Study of neutron emission from target fragmentation in ^{124}Xe + CsI collisions at 3.8 *A* GeV with a compact TOF spectrometer

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INTRODUCTION

A grate number of neutrons are produced together with charged particles and fragments in high energy nucleus – nucleus collisions. But despite the importance of neutron data for testing and development of theoretical models the number of neutron measurements remains very limited due to the methodological difficulties.

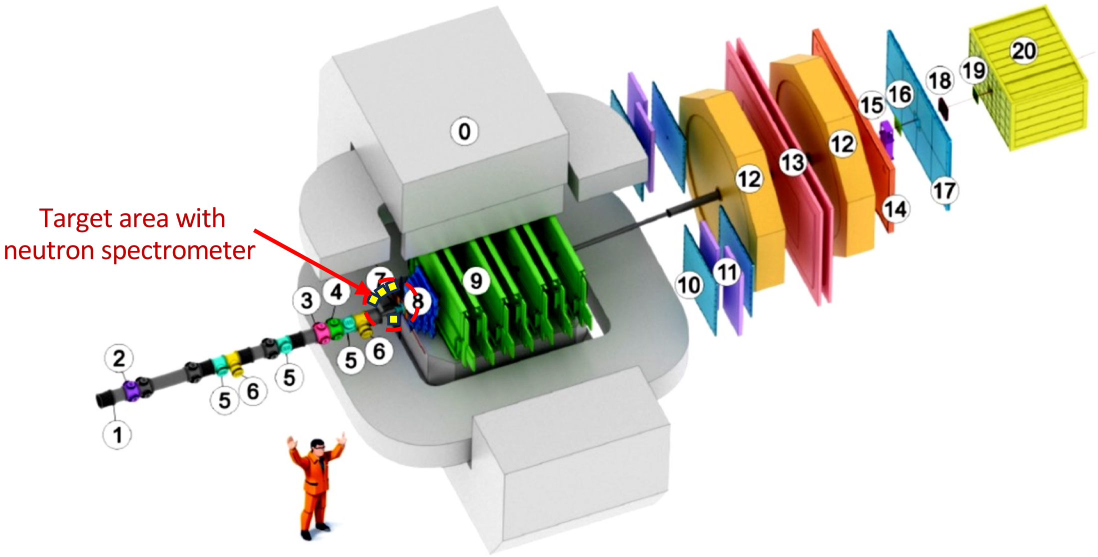
In the Laboratory of High Energy Physics of Joint Institute for Nuclear Research we have developed a compact TOF neutron spectrometer as a part of the BM@N experiment with heavy ion beams of the Nuclotron.

The aim of the spectrometer is study of neutron emission at large angles where contribution of target spectator decay dominates.

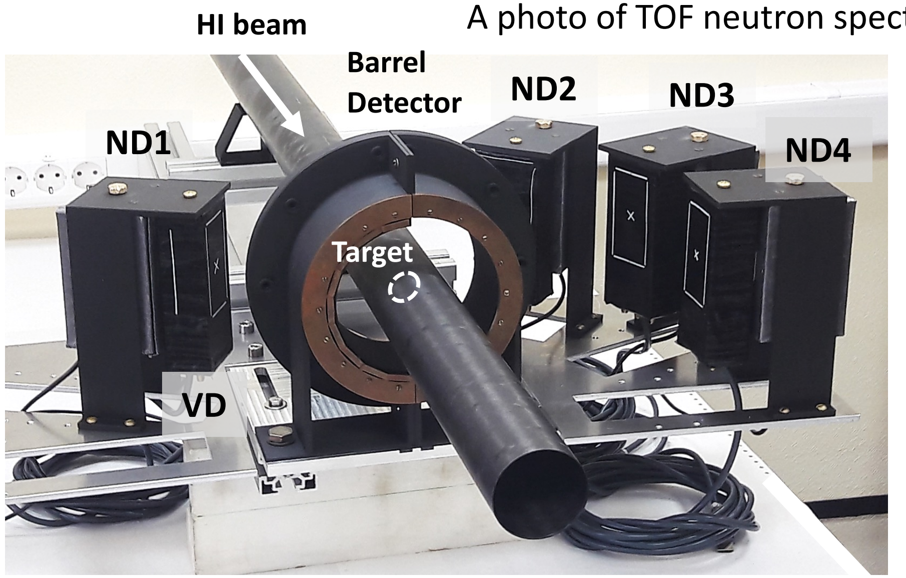
This talk is dedicated to description of the neutron spectrometer and the first results obtained for ^{124}Xe + CsI collisions at energy of 3.8 A GeV

TOF neutron spectrometer of BM@N experiment

BM@N experiment with HI beams of Nuclotron

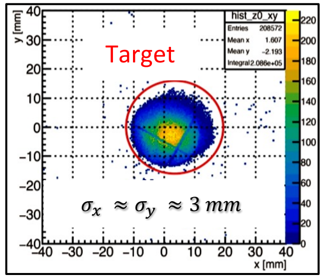


A photo of TOF neutron spectrometer



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	



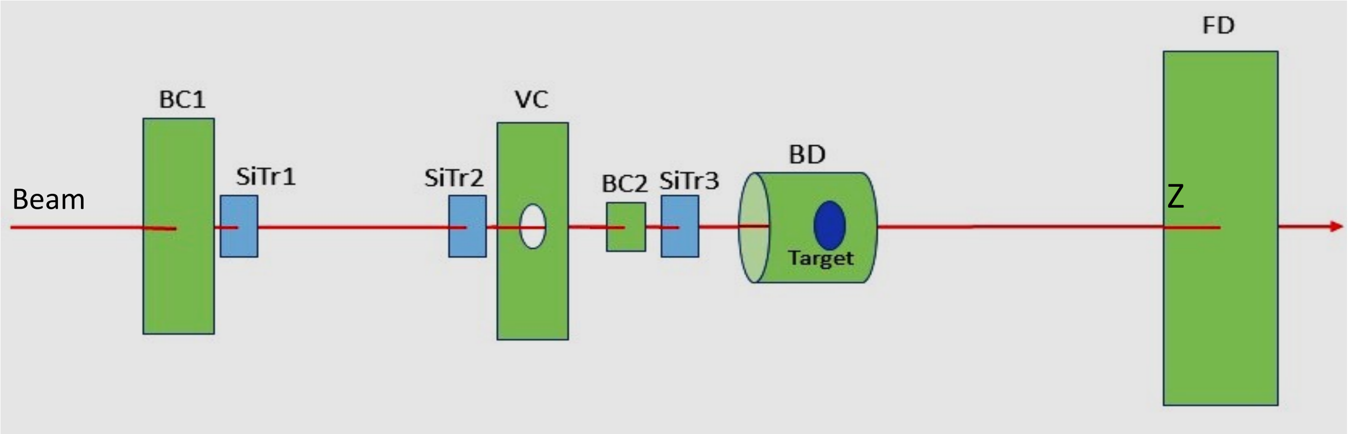
Hits of Xe ions in the target position obtained with forward Si tracker

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

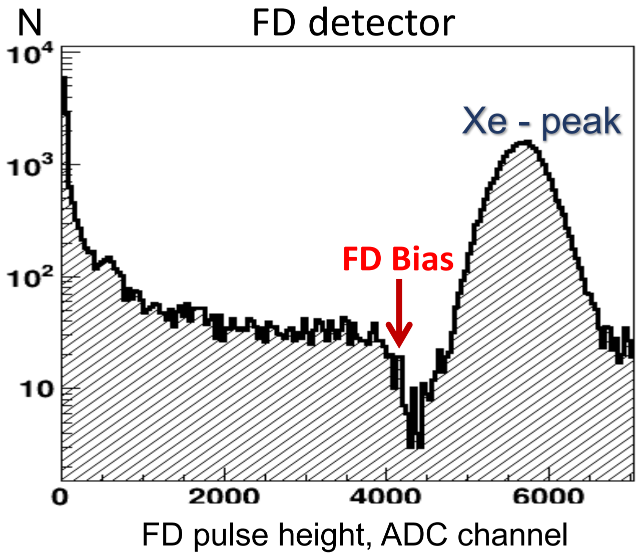
Trigger detector system of the BM@N experiment

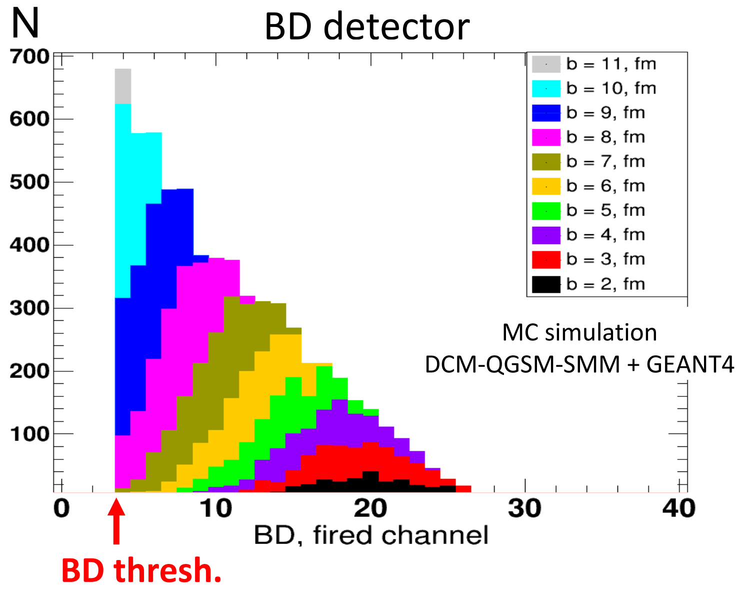


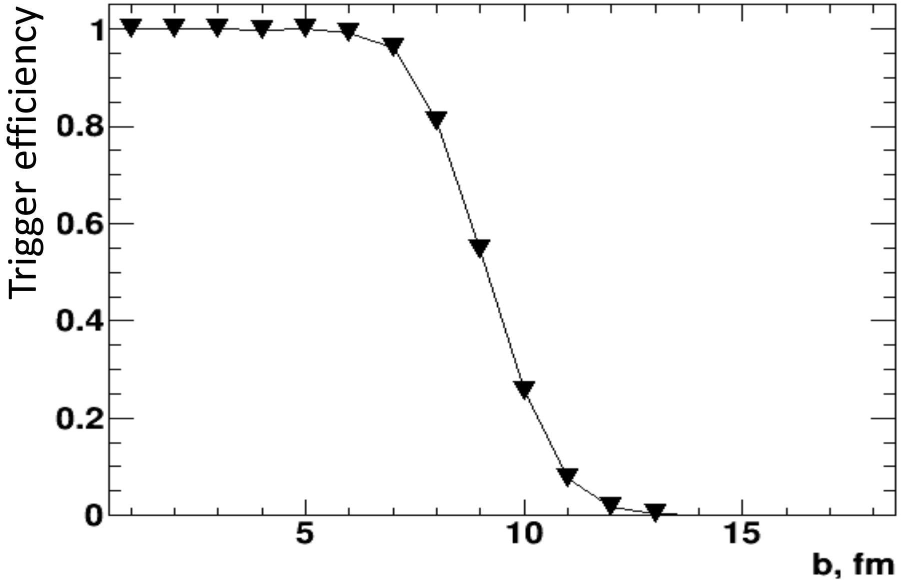
Selection events by trigger detectors FD and BD

Interaction Trigger Logic:

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

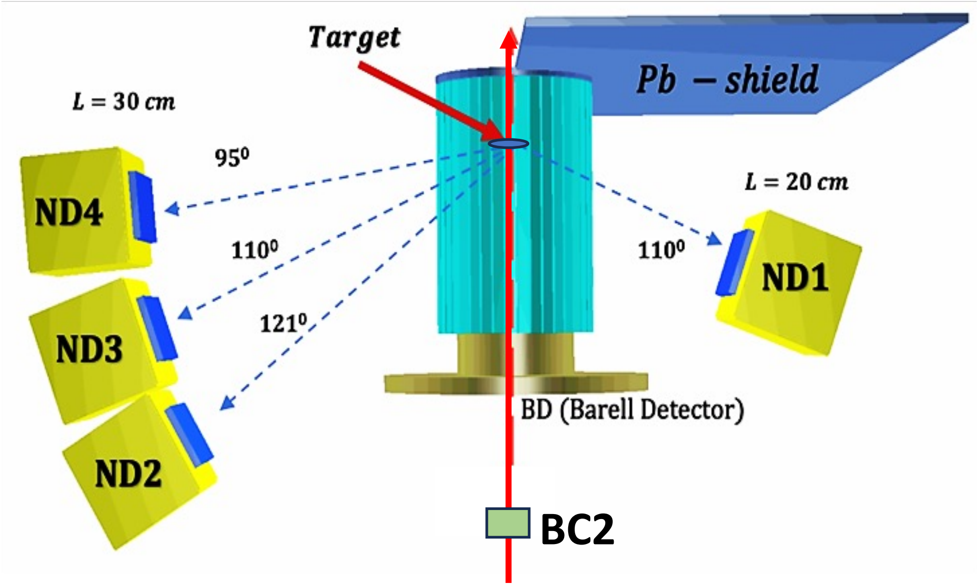






Compact TOF neutron spectrometer

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

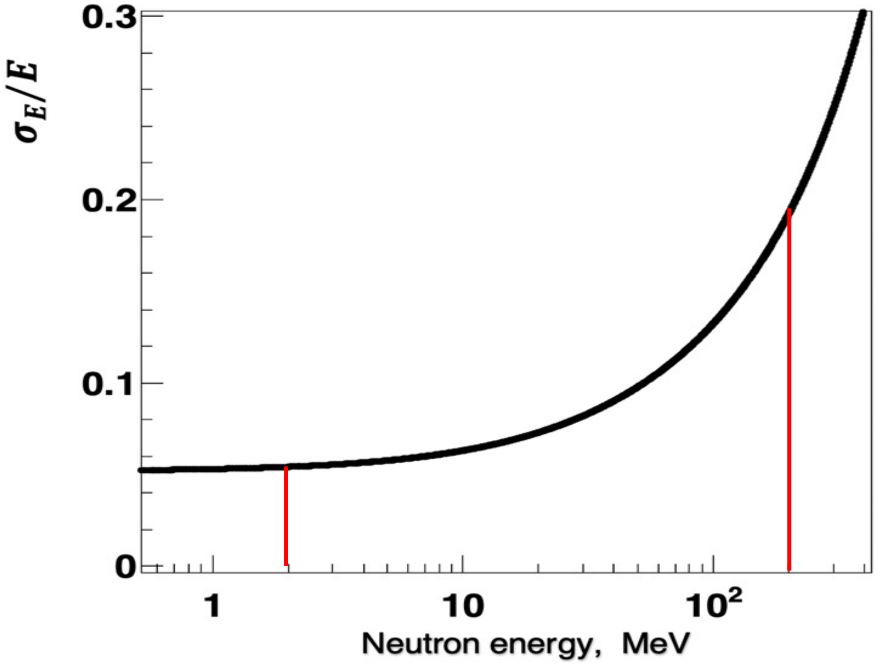


Start Detector – Beam counter BC2

Scint. BC400B, H = 0.125 mm

Two MCP-PMTs XPM85112/A1

Time resolution σ_t = 40 ps

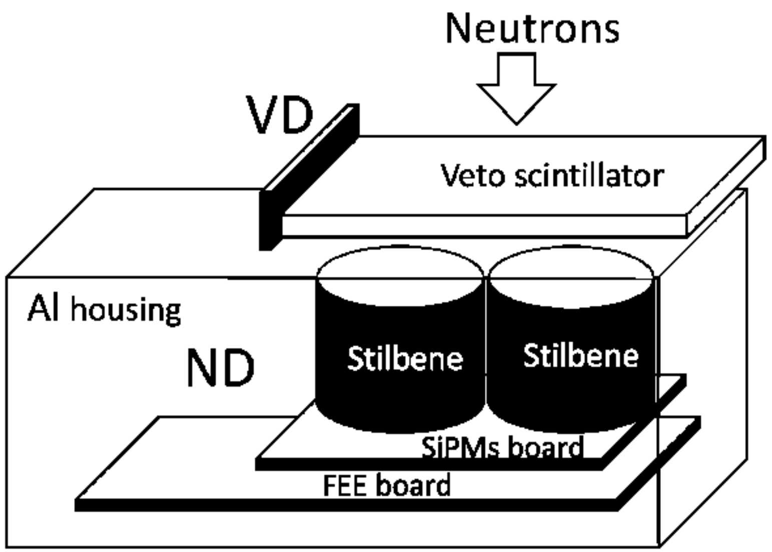


Stop Detectors – Neutron detectors

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.)

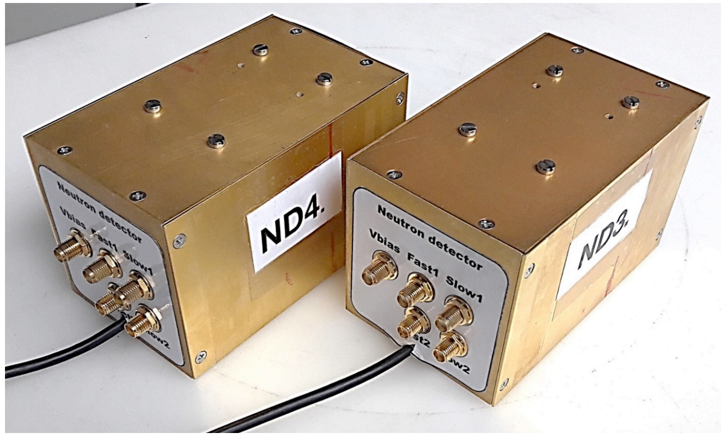
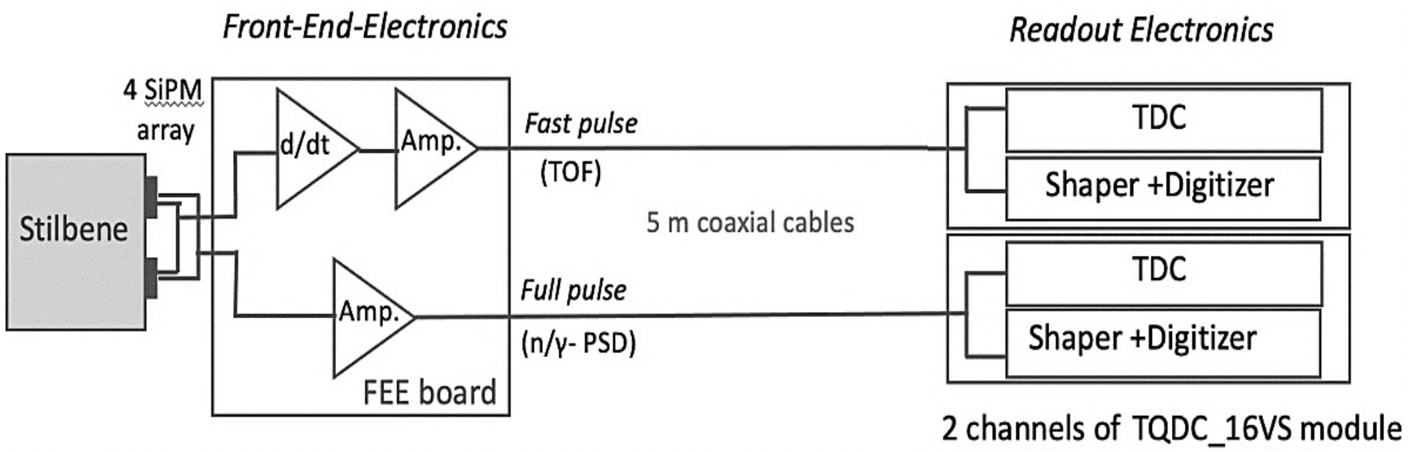


Photo of neutron detectors

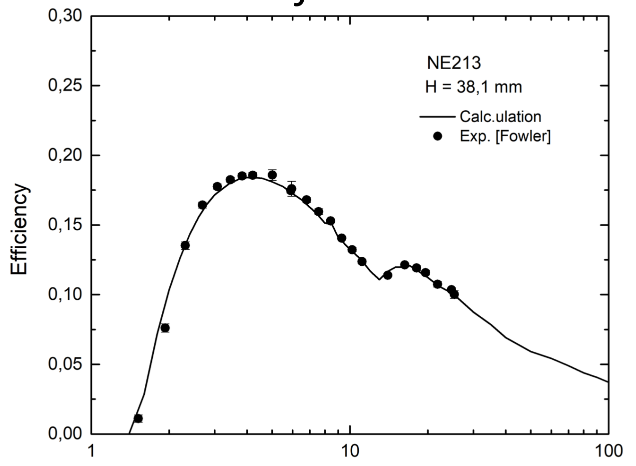


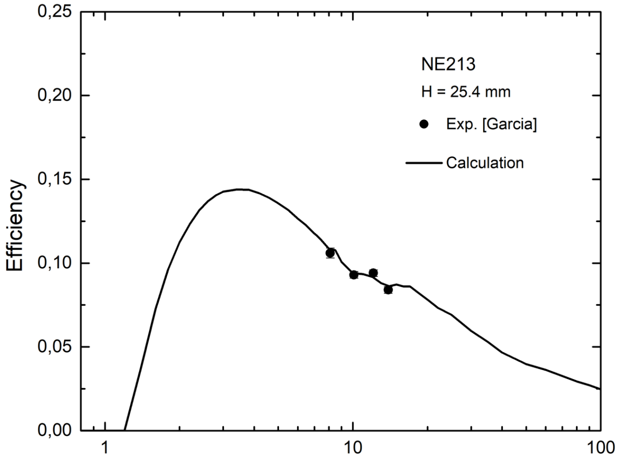
A scheme of data taken channel

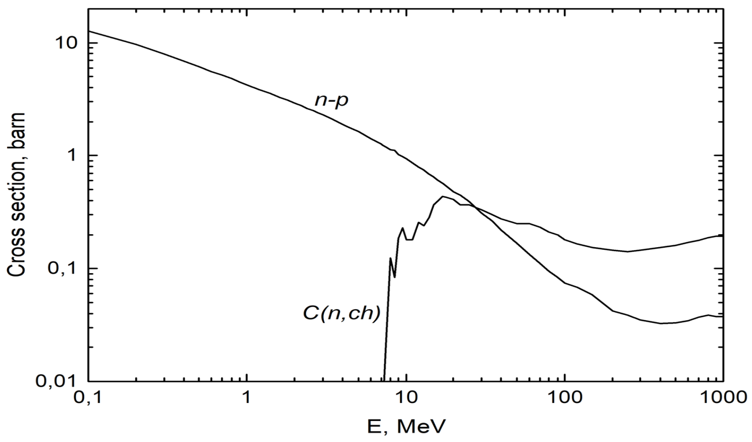
Efficiency determination of thin neutron detectors

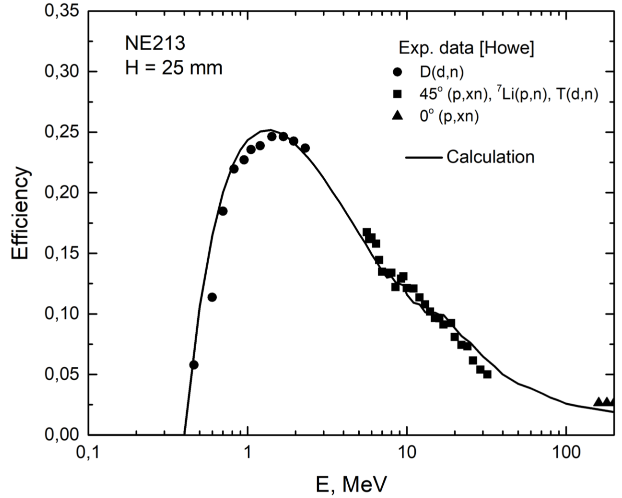
Calculation of detector efficiency using single interaction approach based on cross sections of n-p scattering and n-C reactions with charged particle production

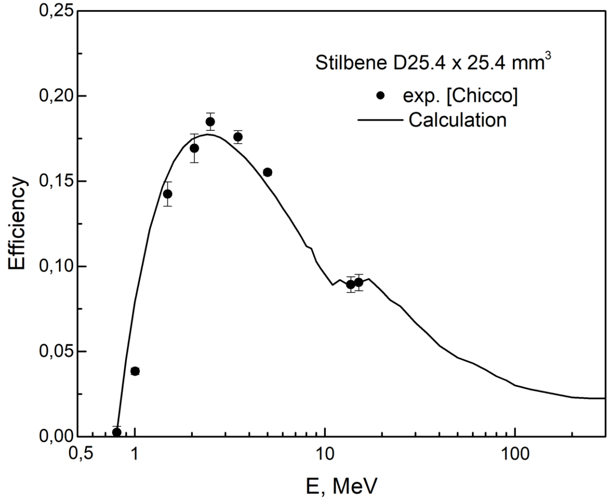
Test of the method with available experimental data

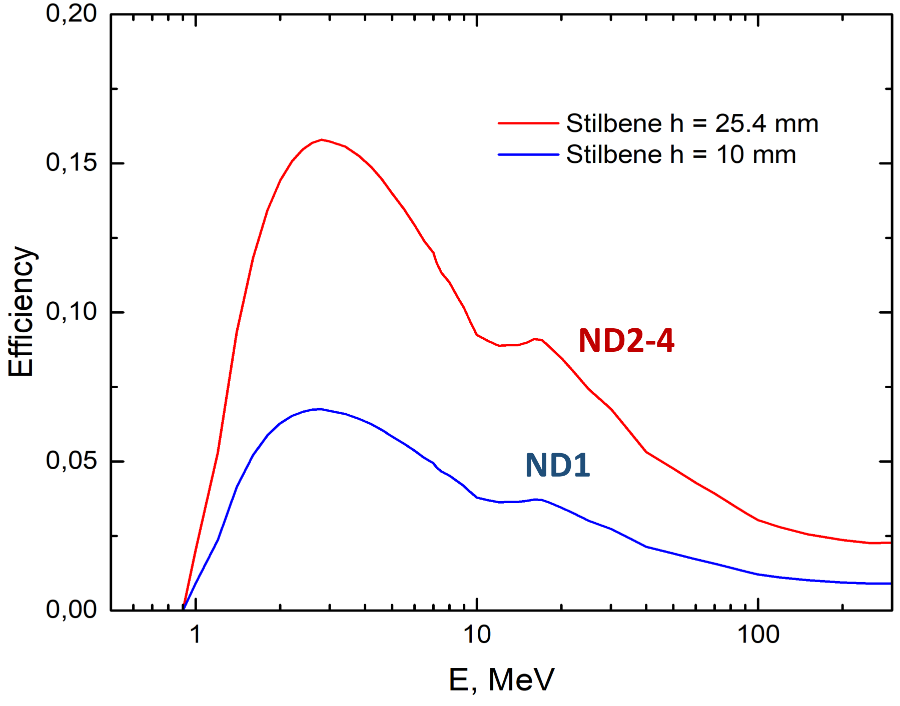










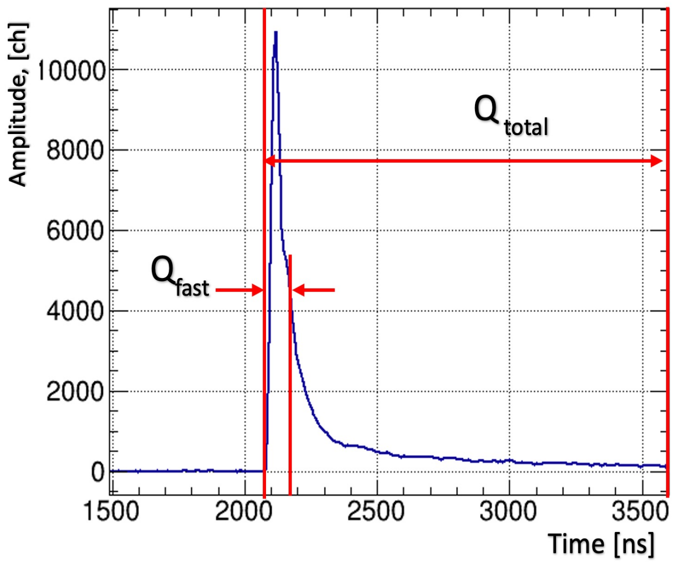


Pulse shape n/γ- discrimination

Quality of pulse shape discrimination:

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

Pulse shape 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}

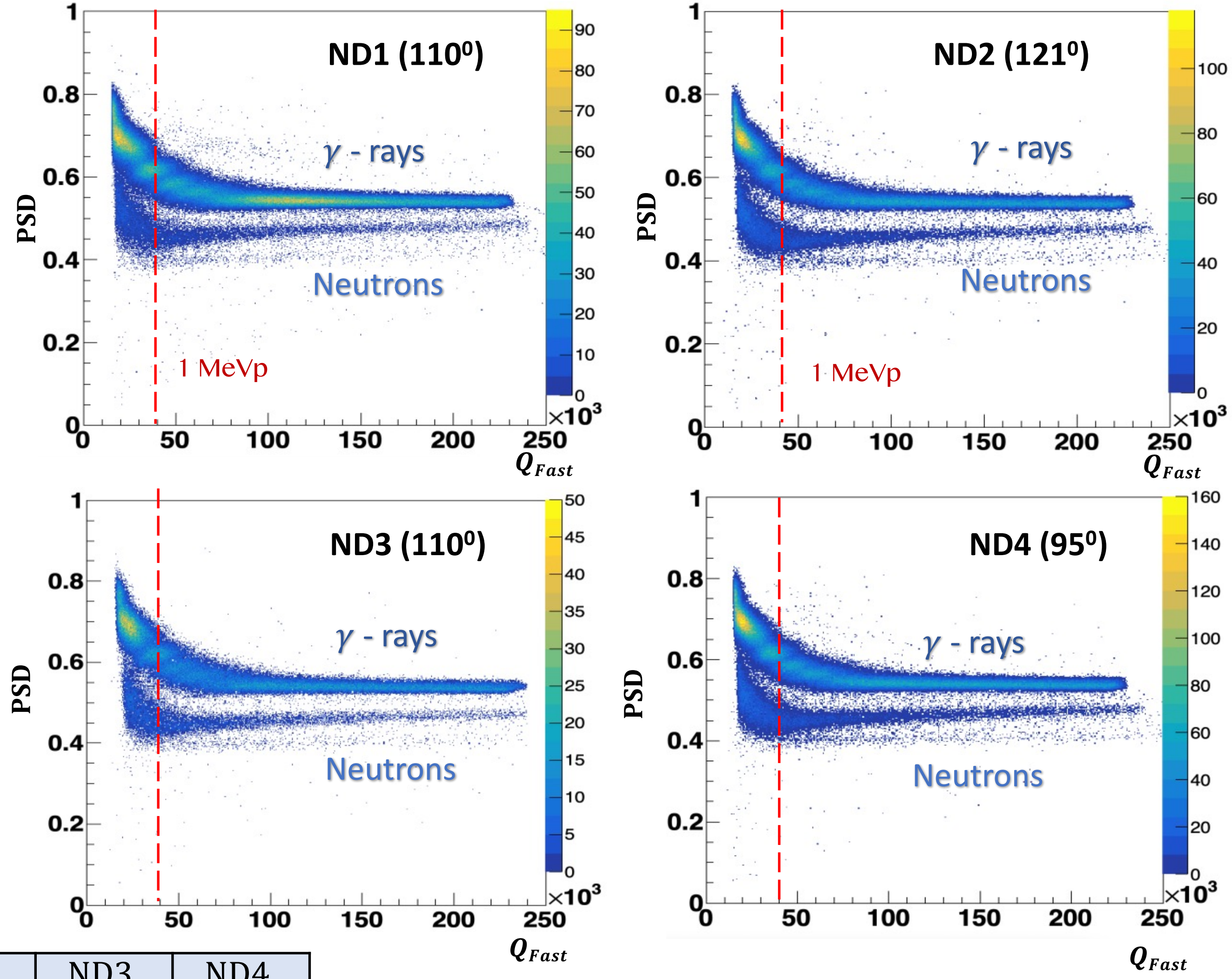
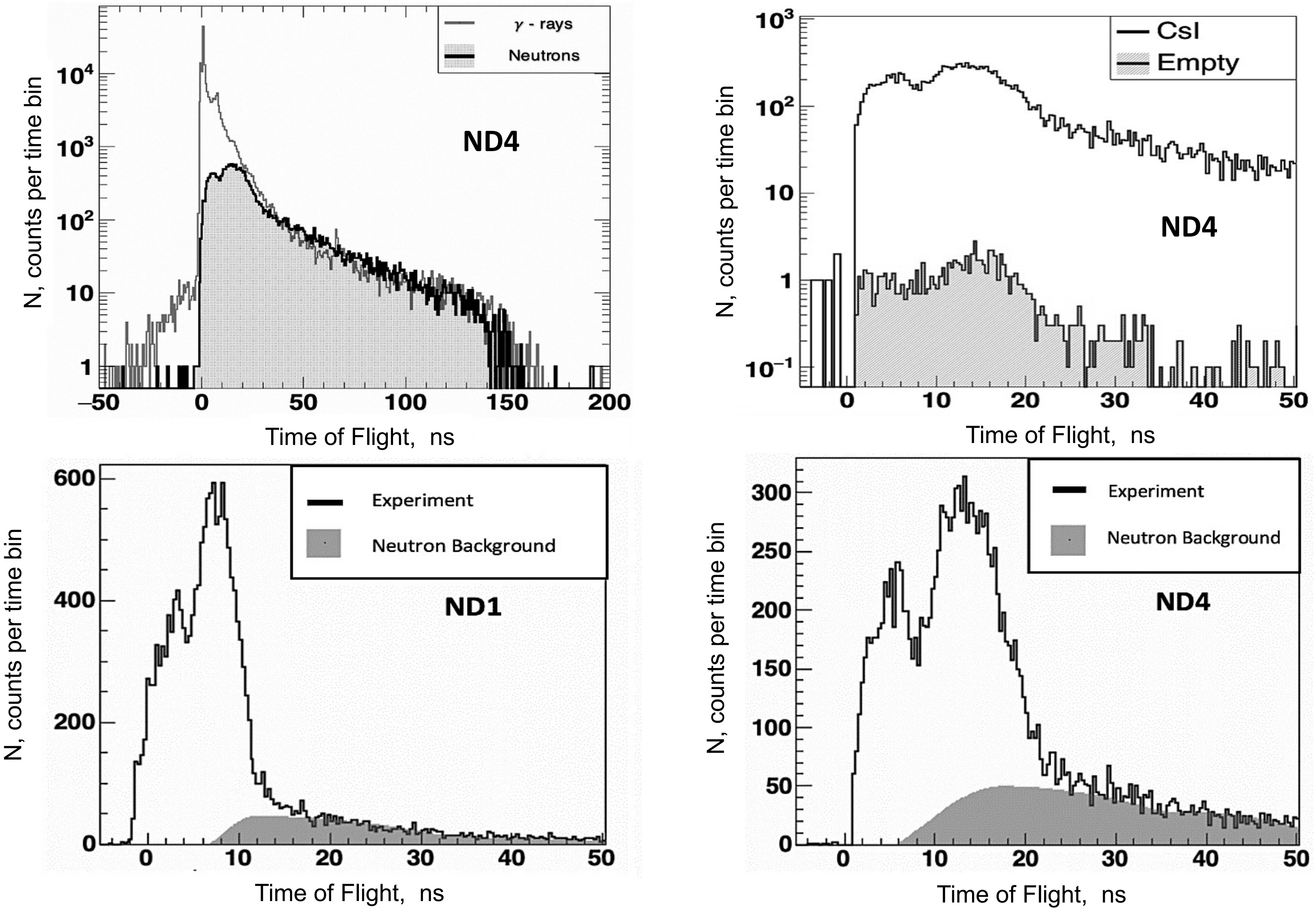


Figure of Merit

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

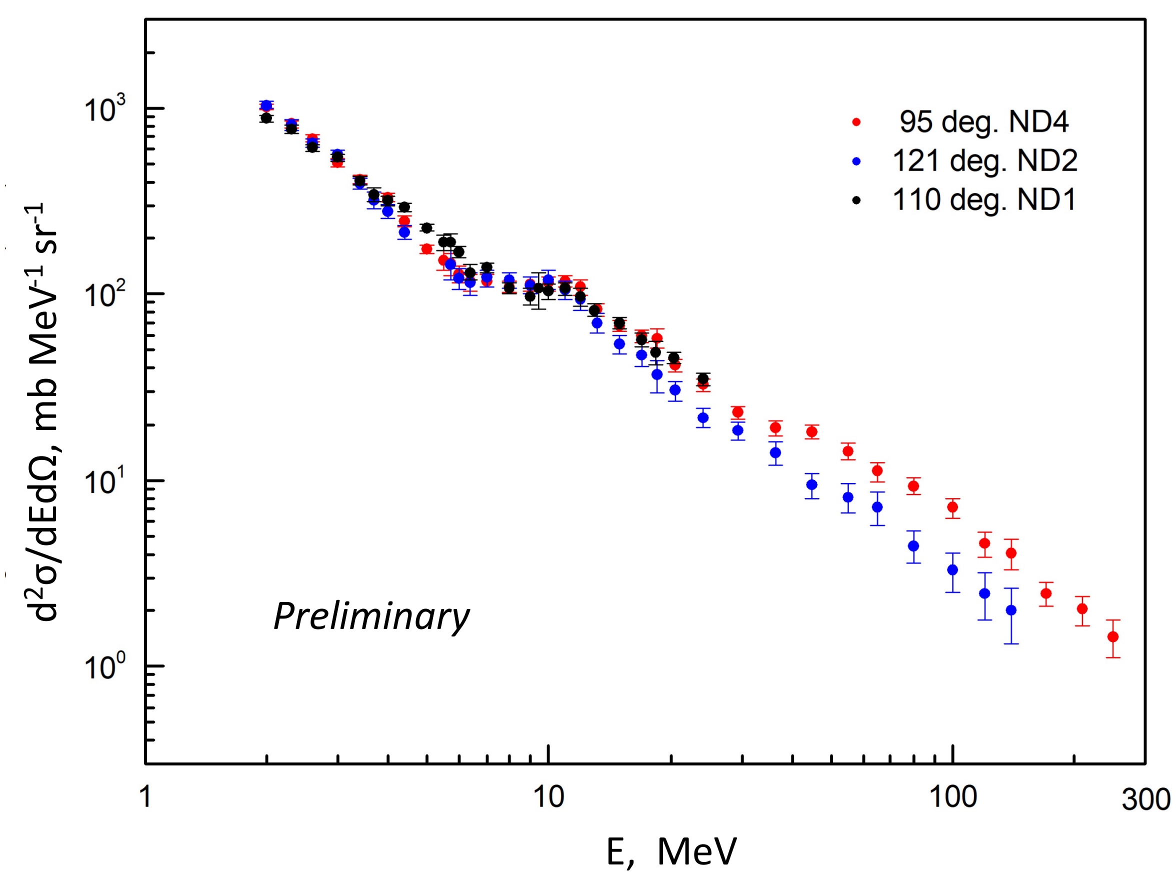
TOF spectra and background contribution



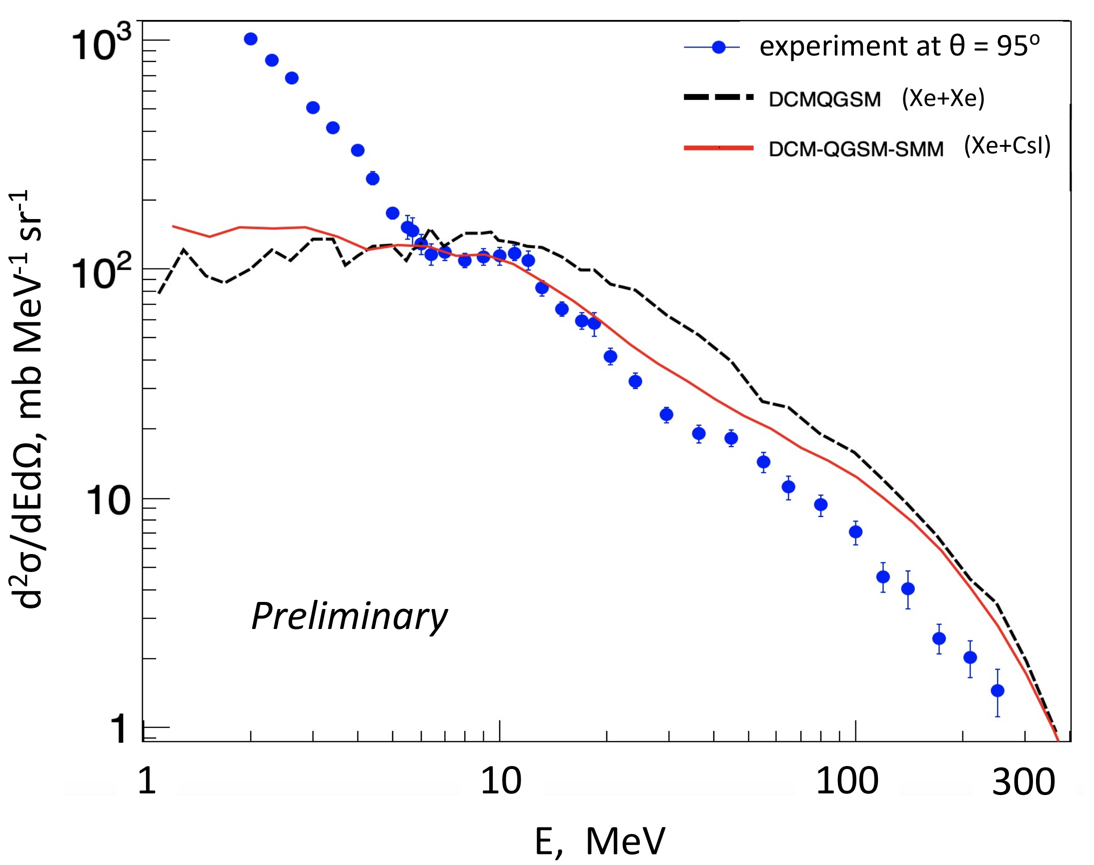
Energy spectra of neutrons

^{124}Xe + CsI, 3.8 A GeV

Energy spectra of neutrons measured with the spectrometer



Comparison with prediction of DSM-QGSM model



In calculation the dependence of trigger efficiency on impact parameter was taken into account

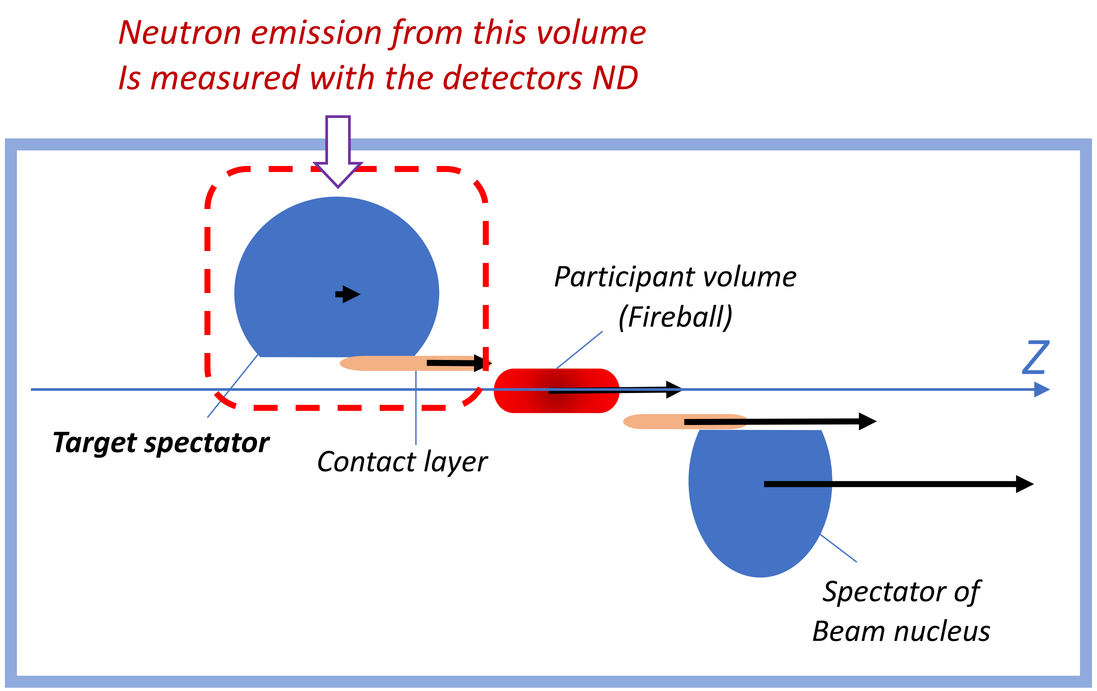
Moving Source Model

The experimental energy spectra of neutrons were analyzed in framework of Moving Source Model (MSM) with three sources:

- ✓ The first source S1 reproduces the hard part of spectra (contribution of contact layer)
- ✓ The second source S2 gives main contribution in the middle part of spectra associated with multifragmentation decay
- ✓ The third source S3 dominates in the low energy part (fragmentation decay + evaporation)

$$\frac{d^2\sigma}{dEd\Omega} = \sum_{i=1}^{3} pA_i \exp(-(\frac{E + m - p\beta_i \cos\theta}{(1-\beta_i^2)^{1/2}} - m)/T_i)$$

E, p – kin. energy and momentum in lab. frame
m – neutron mass
θ – angle in lab. frame
A_i – amplitude
T_i – slope temperature
β_i – longitudinal velocity (v/c)



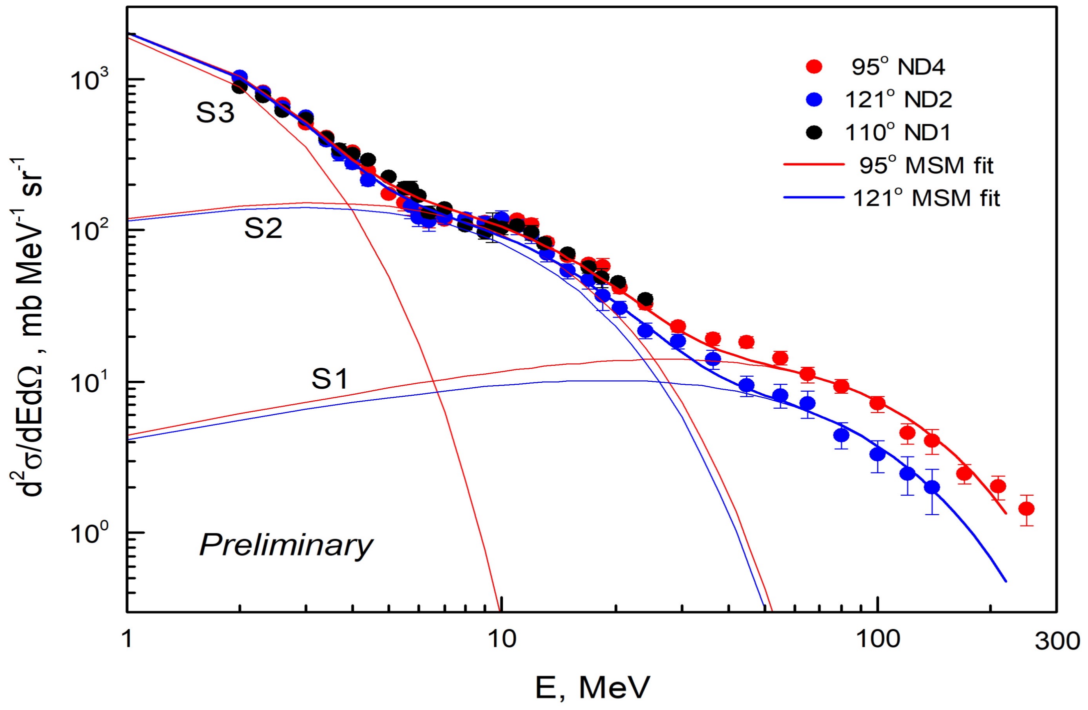
Phenomenological picture of nucleus – nucleus collision

V. I. Yurevich, R. M. Yakovlev, and V. G. Lyapin, Phys. At. Nucl. 75, 192 (2012)

Neutrons from target spectators

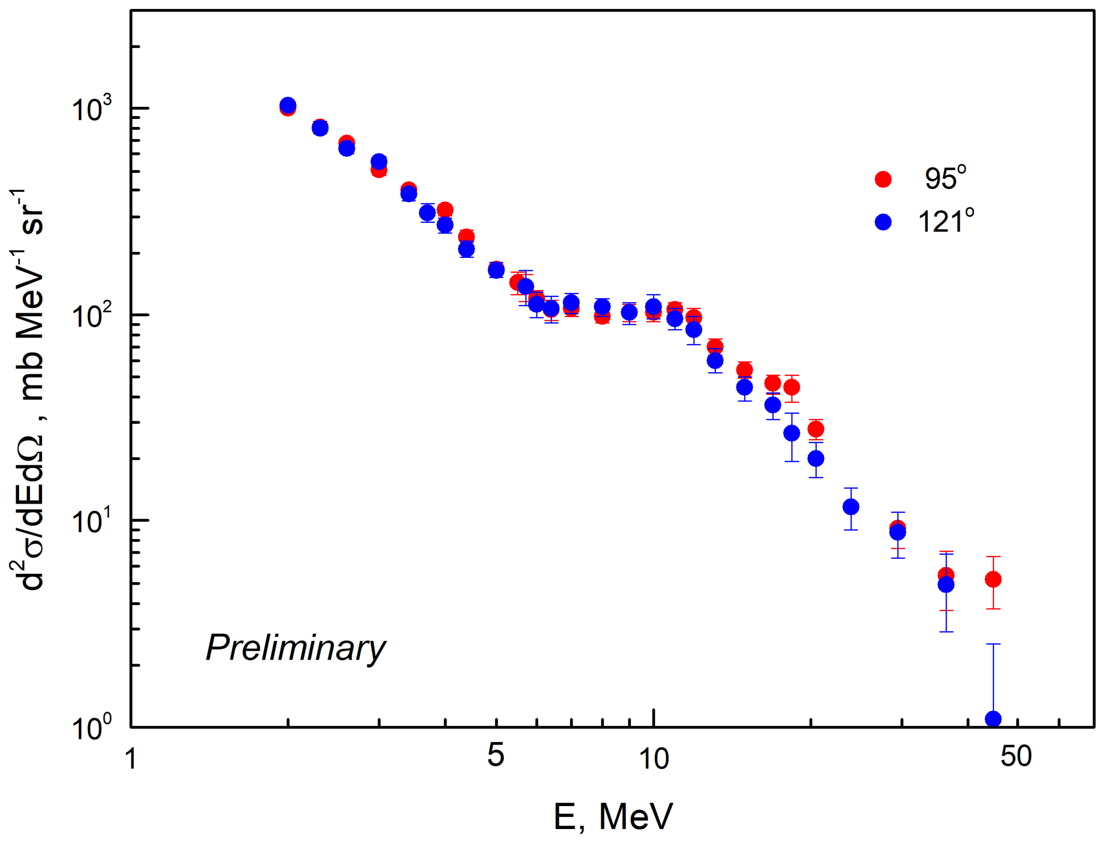
^{124}Xe + CsI, 3.8 A GeV

MSM fitting of the neutron spectra measured



Source	A_i	T_i (MeV)	β_i
S1	0.157	55 ±5	0.18 ±0.02
S2	3.27	6.5 ±0.5	0.015 ±0.010
S3	205	0.8 ±0.1	~0

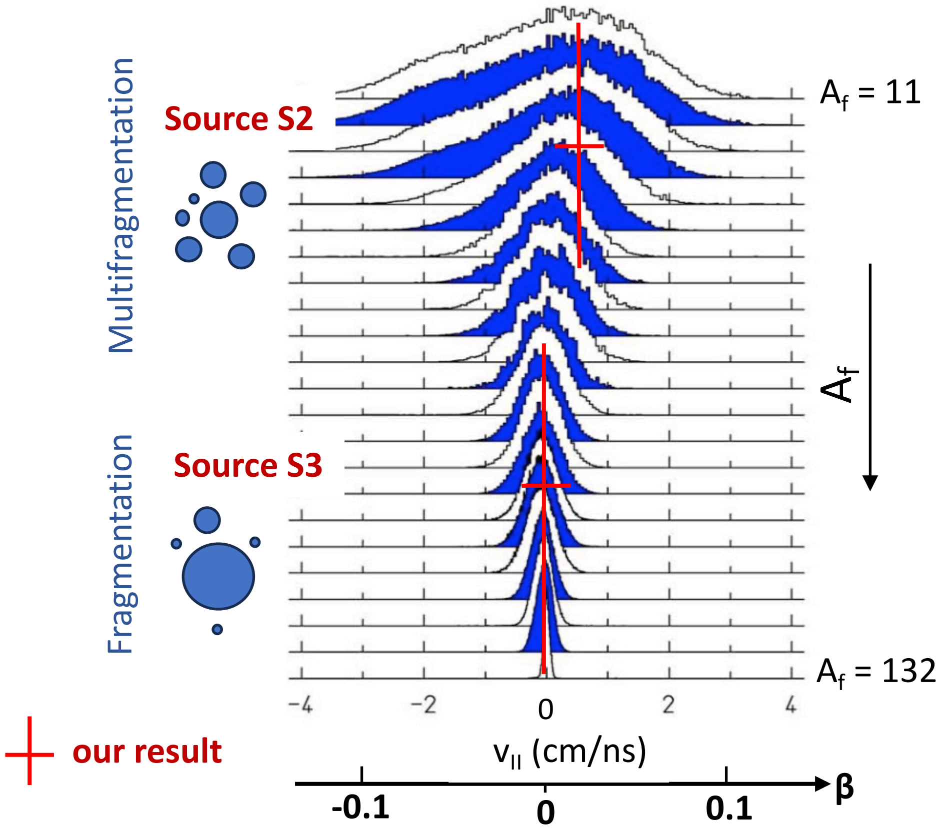
Neutrons spectra from the target spectators obtained by subtraction of the S1-source contribution



Comparison with the results obtained at GSI

The FRagment Separator (FRS)

^{136}Xe + Pb at 1 A GeV



Longitudinal velocity spectra of fragments

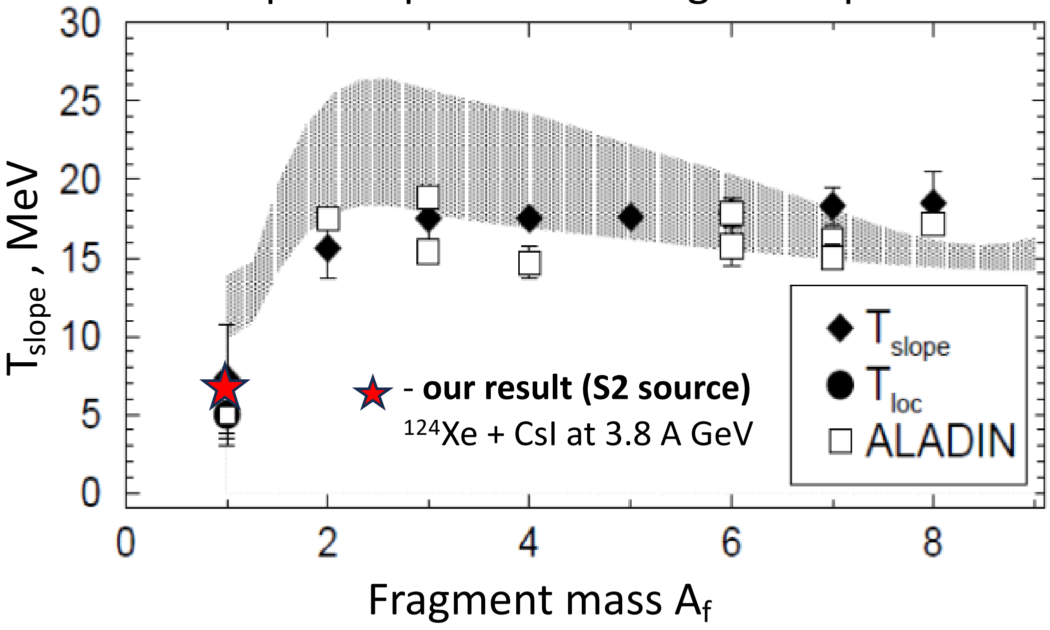
Kinematical properties of spectator fragments in heavy-ion collisions at relativistic energies, Antoine Bacquias, PhD Thesis, Strasbourg, 2008.

ALADIN Collaboration

Au + Au at 600 A MeV

Study of charged fragment production in decay of beam spectators

Slope temperature of fragment spectra



Spectator and participant decay in heavy ion collisions

T. Gaitanos, H.H. Wolter, C. Fuchs,Physics Letters B,Volume 478, Issues 1–3, 2000,

Conclusion and Outlook

- The compact TOF spectrometer developed as a part of BM@N setup is able to study energy spectra of neutrons emitted from target spectators and to get reliable data in energy range from 2 to 200 MeV.
- As the first result, the spectra of neutrons produced in Xe + CsI collisions at 3.8 A GeV were measured.
- A comparison with prediction of DSM-QGSM-SMM model shows satisfactory agreement above ~6 MeV and large underestimation in the lower energy region. It seems, the theoretical model needs in further development for description of low-energy neutron emission.
- It is clearly seen that the measured spectra are formed as a sum of three components/sources. The fitting with MSM expression allows to obtain parameters of the sources and select spectra of neutrons emitted from target spectators.
- Neutron emission from the target spectators is nearly isotropic and two decay processes, fragmentation and multifragmentation (the sources S2 and S3), form the energy spectra of emitted neutrons. The obtained velocities of these sources and the temperature of the S2 source are in good agreement with results of the FRS and ALADIN experiments at GSI.
- A new measurements with the spectrometer will take place in BM@N run 2025 with Xe ions at lower energies.

Thank You for Your Attention!

Backup slides

Pulse shape n/γ- discrimination

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