$H \rightarrow \gamma\gamma$ search and direct photon pair production differential cross section measurement at DØ

Xuebing Bu

USTC/FNAL

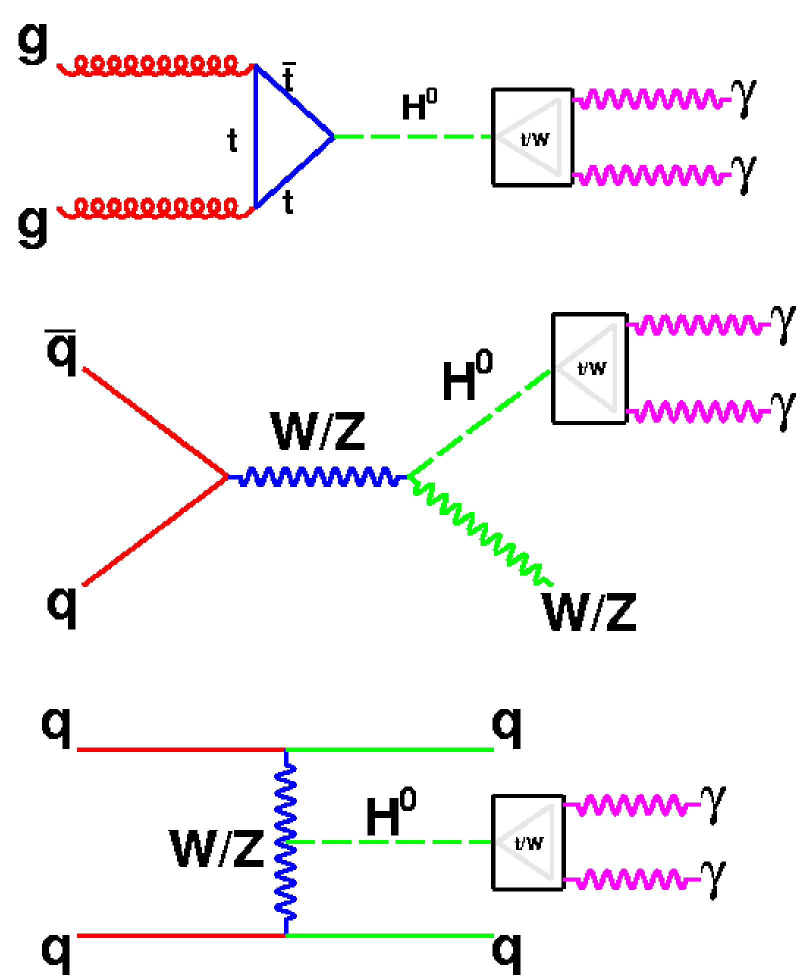
URA thesis award talk

Why search for $H \rightarrow \gamma\gamma$ at Tevatron ?

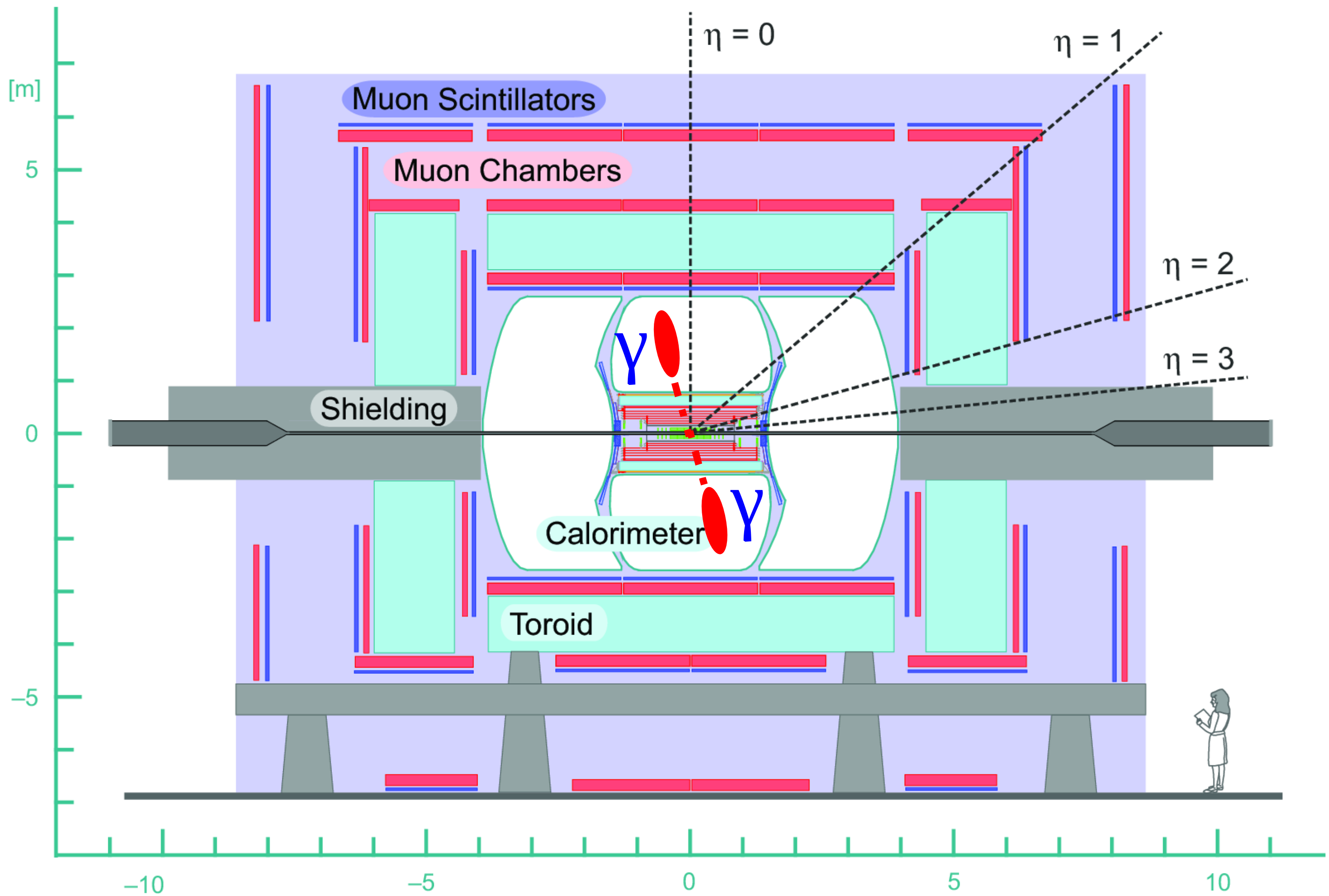
- Higgs boson is undiscovered !
- Clean signature.
- Current direct experimental search + indirect constraint prefer light Higgs boson.
- Contribute to the Tevatron Standard Model Higgs combination, especially in the intermediate mass region around 125 GeV.
- Golden channel for the discovery of Standard Model Higgs at LHC.

$H \rightarrow \gamma\gamma$

- Standard Model Higgs:
  - Gluon fusion
  - Associated production
  - Vector boson fusion
- Examine the inclusive di-photon dataset ($\gamma\gamma$+X) to search for the high mass resonance.



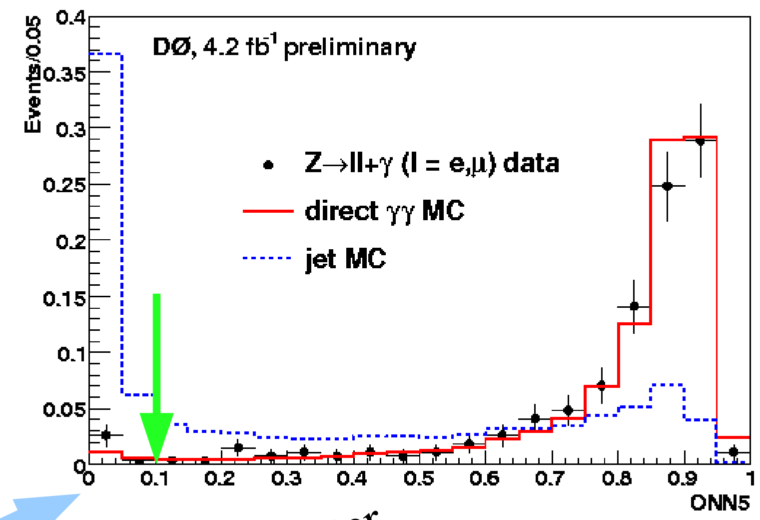
DØ detector

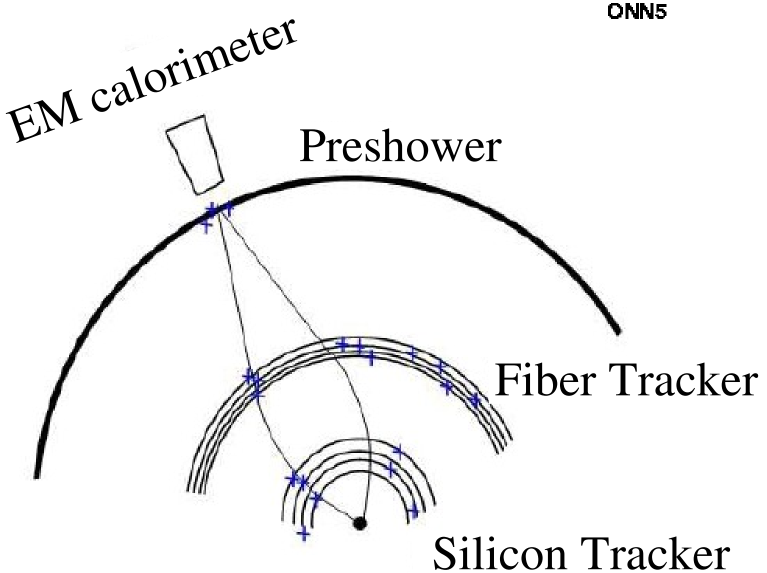


[m]
5
0
–5
–10
–5
0
5
10
η = 0
η = 1
η = 2
η = 3
Muon Scintillators
Muon Chambers
Shielding
Calorimeter
Toroid
γ
γ

Event selection

- Select 2 photons
  - Transverse energy $E_T > 25$ GeV
  - Isolated in calorimeter
  - Isolated in tracker
  - Energy shower shape consistent with photon
  - Neural network discriminant (ONN) > 0.1
  - No spatially well-matched tracks
  - No pattern of hits in the tracker in a road be consistent with an electron

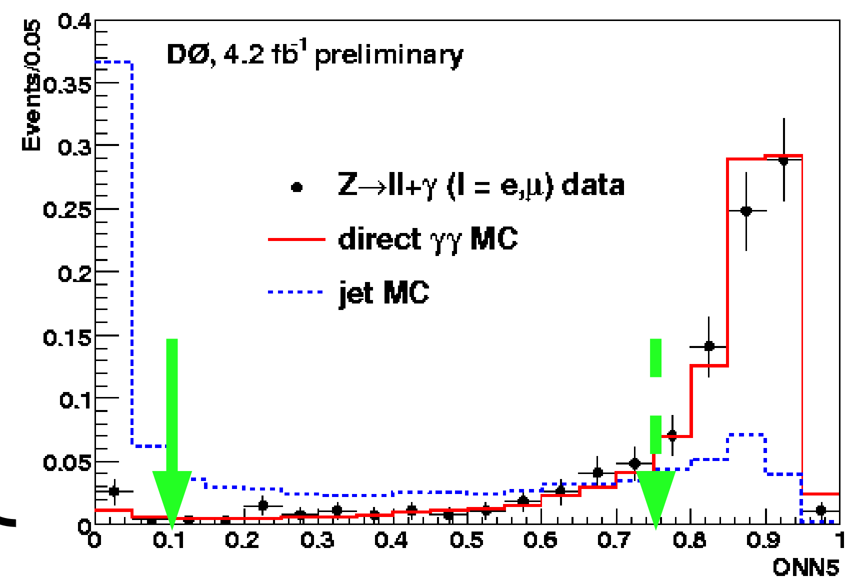




Backgrounds

- Reducible background
  - Z/γ* → ee, both electrons are misidentified as photons, estimated with Geant Monte Carlo.
  - Non-γγ (γ+jet,jet+jet), when the jet(s) is(are) misidentified as photon(s), estimated from data.
- Irreducible background – direct γγ
  - estimated from data.

- Using ONN=0.75 as the boundary to separate the events into 4 categories:
  - Npp: both pass the ONN>0.75
  - Npf: first passes, second fails
  - Nfp: vice-versa
  - Nff: both fail



$$\begin{pmatrix} N_{ff} \\ N_{fp} \\ N_{pf} \\ N_{pp} \end{pmatrix} = E \times \begin{pmatrix} N_{jj} \\ N_{j\gamma} \\ N_{\gamma j} \\ N_{\gamma\gamma} \end{pmatrix}$$

$\epsilon_{j1}, \epsilon_{j2}$ are jet ONN>0.75 efficiencies, estimated from MC, validated from data.

$\epsilon_{\gamma 1}, \epsilon_{\gamma 2}$ are photon ONN>0.75 efficiencies, estimated from MC, corrected from data.

$$E = \begin{pmatrix} (1-\epsilon_{j1})(1-\epsilon_{j2}) & (1-\epsilon_{j1})(1-\epsilon_{\gamma 2}) & (1-\epsilon_{\gamma 1})(1-\epsilon_{j2}) & (1-\epsilon_{\gamma 1})(1-\epsilon_{\gamma 2}) \\ (1-\epsilon_{j1})\epsilon_{j2} & (1-\epsilon_{j1})\epsilon_{\gamma 2} & (1-\epsilon_{\gamma 1})\epsilon_{j2} & (1-\epsilon_{\gamma 1})\epsilon_{\gamma 2} \\ \epsilon_{j1}(1-\epsilon_{j2}) & \epsilon_{j1}(1-\epsilon_{\gamma 2}) & \epsilon_{\gamma 1}(1-\epsilon_{j2}) & \epsilon_{\gamma 1}(1-\epsilon_{\gamma 2}) \\ \epsilon_{j1}\epsilon_{j2} & \epsilon_{j1}\epsilon_{\gamma 2} & \epsilon_{\gamma 1}\epsilon_{j2} & \epsilon_{\gamma 1}\epsilon_{\gamma 2} \end{pmatrix}$$

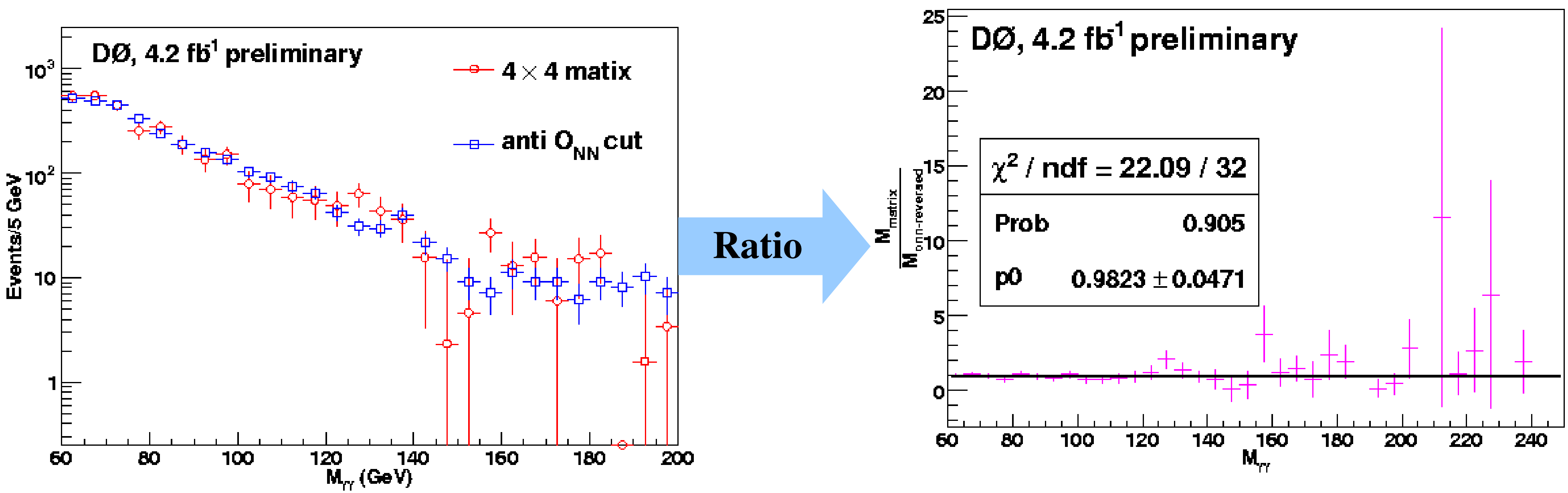
Total	7939
Total - N_{DY}	7722
$N_{\gamma\gamma}$	4538 ± 144
$N_{\gamma j} + N_{j\gamma}$	2189 ± 170
N_{jj}	994 ± 106
non-$\gamma\gamma$	3183 ± 200

Includes potential signal.

The quoted uncertainties are statistical only.

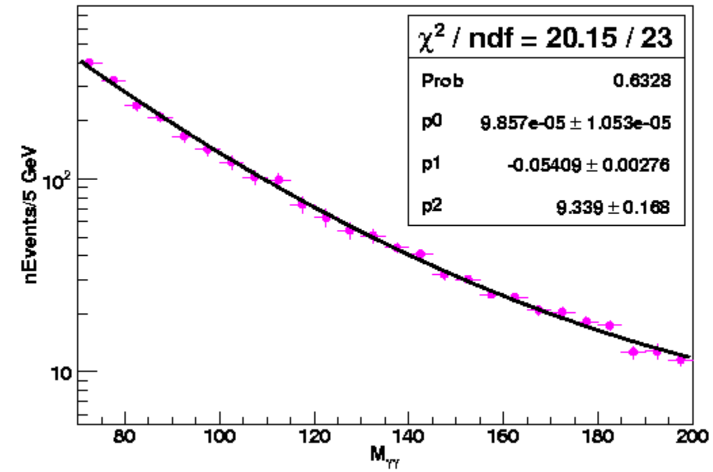
Non-γγ (γ+jet, jet+jet) background

- Shape from reversing the ONN cut (0.1) for one photon candidate.
- Normalization to the number of events from 4X4 matrix method.

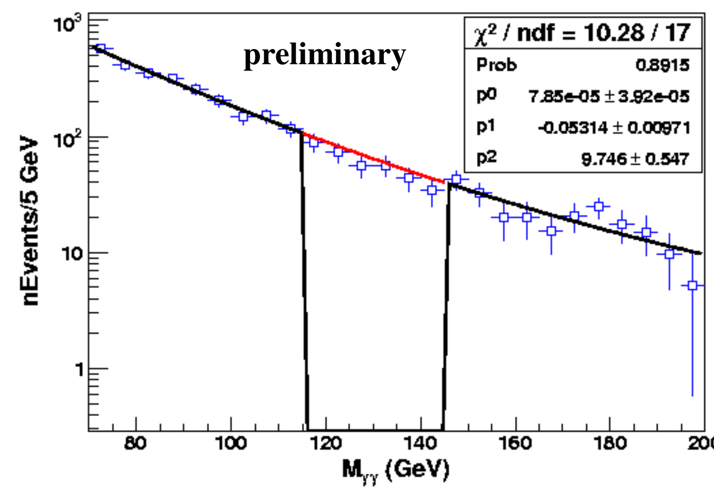


Direct γγ background

- Estimated from data using side-band fitting after the subtraction of the reducible background ($Z \rightarrow ee$, non-γγ).
- The exponential fitting function is validated using NLO predictions.

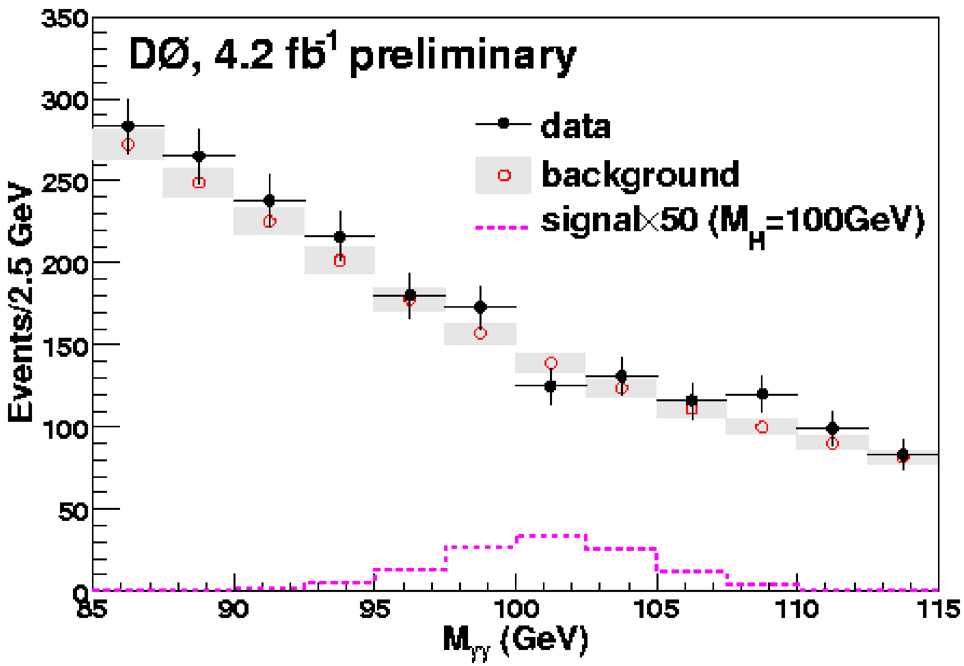


From NLO prediction



From subtracted data

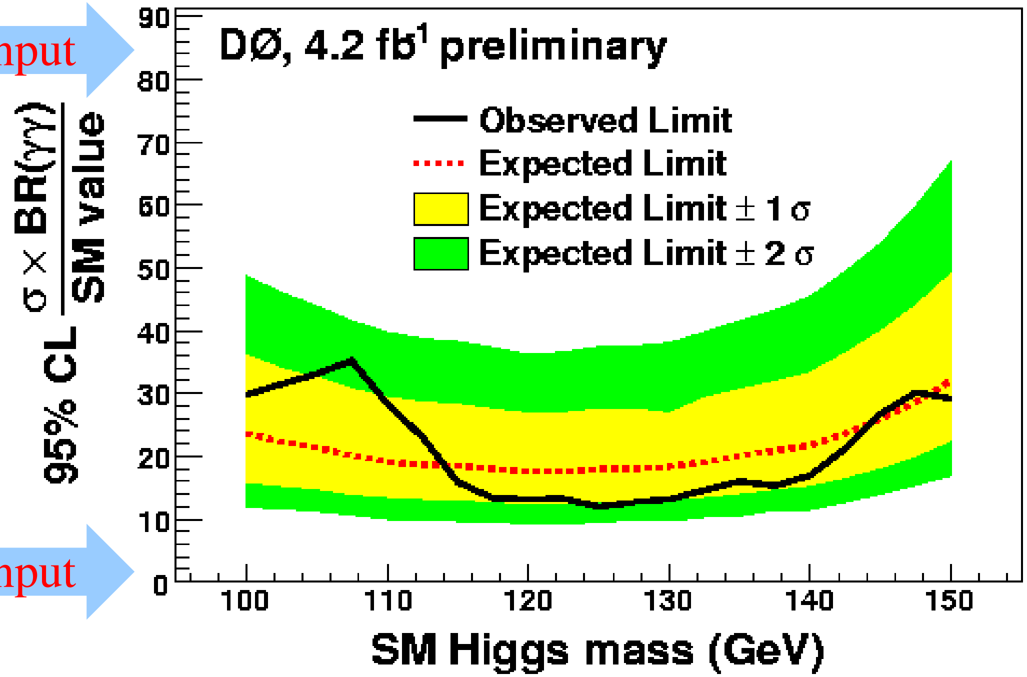
The results



MH=100 GeV as an example !

input

input



Direct photon pair production cross section

- Check the validity of the predictions of perturbative quantum chromodynamics (pQCD) and soft-gluon resummation methods implemented in theoretical calculations.

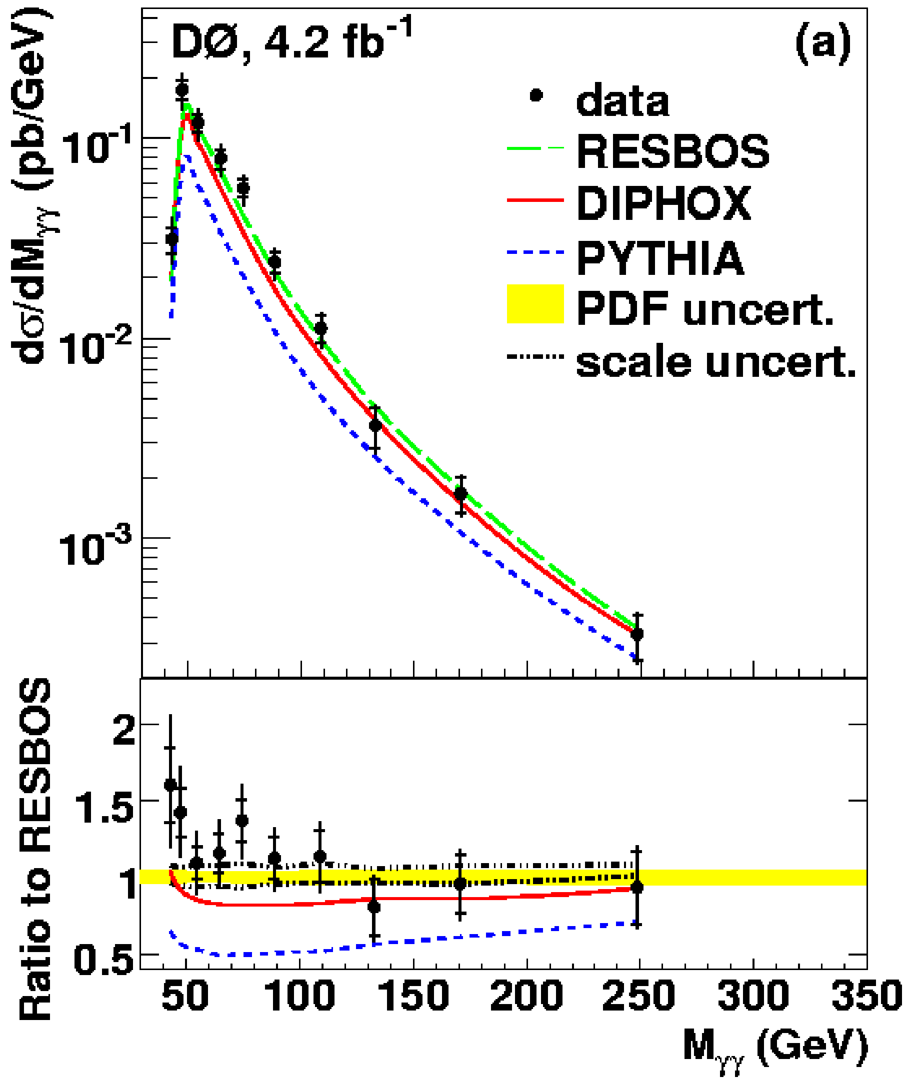
- Dominant background for the H→ γγ search
  - The sensitivity could be enhanced if other kinematic information, e.g. the di-photon transverse momentum, included.

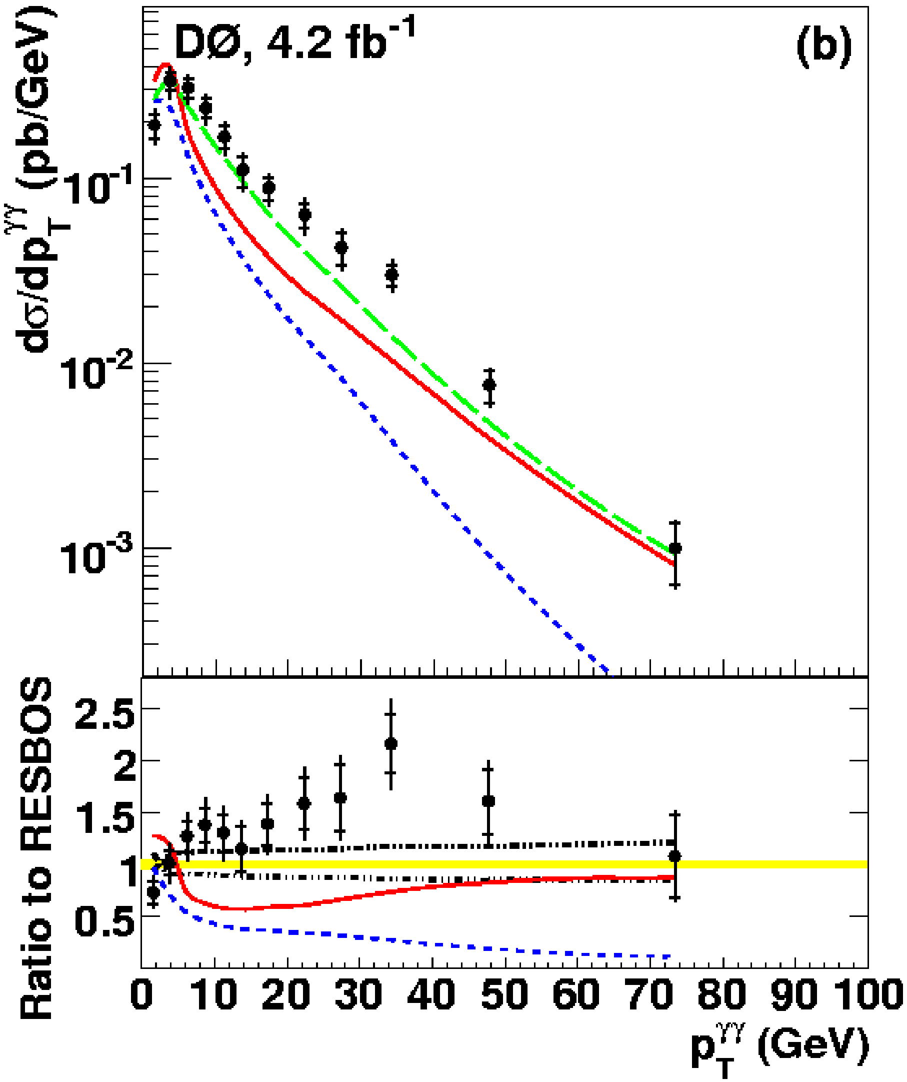
$$\frac{d\sigma}{dX} = \frac{N_{data} - N_{bkg}}{L \cdot Acc \cdot \epsilon_{trigger} \cdot \epsilon_{sel} \cdot \Delta}$$

$$M_{\gamma\gamma}, p_T^{\gamma\gamma}, \Delta\phi_{\gamma\gamma}, \cos\theta_{\gamma\gamma}$$

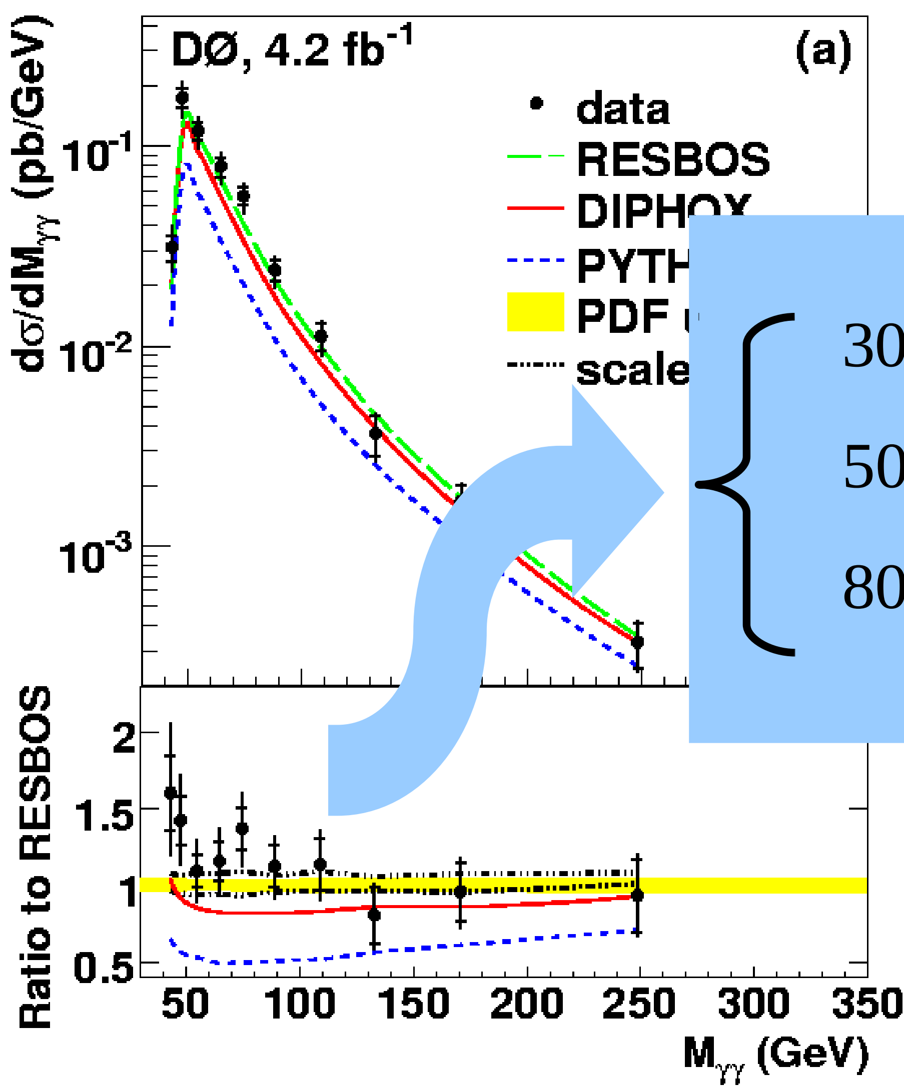
data vs. resbos, diphox and pythia

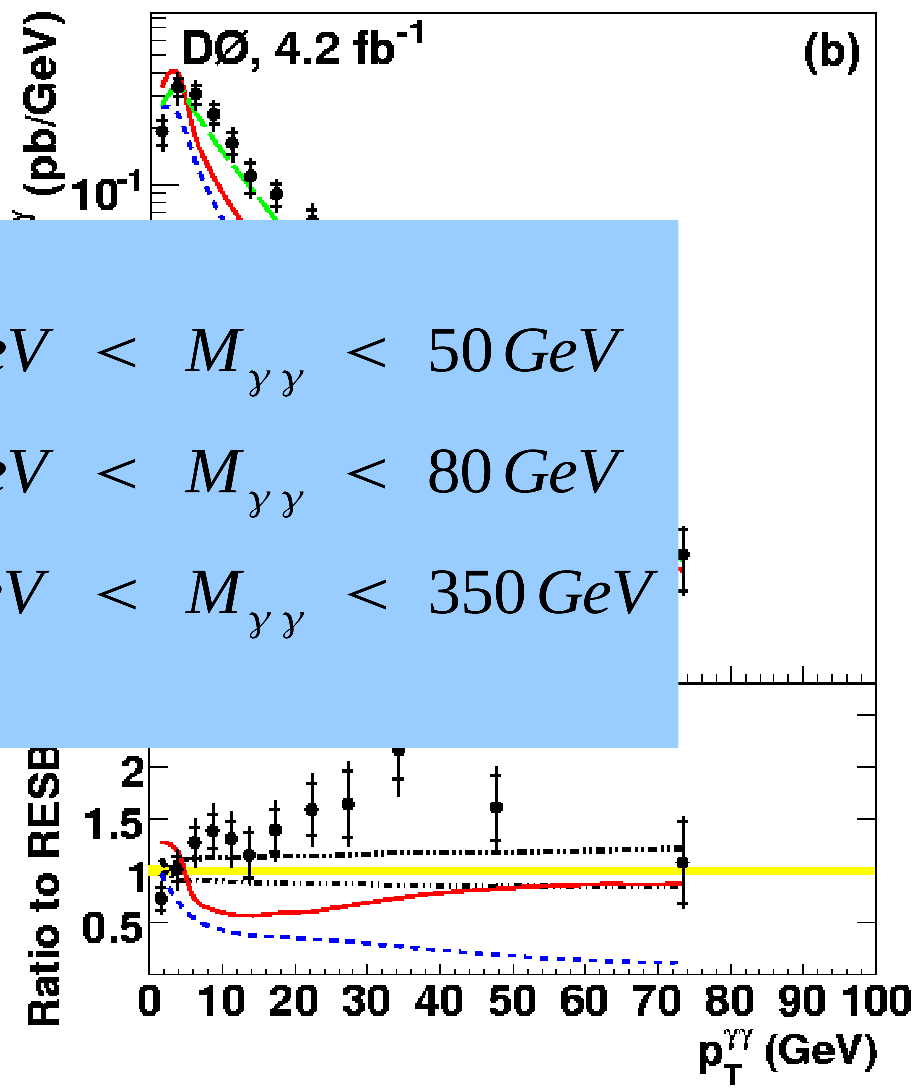
Differential cross sections





Differential cross sections





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

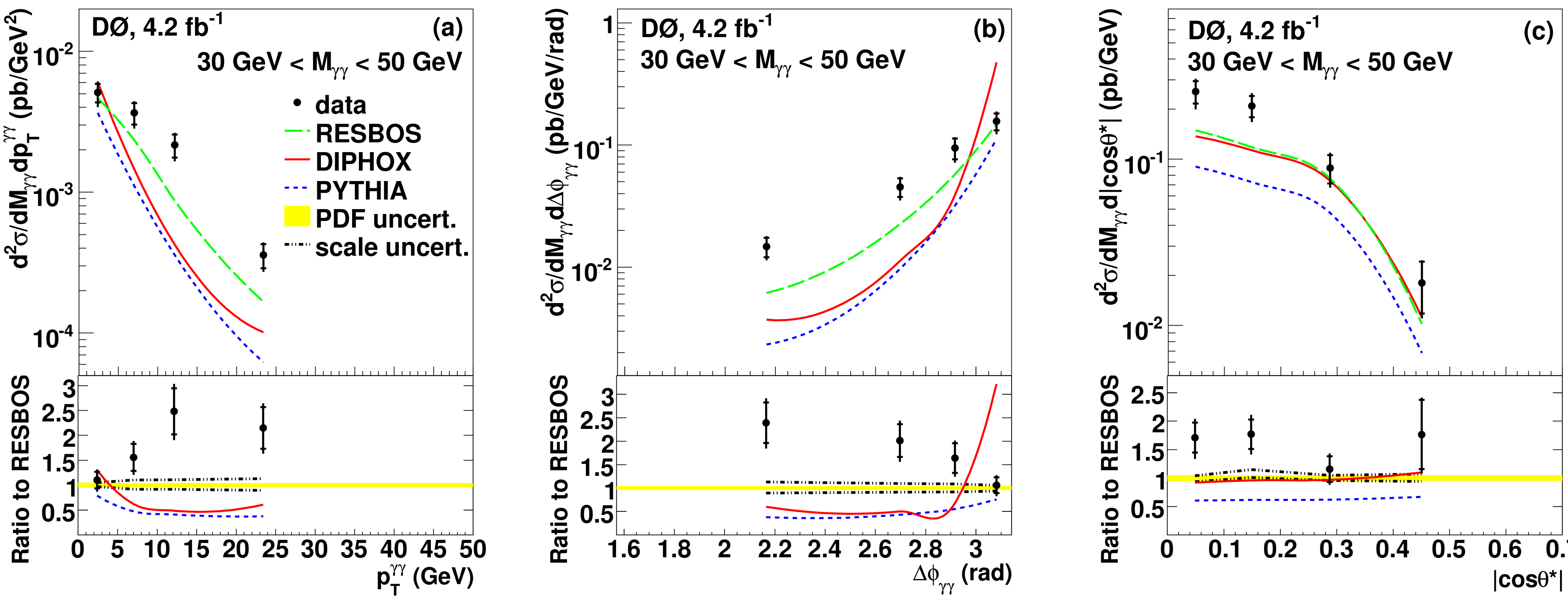
$$50\ GeV < M_{\gamma\gamma} < 80\ GeV$$

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

Differential cross sections in

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

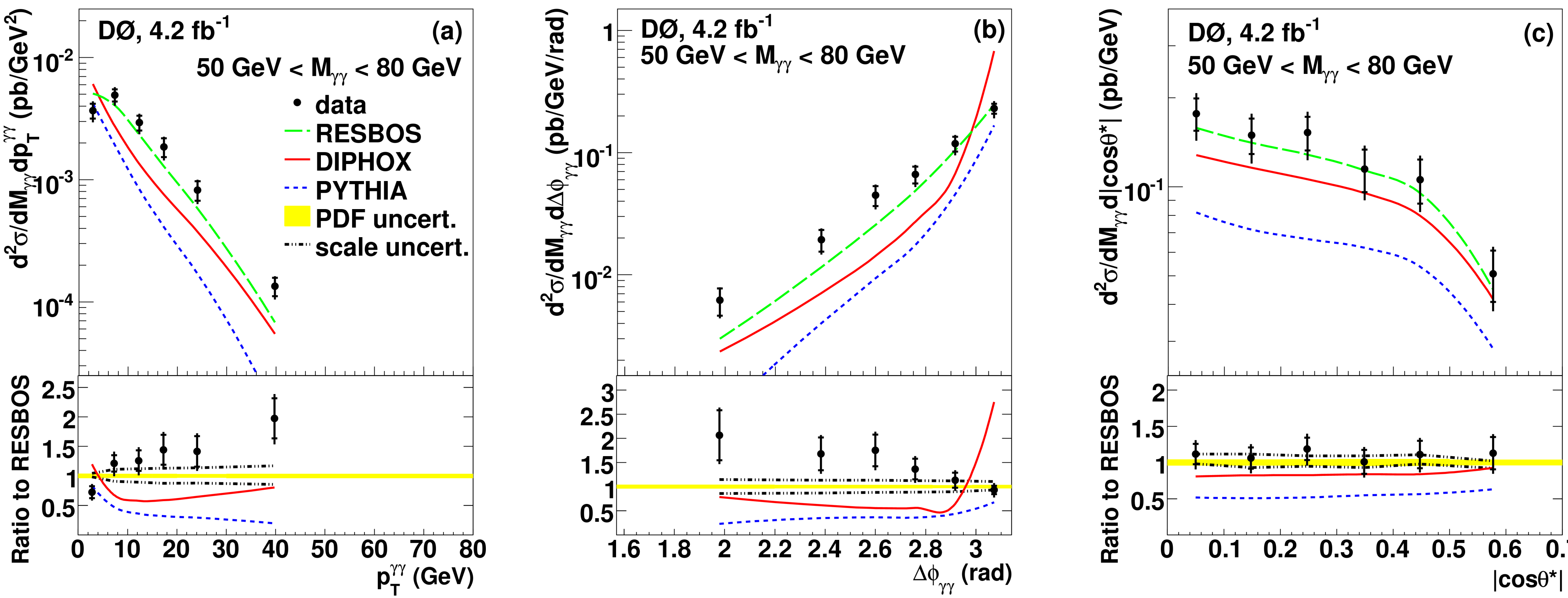
$$\frac{d^2\sigma}{dM_{\gamma\gamma}\cdot dp_T^{\gamma\gamma}} \qquad \frac{d^2\sigma}{dM_{\gamma\gamma}\cdot d\Delta\phi_{\gamma\gamma}} \qquad \frac{d^2\sigma}{dM_{\gamma\gamma}\cdot d\cos\theta}$$



Differential cross sections in

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

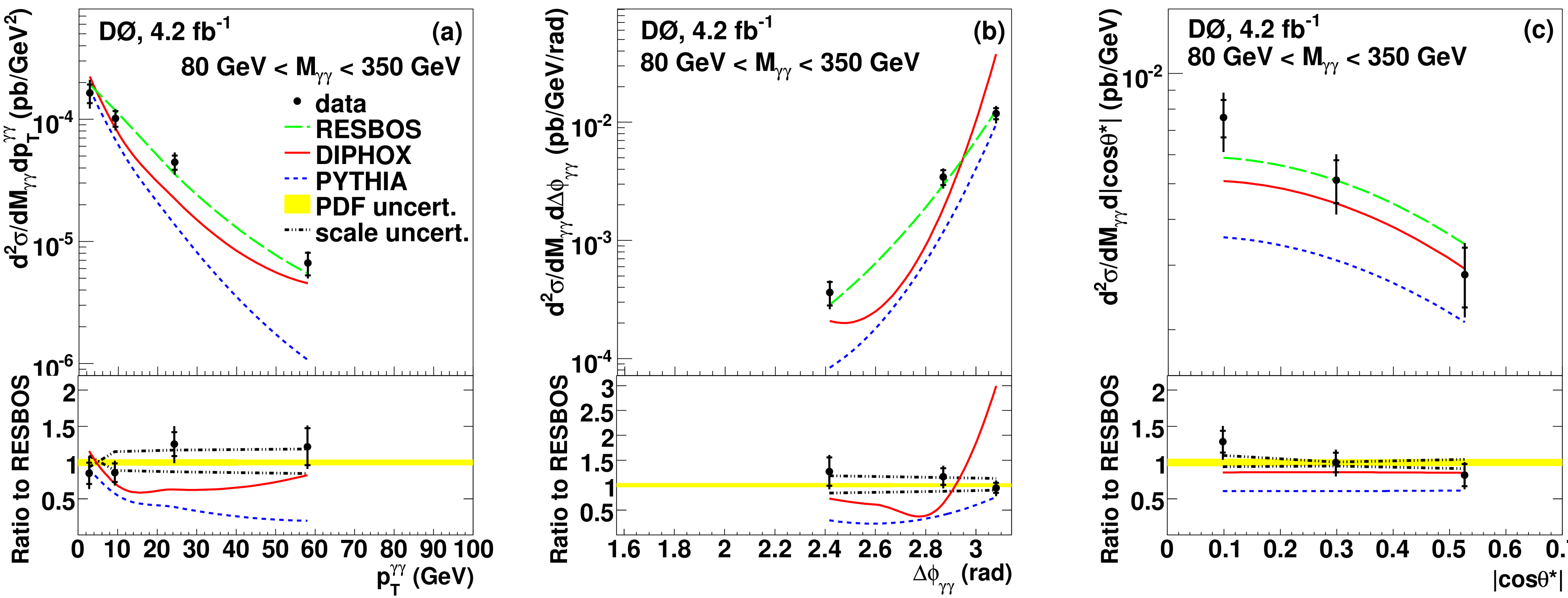
$$\frac{d^2\sigma}{dM_{\gamma\gamma}\cdot dp_T^{\gamma\gamma}} \qquad \frac{d^2\sigma}{dM_{\gamma\gamma}\cdot d\Delta\phi_{\gamma\gamma}} \qquad \frac{d^2\sigma}{dM_{\gamma\gamma}\cdot d\cos\theta}$$



Differential cross sections in

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

$$\frac{d^2\sigma}{dM_{\gamma\gamma}\cdot dp_T^{\gamma\gamma}} \qquad \frac{d^2\sigma}{dM_{\gamma\gamma}\cdot d\Delta\phi_{\gamma\gamma}} \qquad \frac{d^2\sigma}{dM_{\gamma\gamma}\cdot dcos\theta}$$

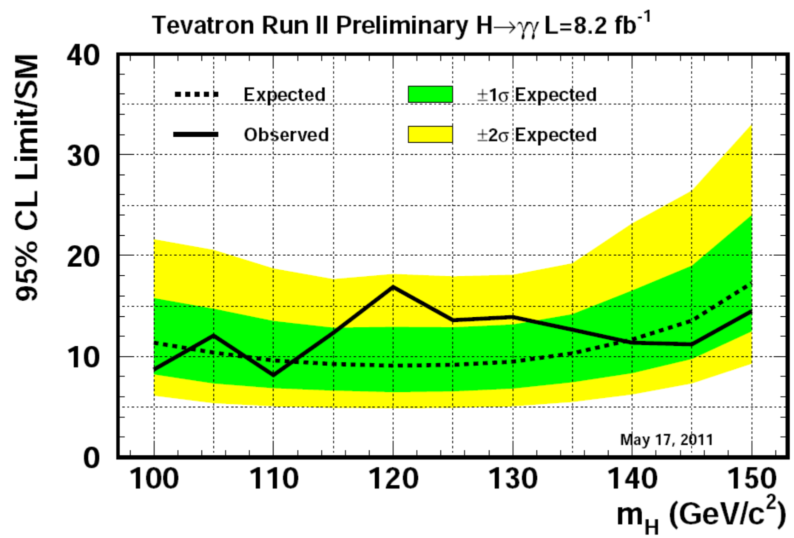


Conclusions

- We presented the measurements of single and double differential cross sections for direct photon pair production:
    - Show necessity to include higher order corrections beyond NLO and resummation to all orders of soft and collinear initial state gluons to describe di-photon production.

Conclusions

- We presented the measurements of single and double differential cross sections for direct photon pair production:
  - Show necessity to include higher order corrections beyond NLO and resummation to all orders of soft and collinear initial state gluons to describe di-photon production.
- We performed the first Higgs $\rightarrow \gamma\gamma$ search at Tevatron. Setting limits a factor of ~15 above Standard Model prediction at 130 GeV.
- Recent Tevatron Higgs $\rightarrow \gamma\gamma$ search results:

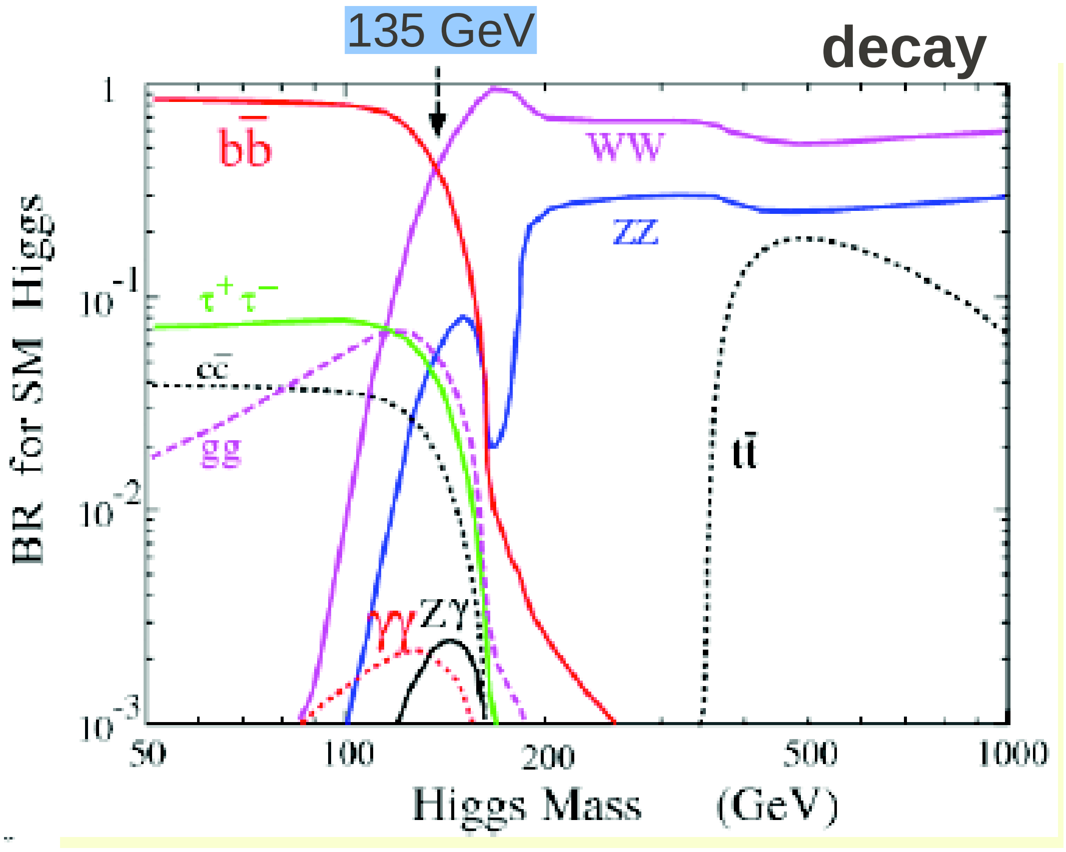


back-up

SM Higgs at Tevatron

- Major decay channels
  H->bb @ MH<135 GeV
  H->WW @ MH>135 GeV

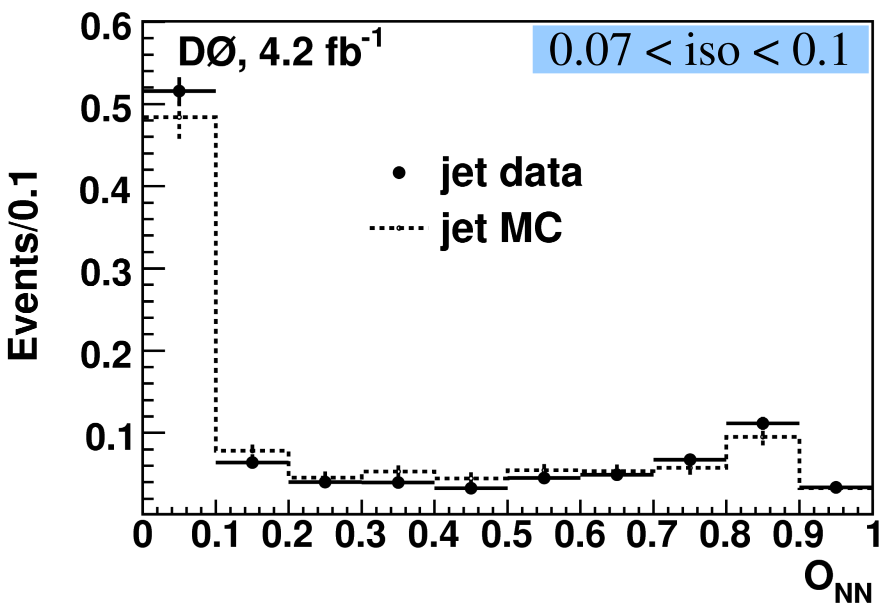
- Current results (limits @95% CL)
  - SM LEP direct search: MH>114.4 GeV
  - SM indirect constraint + LEP direct search: MH<185 GeV

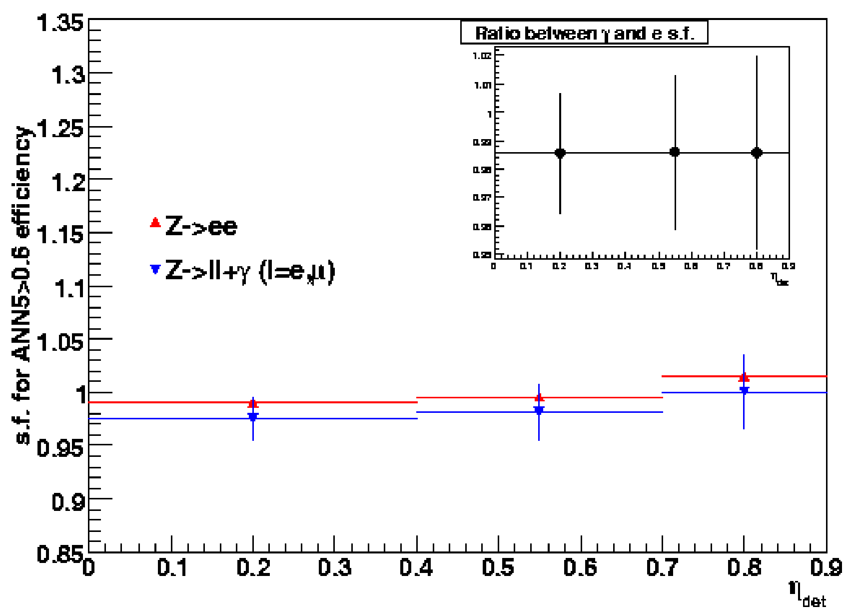


☆ Tevatron is sensitive over the whole "interesting" mass range.

$$\begin{pmatrix} N_{ff} \\ N_{fp} \\ N_{pf} \\ N_{pp} \end{pmatrix} = E \times \begin{pmatrix} N_{jj} \\ N_{j\gamma} \\ N_{\gamma j} \\ N_{\gamma\gamma} \end{pmatrix}$$

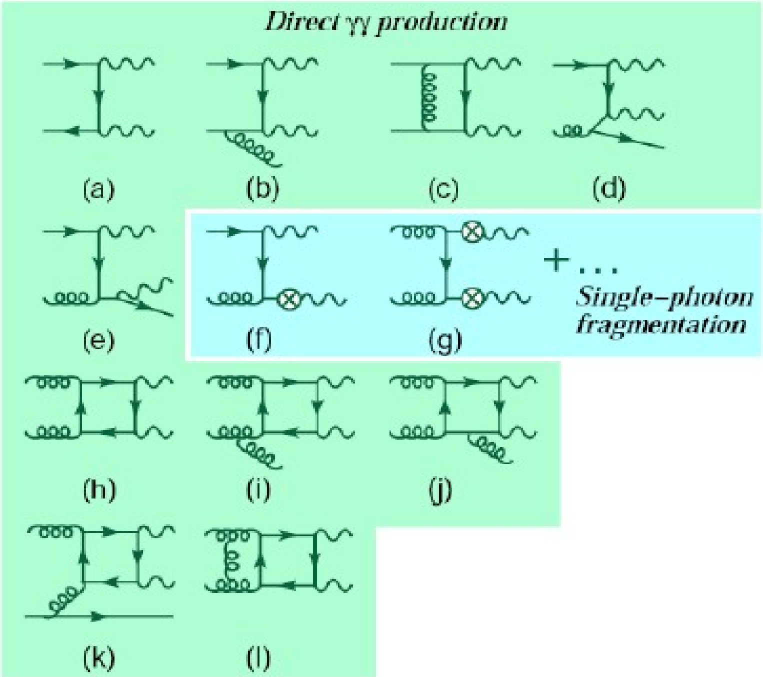
$$E = \begin{pmatrix} (1-\epsilon_{j1})(1-\epsilon_{j2}) & (1-\epsilon_{j1})(1-\epsilon_{\gamma 2}) & (1-\epsilon_{\gamma 1})(1-\epsilon_{j2}) & (1-\epsilon_{\gamma 1})(1-\epsilon_{\gamma 2}) \\ (1-\epsilon_{j1})\epsilon_{j2} & (1-\epsilon_{j1})\epsilon_{\gamma 2} & (1-\epsilon_{\gamma 1})\epsilon_{j2} & (1-\epsilon_{\gamma 1})\epsilon_{\gamma 2} \\ \epsilon_{j1}(1-\epsilon_{j2}) & \epsilon_{j1}(1-\epsilon_{\gamma 2}) & \epsilon_{\gamma 1}(1-\epsilon_{j2}) & \epsilon_{\gamma 1}(1-\epsilon_{\gamma 2}) \\ \epsilon_{j1}\epsilon_{j2} & \epsilon_{j1}\epsilon_{\gamma 2} & \epsilon_{\gamma 1}\epsilon_{j2} & \epsilon_{\gamma 1}\epsilon_{\gamma 2} \end{pmatrix}$$

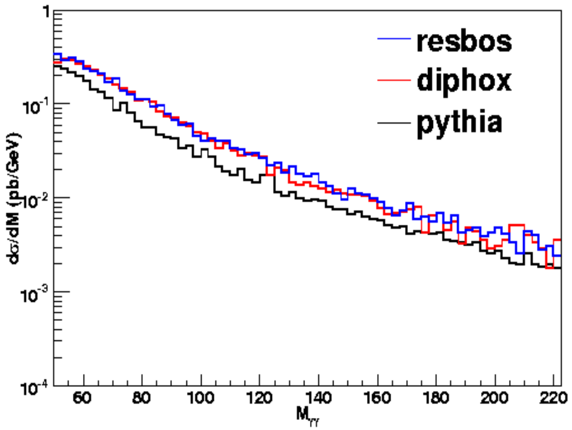




Direct γγ production (DDP) – irreducible background

- Challenge to model by theoretical prediction so far, each generator has its own deficit
  - pythia: LO + parton shower
  - diphox: NLO, except the gg box contribution (LO)
  - resbos: NLO + Resummation of collinear/soft ISR gluons + ~NLO single fragmentation
- However, in the high mass region (Mγγ>50GeV), Mγγ spectrum agrees reasonably very well between diphox and resbos.

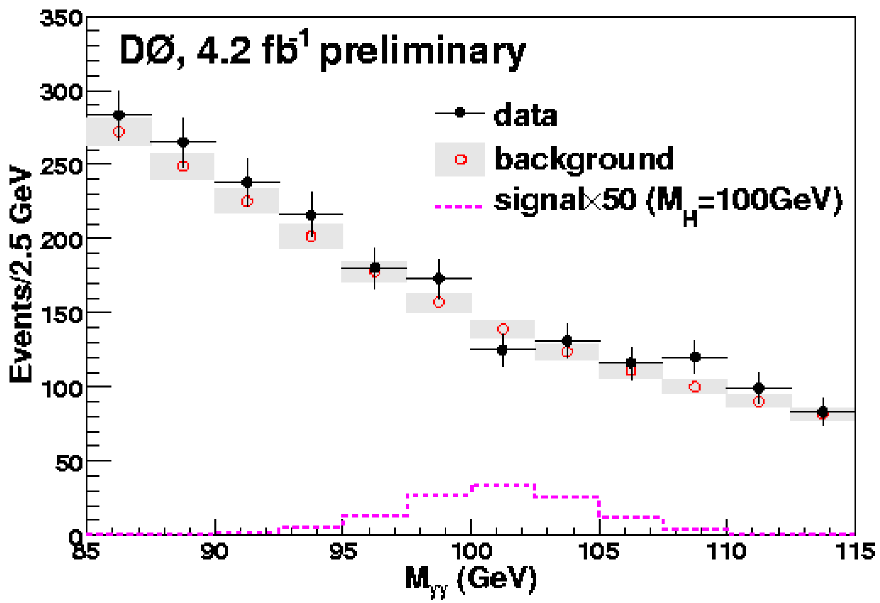


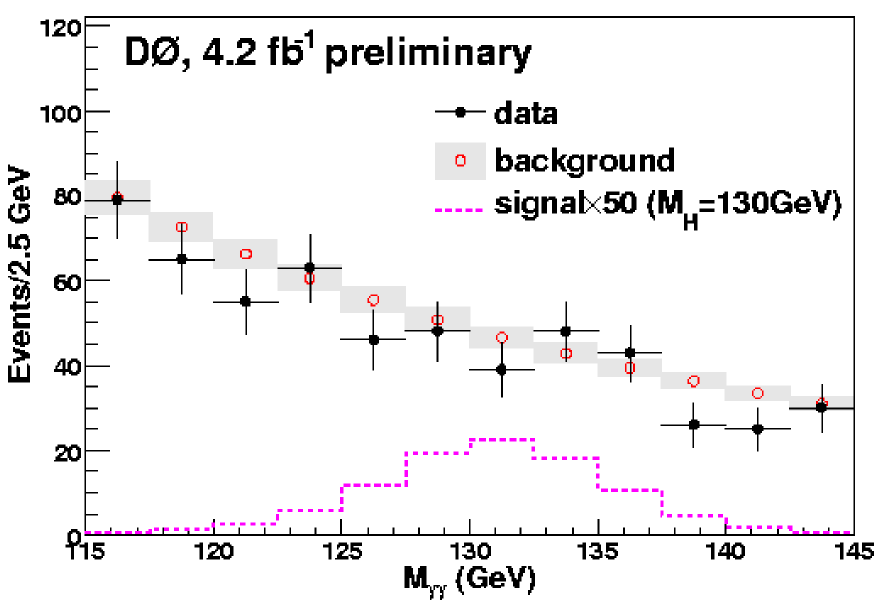


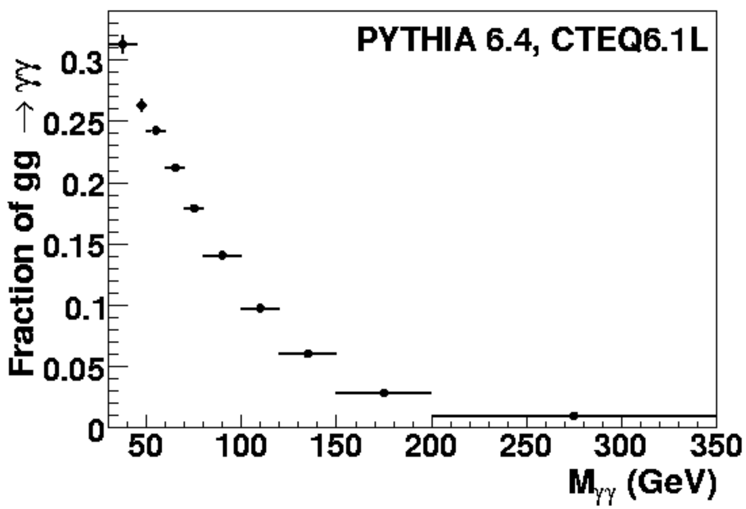
Event yield

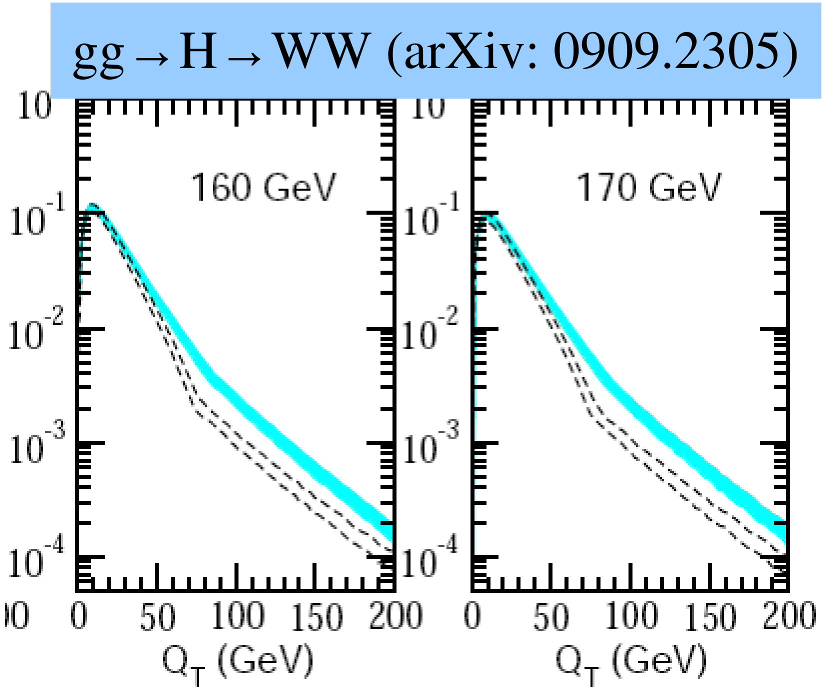
Good agreement between data and SM background prediction:

	100 GeV	110 GeV	120 GeV	130 GeV	140 GeV	150 GeV
$Z/\gamma * \rightarrow ee$	134±27	53±12	17±5	9±3	5±2	3±2
γj+jj	712±102	455±65	299±43	202±29	140±20	100±14
QCD $\gamma\gamma$	1080±96	764±62	539±41	404±28	280±19	207±14
total background	1926±35	1272±21	855±14	615±10	425±7	310±5
data	2029	1289	861	567	412	295
signal	2.53±0.18	2.53±0.18	2.38±0.17	2.01±0.14	1.45±0.10	0.87±0.06






PYTHIA 6.4, CTEQ6.1L
Fraction of gg → γγ
$M_{\gamma\gamma}$ (GeV)


gg → H → WW (arXiv: 0909.2305)
160 GeV
170 GeV
Q_T (GeV)
Q_T (GeV)

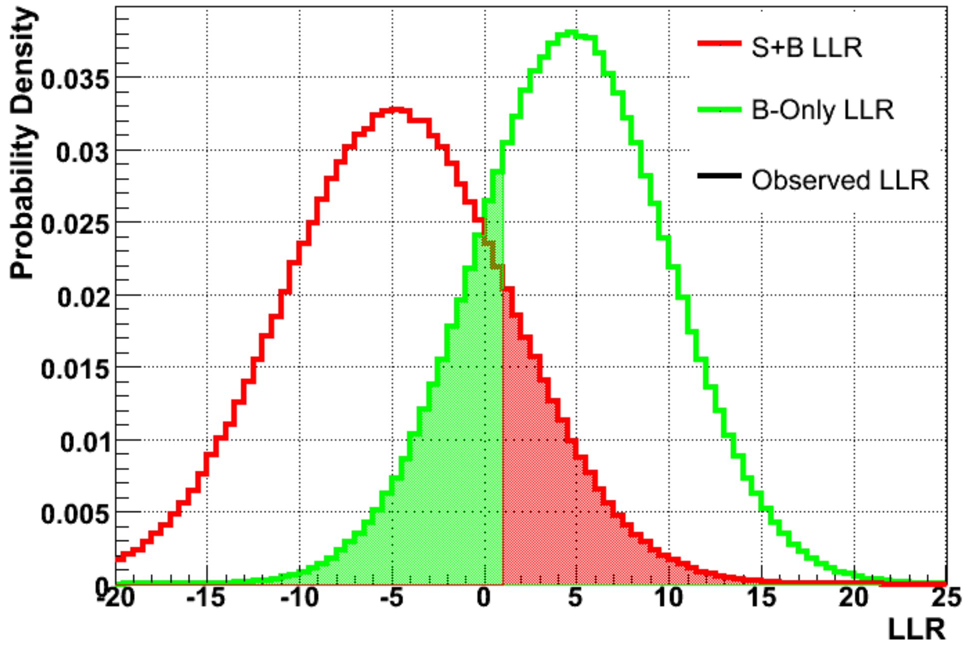
CL Limits calculation

$$Q_i = \frac{\frac{e^{-(s_i+b_i)}\cdot(s_i+b_i)^{d_i}}{d_i!}}{\frac{e^{-b_i}\cdot b_i^{d_i}}{d_i!}} = e^{-s_i}\cdot(1+\frac{s_i}{b_i})^{d_i} \qquad (7.15)$$

where s_i and b_i are the numbers of signal and background events per bin of invariant mass distribution; and d_i is the number of selected events per bin in data. Poisson sampling is performed for d_i in each bin with the poisson mean set to b_i and $s_i + b_i$ respectively for the "background-only" and "signal+ background" hypotheses. And the likelihood ratio is computed as

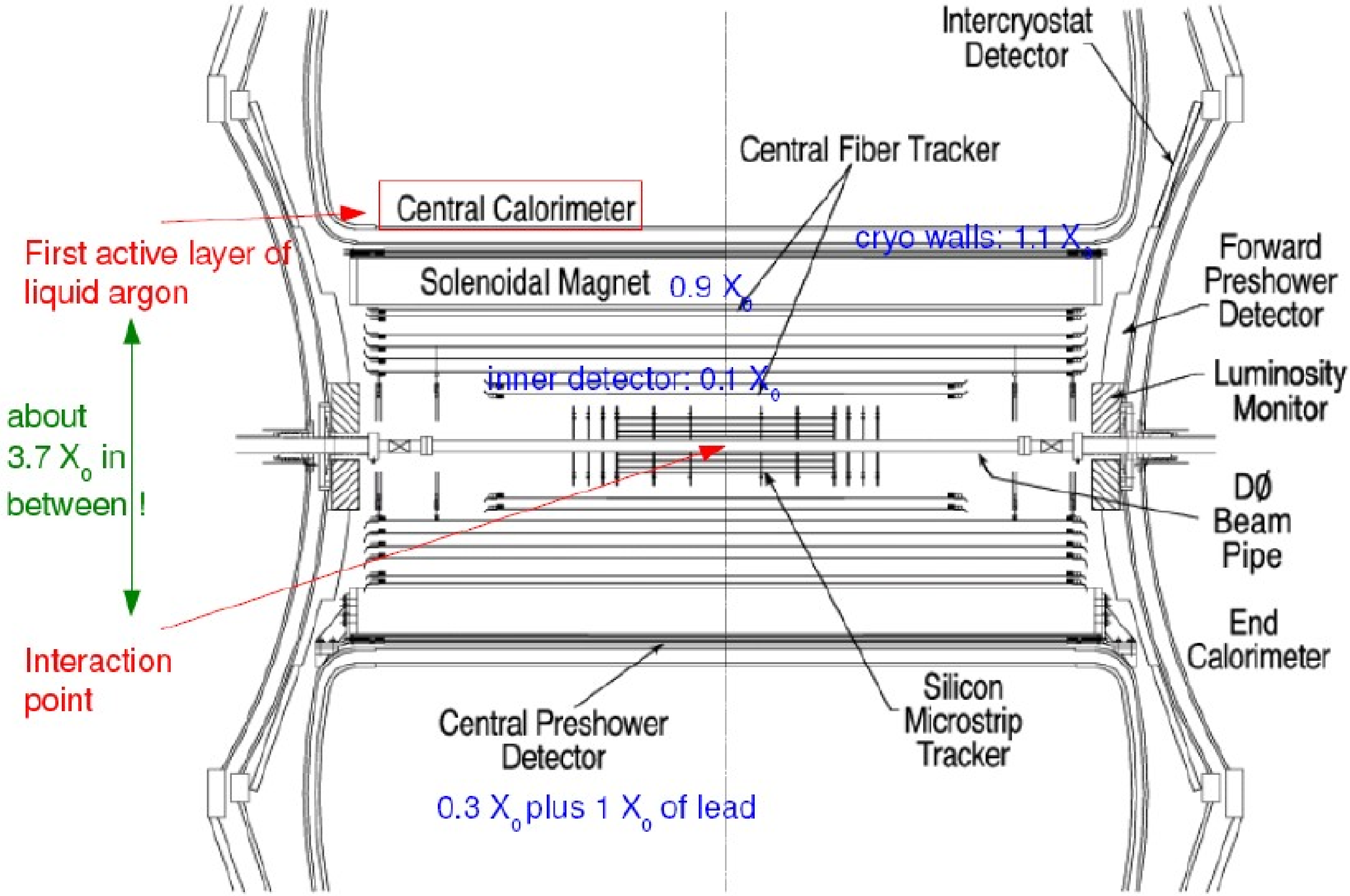
$$Q = \prod_{all\ bins} Q_i \qquad (7.16)$$

Probability distribution function (p.d.f) of the -2lnQ variable under the background-only and signal+background hypotheses can be obtained from the Poisson sampling.



where the two histograms are the p.d.f of the -2lnQ statistic under background-only hypothesis and signal+background hypothesis and the vertical line stands for the value of data. The integral of the signal+background (background-only) p.d.f from the vertical data line to $+\infty$ is called CL_{s+b} (CL_b). If CL_{s+b} <0.05, exclusion can be claimed at 95% C.L. A more conservative exclusion estimator is defined in place of CL_{s+b} as

$$CL_s = \frac{CL_{s+b}}{CL_b}$$


Intercryostat Detector
Central Fiber Tracker
Central Calorimeter
First active layer of liquid argon
cryo walls: 1.1 X0
Solenoidal Magnet
0.9 X0
Forward Preshower Detector
Luminosity Monitor
inner detector: 0.1 X0
about 3.7 X0 in between !
DØ Beam Pipe
End Calorimeter
Interaction point
Silicon Microstrip Tracker
Central Preshower Detector
0.3 X0 plus 1 X0 of lead