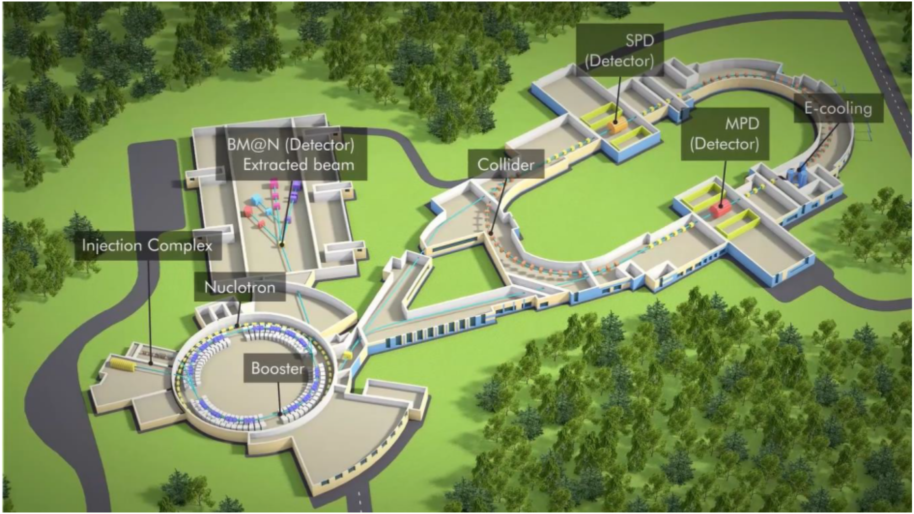
TWENTIETH LOMONOSOV
CONFERENCE August, 19-25, 2021
ON ELEMENTARY PARTICLE PHYSICS
MOSCOW STATE UNIVERSITY

The fixed target BM@N experiment for studies of heavy nucleus interactions at NICA

P. Batyuk for BM@N collaboration

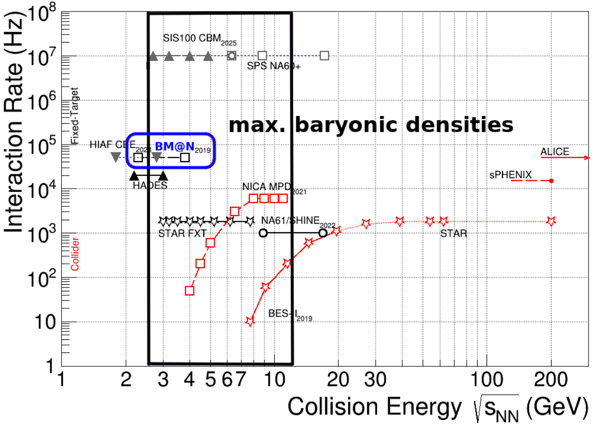
August 21, 2021

NICA (Nuclotron based Ion Collider fAcility)



BM@N: Beams from **p** to **Au**, heavy ion energy **1 - 3.8 AGeV** (lab. system), Au intensity $\sim$ a few 10^6 **Hz**

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):

AuAu @ $\sqrt{s_{NN}} = 2.42$ **GeV**

CBM:

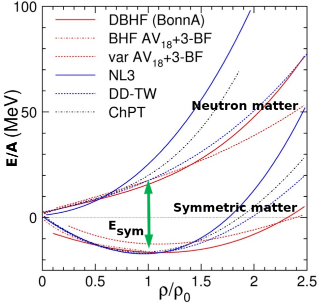
AuAu @ $\sqrt{s_{NN}} =$ **2.5 - 5 GeV**

STAR FXT:

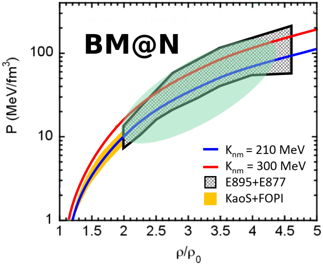
AuAu @ $\sqrt{s_{NN}} = 3 - 7.7$ **GeV**

EoS of symmetric and asymmetric nuclear matter

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



P. Senger, CPOD2021



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

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

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

$$E/A(\rho_0) = -16MeV$$

Nuclear incompressibility:
Curvature $K_{nm} = 9\rho^2\delta^{\mathbf{2}}(\mathbf{E}/\mathbf{A})/\delta\rho^{\mathbf{2}}$

Study of sym. matter EoS at $\rho = 3$ - $5\ \rho_0$

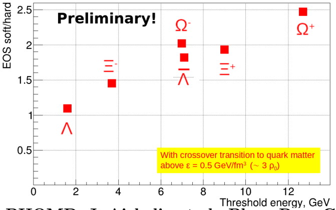
- elliptic flow of protons, mesons and hyperons
- sub-threshold production of strange mesons and hyperons
- extract K_{nm} from data to model predictions

Constrain symmetry energy E_{sym}

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

Sub-threshold production of strange mesons and hyperons

Hyperon yield in heavy ion collisions at 4 AGeV: soft EOS ($K_{nm} = 240$ MeV) / hard EOS ($K_{nm} = 350$) MeV



PHQMD: J. Aichelin et al., Phys. Rev. C 101 (2020) 044905

Hyperon yields at the Nuclotron

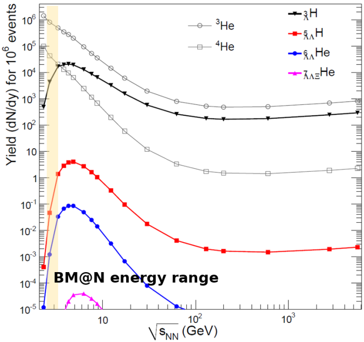
- **AuAu @ 4A GeV, min. bias, multiplicities from statistical model**
- **Beam intensity $10^6/s$, reaction rate $10^4/s$**
- **Experimental run for 2200 hours ($2 \cdot 10^{10}$ interactions, $2 \cdot 10^{12}$ ions)**

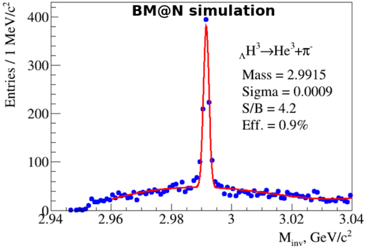
Data from AGS also can be taken into account for comparison

Expected hyperon yields in the BM@N energy range

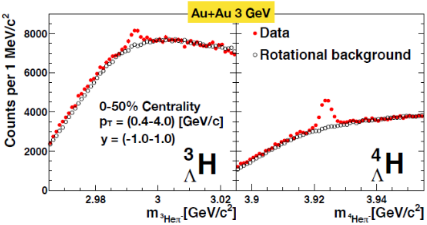
Particle	E_{thr}**(NN)**	**Mult. centr**	**Mult. min bias**	ε **[%]**	**Yield/s [min bias]**	**Yield / 2200 hours [min bias]**
Ξ^-	3.7	$1 \cdot 10^{-1}$	$2.5 \cdot 10^{-2}$	1	2.5	$\mathbf{5 \cdot 10^6}$
Ω^-	6.9	$2 \cdot 10^{-3}$	$5 \cdot 10^{-4}$	1	$5 \cdot 10^{-2}$	$\mathbf{1 \cdot 10^5}$
$\bar{\Lambda}$	7.1	$2 \cdot 10^{-4}$	$5 \cdot 10^{-5}$	3	$1.5 \cdot 10^{-2}$	$\mathbf{3 \cdot 10^4}$
Ξ^+	9.0	$6 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$	1	$1.5 \cdot 10^{-3}$	$\mathbf{3 \cdot 10^3}$
Ω^+	12.7	$1 \cdot 10^{-5}$	$2.5 \cdot 10^{-5}$	1	$2.5 \cdot 10^{-4}$	$\mathbf{5 \cdot 10^2}$

Hypernuclei production





Recent results of STAR, $\sqrt{s_{NN}} = 3$ GeV



$$^3_\Lambda H: \tau = 232.1 \pm 29.2(stat) \pm 36.7(syst)[ps]$$

$$^4_\Lambda H: \tau = 218.3 \pm 7.5(stat) \pm 11.8(syst)[ps]$$

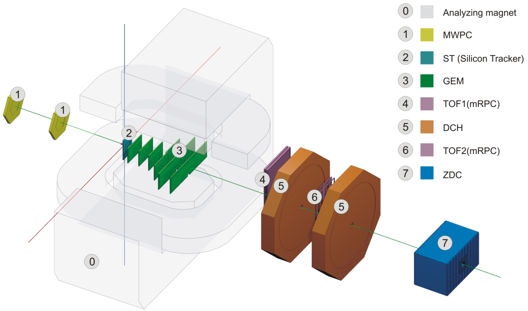
$$^3_\Lambda H \to {}^3He + \pi^- \,(2900\ cand.)$$

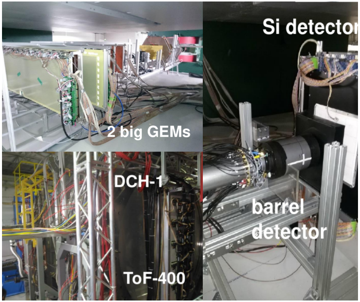
$$^4_\Lambda H \to {}^4He + \pi^- \,(6300\ cand.)$$

Yue-Hang Leung, CPOD2021

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

BM@N, exp. run of 2017





Program:

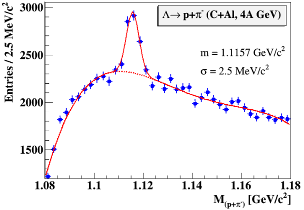
- Trace beam through detectors, align detectors
- Measure inelastic reactions C + target (C, Al, Cu, Pb) $\rightarrow$ X with carbon beam energies of T = 3.5 - 4.5 AGeV

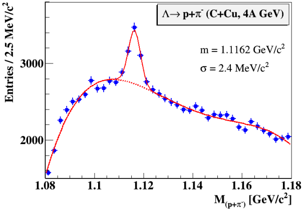
Focus on tests and commissioning of central tracker inside analyzing magnet:

- Five GEM detectors 66 x 41 cm^2 (small) + Two GEM detectors 163 x 45 cm^2 (big)
- One plane of silicon detector

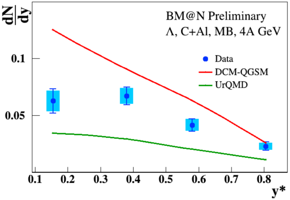
BM@N, exp. run of 2017

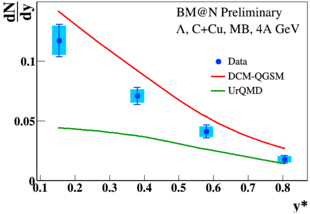
- Λ^0-hyperon yield in C+X @ 4AGeV, min bias interactions
- Measured kinematic range: $0.1 < p_T < 1.05$ GeV/c, $0.03 <$ y* < 0.93

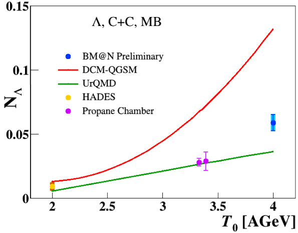




- Width of Λ^0 is 2.4-3 MeV/c^2
- Num. of triggers: CC (4.6M), CAl (5.3M), CCu(5.3M)
- 2.5 days of data taking



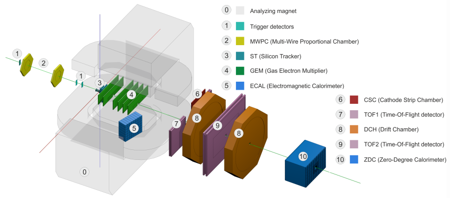




Experimental limitations within the run:

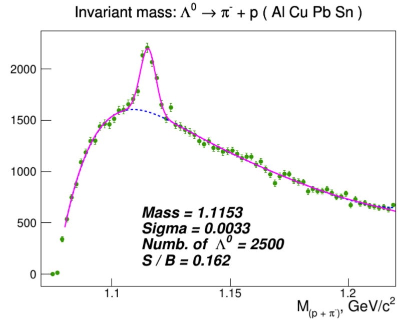
- low granularity tracking systems (small S/B ratio)
- no vacuum beampipe installed

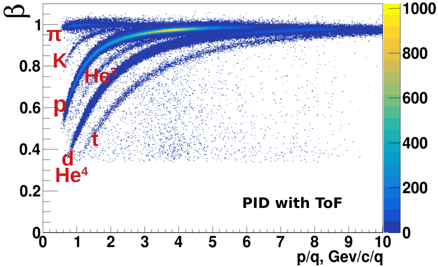
BM@N, exp. run of 2018



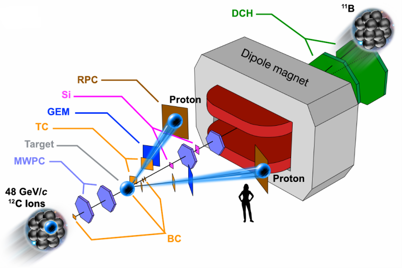
Program:

- Measure inelastic reactions Ar (Kr) + target → X (Al, Cu, Sn, Pb)
- Hyperon production measured in the central tracker
- Charged particles and nuclear fragments identified with ToF





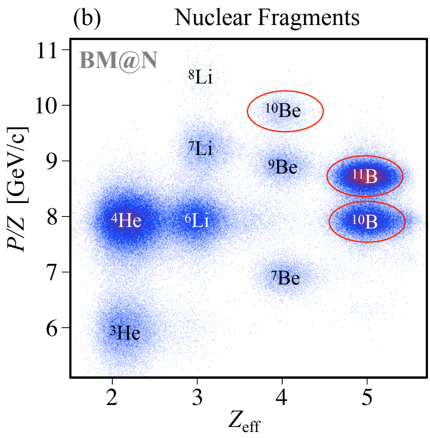
SRC, exp. run of 2018



$$^{12}C + p \rightarrow 2p + ^{10}_{4}Be + p$$ **(pp SRC)**

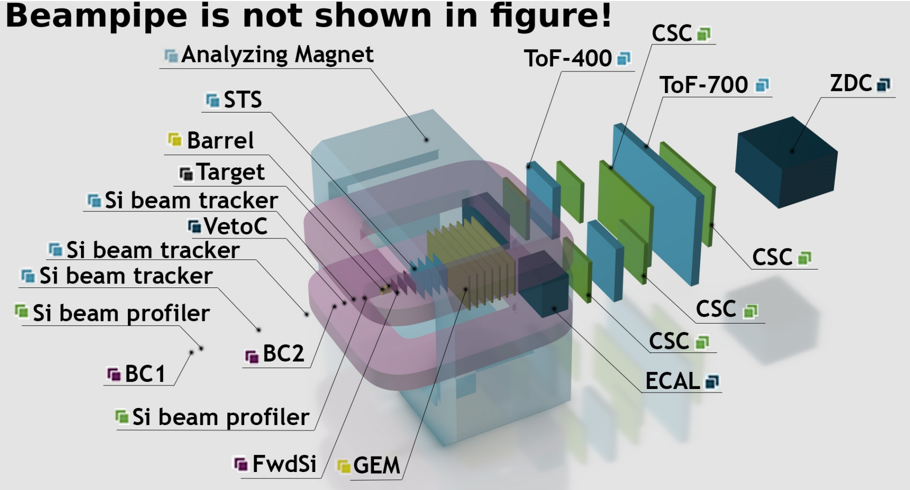
$$^{12}C + p \rightarrow 2p + ^{10}_{5}B + n$$ **(np SRC)**

First exclusive measurement in inverse kinematics probing the residual A-2 nuclear system!

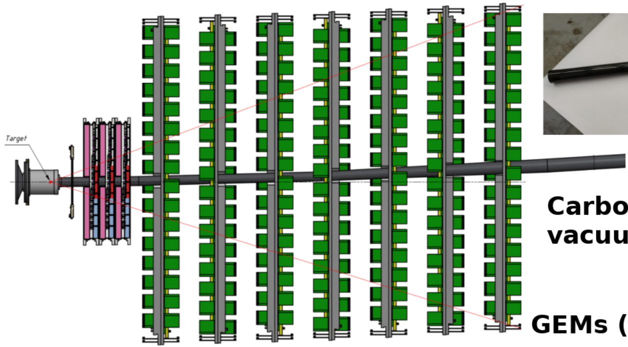


Patsyuk, M., Kahlbow, J., Laskaris, G. et al. Unperturbed inverse kinematics nucleon knockout measurements with a carbon beam. Nat. Phys. 17, 693–699 (2021)

BM@N setup for heavy-ion future program



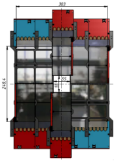
BM@N Hybrid Central Tracker (stage 1, 2022)



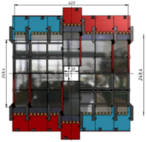
Carbon fiber vacuum beampipe

GEMs (7 stats.)

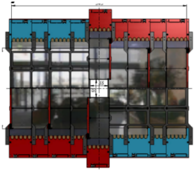
Forward silicon (3 stats.)



10 modules



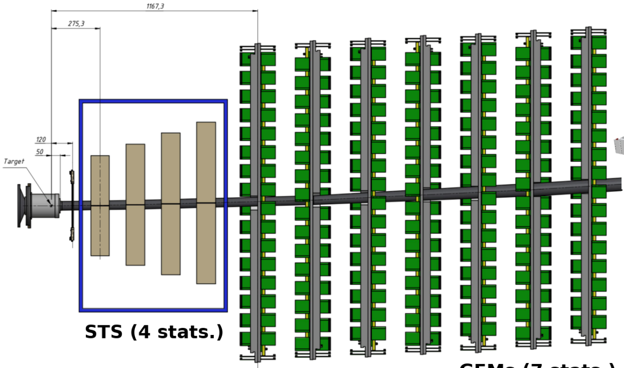
14 modules



18 modules

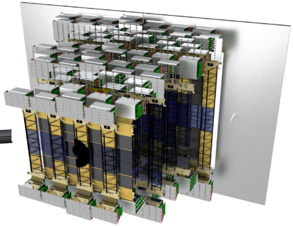
Beam intensities ~ 10^5 Hz

BM@N Hybrid Central Tracker (stage 2, from 2023)



STS (4 stats.)

GEMs (7 stats.)



STS

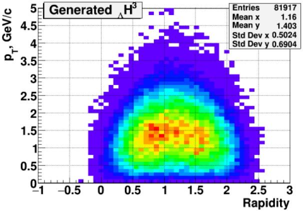
34 ladders
292 modules

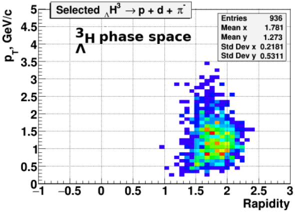
JINR, MSU, GSI/FAIR, Tübingen Uni, WUT

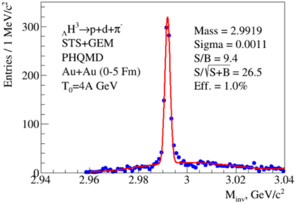
For heavy ion beam intensities of few 10^6 Hz
- **keep 4 STS + 7 GEM**
- **fast FEE and readout electronics**

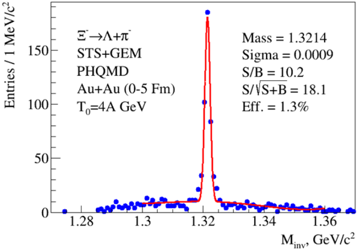
Feasibility study for HI collisions, stage 2 of central tracker

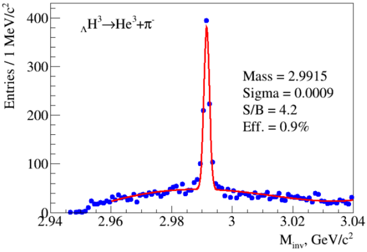
PHQMD model, AuAu @ 4A GeV, b = 0-5 fm, 500k events











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 (2017-carbon, 2018-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 middle weight ion beams (Xe) to be available with BM@N on spring 2022.

Thank you for your attention!

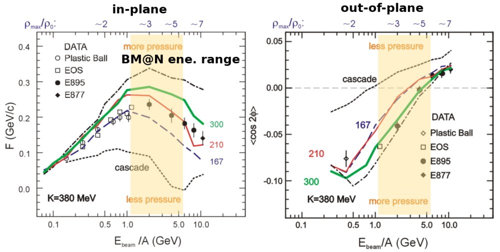
BACKUP

Collective flow of identified particles

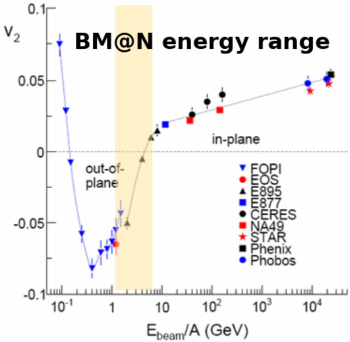
- **collective flow of identified particles (π, p, K, Λ, Ξ, Ω ...) driven by the pressure gradient in the early fireball**
- **Azimuthal angle distribution:**

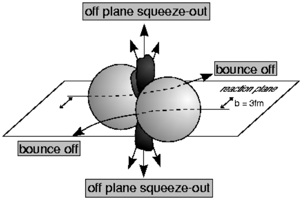
$$dN/d\phi \sim (1 + 2v_1 \cos\phi + 2v_2 \cos 2\phi)$$

Proton flow in AuAu

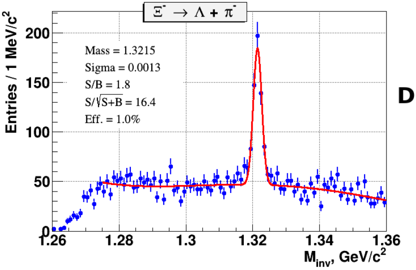


P. Danielewicz, R. Lacey, W.G. Lynch, Science 298 (2002) 1592





Cascade reconstruction in Xe + Sn interactions, stage 1 of central tracker



DCM-QGSM model: Xe + Sn @ 3.9 AGeV, 5M min bias events

phase space of reconstructed Ξ^-