Studies of dense baryonic matter with the BM@N experiment at the Nuclotron

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on behalf of the BM@N collaboration

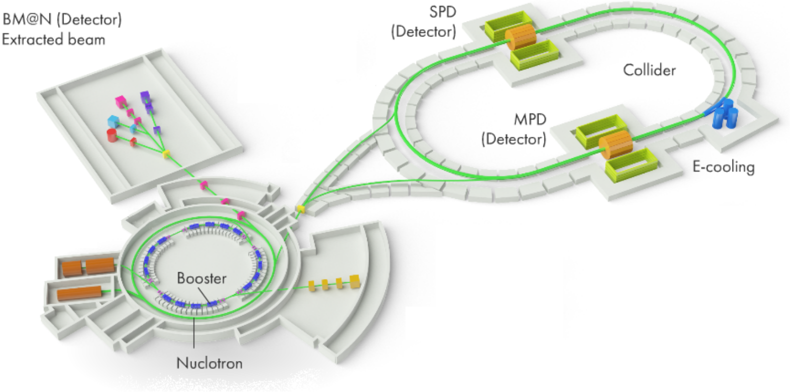
16/07/2022

BM@N

Content

- Physics motivation for the BM@N experiment
- Current studies of experimental data
- Preparation to the heavy ion program
- Conclusion

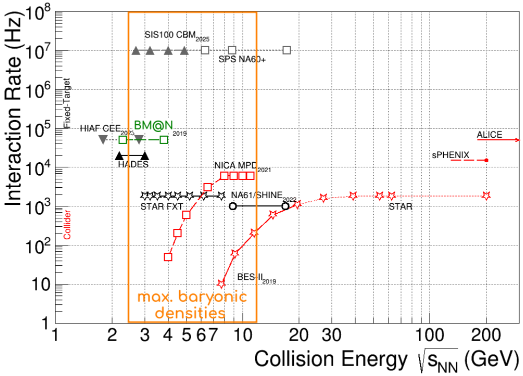
BM@N at NICA complex



Beams from protons to gold, $E_{kin} = 1 - 3.8$ AGeV, Au intensity a few 10^6 Hz

Physics motivation for the BM@N experiment

Heavy ion collision experiments



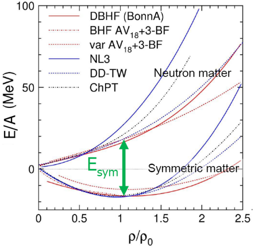
Experiments at the NICA complex:

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

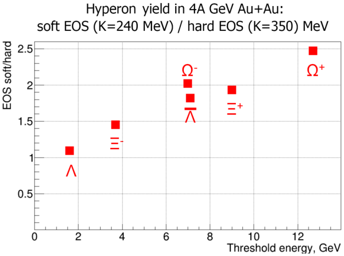
BM@N competitors:

- 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



Ch.Fuchs, EPJA 30 (2006) 5



Phys. Lett. B697 (2011) 203

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

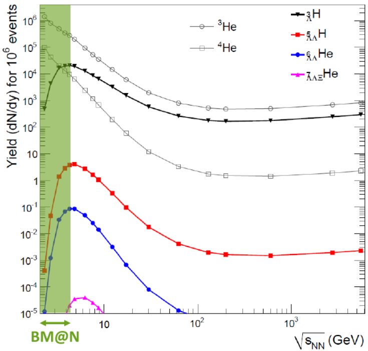
Study symmetric matter EOS at $\rho/\rho_0 = 3 - 5$, $\rho_0 = 0.16\text{fm}^{-1}$:

- 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}:

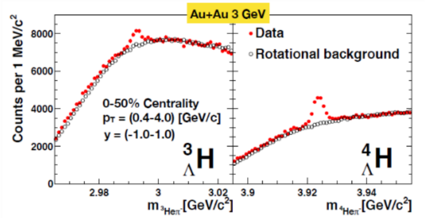
- elliptic flow of neutrons vs protons
- sub-threshold production of particles with opposite isospin

Hypernuclei production



Phys. Rev. C 101 (2020) 044905

Recent STAR results



$^3_\Lambda H \rightarrow ^3He + \pi^-$ (2900 cand.)
$^4_\Lambda H \rightarrow ^4He + \pi^-$ (6300 cand.)

Yue-Hang Leung, CPOD2021

The BM@N energy range is well suited for search and studies of hypernuclei

Comparison HADES, STAR FxT, BM@N

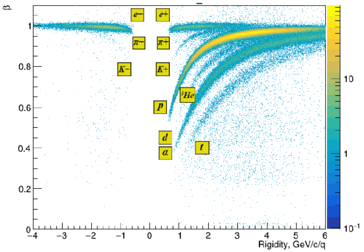
Exp.	year	A+A	E_{kin} AGeV	Statistics	Ξ^-	Ω^-	Hypernuclei
HADES	2012	Au+Au	1.23	$7 \cdot 10^9$	✗	✗	✗
HADES	2019	Ag+Ag	1.58	$1.4 \cdot 10^{10}$	✗	✗	800 ${}^3_\Lambda$H
STAR FxT	2018	Au+Au	2.9	$3 \cdot 10^8$	10^4	✗	10^4 ${}^3_\Lambda$H $6 \cdot 10^3$ ${}^4_\Lambda$H
STAR FxT	2021	Au+Au	2.9	$2 \cdot 10^9$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

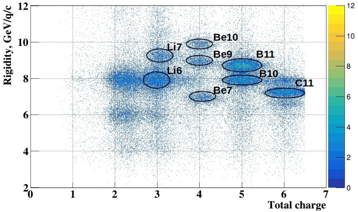
- Reaction rates: HADES $\approx$ 20 kHz, BM@N $\approx$ 20 kHz, STAR FxT $\approx$ 2 kHz
- HADES and BM@N are complementary, no cascade hyperons (Ξ^-, Ω^-) at HADES
- Statistics at BM@N $\approx$70 times higher (Ξ^-) than at STAR FxT

Current studies of experimental data

Particles and fragments identification

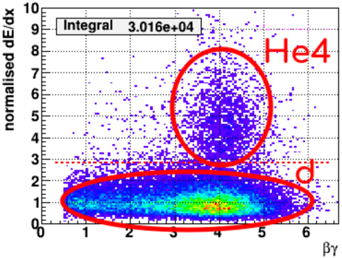
Main goal: yields of charged particles and fragments extraction





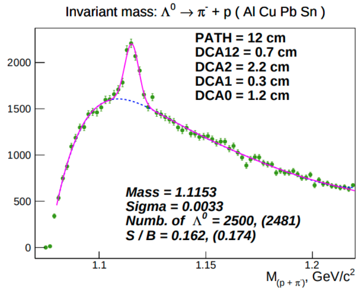
Current studies include

- Fragments separation in C+p reaction by event charge
- Positive and negative mesons separation by TOF
- Deuteron and Helium-4 separation by dE/dx in GEM



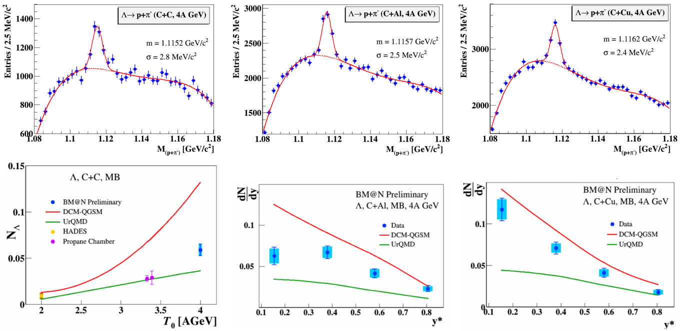
Analysis of Λ^0 yields for data 2018

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



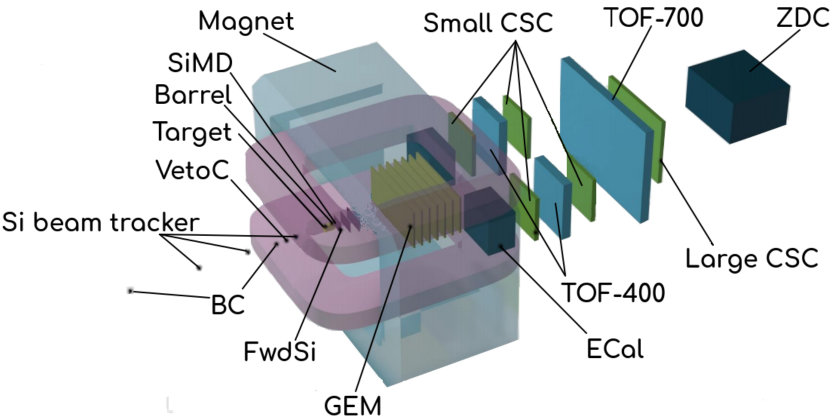
Finalization of Λ^0 analysis for data 2017

- 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)



Preparation to the heavy ion program

Experimental setup

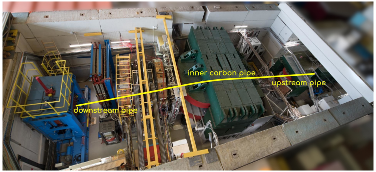


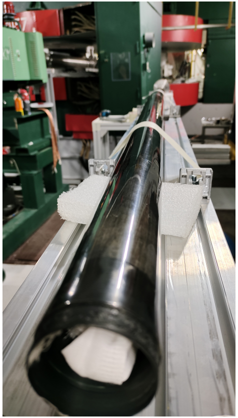
Xe+CsI @ E_{kin} = 3.8AGeV

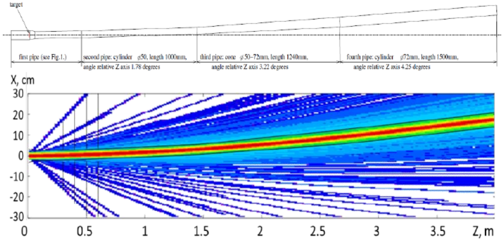
Start of the experiment is going to be in october 2022

Beam pipe

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

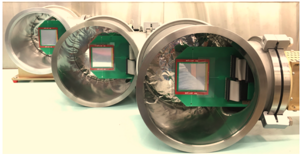






- Beam pipe in te SP-41 magnet is made of 1 mm thick carbon fiber;
- It consists of four parts with a non-flange connectors;
- FLUKA simulations have shown that the proposed beam pipe is well suited to guide the high intensity beam;
- First vacuum tests have shown an insignificant leakage level of side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

Silicon Beam Tracker



Three silicon beam trackers with 32x32 orthogonal strips readout

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

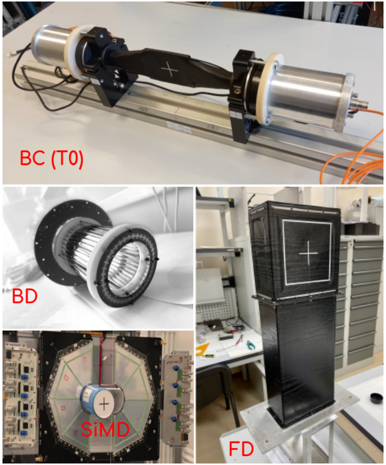
Main goals:

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

Average resolutions for Xe beam passed through SiBT:

- dX = 40-50 μm
- dY = 40-50 μm
- dTx = 0.2 mrad
- dTy = 0.2 mrad

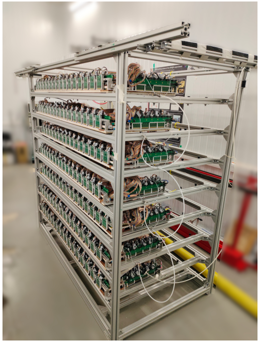
Subsystems. Trigger detectors

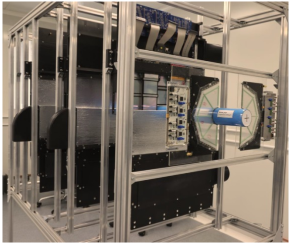


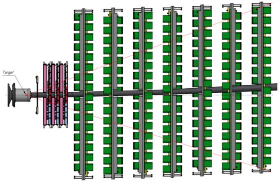
Trigger detectors to be used in 2022:

- 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



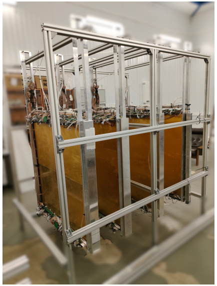
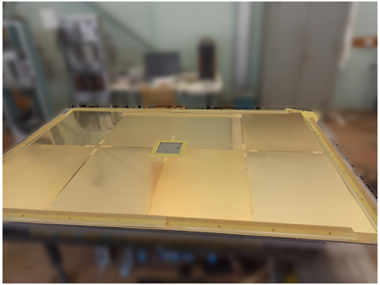




- Inner tracking systen consist of
  - 4 forward silicon detectors.
  - 7 GEM stations ($160 \times 80 \text{cm}^2$).
- Bottom parts of GEM detectors are placed inside the magnet.
- Upper parts of GEM detectors are under cosmic tests.
- 4 silicon detectors ready to be placed right behind the target in front of GEM stations.

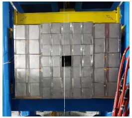
Outer tracking system

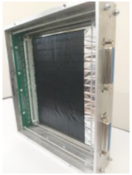
Outer planes support tracks in downstream direction


- Four small Cathod Strip Chambers (SmallCSC, $\approx 1 \times 1\text{m}^2$) placed around near Time-of-Flight
- Large Cathod Strip Chamber (LargeCSC, $\approx 1.5 \times 2\text{m}^2$) placed in front of far Time-of-Flight
- Two Drift Chamders (DCH) placed around far Time-of-Flight

Calorimeters





Forward Hadron Calorimeter

- 20 PSD CBM modules - transverse size $20 \text{x} 20$ cm^2
- 34 MPD/NICA like modules - transverse size $15 \text{x} 15$ 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 $10 \text{x} 160 \text{x} 4$ mm^3
- covers beam hole $15 \text{x} 15$ cm^2

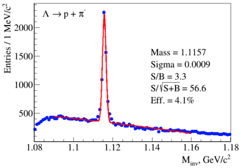
Main goals of the system:

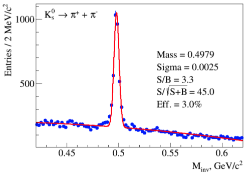
- Centrality determination
- Reaction plane calculation

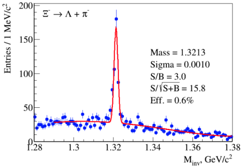
Feasibility study for HI collision

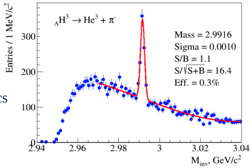
Generator: DCM-SMM, Xe+Sn at $T_0 = 3.9\text{AGeV}(\sqrt{s_{NN}} = 3.296\text{GeV})$
Statistics:

- K_s^0 - 8818 within 50 cm of primary vertex (in 10k events)
- Λ^0 - 10225 within 50 cm of primary vertex (in 10k events)
- Ξ^- - 111 in 10k (54175 in 5M)
- Ω^- - 95 in 5M
- ${}_\Lambda H^3$ - 6309 in 5M enriched ${}_\Lambda H^3$ sample (randomly add 1 ${}_\Lambda H^3$ per 30 events according to $y - p_T$ distribution), scale factor 27.4



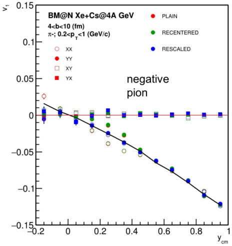


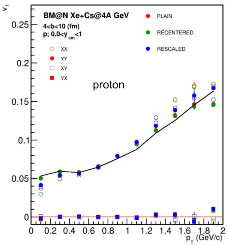


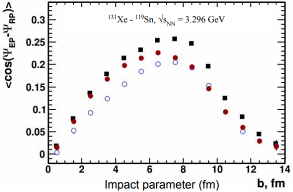


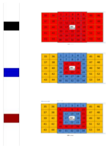
Feasibility study for HI collision

- Spatial asymmetry of the initial pressure distribution transforms into anisotropic emission of produced particles via interaction inside the overlapping region of colliding nuclei
- Anisotropic flow measurements can constrain compressibility of the matter created in the collision
- Tracking system of the BM@N experiment allows to measure directed flow of protons and charged pions





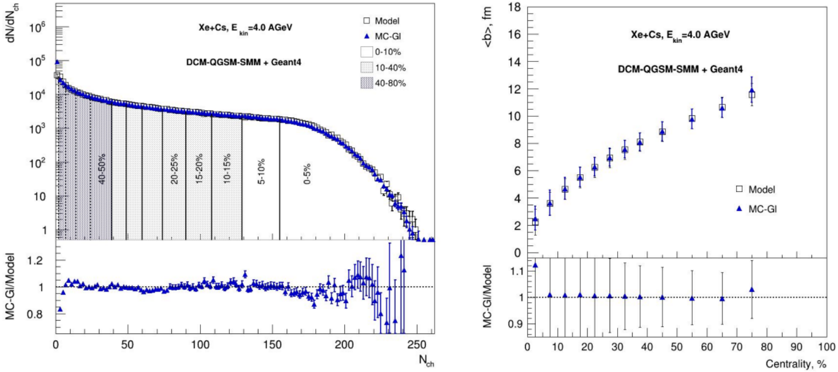




Mikhail Mamaev: ``Performance for spectator symmetry plane estimation with the BM@N experiment'', 15.07.2022

Feasibility study for HI collision

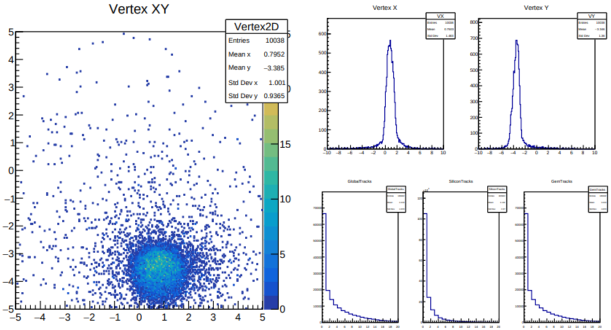
- MC-Glauber and multiplicity fitting procedure is developed for BM@N
- Relation between impact parameter and centrality classes is extracted



Alexandra Andomina: ``Application of the MC-Glauber approach for centrality determination in the BM@N experiment'', 14.07.2022

Data monitoring

- L1 tracking is used for fast track and vertex reconstruction
- New monitoring gives possibility to check vertex, multiplicity and other “high level” distributions
- “No code” approach was implemented to simplify extension of the system



Ilnur Gabdrakhmanov: ``Online data processing and monitoring of the BM@N experiment'', 15.07.2022

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.
- Preparation for next experimental runs (detector construction, physics feasibility study according the BM@N physics program ...) is ongoing.
- We expect beam of Xe to be available with BM@N in autumn 2022.

Thank you!