Status of the BM@N project

M.Kapishin

Baryonic Matter at Nuclotron (BM@N) Collaboration:

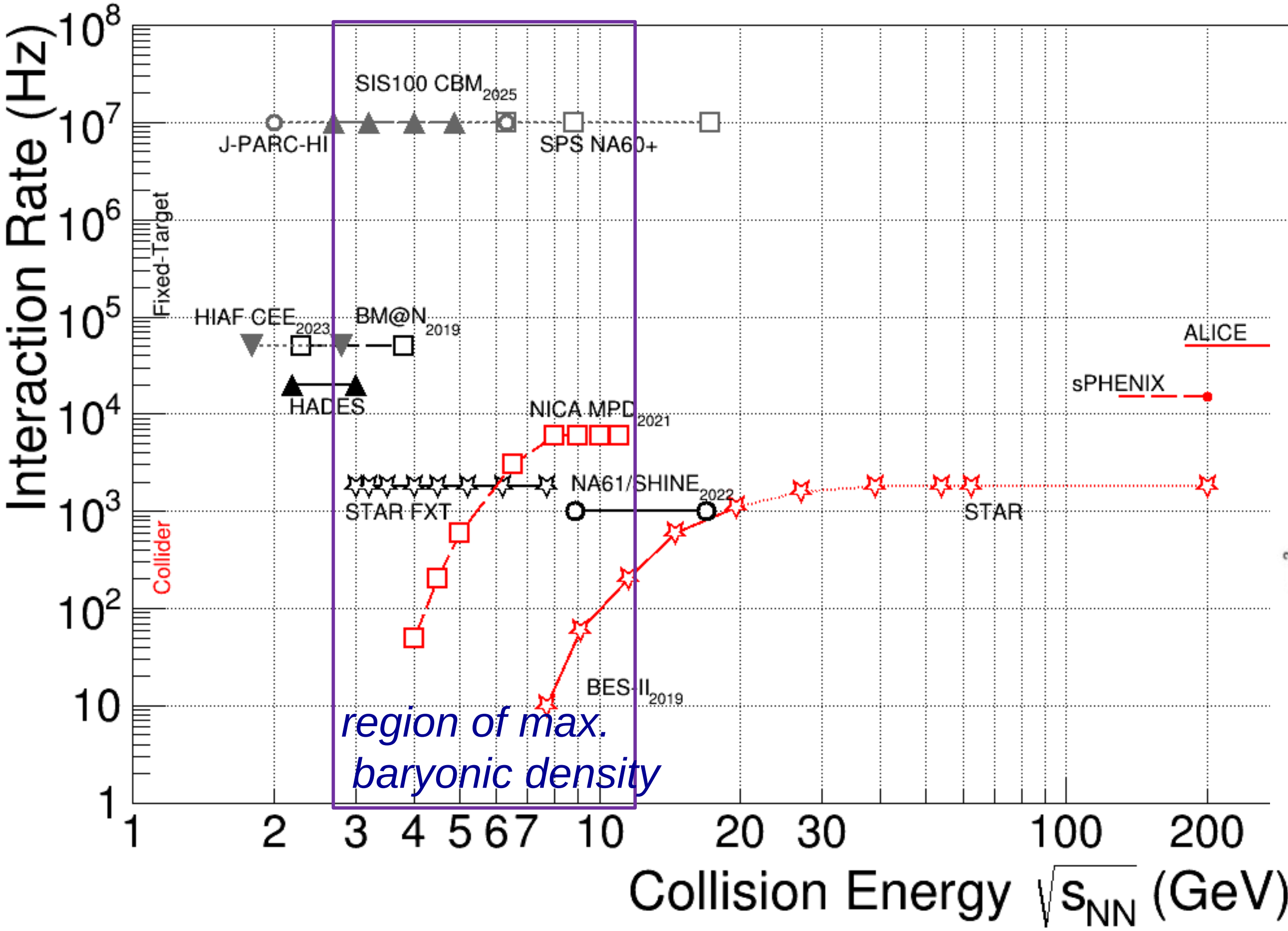
3 Countries, 10 Institutions, 189 participants

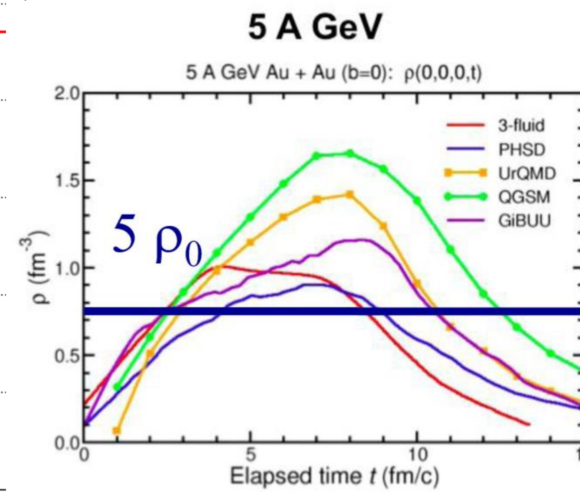
- ***University of Plovdiv, Bulgaria***
- ***St.Petersburg University***
- ***Joint Institute for Nuclear Research***
- ***Institute of Nuclear Research RAS, Moscow***
- ***Shanghai Institute of Nuclear and Applied Physics, CFS, China;***
- ***NRC Kurchatov Institute, Moscow***
- ***Moscow Engineer and Physics Institute***
- ***Skobeltsyn Institute of Nuclear Physics, MSU, Russia***
- ***Moscow Institute of Physics and Technics***
- ***Lebedev Physics Institute of RAS, Moscow***

▪10th meeting of the BM@N collaboration was held in St Petersburg on 15-19 May

▪ Institute of Physics and Technology, Almaty, accepted as an associate member of the Collaboration

Heavy Ion Collision Experiments





BM@N: $\sqrt{s_{NN}}$= 2.3 - 3.3 GeV
MPD: $\sqrt{s_{NN}}$= 4 - 11 GeV

BM@N competitors:

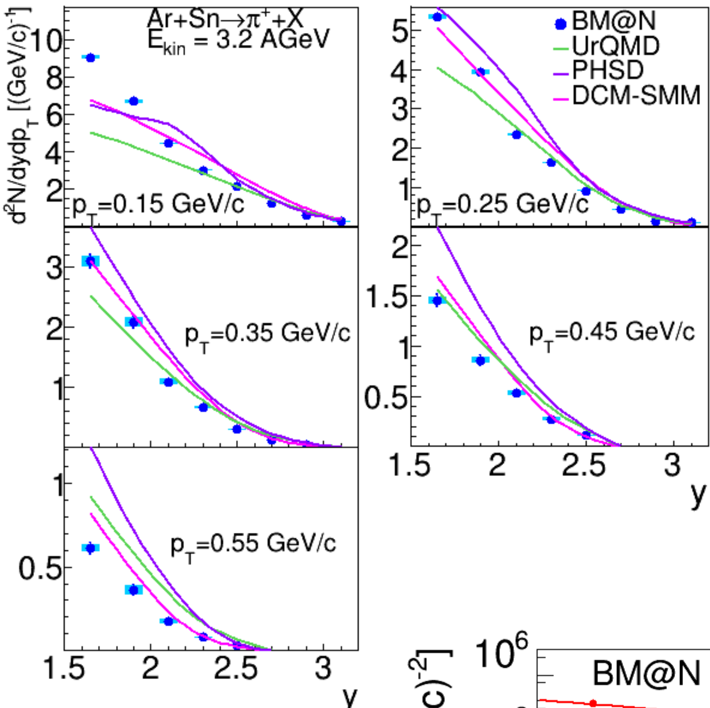
HADES BES (SIS): Au+Au at $\sqrt{s_{NN}}$ = 2.42 GeV, Ag+Ag at $\sqrt{s_{NN}}$ = 2.42 GeV, 2.55 GeV.

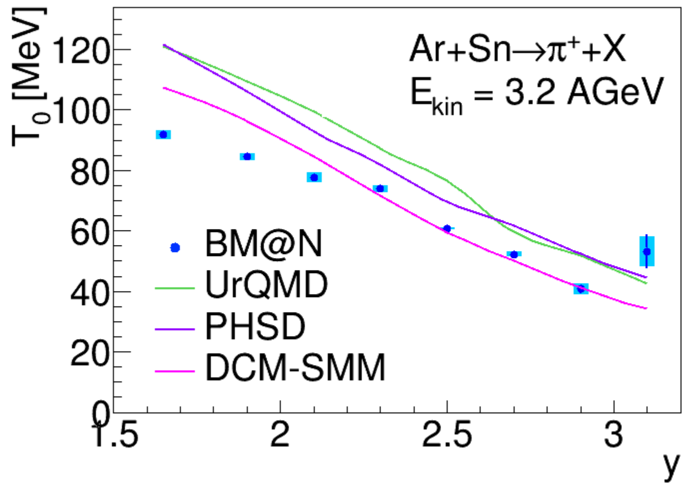
STAR BES (RHIC): Au+Au at $\sqrt{s_{NN}}$ = 3-200 GeV

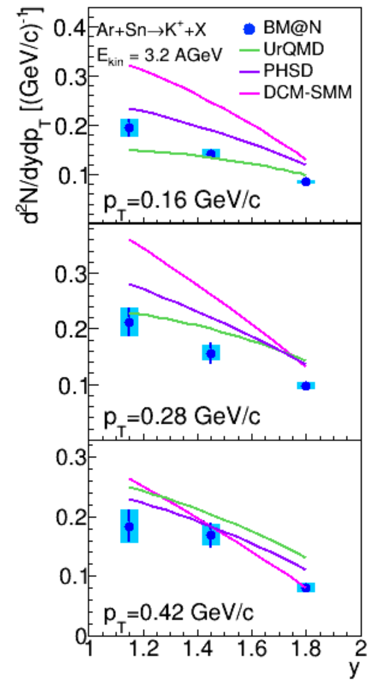
Production of π^+ and K^+ mesons in 3.2 AGeV argon-nucleus interactions at the Nuclotron

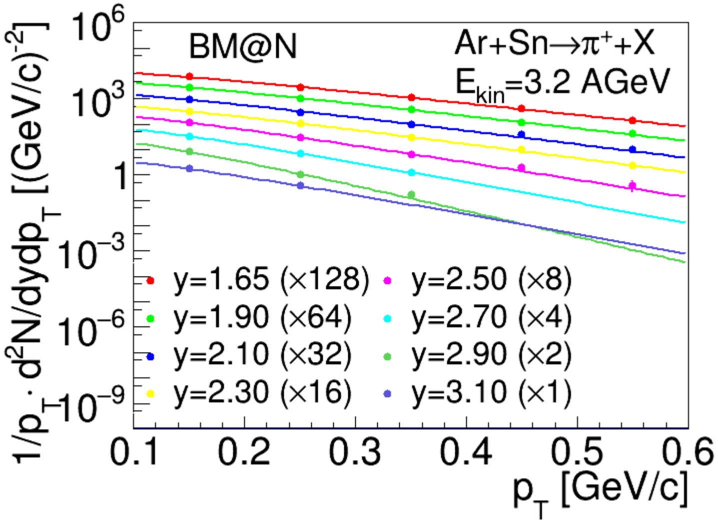
https://arxiv.org/abs/2303.16243v3

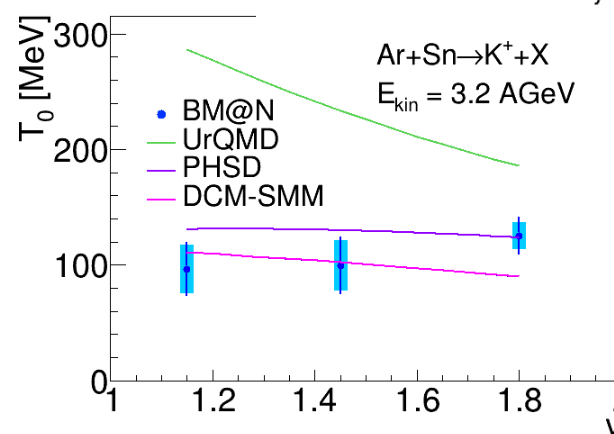
Paper submitted to JHEP









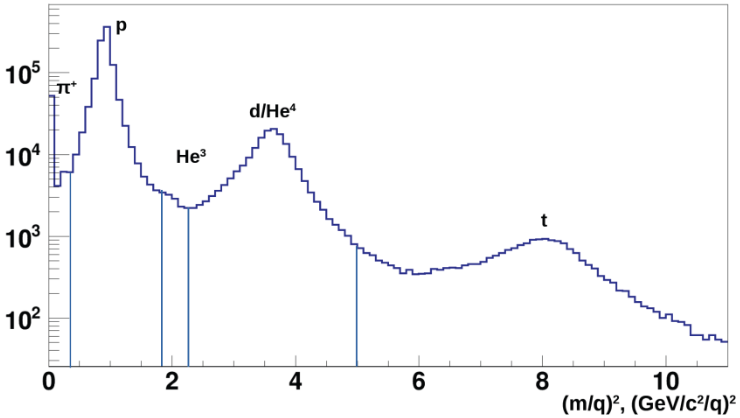


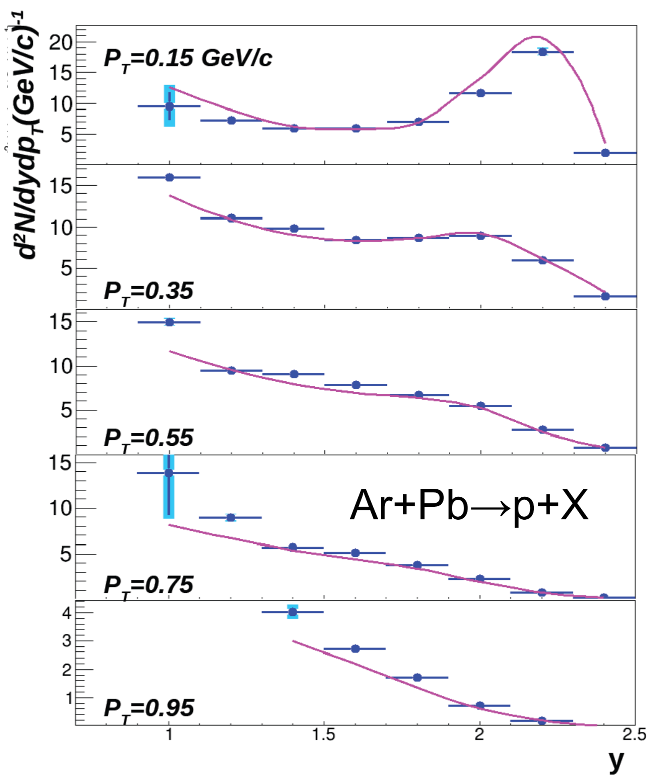
M.Kapishin **BM@N experiment**

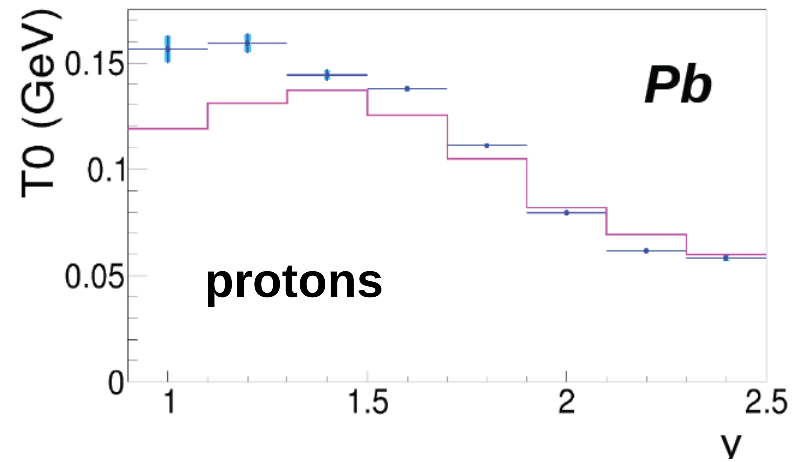
Production of *p, d, t,* ^3He*,* ^4He in 3.2 AGeV argon-nucleus interactions

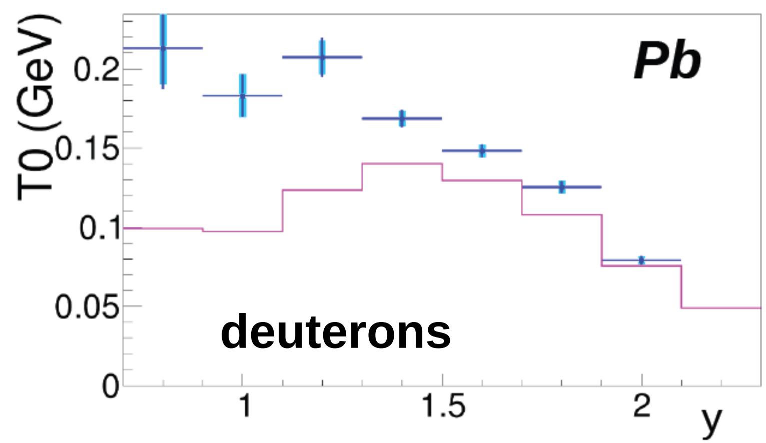
L.Kovachev, Yu.Petukhov, V.Plotnikov, I.Roufanov

$$1/m_T^2 \cdot d^2N/dm_T dy = C \cdot \exp(-(m_T - m)/T_0)$$



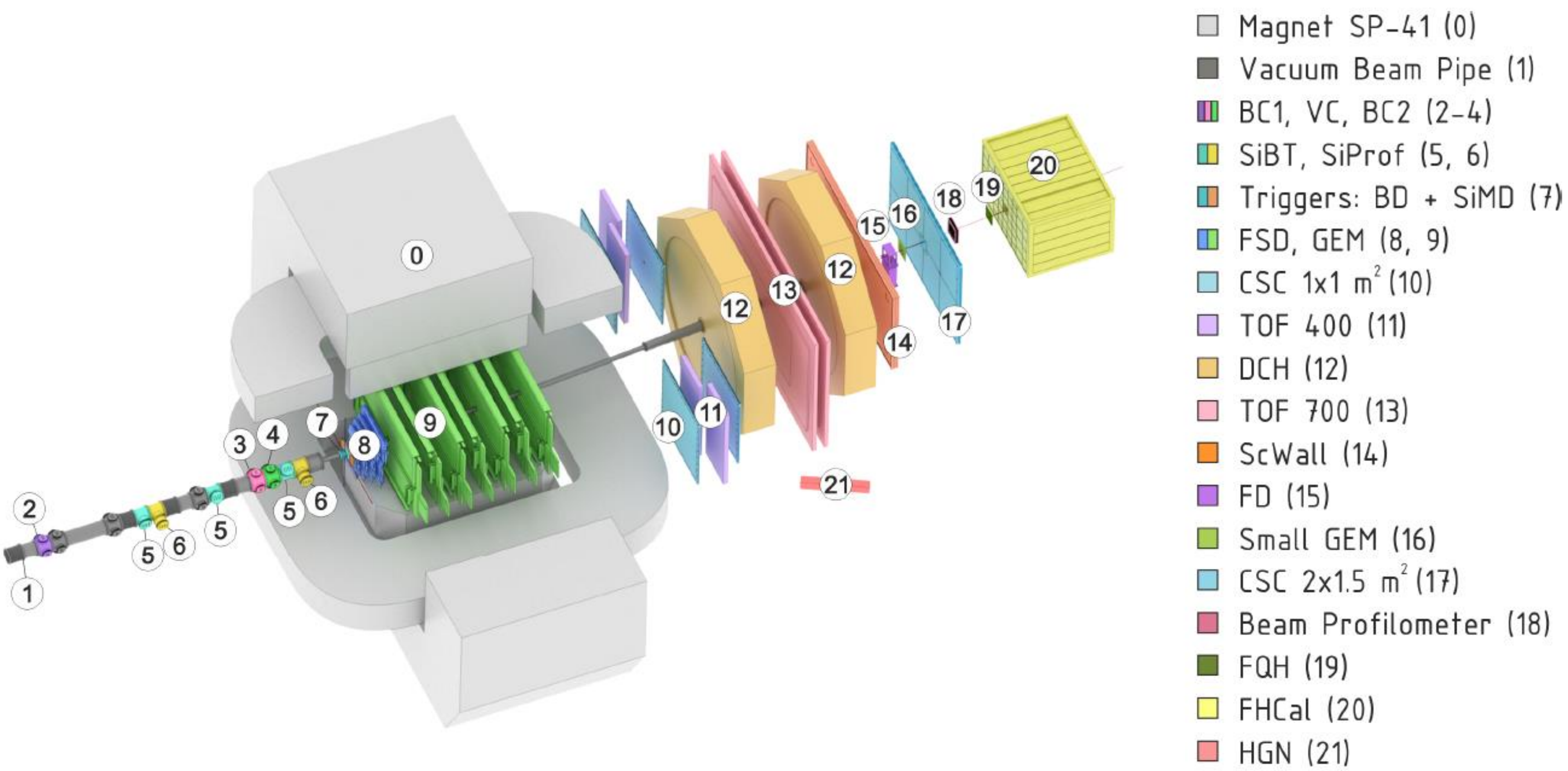






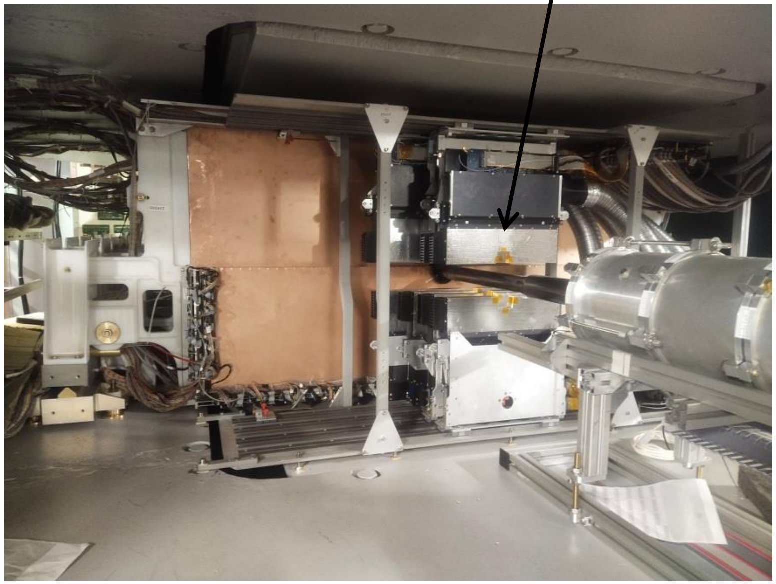
Comparison with DCM-SMM model (magenta)

Configuration of BM@N detector for heavy ion run



BM@N tracking detector installation for heavy ion run

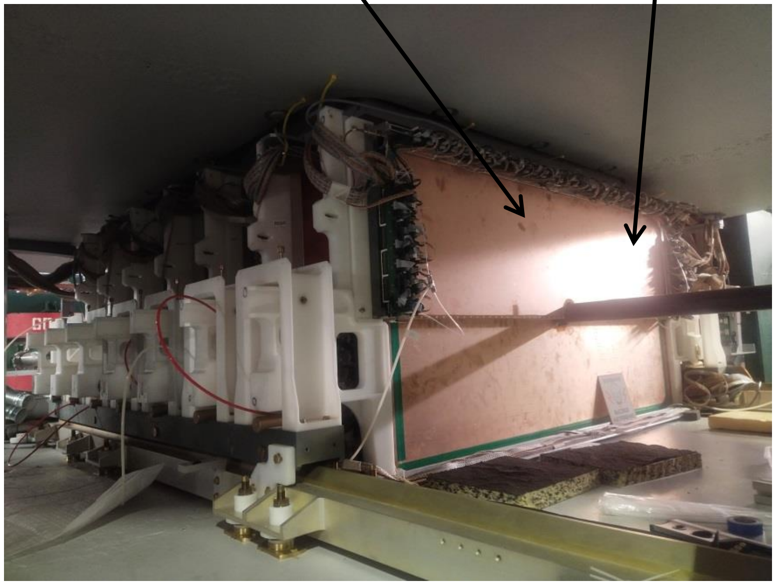
Forward Si tracker detectors in front of GEM detectors



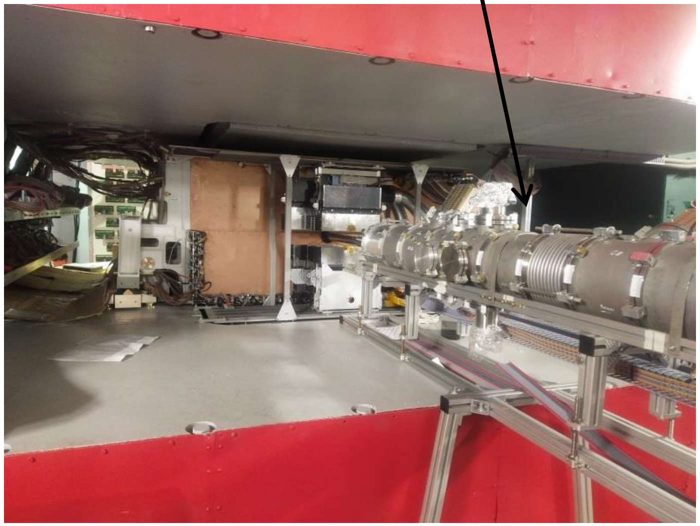
GEM, FST groups + engineer group

GEM detectors on positioning mechanics in magnet

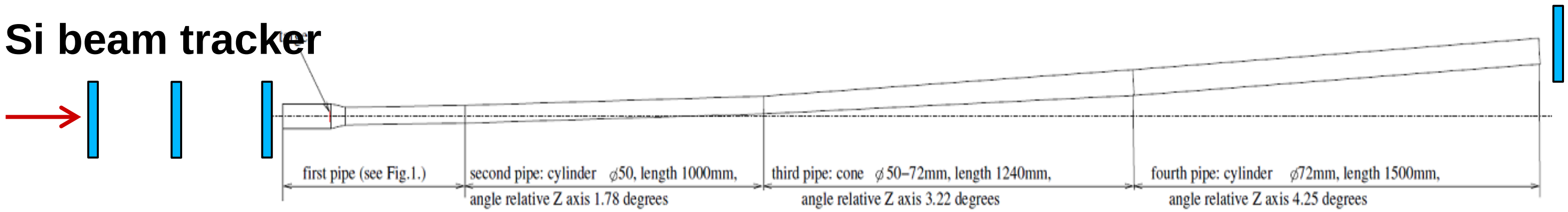
Carbon vacuum beam pipe



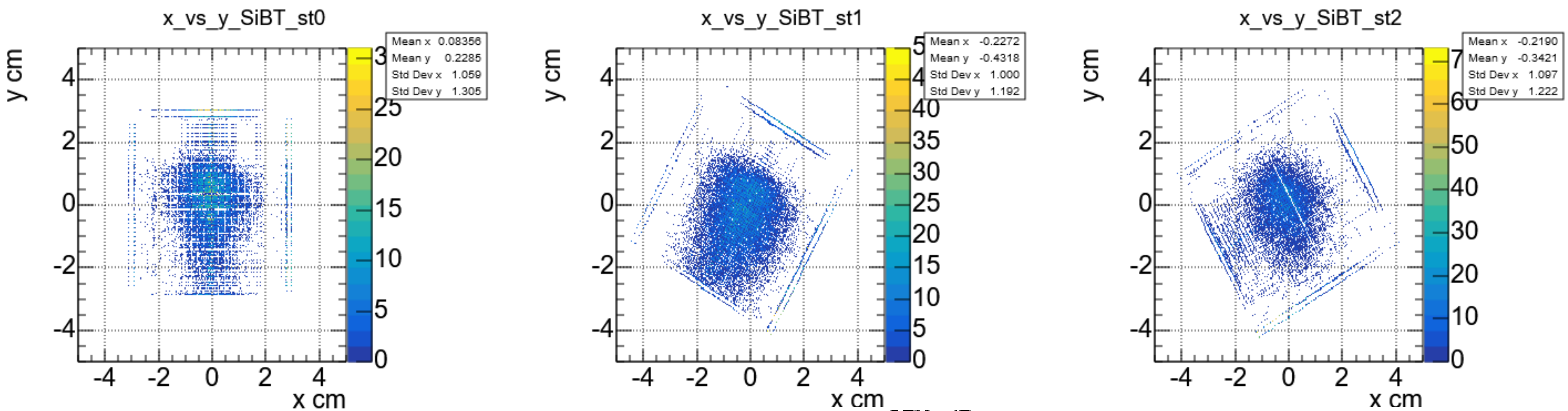
Vacuum boxes for beam detectors

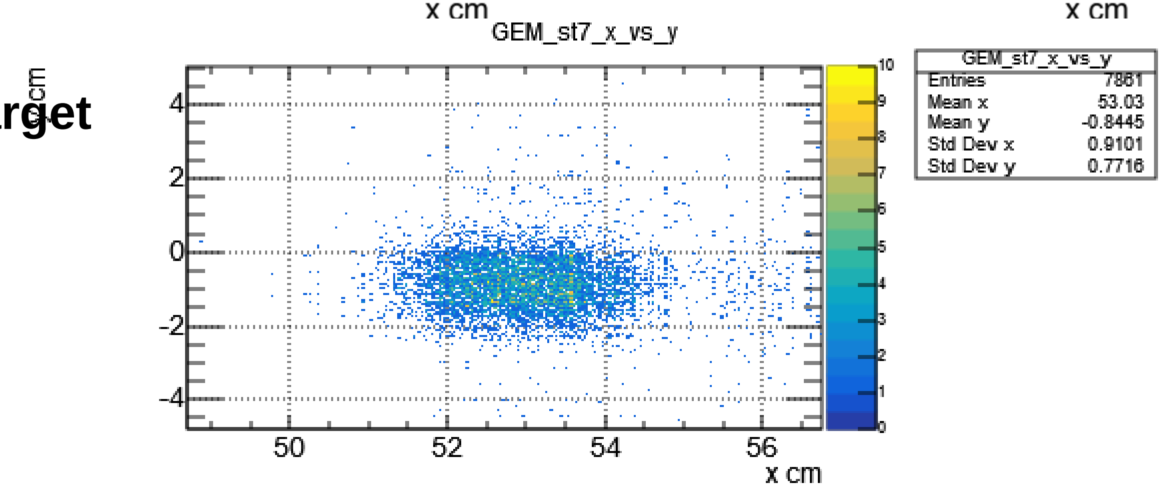


Experimental run in 3.8 AGeV Xe beam with CsI (2%) target



First task of the Xe run → trace beam and monitor its profile in the end of the setup (try to find optimal trajectory to reduce background)



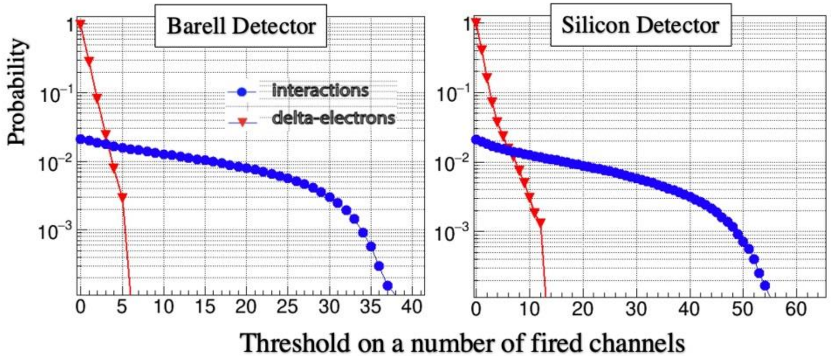


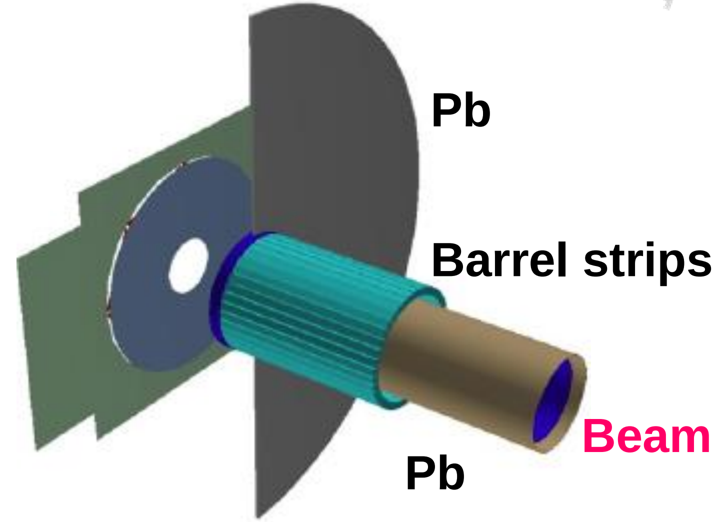
Measured beam spot at target

Ar 2018	Xe 2022
σ_X = 5 mm	7 mm
σ_Y = 5 mm	7 mm

BM@N Trigger detectors

Trigger detectors in target area: multiplicity SiD and Barrel BD

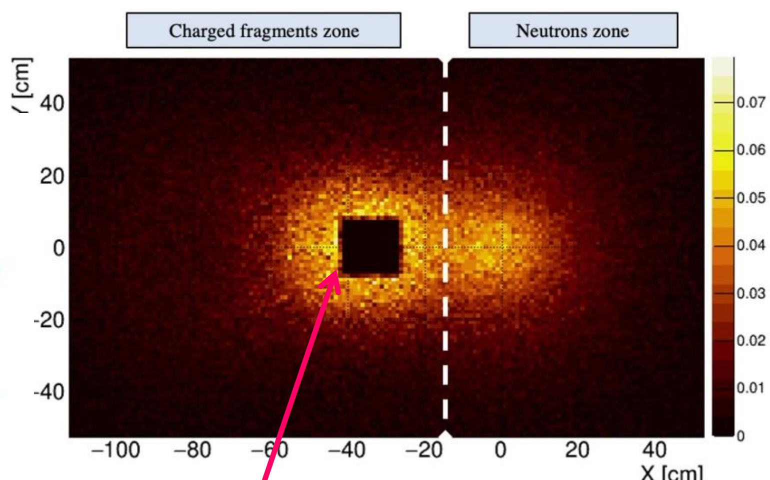




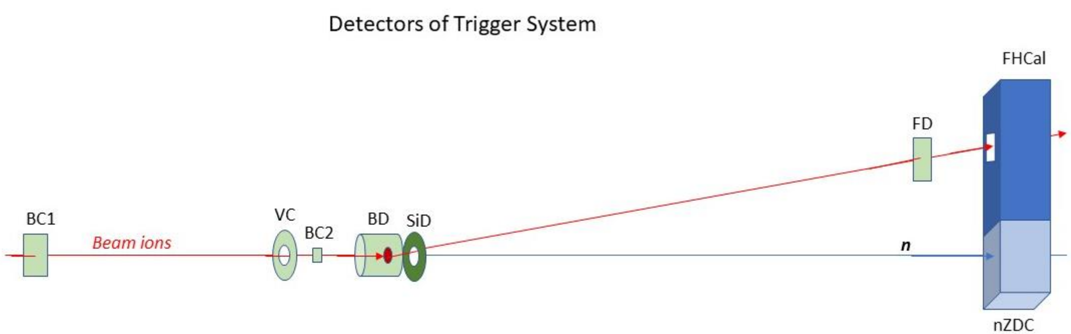
Variants of trigger logics — **fraction**

Beam trigger:	BT = BC1 * BC2 * VC_{veto}	3 %
Min Bias trigger:	MBT = BT * FD Amp < thr	7 %
BD trigger:	CCT1 = BT * N(BD)>3	5 %
Combined trigger:	CCT2 = MBT * CCT1	main

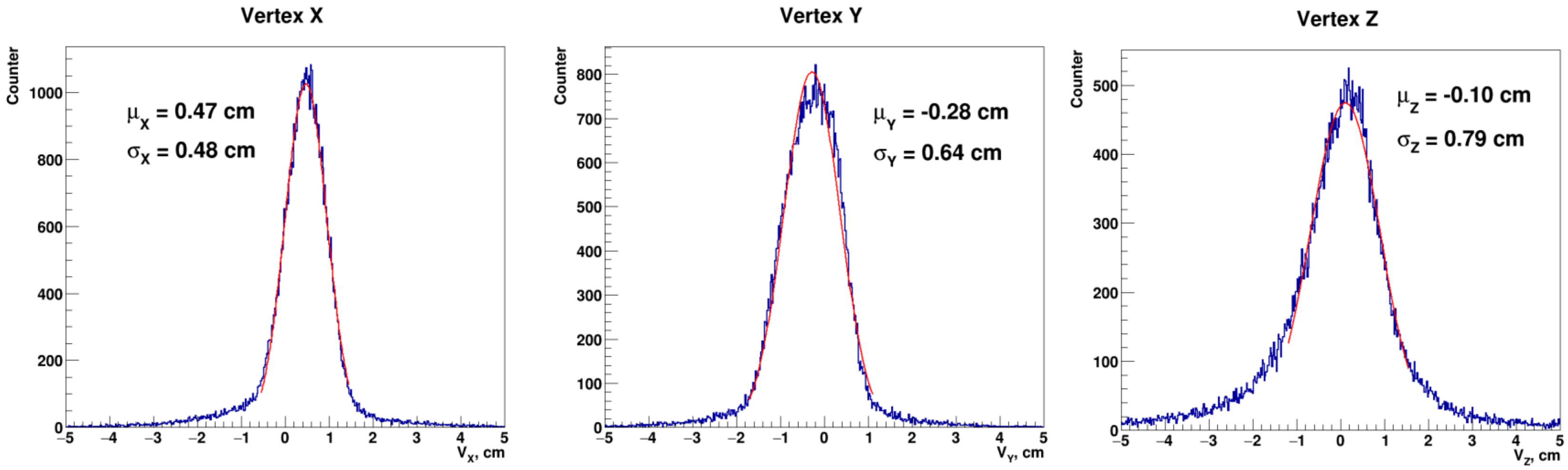
FHCAL rates



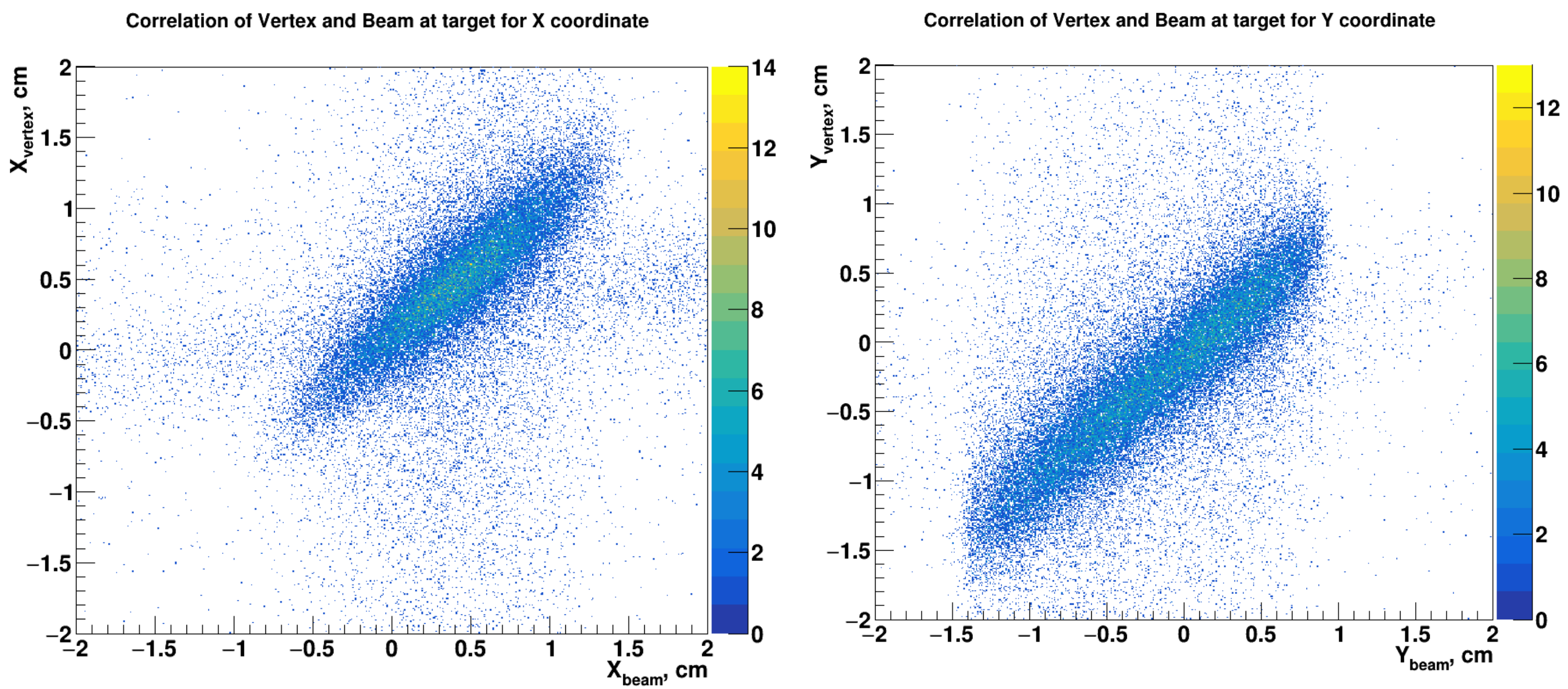
Fragment detector FD



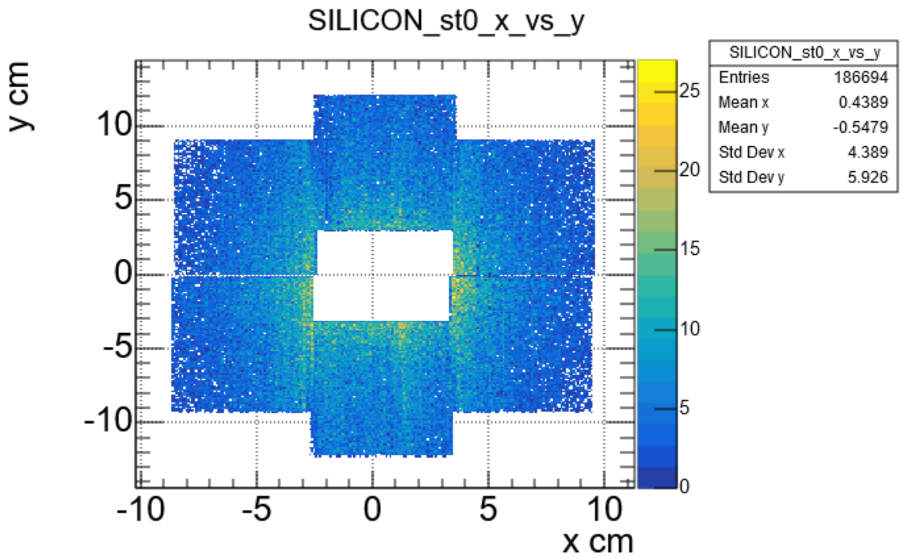
Vertex reconstruction

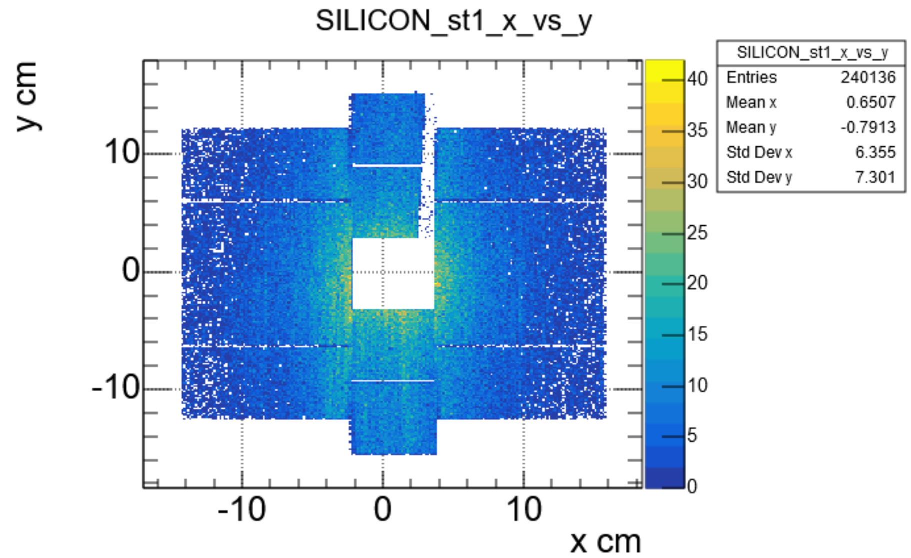


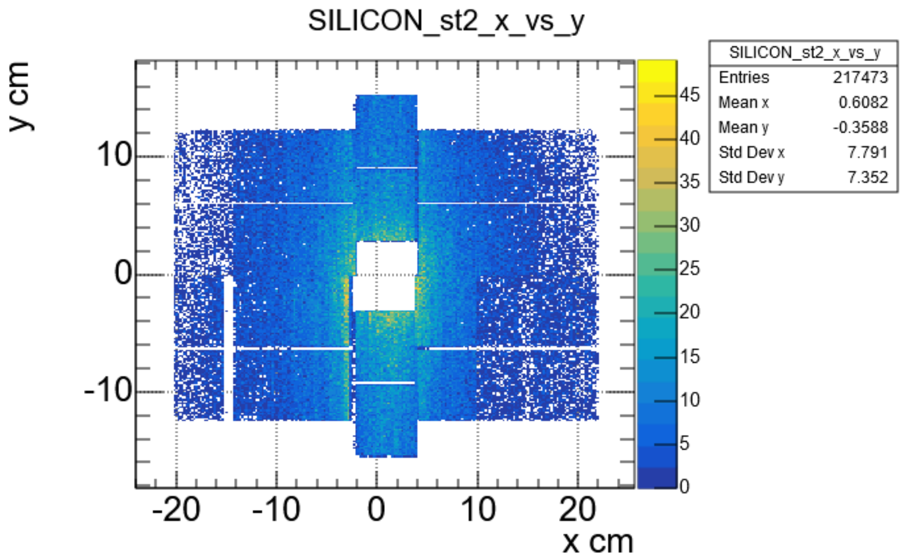
CsI (2%) target

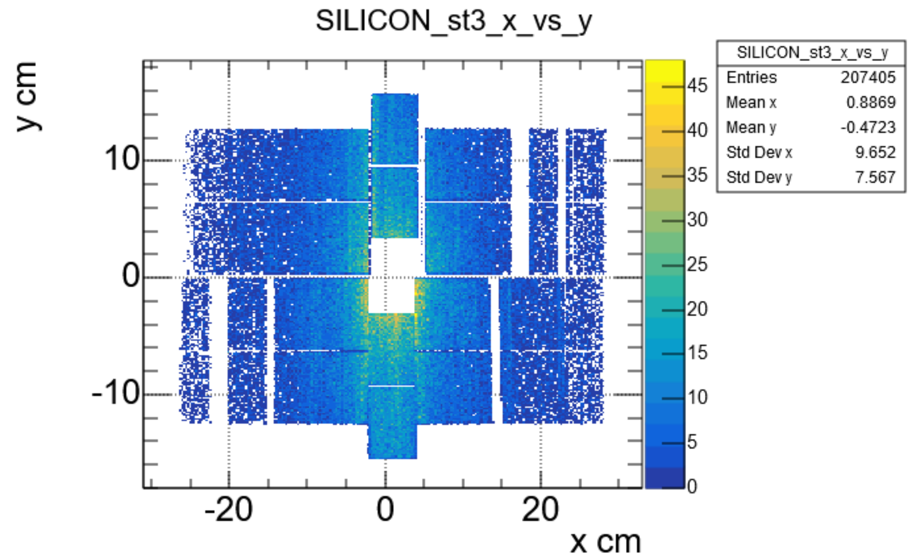


FST hit reconstruction: 4 Si stations



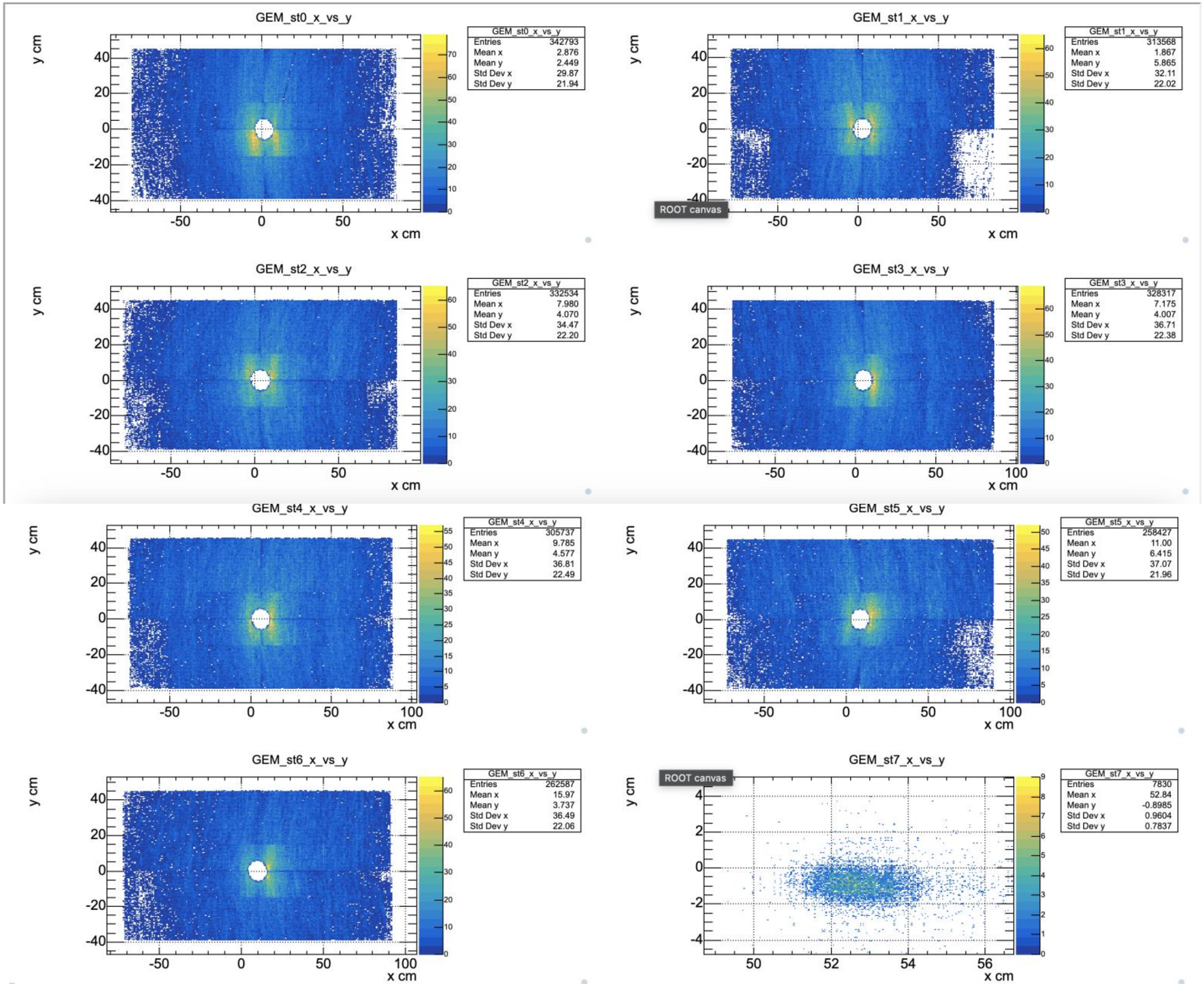






GEM hit reconstruction: 7 stations + small GEM profile meter

GEM Hits

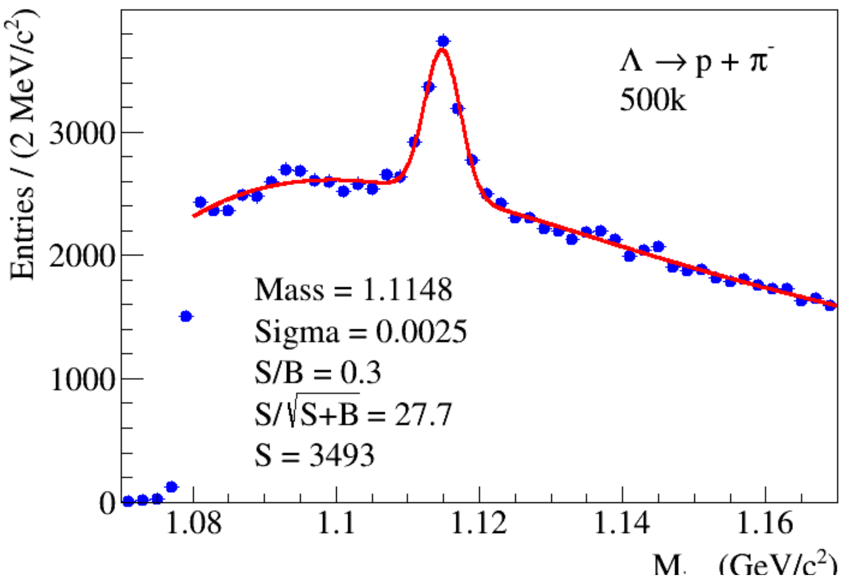


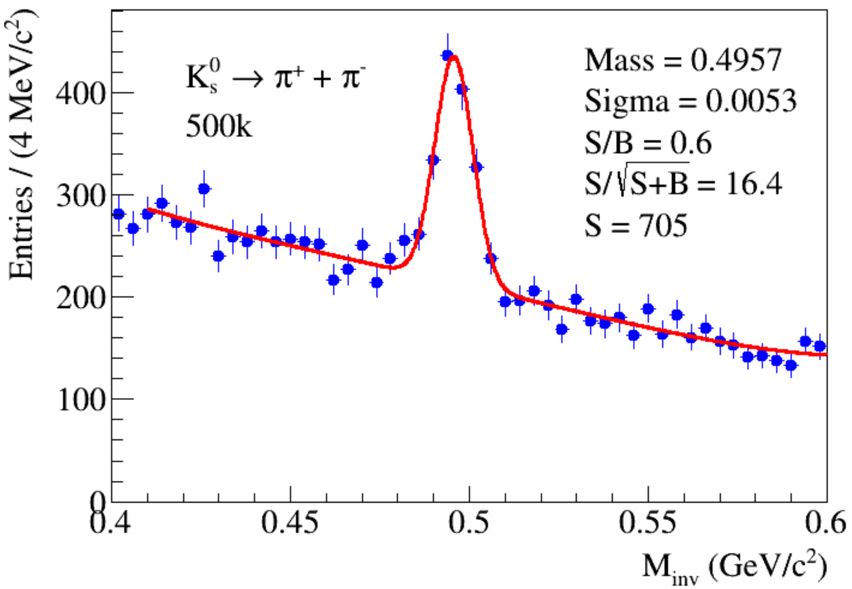
Raw data reconstruction: $\Lambda \to p\pi^-$ and $K^0_s \to \pi^+\pi^-$ signals

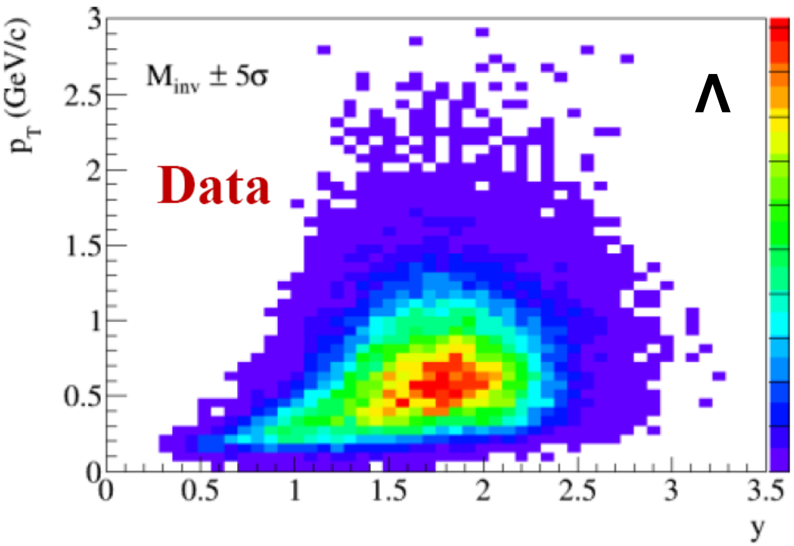
A.Zinchenko, V.Vasendivna

Central tracking activities:

- optimize Vector Finder tracking algorithm
- improve alignment of silicon and GEM tracking detectors



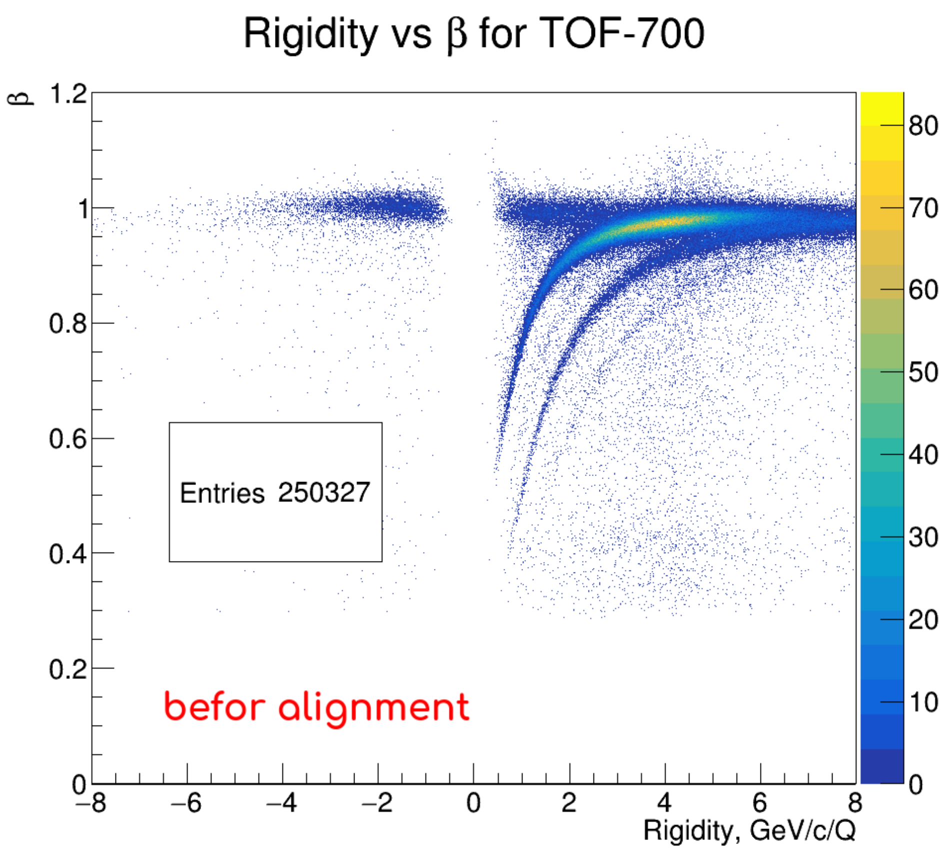


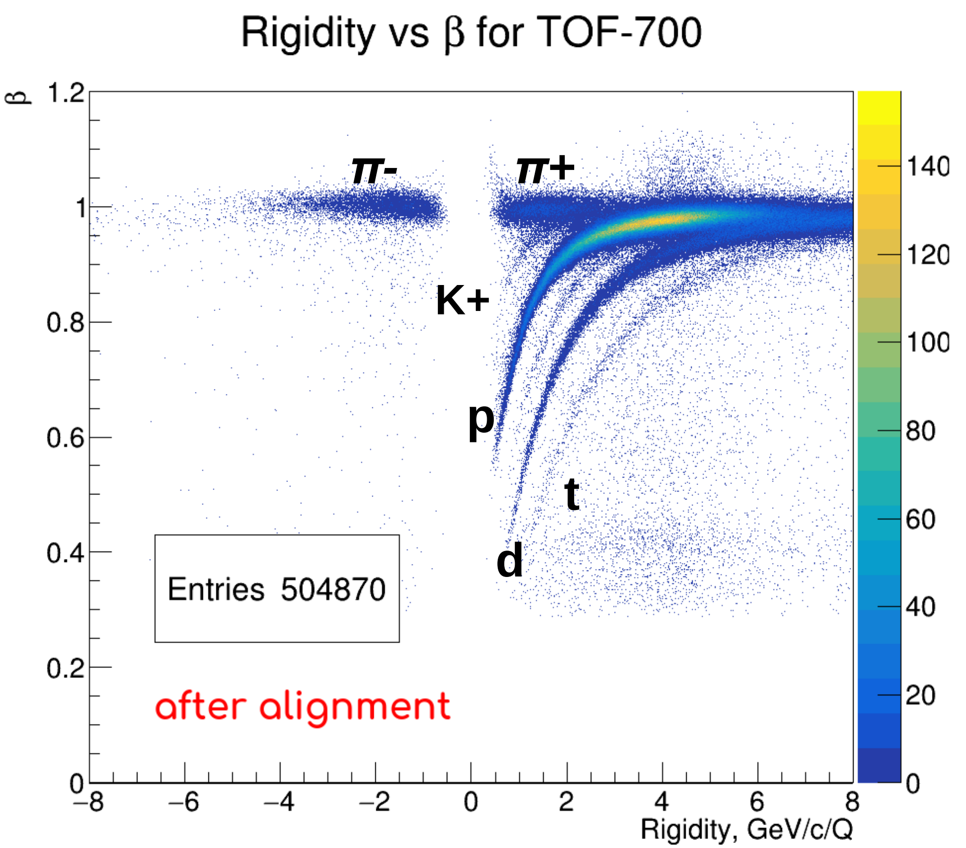


Raw data: ToF-700 π+, K+, p, He3, d, t identification

Still without dedicated ToF calibration

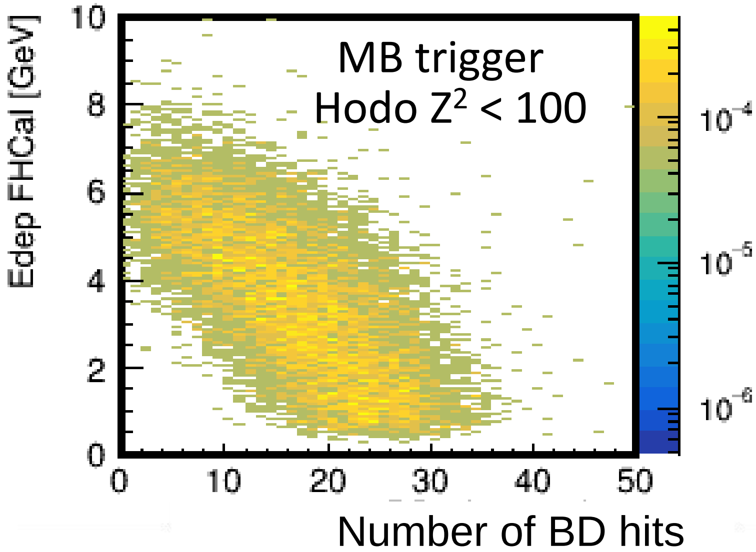
Yu.Petukhov, S.Merts

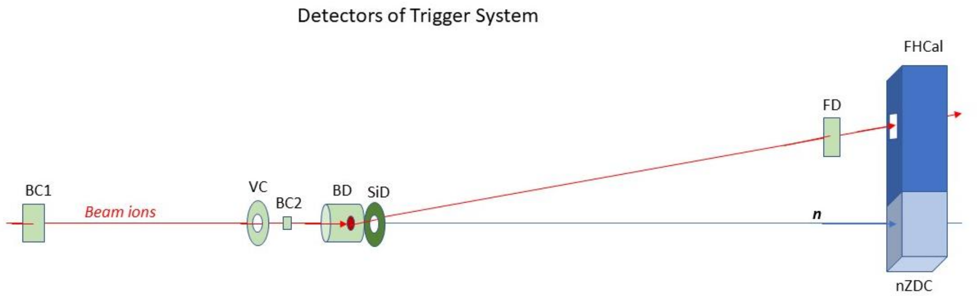


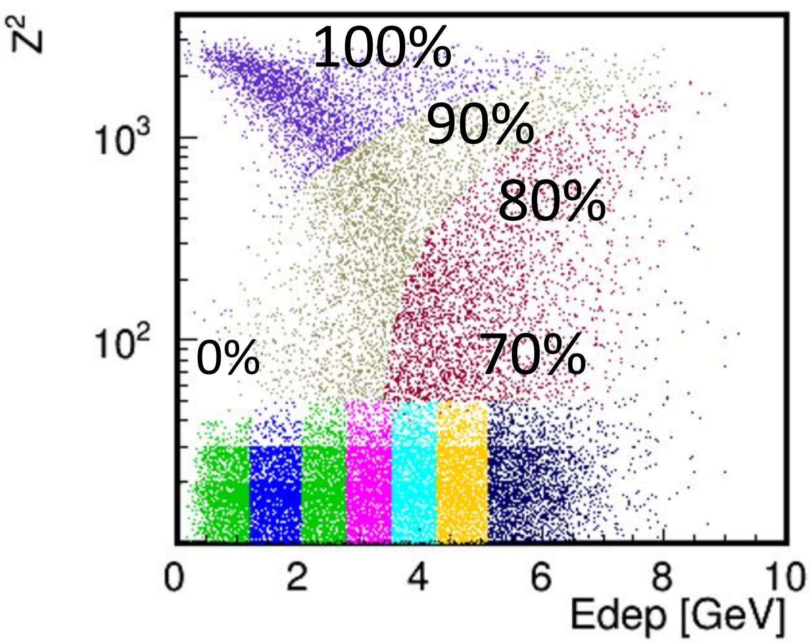


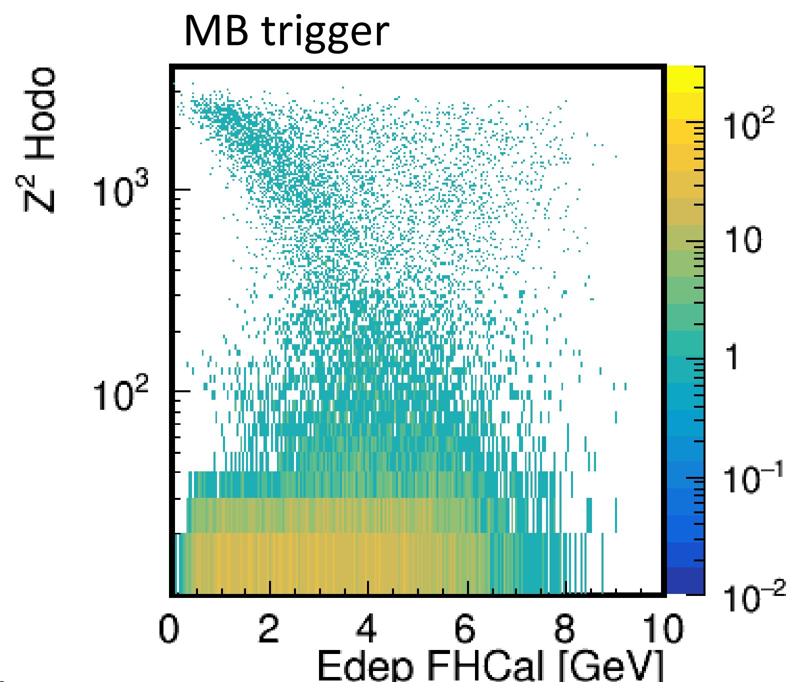
Centrality selection with Hodoscope and FHCal detectors

INR RAS group





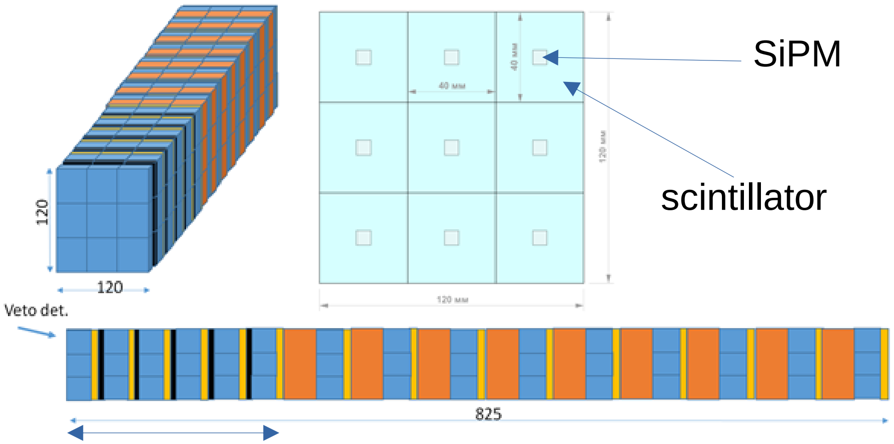




Color bins – 10% of number of events in each bin

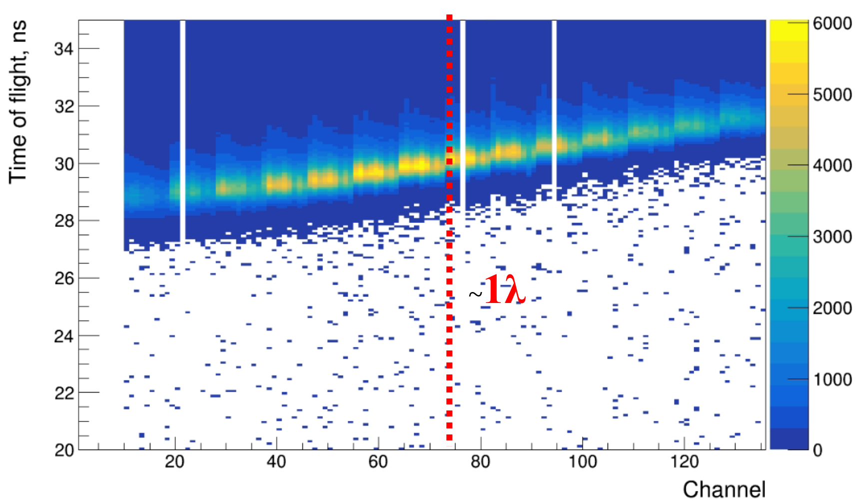
R&D High Granularity Neutron detector prototype

INR RAS, JINR, NRC Kurchatov

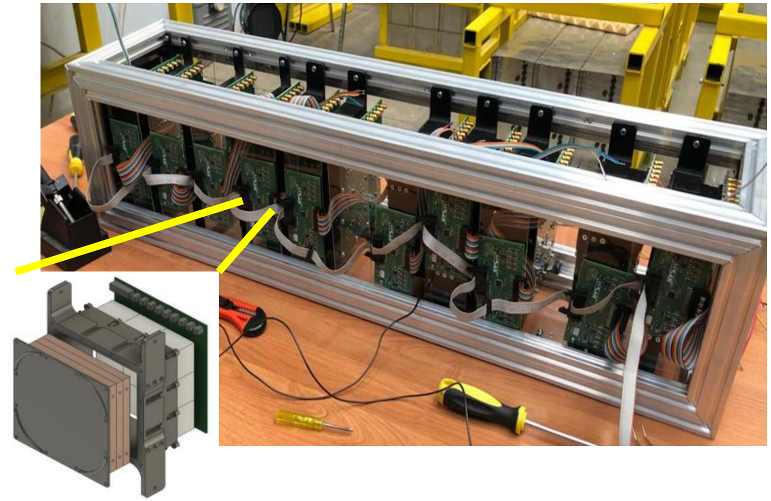


~12X_0

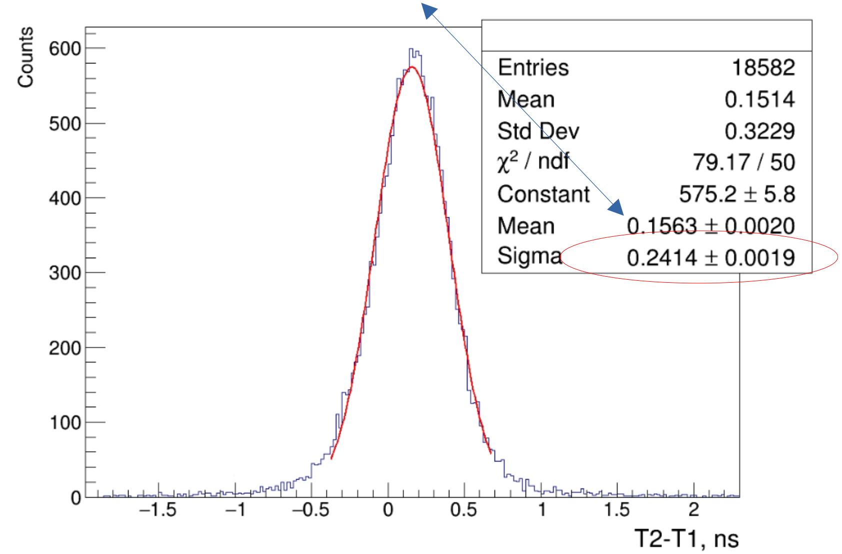
HGN prototype (15 layers, thickness > 2 λ_{int}):
1-st layer – VETO
2-6 layers – γ-detection part (Pb/Scint.)
7-15 layer – n-detection part (Cu/Scint.)



Prototype tested in Xe run

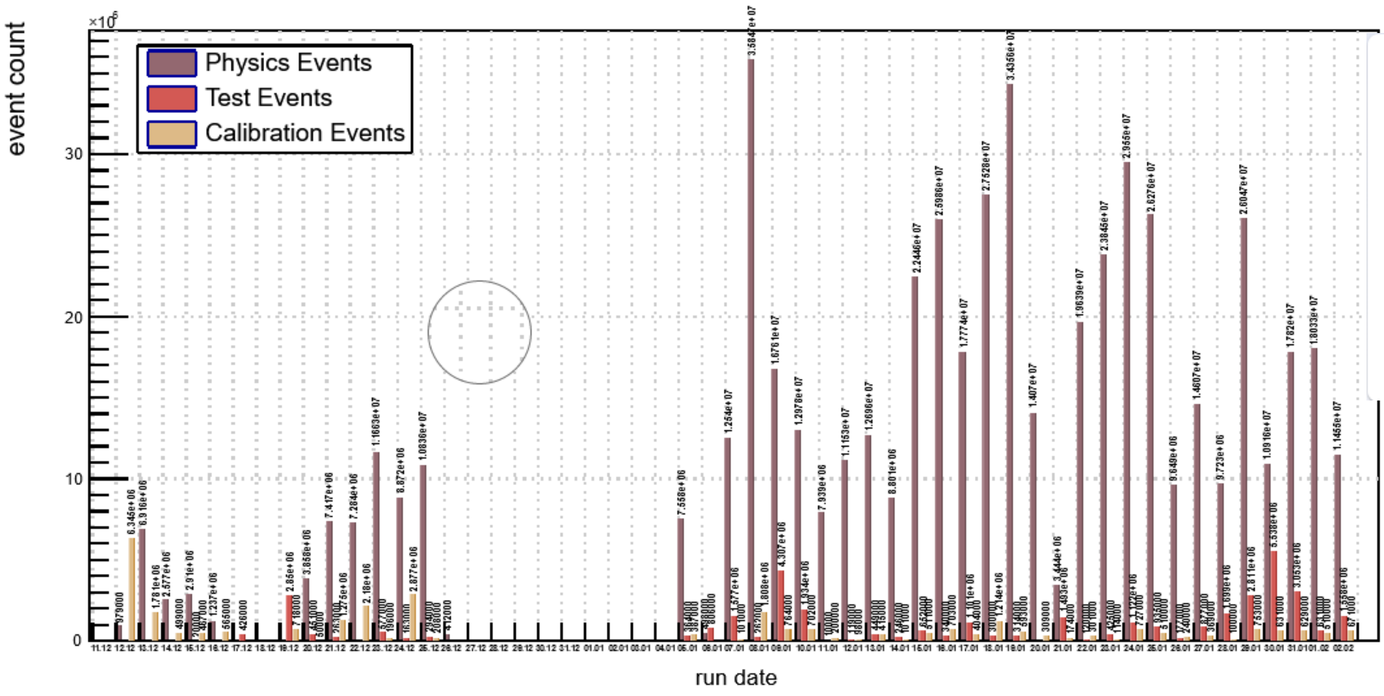


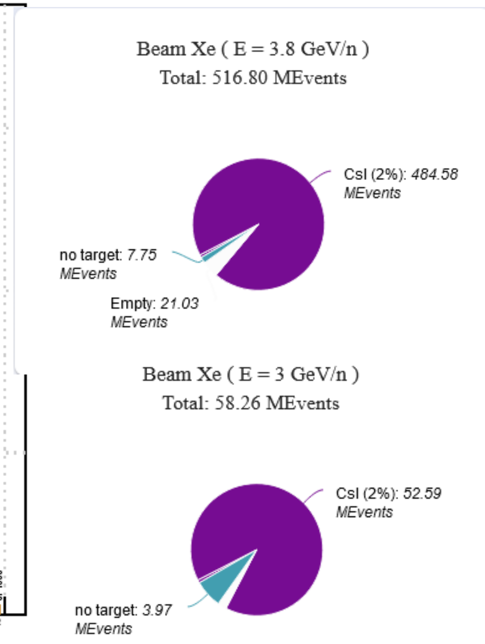
Time resolution between two nearest layers for neutron detection in the BM@N Run.
Single cell time resolution is better then 200ps

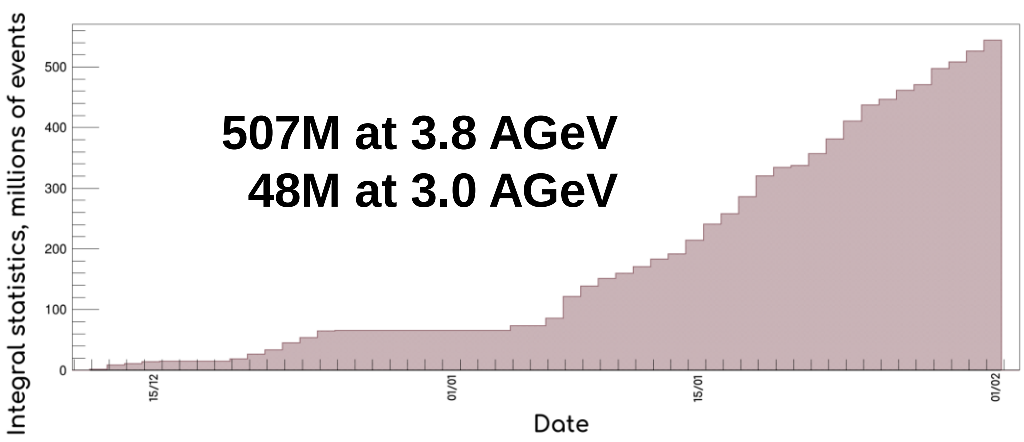


Statistics of recorded interactions

The information is current as of February 07 2023 23:59.







- 3.8 AGeV: Spill ~2.2 s, cycle 12 s, up to 900k Xe ions per spill
- 3.0 AGeV: Spill ~3.5 s (up to 4 s), up to 1.3M ions per spill

Tasks to be completed for the Xe data analysis

- **Optimization of the central tracking algorithm** based on Vector Finder (Si+GEM): A.Zinchenko, I.Roufanov, V.Vasendina, J.Drnoyan
- use Λ and K^0_S signals as test probes for algorithm / alignment optimization
- Version for data processing is completed

- **Particle identification in ToF-400 detectors**: M.Rumyantsev, M.Mamaev
- **Particle identification in ToF-700 detectors**: L.Kovachev, Yu.Petukhov, S.Merts
- Versions for data processing are prepared
- need calibration of time of flight in ToF detectors to constrict the proton mass peak
- need T_0 pile-up / slewing corrections for ToF measurements (trigger group)

- **Centrality measurement with forward detectors**: INR RAS team
- need pile-up corrections of fragment hodoscope signals (beam area)

→ **First processing of full data reconstruction is under way**

BM@N status and next plans in data analysis

- During 2014-2022, the installation configuration with full acceptance of detectors was implemented, experimental runs were carried out in beams of deuterons, carbon and argon ions
- First physics publication has been prepared on the study of the production of π+ and K+ mesons in argon-nucleus interactions at an energy of 3.2 AGeV
- Physics run was carried out in a Xe beam with an energy of 3.8 and 3 AGeV on a CsI target

Next plans in the data analysis:

- analysis of production of hyperons, mesons, light nuclear fragments in Xe+CsI interactions;
- definition of interaction centrality classes
- analysis of collective flow of protons, π±, light nuclear fragments at energy of 3 AGeV
- search for light hyper-nuclei ${}_{\Lambda}H^3$, ${}_{\Lambda}H^4$

Plans for BM@N upgrade and physics runs

If physics run in Xe beam is possible in 2024: beam energy scan in the range of 2-3 AGeV
→ same central tracker configuration based on silicon and GEM detectors
→ complete replacement of external drift chambers with cathode strip chambers

- Physics run in Bi beam is possible after 2024, depends on the implementation of plans for the NICA collider

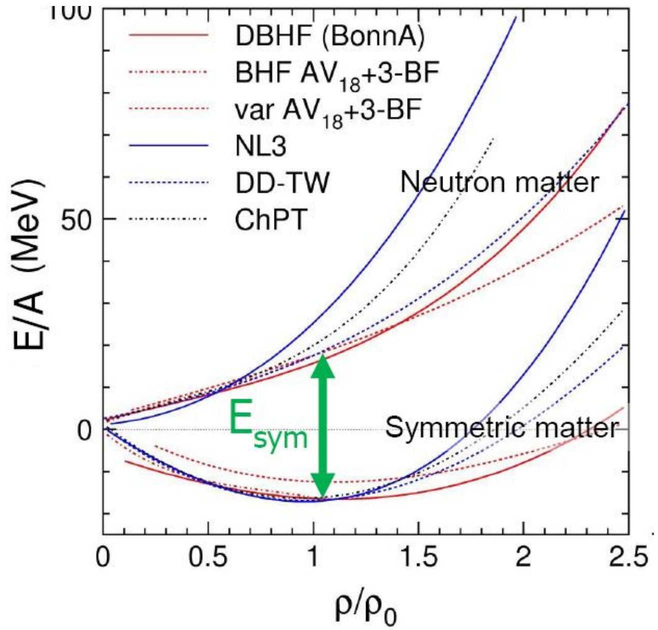
- To be ready for the experiment in the Bi beam, further development of the central tracker is necessary: installation of additional stations of silicon detectors

- It is planned to put into operation a 3-coordinate neutron detector of high granularity to measure neutron yields and collective flow

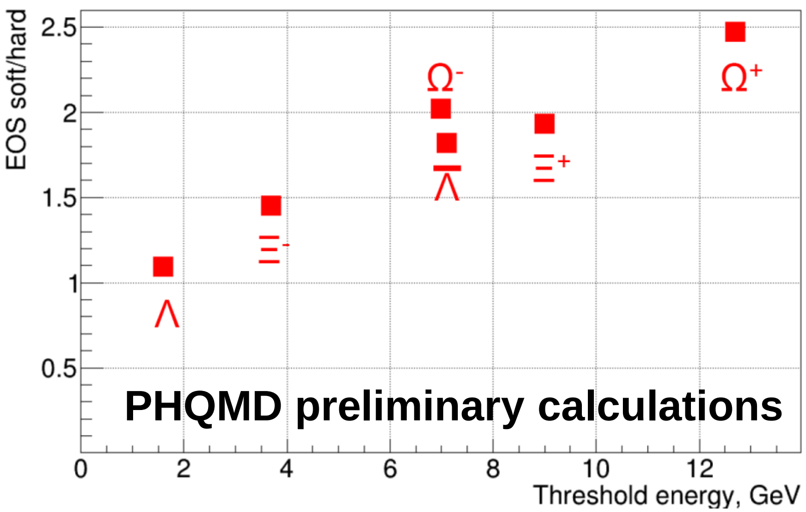
Thank you for attention!

EOS of symmetric and asymmetric nuclear matter

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



Hyperon yield in 4A GeV Au+Au:
soft EOS (K=240 MeV) / hard EOS (K=350) MeV



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

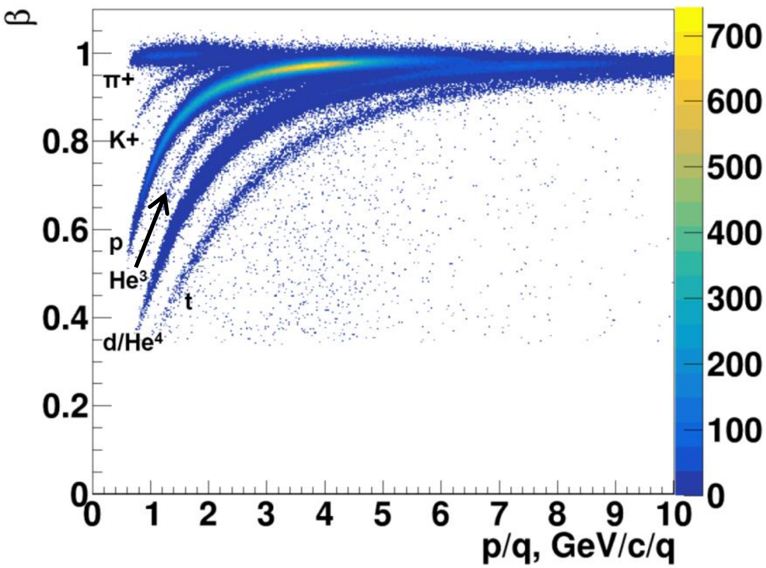
$$E_A(\rho,\delta) = E_A(\rho,0)+E_{sym}(\rho)\cdot\delta^2$$

with $\delta = (\rho_n - \rho_p)/\rho$ $\quad E/A(\rho_o) = -16$ MeV

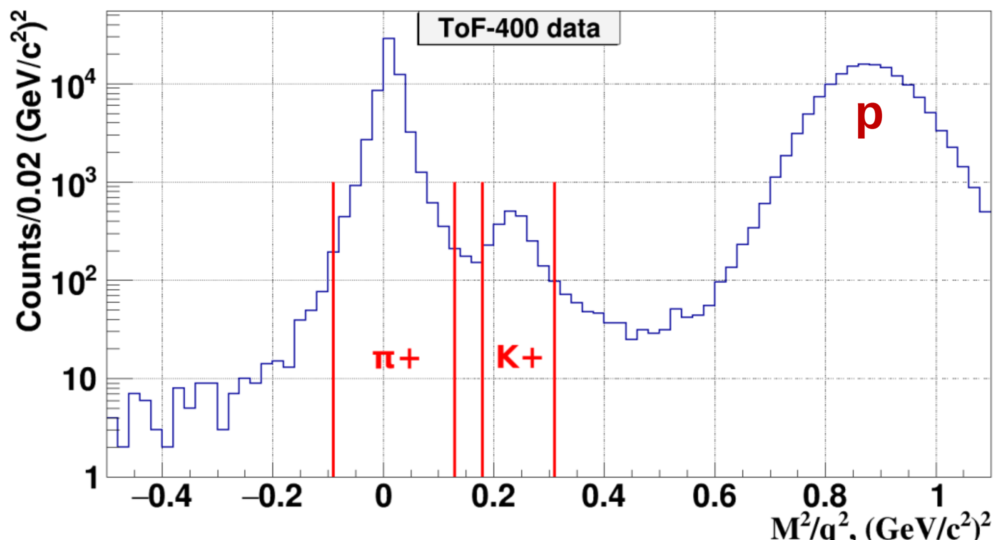
Curvature defined by nuclear incompressibility: $K = 9\rho^2\ \delta^2(E/A)/\delta\rho^2$

►Study symmetric matter EOS at ρ=3-5 ρ_0
→ elliptic flow of protons, mesons and hyperons
→ sub-threshold production of strange mesons and hyperons
→ extract K from data to model predictions
►Constrain symmetry energy E_{sym}
→ elliptic flow of neutrons vs protons
→ sub-threshold production of particles with opposite isospin

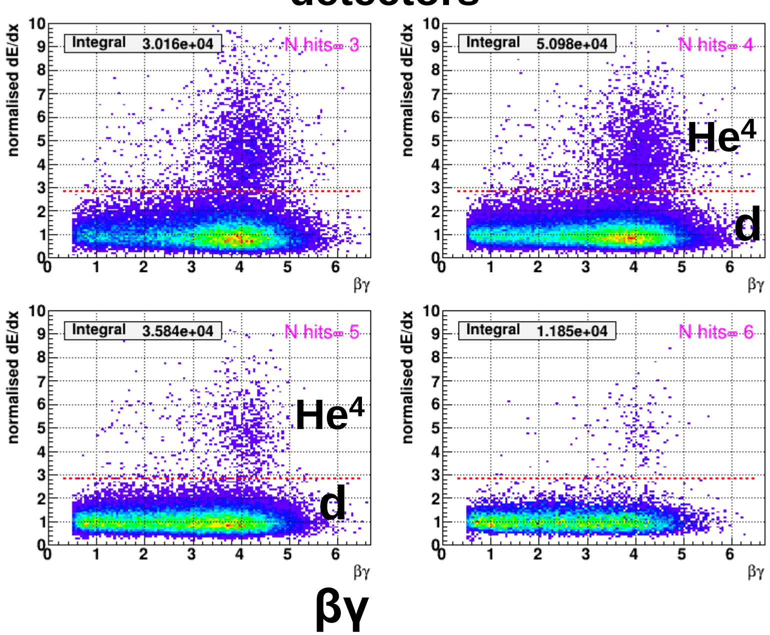
Ar beam data: Identification of π+, K+, p, t, He3, d/He4



Ar beam, 3.2 AGeV, Ar + Al,Cu,Sn → X



He⁴ / d separation by dE/dx in GEM detectors



Ongoing physics analyses of Ar beam data

L.Kovachev, Yu.Petukhov, I.Roufanov, V.Plotnikov: p, d / He4, He3, t in ToF-400 and ToF-700 data

A.Huhaeva (student), V.Plotnikov: π- in ToF-400 data

K.Mashitsin (student), S.Merts: π± in ToF-400 and ToF-700 data (independent tracking)

BM@N Experimental physics run in Xe beam with CsI target

BM@N: Estimated hyperon yields in Xe + Cs collisions

4 A GeV Xe+Cs collisions, multiplicities from PHSD model,
Beam intensity $2.5 \cdot 10^5$/s, DAQ rate $2.5 \cdot 10^3$/s, accelerator duty factor 0.25

$1.8 \cdot 10^9$ interactions
$1.8 \cdot 10^{11}$ beam ions

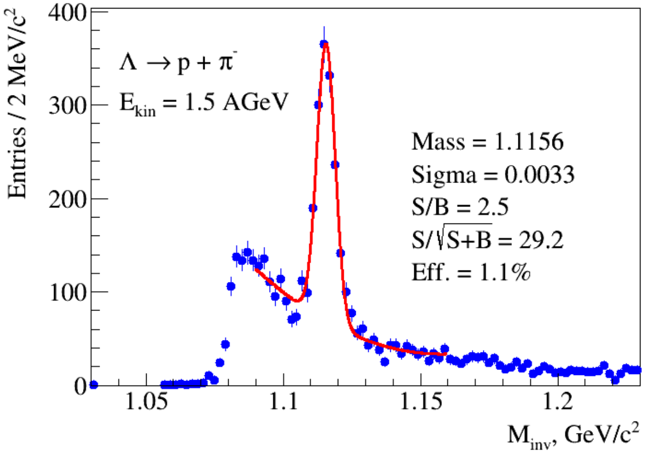
Particle	E_{thr}NN GeV	M b<10 fm	ε %	Yield/s b<10fm	Yield / 800 hours b<10 fm
Λ	1.6	1.5	2	150	$5 \cdot 10^7$
Ξ^-	3.7	$2.3 \cdot 10^{-2}$	0.5	0.55	$2 \cdot 10^5$
Ω^-	6.9	$2.6 \cdot 10^{-5}$	0.25	$3.2 \cdot 10^{-4}$	110
Anti-Λ	7.1	$1.5 \cdot 10^{-5}$	0.5	$3.7 \cdot 10^{-4}$	130

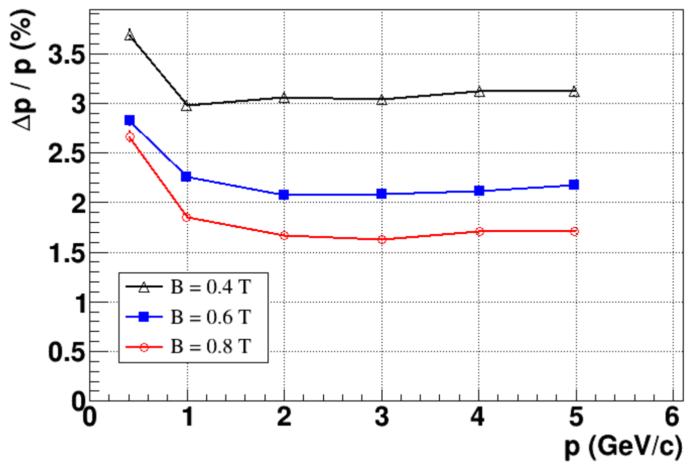
DCM-SMM
x 0.75
x 0.5

Xe + CsI run configuration of hybrid central tracker: 4 Forward Si + 7 GEM stations

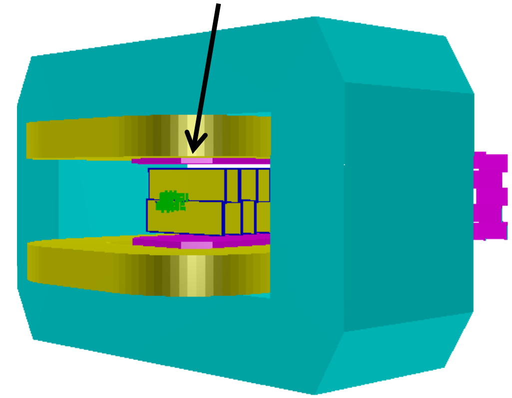
A.Zinchenko, V.Vasendina

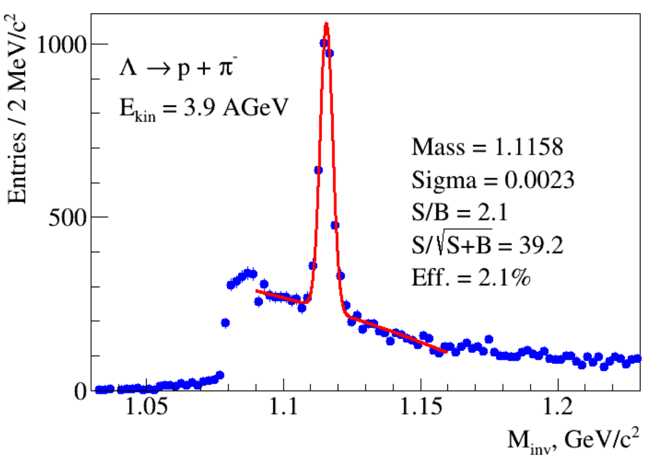
DCM-SMM model: Xe + Sn , T_0= 1.5 - 3.9 AGeV



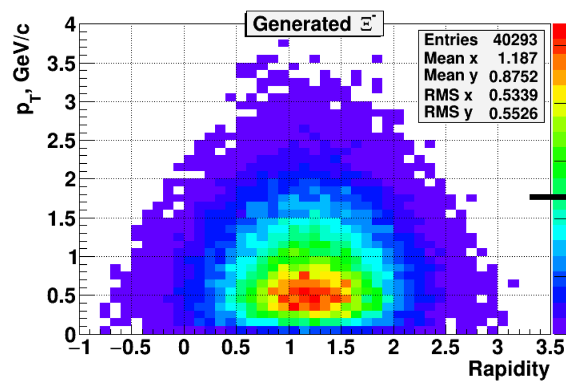


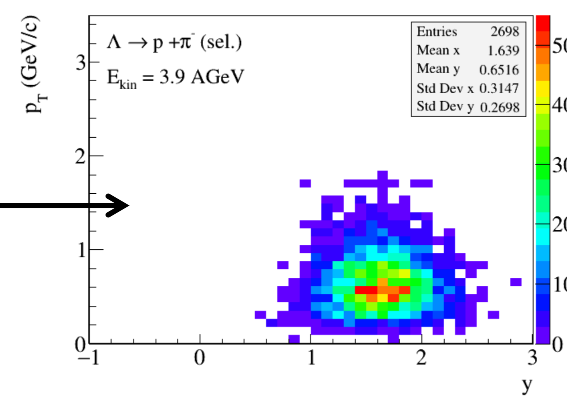
4 Forward Si + 7 GEM





Phase space of reconstructed Λ





Laboratory system

Trigger rates and DAQ capacity

3.8 AGeV: Spill ~2.2 s, cycle 12 s, up to 900k Xe ions per spill

3.0 AGeV: Spill ~3.5 s (up to 4 s), up to 1.3M ions per spill

♥ **Spill nbr. 235164 16.01.2023 18:45:11**

Event statistics, M

Detectors

BC1_low	1836957
BC1	765200
BC2	681683
VC	152651
NBD>L1	130762
NBD>H1	131236
NSiD>L2	0
NSiD>H2	0
FD	701453
nZDC	102589

Triggers

BT	576455
MBT	20761
CCT1	123806
CCT2	9912
NIT	492799

beam

triggers

fragments

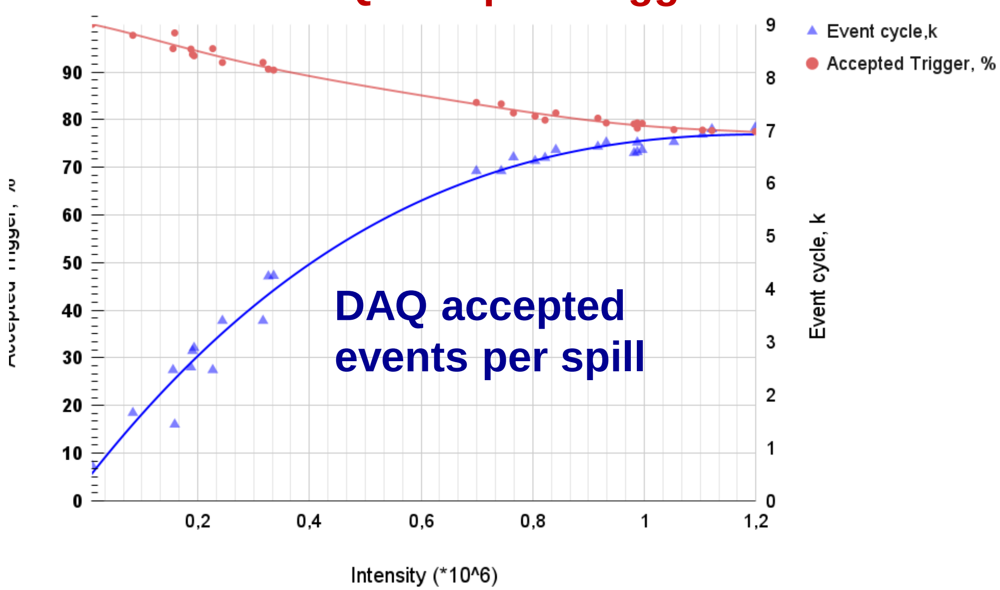
Ratios

BC1_low/BC1	2.40062
BC2/BC1	0.89086
VC/BC1	0.19949
FD/BC1	0.91669
NBD>L1/BC1	0.17089
NBD>H1/BC1	0.17151
NSiD>L1/BC1	0.00000
NSiD>L2/BC1	0.00000
nZDC/BC1	0.13407
BT/BC1	0.75334
MBT/BT	0.03601
CCT1/BT	0.21477
CCT2/BT	0.01719
NIT/BT	0.85488

Internal signals

pCCT1	130882
pCCT2	130930
MBT1	20905
NIT1	492836
DAQ_Busy	0
BT*/DAQ_Busy	459879
pBT	668899

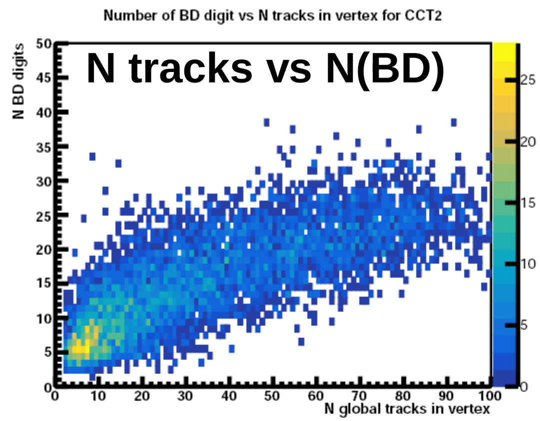
% of DAQ accepted triggers

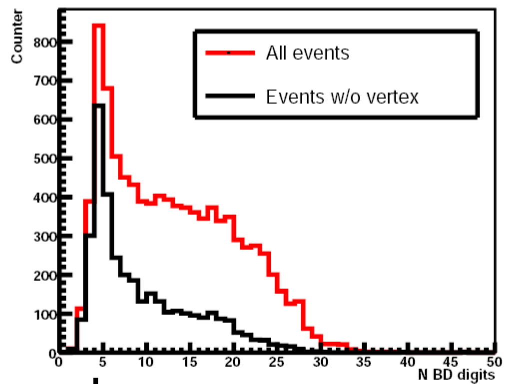


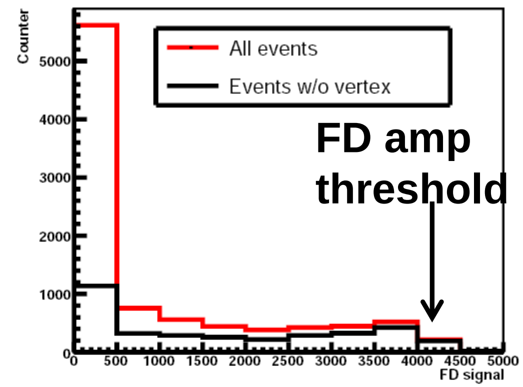
BM@N Trigger selection

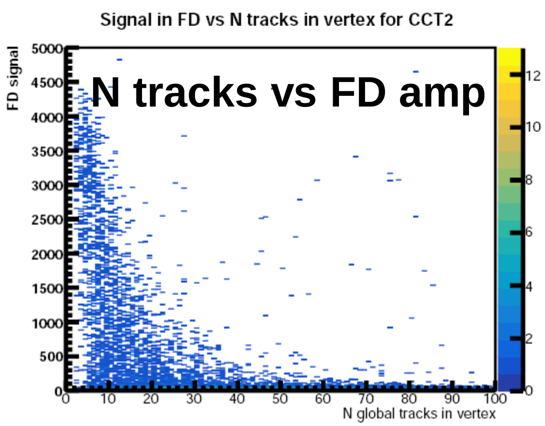
Combined trigger: CCT2 = BT * FD Amp < thr * N(BD) > 3

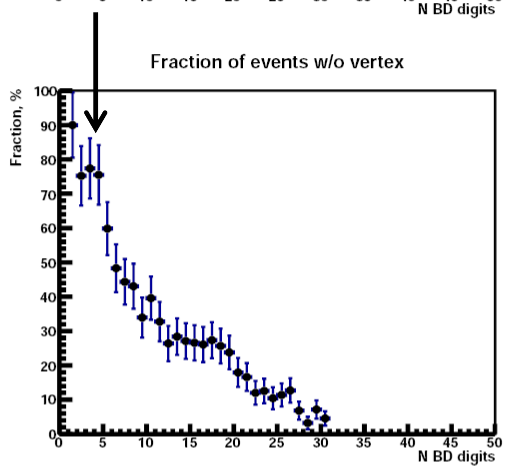
N(BD) > 3   Fraction of events without vertex at target

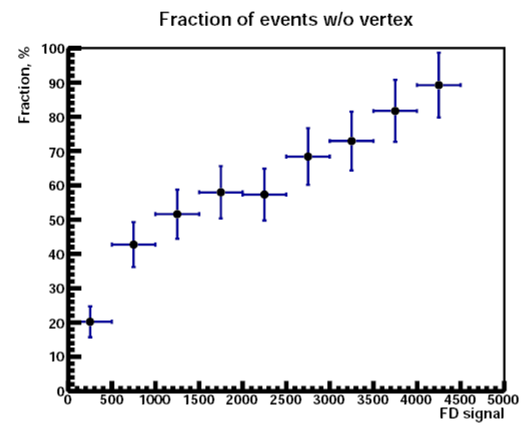




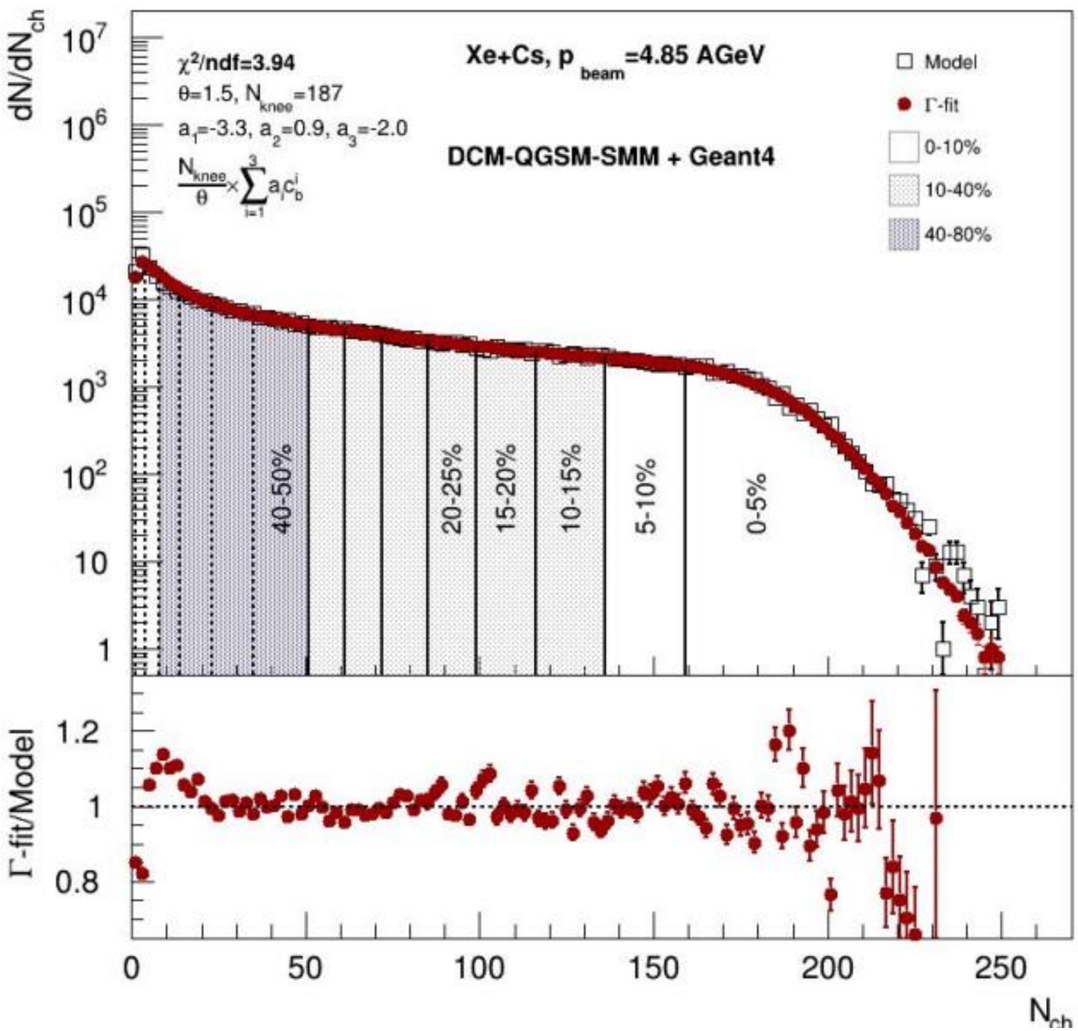






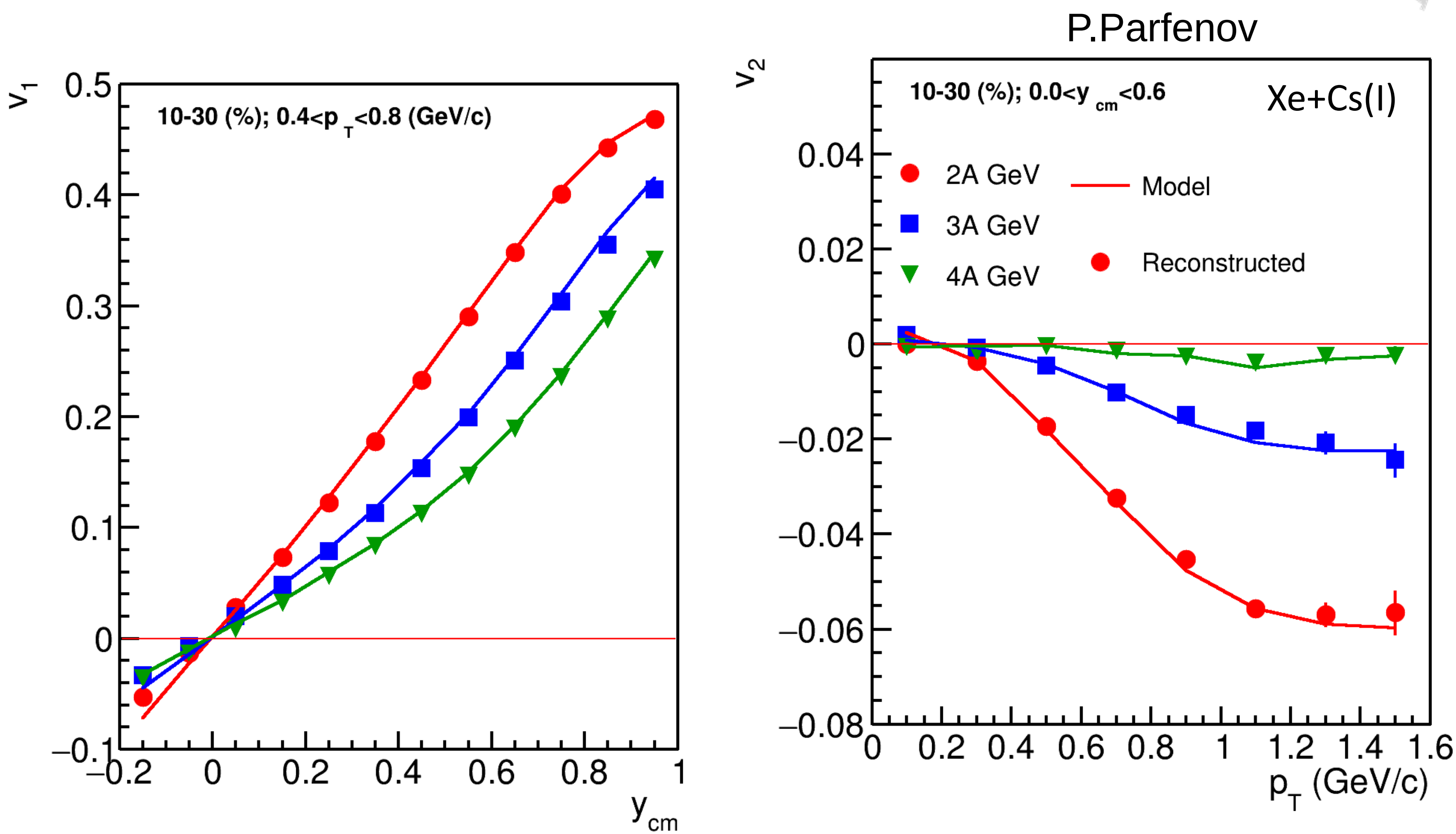


Centrality determination at BM@N



- Fit results are good both for MC-Glauber and Inverse Γ-fit methods
- Impact parameter distributions in centrality classes are well-reproduced

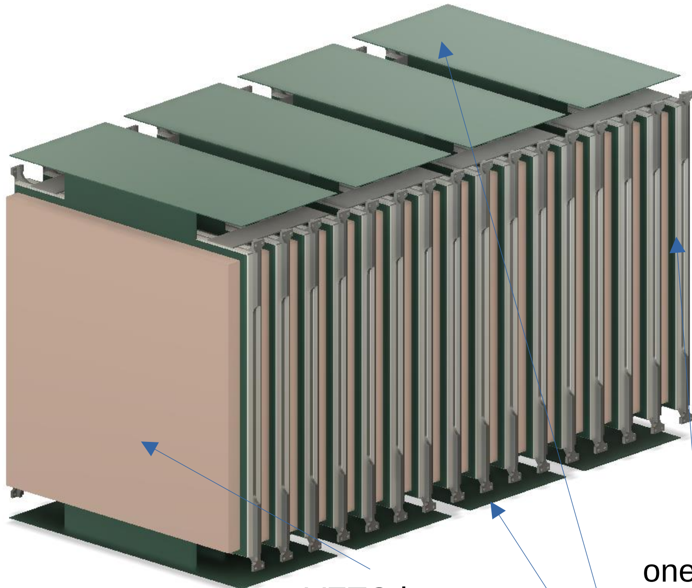
Directed and elliptic flow at BM@N

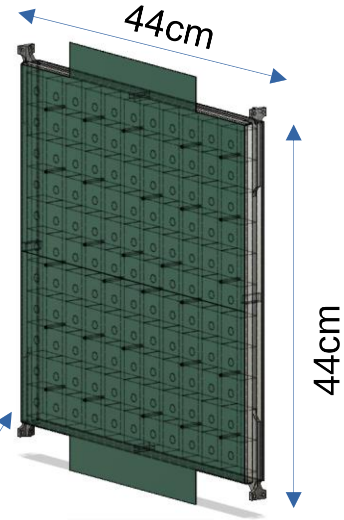


- Good agreement between reconstructed and model data
- Approximately 250-300M events are required to perform multi-differential measurements of v_n

3D High Granularity Neutron detector

INR RAS, JINR, NRC Kurchatov



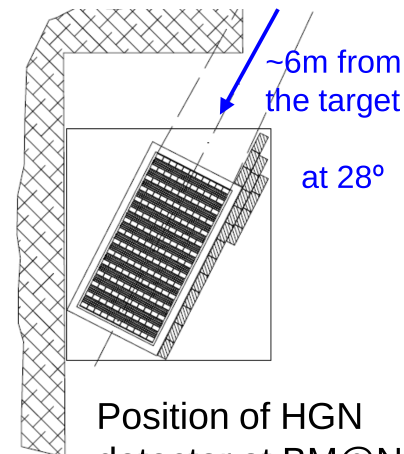


VETO layer

one layer containing 121 cells with individual SiPM read-out

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

→ **plan to design and construct in 2023-2024**

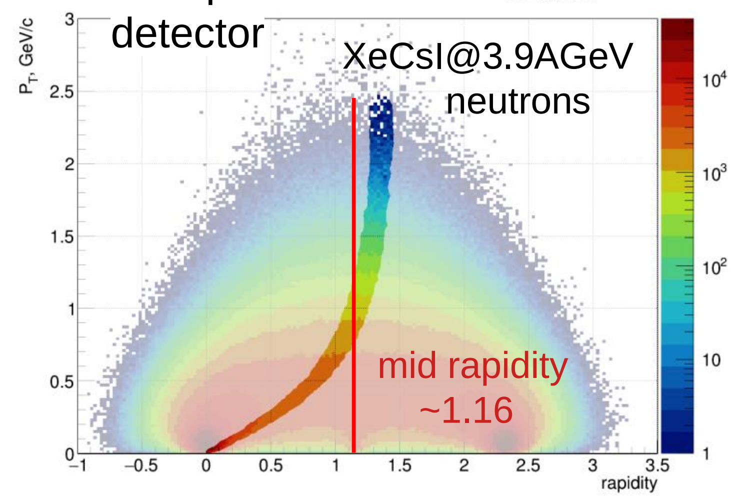


Position of HGN detector at BM@N

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



Beam parameters and setup at different stages of BM@N experiment

Year	2016	2017 spring	2018 spring	2023	2025 and later
Beam	d(↑)	C	Ar	Xe	Bi
Max.intensity / spill	0.5M	0.5M	0.5M	1M	1.5M
Trigger rate, spill	5k	5k	8k	10k	15k
Central tracker status	6 GEM half planes	6 GEM half planes	6 GEM half planes + 3 forward Si planes	7 GEM full planes + 4 forward Si planes	7 GEM full planes + forward Si + STS planes
Experimental status	technical run	technical run	technical run+physics	stage1 physics	stage2 physics