ALICE results for Pb-Pb Collisions

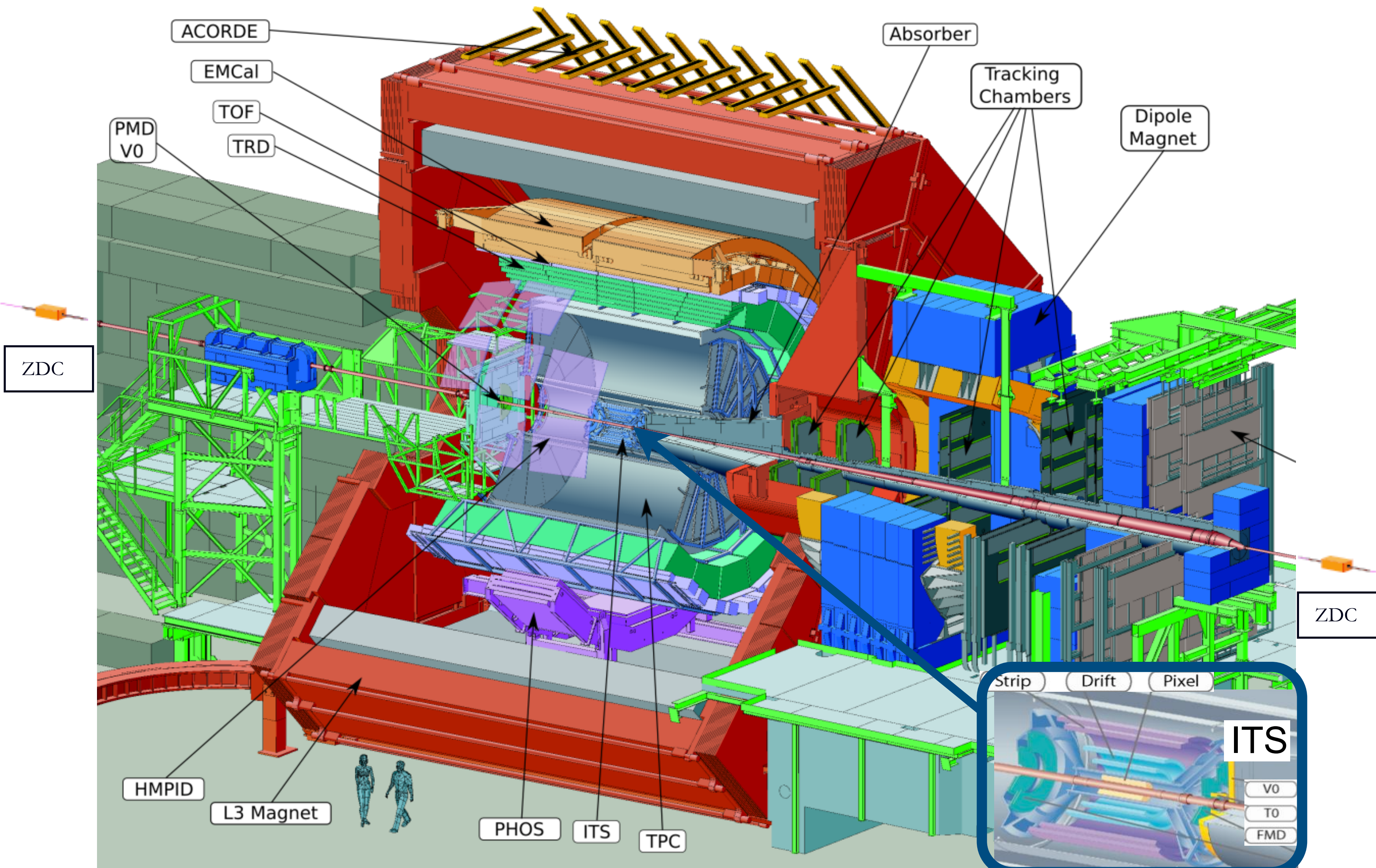
1. ALICE experiment at CERN LHC:
   - Detectors, commissioning and data taking;
   - Reference from pp results and publications.

2. First results with **Pb-Pb** collisions:
   - a) Multiplicity distribution and particle spectra;
   - b) Bulk correlations (HBT, Flow, fluctuations);
   - c) Hard probes (high p_T and heavy flavor via R_{AA}).

3. Summary

Boris HIPPOLYTE for the ALICE Collaboration

The ALICE experiment at CERN LHC



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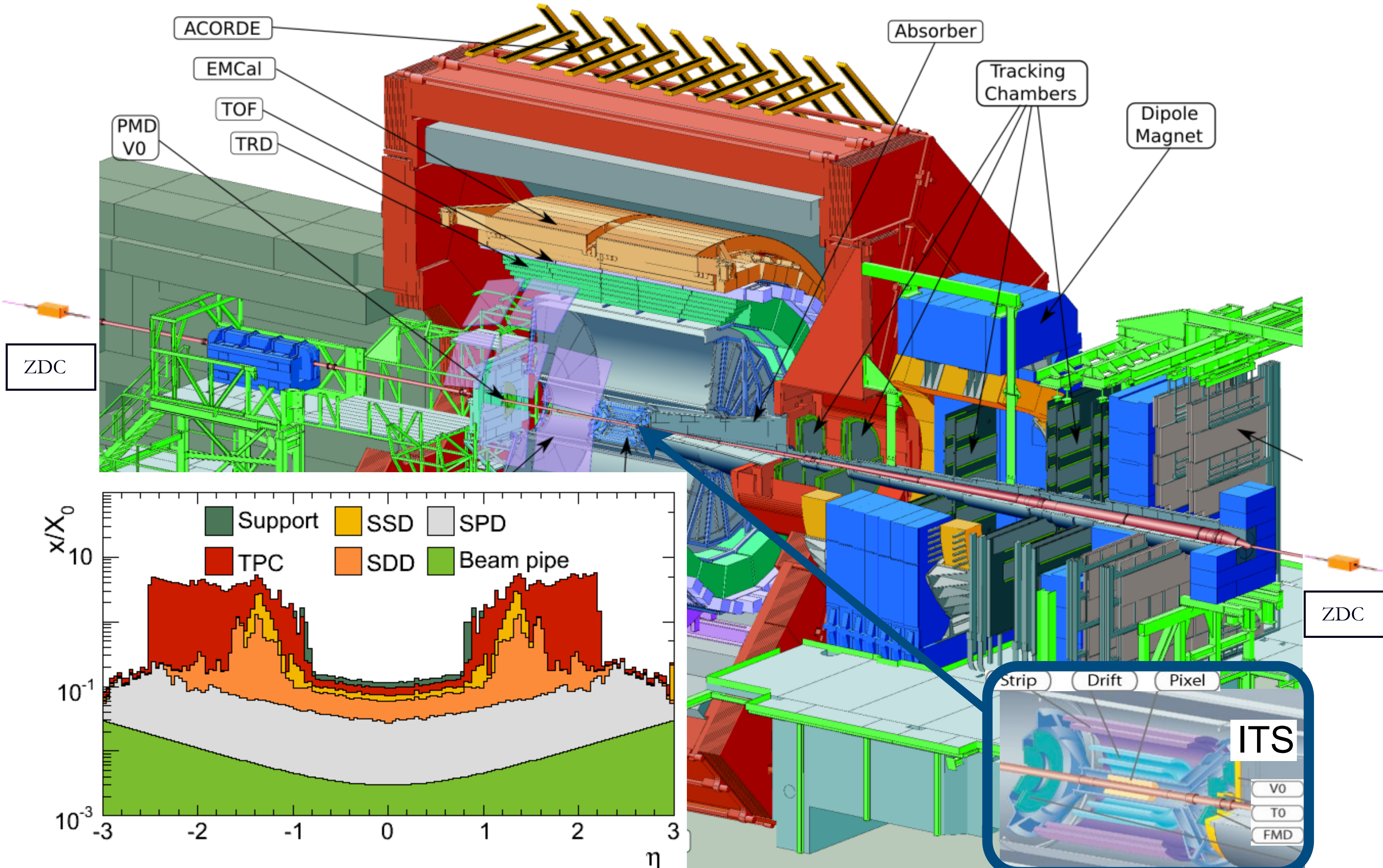
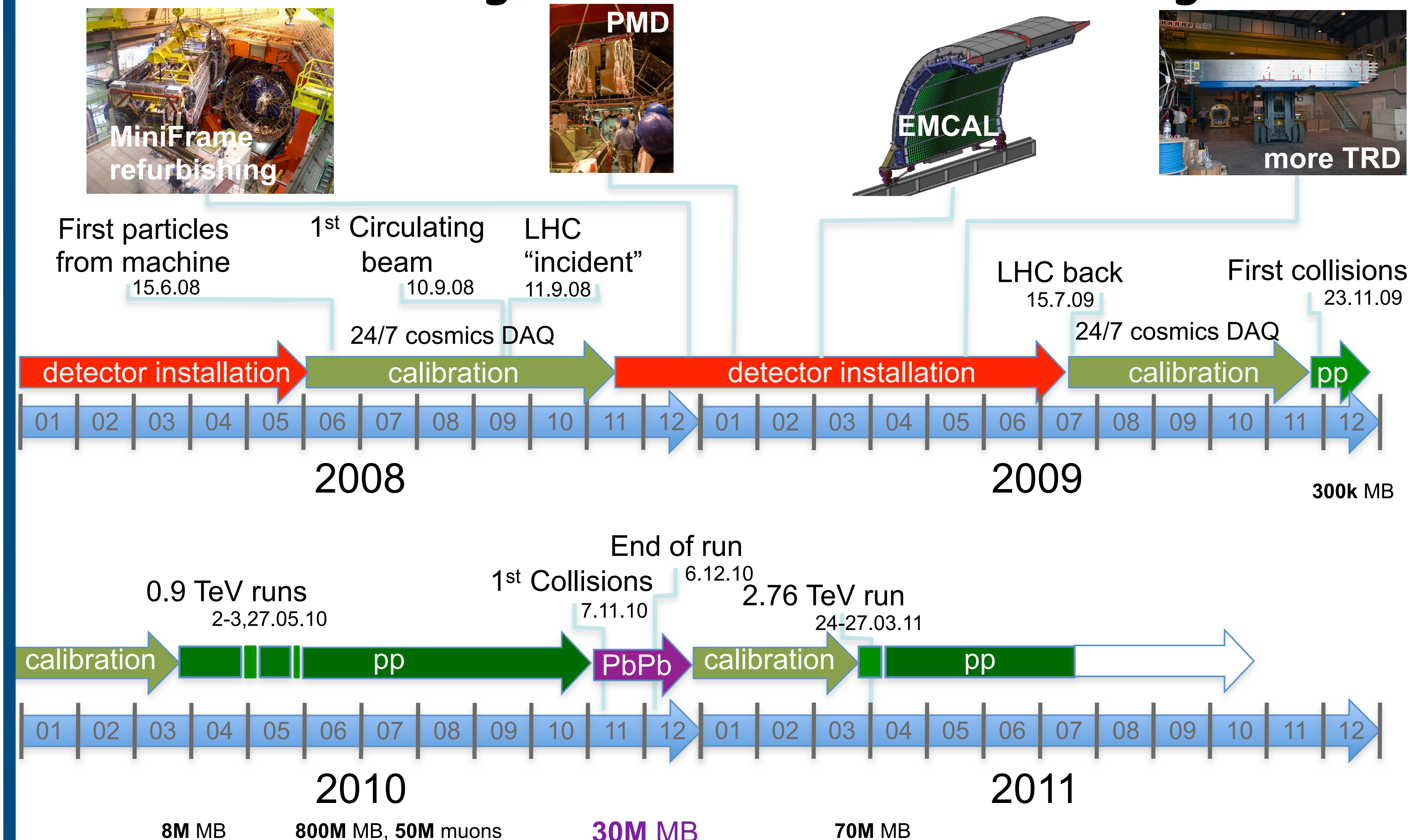


Commissioning, calibration and data taking



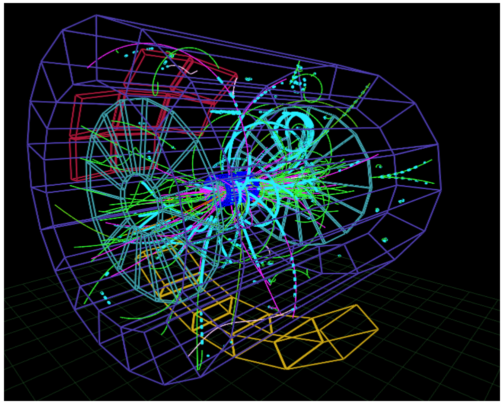
ALICE Physics Results for pp Collisions

Already submitted or published analyses:

- ⇨ Charge particle density or multiplicity
  - 0.9 TeV — Eur. Phys. J C 65 (2010) 111
  - 0.9 TeV & 2.36 TeV — Eur. Phys. J C 68 (2010) 89
  - 7 TeV — Eur. Phys. J C 68 (2010) 345
- ⇨ pbar/p ratio (0.9 TeV and 7 TeV) — Phys. Rev. Lett. 105 (2010) 072002
- ⇨ Momentum distributions (0.9 TeV) — Phys. Lett. B 693 (2010) 53
- ⇨ Identified particle production & p_T spectra
  - π,K,p production (0.9 TeV) — Eur. Phys. J C 71 (2011) 1655
  - Strange particle production (0.9 TeV) — Eur. Phys. J C 71 (2011) 1594
- ⇨ Bose-Einstein correlations (0.9 TeV) — Phys. Rev. D 82 (2010) 052001
  (0.9 and 7 TeV) — arXiv:1101.3665 (to Phys. Rev. D)
- ⇨ Rapidity and p_T of inclusive J/psi (7 TeV) — arXiv:1105.0380 (to Phys. Lett. B)

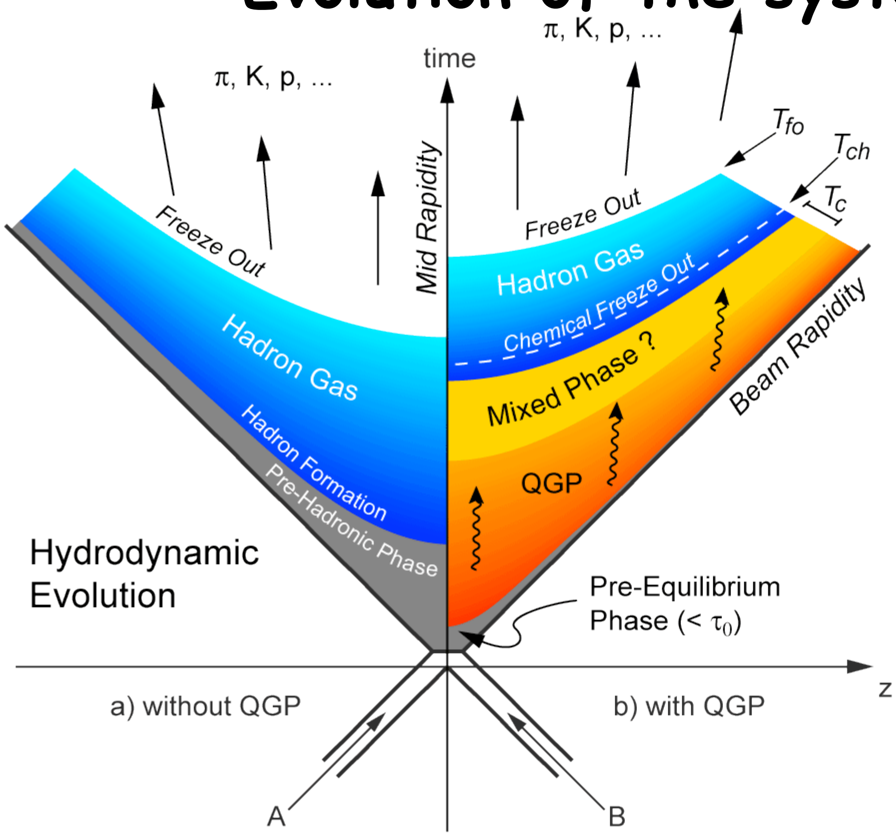
Ongoing analyses:

- ⇨ pQCD: Event topology, azimuthal correlations, jet fragmentation, …
- ⇨ Multi-strange p_T spectra: baryon (charged Ξ & Ω), Resonances...
- ⇨ Heavy Flavour: charm (D^0, D^+, D^*)



QCD session (16:30 Salle Bayard) by Y.Pachmayer, Heavy Flavour production measurements in pp collisions at the LHC with ALICE

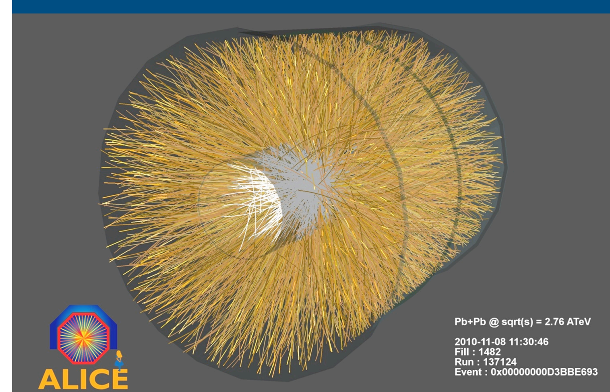
Evolution of the system created in HIC



Nuclei just before collision

- Initial pre-equilibrium state
- hard parton scattering & jet production gluonic fields (Color Glass Condensate)
- Quark-gluon plasma formation
- Thermalization (hydrodynamics)
- QGP expansion and decay
- Phase transition of partons into hadrons
  - hadronisation;
  - rescattering & chemical freeze-out;
  - kinetic freeze-out (stop interacting).

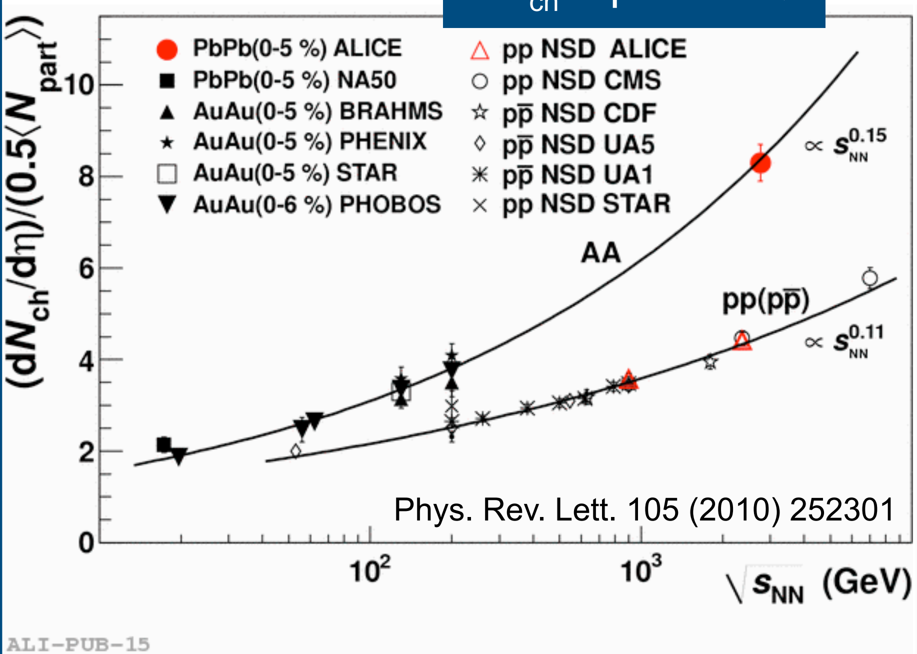
With hadronic states, many observables can be studied to characterize the properties of the Quark Gluon Plasma



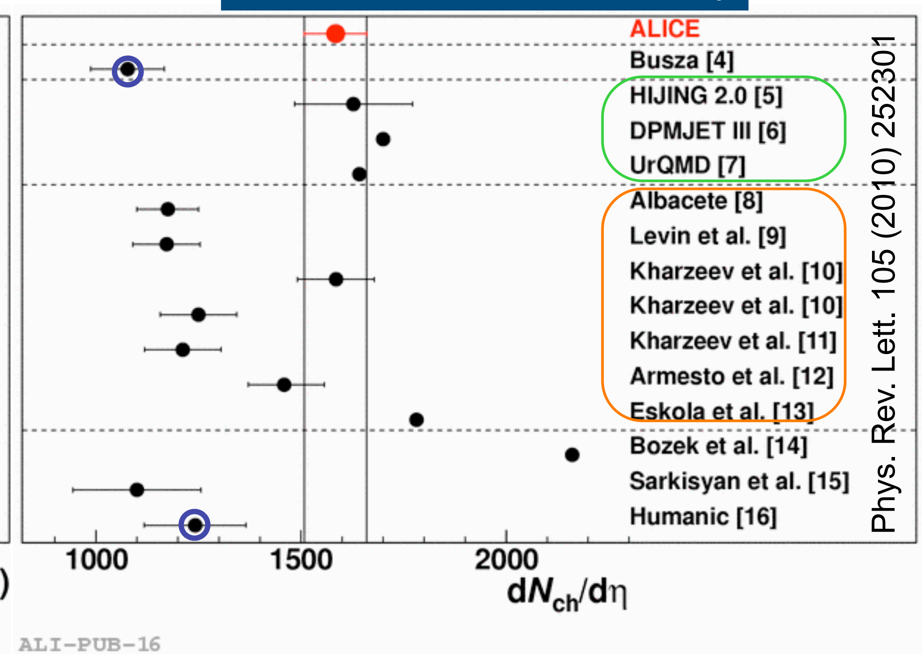
Using the ALICE experiment, measurements are performed for probing the evolution of the system.

Charged Particle Multiplicity: $dN_{ch}/d\eta$ vs. $\sqrt{s_{NN}}$

$dN_{ch}/d\eta$ versus $\sqrt{s}$



Comparisons with Theory



At mid-rapidity and for the most central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

⇨ **1.9** x pp (NSD) at $\sqrt{s_{NN}}$ = 2.36 TeV and **2.2** x Au-Au at $\sqrt{s_{NN}}$ = 0.2 TeV

Power law dependence fits well and faster in Pb-Pb ~ $s^{0.15}$ than in pp ~ $s^{0.11}$

⇨ ALICE measurement: $dN_{ch}/d\eta$ = 1584 ± 4 (stat.) ± 76 (syst.)

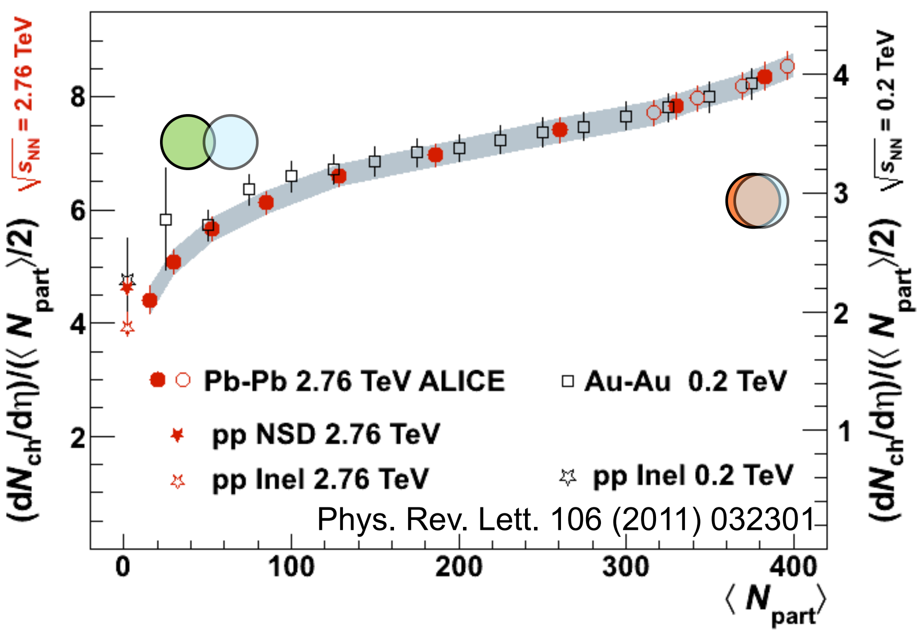
Comparisons with pp extrapolations, pQCD Monte Carlo and Shadowing/ Saturation models

⇨ Based on Bjorken formula, estimation of the energy density: $\varepsilon(\tau)_{LHC} \simeq 3\ \varepsilon(\tau)_{RHIC}$

Centrality dependence of $dN_{ch}/d\eta$

Similar centrality dependence for both LHC and **RHIC** data when scaled by a factor 2.1
(pp values interpolated using 0.9 and 7 TeV)

Important constraint for models with sensitivity to details of initial state, saturation, evolution...



Two-component models:

Soft processes $dN_{ch}/d\eta \sim N_{\text{scattered nucleons}} \sim N_{part}$

⇨ "nuclear amplification" independent of √s

Hard processes $dN_{ch}/d\eta \sim N_{\text{nucleon-nucleon collisions}}$

⇨ contribution increasing with √s and centrality.

p-QCD Monte Carlo:

⇨ **DPMJET**, too strong rise with N_{part}

⇨ **HIJING 2.0**, no quenching but strong centrality dependent gluon shadowing (and fine tuned to 0-5% $dN_{ch}/d\eta$).

Saturation-type models:

⇨ Parameterisation of saturation scale vs. √s and centrality (A);

⇨ Geometric scaling.

Data favours models with moderation of particle production vs. centrality.

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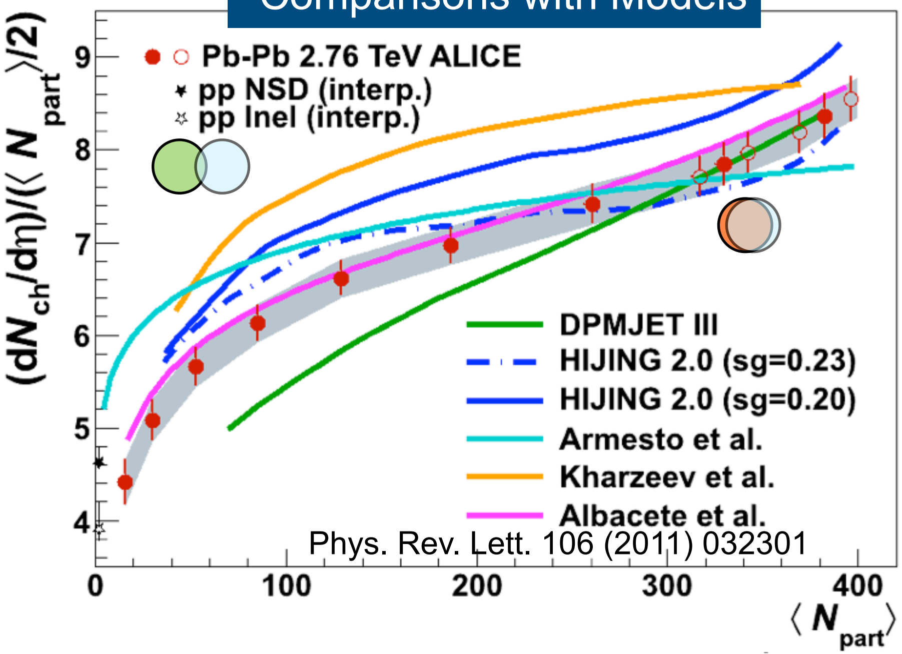

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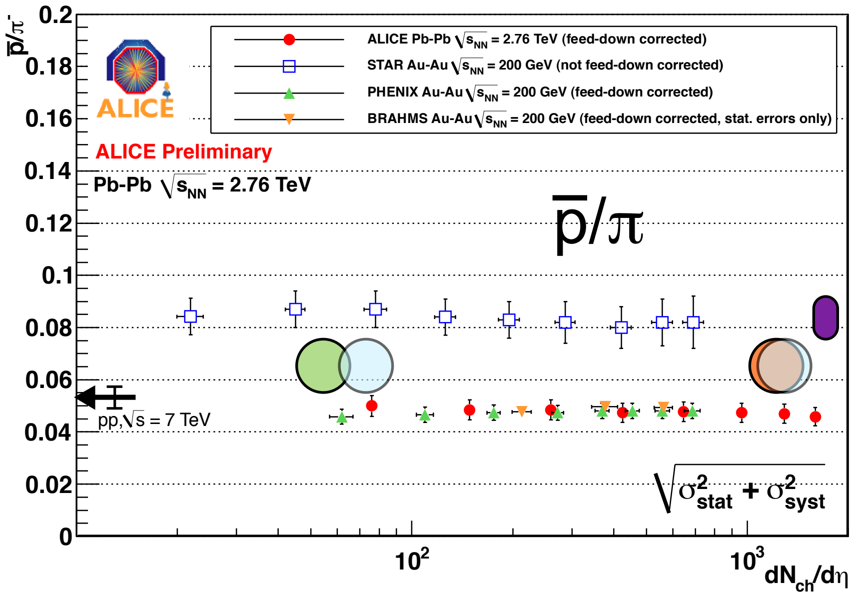
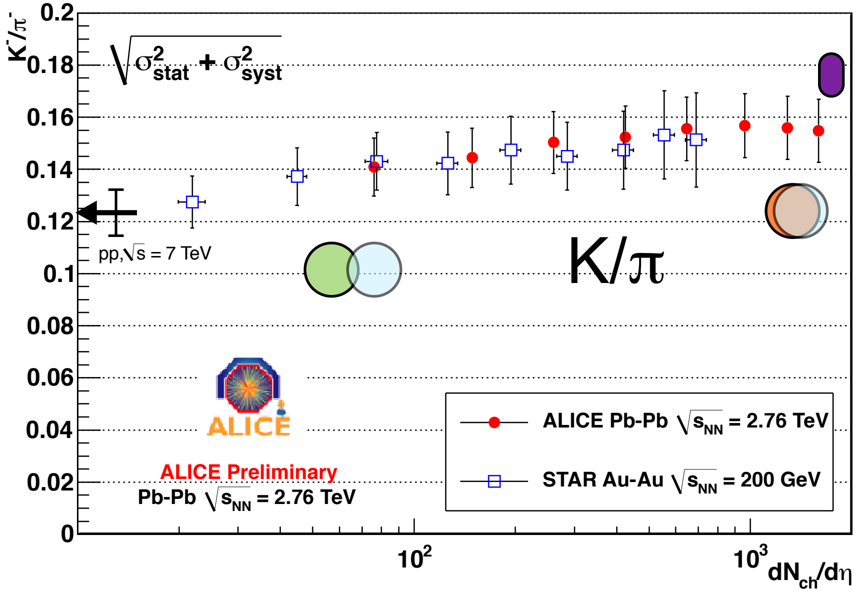
Particle composition vs. $dN_{ch}/d\eta$

see presentation of R. Preghenella

When looking at the **K/π** ratio, similar centrality dependence for both **LHC** and **RHIC** data.

Slight increase with $dN_{ch}/d\eta$ from pp to very central events but value **slightly smaller** than statistical thermal model predictions



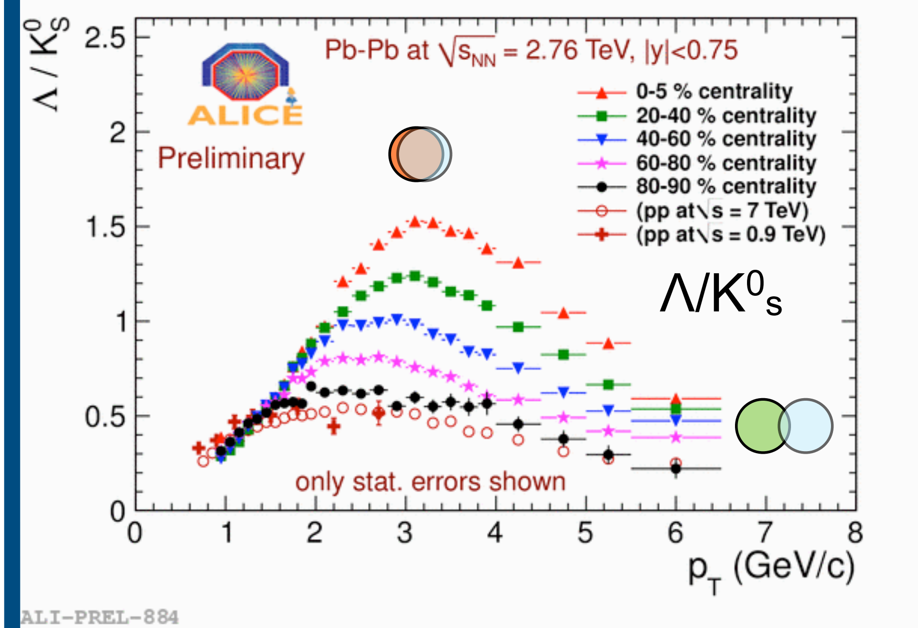


When looking at the p/π ratio, similar centrality dependence for both **LHC** and **RHIC** data.

Flat with $dN_{ch}/d\eta$ from pp to very central events but value **clearly smaller** than statistical thermal model predictions

Particle ratio have the same behaviour vs. centrality than at RHIC energies.

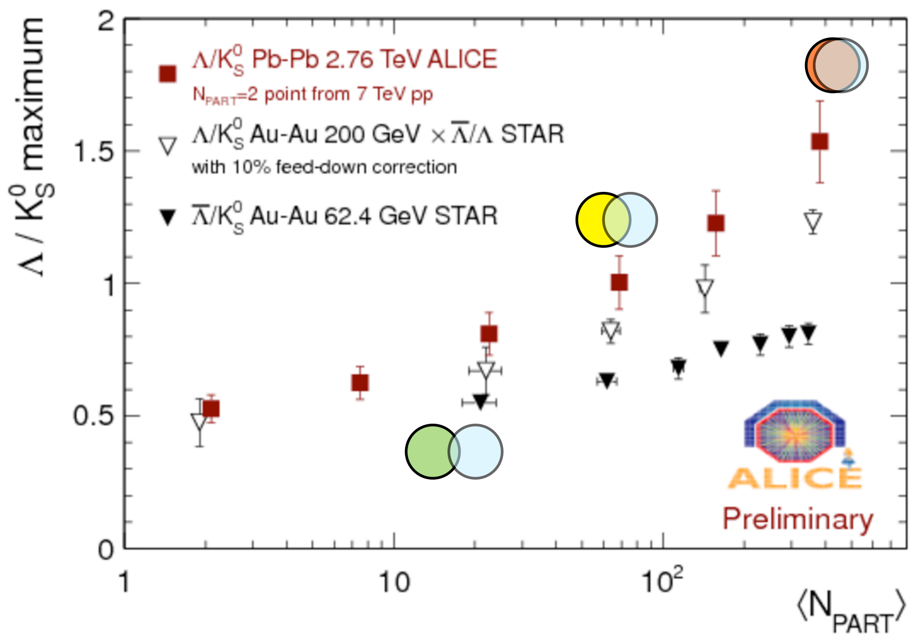
Baryon production and centrality dependence



Transverse momentum (p_T) **region** where **more** baryons than mesons are observed for most central events;

Magnitude decreases from central to peripheral events down to pp ratio.

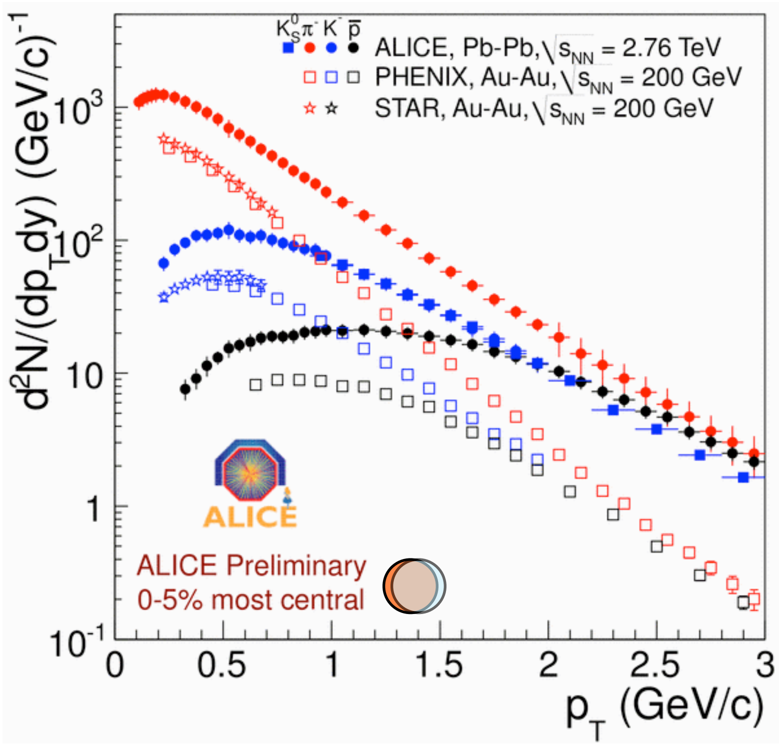
Magnitude increases with both centrality and beam energy when comparing LHC and RHIC: $\sqrt{s_{NN}}$ = 62.4→200→2760 GeV



Baryon/meson vs. p_T increases from pp to a value above unity for central Pb-Pb

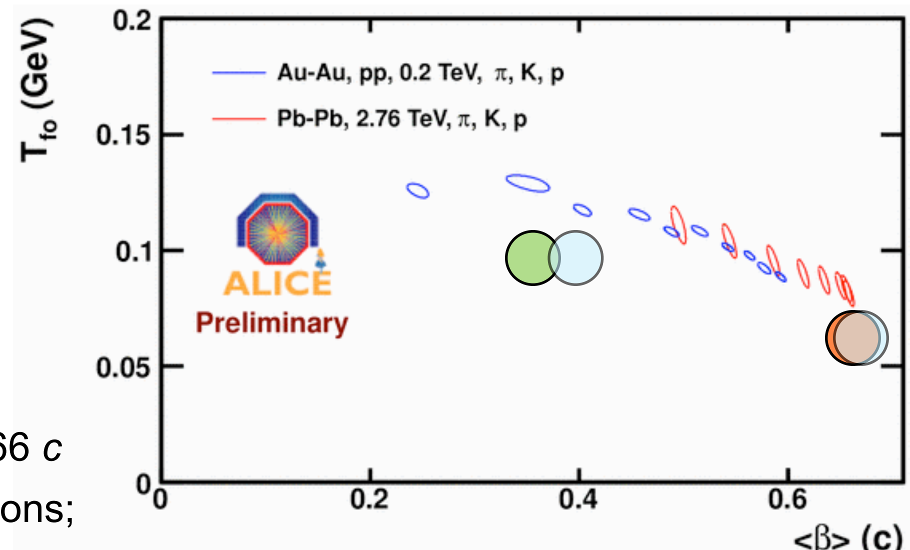
Stronger radial flow observed for π,K,p

see presentation of R. Preghenella



For most central events:

⇨ Transverse momentum spectra change from RHIC to LHC: dramatic effect for the protons.



Radial flow estimated by Blast Wave fit: <β>≃0.66 *c*

⇨ stronger than recent hydrodynamics predictions;

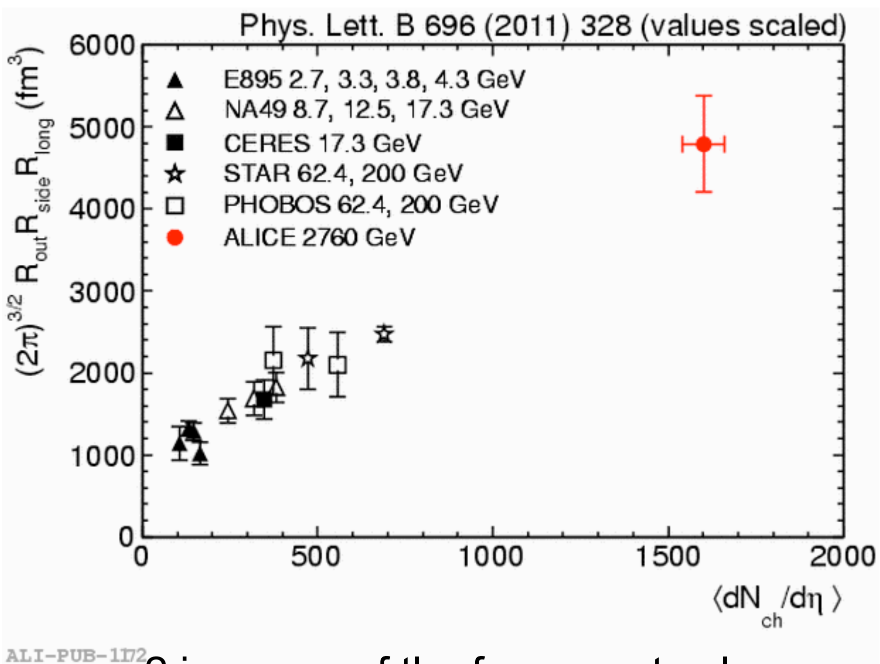
Kinetic freeze-out parameter for LHC data seems to be slightly lower that at RHIC.

Mass and centrality dependence indicate a stronger radial flow at the LHC than at RHIC.

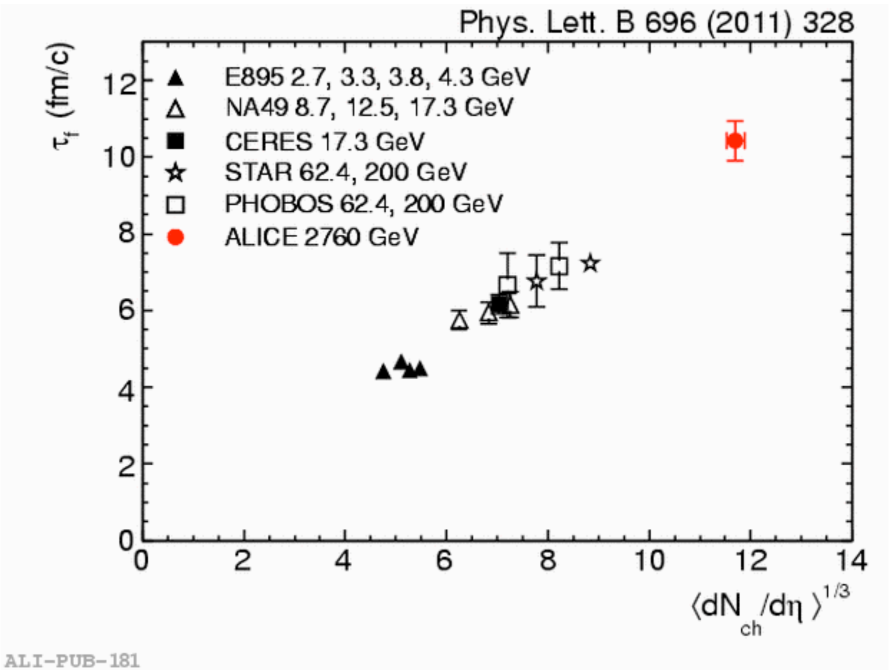
Space-time Evolution of the System

Using HBT, momentum-space two-particle correlations

Homogeneity region, $R_{out} R_{side} R_{long}$



Emission time, τ_f



x2 increase of the freeze-out volume compared to the one at RHIC

$$\tau_f \sim R_{long} \sqrt{m_T/T}$$

Larger homogeneity region at the LHC.

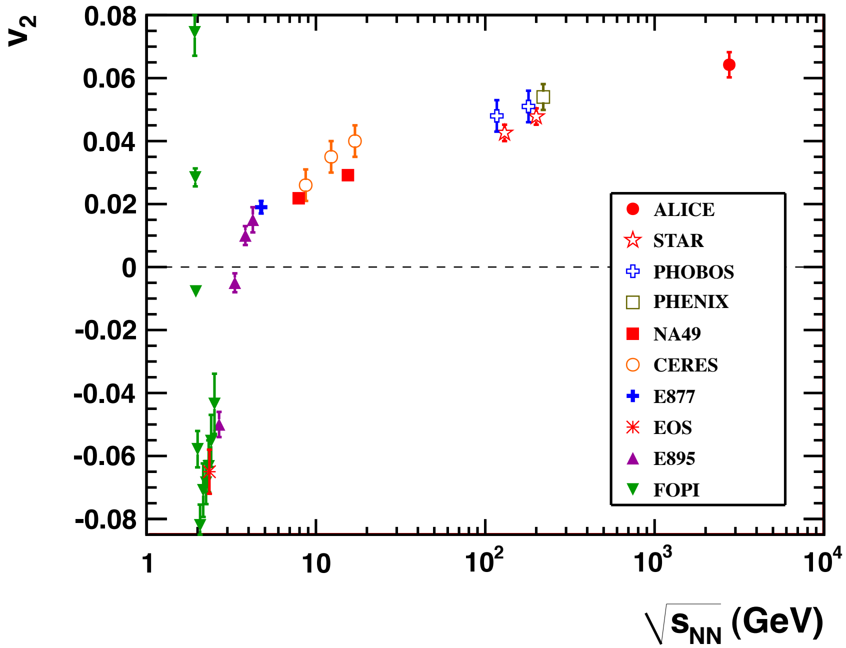
30% longer emission time at the LHC.

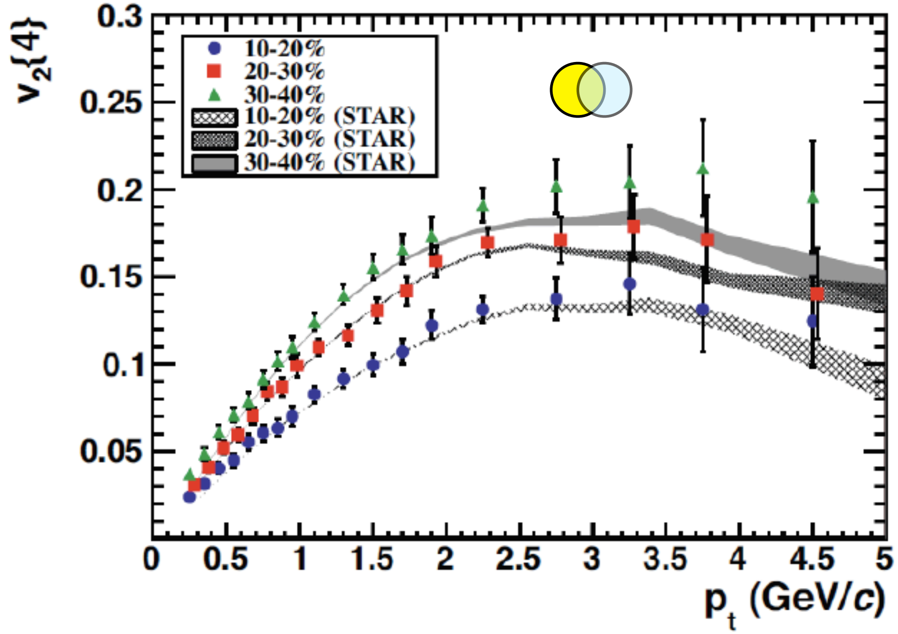
Volume ~ $(2\pi)^{3/2} R_{out} R_{side} R_{long}$

Elliptic Flow: energy, p_T and centrality dependence

Increase of v_2 from RHIC to LHC

K.Aamodt et al. (ALICE Collaboration)
Phys. Rev. Lett. 105, 252302 (2010)





Described by hydrodynamics with:

- ⇨ Glauber geometry;
- ⇨ viscous corrections, η/s still small (~0.1-0.2);
- ⇨ changes expected in space-time evolution.

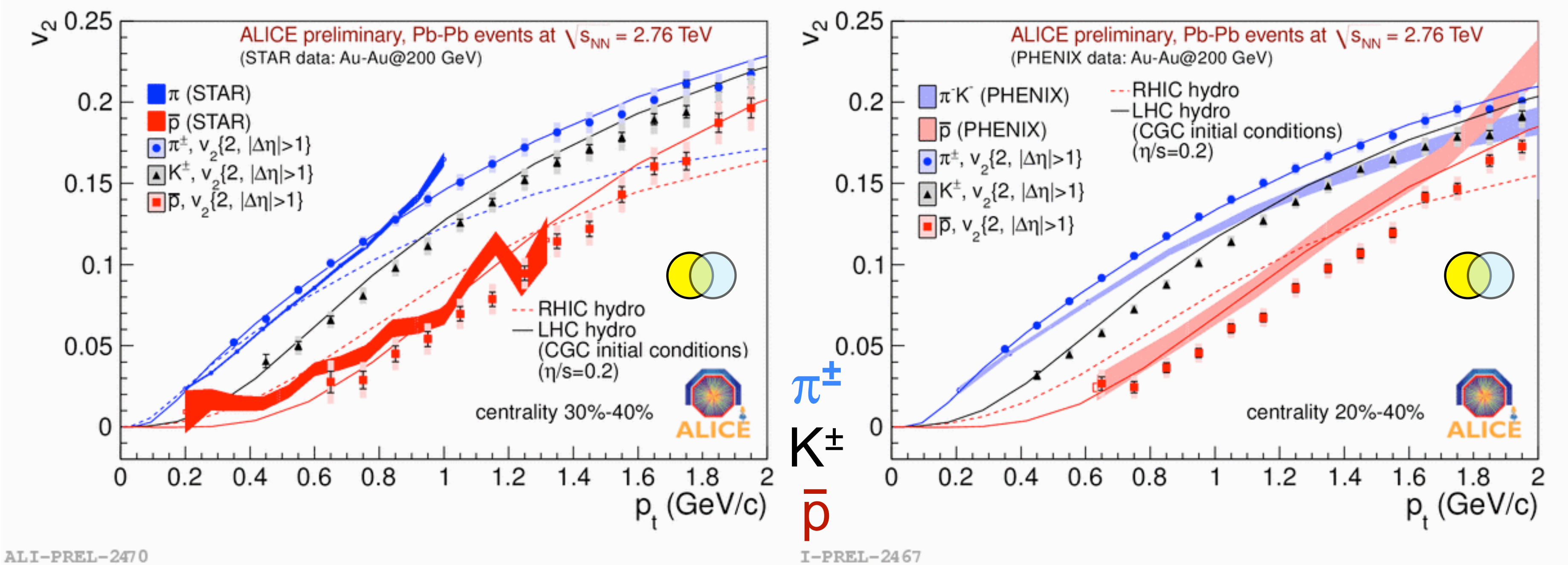
Very little change in charged particle v_2 versus p_T between:

- ⇨ RHIC (STAR) data at 0.2 TeV;
- ⇨ LHC (ALICE) data at 2.76 TeV.

For three centrality classes, consistent with hydro (Heinz; Eskola)

Elliptic flow: PID and mass dependence

M.Krzewicki and R.Snellings for the ALICE Collaboration (QM 2011)



STAR: Phys. Rev. C 77 (2008) 054901

PHENIX: Phys. Rev. Lett. 91 (2003) 182301

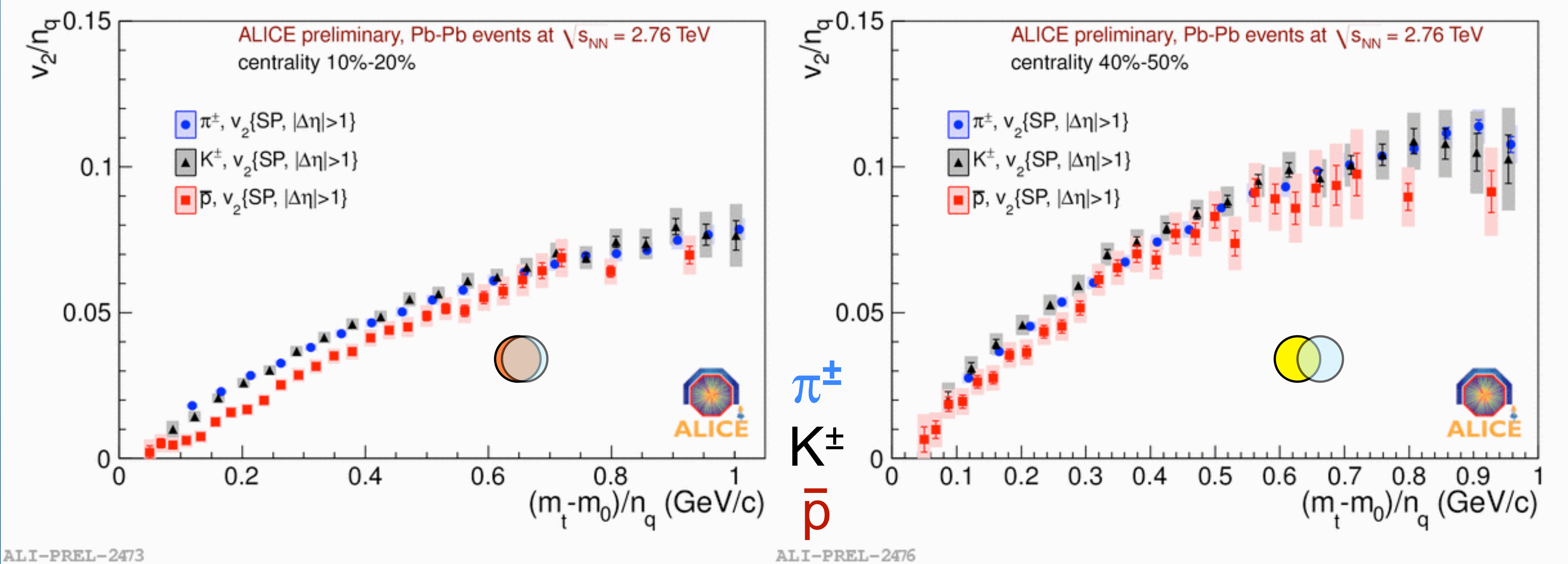
Hydro curves by Shen, Heinz, Huovinen and Song, arXiv:1105.3226

At low p_T, hydro predicts a larger mass-splitting for LHC data than for RHIC (radial flow in spectra)

⇨ CGC initial conditions and η/s ~ 0.2;

Elliptic flow: Constituent Quark Scaling

M.Krzewicki and R.Snellings for the ALICE Collaboration (QM 2011)



Quark scaling:

⇨ appears to work for π and K at low p_T

⇨ does not work for protons at low p_T

⇨ may work (large uncertainties) for π K p at high p_T

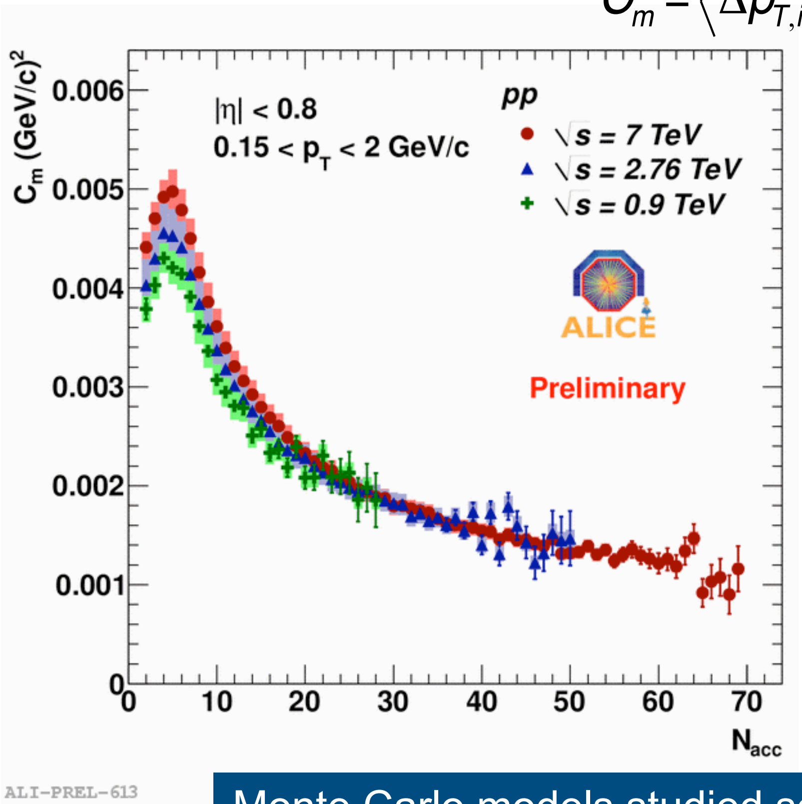
Transverse Momentum Fluctuations

see presentation of P. Christakoglou

Identify fluctuations which may occur close to phase transition for the created system.

⇨ for instance, visualise p_T fluctuations via the 2-particle correlator:

$$C_m = \langle \Delta p_{T,i}, \Delta p_{T,j} \rangle = \frac{1}{\sum_{k=1}^{n_{ev}} N_k} \sum_{k=1}^{n_{ev}} \sum_{i=1}^{N_k} \sum_{j=i+1}^{N_k} \left(p_{T,i} - \langle p_T \rangle_m\right)\left(p_{T,j} - \langle p_T \rangle_m\right)$$



⇨ rather small effect so √ and normalisation by <p_T>;

Monte Carlo models studied so far cannot describe the observed effect.
Detailed studies of the influence of flow and jet correlations may help.

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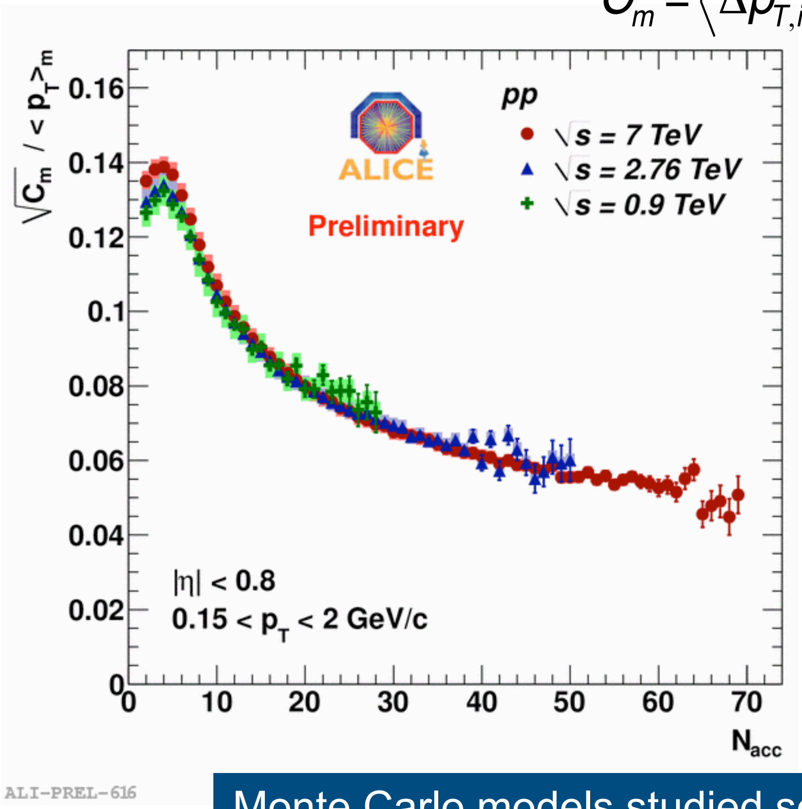

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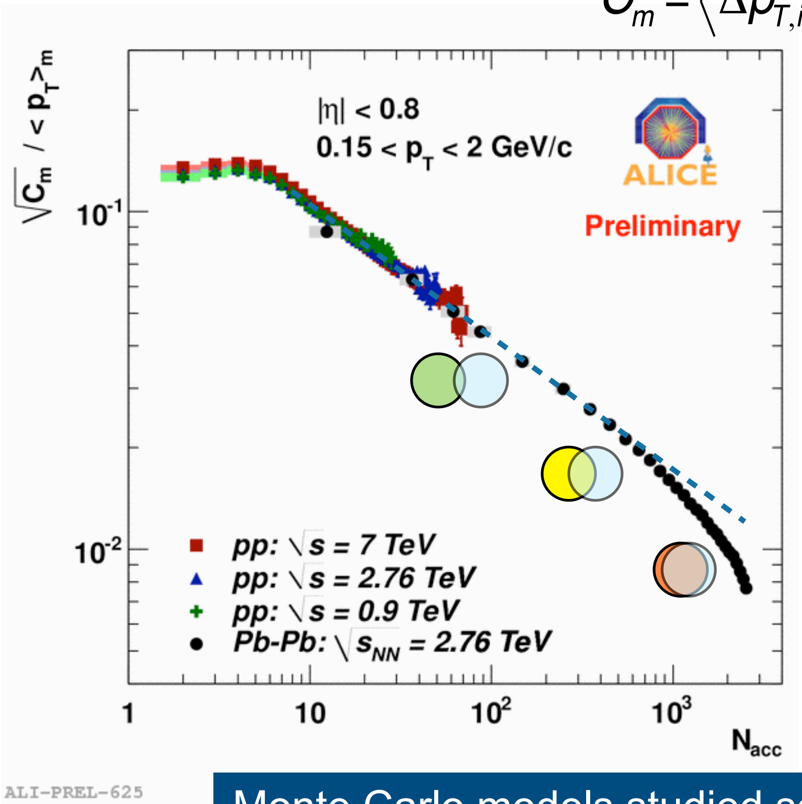


⇨ rather small effect so √ and normalisation by $<p_T>$;

⇨ universal scaling with energy in pp collisions;

⇨ regular evolution from pp to high multiplicity pp and mid-peripheral Pb-Pb: a power law fit the pp baseline up to 30-40% central Pb-Pb events;

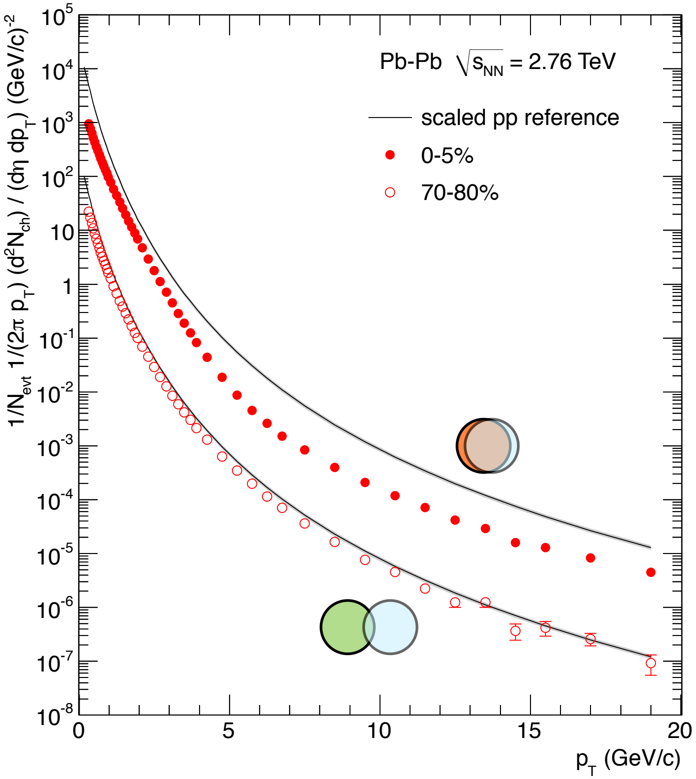
⇨ for more central collisions, the behaviour clearly differs.

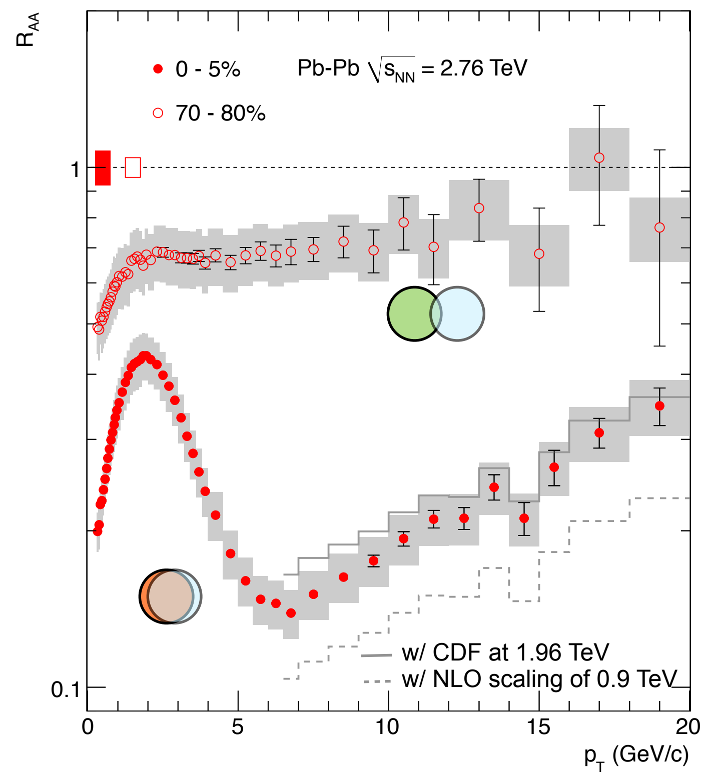
Monte Carlo models studied so far cannot describe the observed effect. Detailed studies of the influence of flow and jet correlations may help.

Suppression of charged particles at high p_T

Hagedorn parameterisation for comparison
Peripheral: ok (power law for p_T > 3 GeV/c)

ALICE Collaboration, Phys. Lett. B696 (2011) 30





Central collisions (0-5%): Exponential shape below p_T = 5 GeV/c

Interpolation for pp reference at 2.76 TeV.

For central collisions, the suppression of charged particle (R_{AA}) production is stronger at the LHC than at RHIC. Minimum observed at p_T = 6-7 GeV/c then increase with p_T.

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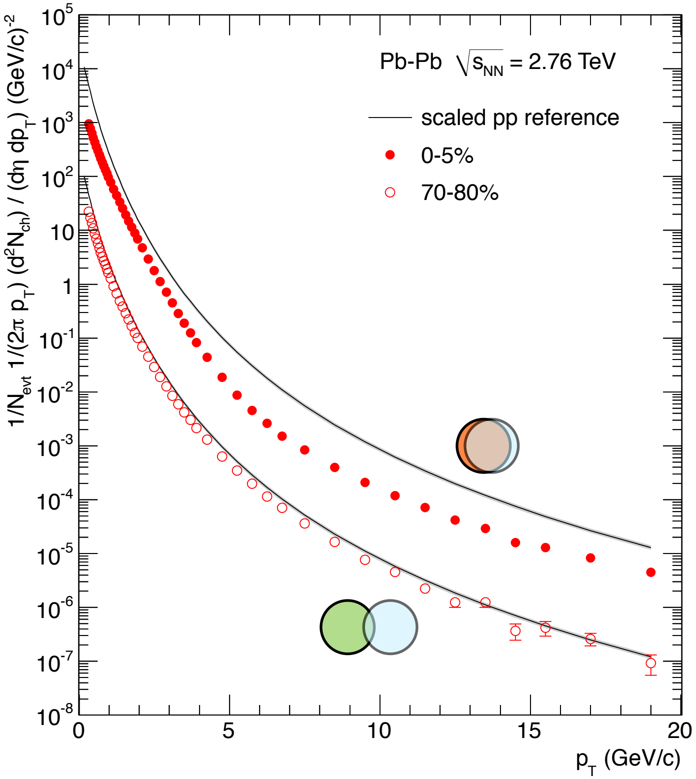

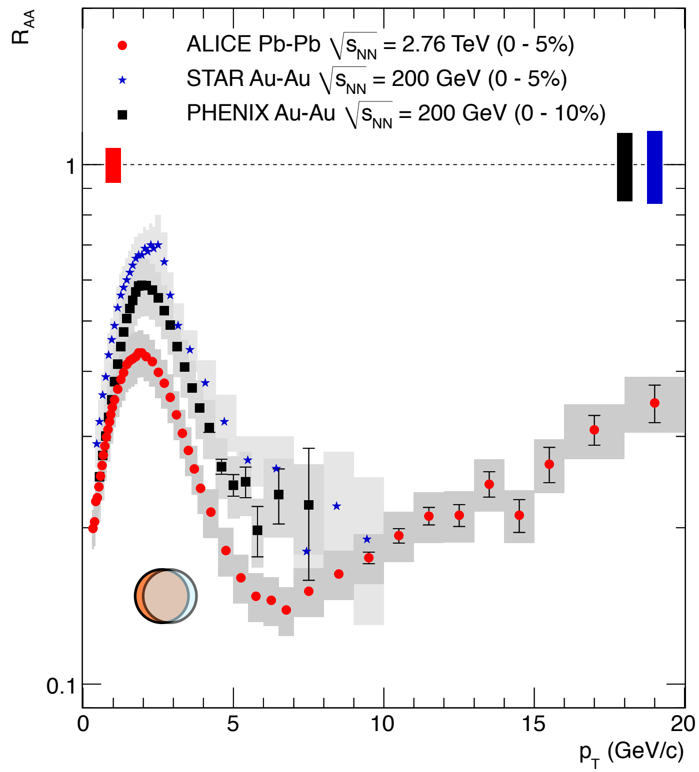

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Interpolation for pp reference at 2.76 TeV.

Comparison with STAR and **PHENIX** at 0.2 TeV

For central collisions, the suppression of charged particle (R_{AA}) production is stronger at the LHC than at RHIC. Minimum observed at p_T = 6-7 GeV/c then increase with p_T.

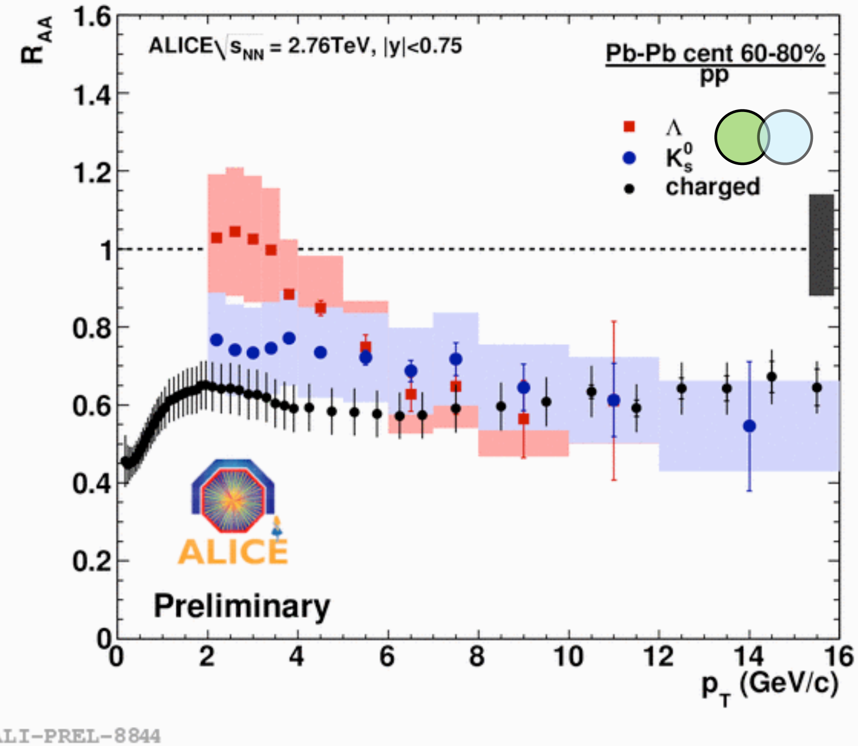
Suppression of identified particles K^0_s and Λ

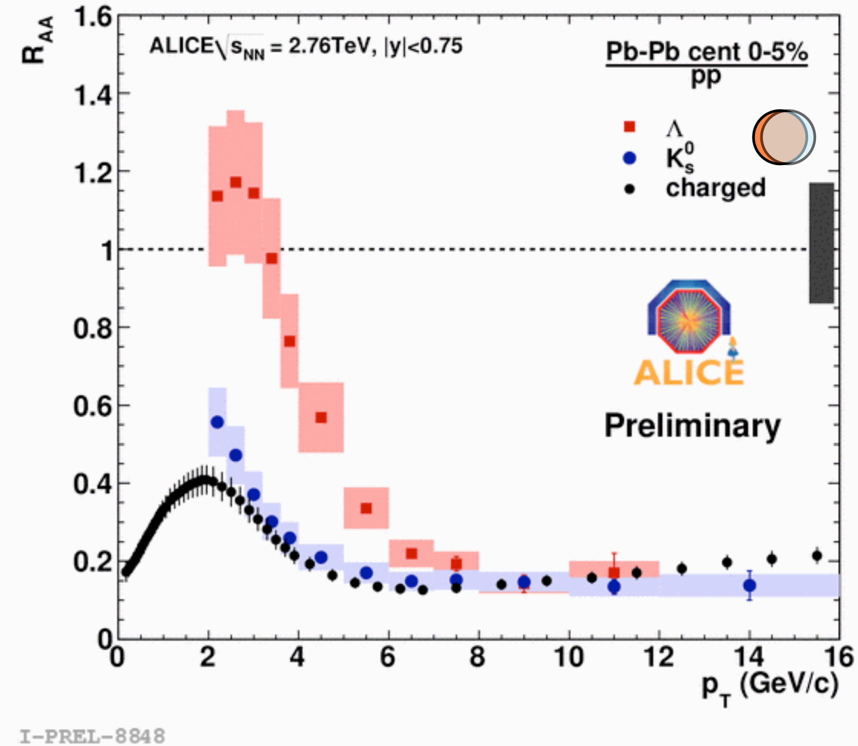
S.Schuchmann for the ALICE Collaboration at QM 2011

For both peripheral (left) and central (right) Pb-Pb collisions:

Strange baryon (Λ): convolution of enhanced production at intermediate p_T and suppression at high p_T

Strange meson (K^0_s): behaviour roughly equivalent to the unidentified particle suppression up to high p_T

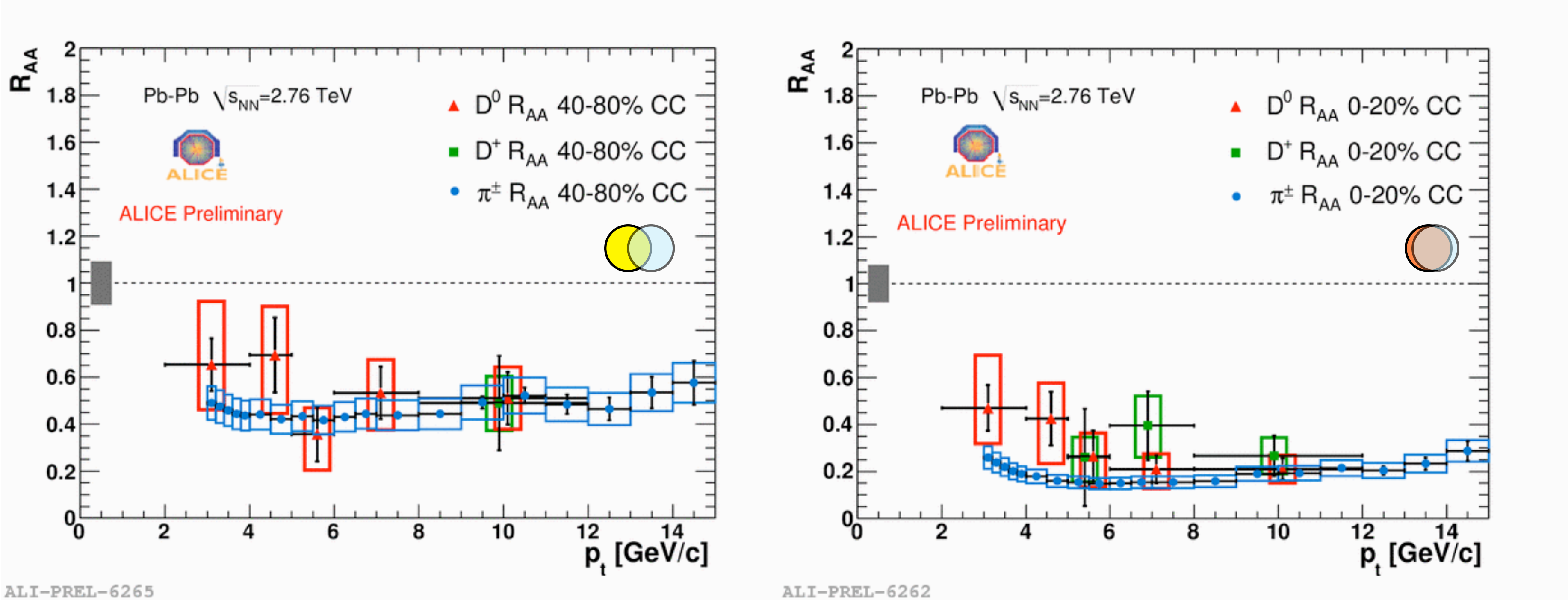




For central collisions, the suppression (R_{AA}) of strange meson K^0_s and baryon Λ is compatible with the charged particle at high p_T (p_T > 8 GeV/c)

Heavy Flavour: R_{AA} of D^0 and D^+

see presentation of D. Stocco (especially for comparison with models)



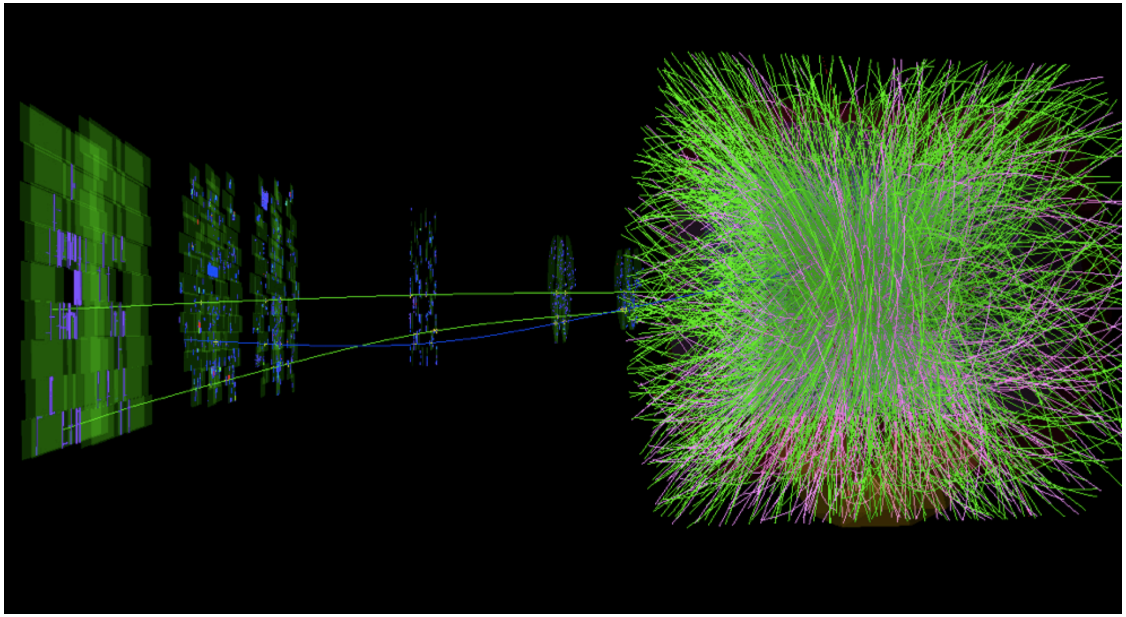
Suppression for charm is also a factor 4-5 for p_T above 5 GeV/c for central collisions
Compatible with pions R_{AA} (slightly larger below p_T = 5 GeV/c)

Probably a hot medium effect (no/little shadowing in this p_T region);
Possibly $R_{AA}(D) \gtrsim R_{AA}(\pi)$ but more statistics needed before concluding.

J/Psi production and R_{AA}

see presentation of L. Bianchi (especially for comparison with models)

Reconstruction of J/psi in the forward region using the muon arm: 2.5<y<4



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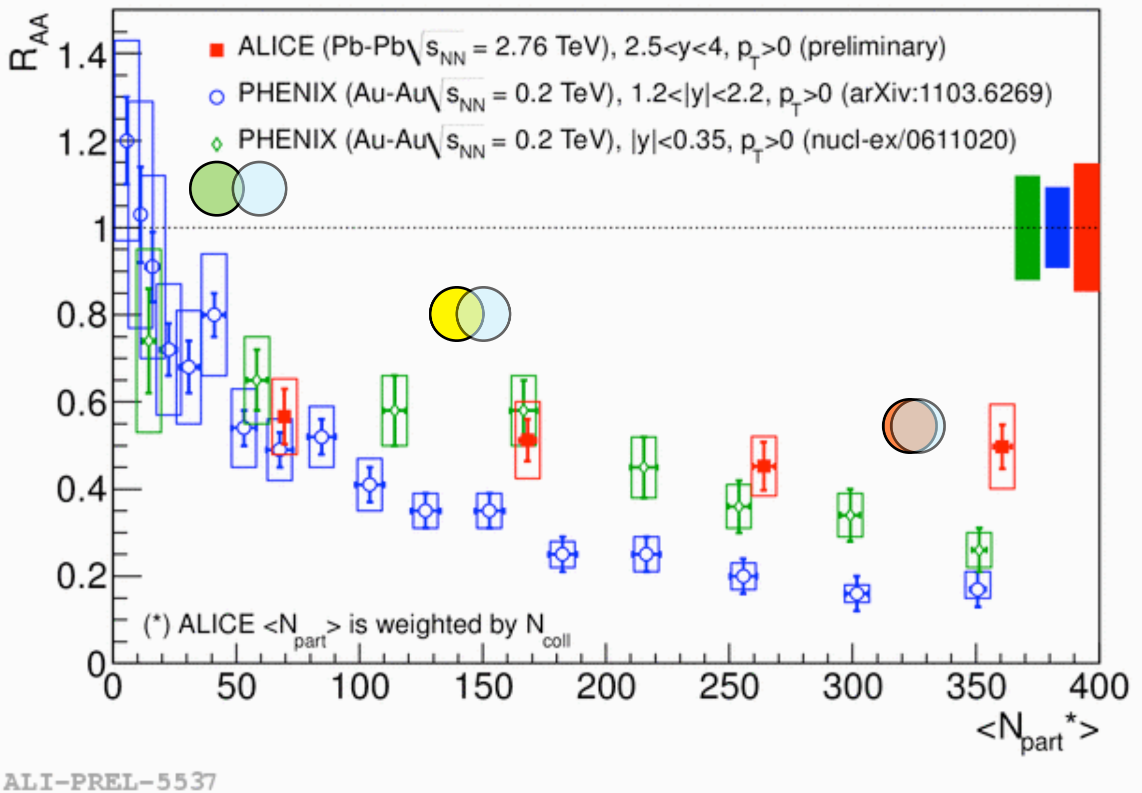

Somehow better agreement with mid-rapidity results than forward ones at RHIC...

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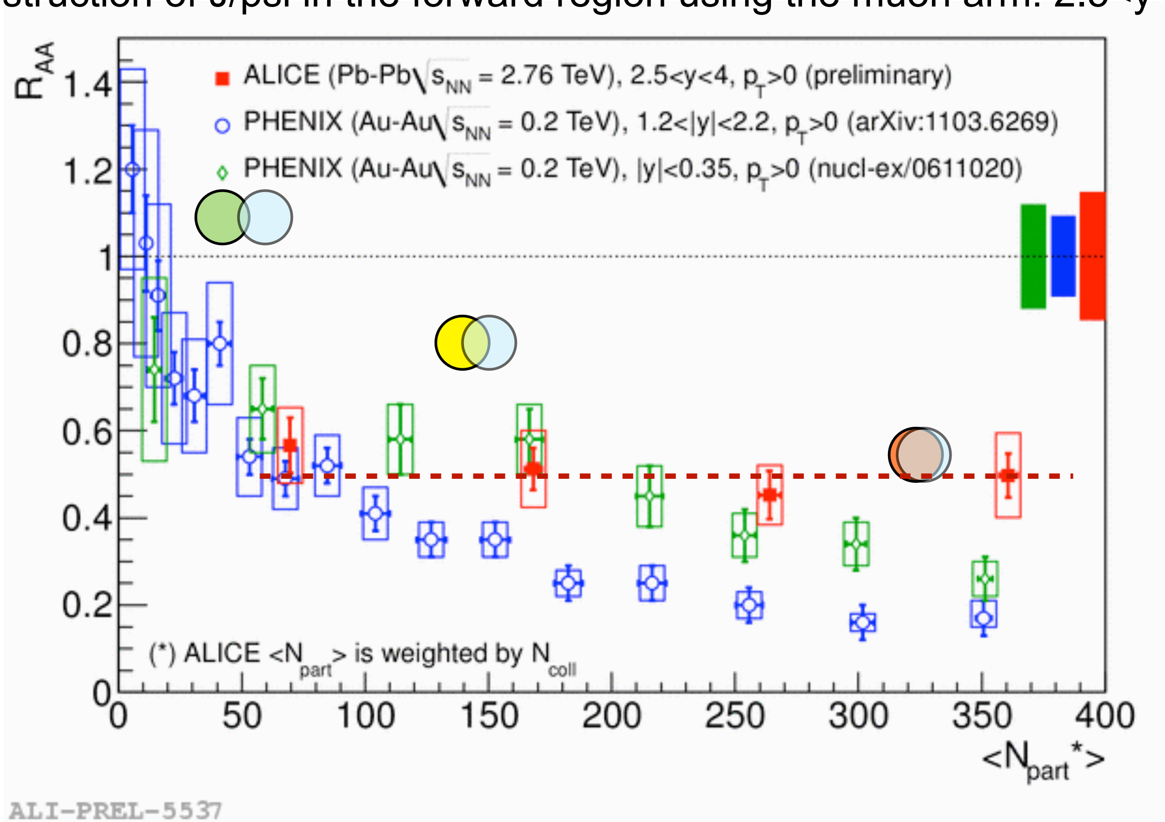


Somehow better agreement with mid-rapidity results than forward ones at RHIC...

The centrality dependence of the inclusive J/psi R_{AA} is not strong in the forward region (note that peripheral bin is still 40-80%).

Summary: first Pb-Pb collisions in ALICE

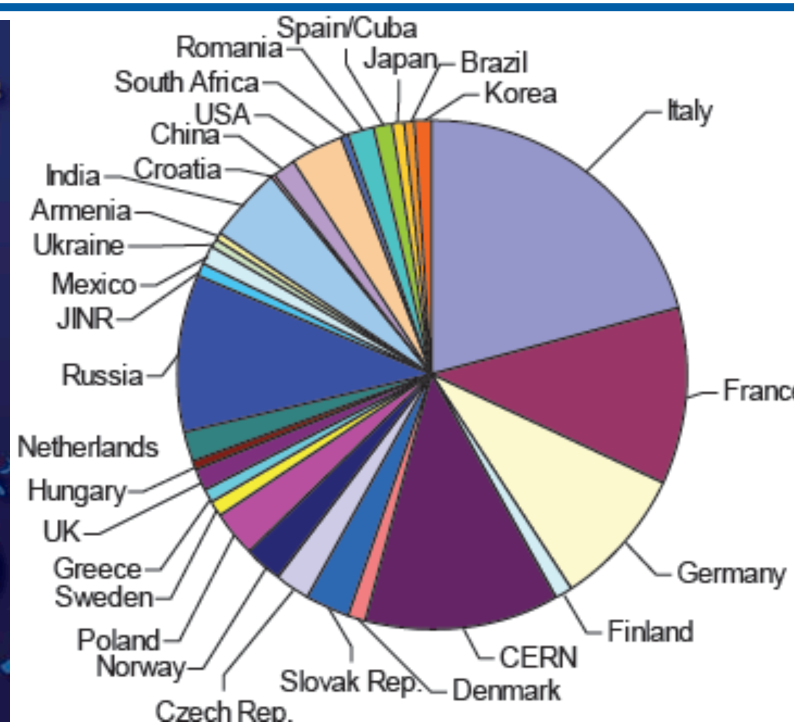
- Data favours models with moderation of particle production vs. centrality;
- Particle ratio have the same behaviour vs. centrality than at RHIC energies;
- Baryon/meson vs. pT increases from pp to a value above unity for central Pb-Pb;
- Mass and centrality dependence indicate a stronger radial flow at the LHC than at RHIC;
- Larger homogeneity region and 30% longer emission time at the LHC;
- Increase of v2 from RHIC to LHC consistent with viscous hydro and η/s still small (~0.1-0.2);
- Intriguing p_T fluctuations;
- Suppression of charged particle (RAA) production is stronger at the LHC than at RHIC but with no strong flavour dependence.

Already submitted or published analyses

Charge particle multiplicity density	Phys. Rev. Lett. 105 (2010) 252301
Elliptic flow of charged particles	Phys. Rev. Lett. 105 (2010) 252302
Suppression of charged particle at high p_T	Phys. Lett. B696 (2011) 30
Centrality dependence of charged multiplicity	Phys. Rev. Lett. 106 (2011) 032301
Two-pion Bose-Einstein correlations	Phys. Lett. B696 (2011) 328
Higher Harmonic Anisotropic Flow Measurements	Phys. Rev. Lett. 107 (2010) 032301

Only a small fraction of the available results: time limit and personal bias...
Many more analyses about to be published with the data recorded end of 2010:
particle spectra, bulk correlation, high p_T measurements (jets), heavy flavour.

ALICE Collaboration



List of other ALICE presentations on Pb-Pb where many details will be given:

- ⇨ 15:00 Panos Christakoglou: First results on the event-by-event fluctuations and correlations in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$~TeV
- ⇨ 15:45 Roberto Preghenella: Transverse momentum spectra of identified charged hadrons with the ALICE detector in Pb-Pb collisions at the LHC
- ⇨ 17:15 Diego Stocco: Heavy flavour measurements in Pb-Pb collisions at $\sqrt{s_{NN}}=2.76$~TeV with the ALICE experiment
- ⇨ 17:45 Livio Bianchi: J/psi production measurements in pp and PbPb collisions in the ALICE experiment at the LHC