Identified light-flavour particle production measured with ALICE at the LHC as a probe of soft QCD and hot hadronic matter

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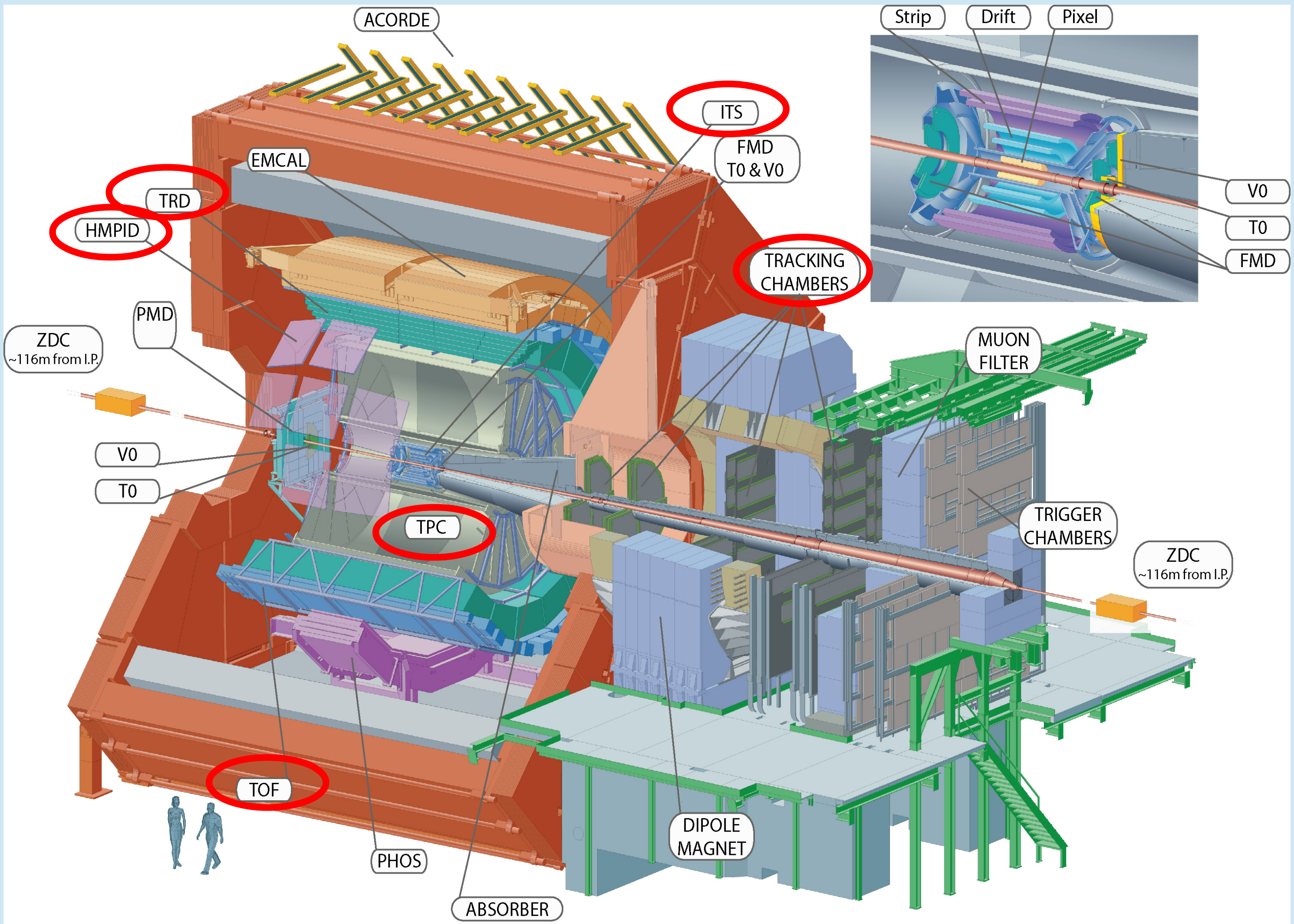
HOT QUARKS 2014, 21-27 September, Las Negras, Spain

Outline

- The ALICE experiment
- Particle production mechanisms: π, K, p spectra in pp and Pb-Pb collisions
- Pb-Pb bulk particle production: low p_T spectra
- p/π, K/π and Φ/π ratios as a function of p_T
- π, K, p: R_{AA}
- Particle ratios in pp collisions
- Particle ratios vs colliding systems
- Thermal models
- Conclusions

The ALICE experiment



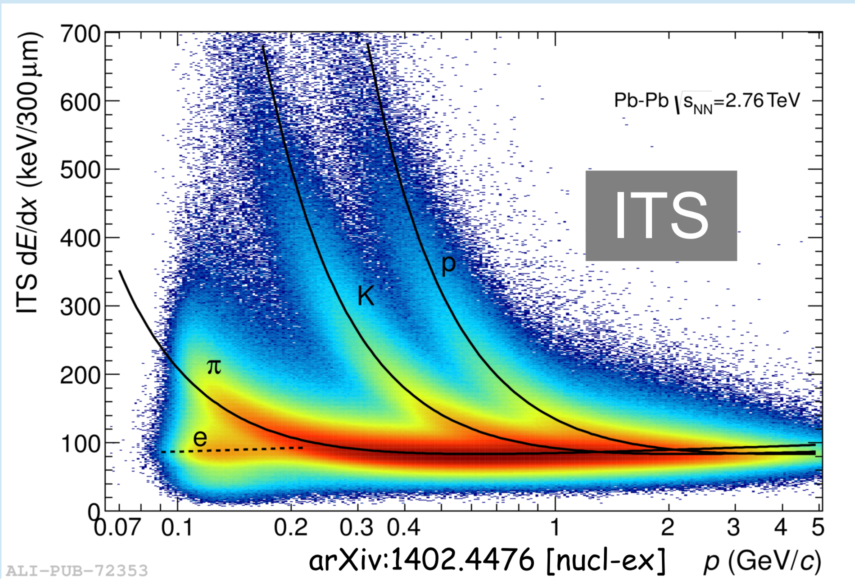
- Low material budget
- Optimized for good PID performance

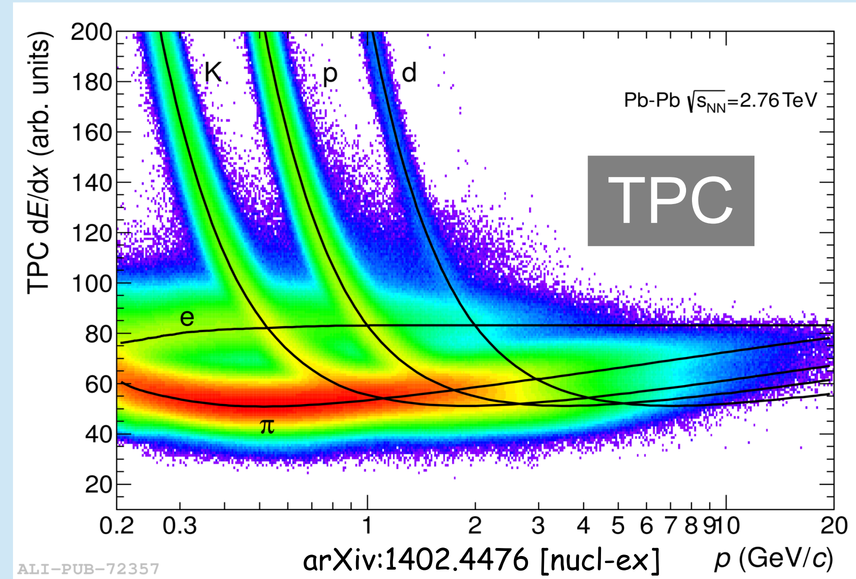
ALICE has several detectors in the central barrel ($|\eta|<0.9$) dedicated to PID

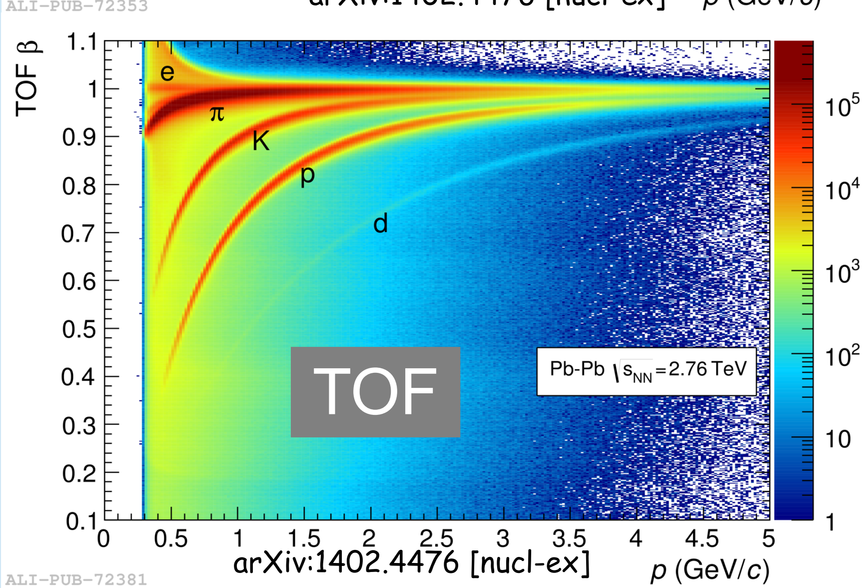
- covering complementary p_t ranges
- using different PID techniques:
  - ITS: dE/dx
  - TPC: dE/dx
  - TRD: Transition Radiation
  - TOF: Time-of-Flight
  - HMPID: Cherenkov Radiation

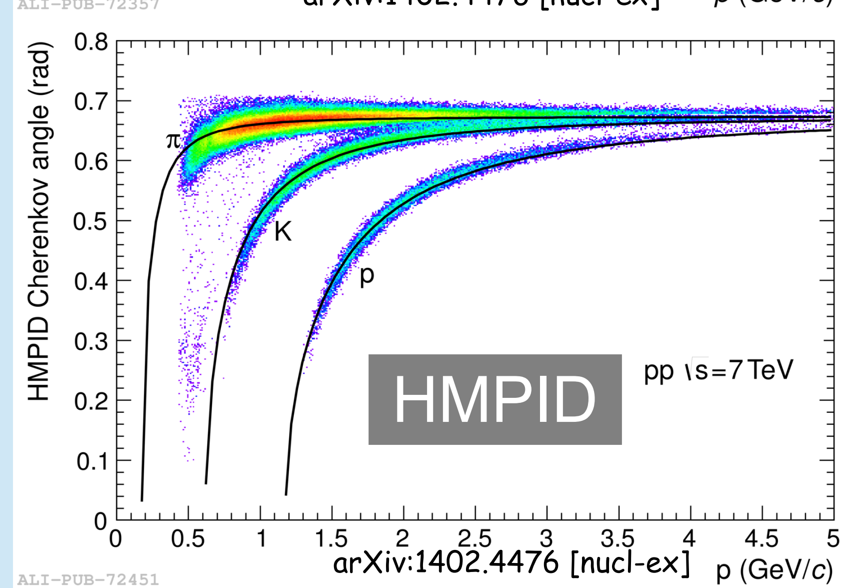
ALICE has a forward muon spectrometer ($-4.0<\eta<-2.5$) for muon ID

Main PID detectors performance

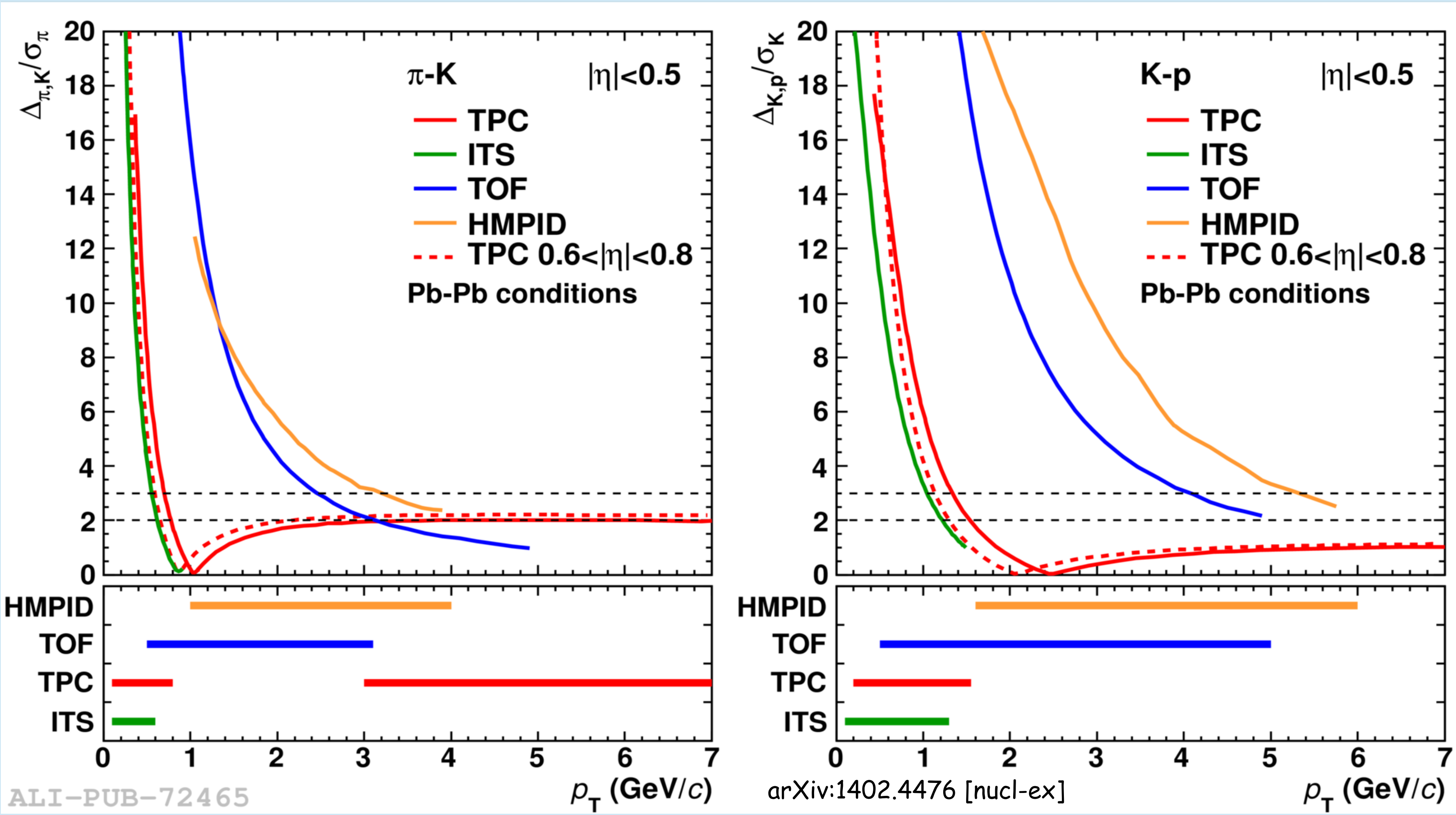








ALICE PID performance



Data taking

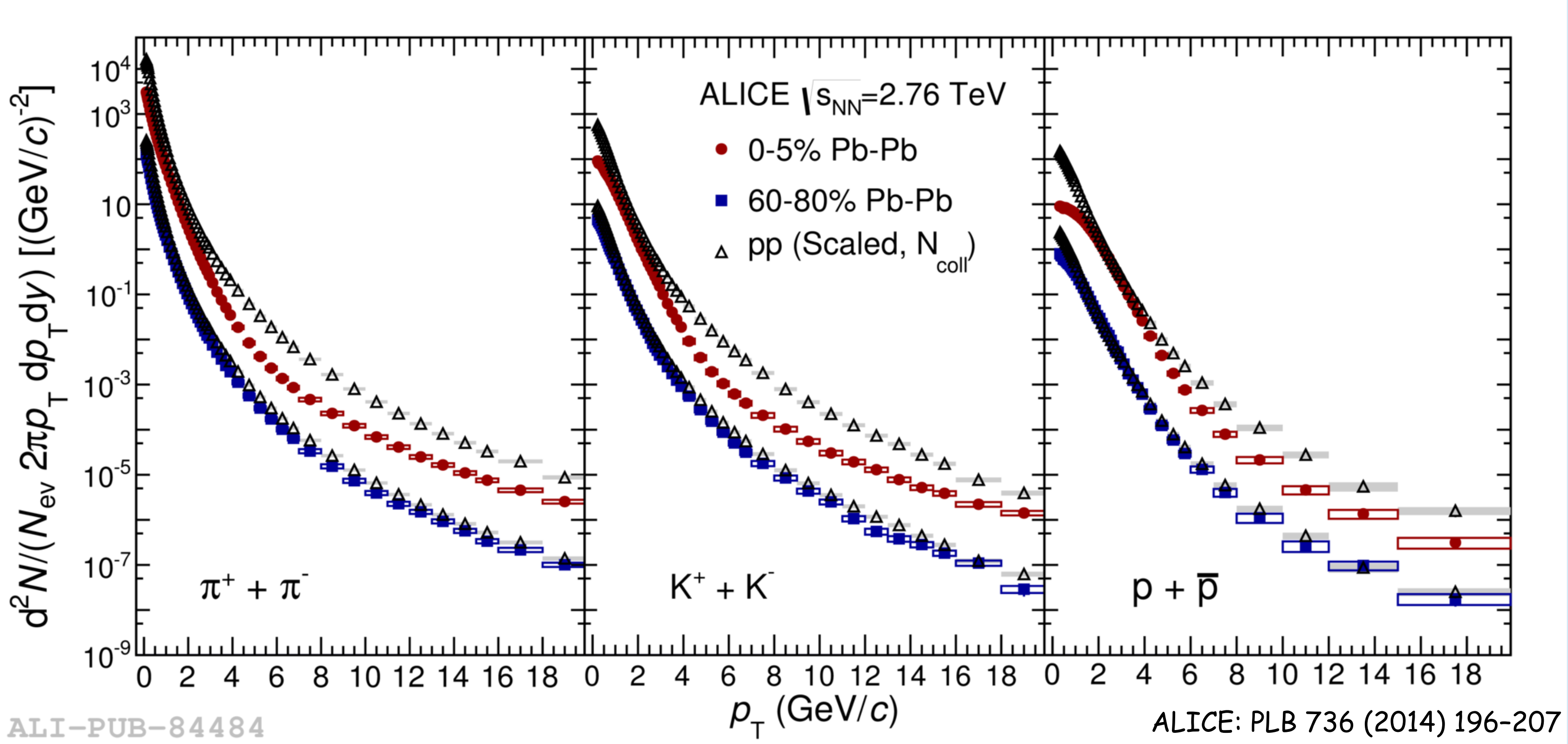
- **pp collisions** @ $\sqrt{s}$ = 0.9-2.76-7.0 TeV:
  - test QCD inspired models and tune fragmentation functions
  - tune MC models
  - provide reference for p-Pb and Pb-Pb data
  - complement other LHC experiment results
- **Pb-Pb collisions** @ $\sqrt{s_{NN}}$ = 2.76 TeV:
  - study the Quark-Gluon-Plasma (QGP)

In this talk

- **p-Pb collisions** @ $\sqrt{s_{NN}}$ = 5.02 TeV:
  - discriminate between initial (cold nuclear matter) and final state (QGP) effects
  - provide reference for Pb-Pb data
  - study properties of QCD at low parton fractional momentum x and high gluon densities

See J. Anielski's talk

Particle production mechanisms: π, K, p spectra

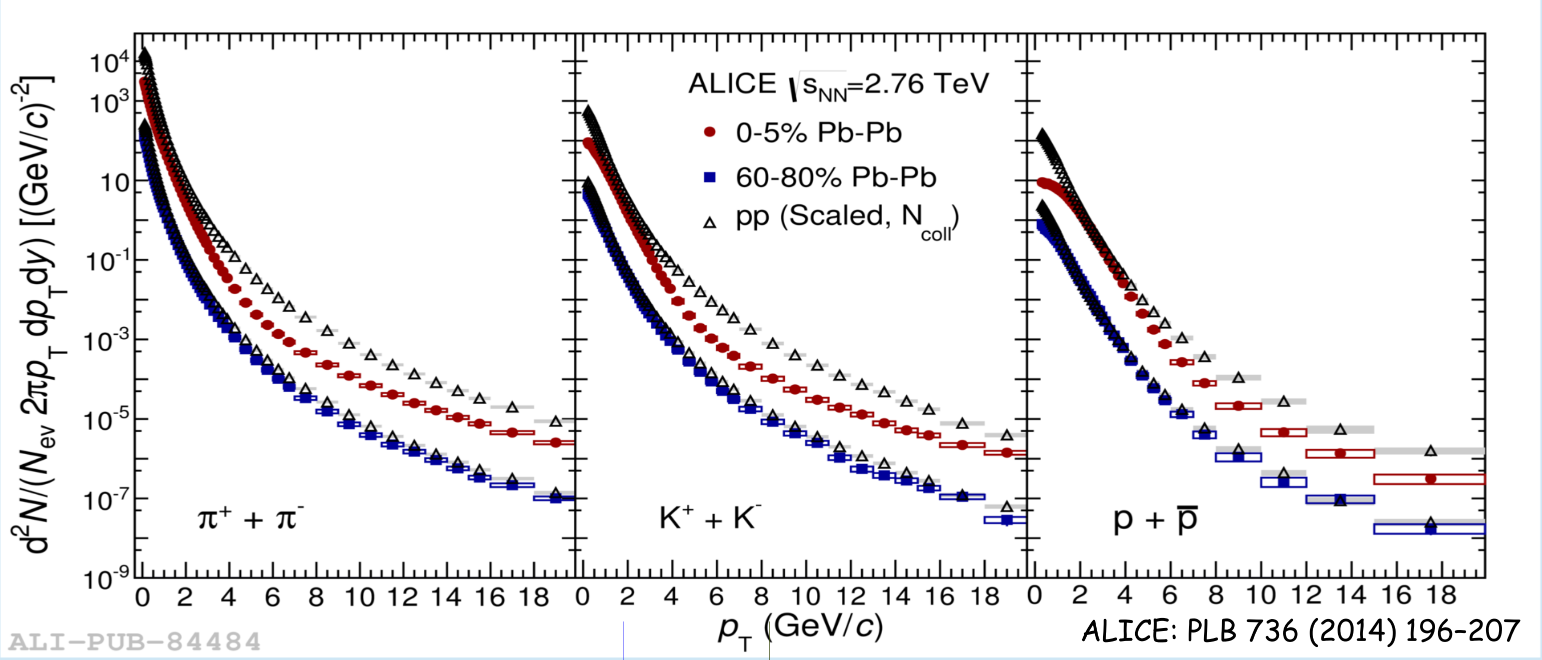


ALICE: PLB 736 (2014) 196-207

- Spectra in pp scaled by N_{coll} and peripheral Pb-Pb collisions are similar
- Spectra in central Pb-Pb collisions are lower at high p_T and flatter at p_T < 2 GeV/c than the ones in pp collisions

How does the medium affect the particle production mechanisms?

π, K, p spectra: the role played by the medium



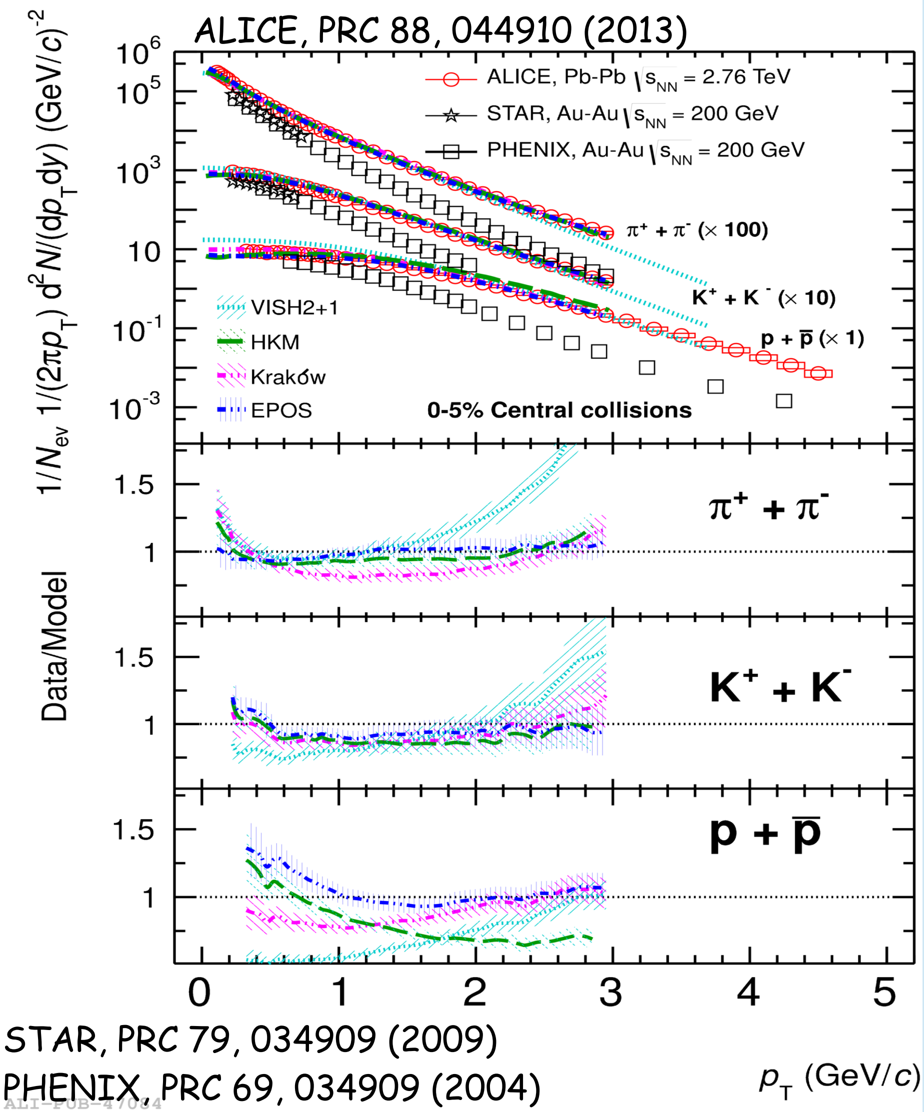
Low p_T (p_T < 2 GeV/c):
- Soft production
- Non-perturbative physics
- Bulk properties

Intermediate p_T (2<p_T < 8 GeV/c):
- baryon/meson enhancement -> new hadronization mechanisms? parton recombination?

High p_T (p_T > 8 GeV/c):
- Hard production
- Perturbative physics
- Jet quenching

Pb-Pb bulk production: low p_T spectra

ALICE, PRC 88, 044910 (2013)



STAR, PRC 79, 034909 (2009)

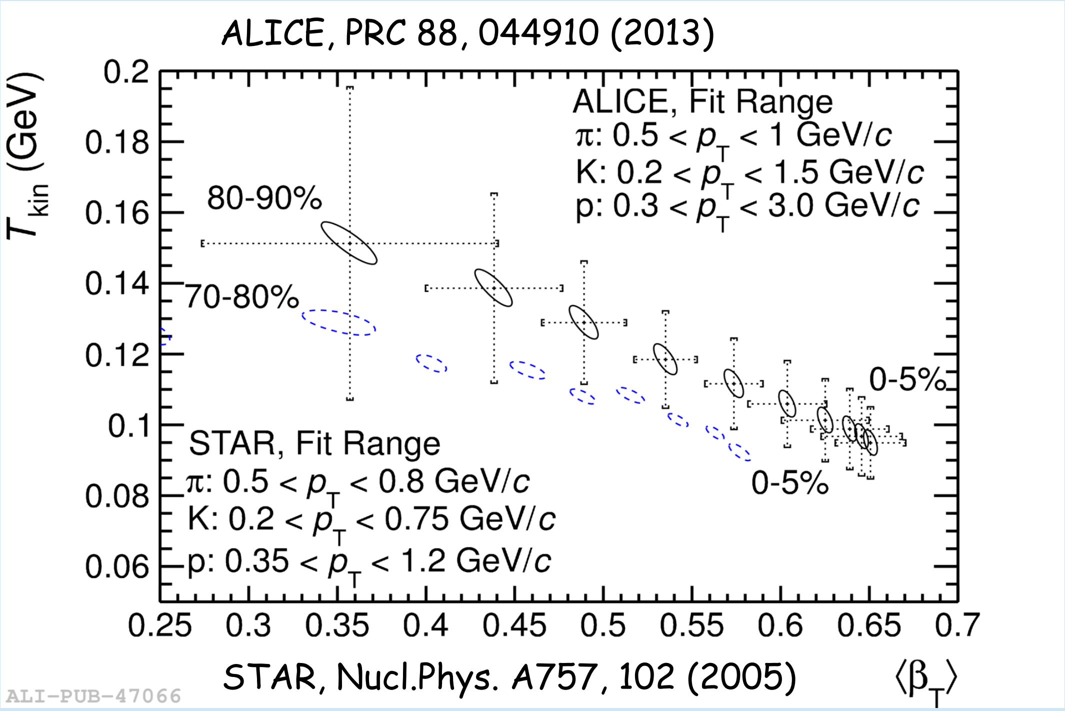
PHENIX, PRC 69, 034909 (2004)

- Harder spectra compared to RHIC -> stronger radial flow (in hydrodynamic models is a consequence of increasing particle density)
- Combined blast wave fit* :
  - $\langle\beta_T\rangle = 0.65 \pm 0.02$ -> 10% higher than RHIC consistent with observation of increasing of mean p_T at LHC compared to RHIC for π, K, p, φ, K*
  - $T_{kin} = 95 \pm 10$MeV -> comparable with RHIC (sensitive to pion fit range due to contribution from resonance decays)

*Schnedermann et al., PRC 48, 2462 (1993)

Pb-Pb bulk production: low p_T spectra

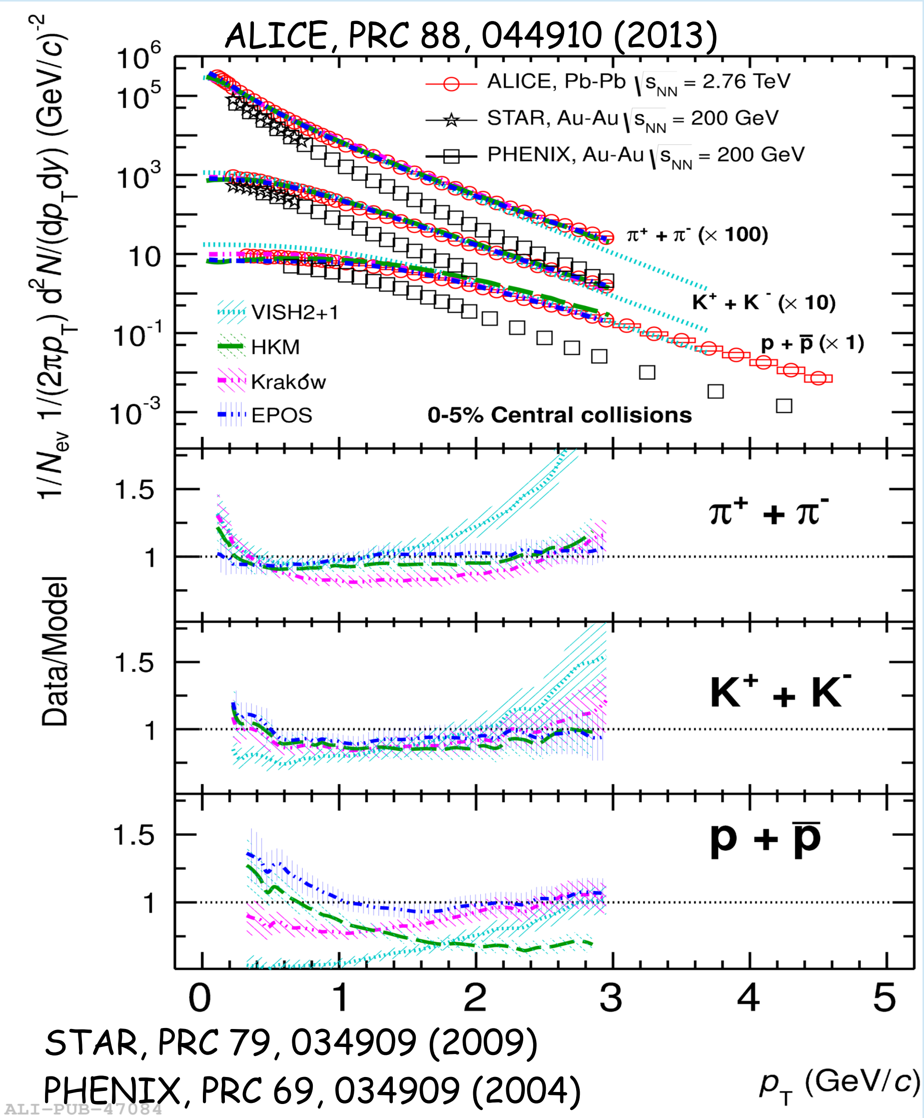
Blast-wave fit parameters for collisions with different centrality at ALICE and RHIC



- ⟨β_T⟩ increases with centrality
- Tkin decreases with centrality

Possible indication of more rapid expansion with increasing centrality
In peripheral collisions it is consistent with the expectation of a shorter lived fireball with stronger radial density gradients

Pb-Pb bulk production: comparison with models

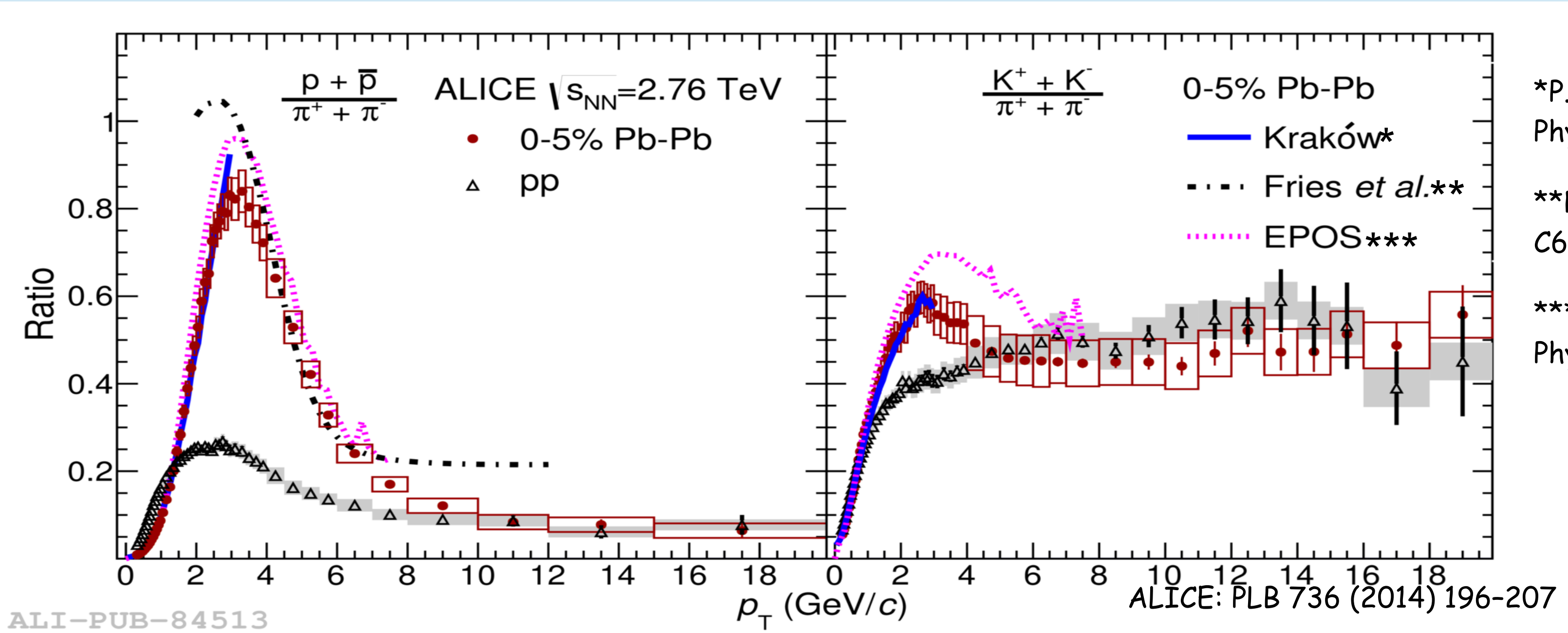


Hydro models:

- VISH2+1: viscous hydrodynamics, no description of hadronic phase
  (Shen et al., PRC 84, 044903 (2011))
- HKM: hydro+UrQMD, hadronic phase builds additional radial flow, mostly due to elastic interactions, and affects particle ratios due to inelastic interactions
  (Karpenko et al., PRC 87, 024914 (2013))
- Krakow: non equilibrium corrections due to bulk viscosity at the transition from hydro description to particles which change the effective Tch
  (Bozek, PRC 85, 064915 (2012))
- EPOS: hydro + UrQMD + jets
  (Werner et al., PRC 85, 064907 (2012))

good description for central collisions

p/π and K/π



*P. Bozek et al. Phys.Rev.C85(2012)064915

**R.J. Fries et al., Phys.Rev. C68(2003)044902

***K.Werner, et al., Phys.Rev.C85(2012)064907

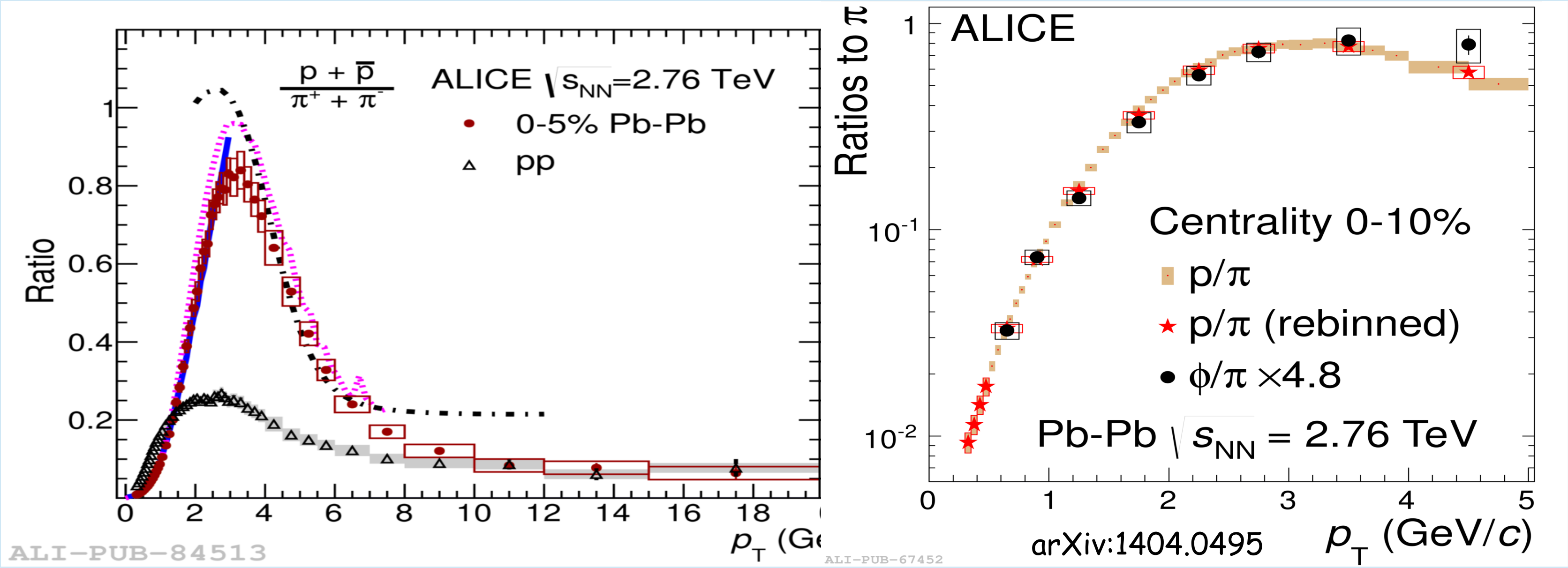
Central Pb-Pb collisions: peak at $p_T \approx 3$ GeV/c higher than at RHIC

hydrodynamic (dependent on hadron mass) or recombination (baryon enhancement)?

- Recombination (Fries et al.) of soft thermal radially flowing partons: describes shape of data
- Hydro model (Kraków): describes the rise of the ratios
- Hydro model + jet quenching (EPOS): qualitatively describes the data but overestimate the peak

BUT ...

p/π and Φ/π

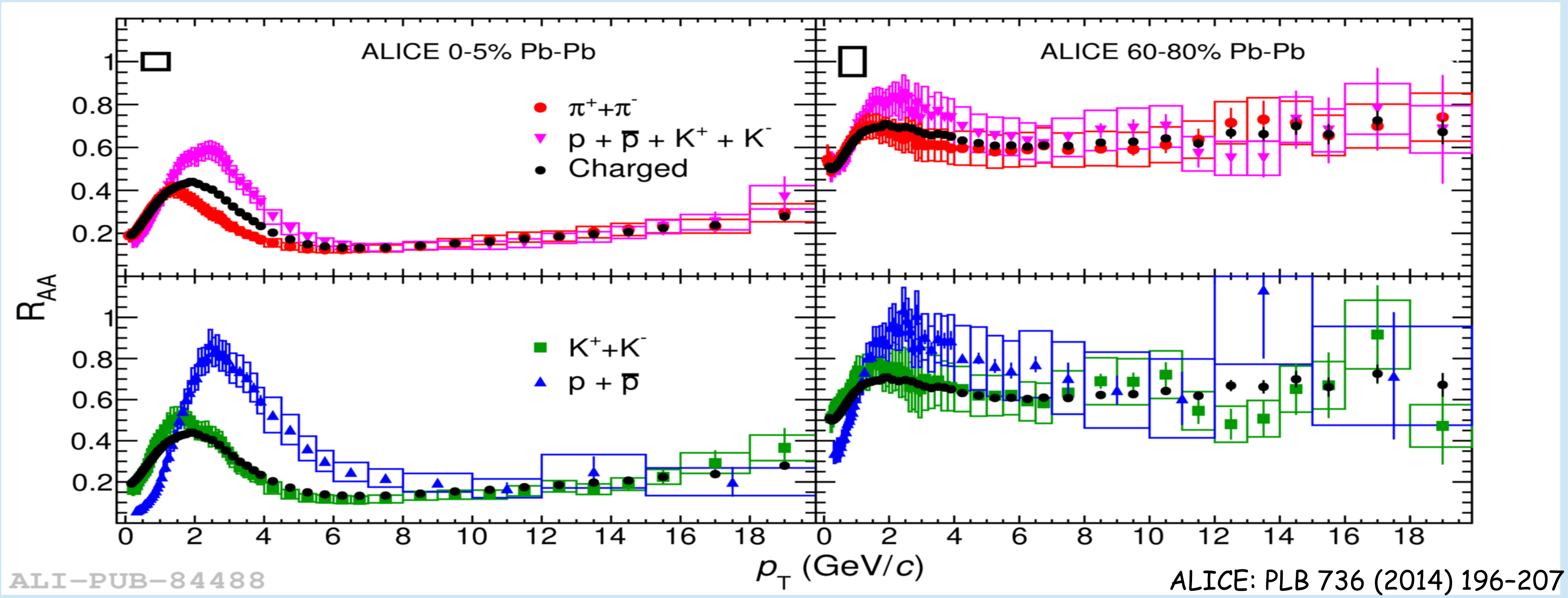


- Shapes of φ/π and p/π are consistent
  -> peak is the result of radial flow (hadron masses) rather than anomalous hadronization processes

- p_T> 10 GeV/c: agreement between pp and Pb-Pb -> parton fragmentation (jet chemistry) not modified by the medium

*P. Bozek et al. Phys.Rev.C85(2012)064915 **R.J. Fries et al., Phys.Rev. C68(2003)044902 ***K.Werner, et al., Phys.Rev.C85(2012)064907

π, K, p: R_{AA}

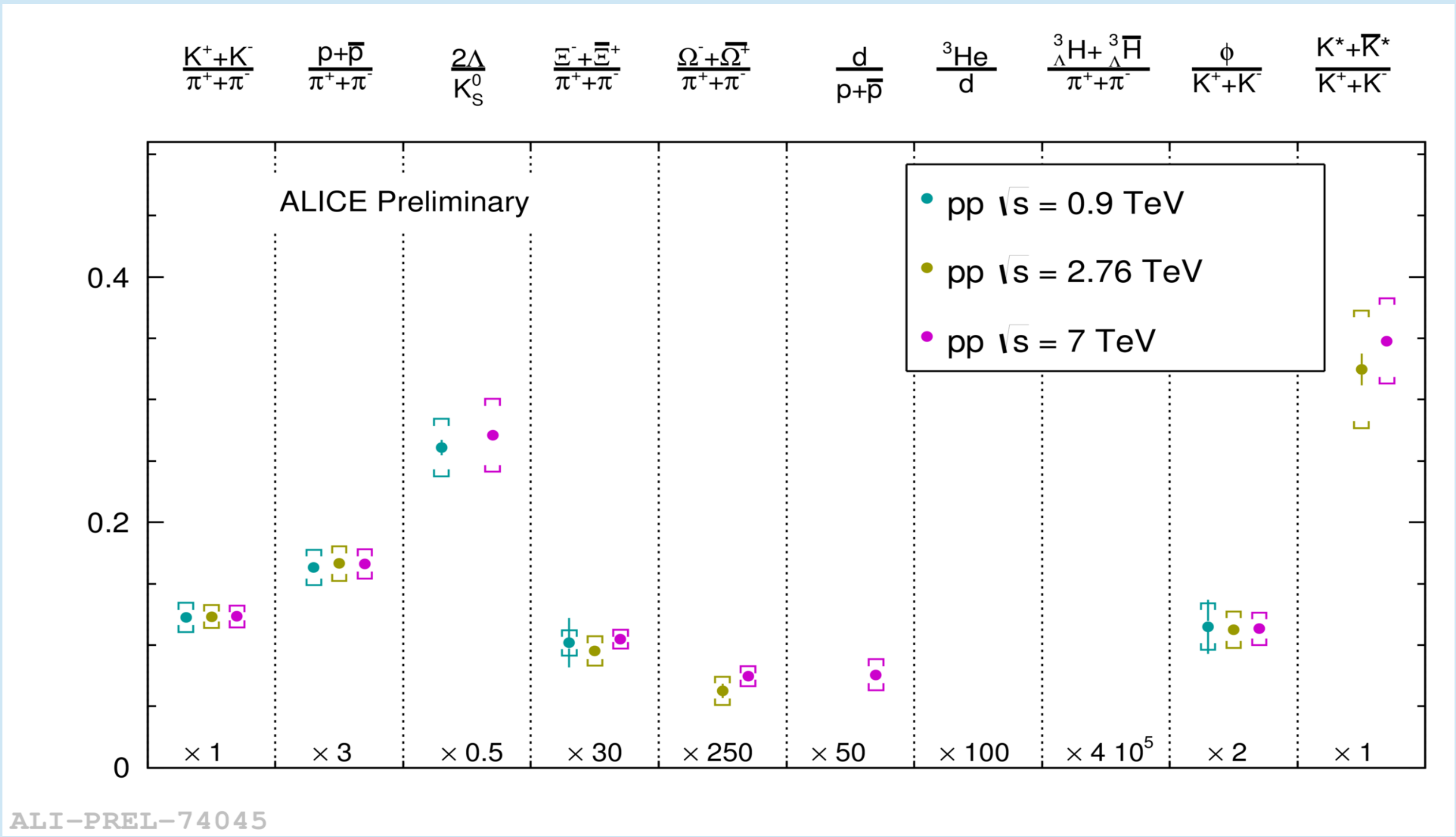


ALICE: PLB 736 (2014) 196-207

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

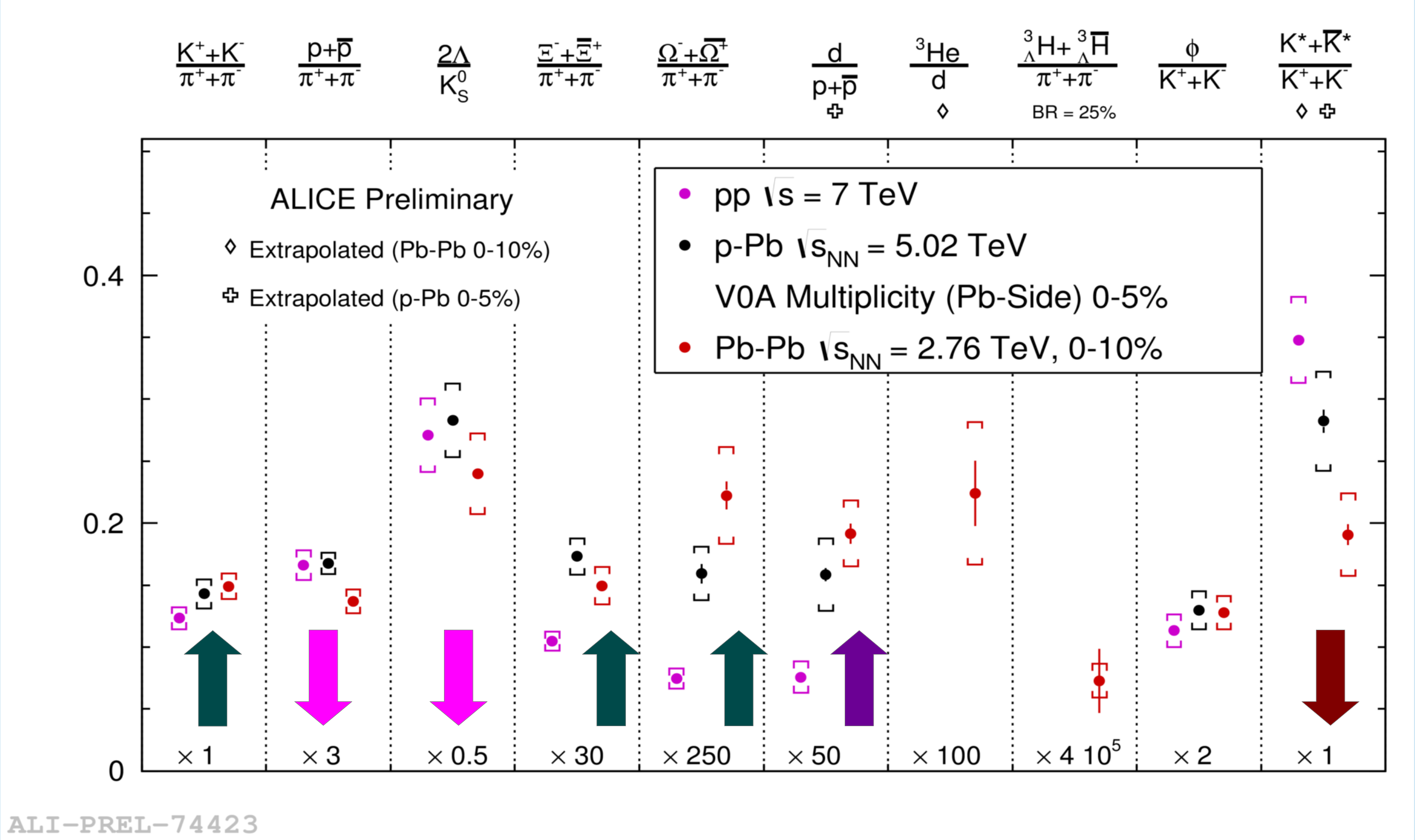
- p_T < 8 GeV/c: p less suppressed than π and K
- p_T > 10 GeV/c same suppression for π, K, p -> particle composition and ratios at high p_T are the same in medium and in vacuum (disfavours models where large energy loss is associated with mass ordering or large fragmentation differences between baryons and mesons)

pp particle ratios vs √s



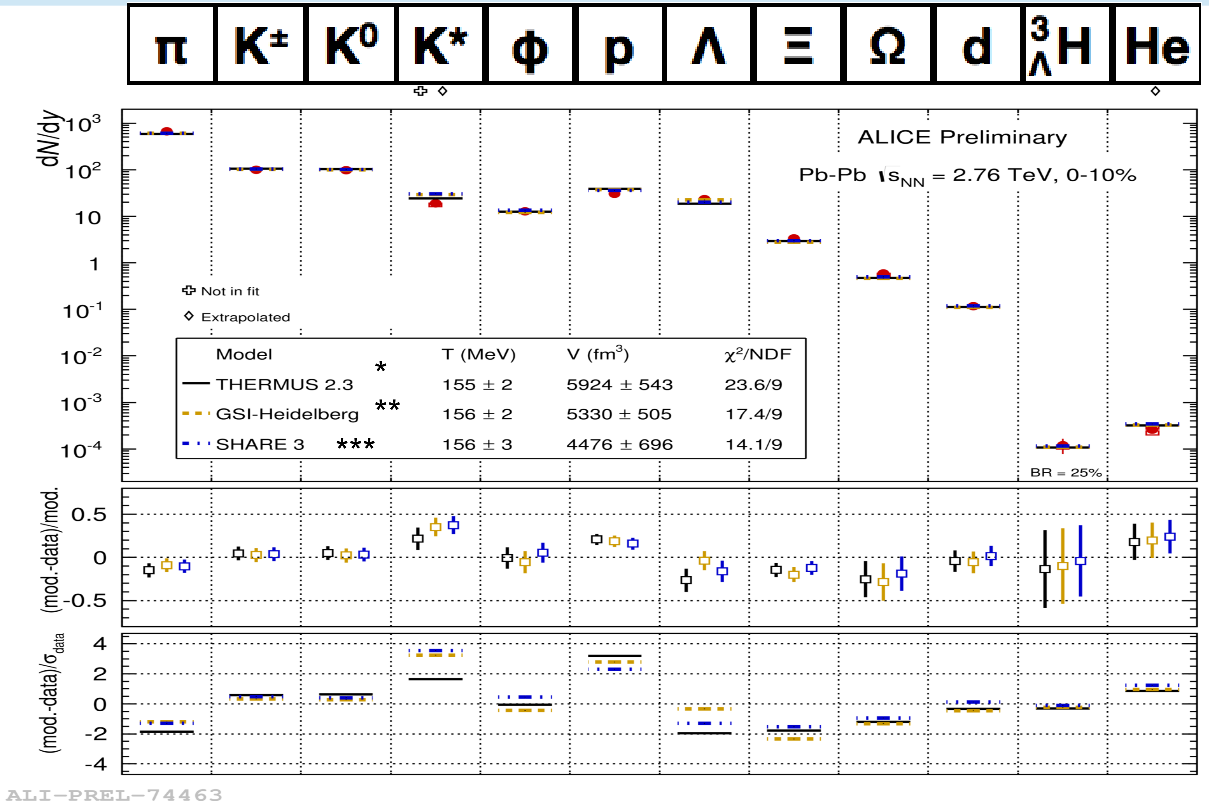
p_T integrated particle ratios measured in pp collisions show no significant energy dependence at the LHC

Particle ratios vs colliding systems: pp, p-Pb, Pb-Pb



- Ratios evolve as a function of the system size: pp, p-Pb, Pb-Pb collisions
  - ***Strangeness* and *deuteron* enhancement**
  - ***K** suppression**
  - ***(Hint of) baryon suppression?***

Thermal models



dN/dy interpreted in terms of thermal models -> properties of the system at the chemical freeze-out:

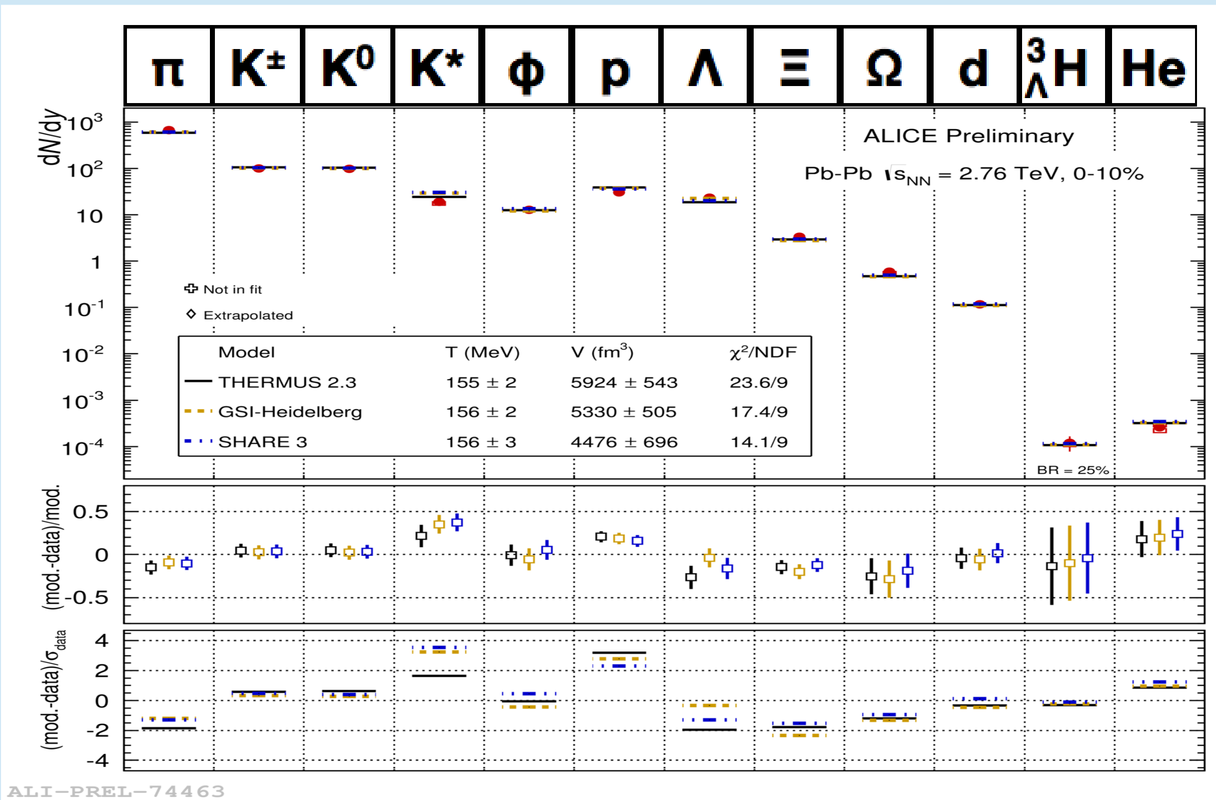
- chemical freeze-out temperature (T_{ch})
- baryochemical potential (μ_B=0 at LHC)
- Volume (V)
- Non equilibrium parameters ($\gamma_{s,q}$ in SHARE model)

3 equilibrium thermal models: THERMUS 2.3*, GSI** and SHARE (γ_s=γ_q=1)***

- Different implementations of equilibrium thermal models yield the same T_{ch} (≈ 156 MeV)
- It is lower than T_{ch} from lower energy extrapolation (≈ 164 MeV)

*S. Wheaton *et al.*, Comp. Phys. Commun. 180 (2009) 84; **A. Andronic et al., PLB 673 (2009) 142; ***M. Petran *et al.*, arXiv:1310.5108v2

Thermal models vs data



- Anomaly of the p with respect to equilibrium model expectations
- Agreement restored if p (and K*) is excluded from the fits (X^2/ndf lower from 2 to 1)

Deviation from thermal ratio:

- final state interactions in hadronic phase
- non equilibrium thermal model ($\gamma_{q,s}$>1)
- flavour dependent freeze-out temperature

Summary

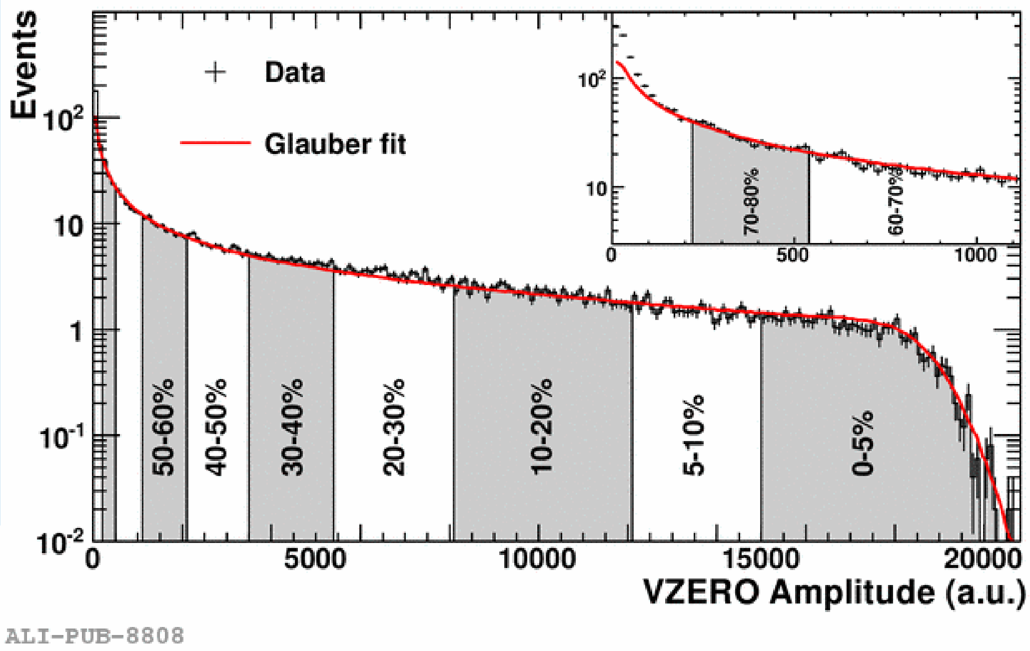
Light flavour measurements in pp and Pb-Pb collisions allow the study of how the presence of the medium produced in Pb-Pb collisions affects the spectral shapes in different momentum regions

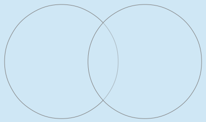
- low p_T spectra in Pb-Pb (bulk particle production): test and tune hydro models + info on radial flow and T_{kin}
- p/π, K/π, Φ/π p_T distributions: "baryon anomaly" at intermediate p_T due to radial flow or anomalous hadronization processes?
- R_{AA} at high p_T universal for hadron species: parton fragmentation not modified by the medium
- particle ratios in Pb-Pb: strangeness and deuteron enhancement + K* and baryon suppression moving from pp to p-Pb to Pb-Pb collisions
- particle yields in Pb-Pb: thermal model fits are quite good but possible anomalous suppression of proton yields in central Pb-Pb collisions

Backup

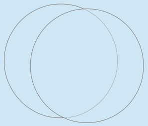
Centrality selection

VZERO amplitude. Curve: Glauber model fit to the measurement. Vertical lines separate the centrality classes used in the analysis, which in total correspond to the most central 80% of hadronic collisions.





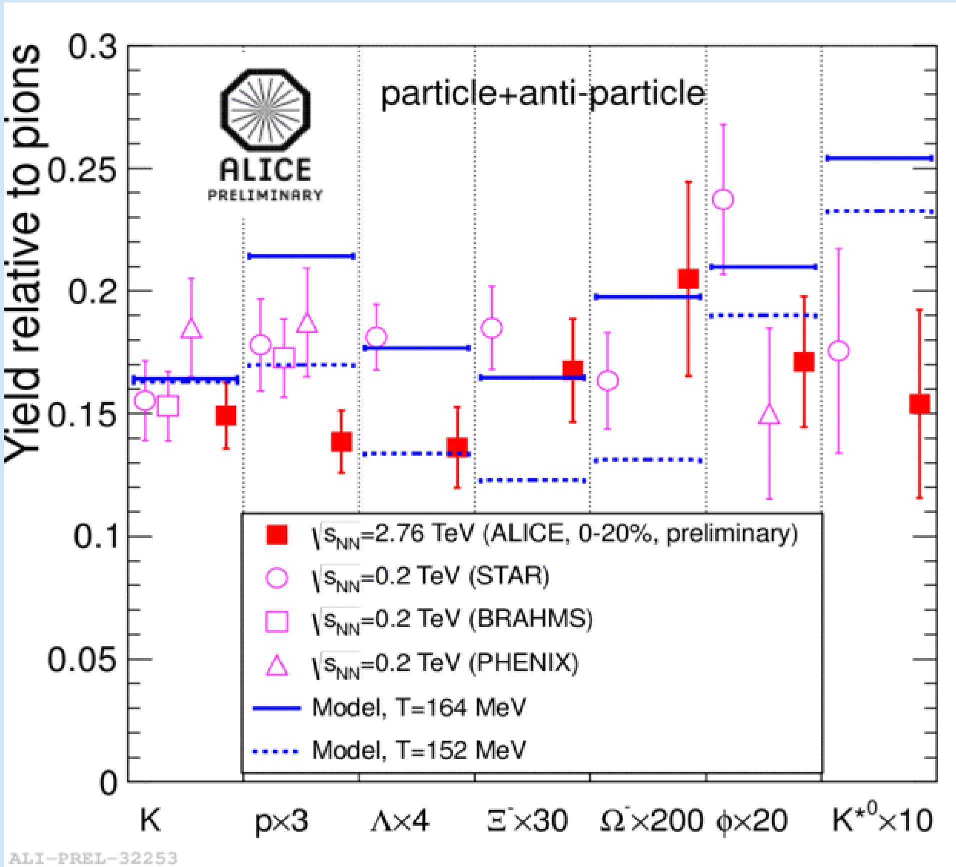
Peripheral



Central

Centrality	$dN_{ch}/d\eta$	$\langle N_{part} \rangle$	$(dN_{ch}/d\eta)/(\langle N_{part} \rangle/2)$
0%–5%	1601 ± 60	382.8 ± 3.1	8.4 ± 0.3
5%–10%	1294 ± 49	329.7 ± 4.6	7.9 ± 0.3
10%–20%	966 ± 37	260.5 ± 4.4	7.4 ± 0.3
20%–30%	649 ± 23	186.4 ± 3.9	7.0 ± 0.3
30%–40%	426 ± 15	128.9 ± 3.3	6.6 ± 0.3
40%–50%	261 ± 9	85.0 ± 2.6	6.1 ± 0.3
50%–60%	149 ± 6	52.8 ± 2.0	5.7 ± 0.3
60%–70%	76 ± 4	30.0 ± 1.3	5.1 ± 0.3
70%–80%	35 ± 2	15.8 ± 0.6	4.4 ± 0.4

Pb-Pb particles ratios



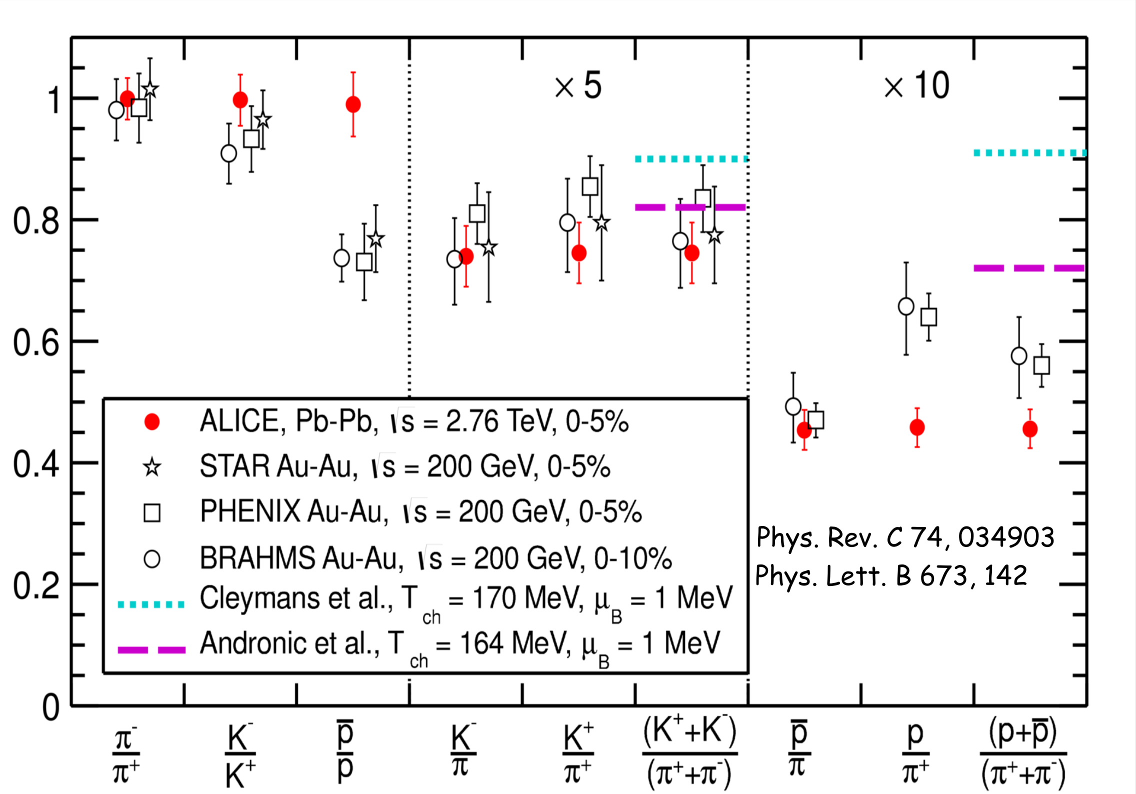
Thermal model predictions:

- T = 164 MeV from lower energies extrapolation* : problems with p and Λ yields and ratios
- T = 152 MeV from the fit (no resonances) to the integrated yelds at midrapidity dN/dy
  - correctly predicts Λ/π
  - misses multi-strange
  - problem with p/π
- p and hyperons do not fit to a single set of thermal params and γ_s=1

Is the ratio at LHC lower than at RHIC?
Particle ratios consistent with RHIC except for p/π and Λ/π

* A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A 772 (2006) 167

Pb-Pb particles ratios



PRL 109, 252301 (2012)

T_{ch} obtained from fit to RHIC data

μ_B extrapolated from lower energies

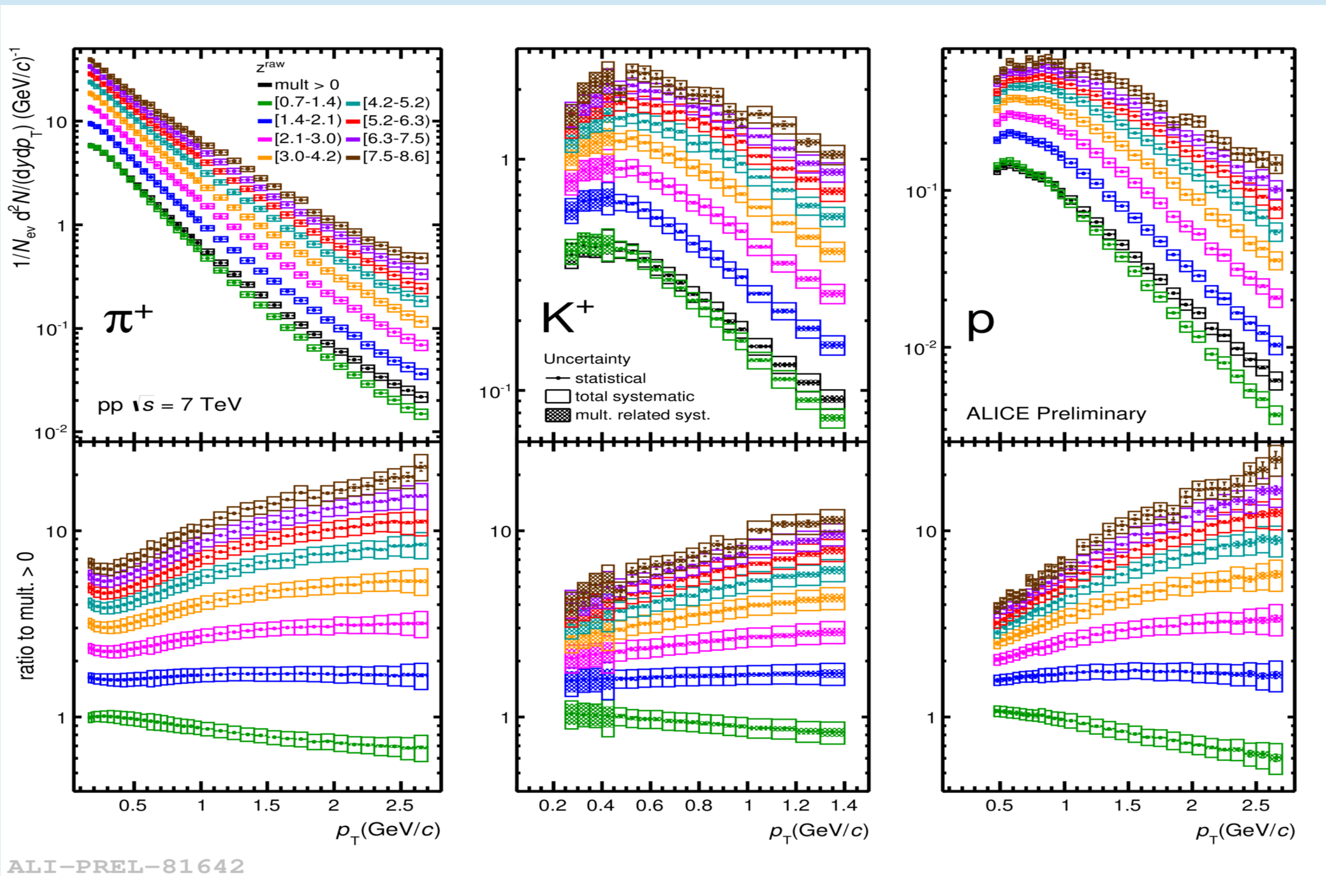
Comparison with 2 thermal model predictions (both models fit RHIC data):

- K/π in line with predictions
- p/π lower than expected by factor 1.5

Deviation from thermal ratio:

- final state interactions in hadronic phase (arXiv:1203.5302) (HKM model (arXiv:1204.5351))
- non equilibrium SHM (Eur. Phys. J. A 35)
- existence of flavour and mass dependent prehadronic bound states in the QGP phase (Phys. Rev. D 85, 014004 and arXiv:1205.3625)

π, K, p spectra in pp @ 7 TeV



$$z^{raw} = \frac{(N_{ch}^{raw})_{limit}}{< N_{ch}^{raw} >_{mult>0}}$$

$$< N_{ch}^{raw} >_{mult>0} = 9.6, |\eta| < 0.8$$

N_{ch}^{raw}	z^{raw}
7 - 12	0.7 - 1.3
13 - 19	1.4 - 2.0
20 - 28	2.1 - 2.9
29 - 39	3.0 - 4.1
40 - 49	4.2 - 5.1
50 - 59	5.2 - 6.2
60 - 71	6.3 - 7.4
72 - 82	7.5 - 8.6

- multiplicity dependence of the shape of the distributions
- multiplicity and mass dependence of the low p_T depletion