ΕΘΝΙΚΟΝ & ΚΑΠΟΔΙΣΤΡΙΑΚΟΝ
ΠΑΝΕΠΙΣΤΗΜΙΟΝ ΑΘΗΝΩΝ
NATIONAL & KAPODISTRIAN
UNIVERSITY OF ATHENS

ALICE

Identified charged hadron production in pp and Pb-Pb collisions with ALICE at the LHC

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University of Athens – Faculty of Physics

ICNFP 2015

Outline

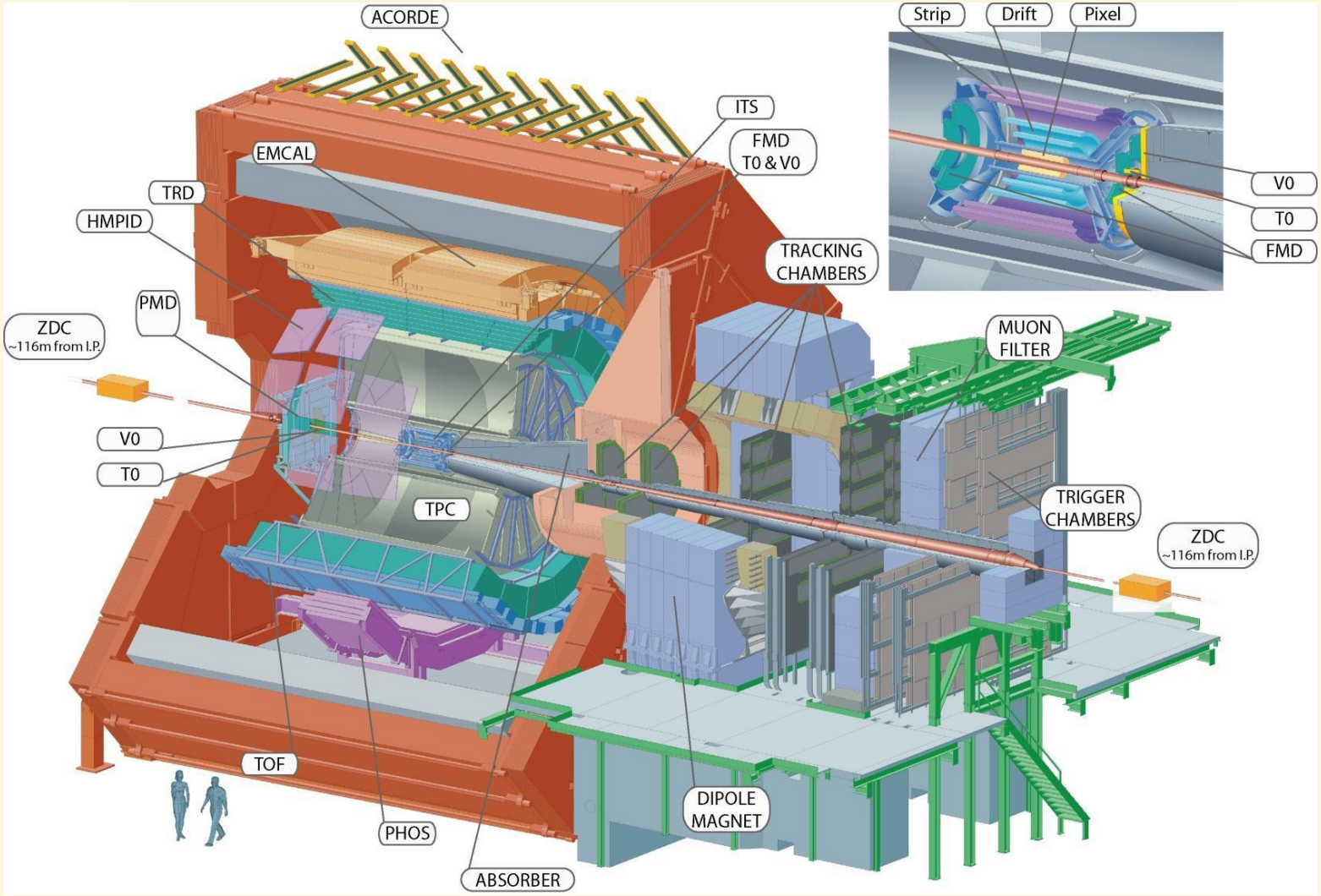
- Introduction
- ALICE Detector and PID
- Results on identified hadrons from :
  - pp Collisions
  - Pb-Pb Collisions
- Nuclear Modification Factors
- Conclusions

Introduction

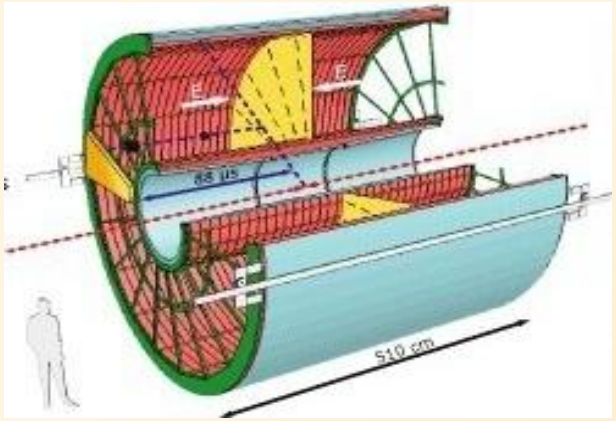
ALICE is designed to study the physics of strongly interacting matter under extremely high temperature and energy density conditions to investigate the properties of the quark-gluon plasma (QGP)

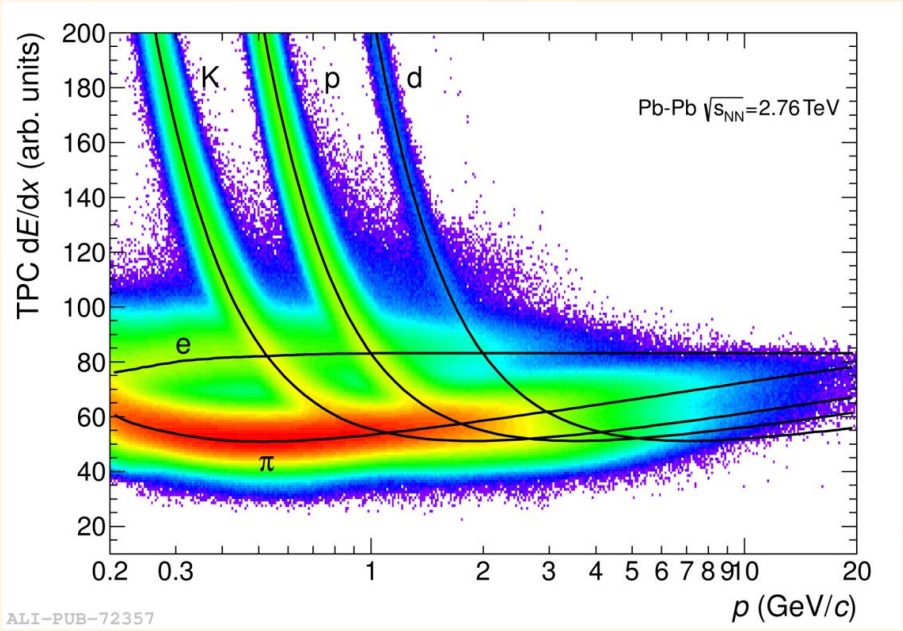
- **pp collisions at $\sqrt{s}$ = 0.9 TeV, 2.76 TeV, 7.0 TeV**
  - Test QCD inspired models
  - Provide reference for p-Pb and Pb-Pb data
- **p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV**
  - Discriminate between initial (cold nuclear matter) and final state (QGP) effects
  - Provide reference for Pb-Pb data
- **Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV**
  - Study the QGP

ALICE Detector



TPC (I)

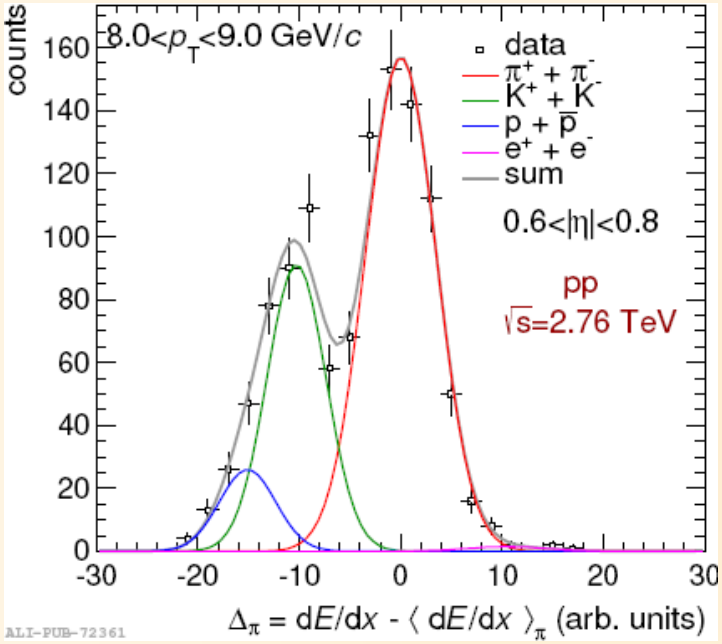


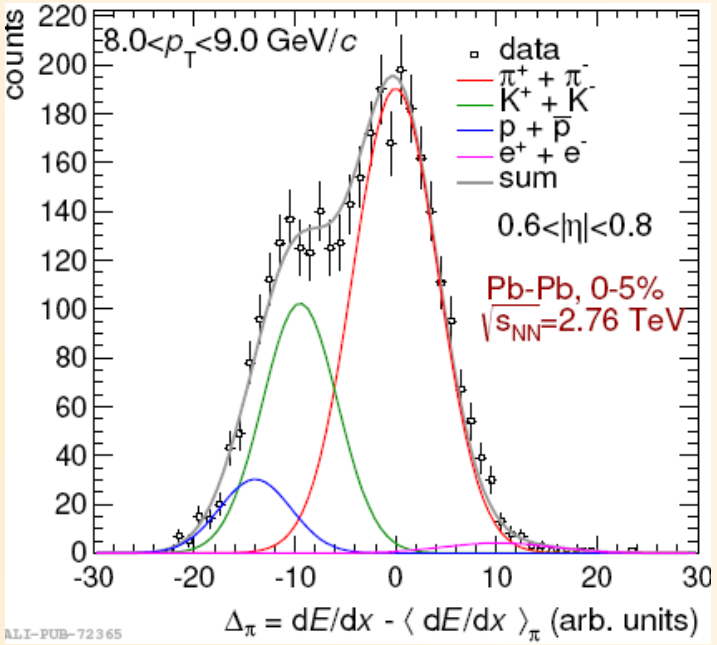


ALICE, Int. J. Mod. Phys. A29 (2014) 1430044

- PID via dE/dx in gas – Ne/CO2 (90:10) – up to 159 samples
- Truncated mean dE/dx calculated and used for a wide range of momentum
- Largest separation achieved at low p (< 2.0 GeV/c)

TPC (II)





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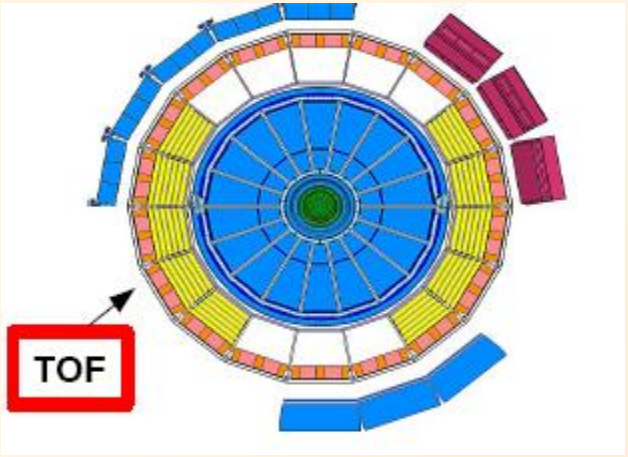
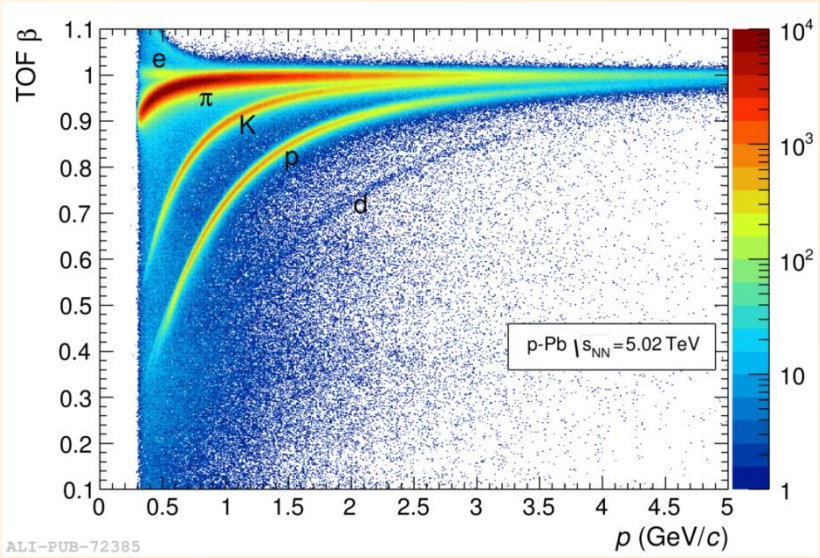
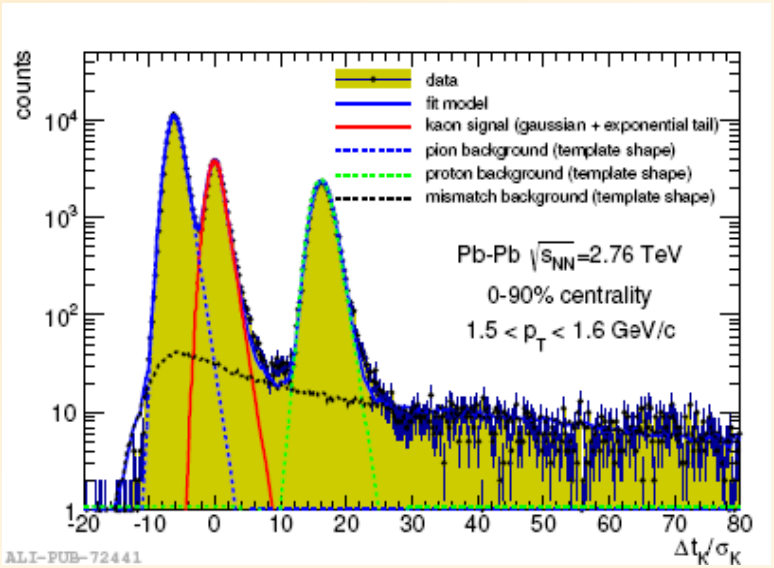
- At high p_T : particles separated on a statistical basis via multi-Gaussian fits

TOF



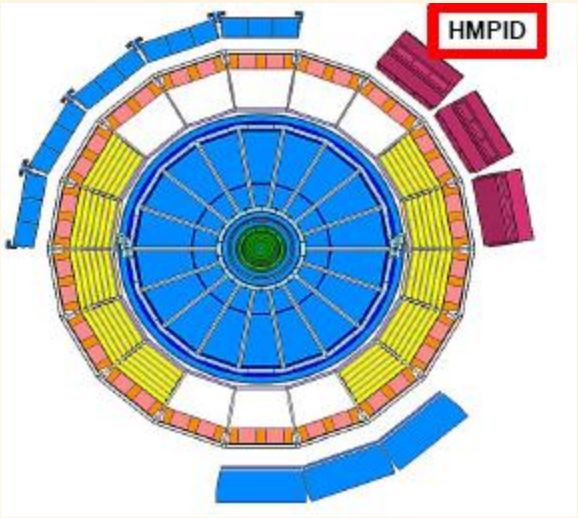
- Time - Of - Flight:
  Multigap Resistive Plate Chambers (MRPC)
  PID at intermediate momenta
- Resolution < 100ps



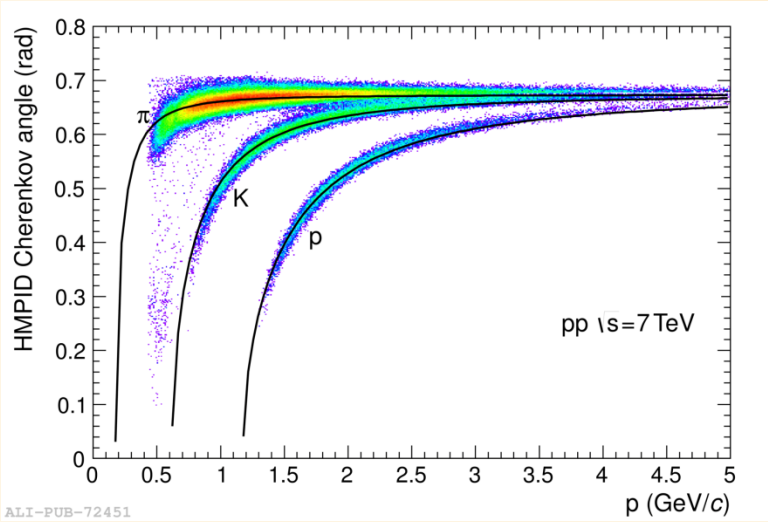


ALICE, Int. J. Mod. Phys. A29 (2014) 1430044

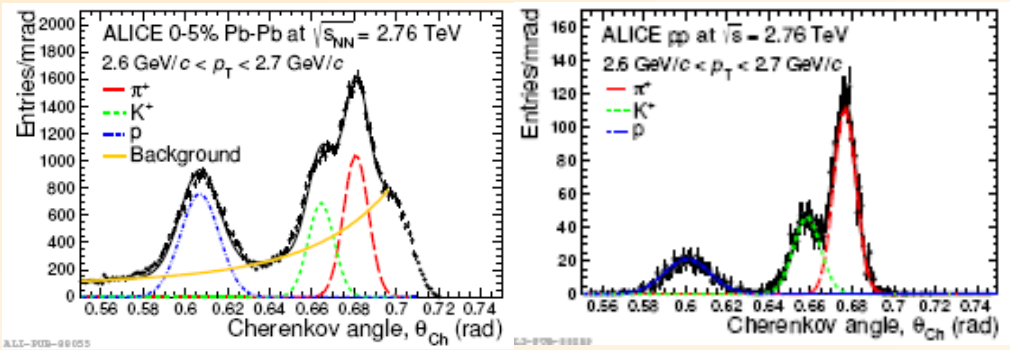
HMPID



- High Momentum Particle Identification Detector : Consists of 7 RICH modules
- Proximity focusing configuration
- 3σ separation for π/K up to 3 GeV/c and for K/p up to 5 GeV/c

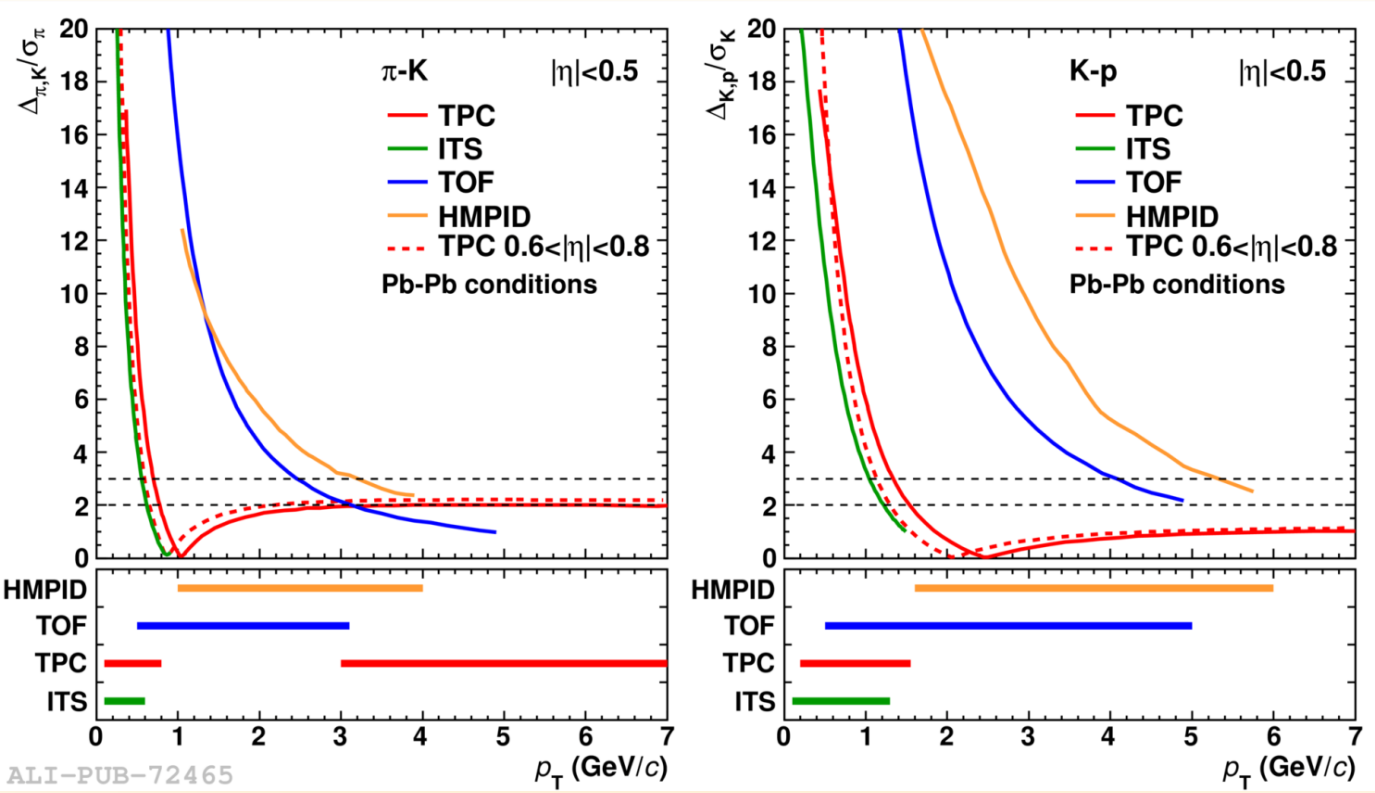


ALICE, Int. J. Mod. Phys. A29 (2014) 1430044



ALICE, Phys. Lett. B 736 (2014) 196-207

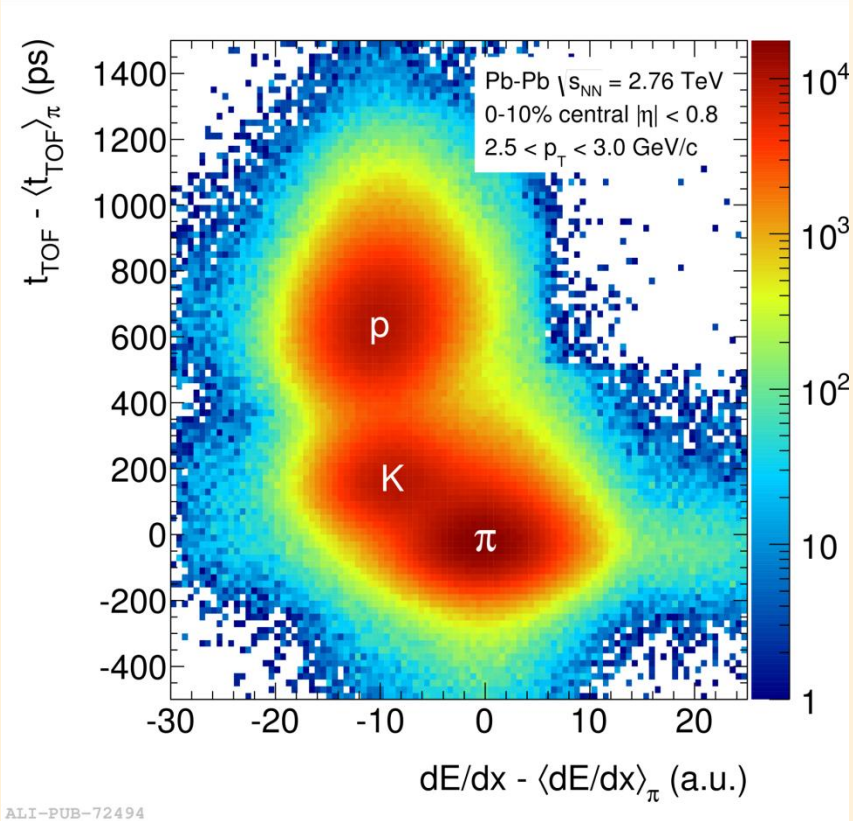
PID Separation Power



ALICE, Int. J. Mod. Phys. A29 (2014) 1430044

- Demonstration of the complementarity of the different detector sysyems. Horizontal bars represent 2σ separation

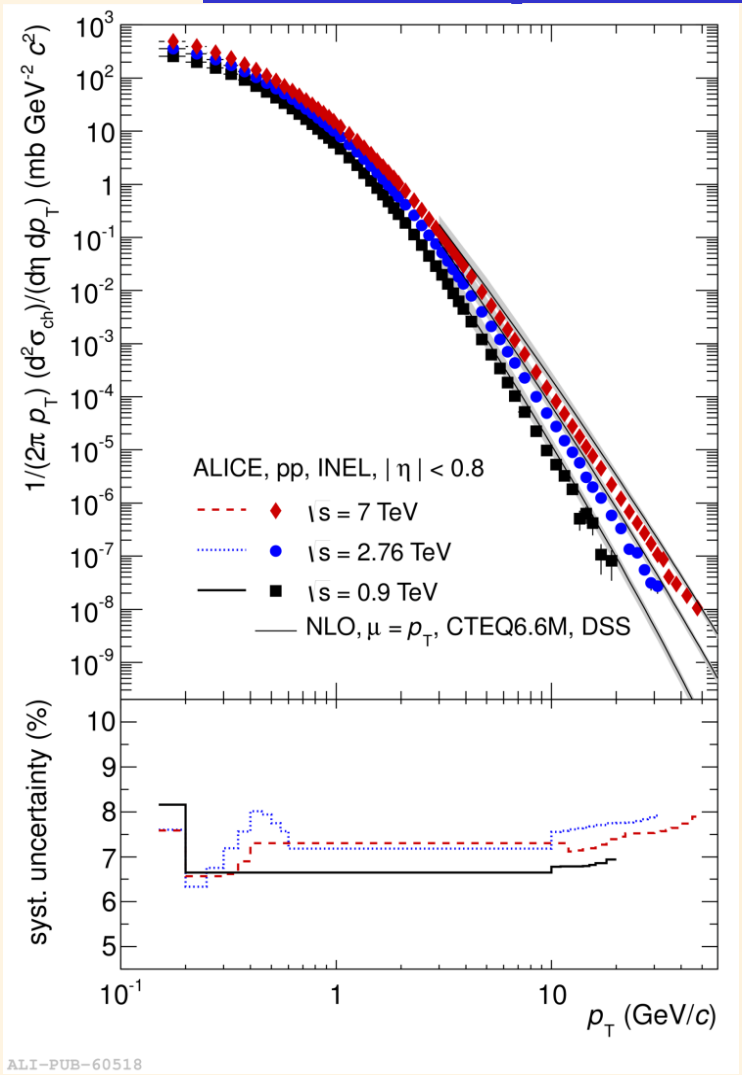
Combined PID



ALICE, Int. J. Mod. Phys. A29 (2014) 1430044

- Separation of hadron species further improved by combining information from multiple detectors

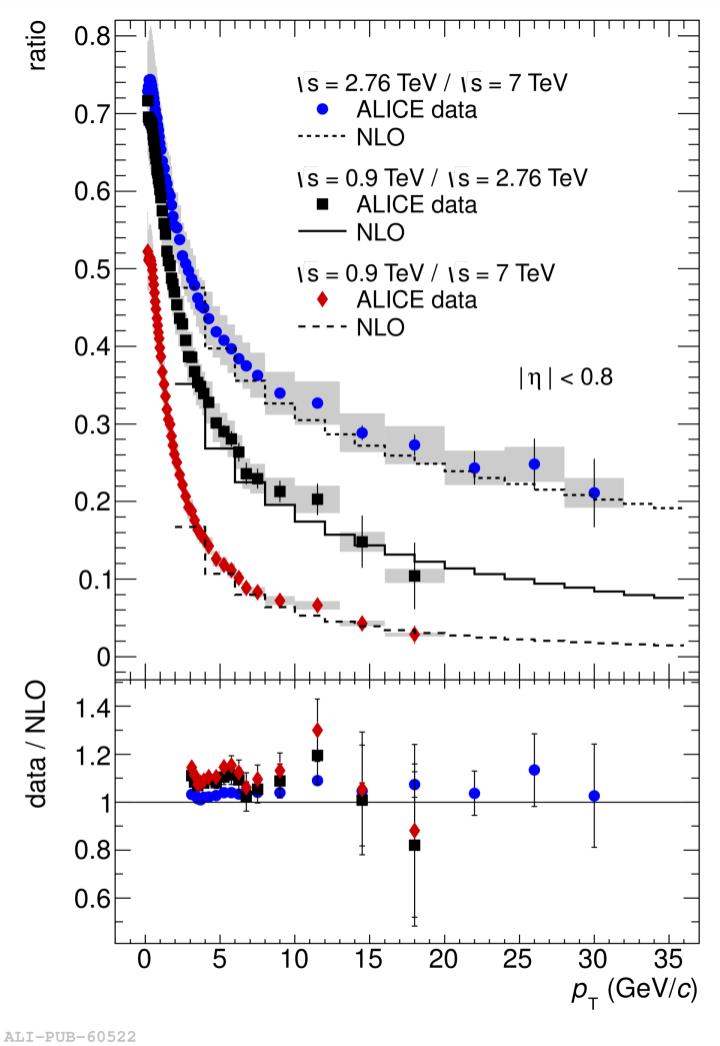
Particle Spectra in pp Collisions (I)



ALICE, Eur. Phys. J. C (2013) 73:2662

- Differential cross-section of charged particles in inelastic pp collisions as a function of p_T
- At high-p_T a clear evolution of the slope from √s = 0.9 to 7 TeV can be observed
- A NLO-pQCD calculation shows a similar evolution of the high-p_T dependence with √s

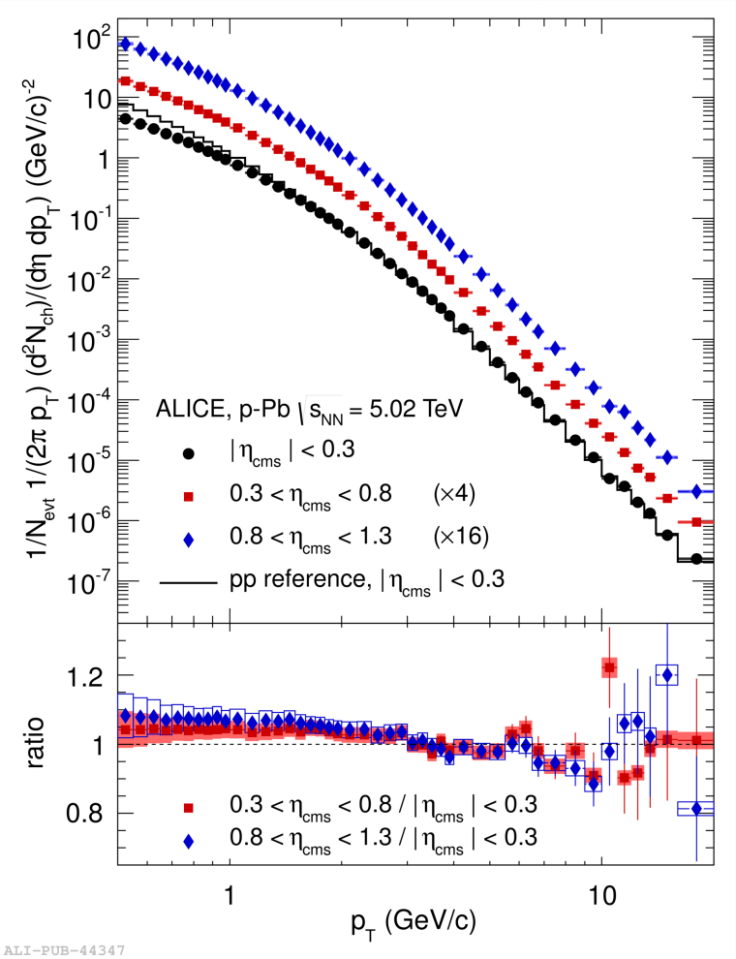
Particle Spectra in pp Collisions (II)



ALICE, Eur. Phys. J. C (2013) 73:2662

- In all three ratios good agreement between data and NLO-pQCD calculations is found
- The relative increase of cross section with √s is well described by NLO-pQCD

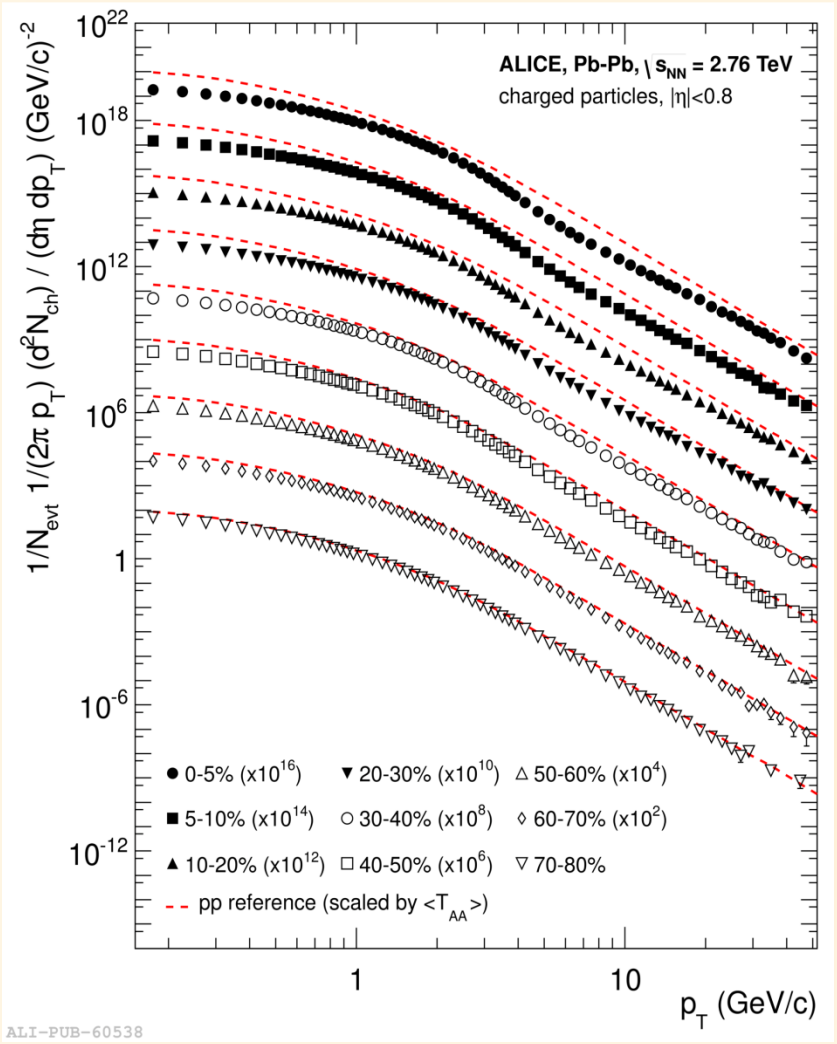
Particle Spectra in p-Pb Collisions



ALICE, Phys. Rev. Lett. 110, 082302 (2013)

- At high-p_T the distributions in p-Pb collisions are similar to those in pp collisions
- Quantative comparison to pp can be done with nuclear modification factors
- More on this later ...

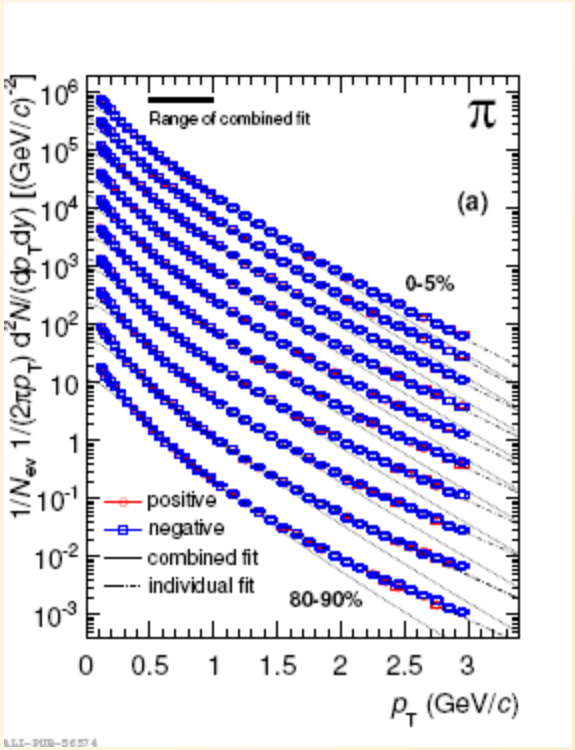
Particle Spectra in Pb-Pb Collisions

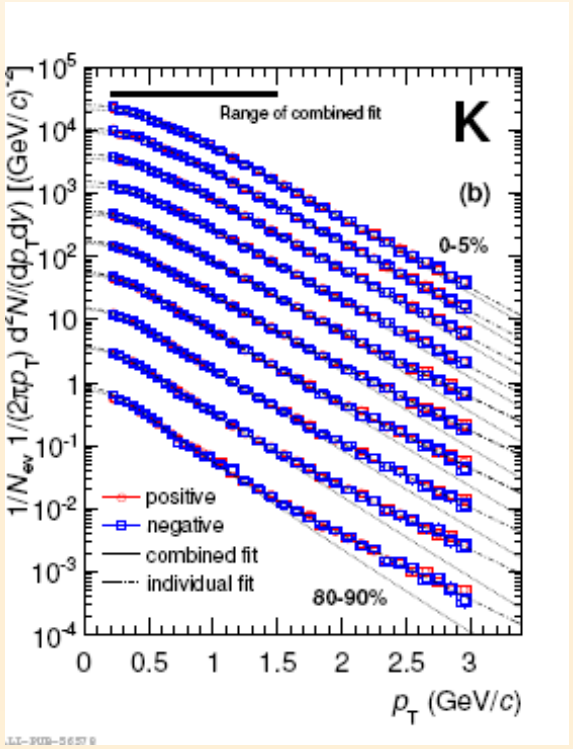


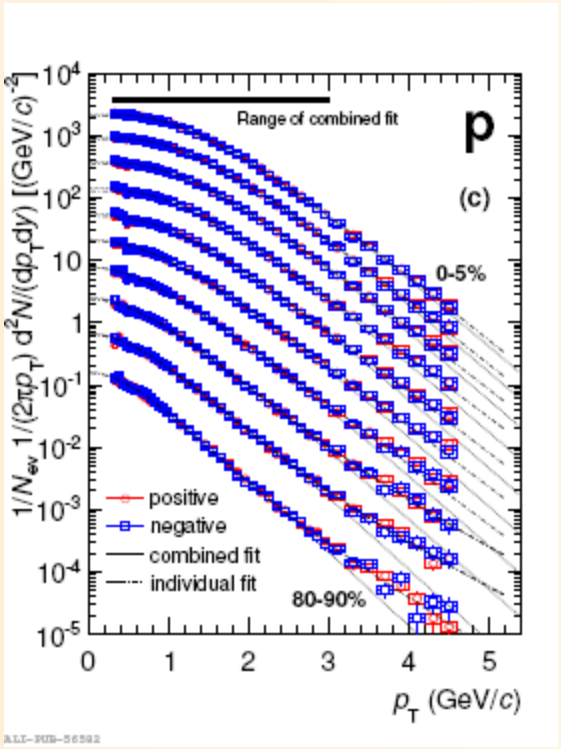
- Inclusive charged particles spectra in different centrality intervals
- At low p_T the spectra differ from the pp reference
- Depletion at high-p_T with increasing centrality → indication of strong suppression of high-p_T particles

ALICE, Phys. Lett. B720 (2013) 52-62

Identified Particle Spectra in Pb-Pb Collisions (I)



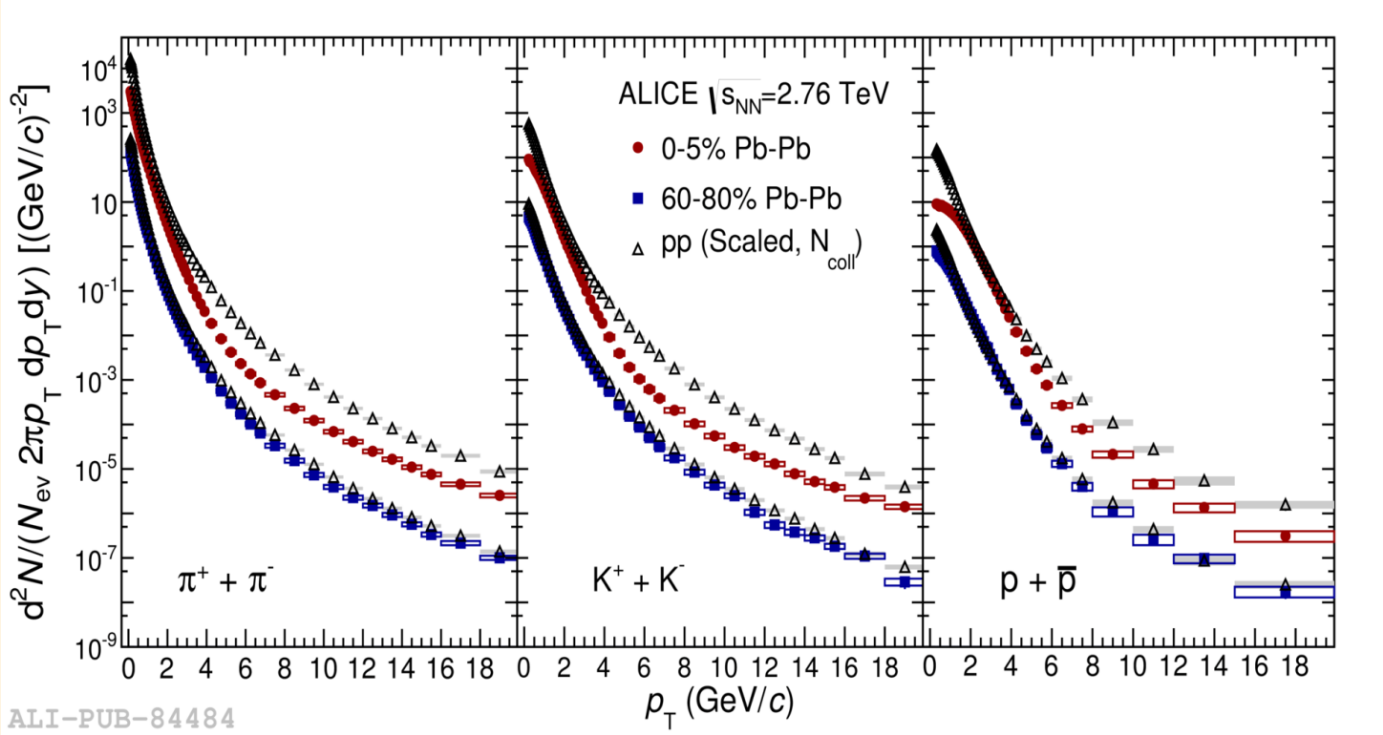




ALICE, Phys. Rev. C88, 044910 (2013)

- Distributions of positive and negative particles compatible within uncertainties at all p_T
- Spectra get harder with increasing centrality

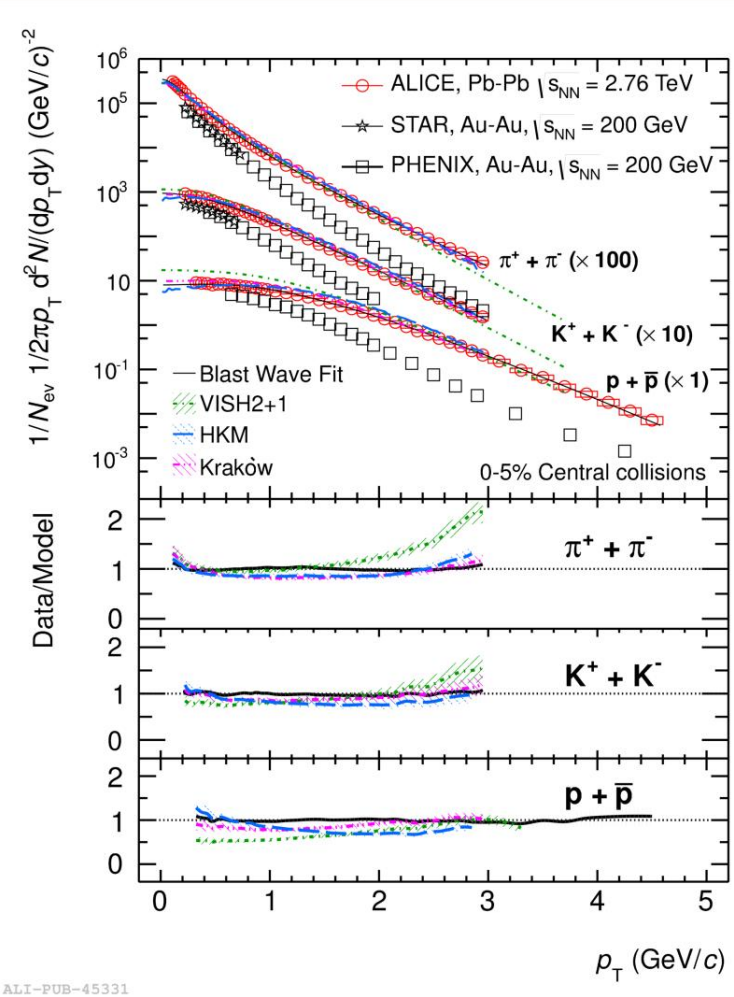
Identified Particle Spectra in Pb-Pb Collisions (II)



ALICE, Phys. Lett. B736 (2014) 196-207

- For peripheral collisions the shapes are similar to the ones in pp.
- For central collisions the spectra exhibit a reduction in the production of high-p_T particles with respect to an N_{coll} – scaled reference

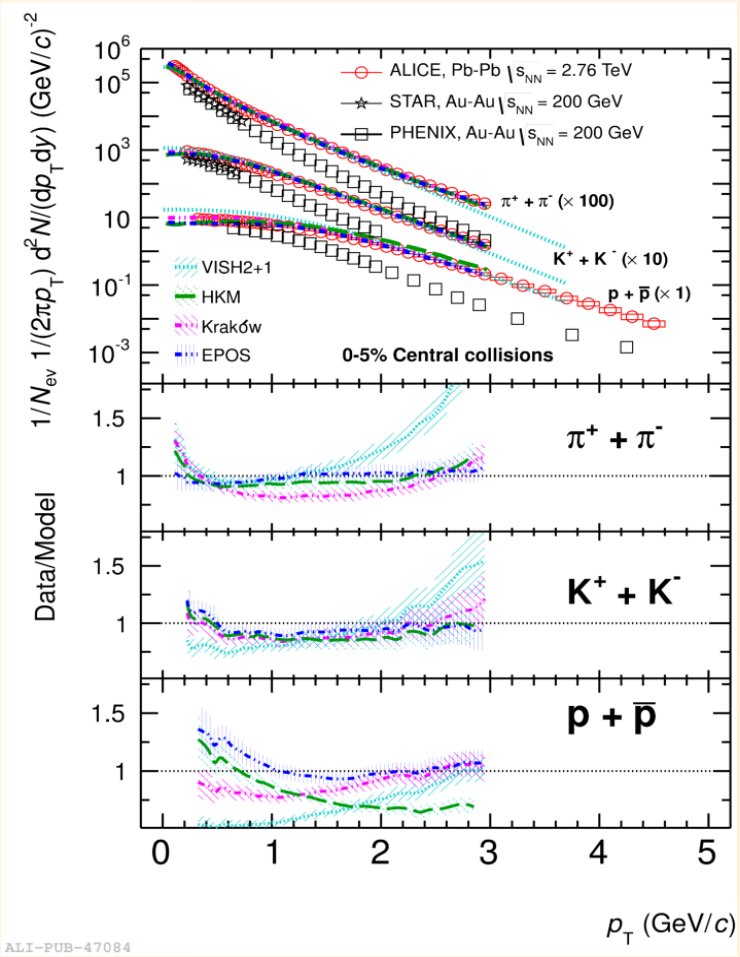
Identified Particle Spectra in Central Pb-Pb



- Data are well described by the blast wave function with $\langle\beta_T\rangle = 0.65 \pm 0.02$ and $T_{kin} = 95 \pm 10$ MeV
- Spectral shapes show a significant change from RHIC to LHC energies, having a harder distribution.
- Within hydrodynamic models, this indicates a stronger radial flow

ALICE, Phys. Lett. B720 (2013) 52-62
STAR, Phys.Rev. C79 , 034909 (2009)
PHENIX, Phys.Rev. C69, 034909 (2004)

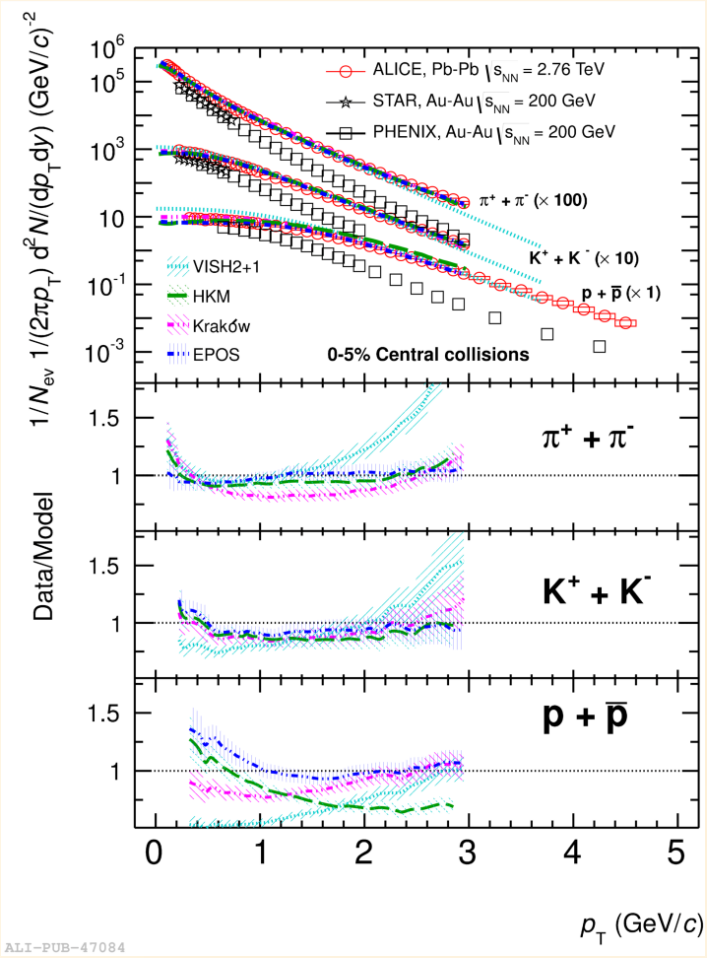
Identified Particle Spectra in Central Pb-Pb Comparison with Models (I)



- VISH2+1:
  Viscous hydrodynamic model,
  no description of hadronic phase
- HKM :
  Model similar to VISH2+1, includes a hadronic cascade model (UrQMD)
- Krakow :
  - Nonequilibrium corrections due to viscosity at the transition from the hydrodynamic description to particles.
  - Model seems successful in reproducing the data

ALICE, Phys. Rev. C 88, 044910 (2013)
STAR, Phys.Rev. C79 , 034909 (2009)
PHENIX, Phys.Rev. C69, 034909 (2004)

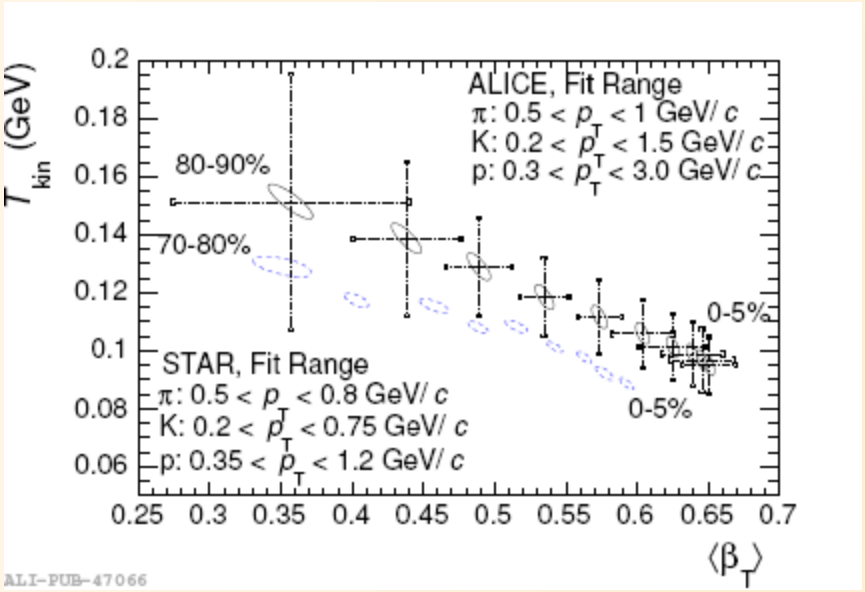
Identified Particle Spectra in Central Pb-Pb Comparison with Models (II)



- EPOS :
- Initial hard scattering creates "flux tubes" which either escape the medium or contribute to the bulk matter.
- Includes a hadronic cascade model (UrQMD).
- Shows a good agreement with the data

ALICE, Phys. Rev. C 88, 044910 (2013)
STAR, Phys.Rev. C79 , 034909 (2009)
PHENIX, Phys.Rev. C69, 034909 (2004)

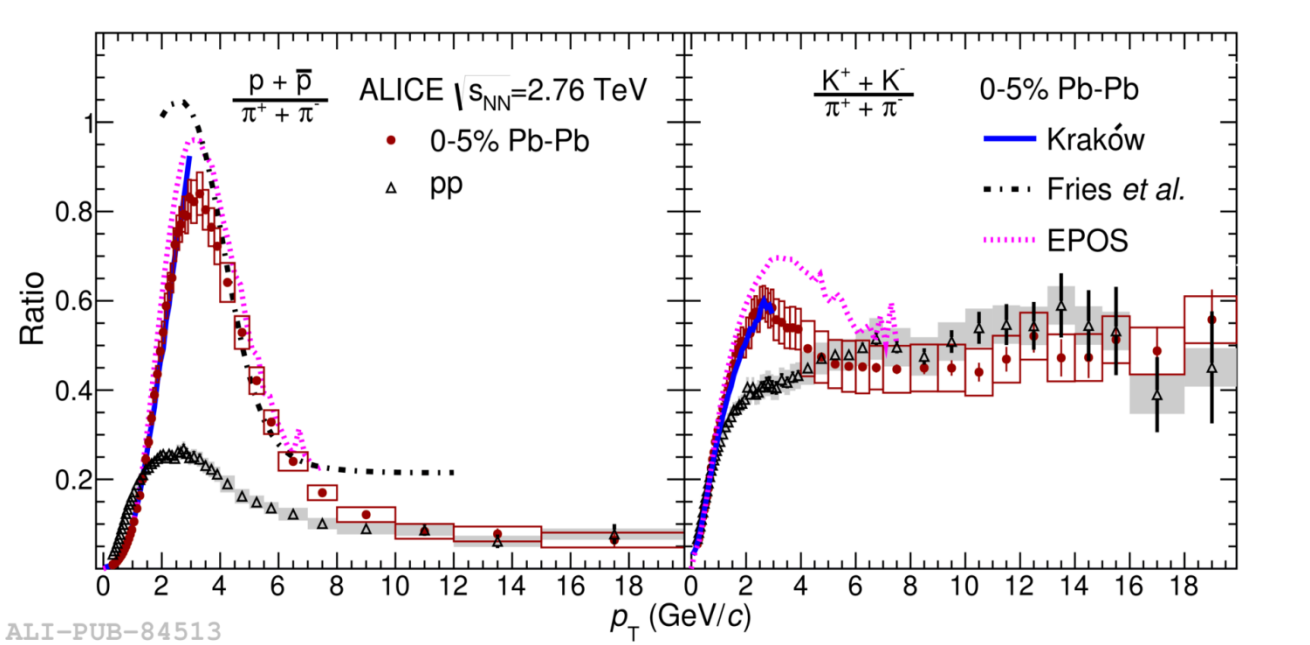
Blast-Wave fit parameters compared to RHIC



- $\langle\beta_T\rangle$ increases and T_{kin} decreases with centrality
- Possible indication of a more rapid expansion with increasing centrality
- In peripheral collisions consistent with the expectation of a shorter lived fireball with stronger radial gradients

ALICE, Phys. Rev. C88, 044910(2013)
STAR, Nucl. Phys. A757 , 102 (2005)

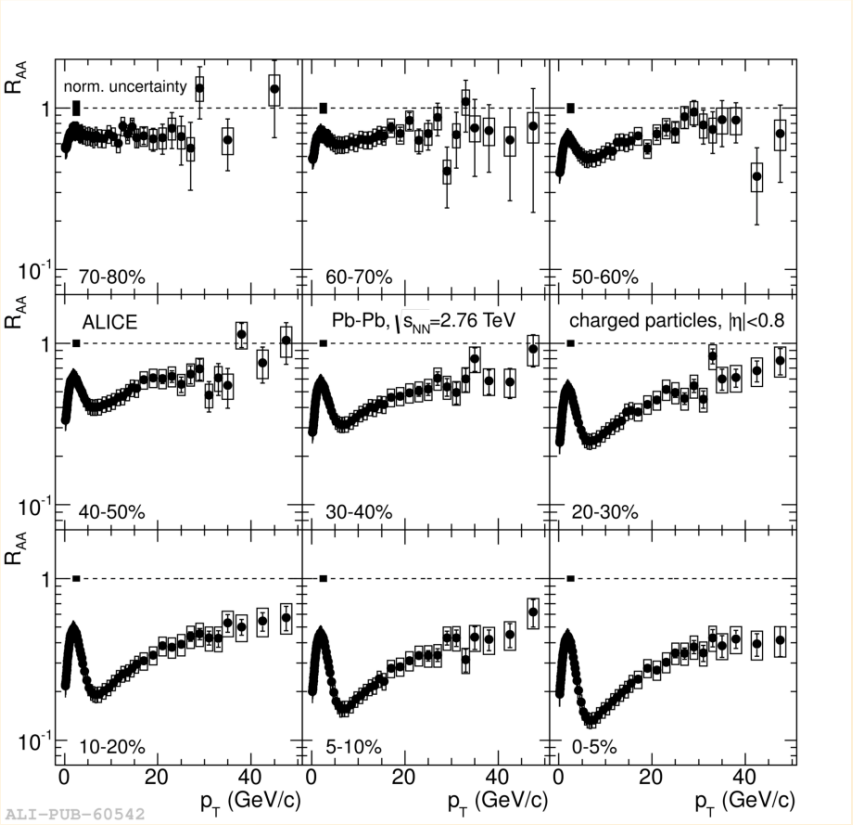
Particle Ratios in pp and Pb-Pb Collisions



ALICE, Phys. Lett. B736 (2014) 196-207

- At intermediate p_T an enhancement of the p/π is observed and the peak reaches ~ 0.83 in central Pb-Pb collisions
- Krakow : Describes the rise of the ratios
- EPOS : Qualitatively describes the data, but overestimates the peak
- Fries et al : Recombination of soft thermal radially flowing partons
  Describes the shape of the data

Nuclear Modification Factor of Inclusive Charged Particles

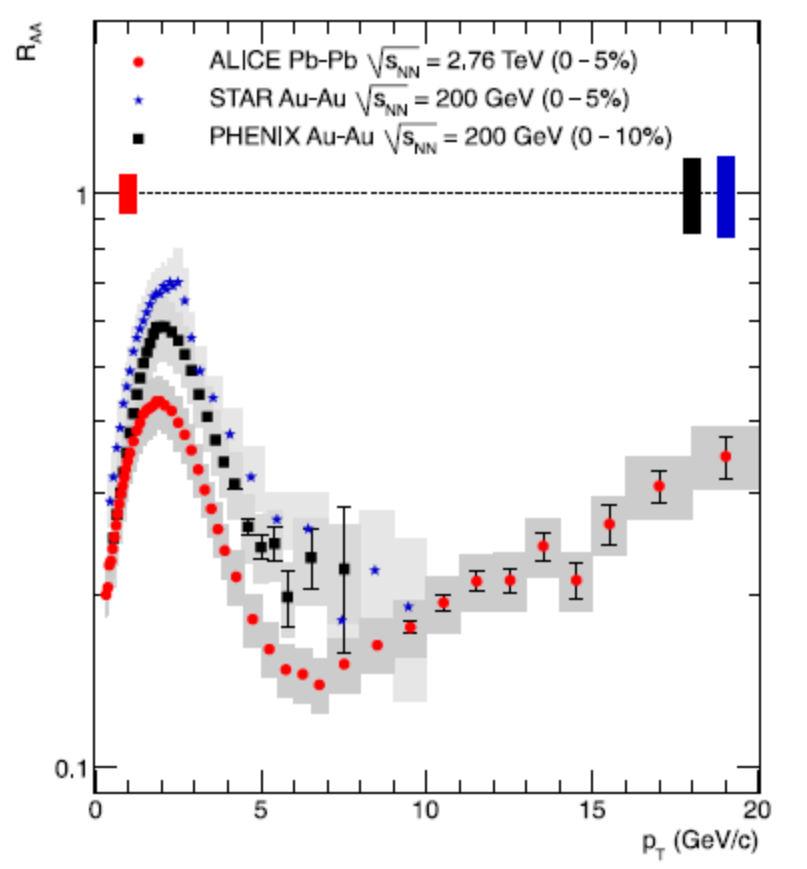


$$R_{AA} = \frac{d^2N_{AA}/dp_T dy}{\langle N_{coll}\rangle d^2N_{pp}/dp_T dy}$$

- Suppression for all centrality intervals
- Larger suppression for more central events
- Minimum around p_T = 6 GeV/c
- Suppression of high-p_T particles strongly depends on event centrality

ALICE, Phys. Lett. B720 (2013) 52-62

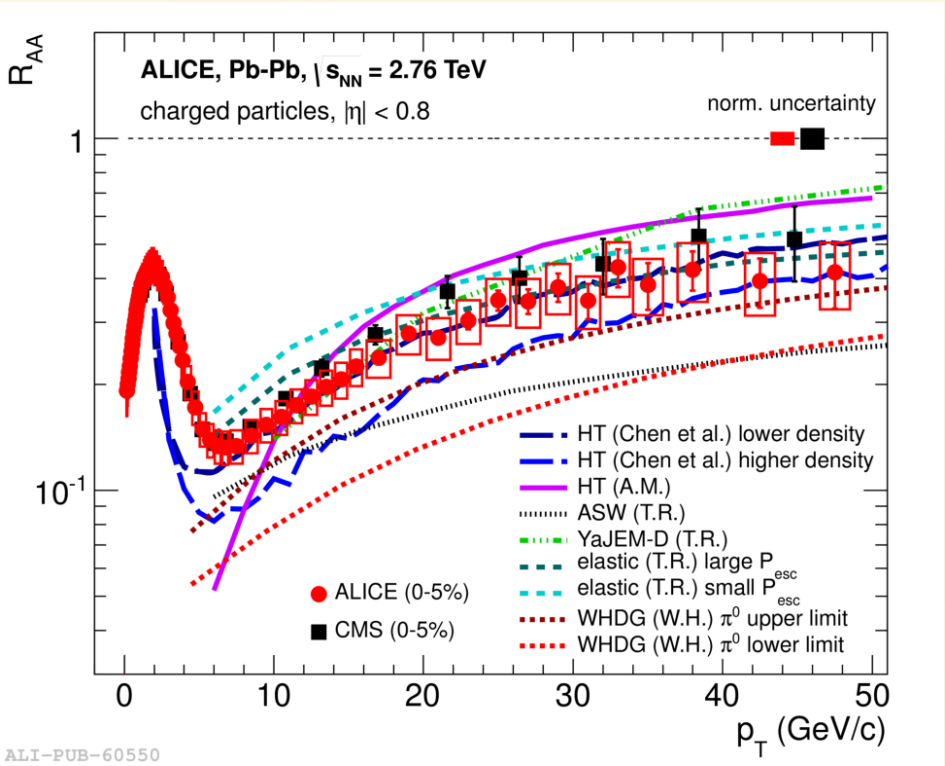
Nuclear Modification Factor in Central Pb-Pb Collisions Comparison with STAR and PHENIX



- Position and shape of the maximum at p_T ~ 2 GeV/c and subsequent decrease, similar at RHIC and LHC
- At p_T ~ 6 GeV/c , R_{AA} smaller than at RHIC. This suggests an enhanced energy loss at LHC and therefore a denser medium

ALICE, Phys. Lett. B696(2011) 30-39
STAR, Phys. Rev. Lett. 91 (2003) 172302
PHENIX, Phys.Rev. C 69 (2004) 034910

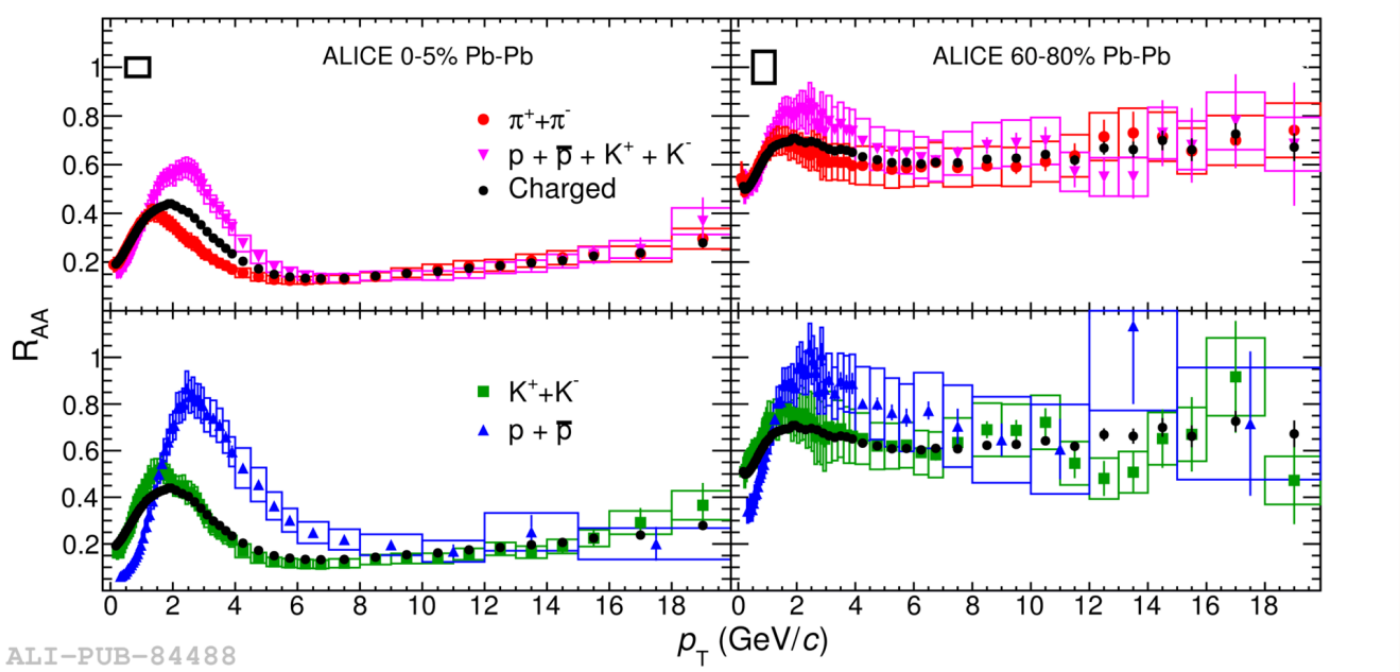
Nuclear Modification Factor of Inclusive Charged Particles Comparison with Models



- ALICE and CMS measurements agree within their statistical and systematic uncertainties
- Model calculations except WHDG use a hydrodynamical description of the medium.

ALICE, Phys. Lett. B720 (2013) 52-62
CMS, Eur. Phys. J. C72 (2012) 1945

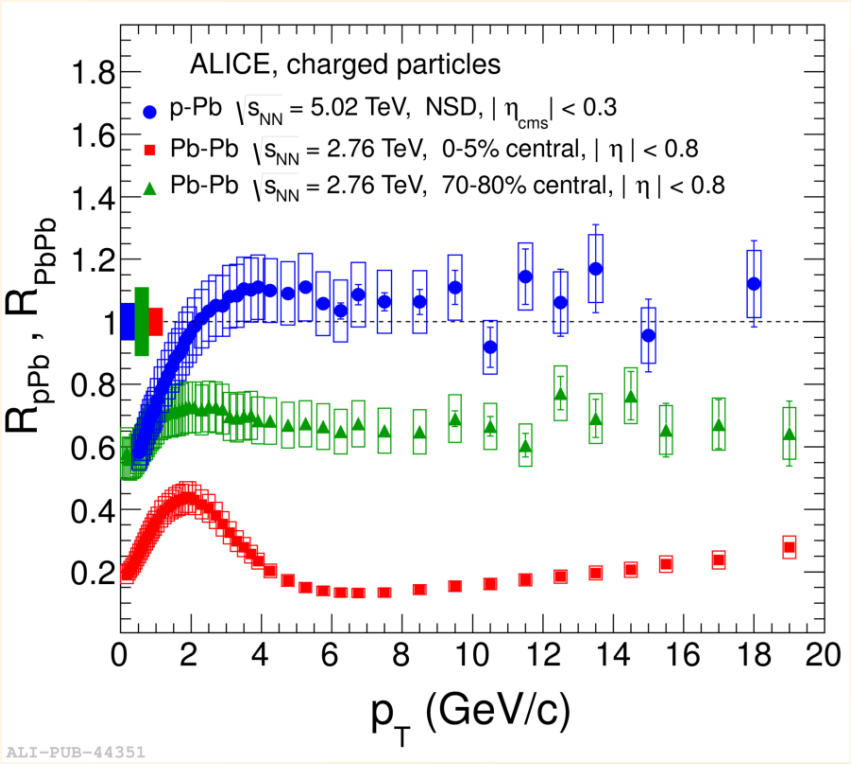
Nuclear Modification Factor of π, K,p



ALICE, Phys. Lett. B736 (2014) 196-207

- p_T > 10 GeV/c : strong suppression for all particles in central collisions
  much smaller suppression in peripheral collisions

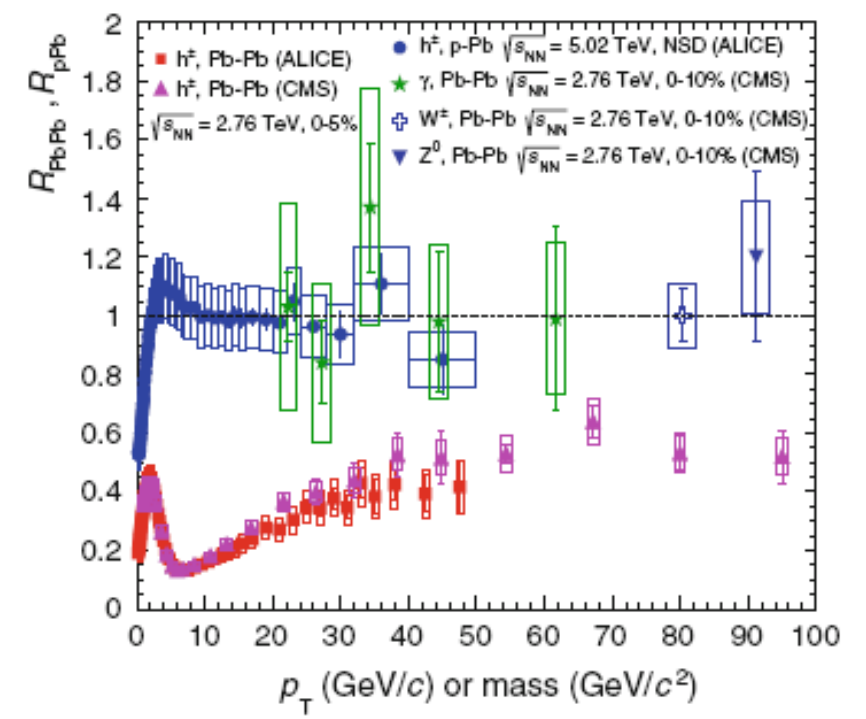
R_{pPb} Compared to R_{PbPb} (I)



ALICE, Phys. Rev. Lett.110 (2013) 082302

- R_{pPb} consistent with unity for p_T > 2 GeV/c
- Strong suppression observed in central Pb-Pb collisions not due to an initial state effect
- May be a fingerprint of the hot matter created in Pb-Pb collisions

R_{pPb} Compared to R_{PbPb} (II)



- R_{pPb} consistent with unity for p_T up to 50 GeV/c
- ALICE p-Pb results at high-p_T consistent with the observation of binary collision scaling in Pb-Pb of observables not affected by QCD hot matter

ALICE, Phys. Rev. Lett.110 (2013) 082302
ALICE, Phys.Lett. B720 (2013) 52
CMS, Eur.Phys.J. C72 (2012) 1945
CMS.Phys.Lett. B 710 (2012) 256
CMS, Phys. Rev.Lett. 106 (2011) 212301
CMS, Phys.Lett.B 715 (2012) 66

Conclusions (I)

- Spectra of inclusive and identified charged particles measured by ALICE in pp, p-Pb and Pb-Pb collisions have been presented
- Central Pb-Pb collisions spectral shapes indicate a strong increase of the radial flow velocity with $\sqrt{s_{NN}}$, which in hydrodynamic models is expected as a consequence of the increasing particle density
- Strong high-p_T production suppression is measured in central Pb-Pb collisions

Conclusions (II)

- No suppression is observed at high-p_T in minimum bias p-Pb collisions
- Strong suppression of high-p_T hadrons observed in central Pb-Pb collisions is not due to an initial state effect but may instead be a signature of the hot matter created in Pb-Pb collisions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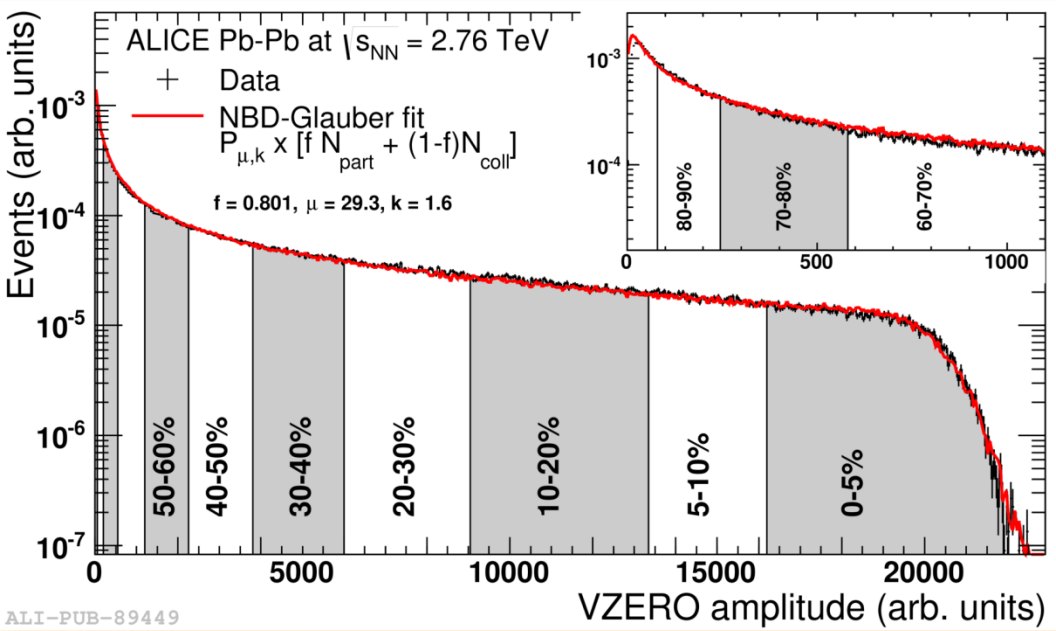
ALICE

Thank you!

Centrality Selection in Pb-Pb Collisions



ALICE, Phys. Rev. C88, 044909 (2013)

- Distribution of the V0 amplitude
  Curve: Glauber model fit to the measurement

Particle Spectra in Central Pb-Pb collisions
Hydrodynamical Models

VISH2+1:

C. Shen, U. Heinz, P. Huovinen, and H. Song, Phys. Rev. C **84**, 044903 (2011).

HKM:

I. Karpenko, Y. Sinyukov, and K. Werner, Phys. Rev. C **87**, 024914 (2013).

Y. Karpenko and Y. Sinyukov, J. Phys. G **38**, 124059 (2011).

Krakow:

P. Bozek, Phys. Rev. C **85**, 034901 (2012).

P. Bozek, Acta Phys. Polon. B **43**, 689 (2012).

EPOS:

K. Werner, I. Karpenko, M. Bleicher, T. Pierog, and S. Porteboeuf-Houssais, Phys. Rev. C **85**, 064907 (2012).