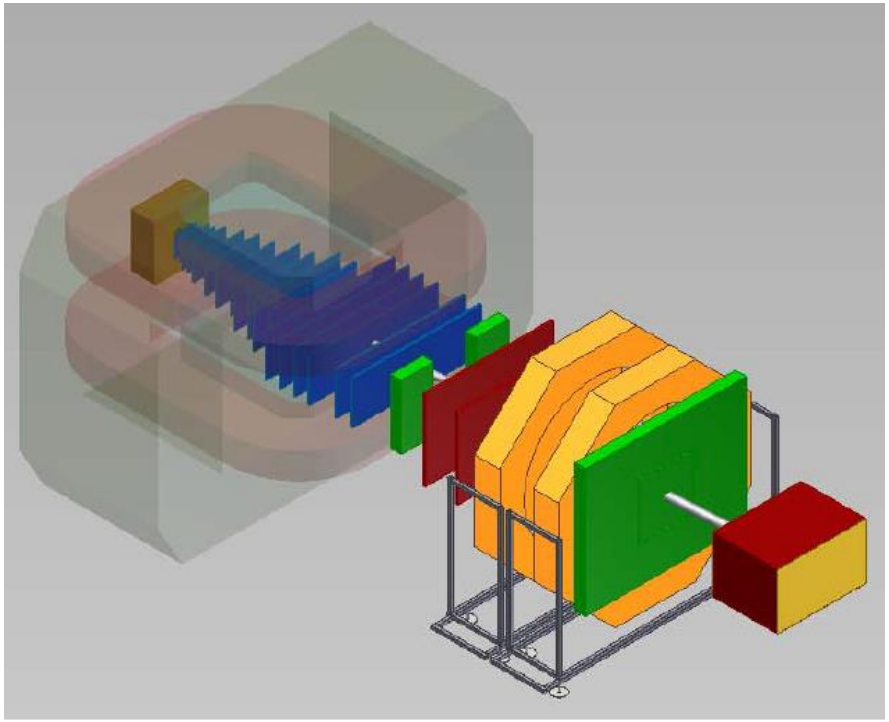
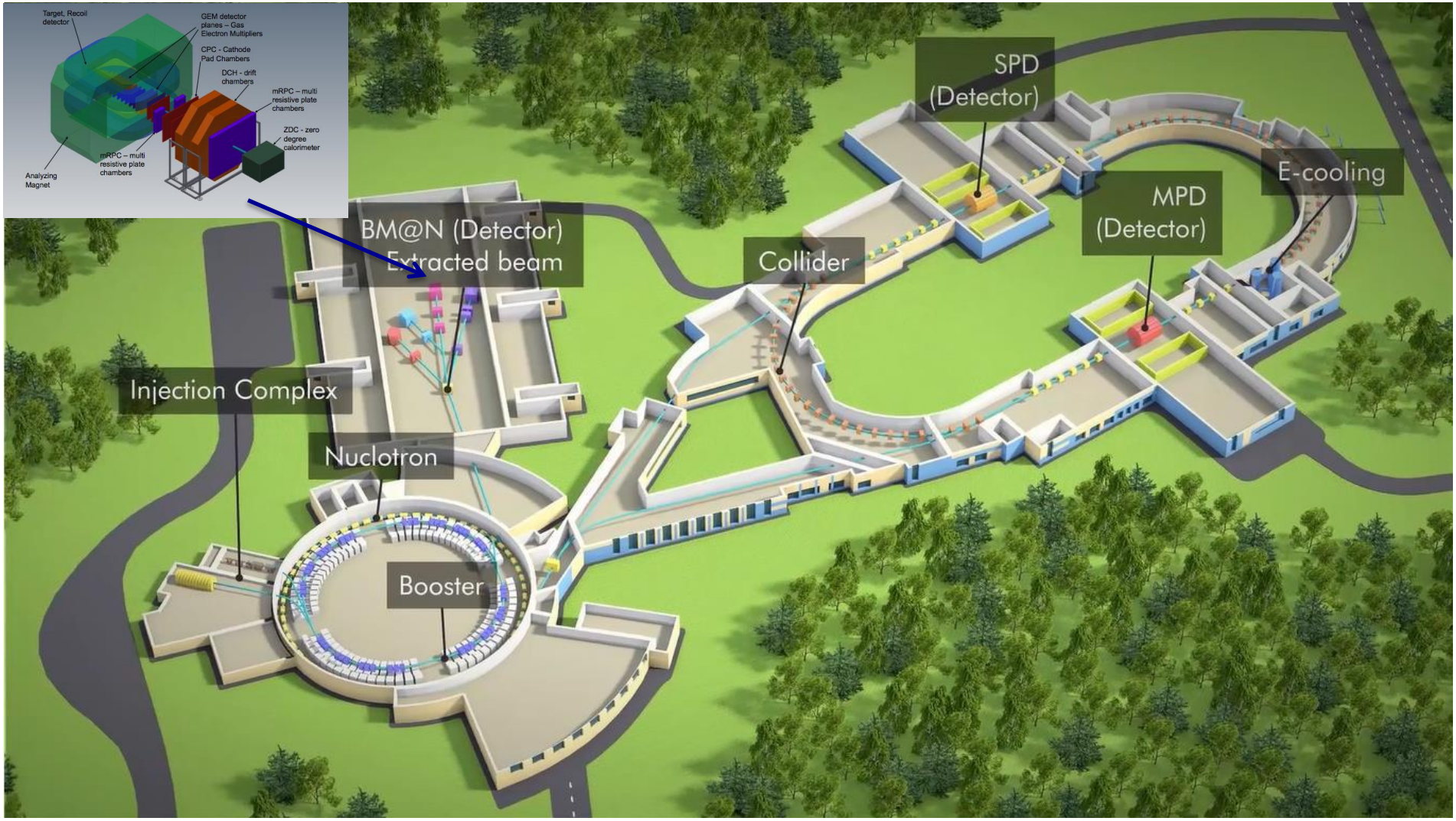
Status of the BM@N project

M.Kapishin



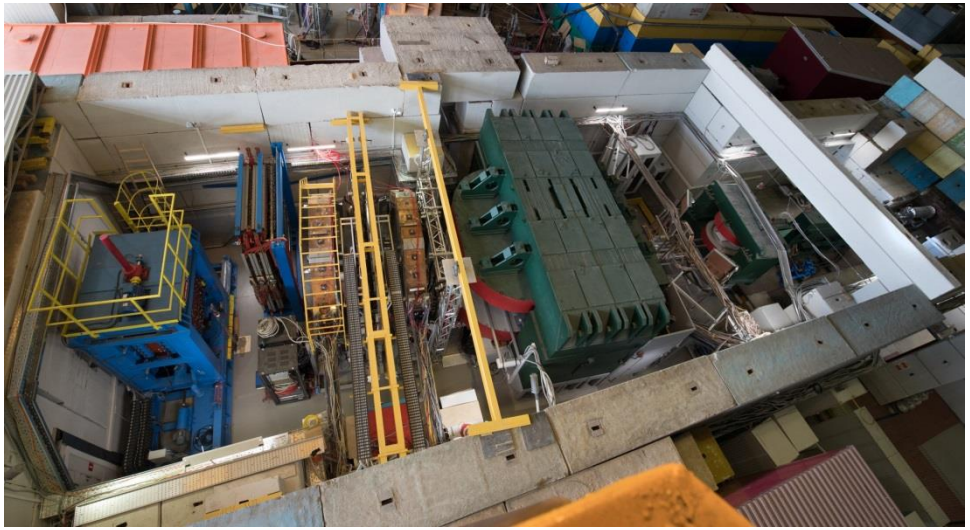
NICA Heavy Ion Complex

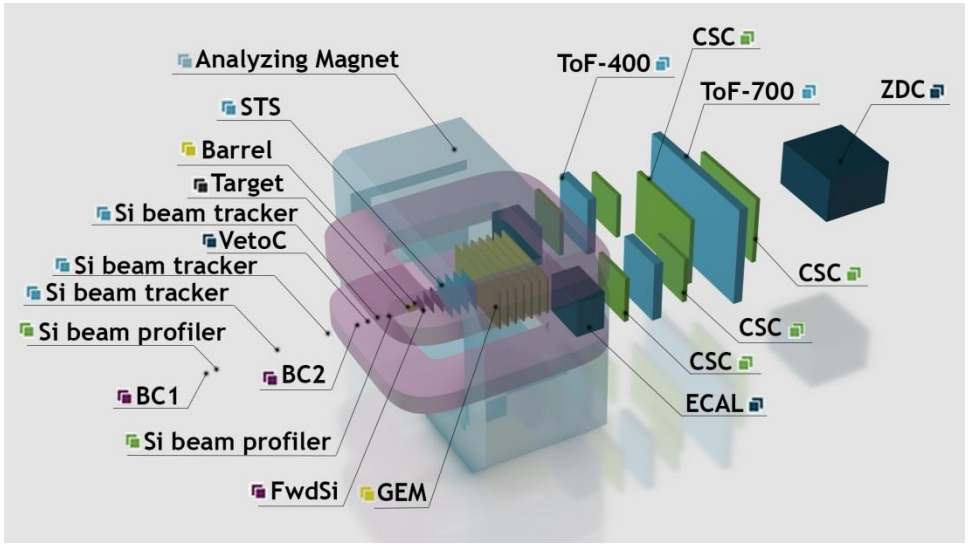
BM@N: heavy ion energy 1- 3.8 GeV/n, beams: p to Au, Intensity ~few 10^6 Hz (Au)



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

Baryonic Matter at Nuclotron (BM@N) Experiment

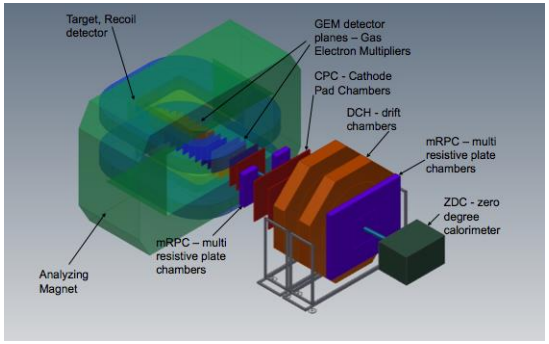




- The 5th Meeting of the BM@N Collaboration took place in April 20-21. The focus of discussion was on recent results obtained in carbon-nucleus and argon-nucleus interaction
- Detailed plans to complete the full coverage of the BM@N set-up for future heavy ion physics program were reviewed
- More than 40 reports were presented at the Collaboration Meeting

Configuration of BM@N detector for heavy ion program

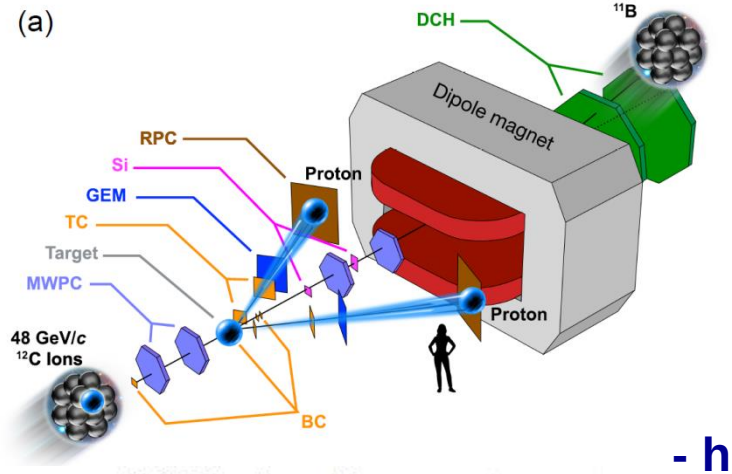
Baryonic Matter at Nuclotron (BM@N) Collaboration:



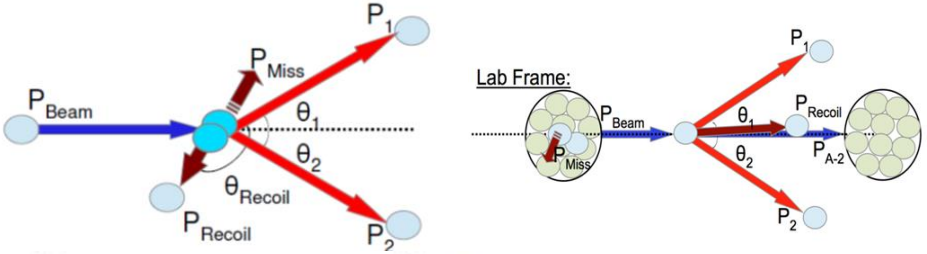
10 Countries, 20 Institutions, 246 participants

- *University of Plovdiv, Bulgaria;*
- *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;*
- *Institute of Applied Physics, Chisinev, Moldova;*
- *Warsaw University of Technology, Poland;*
- *St Petersburg University, Russia;*
- *University of Wroclaw, Poland;*
- *Institute of Nuclear Research RAS, Moscow, Russia*
- *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;*
- *Moscow Institute of Physics and Technics, Moscow, Russia;*
- *Massachusetts Institute of Technology, Cambridge, USA.*

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

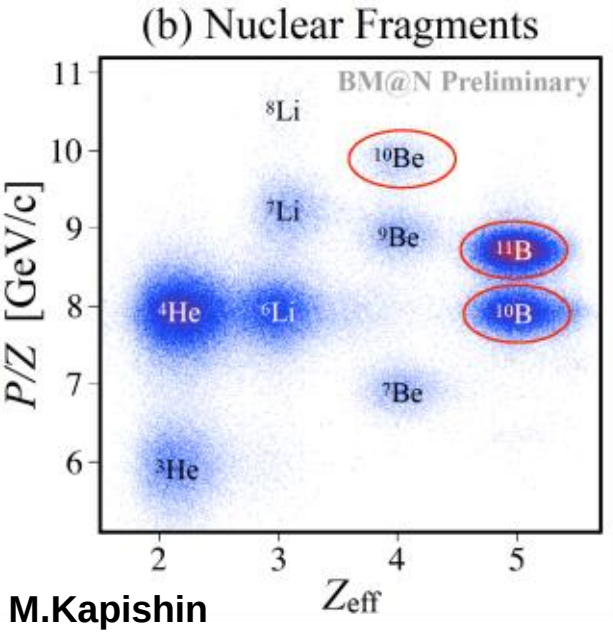


^{12}C Beam Frame **Lab frame**



$$^{12}C + p \rightarrow 2p + {}^{10}_{5}B + n \qquad \text{np SRC}$$

$$^{12}C + p \rightarrow 2p + {}^{10}_{4}Be + p \qquad \text{pp SRC}$$



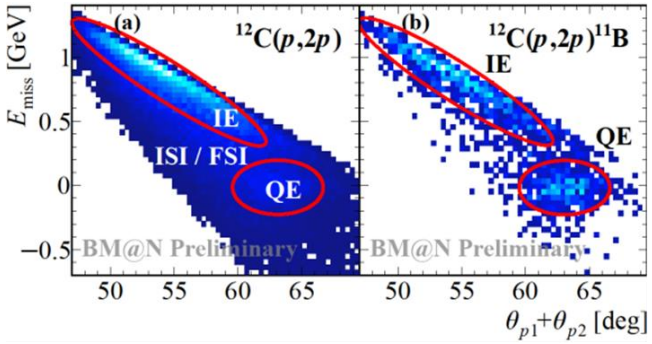
- high momentum ^{12}C beam: 4 GeV/c/nucleon
- (p,2p) ~90°c.m. scattering
- inverse kinematics
- detection of A-1 or A-2 system selects reactions with no multiple scattering

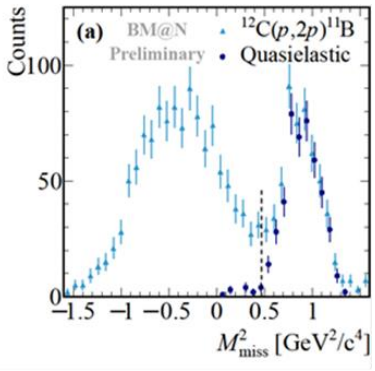
Goals:

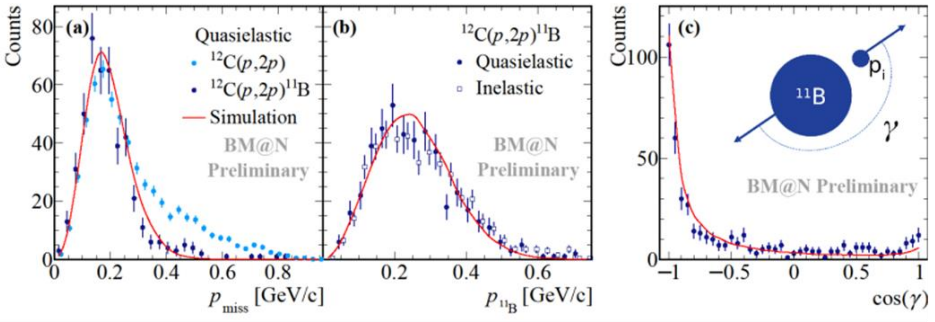
→ extract missing-and recoil-momentum distributions for Quasi-Elastic scattering

→ identify SRC signal in inverse kinematics

First BM@N results on SRC and Single Proton Knockout







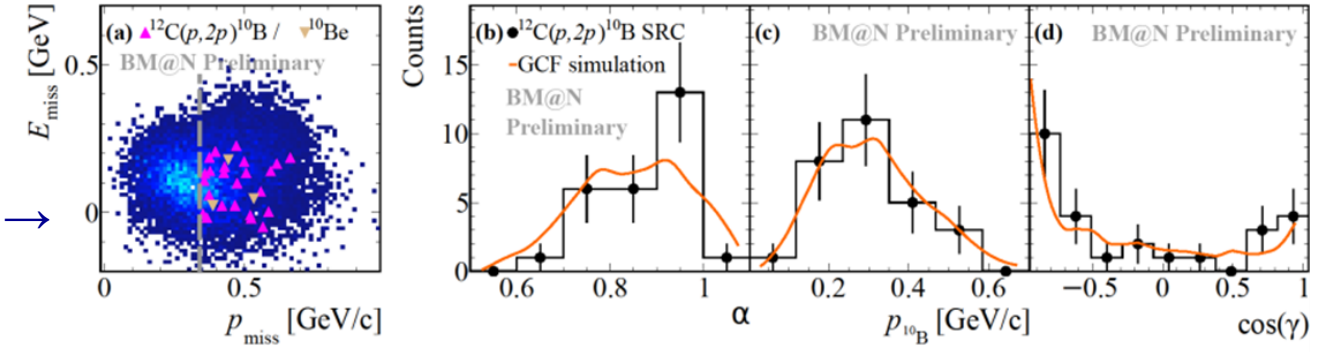
JINR seminar-colloquium:
"The Transparent Nucleus: SRC and single nucleon knockout inverse kinematics measurements using a 48 GeV/c carbon beam at JINR"

Single Proton Knockout:
►exclusive $^{12}C(p,2p)^{11}B$ reaction
►Quasi-Elastic scattering (bound ^{11}B)
►tagging A-1 fragment removes ISI / FSI

- First observation of Final State Interaction suppression and single-step nucleon knockout selection using fragment detection in quasi-elastic reaction **$^{12}C + p \rightarrow 2p + ^{11}B$**

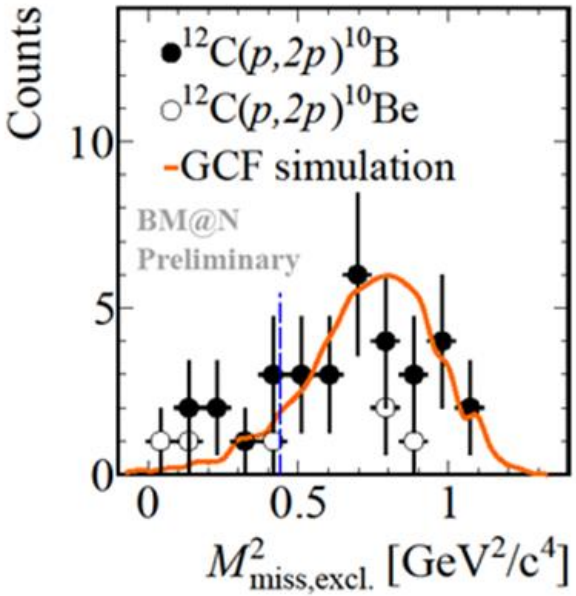
First BM@N result on Short Range Nucleon Correlations

Probe full Momentum Distribution: Mean Field + Short Range Correlations →

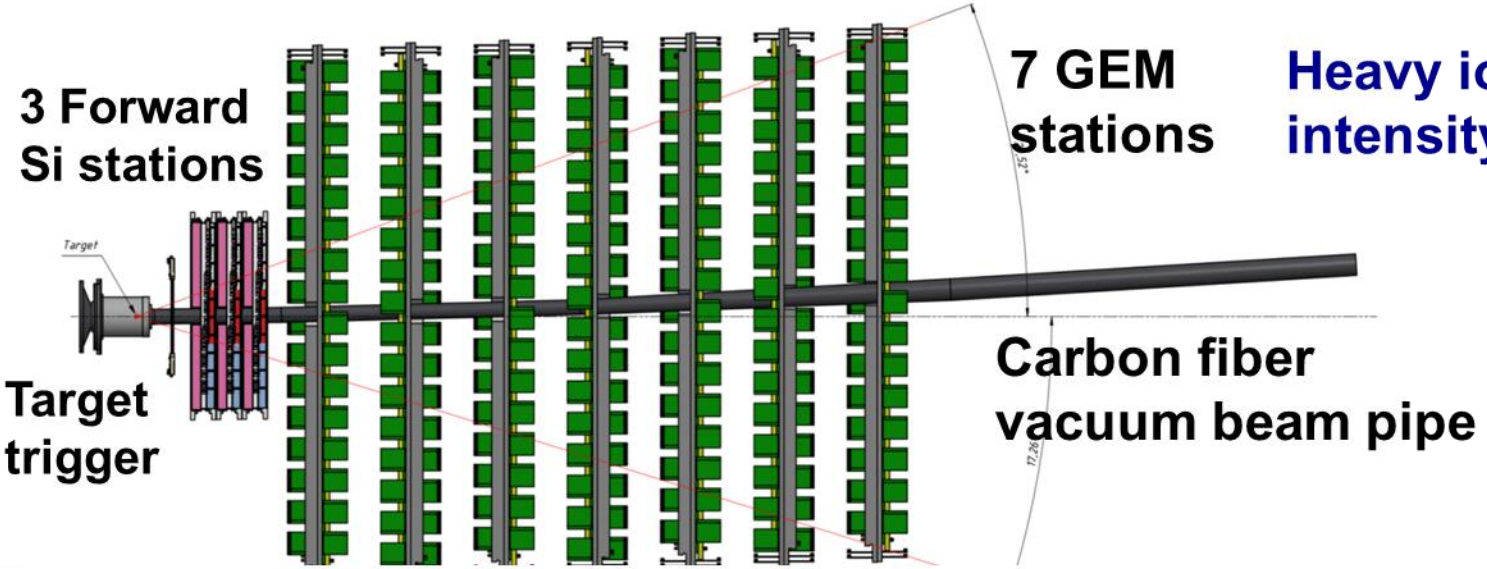


- First observation of SRCs with bound residual A-2 system in reactions:
  $^{12}C + p \rightarrow 2p + {}^{10}B / {}^{10}Be + (n / p)$
  26 ^{10}B events
  3 ^{10}Be events → *np* pair dominance

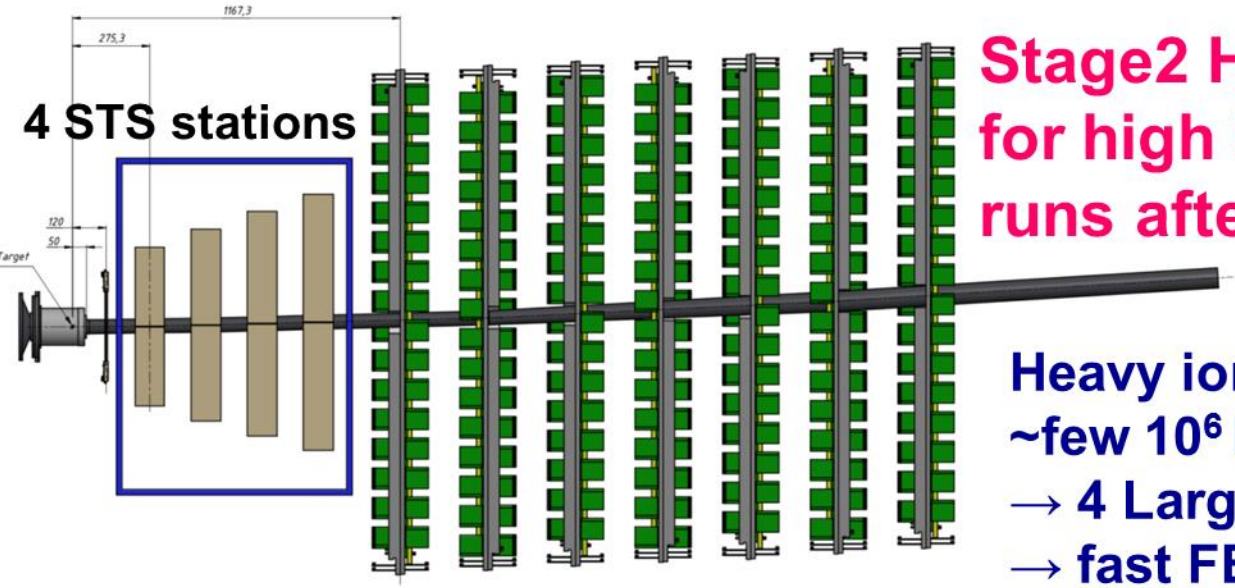
- Direct measurement of SRC pair center mass motion



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



Heavy ion beam intensity ~few 10^5 Hz



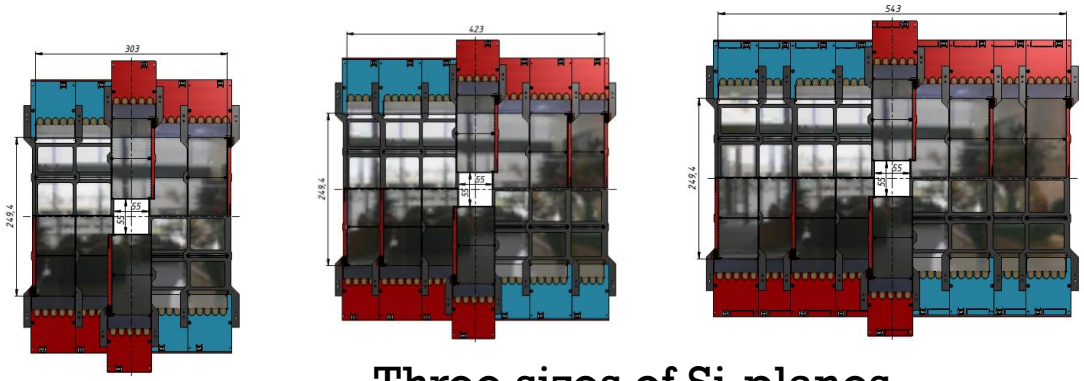
Stage2 Hybrid Central Tracker for high intensity heavy ion runs after 2022: STS +GEM

Heavy ion beam intensity ~few 10^6 Hz

→ 4 Large aperture STS + 7 GEM

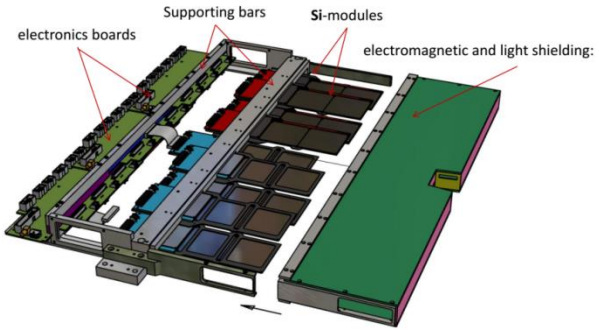
→ fast FEE and readout electronics

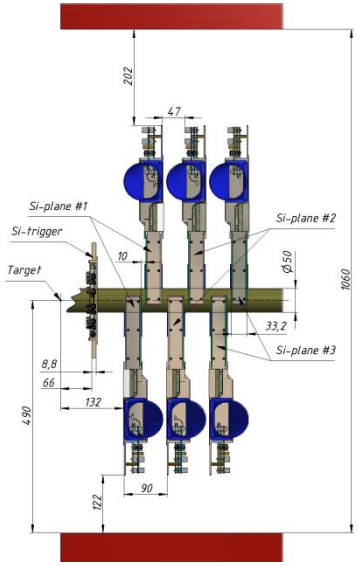
Forward Si tracking detectors

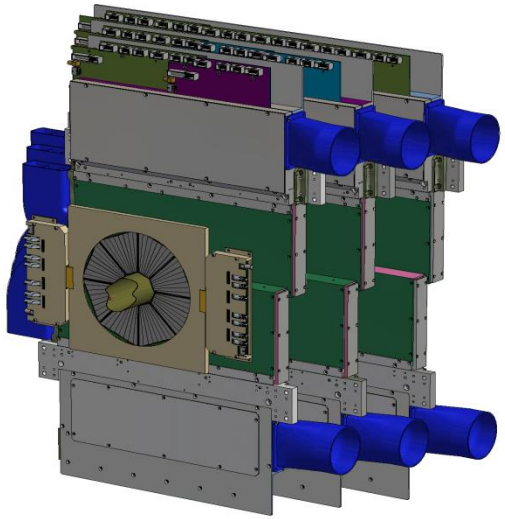


Three sizes of Si-planes

Group of N.Zamiatin





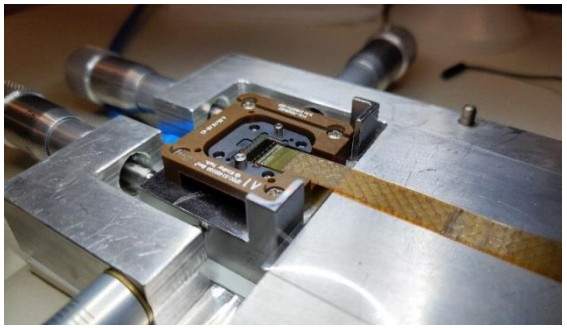


Half-plane design

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 middle 2021**

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



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

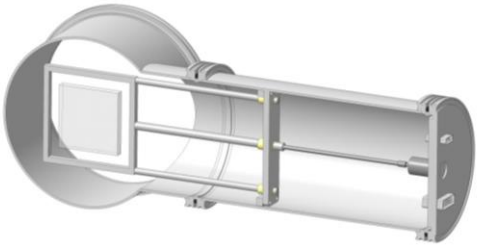
Assessment of STS risks:

- **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**

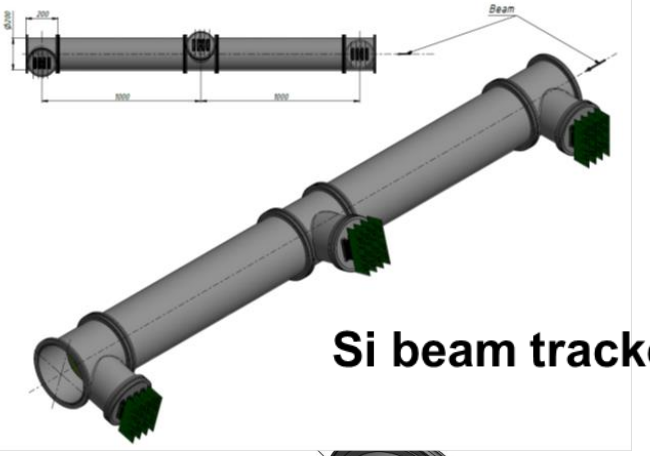
→ probable delay and long commissioning phase

Beam, Si tracking detectors and target station

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



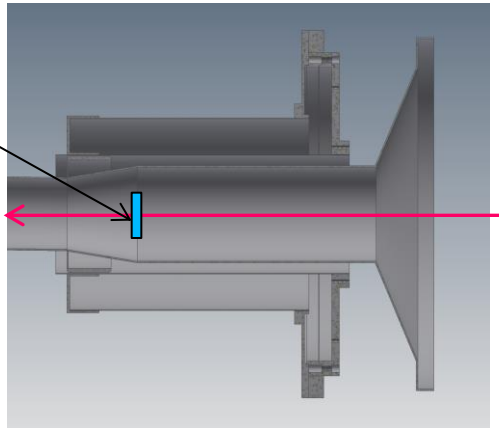
Movable beam profile detector



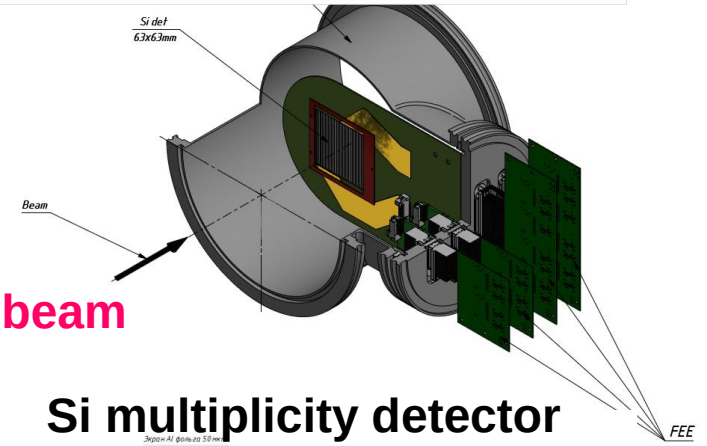
Si beam tracker

Target station with 3 targets in vacuum box

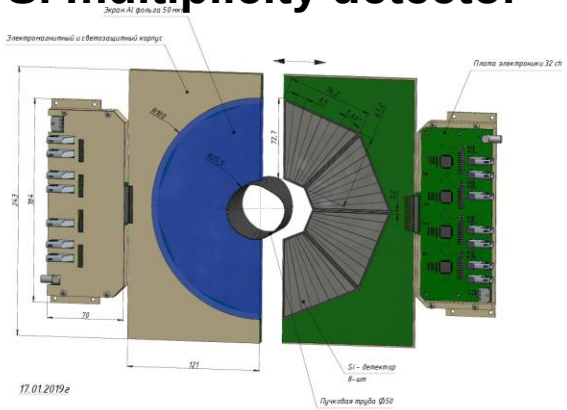
Barrel detector around target



beam



Si multiplicity detector

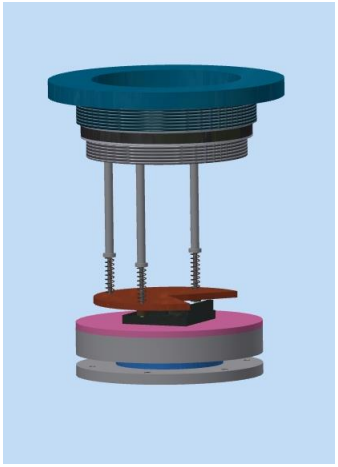


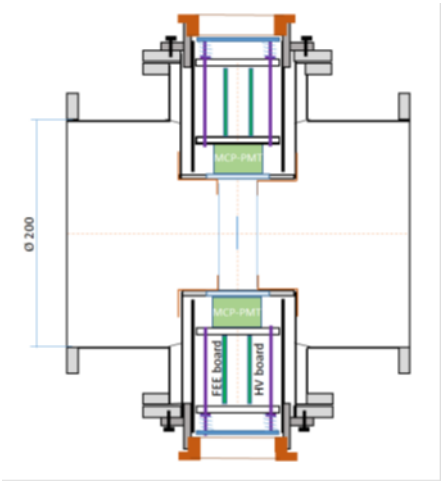
► All detectors and target station to be ready by middle 2021

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

Trigger and T0 detectors for heavy ions

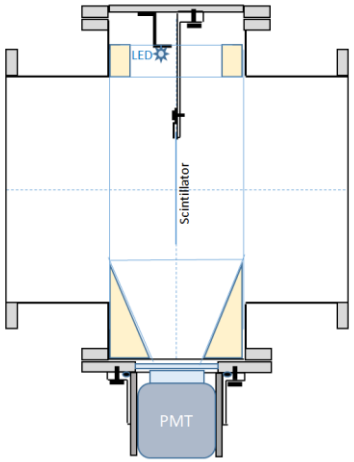
Box for BC2 counter



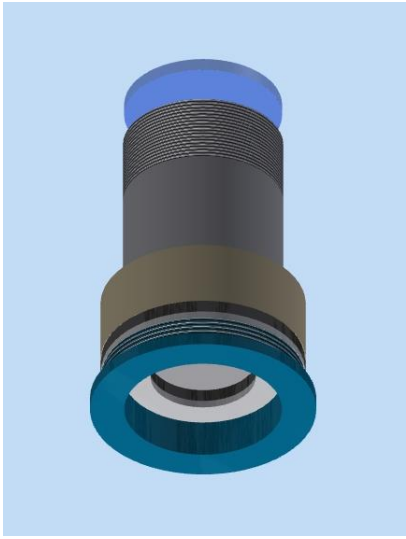


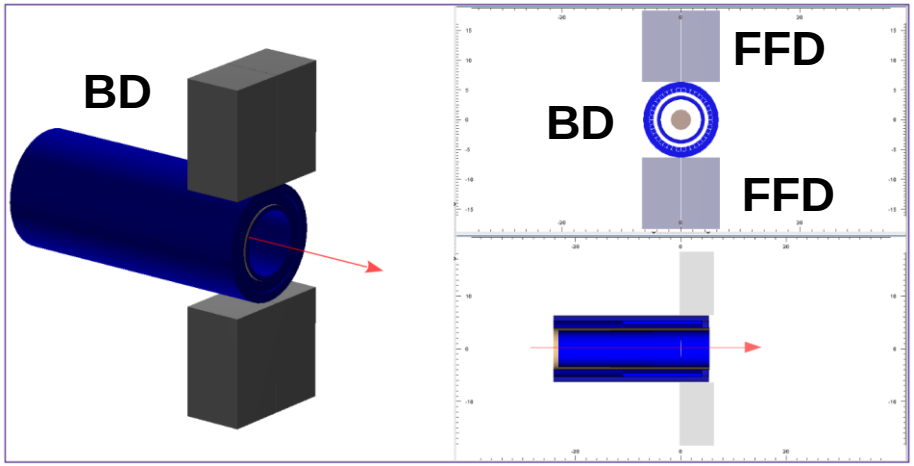
Box for BC1, Veto

beam



Trigger group



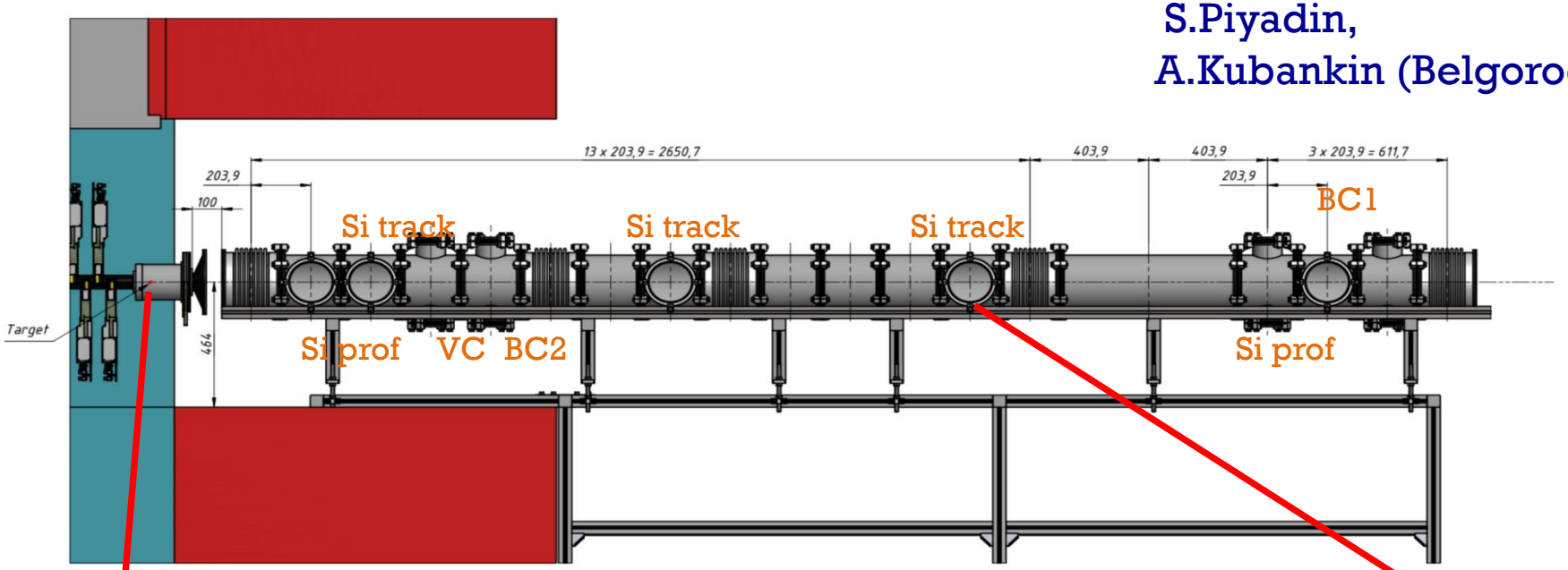


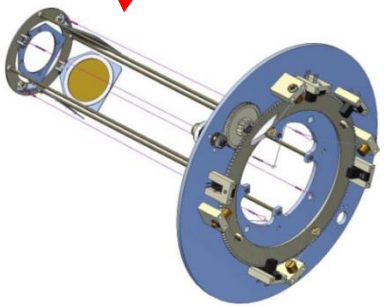
Fast quartz FFD detectors for high intensity heavy ions

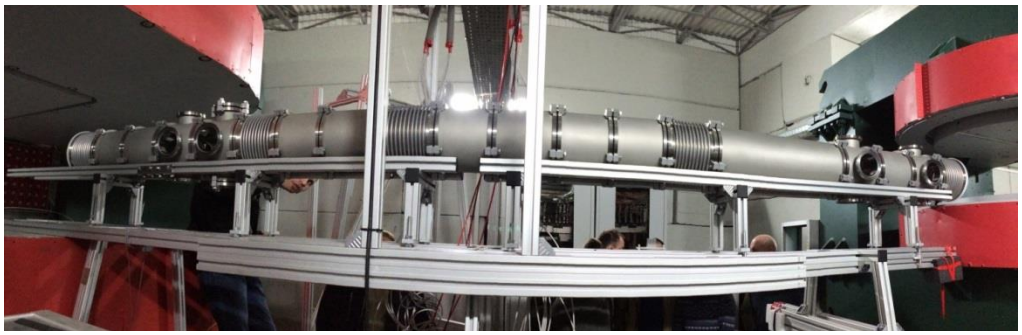
- **T0 and beam scintillator film counters for heavy ion beam intensities $< 10^6$ Hz**
- **FFD T0 detectors and Si beam detectors for higher intensities**
- **Detector performance and efficiency in heavy ion beam should be tested in first run**

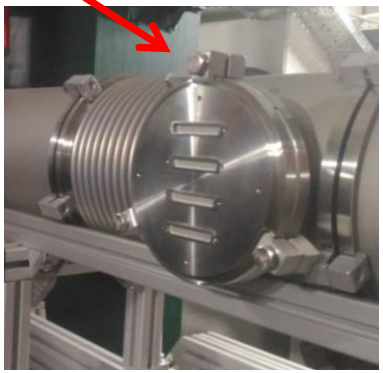
Beam pipe in front of the target

S.Piyadin,
A.Kubankin (Belgorod)









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

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 → spring 2021

Beam, Si tracking detectors and target station:

►All detectors and target station to be ready in spring 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 end of 2020

►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 middle 2021

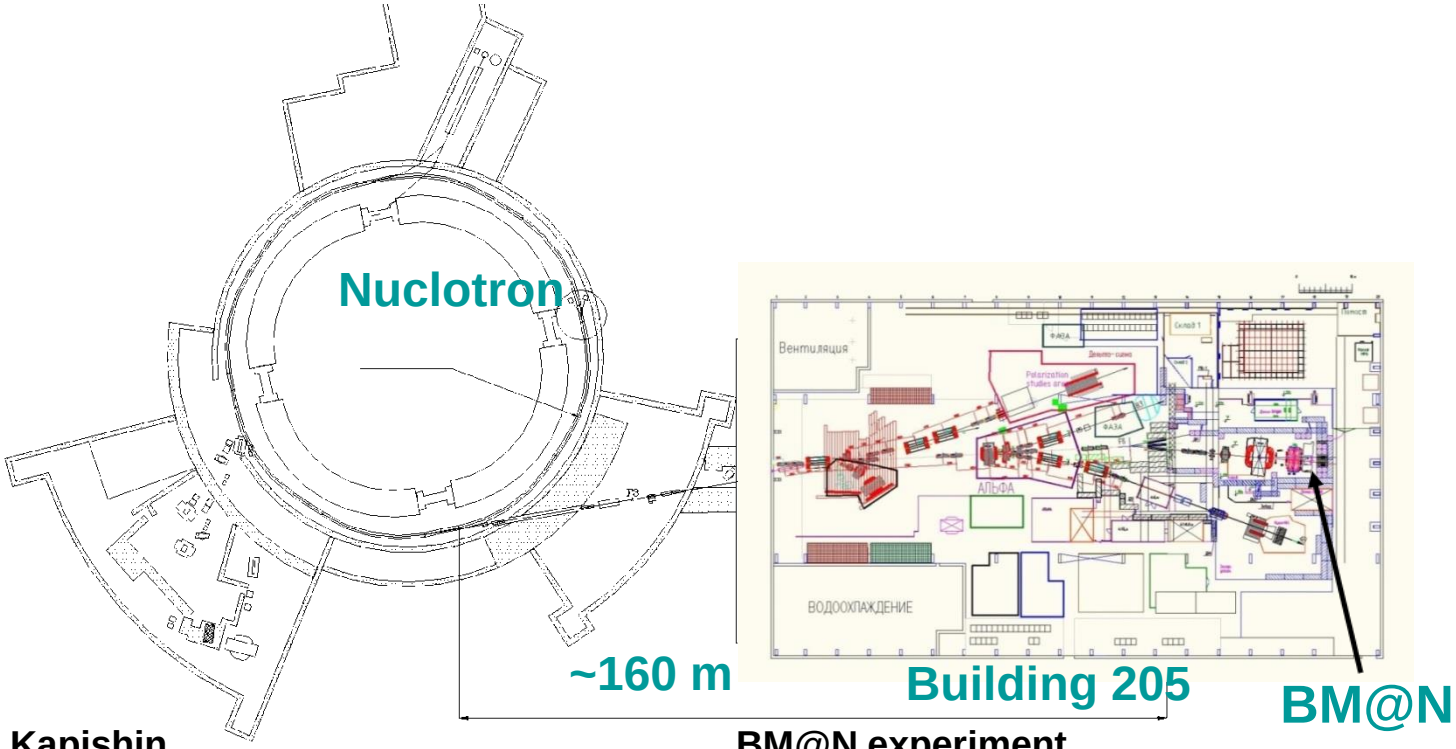
Beam pipe in front of target:

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

Nuclotron - BM@N beam line

► **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 furher delay**
- **Risk of wider beam profile and halo at BM@N**



Thank you
for attention!

BM@N present status and next plans

- First BM@N results on measurement of Short Range Nucleon Correlations and Quasi-Elastic Single Proton Knockout
- TDR report on the large aperture Silicon Tracking System of the BM@N experiment is released
- Progress in hardware development and production for heavy ion program:

►Full set of GEM detectors for the central tracker is delivered to BM@N

►Development of forward silicon detectors, silicon beam detectors is according to time plan

►Development of STS detectors, FEE and readout electronics

►Development and production of cathode strip chambers for the outer tracker

►Beam pipe in front of the target produced and delivered to BM@N

►Prototypes of carbon fiber beam pipe are under tests for vacuum and radiation resistance

►MPD / CBM type of hadron FHCAL calorimeter installed into BM@N setup

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

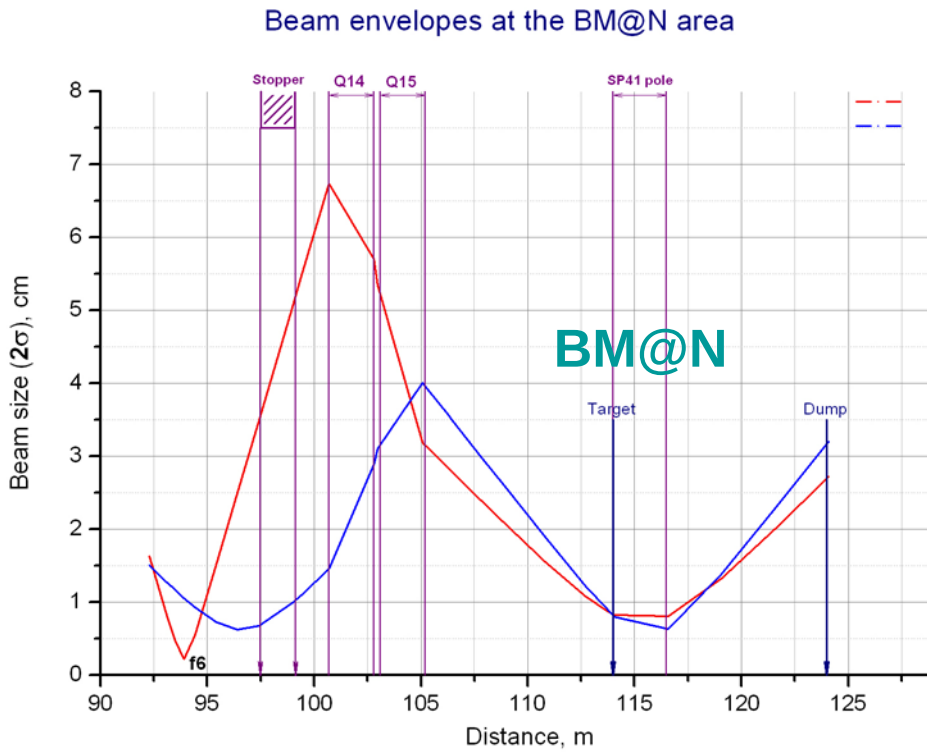
Year	2016	2017 spring	2018 spring	fall 2021	2022
Beam	d(↑)	C	Ar,Kr, C(SRC)	Kr,Xe	up to Au
Max.intensity, Hz	0.5M	0.5M	0.5M	0.5M	0.5M
Trigger rate, Hz	5k	5k	10k	10k	10k
Central tracker status	6 GEM half planes	6 GEM half planes	6 GEM half planes + 3 forward Si planes	7 GEM full planes + forward Si planes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

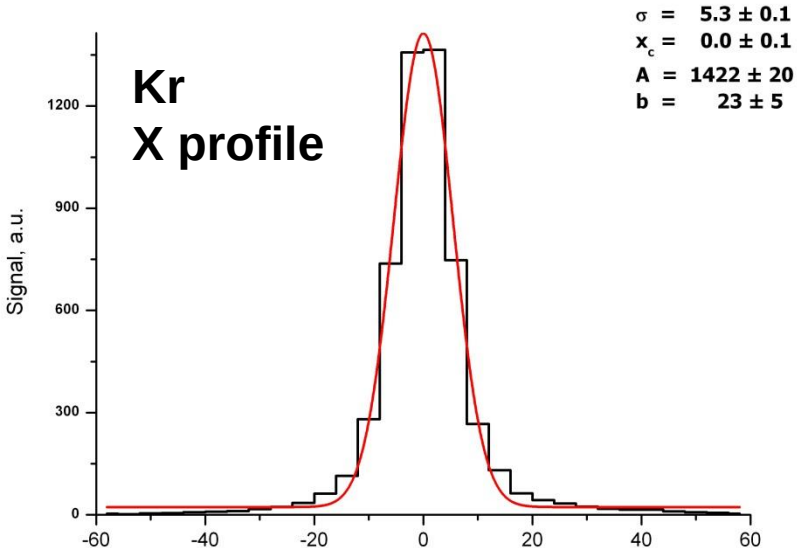
BM@N beam profile

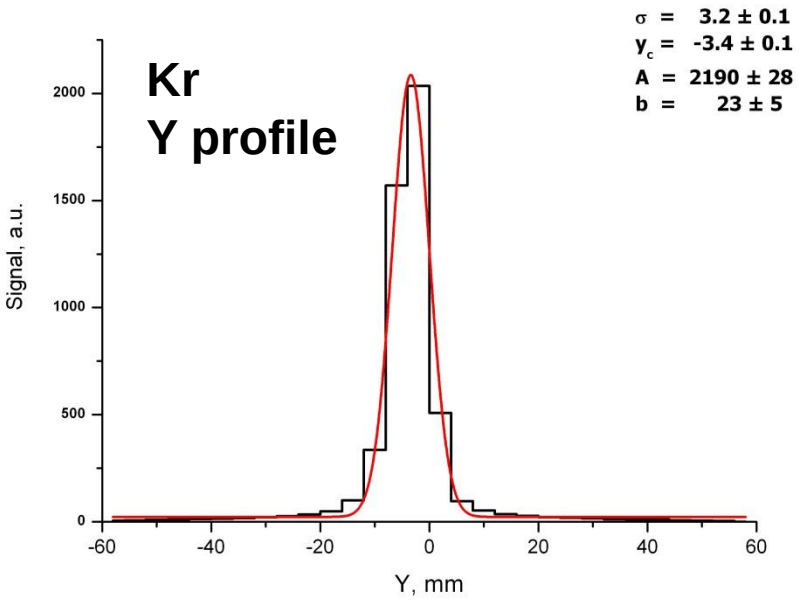
Pavel Rukoyatkin

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







Carbon fibre beam pipe for heavy ion runs

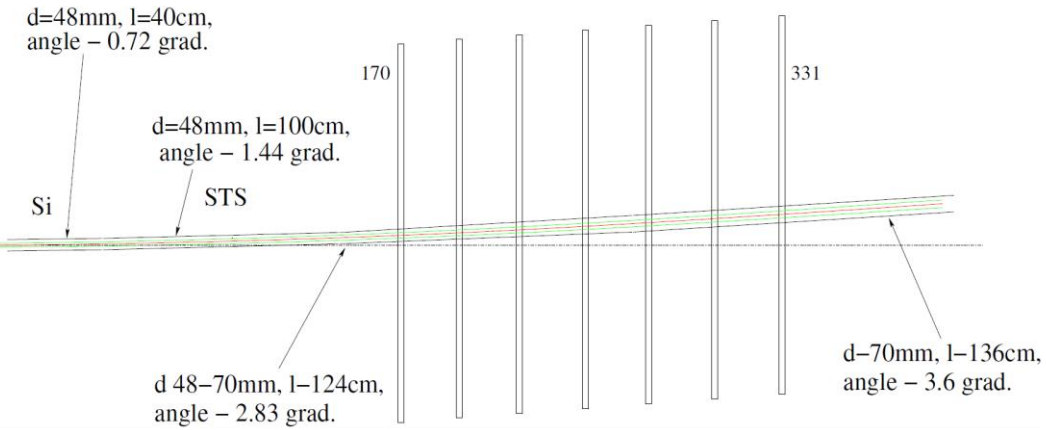
Status and plans:

• 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

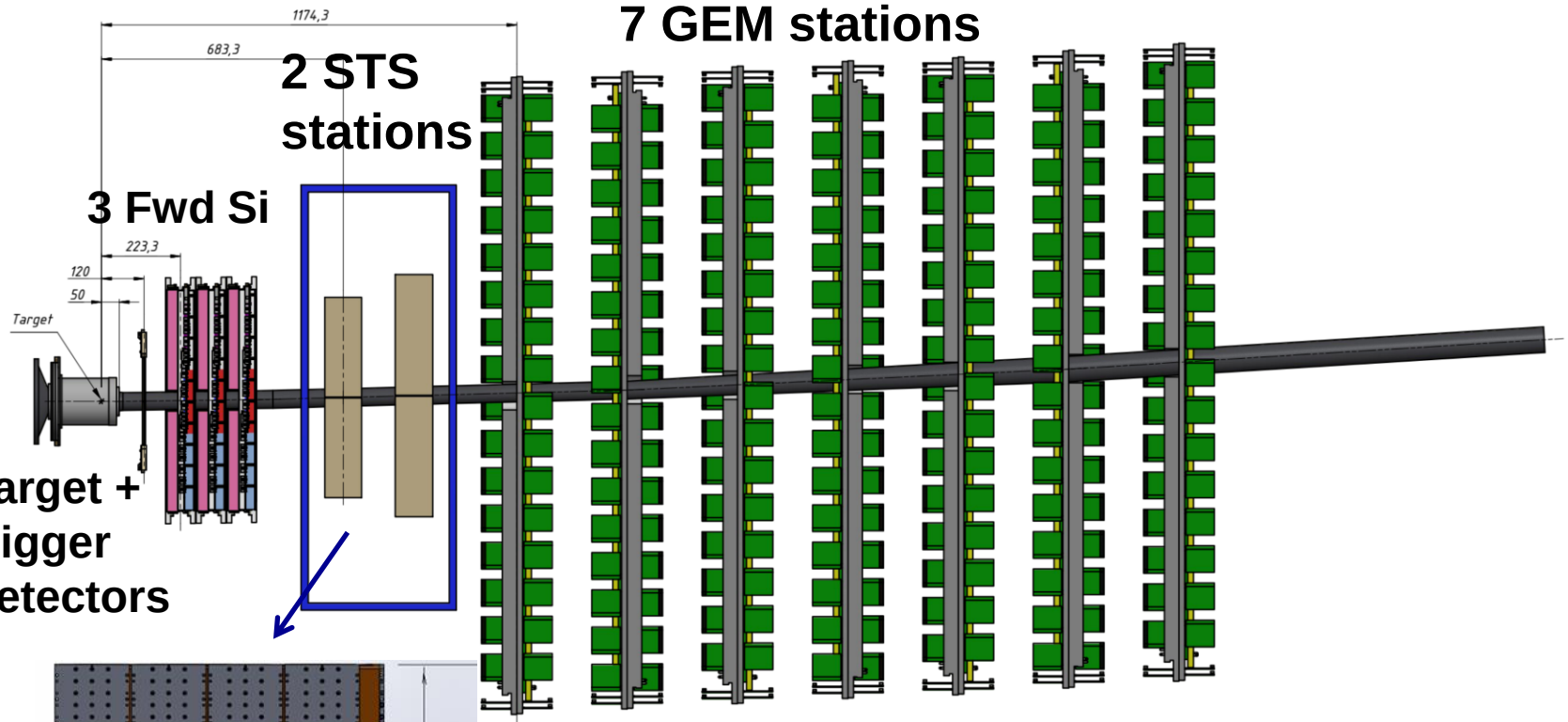
• Irradiation hardness tests performed by NPI CAS Rez group, need irradiation tests of tube connectors

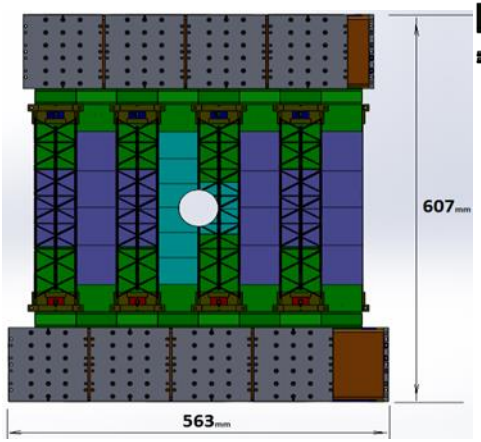


• Vacuum beam pipe should be produced and tested by middle of 2021

• Risk of vacuum leakage due to irradiation of tube connectors

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

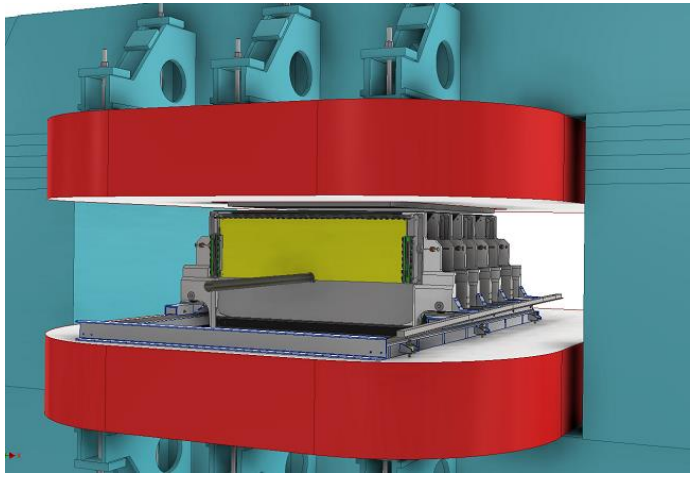


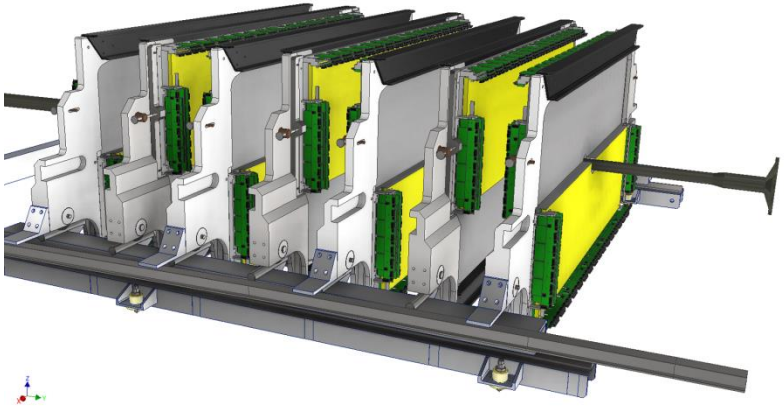


Heavy ion beam intensity ~few 10^5 Hz

GEM central tracker for heavy ion runs

GEM group

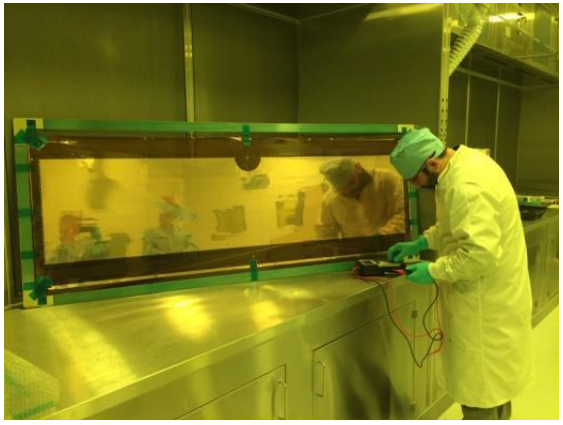




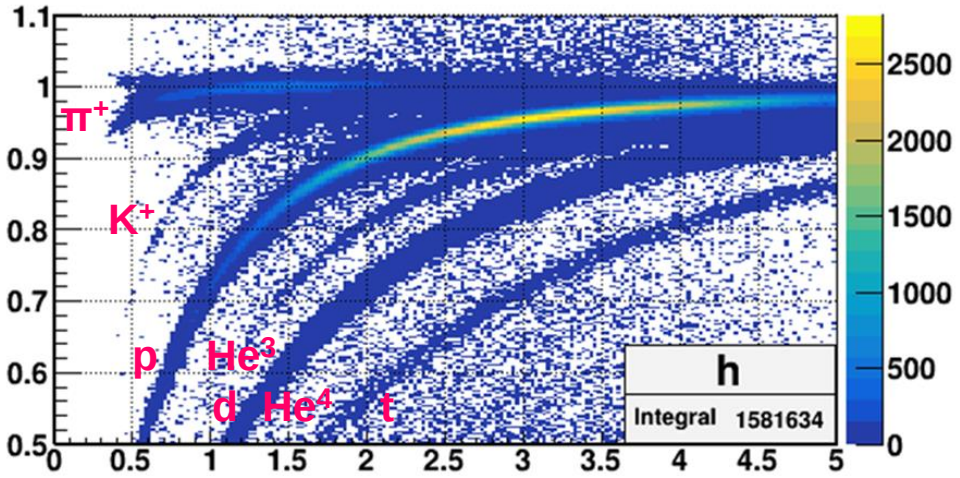
- 7 upper GEM 163x45 cm^2 chambers produced at CERN workshop were integrated into BM@N experimental setup
- 7 lower GEM 163x39 cm^2 chambers were assembled, delivered to BM@N and tested

Setup of GEM detectors for cosmic tests

GEM 163x39 cm^2 chamber assembly process at CERN

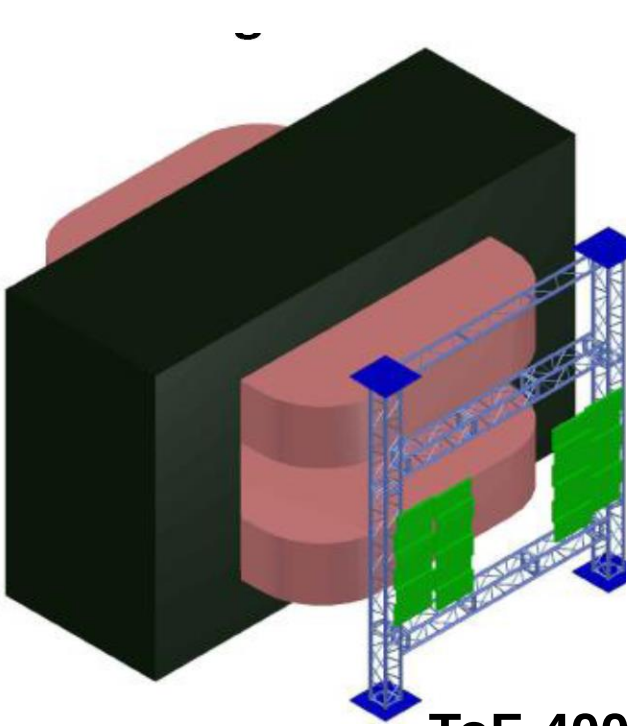


ToF-400 and ToF-700 based on mRPC



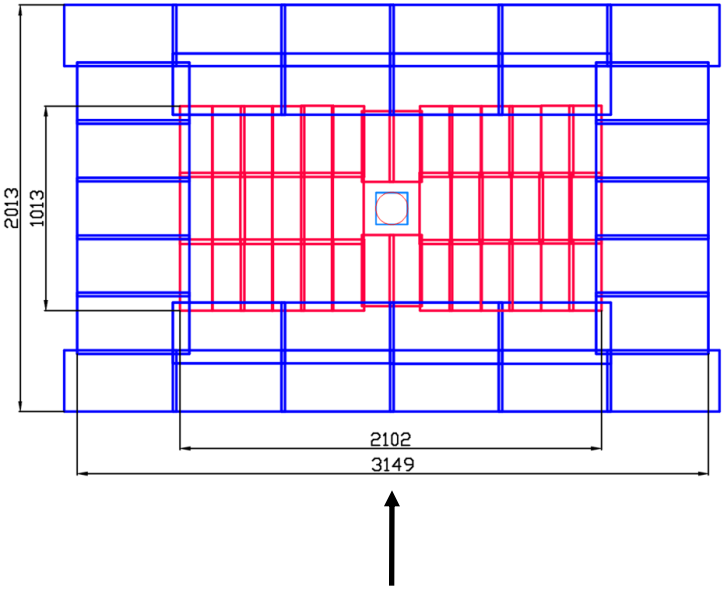
Detectors and readout electronics are ready

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



ToF-400 wall

ToF-700 wall



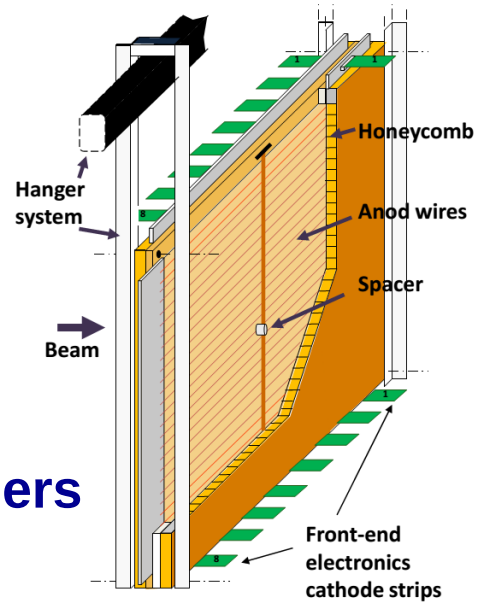
BM@N beam axis

CSC chambers for Outer tracker in heavy ion runs

A.Vishnevsky and team, LHEP JINR

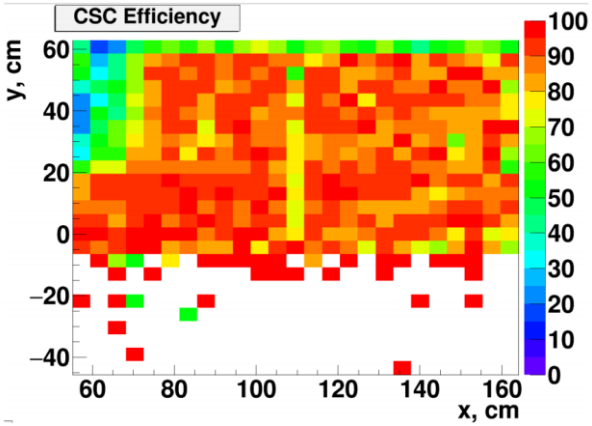
- Four 106x106 cm^2 CSC chambers to be installed in front and behind ToF-400 should be ready by end of 2020

- Two 219x145 cm^2 CSC chambers to be installed in front and behind ToF-700 should be produced in 2021

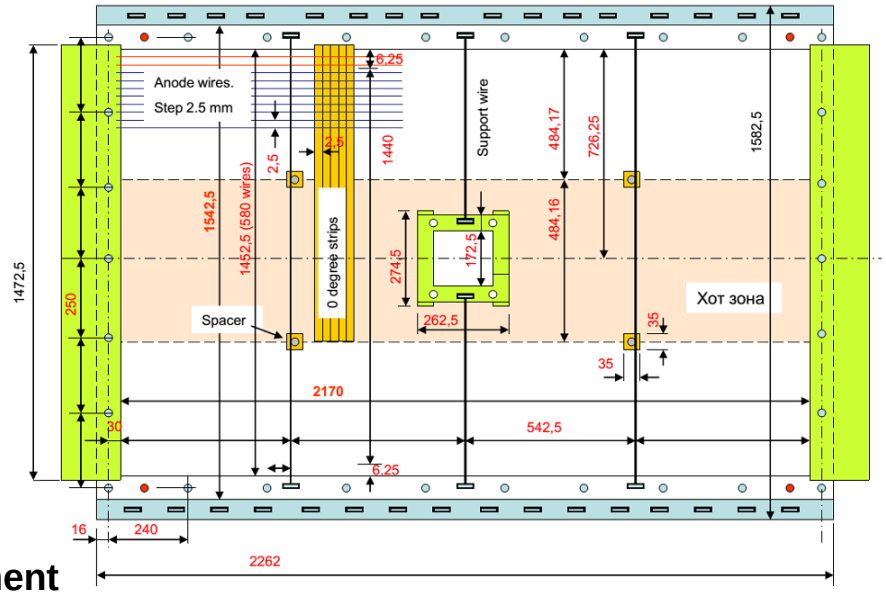


- **Risk of delay in production of big CSC chambers**

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

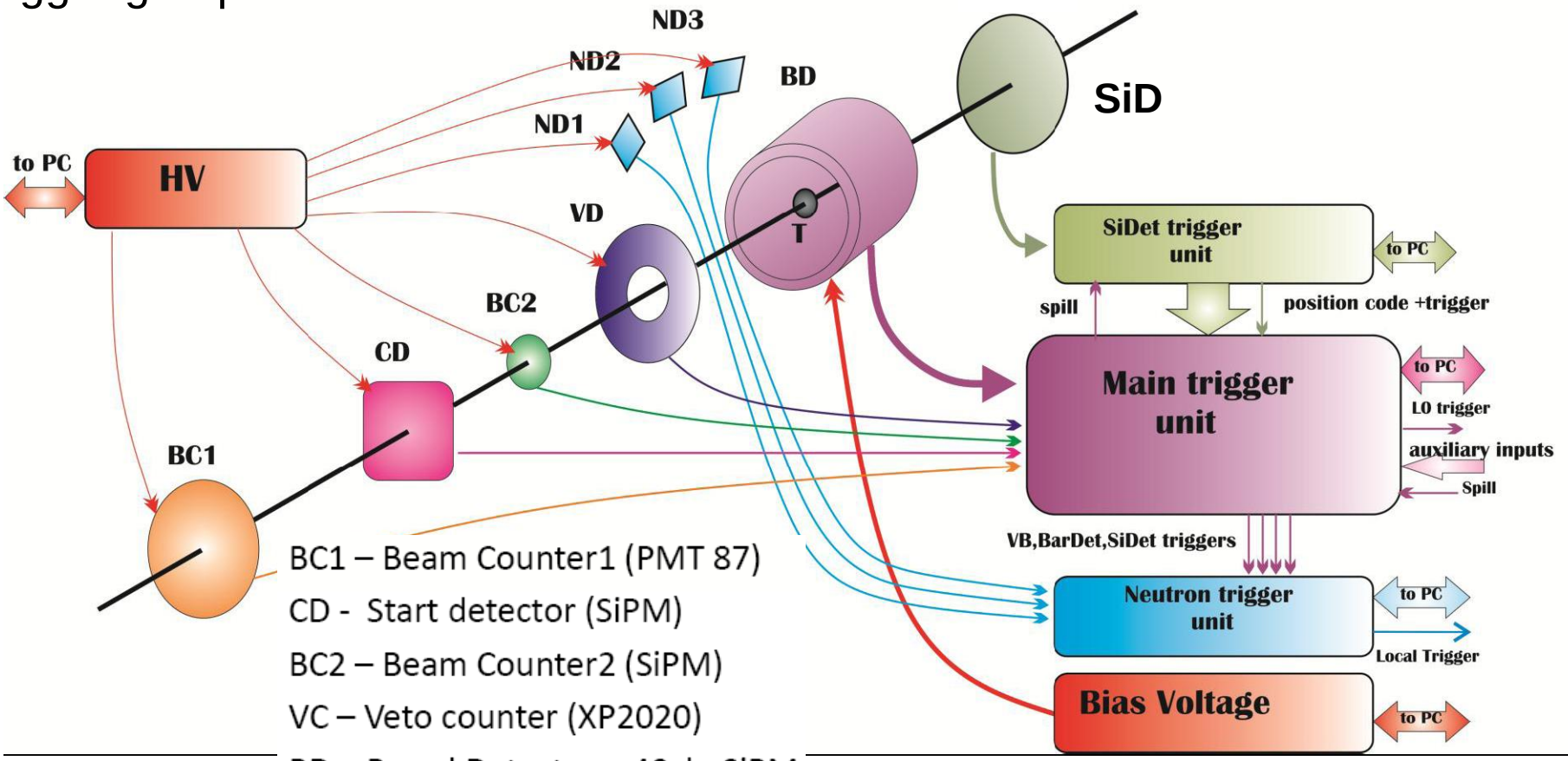


CSC efficiency in Ar run



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

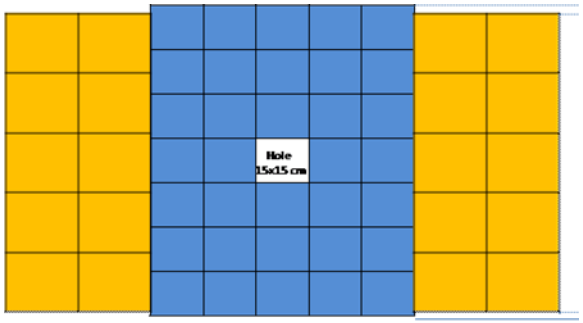
Selection of events with activity in barrel detector: BD ≥ 2, ≥ 3 or forward silicon multiplicity detector SiD (with beam hole)

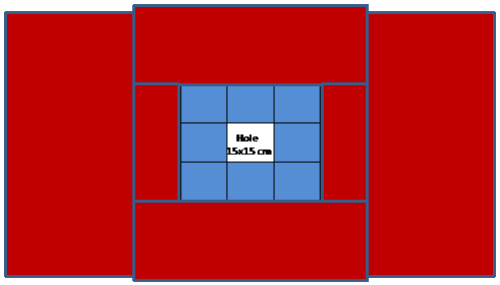
New FHCAL (ZDC) hadron calorimeter

Team of INR RAS, Troitsk

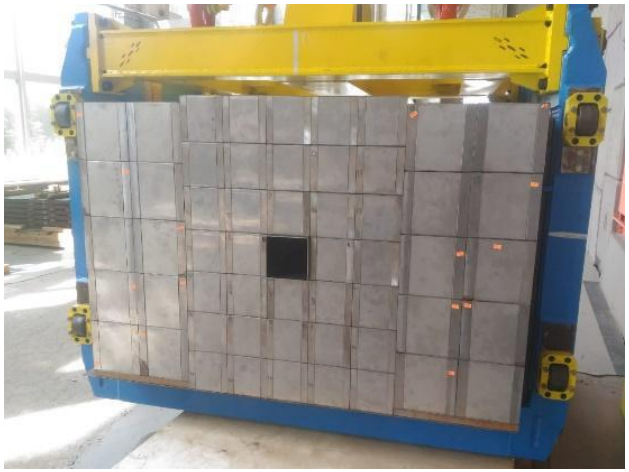
- **FHCAL assembled and installed into BM@N setup**
- **Cosmic tests are under way**

CBM modules MPD modules



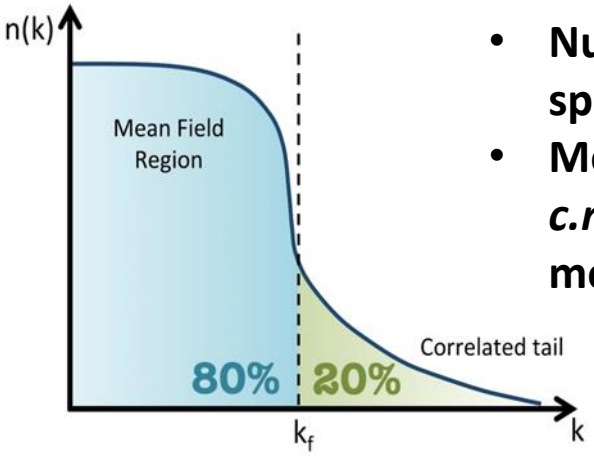


$$A_E = \frac{E_{dep}\,(blue) - E_{dep}\,(red)}{E_{dep}\,(blue) + E_{dep}\,(red)}$$



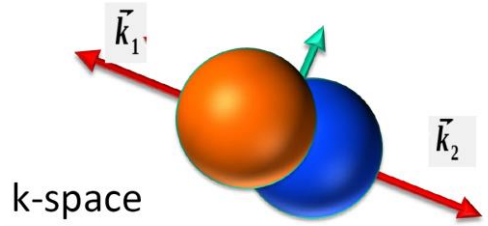
Measure E_{dep} v Asymmetry of E_{dep} and ΣZ^2 with quartz hodoscope in the beam hole to resolve central and peripheral interactions

Short Range Nucleon Correlations (SRC)



- **Nucleon pairs that are close together in space**
- **Momentum space: *high relative* and *low c.m. momentum,* compared to the Fermi momentum (kF)**

r-space



k-space

$k_1 > k_F \quad k_2 > k_F \quad k_1 \simeq k_2$

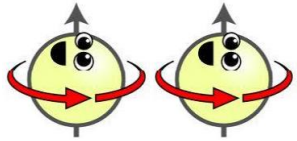
$k_F \approx 250$ MeV/c

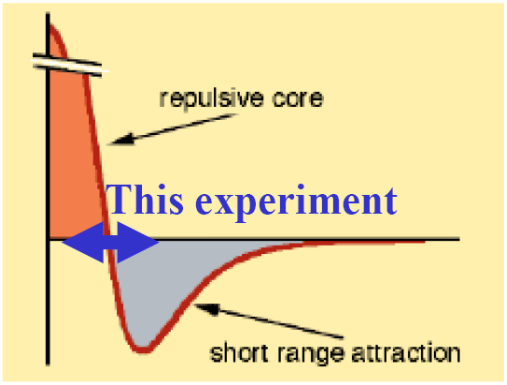
In nuclei the momentum distribution of nucleons can be divided into two distinct regions:

k<kF Mean field region / Single nucleons

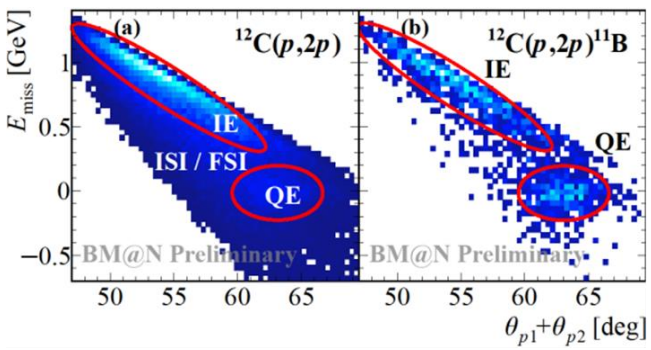
k>k_F Correlated / high momentum region / SRC pairs

np-SRC dominance (tensor force)

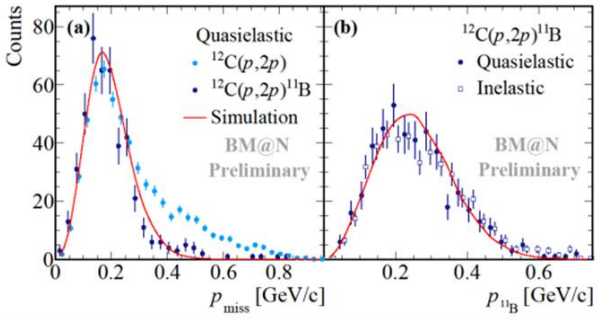


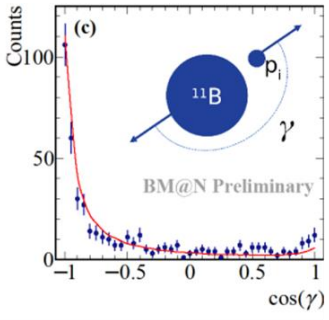


First BM@N results on Single Proton Knockout and SRC



First observation of Final State Interaction suppression and single-step nucleon knockout selection using fragment detection in quasi-elastic reaction **$^{12}C + p \rightarrow 2p + {}^{11}B$**





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

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

26 ^{10}B events

3 ^{10}Be events → *np* pair dominance