Implementation of the BM@N project

M.Kapishin

Baryonic Matter at Nuclotron (BM@N) Collaboration:

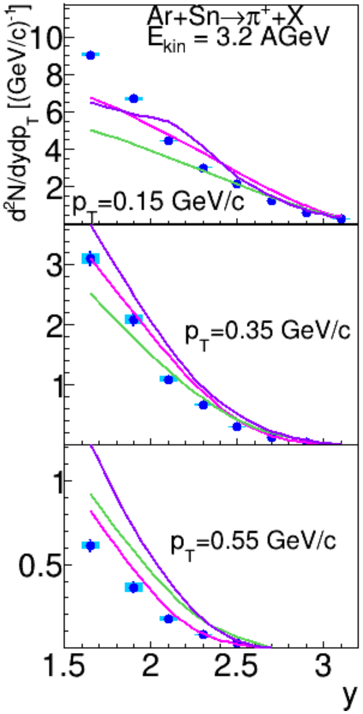
5 Countries, 13 Institutions, 210 participants

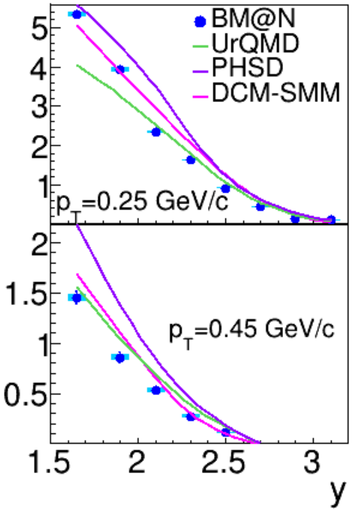
- *University of Plovdiv, Bulgaria*
- *St.Petersburg University*
- *Shanghai Institute of Nuclear and Applied Physics, CFS, China;*
- *Joint Institute for Nuclear Research;*
- *Institute of Nuclear Research RAS, Moscow*
- *NRC Kurchatov Institute, Moscow combined with Institute of Theoretical & Experimental 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**

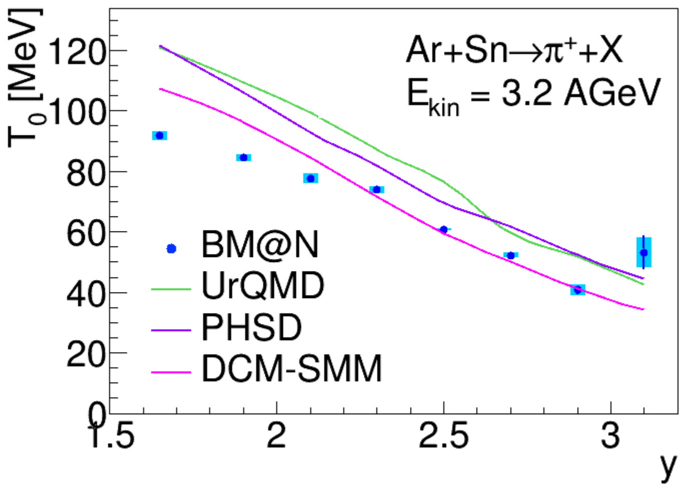
Production of π^+ and K^+ mesons in 3.2 AGeV argon-nucleus interactions at the Nuclotron

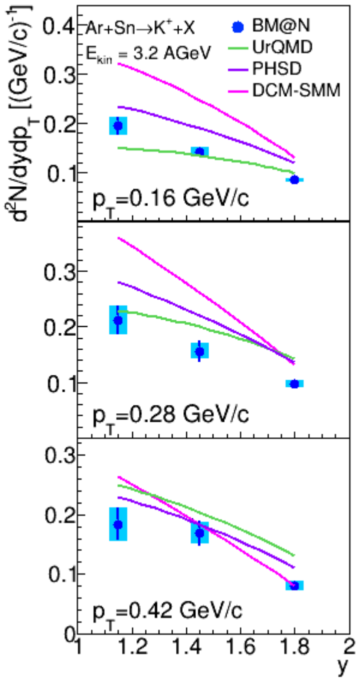
https://arxiv.org/abs/2303.16243v3

Published in JHEP 07 (2023) 174

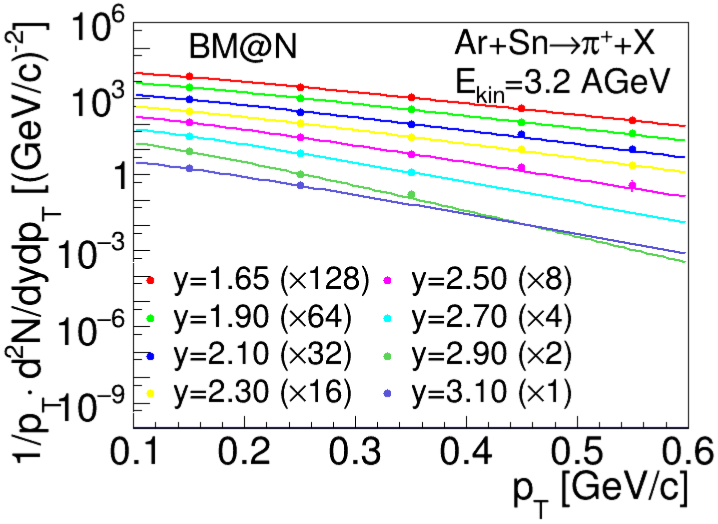


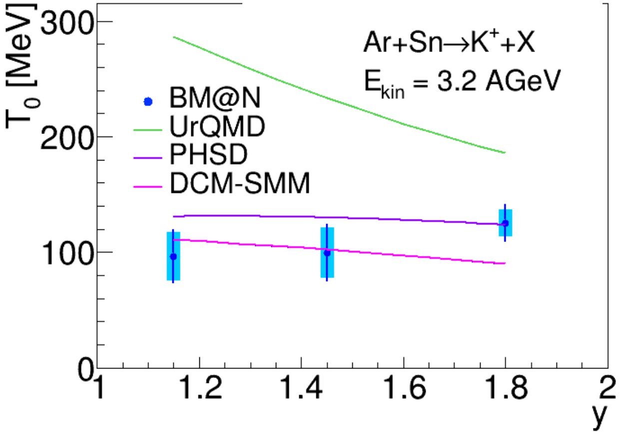




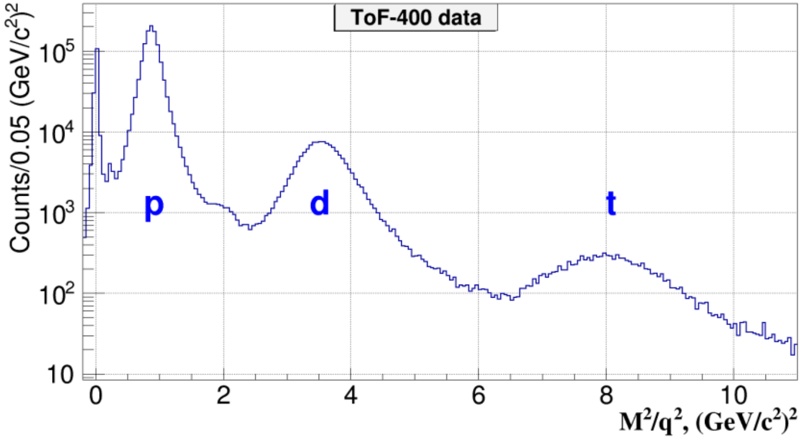


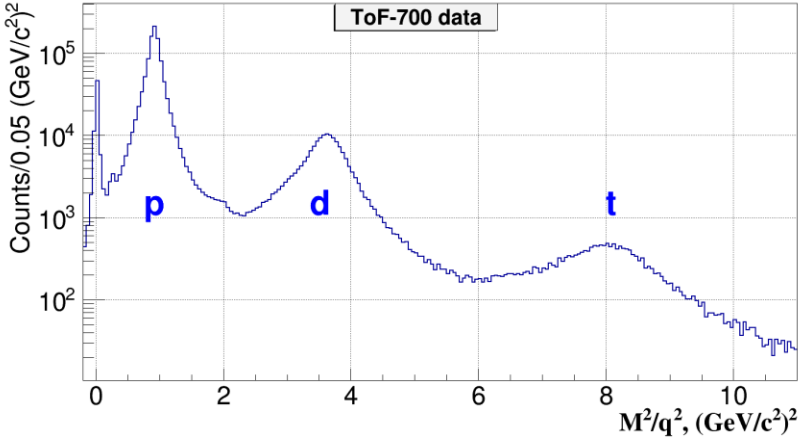
Full centrality range





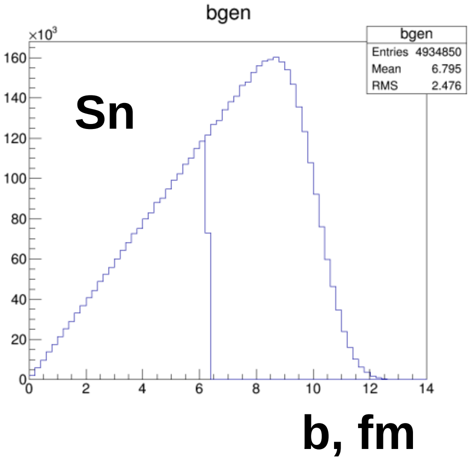
Production of *p, d, t* in 3.2 AGeV argon-nucleus interactions

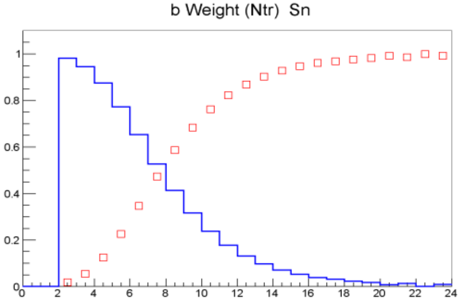


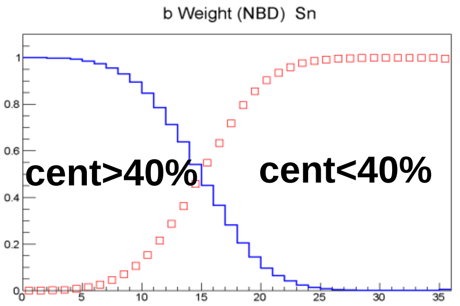


Two classes of centrality <40% and >40% based on barrel detector and track multiplicities

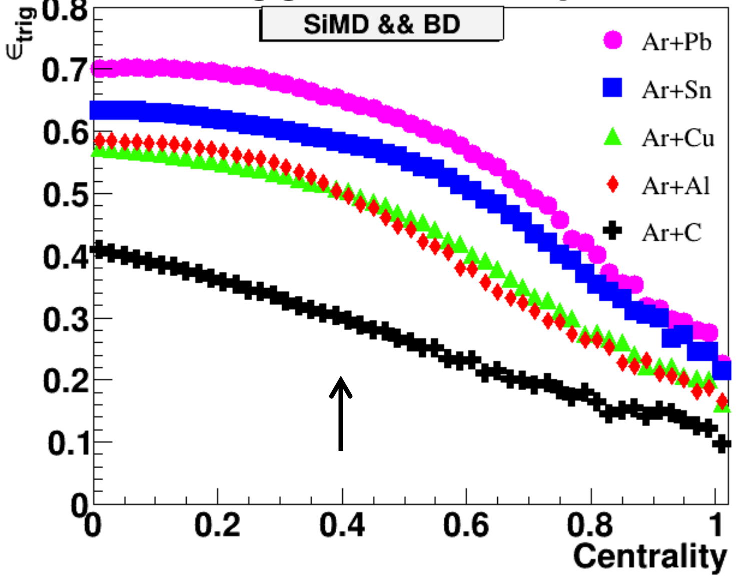
cent<40% cent>40%







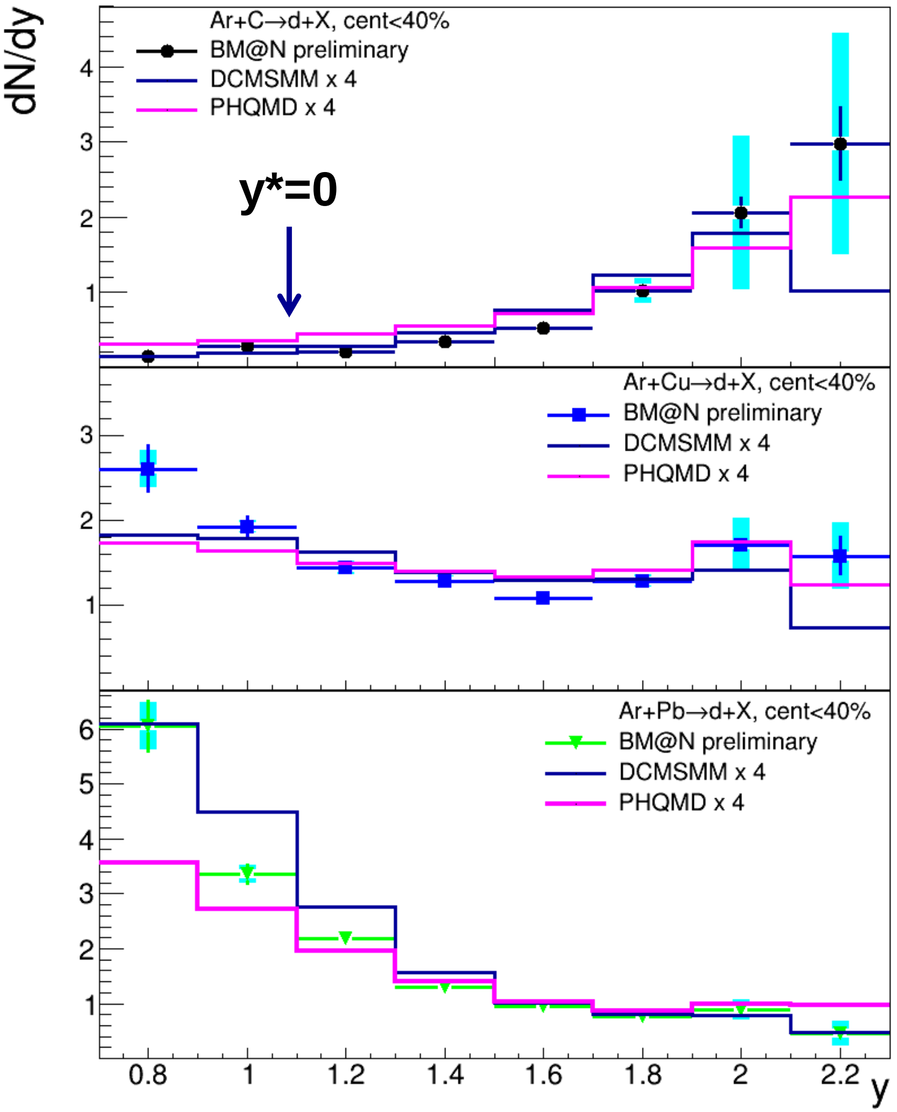
Trigger efficiency

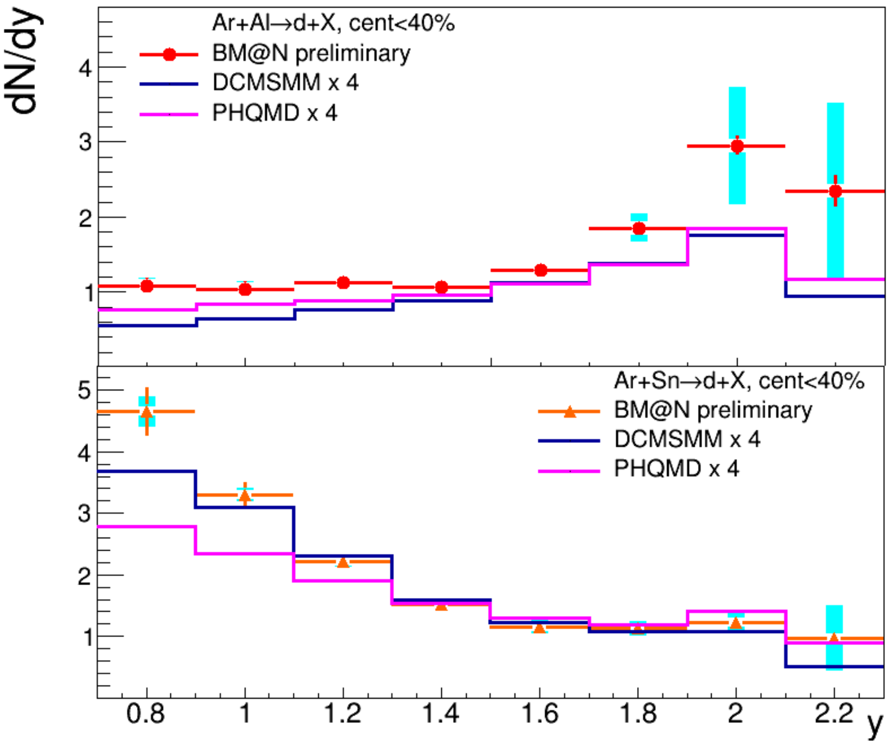


Deuterons: dN/dy dependence on y

$y^* = y_{lab} - 1.08$

Centrality 0-40%



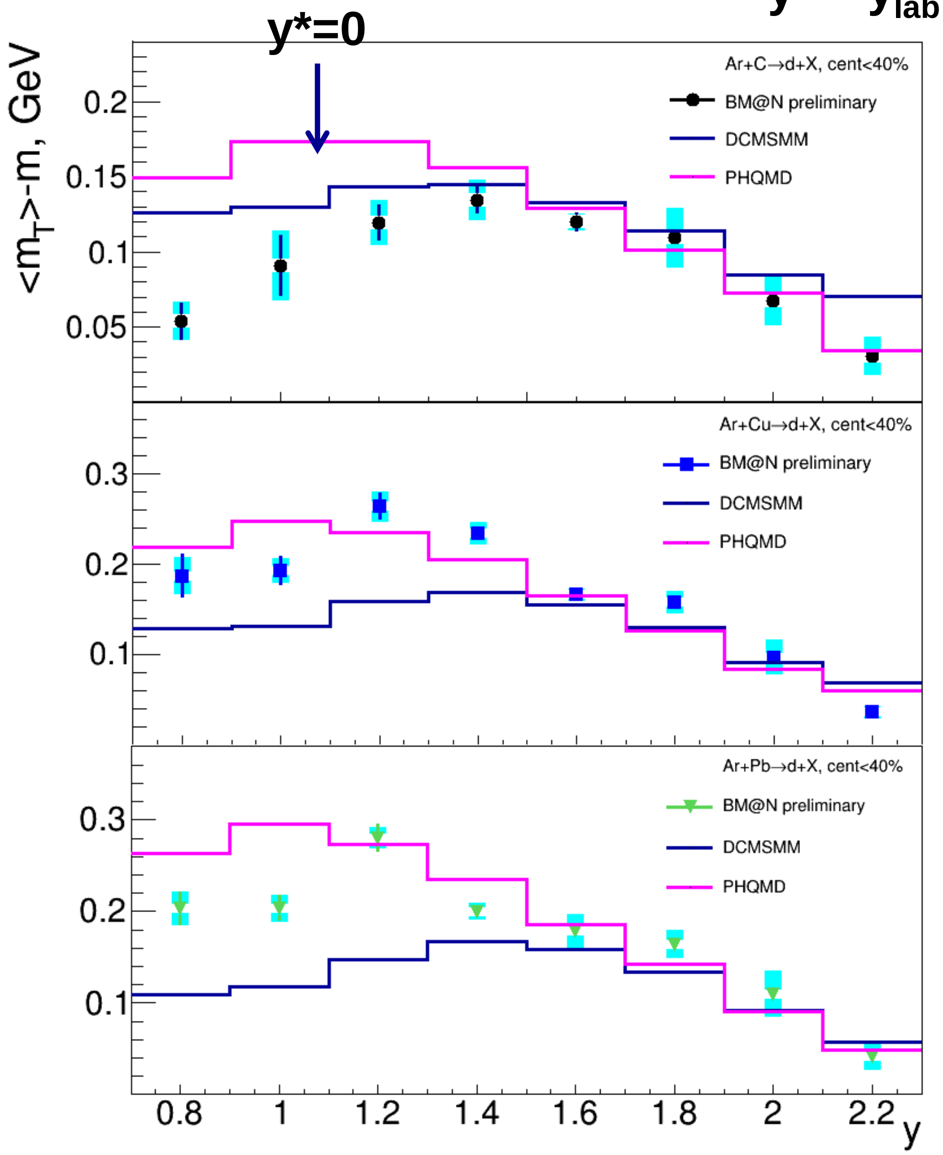


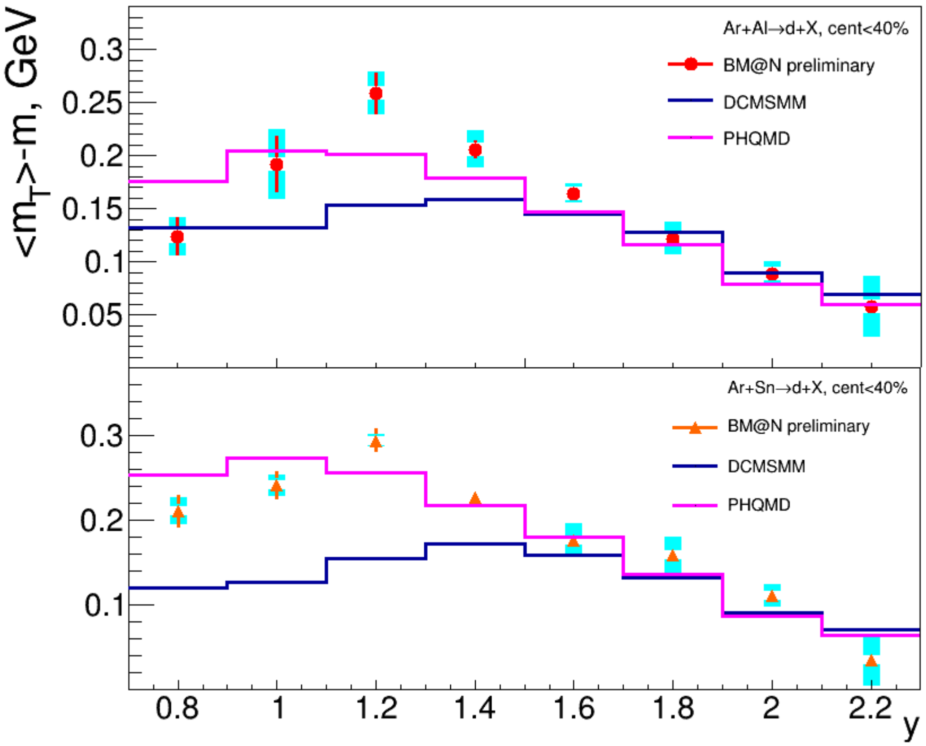
- **dN/dy spectrum softer in interactions with heavier target**
- **DCM-SMM and PHQMD models describe data shape, but are lower in normalization by factor 4**

Deuterons: $\langle m_t \rangle$ dependence on y

$y^* = y_{lab} - 1.08$

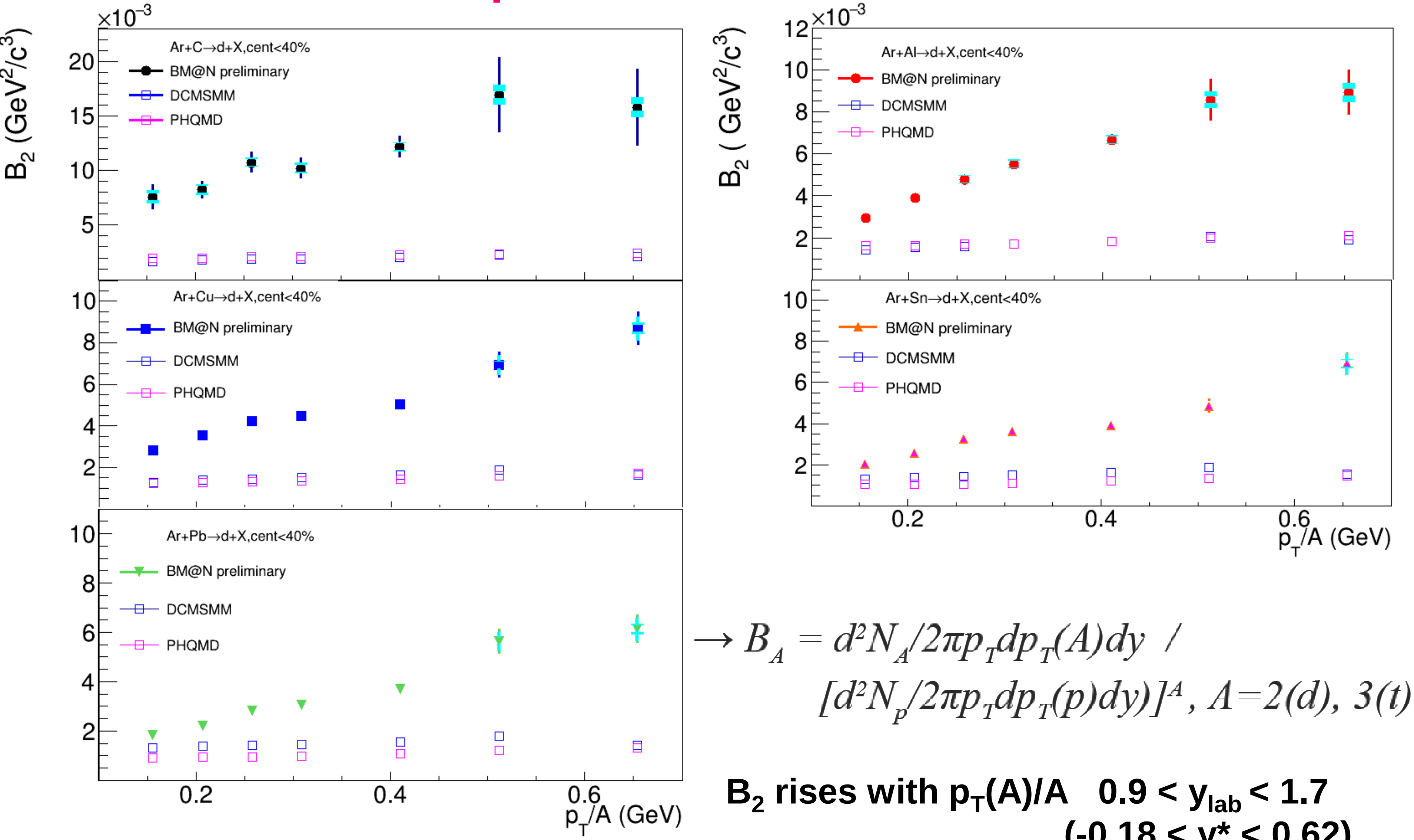
Centrality 0-40%





- **Maximum $\langle m_t \rangle$ at mid-rapidity y***
- **PHQMD model is in better agreement with data at mid-rapidity than DCM-SMM**

Coalescence parameter B_2 for deuteron to proton ratio

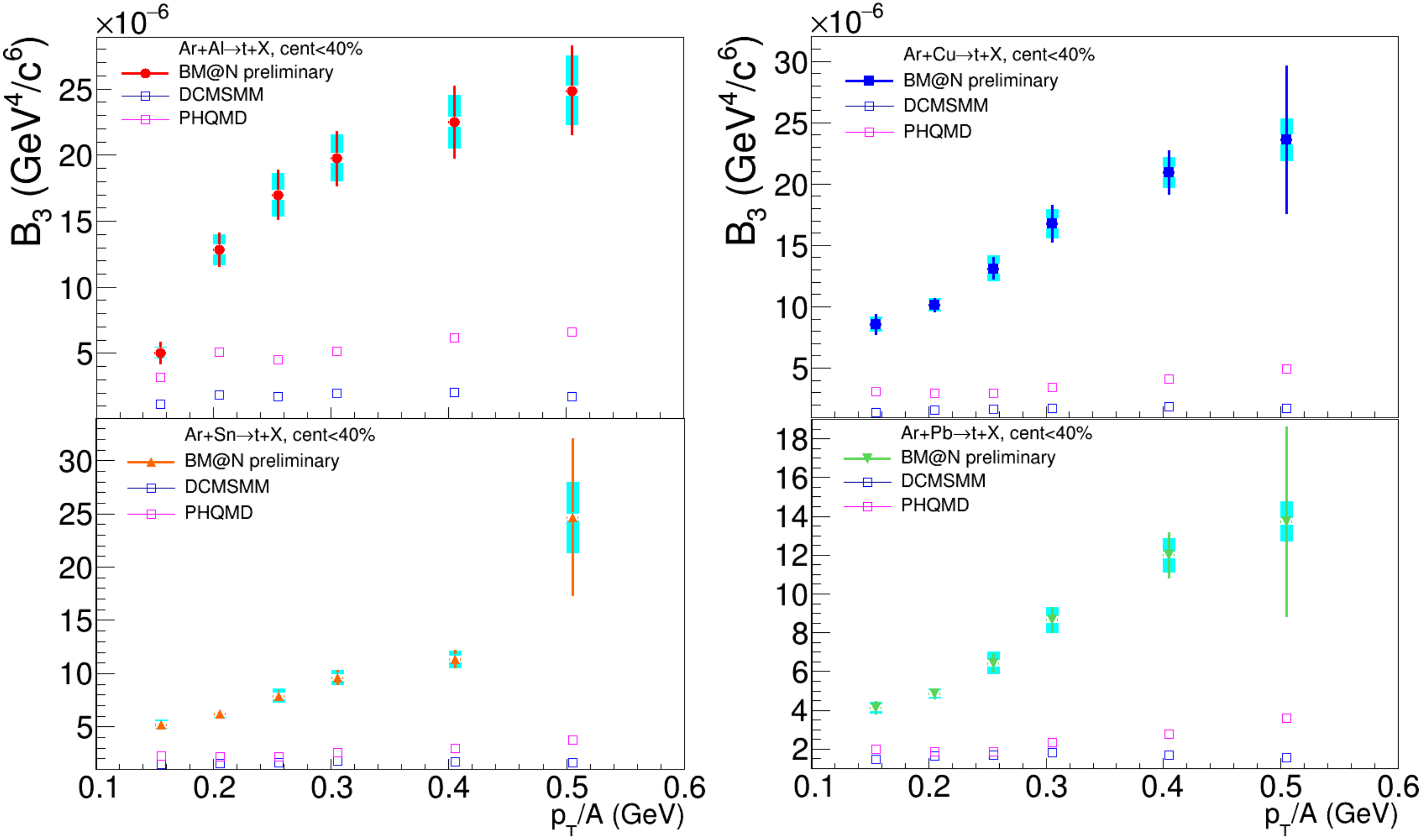


$$\rightarrow B_A = d^2N_A/2\pi p_T dp_T(A)dy \;\; / \;\; [d^2N_p/2\pi p_T dp_T(p)dy)]^A, \; A=2(d),\, 3(t)$$

B_2 rises with $p_T(A)/A$ $0.9 < y_{lab} < 1.7$

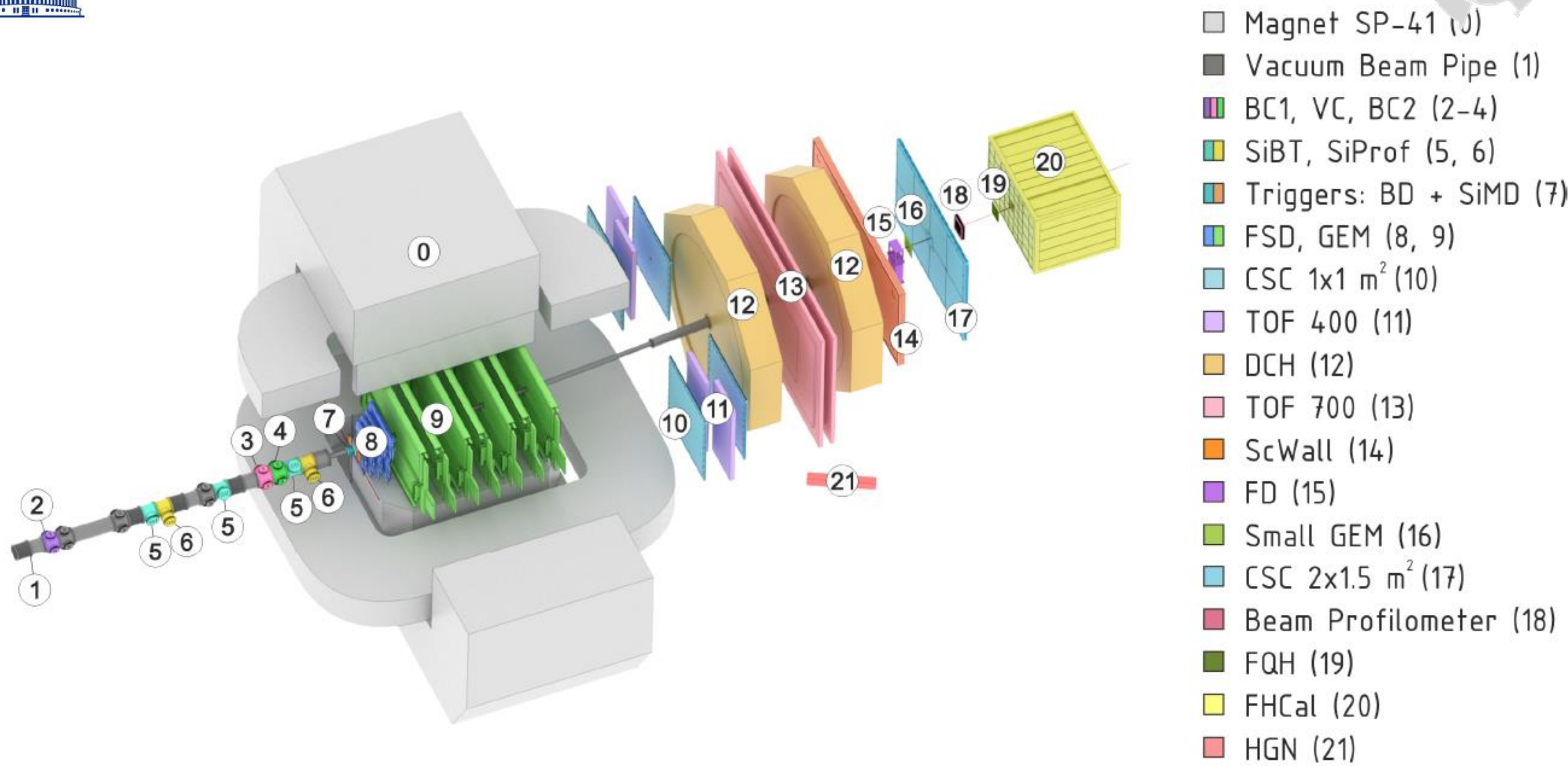
$(-0.18 < y^* < 0.62)$

Coalescence parameter B_3 for triton to proton ratio



B_3 rises with $p_T(A)/A$ $0.9 < y_{lab} < 1.7$
$(-0.18 < y^* < 0.62)$

Configuration of BM@N detector in Xe+CsI 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)

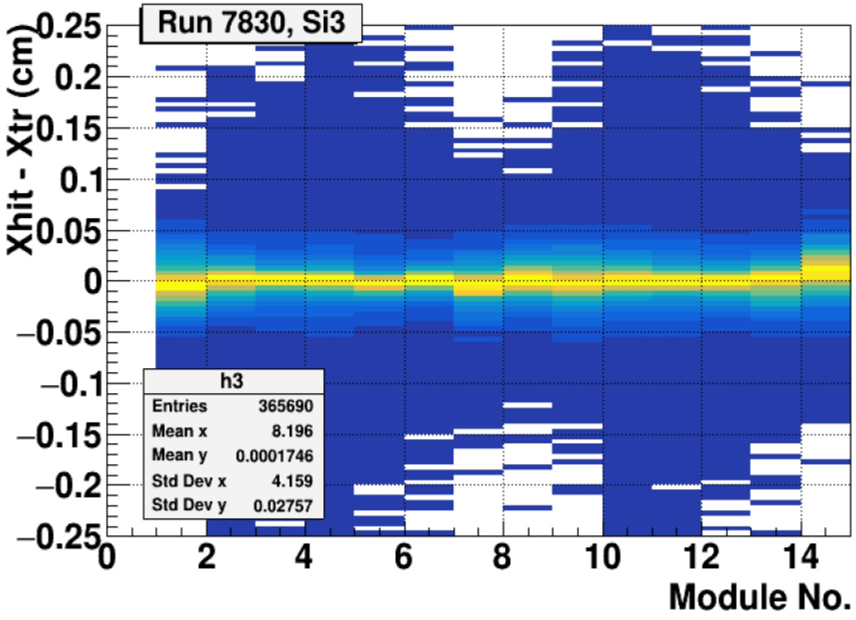
Xe^{124} + CsI interactions:
main trigger cover centrality < 70-75% (85% events)
min bias trigger (7% events), beam trigger (3% events)

→ Collected 507M events at 3.8 AGeV, 48M events at 3.0 AGeV

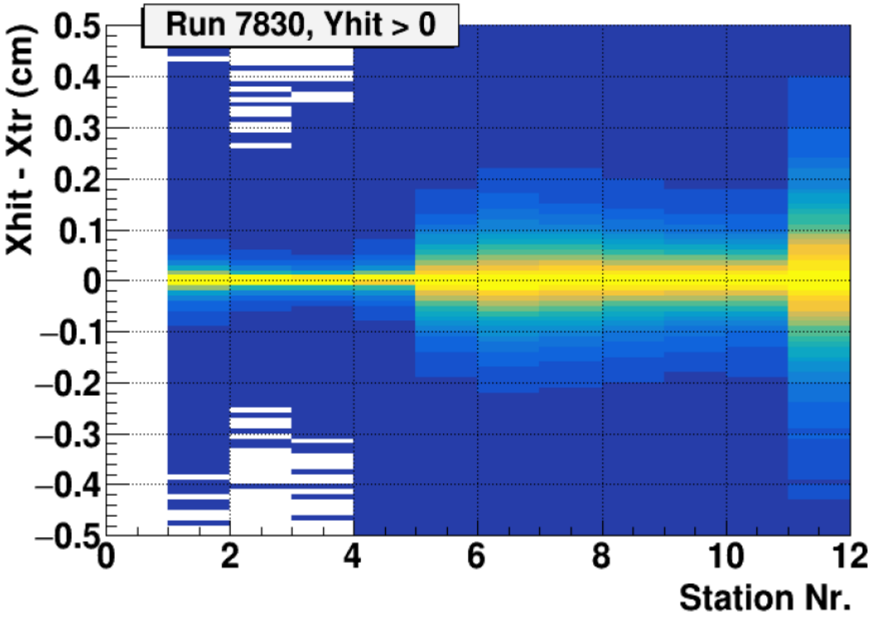
Alignment of Si and GEM detectors

→Minimize deviation of hits in detectors from reconstructed tracks

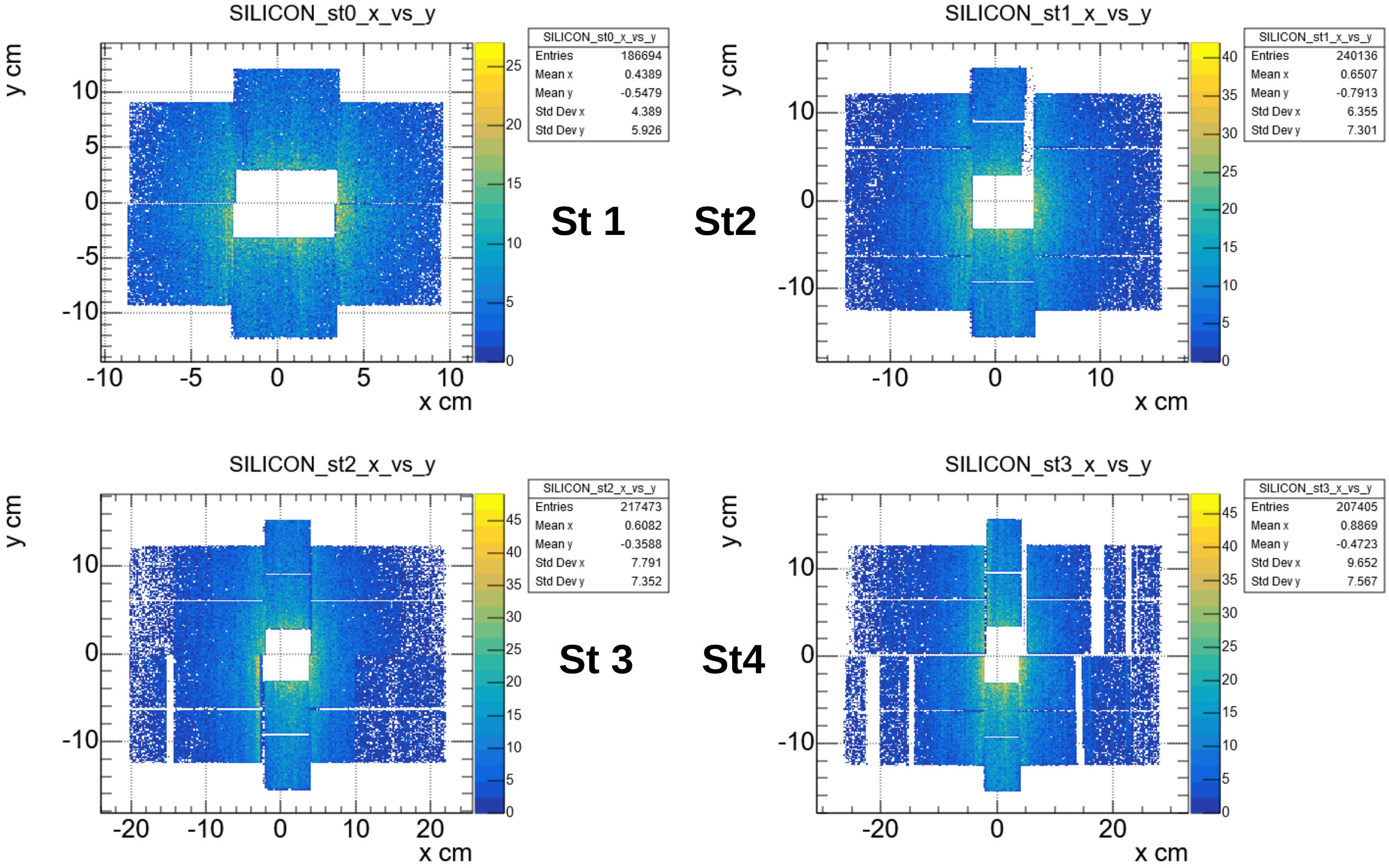
14 modules of 3 Si station



4 Si + 7 GEM stations



FST hit reconstruction in Xe run: 4 Si stations



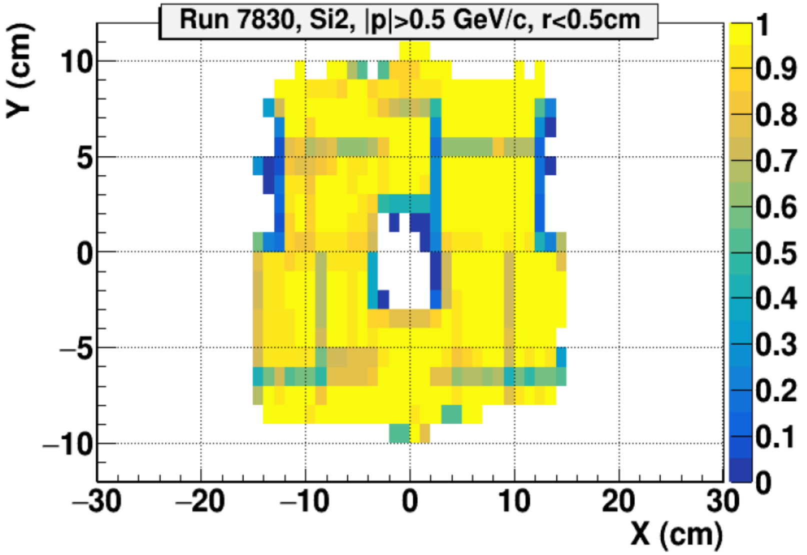
St 1 **St2**

St 3 **St4**

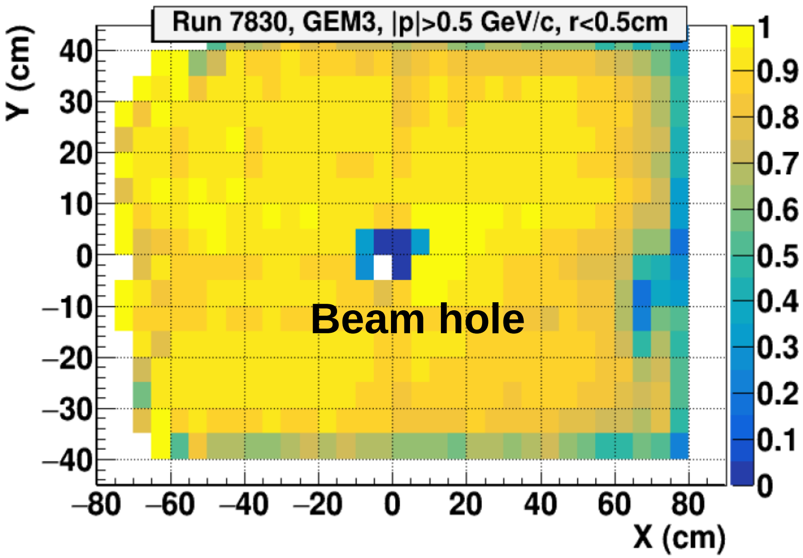
→ Readout cards with defected chips in stations 2, 3 and 4 are replaced

Efficiency of Si and GEM detectors in Si run

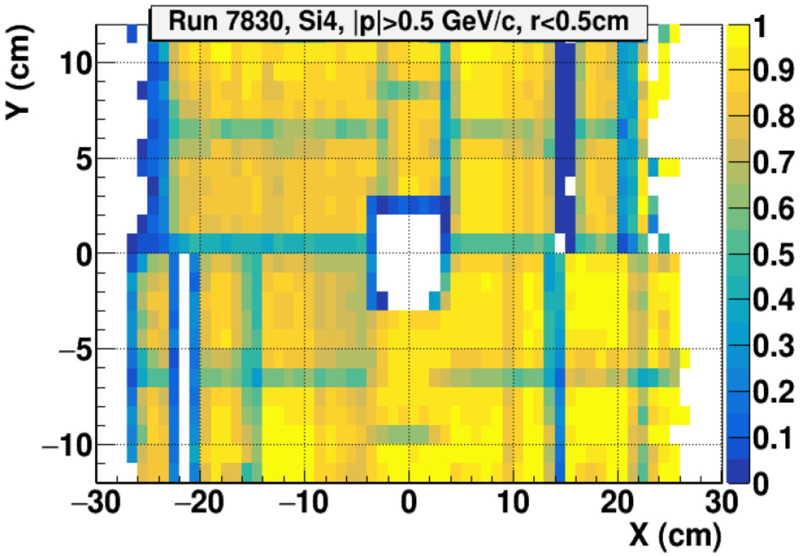
Si-2 station: X/Y map of efficiency



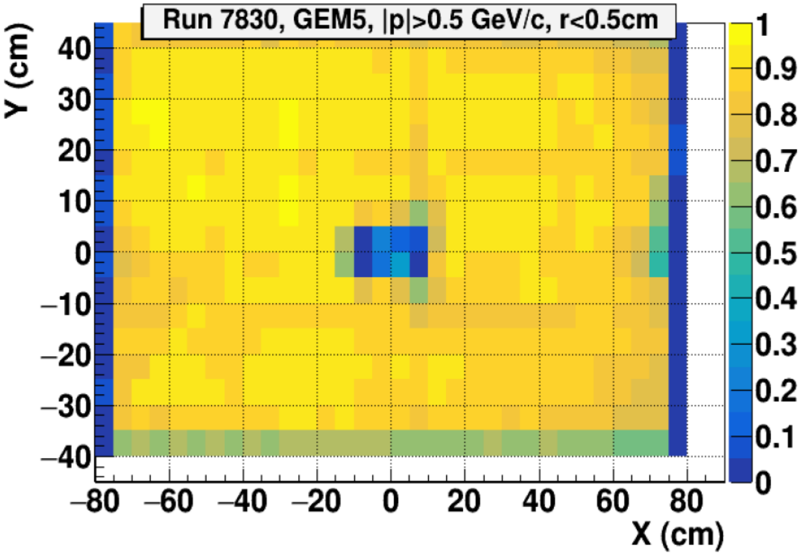
GEM-3: X/Y map of efficiency



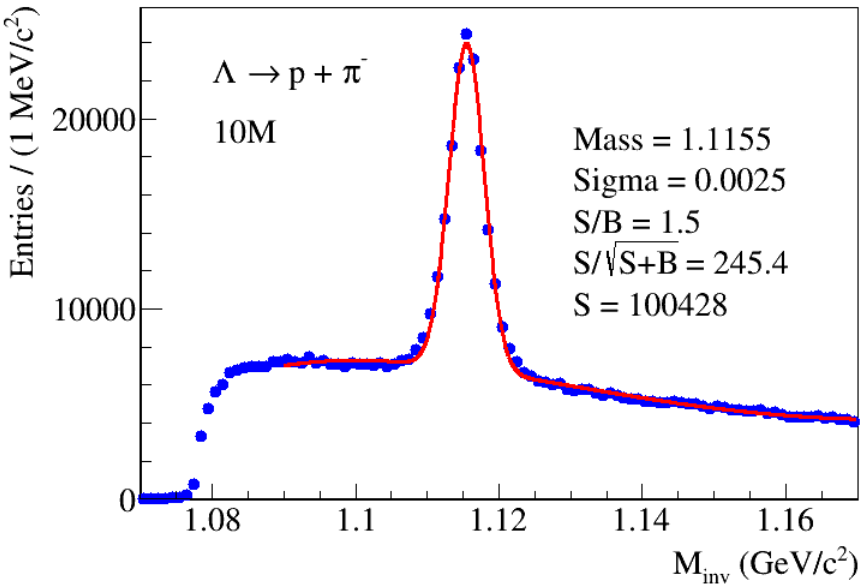
Si-4 station: X/Y map of efficiency

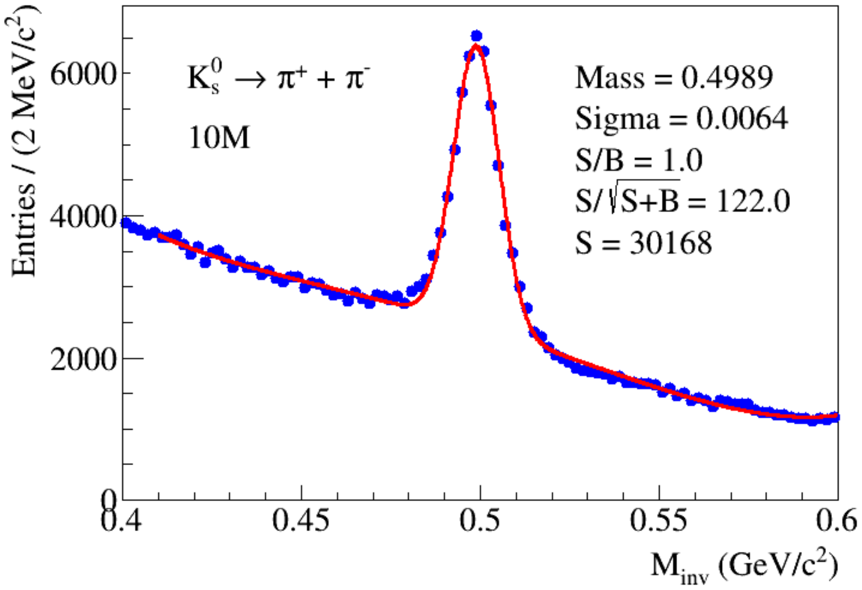


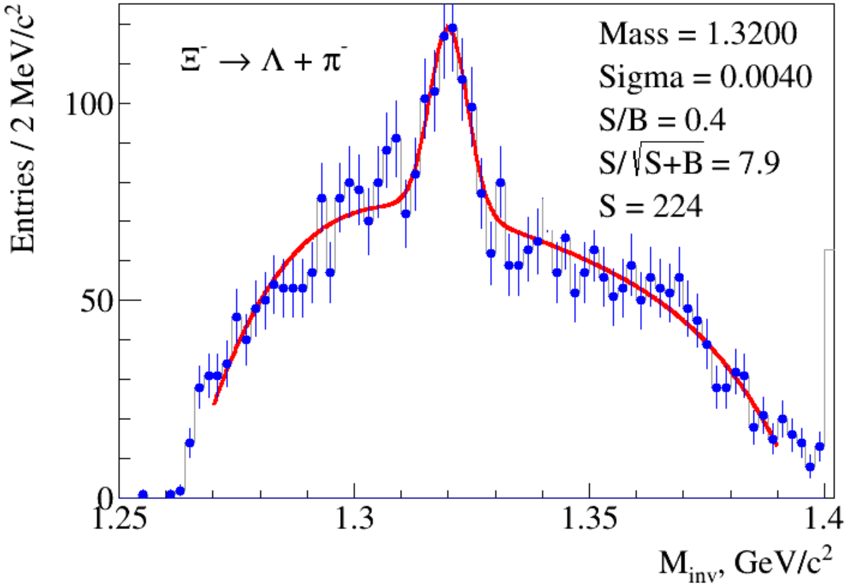
GEM-5: X/Y map of efficiency



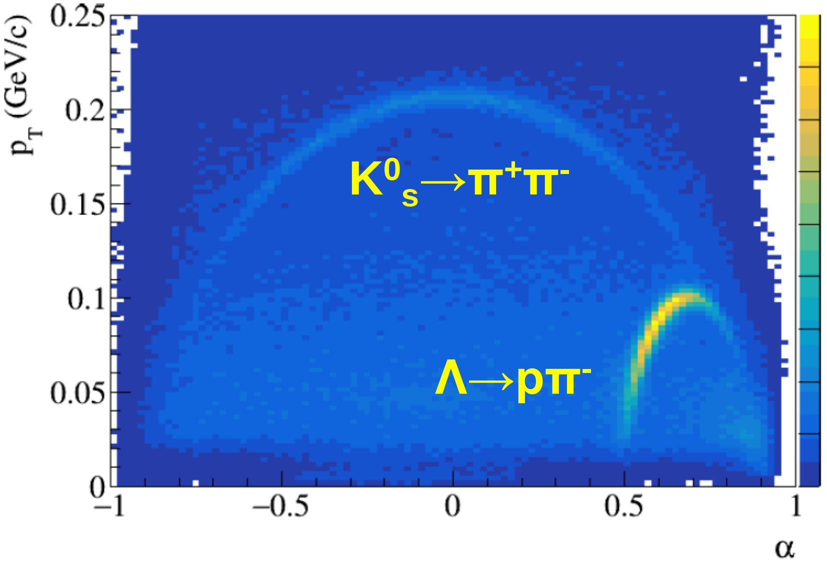
Xe+ CsI data : $\Lambda \rightarrow p\pi^-$, $K^0_s \rightarrow \pi^+\pi^-$, $\Xi^- \rightarrow \Lambda\pi^-$





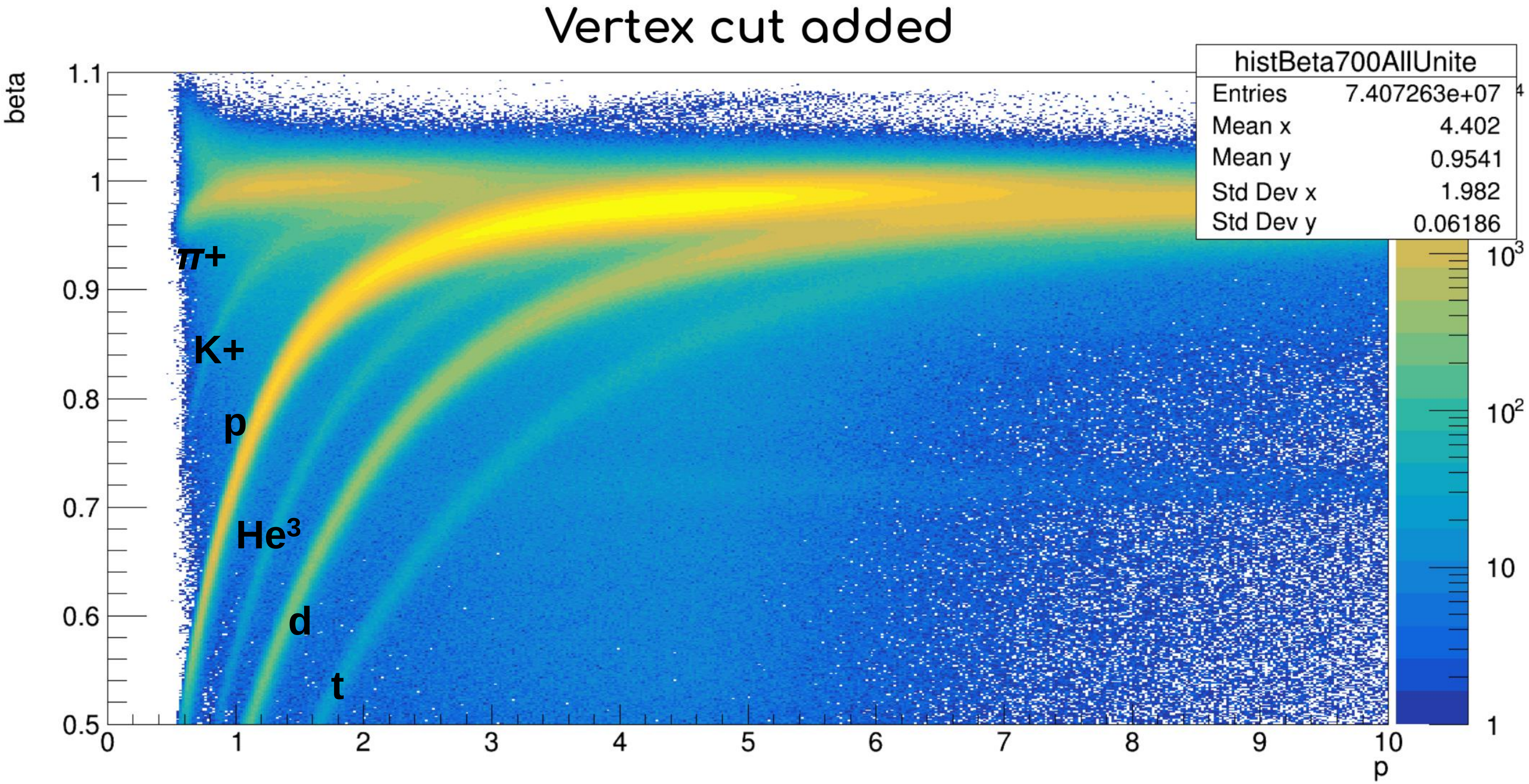


In 500M events expect: 4M Λ, 1.2M K^0_s and 8K Ξ-

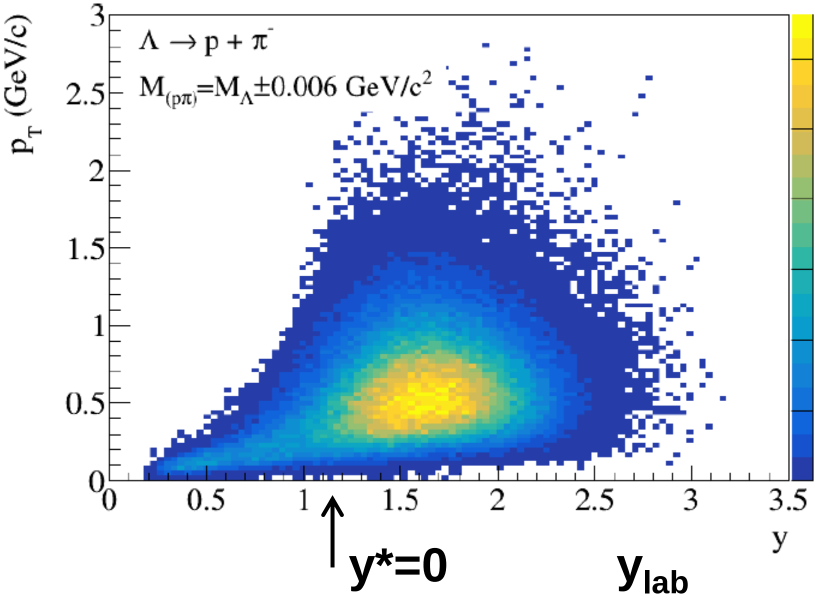


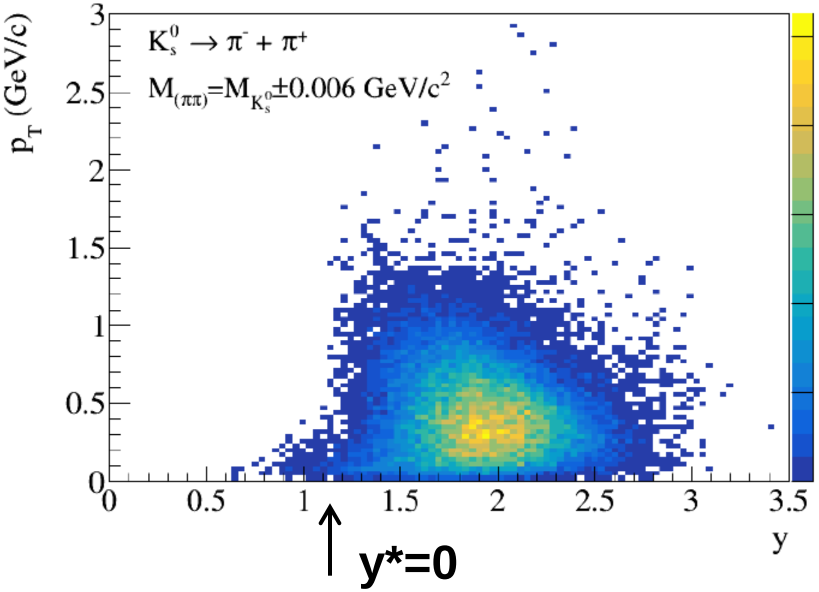
Xe+CsI data: π+, K+, p, He3, d, t identification

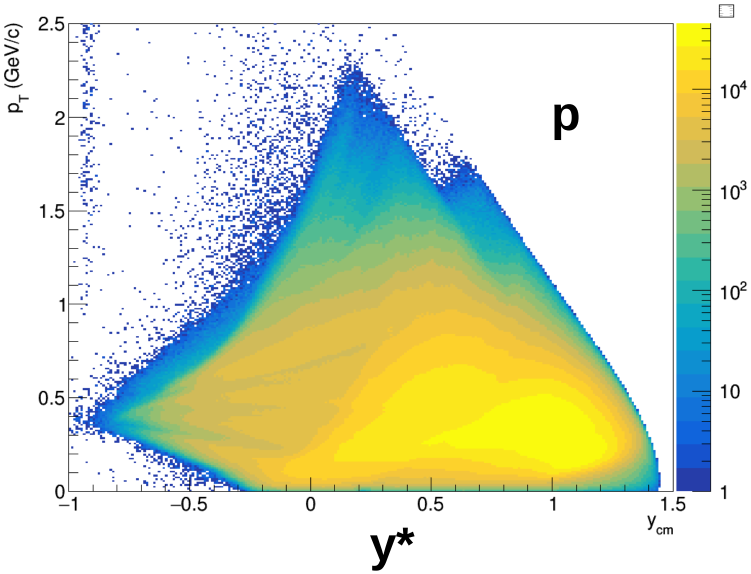
Still need dedicated ToF calibration to constrict proton mass peak

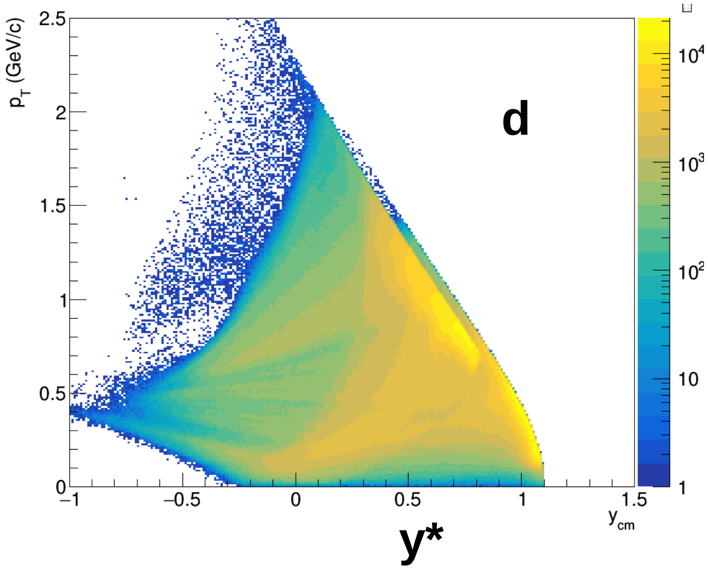


BM@N acceptance for Λ, K^0_s , identified p, d

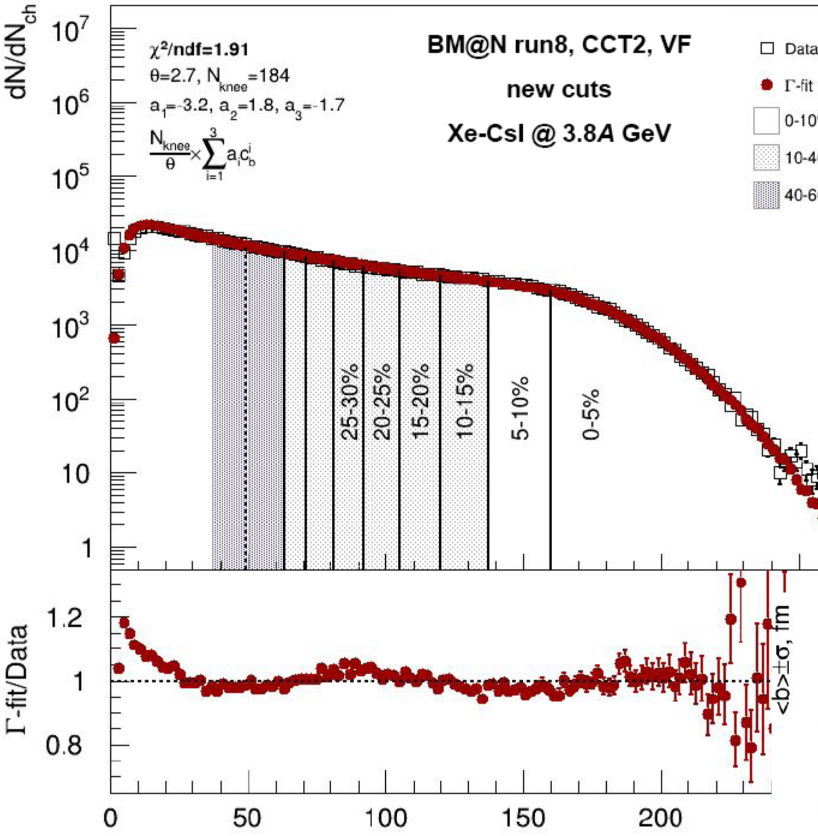






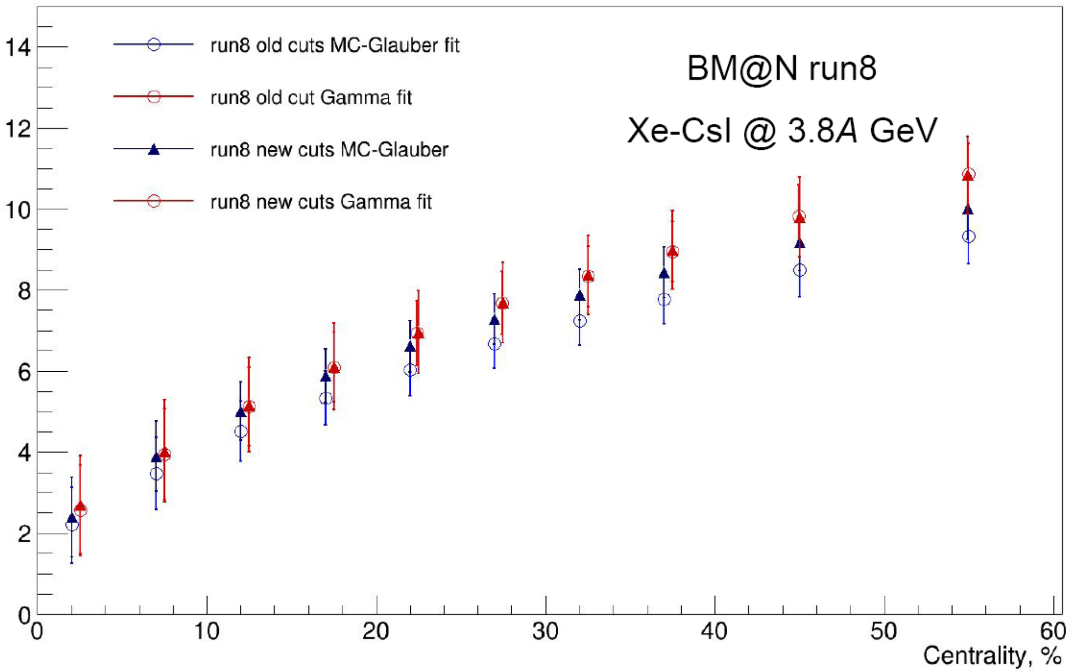


Centrality selection from fits of the track multiplicity



- Parametrization of data track multiplicity N_{ch} by MC Glauber model or Negative Binominal Distribution (Γ-fit) with free parameters
- Extract $P(b \mid N_{ch})$

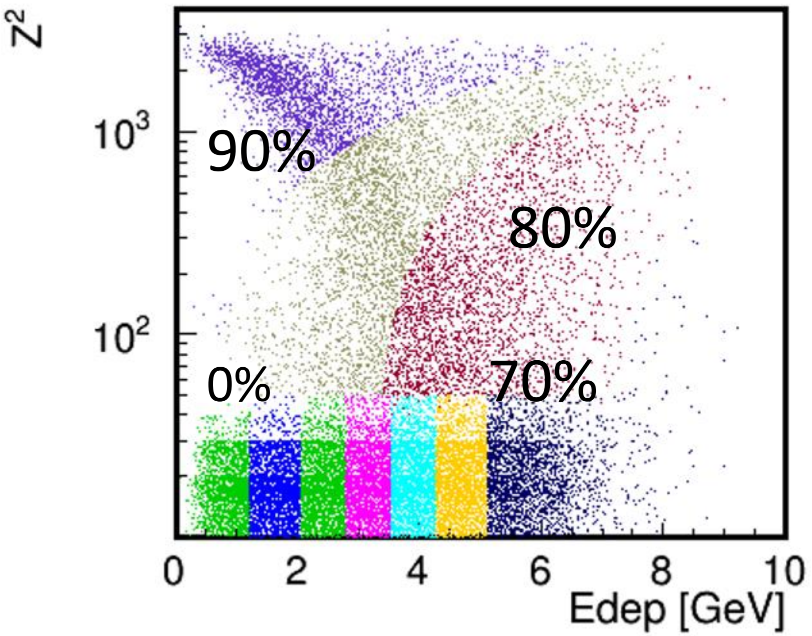
- Still need to correct for trigger efficiency, changes in central tracker (FST, GEM) efficiency

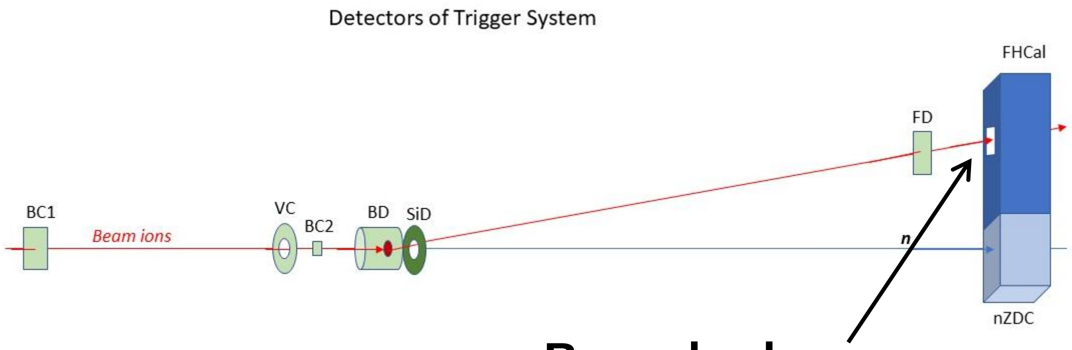


Γ-fit and MC-Glauber fit are in agreement

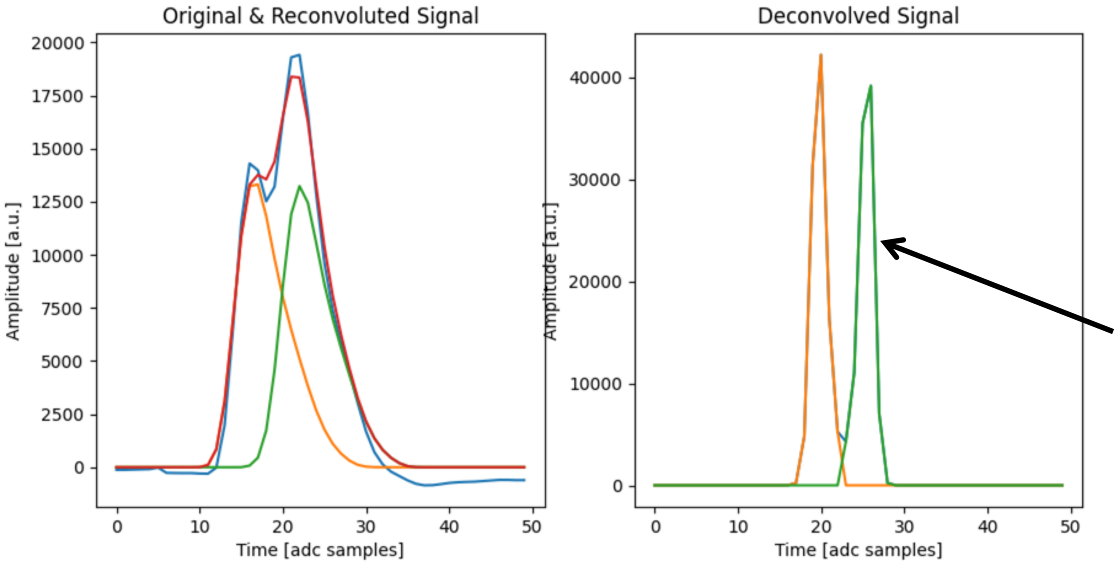
Centrality selection in forward detectors: hodoscope and FHCal

Color bins – 10% of number of events in each bin





Beam hodoscope



~30% events with Z^2 signal pile-up in the beam hodoscope

Need to subtract pile-up to determine centrality unbiased

Pile-up correction in beam hodoscope by signal unfolding

→ remain 4% events with unresolved peaks in multi-ion pile-up

Current status of the Xe data analysis

- **Optimization of the central tracking algorithm** based on Vector Finder (Si+GEM)
  - alignment of the central and outer tracker
  - implementation of a newly measured magnetic field map
  - few iterations to update / improve performance of the central track finder
  - first processing of reconstruction of full set of events is done using DIRAC at MLIT Tier-1,2

→ Reasonable signals of Λ and K^0_S

- **Centrality measurement with forward detectors**:
  - pile-up corrections of fragment hodoscope signals (beam area) are done

Tasks to be completed for physics analyses:

- **Particle identification in ToF-400 and ToF-700 detectors**:
  - finish alignment of ToF-detectors with central tracks in magnetic field
  - need calibration of time of flight to squeeze proton mass peak

- **Topics of physics analyses:**
- analysis of production of Λ, Ξ- hyperons, K^0_S , K±, π± mesons, light nuclear fragments in Xe+CsI interactions;
- analysis of collective flow of protons, π±, light nuclear fragments
- search for light hyper-nuclei $_\Lambda H^3$, $_\Lambda H^4$

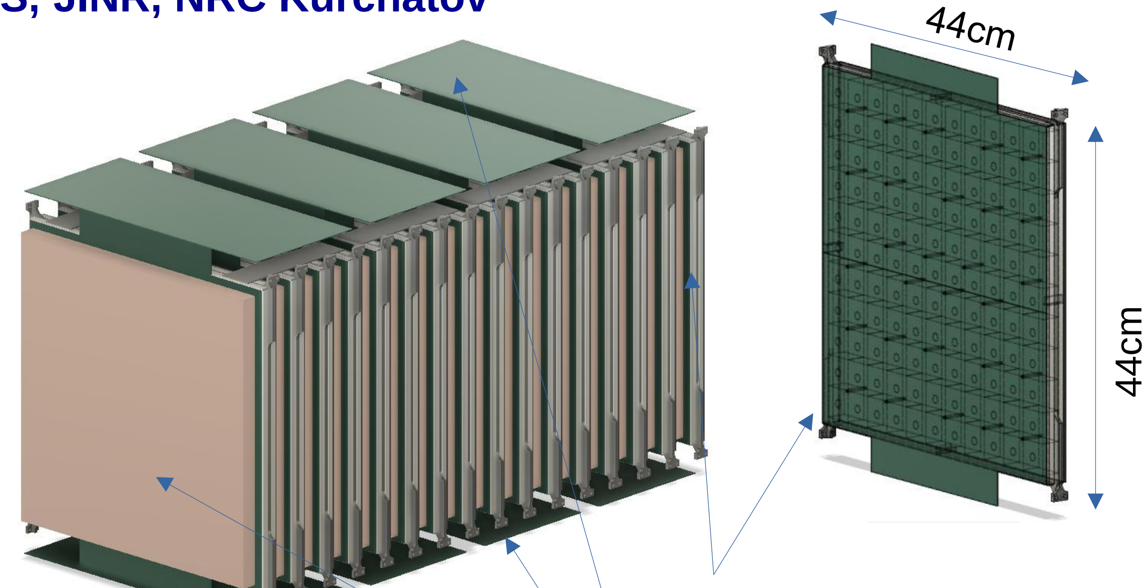
Outer tracker: 2 big 2.1x1.5 m^2 cathode strip chambers installed

Team:
A.Vishnevsky
R.Kattabekov
A.Makankin
A.Morozov
E.Martovitsky
S.Piyadin
V.Spaskov

1st big CSC was installed and operated in the Xe run
2nd big CSC has been tested with cosmic particles and installed for the next experimental run

High Granularity Neutron detector

INR RAS, JINR, NRC Kurchatov

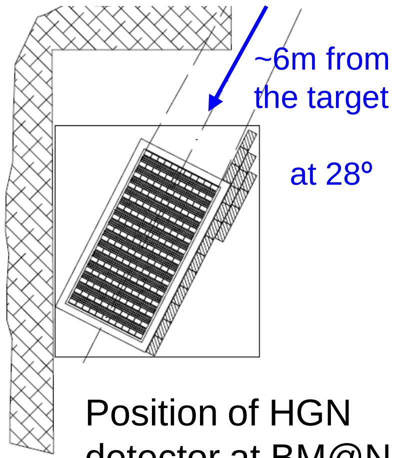


VETO layer

one layer containing 121 cells with individual SiPM read-out

FPGA based fast TDC read-out with additional ToT amplitude measurement

→ plan to construct in 2023-2024

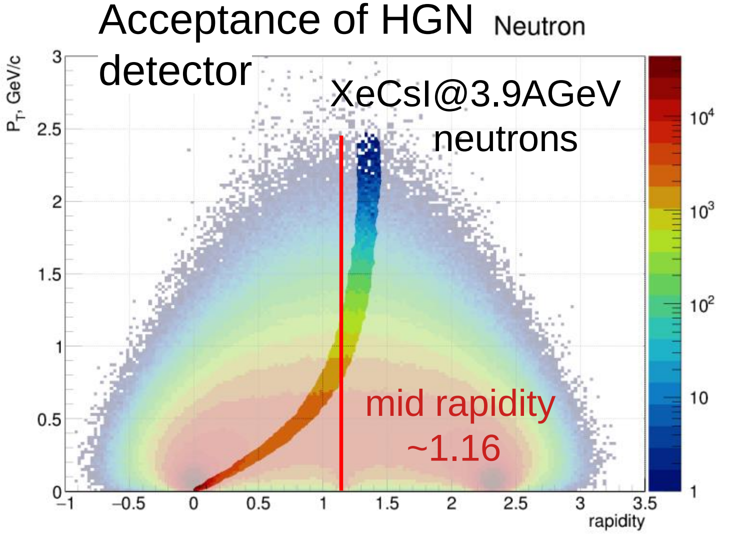


Position of HGN detector at BM@N

HGN detector parameters:

- 11 x 11 cells in one layer
- first layer works as VETO
- next layers: 3cm Cu + 2.5cm scintillator
- number of layers: 16 (~3 λ_{int})
- time resolution of one scint. cell ~ 100ps
- neutron detection efficiency: > 80% @ 1GeV

Acceptance of HGN detector



Plans for BM@N upgrade and physics runs

In case of a physics run in the Xe beam in 2024-2025
(depends on the status of the NICA collider construction):

→ beam energy scan in the range of 2-3 AGeV
→ same central tracker configuration based on silicon FST and GEM detectors,
→ additional 1st vertex plane of silicon STS detectors
→ complete replacement of outer drift chambers with cathode strip chambers

Preparations for a physics run with the Bi beam

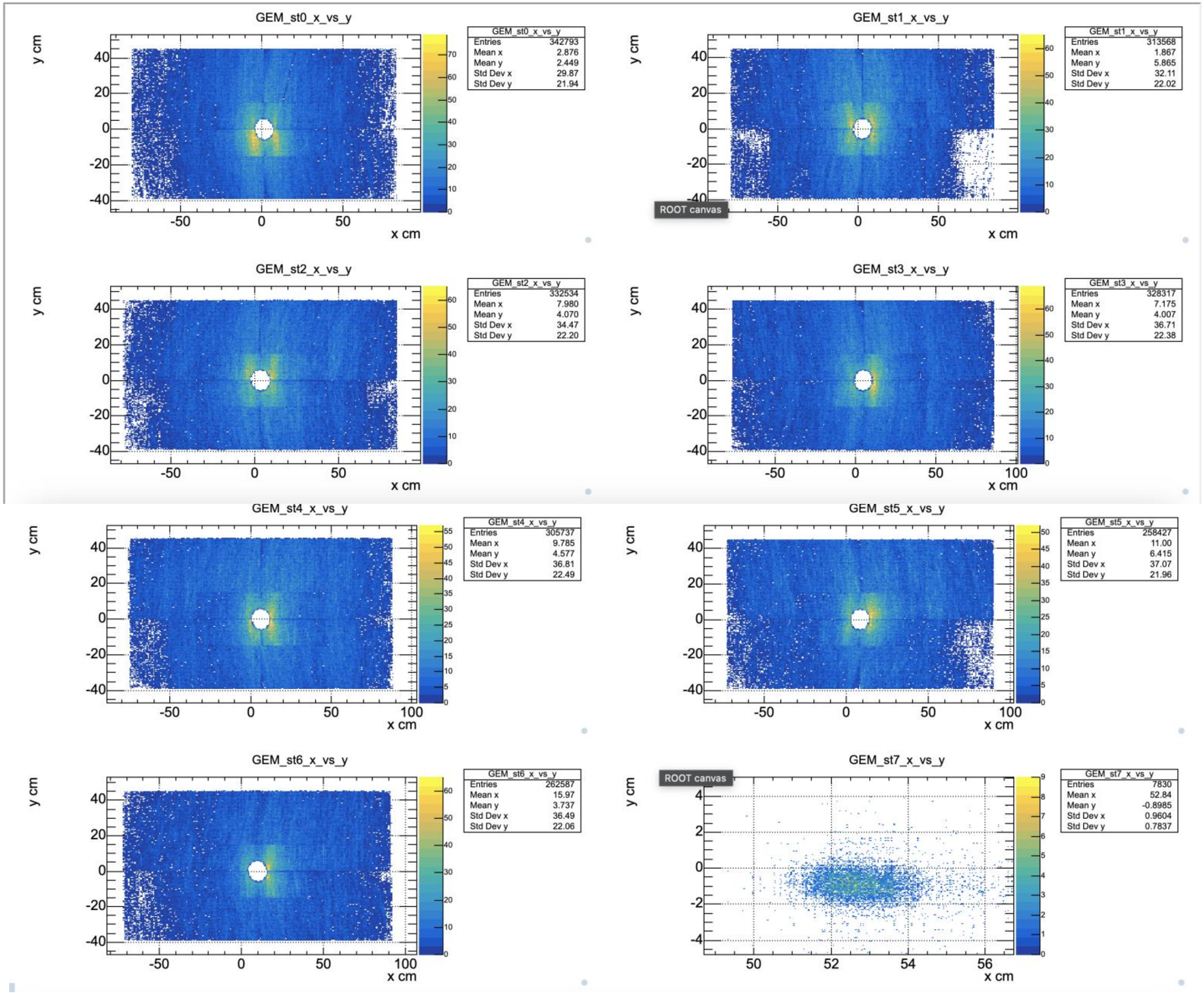
- Further development of the central tracker is foreseen: installation of additional stations of silicon detectors

- It is planned to put into operation a 2-coordinate (X/Y) neutron detector of high granularity to measure neutron yield and collective flow

Thank you for attention!

GEM hit reconstruction: 7 stations + small GEM profile meter

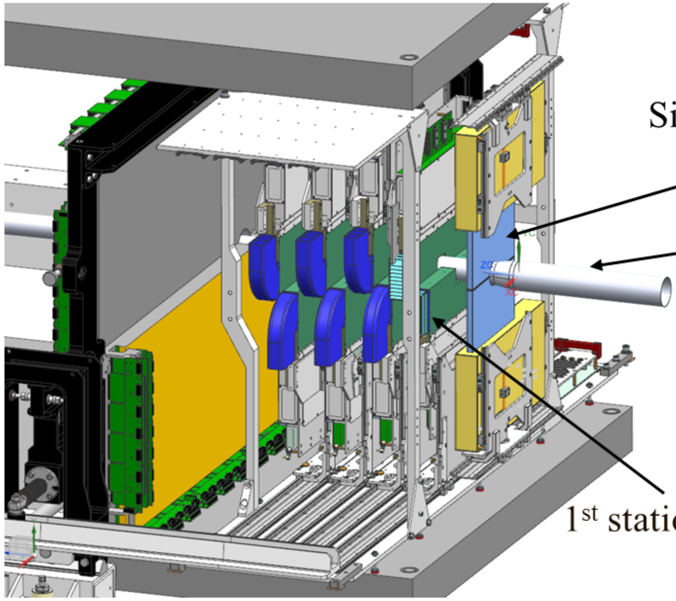
GEM Hits



2-coordinate Si-plane based on STS modules

A new Si-plane based on STS modules to be installed between the **Target** and **Forward Si-Tracker.**

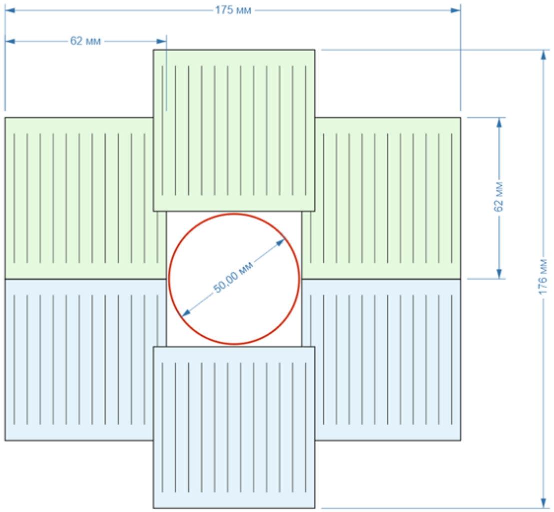
Motivation: to improve track and momentum resolution for the low-momentum particles


Si-plane based on STS modules

Beam pipe

1st station of FwdSi

BM@N setup inside the magnet



Sensitive area of Si-plane

Plan to install and commission the new Si plane in fall 2024

Coalescence factors B_2 and B_3

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

$$\approx B_A\left(E_p\frac{d^3N_p}{dp_p^3}\right)^A, \qquad B_A \propto V_{\rm eff}^{1-A}$$

$$\rightarrow B_A = d^2N_A/2\pi p_T dp_T(A)dy \;\; / \;\; [d^2N_p/2\pi p_T dp_T(p)dy)]^A,\ A=2(d),\ 3(t)$$

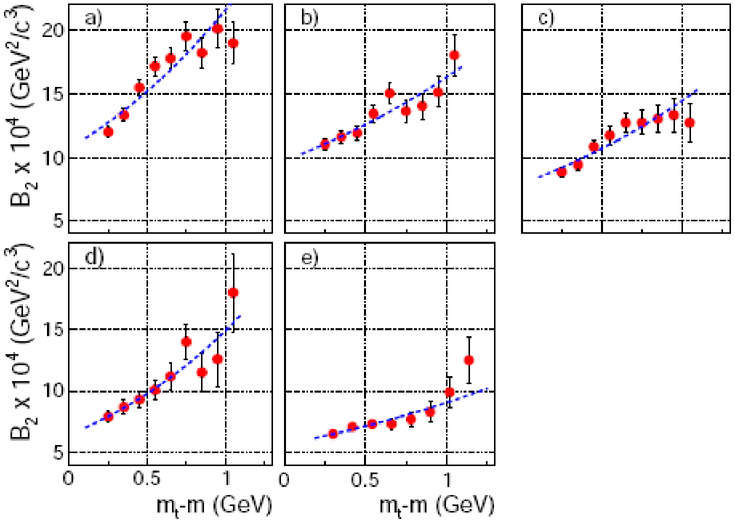
B_A is the coalescence parameter that characterizes the probability of nucleons to form nucleus A.

Coalescence parameter B_A depends on the nucleus mass number A, collision system, centrality, energy, and transverse momentum

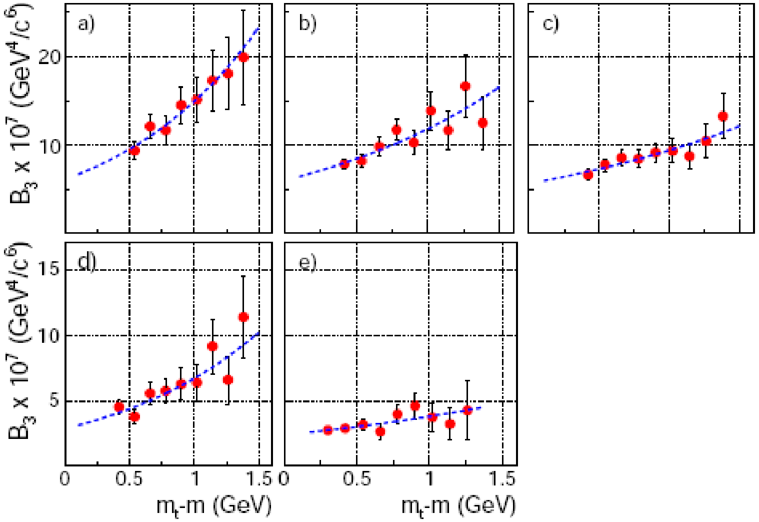
In the coalescence model B_A rises with p_T

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

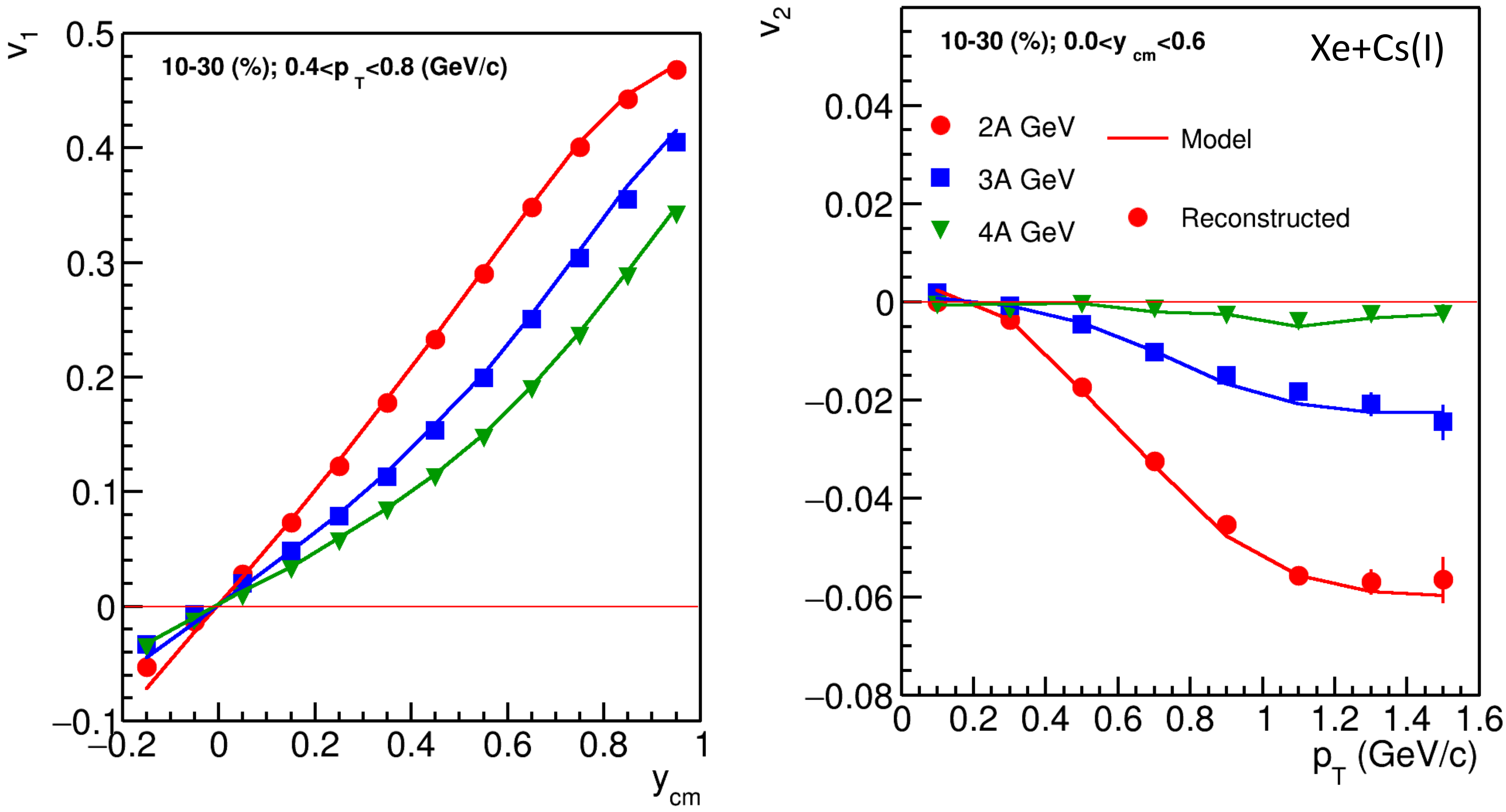
NA49: B_2 for deuterons



NA49: B_3 for tritons, Pb+Pb



Directed and elliptic flow at BM@N



- Good agreement between reconstructed and model data
- Approximately 250-300M events are required to perform multi-differential measurements of v_n