BM@N — the first experiment at the NICA complex

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on behalf of the BM@N collaboration

28/10/2024

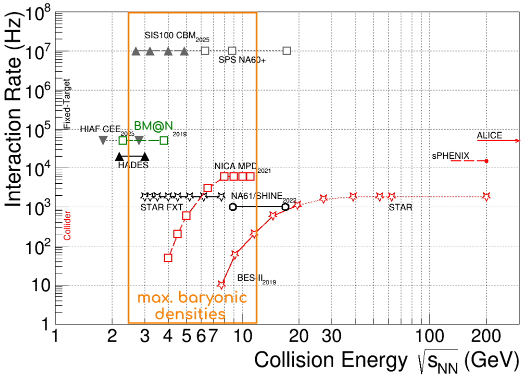
Experiment is people

5 countries, 13 institutions and 214 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
- Institute of Physics and Technology, Satbayev University, Almaty, Kazakhstan
- Physical-Technical Institute of UzAS, Tashkent, Uzbekistan
- High School of Economics University, Moscow, Russia

Physics motivation for the BM@N experiment

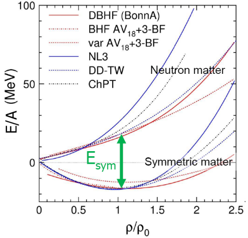
Heavy ion collision experiments

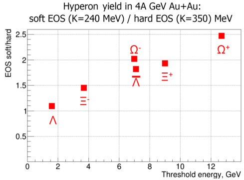


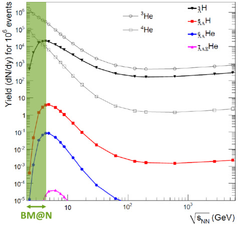
BM@N competitors:

- 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 $\rho/\rho_0 = 3-5$, $\rho_0 = 0.16 \mathrm{fm}^{-1}$:

- 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

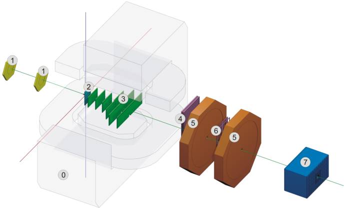
Exp.	year	A+A	E_{kin} AGeV	Statistics	Ξ^-	Ω^-	Hypernuclei
HADES	2012	Au+Au	1.23	$7 \cdot 10^9$	✗	✗	✗
HADES	2019	Ag+Ag	1.58	$1.4 \cdot 10^{10}$	✗	✗	$800\ {}^3_\Lambda$H
STAR FxT	2018	Au+Au	2.9	$3 \cdot 10^8$	10^4	✗	$10^4\ {}^3_\Lambda$H $6 \cdot 10^3\ {}^4_\Lambda$H
STAR FxT	2021	Au+Au	2.9	$2 \cdot 10^9$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

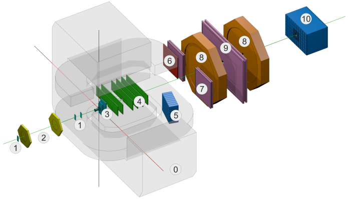
RUN-6 (2017)

C + X @ 3.5-4.5 AGeV



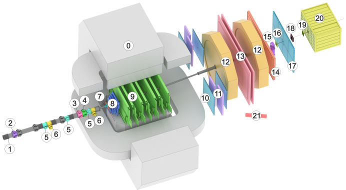
RUN-7 (2018)

Ar + X @ 3.2 AGeV

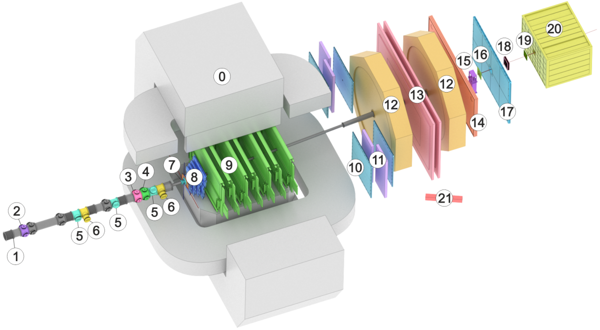


RUN-8 (2022-2023)

Xe + CsI @ 3.0, 3.8 AGeV



Experimental setup in the first heavy ion run

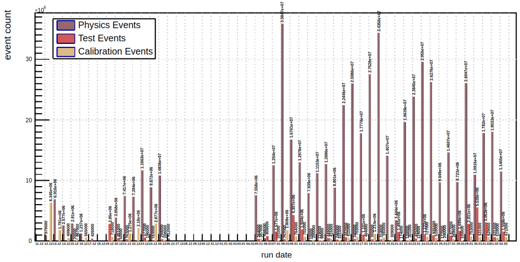


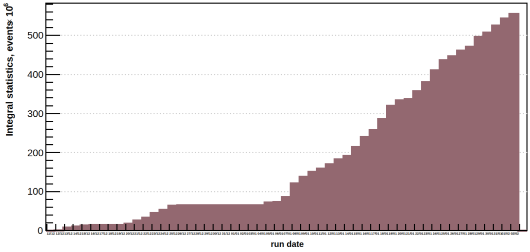
- Magnet SP-41 (0)
- Vacuum Beam Pipe (1)
- BC1, VC, BC2 (2-4)
- SiBT, SiProf (5, 6)
- Triggers: BD + SiMD (7)
- FSD, GEM (8, 9)
- CSC 1x1 m^2 (10)
- TOF 400 (11)
- DCH (12)
- TOF 700 (13)
- ScWall (14)
- FD (15)
- Small GEM (16)
- CSC 2x1.5 m^2 (17)
- Beam Profilometer (18)
- FQH (19)
- FHCal (20)
- HGN (21)

The BM@N detector paper for the Xe+CsI run configuration

NIMA 1065 (2024) 169532, arxiv:2312.17573

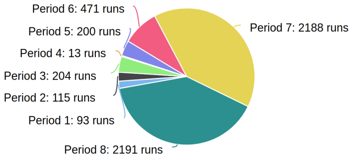
Collected data during Xe run





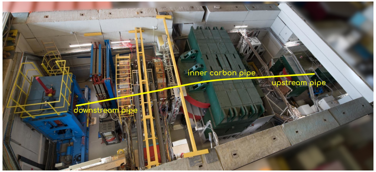
It was two energies of Xe beam:

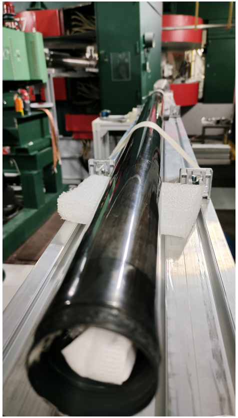
- $507 \cdot 10^6$ events @ 3.8 AGeV
- $48 \cdot 10^6$ events @ 3.0 AGeV

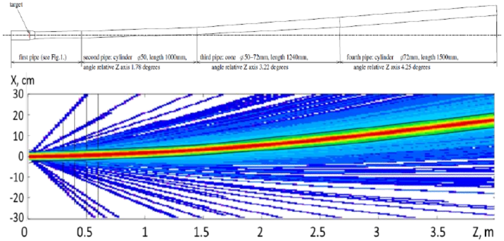


Beam pipe

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

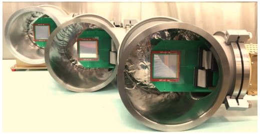






- Beam pipe in te SP-41 magnet is made of 1 mm thick carbon fiber;
- It consists of four parts with a non-flange connectors;
- FLUKA simulations have shown that the proposed beam pipe is well suited to guide the high intensity beam;
- First vacuum tests have shown an insignificant leakage level of side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

Silicon Beam Tracker



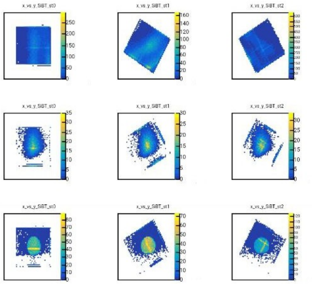
Three silicon beam trackers with 32x32 orthogonal strips readout

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

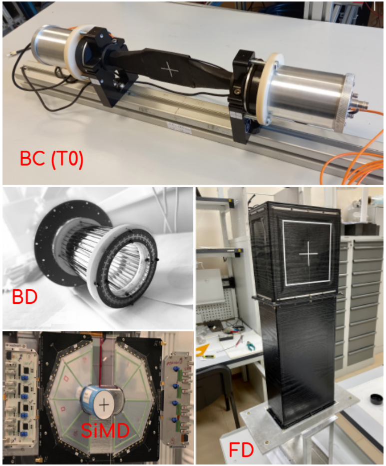
Main goals:

- 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%



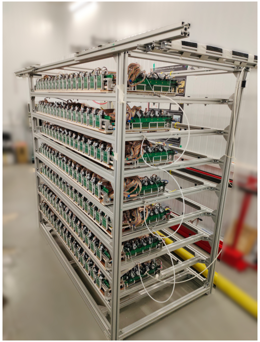
Subsystems. Trigger detectors

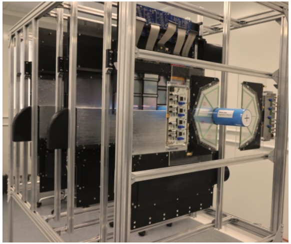


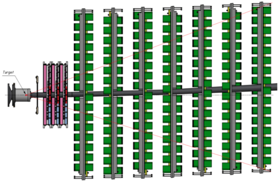
Trigger detectors to be used in 2022:

- 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



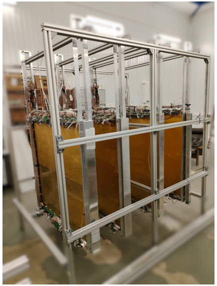
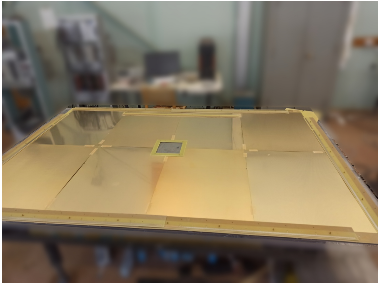




- Inner tracking system consist of
  - 4 forward silicon detectors
  - 7 GEM stations $(160 \times 80\ \mathrm{cm}^2)$
- Right after the target four stations of Silicon Forward Detector was installed
- Seven GEM stations covers the entire magnet aperture

Outer tracking system

Outer planes support tracks in downstream direction

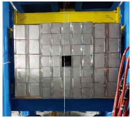

- Four small Cathod Strip Chambers (SmallCSC, $\approx 1 \times 1$ m^2) placed around near Time-of-Flight (TOF-400)
- Large Cathod Strip Chamber (LargeCSC, $\approx 1.5 \times 2$ m^2) placed in front of far Time-of-Flight (TOF-700)
- Two Drift Chamders (DCH) placed around far Time-of-Flight (TOF-700)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

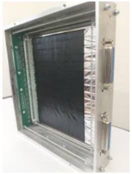
Time-of-Flight system

Main system for PID

- 20 modules of ToF-400 placed between four small CSC to identify particles with low momentum
- 60 modules of ToF-700 placed between two DCH to identify particles with high momentum

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

Current studies of experimental data

Current studies of experimental data

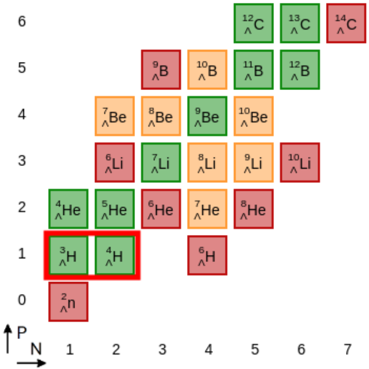
- Production of p, d, t in 3.2 AGeV argon-nucleus interactions
- Production of π^+ and K^+ mesons in 3.2 AGeV argon-nucleus interactions
- Collective flow of protons in Xe+CsI interactions
- Collective flow of hyperons in Xe+CsI interactions
- Λ and K^0_s production in Xe+CsI interactions
- Search of $\Phi(1020)$ in Xe+CsI interactions
- Study of neutron emission from target spectators in Xe+CsI collisions

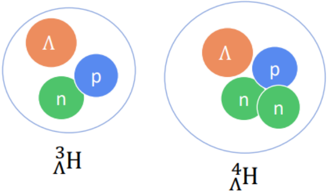
Most of these topics will be presented during AYSS-24

Search of hypernuclei in Xe+CsI collisions

(my current work)

What are hypernuclei?



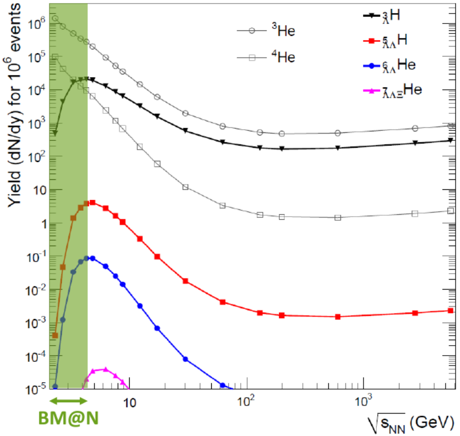


In current work two-particle decays only

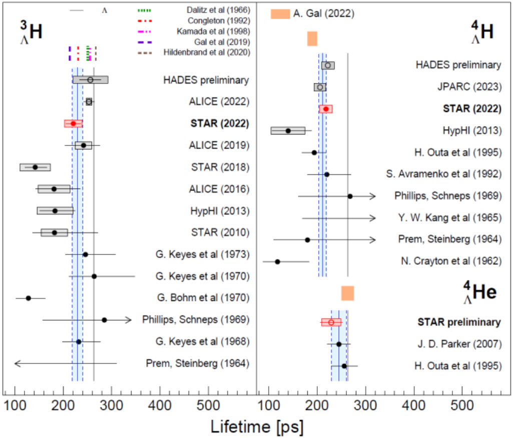
$$^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-} \qquad {}^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi^{-}$$

Why hypernuclei are interesting?

Sigh of phase transform



Lifetime puzzle

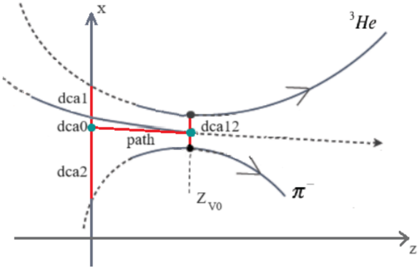


Two directions of research

Simulated data

- Helps to develop, test and tune algorithms
- Gives algorithm efficiency

Decay scheme



Experimental data

- The main goal of research
- Analysis of hypernuclei production, lifetime estimation etc

Two particle decay

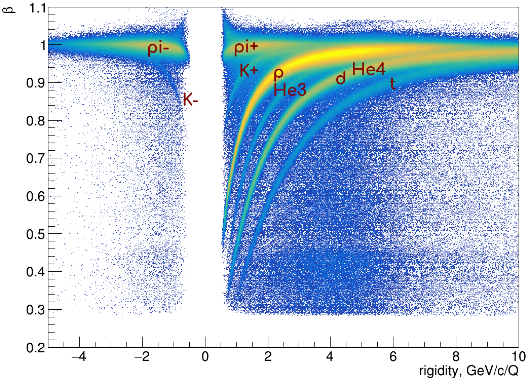
$${}^{3}_{\Lambda}\text{H} \rightarrow {}^{3}\text{He} + \pi^{-}$$

$${}^{4}_{\Lambda}\text{H} \rightarrow {}^{4}\text{He} + \pi^{-}$$

Problems:

- ^{3}He could be selected in momentum range $\approx$ 0.5 - 3.5 GeV/c
- Impossible to separate ^{4}He from deuterons

ToF identification plot



It's not enough to have a ToF technique to identify helium

dE/dx in GEM

Let's try to use GEM detectors for dE/dx extimation

- It was 7 GEM stations in the last experimental run.
- Each track has 1-7 GEM hits, so the energy loss could be estimated as

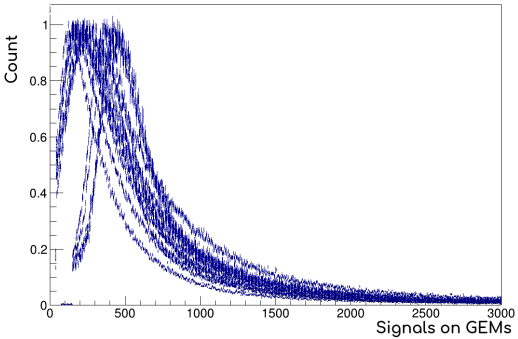
$$\langle\frac{dE}{dx}\rangle = \frac{\sum_{i=1}^{N} q_i}{N}, \text{ where } N > 3, q_i - \text{hit signal}$$

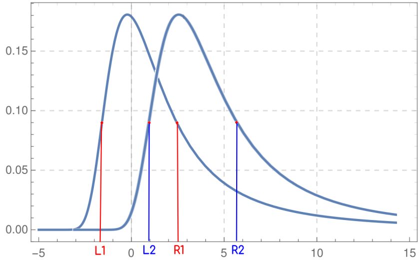
- dE/dx has Landau distribution, so the mean value is shifted by the reason of long "tail".
- The truncated mean was used for analysis (40% hits on track with maximal signal were removed).

Number of GEM hits	3	4	5	6	7
Used hits	2	2	3	4	4
In percent	67	50	60	67	57

GEM signal scaling

The goal: to equalize distributions in the horizontal direction





Linear transformation:

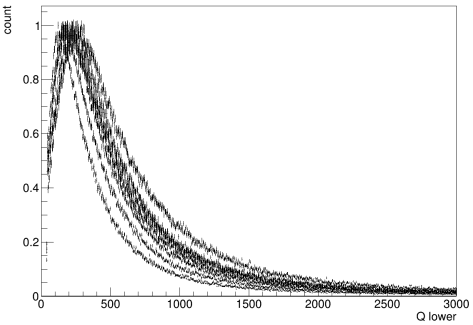
$$L_1 = a \cdot L_2 + b$$

$$R_1 = a \cdot R_2 + b$$

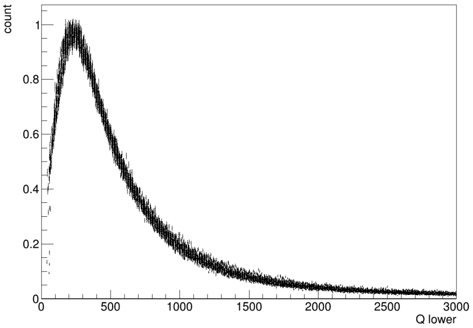
dE/dx in GEM

Signals from 7 GEM detectors

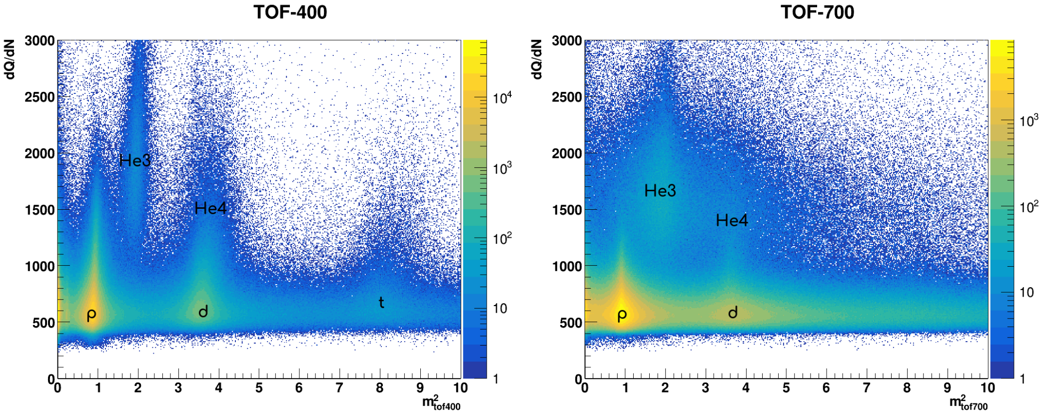
before scaling



after scaling

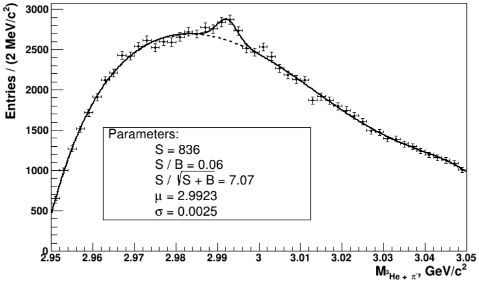


GEM dE/dx vs mass

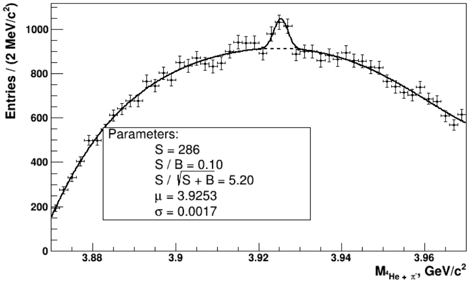


Experimantal data

$^3H_\Lambda$



$^4H_\Lambda$



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.

Be a man*

*of our great team