Production of jets and photons at ATLAS

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on behalf of the ATLAS collaboration

Outline

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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

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Introduction

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- 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 $80 < M_{\gamma\gamma} < 150\text{GeV}$)

Simulated cross sections

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- 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

Simulated cross sections

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- 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
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- **Inclusive Jet and Di-Jet:**
 - Tests the running of α_s
 - New Physics?
(e.g. Sub-structure, Extra dimensions)
- **Direct Photons:**
 - Calibration of Jet energy scale
 - Background for $H \rightarrow \gamma\gamma$

- **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?

- **At Low p_T previous direct photon data poorly described without intrinsic parton k_T**

Intrinsic Parton k_T

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- Direct photon data taken at Tevatron.
- 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

Phase Space

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- 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

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- 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 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

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ATLAS calorimeters

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

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

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Simulated events

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- 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

Jets in ATLAS

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- 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 $\eta\Phi$ $\Delta R^2 = \Delta\eta^2 + \Delta\Phi^2$ 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 γ +jet and Z+jet events are used

Distinguishing γ /Jet

- 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 ($\times 10^4$) 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: $\pi^0 \rightarrow \gamma\gamma$
- Also the photon could be radiated at a wide angle
 - But this is a real signal photon so is a higher order correction

Complications

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- LO Direct Photon processes:
 - Compton $qg \rightarrow q\gamma$ (dominant @ LHC)
 - Annihilation $q\bar{q} \rightarrow g\gamma$

- At HO in α_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)
 - 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

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- 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 η and p_T bins:
 - **Hadronic leakage** —————→ Only isolated π^0 , η , etc. from jets survive
 - **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 ≈ 1 in 3000 jets pass photon ID*

PDF outcomes

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- 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 $\sigma(\text{jet})$ 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 η spectrum of different PDF's ($\sim 10\%$) to be observed

Summary

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- Di-Jets and direct photons have the largest σ
 - 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 γ /jet and γ/π^0 separation needed for γ studies
- Jet and Photon studies will be crucial studying pQCD through parton densities and evolution

Thanks to the Birmingham HEP and ATLAS SM groups

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Backup

Direct Photon LO diagrams

- More often involves low x gluon and high x quark
- Rec of $x_1^{(\text{obs})}$ and $x_2^{(\text{obs})}$:
 - $x_1^{(\text{obs})} = (p_T / \sqrt{s})(e^{\eta_{\text{jet}}} + e^{\eta_\gamma})$ $x_2^{(\text{obs})} = (p_T / \sqrt{s})(e^{-\eta_{\text{jet}}} + e^{-\eta_\gamma})$
- Direct photons may be useful for this calculation as the γ p_T is well known and only the η of the jet is needed

- η 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
 - $\text{ethad1}/\text{et}_{37} = \text{ET leakage into 1st sampling of had calo} / \text{ET in } 3 \times 7$
- Secondary maxima in the 1st layer
 - $\sim \text{e2tsts1}/(1000 + \text{const_lumi} \cdot \text{et}) = \text{2nd maximum in strips} / (1000 + \text{const_lumi} \cdot \text{et})$
 - $\text{e2tsts1} - \text{emins1} = \text{2nd maximum in strips} - \text{energy of strip with minimum between max 1 \& 2}$
- Ratio of cell windows in the 2nd layer
 - $\text{e237}/\text{e277} = \text{uncor. energy in } 3 \times 7 \text{ cells in em sampling 2} / \text{uncor. energy in } 7 \times 7 \text{ cells in em sampling 2}$
 - $\text{e233}/\text{e237} = \text{uncor. energy in } 3 \times 3 \text{ cells in em sampling 2} / \text{uncor. energy in } 3 \times 7 \text{ cells in em sampling 2}$
- Width of the shower in the 1st and 2nd layers
 - weta1 = corrected width in 3 strips in the 1st samp.
 - weta2 = corrected width in 3×5 cells in the 2nd samp
 - wtots1 = total width in em sampling 1 in 20 strips
- Fraction of E in the 1st layer compared to the full cluster
 - f1 = fraction of energy found in 1st em sampling
- Shower shape in the shower core in the 1st layer
 - $\text{fracs1} = \text{energy outside core } (E(\pm 7) - E(\pm 3)) / E(\pm 7)$
- Cluster isolation on $\text{etcone } 20$ 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 3×7
- $e237$ = uncor. energy in 3×7 cells in em sampling 2
- $e277$ = uncor. energy in 7×7 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 3×5 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 $(E(\pm 7) - E(\pm 3)) / E(\pm 7)$

Inclusive Jet Cross Section

Direct photon PDF outcomes

**Reco that matches truth
- Highest $p_T \gamma$ but fails
photonID**

**Example of
background
from a signal
event**

**2 γ 's in jet to ignore
- Both lower p_T but 1
passes photonID**