Status of the BM@N experiment at NICA

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on behalf of the BM@N Collaboration

India-JINR Workshop

12/11/2025

Outline

- The BM@N experiment at the NICA: motivation, collaboration, setup
- Current physics results
- Plans for upcoming physics run
- Summary

The NICA accelerator complex

Three main modes

Collider:
MPD, SPD

Fixed target mode:
BM@N

Applied research:
ARIADNA

The BM@N experiment

BM@N - Baryonic Matter at Nuclotron

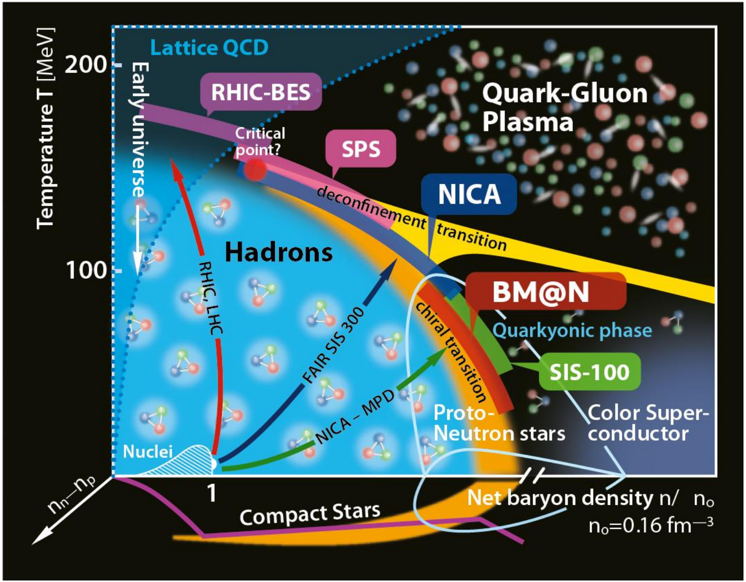
- Fixed target experiment at NICA
- Beam energy: 1 - 4.5 AGeV
- Beams from d to Bi
- Beam intensity up to few 10^6 Hz
- There was carried 8 runs since 2015
- Most recent and interested:
  2017 (C + X)
  2018 (Ar + X)
  2022-2023 (Xe + CsI)

205 Participants, 13 Institutions, 5 Countries

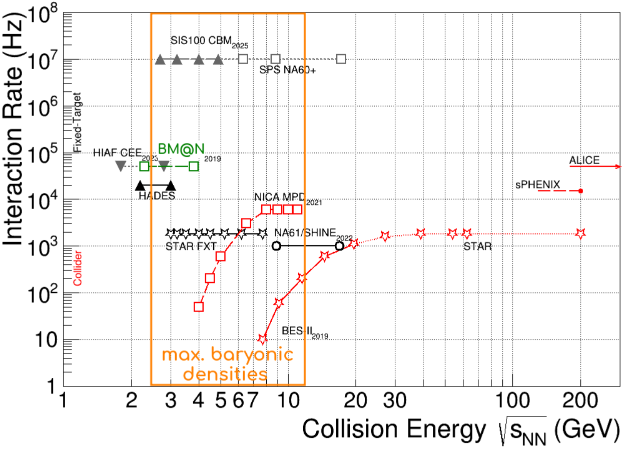
- University of Plovdiv, Plovdiv, Bulgaria
- Saint Petersburg State University, St.Petersburg, Russia
- Joint Institute for Nuclear Research, Dubna, Russia
- Institute of Nuclear Research of RAS, Moscow, Russia
- Shanghai Institute of Nuclear and Applied Physics, Shanghai, China
- NRC Kurchatov Institute, 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
- Institute of Physics and Technology, Almaty, Kazakhstan
- Physical-Technical Institute Uzbekistan Academy of Sciences, Tashkent, Uzbekistan
- High School of Economics, National Research University, Moscow, Russia

Physics motivation for the BM@N experiment

Phase diagram. Yes, again :)



Heavy ion collision experiments



Experiments at the NICA complex:

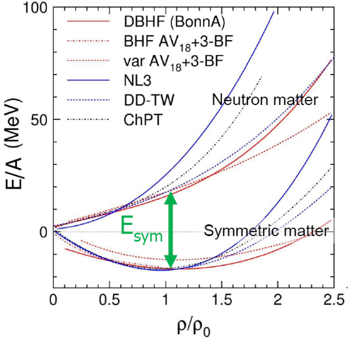
- BM@N, $\sqrt{s_{NN}} = 2.3 - 3.3$ GeV
- MPD_FXT, $\sqrt{s_{NN}} = 2.4 - 3.5$ GeV
- MPD_CLD, $\sqrt{s_{NN}} = 4 - 11$ GeV

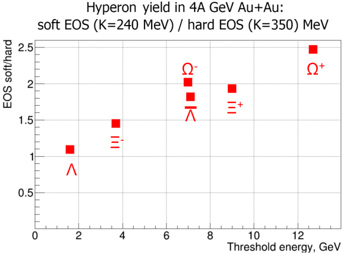
BM@N companions:

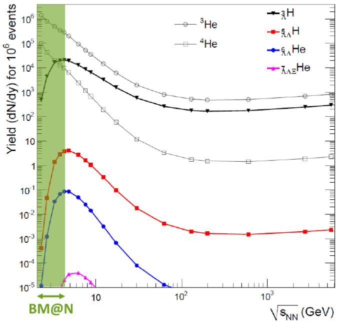
- HADES BES (SIS) Au+Au, $\sqrt{s_{NN}} = 2.42$ GeV
- STAR BES (RHIC) Au+Au, $\sqrt{s_{NN}} = 3 - 200$ GeV
- Future CBM experiment Au+Au, $\sqrt{s_{NN}} = 2.7 - 4.9$ GeV

Goals of the BM@N experiment

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



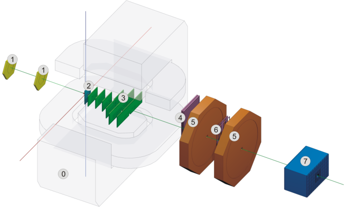




- EoS studying under extreme densities
- Strangeness production
- Critical End Point search
- Flows
- ...

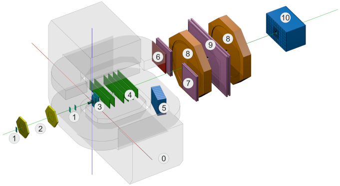
Experimental setup evolution

RUN-6 (2017)



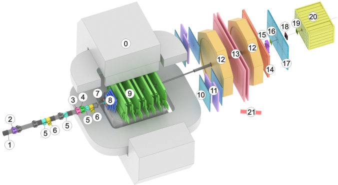
- Beam: C
- Energy: 3.5, 4.0, 4.5 AGeV
- Target: C, Al, Cu, Pb
- Statistics: $\approx 60 \cdot 10^6$

RUN-7 (2018)



- Beam: Ar
- Energy: 3.2 AGeV
- Target: C, Al, Cu, Sn, Pb
- Statistics: $\approx 140 \cdot 10^6$

RUN-8 (2022)

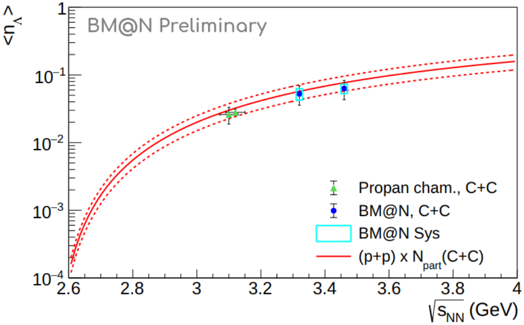


- Beam: Xe
- Energy: 3.0, 3.8 AGeV
- Target: CsI
- Statistics: $\approx 550 \cdot 10^6$

The BM@N spectrometer at the NICA accelerator complex, Nucl.Instrum.Meth.A (2024)

Current physics results

Production of Λ hyperons in C+A @ 4.0(4.5)A GeV



Parametrization for proton-proton collisions scaled to the C + C system

$\langle n_\Lambda \rangle = \langle n_{pp} \rangle \cdot k_{iso} \cdot N_{part},$

where $\langle n_{pp} \rangle = a\frac{(x-1)^b}{x^c}$ - fit based on the Lund String Model

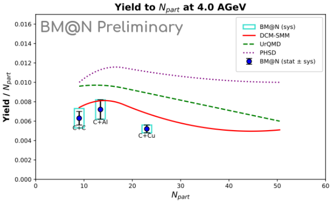
$k_{iso} = \alpha \cdot f_{pp} + \beta \cdot (f_{np} + f_{pn} + f_{nn})$ - isospin correction factor

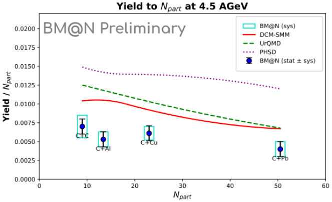
N_{part} - number of participating nucleons

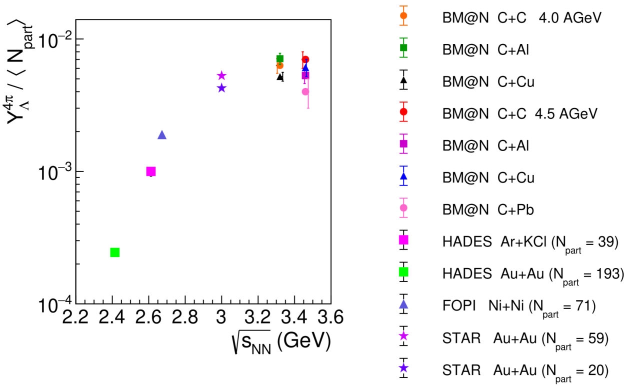
Andersson B. The Lund Model. Cambridge University Press (2023)

The BM@N results for the Λ yields in the C + C collisions at 4.0A and 4.5A GeV are in good agreement with the scaled p + p parameterization model and with measurements on the propan chamber

Production of Λ hyperons in C+A @ 4.0(4.5)A GeV

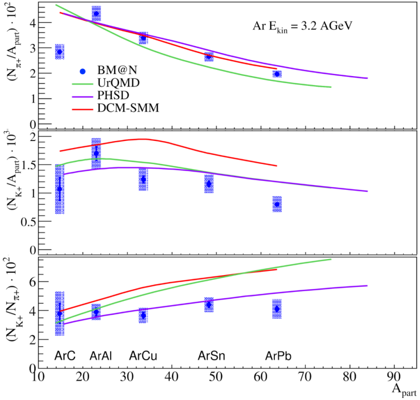


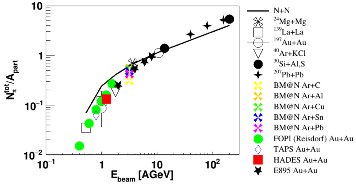


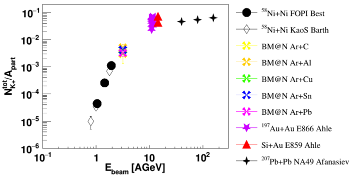


DCM-SMM, PHSD and UrQMD models overestimate Λ yields

Production of π^+ and K^+ in Ar+A @ 3.2A GeV



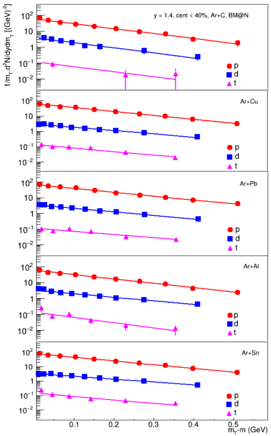




- The ratios of K^+ to π^+ multiplicities show no significant dependence on the mean number of participant nucleons A_{part}
- The PHSD prediction is compatible with this result
- The DCM-SMM and UrQMD models predict a smooth rising of the K^+ to π^+ ratio with A_{part}
- The BM@N results are in trend with the world measured data

Published in J. High Energ. Phys. 2023, 174 (2023) [arxiv:2303.16243]

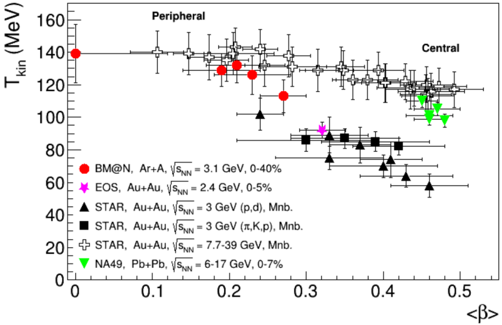
Production of p, d and t in Ar+A @ 3.2A GeV



Blast-Wave model parametrization:

$$\frac{1}{m_T}\frac{d^2N}{dm_T dy} = C(y)\int_0^R m_T K_1\left(\frac{m_T\cosh\rho(r)}{T}\right) I_0\left(\frac{p_T\sinh\rho(r)}{T}\right) r\,dr$$

The average radial flow velocity $\langle\beta\rangle$ and source temperature T at the kinetic freeze-out extracted from fit:

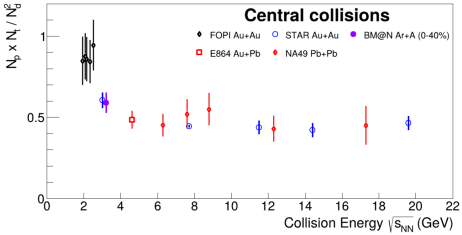


Published in J. High Energ. Phys. 2025, 95 (2025) [arxiv:2504.02759]

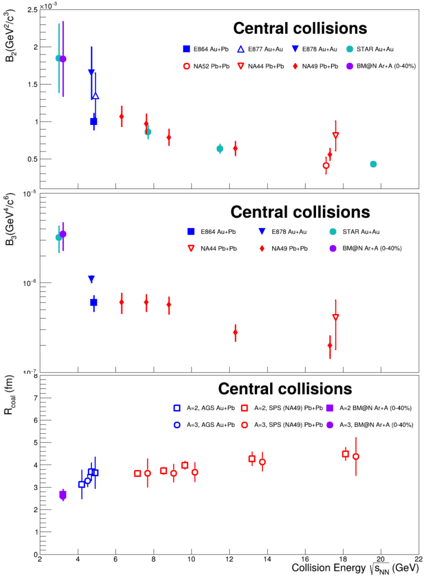
Production of p, d and t in Ar+A @ 3.2A GeV

$$E_A \frac{d^3N_A}{dp_A^3} = B_A \left(E_p \frac{d^3N_p}{dp_p^3}\right)^Z \left(E_n \frac{d^3N_n}{dp_n^3}\right)^{A-Z}$$

B_A is the coalescence parameter that characterizes the probability of nucleons to form nucleus A.



- In the coalescence model, the ratio $\frac{N_p N_t}{N_d^2} \approx 0.3(1+\Delta n)$ is reated to the neutron density fluctuation Δn.
- The coalescence parameters for d and t measured by BM@N follow the increasing trend with the decreasing collision energy.
- The estimated BM@N coalescence radius of $2.5-3$ fm at $p_T = 0$ is practically independent of the target mass.



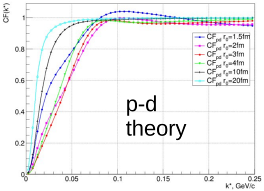
Baryon femtoscopy in Ar+A @ 3.2A GeV

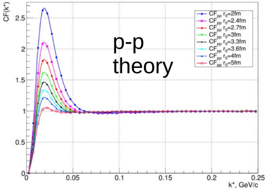
Correlation function:

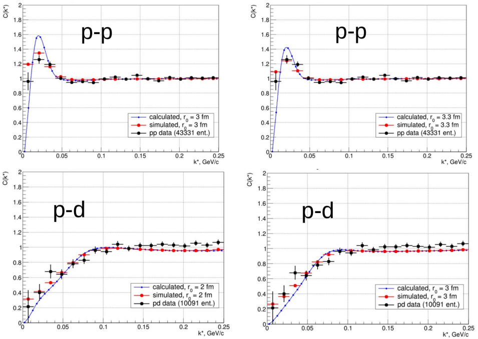
$$C(k^*) = \frac{A(k^*)}{B(k^*)},\ k^* = \frac{1}{2}|\vec{p}_1^* - \vec{p}_2^*|$$

A - correlated pairs

B - mixing pairs







- PID by TOF-400 and TOF-700 to determine the effective radii of proton and deuteron sources
- CFs tend to 1 with increasing source radii, allowing one to estimate $R \approx 3$fm in agreement with the expected value
- Measured CFs agree with theoretical expectations: pp CF peaked at k^* = 20 MeV/c

- p-d: source radius $r_0 = 2.6 \pm 0.3(\text{stat.}) \pm 0.3(\text{syst.})$ fm
- p-p: source radius $r_0 = 3.3 \pm 0.1(\text{stat.}) \pm 0.3(\text{syst.})$ fm

It is not official physic results yet

Directed flow of deuterons and protons in Xe+CsI @ 3.8A GeV

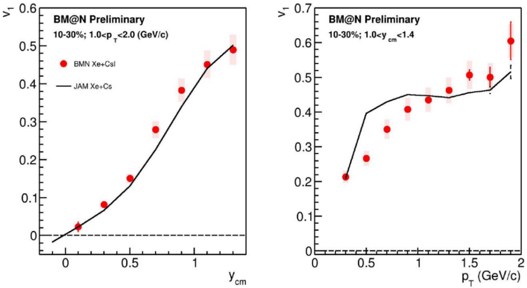
Azimuthal angle distribution of particles:

$$\frac{dN}{d\phi} \propto \frac{1}{2\pi}\left(1 + 2\sum_{n=1}^{\infty} v_n \cos n(\phi - \Psi_{RP})\right),$$

where v_n is an anisotropic flow of n^{th} harmonic

$$v_n = \langle \cos n(\phi - \Psi_{RP})\rangle$$

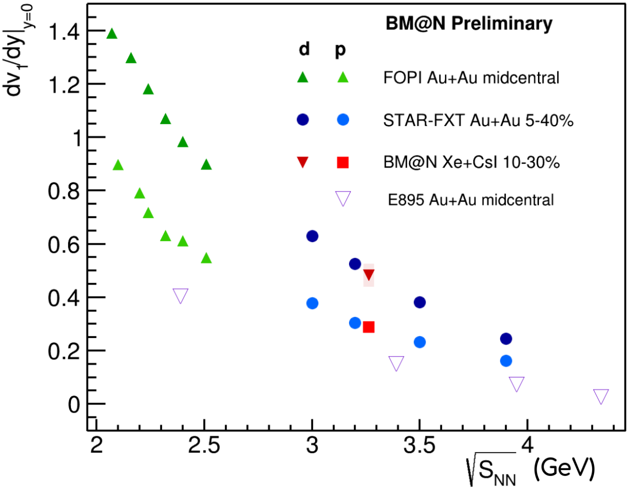
- v_1 - in-plane flow (direct)
- v_2 - out-off-plane flow (elliptic)



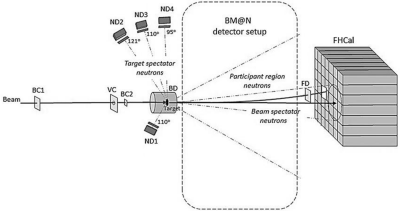
Directed flow of protons was compared with JAM model

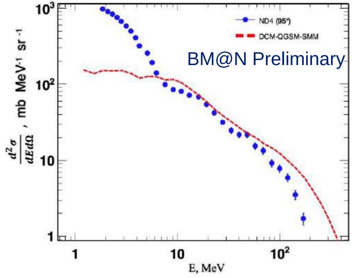
Directed flow of deuterons and protons in Xe+CsI @ 3.8A GeV

- Slope of v_1 was estimated for protons and deuterons
- Scaling factor ≈ 2 could be seen from v_1 slope
- BM@N result is in trend with the STAR FXT Au+Au data



Study of neutron emission from target fragmentation in Xe+CsI @ 3.8A GeV





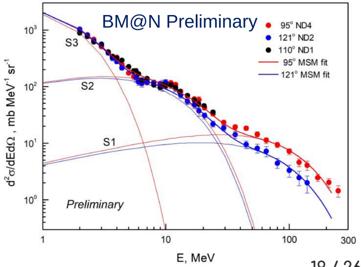
Moving Source Model with three sources used to parametrized data:

$$\frac{d^2\sigma}{dEd\Omega} = \sum_{i=1}^{3} pA_i \exp\left\{-\left(\frac{E+m-p\beta\cos\theta}{\sqrt{1-\beta_i^2}} - m\right)/T_i\right\},$$

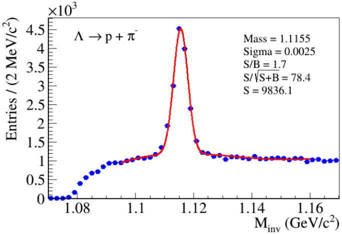
A_i, T_i and β_i are amplitude, temperature and velocity of sources

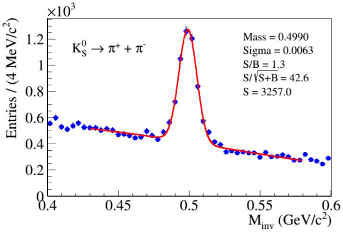
V. I. Yurevich, R. M. Yakovlev, and V. G. Lyapin, Phys. At. Nucl. 75, 192 (2012)

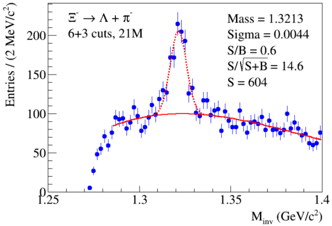
- S1 describes the hard part of the spectra ($T_1 = 55 \pm 5$ MeV)
- S2 reproduces the neutron emission in multifragmentation decay ($T_1 = 6.5 \pm 0.5$ MeV)
- S3 describes the fragmentation decay and evaporation process ($T_1 = 0.8 \pm 0.1$ MeV)



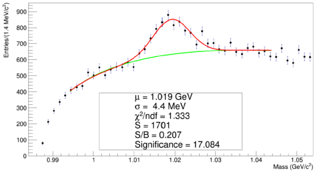
Strangeness in Xe+CsI @ 3.8A GeV





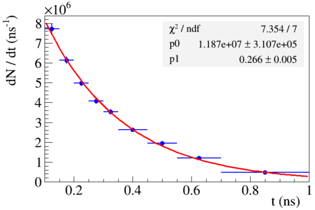


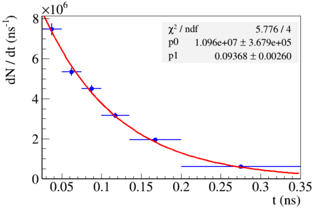
- Stable signals for Λ and K^0_S
- First observations for Ξ^- and $\phi(1020)$
- The work is ongoing, results are preliminary



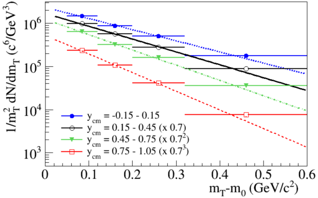
Reconstruction of Λ and K^0_S in Xe+CsI @ 3.8A GeV

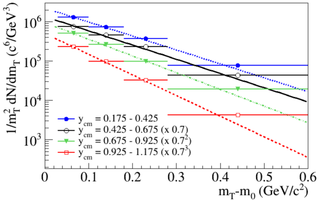
$$\frac{dN}{dt} = \frac{N_0}{\tau} e^{-\frac{t}{\tau}}$$



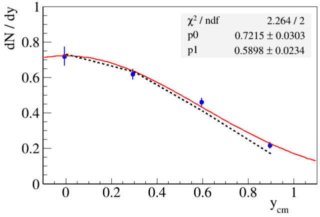


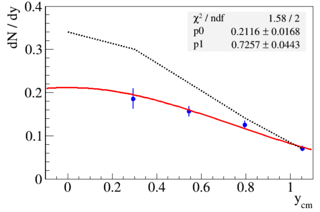
$$\frac{1}{m_T^2}\frac{dN}{dm_T} = C(t)e^{-\frac{m_T - m_0}{T_{eff}}}$$





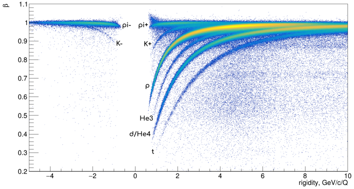
rapidity dependence and DCM-SMM comparision

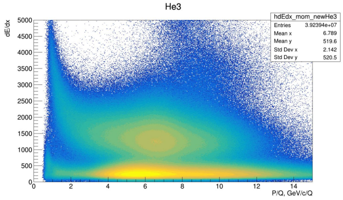


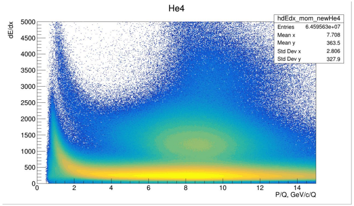


It is not official physic results yet

Observation of hypernuclei signals in Xe+CsI @ 3.8A GeV



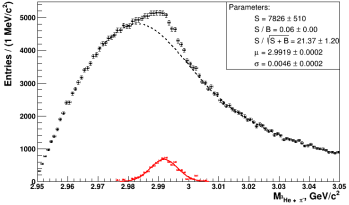




Ongoing improvements:

- Improve $\frac{dE}{dx}$ in GEM detectors for ^{3}He, ^{4}He selection
- Use combined ToF-400 and ToF-700 data for K^+ and K^- identification
- Using TMVA to separate fake tracks (mostly π^-)

$^3_\Lambda H \rightarrow {}^3He + \pi^-$



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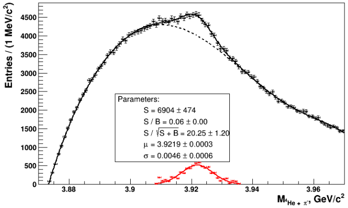
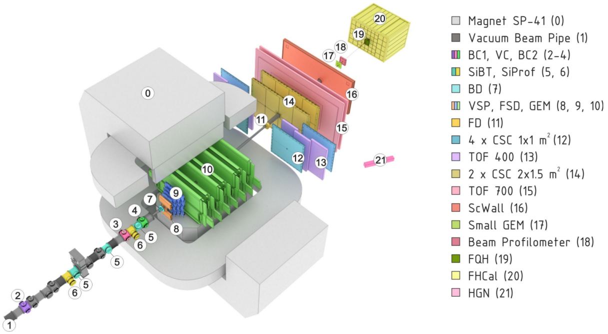


Just signal observation, not physics yet

Plans for upcoming physics runs

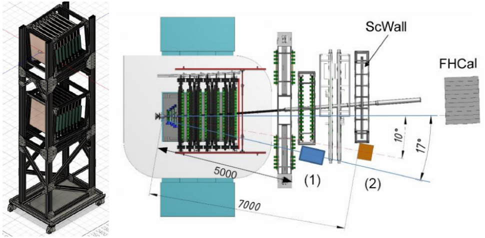


Physics runs in the Xe beam in 2025-2026

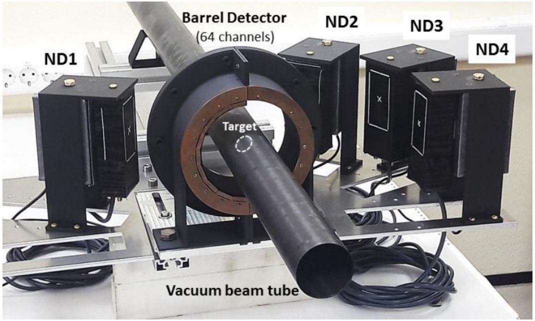
- Beam energy scan: 2 - 3 AGeV
- Same central tracker configuration based on FSD and GEM detectors
- Additional vertex plane of silicon micro-strip detectors
- ToF-400 acceptance extended by factor 1.5
- New Large CSC added to reconstruct tracks behind the magnet

Plans for upcoming physics runs

Upgrade in neutron experimental program



- HGN detector parameters: 2 sub-detectors with 8 layers each
- 11x11 cells in one layer with SiPM read-out
- first layer works as VETO
- next 7 layers: 3cm Cu + 2.5cm scintillator
- time resolution of one scintillator cell is ≈120 ps
- neutron detection efficiency more than 60% at 1 GeV



- new mechanics has been developed
- allows more precise installation of the detectors
- allows to study of neutron energy spectra at small angles to the beam direction
- can be fast installed and dismounted

Summary and Interconnection points

Topics of current physics analyses

- Production of Λ, Ξ^- hyperons, K^0_S, $K^{\pm}$, $\pi^{\pm}$, ϕ mesons, light nuclear fragments
- Collective flow of p, d and Λ
- Femtoscopy of pp, pd, pΛ
- Production light hyper-nuclei ${}^{3}_{\Lambda}$H and ${}^{4}_{\Lambda}$H
- Neutron emission with upgraded detector setup
- ...

Big collaborations: three groups are solving one task to cross-check.
BM@N collaboration: one group is solving three tasks...

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BM@N collaboration: one group is solving three tasks...

We already have many experimental data, which are waiting you!

More information: `bmn.jinr.int`

Let's keep in touch: `merts@jinr.ru`

Thank you!