Measurement of diphoton production cross section at DZero

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On behalf of D0 Collaboration

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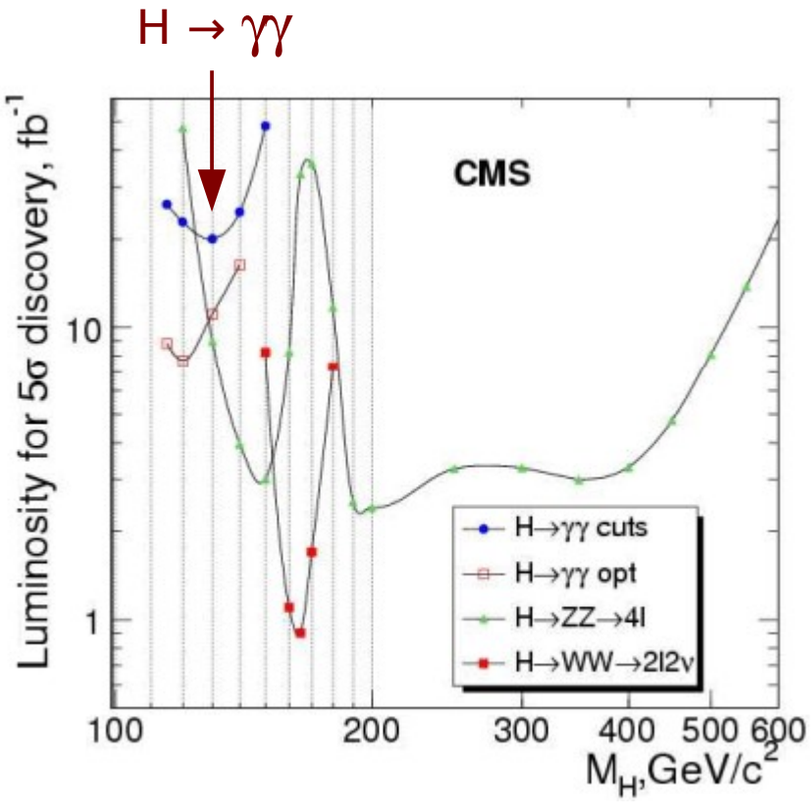
Outline

- Motivations
- Theoretical overview
- Experimental analysis
  - Photon identification
  - Event selection
- Measurements and comparison to theory
- Summary

Motivations

- Prompt photons are produced directly from the hard scattering or fragmentation process, unlike those from π^0, η, K_s^0 meson decays.

- At much smaller rate (< a factor 0.01) the diphoton events may also come from Higgs boson, ED (graviton), SUSY (neutralino) decays.



from J.Phys.Conf.Ser.110:042023 (2008)

gg → H → γγ main discovery channel at LHC for Higgs boson masses up to about 130 GeV

Requires ~26 fb^{-1} of data for 5σ discovery for SM Higgs boson at about 115 GeV (at CMS)

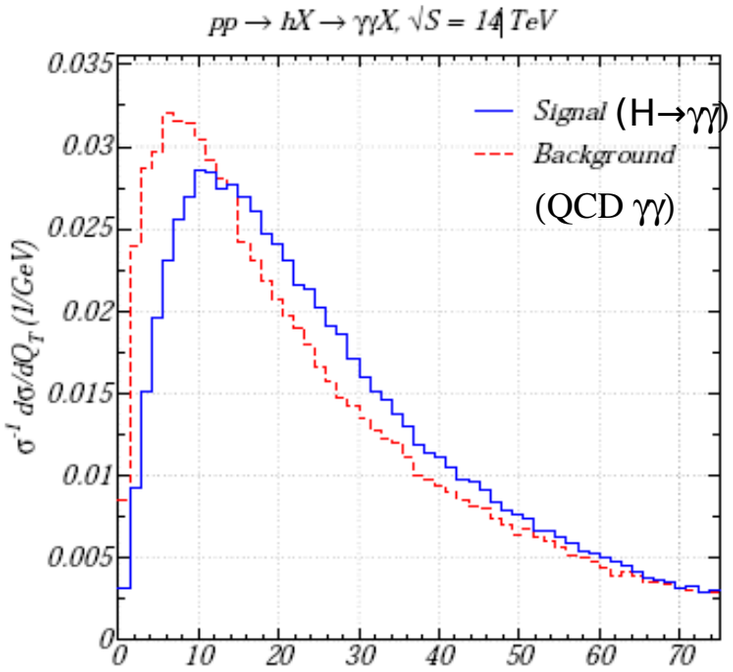
Also requires excellent photon ID and good knowledge of the background

Optimization of the selections to increase the sensitivity requires exploring additional discriminating variables.

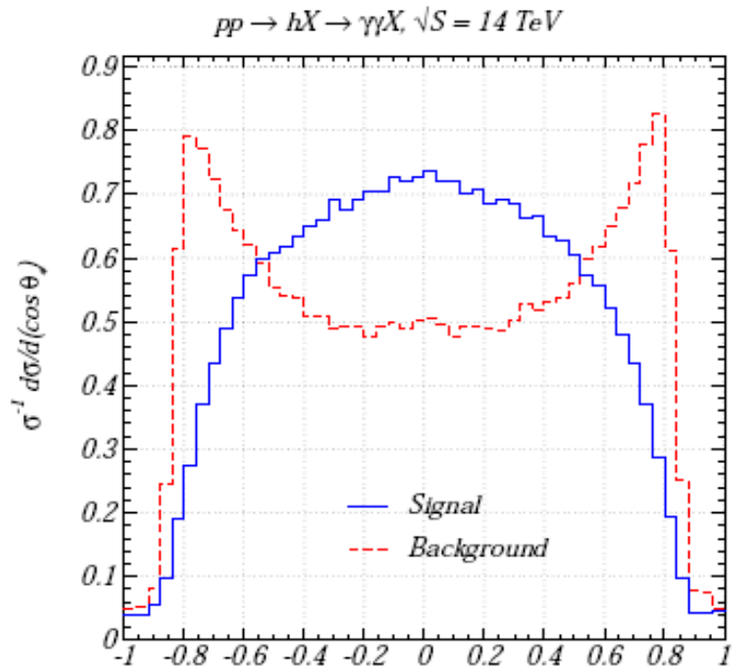
Motivations

- Most kinematic variables behave differently for QCD diphoton and H→$\gamma\gamma$ events in the same mass range. Main reason is different dominating initial states: "$q\bar{q}$" vs "gg"

from PRD76,01309(2007)



qT (GeV)



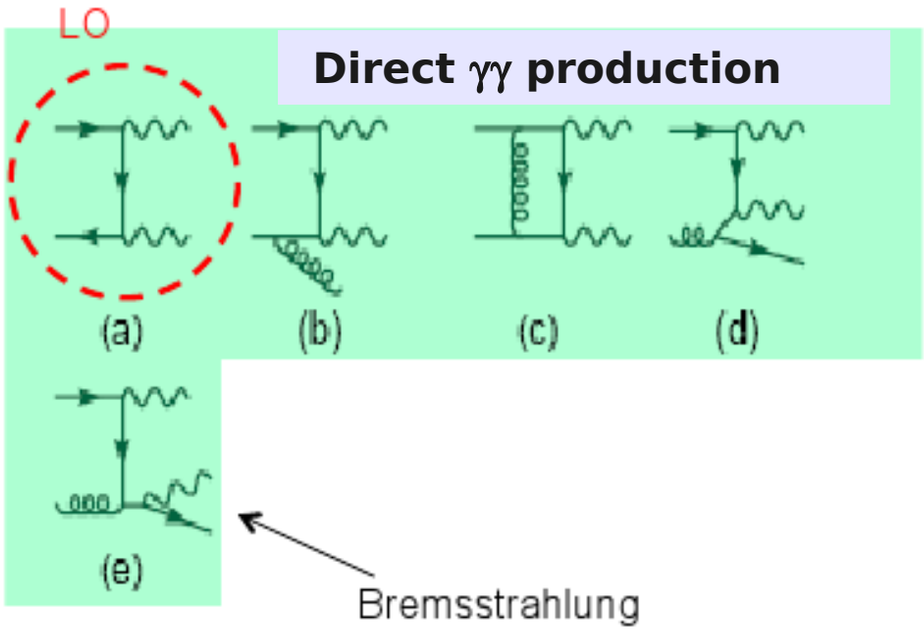
cosθ*

Sensitivity can be significantly improved by utilizing differences in the Higgs decay and QCD diphoton kinematics.

- Dominating contribution to the diphoton cross section is coming from $q\bar{q}\to\gamma\gamma$ events. Tevatron cross section is about 30-50% of that at LHC (@10 TeV) for the mass range 30 – 150 GeV:

=> good opportunity to better study the $\gamma\gamma$ cross section at the Tevatron luminosity.

Prompt diphotons at hadron collider

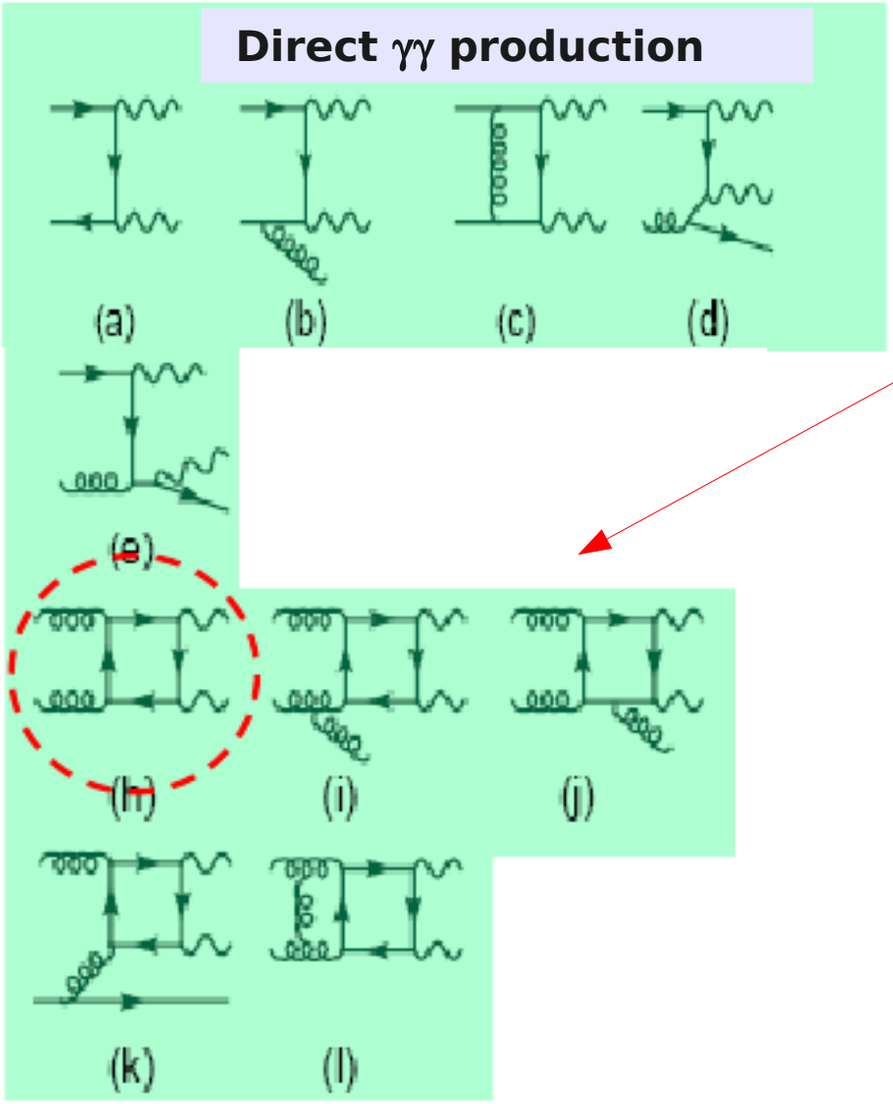


Two main production mechanisms:
- Direct
- Fragmentation

At LO: $q\bar{q}$ scattering only

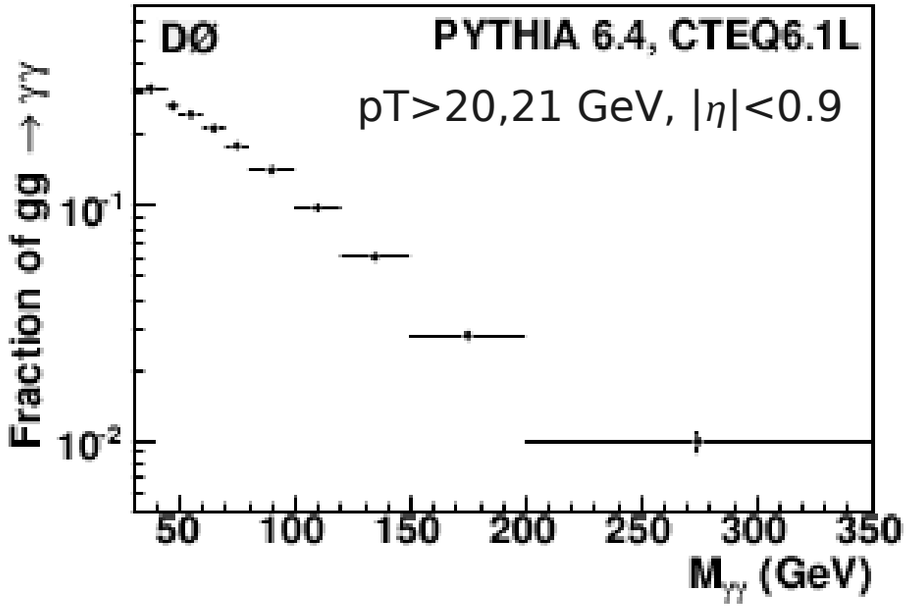
At NLO:
- Virtual corrections
- Real emissions (adds qg → γγ)

Prompt diphotons at hadron collider



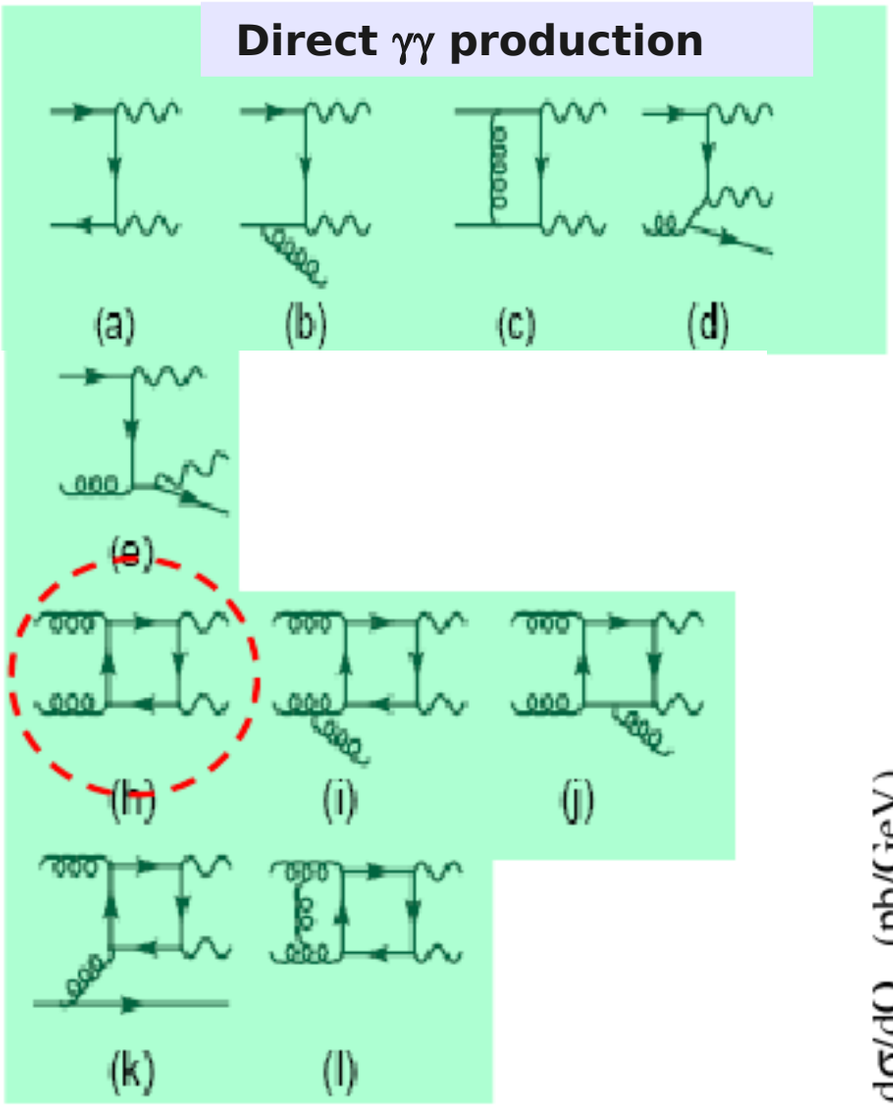
Two main production mechanisms:
- Direct
- Fragmentation

gg scattering: in spite of $O(\alpha_s^2)$ suppression, a large gluon PDF makes this contribution quite significant in some kinematic regions



Can be ~30-40% at small masses (PDF dependent!)

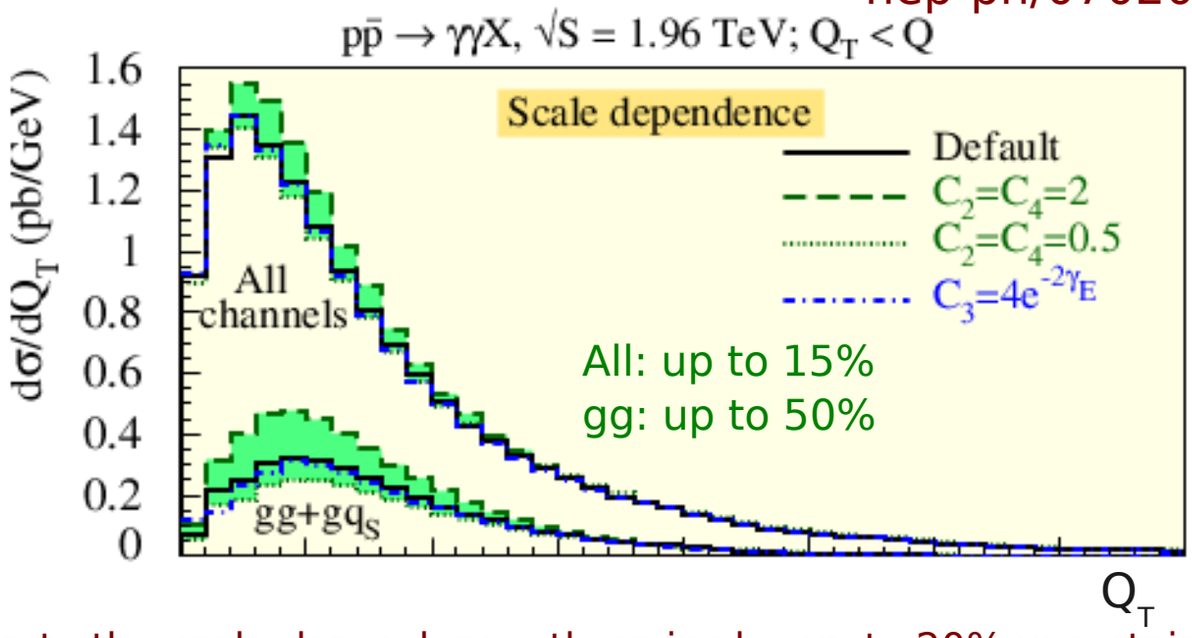
Prompt diphotons at hadron collider



Two main production mechanisms:
- Direct
- Fragmentation

The cross section is enhanced in some kinematic regions due to:
- fragmentation contribution (largely depends on photon selections!)
- in theory: resummation of soft gluon emission

hep-ph/0702003

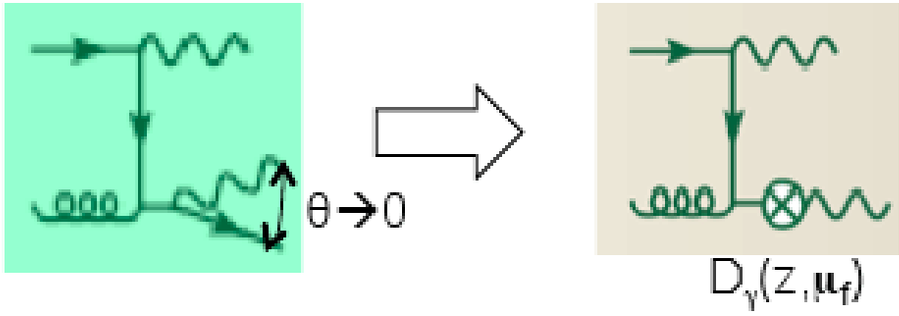


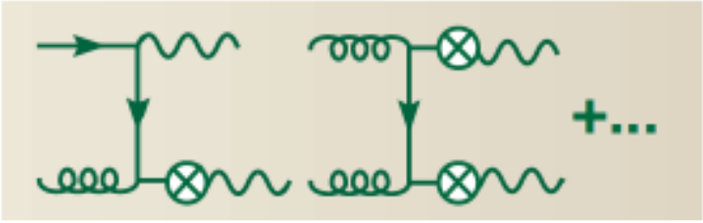
In addition to the scale dependence, there is also up to 20% uncertainty for "gg" channel on the resummation scheme & non-pert. model.

Prompt diphotons at hadron collider

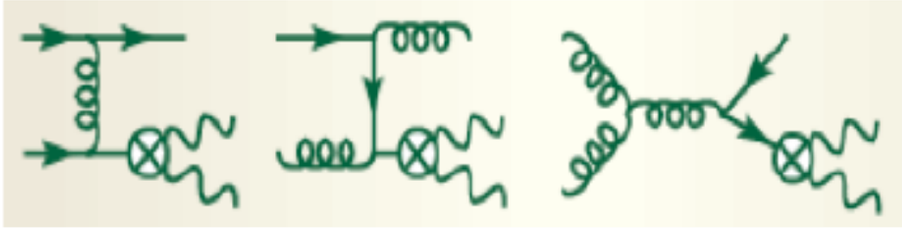
Fragmentation contribution

– Collinear singularities in the final state are factored out into fragmentation functions $D(z,\mu)$





single+double fragmentations



Low-mass/small-angle diphoton pair

– Fragmentation contribution is highly uncertain and can be suppressed experimentally via:

- isolation requirement (E_T^{iso} < 2.5 GeV in D0 meas.)
- $p_T(\gamma\gamma)$ < $M(\gamma\gamma)$ [PRD 76, 013009(2007)]
- $\Delta R(\gamma,\gamma) > 0.4$

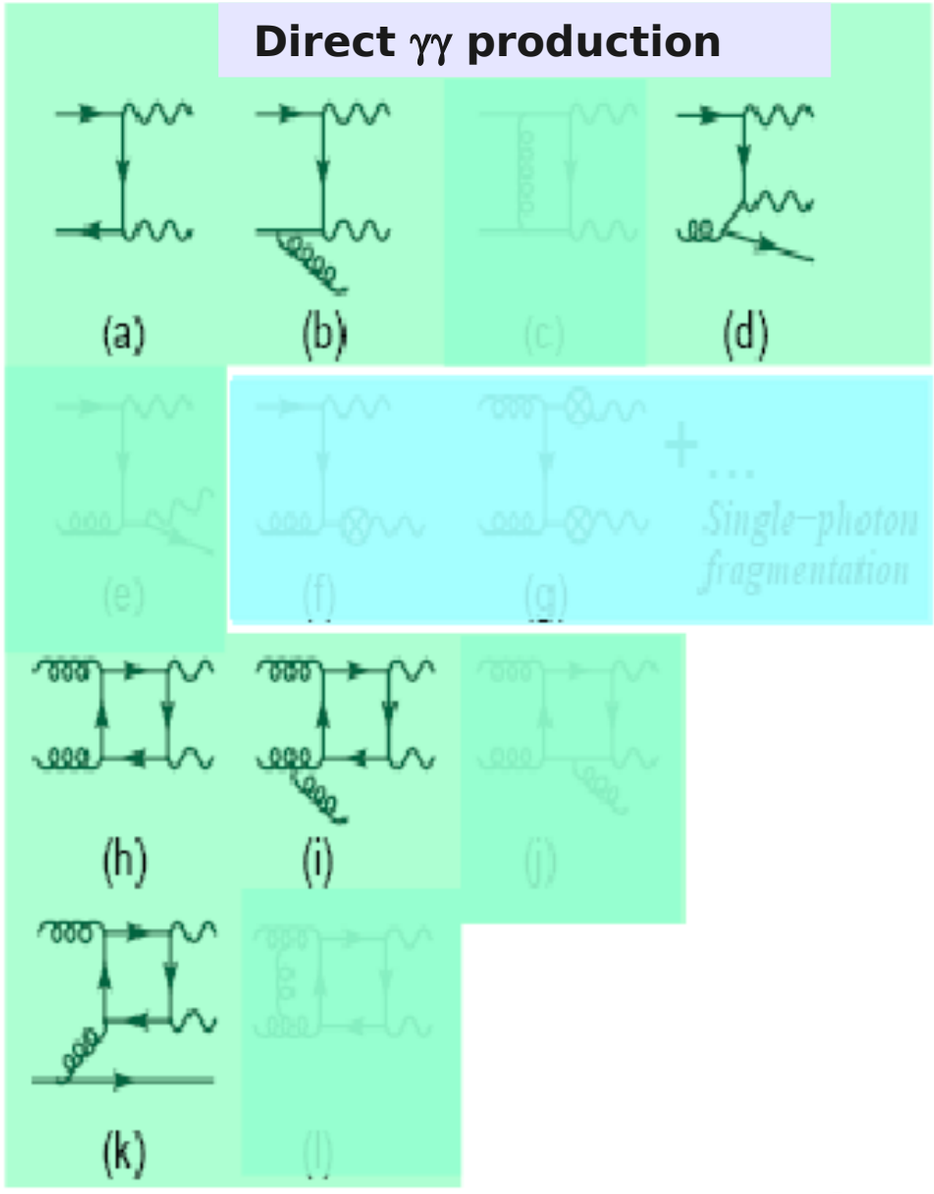
$$E_T^{iso} = \sum_{\substack{\text{partons or hadrons} \\ \text{within } \Delta R < 0.4}} p_{T,i} - p_{T\gamma}$$

Overall: very interesting process to test various ingredients in QCD predictions!

Theory

PYTHIA: JHEP 0605, 026 (2006)

- $q\bar{q} \to \gamma\gamma$ and $gg \to \gamma\gamma$ matrix elements
- All-order resummation to LL accuracy via parton shower
- No fragmentation photons



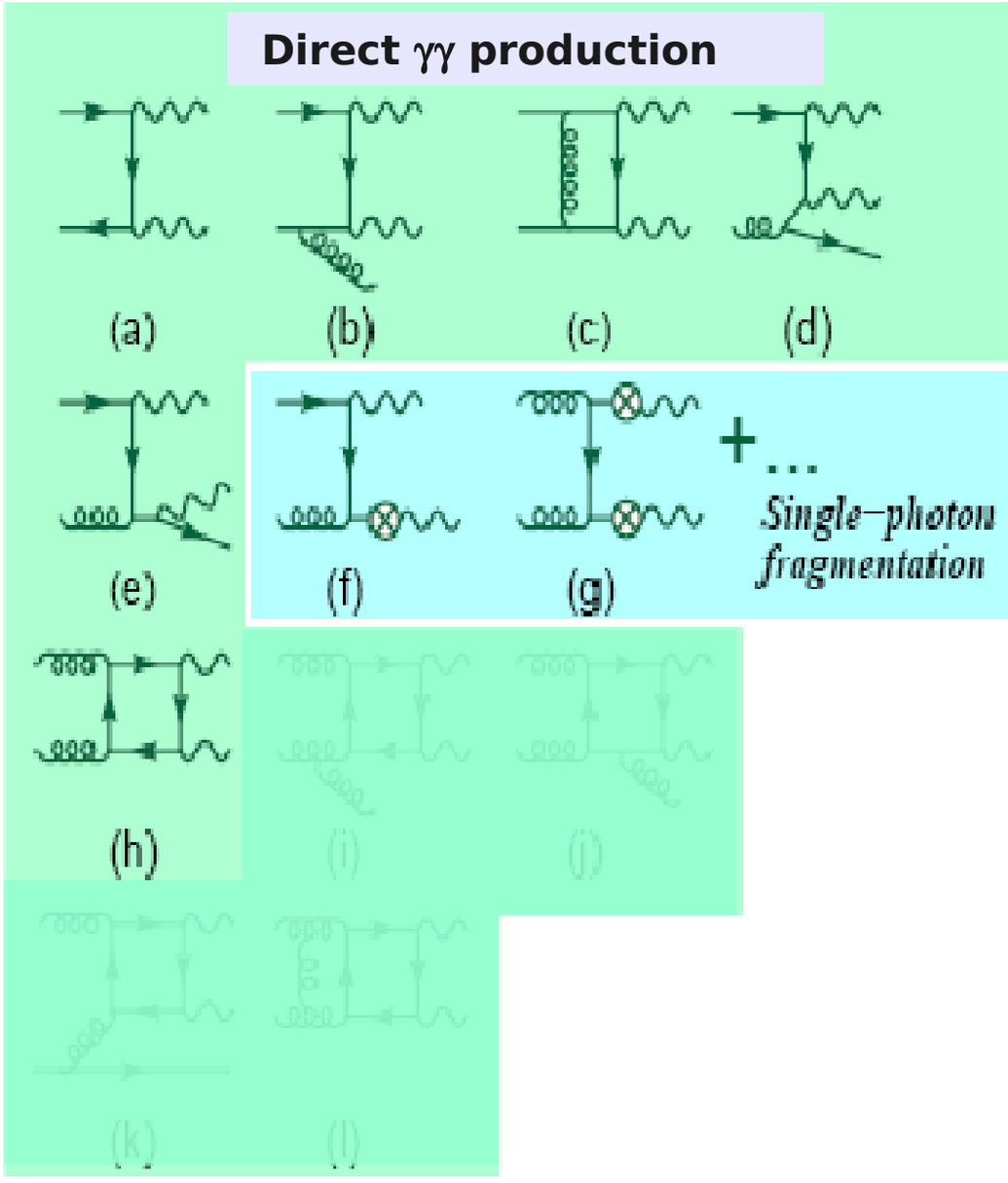
Theory

PYTHIA:

- $qq \to \gamma\gamma$ and $gg \to \gamma\gamma$ matrix elements
- All-order resummation to LL accuracy via parton shower
- No fragmentation photons

DIPHOX: EPJ C16, 311 (2000)

- Fixed order NLO calculation ($gg \to \gamma\gamma$ is at LO)
- No soft gluon resummation
- Single photon fragmentation at NLO



Theory

PYTHIA:

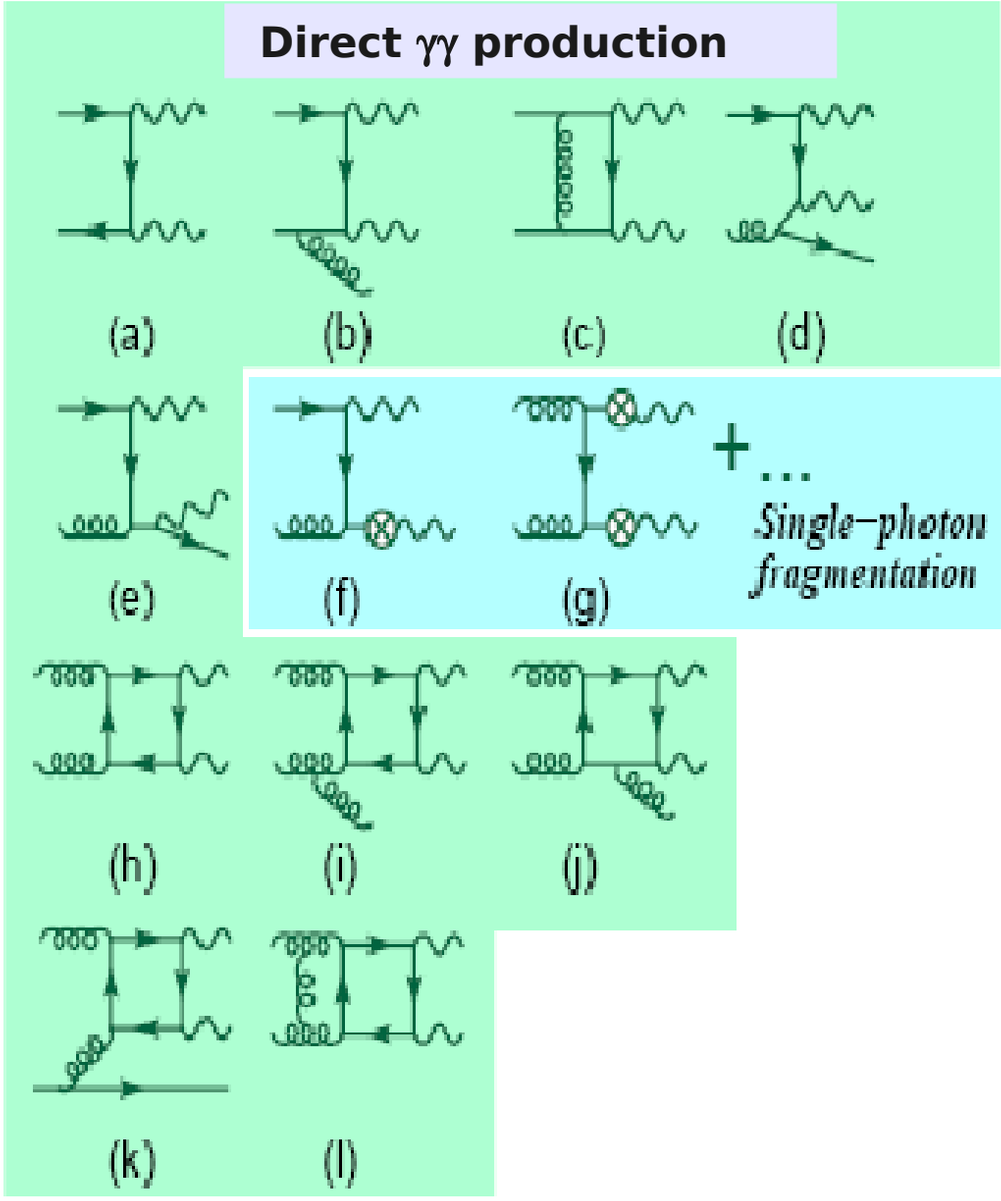
- qq → γγ and gg → γγ matrix elements;
- All-order resummation to LL accuracy; via parton shower;
- No fragmentation photons

DIPHOX:

- Fixed order NLO calculation (gg → γγ is at LO)
- No soft gluon resummation
- Single photon fragmentation at NLO

RESBOS: PRD76,01309(2007)

- NLO $q\bar{q}$ → γγ and gg → γγ
- All orders initial soft gluon resummation to NNLL accuracy matched to NLO
- Single photon fragmentation is included via parameterization that approximates NLO FF rates.



Differential cross sections

We have measured four single differential cross sections:

Sensitive to ISR and fragmentation

Sensitive to PDFs

$$\frac{d\sigma}{dM_{\gamma\gamma}} \qquad \frac{d\sigma}{dp_T^{\gamma\gamma}} \qquad \frac{d\sigma}{d\Delta\phi_{\gamma\gamma}} \qquad \frac{d\sigma}{d|\cos\theta^*|}$$

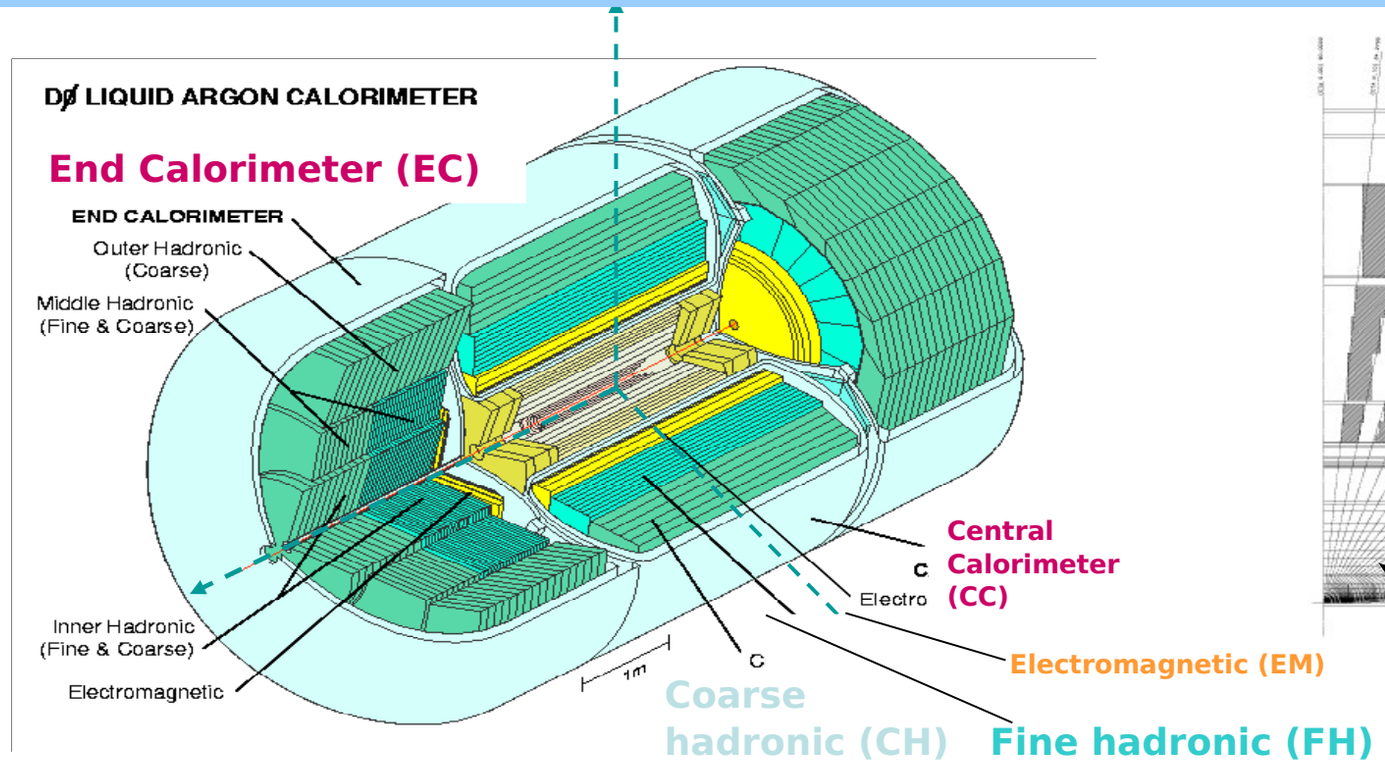
Sensitive to energy scale of the interaction and to New Physics!

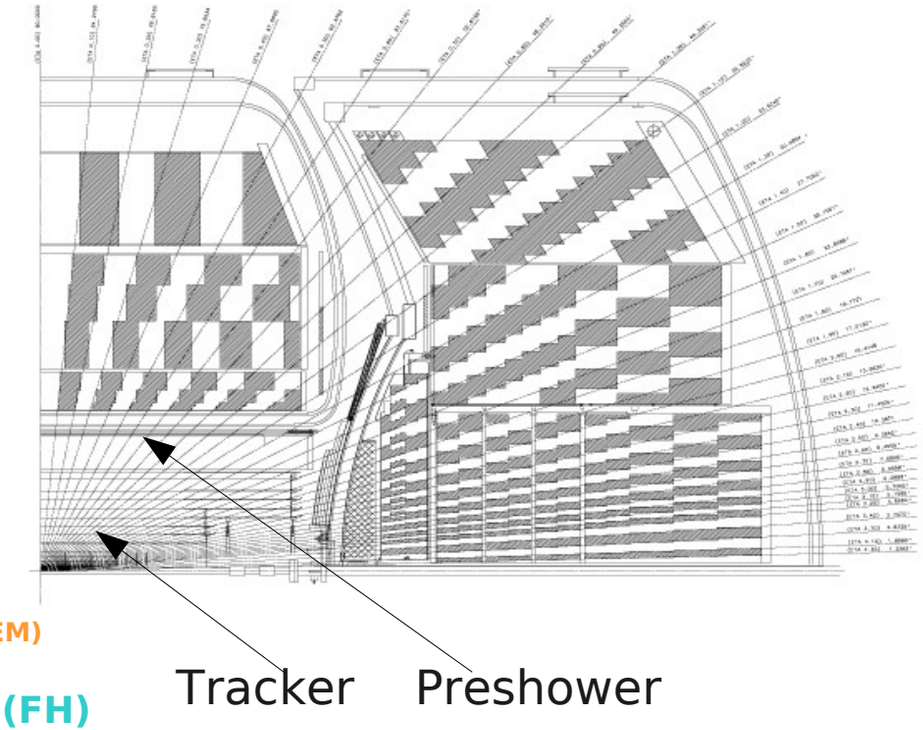
We have also measured double differential cross sections:

$$\frac{d^2\sigma}{dM_{\gamma\gamma}dp_T^{\gamma\gamma}} \qquad \frac{d^2\sigma}{dM_{\gamma\gamma}d\Delta\phi_{\gamma\gamma}} \qquad \frac{d^2\sigma}{dM_{\gamma\gamma}d|\cos\theta^*|}$$

$$\begin{cases} 30 \le M_{\gamma\gamma} < 50 \text{ GeV} \\ 50 \le M_{\gamma\gamma} < 80 \text{ GeV} \\ 80 \le M_{\gamma\gamma} < 350 \text{ GeV} \end{cases}$$

D0 detector





- ✓ Liquid argon active medium and (mostly) uranium absorber
- ✓ Hermetic with full coverage :$|\eta| < 4.2$
- ✓ Segmentation (towers): $\Delta\eta \times \Delta\Phi$ = 0.1x0.1 (0.05x0.05 in 3rd EM layer)
- ✓ EM calorimeter: 4 layers, ~20 X_0
- ✓ Solenoid and preshower detectors before the calorimeter
- ✓ Tracking system

Main data event selections

- Two photons with pT>20, 21 GeV in the central rapidity region $|\eta|<0.9$
- Separated by $\Delta R(\gamma,\gamma) > 0.4$
- $pT(\gamma,\gamma) < M(\gamma,\gamma)$

(helps to suppress fragmentation contributions)

- EM fraction > 97%
- Isolation in the calorimeter:

$$I = \frac{E_{tot}(R=0.4) - E_{EM}(R=0.2)}{E_{EM}(R=0.2)} < 0.07$$

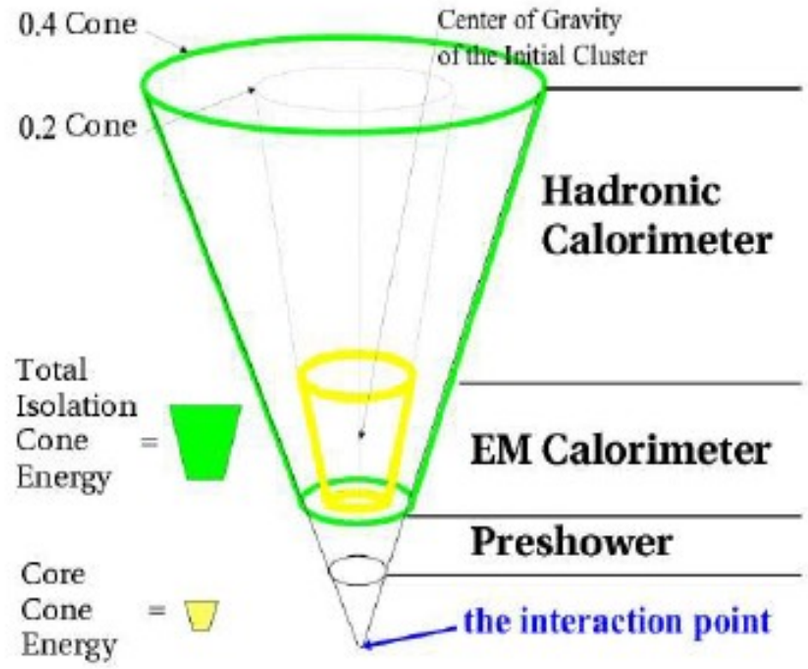
- Isolation in the tracker:

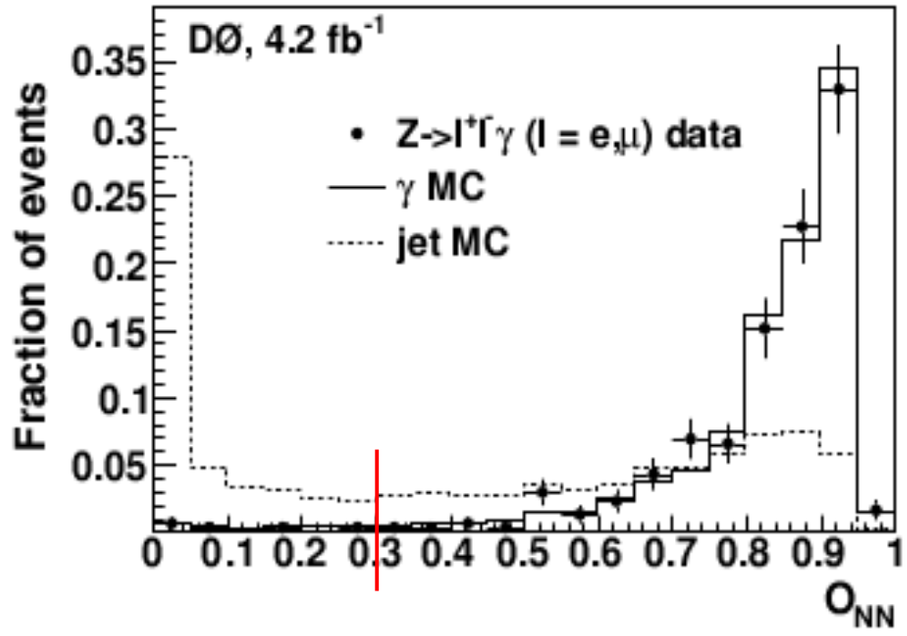
$$p_{T,trk}^{sum} = \sum_{0.05<R<0.4} p_{T,trk} < 1.5 \text{ GeV}$$

- Shower width in EM calorimeter section consistent with EM object
- Cut on photon neural network, NN>0.3 (uses Calo, PS and tracking info)

- Typical diphoton purity in data is ~70%

Main backgrounds: γ+jet (~15%), dijet(~15%) and Z/γ*→ ee (~2%)





Theory predictions

- RESBOS and DIPHOX: CTEQ6.6M, all scales (renorm., fragm., factor.) are set to M(γ,γ)
- PYTHIA v6.420 uses Tune A with CTEQ5L

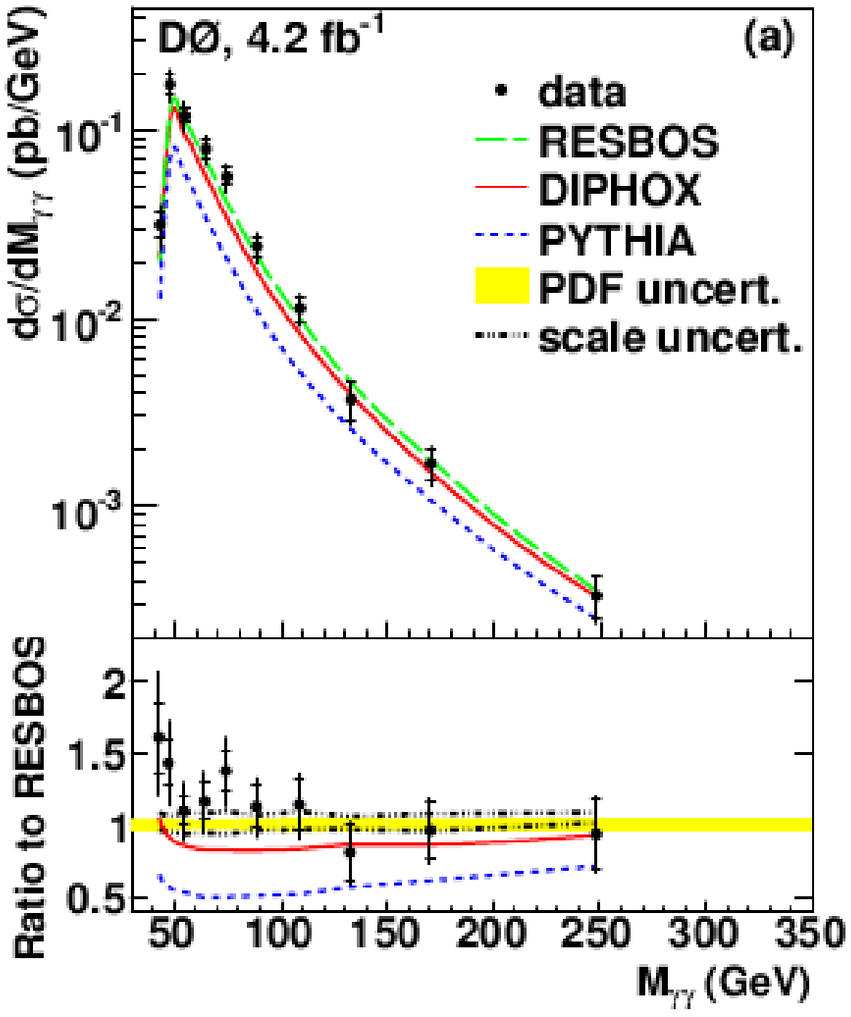
- Predictions from RESBOS and DIPHOX are corrected for non-perturbative effects: underlying events and hadronization

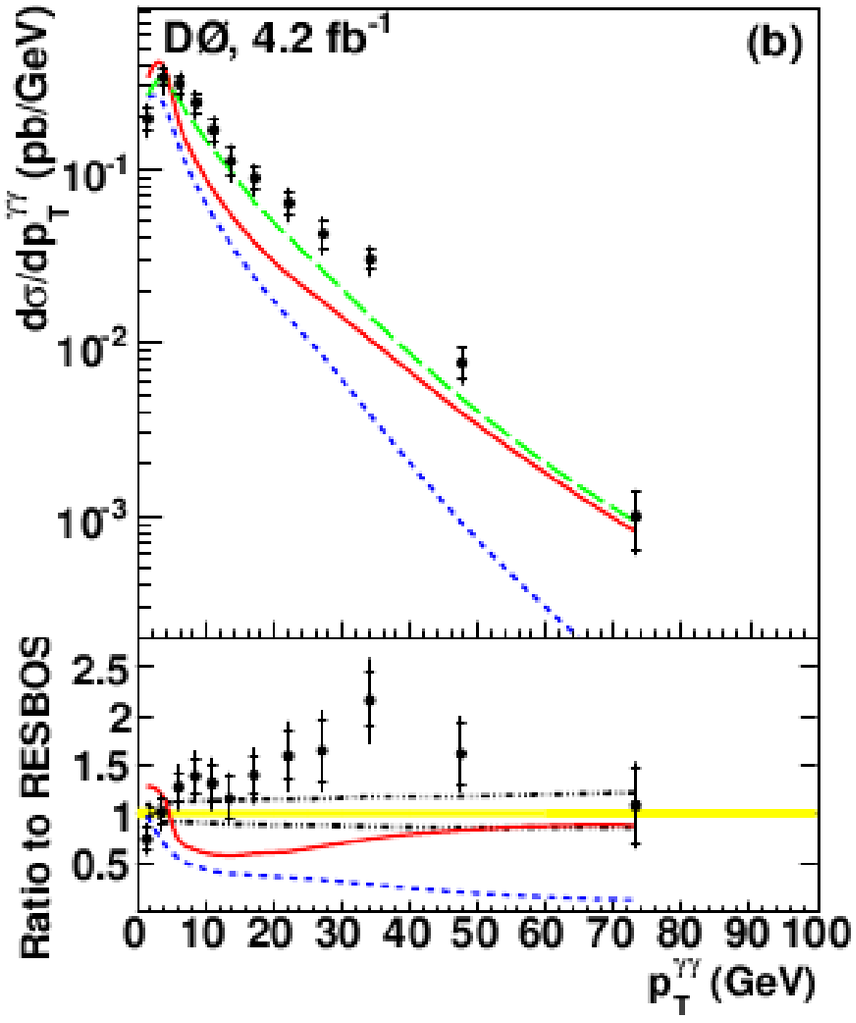
==> done using PYTHIA and considering two UE models: tune A and S0
==> corrections are about 4-5%, almost stable across the bins of all observables (two tunes agree within 0.5%)

- Uncertainties:

– PDF: 3-6%
– Scale variation by a factor 2 up/down: 10-20%

Single differential cross sections

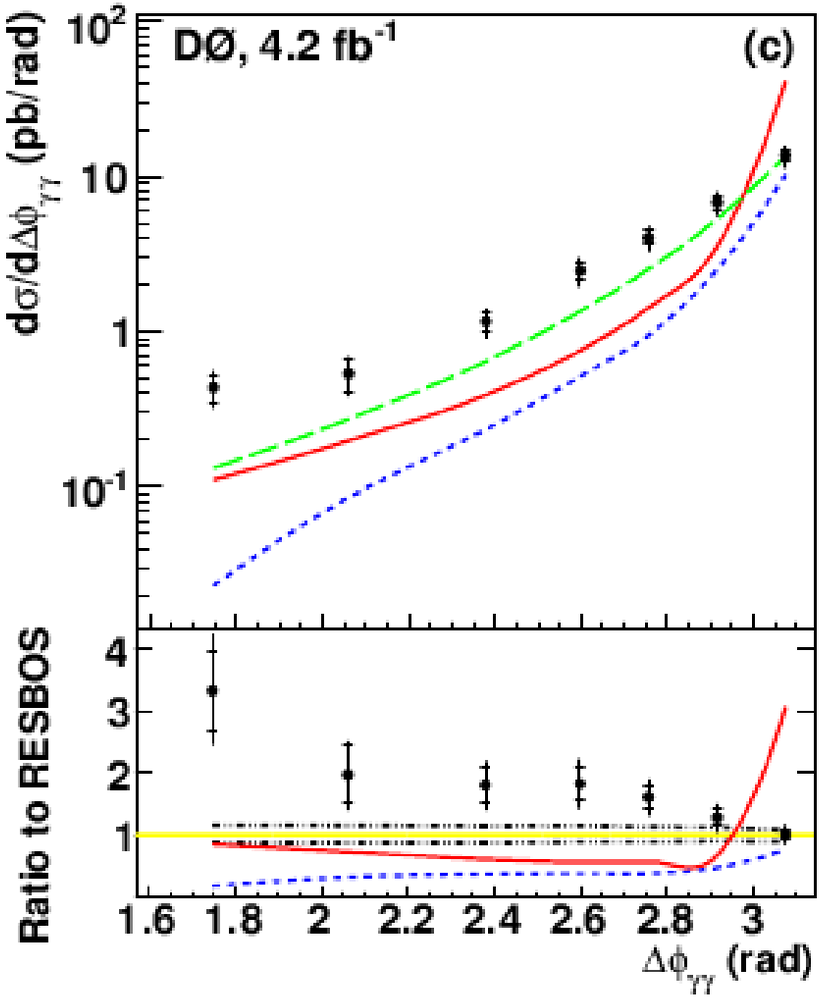


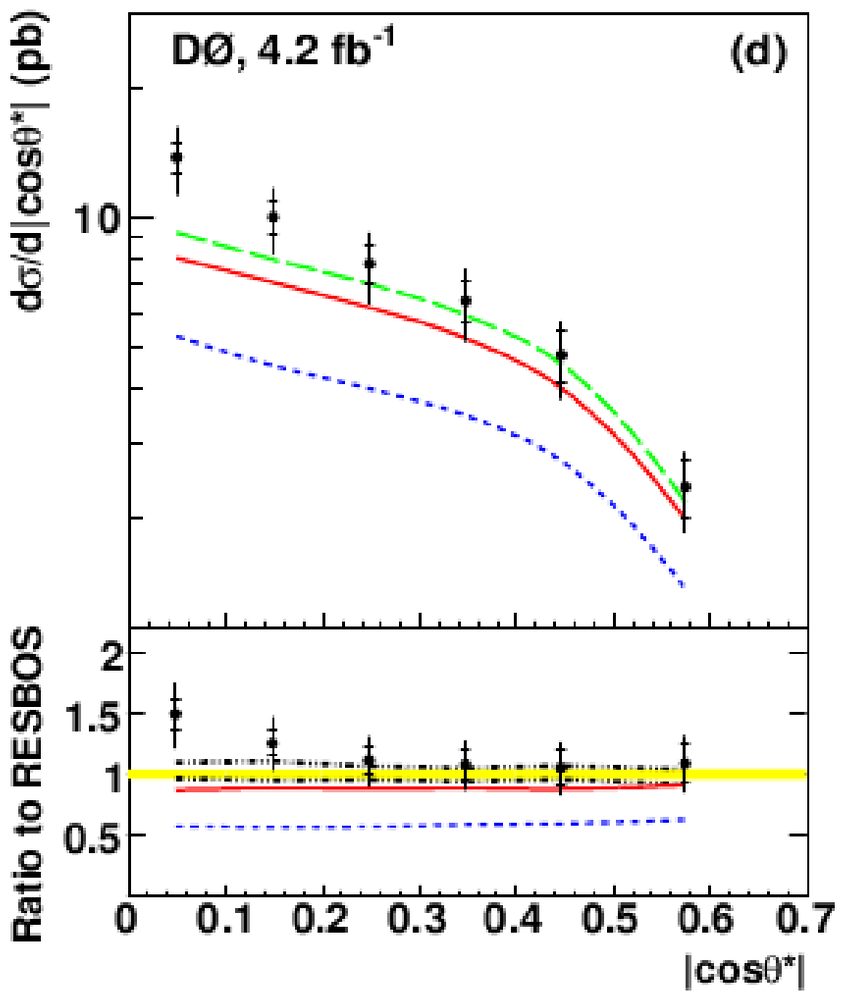


Good agreement between data and RESBOS for M>50 GeV

Data spectrum is harder than predicted:
Need for NNLO?
Unaccounted fragm. contribution?
One can consider $\Delta\Phi<\pi/2$ and $>\pi/2$ regions

Single differential cross sections



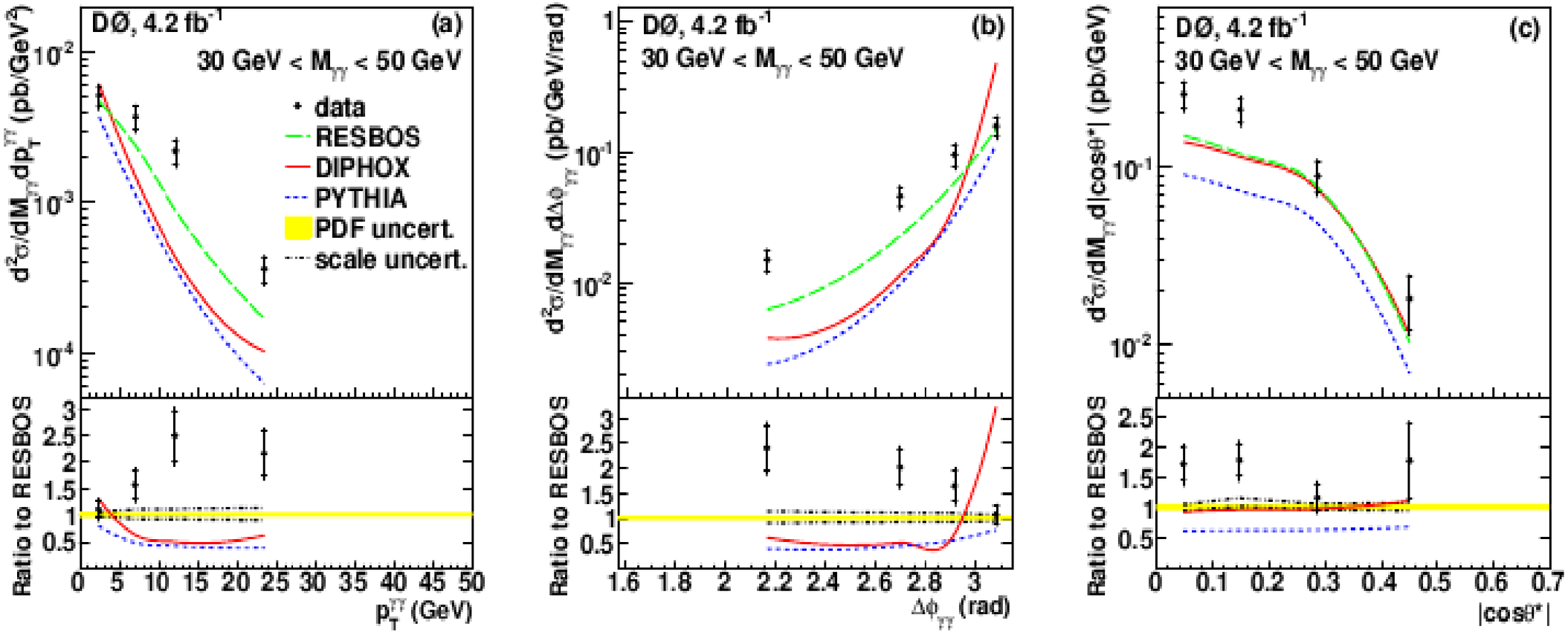


- $\Delta\Phi$ is less sensitive to the energy related effects.
- Like in pT(γ,γ) data spectrum is harder than QCD predictions.

More info can be obtained from angular and pT(γ,γ) spectra for different M(γ,γ) bins.

Differential cross sections: 30<M(γ,γ)<50 GeV

$30 \le M_{\gamma\gamma} < 50$ GeV



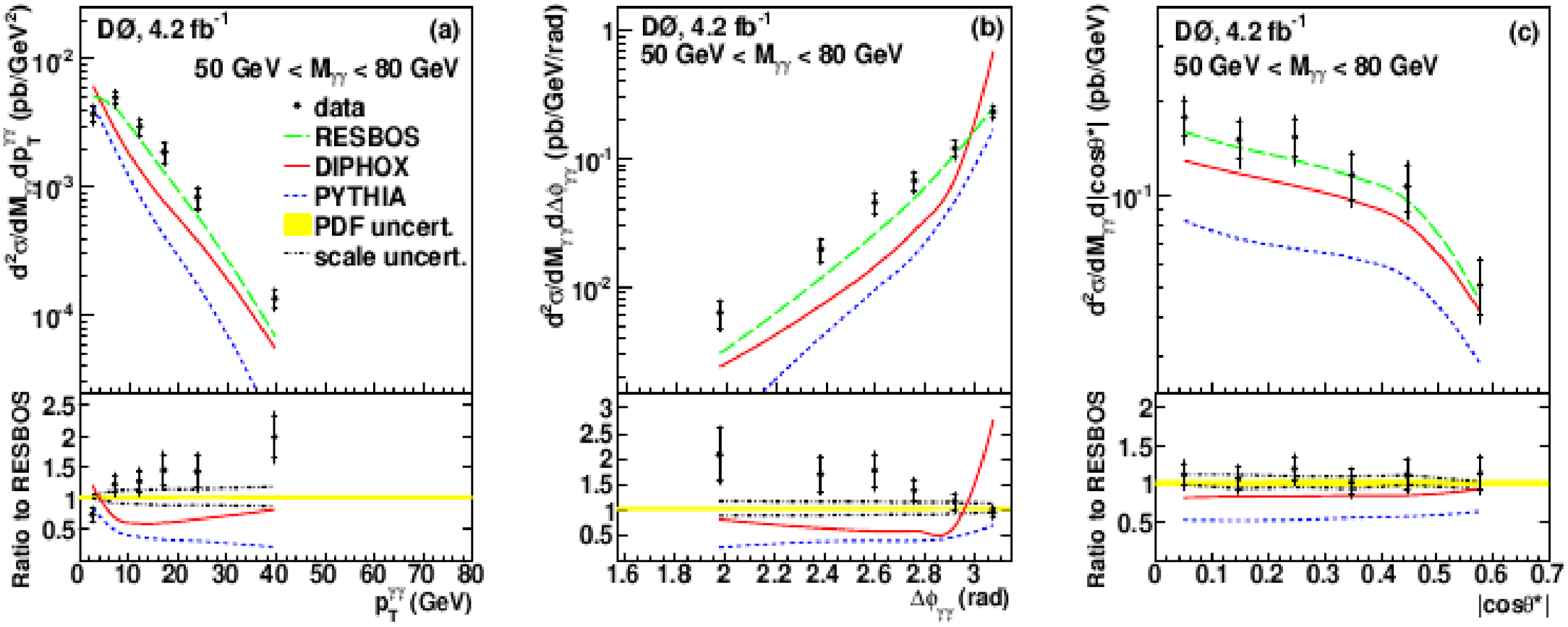
– RESBOS is closest to data, provides good description of rates at small pT(γ,γ) and large $\Delta\Phi$(γ,γ), but underestimates rates at large pT(γ,γ) and small $\Delta\Phi$(γ,γ).

– This mass region has a significant contribution from gg → $\gamma\gamma$ events (~30%)

– NNLO corrections to transverse momentum q_T for gg→H events at Tevatron/LHC can be quite large [0909.2305]

Differential cross sections: 50<M(γ,γ)<80 GeV

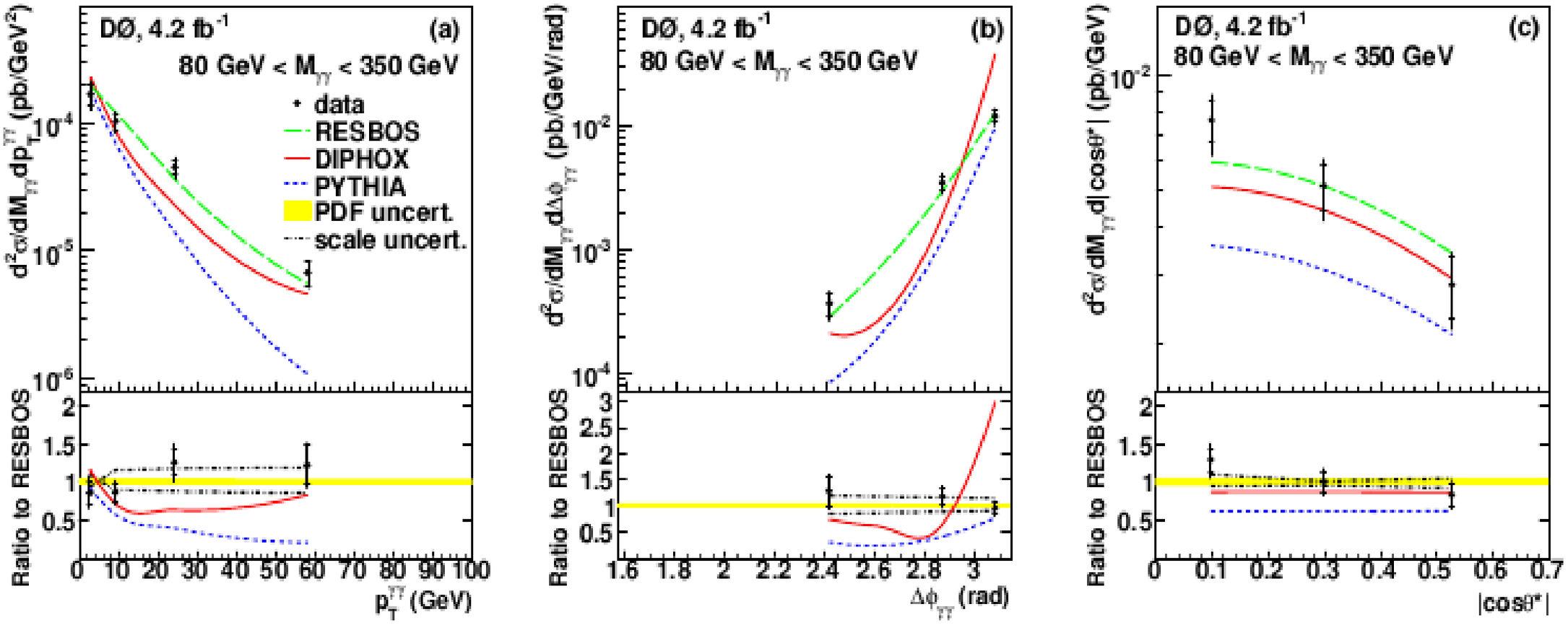
$50 \le M_{\gamma\gamma} < 80$ GeV



Qualitative conclusion is still the same, but agreement is much better than for the mass region 30 < M < 50 GeV.

Differential cross sections: 80<M(γ,γ)<350 GeV

$80 \le M_{\gamma\gamma} < 350$ GeV



- Perfect agreement Data/RESBOS for all variables in all bins.

- This mass region is potentially important for Higgs boson/NP searches!

Summary

- We have measured cross sections of photon pair production, single differential and, for the first time, double differential, using 4.2 fb^{-1} of D0 data:

$$\frac{d\sigma}{dM_{\gamma\gamma}} \qquad \frac{d\sigma}{dp_T^{\gamma\gamma}} \qquad \frac{d\sigma}{d\Delta\phi_{\gamma\gamma}} \qquad \frac{d\sigma}{d|\cos\theta^*|}$$

$$\frac{d^2\sigma}{dM_{\gamma\gamma}dp_T^{\gamma\gamma}} \qquad \frac{d^2\sigma}{dM_{\gamma\gamma}d\Delta\phi_{\gamma\gamma}} \qquad \frac{d^2\sigma}{dM_{\gamma\gamma}d|\cos\theta^*|} \qquad \begin{cases} 30 \le M_{\gamma\gamma} < 50 \text{ GeV} \\ 50 \le M_{\gamma\gamma} < 80 \text{ GeV} \\ 80 \le M_{\gamma\gamma} < 350 \text{ GeV} \end{cases}$$

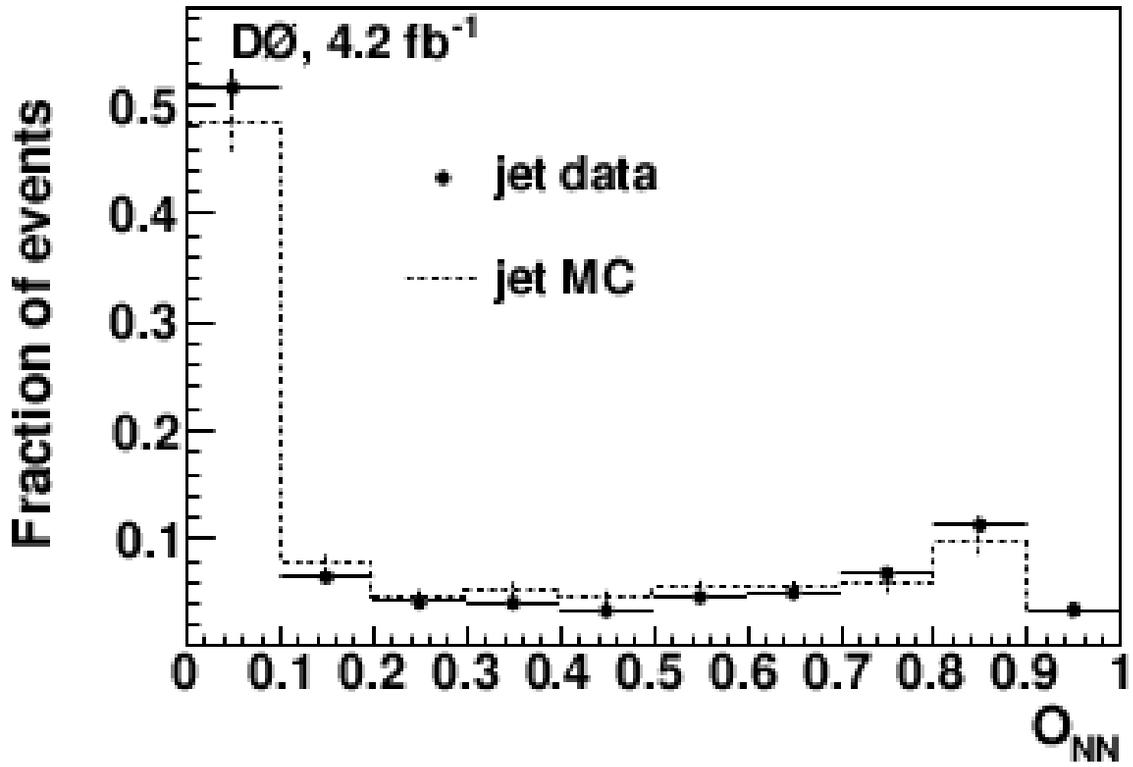
- Measurements are compared with latest theory predictions using RESBOS, DIPHOX and PYTHIA. None of the packages is able to describe data in the whole kinematic region. Most problematic are regions of small masses, large $p_T^{\gamma\gamma}$ and small $\Delta\Phi_{\gamma\gamma}$.

- RESBOS predictions are closest to data, with excellent agreement at M>80 GeV. Resummation works well at low $p_T^{\gamma\gamma}$ and large $\Delta\Phi_{\gamma\gamma}$.

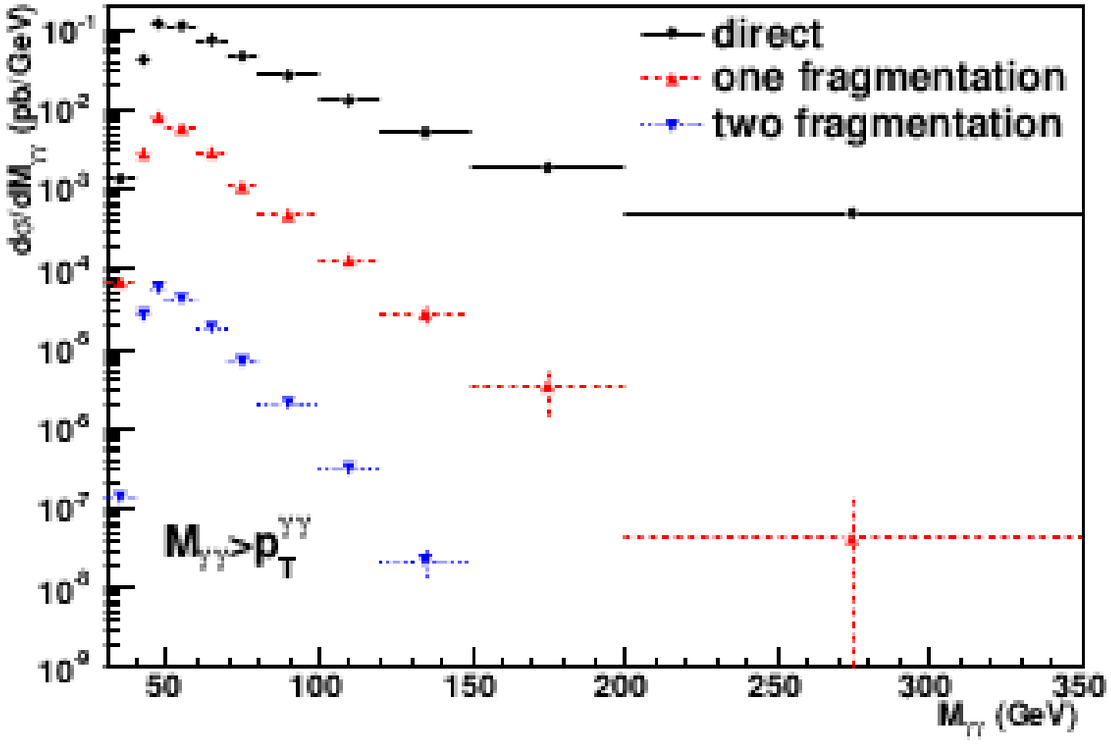
- The measurements should allow further improvements/tuning of QCD theory predictions.

BACK-UP

Test of jet fake rate

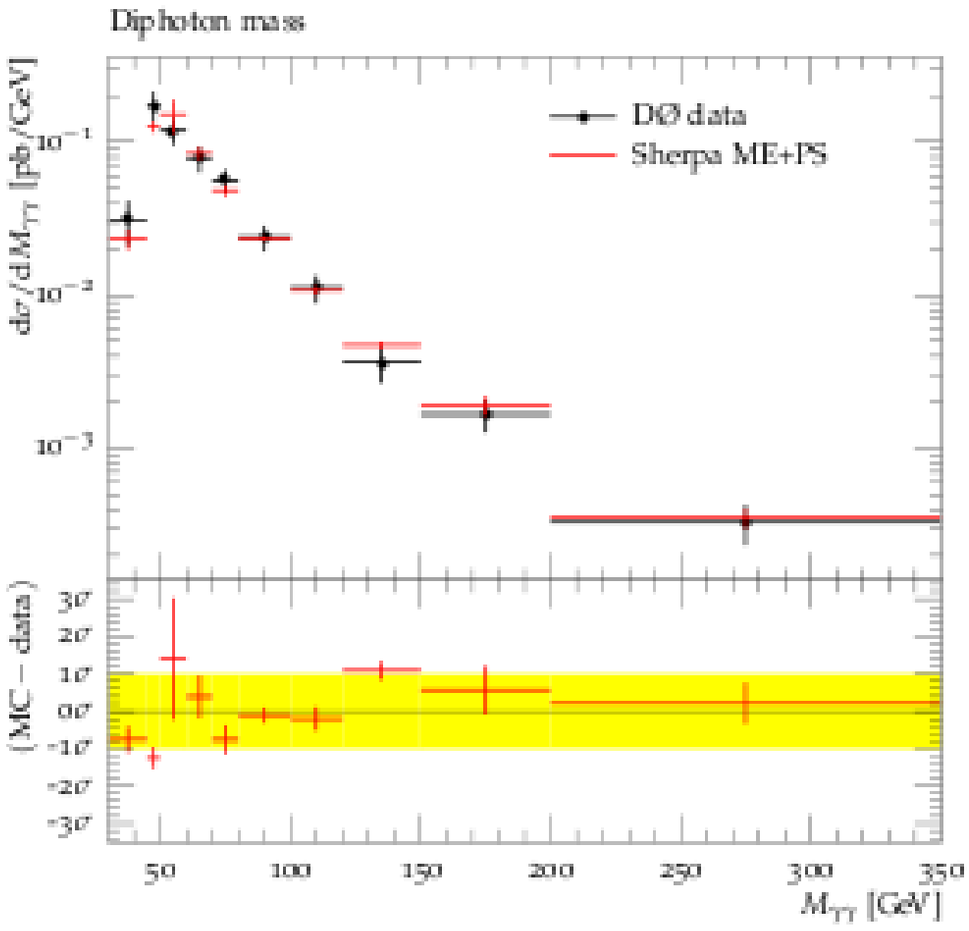


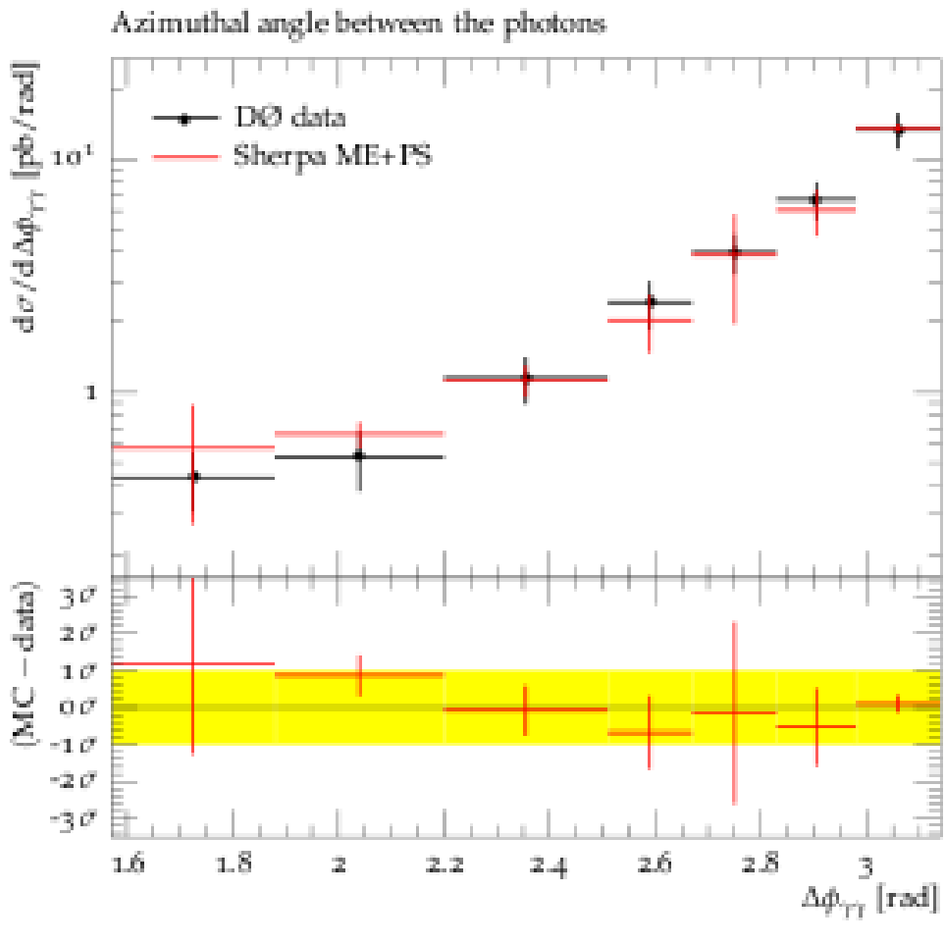
Fragmentation contribution



Sherpa and D0 diphoton data

SHERPA calculations (ME with up to 4 parton in the final state + PS) describe D0 data quite well (F.Siegert, http://fsiegert.web.cern.ch/fsiegert/talks/2010-05-CMS-Hgg.pdf)





– Prompt photon production: LO matrix elements (⇒ "direct" component); interleaved parton shower for QCD⊕QED evolution (⇒ models $D^{\gamma}_{q,g}(z, Q^2)$),PRD81,034026 (2010).

– Good description of ALEPH $D^{\gamma}_{q}(z)$ for 0.7<z<1.0, D0&CDF incl. γ, D0 incl. γ+jet ,..

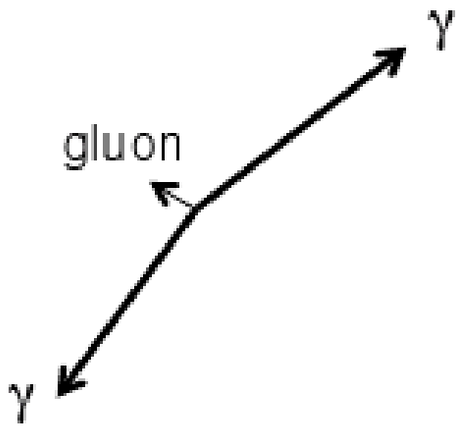
Resummation of soft gluon ISR

- At fixed $M(\gamma\gamma)$, the differential cross section as a function of $p_T(\gamma\gamma)$ is given by:

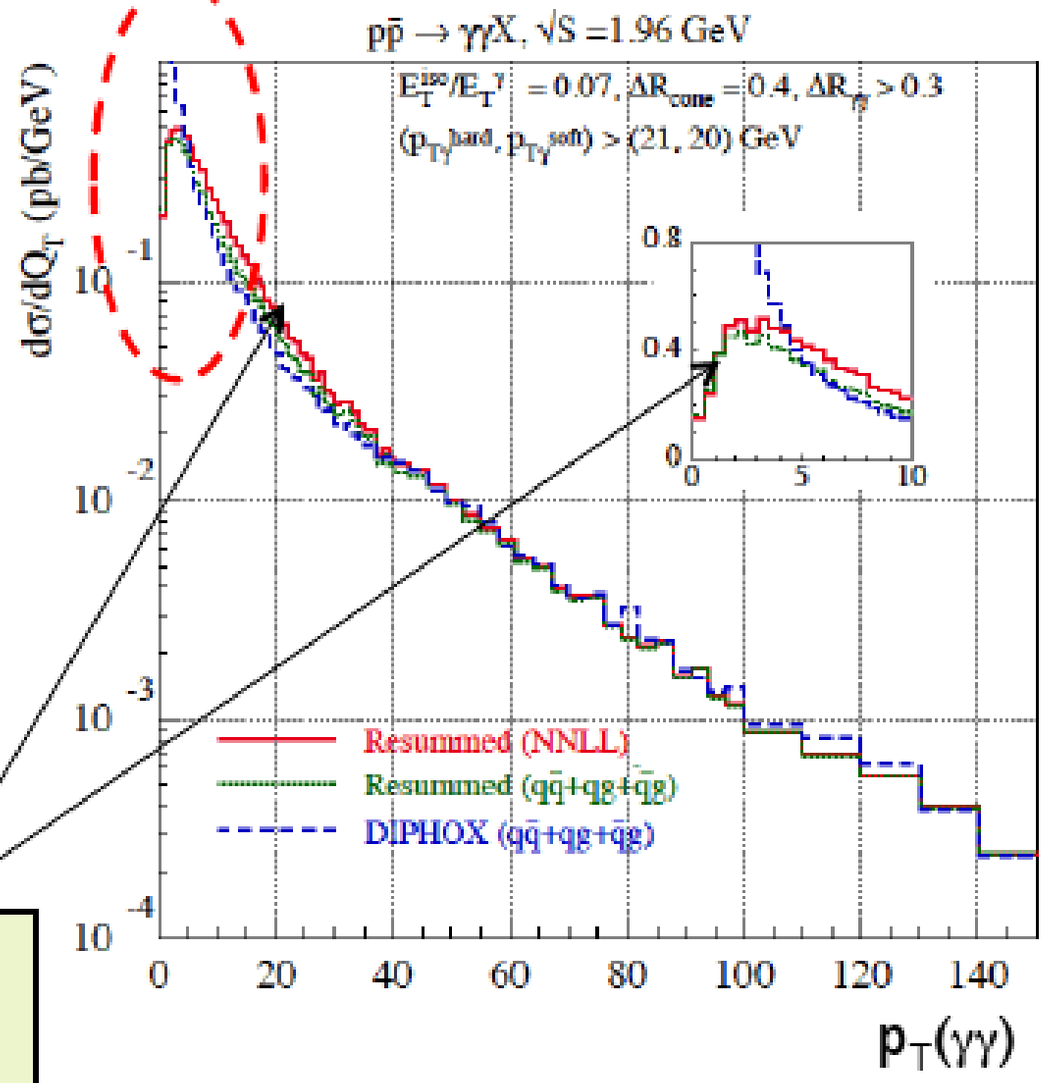
$$\frac{d\sigma}{dp_{T\gamma\gamma}^2} = \sigma_0 \frac{\alpha_s}{\pi} \frac{1}{p_{T\gamma\gamma}^2} \left[a_1 \ln\left(\frac{M_{\gamma\gamma}^2}{p_{T\gamma\gamma}^2} \right) + a_0 \right]$$

Fixed-order calculation less reliable for $p_T(\gamma\gamma) \ll M(\gamma\gamma)$ and diverges as $p_T(\gamma\gamma) \rightarrow 0$.

[Also when $\Delta\phi(\gamma,\gamma) \rightarrow \pi$.]



PRD 76, 013009 (2007)



Physical description of the $p_T(\gamma\gamma)$ and $\Delta\phi(\gamma,\gamma)$ distributions requires all-order resummation of soft and collinear logarithms.

Higgs at the Tevatron

– Very small SM H-->$\gamma\gamma$ production rate: ~3 fb at M_H=115 GeV

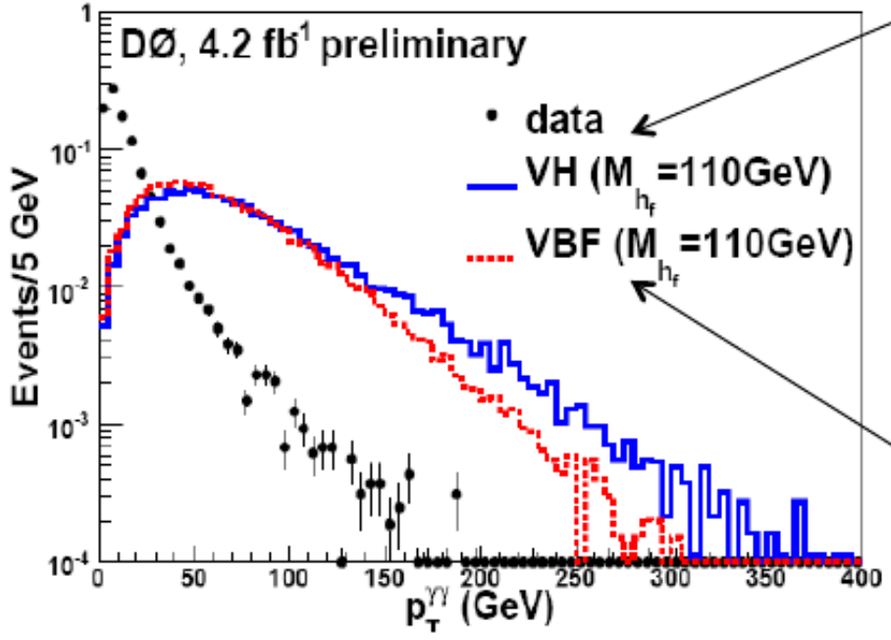
→ Even with 10 fb^{-1}. No observation is expected at the Tevatron.

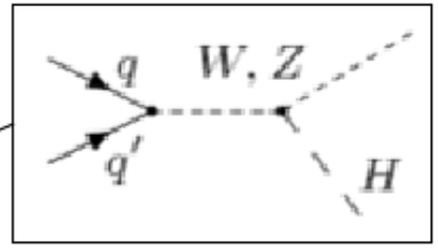
– However, (a) this channel contributes to SM Higgs sensitivity in the difficult intermediate mass range of ~125 GeV; (b) in the models with fermiofobic Higgs (zero couplings to fermions), H-->$\gamma\gamma$ ratio is significantly increased [a factor 33(13) for M_H=110(120) GeV]

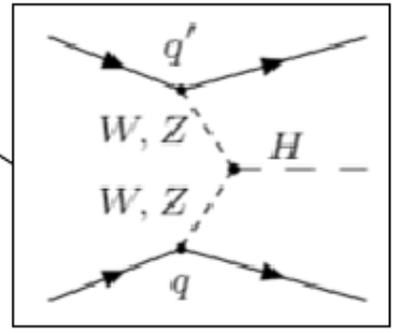
Selections: 2 photons with p_T>25 GeV and $|\eta| < 1.1$

Estimated background: γ+jet and jet+jet - 40%, $\gamma\gamma - 60\%$ (from the sideband fitting)

Sensitivity can be improved via a multivariate analysis using knowledge about the whole kinematic







Photon Pair Production (CDF)

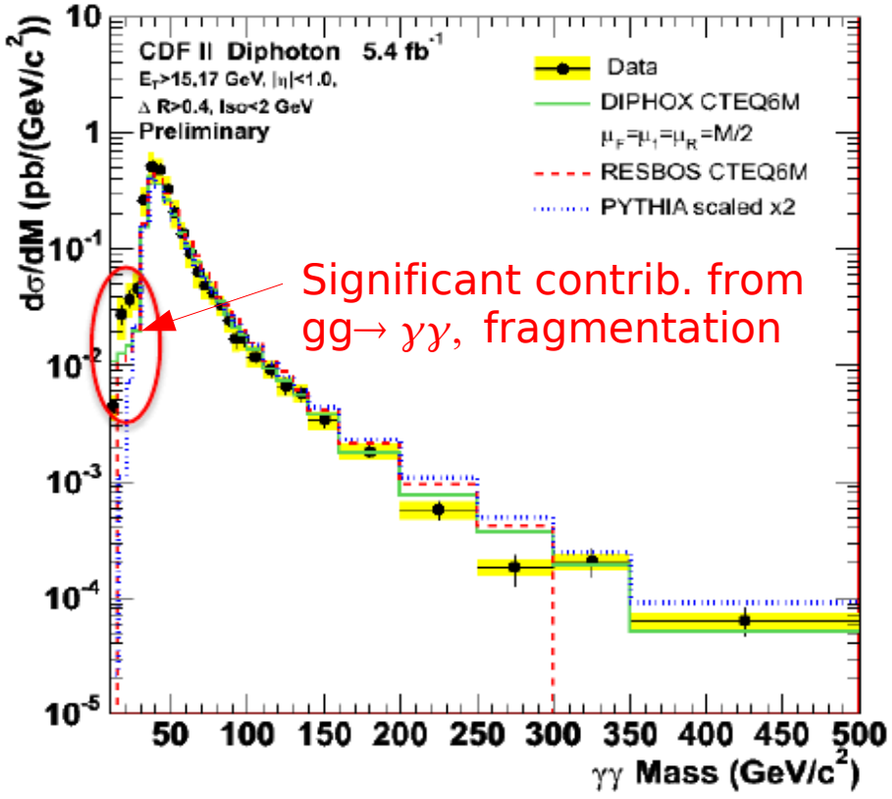
http://www-cdf.fnal.gov/physics/new/qcd/diphoXsec_2010/public_diphoton.html

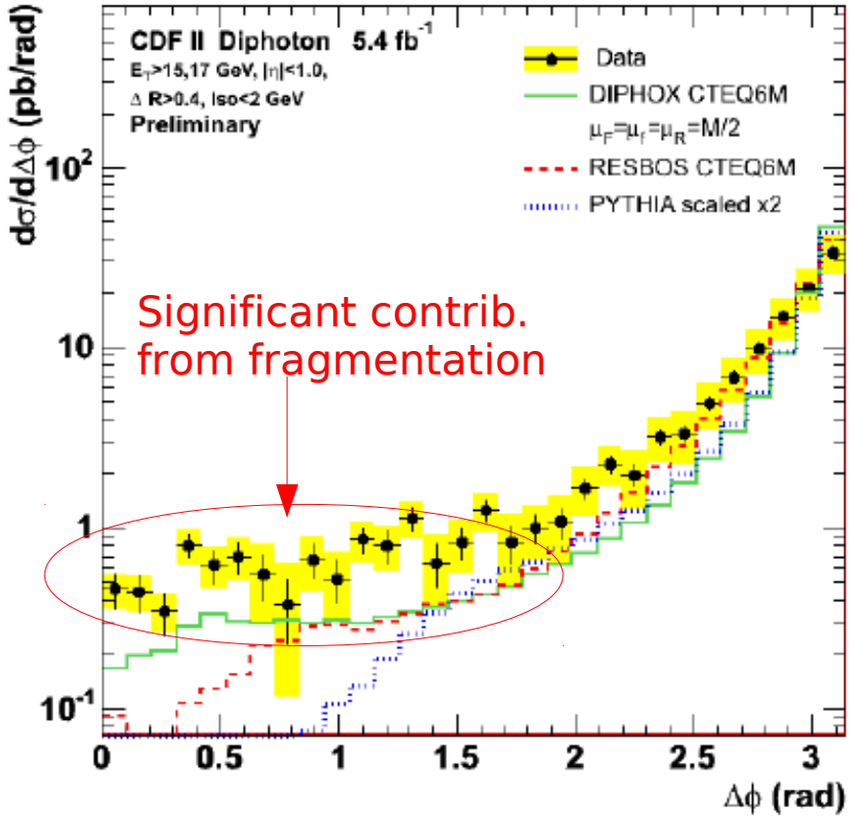
– Isolated (ETsum[R=0.4]< 2 GeV) photons with pT>15 and 17 GeV, |y|<1.0; 5.4 fb-1

– Data are compared with predictions by PYTHIA, DiPhoX, ResBos

– 1D cross sections vs. diphoton Mass, $p_T^{\gamma\gamma}$, $\Delta\phi$.

Preliminary





– None of the models describe the data well in all kinematic regions, in particular at low diphoton mass (M<60 GeV), low $\Delta\phi$ (<1.7 rad) and moderate $p_T^{\gamma\gamma}$ (15-60 GeV)

– Data/Theory: similar conclusion to those from D0 results

Photon Pair Production (CDF)

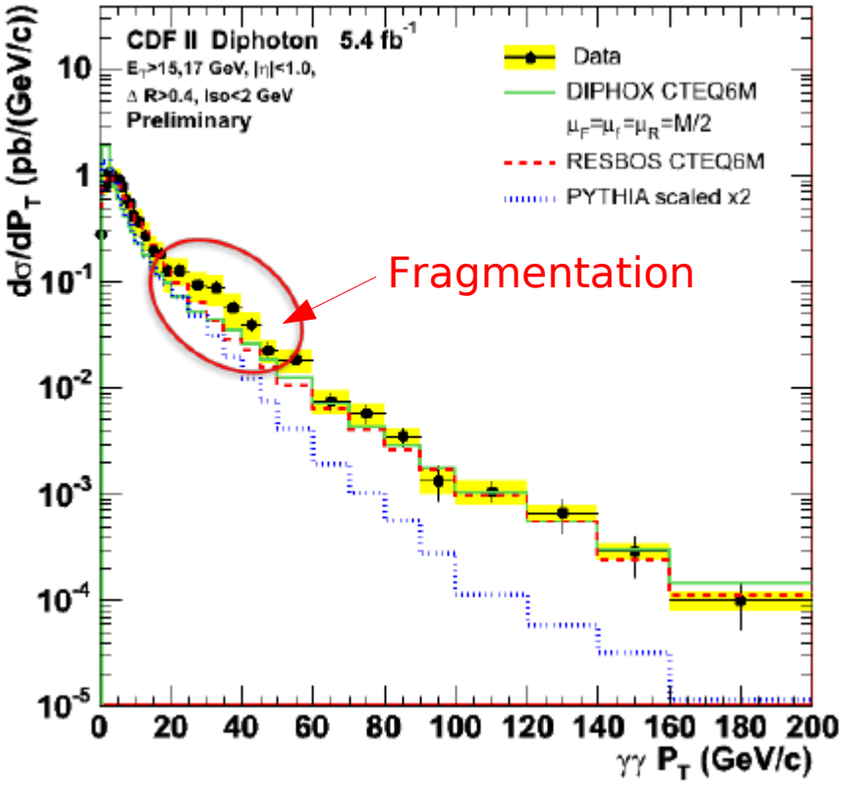
http://www-cdf.fnal.gov/physics/new/qcd/diphoXsec_2010/public_diphoton.html

– Isolated (ETsum[R=0.4]< 2 GeV) photons with pT>15 and 17 GeV, |y|<1.0; 5.4 fb-1

– Data are compared with predictions by PYTHIA, DiPhoX, ResBos

– 1D cross sections vs. diphoton Mass, $p_T^{\gamma\gamma}$, $\Delta\phi$.

Preliminary



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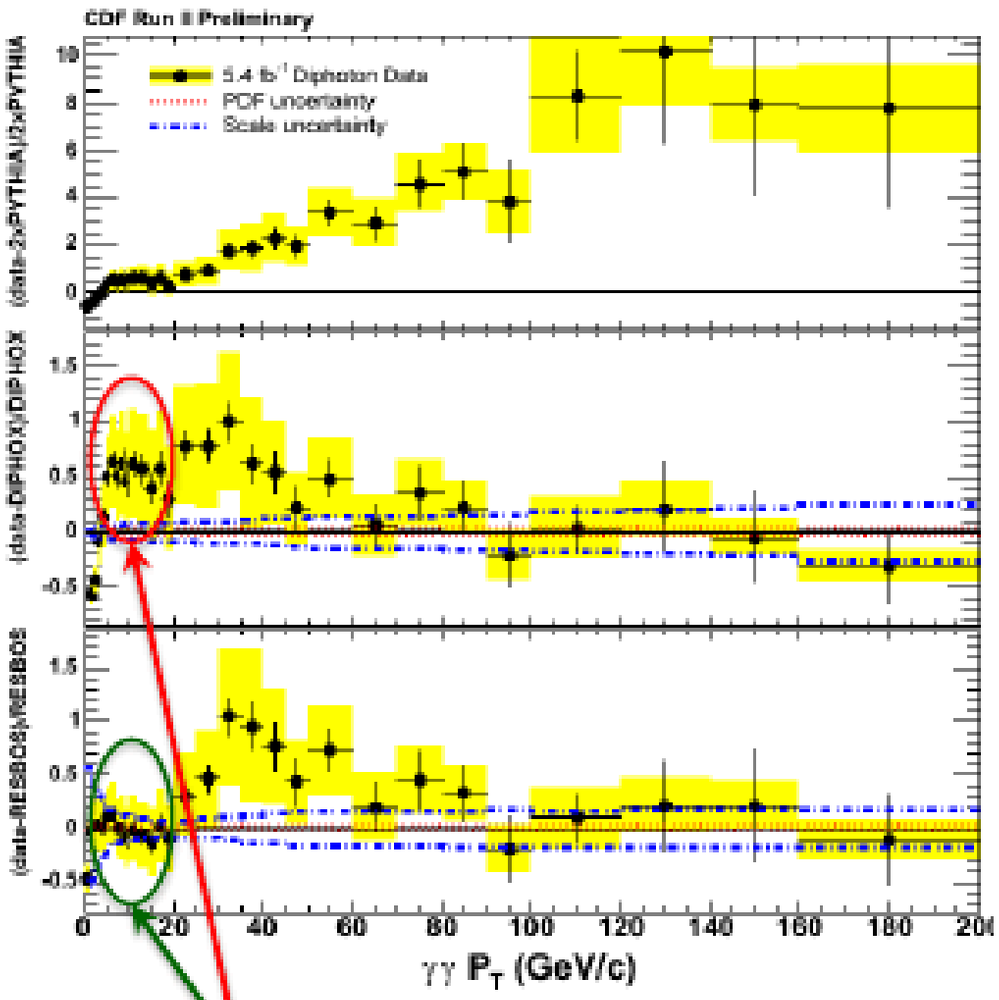
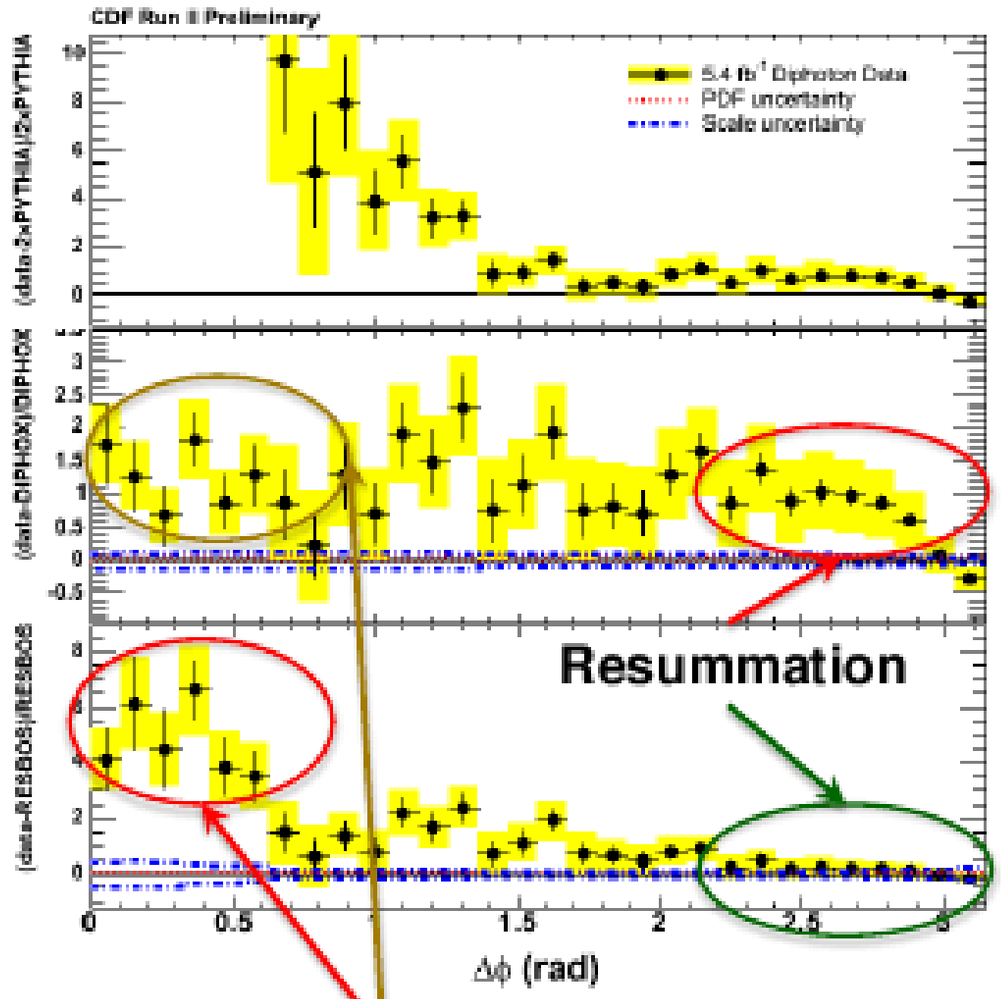
Photon Pair Production (CDF)

Direct Photon Pair Production Differential Cross Sections measured with the CDF Detector: Ratios of Data/Theories

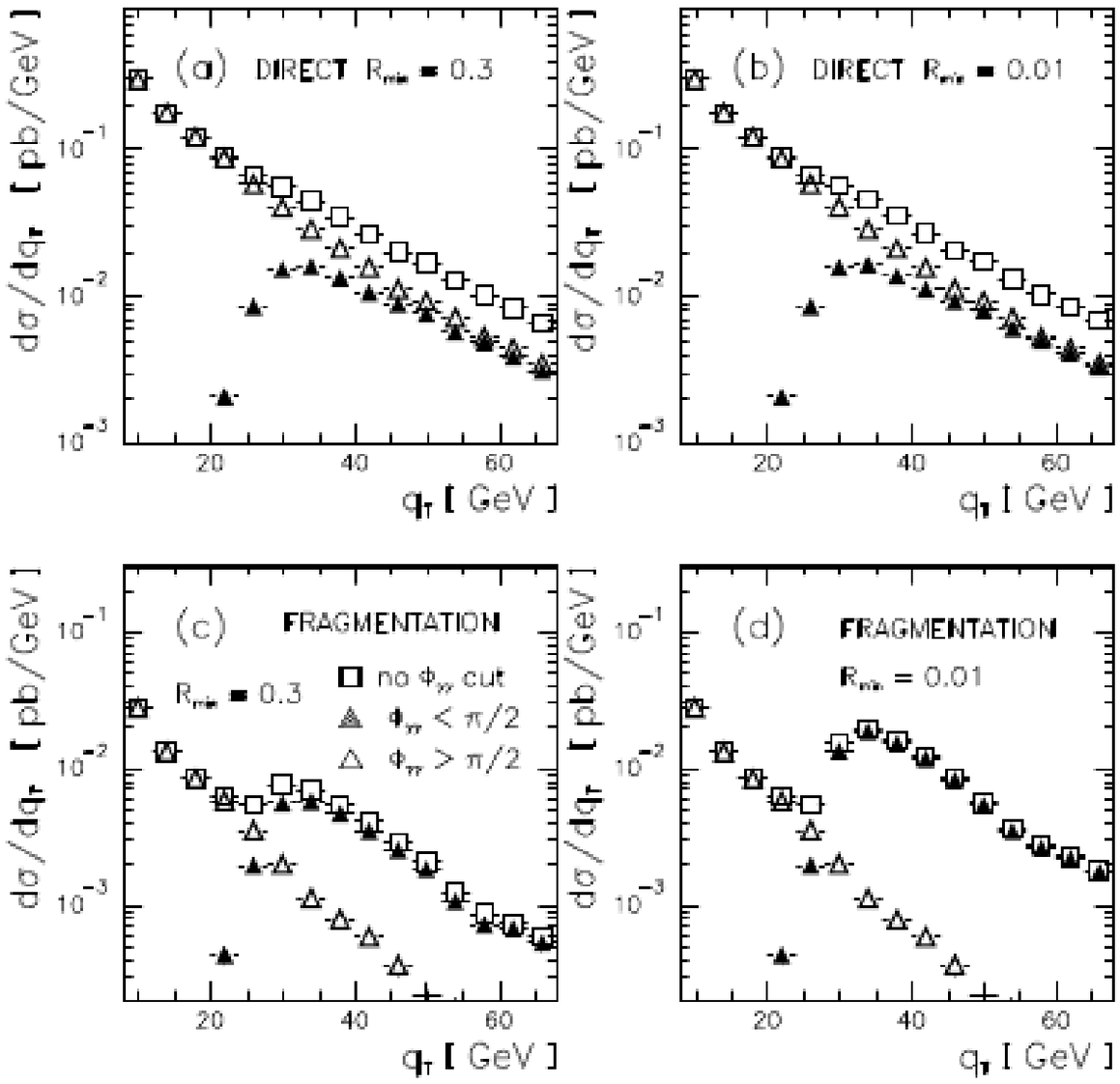




Resummation

Resummation

Fragmentations

Fragmentation vs. qT

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