MEASUREMENT OF ISOLATED DIRECT PHOTONS IN LEAD-LEAD COLLISIONS AT 2.76 TEV WITH THE ATLAS DETECTOR

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On behalf of the ATLAS Collaboration
Quark Matter 2012
August 13-18th, 2012
Isolated Direct Photons in ATLAS, Aug 13-18th, 2012

Properties of QGP

- Opaque to colored partons
  - Jet quenching, changed particles and quarkonia suppression
- Transparent to EM and weekly interacting particles
  - Electro-weak bosons ($\gamma, Z^0, W^\pm$) are supposed not to be affected by the medium
  - They turn out to be a perfect probe for understanding of the suppression mechanism
  - In this talk the latest results from ATLAS on isolated direct photon production will be discussed (ATLAS-CONF-2012-051)

Quark Gluon Plasma (QGP)

One of the main topics of heavy-ion physics is to study QGP
ATLAS Detector

Three main components: Inner tracker, electromagnetic (EM) and hadronic (HAD) calorimeters, and muon system

- **Inner Tracker**: (-2.5, 2.5)
- **HAD Calorimeter**: (-4.9, 4.9)
- **EM Calorimeter**: (-3.2, 3.2)
- **Muon Spectrometer**: (-2.7, 2.7)

**Measurements**

<table>
<thead>
<tr>
<th>Component</th>
<th>$\eta$ Coverage</th>
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</thead>
<tbody>
<tr>
<td>EM Calorimeter</td>
<td>(-3.2, 3.2)</td>
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<td>HAD Calorimeter</td>
<td>(-4.9, 4.9)</td>
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<td>Muon Spectrometer</td>
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</table>

**Photons measured in EM Calo:**
- Lead-LAr samplings
- Three longitudinal sections
- First fine segmented layer discriminates photons from $\pi^0$ and $\eta$ mesons
- 10-17%/$\sqrt{E[GeV]}$

Full azimuthal acceptance
Heavy-ion run at $\sqrt{s_{NN}} = 2.76\text{TeV}$

- In 2011 ATLAS recorded $0.16 \text{ nb}^{-1}$ of Pb+Pb data (c.f. $0.009 \text{ nb}^{-1}$ in 2010)
  - Various High Level Triggers used
  - Photon measurement: $L_{\text{int}} = 0.13 \text{ nb}^{-1}$ which is equivalent to $N_{\text{evt}} = 755M$ minimum bias events in 0-80% centralities
- Data recording efficiency > 95%
- Fraction of data passing data-quality criteria > 99%
Characterize centrality by percentiles of the total cross-section using forward calorimeter (FCal) $\Sigma E_T$ ($3.1<|\eta|<4.9$)
Triggers: EM cluster with $E_T > 16$ GeV at L1
- 100% efficient for photons with $E_T > 20$ GeV

Underlying-event background (UE) is subtracted event-by-event
- Corrections of $O(1$ GeV) even in central events

Photon reconstruction with a sliding window algorithm seeded by clusters of at least 2.5 GeV in the second sampling layer
- Photon energy using all three layers and the presampler
- Photon conversions are not reconstructed in the HI environment
- Nine shower-shape variables used to choose high-quality photons (=tight photons)
Signal is modeled with 450k photon+jet events using PYTHIA 6.4 with minimum bias events from HIJING.

- Total MC (yellow), unconverted (blue) and converted (red) photons.
- Distributions agree well between data and simulation.

\[ \eta \text{ width in layer 1}_{w,3} \] (strip units)

\[ \eta \text{ width in layer 2} \] (\( \eta \) units)

Hadronic energy/cluster energy
6435 tight photon candidates with $p_T > 45$ GeV and $|\eta| < 1.3$ before applying the isolation requirement

Isolation criterion optimized for HI photons: $E_T(R_{iso} = 0.3)$ – transverse energy in a cone of $R_{iso}$ around the photon axis

- Enhancement of data for $E_T(R_{iso} = 0.3) > 0$ due to two components: UE energy fluctuations and di-jet background
- Width of $E_T(R_{iso} = 0.3)$ in 0-10% photon+jet events is 6 GeV

Isolation requirement: $E_T(R_{iso} = 0.3) < 6$ GeV
Photon performance

- Signal is modeled with 450k photon+jet events using PYTHIA 6.4 with minimum bias events from HIJING

  - **Energy scale:**
    - Photon calibration is the same as in p+p collisions
    - Mix of converted and unconverted photons leads to a small underestimate of the energy
    - Correction extracted from MC in four bins in $\eta$, no dependence on centrality

  - **Energy resolution:**
    - Determined using a Gaussian fit in 4GeV intervals to $\sigma(p_T)/p_T$
    - Sampling term extracted as 10-12% for central events
**Double sideband method** used for background subtraction. All photon candidates classified to one of four regions

- **A**: Primary signal region
- **B**: Photons which happen to be in the vicinity of a jet or an UE fluctuation
- **C**: Isolated jet fragments or photons which have shower shape fluctuations which fail the cuts
- **D**: Primary background region

Leak of the signal to other regions is evaluated using MC

Leakage factors $c_i = \frac{N_{\text{sig},i}}{N_{\text{sig},A}}$

$c_i$ range from 0.005-0.06, no dependence on centrality

$$N_{\text{sig},A} = N_{\text{obs},A} - \left( \frac{N_{\text{obs},B} - c_B N_{\text{sig},A}^{\text{obs}}}{N_{\text{obs},D} - c_D N_{\text{sig},A}^{\text{obs}}} \right) \left( N_{\text{sig},C} - N_{\text{sig},A}^{\text{obs}} \right)$$
Photon efficiency and purity

- **Efficiencies** extracted from MC and normalized to all PYTHIA isolated photons with $E_T(R_{iso}=0.3)<6\text{GeV}$ (the isolation removes 1.5% photons)

- Three components of the total efficiency:
  - Reconstruction (95% constant with $p_T$), identification and isolation

- **Purity** derived from data and defined as $N^{\text{sig}}/N^{\text{obs}}$
Systematic uncertainties dominated by the choice of tight photon identification cuts and isolation cone properties.

Total systematic uncertainty of 31% independent of $p_T$ and centrality is assigned.

<table>
<thead>
<tr>
<th>Source</th>
<th>Effect on yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tight cut definition</td>
<td>20%</td>
</tr>
<tr>
<td>Non-tight cut definition</td>
<td>3%</td>
</tr>
<tr>
<td>Isolation criterion</td>
<td>20%</td>
</tr>
<tr>
<td>Energy scale</td>
<td>12%</td>
</tr>
<tr>
<td>Unfolding</td>
<td>3%</td>
</tr>
<tr>
<td>Event counting</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31%</strong></td>
</tr>
</tbody>
</table>
Results: Photon Yields

- Photons with $45 < p_T < 200$ GeV and $|\eta| < 1.3$ in ATLAS

  - 10% larger interval in $\eta$
  - Isolation condition: $E_T(R_{iso} = 0.4) < 5$ GeV
  - Good agreement with the ATLAS measurement

PYTHIA and JETPHOX shown for comparisons
Comparisons of Pb+Pb data with $p+p$ cross sections from JETPHOX 1.3.0
- PDFs: CTEQ 6.6
- BFG fragmentation functions
- No isospin or nPDFs included
- Scale uncertainties: ±13%
- PDF uncertainties at 7 TeV: ±5%

Equivalent to $R_{AA}$ but with MC reference

Good agreement of data and JETPHOX
Photon yields as a function of centrality in bins of $p_T$
- No centrality dependence in any of the measured $p_T$ intervals
- Photon yields in HI collisions scale linearly with $<T_{AA}>$ or equivalently with $<N_{coll}>$

Photon production rates are not affected by QGP
- Isolated direct photons seem to be a perfect probe to help in understanding of the jet quenching phenomenon
Results: $\gamma$ - jet correlations

Photon isolation cuts:
- $60 < p_T < 90$ GeV and $|\eta| < 1.3$
- $|\Delta\phi| > 7\pi/8$

Jet isolation cuts:
- $p_T > 25$ GeV and $|\eta| < 2.1$

Centrality-dependent shift in $x_{J,\gamma} = p_T^{\text{jet}} / p_T^{\gamma}$

More details:
- Z.Citron 1B Tue
- P.Steinberg IVA Thu

Isolated Direct Photons in ATLAS, Aug 13-18th, 2012

ATLAS-CONF-2012-121
Isolated direct photons have been measured in ATLAS

- Eight bins of $p_T$ from 45-200 GeV and integrated over $|\eta|<1.3$

Photon yields have been extracted as a function of $p_T$ and centrality

- After scaling the yields by the mean nuclear thickness $<T_{AA}>$, they are observed to be constant as a function of centrality implying a linear scaling with the number of binary collisions
  - This result establishes the basis for measurements which use photons as unmodified hard probes
- Scaled yields, as a function of $p_T$, are found to be in good agreement with NLO pQCD calculations as implemented in JETPHOX 1.3.0.
Back-up slides
Trigger Strategy in 2010-11

- In 2010: Peak luminosity $3 \times 10^{25}\text{cm}^{-2}\text{s}^{-1}$ which gives 350 Hz of min bias rate at L1
  - Record all min bias events to tape,

- In 2011: Peak luminosity $5.1 \times 10^{26}\text{cm}^{-2}\text{s}^{-1}$ which gives 6 kHz of min bias rate at L1,
  - High Level Trigger (HLT) essential to bring an output rate down to 200 Hz,
  - Two approaches used:
    - Full scan reconstruction at HLT on all minimum bias events triggered by L1 (jets, muons),
    - Region-Of-Interest (RoI)-based reconstruction seeded of the lowest-$p_T$ threshold at L1 (muons, photons, electrons),
  - In addition to min bias data high-$p_T$ jets, muons, electrons, photons and UPC were enhanced

<table>
<thead>
<tr>
<th>Signature</th>
<th>Trigger</th>
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<tbody>
<tr>
<td>Jets</td>
<td>single jet $p_T &gt; 20$ GeV</td>
</tr>
<tr>
<td>Muons</td>
<td>single muon $p_T &gt; 4$ GeV, di-muon $p_T &gt; 2$ GeV</td>
</tr>
<tr>
<td>Egamma</td>
<td>single egamma $p_T &gt; 14$ GeV, di-egamma $p_T &gt; 5$ GeV</td>
</tr>
<tr>
<td>UPC</td>
<td>low track multiplicity cut</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stream</th>
<th>Events Taken</th>
<th>Reco CPU/evt [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min Bias</td>
<td>60M</td>
<td>70</td>
</tr>
<tr>
<td>Hard Probes</td>
<td>54M</td>
<td>140</td>
</tr>
<tr>
<td>UPC</td>
<td>6.6M</td>
<td>30</td>
</tr>
</tbody>
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Shower shape variables

- $R_\eta$ - ratio of energies deposited in a 3x7 ($\eta \times \phi$) window to that deposited in a 7x7 window, in units of the second layer cell size
- $\omega_{\eta,2}$ - RMS width of the energy distribution of the cluster in the second layer in the $\eta$ direction
- $R_\phi$ - ratio of energies deposited in a 3x3 window in the second layer to that deposited in a 3x7 window, in units of the second layer cell size
- $R_{\text{had}}$ - ratio of $E_T$ measured in the hadronic layer to $E_T$ of the photon cluster
- $R_{\text{had1}}$ - ratio of $E_T$ measured in the first sampling layer of the hadronic calo to $E_T$ of the photon cluster
- $\omega_{s,\text{tot}}$ - total RMS of the $E_T$ distribution in the $\eta$ direction in the first sampling “strip” layer
- $\omega_{s,3}$ - RMS width of the three “core” strips including and surrounding the cluster maximum in the strip layer
- $F_{\text{side}}$ - fraction of $E_T$ in seven first-layer strips surrounding the cluster maximum, not contained in the three core strips
- $E_{\text{ratio}}$ - asymmetry between the transverse energies in the first and second maxima in the strip layer
- $\Delta E$ - difference between $E_T$ of the first maximum, and the minimum cell $E_T$ between the first two maxima
Glauber fits for ATLAS

- We are using FCal energy sum, as before
  - R=6.62 fm, a=0.546 fm (skin depth)
- Assume both participants and collisions contribute
  - “Two component model”, controlled by parameter “x”

\[ \sum E_{T,FCal} = E_{T,pp} \left( (1 - x) \frac{N_{part}}{2} + xN_{coll} \right) \]
  - x=0.13±0.01(stat)±0.05(syst) found to describe RHIC data

- Incorporate FCal energy resolution and noise
  - Let detector noise be a free parameter (sum of cells)
  - Resolution assumed to be 100%/\sqrt{(E(\text{GeV}))}

- Input data distribution is FCal Et from mbSpTrk selection
  - Cuts requiring good vertex (>1 track), MBTS (DeltaT<3ns), ZDC (AND)