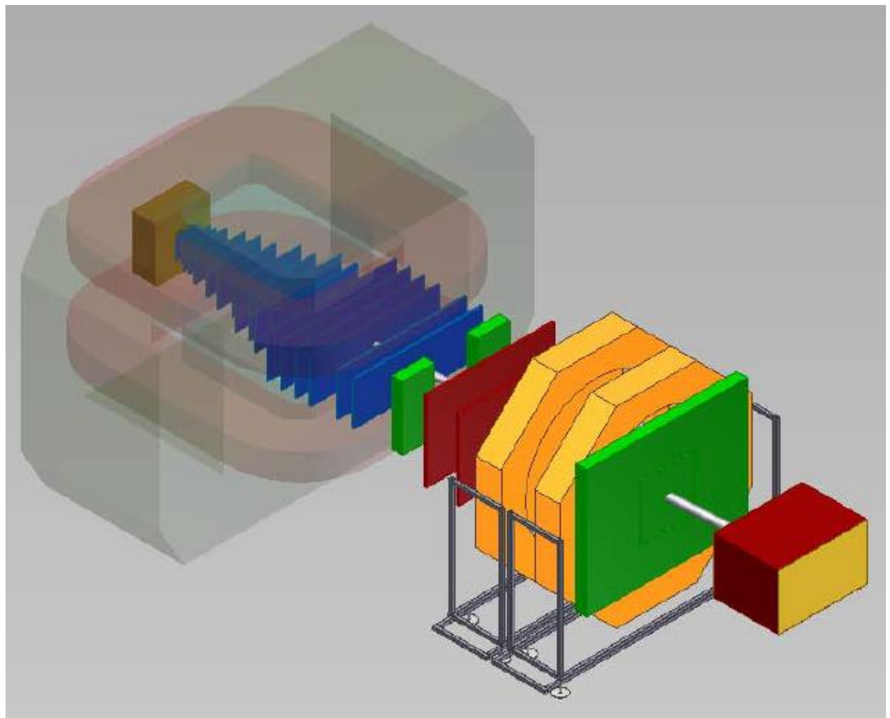
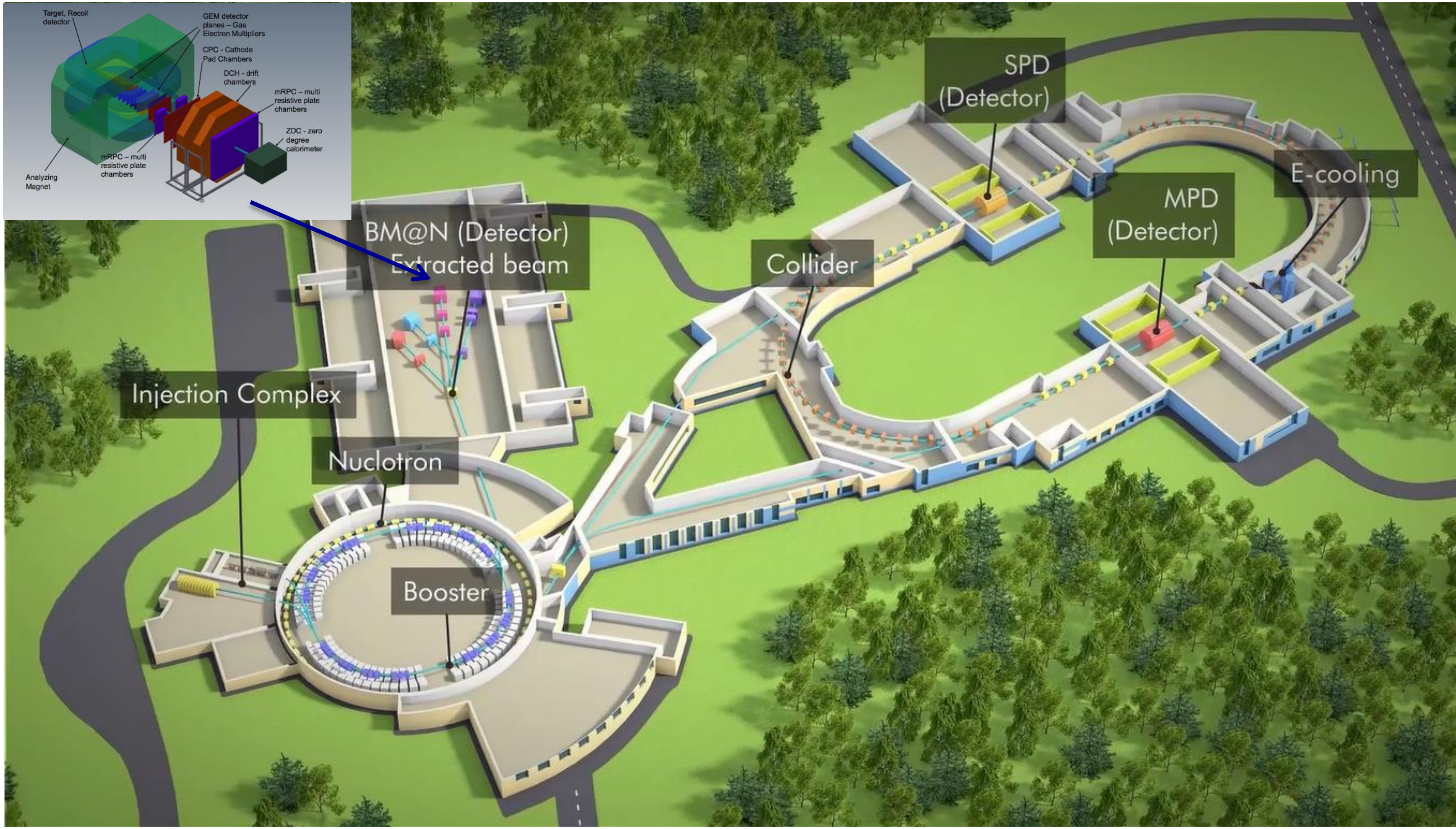
Status of the BM@N experiment

M.Kapishin



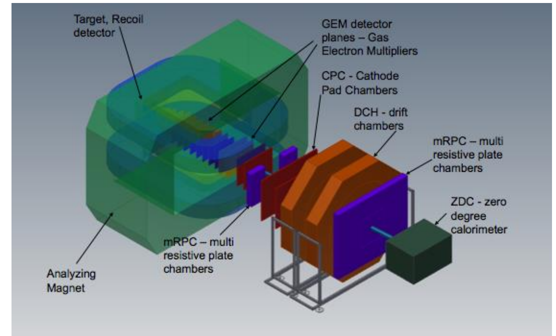
NICA Heavy Ion Complex

BM@N: heavy ion energy 1- 3.8 GeV/n, beams: p to Au, Intensity ~few 10^6 Hz (Au)



Maximum energy of 3.8 GeV/n is limited by 17 kGauss Nuclotron magnetic field

Baryonic Matter at Nuclotron (BM@N) Collaboration:



11 Countries, 19 Institutions, 244 participants

- *University of Plovdiv, Bulgaria → MoU signed;*
- *UCAS, Beijing, China → left BM@N;*
- *Shanghai Institute of Nuclear and Applied Physics, CFS, China;*
- *Tsinghua University, Beijing, China;*
- *Nuclear Physics Institute CAS, Czech Republic;*
- *CEA, Saclay, France;*
- *TU Darmstadt & GSI Darmstadt, Germany;*
- *Tubingen University, Germany;*
- *Tel Aviv University, Israel;*
- *Joint Institute for Nuclear Research;*
- *Almaty Institute of Physics & Technology, Kazakhstan → left BM@N;*
- *Institute of Applied Physics, Chisinev, Moldova;*
- *Warsaw University of Technology, Poland;*
- *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;*
- *Massachusetts Institute of Technology, Cambridge, USA.*

BM@N Executive Committee

Dmitry Dementev	JINR, Dubna, Russia	
Konstantin Gertsenberger	JINR, Dubna, Russia	
Or Hen	MIT, Cambridge, MA, USA	
Vyacheslav Slepnev	JINR, Dubna, Russia	
Arkadiy Taranenko	MEPhI, Moscow, Russia	
Andrej Kugler	Nuclear Physics Institute, CAS, Řež, Czech Republic	New elected
Nikolay Zamiatin	JINR, Dubna, Russia	
Alexander Zinchenko	JINR, Dubna, Russia	Newly elected
Mikhail Kapishin, Spokesperson	JINR, Dubna, Russia	
Peter Senger, Deputy Spokesperson	MEPhI, Moscow, Russia GSI, Darmstadt, Germany	
Anna Maksymchuk, Project Manager	JINR, Dubna, Russia	
Hans Rudolf Schmidt, IB Chair	Tubingen U., Tubingen, Germany	

BM@N working group activities

Detector board meetings
Technical coordinator Anna Maksymchuk

Data analysis meetings
(Mikhail Kapishin, one per month)

Regular meetings of Physics and Analysis working groups (PAWG) and Technical working groups (TWG)

Hyperon reconstruction, simulation and analysis (PAWG)
Convener: Alexander Zinchenko

Particle identification and analysis (TWG+PAWG)
Convener: Mikhail Rumyantsev

Event reconstruction and simulation (TWG)
Convener: Sergey Merts

Software development and data quality analysis (TWG) Conveners: Konstantin Gertsenberger, Pavel Batyuk

SRC data analysis and simulation (PAWG)
Conveners: Or Hen, Maria Patsyuk

ZDC centrality and ECAL data analysis and simulation (TWG)
Conveners: Sergey Morozov, Sergey Afanasiev, Alexey Stavinskiy

Present contributions of participating Institutions

Institution	Detector development	Analysis and software development
MEPhI, Moscow	GEM, GEM+STS TDR	
NPI CAS, Rez	Carbon beam pipe	
INR RAS, Moscow	New FHCAL	Centrality with ZDC in C+A data
WTU, Warsaw	STS readout electronics	
MIPT, Moscow		Visualization and web-services
ITEP, Moscow		Centrality with ZDC in Ar+A data, ECAL
SINP, Moscow Tubingen University	STS development	 STS simulation
Tev Aviv University MIT Cambridge, MA CEA, Saclay		SRC analysis
Plovdiv University		Particle identification
LIT JINR		DCM SMM model, DCH reconstruction, software for data processing, computing

+ JINR LHEP major contributions

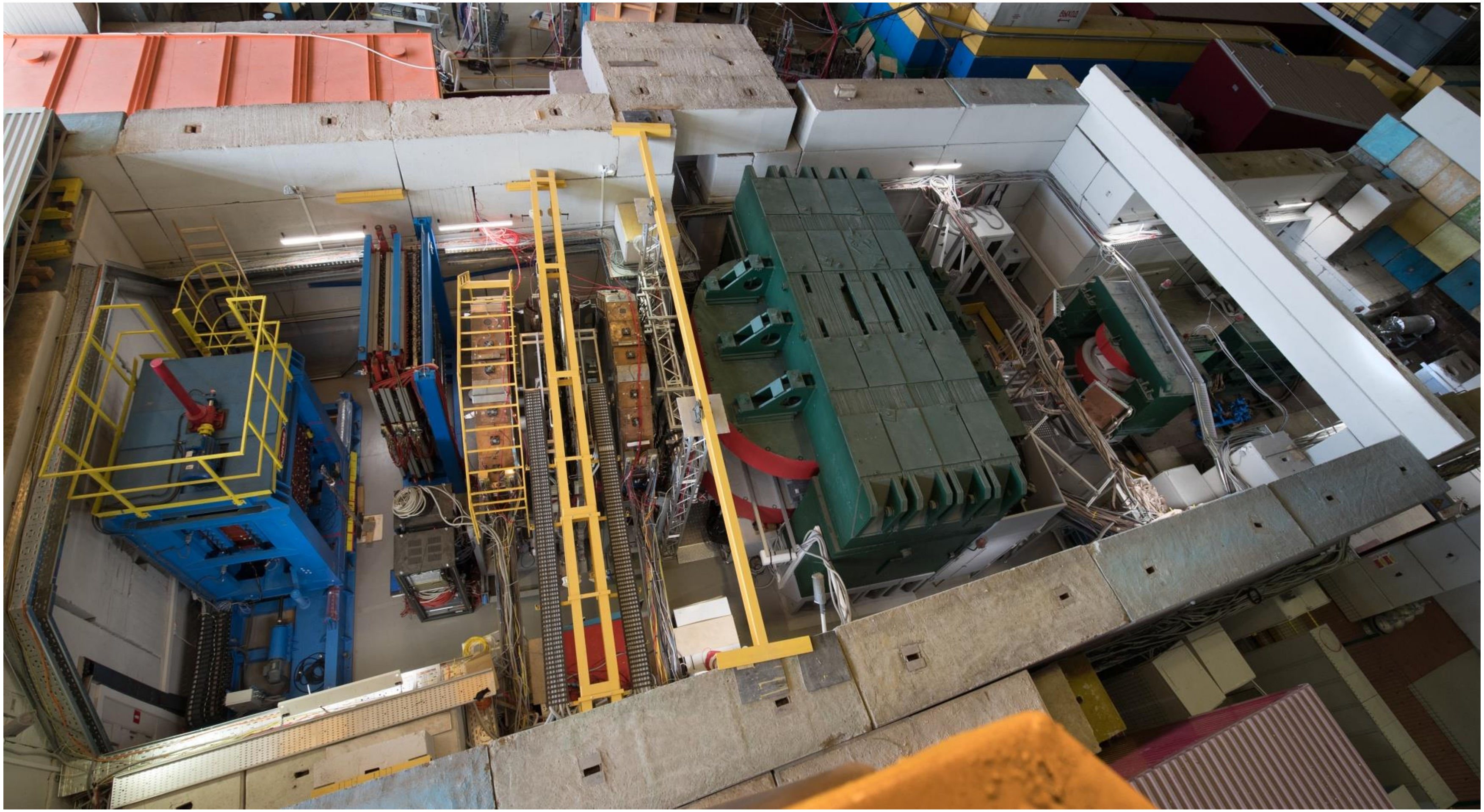
Draft of BM@N paper on physics results presented to BM@N Collaboration

Production of Λ hyperons in 4 and 4.5 AGeV carbon-nucleus interactions at the Nuclotron

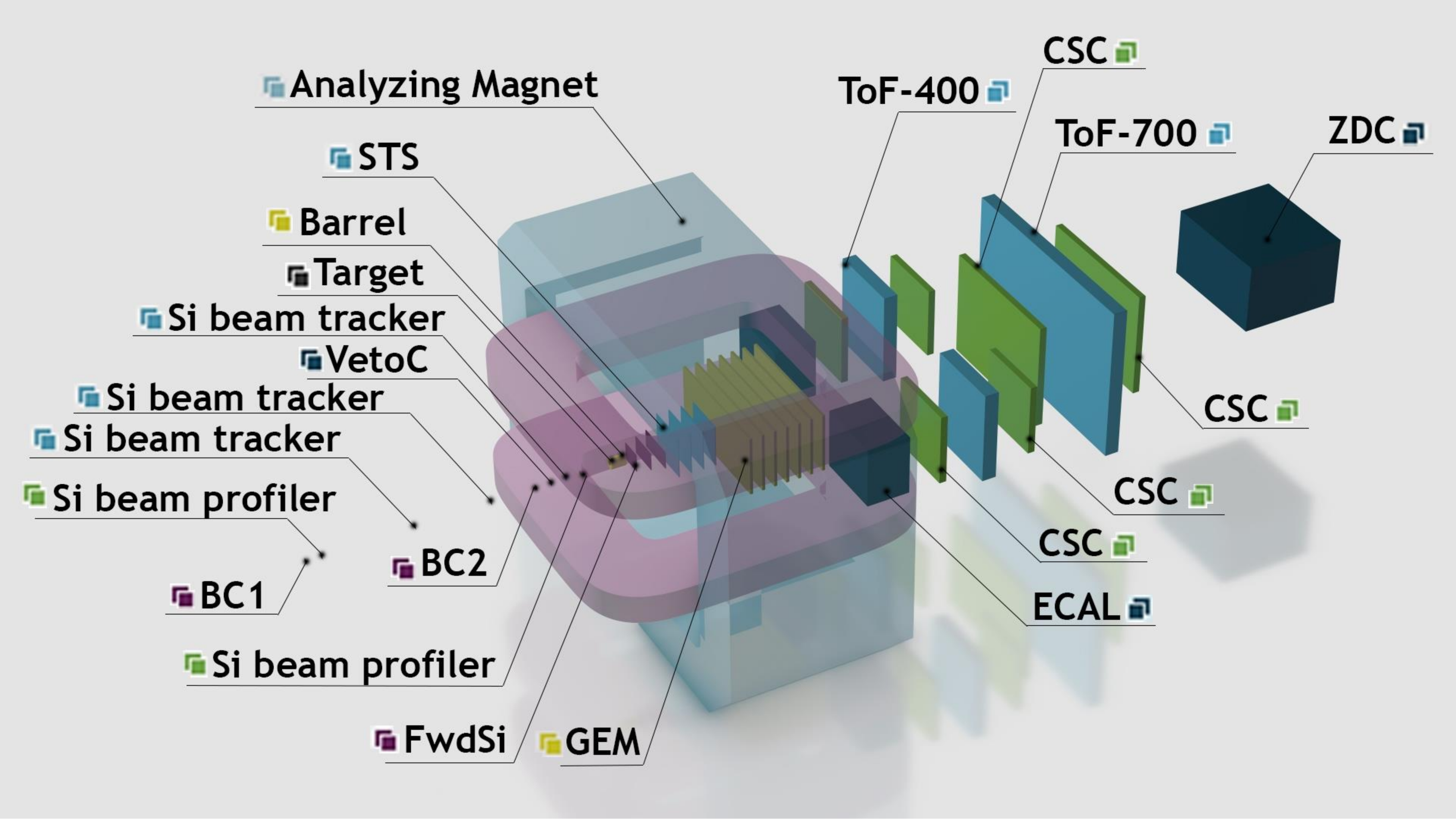
The BM@N (Baryonic Matter at Nuclotron) is the first experiment undertaken at the accelerator complex of NICA-Nuclotron. The BM@N scientific program comprises studies of dense nuclear matter in heavy ion beams of the intermediate energy range between the SIS-18 and NICA/FAIR facilities. The first experimental run was performed in the carbon beam of the 4 and 4.5 AGeV kinetic energy with fixed targets. First physics results are presented on Λ hyperon production in carbon-nucleus interactions. Transverse momentum, rapidity spectra and yields of Λ hyperons are measured. The results are compared with predictions of theoretical models and with the experimental data on carbon-carbon interactions measured at lower energies.

Gleb Pokatashkin (JINR) who performed the analysis left BM@N

BM@N detector: March 2018



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



Initial Hybrid Central Tracker for heavy ion runs in 2021: Forward Si + GEM

GEM group
Group of N.Zamiatin

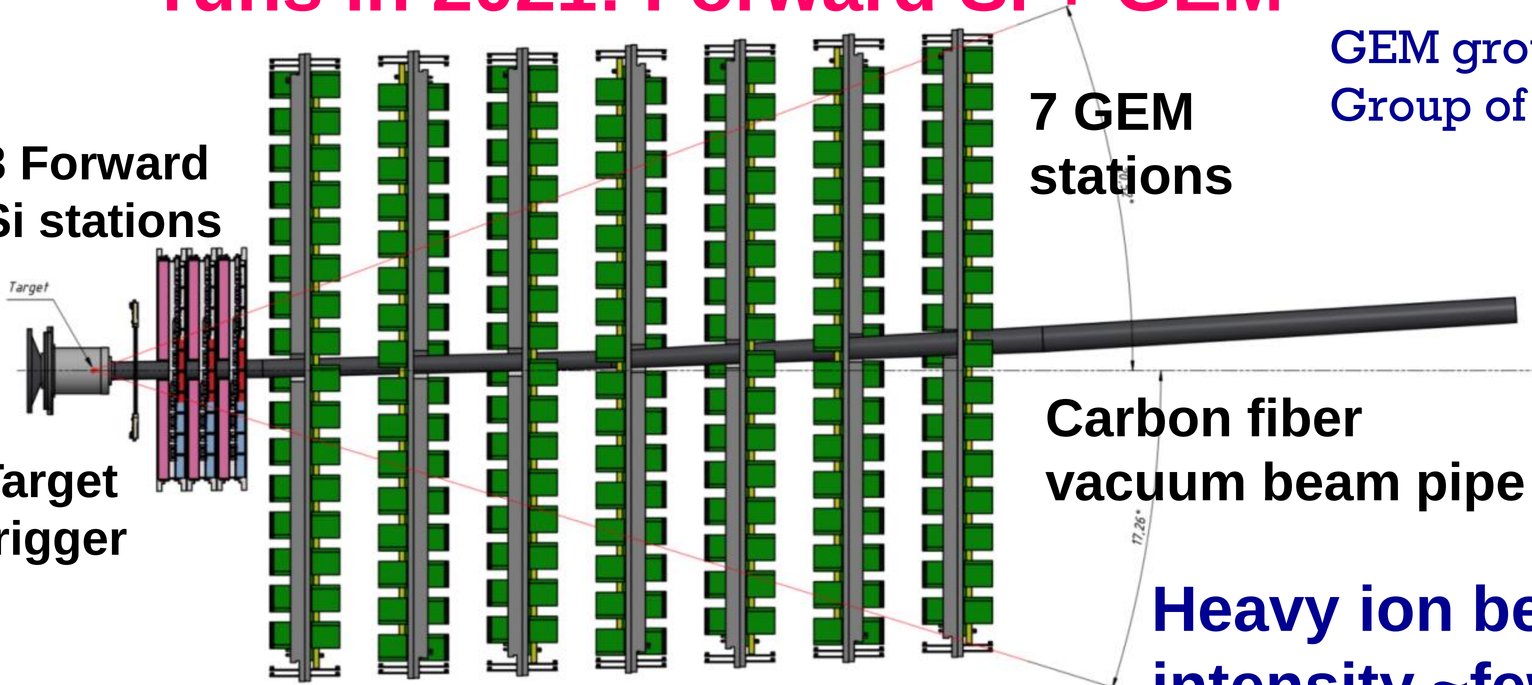
3 Forward Si stations

Target trigger

7 GEM stations

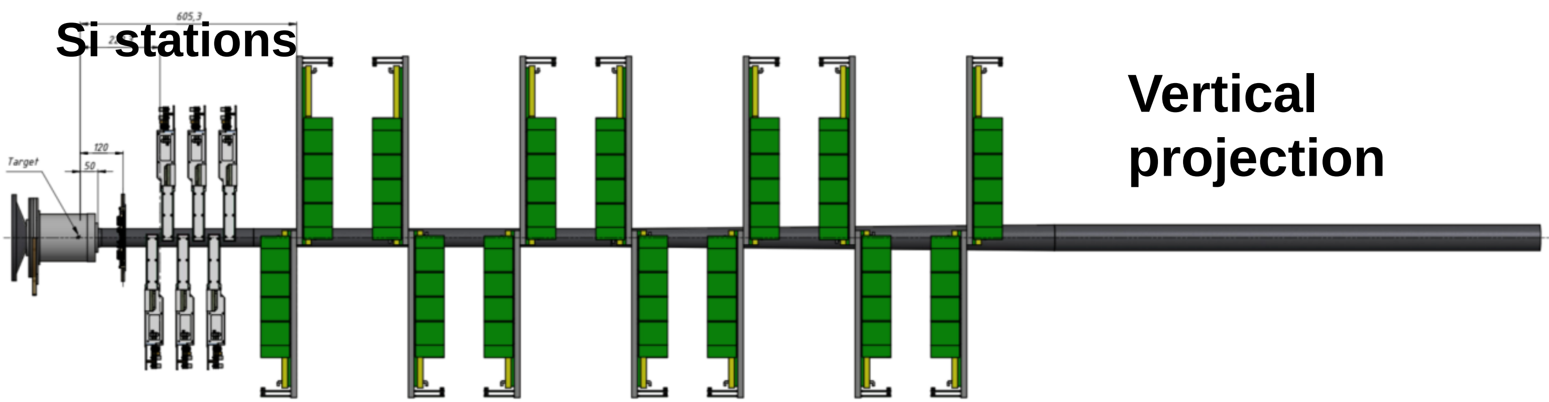
Carbon fiber vacuum beam pipe

Heavy ion beam intensity ~few 10^5 Hz

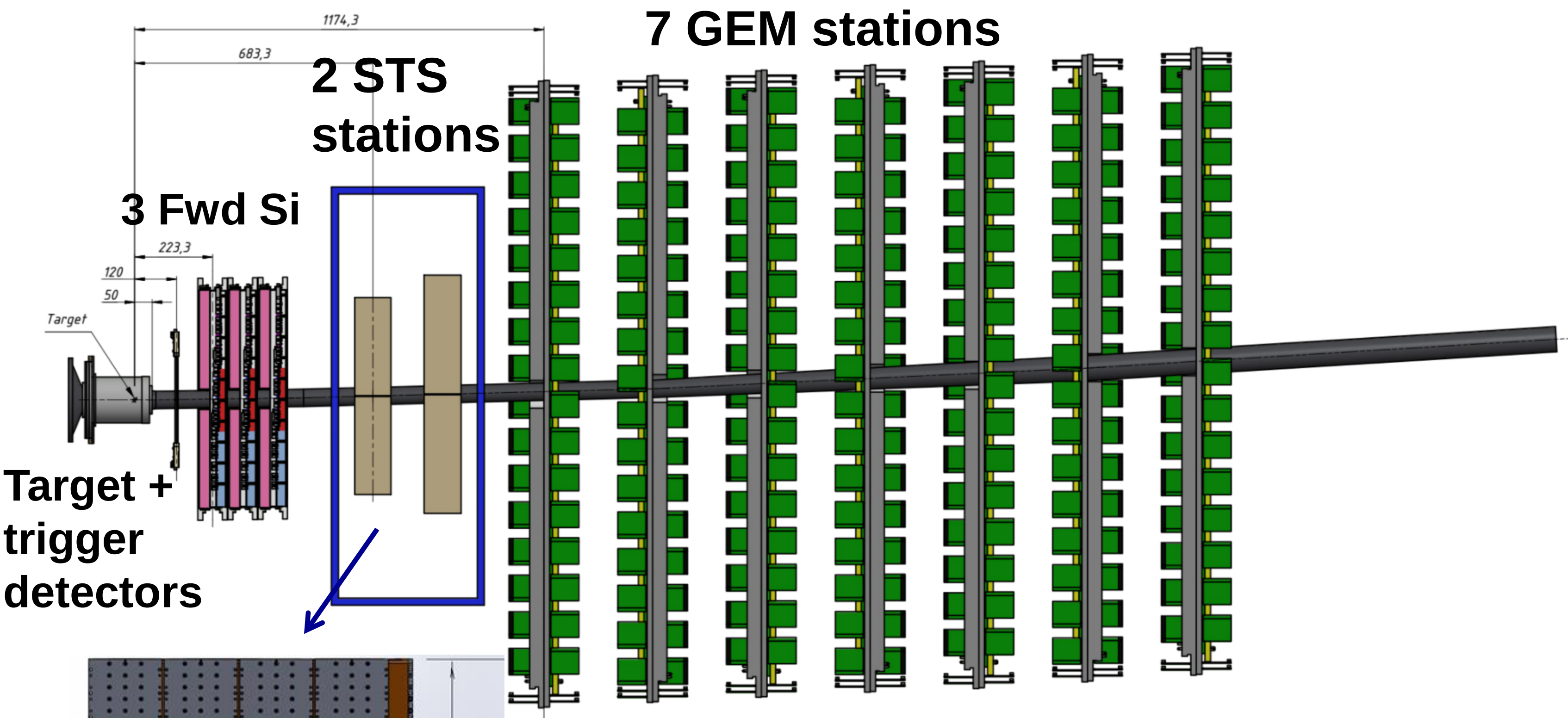


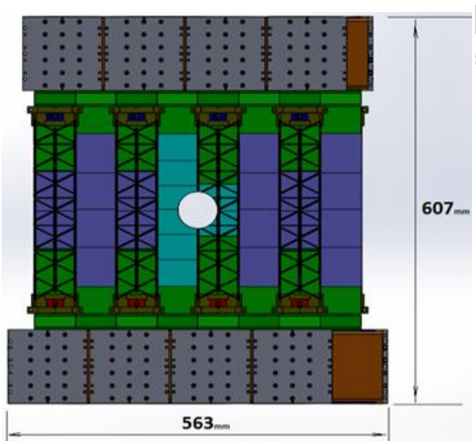
3 Forward Si stations

Vertical projection



Stage 1 Hybrid Central Tracker for heavy ion runs in 2022: Forward Si + 2 STS + GEM





Heavy ion beam intensity ~few 10^5 Hz

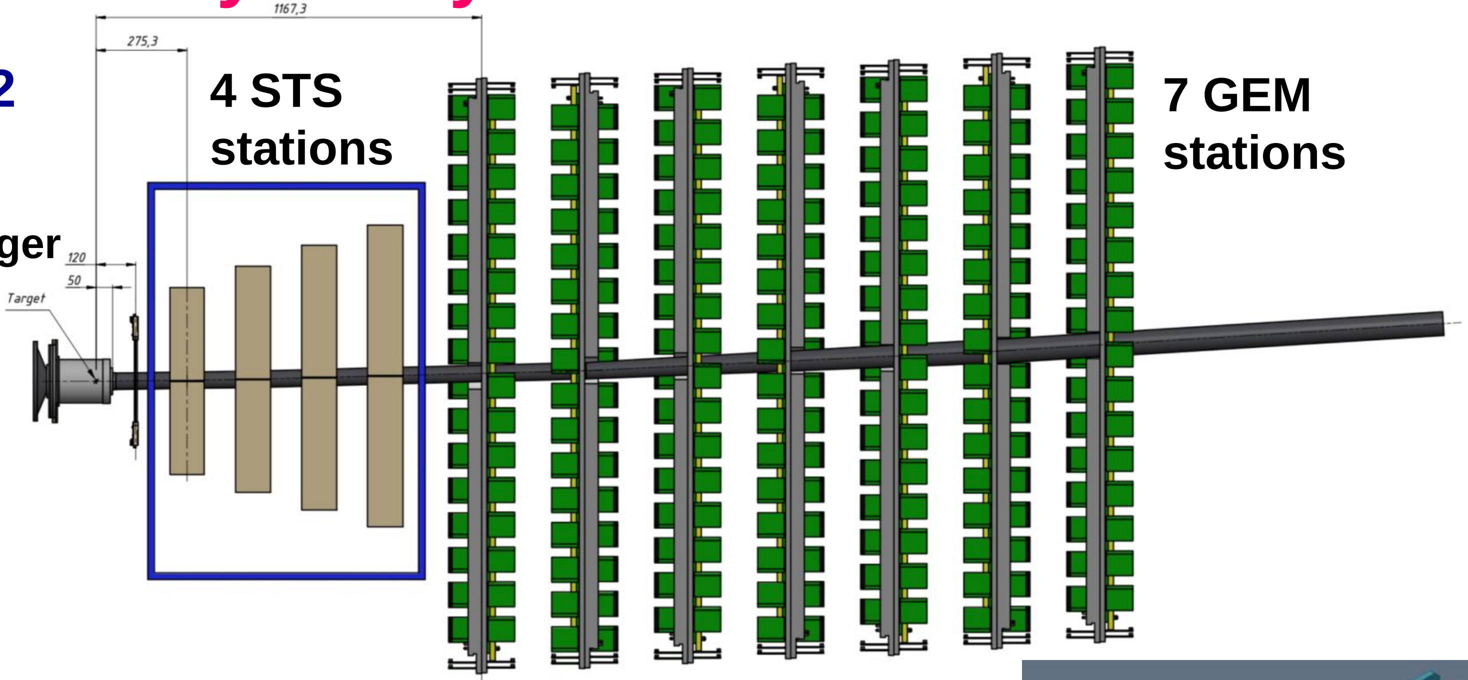
Stage2 Hybrid Central Tracker for high intensity heavy ion runs: STS +GEM

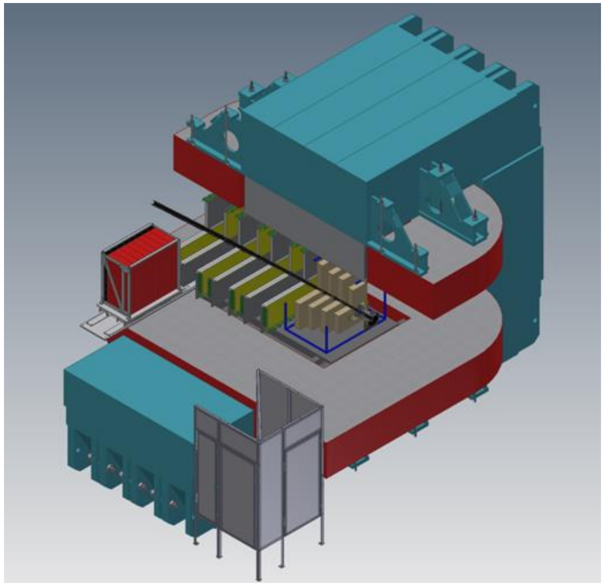
after 2022

4 STS stations

7 GEM stations

Target + trigger detectors





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

Status of 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 according to time schedule → spring 2021

Beam, Si tracking detectors and target station:

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

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

GEM tracking detectors:

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

►No proven fast FEE for high intensity beam

BM@N STS tracker:

►Complicated module, readout cables and ladder assembly, FEB board and GBTxEMU data transmission board are still in development

►Trigger mode in BM@N instead of free stream for CBM should be proven → probable delay and long commissioning phase

CSC chambers for Outer tracker:

►4 chambers to be ready by end of 2020

►Risk of delay in production of 2 big CSC chambers

ToF identification systems:

►Detectors and readout electronics are ready

►Full setup of ToF-400 and ToF-700 was already in operation in spring 2018

Status of upgrade and possible risks

Trigger and T0 detectors:
- 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

New FHCAL hadron calorimeter:
- FHCAL assembled and installed into BM@N setup, need dE/dx hodoscope

Carbon fibre beam pipe inside BM@N:
- Vacuum beam pipe should be produced and tested by middle 2021
- Risk of vacuum leakage due to irradiation of tube connectors

Beam pipe in front of target:
Design and production of beam pipe by Belgorod University
- Beam pipe elements and detector boxes are delivered to Dubna

Booster-Nuclotron, transport channel to BM@N:

► Uncertainty due to upgrade of infrastructure for Nuclotron and extracted beams: new cryogenic station, new power station for beam transport channels, new vacuum beam line

- Expect heavy ion beams in fall 2021, but there is risk of furhter delay
- Risk of wider beam profile and halo at BM@N

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

Year	2016	2017 spring	2018 spring	fall 2021	2022
Beam	d(↑)	C	Ar,Kr, C(SRC)	Kr,Xe	up to Au
Max.intensity, Hz	0.5M	0.5M	0.5M	0.5M	0.5M
Trigger rate, Hz	5k	5k	10k	10k	10k
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 + 2 large STS planes
Experimental status	technical run	technical run	technical run+physics	physics run	stage1 physics

Scenario for new SRC run in fall 2021

► Need SRC physics result from 2017 run to prove that the approach is right

► Need improved detector setup, in particular, identification of arm protons

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

• beam pipe within BM@N magnet, Si, GEM central tracker are obstacles for SRC nuclear fragments → shift aside the whole central tracker with beam pipe

• vacuum beam pipe from quadruple should be dismounted to install H_2 target, beam and fragment detectors

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

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

►Accelerator team are interested first of all to run Booster + Nuclotron with heavy ions, but BM@N need vacuum transport channel for heavy ion run

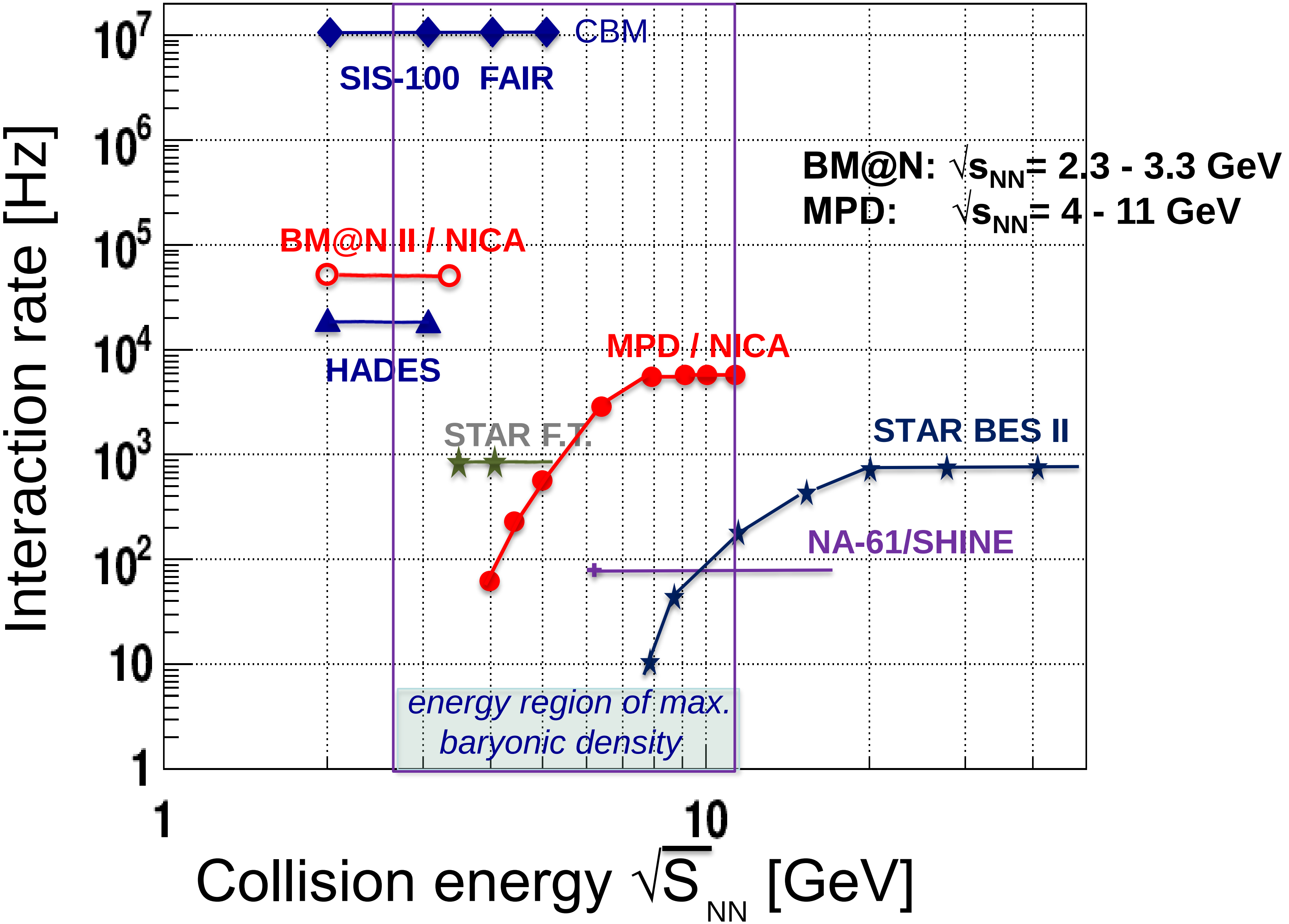
► Possible scenario for new SRC run in fall 2021:

• if vacuum transport channel to BM@N is not ready

• if there is delay with Booster + Nuclotron operation → run only Nuclotron with laser ion source

Thank you for attention!

Heavy Ion Collision Experiments



Nuclotron - BM@N beam line

►Upgrade of Nuclotron - BM@N transport channel for heavy ion program:

→ replace air intervals / foils with vacuum beam pipe along 160 m of BM@N transport line to get minimum dead material

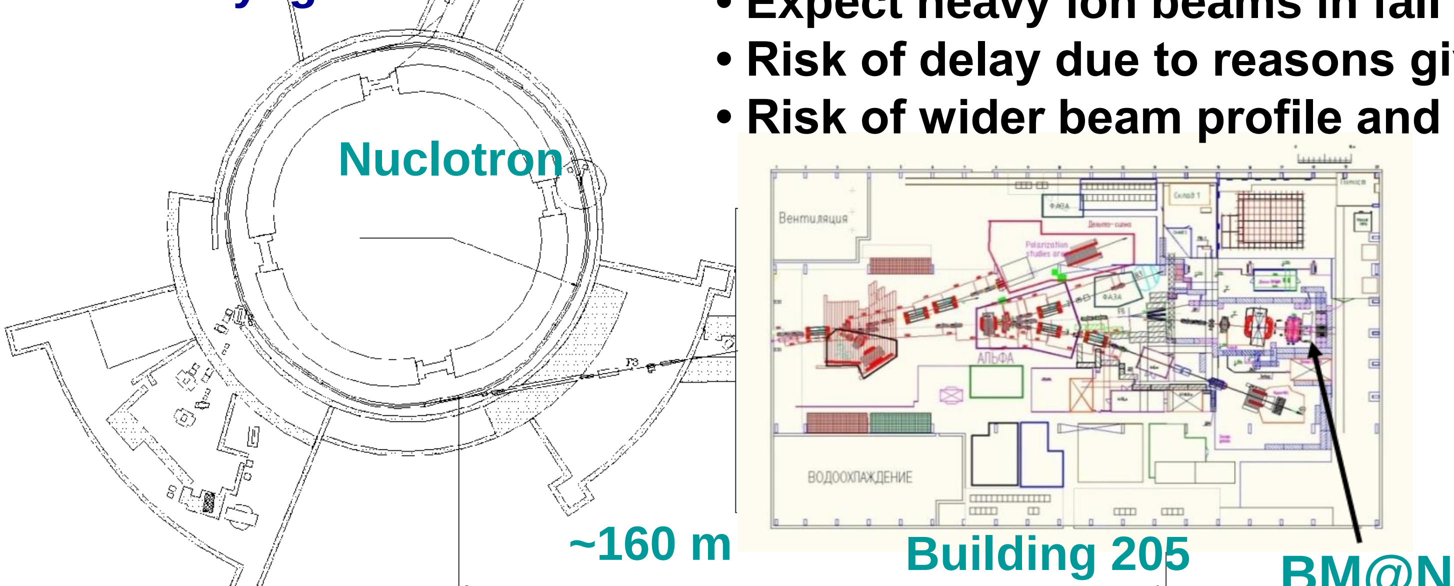
→ implement non-destructive beam position monitoring on movable vacuum inserts

→ implement vacuum beam pipe inside BM@N from target to end

►Replacement of transformers, power supplies and cables to power magnetic elements of the transport channel (need a new building to place transformers)

►To use heavy ion beams from Booster-Nuclotron need construction of a new powerful cryogenic station

- **Expect heavy ion beams in fall 2021**
- **Risk of delay due to reasons given above**
- **Risk of wider beam profile and halo at BM@N**



BM@N experiment

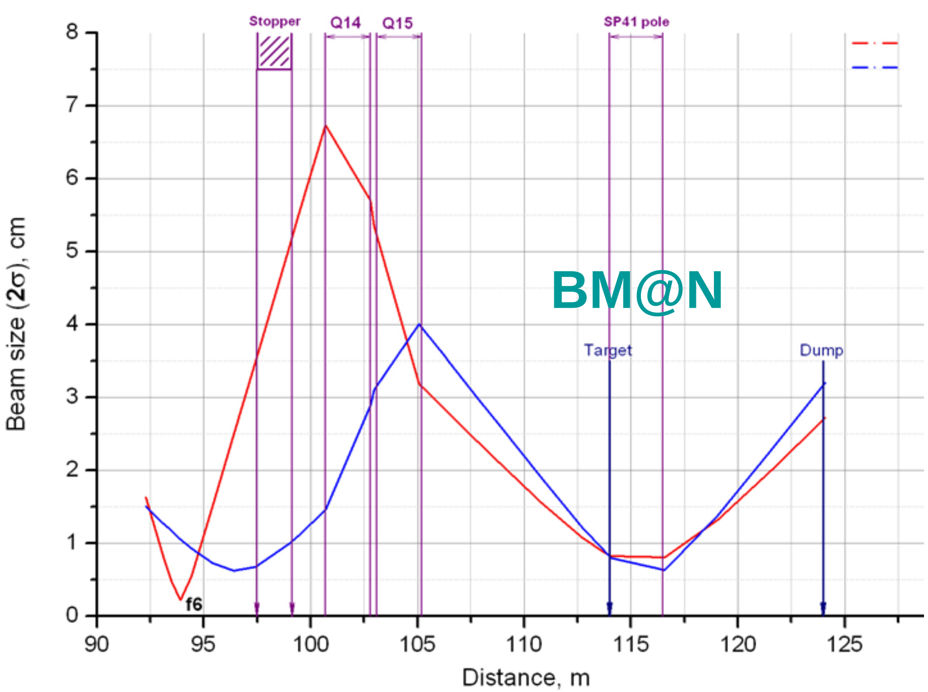
BM@N beam profile

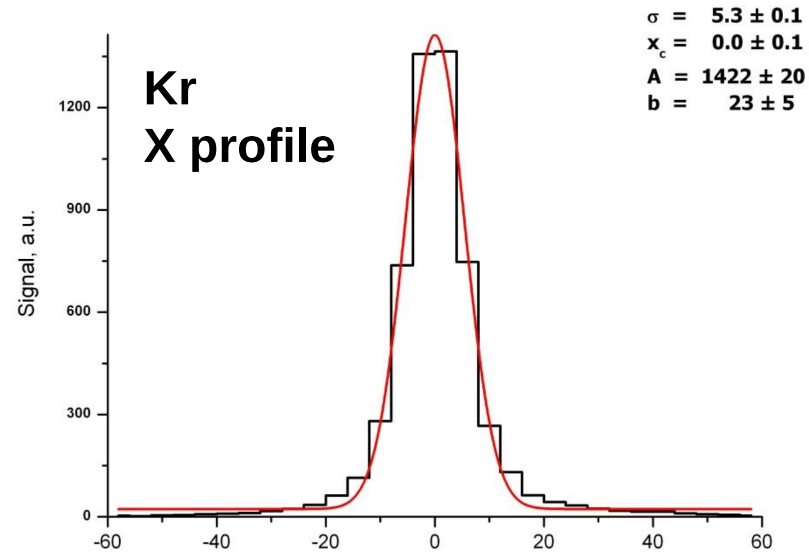
Pavel Rukoyatkin

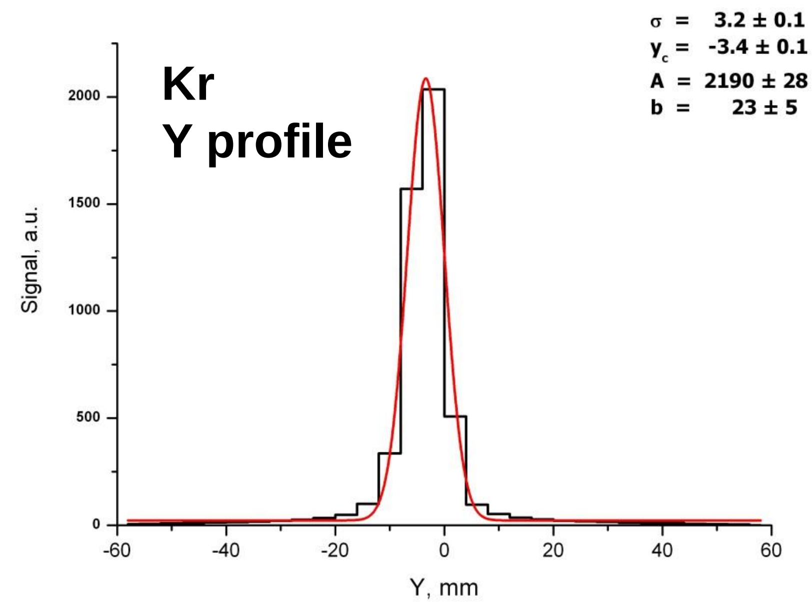
C^{12}, Ar, Kr beam profiles measured by Nuclotron beam group

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

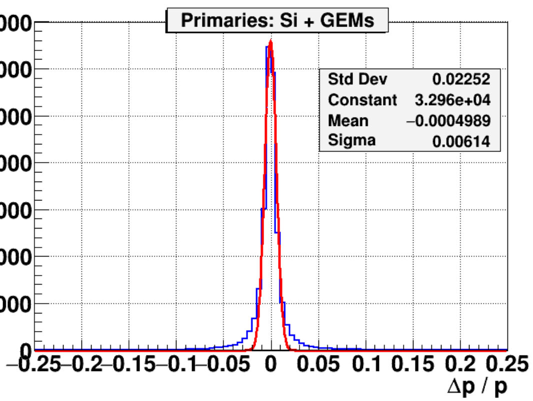


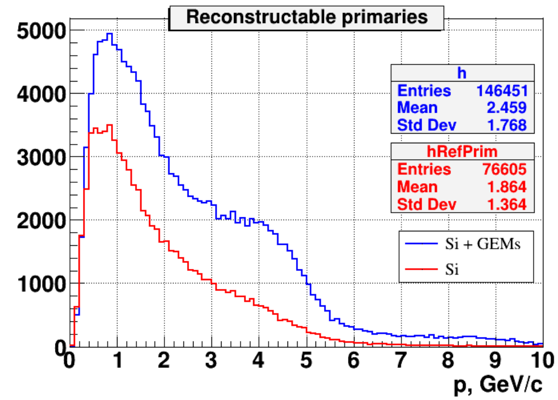


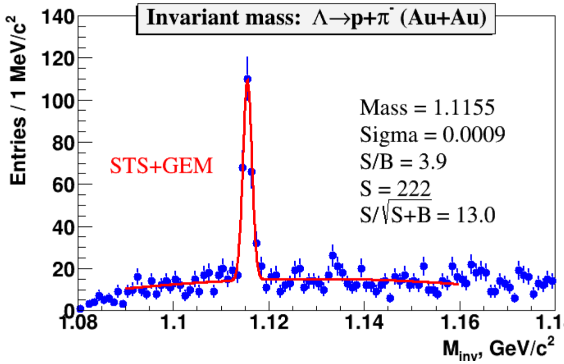


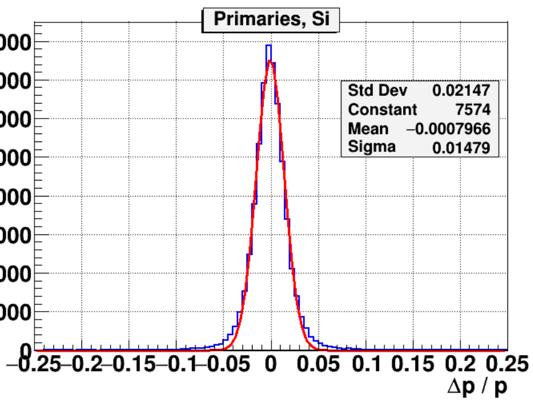
Hybrid central tracker for heavy ion runs: STS vs STS +GEM

A.Zinchenko, P.Senger





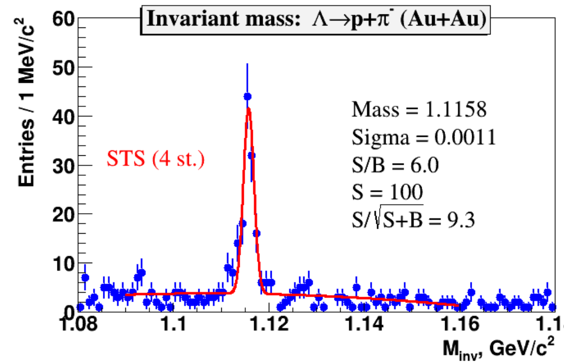




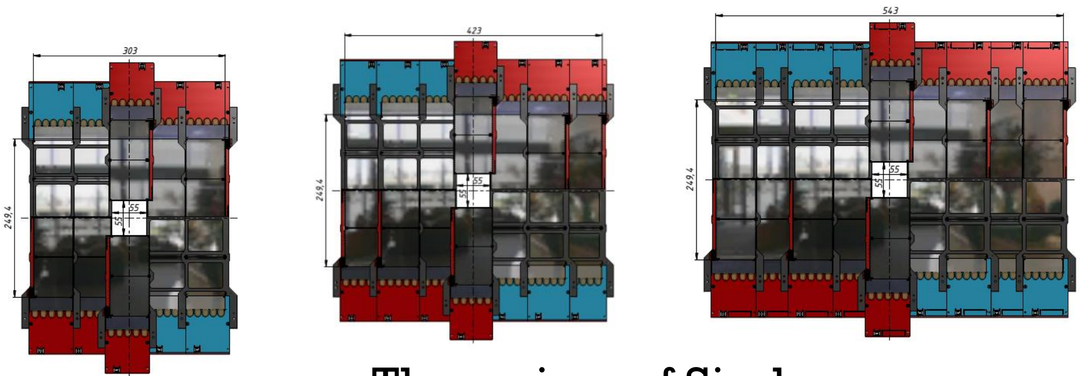
Hybrid STS + GEM tracker:

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

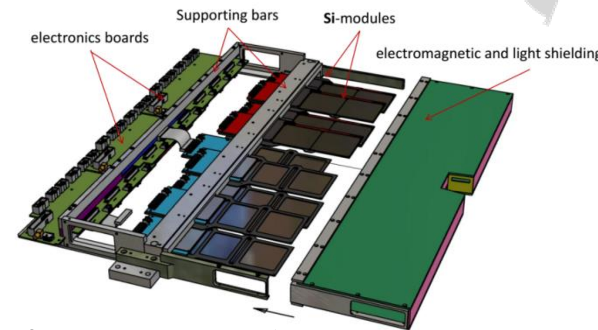
►2 times better momentum resolution



Forward Si tracking detectors

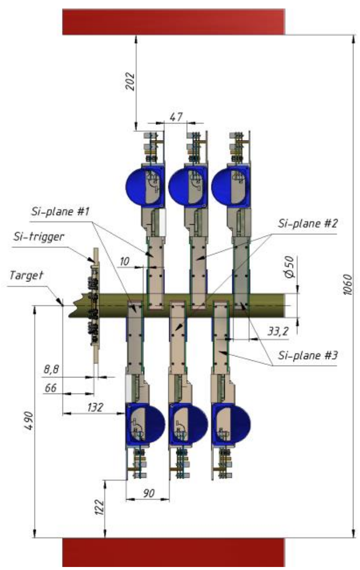


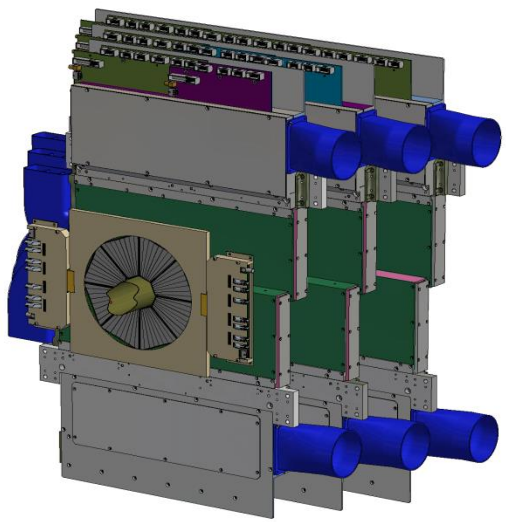
Three sizes of Si-planes



Half-plane design

ASICs VATAGP7.1 (IDEAS, Norway)



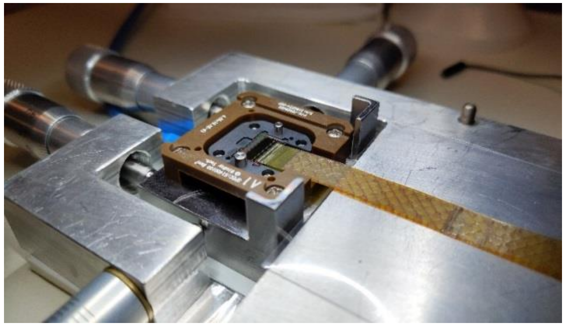


• Proven technology and FEE readout electronics → used in C, Ar, Kr runs
• Development, production, tests and installation according to time schedule → spring 2021

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

→ see talk on Forward Silicon detectors

Status of BM@N STS



Quality Assurance tests of the modules were developed and tested on the first assembled modules.

Ladder Assembly Device and corresponding fixtures were developed and produced for the assembly of BM@N and CBM ladders. Accuracy of the sensor positioning is tested.

Dec 2019: TDR - Joint effort by the groups from JINR, NRNU MEPhI, SINP MSU, GSI, WUT

Support from BMBF: in-kind contribution of Germany to NICA → active participation of GSI in BM@N STS

→ see talk on STS tracking system

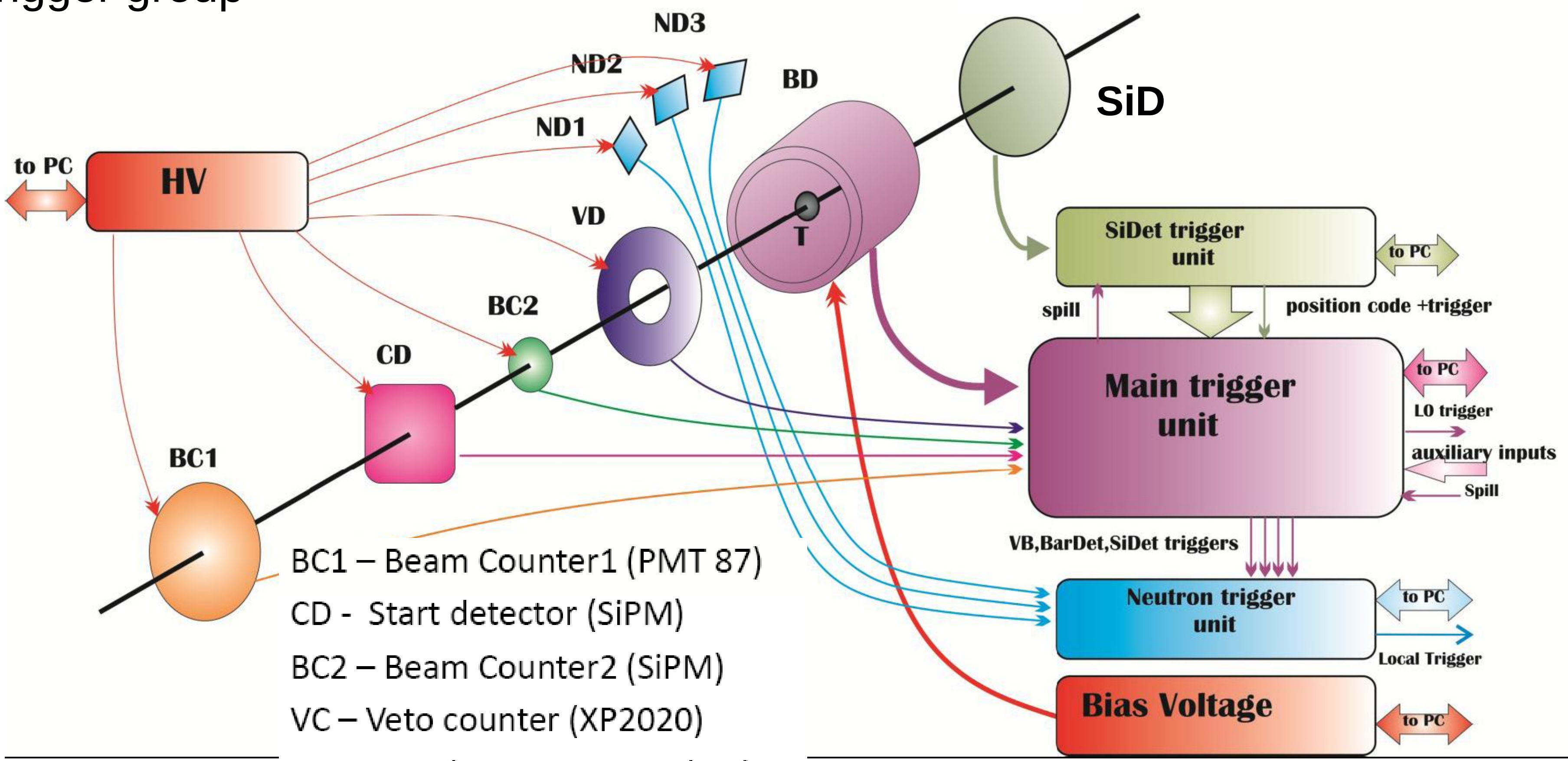
Assessment of STS risks:

- **Complicated module, readout cables and ladder assembly, FEB board and GBTxEMU data transmission board are still in development**
- **Trigger mode in BM@N instead of free stream for CBM should be proven**

→ probable delay and long commissioning phase

Trigger detectors: beam counters and barrel detector

Trigger group



BC1 – Beam Counter1 (PMT 87)

CD - Start detector (SiPM)

BC2 – Beam Counter2 (SiPM)

VC – Veto counter (XP2020)

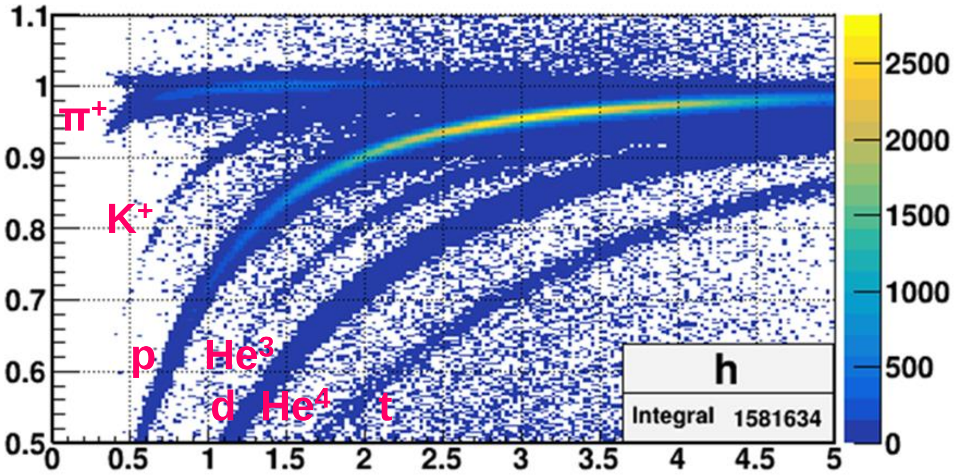
BD – Barrel Detector – 40ch. SiPM

T – target

SiDet – Silicon Detector

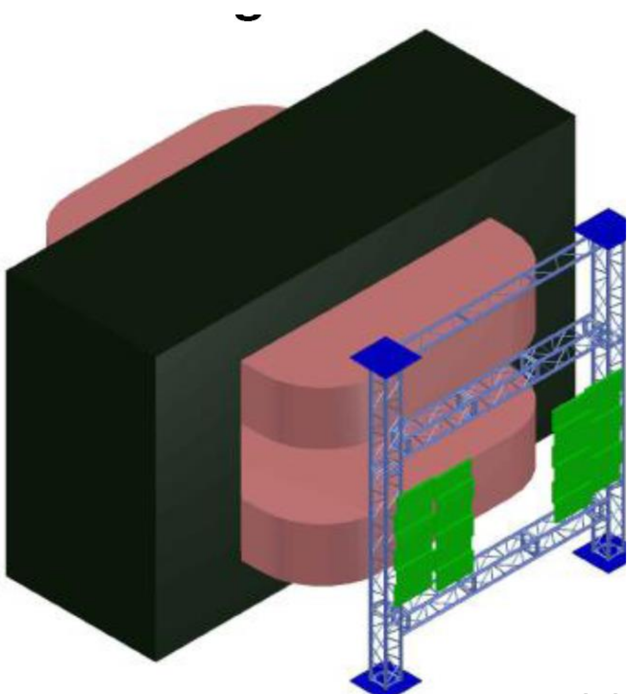
Selection of events with activity in barrel detector: BD ≥ 2, ≥ 3 or forward silicon multiplicity detector SiD (with beam hole)

ToF-400 and ToF-700 based on mRPC



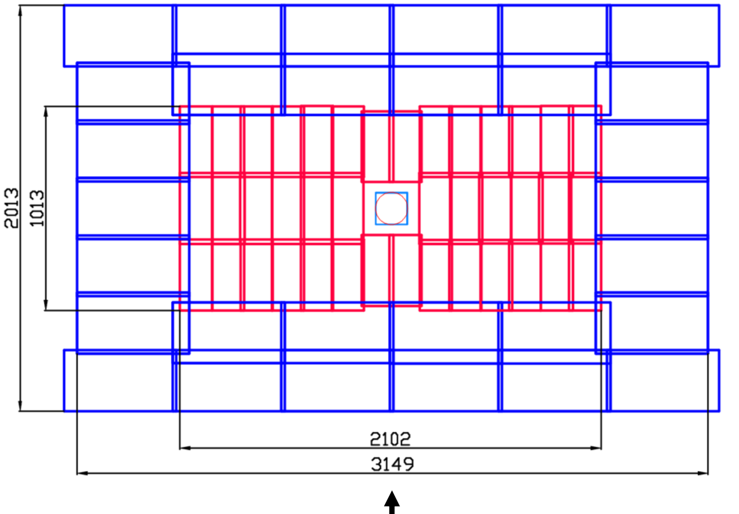
Detectors and readout electronics are ready

Full setup of ToF-400 and ToF-700 was already in operation in Spring 2018



ToF-400 wall

ToF-700 wall

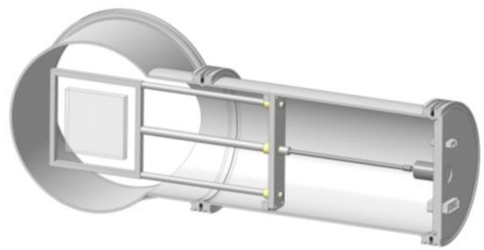


BM@N beam axis

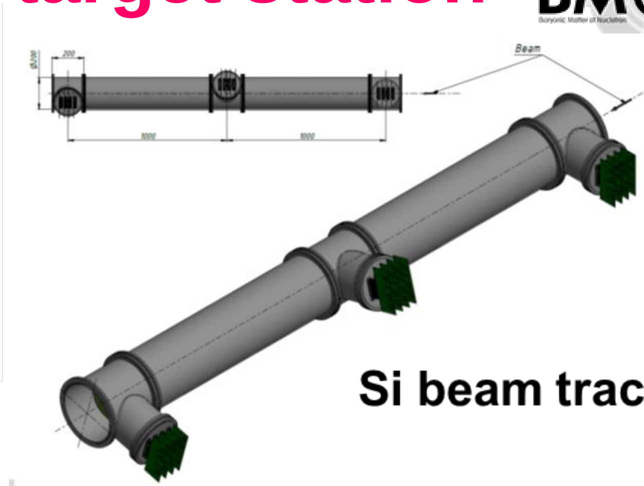
M.Kapishin

Beam, Si tracking detectors and target station

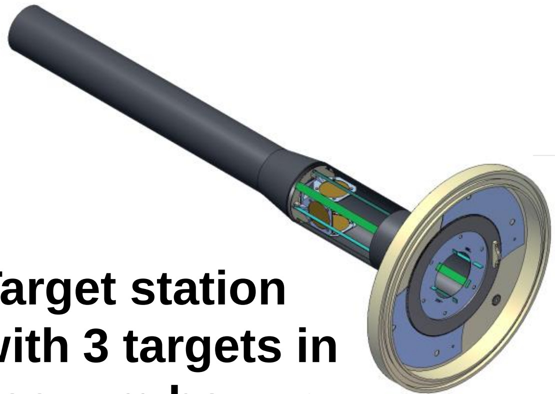
S.Piyadin, Yu.Gusakov
A.Kubankin group (Belgo
Group of N.Zamiatin



Movable beam
profile detector

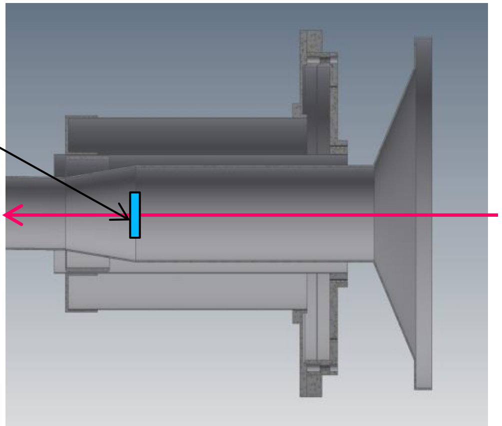


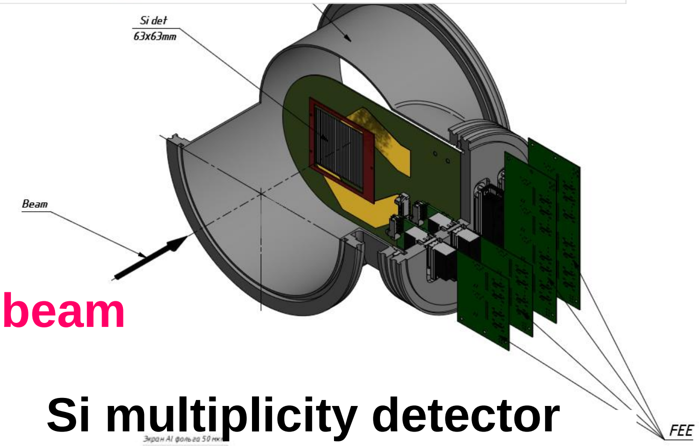
Si beam tracker



Target station
with 3 targets in
vacuum box

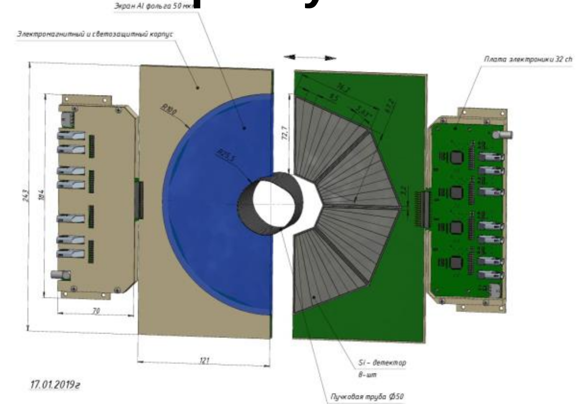
Barrel detector
around target





beam

Si multiplicity detector



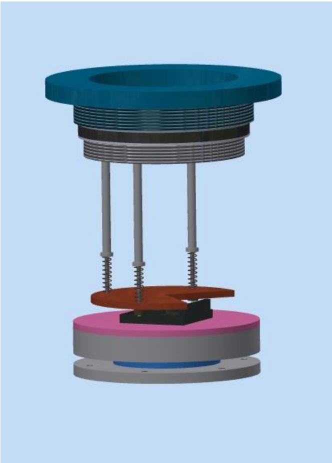
►All detectors and target station to be ready by spring 2021

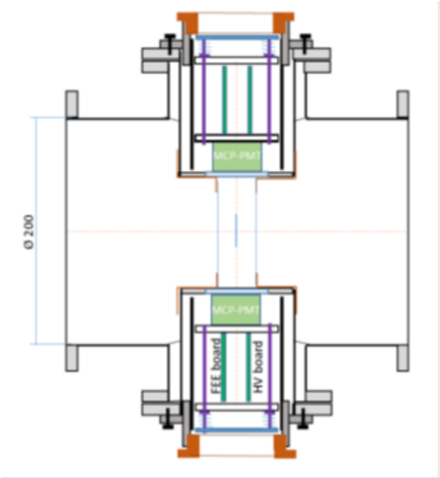
► Detector performance in heavy ion beam should be tested in first run

Trigger and T0 detectors for heavy ions

Trigger group

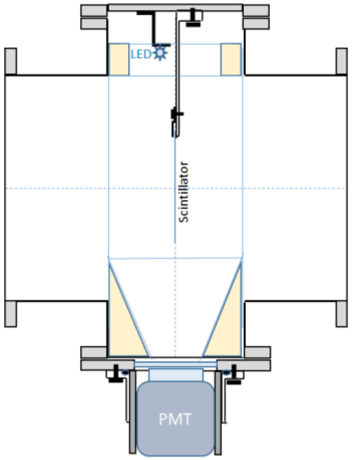
Box for BC2 counter

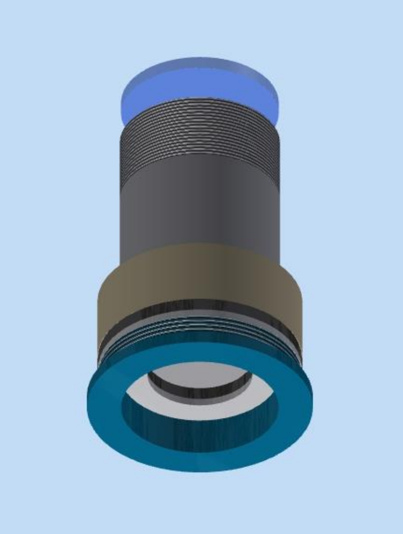


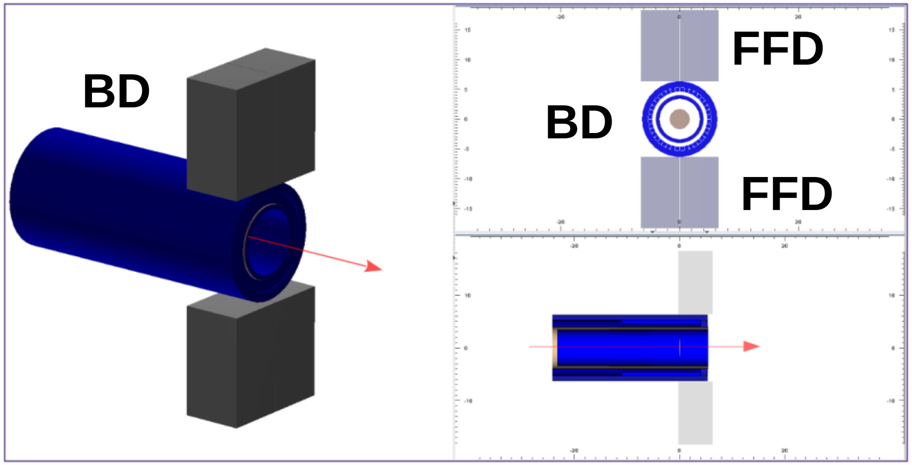


beam

Box for BC1, Veto







Fast quartz FFD detectors for high intensity heavy ions

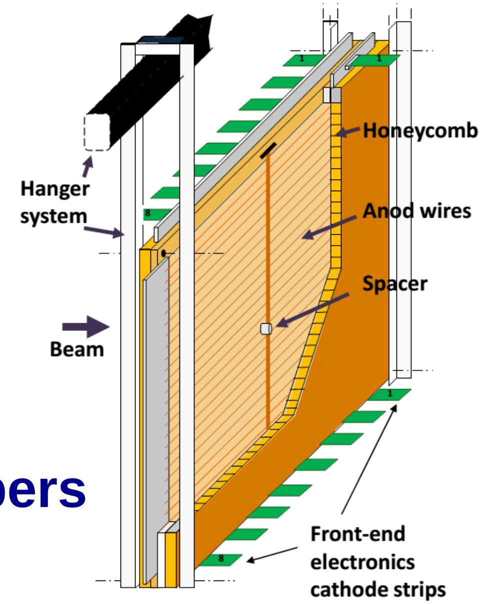
- T0 and beam scintillator film counters for heavy ion beam intensities $< 10^6$ Hz
- FFD T0 detectors and Si beam detectors for higher intensities
- Detector performance and efficiency in heavy ion beam should be tested in first run

CSC chambers for Outer tracker in heavy ion runs

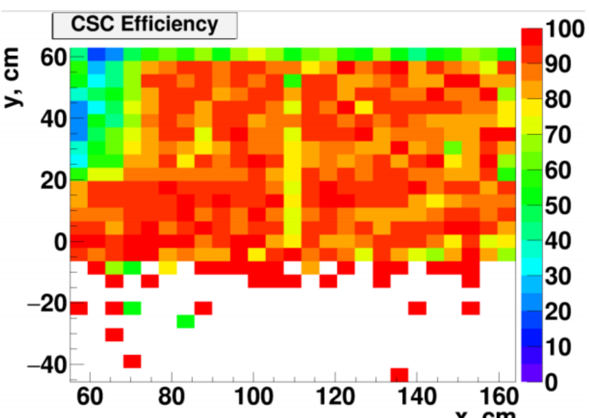
A.Vishnevsky and team, LHEP JINR

- 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

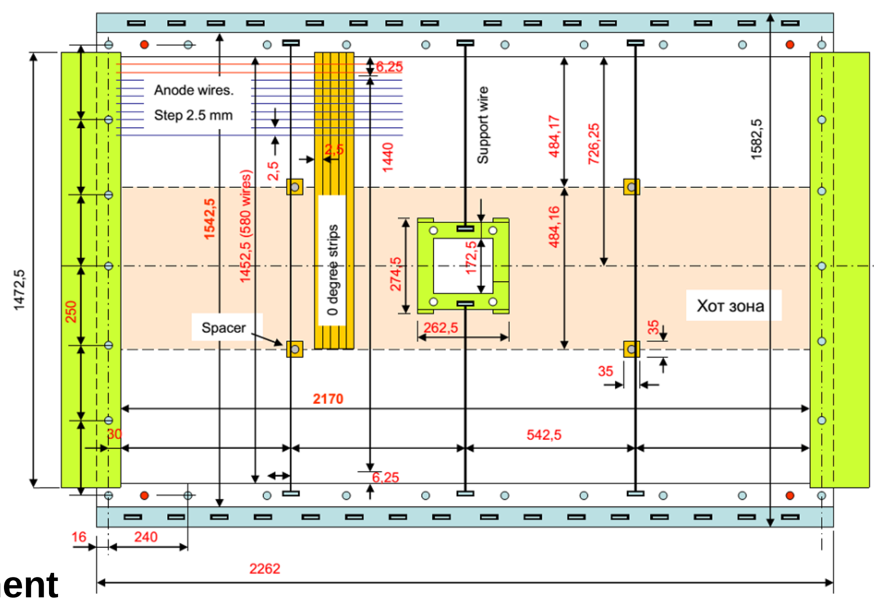
- **Risk of delay in production of big CSC chambers**



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



CSC efficiency in Ar run

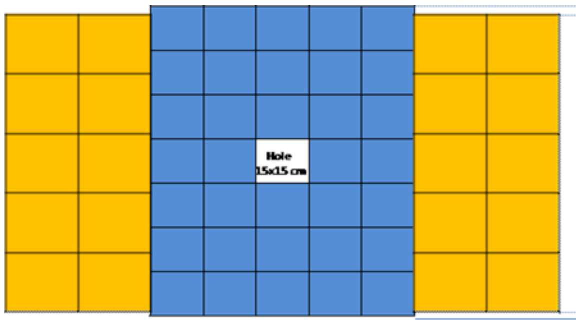


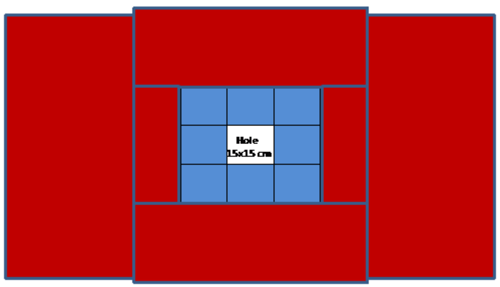
New FHCAL (ZDC) hadron calorimeter

Team of INR RAS, Troitsk

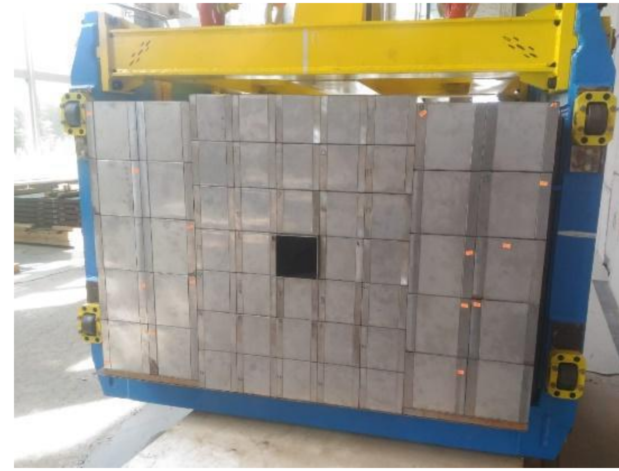
- **FHCAL assembled and installed into BM@N setup**
- **Cosmic tests are under way**

CBM modules MPD modules





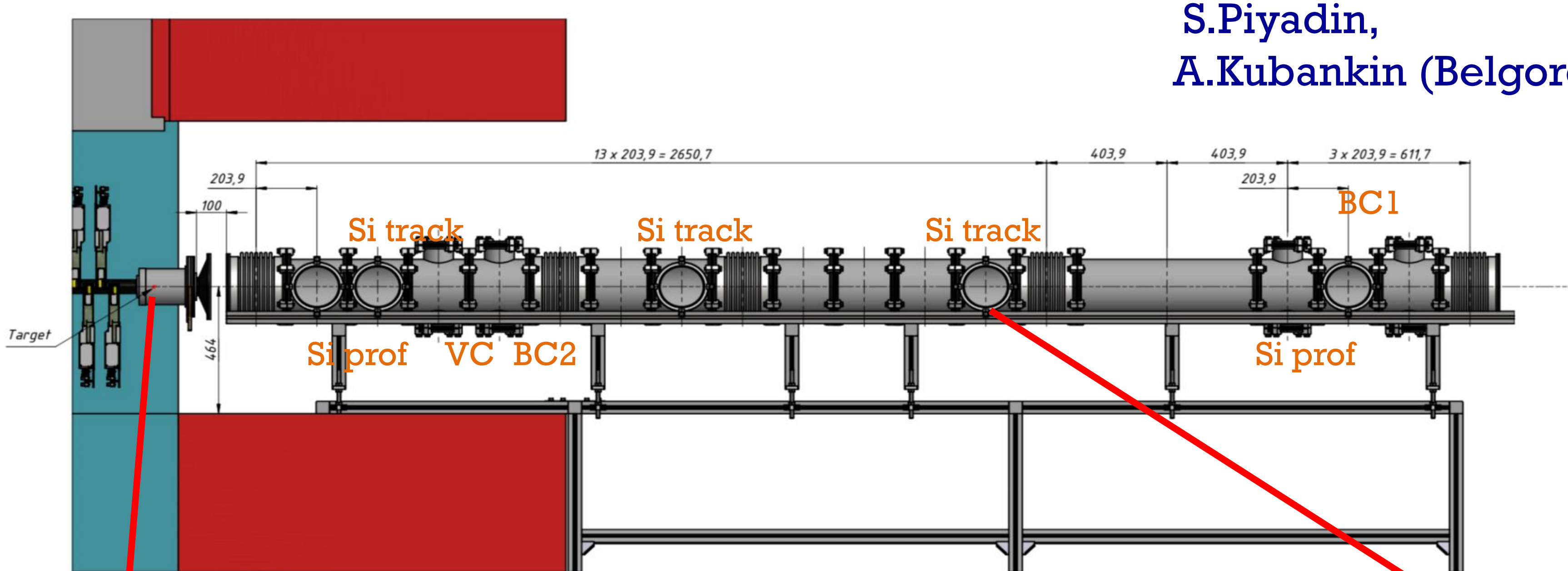
$$A_E = \frac{E_{dep}\,(\text{blue}) - E_{dep}\,(\text{red})}{E_{dep}\,(\text{blue}) + E_{dep}\,(\text{red})}$$

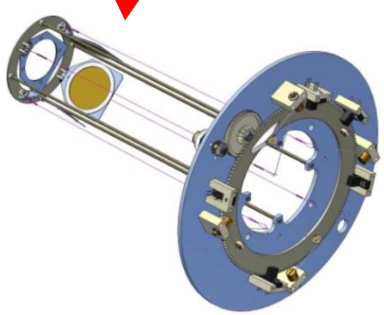


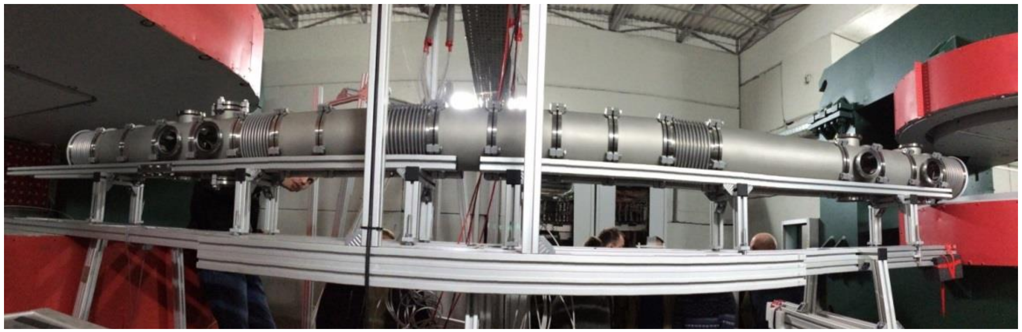
Measure E_{dep} v Asymmetry of E_{dep} and $\Sigma\, Z^2$ with quartz hodoscope in the beam hole to resolve central and peripheral interactions

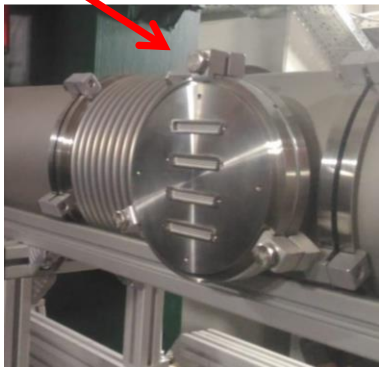
Beam pipe in front of the target

S.Piyadin,
A.Kubankin (Belgorod)









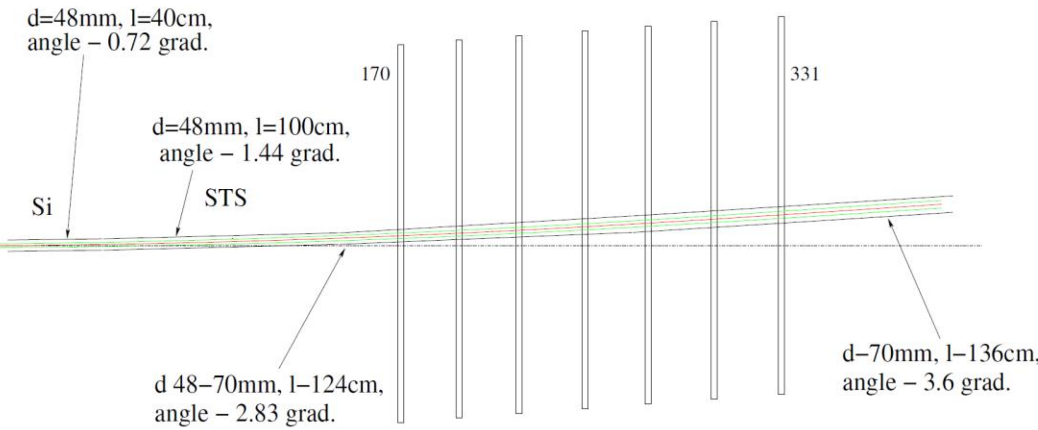
- Design and production of beam pipe by Belgorod University
- Beam pipe elements and detector boxes are delivered to Dubna

Carbon fibre beam pipe for heavy ion runs

Status and plans:

- Carbon fiber vacuum beam pipe consist of several sections to provide bending of the beam
- Possibility to reassemble sections → use thin removable tube connectors

- Vacuum tests of 1m test sample performed in LHEP JINR, selection of proper type of tube connector needed
- Irradiation hardness tests performed by NPI CAS Rez group, need irradiation tests of tube connectors



- **Vacuum beam pipe should be produced and tested by middle of 2021**
- **Risk of vacuum leakage due to irradiation of tube connectors**