Development of scintillation detectors with picosecond time resolution for the BM@N experiment

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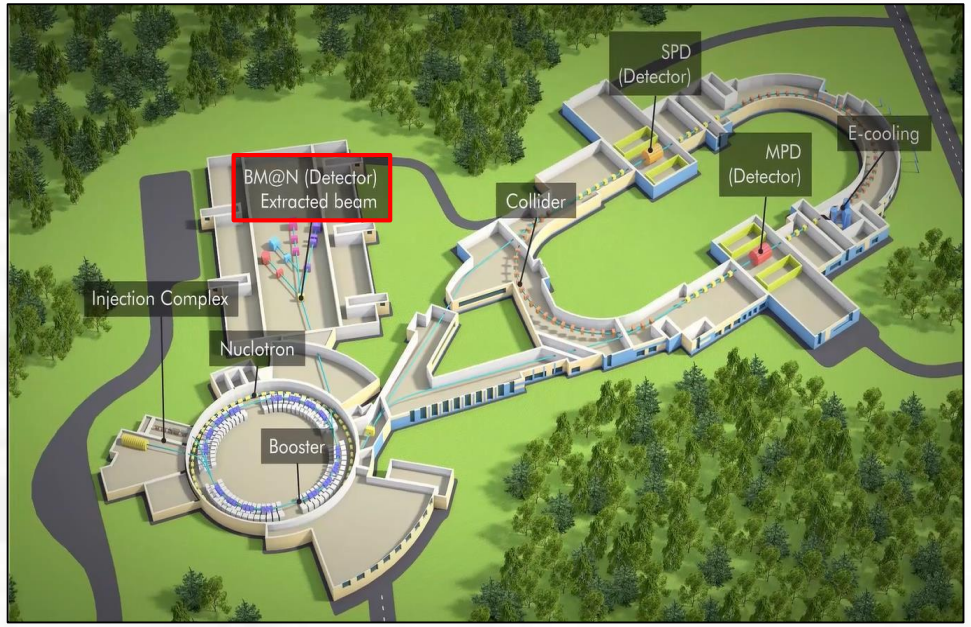
BM@N experiment at NICA accelerator complex

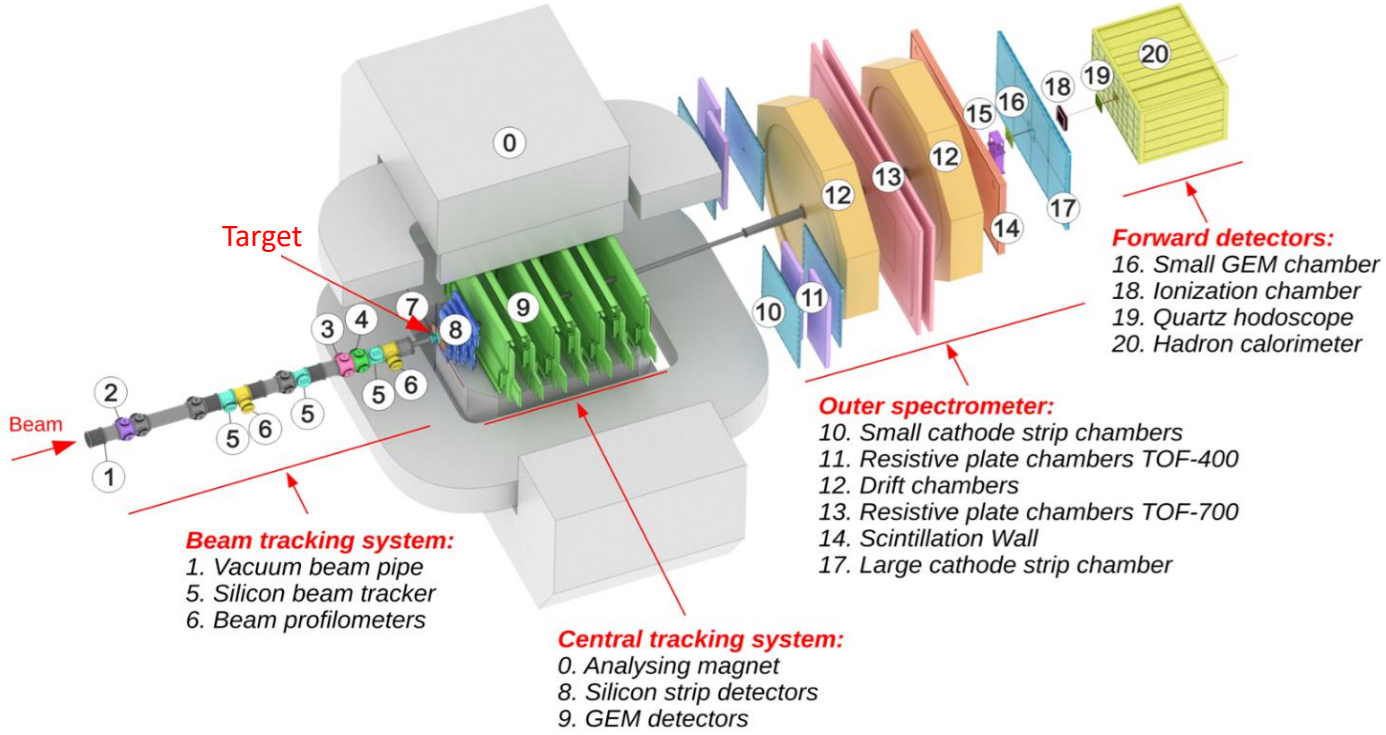


NICA Complex

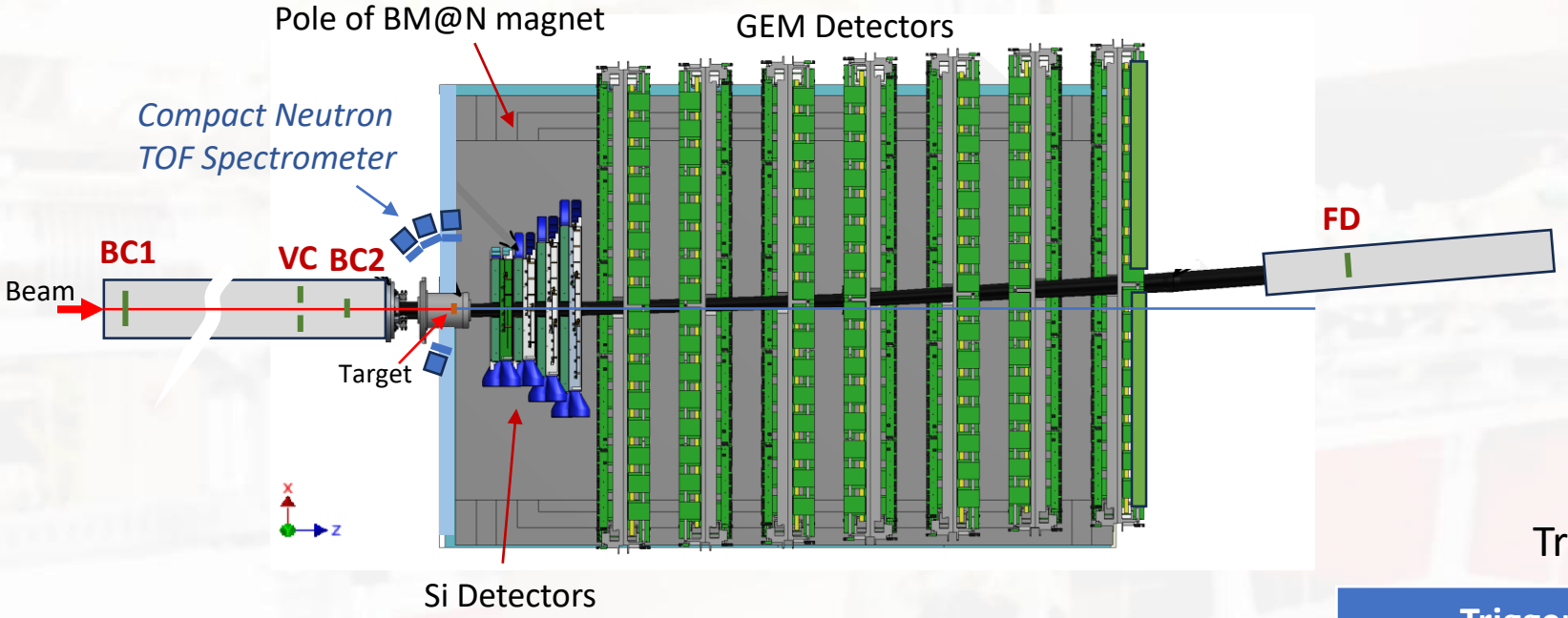
Baryon Matter at Nuclotron (BM@N) is fixed target experiment with heavy ion beam of Nuclotron at energy of 2 – 4 A GeV aiming to study properties of dense and hot nuclear matter in nucleus – nucleus collisions.

BM@N spectrometer

BM@N is magnetic spectrometer with a large set of various detectors measuring tracks, time and energy deposition of charged particles emitted from interaction point.



Beam and trigger detectors



Detector	Comment
Beam Counter BC1	4 m in front of target
Veto Counter VC	a hole for beam ions, veto for beam halo
Beam Counter BC2	1 m in front of target, t0- detector
Fragment Detector FD	4m behind of target
Barrel Detector BD	multichannel detector with a target inside

- A set of beam detectors with plastic scintillators (BC1, VC, BC2, FD and BD) aiming to register of incoming heavy ions to a target with fast triggering Interactions in the target.
- Deu to a high time resolution, the BC2 counter provide t0- pulse for TOF detectors of BM@N spectrometer and compact neutron spectrometer.

Triggers for Physics Run

Trigger type	Condition
Beam Trigger	$BT = BC1 \cdot \overline{VC} \cdot BC2$
Minimum Bias Trigger	$MBT = BT \cdot \overline{FD}$
Central Collision Trigger	$CCT = MBT \cdot BD\ (n \geq 4)$

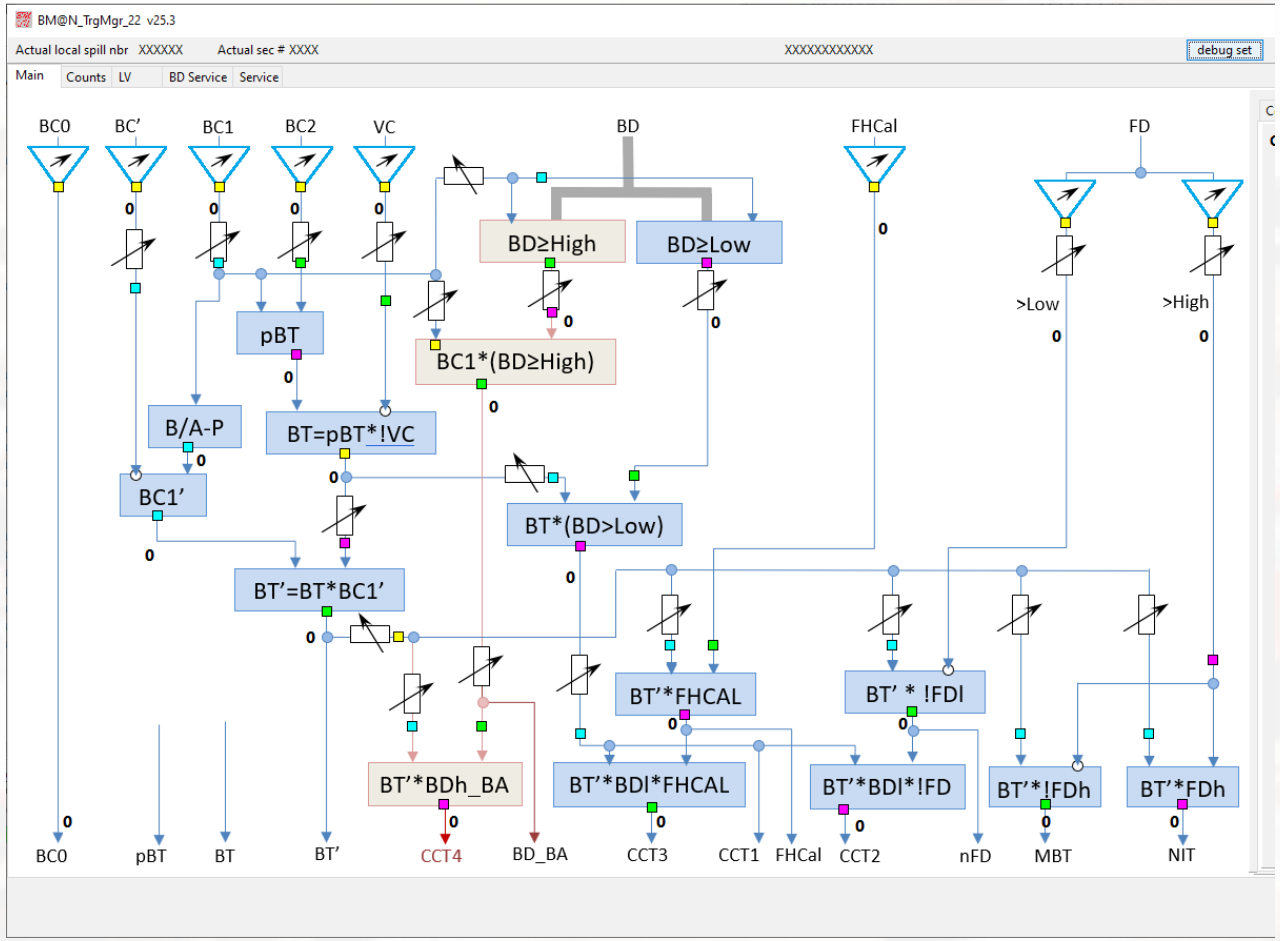
Requirements for beam detectors and trigger

- Minimum materials in beam line (minimizing beam loss and production of background particles)
- Time resolution of t0- pulse σ_t < 50 ps
- Minimal delay and time jitter of detector pulses to trigger electronics
- Trigger processing time < 100 ns
- Trigger efficiency of ~100% for interactions in target from peripheral to central collisions

Detector design concept

- Thin and fast plastic scintillators installed in vacuum beam pipe (BC400B, 0.15 – 0.25 mm)
- Fast PMTs operating in magnetic field of B = 1 T (Hamamatsu R2490-07)
- Light guides made from thin Al- mylar

TOU and trigger logic

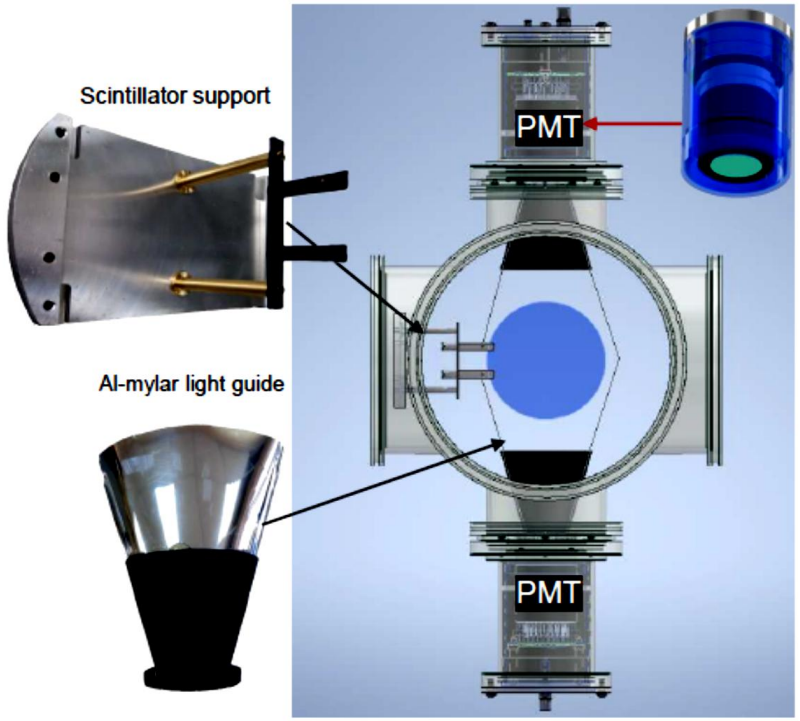


View of the TOU manager

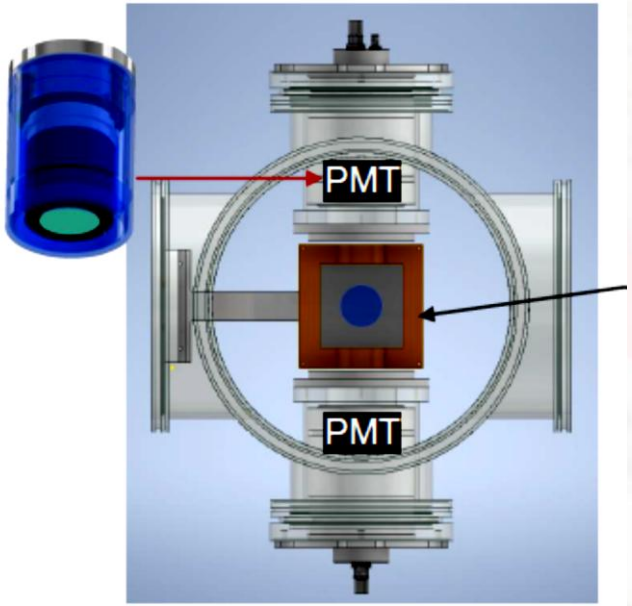
View of the TOU

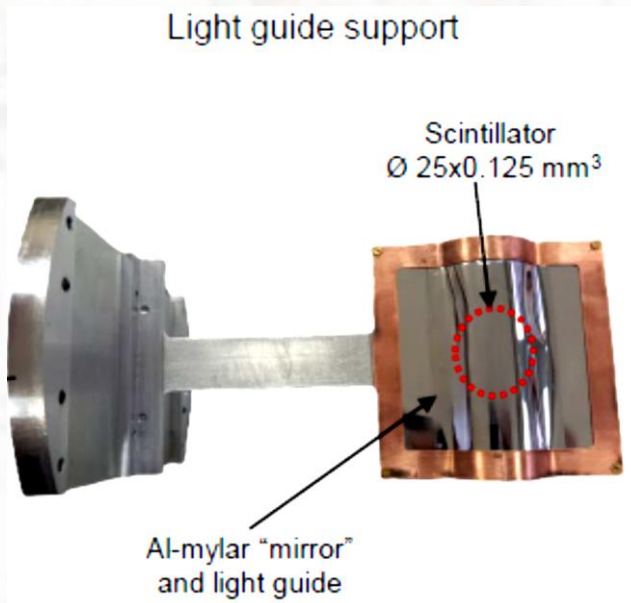
Design of Beam Counters

Detector	PMT (mesh dynodes)	Radiator
BC0, BC1	Hamamatsu R2490-07	Scint. BC400B Ø 100 x 0.25 mm³
VC	Hamamatsu R2490-07	Scint. Ø 100 x 0.25 mm³ Ø 25 mm hole



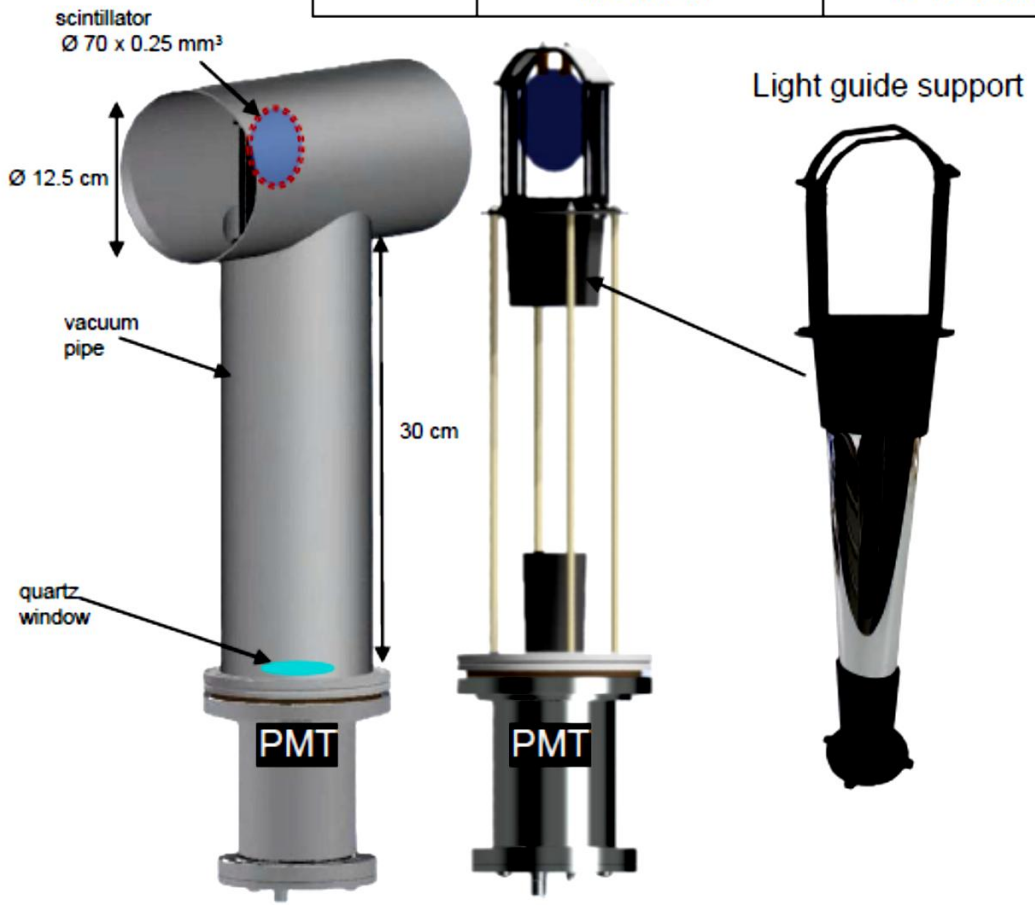
Detector	PMT (mesh dynodes)	Radiator
BC2	Hamamatsu R2490-07	Scint. BC400B Ø 25 x 0.125 mm³

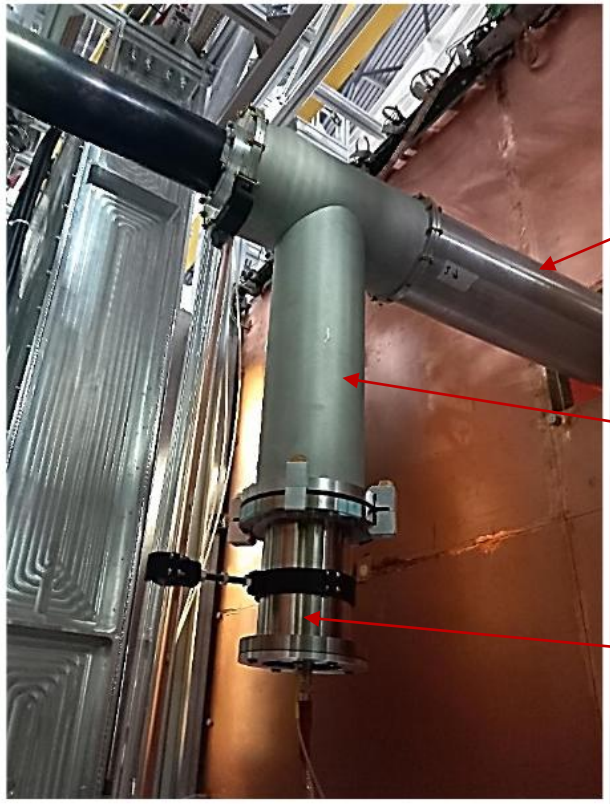




Design of FD counter

Detector	PMT (mesh dynodes)	Radiator
FD	Hamamatsu R2490-07	Scint. BC400B Ø 70 x 0.25 mm³



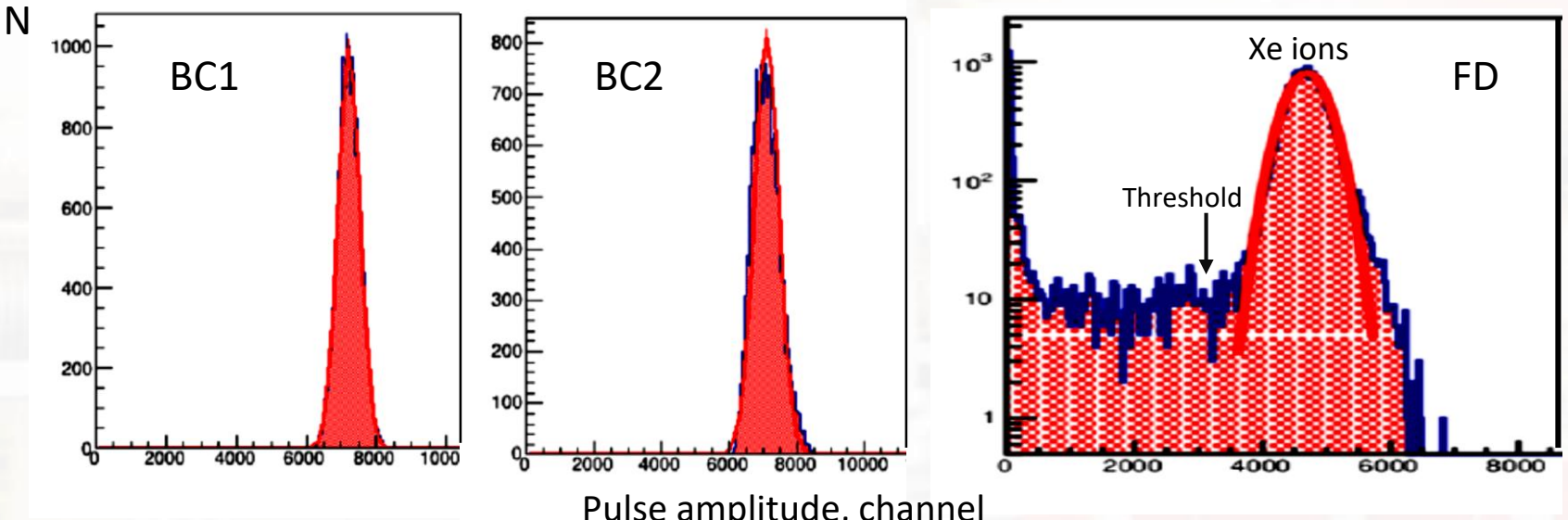


Scintillator thickness	σ/A (%)
0.50 mm	5.3
0.25 mm	6.9

Study of beam detector performance

Amplitude distributions

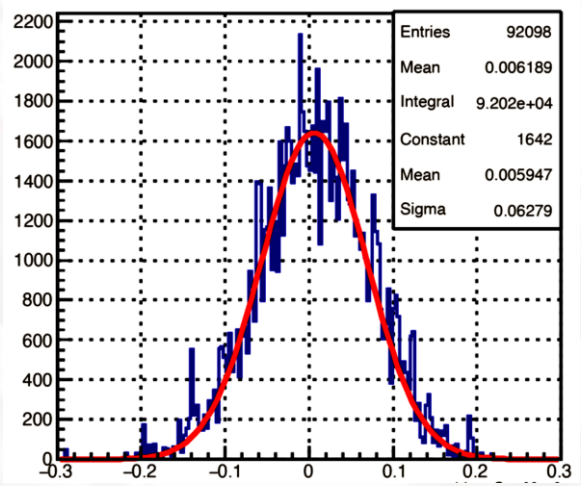
Run 2



Runs with Xe- ion beam and CsI target

Amplitude resolution	
BC1	4.4%
BC2	5.2%
FD	6.9%

Time resolution



Run 2

σ_t(BC) ≈ 44.5 ps

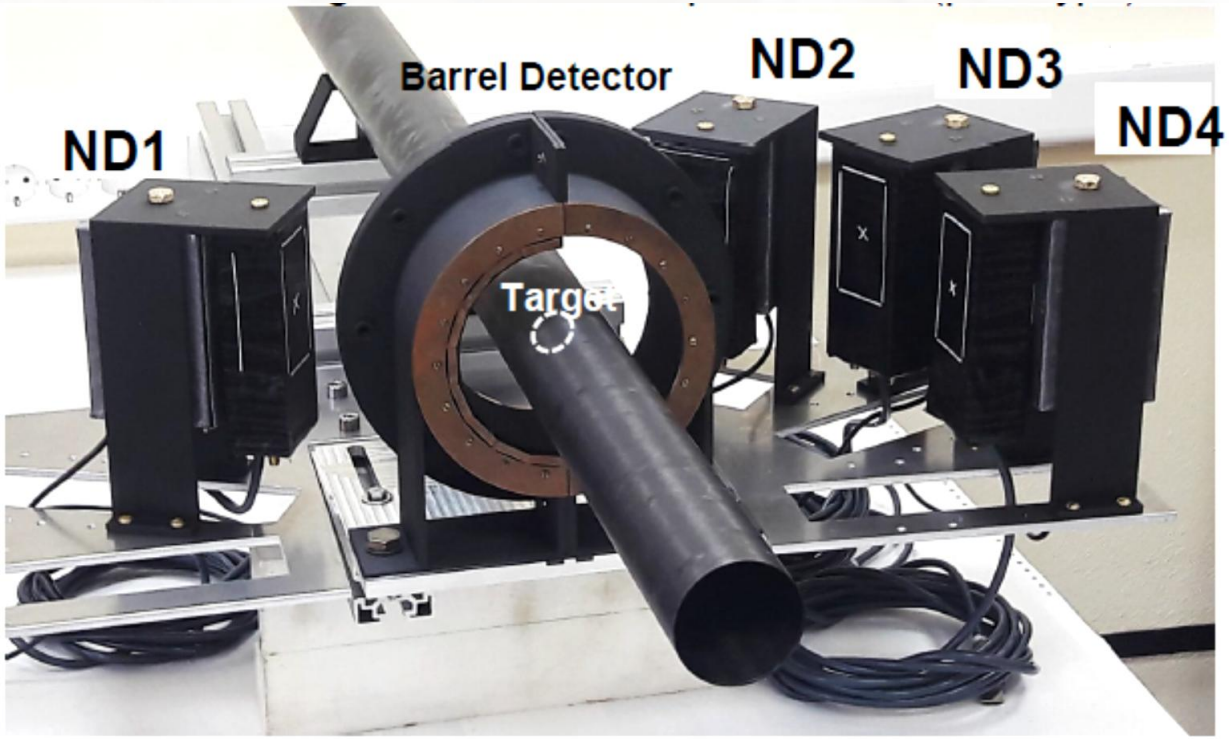
Run 1

Detectors	σ_i, ps
BC1	43
BC2	38
(BC1&BC2)	28.2

Neutron detectors with ps- time resolution

New neutron detectors with stilbene and SiPMs readout were developed for a compact neutron TOF spectrometer in BMN experiment. Aim of the spectrometer – study neutron emission at large angles in neutron energy interval from 2 to 200 MeV.

Extra short flight path of 30 cm is used thanks to 110 ps time resolution of ND



TOF measurements:

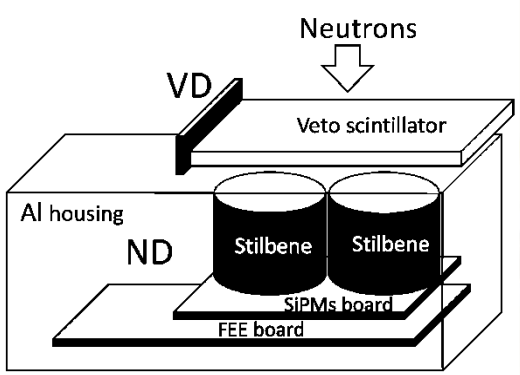
BC2(T0) – beam start detector

ND1 – ND4 – neutron stop detectors

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

* 2 units per detector

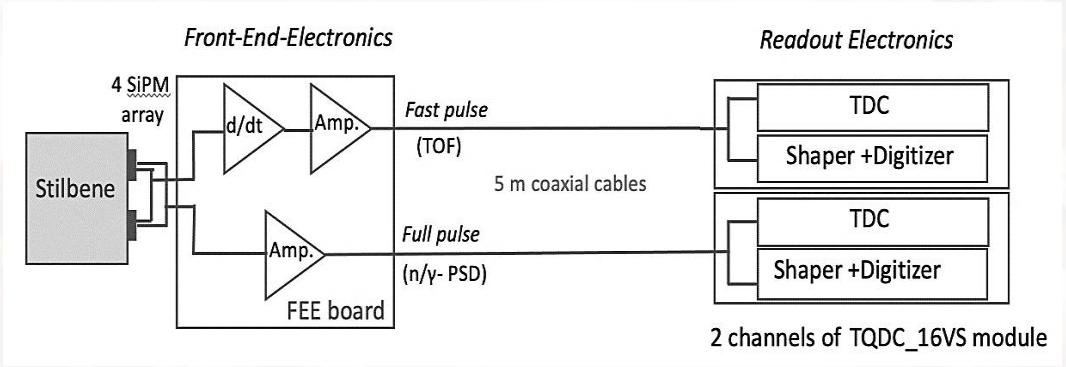
Neutron detector



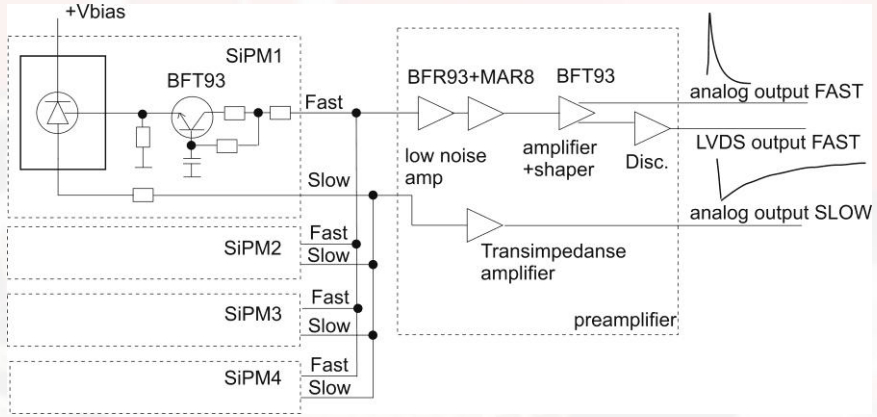
A scheme of the detector construction

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

Photo of neutron detectors



A scheme of data taken channel

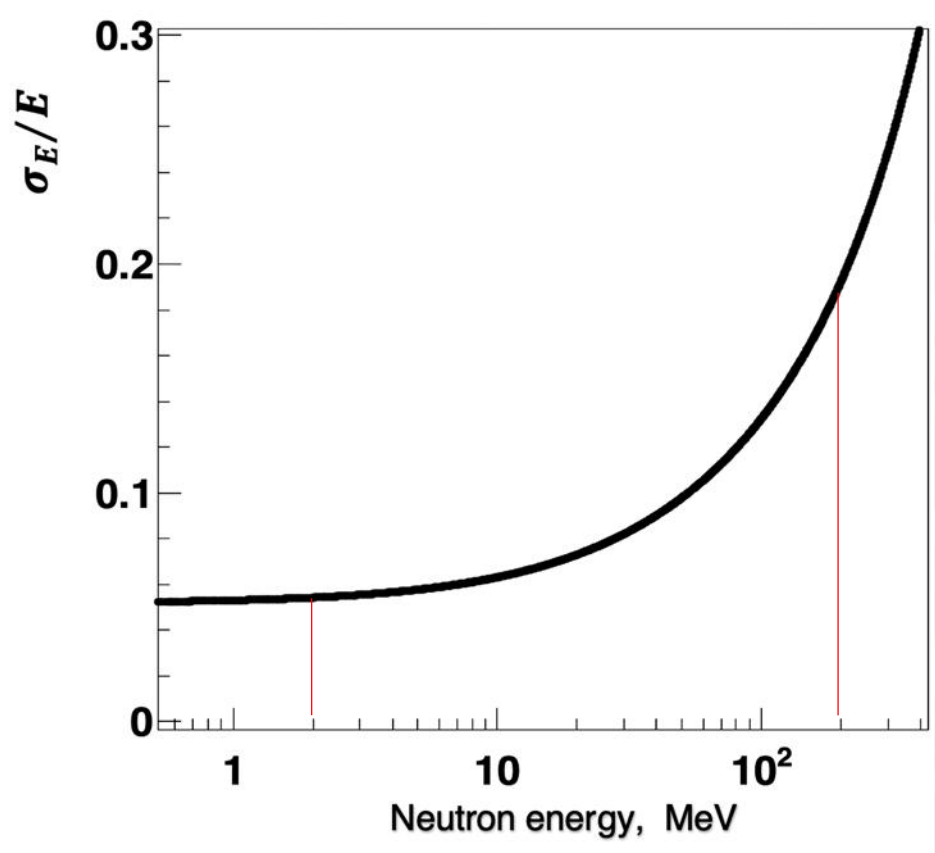


Schematic diagram of the FEE

Spectrometer characteristics

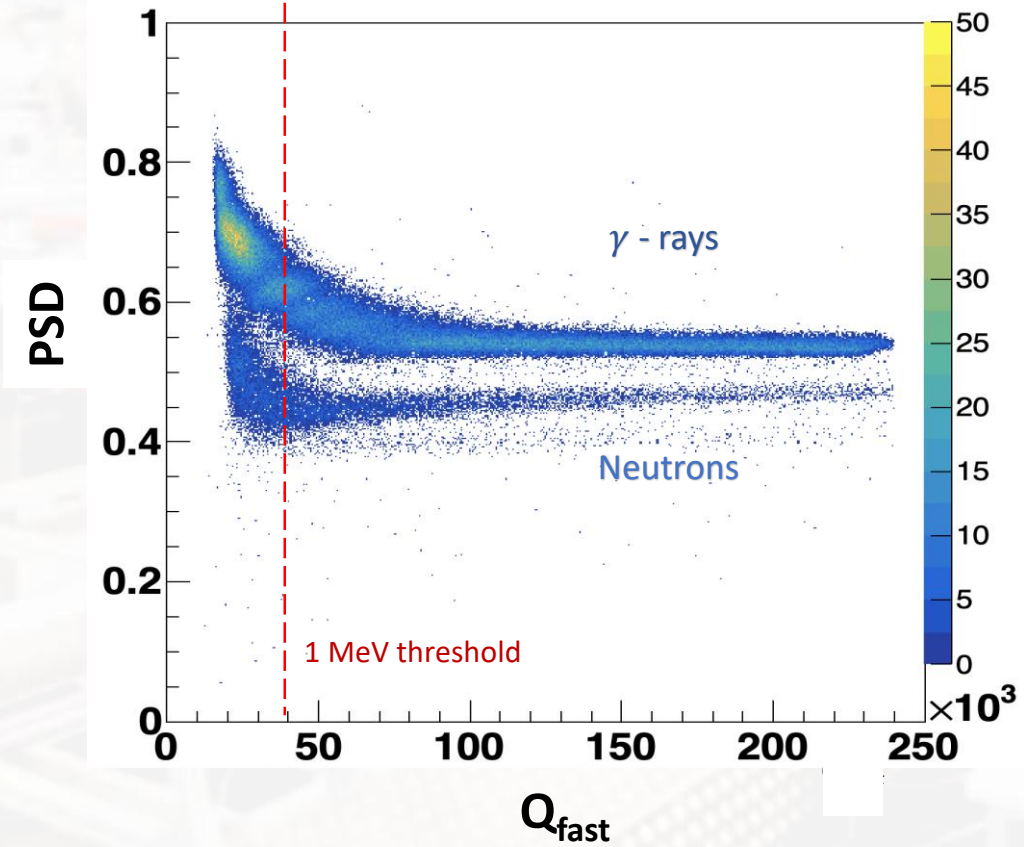
Time resolution is estimated using γ-peak in TOF spectrum

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



n/γ – pulse shape discrimination (PSD)

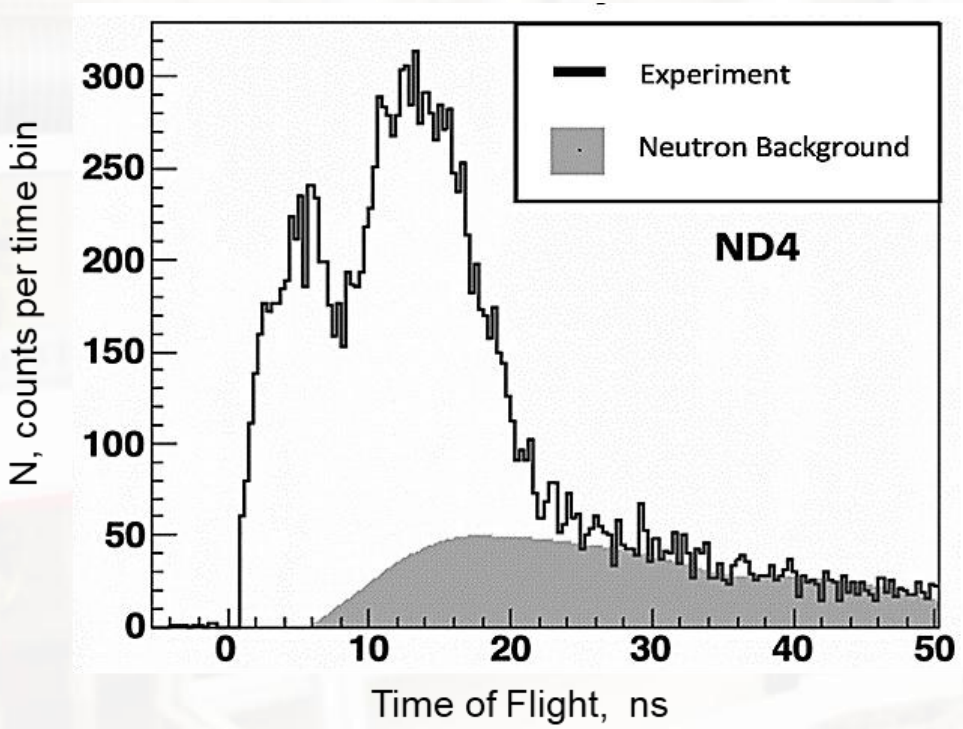
	ND1	ND2	ND3	ND4
FOM (1 MeV)	1.98	2.17	2.28	2.47



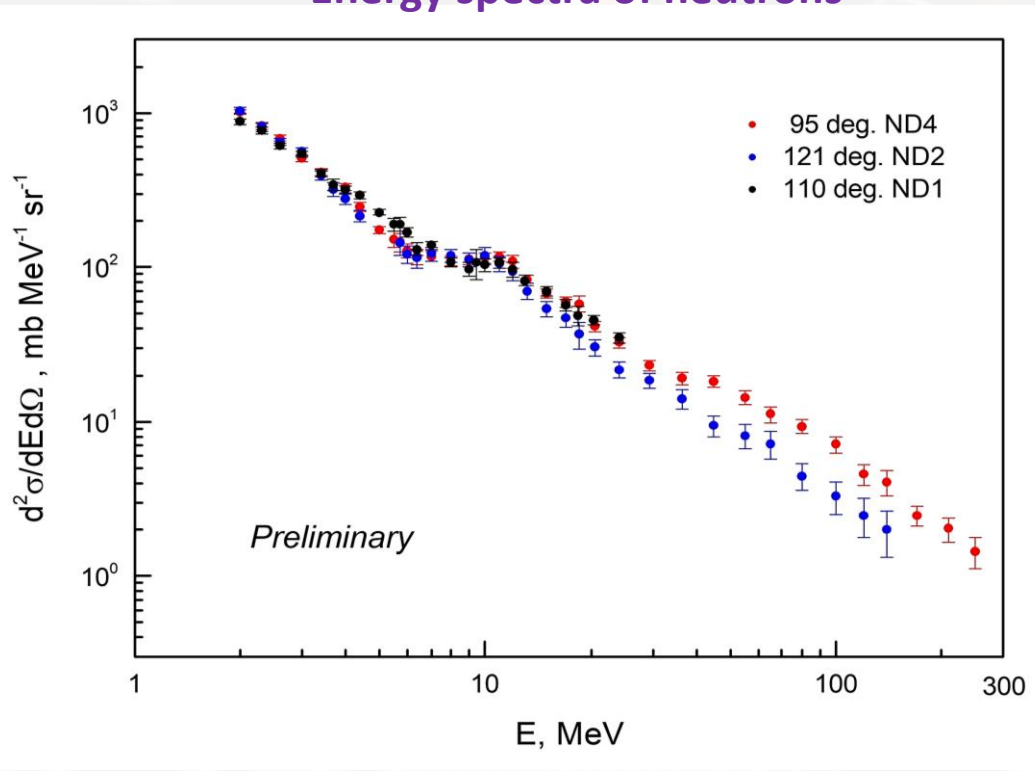
Example of neutron measurement

Neutron measurements with the spectrometer in run with Xe-ion beam at energy of 3.8 A GeV and CsI target (2% of interaction probability)

Time-of-flight spectrum



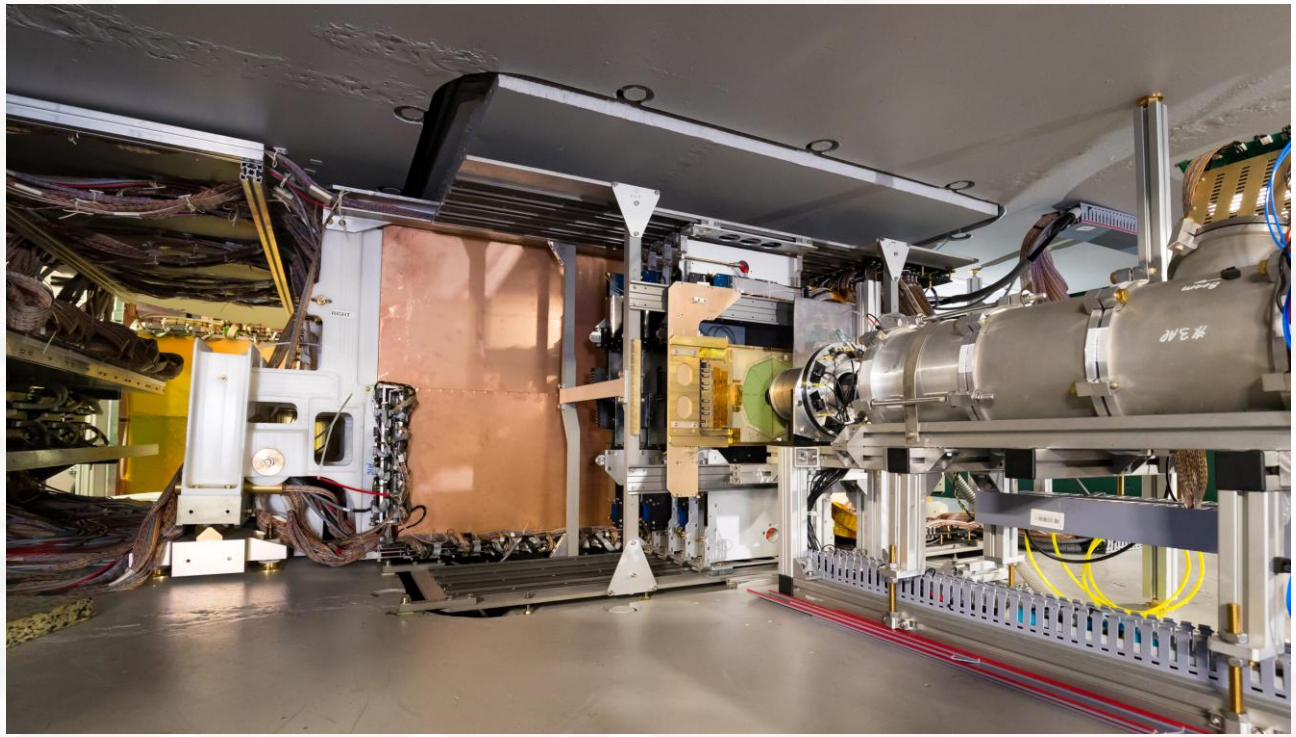
Energy spectra of neutrons



Neutron background was estimated by simulation with GEANT4

Conclusion

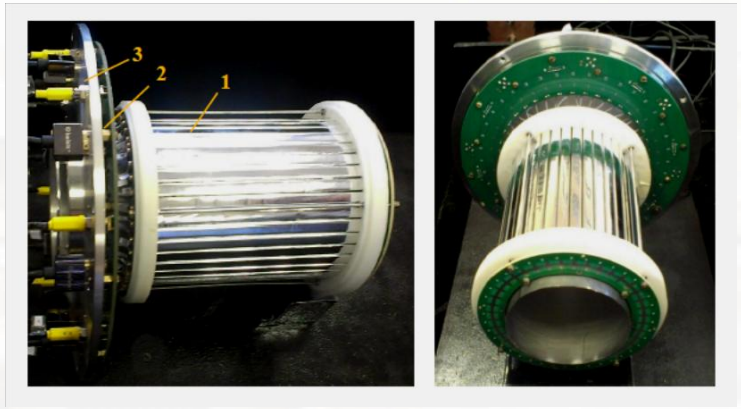
- ✓ **New design of scintillation counters with thin plastic scintillators, Al-mylar light guide and PMT Hamamatsu R2490-07 shows long-term stable operation in strong magnetic field at beam intensity of Xe ions of ~10^5 per second.**
- ✓ **The counters provide required time resolution of < 50 ps and can be used as to-detectors for TOF detectors of BM@N experiment.**
- ✓ **The new neutron detectors based on stilbene scintillator with SiPMs readout provide time resolution of ~110 ps and high suppression of gamma-ray background by pulse-shape discrimination method. The achieved characteristics allow to realize "table-scale" TOF spectrometer with short flight path and low contribution of neutron background.**
- ✓ **The obtained results are a part of upgrade program of BM@N setup in preparation to future runs with heavy ion beams.**



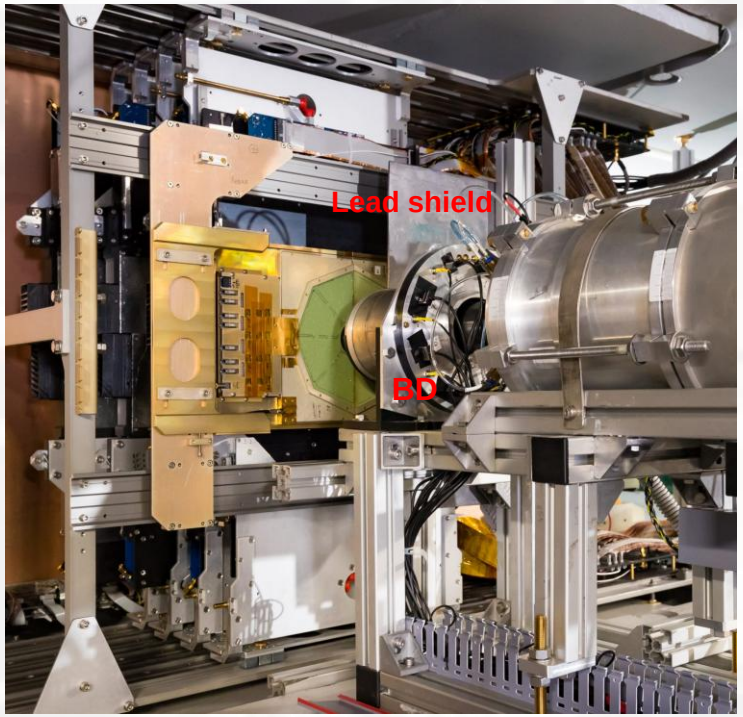
THANK YOU FOR YOUR ATTENTION

Barrel detector as multiplicity counter

Target is located inside the BD



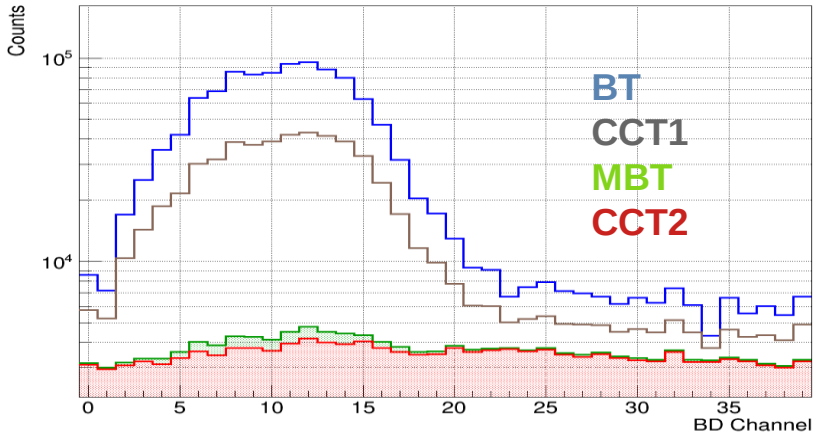
Barrel Detector (BD):
1 – 40 scintillation strips, 150 x 7 x 7 mm, BC418
2 – the board with SiPMs, Sensl C-series, 6 x 6 mm
3 – the board of front-end electronics.

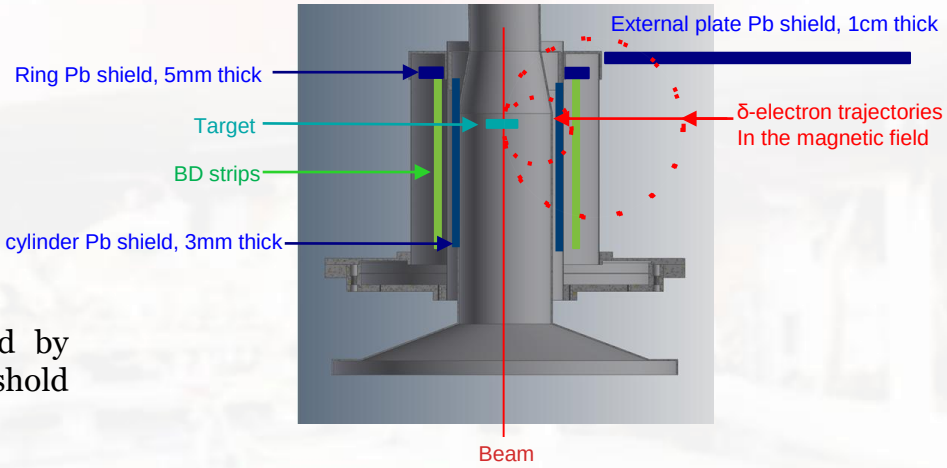


Readout:
signals from every channel in BD are digitized by multihit TDC providing timer and time-over-threshold width

Strong background hits from δ – electrons, curved in the magnetic field and hitting right side of the BD.

Distribution of hits in BD strips for different triggers



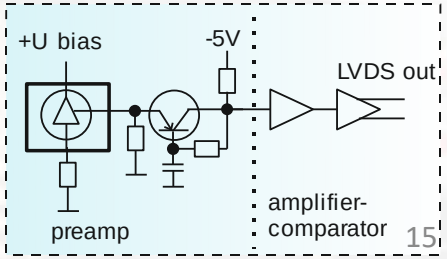


Target section of carbon vacuum pipe and BD

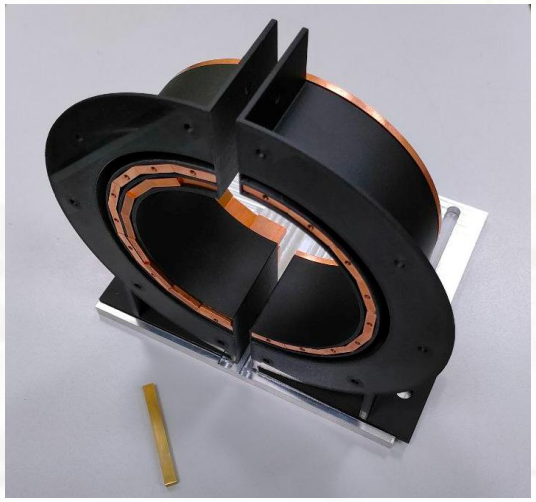
Settings in Xe 2023 run:

CCT1 = BT * BD(≥4)

Main physics trigger - CCT2 = MBT * BD(≥4)

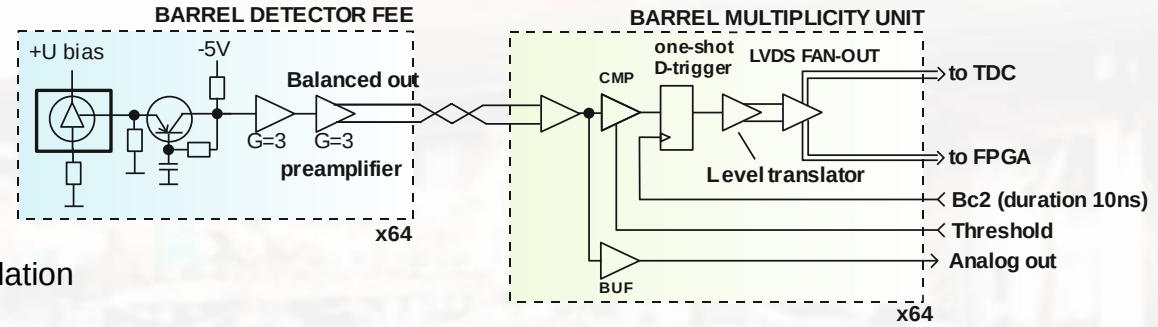


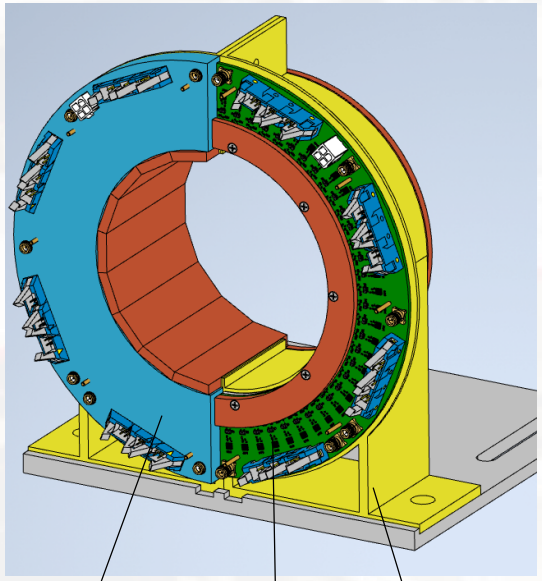
New Barrel Detector



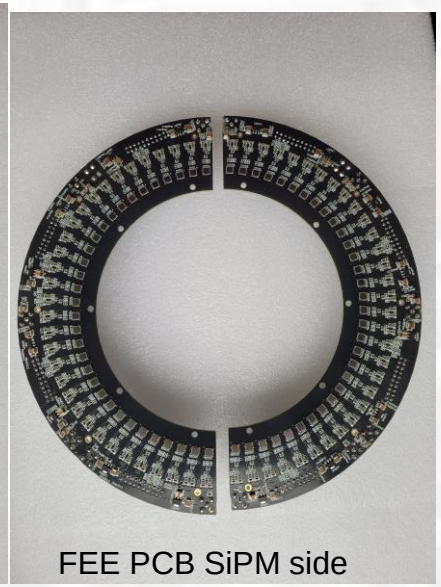
Upgrades for future runs with heavier beam ions (Bi)

- Larger number of channels - 64 scintillation strips 57×7×5 mm^3
- Readout by 3×3 mm^2 SiPMs (J-ser. SensL)
- Cu layer inside BD for delta-electron absorption
- Shorter strips, easier to protect and position
- Larger inner diameter
- Consists of two parts (left /right) for simple installation






FEE PCB connectors side


FEE PCB SiPM side

Mechanics:completed, assembled

FEE : completed, currently been tested

Multiplicity logic module: components available, about half a year needed for production

Scintillators, SiPMs : available

Simulation: done