SQM 2015

15th international conference on strangeness in quark matter

6th – 11th July, Dubna, Russia

Light flavour hadron production at intermediate and high p_{T} measured with the ALICE detector

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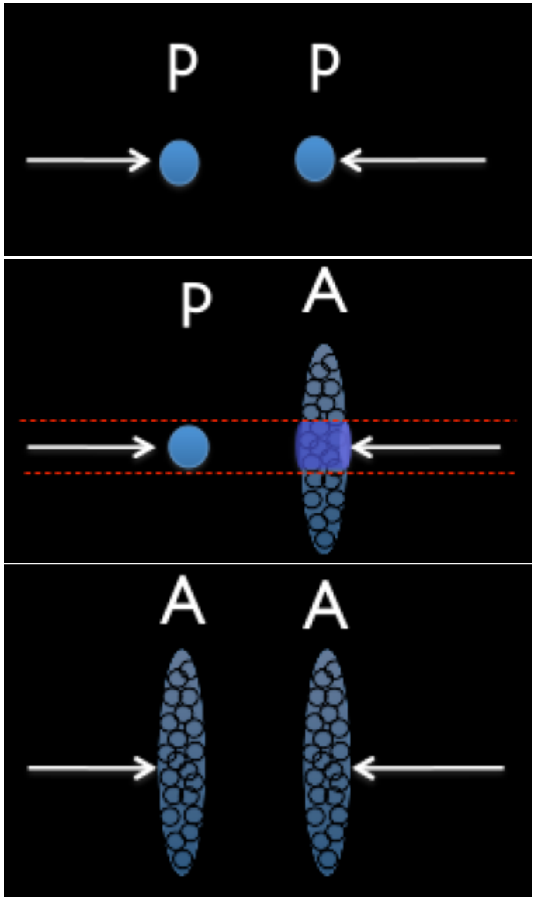
Outline

- ❑ ALICE goal
- ❑ Charged hadrons identification at intermediate (≈2 GeV/c - 10 GeV/c) and high p_T ($\gtrsim$10 GeV/c) with ALICE
- ❑ pp results: comparison to NLO pQCD calculations
- ❑ Pb-Pb results
- ❑ p-Pb results
- ❑ nuclear modification factor in Pb-Pb and p-Pb collisions
- ❑ Conclusions

ALICE goal

ALICE is designed to study the physics of strongly interacting matter under extremely high temperature and energy densities to investigate the properties of the quark-gluon plasma.



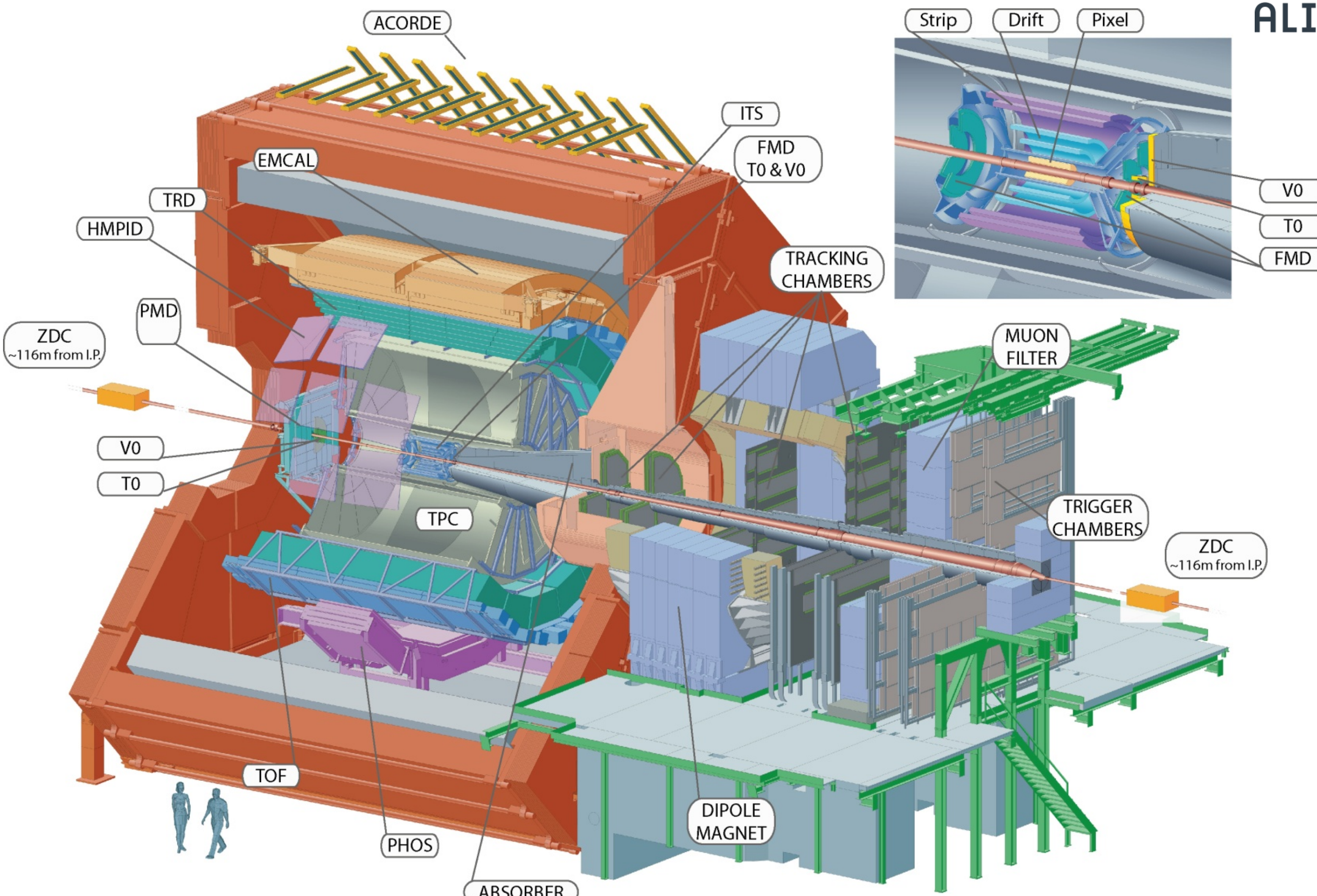
- Proton-proton collisions:
  - high energy QCD reference.
  - collected pp data at $\sqrt{s}$ = 0.9 TeV, 2.76 TeV, 7 TeV, 8 TeV (2009, 2010, 2011, 2012)

- proton-nucleus collisions:
  - initial state/cold nuclear matter.
  - collected p-Pb data at $\sqrt{s_{NN}}$ = 5.02 TeV (2012, 2013)

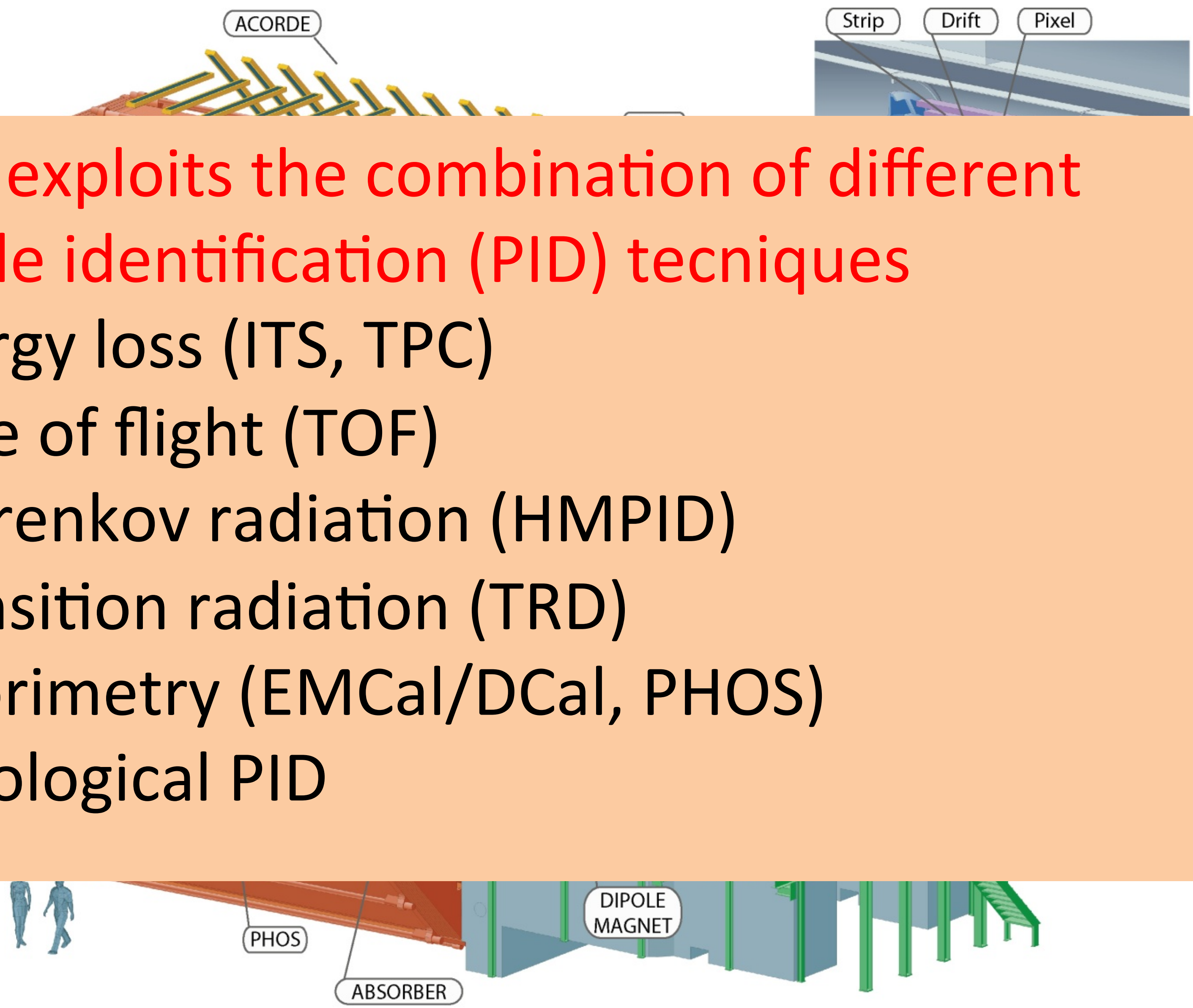
- nucleus-nucleus collisions:
  - quark-gluon plasma formation!
  - collected Pb-Pb data at $\sqrt{s_{NN}}$ = 2.76 TeV (2010, 2011)

ALICE has measured the yields of produced charged pions, kaons and protons in a wide momentum range and in several colliding systems.

ALICE detectors: $\pi^{\pm}$, $K^{\pm}$ and $p(\bar{p})$ PID



ALICE detectors: $\pi^{\pm}$, $K^{\pm}$ and $p(\bar{p})$ PID



ALICE exploits the combination of different particle identification (PID) tecniques

- Energy loss (ITS, TPC)
- Time of flight (TOF)
- Cherenkov radiation (HMPID)
- Transition radiation (TRD)
- Calorimetry (EMCal/DCal, PHOS)
- Topological PID

ALICE detectors: $\pi^{\pm}$, $K^{\pm}$ and $p(\bar{p})$ PID

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- Energy loss (ITS, TPC)
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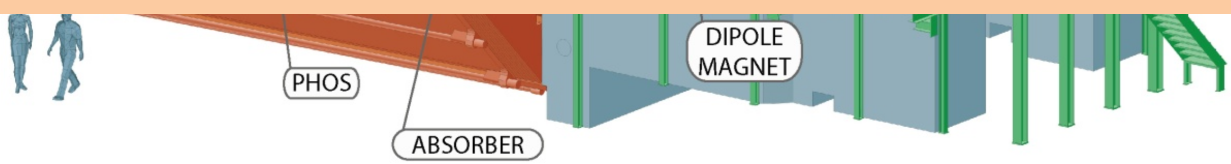
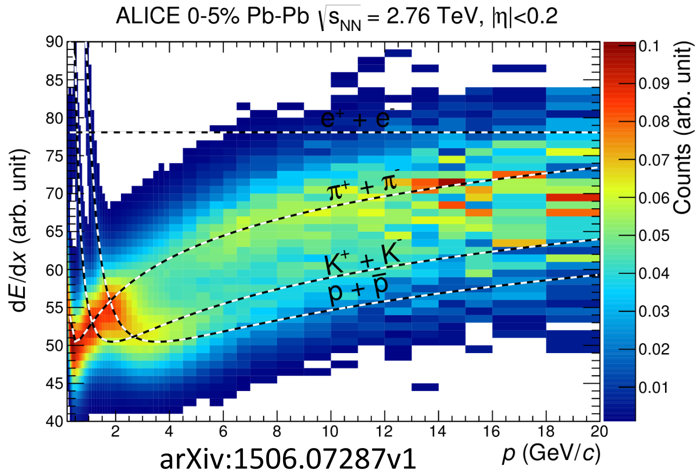
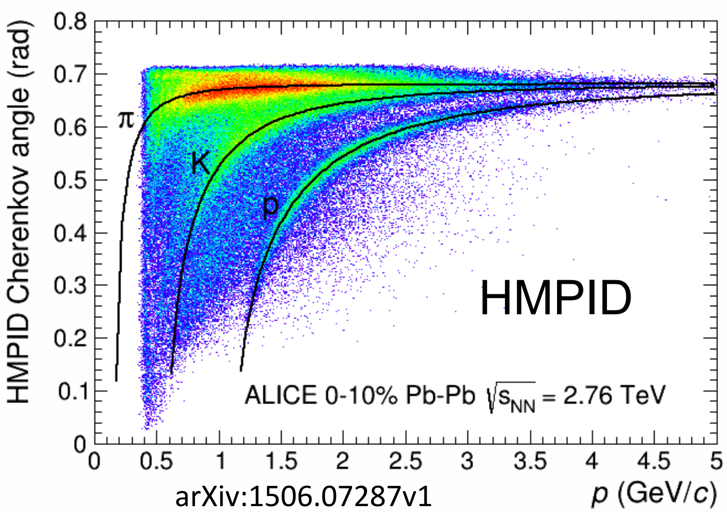
Intermediate, high p_T



ALICE detectors: $\pi^{\pm}$, $K^{\pm}$ and $p(\bar{p})$ PID

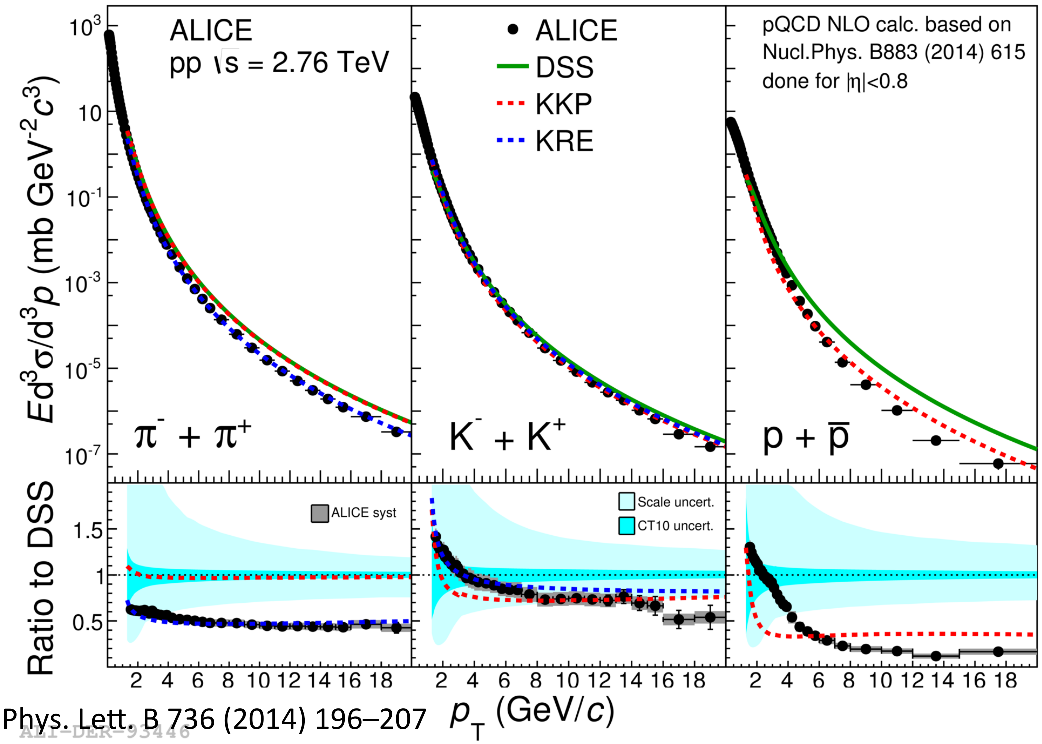


- Up to 159 pad rows in Ne-CO_2 gas mixture: $\sigma_{dE/dx} \approx 5\%$.
- A truncated mean dE/dx is calculated and used for a wide range of momentum.
- The largest separation is achieved at low-p_T ($p_T \leq 0.7$ GeV/c).
- for higher p_T (3-20 GeV/c) statistical PID is done exploiting the features of dE/dx in the relativistic rise regime.



- HMPID consists of seven RICH counters; liquid C_6F_{14} Cherenkov radiator
- PID performed by means of statistical unfolding
- Cherenkov emission angle measurements enable 3σ separation for π/k up to 3 GeV/c and for K/p up to 5 GeV/c

p_T pectra in pp collisions: comparison to NLO pQCD calculations



Phys. Lett. B 736 (2014) 196–207

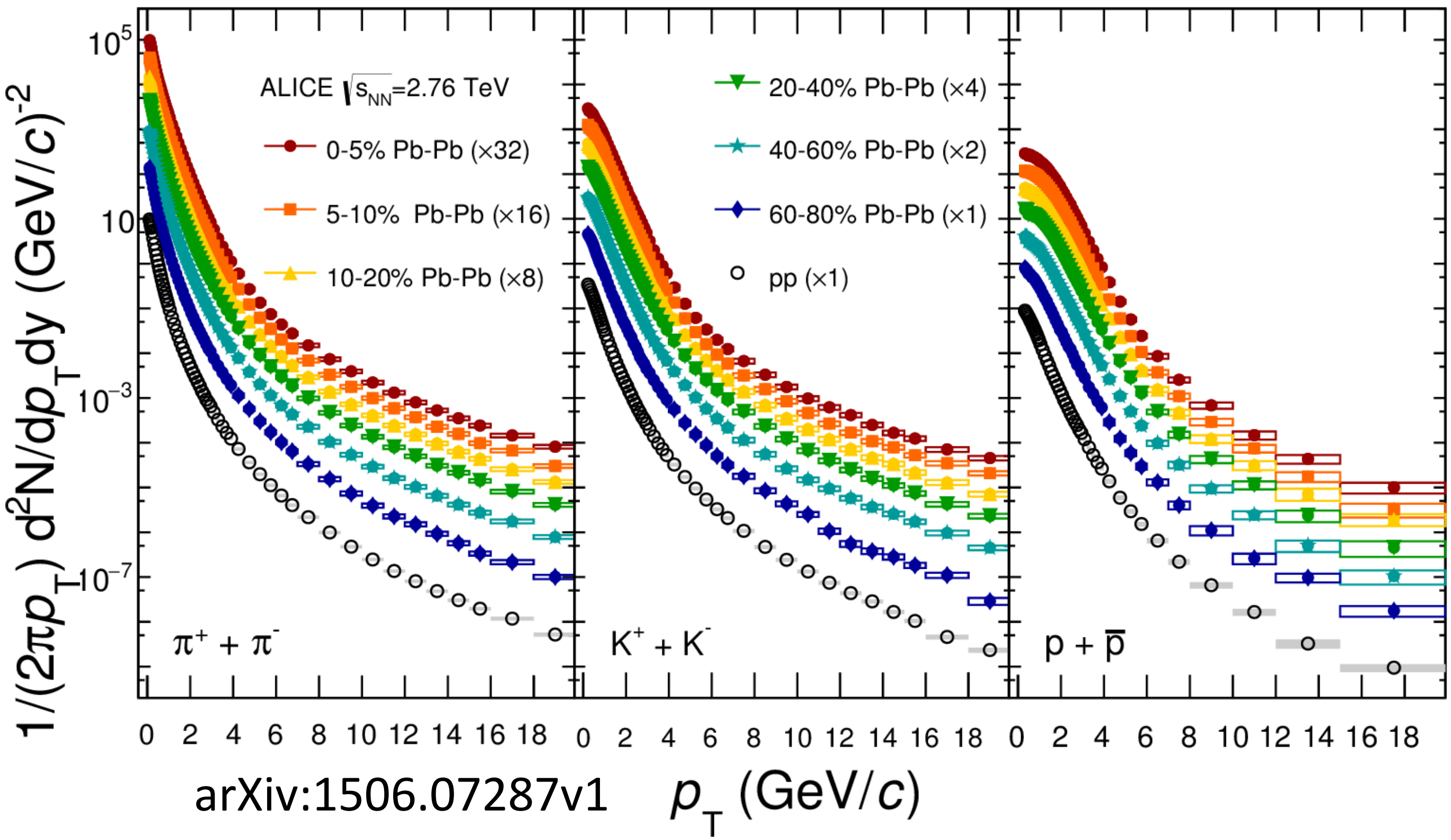
DSS: de Florian, Sassot, and Stratmann,
PRD 75 (2007) 114010 and
PRD 76 (2007) 074033

KKP: Kniehl, Kramer, and Potter,
NPB 582 (2000) 514

KRE: Kretzer,
PRD 62 (2000) 054001

- The same Kretzer Fragmentation Functions (KRE) describe well the charged particle spectra (NPB 883 (2014) 615) and also the identified spectra.
- Kaon spectra are well described by all sets of FFs. Protons have largest differences.
- The pQCD understanding of particle spectra is also important to determine the relative weight of quark and gluon jets in energy loss calculations

p_T spectra in Pb-Pb collsions

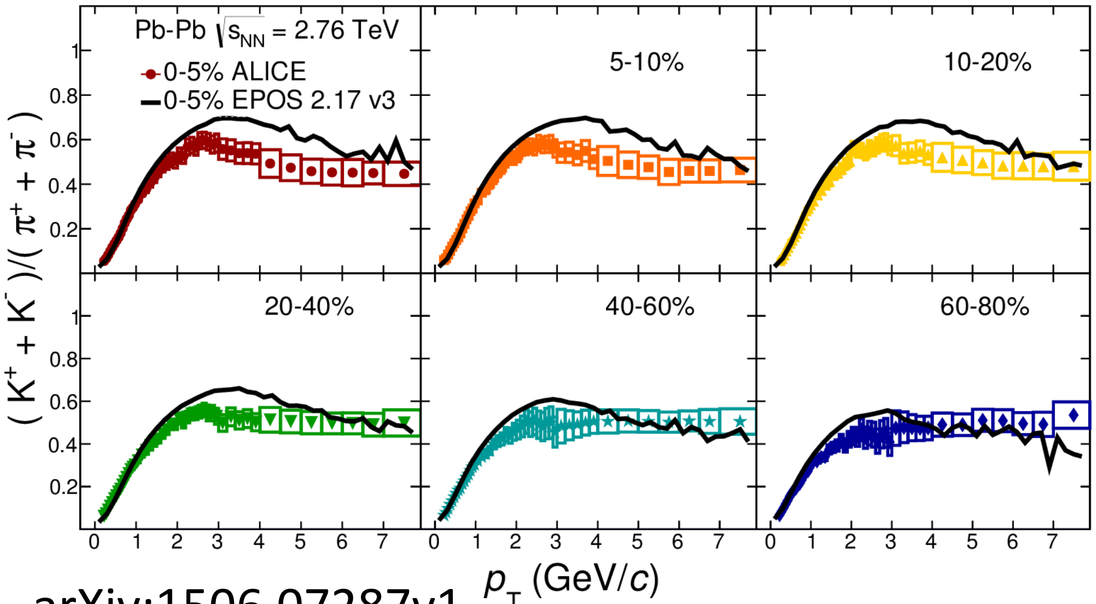


arXiv:1506.07287v1

- For $p_T < 3$ GeV/c a hardening of the spectra is observed going from peripheral to central events. This effect is mass dependent and is characteristic of hydrodynamic flow

- For high p_T ($\gtrsim$ 10 GeV/c) the spectra follow a power law shape as expected from pQCD

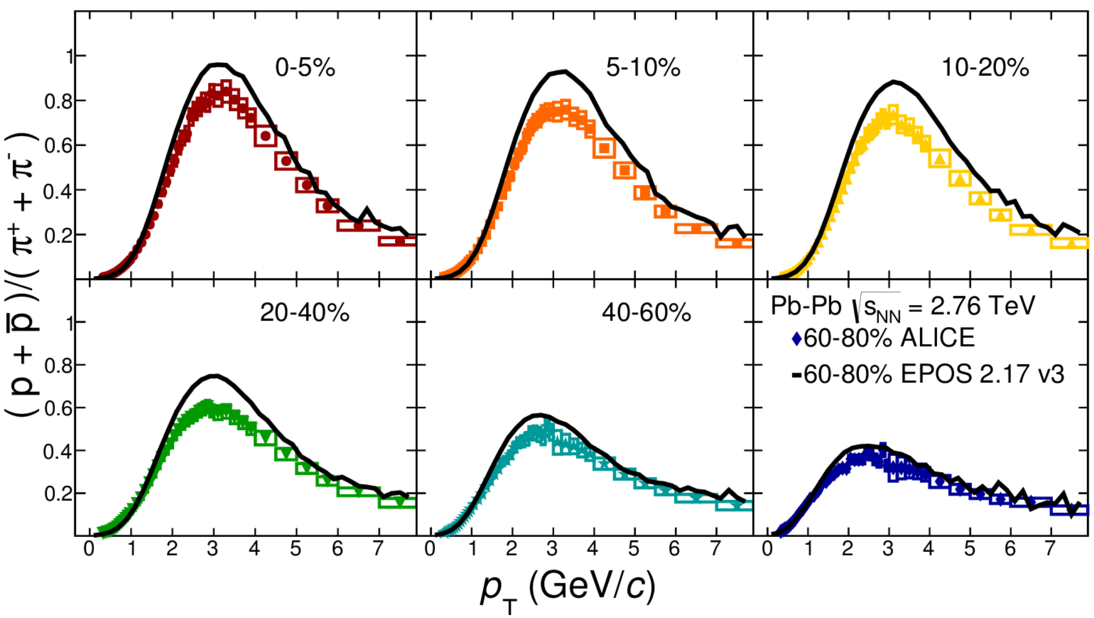
Intermediate p_T: comparison with EPOS



arXiv:1506.07287v1

EPOS model 2.17-3
K. Werner, PRL 109, 102301 (2012) “fluid-jet interaction”. Works over the entire p_T range.

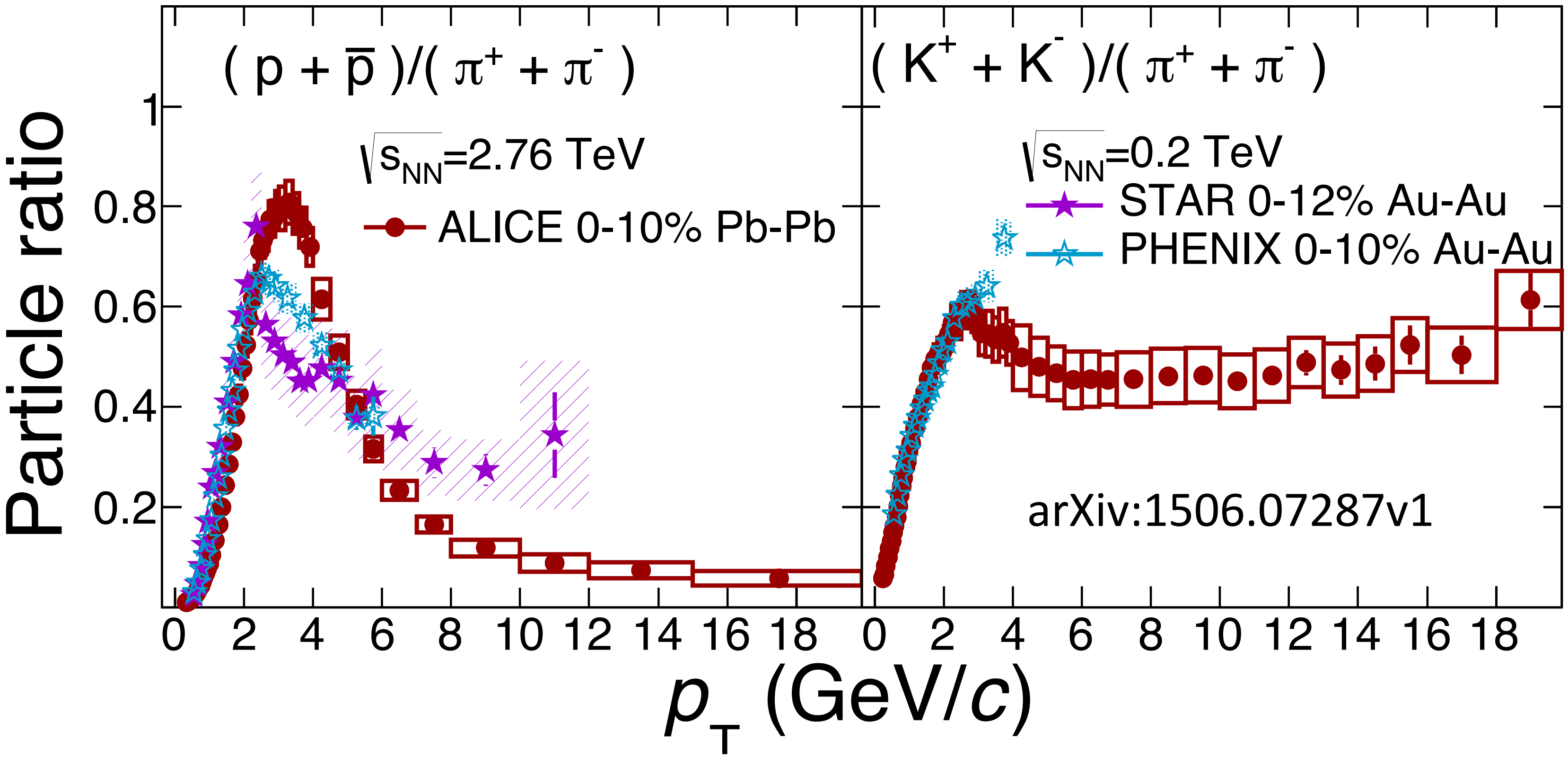
Hydrodynamical phase + hadronization processes at intermediate p_T where the interaction between bulk matter and jets is considered



Baryon-meson effect where a quenched jet hadronizes with flowing medium quarks

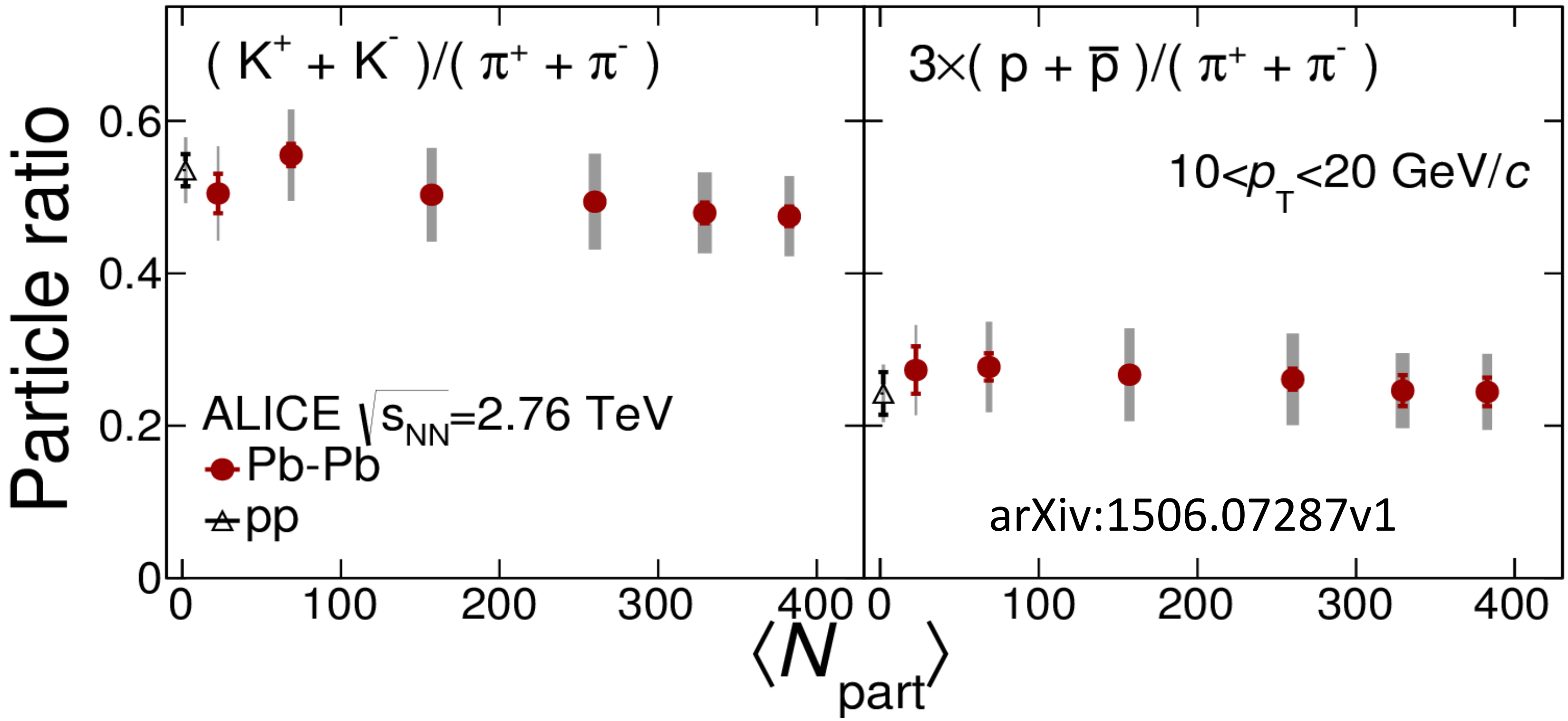
- centrality dependence well reproduced, even for very peripheral events.
- magnitude of both the p-to-π and the K-to-π peak is overpredicted.

Intermediate p_T: comparison to RHIC



- The p-to-π peak at LHC is approximately 20% larger than at RHIC, consistent with an average larger radial flow velocity.
- The K-to-π ratio measured by PHENIX is similar to the ALICE one

Particle ratios in Pb-Pb collisions at high p_T

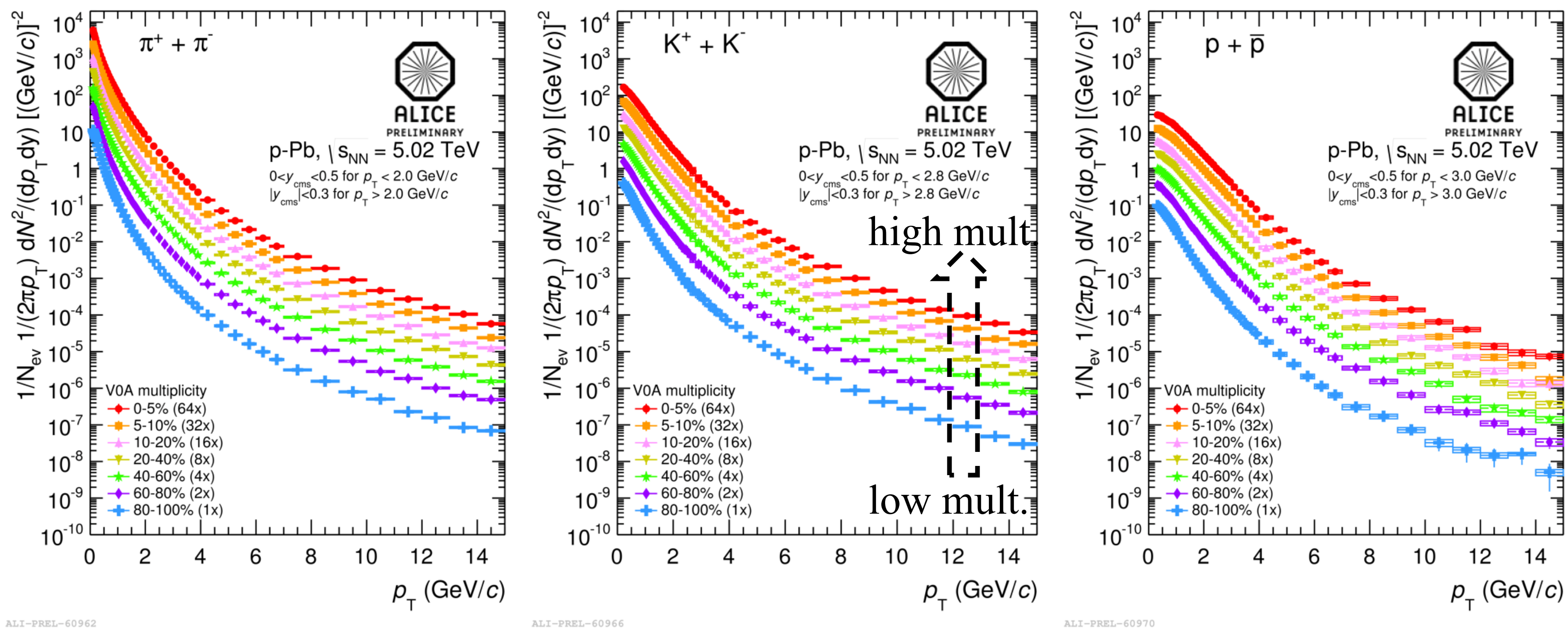


How similar are the high p_T ratios vs collisions centrality?!

- We have computed the integrated particle ratios for $10 < p_T < 20$ GeV/c.
  - charged particle tracking systematic uncertainty cancels
  - K-to-π (p-to-π) ratio as a function of N_{part} is constant within the systematic uncertainty of ≈10% (≈20%) and consistent with the pp value (parton fragmentation in the vacuum).

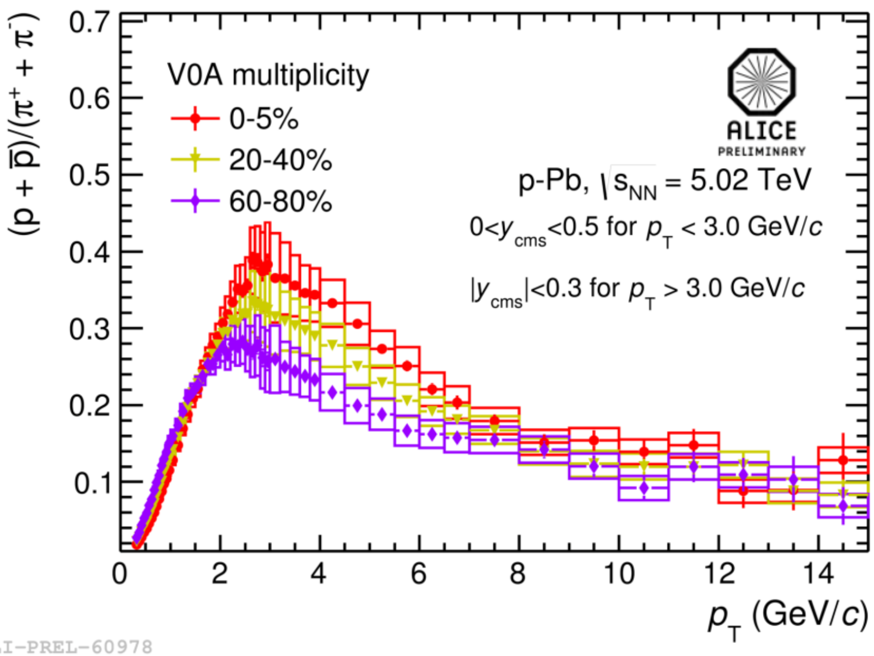
p_T spectra in p-Pb collisions

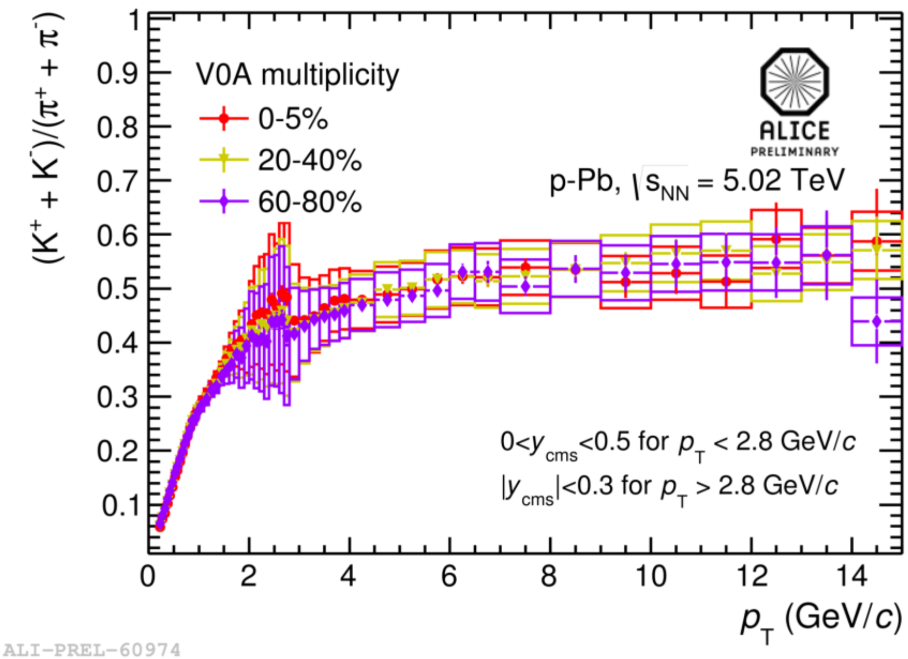
- Hardening with multiplicity and particle mass
- Reminiscent of observed effects in Pb-Pb
  - Attributed to radial flow/recombination
  - In hydrodynamic picture particles are pushed by the expanding hot medium
  - Sensitive to pressure gradient and particle mass
  - Indication for collective effects in p-Pb?!



Results for low p_T : **ALICE, PLB 728 (2014) 25-38**

Particle ratios in p-Pb collisions





- p-to-π ratio:
  - shows a peak, which is more pronounced for higher multiplicities
  - drops to 0.1 at high p_T (as in Pb-Pb)

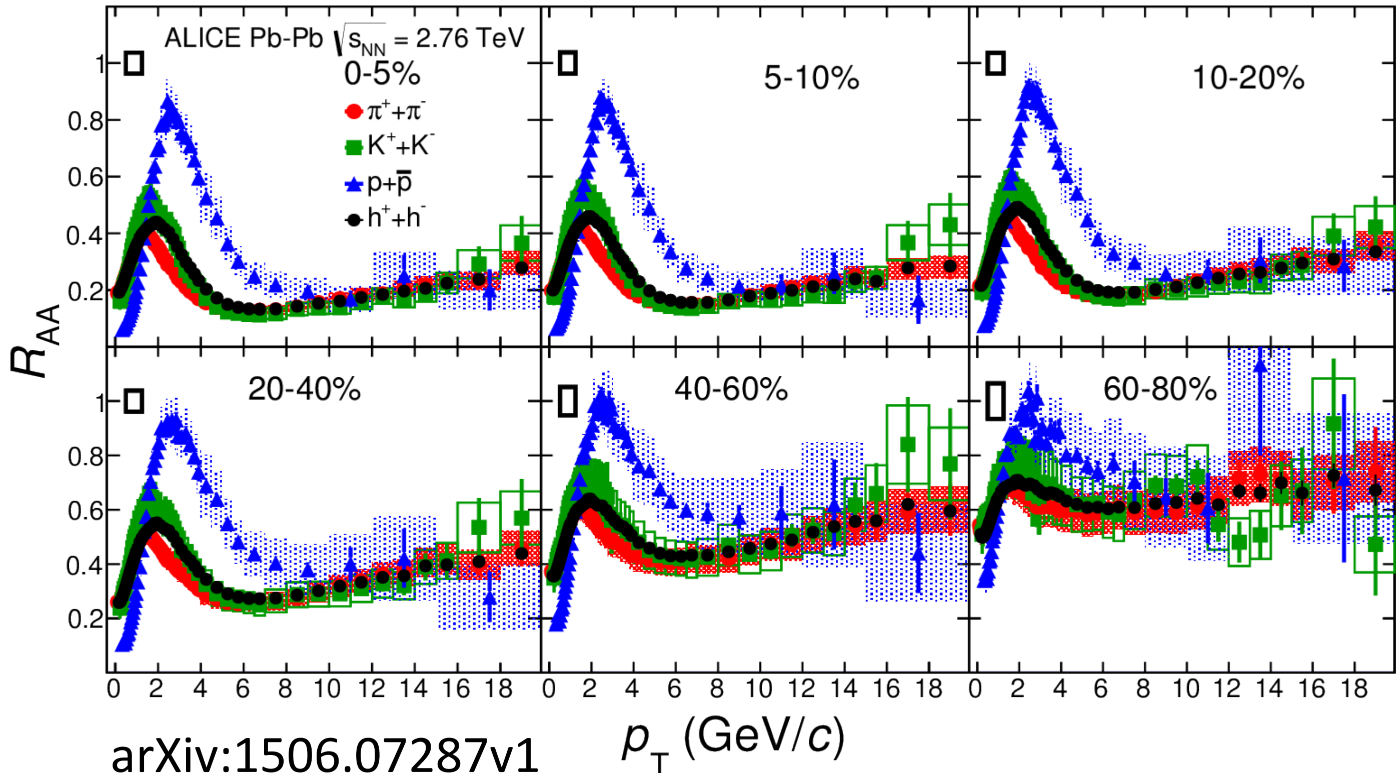
- K-to-π ratio:
  - saturates at 0.5 for high p_T (as in Pb-Pb)
  - does not shows strong multiplicity dependence

The nuclear modification factor: R_{AA}

ALICE

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

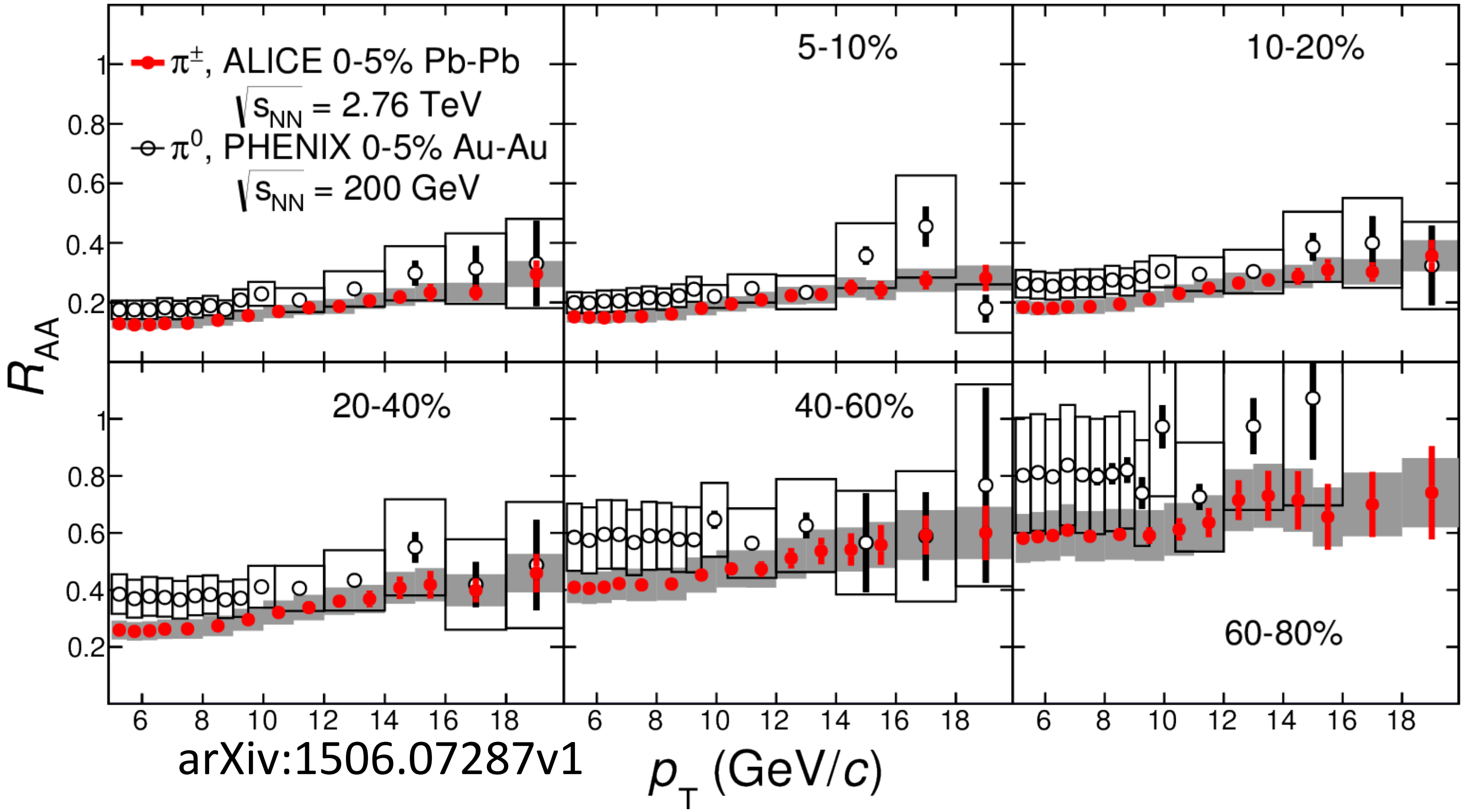
$$\langle T_{AA}\rangle \sigma^{pp} = \langle N_{coll}\rangle$$



arXiv:1506.07287v1

- For $p_T < \approx 8 - 10$ GeV/c: R_{AA} for π and K are compatible and are smaller than R_{AA} for p.
- At high p_T : R_{AA} for π, K and p are compatible.

The pion R_{AA} at RHIC and at LHC



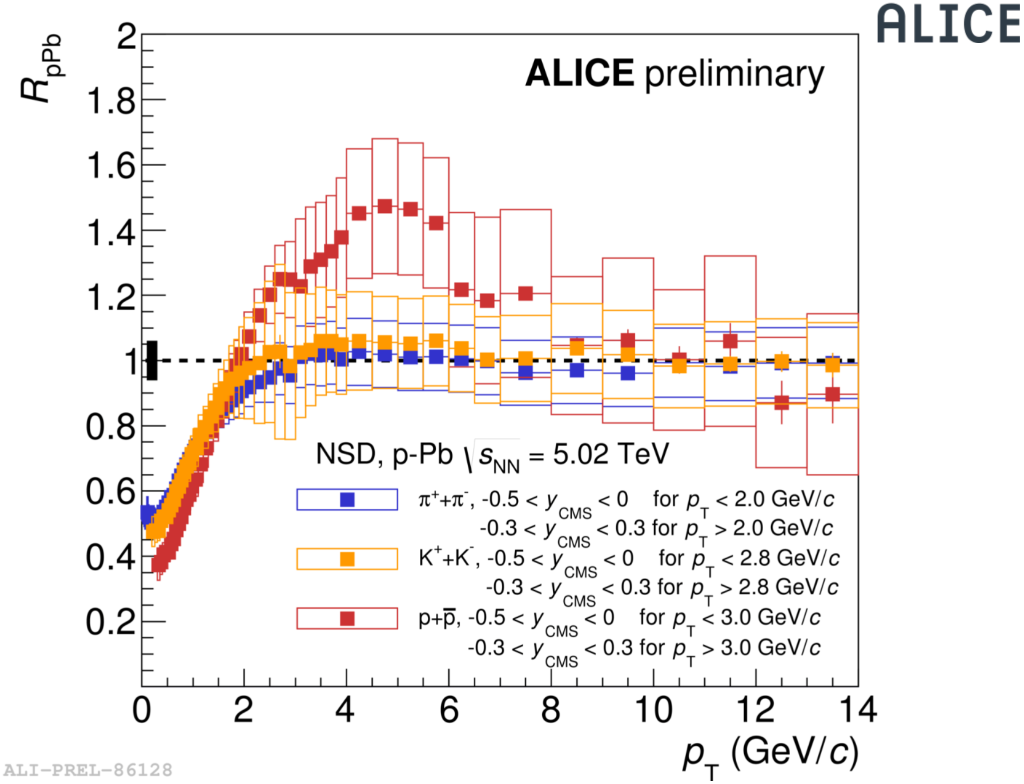
arXiv:1506.07287v1

- ALICE results are below the PHENIX values
- Centrality evolution very similar
- Energy loss is "scaled up" at the LHC
  - the pp spectra at LHC energies are significantly harder, so a larger energy loss is needed to get a similar R_{AA}.

Nuclear modification factor: R_{pPb}

$$R_{\mathrm{pPb}} = \frac{\mathrm{d}^2 N_{\mathrm{pPb}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}{\langle T_{\mathrm{pPb}}\rangle \mathrm{d}^2\sigma_{\mathrm{pp}}^{\mathrm{INEL}}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}$$

$$<T_{\mathrm{pPb}}>\sigma^{pp} = <N_{coll}>$$



- pp reference at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV is obtained interpolating available data (2.76 TeV and 7 TeV)
  - Power-law fit: $(\sqrt{s_{\mathrm{NN}}})^{\alpha}$
- Protons show peak at intermediate p_{T}
- R_{pPb} of π and K not show peak and flat above 2 GeV/c
- mass ordering in the Cronin peak, strong enhancement of protons
- no suppression at high p_{T} (> 8-10 GeV/c)

R_{pPb} vs centrality will be show in the talk of A. Toia!!

Conclusions

- Pions, kaons and protons production at intermediate and high p_T measured by ALICE in pp, p-Pb and Pb-Pb collisions has been presented

- NLO pQCD calculations for π, K, p production in pp collisions favors the Kretzer Fragmentation Functions

- The intermediate p_T region ($\approx 2 < p_T < \approx 8 - 10$ GeV/c) reveals some complications in the description of the transition from soft regime to partons fragmentation

- Nuclear modification factor in Pb-Pb collisions for high p_T (> ≈10 GeV/c) does not depend on particle species:
  - chemical composition of leading particles from jets in the medium is similar to that of vacuum jets

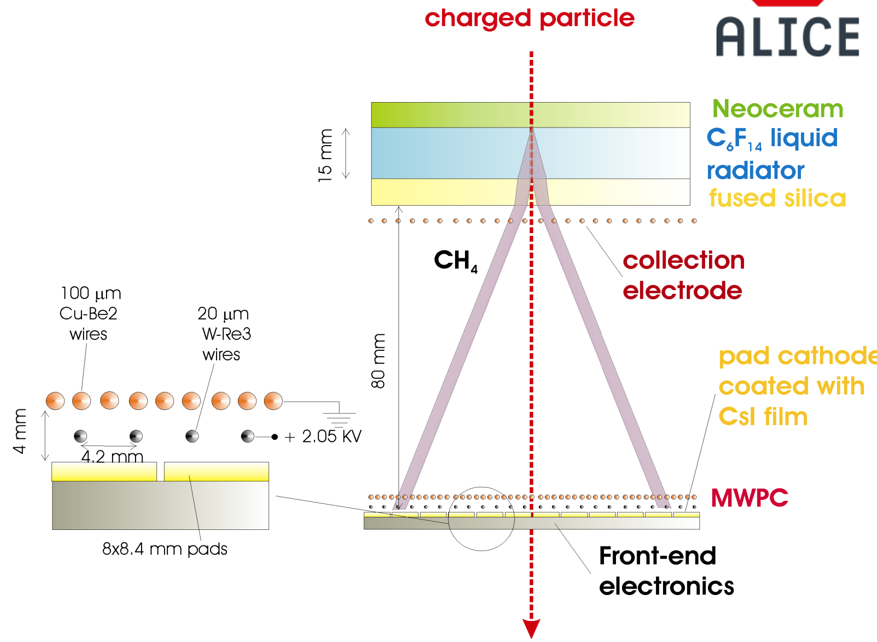
- Nuclear modification factor in p-Pb collisions:
  - mass ordering in the Cronin peak, strong enhancement of protons
  - no suppression at high p_T → suppression observed in central Pb-Pb collisions is not due to an initial-state effect but rather to a fingerprint of the hot matter created in heavy ion collisions

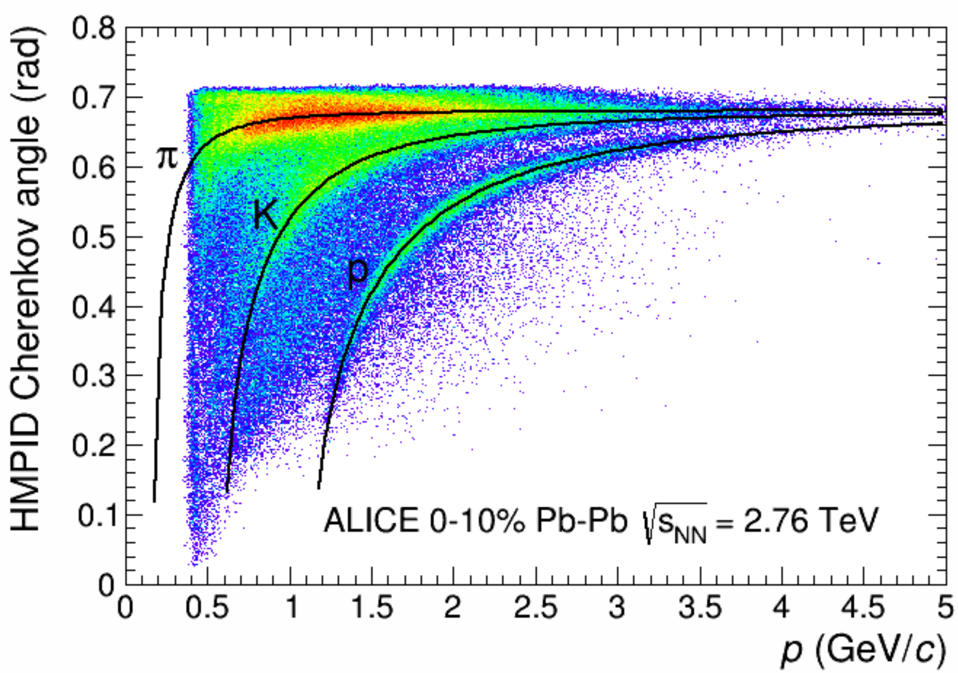
Backup

ALICE-HMPID detector

- The ALICE-HMPID (High Momentum Particle Identification Detector) performs charged particle identification by means of the measurement of the emission angle of Cherenkov radiation and of the momentum information provided by the tracking devices.

- It consists of seven identical proximity focusing RICH (Ring Imaging Cherenkov) counters.



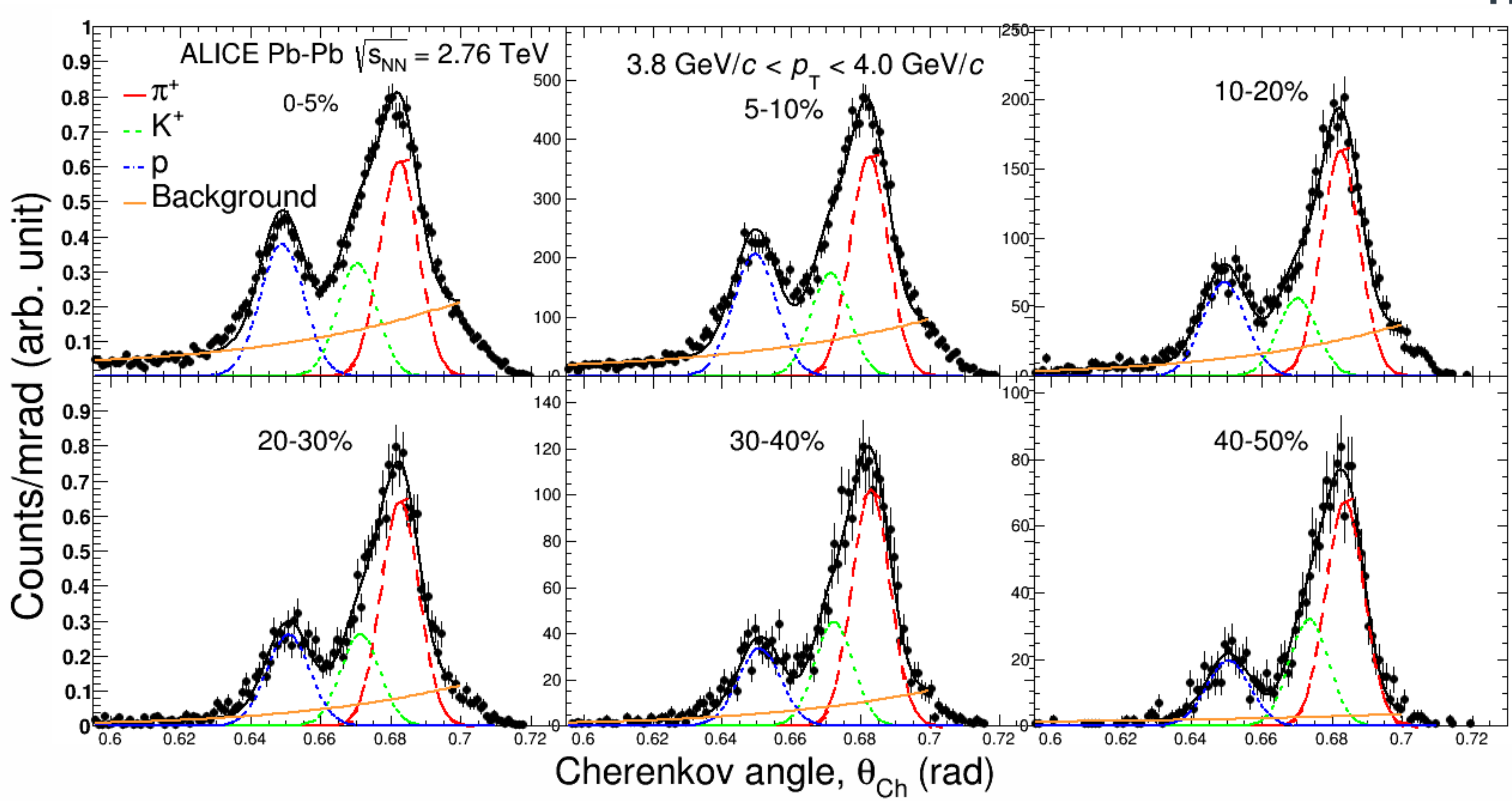


- liquid C_6F_{14} Cherenkov radiator

- Cherenkov emission angle measurements enable 3σ separation for p/k up to 3 GeV/c and for K/p up to 5 GeV/c

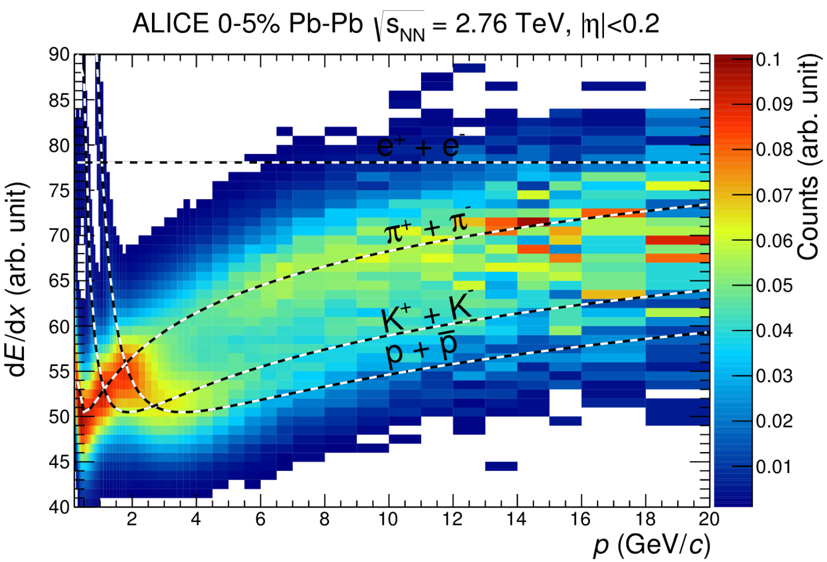
- PID range:
  π/K: 1.5 – 4 GeV/c
  p: 1.5 - 6 GeV/c

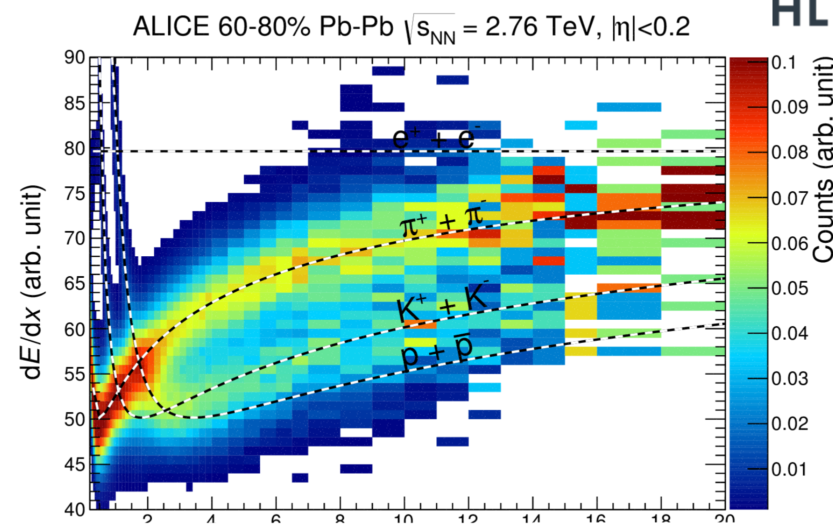
ALICE-HMPID detector



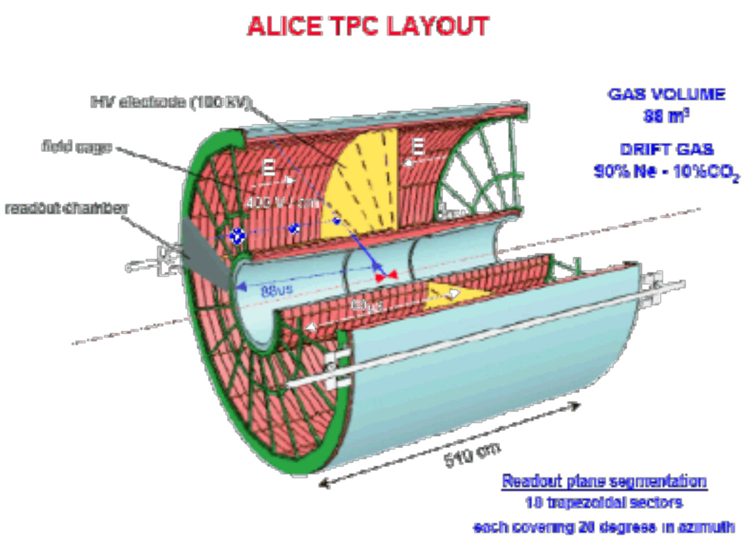
- The PID respsonses for π, K, and p are Gaussians and independent of centrality.
- The background is caused by wrongly assigned rings, well reproduced by MC. It is described by a 6th degree polynomial. The small shoulder at $\theta_{ch} \approx 0.7$ rad which is an effect of the chamber geometry.

ALICE-TPC detector



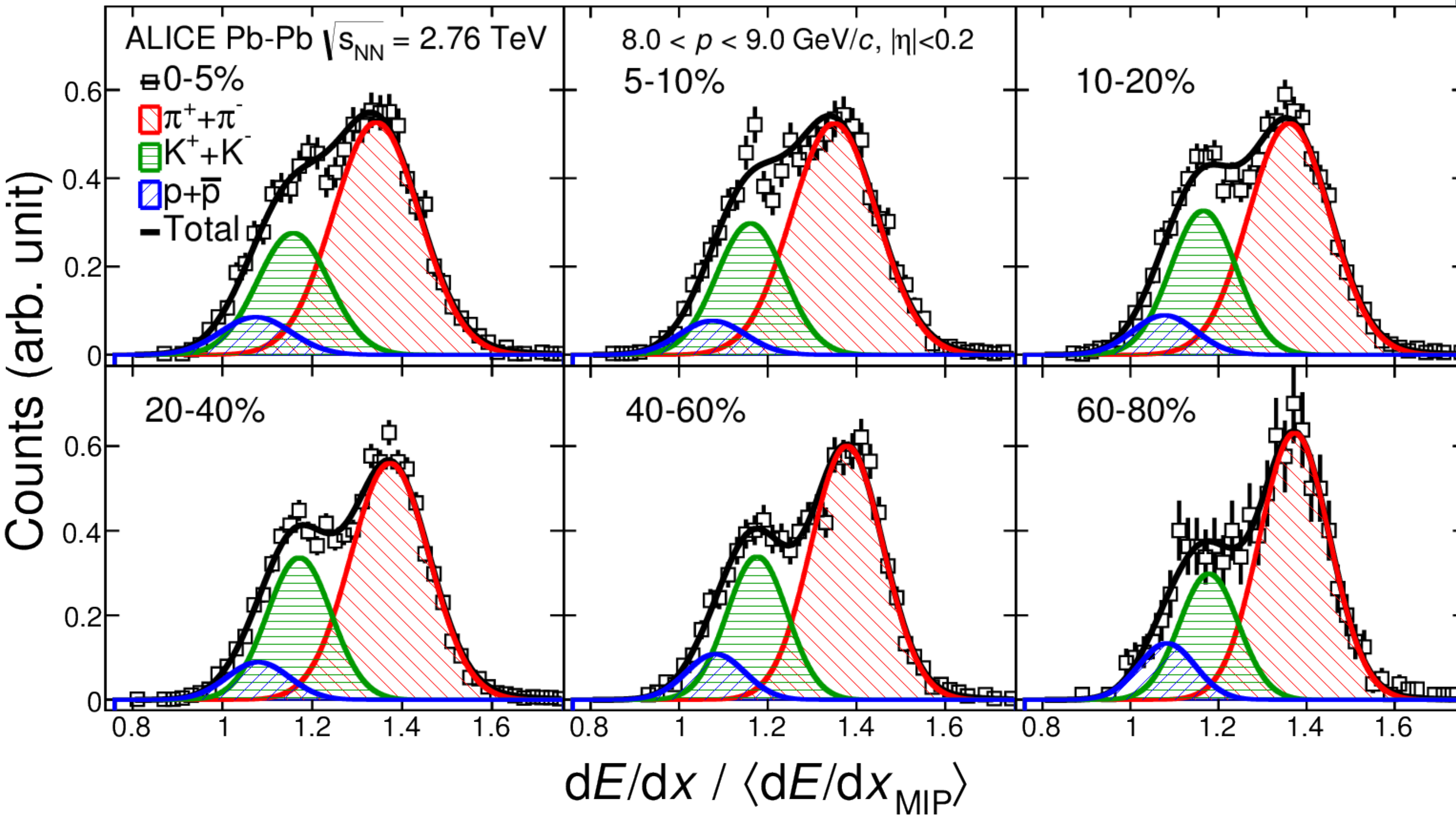


arXiv:1506.07287v1



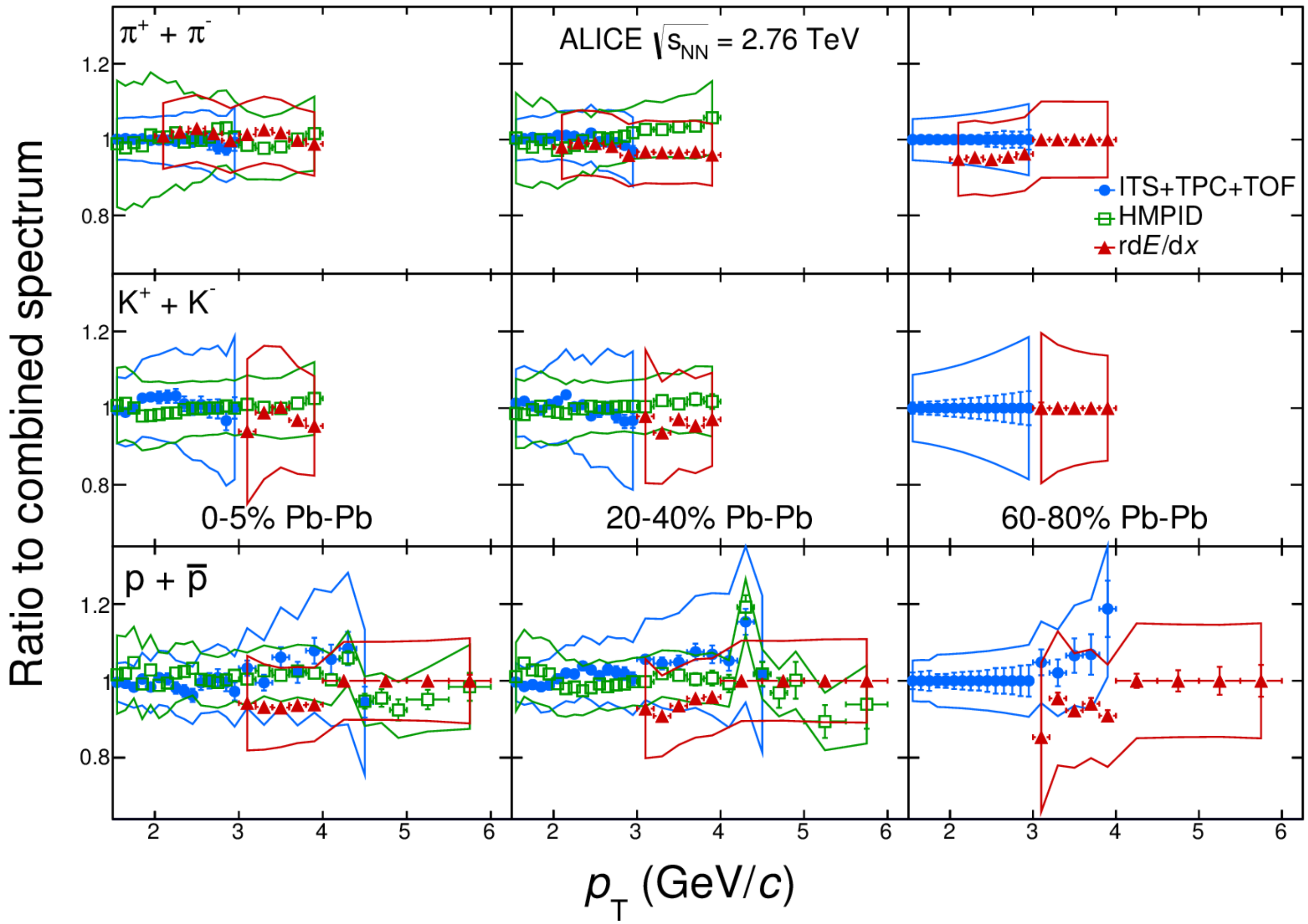
- Up to 159 pad rows in Ne-CO_2 gas mixture: $\sigma_{dE/dx} \approx$ 5%.
- The ALICE TPC provides fully contained charge particle tracks for $|\eta| < 0.8$
- Each of the tracks also has a specific energy loss dE/dx usable for PID
- for high p_T (3-20 GeV/c) statistical PID is done exploiting the features of dE/dx in the relativistic rise regime.

ALICE-TPC detector



The PID responses for π, K, and p are Gaussians (e is < 1%). The means and widths are fixed to the calibrated values.

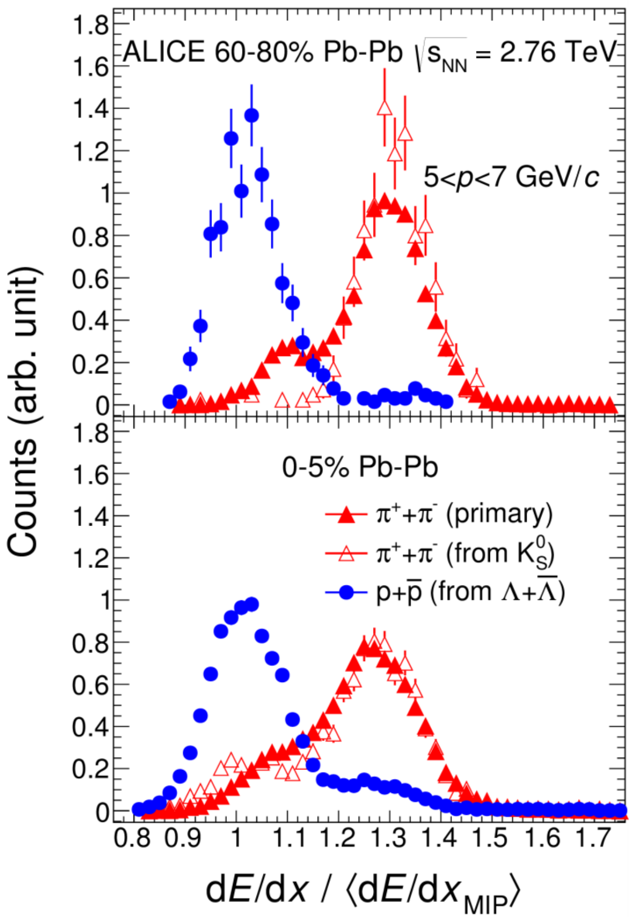
Spectra combination

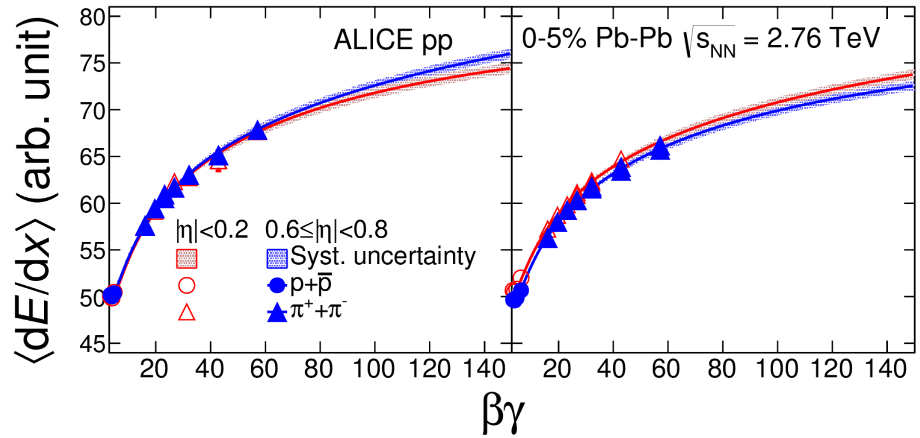


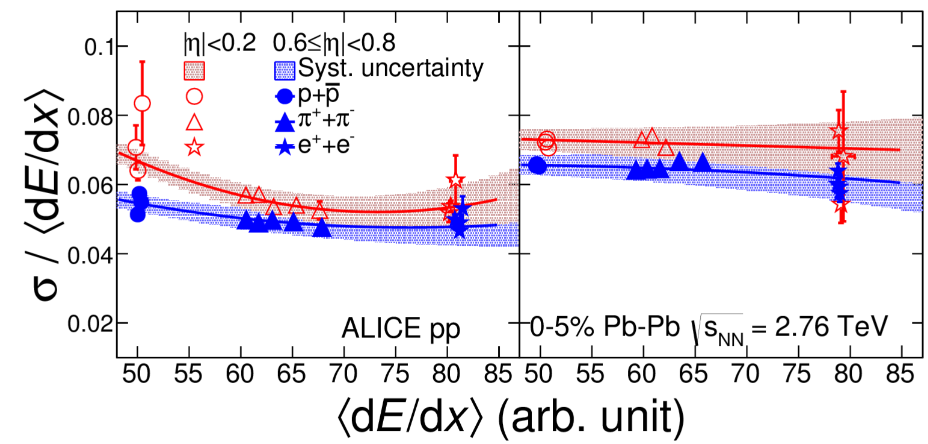
ALICE Lower p_T results (ITS+TPC +TOF) are from PRC 88 (2013) 044910.

Measurements are combined using a weighted average where the weights are the systematic uncertainties (except for a common 3% uncertainty that is subtracted and directly added to the final spectrum).

Calibrating the dE/dx response

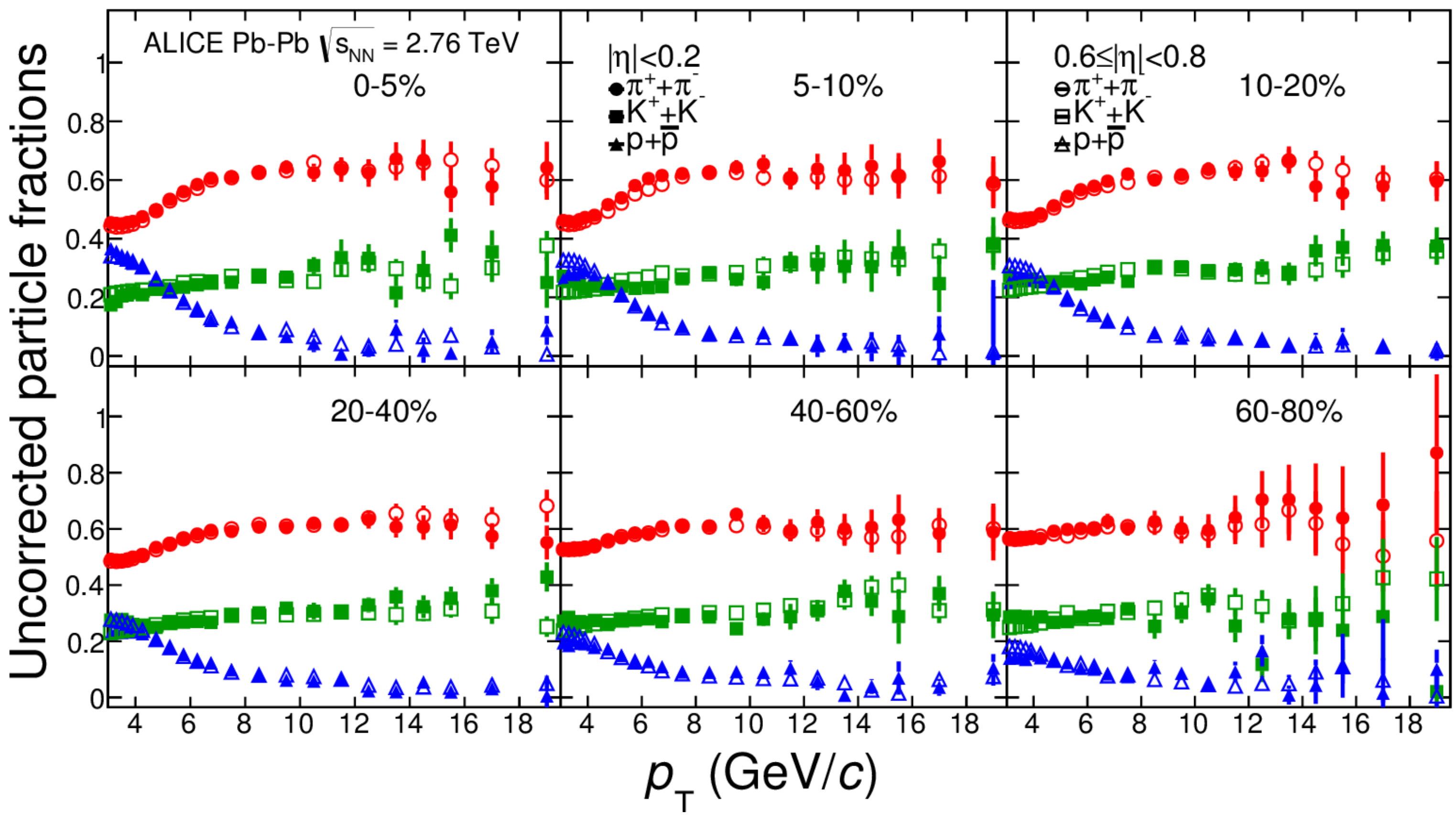






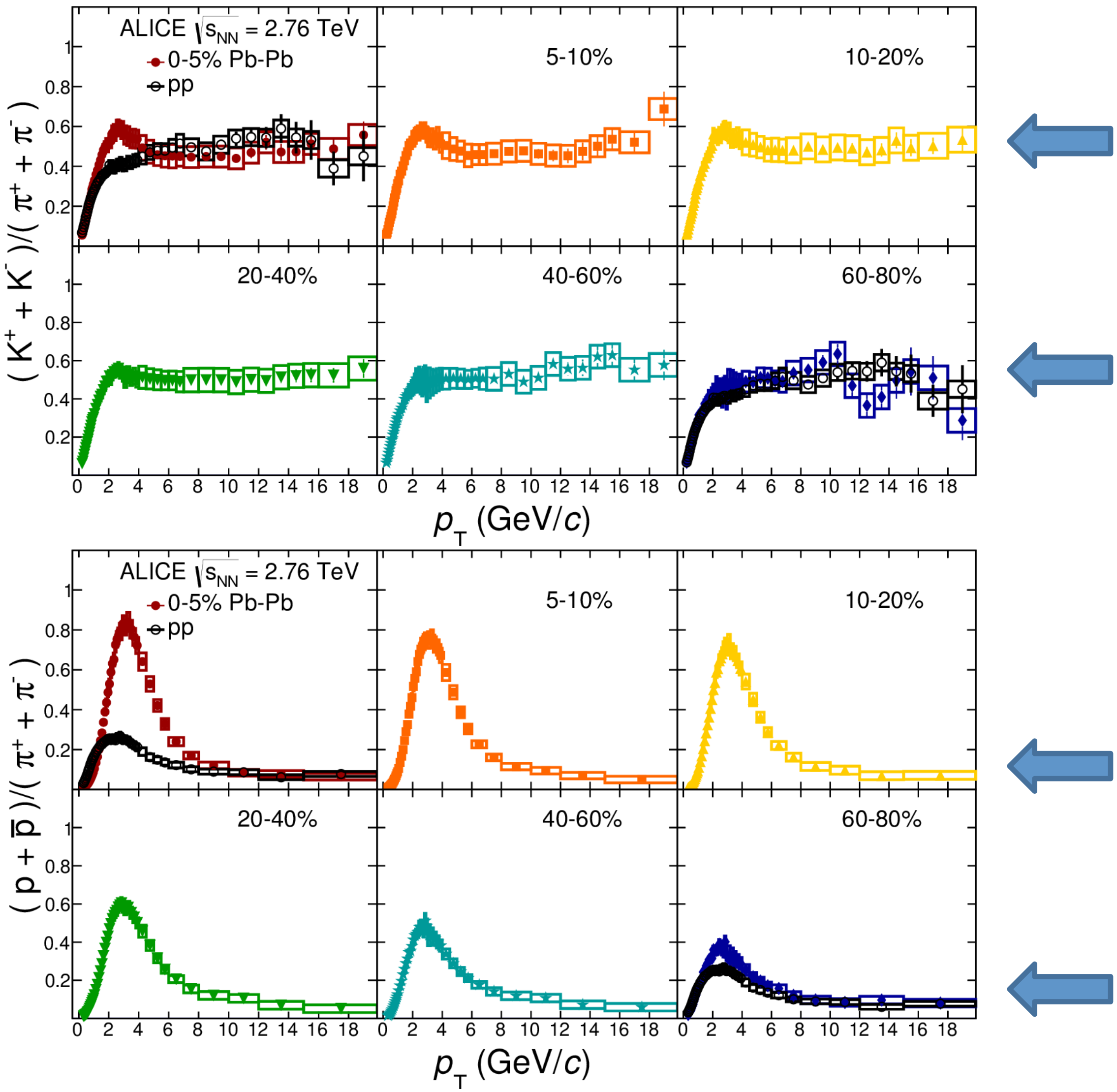
The dE/dx response is calibrated using tracks identified from their time-of-flight (TOF) or topology (V^0s and ϒ–conversions)

The relative particle composition as a function of p_T



The fraction of π, K, and p are extracted for each |η| slice and then averaged for |η|<0.8. The final spectra are essentially obtained by multiplying with the invariant charge particle yields.

Particle ratios in Pb-Pb collisions at high p_T

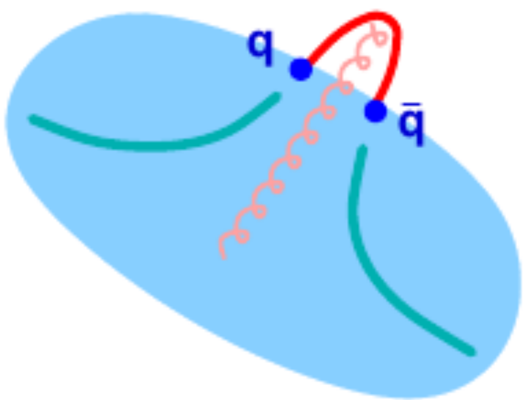


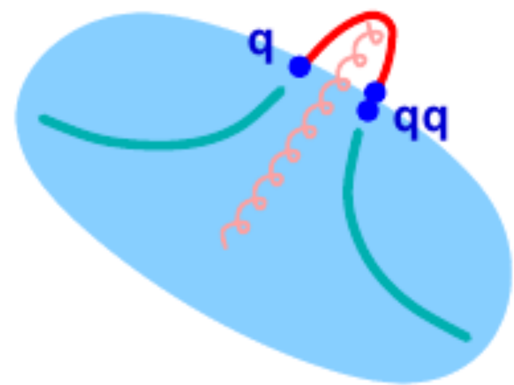
The behavior at high p_T (p_T>10 GeV/c) is independent of centrality (and the same as in pp collisions)

EPOS model 2.17-3

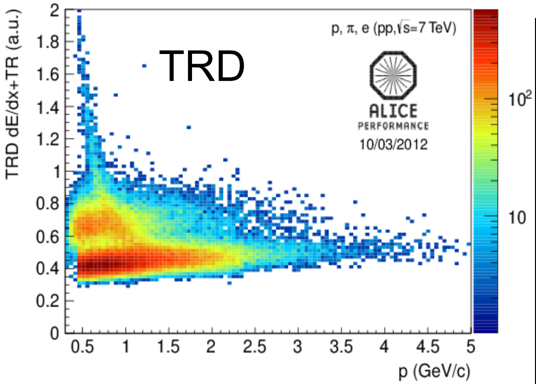
K. Werner, PRL 109, 102301 (2012) "fluid-jet interaction"

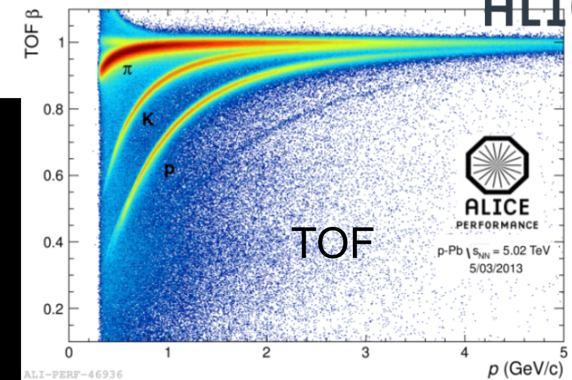
"Considering transverse fluid velocities up to 0.7*c*, and thermal parton momentum distributions, one may get a "push" of a couple of GeV to be added to the transverse momentum of the string segment. This will be a crucial effect for intermediate p_T jet hadrons."

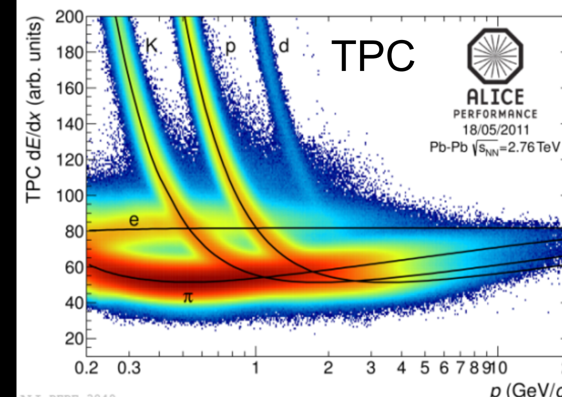


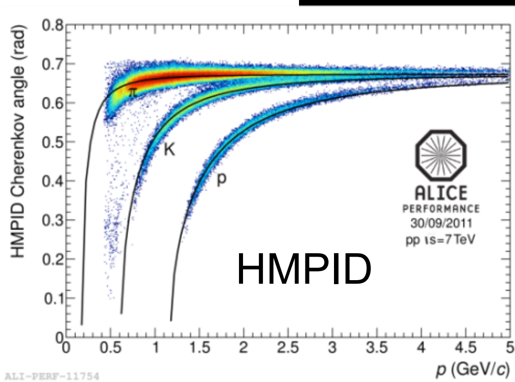


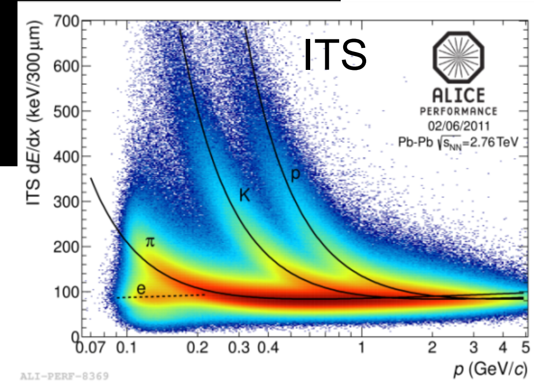
Charged particle PID in ALICE (central barrel)







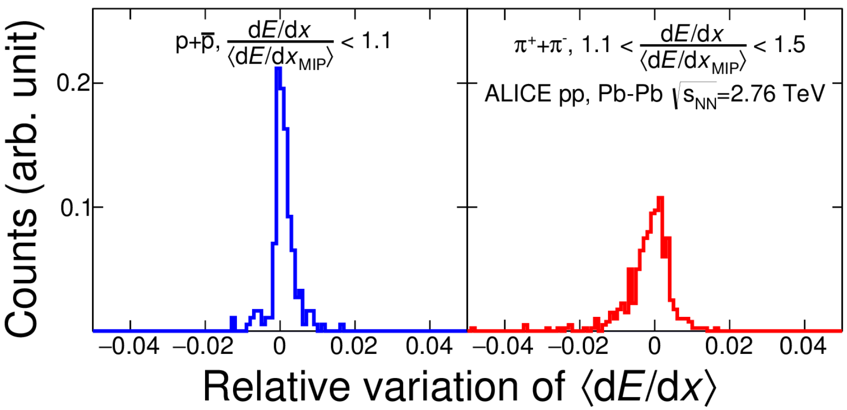


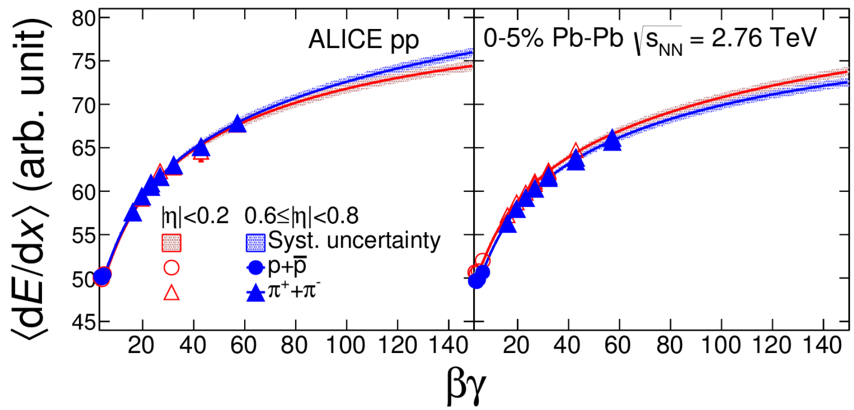


The ALICE experiment is optimized for charged particle tracking **and hadron identification** for |η|<0.8

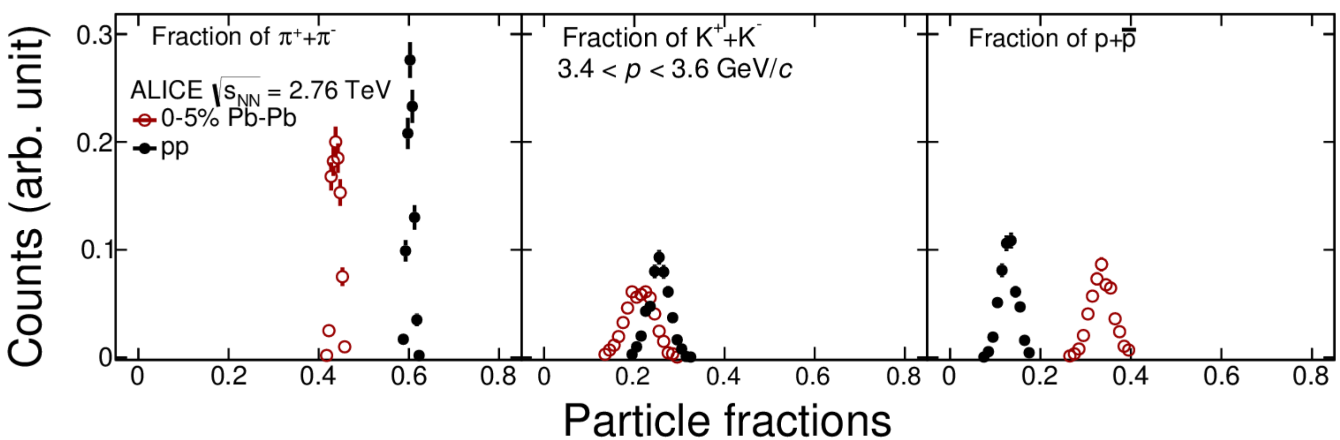
Systematic uncertainties of TPC dE/dx method

The uncertainty on the <dE/dx> parametrizaton is estimated from the deviations of the calibrations (similar for all centralities)

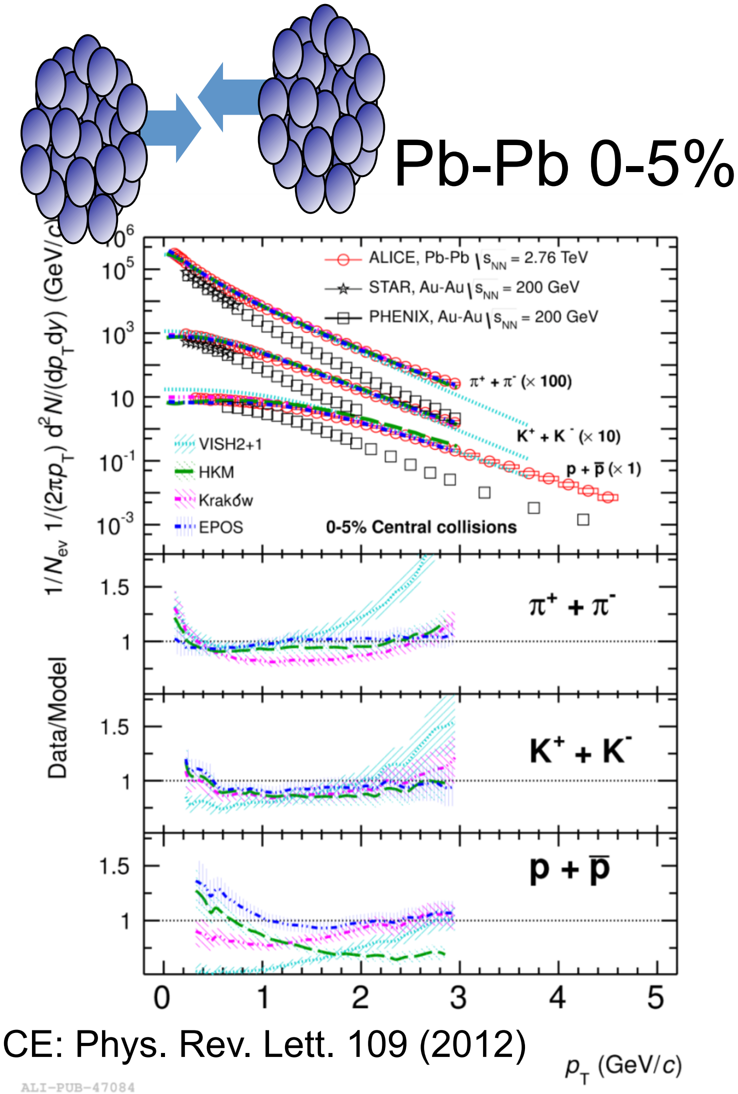




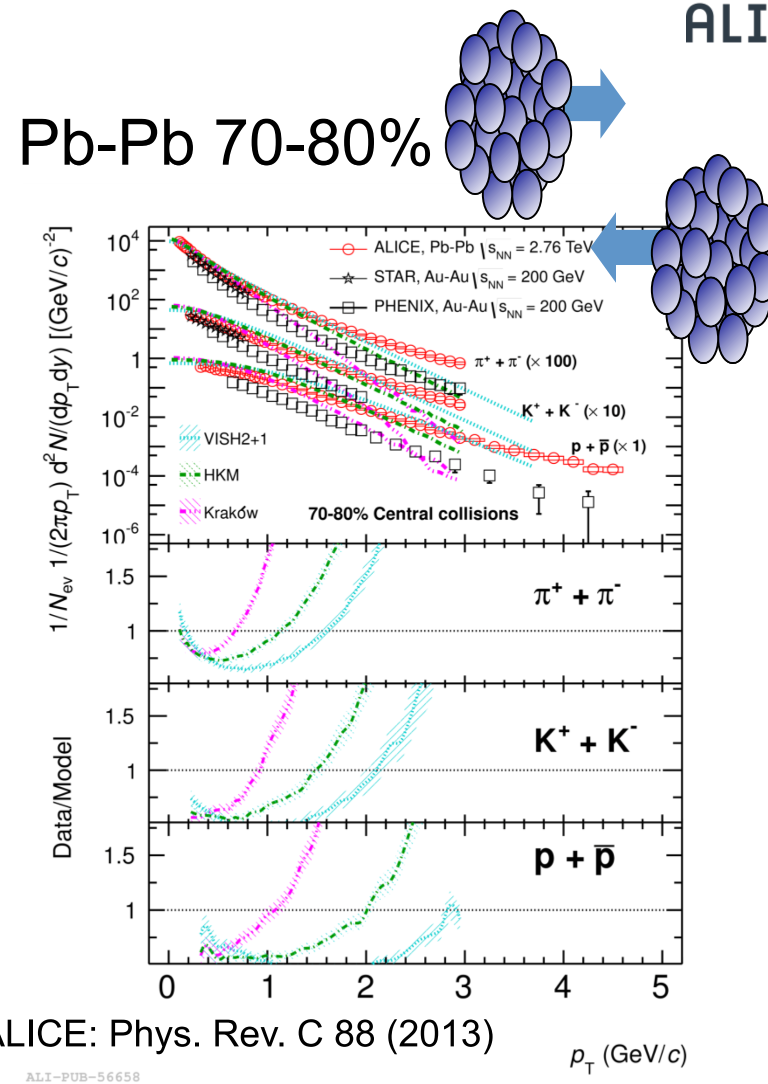
The fit constraints are randomly varied using these uncertainties (and the resolution σ) to obtain the syst. uncert. on the fractions



Bulk production: low p_T spectra



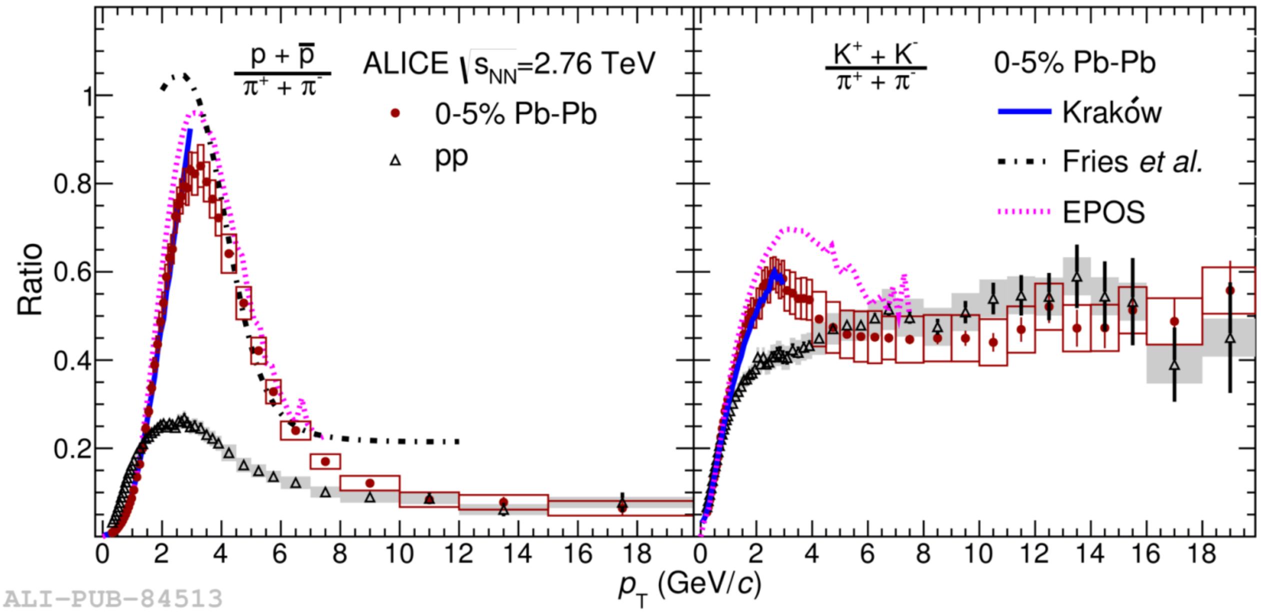
ALICE: Phys. Rev. Lett. 109 (2012)



ALICE: Phys. Rev. C 88 (2013)

- Hydrodynamic models describe well the spectra in central Pb-Pb collisions
- The same models typically fail to describe the p_T spectra in peripheral collision

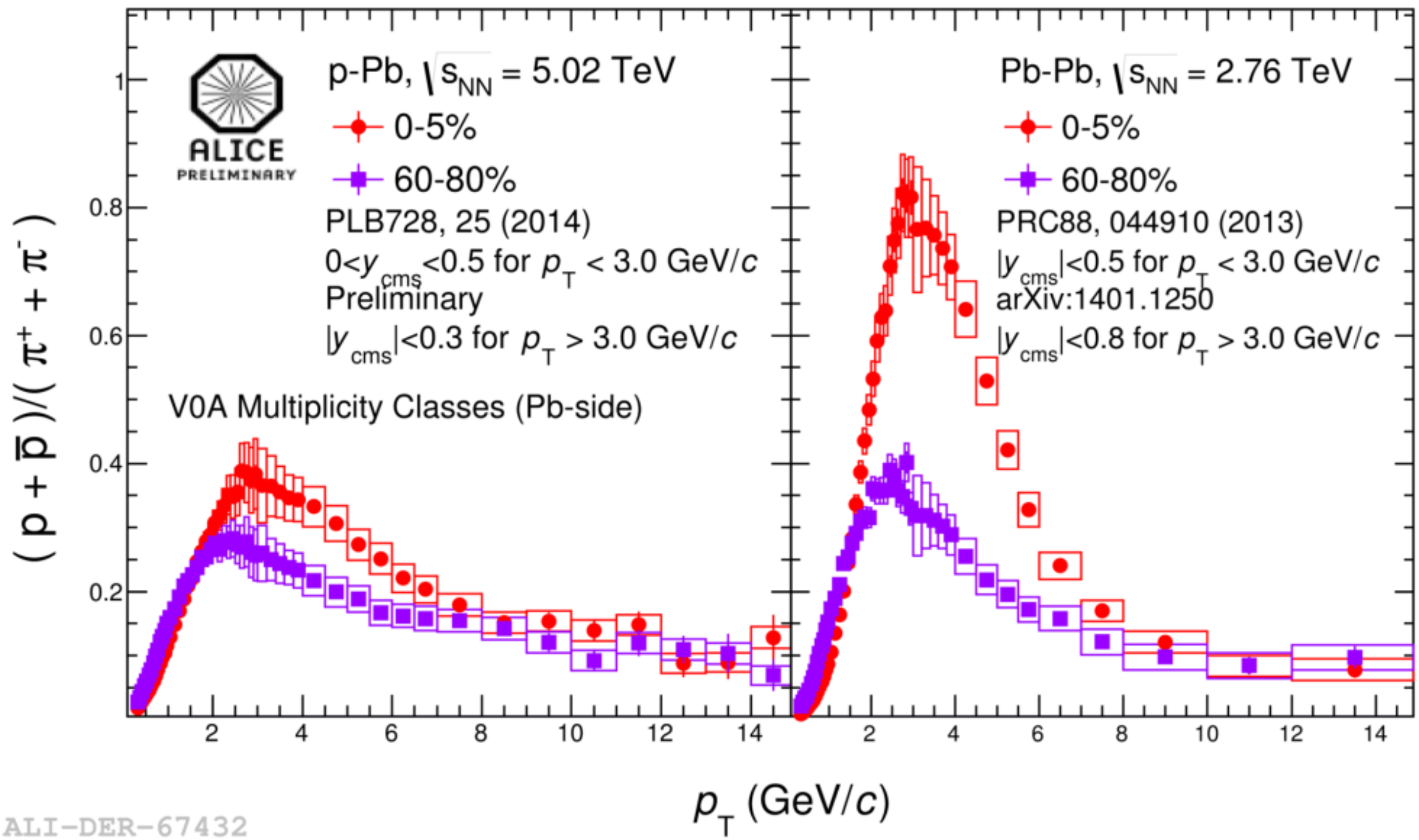
Particle ratios compared to models



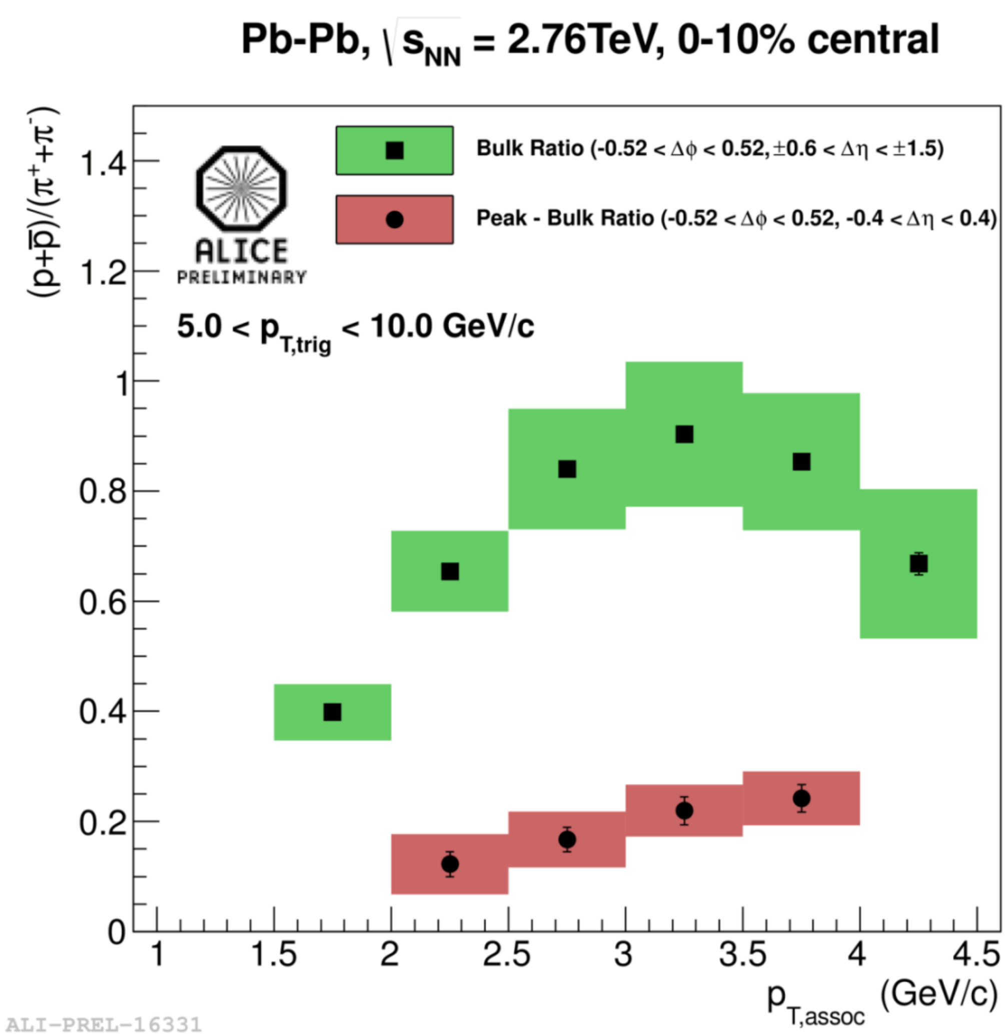
- Kraków: PRC85, 064915 (2012)
- HKM: PRC87, 024914 (2013)
- Fries: PRL90, 202303 (2003) and private communication
- EPOS: PRL109, 102301 (2012) and private communications

Kraków+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)

Comparisons between the different colliding systems: high p_T particle ratios in p-Pb and Pb-Pb



p/π ratio in peak-bulk

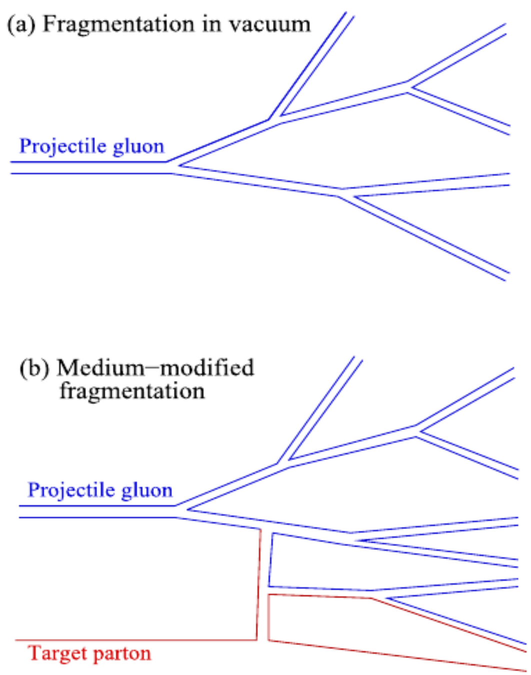


When the p/π ratio in the peak is corrected for bulk effects using an η gap one finds that the ratio is dominated by the bulk.

So the ratio does not seem to be driven by hard physics.

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

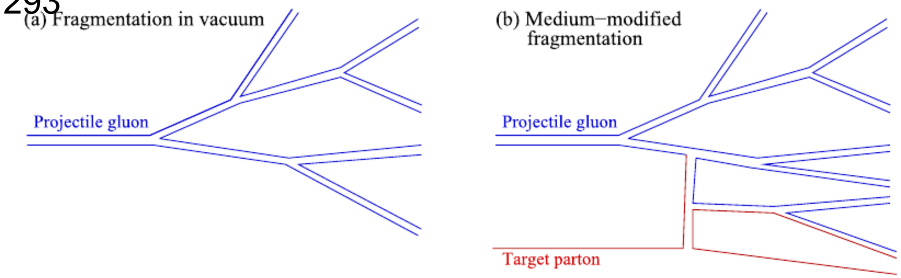


S. Sapeta and U.A. Wiedemann, Eur.Phys.J. C55 (2008) 293:

- 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. <u>This changes the color flow in the parton shower and is thus likely to affect hadronization</u>."
- Direct
  - "In addition, flavour 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 from this and similar models that are ruled out