JOINT INSTITUTE FOR NUCLEAR RESEARCH

TOF neutron spectrometer, study of the performance and status of data analysis

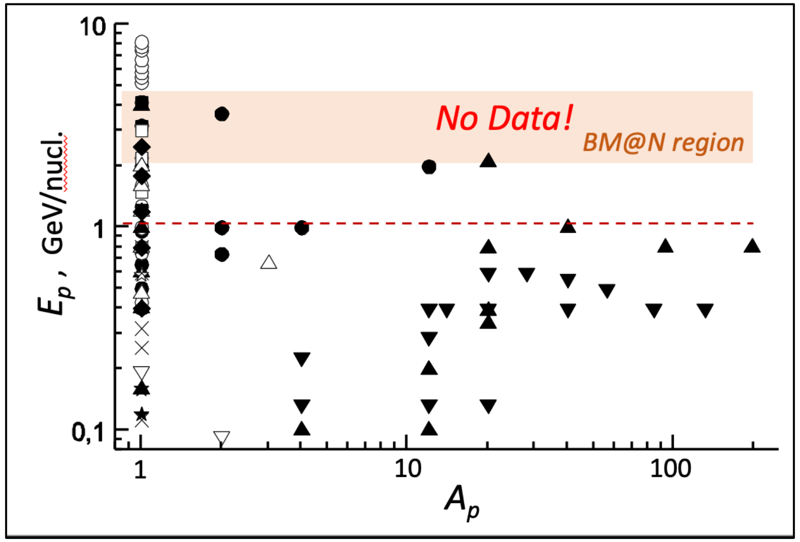
N. Lashmanov, V. I. Yurevich, S. A. Sedykh, V. Yu. Rogov, S. V. Sergeev, V. V. Tikhomirov, A. A.Timoshenko

Aim of neutron measurements

Study of neutron emission from decay of target spectator in high-energy *AA*- collisions by measurement of neutron energy spectra at large angles and different collision centrality

These data are very important for development of theoretical models and codes.
At present the description of spectator fragmentation is one of the key problems of the existing models.

It is important to say that selection of events with direct neutrons on a high level of background from gamma-rays, neutrons and charged particles is ambitious and not trivial methodical task.
The difficulty to perform such measurements is the reason why there are no such experimental neutron data in beam energy range above 1 GeV per nucleon.



Task for BM@N run 2022-23

During the run with beam of 3.9- A GeV Xe ions and CsI target we made the first attempt to measure the energy spectra of neutrons from target spectator decay in wide energy interval from 1 to 300 MeV.
Main aim for us was to prove that we are able to solve the methodical problems at BM@N setup and to get the valid neutron data.

For this purpose, a special concept of the neutron TOF spectrometer was developed and applied in the last BM@N run.

Concept of Neutron Spectrometer

Main features of the spectrometer

- ✓ Small flight path (L = 30 cm) ⇒ Important for separation of direct neutrons from background neutrons in time-of-flight spectrum
- ✓ High time resolution ($\sigma_t \sim 150$ ps) ⇒ Important for good energy resolution
- ✓ Suppression of gamma-rays using stilbene crystals and PSD method ⇒ Important for discrimination of gamma-ray background
- ✓ Suppression of ch. particles with Veto-detector and PSD method ⇒ Important for discrimination of ch. particles background
- ✓ Neutron detectors with SiPM readout ⇒ Important for operation in magnetic field of 0.9 T
- ✓ Information about collision centrality comes from main BM@N detectors (number of tracks) ⇒ Important for study of neutron emission as a function of centrality

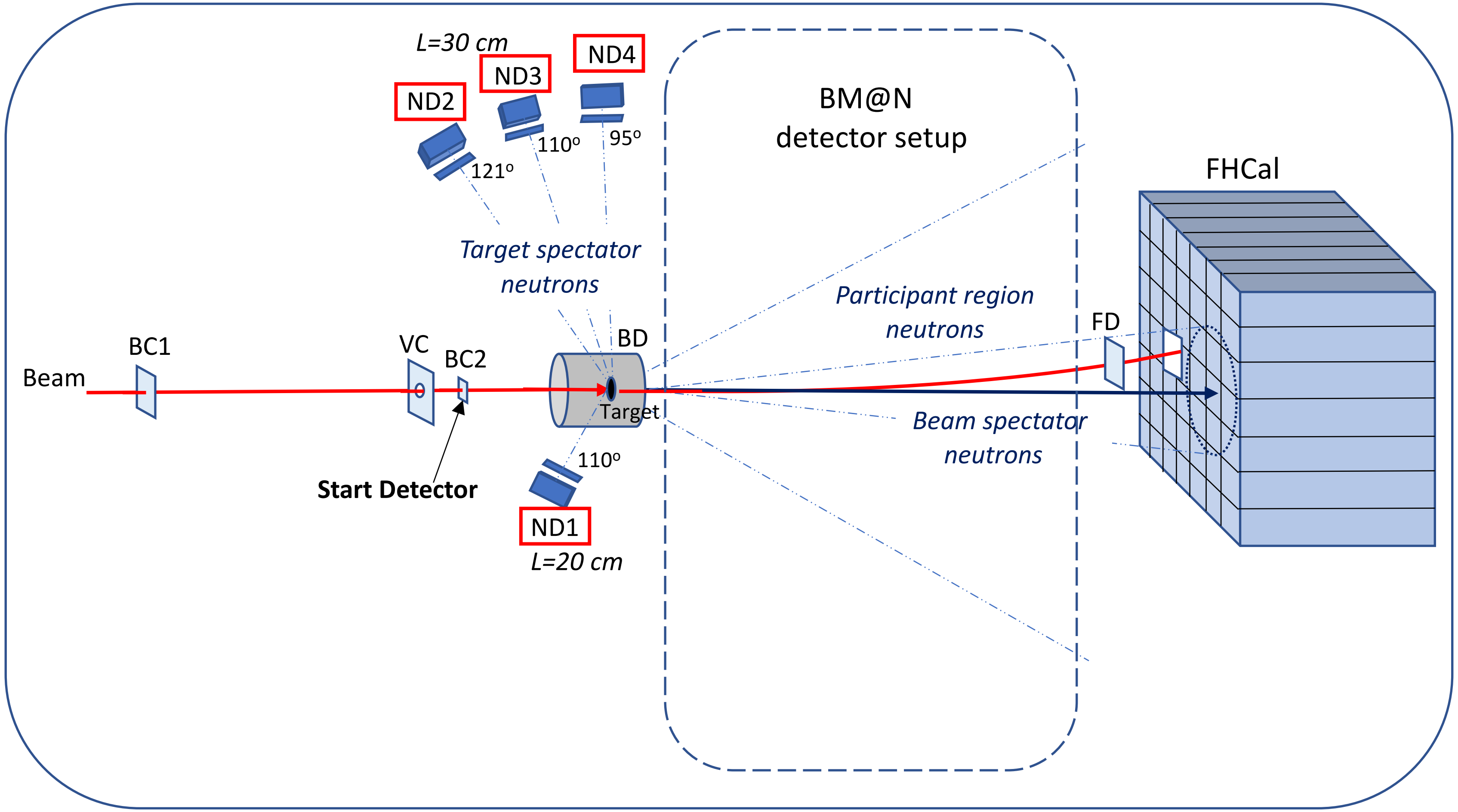
TOF Neutron Spectrometer

What we measure?

^{124}Xe + CsI (2%), 3.9 *A* GeV

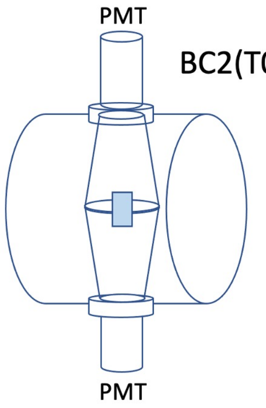
Neutron energy spectra from target spectator decay in energy range of 1 – 300 MeV.

$$\frac{d^2\sigma}{dE_n d\Omega}$$



Start Detector (Bc2)

Detector	PMT	Radiator	Time resolution, σ, ps	Amplitude resolution, $\frac{\sigma}{<A>}$
BC2	MCP-PMT XPM85112/A1-Q400 (Photonis)	Plastic (34x34x0.15 мм^3)	38	0.082



Trigger for neutron data taking

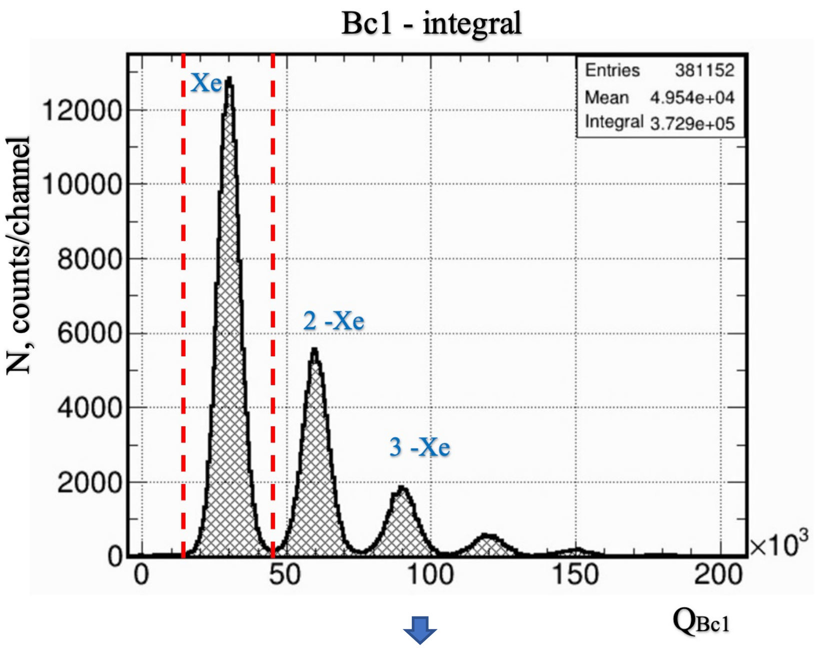
Trigger type:

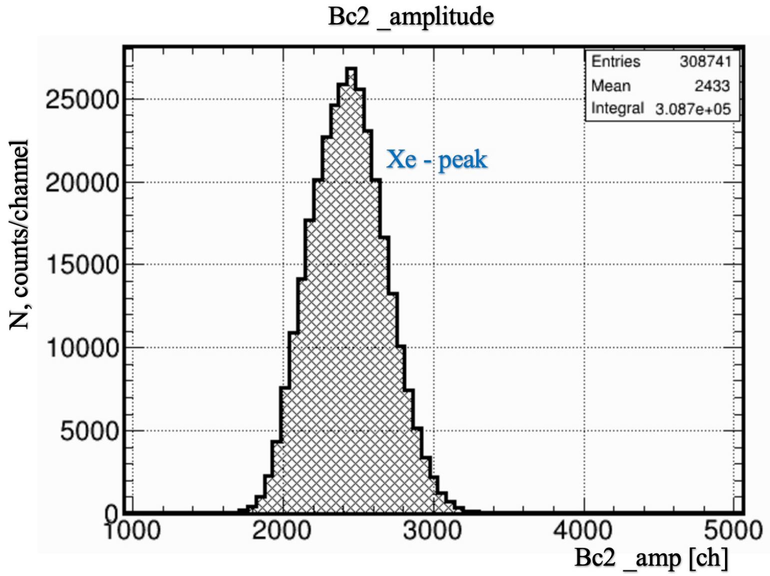
CCT2 = BC1 * BC2 * VC_{veto} * FD_{veto} * BD(N>3)

Counting Rates (ND4)

Run #	N (*Triggers*)	N ($^1_0 n$)	N (γ)	N(*charge*)	N(Nd4&Veto)
7639	312521	502	3619	18302	1206
7640	248042	414	2957	14653	965
7643	304648	493	3510	17821	1070
7644	334161	517	3818	19655	1269

Processed runs	8018772	12227	85449	448767	30452





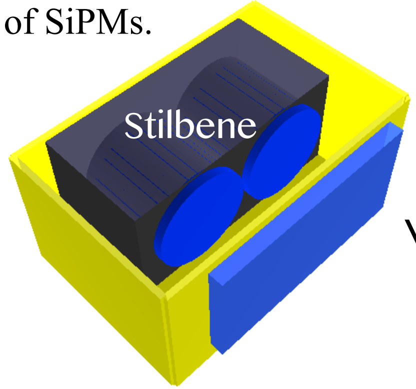
Neutron Detectors

ND1 with 2 stilbene crystals 30-mm diam. × 10 mm

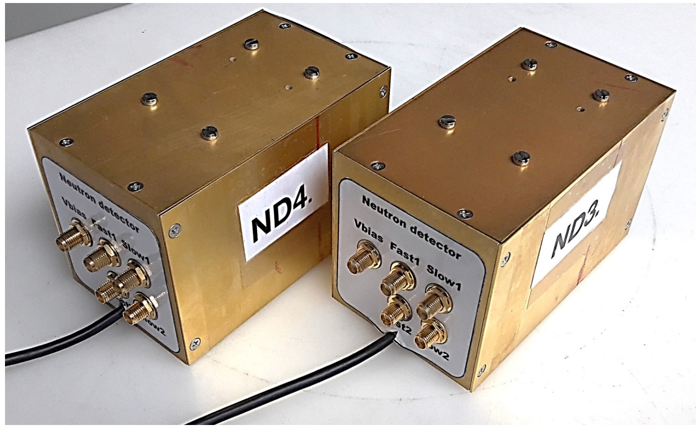
ND2, ND3, ND4 with 2 stilbene crystals 25.4-mm diam. × 25.4 mm

Scintillation photons are detected with 4 units of SiPMs 6x6 mm^2 , SensL, J-ser.

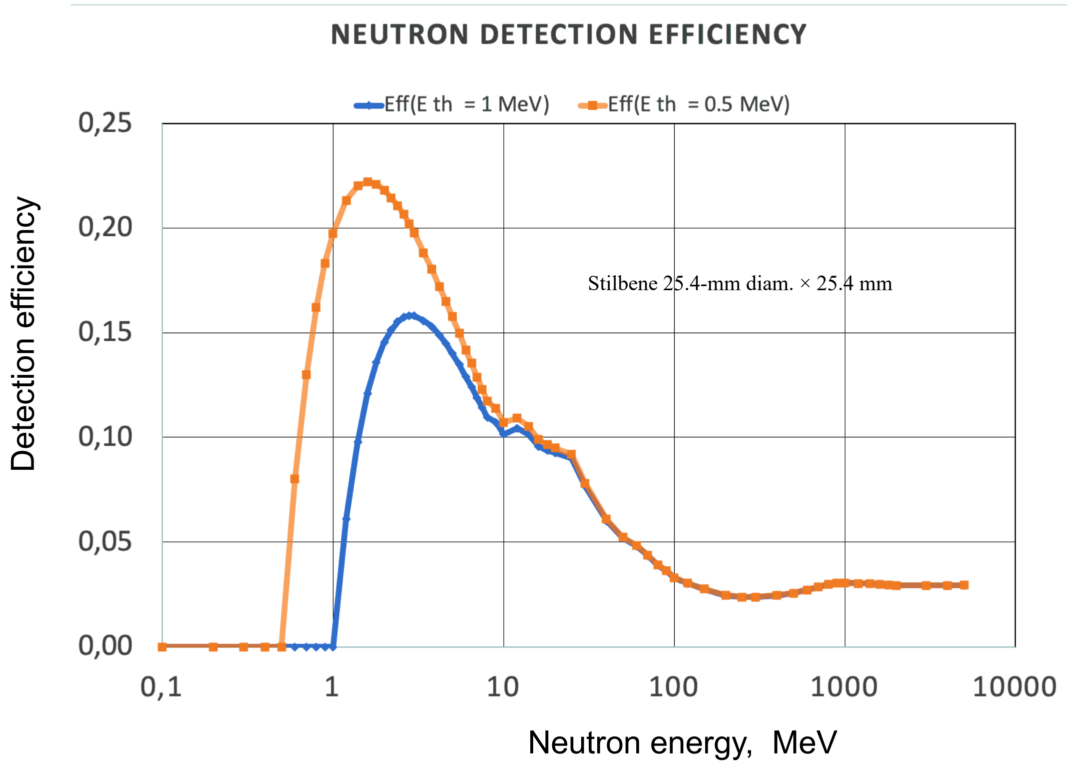
Veto-Detectors: plastic scintillators with 2 units of SiPMs.



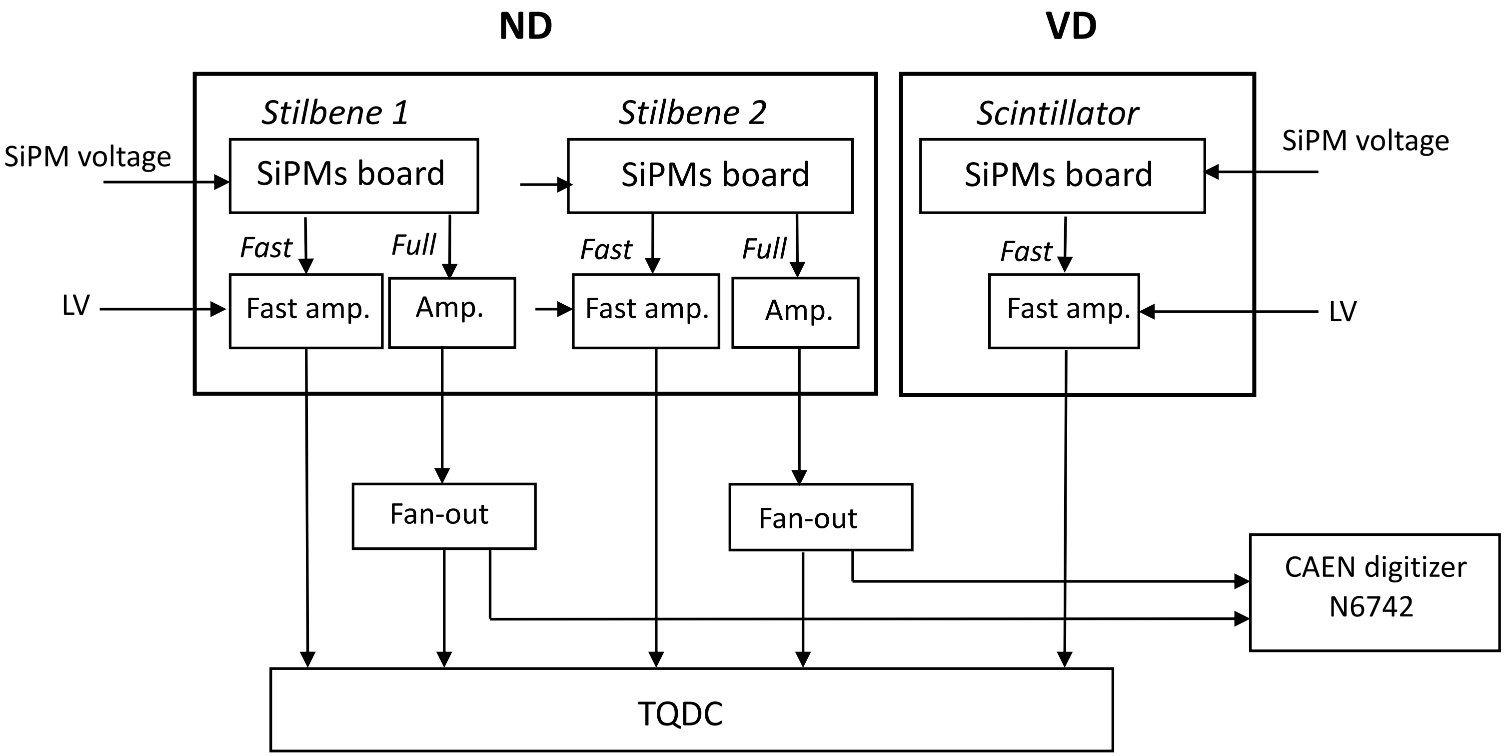
Neutron detectors

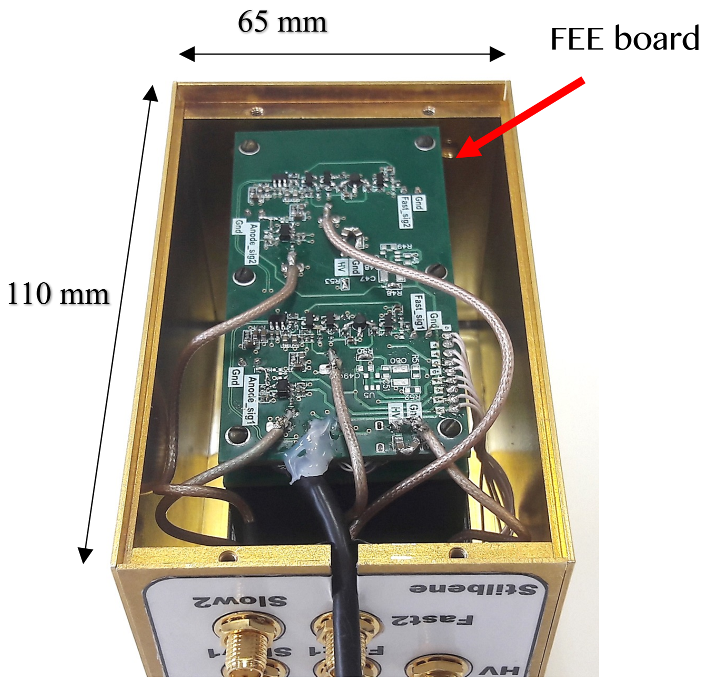


Stilbene with SiPMs



Electronics and DAQ

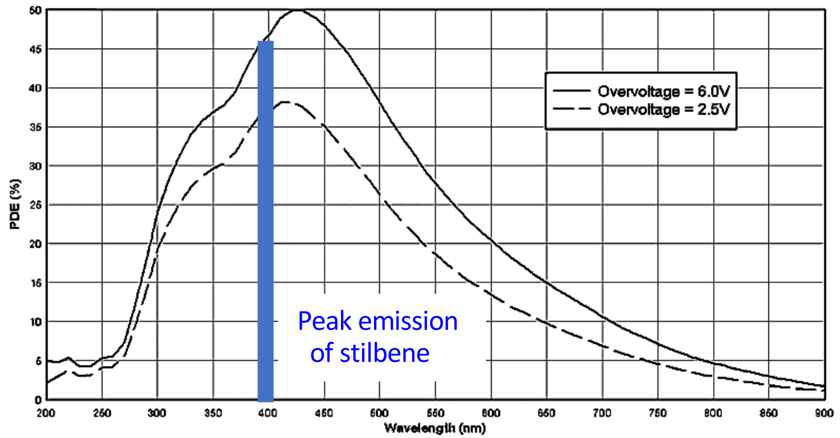




Characteristics of Stilbene

	Density gm/cm^3	Wavelength nm	Refractive index	Decay time ns	Light yield Photons/MeV n	γ
Stilbene	1.25	390	1.626	3.5–4.5	10,700	14,000

Photon detection efficiency of SensL SiPM

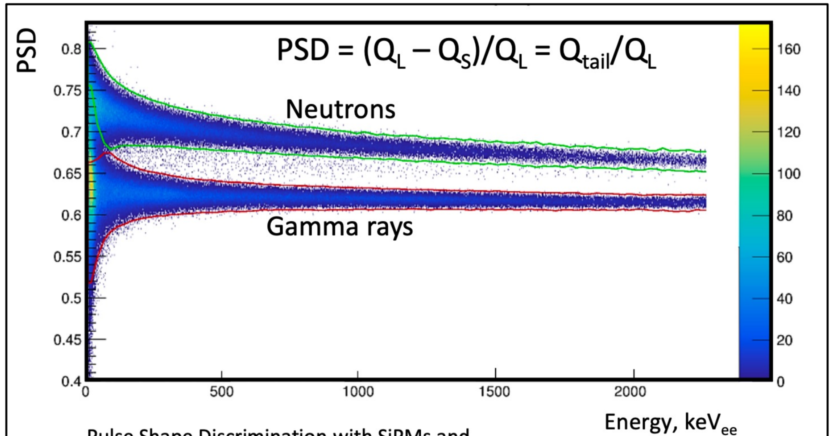


Decay time components of stilbene

Particle specie	Fast [ns]	Intermediate [ns]	Slow[ns]
gamma	5.21 (95 %)	21.33 (3 %)	134.77 (2 %)
neutron	5.01 (95 %)	27.70 (4 %)	253.19 (1 %)

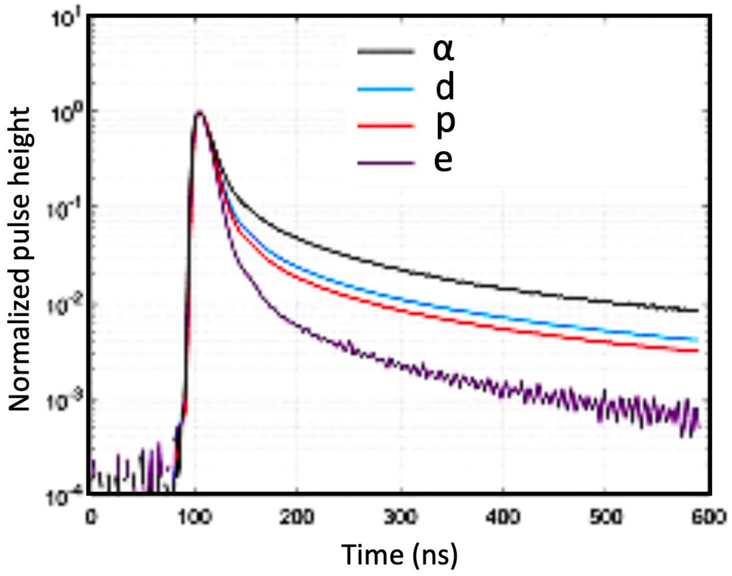
H.D. Kim et al. "Characteristics of a stilbene scintillation crystal in a neutron spectrometer". In: Radiation Measurements 58 (Nov. 2013), pp. 133–137.

Pulse Shape Discrimination Method



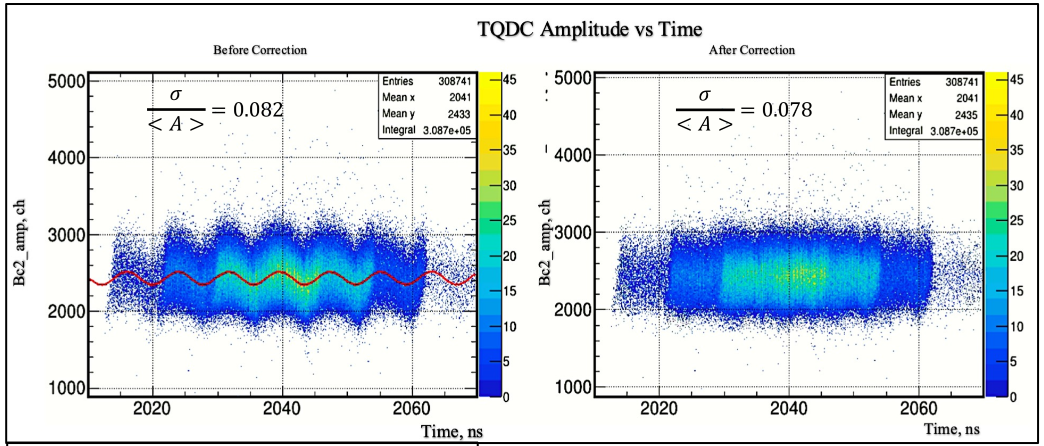
Pulse Shape Discrimination with SiPMs and Stilbene Crystals for Neutron Imaging
Christian Wysotzki (2018)

Pulse shape for different particles



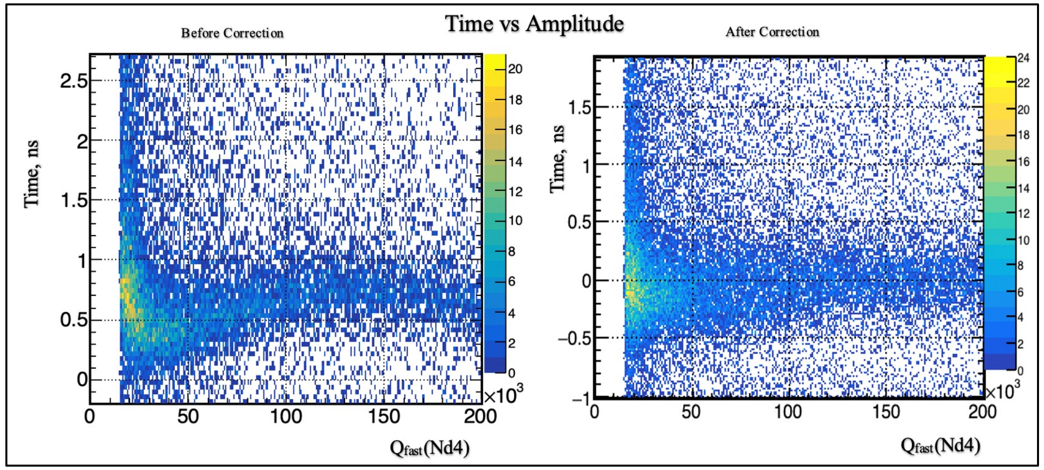
Time resolution

$TQDC\ -\ Correction\ for\ BC2$



$\boldsymbol{Fit\ Function}$: $p_0 * \sin(p_1 x + p_2) + p_3$

$Correction\ for\ ND4$



$\sigma_{(Nd4-Bc2)} = 0.139$ [ns];

$\sigma_{Bc2} = 0.038$ *[ns]*

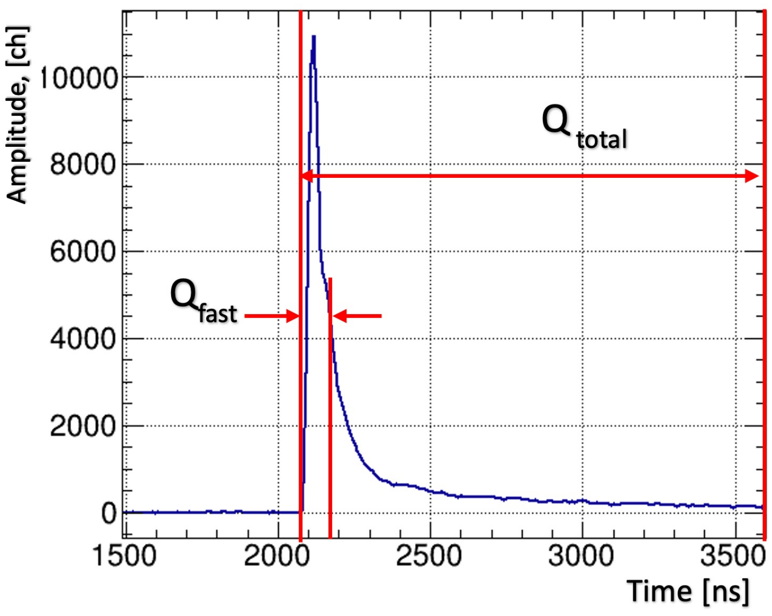
$\boldsymbol{\sigma_{Nd4} = 0.134}$ ***[ns]***

Neutron TOF spectrometers

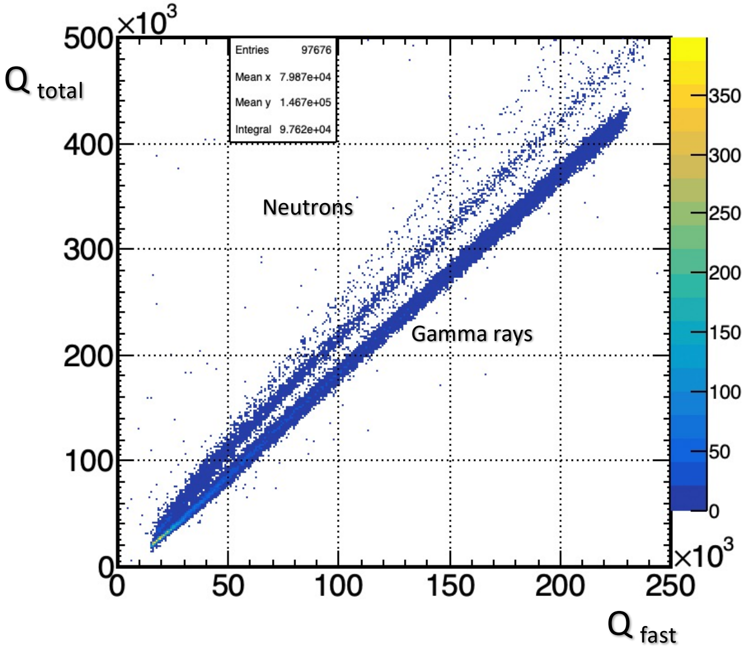
Accelerator	Detector (cm)	Efficiency	Path (m)	σ_t (ns/m)	*n/γ*
TOF spectrometer BM@N/JINR	**Stilbene D2.54x2.54, D3x1**	Calc.	**0.3**	**0.45**	Yes
SATURNE / Saclay	NE213 D12.7x5.1 NE213 D16x20	Exp./Calc.	8.5	0.24 0.18	Yes Yes
Synchrophasotron / JINR	Stilbene D4x1 Stilbene D5x5 Plast. scintill. D12x20	Exp. Exp./Calc. Exp.	0.5 - 0.7 0.7 - 1.2 1.5 - 2	0.8 0.7 - 0.4 0.3 - 0.25	Yes Yes No
Synchrotron / ITEP	Plast. scintill. D20x20	Exp./Calc.	1.5	0.3	No
Synchrotron / ITEP	Liquid scintill. D12.7x15.2 NE110 20x20x11.5	Calc.	2, 3	0.3, 0.2	Yes No
PS / KEK	NE213 D5.08x5.08, D12.7x12.7	Exp./Calc.	0.6 - 0.9 1 - 1.5	0.8 - 0.6 0.5 - 0.3	Yes Yes
HIMAC/NIRS	NE213 D12.7x12.7	Exp./Calc.	3 - 5	0.3 - 0.2	Yes

Pulse Shape Discrimination and Suppression of Background

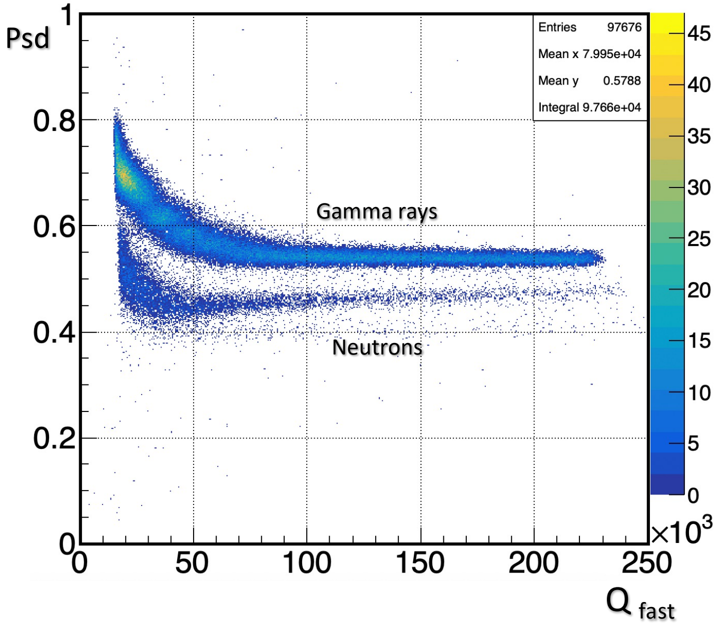
Waveform of Nd4 detector (TQDC)



n/γ - pulse shape discrimination



$$Psd\ parameter = 1 - \frac{Q_{total} - Q_{fast}}{Q_{total}}$$

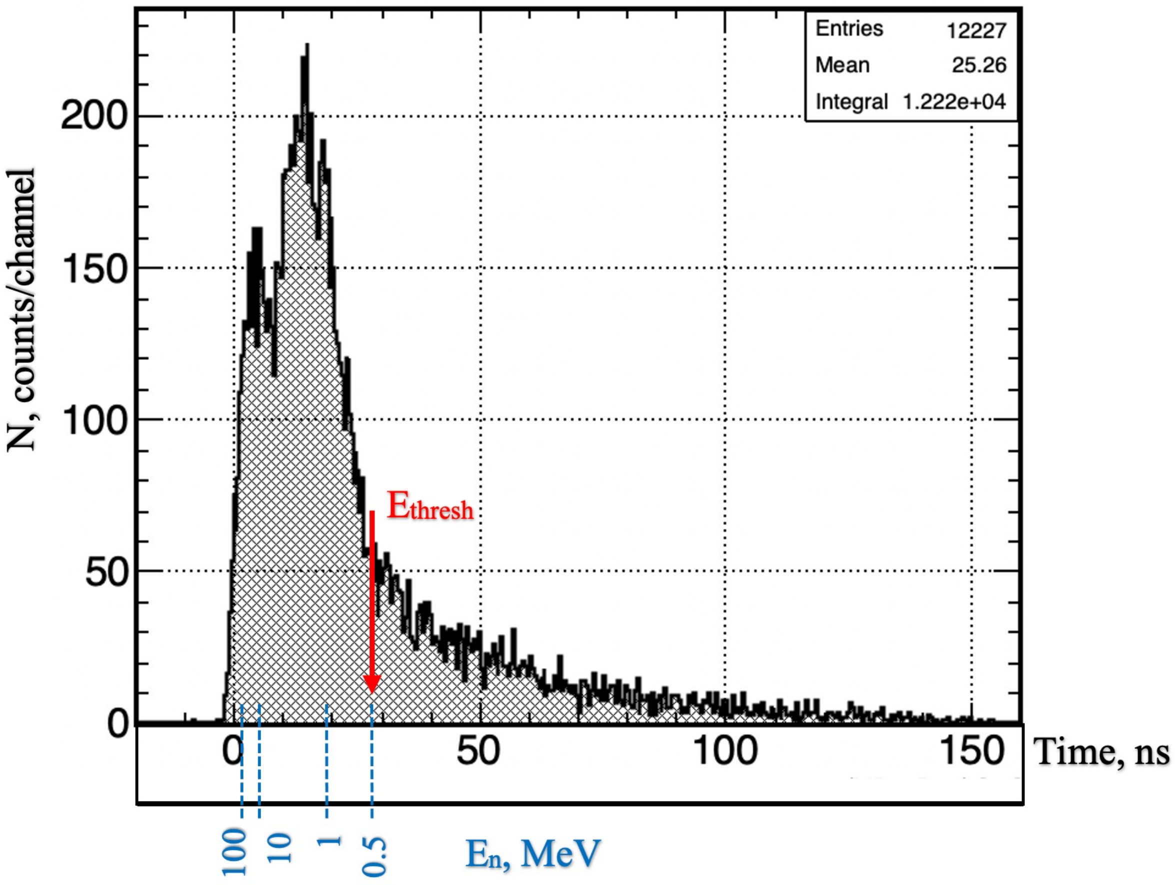


Q_{total} - is integrated charge of the total signal.

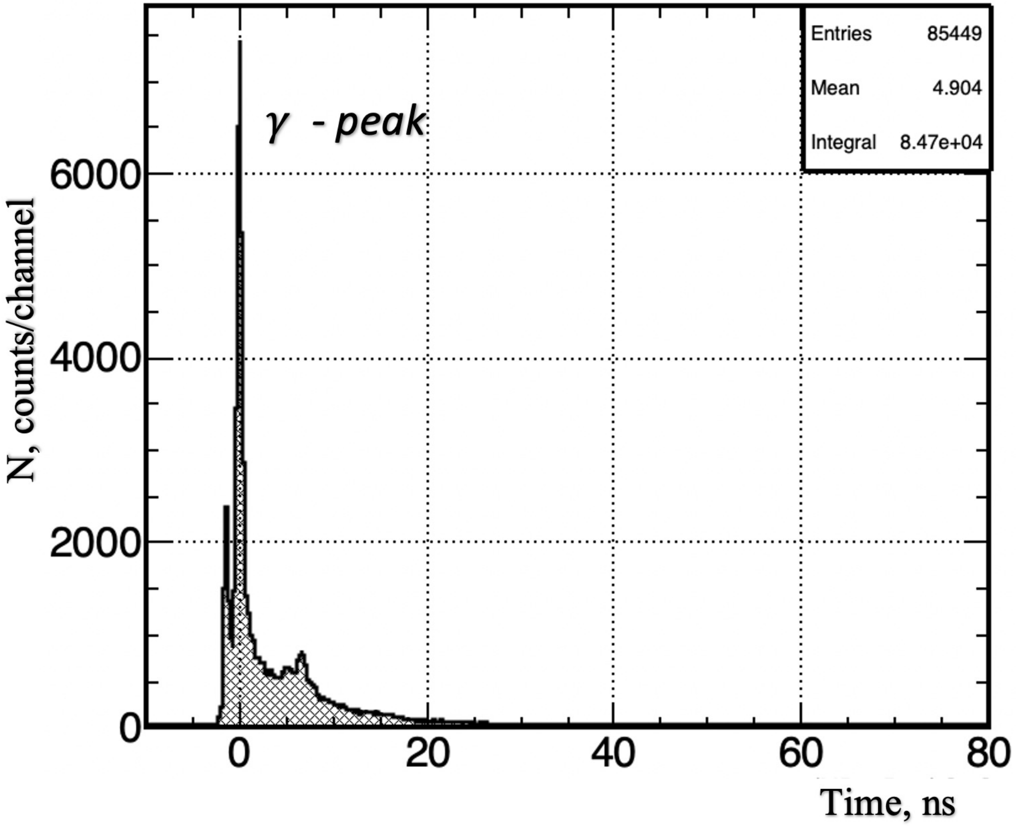
Q_{fast} - is integrated charge from beginning of radiation signal to specific point.

Analysis of TOF Spectra (Nd4)

n - TOF spectrum



γ - TOF spectrum



Example of Neutron Energy Spectrum

^{124}Xe + CsI collisions

Beam energy – 3.9 GeV/nucleon;

Trigger – CCT2;

Detector – ND4;

Angle – 95^0

$$\frac{d^2F}{dEd\Omega} = \frac{\Delta N}{\Delta E \cdot \Delta\Omega \cdot \varepsilon(E) \cdot k}$$

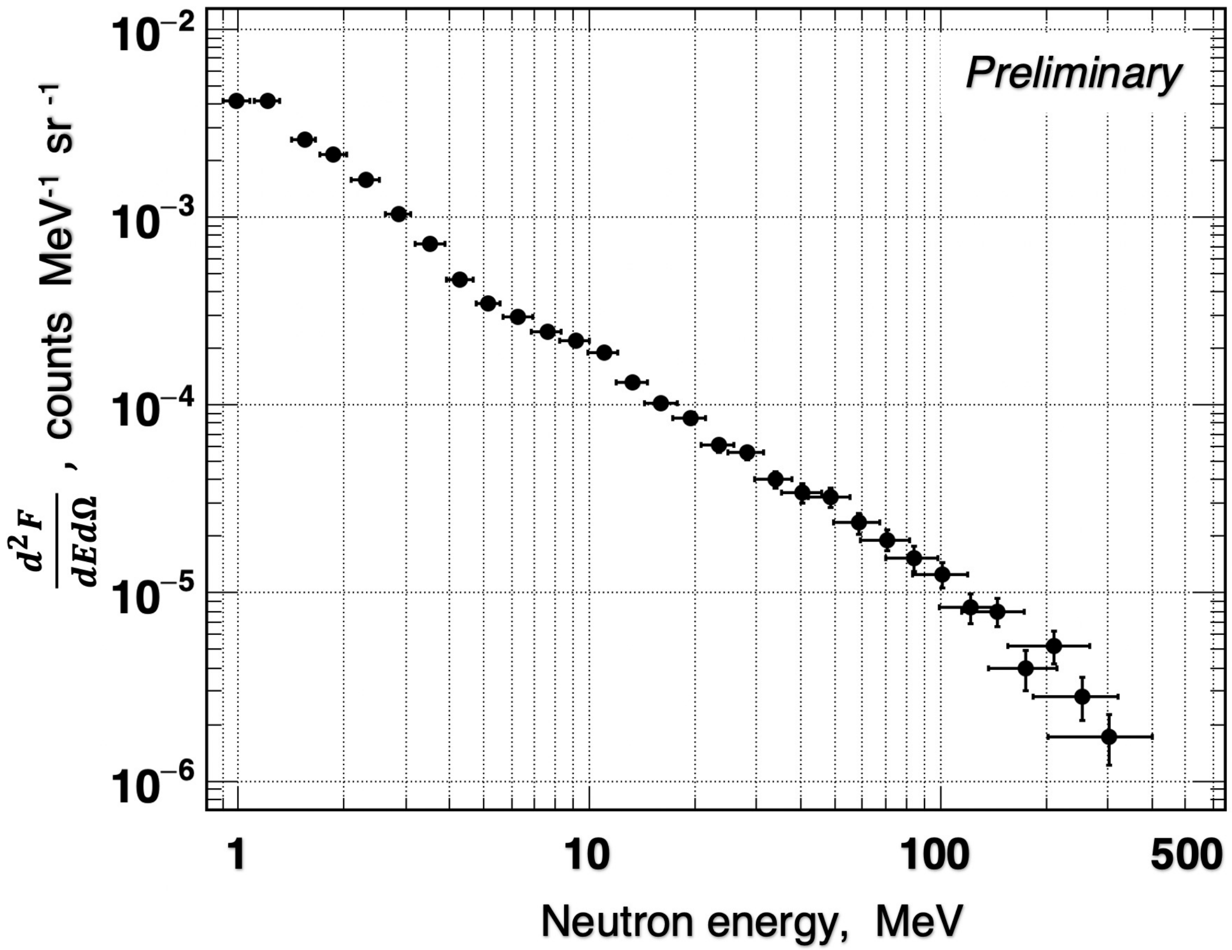
ΔN - is the number of detected neutrons;

ΔE - is the energy bin width;

$\Delta\Omega$ - is the solid angle for each neutron detector;

$\varepsilon(E)$ - is the neutron detection efficiency;

k - is a factor which corrects data acquisition.



Conclusion

- A TOF neutron spectrometer based on stilbene crystals has been developed for measuring energy spectra of neutrons at large angles in the BM@N experiment.

- Using the TOF method with a short flight path and n/g pulse shape separation, it was possible to significantly suppress the background in neutron detectors.

- As a result of the measurements, a preliminary energy spectrum of neutrons from the decay of the target spectator was obtained in a wide energy interval from 1 to 300 MeV at an angle of 95°.

- The performed analysis proves that we can obtain reliable neutron spectra with good statistics using the developed spectrometer. Here some preliminary results were presented and the analysis is continued.

JOINT INSTITUTE
FOR NUCLEAR RESEARCH

BM@N
Baryonic Matter at Nuclotron

Thank you for your attention !