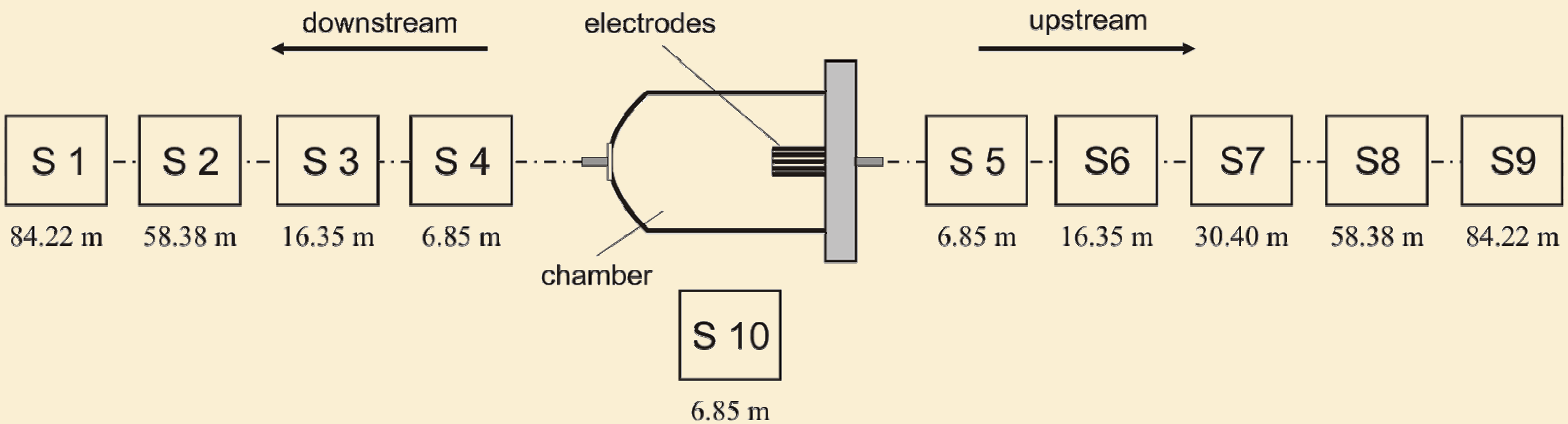
Experimental setup – PF 1000 facility

- **PF 1000 facility**
  - **IPPLM in Warsaw**
  - **Device axis – horizontal**
  - **Neutron yield up to 10^{11} neutrons**

$$D + D \rightarrow {}^{3}He(0.82\ MeV) + n(2.45\ MeV)$$



PF 1000 facility.

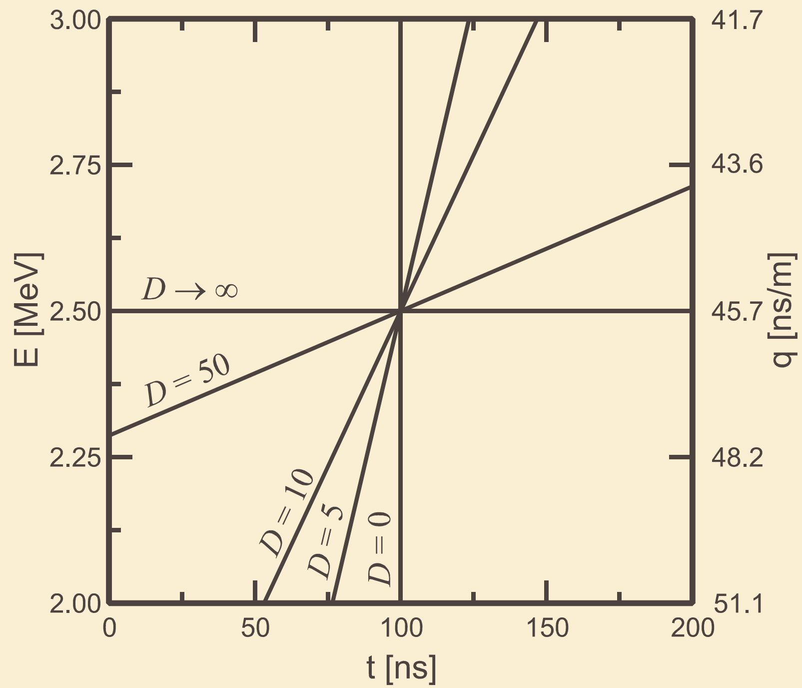


PF 1000 – scheme of the time-resolved neutron diagnostic system (Oct. 2006).

Reconstruction method

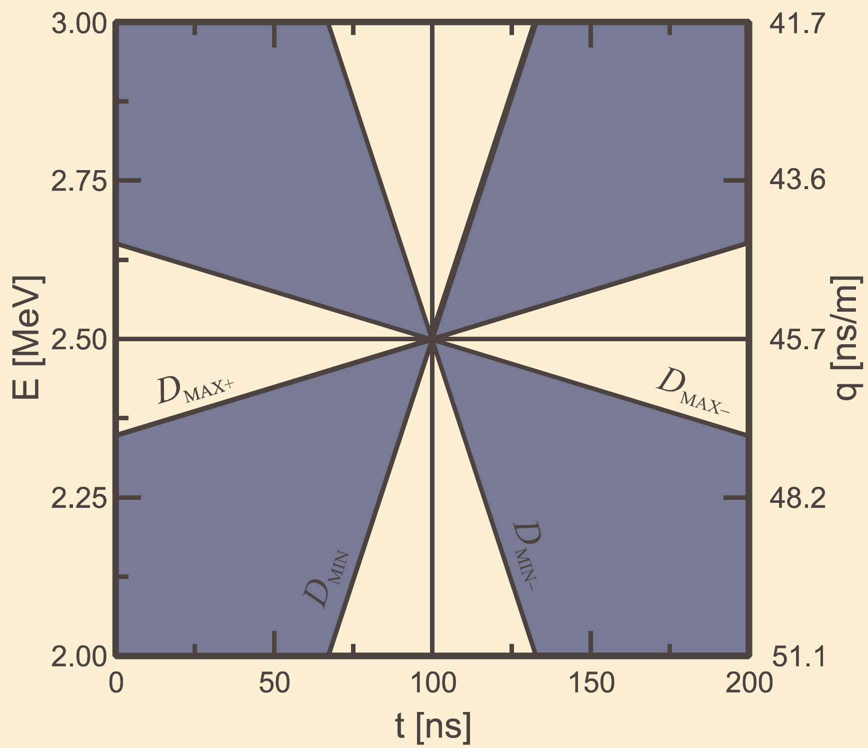
- The aim is to reconstruct the neutron time-resolved energy spectra $f(t, E)$ on the basis measured neutron signals.
  - Time-of-flight method
  - Inverse problem (we can find several right solutions)
  - Limited data set tomography

- Monte-Carlo method
  - Tiseanu, Decker, Kies (1996)



Detectors in the opposite direction

- Why?
- During the tomographic reconstruction we gain information from greater angle of view.

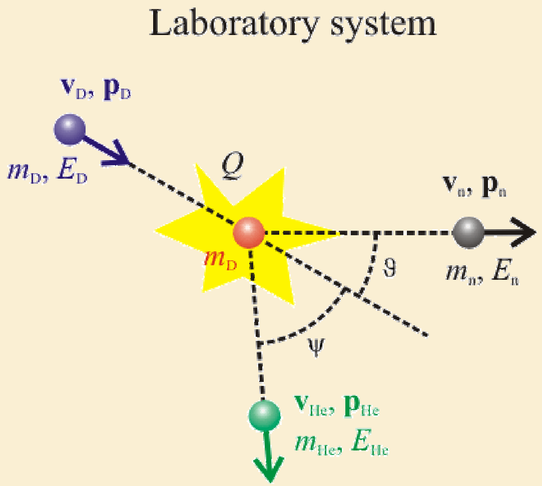


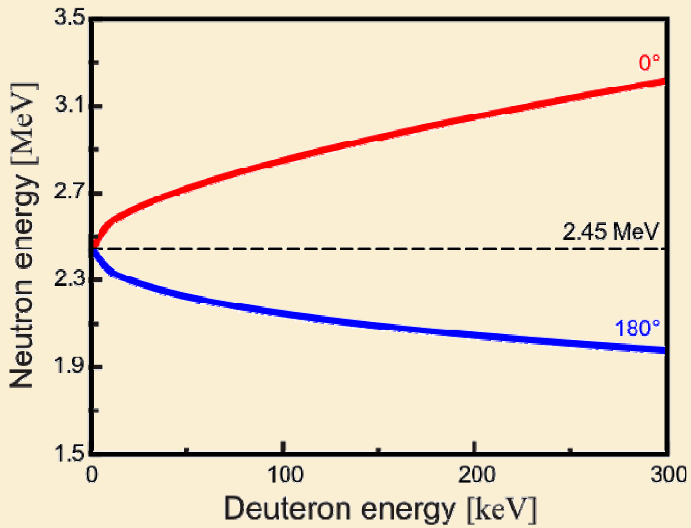
Detectors in the opposite direction

- How?
- We presume following: If one neutron has arisen (from DD reaction) with given energy in downstream direction the other neuron has arisen (with the probability according to anisotropy in neutron yield) with corresponding energy in the upstream direction.
  - The transformation of the neutron energy
  - The anisotropy in neutron yields
    - From neutron energy spectra
    - Angular measurement and subtract influence of experimental vessel

The transformation of the neutron energy

$$E_n(E_D,\vartheta) = E_D \frac{m_n}{2(m_n + m_{He})} \cdot \left(\cos\vartheta + \sqrt{\frac{m_{He}}{m_n}\left(1 + \frac{2Q}{E_D}\right) - \sin^2\vartheta} \right)^2$$

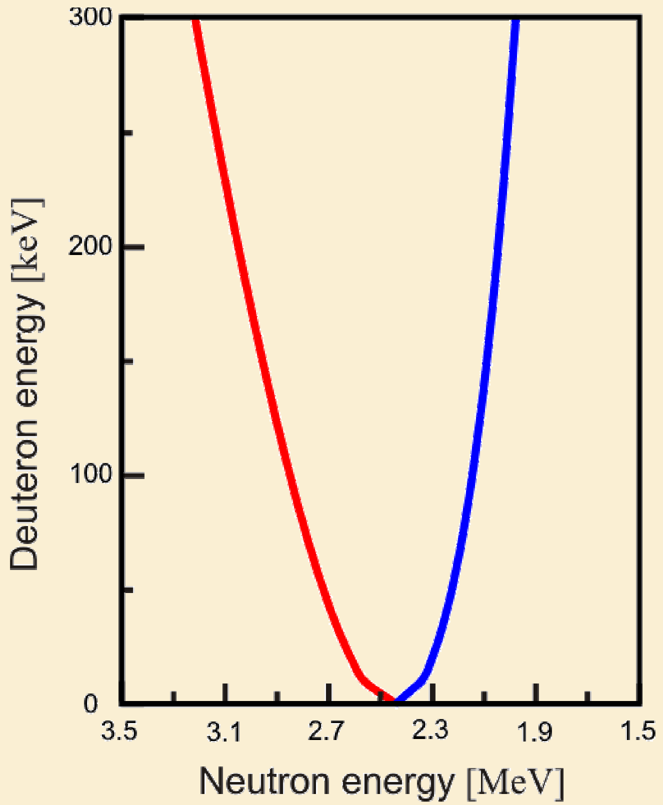


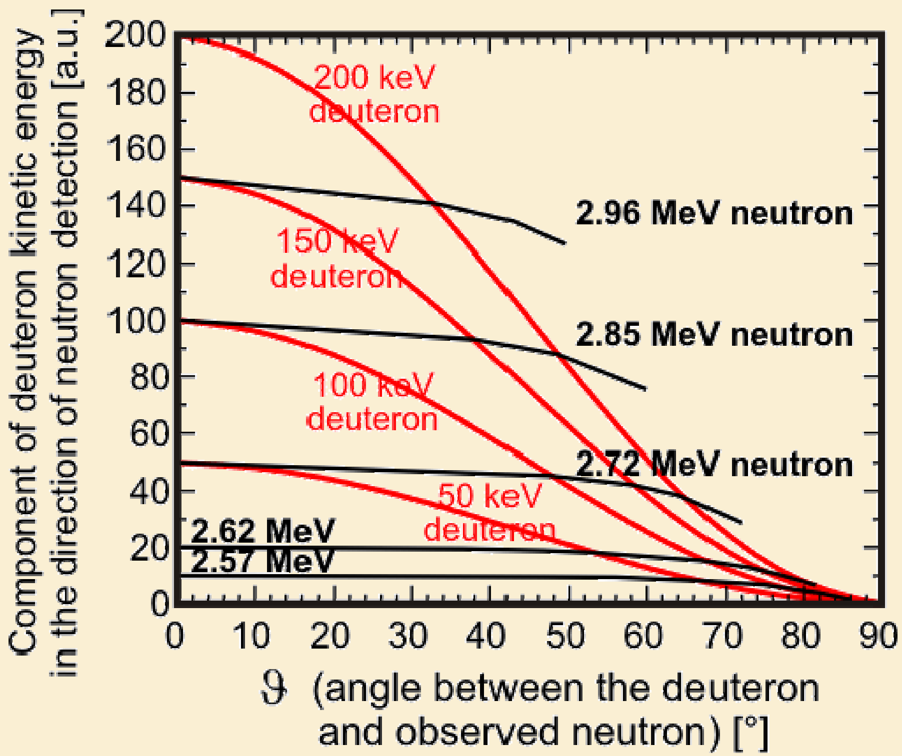


- The influence of various angle of neutron production was discussed. The error of determination of neutron energy was estimated ±0.05 MeV.

Component of deuteron kinetic energy

$$E_{\mathrm{n}}(E_{\mathrm{D}}, \vartheta) \quad \rightarrow \quad E_{\mathrm{D}}(E_{\mathrm{n}})$$





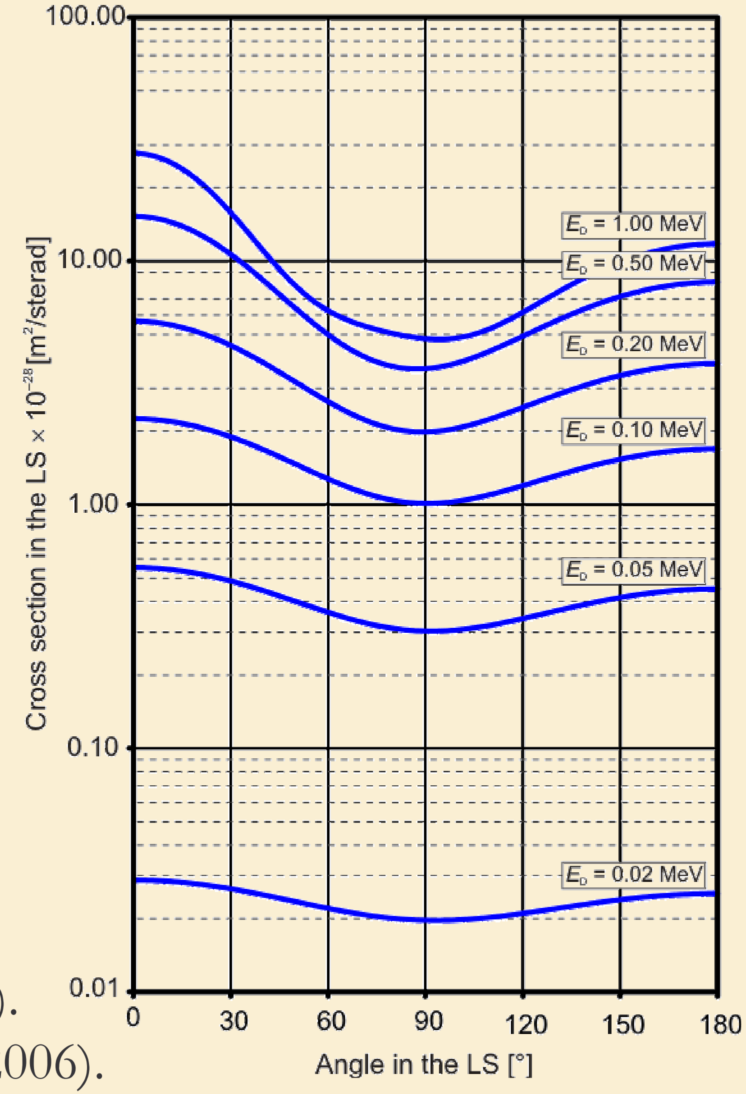
The anisotropy in the neutron yield

$$E_n(E_D, \vartheta) \quad \rightarrow \quad E_D(E_n)$$

$$Y = N_D \cdot p_{DD} = N_D \cdot \frac{l}{\lambda_{DD}} = N_D \cdot l \cdot n_i \cdot \sigma(E_D)$$

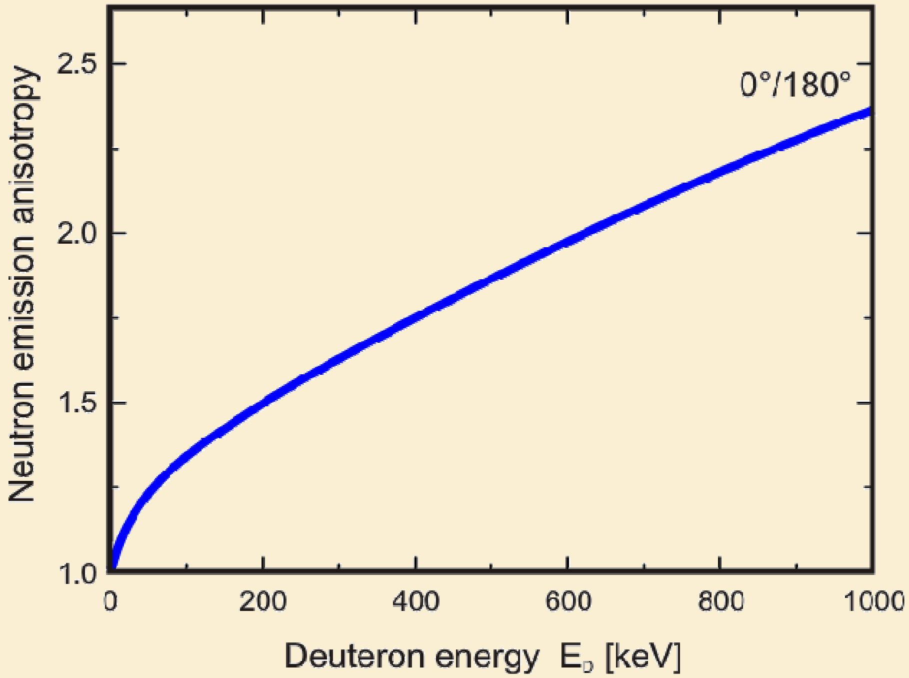
$$\frac{d\sigma}{d\Omega} = \sigma_0 (A_0 + A_2 P_2(\cos\vartheta) + A_4 P_4(\cos\vartheta) + \ldots)$$

$$\frac{d\sigma}{d\Omega_{LS}} = \frac{d\sigma}{d\Omega} \cdot \frac{\left(1 + 2\zeta\cos(\vartheta) + \zeta^2\right)^{3/2}}{1 + \zeta\cos(\vartheta)}$$



M. Drosg, O. Schwerer, IAEA, Vienna (1987).
M. B. Chadwick et al., Nuclear Data Sheets (2006).

The anisotropy in neutron yields

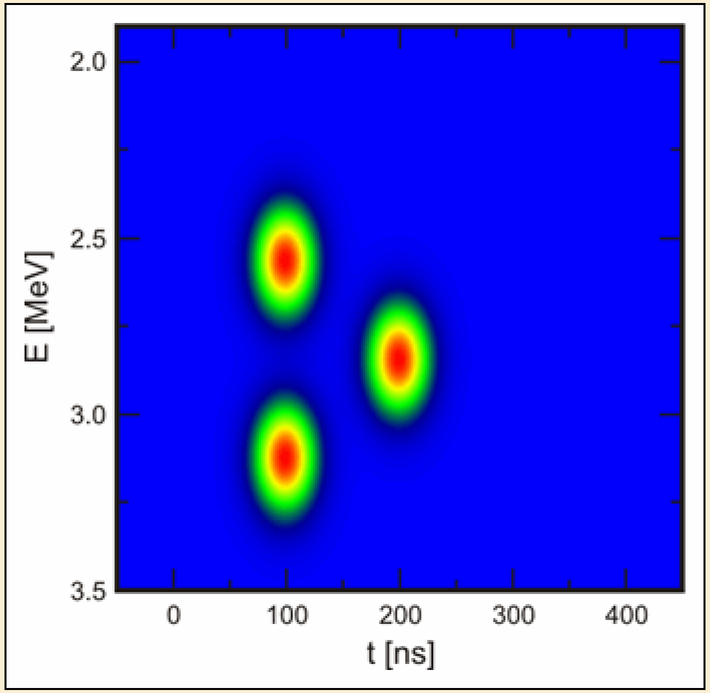


- Axial anisotropy of neutron yields was included during both direction calculations
- Results do not differ qualitatively to previous calculations without anisotropy

Advantages of usage neutron signals from opposite directions

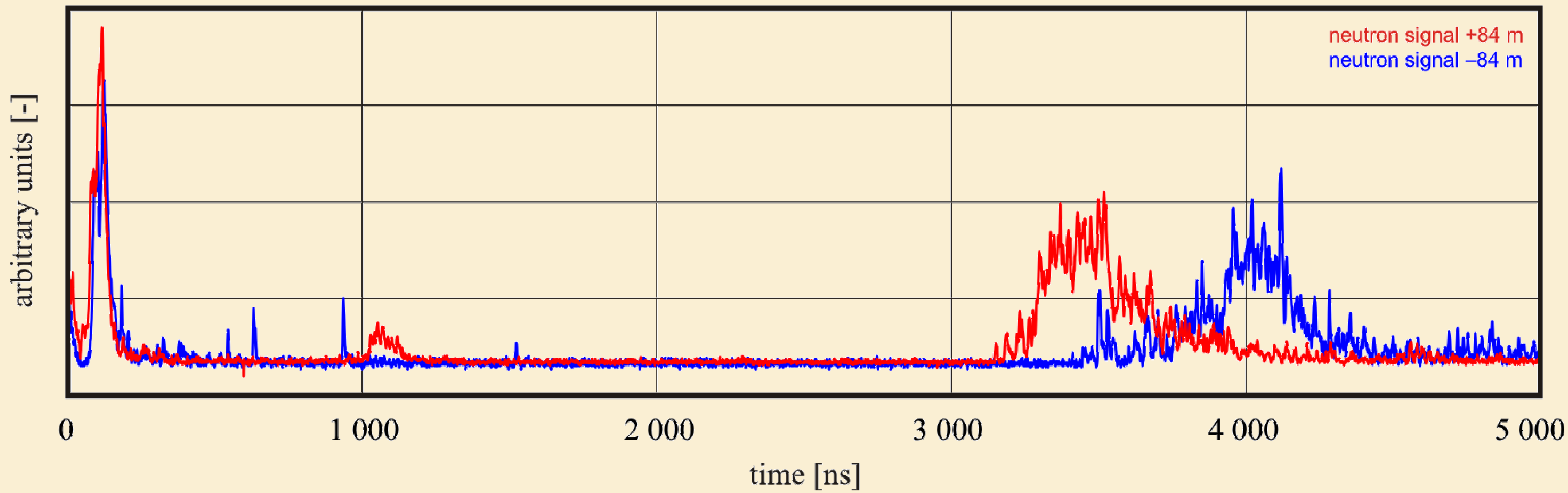
- "Better" reconstruction
  - Greater range of angle of view

- Smaller influence
  of scattered neutrons

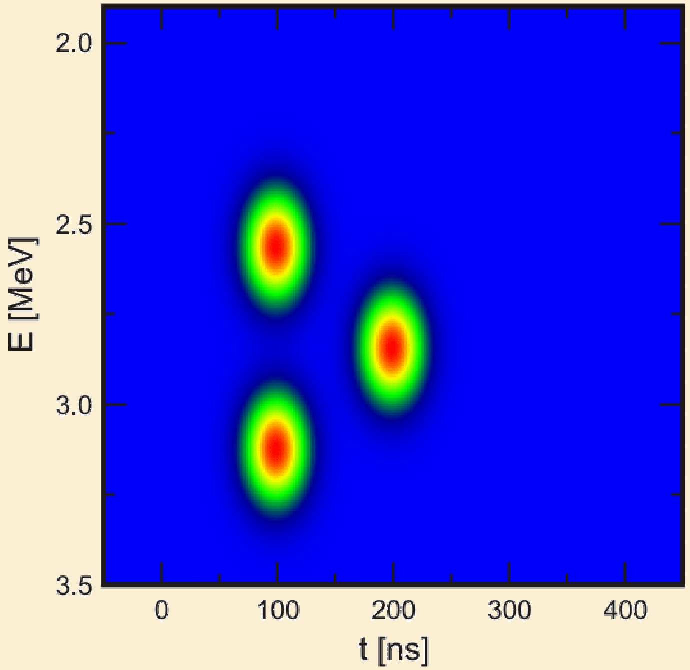


Influence of scattered neutrons

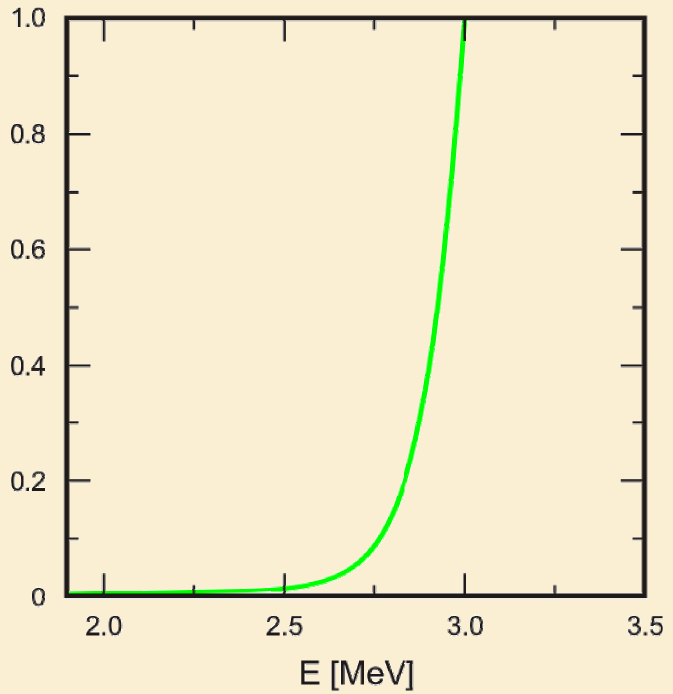
- Smaller influence of scattered neutrons – it is follows from transformation of neutron energy
- If we record scattered neutron (with small energy) in one direction we can not find correspond neutron with higher energy in the other direction



Influence of scattered neutrons



The test distribution function.

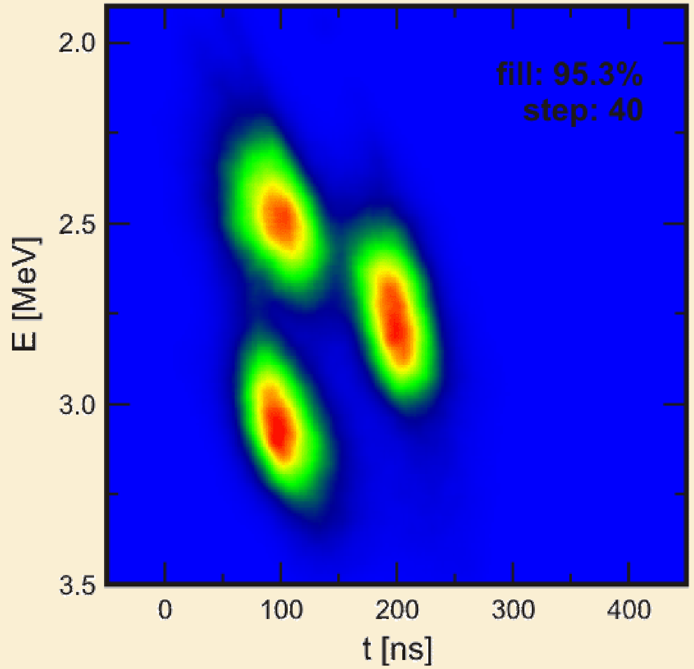


$$f(t, E_{\mathrm{n}})$$

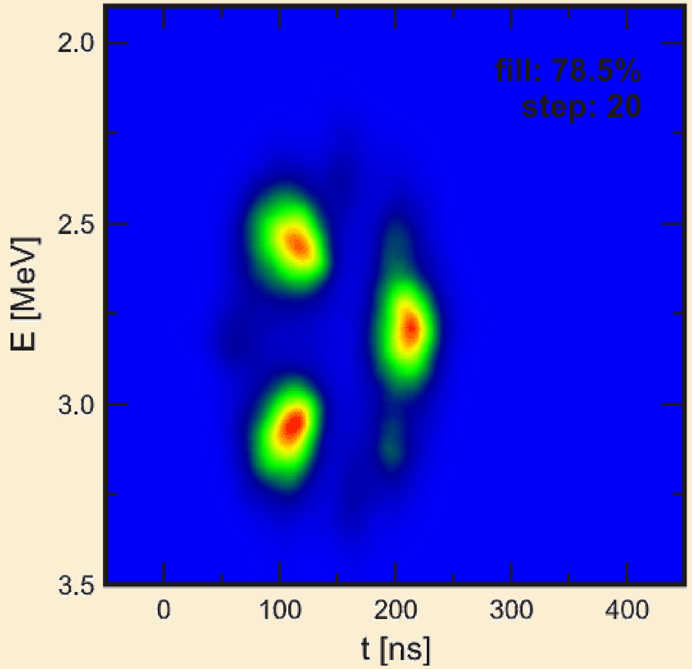
$$g(E_{\mathrm{n}}) = \mathrm{e}^{\frac{E_{\mathrm{n}} - E_0}{0.1}}$$

$$f(t, E_{\mathrm{n}}) * g(E_{\mathrm{n}})$$

Influence of scattered neutrons

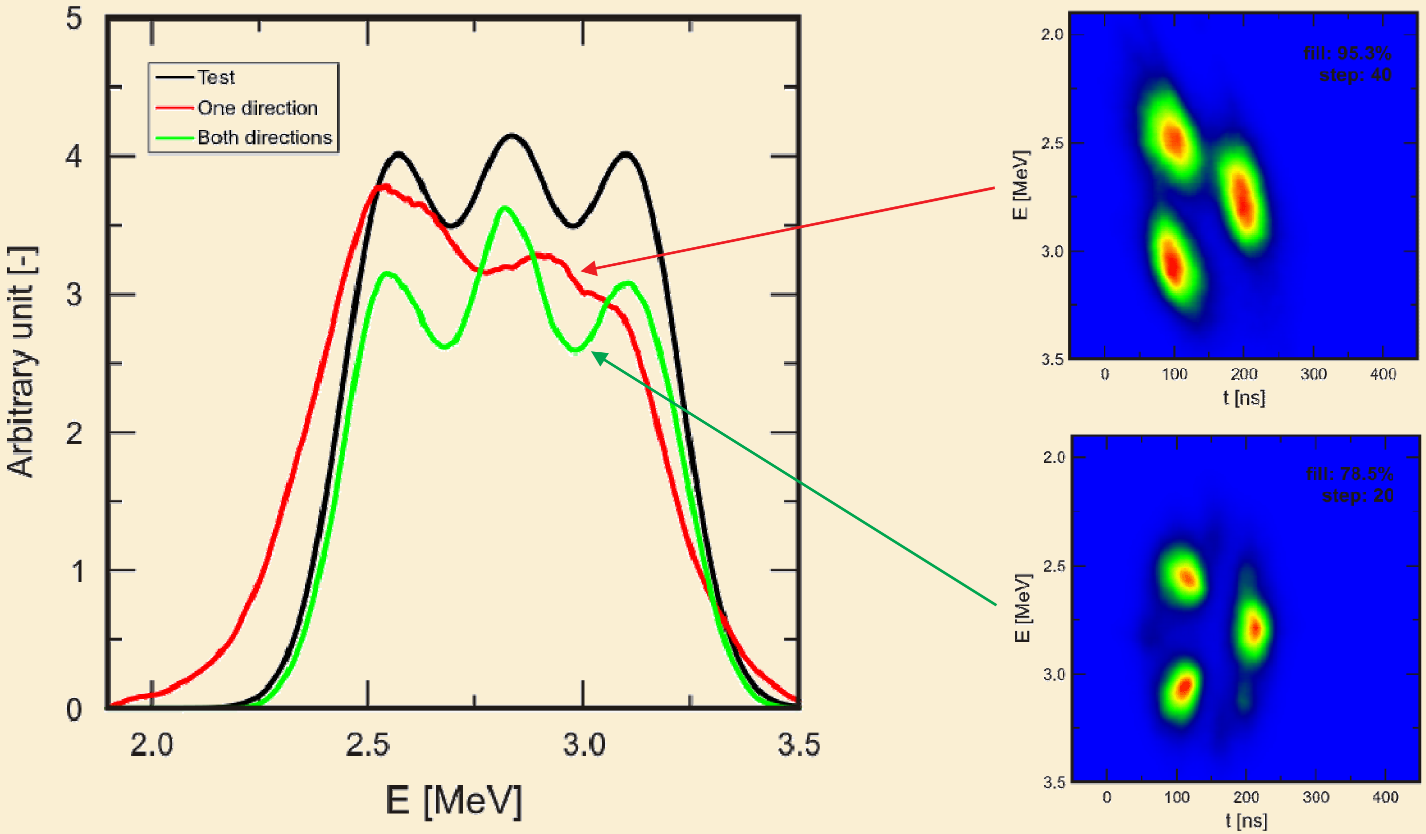


The test function reconstructed from 9 detector signals – one direction (distances from 6.85 m to 84.22 m).



The test function reconstructed from 9 detector signals – both directions (same distances as in experiment in October 2006).

Influence of scattered neutrons



- When we use neutron signals from both directions, scattered neutrons do not shift the energy spectra but shift the time of neutron production

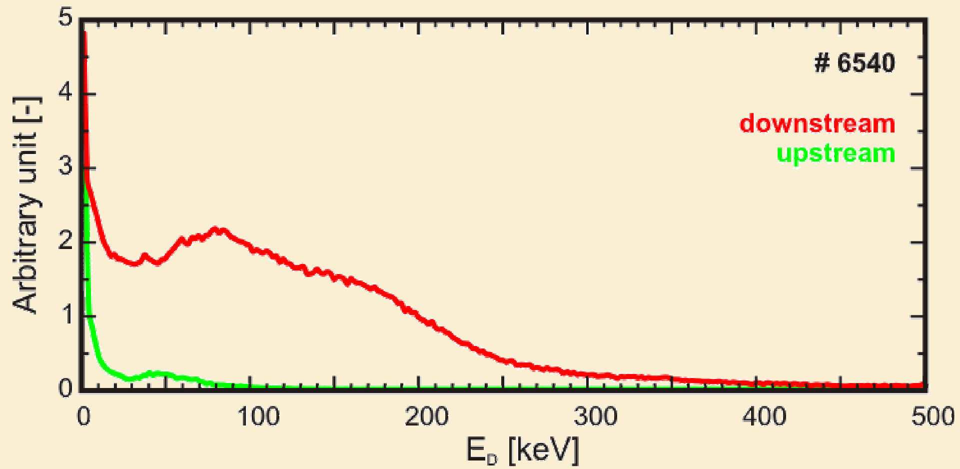
Program Neutrons – status

- Developed in FORTRAN language from November 2005

- Main part of the program (February 2006)
- Another program for numerical testing (February 2006)
- Employ both directions of neutron detection
  - The transformation of the neutron energies (end of the year 2006)
  - The anisotropy in neutron yield (May 2007)
- Influence of the scattered neutrons (September 2007)

Results

Shot #	Neutron yield	Axial anisotropy
6540	2.18×10^{11}	1.29
6552	1.88×10^{11}	1.24
6555	2.15×10^{11}	1.17
6565	7.34×10^{10}	1.13
6573	4.12×10^{10}	1.08



Component of deuteron kinetic energy in the direction of neutron detection.

Conclusions

- The usage of the neutron signals from opposite directions is very advantageous
  - Better reconstruction of neutron energy spectra
  - Smaller influence of scattered neutrons
- The component of the deuteron kinetic energy of deuteron which produce fusion neutron can be calculated from neutron energy spectra
- The anisotropy of the neutron production can be calculated from neutron energy spectra
- There are energy below 10 keV in the component of the deuteron kinetic energy → fusion deuterons has radial component of the velocity → mechanism is not linear beam-target

Future work

- More accurate calculation during transformation of neutron energy (including various angle of the neutron production)
- Optimization of the reconstructed spectra – Genetic Algorithm (Josef Vermach, bachelor thesis, 2008/9)

- Measurement of the radial neutron energy spectra – PF 1000 experiments in January 2008, detectors at long distances (40 m)
- Evaluation of the influence of the neutron detector (scintillation probe, photomultiplier) and including it into calculations

Thank you for your attention