BM@N experiment status

M.Kapishin

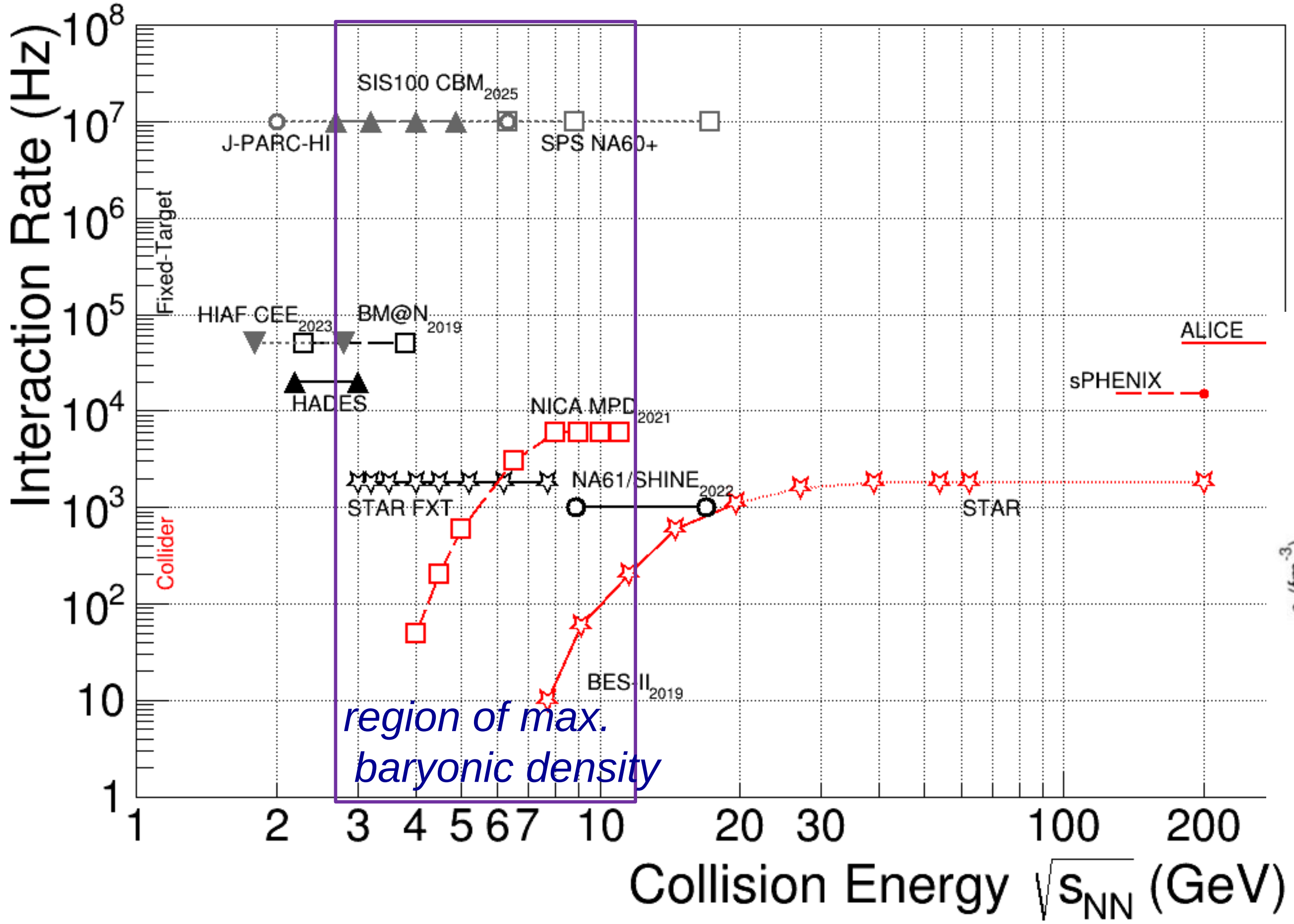
Baryonic Matter at Nuclotron (BM@N) Collaboration:

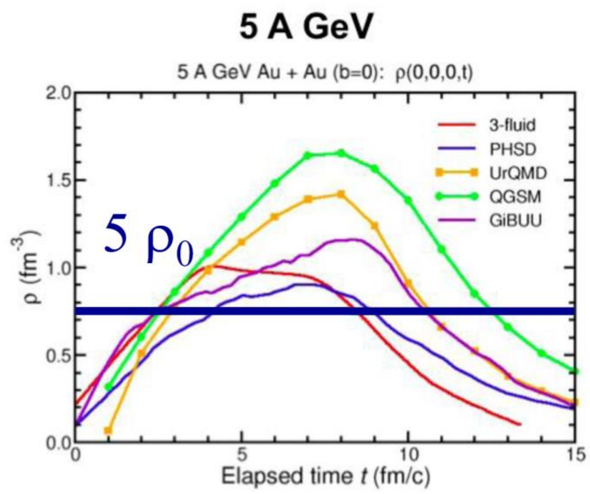
3 Countries, 10 Institutions, 189 participants

- *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*

Consider today at IB Institute of Physics and Technology, Almaty, to enter the Collaboration

Heavy Ion Collision Experiments





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

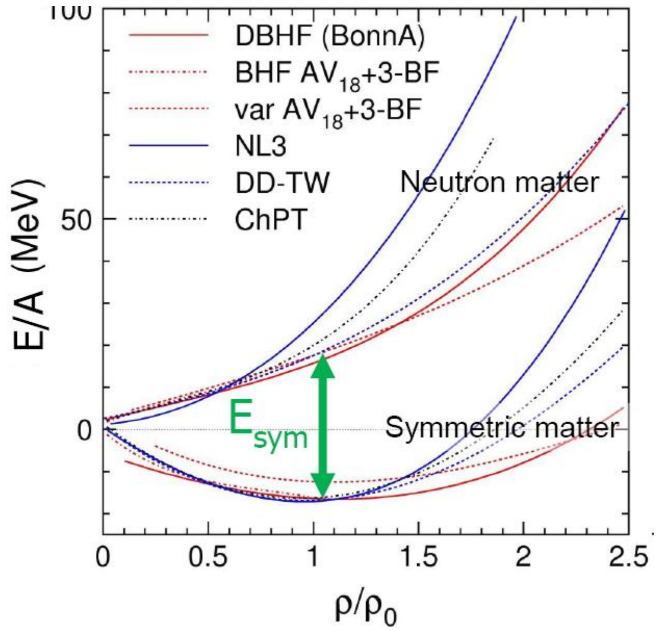
BM@N competitors:

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

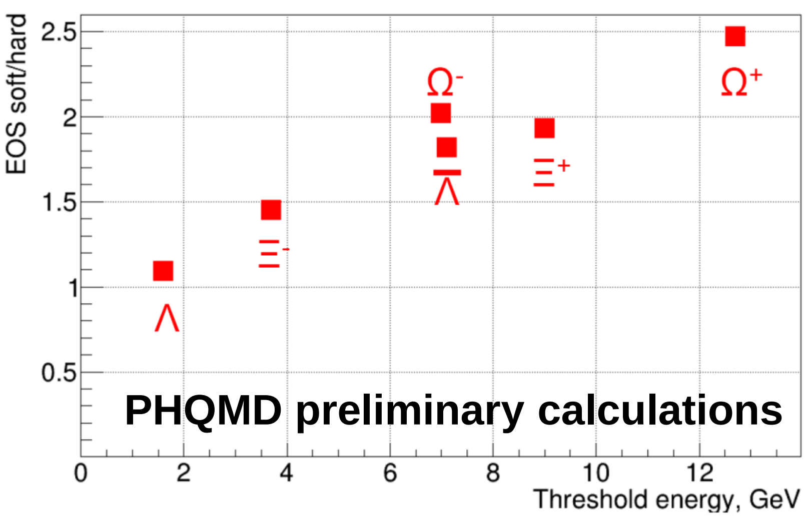
STAR BES (RHIC): Au+Au at $\sqrt{s_{NN}}$ = 3-200 GeV

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

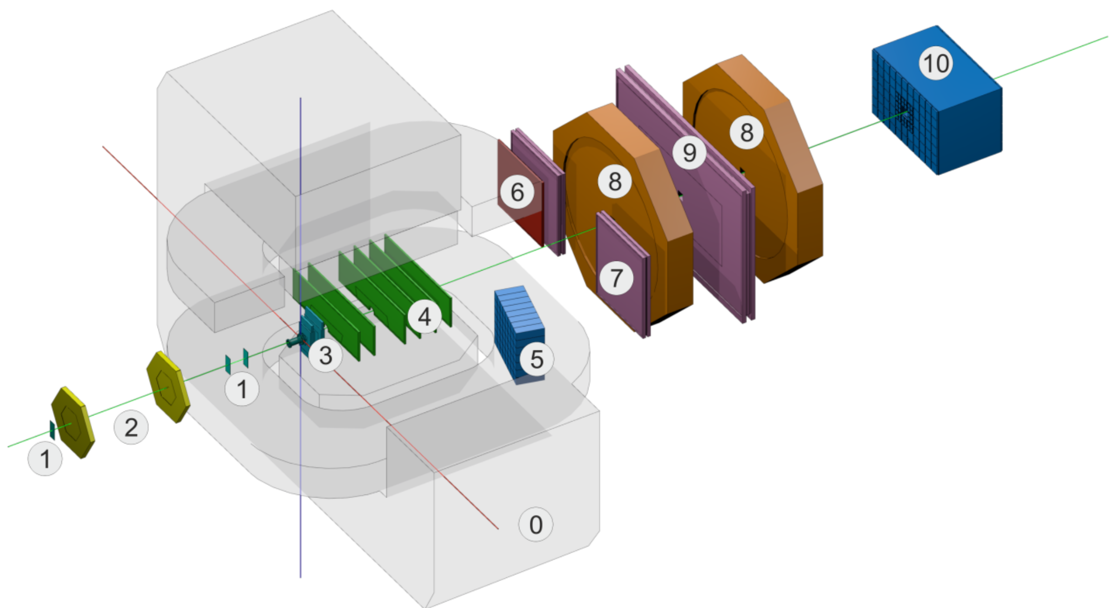
$$E_A(\rho,\delta) = E_A(\rho,0)+E_{sym}(\rho)\cdot\delta^2$$

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

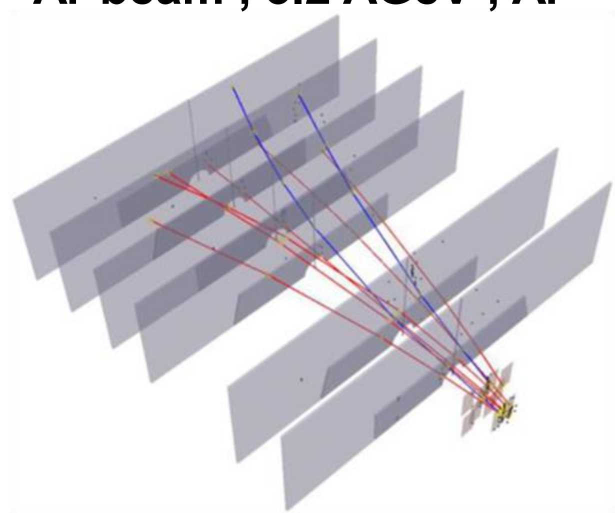
BM@N setup in experimental run with 3.2 AGeV Ar beam, 2018



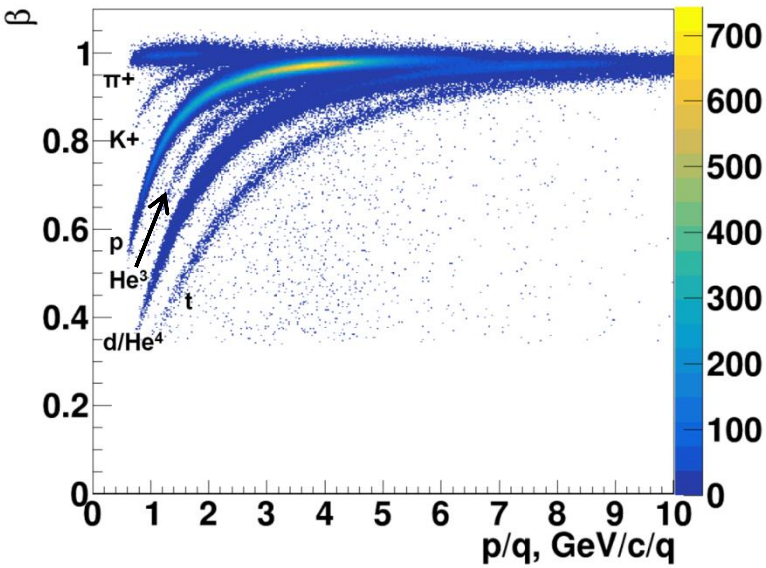
0. Analyzing magnet
1. Trigger detectors
2. MWPC (Multi-Wire Proportional Chamber)
3. ST (Silicon Tracker)
4. GEM (Gas Electron Multiplier)
5. ECAL (Electromagnetic Calorimeter)
6. CSC (Cathode Strip Chamber)
7. TOF1 (Time-Of-Flight detector)
8. DCH (Drift Chamber)
9. TOF2 (Time-Of-Flight detector)
10. ZDC (Zero-Degree Calorimeter)

Tracking GEM detectors only in upper part of magnet

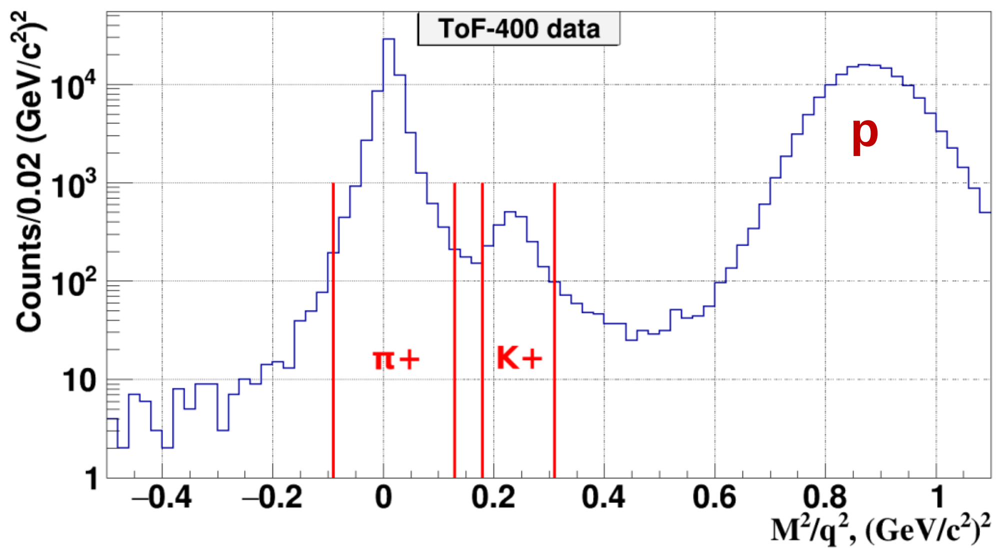
Ar beam , 3.2 AGeV , Ar + Al,Cu,Sn → X



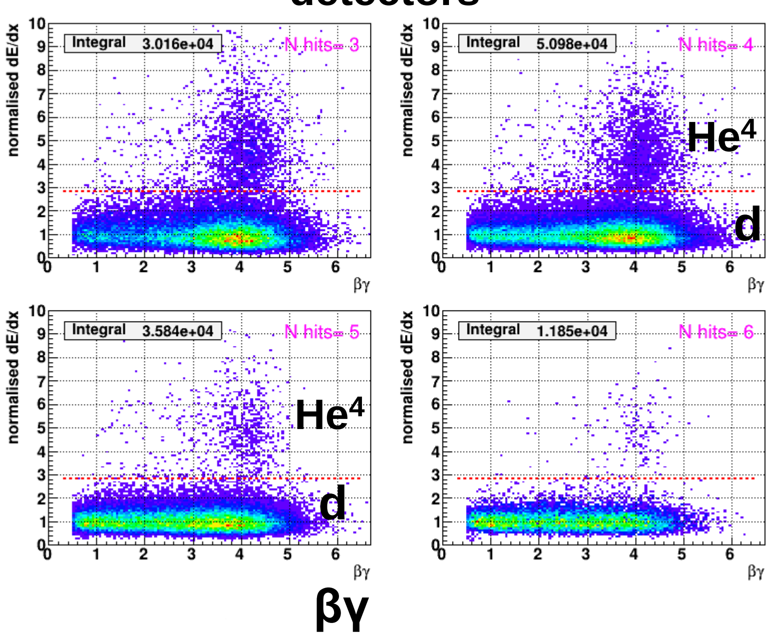
Identification of π+, K+, p, t, He3, d/He4



Ar beam , 3.2 AGeV , Ar + Al,Cu,Sn → X



He^4 / 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

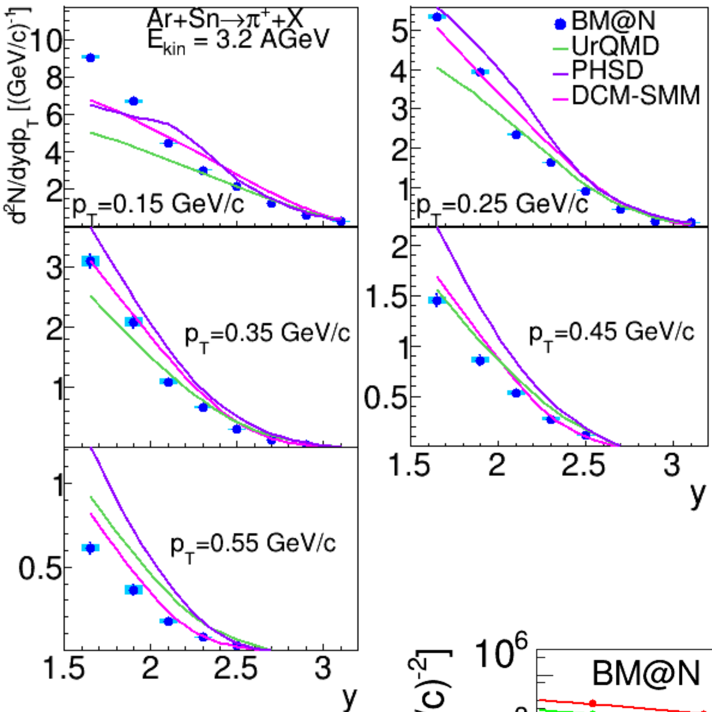
A.Huhaeva (student), V.Plotnikov: π- in ToF-400 data

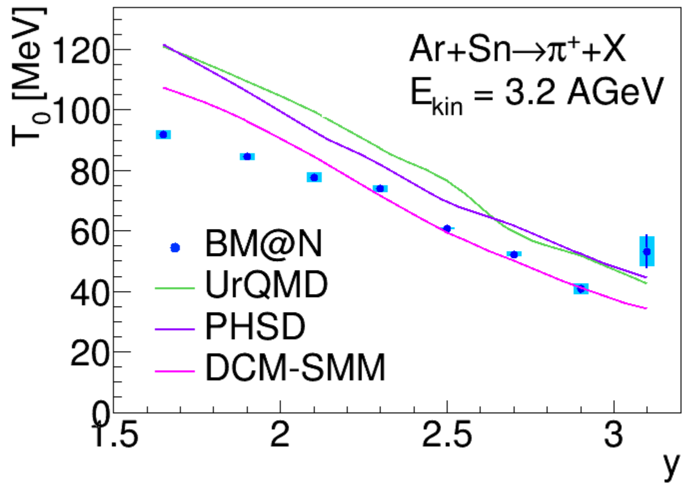
K.Mashitsin (student), S.Merts: π± in ToF-400 and ToF-700 data (independent tracking)

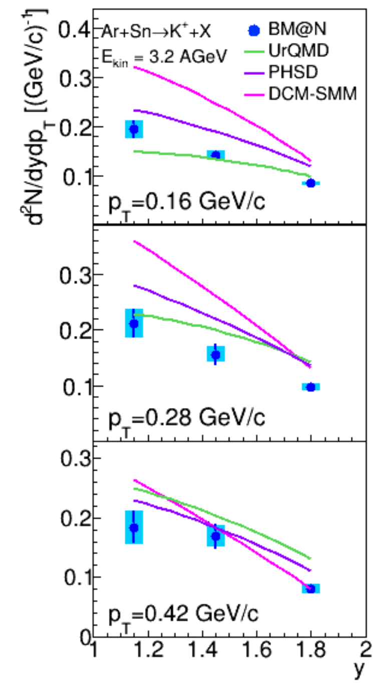
Production of π^+ and K^+ mesons in 3.2 AGeV argon-nucleus interactions at the Nuclotron

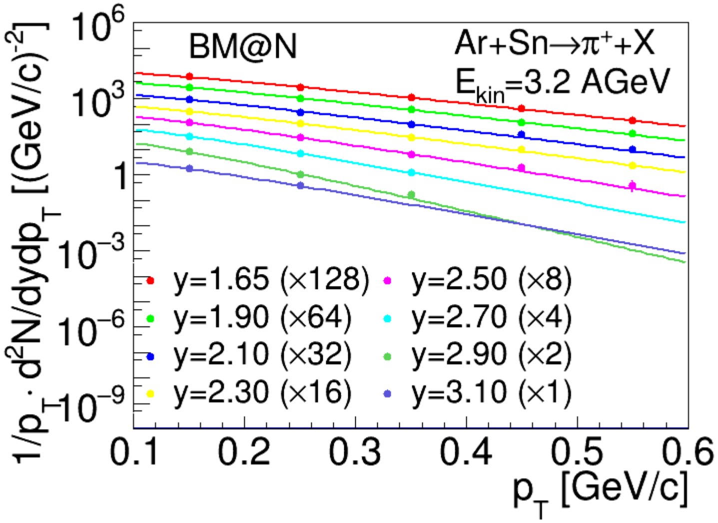
https://arxiv.org/abs/2303.16243v3

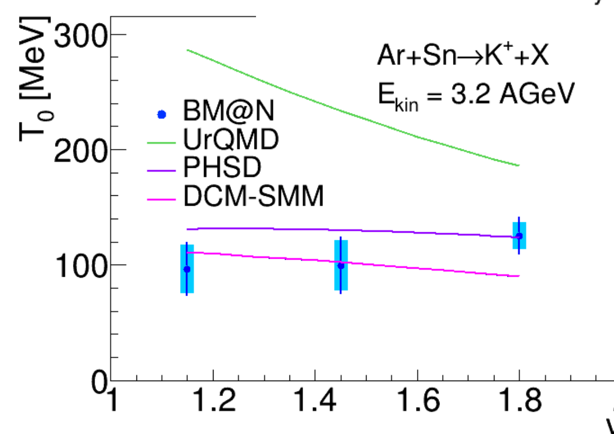
Paper submitted to JHEP







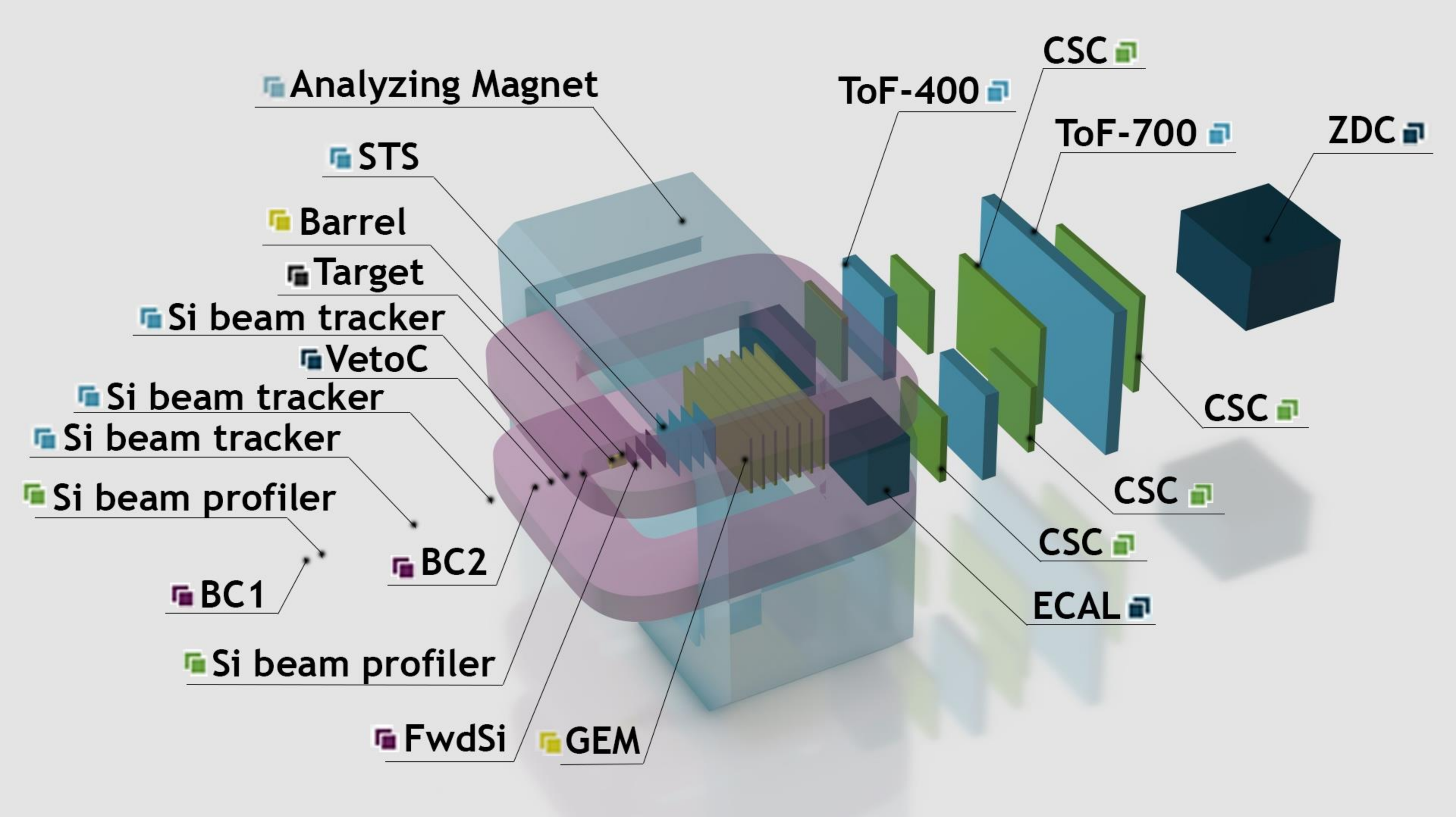




M.Kapishin

BM@N experiment

Configuration of BM@N detector for heavy ion program (without beampipe)



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

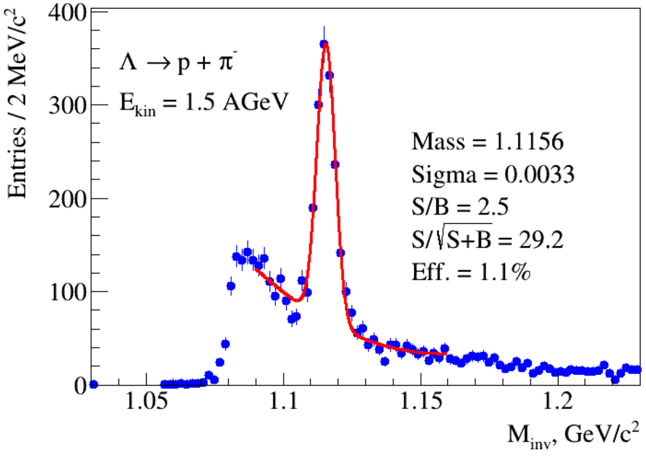
Particle	E_{thr}NN GeV	M b<10 fm	ε %	Yield/s b<10fm	Yield / 800 hours b<10 fm
Λ	1.6	1.5	2	150	$5 \cdot 10^7$
Ξ^-	3.7	$2.3 \cdot 10^{-2}$	0.5	0.55	$2 \cdot 10^5$
Ω^-	6.9	$2.6 \cdot 10^{-5}$	0.25	$3.2 \cdot 10^{-4}$	110
Anti-Λ	7.1	$1.5 \cdot 10^{-5}$	0.5	$3.7 \cdot 10^{-4}$	130

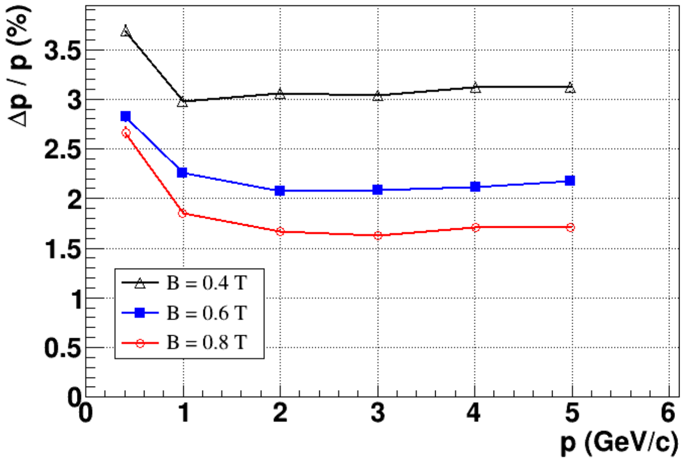
DCM-SMM
x 0.75
x 0.5

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

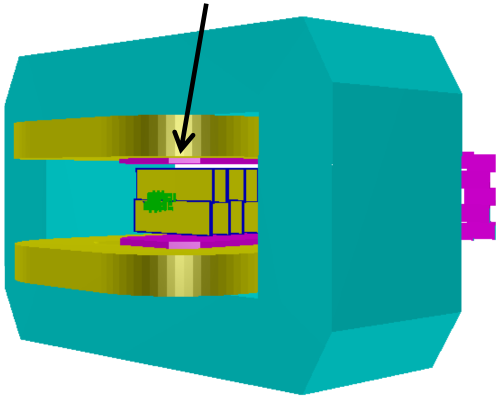
A.Zinchenko, V.Vasendina

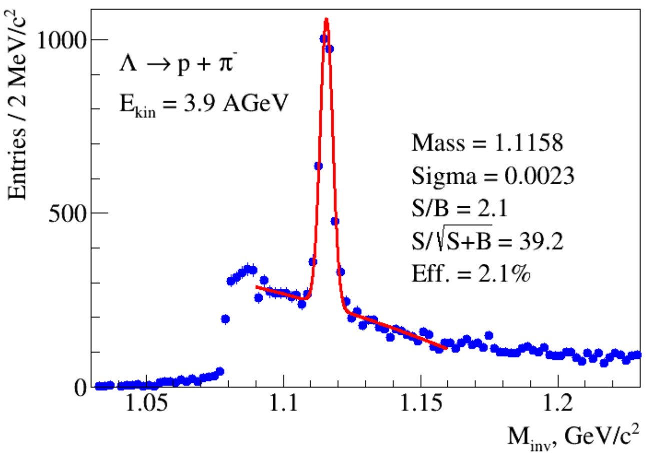
DCM-SMM model: Xe + Sn , T_0= 1.5 - 3.9 AGeV



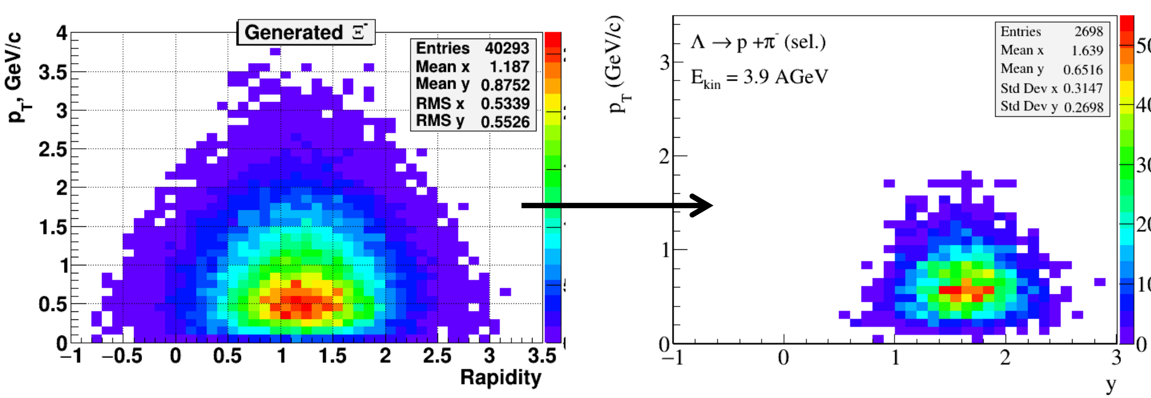


4 Forward Si + 7 GEM





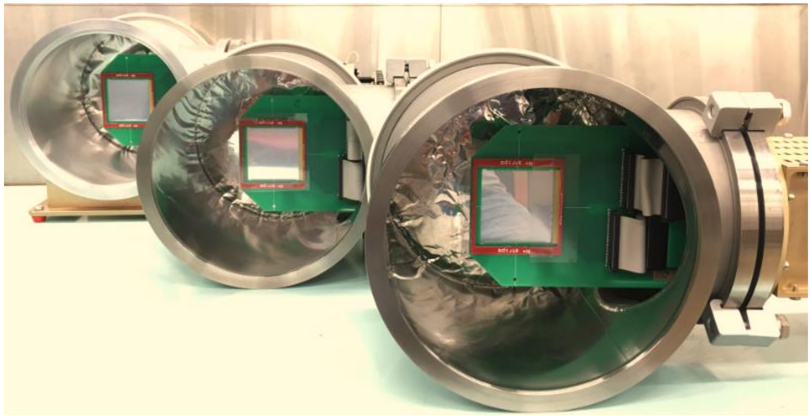
Phase space of reconstructed Λ



Laboratory system

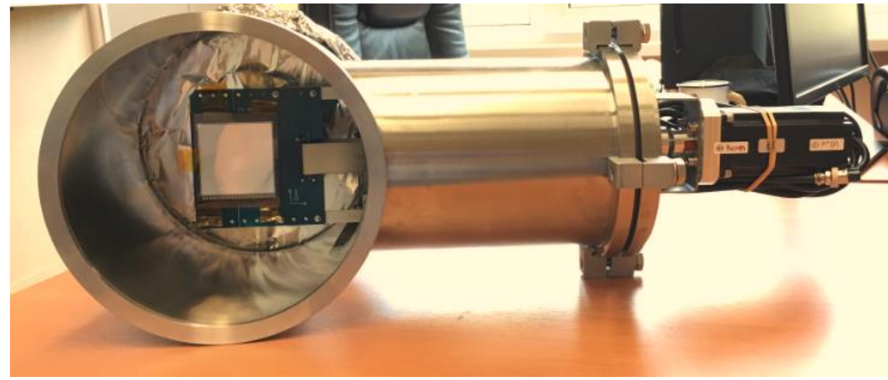
BM@N detector preparation for heavy ion run

3 Silicon beam tracking detectors



FST group

Beam profile meter with Si detector and positioning mechanics



Outer tracker: Cathode Strip Chambers → 4 CSC of 106x106 cm2

Outer tracker group

Big CSC 220x145 cm2

Silicon beam tracking detector in SRC setup

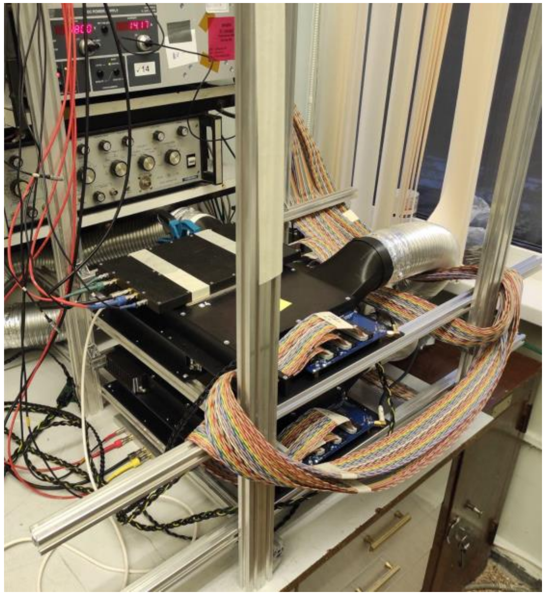
INR RAS group

Forward hodoscope in front of FHCAL

Forward Silicon Tracker for heavy ion run

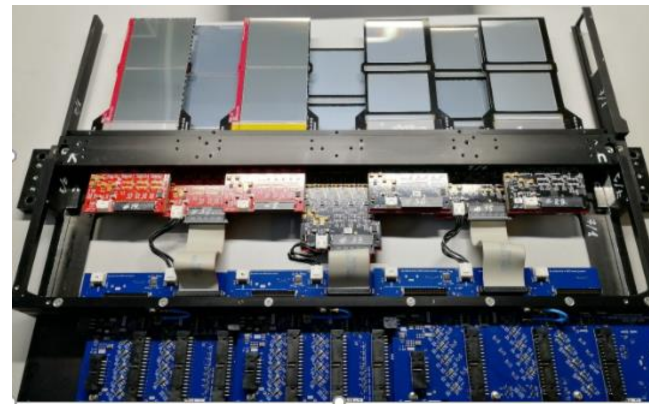
FST group

Setup for FST tests with cosmic rays

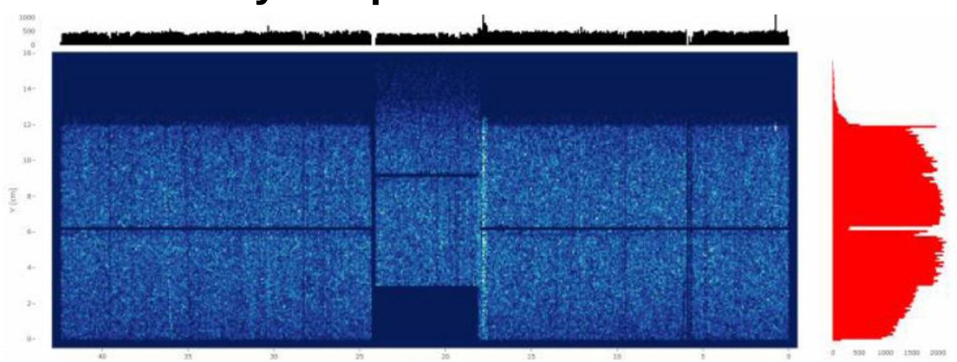


FST support mechanics

Assembled FST half station of 7 detectors



Cosmic ray X/Y profile of FST half station

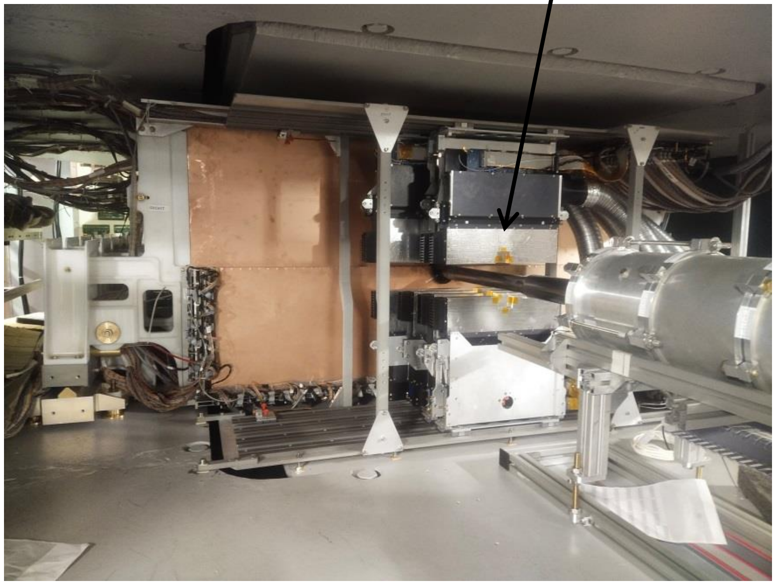


FST modules in SRC setup

►All 48 modules and 4 FST stations with 6, 10,14,18 modules are assembled, tested and installed

BM@N tracking detector installation for heavy ion run

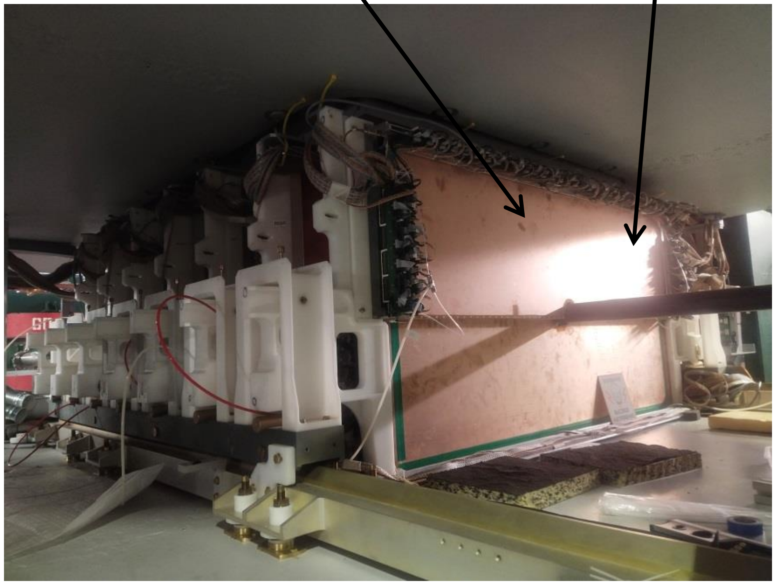
Forward Si tracker detectors in front of GEM detectors



GEM, FST groups + engineer group

GEM detectors on positioning mechanics in magnet

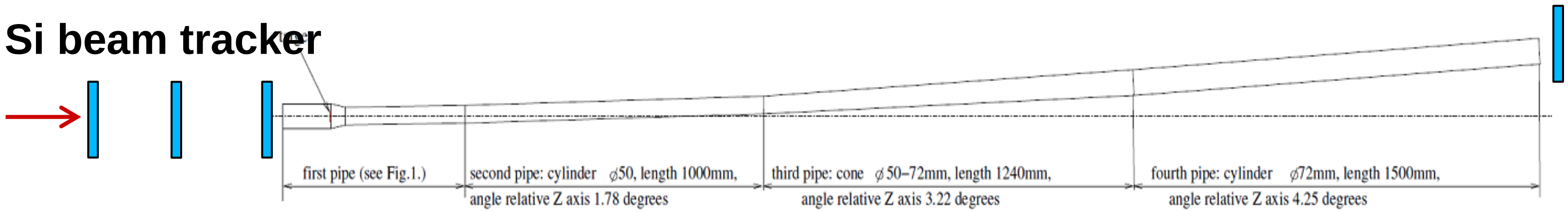
Carbon vacuum beam pipe



Vacuum boxes for beam detectors

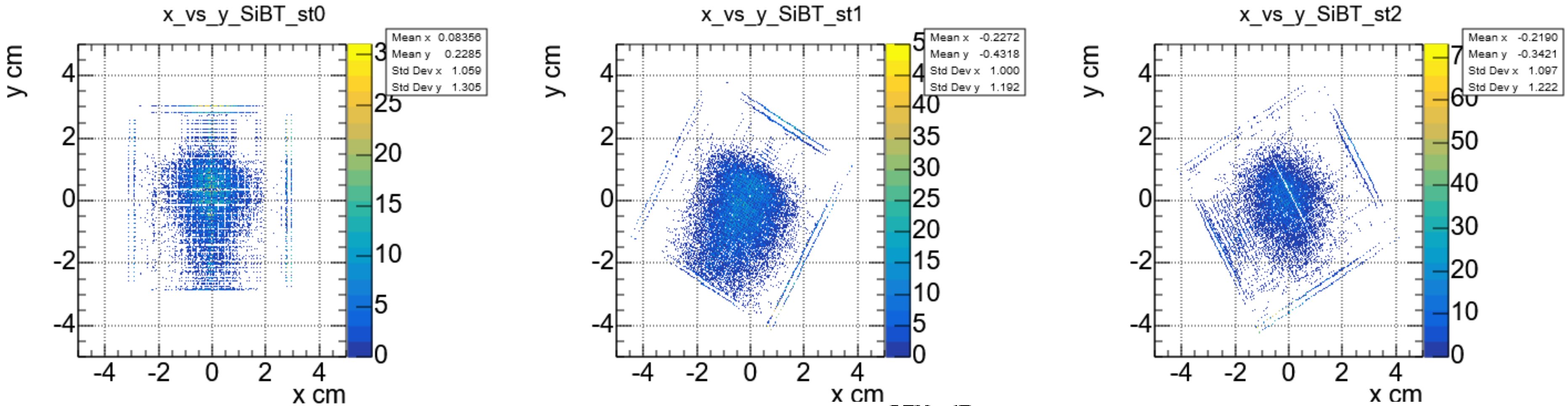
Experimental run in 3.85 AGeV Xe beam with CsI (2%) target

Si beam tracker



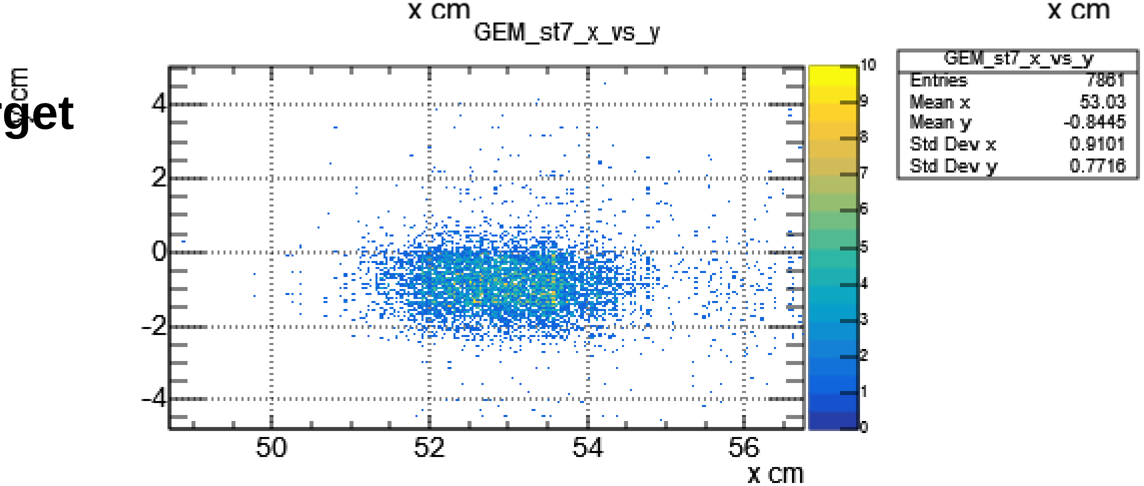
Small GEM as beam profile meter

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)

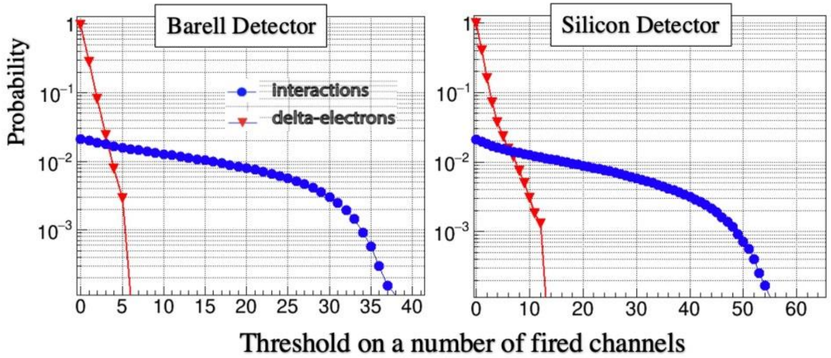


Measured beam spot at target

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



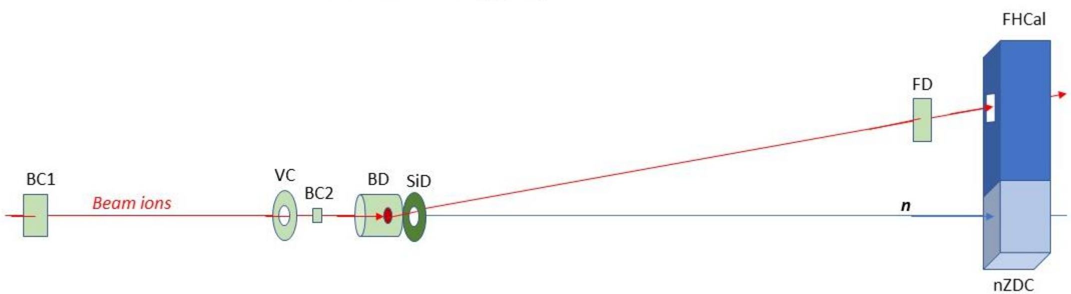
BM@N Trigger detectors



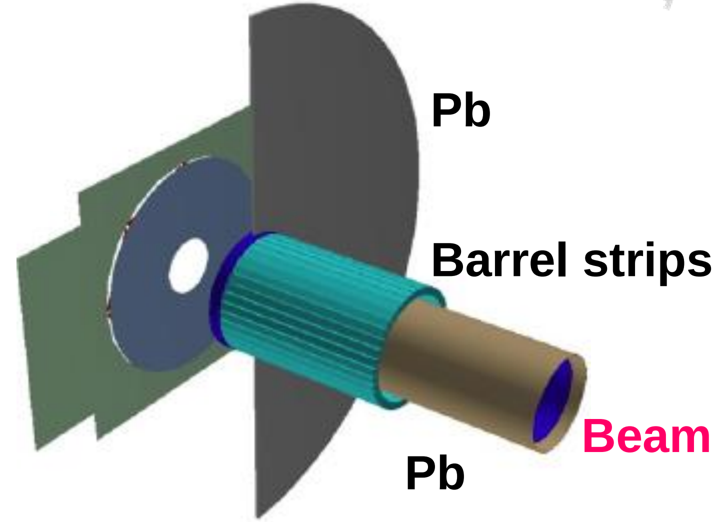
Variants of trigger logics — **fraction**

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 %

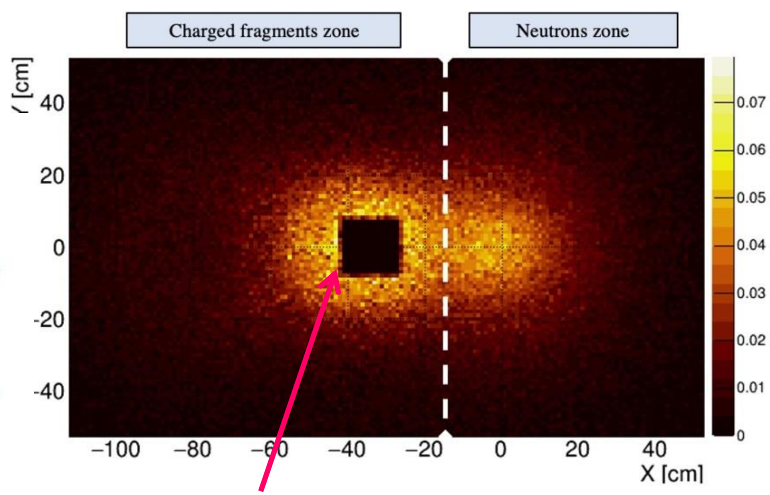
Combined trigger: CCT2 = MBT * CCT1 — main



Trigger detectors in target area: multiplicity SiD and Barrel BD

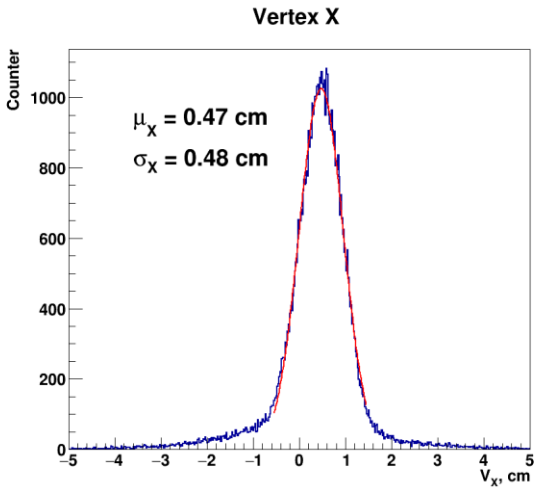


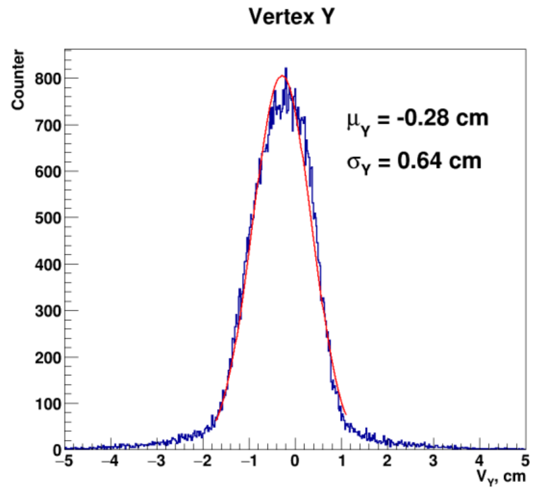
FHCAL rates

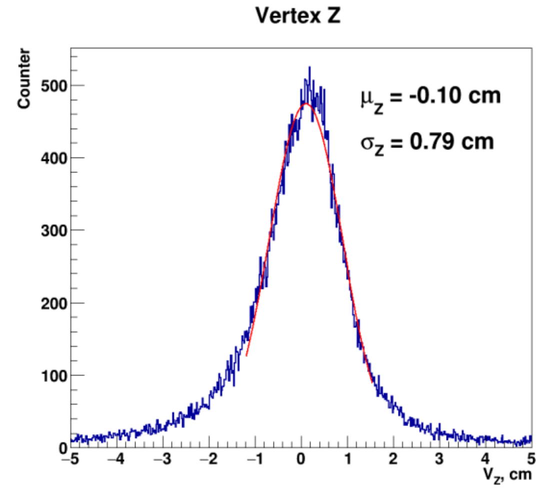


Fragment detector FD

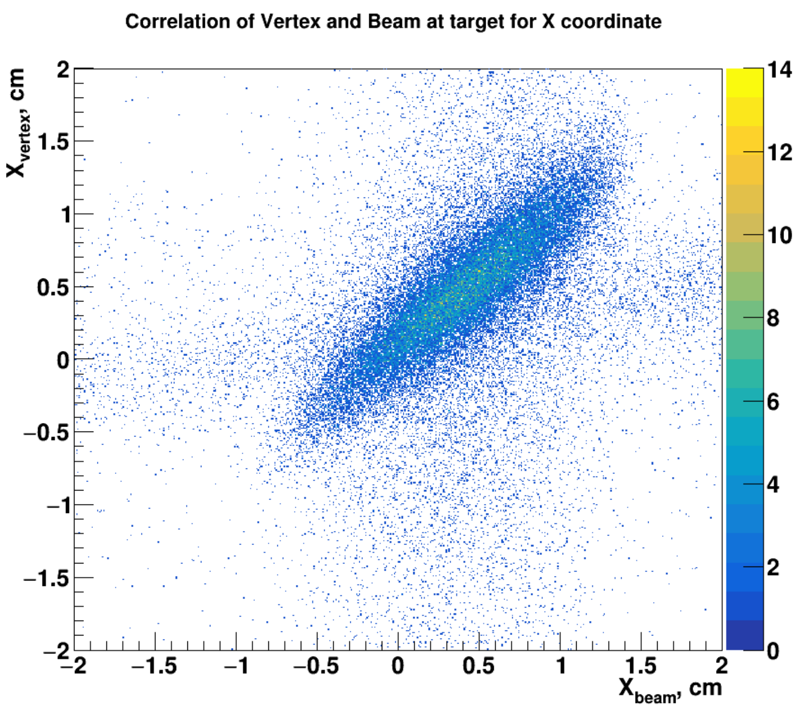
Vertex reconstruction

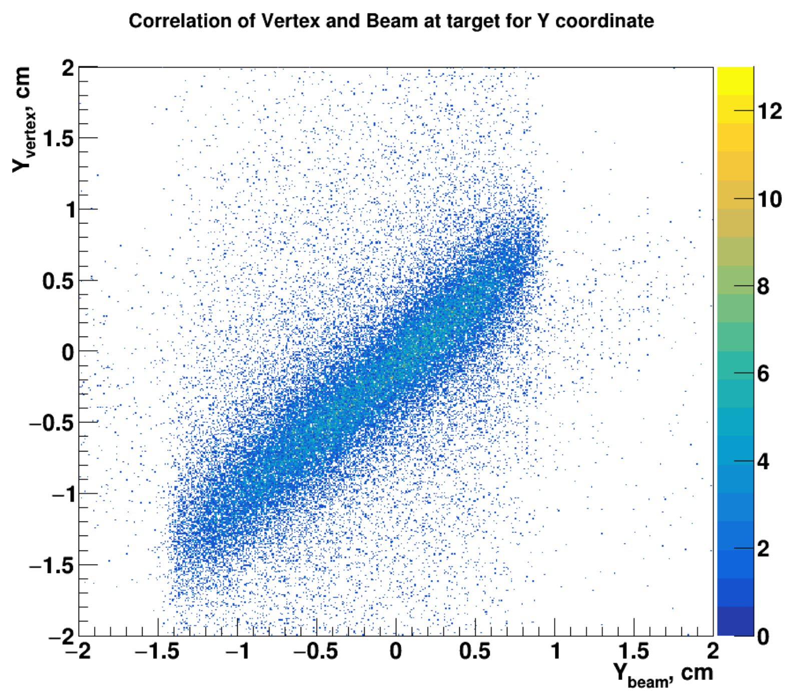




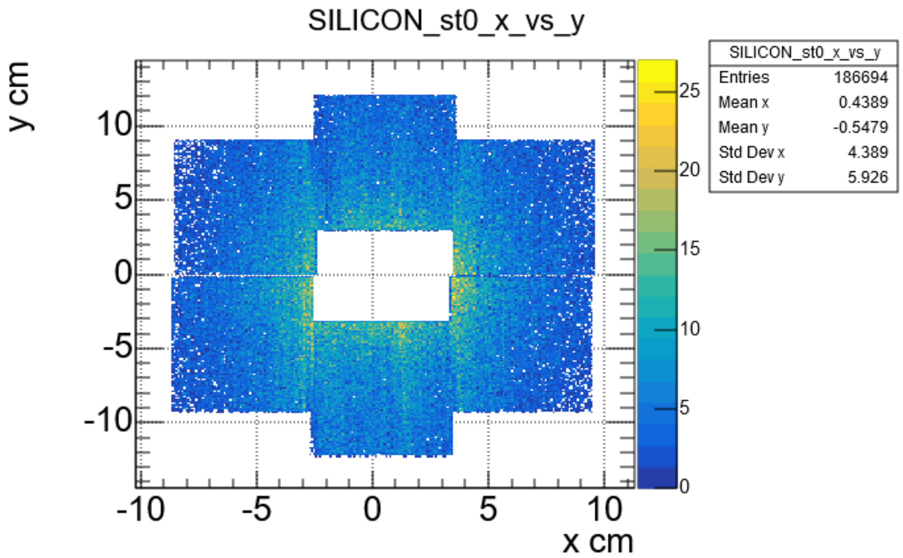


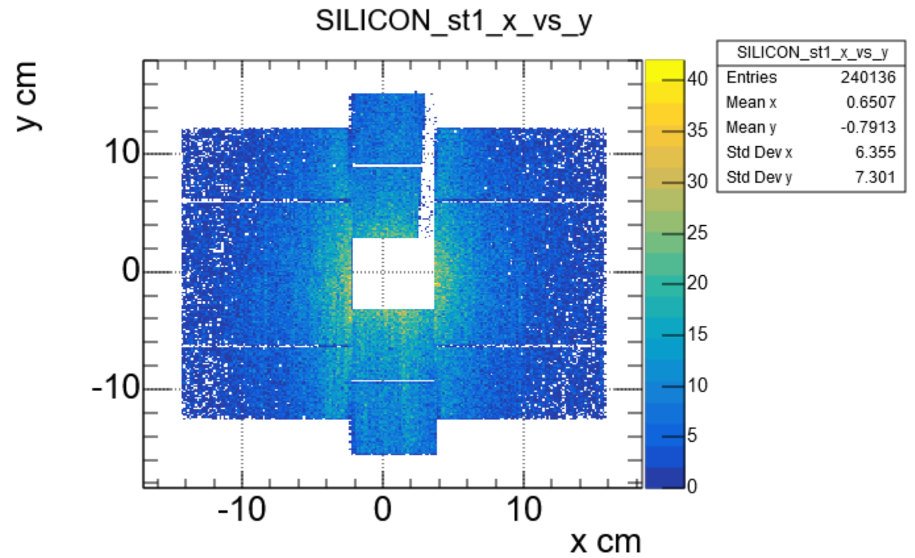
CsI (2%) target

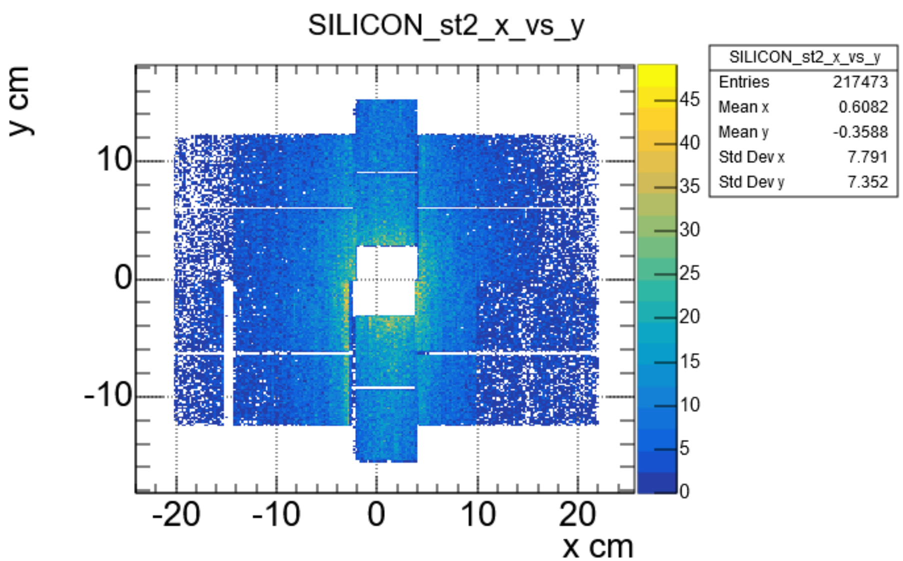


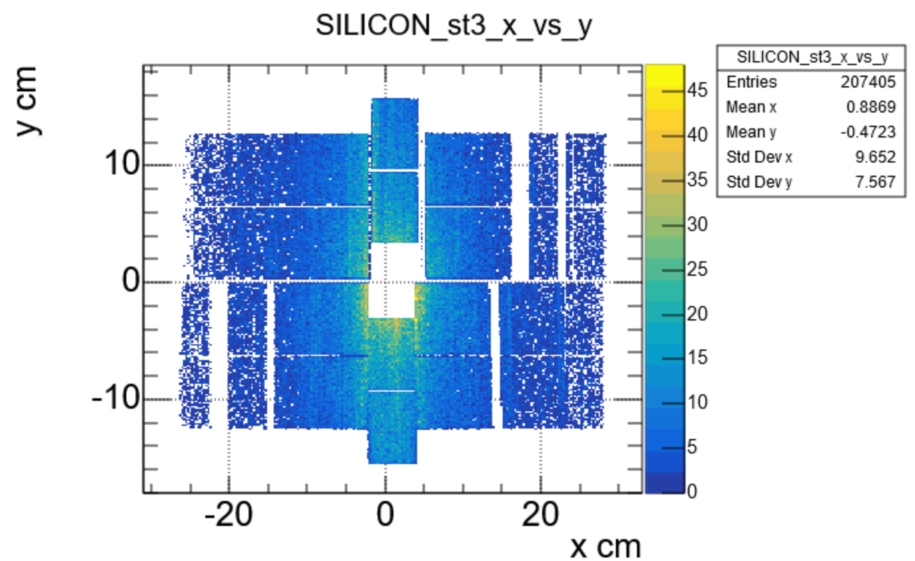


FST hit reconstruction: 4 Si stations



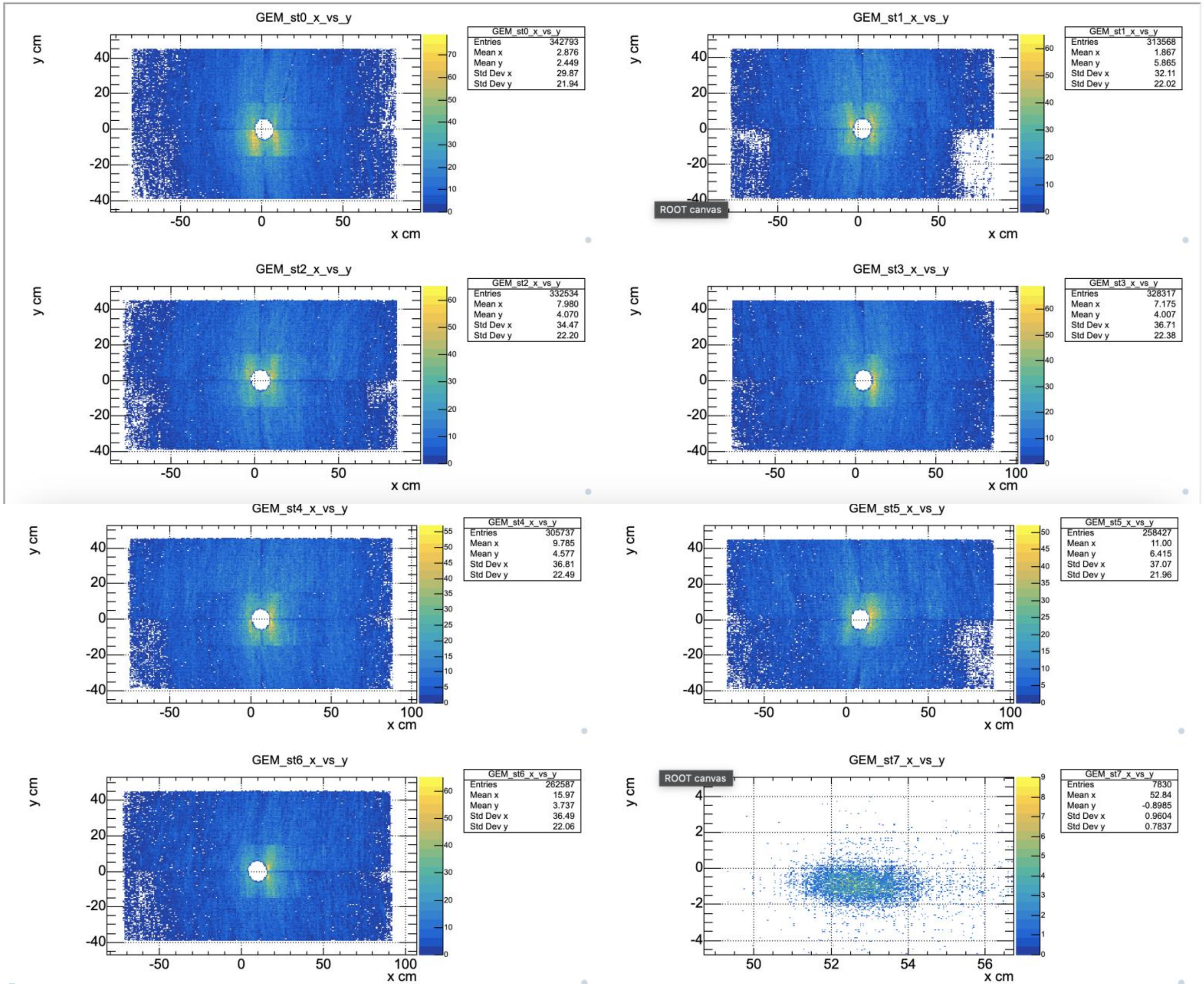






GEM hit reconstruction: 7 stations + small GEM profile meter

GEM Hits

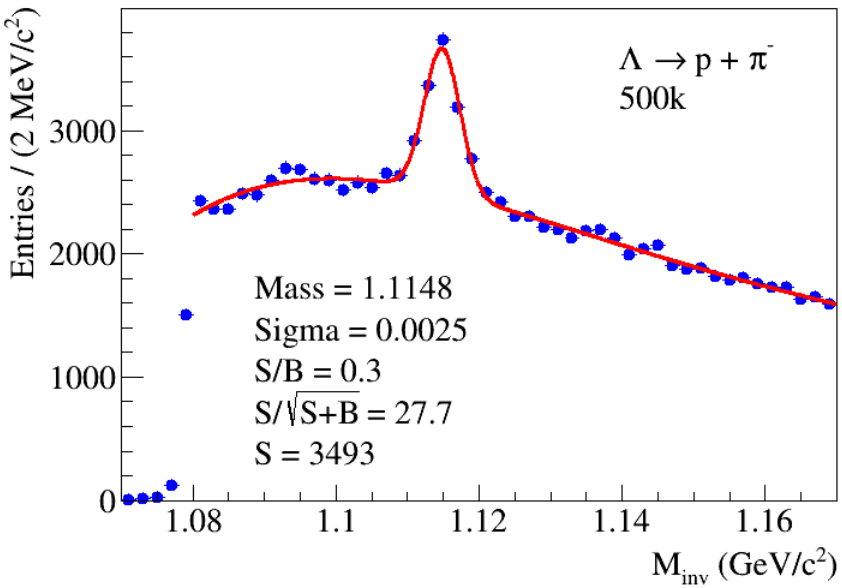


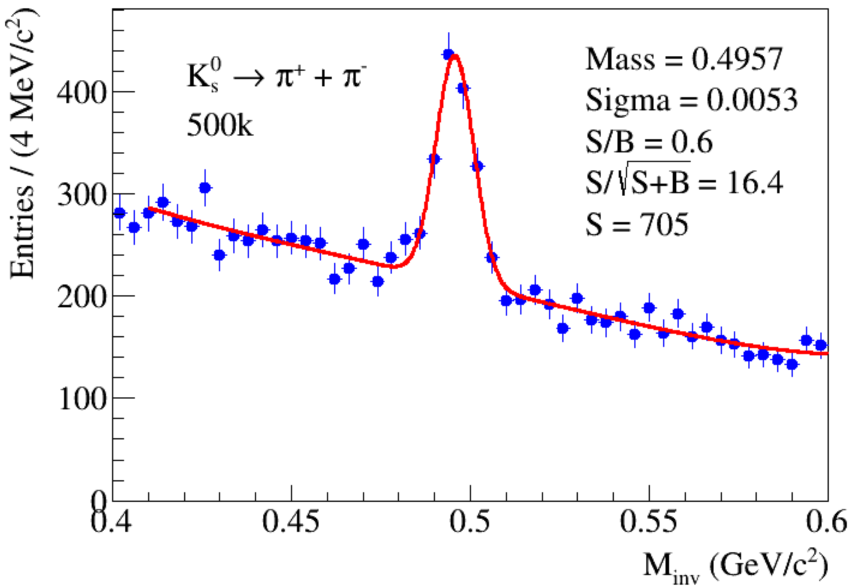
Raw data reconstruction: $\Lambda \rightarrow p\pi^-$ and $K^0_s \rightarrow \pi^+\pi^-$ signals

A.Zinchenko, V.Vasendivna

Central tracking activities:

- **optimize Vector Finder tracking algorithm to cope with defected FST modules**
- **improve alignment of silicon and GEM tracking detectors**



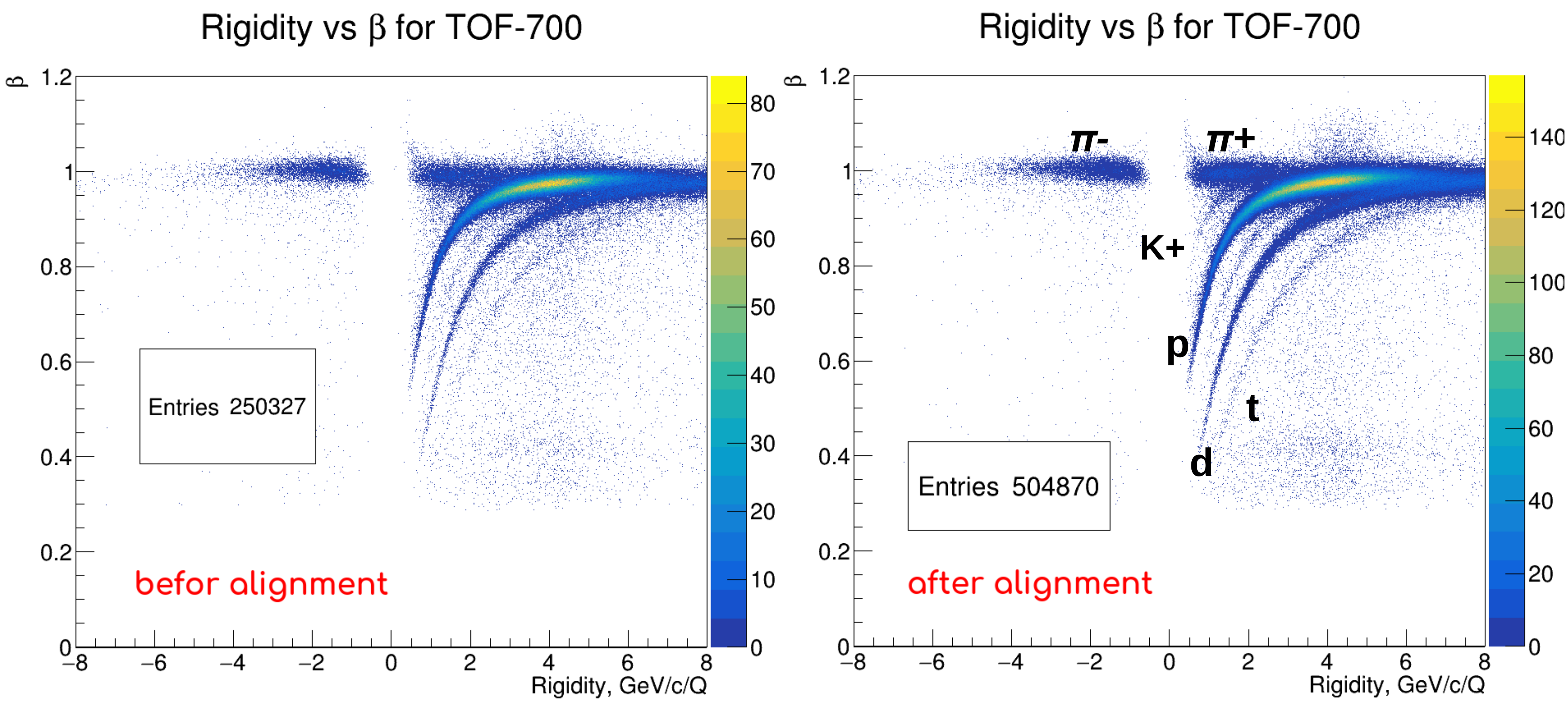


2 times smaller signal Λ than from DCM-SMM prediction with reconstruction efficiency of 2%

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

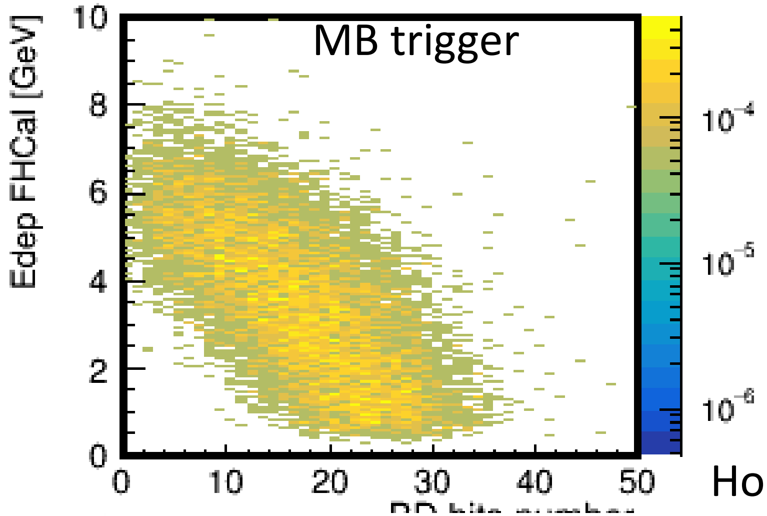
Still without dedicated ToF calibration

Yu.Petukhov, S.Merts

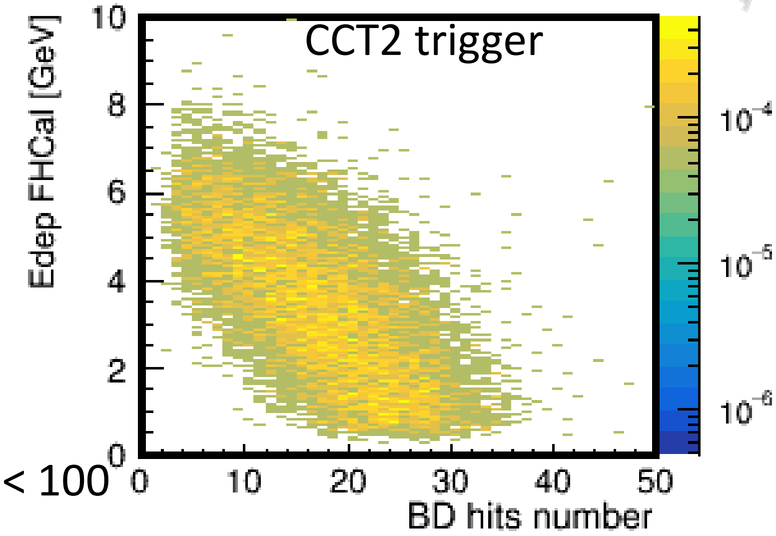


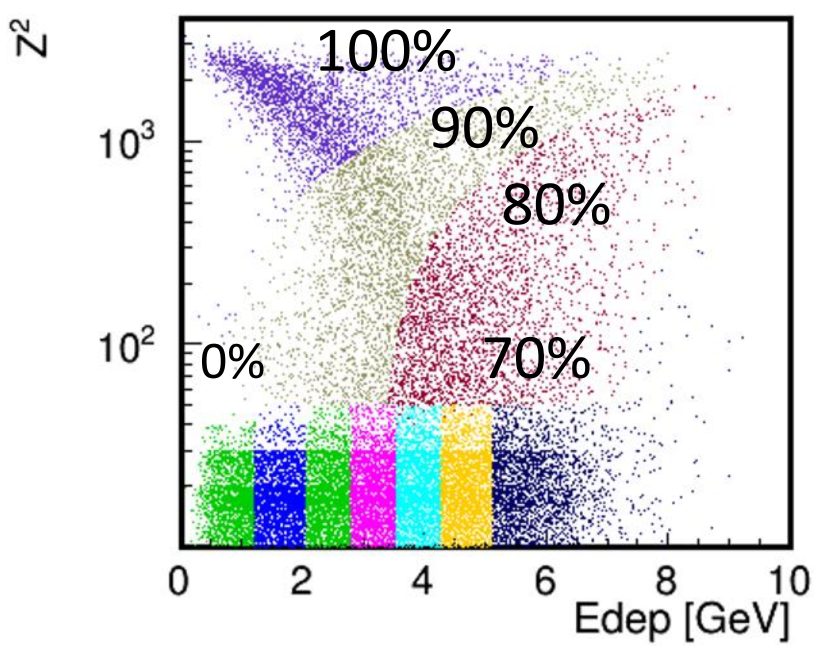
Centrality selection with Hodoscope and FHCal detectors

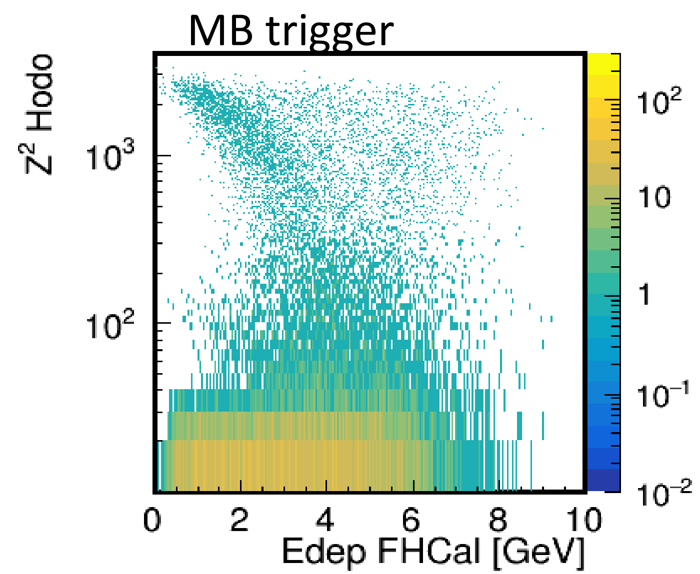
INR RAS group



Hodo $Z^2 < 100$



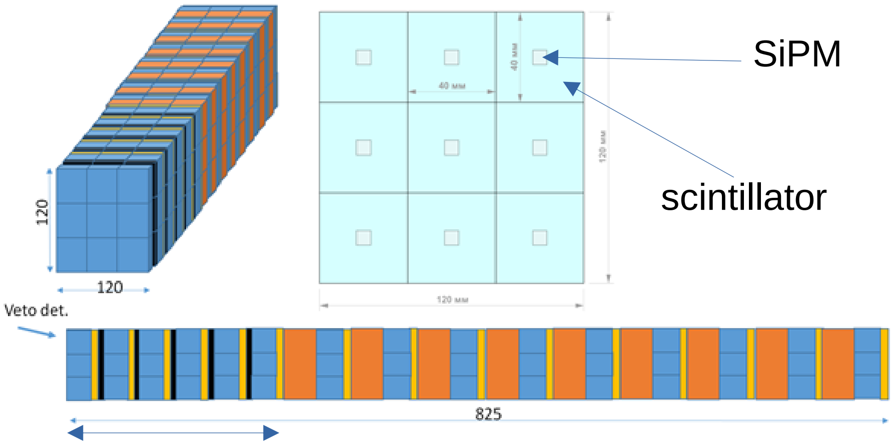




Color bins – 10% of number of events in each bin

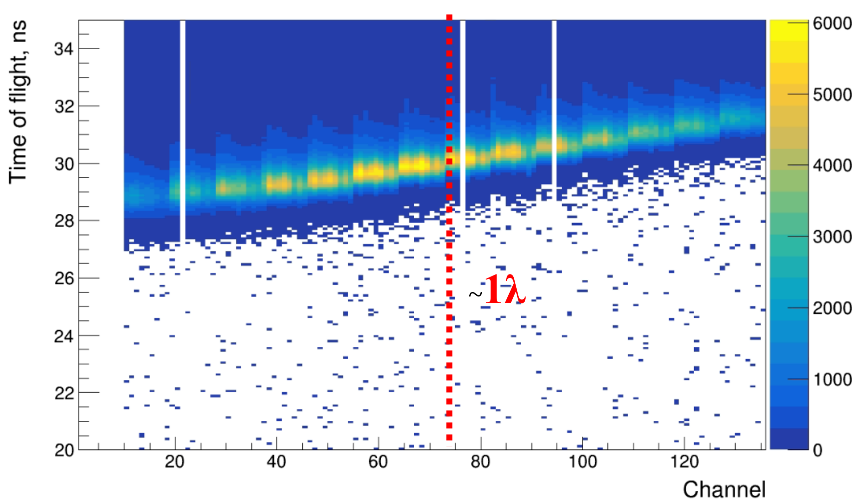
R&D High Granularity Neutron detector prototype

INR RAS, JINR, NRC Kurchatov

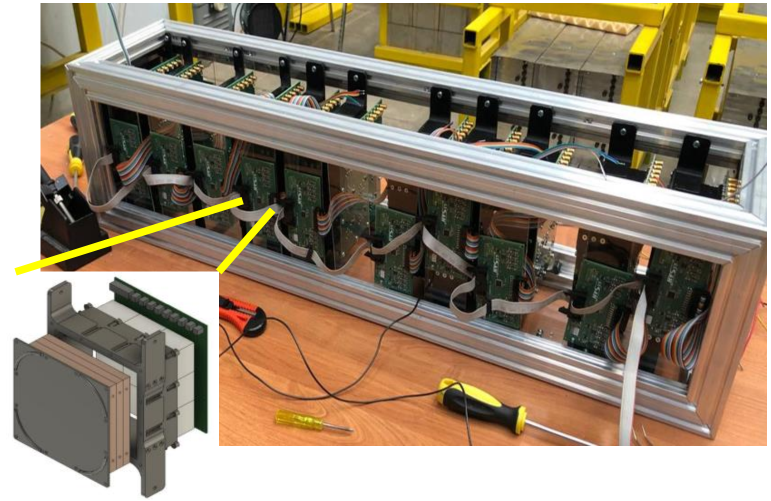


~12X$_0$

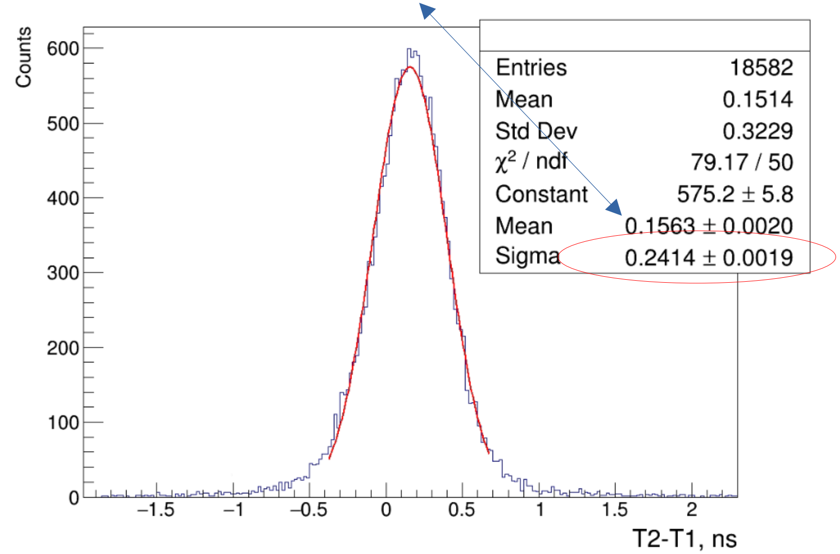
HGN prototype (15 layers, thickness > 2 λ_{int}):
1-st layer – VETO
2-6 layers – γ-detection part (Pb/Scint.)
7-15 layer – n-detection part (Cu/Scint.)



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



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

beam

BT	576455
MBT	20761
CCT1	123806
CCT2	9912
NIT	492799

triggers

fragments

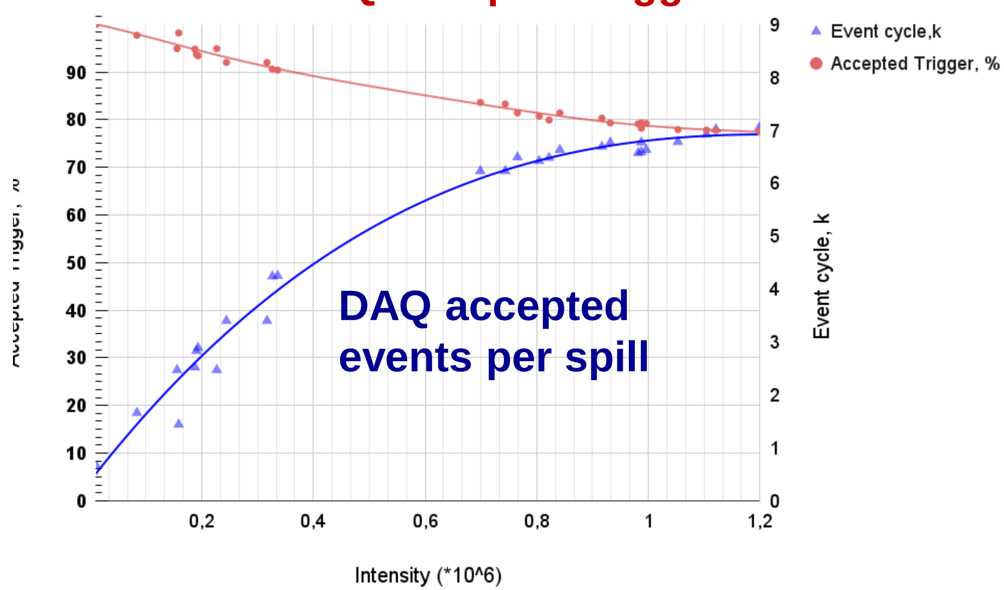
Ratios

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

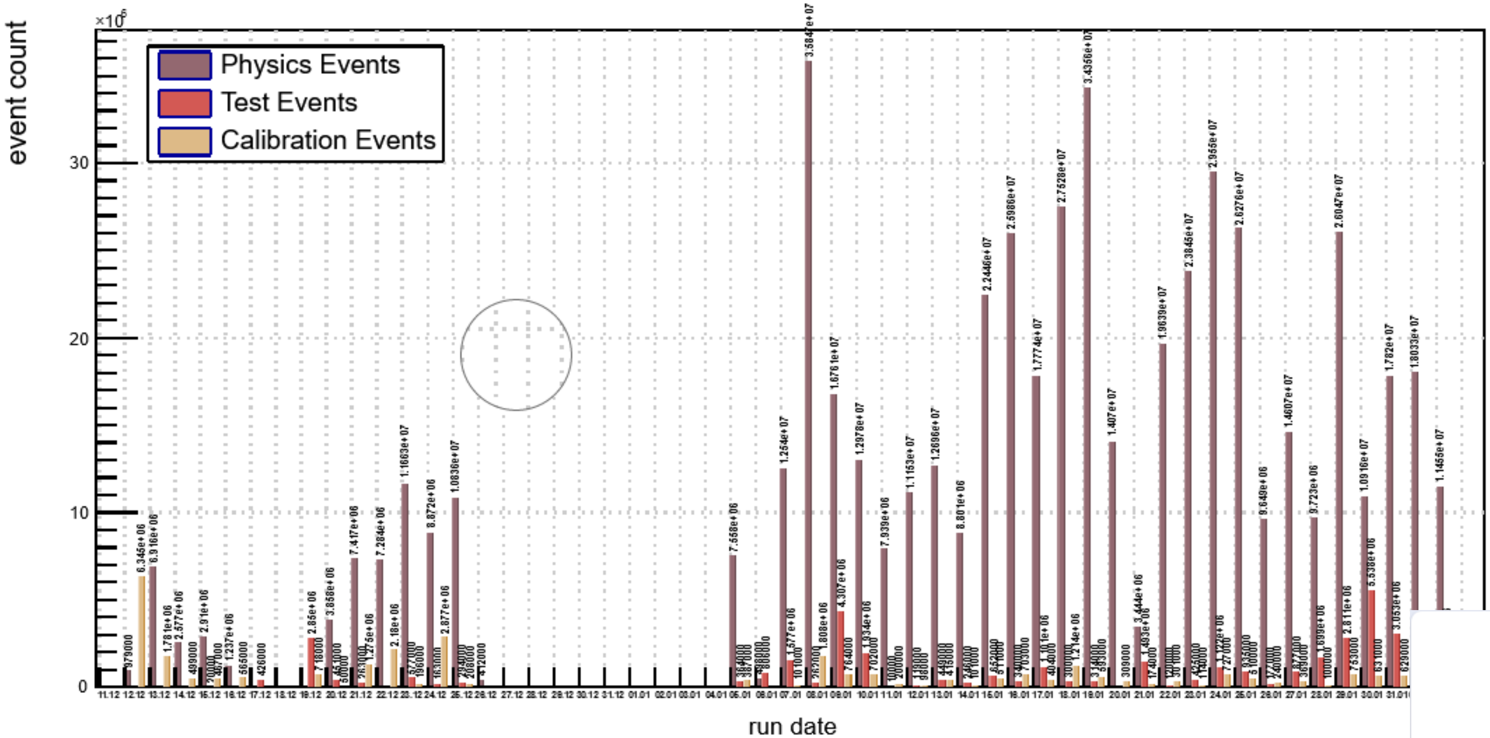
pCCT1	130882
pCCT2	130930
MBT1	20905
NIT1	492836
DAQ_Busy	0
BT*/DAQ_Busy	459879
pBT	668899

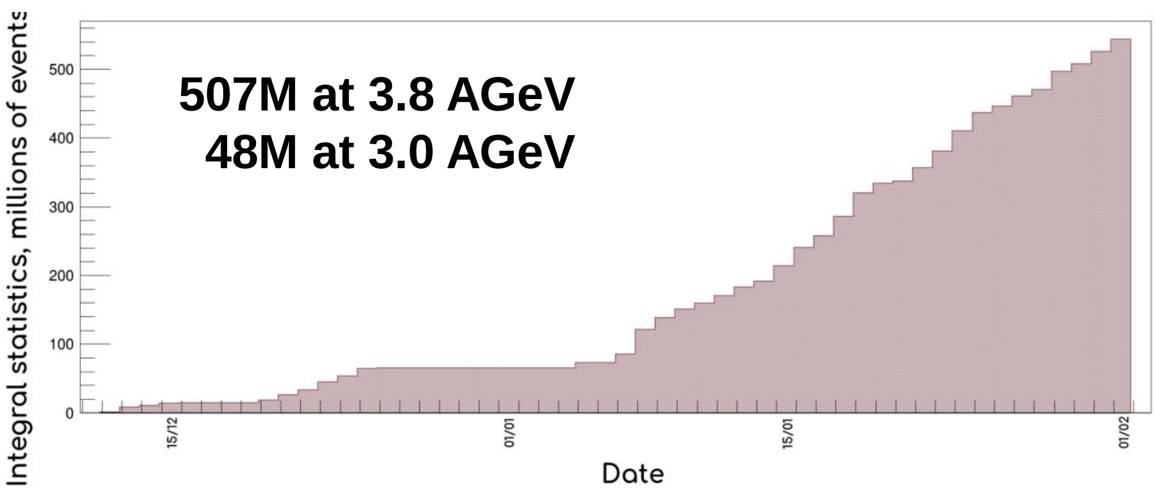
% of DAQ accepted triggers

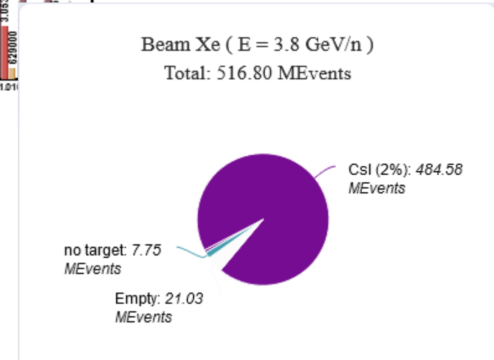


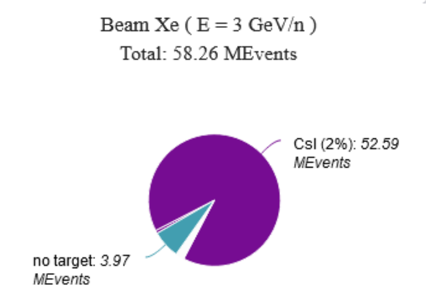
Statistics of recorded interactions

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









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

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
- include Si modules with one defected coordinate into tracking algorithm: optimize tracking efficiency and fraction of fake tracks
- improvement of alignment of upper and lower detectors
- use Λ and K^0_S signals as test probes for algorithm / alignment optimization
- compare results of tracking in data and simulation

- **Particle identification in ToF-400 detectors**: M.Rumyantsev, M.Mamaev
- alignment of middle size CSC-1 to 4 and two arms of ToF-400 detectors relative to extrapolated central tracks
- calibration of time of flight in ToF-400 to constrict the proton mass peak

- **Particle identification in ToF-700 detectors**: L.Kovachev, Yu.Petukhov, S.Merts
- alignment of big CSC, drift chambers and ToF-700 detectors relative to extrapolated central tracks (large hit combinatorics in drift chambers): P.Alexeev, N.Voitishin
- calibration of time of flight in ToF-700 detectors to constrict the proton mass peak

Tasks to be completed for the Xe data analysis

- **Si beam tracker alignment and matching beam tracks to central vertex**: A.Druck, S.Merts
- define position and angle of beam track candidates
- Study pile-up correlation with beam trigger detectors

- **For centrality measurement with forward detectors**: INR RAS team
- beam hodoscope amplitude correction due to pile-up signals
- Scint Wall alignment relative to extrapolated central tracks (P.Alexeev)

- **T_0 pile-up / slewing corrections for ToF measurements** (M.Zavertyaev, trigger group)

- **Finalize the re-measured magnetic field map**: S.Merts + student

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 nuclei and argon
- 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
- Physical 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 ${}_{\Lambda}H^{3}$, ${}_{\Lambda}H^{4}$

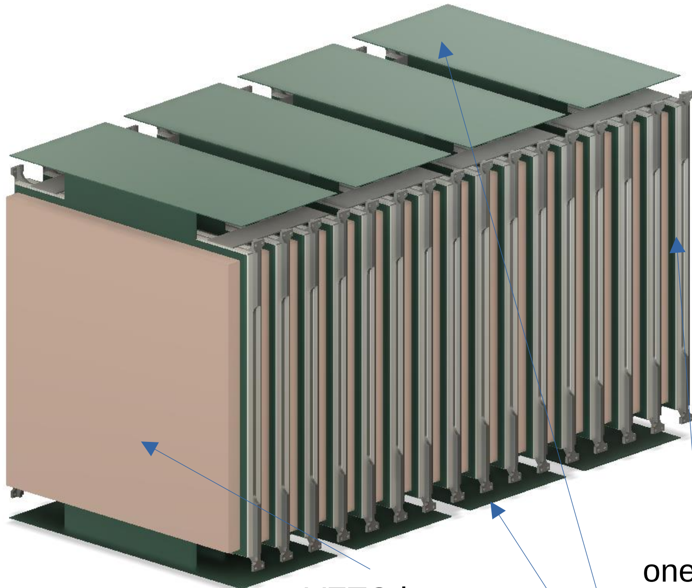
Plans for BM@N upgrade and physics runs

In 2024, physical run in Xe beam is possible: 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

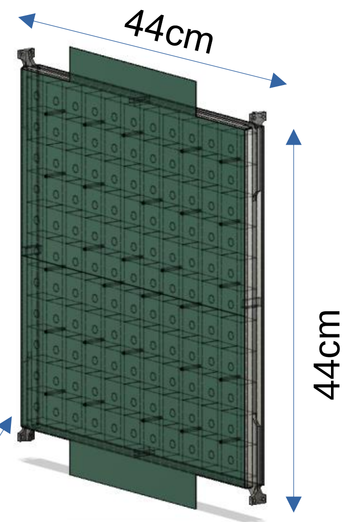
- Physical run in Bi beam is possible after 2024, depends on the implementation of plans for the NICA collider
- To be ready for the experiment in the Bi beam, further development of the central tracker is necessary: installation of additional stations of silicon detectors
- It is planned to put into operation a 3-coordinate neutron detector of high granularity to measure neutron yields and collective flow

3D High Granularity Neutron detector

INR RAS, JINR, NRC Kurchatov



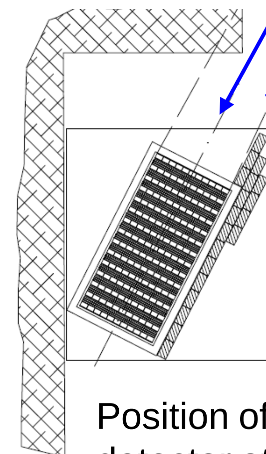
VETO layer



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**

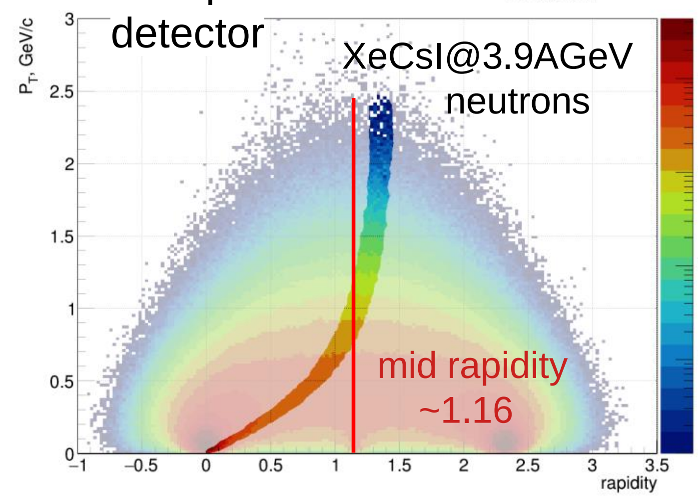


Position of HGN detector at BM@N

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

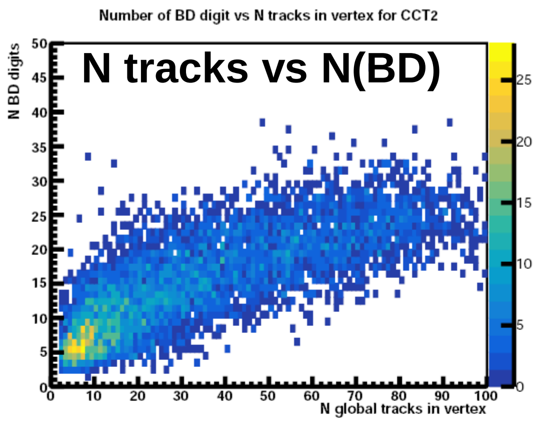


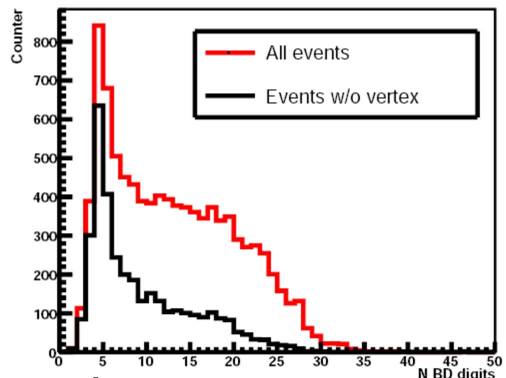
Thank you for attention!

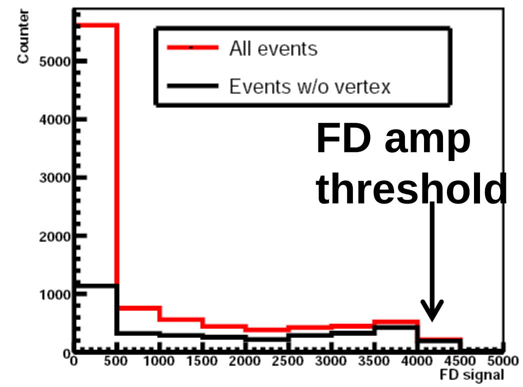
BM@N Trigger selection

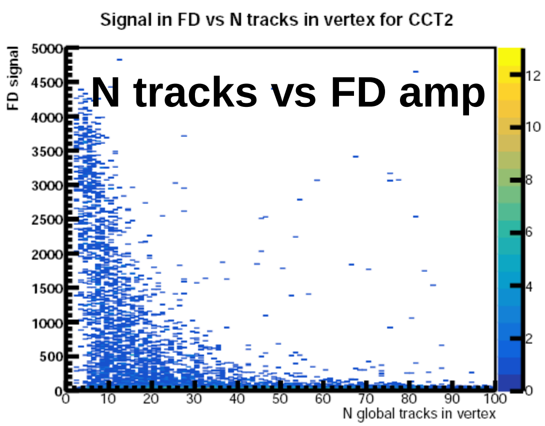
Combined trigger: CCT2 = BT * FD Amp < thr * N(BD) > 3

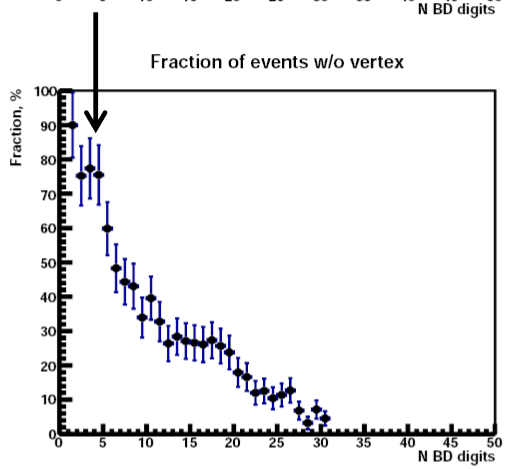
N(BD) > 3 **Fraction of events without vertex at target**

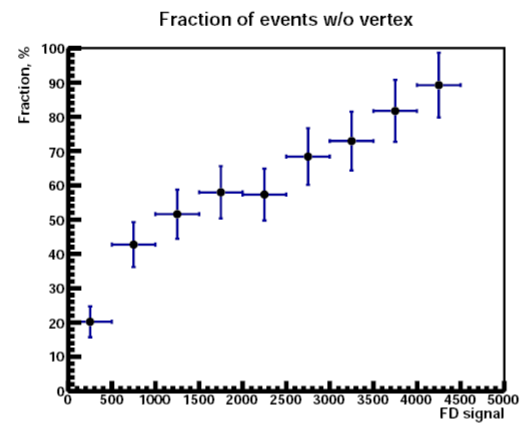








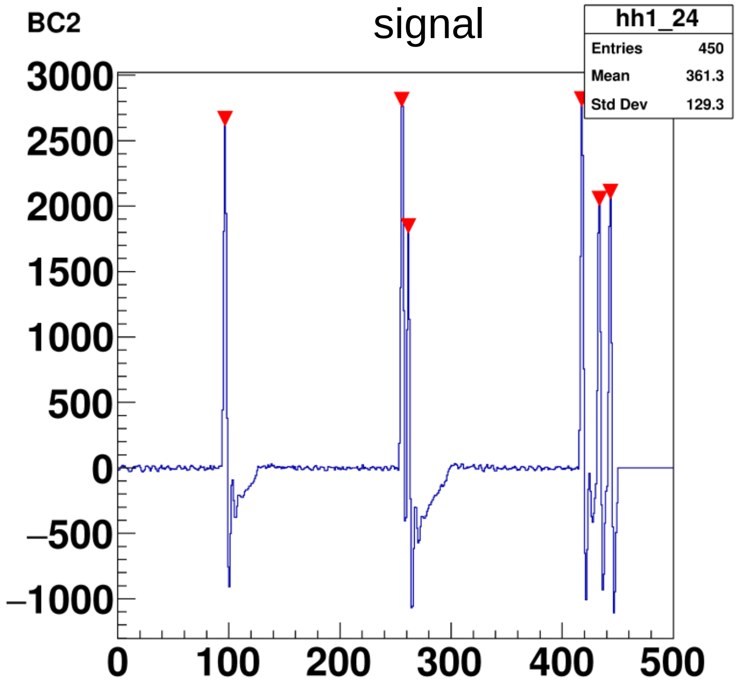




Pile-up of trigger signals: 80-100 ns time intervals between beam ions

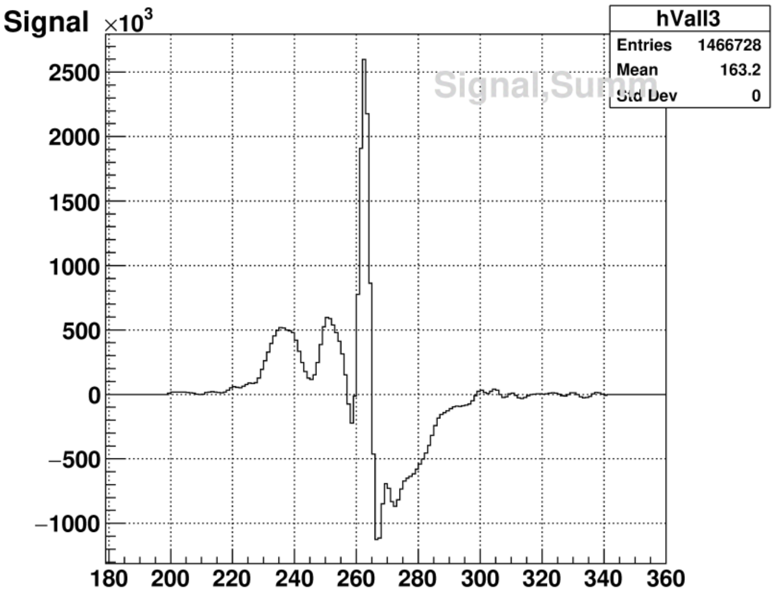
1 event:

trigger BC2 signal



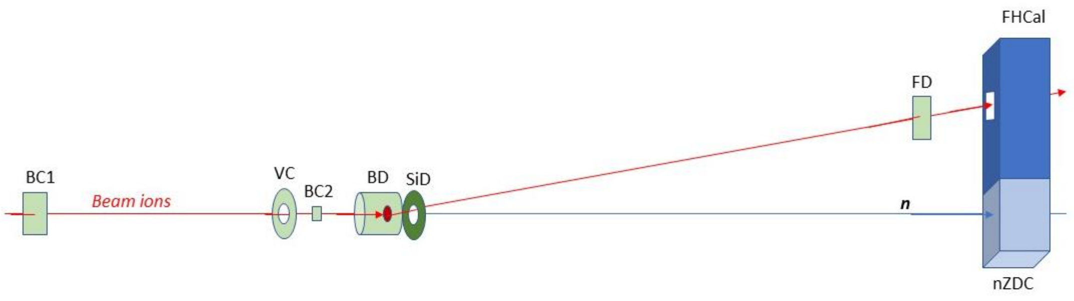
8 ns TQDC bins

Averaged over 25k events: selected 2 pile-up and trigger BC2 signal



8 ns TQDC bins

Detectors of Trigger System

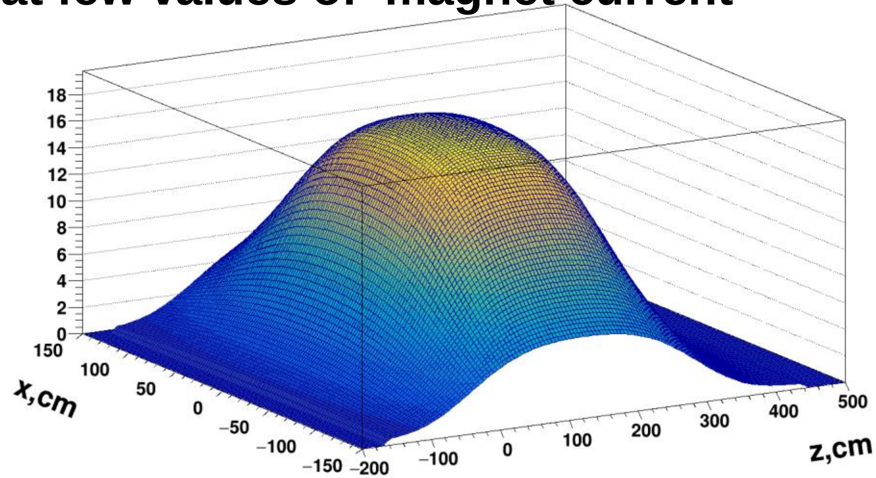


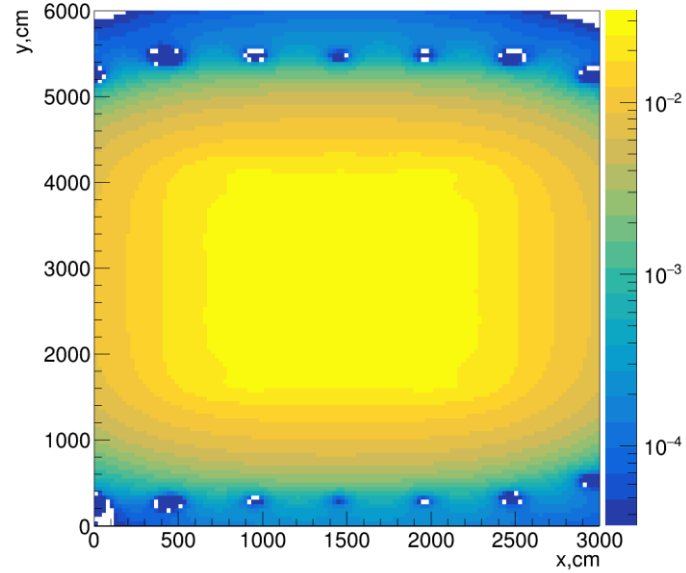
Min Bias trigger: MBT = BC1* BC2 * VC_{veto}* FD Amp < thr

Magnetic field map re-measurement

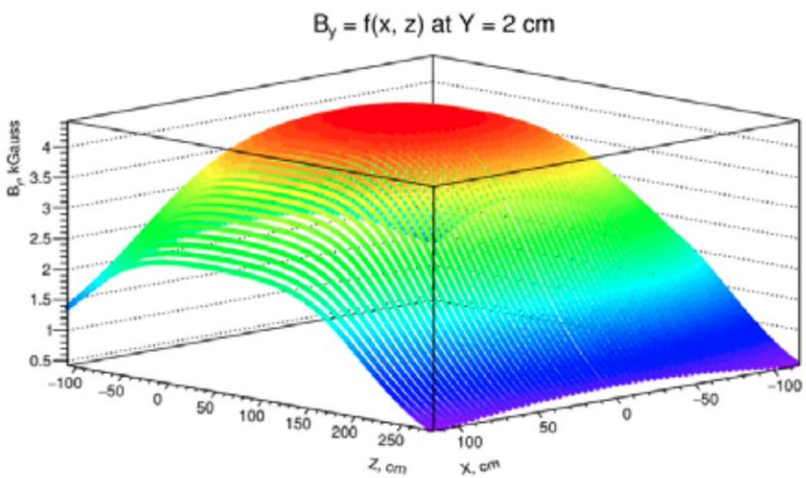
New map measured in a wider X,Z range at few values of magnet current

S.Piyadin, R.Shindin, S.Merts, T.Parphilo, B.Kondratiev, M.Mamaev and a team of shifters

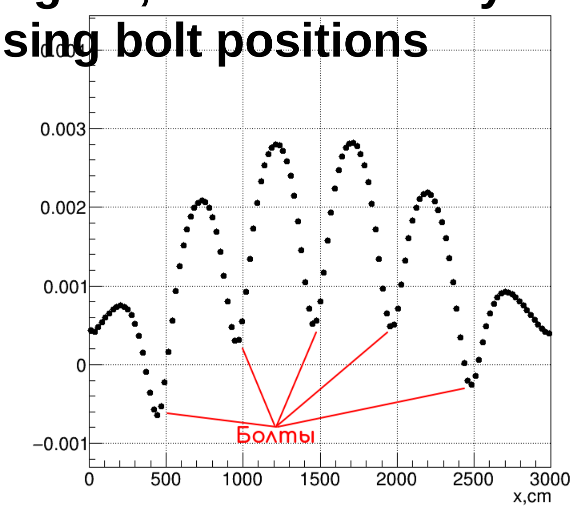




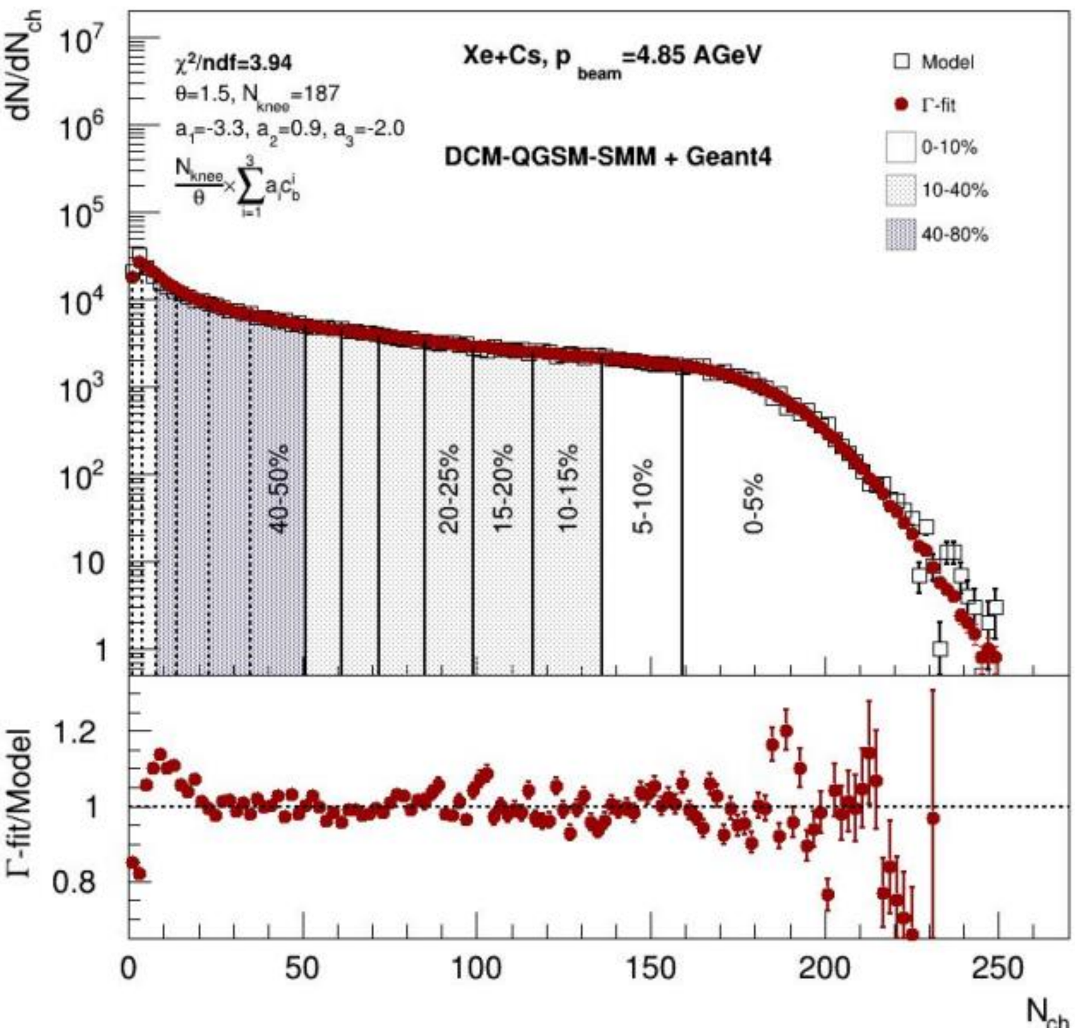
Old map measured in a restricted X,Z range at lower magnet current



Align X,Z coordinate system using bolt positions



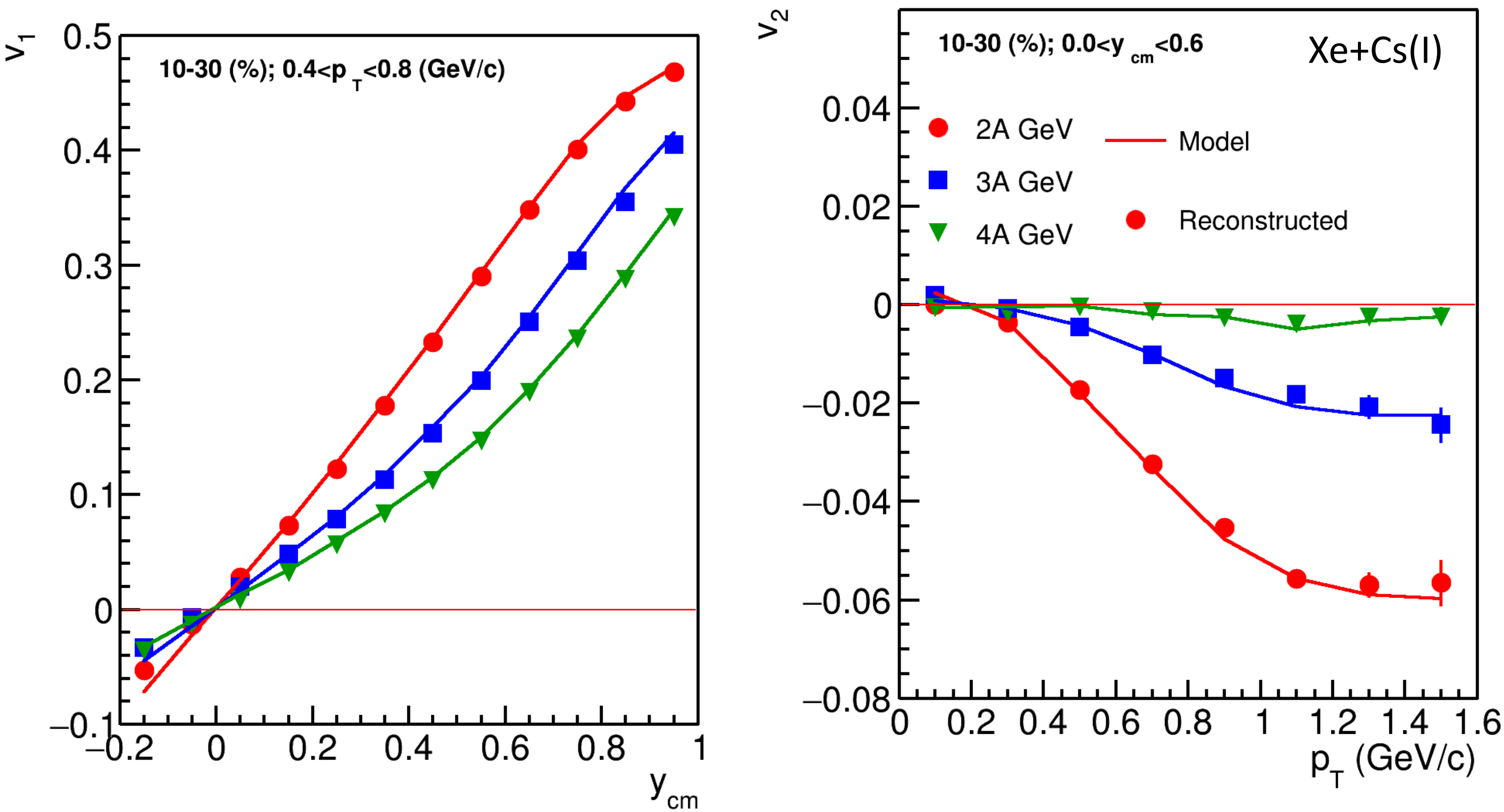
Centrality determination at BM@N



- 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

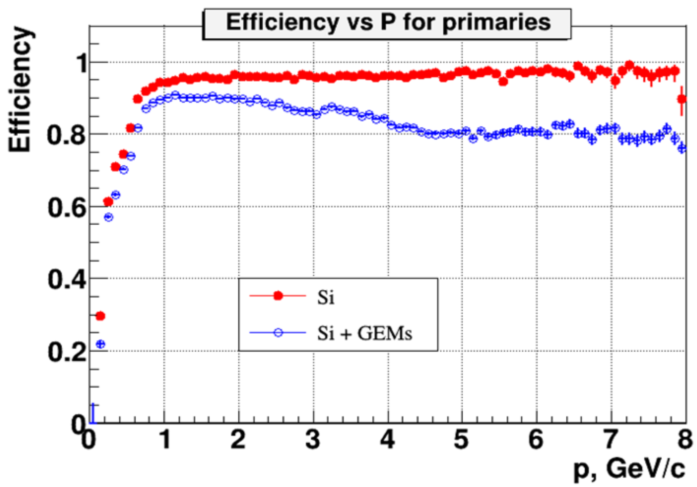
P.Parfenov

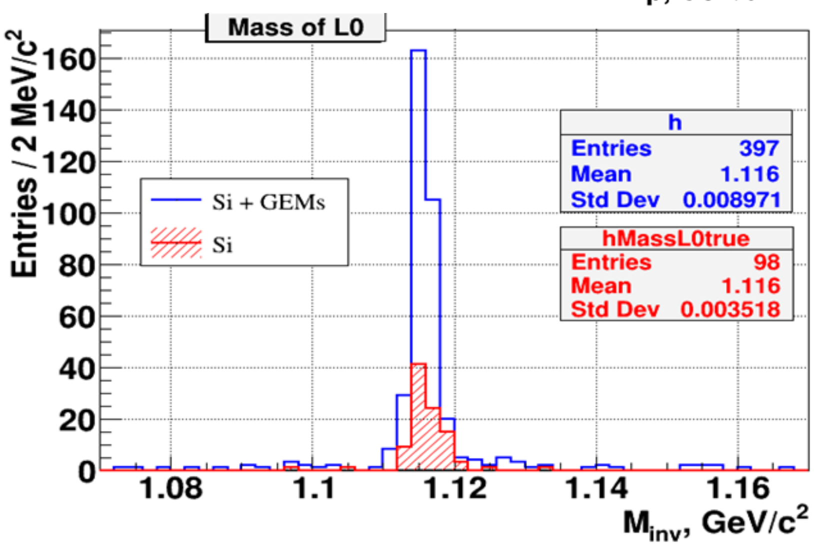


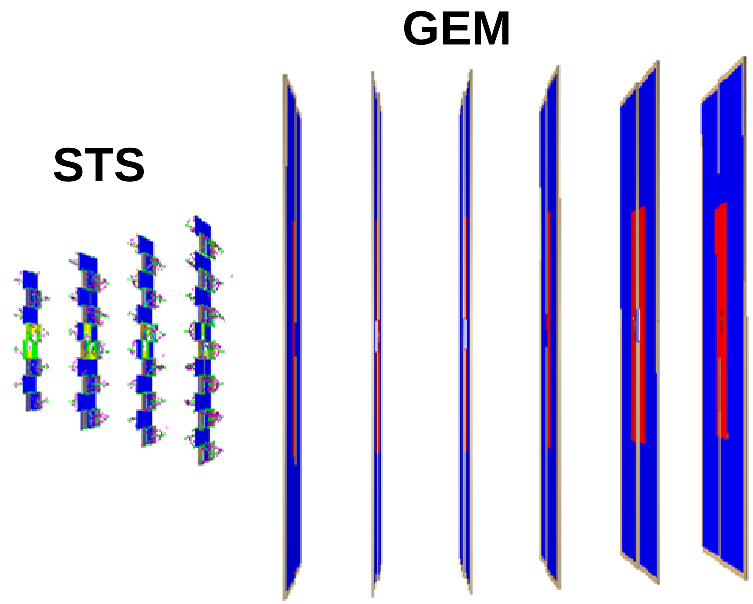
- Good agreement between reconstructed and model data
- Approximately 250-300M events are required to perform multi-differential measurements of v_n

Simulation of hybrid central tracker for heavy ion runs: STS +GEM

QGSM model, Au+Au, T_0 = 4 AGeV

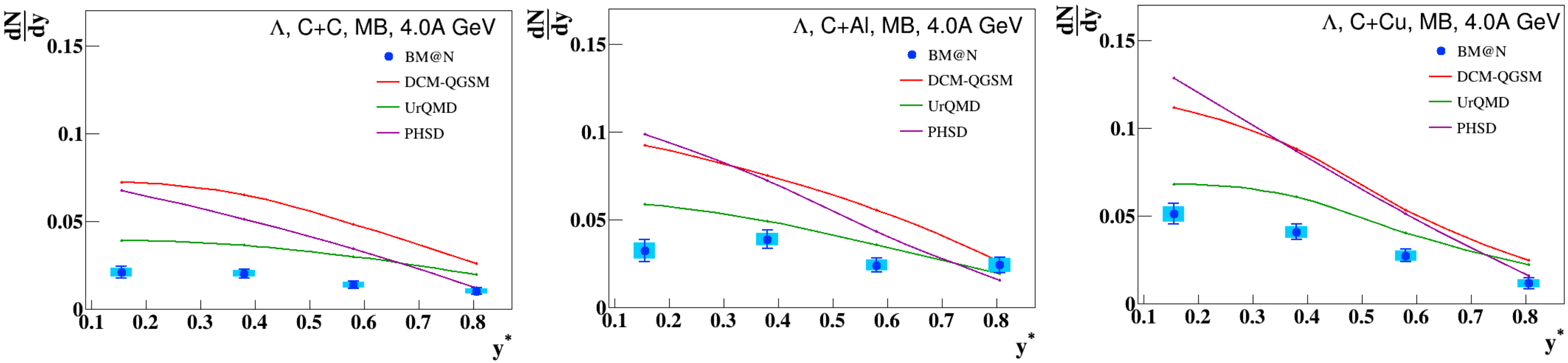






Hybrid STS + GEM tracker:
► 4 times increase in number of reconstructed Λ hyperons

Λ hyperon yield in 4A GeV carbon- nucleus interactions



- **Yield of Λ in C+C, C+Al, C+ Cu minimum bias interactions in dependence on rapidity y* in c.m.s. transverse momentum p_T**
- **Comparison with predictions of DCM-QGSM, UrQMD , PHSD models**

$$1/p_T \cdot d^2N/dp_T dy = A \cdot exp(-(m_T - m_\Lambda)/T), \quad m_T = \sqrt{(m_\Lambda^2 + p_T^2)}$$