Детекторы триггерных систем экспериментов BM@N, SRC и MPD

Сергей Седых

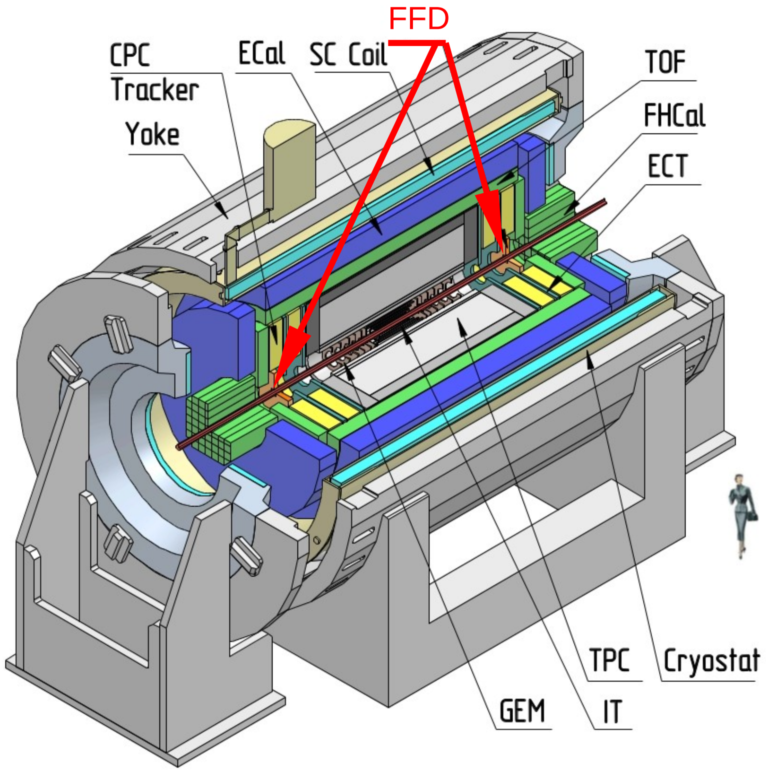
(отчёт о научной деятельности за 5 лет)

22 февраля 2024

Presentation order:

1) Fast Forward Detector of the MPD
2) Trigger detectors of BM@N
3) Trigger detectors of SRC at BM@N

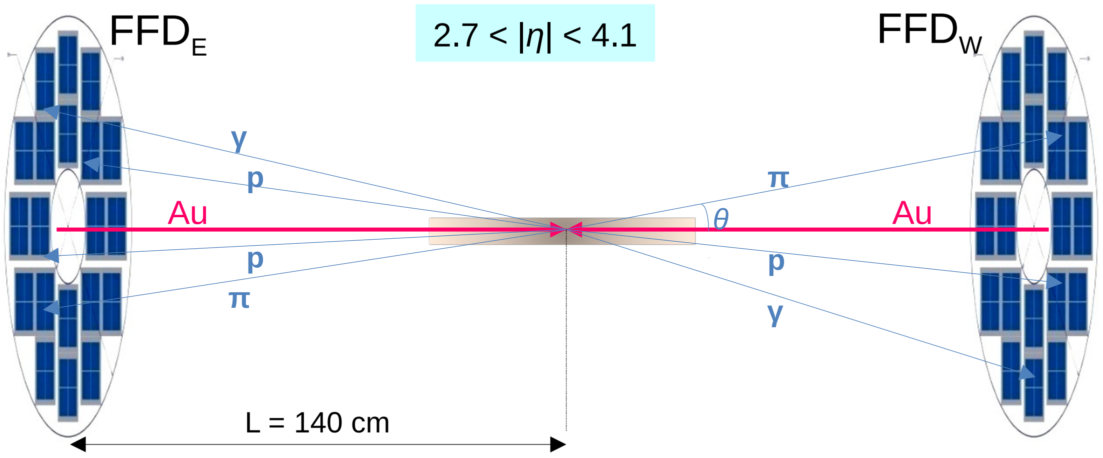
FFD concept and requirements



FFD is one of the trigger subsystems.

FHCal is also expected to be integrated
in the trigger (slower but with larger acceptance).

TOF can also be considered.



Fast interaction trigger & T0 detector for TOF

Trigger is based on coincidence of signals in two sub-detectors

t_E-t_W => localization of interaction point ΔZ < 3 cm

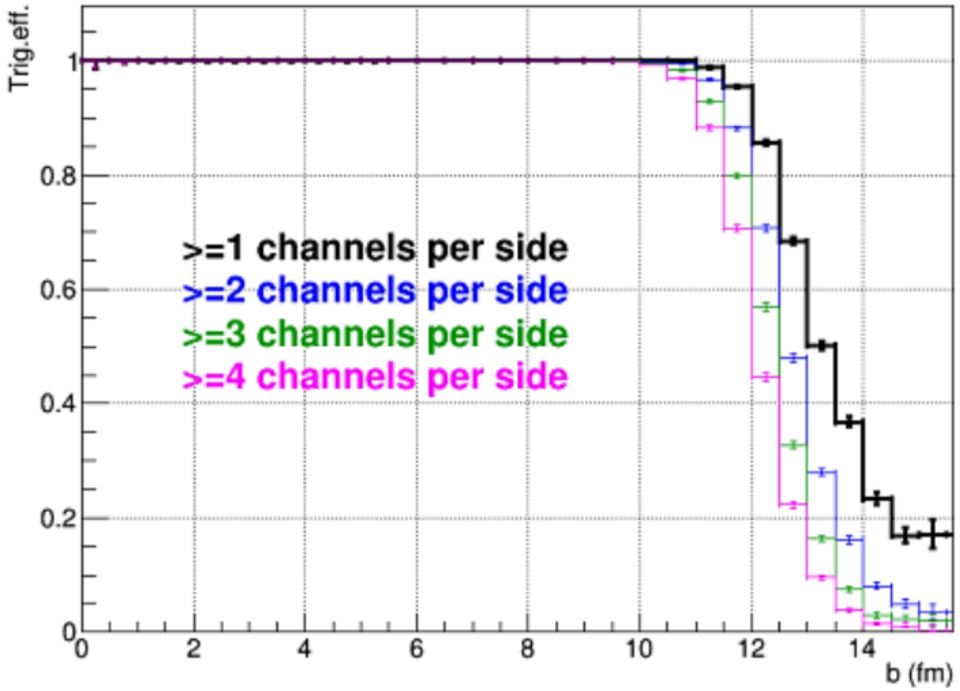
Condition on multiplicity of hits in each arm (80 cells in each arm)

Offline t_0 time for TOF better than 50 ps

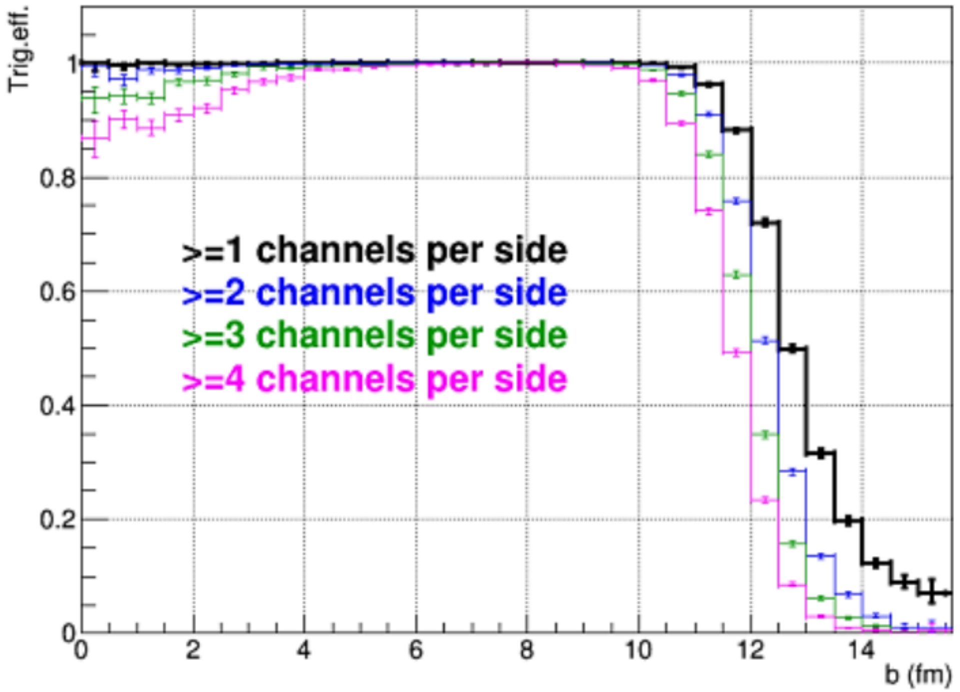
Expected trigger efficiency

V.Riabov
DCM-QGSM-SMM

Au + Au √s = 11 GeV



Au + Au √s = 5 GeV



- Efficiency is ~ 100% in central and semi-central collisions
- “ at least one-channel per side” is a preferred option for FFD triggering

More simulation results in:

Riabov V:	Fixed target trigger efficiency,	Cross-PWG 2023-02-22, 2023-05-30, 2023-11-28
	Light collision systems,	Cross-PWG 2023-07-25
	Trigger mass productions,	Cross-PWG 2023-06-24
	PHQMD trigger efficiency,	Cross-PWG 2022-09-06
Ivanishev D:	Trigger studies in the collider mode,	Cross-PWG 2023-08-22

FFD team:

Vladimir Yurevich – leader of the FFD project

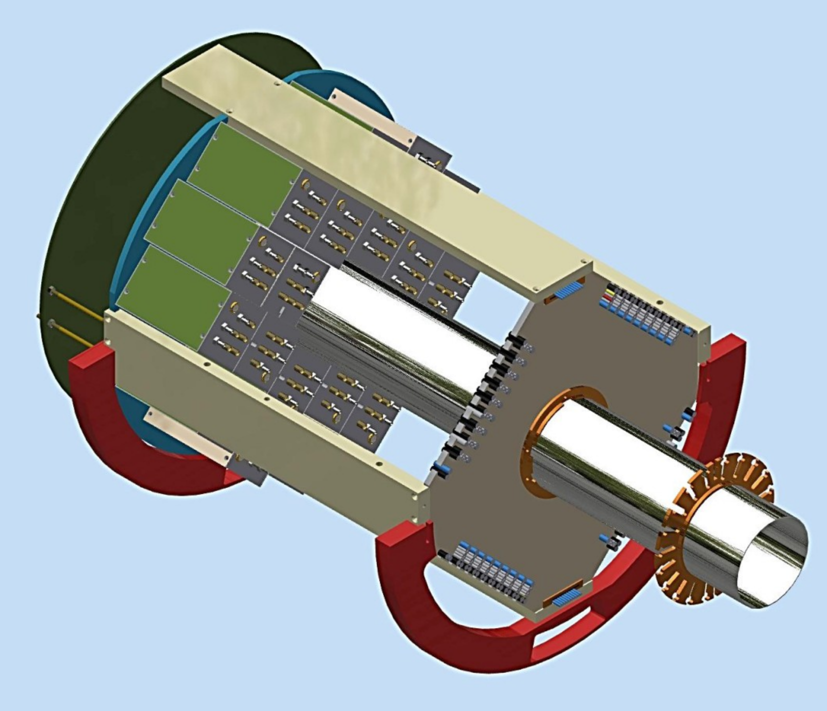
Sergey Sergeev – electronics and Detector Control System
Viktor Rogov – electronics and cables
Pavel Grigoriev – electronics and software

Vladimir Tikhomirov – mechanics and cooling
Vitaliy Azorskiy – mechanics
Aleksander Timoshenko – mechanics

Nikita Lashmanov – tests and study of the FFD performance,
FFD implementation in MpdRoot
Sergey Sedykh – tests and study of the FFD performance

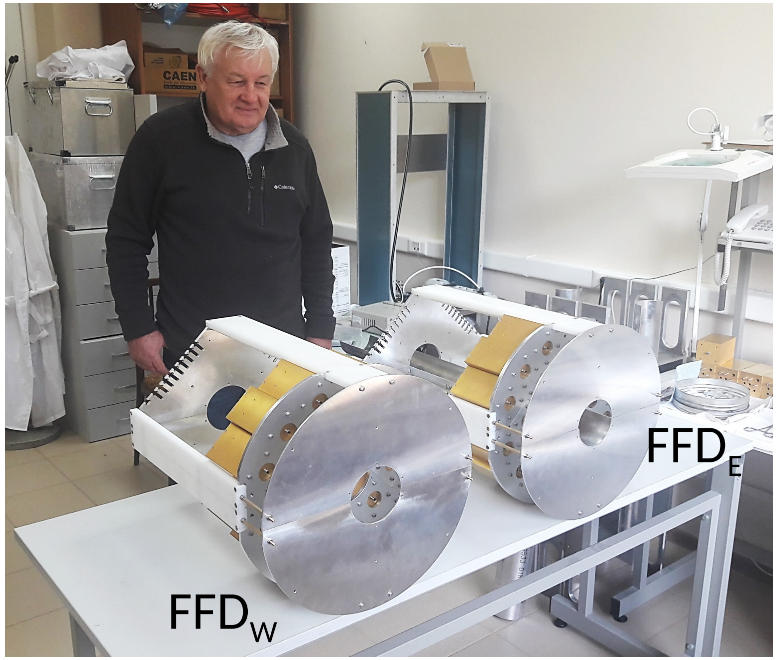
FFD Mechanics

Vladimir Tikhomirov



Design of FFD sub-detector

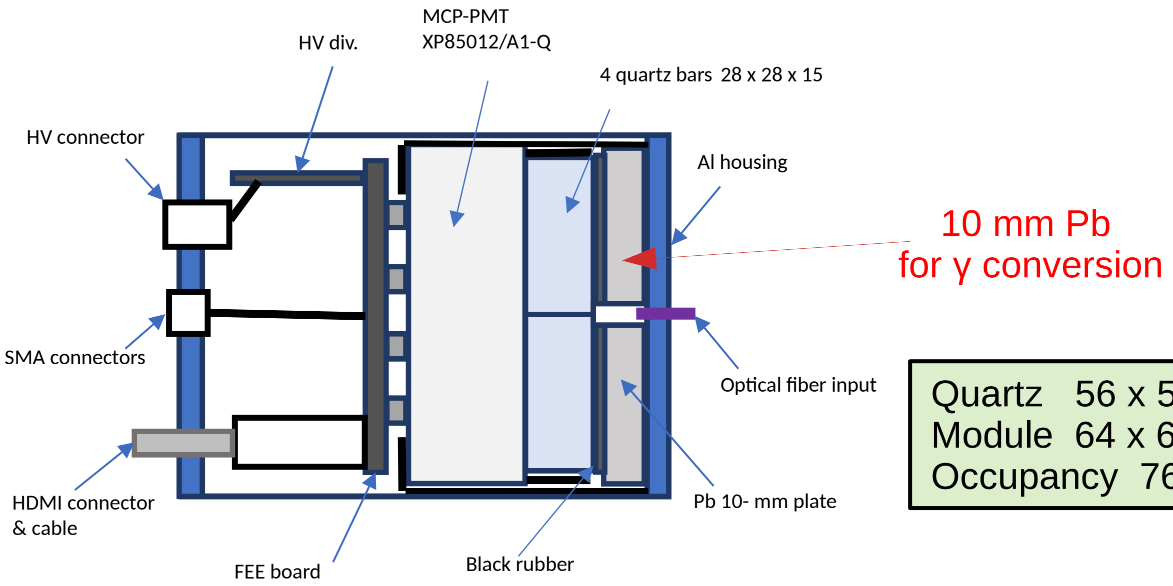
Tools for FFD installation



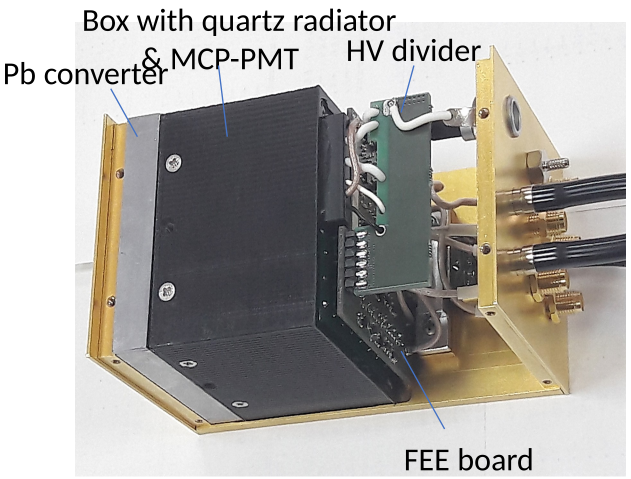
Current status: All mechanics is ready for installation in the MPD

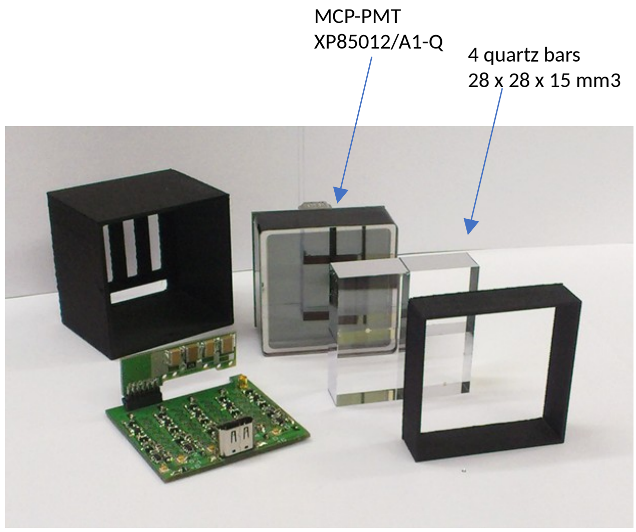
FFD Modules

Viktor Rogov
Vladimir Yurevich

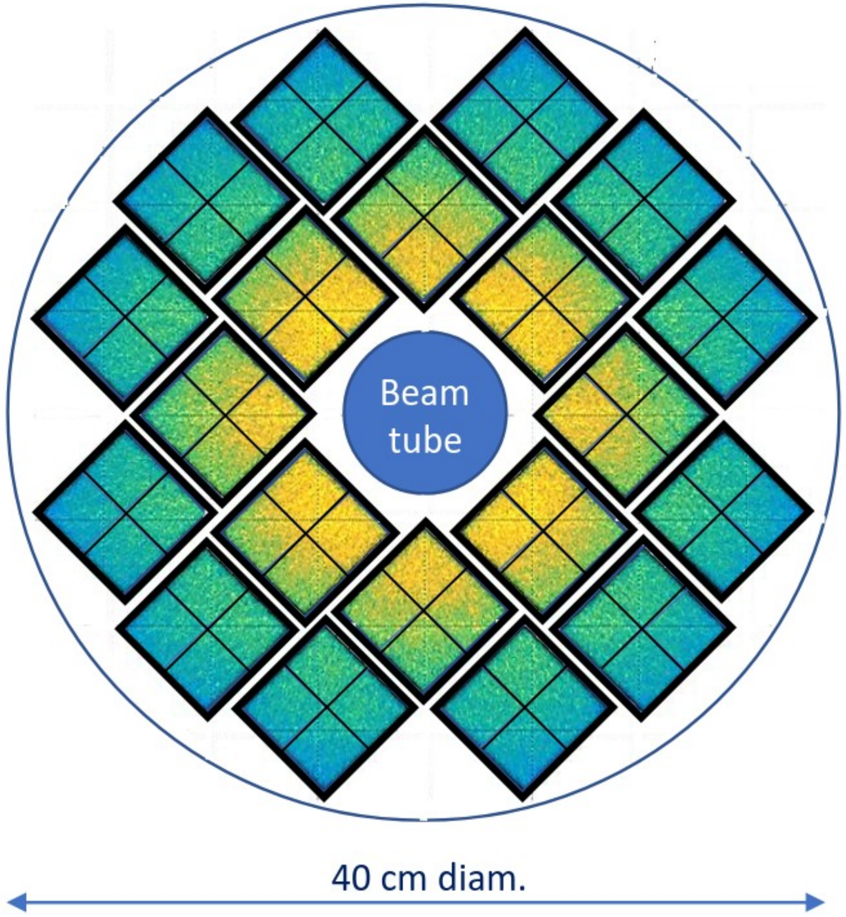


Quartz 56 x 56 mm^2
Module 64 x 64 mm^2
Occupancy 76.6%





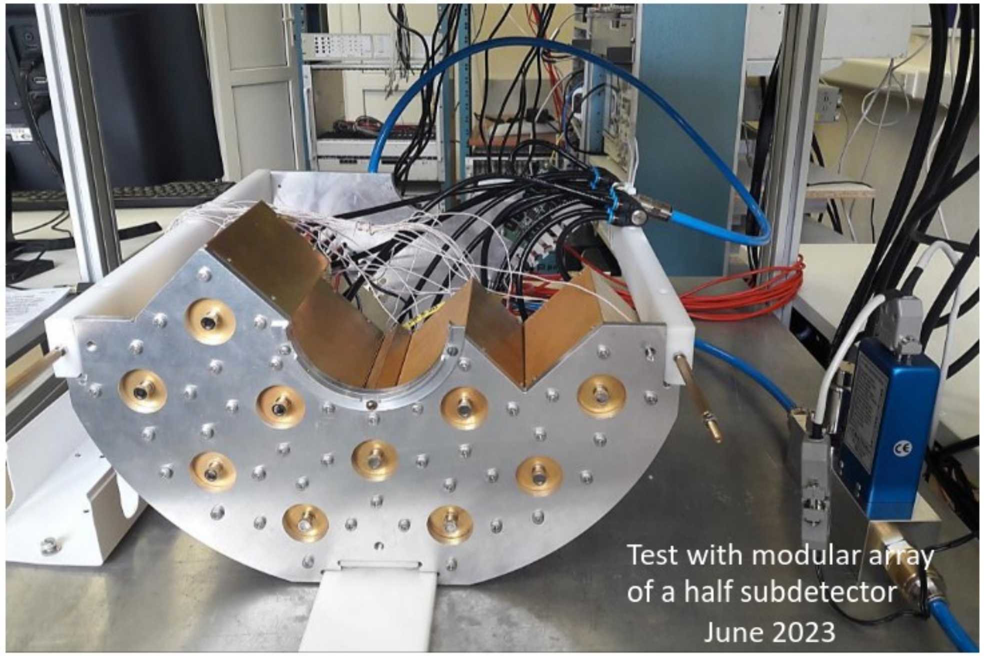
80 cells in 20 FFD modules



Status:
All 2 x 20 FFD modules are produced

FFD cooling system

Vladimir Tikhomirov
Sergey Sergeev



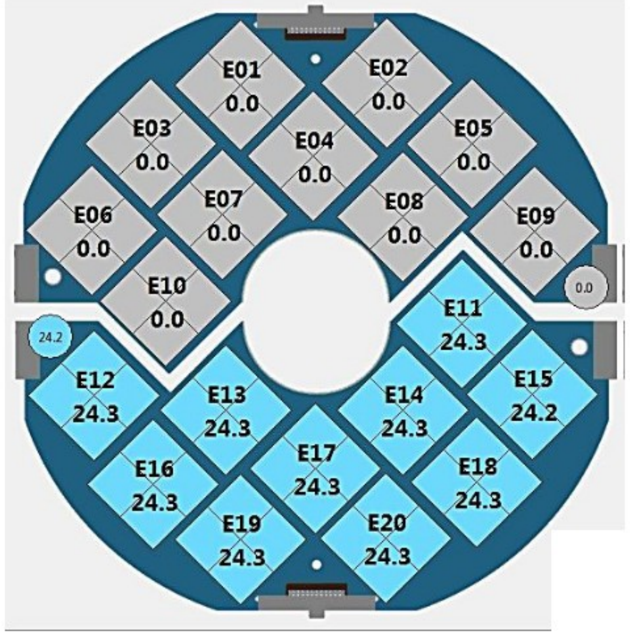
Temperature inside modules

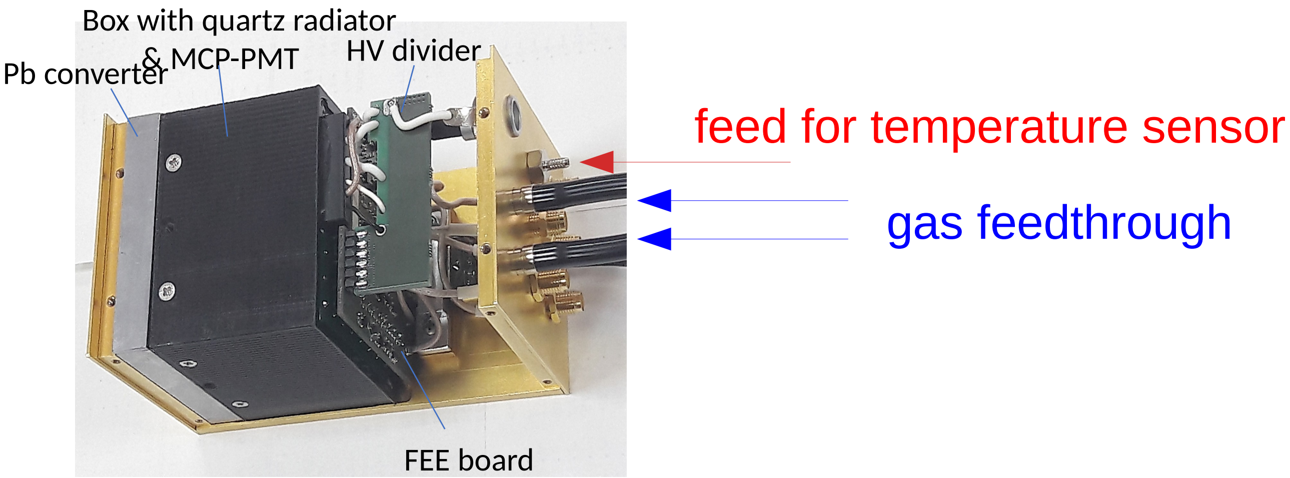
No air flow	Air flow 40 l/min
+8° C	+4° C

Air of room temperature was used in the tests

We expect that during MPD operation a flow of cool and dry air (nitrogen) will be used.

Interface for temperature monitoring





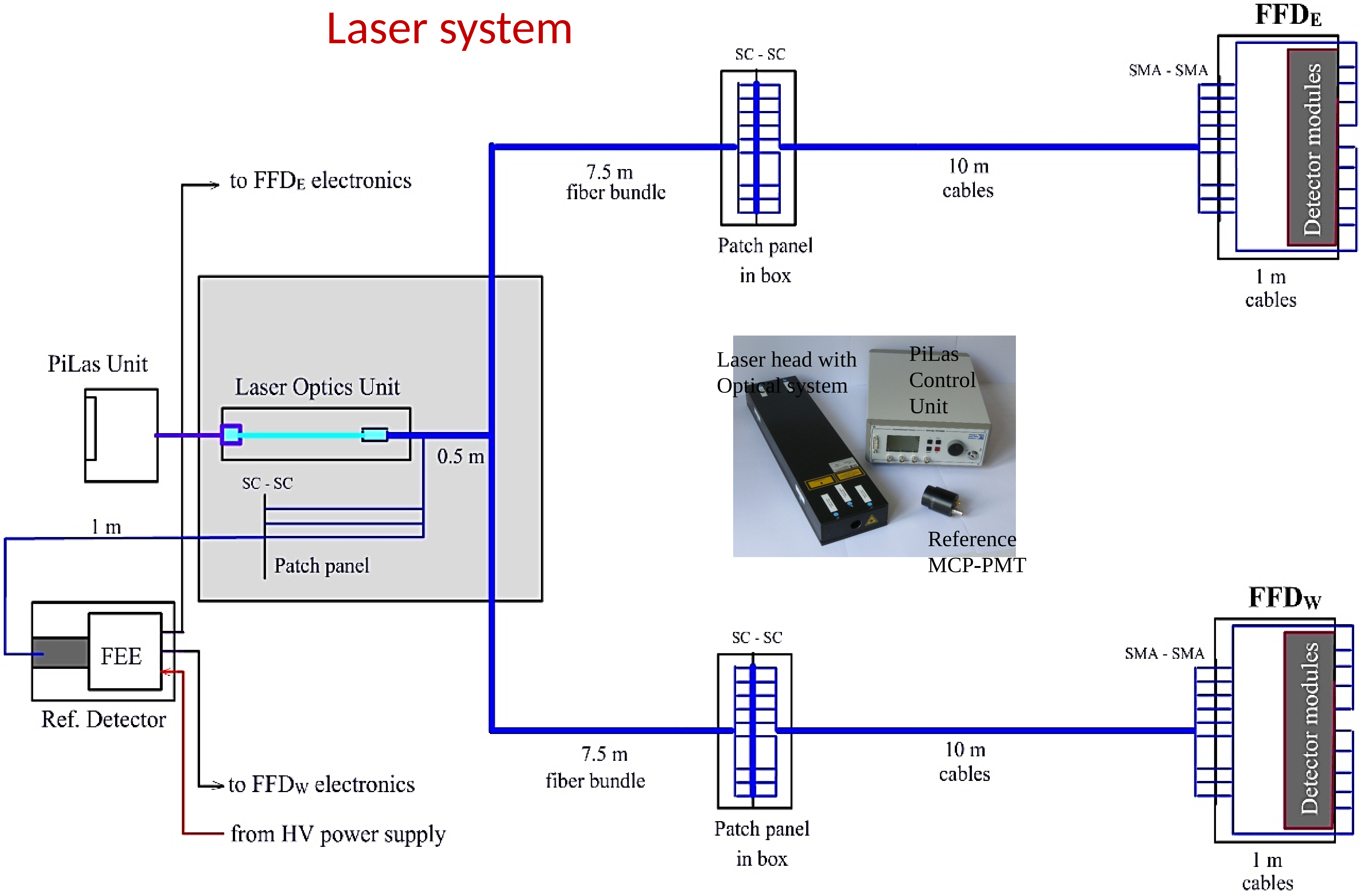
Laser system

Laser system components

PiLas laser, 407 nm, 100Hz - 1MHz, FWHM 26ps

Reference Detector
MCP-PMT with <30 ps time resolution

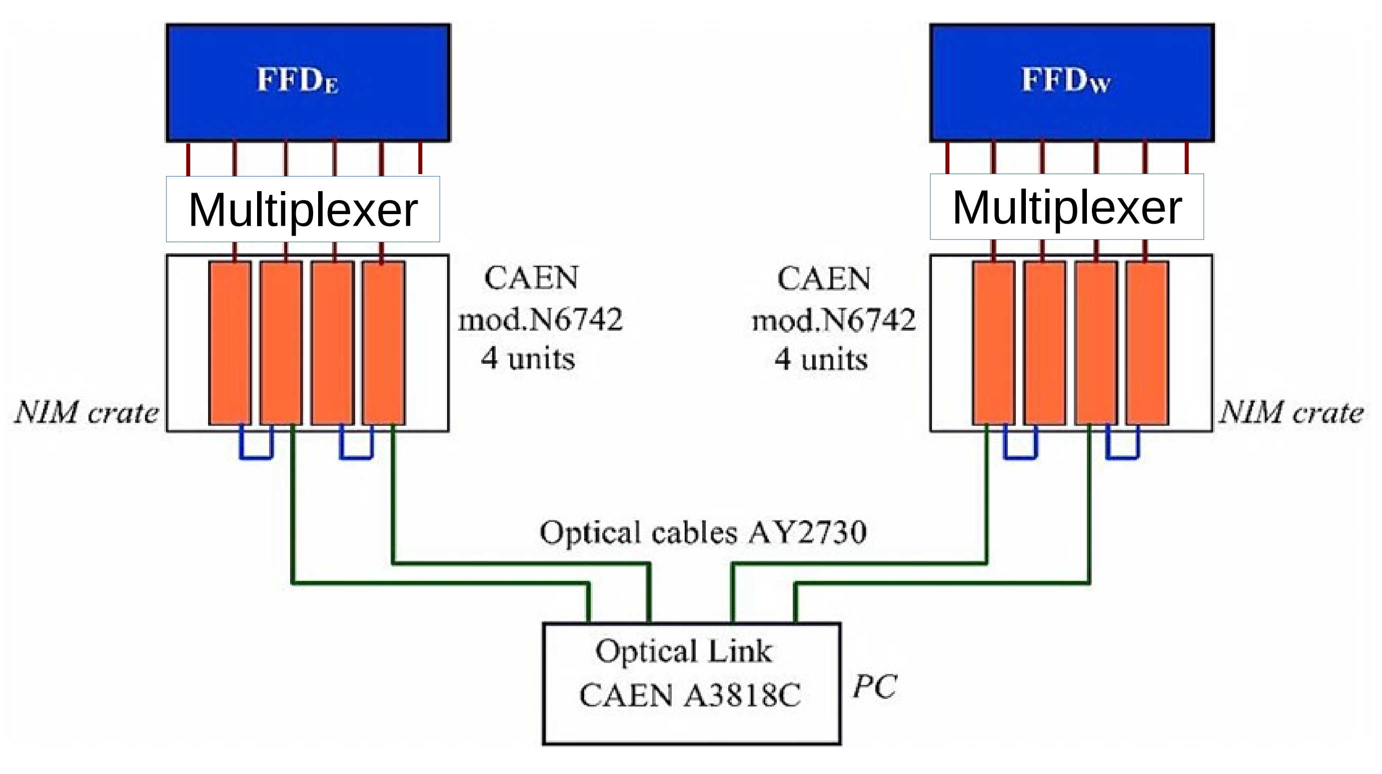
- Fiber bundles
  7.5 m (2 x 60 fibers)
- Patch panels
- Set of optical cables
  10 m (2 x 20 pcs.)
  1.5 m (2 x 20 pcs.)



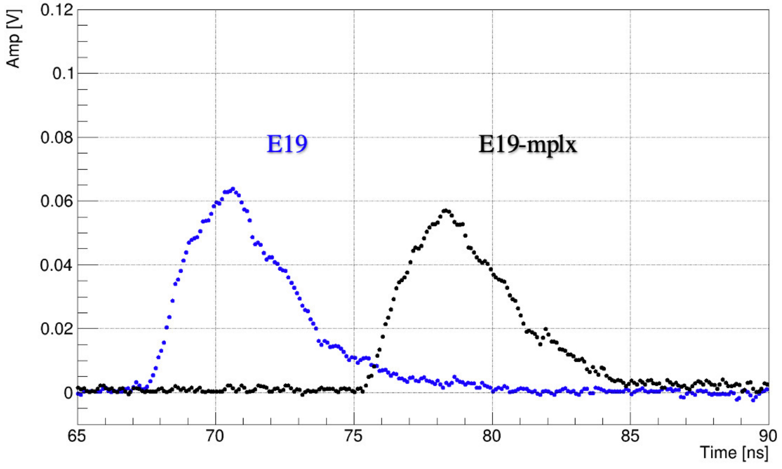
Status:
all components available, checked
and being used for testing modules and electronics

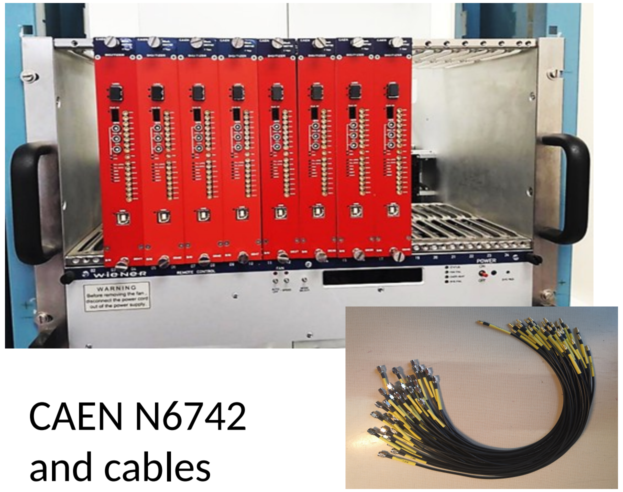
Readout electronics for detector control and calibration

Sergey Sedykh
Nikita Lashmanov



Test of multiplexer with laser system and 1GHz LeCroy Waverunner 9104





CAEN N6742 and cables

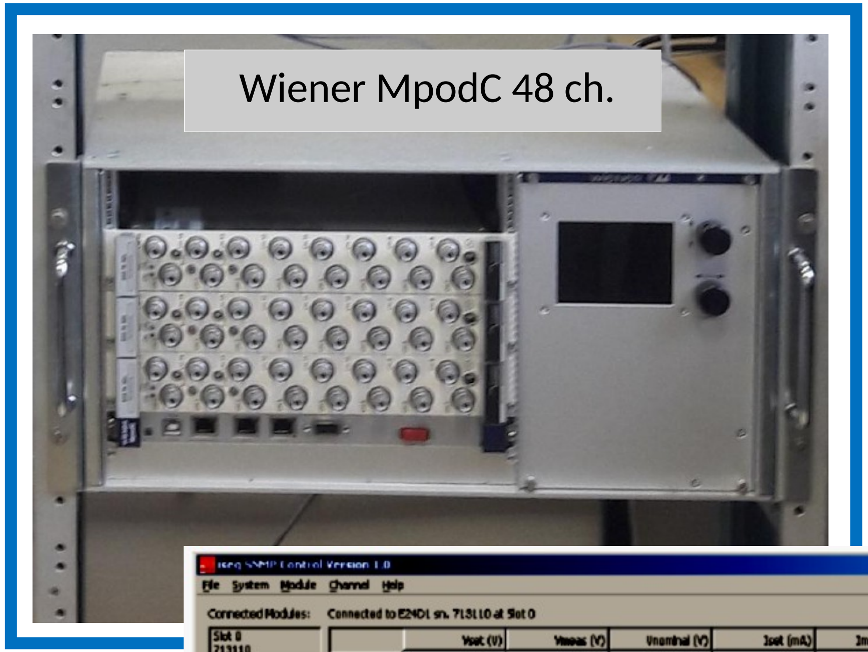
Current status:

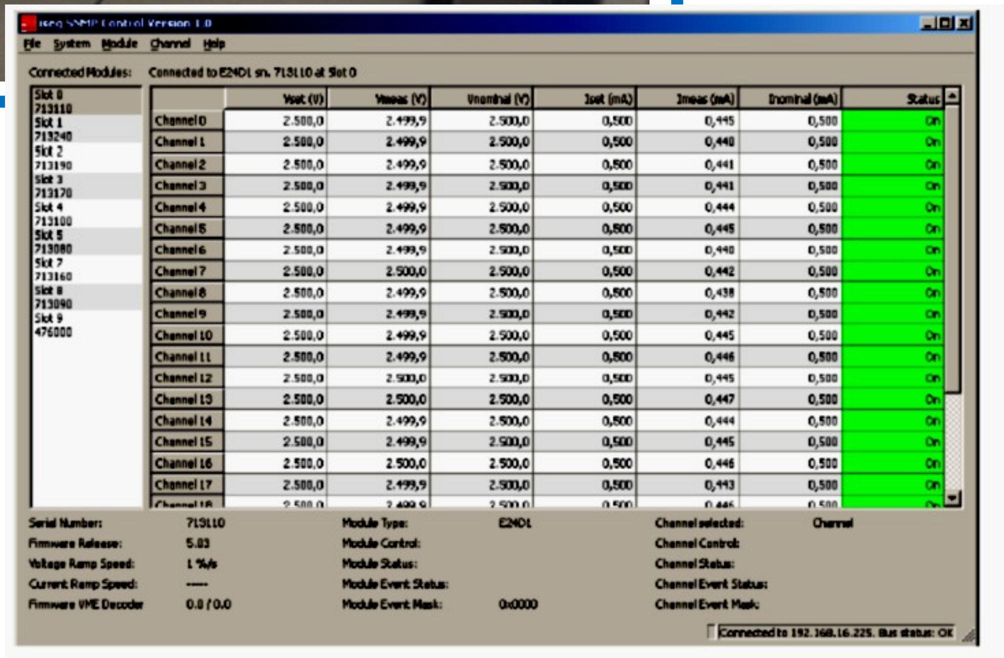
- all parts are available.
- multiplexers are tested

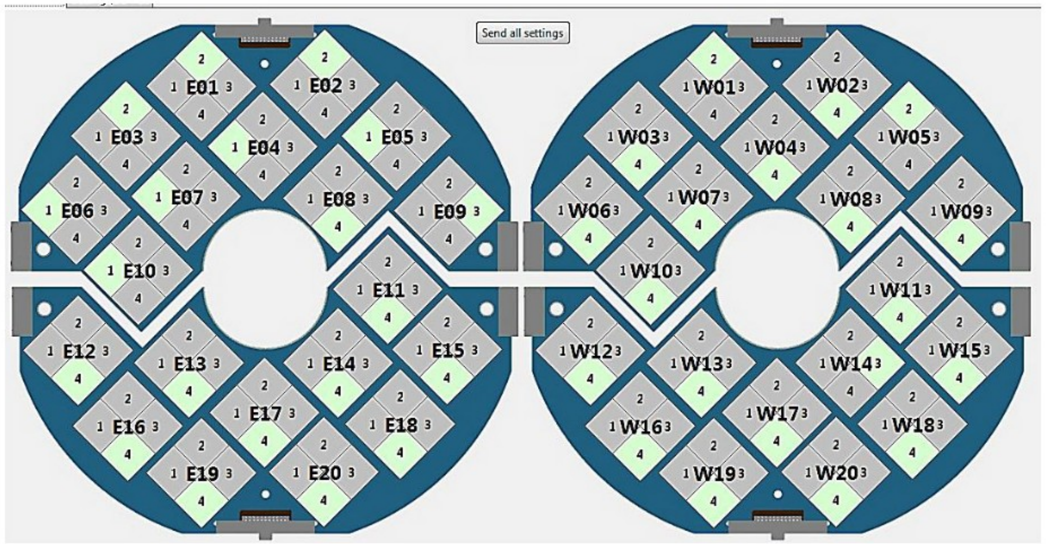
Not ready:

- chain readout of several CAEN N6742
- customized interface

High voltage system





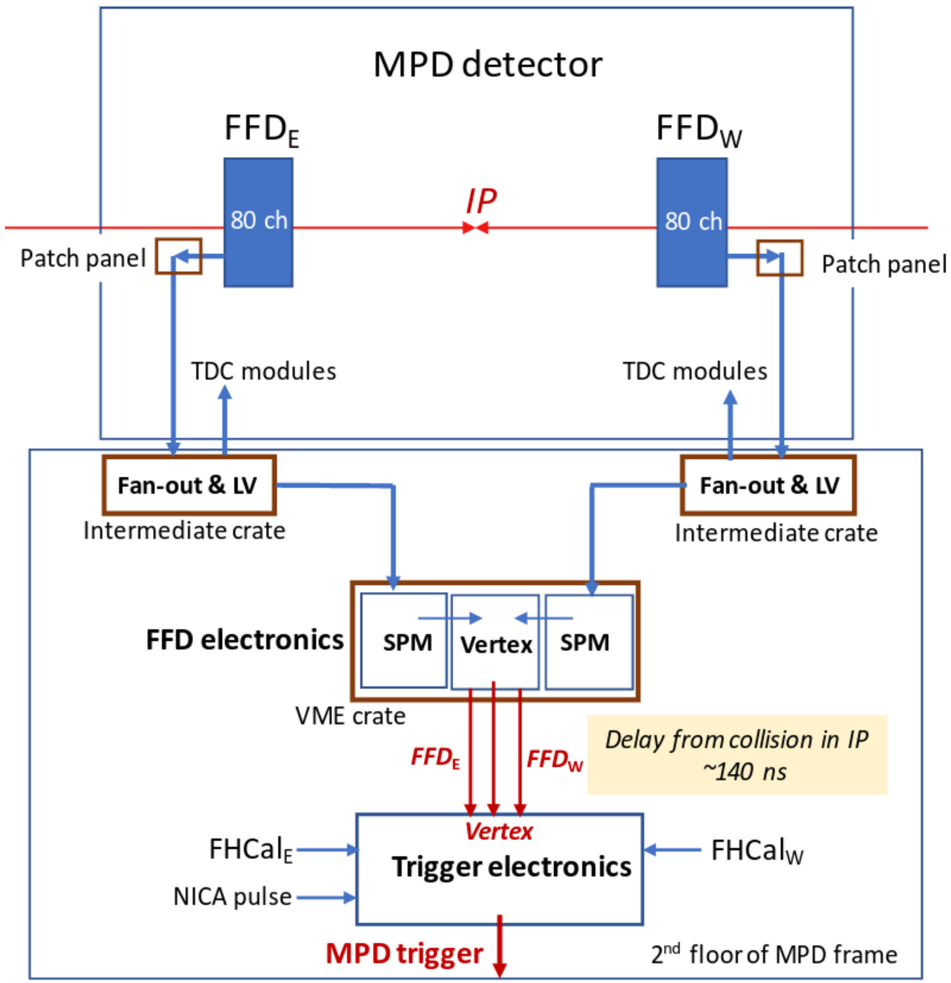


High voltage interface

Current status:
ready for testing sets of modules

Read-out and trigger electronics

Pavel Grigoriev
Sergey Sergeev

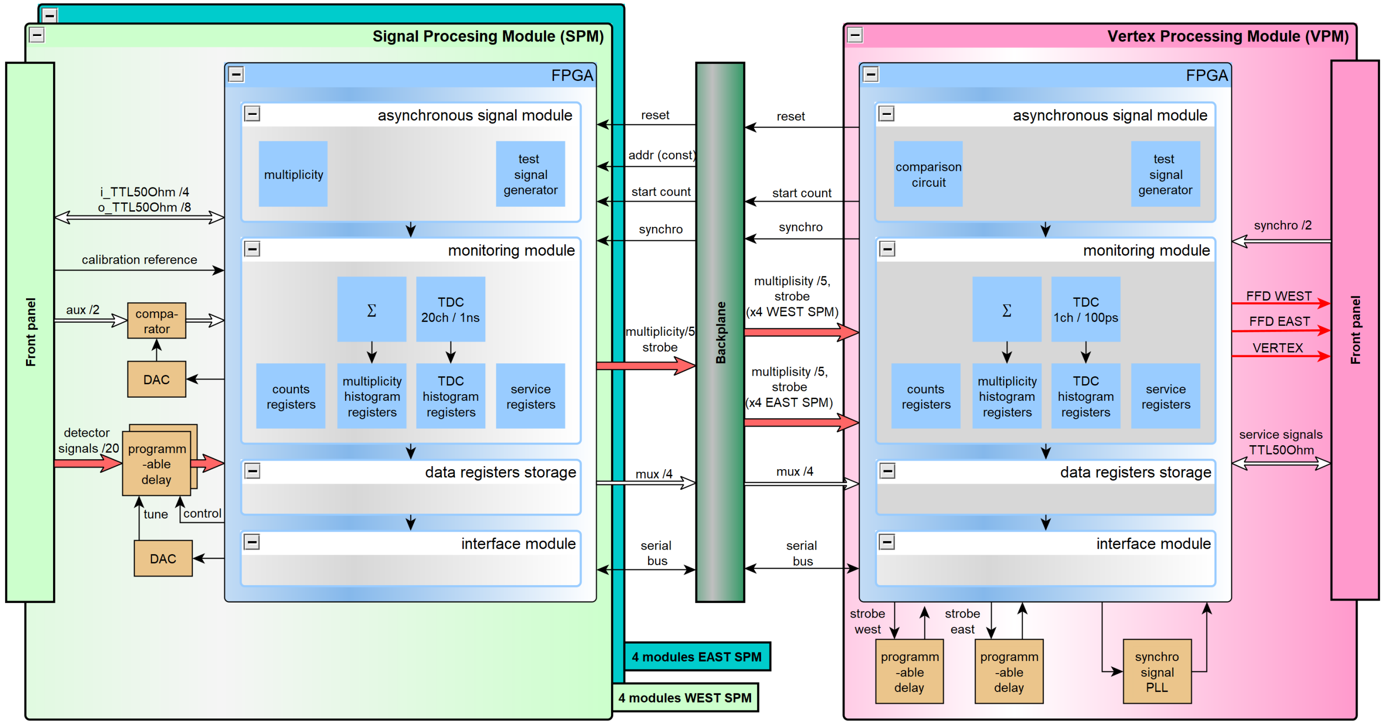


TDC: 10 modules TDC72VHL, ready (DAQ group)

Fan-out & LV: ready (Dec.2023 – Jan.2024)

SPM (Signal Processing Module): 2 out of 8 ready for testing

VPM (Vertex Processing Module): design finished, all parts available



Tests with the laser system

Sergey Sedykh
Nikita Lashmanov

Uniformity of 2 x 60 splitting (11.2018)
within ±20%: East 35/60, West 29/60

Quadrants comparison and cross talk (12.2018)
small diagonal cross talk

Uniformity of split within FFD module (07.2020)

Comparison of TDC channels (08.2020)

Jitter in BM@N trigger module fan-out (09.2020)

Different HDMI cables, type and length (10.2020)

Check of remade HDMI cables (12.2020)

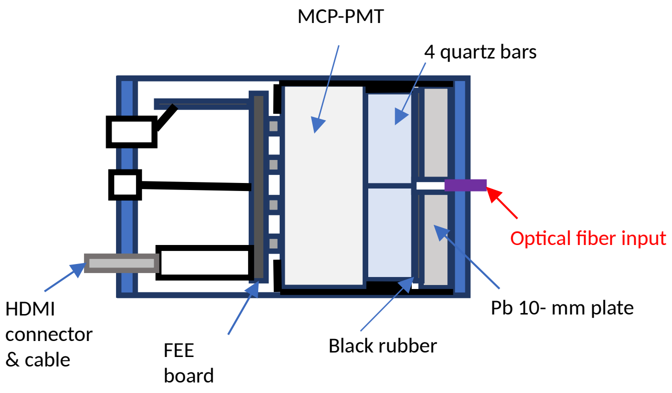
Different FEE amplification (12.2020)

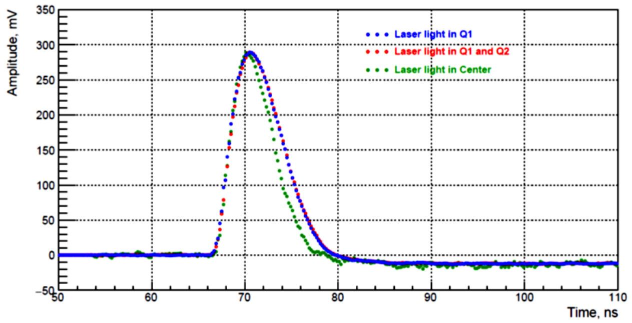
Test of all East modules (04.2021)
2 out of 20 had some faults

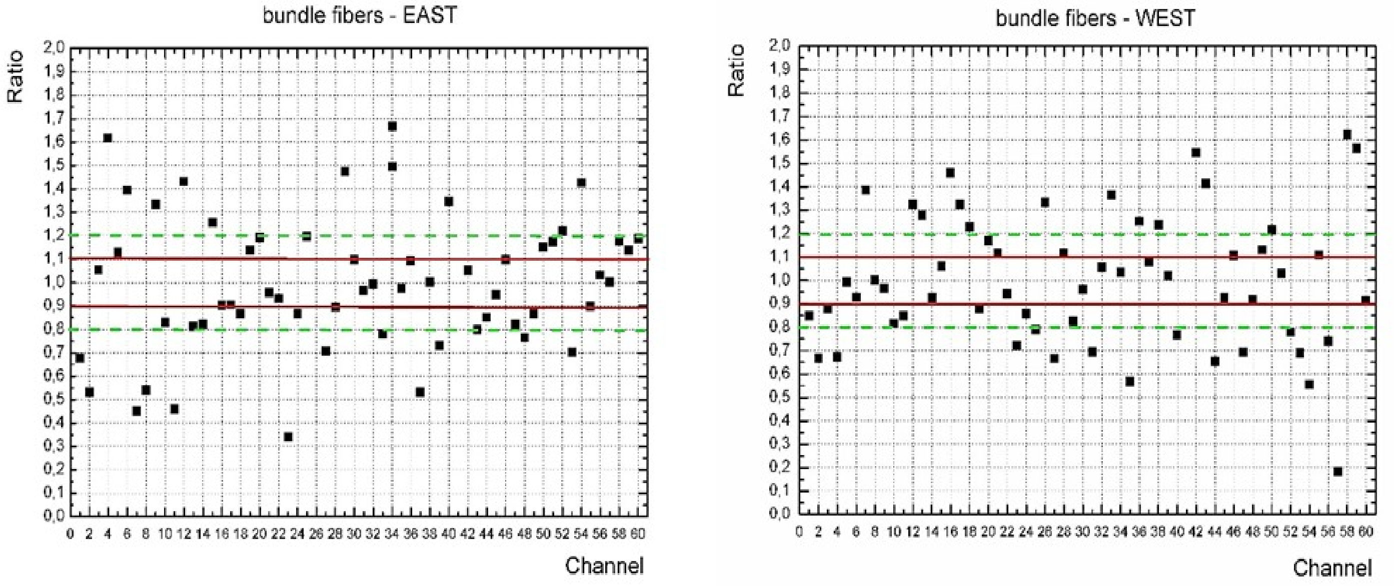
Test of multiplexers (08.2021)

Test of all West modules (10.2021)
2 out of 20 had some faults

Plans for spring-summer 2024:
test FFD fan-outs, SPM, VPM

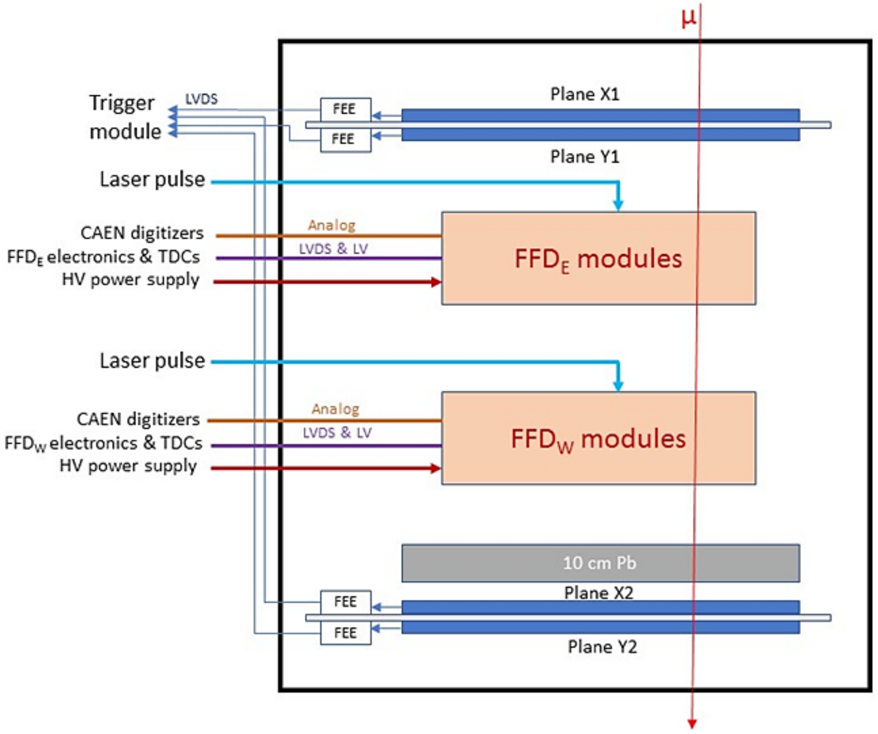






Special stand for tests of FFD with cosmic muons

A special stand was created in 2018 for test measurements with the FFD modular arrays and all FFD sub-systems to study FFD operation and performance



A scheme of the stand for tests with cosmic muons

Production of the scintillation planes

Each scintillation plane has dimensions 50 × 50 × 1 cm^3 and consists of 10 strips. Crossing of the strips of X- and Y- planes on the top and bottom of the stand provides information about direction of incoming cosmic muons.
The scintillation light is detected with two SiPMs placed on the strip's ends.

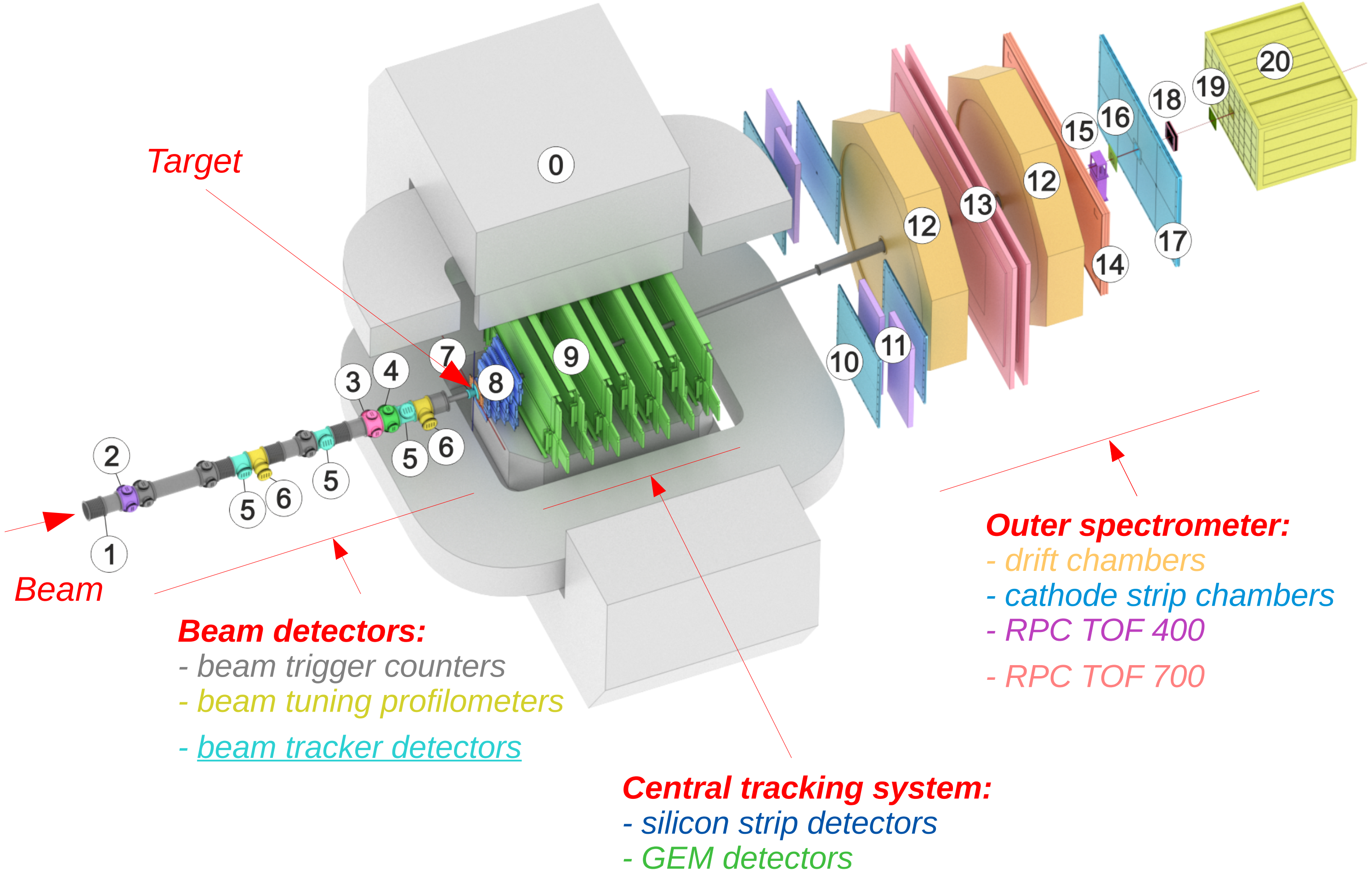
The stand sub-systems:

- Four scintillation planes with electronics
- Trigger module (FPGA Altera Cyclon V)
- HV crate
- readout electronics (TDC72VHL)
- readout electronics (digitizers CAEN mod.N6742)
- Laser system
- Control system

Planned Tests for 2024

- Combined time resolution by group of modules
- Laser vs Cosmic muons pulse height
- Test of readout and trigger electronics
- Long-term test (need temperature control)
- Cable and fibers lay-out is non-trivial

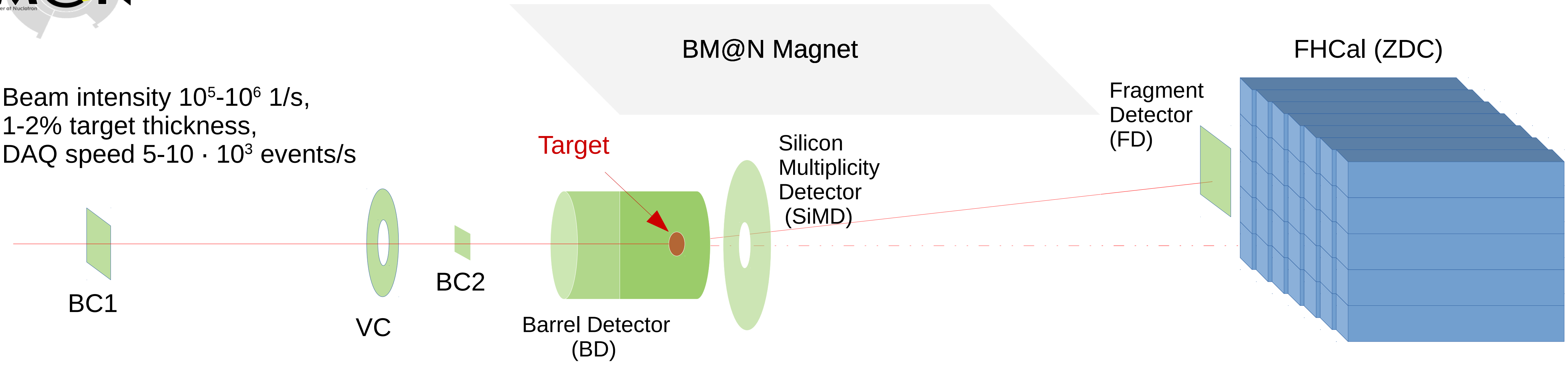
Configuration of BM@N detector in ^{124}Xe run (Jan. 2023)



- 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)

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

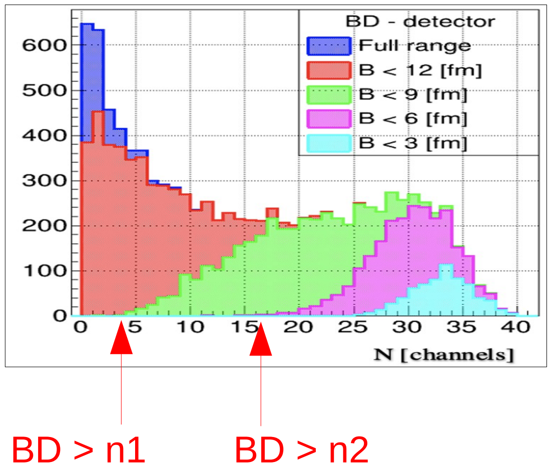


Trigger type	Trigger logic
Beam Trigger (BT)	BT = BC1 * VC_{veto} * BC2
No Interaction Trigger (NIT)	NIT = BT * FD
Min. Bias Trigger (MBT)	MBT = BT * FD_{veto}
Centrality Trigger 1 (CCT1)	CCT1 = BT * BD(>n1) * SiMD(>m1)
Centrality Trigger 2 (CCT2)	CCT2 = MBT * BD(>n2) * SiMD(>m2)

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.

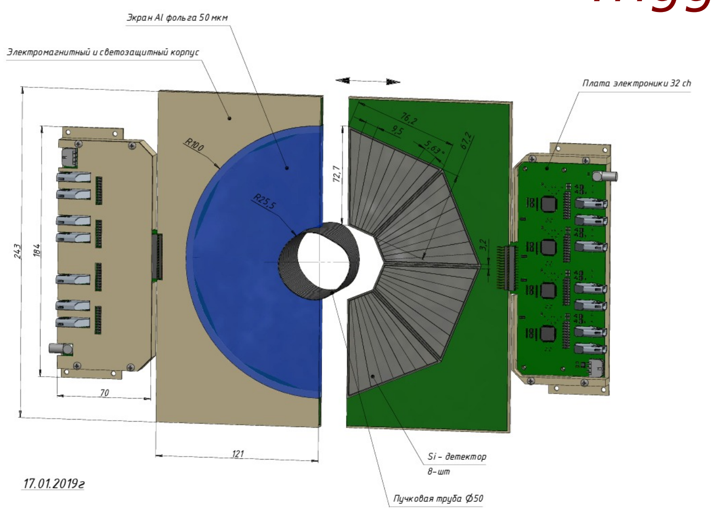


Beam pipe and detectors upstream of the target

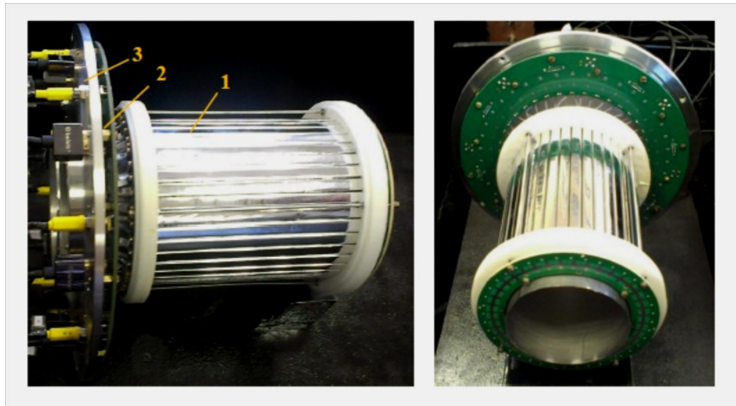
Kubankin A.
and Belgorod team

Piyadin S. and Co.

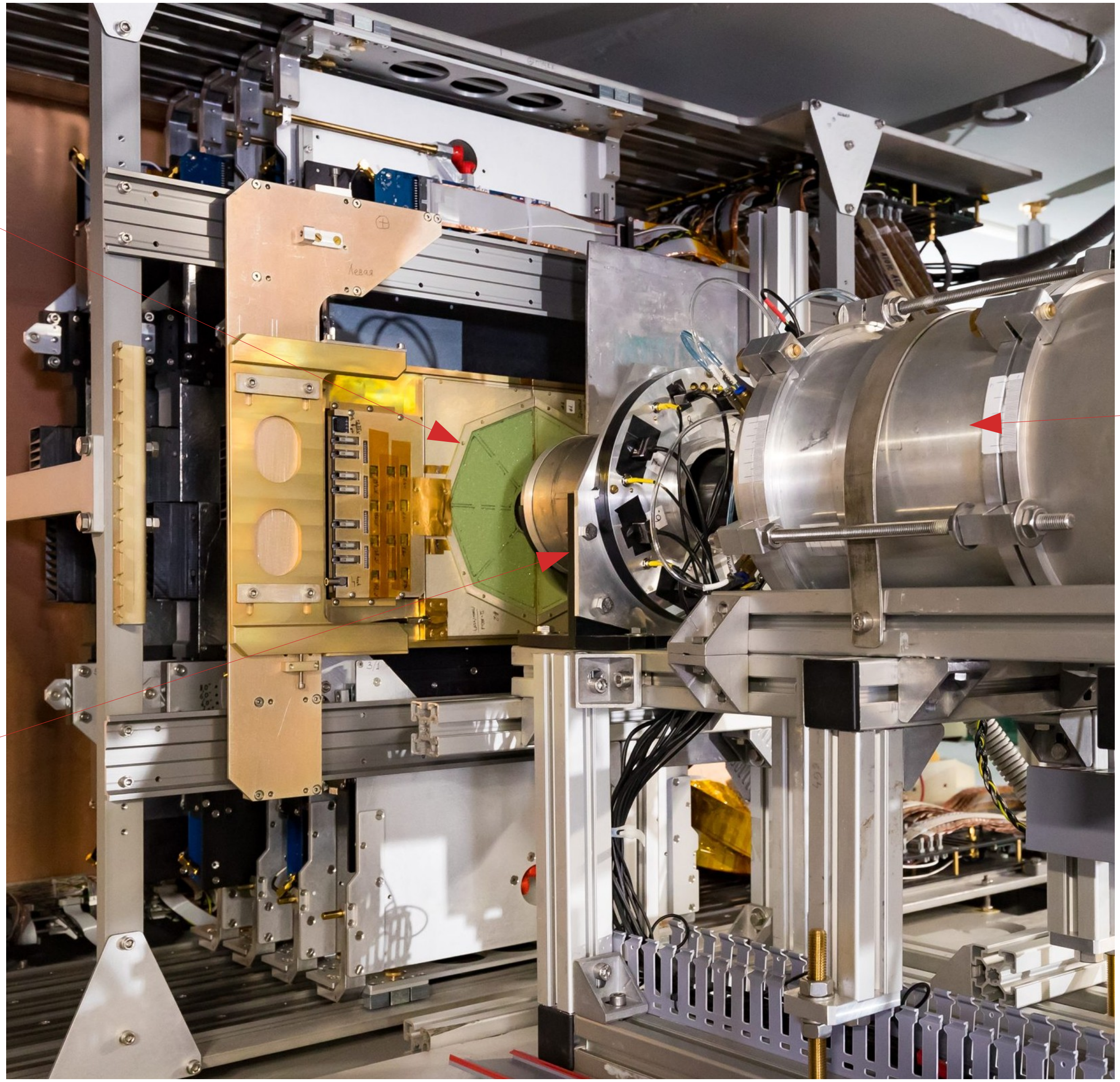
Trigger multiplicity detectors in the target area



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

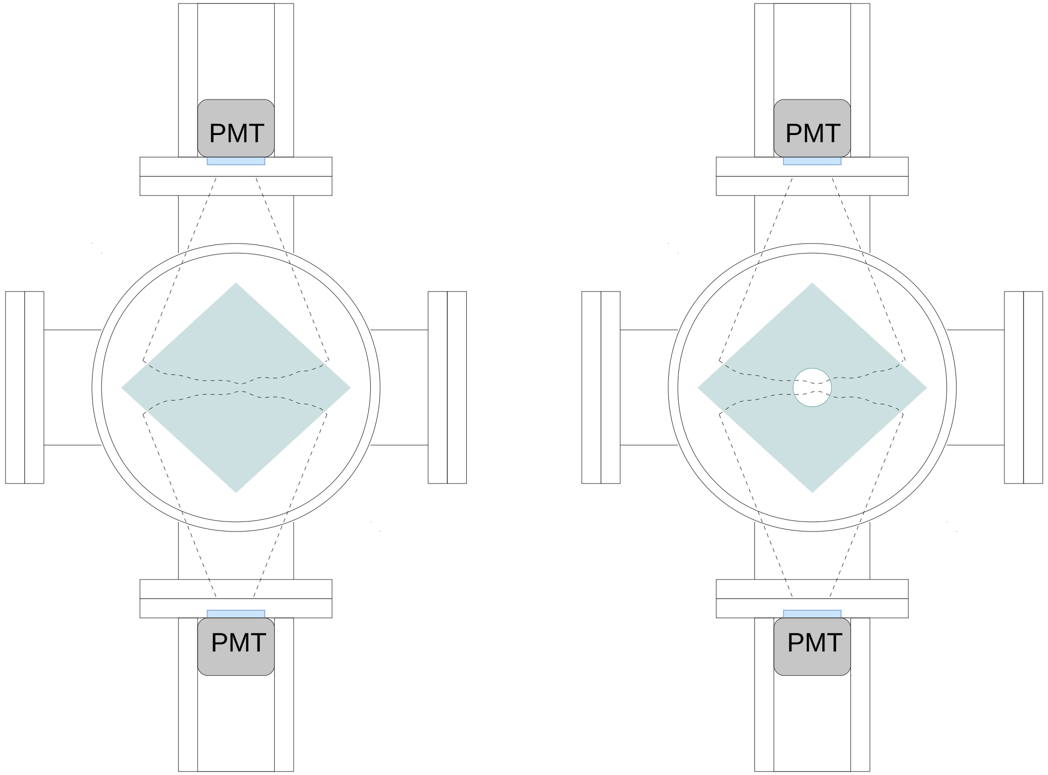


Barrel Detector (BD):
1 – 40 scintillation strips, 150 x 7 x 7 mm, BC418
2 – the board with SiPMs, Sensl C-series, 6 x 6 mm
3 – the board of front-end electronics.



Beam

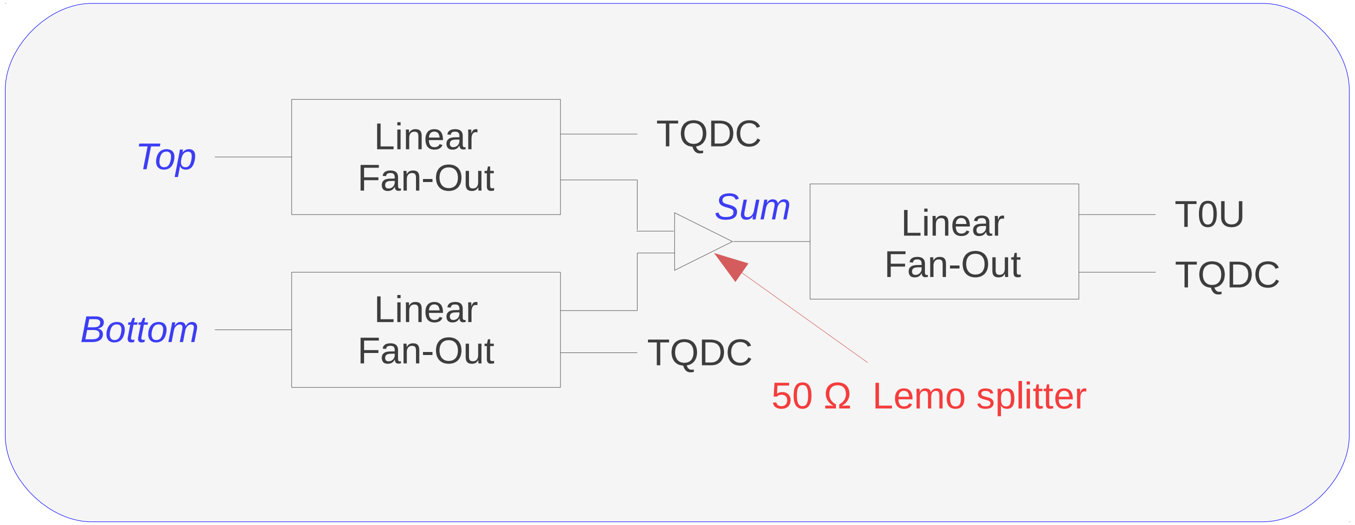
Design and read-out of BC1, VC



Vacuum components
made by the Belgorod group

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

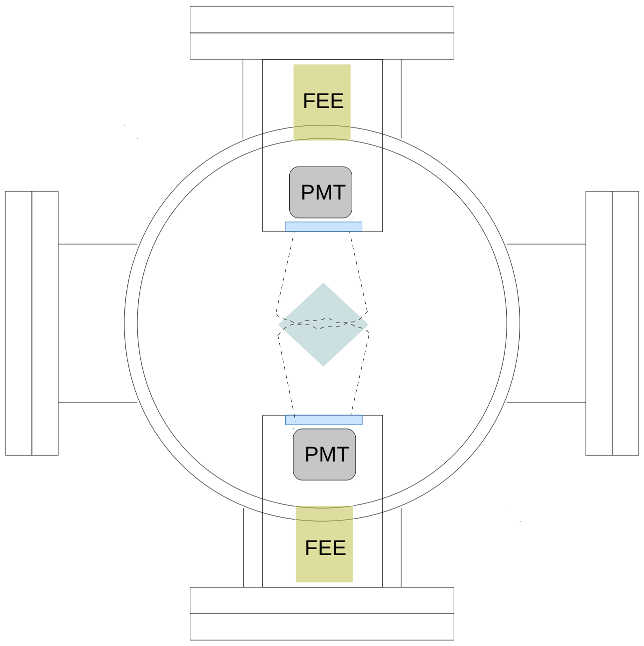
“Air”-lightguides from Al-mylar



Design and read-out of BC2

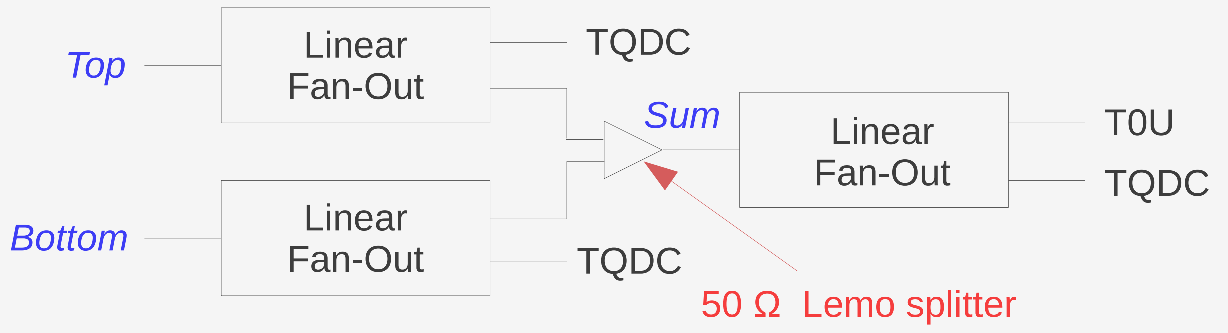
Detector	PMT	Radiator
BC2	Photonis XPM85112/A1 Q400 25x25 mm^2	Scint. BC400B 34 x 34 x 0.15 mm^3

“Air”-lightguides from Al-mylar



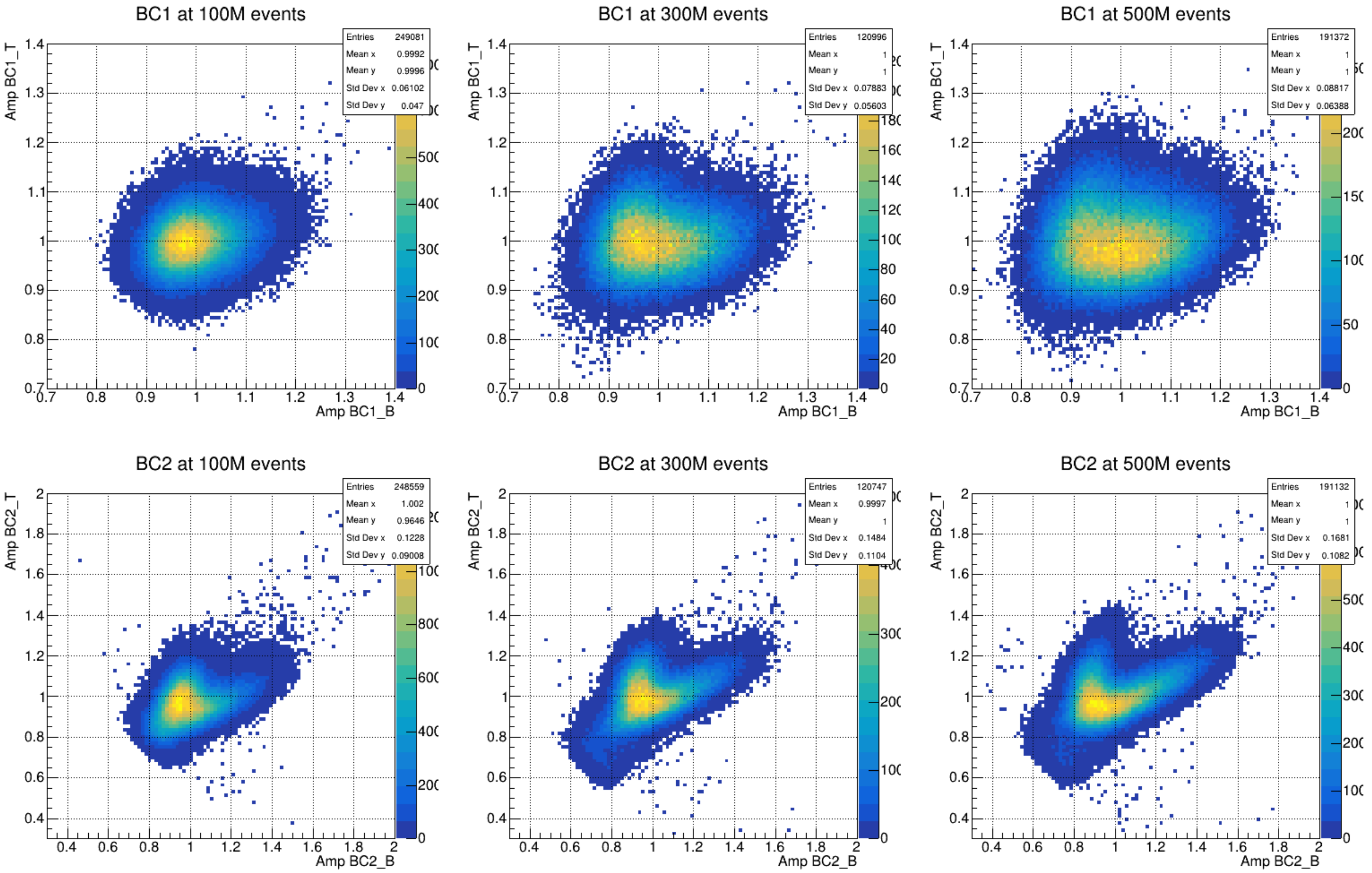
Vacuum components made by the Belgorod group

Two signals from each PMT: Anode and MCP



Additional read-out of LVDS signals from FEE into TDC72VHL.
Both, TQDC and TDC provide high resolution timing.

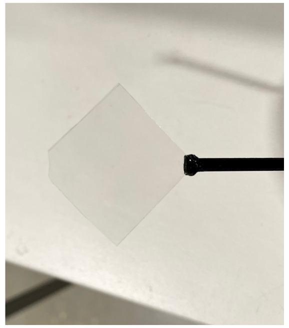
Indication of radiation damage in BC1 and BC2



More pronounced in BC2

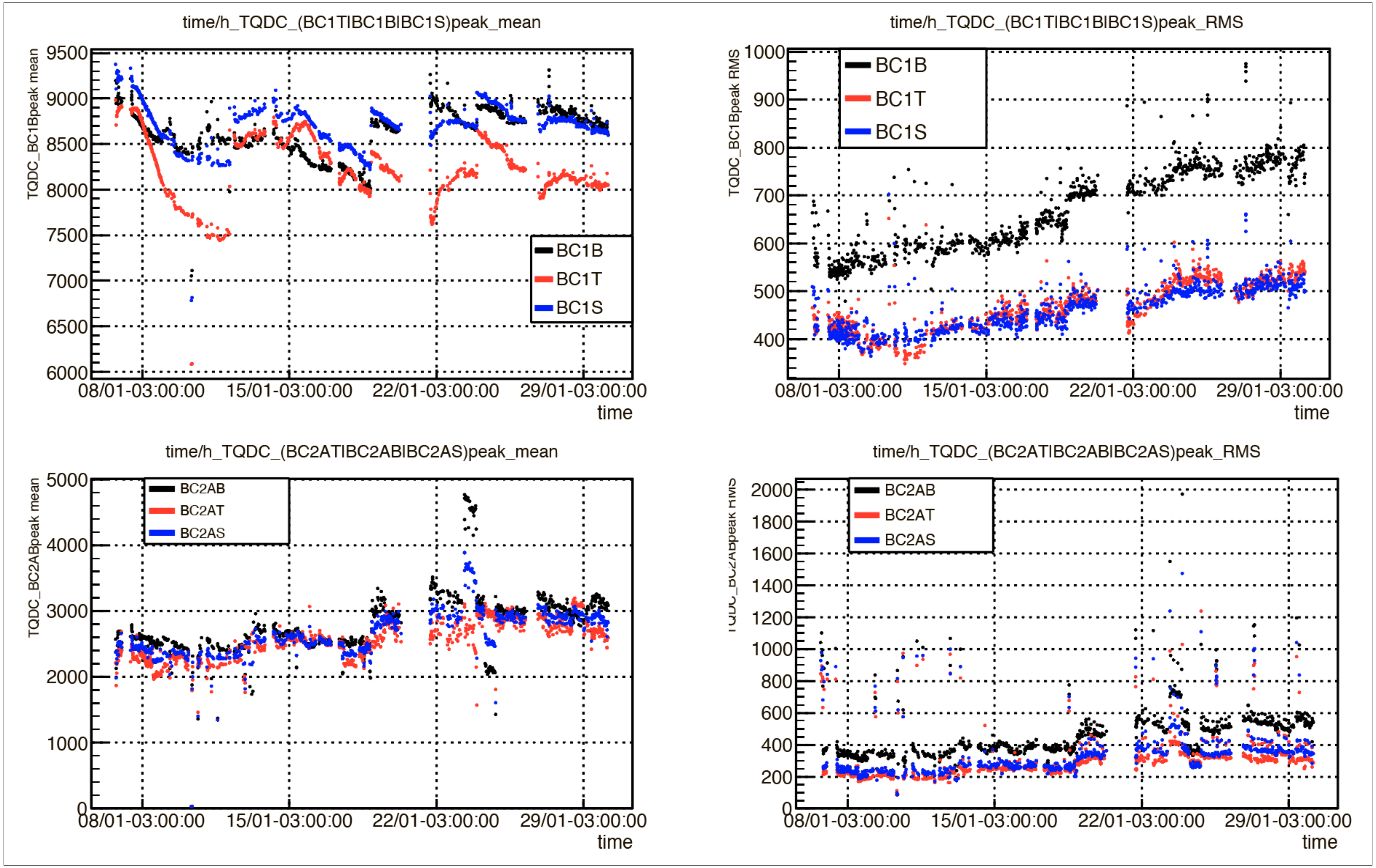
Might require scintillator change during the run

Cherenkov prototypes are hard to test without heavy ion beams



No visible loss in transparancy of the BC2 scintillator. Study is planned by the LPI RAS group

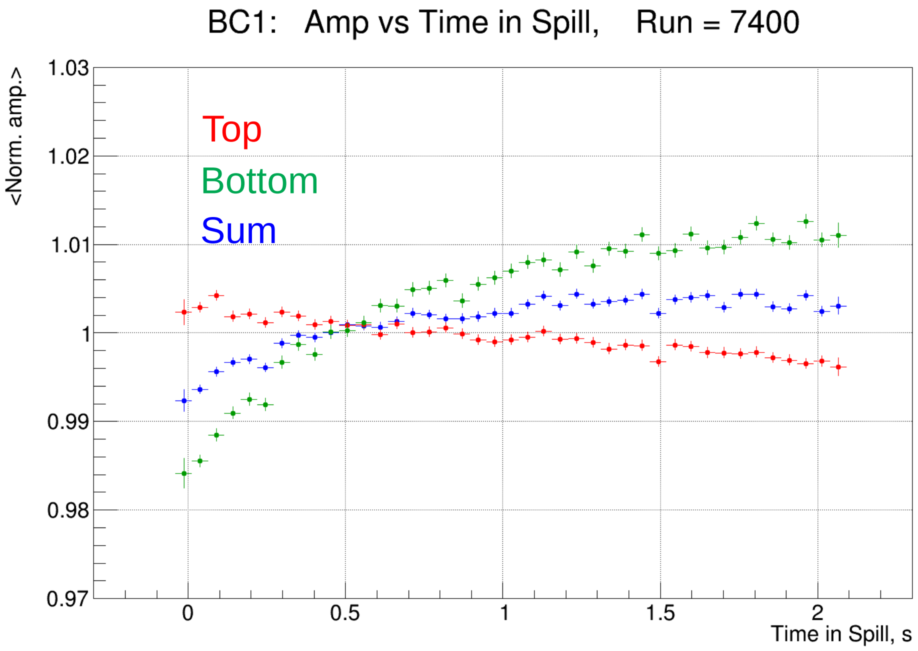
Monitoring of BC stability during the run
(*some increase in HV was needed*)

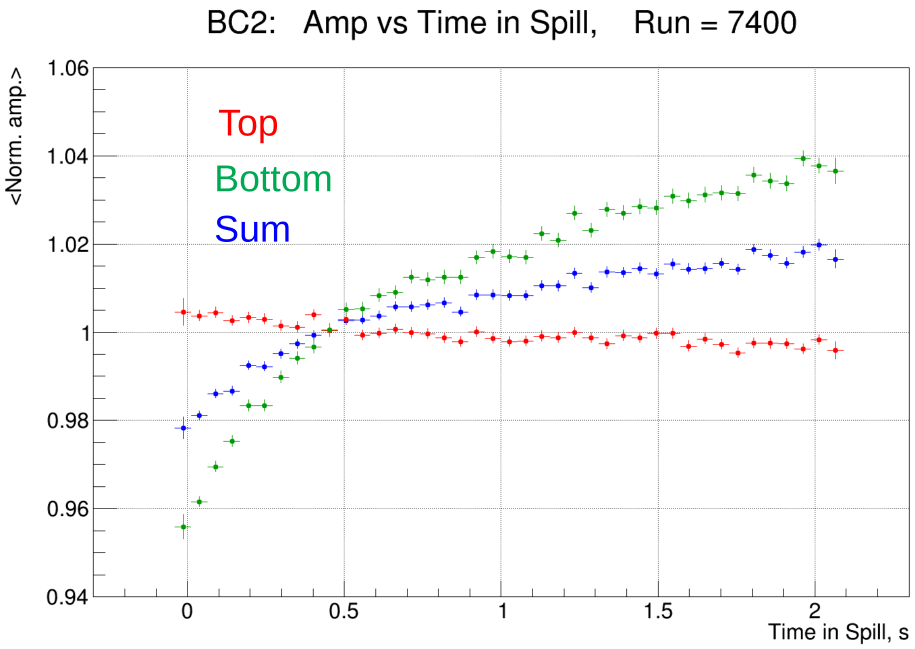


Oleg Golosov
MEPhI-group

Trigger detectors online monitoring
I. Gabdrakhmanov

BC1 and BC2: Amplitude stability in spill. Offline resolution





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

Offline amplitude resolution

Detector	σ (%)
BC1	4.8
BC2	7.1

Good resolution of BTr3 is very important for offline rejection of upstream interactions

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 (prepared by V.Velichkov).

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

Resolution of BC2 is good enough, but poorer than expected for this type of PMT.

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

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

i,j: BC1, BC2, FD1

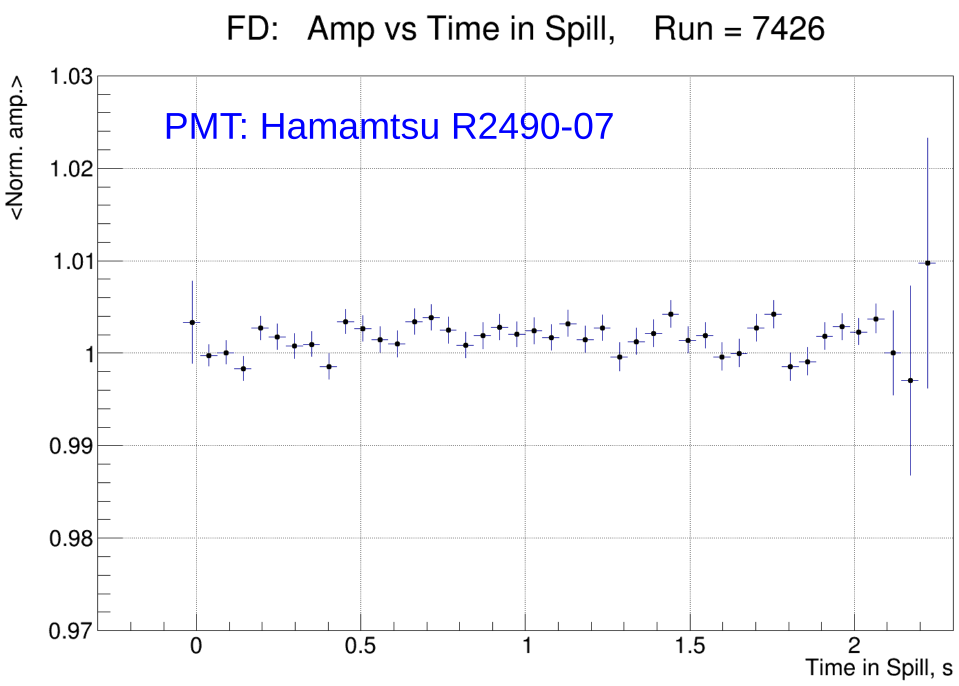
Detectors	σ_{ij}, ps
BC1 - BC2	57
BC1 - FD1	61
BC2 - FD1	58
(BC1&BC2) - FD1	52

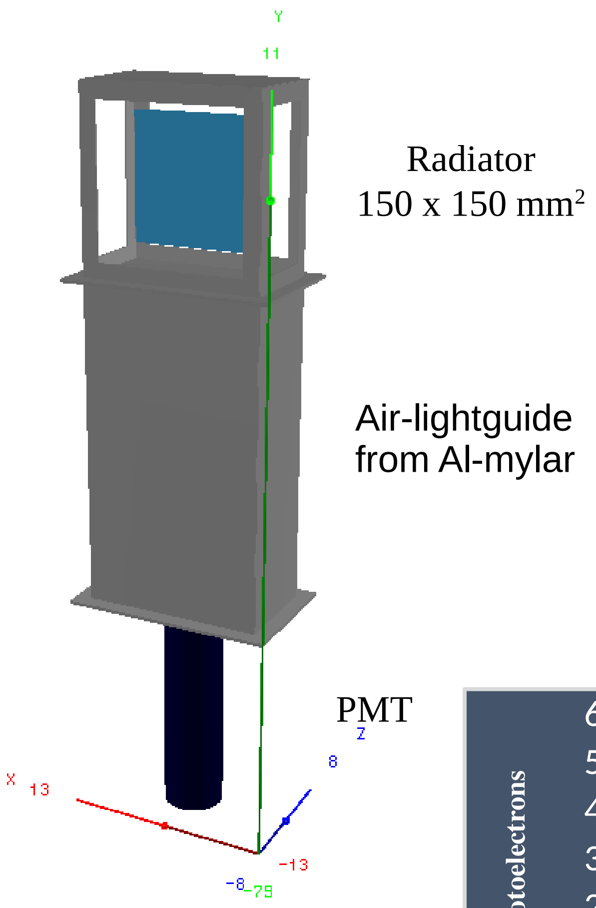
Detectors	σ_i, ps
BC1	43
BC2	38
FD1	44
(BC1&BC2)	28.2
	28.5

FD design and response

Nikita Lashmanov, Vladimir Yurevich

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	9.1 → 6.7 → 5.3





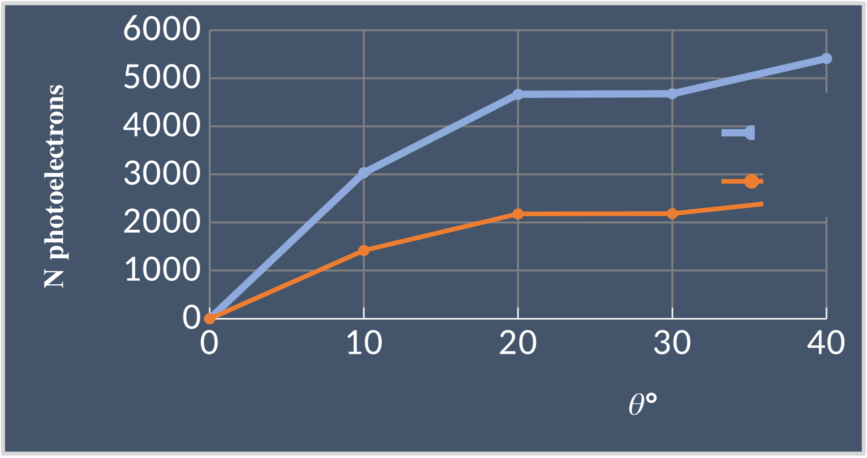
Non-stable base for XP2020 at the beginning of the spill

Significantly better resolution with scintillator radiator

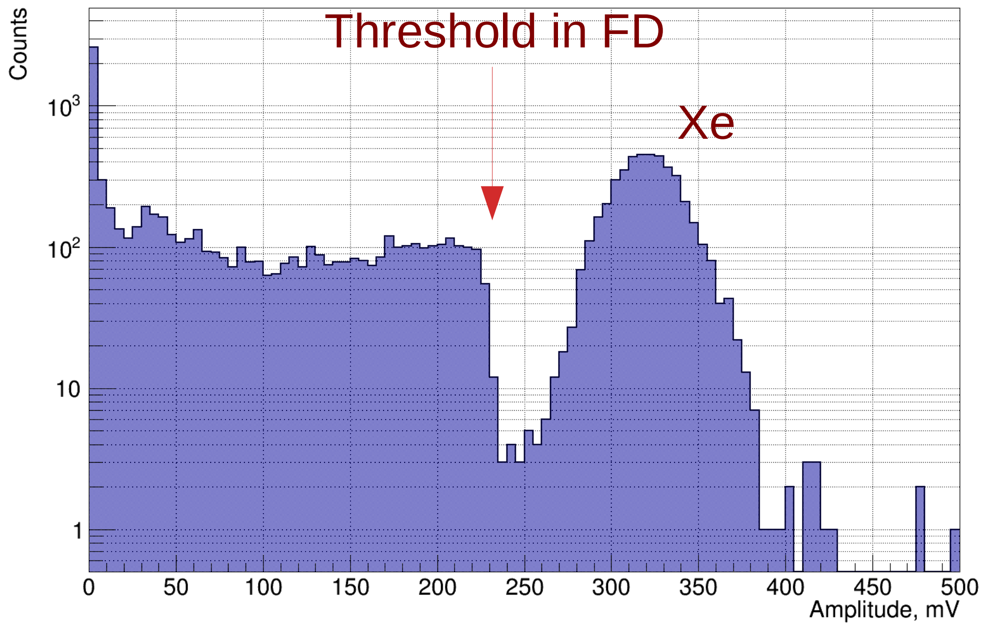
Less than expected photoelectron statistics with the quartz radiator

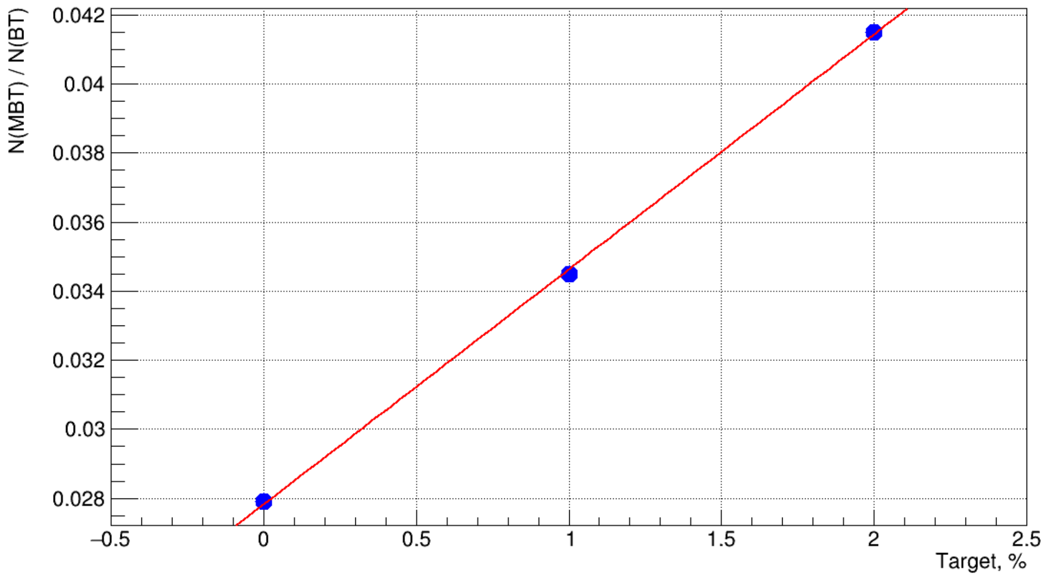
Quartz hodoscope has 2% resolution (FHCal group) and will be used in offline analysis

Simulation (N.Lashmanov)



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



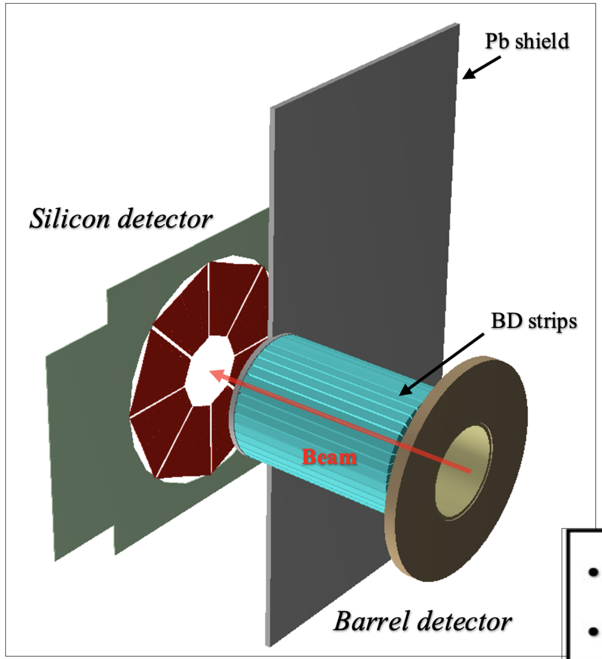


Even with conservatively low threshold
in FD amplitude, typical ratio of N(MBT) / N(BT)
for 2% target was ~0.04,
i.e. with significant background

Good linearity with Empty, 1%, 2% targets;
N(MBT) / N(BT) for “empty target” ~0.028

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

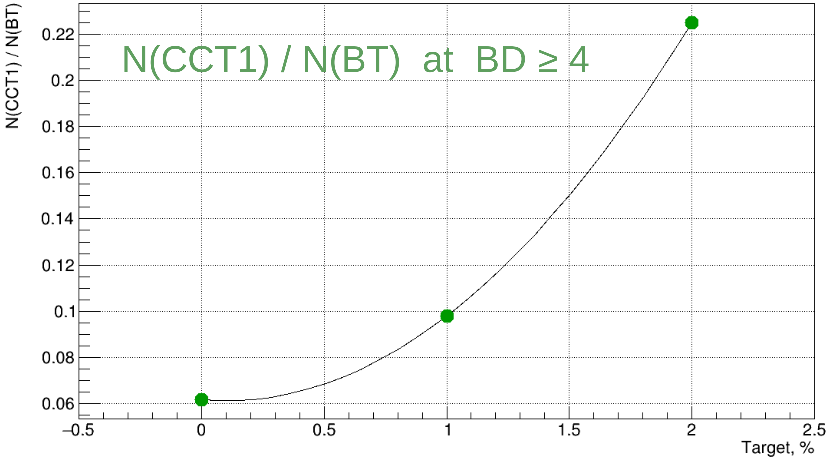
Response of Barrel Detector and trigger CCT1 = BT • (BD≥n)



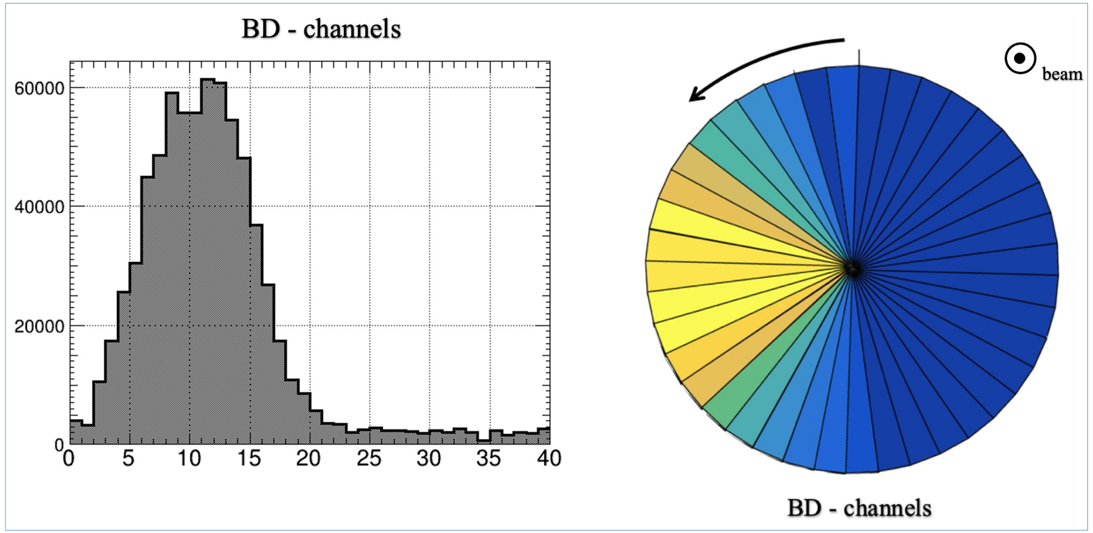
Even with added Pb-shielding,
the background from δ-electrons is significant
and larger, than predicted by Geant4 simulations

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

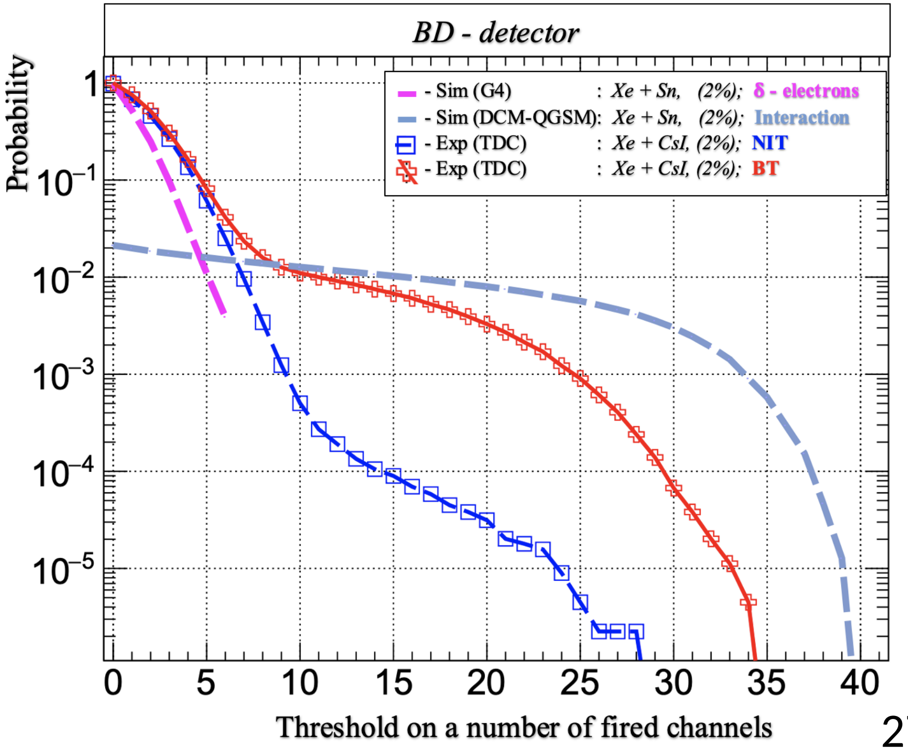
In addition, CCT1 rate is very non-linear
with 1% and 2% targets, indication of
high sensitivity to pile-up of beam ions



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



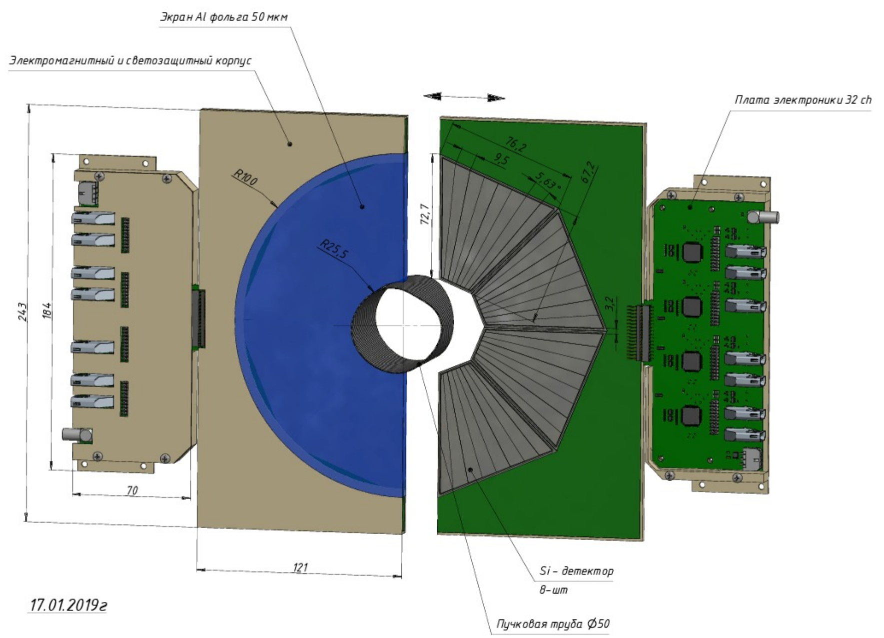
NIT
events



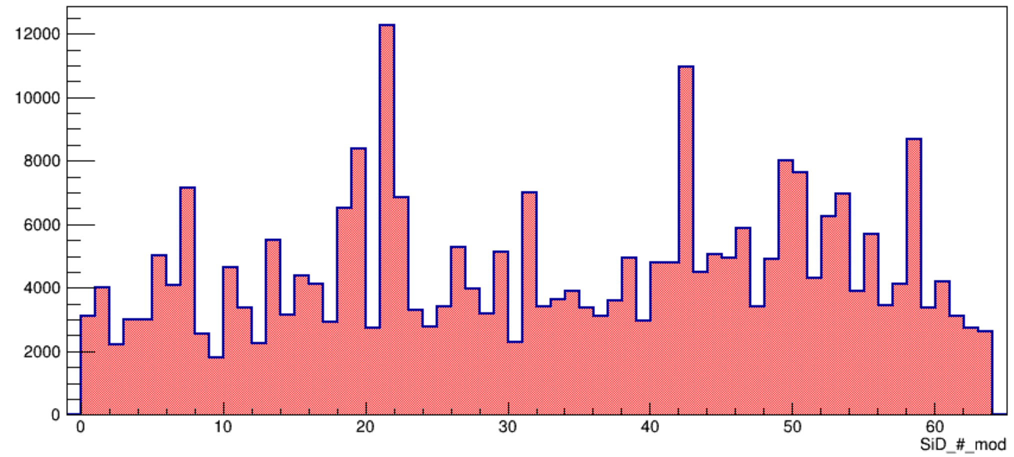
Response of Si Multiplicity Detector

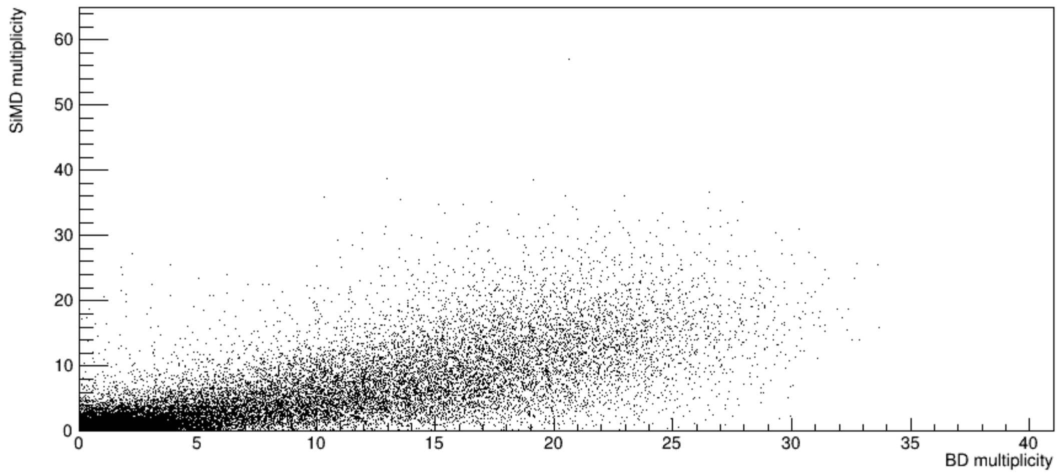
Group of N.Zamjatin

Xe Beam 3 GeV/n, data taking with MBT trigger



- all 64 channels are working
- clear correlation of hits multiplicity in SiMD and BD

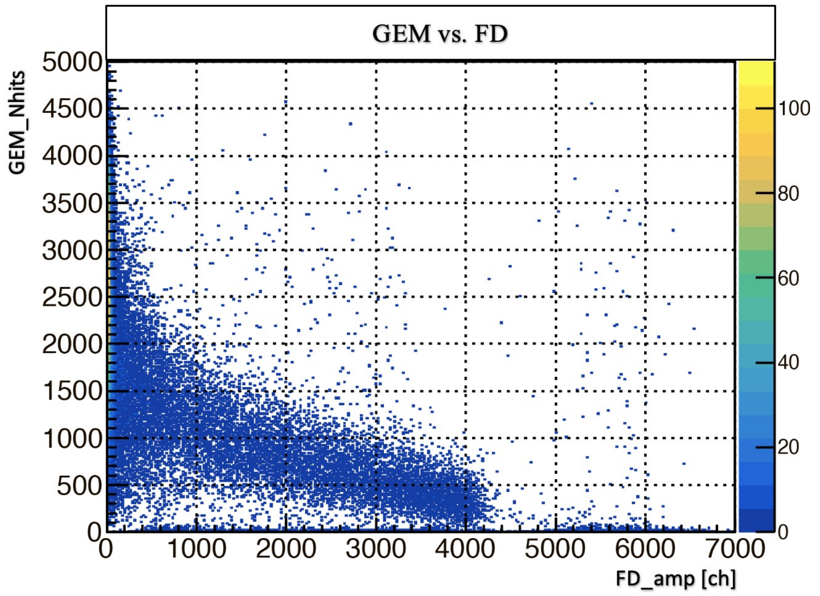




Detector parameters:
- opening for the beam. Dia. 50 mm
- 8 trapeziodal detectors
- 64 strips in total
- 525 µm thick

First look analysis by N. Lashmanov

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



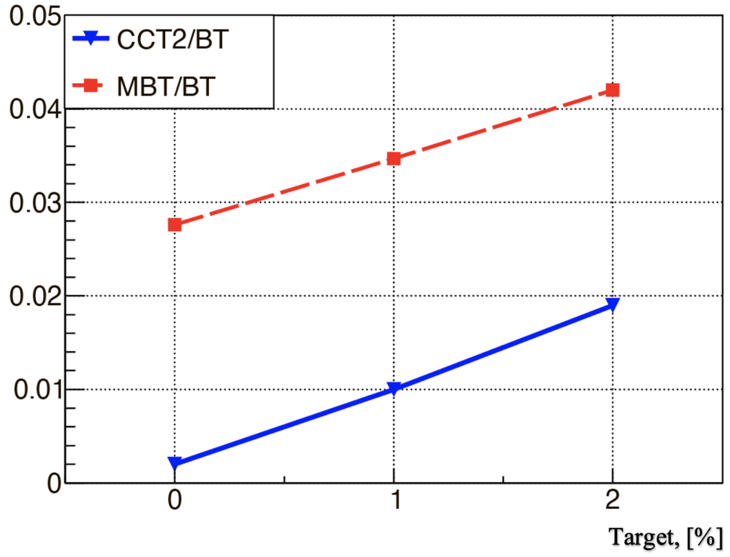
The backgrounds in triggers MBT and CCT1 are suppressed when MBT and CCT1 are combined in CCT2

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

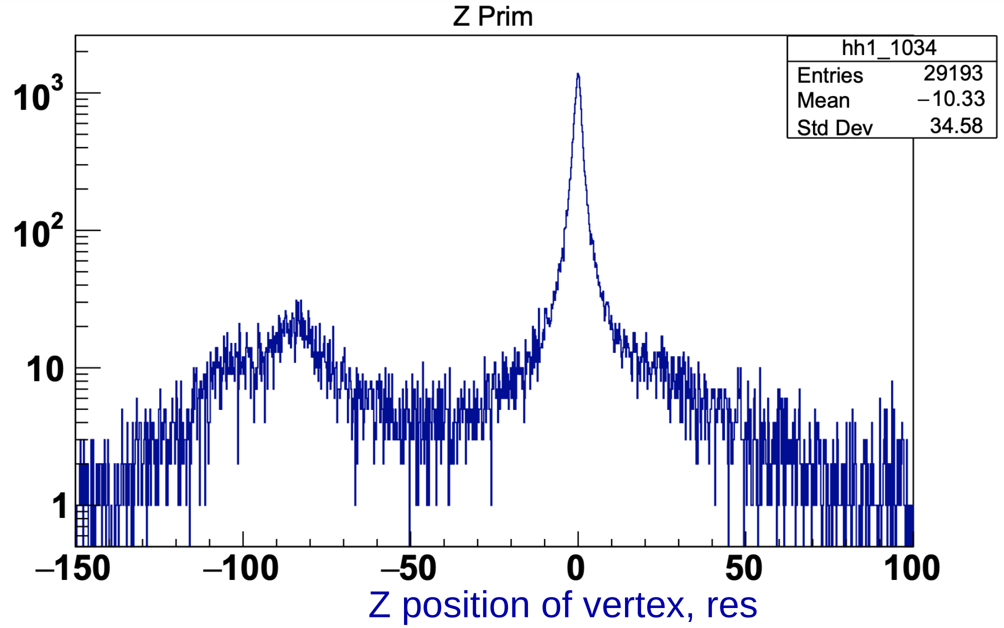
Estimated centrality of collected events ~70%

N(CCT2) / N(BT) at BD ≥ 4



“Regular” mix of triggers used in data taking

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



BM@N trigger 2023 Xe run: summary and outlook

In general, the trigger system can be used in the next run (assuming, Xe 2024) without major changes.

BC2: – replace scintillator with a fresh one;
– prepare mount for different PMT (BC1 type R2490-07, this will remove negative tail overshoot).

FD: – prepare stable base for XP2020/Q and make another test with the quartz radiator.

BD: – major redesign for Bi runs: two halves, more inner Pb-shielding, shorter scintillation strips

SiMD: – not needed used in heavy ion beams, complete analysis of the test data,
keep for future runs with light ion beams.

Beam trigger: – additional threshold on BC1 amplitude in order to veto pile-up of beam ions.

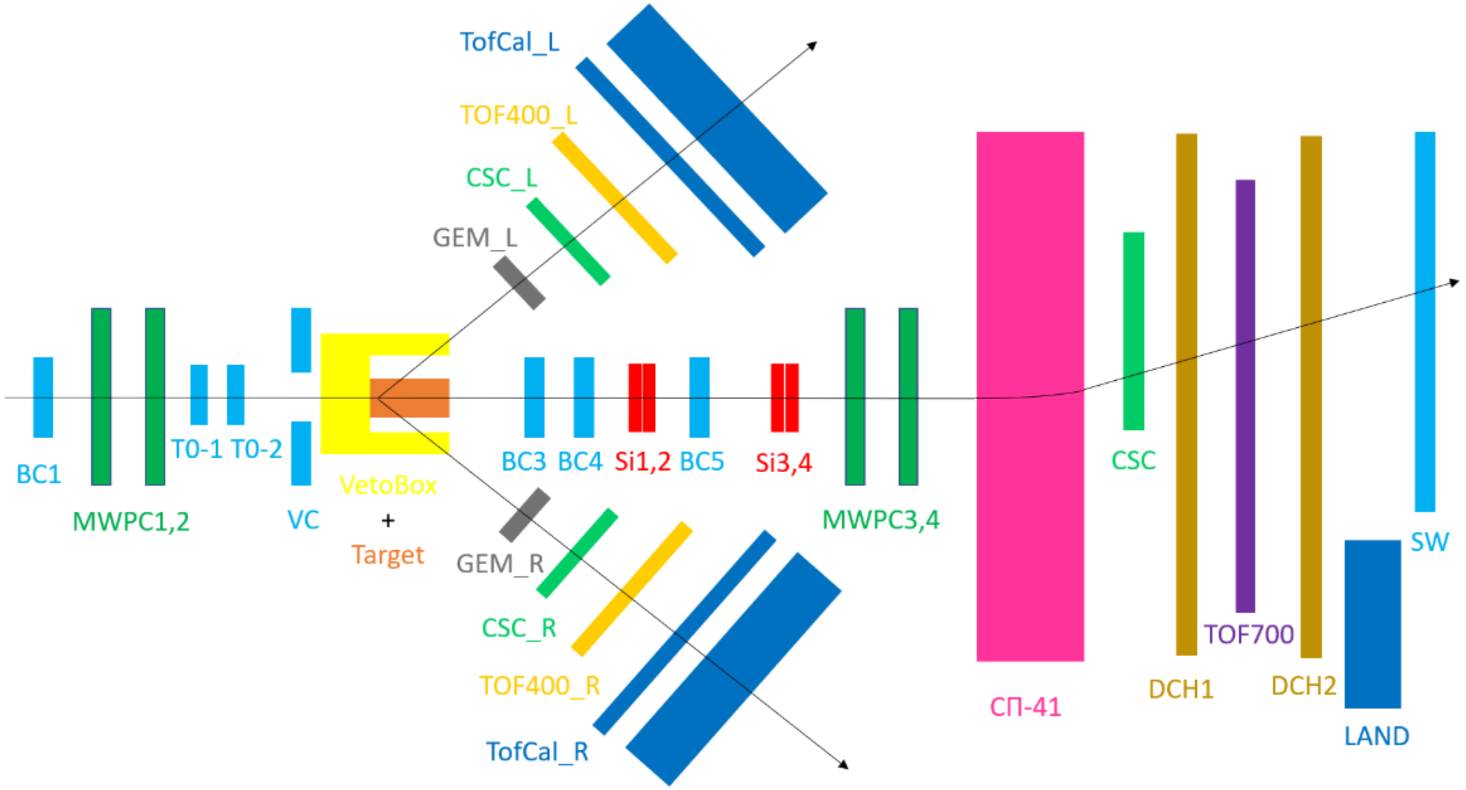
CCT1, CCT2: – no need to have two thresholds in the Barrel Detector.

MBT: – **add second threshold on FD amplitude, “soft” threshold in MBT and “hard” in CCT**.

Prototypes with Cherenkov radiators in BC1, BC2 and FD: design and prepare for testing in the next run.

SRC at BM@N setup in the 2022 run

$^{12}C + LH2$



Main reactions of interest:

$^{12}C(p,2p)$
$^{12}C(p,2p)^{11}B$
$^{12}C(p,2p)^{10}B$
$^{12}C(p,2p)^{10}Be$

Trigger detectors:

BC1, T0-1, T0-2, VC
BC3, BC4, BC5
TofCal_L, TofCal_R

Beam trigger (BT):
BC1 • T0-1 • T0-2 • !VC

ARM-AND trigger:
BT • TofCal_L • TofCal_R

Fragment trigger (not used):
BT • !BC3 • !BC4 • !BC5

Laser 10 Hz

Typical Trigger Mix:
ARM-AND + BT/700 + Laser

Spill ~*2.5 s*, Beam intensity ~$5{\cdot}10^5$ / spill, Event rate *3-5k/spill*
Background ^{12}C events in BC3 in ARM-AND trigger ~20% was considered acceptable

BC3-BC5 Preparation, Nov. 2021 – Feb.2022

T.Atovullaev, K.Alishina
with help from O.Gavrishyuk

Silicon glue
RTV615 Momentive

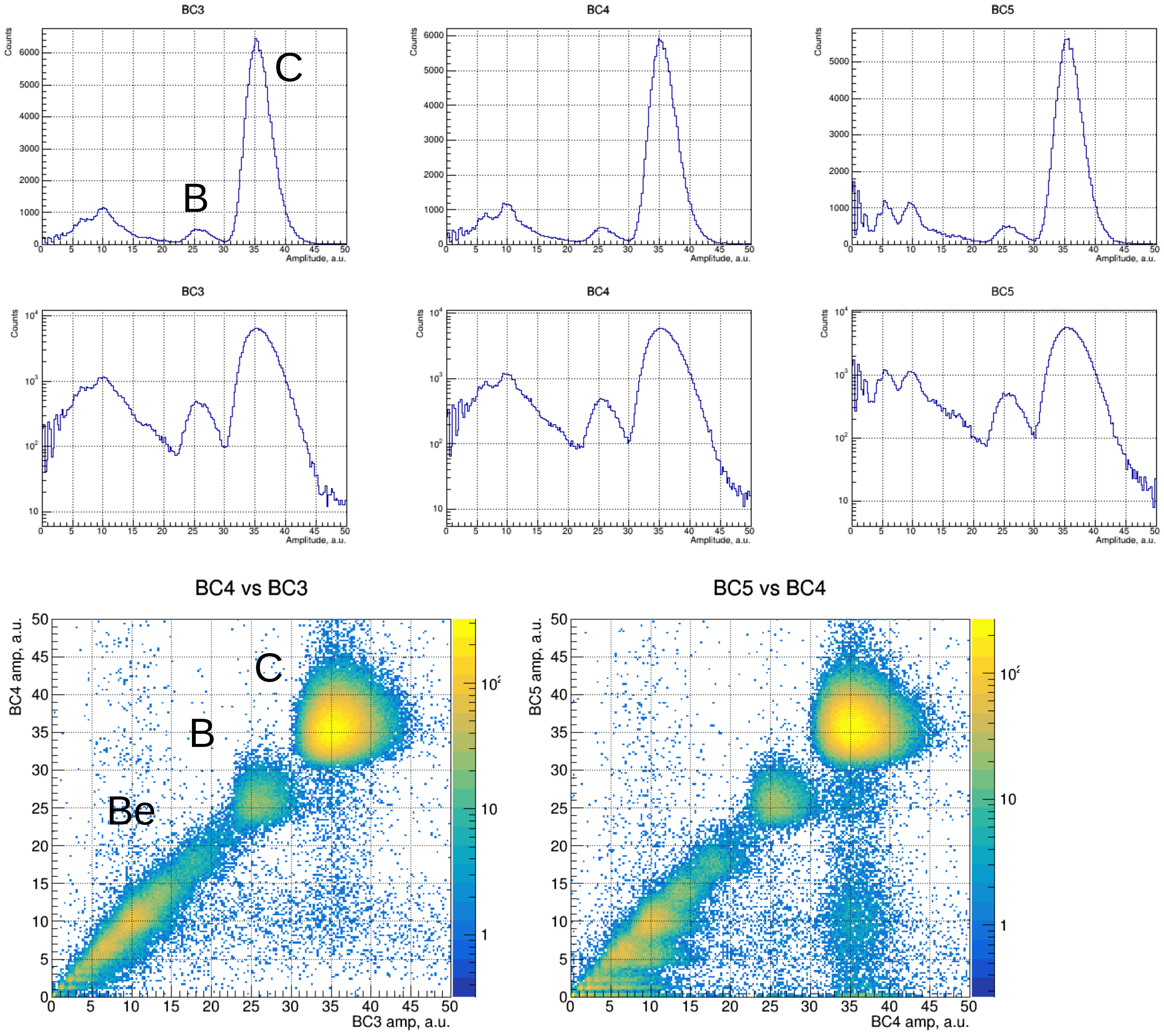
Light guides made
in TAU

Epoxy Polytec EP

Beam

Pre-Run tests: response to cosmics,
PMT stability with Laser (100 Hz) + LED (10Hz–10MHz),
several “Dry runs” with Laser trigger and full DAQ read-out.

BC3-BC5 amplitude resolution



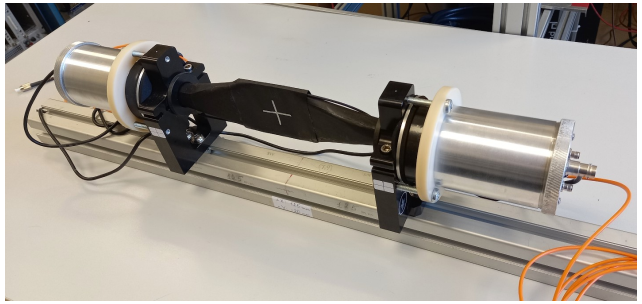
PMT: R7724-10
Scintillator: BC408

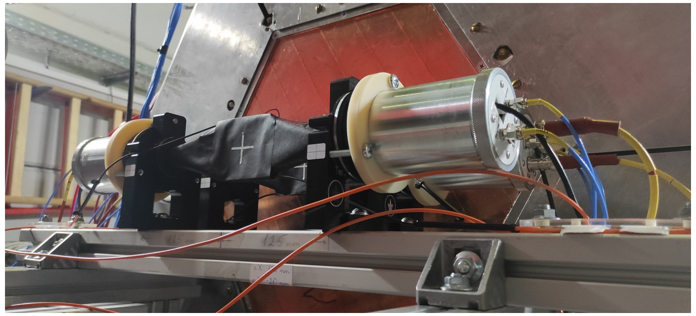
BC3, BC4: 100 x 100 x 3 mm^3
BC5: 100 x 100 x 5 mm^5

As expected, BC3-5 show clean "C","B" separation in both, online data taken with CAEN and detailed offline TQDC analysis performed by T.Atovullaev and Stepan Cherepanov (MSU student)

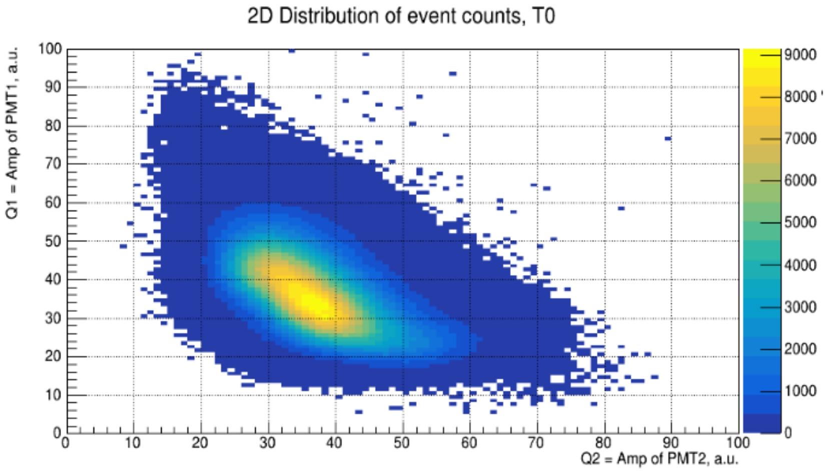
Plan to check possible improvement if one adds XY non-uniformity correction using tracking

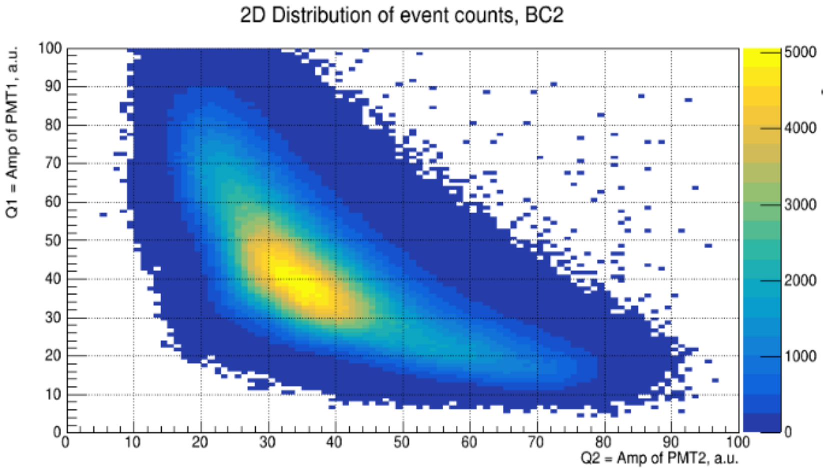
T0-1, T0-2 time resolution





Installed in the beamline





MCP PMT:
Photonis XPM85112/A1 Q400

Scintillator: BC418
Size: 60 x 60 x 1 mm^3

Unexpectedly non-uniform light collection, and low photostatistics

Time resolution (ps):

T0-1	65 ± 5
T0-2	55 ± 5
T0	**46 ± 5**
BC3	48 ± 5
BC4	69 ± 3
BC5	73 ± 3

T0 + BC3 ~30

Thank you for your attention