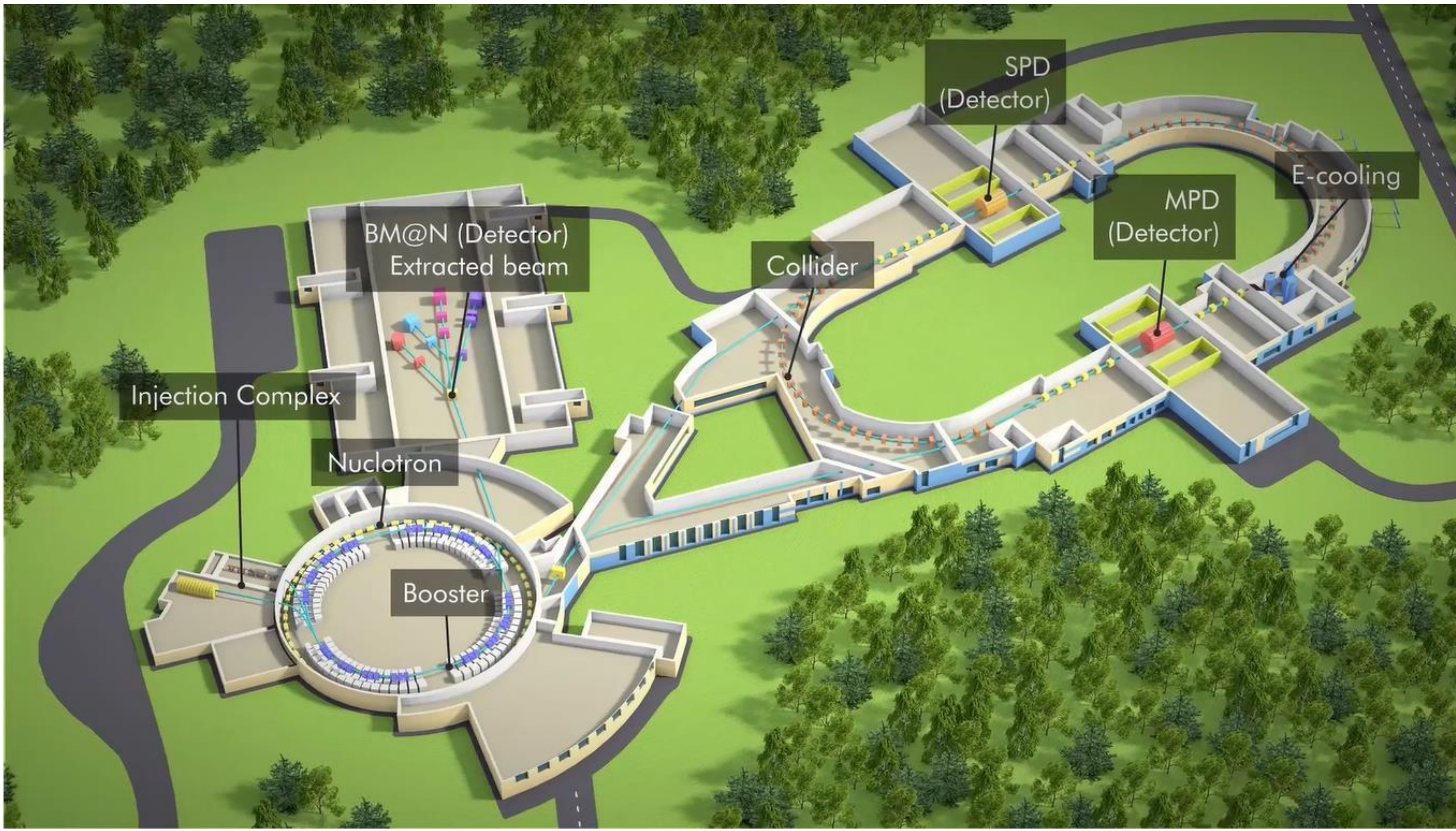
BM@N experiment for studies of baryonic matter at the Nuclotron

A.Maksymchuk on behalf of the BM@N Collaboration

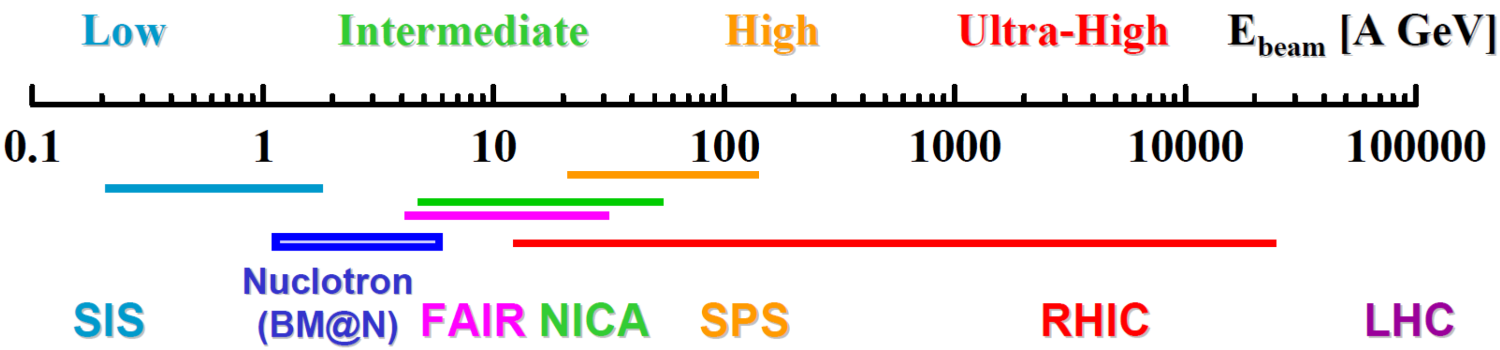
Complex NICA

BM@N: heavy ion energy 1 - 4.5 GeV/n, beams: p to Au, Intensity ~few 10^6 /s (Au)



Physics possibilities at the Nuclotron

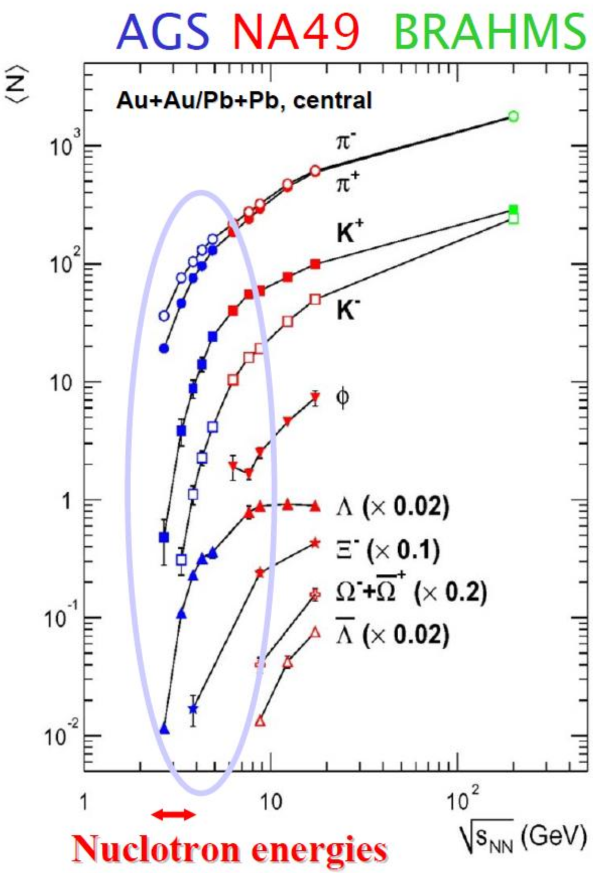
Heavy ion collisions experiments



BM@N scientific program comprises studies of nuclear matter in intermediate range between SIS-18 and NICA/FAIR

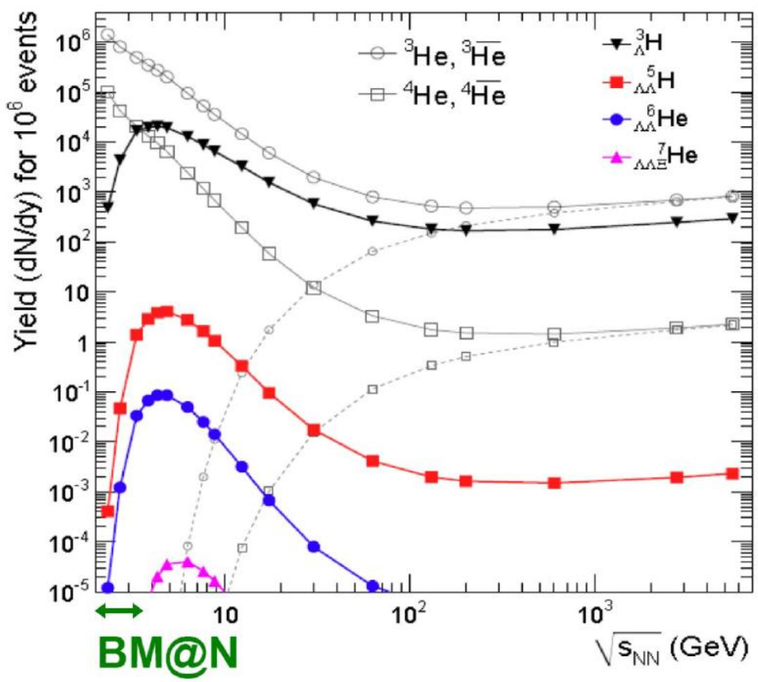
Physics possibilities at the Nuclotron

In A+A collisions: Opening thresholds for strange and multistrange hyperon production



$\sqrt{s}$=2.3-3.5 GeV

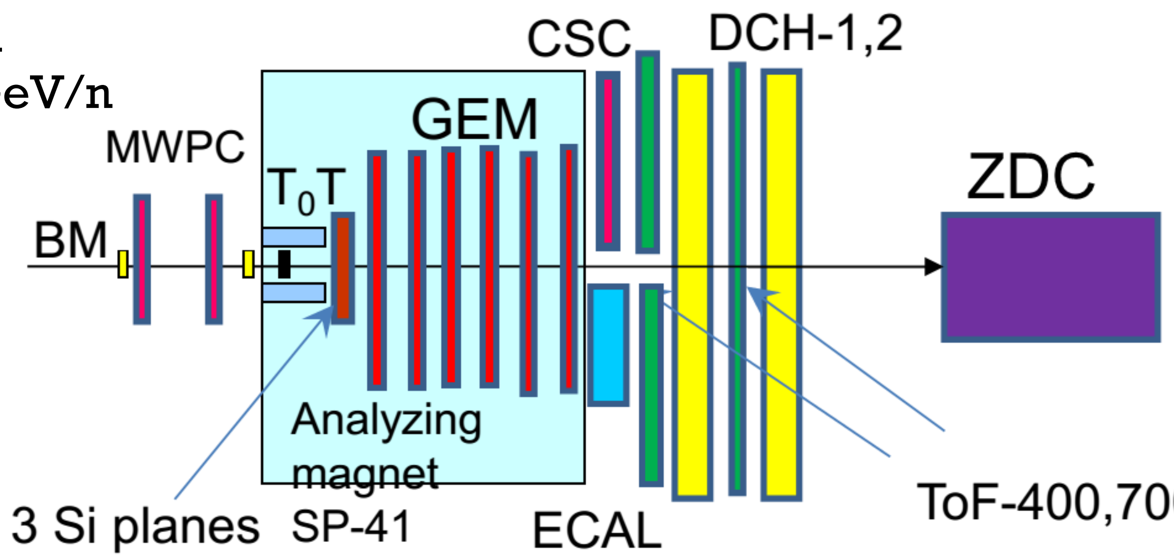
In heavy-ion reactions: production of hypernuclei through coalescence of Λ with light fragments enhanced at high baryon densities



Maximal yield predicted for $\sqrt{s}$=4-5A GeV

BM@N run with Ar and Kr beams in March 2018

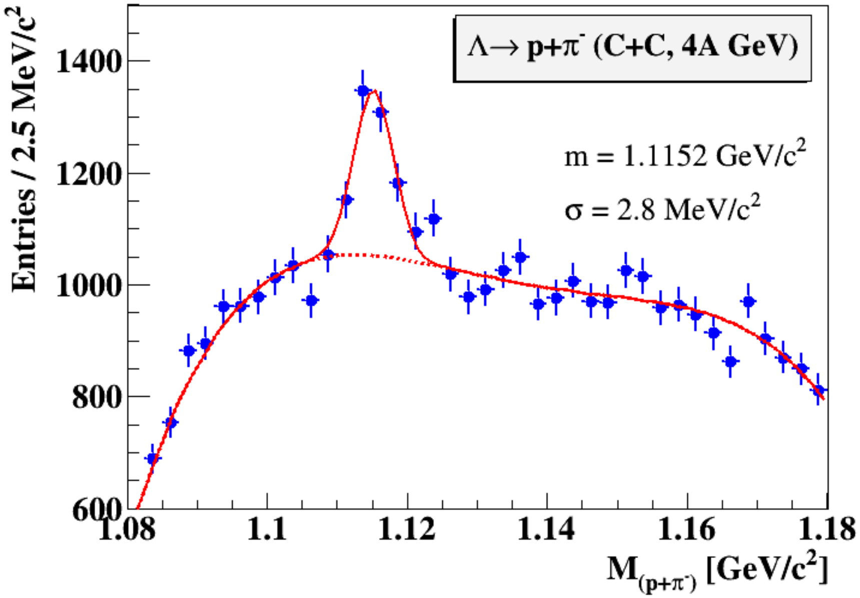
Ar beam, T_0= 3.2 GeV/n
Kr beam, T_0= 2.3 (2.9) GeV/n

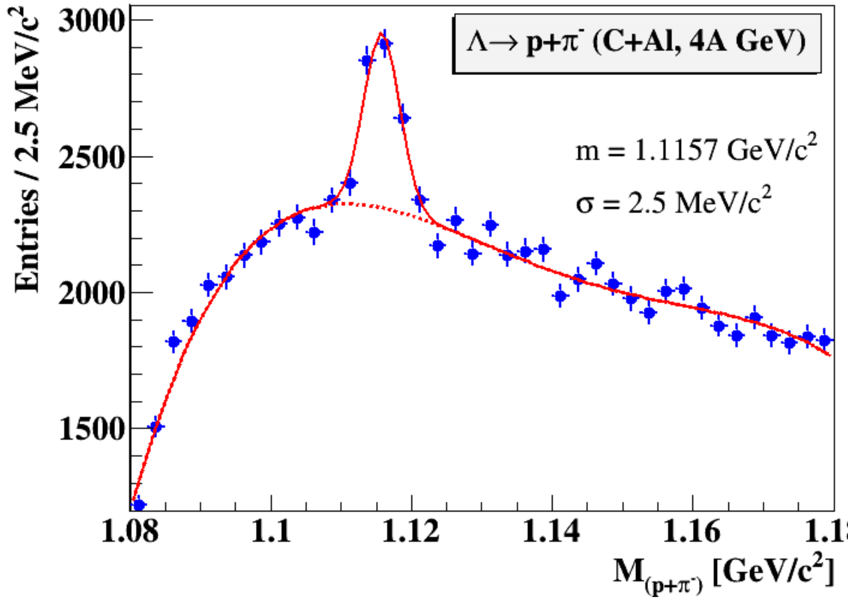


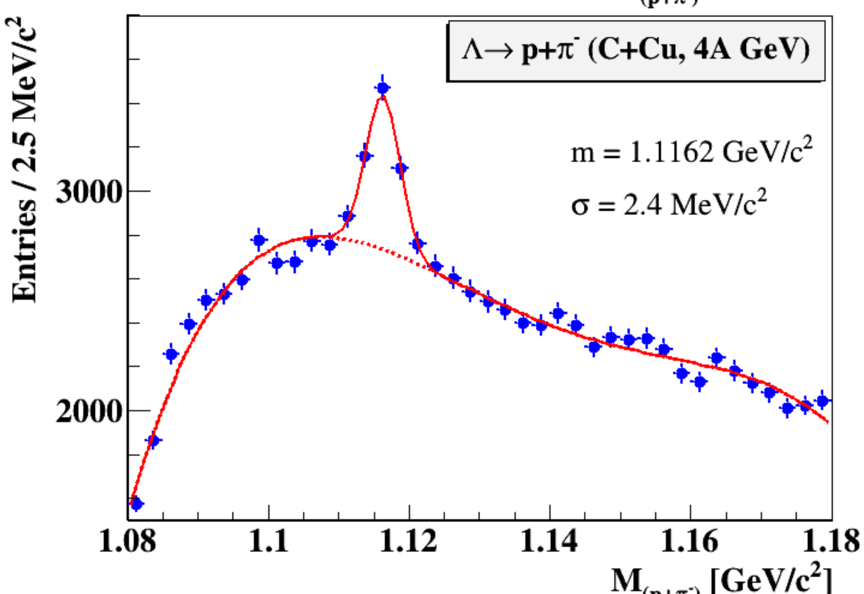
- Central tracker inside analyzing magnet → 6 GEM detectors 163 x 45 cm2 and 3 forward Si strip detectors for tracking
- Full ToF-400, ToF-700, T0 + Trigger barrel and Si detectors, full ZDC, part of ECAL, CSC and DCH chambers as outer tracker

Program: Measure inelastic reactions Ar (Kr) + target → X on targets Al, Cu, Sn, Pb
→ Hyperon production measured in central tracker (Si + GEM)
→ Charged particles and nuclear fragments identified with ToF-400,700
→ Gamma and multi-gamma states identified in ECAL
→ 130 M events in Ar beam, 50 M events in Kr beam

Λ hyperon signals in 4 A GeV Carbon-nucleus interactions







C beam 4 AGeV
C + C,Al,Cu → Λ + X
Λ signal width 2.4 – 3 MeV

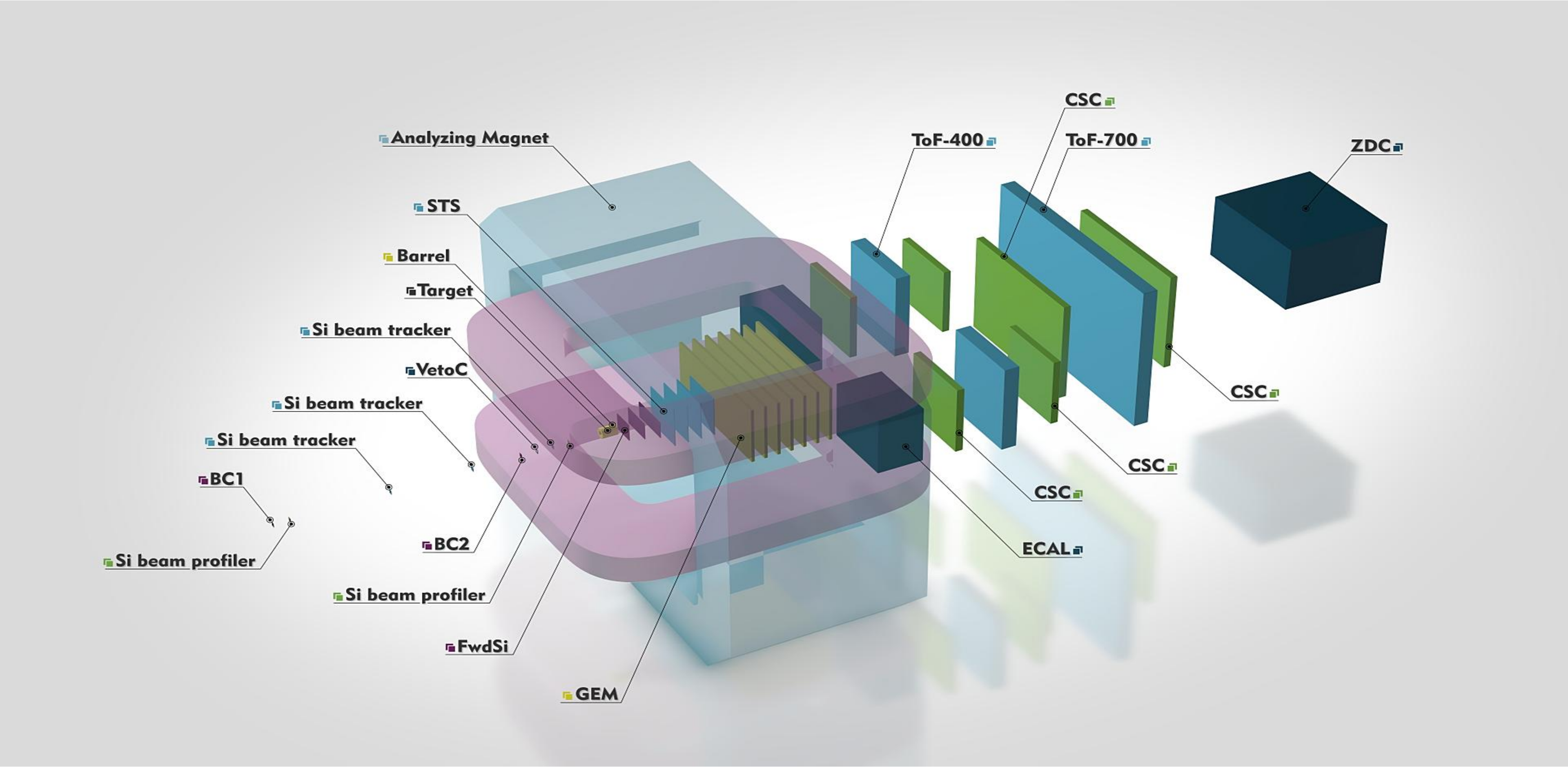
C+C: 4.6M triggers
C+Al: 5.3M triggers
C+Cu: 5.3M triggers

2.5 days of data taking

Beam parameters and setup at different stages of BM@N experiment

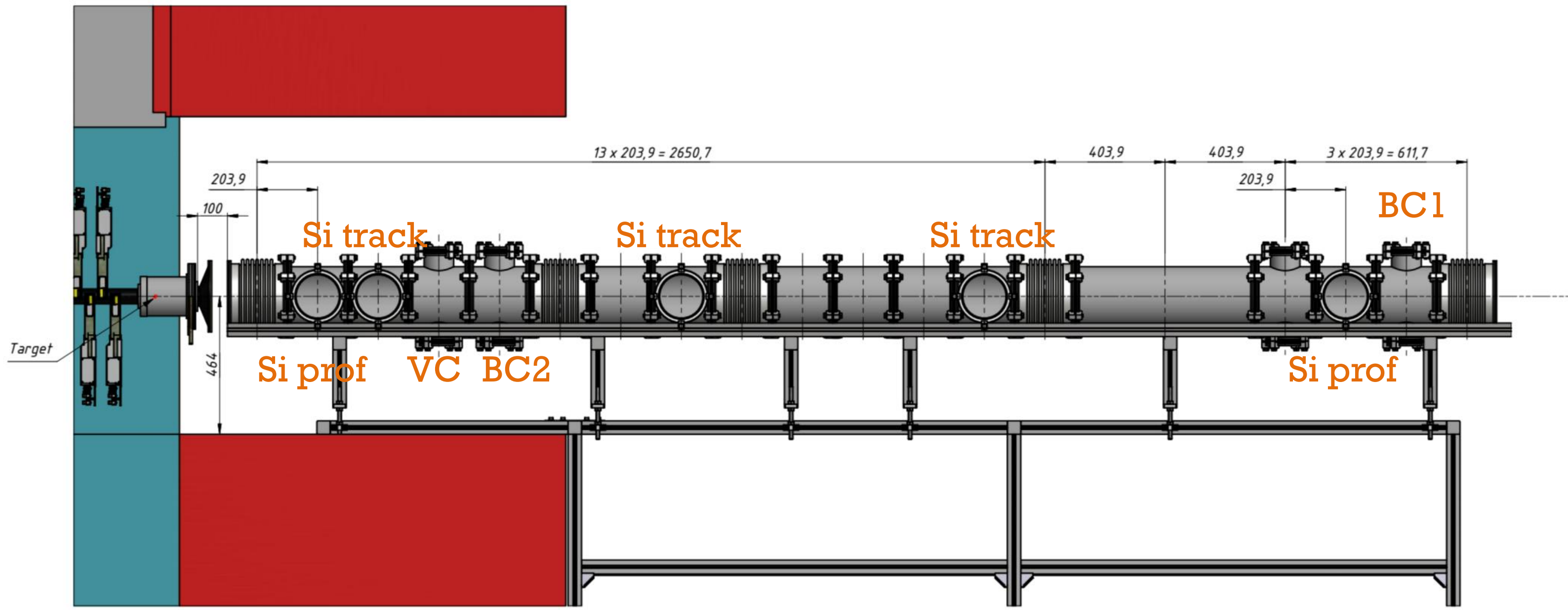
Year	2016	2017 spring	2018 spring	2021	2022 and later
Beam	d(↑)	C	Ar,Kr, C(SRC)	Kr,Xe	up to Au
Max.intensity, Hz	0.5M	0.5M	0.5M	0.5M	2-5M
Trigger rate, Hz	5k	5k	10k	10k	20k→50k
Central tracker status	6 GEM half planes	6 GEM half planes	6 GEM half planes + 3 forward Si planes	7 GEM full planes + forward Si planes	7 GEM full planes + forward Si + large STS planes
Experimental status	technical run	technical run	technical run+physics	stage1 physics	stage2 physics

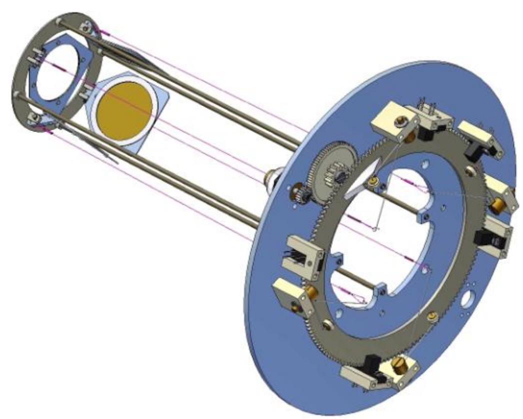
BM@N Experimental Setup



Full detector configuration for heavy ion program

Beam pipe before the target, target station



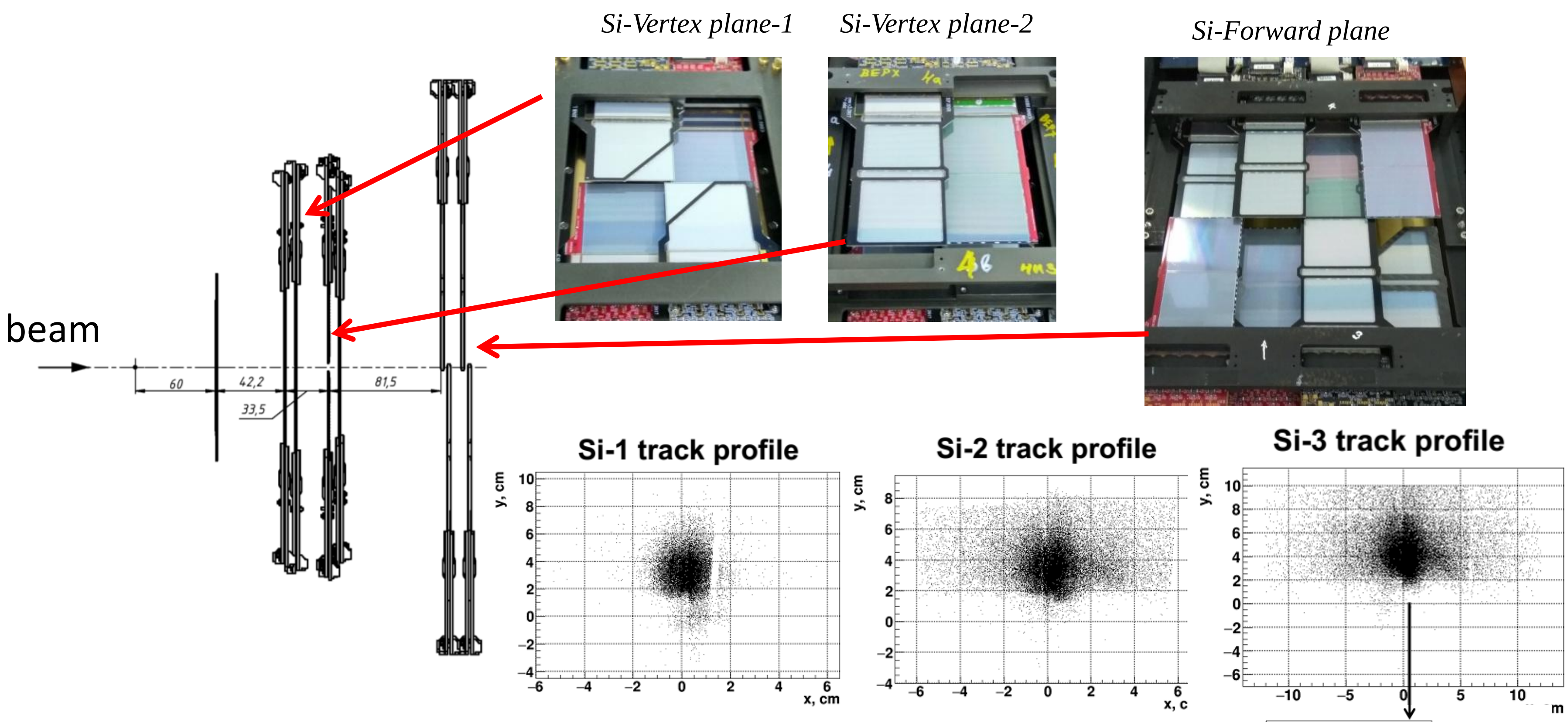


Target station:

Three different target types with d = 30mm and 1 empty target are foreseen for data taking and background evaluation;

Operational in vacuum and magnetic field.

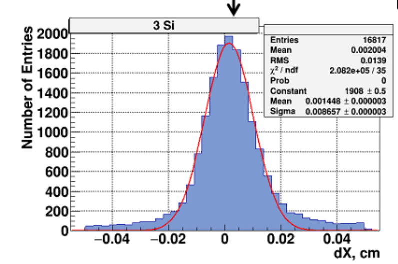
Forward Si tracking detectors performance at Ar and Kr beams (March 2018)



• Si-Forward plane consists of two-coordinate Si sensors, X-X'(±2.5°) with strip pitch of 95/103 μm, sensitivity area 25 × 25 cm², 10240 strips

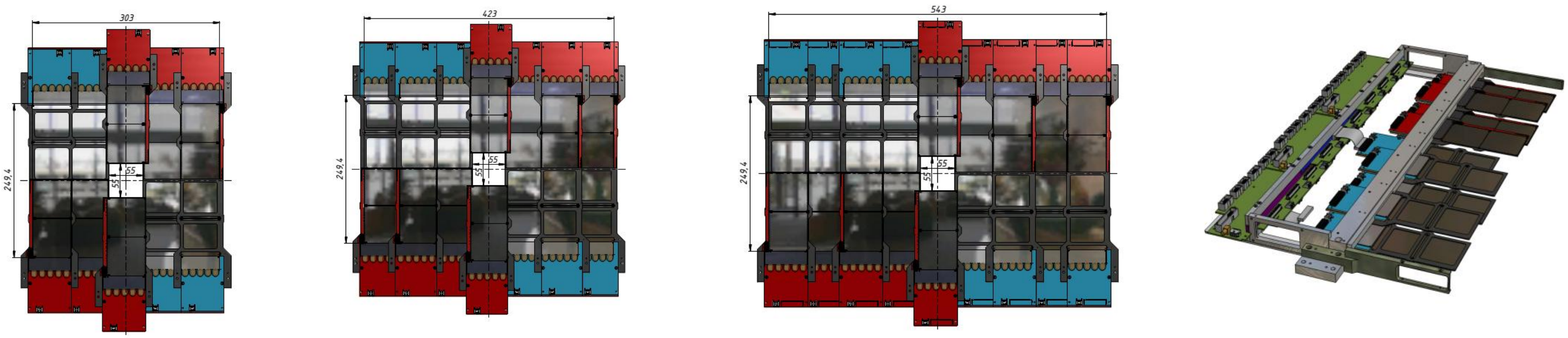
•Vertex plane-1 consists of 4 modules with sensitivity area 12,5×12,5cm², 5120 strips

• Vertex plane-2 consists of 2 modules with sensitivity area 12,5×12,5cm², 2560 strips

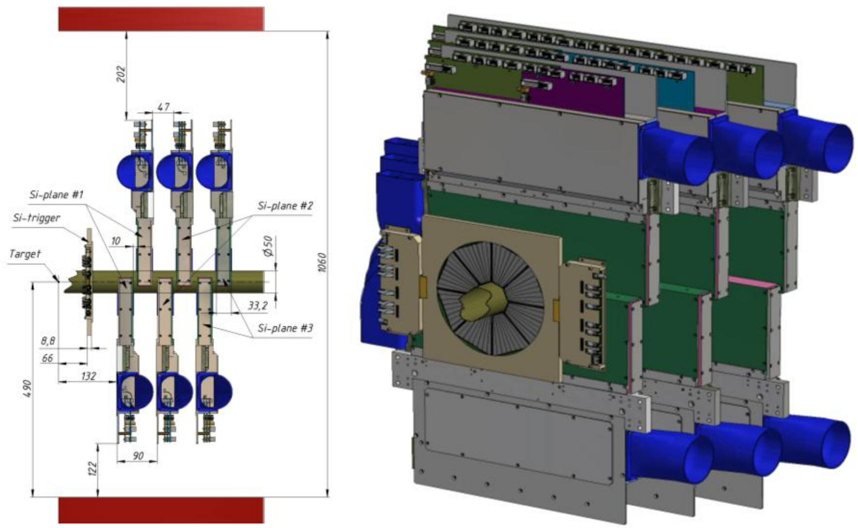


Si-3 detector residual vs GEM+Si track ~ 86 μm

Upgrade of the forward Si tracking detectors



Three sizes of Si-planes



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***

Readout ASIC VATAGP7.1.
Number of sensitive pre-amplifier (CSA) inputs - 128
Input charges (dynamic range) - -30fC ÷ +30fC
Peaking time (slow shaper) - 500ns (typ.)
Good linearity for charges up to +/- 15fC
Reading clock - 4,6MHz

02.2020 – integration of the Si forward tracking detectors into BM@N setup

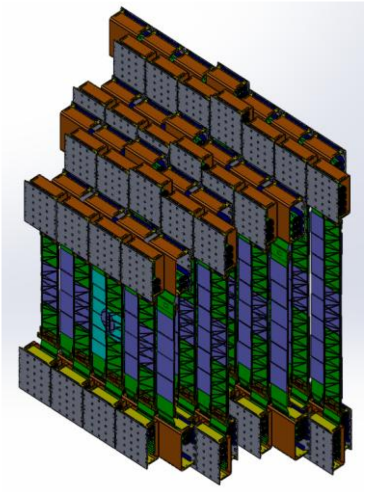
Tentative Design of the BM@N STS

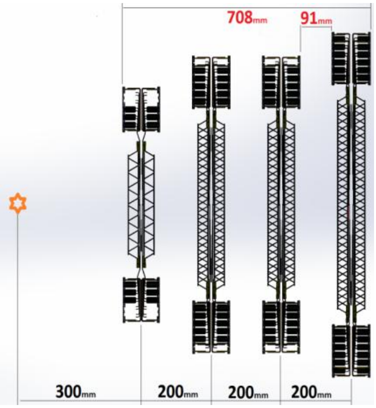
Preliminary layout of BM@N STS was developed.

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

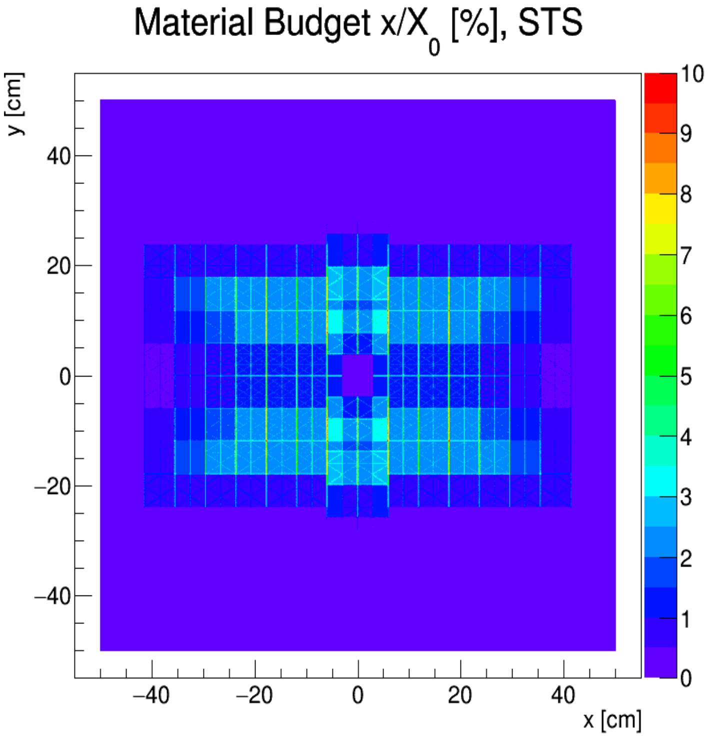
Four stations are based on CBM-type modules with double-sided microstrip silicon sensors:

- Pitch 58μ
- Stereo angle 7.5°
- Thickness 300μ
- Sizes: 62x62, 62x42, 62x22 mm²
- 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

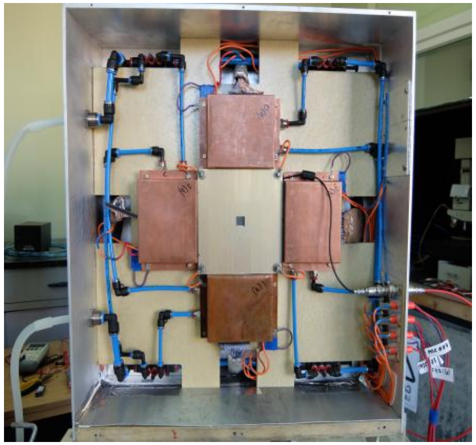
Plans:
2021 – first 42 modules integration into BM@N;
2022 – BM@N STS full configuration (292 modules)

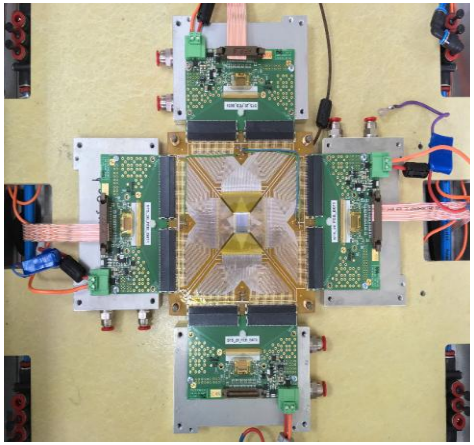
Assembling of BM@N STS modules at JINR

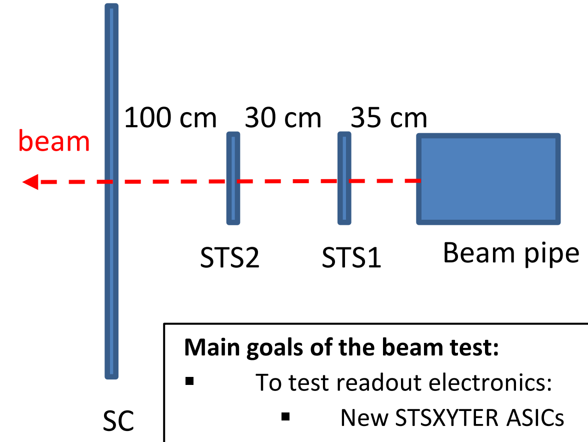
- Two clean rooms are already equipped for the module assembly
- Full set of jigs was developed, produced and tested on mockups
- QA procedure for all steps of assembling was developed
- Two technicians and two engineers are currently fully involved into assembling of BM@N modules
- First operable module was assembled and now is under tests

Assembling of the mockups of BM@N STS modules

Beam test of the STS modules at LINAC-200







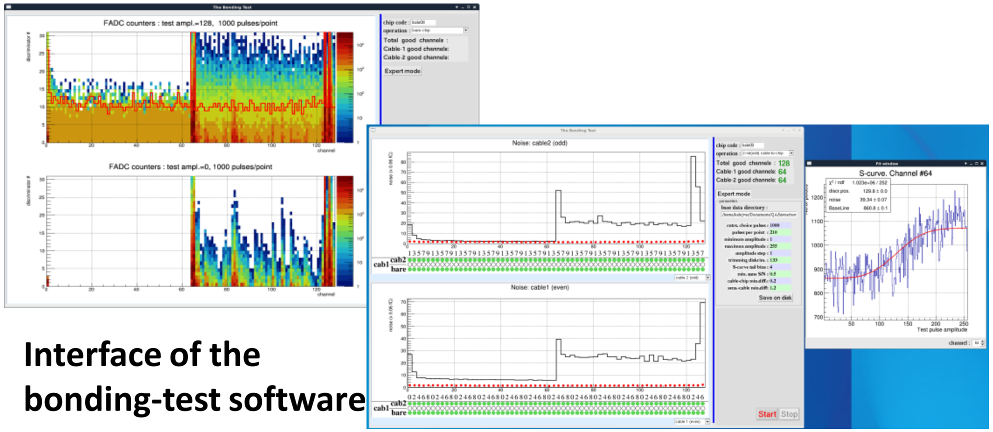
STS1,2 – Test stations with double-sided microstrip silicon sensors 15*15 mm²

SC – scintillator counter 200*200 mm²

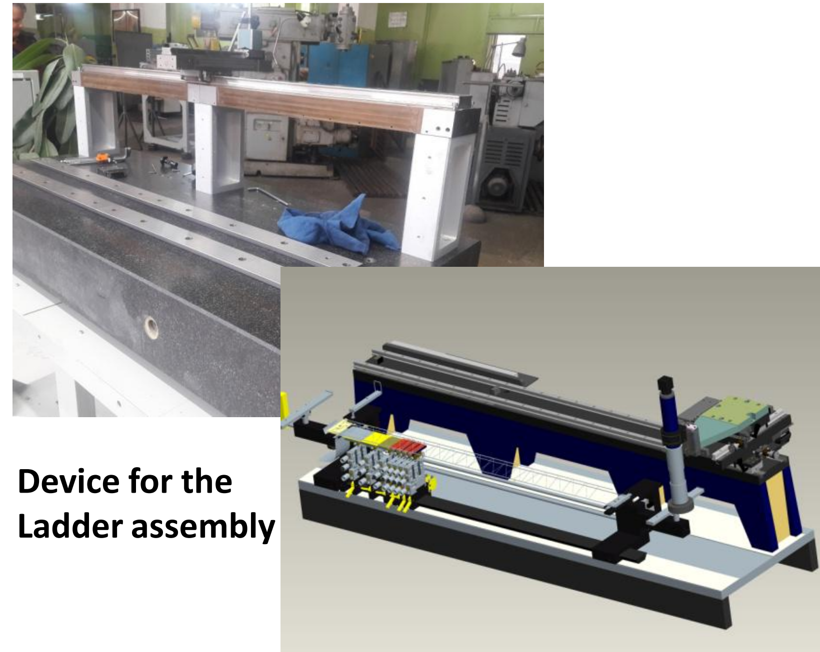
Main goals of the beam test:

- To test readout electronics:
  - New STSXYTER ASICs
  - TS system
  - DAQ System
- Data collection in two modes:
  Free streaming and with a time reference to the trigger signal

Status of the BM@N STS



Interface of the bonding-test software



Device for the Ladder assembly

Assembled module under the shielding cover

Module Assembly

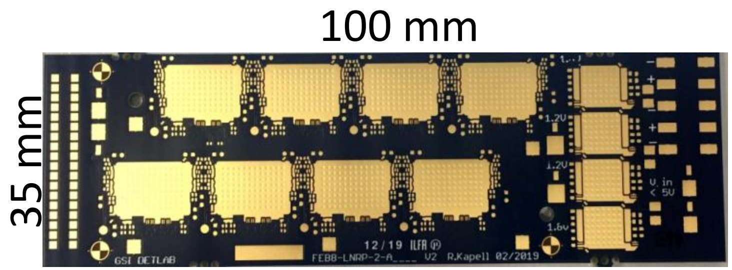
- Assembling of BM@N STS modules has been started in 2019. First modules were assembled.
- Quality assurance system was developed for the tests of the bonding quality during the assembly. It was tested and implemented in the assembly process and DB.
- Full assembling procedure including technological line, DB, QA, endurance and long-term stability tests should be finalized till the end of 2019

Ladder Assembly

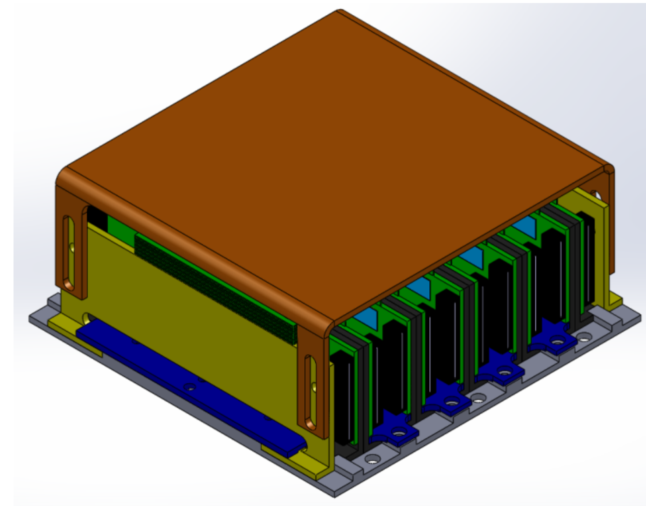
- All components of the ladder assembly device are in the sight
- Complete device should be delivered in the end of June
- Commissioning, staff training and start of ladder assembly supposed at August – September 2019

Status of the BM@N STS

Data processing boards during beam time



New FEB8 designed by R. Kapell



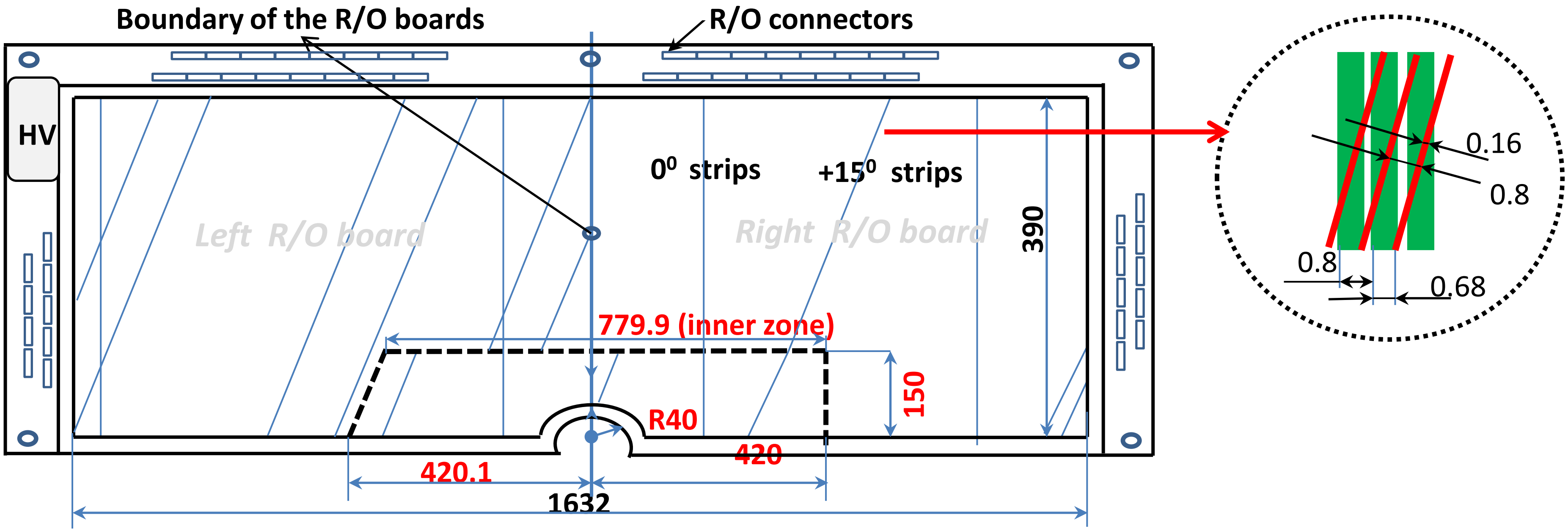
Readout electronics

- New design of the Front-end Board for BM@N STS is under developing. Will be optimized for the new version of ASIC and LDOs, requirements on the cooling and integration. Will be produced in the Oct. 2019
- Firmware for the Data Processing boards with GBT interface was developed and tested during the beam-time at Linac-200
- The following institutes are participating: GSI (Coordination), WUT (Firmware), MSU(FEB design)

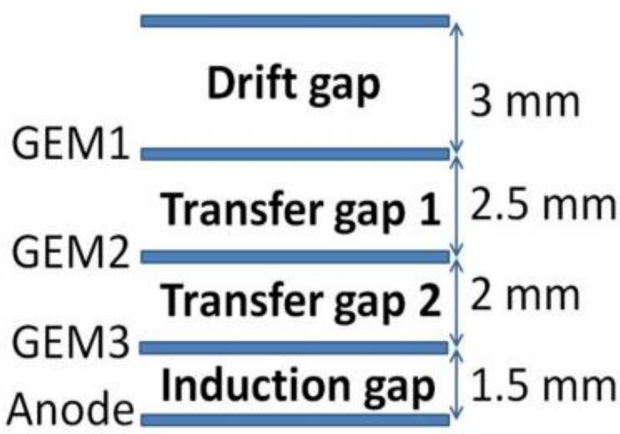
Cooling

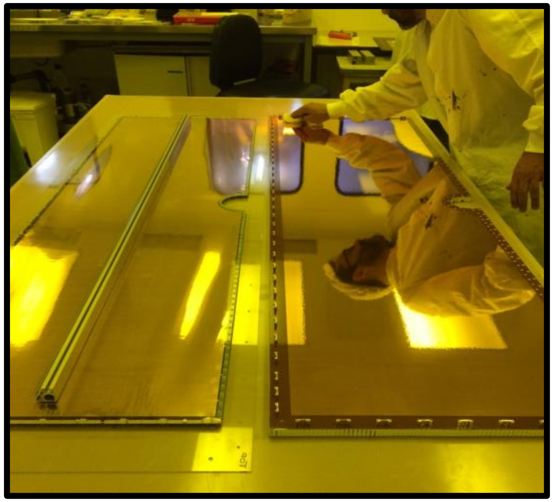
- Thermal simulations of the BM@N STS are now undergoing
- Thermal mockup of the FEB box will be assembled and tested in June 2019
- Thermal mockup of the quarter station will be assembled and tested in Oct 2019
- 2* 14 kW chillers are already in the site
- Thermal simulations will be performed together with a group from WUT and MSU

First BM@N GEM 1632x390 mm^2 chamber was assembled at CERN (December 2018)



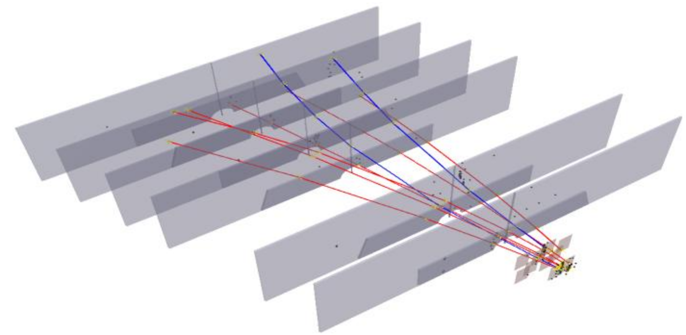
Schematic cross section of BM@N triple GEM detector





GEM central tracking system performance at Ar and Kr beams (March 2018)

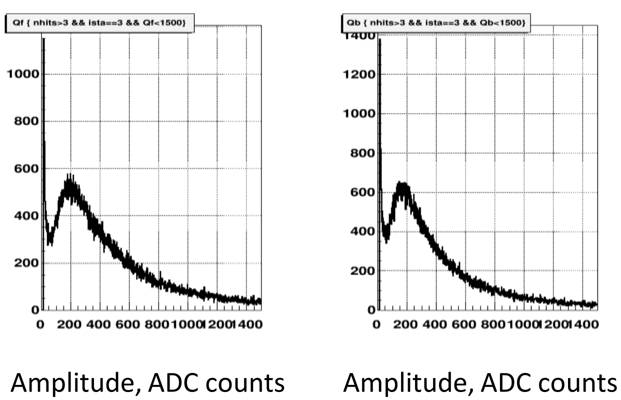
GEM group



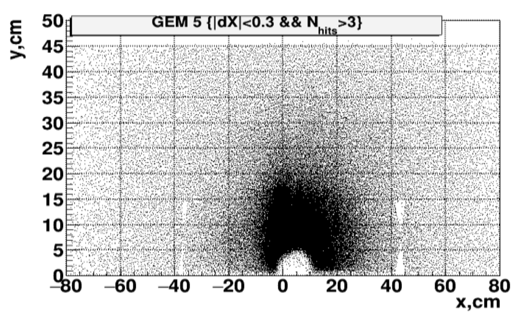
Example of the event reconstruction in the central tracker in Ar+Al interaction

Seven GEM 1632x450 mm^2 chambers produced at CERN workshop were integrated into BM@N experimental setup.

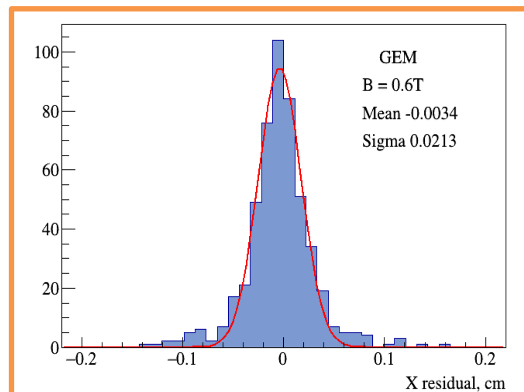
Pile-up suppression in Ar, Kr runs: 3 μs before and 0.5 μs after trigger signal



GEM X&Y amplitude distributions

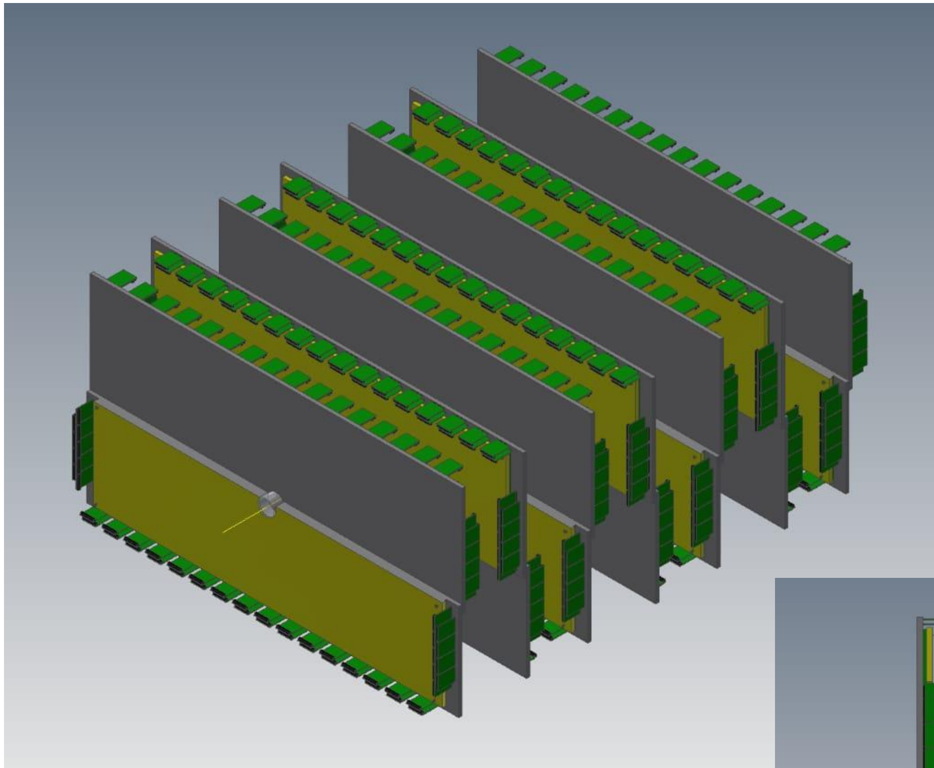


Fragments of Ar beam in one of the GEM chambers

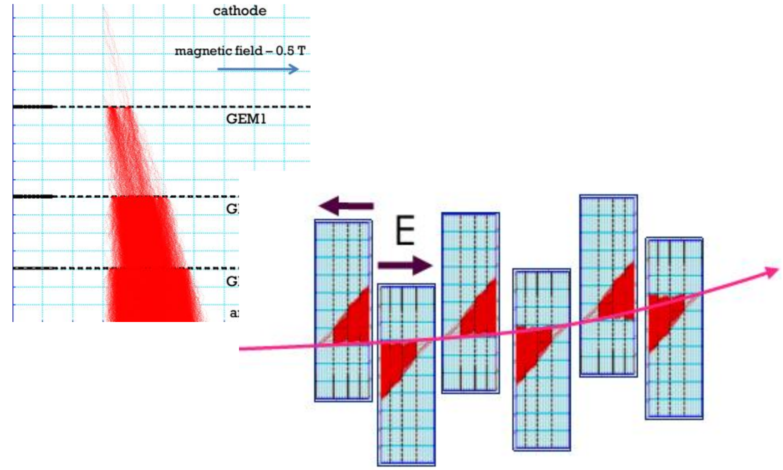


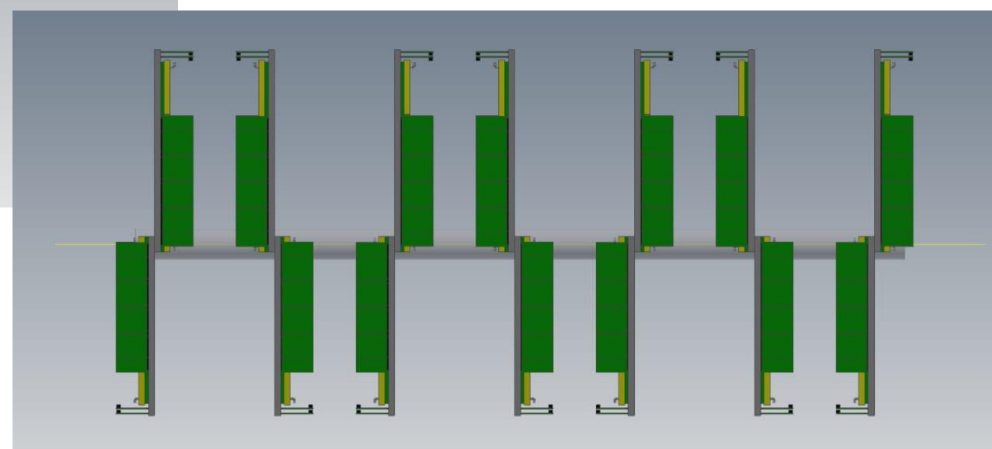
Magnetic field 0.6 T,
Ar(80)/Isobutane(20),
Ar beam, Edrift = 1.5kV/cm

Scheme of the GEM full planes configuration inside the magnet



Lorentz shifts of an electron avalanche in GEM planes

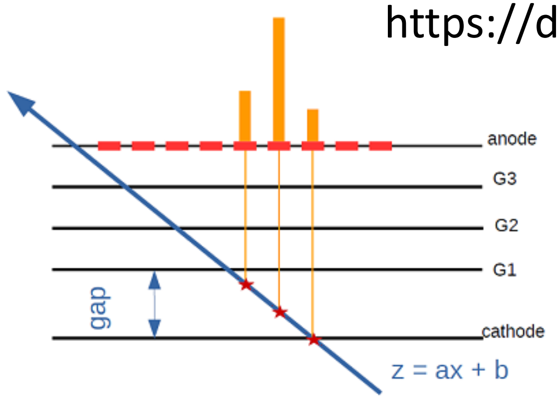




End of the 2019 – mechanics production, installation of the GEM planes.

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

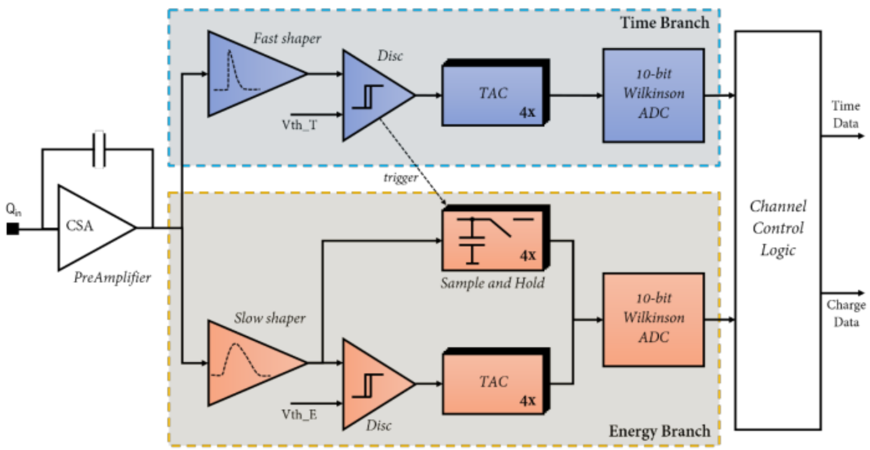
https://doi.org/10.1016/j.nima.2018.09.010



- 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

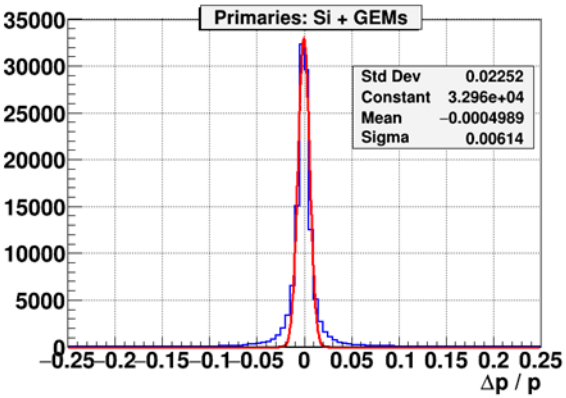


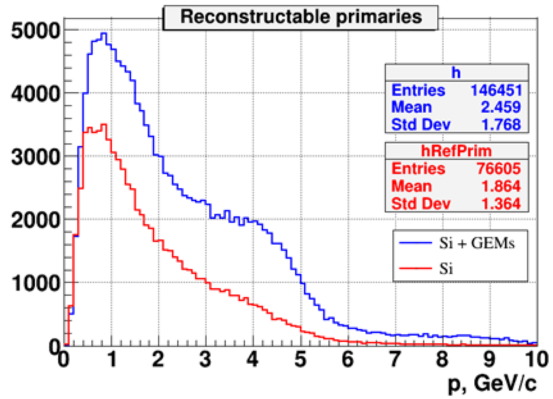
TIGER V2. Programmable gain: range 50-300 fC Input
Sustained event rate > 100 kHz/ch

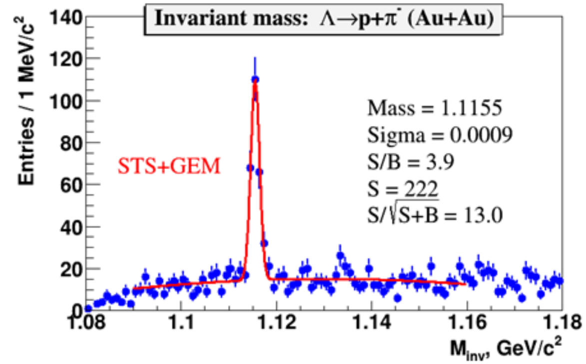
Measured performance of the TIGER ASIC:
Input charge 5-55 fC
TDC resolution 30 ps RMS
Time-walk (5-55 fC range) 12 ns
Average gain 10.75 mV/fC
Nonlinearity (5-55 fC range) 0.5%
RMS gain dispersion 3.5%
Noise floor (ENC) 1500 $e-$
Noise slope 10 $e-$/pF
Maximum power consumption 12 mW/ch

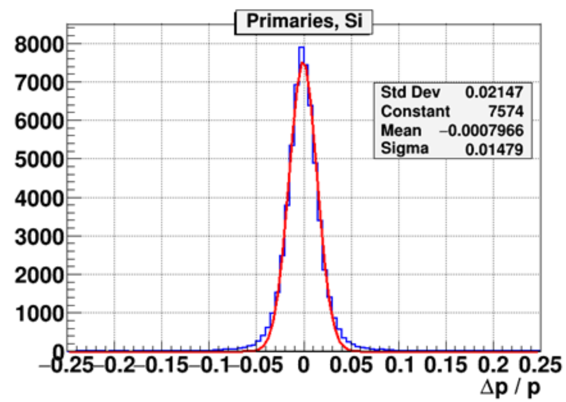
First tests with BM@N GEMs are planed 10.2019 at CERN

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

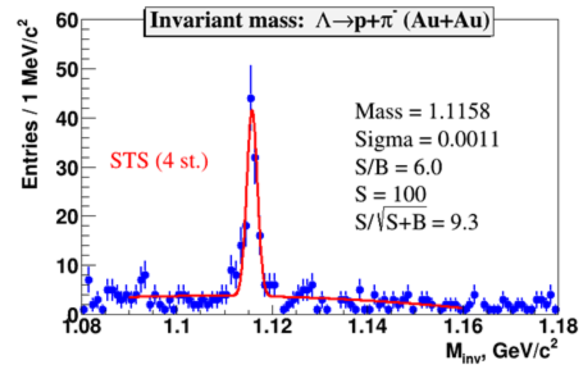








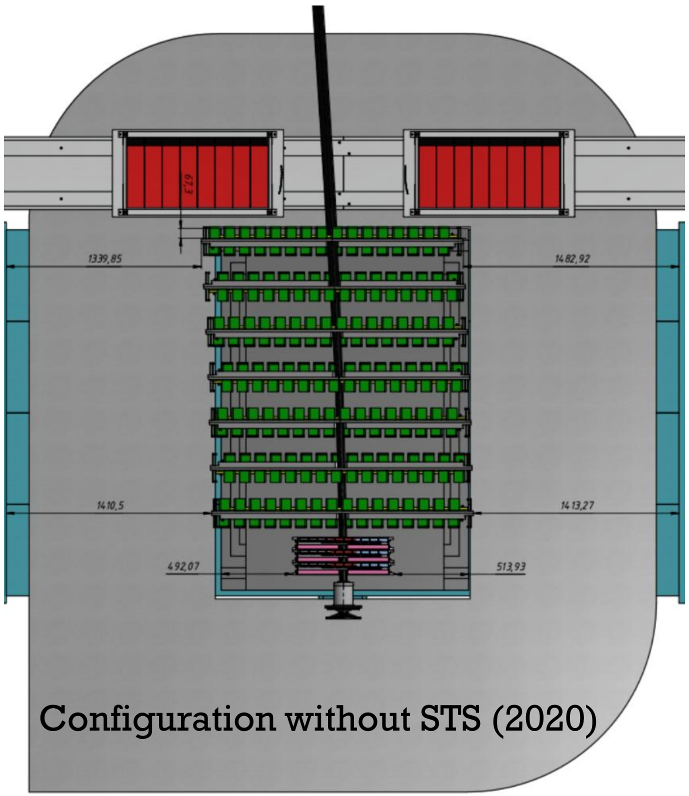
Hybrid STS + GEM tracker:
► 2 times increase in number of reconstructed tracks and Λ hyperons
►2 times better momentum resolution



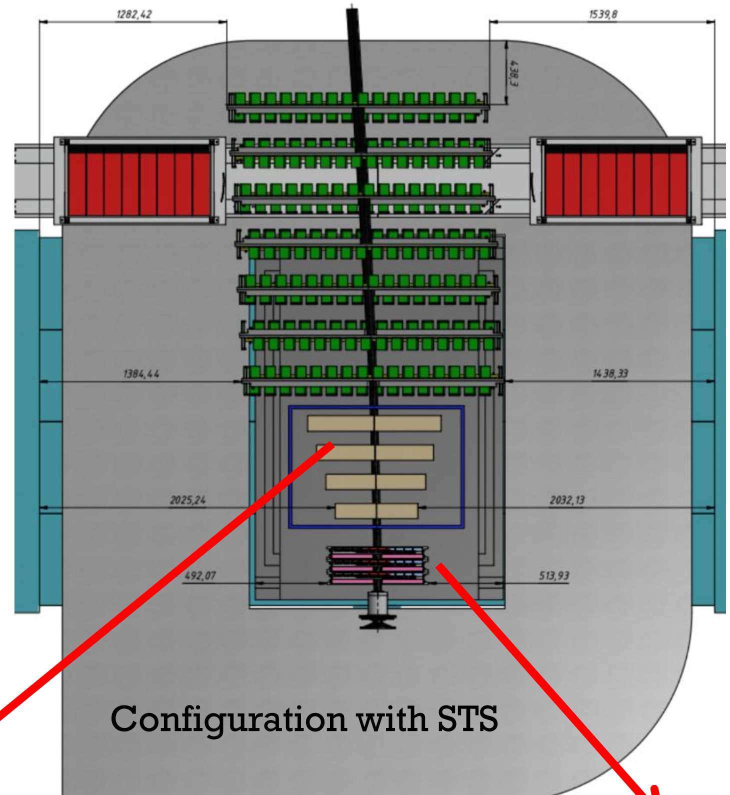
Forward Si+ STS +Gem configuration

Four configurations of the tracking detectors are foreseen:

- Forward Si + 7 GEMs: beam intensity few 10^5 Hz , 2020 - 2021
- Forward Si + 1 pilot STS station + 7 GEMs: beam intensity few 10^5 Hz , 2021
- Forward Si + 4 STS stations + 7 GEMs: beam intensity few 10^5 Hz, 2022
- 4 STS stations + 7 GEMs (fast FEE): high beam intensity few 10^6 Hz, 2022-



Configuration without STS (2020)



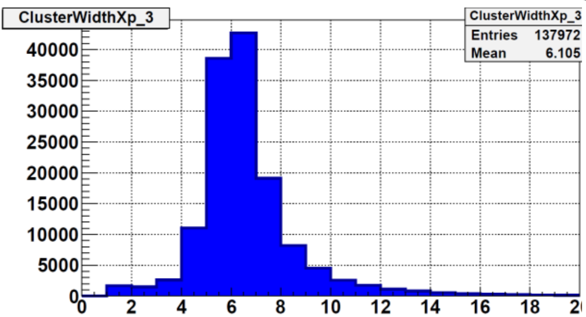
Configuration with STS

2021 year – "pilot" configuration
2022 year – full configuration

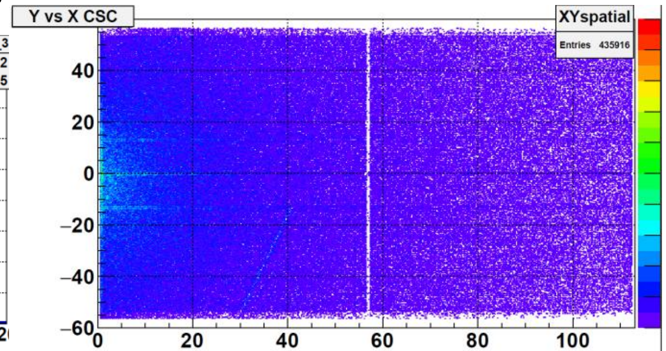
Forward Si will be removed after integration of STS full configuration into BM@N setup (2022 year, high beam intensity - few 10^6 Hz)

Performance of 1065x1065 mm^2 CSC chamber in Ar, Kr runs

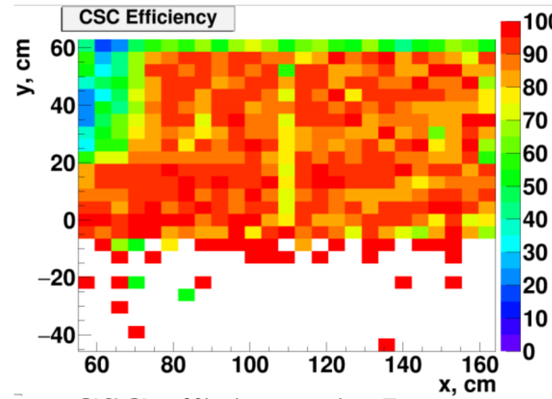
C, Ar and Kr runs in March 2018: CSC chamber is installed in front of ToF-400 to check its performance as outer tracker for heavy ions



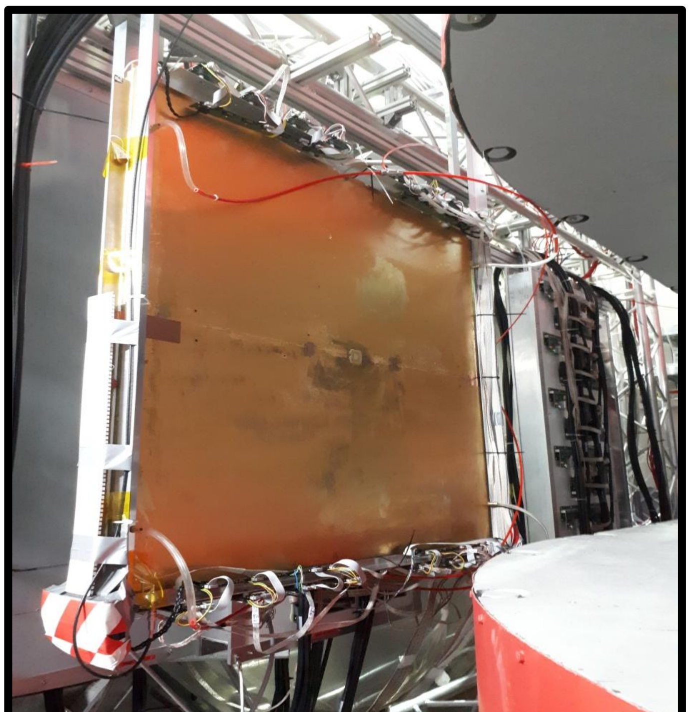
Cluster width

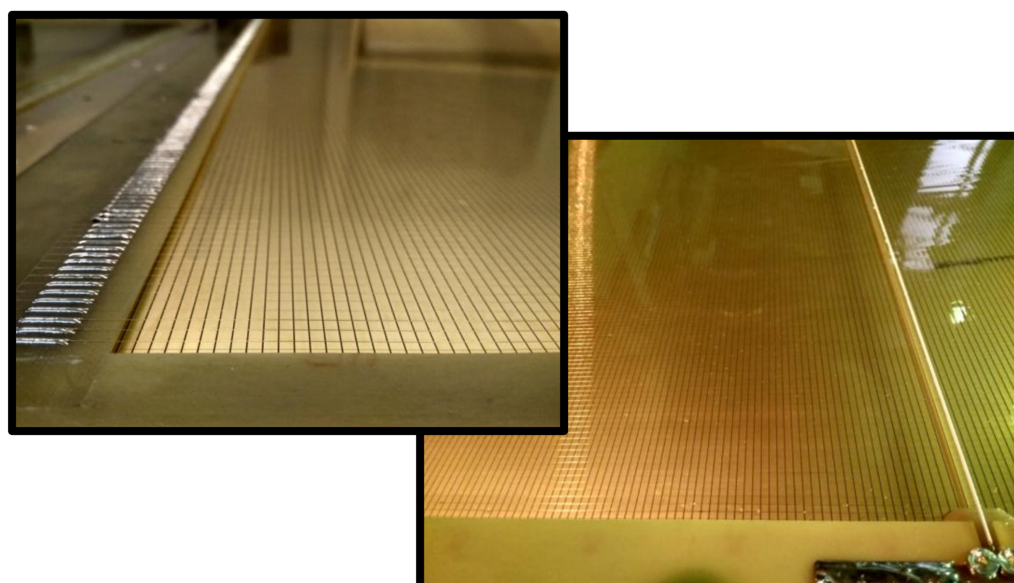


Events distribution on the chamber surface in Kr run

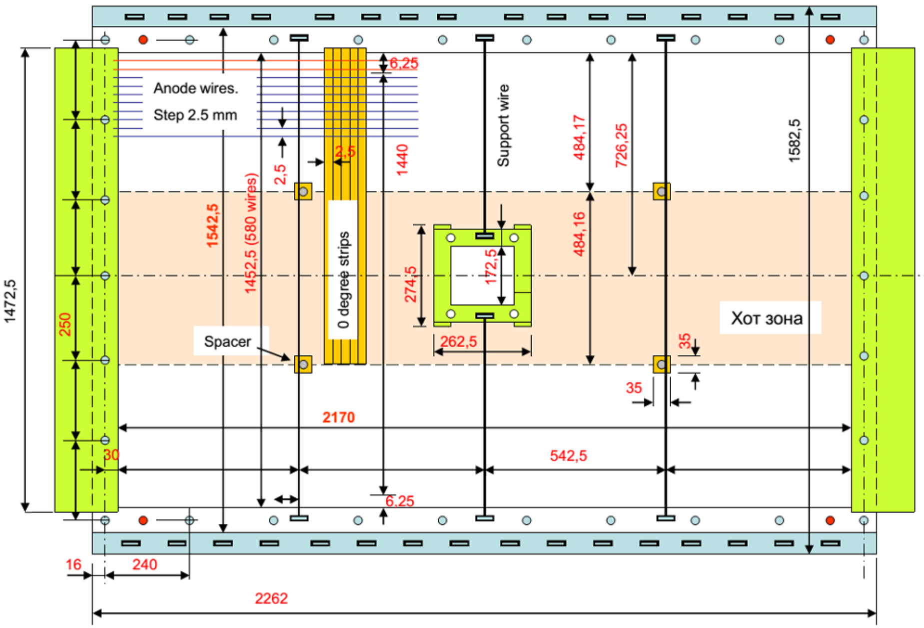


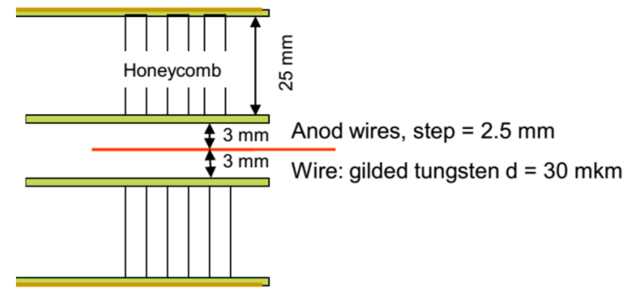
CSC efficiency in Ar run
Track extrapolated from GEM
Residual (CSC_hit – GEM) < 2cm





Schematic view of 2190x1453 mm^2 CSC

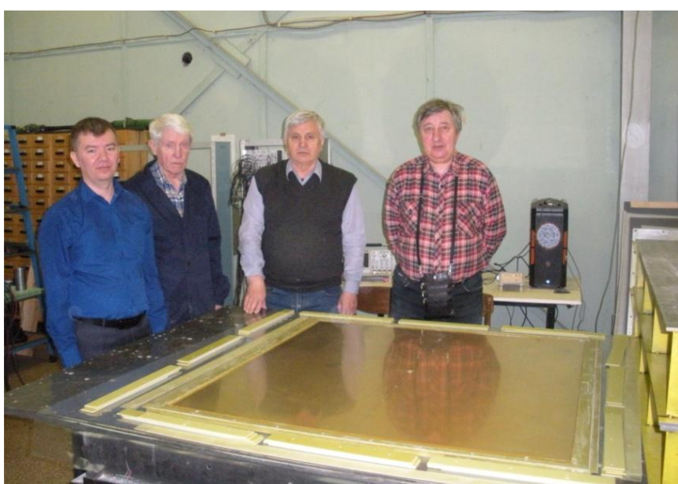




Two cathode planes with strips inclined at 0° and 15°

Each cathode plane consists of 8 printed circuit boards.

Each pcb is divided on hot and cold zones.

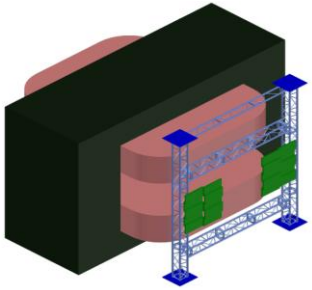


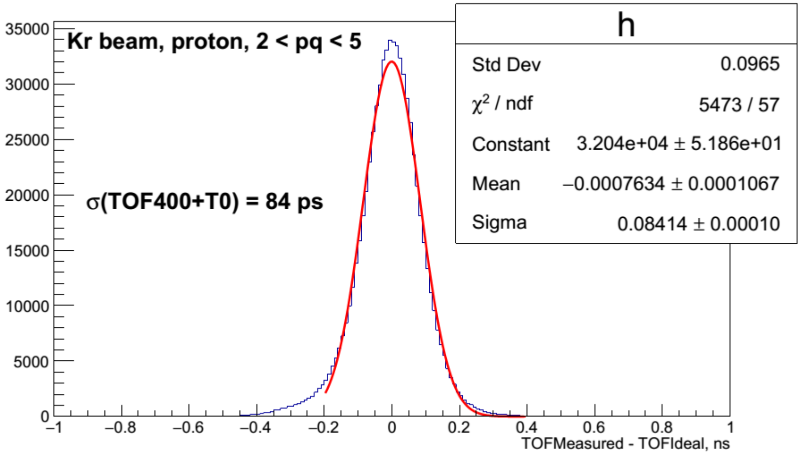
CSC assembly team

Two 2190x1453 mm^2 CSC chambers are to be installed before and after ToF-700

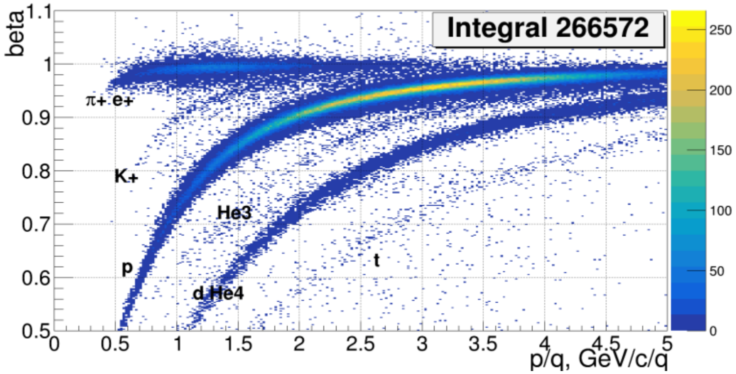
Design and assembly – JINR LHEP

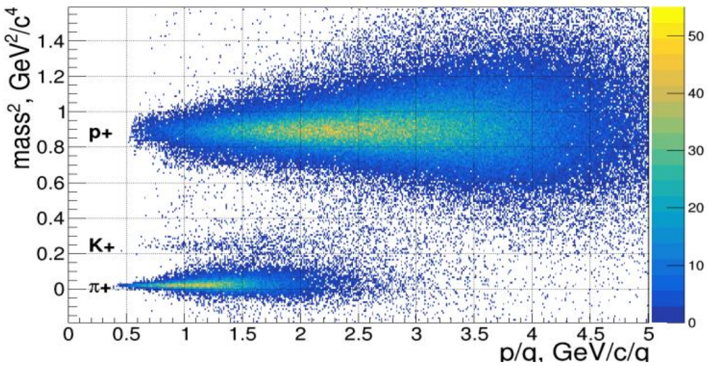
Status ToF-400





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

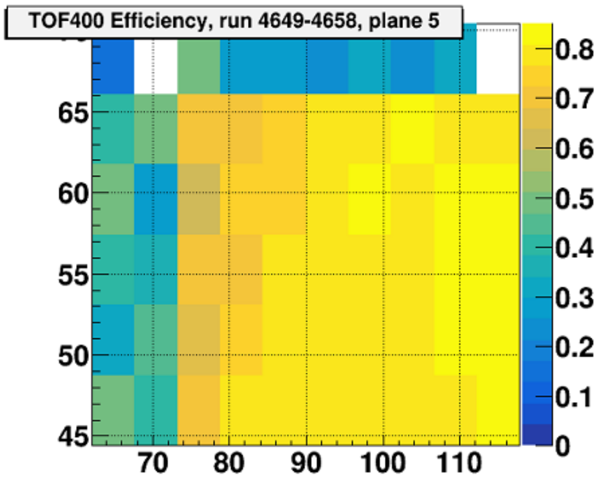


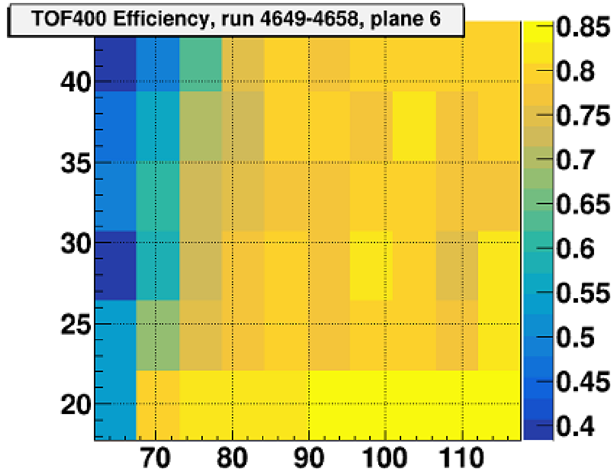


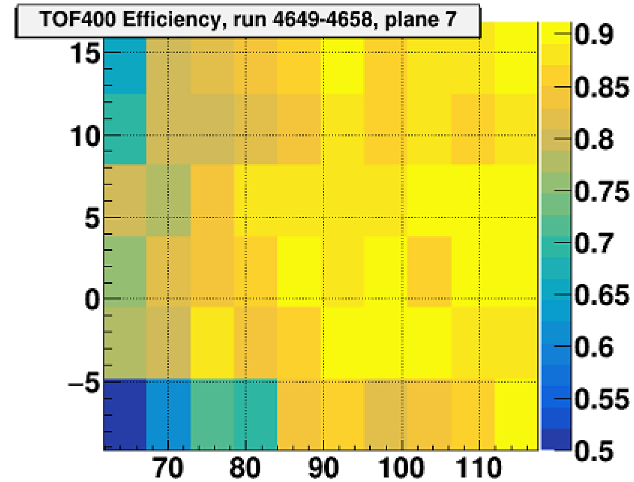
Proton Mass^2 = 0,894 +- 0,081 GeV^2/c^4, Pion Mass^2 = 0,021 +- 0,016 GeV^2/c^4

Status ToF-400

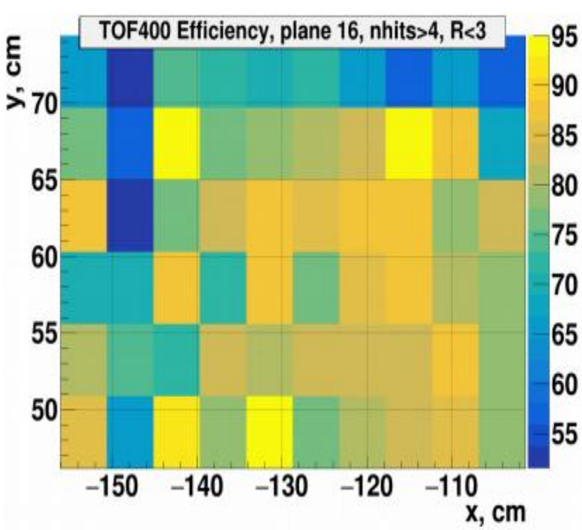
Examples of the efficiency distributions for the ToF – 400 planes located downstream CSC
GEM+CSC tracks extrapolated/ Residual < 3cm/Average efficiency~90%

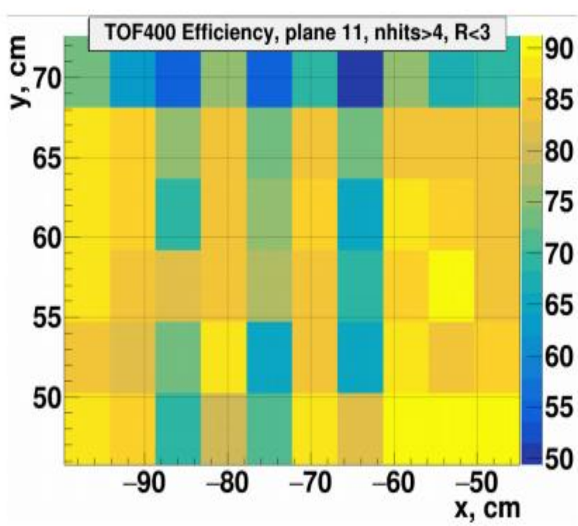


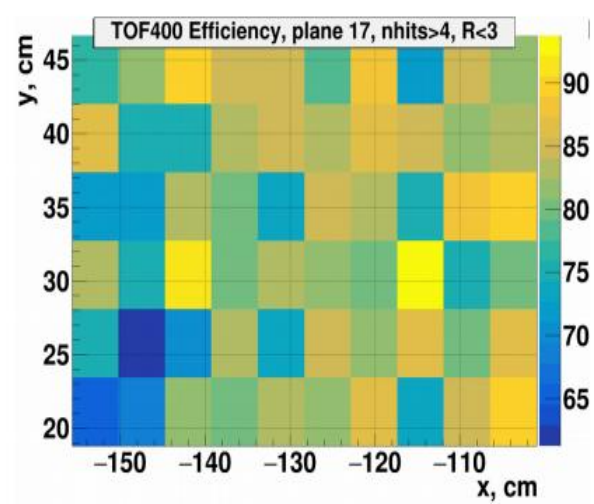




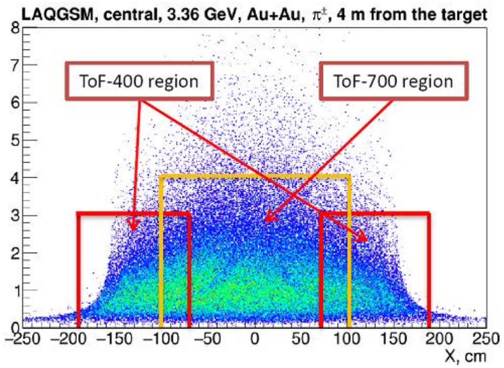
Examples of the efficiency distributions for the ToF – 400 planes (right arm, CSC is not installed)
GEM tracks extrapolated/ Residual < 3cm/Average efficiency~80%

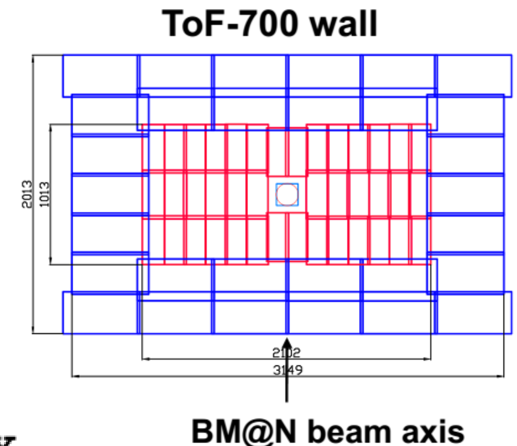




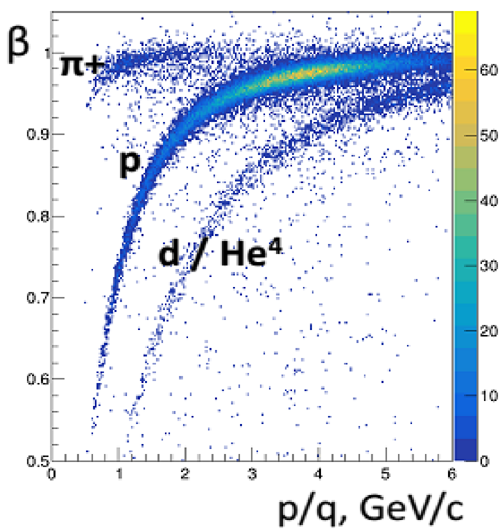


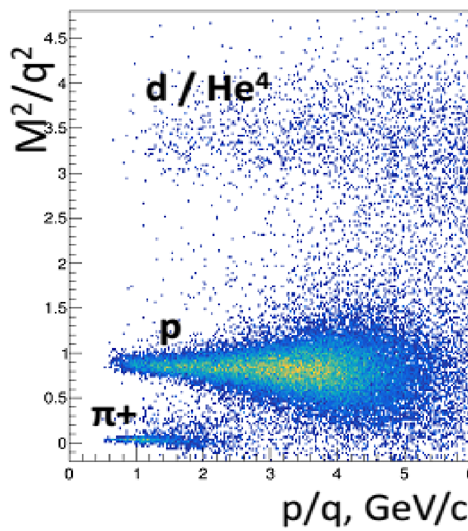
Status ToF-700

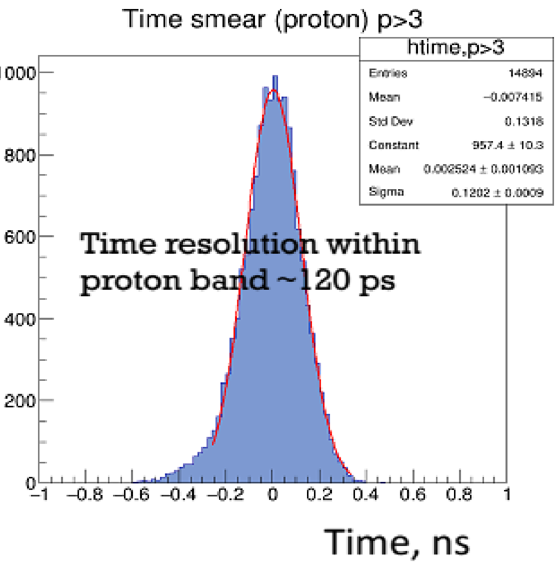




Ar beam , 3.2 AGeV , Ar + Al,Cu → X







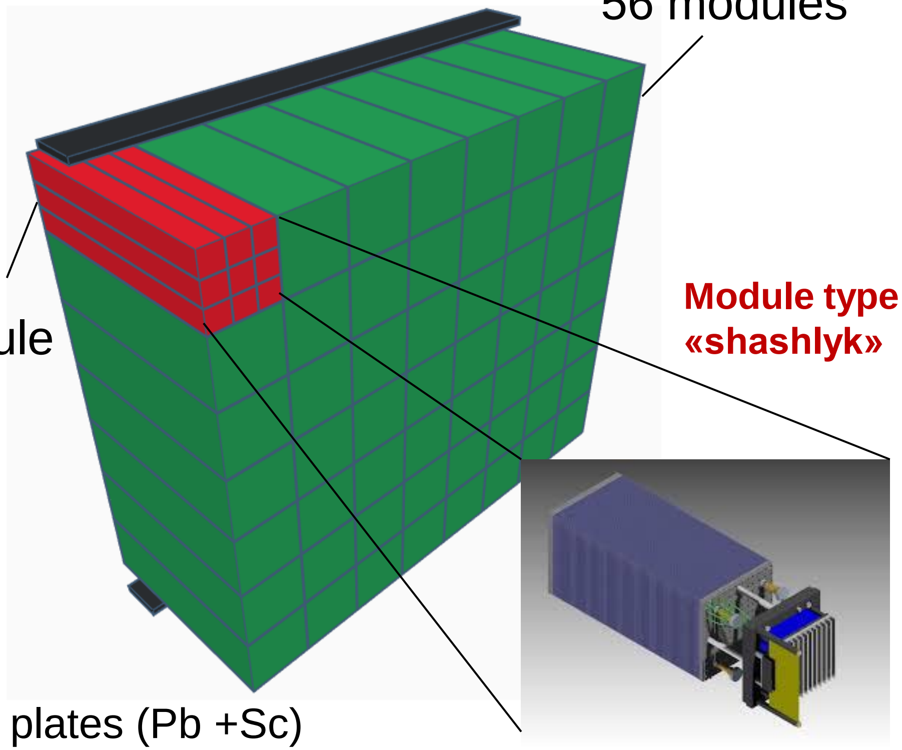
Efficiency estimated for pair of chambers located one for another is ~96%

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

ECal Design

56 modules

9 cells
In module



Module type «shashlyk»

220 plates (Pb +Sc)

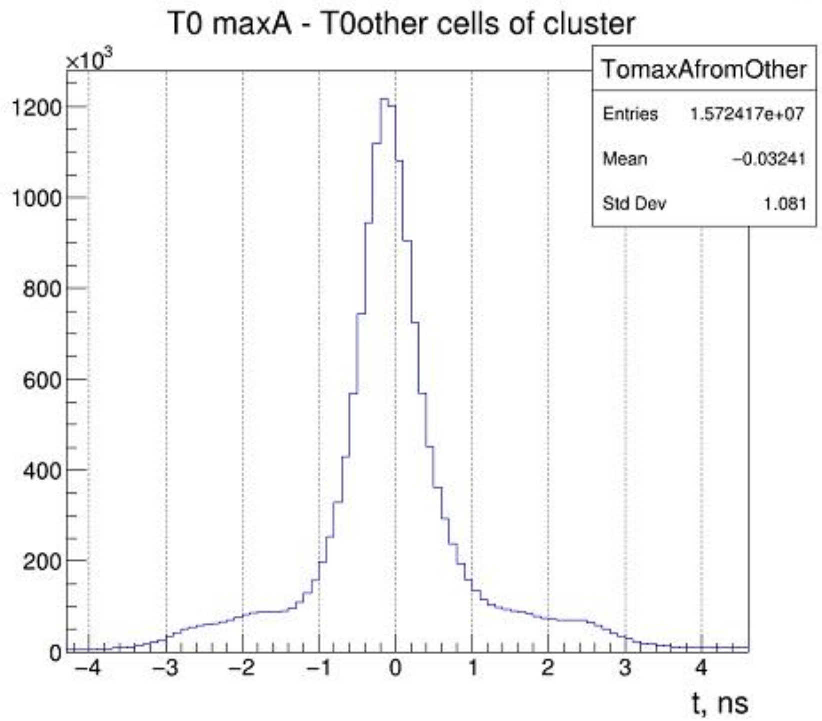
504 cells with MPPC (SiPM) (multipixel photon counter)

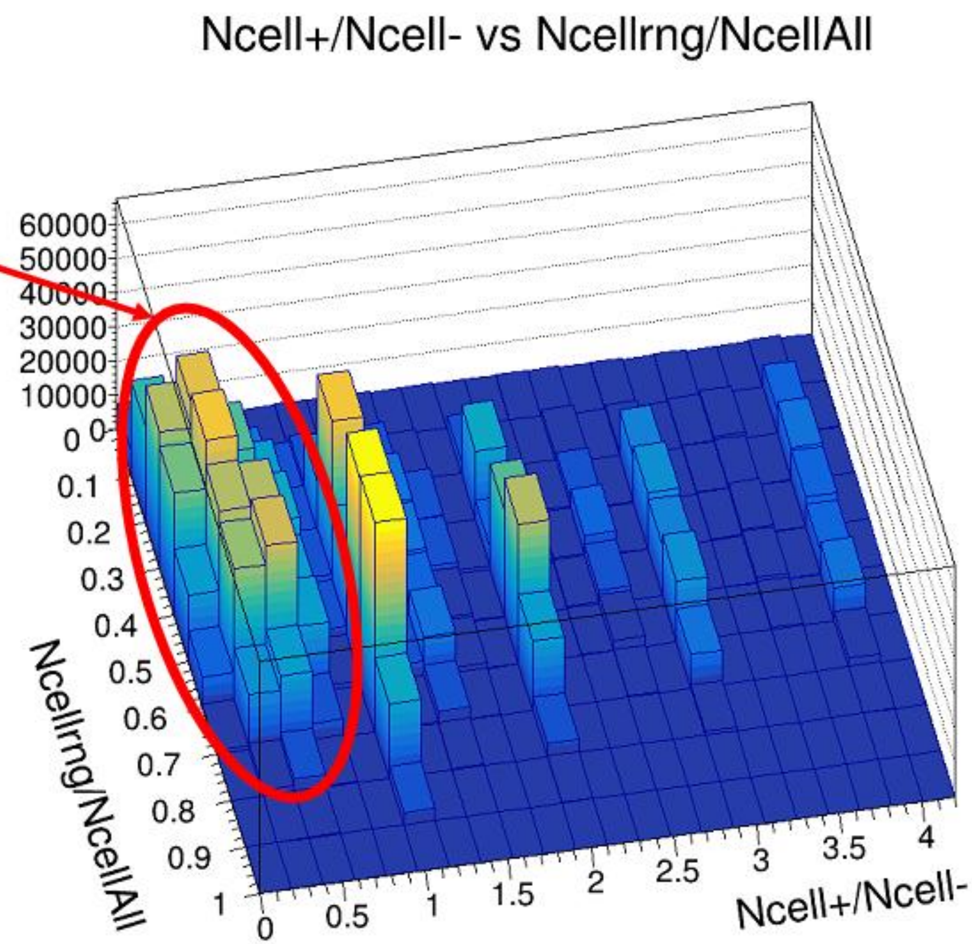
Location of Ecal in the magnet SP-41

$$\frac{(2.98\pm0.05)\%}{\sqrt{E}} \oplus (2.94\pm0.04)\%$$

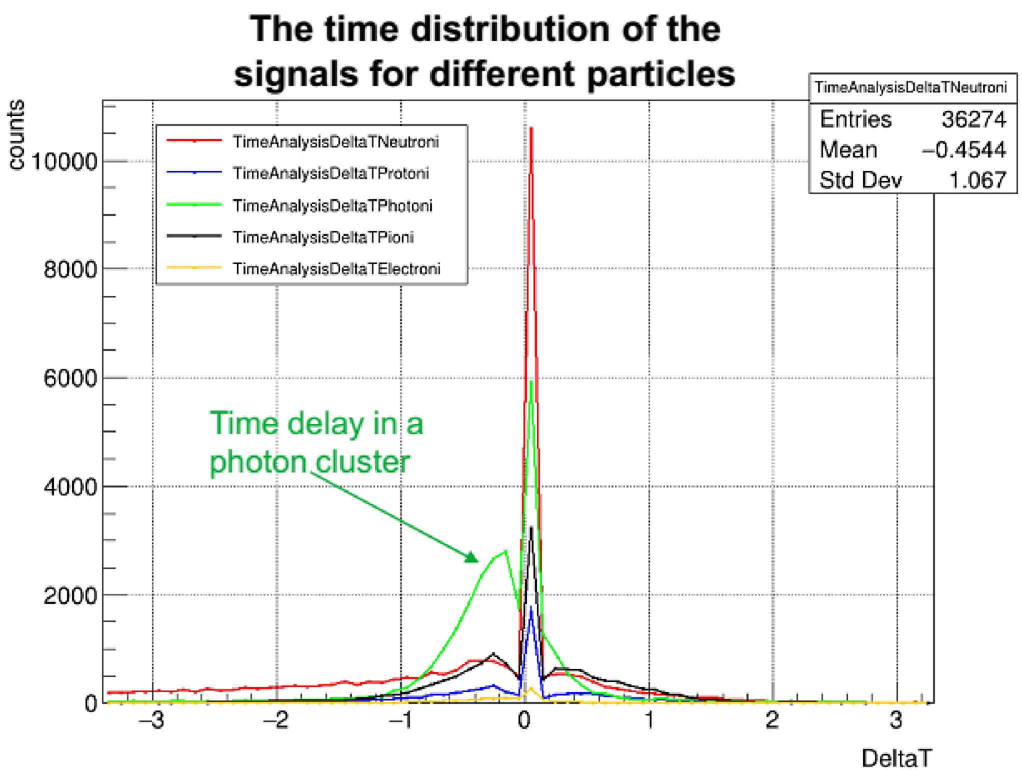
The selection of electromagnetic shower using time analysis of signals

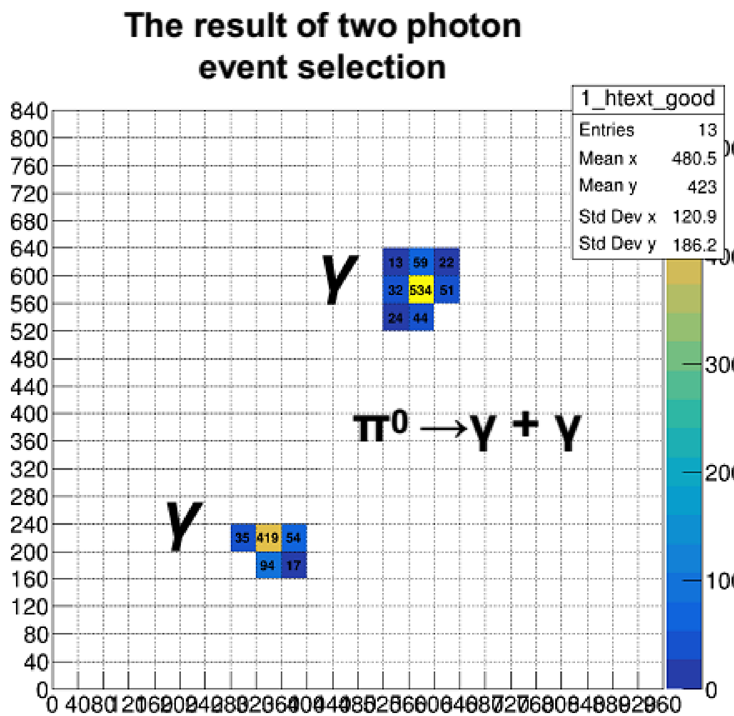
$$\frac{Ncells(> 0.2)}{Ncells(< -0.1)} < 1$$





The result of the time analysis two photons event selection





Condition for photons separation → $\dfrac{\text{Ncells}(> 0.2)}{\text{Ncells}(< -0.1)} < 1$

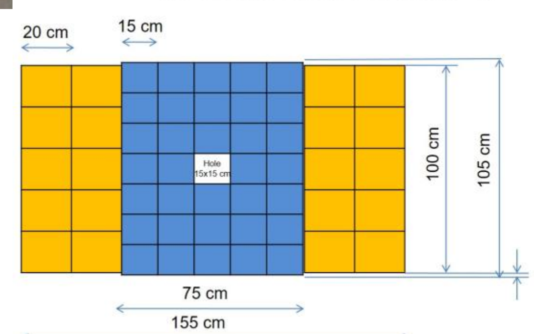
The result from 55 nuclotron run

ZDC Status

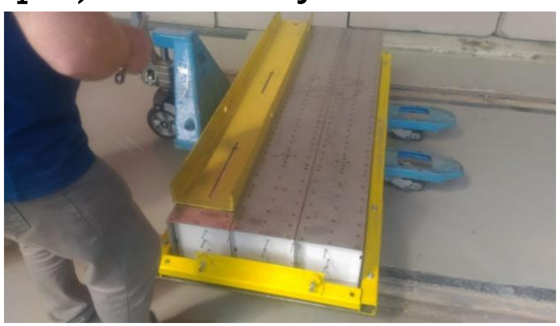
35 FHCAL MPD modules (16_BM@N+19_MPD)

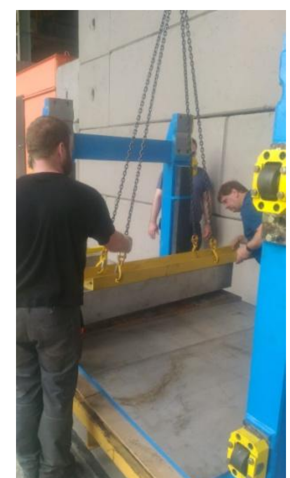
To be replaced

20 PSD CBM modules



Transportation of CBM modules (20 pcs), FHCAL BM@N modules (16 pcs) and FHCal MPD modules (19 pcs) from INR at JINR was performed.

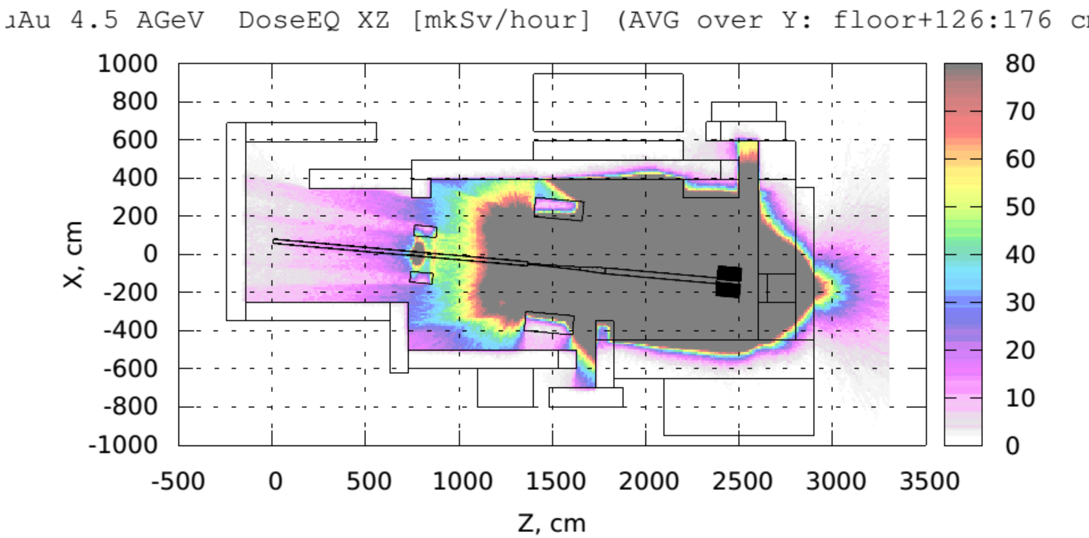




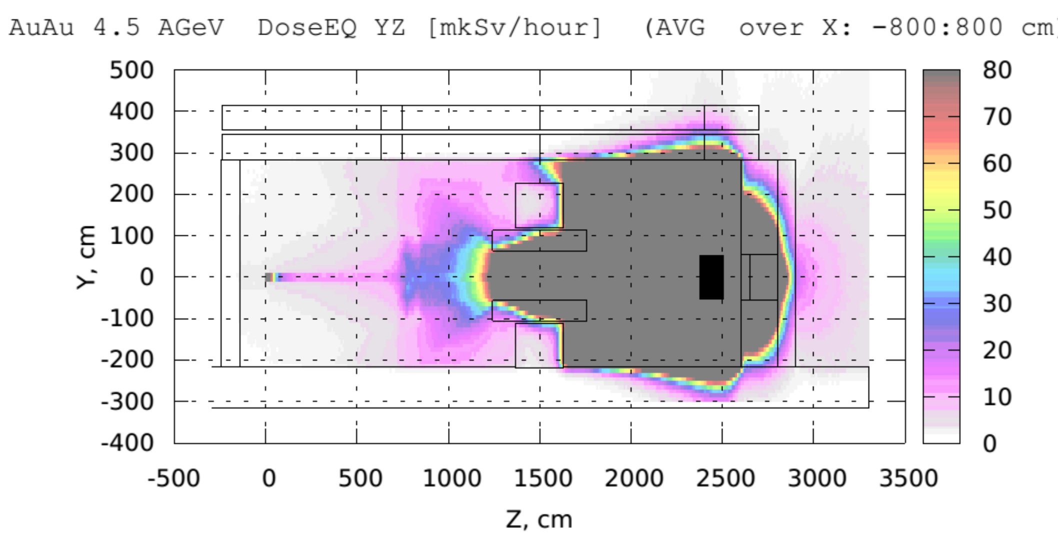
Motivation for MPD/CBM hadron calorimeter:

- Modern technics;
- Light yield ~x10 higher;
- Detection of low energies;
- Stable operation at high count rates;
- Experience in operation for later MPD/CBM experiments

Biological Protection Calculation for Au+Au interactions



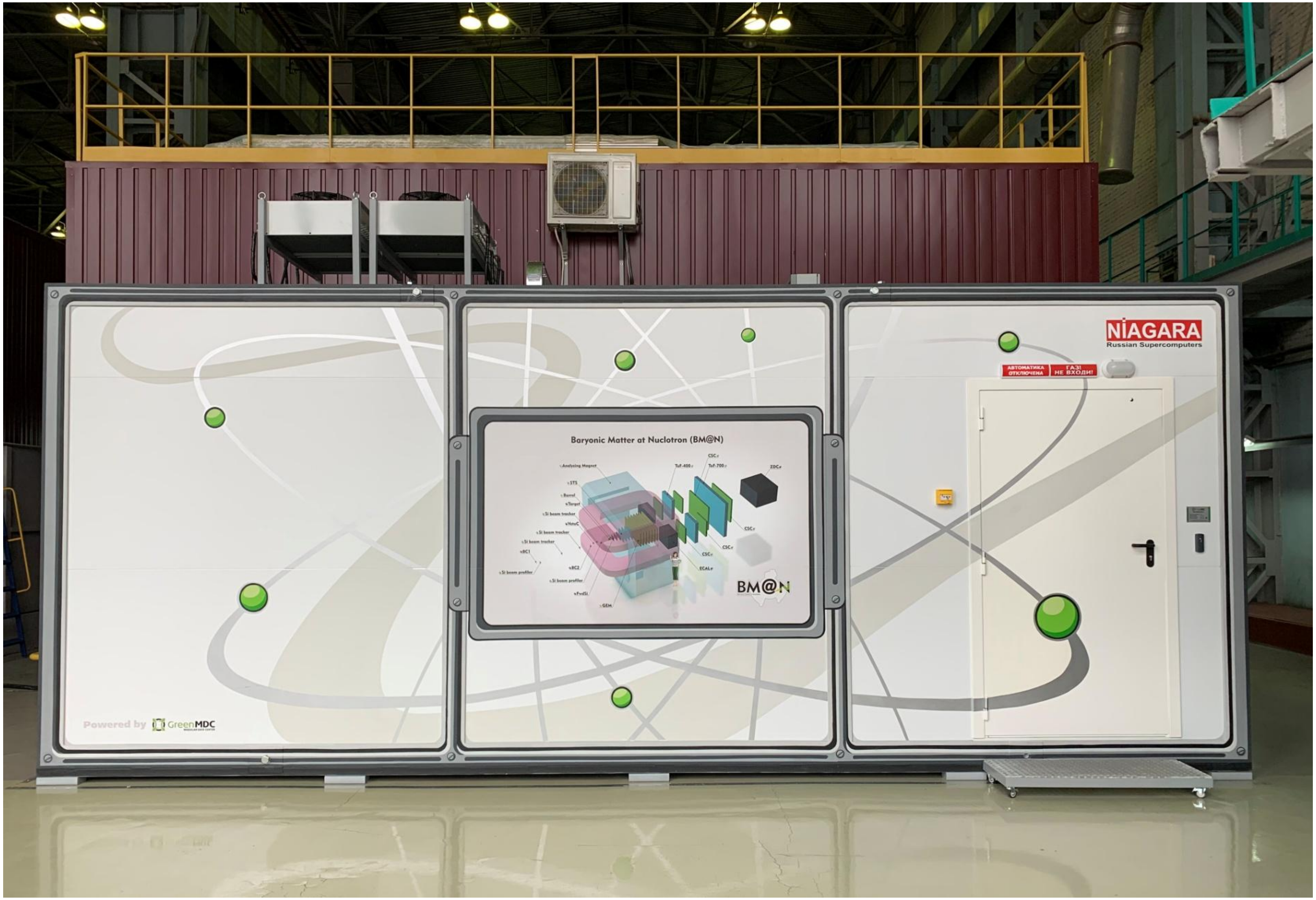
XZ projection



YZ projection

Additional protection to be built before heavy ion beams are delivered to the BM@N experimental setup

MDC(Mobile data storage and DAQ center) was installed at 205 bld.



Summary:

Detector Subsystem	Status	Upgrade Status
Beam pipe before the target, target station		end of 2019
Forward Si detectors	3 small planes	3 full-size planes (02.2020)
STS BM@N		42 modules (2021) 292 modules (2022)
GEM	7 top half-planes + 1 bottom half-plane	7 full planes (2019)
CSC	1 chamber 1065x1065 mm^2	4 chambers 1065x1065 mm^2(2019) 2 chambers 2190x1453 mm^2(2020-21)
ECAL	one arm	two arms (2019)
ToF-400	full configuration	
ToF-700	full configuration	
ZDC	ZDC Pb+Sci sandwitch	ZDC (MPD/CBM type) (2019)

Summary:

The international collaboration BM@N was established in April 2018 (230 members, 21 institutions, 11 countries).

-BM@N technical runs performed with deuteron and carbon beams at energies T0 = 3.5 - 4.6 AGeV and with Ar beam of 3.2 AGeV and Kr beam of 2.4 AGeV

- Major sub-systems are operational, but are still in limited configurations

- Algorithms for event reconstruction and analysis are being developed, signals of Λ hyperon decays are reconstructed

Major BM@N plans for heavy ion program:
- Collaborate with CBM to produce and install large aperture STS silicon detectors in front of GEM setup

- Extend GEM central tracker and CSC outer tracker to full configuration

- Implement vacuum beam pipe through BM@N setup

BM@N Collaboration: 21 Institutions from 11 countries, 230 participants