ALICE

Transverse momentum distributions of identified hadrons in p–Pb collisions at $\sqrt{s}$ = 5.02 TeV measured with ALICE at the LHC

ALICE, arXiv:1307.6796 [nucl-ex]

Jonas Anielski for the ALICE collaboration

Westfälische Wilhelms-Universität Münster

Outline

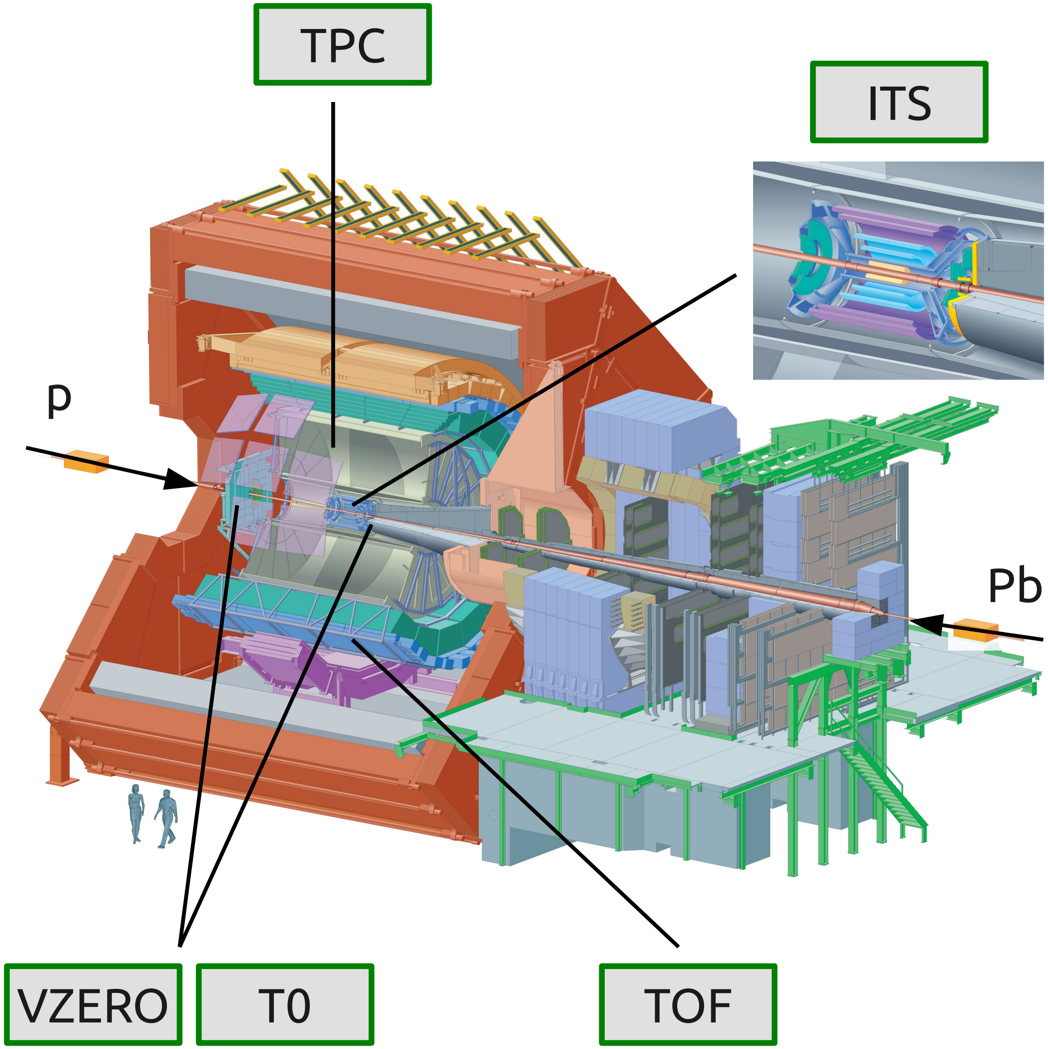
- ALICE overview
  - Detector, multiplicity selection and particle identification
- Transverse momentum distributions
  - $\pi^{\pm}$, $K^{\pm}$, K^0_s, p ($\bar{p}$), Λ ($\bar{\Lambda}$)
- Hadron-production vs. multiplicity
  - $\langle p_T \rangle$ as a function of charged-particle multiplicity
  - Particle production ratios (vs. p_T)
  - Comparison with pp and Pb-Pb collisions
- Spectral shape analysis and model comparison
  - Global blast-wave fits and parameters
  - Comparison with pp and Pb-Pb collisions and models
- Summary and conclusions

The ALICE experiment

A Large Ion Collider Experiment

PID over wide p_T range with several techniques:

- energy loss (dE/dx)
- time-of-flight
- topological decays



Subdetectors used for this analysis

TPC	tracking + vertexing + PID (dE/dx)
TOF (T0)	PID (time-of-flight)
ITS	tracking + vertexing + PID (dE/dx)
VZERO	trigger, beam-BKG rejection multiplicity classes

Data sample

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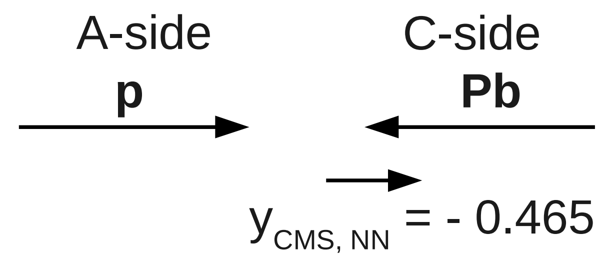
Data sample: **p-Pb collisions** collected in 2013 at the LHC $\mathbf{\sqrt{s_{NN}} = 5.02}$ **TeV**

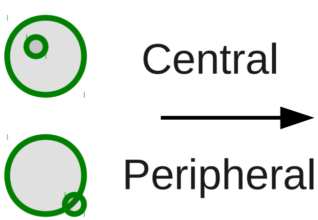


- asymmetric energy/nucleon in the two beams
  - cms moves with rapidity $y_{CMS} = -0.465$
  - acceptance of TPC and TOF $|\eta_{LAB}| < 0.9$

    → measurement in $0.0 < y_{CMS} < 0.5$

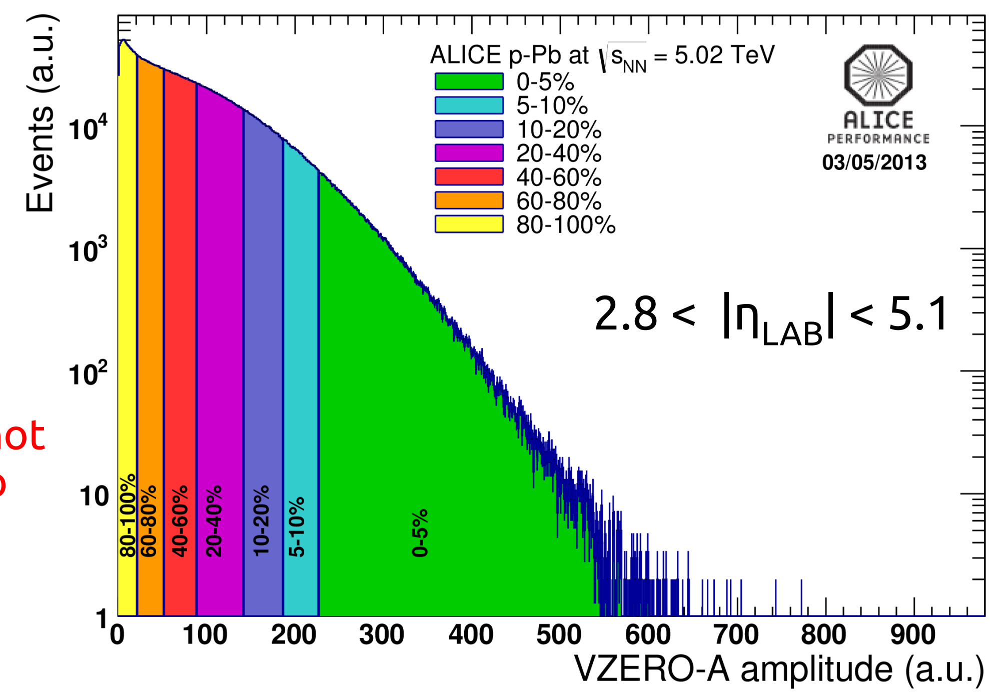
Definition of seven multiplicity classes:

- slices in VZERO-A (V0A) amplitude



correlation between impact parameter and multiplicity is not as straight-forward as in Pb-Pb

talk A. Morsch Thursday



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p_T spectra in several multiplicity classes

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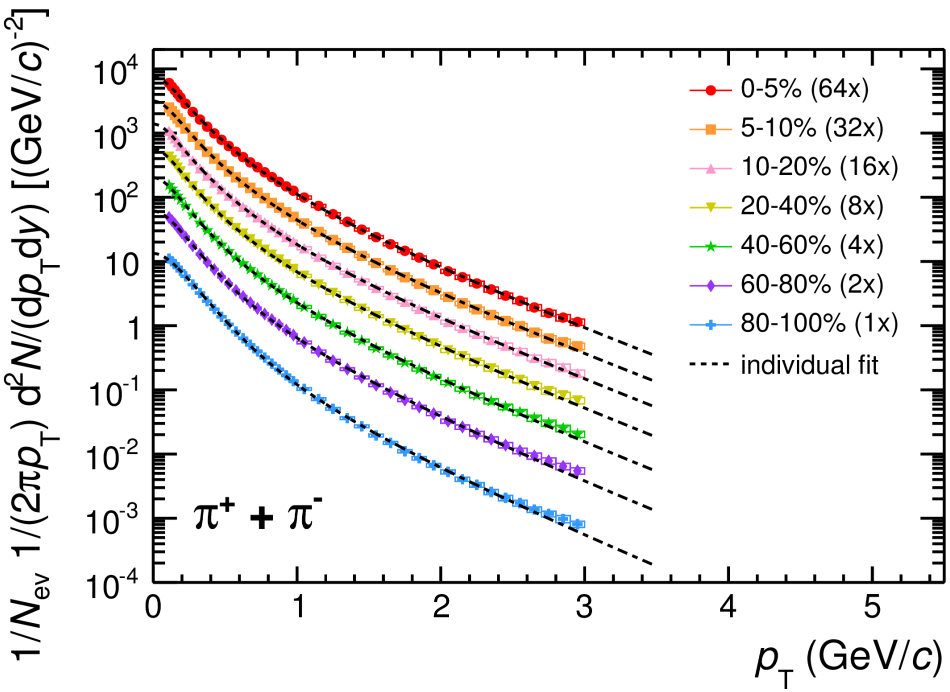
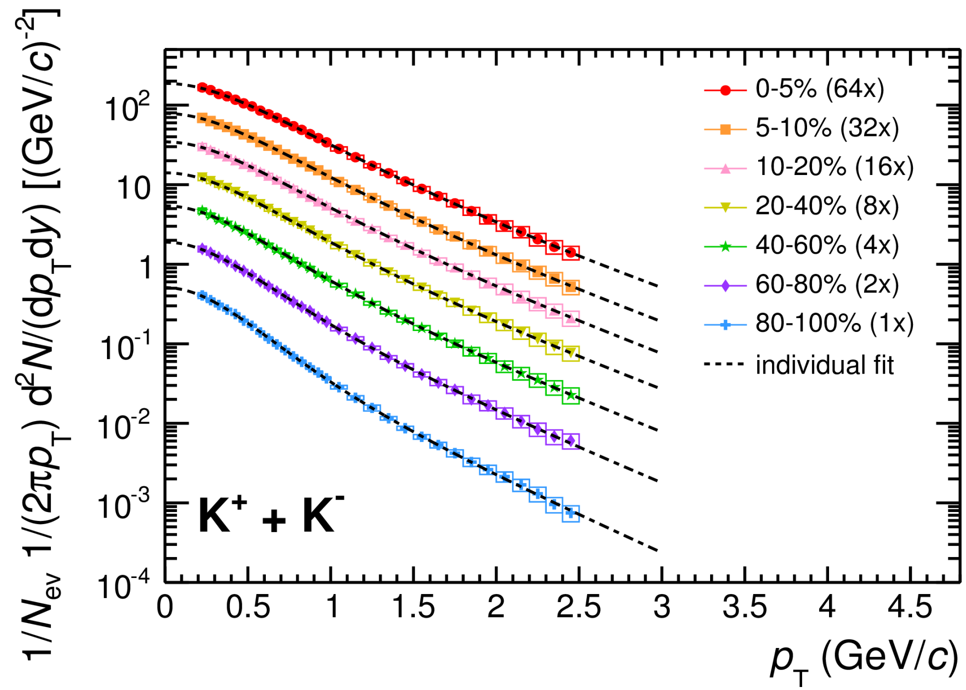
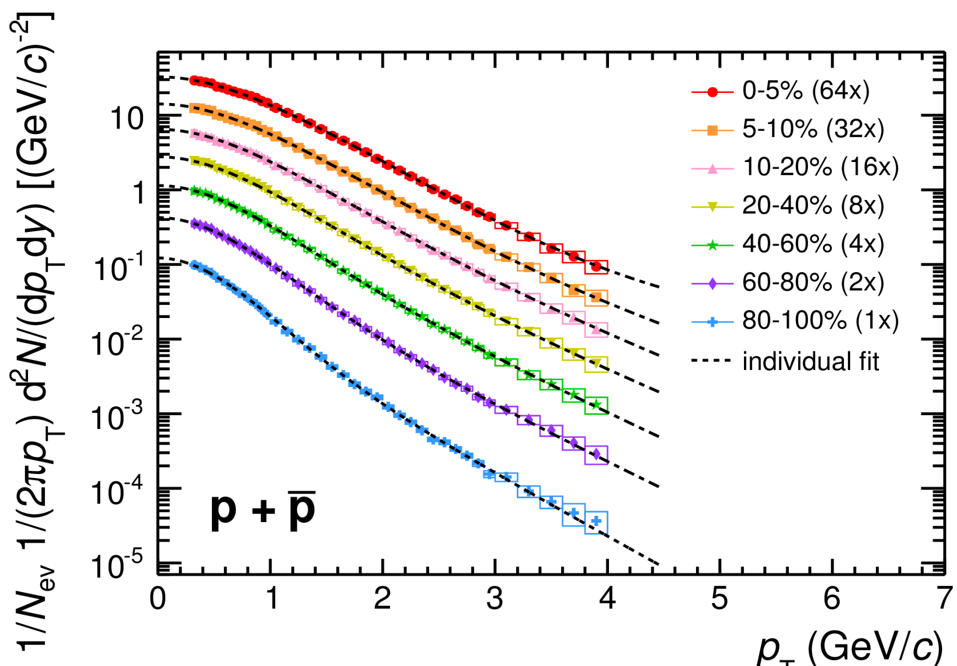




Dotted lines: individual blast-wave fits for low and high p_T extrapolation

Particle	p_T range (GeV/c)
$\pi^{\pm}$	0.1 – 3.0
$K^{\pm}$	0.2 – 2.5
$p(\bar{p})$	0.3 – 4.0
K^0_s	0.0 – 8.0
$\Lambda(\bar{\Lambda})$	0.6 – 8.0



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p_T spectra in several multiplicity classes

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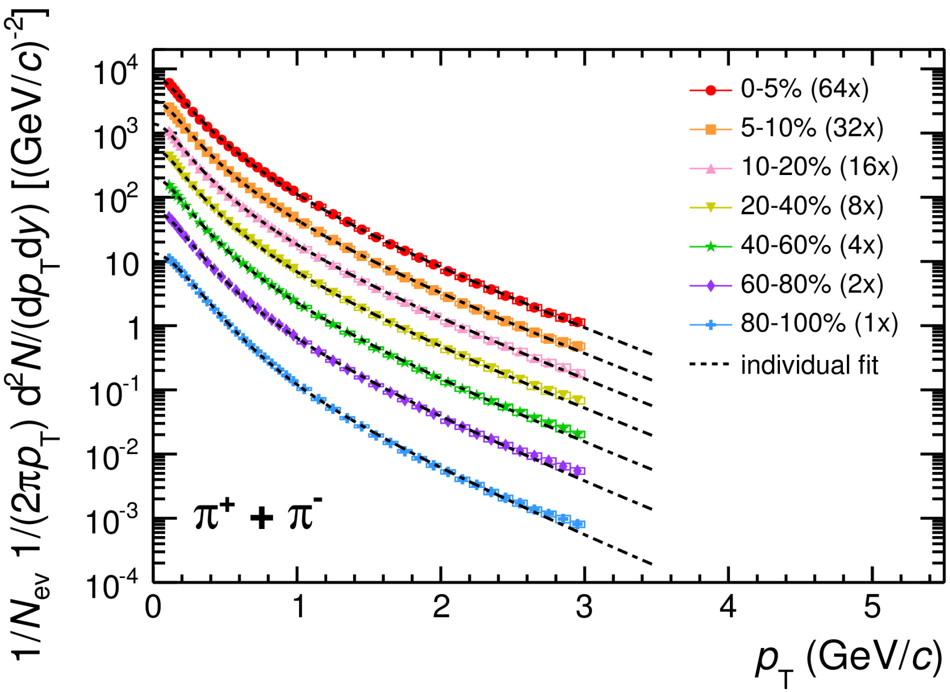

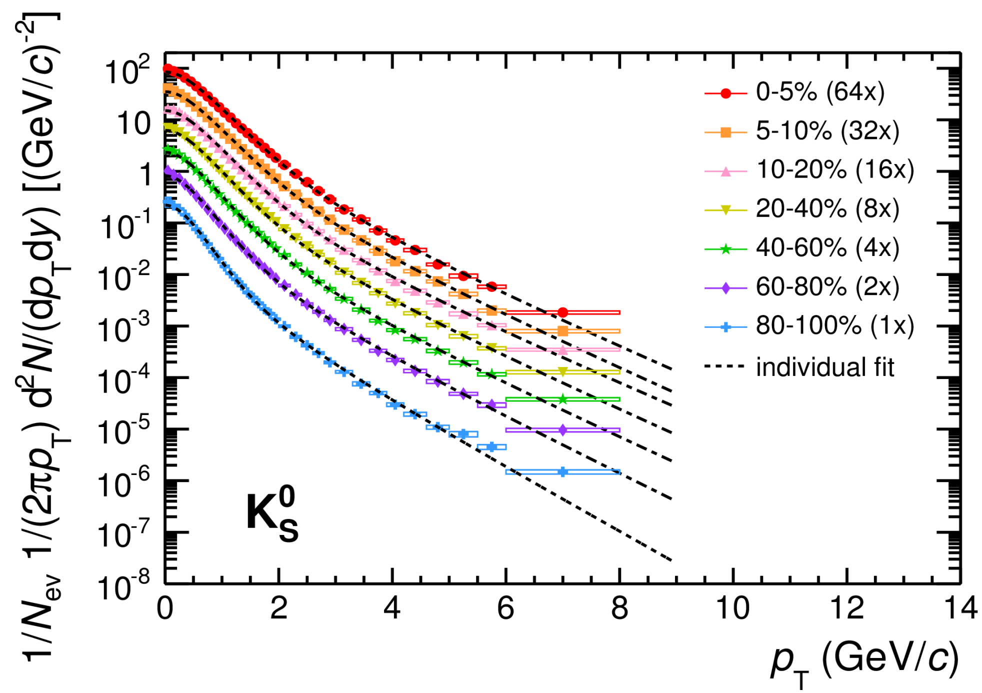

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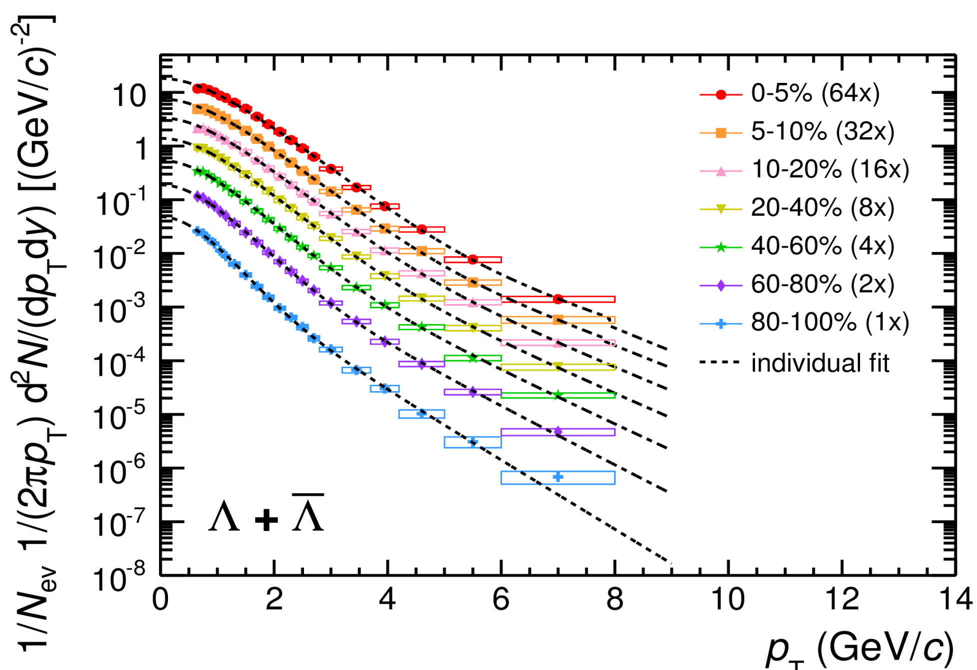

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<p_T> vs. charged multiplicity

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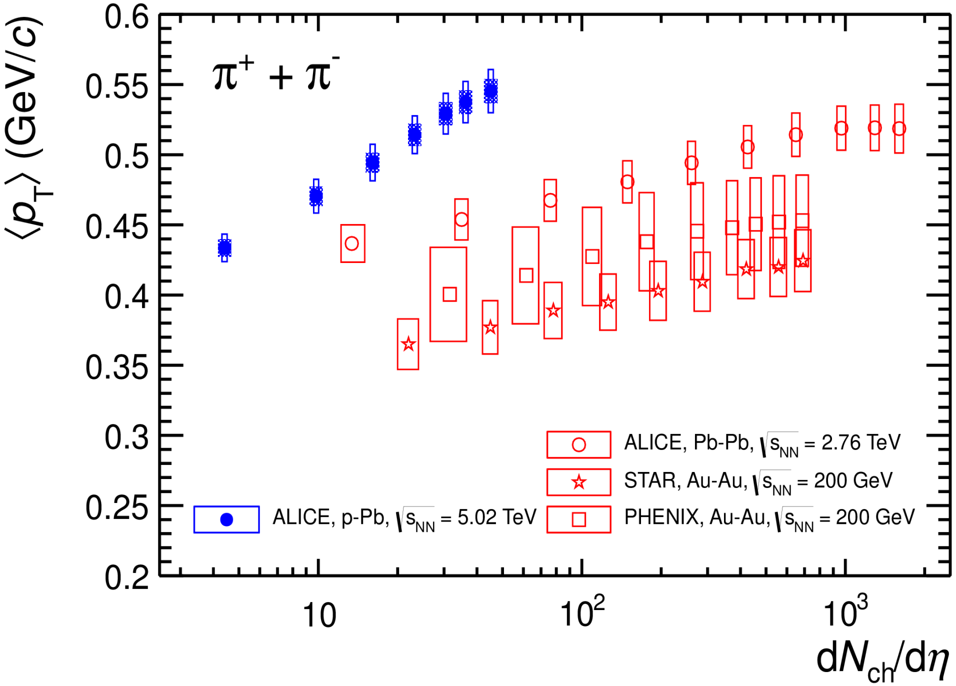
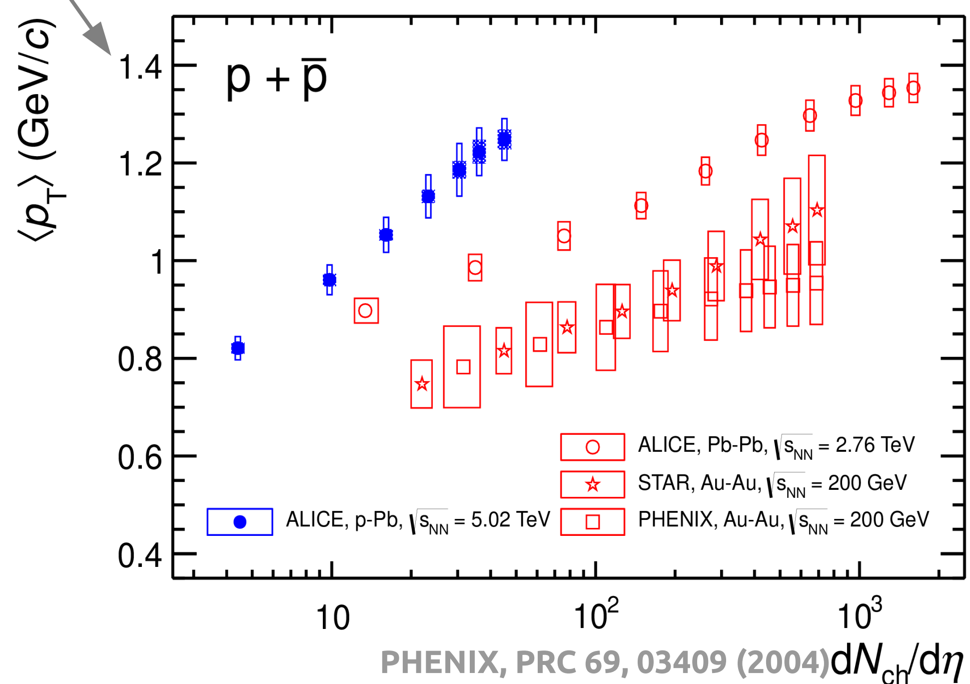
different scales





Identified-hadron <p_T> vs. dN_{ch}/dη

PHENIX, PRC 69, 03409 (2004)
ALICE, arXiv:1303.0737 [hep-ex]
STAR, PRC 79, 034909 (2009)
STAR, PRL 108, 072301 (2012)

→ <p_T> increases with multiplicity in p-Pb for all particles

→ mass ordering: larger mass → larger <p_T>

→ p-Pb values higher than Pb-Pb for similar multiplicity → **harder spectra**

→ <p_T> of protons in p-Pb smaller than in Pb-Pb for highest multiplicity bin

K/π and p/π vs. p_T as a function of multiplicity

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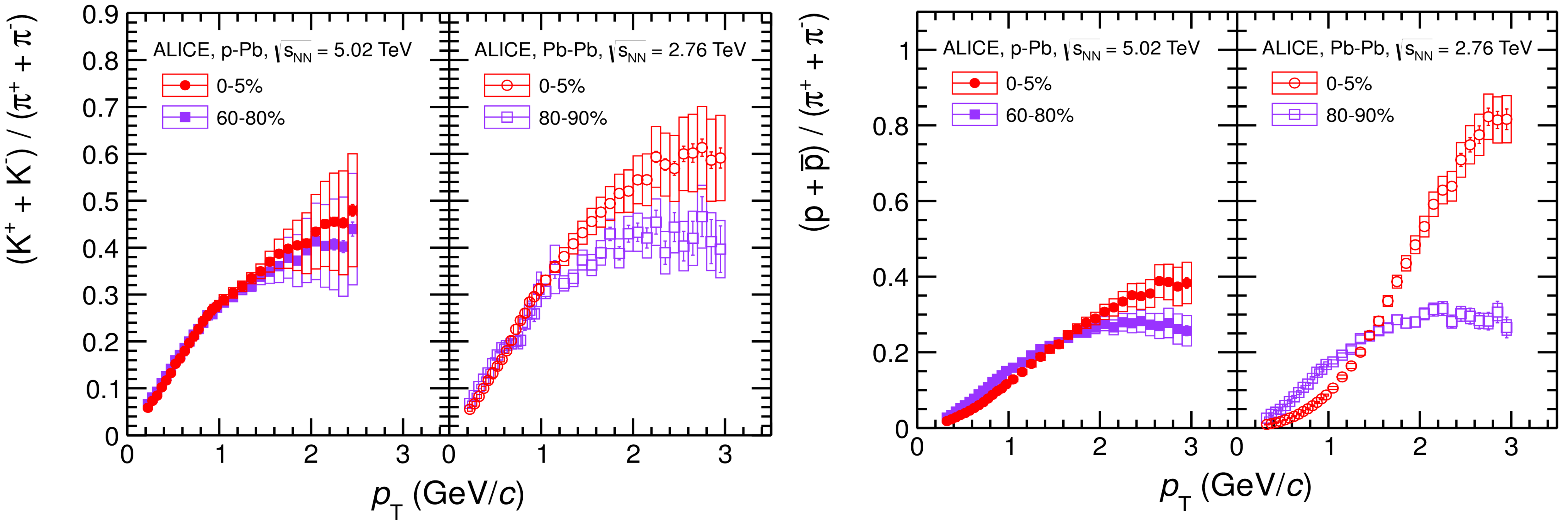
Note: systematic errors are largely correlated across multiplicity
multiplicity uncorrelated errors are drawn as a band for p-Pb

ALICE, arXiv:1303.0737 [hep-ex]



K/π ratio vs p_T:

→ small increase at intermediate p_T with increasing multiplicity

p/π ratio vs p_T:

→ increase at intermediate p_T with increasing multiplicity
→ corresponding depletion at low p_T
→ stronger effect than in K/π

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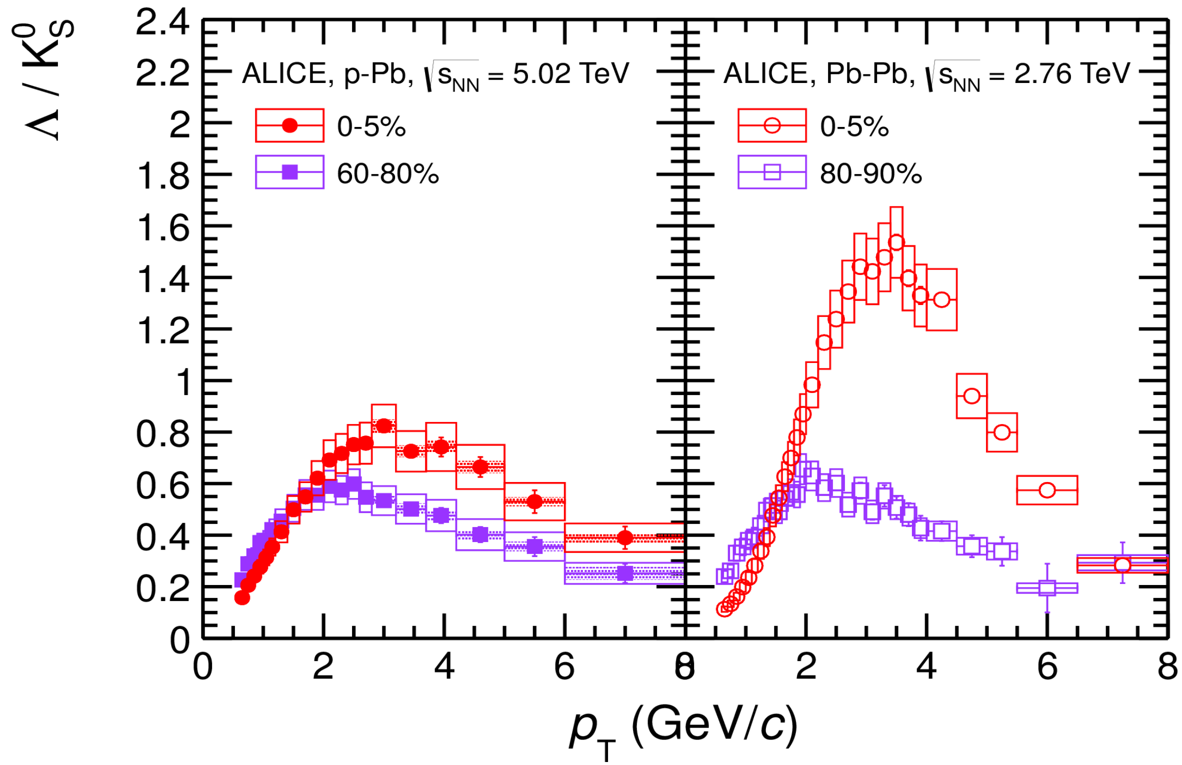
Λ/K^0_s vs. p_T

ALICE, arXiv:1307.5530 [nucl-ex]



Λ/K^0_s ratio vs p_T:

- similarities between p-Pb and Pb-Pb
- <u>increase</u> at intermediate p_T with increasing multiplicity
- corresponding <u>depletion</u> at low p_T
  - **more pronounced than p/π**

The increase at intermediate momenta and the corresponding decrease is commonly attributed to collective flow and/or recombination in Pb-Pb collisions.

talk L. Hanratty Thursday

The same qualitative effect is observed in p-Pb, although it is much weaker!

Multiplicity scaling – Lambda over K^0_s

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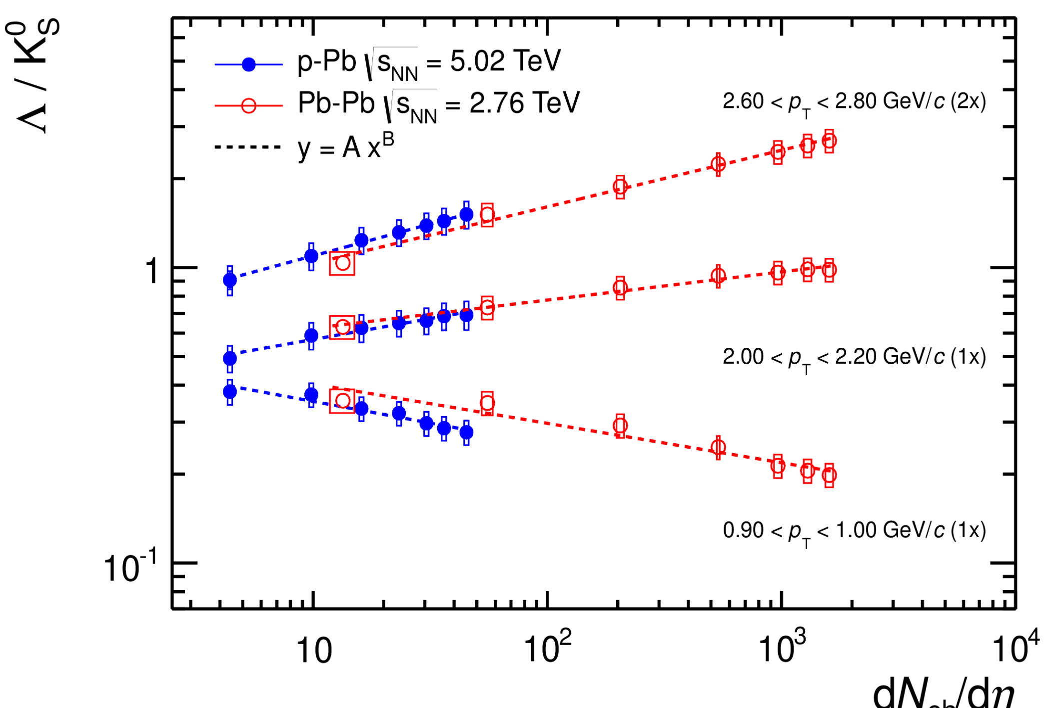
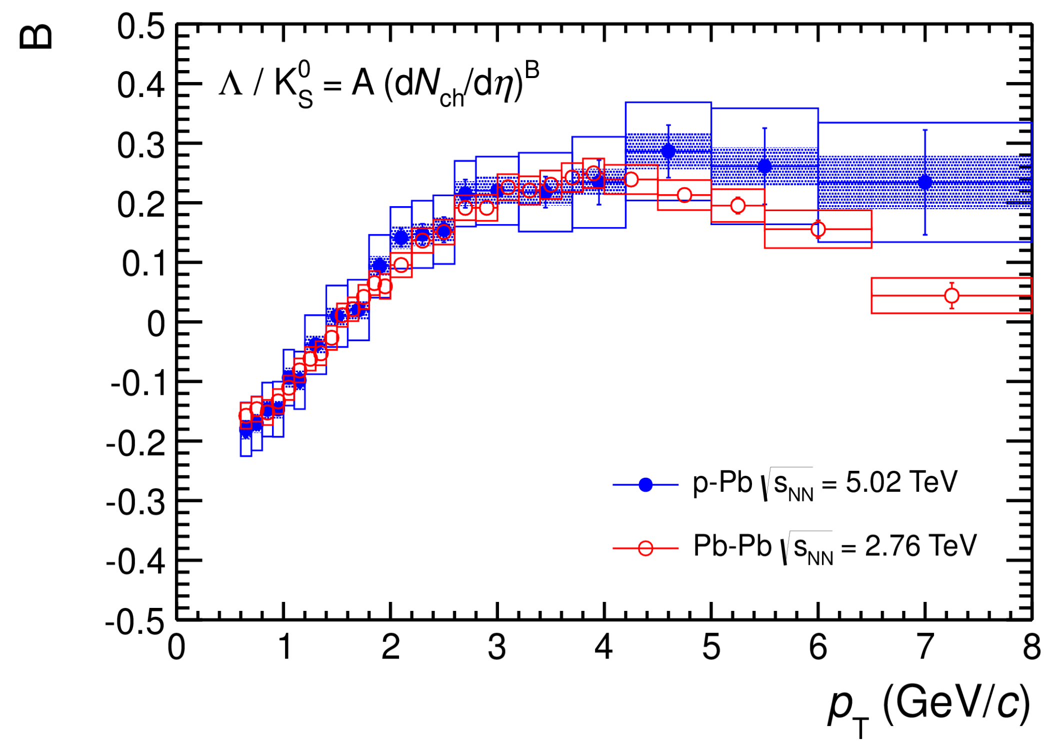
Quantitative study and comparison of the multiplicity dependence of particle ratios:

- similar increase of Λ/K^0_s for similar increase of $dN_{ch}/d\eta$ in p-Pb and Pb-Pb
- fit Λ/K^0_s (at given p_T) vs. $dN_{ch}/d\eta$ with power-law ($y=Ax^B$) for p-Pb and Pb-Pb
- **same power-law scaling exponent (B) in p-Pb and Pb-Pb**
- scaling also holds for p/π

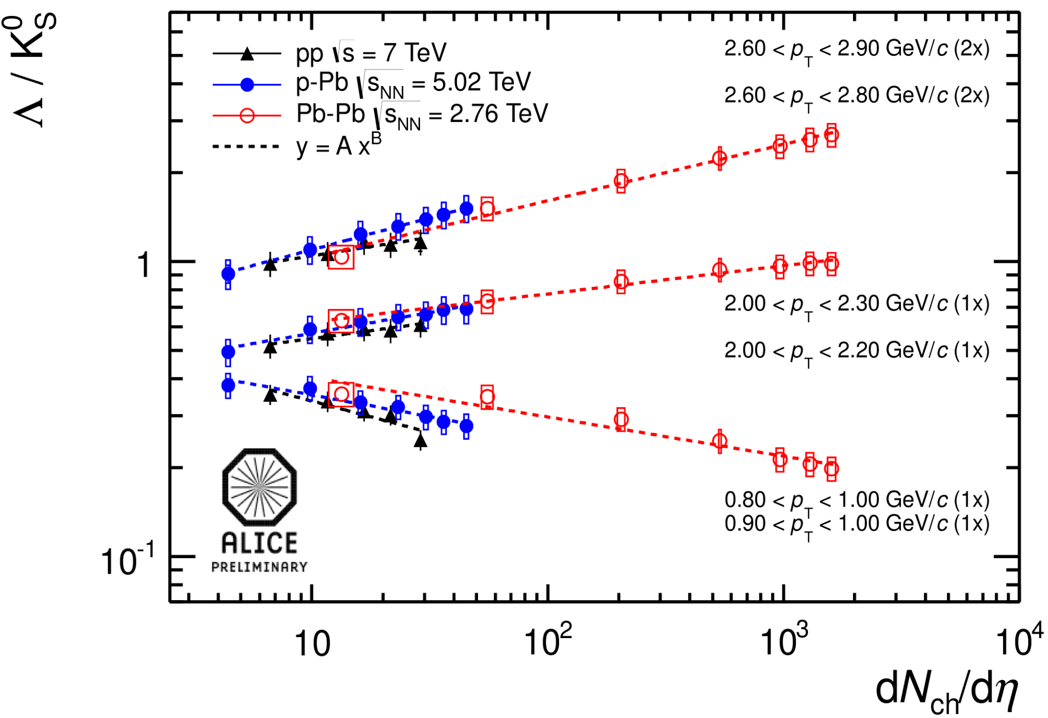


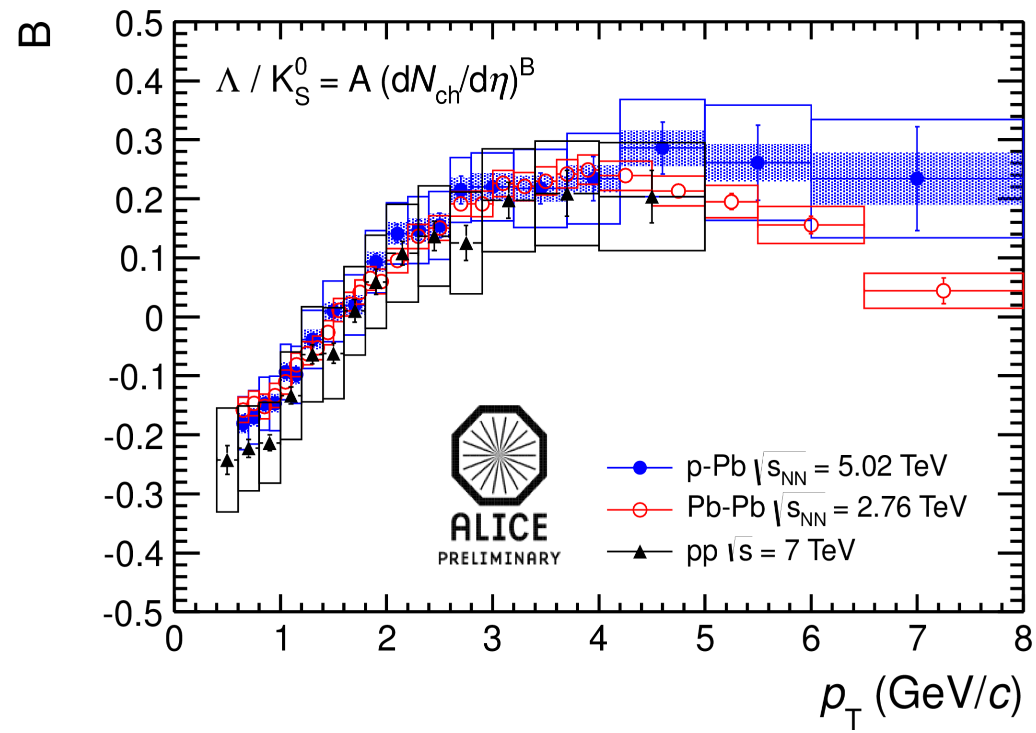


Adding pp to the picture

What about pp collisions as a function of multiplicity?

- same power-law scaling exponent (B) from p-Pb and Pb-Pb collisions **works also for pp collisions**
- **Caveat: Λ/K^0_s ratio in pp collisions is sensitive to bias by multiplicity selection at mid-rapidity**





p-Pb Blast-Wave analysis

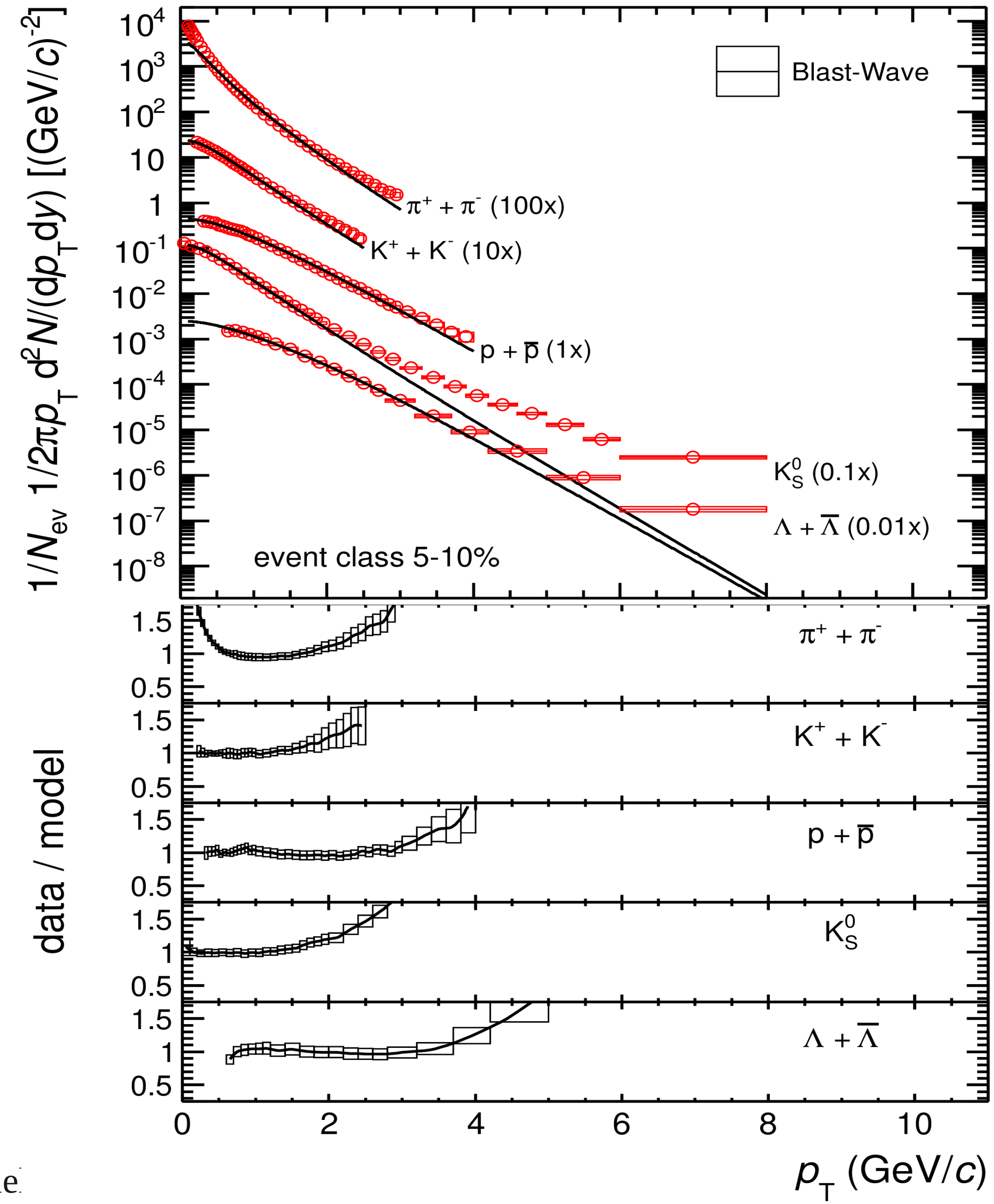
π/K/p/K^0_s/L Blast-Wave analysis:

- hydro-motivated <u>Blast-Wave model</u>
  Schnedermann, PRC 48, 2462 (1993)

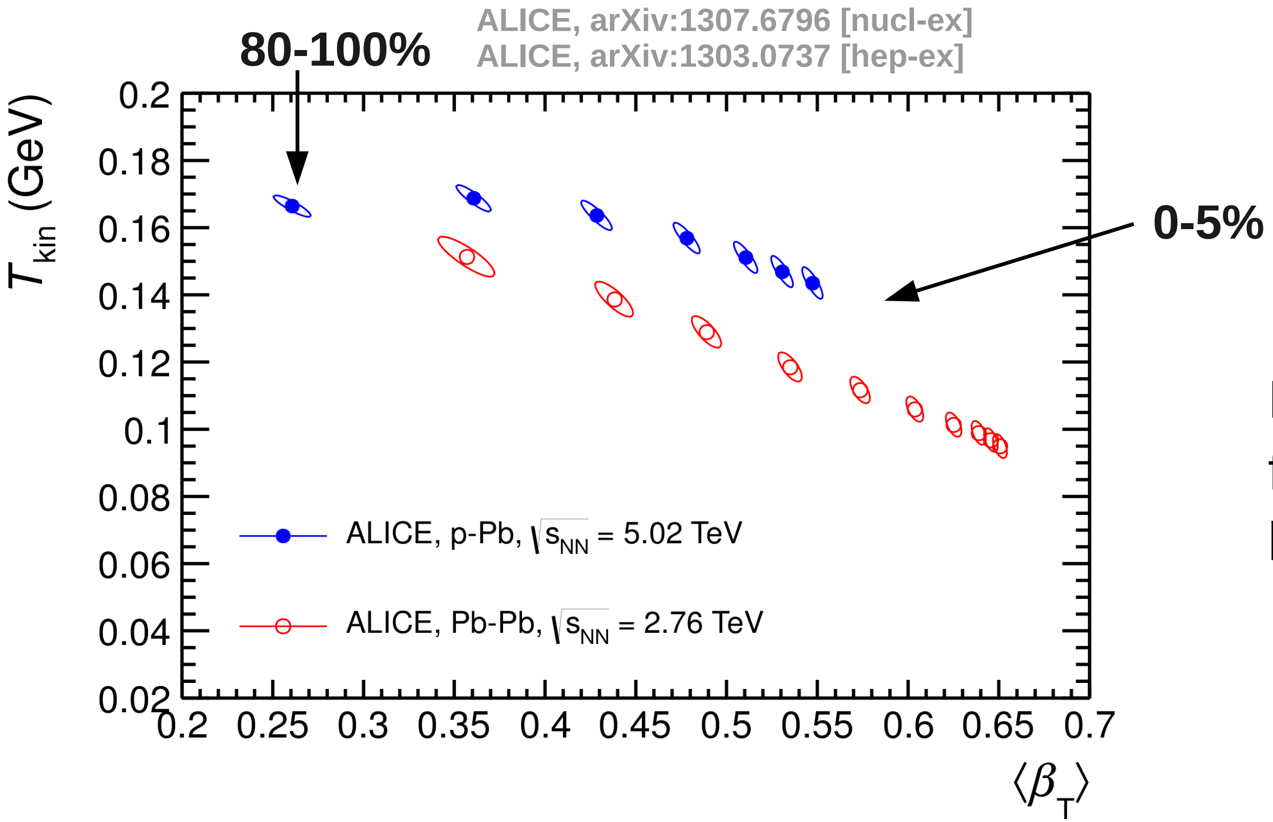
- <u>simultaneous fit of all particles</u> with 3 parameters:
  - $<\beta_T>$ radial flow
  - T_{fo} freeze-out temperature
  - n velocity profile

- global fit performed in the following p_T ranges:

π	0.5 – 1.0 GeV/c
K	0.2 – 1.5 GeV/c
p	0.3 – 3.0 GeV/c
K^0_s	0.0 – 1.5 GeV/c
Λ	0.6 – 3.0 GeV/c



Blast-Wave parameters



Excluding Λ and K^0_s from the fit does not change the parameters significantly

π/K/p/K^0_s/L Blast-Wave analysis:

- T_{fo} is similar in Pb-Pb and p-Pb
- <β_T> is larger in p-Pb for same multiplicity

→ stronger collective flow for smaller system size?
Shuryak, arXiv:1301.4470 [hep-ph]

Blast-Wave parameters

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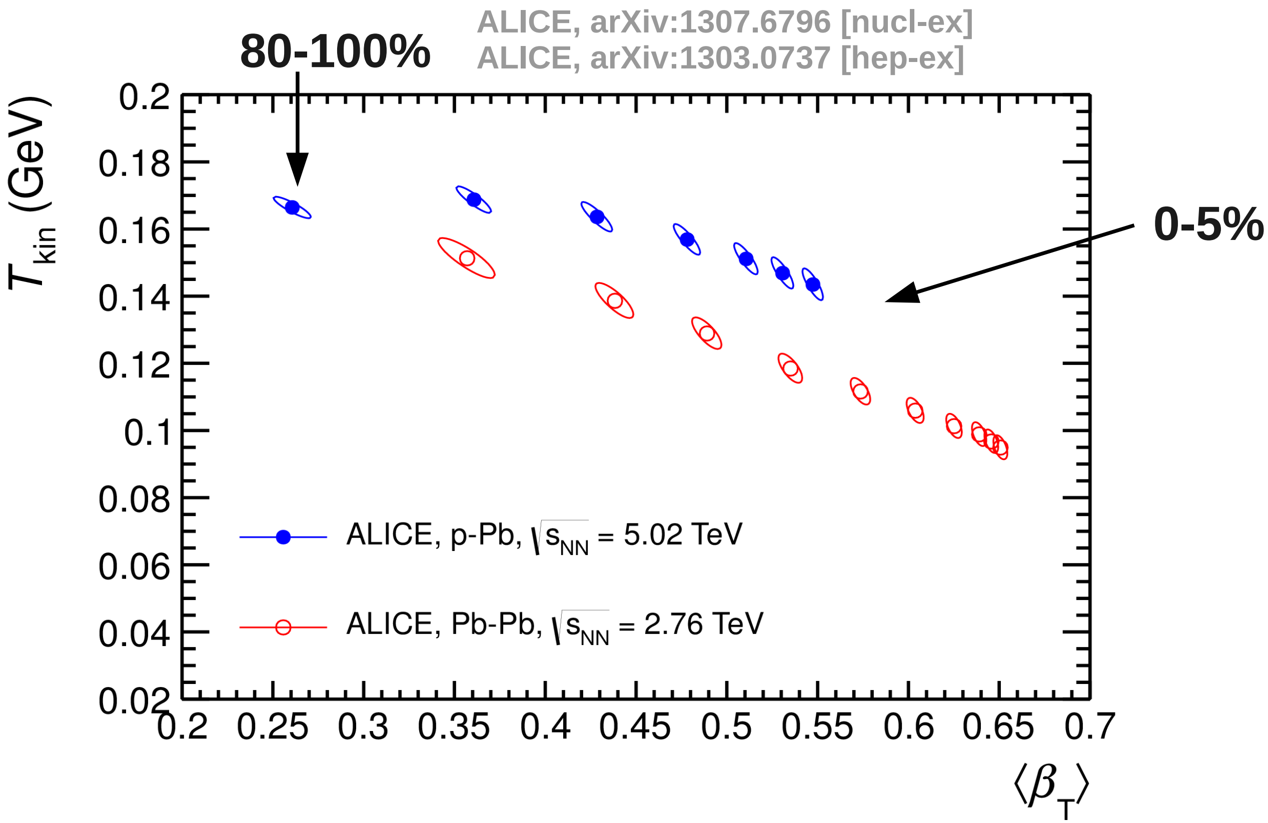


Excluding Λ and K^0_s from the fit does not change the parameters significantly

What about pp?

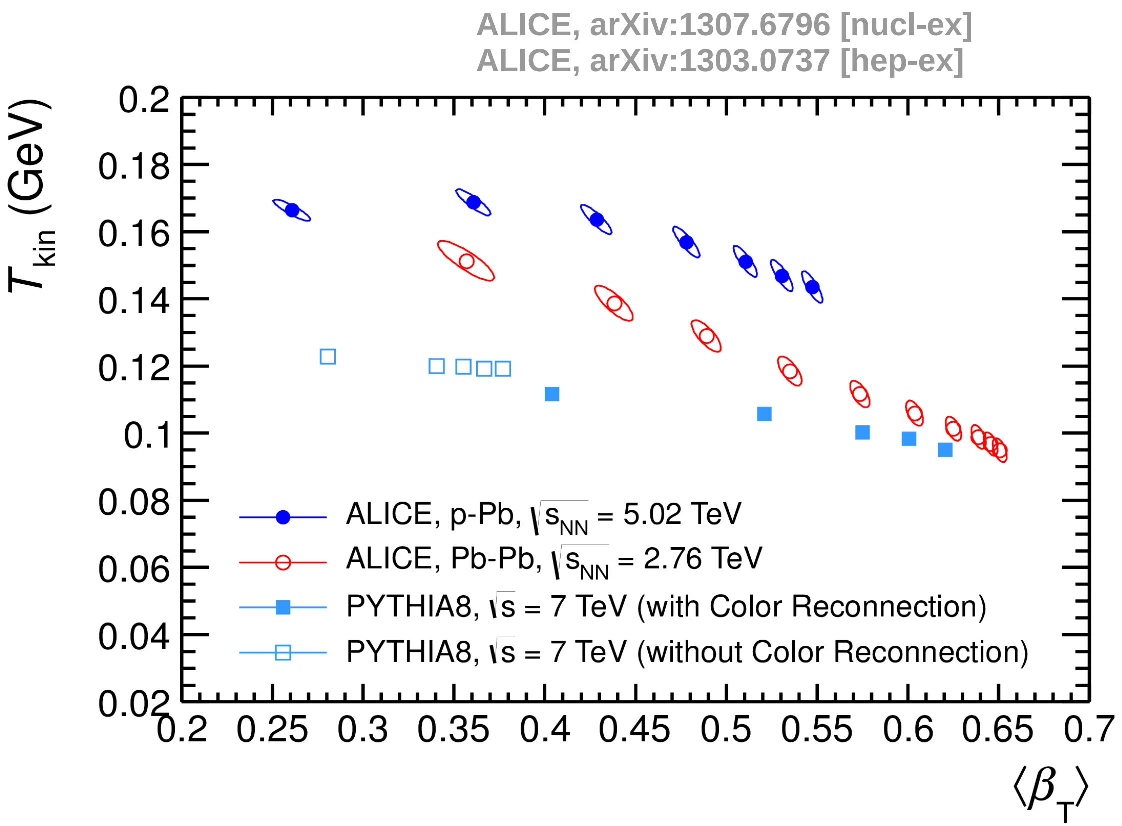
$\pi/K/p/K^0_s$/L Blast-Wave analysis:

- T_{fo} is similar in Pb-Pb and p-Pb
- $<\beta_T>$ is larger in p-Pb for same multiplicity

→ stronger collective flow for smaller system size?

Shuryak, arXiv:1301.4470 [hep-ph]

BW parameters – including PYTHIA

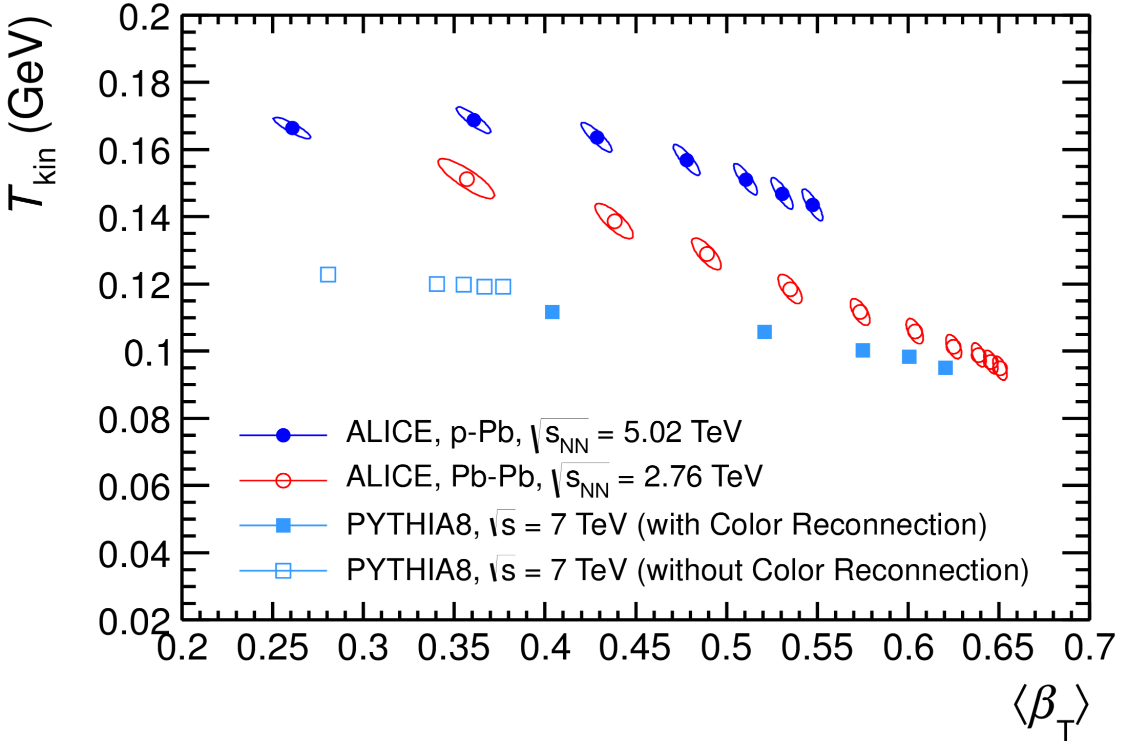


π/K/p Blast-Wave analysis:

Blast-Wave fit results from PYTHIA (with **C**olor **R**econnection) show similar trend, but it does not include collective flow

BW parameters – including PYTHIA

ALICE, arXiv:1307.6796 [nucl-ex]
ALICE, arXiv:1303.0737 [hep-ex]



And pp data?

π/K/p Blast-Wave analysis:

Blast-Wave fit results from PYTHIA (with **C**olor **R**econnection) show similar trend, but
it does not include collective flow

BW parameters – adding pp to the picture

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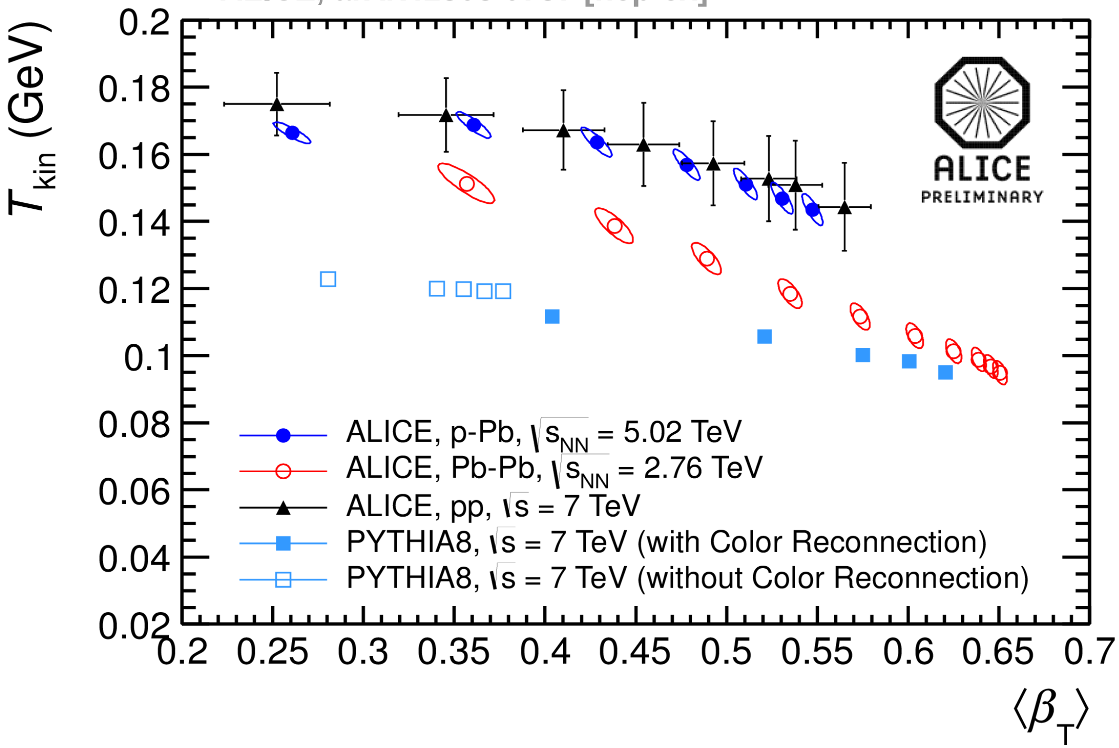
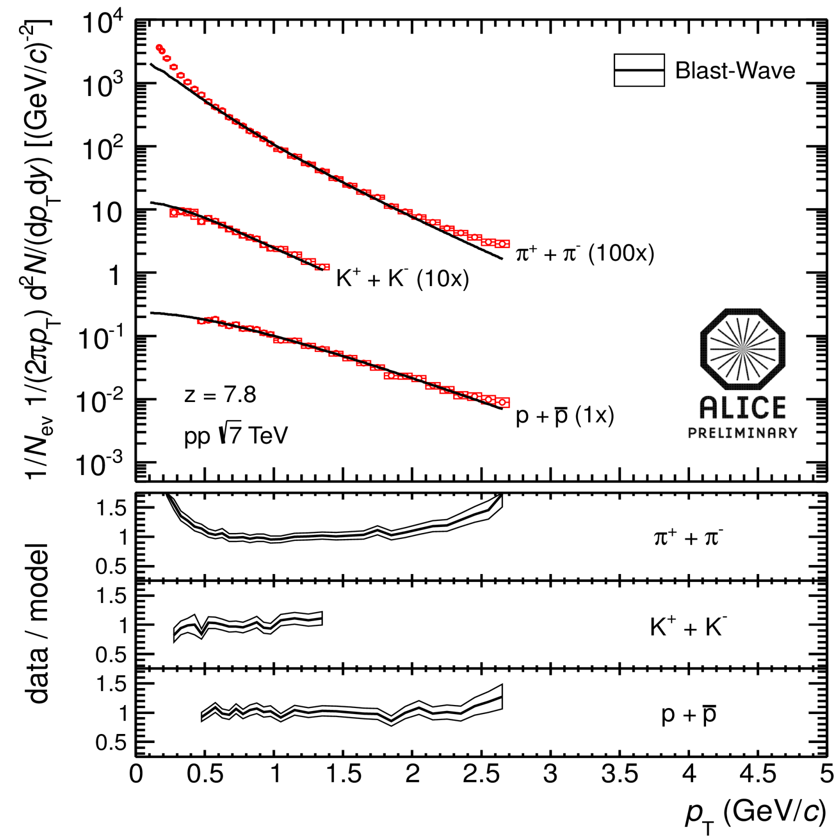
ALICE, arXiv:1307.6796 [nucl-ex]
ALICE, arXiv:1303.0737 [hep-ex]

pp data preliminary



Blast-Wave fit to high multiplicity pp events



- z = x: the multiplicity is x times the average multiplicity
- multiplicity selected in |η| < 0.8

π/K/p Blast-Wave analysis:

- shows same behavior as p-Pb and Pb-Pb
- only π/K/p fitted – slightly different ranges:

π	0.5 – 1.0 GeV/c
K	0.3 – 1.5 GeV/c
p	0.5 – 2.5 GeV/c

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Comparison with (hydro-)models

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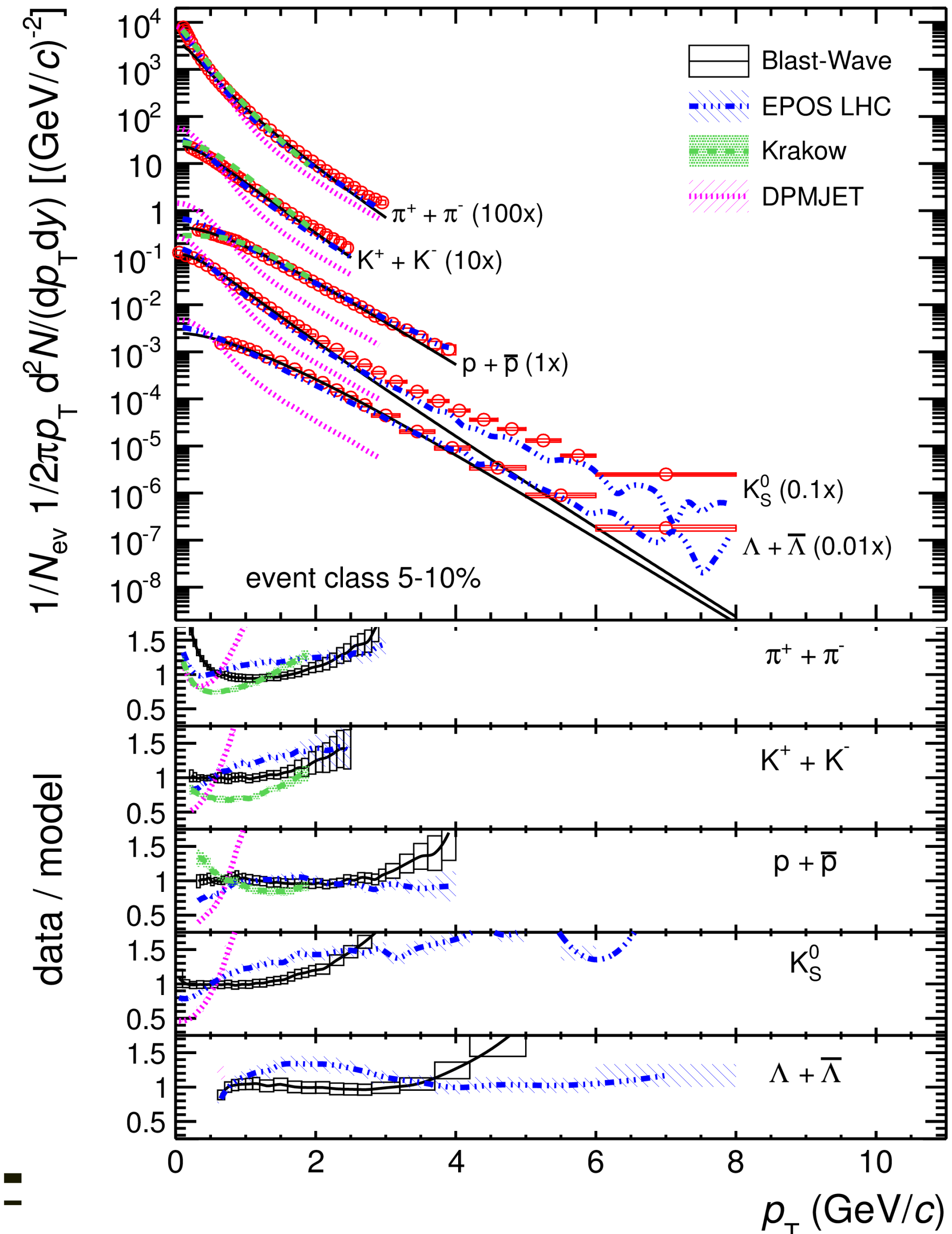


EPOS LHC: Pierog et al., arXiv:1306.0121 [hep-ph]

- initial hard and soft scattering create "flux tubes", which either escape the medium and hadronize as jets, or contribute to the bulk matter, described in terms of hydrodynamics
- can reproduce the pion and proton spectra within 20%
- stronger deviations for kaons and lambdas

Kraków: Bozek, PRC85, 014911 (2012)

- hydrodynamical model
- reproduces spectra reasonably well for protons
- pion and kaons deviate for p_T >1 GeV/c
- possible onset of non-hydro effect above 1 GeV/c

DPMJET:

- QCD- inspired – based on the Gribov-Glauber approach and treats soft and hard scattering processes in an unified way
- can reproduce $dN_{ch}/d\eta$
- fails to describe p_T distributions of identified particles

Summary and conclusions

ALICE has measured the transverse momentum distributions of identified hadrons in p-Pb in several multiplicity classes

- $\pi^{\pm}$, $K^{\pm}$,K^0_s, p ($\bar{p}$), Λ ($\bar{\Lambda}$) spectra over a wide p_T range

Hadron production vs. multiplicity

- integrated particle ratios similar to the ratios from pp and Pb-Pb collisions
- $\langle p_T \rangle$ increases with multiplicity (higher than Pb-Pb for same $dN_{ch}/d\eta$)
- multiplicity dependence of p/π and Λ/K^0_s vs. p_T with $dN_{ch}/d\eta$ in p-Pb collisions
  - seems to be independent of collision system

Spectral shape analysis and hydro models

- Blast-Wave model fits to π , K and p (few parameters characterize shapes)
  - similarities with Pb-Pb, pp (PYTHIA and data) shows the same trend
- EPOS LHC and Kraków model give reasonable agreement with data

Collective effects in p-Pb

- the results of the Blast-Wave analysis are not conclusive, but current results do not exclude hydro-like collective flow in p-Pb collisions
- other effects (color reconnection in PYTHIA) can mimic flow-like patterns

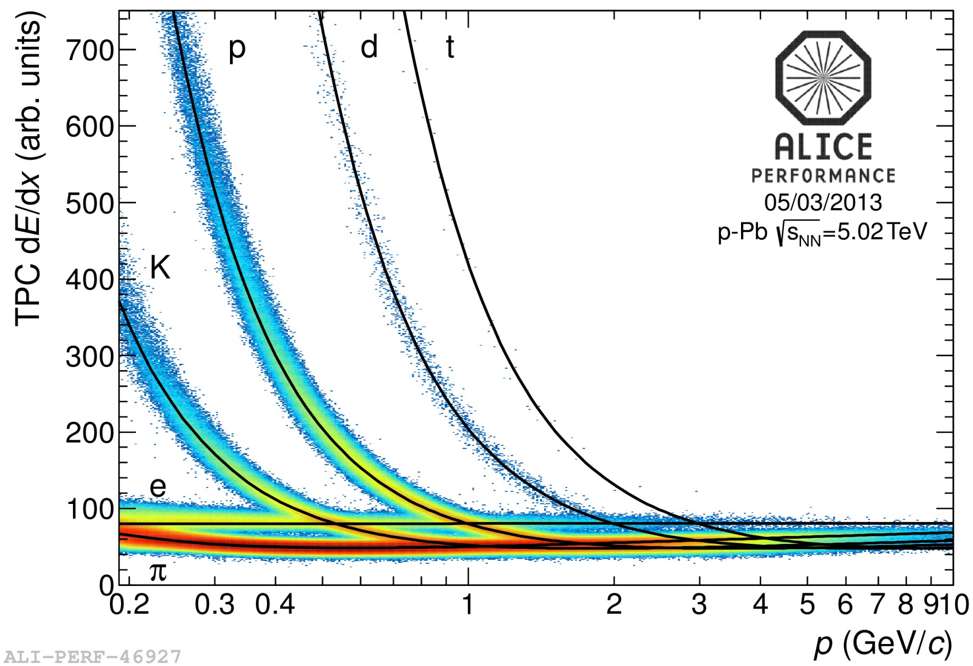
Thank you for your attention!

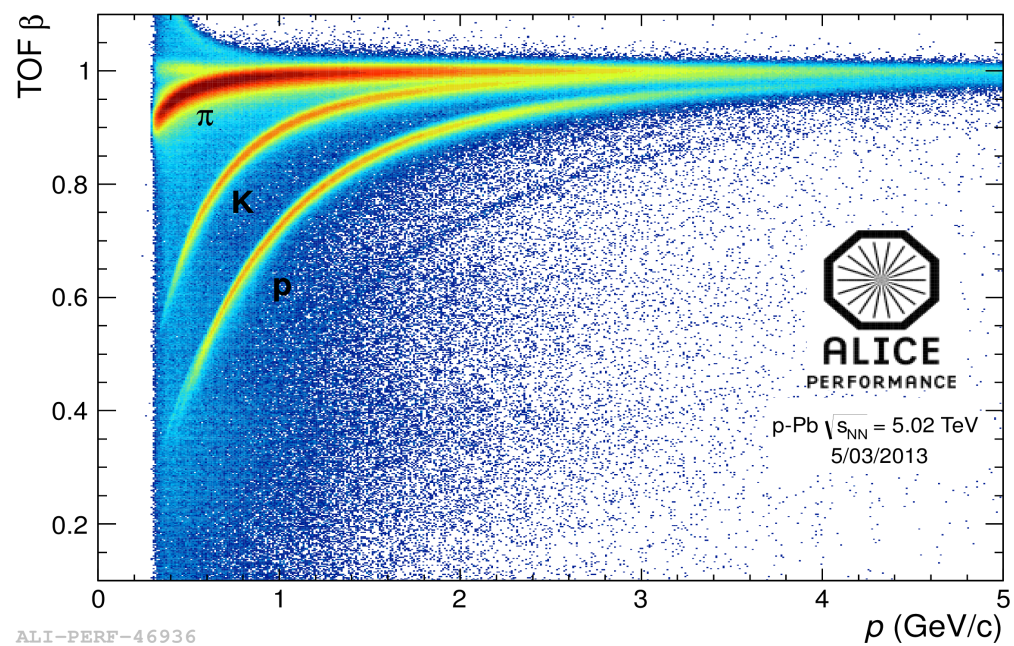
BACKUP

Particle **Id**entification: $\pi^{\pm}$, $K^{\pm}$, p ($\bar{p}$)

TPC:
- main tracking detector
- PID via d*E*/dx in gas
- up to 159 samples
- σ ~ 5%

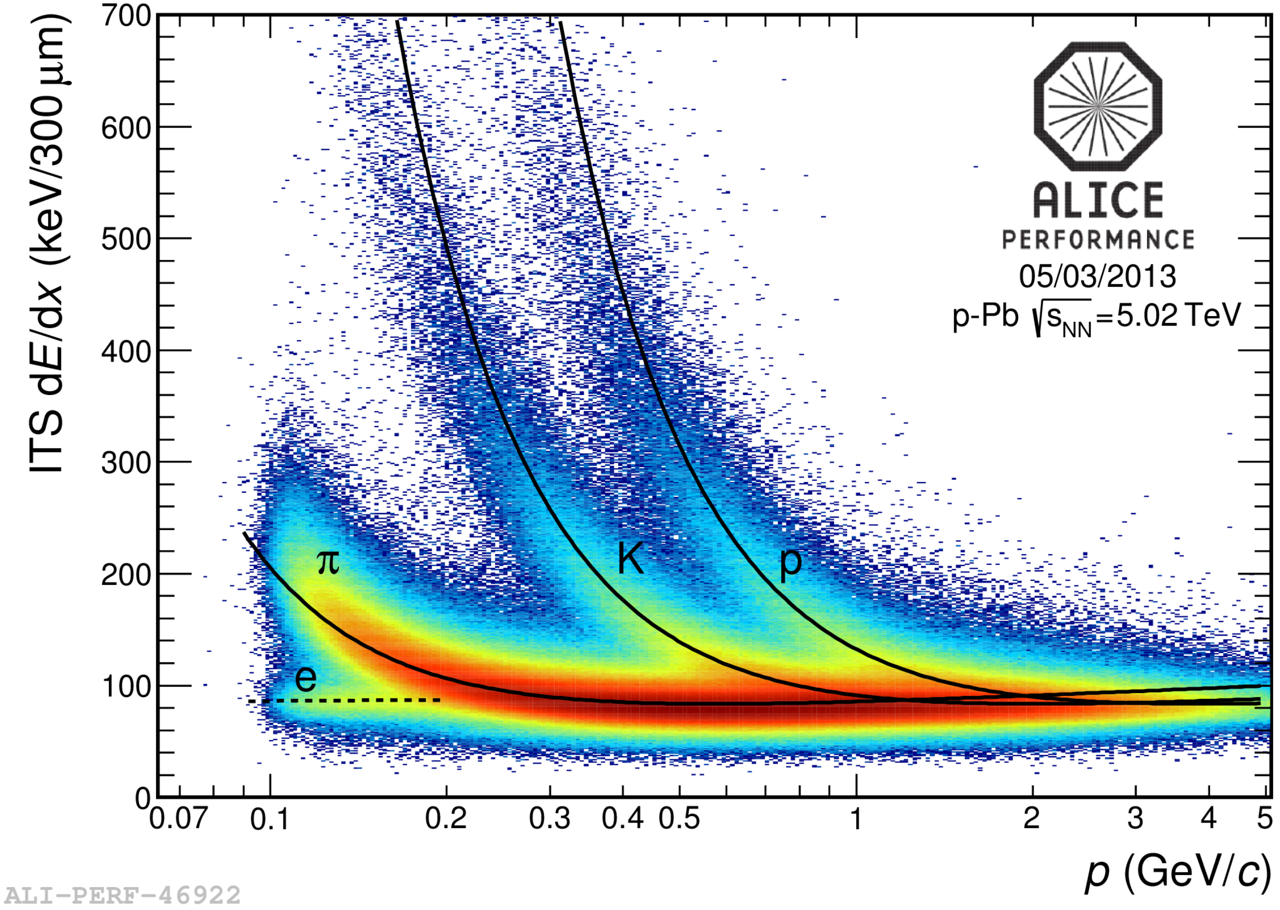
TOF:
- PID at intermediate momenta
- PID via time-of-flight
- 3σ K/π separation up to 2.5 GeV/*c*
- 3σ p/π separation up to 4.5 GeV/*c*





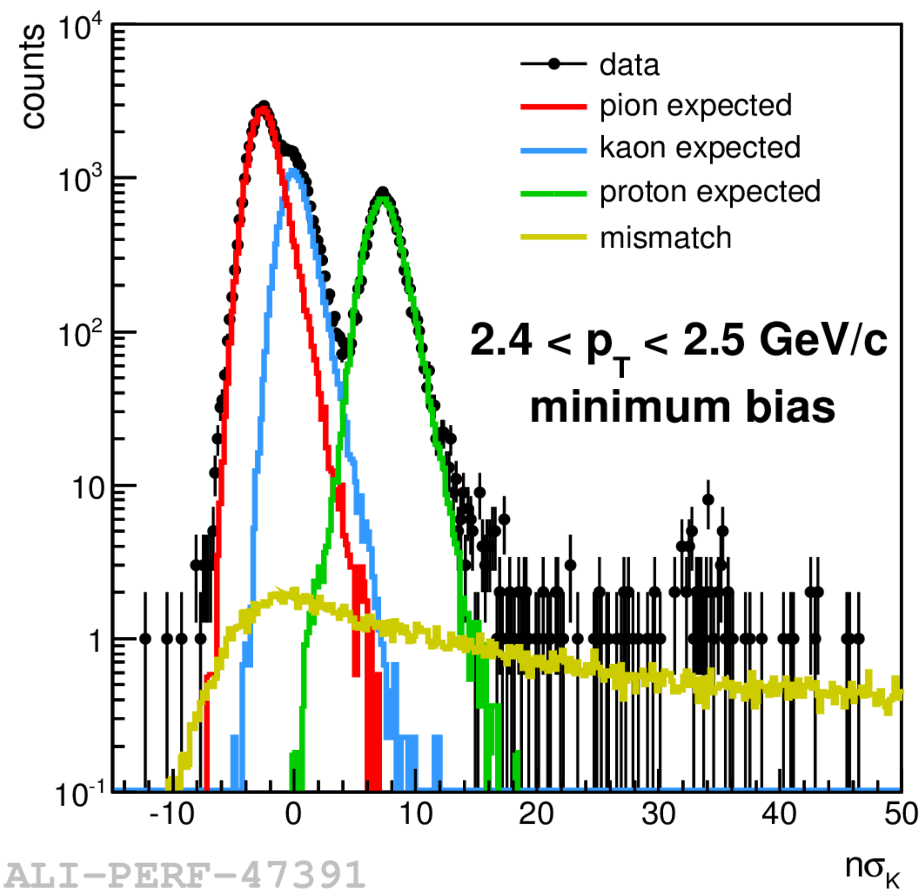
ITS Particle Identification: π± , K ±, p ($\bar{p}$)

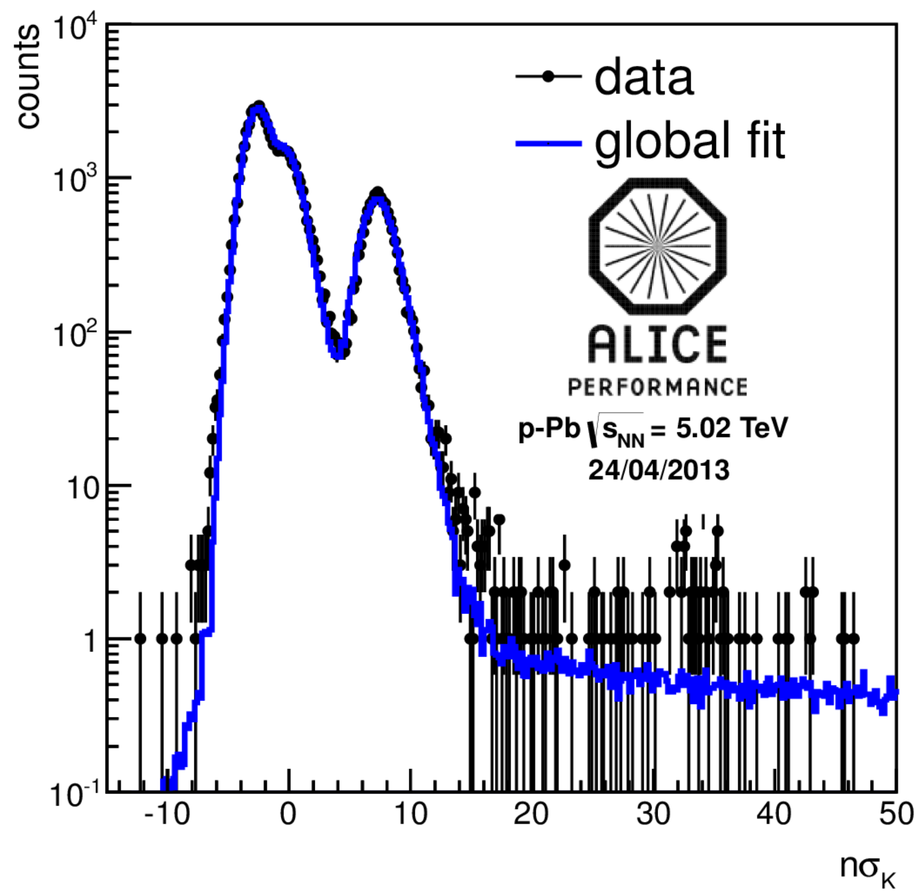
ITS standalone particle identification



PID with TOF signal

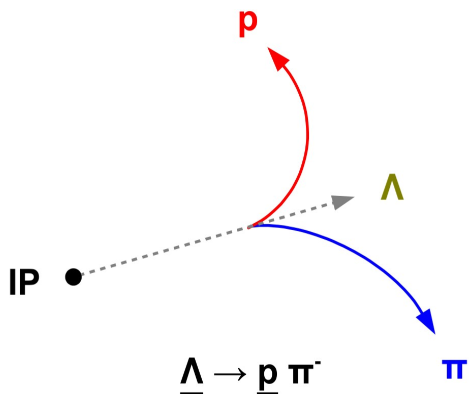
Here with kaon hypothesis for expected arrival time



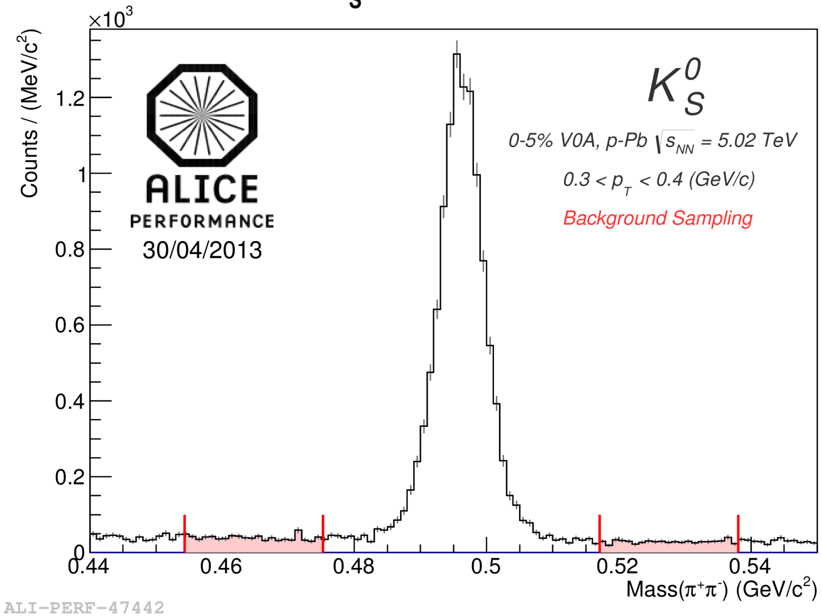


Topological reconstruction: K^0_s, Λ ($\overline{\Lambda}$)

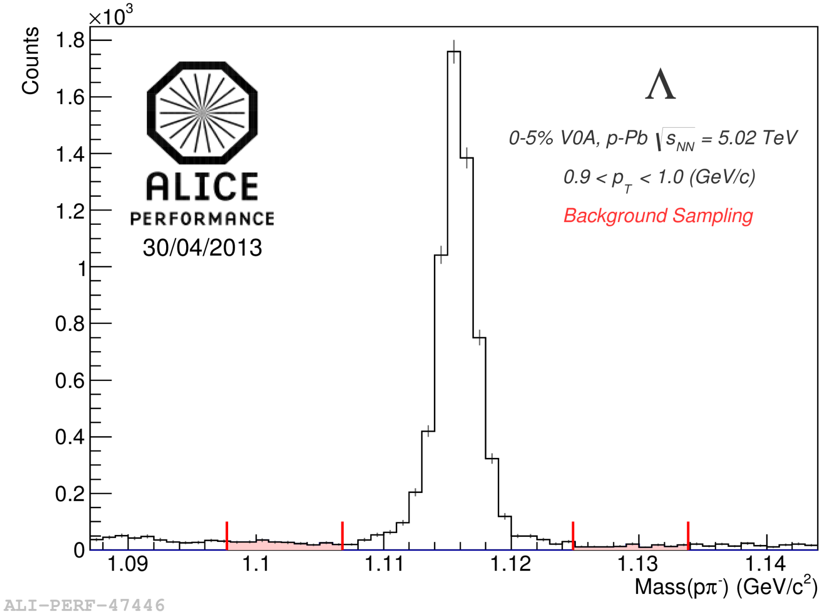
V0-decays: topological reconstruction
- PID over large p_T range
- TPC dE/dx PID for daughters
- Invariant mass extraction of signal



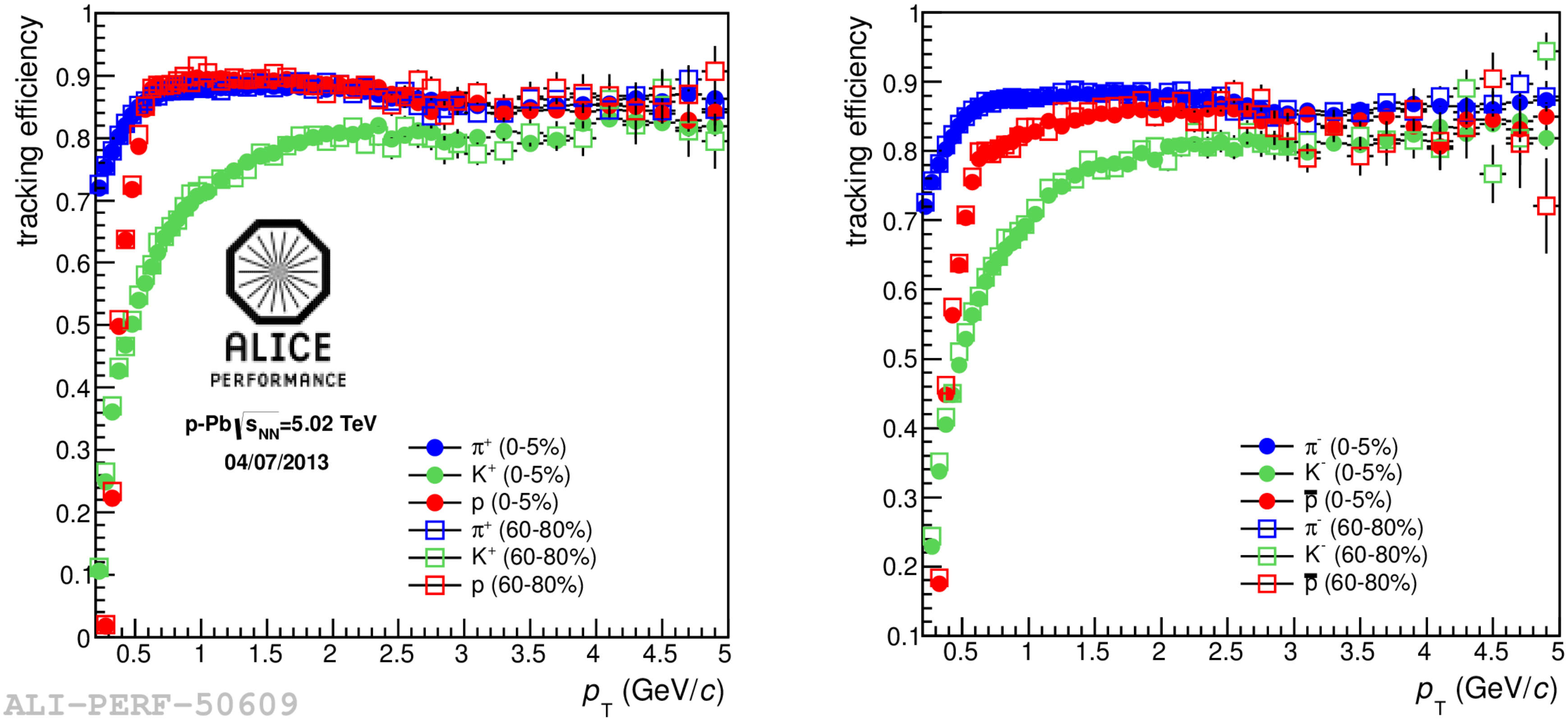
$K^0_S \rightarrow \pi^+ \pi^-$



$\Lambda \rightarrow p\, \pi^-$
$\overline{\Lambda} \rightarrow \overline{p}\, \pi^+$

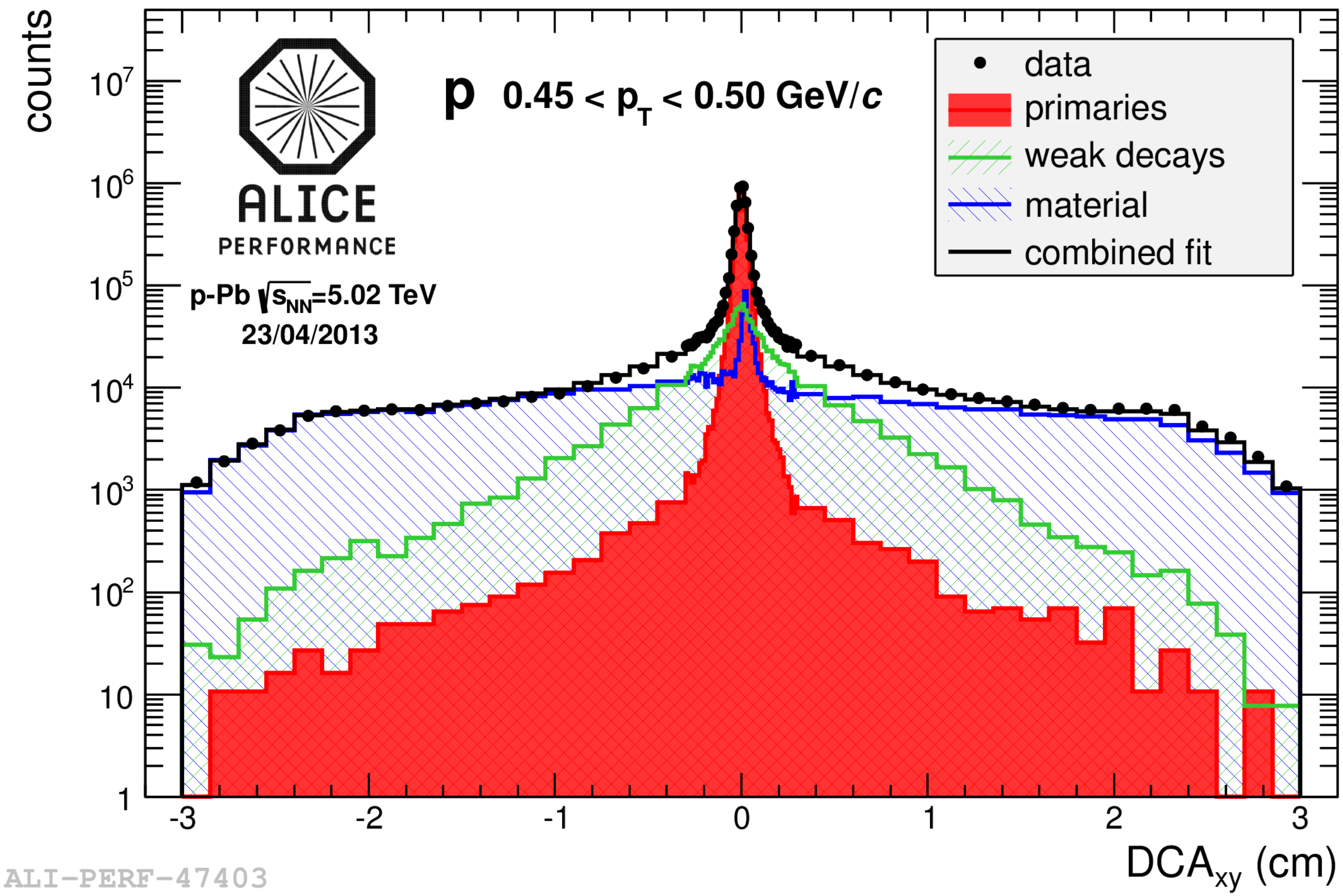


Tracking efficiency



Correction for secondary particles

data-driven approach to subtract the contribution from secondary particles



$\langle p_T \rangle$ vs. multiplicity

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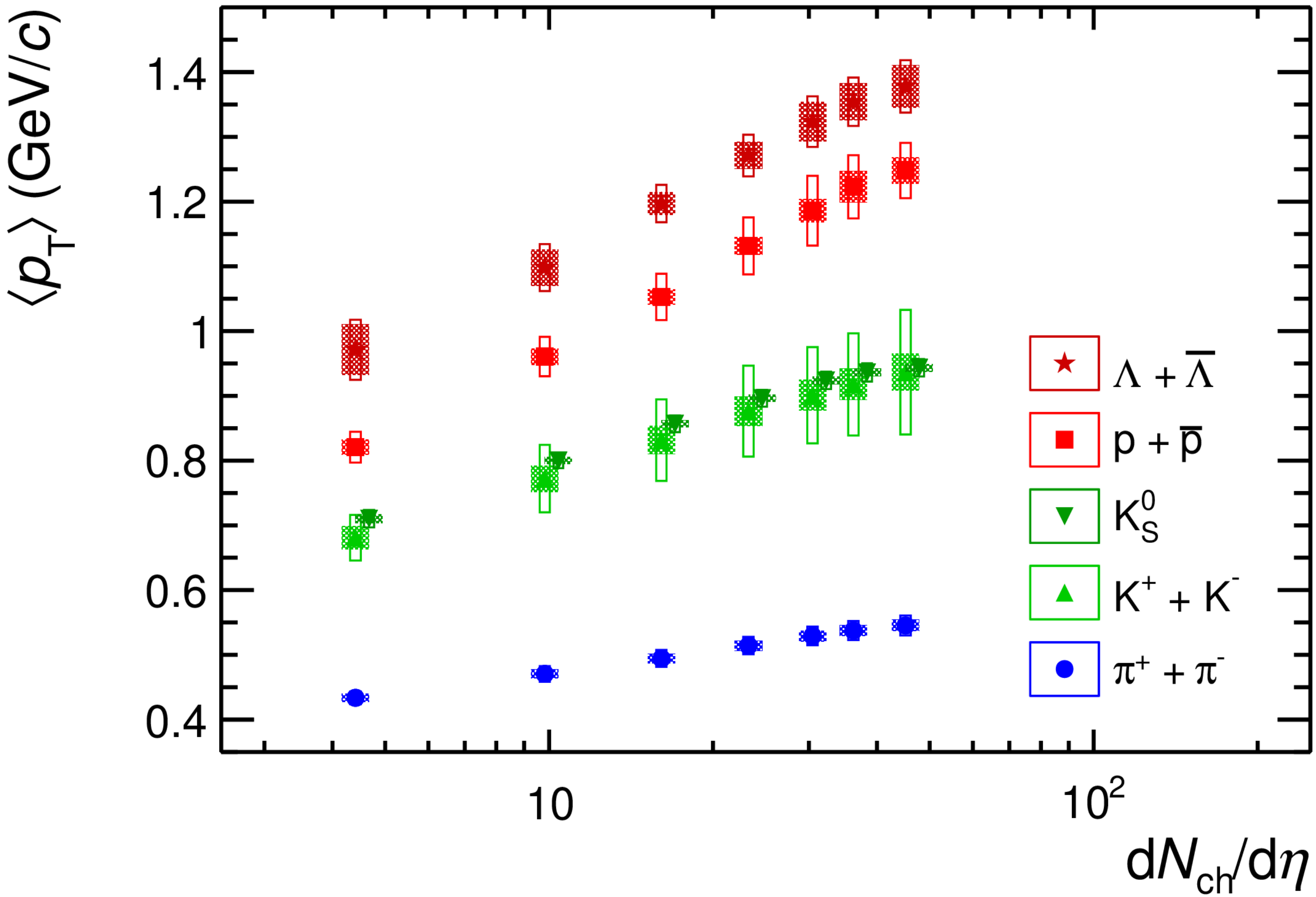

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$\langle p_T \rangle$ of kaons vs. charged-particle multiplicity

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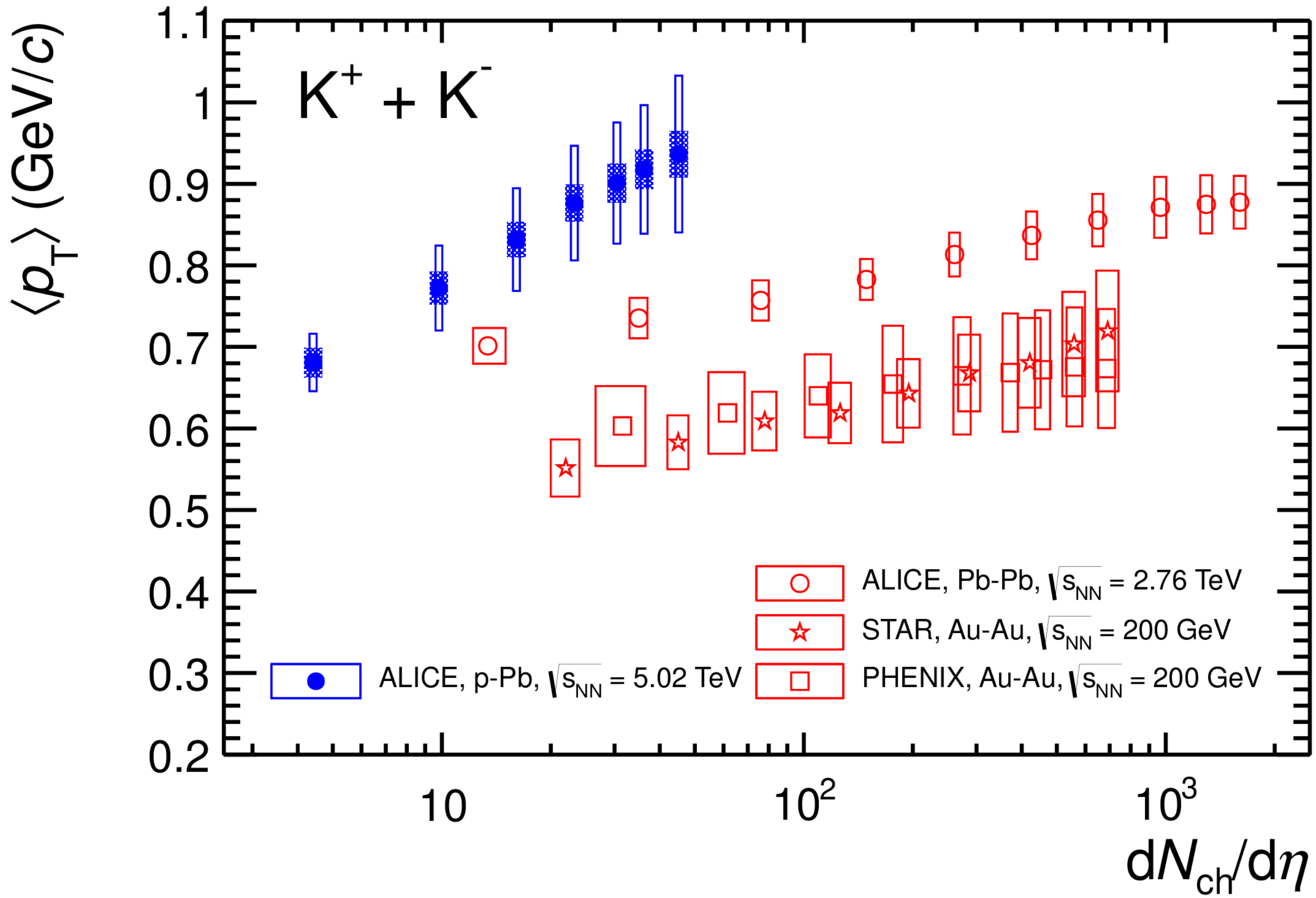

Particle ratios vs. charged-particle multiplicity

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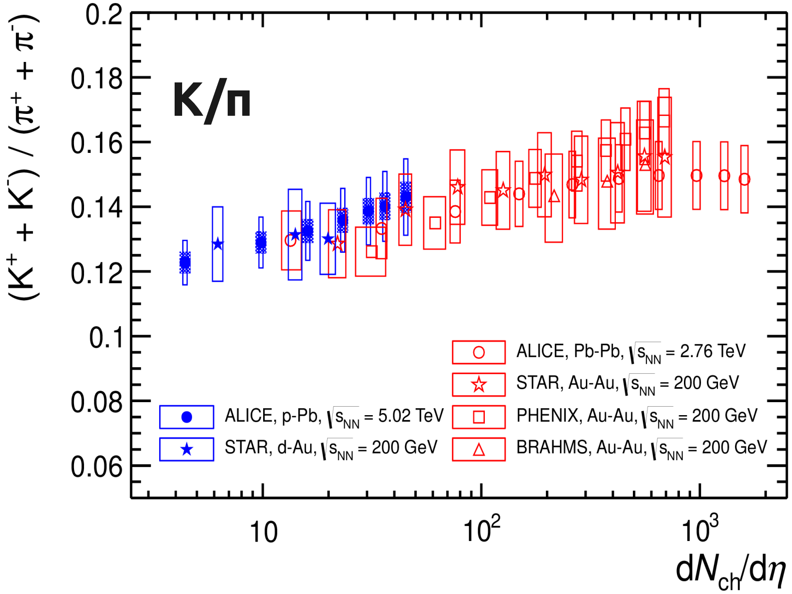

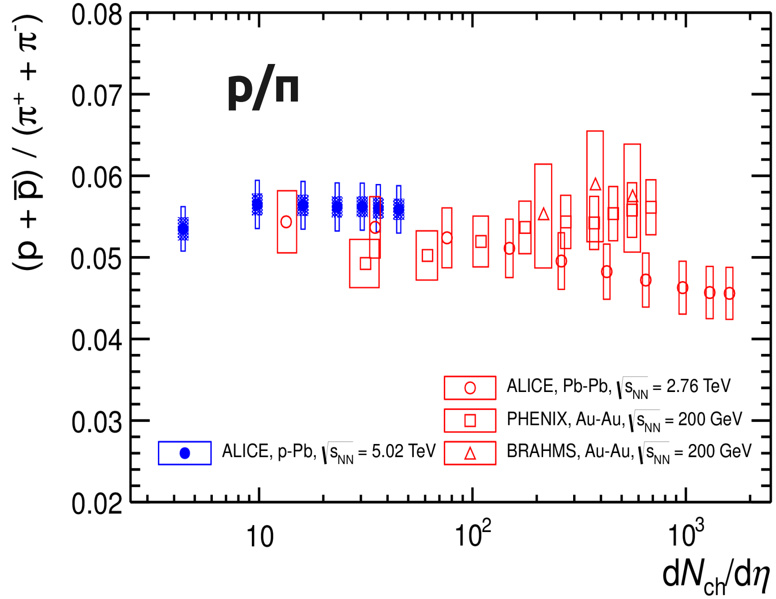

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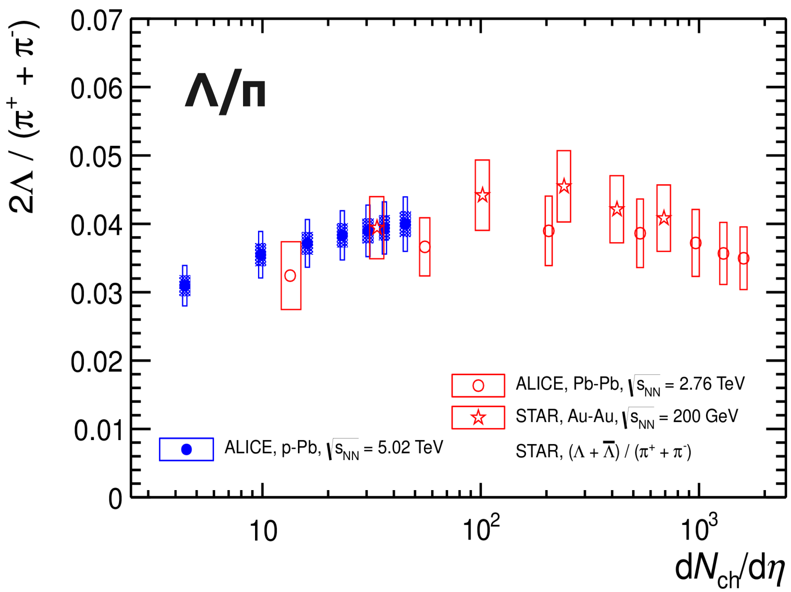


integrated particle ratios in pp, Pb-Pb and lower energy RHIC results are similar

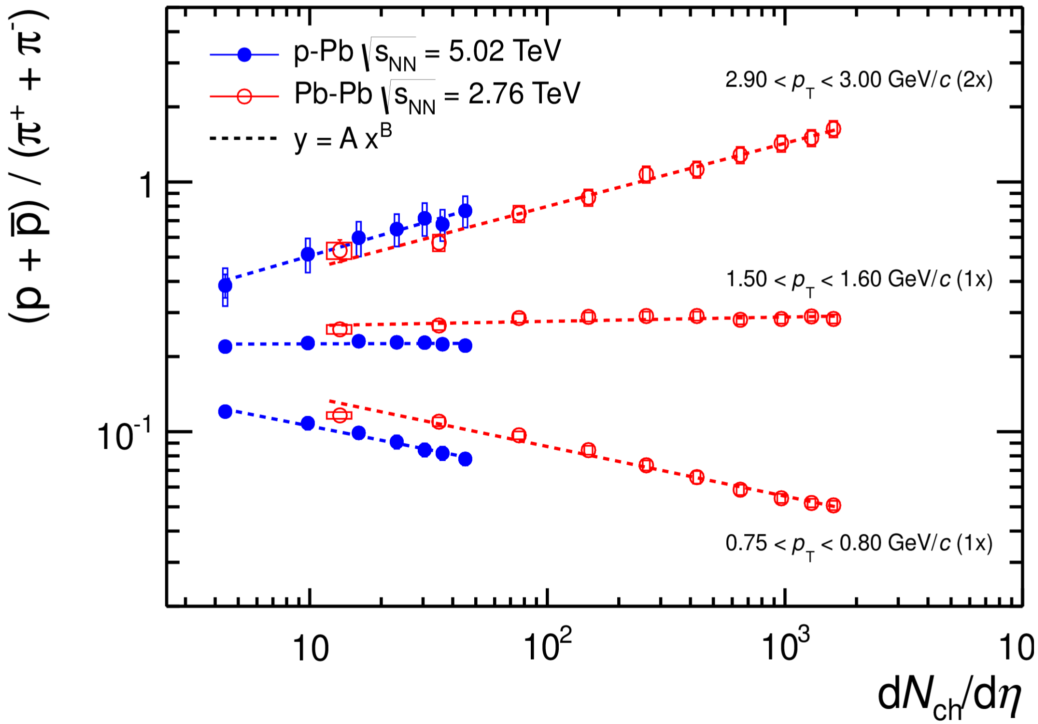
K/π and **Λ/π:**
→ hints a small increase with multiplicity

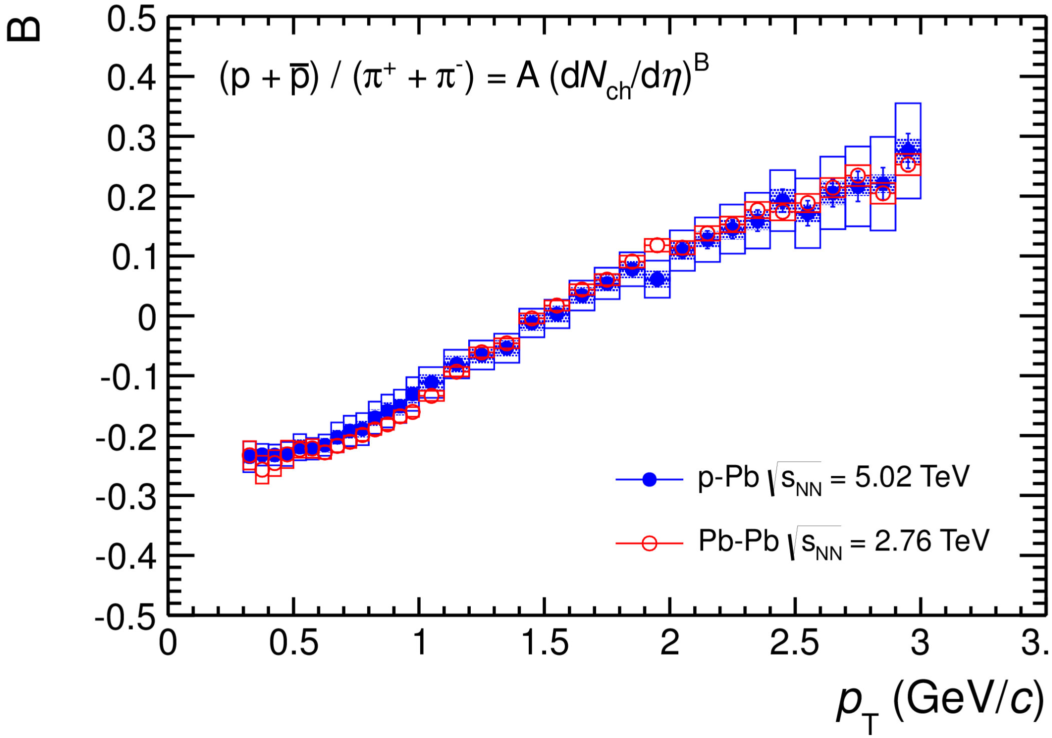
p/π:
→ no significant evolution with multiplicity

Multiplicity scaling – Proton over pion ratio

Quantitative study and comparison of the multiplicity dependence of particle ratios:

- similar increase of p/π for similar increase of dN_{ch}/dη
- fit p/π (at given p_T) vs. dN_{ch}/dη with power-law ($y=Ax^B$) for p-Pb and Pb-Pb
- same power-law scaling exponent (B) in p-Pb and Pb-Pb





Selection bias in pp

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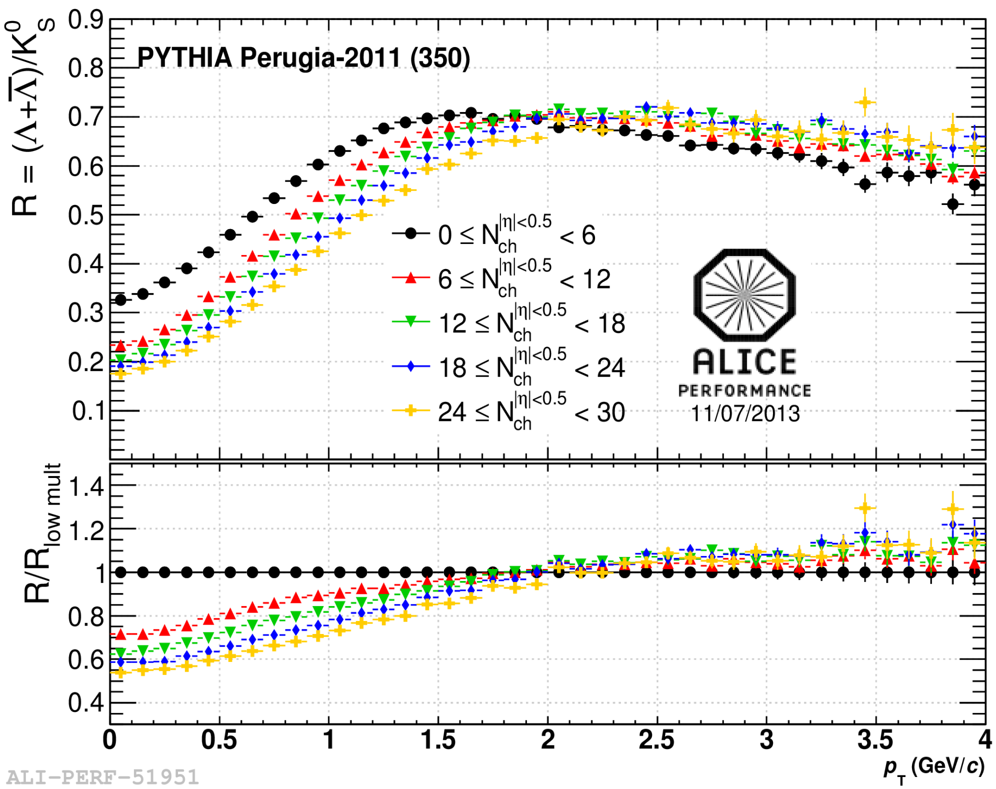
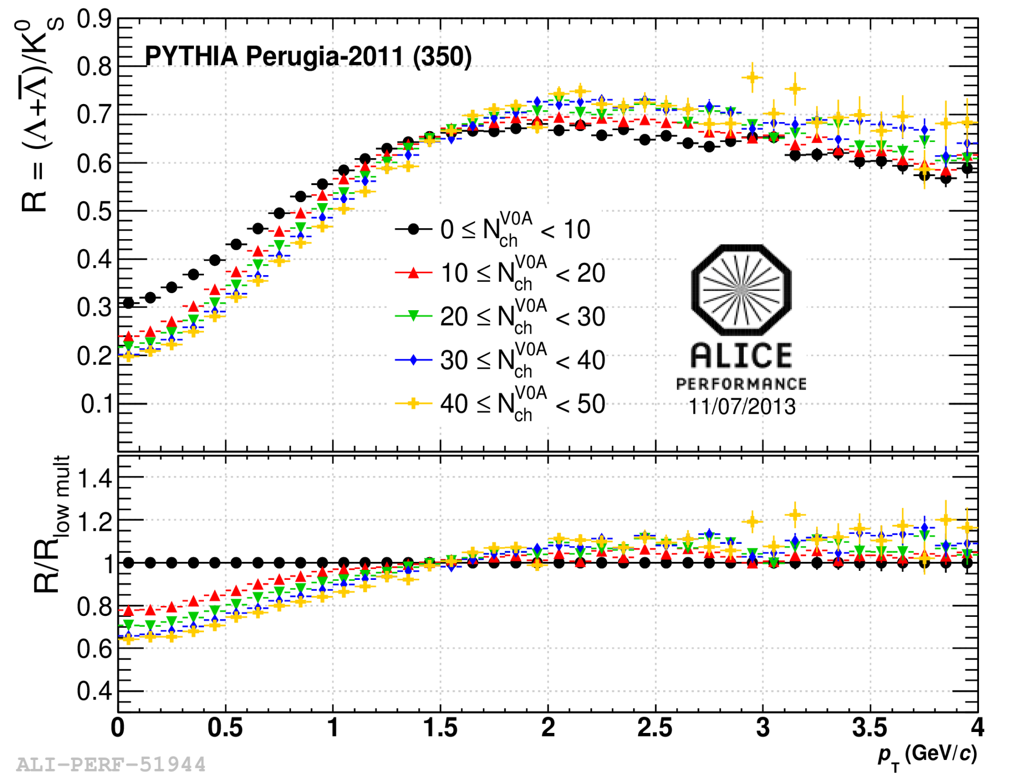
PYTHIA study: selecting multiplicity in different pseudorapidity ranges

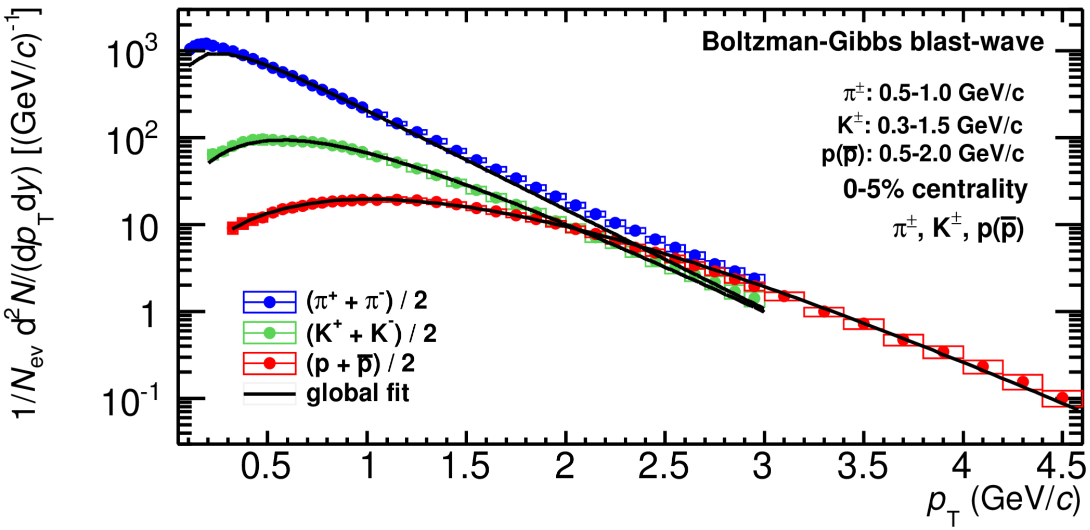
selection in |η|<0.5

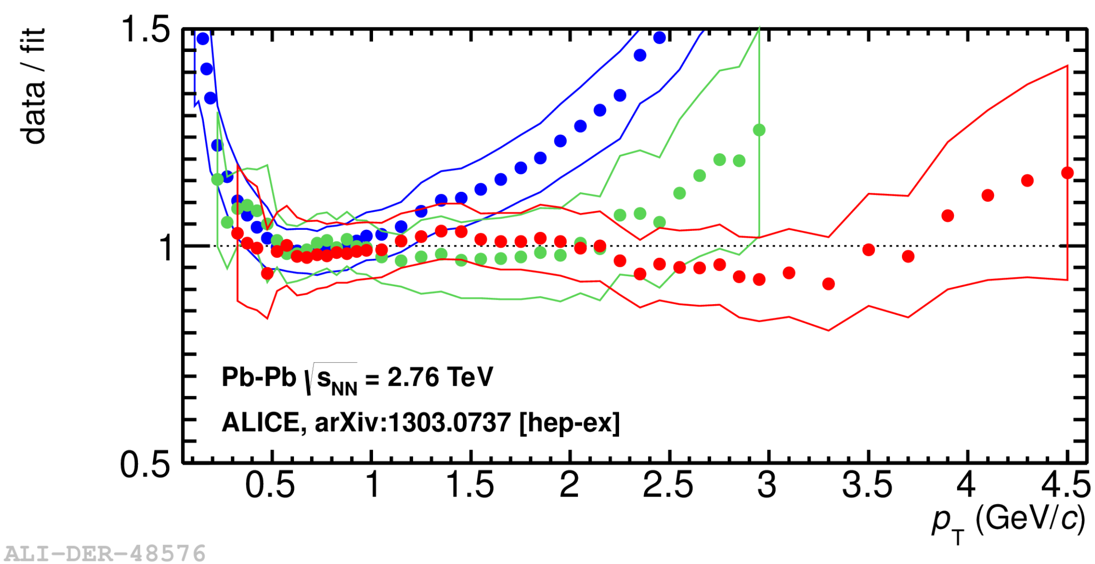


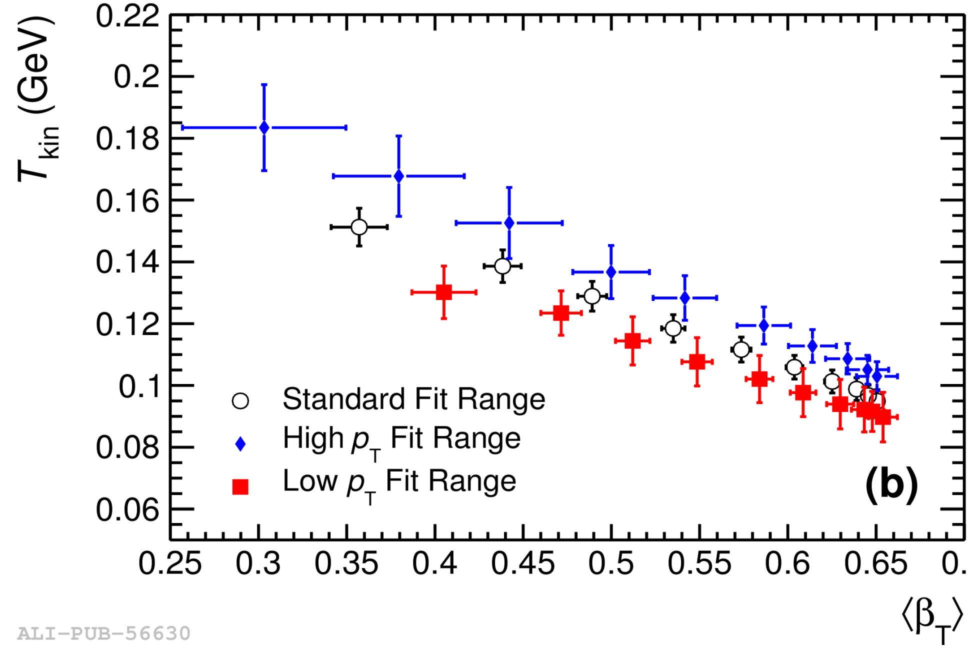
selection in 2.8 < η < 5.1 (V0A)



Blast-Wave fit to Pb-Pb







range	Pi	K	p
stand	0.5 – 1.0	0.2 – 1.5	0.3 – 3.0
low	0.5 – 0.8	0.2 – 1.0	0.3 – 1.5
high	0.7 – 1.3	0.5 – 1.5	1.0 – 3.0

Blast-Wave fit parameters p-Pb and Pb-Pb

$$\frac{dN}{p_\perp dp_\perp} \propto \int_0^R r\,dr\,m_\perp I_0\left(\frac{p_\perp \sinh\rho}{T_{\rm kin}}\right) K_1\left(\frac{m_\perp \cosh\rho}{T_{\rm kin}}\right)$$

$$\rho = \tanh^{-1}\beta$$

$$\beta = \beta_S (r/R)^n$$

$$\langle\beta\rangle = \frac{2}{2+n}\beta_S$$