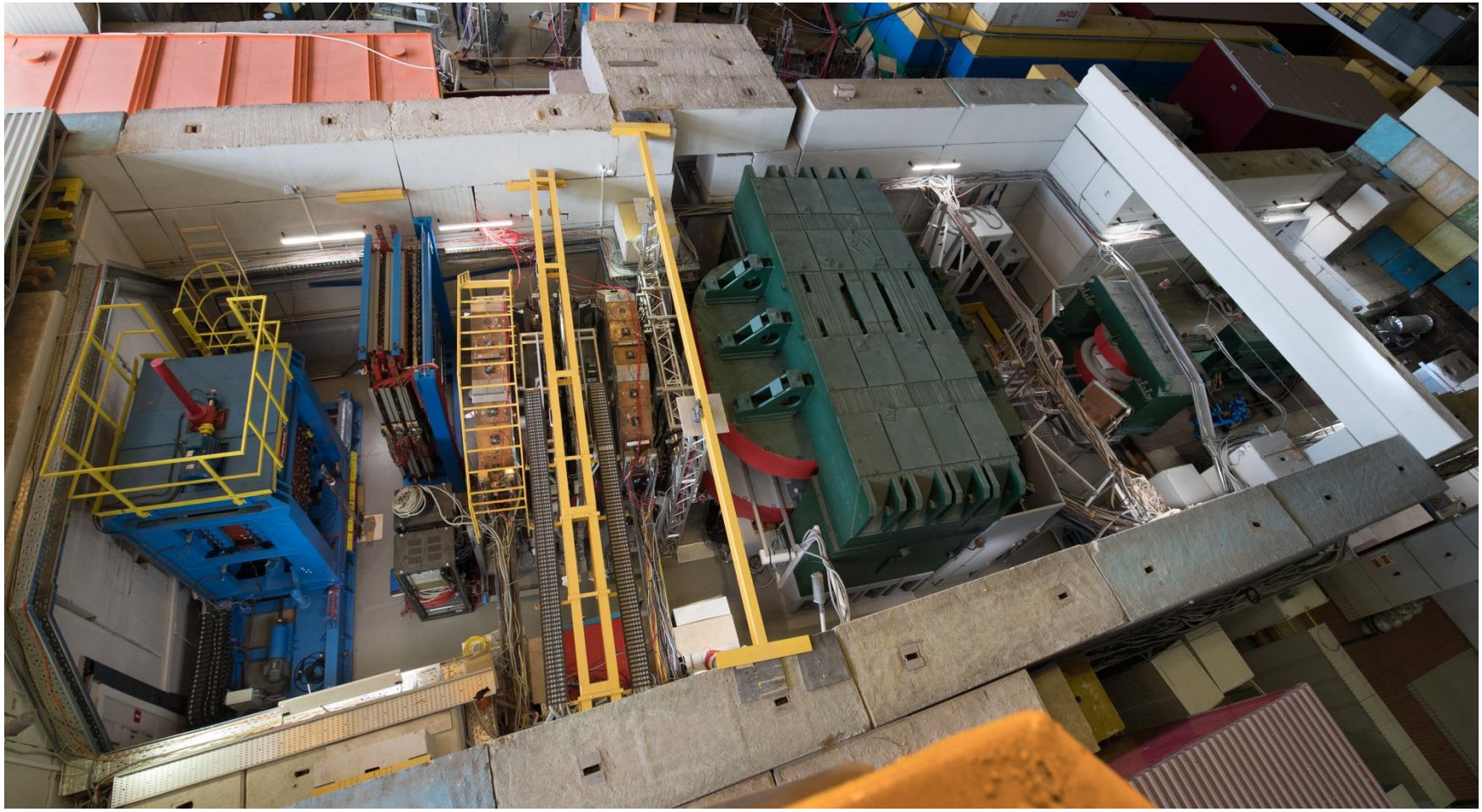
Status of the BM@N experiment
(Project prolongated at JINR for 2022-23)

M.Kapishin



Baryonic Matter at Nuclotron (BM@N) Collaboration:

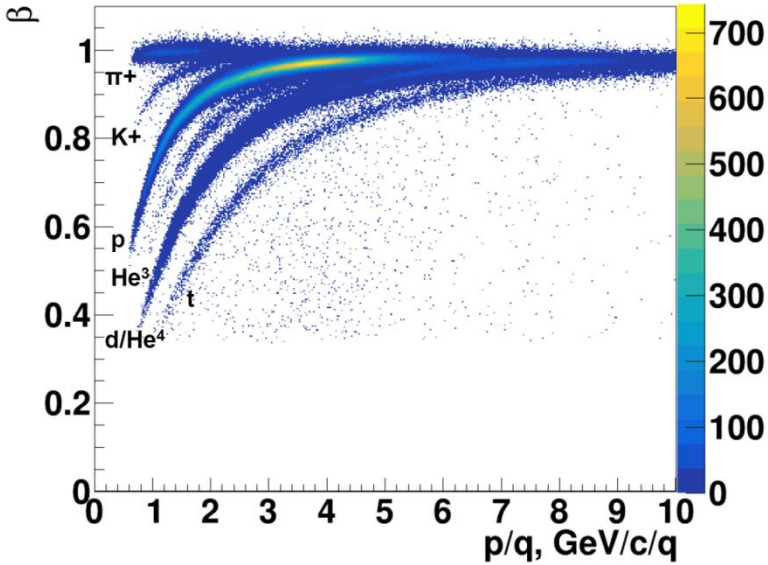
10 Countries, 19 Institutions, 234 participants, 11 Institutions signed MoU + JINR

- ***University of Plovdiv, Bulgaria → MoU signed;***
- ***St.Petersburg University → MoU signed;***
- ***Shanghai Institute of Nuclear and Applied Physics, CFS, China;***
- ***Nuclear Physics Institute CAS, Czech Republic→ MoU signed;***
- ***CEA, Saclay, France;***
- ***TU Darmstadt, Germany;***
- ***GSI & FAIR, Germany;***
- ***Tubingen University, Germany → MoU signed;***
- ***Tel Aviv University, Israel;***
- ***Joint Institute for Nuclear Research;***
- ***Warsaw University of Technology, Poland→ MoU 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 → MoU signed;***
- ***Moscow Engineer and Physics Institute, Russia → MoU signed;***
- ***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 talks at conferences in 2021:

- **P.Senger, International conference on Critical Point and Onset of De-confinement (CPOD 2021)**
- **D.Dementiev,19th International Conference on Strangeness in Quark Matter (SQM 2021)**
- **P.Senger + A.Maksymchuk + Al.Zinchenko 10th International Conference on New Frontiers in Physics (ICNFP 2021)**
- **P.Batyuk, 20th Lomonosov Conference on Elementary Particle Physics**

Ongoing analyses of Carbon / Ar runs



light fragments in SRC data

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

Yields of $\pi^{\pm}$, K^{+}, p, t, He^3, d/He^4 in *argon - nucleus* interactions (combination of ToF-400 and ToF-700)
Several parallel analyses:
V.Plotnikov: π+, K+ in ToF-400 data
K.Alishina (PhD student): p, t, He^3, d/He^4 in ToF-400 data

L.Kovachev, Yu.Petukhov: p, t, He^3, d/He^4 in ToF-700 data
A.Huhaeva (student): π±, K+ in ToF-700 data

K.Mashitsin (student), S.Merts: π± in ToF-400 and ToF-700 data (independent tracking)

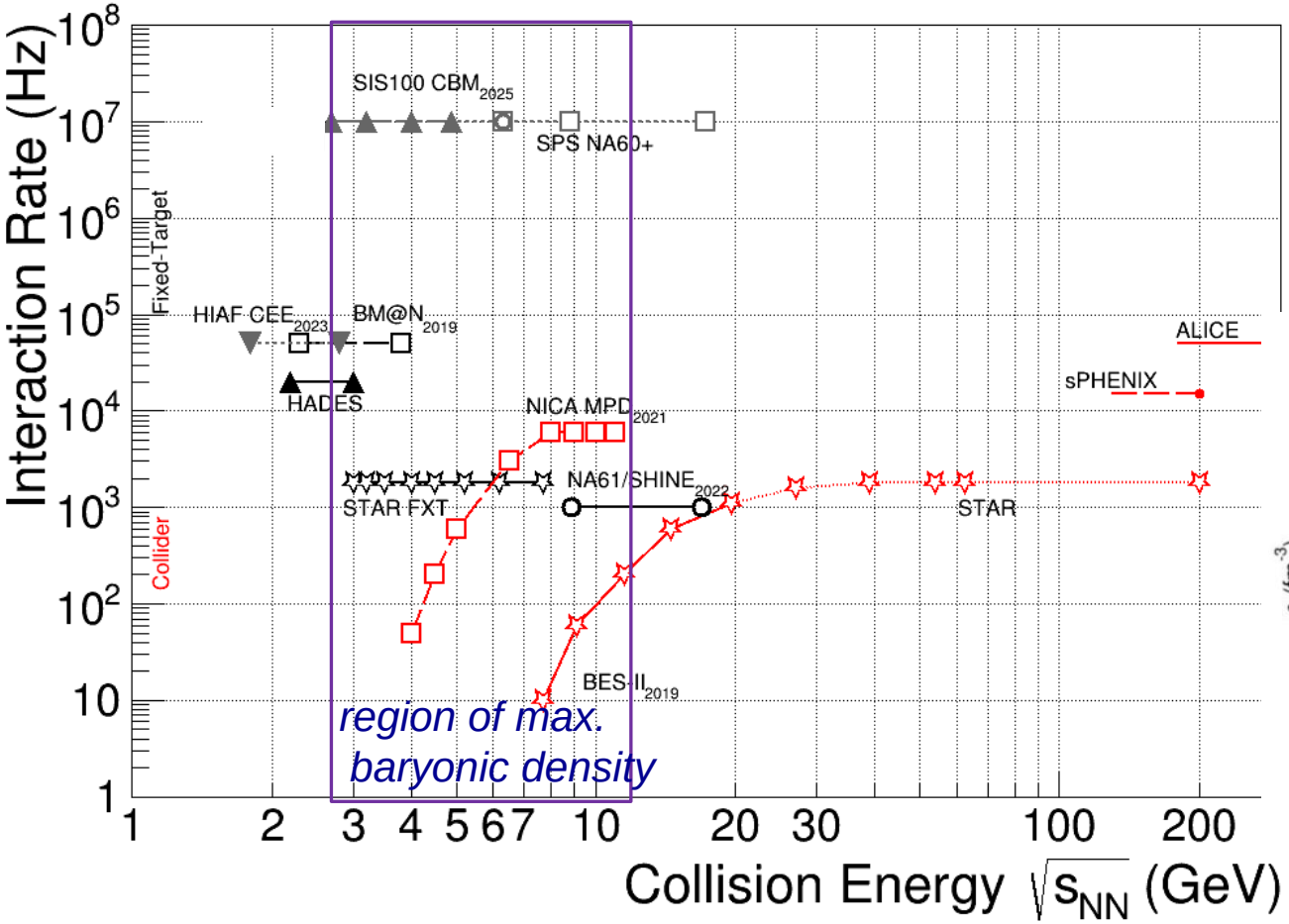
P.Batyuk: Yields of Λ hyperons in *argon - nucleus* interactions

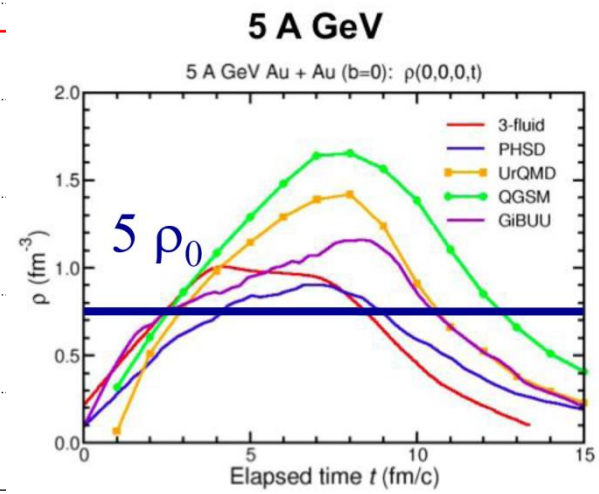
Yu.Stepanenko: Yields of Λ hyperons in *carbon - nucleus* interactions at 4.0, 4.5 AGeV, C+ C,Al,Cu → Λ + X

A.Druck (PhD student), S.Merts: Light fragments in C+p data at 3.14 AGeV/c (SRC run)

Setbacks: Neither of analyses is on the level of the physics result
No mini DST are available → every time run over all the events, a long analysis procedure

Heavy Ion Collision Experiments





BM@N: $\sqrt{s_{NN}}$= 2.3 - 3.3 GeV
MPD: $\sqrt{s_{NN}}$= 4 - 11 GeV

BM@N competitors:

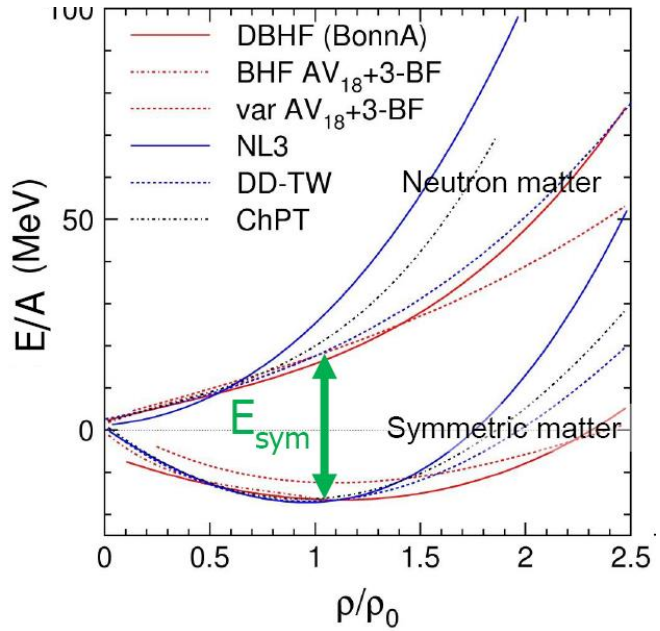
HADES BES (SIS): Au+Au at $\sqrt{s_{NN}}$ = 2.42 GeV, Ag+Ag at $\sqrt{s_{NN}}$ = 2.42 GeV, 2.55 GeV.

STAR BES (RHIC): Au+Au at $\sqrt{s_{NN}}$ = 3-200 GeV

Future CBM experiment: Au+Au at $\sqrt{s_{NN}}$~ 2.7 – 4.9 GeV

EOS of symmetric and asymmetric nuclear matter

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



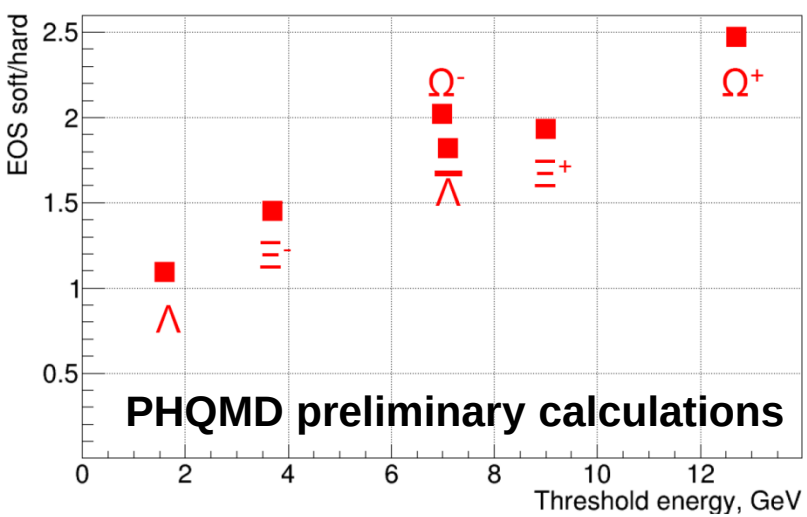
EOS: relation between density, pressure, temperature, energy and isospin asymmetry

$$E_A(\rho,\delta) = E_A(\rho,0)+E_{sym}(\rho)\cdot\delta^2$$

with $\delta = (\rho_n - \rho_p)/\rho$ $\quad E/A(\rho_o) = -16$ MeV

Curvature defined by nuclear incompressibility: $K = 9\rho^2\ \delta^2(E/A)/\delta\rho^2$

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



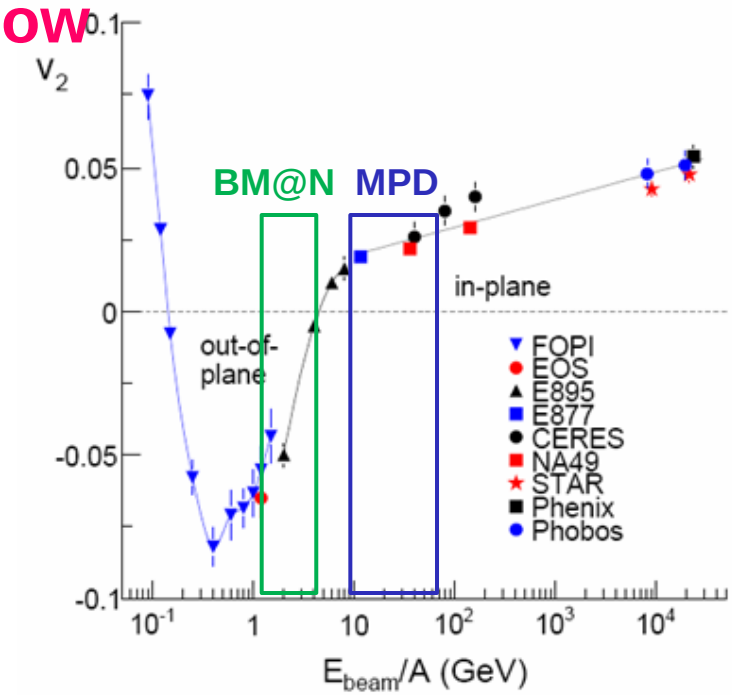
►Study symmetric matter EOS at ρ=3-5 ρ_0
→ elliptic flow of protons, mesons and hyperons
→ sub-threshold production of strange mesons and hyperons
→ extract K from data to model predictions
►Constrain symmetry energy E_{sym}
→ elliptic flow of neutrons vs protons
→ sub-threshold production of particles with opposite isospin

Study of EoS: Collective flow of identified particles

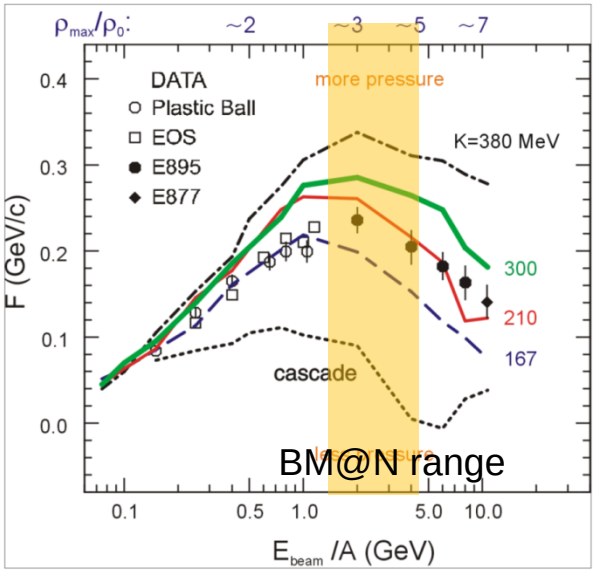
- collective flow of identified particles (π,K,p,Λ,Ξ,Ω,...) driven by the pressure gradient in the early fireball

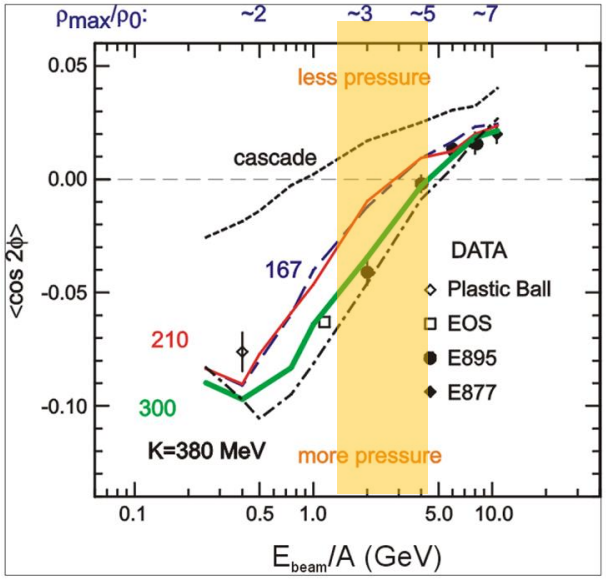
→ Nuclear incompressibility: $K = 9\rho^2\ \delta^2(E/A)/\delta\rho^2$

Azimuthal angle distribution:
$dN/d\varphi \propto (1 + 2v_1 \cos\varphi + 2v_2 \cos 2\varphi)$

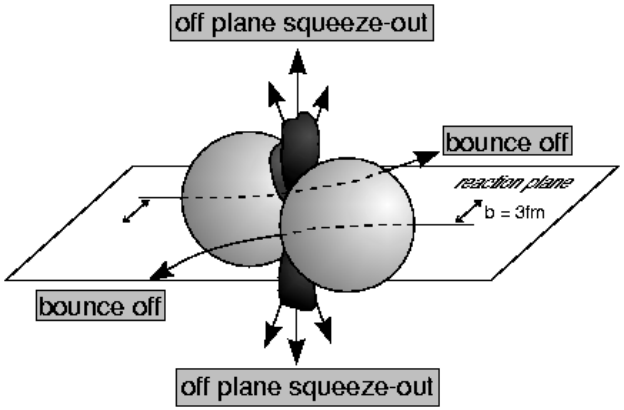


Proton flow in Au+Au collisions
in-plane flow ~ v_1 out-of-plane flow v_2





P. Danielewicz, R. Lacey, W.G. Lynch, Science 298 (2002) 1592



M.Kapishin

BM@N experiment

NICA main competitor → STAR experiment: BES Fixed Target program
Collected $2 \cdot 10^9$ interactions of Au+Au at $\sqrt{s}$ = 3 GeV in 2021

Plan for BM@N Experimental physics run for 800 hours (33 days) in spring 2022

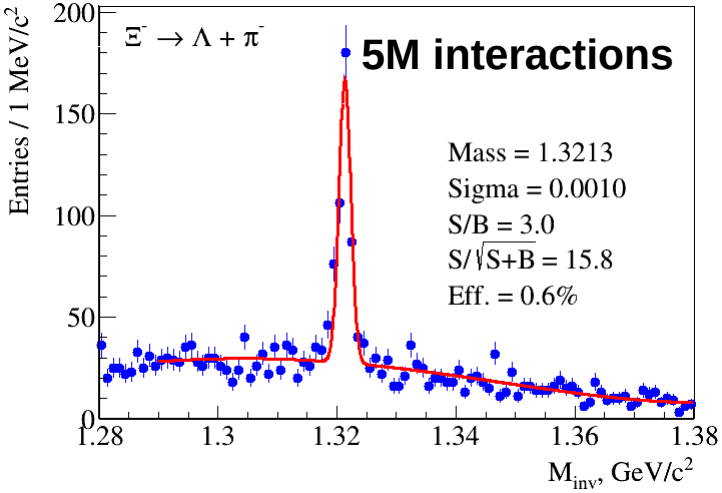
BM@N: Estimated hyperon yields in Xe + Cs collisions

4 A GeV Xe+Cs collisions, multiplicities from PHSD model,
Beam intensity $2.5 \cdot 10^5$/s, DAQ rate $2.5 \cdot 10^3$/s, accelerator duty factor 0.25

$1.8 \cdot 10^9$ interactions
$1.8 \cdot 10^{11}$ beam ions

Particle	E_{thr}NN GeV	M b<10 fm	ε %	Yield/s b<10fm	Yield / 800 hours b<10 fm
Λ	1.6	1.5	3	220	$0.8 \cdot 10^8$
Ξ^-	3.7	$2.3 \cdot 10^{-2}$	1	1.1	$4 \cdot 10^5$
Ω^-	6.9	$2.6 \cdot 10^{-5}$	1	$1.3 \cdot 10^{-3}$	470
Anti-Λ	7.1	$1.5 \cdot 10^{-5}$	3	$2.2 \cdot 10^{-3}$	800

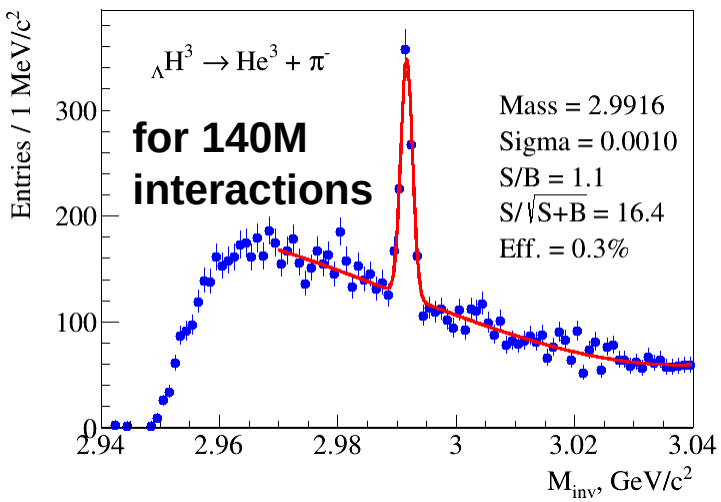
Feasibility studies for first physics run: Ξ^- and $_\Lambda H^3$ reconstruction in Xe +A interactions: 3 Forward Si + GEM

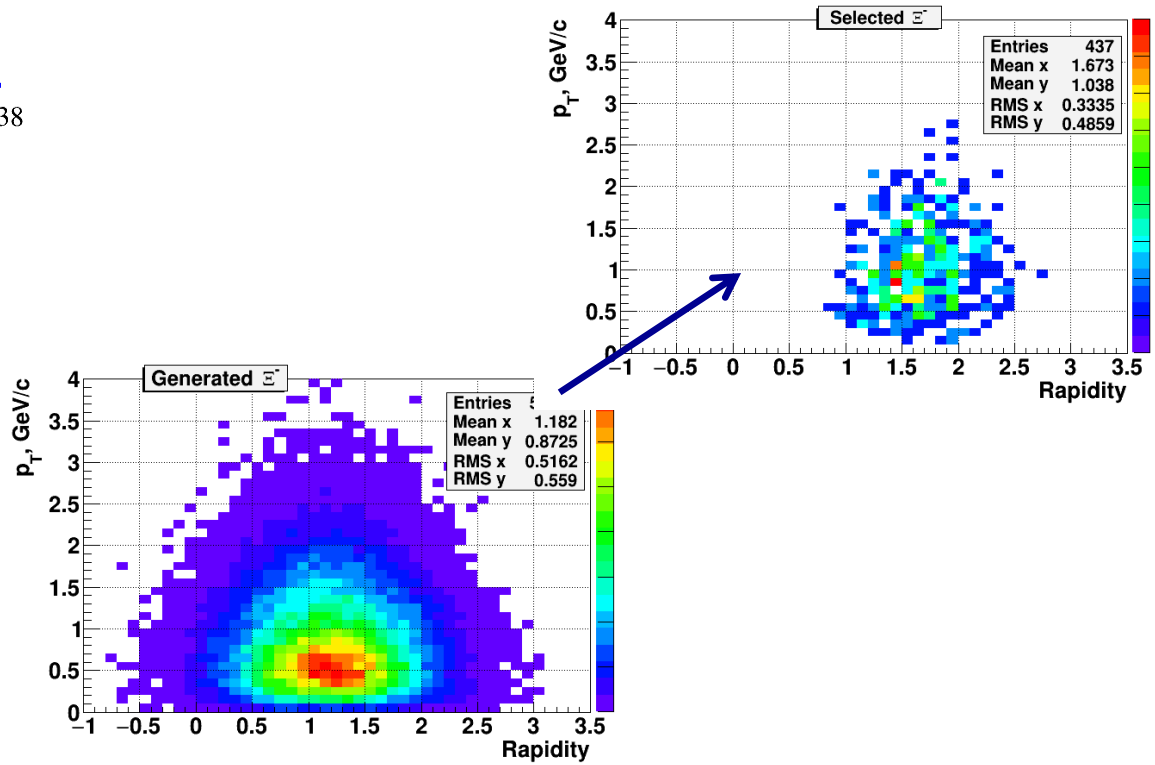


DCM-SMM model: Xe + Sn , T_0= 3.9 AGeV

Talk of A.Zinchenko, Feasibility studies for heavy ion collisions

phase space of reconstructed Ξ^-





Plan for BM@N experimental physics run with Au (Bi) beam for 800 hours (33 days) in spring 2023

BM@N: Estimated hyperon yields in Au+Au collisions

4 A GeV min. bias Au+Au collisions, multiplicities from statistical model,
Beam intensity $2.5 \cdot 10^5$/s , DAQ rate $2.5 \cdot 10^3$/s, accelerator duty factor 0.25

Experimental run for 800 hours (33 days)

$1.8 \cdot 10^9$ interactions
$1.8 \cdot 10^{11}$ beam ions

Particle	E_{thr}NN GeV	M central	M m.bias	ε %	Yield/s m. Bias	Yield / 800 hours m. Bias
Ξ^-	3.7	$1 \cdot 10^{-1}$	$2.5 \cdot 10^{-2}$	1	2.5	$4.5 \cdot 10^5$
Ω^-	6.9	$2 \cdot 10^{-3}$	$5 \cdot 10^{-4}$	1	$5 \cdot 10^{-2}$	$0.9 \cdot 10^4$
Anti-Λ	7.1	$2 \cdot 10^{-4}$	$5 \cdot 10^{-5}$	3	$1.5 \cdot 10^{-2}$	2700
Ξ^+	9.0	$6 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$	1	$1.5 \cdot 10^{-3}$	270
Ω^+	12.7	$1 \cdot 10^{-5}$	$2.5 \cdot 10^{-6}$	1	$2.5 \cdot 10^{-4}$	45
					${}_{\Lambda}^{3}H$	$0.9 \cdot 10^5$

Comparison HADES, STAR FxT, BM@N

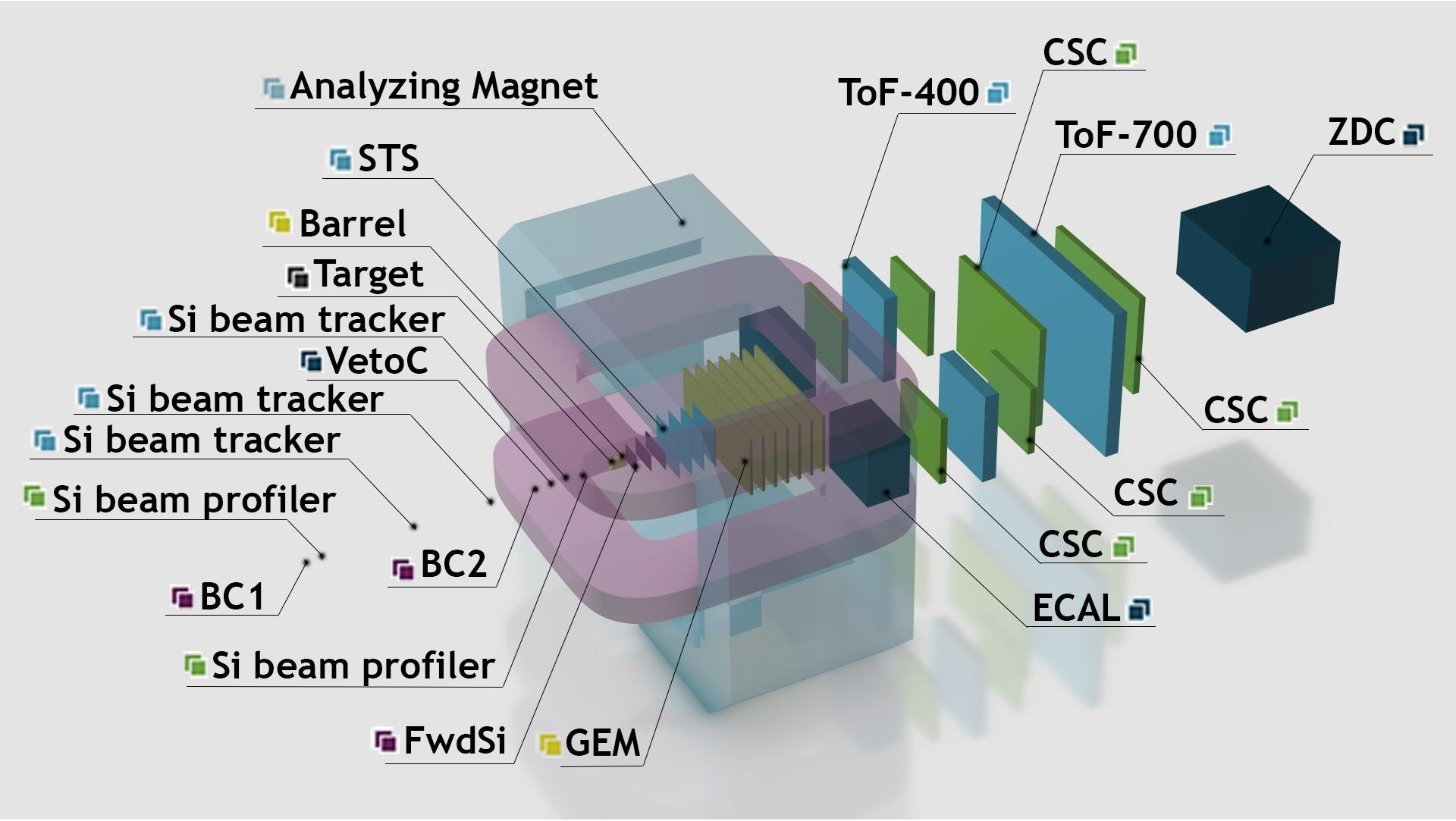
	year	A+A	E_{kin} A GeV	# Events	Rare Observables		
					e^+e^-	Ξ^-, Ω^-	hypernuclei
HADES	2012	Au+Au	1.23	$7\cdot10^9$	✓	---	---
HADES	2019	Ag+Ag	1.58	$1.4\cdot10^{10}$	✓	---	800 ${}^3_\Lambda H$
STAR FxT	2018	Au+Au	2.9	$3\cdot10^8$	---	10^4 Ξ^-	10^4 ${}^3_\Lambda H$, $6\cdot10^3$ ${}^4_\Lambda H$,
STAR FxT	2021 planned	Au+Au	2.9	$2\cdot10^9$	---	$7\cdot10^4$ Ξ^-, Ω^- ?	$7\cdot10^4$ ${}^3_\Lambda H$, $4\cdot10^4$ ${}^4_\Lambda H$, ${}^5_\Lambda He$, ${}^7_\Lambda Li$, ${}^7_\Lambda He$, ?
BM@N	simulated	Au+Au	3.8	$2\cdot10^{10}$ in 3 months	---	$5\cdot10^6$ Ξ^- Expected: 10^5 Ω^- $3\cdot10^4$ anti-Λ $5\cdot10^2$ Ω^+	10^6 ${}^3_\Lambda H$, ${}^4_\Lambda H$, ${}^5_\Lambda He$, ${}^7_\Lambda Li$, ${}^7_\Lambda He$, Expected: 10^2 ${}^5_{\Lambda\Lambda}H$

Reaction rates: HADES ≈ 20 kHz, BM@N ≈ 20 kHz, STAR FxT ≈ 2 kHz
Energy Au beams: HADES: 0.2 - 1.25 A GeV, BM@N: 1.5 – 3.8 A GeV, STAR FxT: > 2.9 A GeV

<u>Conclusion:</u>

HADES and BM@N are complementary , no cascade hyperons (Ξ^-,Ω^-) at HADES
Statistics at BM@N ≈70 times higher (Ξ^-) than at STAR FxT

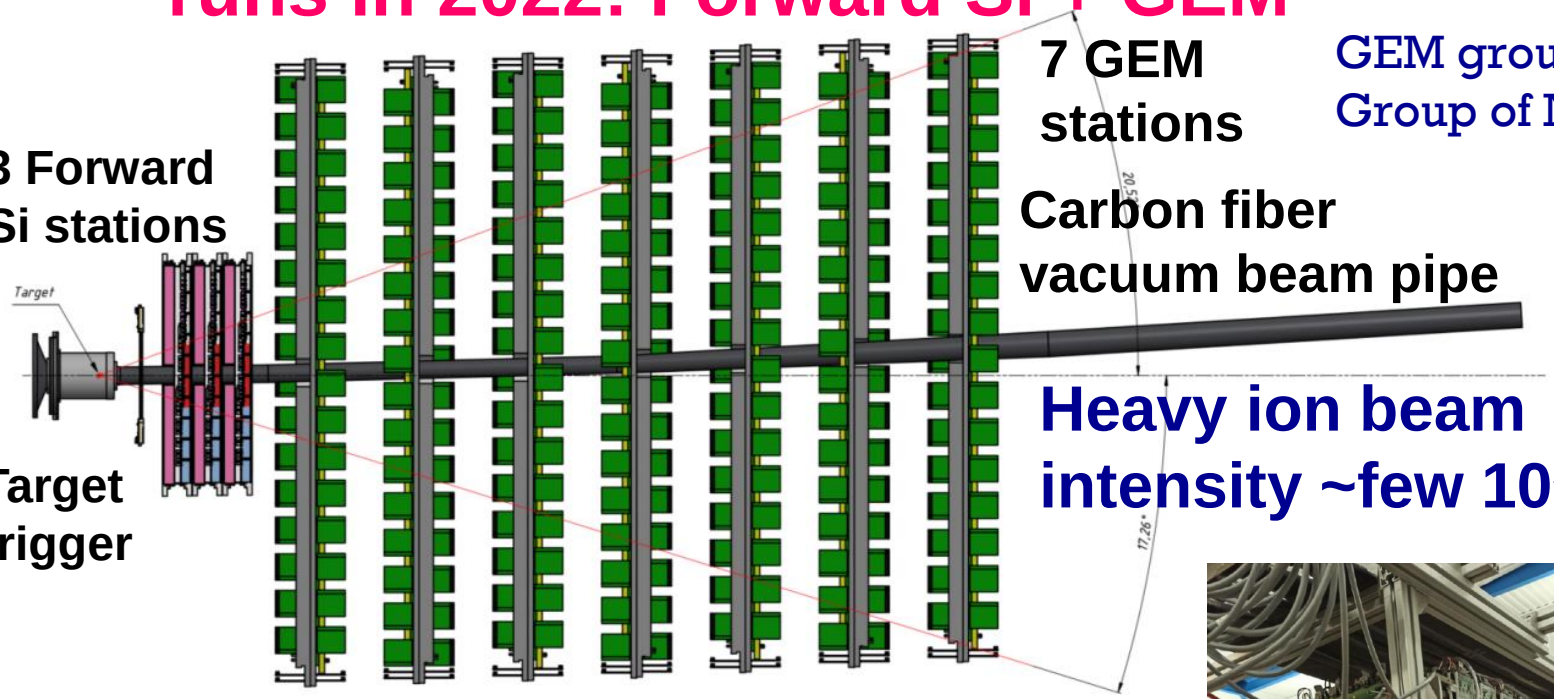
Configuration of BM@N detector for heavy ion program (without beampipe)



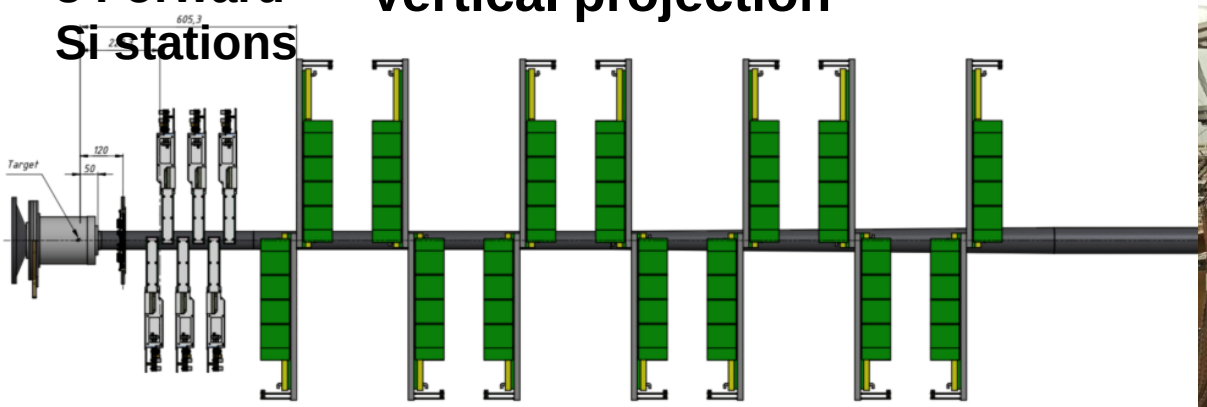
→ See talk of A.Maksymchuk on Upgrade of the BM@N detectors and dedicated talks on sub-systems

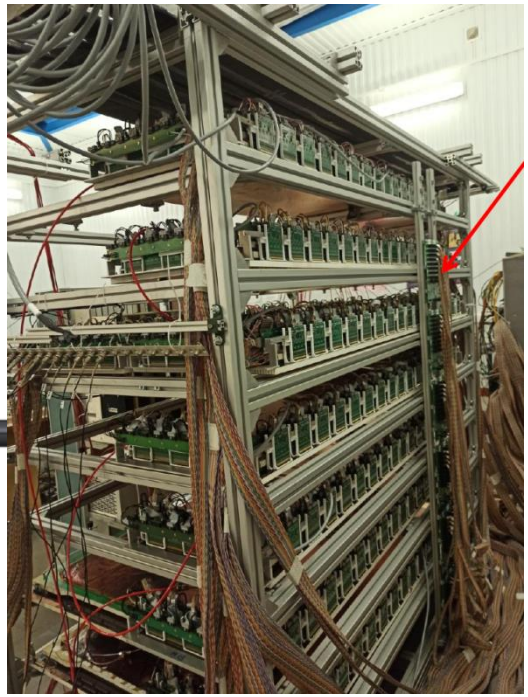
Initial Hybrid Central Tracker for heavy ion runs in 2022: Forward Si + GEM

GEM group
Group of N.Zamiatin



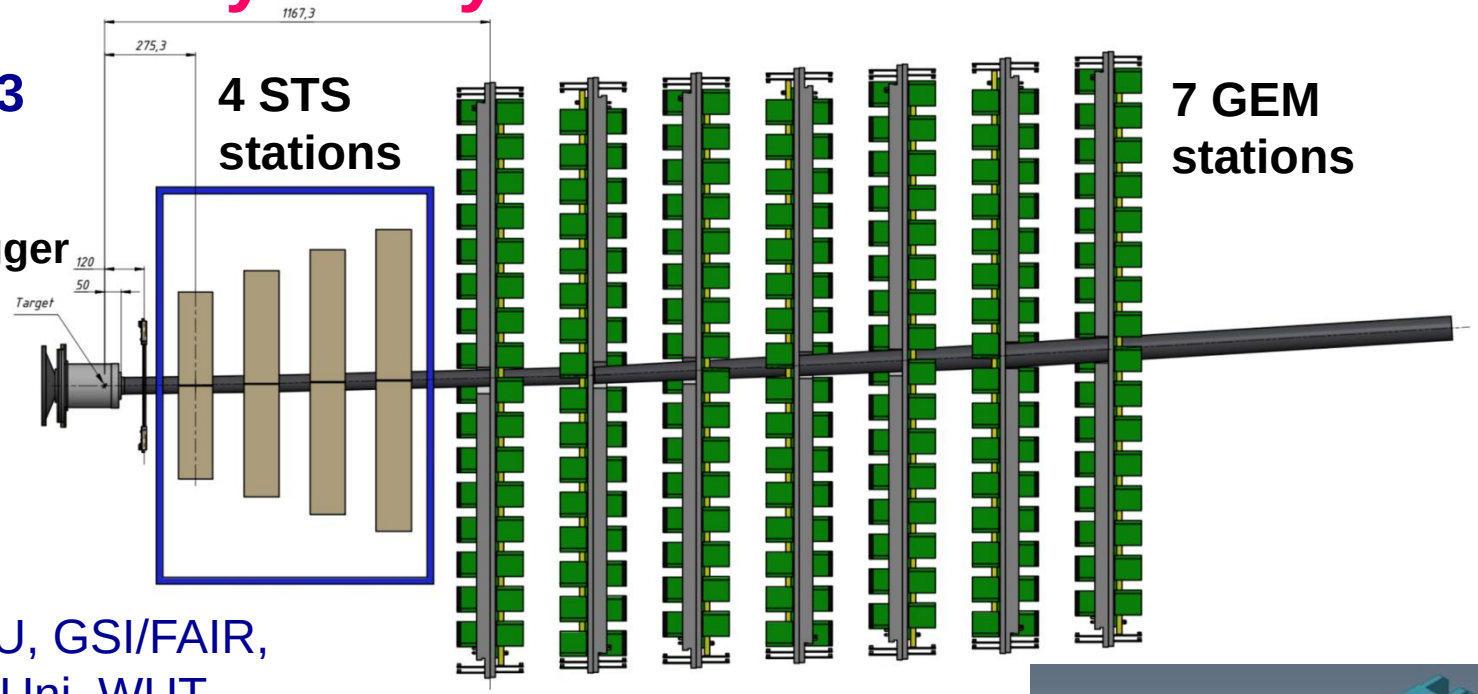
Heavy ion beam intensity ~few 10^5 Hz





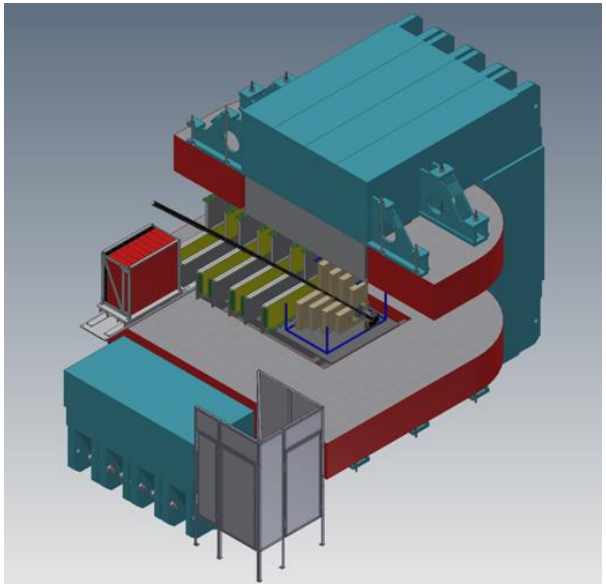
Stage2 Hybrid Central Tracker for high intensity heavy ion runs: STS +GEM

after 2023



JINR, MSU, GSI/FAIR, Tübingen Uni, WUT

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

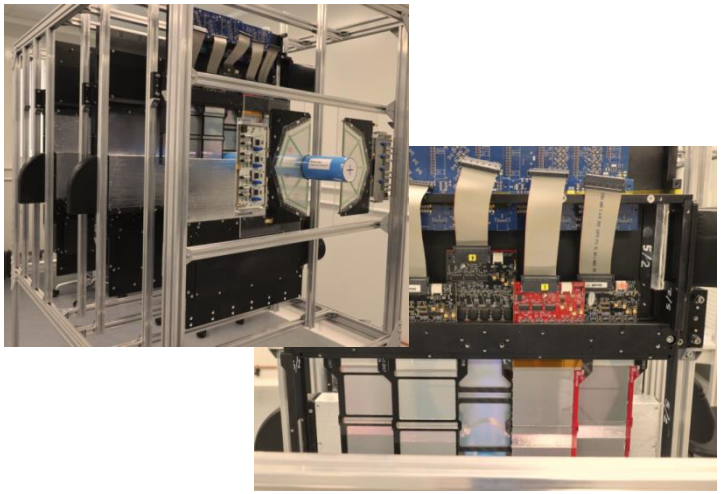


BM@N main detector activities towards heavy ion run

Central tracking system

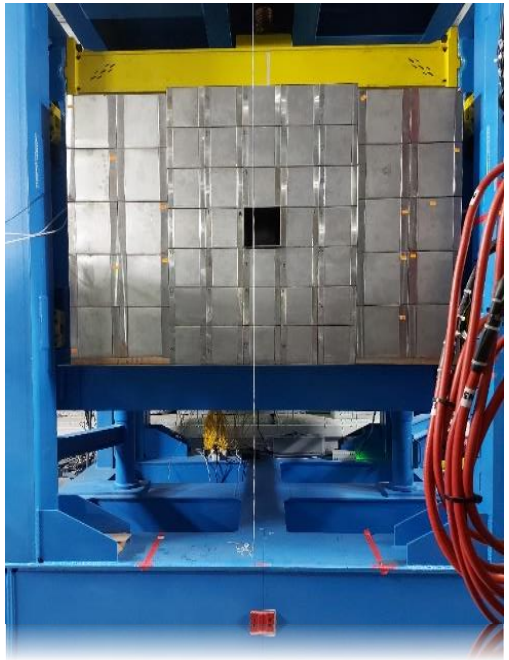
GEM detectors

Forward Silicon Tracker

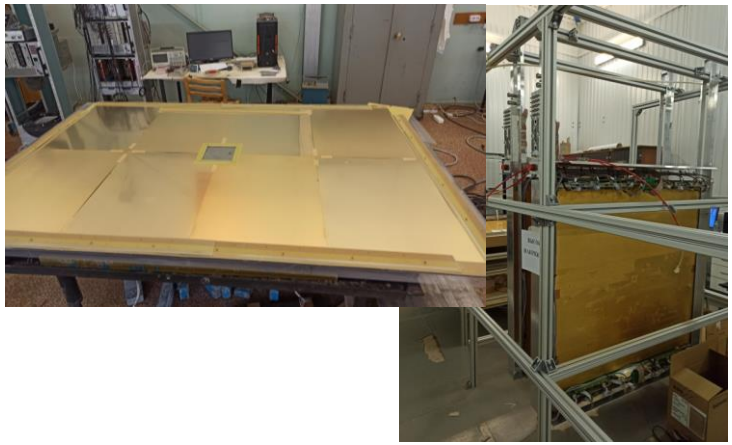


Carbon fiber vacuum beam pipe

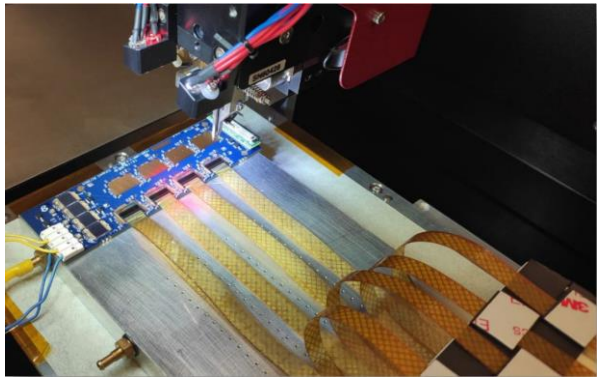
Forward Hadron Calorimeter and Hodoscope



Outer tracker: Cathode Strip Chambers



Silicon Tracking System



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 → end 2021

Beam, Si tracking detectors and target station:

►All detectors and target station to be ready in end 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 are ready

►1st big CSC chamber expected in spring 2022, second → end 2022

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 end 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

Towards BM@N heavy ion and other studies

- **Struggle of the accelerator team to put Booster – Nuclotron complex into operation (talk of Eugeny Siresin)**

- **Progress in the construction of the vacuum transport channel between Nuclotron and BM@N by the Belgorod group (status in the talk of Anna Maksymchuk)**

- **Activities to simulate and define the design of high granularity large aperture neutron detector for measurements of neutron azimuthal fluxes and symmetry energy (talks Vladimir Yurevich, INR RAS and KI ITEP on October 5 after 16.00)**

- **Can BM@N perform studies complementary to SPD and measure exclusive processes in polarized deuteron beam (talks Vladimir Ladygin and Yuri Uzikov on October 7 before noon)**

- **Models of nucleus-nucleus interactions and simulation of nuclear fragments (talks of Genis Musulmanbekov and Victor Kireev)**

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)	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

SRC physics run with C12 beam in December 2021 (1 month of data taking)

- **Only Nuclotron with laser source is sufficient**
- **No need for full vacuum transport channel from Nuclotron to BM@N**

Limitations / requirements for BM@N physics run with Xe beam in spring 2022 (800 hours of physics data taking)

- **Need Booster – Nuclotron accelerator system**
- **Need 2 months for transition from SRC set-up to heavy ion setup**
- **Full vacuum transport channel from Nuclotron to BM@N**
- **Xe beam of maximal possible energy (up to 3.9 AGeV)**
- **Need few days for technical run before physics run to prove beam quality and detector response, in case of problems → postpose physics run**
- **Time limit for Nuclotron cooling due to dirty water in Dubna river → 1st / 2nd week of April and later, i.e. April is problematic for physics run**
- **If SRC run extends to January 2022:**
  → only chance to shift BM@N physics run to April - May 2022

Requirements for BM@N physics run with Bi beam in spring 2023 (800 hours of physics data taking)

- **Full vacuum transport channel from Nuclotron to BM@N**
- **Bi beam of maximal possible energy (up to 3.8 AGeV)**
- **Need 1 week technical run before physics run to prove beam quality and detector response**

Thank you
for attention!