Method of studying high p_T particles in p+p and p+Pb collisions at CERN SPS energies

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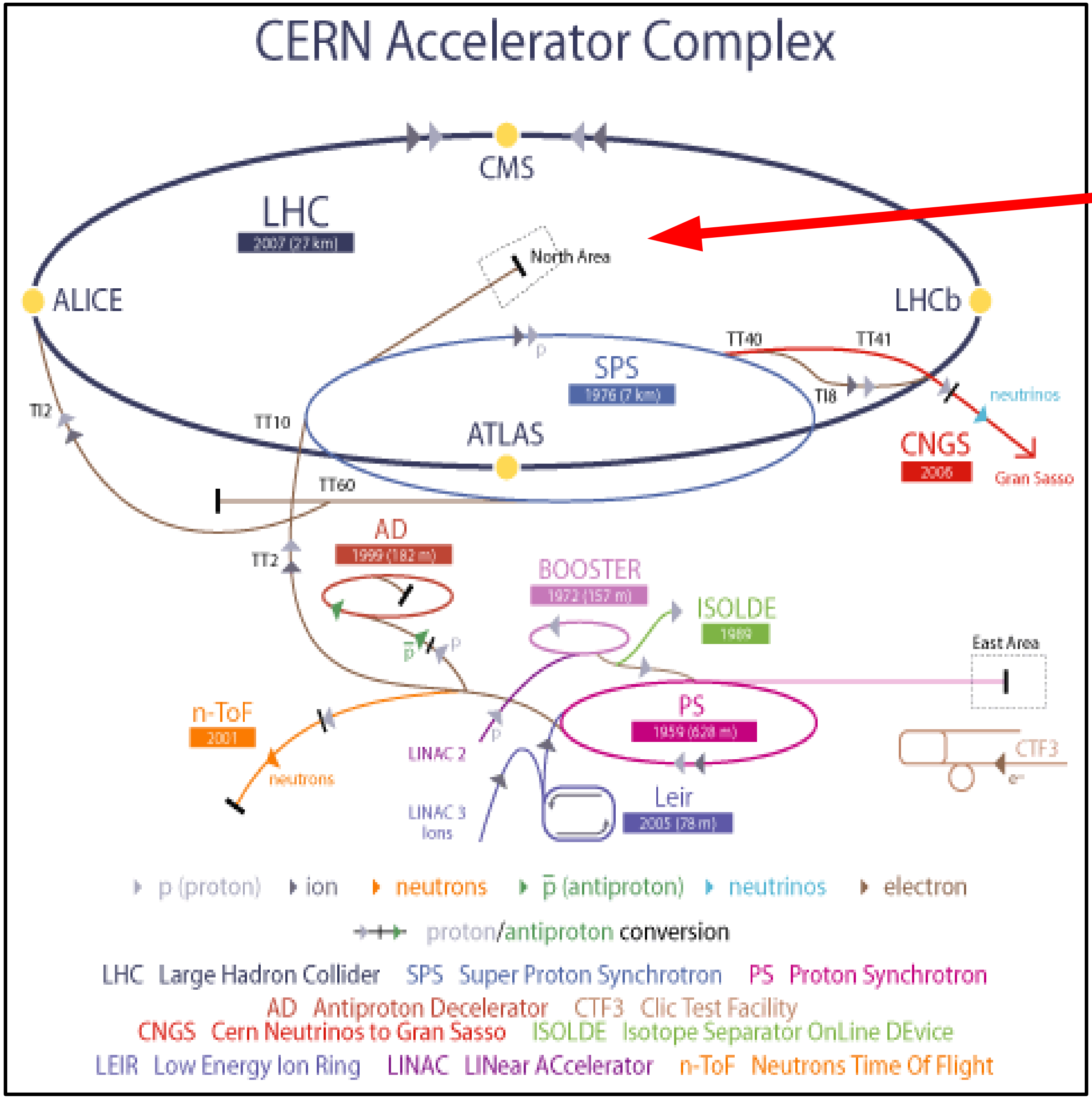
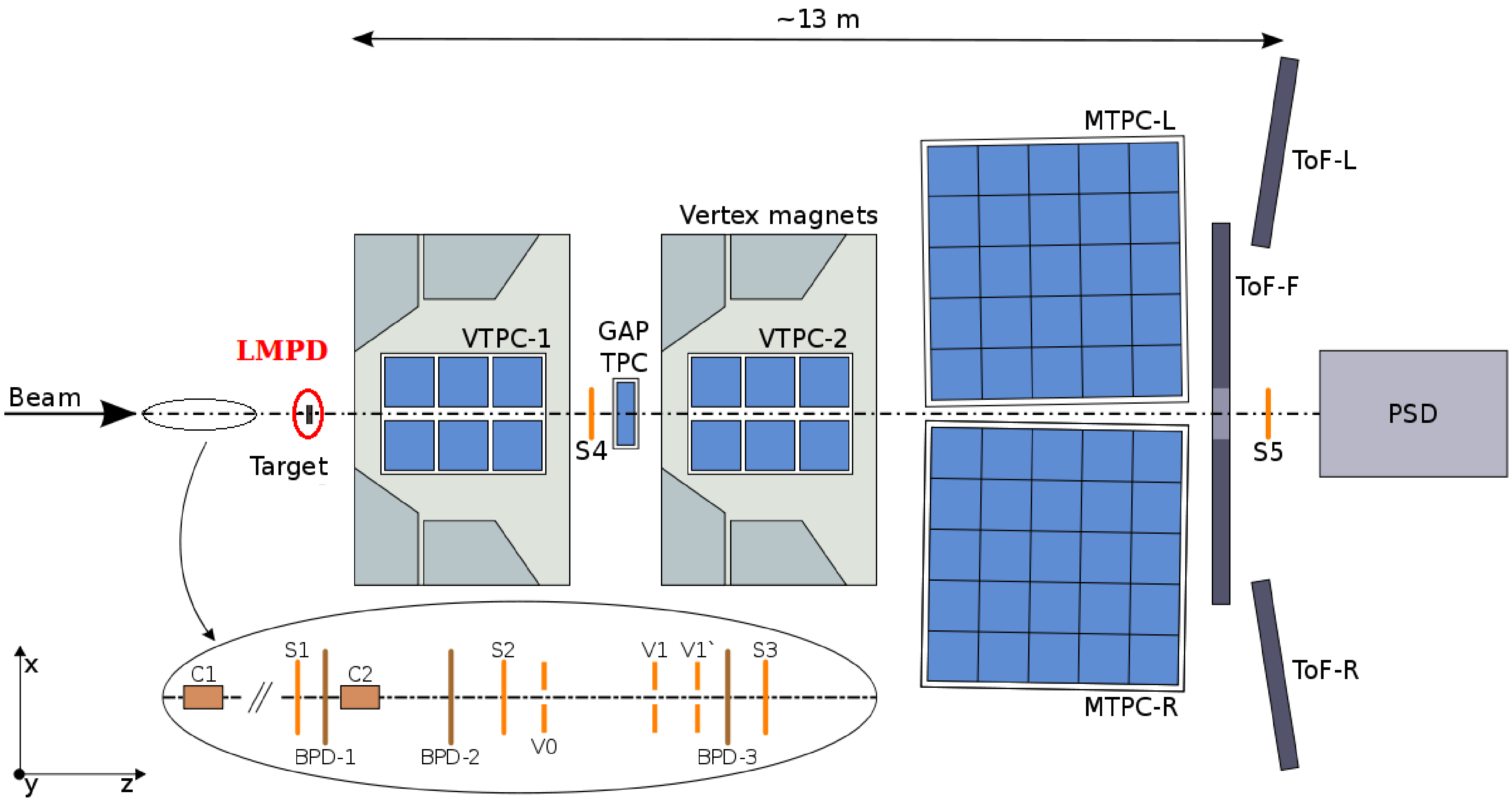
NA61/SHINE at CERN SPS



The main goals of the experiment:

- Search for the critical point of strongly interacting matter
- Detailed study of the onset of deconfinement
- **Study of high transverse momentum phenomena in p+p and p+A**
- Reference measurements for neutrino and cosmic-ray experiments

NA61/SHINE at CERN SPS



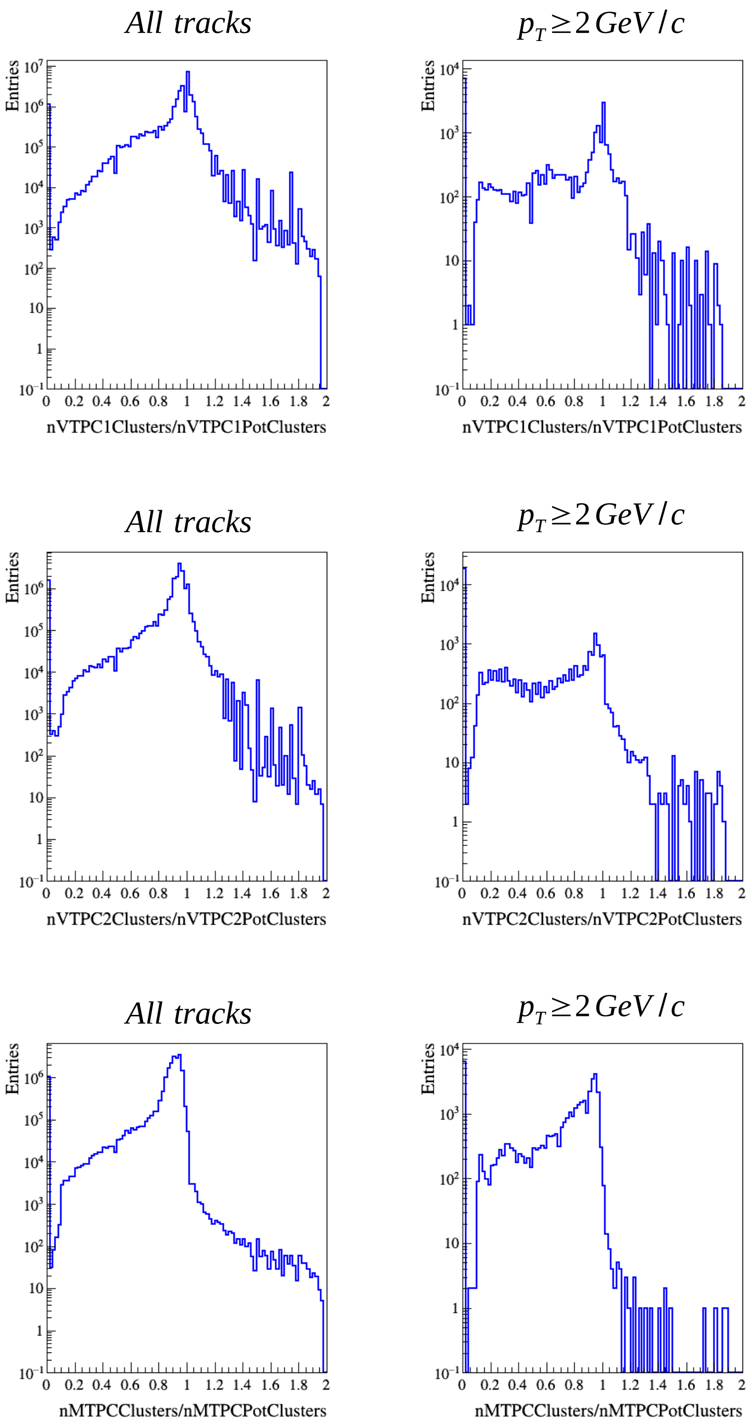
- Large acceptance hadron spectrometer with excellent capabilities for momentum, charge and mass measurements
- Centrality measurements → LMPD in p+Pb, PSD in A+A collisions

Data taking periods (p+p and p+Pb @ 158 GeV/c)

Target	*Year*	*Number of events (Target In)*	*Number of events (Target out)*
LHT	2009	3.55M	0.43M
	2010	**47.3M**	**4.20M**
	2011	13.06M	1.18M
Pb (0.5 mm)	2012, July	2.82M	0.27M
Pb (1 mm)	**2012, July**	**1.31M**	**0.14M**
	2012, Sept	**9.40M**	**0.93M**
	2014	18.94M	1.91M

Strategy for track selection

- Particles are detected in the TPCs → a track can have measured clusters in VTPC1, in VTPC2 and in MTPC
- Number of potential clusters is calculated for each track → how many clusters should belong to an ideally detected particle with the given momentum
- The Number of Clusters / Number of Potential Clusters ratio should be close to 1 for a well detected and well fitted track

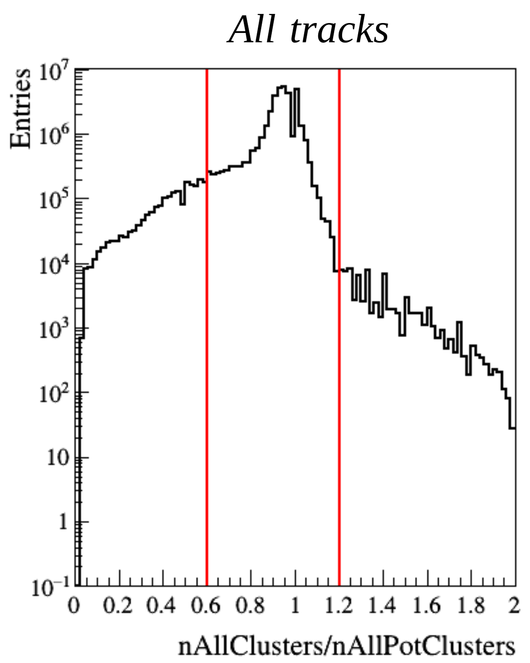


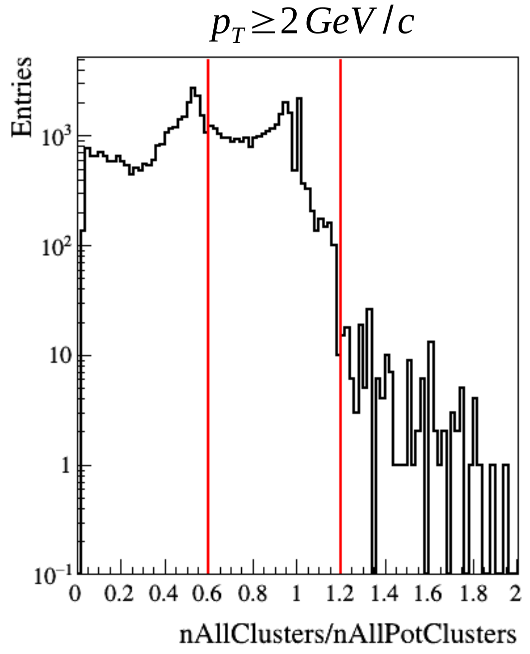
Strategy for track selection

- By using the nClusters/nPotClusters ratio, one can define “good” and “bad” tracks
- Good tracks: 0.6 ≤ nClusters/nPotClusters ≤ 1.2

Track selecting method:

- Study the 3D phase space (p_T, Φ, rapidity) distributions of “bad” and “good” tracks
- Find a phase-space region where the fraction of the wrongly fitted tracks is low
- Apply a 3 dimensional phase space cut to select this clean momentum space region





Φ – p_T – y phase-space

For a track with 4-momentum (E,p_x,p_y,p_z) and charge $q=\pm1$:

- Φ: charge-reflected azimuthal angle
- p_T: transverse momentum
- Rapidity (y)
  - to calculate rapidity, the mass of the particle is needed
  - unidentified hadrons → different particle mass hypotheses were used (pion, proton, kaon)

$$\Phi = \arctan\left(\frac{p_y}{q \cdot p_x}\right)$$

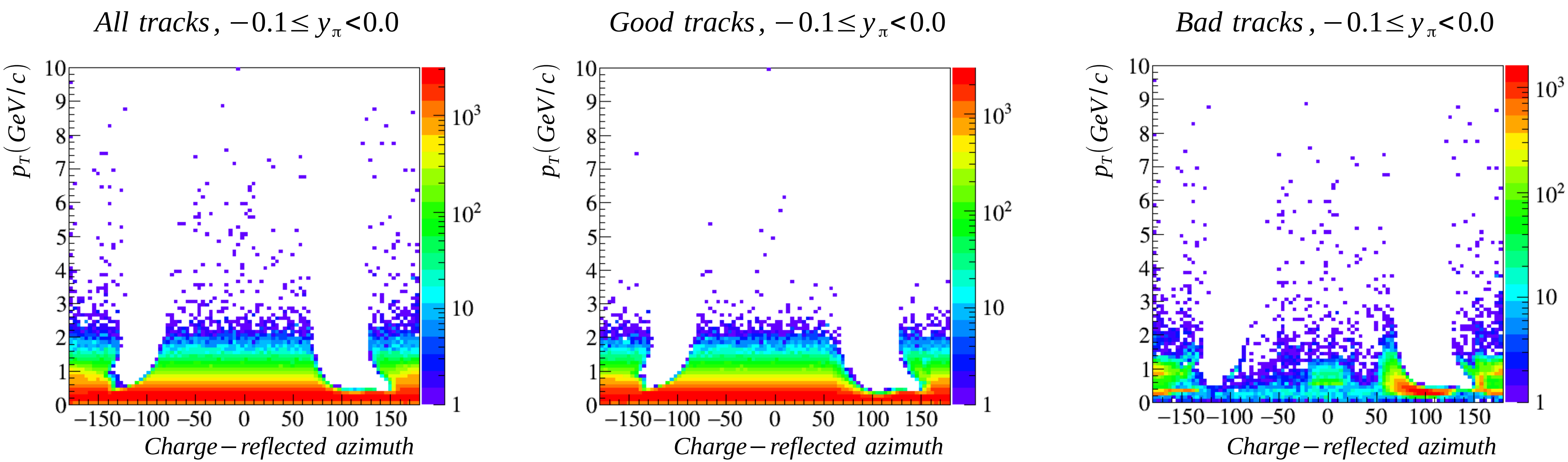
$$p_T = \sqrt{p_x^2 + p_y^2}$$

$$y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$$

Phase-space cut:

- for each rapidity bin, the Φ-p_T 2D distributions were studied
- the selection of the accepted region was guided by the number of potential clusters and by the good/bad track ratios

Phase-space distribution of good and bad tracks



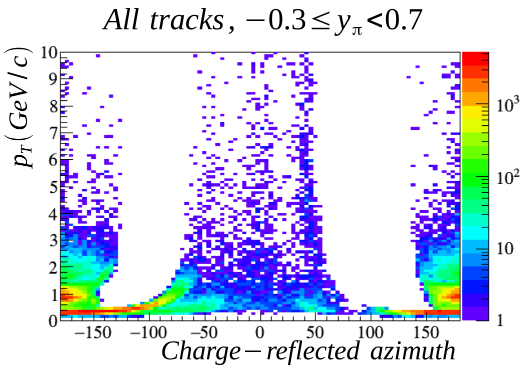
- Rapidity was calculated with pion mass assumption
- The high p_T region is dominated by bad tracks

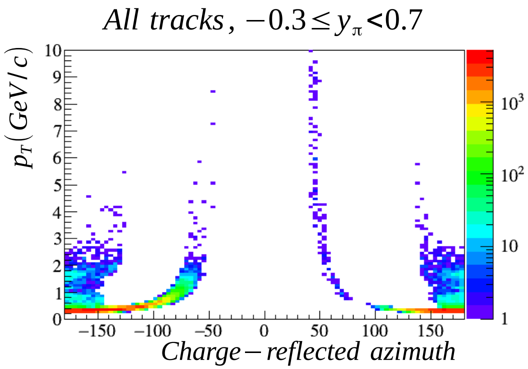
Rejection of discontinuous tracks

- The high p_T region is populated by misfitted tracks
- These fake tracks have:
  - 0 clusters in a given TPC but more than 0 potential clusters

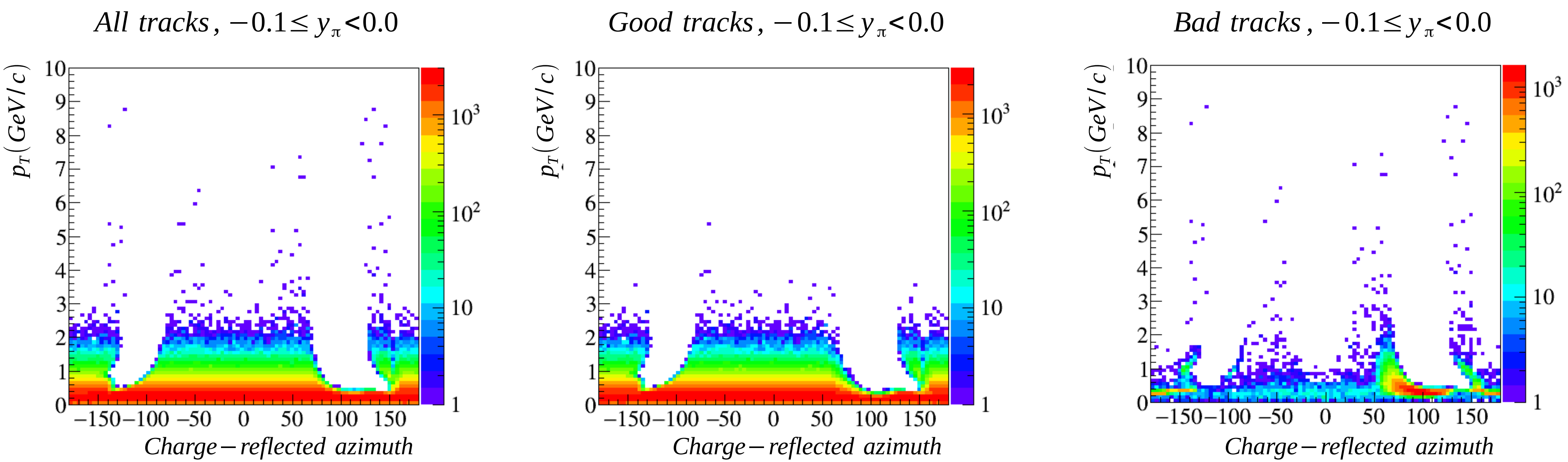
    or
  - more than 0 clusters in a given TPC but 0 potential clusters

- ***Example***: discontinuous tracks in VTPC1
  - Φ-p_T distribution for mid-rapidity tracks
  - *Top plot*: nVTPC1Clusters=0 and nVTPC1PotClusters>0
  - *Bottom plot:* nVTPC1Clusters=0 and 0<nVTPC1PotClusters<10
  - Rejecting tracks with nVTPC1PotClus>10 if nVTPC1Clus=0 cleans the phase-space around $\Phi \approx 0$



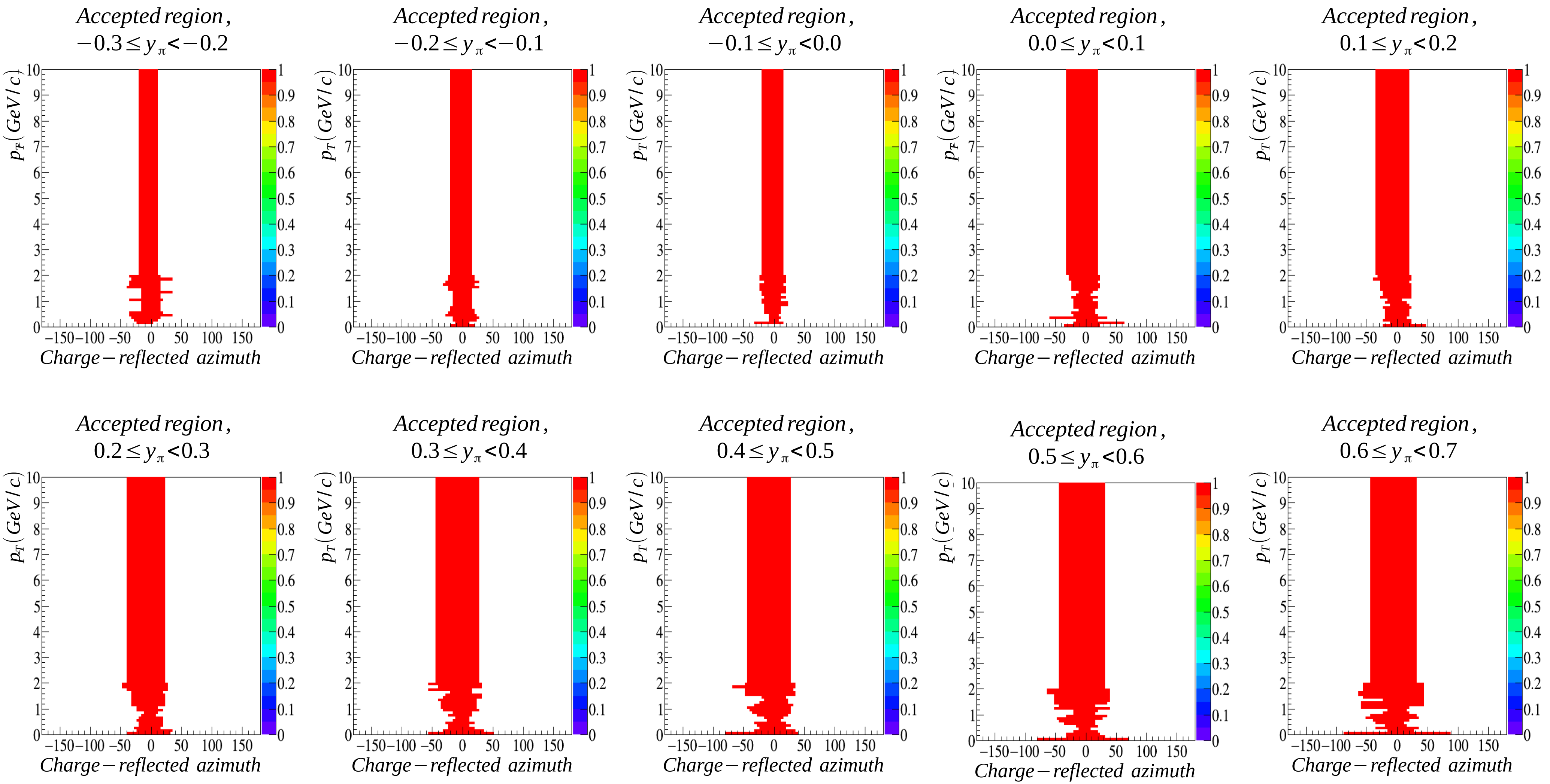


Phase-space distributions after the rejection of discontinuous tracks

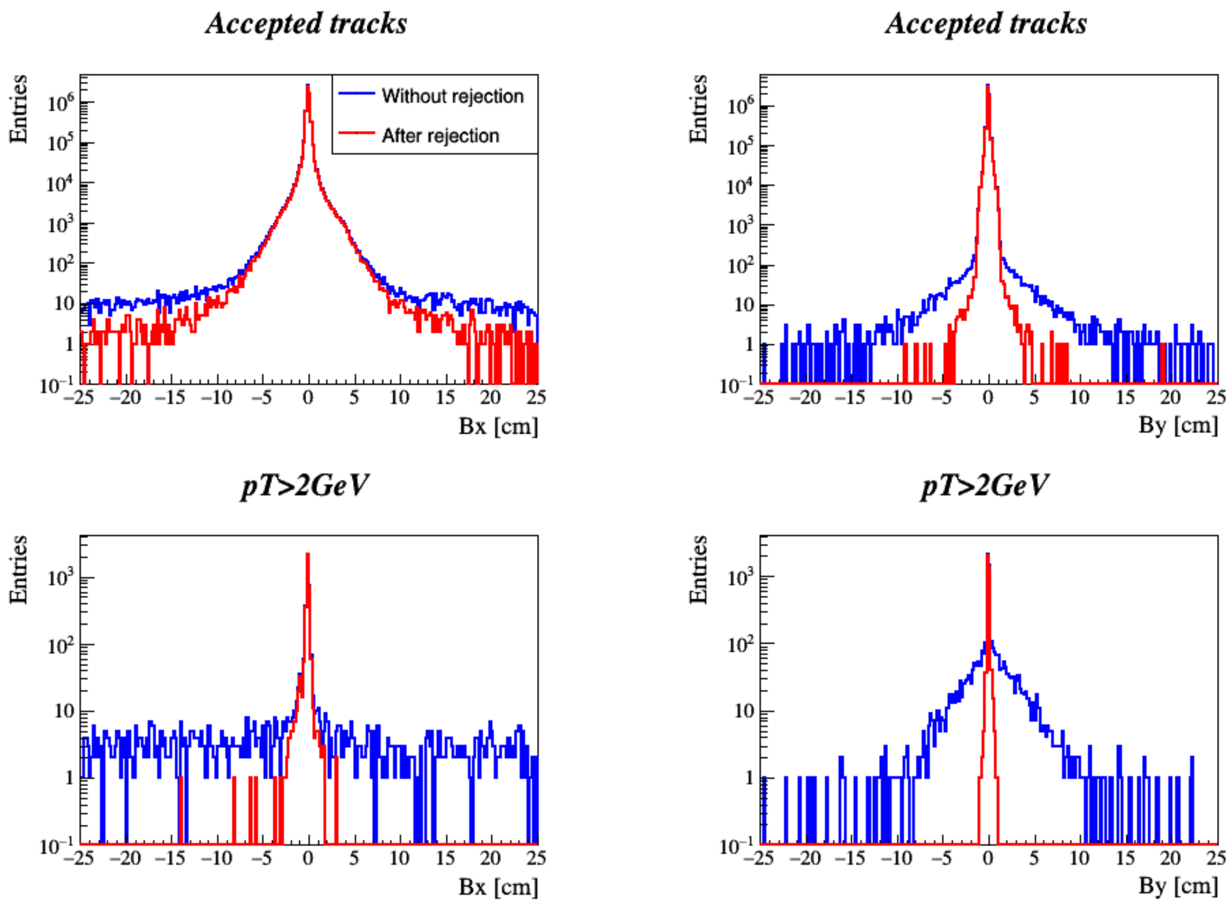


- Rapidity was calculated with pion mass assumption
- After the rejection of discontinuous tracks, the bad tracks disappear from the high p_T region around $\Phi \approx 0$, the rest can be removed by the 3 dimensional phase-space cut

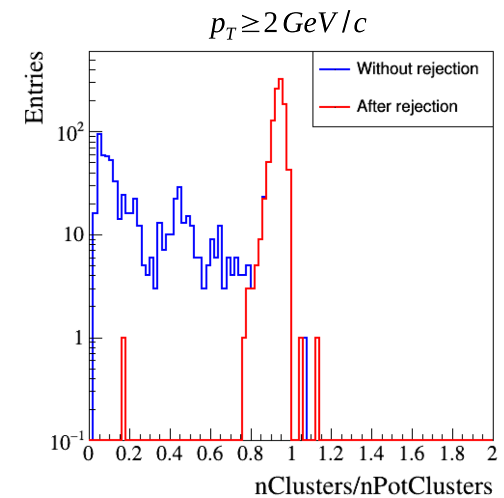
Acceptance map with pion mass assumption



Properties of accepted tracks



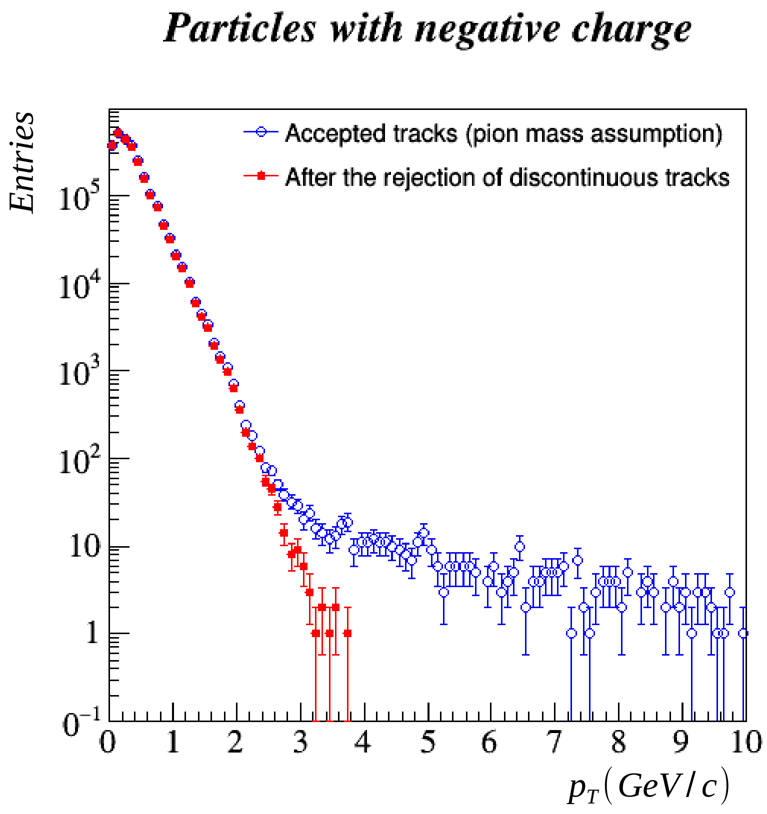
nAllClusters/nAllPotClusters ratio for high p_T tracks in the accepted phase-space

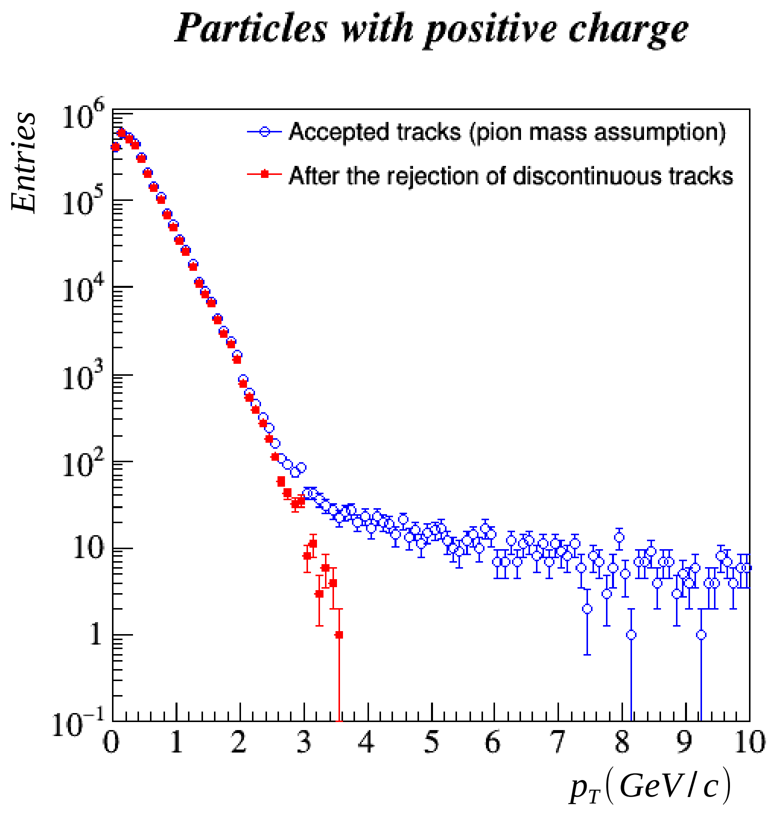


Impact parameter: distance of the extrapolated track from the main vertex position in horizontal (bx) and vertical (by) plane

- *Top plots*: impact parameter distributions of all accepted tracks; *Bottom plots*: p_T>2GeV/c
- *Blue lines:* all tracks; *Red lines:* after rejecting the discontinuous tracks
- The rejection of the discontinuous tracks decreases/removes the background with high impact parameter

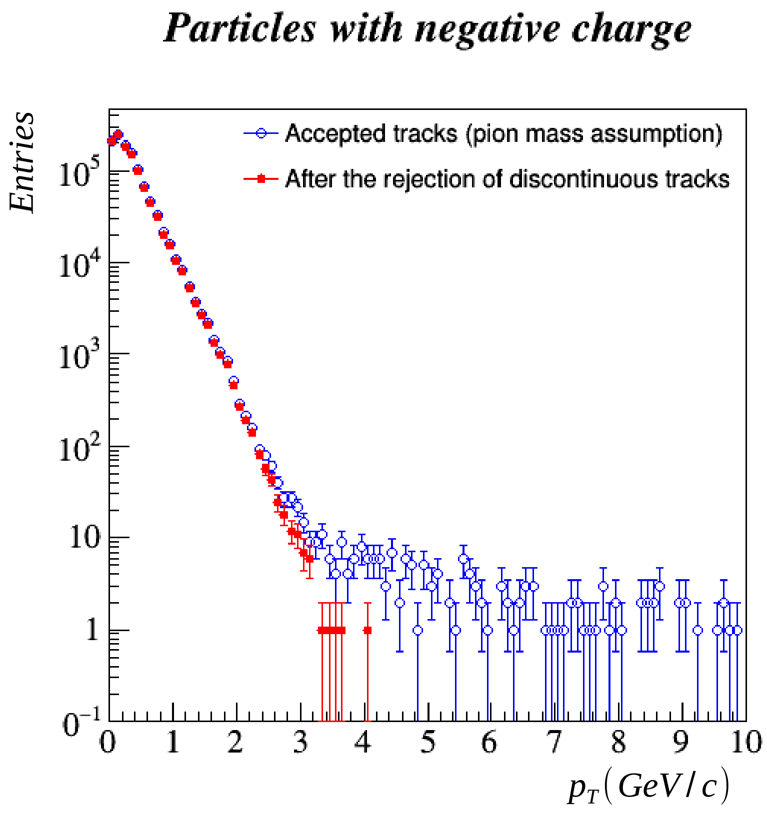
p_T distribution of charged particles in p+p collisions

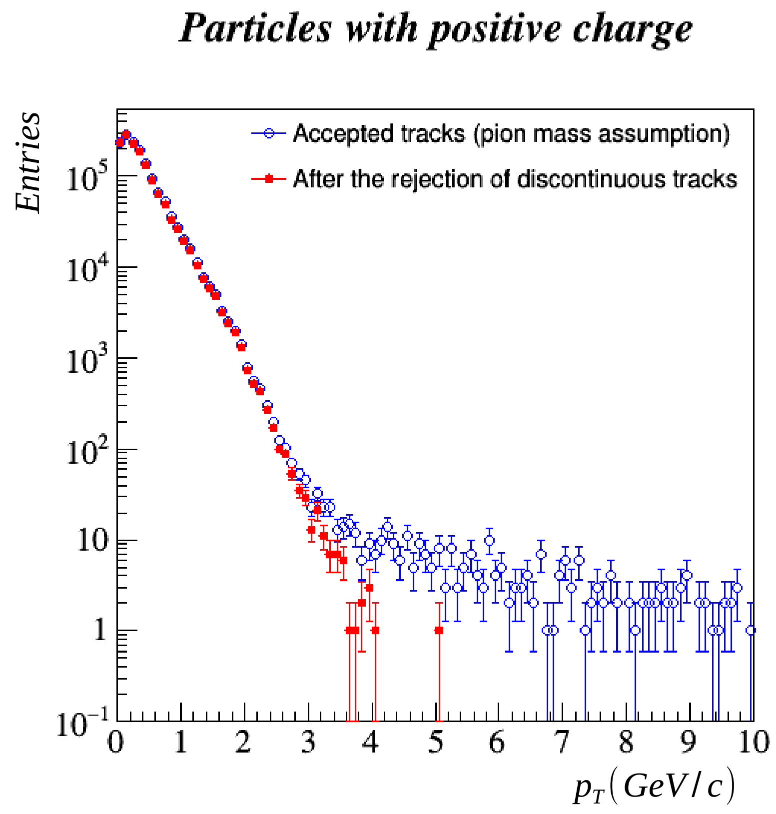




- p_T distributions of unidentified charged hadrons from the accepted phase-space
- The rejection of the discontinuous tracks removes the background of fake tracks at high p_T

p_T distribution of charged particles in p+Pb collisions





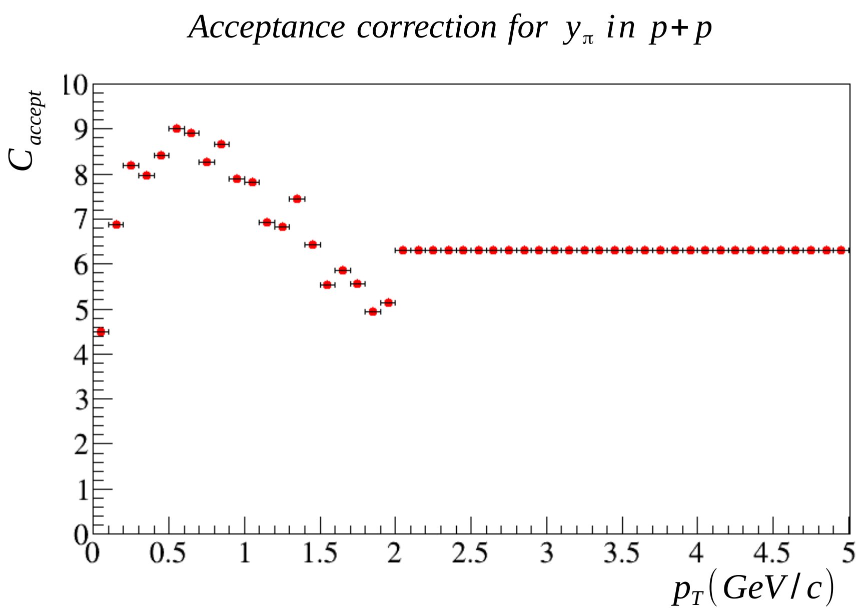
- p_T distributions of unidentified charged hadrons from the accepted phase-space
- The rejection of the discontinuous tracks removes the background of fake tracks at high p_T

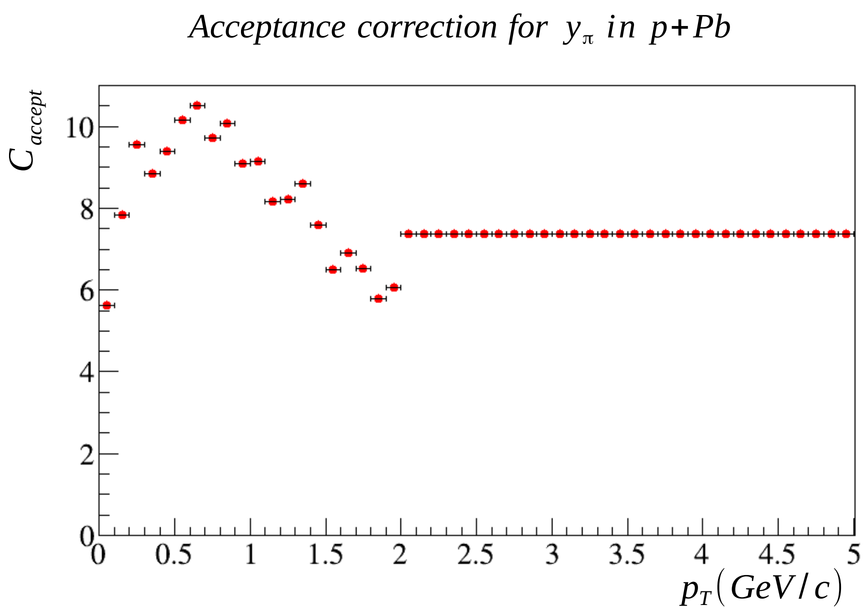
Acceptance correction

- The accepted Φ region is p_T and rapidity dependent
- Extrapolation needed to the full -180°< Φ < 180° coverage
- In p+p collisions: flat rapidity distribution can be assumed around mid-rapidity (-0.3 ≤ y < 0.7)
- In p+Pb collisions: rapidity spectra is not symmetric, correction for the y-dependence has to be done
- Calculation of the correction factor:
  - at each p_T and rapidity bin (with different mass assumptions), the volume of the accepted Φ interval has to be divided by 360°
  - For a given p_T bin, the correction factor is:

$$C_{accept} = \frac{\sum_{rapidity\,bins} \Phi_{accept}}{\sum_{rapidity\,bins} 360°}$$

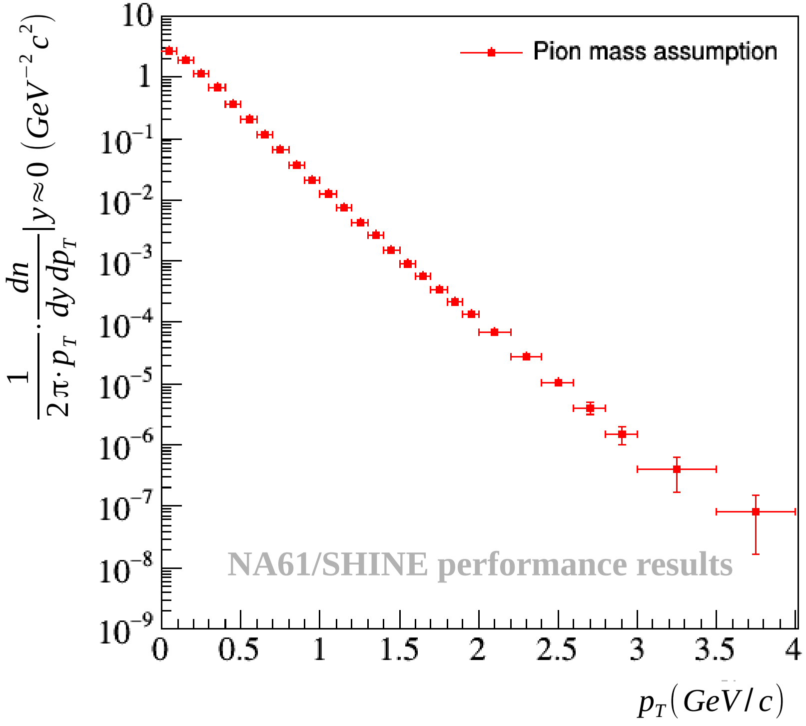
Acceptance correction factors with pion mass assumption



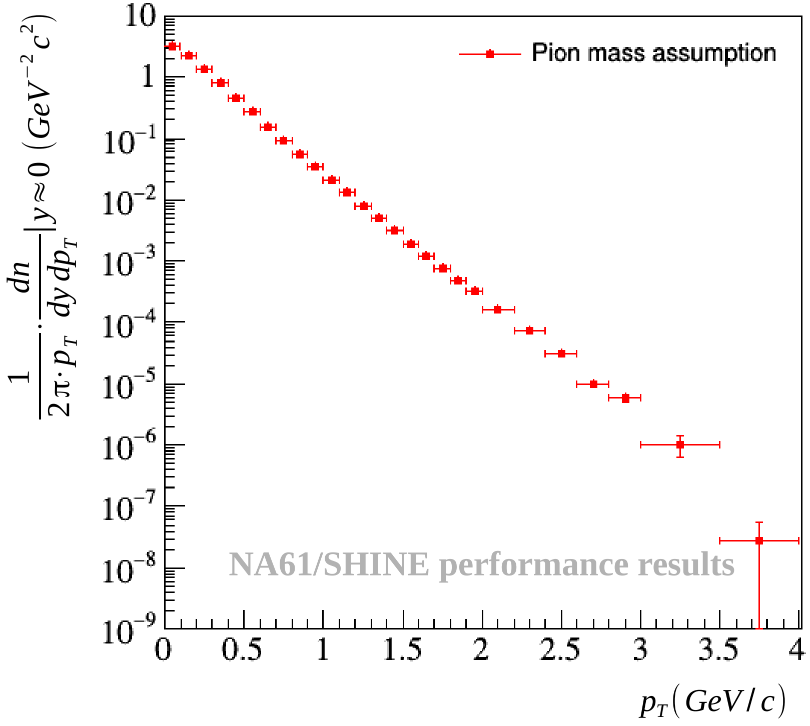


Acceptance corrected spectra in p+p collisions

Particles with negative charge

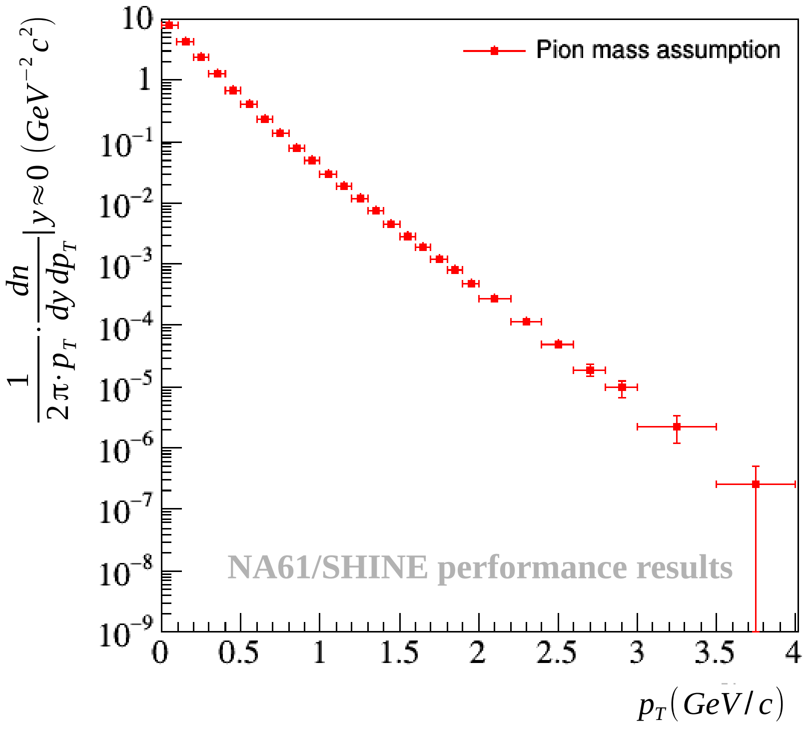


Particles with positive charge

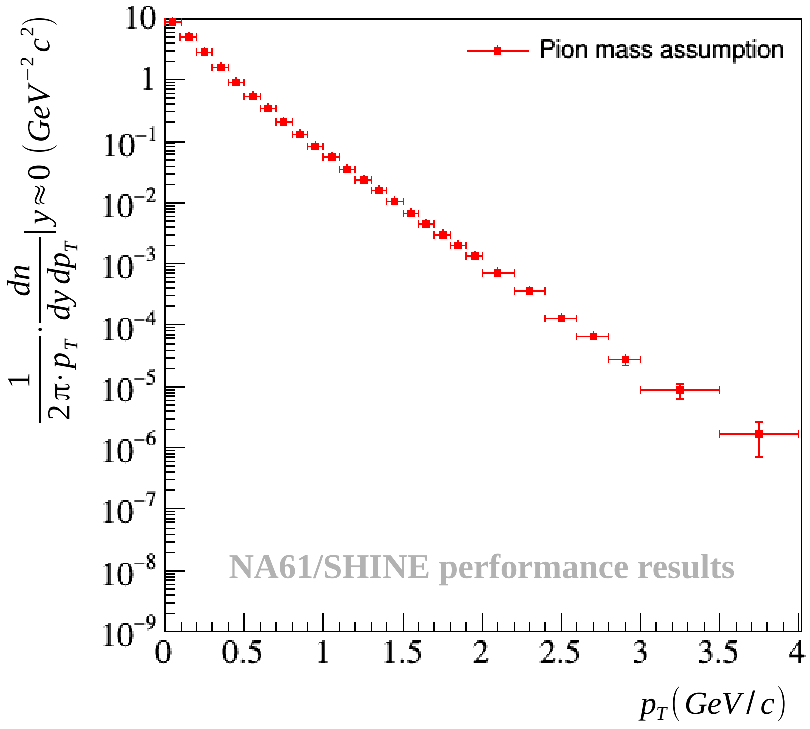


Acceptance corrected spectra in p+Pb collisions

Particles with negative charge

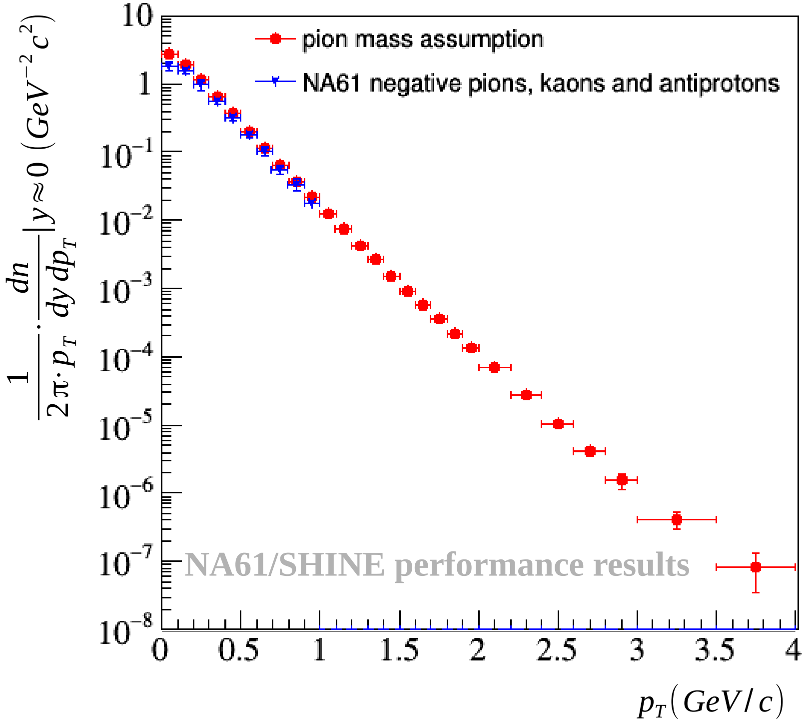


Particles with positive charge

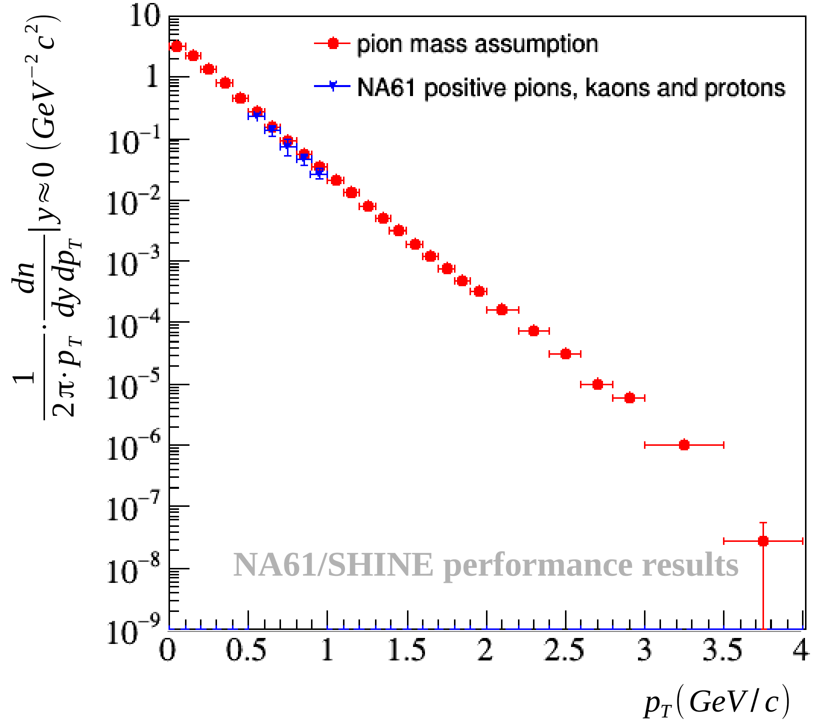


Comparison with NA61 low p_T results in p+p

Particles with negative charge



Particles with positive charge



- Comparison with published NA61 results on particle spectra in p+p collisions (only statistical uncertainties are shown on the plots)

1) Measurements of $\pi^{\pm}$, $K^{\pm}$, p and p-bar spectra in proton-proton interactions at 20, 31, 40, 80 and 158 GeV/c with the NA61/SHINE spectrometer at the CERN SPS (Eur. Phys. J. C 77 (2017) 671)
2) Measurement of negatively charged pion spectra in inelastic p+p interactions at p_{lab} = 20, 31, 40, 80 and 158 GeV/c (Eur. Phys. J. C 74 (2014) 2794)

Summary

- High statistics p+p and p+Pb data was taken for the study of high transverse momentum phenomena
- The contribution of the misfitted tracks in the high p_T region is significant → with the rejection of these fake tracks, the tail of the p_T spectra at high values disappears
- With this method, particle production can be studied up-to $p_T \sim 4$ GeV/c

Thank You for Your Attention!

Backup slides

Event cuts

- Event cuts for **pp:**
  - → ***T2 trigger***
  - → ***WFA cut:*** has WFA info; 1 hit in S11 in ±3 μs time-window
  - → ***BPD cut:*** has BPDs; Good BPD1; Good BPD2; Good BPD3
  - → ***MV cut*****:** has MV and PV; PrimaryFitZ; FitQuality Perfect
  - → ***Vertex Z cut:*** -600cm < z < -560cm
- Event cuts for **pPb:**
  - → ***T2 trigger***
  - → ***WFA cut:*** has WFA info; 1 hit in S11 in ±3 μs; 1 hit in T4
  - → ***BPD cut:*** has BPDs; Good BPD3; Good BPD1 or BPD2
  - → ***MV cut:*** has MV and PV; PrimaryFitZ; FitQuality Perfect
  - → ***Vertex Z cut:*** -590cm < z < -575cm

Event statistics

	p+p (2010)		p+Pb (2012, 1mm)	
	Full target	Empty target	Target in	Target out
All	35769787	3350616	10357794	967363
T2 trigger	33716620	2688480	9474514	736368
WFA cut	31018344	2472286	8207701	636680
BPD cut	25247566	1869072	6651240	384221
MV cut	21709812	1289584	6041887	266228
Vertex Z cut	19396548	690418	4806237	9448

Event statistics