DØ Results on Diphoton Direct Production and Photon + b and c Jet Production

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On behalf of the DØ Collaboration

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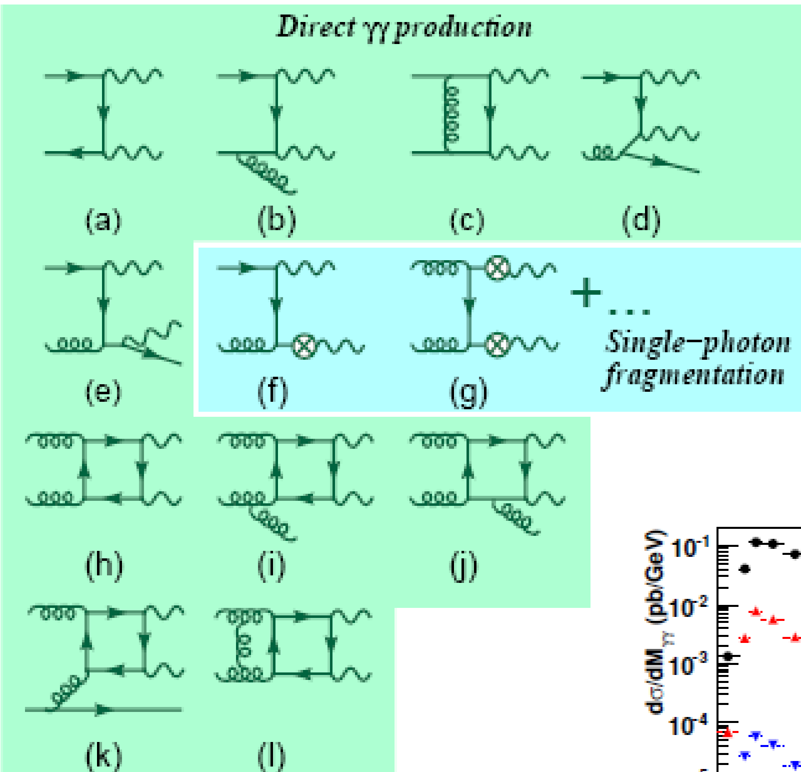
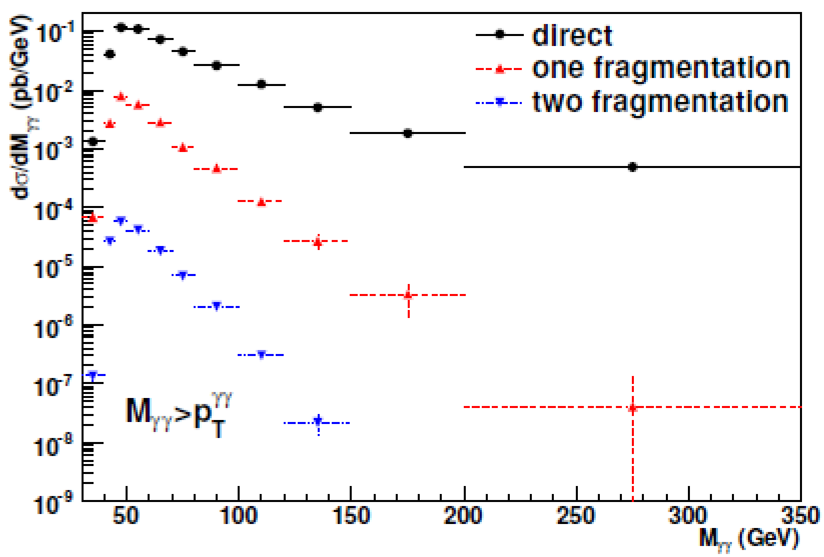
Shedding Light on QCD

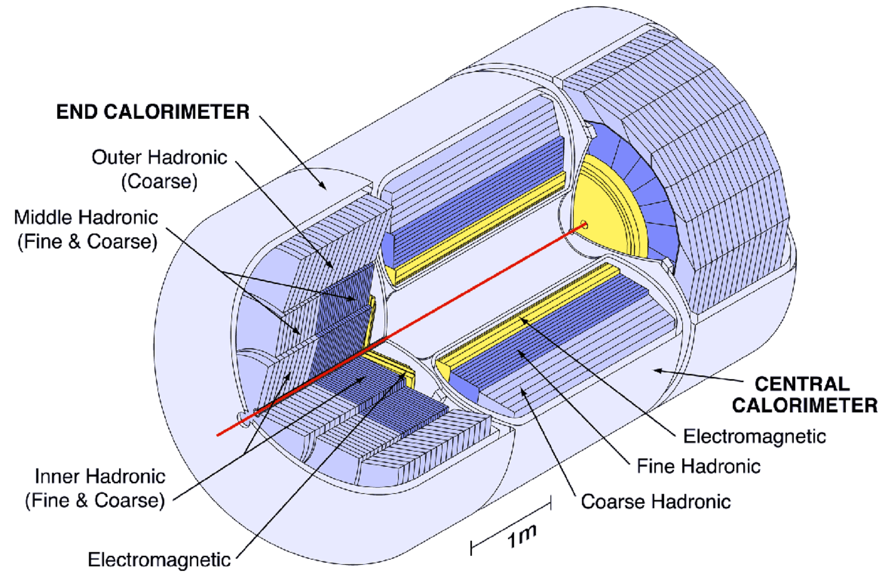


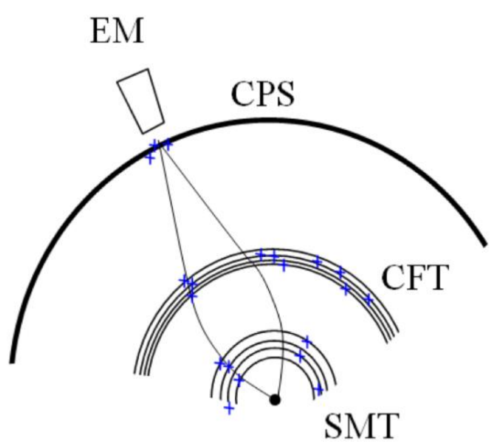
- Important test of pQCD
  - Soft gluon resummation
- Major background to H→γγ
- Classes of Production
  - Direct *(a-e & h-i)*
    - "Born & Box" diagrams
  - Single Fragmentation *(f)*
  - Double Fragmentation *(g)*



Finding a Photon

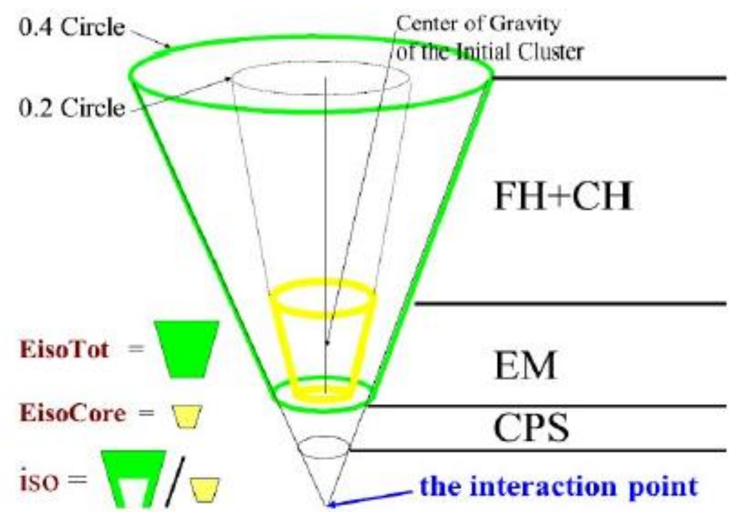
- D0 Electromagnetic Calorimeter
  - Approx 20 radiation lengths thick
  - Coverage $|\eta| < 1.1$ & $1.5 < |\eta| < 3.2$
  - $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ (0.05x0.05 at shower max)
- High precision tracking
  - Silicon microstrip tracker
  - Central fiber tracker
  - Central & forward preshower detectors

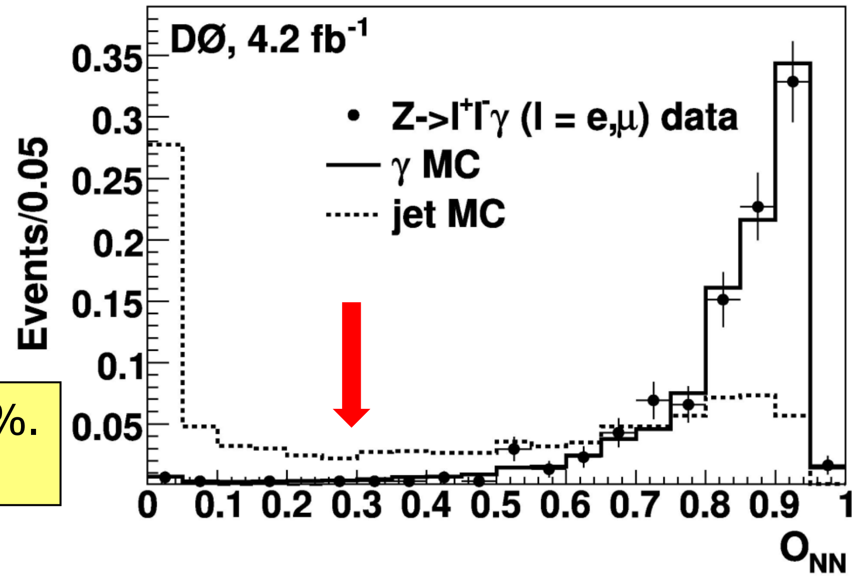




Finding a Photon

- Central photons are selected from EM clusters reconstructed within a cone with radius R=0.2 requiring:
  - High EM fraction: >97%
  - Isolated in the calorimeter
  - Isolated in the tracker
  - Shower width in 3rd EM layer consistent with an EM object.
- Photon purity is further improved by using an Artificial Neural Net (ANN) for identification
- Inputs:
  - Tracker isolation
  - Number of EM1 cells within R<0.2
  - Number of EM1 cells within 0.2<R<0.4
  - Number CPS clusters within R<0.1
  - Squared-energy-weighted width of energy deposition in the CPS



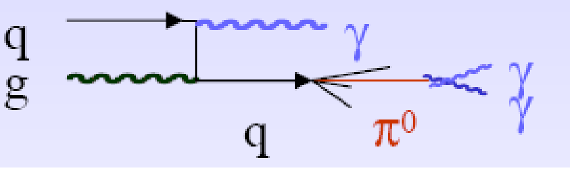


Photon efficiency: 98%. Systematic uncertainty 1.5%. Rejects ~40% of misidentified jets.

Direct Diphotons

- 8.5 fb^{-1} of data collected with a variety of di-EM triggers
  - Trigger efficiency after offline selection is ~100%
- Require
  - 2 photons with p_T>18(17) GeV, |η|<0.9, E_T^{iso}<2.5 GeV
  - ΔR(γ,γ)>0.4
  - No min. requirements on Δϕγγ, Mγγ or p_T(γγ)<M(γγ)
- Primary vertex with highest number of tracks required to have $|z_{PV}|$<60 cm.
  - Photon kinematics computed with respect to this vertex.

$$E_T^{iso} = \sum_{\substack{\text{partons or hadrons} \\ \text{within } \Delta R<0.4}} p_{T,i} - p_{T\gamma}$$



$$\frac{d\sigma}{dX} = \frac{N_{\gamma\gamma}}{\varepsilon \cdot A \cdot L \cdot \Delta}; \quad X = M_{\gamma\gamma}, p_T^{\gamma\gamma}, \Delta\phi_{\gamma\gamma}, |\cos\theta^*|$$

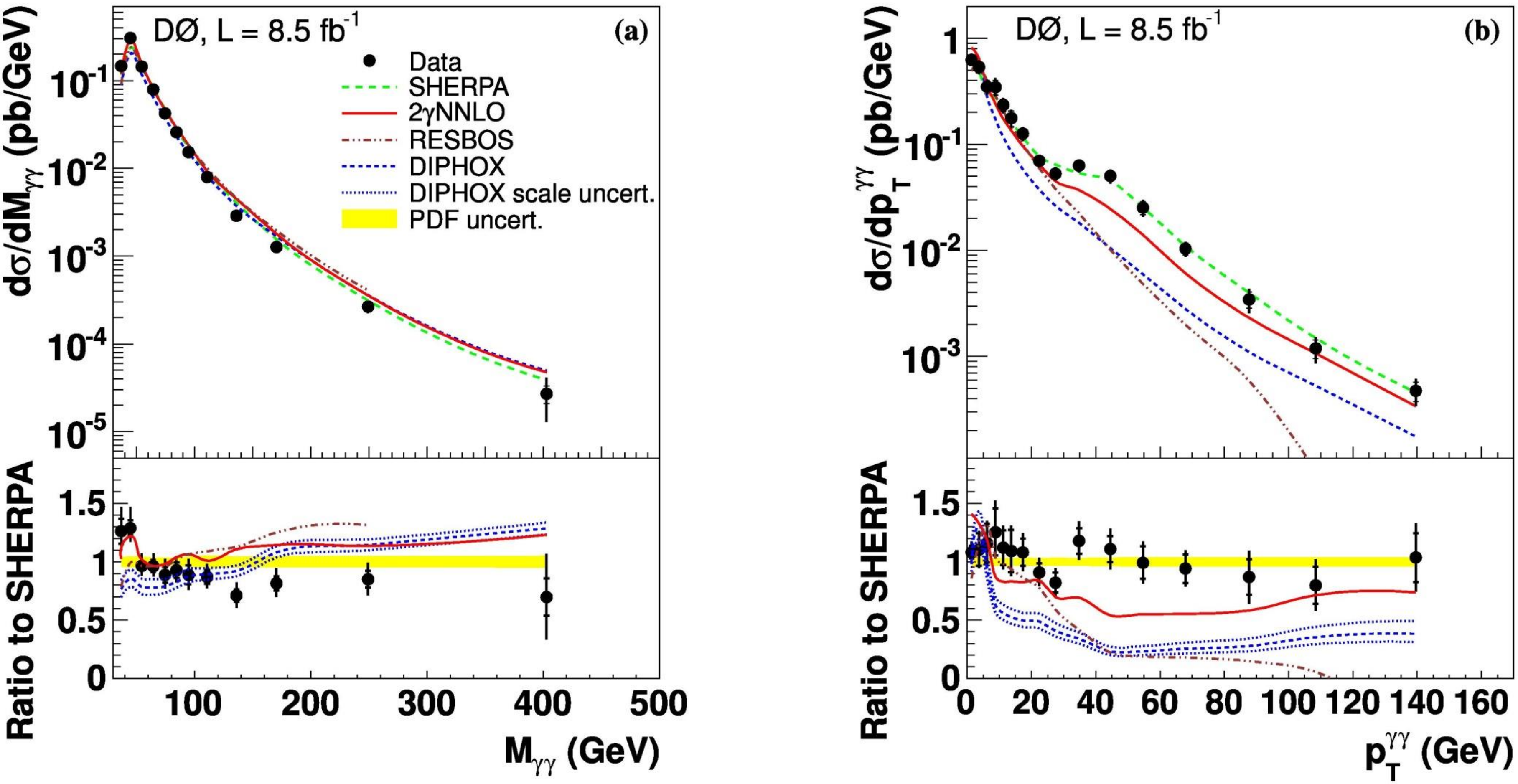
- $N_{\gamma\gamma}$: Estimated number of prompt diphoton events
- ε: Event selection efficiency
- A: Event acceptance
- L: Integrated luminosity
- Δ: Bin width

DATA	34020
γγ	20255 +/- 398
γ+jet	2575+/- 516
Dijet	10992+/- 344
Z/γ* ->ee	198+/- 14

$\gamma\gamma$ Differential Cross-Sections

Submitted to PLB
[arXiv:1302.6508]

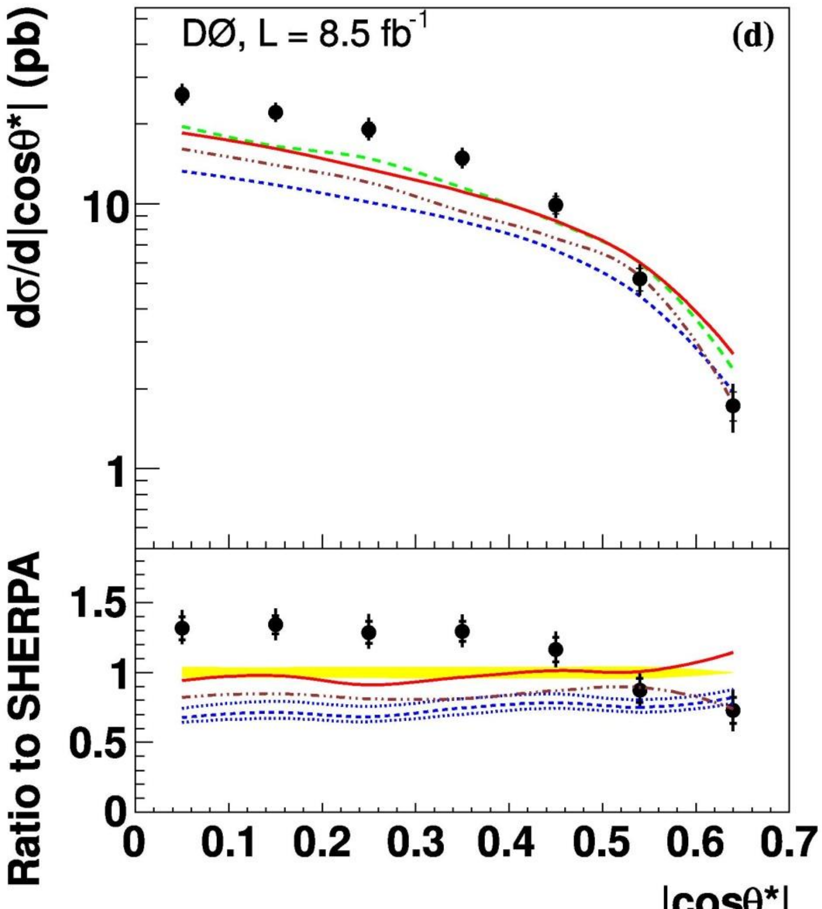
All $\Delta\phi_{\gamma\gamma}$



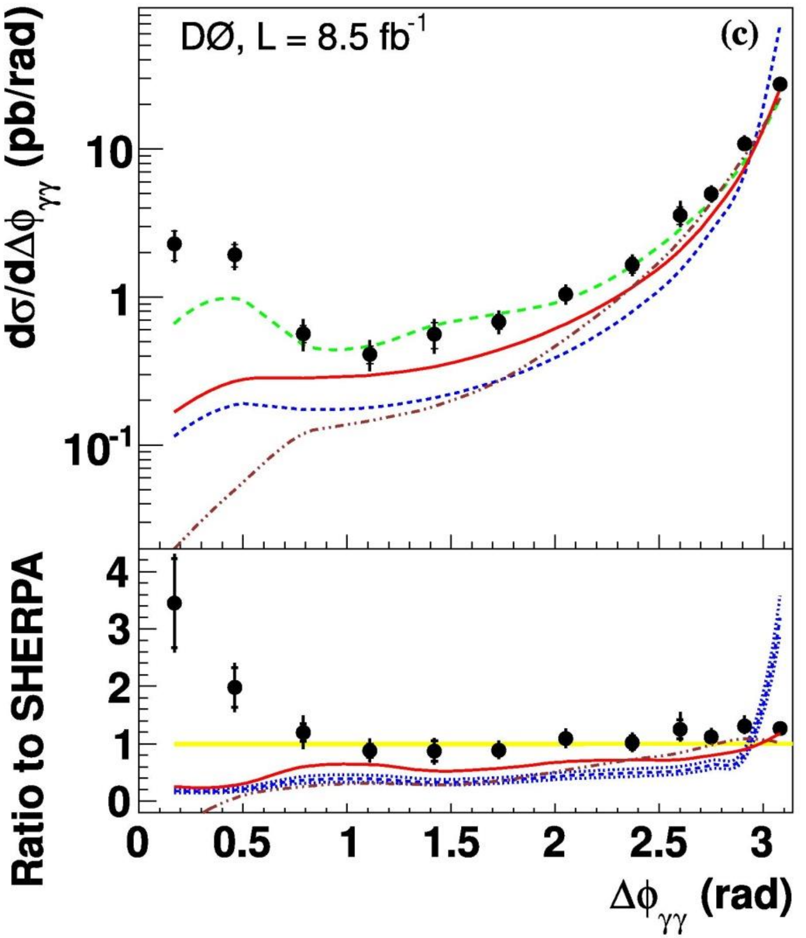
Double Differential Cross-Sections

arXiv:1302.6508

All $\Delta\phi_{\gamma\gamma}$



Differential $\Delta\phi_{\gamma\gamma}$

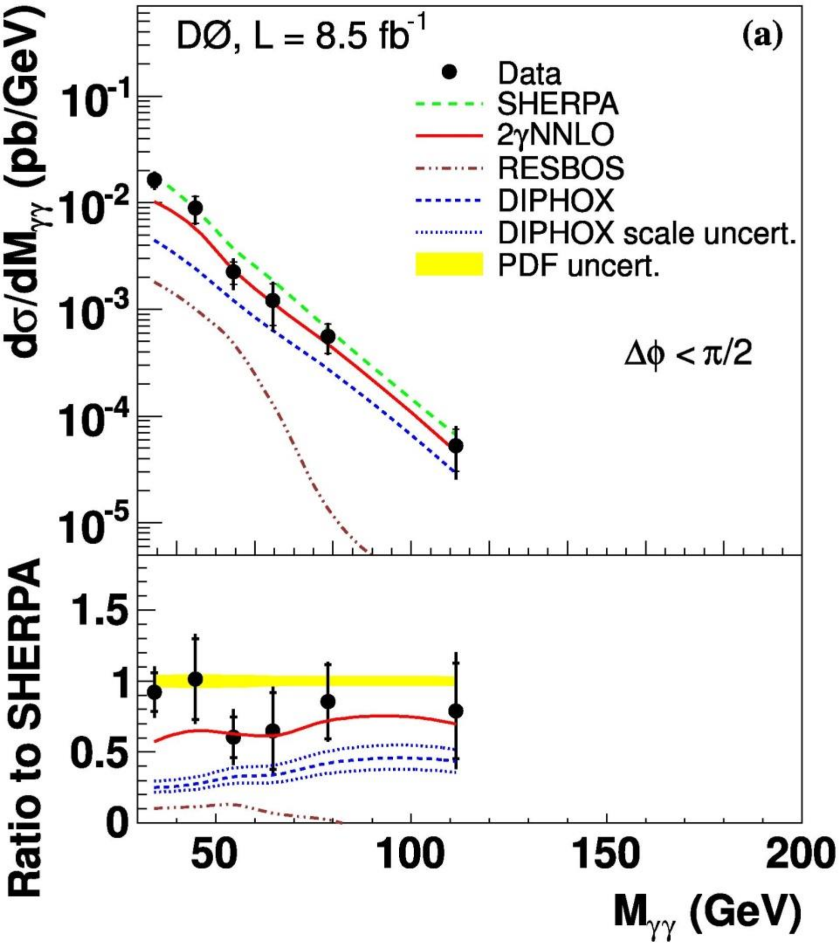


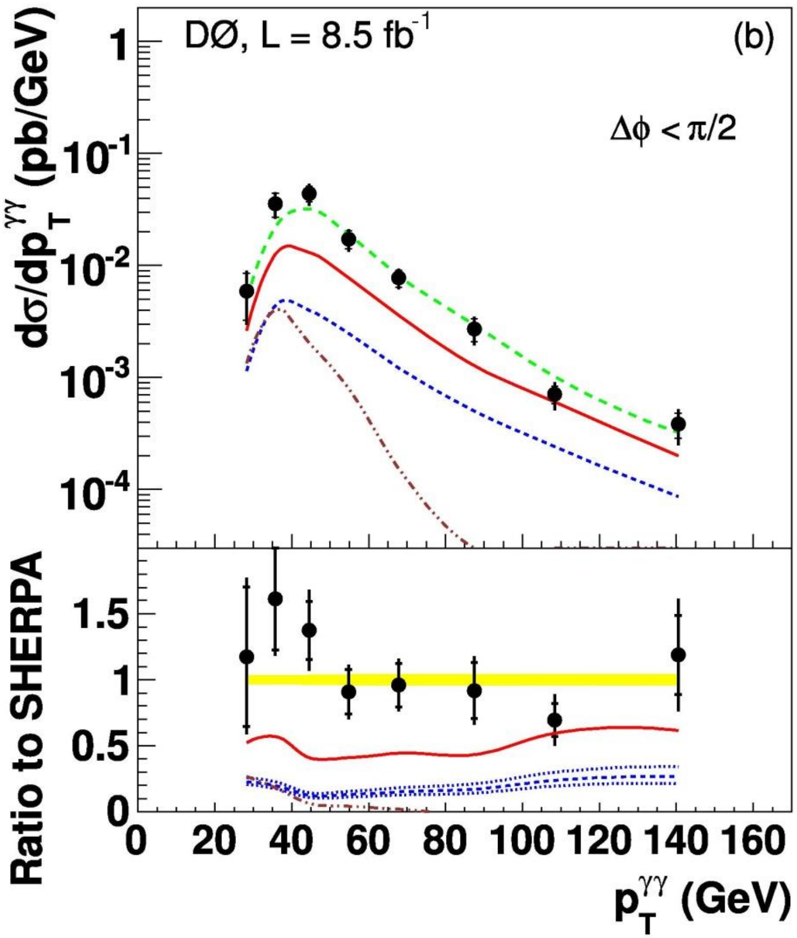
$\gamma\gamma$ Differential Cross-Sections

arXiv:1302.6508

$\Delta\phi_{\gamma\gamma} < \pi/2$

- Expect larger contribution from fragmentation here





$\gamma\gamma$ Differential Cross-Sections

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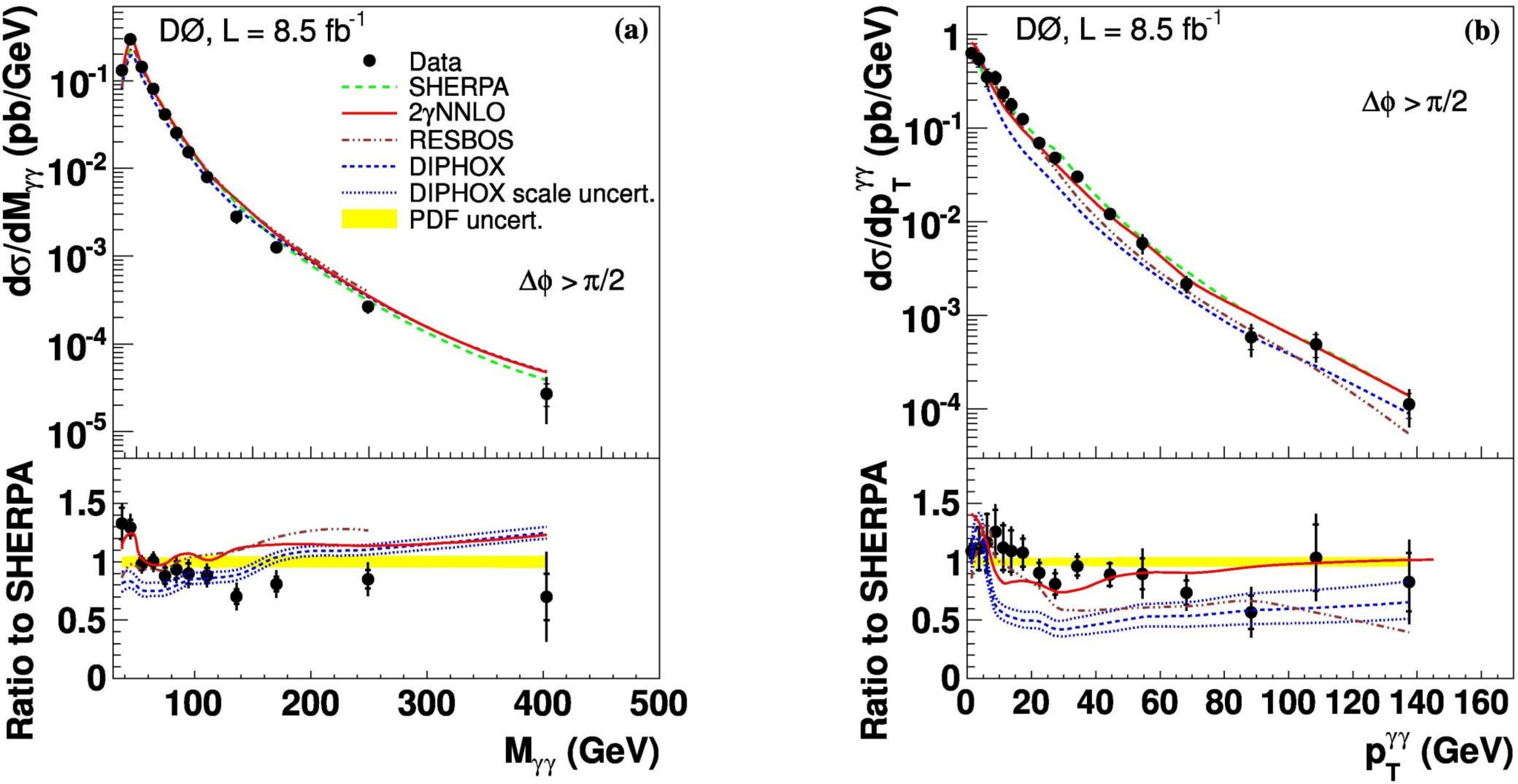
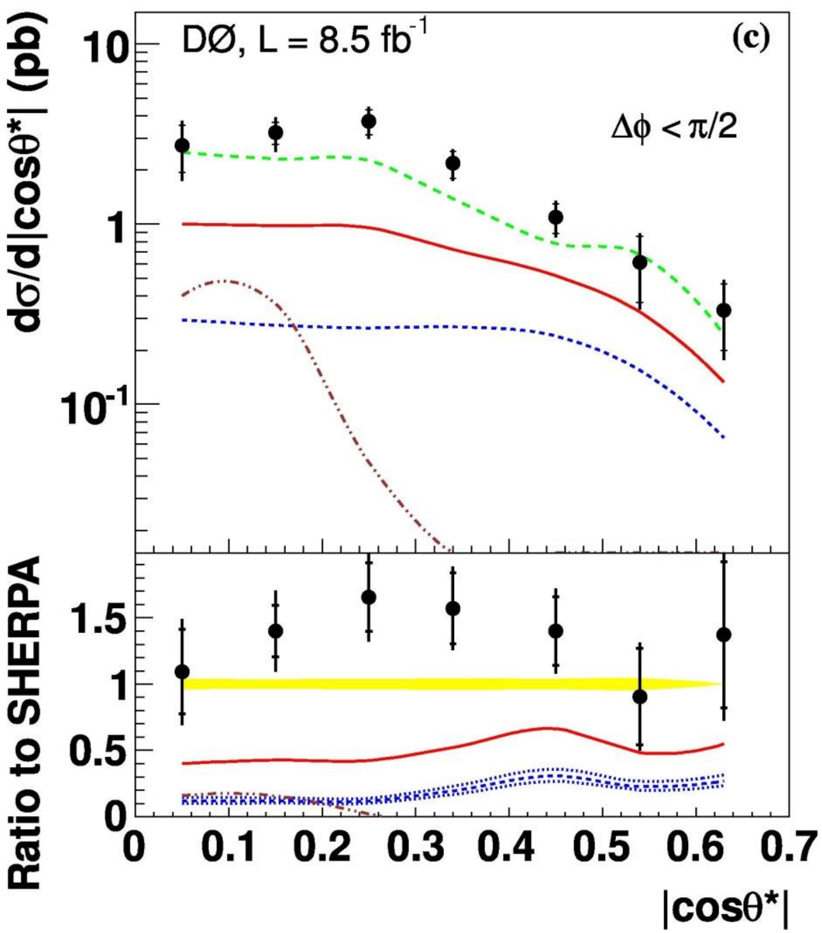


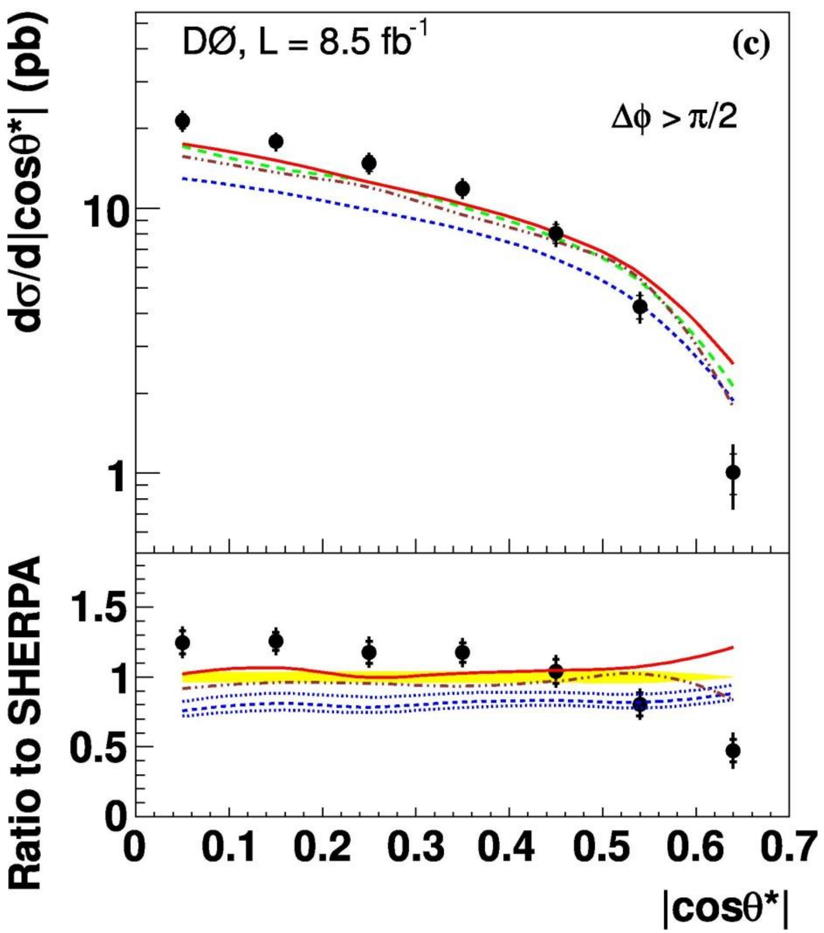
γγ Differential Cross-Sections: |cosθ*|

arXiv:1302.6508

$\Delta\phi_{\gamma\gamma}<\pi/2$

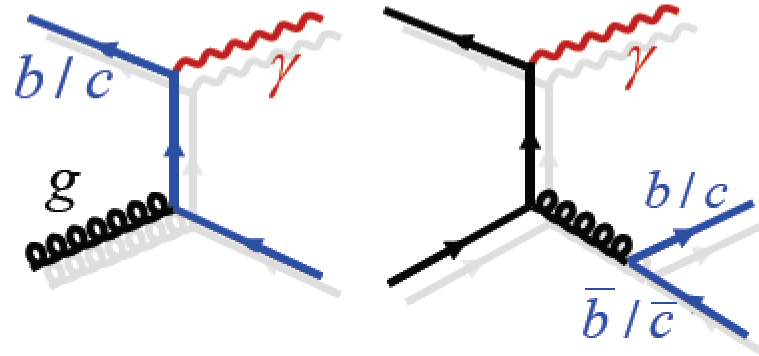


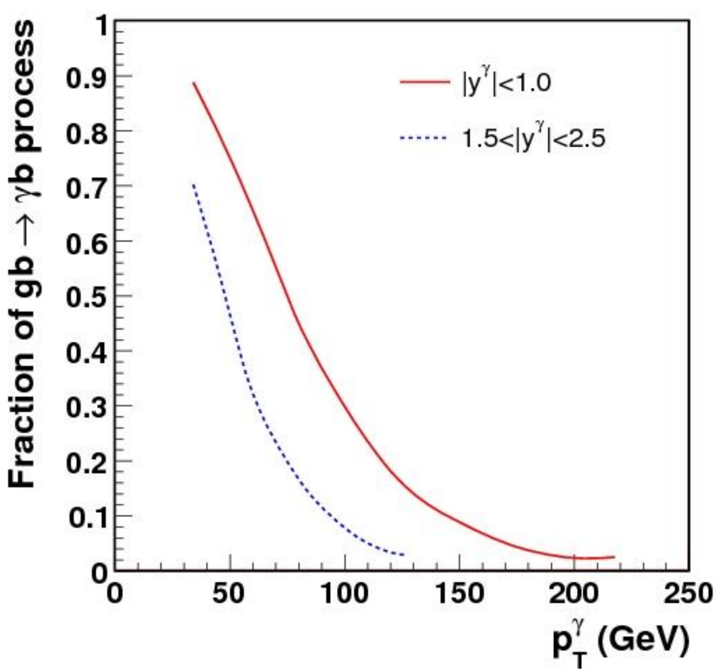
$\Delta\phi_{\gamma\gamma}>\pi/2$



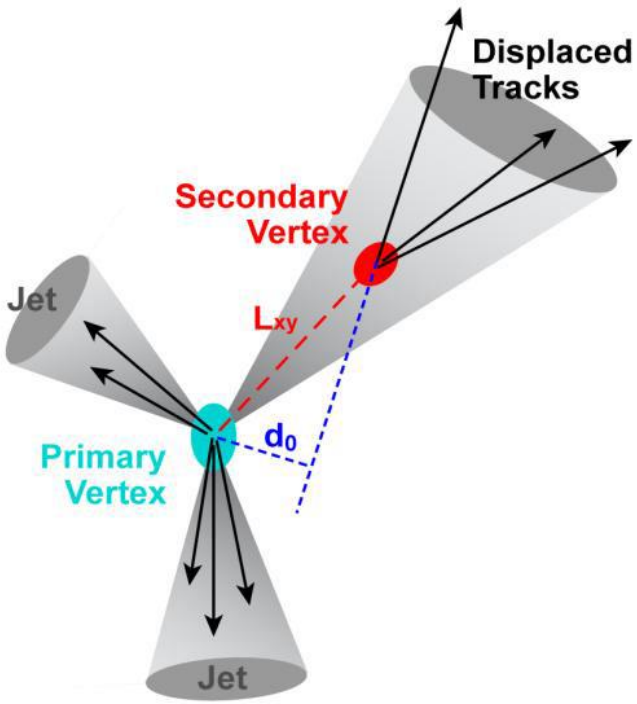
Photon + Heavy Flavor Jets

- Primary production proceeds through Compton scattering (lower p_T^{γ}) and quark annihilation (higher p_T^{γ}).
  - Sensitive to b/c quark PDFs, gluon splitting
- Contributions from fragmentation suppressed by requiring an isolated photon.
- Backgrounds primarily from light jets
  - Photon mis-ID
  - Contamination of heavy flavor jets





Identifying b Jets

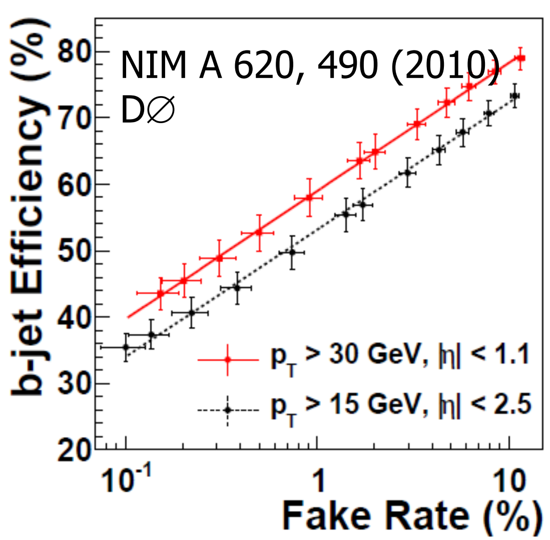


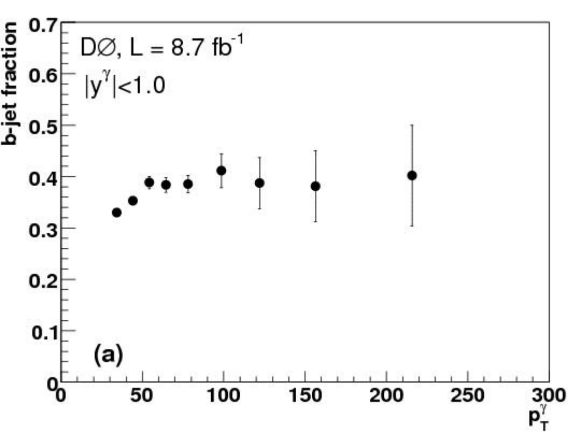
MVA Discriminant:

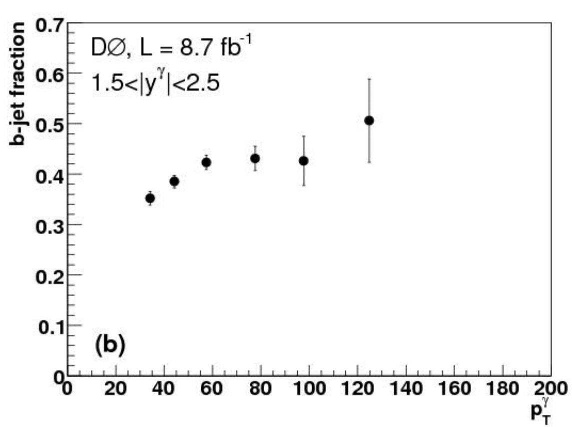
Combination of variables sensitive to Secondary Vertices

- **Number of SV**
- **Invariant Mass of Tracks in SV**
- **Number of Tracks Used to Reconstruct SV**
- **2D Decay Length Significance of SV**
- **Weighted combination of transverse IP significances**
- **Probability of jet tracks to originate from PV**

Fit SV mass templates to determine b-jet fraction

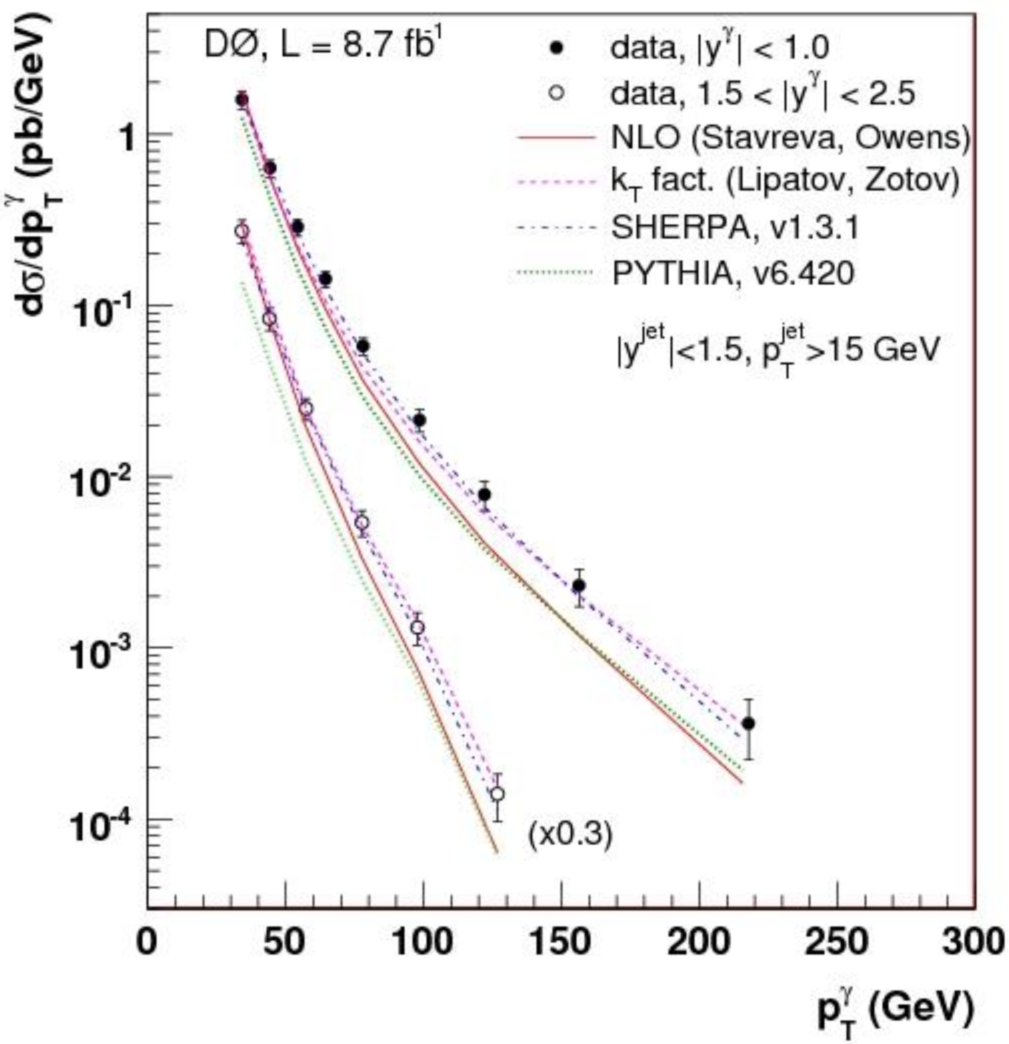






γ + b-jet Cross Section

PLB 714, 32 (2012)



$$\frac{d\sigma}{dp_T^\gamma} = \frac{N_{evt} \times f_\gamma \times f_b}{A \times \varepsilon \times L \times \Delta p_T^\gamma}$$

Compare to NLO
(T. Stavreva & J.F. Owens)
–μF, μR set to p_T^γ
-CTEQ6.6M PDFs

Also compare to PYTHIA and SHERPA
- SHERPA allows for extra hard partons in addition to b-quark

kT-factorization (Lipativ & Zotov)
- Account for additional soft gluon radiation

γ + b-jet Cross Section

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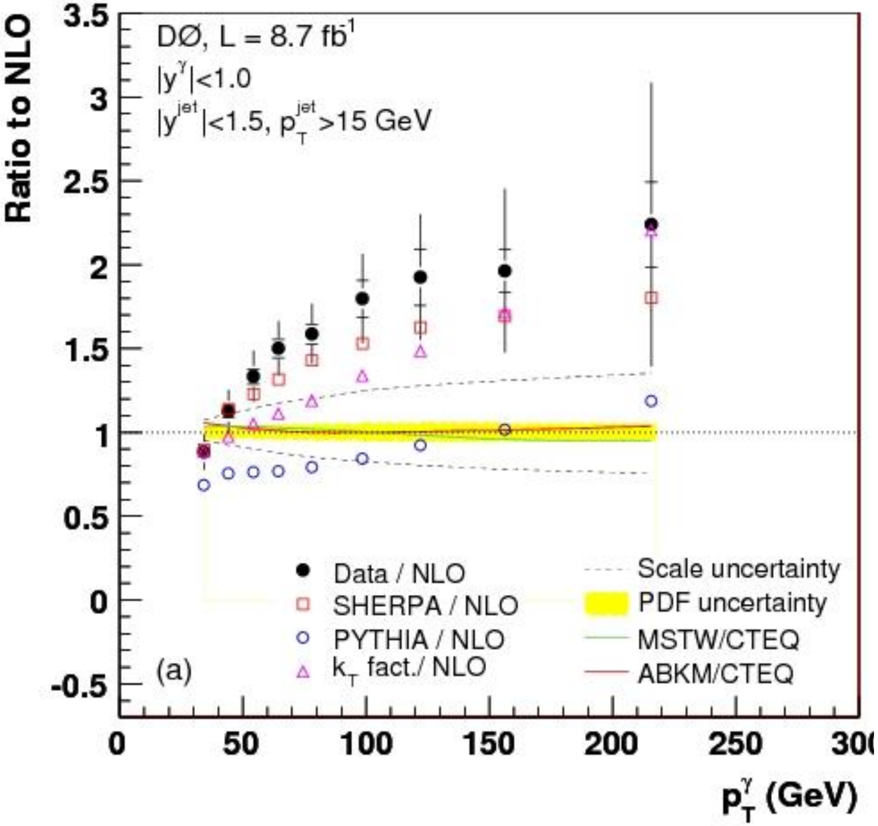
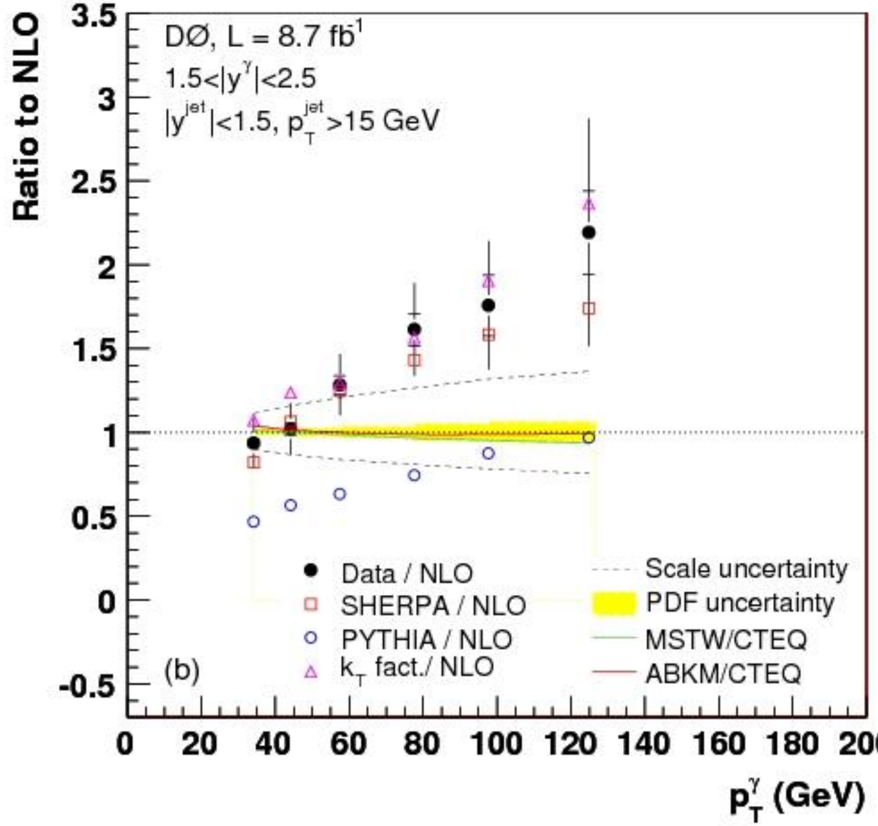
Central Photons

Forward Photons

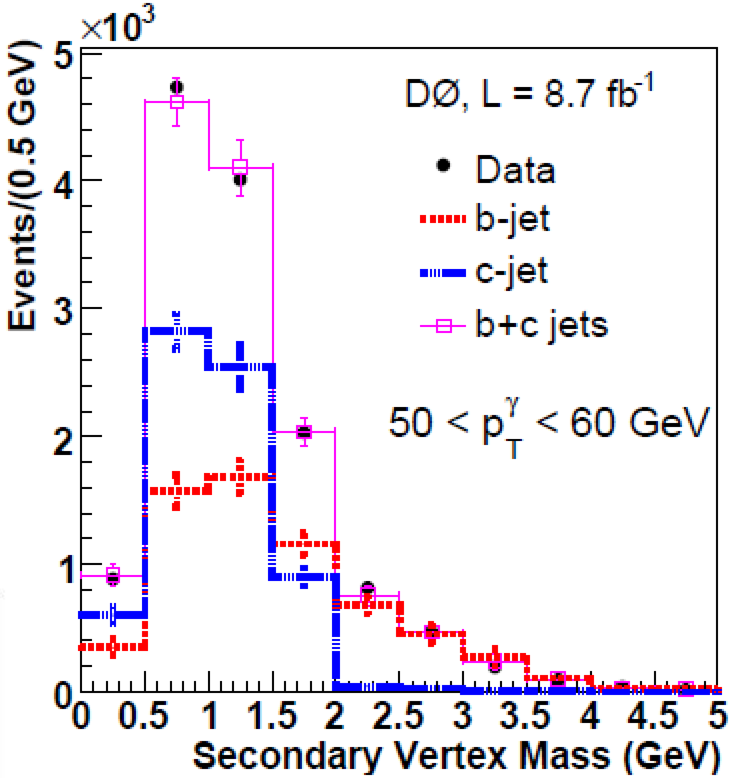


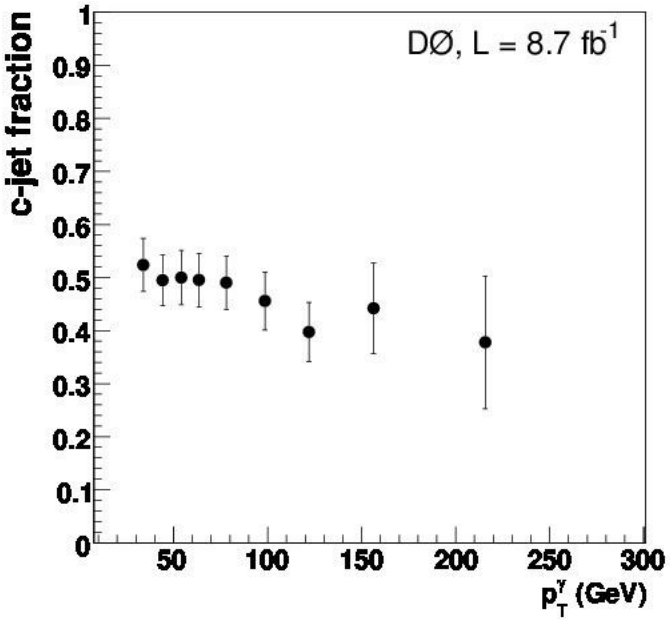


NLO agreement good at low $p_T\gamma$; disagreement in shape (central & forward) at higher p_T^γ.

Identifying c-jets

- Start with sample of γ+jets
- Enrich heavy flavor content with tight b-tagging
  - Light jets 1-5%
  - Remaining light jets estimated after final selection and subtracted
- Determine fraction of c-jets by fitting SV mass templates of b-jets and c-jets

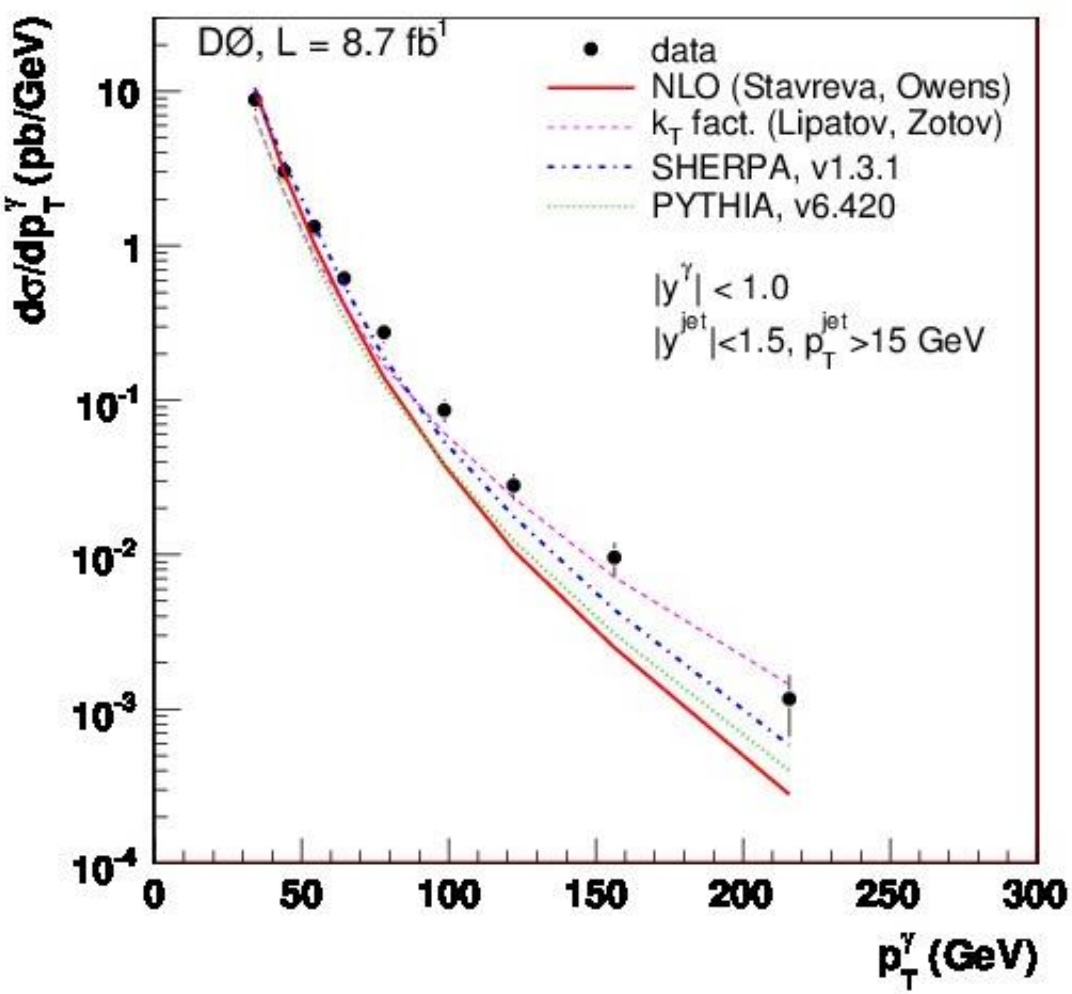




γ+c-jet Cross Section

PLB 719, 6 (2013)

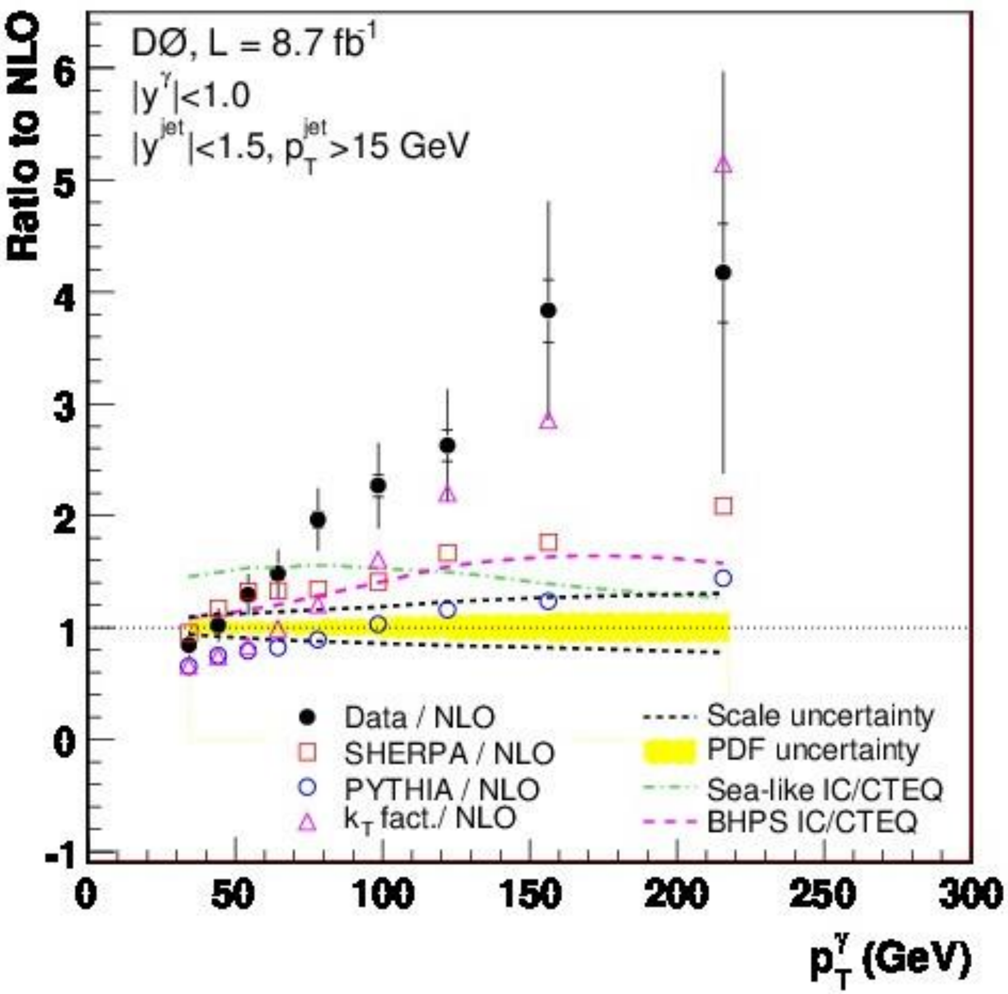
$$\frac{d\sigma}{dp_T^{\gamma}} = \frac{N_{evt} \times f_{\gamma} \times f_b}{A \times \varepsilon \times L \times \Delta p_T^{\gamma}}$$



- Similar theory comparisons as with γ+b-jet
- Again, good agreement at low p_T^{γ}

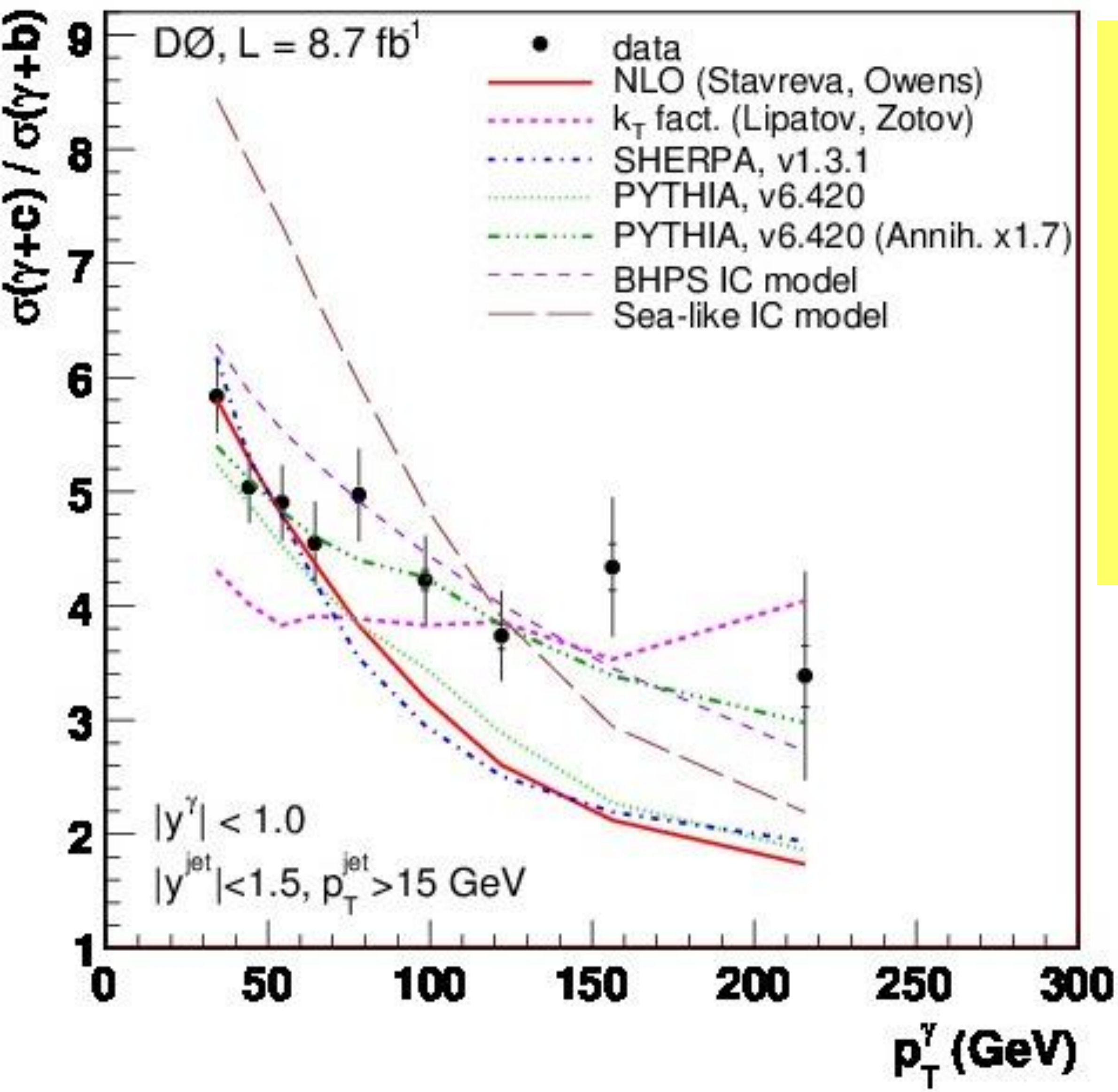
γ+c-jet Cross Section

PLB 719, 6 (2013)



Also compare to PDF models with intrinsic charm (BHPS IC)
-Better agreement but still low
-Need for higher order pQCD, better estimates of g->cc splitting

σ(γ+c-jet)/σ(γ+b-jet)



- Ratio ➔ Cancellation of many common systematic uncertainties
- Lower p_T^{γ}:
  - Good agreement with NLO, SHERPA, and PYTHIA
- Higher p_T^{γ}:
  - Data shows higher ratios

Conclusions

D0 Direct Diphoton Results

Measurements of cross sections for direct diphoton production at $\sqrt{s}=1.96$ TeV with 8.5 fb^{-1}, in three ranges of $\Delta\phi_{\gamma\gamma}$

- High statistics sample allowing precision measurements over a wide kinematic range
- Measurements are compared to state-of-art theoretical predictions such as DIPHOX and RESBOS, as well as PYTHIA.
- None of the theoretical predictions fully describes the data in all kinematic regions of the four variables considered.

Photon + b-jet & c-jet Results

Measurement of cross section of γ+b-jet at $\sqrt{s}=1.96$ TeV with 8.7 fb^{-1}.

- Significant discrepancies at high photon p_T.

Need for higher-order theory predictions.

Measurement of cross section of γ+c-jet at $\sqrt{s}=1.96$ TeV with 8.7 fb^{-1}.

- Similar discrepancies at high photon p_T.
- Ratio $\sigma(\gamma$+c-jet$)/\sigma(\gamma$+b-jet$)$ suggest larger g→cc contributions