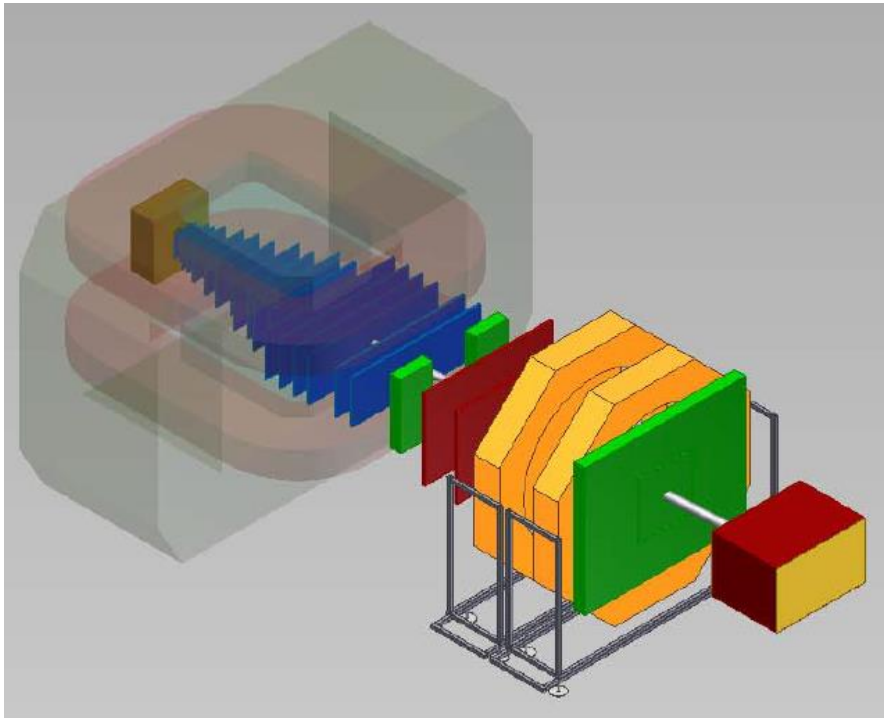
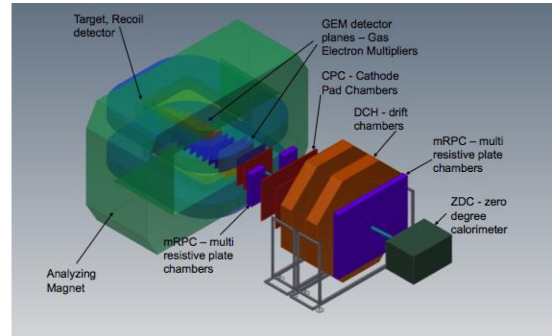
Status of the BM@N experiment

M.Kapishin



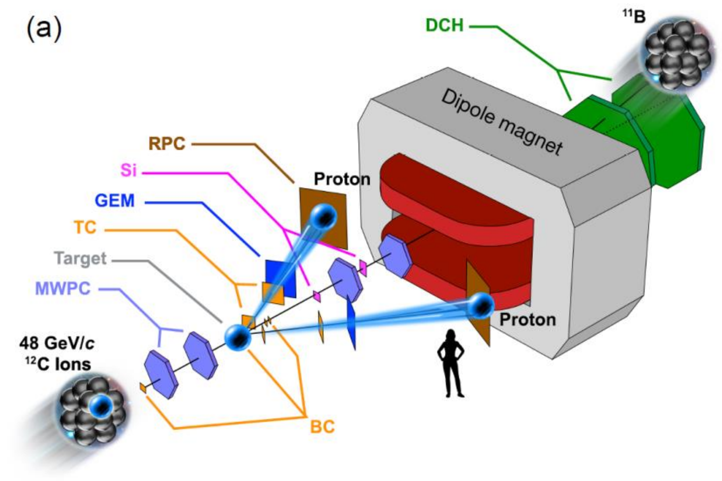
Baryonic Matter at Nuclotron (BM@N) Collaboration:



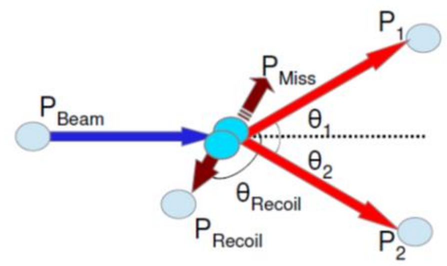
10 Countries, 19 Institutions, 255 participants

- *University of Plovdiv, Bulgaria → MoU signed;*
- *St.Petersburg University;*
- *Shanghai Institute of Nuclear and Applied Physics, CFS, China;*
- *Tsinghua University, Beijing, China → leave BM@N;*
- *Nuclear Physics Institute CAS, Czech Republic→ MoU signed;*
- *CEA, Saclay, France;*
- *TU Darmstadt, Germany;*
- *GSI & FAIR, Germany → joined BM@N;*
- *Tubingen University, Germany → MoU signed;*
- *Tel Aviv University, Israel;*
- *Joint Institute for Nuclear Research;*
- *Institute of Applied Physics, Chisinev, Moldova → leave BM@N, join JINR group;*
- *Warsaw University of Technology, Poland → MoU just signed;*
- *University of Wroclaw, Poland → MoU signed;*
- *Institute of Nuclear Research RAS, Moscow, Russia → MoU signed;*
- *NRC Kurchatov Institute, Moscow;*
- *Institute of Theoretical & Experimental Physics, NRC KI, Moscow, Russia;*
- *Moscow Engineer and Physics Institute, Russia;*
- *Skobeltsin Institute of Nuclear Physics, MSU, Russia → MoU signed;*
- *Moscow Institute of Physics and Technics, Moscow, Russia → MoU signed;*
- *Massachusetts Institute of Technology, Cambridge, USA.*

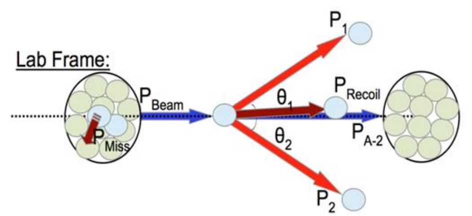
BM@N: study Short Range Nucleon Correlations with hard inverse kinematic reactions



^{12}C Beam Frame



Lab frame

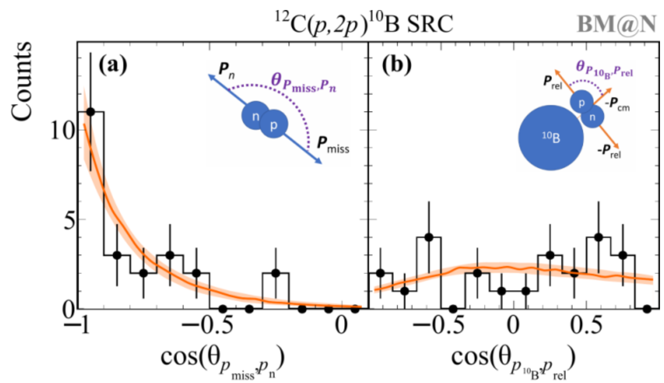


First observation of SRCs with bound residual A-2 system in reactions:

$^{12}C + p \rightarrow 2p + {}^{10}B\ /\ {}^{10}Be + (n\ /\ p)$

23 ^{10}B events

2 ^{10}Be events $\rightarrow$ *np* pair dominance



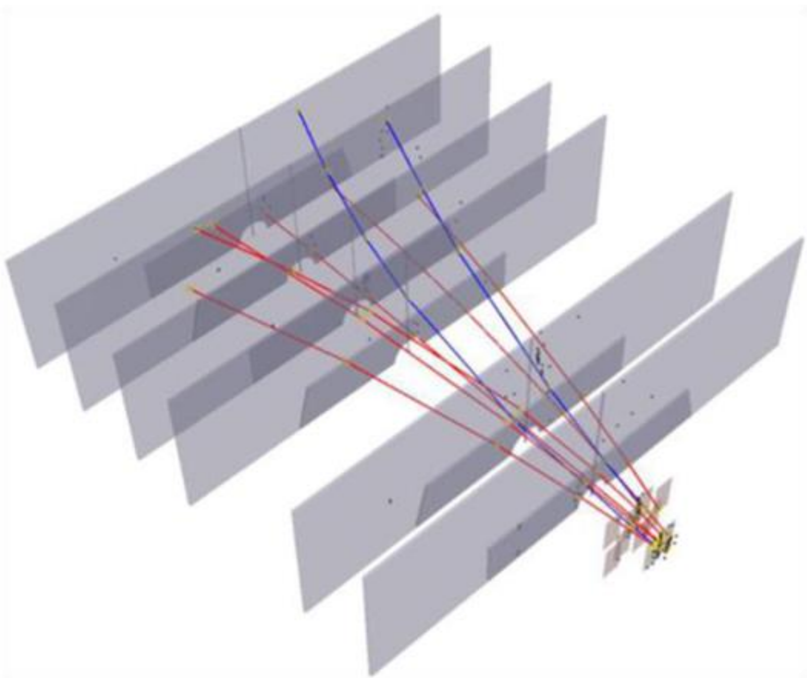
BM@N SRC paper:

"The Transparent Nucleus: unperturbed inverse kinematics nucleon knockout measurements with a 48 GeV/c carbon beam"

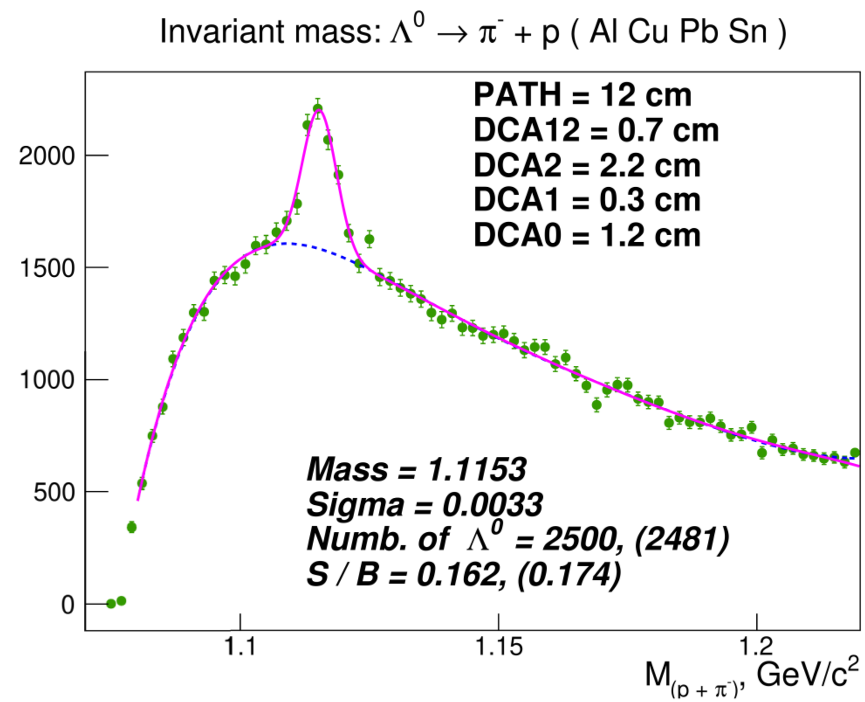
accepted for publication in Nature Physics

Λ hyperon signals in 3.2A GeV Argon-nucleus interactions

P.Batyuk



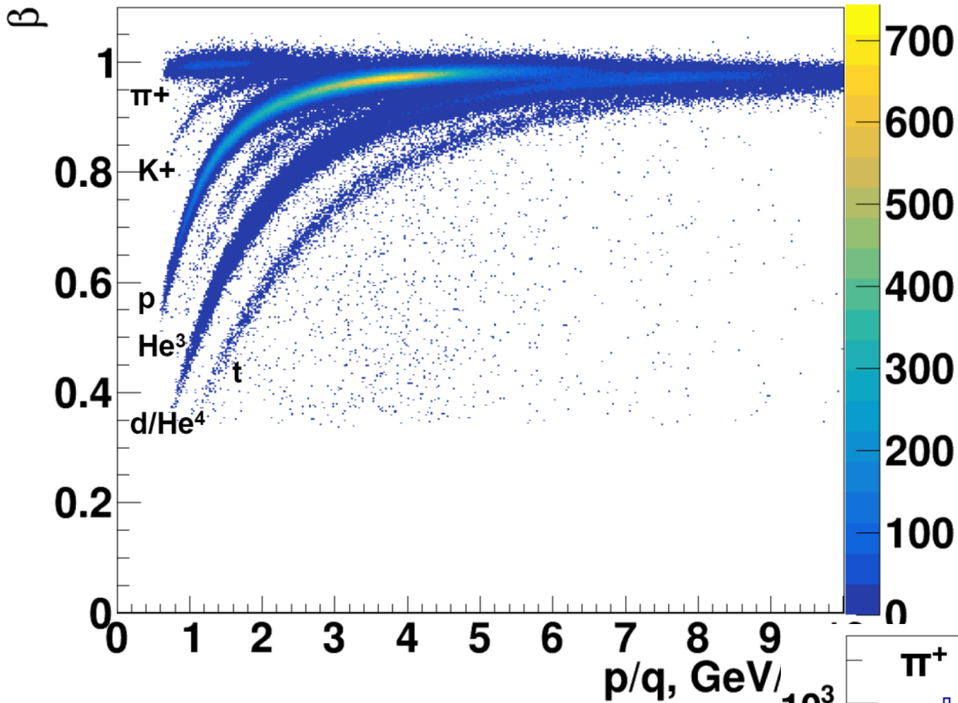
Ar+Cu interaction reconstructed in central tracker



Ar (3.2 AGeV) + Target → Λ + X
Λ signal width 3.3 MeV

Aim:
Yields of Λ hyperons in *argon - nucleus* interactions

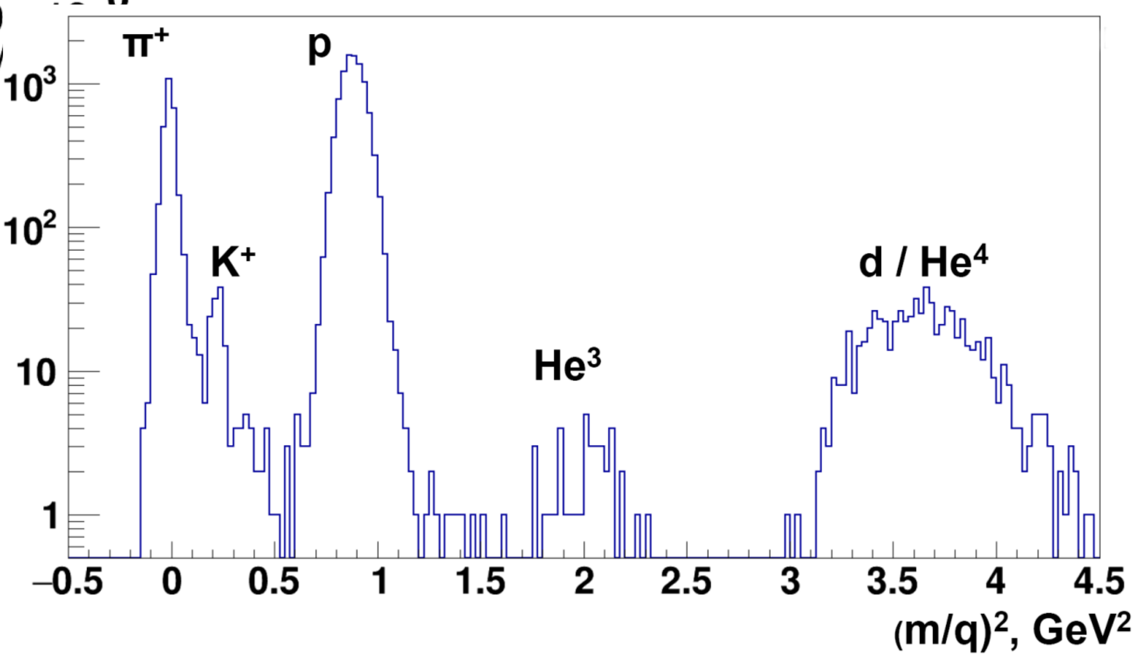
Status of TOF-700 particle identification



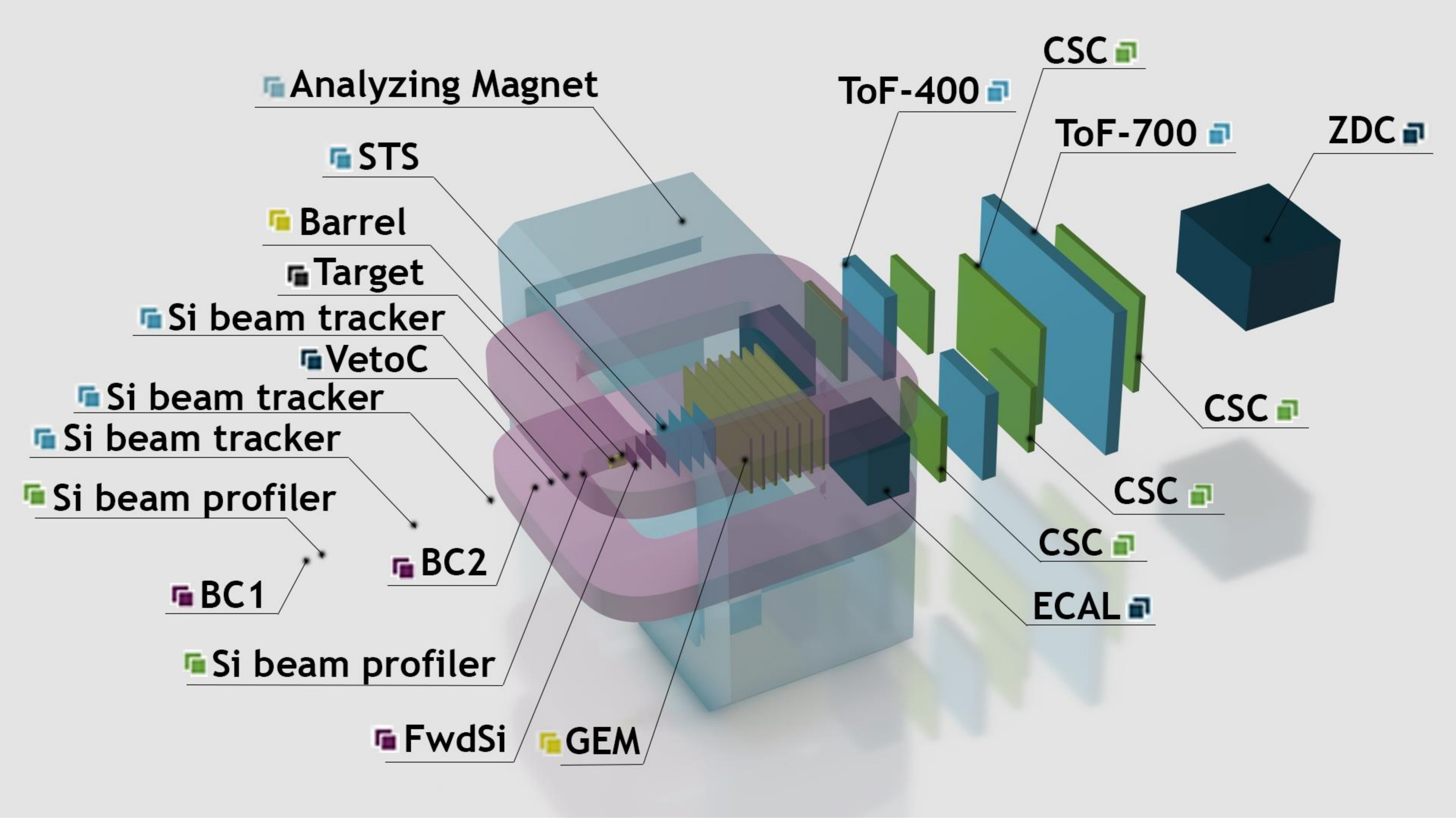
L.Kovachev, Yu.Petukhov

Ar beam , 3.2 AGeV ,
Ar + Al,Cu,Sn → X

Aim:
Yields of π, p, t, He^3, d/He^4 in *argon - nucleus* interactions (combination of ToF-400 and ToF-700)

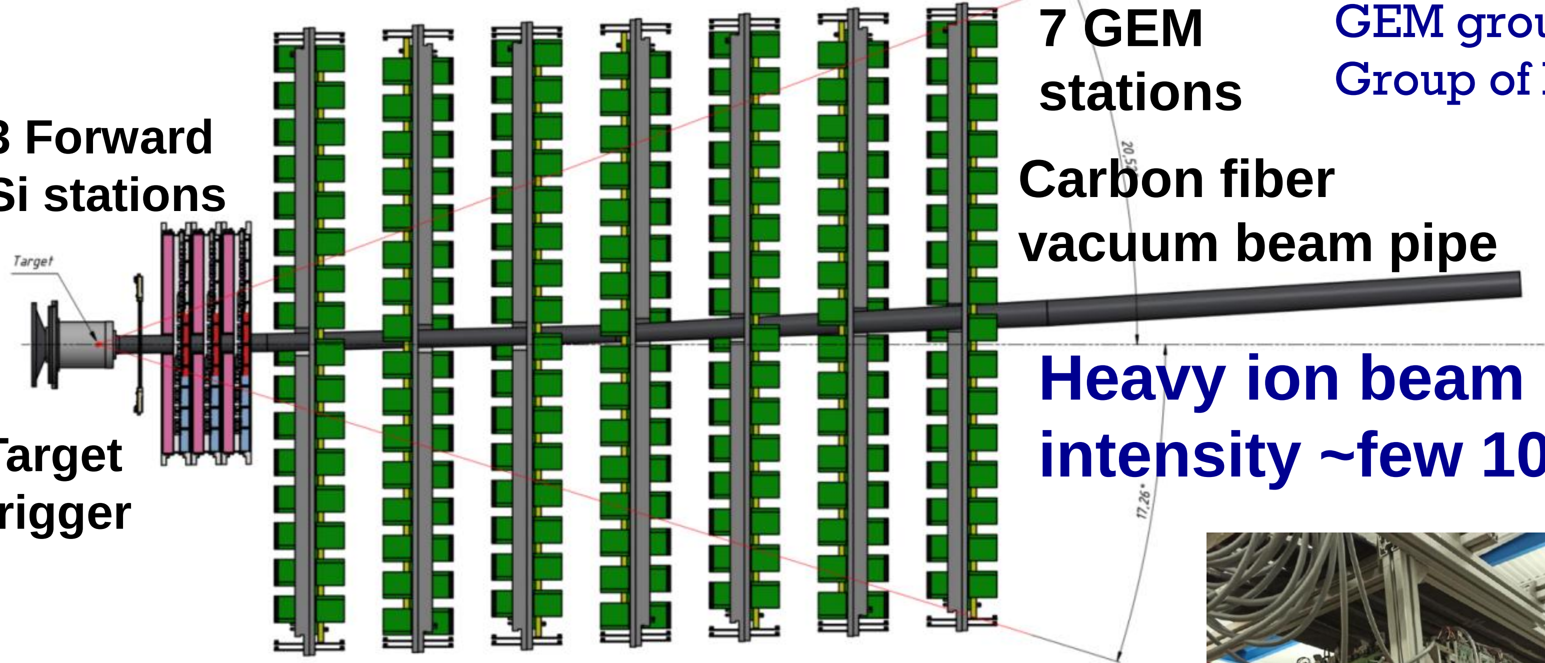


Configuration of BM@N detector for heavy ion program (without beampipe)



Initial Hybrid Central Tracker for heavy ion runs in 2022: Forward Si + GEM

GEM group
Group of N.Zamiatin



7 GEM stations

3 Forward Si stations

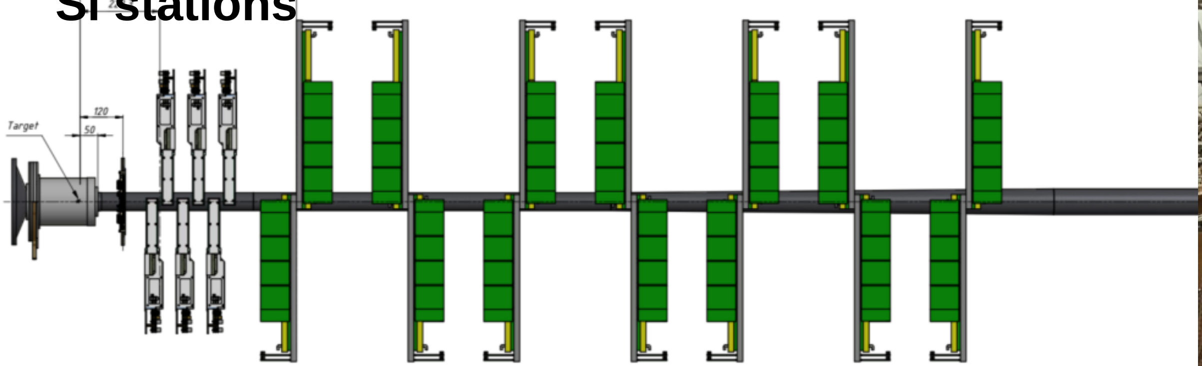
Carbon fiber vacuum beam pipe

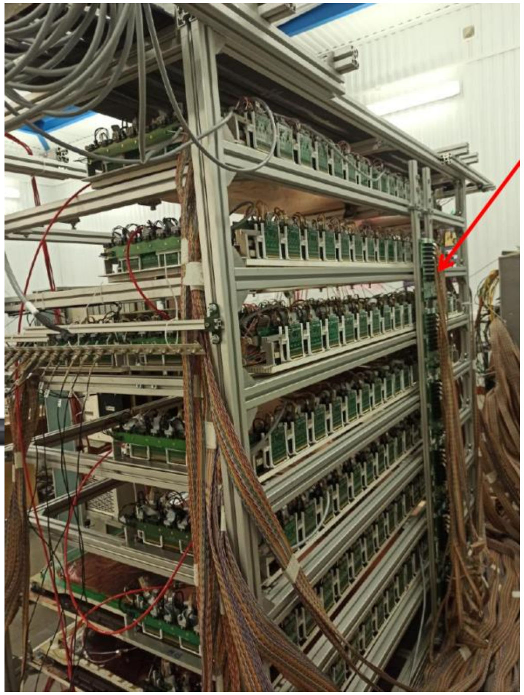
Target trigger

Heavy ion beam intensity ~few 10^5 Hz

3 Forward Si stations

Vertical projection





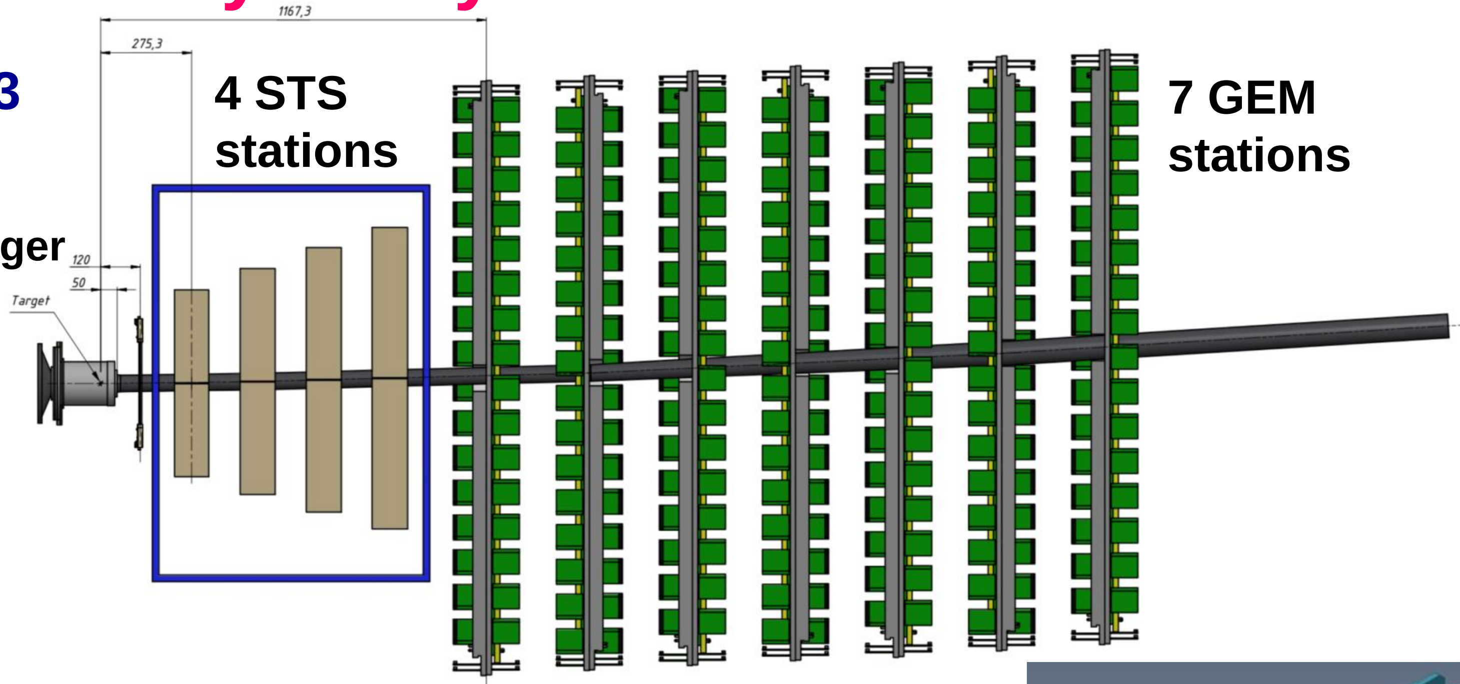
Stage2 Hybrid Central Tracker for high intensity heavy ion runs: STS +GEM

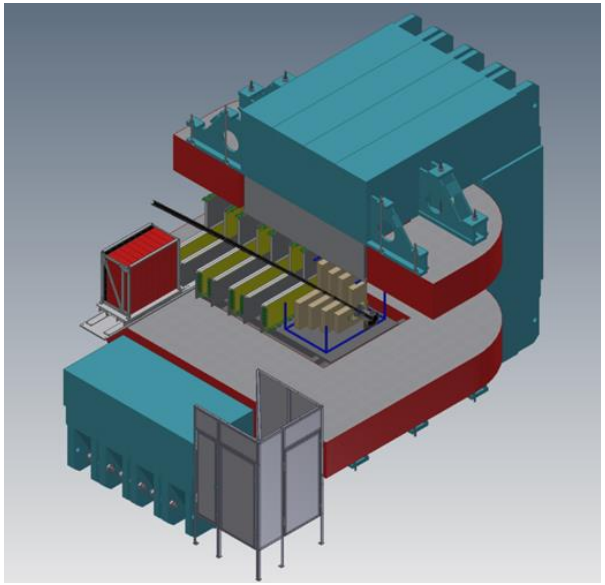
after 2023

Target + trigger detectors

4 STS stations

7 GEM stations



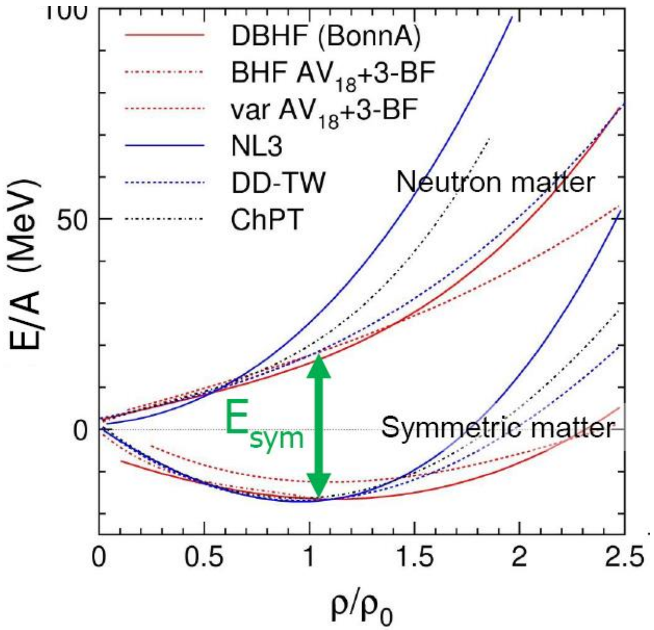


For heavy ion beam intensities of few 10^6 Hz
→ keep 4 STS + 7 GEM
→ fast FEE and readout electronics

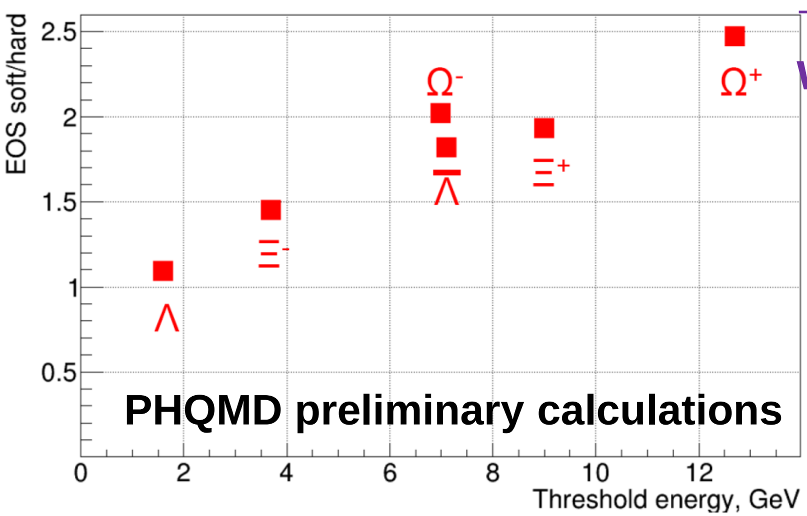
EOS of symmetric and asymmetric nuclear matter

Ch. Fuchs and H.H. Wolter, EPJA 30 (2006) 5

from talks of Peter Senger



Hyperon yield in 4A GeV Au+Au:
soft EOS (K=240 MeV) / hard EOS (K=350) MeV

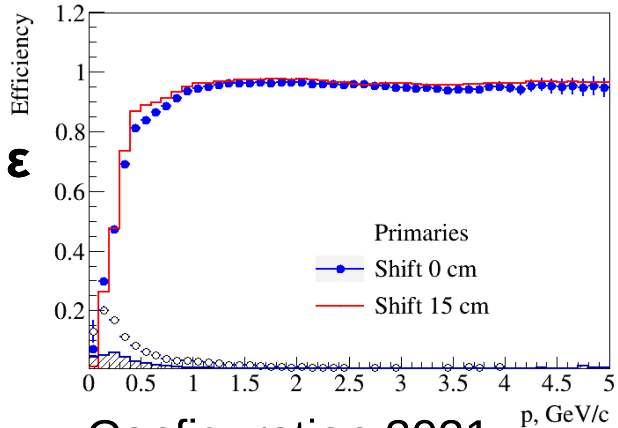


►Study symmetric matter EOS at ρ=3-5 ρ_0
→ elliptic flow of protons, mesons and hyperons
→ sub-threshold production of strange mesons and hyperons
→ extract incompressibility factor K from data to model predictions

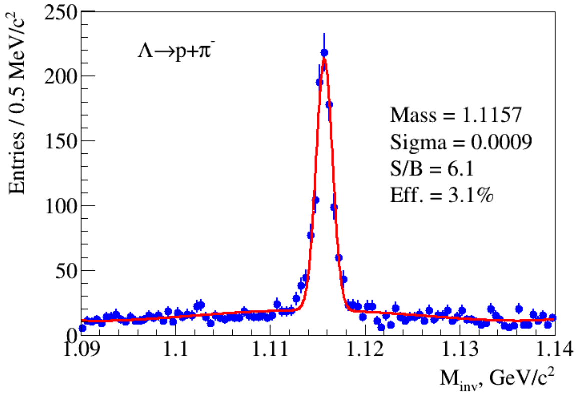
►Constrain symmetry energy E_{sym}
→ elliptic flow of neutrons vs protons
→ sub-threshold production of particles with opposite isospin

1^{st} stage of hybrid central tracker: 3 Forward Si + GEM (Fall 2021 configuration)

A.Zinchenko, V.Vasendina

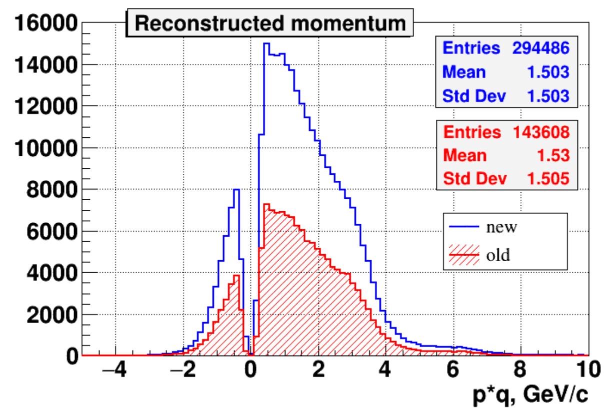


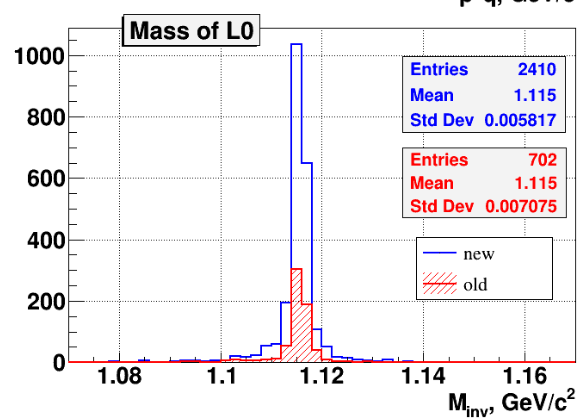
Configuration 2021



► A task force group was formed to perform event simulation and reconstruction in New configuration

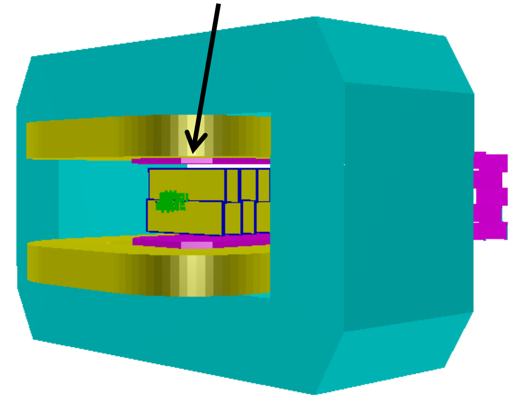
DCM-QGSM model
Kr + Pb , T_0= 2.4 AGeV



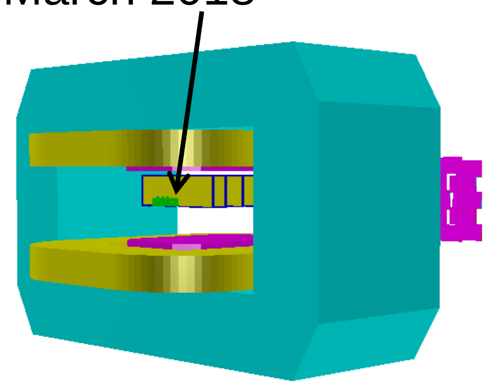


New vs Old (2018) configuration
ε(track) increased by 2
ε(Λ) increased by 3.5

3 Forward Si + 7 GEM, New configuration 2021



Old configuration, March 2018

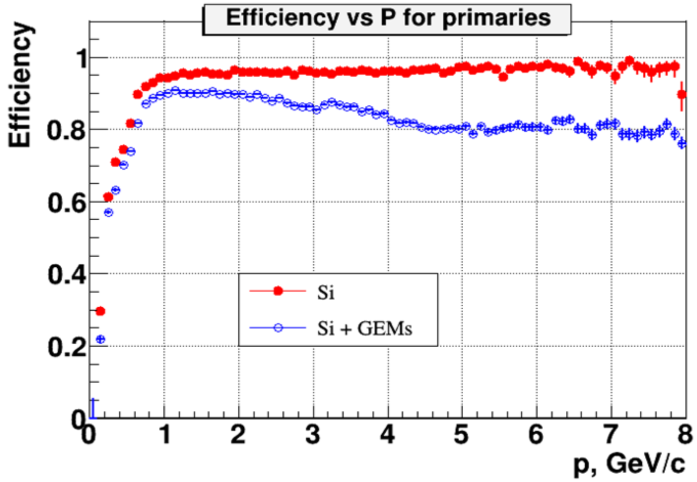


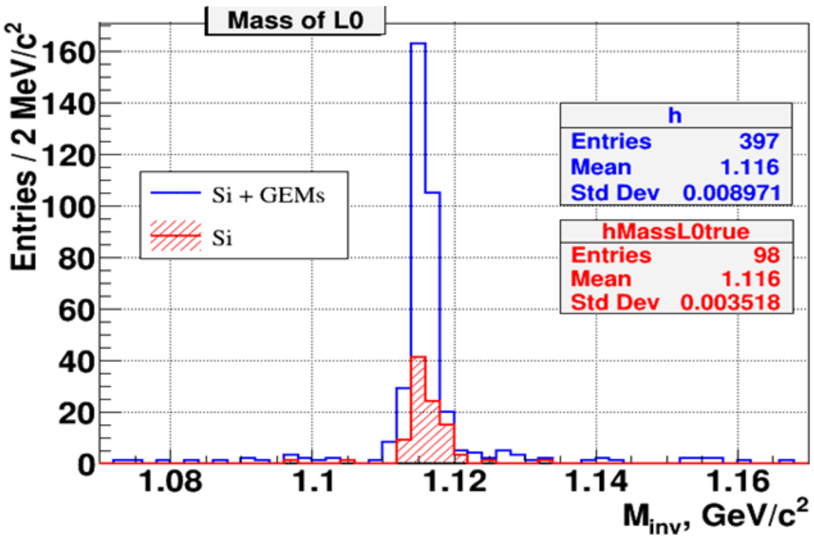
Only upper part equipped with detectors

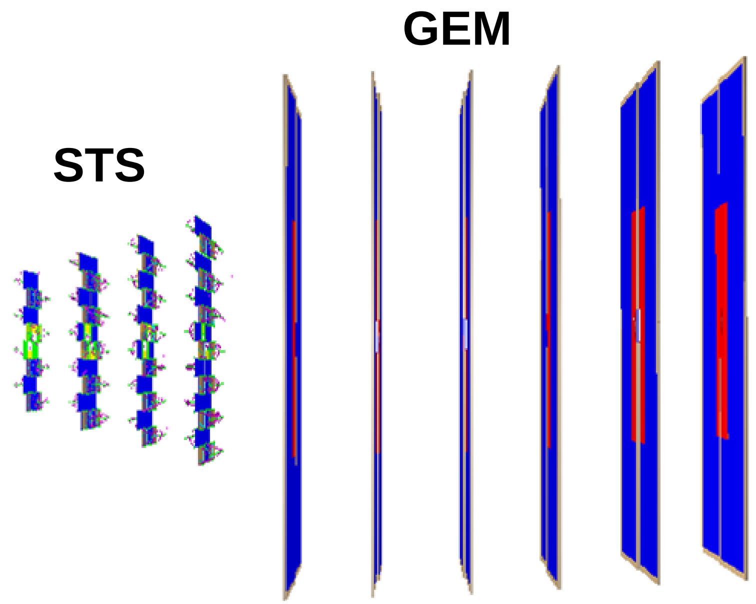
Simulation of hybrid central tracker for heavy ion runs: STS +GEM

A.Zinchenko, V.Vasendina

QGSM model, Au+Au, T_0 = 4 AGeV

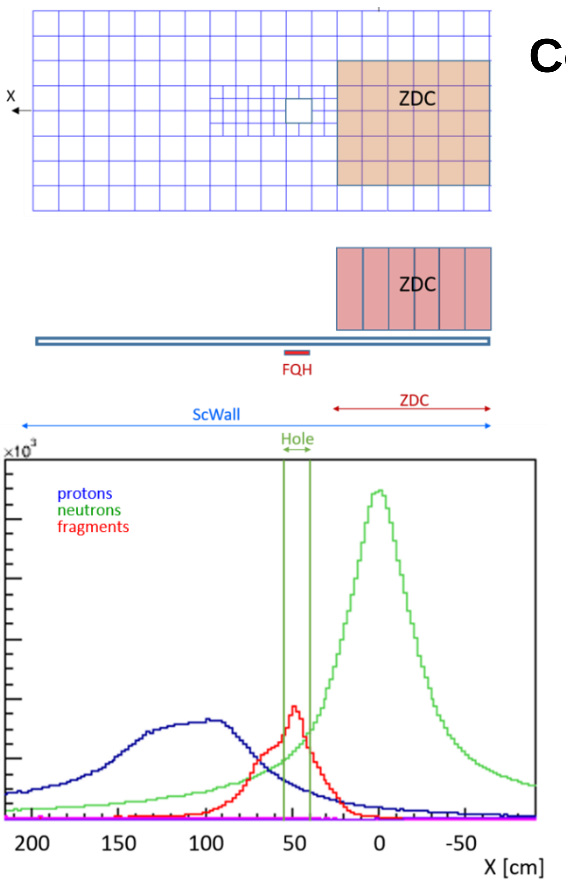




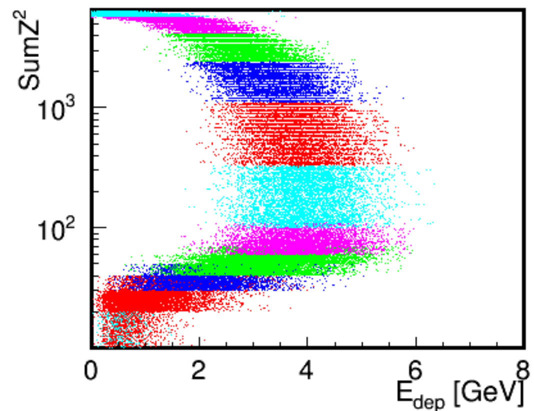


Hybrid STS + GEM tracker relative to STS alone:
► 4 times increase in number of reconstructed Λ hyperons

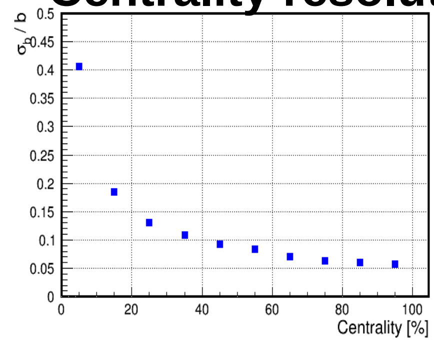
Centrality and EP with FHCAL , Scint Wall and FQH

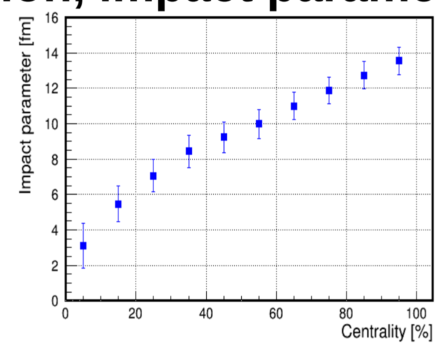


Centrality determination: Z^2 (FQH + ScWall) vs E_{dep} (ZDC)

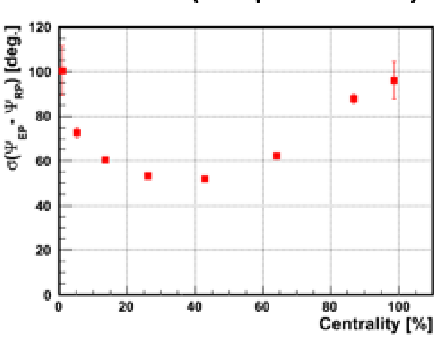


Centrality resolution, impact parameter

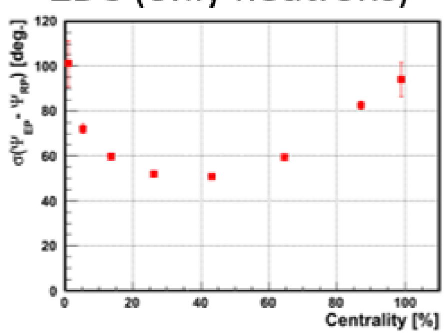




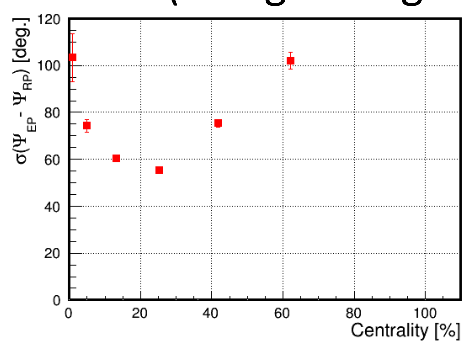
ZDC (all particles)



ZDC (only neutrons)



ScWall (charged fragments)

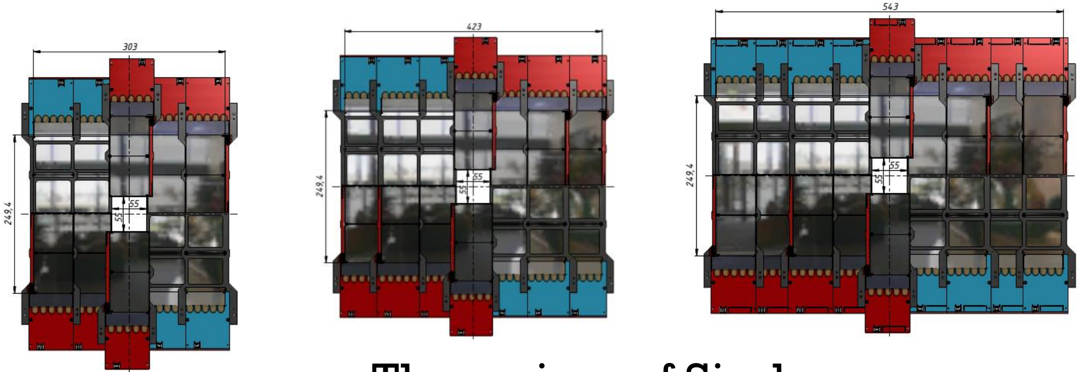


Event Plane resolution

M.Kapishin

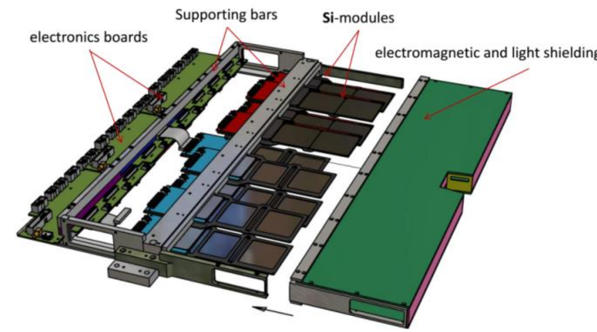
BM@N experiment

Forward Si tracking detectors

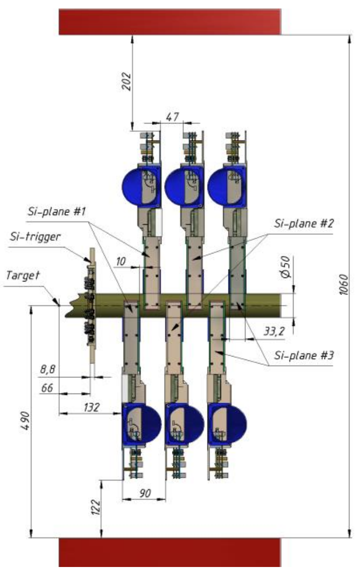


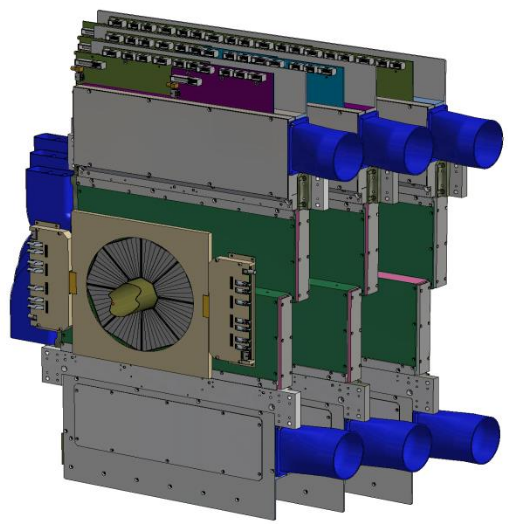
Three sizes of Si-planes

Group of N.Zamiatin



Half-plane design





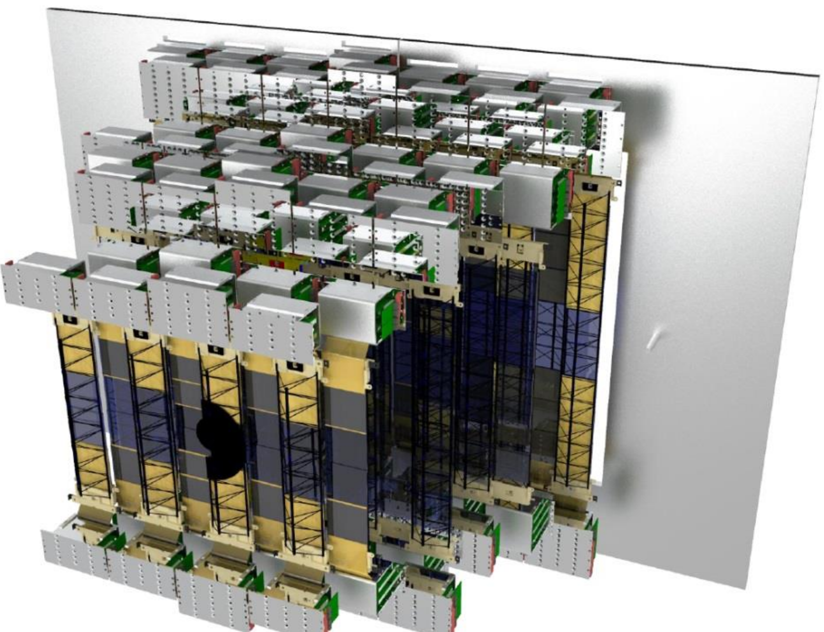
ASICs VATAGP7.1 (IDEAS, Norway)

- **Proven technology and FEE readout electronics → used in C, Ar, Kr runs**
- **Development, production, tests and installation according to time schedule → by autumn 2021**

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

Development of STS tracking system

4 STS stations

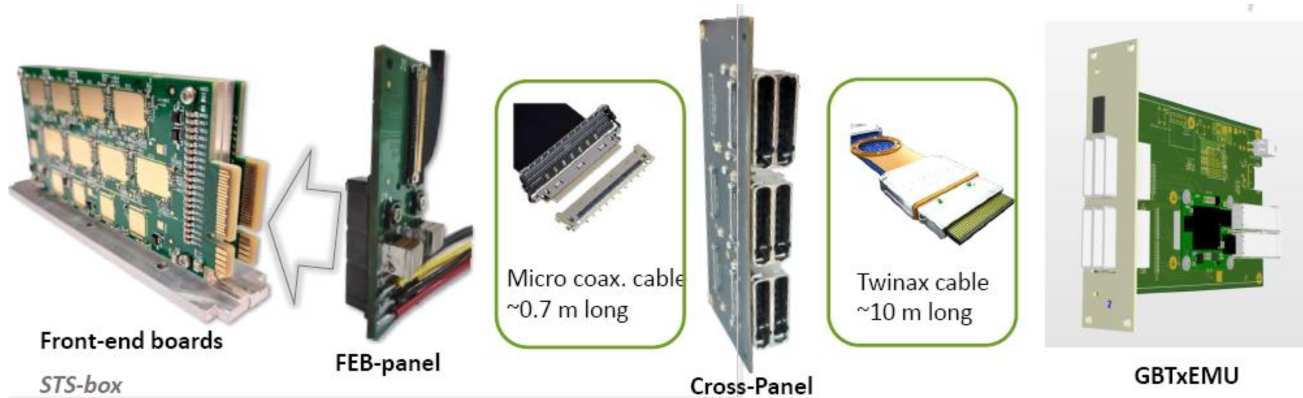


JINR, MSU, GSI, WUT groups

Current activities:

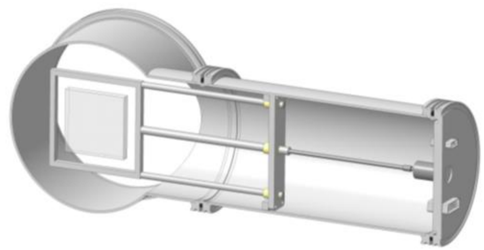
- **Module & ladder assembly**
  Delay of component delivery from GSI
- **Mainframe development**
- **STS-XYTER ASIC certification**
- **FEB v2.1 development**
- **Readout electronics development**
  GBT x EMU board
  FEB to GBTxEMU connectors

34 ladders
292 modules

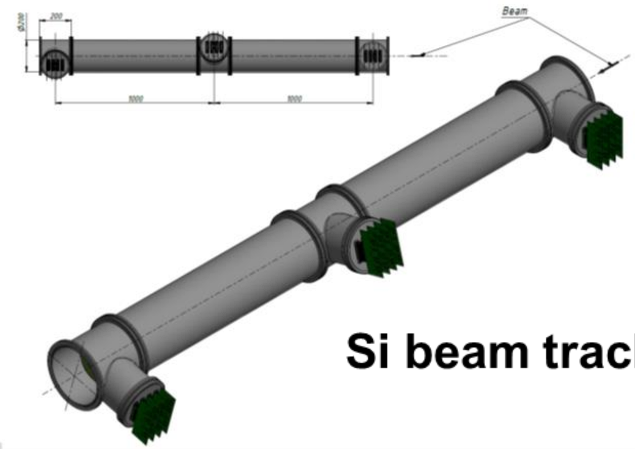


Beam, Si tracking detectors and target station

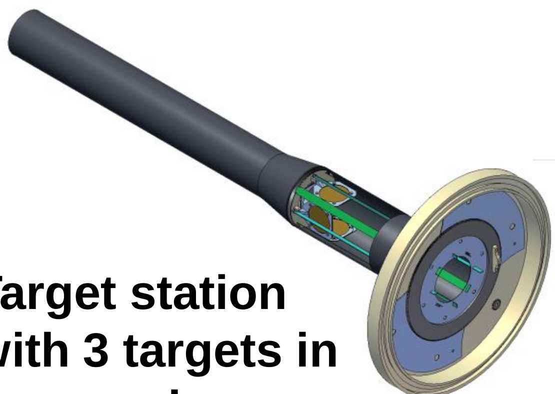
S.Piyadin, Yu.Gusakov
A.Kubankin group (Belgo
Group of N.Zamiatin



Movable beam profile detector

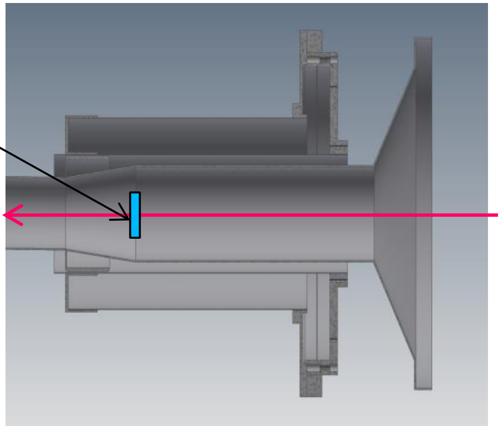


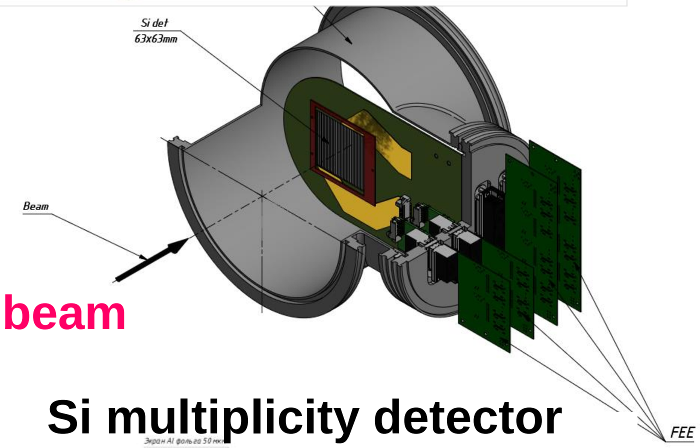
Si beam tracker



Target station with 3 targets in vacuum box

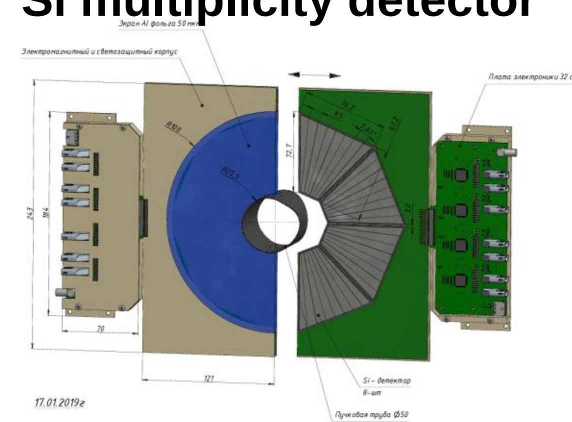
Barrel detector around target





beam

Si multiplicity detector



►All detectors and target station to be ready by autumn 2021

► Detector performance in heavy ion beam should be tested in first run

Status of BM@N upgrade and possible risks

Forward Si tracking detectors:

►Proven technology and FEE readout electronics → used in C, Ar, Kr runs

►Development, production, tests and installation → autumn 2021

Beam, Si tracking detectors and target station:

►All detectors and target station to be ready in autumn 2021

GEM tracking detectors:

►All detectors produced at CERN, → tested in C, Ar, Kr runs

►No proven fast FEE for high intensity run

Trigger and T0 detectors:

► Detector performance in heavy ion beam should be tested in first run

Large aperture STS tracker:

►Complicated module, readout cables and ladder assembly → probable delay and long commissioning phase

CSC chambers for Outer tracker:

►4 chambers to be ready by middle 2021

►Risk of delay in production of 2 big CSC chambers

Time of Flight identification system:

►Detectors and readout electronics are in operation since 2018

Carbon fibre beam pipe inside BM@N:

►Vacuum beam pipe should be produced and tested by autumn 2021

Beam pipe in front of target:

► Beam pipe elements and detector boxes are delivered to BM@N

New FHCAL hadron calorimeter:

►FHCAL installed into BM@N setup, FQH hodoscope and Scint Wall in construction

Plans for 2021 – 22 experimental runs

Uncertainties for launching of heavy ion physics program:

- **Vacuum transport channel from Nuclotron to BM@N is critical for operation with middle and heavy ion beams**
- **Accelerator team need time to put Booster – Nuclotron system into routine operation**

► Plan to start with a new SRC run in December 2021 with carbon beam provided by Booster-Nuclotron or Nuclotron alone
► risks: performance of new detectors, travel restrictions, logistics
► critical is a new detector to separate protons from pions in the proton arms to improve data quality

► SRC configuration is not consistent with the BMN setup for heavy ions

► To switch from SRC to BM@N heavy ion program need two months to install and align vacuum carbon beam pipe and target, beam Si tracker, Forward Si, GEM, CSC, FHCAL, trigger detectors

► We consider to start BM@N heavy ion program with a middle weight ion beams (Kr, Xe) in Spring 2022

► operate 1st stage of hybrid central tracker (3 Fwd Si + 7 GEM)

SRC setup vs BM@N heavy ion setup

► **SRC configuration is not consistent with the BMN setup for heavy ions:**

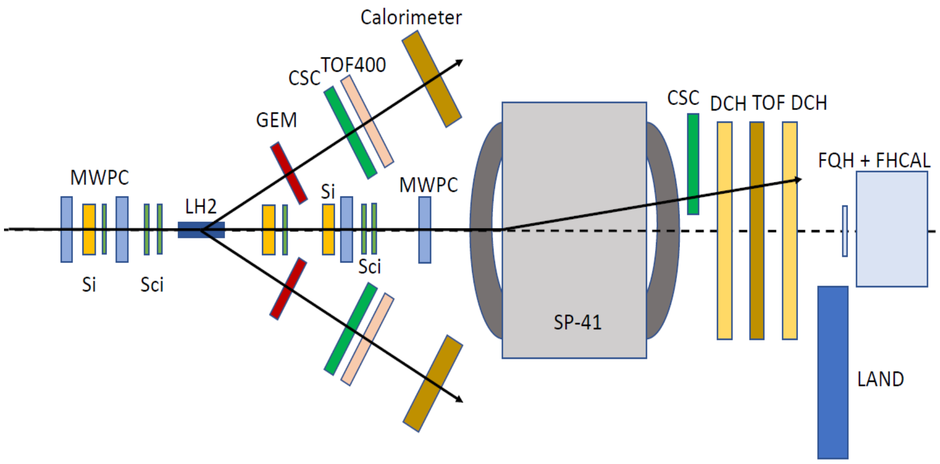
• **delicate beam pipe within BM@N magnet, Si, GEM central tracker are obstacles for SRC nuclear fragments,**

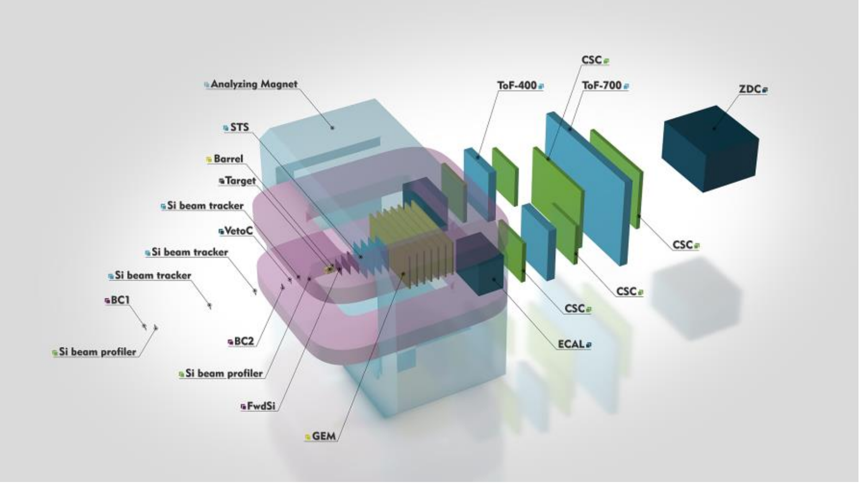
→ In future BMN central detectors / beam pipe will be removed / re-installed only in case major repair / upgrade

• **vacuum beam pipe from quadruple should be dismounted to install SRC H2 target, beam and fragment detectors**

→ need a couple of months between SRC and heavy ion run to reconfigure and align BM@N detectors

• **DCH chambers are used for SRC, but are not suitable for heavy ions**





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

Year	2016	2017 spring	2018 spring	2022 spring	2023	After 2023
Beam	d(↑)	C	Ar,Kr, C(SRC)	Kr,Xe	Au (Bi)	Au (Bi)
Max.intensity, Hz	0.5M	0.5M	0.5M	0.5M	0.5M	2M
Trigger rate, Hz	5k	5k	10k	10k	10k	up to 50k
Central tracker status	6 GEM half planes	6 GEM half planes	6 GEM half planes + 3 forward Si planes	7 GEM full planes + 3 forward Si planes	7 GEM full planes + 4 forward Si + 2 large STS planes	7 GEM full planes + 4 large STS planes
Experimental status	technical run	technical run	technical run+physics	stage 1 physics	stage1 physics	High rate stage 2 physics

4. Estimated uncertainties and risks in the Project

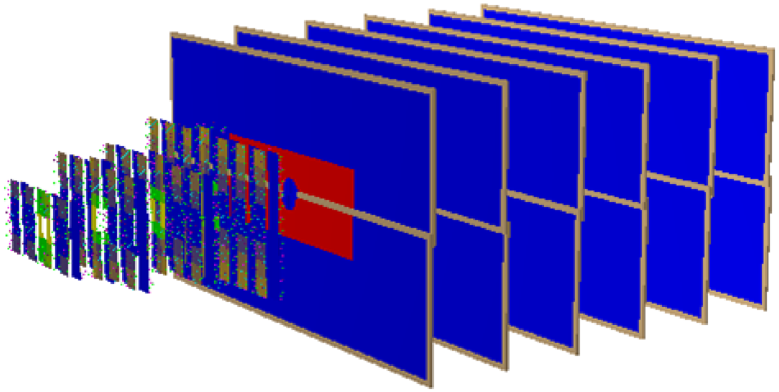
We consider the following uncertainties and risks in the project realization:

- Due to a possible delay with the construction of the full vacuum transport channel from the Nuclotron to BM@N the start of heavy ion beam runs could be postponed. Interactions of the heavy ion beam in the air and beam channel elements could cause unacceptable halo background and a wider spread of the beam for the efficient detector operation. The installation of a collimator would reduce the level of background originated from the transport channel.
- Uncertainty in putting into stable routine operation of the Booster-Nuclotron accelerator complex could cause delay of the start of the heavy ion program
- Putting the NICA collider into operation could limit the capacity of the accelerator division to perform experimental runs at the Booster-Nuclotron complex. As a result the accelerator time requested to fulfill the project goals could be achieved later in time.
- Probable delay and long commissioning phase of the installation and putting into operation of the large aperture silicon tracking system STS. As a result, the high intensity heavy ion beam runs with the final BM@N configuration could be delayed.
- A fast FEE electronics for GEM and CSC readout in the high intensity heavy ion beam runs could be not available due to the delivery restrictions. As a result, BM@N will be operated at the beam intensity of few 10^5 Hz.
- Probable delay in the construction of two big CSC chambers of the outer tracking system. The existing DCH drift chambers could be used instead for the middle weight ion beams.
- The response of the beam silicon and trigger detectors could deteriorate due to high ion fluxes. Spare exemplars of the detectors are foreseen for replacement.

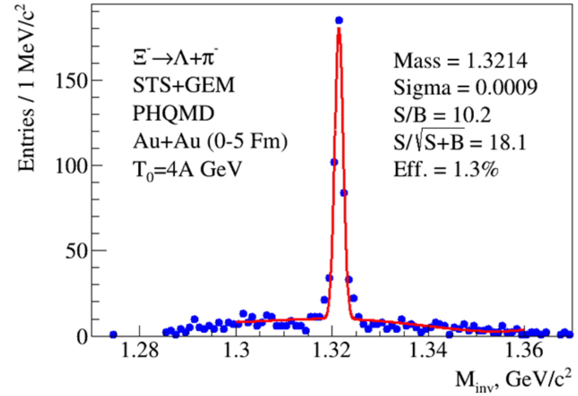
Thank you
for attention!

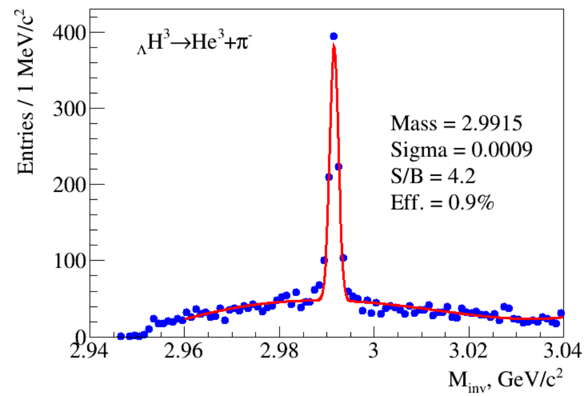
Simulation of hybrid central tracker for heavy ion runs: Ξ^- and $_\Lambda H^3$ reconstruction

A.Zinchenko, V.Vasendina

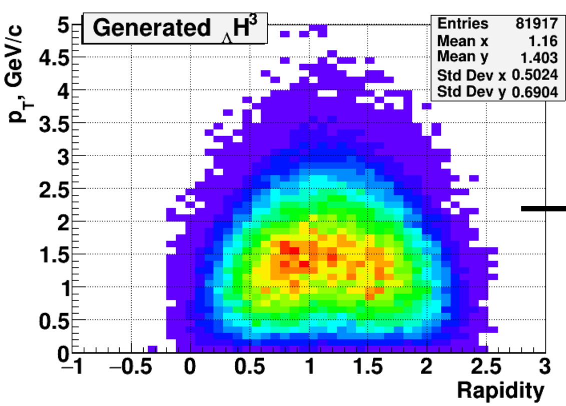


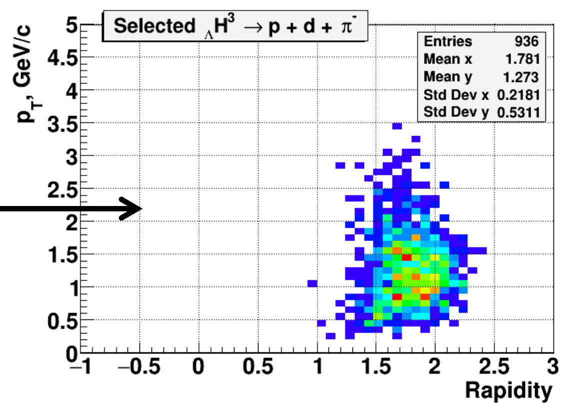
PHQMD model, Au+Au, T_0 = 4A GeV, b = 0-5 fm, 500k events

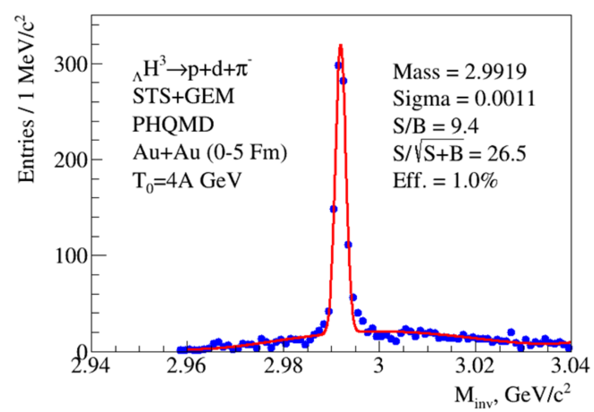




$_\Lambda H^3$ phase space

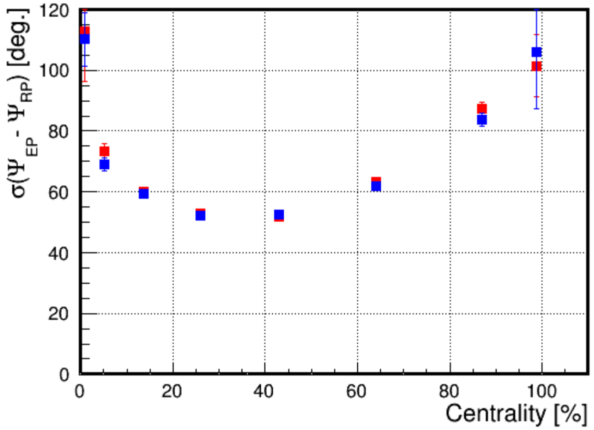




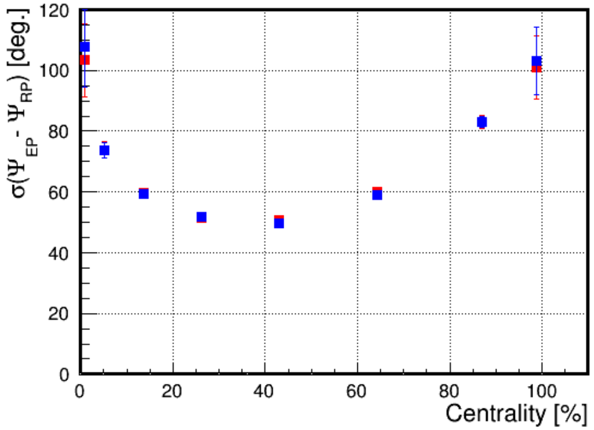


Event plane resolution

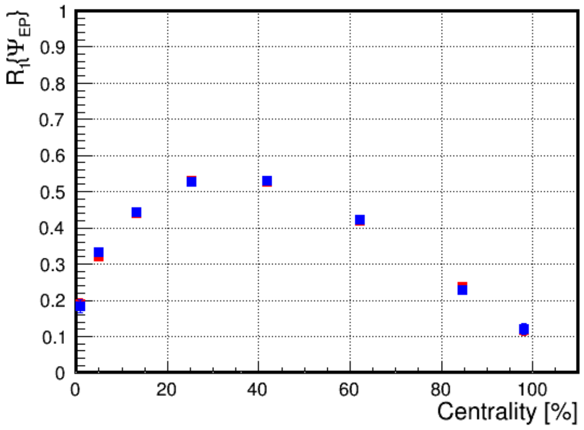
ZDC (all particles)

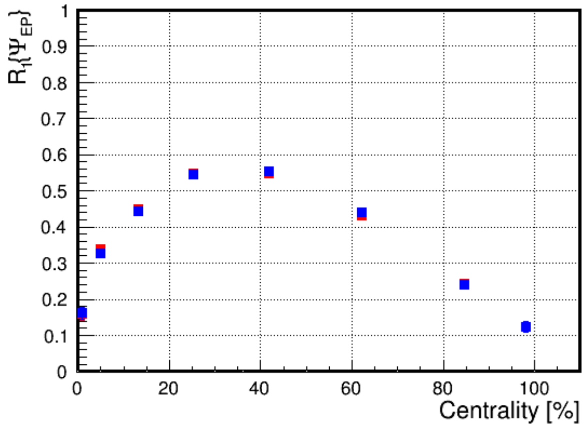


ZDC (only neutrons)



ZDC 36 modules 15x15 cm^2
ZDC 144 modules 7,5x7,5 cm^2



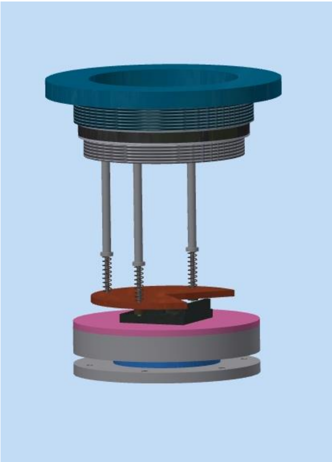


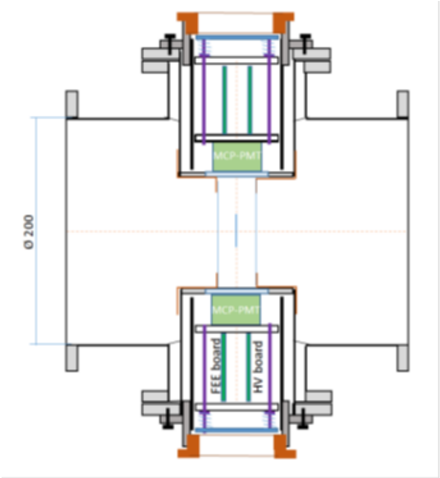
Trigger and T0 detectors for heavy ions

Box for BC2 counter

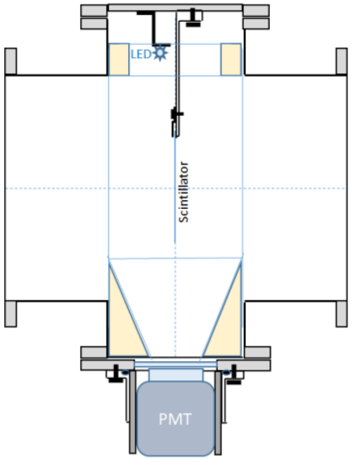
Box for BC1, Veto

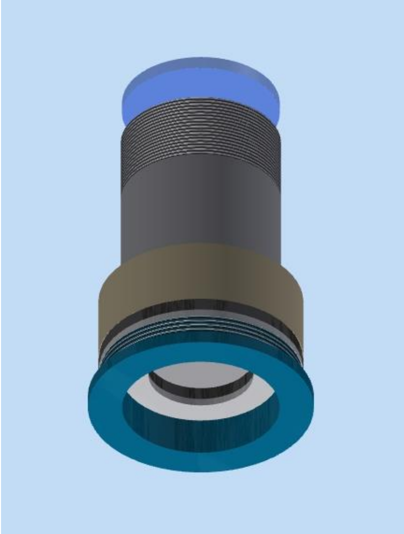
Trigger group

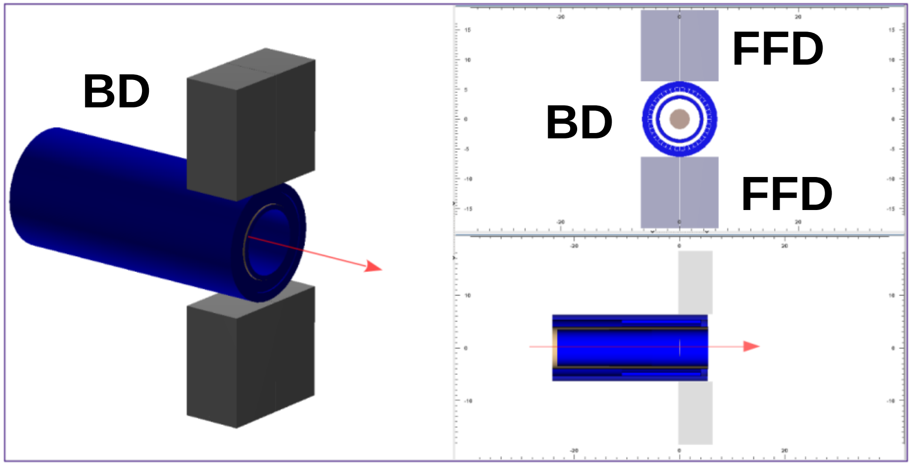




← beam







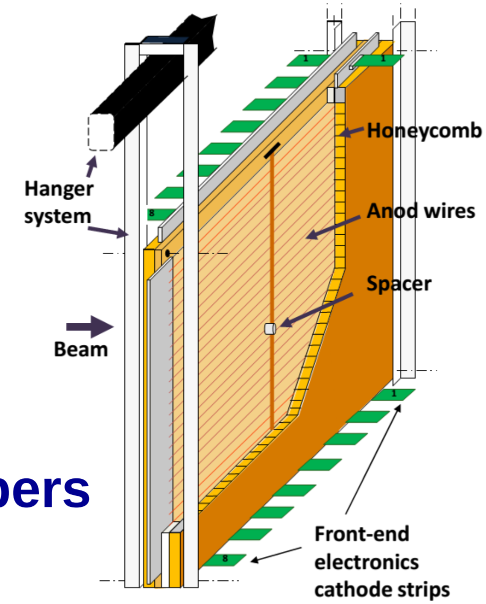
Fast quartz FFD detectors for high intensity heavy ions

- **T0 and beam scintillator film counters for heavy ion beam intensities $< 10^6$ Hz**
- **FFD T0 detectors and Si beam detectors for higher intensities**
- **Detector performance and efficiency in heavy ion beam should be tested in first run**

CSC chambers for Outer tracker in heavy ion runs

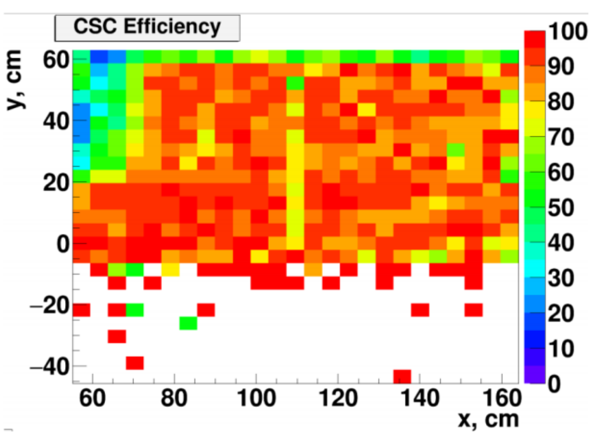
A.Vishnevsky and team, LHEP JINR

- Four 106x106 cm^2 CSC chambers to be installed in front and behind ToF-400 should be ready by end of 2020
- Two 219x145 cm^2 CSC chambers to be installed in front and behind ToF-700 should be produced in 2021

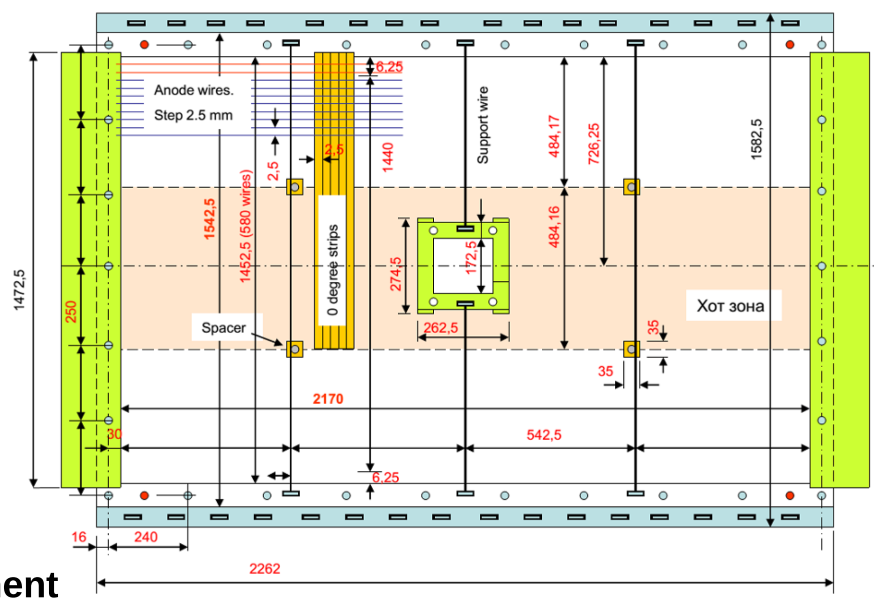


- **Risk of delay in production of big CSC chambers**

First 106x106 cm^2 CSC chamber in BM@N Ar run

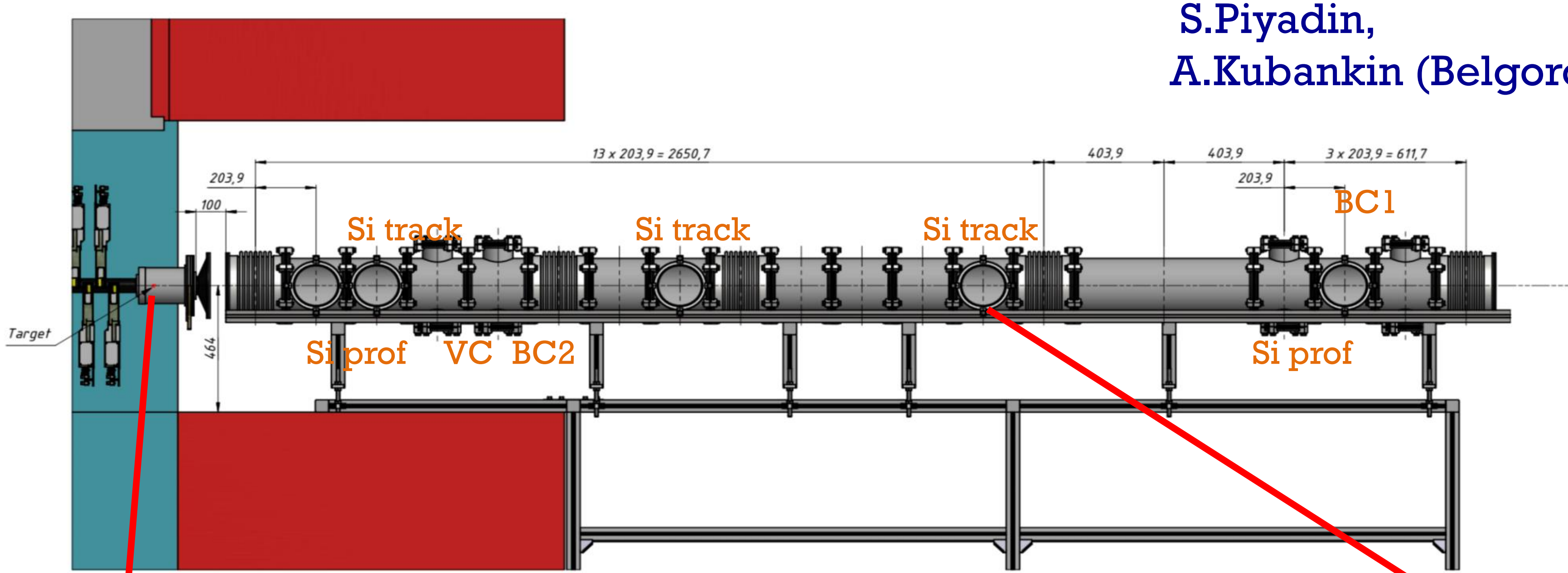


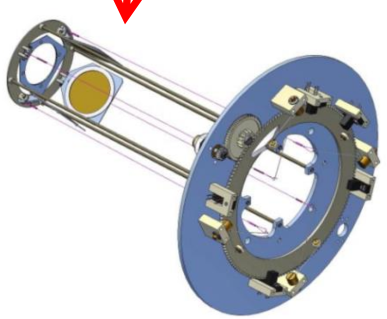
CSC efficiency in Ar run

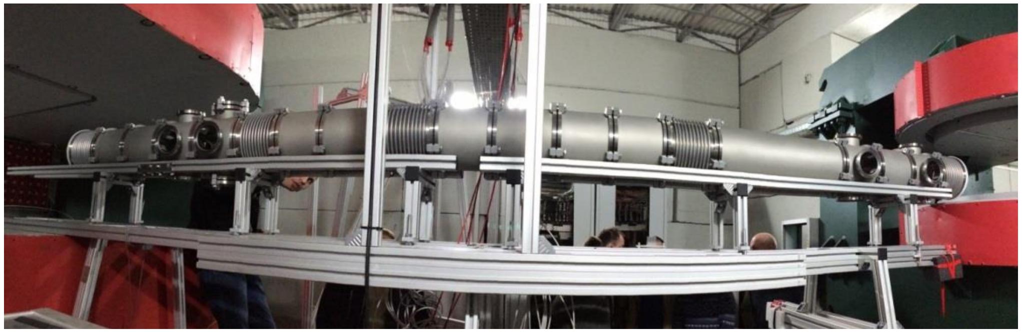


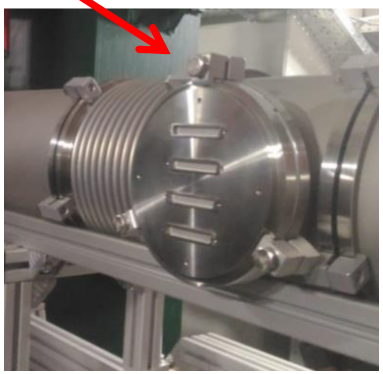
Beam pipe in front of the target

S.Piyadin,
A.Kubankin (Belgorod)









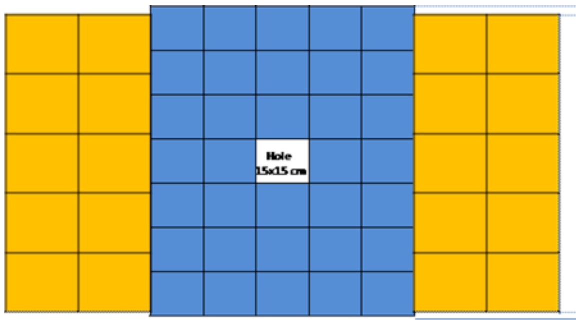
- **Design and production of beam pipe by Belgorod University**
- **Beam pipe elements and detector boxes are delivered to Dubna**

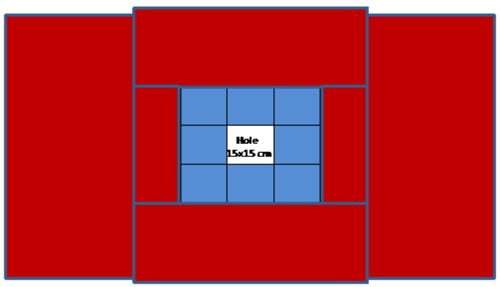
New FHCAL (ZDC) hadron calorimeter

Team of INR RAS, Troitsk

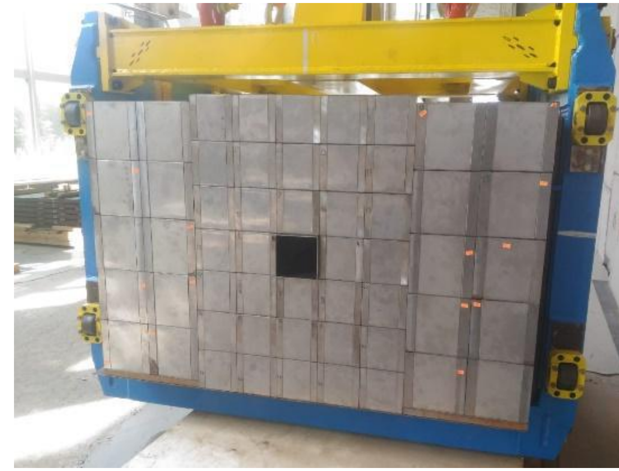
- **FHCAL assembled and installed into BM@N setup**
- **Cosmic tests are under way**

CBM modules MPD modules





$$A_E = \frac{E_{dep}\,(\text{blue}) - E_{dep}\,(\text{red})}{E_{dep}\,(\text{blue}) + E_{dep}\,(\text{red})}$$



Measure E_{dep} v Asymmetry of E_{dep} and $\Sigma\, Z^2$ with quartz hodoscope in the beam hole to resolve central and peripheral interactions

BM@N beam profile

Pavel Rukoyatkin

C^{12} , Ar, Kr beam profiles measured by Nuclotron beam group

C^{12} 2017	Ar 2018	Kr 2018
σ_X = 6 mm	5 mm	5.3 mm
σ_Y = 4.9 mm	5 mm	3.2 mm

Beam envelopes at the BM@N area