Identified particle production in p-Pb measured with the ALICE detector

Peter Christiansen
(Lund University)
for the ALICE Collaboration

ALICE

LUNDS UNIVERSITET

Outline

- Introduction
- Particle IDentification (PID) with ALICE
- Measurements of p_T spectra of
  π, K , K^0_S, p, and Λ
- Theory motivated interpretations
- Data driven interpretation
- Discussion
- Conclusions

A simple pre-LHC physics picture of different colliding systems

	Inelastic pp	Pb-Pb	Inelastic p-Pb
Initial interactions	Color transfer between partons Multi Parton Int.	Interactions between dense gluon fields	Dense gluon fields (Pb) probed by partons (p)
Cold Nuclear Matter	No	Yes (e.g. J/Psi "absorption")	Yes
Hot Nuclear Matter	No	Hydrodynamic expansion, quenching, quarkonia dissociation, ...	No
Hadronization (Chemical freezeout)	String breaking MPI: color reconnection	Statistical model	Closer to pp
Kinetic freezeout	No	Hadronic rescattering	No

Pre-LHC questions for p-Pb physics:
Are the dense gluon fields well described by CGC?
What is the magnitude of cold nuclear matter effects?

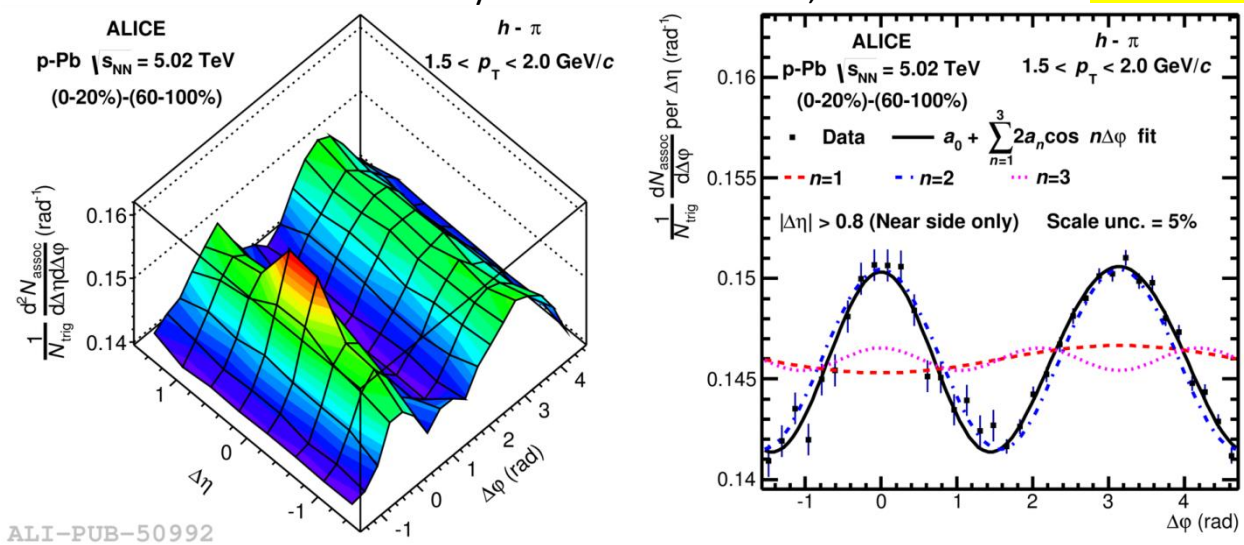
Using Particle IDentification to study the double ridge

See talk by Paul Kujier

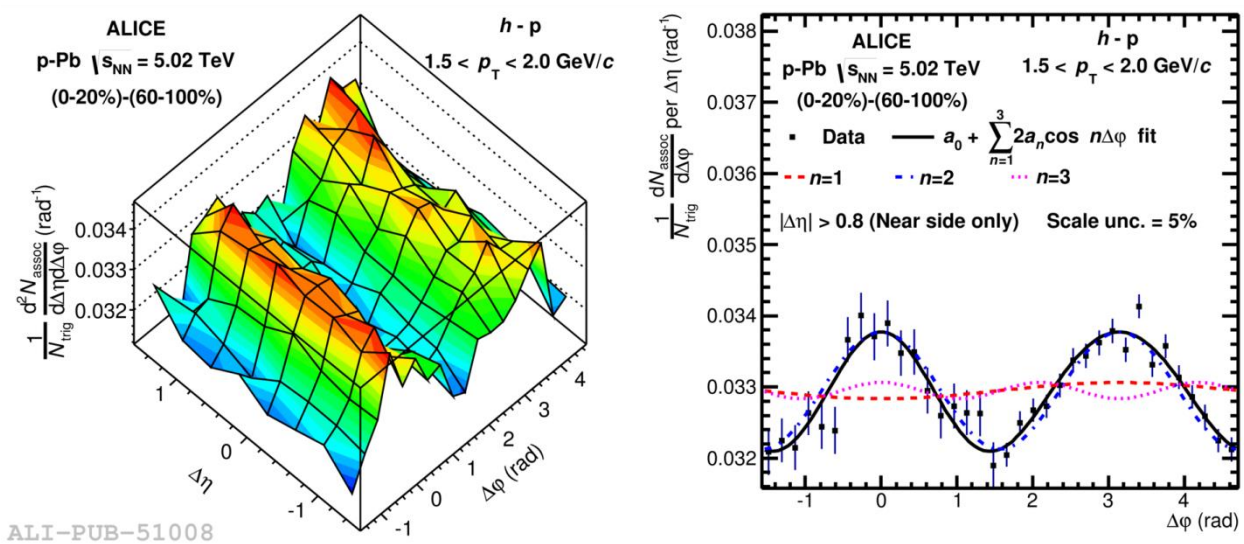
Physics Letters B In Press, arXiv:1307.3237

Identified particles in p-Pb by ALICE (P. Christiansen, Lund)

Pion-hadron correlations

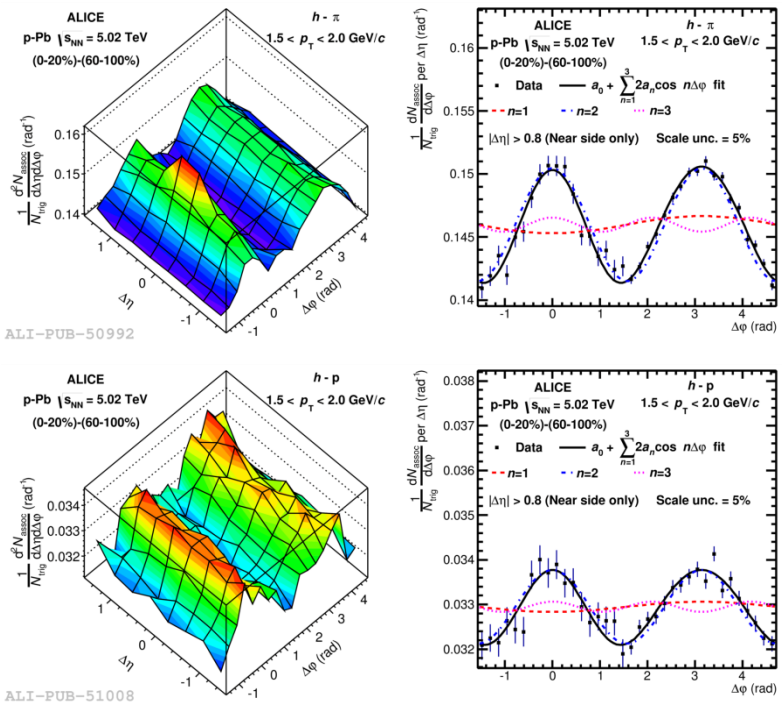


Proton-hadron correlations

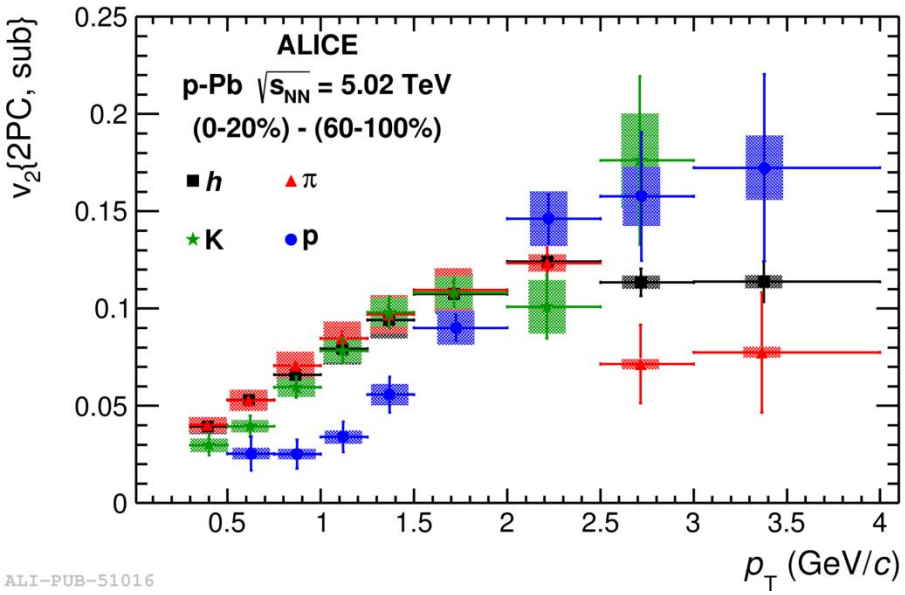


Using Particle IDentification to study the double ridge

See talk by Paul Kujier



Fourier coefficients:



Physics Letters B In Press, arXiv:1307.3237

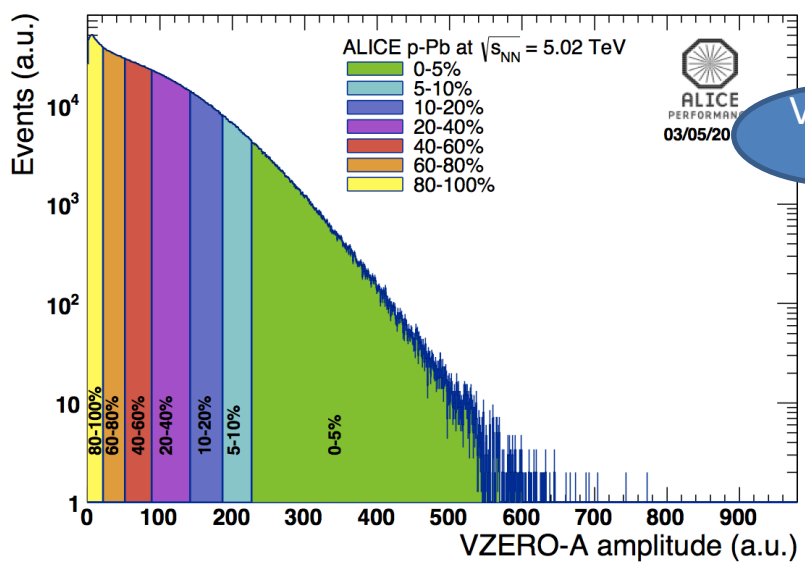
- Clear mass ordering

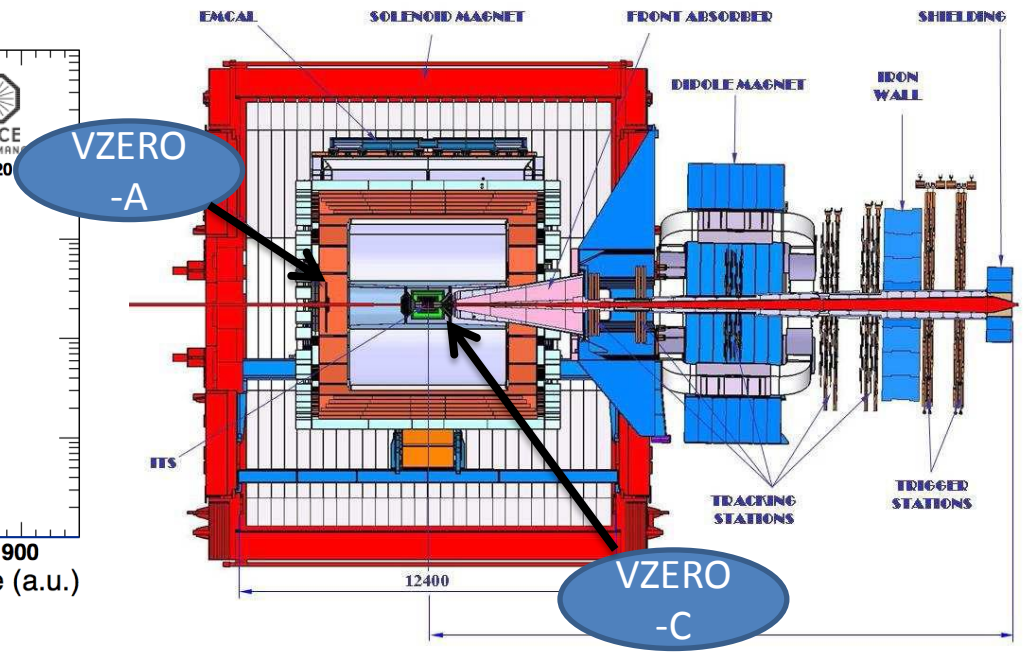
New questions for p-Pb collisions

- What is the origin of the double ridge structure observed in p-Pb collisions?
  - Initial state effects? (CGC?)
  - Formation of collective medium? (hydrodynamics?)
    - Is this a Hot or "Cold" QCD effect?
  - Alternative explanation?
- Strong indications for a coming paradigm change!
- Question: what can we learn from bulk production of identified particles?
  - Are there indications for final state effects such as radial flow?

ALICE: trigger and multiplicity

p ⟶ ⟵ Pb ($y_{CM}=y_{LAB}+0.465$ ⟶)



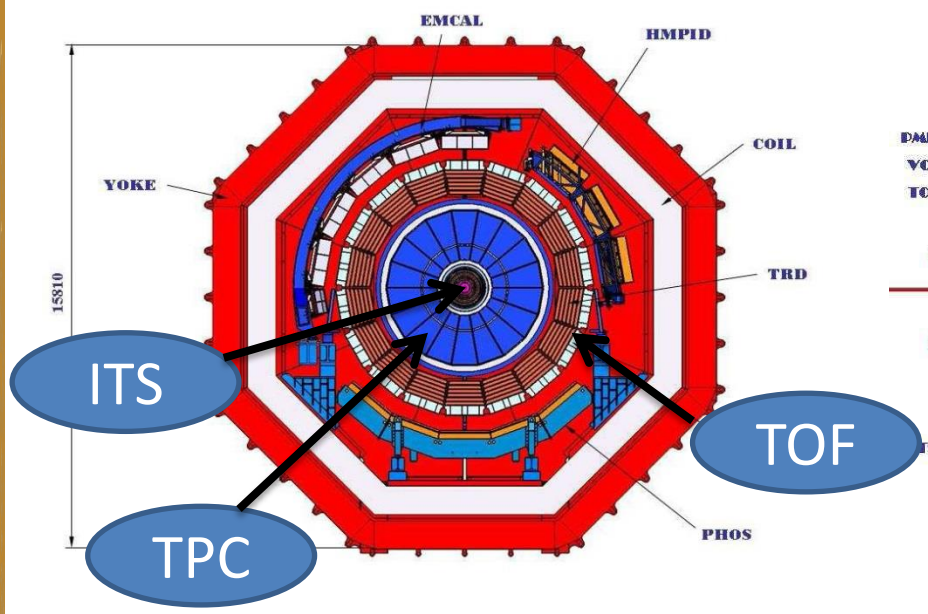


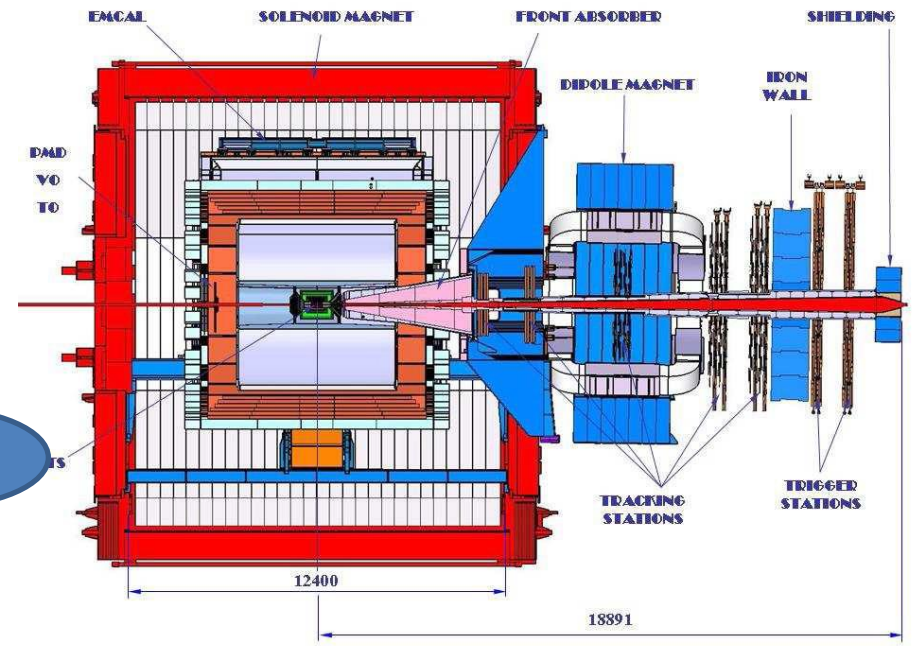
- VZERO used for triggering and multiplicity (A side)
- Fluctuations in the number of hard scatterings are important because of the small number of participants ⟹ weaker multiplicity vs. impact parameter correlation than in Pb-Pb

See talk by Alberica Toia

ALICE: tracking and PID

p → ← Pb ($y_{CM}=y_{LAB}+0.465$ →)

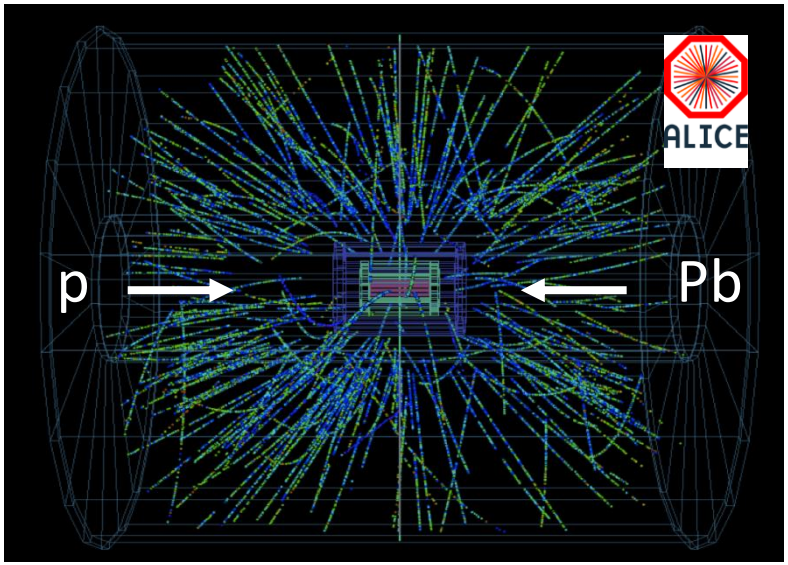


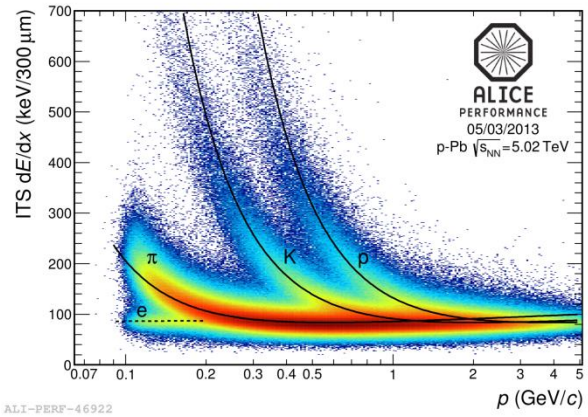


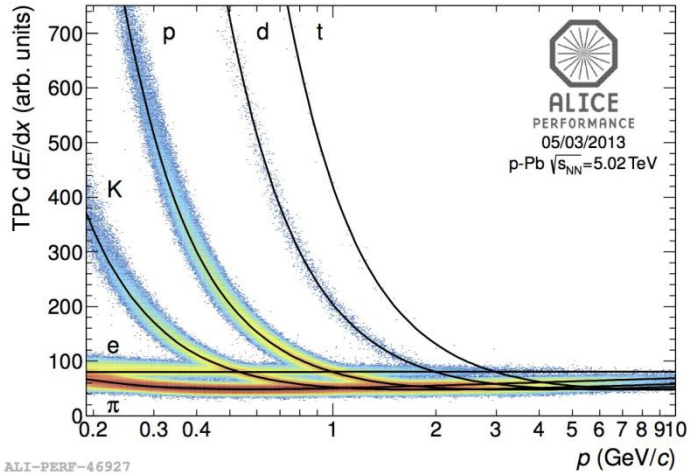
- Detectors used in this analysis
  - Inner Tracking System (tracking, PID)
  - Time Projection Chamber (tracking, PID)
  - Time Of Flight (PID)

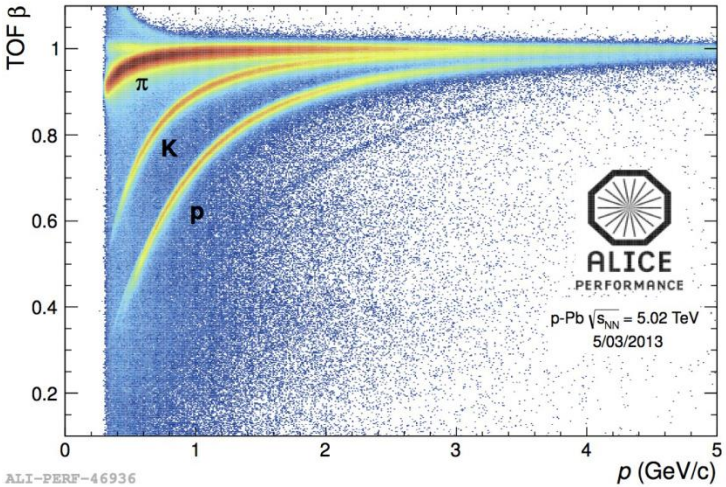
Identification of primary tracks

p-Pb event display
$\sqrt{s_{NN}}$ = 5.02 TeV

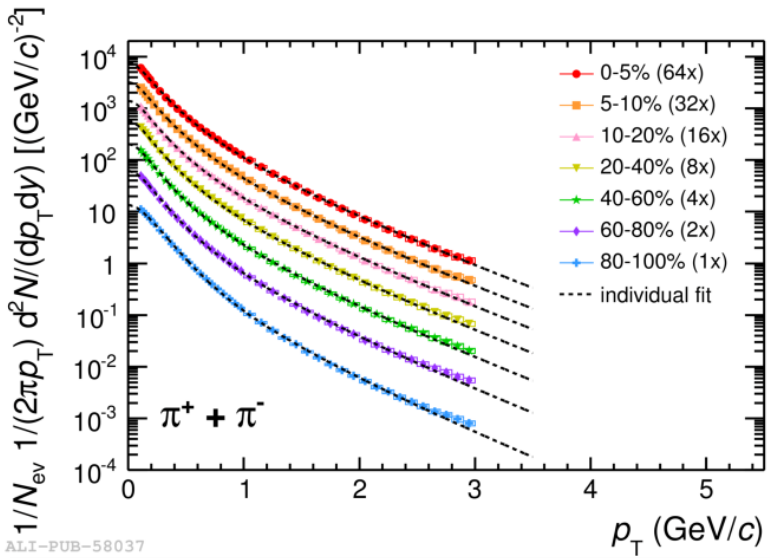


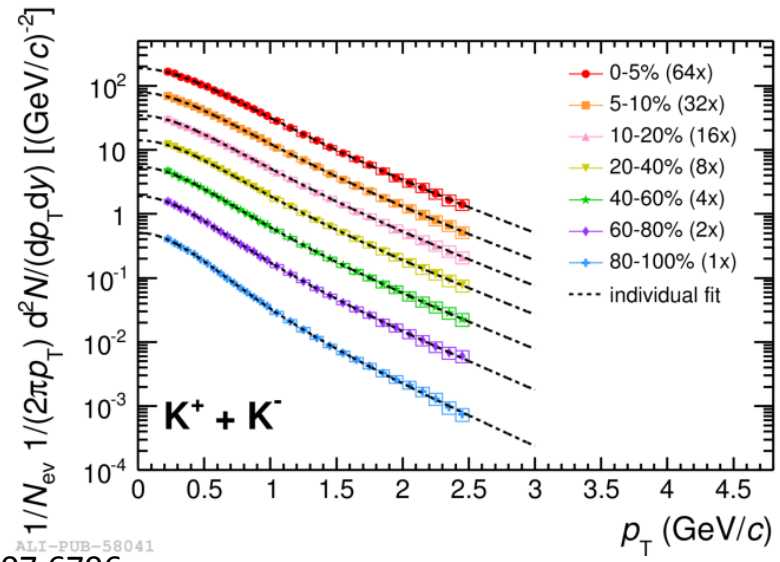




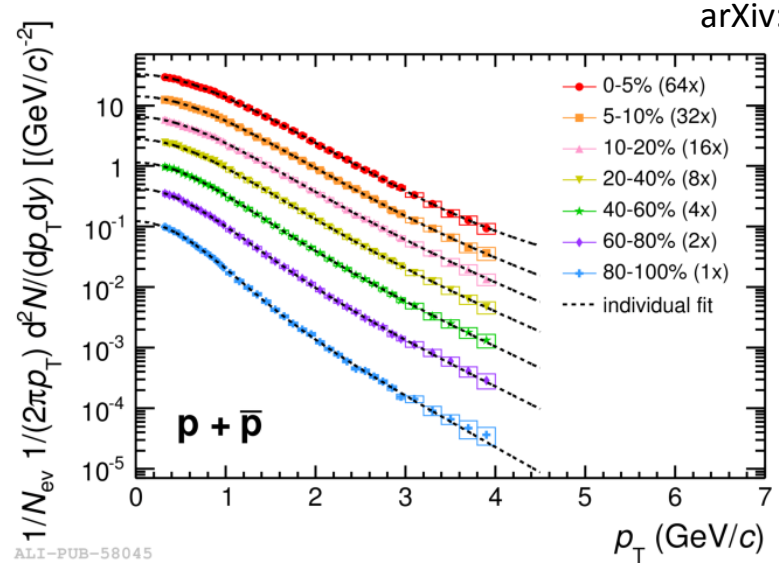


Spectra of π, K, p in p-Pb collisions



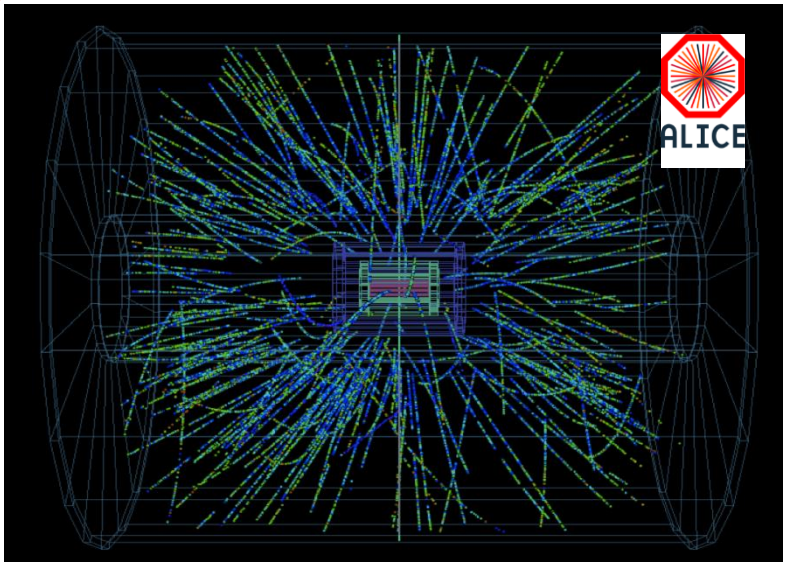


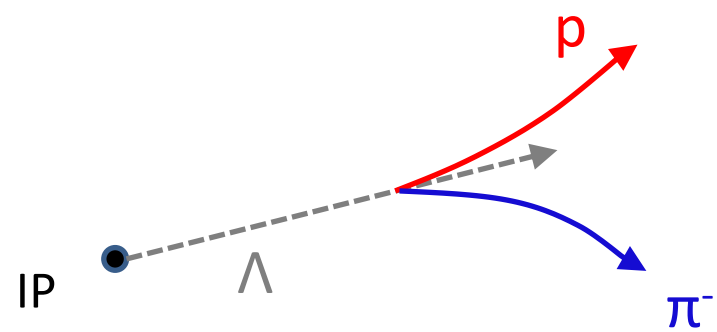
arXiv:1307.6796



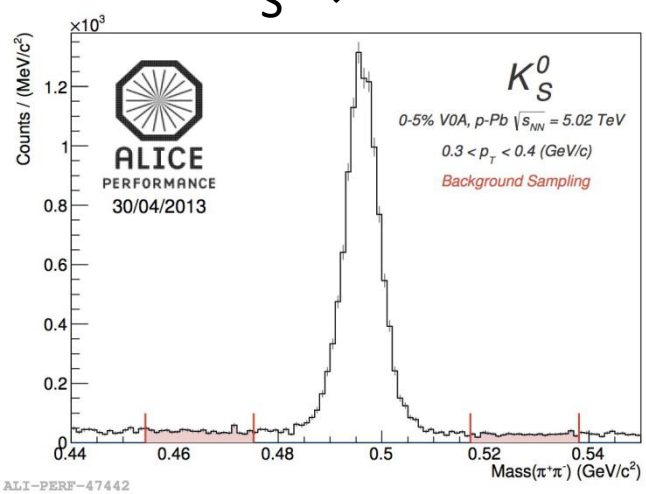
- Rapidity interval $0 < y_{CM} < 0.5$
- Dashed lines are individual blast-wave fits

Topological identification of V^0s

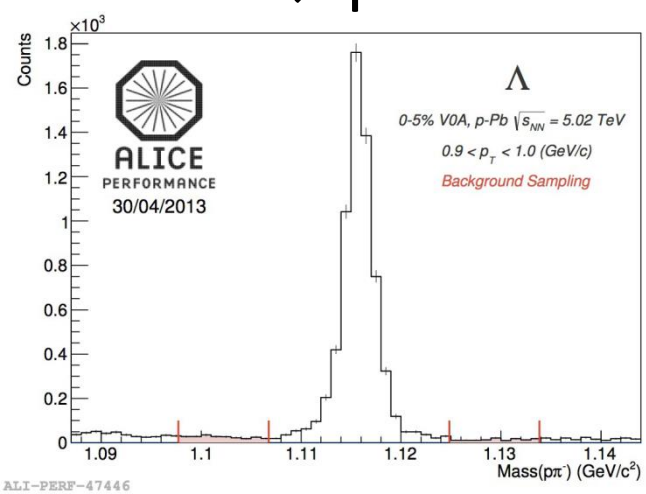




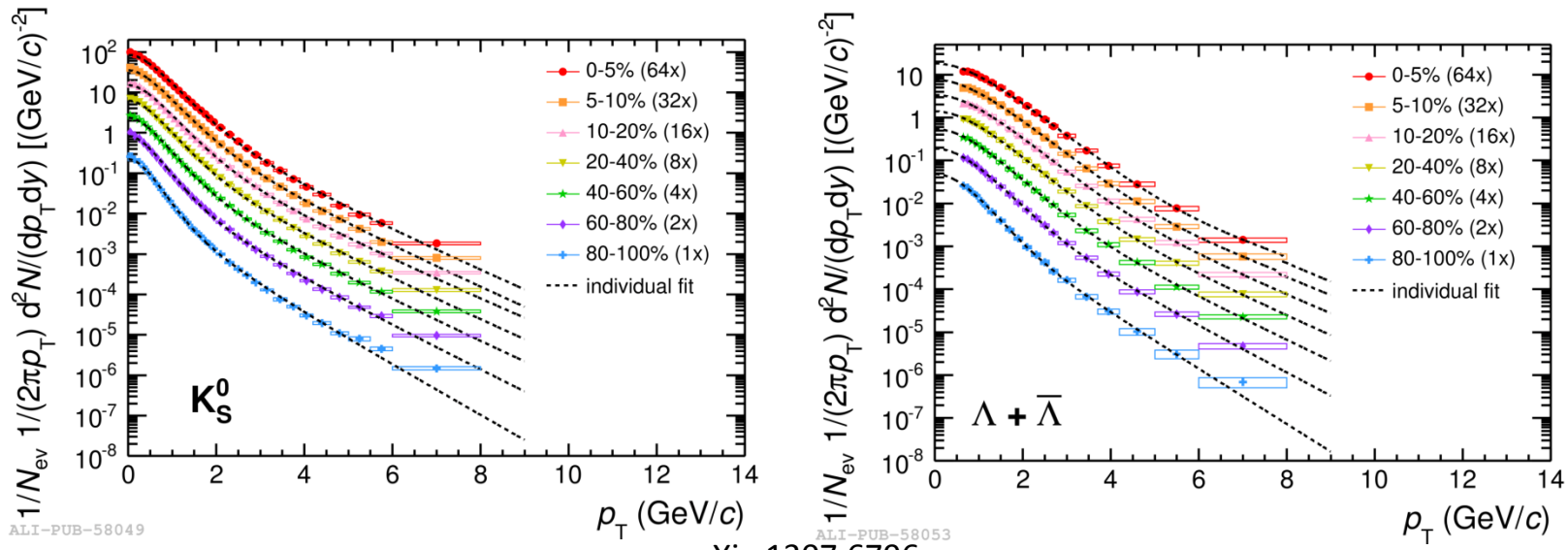
$K^0_S \rightarrow \pi^+ + \pi^-$



$\Lambda \rightarrow p + \pi^-$



Spectra of K^0_S and Λ in p-Pb collisions

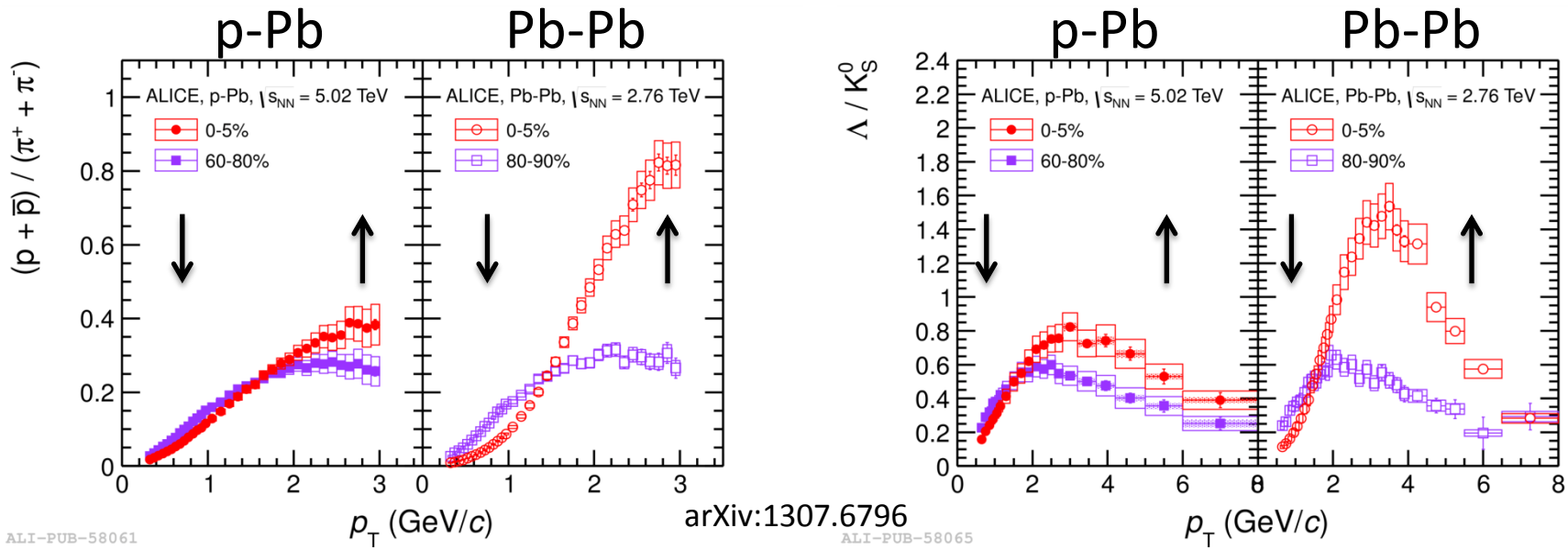


arXiv:1307.6796

- Rapidity interval $0 < y_{CM} < 0.5$
- Dashed lines are individual blast-wave fits

- p_T coverage:
  π: $0.2 < p_T < 3.0$ GeV/c
  K: $0.25 < p_T < 2.5$ GeV/c
  K^0_S: $0.0 < p_T < 8.0$ GeV/c
  p: $0.45 < p_T < 4.0$ GeV/c
  Λ: $0.6 < p_T < 8.0$ GeV/c

Features of the data



arXiv:1307.6796

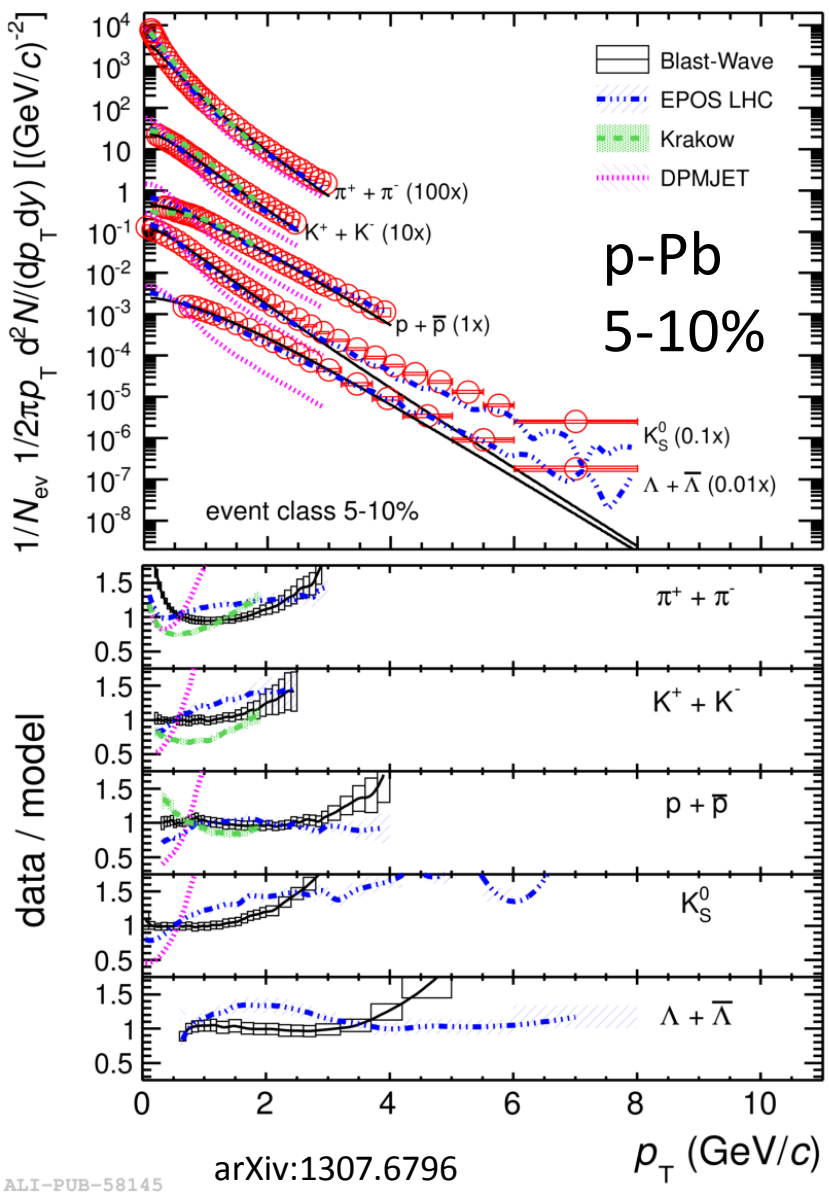
- Characteristic evolution of p/π and Λ/ K^0_S with multiplicity is reminiscent of Pb-Pb where it is believed to be due to radial flow
- NB! The solid boxes for p-Pb ratios indicate the uncorrelated systematic error
  ⟹ the relative trend can be measured rather precisely

Integrated particle ratios and <p_T> will be covered by Francesco Barile

Which models can capture these features?

- Models
  - Blast-wave (next slides)
  - EPOS LHC (full event generator including hydro)
  - Krakow (hydro calculation focused on low p_T)
  - DPMJet (PHOJET pp + nuclei via Glauber-Gribov theory)

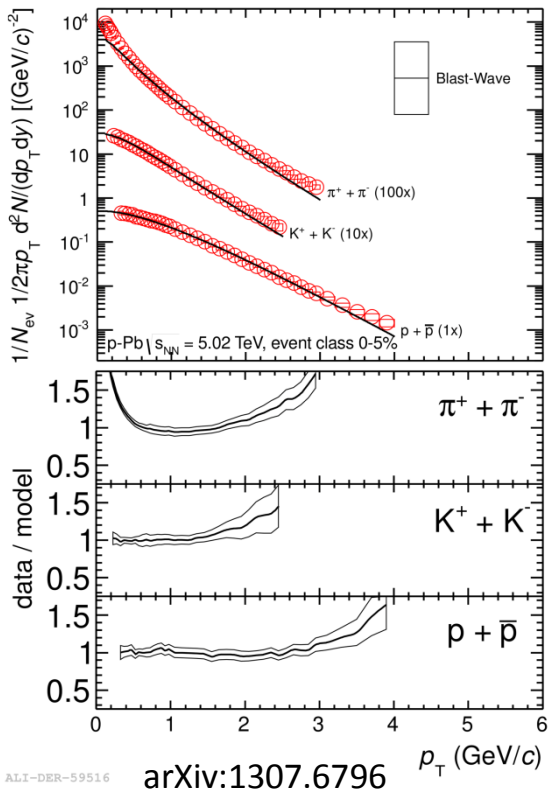
- Only models which employ hydrodynamics can describe the p_T spectra



arXiv:1307.6796

A blast wave study of the data

p-Pb 0-5%



arXiv:1307.6796

- Simultaneous fits
  π: $0.5 < p_T < 1.0$ GeV/c
  K: $0.2 < p_T < 1.5$ GeV/c
  pp: $0.3 < p_T < 1.5$ GeV/c
  p: $0.3 < p_T < 3.0$ GeV/c
  pp: $0.5 < p_T < 2.5$ GeV/c

- Adding
  K^0_S ($0.0 < p_T < 1.5$ GeV/c)
  and
  Λ ($0.6 < p_T < 2.0$ GeV/c)
  does not significantly change extracted parameters

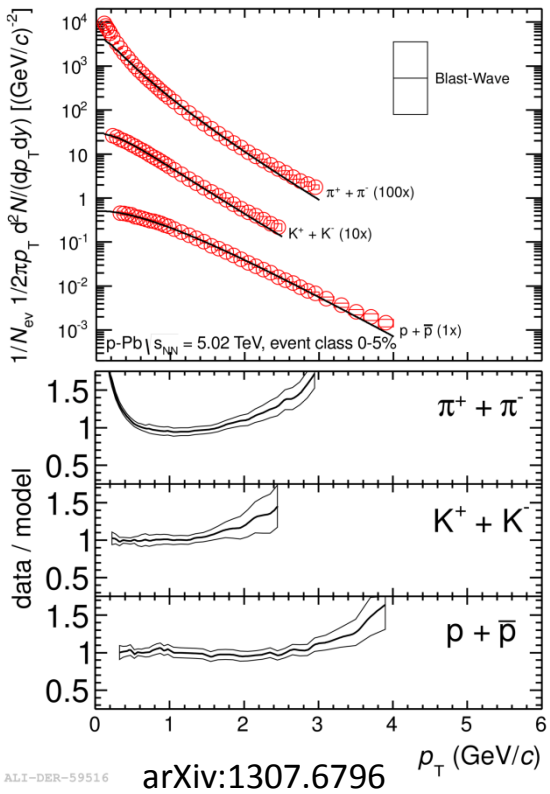
Schnedermann et al, Phys. Rev. C 48, 2462 (1993)

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

$$\rho = \tanh^{-1}\beta_T$$
$$\beta_T = \beta_S (r/R)^n$$
$$\langle\beta_T\rangle = \frac{2}{2+n}\beta_S.$$

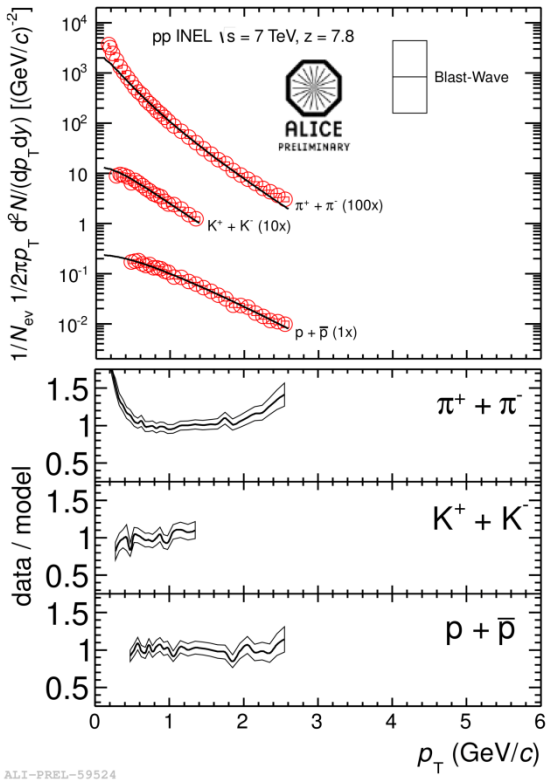
A blast wave study of the data

p-Pb 0-5%



arXiv:1307.6796

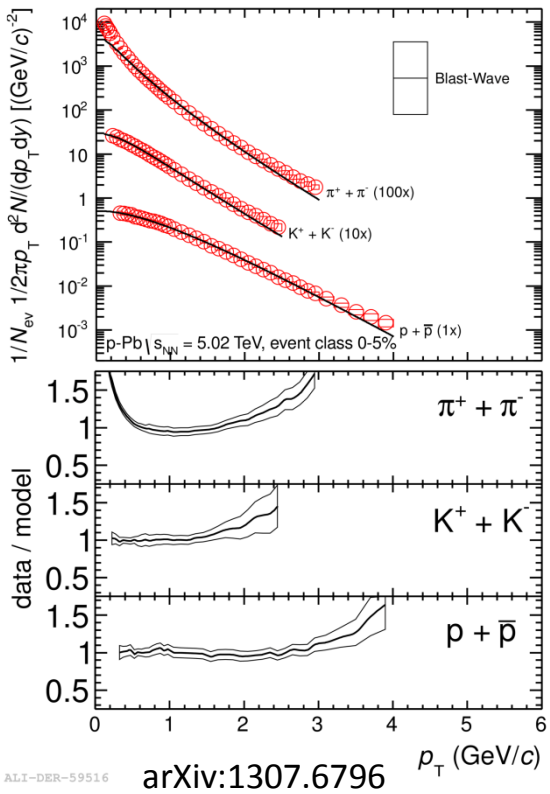
pp highest mult √s = 7 TeV



The description of p-Pb and pp data by the blast-wave fit is reasonable without being excellent

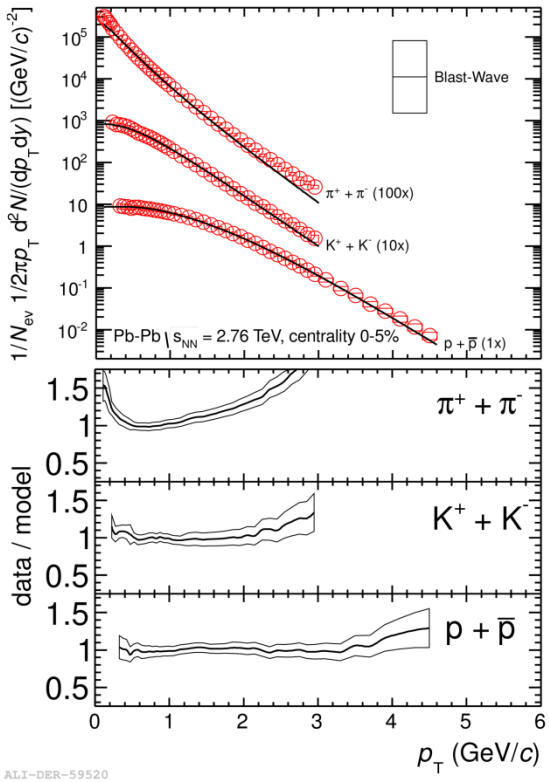
A blast wave study of the data

p-Pb 0-5%



arXiv:1307.6796

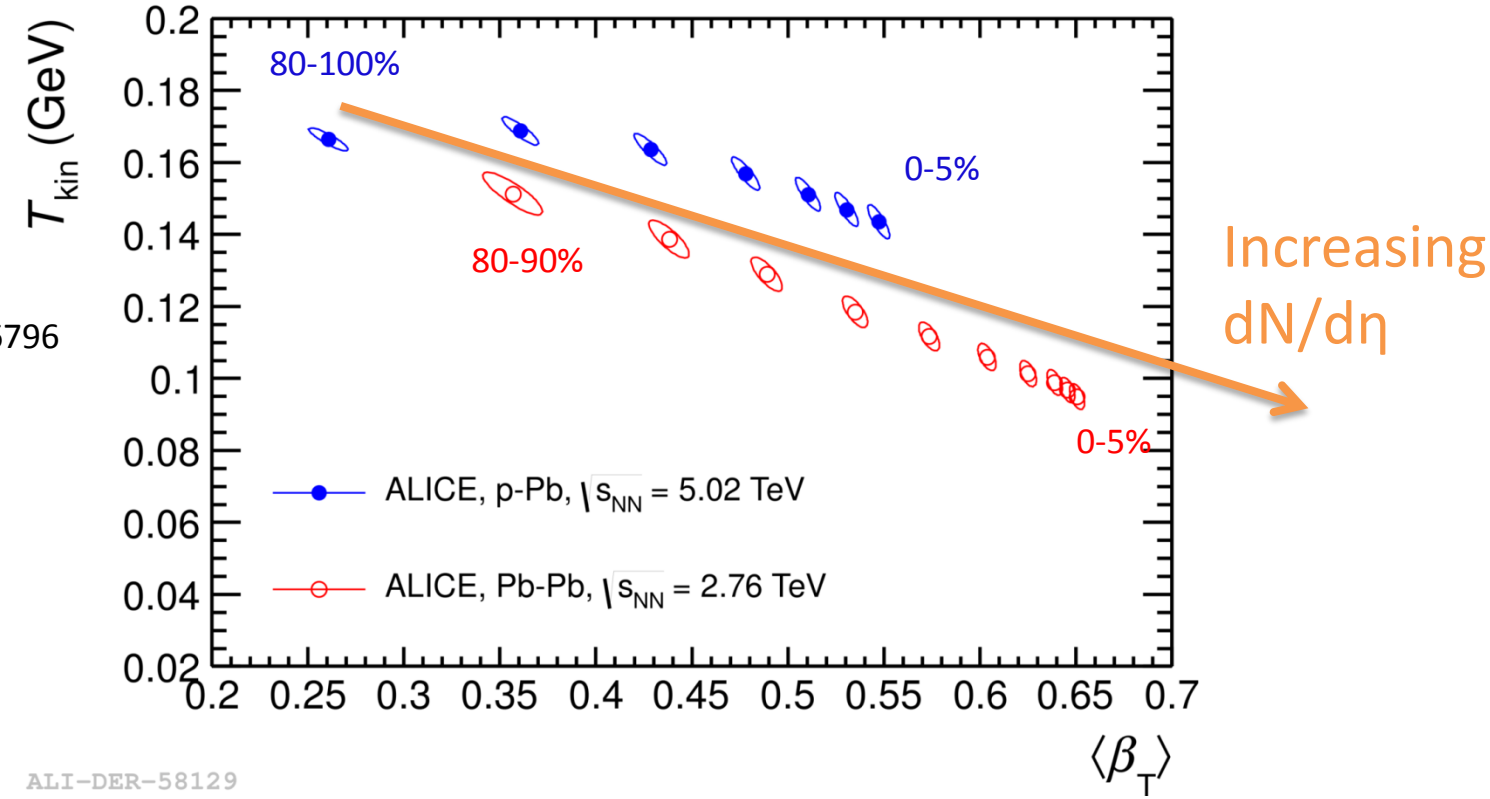
Pb-Pb 0-5% $\sqrt{s_{NN}}$ = 2.76 TeV



The p_T region where the blast-wave fit describes the data is in general broader for Pb-Pb

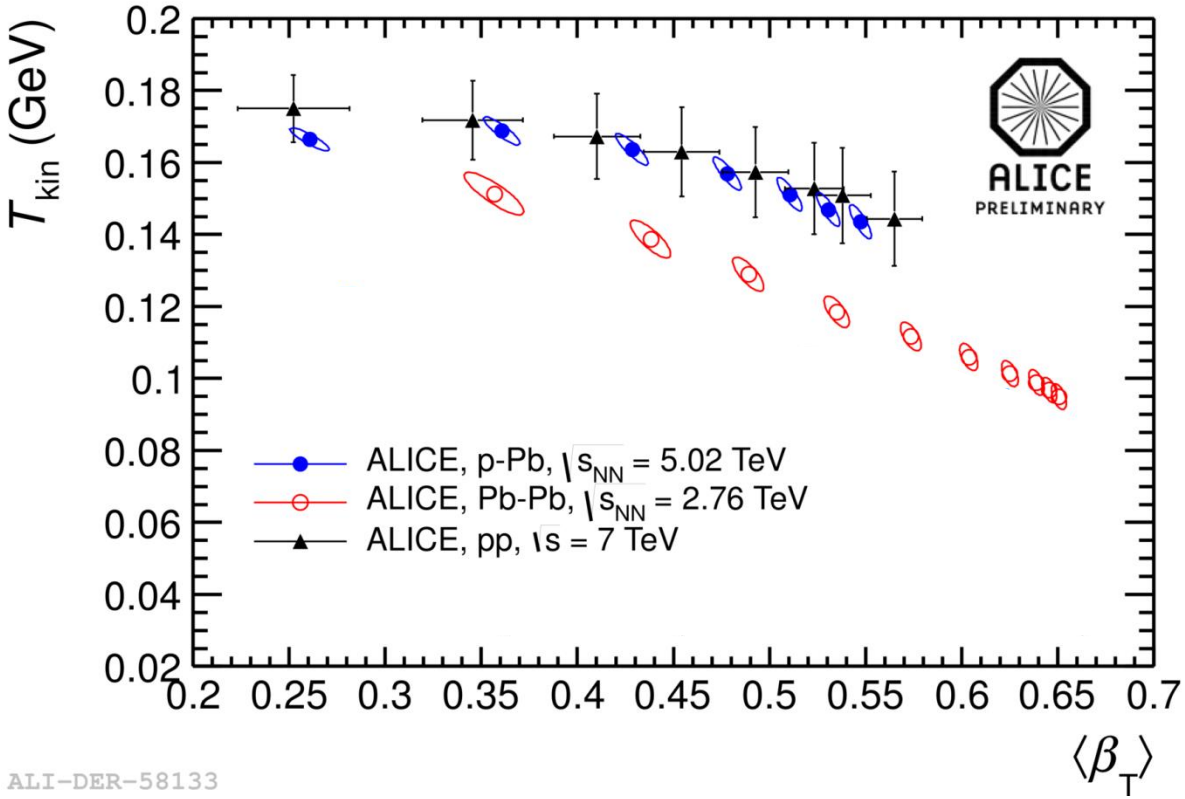
Summarizing the results from the blast-wave studies

arXiv:1307.6796



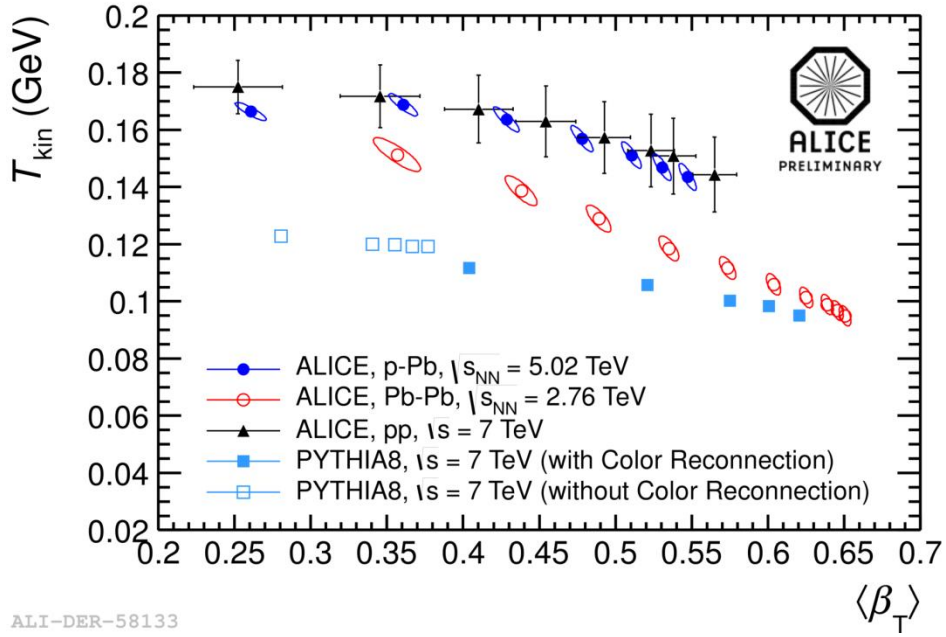
There is a strong common trend between the parameters extracted from Pb-Pb and p-Pb

Summarizing the results from the blast-wave studies



Even the pp data seems to follow the same trend!
It seems that if we ascribe the change in spectral shape to radial flow in p-Pb then the same can be done in pp

Summarizing the results from the blast-wave studies



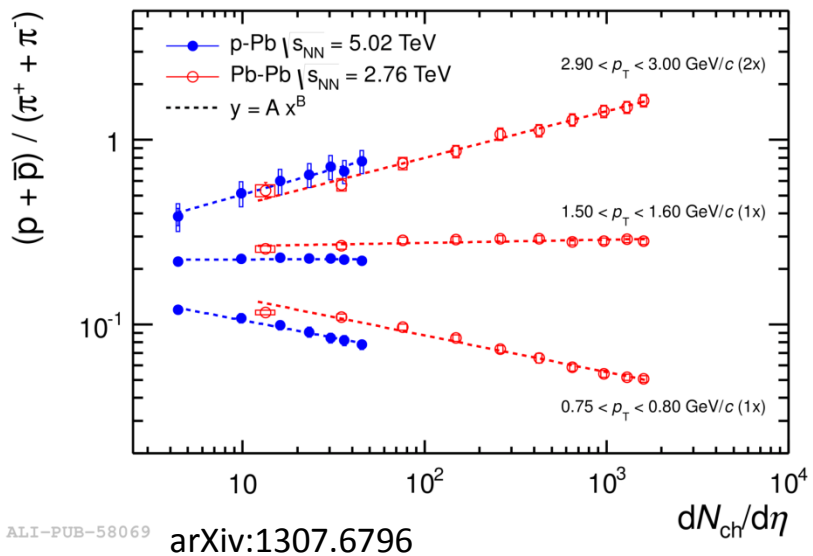
BUT also simulated PYTHIA8 pp events follow a <u>qualitatively</u> similar trend when Color Reconnection (CR) is enabled

CR has been shown to mimic radial flow but without requiring the formation of a medium [Ortiz et al, PRL111, 042001 (2013)]

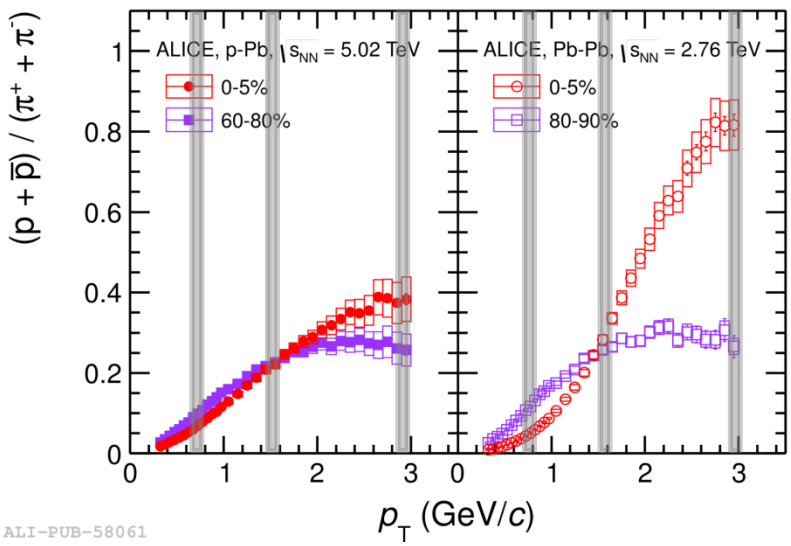
$\Rightarrow$ No unique theoretical interpretation of hydro/medium

$\Rightarrow$ Can we learn more in another way?

Data driven approach

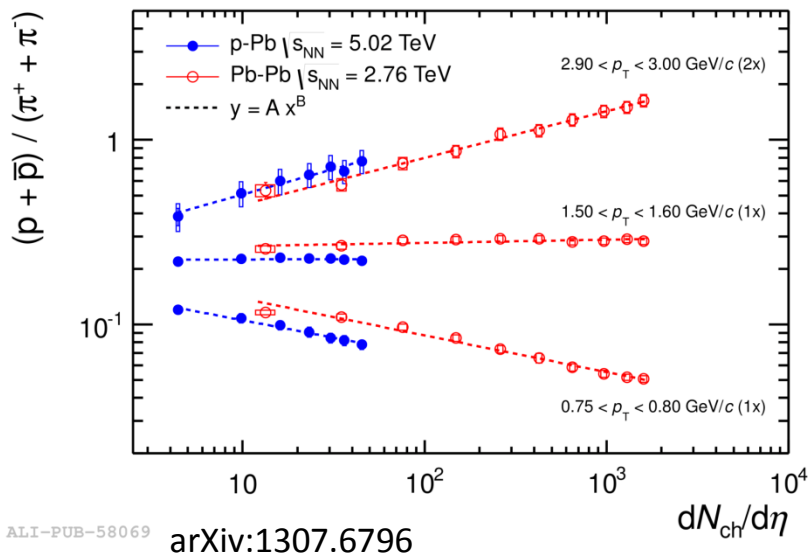


arXiv:1307.6796

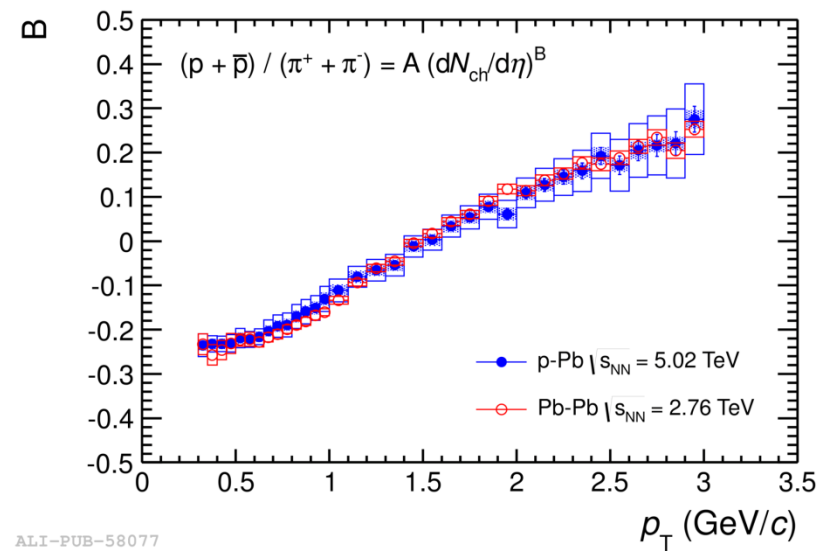


- Fit the evolution of the p/π ratio with dN/dη in each p_T interval with a power law function: $y=Ax^B$

Data driven approach

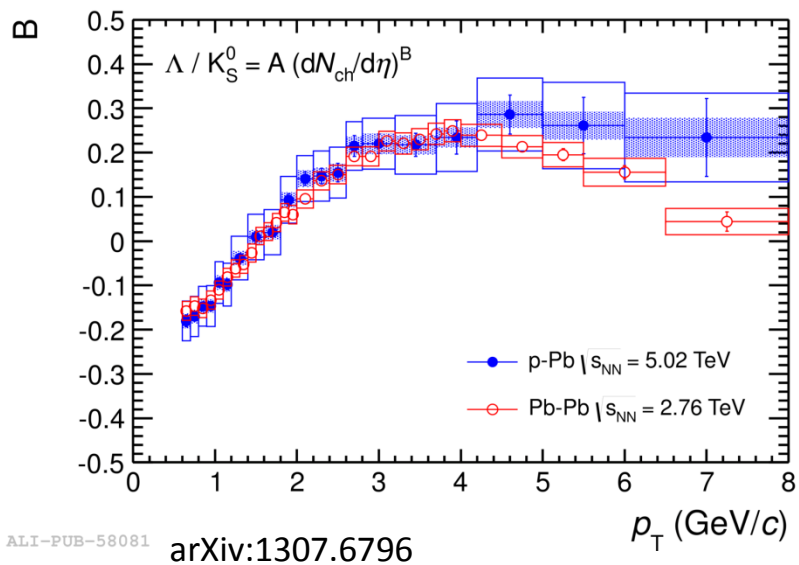


arXiv:1307.6796

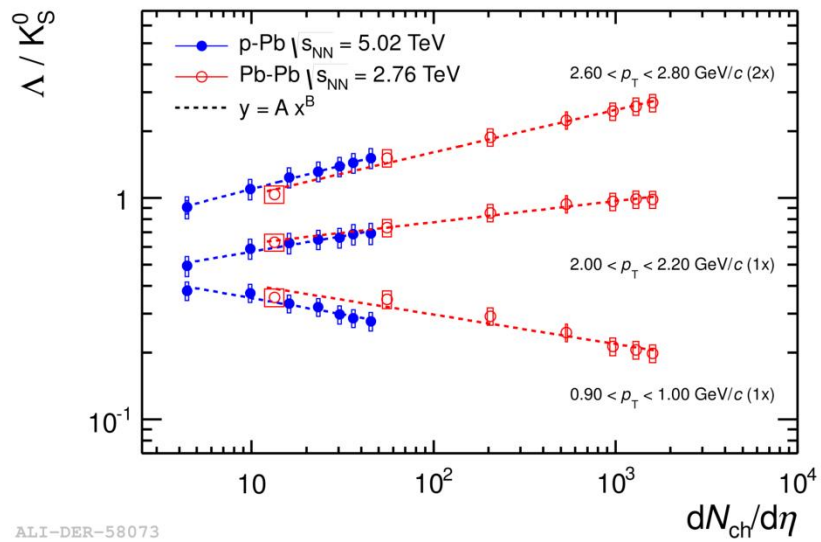


- Fit the evolution of the p/π ratio with dN/dη in each p_T interval with a power law function: $y=Ax^B$
- Compare the extracted exponents B

Similar studies with Λ/K^0_S

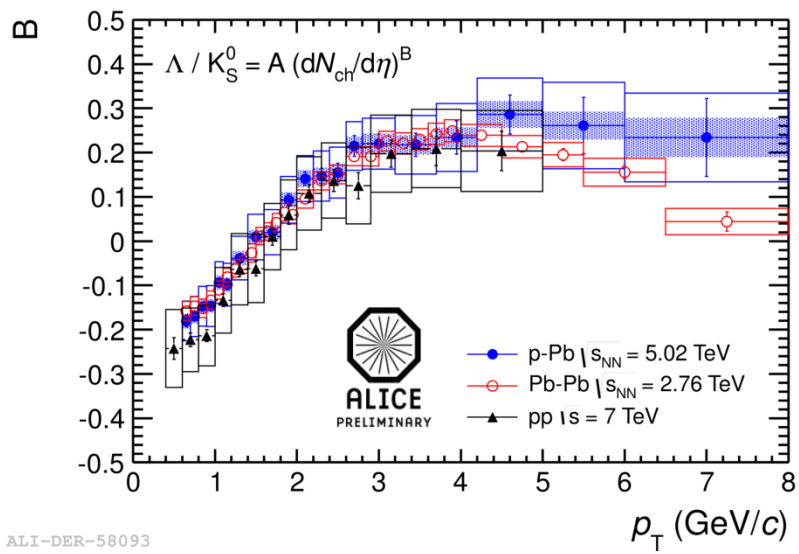


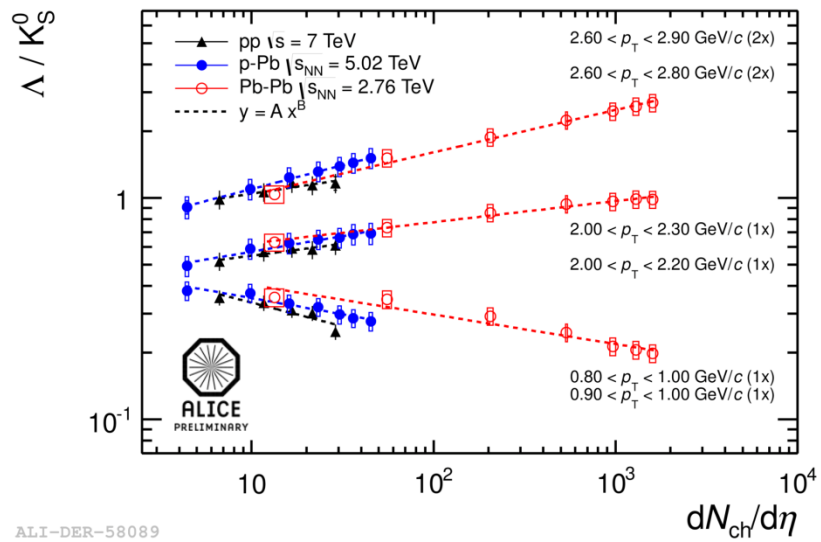
arXiv:1307.6796



- Using Λ/K^0_S allows one to extend the p_T range to cover also the region of the baryon peak (p_T~3GeV/c) where the scaling also seems to hold

Similar studies with Λ/K^0_S: adding pp





- The way the multiplicity is defined in pp biases the p/π ratios (significantly more than the Λ/K^0_S)
- The evolution of Λ/K^0_S (p/π) with dN/dη is similar for all 3 (2) systems
  ⇒ surprising suggestive pattern that similar physics is driving the ratios for all systems and for all sizes (no evidence for an onset in dN/dη) ....

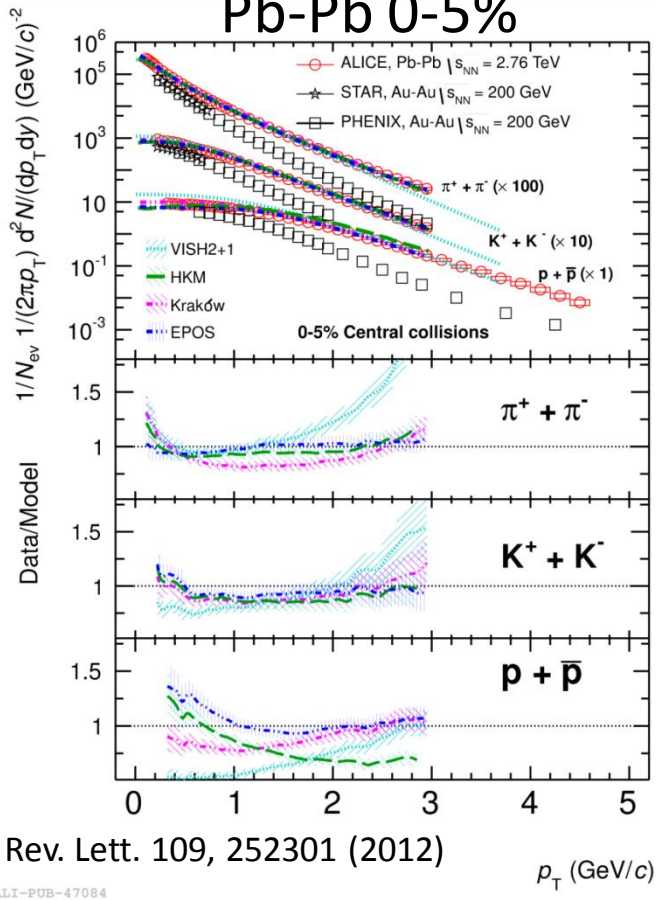
.... but it also raises additional questions

- Is the scaling in particle ratios and dN/dη meaningful?
  - They do not appear to be particularly fundamental quantities in e.g. a hydro model?
- What is the role of the initial geometry?
  - For pp and p-Pb it is limited by proton area suggesting a weak multiplicity dependence of the initial area While for Pb-Pb the nuclear overlap has a strong multiplicity dependence
- How does the absolute dN/dη affect this?
  - Varying e.g. the center of mass energy?

- Have a look at the last two questions here

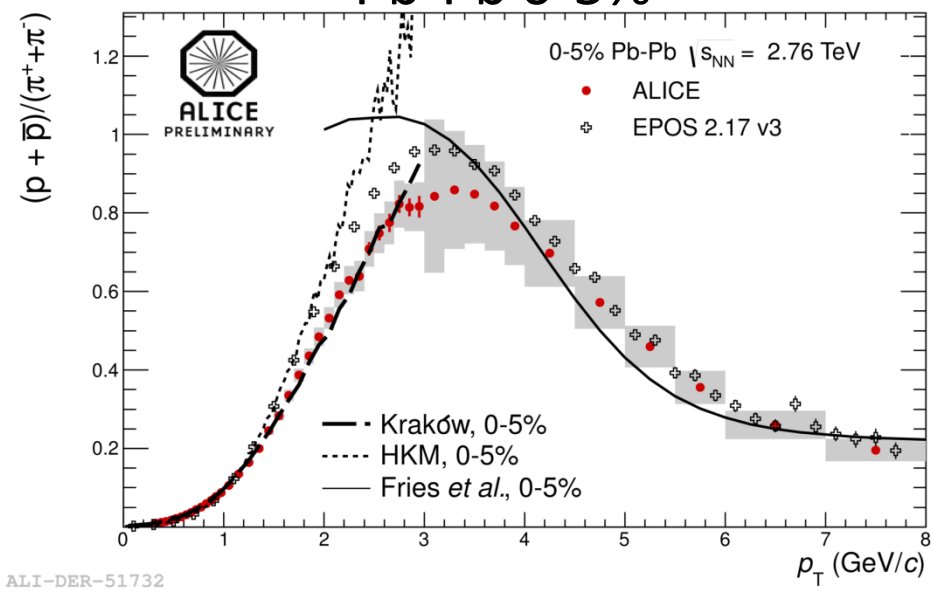
Geometry: is the Pb-Pb centrality evolution described by hydro?

Pb-Pb 0-5%



Phys. Rev. Lett. 109, 252301 (2012)

Pb-Pb 0-5%

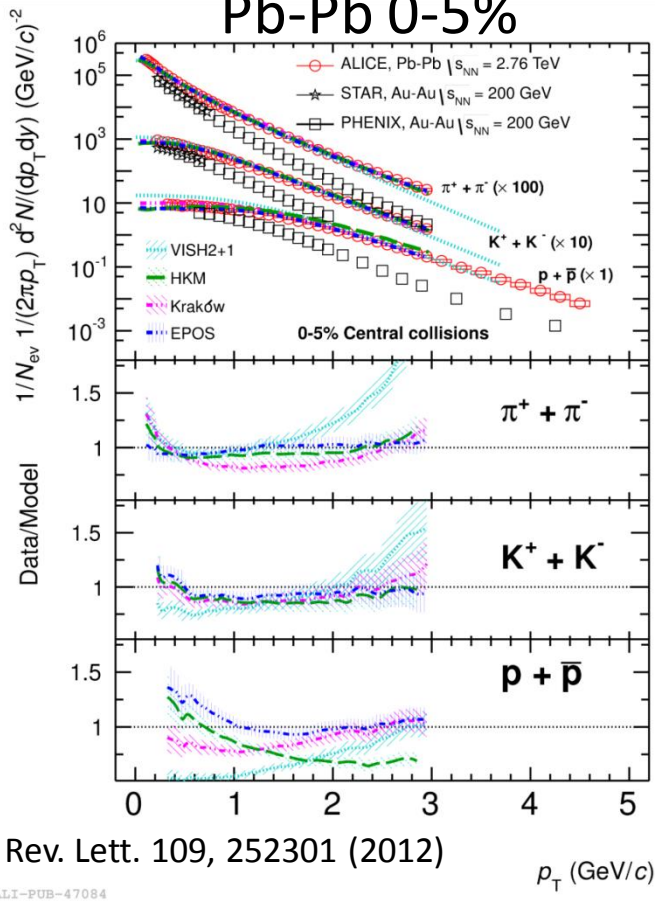


Krakow: PRC85, 064915 (2012)
HKM: PRC87, 024914 (2013)
Fries: PRL90, 202303 (2003) and private communication
EPOS: PRL109, 102301 (2012) and private communications

- Near ideal hydrodynamics with some implementation of the hadronic phase describes well p_T spectra in central collisions

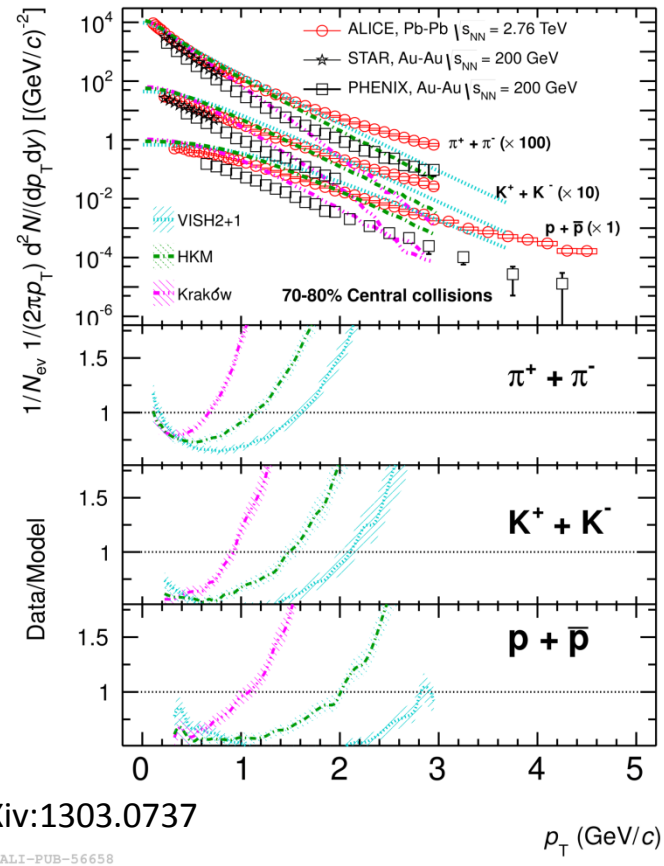
Geometry: is the Pb-Pb centrality evolution described by hydro?

Pb-Pb 0-5%



Phys. Rev. Lett. 109, 252301 (2012)

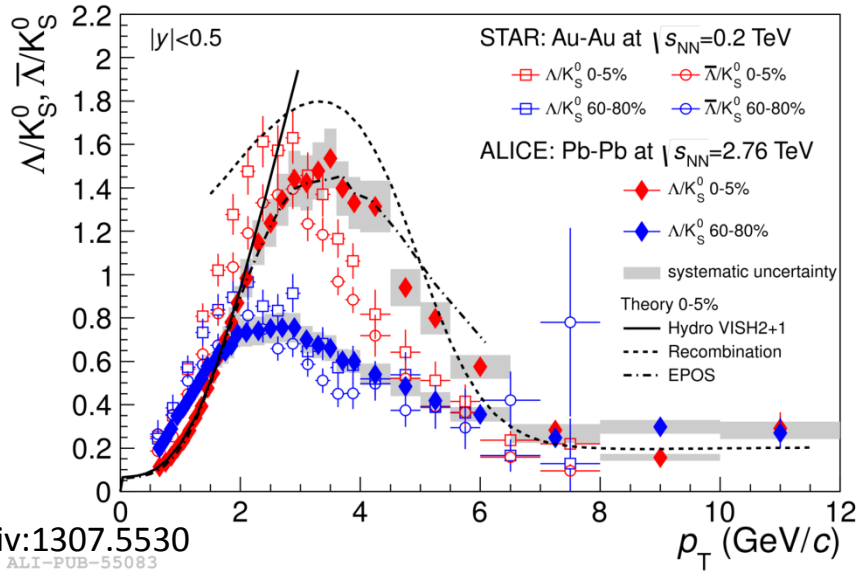
Pb-Pb 70-80%



arXiv:1303.0737

- The same models fail to describe the p_T spectra in peripheral collisions
- Typically hydro has not been expected to work in peripheral collisions but if it is at work in p-Pb and pp collisions should it not work there?

How does varying $\sqrt{s_{NN}}$ affect the ratios?



arXiv:1307.5530

At RHIC Λ-bar / Λ ~ 0.8.
In the statistical model for fixed T and μ_B<<T one expects (Λ+Λ-bar)/K^0_s to be insensitive to μ_B
So if the underlying ratios are similar we expect LHC ratios to lie between RHIC ratios

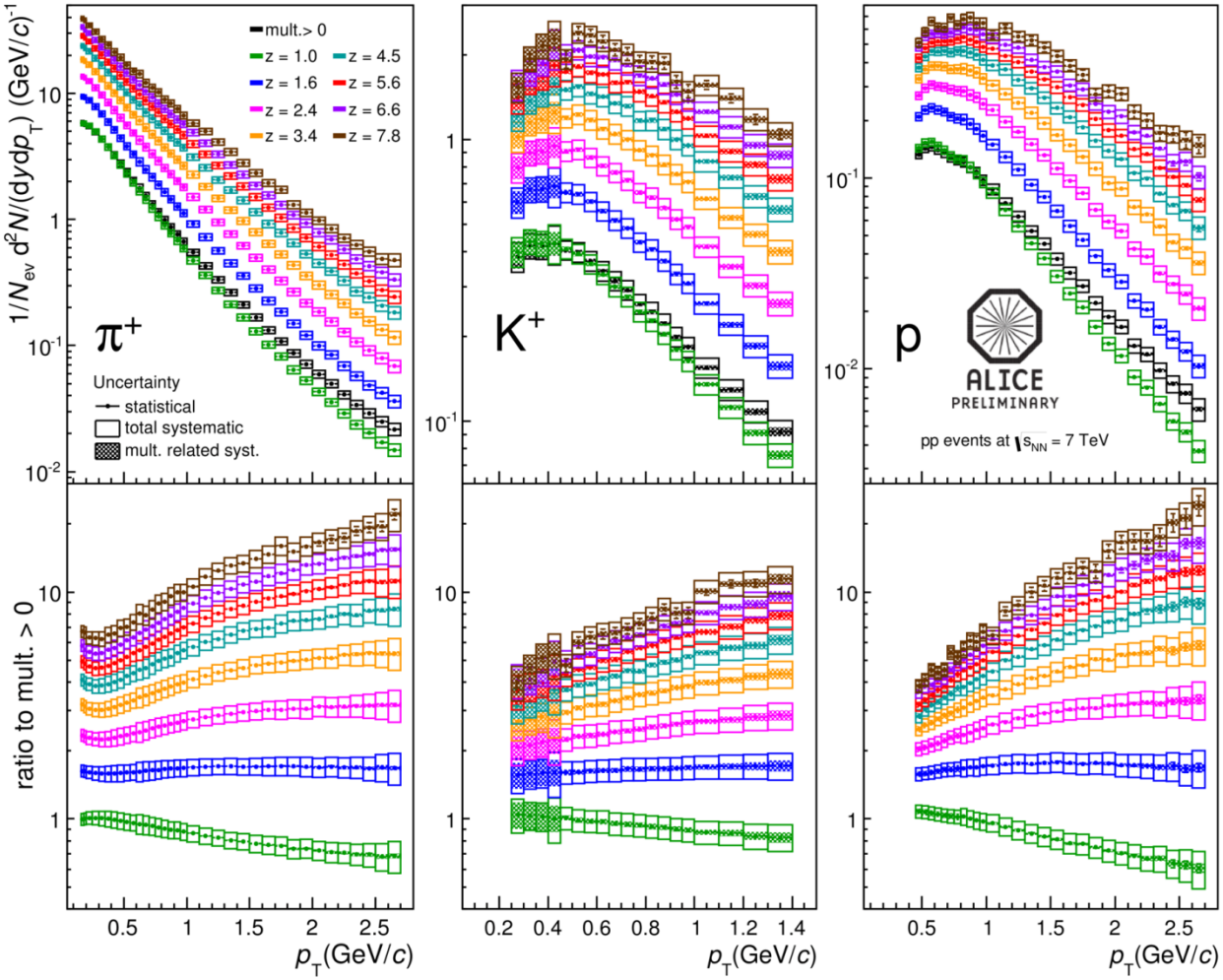
- For peripheral events (blue points) the ratios are similar while for central events (red points) there is a clear difference
- The absolute increase of dN/dη from RHIC to LHC is ~2.1 in both centrality classes
  ⇒ Different scaling at RHIC and LHC
  ⇒ The smaller peripheral system seems less responsive to the increase in energy density.
  Is this consistent with hydrodynamics in small systems?

Conclusions

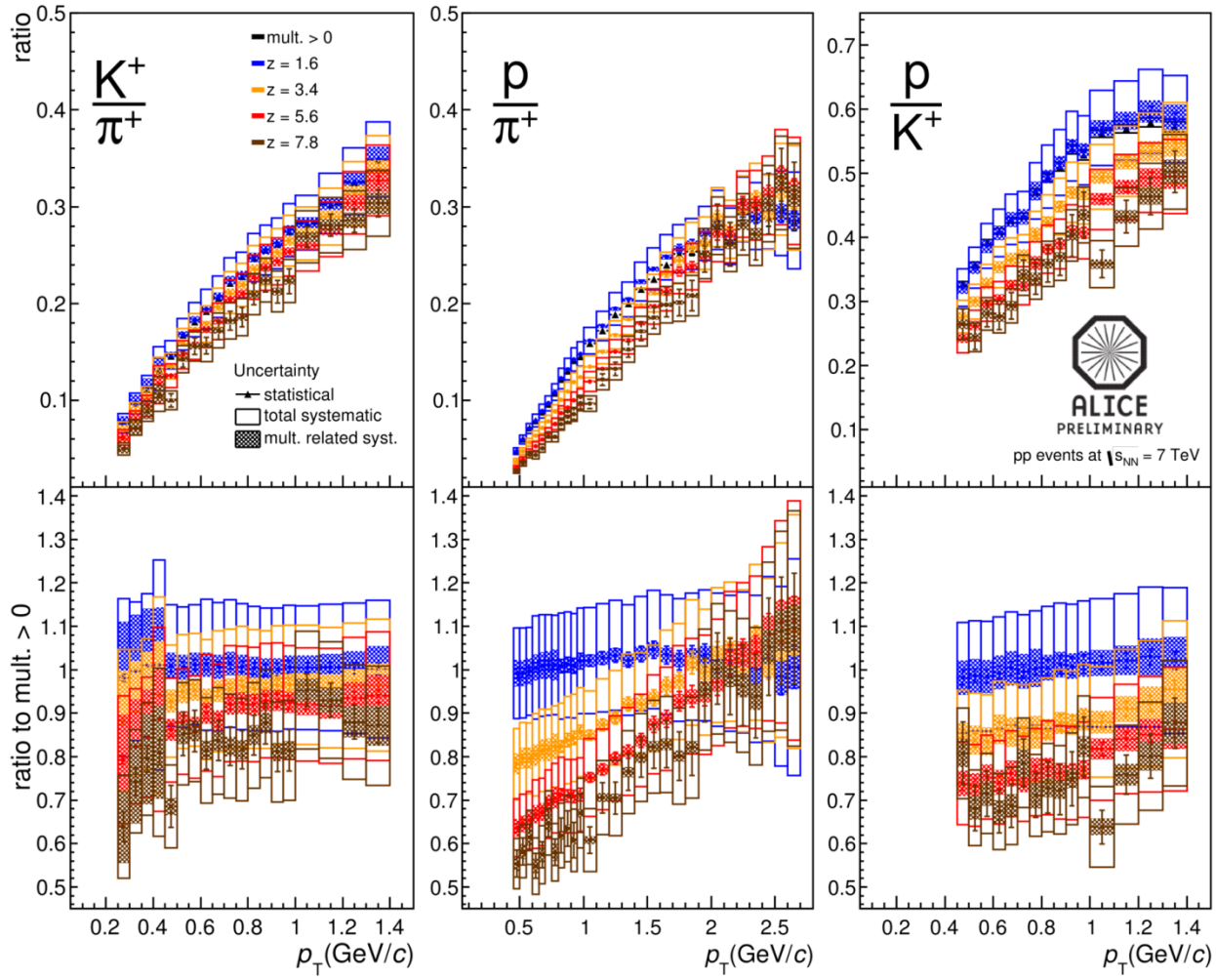
- The p_T spectra of π, K , K^0_S, p, and Λ as a function of multiplicity in p-Pb were reported
- These p-Pb spectra show similar trends as associated with radial flow in Pb-Pb
  - Spectra are best described by models incorporating a hydrodynamical phase
  - Blast-wave analysis shows similar multiplicity dependence as in Pb-Pb
  - The evolution of particle ratios with p_T and multiplicity seems to follow the same trend across all collision systems
- Taken together there are strong indications for final state effects in both p-Pb (and pp), but some uncertainty as to whether this is hydrodynamical or due to another mechanism

Backup slides

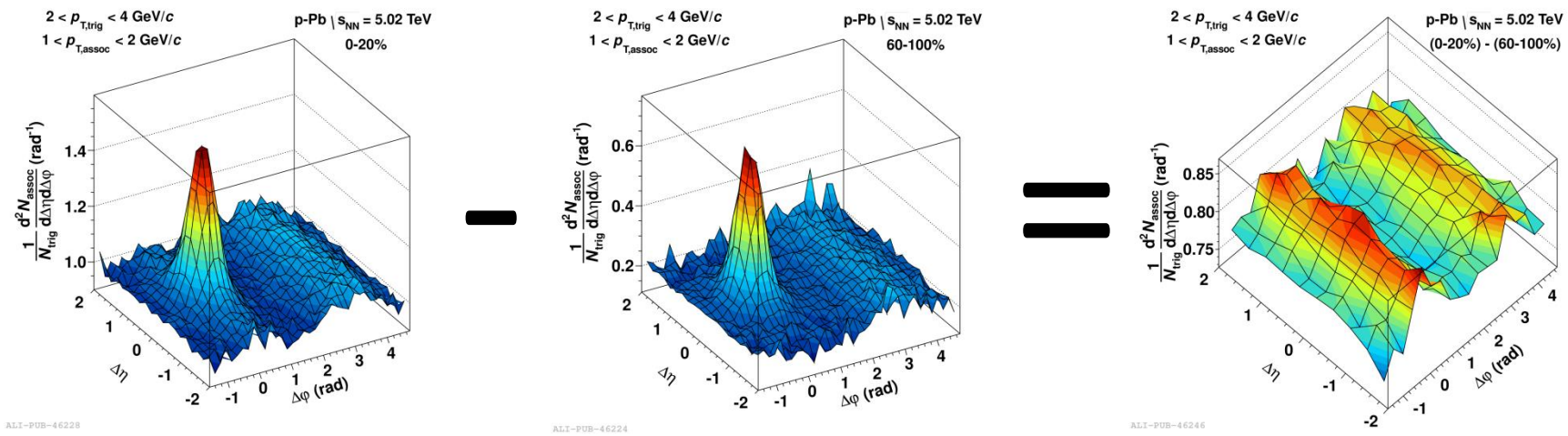
7 TeV pp spectra vs mult



7 TeV pp ratios vs mult

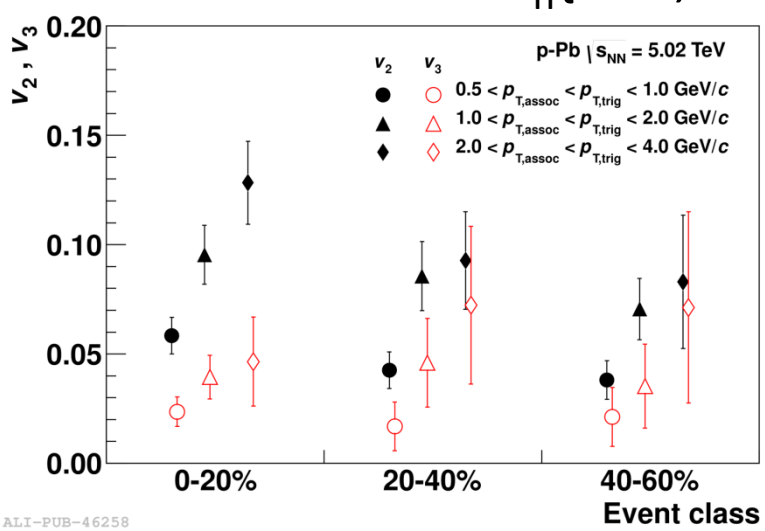


The double ridge in p-Pb collisions



Physics Letters B 719 (2013)

Fourier coefficients: v_n{2PC,sub}



- Double ridge structure
- Reminiscent of azimuthal flow in Pb-Pb collisions

Sum of particles and antiparticles

- At lower CM energies Λ-bar/ Λ << 1.
- In the statistical model (neglecting feeddown):
  - $N_{\Lambda} \propto e^{+\mu B/T} * e^{-m/T}$
  - $N_{\Lambda\text{-bar}} \propto e^{-\mu B/T} * e^{-m/T}$
- When $\mu_B << T$:
  - $N_{\Lambda}+N_{\Lambda\text{-bar}} \propto (1+ \mu_B/T + 1 - \mu_B/T) * e^{-m/T} \sim 2*e^{-m/T}$
- So $(N_{\Lambda}+N_{\Lambda\text{-bar}})/(2*NK^0_s)$ is roughly independent of μ_B.