Status of the BM@N experiment

M.Kapishin

BM@N experiment

Baryonic Matter at Nuclotron (BM@N) Collaboration:

5 Countries, 13 Institutions, 207 participants

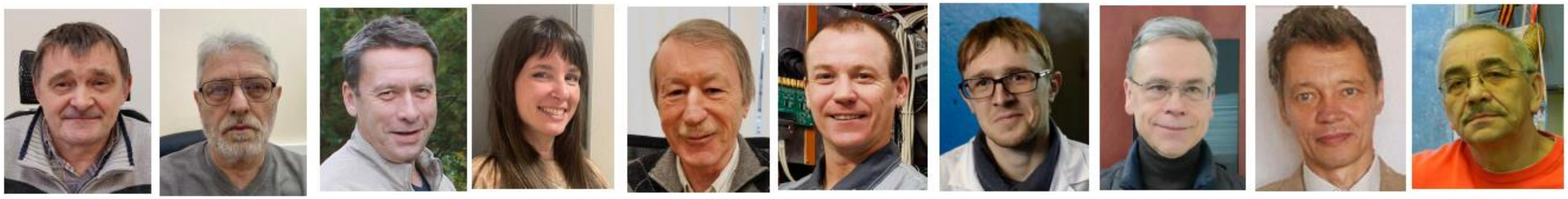
- *University of Plovdiv, Bulgaria*
- *St.Petersburg University*
- *Shanghai Institute of Nuclear and Applied Physics, CFS, China;*
- *Joint Institute for Nuclear Research;*
- *Institute of Nuclear Research RAS, Moscow*
- *NRC Kurchatov Institute, Moscow combined with Institute of Theoretical & Experimental Physics, NRC KI, Moscow*
- *Moscow Engineer and Physics Institute*
- *Skobeltsyn Institute of Nuclear Physics, MSU, Russia*
- *Moscow Institute of Physics and Technics*
- *Lebedev Physics Institute of RAS, Moscow*
- *Institute of Physics and Technology, Almaty*
- Physical-Technical Institute Uzbekistan Academy of Sciences, Tashkent
- High School of Economics, National Research University, Moscow

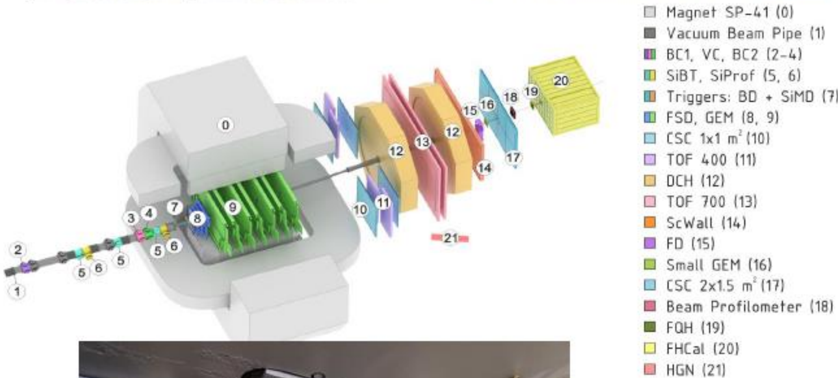
JINR prizes 2024

For physics instruments and methods

First prize *“Development of the BM@N spectrometer at the NICA accelerator complex”*

M.N.Kapishin, S.N.Bazylev, S.V.Khabarov, E.M.Kulish, A.M.Makankin, S.M.Piyadin, M.M.Rumyantsev, S.A.Sedykh, V.I.Yurevich, N.I.Zamyatin





Abstract

The BM@N spectrometer is designed to conduct fixed-target experiments with extracted beams of the Booster-Nuclotron accelerator complex and is the first large experimental setup created within the NICA project. The main goal of the BM@N physics program is to study dense nuclear matter formed in nucleus-nucleus collisions at beam energies of 1.5 – 5 AGeV. The program includes a series of measurements in beams of light (C), medium (Ar, Kr) and heavy (Xe, Bi) relativistic nuclei. To implement this program, over the past few years, the experimental setup has been equipped with modern detector systems. A range of works was carried out to prepare the spectrometer for experiments with heavy ion beams. **In December 2022 – January 2023, the first physics run was performed at the set-up with the Xe + CsI reaction at Xe beam energies of 3.0 AGeV and 3.8 AGeV. During the run, experimental data with statistics of more than 500 million events were collected, and all detector subsystems demonstrated performance compliant with the design parameters.** A detailed technical description of the spectrometer and its major subsystems is presented in a paper published in 2024 in the journal Nuclear Instruments and Methods.

Second prize:

“Development of the software complex for the implementation of a unified architecture for distributed data processing and storage at the BM@N/NICA experiment”.

Authors: E. Alexandrov, I. Alexandrov, N. Balashov, A. Chebotov, I. Filozova, K. Gertsenberger, P. Klimai, A. Moshkin, I. Pelevanyuk, G. Shestakova.

Production of protons, deuterons and tritons in argon-nucleus interactions at 3.2 A GeV

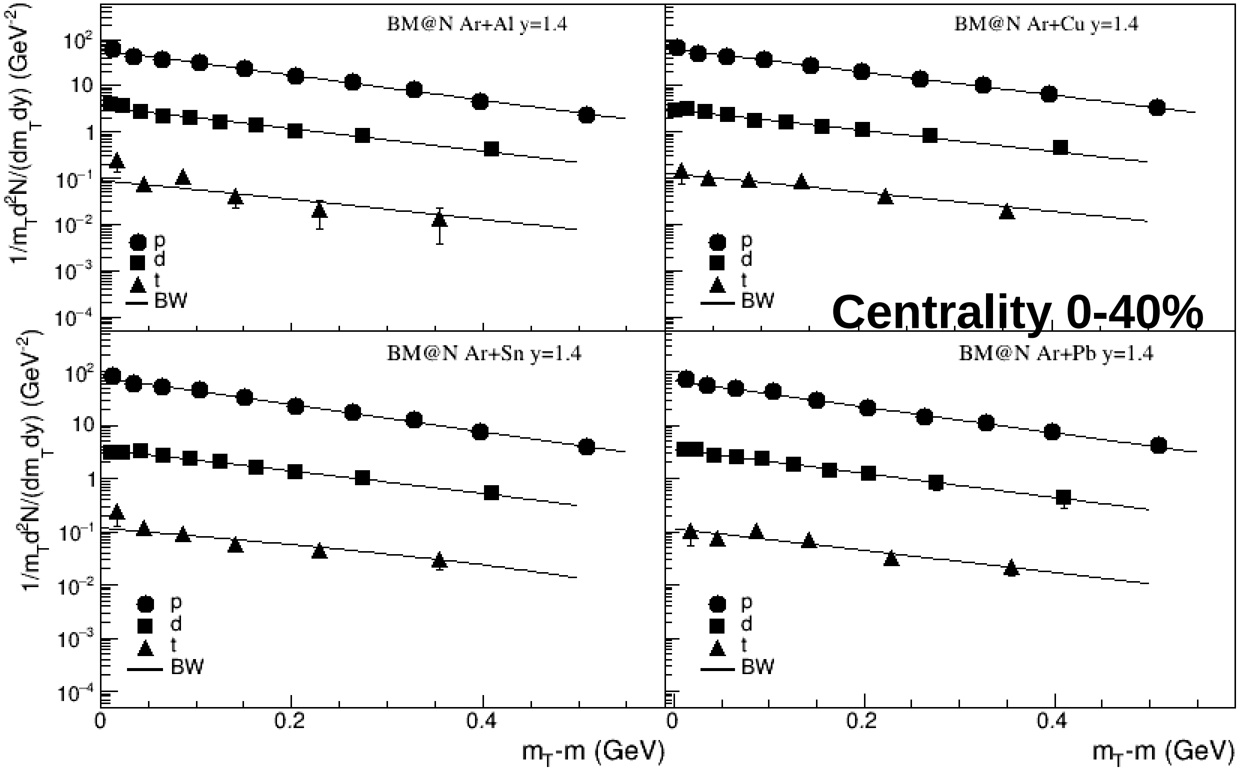
BM@N Collaboration

Abstract

Results of the BM@N experiment at the Nuclotron/NICA complex on the production of protons, deuterons and tritons in interactions of an argon beam of 3.2 A GeV with fixed targets of C, Al, Cu, Sn and Pb are presented. Transverse mass spectra, rapidity distributions and multiplicities of protons, deuterons and tritons are measured. The results are treated within a coalescence approach and compared with predictions of theoretical models and with other measurements.

arXiv:2504.02759 → paper accepted by JHEP

Blast-Wave model fit of p,d,t spectra



The fitted temperature of ~120-130 MeV and transverse expansion velocity of ~0.2-0.25c are practically the same for Ar + Al, Cu, Sn, Pb interactions

except for a smaller flow indicated for Ar+C

	Ar+C	Ar+Al	Ar+Cu	Ar+Sn	Ar+Pb
T , MeV	140 ± 18	129 ± 10	132 ± 11	113 ± 10	126 ± 12
$\langle\beta\rangle$	$0.0\pm^{0.12}_{0.0}$	0.19 ± 0.05	0.21 ± 0.04	0.27 ± 0.03	0.23 ± 0.05
χ^2/ndf	44/49	127/55	113/55	86/55	172/55

BM@N experiment

Coalescence parameters B_2 (d) and B_3 (t)

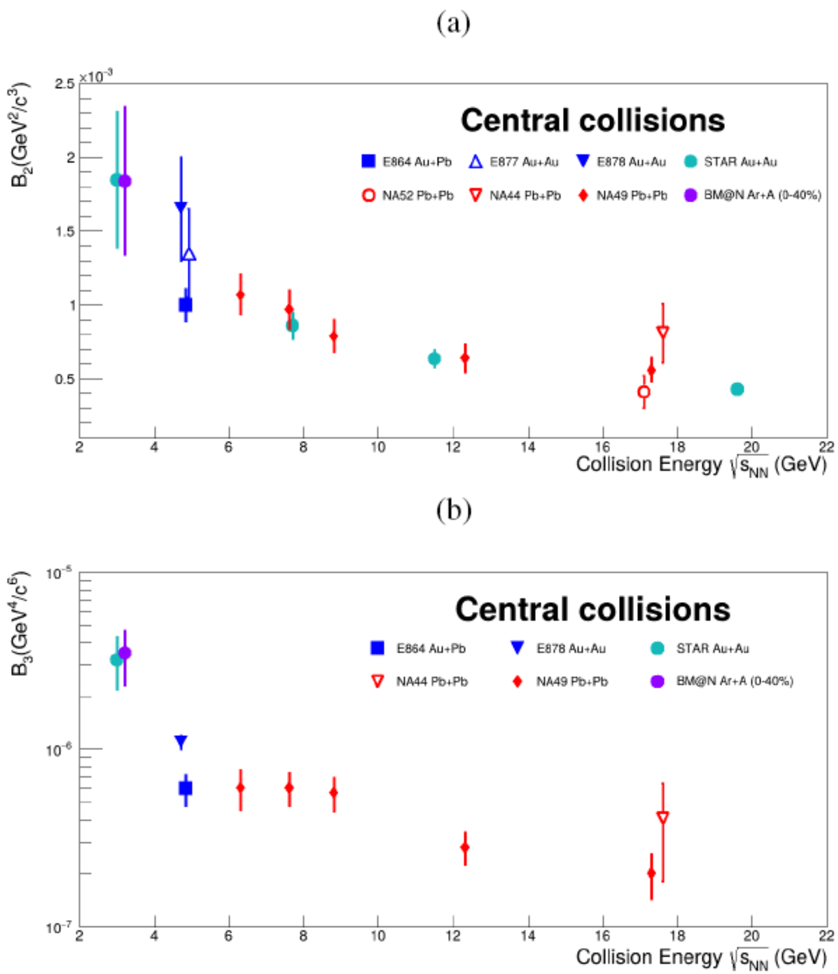


Figure 15. Coalescence parameters $B_2(p_T = 0)$ (a) and $B_3(p_T = 0)$ (b) for deuterons and tritons as functions of the nucleon-nucleon center-of-mass energy. The BM@N result is the weighted average value calculated in the rapidity range $-0.18 < y^* < 0.22$ for Ar+Al, Cu, Sn and Pb interactions with centrality 0–40%.

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.

$$B_2 = \frac{3\,\pi^{3/2}\,\langle \mathcal{C}_\mathrm{d}\rangle}{2m_t\,\mathcal{R}_\perp^2(m_t)\,\mathcal{R}_\parallel(m_t)}\,e^{2(m_t-m)\left(\frac{1}{T_\mathrm{p}^*}-\frac{1}{T_\mathrm{d}^*}\right)}$$

$$R_{coal} = \sqrt[3]{R_\parallel R_\perp^2}$$

Compound yield ratio $N_p\ N_t\ /\ N_d^2$

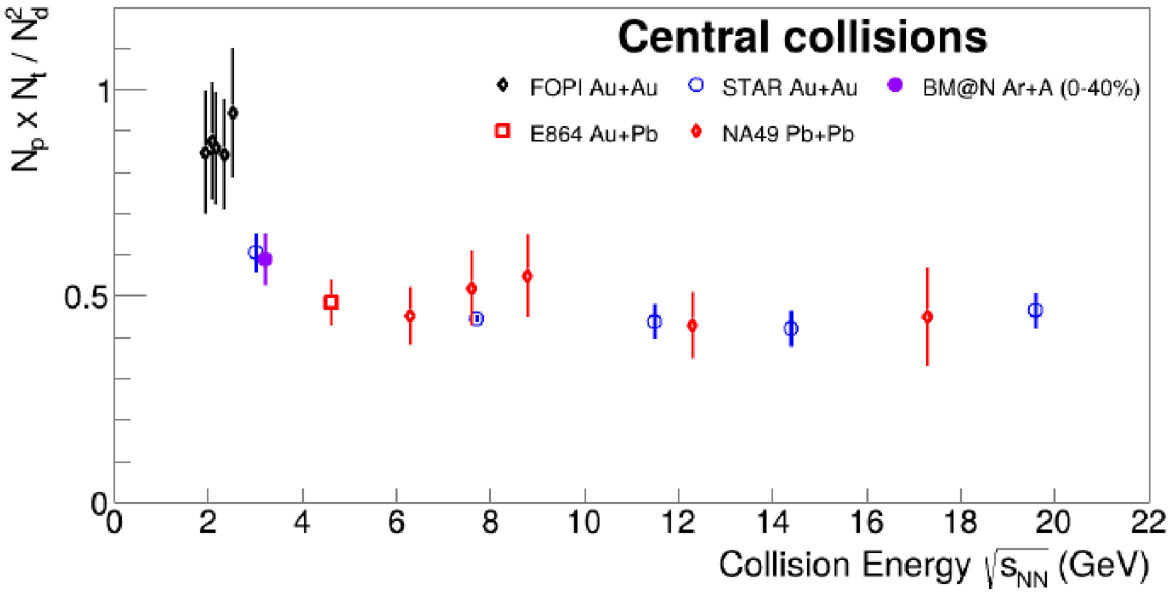


Figure 23. Compound yield ratio $N_p \cdot N_t/N_d^2$ of protons (N_p) and tritons (N_t) to deuterons (N_d^2) as a function of the center-of-mass energy of nucleus-nucleus interactions. The BM@N result represents the weighted average value in the rapidity range $-0.18 < y^* < 0.22$ calculated for Ar+Al, Cu, Sn and Pb interactions with centrality 0–40%.

In the Coalescence model, the ratio $N_p\ N_t\ /\ N_d^2 \approx 0.3\ (1 + \Delta n)$ is a measure of the neutron density fluctuation Δn

Irregular increase is expected near the critical point of the phase transition between the quark-gluon and hadron matter.

The measured BM@N ratio agrees with that of STAR and confirms the increase with the decreasing collision energy, expected in the coalescence model.

Production of Λ hyperons in 4.0 AGeV and 4.5 AGeV carbon-nucleus interactions at the Nuclotron

for BM@N Collaboration

April, 2025

Abstract

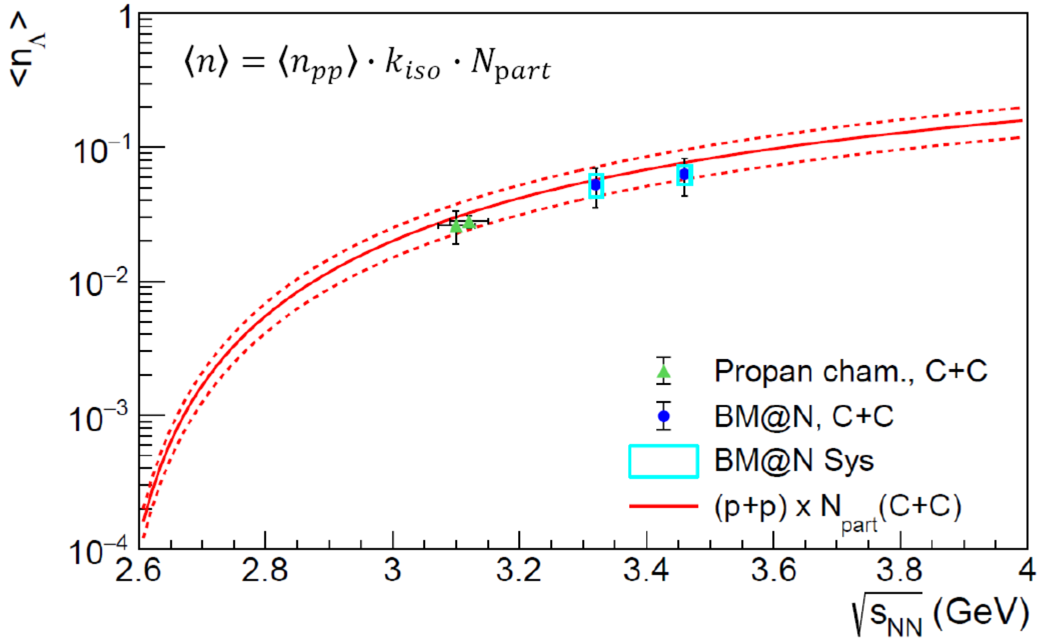
The BM@N experiment (Baryonic Matter at the Nuclotron) is the first experiment undertaken at the JINR NICA-Nuclotron accelerator complex. The BM@N scientific program comprises studies of dense nuclear matter in heavy ion beams of the intermediate energy range between the SIS-18 and NICA/FAIR facilities. In this paper the results of the analysis of data are collected with the carbon beam at the 4.0 and 4.5 AGeV kinetic energy interacting with the different solid targets (C, Al, Cu, Pb). Transverse momentum, rapidity spectra and yields of Λ hyperons are measured. The results are compared with the theoretical models predictions and with the experimental data on carbon-carbon interactions measured at lower energies.

→draft in circulation in the BM@N Collaboration

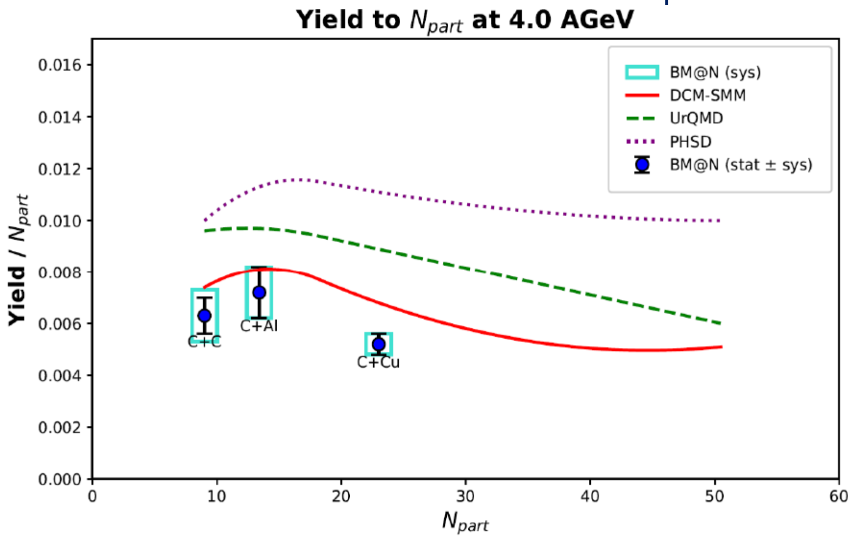
Energy and N_{part} dependence of Λ yields in C+C, Al, Cu, Pb interactions

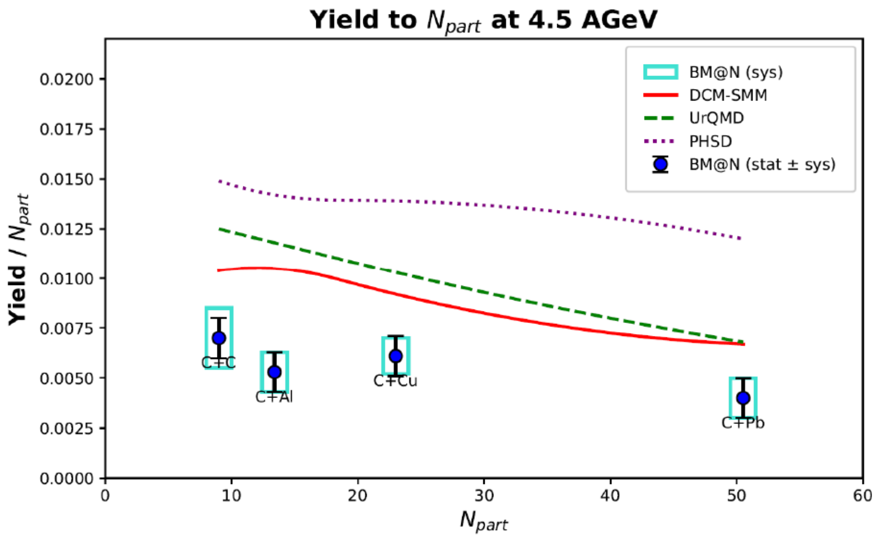
K.Alishina, Yu.Stepanenko, M.Zavertyaev

Parameterisation for proton-proton collisions (pp) scaled to the C + C system



Λ yield normalized to N_{part}





DCM-SMM, PHSD and UrQMD models overestimate Λ yields →

BM@N experiment

Directed flow of deuterons and protons in Xe+CsI interactions

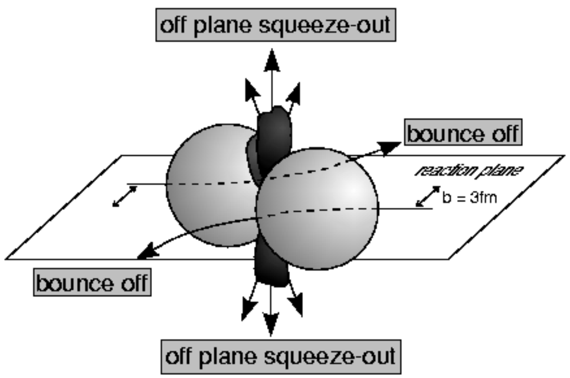
BM@N Preliminary: MEPhI group

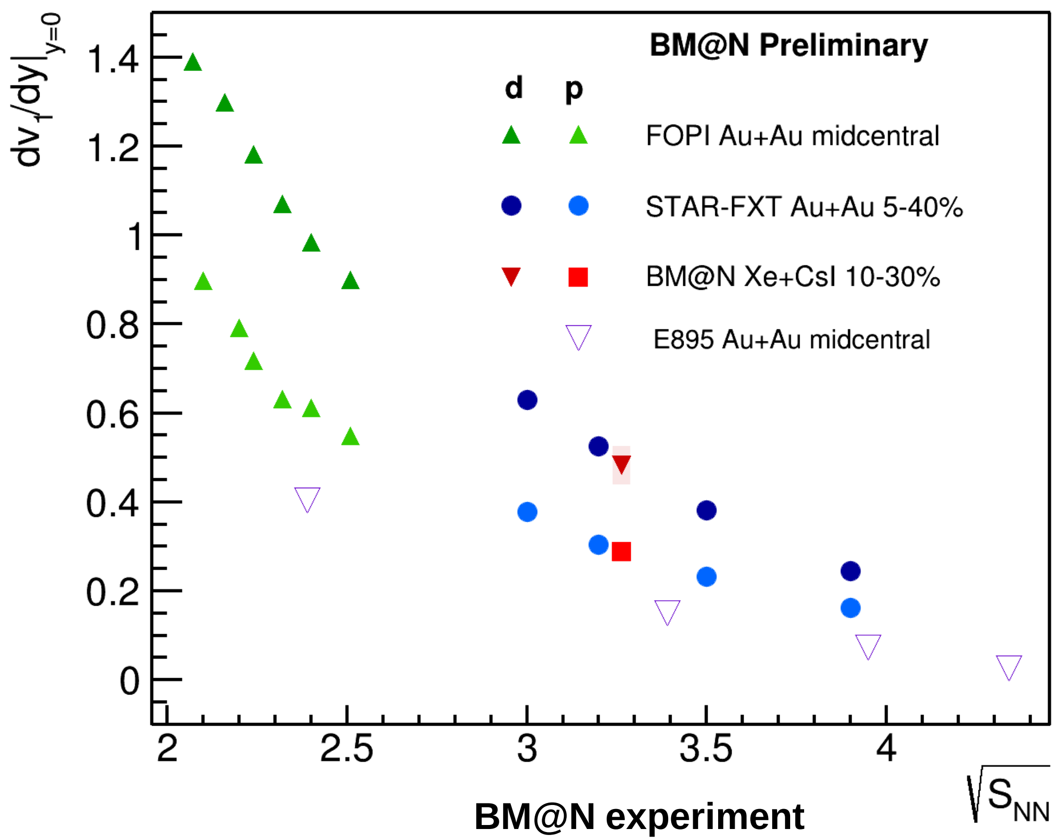
Azimuthal angle distribution:

$dN/d\varphi \propto (1 + 2v_1 \cos\varphi + 2v_2 \cos2\varphi)$

→ **Directed flow *v*1 of protons and deuterons scales with A (1:2)**

→ **BM@@N result is in line with the STAR FXT Au+Au data**



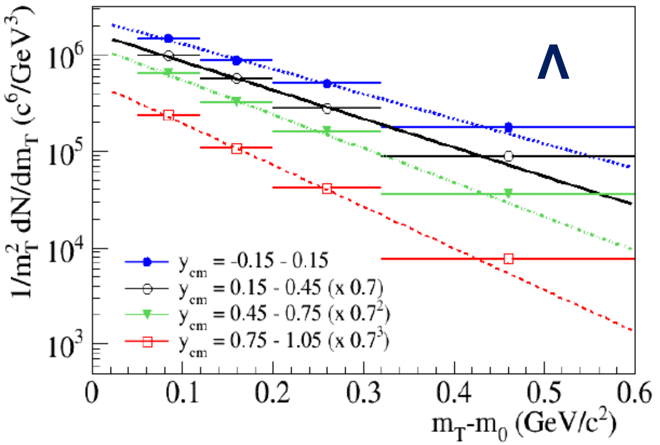


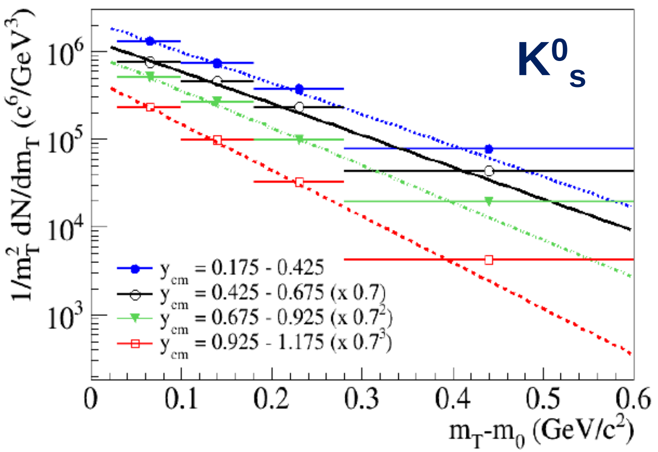
Towards Λ and K^0_s yields in Xe+CsI interactions

A.Zinchenko and the team

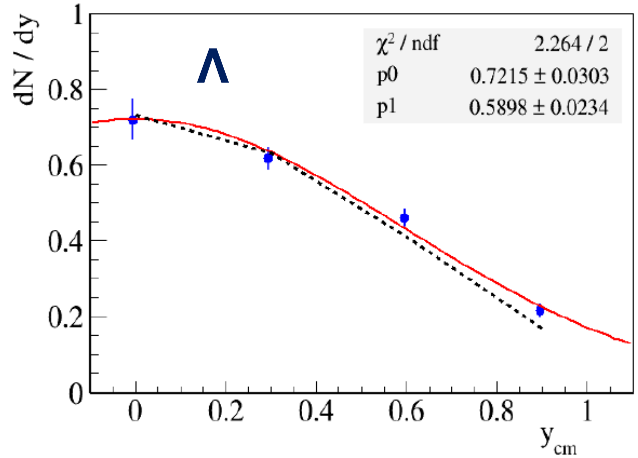
Transverse mass spectra of Λ and K^0_s

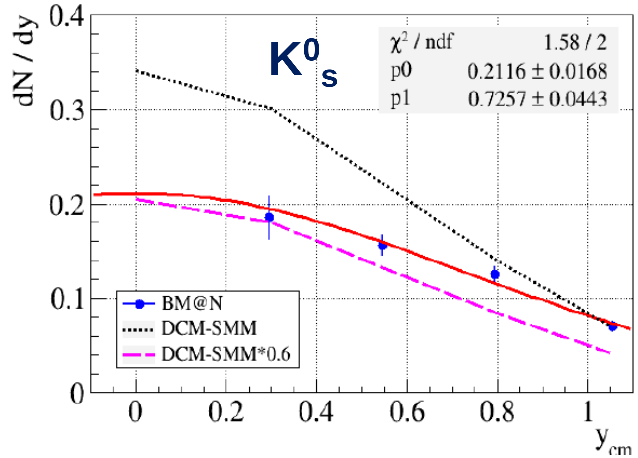
$$\frac{1}{m_T^2}\frac{dN}{dm_T} = C(t)\cdot\exp\left(-\frac{m_T - m_0}{T_{eff}}\right)$$



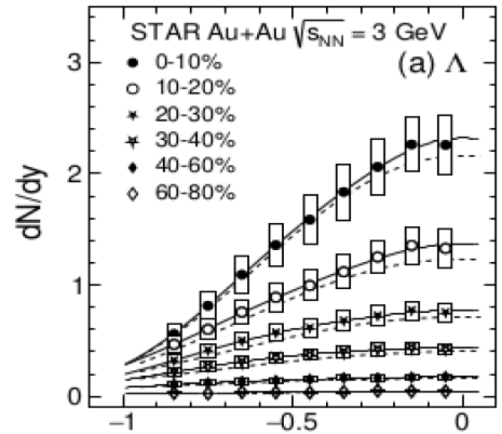


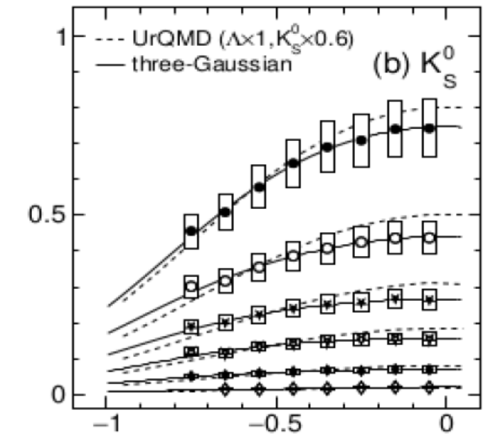
Rapidity spectra of Λ and K^0_s compared with DCM-SMM model





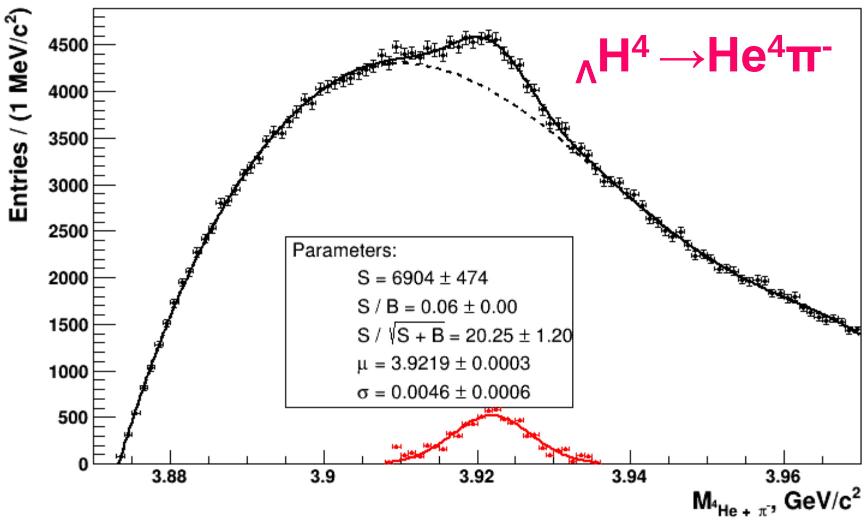
STAR results

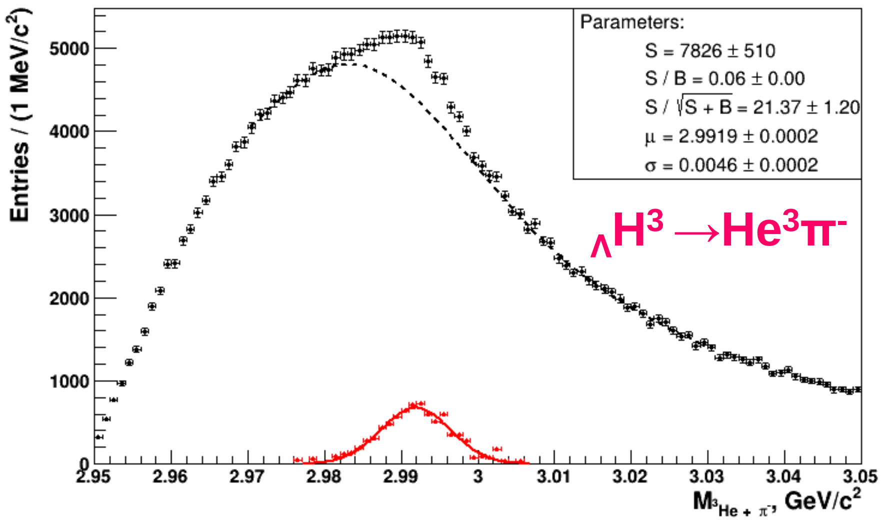


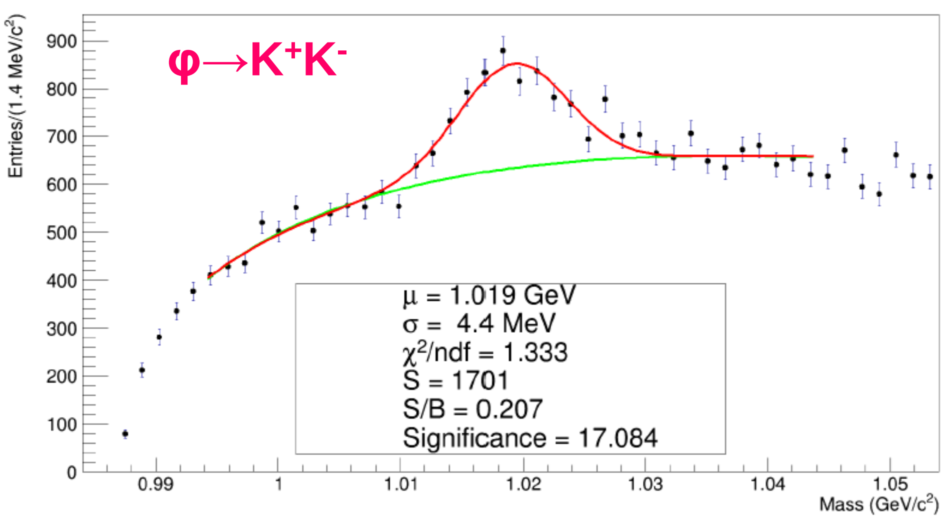


${}_{\Lambda}H^3$, ${}_{\Lambda}H^4$, φ decays in Xe+CsI interactions

S.Merts, R.Barak







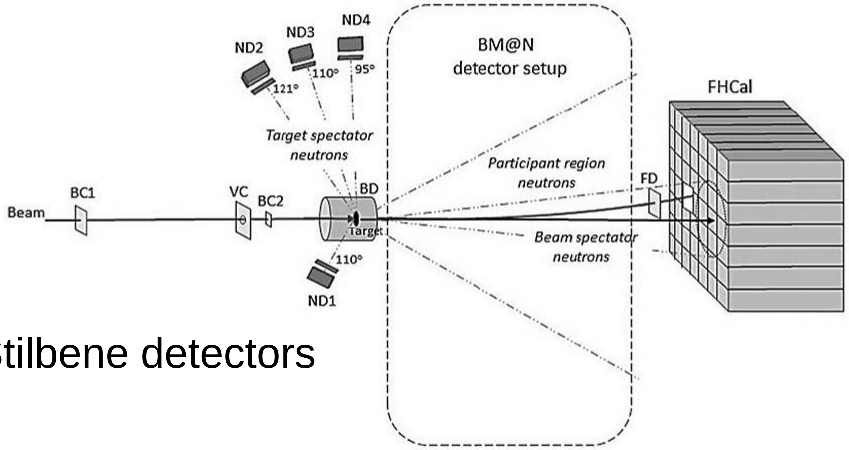
Ongoing improvements:

- **Improve dE/dx in GEMs for He^3, He^4 selection**

- **Use combined ToF-400 and ToF-700 data for K^+K^- identification**

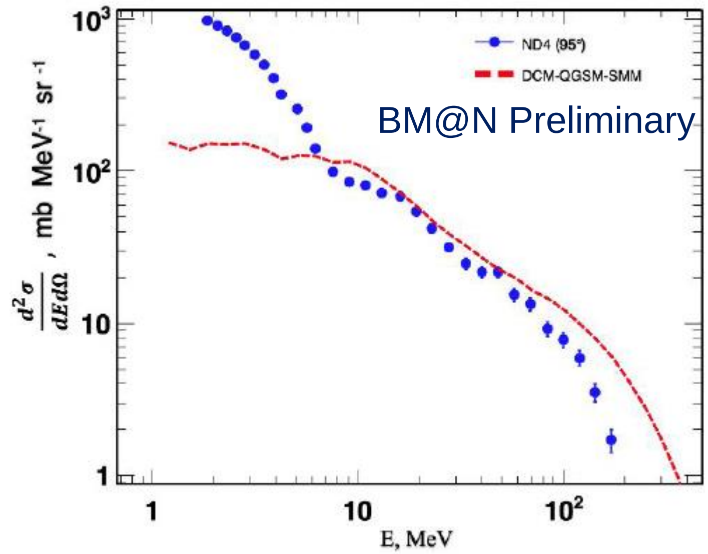
Study of neutron emission from target fragmentation in ^{124}Xe + CsI collisions at 3.8 A GeV

N.Lashmanov, V.Yurevich



Stilbene detectors

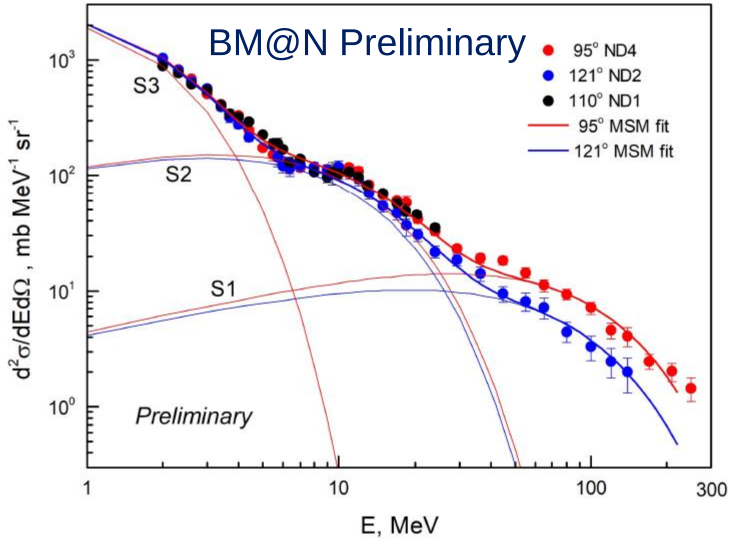
Compare neutron spectra with DCM-SMM model

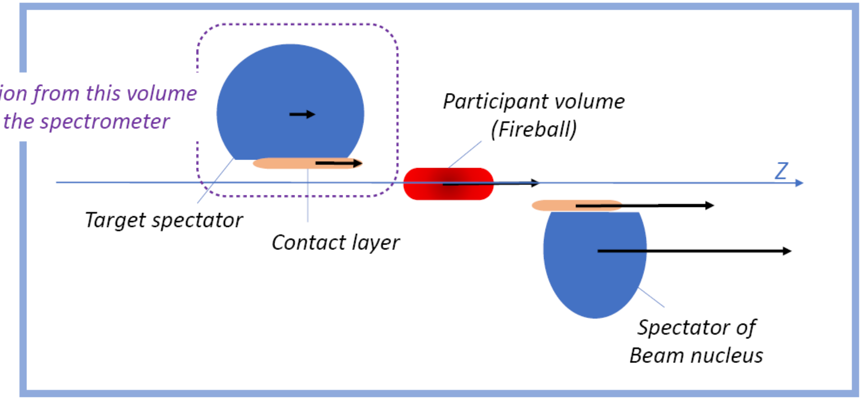


Moving Source model:

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

Total neutron spectra





Baryon femtoscopy in Ar+A collisions

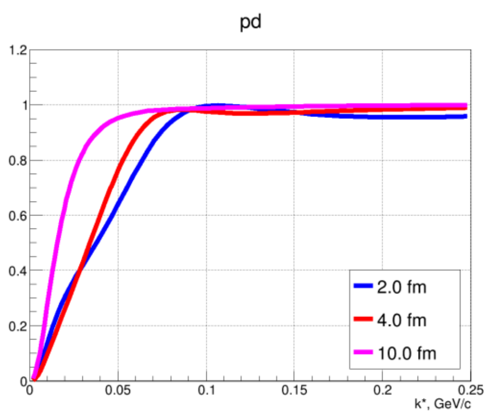
Correlation function:

$$C(k^*) = \frac{A(k^*)}{B(k^*)}$$

$$k^* = \frac{1}{2} \cdot |\overrightarrow{p_1^*} - \overrightarrow{p_2^*}|$$

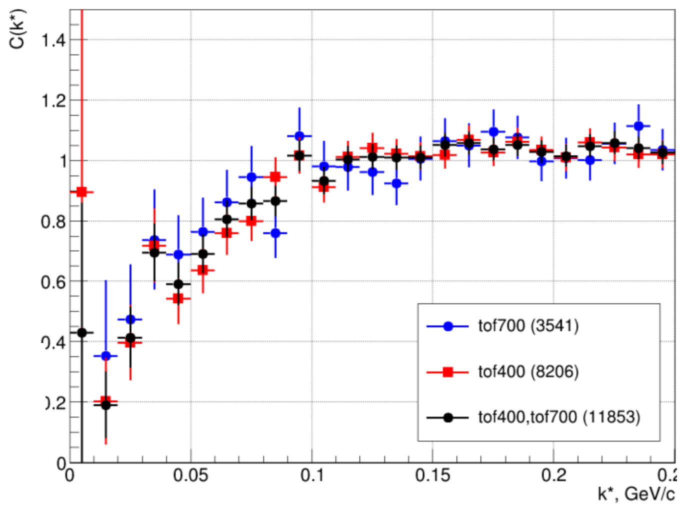
A **- correlated pairs**
B **- uncorrelated (mixing)**

Mid rapidity range
0.5 < y ≤ 1.7

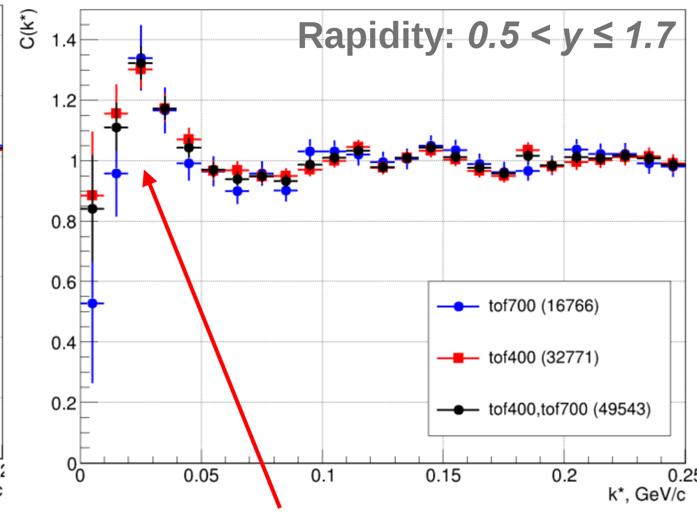


Using particles identified by TOF-400 and TOF-700 detectors to determine the effective radii of proton and deuteron sources

proton - deuteron



proton - proton



CFs tend to 1 with increasing source radii, allowing one to estimate R ~3fm in agreement with the expected value

Measured CFs agree with theoretical expectations: pp CF peaked at k* = 20 MeV/c

Status of data analysis and plans for next physics runs

Topics of current physics analyses:

- analysis of production of Λ, Ξ- hyperons, K^0_S , K±, π±, φ mesons, light nuclear fragments in Xe+CsI interactions;
- collective flow of protons, deuterons, Λ
- femtoscopy of pp, pd, pΛ
- light hyper-nuclei $_\Lambda H^3$, $_\Lambda H^4$

Physics run in the Xe beam in 2025

→ beam energy scan: 2 - 3 AGeV
→ same central tracker configuration based on silicon micro-strip and GEM detectors,
→ additional 1st vertex plane of silicon micro-strip detectors
→ ToF-400 acceptance extended by 1.5

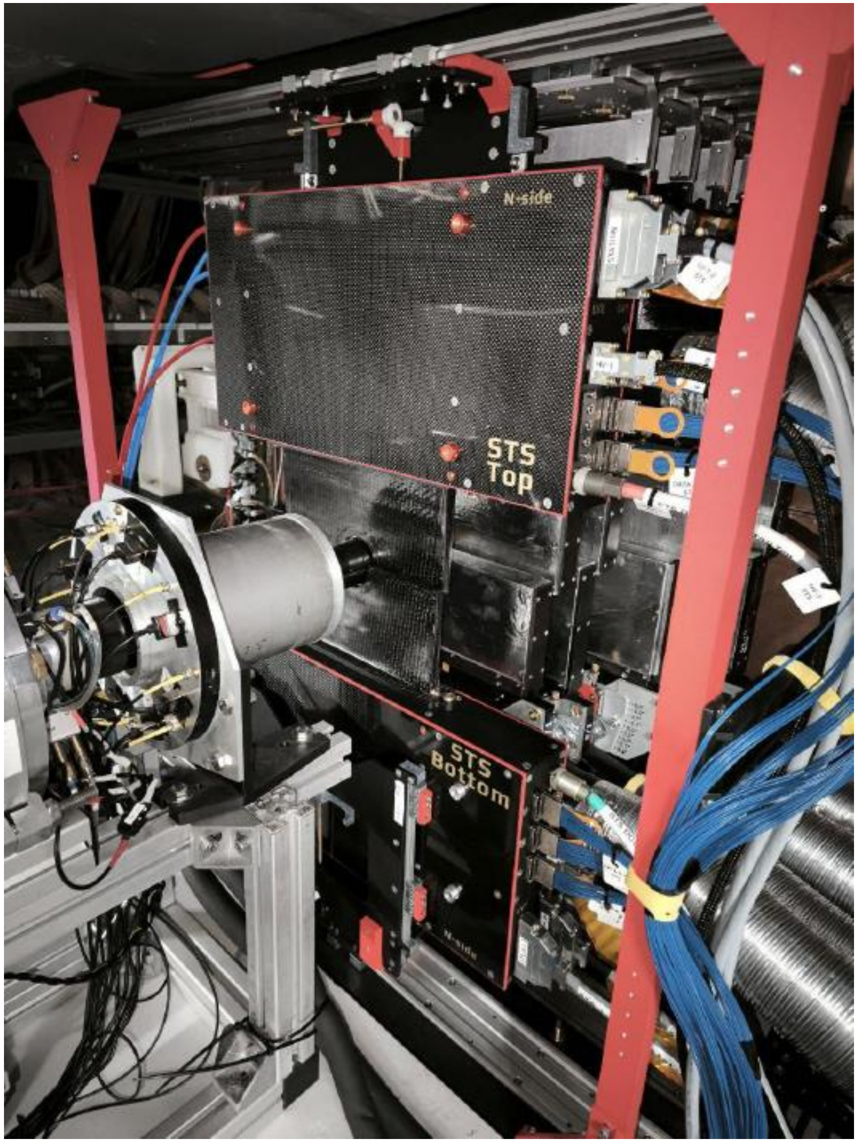
Preparations for a physics run with the Bi beam

- Further development of the central tracker is foreseen: installation of additional station of silicon micro-strip detectors
- It is planned to put into operation a 2-coordinate (X/Y) neutron detector of high granularity to measure neutron yield and collective flow

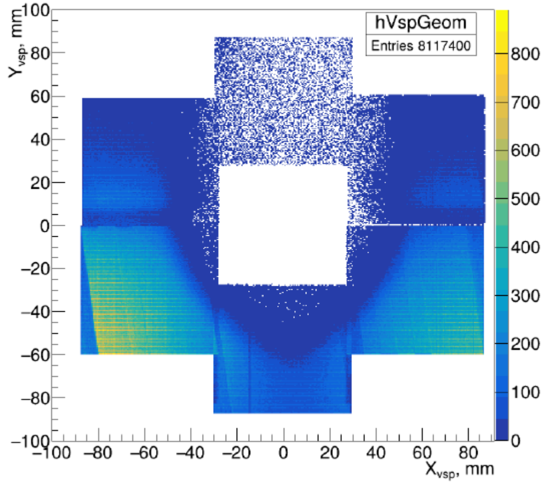
2-coordinate Si-plane based on STS modules

STS group

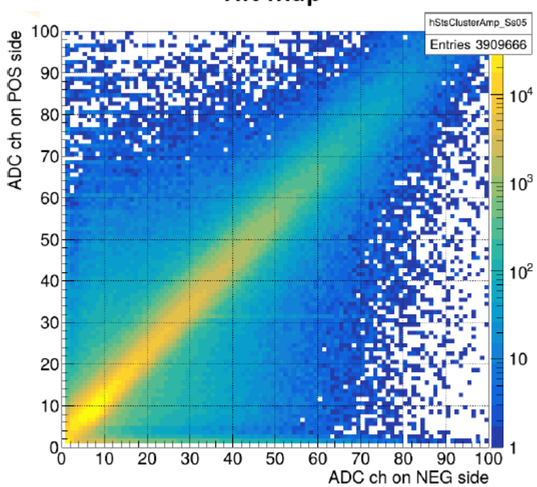
Si-plane installed behind the target and Barrel detector



Ru-106 source, positions are below the Si-plane



Hit map



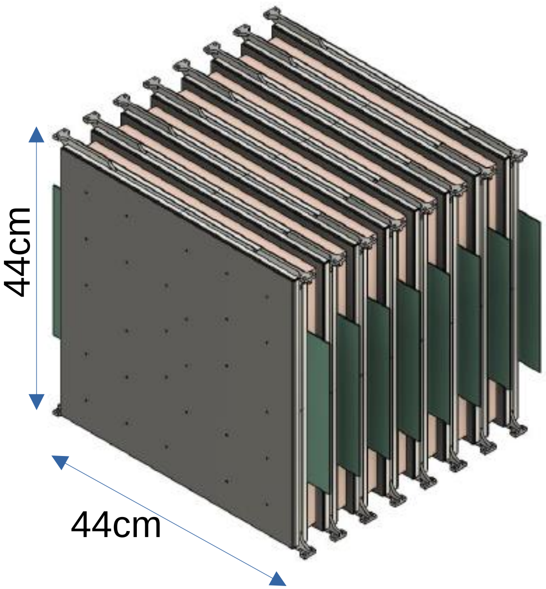
Correlations between hit amplitudes at p-and n- sides

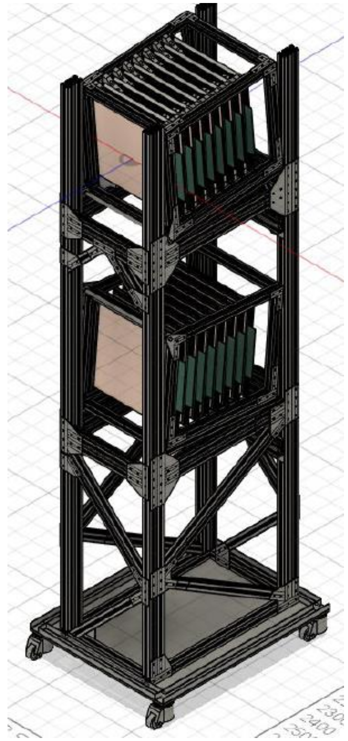
BM@N experiment

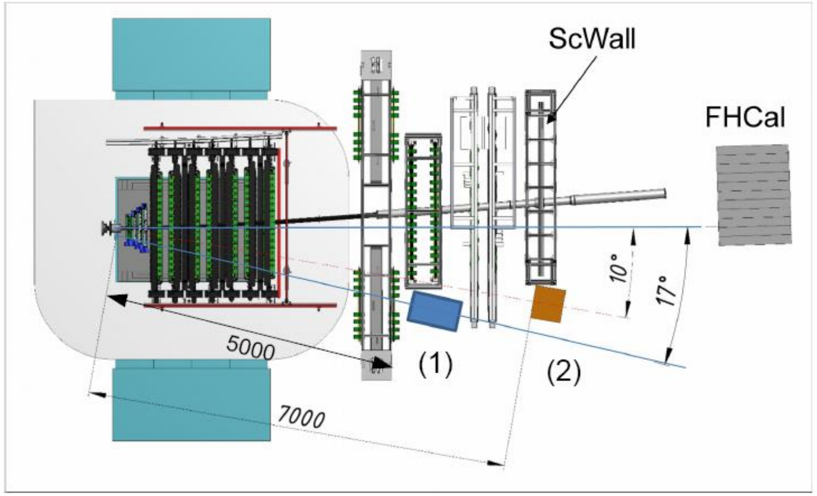
New neutron detector of high granularity

→ **plan to install in 2026**

INR RAS, LHEP, Kurchatov NRS

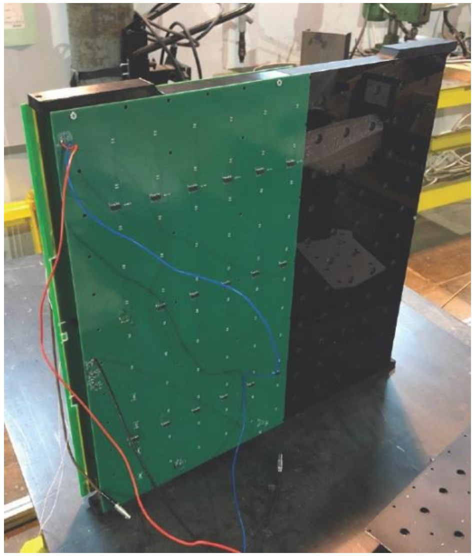






2 positions of HGN detector at BM@N: at 10° and 17°

HGN detector parameters: 2 sub-detectors with 8 layers each (~1.5 λ_{int})
- 11 x 11 cells in one layer with SiPM read-out
- first layer works as VETO
- next 7 layers: 3cm Cu + 2.5cm scintillator
- FPGA based fast TDC read-out with additional ToT amplitude measurement
  - time resolution of one scint. cell ~ 120ps
  - neutron detection efficiency: > 60% @ 1GeV



BM@N conferences , PhD activities

BM@N presented / submitted talks at conferences in 2025:

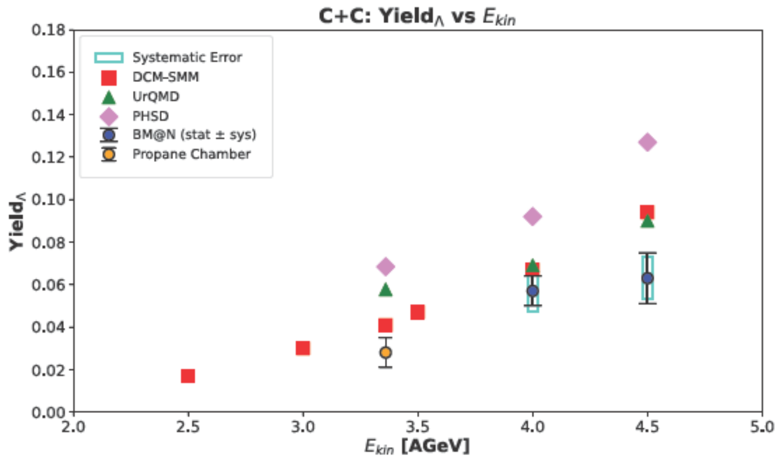
Conference of the Nuclear Physics Section of the Russian Academy of Sciences, Moscow, February 2025
Conference Nucleus-2025, St.Petersburg, July 1 – July 6, 2025
QFTHEP'270 Workshop, Moscow, June 30 – July 5, 2025
26th International Baldin Seminar on High Energy Physics Problems “Relativistic nuclear physics and quantum chromodynamics”, Dubna, September 2025

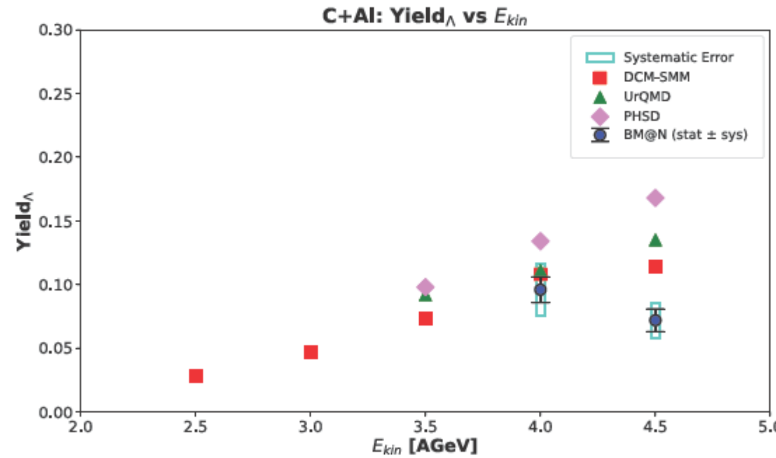
- 1 candidate dissertation on the 1st BM@N physical result defended in 2024
- 10 young scientists and PhD students (LHEP, MEPhI, INR RAS) are doing physics analyses at BM@N for future dissertations

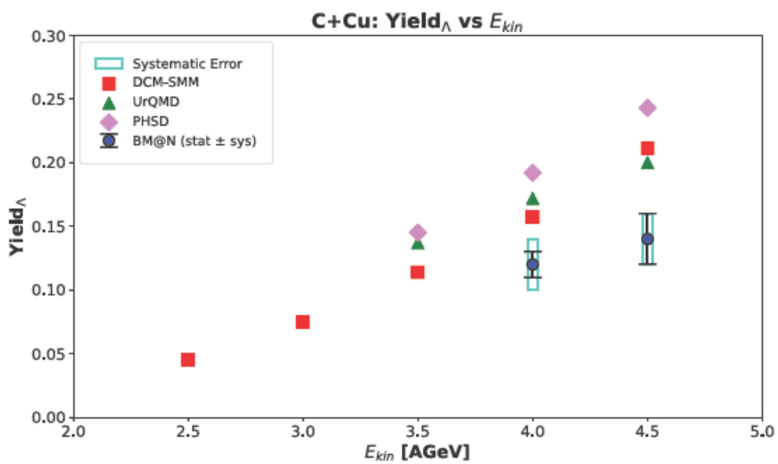
Thank you
for attention!

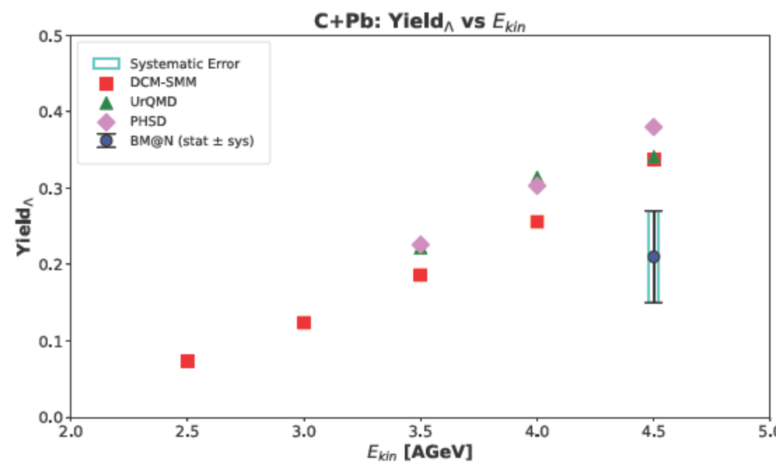
Energy dependence of Λ yields in C+C, Al, Cu, Pb interactions

DCM-SMM, PHSD and UrQMD models overestimate Λ yields









Coalescence radii vs collision energy

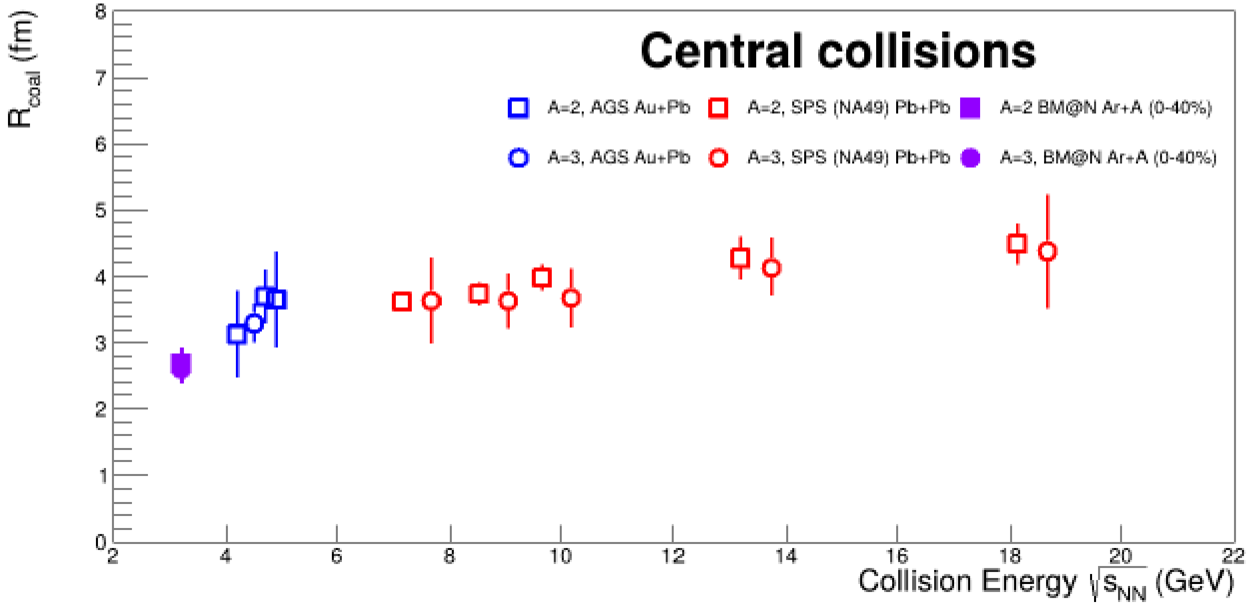


Figure 16. Coalescence radii R_{coal} for deuterons and tritons as a function of the nucleon-nucleon center-of-mass energy. The BM@N result is the weighted average value calculated in the rapidity range $-0.18 < y^* < 0.22$ for Ar+Al, Cu, Sn and Pb interactions with centrality 0–40%.

$$B_2 = \frac{3\,\pi^{3/2}\,\langle \mathcal{C}_\mathrm{d} \rangle}{2m_t\,\mathcal{R}_\perp^2(m_t)\,\mathcal{R}_\parallel(m_t)}\,e^{2(m_t-m)\left(\frac{1}{T_\mathrm{p}^*}-\frac{1}{T_\mathrm{d}^*}\right)} \qquad R_{coal} = \sqrt[3]{R_\parallel R_\perp^2}$$

The estimated BM@N coalescence radius of ~2.5-3 fm at zero p_T appears to be practically independent of the target mass.

Moving Source Model

The experimental energy spectra of neutrons were analyzed in framework of Moving Source Model (MSM) with three sources:

- ✓ The first source S1 reproduces the hard part of spectra (contact layer)
- ✓ The second source S2 gives main contribution in the middle part of spectra (multifragmentation decay)
- ✓ The third source S3 dominates in the low energy part (fragmentation decay + evaporation)

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

E, p – kin. energy and momentum in lab. frame
m – neutron mass
θ – angle in lab. frame

A_i – amplitude
T_i – slope temperature
β_i – longitudinal velocity (v/c)

Source	A_i	T_i (MeV)	β_i
S1	0.157	55 (±5)	0.18 (±0.2)
S2	3.27	6.5 (±0.5)	0.015 (±0.010)
S3	205	0.8 (±0.1)	~0