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


Iwona Grabowska-Bold (AGH UST, Kraków)

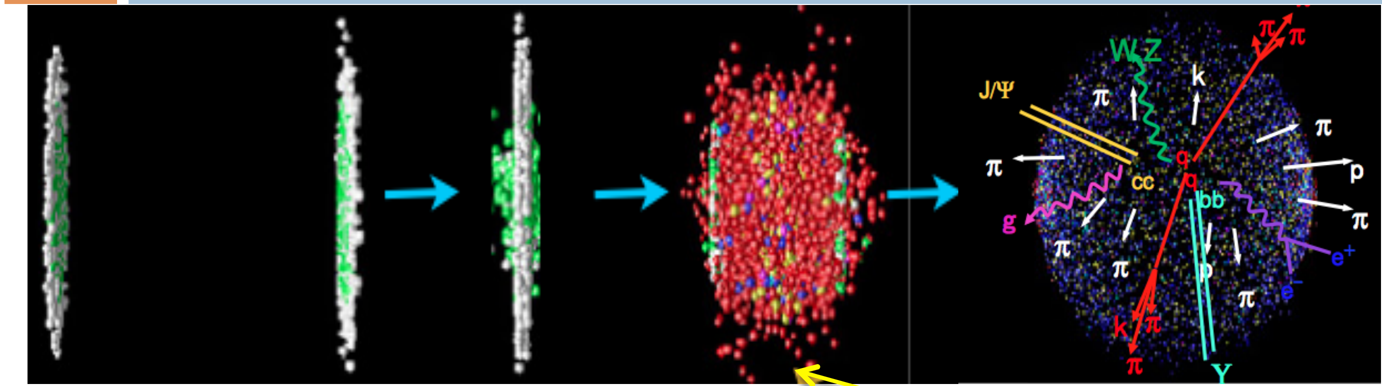
*On behalf of the ATLAS Collaboration*


*Quark Matter 2012*

August 13-18th, 2012

# Introduction



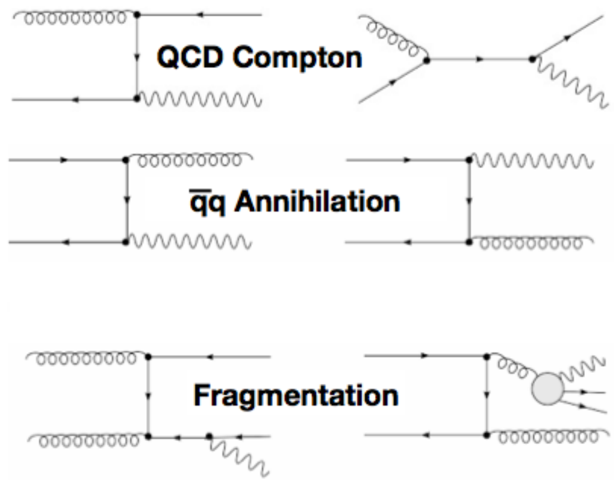



One of the main topics of heavy-ion physics is to study QGP

Quark Gluon Plasma (QGP)

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)

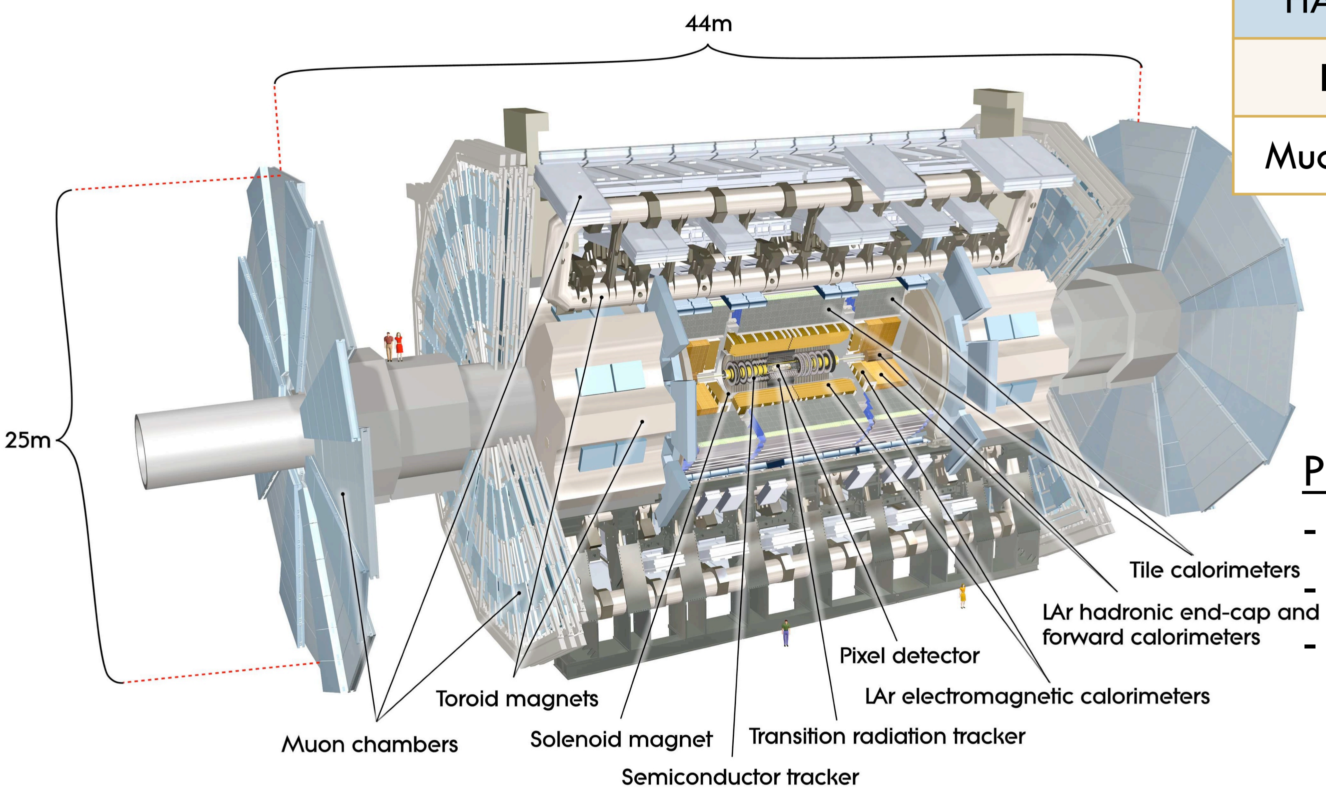


# ATLAS Detector



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

| Measurements | $\eta$ coverage |
|---|---|
| EM Calorimeter | (-3.2, 3.2) |
| HAD Calorimeter | (-4.9, 4.9) |
| Inner Tracker | (-2.5, 2.5) |
| Muon Spectrometer | (-2.7, 2.7) |



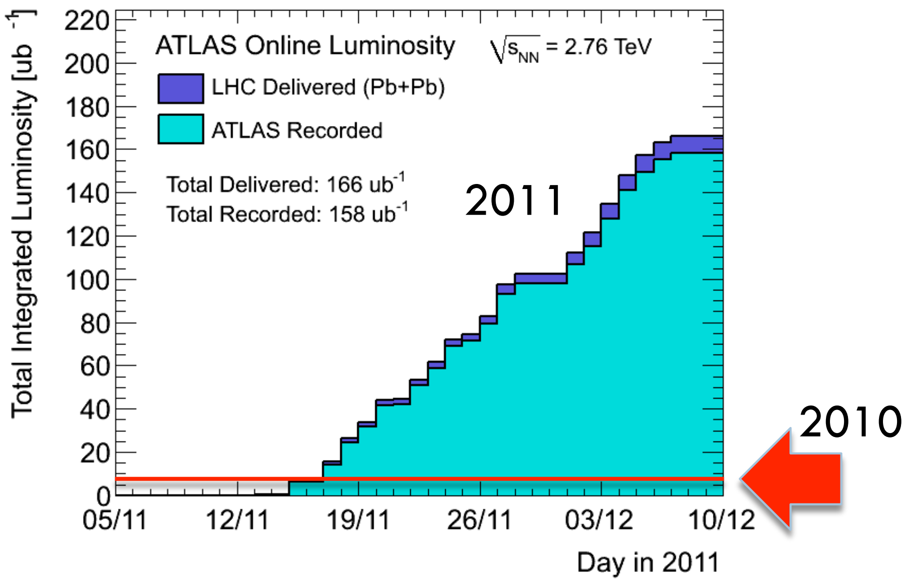

Photons measured in EM Calo:

- Lead-LAr samplings
- Three longitudinal sections
- First fine segmented layer discriminates photons from $\pi^0$ and $\eta$ mesons
- 10-17%/√E[GeV]

Full azimuthal acceptance

# Data sample






| Inner Tracking Detectors | | | Calorimeters | | | | Muon Detectors | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pixel | SCT | TRT | LAr EM | LAr HAD | LAr FWD | Tile | MDT | RPC | CSC | TGC |
| 99.7 | 100 | 100 | 99.2 | 100 | 100 | 100 | 100 | 99.6 | 100 | 100 |

Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV between November 8th and 17th (in %).

- Heavy-ion run at $\sqrt{s_{NN}} = 2.76 TeV$
  - In 2011 ATLAS recorded 0.16 nb$^{-1}$ of Pb+Pb data (c.f. 0.009 nb$^{-1}$ in 2010)
    - Various High Level Triggers used
    - Photon measurement: $L_{int}$=0.13 nb$^{-1}$ which is equivalent to $N_{evt}$=755M minimum bias events in 0-80% centralities
  - Data recording efficiency > 95%
  - Fraction of data passing data-quality criteria > 99%

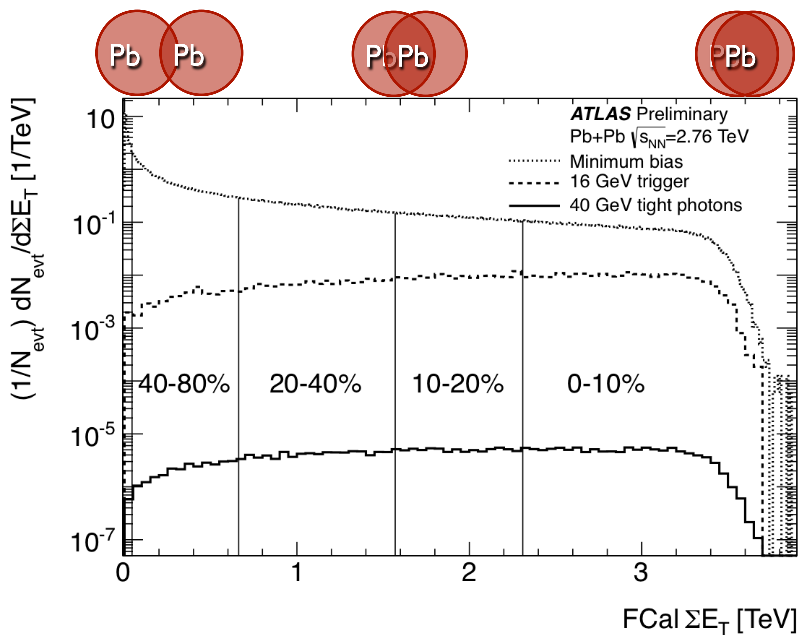
# Centrality

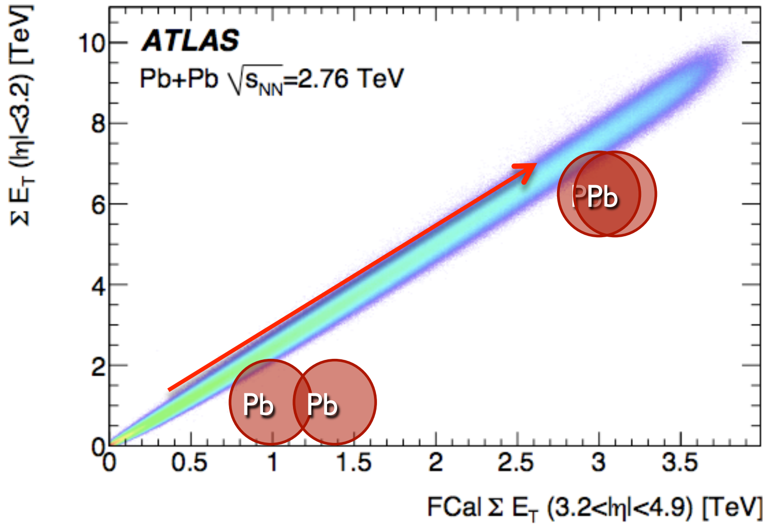
Characterize centrality by percentiles of the total cross-section using forward calorimeter (FCal) $\Sigma E_T$ ($3.1<|\eta|<4.9$)

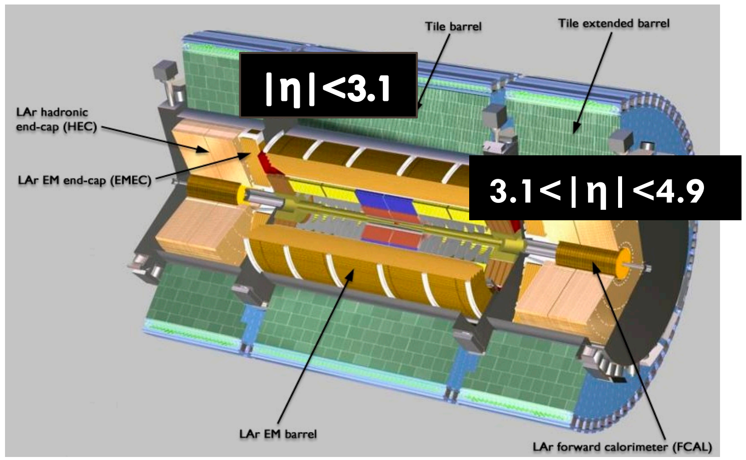
Peripheral collisions

Mid-central collisions

Central collisions



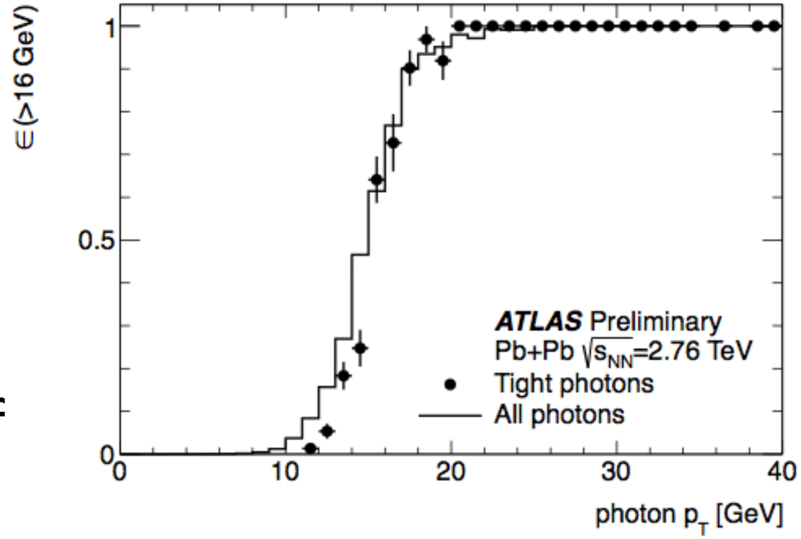



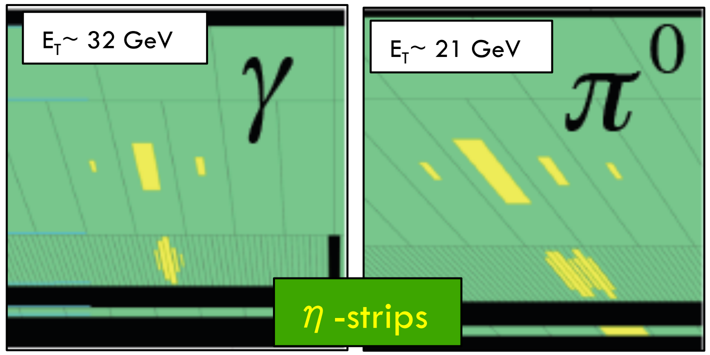



# Analysis selection



- Trigger: 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)

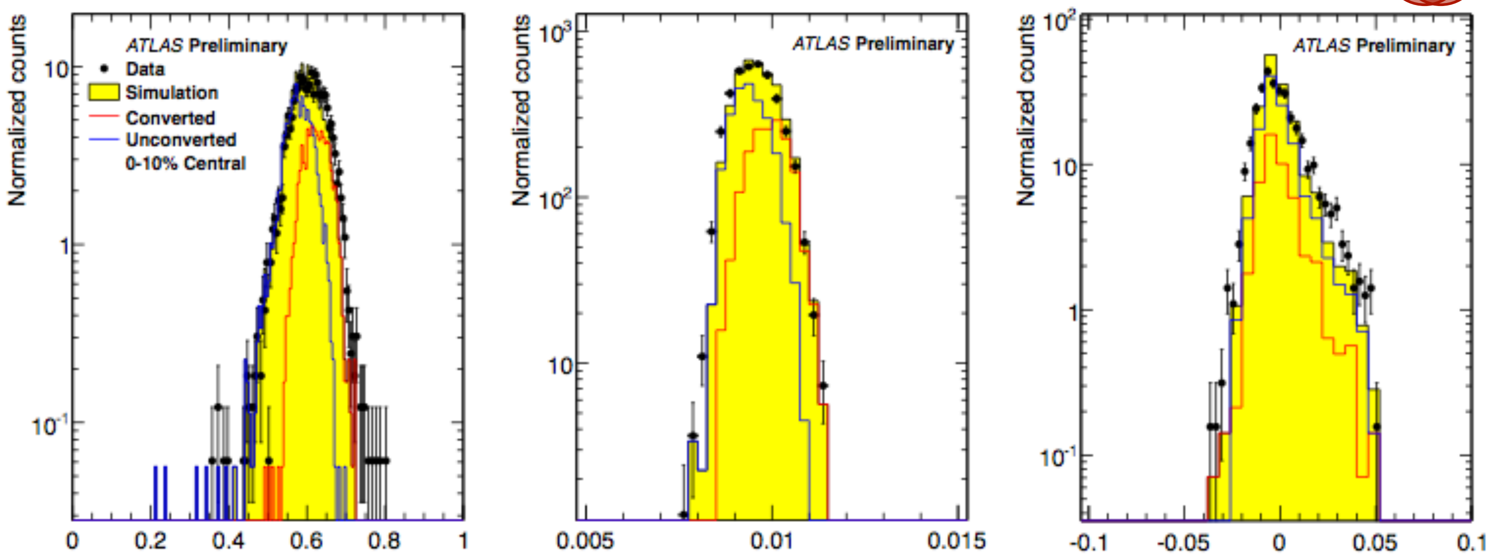


# Shower shapes

- 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

PbPb




$\eta$ **width in layer 1 (strip units)**

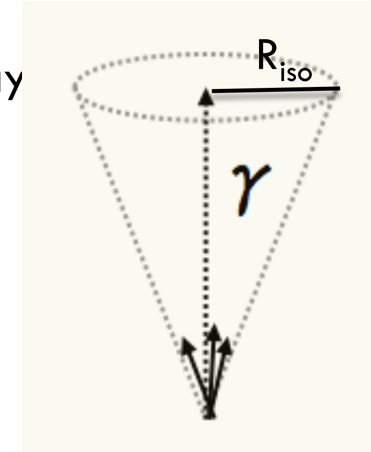
$\eta$ **width in layer 2 ($\eta$ units)**

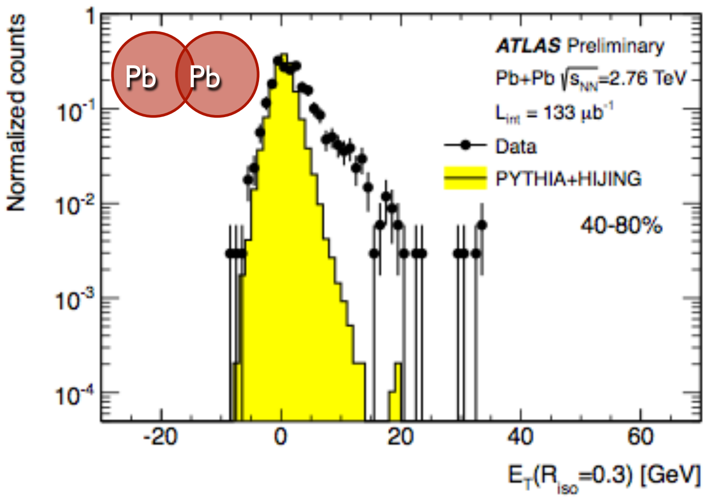
**Hadronic energy/ cluster energy**

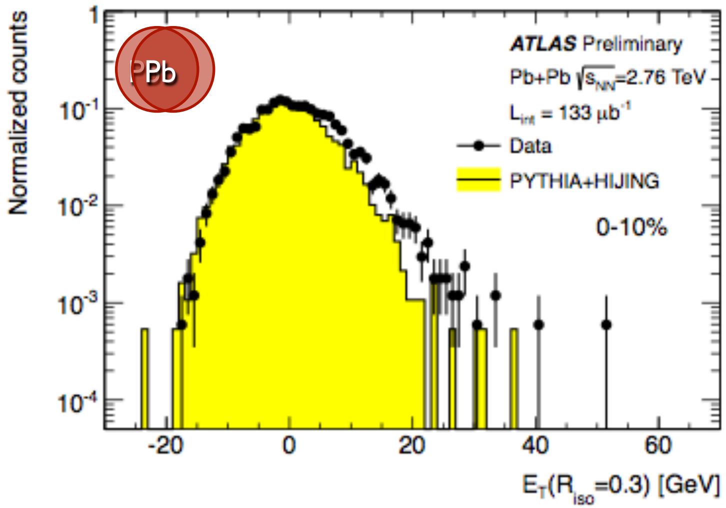
# Photon isolation



- 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



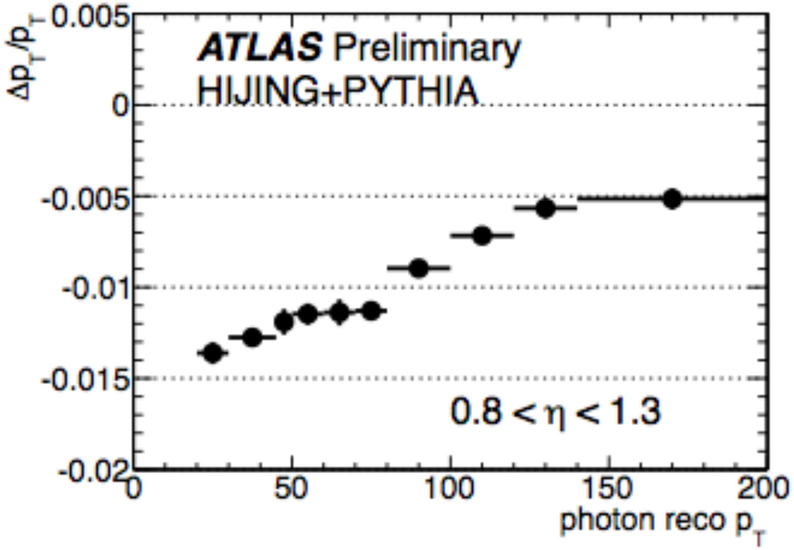



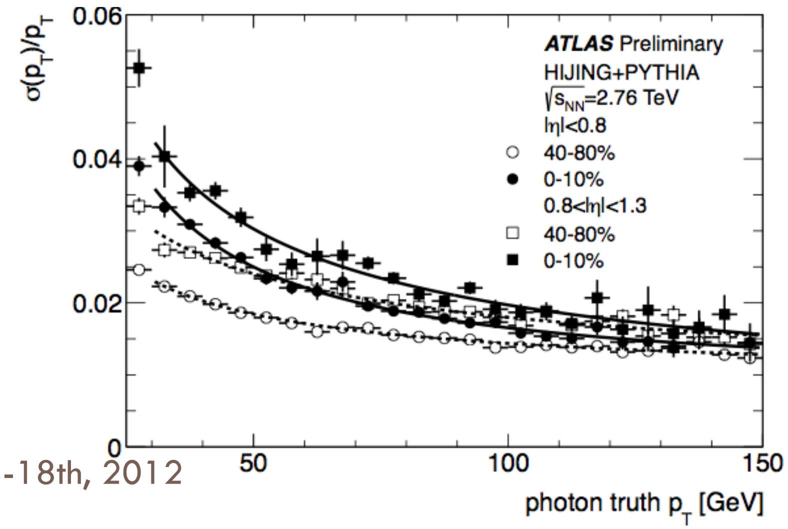



# Photon performance



- 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

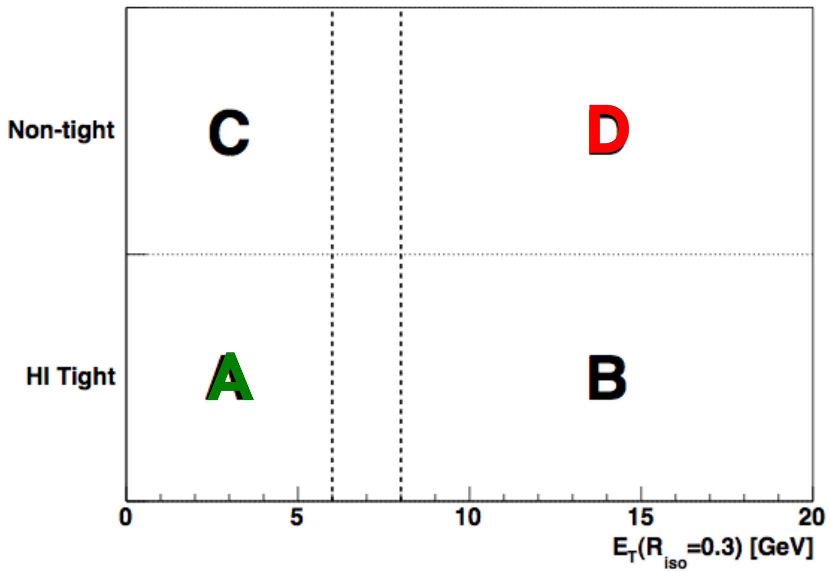


# Background Extraction



- 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



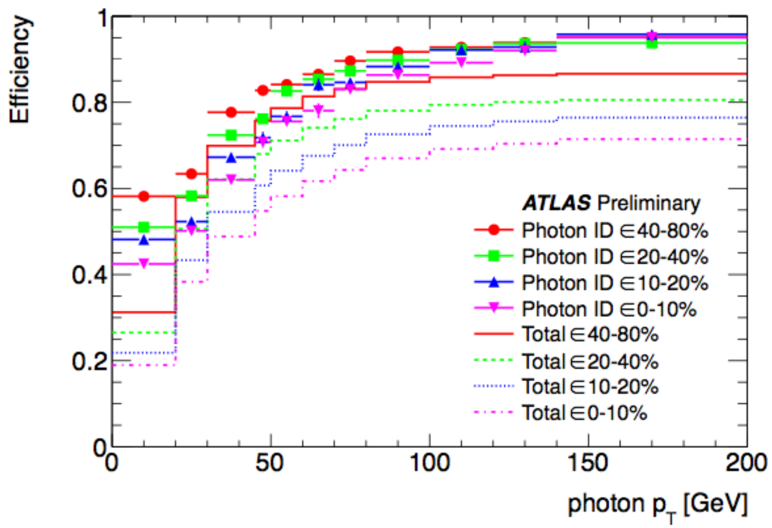

- Leak of the signal to other regions is evaluated using MC
  - Leakage factors $c_i=N^{sig}_i/N^{sig}_A$
  - $c_i$ range from 0.005-0.06, no dependence on centrality

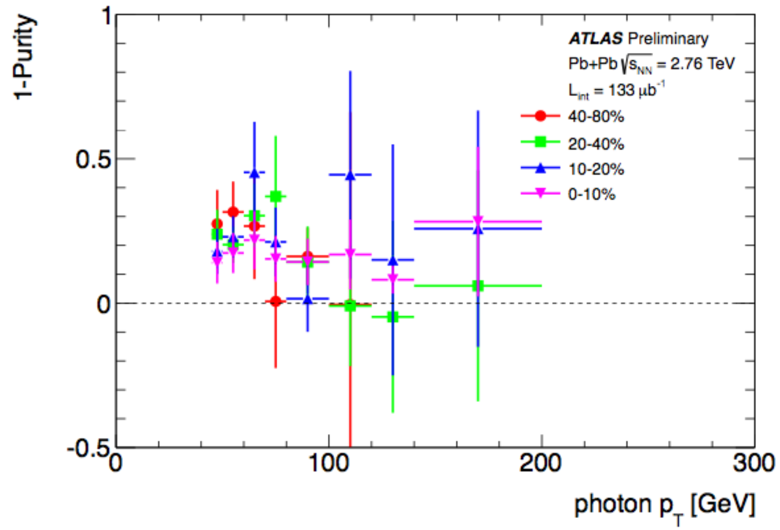
$$N_A^{sig} = N_A^{obs} - \left(N_B^{obs} - c_B N_A^{sig}\right) \frac{\left(N_C^{obs} - c_C N_A^{sig}\right)}{\left(N_D^{obs} - c_D N_A^{sig}\right)}$$

$N^{sig}_A$ extracted

# Photon efficiency and purity

- Efficiencies extracted from MC and normalized to all PYTHIA isolated photons with $E_T(R_{iso}=0.3)<6GeV$ (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 $N^{sig}_A/N^{obs}_A$



# Systematic uncertainties

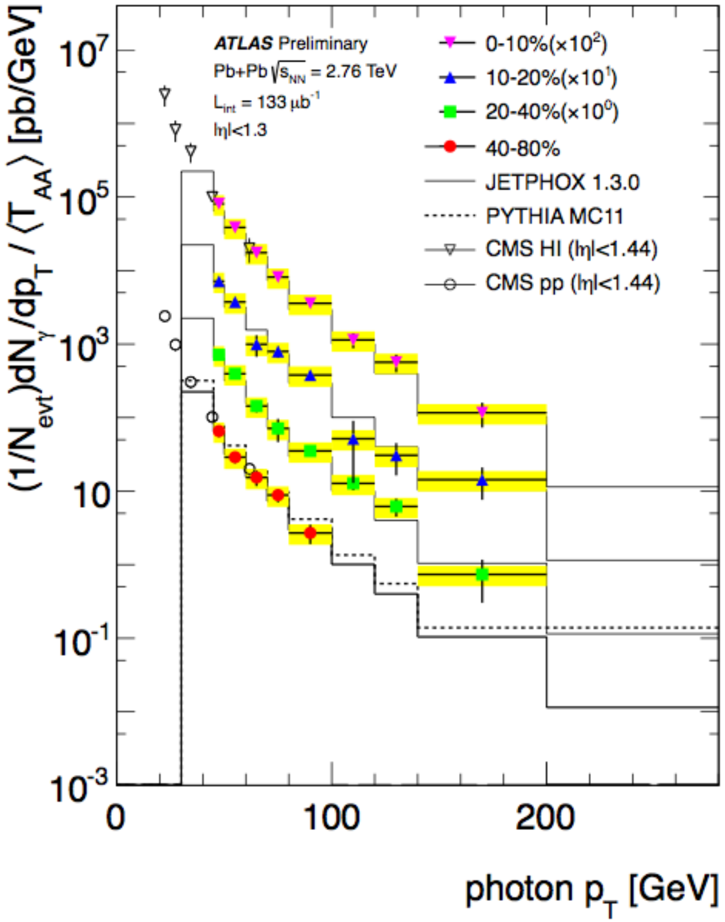


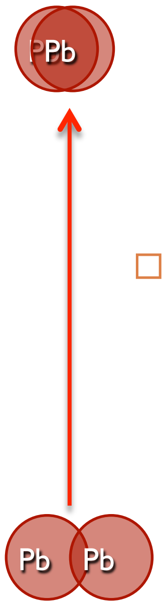
| Source | Effect on yield |
|---|---|
| Tight cut definition | 20% |
| Non-tight cut definition | 3% |
| Isolation criterion | 20% |
| Energy scale | 12% |
| Unfolding | 3% |
| Event counting | 1% |
| **Total** | **31%** |

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.

# Results: Photon Yields



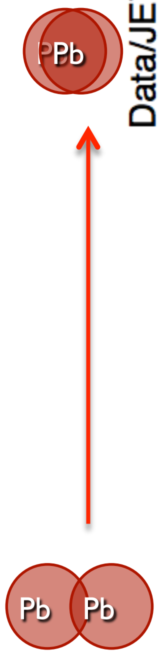

- Photons with $45<p_T<200$ GeV and $|\eta|<1.3$ in ATLAS

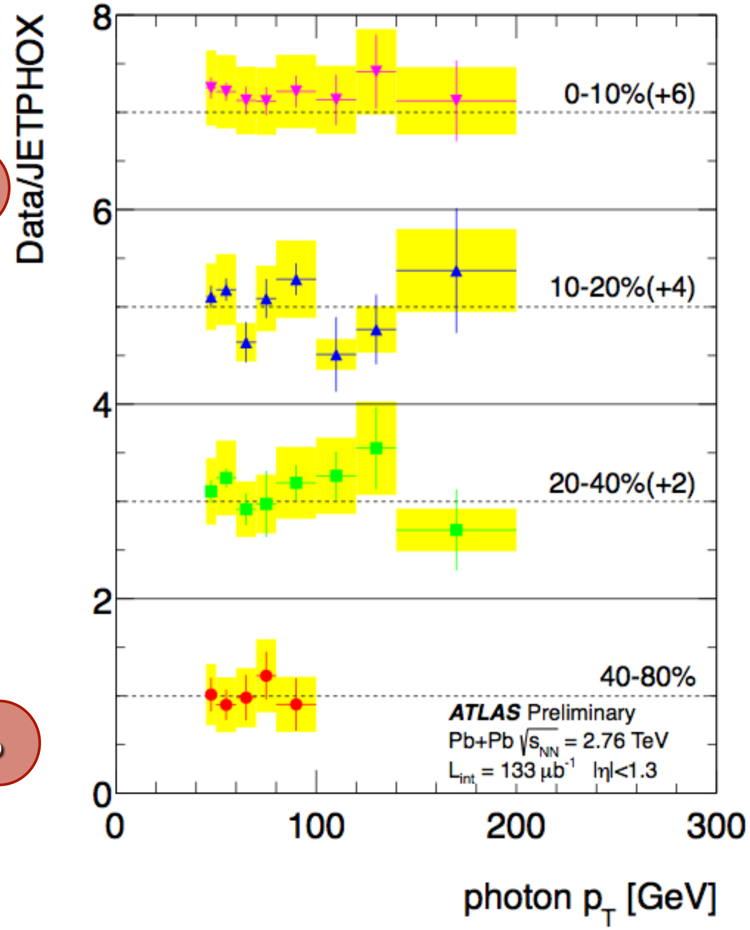
$$\frac{1}{N_{\mathrm{evt}}}\frac{dN_\gamma}{dp_T}(p_T, c) = \frac{N_A^{\mathrm{sig}}}{\epsilon_{\mathrm{tot}} \times N_{\mathrm{evt}} \times \Delta p_T}$$

- CMS *p+p* and Pb+Pb at 2.76 TeV: Phys. Lett. B **710**, 256 (2012)
  - 10% larger interval in $\eta$
  - Isolation condition: $E_T(R_{iso}=0.4)$ <5GeV
  - Good agreement with the ATLAS measurement
- PYTHIA and JETPHOX shown for comparisons

# Results: Data vs. Theory

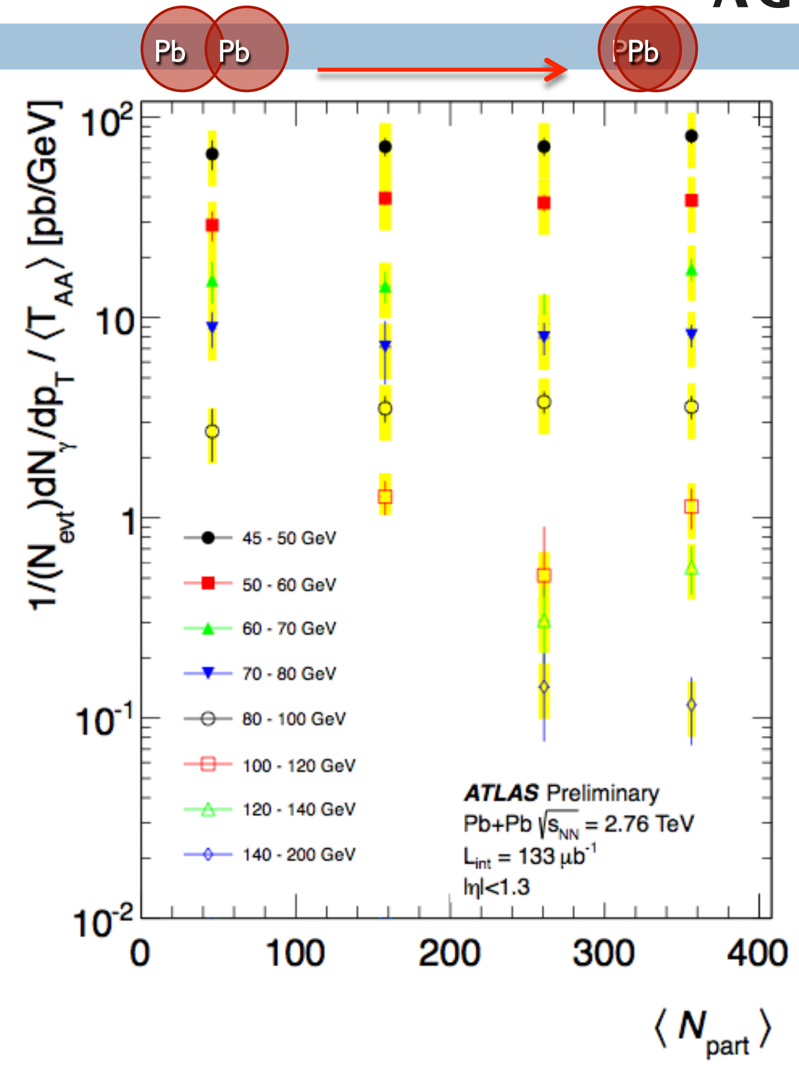
- Comparisons of Pb+Pb data with *p*+*p* cross sections from JETPHOX 1.3.0
  - PDFs: CTEQ 6.6
  - BFG fragmentation functions
  - No isospin or nPDFs included
  - Scale uncertainties: ±13%
  - PDF uncertainties at 7 TeV: ±5%
- Equivalent to $R_{AA}$ but with MC reference
- Good agreement of data and JETPHOX



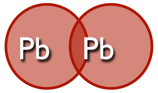



# Results: Photon Yield Scaling

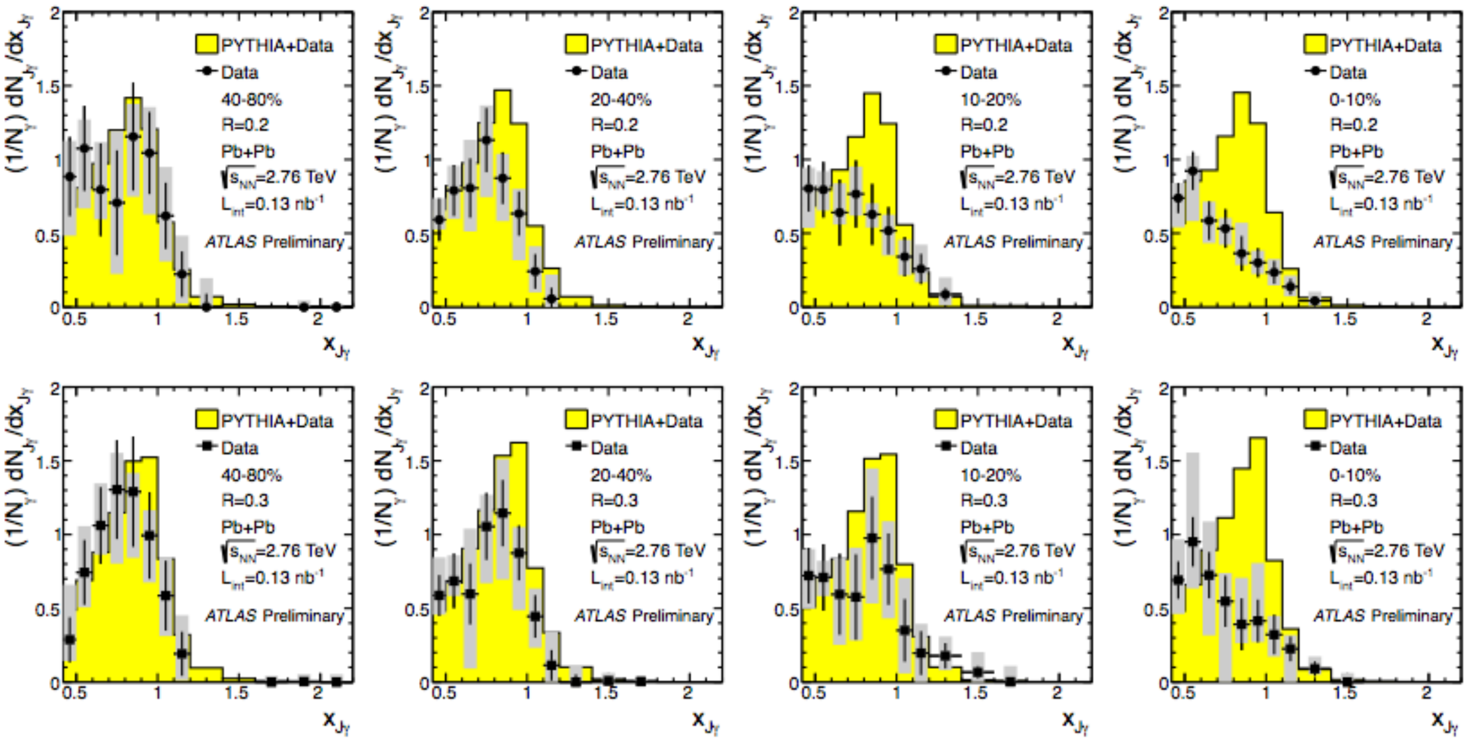
- Photon yields as a function of centrality in bins of $p_T$
  - No centrality dependence in any of the measured $p_T$ intervals
  - Photon yields in HI collisions scale linearly with $\langle T_{AA} \rangle$ or equivalently with $\langle N_{coll} \rangle$
- Photon production rates are not affected by QGP
  - Isolated direct photons seem to be a perfect probe to help in understanding of the jet quenching phenomenon



# Results: $\gamma$ - jet correlations




$x_{J\gamma} = p_T^{jet} / p_T^{\gamma}$


Photons: $60 < p_T < 90$ GeV and $|\eta| < 1.3$
Jets: $p_T > 25$ GeV and $|\eta| < 2.1$
$|\Delta\varphi| > 7\pi/8$

Centrality-dependent shift in $x_{J\gamma}$

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

ATLAS-CONF-2012-121

# Summary



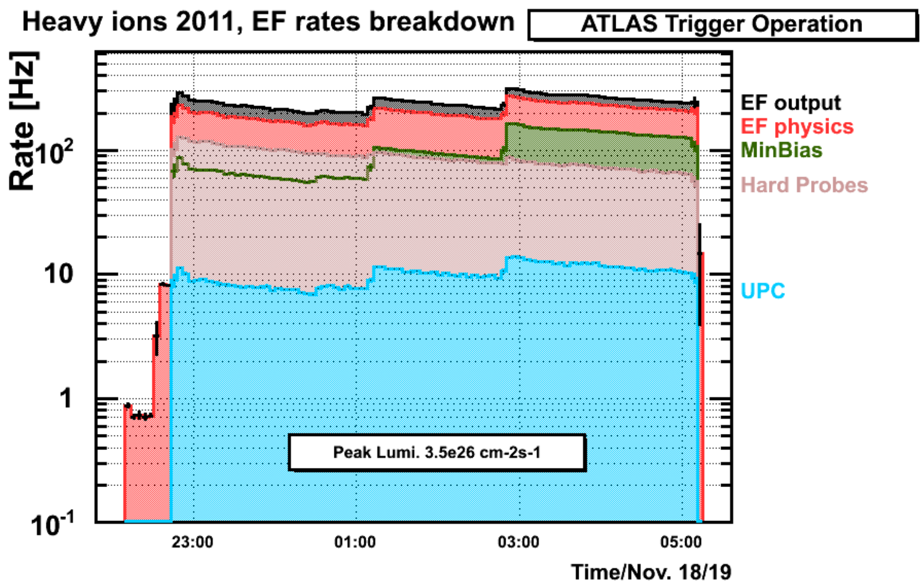
- Isolated direct photons have been measured in ATLAS
  - Eight bins of $p_T$ from 45-200 GeV and integrated over $|\eta|<1.3$
- Photon yields have been extracted as a function of $p_T$ and centrality
  - After scaling the yields by the mean nuclear thickness $\langle T_{AA} \rangle$, they are observed 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 $3\times10^{25}cm^{-2}s^{-1}$ which gives 350 Hz of min bias rate at L1
  - Record all min bias events to tape,
- In 2011: Peak luminosity $5.1\times10^{26}cm^{-2}s^{-1}$ 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




| Signature | Trigger |
|---|---|
| Jets | single jet $p_T$> 20 GeV |
| Muons | single muon $p_T$>4 GeV<br>di-muon $p_T$>2 GeV |
| Egamma | single egamma $p_T$>14 GeV<br>di-egamma $p_T$>5 GeV |
| UPC | low track multiplicity cut |

| Stream | Events Taken | Reco CPU/evt [s] |
|---|---|---|
| Min Bias | 60M | 70 |
| Hard Probes | 54M | 140 |
| UPC | 6.6M | 30 |

# Shower shape variables



- $R_{\eta}$-ratio of energies deposited in a 3x7 ($\eta$ x$\varphi$) 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
- $R_{\varphi}$-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
- $R_{had}$-ratio of $E_T$ measured in the hadronic layer to $E_T$ of the photon cluster
- $R_{had1}$-ratio of $E_T$ measured in the first sampling layer of the hadronic calo to $E_T$ of the photon cluster
- $\omega_{s,tot}$-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
- $F_{side}$-fraction of $E_T$ in seven first-layer strips surrounding the cluster maximum, not contained in the three core strips
- $E_{ratio}$-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**
- **Use standard Glauber MC (http://arXiv.org/abs/arXiv:0805.4411)**
  - R=6.62 fm, a=0.546 fm (skin depth)
- **Assume both participants and collisions contribute**
  - "Two component model", controlled by parameter "x"

$$\Sigma E_{T,FCal} = E_{T,pp}\left((1-x)\frac{N_{part}}{2} + xN_{coll}\right)$$

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