Light flavour measurements with ALICE at the LHC: elliptic flow and particle spectra

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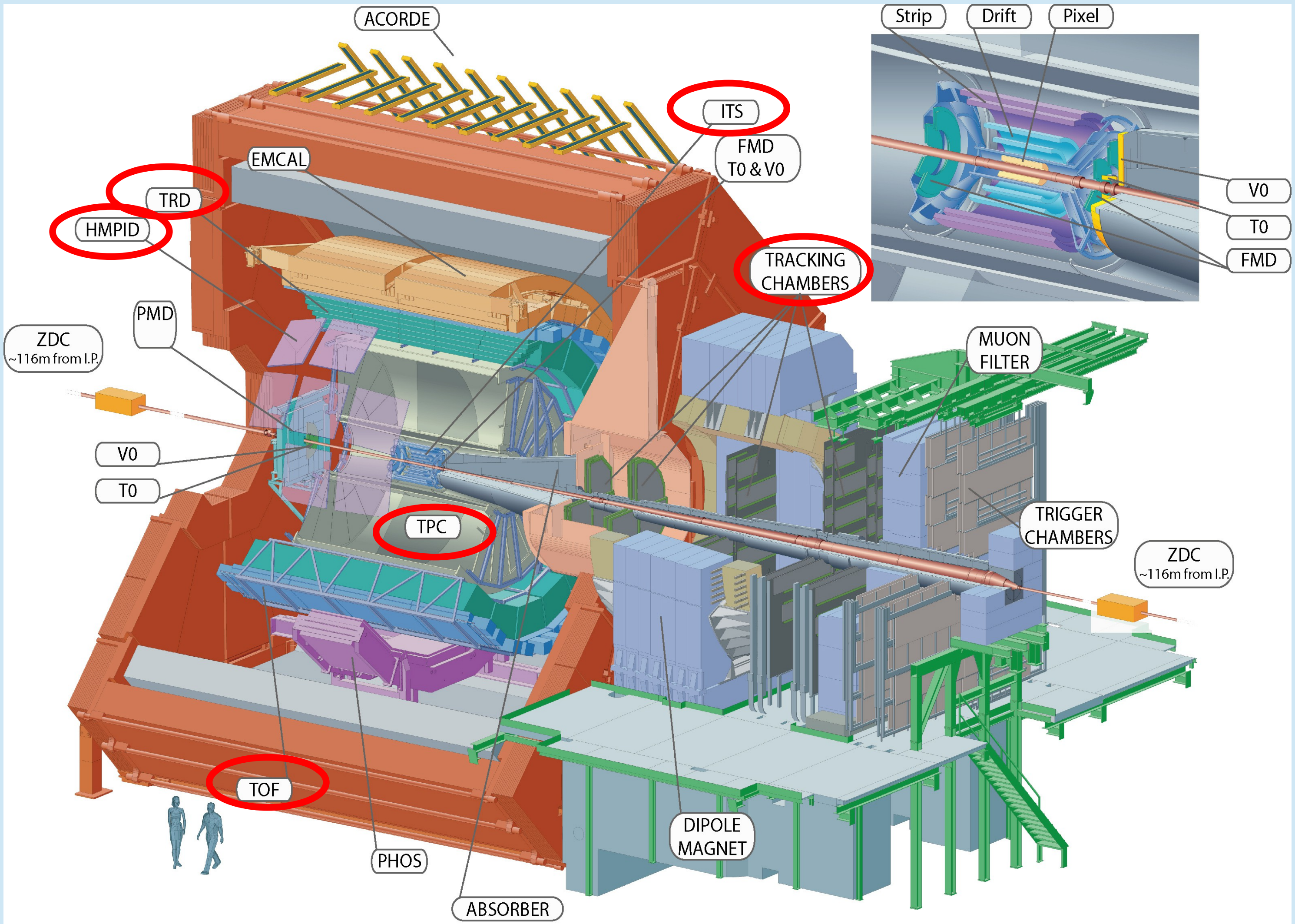
Outline

- The ALICE experiment
- Pb-Pb collisions and QGP signatures
- Elliptic flow
- Transverse momentum spectra
- Particles ratios
- Baryon/meson ratio

The ALICE experiment



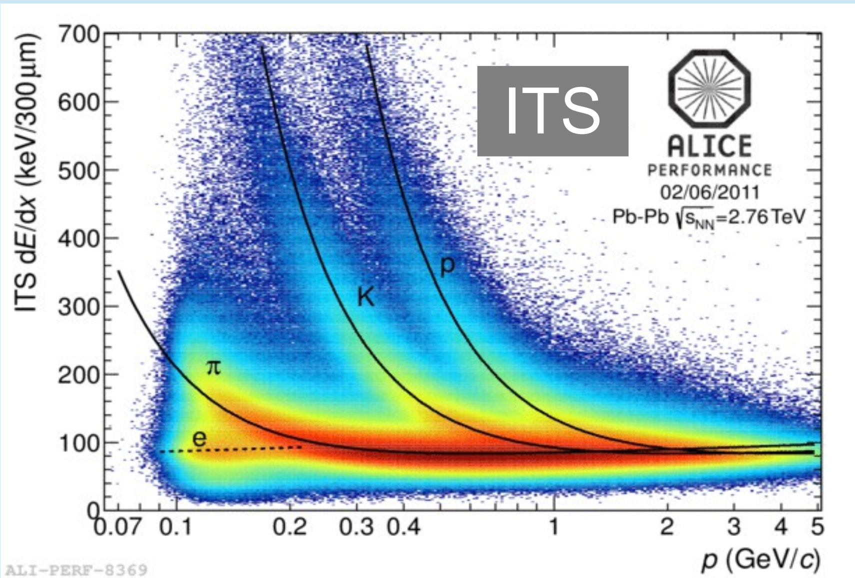
- Low material budget
- Optimized for good PID performance

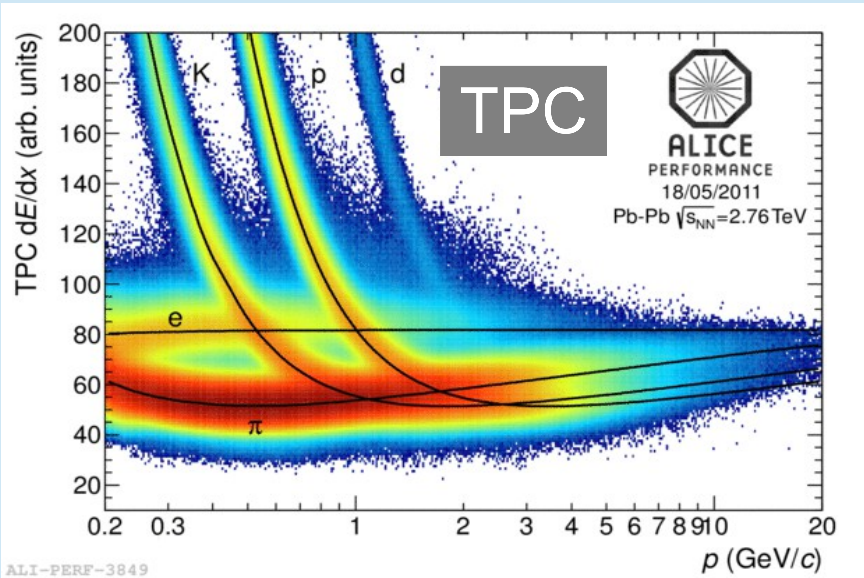
ALICE has several barrel detectors ($|\eta|<0.9$) dedicated to PID

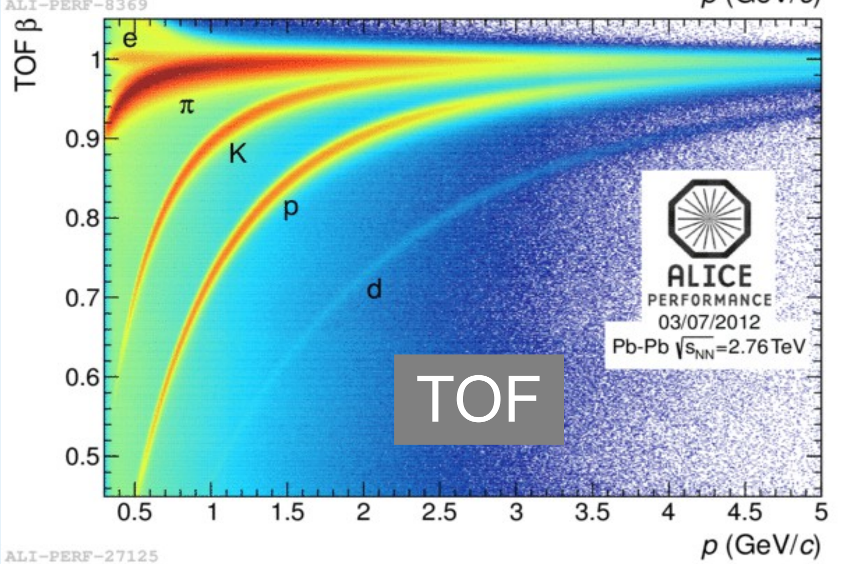
- covering complementary p_t ranges
- using different PID techniques
  - ITS: dE/dx
  - TPC: dE/dx
  - TRD: Transition Radiation
  - TOF: Time-of-Flight
  - HMPID: Cherenkov Radiation

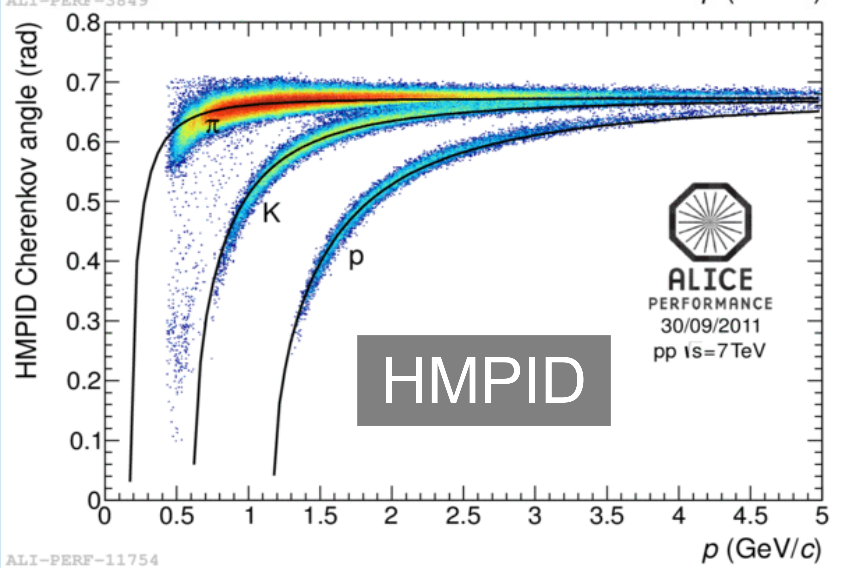
ALICE has a forward muon spectrometer ($-4.0<\eta<-2.5$) for muon ID

Main PID detectors performance

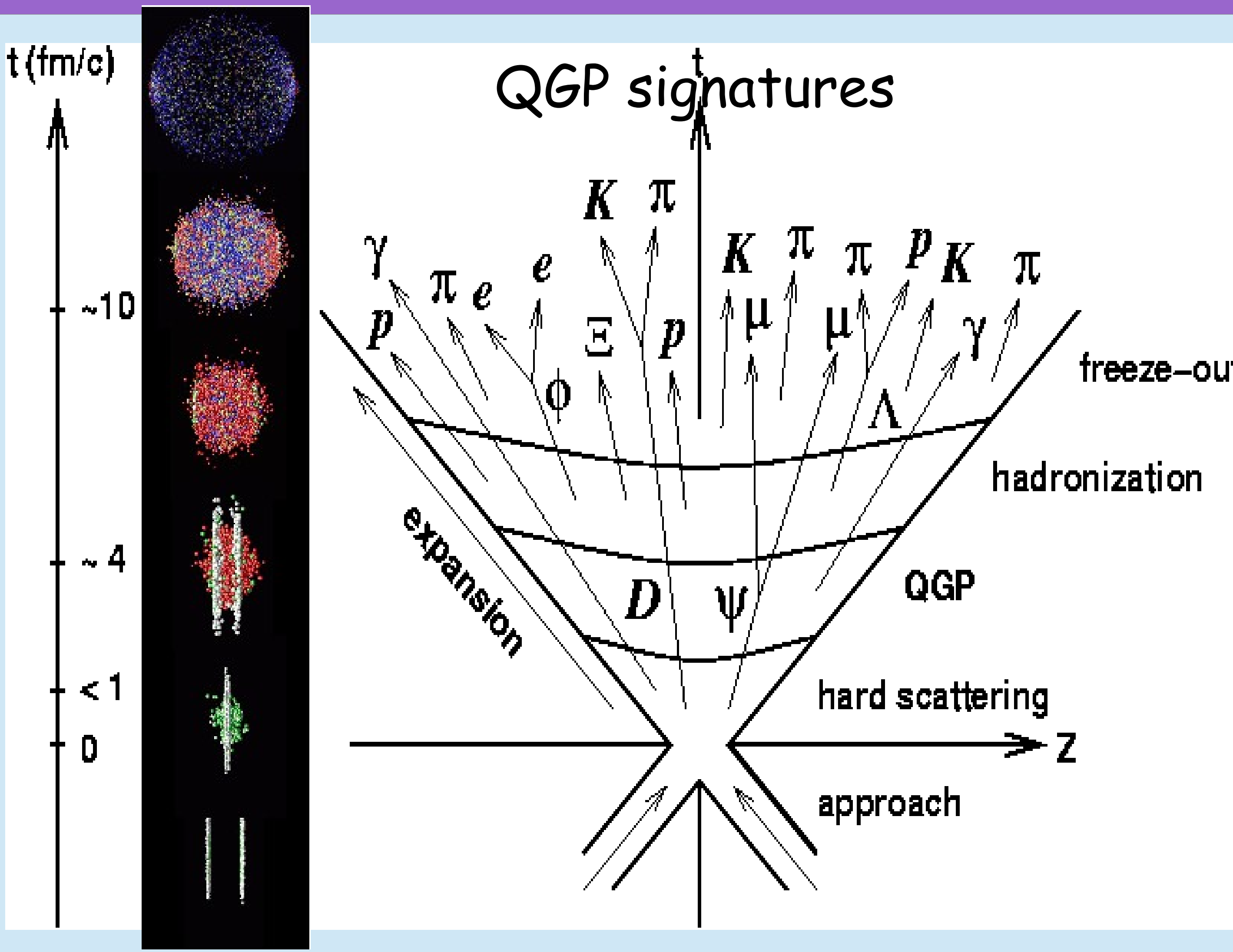








Heavy-ion collisions



Kinetic: no elastic collisions

Chemical: no inelastic collisions

First bound states

Thermalized medium

Heavy quarks + jets +
direct photons

QGP signatures

- Hard probes:
  - produced in the first stages of the collisions
    - heavy quarks, high p_T spectra (jets), thermal photons and dielectrons, ...
- Soft probes:
  - produced in the late stages of the collisions
    - particle abundances, low p_T spectra, strangeness enhancement, elliptic flow, resonances production...

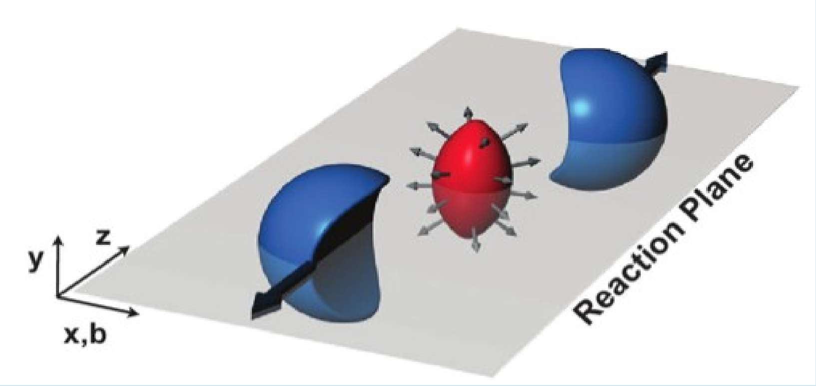
Particle IDentification

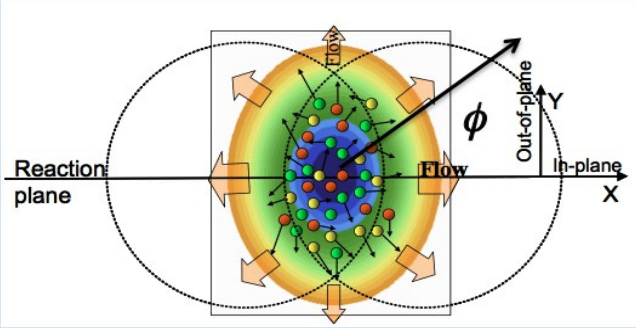
- To understand better the QGP properties not only Nucleus-Nucleus collisions have to be studied but also pp and p-Nucleus collisions
  - provide a reference for Pb-Pb results
  - give the possibility to decouple initial and final state effects
  - are fundamental to tune Monte Carlo models
  - are of interest in themselves

In this talk only Pb-Pb results are shown

QGP anisotropic flow

Initial spatial azimuthal anisotropy of overlap region of colliding nuclei in non central collisions is converted, via interactions, into anisotropy in momentum space
Magnitude of anisotropy depends on centrality -> impact parameter determines eccentricity





Anisotropy from Fourier expansion of particle yield

$$\frac{dN}{Nd\phi} \propto 1 + 2v_2 \cos\left(2(\phi - \Psi_{RP})\right) + \textit{higher harmonics } (v_3, v_4, \ldots)$$

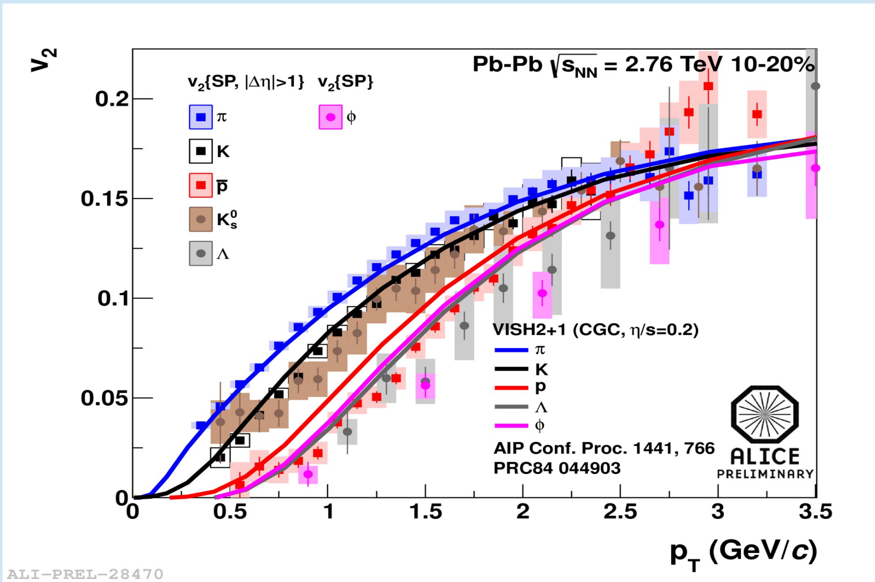
$$v_n = \langle \cos[n(\phi - \Psi_R)] \rangle$$

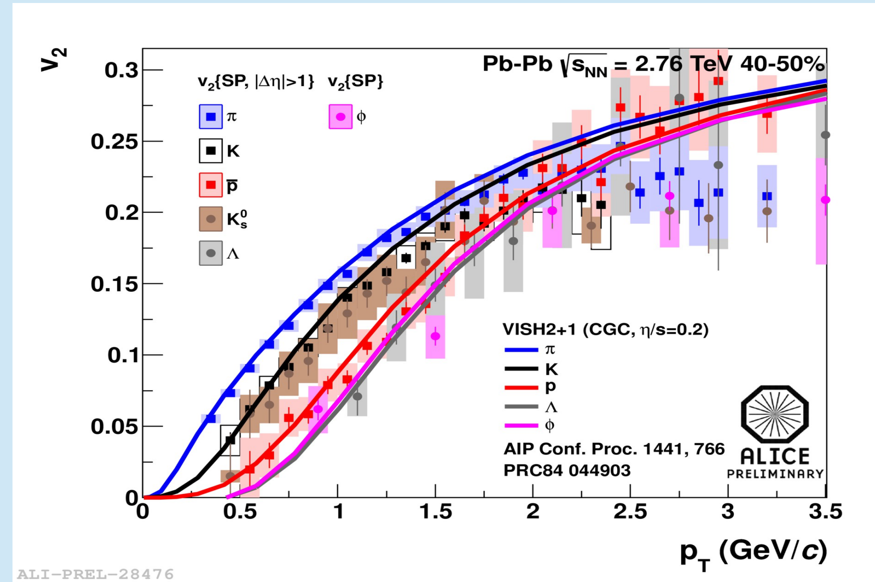
- v1 = directed flow
- v2 = elliptic flow (strength of collectivity)
- v3 = triangular flow

Initial shape fluctuations dependent on η/s (shear viscosity over entropy density)

Hydrodynamic models seem to favour a low value of η/s at both RHIC and LHC energies

Elliptic flow





- Mass ordering
- Centrality dependence
- Mass splitting at LHC larger than at RHIC consistent with larger radial flow
- Comparison with viscous-hydro predictions
  - good agreement with VISH2+1 * ($\eta/s = 0.2$) at low p_T in peripheral collisions but problem for heavier particles especially in more central collisions
  - adding hadronic rescattering (UrQMD) after the hydro stage reproduces better v2

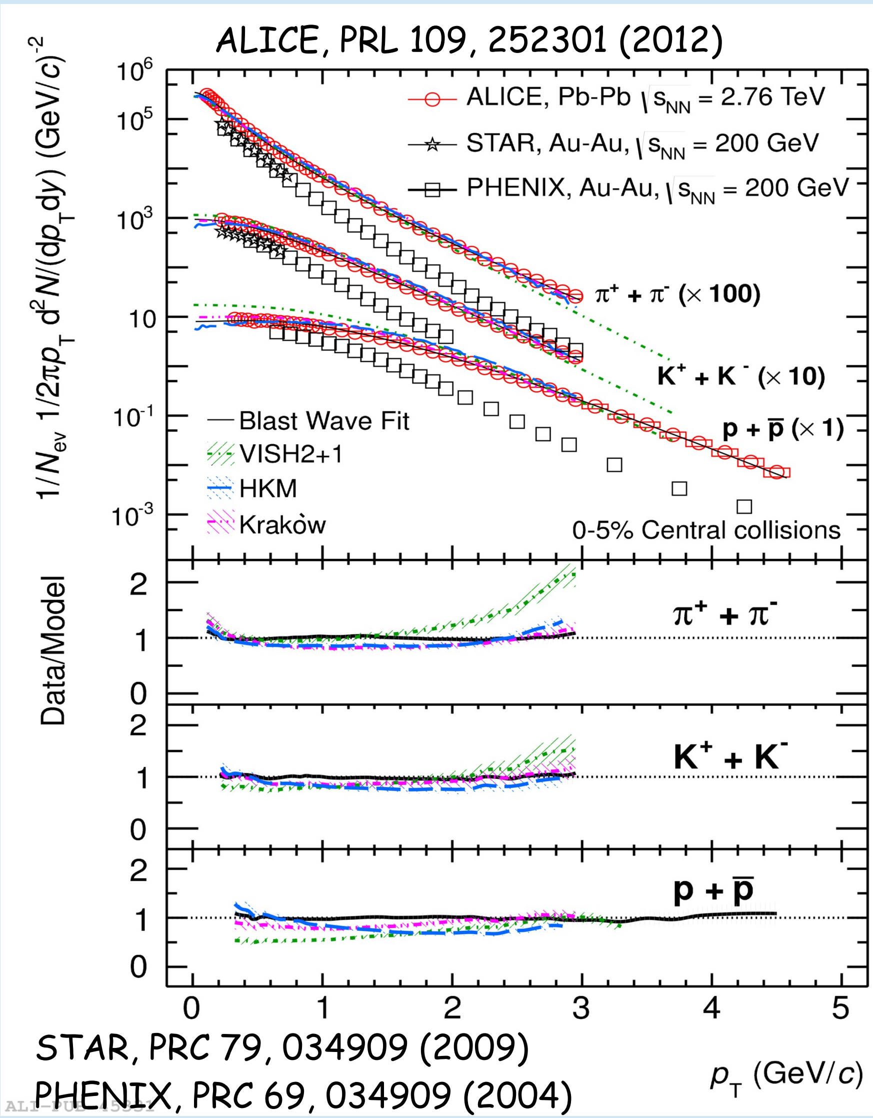
*Shen et al., PRC 84, 044903 (2011)

Bulk particles production: light flavour low p_T spectra

Foundamental to study collective and thermal properties of QGP -> signals produced in the QGP phase have to be folded with space-time evolution of the whole system

- low p_T spectra: described by hydrodynamic models reflect conditions at "kinetic freeze-out" (no more elastic interactions) -> *give information about*:
  - collective transverse expansion (radial flow) -> average transverse velocity $\langle\beta_T\rangle$
  - kinetic freeze-out temperature T_{kin}
- particle abundances: described by thermal models (in thermal and chemical equilibrium) -> *give information about*:
  - chemical freeze-out temperature T_{ch}
  - baryochemical potential μ_B (net baryon content)
- baryon/meson ratio: info on bulk particles production mechanism

Pb-Pb primary hadron spectra



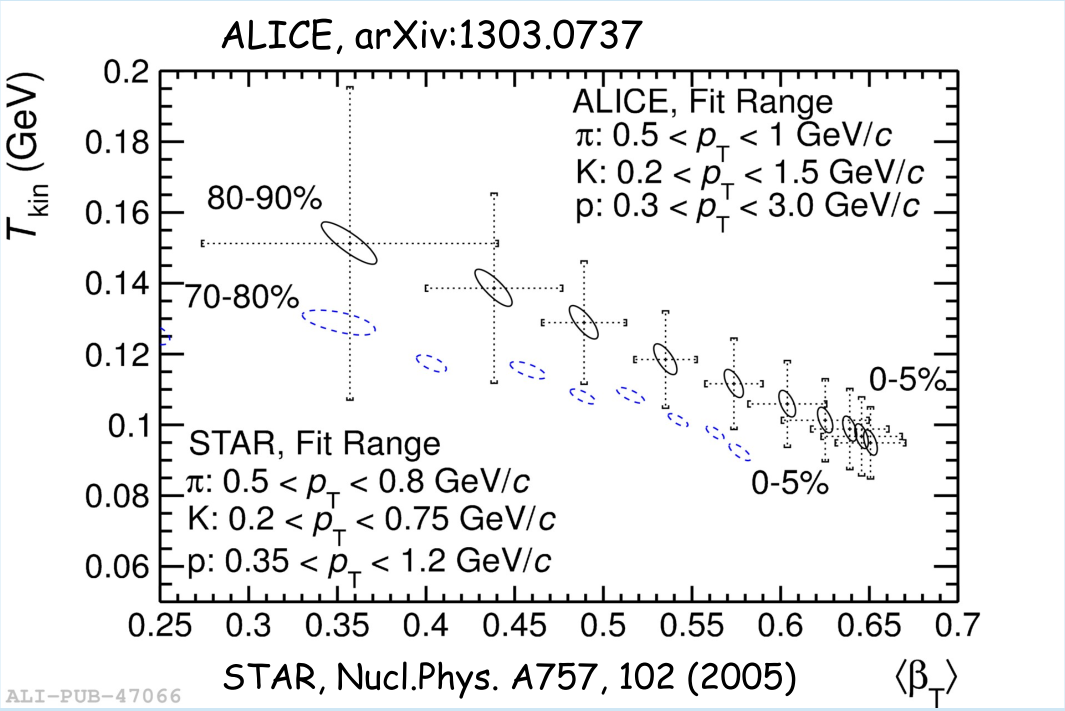
- Harder spectra compared to RHIC -> stronger radial flow (in hydrodynamic models is a consequence of increasing particle density)
- Combined blast wave fit* :
  - $\langle\beta_T\rangle$ = 0.65 ± 0.02 -> 10% higher than RHIC consistent with observation of increasing of mean p_T at LHC compared to RHIC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

> **Blast wave model*: thermalized volume elements, expanding in a common velocity field
> Parameters: T_{kin}, $\beta_T = \beta_S \cdot (r/R)^n$

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

Pb-Pb primary hadron spectra

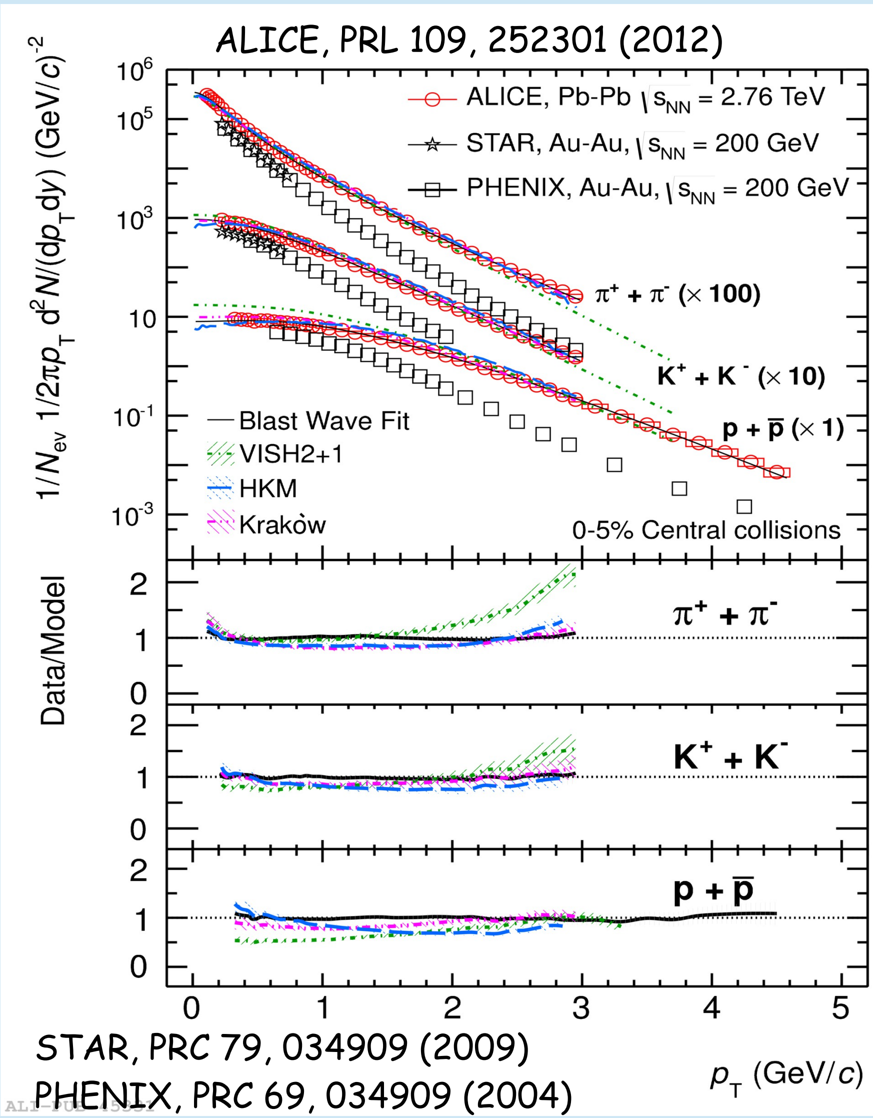
Blast-wave* fits parameters for collisions with different centrality at ALICE and RHIC



- ⟨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 gradients

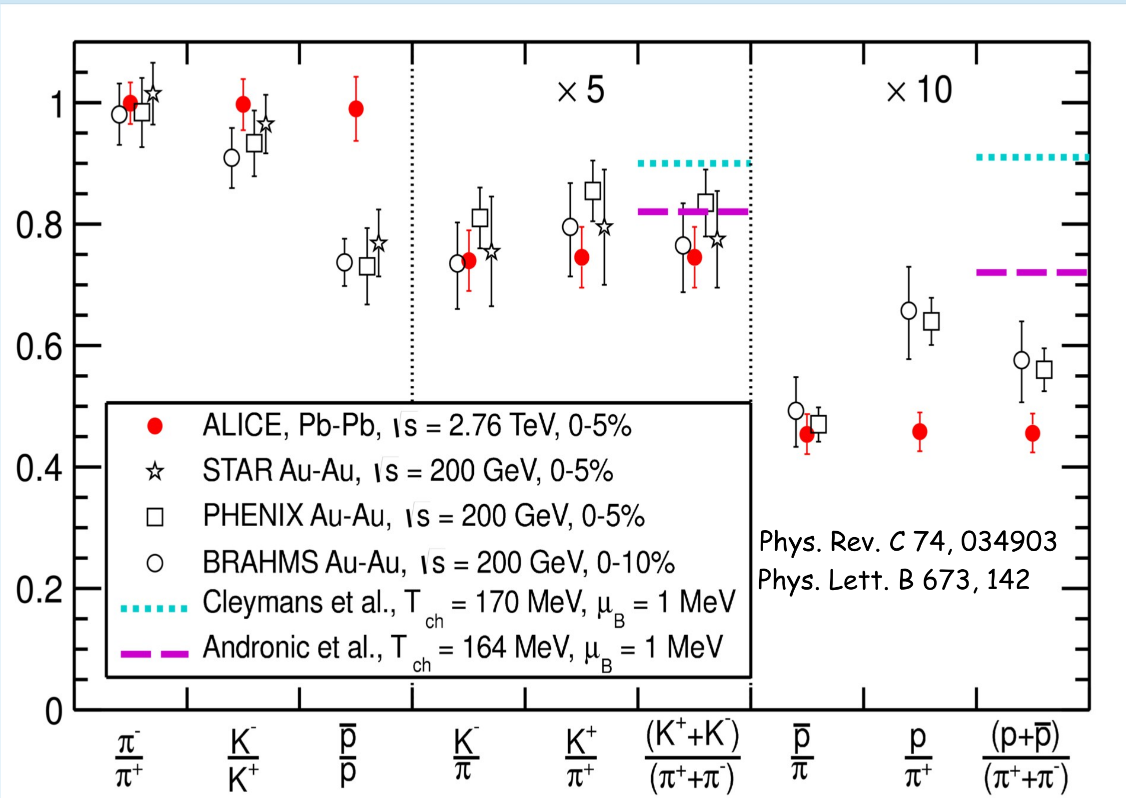
Pb-Pb primary hadron spectra



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., arXiv:1204.5351)
- Krakow: introduces non equilibrium corrections due to bulk viscosity at the transition from the hydrodynamic description to particles which change the effective Tch
  (Bozek, PRC 85, 034901 (2012))

Pb-Pb particles ratios



PRL 109, 252301 (2012)

T_{ch} obtained from fit to RHIC data

μ_B extrapolated from lower energies

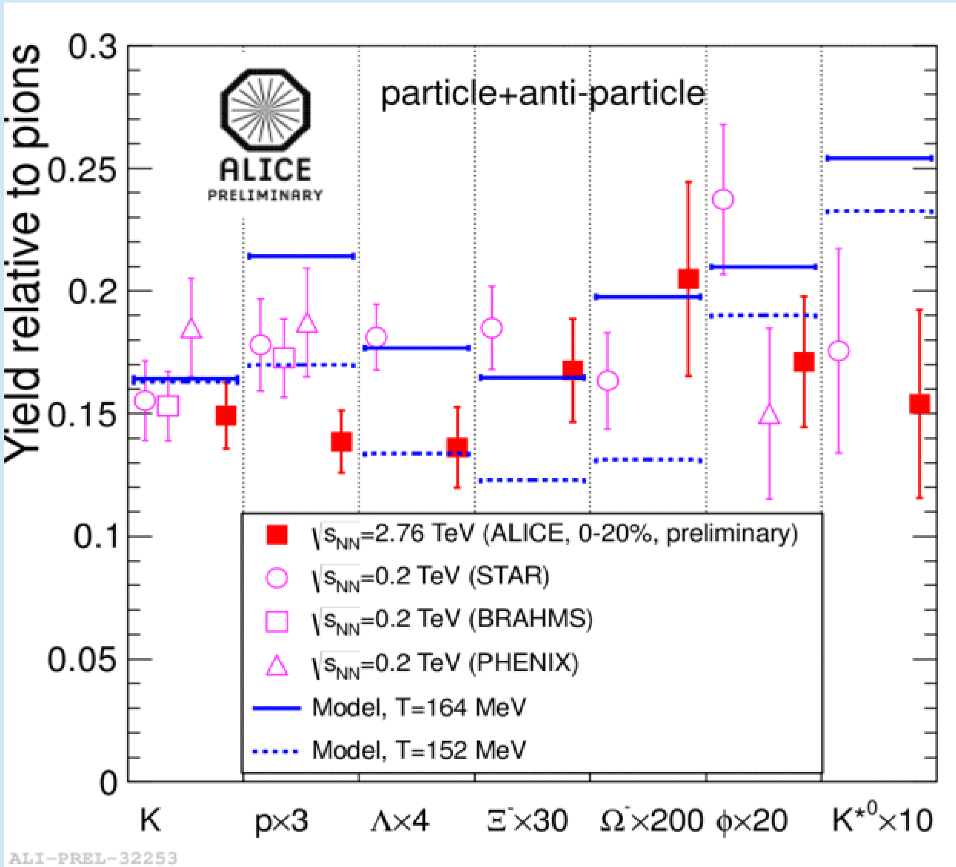
Comparison with 2 thermal model predictions (both models fit RHIC data):

- 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 flavor and mass dependent prehadronic bound states in the QGP phase (Phys. Rev. D 85, 014004 and arXiv:1205.3625)

Pb-Pb particles ratios



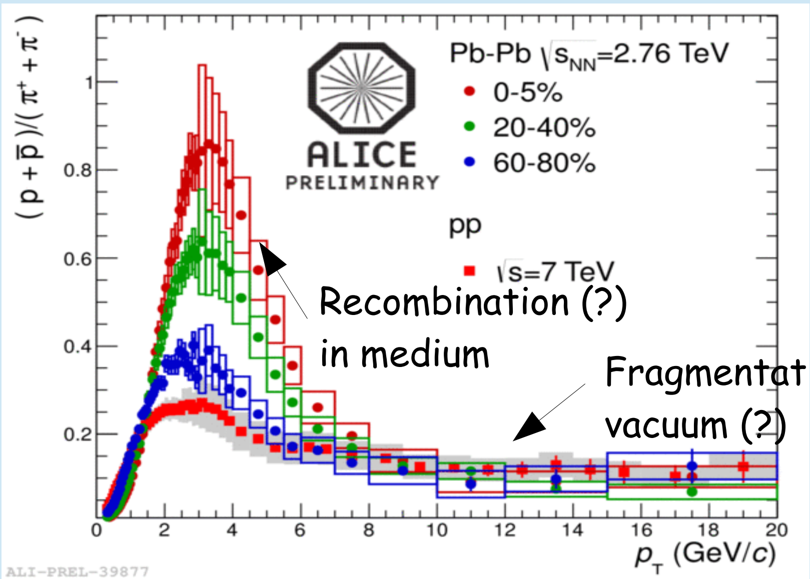
Thermal model predictions:

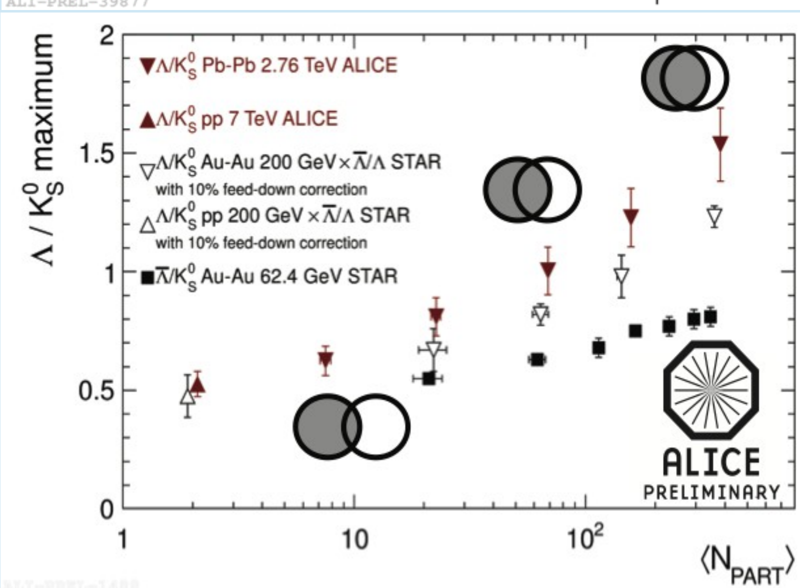
- T = 164 MeV from lower energies extrapolation* : problems with p and Λ yields and ratios
- T = 152 MeV from the fit (no resonances) to the integrated yelds at midrapidity dN/dy
  - correctly predicts Λ/π
  - misses multi-strange
  - problem with p/π
- p and hyperons do not fit to a single set of thermal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





2 GeV/c < p_T < 7 GeV/c

- enhancement respectively to pp
- enhancement increases with centrality
- higher at LHC respect to RHIC
- qualitatively consistent with hadron formation from medium constituents

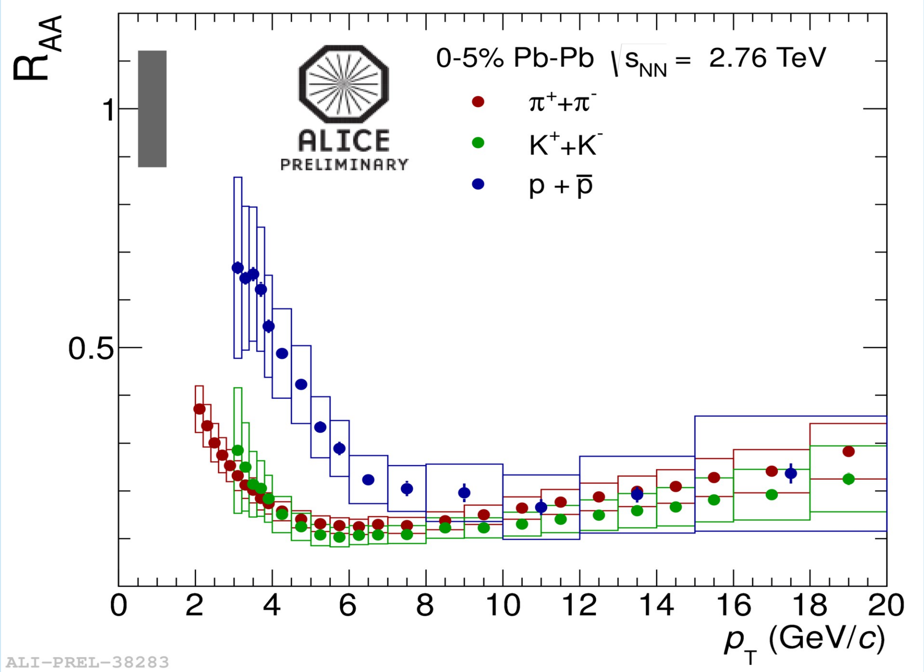
p_T > 10 GeV/c

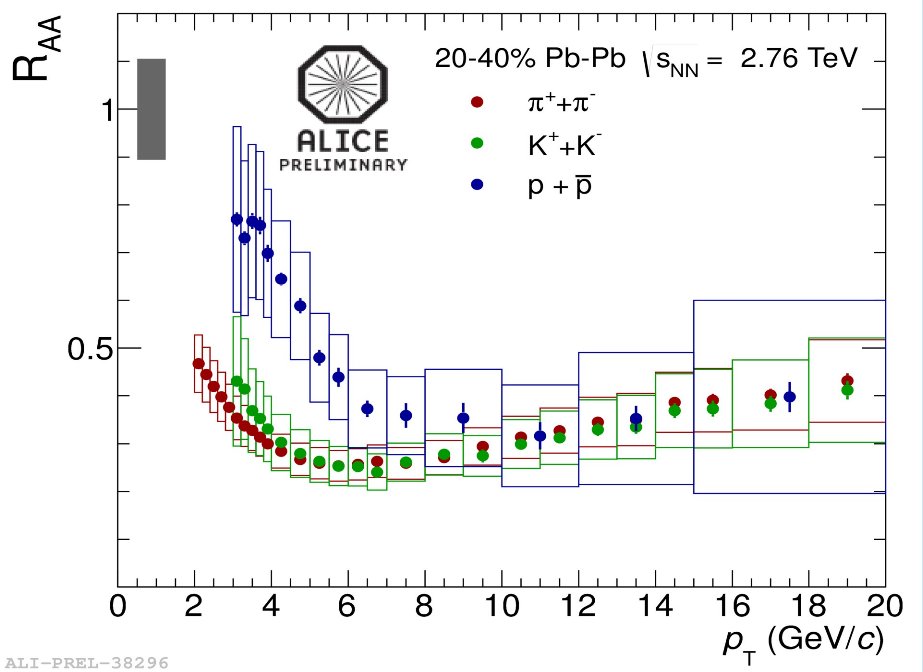
- ratio similar to pp value -> parton fragmentation (jet chemistry) not modified by the medium

Light flavour high p_T spectra

Suppression of high p_T spectra

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





R_{AA} compatible at high p_T for pions, kaons, protons

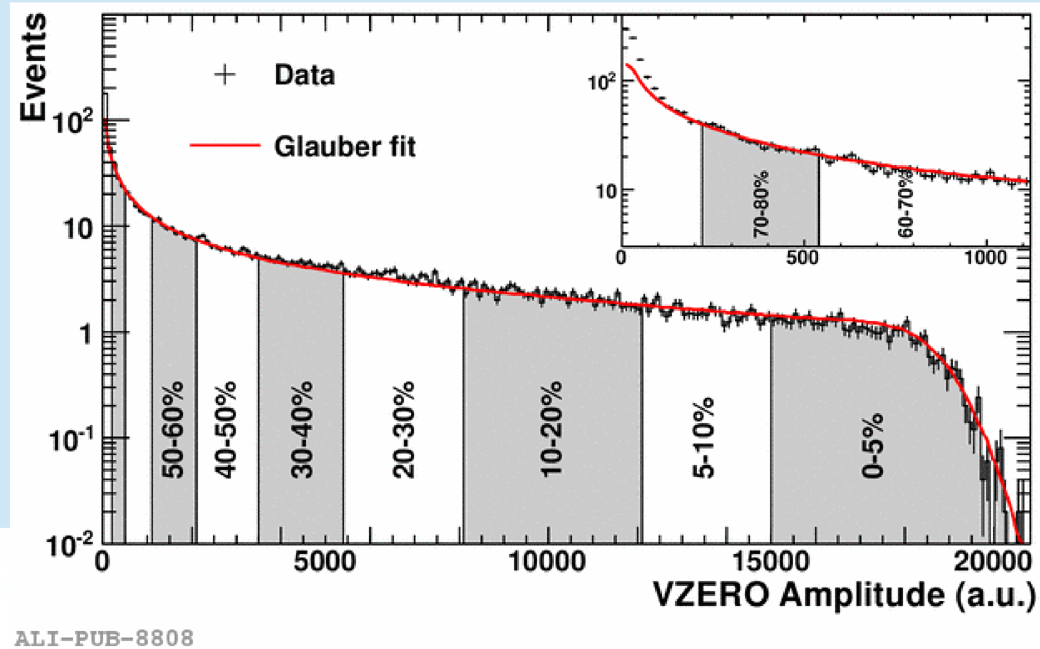
Summary

- The ALICE experiment has already provided many interesting and unique results on QGP properties based on the first Pb-Pb data collected in 2010 and 2011
- Light flavour measurements give the possibility to test and tune thermal and hydro models and to study the particles production and energy loss mechanisms

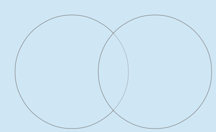
Backup

Centrality selection

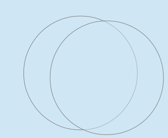
VZERO amplitude. Curve: Glauber model fit to the measurement. Vertical lines separate the centrality classes used in the analysis, which in total correspond to the most central 80% of hadronic collisions.



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



Peripheral



Central