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Strangeness production study at NICA/MPD and BM@N

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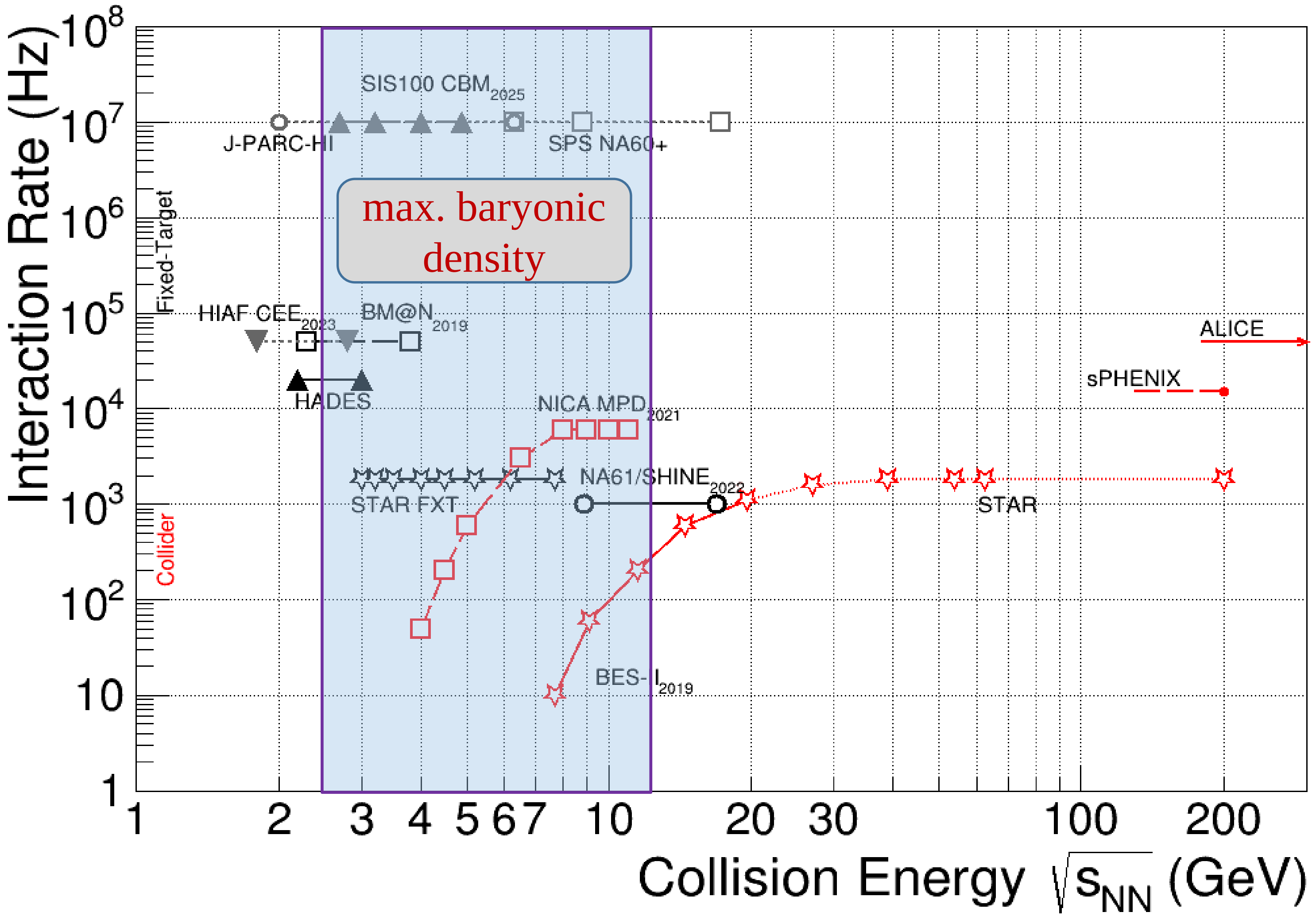
On behalf of the MPD and the BM@N collaborations

Outline

- ✓ NICA Project: *niche, tasks and observables*
- ✓ NICA Complex: *parameters*
- ✓ MPD detector performance: *geometry, track reconstruction, particle identification*
- ✓ Hyperon simulation at MPD
- ✓ BM@N detector: *geometry, track reconstruction*
- ✓ Hyperon simulation at BM@N
- ✓ Summary

Heavy Ion Collision Experiments



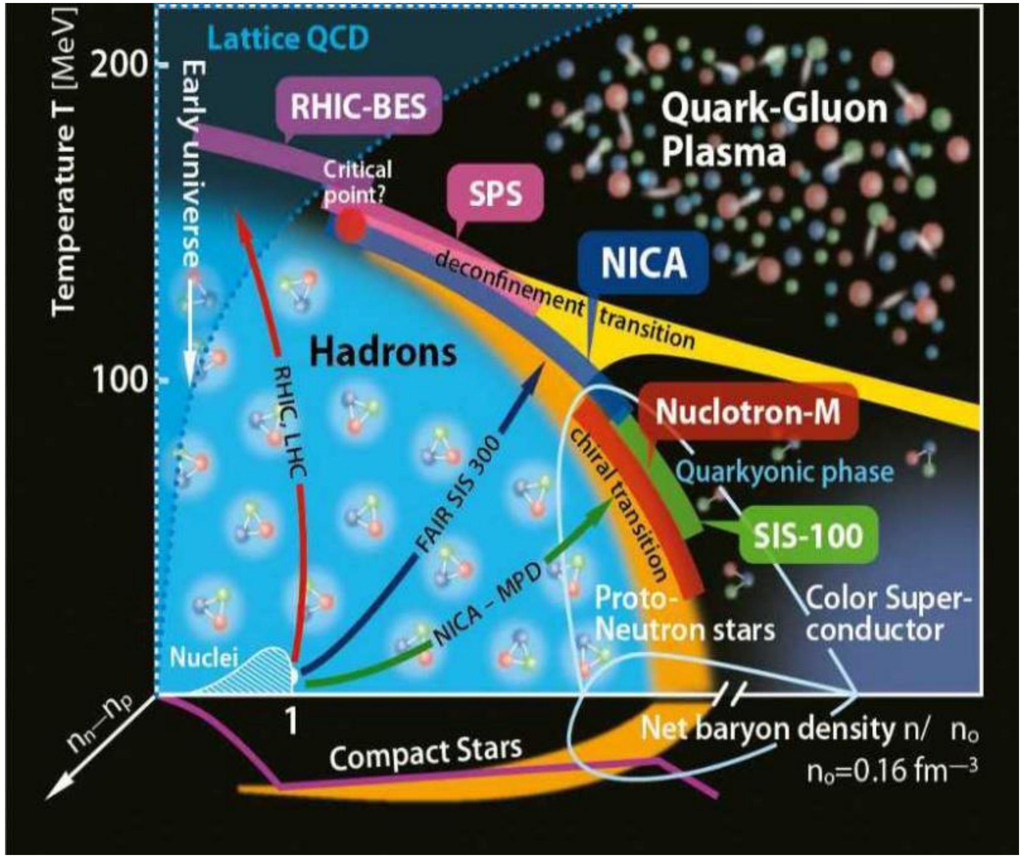
Experiments at the NICA complex:

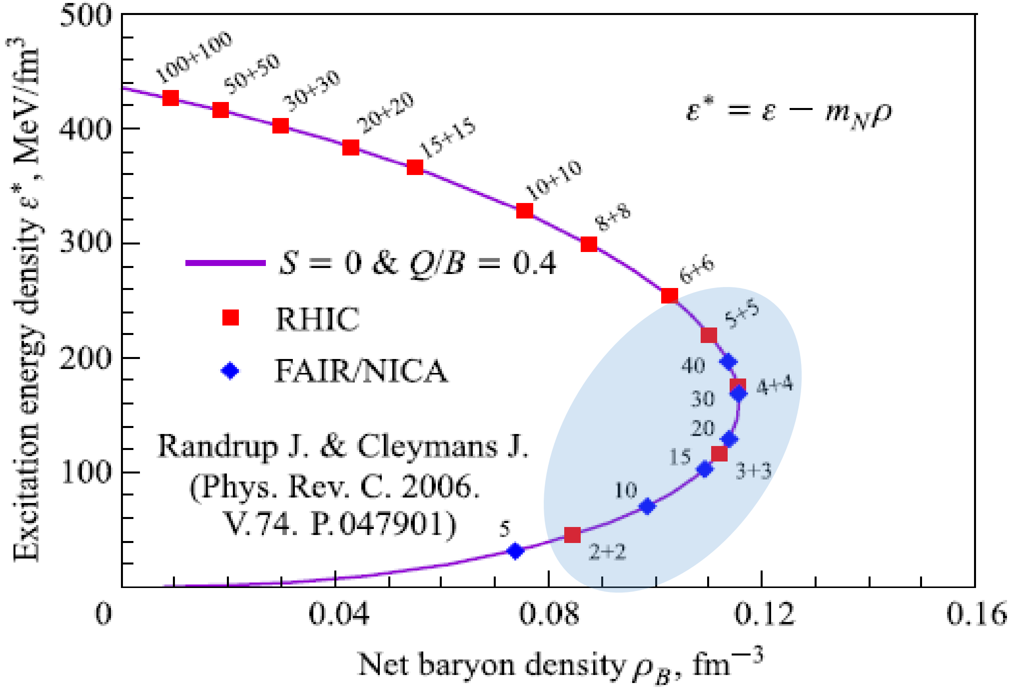
BM@N: $\sqrt{s_{NN}}$ = 2.3 – 3.3 GeV
MPD: $\sqrt{s_{NN}}$ = 4 – 11 GeV

MPD and BM@N competitors:

- ✓ HADES BES (SIS)
  Au+Au @ $\sqrt{s_{NN}}$ = 2.42 GeV
  Ag+Ag @ $\sqrt{s_{NN}}$ = 2.42 GeV, 2.55 GeV
- ✓ STAR BES (RHIC)
  Au+Au @ $\sqrt{s_{NN}}$ = 3 – 200 GeV
- ✓ Future experiment - CBM (FAIR)
  Au+Au @ $\sqrt{s_{NN}}$ ~ 2.7 – 4.9 GeV

NICA niche in HIC and Strangeness production





- ✓ NICA (μB = [320-850] MeV) - highest net baryon density
- ✓ Non-trivial energy dependence of multiple probes: strangeness production, flow, hyperon polarization
- ✓ High luminosity guarantees sufficient event rate for rare probes (hypernuclei and multistrangeness)

- ✓ 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?)

NICA Complex in Dubna

NICA parameters:

2 Interaction points: MPD and SPD
Beams: from p to $^{197}Au^{79+}$
Collision energy: $\sqrt{s_{NN}}$ = 4 – 11 GeV (nuclei)
Luminosity: 10^{27} $cm^{-2}s^{-1}$ (Au), 10^{32} $cm^{-2}s^{-1}$ (p)

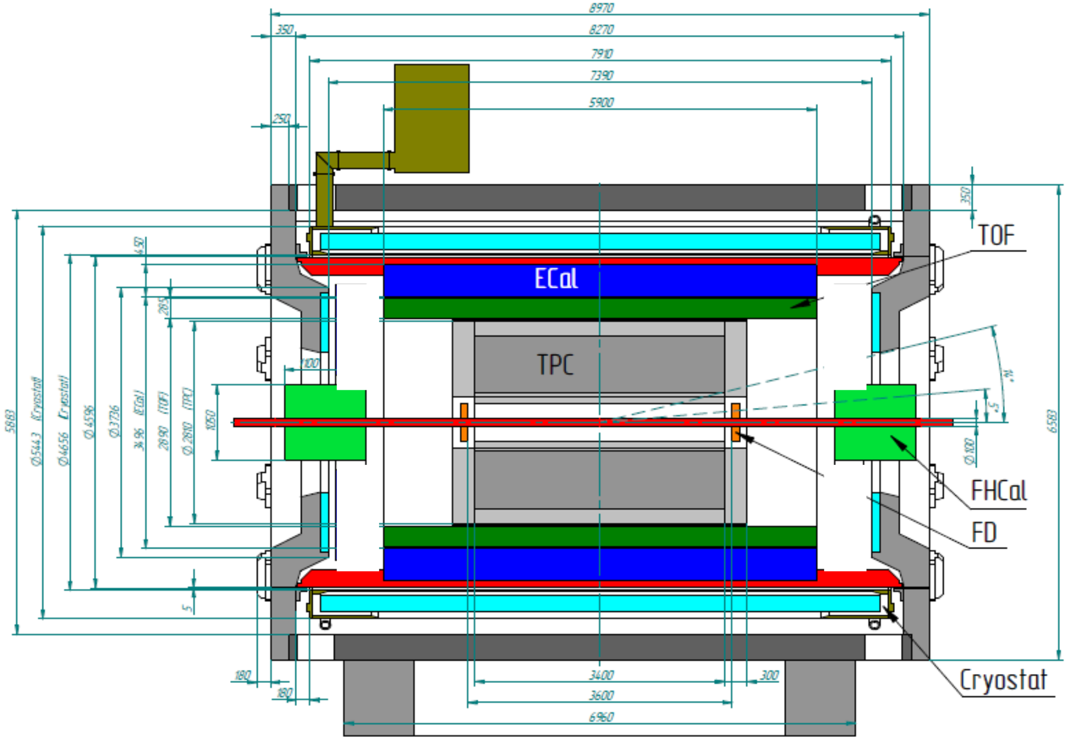
Fixed target: BM@N
Beams: from p to $^{197}Au^{79+}$
Collision energy: $\sqrt{s_{NN}}$ = 2.3 – 3.3 GeV
Intensity: ~few 10^6 /s

- ✓ New flagship project at JINR (Dubna)
- ✓ Based on the technological development of the Nuclotron facility
- ✓ Optimal usage of the existing infrastructure
- ✓ Modern facility incorporating new technological concepts

Multi-Purpose Detector at NICA

- ✓ Hermeticity, homogenous acceptance: 2π in azimuthal angle
- ✓ Highly efficient 3-D track reconstruction ($|\eta|<1.8$), 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

MPD Collaboration:
10 Countries
> **450** participants
31 Institutes and JINR



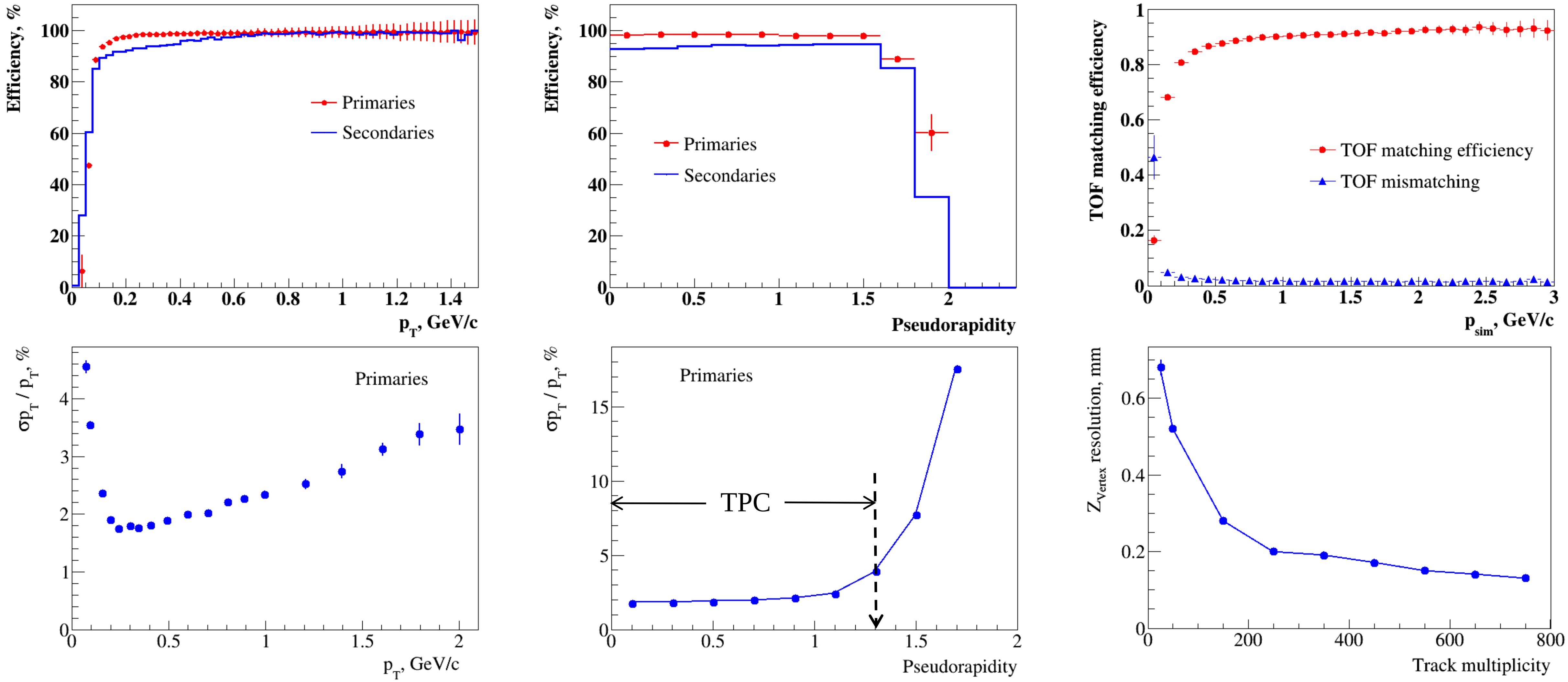
MPD at Stage 1:

Magnet: 0.5 T superconductor
Tracking: TPC
Particle ID: TOF, ECal, TPC
T0, Triggering: FD
Centrality, Event plane: FHCal

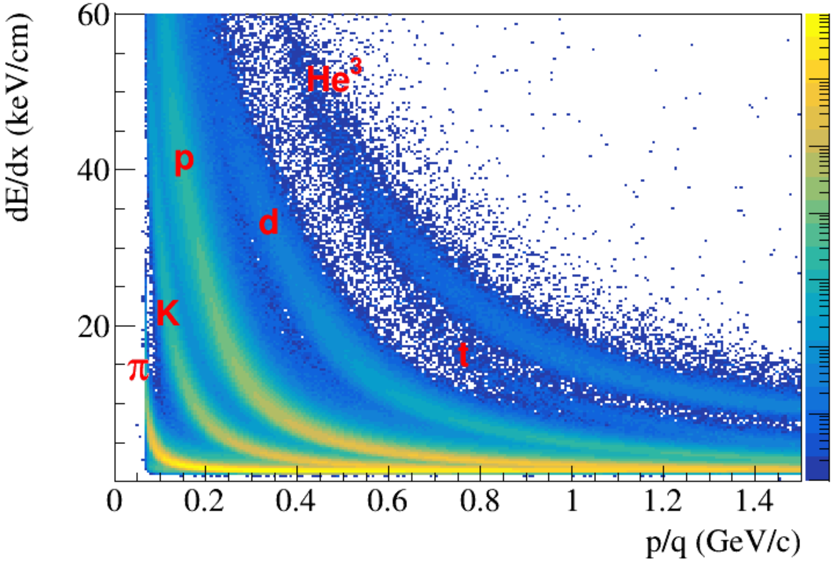
- ✓ TPC tracking: $|\eta| < 1.6$ ($N_{hits} > 15$)
- ✓ TOF coverage: $|\eta| < 1.4$
- ✓ PID: combined $|\eta| < 1.4$, $0.1 < p < 3$ GeV/c limited in $1.4 < |\eta| < 1.6$ (*dE/dx* only)

MPD event simulation and reconstruction

Based on realistic event simulation within the MPDRoot framework



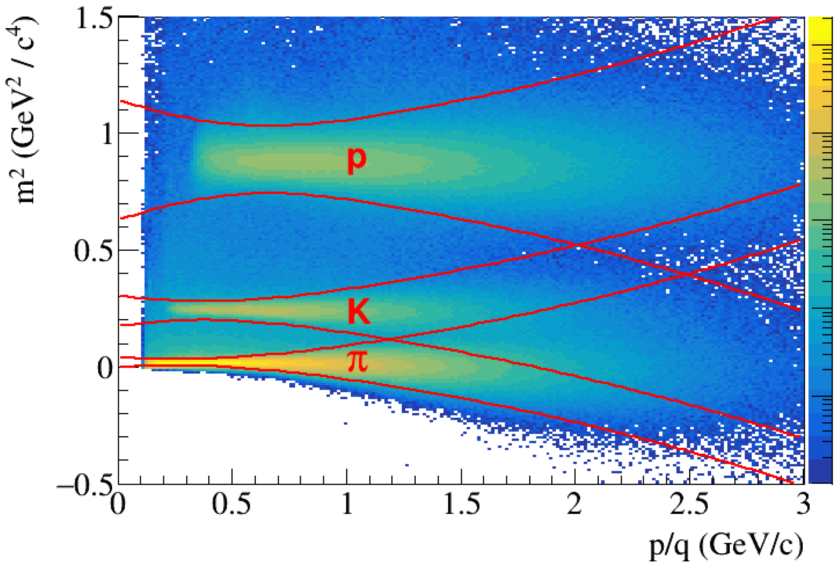
PID performance in TPC & TOF

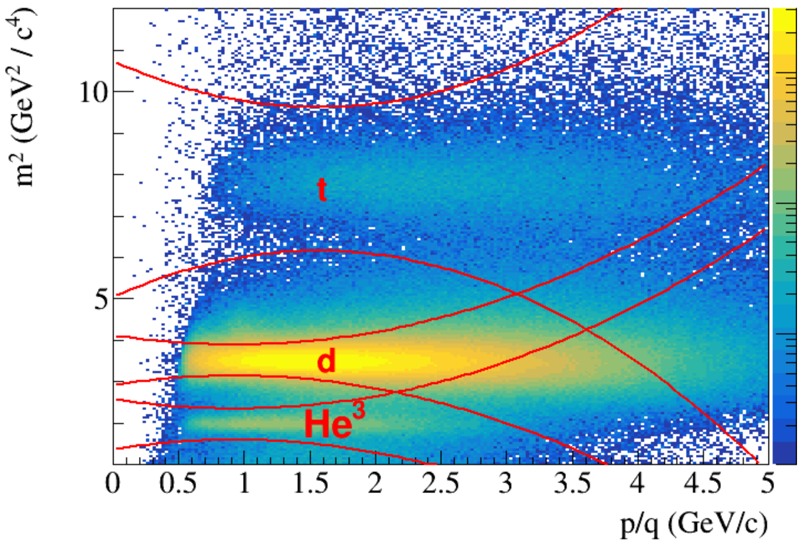


dE/dx in TPC vs momentum and m^2 in TOF vs momentum

Selection criteria for events and tracks:

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

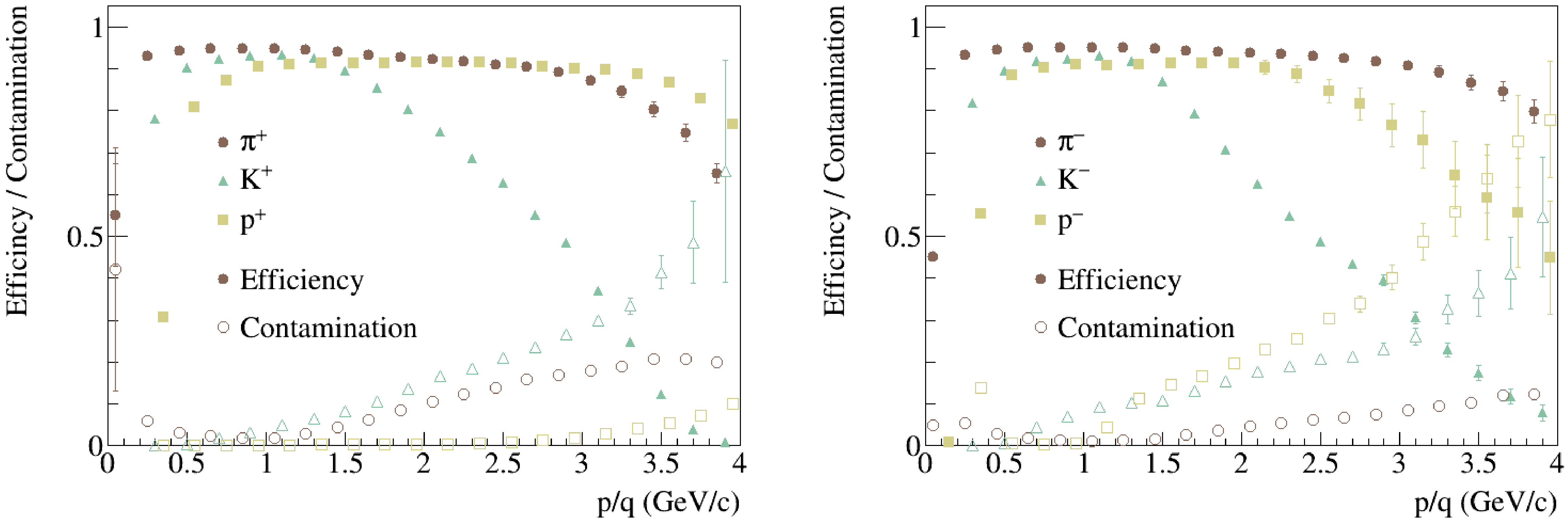




Mass square calculated using the measurements of momentum (p), time-of-flight (T) and trajectory length (L):

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

PID: Efficiency and Contamination



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

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

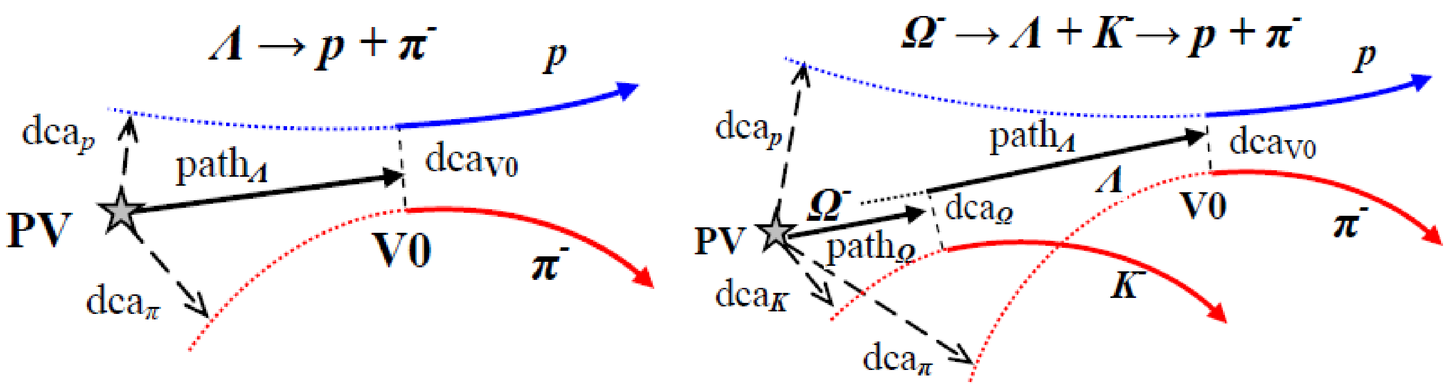
Data set

- ✓ **Generator:** PHSD, Au+Au @ 11 GeV, min. bias, 8M events (~6 hours of running time at starting luminosity - 1/20 of design value)
- ✓ **Detectors:** TPC and 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:** $|\eta| < 1.3$, $N_{TPC\_hits} \geq 10$ (for reconstructed tracks)
- ✓ **Particle Identification:** *dE/dx* in TPC & m^2 in TOF, $N_{TPC\_hits} \geq 20$ (for identified tracks)
- ✓ **Vertex reconstruction:** Kalman filter based formalism working on MpdParticle objects

Goals of Hyperons analysis. 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
- ✓ Topological Cuts Method vs Machine Learning

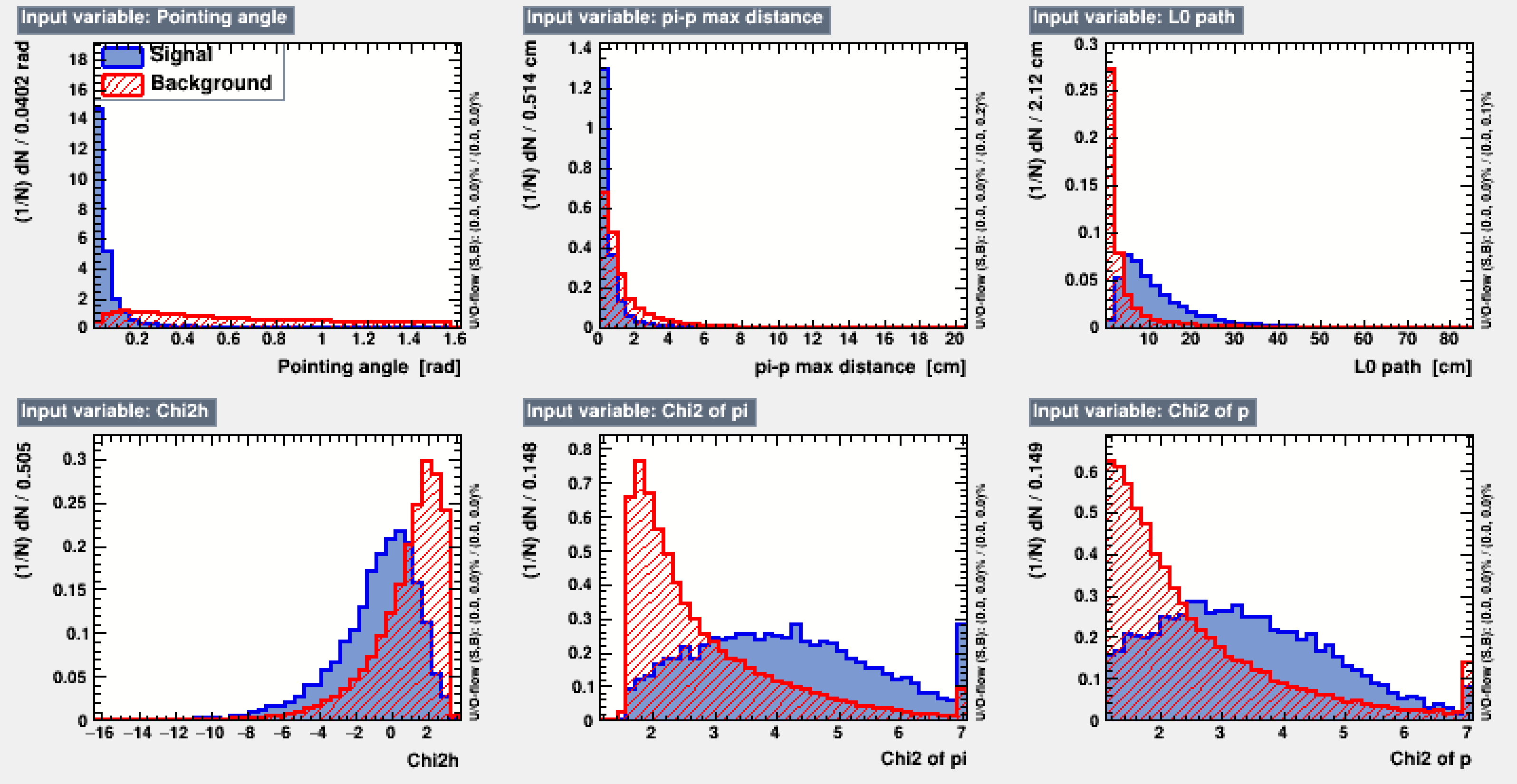


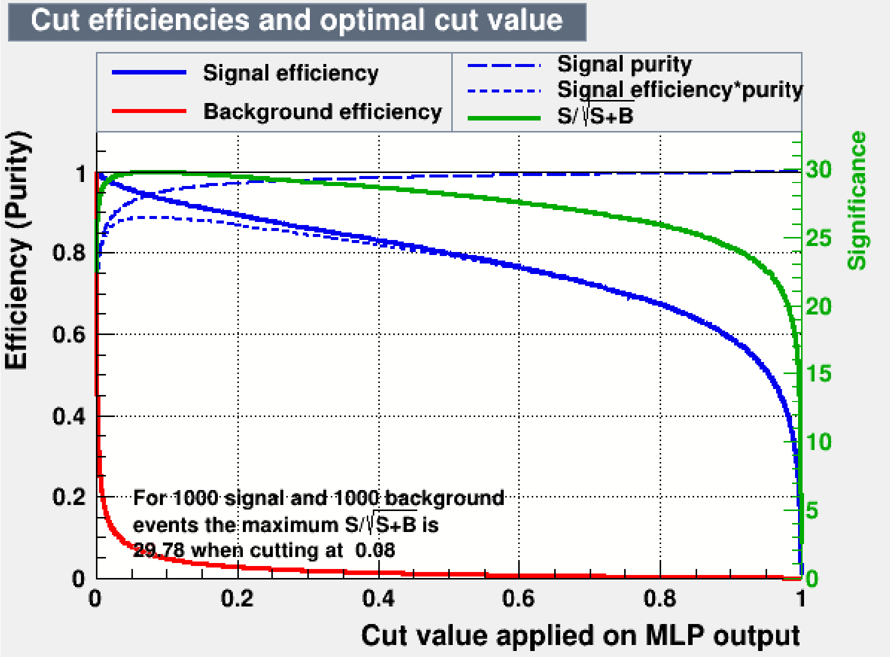
Event topology:

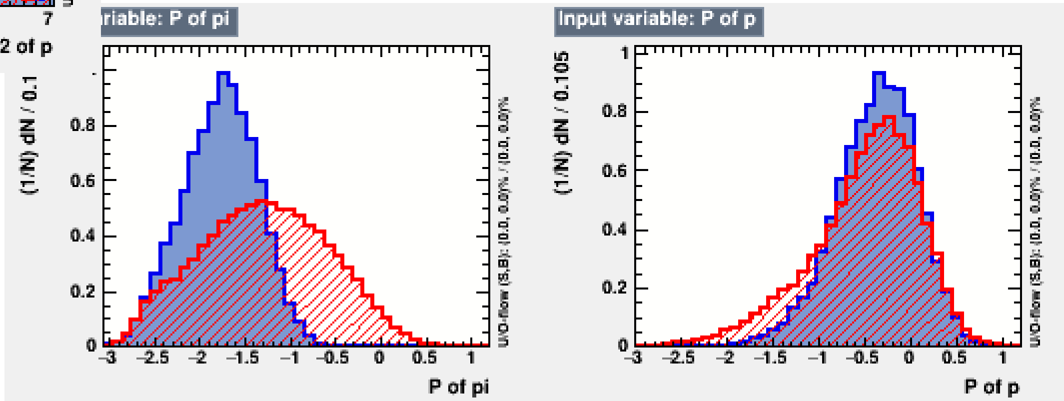
PV – primary vertex
V0 – vertex of hyperon decay
dca – distance of the closest approach
path – decay length

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***

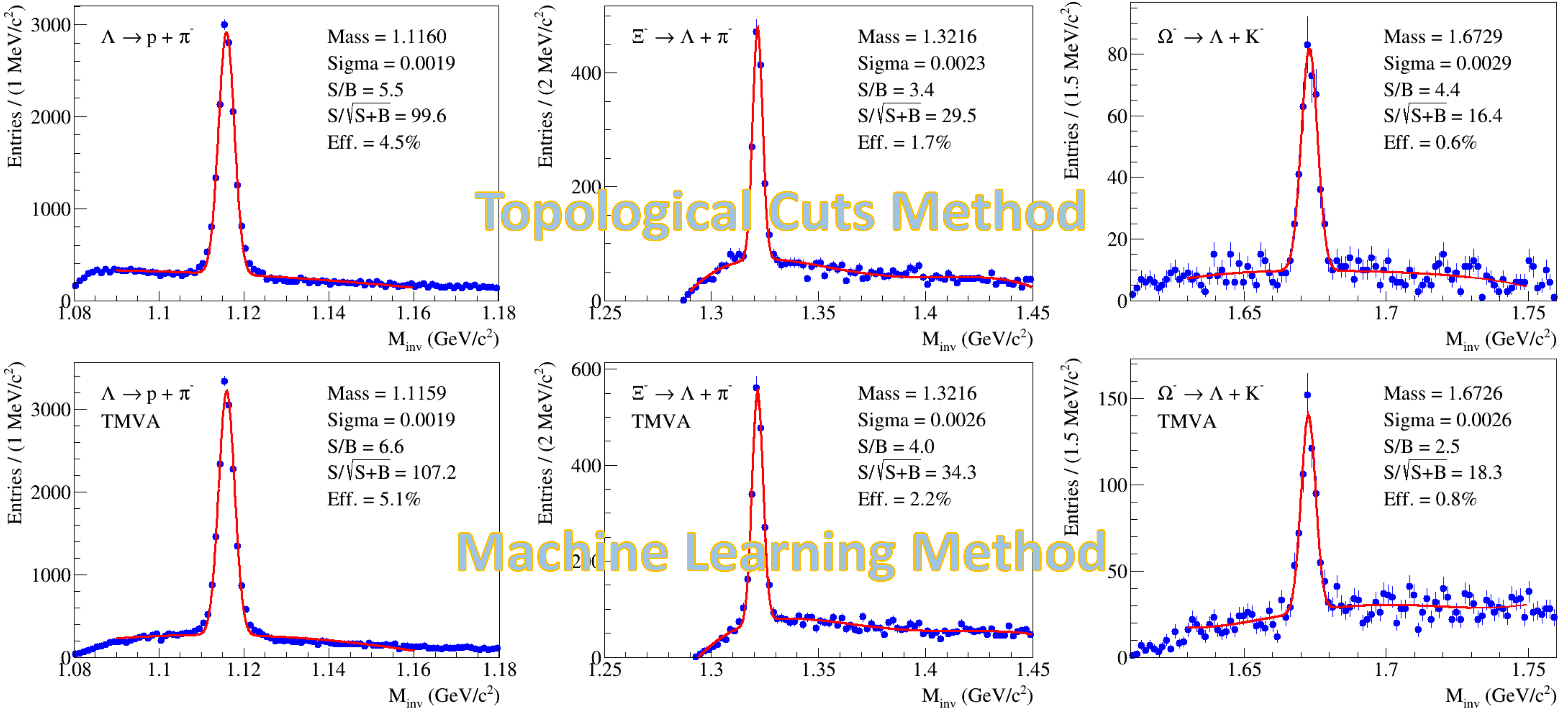
Λ reconstruction: TMVA method



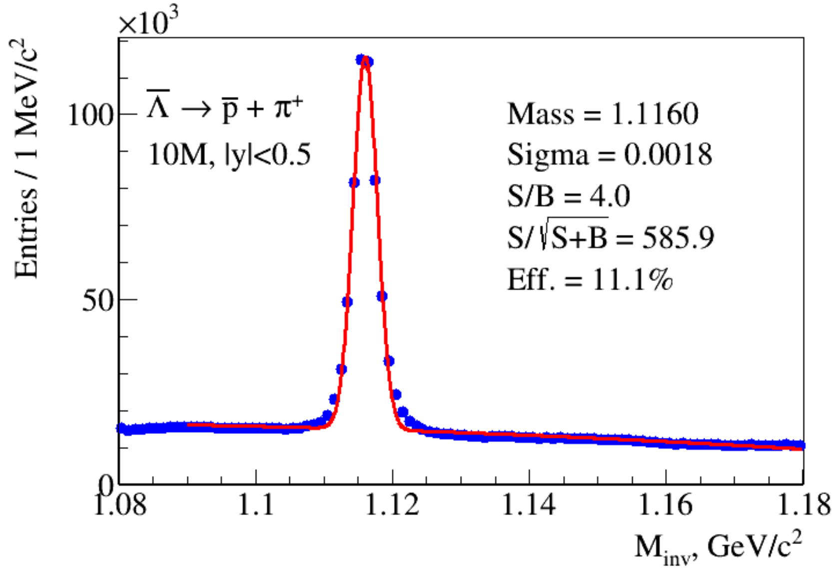


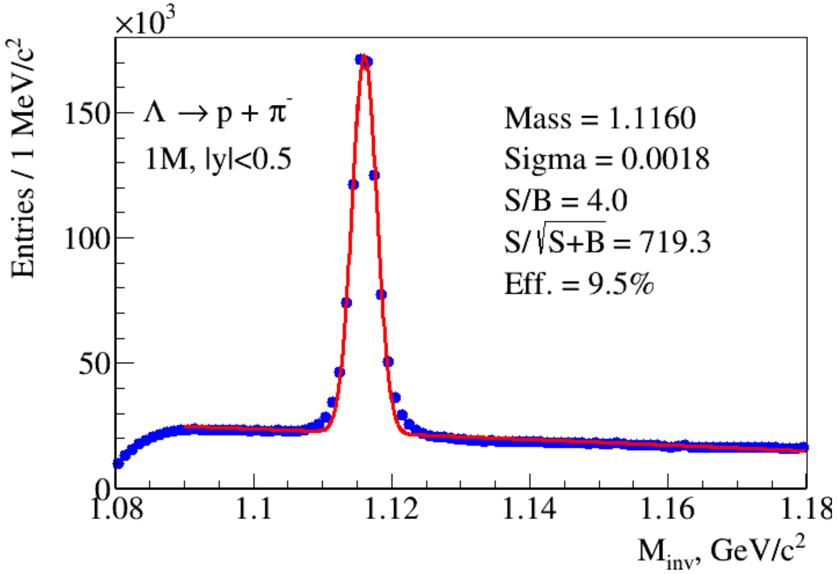


Hyperon reconstruction: TC vs TMVA



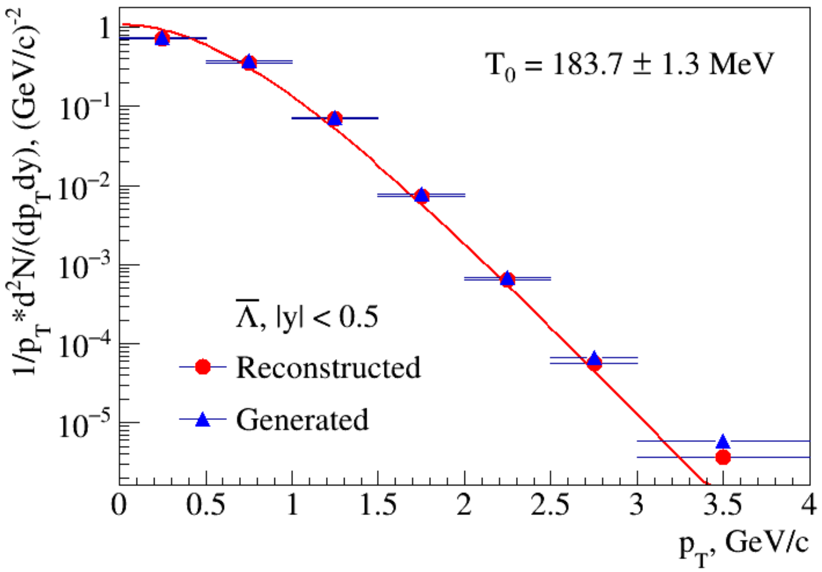
Hyperon reconstruction

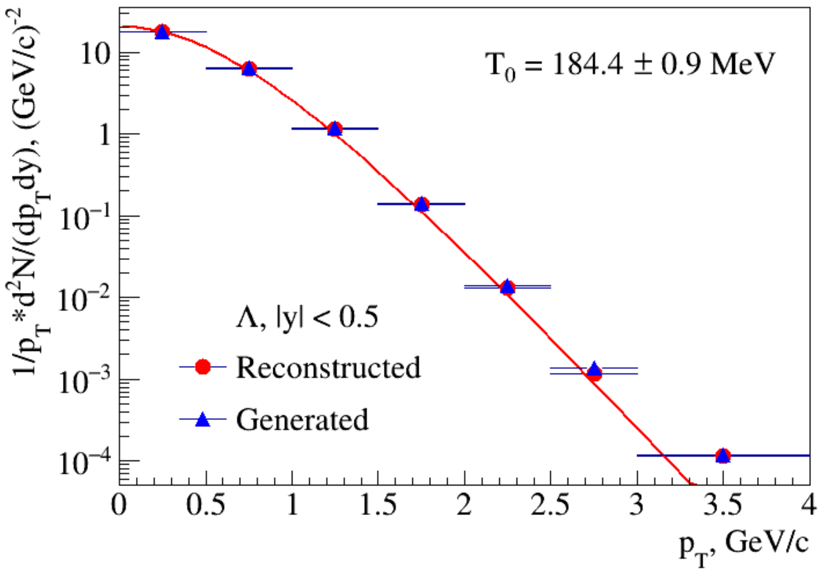


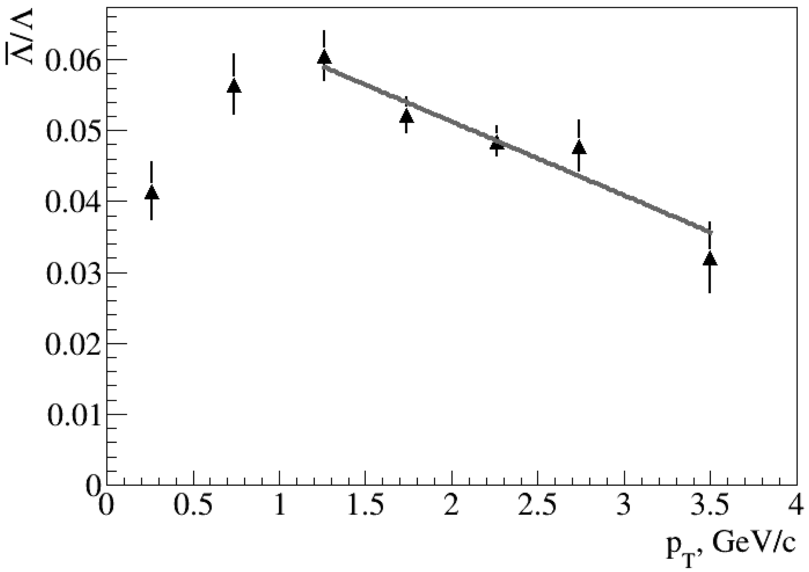


PHQMD, Bi+Bi @ 9 GeV, 40M events, |y|<0.5

Topological Cuts Method

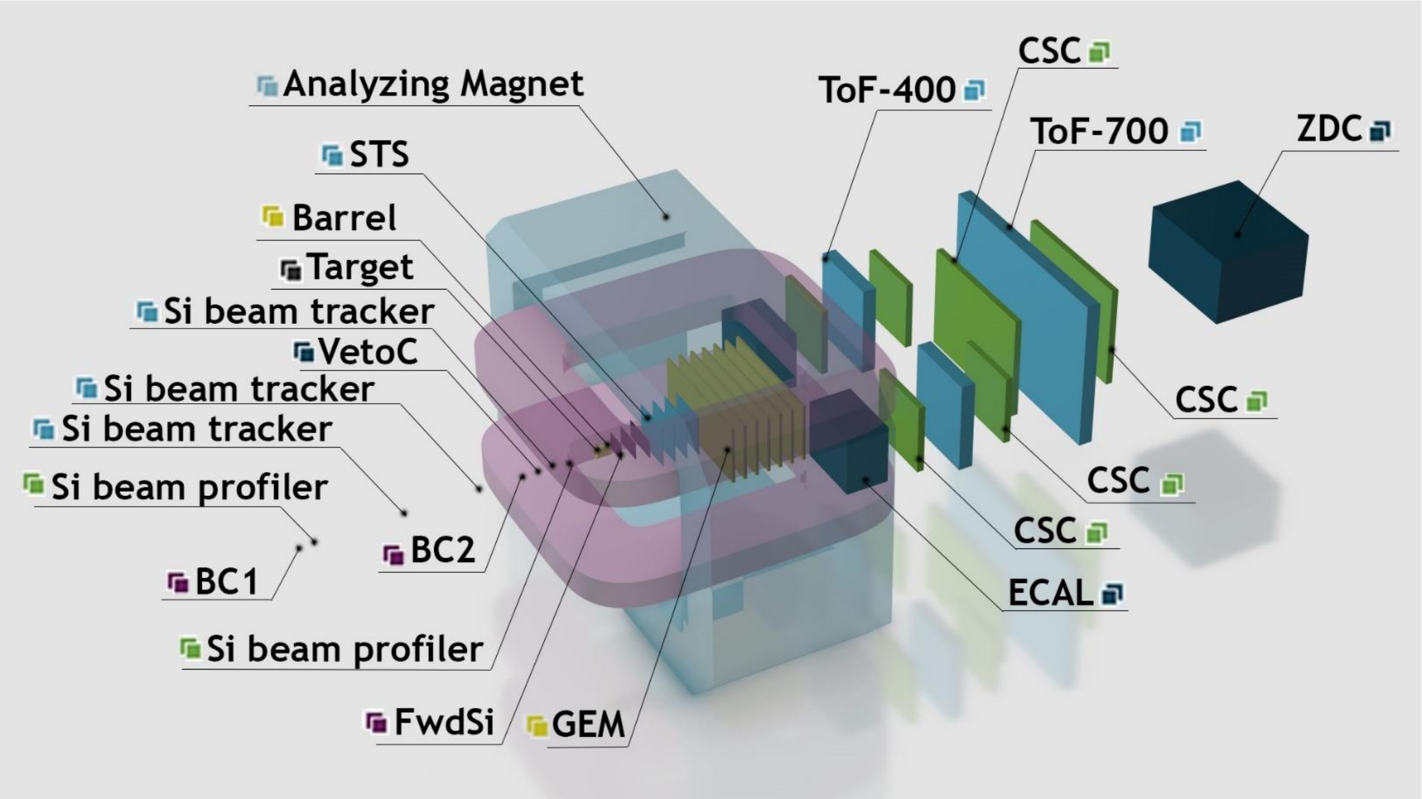


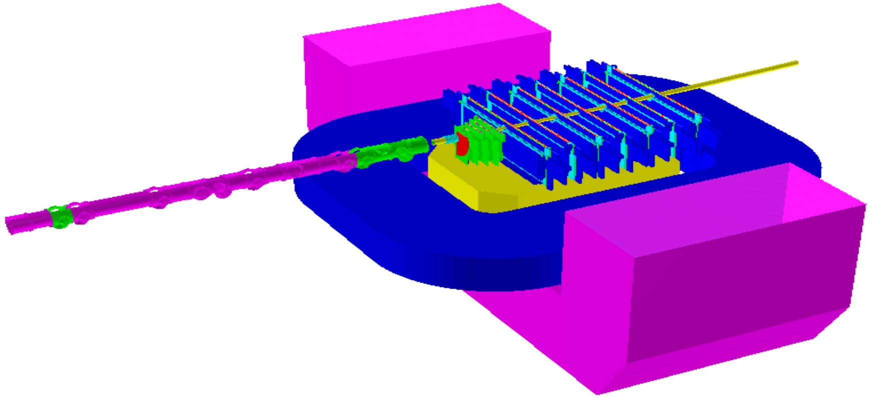




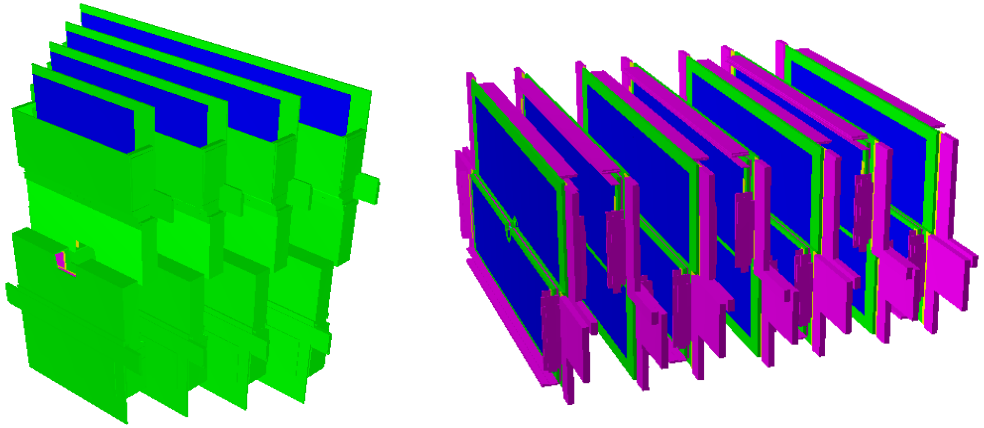
BM@N detector for heavy ion program

Detector geometry without beampipe



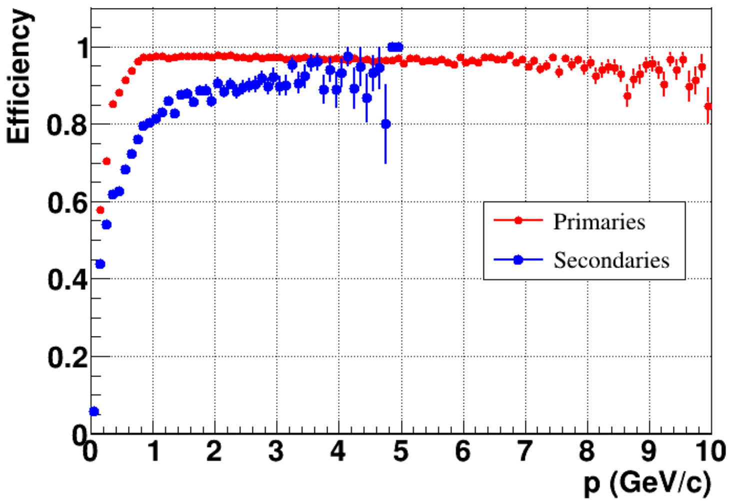


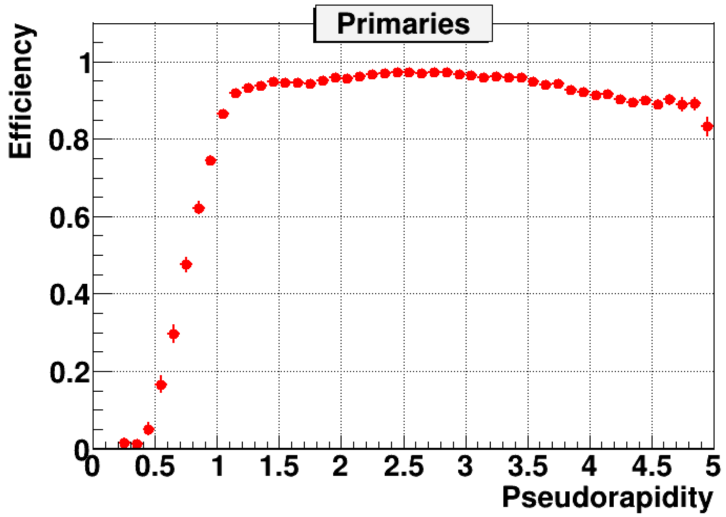
Detector geometry in Run 8

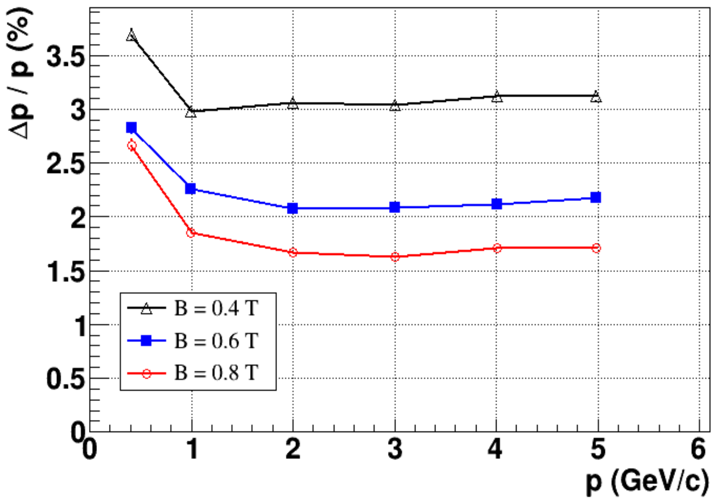


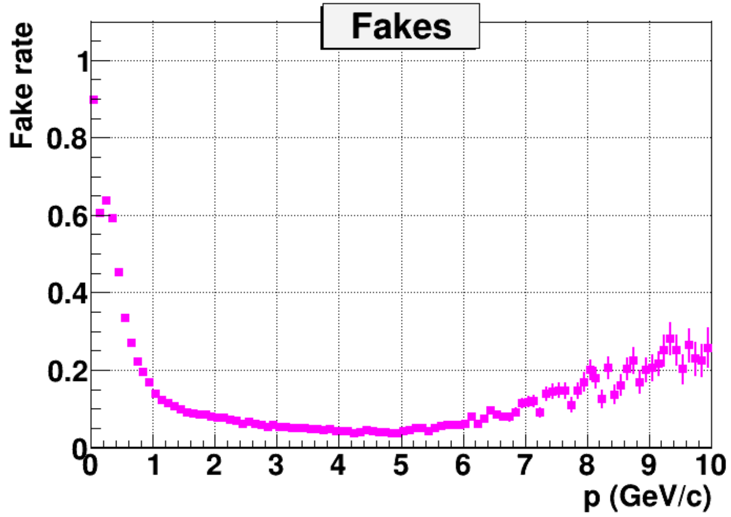
BM@N event simulation and reconstruction

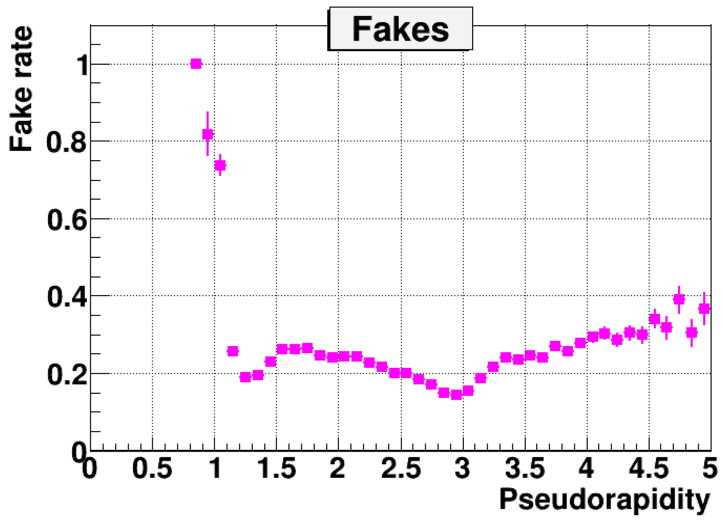
Based on realistic event simulation within the BMNRoot framework

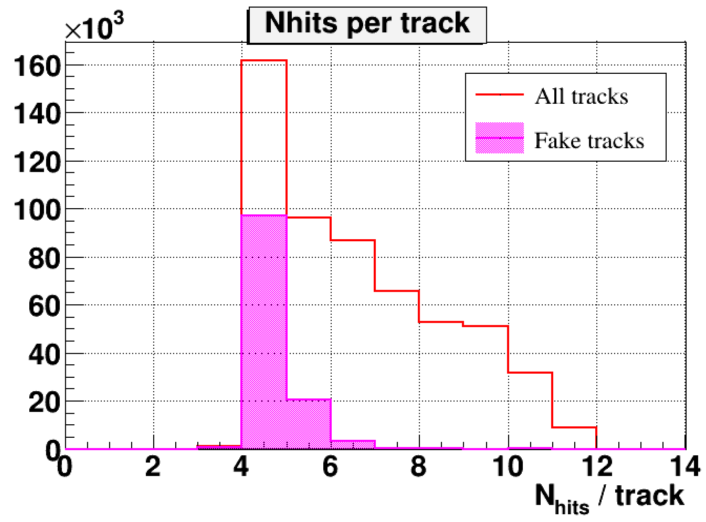






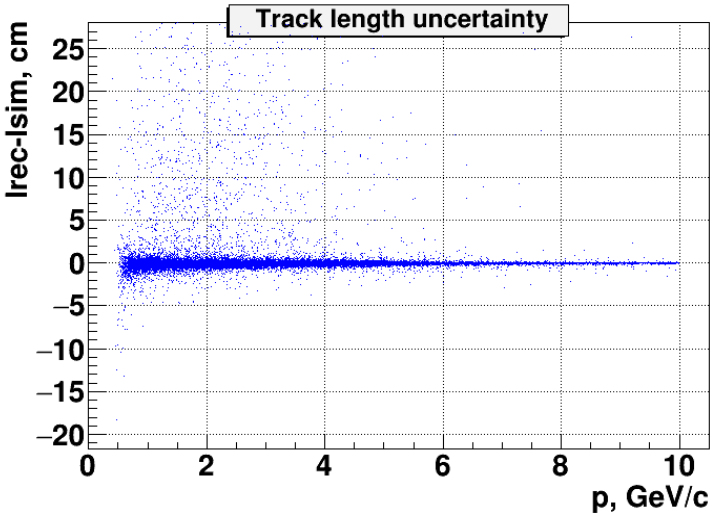


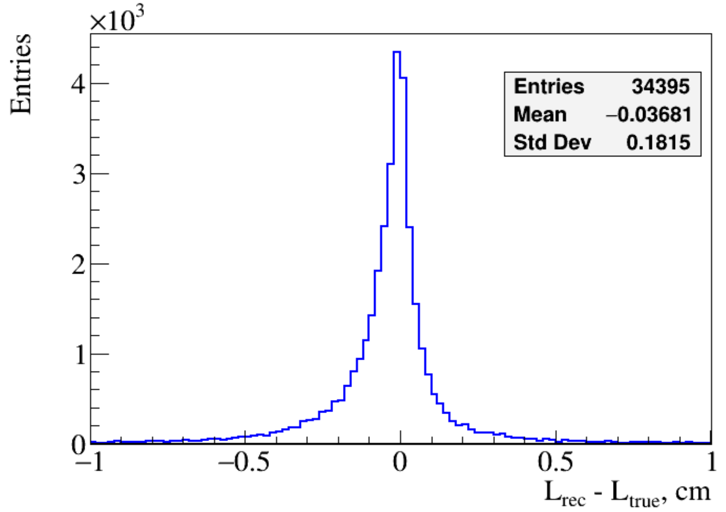


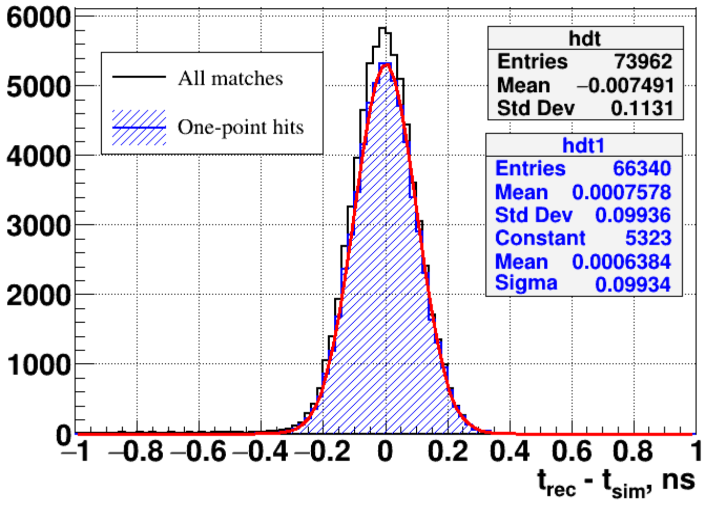


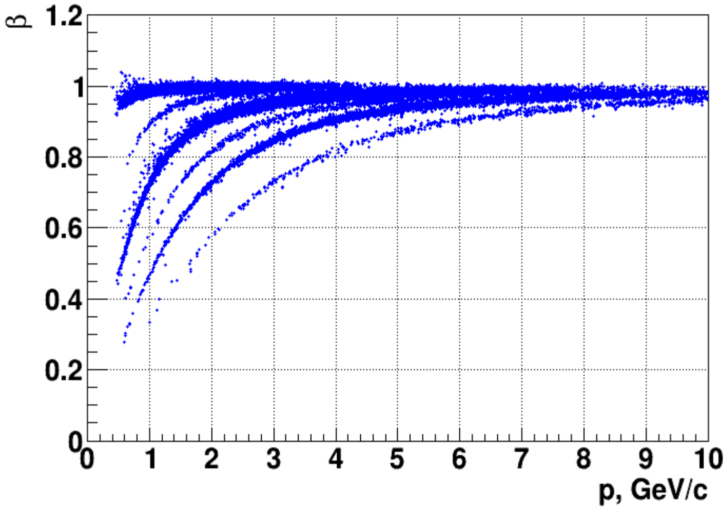
BM@N TOF performance

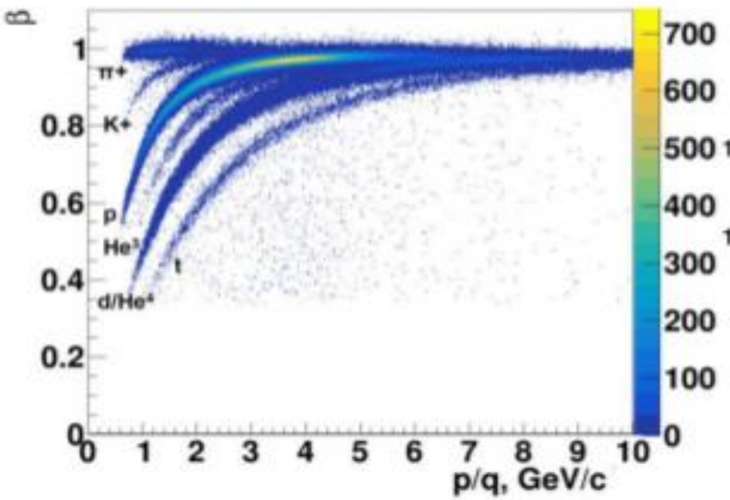
Based on realistic event simulation within the BMNRoot framework

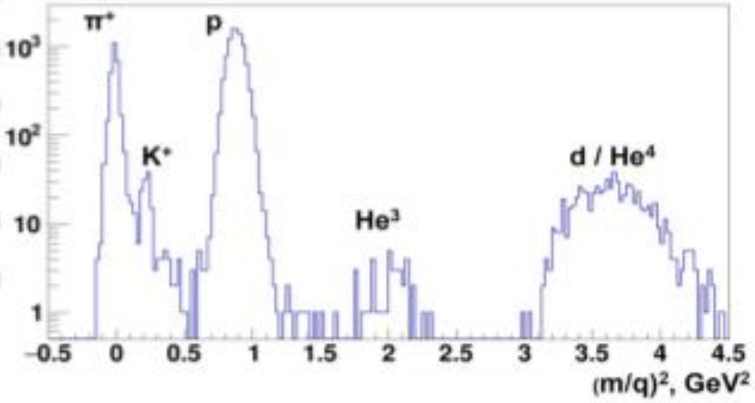












Data set

- ✓ **Detectors in Run 8**: Si (3 stations) + GEMs (7 stations)
- ✓ **Generator:** DCM-SMM, min. bias Xe+CsI at

  T_0 = 1.5A GeV ($\sqrt{s_{NN}}$ = 2.521 GeV) – B = 4 kG

  T_0 = 2.9A GeV ($\sqrt{s_{NN}}$ = 2.998 GeV) – B = 6 kG

  T_0 = 3.9A GeV ($\sqrt{s_{NN}}$ = 3.296 GeV) – B = 8 kG
- ✓ **Statistics:**

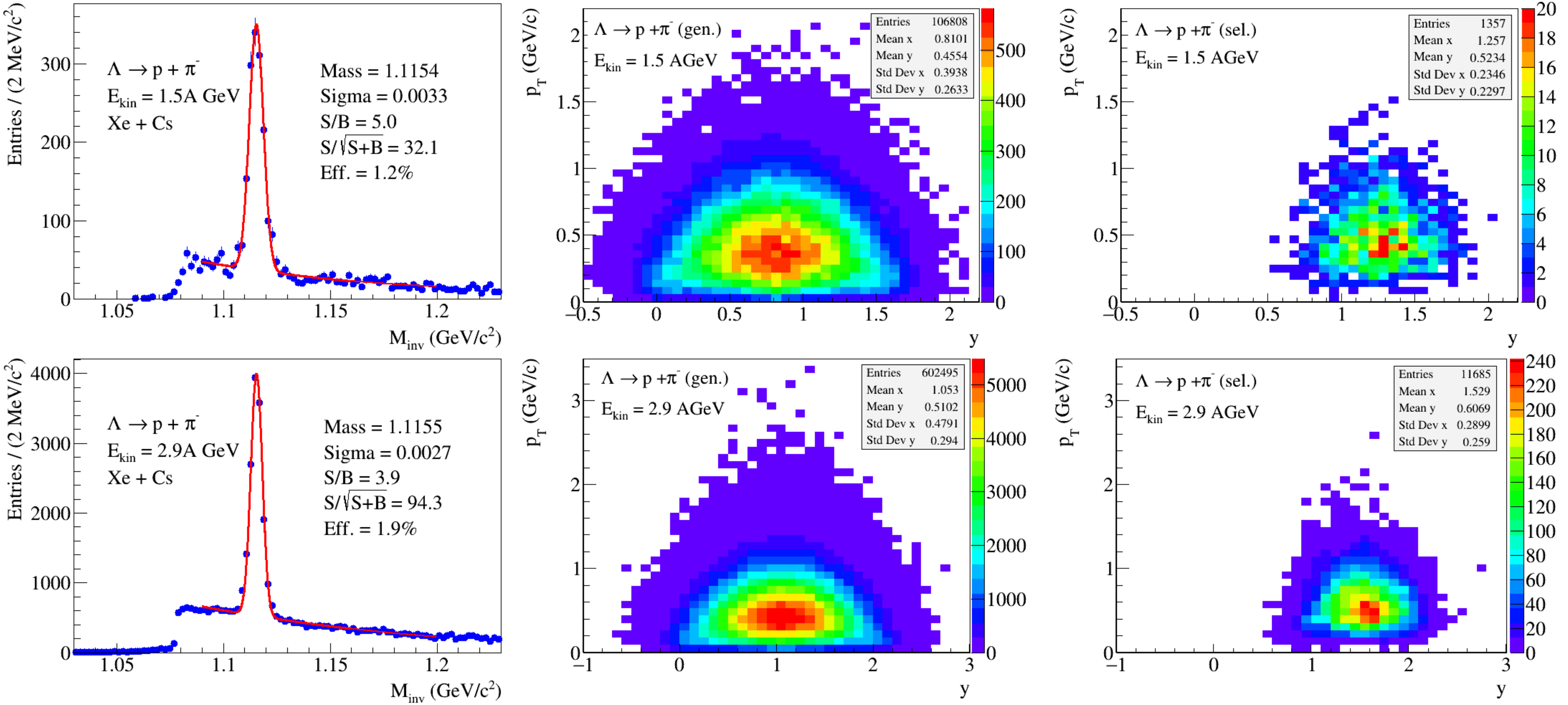
  Λ – 0.11/event at 1.5 GeV, 0.60/event at 2.9 GeV, 1.1/event at 3.9 GeV

  Ξ – 0.012/event at 3.9 GeV
- ✓ **Track reconstruction:** Vector Finder (VF)– homemade (import substitution) package
- ✓ **Selection:**

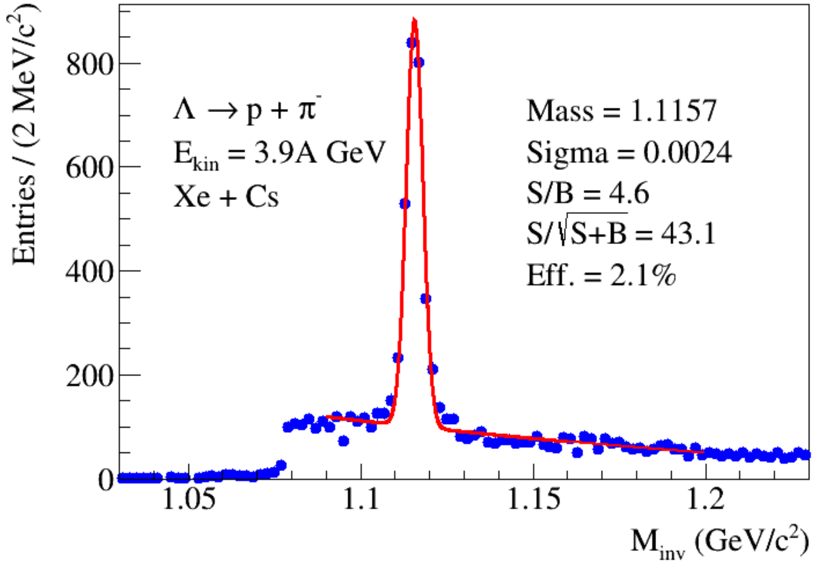
  Λ – Topological Cuts method

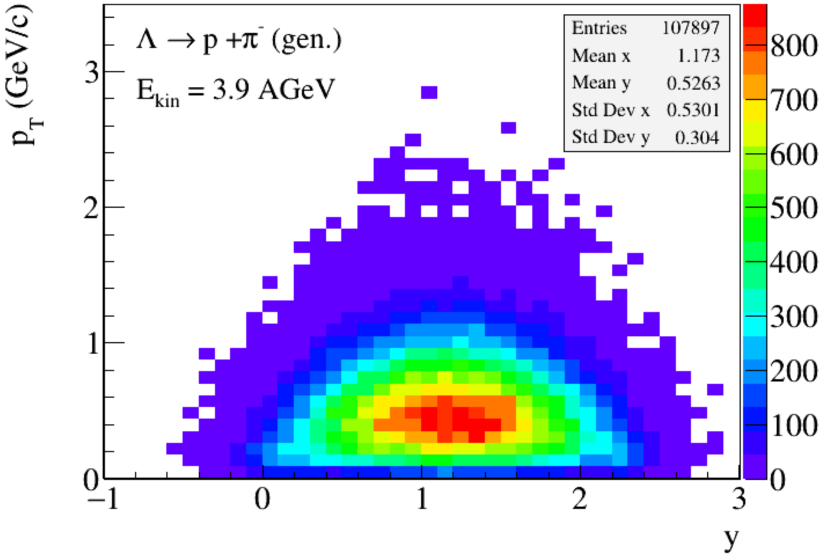
  Ξ – Machine Learning method

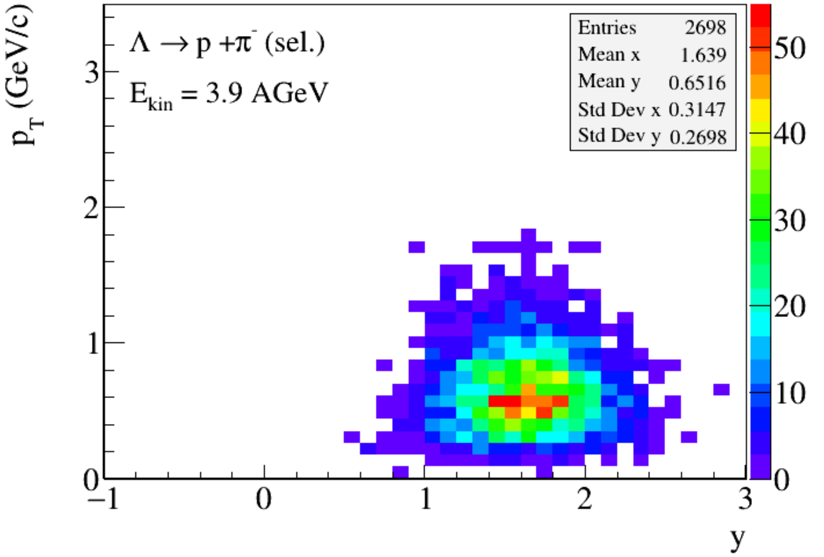
Λ reconstruction at 1.5 and 2.9A GeV (1M events)

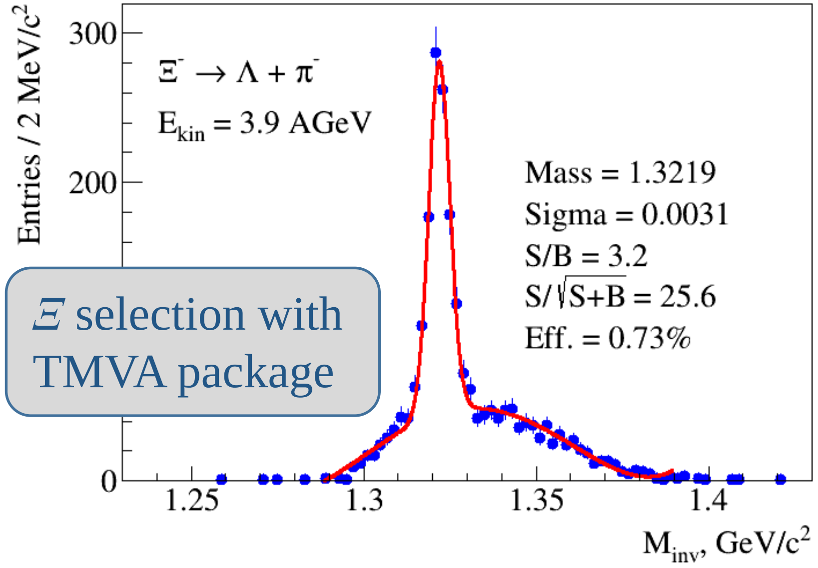


Λ and Ξ reconstruction at 3.9A GeV (100k and 10M events)

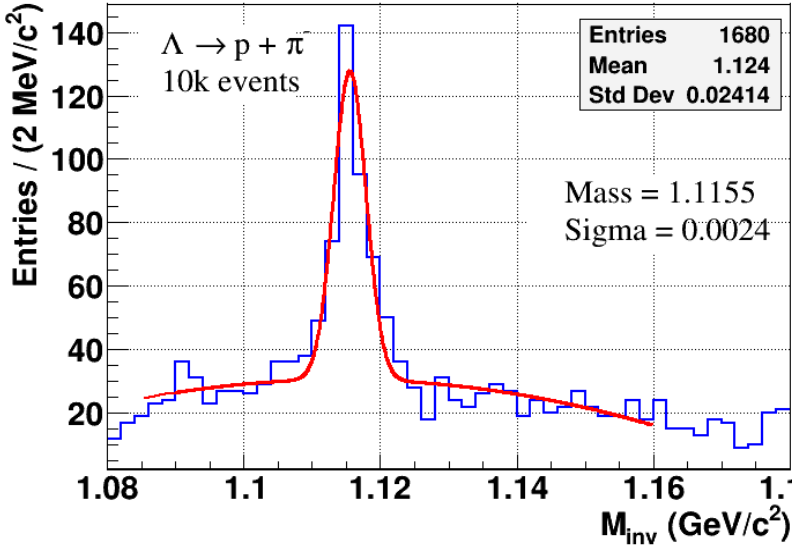


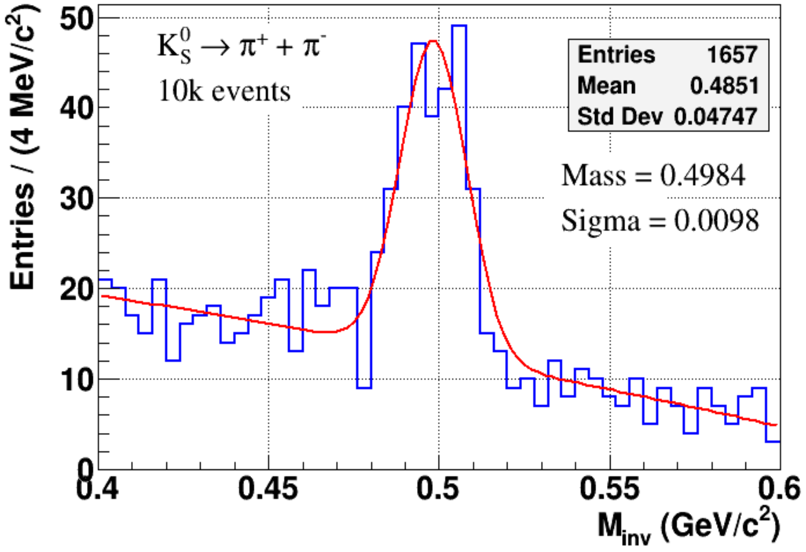






Ξ selection with TMVA package





Plan for BM@N Experimental physics run (Run 8)

BM@N: Estimated hyperon yields in Xe+Cs collisions
4A 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

Summary

✓ The MPD project has gained quite some experience working with simulated data. Currently the activity is underway to prepare a paper on detailed analysis of simulated data in the colliding system expected in the first physics run. The data analysis procedures are being improved and optimized.

✓ The BM@N experiment is at the beginning of the first heavy ion run with the full detector configuration. The reconstruction and analysis software is in the process of being tested and tuned for the real data.