Latest QCD results in p+p and Pb+Pb collisions from ATLAS

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Data collected in 2010-2011

ATLAS Online Luminosity $\sqrt{s} = 7$ TeV

**pp 2010**
- Total Delivered: 48.1 pb$^{-1}$
- Total Recorded: 45.0 pb$^{-1}$

**pp 2011**
- Total Delivered: 5.61 fb$^{-1}$
- Total Recorded: 5.25 fb$^{-1}$

ATLAS Online Luminosity $\sqrt{s_NN} = 2.76$ TeV

**PbPb 2010**
- Total Delivered: 166 ub$^{-1}$
- Total Recorded: 158 ub$^{-1}$

**PbPb 2011**
- ~160 μb$^{-1}$
Particle production

d\(\frac{dN_{\text{ch}}}{d\eta}\) distribution in a wide pseudorapidity range \(|\eta|<2.5\)

- three energies available: 900 GeV, 2.36 TeV and 7 TeV
- an increase in the number of particles by a factor ~2 from 900 GeV to 7 TeV
- data above predictions from all models

Particle production

Particle pseudorapidity density at $\eta=0$

An attempt to identify regions with a better data-MC agreement:
- energy dependence studied
- minimal transverse momentum $p_T>100$ MeV or $p_T>500$ MeV
- events with different minimal number of tracks ($n_{ch} \geq 1$, $n_{ch} \geq 2$ or $n_{ch} \geq 6$)

Data points always above predictions from Monte Carlo models

measured yields range up to 10 orders of magnitude
• differences in some $p_T$ ranges
• PHOJET closest to the data

Particle production

dN_{ev}/dN_{ch} distribution

- differences in low n_{ch} region possibly due to large diffractive component
- poor agreement at large n_{ch}

Two-particle correlations

\[ R(\Delta \eta, \Delta \phi) = \frac{\langle (n_{ch} - 1) F(n_{ch}, \Delta \eta, \Delta \phi) \rangle_{ch}}{\langle B(n_{ch}, \Delta \eta, \Delta \phi) \rangle_{ch}} - \frac{\langle (n_{ch} - 1) B(n_{ch}, \Delta \eta, \Delta \phi) \rangle_{ch}}{\langle B(n_{ch}, \Delta \eta, \Delta \phi) \rangle_{ch}} \]

\[ F(n_{ch}, \Delta \eta, \Delta \phi) = \left\langle \frac{2}{n_{ch}(n_{ch}-1)} \sum_{i} \sum_{j \neq i} \delta(\eta_i - \eta_j - \Delta \eta) \delta(\phi_i - \phi_j - \Delta \phi) \right\rangle \]

\[ B(n_{ch}, \Delta \eta, \Delta \phi) \] — background obtained from single particle distribution

\textit{arXiv:1203.3549v1 [hep-ex]}
Two-particle correlations in pseudorapidity, integrated over $\Delta \phi$:

- narrower at larger energy
- narrower in the events with higher multiplicity (not shown here)
- MC does not describe $R(\Delta \eta)$ satisfactorily

$\sqrt{s} = 900$ GeV, $n_{ch} \geq 2$

$0 < \Delta \phi < \pi$

ATLAS

$\sqrt{s} = 7$ TeV, $n_{ch} \geq 2$

$0 < \Delta \phi < \pi$

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arXiv:1203.3549v1 [hep-ex]
Two-particle correlations in azimuth, integrated over $\Delta \eta$ in short-range ($0 < \Delta \eta < 2$) or long-range ($2 < \Delta \eta < 5$):

- **Short-range correlation**: the main maximum at $\Delta \phi = 0$ increases with energy, the second maximum at $\Delta \phi = \pi$ is approximately constant.
- **Long-range correlations**: a maximum at $\Delta \phi = \pi$ only.
- **MC describes the shape of $R(\Delta \phi)$, but not the correlation strength**.

arXiv:1203.3549v1 [hep-ex]
Forward-backward multiplicity correlation in symmetric bins in pseudorapidity:

- stronger in 7 TeV than at 900 GeV
- correlation decreasing with the distance in $\eta$
- correlation falling down with transverse momentum (not shown)
- MC models give similar correlations, but predict different values and/or different trends

\[
\rho_{fb} = \frac{\left\langle (n_f - \langle n_f \rangle)(n_b - \langle n_b \rangle) \right\rangle}{\sqrt{\left\langle (n_f - \langle n_f \rangle)^2 \right\rangle \left\langle (n_b - \langle n_b \rangle)^2 \right\rangle}}
\]
Partons producing jets are emitted back-to-back \((\Delta \phi \approx \pi)\)

QCD predicts azimuthal decorrelation especially in the multijet events

MC models successfully describe the measured distributions

Disappearance of one of the jets - attributed to interactions of partons in the hot and dense medium created in heavy ion collisions.

Quantitative description of the jet suppression:

- dijet energy asymmetry

\[ A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}} \]

- dijet azimuthal angle difference

\[ \Delta \phi = \left| \phi_1 - \phi_2 \right| \]
Asymmetry of jet energy in PbPb collisions at 2.76 TeV:
- in peripheral collisions is similar to that in pp collisions
- becomes much larger for more central events
- in HIJING+PYTHIA the dependence on centrality is much smaller.

\[ A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}} \]

jet size parameter \( R = 0.4 \)
Jets in PbPb collisions

Azimuthal dijet decorrelation almost independent of centrality
(with some combinatoric contribution for 0-20% centrality)

\[ \Delta \phi = |\phi_1 - \phi_2| \]

ATLAS-CONF-2011-075.
Jets in PbPb collisions

Azimuthal dijet decorrelation almost independent of centrality (no combinatoric contribution for R=0.2)

\[ \Delta \phi = |\phi_1 - \phi_2| \]

ATLAS-CONF-2011-075.
Jets in PbPb collisions

Jet yields in PbPb collisions at 2.76 TeV:
- increase with centrality of PbPb collisions (~30 times)
- after scaling by the number of nucleon-nucleon collisions the trend becomes opposite - in peripheral collisions scaled yields are ~ 2 times larger

**ATLAS-CONF-2011-075.**
Jets in PbPb collisions

Relative jet yields - yields for centrality 0-10%, ..., 50-60% - divided by the yield for peripheral collisions (60-80%):

\[
R_{CP} = \frac{1}{N_{coll}^{centr}} \frac{1}{N_{ev}^{centr}} \frac{\frac{dN_{jet}^{centr}}{dE_T}}{\frac{dN_{jet}^{60-80\%}}{dE_T}}
\]

- similar dependence on centrality in different jet energy ranges
- \(R_{CP}\) is smaller for more energetic jets

**ATLAS-CONF-2011-075.**
Jets in PbPb collisions

Relative jet yields - yields for centrality 0-10%, ..., 50-60% - divided by the yield for peripheral collisions (60-80%):

\[ R_{CP} = \frac{\frac{1}{N_{\text{coll}}^{\text{centr}}} \cdot \frac{1}{N_{\text{ev}}^{\text{centr}}} \cdot \frac{dN_{\text{jet}}^{\text{centr}}}{dE_T}}{\frac{1}{N_{\text{coll}}^{60-80\%}} \cdot \frac{1}{N_{\text{ev}}^{60-80\%}}} \cdot \frac{dN_{\text{jet}}^{60-80\%}}{dE_T} \]

\( R = 0.2 \)

\( \Rightarrow \) the same \( R_{CP} \) in all three jet energy ranges
Jets in PbPb collisions

Transverse and longitudinal structure of jets

\[ j_T = p_T^{\text{had}} \sin(\Delta R) \]
\[ z = \frac{p_T^{\text{had}}}{E_T} \cos(\Delta R) \]

Comparison of longitudinal structure in 0-10% and 40-80% centralities

- No evidence of significant softening of jets.

ATLAS-CONF-2011-075.
Particle production in PbPb collisions

Charged particle spectra in PbPb collisions at 2.76 TeV:
- measured up to ~30 GeV as a function of centrality and \( \eta \) (not shown)
- \( R_{CP} \) drops between 2-7 GeV to the values observed at RHIC
- above 7 GeV \( R_{CP} \) increases reaching 0.5 for the most central collisions

**ATLAS-CONF-2011-079.**
for $J/\psi$ $R_{CP}=0.5$ for the most central collisions

$Z$ boson and $W$ boson measurements are consistent with no suppression, $R_{CP}=1$
Due to fluctuations of nucleon positions the shape of the overlap is frequently deformed and higher order components of a Fourier series are necessary:

$$dN \over d(\phi - \psi_n) \sim 1 + 2v_n \cos(n(\phi - \psi_n))$$

Components up to $n=6$ are large enough to be determined with sufficient accuracy.

Presence of flow is explained by hydrodynamics and requires a fluid with very low viscosity.

Elliptic flow $v_2$ dependence on

- transverse momentum
- pseudorapidity

in the most central events flow is small

the largest $v_2$ values are obtained for centrality 30-50%

the maximal $v_2$ value is reached for transverse momentum 3-4 GeV

$v_2$ is approximately flat in the pseudorapidity range $|\eta| < 2$

Comparison of $v_n$ values:

- $v_2$ is the largest - with exception of the most central events
- dependence on $p_T$ for all $v_n$ components is similar, they increase with $p_T$ up to 3–4 GeV and then decrease
- approximate scaling of $\frac{v_n^{1/n}}{v_2^{1/2}}$

[Graphs and plots showing the comparison of $v_n$ values across different pseudorapidity bins and $p_T$ ranges.]

arXiv:1203.3087v2 [hep-ex]
Flow in PbPb collisions - two particle correlations method

Decomposition of two-particle correlations:

\[
\frac{dN}{d\Delta \phi} \sim 1 + 2 \sum_{n=1}^{\infty} v_{n,n} \cos(n \Delta \phi)
\]

Factorization in the case of collective expansion:

\[
v_{n,n}(p_T^a, p_T^b) = v_n(p_T^a) v_n(p_T^b)
\]

- Calculations of \(v_{n,n}\) coefficients in slices of \(|\Delta \eta|\) and \(p_T\)
- in central and semicentral collisions for \(|\Delta \eta|>2\) and \(p_T < 3\) GeV
  factorization of coefficients expected in collective expansion and reflecting initial nucleon fluctuations is valid
- no factorization for larger momenta (effects from jets) and \(v_{1,1}\) (momentum conservation)

arXiv:1203.3087v2 [hep-ex]
Analysis of PbPb data from 2011

Preliminary performance results

\[ \frac{dN}{dm_{\mu\mu}} \text{ [GeV\textsuperscript{-1}]} \]

\[ m_{\mu\mu} \text{ [GeV]} \]

- Pb+Pb data 2011
- \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \)
- \( \int L dt \approx 40 \mu b^{-1} \)
- \( p_T^{\mu^+}, p_T^{\mu^-} > 3 \text{ GeV} \)
New data to be collected

- **pp collisions at 8 TeV**

- **pPb collisions in November 2012**
Particle production in PbPb collisions

Charged particle multiplicity:
- three reconstruction methods applied
- measurements without magnetic field used to register particles with $p_T$ downto 30 MeV
- multiplicity increasing with energy faster than logarithmically, but slower than predicted by Landau hydrodynamics
- the centrality dependence of particle density scaled by the number of participants (at $\eta=0$) has the same shape as at RHIC - when the factor of 2 increase is taken into account

Asymmetry increasing for more central events
Values of $A_J$ obtained for $R=0.2$ are very close to that for $R=0.4$

ATLAS-CONF-2011-075.
Jet yields in PbPb collisions at 2.76 TeV:

- increase with centrality of PbPb collisions (~30 times)
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ATLAS-CONF-2011-075.
Jets in PbPb collisions

Three ranges of leading jet energy: 100-125 GeV, 125-150 GeV, 150-200 GeV

- asymmetry more pronounced for lower energy of the leading jet

\[ A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}} \]

\( R = 0.4 \)

ATLAS-CONF-2011-075.
Disappearance of jets at LHC

\[ p+p \]

\[ \text{Calorimeter Towers} \]

\[ \text{Tracks} \]

\[ \text{ATLAS} \]

\[ \text{Run: 169045} \]
\[ \text{Event: 1914004} \]
\[ \text{Date: 2010-11-12} \]
\[ \text{Time: 04:11:44 CET} \]

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Centrality of PbPb collisions

Distribution of the signals registered in the Forward Calorimeter (FCal) is divided into bins with the same number of events (10% of the total).

Fraction of the sampled non-Coulomb inelastic cross section after all trigger selection cuts is estimated to be $100\% \pm 2\%$. 