Development of the interaction trigger system for study of nucleus-nucleus collisions at BM@N/NICA experiment

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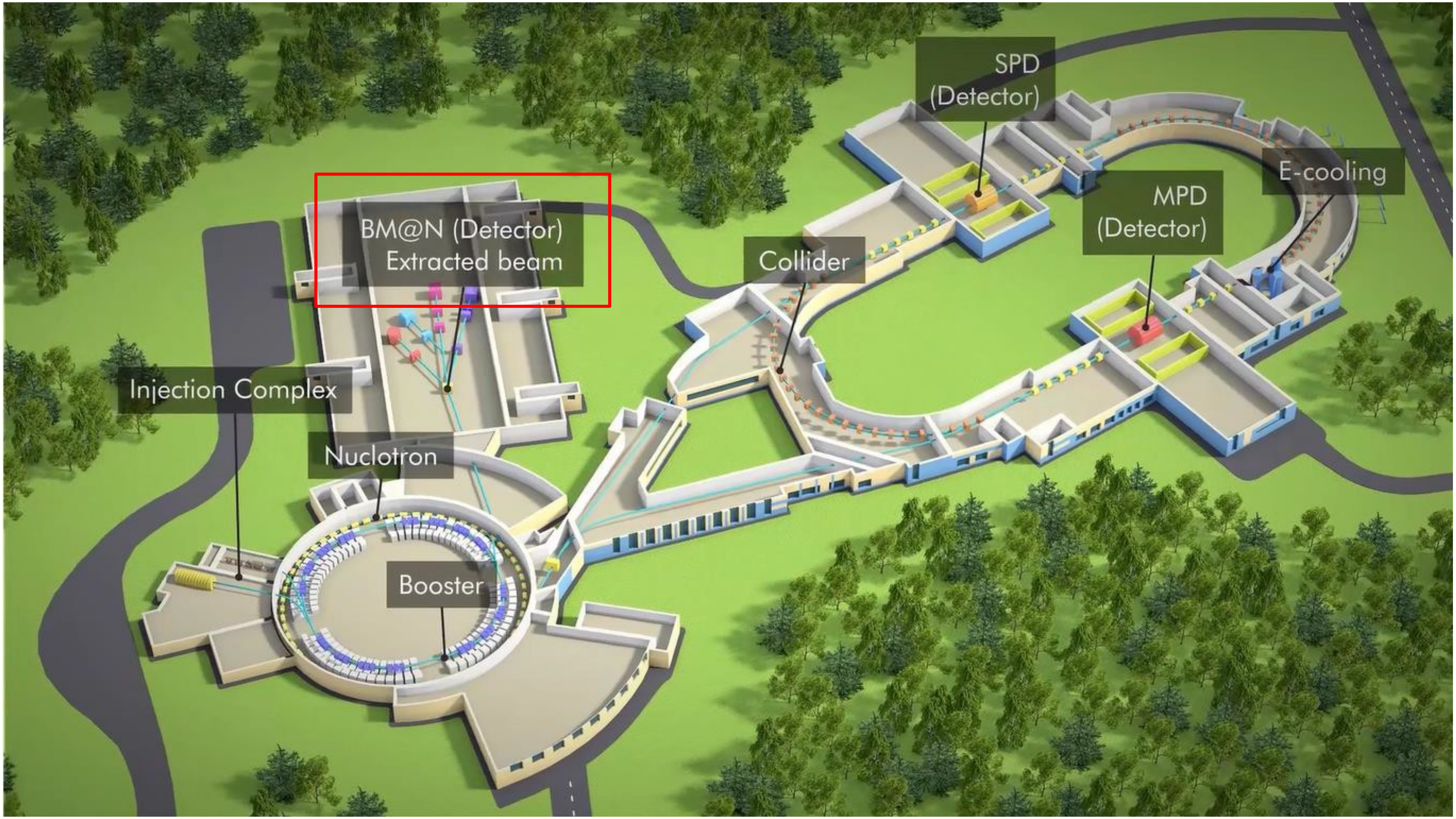
TIPP2023   4-8 September 2023

NICA accelerator complex and main experiments

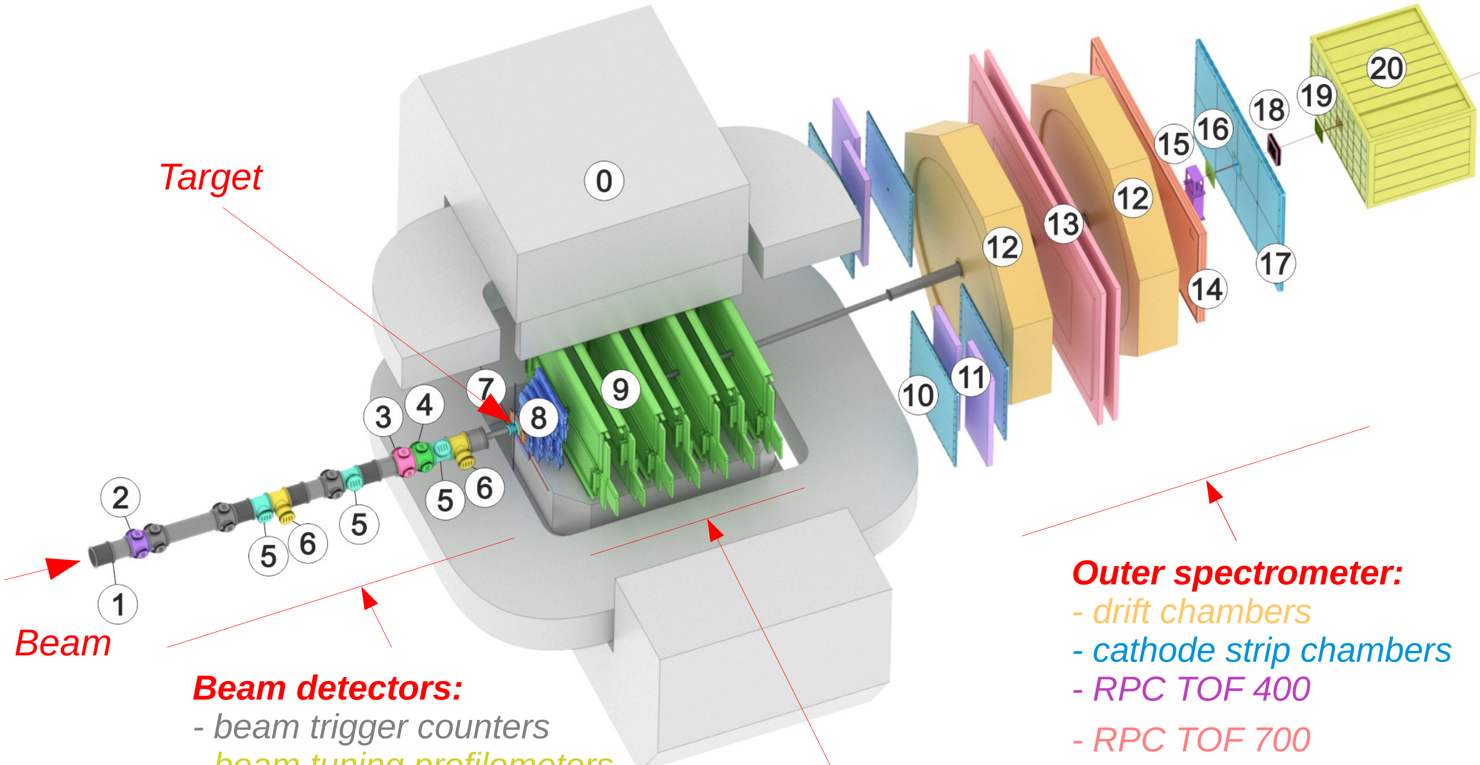


Collider beams: from p,d to ^{197}Au, ^{209}Bi
Energy: 1-3.8 GeV/u (heavy ions)
Luminosity: ≥ 10^{27} $cm^{-2}s^{-1}$

Extracted beams: ^{12}C,$^{36-40}$Ar,$^{78-86}$Kr,$^{124-136}$Xe,^{209}Bi
Intensity: up to few times 10^6 1/s
Spill duration: up to 20 s

In 2023 Xe run: Nuclotron cycle 12 s; 3.8 A·GeV, spill ~2.2 s, intensity $3÷4·10^5$ 1/s
3.0 A·GeV, spill 3÷4 s, intensity $3÷4·10^5$ 1/s

Configuration of BM@N detector in ^{124}Xe run (Jan. 2023)



- Magnet SP-41 (0)
- Vacuum Beam Pipe (1)
- BC1, VC, BC2 (2-4)
- SiBT, SiProf (5, 6)
- Triggers: BD + SiMD (7)
- FSD, GEM (8, 9)
- CSC 1x1 m^2 (10)
- TOF 400 (11)
- DCH (12)
- TOF 700 (13)
- ScWall (14)
- FD (15)
- Small GEM (16)
- CSC 2x1.5 m^2 (17)
- Beam Profilometer (18)
- FQH (19)
- FHCal (20)

Beam detectors:
- beam trigger counters
- beam tuning profilometers
- beam tracker detectors

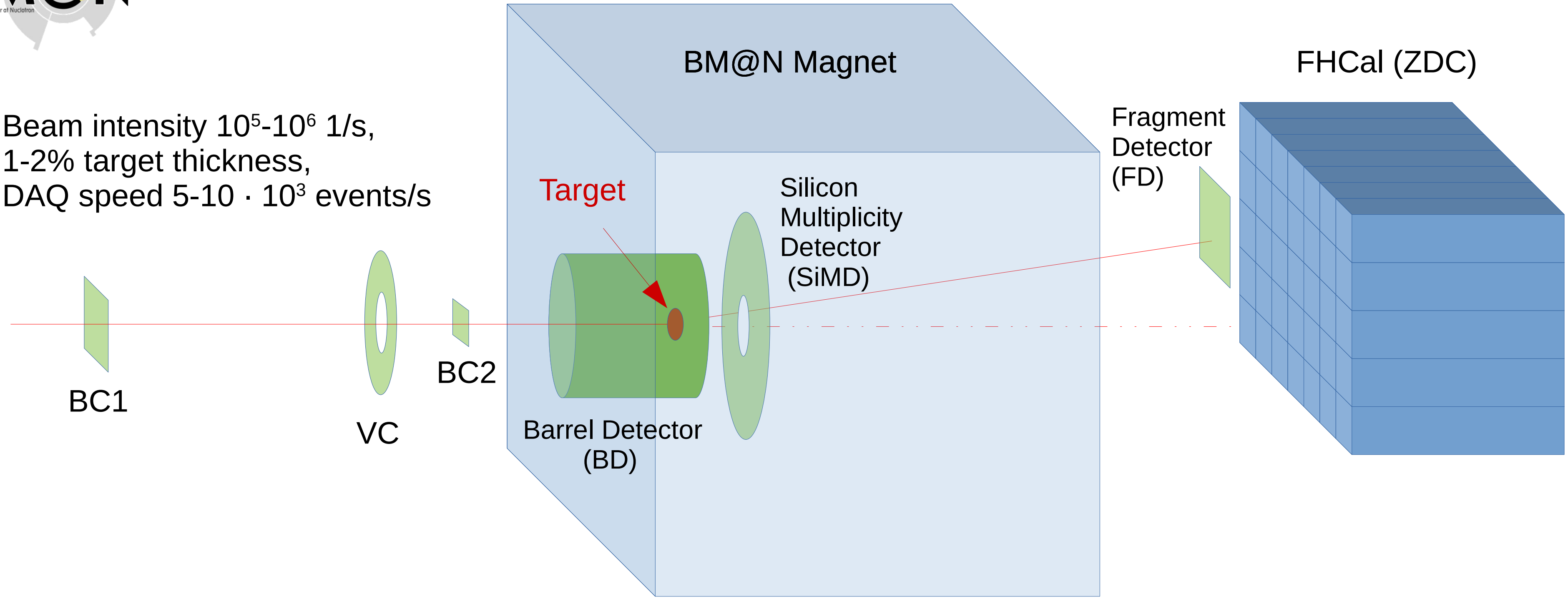
Central tracking system:
- silicon strip detectors
- GEM detectors

Outer spectrometer:
- drift chambers
- cathode strip chambers
- RPC TOF 400
- RPC TOF 700

Physics topics:
- π, K, Λ, p, d, light ions, neutrons (yield, spectra, flow, ratios);
- light hypernuclei production;
- Ξ, Ω sub-threshold production;
- particle correlations, etc.

Trigger signals (used or considered)

Beam intensity 10^5-10^6 1/s,
1-2% target thickness,
DAQ speed 5-10 · 10^3 events/s

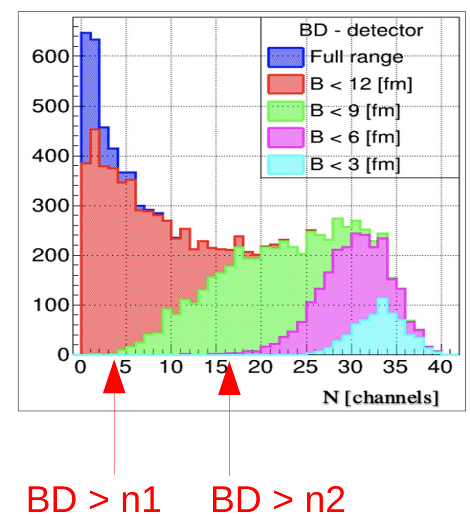


Trigger type	Trigger logic
Beam trigger	**BT = BC1 * !VC * BC2**
No Interaction	**NIT = BT * FD**
Minimum bias	**MBT = BT * !FD**
Centrality 1	**CCT1 = BT * BD (>n1) * SiMD (>m1)**
Centrality 2	**CCT2 = BT * BD (>n2) * SiMD (>m2)**

Two threshold levels were prepared in trigger logic for multiplicity detectors, one was sufficient.

Adding SiMD in the trigger was tested but not used during data taking in Xe run.

In addition, energy deposition in FHCal modules (all or only the neutron part) was also considered as potential trigger signals; data were collected for evaluation.

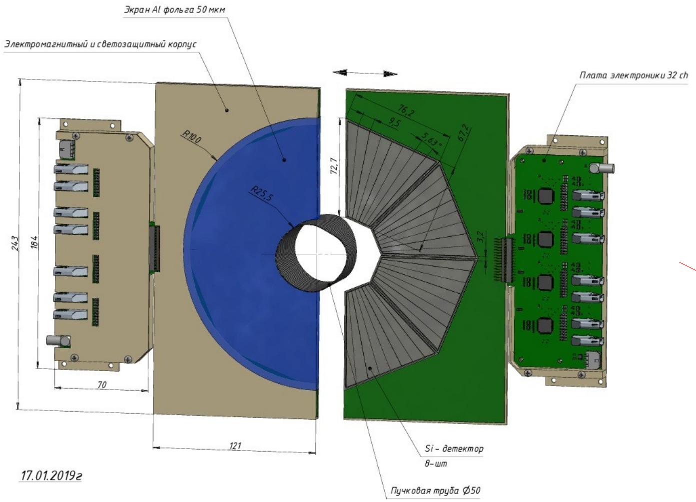


Beam pipe and detectors upstream of the target

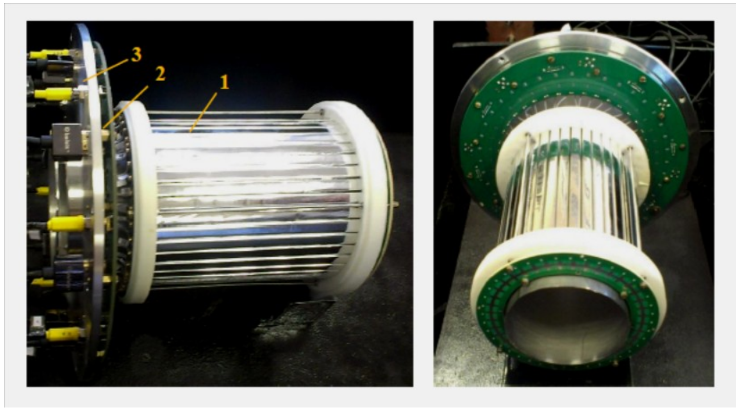
BC1 Trigger electronics VC, BC2

Trigger multiplicity detectors in the target area

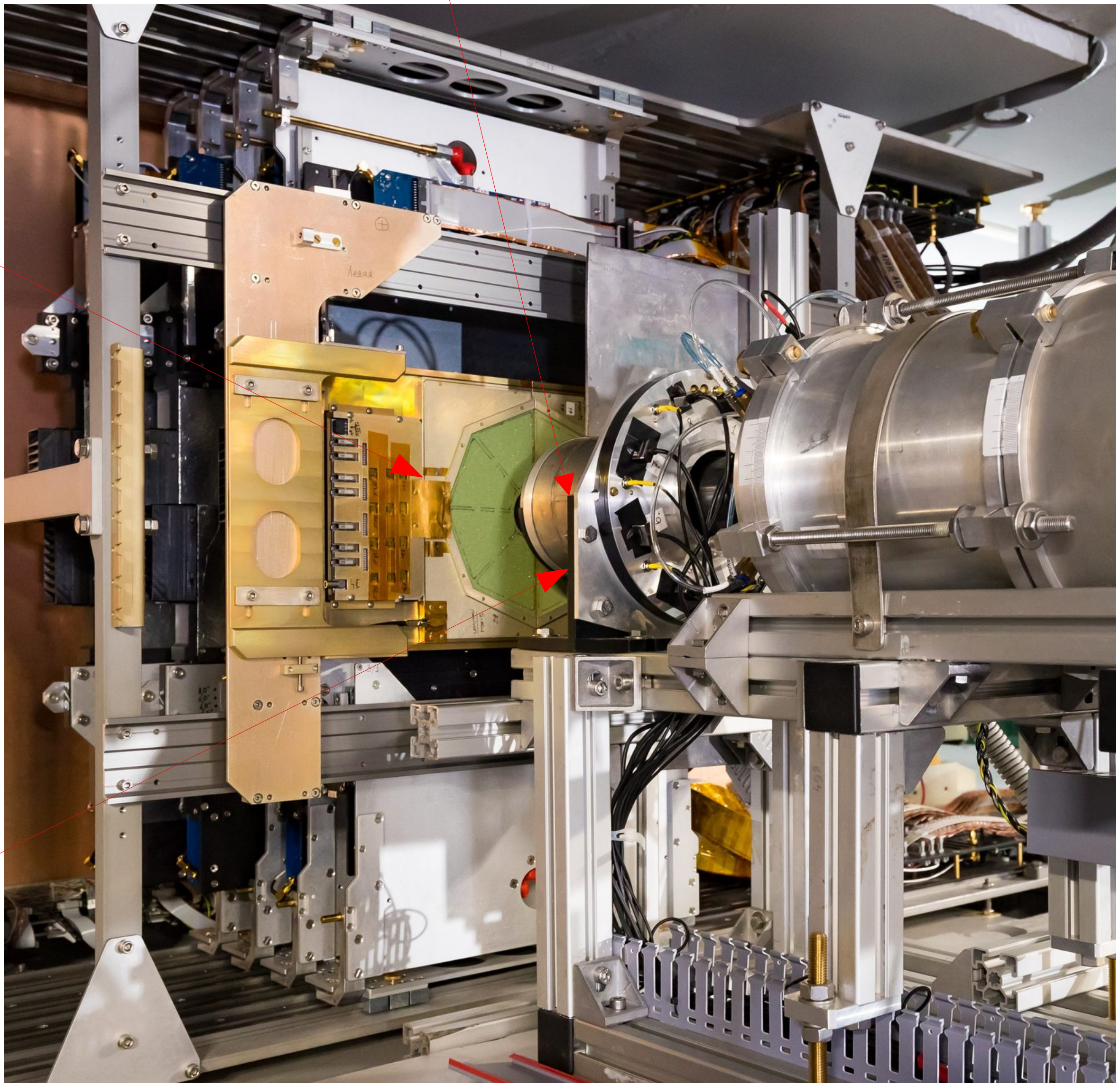
Target is located inside the BD



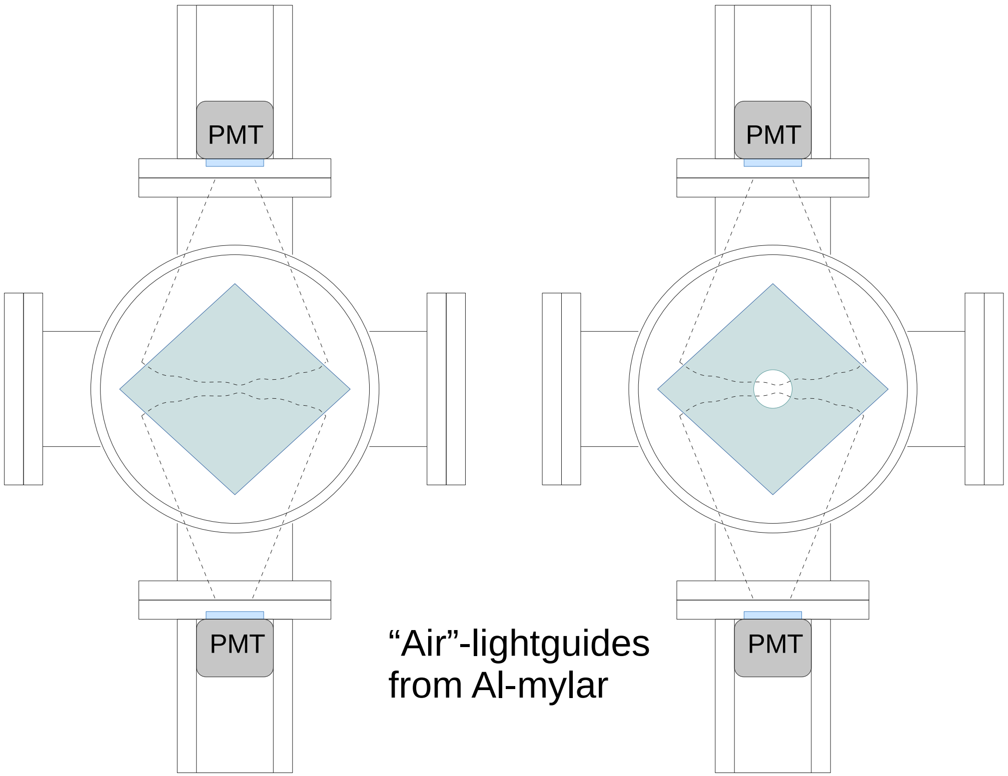
Silicon Multiplicity Detector (SiMD):
64 strips, 525 µm thick



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.



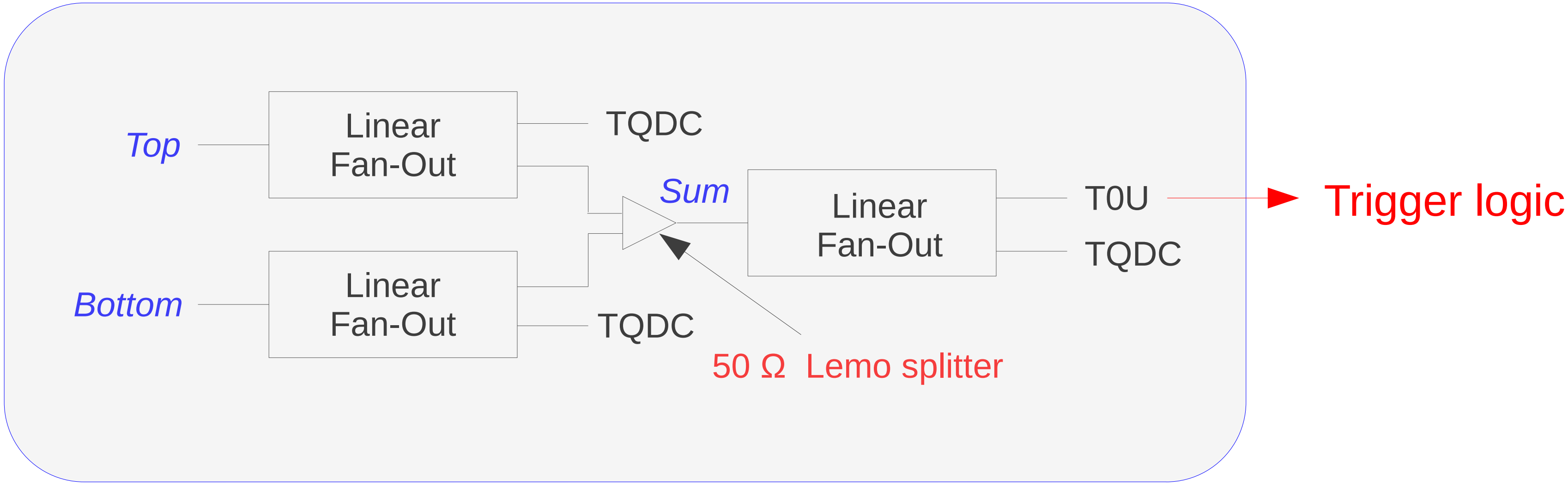
Design and read-out of BC1, VC



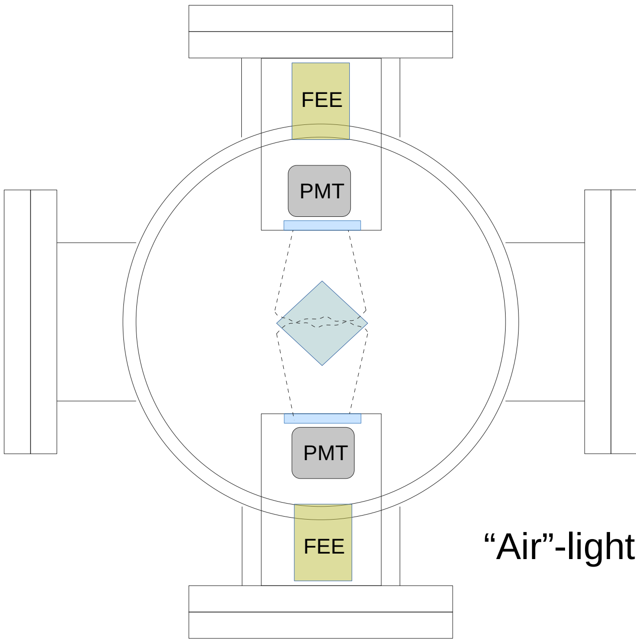
“Air”-lightguides
from Al-mylar

Detector	PMT	Radiator
BC1	Hamamatsu R2490-07	Scint. BC400B 100 x 100 x 0.25 mm^3
VC	Hamamatsu R2490-07	Scint. 113 x 113 x 4 mm^3 Ø 25 mm

Mesh dynodes PMTs, Veto Counter operates in the magnetic field, also have good timing.



Design and read-out of BC2

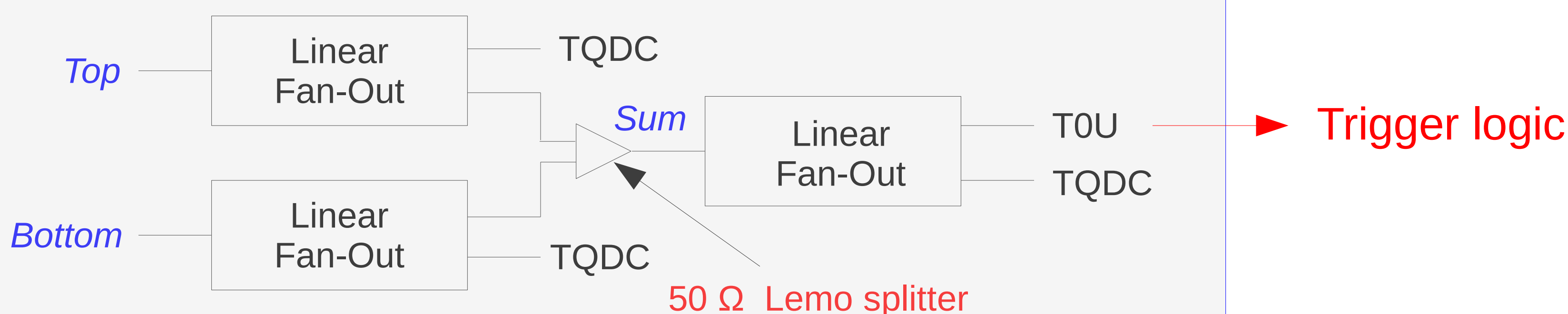


“Air”-lightguides from Al-mylar

Detector	PMT	Radiator
BC2	Photonis XPM85112/A1 Q400 25x25 mm^2	Scint. BC400B 34 x 34 x 0.15 mm^3

MCP PMTs, need to work in the magnetic field and to have excellent timing capabilities.

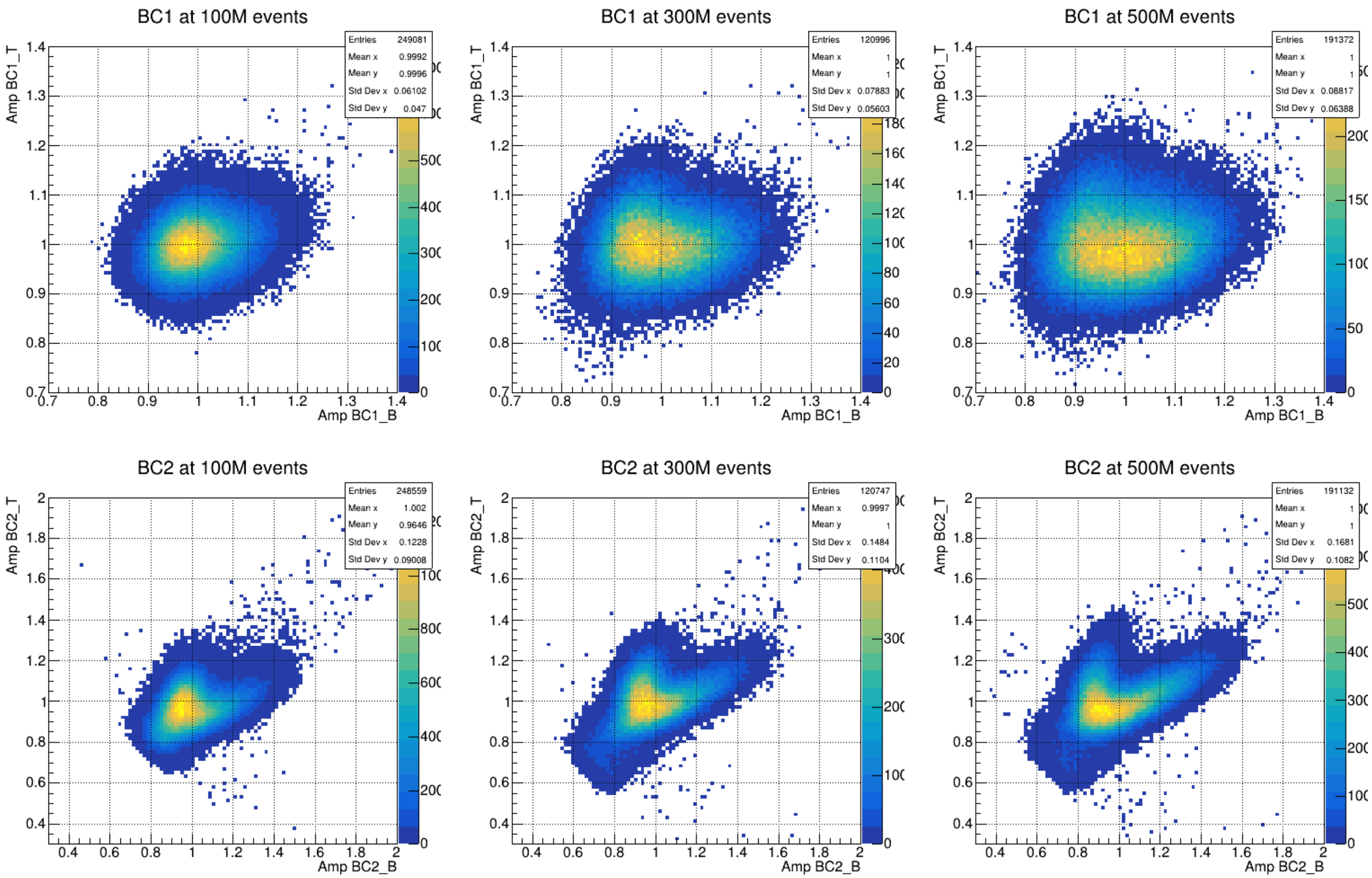
Two signals from each PMT: Anode and MCP



Additional read-out of LVDS signals from FEE into multihit TDC72VHL (based on CERN’s HPTDC chip).
Both, TQDC and TDC provide high resolution timing.

Indication of radiation damage in BC1 and BC2

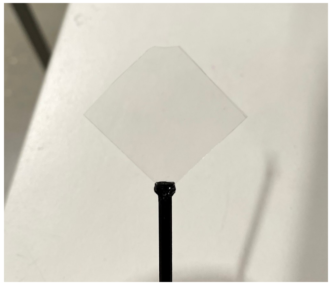
Top PMT Amp vs Bottom PMT Amp



More pronounced in BC2

Might require scintillator change during the run

Cherenkov prototypes are hard to test without heavy ion beams



BC2 scintillator check after the run: no visible loss in transparancy.

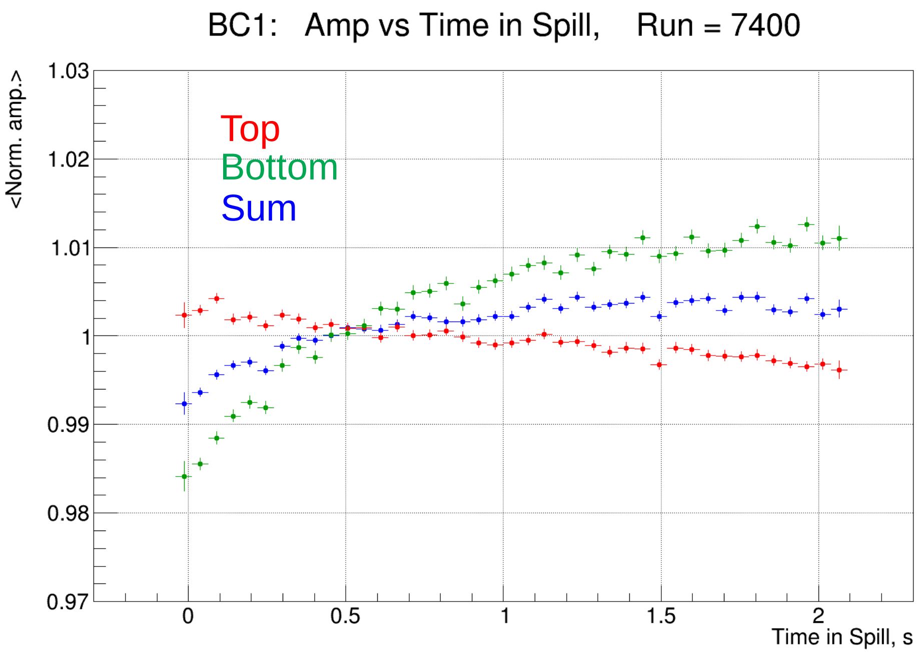
Study is planned by the LPI RAS group

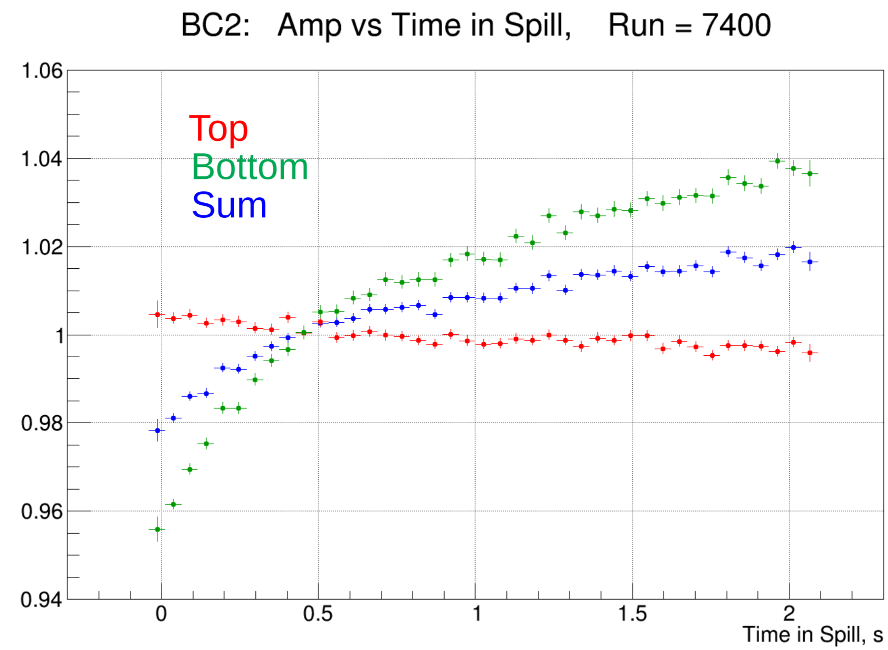
Offline amplitude resolution:

BC1 $\sigma(Xe) = 4.8\ \%$

BC2 $\sigma(Xe) = 7.1\ \%$

BC1 and BC2: Amplitude stability in spill





- stable at 2-4 % level
- can be sensitive to (X,Y) beam movement during spill
- next step is to add Beam Tracker into analysis

Time resolution of BC1 and BC2

Measured with additional FD1 counter, placed behind the FHCal hole.

FD1 is similar to BC1 in design, PMTs and scintillator.

Each of BC1 and BC2 have ≤ 45 ps resolution.
Combined, they can provide ≤ 30 ps resolution.

$$\Delta t_{ij} = t_i - t_j$$

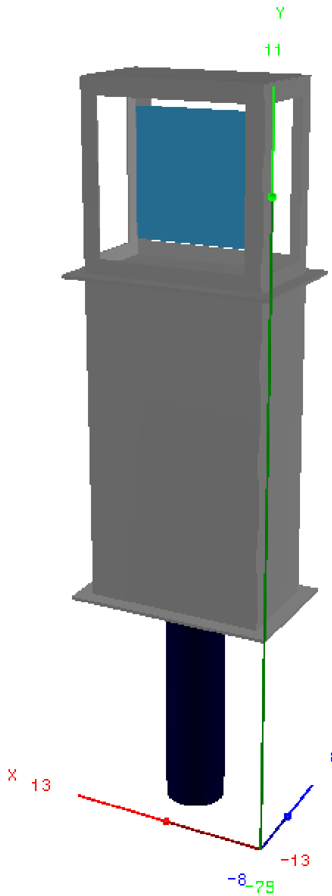
$$\sigma_{ij}^2 = \sigma_i^2 + \sigma_j^2$$

i,j: *BC1, BC2, FD1*

Detectors	σ_{ij}, ps
BC1 - BC2	57
BC1 - FD1	61
BC2 - FD1	58
(BC1&BC2) - FD1	52

Detectors	σ_i, ps
BC1	43
BC2	38
FD1	44
(BC1&BC2)	28.2
	28.5

FD design and response



Radiator
150 x 150 mm^2

Air-lightguide
from Al-mylar

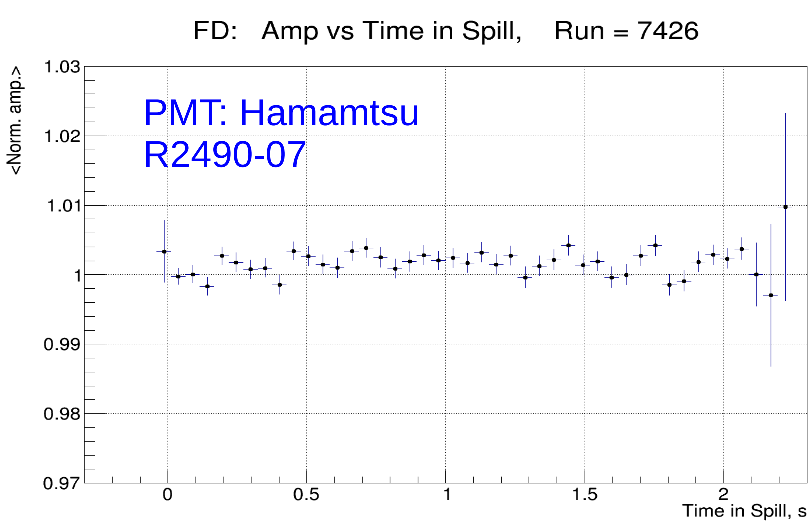
PMT

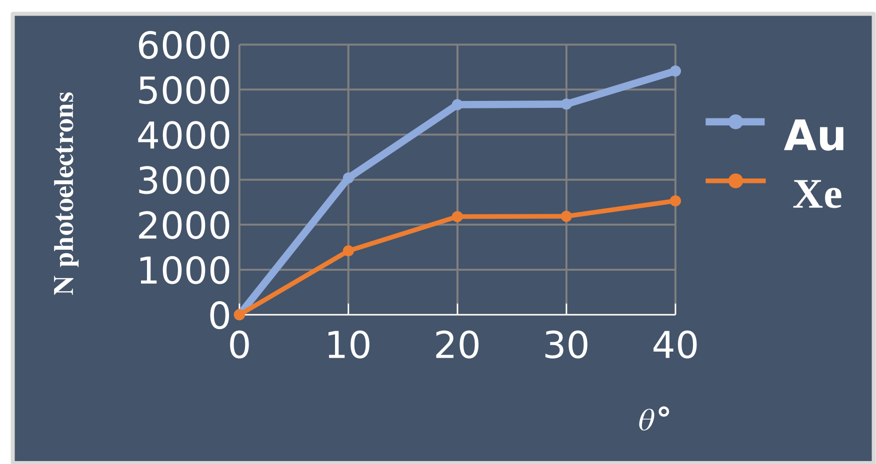
PMT	Radiator	σ/A (%)
XP2020	Scint. 0.5 mm	6.0
XP2020	Quartz 1 mm	17.0
XP2020/Q	Quartz 1 mm	11.7
R2490-07	Scint. 0.5 mm	6.7 → 5.3

Significantly better resolution with scintillator radiator

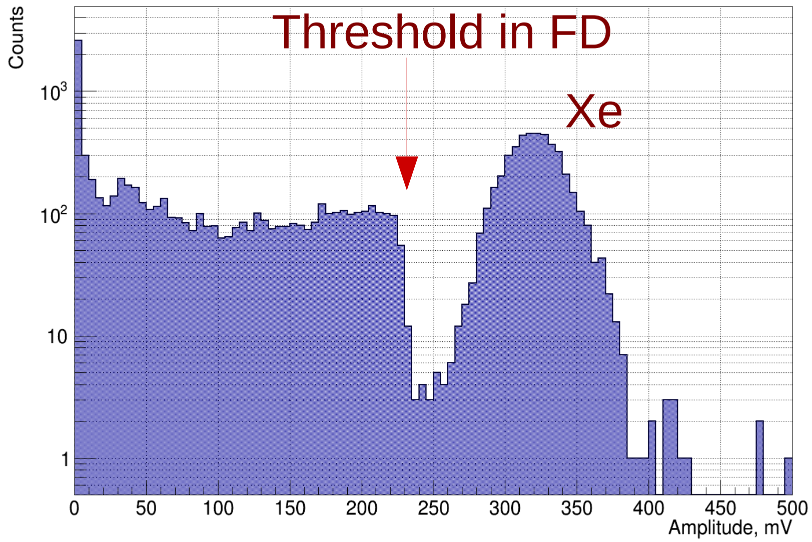
Fragment Z resolution in offline analysis will be significantly Improved by the quartz hodoscope (σ(Xe) ≈ 2%)

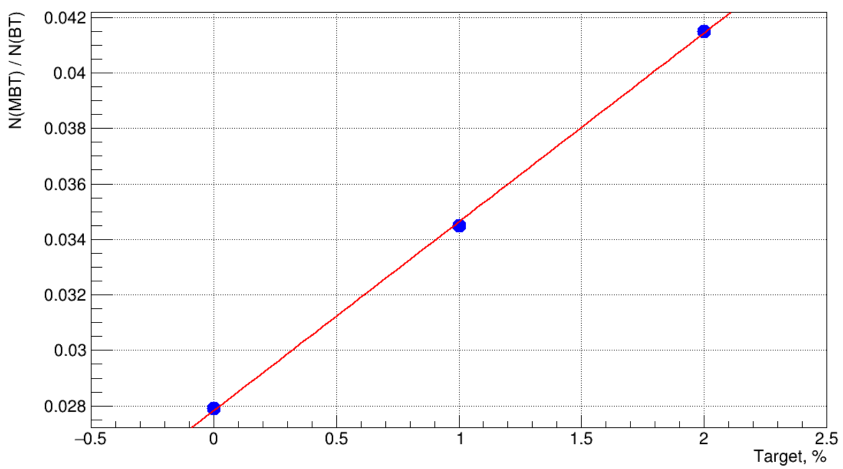
Photostatistics with quartz radiator is significantly less than what was predicted by simulations





Minimum Bias Trigger (MBT = BT • FD_{veto})





Material	Thickness, mm	Interaction probability %
Si BeamTracker	0.175	0.30
Ti vacuum window	0.08	0.17
FD, black tape, etc.	0.5	0.94
Air	150	0.21
FD, scint.	~0.1	~0.2
BC2, scint.+Mylar	~0.04	~0.1
		Total ~1.9

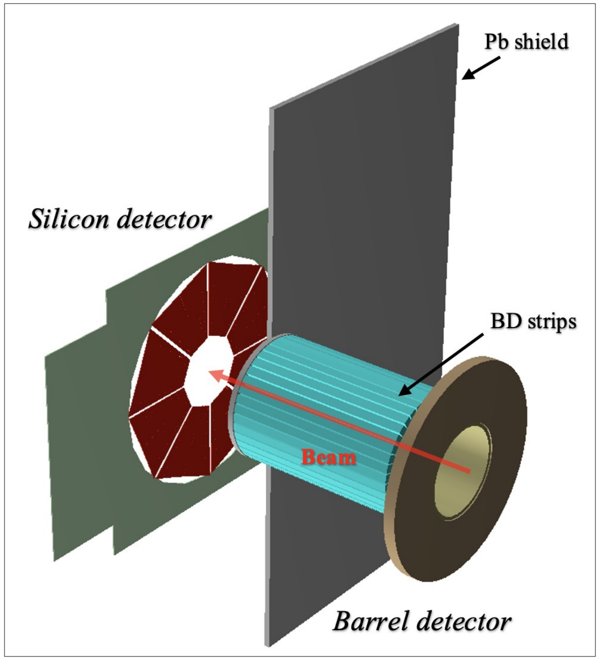
Even with conservatively low threshold in FD amplitude, typical ratio of N(MBT) / N(BT) for 2% target was ~0.04, i.e. with significant background

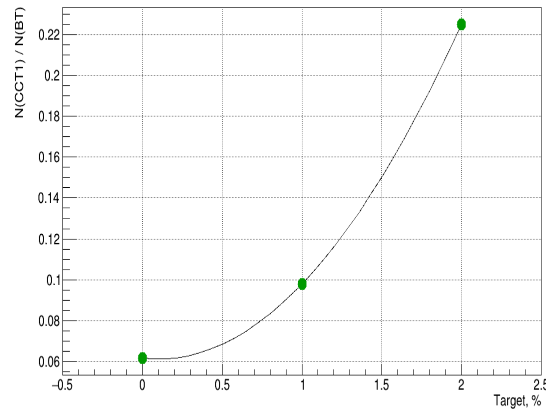
Good linearity with Empty, 1%, 2% targets;

N(MBT) / N(BT) for “empty target” ~0.028

Upgrade planned for the next run: 1) put the FD scintillator in vacuum similar to BC1;
2) verify suspected additional background from two close beam ions (the second comes during the dead time of the discriminator).

Response of the Barrel Detector and trigger CCT1 = BT • (BD≥n)



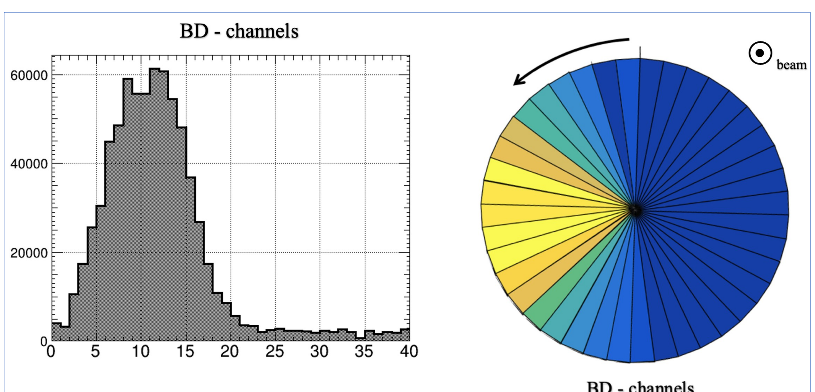


Even with added Pb-shielding, the background from δ-electrons is significant and larger, than predicted by Geant4 simulations.

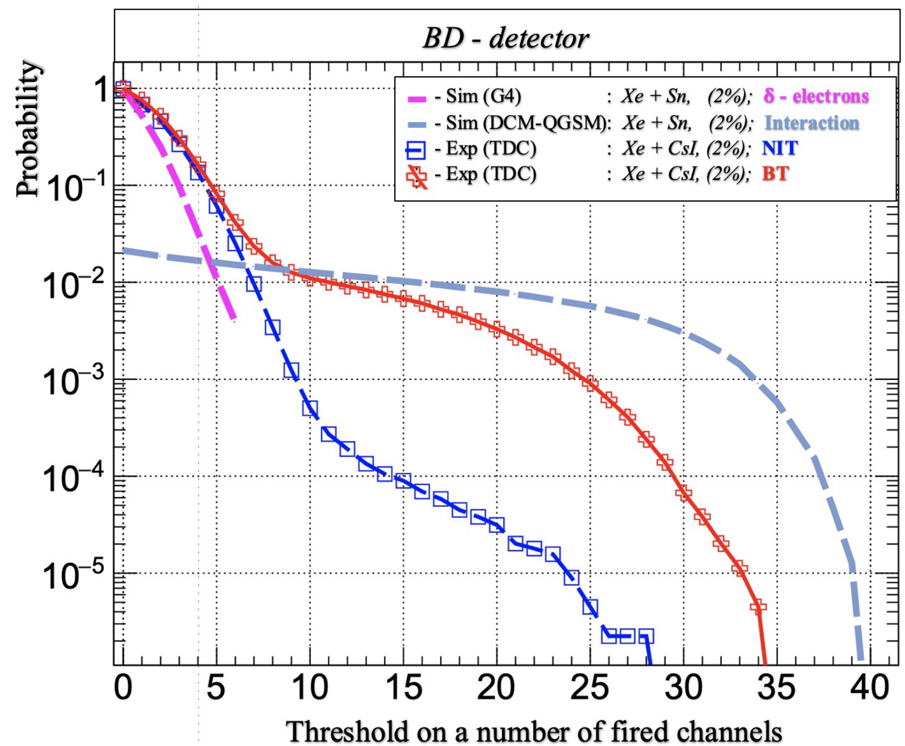
At BD ≥ 4 and 2% target, N(CCT1) / N(BT) is 0.22, while 0.02-0.04 was expected.

In addition, CCT1 rate is very non-linear with 1% and 2% targets, indication of high sensitivity to pile-up of beam ions

- *Inner shield*: Pb - cylinder 0.3 cm thick;
- *Outer shield*: 25 x 50 cm², L = 0.5 cm.



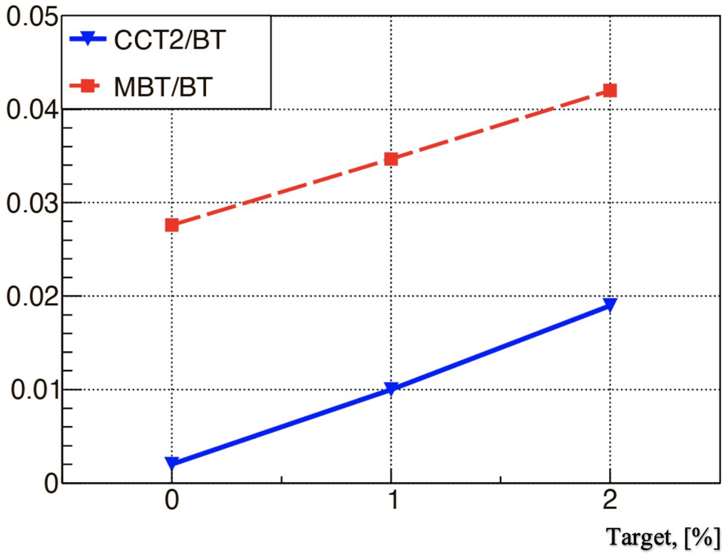
Distribution of hits in BD from δ-electrons background



BD ≥ 4

Central collisions trigger CCT2 = MBT • (BD≥n)

N(CCT2) / N(BT) at BD ≥ 4



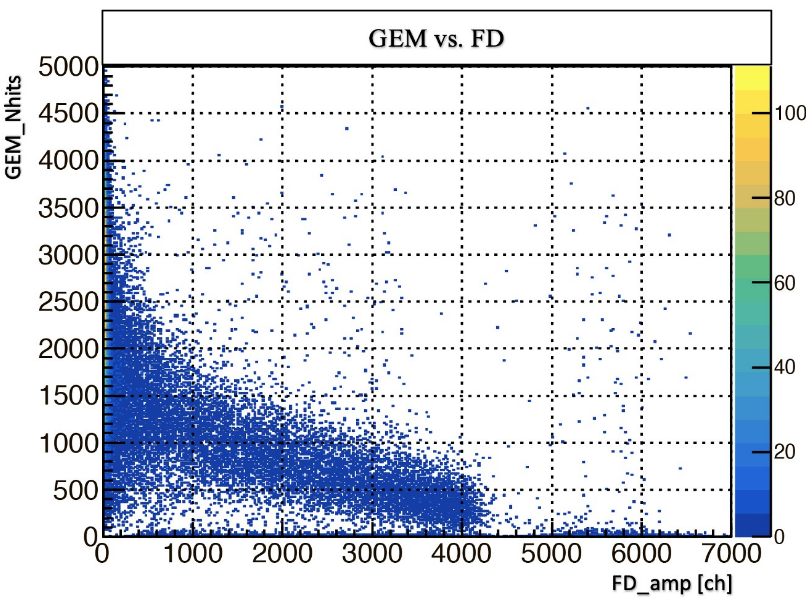
The backgrounds in triggers MBT and CCT1 are suppressed when MBT and CCT1 are combined in CCT2

Some non-linearity with 1% and 2% targets remains in CCT2, but becomes much smaller

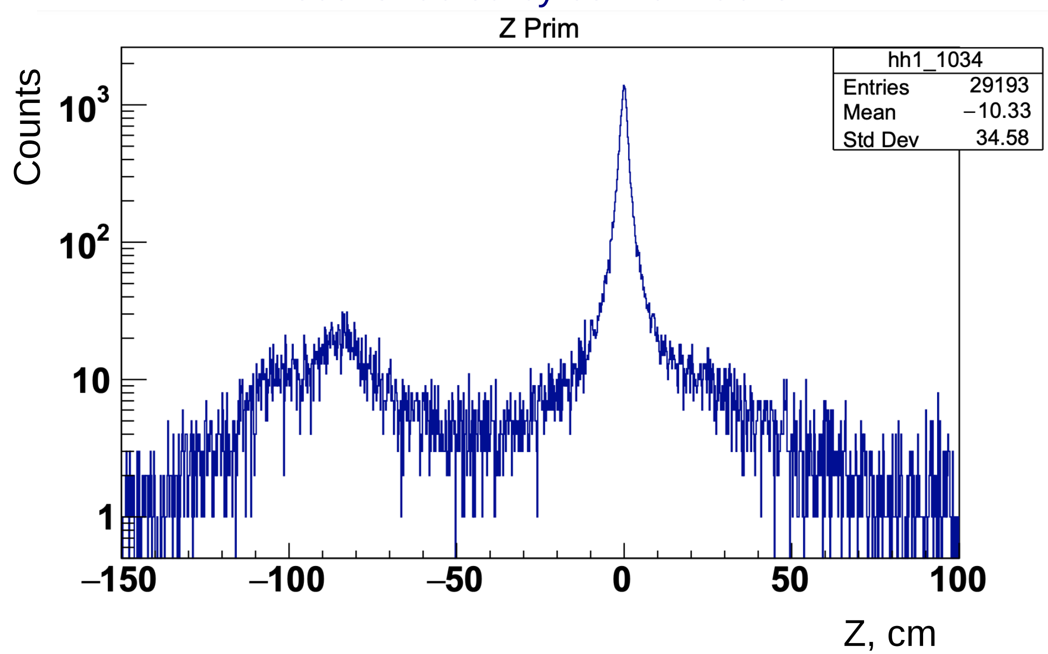
Correlation plots in various detectors were used in order to confirm the validity of the trigger

“Regular” mix of triggers used in data taking

Trigger	Downscaling factor	Fraction, %
BT	2000	3
MBT	35	7
CCT1	230	5
CCT2	1	85

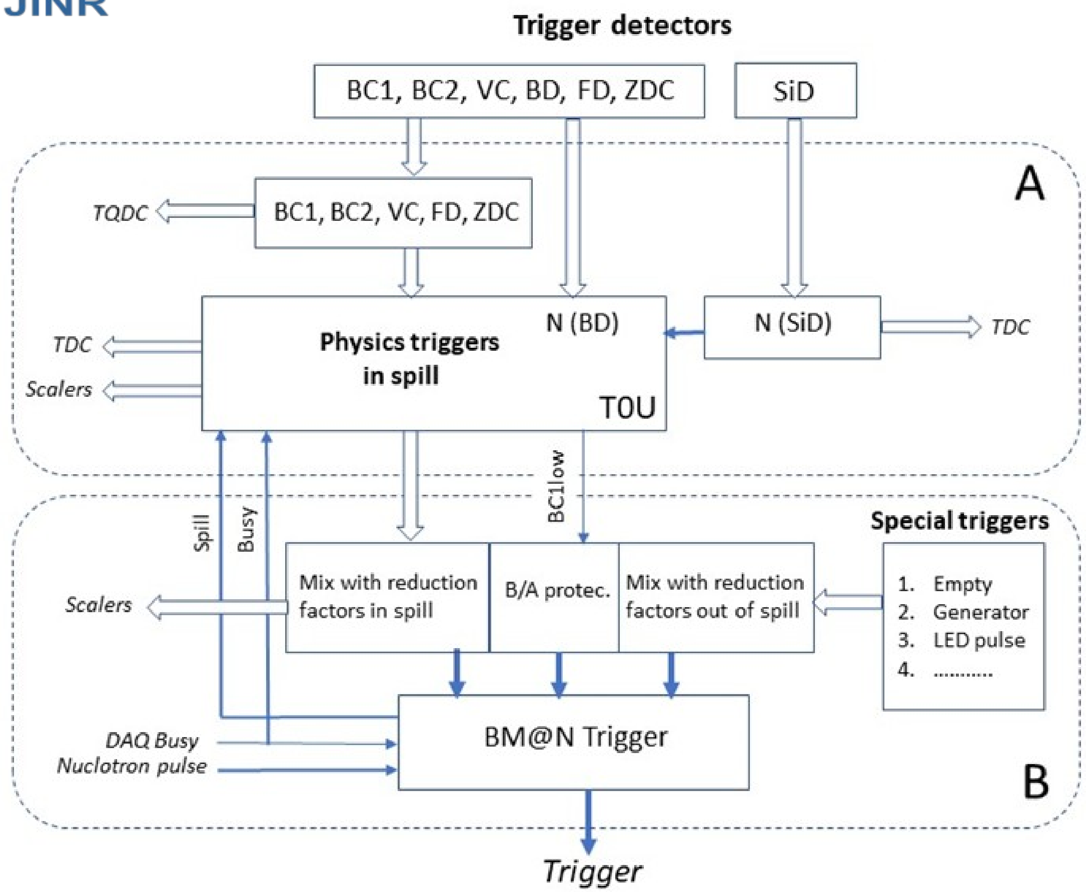


Z coordinate of primary vertex reconstructed by central tracker



Centrality of events selected by CCT2 is ~70 % (estimated in offline analysis).

Sub-parts in trigger electronics



Part A
(managed by the trigger group):

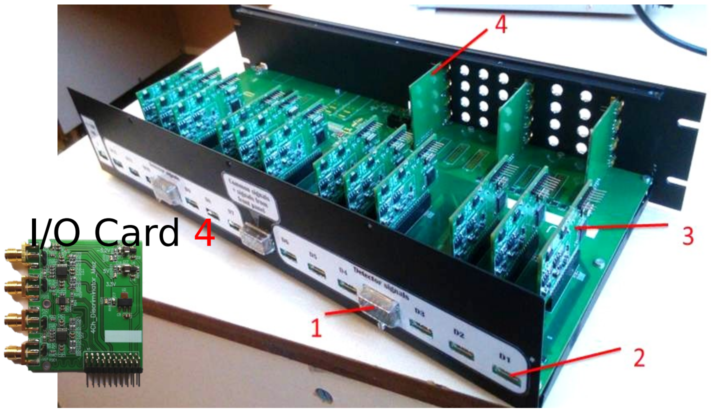
generates physics triggers.

Part B
(managed by the DAQ group):

makes downscaling of the physics triggers (up to 16 triggers can be provided);

makes Before/After protection;

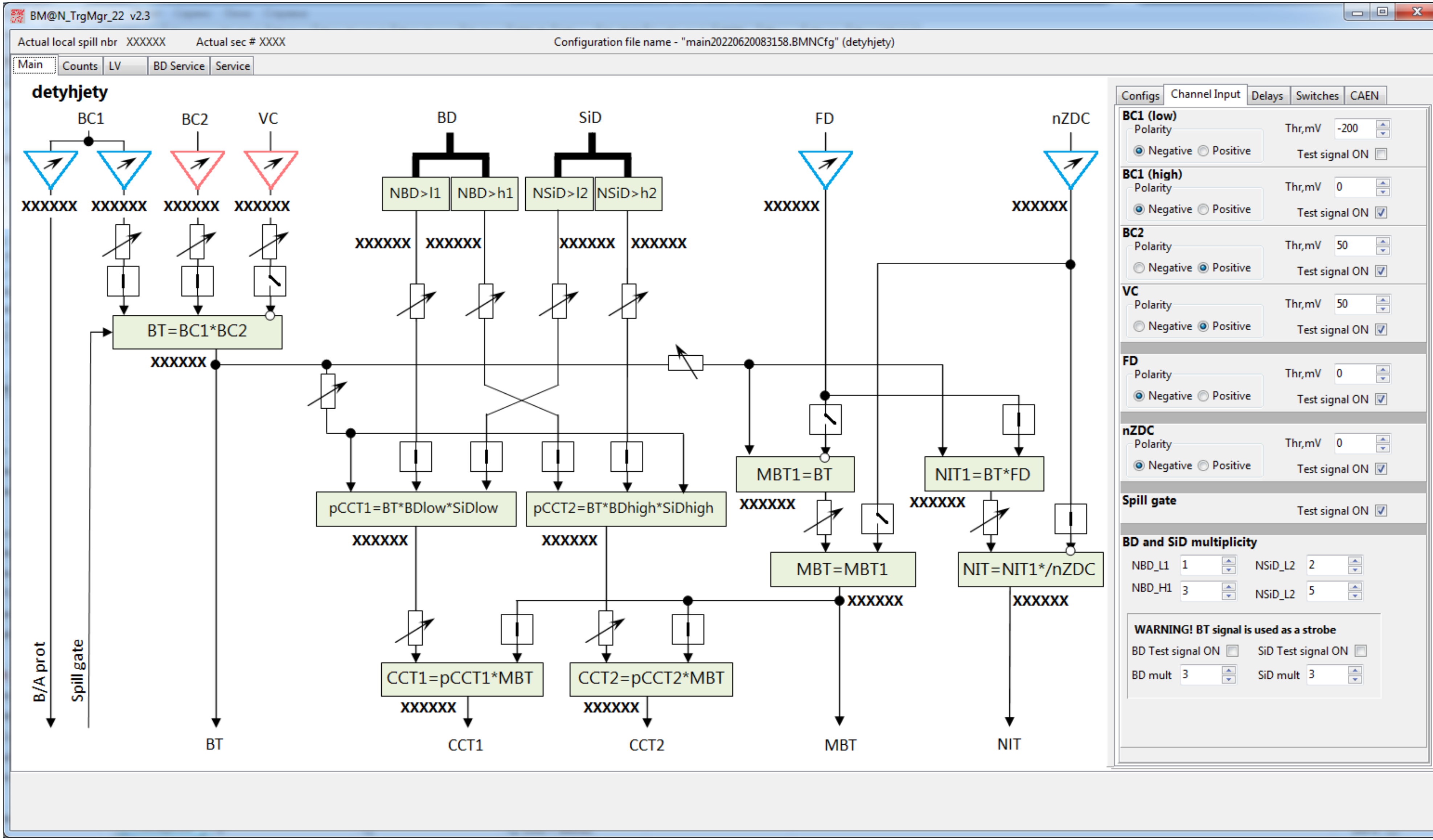
generates special triggers.



T0U Module Functionality:

- Implements trigger logic in FPGA;
- Recieves or provides I/O analog, NIM, TTL signals via cards 4;
- Recieves LVDS signals via HDMI connectors 2;
- Provides LV to FEE (cards 3, HDMI connectors 2);
- Forms input signals to TDC (Molex connectors 1).

T0U trigger logic scheme and interface



Summary and outlook

The developed trigger system for the fixed-target BM@N experiment allows fast and efficient selection of relativistic heavy ions interactions in the target.

The trigger is based on a combination of beam ion / fragment registration downstream of the target and measurement of multiplicity of the produced charged particles.

All major components of the trigger system were successfully implemented and used in the recent BM@N run with ^{124}Xe beam.

In the course of preparation to the experiments with the heaviest beam ions (^{197}Au, ^{209}Bi), the upgrade of the trigger system will be focused on more strict rejection of the pile-up events and on replacement of scintillator trigger counters with quartz detectors.