HEP 2013
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Identified charged pion, kaon, and proton production in pp and Pb-Pb collisions at LHC energies measured with ALICE

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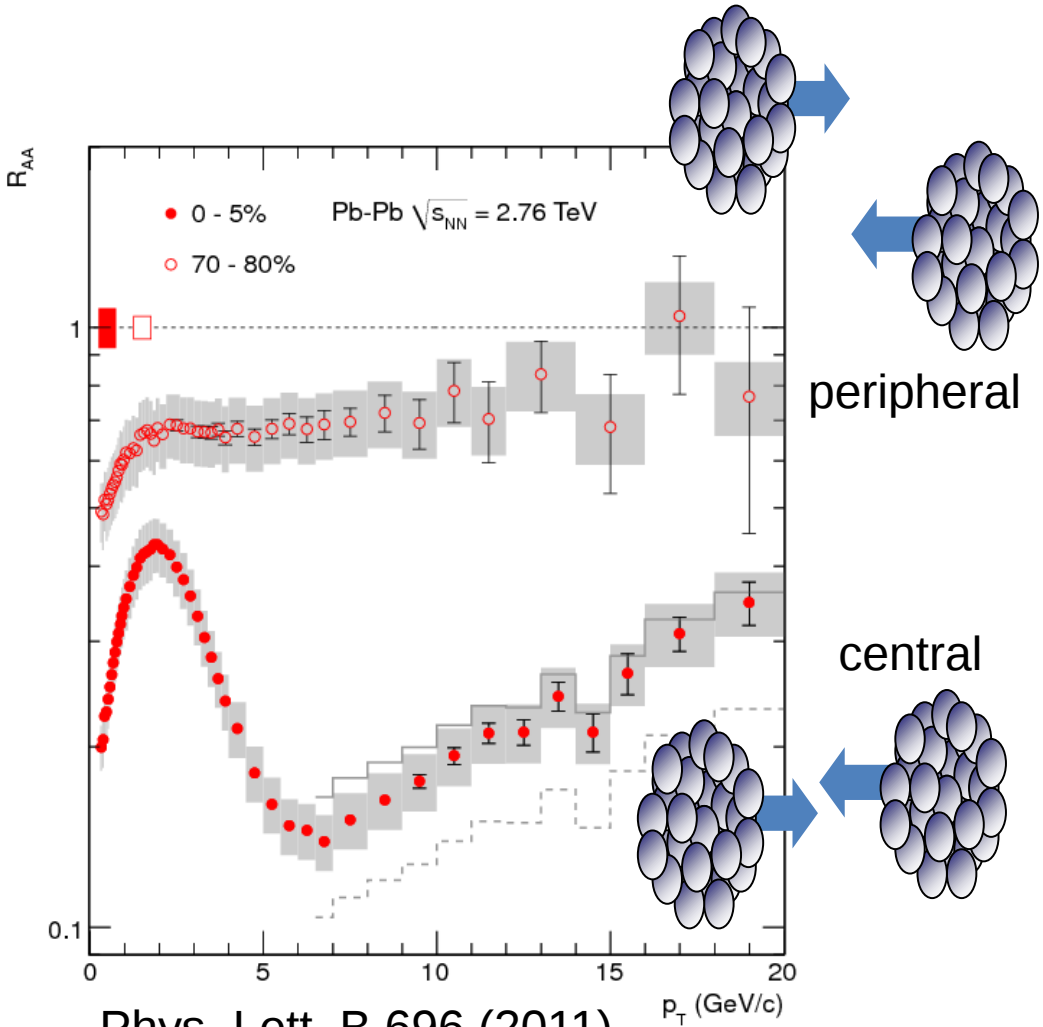
The nuclear modification factor R_{AA} for unidentified hadrons

$$R_{AA} = \frac{d^2N^{AA}/dp_T d\eta}{\langle T_{AA}\rangle d^2\sigma^{pp}/dp_T d\eta}$$

$\langle T_{AA}\rangle\sigma^{pp}=\langle N_{coll}\rangle$
N_{coll} is the number of binary collisions

For perturbative QCD processes:
$R_{AA}<1$: suppression
$R_{AA}=1$: no nuclear effects
$R_{AA}>1$: enhancement

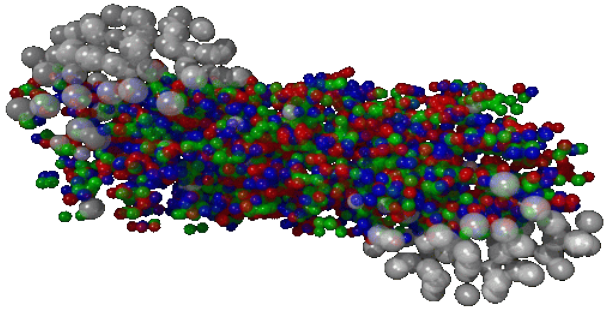


Phys. Lett. B 696 (2011)

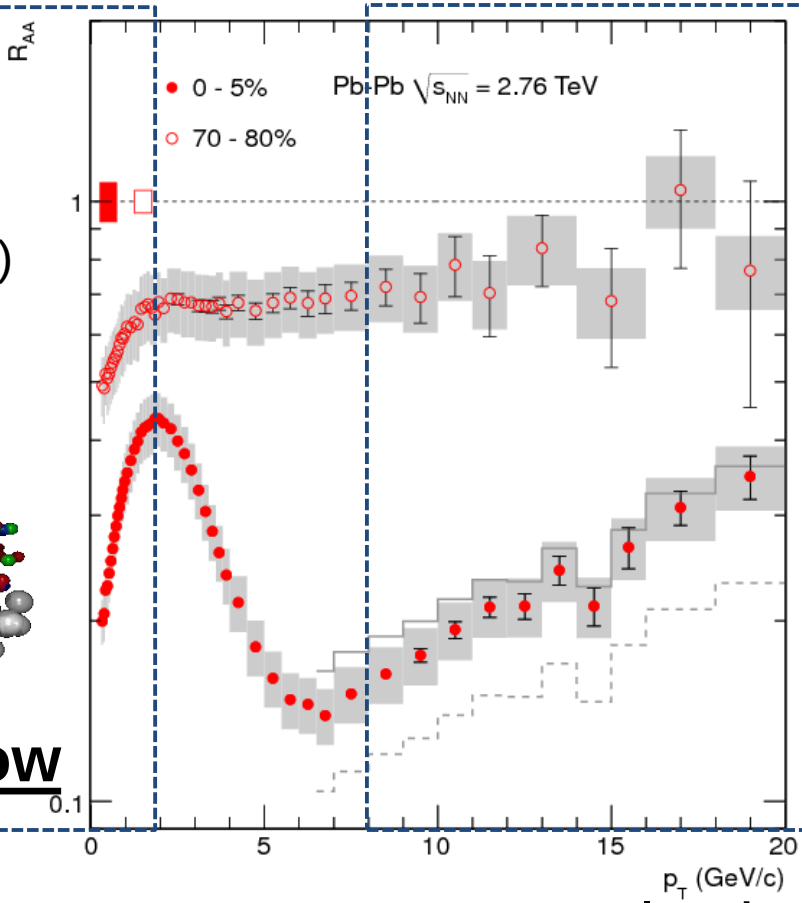
What happens when we collide Pb-Pb: 3 answers?

SOFT

Non-perturbative physics
Bulk properties (=medium)
"Low p_T"

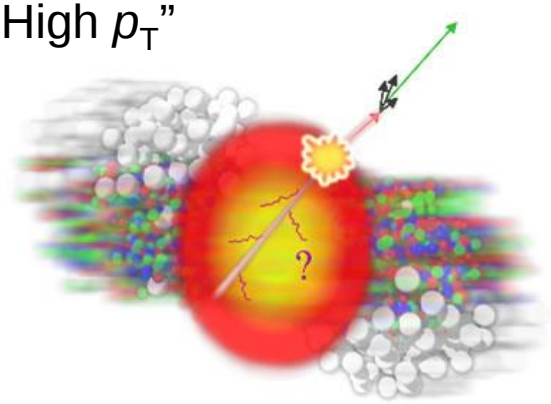


PID: ratios and flow



HARD

Perturbative physics
Rare process: jet (=probe)
"High p_T"

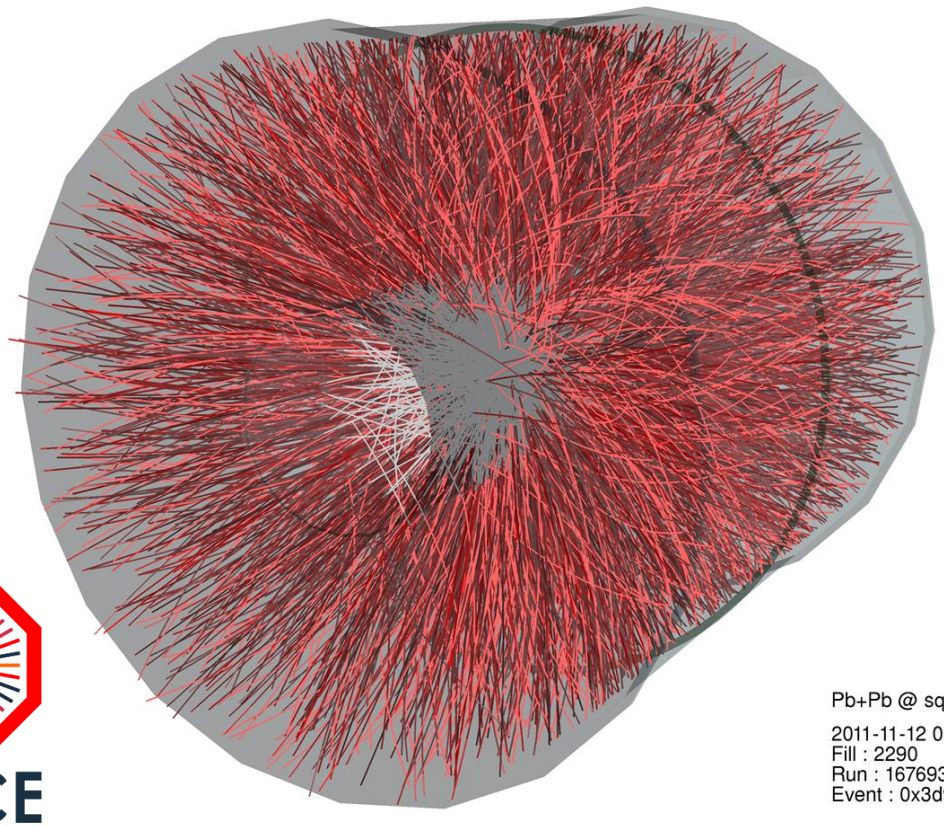


PID: jet quenching

INTERMEDIATE

Interplay between soft and hard?
PID: baryon anomaly

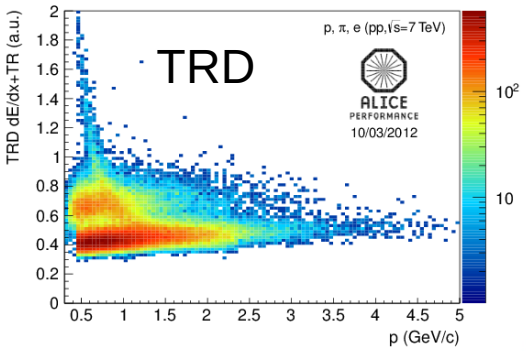
ALICE as a charged Particle IDentification detector

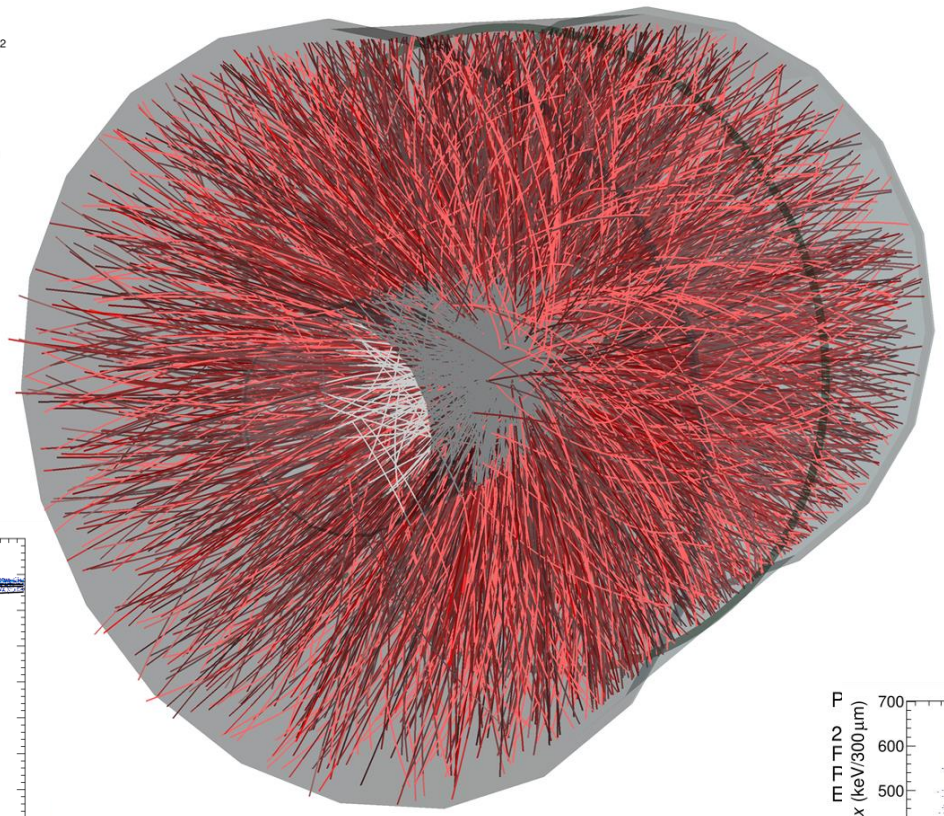


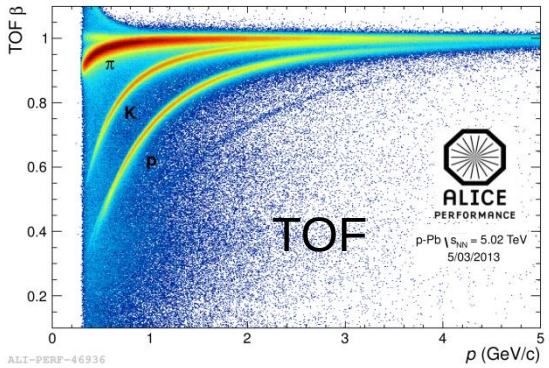
ALICE

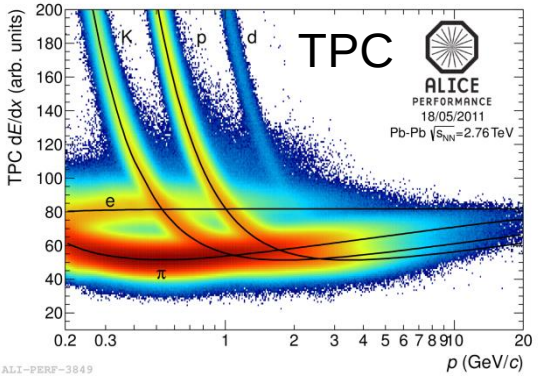
The ALICE experiment is optimized for charged particle tracking **and hadron identification** for |η|<0.8

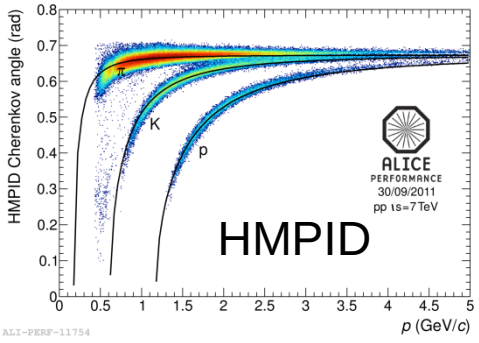
ALICE as a charged PID detector (central barrel)

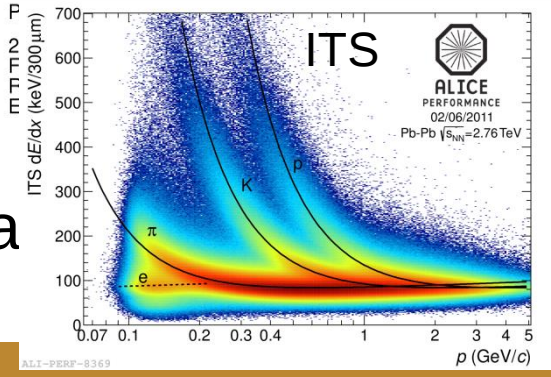






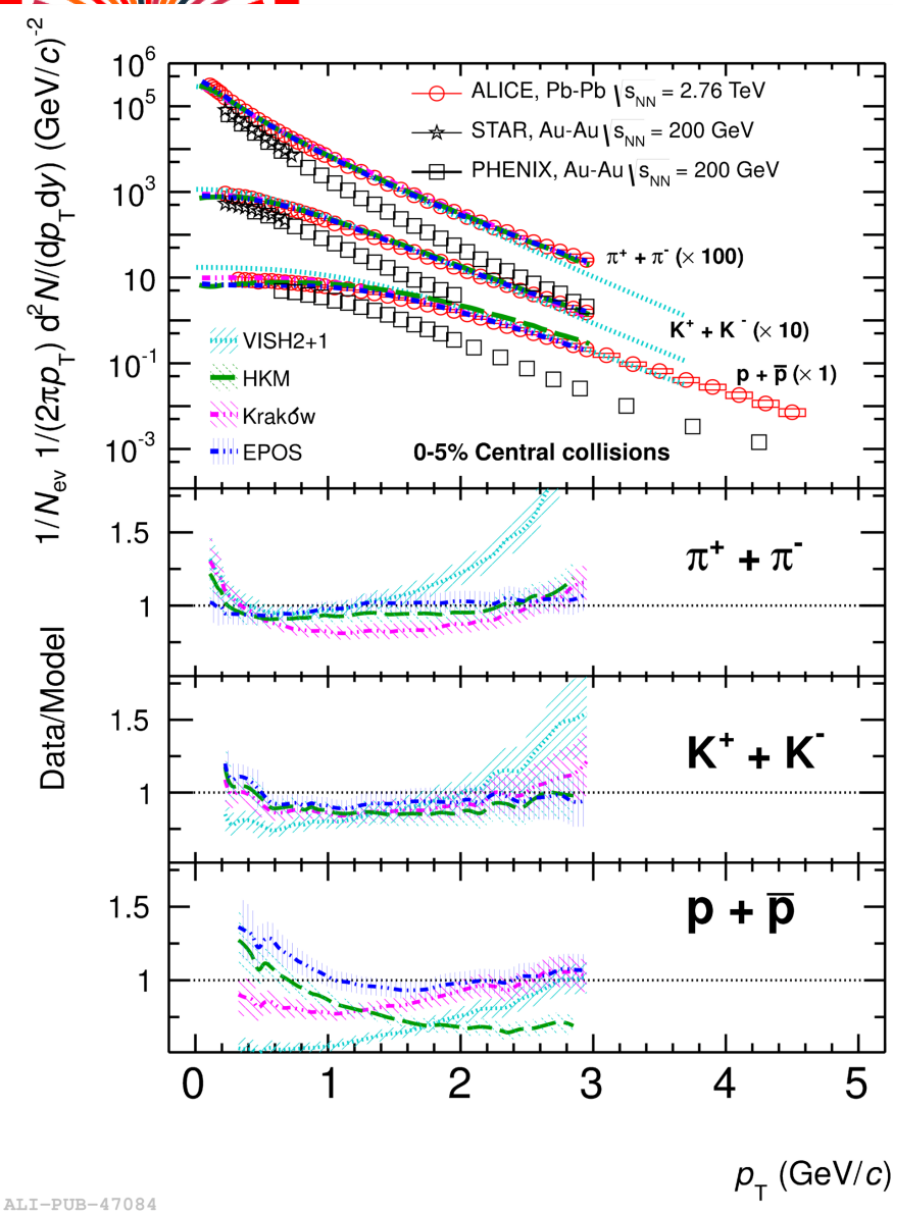






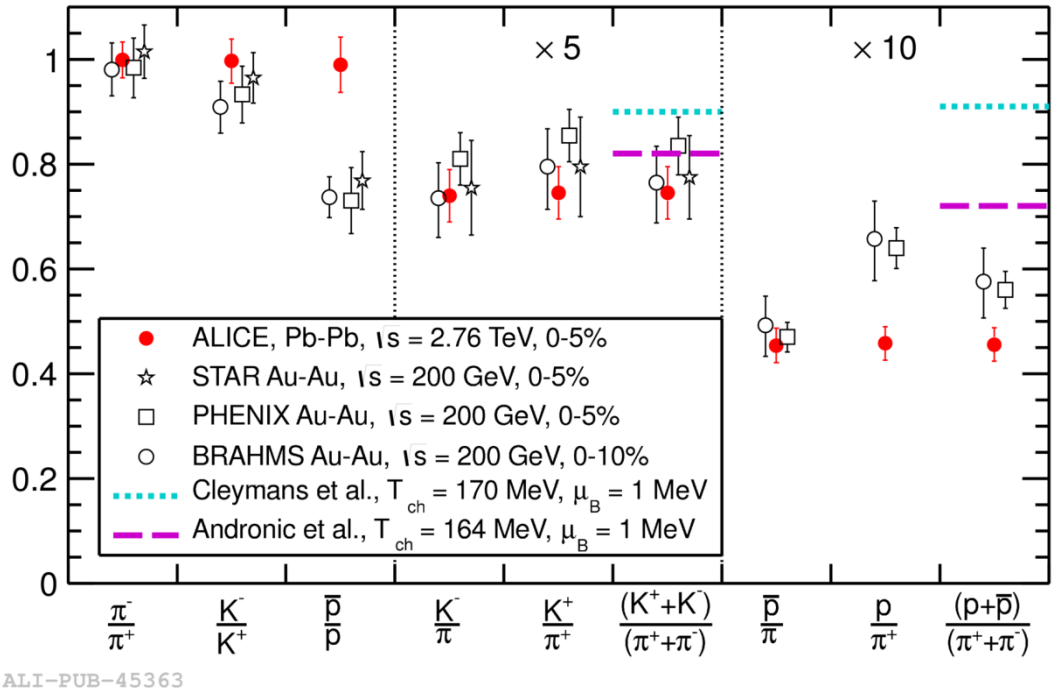
The ALICE experiment is optimized for cha ng
and hadron identification for |η|<0.8

Bulk production (low p_T)



Spectra in central collisions well described by hydrodynamics.

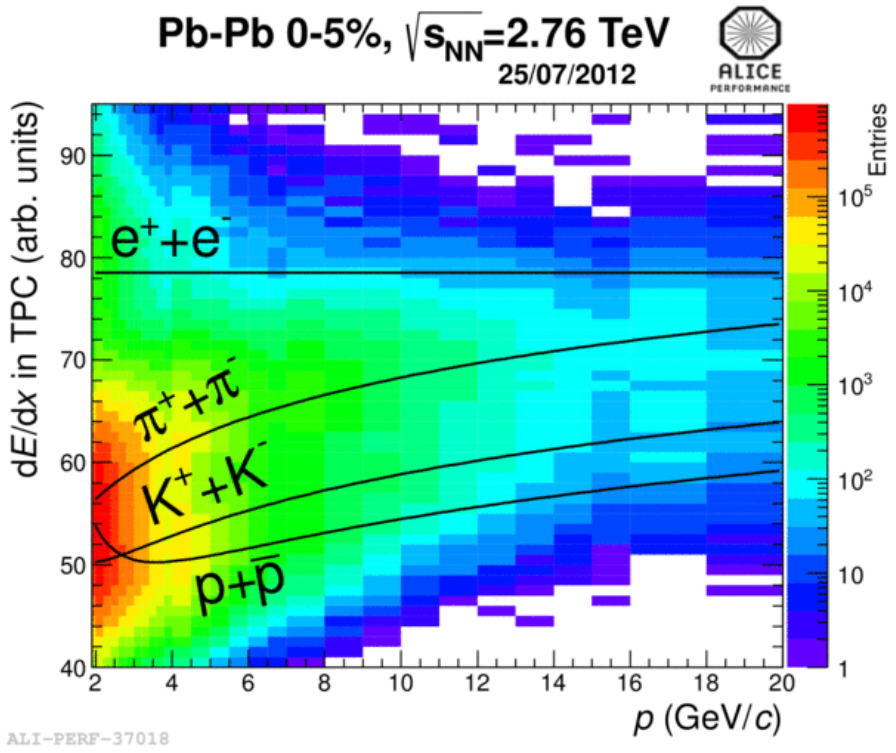
Phys. Rev. Lett. 109, 252301 (2012)

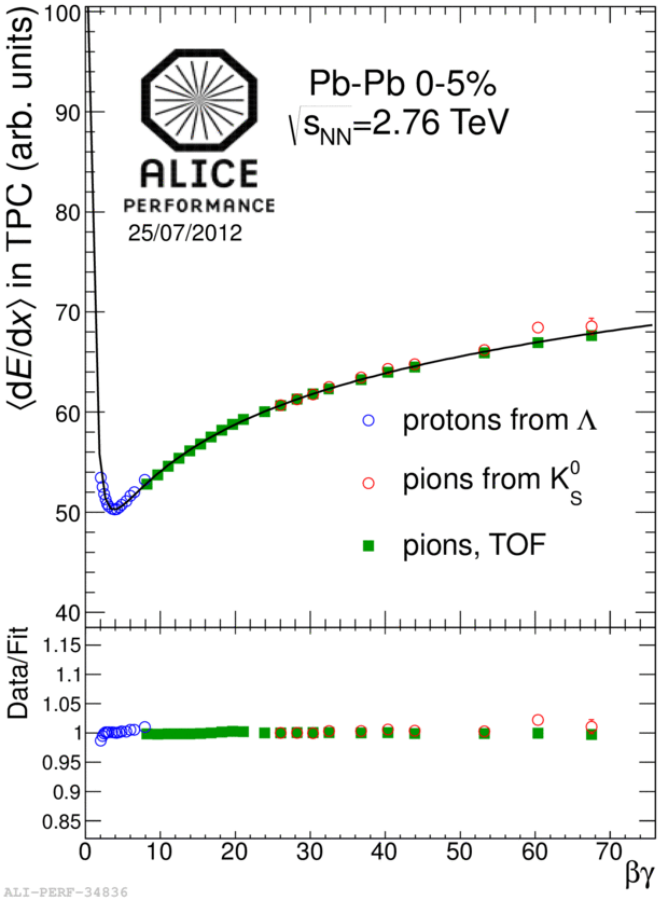


Statistical model calculations agrees with most ratios. Proton disagreement might indicate: non-equilibrium effects [arXiv:1303.2098], annihilation in hadronic stage [arXiv:1212.2431], or a flavor hierarchy of freeze-out temperatures [PRD 85, 014004 (2012)].

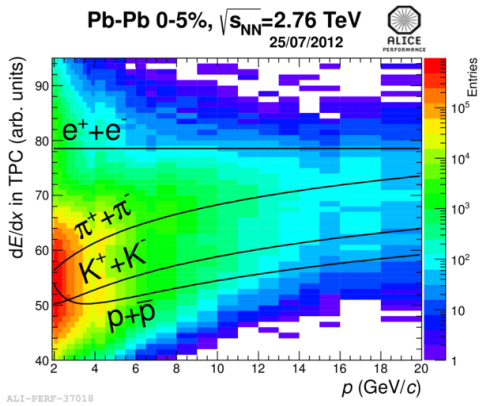
Particle identification at high p_T using TPC dE/dx

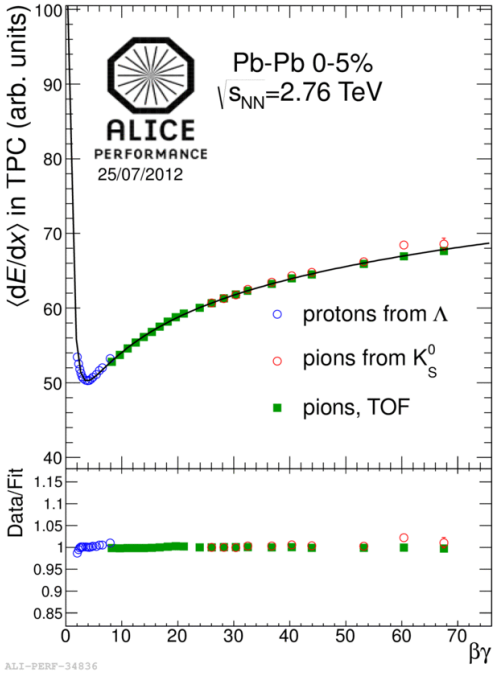
Pushing the separation to the relativistic rise





Particle identification at high p_T using TPC dE/dx

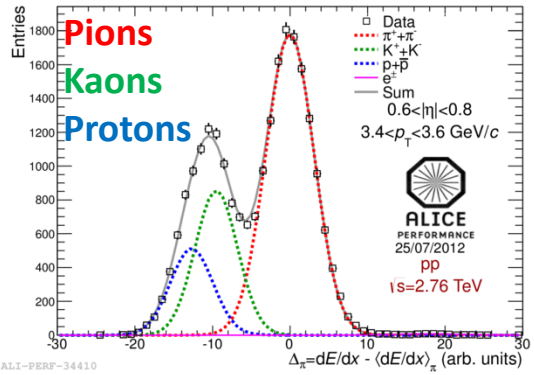




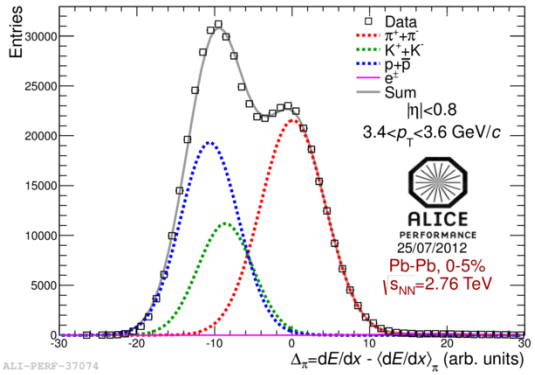
Baryon anomaly in central Pb-Pb. Quark recombination?

p_T ↓

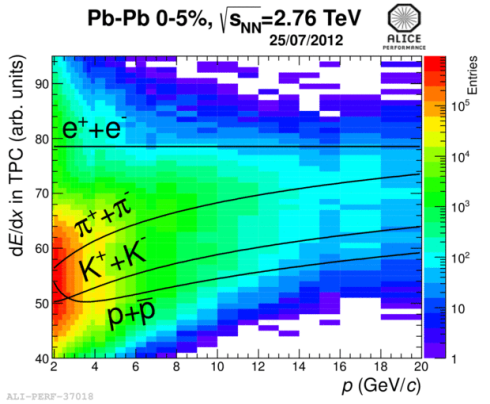
pp

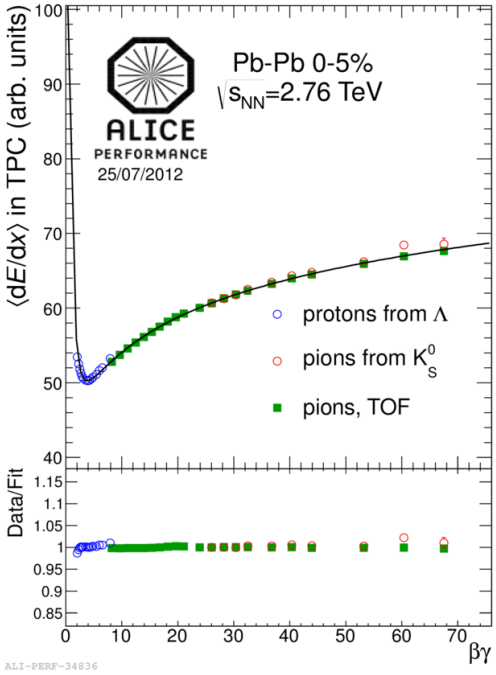


central Pb-Pb



Particle identification at high p_T using TPC dE/dx



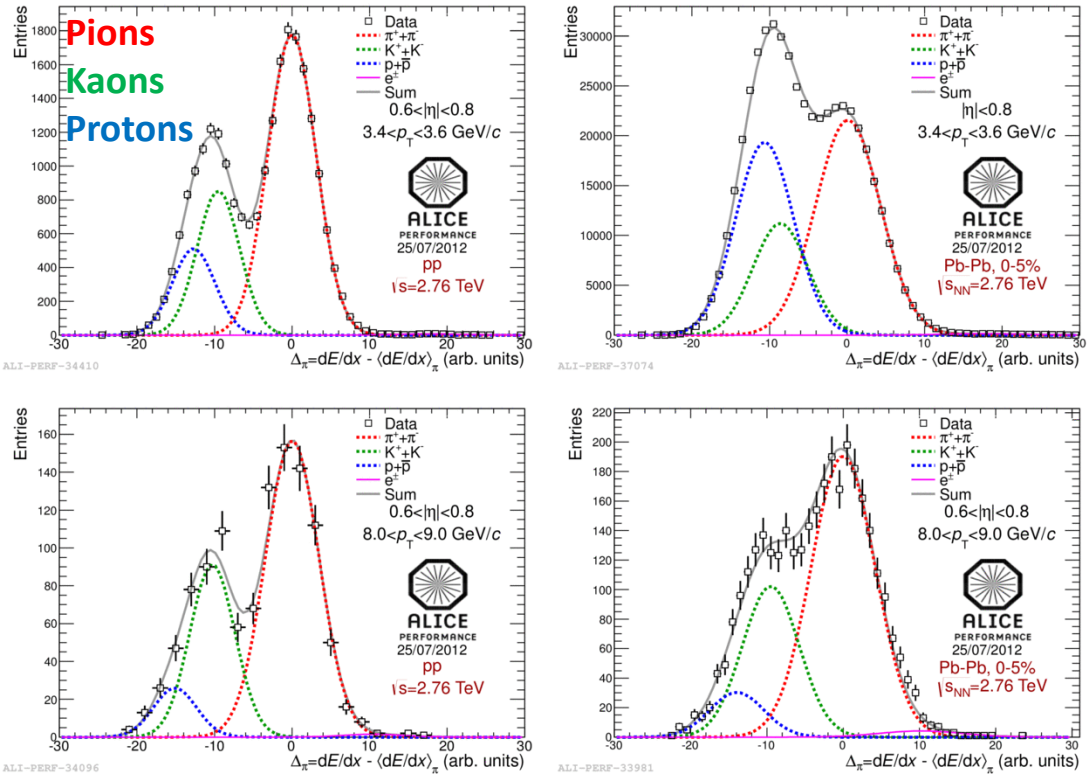


Baryon anomaly in central Pb-Pb. Quark recombination?

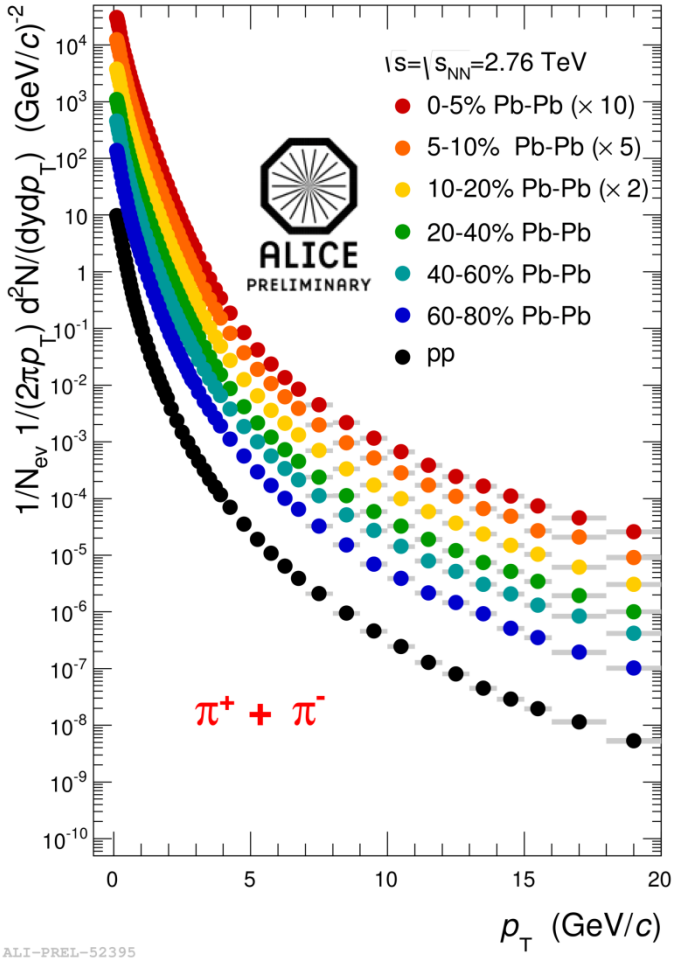
p_T ↓

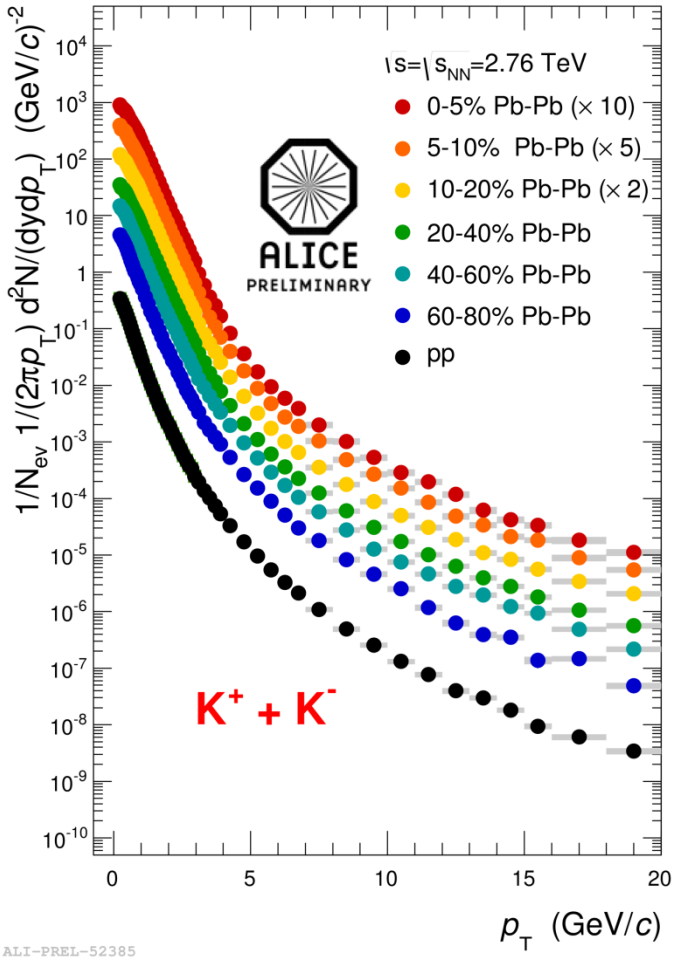
Baryon anomaly not observed at high p_T, opposite to what was speculated pre-LHC.

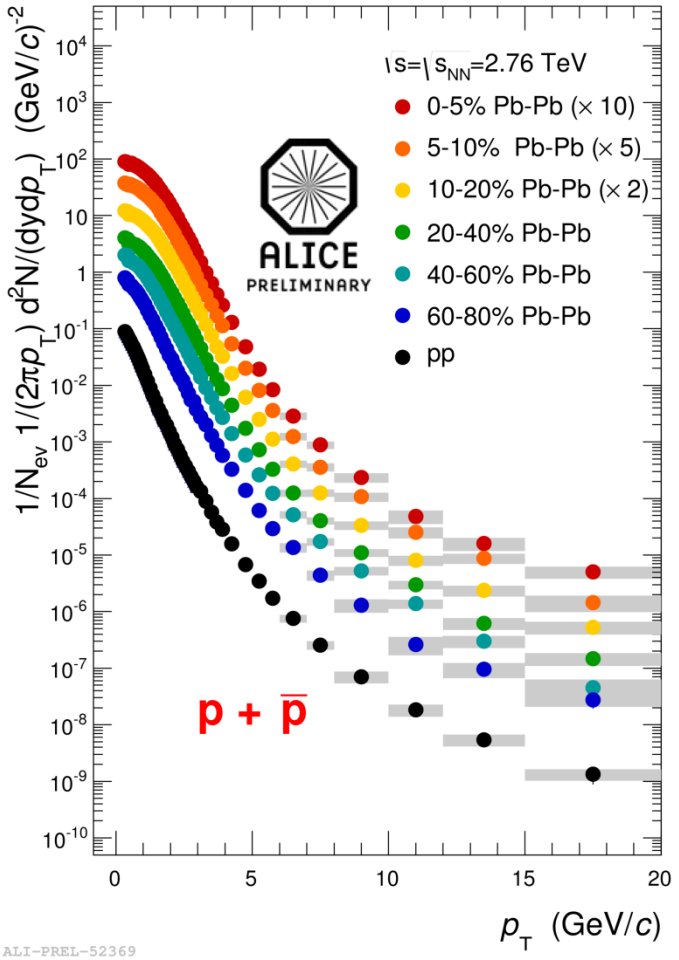
pp **central Pb-Pb**



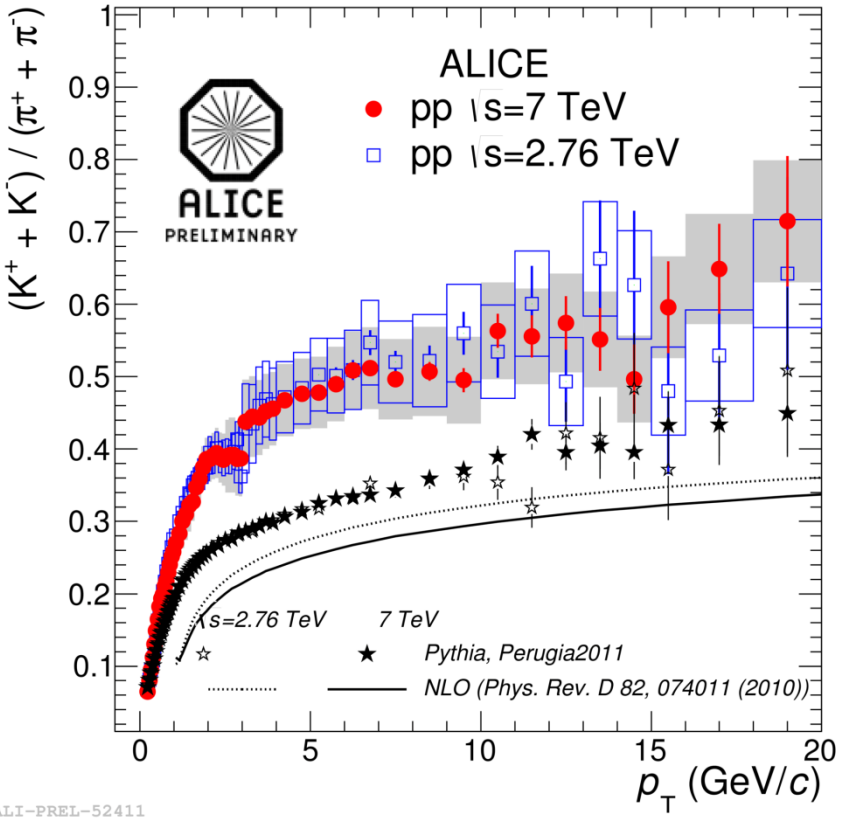
Identified π, K, and p spectra

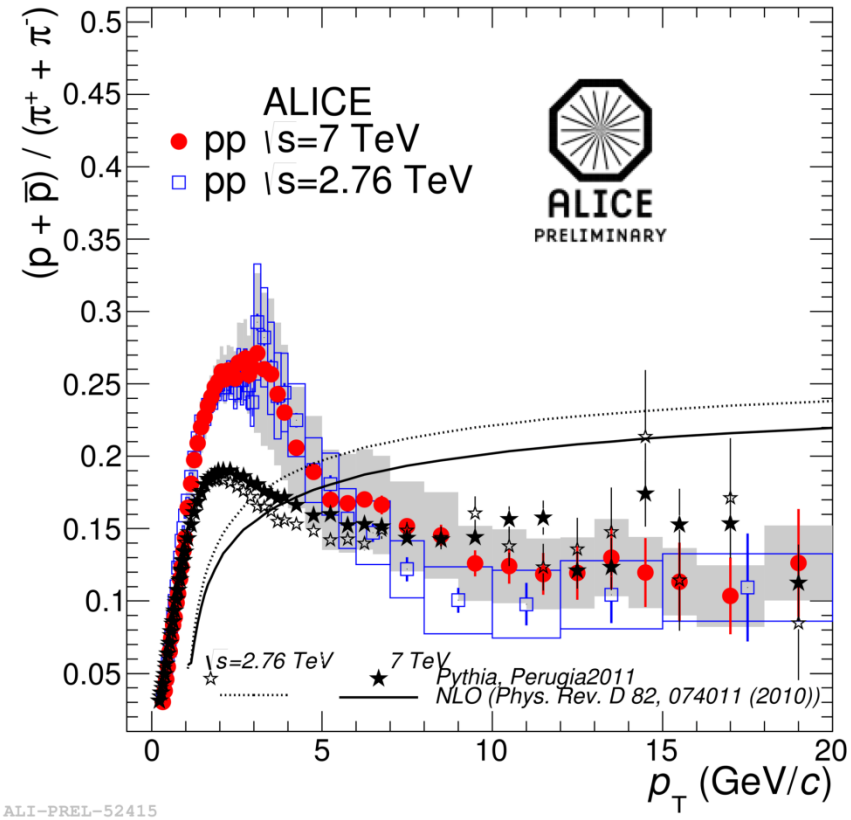






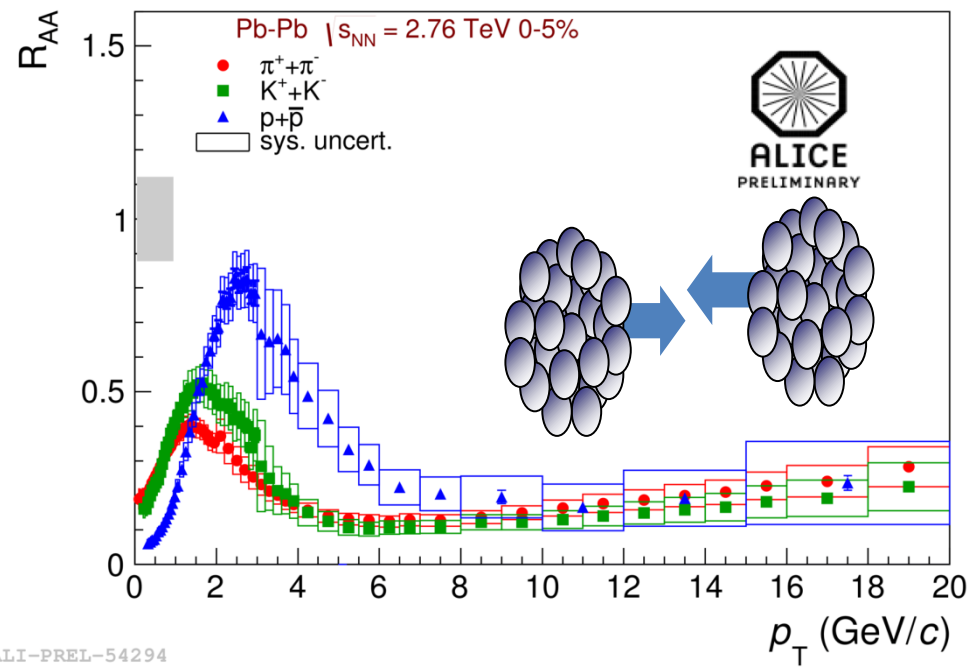
Particle ratios in pp collisions (√s=2.76 and 7 TeV)

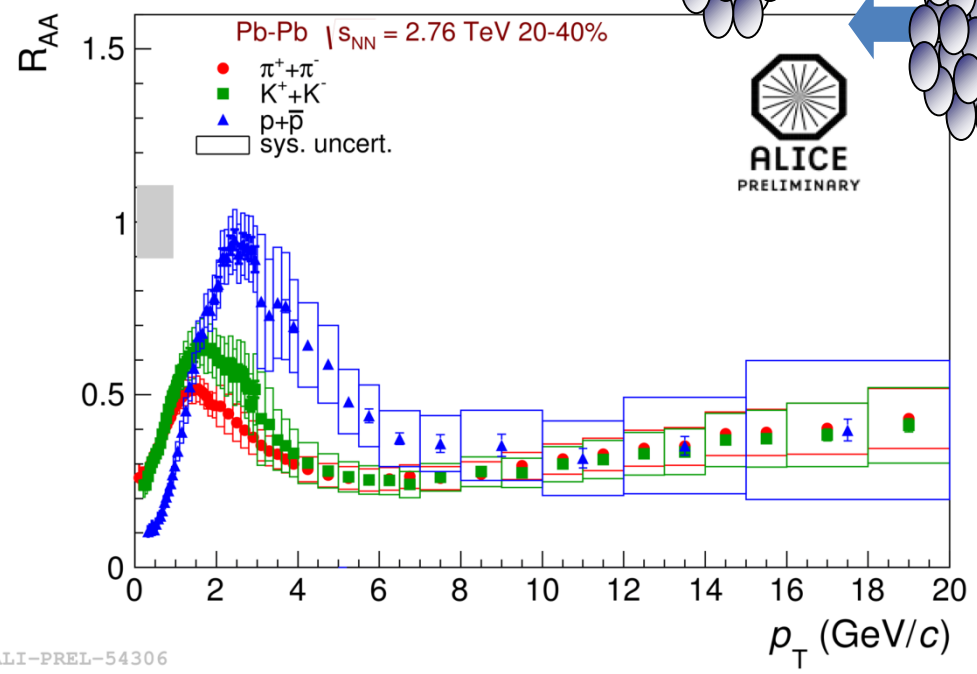




Identified high p_T production is not well described by theory. The peak in the proton to pion ratio in PYTHIA is related to color reconnection which gives a flow-like effect [arXiv:1303.6326]

R_{AA} identified hadrons



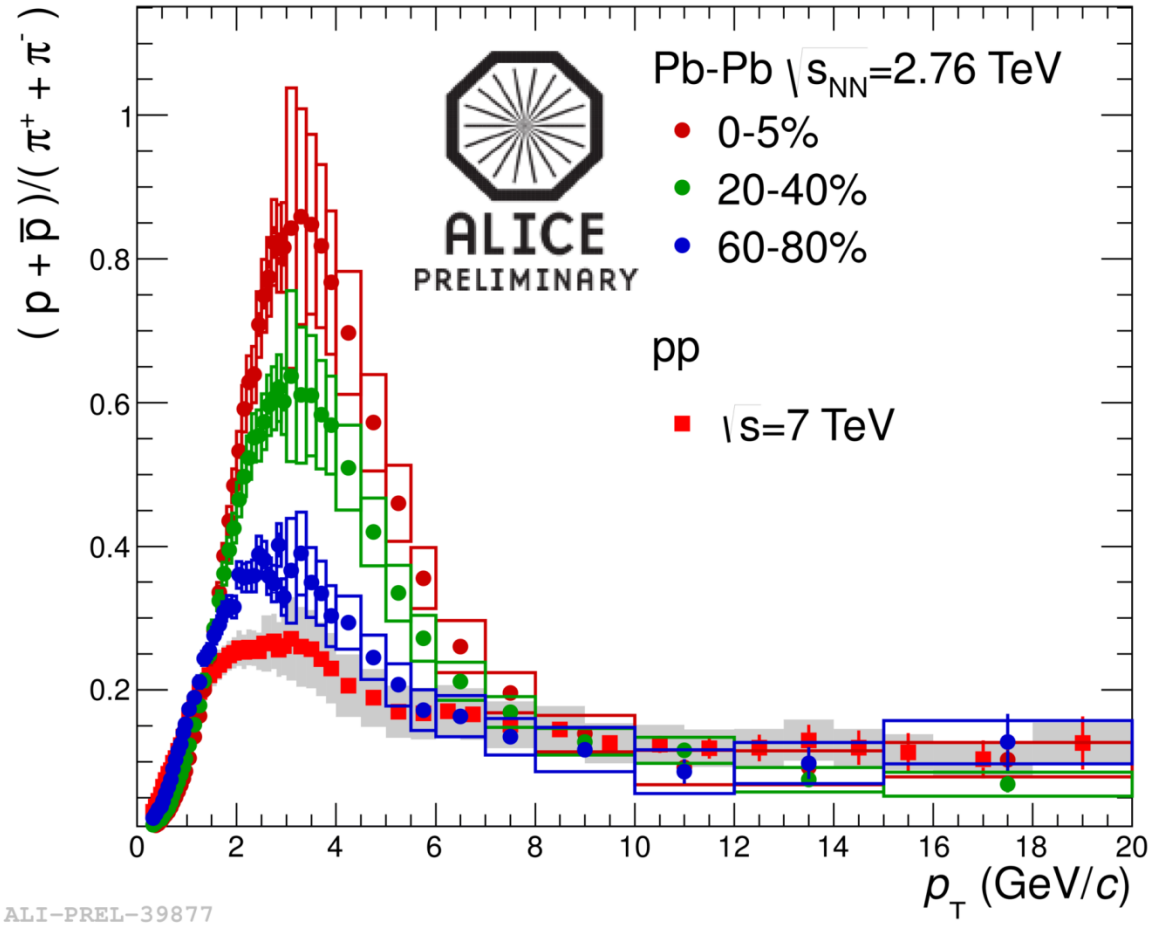


For p_T < 8 GeV/c: R_{AA} for π and K compatible and smaller than R_{AA} for p.

At high p_T above 10 GeV/c the R_{AA} for π, K and p are compatible.

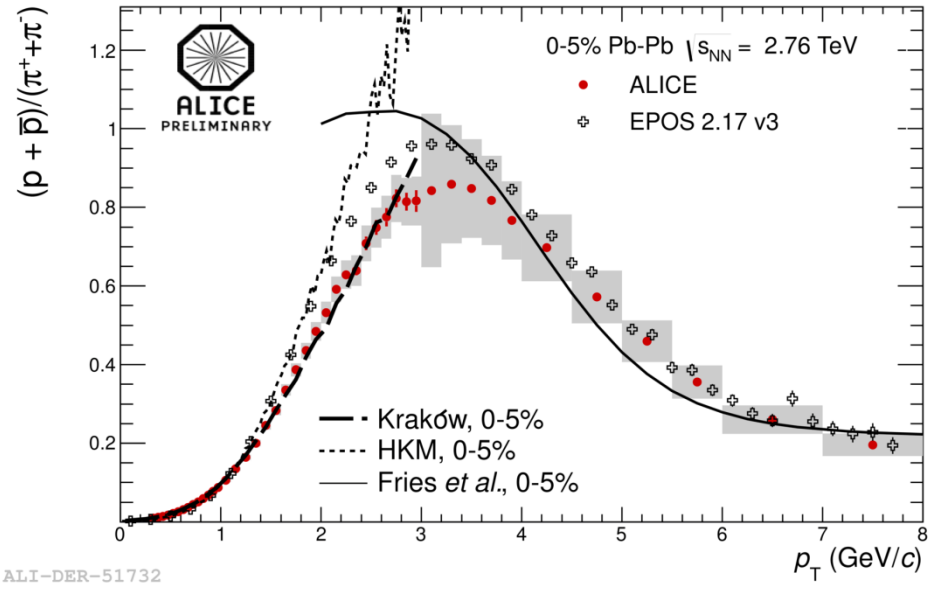
This suggest that leading particle jet hadron chemistry (flavor or baryon number transfer, and color flow) effects are small if present

The dominant effect is the collective medium response



The dominant effect that can be observed with PID is at $p_T < 8$ GeV/c and due to the medium. Hydrodynamics, recombination, or ?

Particle ratios compared to models



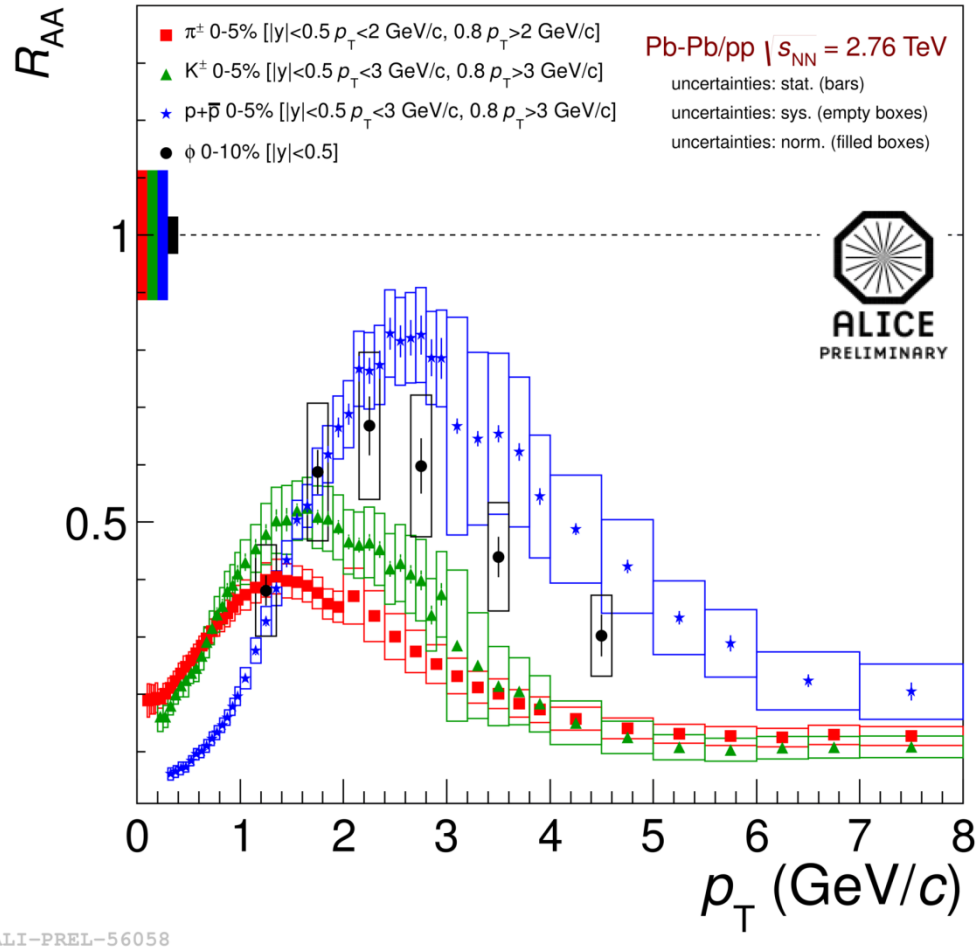
Krakow+HKM: hydrodynamic (low p_T) models

Fries: recombination
3 quarks → baryon,
2 quarks → meson

EPOS: hydrodynamics (low p_T) → medium modified fragmentation for quenched jets (intermediate p_T) → vacuum fragmentation (high p_T)

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

Comparing pions and protons to heavy mesons: ϕ (1020)



The R_{AA} for ϕ mesons follows p for $p_T < 2$ GeV/c (hydrodynamic medium region)

For $p_T > 2$ GeV/c the R_{AA} for ϕ mesons is in between π and p

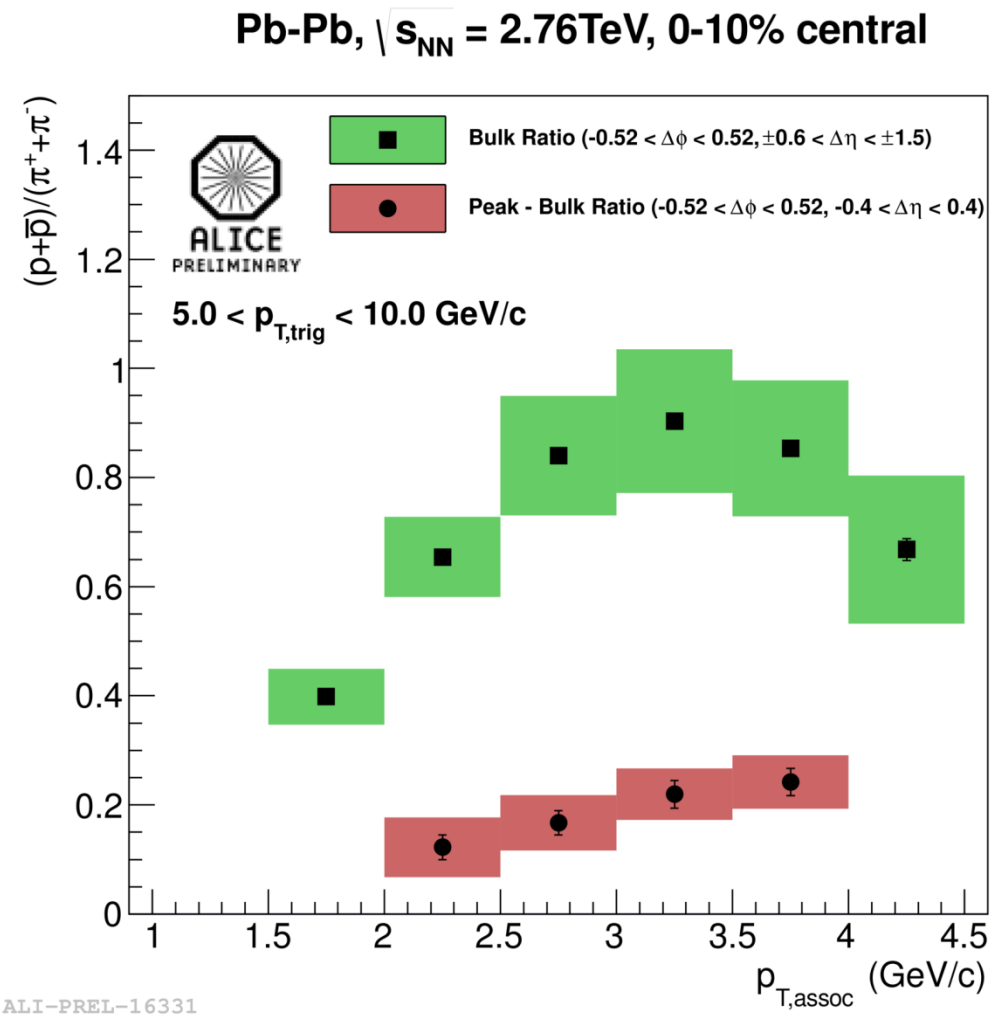
Conclusions

- The low p_T spectra can be described by hydrodynamics and most yields are in agreement with statistical model predictions
- The R_{AA} for pions, kaons, and protons for p_T > 8-10 GeV/c shows no particle species dependence suggesting that there is little interplay between the fragmentation process and the medium
- The intermediate p_T region ($2 < p_T < 8$ GeV/c) is rich in exciting physics where PID provides much additional information as can be seen in the large baryon to meson ratio

Thank you!

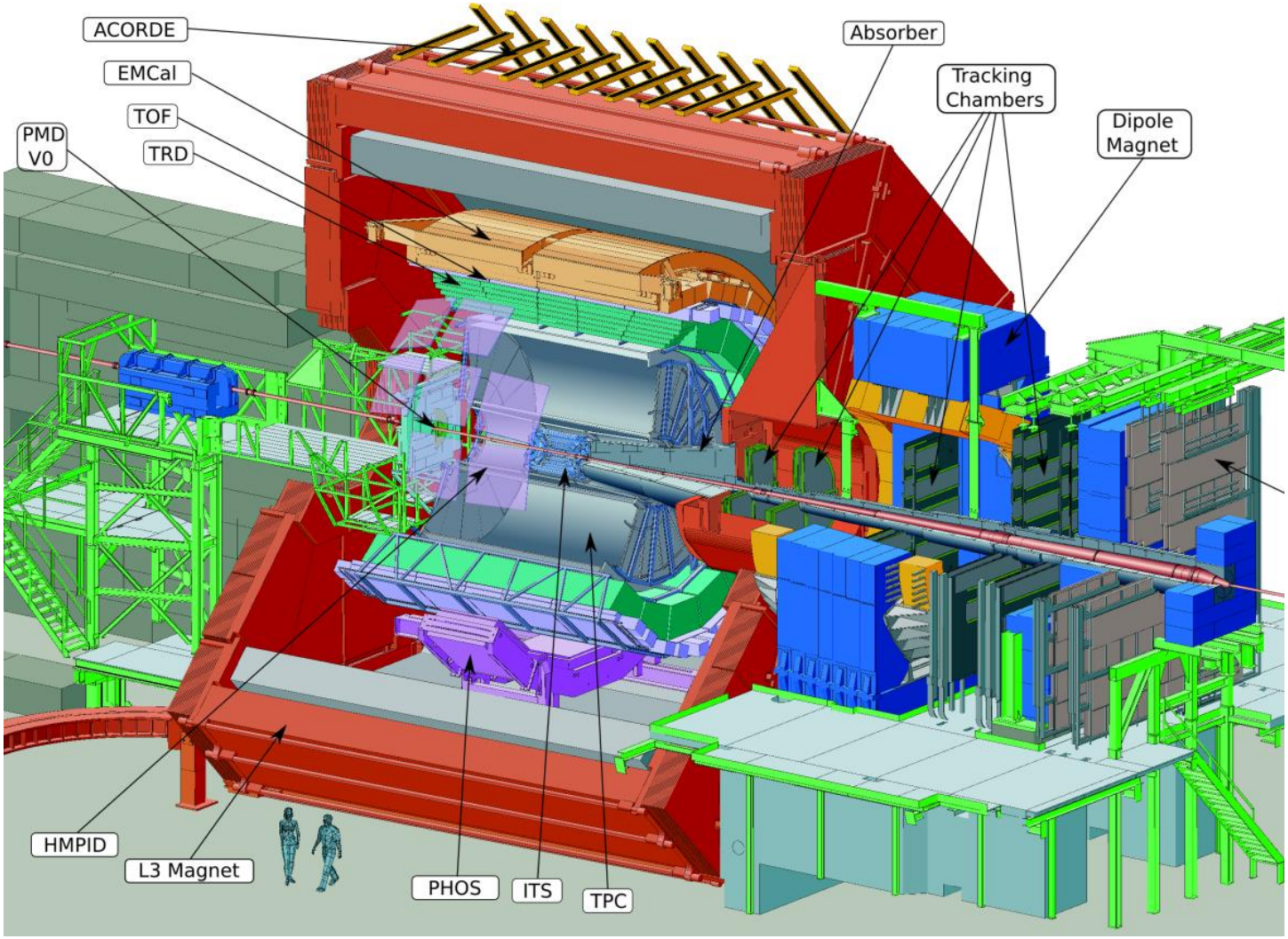
Backup slides

p/π ratio in peak-bulk

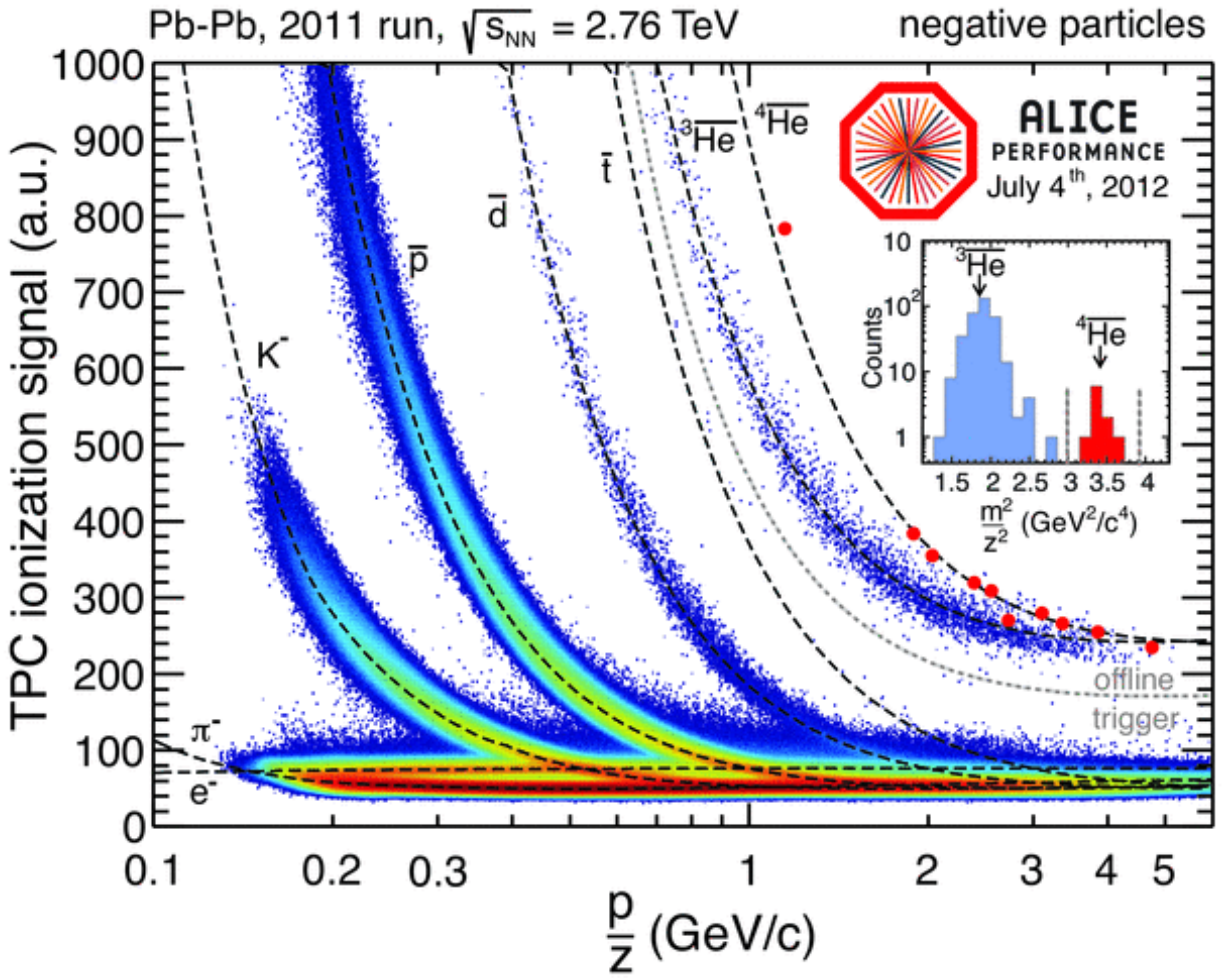


When the p/π ratio in the peak is corrected for bulk effects using an η gap one finds that the ratio is dominated by the bulk.
So the ratio does not seem to be driven by hard physics.

The ALICE experiment at LHC

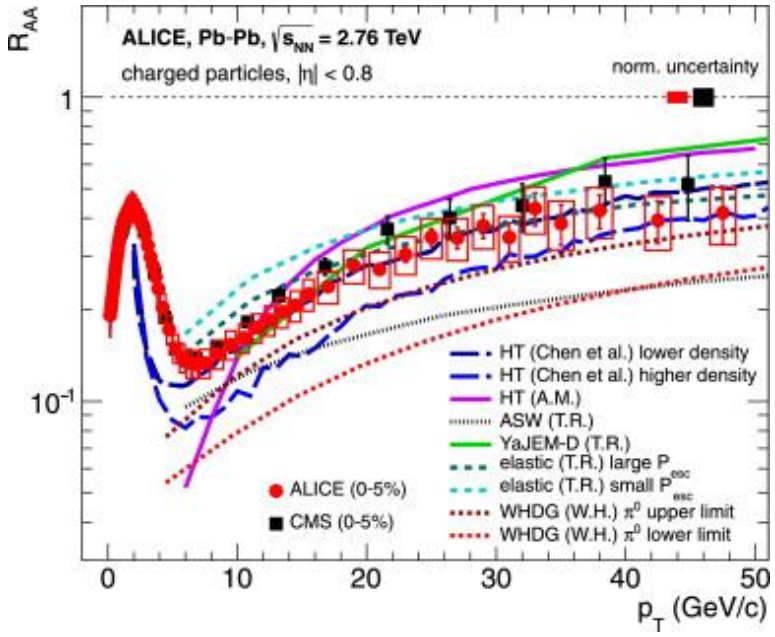


TPC dE/dx performance at low p_T



R_{AA} for unidentified charged particles

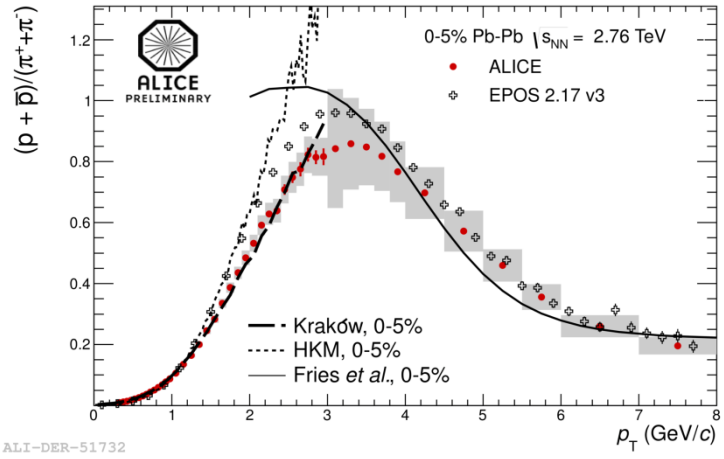
$$R_{AA} = \frac{d^2N^{AA}/dp_T d\eta}{\langle T_{AA}\rangle d^2\sigma^{pp}/dp_T d\eta}$$



Physics Letters B 720 (2013)

- Several models capture the essential features (but some miss absolute scale)
- The relative particle species dependent effects should be easier to describe as complicated space time dynamics probably falls out in the “double ratio”

EPOS: baryon to meson enhancement (1/2)



EPOS2.17v3

K. Werner,

Phys. Rev. Lett. 109, 102301 (2012)

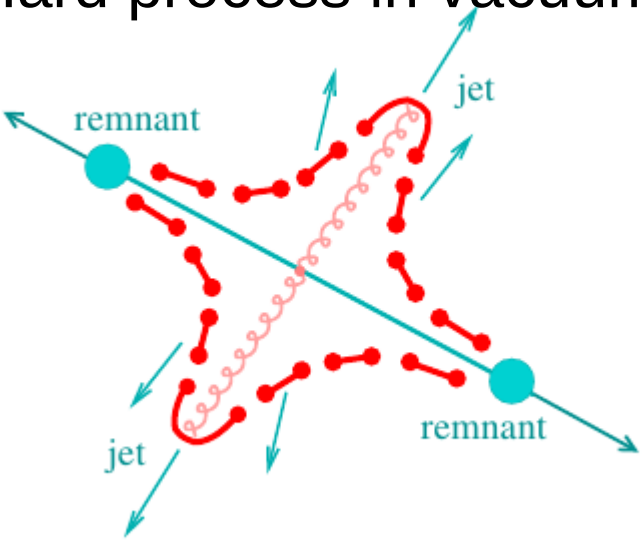
Calculation for Λ/K^0_s.

Hard scatterings only, but 3 possibilities for produced string segments

- no energy to escape → hydrodynamically “soft hadrons”
- energy to escape and formed outside bulk → jets
- energy to escape, but formed inside bulk → affected by the flowing matter (“fluid-jet interaction”).

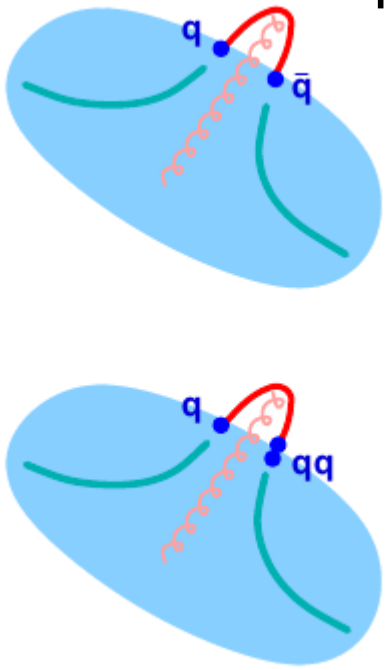
EPOS: baryon to meson enhancement (2/2)

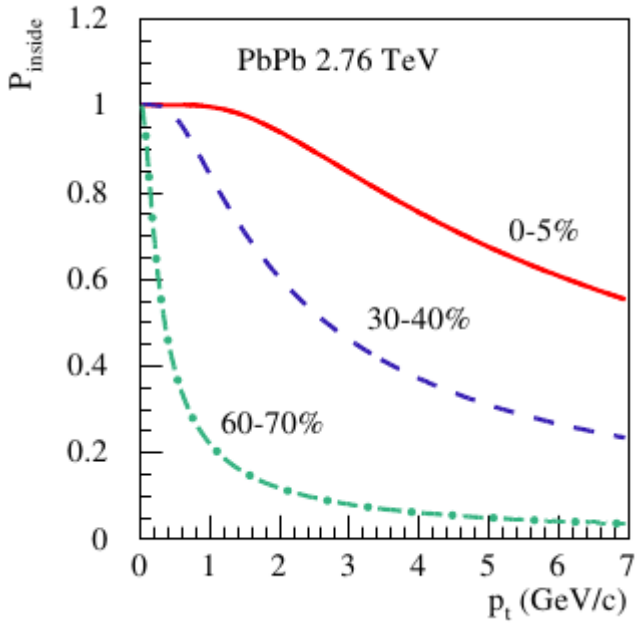
Hard process in vacuum



Schwinger mechanism

Extra medium process (and probability)

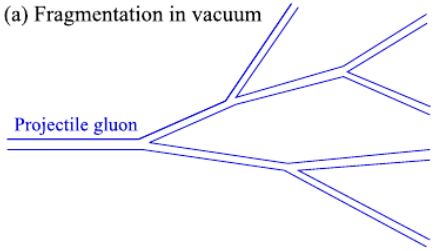


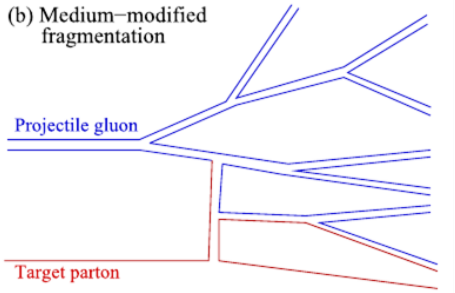


"Considering transverse fluid velocities up to 0.7*c*, and thermal parton momentum distributions, one may get a "push" of a couple of GeV to be added to the transverse momentum of the string segment. This will be a crucial effect for intermediate p_T jet hadrons."

Why do we expect particle species dependent modifications even at higher p_T?

- Large effects at intermediate p_T – does this effect just disappear?
- The low value of R_{AA} suggests that most hard partons interacts strongly with the medium



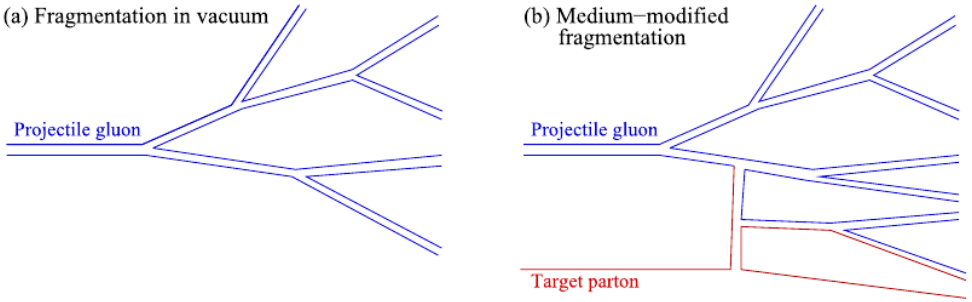


S. Sapeta and U.A. Wiedemann, Eur.Phys.J. C55 (2008) 293:

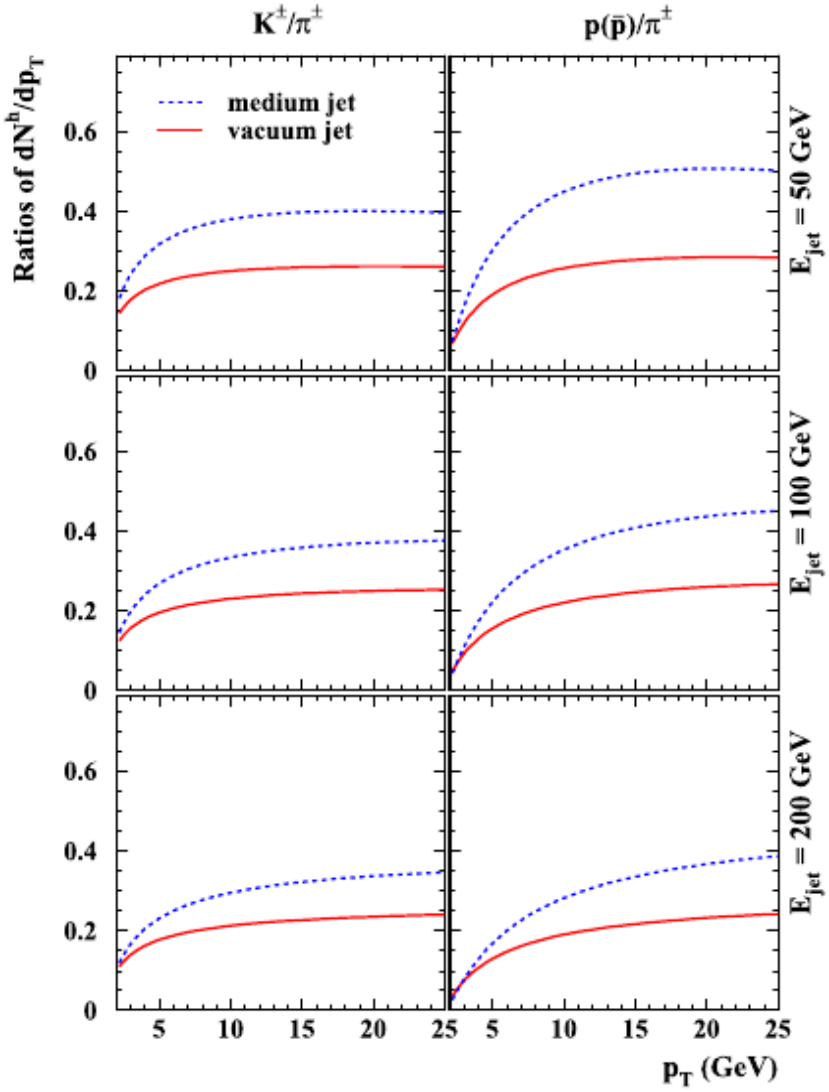
- Indirect
  - "in all models of radiative parton energy loss, the interaction of a parent parton with the QCD medium transfers color between partonic projectile and target. This changes the color flow in the parton shower and is thus likely to affect hadronization."
- Direct
  - "In addition, flavor or baryon number could be exchanged between medium and projectile."

A general model with particle species dependent modifications

S. Sapeta and U.A. Wiedemann, Eur.Phys.J. C55 (2008) 293



- Effect inside jet
- But for p_T >> 8 GeV/*c* we expect all hadrons to belong to jets
- Prediction incompatible with data
- Question: what do we learn about the interaction between parton and medium?



Color anomalous baryons fragmentation

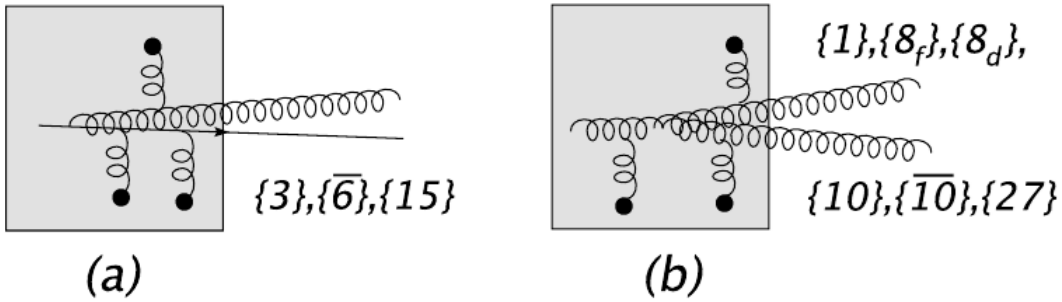
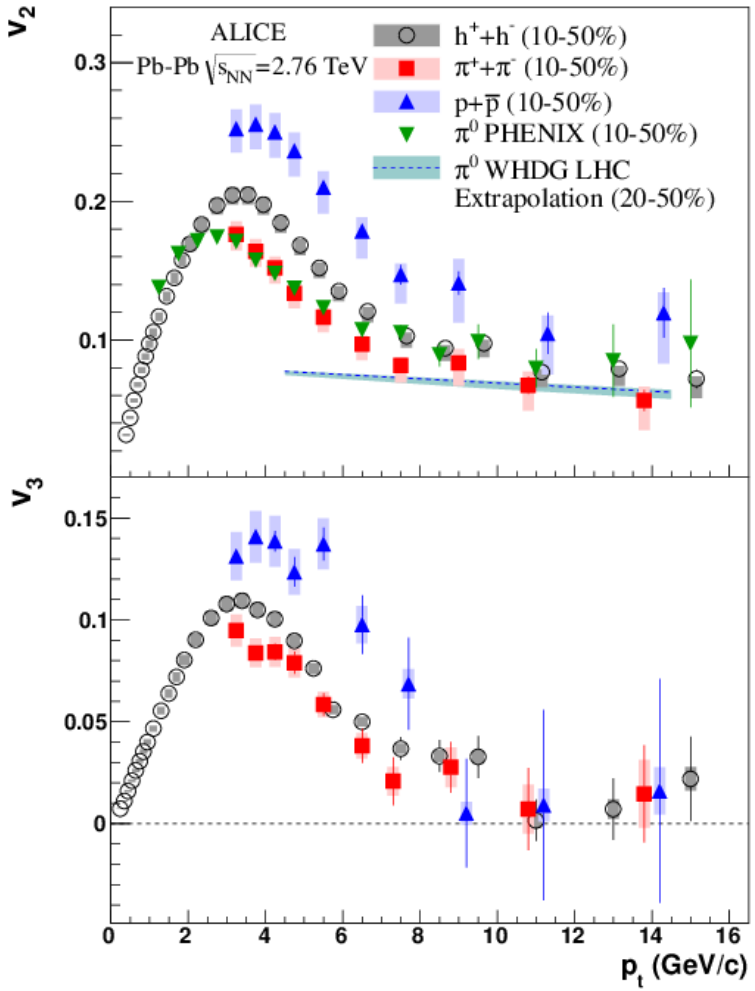


Fig. 1 The $q \rightarrow gq$ (**a**) and $g \rightarrow gg$ (**b**) transitions in the medium and possible color states of the final two parton systems

- Color anomalous baryon fragmentation (P. Aurenche, B.G. Zakharov, Eur.Phys.J. **C71** (2011) 1829.). The model is aimed at explaining the baryon anomaly but these effects persists out to higher p_T.
  - A hard scattered quark (triplet) can pickup a gluon from the medium → sextet state
  - a gluon (octet) can pick up another gluon → decuplet state
  - The fragmentation of these color states is very different from normal quark (triplet) and gluon (octet) states and relies on string junction (soft effect).

Elliptic and triangular flow for identified particles at high p_T



- The v_2 and v_3 also peaks in the intermediate p_T region
  - Large particle species dependence
- End of hydrodynamic flow for $p_T \geq$ 9-10 GeV/c ?
  - Triangular flow which is not sensitive to collision geometry becomes small
  - No or small particle species dependence for v_2 (little mass dependence)
  - And pion v_2 is well described by jet quenching prediction

Physics Letters B 719 (2013) 18–28