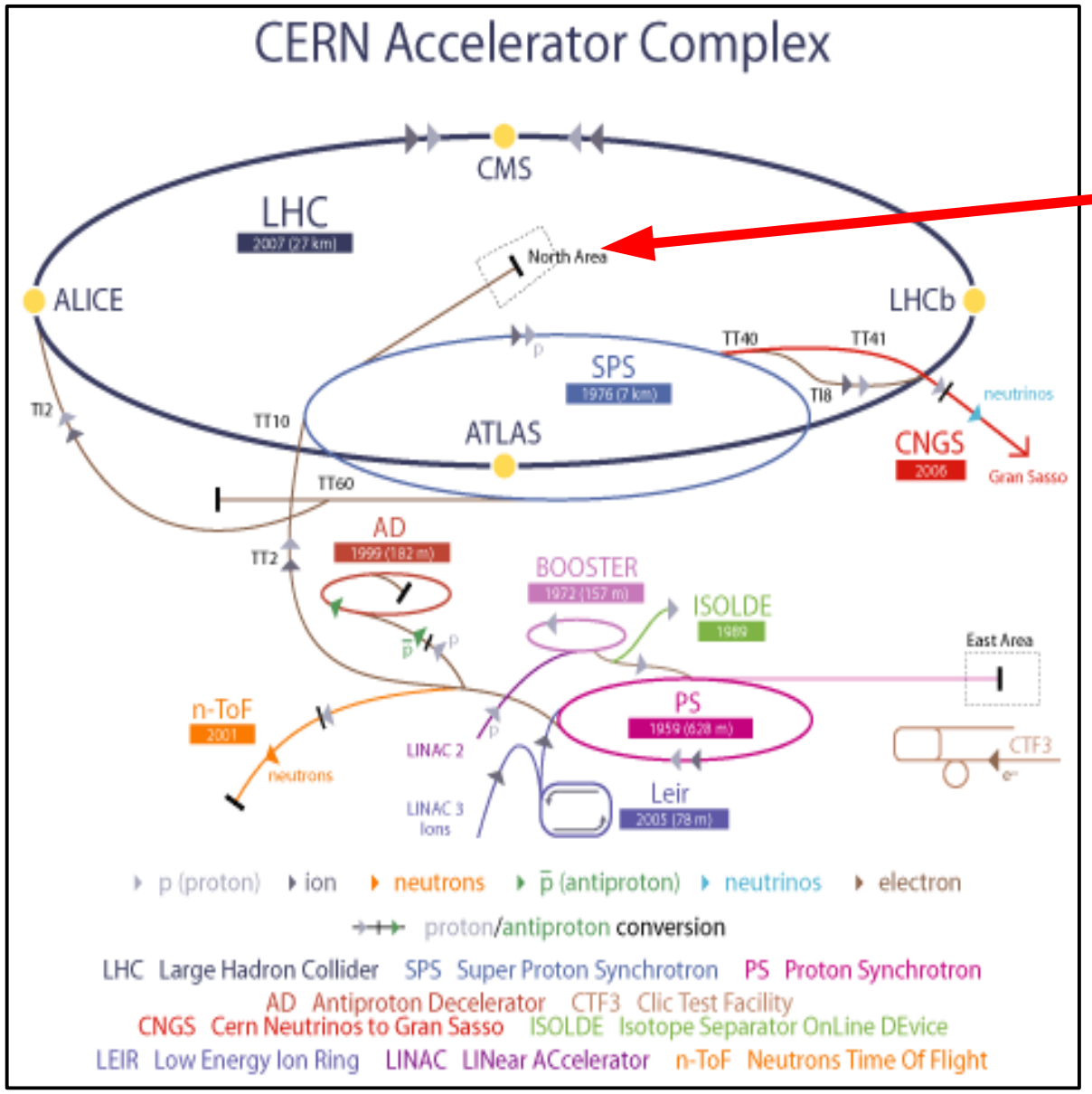
High p_T particle spectra from the NA61/SHINE experiment

Krisztina Márton
for the NA61/SHINE Collaboration

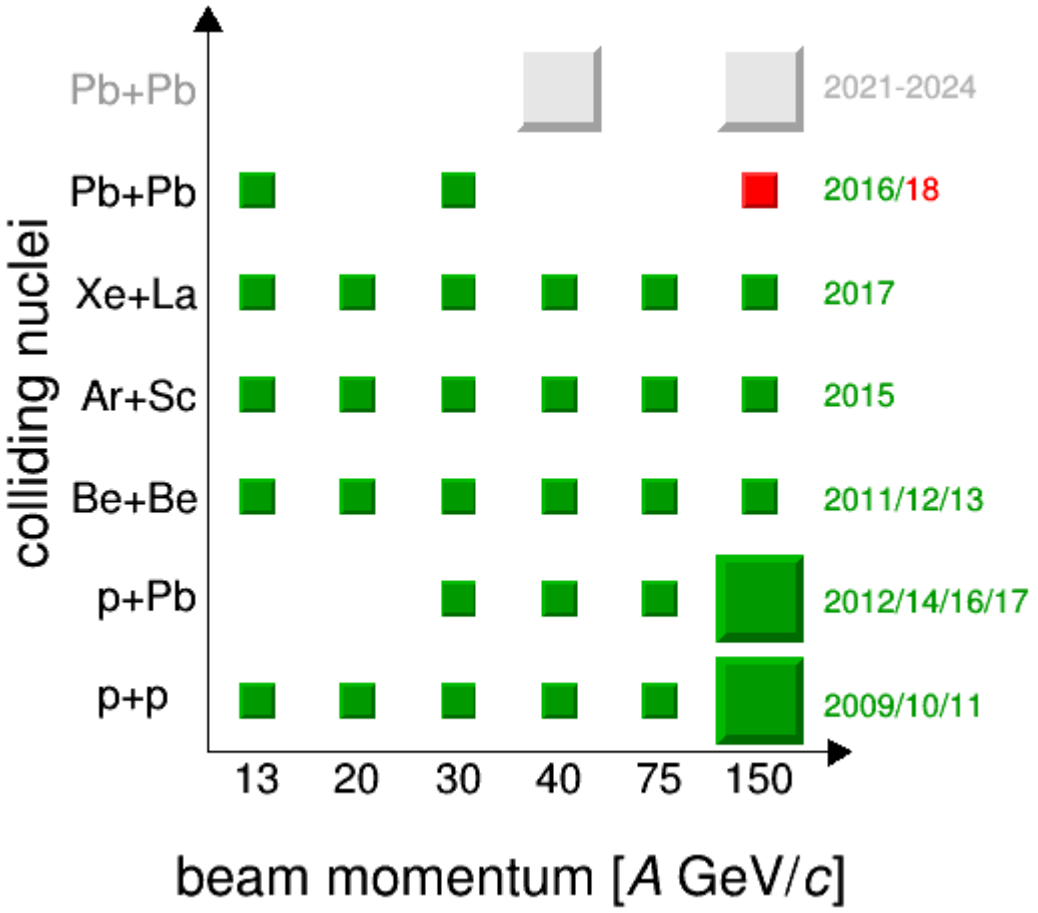
Wigner RCP, Budapest, Hungary

NA61/SHINE at CERN SPS



- **S**PS **H**eavy **I**on and **N**eutrino **E**xperiment
- Fixed-target experiment at CERN SPS
- Studies the hadron production in proton-proton, hadron-nucleus and nucleus-nucleus collisions
- 12 countries, 29 institutions, 141 authors

Physics program of NA61/SHINE



Main goals of the experiment:

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

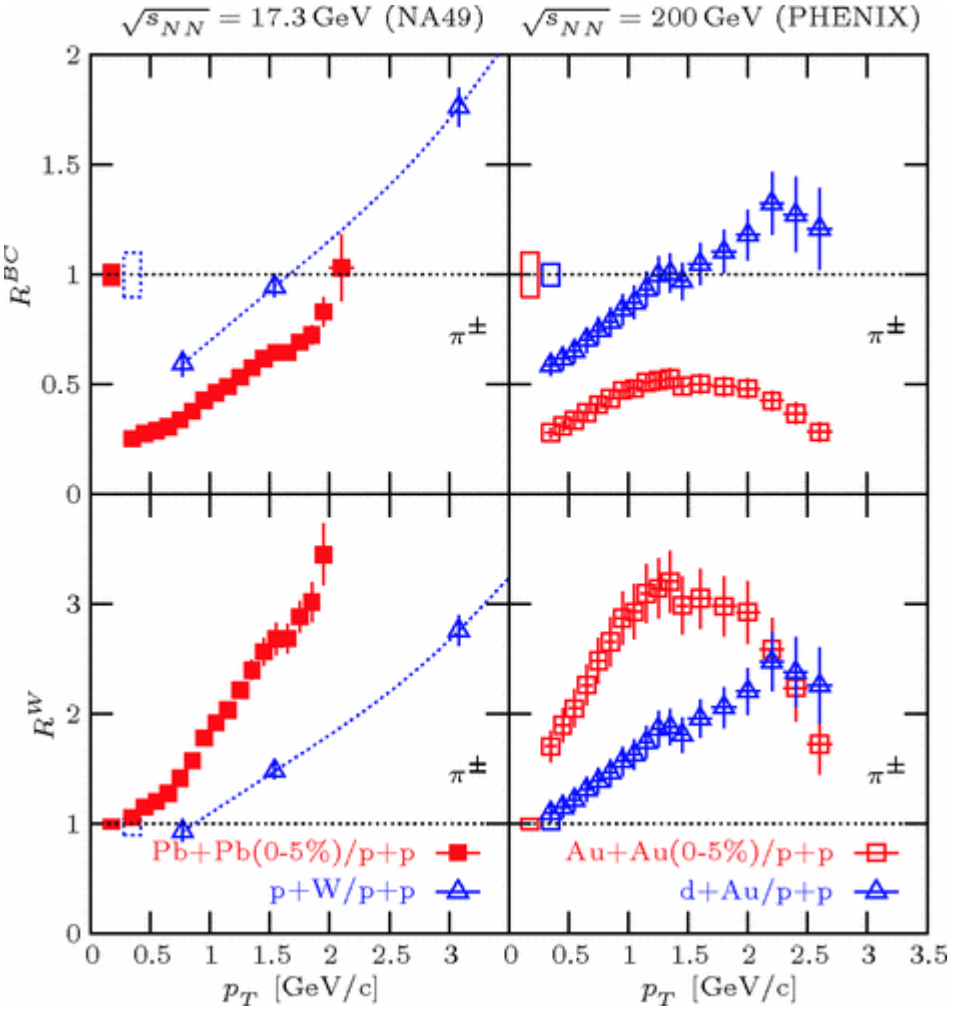
Why should we study high p_T particles?

- p+p and p+A collisions are important reference systems for A+A interactions
- BNL-RHIC: suppression of high p_T hadrons was observed in central A+A collisions relative to p+p → sign of parton energy loss in the formed hot and dense strongly interacting matter

How the nuclear modification factor looks like at CERN SPS energies?

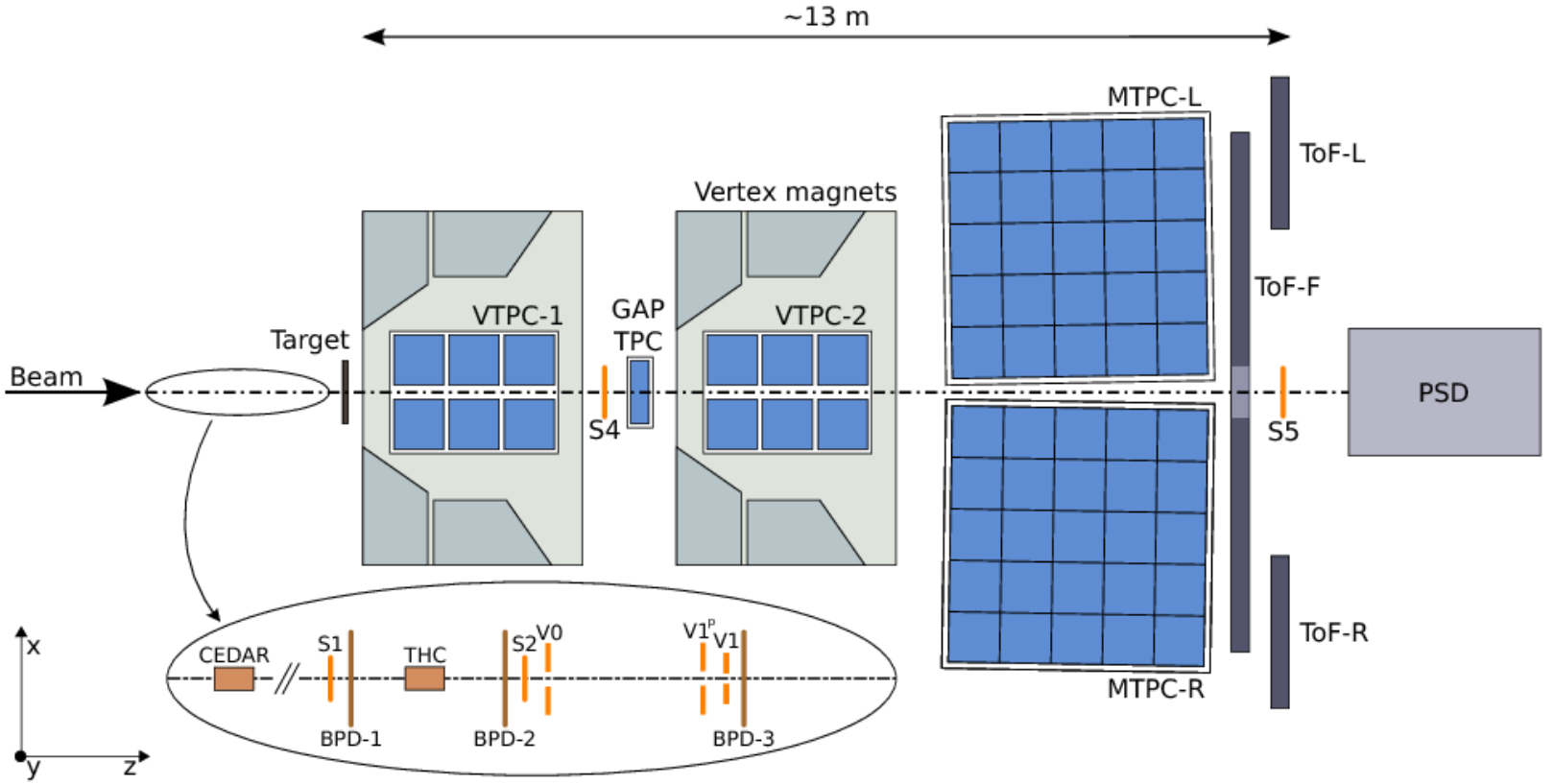
- p_T spectra was measured by NA49
  - up to 4.5 GeV/c in central Pb+Pb
  - up to 2.5 GeV/c in p+p and in p+Pb

→ What will happen above 2 GeV/c?



(C.Alt et al (the NA49 Collaboration): Physical Review C77 (2008) 034906)

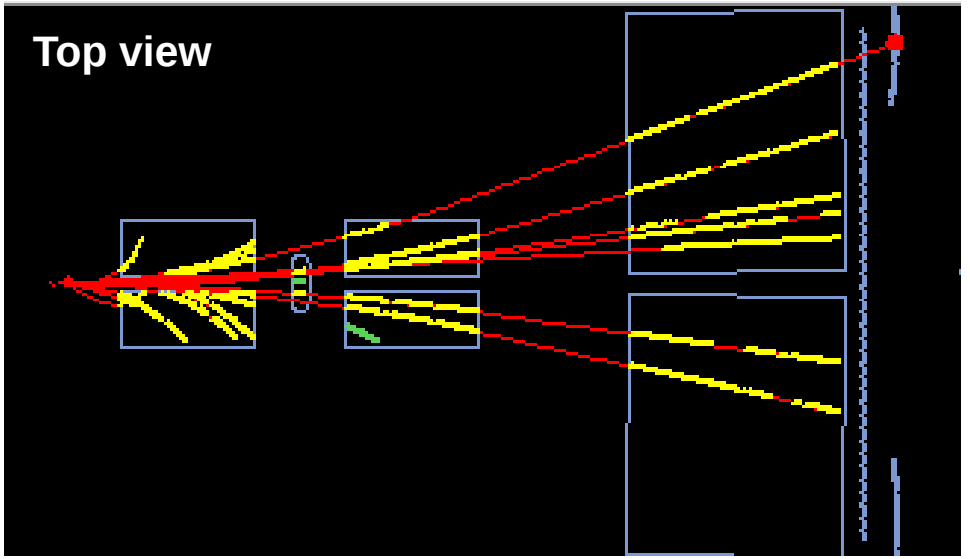
NA61/SHINE detector system

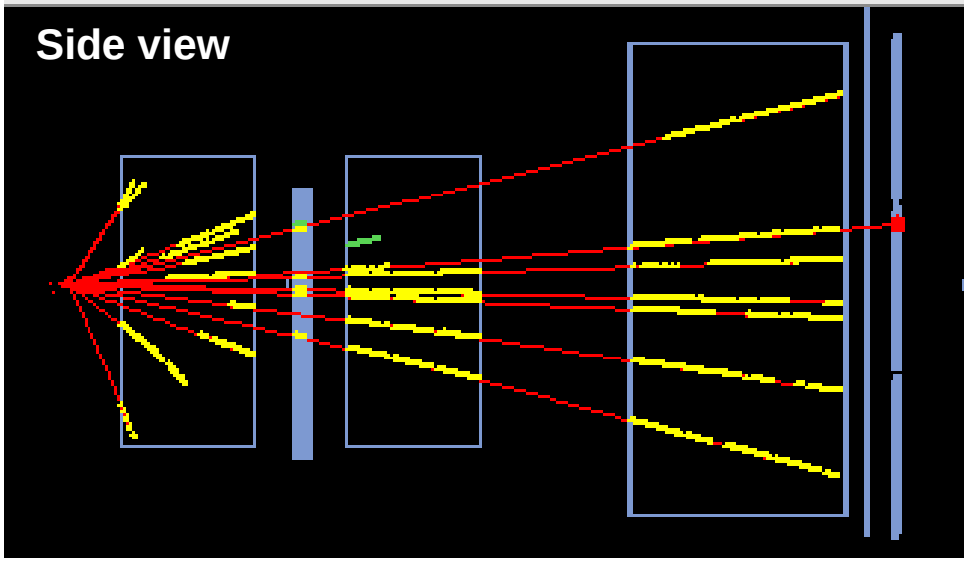


- Large acceptance hadron spectrometer with excellent capabilities for momentum, charge and mass measurements
- Main tracking devices: 4 large volume Time Projection Chambers

Events in NA61/SHINE

- 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 high p_T track selection

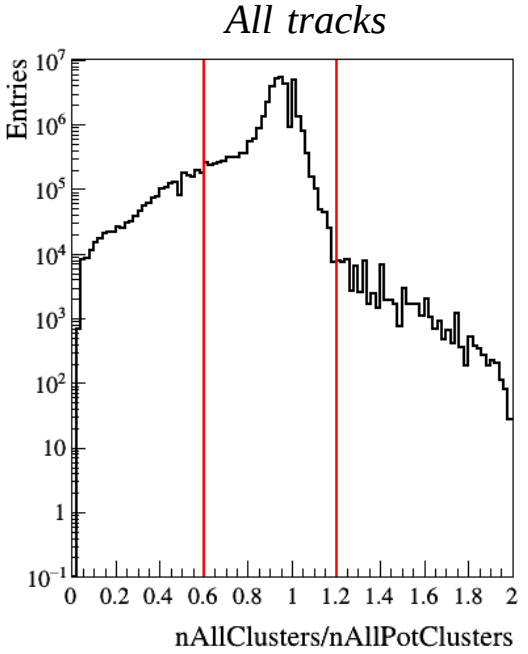
- By using the nClusters/nPotClusters ratio, one can define “good” and “bad” tracks
- Bad tracks: nClusters/nPotClusters < 0.6

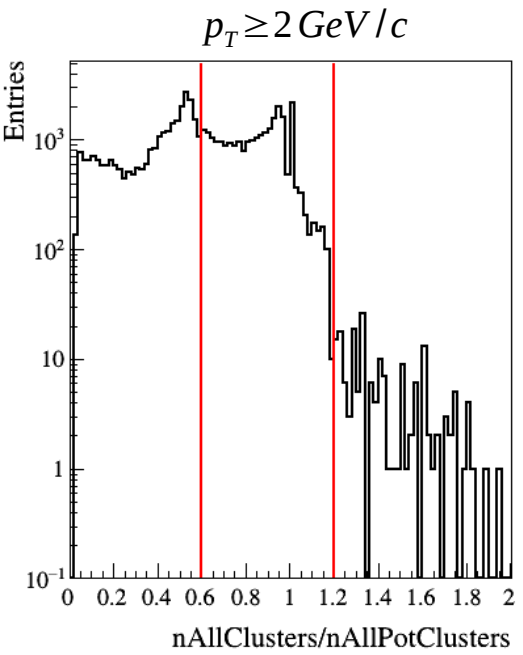
or

1.2 < nClusters/nPotClusters

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





$\Phi - p_T - y$ 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)

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

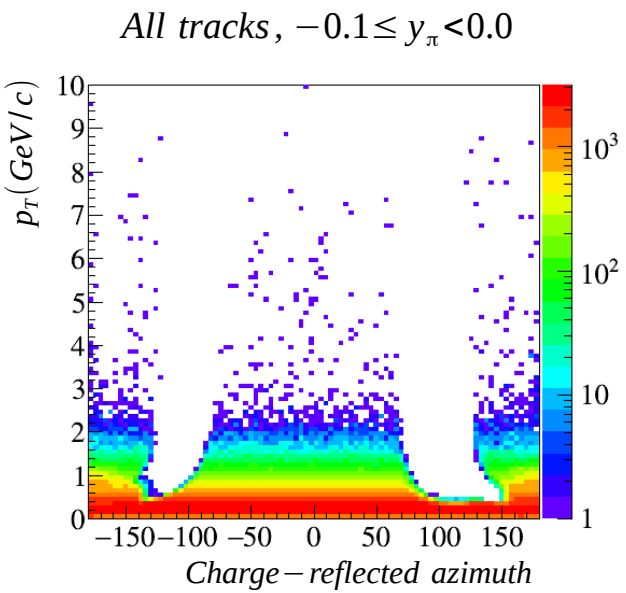
$$p_T = \sqrt{p_x^2 + p_y^2}$$

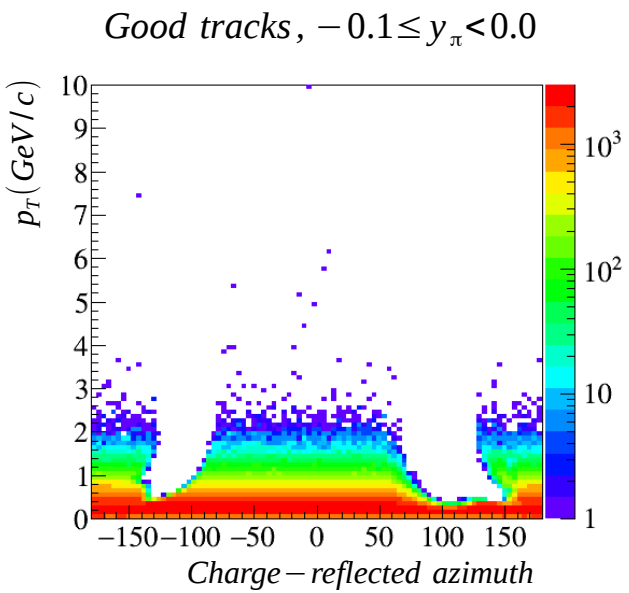
$$y = \frac{1}{2}\ln\left(\frac{E + p_z}{E - p_z}\right)$$

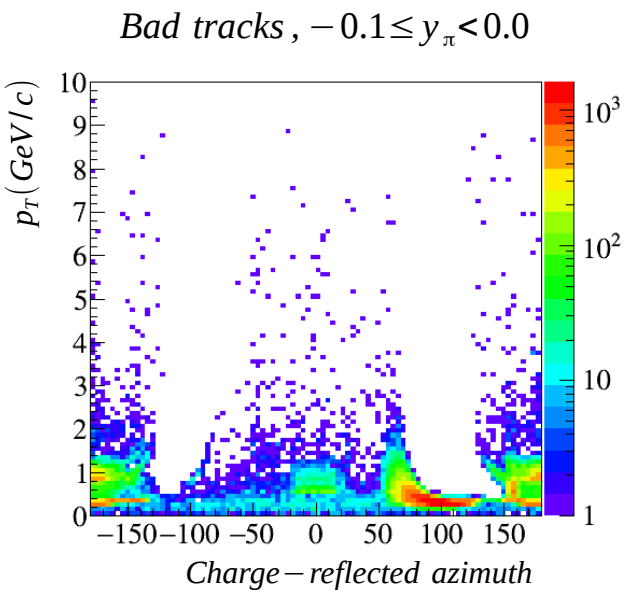
Phase-space cut:

- 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





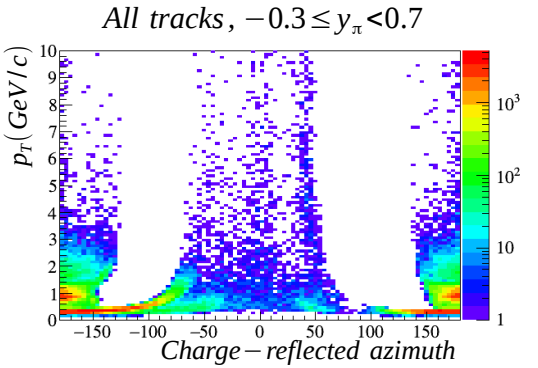


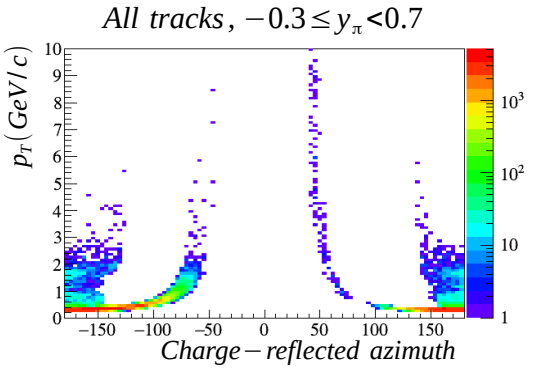
- Rapidity was calculated with pion mass assumption
- The high p_T region is dominated by bad tracks

Rejection of discontinuous tracks

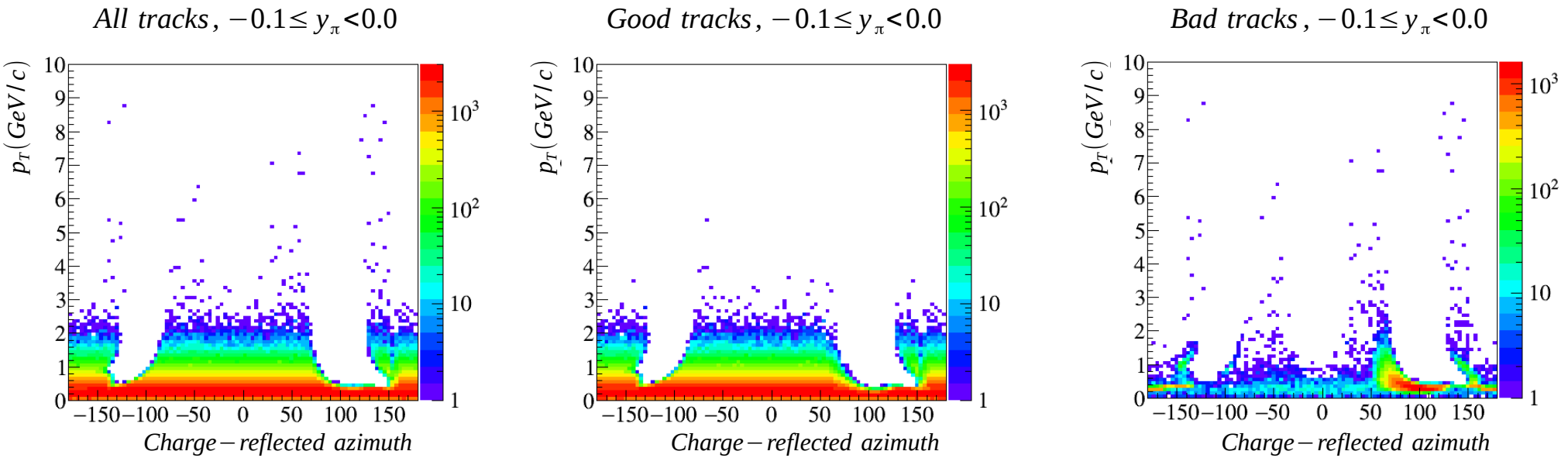
- The high p_T region is populated by misfitted tracks
- These fake tracks have:
  - 0 clusters in a given TPC but more than 0 potential clusters
    or
  - more than 0 clusters in a given TPC but 0 potential clusters

- ***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 $\Phi \approx 0$



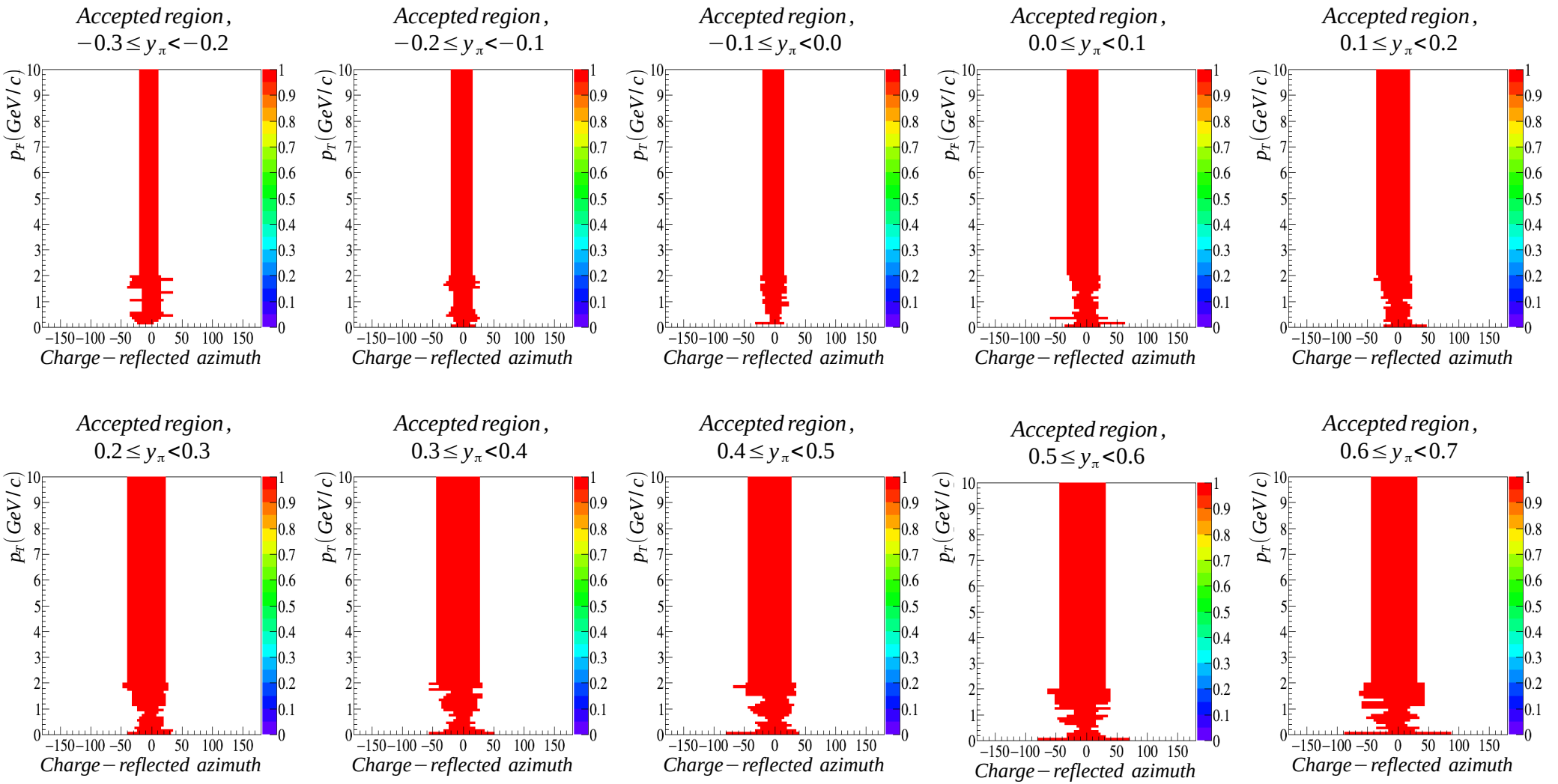


Phase-space distributions after the rejection of discontinuous tracks

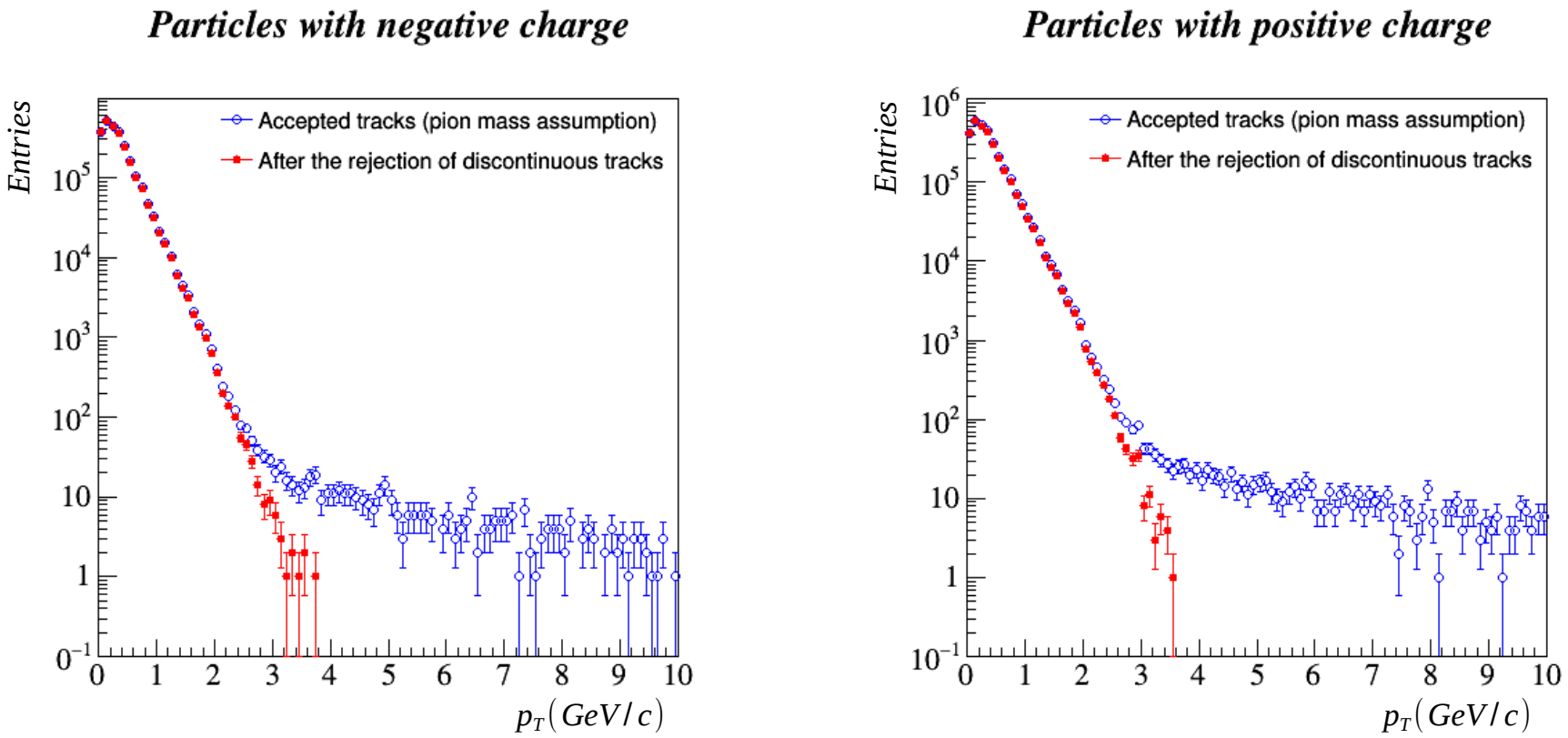


- Rapidity was calculated with pion mass assumption
- After the rejection of discontinuous tracks, the bad tracks disappear from the high p_T region around $\Phi \approx 0$, the rest can be removed by the 3 dimensional phase-space cut

Acceptance map with pion mass assumption

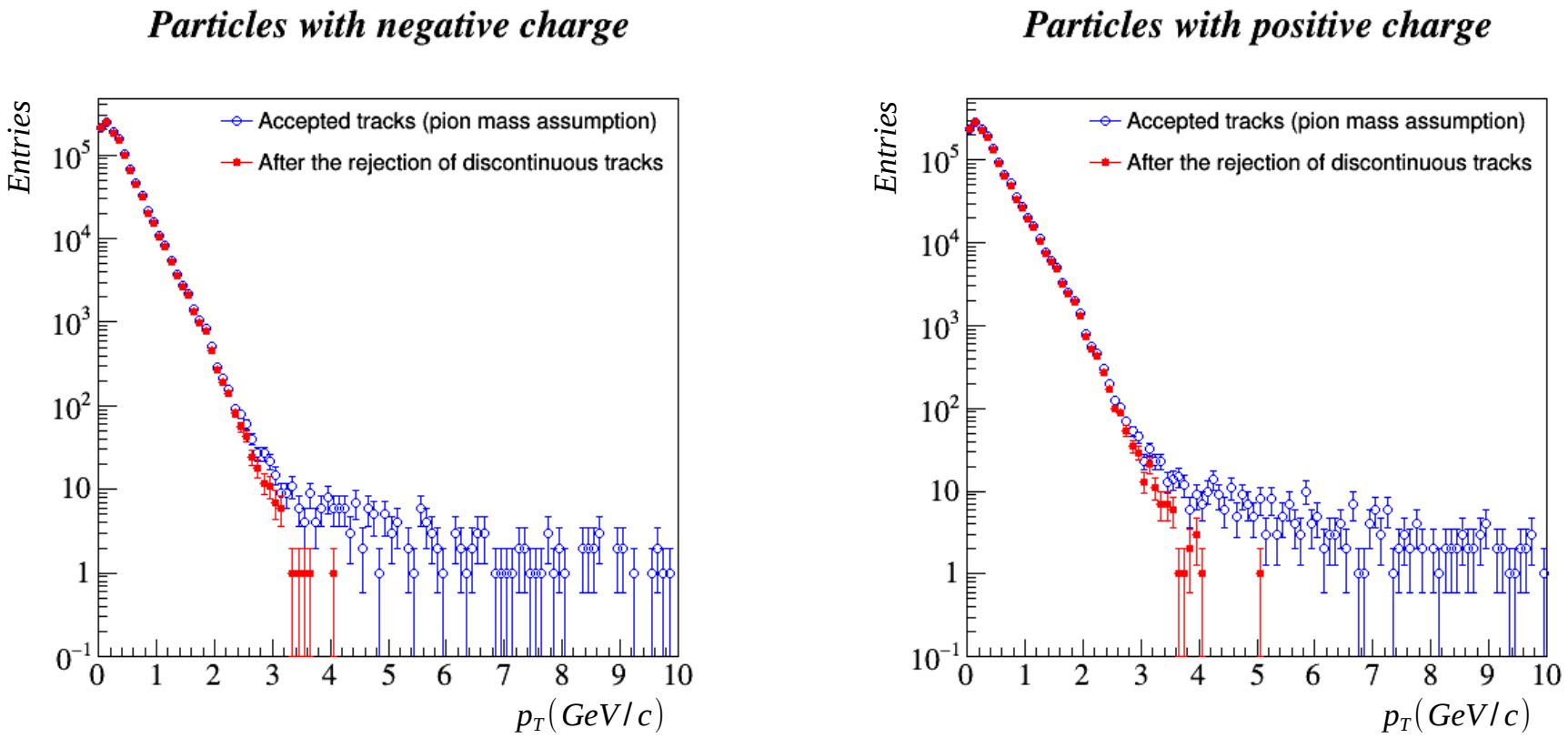


p_T distribution of charged particles in p+p collisions



- 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

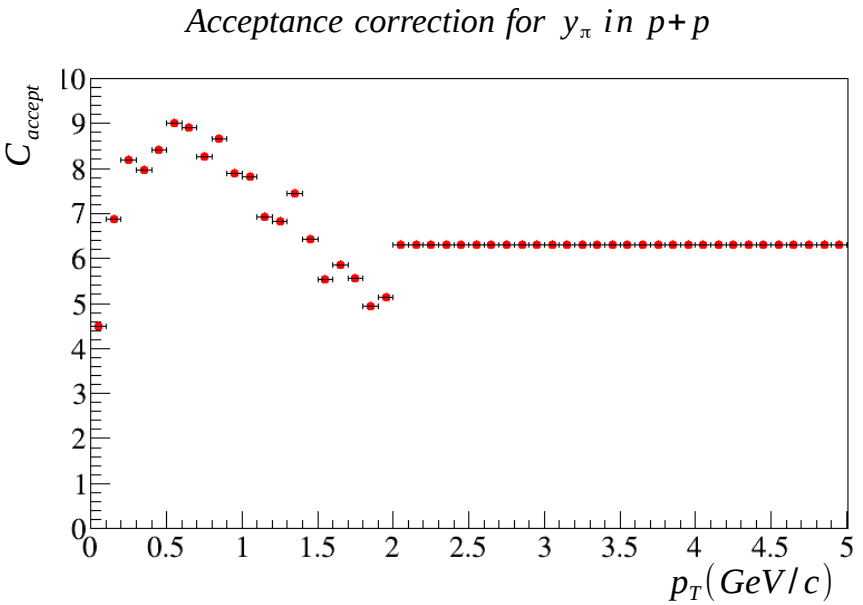


- p_T distributions of unidentified charged hadrons from the accepted phase-space
- The rejection of the discontinuous tracks removes the background of fake tracks at high p_T

Acceptance correction

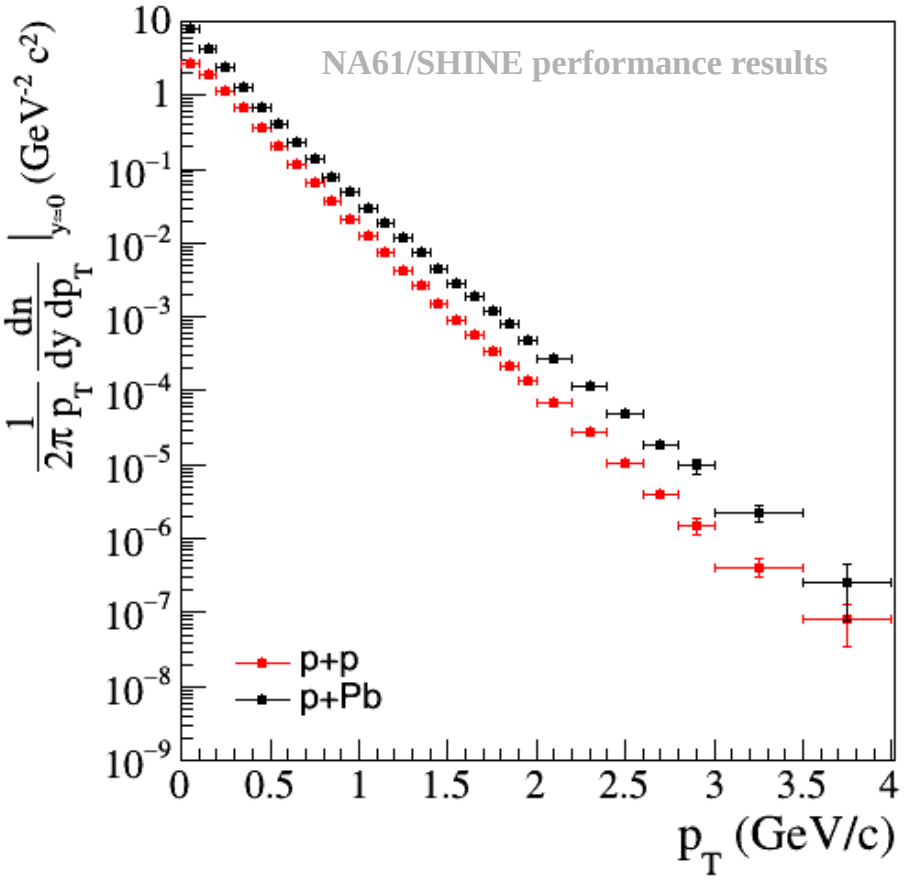
- The accepted Φ region is p_T and rapidity dependent
- Extrapolation needed to the full -180°< Φ < 180° coverage
- In p+p collisions: flat rapidity distribution can be assumed around mid-rapidity (-0.3 ≤ y < 0.7)
- In p+Pb collisions: rapidity spectra is not symmetric, correction for the y-dependence has to be done
- Acceptance correction factor:

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

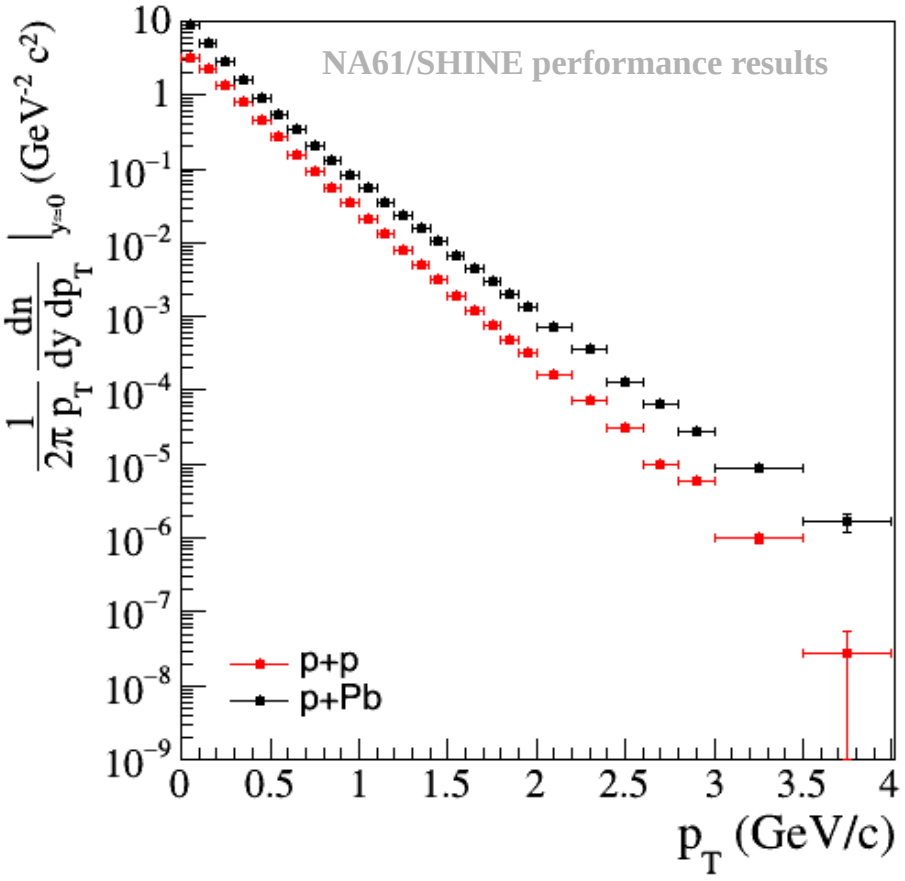


Acceptance corrected spectra in p+p and p+Pb collisions

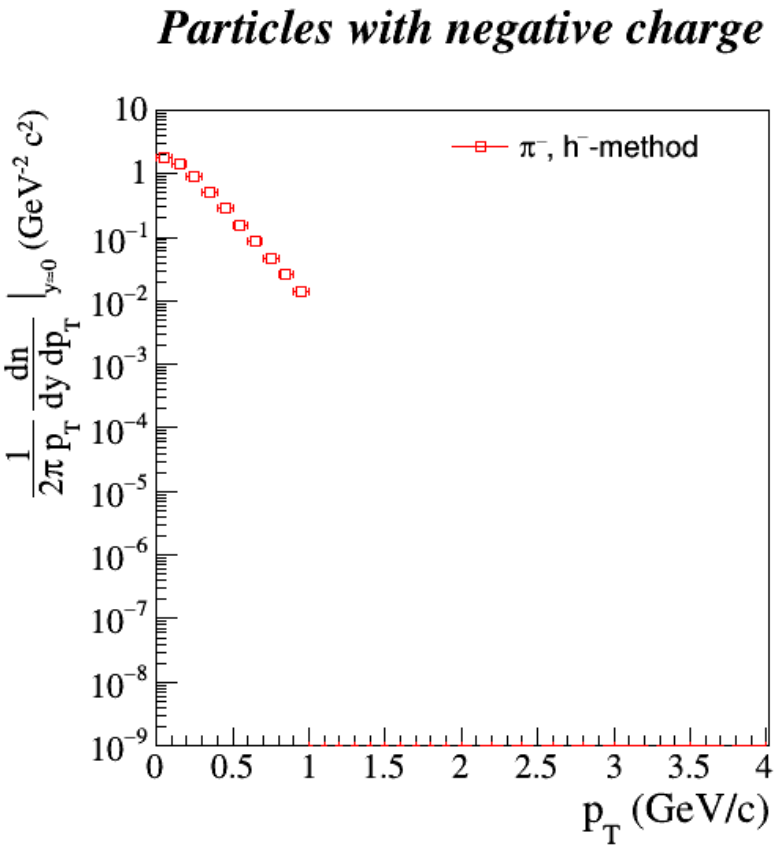
Particles with negative charge



Particles with positive charge



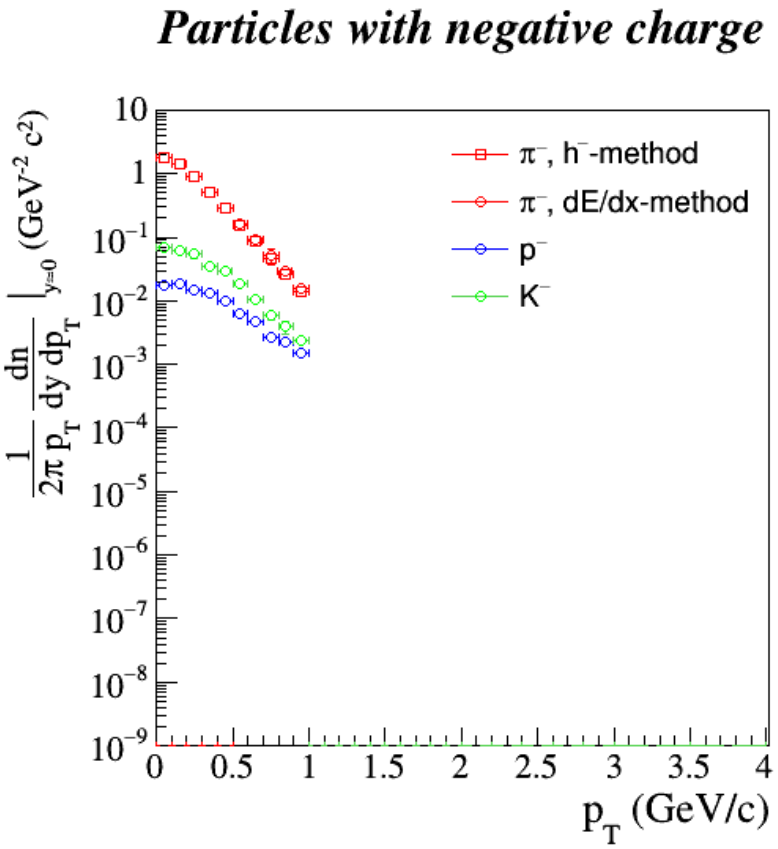
Spectra in p+p collisions in NA61

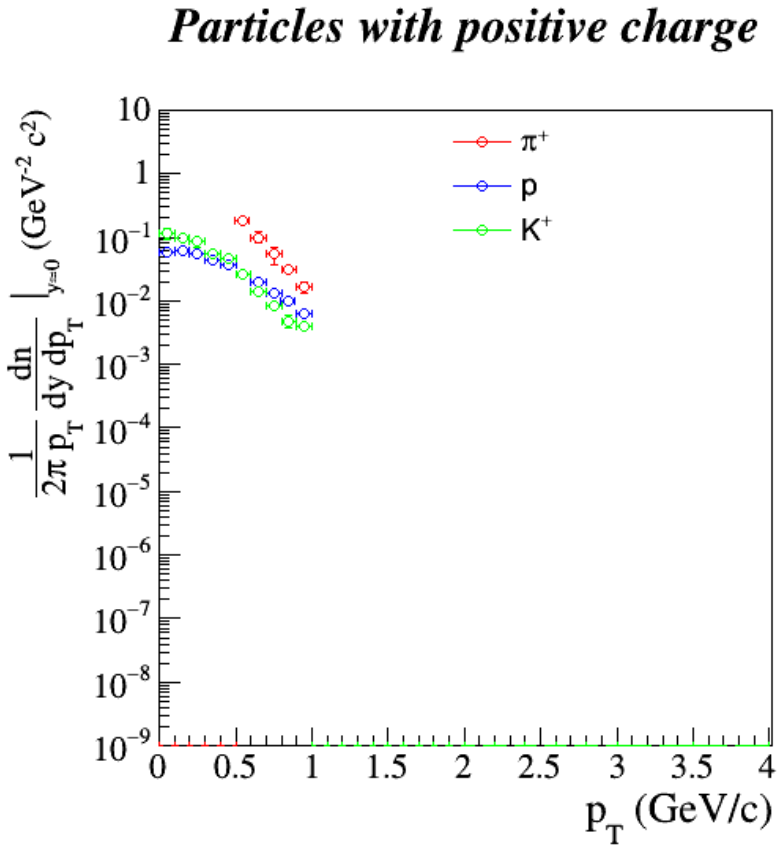


Comparison of published NA61 results on particle spectra in p+p collisions (only statistical uncertainties are shown on the plots)

1) 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)

Spectra in p+p collisions in NA61





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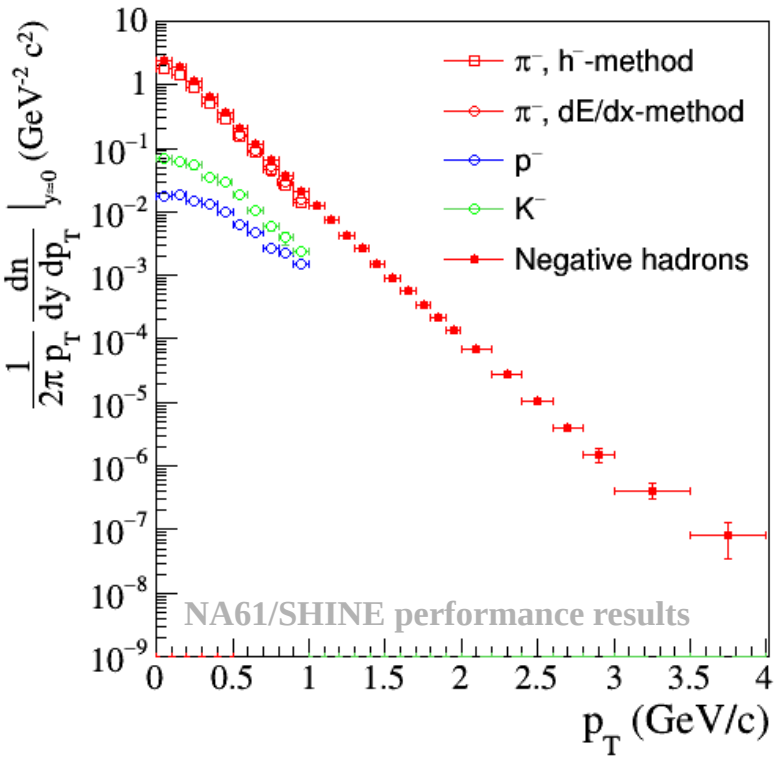
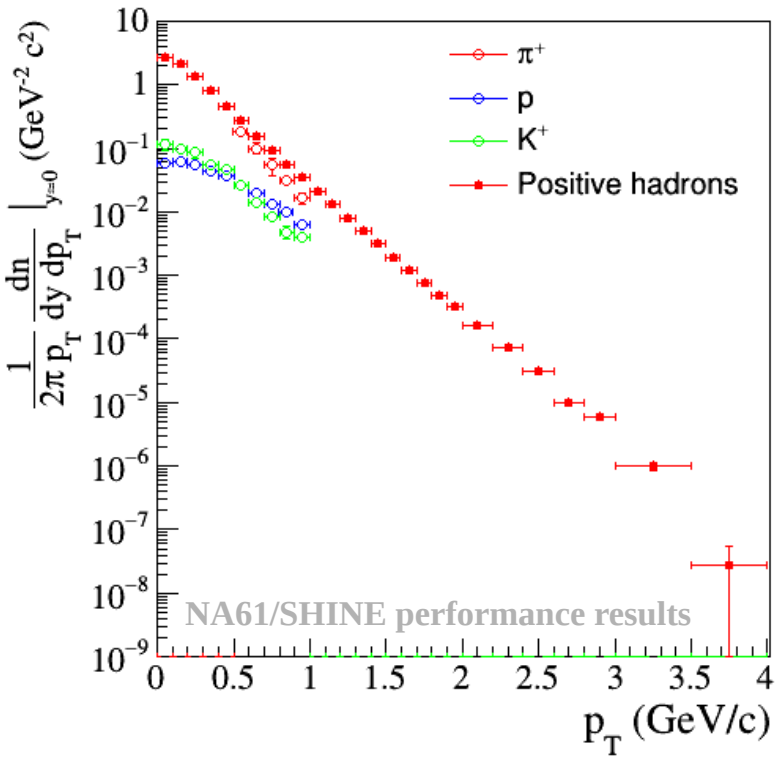


Particles with positive charge



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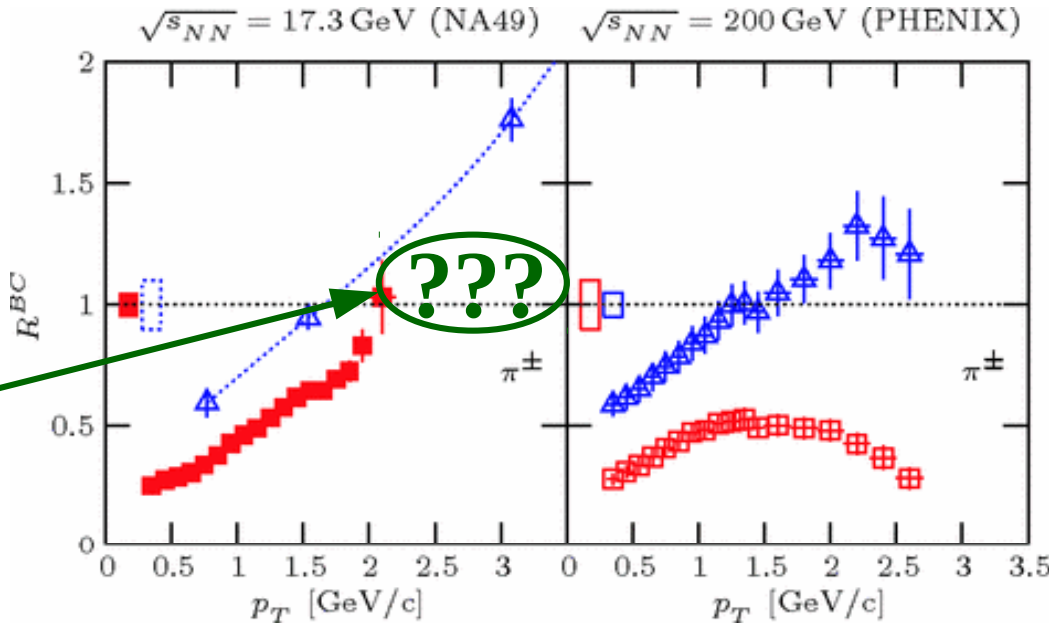
Summary and outlook

- 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
  → a special track selecting method is needed to remove fake tracks
- With this method, particle production can be studied up-to $p_T \sim 4$ GeV/c

Plans for the close future:

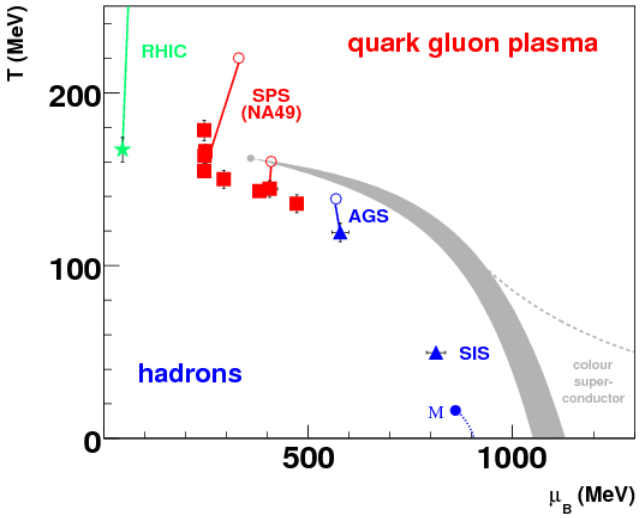
- After particle identification, the comparison to Pb+Pb data and the study of the nuclear modification factor will be possible in the high p_T region

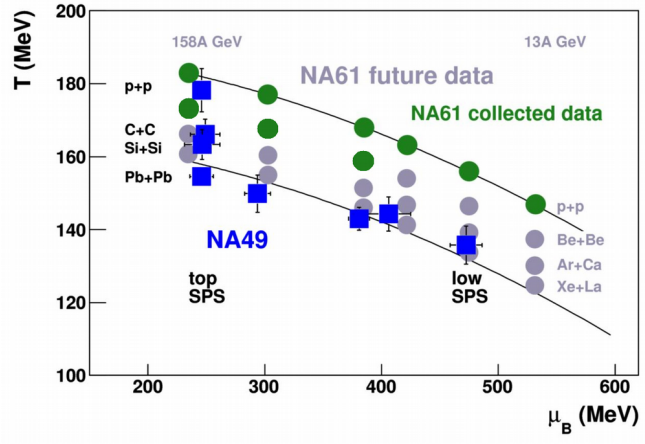


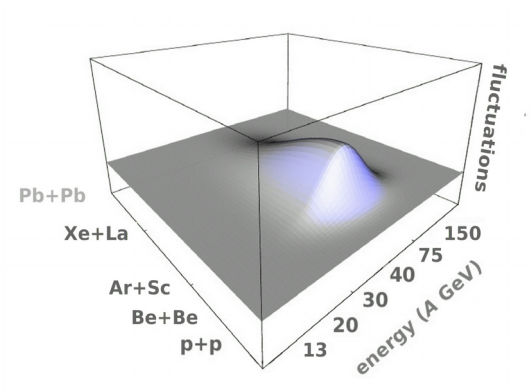
Thank You for Your Attention!

Backup slides

Critical point and the onset of deconfinement

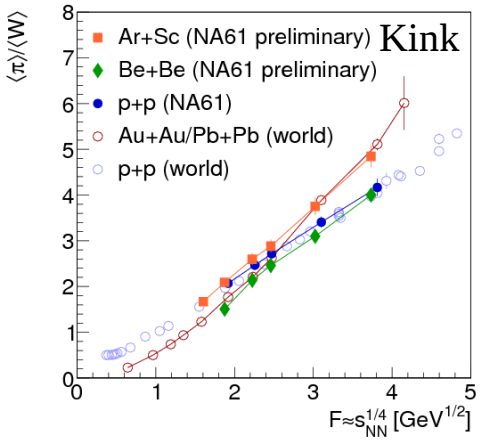


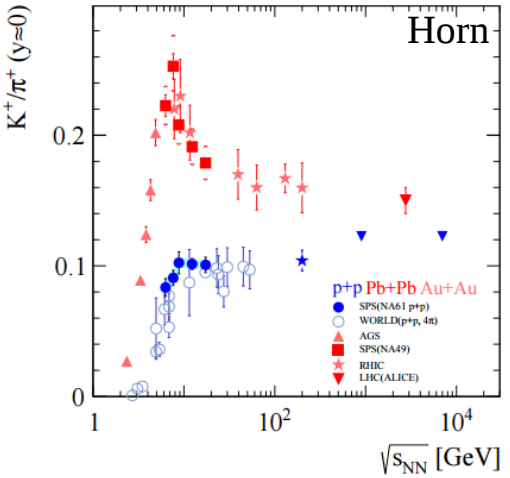


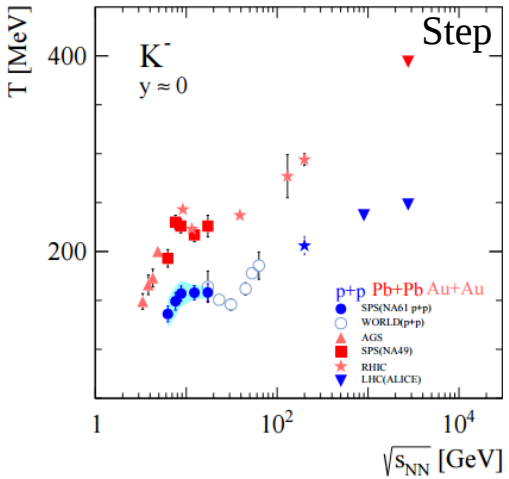


Onset of deconfinement:

- Kink: total pion multiplicity divided by the number of inelastically interacting nucleons as a function of Fermi energy
- Horn: ratio of multiplicity of positively charged kaons and pions as a function of energy in the center of mass frame
- Step: inverse slope parameter of the transverse mass spectrum of positively charged kaons



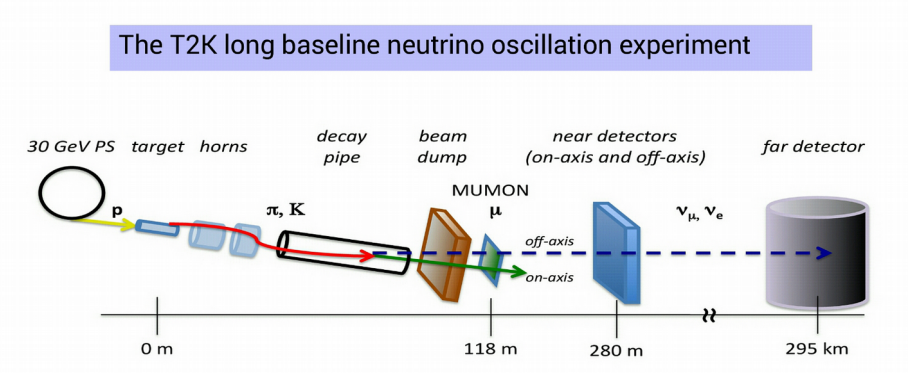




Reference for neutrino and cosmic ray experiments

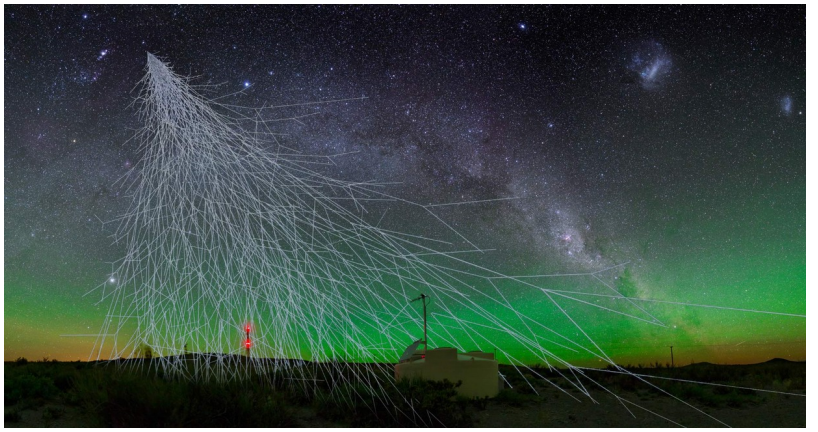
Neutrino experiments

- T2K (Japan): neutrino beams form JPARC to the Super-Kamiokande to study neutrino oscillation → initial neutrino fluxes are important
- NA61 measures the productions of charged pions and kaons at p_{beam} = 31 GeV/c in interactions of protons with a 2cm graphite target and with a 90cm thick T2K replica (carbon) target



Cosmic ray experiments

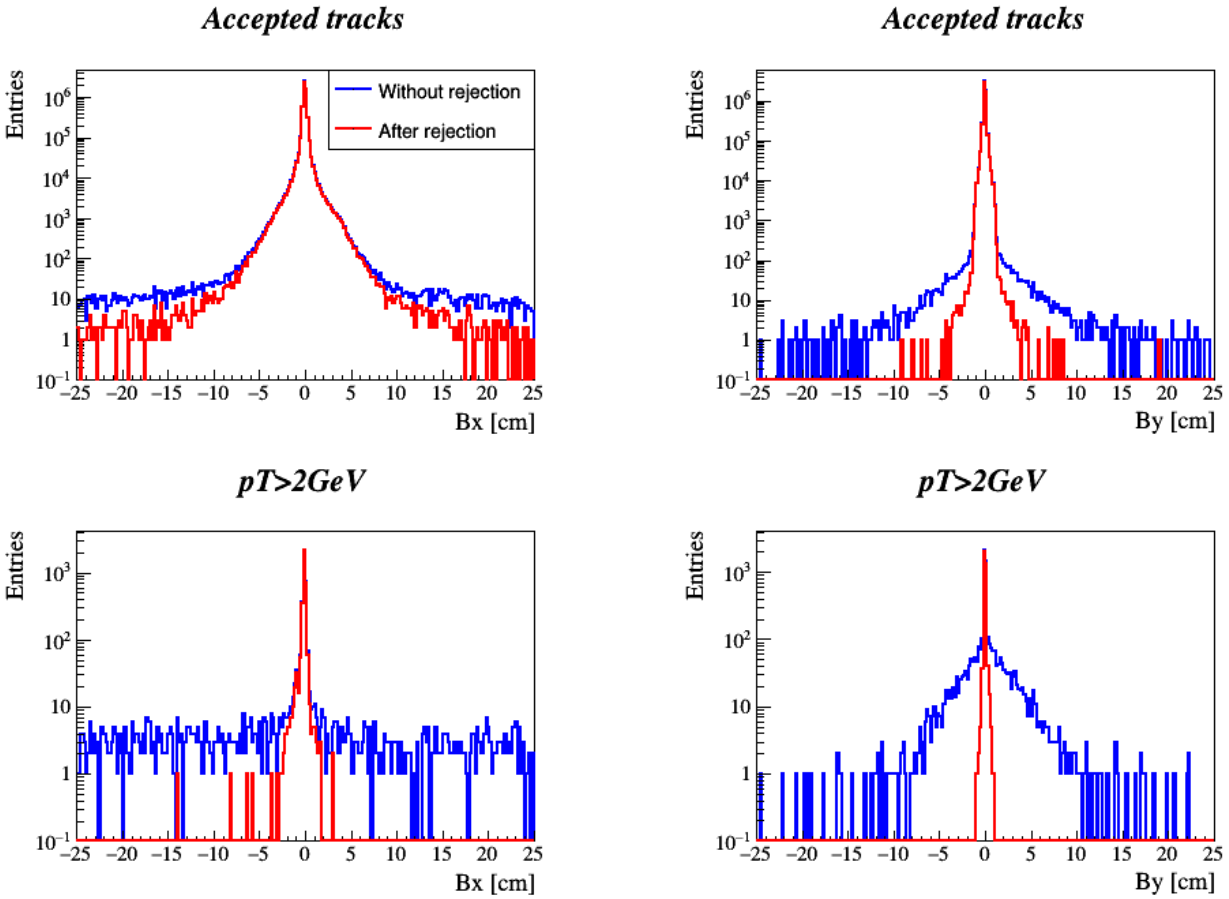
- Pierre Auger Observatory: detects cosmic rays by measuring particles from atmospheric showers reaching detectors on the ground
- NA61 measures π^-+C interactions at 158 GeV/c and 350 GeV/c to reduce systematic uncertainties in simulations of the showers used to reconstruct properties of the initial cosmic ray particles



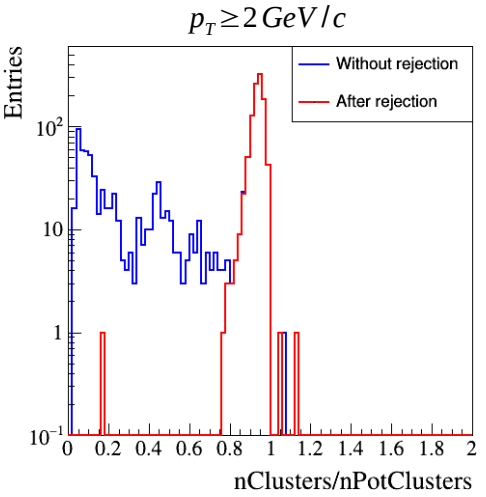
Collected data in p+p and p+Pb @ 158 GeV/c

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

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