Inclusive Prompt $\gamma$ Production at CDF

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Introduction and Motivation

- Test pQCD predictions over several orders of magnitude
- The gluon-mediated production dominates up to 150 GeV → the high statistics Tevatron datasets can further constrain the gluon PDF

Advantages over pure QCD
- Point-like coupling of quarks and photons
- No need of algorithms to define photons
- Better energy resolution (EM calorimeters)

- Probe photon techniques over a wide energy range
- Irreducible background for important searches (f.ex. light Higgs)

The Tevatron is a **p-pbar collider at $\sqrt{s}=1.96$ TeV** located Fermilab (Illinois, USA)

In Run II (2001) it has **already delivered more than 6 fb$^{-1}$** of data

Current previsions expect a **total dataset of more than 8 fb$^{-1}$**

**Excellent performance:**
- Typical inst. luminosity $> 3.0 \times 10^{32}$ cm$^2$ s$^{-1}$
- Record inst. lum. $3.6 \times 10^{32}$ cm$^2$ s$^{-1}$
- Delivered $> 6$ fb$^{-1}$
CDF Detector

CDF is a multipurpose particle detector

- Silicon Vertex detector (L00, SVXII, ISL)
- Central Drift Chamber (COT)
- SC solenoid (B=1.4T)
- Calorimeters (central: CEM, CHA, WHA) (forward: PEM, PHA)
- Muon chambers

Photons are detected as clusters of 2-3 towers in the CDF calorimeters

γ and π^0 separation in the CEM:
- CES: strip-wire chamber situated at the shower maximum position measures photon candidate position and shower shape (2mm resolution in each direction for 50 GeV electrons)
- CPR: pre-radiator detector located before the calorimeter
Photon detection

- **Main background**: photons from light meson decays
  - Suppressed by requiring isolated photons
  - **isolation** $E_T$ : $\text{Iso} = \text{energy in a cone of radius } \sim 0.4 \text{ around the photon}$

- **Background** surviving the isolation cuts must be subtracted using statistical techniques:
  - **CES/CPR**: Use information from the CES and CPR detectors
  - **Isolation-shape templates**: Fit the calorimeter isolation in the data to signal and background templates
Inclusive photon cross section

**Photons**
- Central: $|\eta|<1.0$
- $E_T>30$ GeV
- Isolated: Iso<2.0 GeV
- Missing $E_T<0.8E_T$

**Luminosity:** $L = 2.5 \text{ fb}^{-1}$

**Data**

**Fit Result:**
- $\chi^2$ fit that takes into account the statistical uncertainties in the templates and in the data

**Signal:**
- inclusive photon MC

**Bkg:**
- photons from meson decays in dijet MC

**CDF Run II Preliminary**

- CDF Data, $L=2.5 \text{ fb}^{-1}$
- Fit result: $fS+(1-f)B$
- S: Photon MC
- B: Dijet MC
  - (no systematics included)

Signal Fraction (iso<2 GeV)

$f = 0.911 \pm 0.009$

$70<p_T^\gamma<80$ GeV/c
The signal fraction goes from $\sim 70\%$ to $\sim 98\%$ as the photon $E_T$ increases.

**Systematic uncertainty in the signal fraction:**
- 13% at low $E_T$ to 5% at high $E_T$
- Estimated using:
  - Templates from electrons in Z decays in DATA samples
  - The CES/CPR methods
  - 2-bin templates (removes details in the shape)
The cross section unfolding

Correct the cross section for acceptance, efficiency and resolution effects back to hadron level

\[ U = \frac{\text{Reconstructed photons passing offline cuts}}{\text{Generated photons with } E_T > 30 \text{ GeV, } |\eta| < 1.0 \text{ and iso } < 2 \text{ GeV}} \]

Vary between 64% and 69% as the photon \( E_T \) increases and do not present strong \( E_T \) dependence.
The Cross Section

- Uses ~6 times more statistics than previous results
- Extends the $E_T$ coverage up to 400 GeV
- Tests the pQCD predictions over 6 orders of magnitude

Total systematic uncertainty is ~10-15%
- signal fraction (dominant at low $E_T$)
- photon energy scale (dominant at high $E_T$)
Predictions are corrected for the non-pQCD contributions of the UNDERLYING EVENT.

The UE tends to decrease the cross section due to its contribution to the energy in the isolation cone. Estimated using two different UE Tunes in PYTHIA MC.

The correction is of ~9% and flat in $E_T$. 

CDF Run II Preliminary

- CDF data, L=2.5 fb$^{-1}$
- systematic uncertainty
- NLO pQCD JETPHOX
- CTEQ6.1M / BFG II
- $\mu_0=\mu_F=\mu_R=p_T$
- CTEQ6.1M PDF uncertainties
- scale dependence
  - $\mu=0.5p_T$ and $\mu=2p_T$. 

<table>
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<th>Isolation cone</th>
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<td>Isolation [GeV]</td>
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Agreement between data and theory

But different shape at low $E_T$

- Not covered by theoretical or experimental uncertainties
- Already observed by DØ Run II, Tevatron Run I and UA2

**Comparison to theory**

**UNCERTAINTIES**

- **PDF uncertainty**
  - $\sim 5\%$ at low $E_T$
  - $\sim 15\%$ at high $E_T$

- **Scale dependence**
  - $\sim 15\%$ at low $E_T$
  - $\sim 8\%$ at high $E_T$

- **In the measurement**
  - $\sim 10$ to $15\%$
Photon+bjet

Sensitive to the b content of the proton

Combination of two results with 208 and 340 pb$^{-1}$

- 208 pb$^{-1}$: dedicated secondary vertex trigger
- PHOTONS: $|\eta|<1.1$, $E_T>20$ GeV, Iso<1.0 GeV
- JETS: $|\eta|<1.5$, $E_T>20$ GeV, $\Delta R(\gamma,j)>0.7$

B-tagging:
Presence of a displaced secondary vertex

b-contribution extracted using the secondary vertex invariant mass

Agreement between data and theory
Limited statistics

CDF Run II

Data (208-340 pb$^{-1}$)
NLO QCD ($\mu_{ren} = \mu_{fact} = p_T$)
PYTHIA

CTEQ6.6M PDFs

Displaced track
Primary vtx
Secondary vtx
$d_0$

CDF Run II Preliminary
Data: $L \sim 340$ pb$^{-1}$
B fraction
C fraction
Light fraction

No. events

Mass of secondary vertex (GeV/c$^2$)
**Irreducible background to**
SM Higgs searches (H→γγ)
BSM searches (SUSY with light gravitino, extra-dimensions)

**Photons:**
|η^{1,2}|<0.9
E_{T}^{γ^{1}} > 14 GeV, E_{T}^{γ^{2}} > 13 GeV
Iso^{1,2} < 1.0 GeV

**DIPHOX:**
- NLO prompt diphotons
- NLO fragmentation (1 or 2 γ)
  - High q_{T}^{γγ}, small ΔΦ and low mass
- NNLO gg→γγ

**ResBos:**
- NLO prompt diphotons
- LO fragmentation with resummed initial state gluon radiation (low q_{T}^{γγ})

Well described by DIPHOX and ResBos in the different regions
PYTHIA also describes the shape (underestimates x-section by a factor 2)
Summary

- Latest CDF results with luminosities up to 2.5 fb$^{-1}$

  - Inclusive photon
    - Agreement with theory
    - But different shape at low $E_T$

  - Photon+bjet
    - Agreement with theory
    - Limited statistics

  - Diphoton
    - Old (but very important) measurement
    - Update with more statistics?

Still more to come at the Tevatron and at the LHC!
Backup slides
Inclusive Photon DØ result

Same shape as measured by CDF, especially at low $p_T$
Total systematic uncertainty in the inclusive photon cross section goes from 10 to 15% depending on the photon $E_T$.

The major contributions are due to the signal fractions at low $E_T$ and the photon energy scale at high $E_T$.

Uncertainty in the photon purity
The photon energy scale

- Photon energy scale corrected back to generator level with the Z mass scale in both data and MC
- Z mass from electrons in $Z \rightarrow ee$ decays in data and run-dependent MC

$$E^{\text{scale}} = \frac{M_z^{\text{rec}}}{M_z^{\text{PDG}}}$$

- Correction in the data is run-dependent and increases with luminosity (mean ~ 0.994)
- In MC, constant at ~ 1.0035
NLO fragmentation contribution
- High $q_T$, small $\Delta \Phi$ and low mass
- Resummed initial state gluon radiation
- Low $q_T$

Measurement with $\Delta \Phi(\gamma, \gamma) > \pi/2$
further tests fragmentation part

$E_T^1 > 14 \text{ GeV}, E_T^2 > 13 \text{ GeV}$

$|\eta_1^{\gamma\gamma}| < 0.9$

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