The first physics results of the BM@N experiment

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on behalf of the BM@N collaboration

27/04/2023

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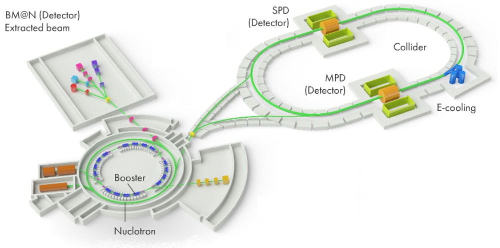
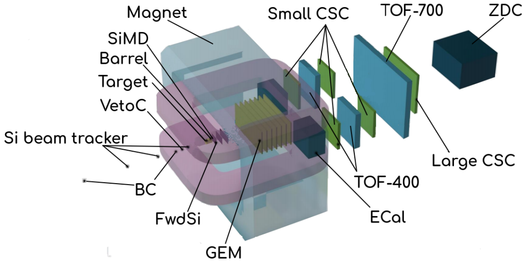
- Experimental setup during the first heavy ion run
- First experimental results
- Conclusion

BM@N - Baryonic Matter at Nuclotron





There was carried 8 runs. But most recent and interested were in 2017 (C + X), 2018 (Ar + X) and 2022-2023 (Xe + CsI)

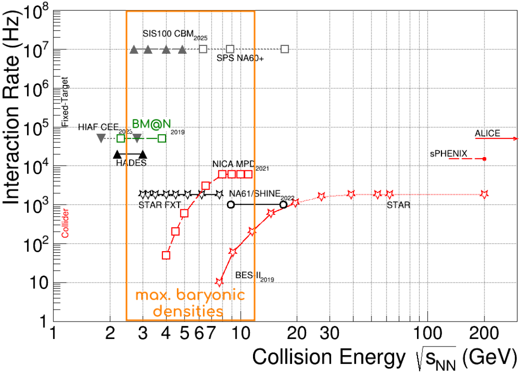
Experiment is people!

3 countries, 10 institutions and 188 participants

- University of Plovdiv, Plovdiv, Bulgaria
- Saint Petersburg State University, St.Petersburg, Russia
- Joint Institute for Nuclear Research, Dubna, Russia
- Institute of Nuclear Research of RAS, Moscow, Russia
- Shanghai Institute of Nuclear and Applied Physics, Shanghai, China
- NRC Kurchatov Institute, Moscow, Russia
- Moscow Engineer and Physics Institute, Moscow, Russia
- Skobeltsin Institute of Nuclear Physics, Moscow, Russia
- Moscow Institute of Physics and Technics, Moscow, Russia
- Lebedev Physics Institute of RAS, Moscow, Russia

Physics motivation for the BM@N experiment

Heavy ion collision experiments



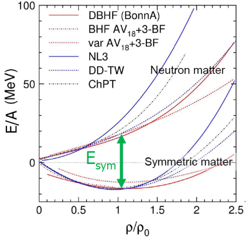
Experiments at the NICA complex:

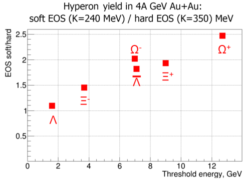
- BM@N, $\sqrt{s_{NN}} = 2.3 - 3.3$ GeV
- MPD, $\sqrt{s_{NN}} = 4 - 11$ GeV

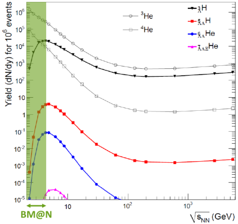
BM@N competitors:

- HADES BES (SIS) Au+Au, $\sqrt{s_{NN}} = 2.42$ GeV
- STAR BES (RHIC) Au+Au, $\sqrt{s_{NN}} = 3 - 200$ GeV (10^9 events at 3 GeV in 2021)
- Future CBM experiment Au+Au, $\sqrt{s_{NN}} = 2.7 - 4.9$ GeV

Goal of the BM@N experiment







Study symmetric matter EOS at $\rho/\rho_0 = 3-5$, $\rho_0 = 0.16\text{fm}^{-1}$:

- elliptic flow of protons, mesons and hyperons
- sub-threshold production of strange mesons and hyperons
- extract nuclear incompressibility (K_{nm}) from data to model predictions

Constrain symmetry energy E_{sym}:

- elliptic flow of neutrons vs protons
- sub-threshold production of particles with opposite isospin

EoS: relation between density, pressure, temperature, energy and isospin asymmetry $E_A(\rho,\delta) = E_A(\rho,0) + E_{sym}(\rho)\cdot\delta^2$

$\delta = (\rho_n - \rho_p)/\rho$

Nuclear incompressibility: $K_{nm} = 9\rho^2 \frac{\partial^2}{\partial\rho^2}(E/A)|_{\rho=\rho_0}$

Comparison HADES, STAR FxT, BM@N

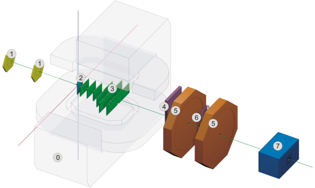
Exp.	year	A+A	E_{kin} AGeV	Statistics	Ξ^-	Ω^-	Hypernuclei
HADES	2012	Au+Au	1.23	$7 \cdot 10^9$	✗	✗	✗
HADES	2019	Ag+Ag	1.58	$1.4 \cdot 10^{10}$	✗	✗	$800\ ^3_\Lambda$H
STAR FxT	2018	Au+Au	2.9	$3 \cdot 10^8$	10^4	✗	$10^4\ ^3_\Lambda$H $6 \cdot 10^3\ ^4_\Lambda$H
STAR FxT	2021	Au+Au	2.9	$2 \cdot 10^9$	$7 \cdot 10^4$	✗	$7 \cdot 10^4\ ^3_\Lambda$H $4 \cdot 10^4\ ^4_\Lambda$H
BM@N full program	sim.	Au+Au	3.8	$2 \cdot 10^{10}$	$5 \cdot 10^6$	10^5	$10^6\ ^3_\Lambda$H $^4_\Lambda$H, $^5_\Lambda$He $^7_\Lambda$Li, $^7_\Lambda$He $10^2\ ^5_{\Lambda\Lambda}$H

- Reaction rates: HADES $\approx$ 20 kHz, BM@N $\approx$ 20 kHz, STAR FxT $\approx$ 2 kHz
- HADES and BM@N are complementary, no cascade hyperons (Ξ^-, Ω^-) at HADES
- Statistics at BM@N $\approx$70 times higher (Ξ^-) than at STAR FxT

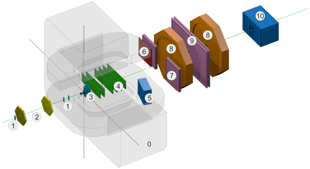
Experimental setup in the first heavy ion run

Experimental setup evolution

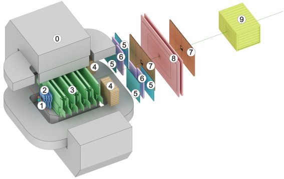
RUN-6 (2017)



RUN-7 (2018)

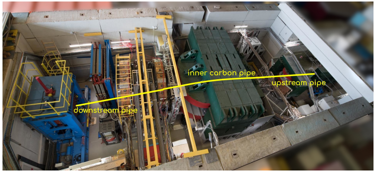


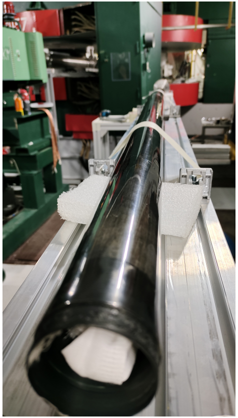
RUN-8 (2022)

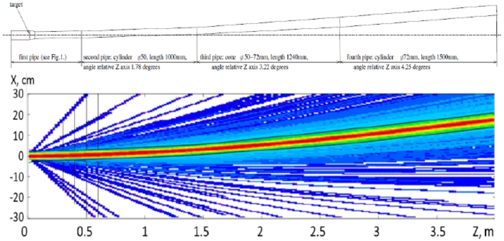


Beam pipe

Total length of the vacuum ion beam pipe from Nuclotron to BM@N is about **160 m.**

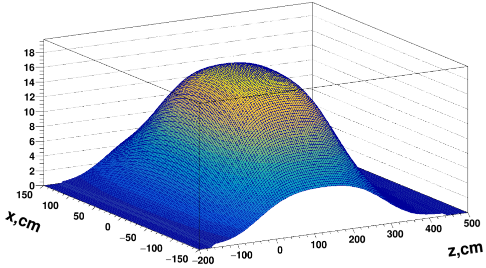


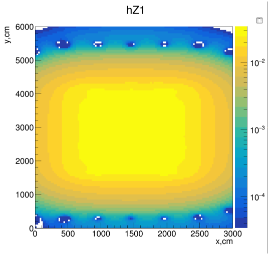


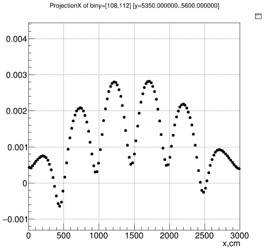


- Beam pipe in te SP-41 magnet is made of 1 mm thick carbon fiber;
- It consists of four parts with a non-flange connectors;
- FLUKA simulations have shown that the proposed beam pipe is well suited to guide the high intensity beam;
- First vacuum tests have shown an insignificant leakage level of side surfaces of the sample, vacuum up to 10^{-5} Torr.

Magnetic field measurement

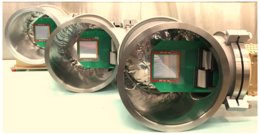






- New magnetic field measurements were done
- The region of measurements is much larger than for the old field map
- "Boltometry"approach was used to align measured grid in the BM@N coordinate system

Silicon Beam Tracker



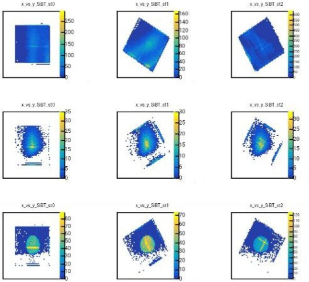
Three silicon beam trackers with 32x32 orthogonal strips readout

- placed in beam pipe in 100 cm from each other
- rotated relative to each other by 30 degrees.

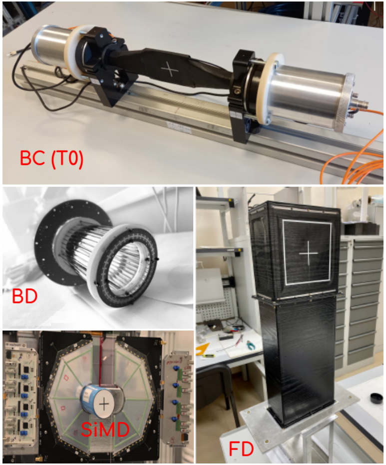
Main goals:

- To improve vertex resolution in transverse direction
- To monitor beam behavior during experimental run
- To reconstruct beam angles

Experimental efficiensies: 95,7%, 88.7%, 93.5%



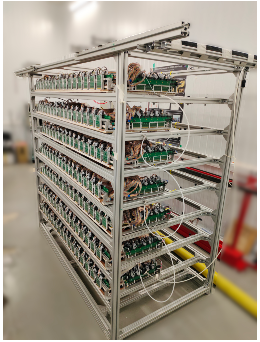
Subsystems. Trigger detectors

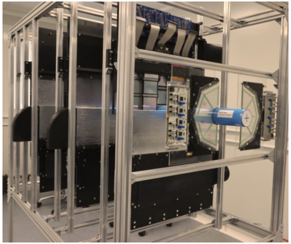


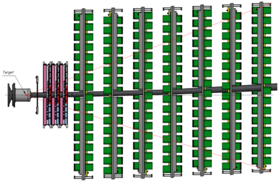
Trigger detectors to be used in 2022:

- T0 - start signal for DAQ
- VC, BC - beam trigger formation
- BD - barrel detector for counting particles under high polar angle
- SiMD - silicon multiplicity detector for counting particles under small polar angles
- FD - fragment detector for vetoing non-interaction events and generating trigger for central and semi-central events

Inner tracking system



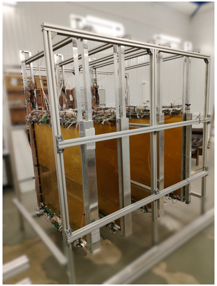
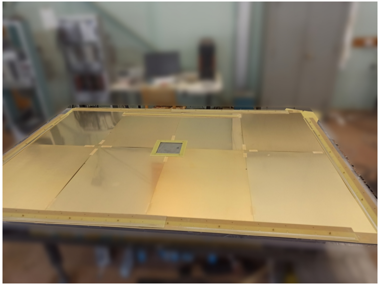




- Inner tracking system consist of
  - 4 forward silicon detectors
  - 7 GEM stations ($160 \times 80 \text{cm}^2$)
- Right after the target four stations of Silicon Forward Detector was installed
- Seven GEM stations covers the entire magnet aperture

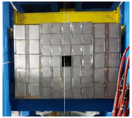
Outer tracking system

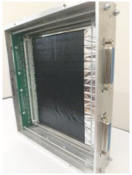
Outer planes support tracks in downstream direction


- Four small Cathod Strip Chambers (SmallCSC, $\approx 1 \times 1\mathrm{m}^2$) placed around near Time-of-Flight (TOF-400)
- Large Cathod Strip Chamber (LargeCSC, $\approx 1.5 \times 2\mathrm{m}^2$) placed in front of far Time-of-Flight (TOF-700)
- Two Drift Chamders (DCH) placed around far Time-of-Flight (TOF-700)
- One small GEM ($\approx 10 \times 10\mathrm{cm}^2$) was installed after the outer tracking detectors crossing beam trajectory

Calorimeters





Forward Hadron Calorimeter

- 20 PSD CBM modules - transverse size 20x20 cm^2
- 34 MPD/NICA like modules - transverse size 15x15 cm^2

Scintillation Wall

- registration of fragments in the ScWall allows to measure fragments multiplicities to tune parameters in fragmentation models

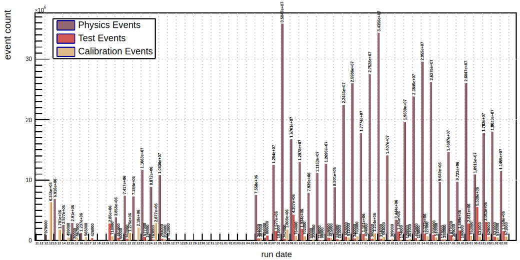
Hodoscope

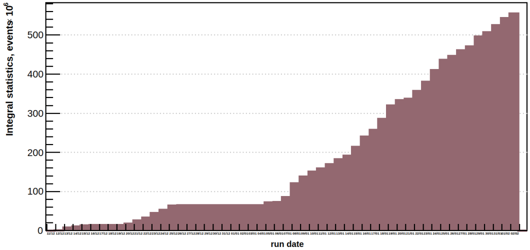
- measurement of fragments charge in the FHCal beam hole
- 16 quartz strips with sizes 10x160x4 mm^3
- covers beam hole 15x15 cm^2

Main goals of the system:

- Centrality determination
- Reaction plane calculation

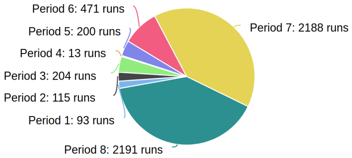
Collected data during Xe run





It was two energies of Xe beam:

- $507 \cdot 10^6$ events at 3.8 AGeV
- $48 \cdot 10^6$ events at 3.0 AGeV

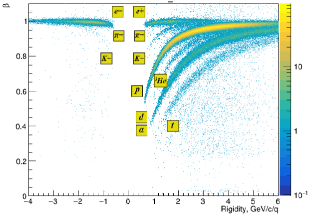


Current studies of experimental data

Particles and fragments identification

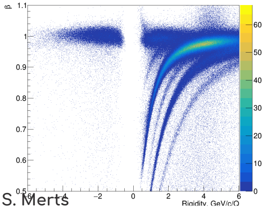
Main goal: yields of charged particles and fragments extraction

TOF-400, 2018



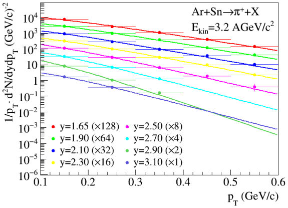
TOF-700, 2022

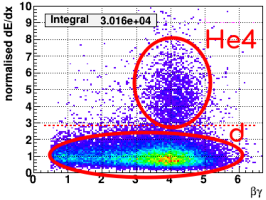
Rigidity vs β for TOF-700



Current studies include

- Positive and negative particles separation by TOF systems
- Attempt to separate deuteron and Helium-4 by dE/dx in GEM

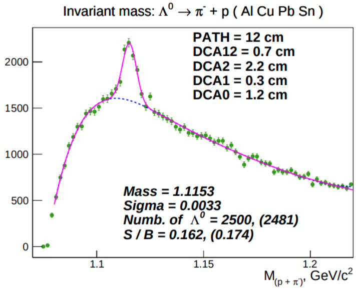




Lambda analysis

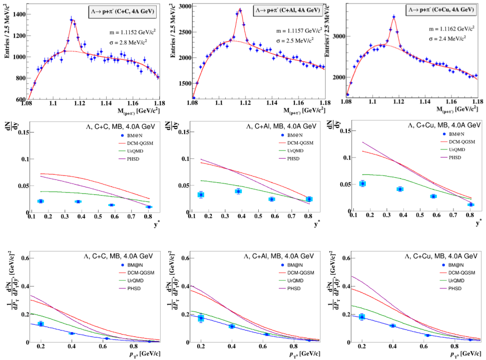
Analysis of Λ^0 yields for data 2018

- Ar+A @ 3.2 AGeV
- Λ^0 mass resolution is about $3.3\mathrm{MeV}/c^2$

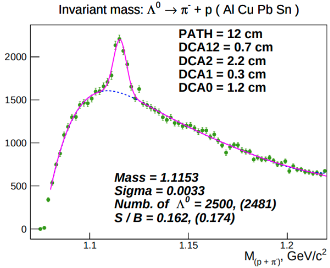


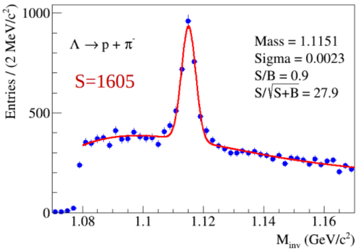
Finalization of Λ^0 analysis for data 2017

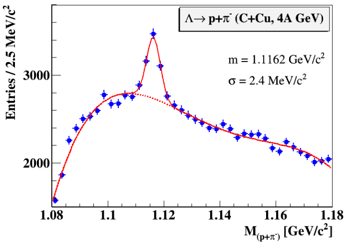
- C+A @ 4 AGeV
- Λ^0 mass resolution is $2.4 - 3.0\mathrm{MeV}/c^2$
- Statistics: CC(4.6M), CAl(5.3M), CCu(5.3M)

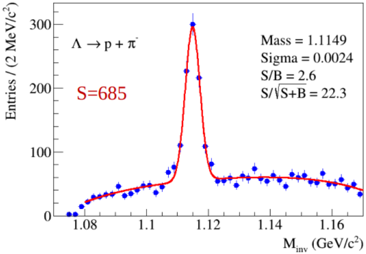


Lambda data comparison









Conclusion

- BM@N energy range is very promising (study of EoS, hypernuclei, (multi-)hyperons, collective flow ...).
- BM@N already recorded experimental data from a set of technical runs (carbon, argon-krypton). Physics analysis of data is in its active phase, results expected to be published in the nearest future.
- The longest and successful experimental run with heavy ions was held in 2022-2023.
- Physics analysis of charge particles, hyperons and hypernuclei production, flows etc. for new Xe data is ongoing.

Thank you!