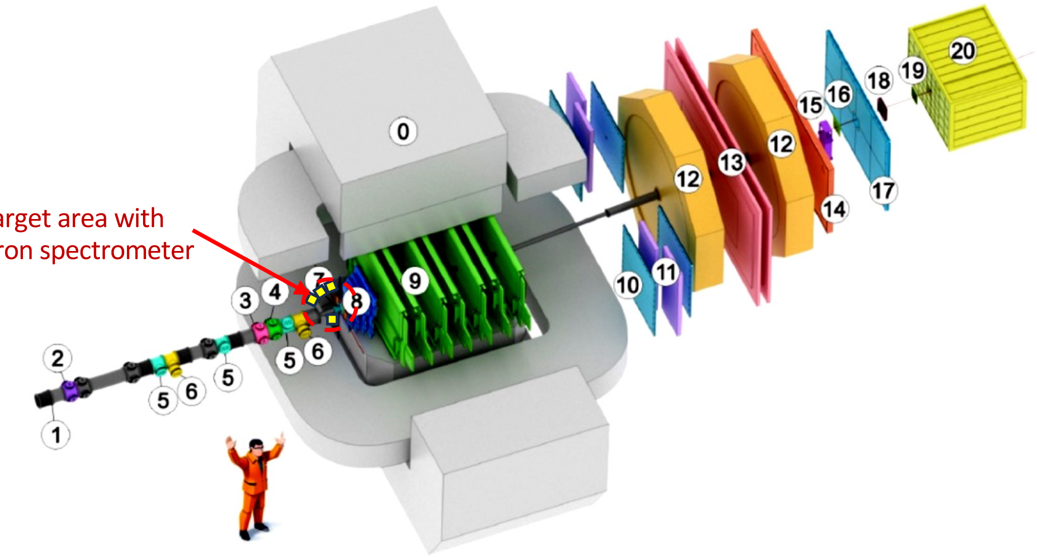
Compact Time-of-Flight Neutron Spectrometer with Digital Signal Processing

N. Lashmanov, V. I. Yurevich, V. Yu. Rogov, S. A. Sedykh, S. V. Sergeev, M. N. Kapishin, S. M. Piyadin, S. N. Bazilev, I. V. Slepnev, V. K. Velichkov, V. V. Tikhomirov, A. A. Timoshenko, I. A. Filippov, A. V. Shutov, A. V. Schipunov

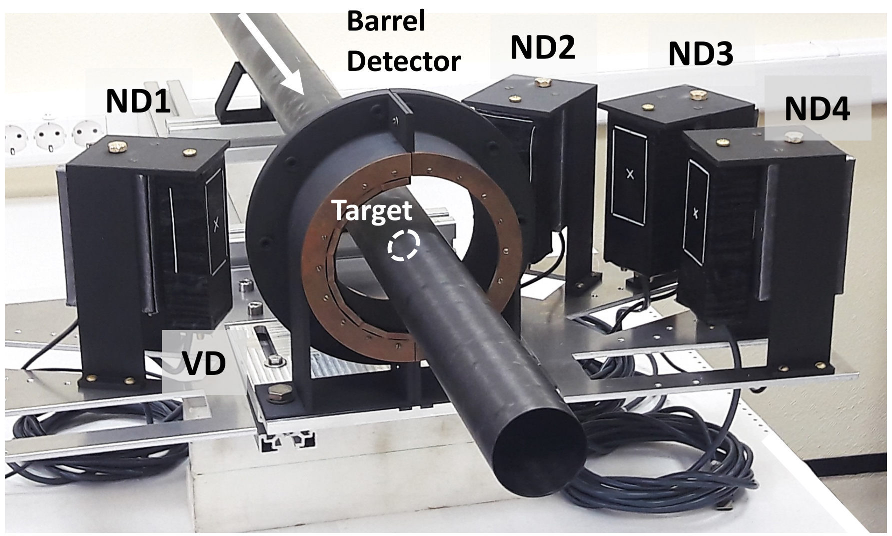
Joint Institute for Nuclear Research, Dubna, Russia

TOF neutron spectrometer of BM@N experiment

BM@N experiment with HI beams of Nuclotron

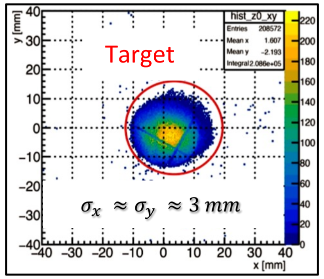


A photo of TOF neutron spectrometer



Spectrometer performance was studied in BM@N Run with Xe-ion beam with energy of 3.8 A GeV and CsI target

Beam		Target
Beam ions:	^{124}Xe	2% CsI
Energy:	3.8 *A* GeV	D32 × 1.75 mm
Intensity:	~ 6 10^5 ion/spill	
Spill duration:	~ 2.5 s	



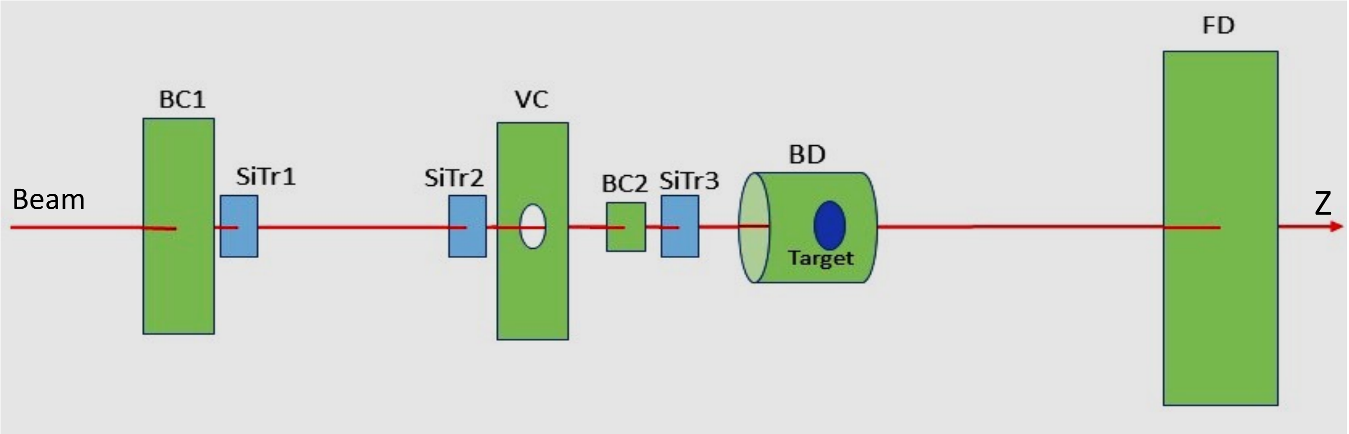
Hits of Xe ions in the target position obtained with forward Si tracker

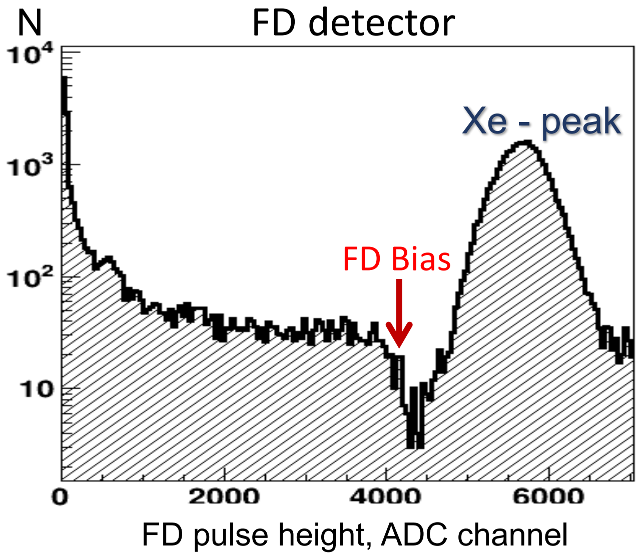
Main features of the spectrometer:

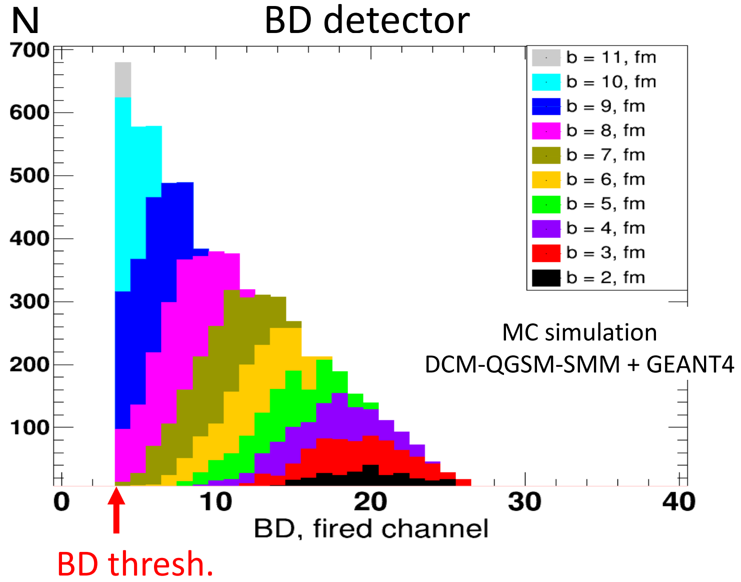
- ✓ Small flight path *L* ~ 0.3 m to minimize background
- ✓ High time resolution with $\sigma_t \approx 100$ ps
- ✓ Effective suppression of gamma-rays by PSD method
- ✓ Digital signal processing
- ✓ Off-line event-by-event analysis
- ✓ Application of SiPMs instead PMTs in magnetic field

Selection of interactions in the target

Trigger detector system of the BM@N experiment



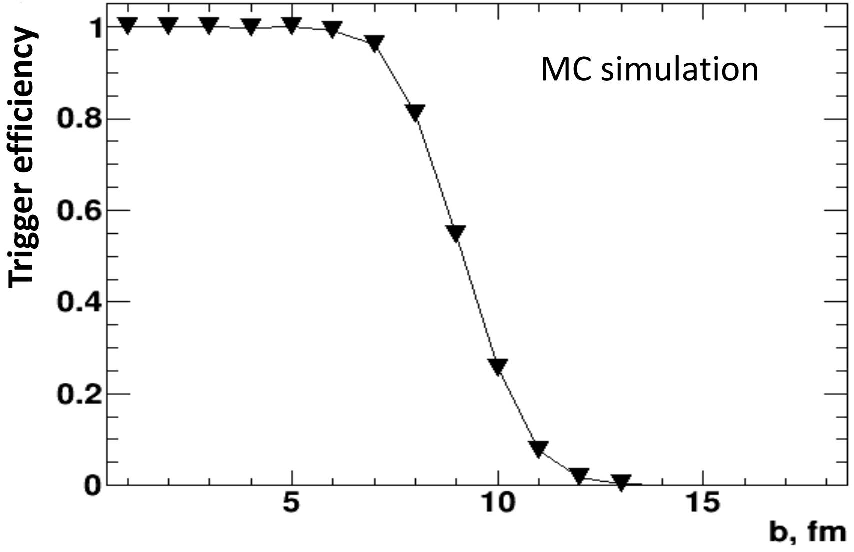




Event selection by trigger detectors FD and BD

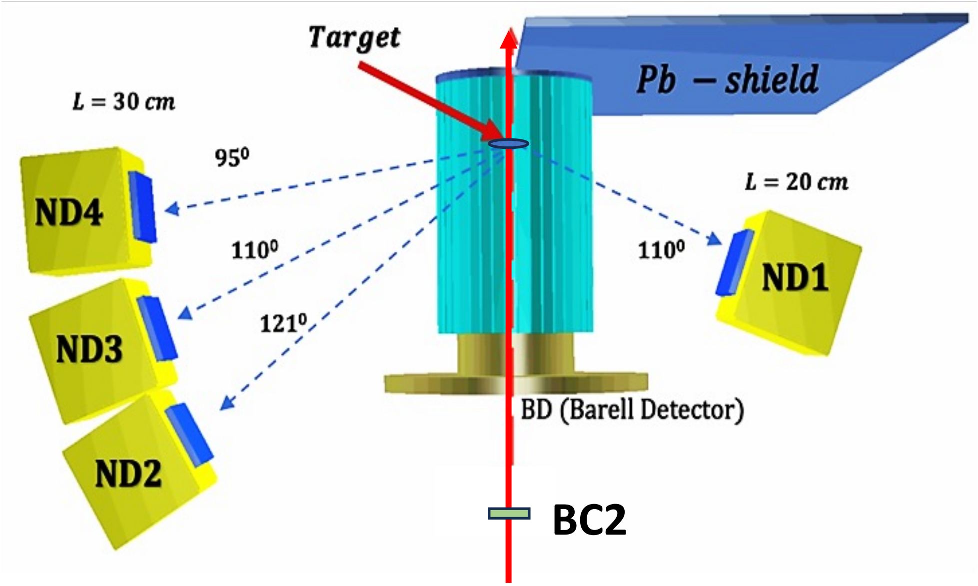
Interaction Trigger Logic:

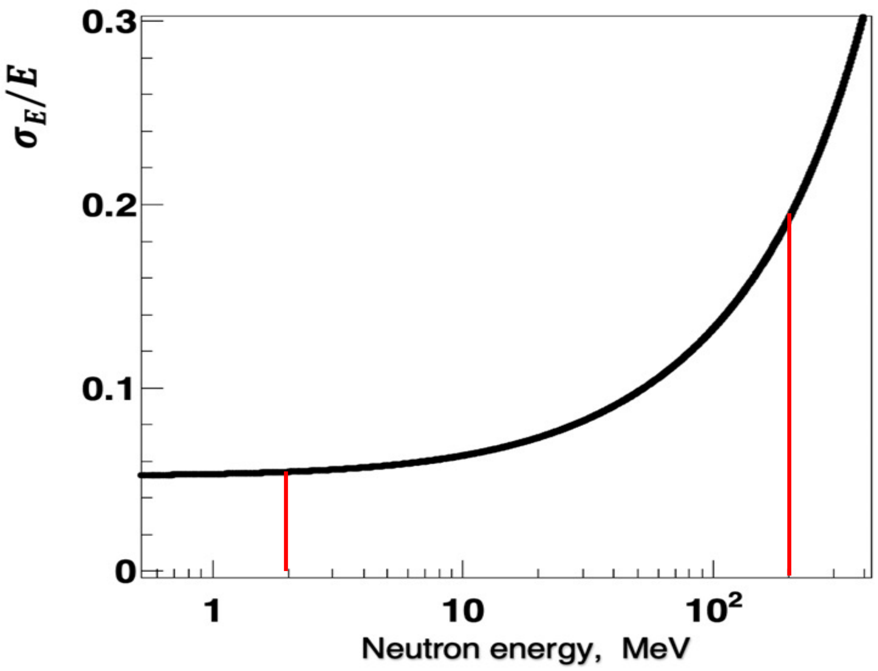
IT = BC1 * $\overline{\text{VC}}$ * BC2 * $\overline{\text{FD}}$ * BD(N>3)



The compact TOF neutron spectrometer

"Table-scale" spectrometer with small flight path for measurements in energy range 2 – 200 MeV





Start Detector – Beam counter BC2

Scint. BC400B, H = 0.125 mm

Two MCP-PMTs XPM85112/A1

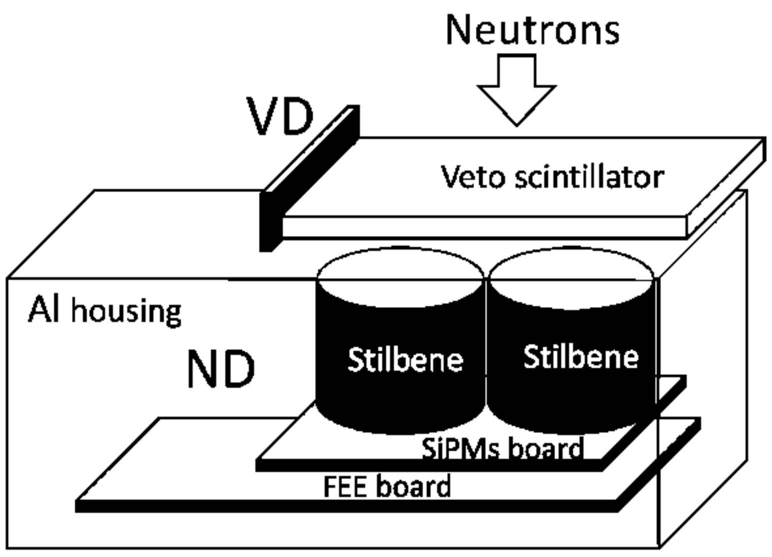
Time resolution σ_t = 40 ps

Stop Detectors – Neutron detectors

Detector	Stilbene*	Angle θ	Flight path	Time resolution
ND1	D3×1 cm	110°	20 cm	**128 ps**
ND2	D2.5×2.5 cm	121°	30 cm	**114 ps**
ND3	D2.5×2.5 cm	110°	30 cm	**118 ps**
ND4	D2.5×2.5 cm	95°	30 cm	**110 ps**

* 2 units per detector

Neutron detectors



A scheme of the detector construction

Stilbene with four SiPMs
6×6 mm^2 (SensL, J ser.)

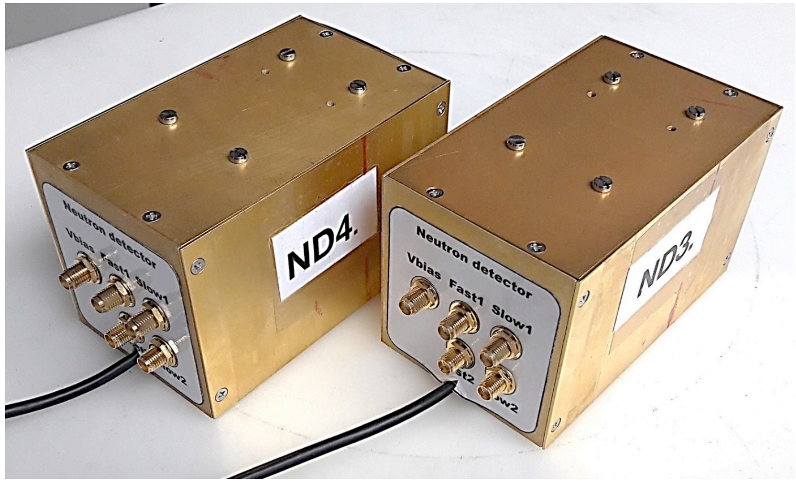
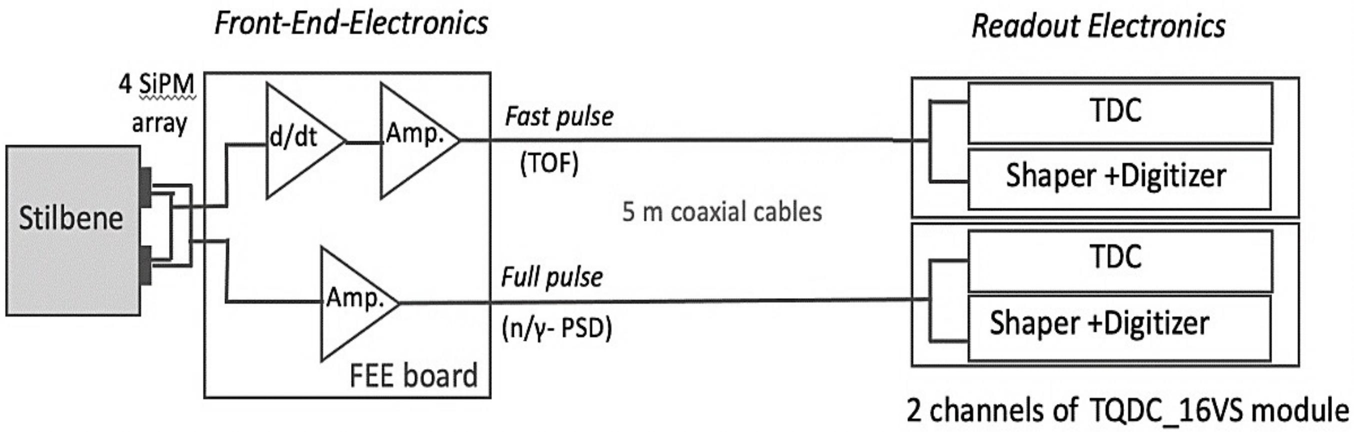


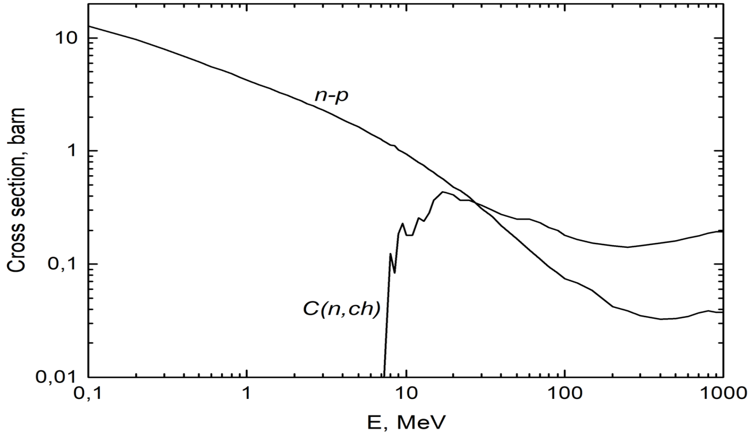
Photo of neutron detectors



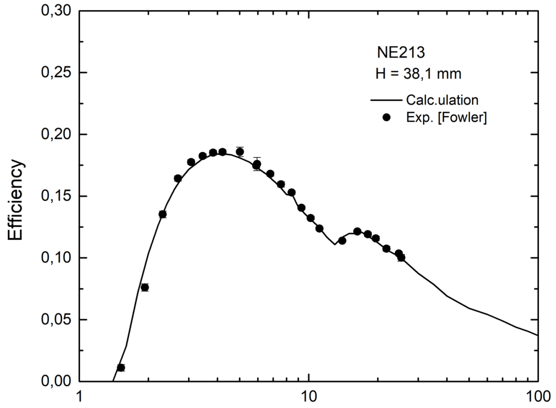
A scheme of data taken channel

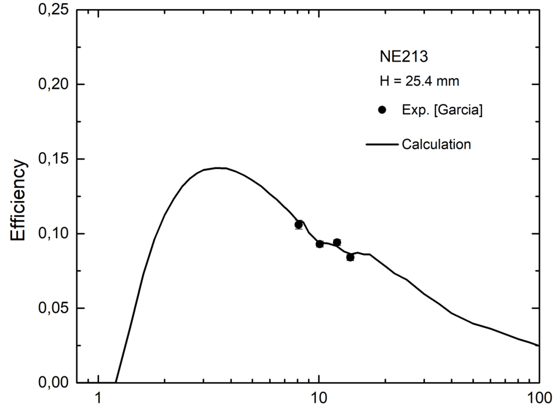
Neutron detector efficiency

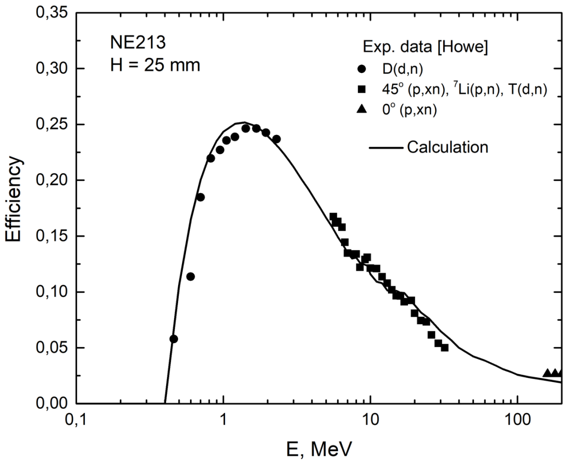
Calculation of efficiency for thin neutron detectors using a single interaction approach based on cross sections of n-p scattering and n-C reactions with charged particle production

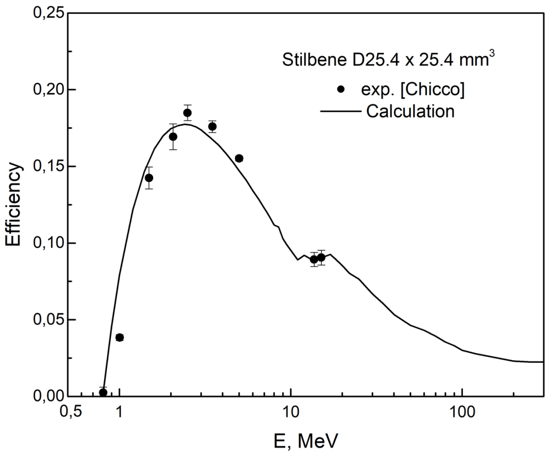


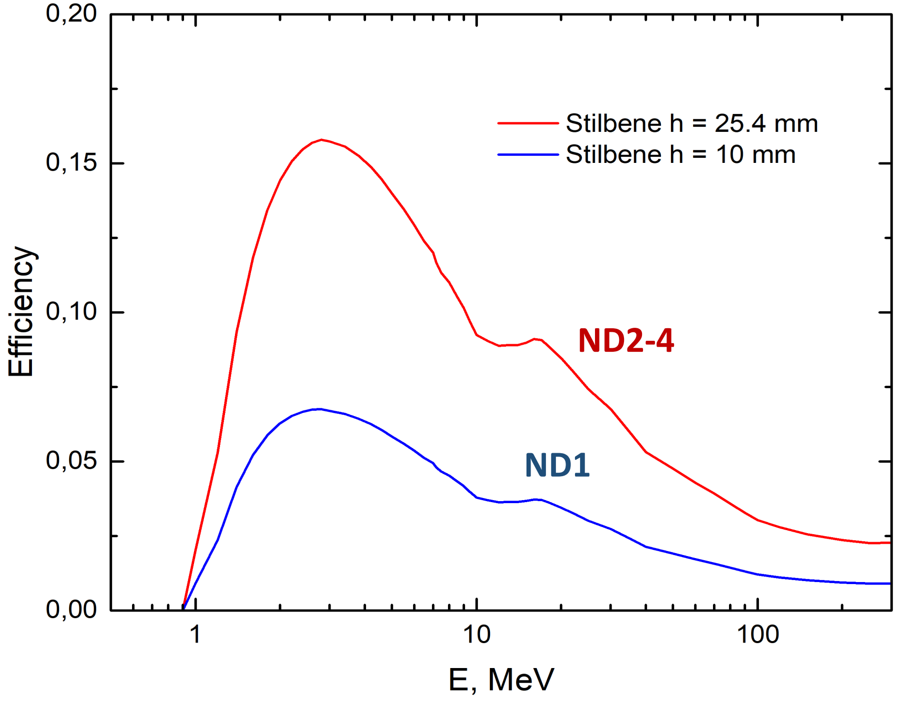
Test of the method with available experimental data









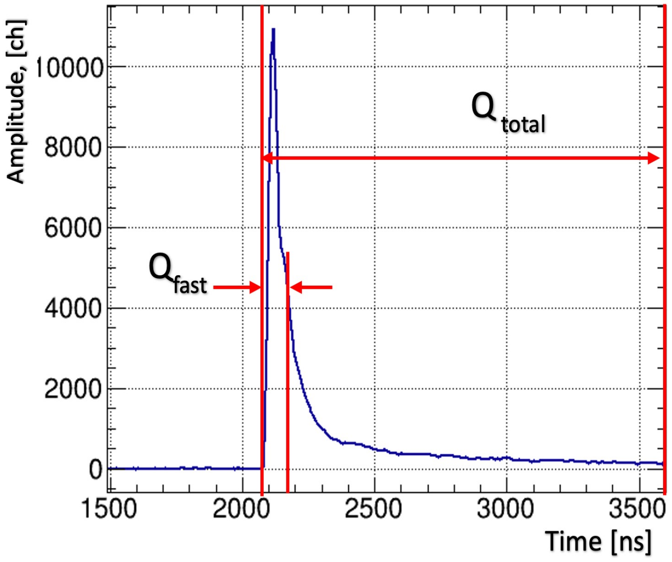


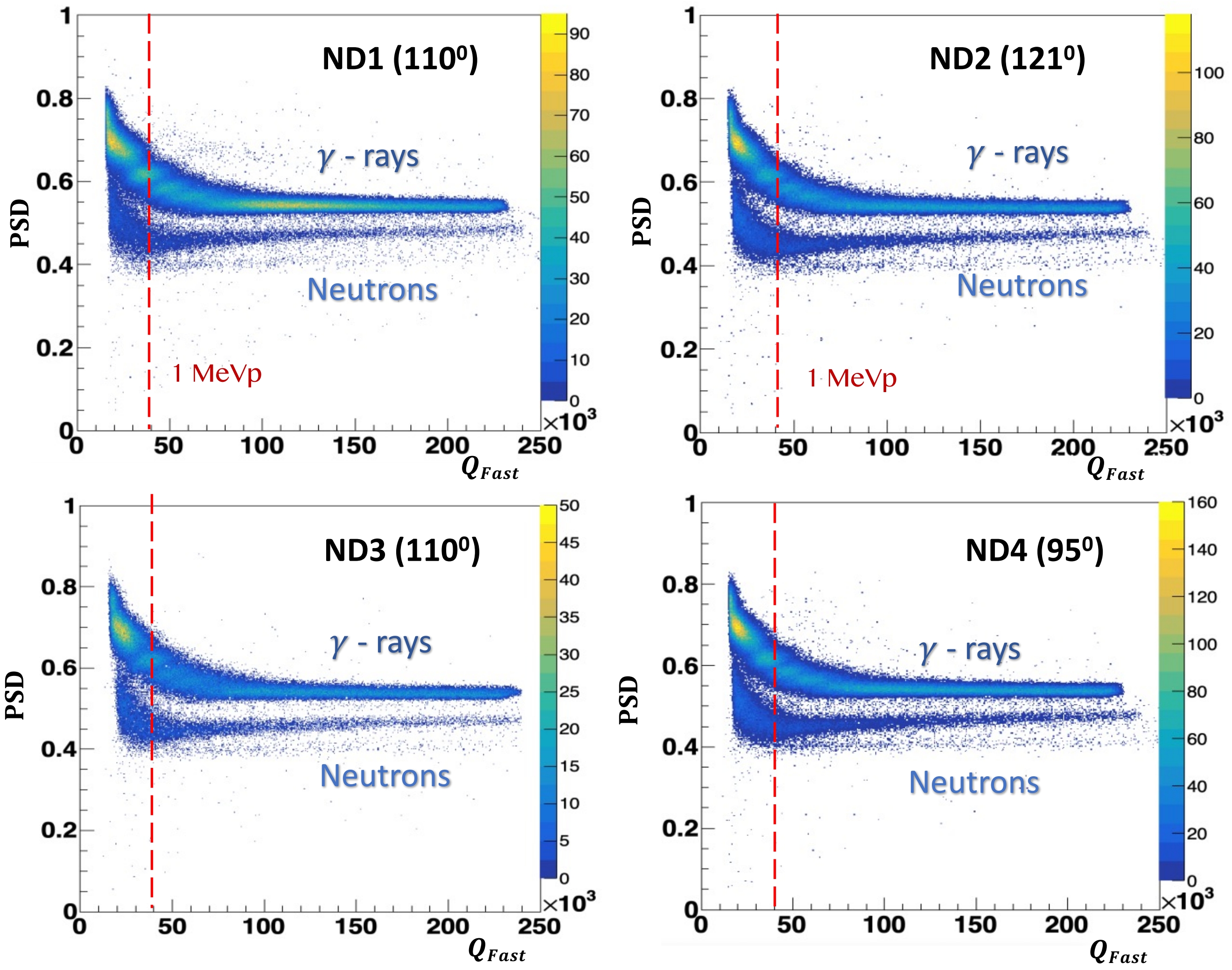
Pulse shape n/γ- discrimination

Quality of pulse shape discrimination:

$$PSD = \frac{Q_{fast}}{Q_{total}}$$

Waveform of Neutron Detector (TQDC)





T_{fast} = 0.12 μs : time window for charge integration Q_{fast}

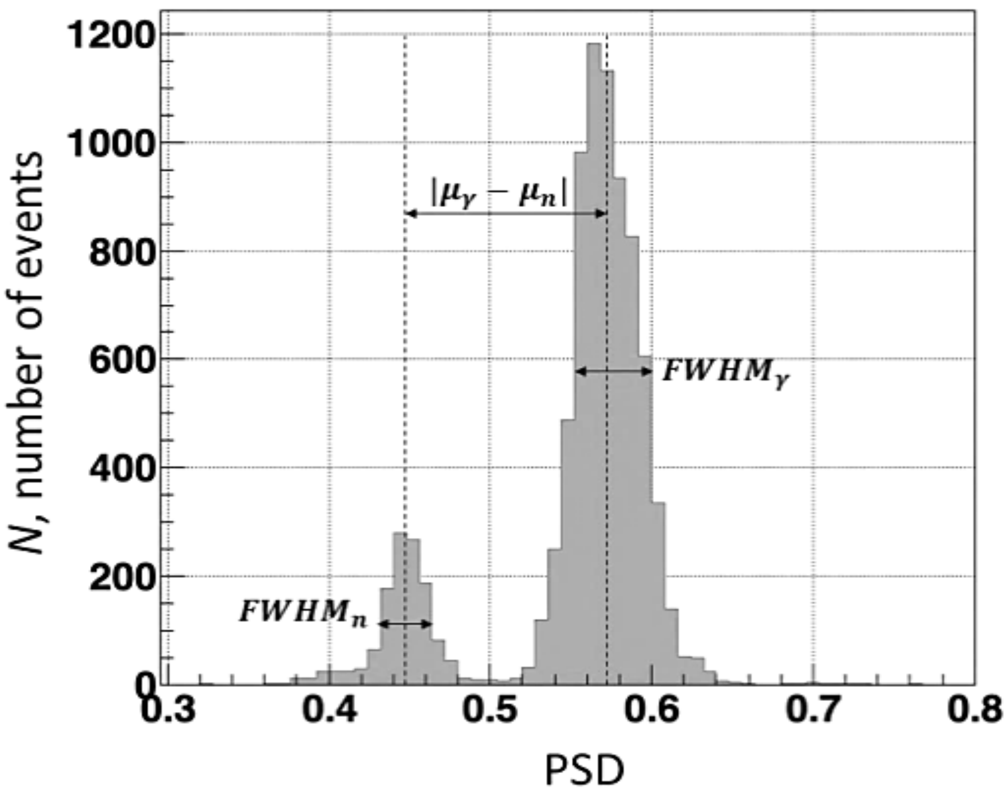
T_{total} = 1.5 μs. : time window for charge integration Q_{total}

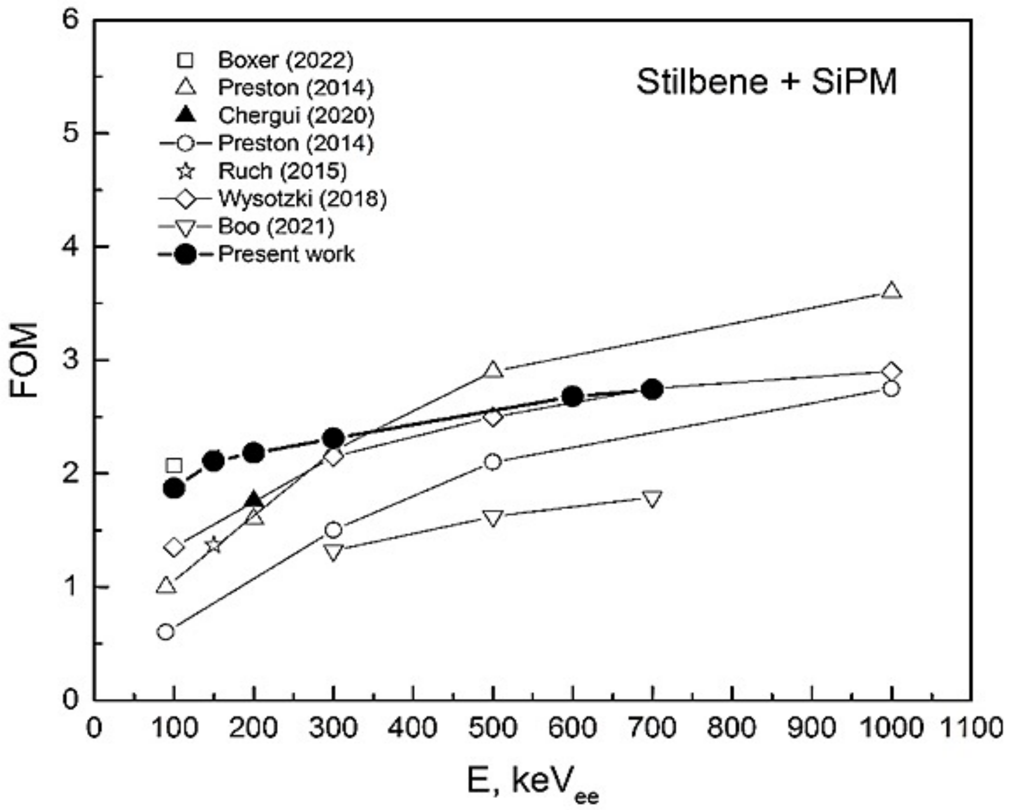
The integration time intervals are determined by pulse processing in TQDC module

Pulse shape n/γ- discrimination

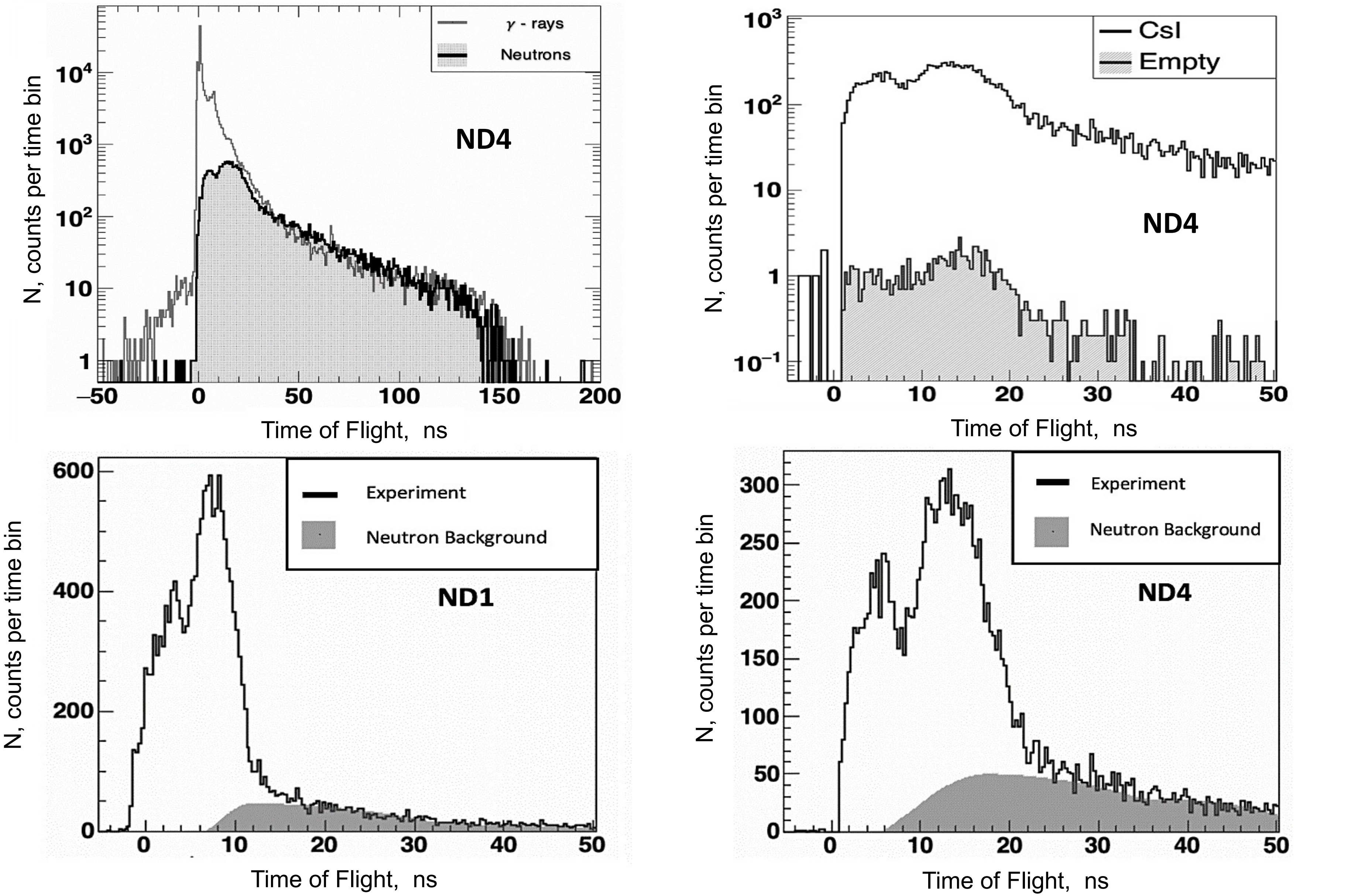
Figure of Merit: $FOM = \dfrac{|\mu_\gamma - \mu_n|}{FWHM_\gamma + FWHM_n}$

	ND1	ND2	ND3	ND4
FOM(1 MeVp)	**1.98**	**2.17**	**2.28**	**2.47**





TOF spectra and background contribution



Energy spectra of neutrons

Data processing procedure

$$\frac{d^2\sigma}{dE d\Omega} = \frac{\Delta N}{\Delta E \cdot \Delta\Omega \cdot \varepsilon(E) \cdot n \cdot I \cdot k_1 \cdot k_2}$$

E – kin. energy of neutron

ΔN – the number of events in the energy interval ΔE

ΔΩ – the solid angle

ε(E) – the detector efficiency at neutron energy E

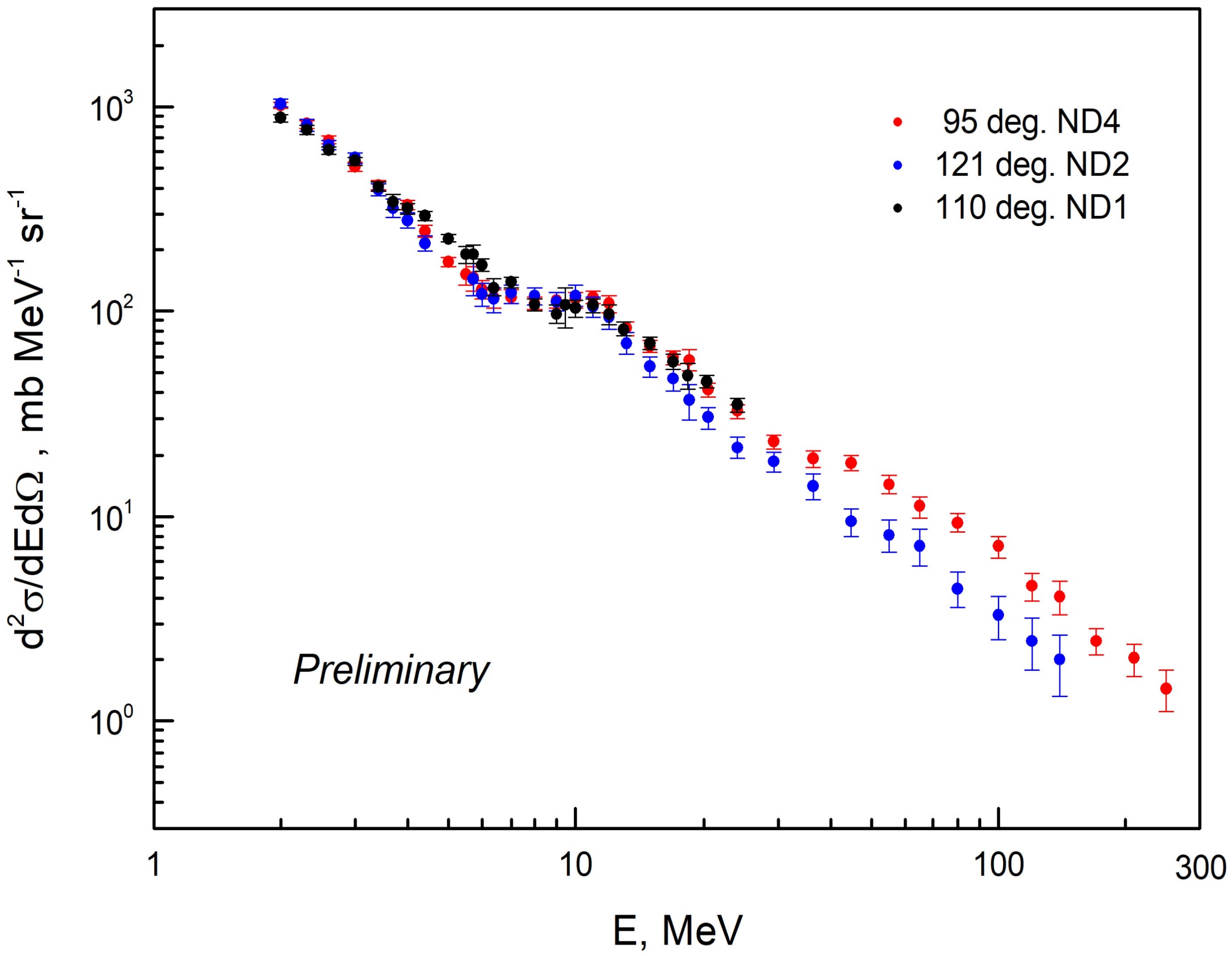
n – the number of target nuclei per 1 cm^2

I – the number of beam ions

k_1 – the correction factor for the dead time (DAQ busy) and B/A protection

k_2 – the correction factor for the selection of events with one incident beam ion in a time interval of ± 1.5 μs

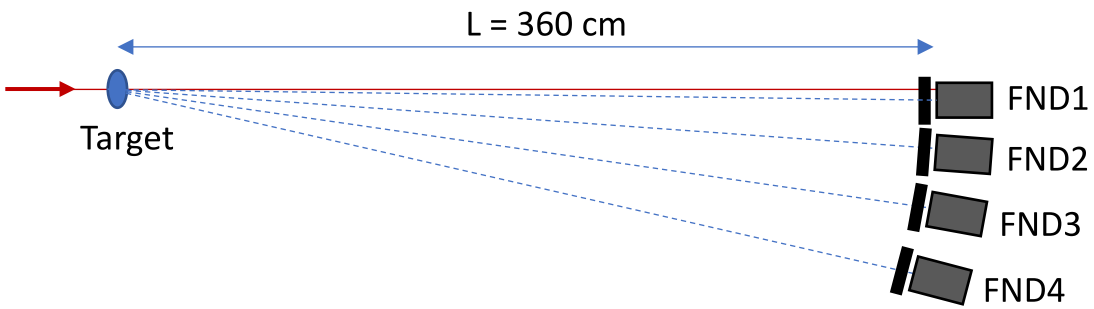
^{124}Xe + CsI, 3.8 A GeV

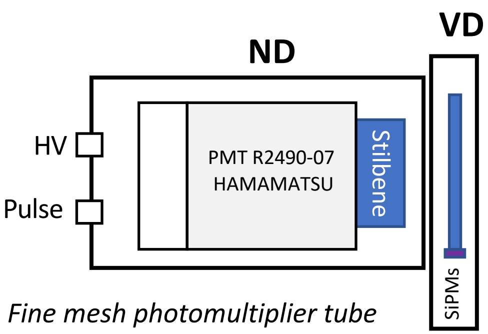


Aim of the measurements

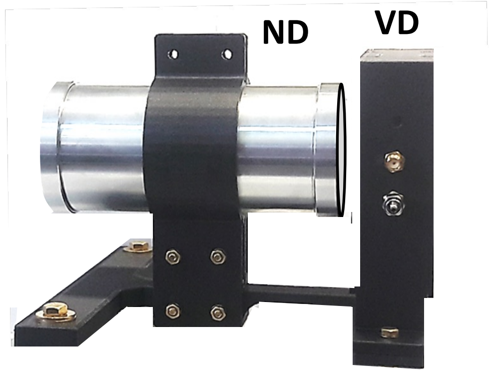
Energy range: 50 – 5000 MeV

- ✓ Study neutron emission from beam spectators and comparison with prediction of theoretical models and spectra from target spectators
- ✓ Study of energy and angular distribution of neutrons coming to nZDC



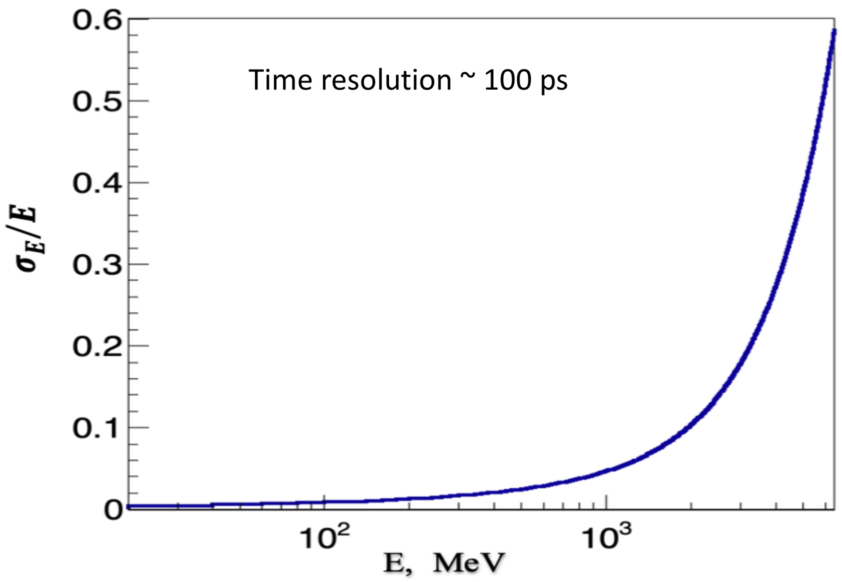


Fine mesh photomultiplier tube operating in magnetic field



Neutron Detectors

Detector	Stilbene	Angle
FND1	D31 × 31 mm^3	3^o
FND2	D31 × 31 mm^3	6^o
FND3	D40 × 20 mm^3	9^o
FND4	D40 × 20 mm^3	12^o



Conclusion

- The compact TOF neutron spectrometer with stilbene crystals and short flight path has been developed for measuring energy spectra of neutrons at large angles in the BM@N experiment
- The great importance of n/γ pulse shape discrimination for suppression of gamma-ray background was shown in run with beam of Xe ions
- As a preliminary result, the energy spectra of neutrons were obtained in energy interval from 2 to 200 MeV at several large angles in Xe + CsI collisions at 3.8 GeV/nucleon
- The study of spectrometer performance proves that we can obtain reliable neutron spectra in wide energy interval with good statistics in collisons of heavy nuclei at high energies
- Future plans concern implementation to the spectrometer of new neutron detectors at small angles to study neutron emission from beam spectators

Thank You for Your Attention!