JOINT INSTITUTE
FOR NUCLEAR RESEARCH

BM@N
Baryonic Matter at Nuclotron

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

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

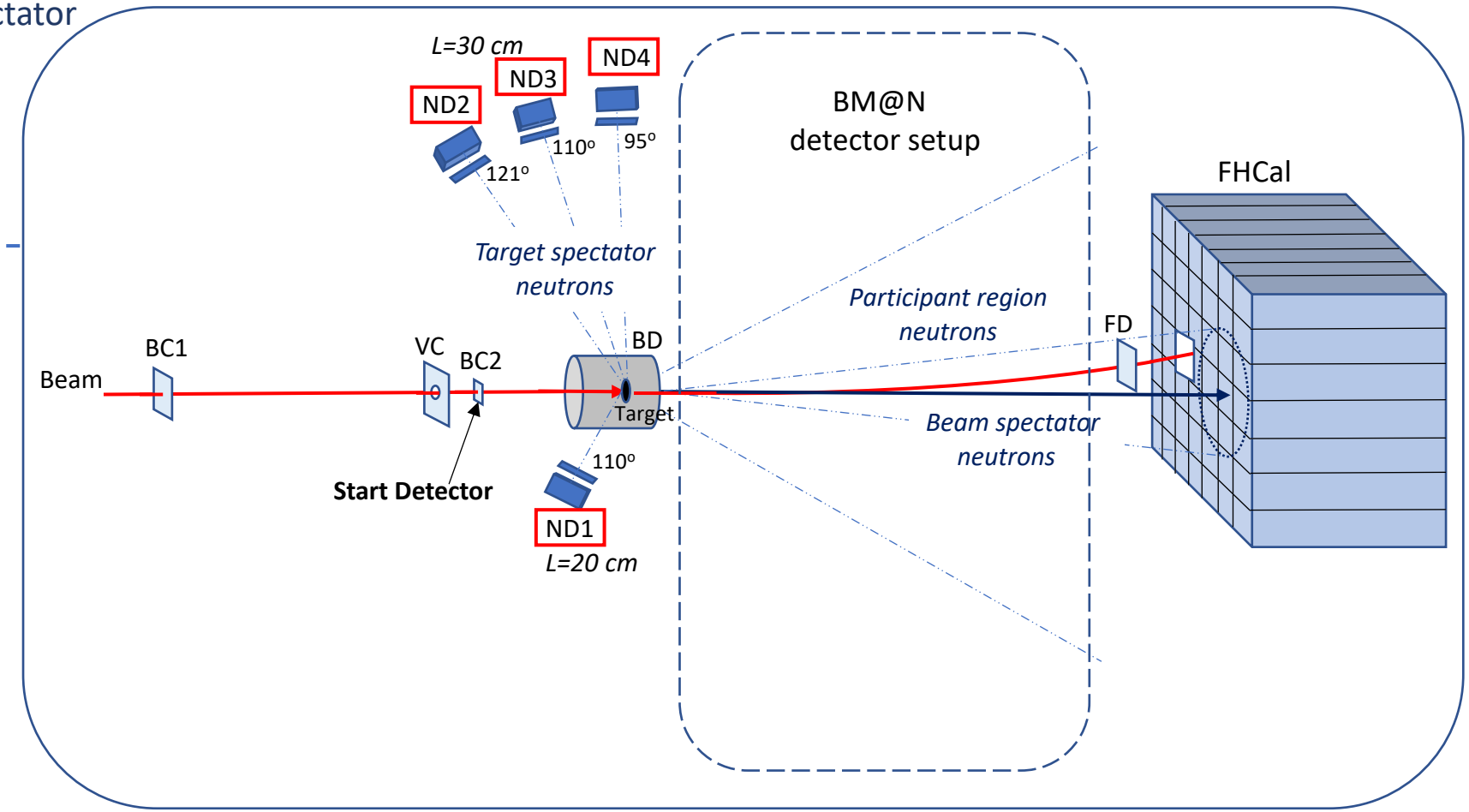
TOF Neutron Spectrometer

What we measure?

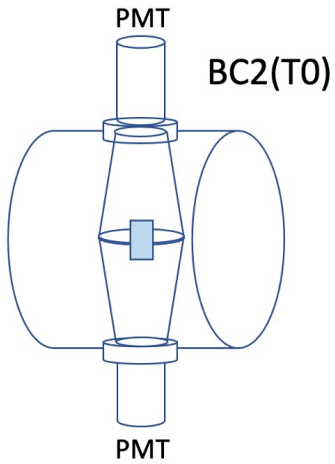
Neutron energy spectra from target spectator decay in energy range of 1 – 300 MeV.

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

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



Start Detector (Bc2)



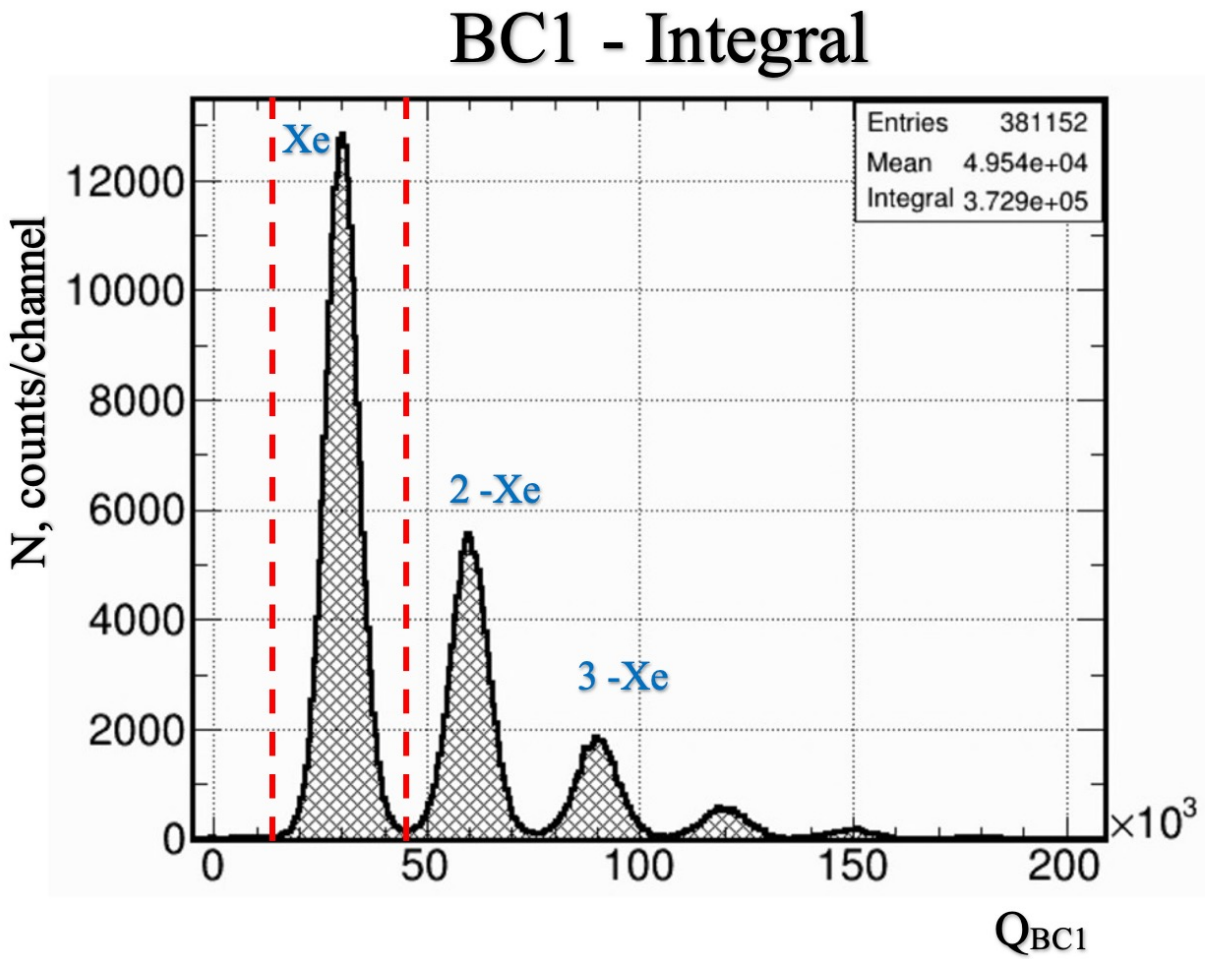
Detector	PMT	Radiator	Time resolution, σ, ps	Amplitude resolution, $\frac{\sigma}{<A>}$
BC2	MCP-PMT XPM85112/A1-Q400 (Photonis)	Plastic (34x34x0.15 мм^3)	38	0.082

Trigger for neutron data taking

Trigger type:

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

Cut(BC1): $12000 < Q_{BC1} < 47000$



Counting Rates (ND4)

Run #	N (Triggers)	N (^1_0n)	N (γ)	$ND4$ && $Veto$ && $N(^1_0n)$	$ND4$ && $Veto$
7634	445142	720	5137	94	1757
7638	452677	759	5281	103	1721

$\frac{N(^1_0n)}{N(Triggers)}$	$\frac{N(\gamma)}{N(Triggers)}$	$\frac{ND4 \,\&\&\, Veto \,\&\&\, N(^1_0n)}{N(Triggers)}$	$\frac{ND4 \,\&\&\, Veto}{N(Triggers)}$
1,62E-03	*1,15E-02*	*2,11E-04*	*3,80E-03*

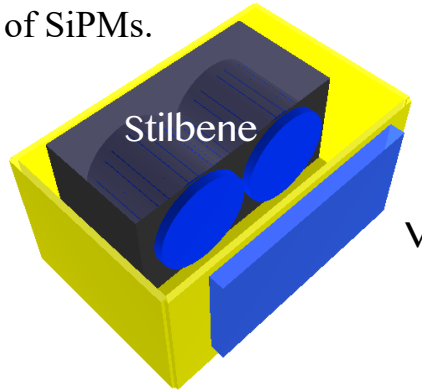
Neutron Detectors

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

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

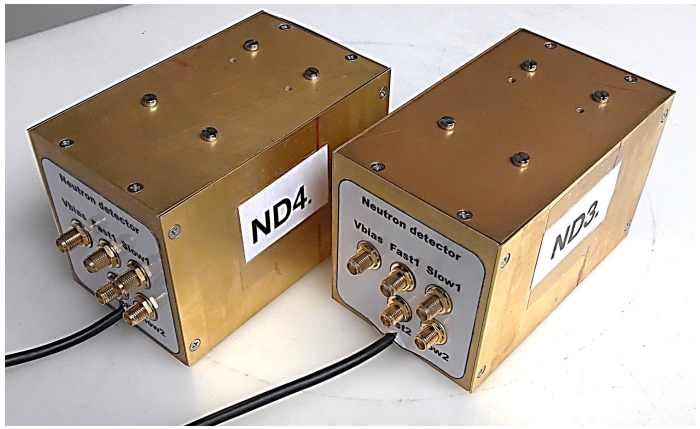
Scintillation photons are detected with 4 units of SiPMs 6x6 mm^2 , SensL, J-ser.

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

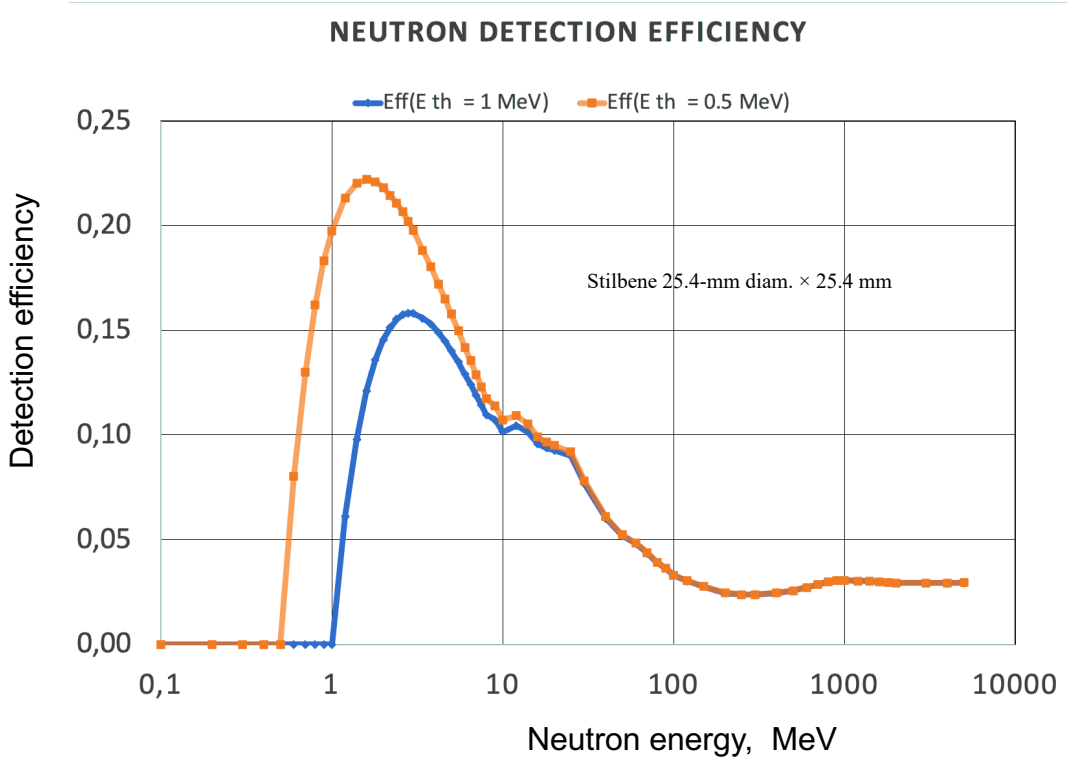


Veto

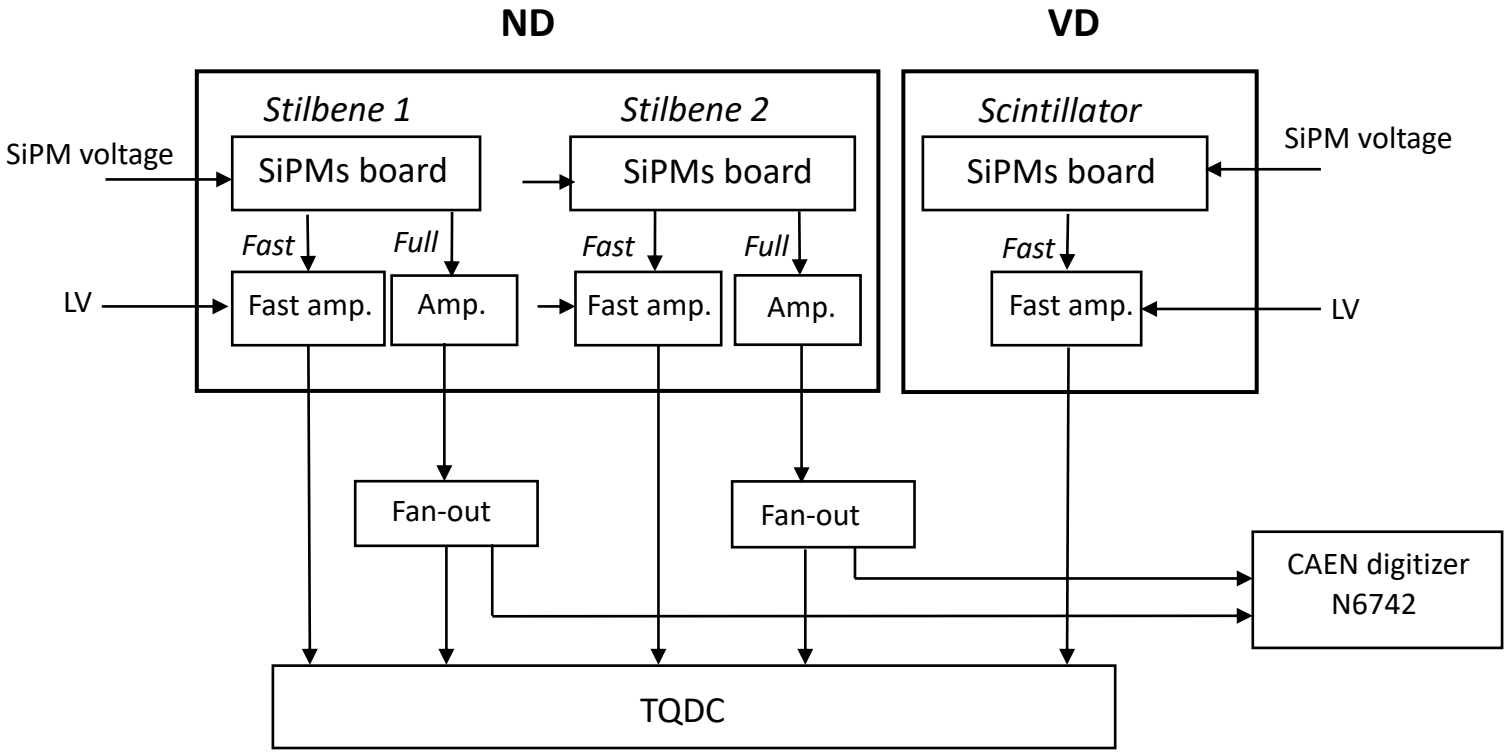
Neutron detectors

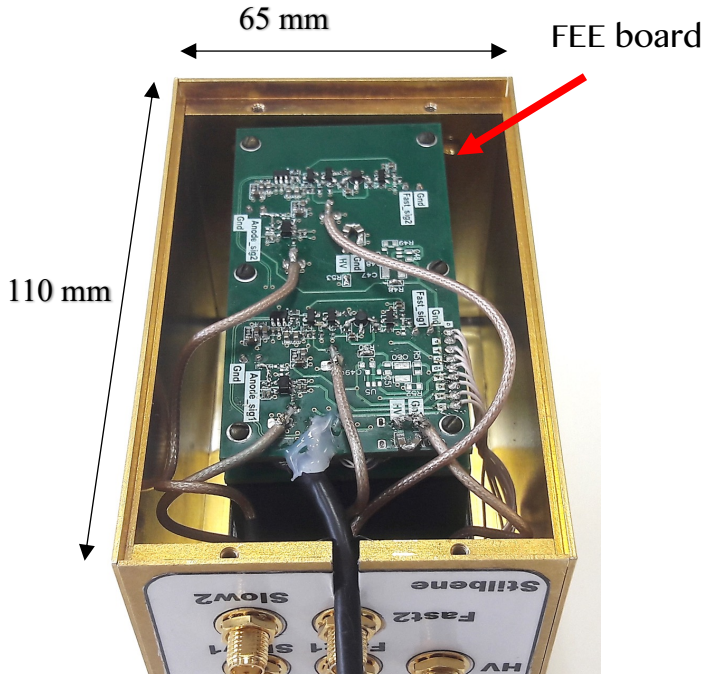


Stilbene with SiPMs



Electronics and DAQ

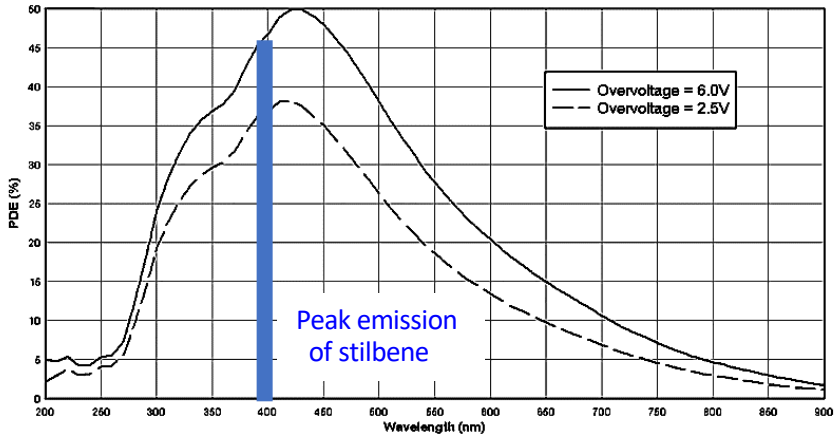




Characteristics of Stilbene

	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

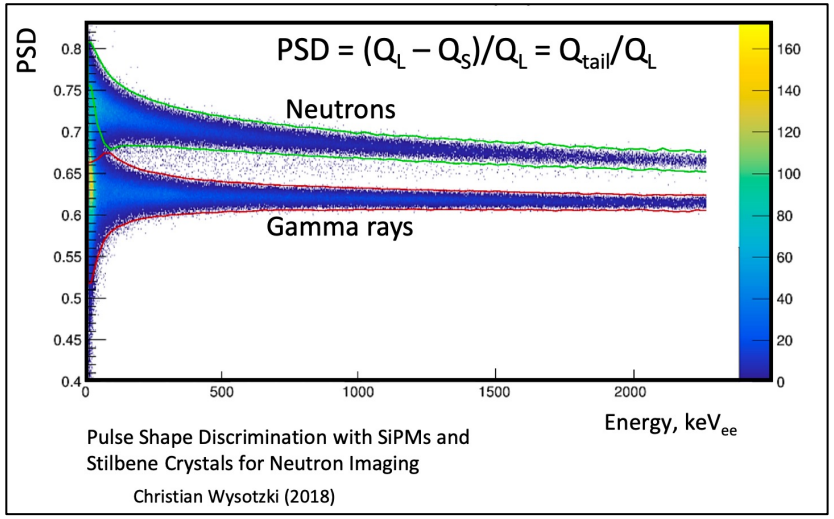


Decay time components of stilbene

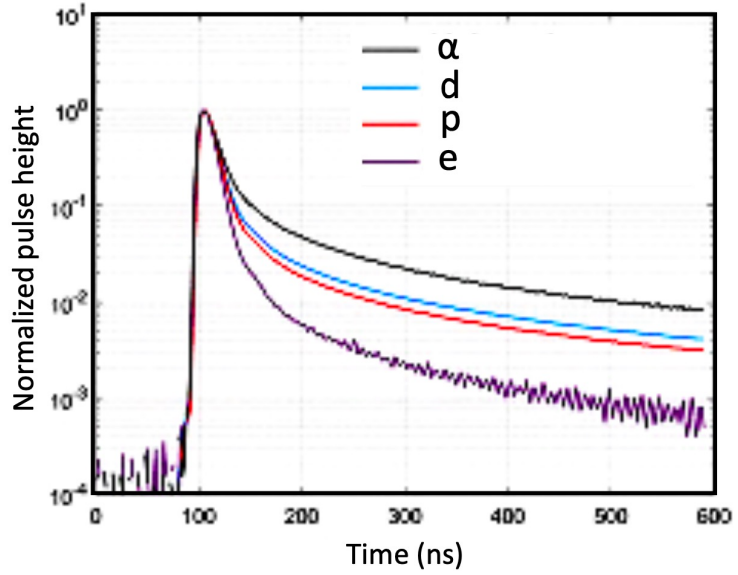
Particle specie	Fast [ns]	Intermediate [ns]	Slow[ns]
gamma	5.21 (95 %)	21.33 (3 %)	134.77 (2 %)
neutron	5.01 (95 %)	27.70 (4 %)	253.19 (1 %)

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

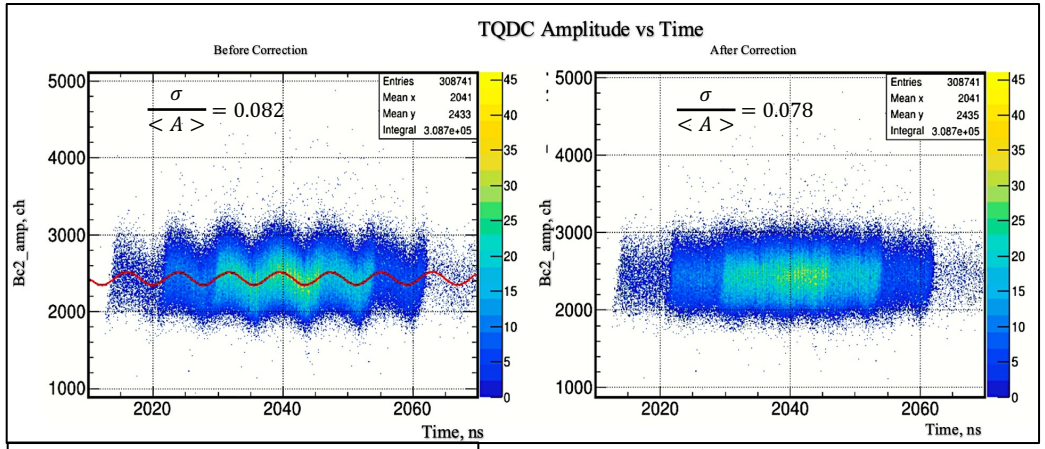


Pulse shape for different particles



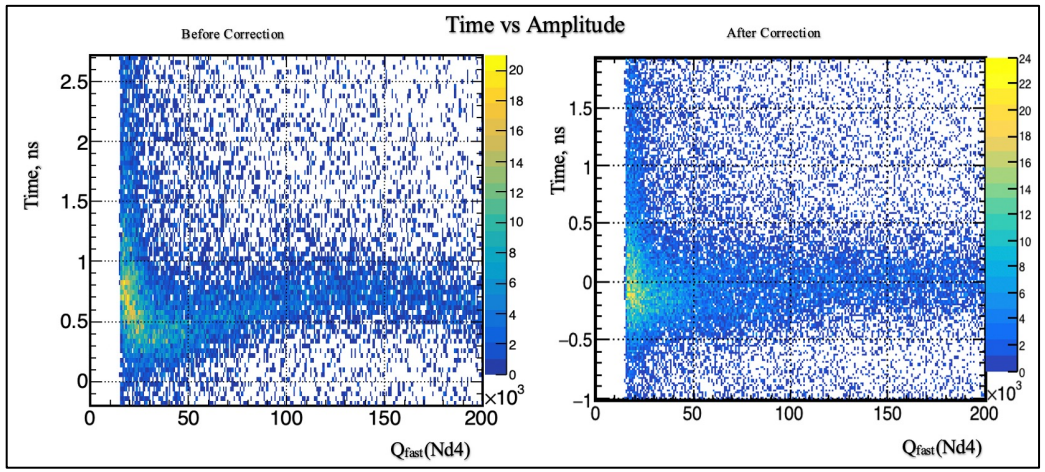
Time resolution

$TQDC - Correction\ for\ BC2$

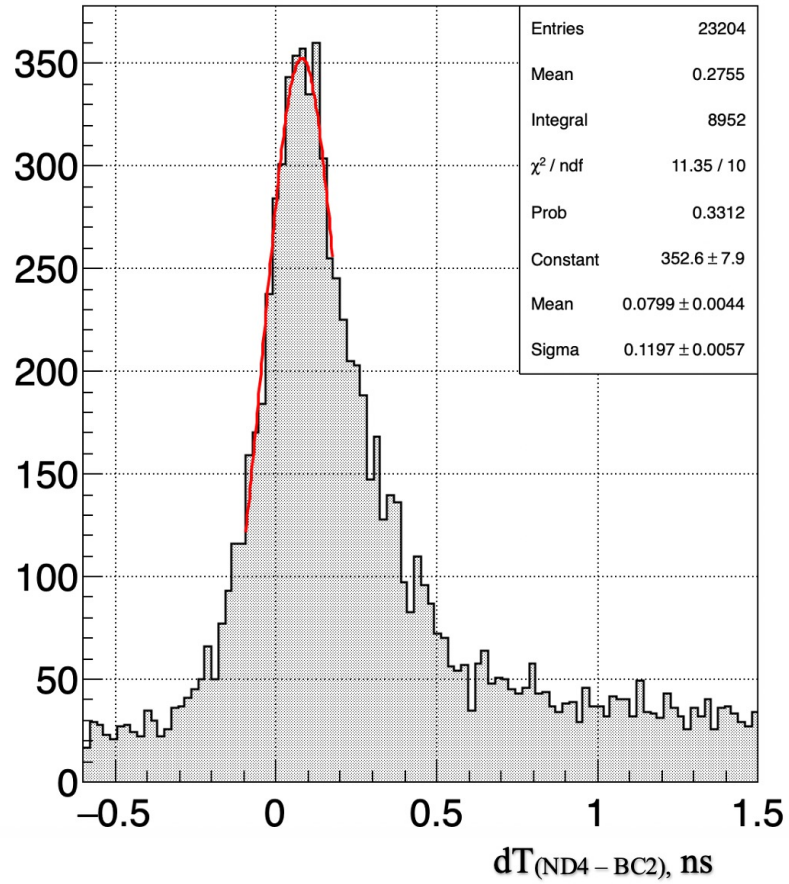


Fit Function: $p_0 * \sin(p_1 x + p_2) + p_3$

$Correction\ for\ ND4$



σ_{Nd4} [ps]	$\sigma_{ND4-BC2}$ [ps]	σ_{BC2} [ps]
113 ± 12	120	38

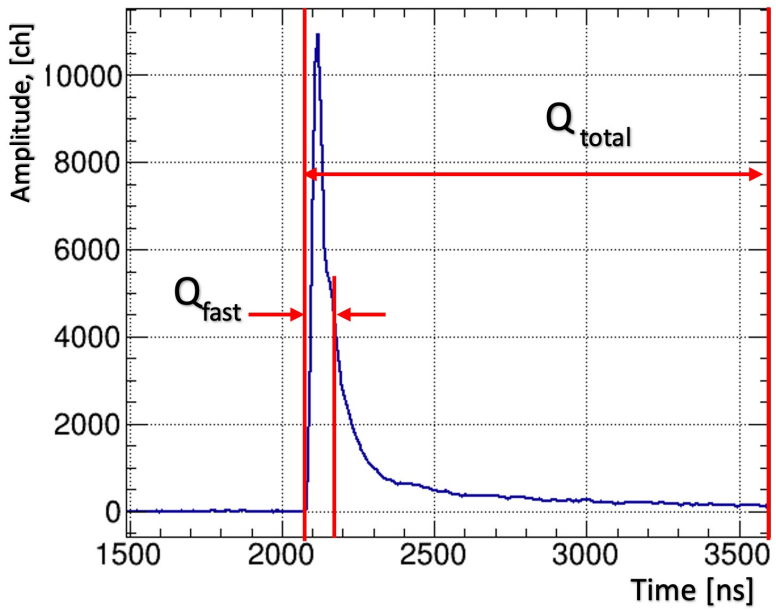


Neutron TOF spectrometers

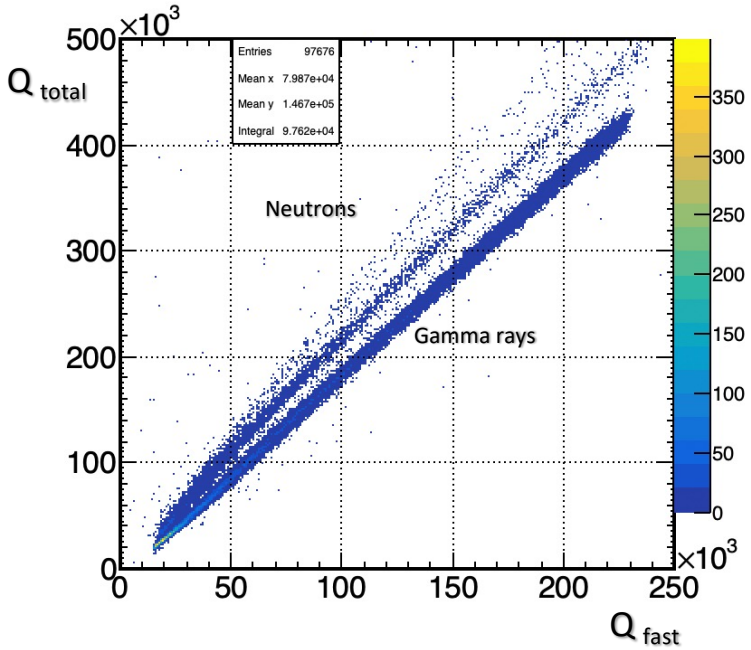
Accelerator	Detector (cm)	Efficiency	Path (m)	σ_t (ns/m)	*n/γ*
TOF spectrometer BM@N/JINR	**Stilbene D2.54x2.54, D3x1**	Calc.	**0.3**	**0.38**	Yes
SATURNE / Saclay	NE213 D12.7x5.1 NE213 D16x20	Exp./Calc.	8.5	0.24 0.18	Yes Yes
Synchrophasotron / JINR	Stilbene D4x1 Stilbene D5x5 Plast. scintill. D12x20	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

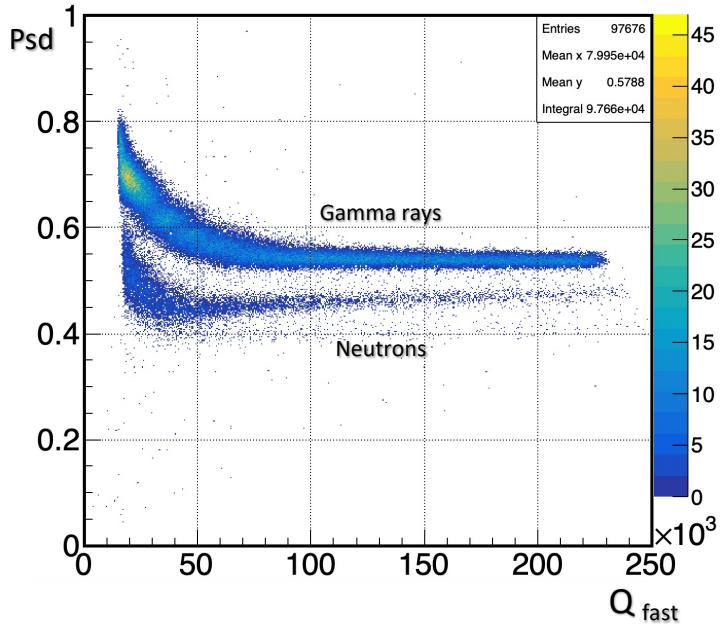
Waveform of Nd4 detector (TQDC)



***n*/γ - pulse shape discrimination**



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

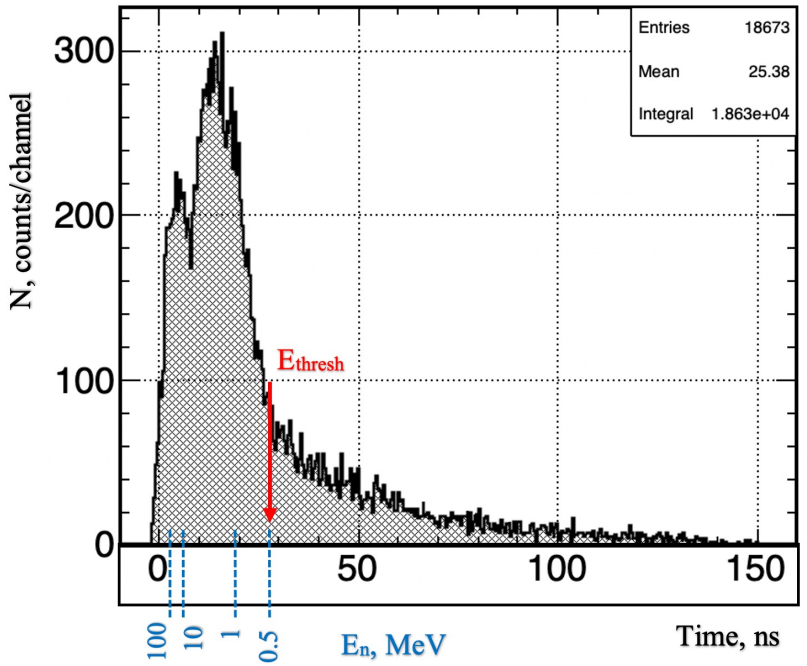


Q_{total} - is integrated charge of the total signal.

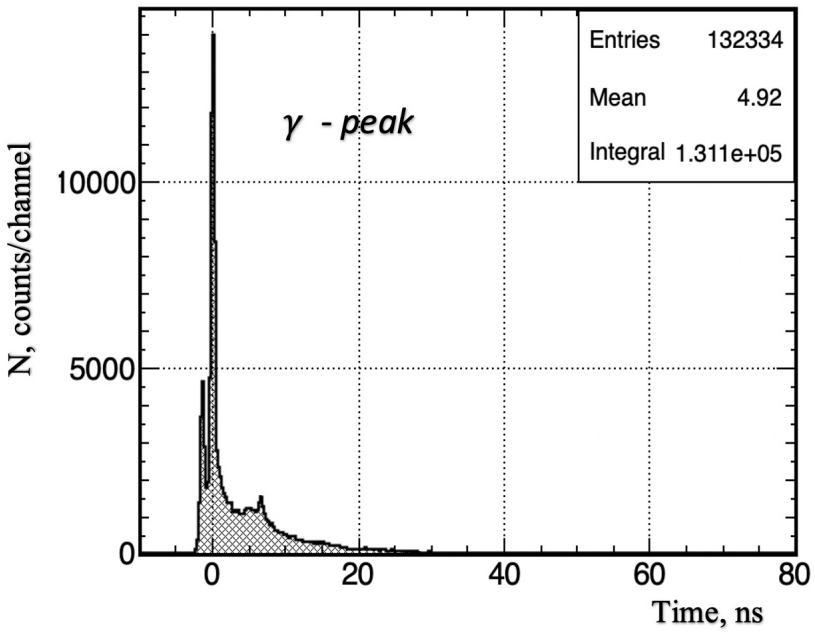
Q_{fast} - is integrated charge from beginning of radiation signal to specific point.

Analysis of TOF Spectra (Nd4)

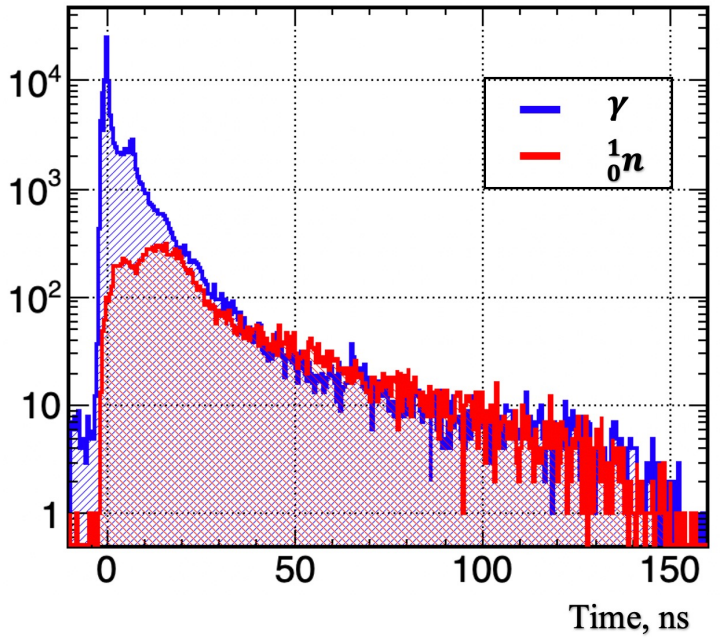
n - TOF spectrum

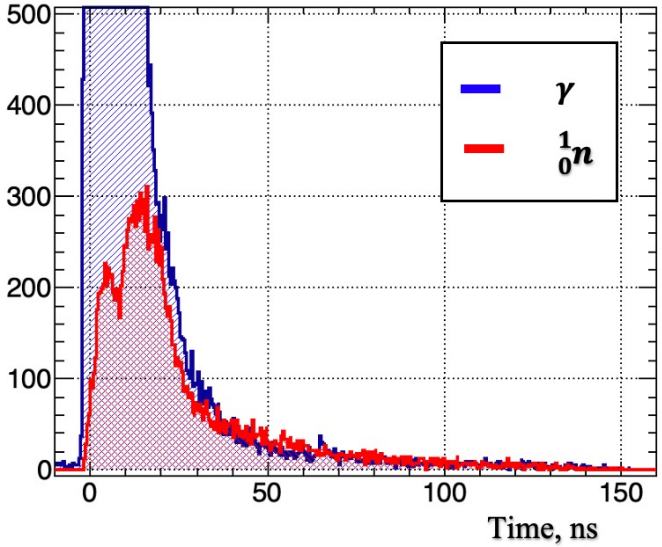


γ - TOF spectrum



n_γ - TOF spectrum





Example of Neutron Energy Spectrum (ND4)

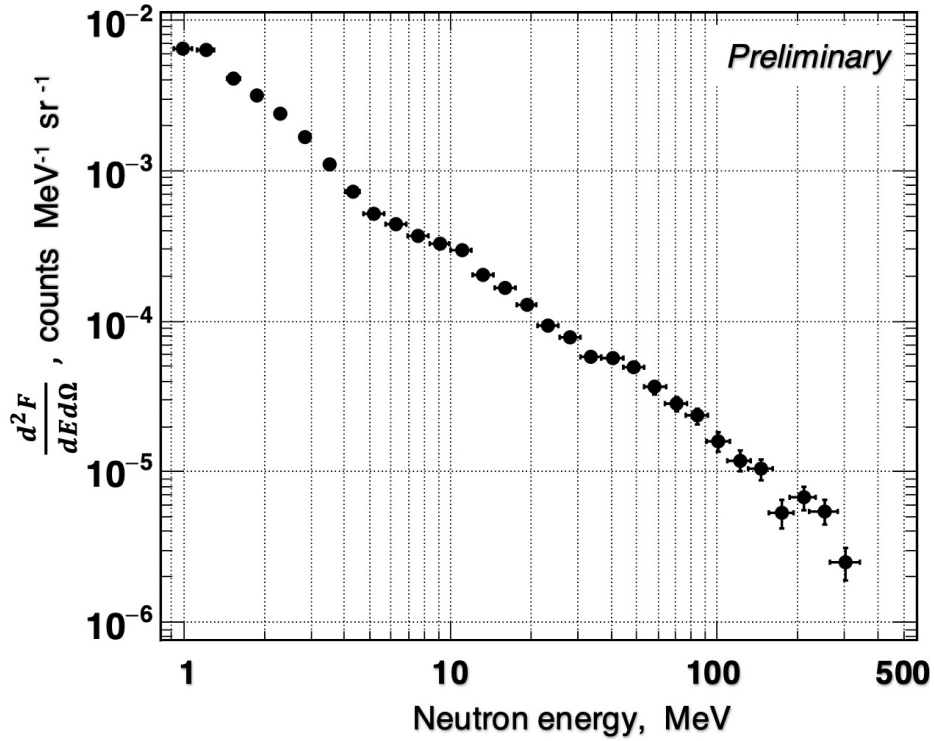
^{124}Xe + CsI collisions

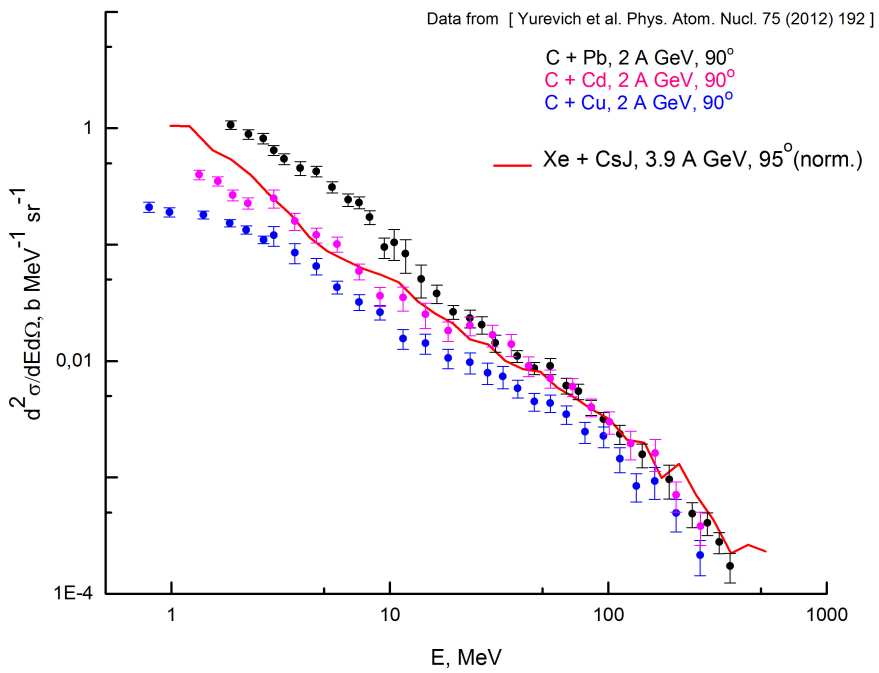
Beam energy – 3.9 GeV/nucleon;

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.

Example of Neutron Energy Spectrum (ND3)

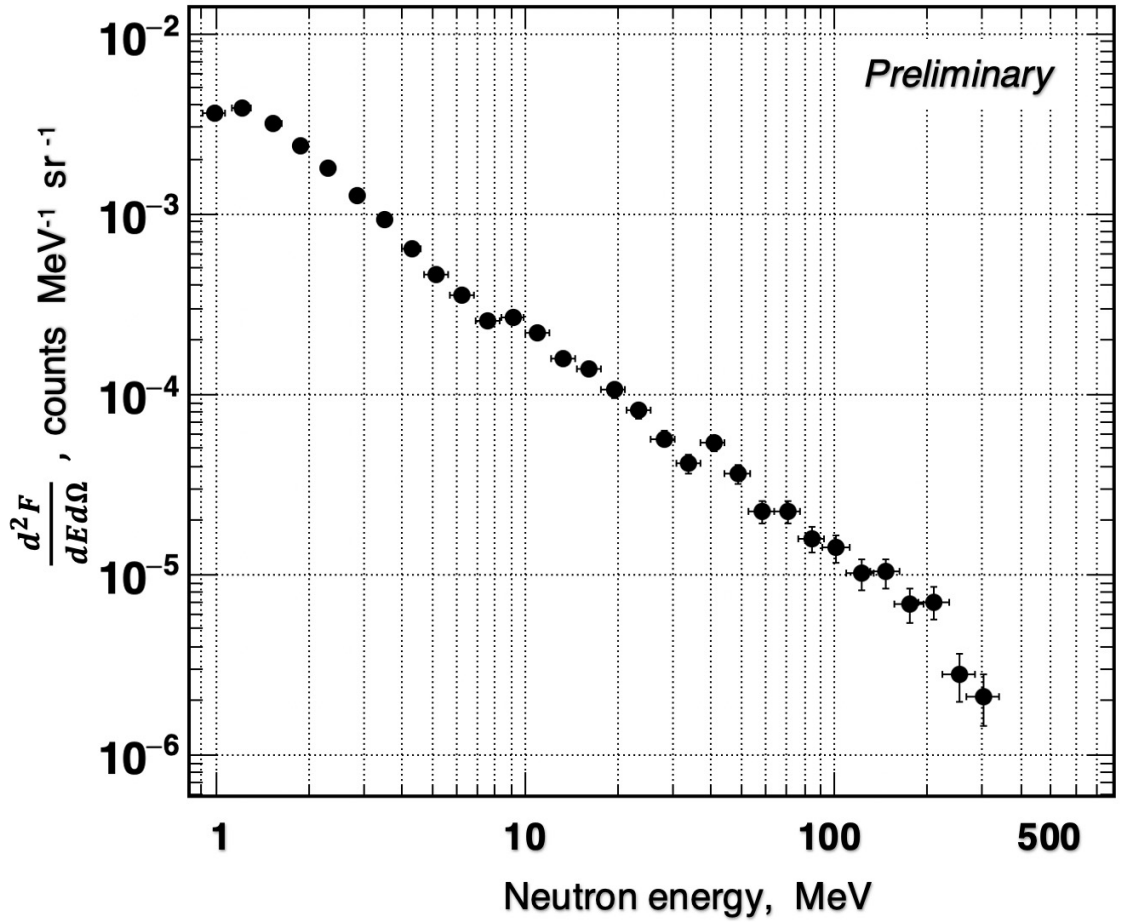
^{124}Xe + CsI collisions

Beam energy – 3.9 GeV/nucleon;

Trigger – CCT2;

Detector – **ND3**;

Angle – 110^0



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

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.

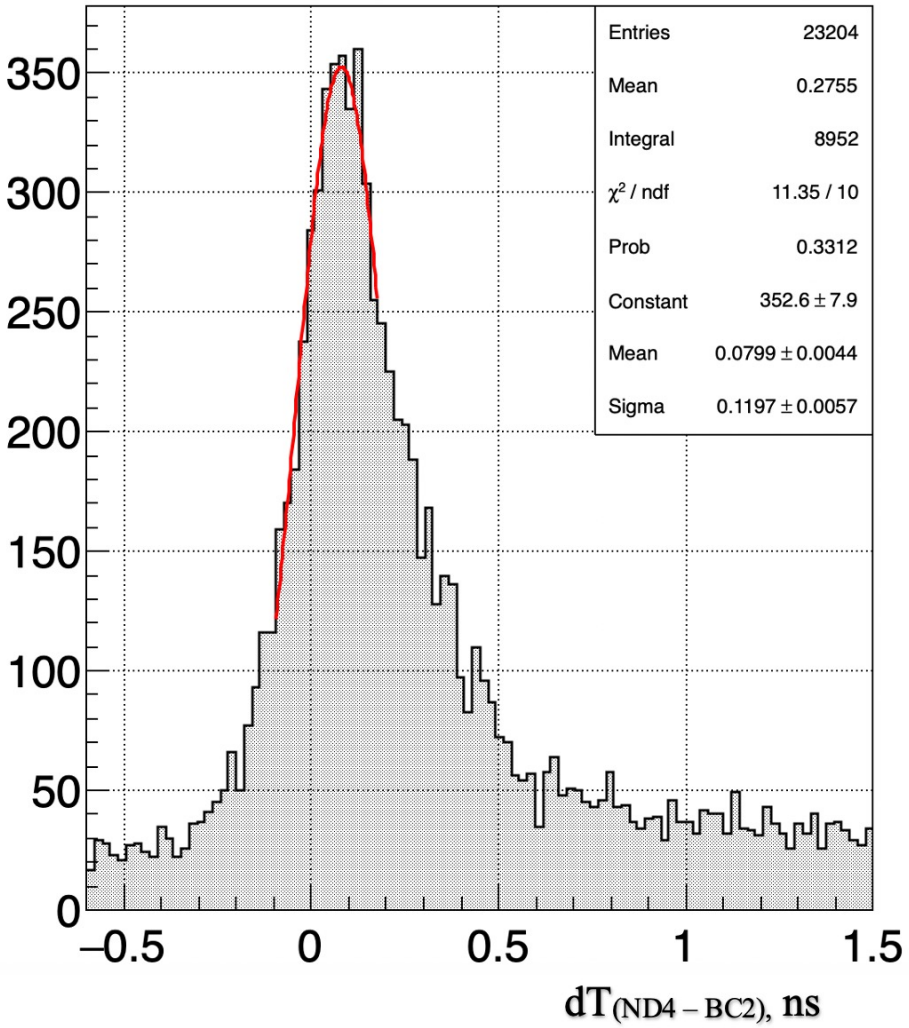
JOINT INSTITUTE
FOR NUCLEAR RESEARCH

BM@N

Thank you
for your attention !

Time resolution (ND4)

1) gaus : sigma = 119.7 ps



2) gaus + pol9(), sigma = 97.7 ps