Production of jets and photons at ATLAS

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Many processes involving jets and photons,
- Will mainly refer to direct photons and inclusive di-jet events as these events have the highest cross section at the LHC

Introduction
Motivations
LHC and ATLAS
Selecting jets and photons
Cross Sections
Summary
Introduction

- Jets are as close as we get to the individual quarks or gluons
  - Parton level process is obscured by hadronisation, jet algorithms, etc.
- Inclusive di-jet events give a good probe into parton densities with a large cross section $\sigma=4.5\text{mb}$ $p_{T\gamma}>25\text{GeV}$
  (NLOJET++)
- Photons are a complementary probe of parton densities
  - Free from uncertainties of jet reconstruction
  - Direct photons $\sigma=0.2\mu\text{b}$ $p_{T\gamma}>25\text{GeV}$
    (JETPHOX)
  - Di-photon $q\bar{q},qg \rightarrow \gamma\gamma$ $\sigma=21\text{pb}$ $gg \rightarrow \gamma\gamma$ $\sigma=8\text{pb}$ $p_{T\gamma}>25\text{GeV}$
    (RESBOS $80<M_{\gamma\gamma}<150\text{GeV}$)
• Di-jet and direct photon events will be observable with relatively small data samples already in a new region of $p_T$
  → Larger statistics will probe even higher $p_T$ region
• Need to understand these processes before doing searches
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Simulated cross sections

- Di-jet $d\sigma/dE_T$ [nb/GeV]
- Direct Photon $d\sigma/dp_T$ [nb/GeV]
- Di-Photon $d\sigma/dp_T$ [pb/GeV]
Motivations

- **Inclusive Jet and Di-Jet:**
  - Tests the running of $\alpha_s$
  - New Physics?
    (e.g. Sub-structure, Extra dimensions)

- **Gluon Distribution and Parton Evolution Dynamics**
  - Large uncertainty at high $x$
  - Important as is discovery region
  - At low $x$:
    - No direct data constraint for $x \leq 10^{-4}$
    - Is DGLAP evolution sufficient?

- **Direct Photons**:
  - Calibration of Jet energy scale
  - Background for $H \rightarrow \gamma \gamma$

- **Gluon at $Q^2 = 10^4$ GeV$^2$**

- **At Low $p_T$** previous direct photon data poorly described without intrinsic parton $k_T$
Direct Photons in \( \bar{p}p \) at \( \sqrt{s} = 1.8 \) TeV

- Data-theory discrepancy can be explained by adding intrinsic parton \( k_T \)
- Or maybe our deeper understanding needs improving?
- Interesting features at low \( p_T \) but can still probe the gluon PDF at higher \( p_T \)


- Both Di-jets and direct photons cover a wide range of $x$ for a large range of $Q^2$ (or $p_T^2$).
- Most of this area has not been observed before.
- Can test the evolution from HERA to LHC.
- Low $x$ region $x \sim 10^{-4}$ accessed at scales where perturbative QCD is clearly applicable for the first time.
- To reach even lower $x$ values need lower $Q$ ($p_T$) or more forward detectors.
ATLAS @ the LHC

- pp collisions @ 14TeV
- Design L=10^{34} \text{ cm}^{-2}\text{s}^{-1}
- Beam commissioning to start very shortly.
- Initial collisions @ 10TeV
- First month $\int L$ of the order of a few $\text{pb}^{-1}$

Cooling as of 30/06/08

- Inner detector (tracking) $|\eta|<2.5$
- 2T solenoid magnet
- Ecal + Hcal Calorimeters
- Muon System with 4T toroidal magnet system
ATLAS calorimeters

- Detecting jets + γ's requires high resolution and segmentation
- Ecal (LAr) |η|<3.2
  - Goal: $\sigma_E/E=10%/\sqrt{E}$ for EM objects
- Hadronic (Scintillating TILE & HEC) |η|<3.2
  - Goal: $\sigma_E/E=50%/\sqrt{E}$ for jets

- In the LAr barrel there are 3 layers:
  - Strips in $\eta$
    - For $\pi^0/\gamma$ separation
  - Middle sampling (square Cells)
    - Most energy deposited here
  - Rear Cells
    - Also has a presampler |η|<1.8
Simulated events

- Top direct photon
  - $p=786$ GeV Photon
  - $E=722$ GeV Jet

- Bottom di-jet
  - $E=682$ GeV Jet
  - $E=622$ GeV Jet

- Back to back in the transverse plane

- The jet/photon rapidities depend on the momentum fractions carried by the incoming partons
• To reconstruct a jet an algorithm is used on energy deposits in the calorimeter
• Key elements of the algorithm are that it should be fast, understood theoretically, easy to calibrate, infra-red safe and applicable at a parton level

• In ATLAS there is a choice of algorithm and size:
  • Cone - radius=0.4/0.7 in $\Delta R^2=\Delta \eta^2+\Delta \phi^2$ around highest $p_T$ seed
  • Kt - merges particles of similar momentum with a distance parameter=0.4/0.6 to control the merging

• Jet Energy Scale is the largest uncertainty in Jet measurements
  • Rely on accurate calibration, e.g. from in-situ measurement for which $\gamma+$jet and $Z+$jet events are used
• Have to decide whether a calorimeter deposit is a jet or whether it has come from a photon

• There is a low fake probability but the di-jets have a much larger cross section (x10⁴) than direct photons

• For a jet to be misidentified as a photon most of the jet energy has to end up in the ECAL
  → Largest source of these photons is: π⁰→γγ

• Also the photon could be radiated at a wide angle
  → But this is a real signal photon so is a higher order correction
• LO Direct Photon processes:
  • Compton $qg \rightarrow q\gamma$ (dominant @ LHC)
  • Annihilation $qq \rightarrow g\gamma$

• At HO in $\alpha_s$: $gg \rightarrow g\gamma$ has the same event topology
• But also at HO is the Bremsstrahlung process which is difficult to handle (experimentally and theoretically)
  $\rightarrow$ depends on isolation cuts used

• As well as this 70% of photons will convert before reaching the calorimeter, although most of these convert in the solenoid
  • Can use tools to recover those that convert in the tracker
Photon Identification

- Firstly apply a track veto to remove electrons
- Then by using the fine granularity of the calorimeter the photon shower shape can be studied.
- Apply ID cuts, separated into $\eta$ and $p_T$ bins:
  - Hadronic leakage
  - Ratio of cell windows in the 2nd layer
  - Width of the shower in the 1st and 2nd layers
  - Secondary maxima in the 1st layer
  - Fraction of $E$ in the 1st layer compared to the full cluster
  - Shower Shape in the shower core in the first layer

Only $\approx 1$ in 3000 jets pass photon ID*

Only isolated $\pi^0$, $\eta$, etc. from jets survive

• Pseudo Inclusive Jet data was passed through a global (Zeus) fit which showed that ATLAS could constrain the high x-gluon.

• The jet uncertainty is dominated by the jet energy scale, an error on this of 1% leads to a $\sigma(jet)$ error of 10%.

• The jet energy scale does not apply to direct photon events so they will have a much smaller uncertainty.

• This should allow the differences in the $\eta$ spectrum of different PDF's (~10%) to be observed.
• Di-Jets and direct photons have the largest $\sigma$
  • Will be the first high $p_T$ data taken
  • Need to be well understood before searches can take place

• The LHC is preparing for first data later this year
  • Both Di-jets and direct photons will be seen
  • It will be entering a new region of phase space

• ATLAS has been carefully designed for high $\gamma$/jet and $\gamma/\pi^0$ separation needed for $\gamma$ studies

• Jet and Photon studies will be crucial studying pQCD through parton densities and evolution

Thanks to the Birmingham HEP and ATLAS SM groups
Backup
Direct Photon LO diagrams

- More often involves low $x$ gluon and high $x$ quark
- Rec of $x_1^{(obs)}$ and $x_2^{(obs)}$:
  - $x_1^{(obs)} = \frac{p_T}{\sqrt{s}}(e^{\eta_{jet}} + e^{\eta_{\gamma}})$
  - $x_2^{(obs)} = \frac{p_T}{\sqrt{s}}(e^{-\eta_{jet}} + e^{-\eta_{\gamma}})$
- Direct photons may be useful for this calculation as the $\gamma$ $p_T$ is well known and only the $\eta$ of the jet is needed
\( \eta \) bins: [0.7, 1.0, 1.5, 1.8, 2.0, 2.5] 
\( p_T \) bins: [30, 40, 50, 60, 70, 80] GeV

Hadronic leakage eta dependent for \( \eta < 0.8 \) and \( \eta > 7.5 \) GeV

- \( \text{ethad}_1/\text{et}_37 = \text{ET leakage into 1st sampling of had calo / ET in 3x7} \)

Secondary maxima in the 1st layer

- \(~e2tsts1/(1000+\text{const_lumi*et}) = 2nd maximum in strips / (1000+\text{const_lumi*et})~\)
- \( e2tsts1-\text{emins1} = 2nd \text{ maximum in strips - energy of strip with minimum between max 1 & 2} \)

Ratio of cell windows in the 2nd layer

- \( e237/e277 = \text{uncor. energy in 3x7 cells in em sampling 2 / uncor. energy in 7x7 cells in em sampling 2} \)
- \( e233/e237 = \text{uncor. energy in 3x3 cells in em sampling 2 / uncor. energy in 3x7 cells in em sampling 2} \)

Width of the shower in the 1st and 2nd layers

- \( \text{weta}_1 = \text{corrected width in 3 strips in the 1st samp.} \)
- \( \text{weta}_2 = \text{corrected width in 3x5 cells in the 2nd samp} \)
- \( \text{wtots}_1 = \text{total width in em sampling 1 in 20 strips} \)

Fraction of E in the 1st layer compared to the full cluster

- \( f1 = \text{fraction of energy found in 1st em sampling} \)

Shower shape in the shower core in the 1st layer

- \( \text{fracs}_1 = \text{energy outside core (E(\pm7)-E(\pm3))/E(\pm7)} \)
- Cluster isolation on etcone 20 is there but set to be 1000

PhotonID details
Photon Param's

- etcone = ET in a cone of R=0.45 in EM calo
- etcone20 = ET in a cone of R=0.20 in EM calo
- etcone30 = ET in a cone of R=0.30 in EM calo
- etcone40 = ET in a cone of R=0.40 in EM calo
- etaBE2 = eta from the second sample
- et37 = ET in 3x7
- e237 = uncor. energy in 3x7 cells in em sampling 2
- e277 = uncor. energy in 7x7 cells in em sampling 2
- ethad1 = ET leakage into 1st sampling of had calo
- weta1 = corrected width in 3 strips in the 1st samp.
- weta2 = corrected width in 3x5 cells in the 2nd samp
- f1 = fraction of energy found in 1st em sampling
- e2tsts1 = 2nd maximum in strips
- emins1 = energy of strip with minimum between max 1 & 2
- wtots1 = total width in em sampling 1 in 20 strips
- fracs1 = energy outside core (E(±7)-E(±3))/E(±7)
Inclusive Jet Cross Section

Direct photon PDF outcomes

- $p_T > 30$ GeV
- $p_T > 110$ GeV
- $p_T > 300$ GeV
Reco that matches truth
- Highest $p_T\gamma$ but fails photonID

Example of background from a signal event

2 $\gamma$'s in jet to ignore
- Both lower $p_T$ but 1 passes photonID