Study of neutron emission from target spectators in ^{124}Xe + CsI collisions at 3.8 *A* GeV

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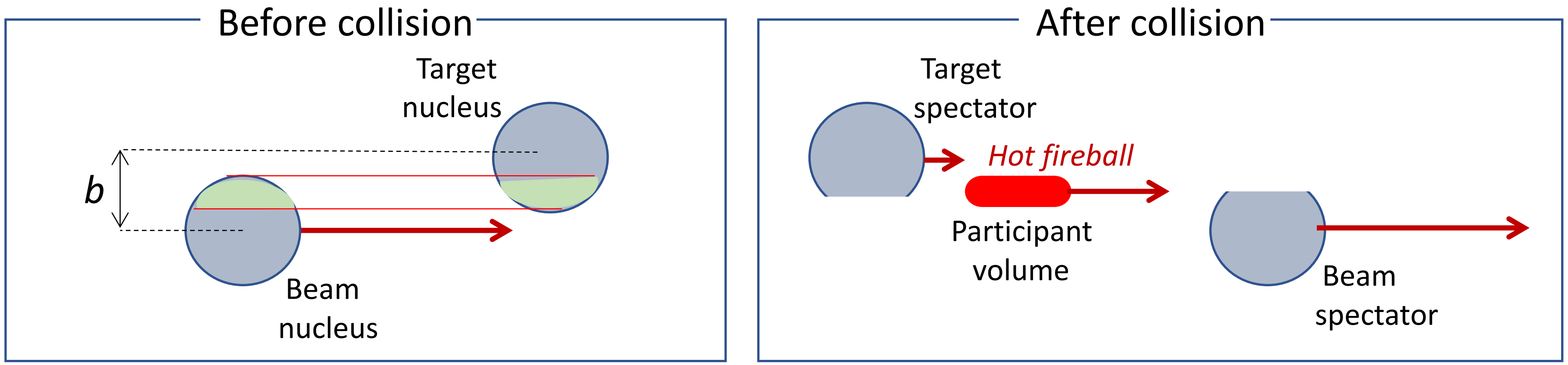
The 7th International Conference on Particle Physics and Astrophysics (ICPPA-2024)

Aim of the neutron measurements

Participant – Spectator picture of *AA*- collisions



In collisions of similar nuclei, properties and decay process of target and beam spectators are the same.

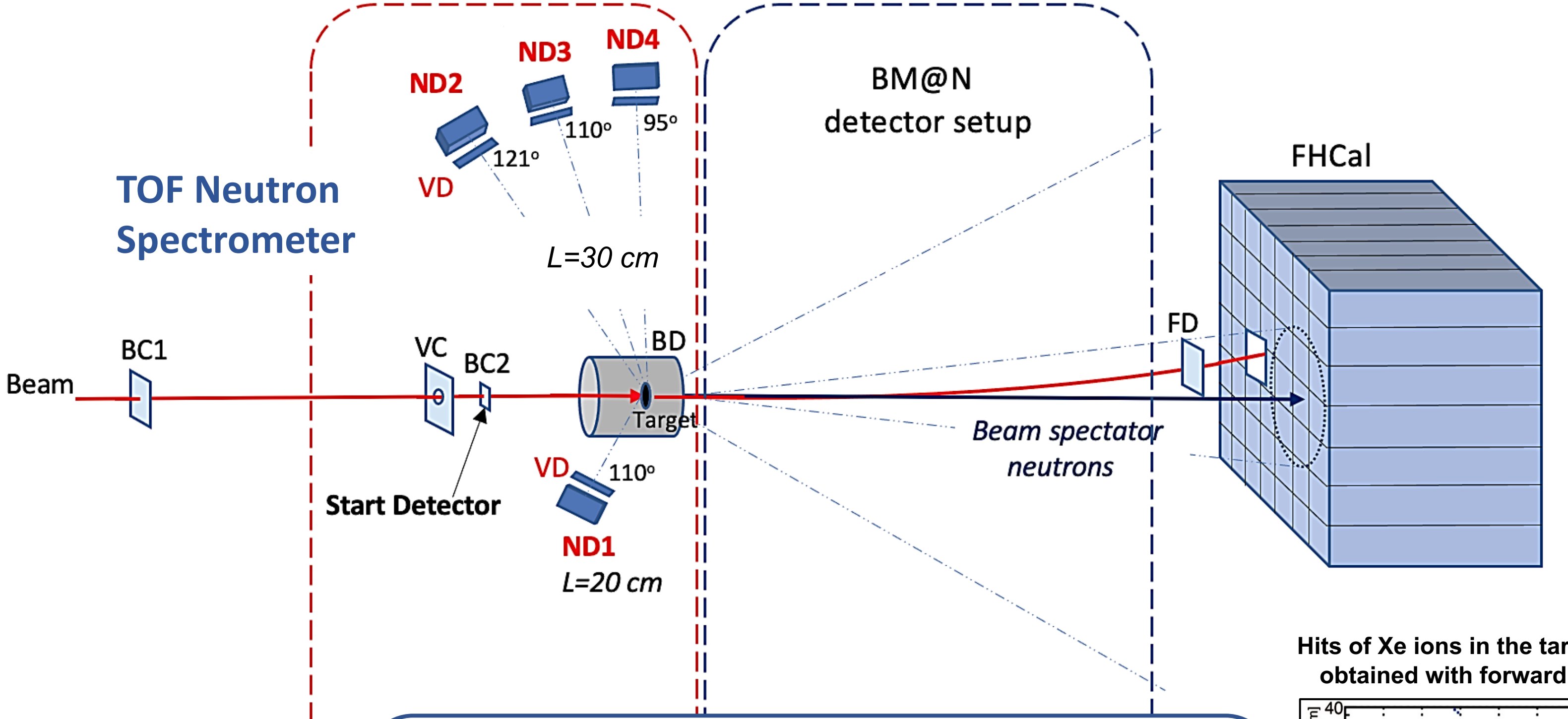
But in fixed target experiments, the neutrons of beam spectator are emitted at small angles with GeV energies in lab. frame due to the Lorentz boost.

Therefore, the best way for study of energy and angular distributions of neutrons from spectator decay is measuring neutrons from target spectators having small velocity in the lab. frame.

Aim of this experiment is careful measurement of double-differential neutron production cross section at large angles where neutrons from decay of target spectators are dominating.

Compact TOF Neutron Spectrometer

BM@N run Dec.2022 – Feb.2023



Neutron Detectors

Detector	θ (deg.)	L (cm)	Stilbene (mm)
ND1	**110°**	**20**	**D30×10**
ND2	**121°**	**30**	**D25.4×25.4**
ND3	**110°**	**30**	**D25.4×25.4**
ND4	**95°**	**30**	**D25.4×25.4**

BC2 – Start detector (T0)

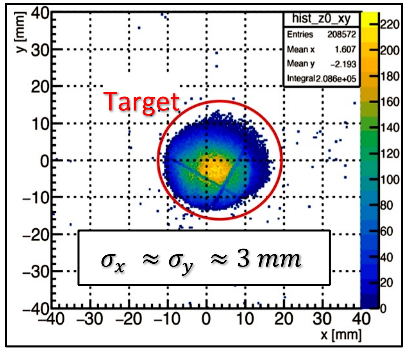
Scintillator: BC-400B, 34×34×0.15 mm^3

PMT: XPM85112/A1 (Photonis), 2 units

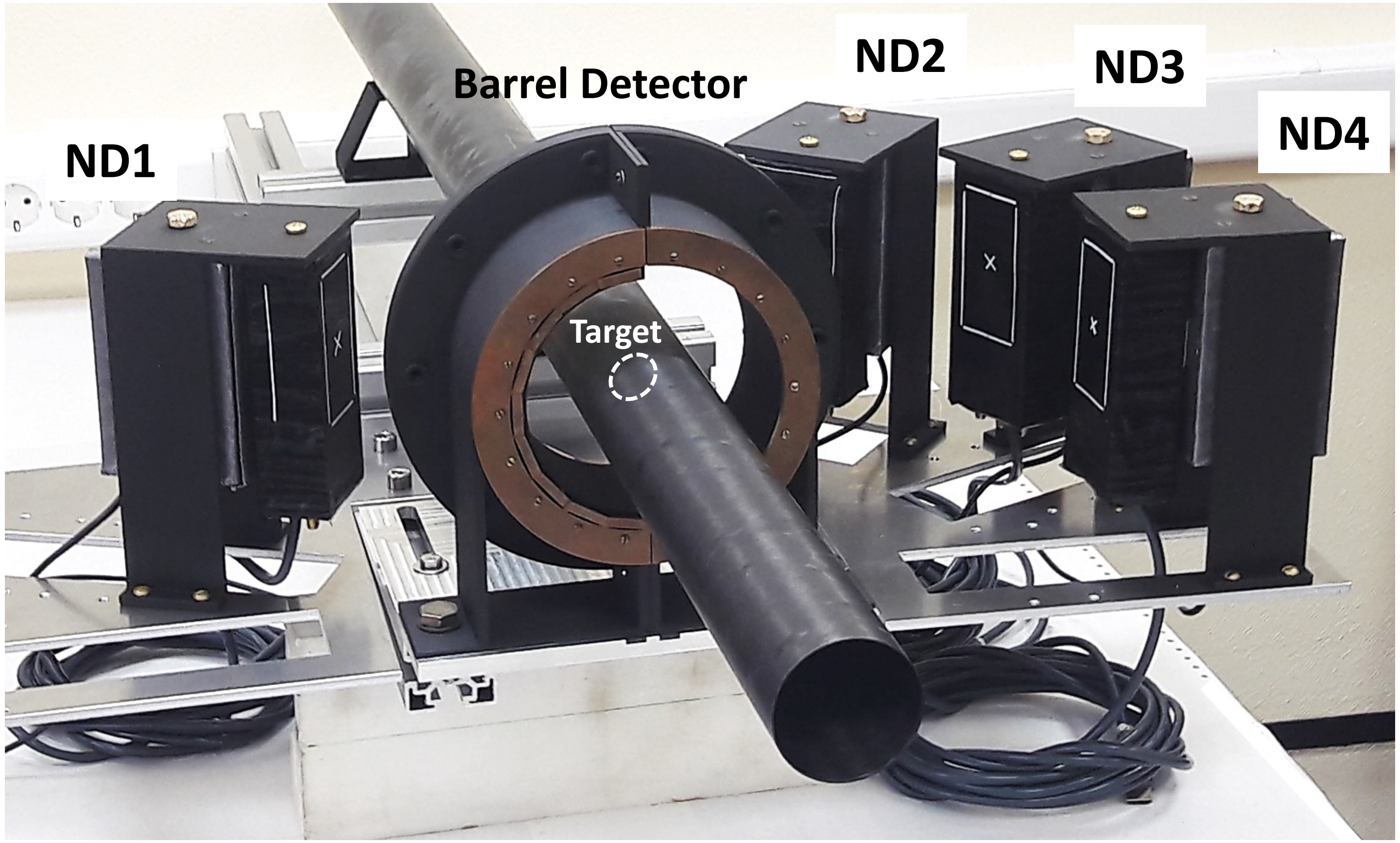
Time resolution: **σ_t = 40 ps**

	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



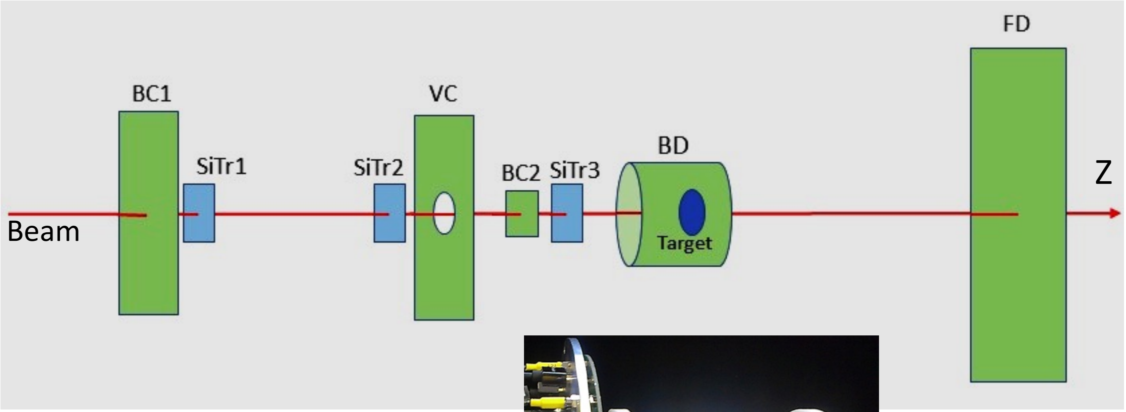
The compact TOF Neutron Spectrometer 2024

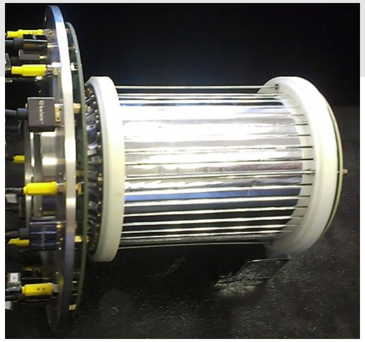


A new design of the neutron spectrometer (prototype)

Selection of Interactions in the Target

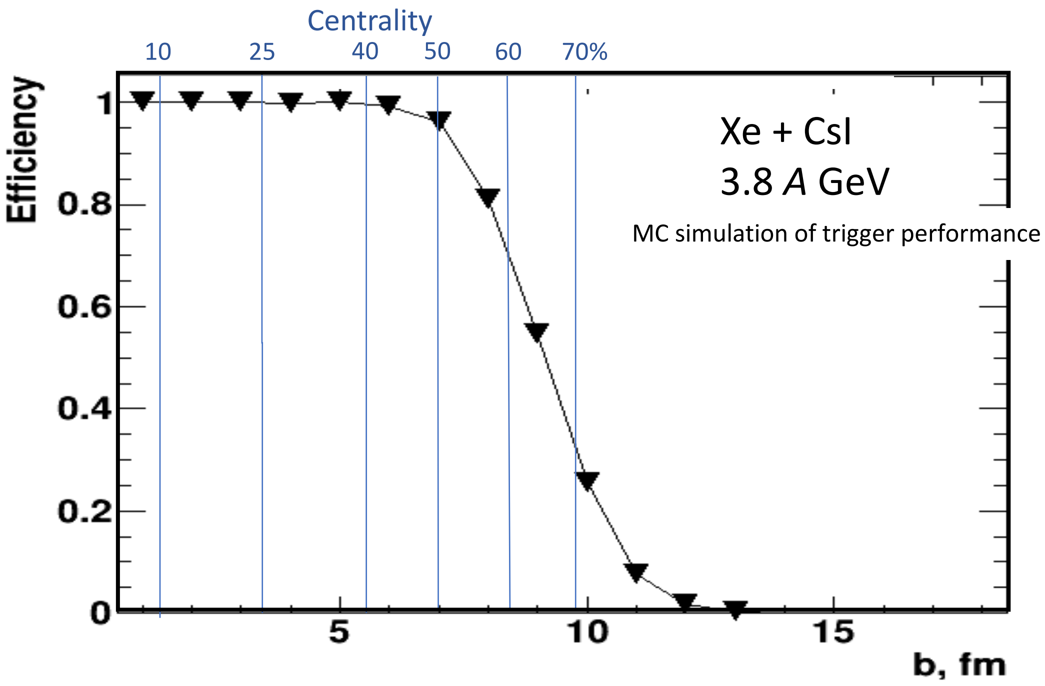
Trigger detector system of the BM@N experiment





Barrel Detector (BD)
40 scintillation strips

Trigger efficiency



Interaction Trigger Logic:

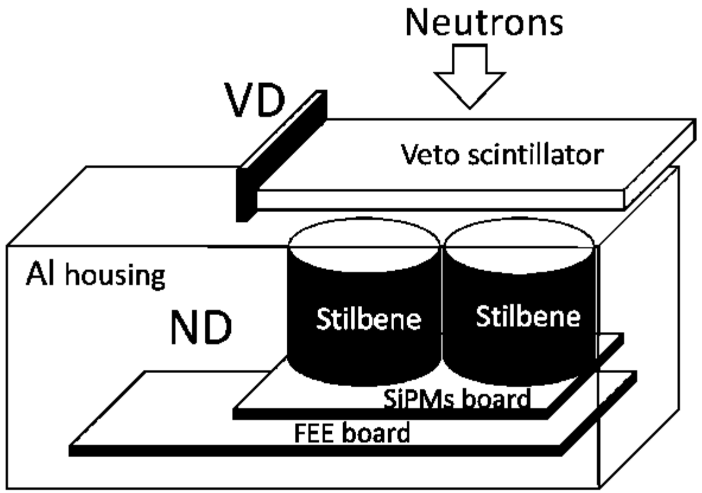
Min. Bias Trigger (MBT) = BC1 * $\overline{\text{VC}}$ * BC2 * $\overline{\text{FD}}$

Main interaction trigger (CCT) = MBT * BD(N>3)

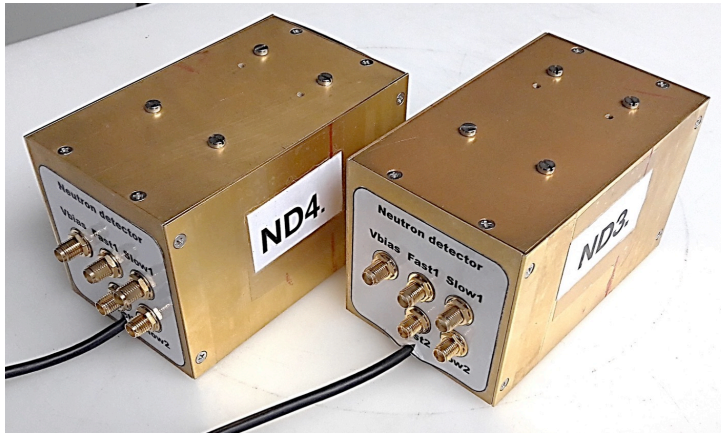
Only events with one Xe ion in 3.6- μs interval in BC1 were used in the neutron data analysis

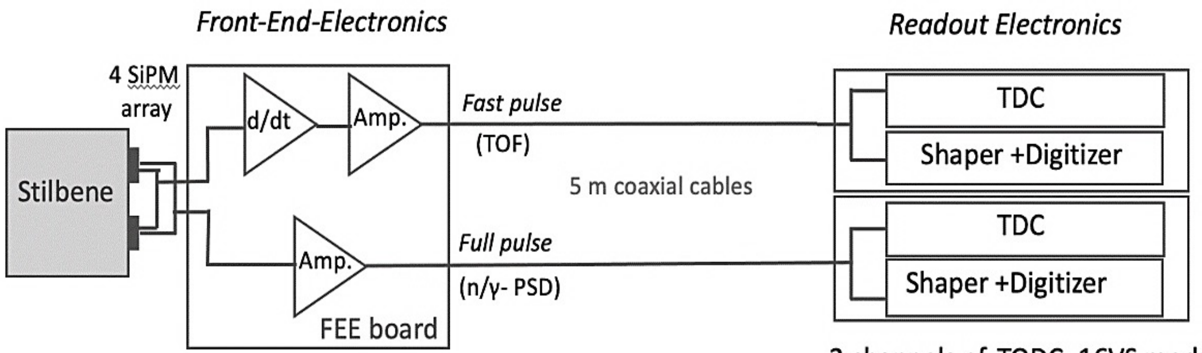
The interaction trigger allows to collect data from central to peripheral collisions if the BD response is >3 fired strips

Neutron Detectors

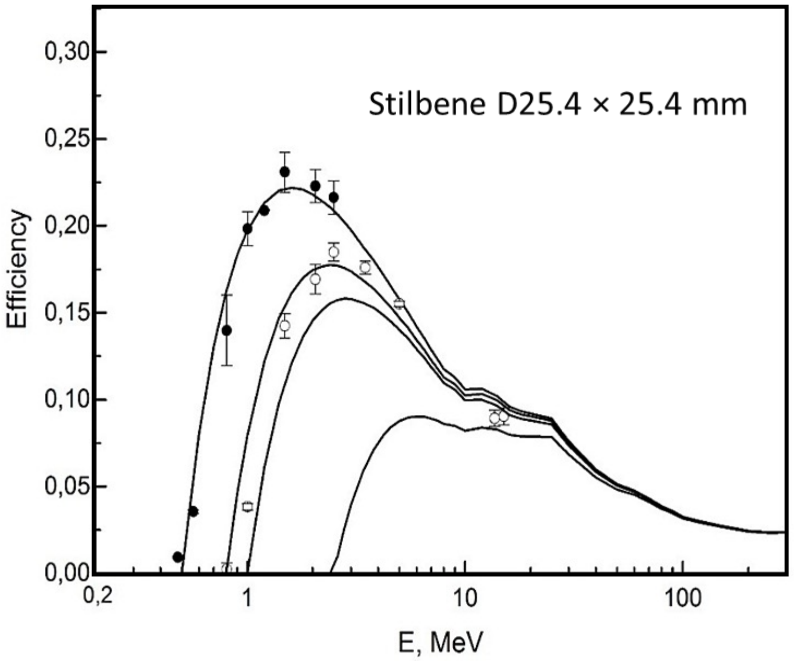


Detection of scintillation photons with four SiPMs 6×6 mm^2, SensL, J ser.





2 channels of TQDC_16VS module



Pulse shape n/γ- discrimination

Quality of pulse shape discrimination:

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

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

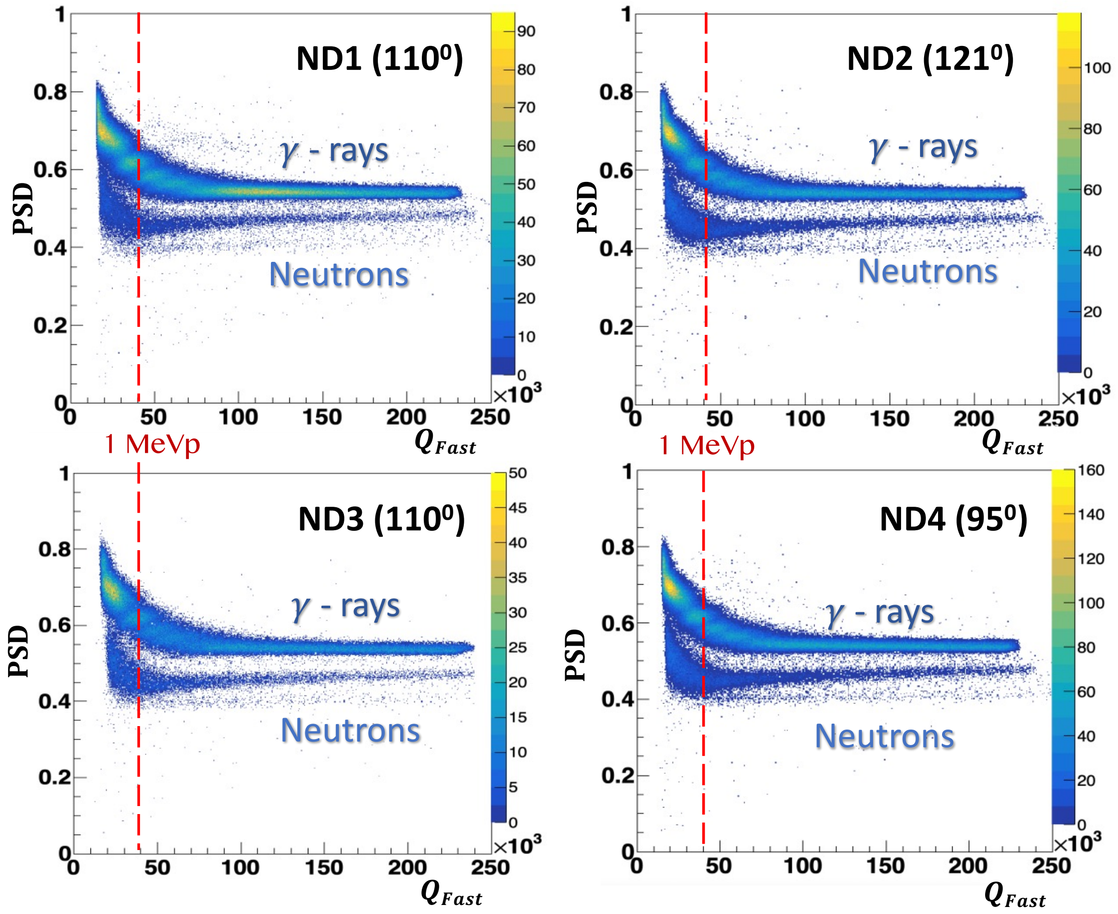
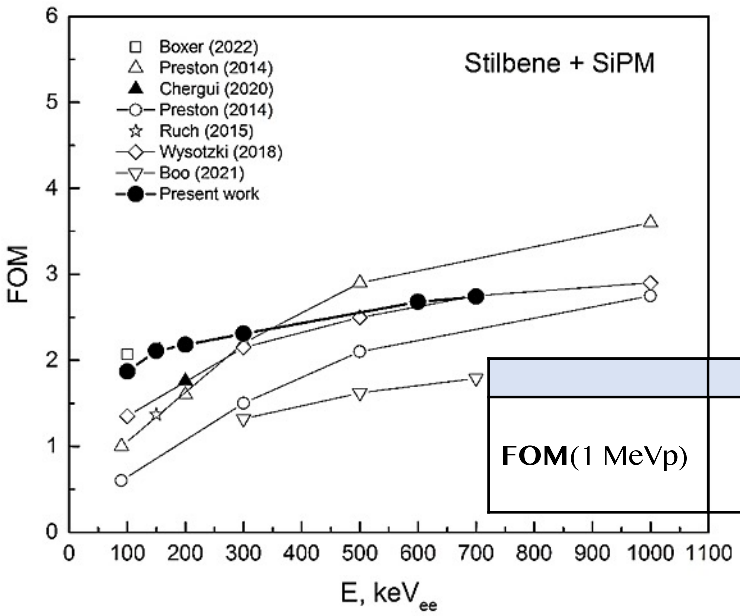
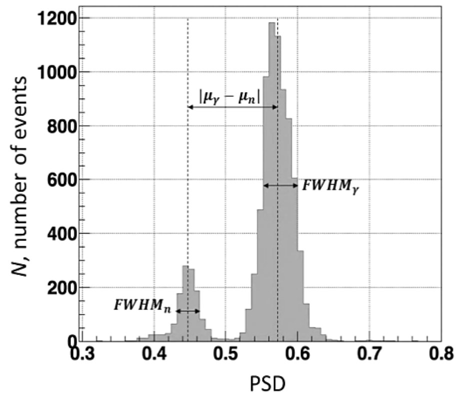


Figure of Merit: $$FOM = \frac{|\mu_\gamma - \mu_n|}{FWHM_\gamma + FWHM_n}$$



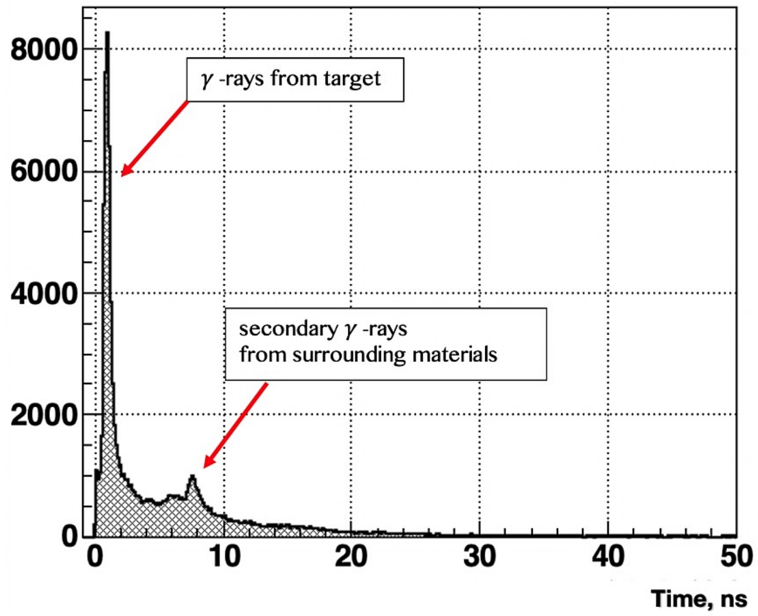


	ND1	ND2	ND3	ND4
FOM(1 MeVp)	1.98	2.17	2.28	2.47

Time resolution of Neutron Detectors is estimated by a half of maximum of gamma-peak and time resolution of the T0- detector

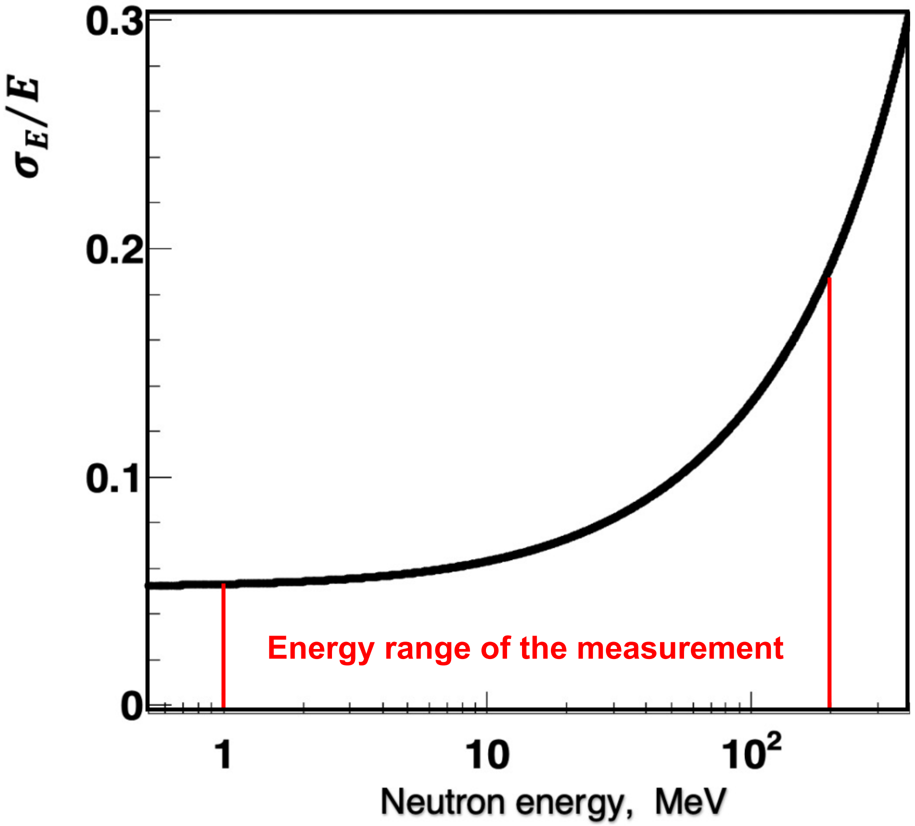
	ND1	ND2	ND3	ND4
σ_t (ps)	128	114	118	110

TOF spectrum of γ-rays

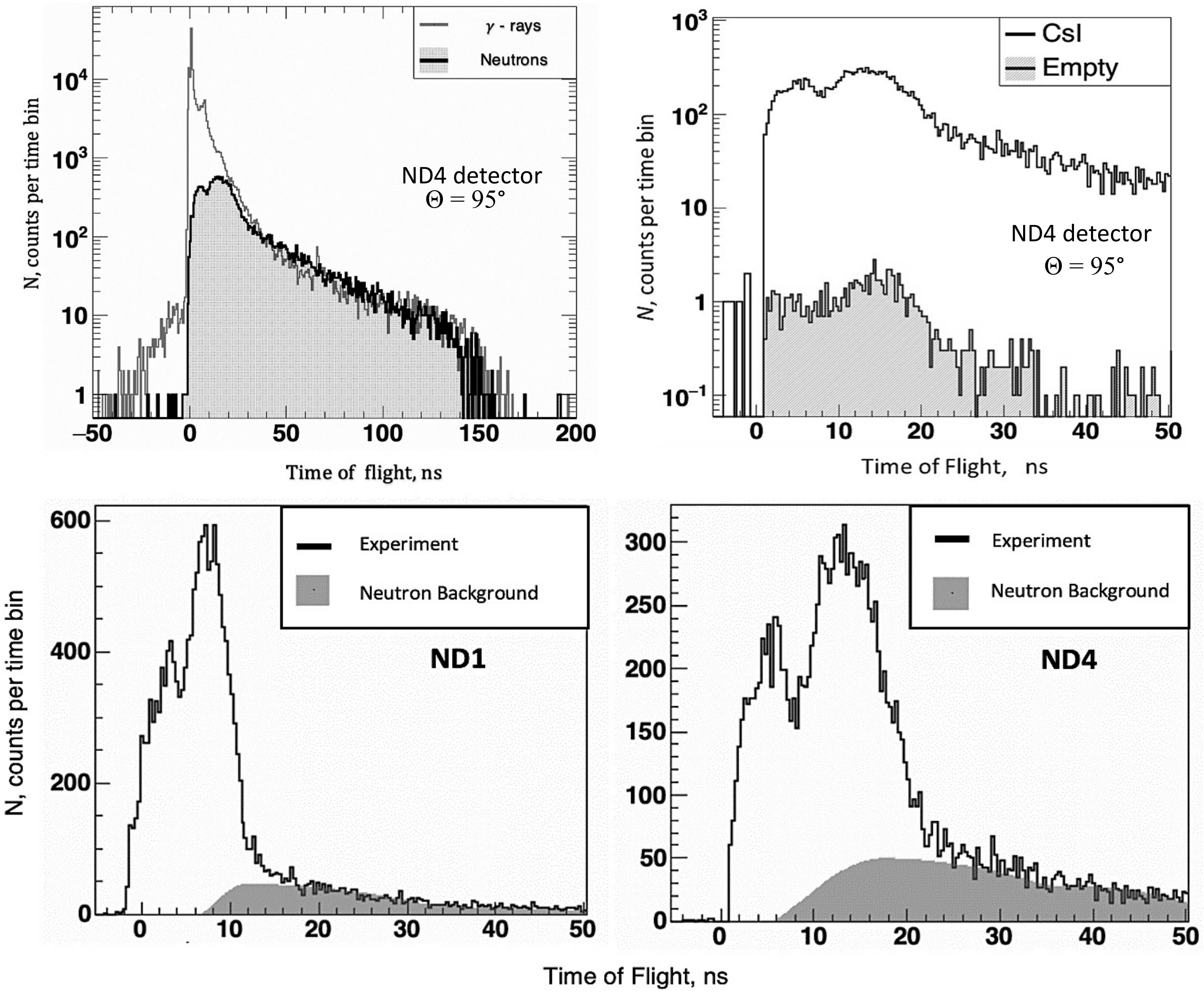


Energy resolution of the TOF measurements:

$$\frac{\sigma_E}{E} = \gamma(\gamma+1)\left[\left(\frac{\sigma_l}{l}\right)^2 + \left(\frac{\sigma_t}{t}\right)^2\right]^{1/2}$$



TOF spectra and background contribution

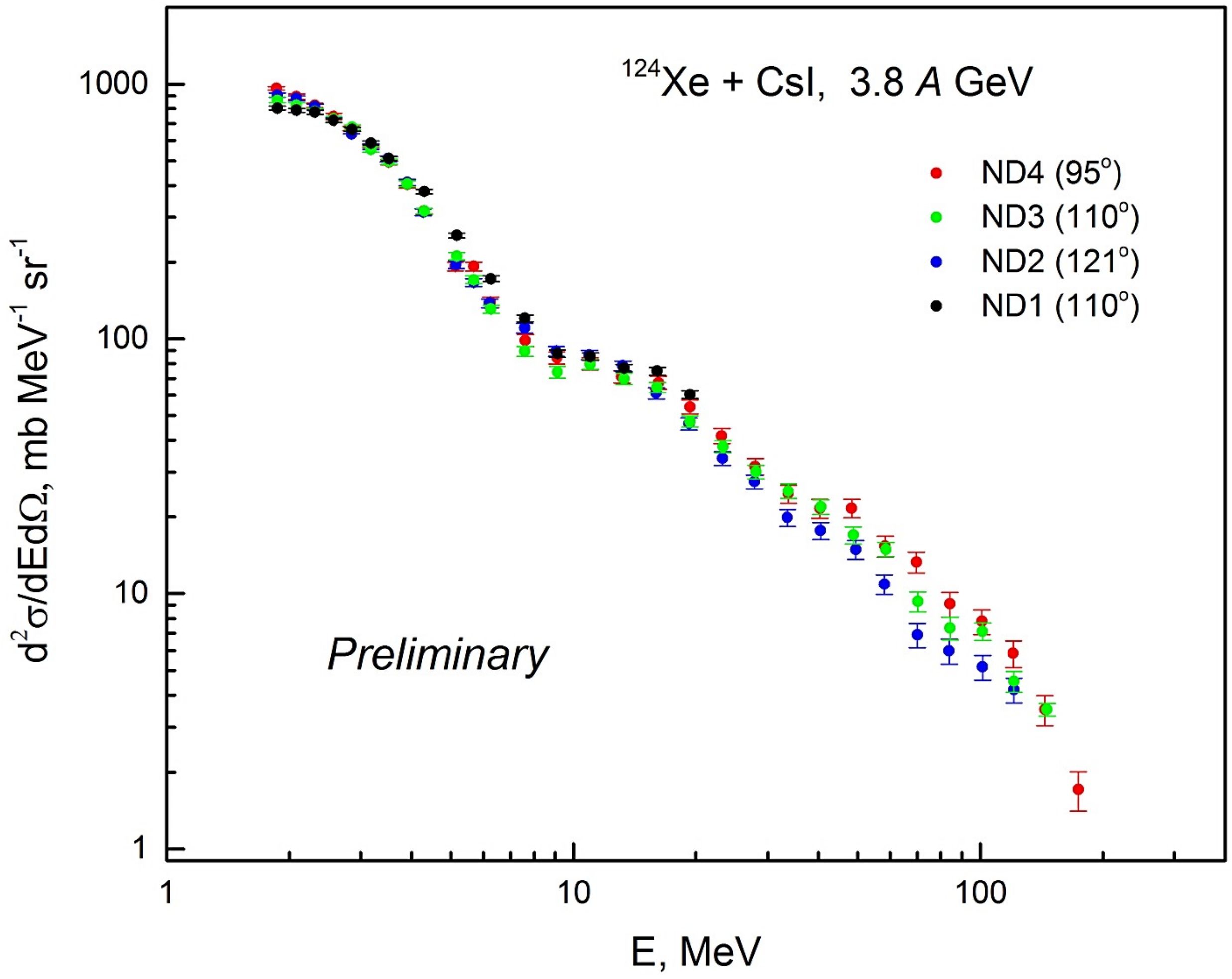


Energy spectra of neutrons

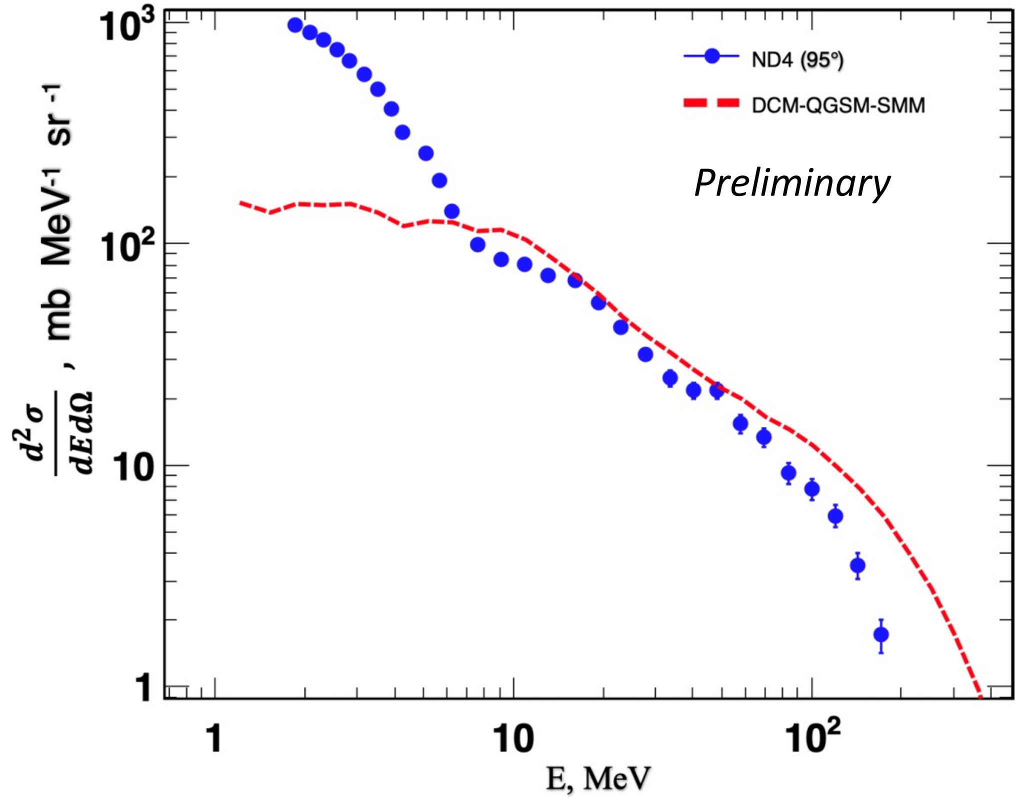
Data processing procedure

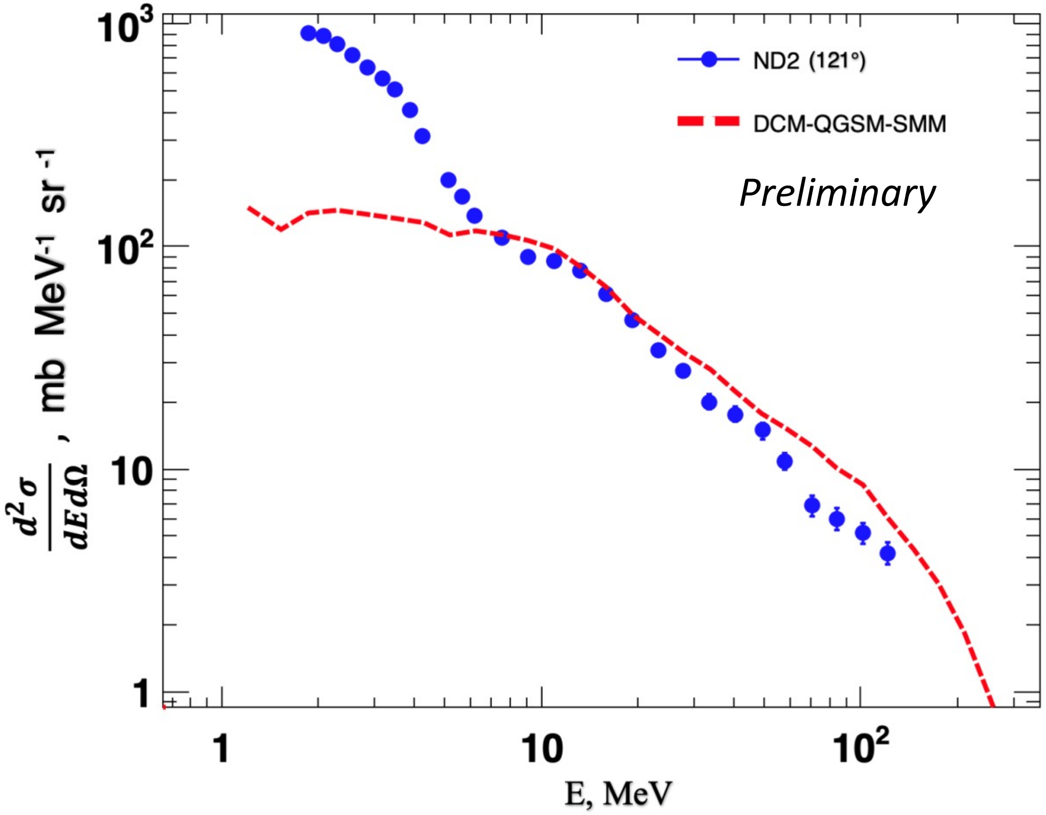
$$\frac{d^2\sigma}{dEd\Omega} = \frac{\Delta N}{\Delta E \cdot \Delta\Omega \cdot \varepsilon(E) \cdot n \cdot I \cdot k_1 \cdot k_2}$$

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



Comparison with prediction of DCM-QGSM-SMM model



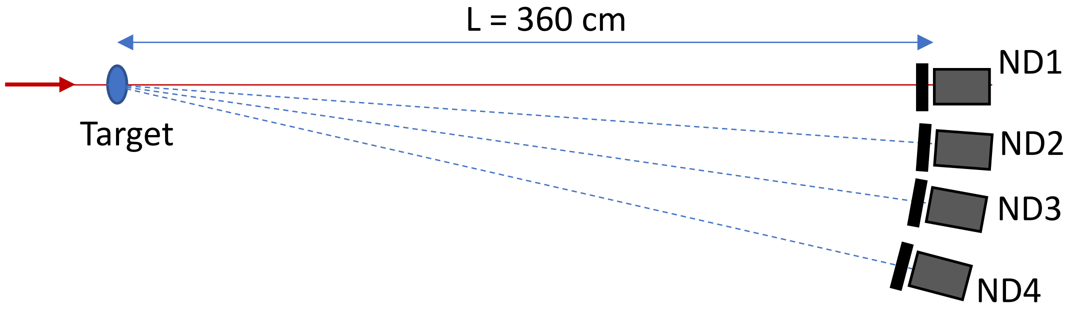


The model needs in further development to include the neutron evaporation

A comparison with predictions of other theoretical models is in progress

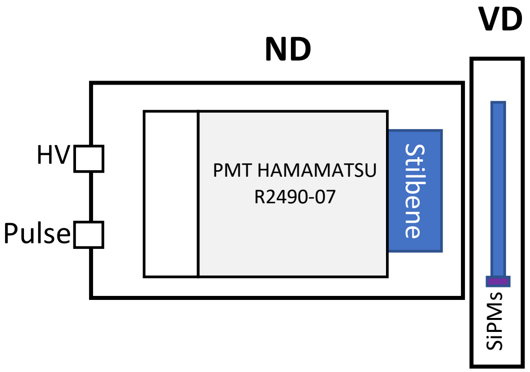
New neutron detectors for measurements at small angles

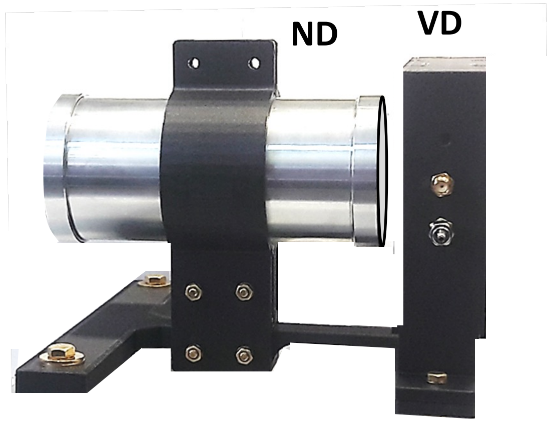
Energy range: 50 – 5000 MeV



Neutron Detectors

Detector	Stilbene	Angle
ND1	D31 × 31 mm	0^{o}
ND2	D31 × 31 mm	3^{o}
ND3	D40 × 20 mm	7^{o}
ND4	D40 × 20 mm	12^{o}





Aim of the measurements

- ✓ Study neutron emission from beam spectators and comparison with theoretical models and results of the compact TOF spectrometer
- ✓ To get reference data for HGND project
- ✓ Study of energy and angular distribution of neutrons coming to nZDC

The event statistics required is obtained in one-day measurement
(with and without target)

Conclusion

1. Existing neutron time-of-flight spectrometers use flight distances of several meters (hall scale). We have succeeded in creating a compact time-of-flight spectrometer (table scale) covering a wide range of neutron energies from 1 to 200 MeV.

2. The high time resolution of ~119 ps and very good gamma-ray discrimination with the PSD method are main features of the spectrometer.

3. With this spectrometer the neutron emission from target spectators in Xe + CsI collisions at 3.8 *A* GeV was studied by measuring double-differential neutron production cross section.

4. The neutron emission in low energy region is closed to isotropic.

5. Comparison of the experimental spectra with prediction of the DCM-QGSM-SMM model shows satisfactory agreement above energy of 8 MeV and essential underestimation by the model at low energies. It seems, the model needs improvement by including neutron evaporation stage.

6. The new design of the spectrometer with detectors at small angles is developing for the future BM@N runs.