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Event reconstruction and physics signal selection in the MPD experiment at NICA

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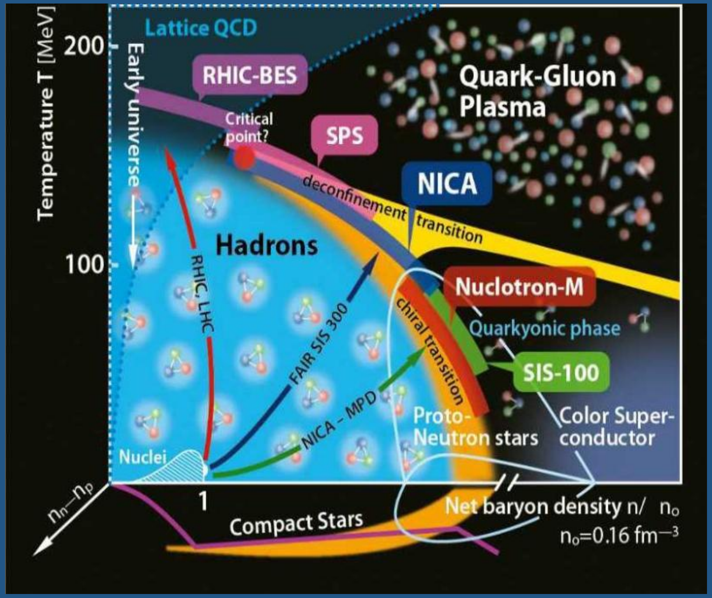
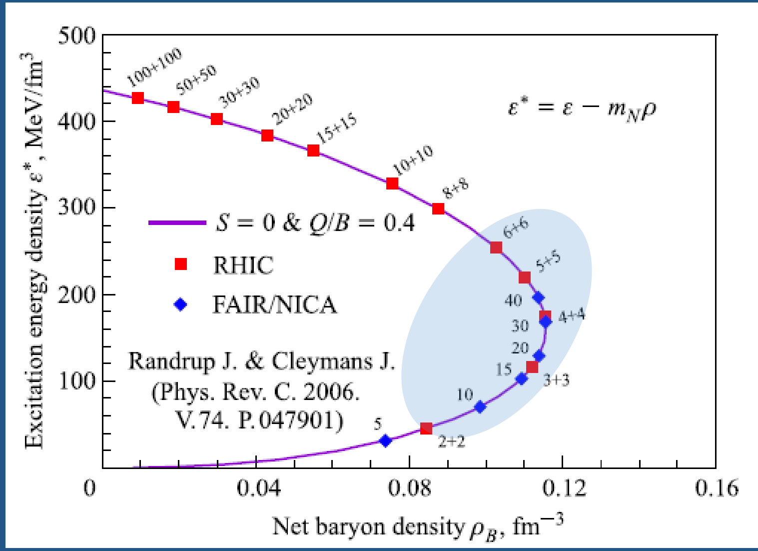
Outline

- MPD / NICA project
- Software requirements for physics observables
- Event reconstruction activity paradigm
- Current status of the MPD detector performance
- Inner Tracker performance
- Hyperon reconstruction
- Hypernuclei reconstruction (new *dE/dx* & PID)
- Summary and outlook

MPD / NICA project in HIC





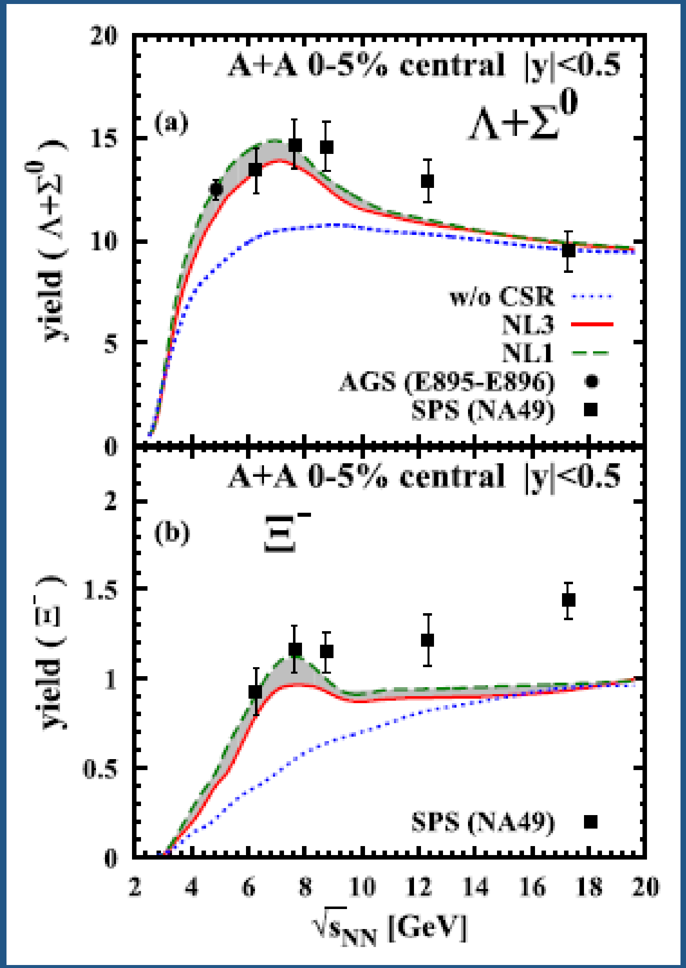
QCD matter under extreme conditions
(NICA niche – high μ_B)

✓ NICA (μ_B = [320-850] MeV) - highest net baryon density: essential to probe deconfinement and CSR

✓ Non-trivial energy dependence of multiple probes: strangeness production, flow, hyperon polarization

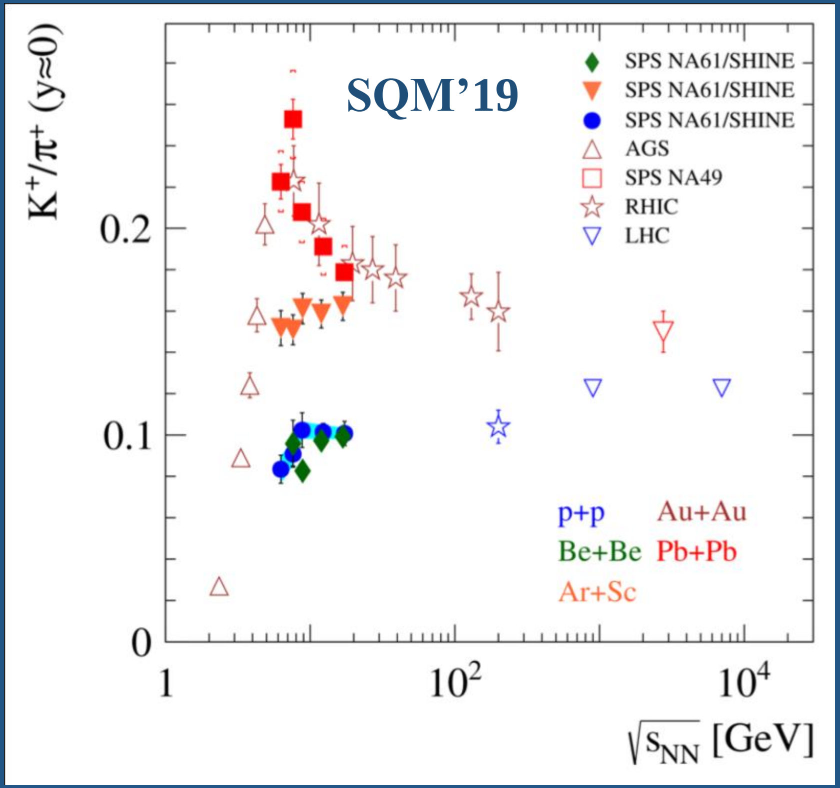
✓ High luminosity guarantees sufficient event rate for rare probes (hypernuclei and multistrangeness)

PRC 94, 044912 (2016)

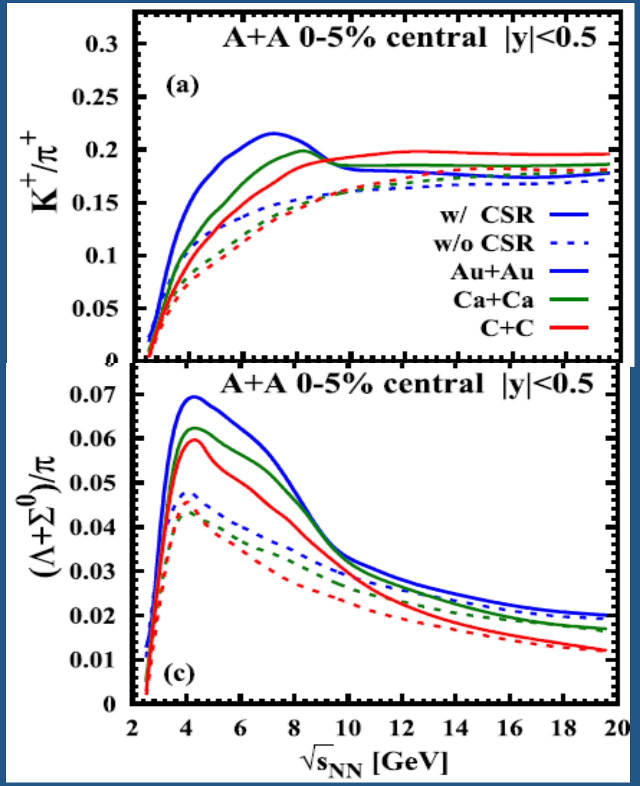


NICA / MPD physics cases: Strangeness

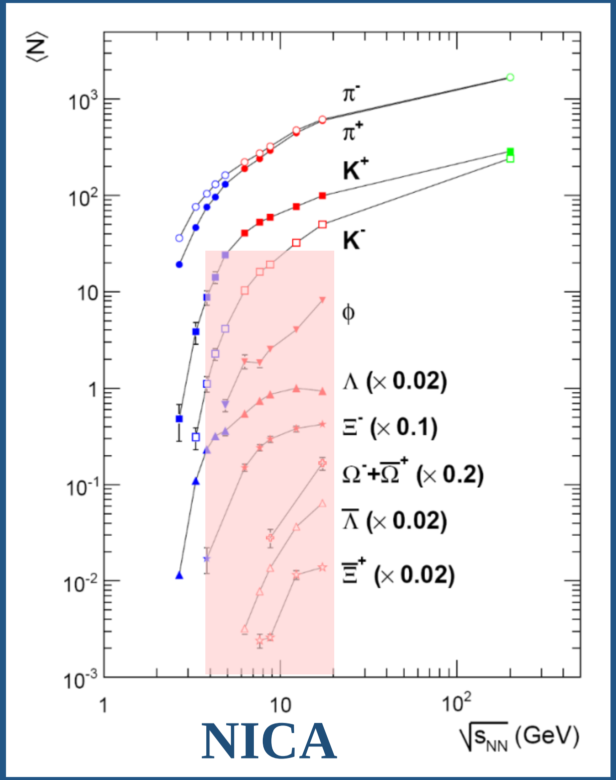
- Excitation function of hadrons, including strangeness (yields, spectra, and ratios)
- Nuclear matter EOS, in-medium effects, and chemical equilibration can be probed
- Hyperons sensitive to early stage and phase transformations in QCD medium
- Non-monotonic strangeness-to-entropy ratio seen in heaviest systems (phase transformation?)



System size and energy dependence is not fully understood



Theory predicts the largest effect for the hadron ratios due to CSR in dense matter



Lack of data on multistrangeness in different collision systems at NICA energies!

MPD / NICA physics and software requirements

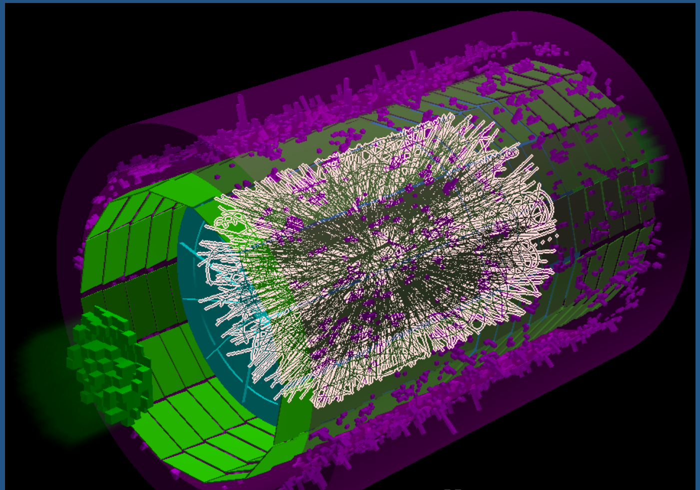
Task and Observables	Software requirements
Bulk properties, EOS	
particle yields & spectra, ratios, femtoscopy, flow	PV & V_0 reconstruction, track reconstruction, PID
In-Medium modification of hadron properties	
dileptons resonances	*ee* PID (conversion & hadron rejection, pion suppression factor: 4-5 orders of magnitude), track reconstruction
Deconfinement (chiral) phase transition at high r_B	
strangeness production Chiral Magnetic (Vortical) effect	PV & V_0 reconstruction, track reconstruction, PID
QCD Critical Point	
event-by-event fluctuations and correlations	Kinks
***YN*, *YY* interactions in nuclear matter**	
hypernuclei	PID of light nuclei (d, t, He^3, He^4), good vertexing
Charm ???	
Charm mesons	ITS tracking, perfect vertexing

Event reconstruction activity paradigm

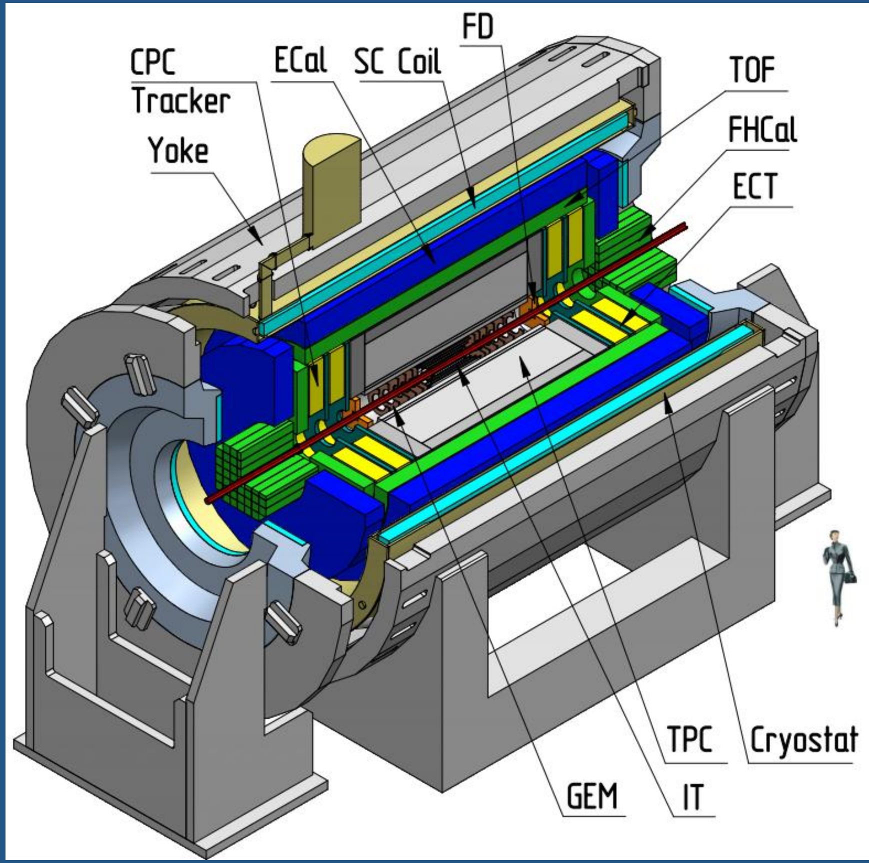
- The core activity – track reconstruction in different subdetectors. Good results require high quality input information, hence, attention is paid to lower level reconstruction tasks (e.g., cluster charge and hit coordinate reconstruction in TPC) . This work relies on realistic simulation of the detector response, hence, detector response simulation is covered as well.
- Track reconstruction results are used for primary and secondary vertex finding and reconstruction of particle decays, and, eventually, for construction of some variables for physics analyses. They serve for quality checking of the tracking and provide feedback for the core task. Hence, higher level reconstruction tasks and even some physics (proto)analyses are also touched.

MultiPurpose Detector @ NICA

- ✓ MPD – collider detector with wide and uniform acceptance and sufficiently fast to study rare probes
- ✓ Hermeticity, homogenous acceptance : 2π in azimuthal angle
- ✓ Highly efficient 3-D track reconstruction (|η|<1.8), high resolution vertexing
- ✓ Powerful PID: *π/K* up to 1.5 GeV/c, *K/p* up to 3 GeV/c, ECal for *γ*, *e*
- ✓ Careful event characterization: impact parameter & event plane reconstruction
- ✓ Minimal dead time, event rate capability up to ~ 6 kHz


Au+Au collision in MPD

Magnet: 0.5 T superconductor
Tracking: TPC, ECT, IT
ParticleID: TOF, ECal, TPC
T0, Triggering: FD
Centrality, Event plane: FHCal



Realistic MPD tracking

Simulation procedure (digitization):

- Primary ionization (ionization clusters)
- Drift and diffusion of ionization electrons
- Gas gain fluctuations (Polya distribution)
- Pad response (charge distribution on pad plane)
- Electronics shaping
- Signal digitization (ADC overflow)

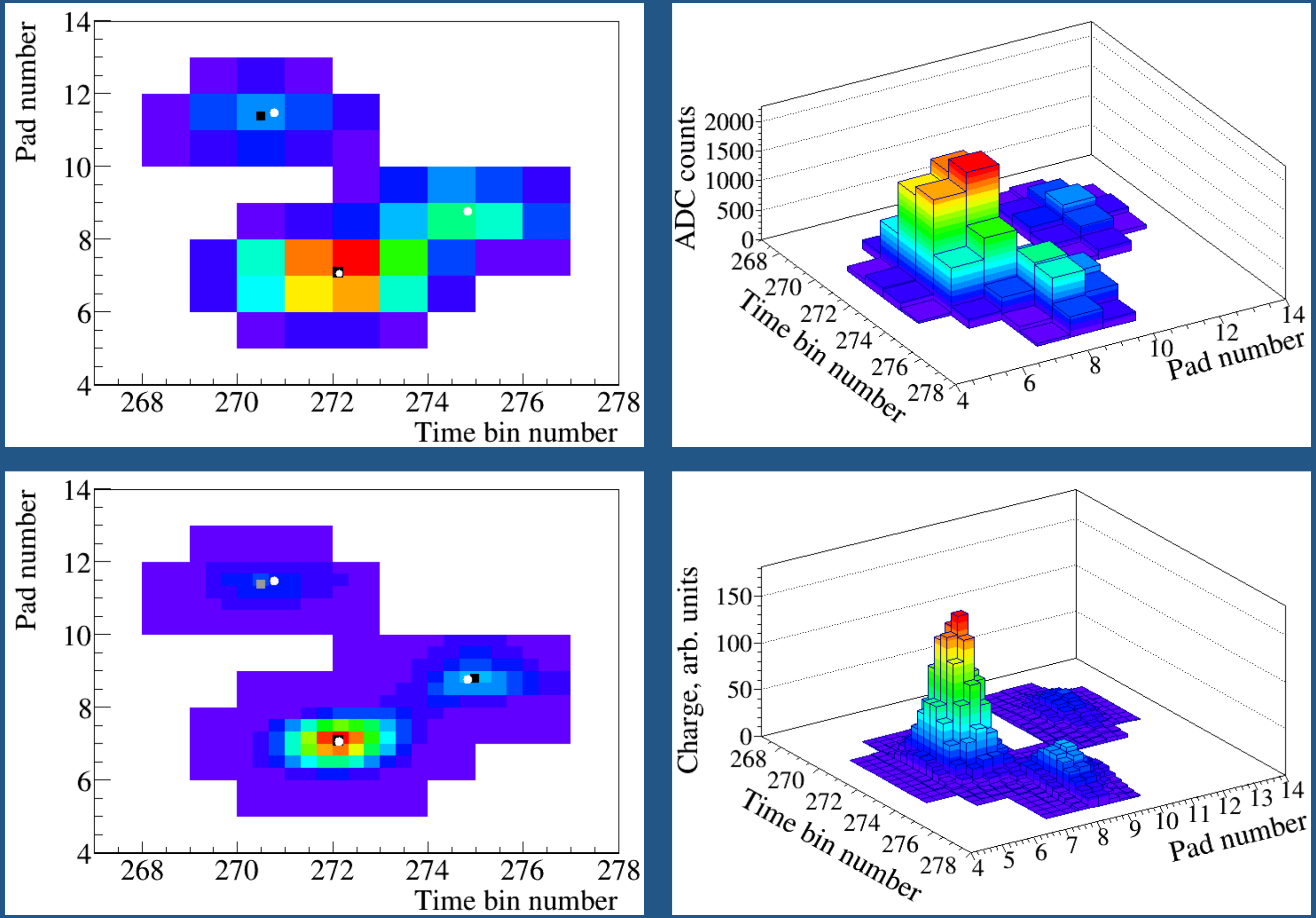
Cluster / hit reconstruction

- Precluster finder (group of adjacent pixels in time bin – pad space)
- Hit finder ("peak-and-valley" algorithm either in time bin – pad space (for simple topologies) or in time-transverse coordinate pixel space after Bayesian unfolding (for more complicated topologies)) → COG around local maxima

TPC parameters

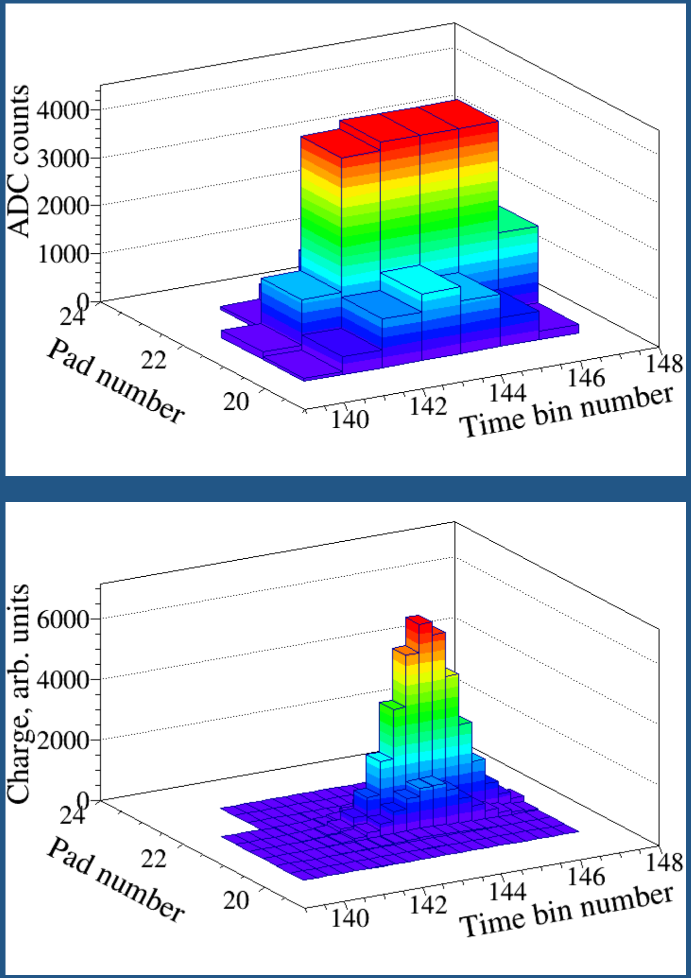
Parameter	Value
Magnetic field	0.5 T
Drift gas	P10 (90% *Ar* + 10% CH_4)
Drift velocity	5.45 cm/μs
Transverse diffusion at 0.5 T	185 μm/√cm
Longitudinal diffusion	320 μm/√cm
Pad size	5x12 mm^2 (27 rows) + 5x18 mm^2 (26 rows)
Charge spread σ	0.196 mm
Electronics shaping time	180 ns (FWHM)
ADC dynamic range	10 bits
ADC sampling frequency	10 MHz

Cluster topologies and MLEM procedure



Before

After MLEM



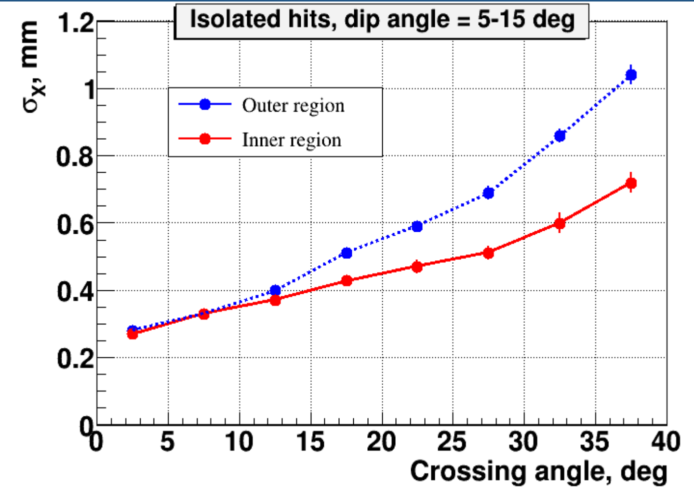
2D and 3D views of a precluster of three tracks. The true hit coordinates are indicated by circles, the reconstructed ones are shown by squares. On the top left plot one hit has not been reconstructed. Bottom – 2D and 3F views of the same precluster after the MLEM procedure.

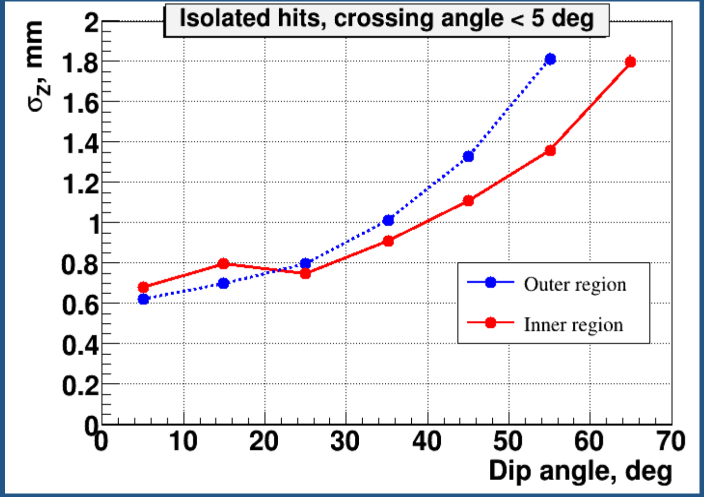
3D view of a cluster with overflows. Top – ADC output; Bottom – after MLEM procedure .

MPD tracking efficiency

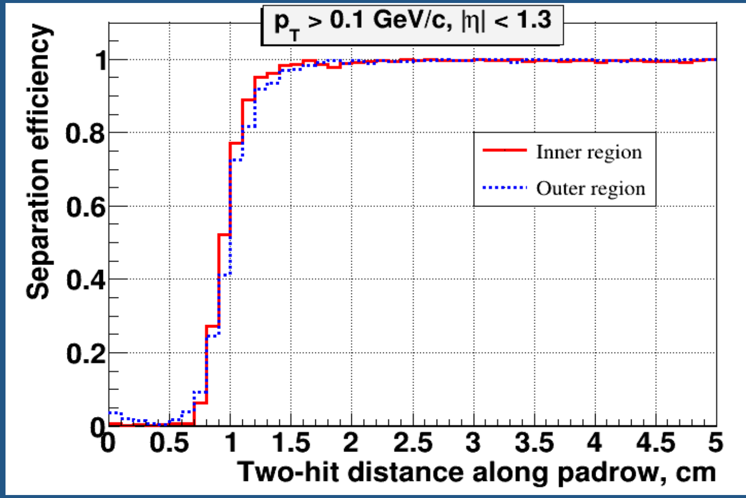
UrQMD, central (0-3 fm), Au+Au at 9 GeV

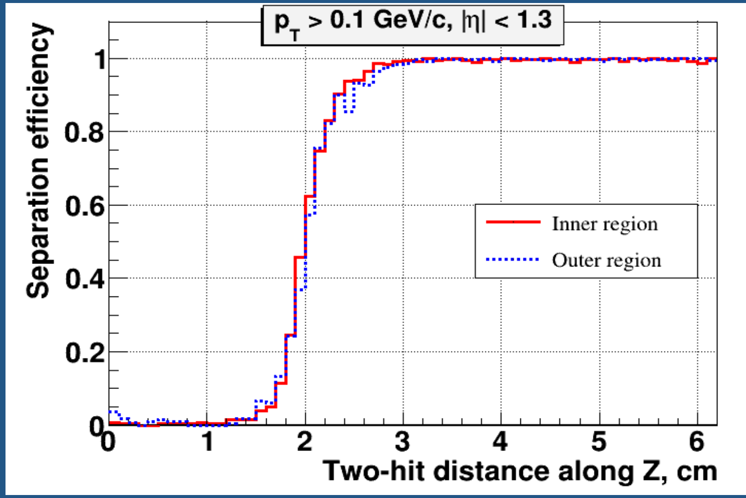
Coordinate resolution

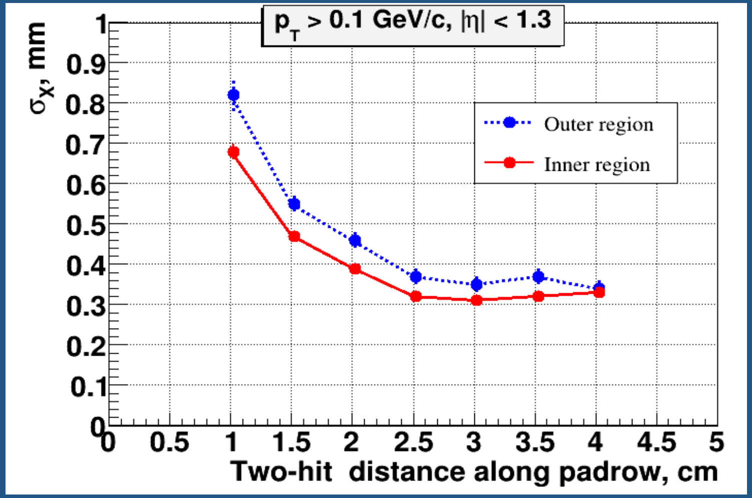


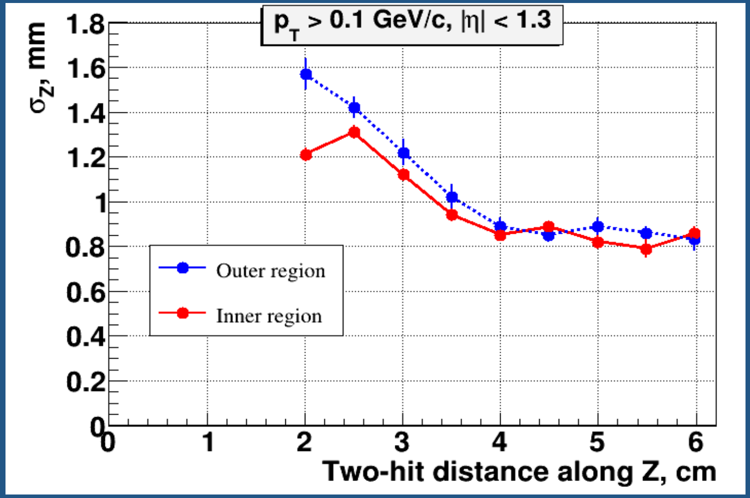


Double-hit resolution







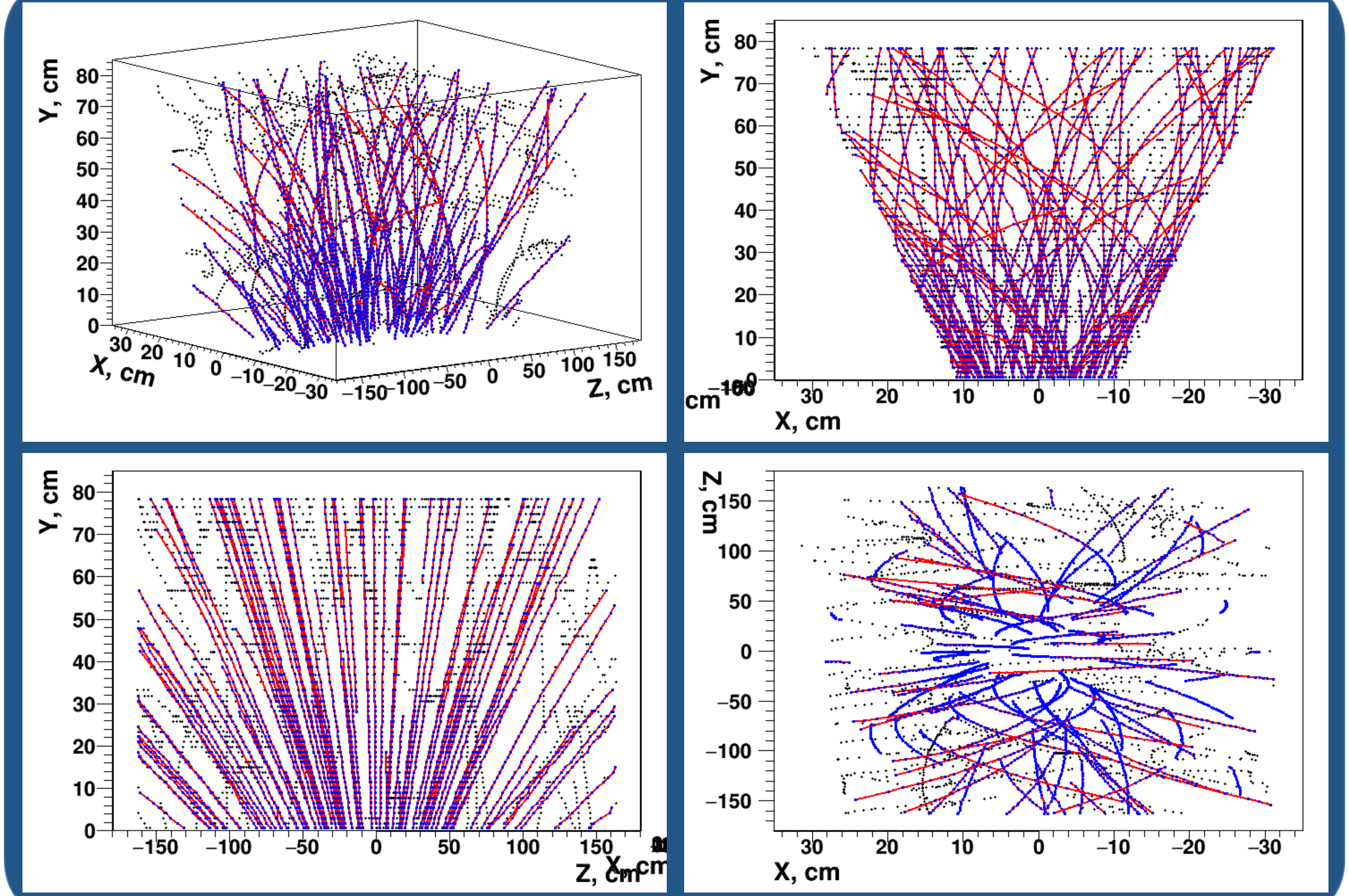


Track reconstruction

Two-pass Kalman filter with track seeding using outer hits (1st pass) or leftover inner hits (2nd pass)

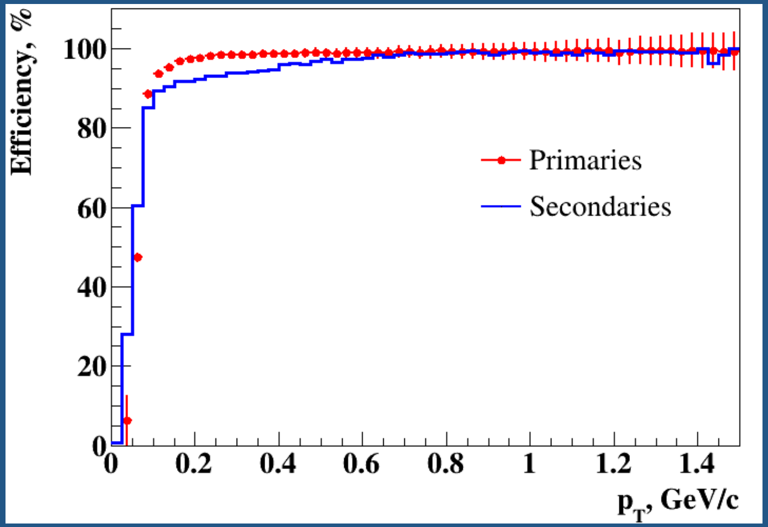
Some statistics:

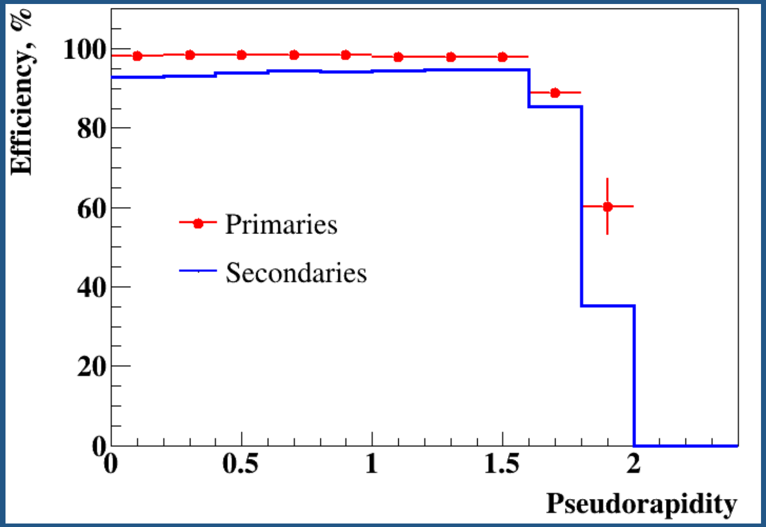
rec. points = 4867,
hits on tracks = 3127,
tracks = 102

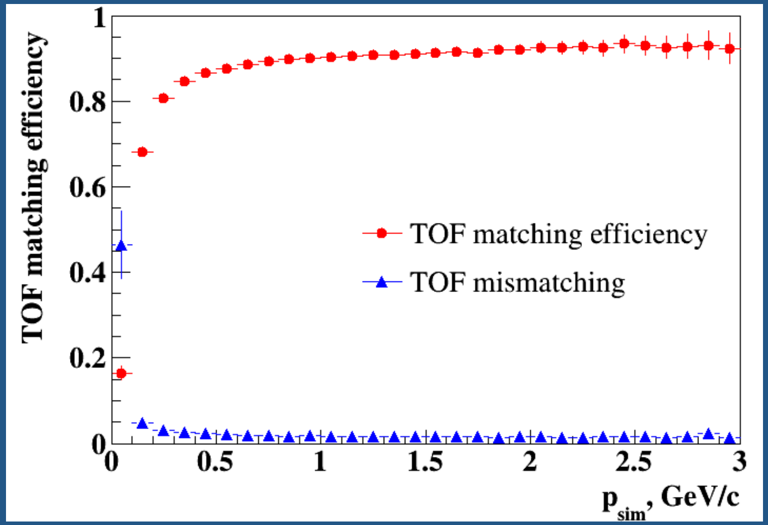


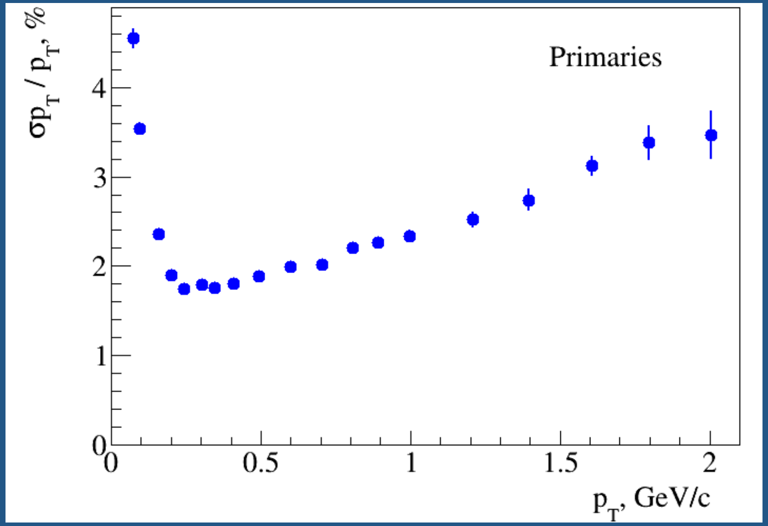
Realistic MPD simulation and reconstruction

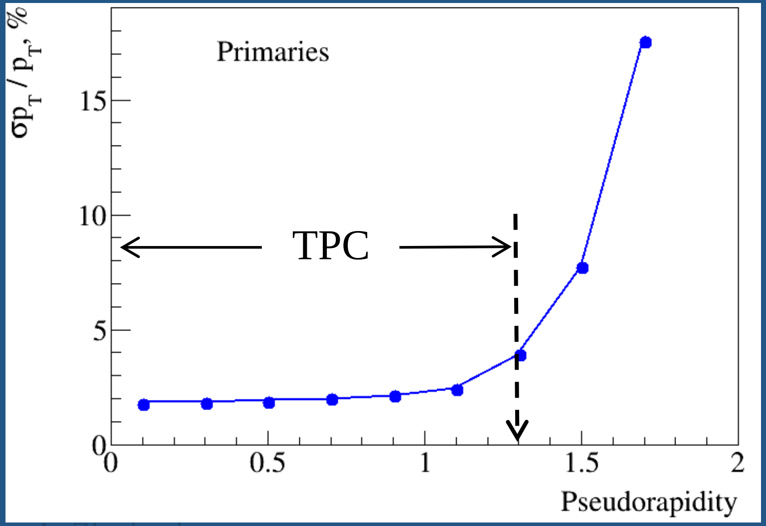
Based on realistic event simulation within the MPDRoot framework

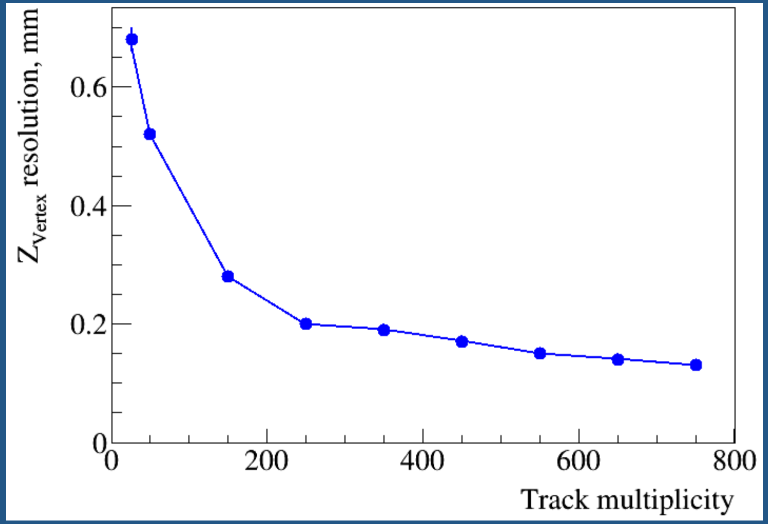






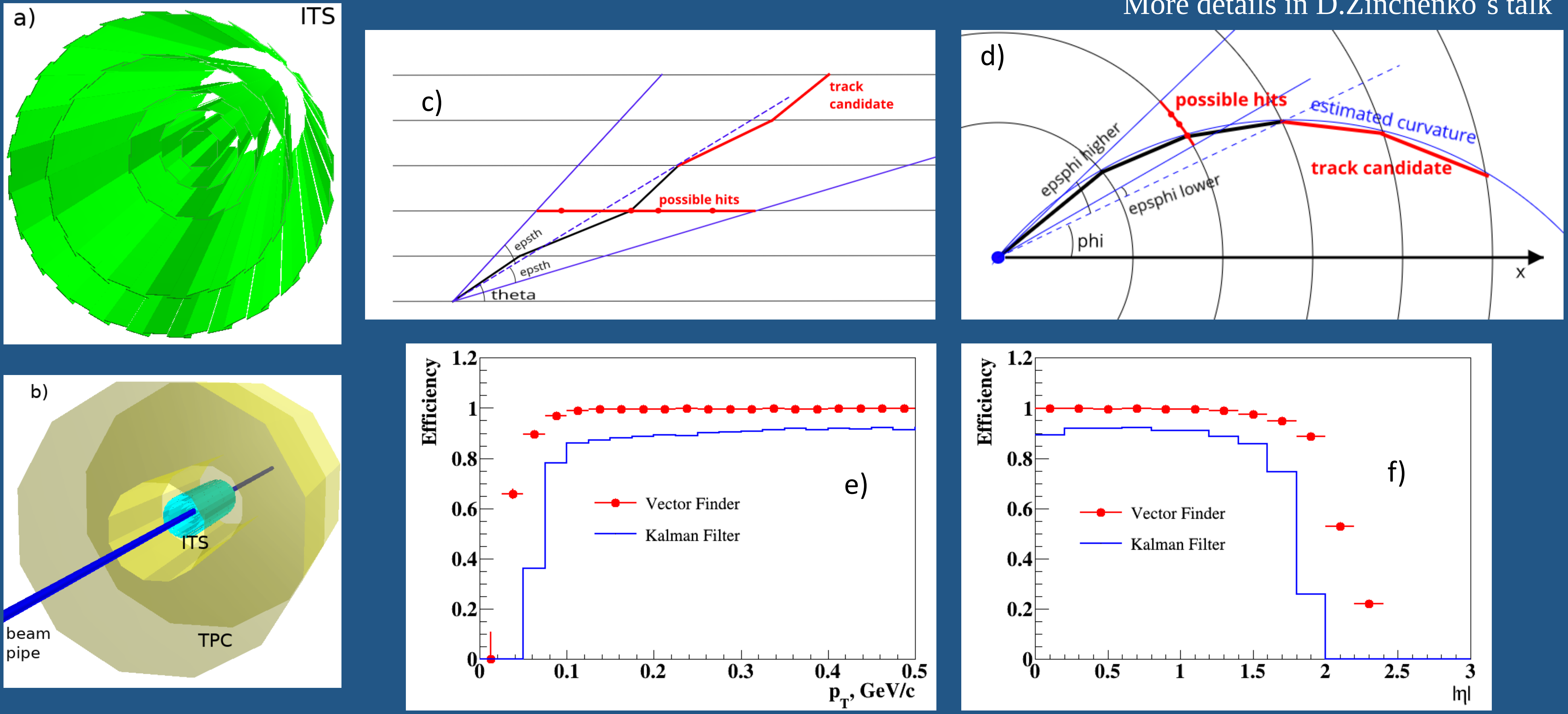




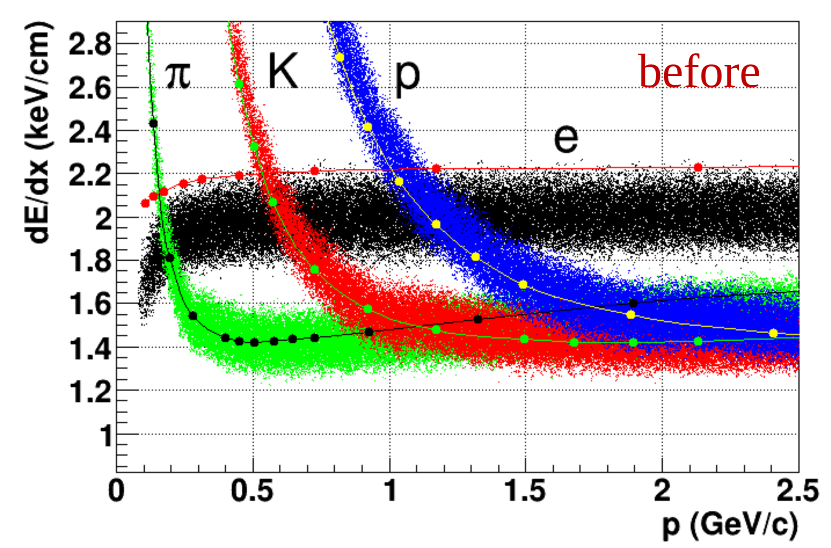


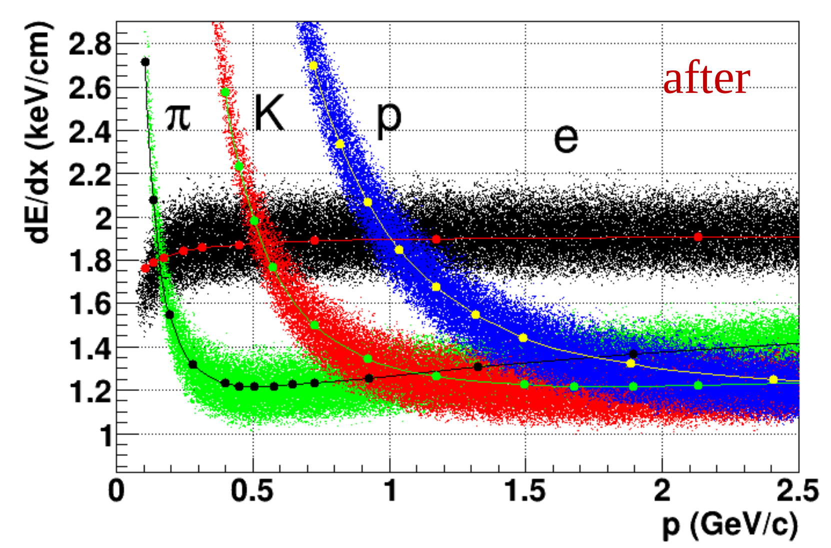
Inner Tracker performance

More details in D.Zinchenko`s talk



New *dE/dx* performance in TPC





More details in I.Rufanov`s talk

dE/dx vs momentum for TPC/MPD
Box generator (*e*, *π*, *K*, *p*);
Curves – STAR standard function
(Bicshel`s functions)
[NIM A558 (2006) 419-429]

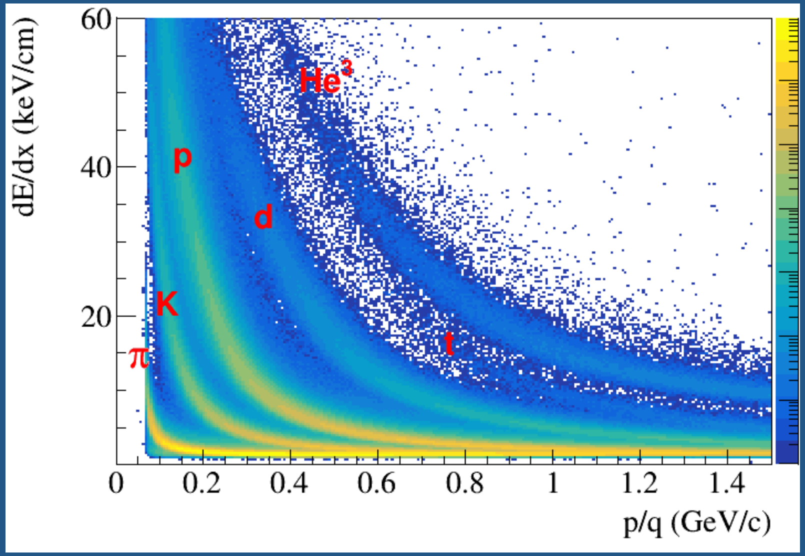
	ALICE	STAR	MPD
Gas	85% *Ne* mix	P10	P10
N rows x pitch (mm):			
Inner pads	64 x 7.5 mm	13 x 12 mm	26 x 12 mm
Outer pads	64 x 10 mm	32 x 20 mm	27 x 18 mm
Outer-2 pads	32 x 32 mm	–	–
P10 mixture – 90% *Ar*, 10% methane			

Data vs MC with old parameterization *dE/dx* in GEANT3:

- Essentially (~20%) underpredicts relativistic rise of the ionization energy loss as seen from comparison of pion and electron bands
- Overpredicts energy loss at low momentum (protons at *p*<1 GeV/c)
- Gives shifted momentum of intersections of electron and other particles bands
- Gives distorted input for realistic PID

New *dE/dx* parametrization (Garfield++) in GEANT gives a good agreement with STAR data

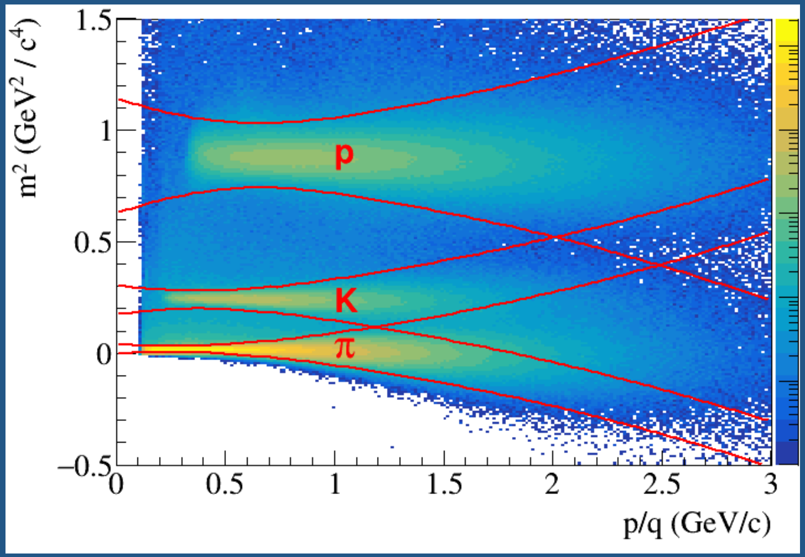
New PID performance in TPC & TOF

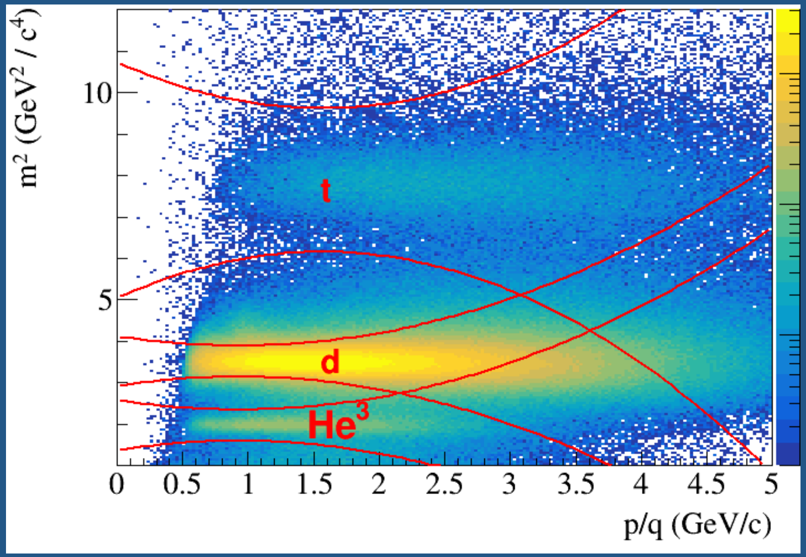


dE/dx in TPC vs momentum and
m^2 in TOF vs momentum

Selection criteria for events and tracks:

1. $|Z_{PV}| < 50$ cm
2. Primary particles
3. $N_{TPC\_hits} \geq 27$
4. $|\eta| < 1.3$





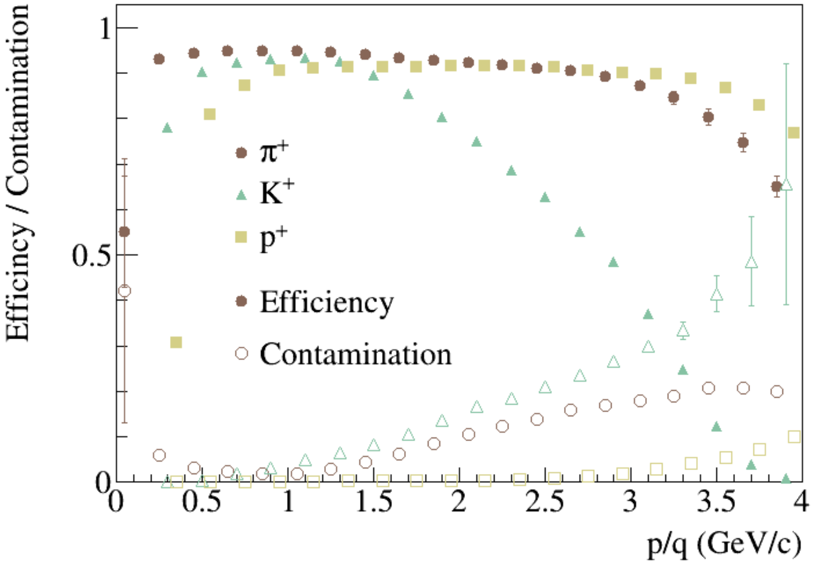
Data set:

PHQMD, *Bi*+*Bi* at
$\sqrt{s_{NN}}$ = 8.8 GeV

Mass square calculated using the measurements of momentum (*p*), time-of-flight (*T*) and trajectory length (*L*):

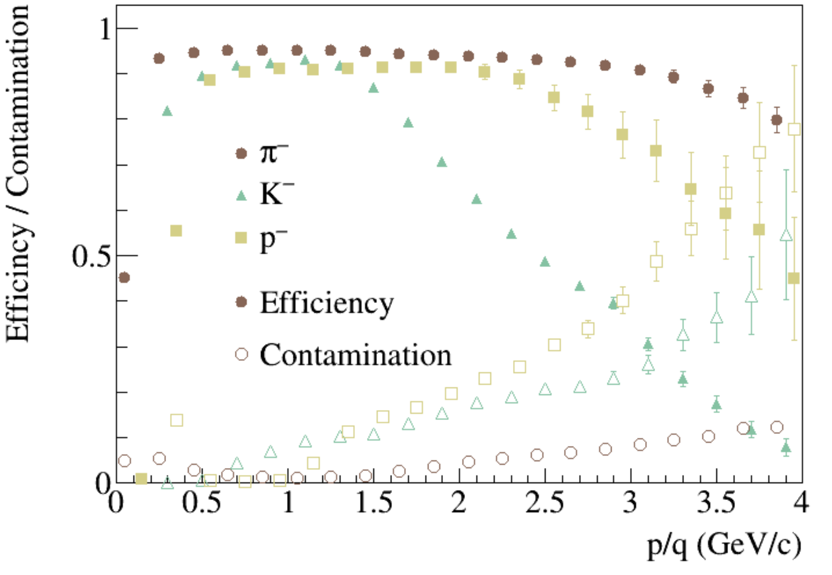
$$m^2 = p^2\left(\frac{c^2T^2}{L^2} - 1\right)$$

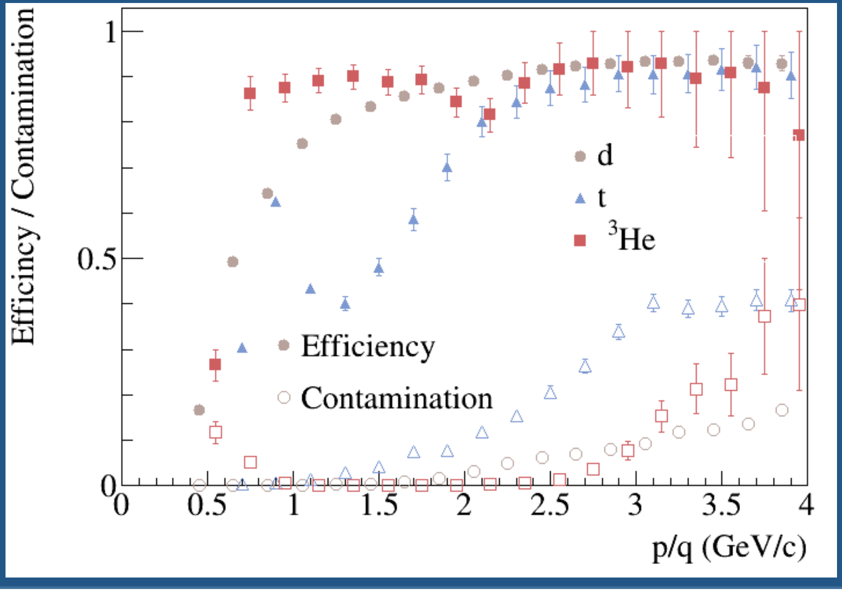
PID: Efficiency and Contamination



$$\text{Eff.} = \frac{\text{particles which are correctly identified}}{\text{all particles of a given species (PDG)}}$$

$$\text{Cont.} = \frac{\text{particles which are falsely identified}}{\text{all identified particles of a given species}}$$





Data set for hyperon simulation

- ✓ **Generators:** PHSD, *Au+Au* @ 11 GeV, min. bias, 8M events (~6 hours of running time at starting luminosity - 1/20 of design value)
- ✓ **Detectors:** start version of MPD with up-to-date TPC & TOF
- ✓ **Cluster / hit reconstruction:** precluster finder *(group of adjacent pixels in time bin – pad space*); hit finder *("peak-and-valley" algorithm either in time bin – pad space (for simple topologies) or in time-transverse coordinate pixel space after Bayesian unfolding (for more complicated topologies))*→ COG around local maxima
- ✓ **Track reconstruction:** two-pass Kalman filter with track seeding using outer hits (*1st pass*) or leftover inner hits (*2nd pass*)
- ✓ **Track acceptance criterion:** $|\eta| < 1.3$, $N_{hits} \geq 10$
- ✓ **Particle Identification:** *dE/dx* in TPC & m^2 in TOF
- ✓ **Vertex reconstruction:** Kalman filter based formalism working on MpdParticle objects

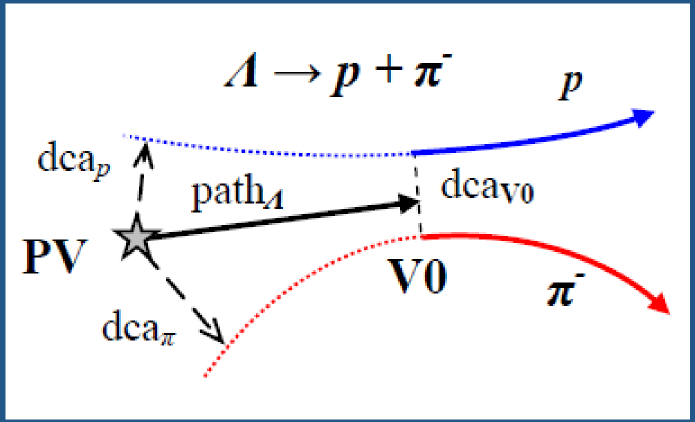
Analysis goals and Event topology

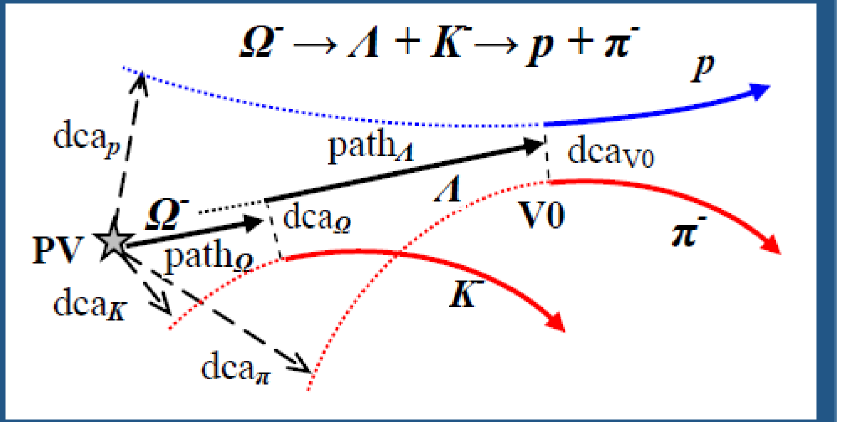
Goals:

- ✓ Secondary Vertex Reconstruction algorithms development for multistrangeness analysis
- ✓ Optimization of selection criteria in p_T and centrality
- ✓ Analysis macros for invariant spectra reconstruction
- ✓ Estimates of MPD efficiency and expected event rates

Analysis method:

Secondary Vertex Finding Technique





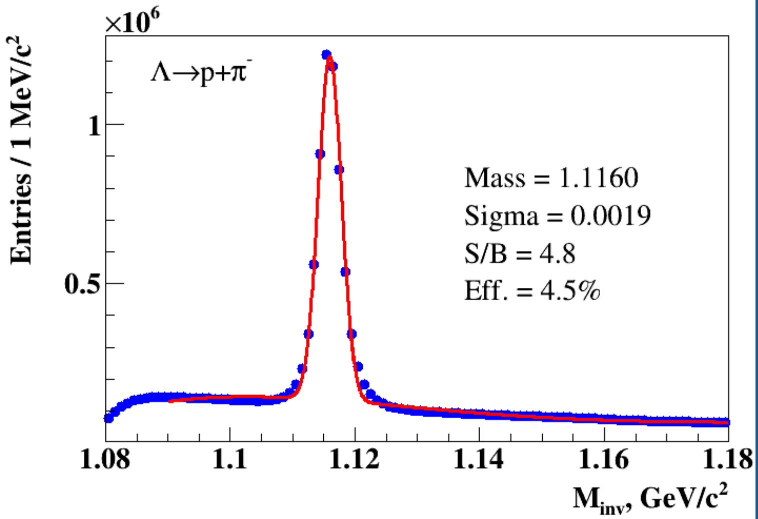
Event topology:

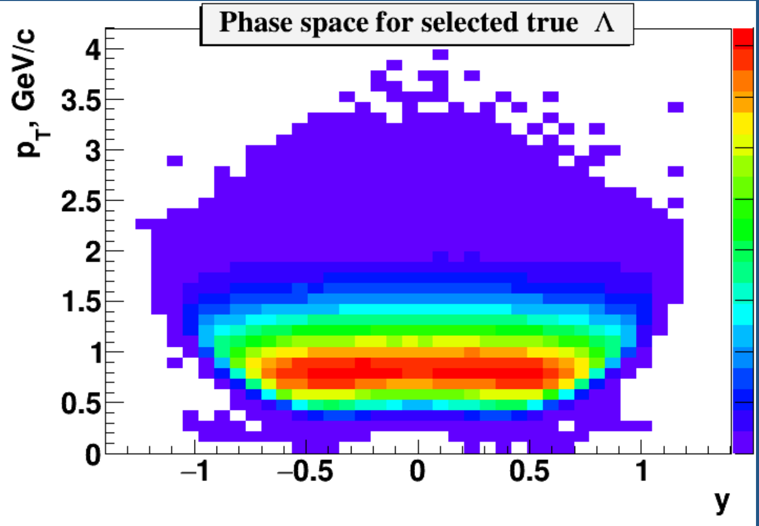
- PV – primary vertex
- V_0 – vertex of hyperon decay
- dca – distance of the closest approach
- path – decay length

Efficiency = (reconstructed, identified and selected *Hyp* at $|\eta| < 1.3$) / (all generated *Hyp* after GEANT, radius ≤ 50 cm from PV) – ***includes branching ratios, detector acceptance and reconstruction efficiency***

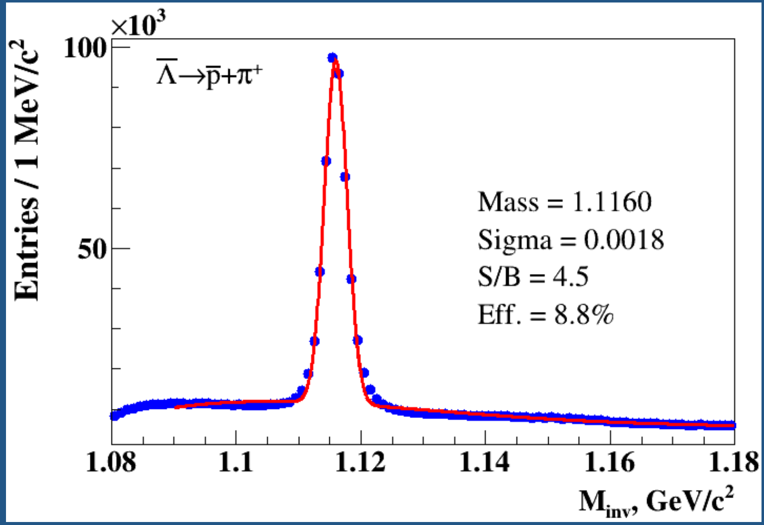
Λ, $\bar{\Lambda}$, Ξ^- reconstruction

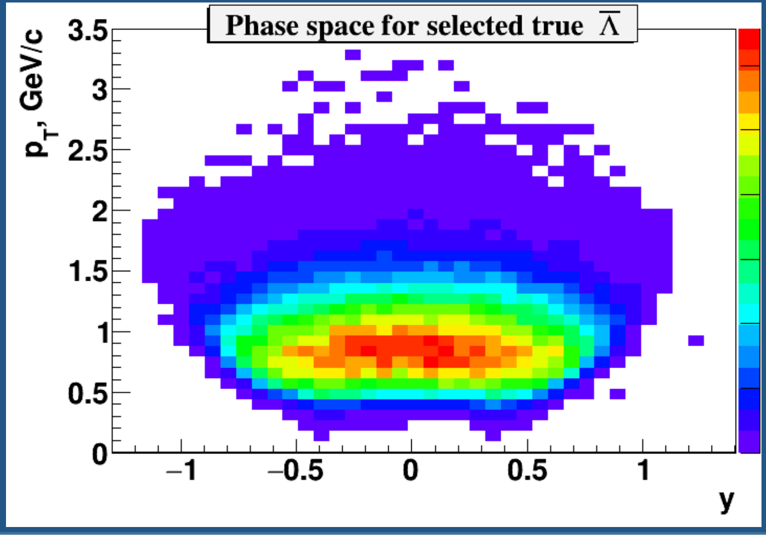
Eff. (for |*y*|<0.5) =10.4%



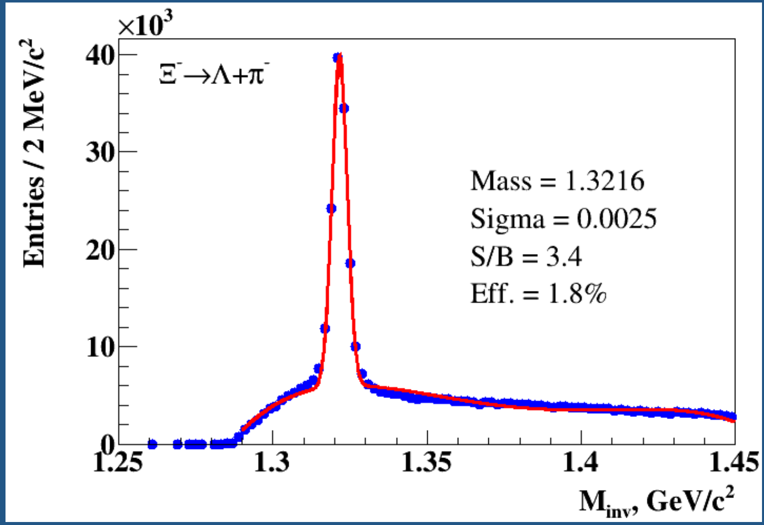


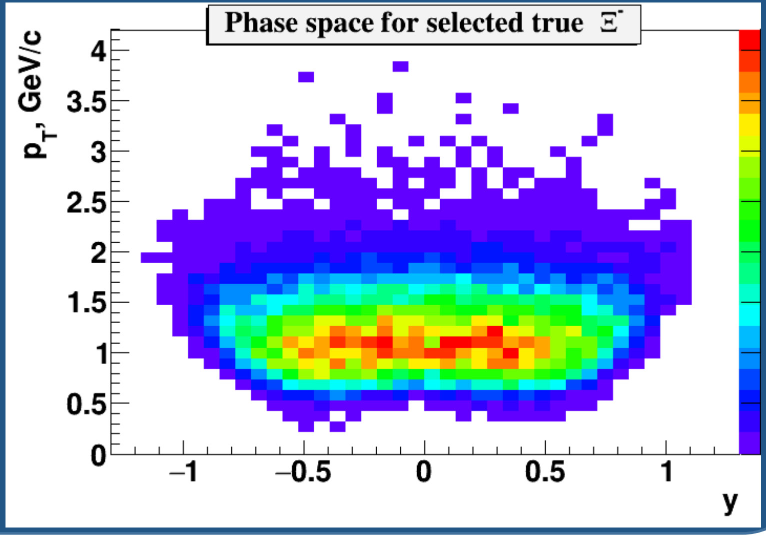
Eff. (for |*y*|<0.5) =14.1%





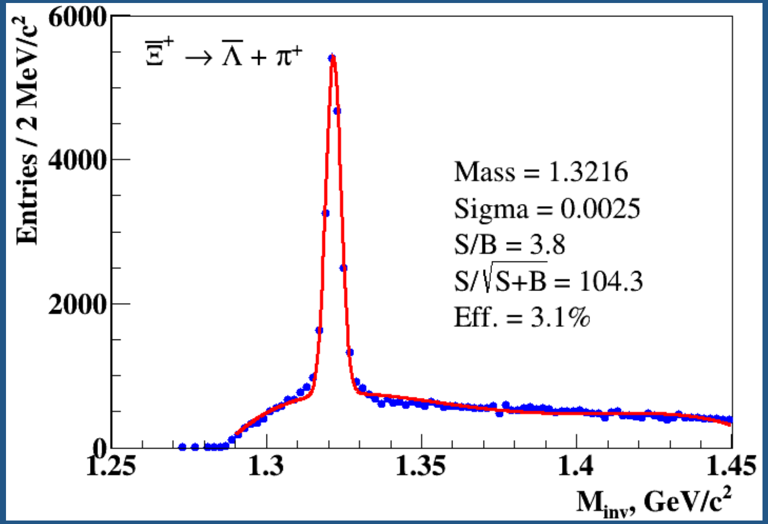
Eff. (for |*y*|<0.5) =3.6%

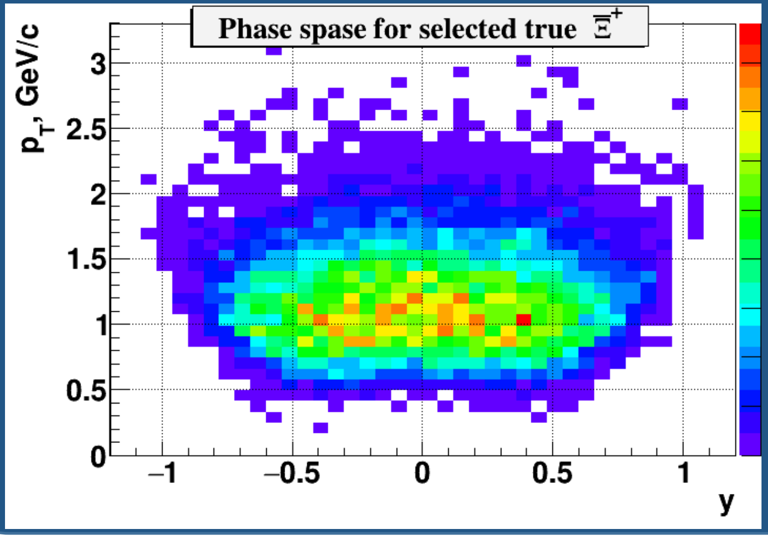




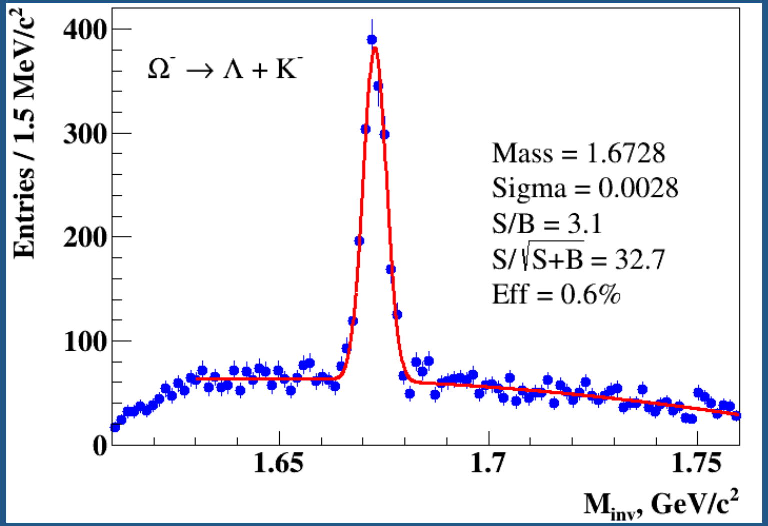
$\bar{\Xi}^+$, Ω^-, $\bar{\Omega}^+$ reconstruction

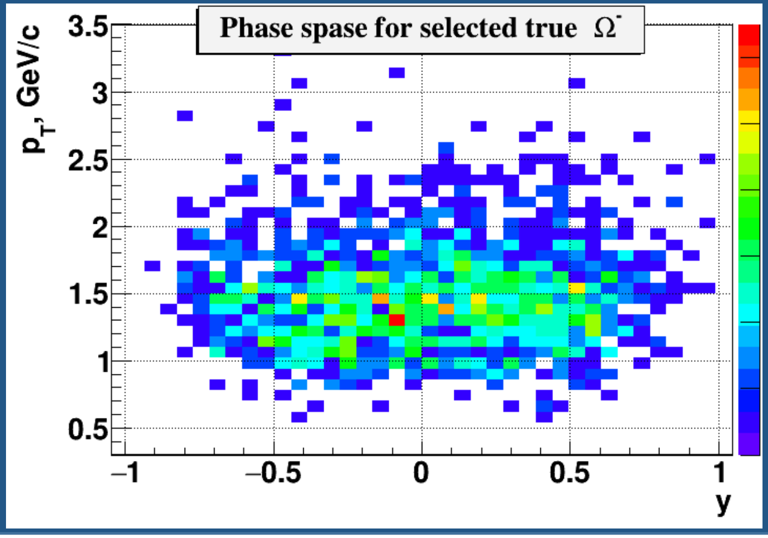
Eff. (for $|y|$<0.5) =4.7%



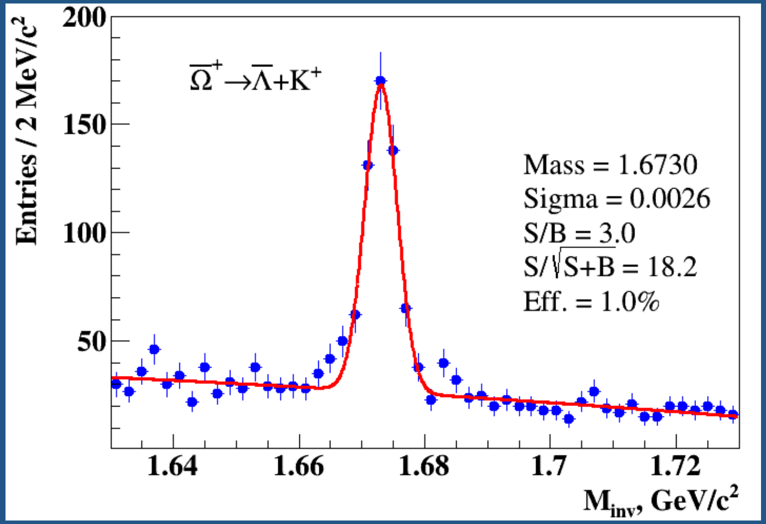


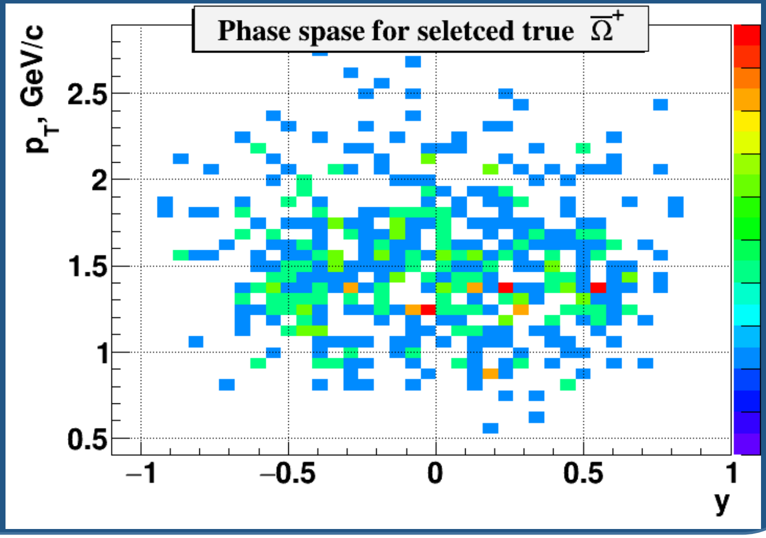
Eff. (for $|y|$<0.5) =1.1%





Eff. (for $|y|$<0.5) =1.5%

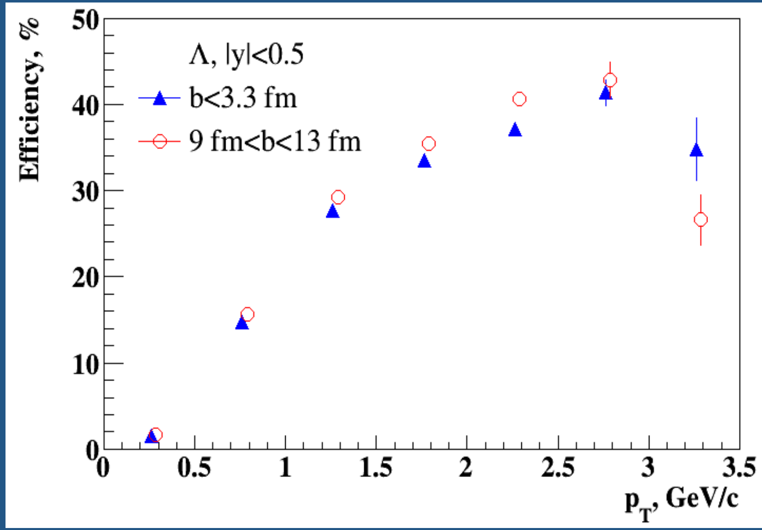


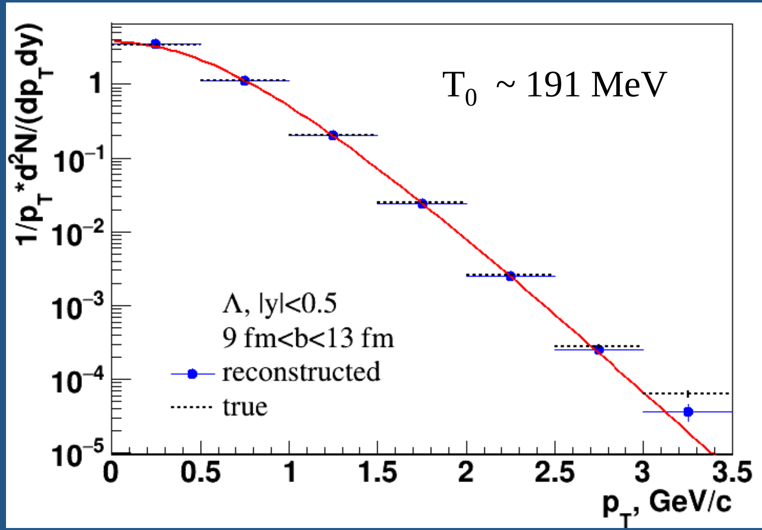


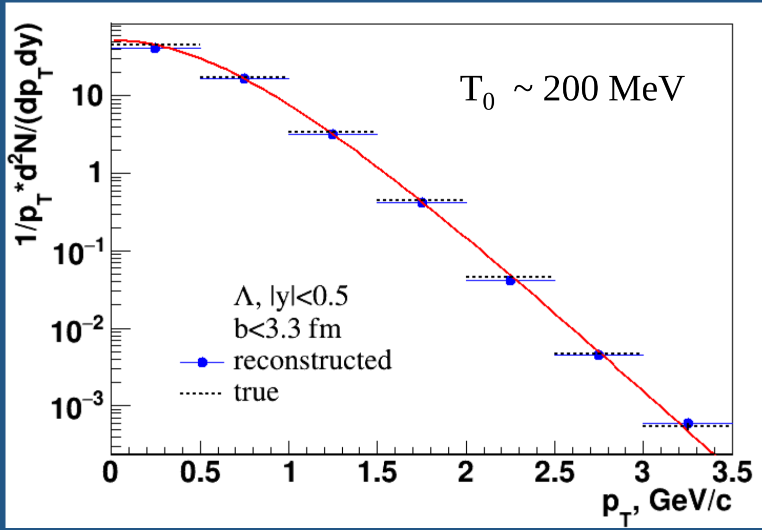
Λ & Ξ^- reconstruction: efficiency and p_T spectra

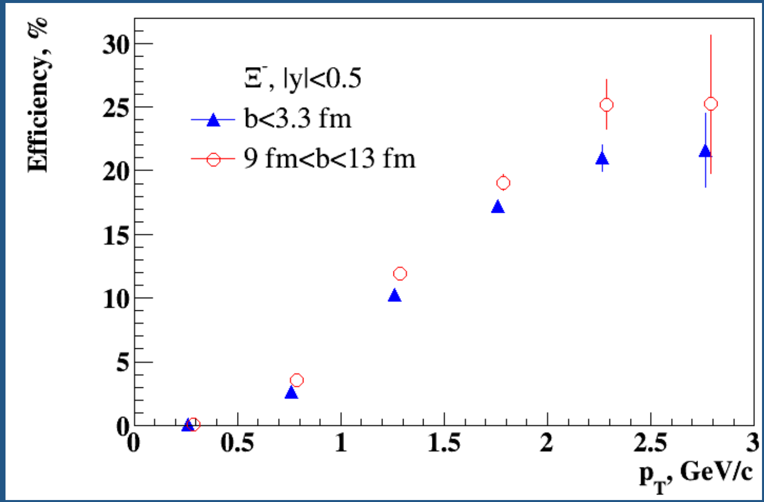
Efficiency of true *Hyp* in p_T and *b* bins for $|y|<0.5$: (reco & select *Hyp*) / (all gen *Hyp*)

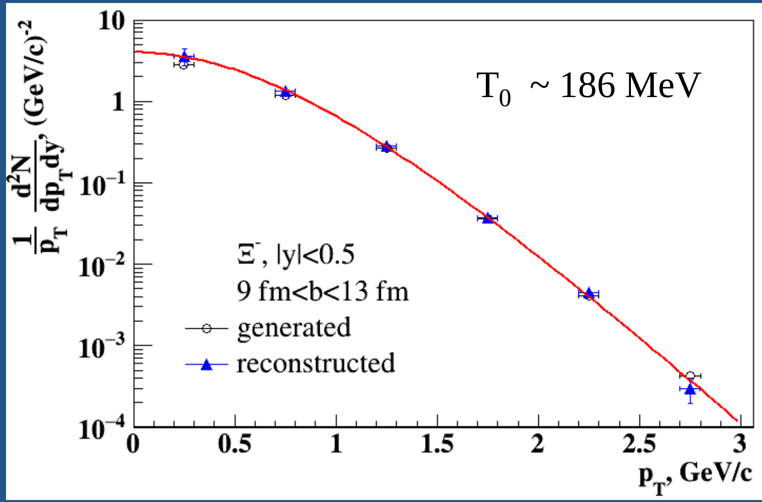
Reconstructed invariant p_T spectrum: fit of selected *Hyp* in each bin (Gauss ± 3σ) / Eff.

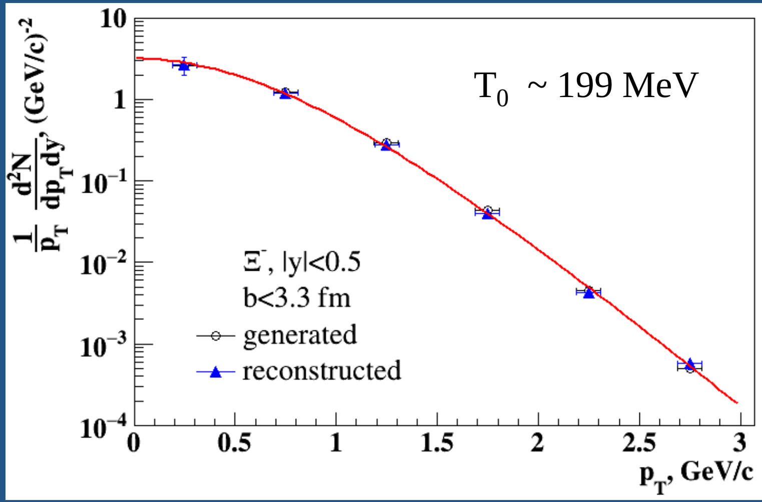








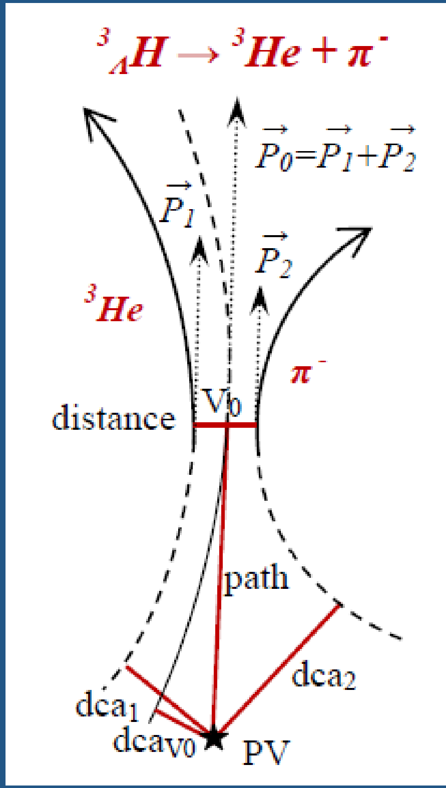




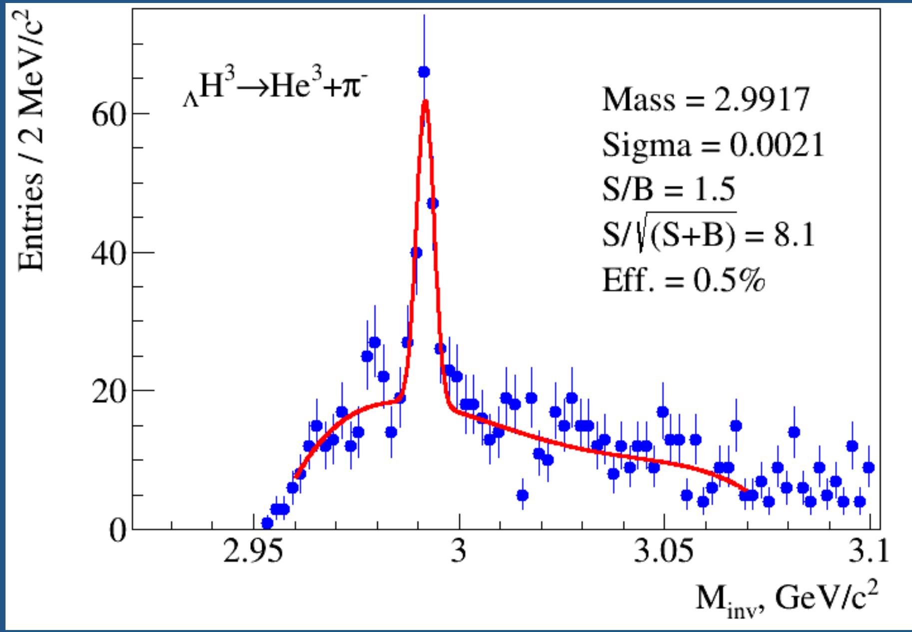
Data set for hypernuclei simulation

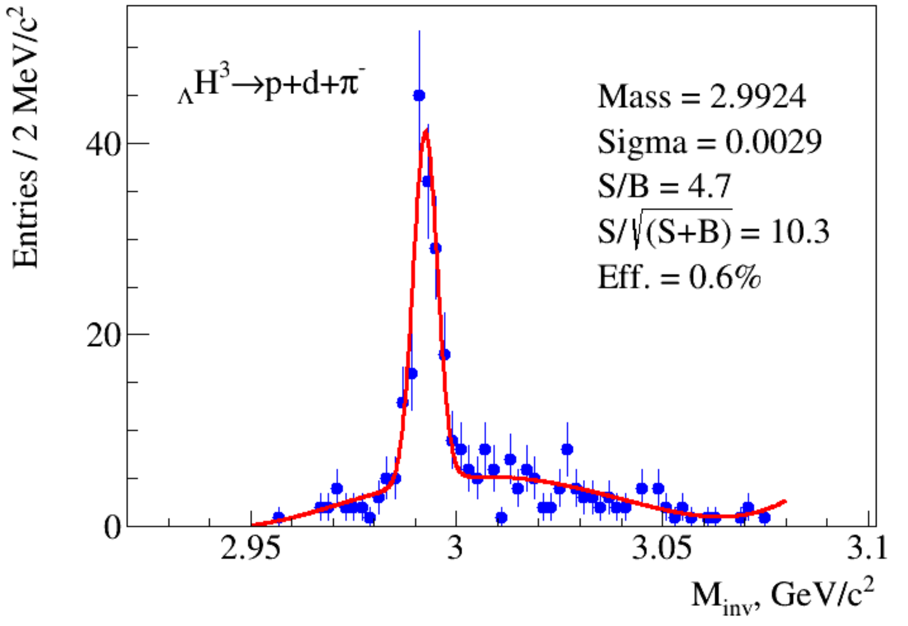
- **Generators:** DCM-QGSM, Au+Au @ 5 GeV, central, 0.9M events
- **Detectors:** start version of MPD with up-to-date TPC & TOF
- **Cluster / hit reconstruction:** precluster finder (*group of adjacent pixels in time bin – pad space*); hit finder (*"peak-and-valley" algorithm either in time bin – pad space (for simple topologies) or in time-transverse coordinate pixel space after Bayesian unfolding (for more complicated topologies)*) $\rightarrow$ COG around local maxima
- **Track reconstruction:** two-pass Kalman filter with track seeding using outer hits (*1st pass*) or leftover inner hits (*2nd pass*)
- **Track acceptance criterion:** $|\eta| < 1.3$, $N_{hits} \geq 10$
- **NEW energy loss** simulation in gas TPC: Garfield++ parameterization in GEANT3
- **NEW PID:** dE/dx in TPC & m^2 in TOF
- **Vertex reconstruction:** Kalman filter based formalism working on MpdParticle objects

Hypernuclei reconstruction



More details in J.Drnoyan`s talk





Event topology:

- ✓ PV – primary vertex
- ✓ V_0 – vertex of hyperon decay
- ✓ dca – distance of the closest approach
- ✓ path – decay length

Decay channel	Branching ratio	Decay channel	Branching ratio
$\boldsymbol{\pi^- + {}^3He}$	**24.7%**	$\pi^- + p + p + n$	1.5%
$\pi^0 + {}^3H$	12.4%	$\pi^0 + n + n + p$	0.8%
$\boldsymbol{\pi^- + p + d}$	**36.7%**	$d + n$	0.2%
$\pi^0 + n + d$	18.4%	$p + n + n$	1.5%

Summary and outlook

- Current status of the event reconstruction activity in MPD has been presented and performance level achieved shown.
- Some work is still in progress – track reconstruction in ITS for the upgrade project and TPC energy loss and response simulation and cluster / hit reconstruction.
- Future MPD commissioning run will certainly have an impact on this activity.

Thank you for attention!