First Results from Heavy Ion Collisions at the LHC

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Outline

• LHC, ATLAS, CMS, and ALICE, in brief
• The heavy ion beam in LHC
• First physics results
LHC
Large Hadron Collider

- Collides protons with protons, 7 TeV each direction, total 14 TeV
- p-p luminosity: starting with $10^{31} \text{ cm}^{-2}\text{s}^{-1}$, then increasing to $10^{33}$, then $10^{34}$
- Collides heavy ions: Pb-Pb at total 5.5 TeV/nucleon
- Pb-Pb design luminosity: $10^{27} \text{ cm}^{-2}\text{s}^{-1}$

Current status:

- p-p running at 7 TeV total, $2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- Pb-Pb running at 2.8 TeV/nucleon total, $3 \times 10^{25} \text{ cm}^{-2}\text{s}^{-1}$
The LHC Accelerator Layout

- 1232 superconducting dipole magnets, **8.33 Tesla**, 11700 A at 1.9 K
- in total, dipoles contain 7600 km of 36-strand braided superconducting cable weighing 1200 tons
- **27 km** circumference
- **362 MJ per beam**
- Bunch crossing rate ~40 MHz (25 ns bunch spacing)
- 2808 bunches in each ring, $10^{11}$ protons per bunch
Large Hadron Collider - View in Tunnel
Collider cycle: inject, ramp, squeeze, collide

Achieved p-p luminosity of 2E32 - next barriers may be ‘electron clouds’ and unexplained emittance blowup.

– Strong vacuum and e-cloud activity with 50 ns beams for trains of 24 and 36 bunches.

– Trains of 24/36 bunches with 50 ns spacing could barely be injected, and could not be ramped.

– Success when scrub (‘clean’) the vacuum chamber with beam
Vacuum Pressure vs. 24b Train Spacing

Dp VGPB.2.5L3.B vs tsep for 24+24

Pressure increase in LSS3

Tsep micro sec
Emittances for Diff. Bunches (24b Trains)

Also big emittance blow-up measured for 36b trains
Optics Measurements for Heavy Ions

• Very similar to proton optics (at injection, at flat top, before and after squeeze)

At injection (450 Z GeV)

After squeeze (3.5 Z TeV)

• Emittances at injection around 1-2 µmrad (with Pb-γ, factor 2.5 smaller than p-γ).
• Emittances on flat top 1.5-3 µmrad
ATLAS, CMS, ALICE
4558 members
170 institutions
40 countries
700 students

ATLAS Collaboration
Layers and Angle ($\eta$) Coverage in ATLAS

$$\eta = -\ln(\tan(\theta/2))$$

179.9° 179° 170° $\eta$ 10° 1° 0.1°
# ATLAS Detector Status

<table>
<thead>
<tr>
<th>Subdetector</th>
<th>Number of Channels</th>
<th>Approximate Operational Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixels</td>
<td>80 M</td>
<td>97.4%</td>
</tr>
<tr>
<td>SCT Silicon Strips</td>
<td>6.3 M</td>
<td>99.2%</td>
</tr>
<tr>
<td>TRT Transition Radiation Tracker</td>
<td>350 k</td>
<td>98.0%</td>
</tr>
<tr>
<td>LAr EM Calorimeter</td>
<td>170 k</td>
<td>98.5%</td>
</tr>
<tr>
<td>Tile calorimeter</td>
<td>9800</td>
<td>97.3%</td>
</tr>
<tr>
<td>Hadronic endcap LAr calorimeter</td>
<td>5600</td>
<td>99.9%</td>
</tr>
<tr>
<td>Forward LAr calorimeter</td>
<td>3500</td>
<td>100%</td>
</tr>
<tr>
<td>LVL1 Calo trigger</td>
<td>7160</td>
<td>99.9%</td>
</tr>
<tr>
<td>LVL1 Muon RPC trigger</td>
<td>370 k</td>
<td>99.5%</td>
</tr>
<tr>
<td>LVL1 Muon TGC trigger</td>
<td>320 k</td>
<td>100%</td>
</tr>
<tr>
<td>MDT Muon Drift Tubes</td>
<td>350 k</td>
<td>99.7%</td>
</tr>
<tr>
<td>CSC Cathode Strip Chambers</td>
<td>31 k</td>
<td>98.5%</td>
</tr>
<tr>
<td>RPC Barrel Muon Chambers</td>
<td>370 k</td>
<td>97.0%</td>
</tr>
<tr>
<td>TGC Endcap Muon Chambers</td>
<td>320 k</td>
<td>98.6%</td>
</tr>
</tbody>
</table>

Notes:
- Muons do not include the EE chambers (under installation)
• 25 m diameter
• 46 m total length
• 7000 tons weight
• ~3000 km of cables
• Installed just across from the CERN main site, 92 meters below ground
• ATLAS cavern: 55 m long, 32 m wide, 35 m high: detector assembled in situ
Candidate for 
$Z \rightarrow \mu \mu$ decay

- $p_T(\mu^+) = 45$ GeV
- $\eta(\mu^+) = 2.2$
- $p_T(\mu^-) = 27$ GeV
- $\eta(\mu^-) = 0.7$
- $m_{\mu\mu} = 87$ GeV

Collected on 10 May 2010.
K⁰ decay reconstructed

Particle ID through dE/dx (pixel tracker)

Identified φ mesons from φ→K⁺ K⁻ decay
**Christophe Clement**

**Physics at LHC, DESY, June 9th, 2010**

**ATLAS First Physics Results**

**Goal:** Test performance of the ATLAS ID and tracking software

Systematics are under study

Basis for more advanced B-physics analyses

eg. including cascade decay of heavy baryons...

<table>
<thead>
<tr>
<th>Quantity (MeV)</th>
<th>ATLAS (stat only)</th>
<th>PDG (stat(+)(syst))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1322.2±0.07</td>
<td>1321.71±0.07</td>
<td></td>
</tr>
<tr>
<td>1672.78±0.33</td>
<td>1672.45±0.29</td>
<td></td>
</tr>
<tr>
<td>892.1±0.7</td>
<td>891.66±0.26</td>
<td></td>
</tr>
<tr>
<td>49.8±2.1</td>
<td>50.8±0.9</td>
<td></td>
</tr>
</tbody>
</table>

Reasonable agreement at this stage with PDG 09

See also talk by Jed Biesiada

**Motivations**

Study fragmentation model of strange quarks,

Look for flaws in material modelling

Test the magnetic field modelling of the ID

Check the alignment,...

**Selections** ($L \sim 190 \mu b^{-1}$)

- Oppositely charged tracks, $p_T > 100$ MeV,
- Decay vertex fit,
- Transverse distance $L_T$ between PV and $p$,
- $\cos$ (line of flight, momentum $p$) $\sim 1$

• ATLAS measurements have only statistical errors at the moment

• Reasonable agreement of the fitted masses with PDG values

=> Good accuracy of the momentum scale

=> Good modelling of the ID 2T solenoid field (0.4mT map)

• Proper decay time agreement in $K_{S0}$

=> excellent modelling of track efficiency and $p_T/p$ versus $R$

No efficiency or acceptance corrections yet

Basis for future production and cross section measurements
$D^0 \rightarrow K^- \pi^+$

$D^{*+} \rightarrow D^0 \pi^+_s \rightarrow (K^- \pi^+) \pi^+_s$ ($\pi^+_s = \text{soft pion}$)

$D^+ \rightarrow K^- \pi^+ \pi^+$

$D_{s^+} \rightarrow \Phi \pi^+ \rightarrow (K^+ K^-)\pi^+$
The Monte Carlo.

The parameters of the signal and the background normalization are varied in the fit to the data, while the parameters of the polynomial were extracted from the Monte Carlo simulation.

Figure 28: Distribution of conversion candidate radius, (a), and energy and hit energy, no nearby track hits.

The invariant mass distribution of the photon pairs is shown in Fig. 29 from the data and Monte Carlo. The Monte Carlo is normalized to the same number of conversion candidates in the data, although in simulations true Dalitz decays, neutral mesons is shown in sub-figure (a). The Monte Carlo simulation and the filled component shows the expected contribution from the Dalitz decays (true Dalitz decays) Monte Carlo (true conversions) Monte Carlo (conversion candidates) Monte Carlo (background) Data 2009 (s = 0.9 TeV) Fit to data

As can be seen from Fig. 30, the number of events / 0.2 MeV taken from the Monte Carlo simulation while their normalizations are from the data, 527 entries / 30 MeV, agrees with the mass obtained using the fitted mean for the peak with the fit superimposed to the data. The Monte Carlo simulation. The following comparison between data and Monte Carlo simulations should not be taken as a precise analysis of the underlying processes.

Reconstructed neutral pions

Reconstructed eta mesons
(tighter cuts - greater cluster energy and hit energy, no nearby track hits)
Jets at 7 TeV

$J/\psi$ from muon systems
ATLAS Detector - Grid

ATLAS simulation and data analysis require the resources of the **LHC Computing Grid**

- Raw data + processed data + simulation > 550 Mbytes/s
- Data processing + event simulation needs 20,000 processors full time

140 Tier
2 sites in 32 countries

Nov 13:

<table>
<thead>
<tr>
<th>sites</th>
<th>countries</th>
<th>totalCPU</th>
<th>freeCPU</th>
<th>runJob</th>
<th>waitJob</th>
<th>seAvail TB</th>
<th>seUsed TB</th>
<th>maxCPU</th>
<th>avgCPU</th>
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<tr>
<td>264</td>
<td>55</td>
<td>79136</td>
<td>32853</td>
<td>51878</td>
<td>4038472</td>
<td>548863.84</td>
<td>3246227.52</td>
<td>105584</td>
<td>75531</td>
</tr>
</tbody>
</table>
ATLAS Trigger

Interaction rate
~1 GHz

Bunch crossing rate 40 MHz

LEVEL 1 TRIGGER
< 75 (100) kHz

Regions of Interest

LEVEL 2 TRIGGER
~ 1 kHz

EVENT FILTER
~ 100 Hz

CALO MUON TRACKING

Pipeline memories

Derandomizers

Readout drivers (RODs)

Readout buffers (ROBs)

Event builder

Full-event buffers and processor sub-farms

Data recording
ATLAS p-p Physics

Increase in energy of factor of 7 over previous machine (Tevatron)

Larger cross sections, access to much larger particle masses

- **Discovery**: Higgs, SUSY, Technicolor, other new Physics Beyond the Standard Model, mini black holes, extra dimensions, dark matter...

- **Precision**: Top quark, W/Z, rare decays, other QCD...

- **Technical**: Jet physics, complex event topology, triggering, flavor tagging...
The Experimental Challenges

Interesting cross sections are often small

Large QCD backgrounds have theoretical uncertainties factor 3-4
CMS detector at the LHC

EM Calorimeter (ECAL)

Hadron Calorimeter (HCAL)

Beam Scintillator Counters (BSC)

Forward Calorimeter (HF)

TRACKER (Pixels and Strips)

MUON (Barrel)

MUON (Endcaps)
The HI beam in LHC
First ramp to full energy was on Nov 5

First collisions were on Nov 7

Duration of physics data-taking ~ 4 weeks
# Key Parameters of LHC Pb from LHC Design Report

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Early Beam</th>
<th>Nominal</th>
</tr>
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<tbody>
<tr>
<td>Energy per nucleon</td>
<td>TeV</td>
<td>2.76</td>
<td>2.76</td>
</tr>
<tr>
<td>Initial ion-ion Luminosity $L_0$</td>
<td>cm$^{-2}$ s$^{-1}$</td>
<td>$\sim 5 \times 10^{25}$</td>
<td>$1 \times 10^{27}$</td>
</tr>
<tr>
<td>No. bunches, $k_b$</td>
<td></td>
<td>62</td>
<td>592</td>
</tr>
<tr>
<td>Minimum bunch spacing</td>
<td>ns</td>
<td>1350</td>
<td>99.8</td>
</tr>
<tr>
<td>$\beta^*$</td>
<td>m</td>
<td>1.0</td>
<td>0.5 /0.55</td>
</tr>
<tr>
<td><strong>Number of Pb ions/bunch</strong></td>
<td></td>
<td>$7 \times 10^7$</td>
<td>$7 \times 10^7$</td>
</tr>
<tr>
<td>Transv. norm. RMS emittance</td>
<td>$\mu$m</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Longitudinal emittance</td>
<td>eV s/charge</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Luminosity half-life (1,2,3 expts.)</td>
<td>h</td>
<td>14, 7.5, 5.5</td>
<td>8, 4.5, 3</td>
</tr>
</tbody>
</table>

At full energy, luminosity lifetime is determined mainly by collisions ("burn-off" from ultraperipheral electromagnetic interactions) $\sigma \approx 520$ barn

Do something like this but at reduced energy in 2010

Probably unattainable without "cryo-collimators" at least
# Target luminosity in 2010 vs. “Nominal”

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Early (2010/11)</th>
<th>Nominal</th>
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</thead>
<tbody>
<tr>
<td>$\sqrt{s_{\text{NN}}} \text{ (per colliding nucleon pair)}$</td>
<td>TeV 2.76</td>
<td>5.5</td>
</tr>
<tr>
<td>Number of bunches</td>
<td>62{137}</td>
<td>592</td>
</tr>
<tr>
<td>Bunch spacing</td>
<td>1350{600}</td>
<td>99.8</td>
</tr>
<tr>
<td>$\beta^*$</td>
<td>m 3.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Pb ions/bunch</td>
<td>$7 \times 10^7$</td>
<td>$7 \times 10^7$</td>
</tr>
<tr>
<td>Transverse norm. emittance</td>
<td>(\mu m) 1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Initial Luminosity ($L_0$)</td>
<td>(\text{cm}^{-2}\text{s}^{-1}) (0.7{3} \times 10^{25})</td>
<td>(10^{27})</td>
</tr>
<tr>
<td>Stored energy ($W$)</td>
<td>MJ 0.2</td>
<td>3.8</td>
</tr>
<tr>
<td>Luminosity half life (1,2,3 expts.)</td>
<td>$\tau_{\text{IBS}=7-30}$</td>
<td>8, 4.5, 3</td>
</tr>
</tbody>
</table>

Caveat: assumes design emittance
Initial interaction rate: 50-100 Hz (5-10 Hz central collisions b = 0–5 fm)

\(~10^8\) interaction/\(10^6\)s (~1 month)

In 2010: integrated luminosity \(1-3 \{8\} \mu\text{b}^{-1}\)
Collimation setup

- Collimation of heavy ions very different from protons
  - Nuclear interactions (hadronic fragmentation, EM dissociation) in primary collimator material.
  - Staged collimation principle does not work.

- Set-up a single stage collimation system
  - Only primary collimators are effective
  - Retract secondaries (a little or completely)
  - Setup of TCPs, TCTs adjusted for orbit etc at
    - Injection
    - Pre-collision
    - Collision
  - Shorter time than for p-p
Rapid and Successful Commissioning

<table>
<thead>
<tr>
<th>Experiment Status</th>
<th>ATLAS</th>
<th>ALICE</th>
<th>CMS</th>
<th>LHCb</th>
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<tbody>
<tr>
<td>Instantaneous Lumi (ub.s)^-1</td>
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<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
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<tr>
<td>BRAN Luminosity (ub.s)^-1</td>
<td>0.000</td>
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<td>Inst Lumi/CollRate Parameter</td>
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<td>0.00e+00</td>
<td>0.00e+00</td>
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<td>BKGD 1</td>
<td>0.002</td>
<td>0.244</td>
<td>0.000</td>
<td>0.122</td>
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<tr>
<td>BKGD 2</td>
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<td>0.000</td>
<td>0.000</td>
<td>0.407</td>
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<tr>
<td>BKGD 3</td>
<td>0.000</td>
<td>1.628</td>
<td>0.098</td>
<td>0.044</td>
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</table>

LHCb VELO Position: OUT, Gap: 58.0 mm

Performance over the last 24 Hrs

<table>
<thead>
<tr>
<th>Intensity vs Time</th>
<th>Updated: 21:48:16</th>
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<tbody>
<tr>
<td>1.4E10</td>
<td></td>
</tr>
<tr>
<td>1.2E10</td>
<td></td>
</tr>
<tr>
<td>1.0E10</td>
<td></td>
</tr>
<tr>
<td>8.0E9</td>
<td></td>
</tr>
<tr>
<td>6.0E9</td>
<td></td>
</tr>
<tr>
<td>4.0E9</td>
<td></td>
</tr>
<tr>
<td>2.0E9</td>
<td></td>
</tr>
</tbody>
</table>

- B1 Inj., Circ. & Capture
- B2 Inj., Circ. & Capture
- Optics Checks
- BI Checks
- Collimation Checks
- First Ramp
- Collimation Checks
- Squeeze
Rates and Luminosities in ATLAS, heavy ion run
Physics Results

Initial State \quad Initial Overlap \quad Thermalization \quad QGP \quad Hadronization \quad Hadron Gas

$\sqrt{s_{NN}}$

SPS PbPb 17.3 GeV

RHIC AuAu 200 GeV

LHC PbPb 2760 GeV
First Physics Results

• Published or submitted:
  - Dijet asymmetry (~‘jet quenching’), ATLAS
  - J/Ψ suppression vs. centrality, and first observation of Z production, ATLAS
  - elliptical flow (\(v_2\)), ALICE
  - charged particle multiplicity and its centrality dependence (2 papers), ALICE
  - 2-pion Bose-Einstein correlations, central collisions, ALICE

• Numerous other public results
Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS Detector at the LHC

G. Aad et al. (The ATLAS Collaboration)*

Using the ATLAS detector, observations have been made of a centrality-dependent dijet asymmetry in the collisions of lead ions at the Large Hadron Collider. In a sample of lead-lead events with a per-nucleon center of mass energy of 2.76 TeV, selected with a minimum bias trigger, jets are reconstructed in fine-grained, longitudinally-segmented electromagnetic and hadronic calorimeters. The underlying event is measured and subtracted event-by-event, giving estimates of jet transverse energy above the ambient background. The transverse energies of dijets in opposite hemispheres is observed to become systematically more unbalanced with increasing event centrality leading to a large number of events which contain highly asymmetric dijets. This is the first observation of an enhancement of events with such large dijet asymmetries, not observed in proton-proton collisions, which may point to an interpretation in terms of strong jet energy loss in a hot, dense medium.

- Paper submitted on Nov 25, accepted by PRL

Indirect jet quenching @ RHIC

Direct quenching @ LHC?
Key question:

- How do parton showers in hot medium (quark gluon plasma) differ from those in vacuum?

From “Jet Quenching in Heavy Ion Collisions”, U. Wiedemann, arXiv:0908.2306
Heavy Ion Collision Event with 2 Jets
• ATLAS luminosity profile vs day

⇒ Data-taking efficiency > 95%

• Paper used runs corresponding to 1.7 \( \mu b^{-1} \) (Nov 8 - 17)

Fraction of data passing data quality selection
Event Centrality

- Triggers: minimum-bias trigger scintillators, ZDC

- Characterize centrality by percentiles of total cross-section using forward calorimeter (FCal) $\Sigma E_T$

$$\Rightarrow (3.2 < |\eta| < 4.9)$$
Peripheral, symmetric dijet event
More central, asymmetric dijet event
Even more central collision, more asymmetric dijet
Central event, with split dijet + additional activity

- Use anti-\( k_t \) clustering algorithm
- Cone-like but infrared and collinear safe

- Perform anti-\( k_t \) reconstruction prior to any background subtraction
  - \( R = 0.4 \) for main analysis
  - \( R = 0.2, 0.6 \) for cross-check (+ physics)

- Input: \( \Delta \eta \times \Delta \phi = 0.1 \times 0.1 \) towers
• Take maximum advantage of ATLAS segmentation
  – Underlying event estimated and subtracted for each longitudinal layer and for 100 slices of $\Delta\eta = 0.1$
  \[ E_{T_{sub}} = E_{T_{cell}} - \rho_{layer}(\eta) \times A_{cell} \]
  – $\rho$ is energy density estimated event-by-event
    \[ \Rightarrow \text{From average over } 0 < \phi < 2\pi \]
• Avoid biasing $\rho$ due to jets
  – Using anti-kt jets:
    \[ \Rightarrow \text{Exclude cells from } \rho \text{ if } D = \frac{E_{T_{max}}}{\langle E_T \rangle} > 5 \]
  – Cross check
    \[ \Rightarrow \text{Sliding Window algorithm} \]
• NO jet removal on basis of $D$, or any other quantity
Before subtraction

\[ \Sigma E_T \Delta \eta \Delta \phi = 0.1 \times 0.1 \text{ towers} \]

After subtraction, underlying event at zero

Event structure, topology unchanged by subtraction.
• Use $R = 0.4$ anti-kt jets
  – calibrated using energy density cell weighting
• Select events with leading jet, $E_{T1} > 100$ GeV, $|\eta| < 2.8$
  ⇒ 1693 events after cuts in $1.7 \mu$b$^{-1}$
• Sub-leading: highest $E_T$ jet in opposite hemisphere, $\Delta \phi > \pi/2$ with $E_{T2} > 25$ GeV, $|\eta| < 2.8$
  ⇒ 5% of selected have no sub-leading jet
• Introduce new variable to quantify dijetimbalance
  – Not used before in jet quenching literature:
  ⇒ Asymmetry: $A \equiv \frac{E_{T1} - E_{T2}}{E_{T2} + E_{T1}}$
• Robust variable:
  – Residual subtraction errors cancel in numerator
  – Absolute jet energy scale errors cancel in ratio.
Peripheral Collisions (40-100%)

- Pb+Pb di-jet asymmetry ($A_J$), acoplanarity ($\Delta \phi$)
  - Compare to p+p data, and PYTHIA (7 TeV) dijet events embedded in HIJING

$$A \equiv \frac{E_{T_1} - E_{T_2}}{E_{T_2} + E_{T_1}}$$
For more central collisions, see:

- Reduced fraction of jets with small asymmetry
- Increased fraction of jets with large asymmetry

⇒ For all centralities, $\Delta \phi$ strongly peaked at $\pi$
⇒ Possible small broadening in central collisions
$R_{AA}$ from ALICE

Rise at higher $p_T$ never seen clearly before!
R_{AA} from ALICE

Pb-Pb $\sqrt{s_{nn}} = 2.76$ TeV

0 - 5%

70 - 80%

Rise at higher pT never seen clearly before!
Measurement of the centrality dependence of $J/\psi$ yields and observation of $Z$ production in lead-lead collisions with the ATLAS detector at the LHC

G. Aad et al. (The ATLAS Collaboration),

Abstract

Using the ATLAS detector, a centrality-dependent suppression has been observed in the yield of $J/\psi$ mesons produced in the collisions of lead ions at the Large Hadron Collider. In a sample of minimum-bias lead-lead collisions at a nucleon-nucleon centre of mass energy $\sqrt{s_{NN}} = 2.76$ TeV, corresponding to an integrated luminosity of about $6.7 \mu b^{-1}$, $J/\psi$ mesons are reconstructed via their decays to $\mu^+\mu^-$ pairs. The measured $J/\psi$ yield, normalized to the number of binary nucleon-nucleon collisions, is found to significantly decrease from peripheral to central collisions. The centrality dependence is found to be qualitatively similar to the trends observed at previous, lower energy experiments. The same sample is used to reconstruct $Z$ bosons in the $\mu^+\mu^-$ final state, and a total of 38 candidates are selected in the mass window of 66 to 116 GeV. The relative $Z$ yields as a function of centrality are also presented, although no conclusion can be inferred about their scaling with the number of binary collisions, because of limited statistics. This analysis provides the first results on $J/\psi$ and $Z$ production in lead-lead collisions at the LHC.
Di-lepton studies

- Quarkonia dissociation due to color screening is considered as a promising signature of quark-gluon plasma (QGP) formation
  - Various quarkonia states are expected to “melt” at different temperatures,

- $J/\psi$ suppression has already been seen at SPS and RHIC but details are poorly understood, interplay of cold and hot effects,
- $J/\psi$ enhancement by regeneration of $J/\psi$ from the (large) number of uncorrelated $cc$ pairs could also be tested at the LHC,
Figure 4: The di–muon invariant mass (left) after the selection described in the text. The value of $R_{cp}$ (right) computed with the 38 selected $Z$ candidates. The statistical errors are shown as vertical bars while the grey boxes also include the combined systematic errors. The darker box indicates that the 40-80– bin is used to set the scale for all bins, but the uncertainties in this bin are not propagated into the more central ones.

5. Conclusion

The first results on $J/\psi$ and $Z \rightarrow \mu^+ \mu^-$ relative yields measured in lead+lead collisions obtained with the ATLAS detector at the LHC during this initial heavy ion data taking period as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We thank CERN for the efficient commissioning and operation of the LHC during this initial heavy ion data taking period as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

Acknowledgements

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ATLAS:
First observation of Z boson production in heavy ion collisions!
The "relative yield" is defined by normalizing to the yield found in the most
yield of
represents a well-defined fraction of the minimum bias events. The corrected
characterized in each centrality bin and the width of the centrality bin
reconstructed
With the chosen transverse momentum cuts on the decay muons of the
background subtraction but before any other correction are listed in Table 1.
The number of
Centrality-dependent e
are applied to the resulting signal yields. The number of
background yields at different centrality bins, as described in the text, as a function of centrality. The
yield as a function of centrality normalized to the most pe-
terence is observed as a deviation from the simplest expectation
indicating a deviation from the simplest expectation, as described in the text, as a function of centrality. The
systematic uncertainty in this bin is shown as a function of centrality between the measured relative
systematic errors. The darker box indicates that the 40-80% bin is used to set the scale for
all bins, but the uncertainties in this bin are not propagated into the more central ones. Statistical errors are shown as vertical bars while the grey boxes also include the combined
systematic uncertainties in quadrature. A clear decrease of the relative yield is observed as a function of centrality in the right panel of Figure 3. The data points are
normalized to the sum of the pseudorapidities of the two muons with
the chosen transverse momentum cuts on the decay muons. An additional cosmic ray rejection cut
is shown as a function of centrality in the right panel of Figure 3. The data points are
consistent with their average, giving a significance of
function of centrality in the right panel of Figure 3. The data points are
not consistent with their average, giving a significance of
three degrees of freedom, computed conservatively ignoring any correlations
among the systematic uncertainties. Instead, a significant decrease of
the relative yield is observed as a function of centrality normalized to the most peripheral bin. The expected relative yields from the normalized yields are also shown as boxes, reflecting 1-Centrality %

**J/Ψ for four centrality bins**

<table>
<thead>
<tr>
<th>ATLAS</th>
<th>Pb+Pb (\sqrt{S_{NN}} = 2.76) TeV</th>
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<tbody>
<tr>
<td></td>
<td><strong>J/ψ</strong> yield</td>
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<td>Expected yield from R_{coll}</td>
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<td>J/ψ yield</td>
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<td>Normalized J/ψ yield</td>
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**J/Ψ yield and normalized yield vs. centrality**

Events / [0.05 GeV]

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<tr>
<td>ATLAS</td>
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<td>Events / [0.05 GeV]</td>
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<td>Dimuon mass (GeV/c²)</td>
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**CMS**

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<td>Events / [0.05 MeV/c²]</td>
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High $p_T \gamma \rightarrow \mu^+\mu^-$

CMS: Upsilon

CMS: $Z^0 \rightarrow \mu^+\mu^-$
Elliptic flow of charged particles in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV
(The ALICE Collaboration)

We report the first measurement of charged particle elliptic flow in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ALICE detector at the CERN Large Hadron Collider. The measurement is performed in the central pseudorapidity region ($|\eta| < 0.8$) and transverse momentum range $0.2 < p_t < 5.0$ GeV/c. The elliptic flow signal $v_2$, measured using the 4-particle correlation method, averaged over transverse momentum and pseudorapidity is $0.087 \pm 0.002$ (stat) $\pm 0.004$ (syst) in the 40–50% centrality class. The differential elliptic flow $v_2(p_t)$ reaches a maximum of 0.2 near $p_t = 3$ GeV/c. Compared to RHIC Au–Au collisions at $\sqrt{s_{NN}} = 200$ GeV, the elliptic flow increases by about 30%. Some hydrodynamic model predictions which include viscous corrections are in agreement with the observed increase.

*large $v_2$ is the strongest evidence for the “s” in “sQGP”*
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Elliptic flow results from ALICE

http://arxiv.org/abs/1011.3914
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http://arxiv.org/abs/1011.3914
Theoretical descriptions of particle production in nuclear collisions fall into two broad categories: two-component models combining perturbative QCD processes (e.g., jets and mini-jets) with soft interactions, and saturation models with various parametrizations for the energy and centrality dependence of the multiplicity.

For nucleus–nucleus collisions, significant inelastic O–SqP pp and p collisions over a wide range of collision energies [Zc–Z] have been presented. The average multiplicity dN/dy for pp and p collisions has been measured. Although the former overpredicts the magnitude, the latter underpredicts the magnitude.

In Fig. 3, we compare the measured charged particle pseudo-rapidity density per participant pair for central nucleus–nucleus and non-single participant pair for lower energy data. The energy dependence of the hadronic cross section is significantly larger than those measured at RuvpS and indiT. The result presented in this letter provides an essential constraint for models describing high energy collisions. We find dN/dy significantly larger than those measured at RuvpS and indiT.

The average multiplicity dN/dy for nucleus–nucleus collisions is close to the state phase space of scattered partons. However, the calculation based on the two-component Dual Parton Model xDPMJET [76] with string fusion exhibits some discrepancies.

In Fig. 4, we show the comparison of this measurement with model predictions and experimental data. The Landau (PAS) and hadronic rescattering (Zb) underpredicts the measurement while a model incorporating scaling and saturation scale [Zs] underpredicts the measurement [Z].

For Pb–Pb collisions at geometrical scaling model with a strong dependence of the saturation scale on nuclear mass and collision scattering and particle production is reduced by nonlinear interactions and parton recombination. They are all different implementations of the saturation picture, where the number of soft gluons available decreases by a factor of about 8 from peripheral to midrapidity in Pb–Pb collisions at √sNN (GeV).

The average multiplicity per participant pair for our centrality selection is found to be very similar for the measurement and hydrodynamic model in which mutual parton recombination and dissipation are important. However, the average multiplicity per participant pair for central nucleus–nucleus and non-single participant pair for lower energy data significantly underpredicts the magnitude.

http://arxiv.org/abs/1011.3916

http://arxiv.org/abs/1012.1657

http://arxiv.org/abs/1011.5821
Two-pion Bose–Einstein correlations in central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

The ALICE Collaboration*

Abstract

The first measurement of two-pion Bose–Einstein correlations in central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at the Large Hadron Collider is presented. We observe a growing trend with energy now not only for the longitudinal and the outward but also for the sideward pion source radius. The pion homogeneity volume and the decoupling time are significantly larger than those measured at RHIC.
Bose-Einstein results from ALICE

Relative to RHIC:
- source radii bigger by 10-35%
- volume twice as big
- time is 40% longer

three dimensions

"the fireball formed in nuclear collisions at the LHC is hotter, lives longer, and expands to a larger size at freeze-out as compared to lower energies."
Conclusions

• LHC now providing relativistic heavy ion collisions with TeV/nucleon beams:

• Clean, energetic jets a new probe; heavy quarks and heavy mesons plentiful, allowing new studies

• Hermetic detectors with excellent tracking, calorimetry, and muon systems

• The sQGP discovered by RHIC is affirmed and seen with unprecedented clarity after only a few days of running: jet quenching and strong elliptic flow

• Expect new discoveries soon!