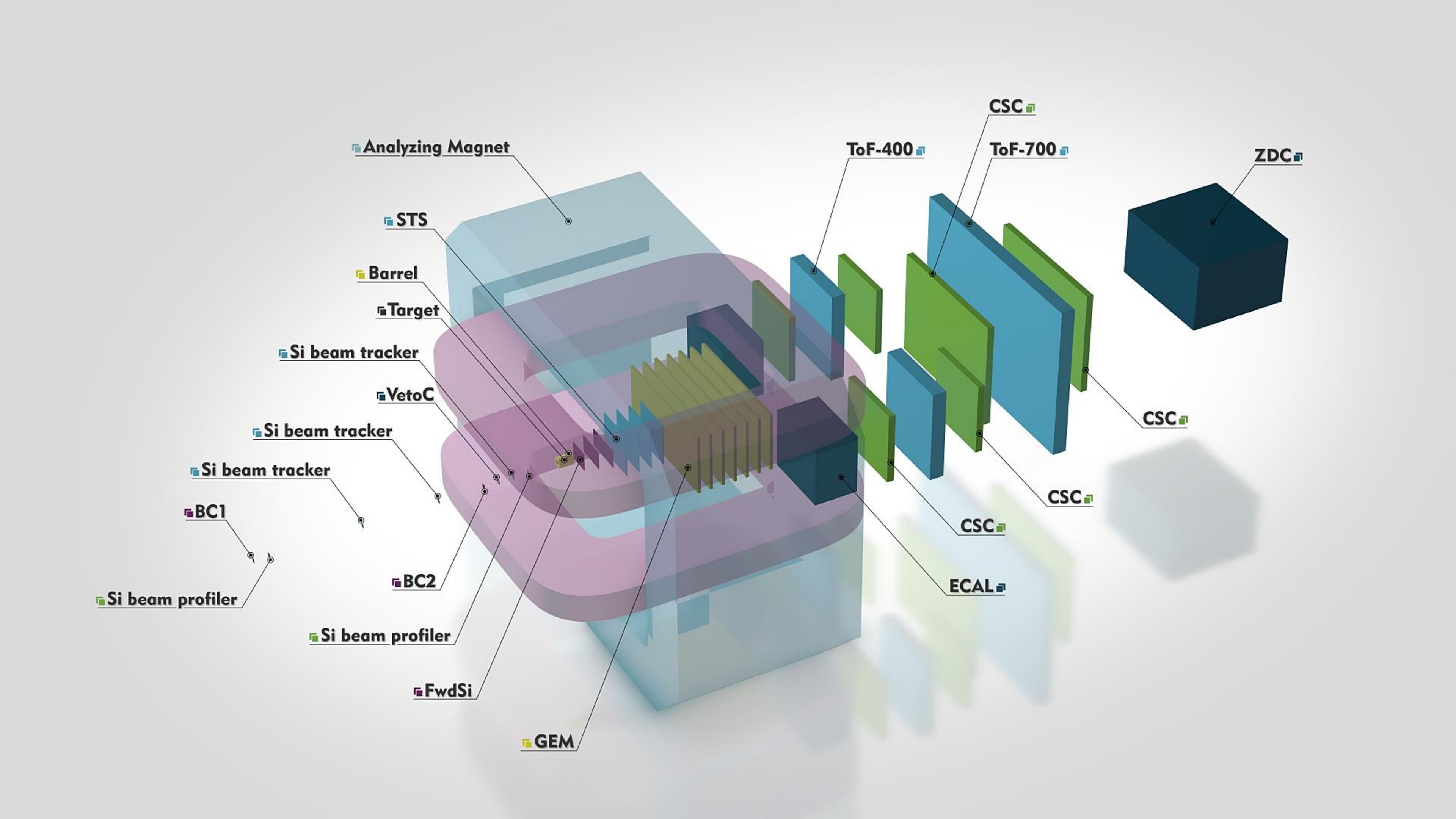
Upgrade of the BM@N detectors

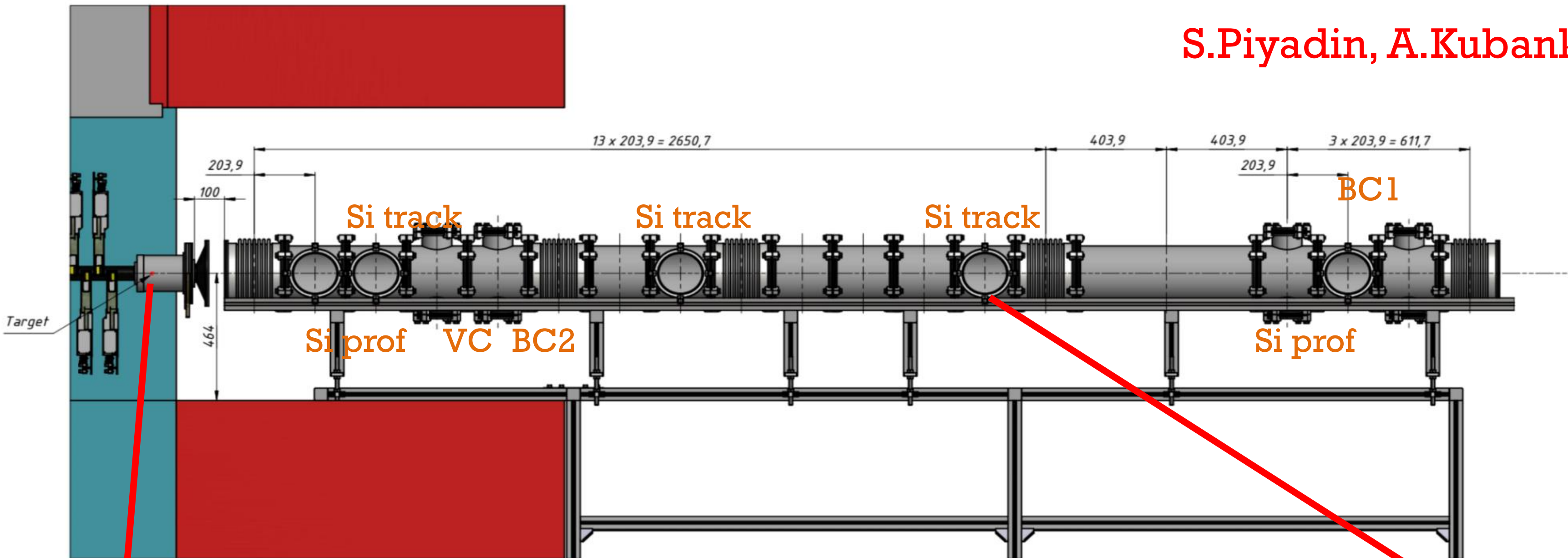
Anna Maksymchuk on behalf of the BM@N Collaboration
20/04/2020

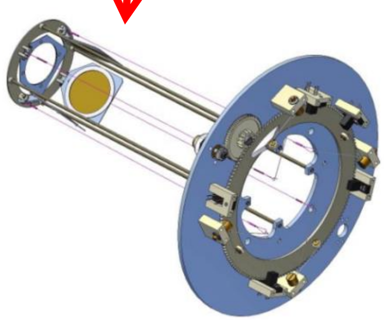
BM@N Experimental Setup

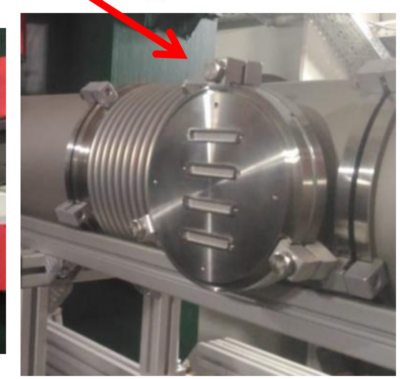


Beam pipe before the target

S.Piyadin, A.Kubankin





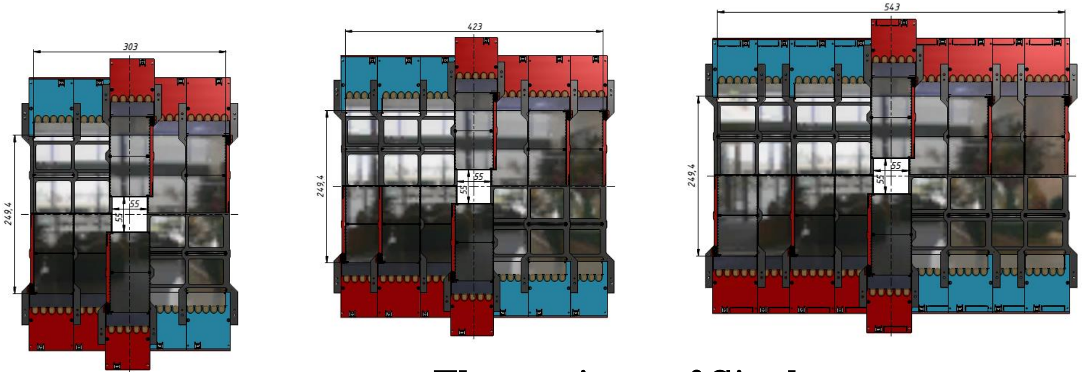


Four stainless steel vacuum boxes downstream the target will be replaced by aluminum ones.
The design and production of the target station mechanics will be performed by A.Kubankin group

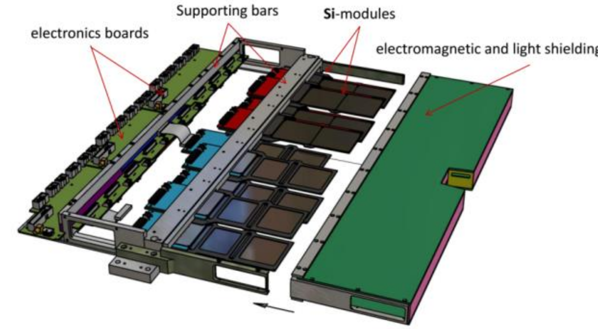
See talk of S.SEDYKH

Production of the beam pipe: Belgorod University

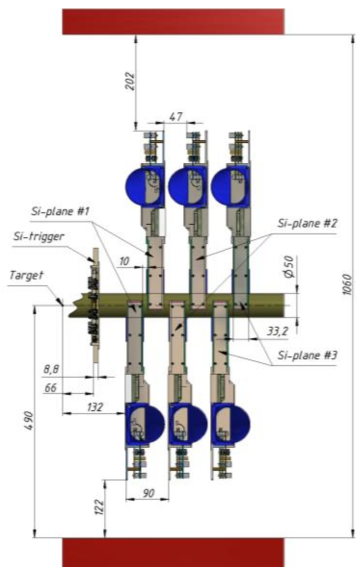
Upgrade of the forward Si tracking detectors

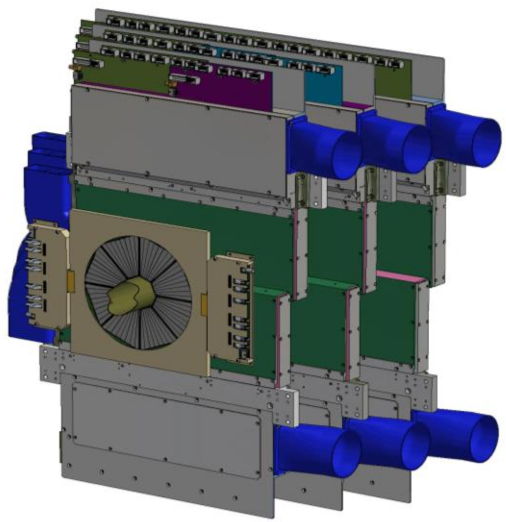


Three sizes of Si-planes



Half-plane design





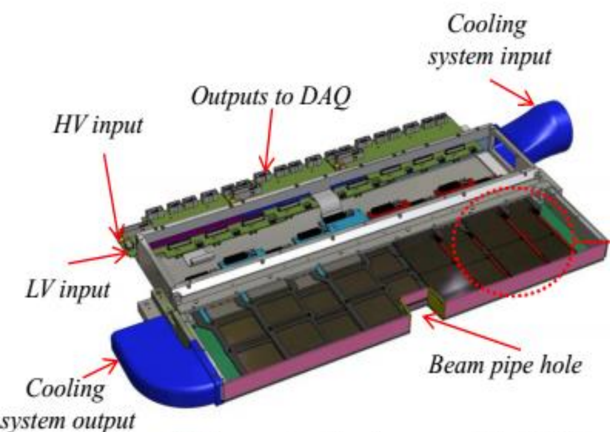
Design of the Si-planes
on the BM@N beam-channel

Station#	Number of DSSD modules	DSSD station square	Number of Readout channels
Station1	10	720 cm^2	12800
Station2	14	1008 cm^2	17920
Station3	18	1296 cm^2	23040
Total	***42***	***~0.3 m^2***	***53760***

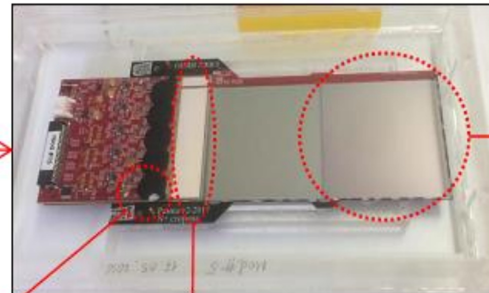
group of N.Zamiatin

Upgrade of the forward Si tracking detectors

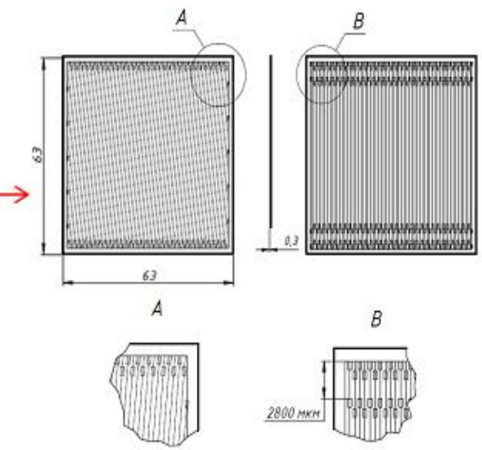
See talk of B.Topko

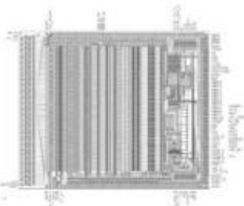


Silicon half-plane with FEE

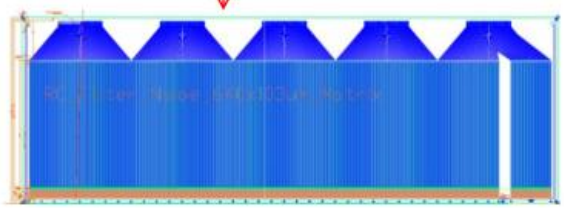


Silicon Detector Module





ASIC VATAGP7.1 (5 chips on each side of module)
Number of CSA: 128 channels
Dynamic range: ±30 fC
Peaking time (slow/fast shaper): 500 ns/ 50ns
Noise (ENC): 70e +12e/pF (typ.)
Voltage supply: +1.5 V, -2.0 V
Gain from input to output buffer: 16.5 μA/fC
Output Serial analog multiplexer clock speed: 3.9 MHz
Power dissipation per channel: 2.2 mW



Pitch Adapter (n+) side
sapphire plates with an epitaxial layer of silicon (SOI)
Number of channels: 640
Value of poly-Si resistors: ≈ 1 MΩ
Value of integrated capacitors: ≈ 120 pF
Capacitor working voltage: 100 V
Capacitor breakdown voltage: >150 V

Size: 63x63x0,3 mm^3 (on 4" – FZ-Si wafers)
Topology: double sided microstrip (DSSD)
(DC coupling)
Pitch p^+ strips: 95 μm;
Pitch n^+ strips 103 μm;
Stereo angle between p^+/n^+ strips: 2.5^0
Number of strips: 640 (p^+)× 640(n^+)

Plans:
- DSSD, Pitch adapters, ASICs VATAGP7.1, FEE PCBs are delivered and ready for assembly
- Cross boards and mechanical support for FwdSi detectors installation inside the magnet are being designed at the moment

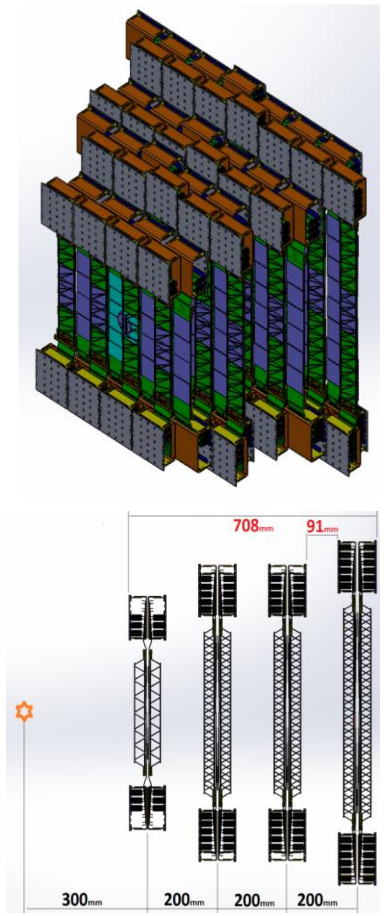
BM@N STS

Preliminary layout of BM@N STS was developed.

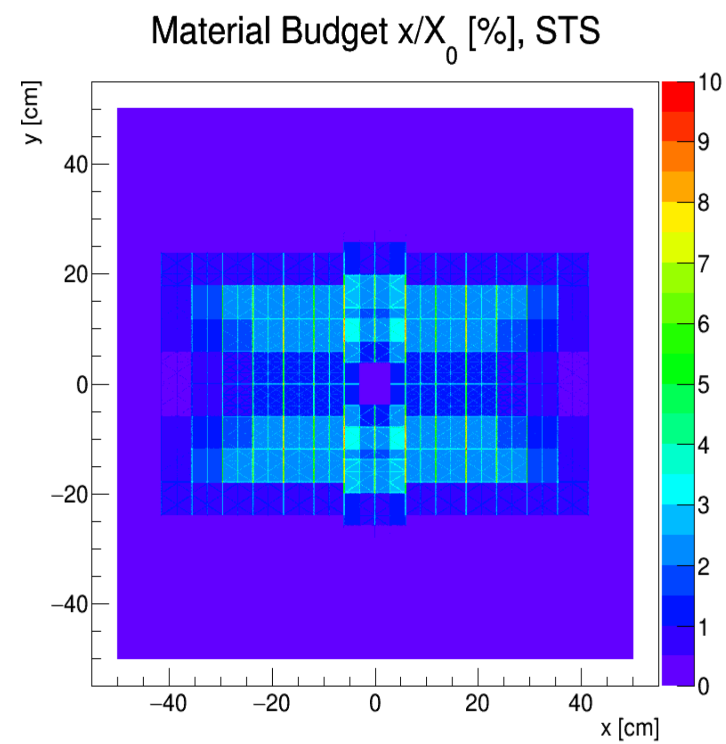
Geometry was tested in simulations in CbmRoot (E. Lavrik) and BmnRoot (S. Mertz)

Four stations are based on CBM-type modules with double-sided microstrip silicon sensors:

- Pitch 58μ
- Stereo angle 7.5°
- Thickness 300μ
- Sizes: 62x62, 62x42, 62x22 mm^2
- Produced by two vendors: CiS (Germany) & Hamamatsu (Japan)



Tentative design of BM@N STS stations



Total material budget (by E. Lavrik)

Number of modules: 292
Number of channels: ~600k
Power consumption: ~15 kW

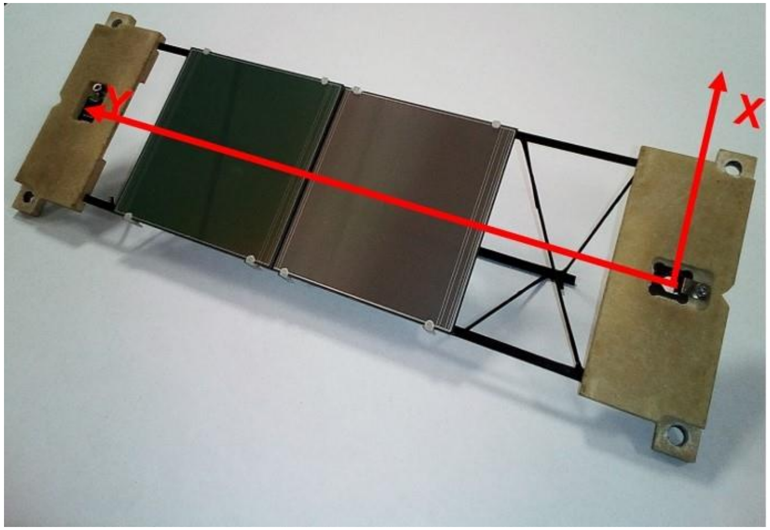
Plans:
2022 – "pilot" configuration, first 42 modules integration into BM@N;
After 2022 – BM@N STS full configuration (292 modules)

See talk of D. DEMENTYEV

Status of BM@N STS

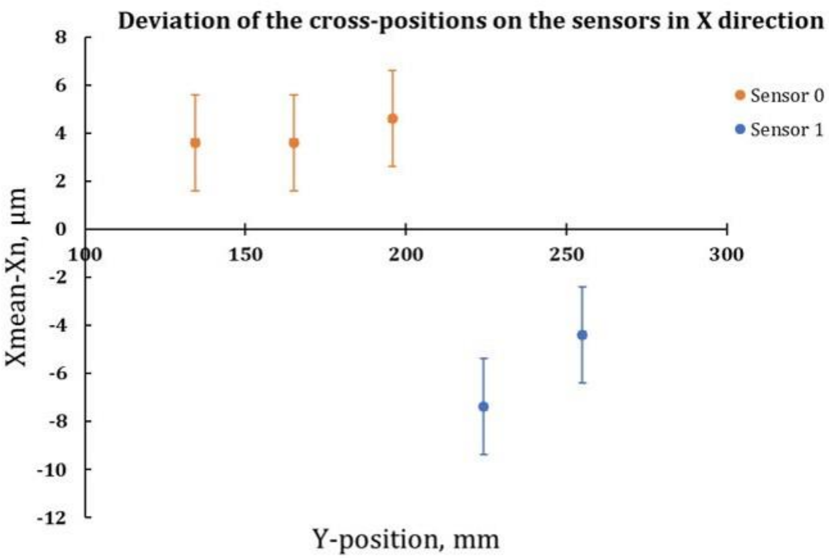
STS group

See talk of D.Dementev



Mockup of STS ladder

Mockup of the ladder with 2 sensors was assembled to test the Ladder assembly device. Measured deviation of the X coordinate (perpendicular to the strips on N-side) from the mean value is less than 8 μm.



Deviations of X coordinates of the fiducial marks on the sensors from the mean value

Delays caused by pandemic control measures.

Total delay is expected to be ~ from 2*T to 3*T, where T - quarantine period in Russia.

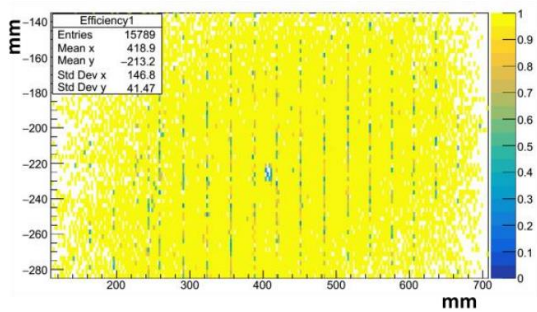
Main delays are caused by:

- Construction of the clean areas;
- Procurements of equipment for cooling and power systems, cables & electronics.
- Postponing of the start of the serial production of STS modules

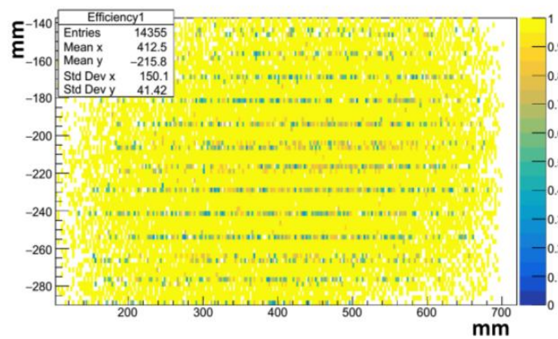
GEM group

GEM central tracking system

Stand for cosmic tests



Spatial efficiency for
Different sector design

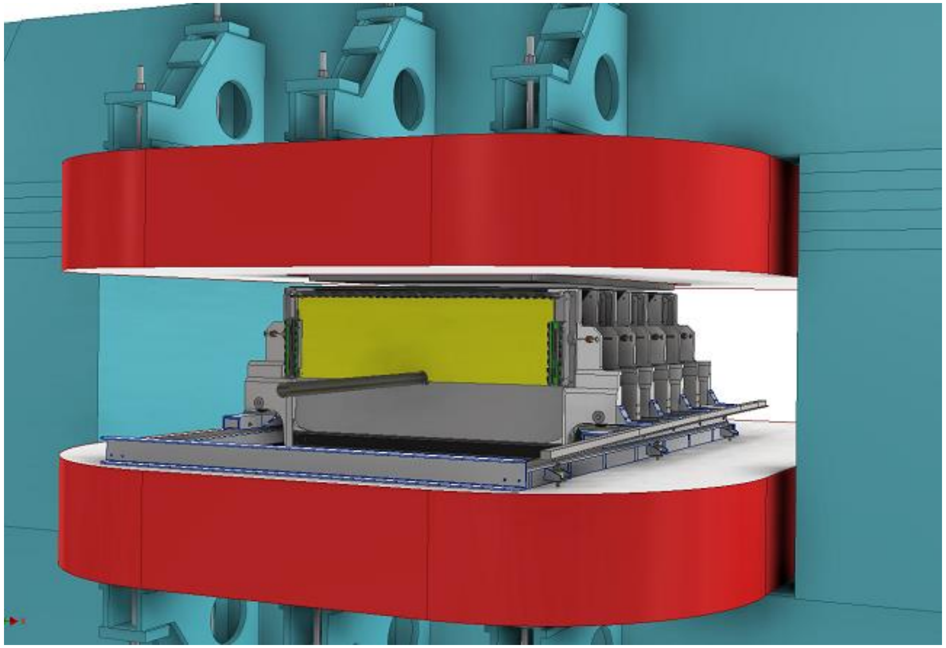


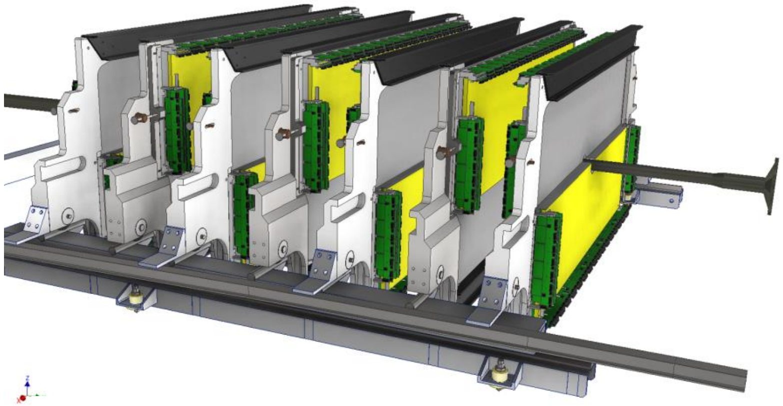
Four last1632x390 mm^2 GEM chambers were assembled at CERN

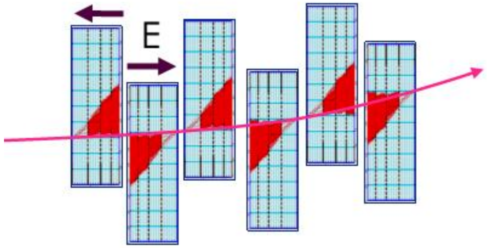
New bracing system for FEE was designed and produced

- Seven GEM 1632x450 mm^2 chambers produced at CERN workshop were integrated into BM@N experimental setup. One was defected and repaired at CERN.
- Seven GEM 1632x390 mm^2 chambers were assembled and delivered to JINR.
- Two spare chambers are to be produced by the end of 2020

Preliminary mechanics design for GEM planes precise installation inside the magnet







Upgrade plans:

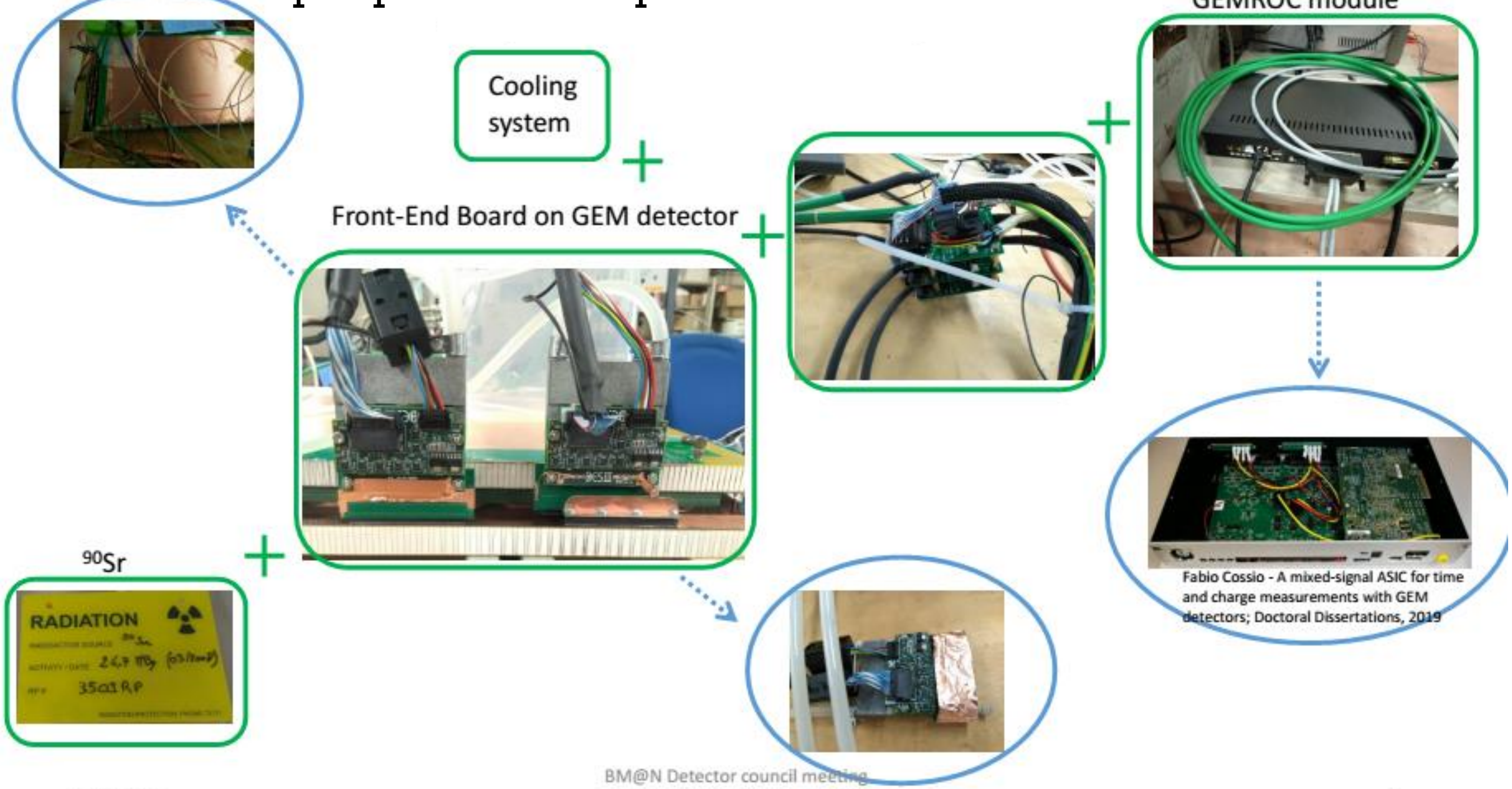
09.2020 – development of the mechanics design (Pelcom Dubna) and mechanics production for GEM planes precise installation inside the magnet.

12.2020 – integration of the full GEM planes into the experimental setup (electronics based on the VA-163 chips, ~90000 readout channels)

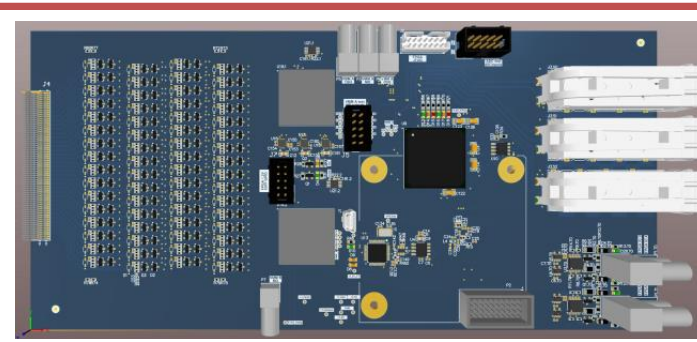
2022 - Development, tests and integration of FEE based on VMM3/TIGER ASICs.

Development of new FEE based on TIGER/VMM3a

TIGER (**T**urin **I**ntegrated **G**em **E**lectronics for **R**eadout) tests at CERN. First run of TIGER FEE on GEM detector was performed. Next tests were planned on March 2020 at JINR, but postponed due to pandemic control measures.



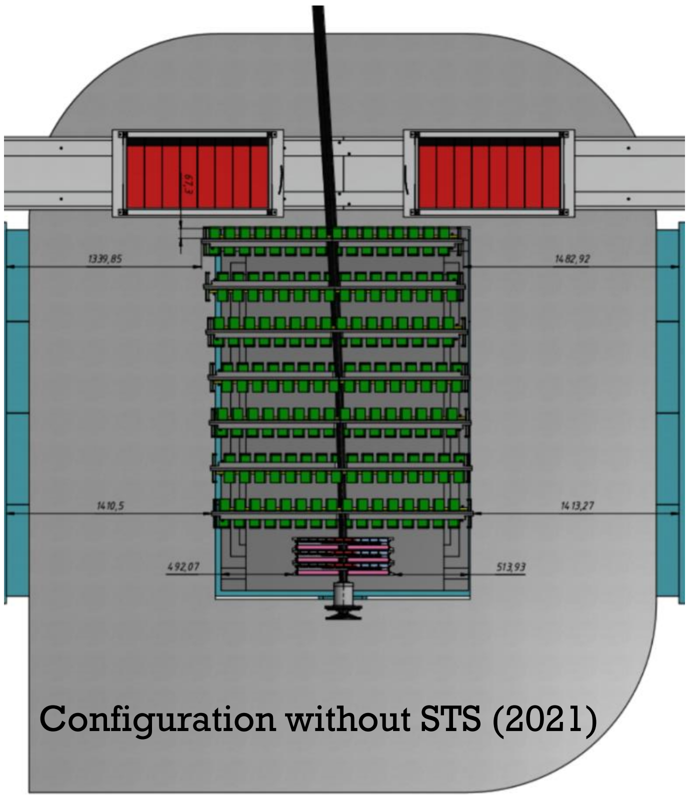
Kintex7 based 128ch GEM evaluation board was designed for **VMM3a** tests.

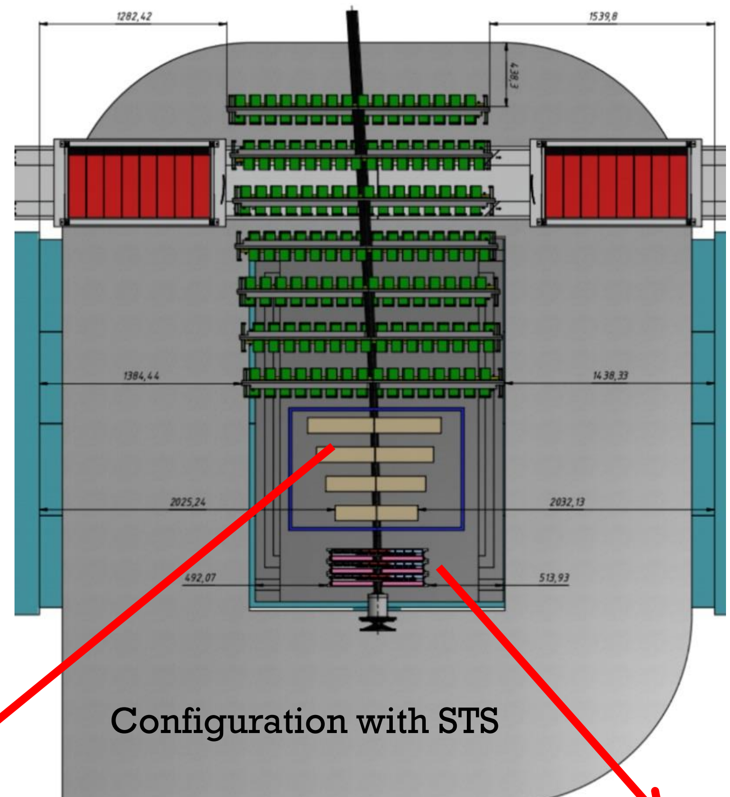


Forward Si+ STS +Gem configuration

Four configurations of the tracking detectors are foreseen:

- Forward Si + 7 GEMs: beam intensity few 10^5 Hz , 2021
- Forward Si + “pilot” STS station + 7 GEMs: beam intensity few 10^5 Hz , 2022
- Forward Si + 4 STS stations + 7 GEMs: beam intensity few 10^5 Hz, after 2022
- 4 STS stations + 7 GEMs (fast FEE): high beam intensity few 10^6 Hz, after 2022-

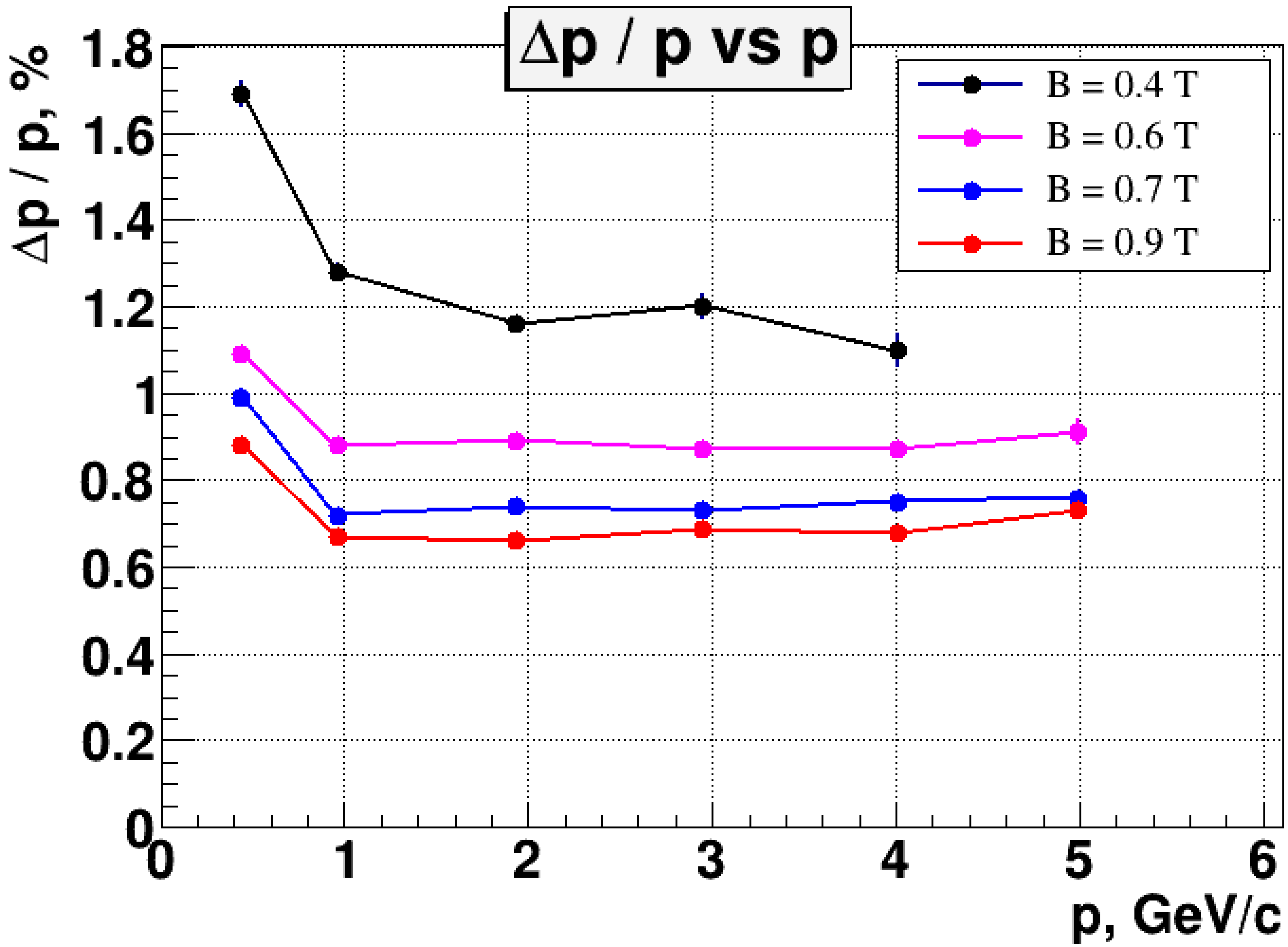




2022 year – “pilot” configuration
After 2022 year – full configuration

Forward Si will be removed after integration of STS full configuration into BM@N setup (after 2022 year, high beam intensity - few 10^6 Hz)

Hybrid central tracker STS+GEM momentum resolution for different magnetic field values



A.Zinchenko

Beam pipe inside the SP-41 magnet

S. Piyadin, V. Spaskov

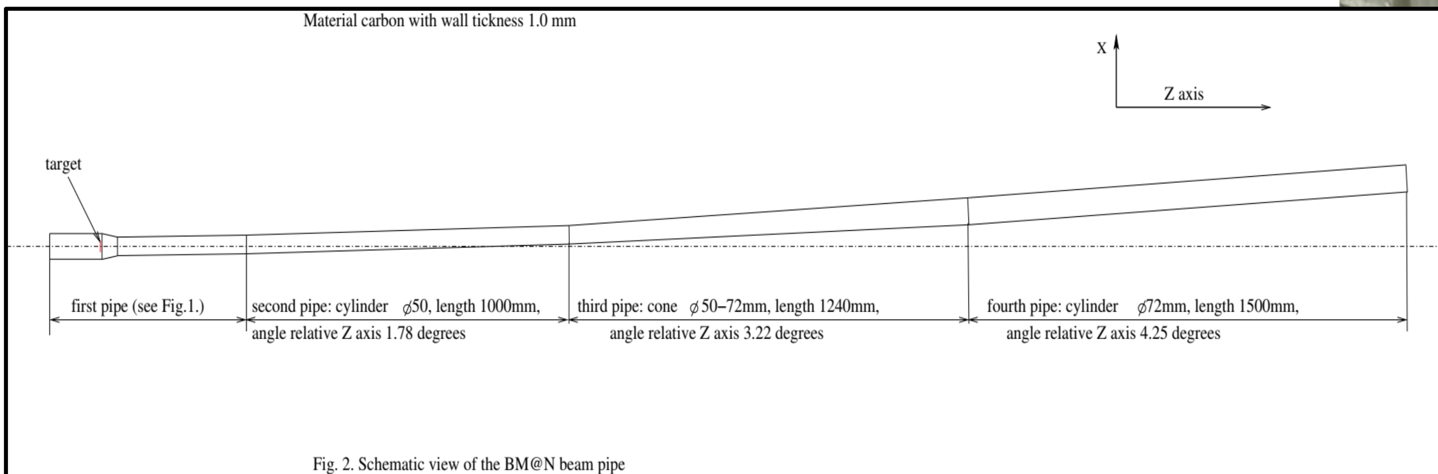
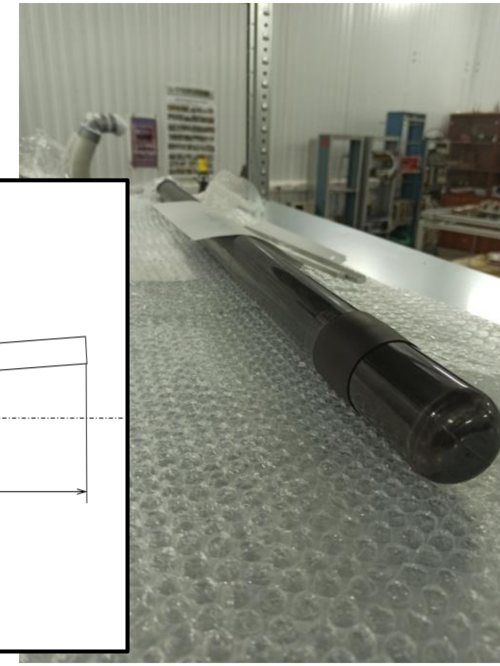


Fig. 2. Schematic view of the BM@N beam pipe



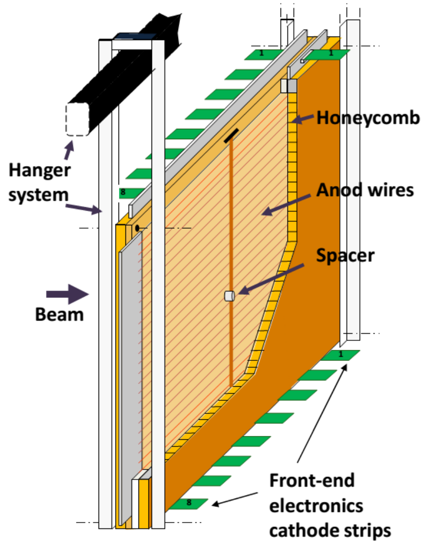
Test sample of the carbon beam pipe

- DD “Arkhipov” (Moscow, Russia) – 1m test sample of carbon beam pipe is ready
- Vacuum tests have shown an insignificant level leakage level of side surfaces of the sample, vacuum up to 10^{-5} .
- The design of the flange connections is not yet finished.
- Agreement on cooperation to be signed with “SYNTEZ-PROJECT” LLC (Moscow, Russia) for flange connections design

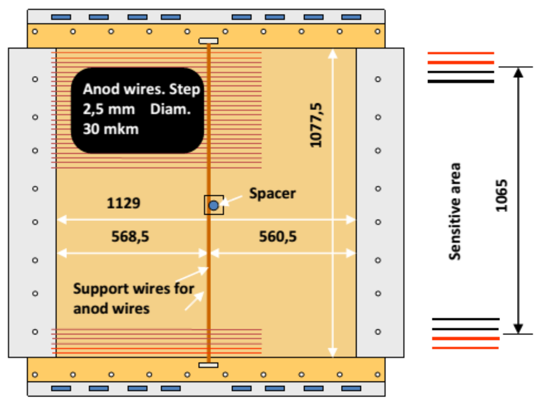
1065x1065 mm^2 CSC chamber

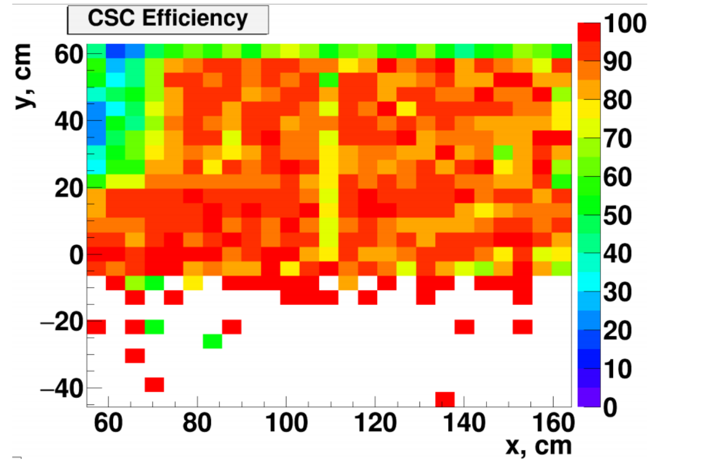
CSC group

C, Ar and Kr runs in March 2018: CSC chamber is installed in front of ToF-400 to check its performance as outer tracker for heavy ions

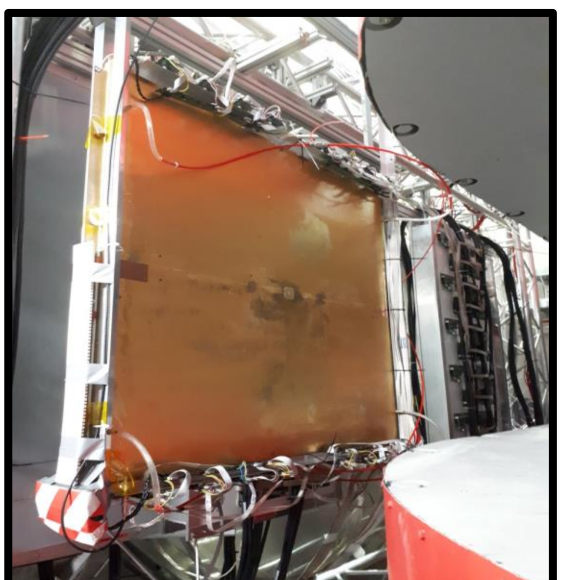


Anod wires geometry





CSC efficiency in Ar run
Track extrapolated from GEM
Residual (CSC_hit – GEM) < 2cm



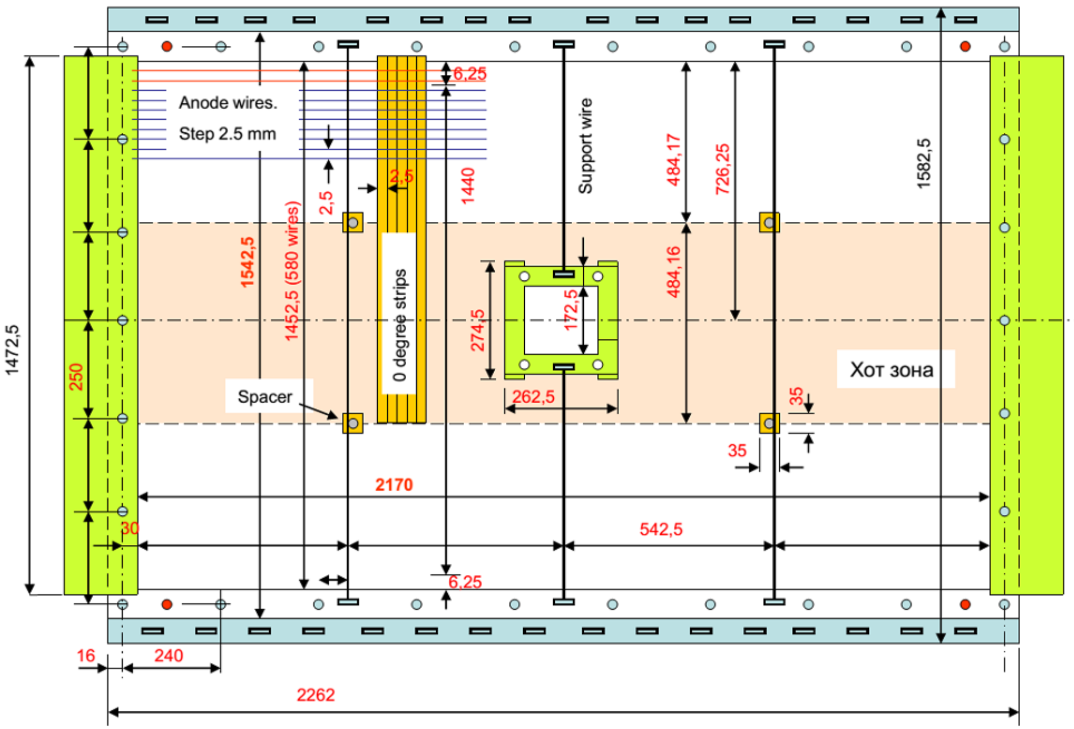
One CSC 1065x1065 mm^2 is produced and tested at Nuclotron beam.

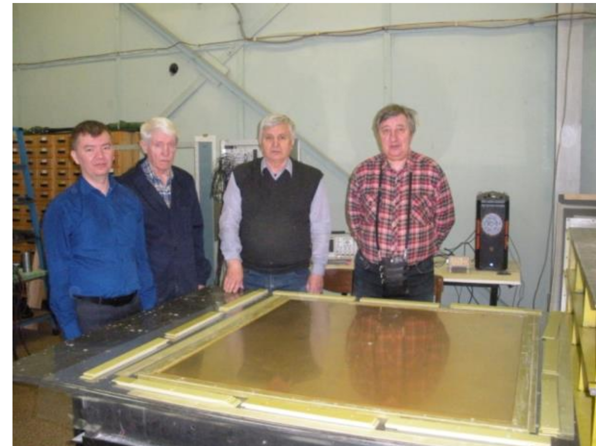
Plans:

- assembly of the three1065x1065 mm^2 chambers is at the final stage: gluing process is finished; delays with wire boning is due to pandemic control measures at JINR
- in autumn 2020 assembled chambers are to be tested with r/a source and at cosmic stand

2190x1453 mm^2 CSC chamber

CSC group





Two cathode planes with strips inclined at 0° and 15°

Each cathode plane consists of 8 printed circuit boards.

Each pcb is divided on hot and cold zones.

Design of the first PCB is finished.

Design and assembly – JINR LHEP

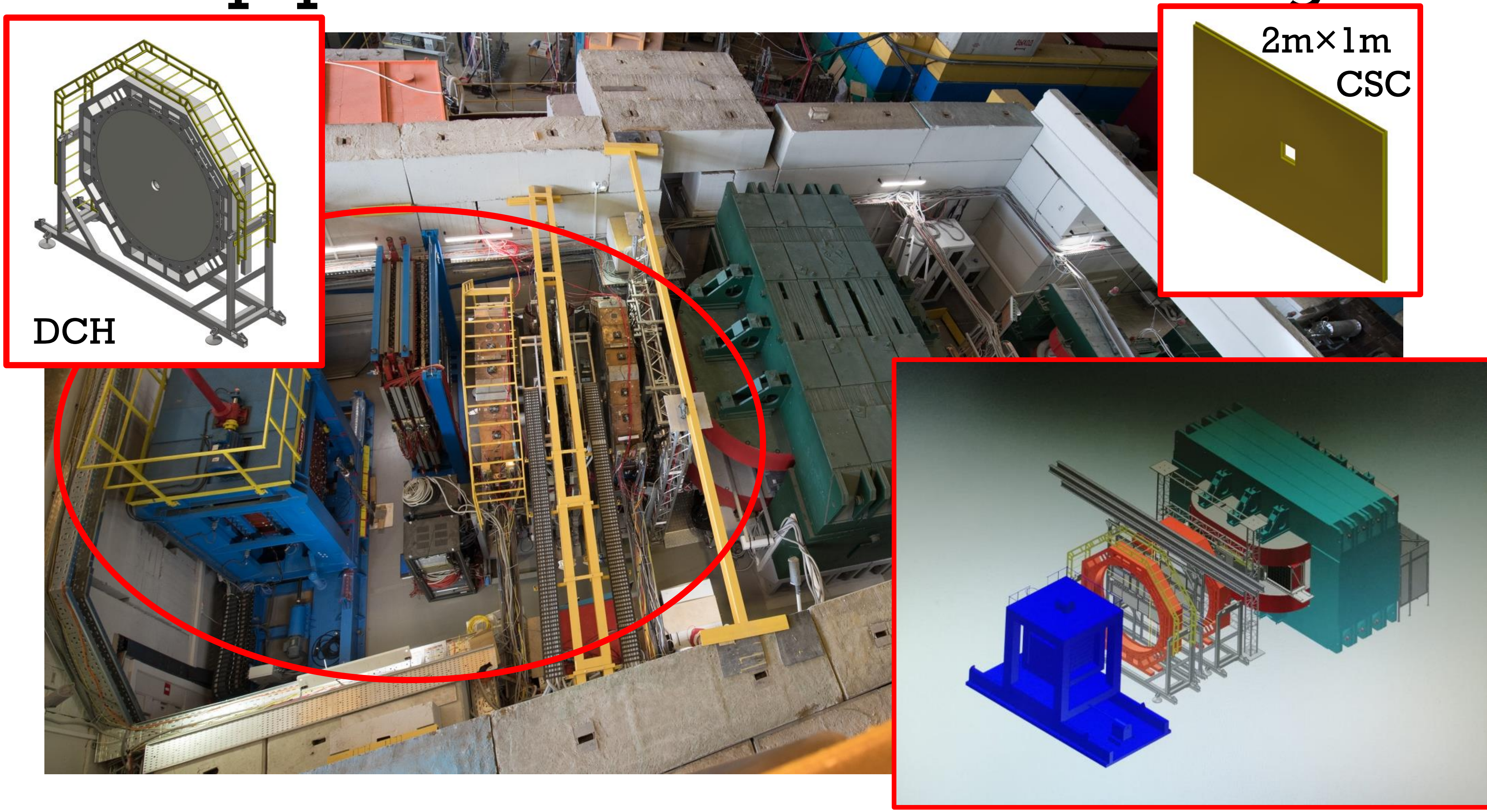
Production plans:

- 09.2020 – design and production of the cathode planes for 2190x1453 mm^2 CSC chambers

- 03.2021 – Assembly of the 2190x1453 mm^2 CSC

- 09.2021 – All chambers are integrated into the BM@N experimental setup

Beam pipe downstream the SP-41 magnet



Possible candidate for development and production of the aluminum beam pipe downstream the SP-41 magnet is A. Kubankin group (Belgorod University).
3D model development of the detectors after the SP-41 magnet is at the final stage.

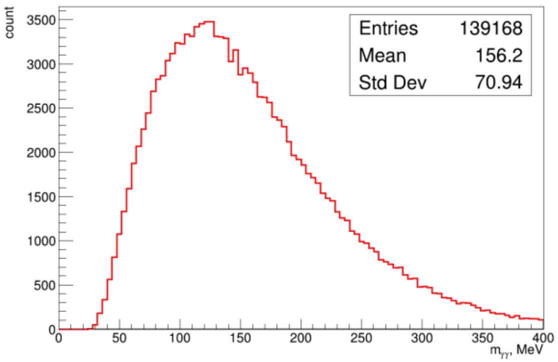
S. Piyadin

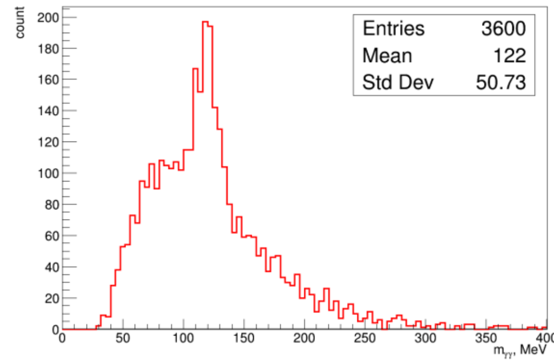
ECAL group

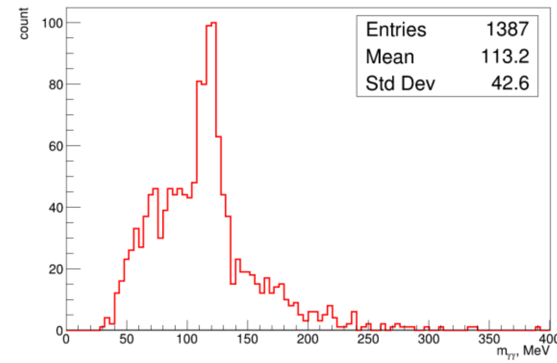
ECAL Status

ECAL γ-selection criteria (GEANT4, DCMQGSM KrSn 2.36AGeV mb, ~1M ev.)

Effective mass distributions



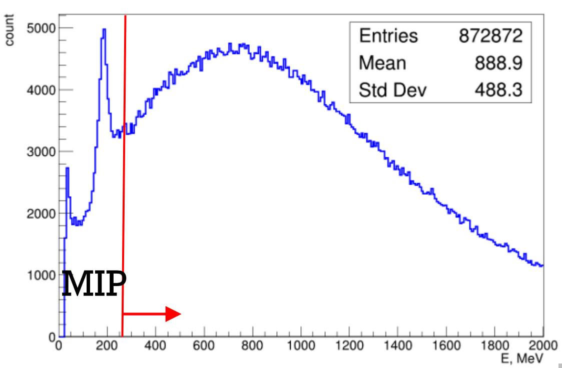


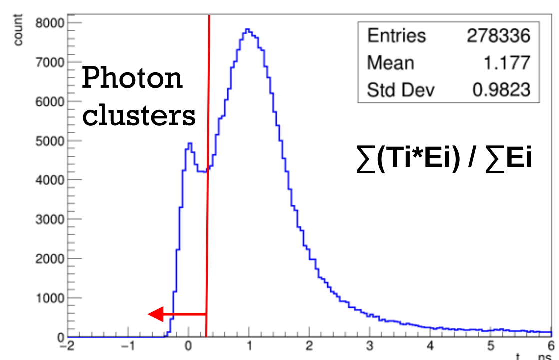


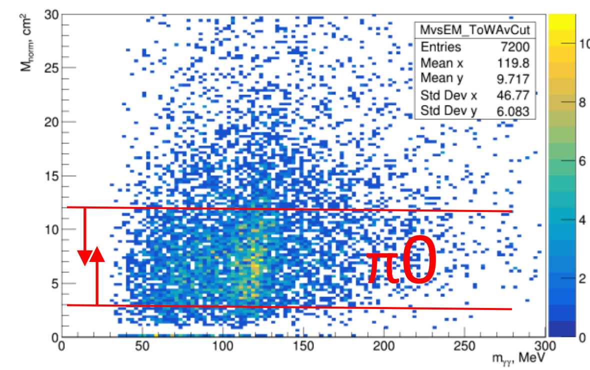
$R_{cluster}$= 10 cm, E_{cell}> 10 MeV, $E_{cluster}$> 250 MeV, Θ > 6°

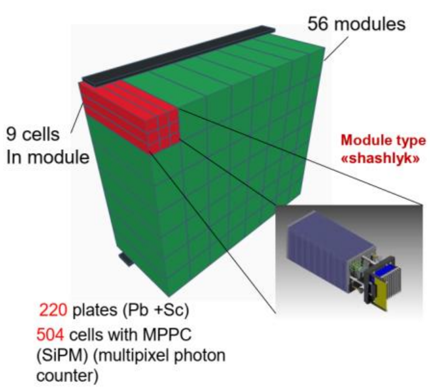
T_{wa} < 0.3 ns

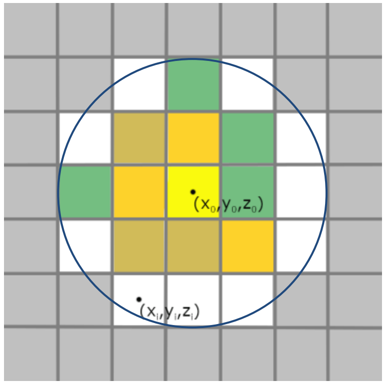
2 < M_{norm} < 12











$$M_{norm} = \frac{\sum E_i \times ((x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2)}{\sum E_i}$$

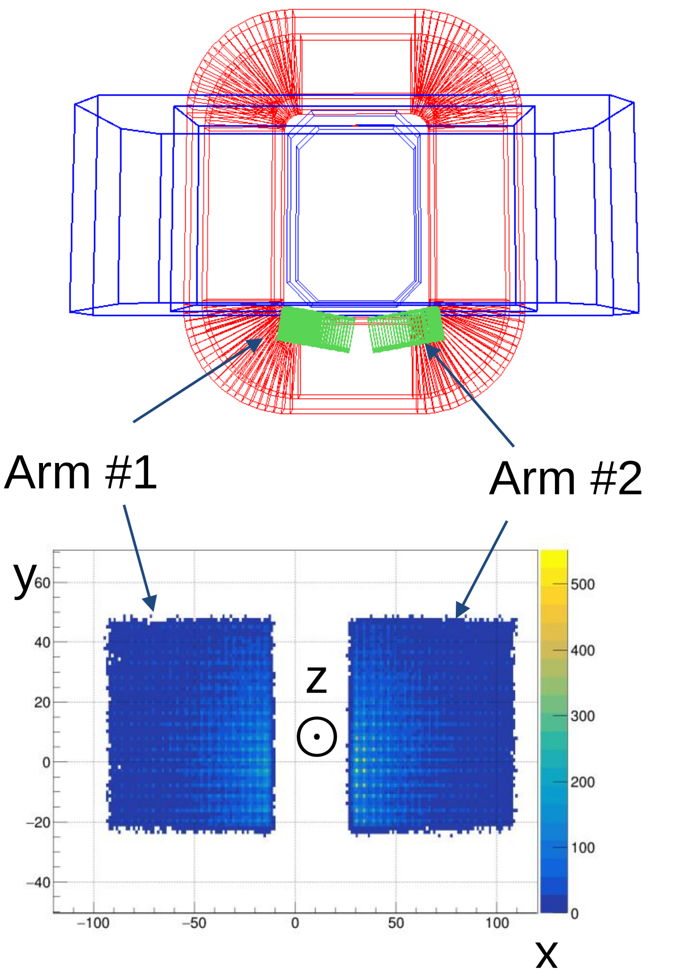
21 cells in cluster with R=10 cm

ECAL group

ECAL Status

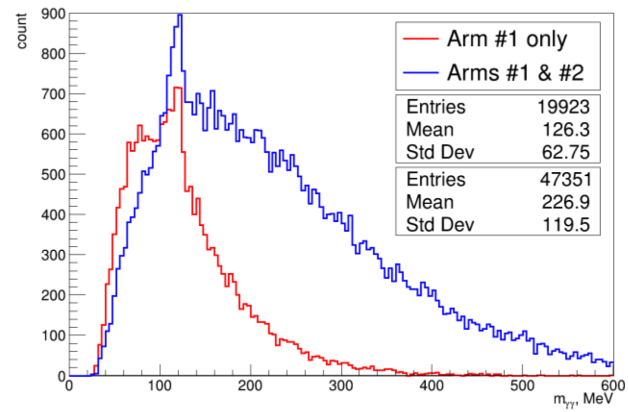
Extending ECAL working range (GEANT4, LAQGSM CC 4AGeV mb, 300k ev.)

ECAL position in the simulation



Weighted average cluster positions (lab coords)

Effective mass



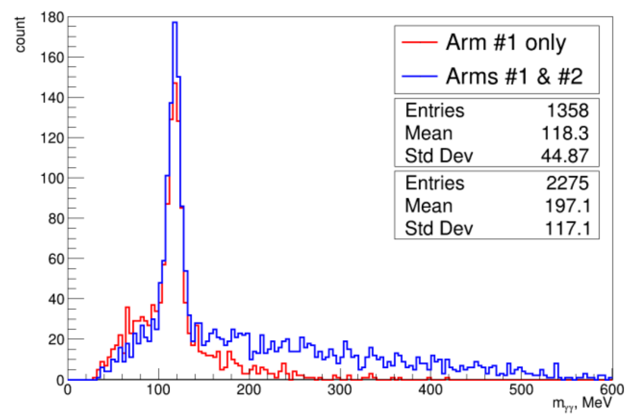
E_{cell} > 10 MeV

$R_{cluster}$= 10 cm

$E_{cluster}$> 250 MeV

Θ>6°

Effective mass, additional cuts

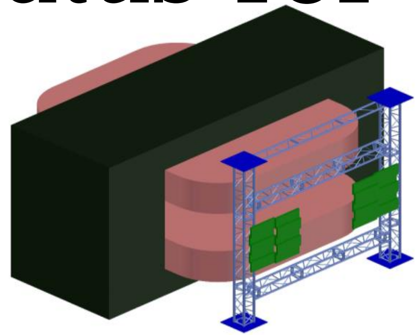


M_{norm} > 2 cm^2

M_{norm} < 12 cm^2

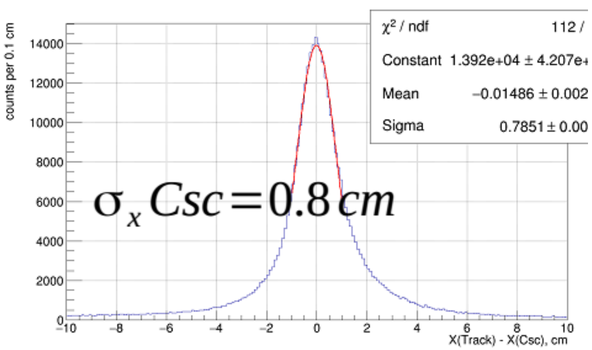
T_{wa} < 0.3 ns

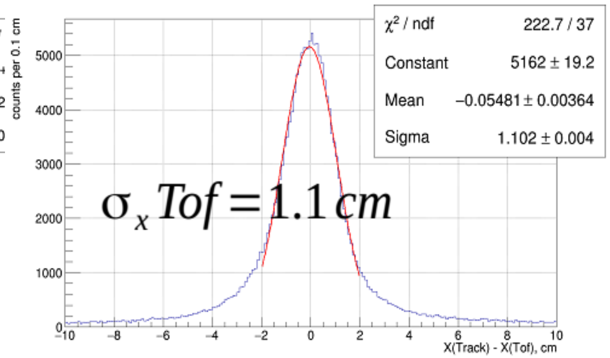
Status ToF-400



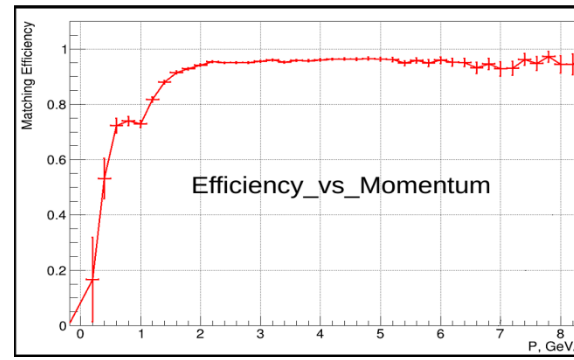
ToF-400
+ V.Plotnikov
+M.Rumyantsev

Residuals of CSC and ToF-400

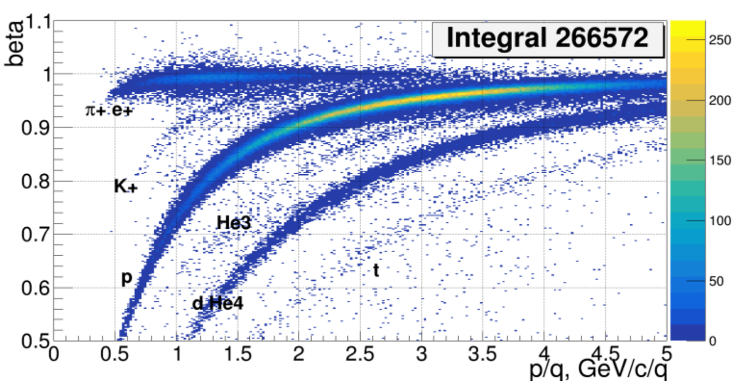


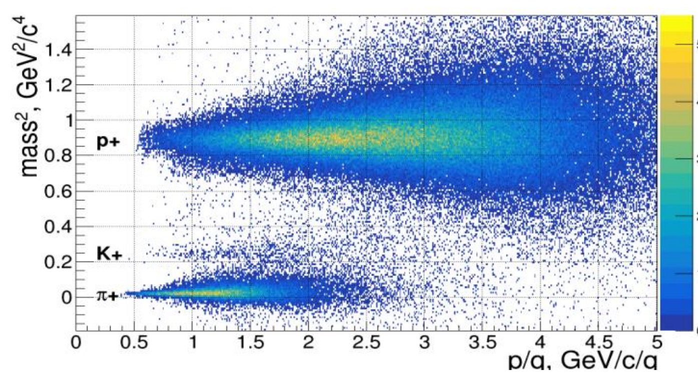


Matching efficiency of GEM+CSC track to ToF-400



Preliminary result of identification, GEM+CSC track extrapolated to ToF-400

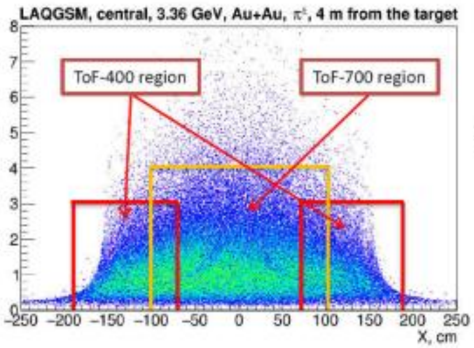




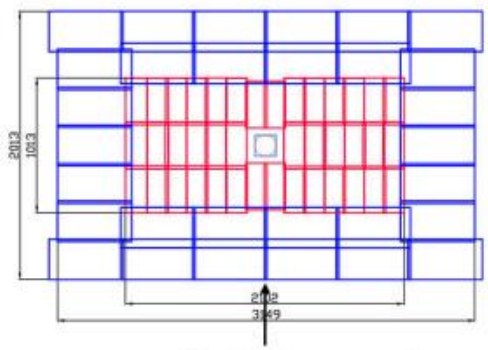
Proton Mass^2 = 0,894 +- 0,081 GeV^2/c^4, Pion Mass^2 = 0,021 +- 0,016 GeV^2/c^4

Status ToF-700

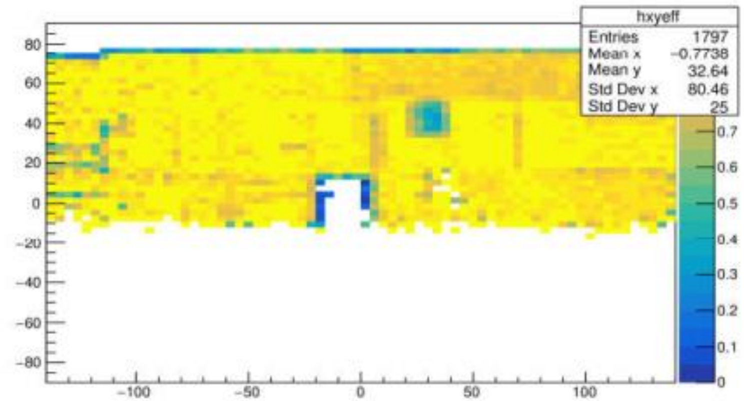
Yu.Petukhov, L.Kovachev



ToF-700 wall

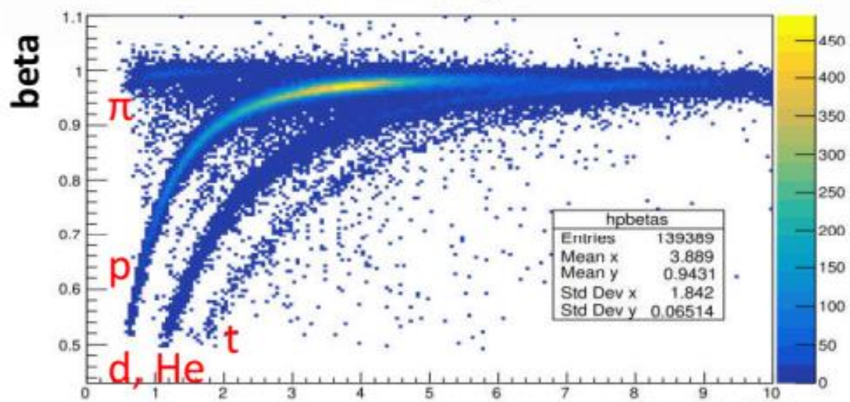


BM@N beam axis



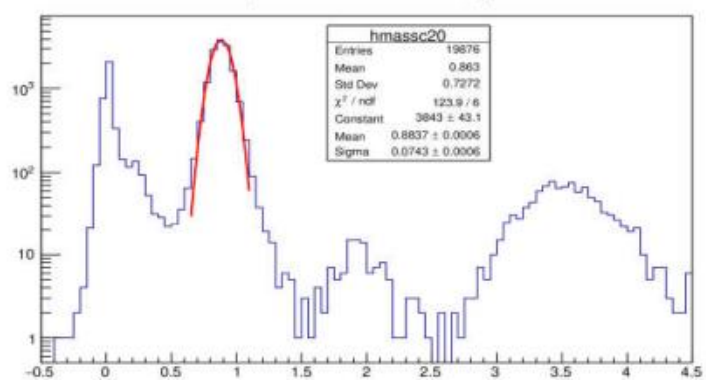
ToF-700 efficiency, GEM+DCH+TOF700 vs GEM+DCH tracks

Argon beam, 3.2 AGeV



p/q, GeV/c

Mass, chamber corrections, p<2.0



(m/q)^2, (GeV/qc^2)^2

Preliminary result of identification, GEM+DCH track extrapolated to ToF-700

ToF-700 time calibration procedure was developed. Final tests of the algorithm are performed.

Status of new FHCal

group of INR RAS Troitsk

FHCal front view.

FHCal was assembled and installed on the moving platform in June 2019.

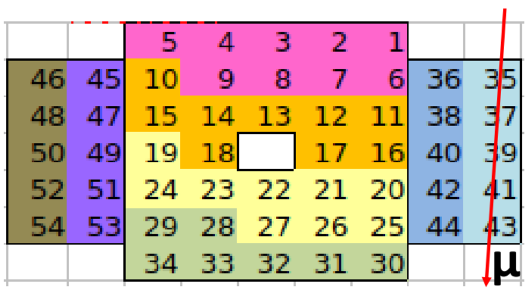
FHCal back side view.

FEE and readout electronics were installed and tested at the end of 2019.

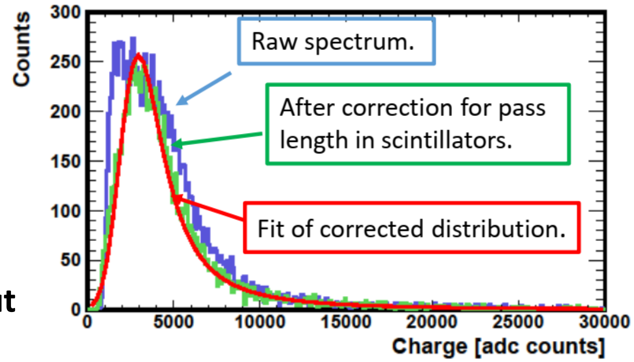
Photodetectors – 438 Hamamatsu MPPC: S12572-010P

FEE – 54 boards
Readout – 8 ADC64, 62.5MS/s boards.

- Central part – 34 MPD-like modules with 15x15 cm^2 transverse sizes. Longitudinal segmentation - 7 sections.
- Outer part – 20 CBM modules with 20x20 cm^2 transverse sizes. Longitudinal segmentation – 10 sections.



Connection diagram of 8 ADC boards for signals readout from 54 modules of the FHCal.

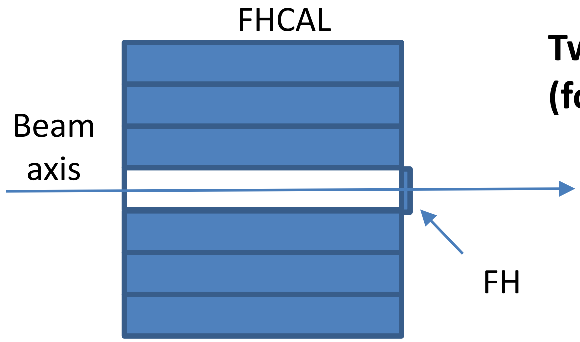


FHCAL tests with cosmic muons

- Each group of modules was readout by its own ADC. Since the ADC's were not synchronized, each group was tested separately.
  Common *trigger* is needed for simultaneous calibration of all FHCAL modules with cosmic muons.
- Analog adders of signals from top/bottom rows of modules have been already constructed.
  New FHCAL cosmic tests and modules calibration will be done after access at JINR will be opened.

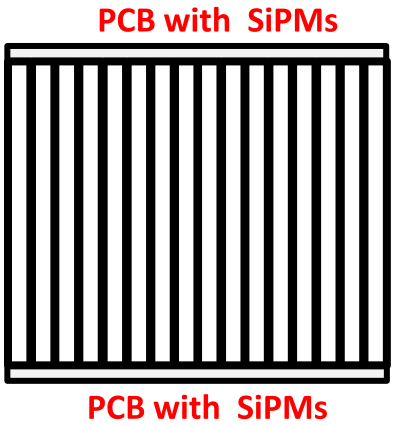
Status of development of Forward Hodoscope in FHCal beam hole

group of INR RAS Troitsk



Two version with scintillator and quartz strips (for light and heavy ion beams) are developed.

- **16 quartz or scintillator strips;**
- **strip size: 10x160x4 mm^3;**
- **it covers beam hole 15x15 cm^2.**



FH is proposed to use for:

- **Correction of E_{dep} in FHCAL**
- **Alignment of the FHCAL**
- **MB trigger**

Quartz/scintillator strips, boards with MMPCs for scintillator and FEE for FH are ready.
One TQDC for readout is available.

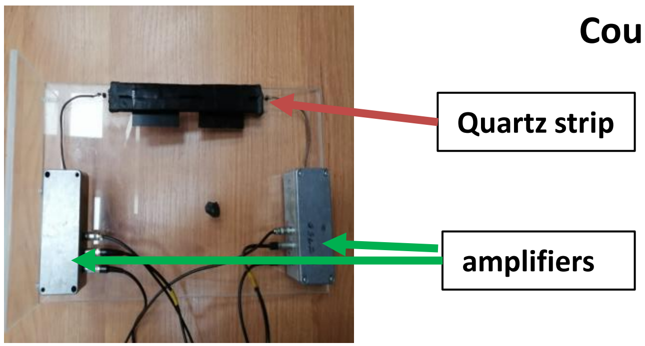
Assembling of FH is planned immediately after resuming work at institutes.

Beam tests of one quartz strip at LPI RAS and at GSI

group of INR RAS Troitsk

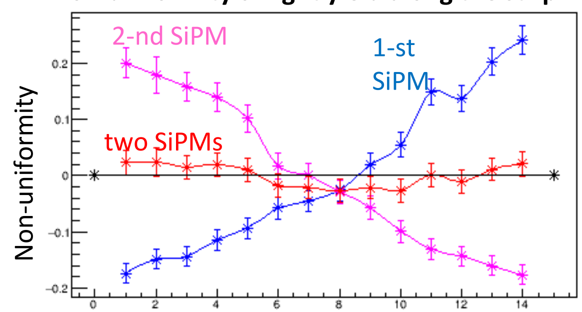
- **January 2020.** **Synchrotron "PAKHRA", LPI RAS, Troitsk, Moscow.**

Energy E_e=700 MeV;
Count rate ~ 50 Hz.



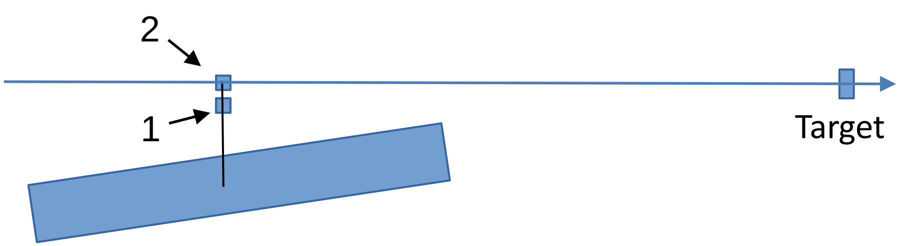
$N_{ph.el.}$ ~ 5
from both MPPCs on the strip ends

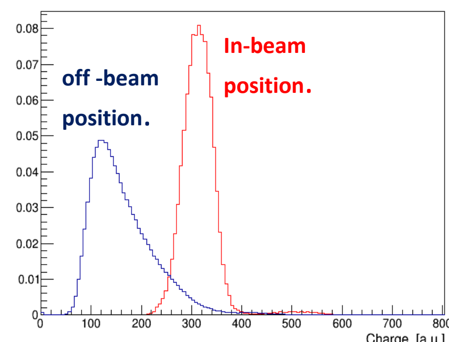
Non-uniformity of light yield along the strip.



- **March 2020.** **SIS100, GSI, Darmstadt, Germany.**

Pb(67+) + Au (2.5cm), Beam rate: 10^8 ions/sec
Quartz strip position:
(1) ~1.5cm from beam axis, (2) on the beam axis





Quartz strip charge spectra at HV= 66V (reduced voltage).

All the detector's and electronics parts of Forward Hodoscope are produced.
The beam tests of hodoscope elements were done on electron and heavy ions beams.
The full assembling of the hodoscope and installation at FHCal is planned at the Fall 2020.

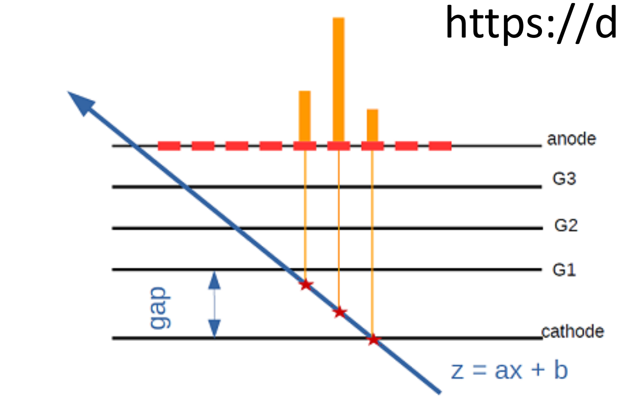
Summary:

Detector Subsystem	Upgrade Status
Beam pipe before the target	installed
Beam pipe downstream the target, in SP-41 magnet	will be installed - middle 2021
Beam pipe downstream the SP-41 magnet	will be installed – spring 2021
Trigger and T0 detectors	Spring 2021
Si beam tracking detectors, profilometers	Spring 2021
Forward Si detectors	3 full-size planes (Spring 2021)
STS BM@N	42 modules (2021) 292 modules (2022)
GEM	7 top half-planes + 7 bottom half-planes(assembled)
CSC	4 chambers 1065x1065 mm^2(09.2020) 2 chambers 2190x1453 mm^2(2020-21)
ECAL	two arms (End of 2020)
ToF-400 and ToF-700	full configuration
ZDC(MPD/CBM type)	installed

Backup

TIGER (**T**urin **I**ntegrated **G**em **E**lectronics for **R**eadout)

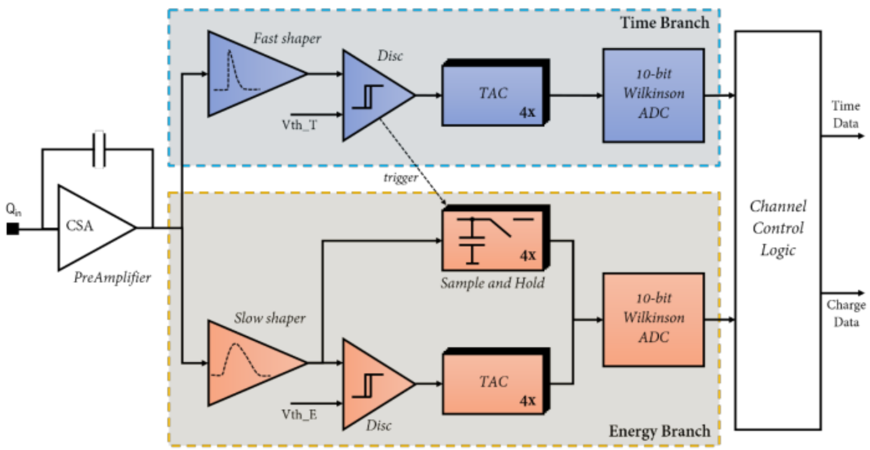
https://doi.org/10.1016/j.nima.2018.09.010



- If known the drift velocity, time information can be used to assign to each fired strip a 2D point
- Particle track is reconstructed from these coordinates
- The spatial resolution can be improved in magnetic field, especially for angled tracks

TIGER v1 - 64-channel readout ASIC was tested at BESIII Experiment (New Inner Tracker based on **Cylindrical Gas Electron Multiplier**)

TIGER channel architecture



TIGER V2. Programmable gain: range 50-300 fC Input

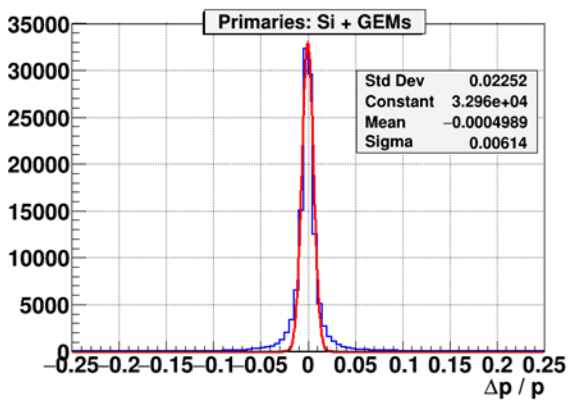
Sustained event rate > 100 kHz/ch

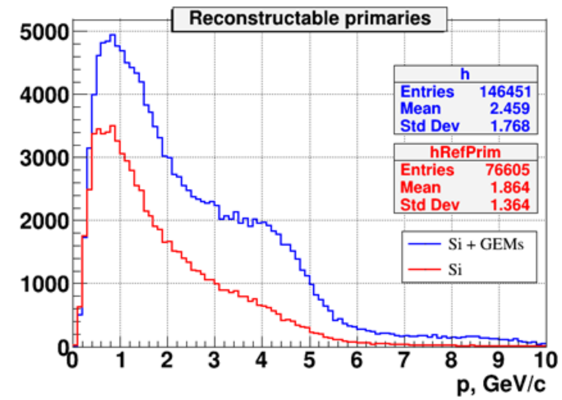
Measured performance of the TIGER ASIC:

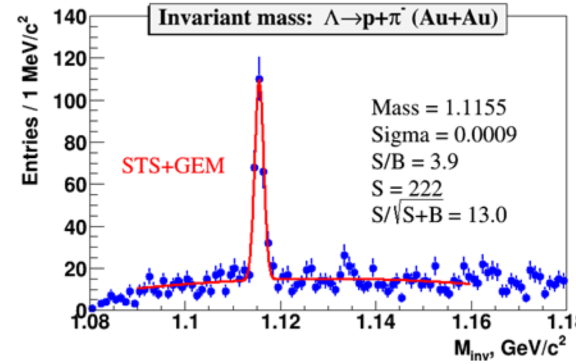
Input charge 5-55 fC
TDC resolution 30 ps RMS
Time-walk (5-55 fC range) 12 ns
Average gain 10.75 mV/fC
Nonlinearity (5-55 fC range) 0.5%
RMS gain dispersion 3.5%
Noise floor (ENC) 1500 e^-
Noise slope 10 e^-/pF
Maximum power consumption 12 mW/ch

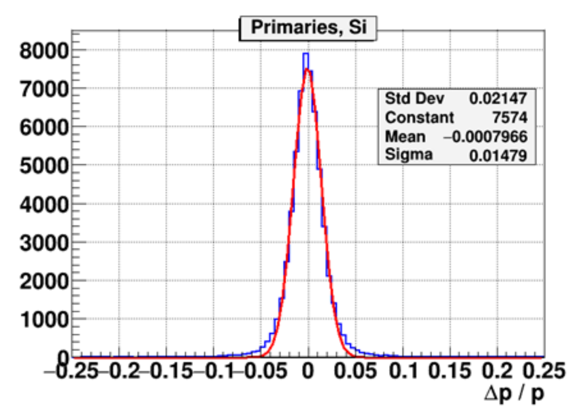
First tests with BM@N GEMs are planed in November 2019 at CERN

Hybrid central tracker for heavy ion runs: STS vs STS+GEM





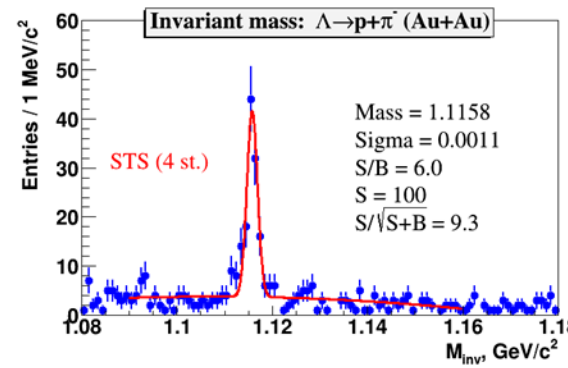




Hybrid STS + GEM tracker:

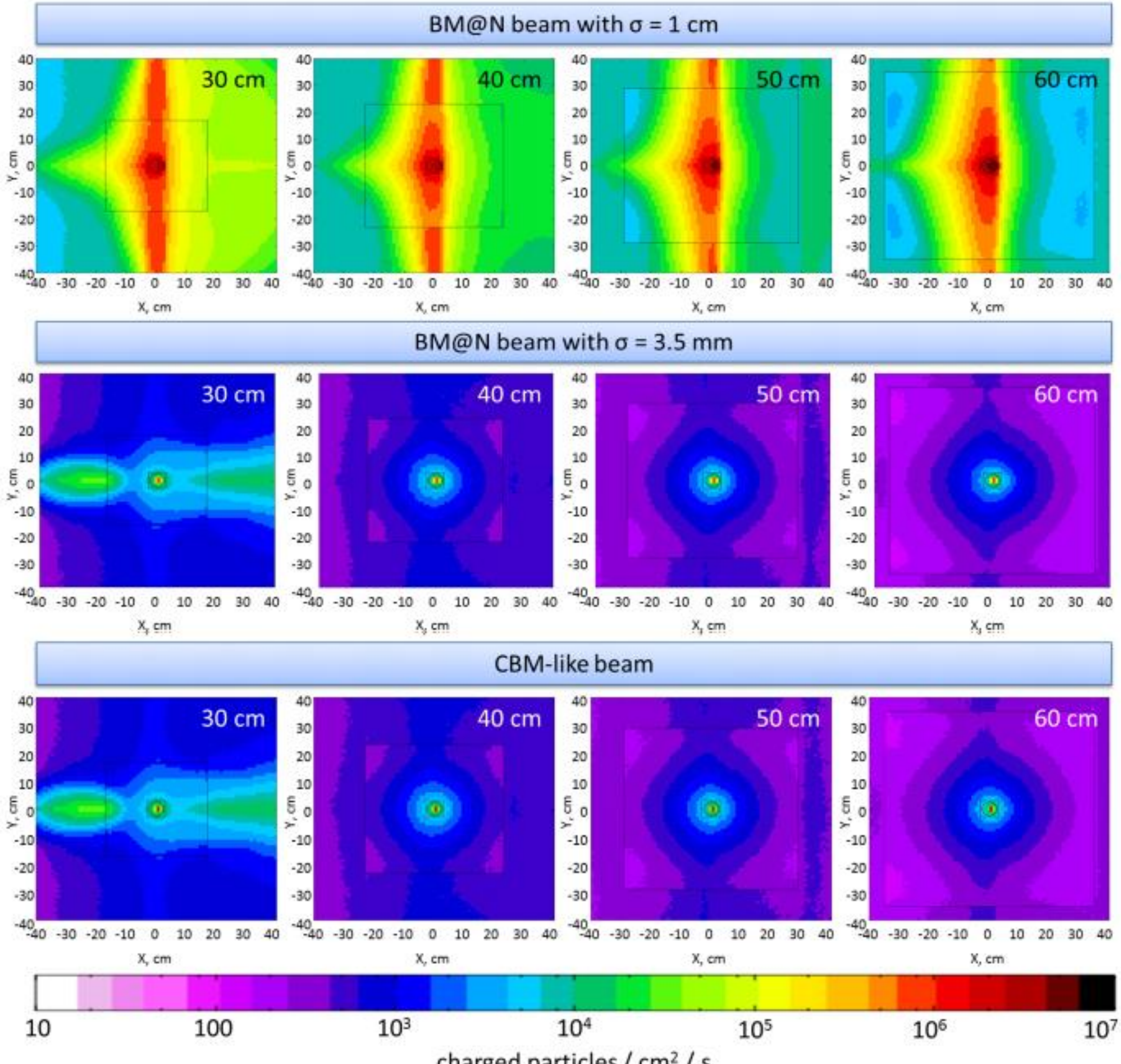
► 2 times increase in number of reconstructed tracks and Λ hyperons

►2 times better momentum resolution



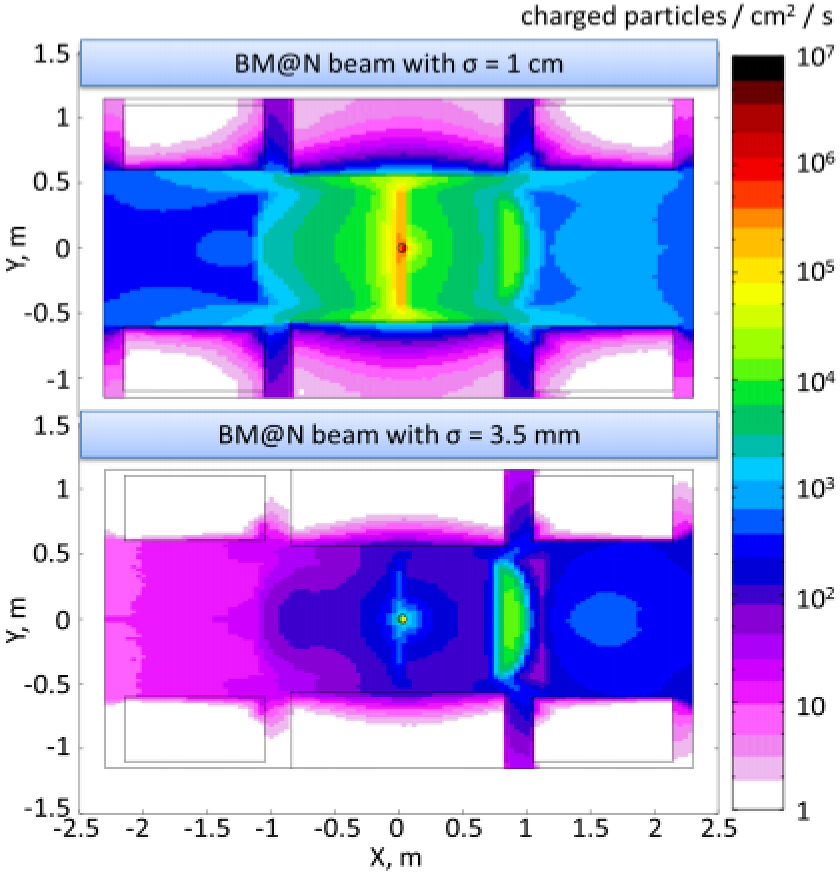
A. Zinchenko, P. Senger

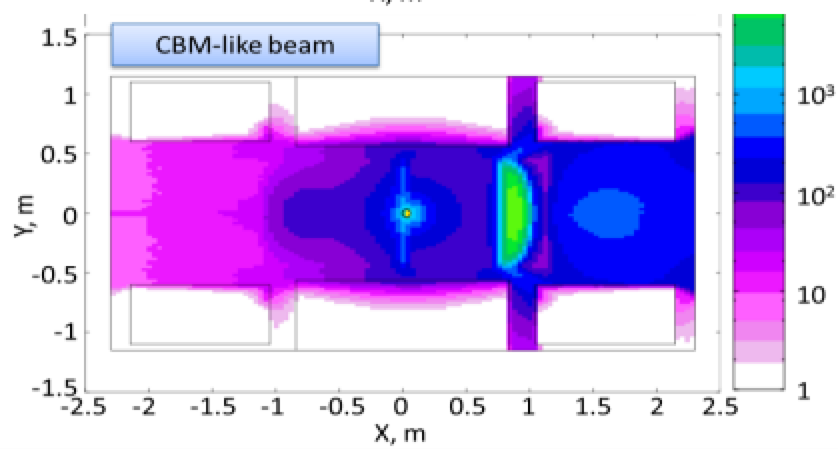
Charged particle densities in the four STS stations



Anna Senger (GSI)

Charged particles in GEM stations at z = 2 m





Anna Senger (GSI)

BM@N beam with σ = 1 cm (2x10[6] Au ions/s):
Delta electron rate: 200 kHz/cm²

Electron rate on one strip (inner zone):
$200\ \mathrm{kHz/cm^2} \cdot 1.2\ \mathrm{cm^2} = 240\ \mathrm{kHz}$
Channels busy: 240 kHz·2 μs = **48 %**

Electron rate on one strip (outer zone):
$200\ \mathrm{kHz/cm^2} \cdot 2.4\ \mathrm{cm^2} = 480\ \mathrm{kHz}$
Channels busy: 480 kHz·2 μs = **96 %**

BM@N beam with σ = 0.35 cm (2x10[6] Au ions/s):
Delta electron rate: 2 kHz/cm²

Electron rate on one strip (inner zone):
$2\ \mathrm{kHz/cm^2} \cdot 1.2\ \mathrm{cm^2} = 2.4\ \mathrm{kHz}$
Channels busy: 2.4 kHz·2 μs = **0.48 %**

Electron rate on one strip (inner zone):
$2\ \mathrm{kHz/cm^2} \cdot 2.4\ \mathrm{cm^2} = 4.8\ \mathrm{kHz}$
Channels busy: 4.8 kHz·2 μs = **0.96 %**