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
The ALICE experiment at CERN LHC

B. Hippolyte

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Commissioning, calibration and data taking

First particles from machine
15.6.08

1st Circulating beam
10.9.08

LHC “incident”
11.9.08

24/7 cosmics DAQ

LHC back
15.7.09

First collisions
23.11.09

detector installation

2008

01 02 03 04 05 06 07 08 09 10 11 12

0.9 TeV runs
2-3,27.05.10

1st Collisions
7.11.10

End of run
6.12.10

2.76 TeV run
24-27.03.11

PbPb

2009

01 02 03 04 05 06 07 08 09 10 11 12

300k MB

8M MB 800M MB, 50M muons 30M MB 70M MB

MiniFrame refurbishing

PMD

EMCAL

more TRD

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ALICE Physics Results for pp Collisions

Already submitted or published analyses:

- Charge particle density or multiplicity
  - 0.9 TeV
  - 0.9 TeV & 2.36 TeV
  - 7 TeV
- pbar/p ratio (0.9 TeV and 7 TeV)
- Momentum distributions (0.9 TeV)
- Identified particle production & pT spectra
  - π,K,p production (0.9 TeV)
  - Strange particle production (0.9 TeV)
- Bose-Einstein correlations (0.9 TeV)
  - (0.9 and 7 TeV)
- Rapidity and pT of inclusive J/psi (7 TeV)

Ongoing analyses:

- pQCD: Event topology, azimuthal correlations, jet fragmentation, ...
- Multi-strange pT spectra: baryon (charged Ξ & Ω), Resonances...
- Heavy Flavour: charm (D0, 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

- 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.
Power law dependence fits well and faster in $\text{Pb-Pb} \sim s^{0.15}$ than in $\text{pp} \sim s^{0.11}$

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

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

$\Rightarrow$ Based on Bjorken formula, estimation of the energy density: $\epsilon(\tau)_{\text{LHC}} \approx 3 \epsilon(\tau)_{\text{RHIC}}$

At mid-rapidity and for the most central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV
$\Rightarrow$ 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
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 $dN_{ch}/d\eta \sim N_{\text{scattered nucleons}} \sim N_{\text{part}}$

- “nuclear amplification” independent of $\sqrt{s}$

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

- contribution increasing with $\sqrt{s}$ and centrality.

**p-QCD Monte Carlo:**

- DPMJET, too strong rise with $N_{\text{part}}$

- 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. $\sqrt{s}$ and centrality (A);

- Geometric scaling.

Data favours models with moderation of particle production vs. centrality.
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Particle composition vs. $dN_{ch}/d\eta$

When looking at the $K/\pi$ 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 $p/\pi$ 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.

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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: $\sqrt{s_{NN}} = 62.4 \rightarrow 200 \rightarrow 2760$ GeV

Baryon/meson vs. $p_T$ 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.

For most central events:

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

Radial flow estimated by Blast Wave fit: $<\beta> \approx 0.66 \, c$

- stronger than recent hydrodynamics predictions;

Kinetic freeze-out parameter for LHC data seems to be slightly lower than 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, \( \tau_f \)

\[ \tau_f \sim R_{long} \sqrt{m_T / T} \]

\( x^2 \) increase of the freeze-out volume compared to the one at RHIC

Larger homogeneity region at the LHC.

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

30% longer emission time at the LHC.
Described by hydrodynamics with:

- Glauber geometry;
- viscous corrections, \( \eta/s \) 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)


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 $\eta/s \sim 0.2$;
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

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

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

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

⇒ rather small effect so $\sqrt{\text{and normalisation by } \langle p_T \rangle}$;

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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⇒ rather small effect so $\sqrt{\cdot}$ and normalisation by $\langle p_T \rangle$;

⇒ universal scaling with energy in pp collisions;

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\[ C_m = \langle \Delta p_{T,i}, \Delta p_{T,j} \rangle = \frac{1}{n_{av}} \sum_{k=1}^{N_k} \sum_{i=1}^{N_k} (p_{T,i} - \langle p_T \rangle_m) (p_{T,j} - \langle p_T \rangle_m) \]

\[ \sum_{k=1}^{N_k} N_k \]

\( \Rightarrow \) rather small effect so \( \sqrt{\cdot} \) and normalisation by \( \langle p_T \rangle \);

\( \Rightarrow \) universal scaling with energy in pp collisions;

\( \Rightarrow \) 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;

\( \Rightarrow \) 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 $p_T$

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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Suppression of charged particles at high $p_T$

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

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

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 $p_T$. 


Interpolation for pp reference at 2.76 TeV.

Comparison with STAR and PHENIX at 0.2 TeV

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Suppression of identified particles $K^0_s$ and $\Lambda$

S. Schuchmann for the ALICE Collaboration at QM 2011

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

Strange baryon ($\Lambda$): 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 $\Lambda$ 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 $R_{AA}(D) \geq R_{AA}(\pi)$ but more statistics needed before concluding.

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

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. \( p_T \) 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 \( v_2 \) from RHIC to LHC consistent with viscous hydro and \( \eta/s \) 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
- Elliptic flow of charged particles
- Suppression of charged particle at high \( p_T \)
- Centrality dependence of charged multiplicity
- Two-pion Bose-Einstein correlations
- Higher Harmonic Anisotropic Flow Measurements

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.
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 $\sqrt{s_{\text{NN}}} = 2.76$~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 $\sqrt{s_{\text{NN}}} = 2.76$~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