From H→ γγ search to direct photon pair production differential cross section measurement at DØ

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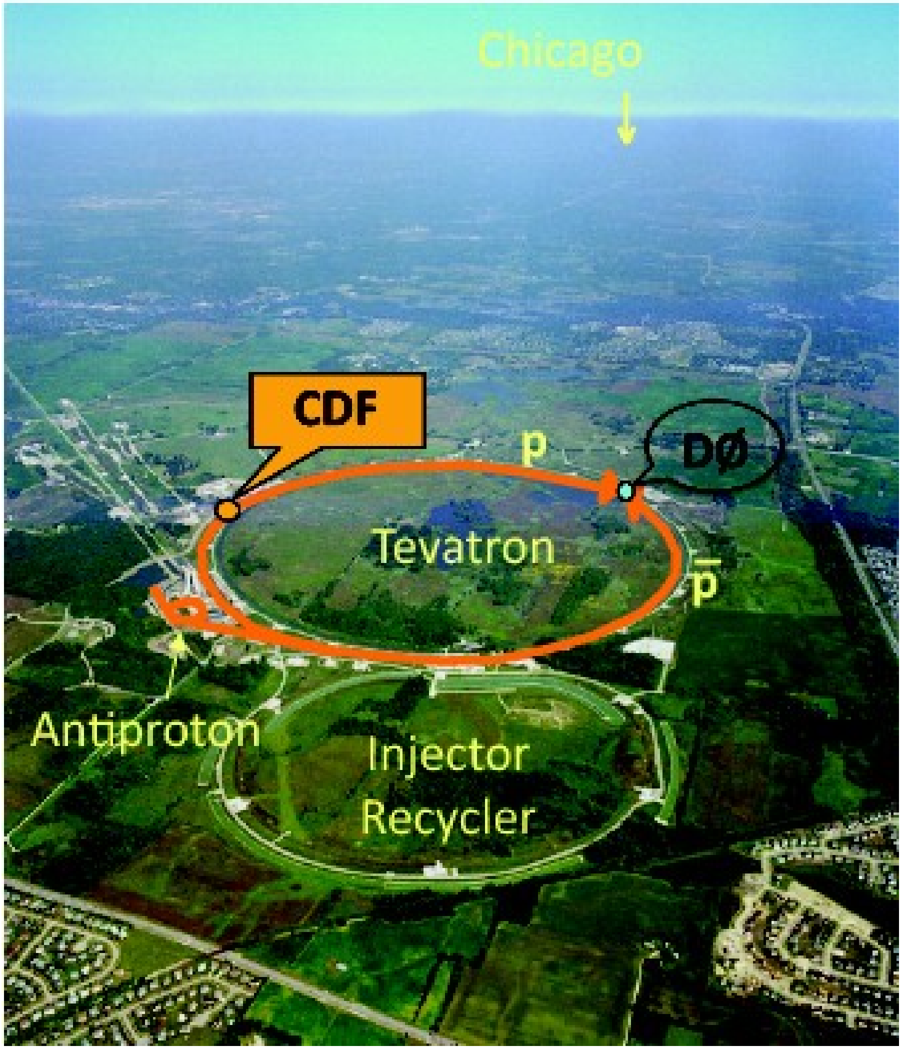
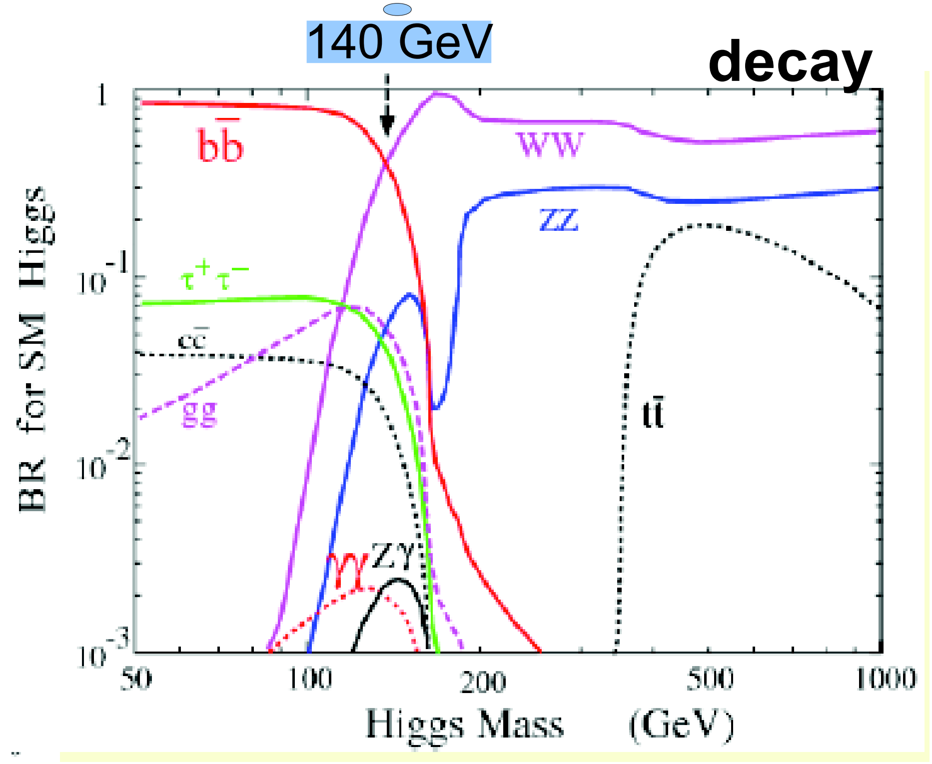
Outline

- Motivation
- Standard Model Higgs→ $\gamma\gamma$ search
- Direct photon pair production differential cross section measurement
- Conclusions



Motivation

- Di-photon production:
  - Search for new phenomena
  - Search for Higgs boson
    - M_H>114.4 GeV (LEP)
    - Exclusion M_H = 163-166GeV (Tevatron Run II preliminary)
    - Contributes to the Tevatron combination in the difficult intermediate mass region (110-140GeV)
    - Golden channel at LHC (M_H<150 GeV)



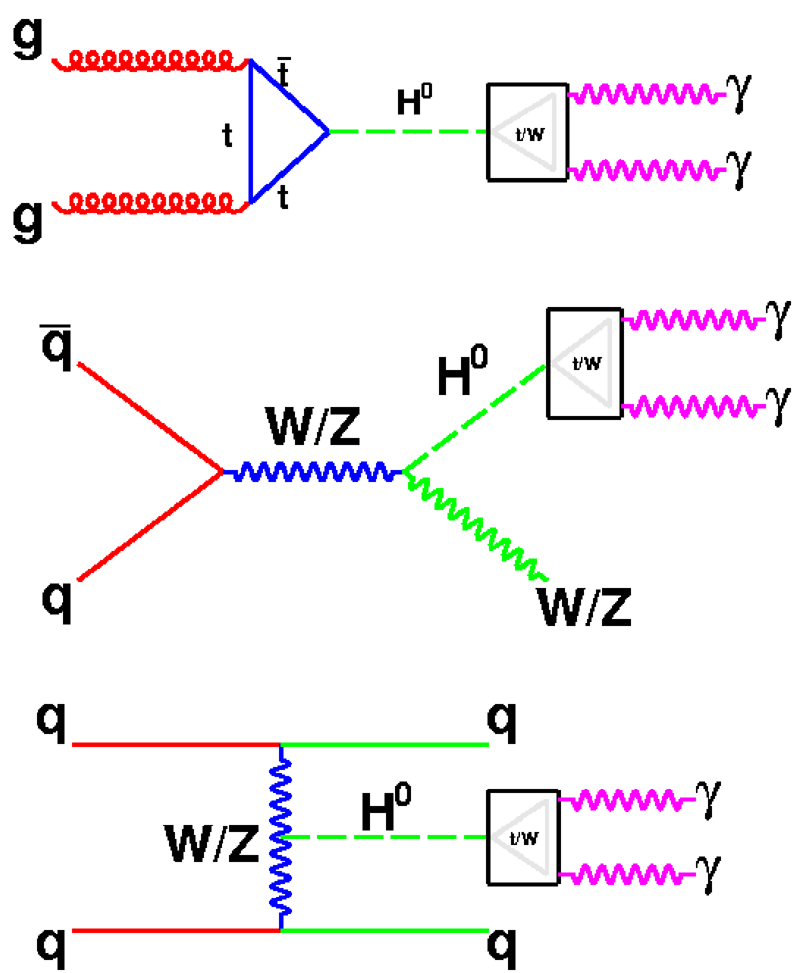
SM Higgs→$\gamma\gamma$ search

DØ Note 5858-CONF (2009)

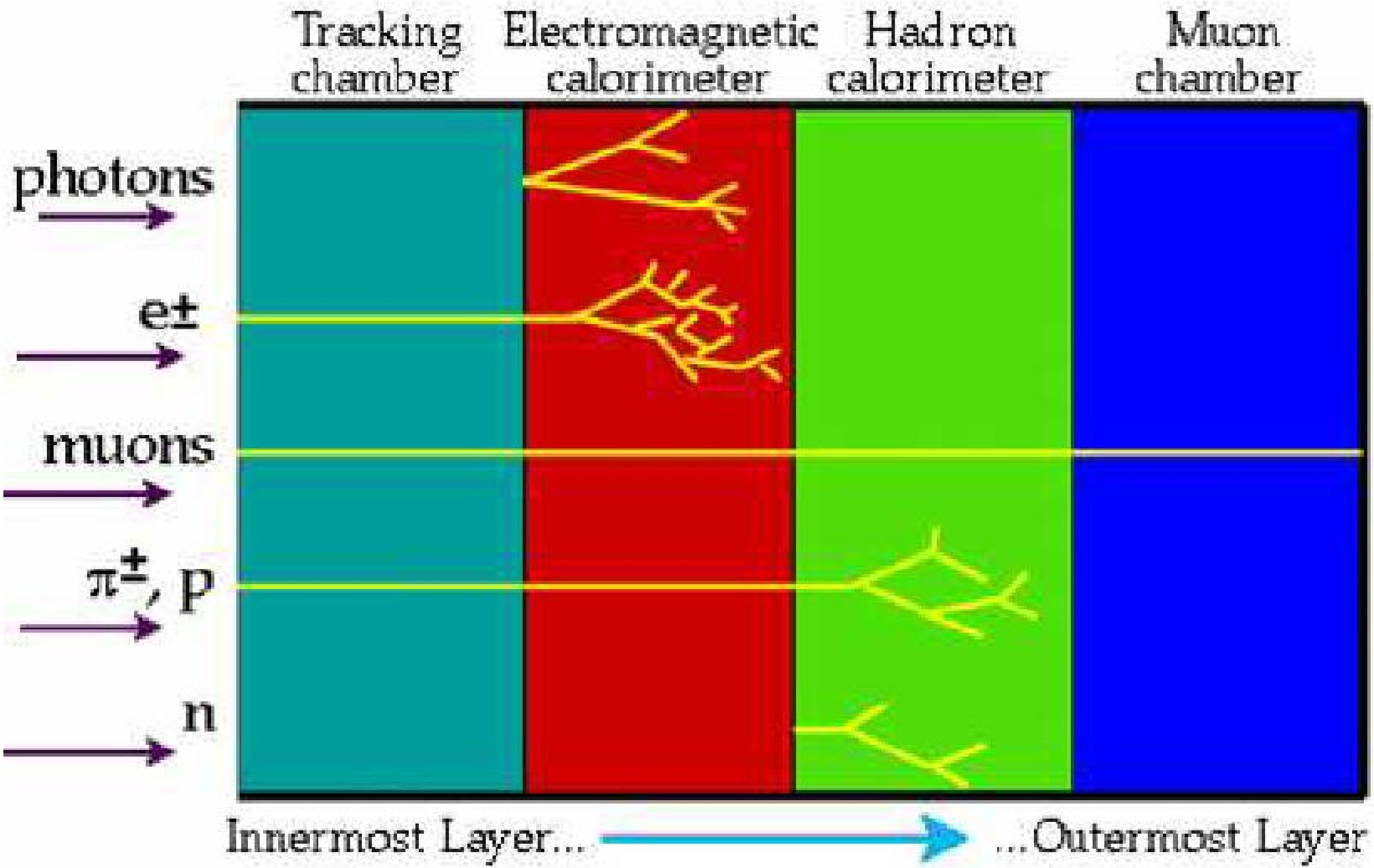
Phys. Rev. Lett. 102, 231801 (2009)

H→ γγ

- Model-independent approach:
  - Examine the inclusive di-photon dataset (γγ+X) to search for the high mass resonances
  - SM Higgs is used as a possible model:
    - Gluon fusion (ggH)
    - Associated production (VH)
    - Vector boson fusion (VBF)



Photon identification

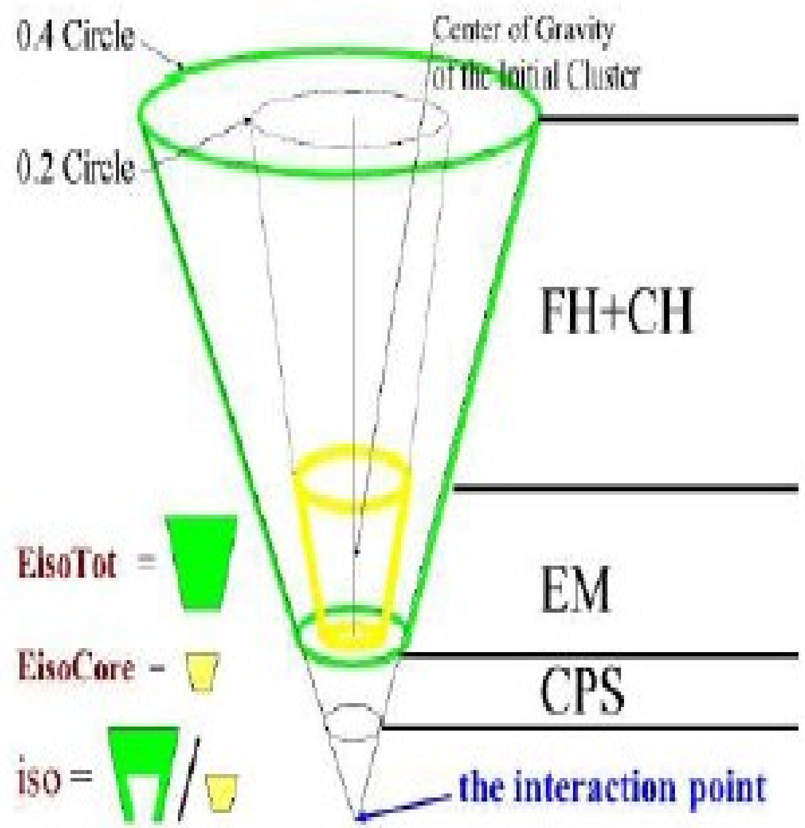


Reconstruct EM cluster

- Central photons ($-1.1 < \eta < 1.1$) are selected from EM clusters (reconstructed within R=0.2 cone):

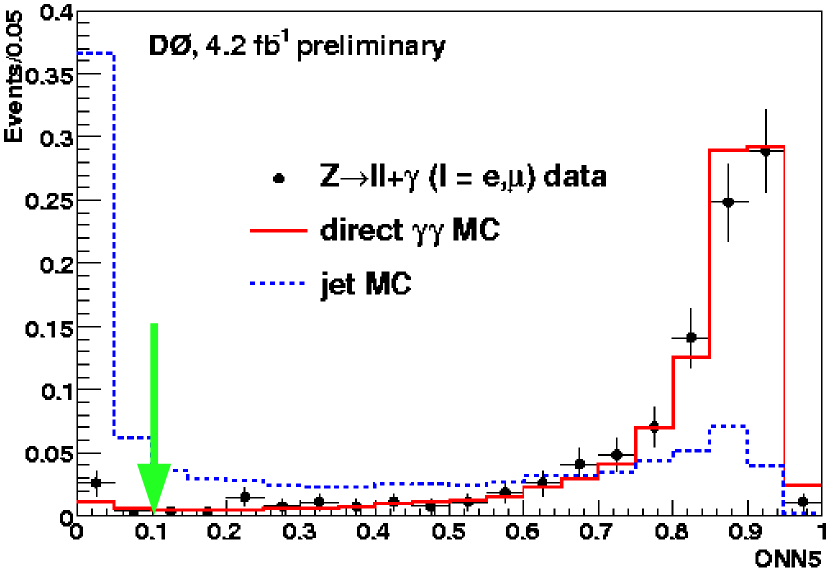
$\epsilon \sim 90\%$ (for the first four criteria below):

  - Most energy in EM calorimeter: EM energy fraction > 97%.
  - Isolated in the calorimeter: iso<0.07.
  - Isolated in the tracker: $\sum_{0.05 < dR < 0.4} p_T^{track} < 2$ GeV
  - Shower width in the third-EM layer is consistent with the EM.
  - Difference between data and MC simulation is calibrated with using $Z \to ee$ events.



Separate γ and jet

- To suppress the jets mis-identified as photons
  - Training samples: γ and jet MC
  - Testing samples: $Z \to ee$ data&MC, $Z \to l\,l + \gamma\,(l = e, \mu)$ data
  - Input variables:
    - # of EM1 cells in R<0.2
    - # of EM1 cells in 0.2<R<0.4
    - Tracker isolation
    - # of CPS clusters in R<0.1
    - Energy-squared-weighted width of the energy deposited in CPS



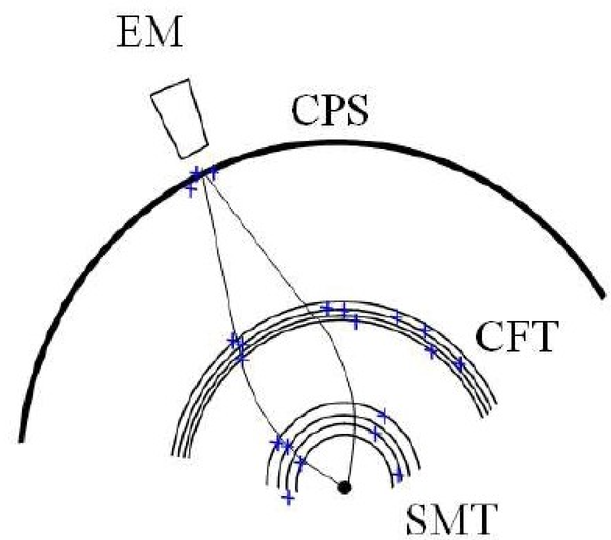
Photon candidatess: ONN>0.1
~98% efficiency for photons.
~50% reduction for jets

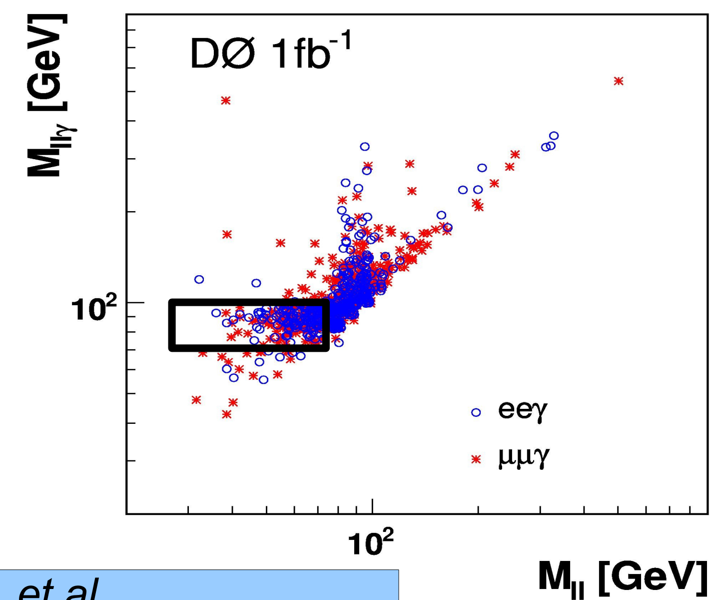
Separate γ and electron

- To suppress the electrons mis-identified as photons

$\epsilon \sim 90\%$ {
  - No-spatially well-matched track;
  - No pattern of hits in the tracker in a road around the EM cluster consistent with electron.

  - efficiency loss mainly due to ~6% conversion rate estimated from MC(1)
  - Difference between data and Monte Carlo simulation is calibrated with using $Z \rightarrow l\,l + \gamma\,(l = e, \mu)$ events.

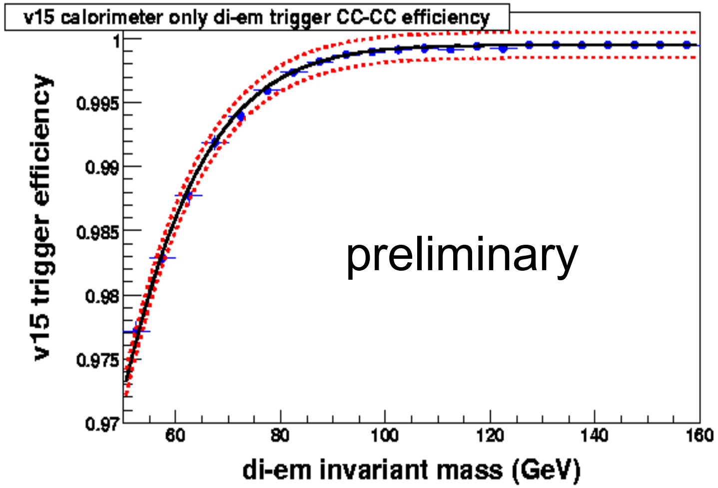




(1) X. Bu, L. Han, Y. Liu, H. Yin, *et al*
"Search for Scalar Neutrino Superpartners in e+μ Final States"
Phys. Rev. Lett. 100, 241803 (2008)

Event selection

- Select two photons with pT>25 GeV
- Di-photon mass $M_{\gamma\gamma}$>60 GeV
- Trigger efficiency: ~100%

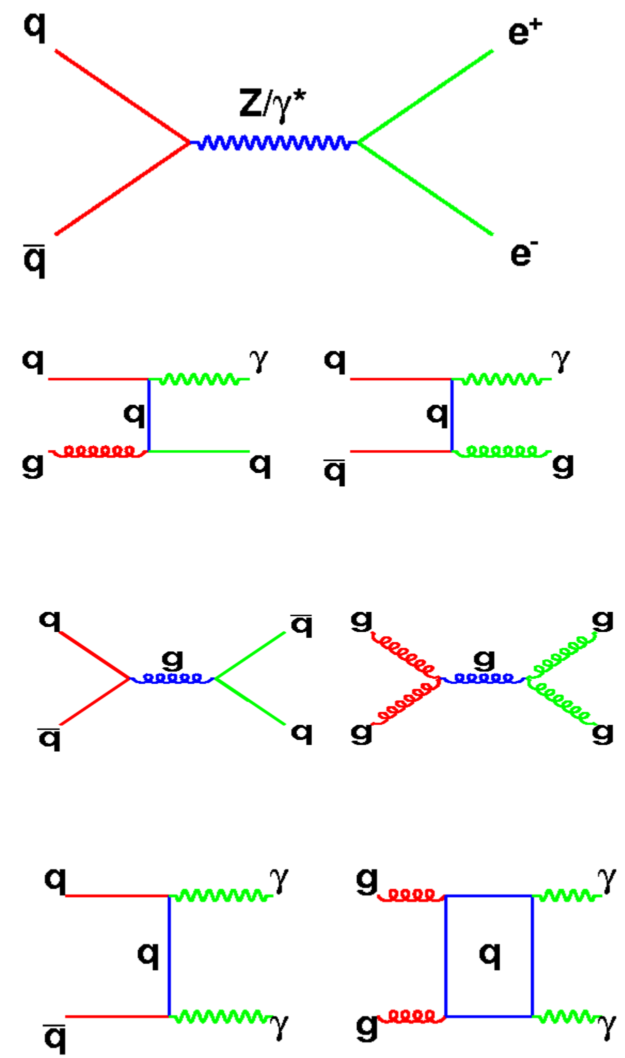


  - Signal efficiency (~20%) is dominant by the geometrical acceptance, and independent of production mechanism.

	100 GeV	110 GeV	120 GeV	130 GeV	140 GeV	150 GeV
ϵ_{sel}(ggH)	0.195±0.001	0.200±0.001	0.207±0.001	0.213±0.001	0.216±0.001	0.219±0.001
ϵ_{sel}(VH)	0.185±0.001	0.195±0.001	0.203±0.001	0.209±0.001	0.218±0.001	0.219±0.001
ϵ_{sel}(VBF)	0.198±0.001	0.211±0.001	0.218±0.001	0.226±0.001	0.233±0.001	0.238±0.001

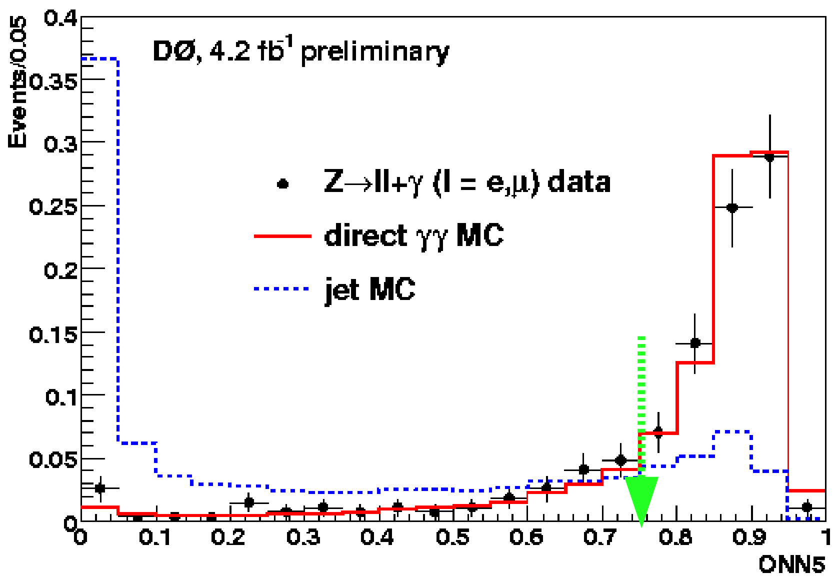
Backgrounds

- Reducible background
  - $Z/\gamma^* \rightarrow ee$, both electrons are misidentified as photons, estimated with Geant MC.
  - Non-$\gamma\gamma$ (γ+jet,jet+jet), when the jet(s) is(are) misidentified as photon(s), estimated from data.
- Irreducible background – direct $\gamma\gamma$
  - estimated from data



4X4 Matrix Method

- Using ONN=0.75 as a boundary to separate the events to 4 categories:
  - Npp: both pass the ONN>0.75
  - Npf: first passes, second failes
  - 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.
$\epsilon_{\gamma 1}, \epsilon_{\gamma 2}$ are photon ONN>0.75 efficiencies.

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

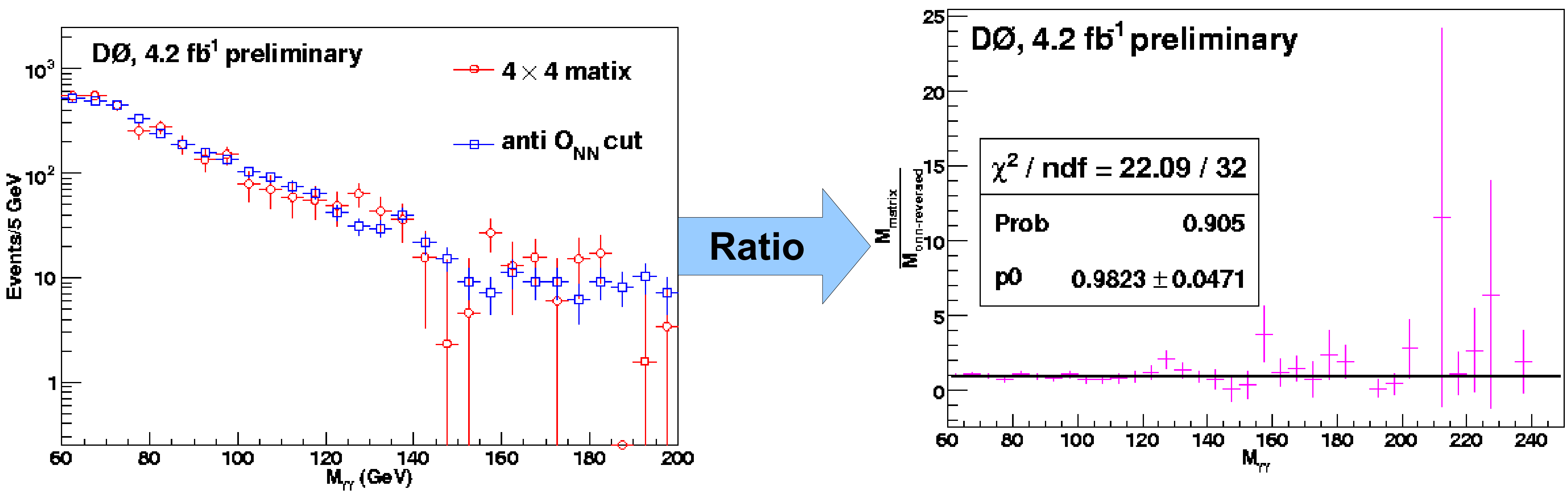
Total	7939
Total - N_{DY}	7722.7
$N_{\gamma\gamma}$	4538.8 ± 144.7
$N_{\gamma j} + N_{j\gamma}$	2189.0 ± 170.3
N_{jj}	994.9 ± 106.6
non-$\gamma\gamma$	3183.9 ± 200.9

Includes potential signal.

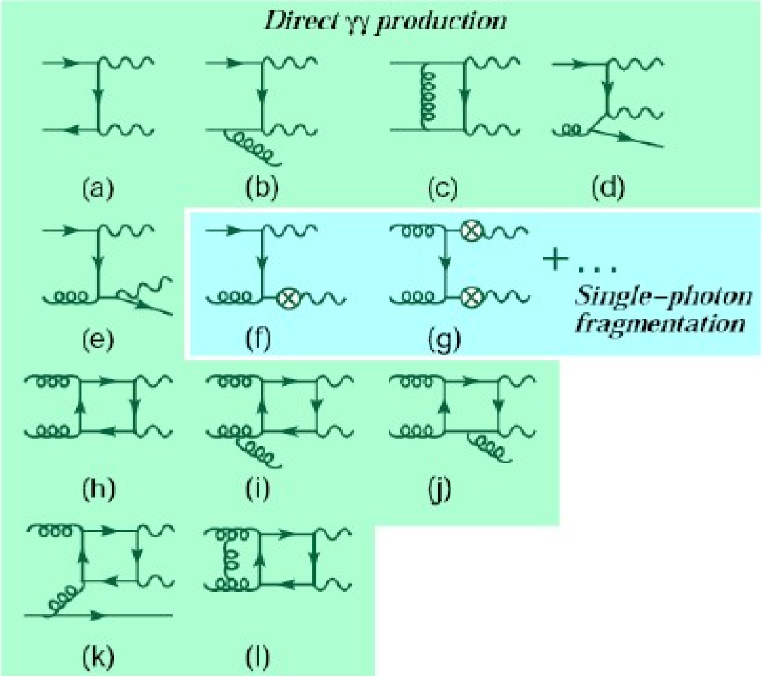
The quoted uncertainties are statistical only.

Non-γγ (γ+jet, jet+jet) background

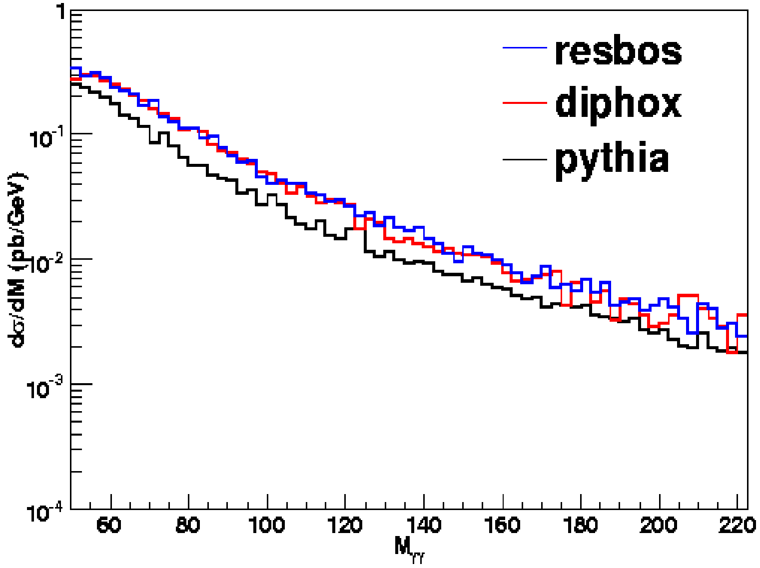
- Shape from reversing the ONN cut (0.1) for one photon candidate.
- Normalization to the number of events from 4X4 matrix method.



Direct γγ production (DDP) – irreducible background

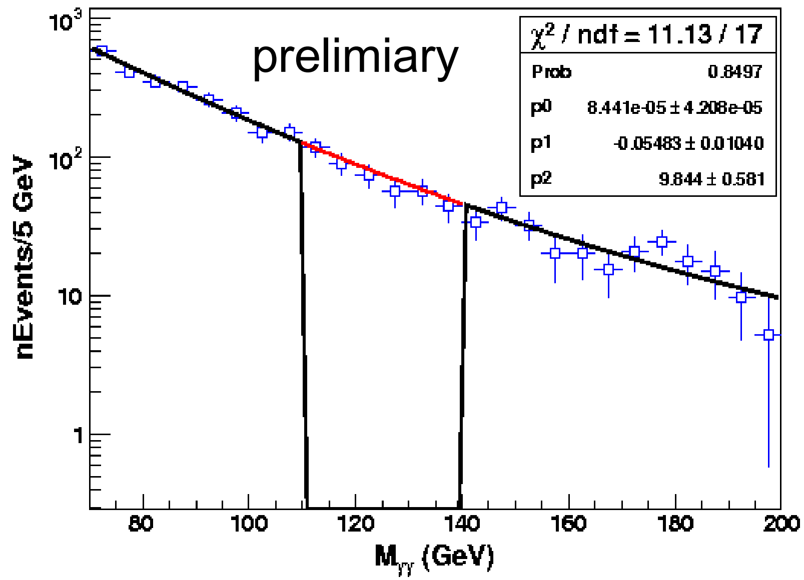


- Challenge to model by theoretical prediction so far, each generator has its own deficit
  - Pythia
  - Resbos
  - Diphox
- However, in the high mass region ($M_{\gamma\gamma}$>50GeV), $M_{\gamma\gamma}$ spectrum agrees reasonably very well between diphox and resbos.



Direct γγ production (DDP) – irreducible background

- DDP background is estimated from data with using side-band fitting after subtraction of the reducible background
  - avoid ~20% uncertainty on the theory cross section
  - Fitting range: [70,200]GeV, with excluding the ±15GeV signal regions.
  - Validate the shape from the full pythia MC after reweighting to diphox at generator level.



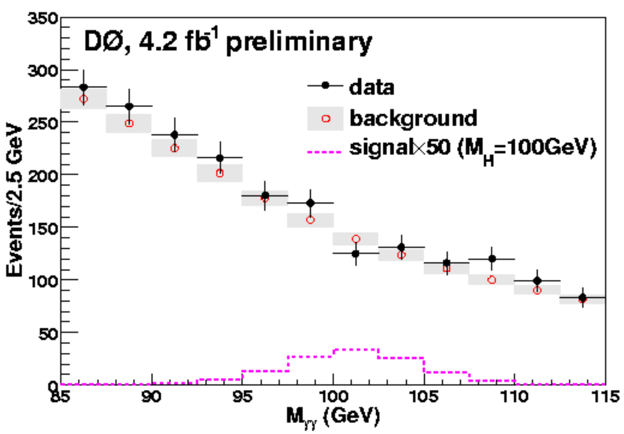
systematic uncertainties

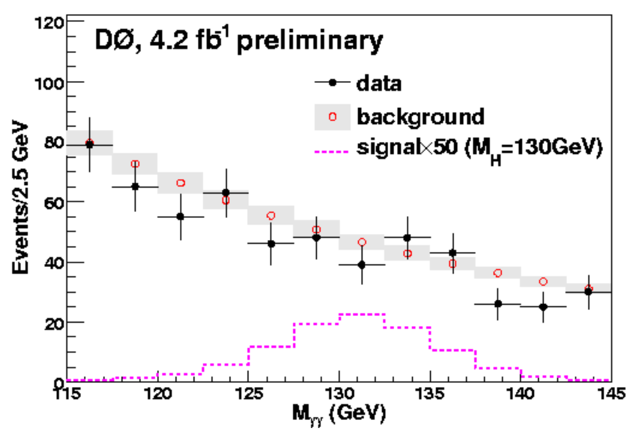
source	uncertainty (%)
Luminosity	6.1
Trigger	0.1
PDF for $H \rightarrow \gamma\gamma$ acceptance	1.7-2.2
Photon ID efficiency	2.9
Drell-Yan cross section	3.9
Photon energy scale	shape(0.06)
Background subtraction	shape(10-15)

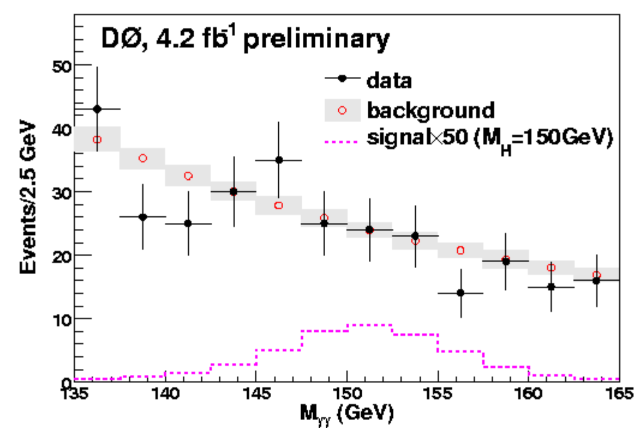
Event yield

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

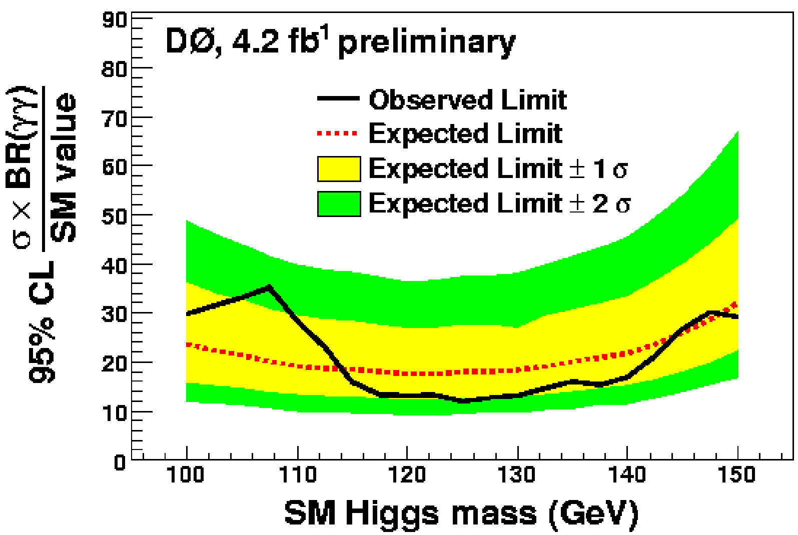






Results: SM Higgs

- 95% C.L. limits
  - Use diphoton mass spectrum.
  - Almost mass independent.
  - Contributes ~5% for 115<M_H<130 GeV in the DØ SM Higgs combination.
  - Improved ~20% by comparison with the 2.7 fb^{-1} published results (2)



(2) X. Bu, L. Han, Y. Liu, *et al*
"Search for Resonant Diphoton Production with the DØ Detector"
Phys. Rev. Lett. 102, 231801 (2009)

Direct Photon Pair production differential cross section measurement

– arXiv:hep-ph/1002:4917,
submitted to Phys. Lett. B

1D differential X-sections

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

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

data vs. resbos, diphox and pythia

1D differentail X-sections

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

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

data vs. resbos, diphox and pythia

bin width

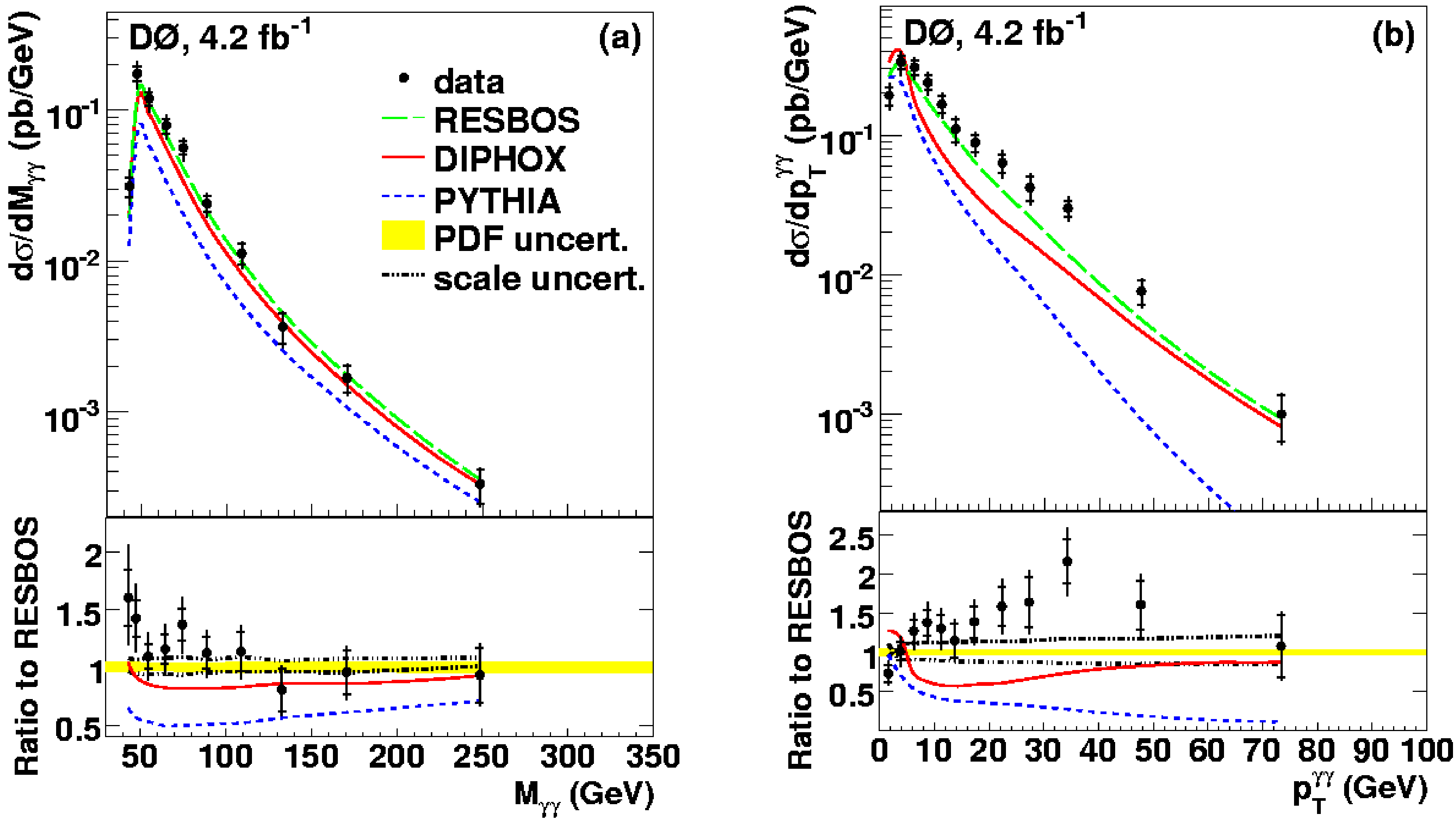
diphoton selection efficiency, estimated from data

instantaneous luminosity

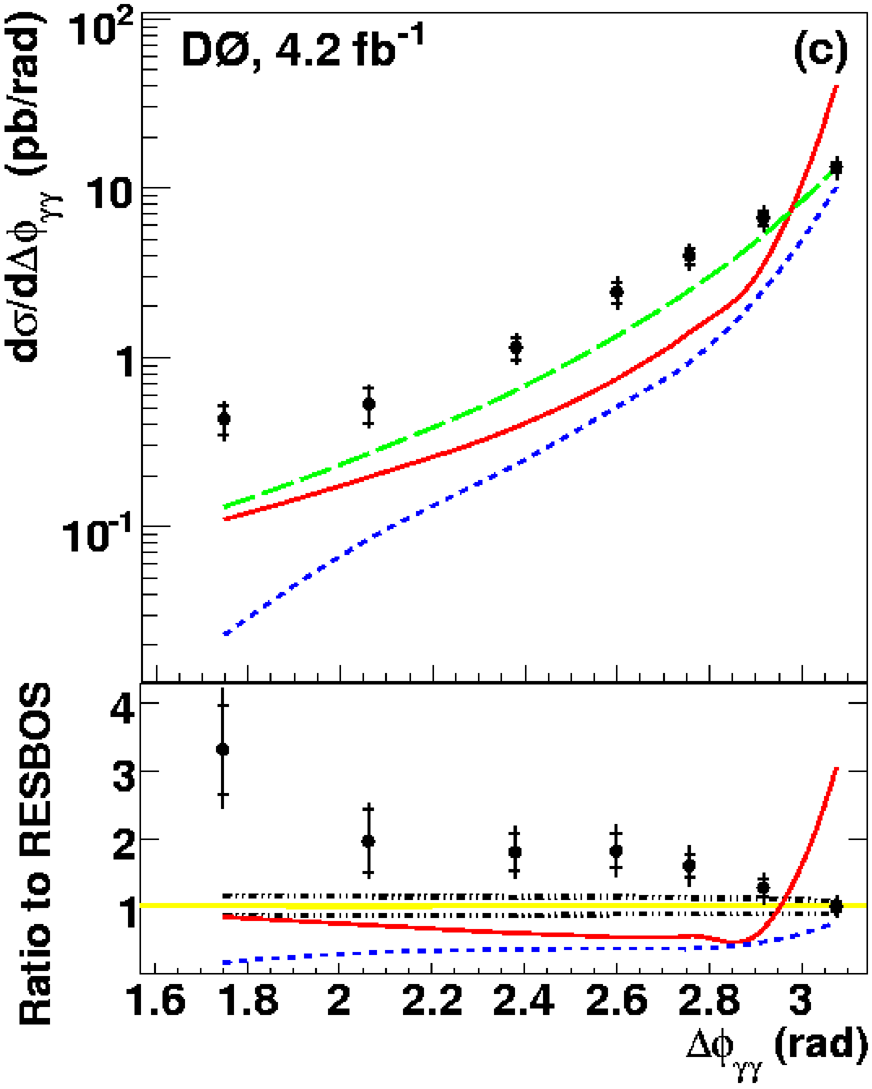
diphoton trigger efficiency, pretty high, estimated from data

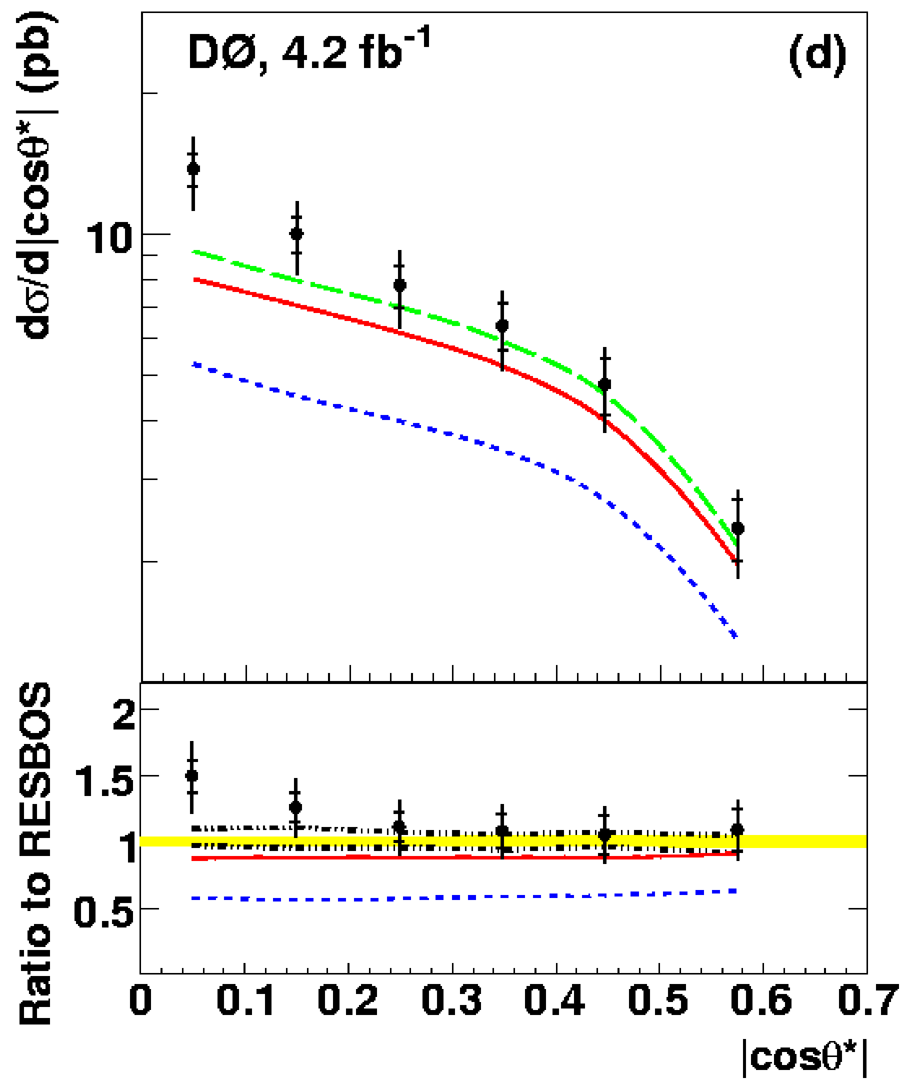
Acceptance, estimated from resbos MC

1D differential X-sections



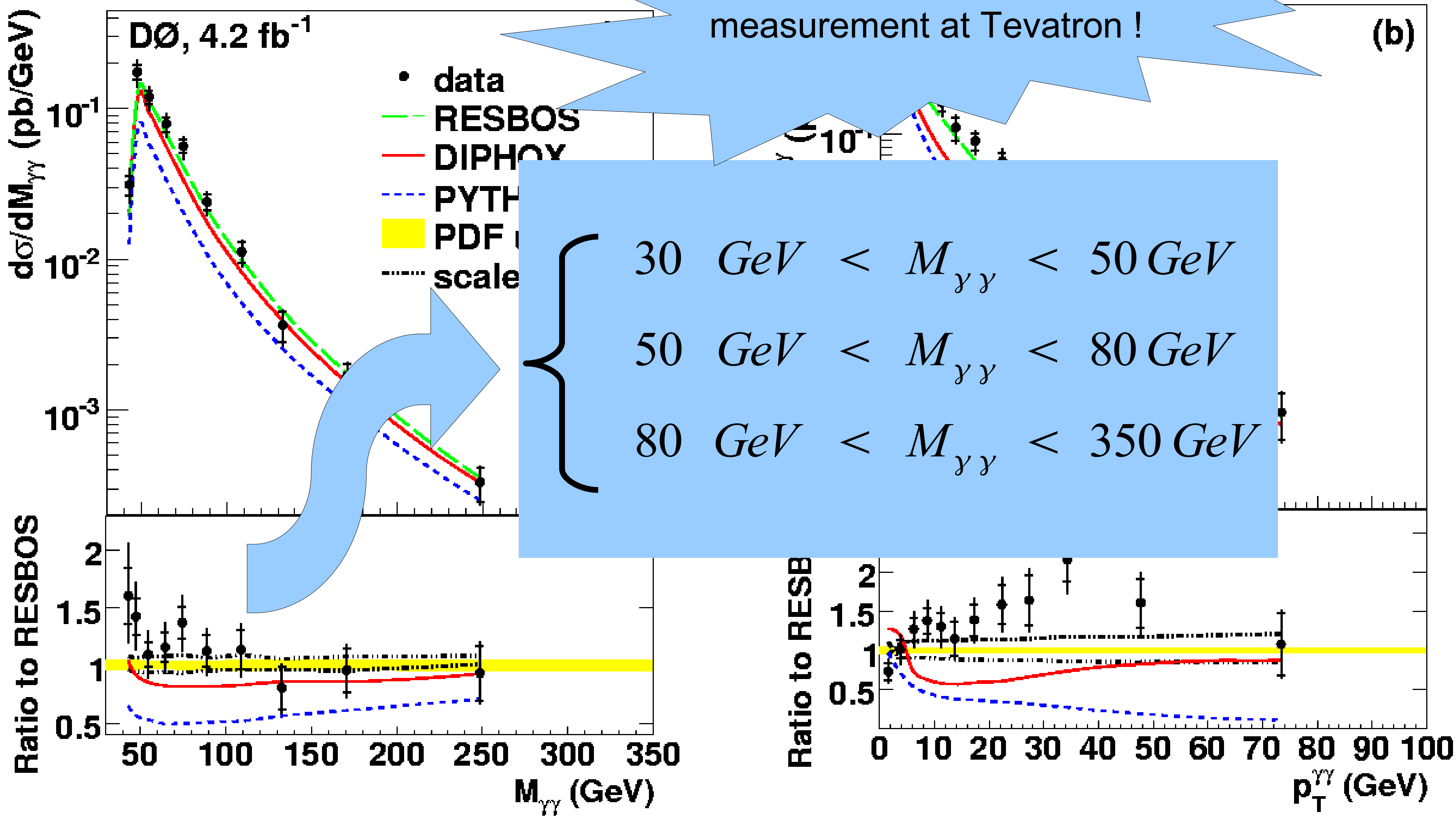
1D differential X-sections





1D differential X-sections

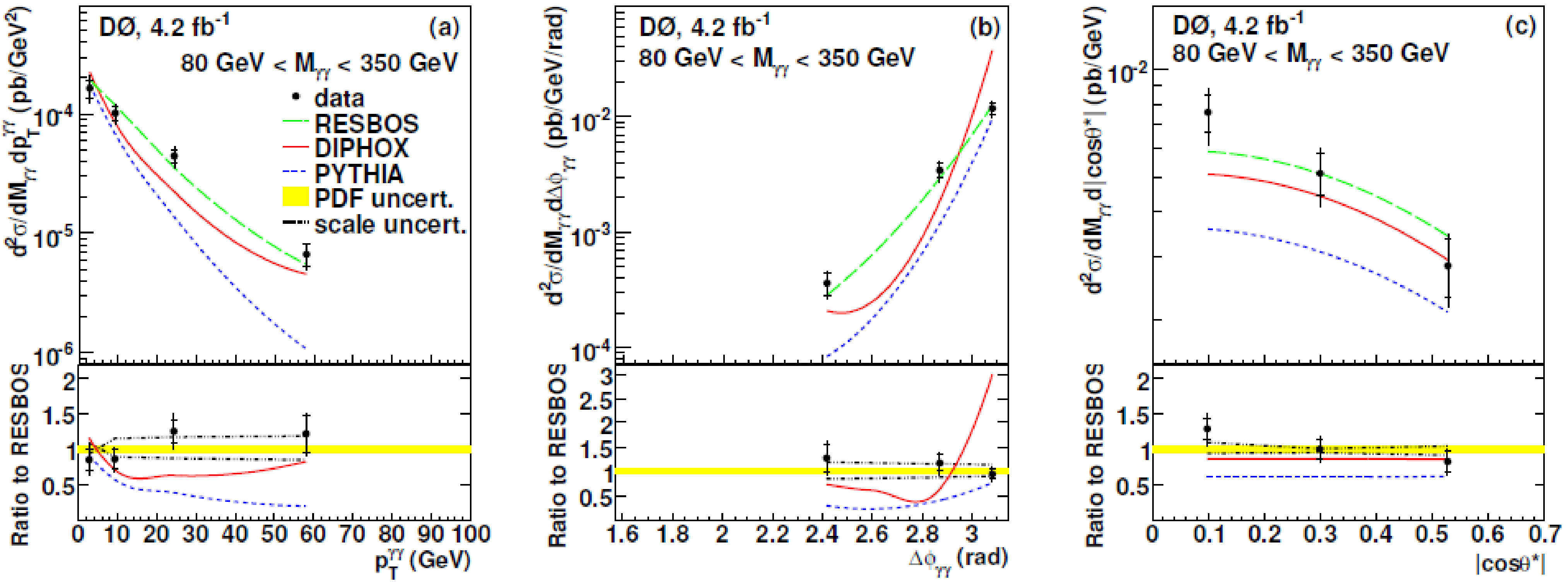
First 2D X-sections measurement at Tevatron !



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

2D differential X-sections

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

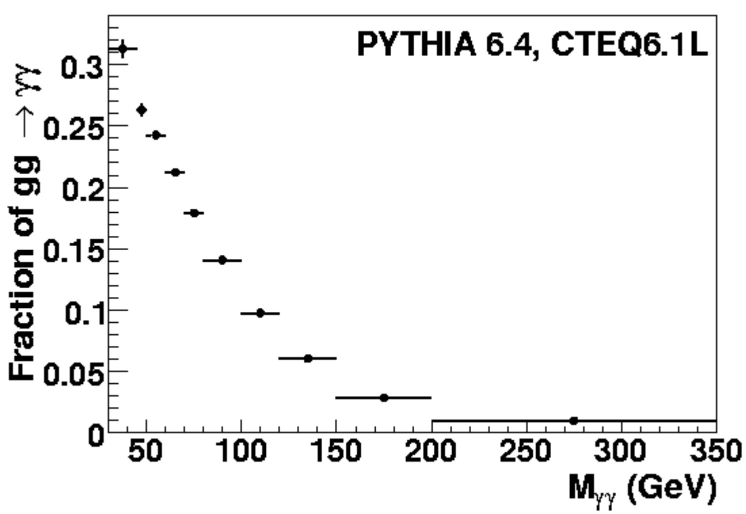


Conclusion I

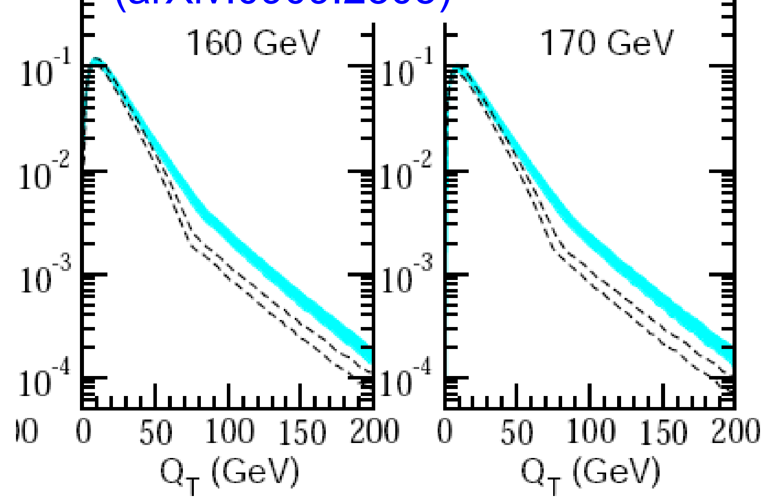
- Photon(electron) identification
  - Develop several brand-new electron and photon reconstruction variables with using artificial neural network, which are proved to be well modeled by the Monte Carlo simulation, and extensively used since then.
  - Totally redesign the DØ electron and photon reconstruction to cope with the high luminosity..
- SM Higgs search
  - 2.7 fb^{-1} results has been published in PRL 102 231801 (2009), which represents the first kind of search at Tevatron.
  - 4.2 fb^{-1} preliminary results
    - Contributes significantly to the DØ SM Higgs combination in the intermediate mass region (115 < MH < 130 GeV).
    - Almost mass independent.

Conclusion II

- Direct Photon Pair differential cross section measurement
  - Represents the first kind of measurement at DØ, especially the first double differential ones at Tevatron.
  - The results show that none of considered theoretical predictions is able to describe the data in all kinematic regions, and also show the necessity of including higher order corrections beyond NLO as well as the resummation to all orders of soft and collinear initial state gluons.
  - Submitted to Phys. Lett. B (arXiv:hep-ph/1002:4918)



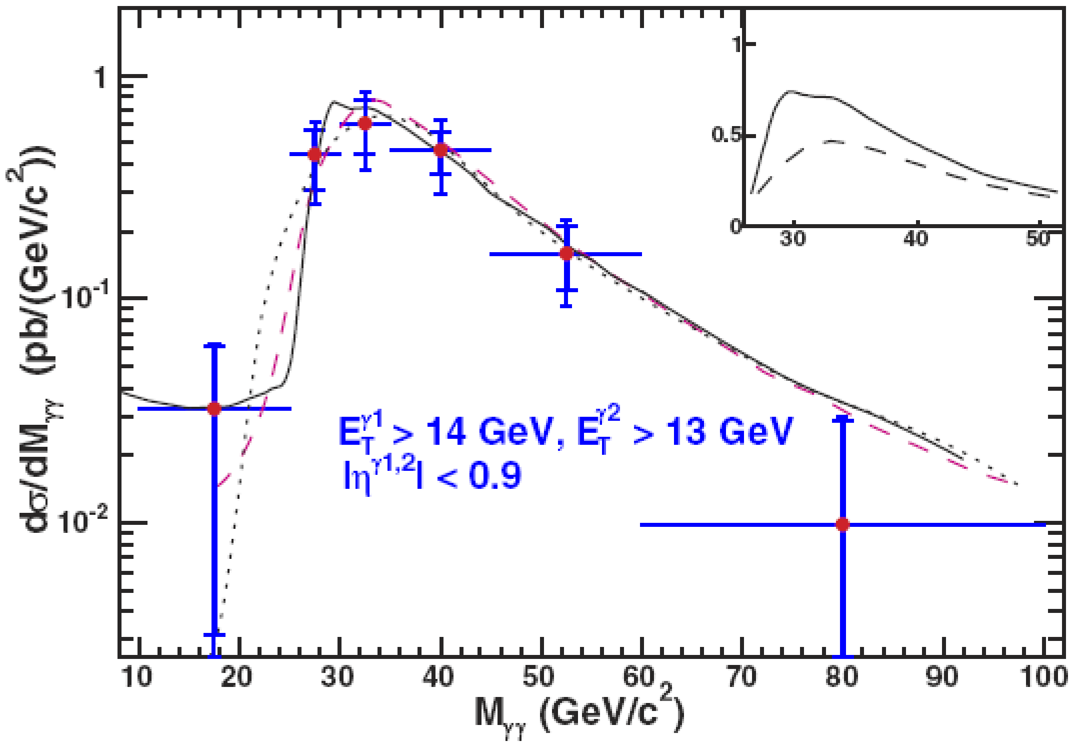
Resbos: gg->H->WW (arXiv:0909.2305)

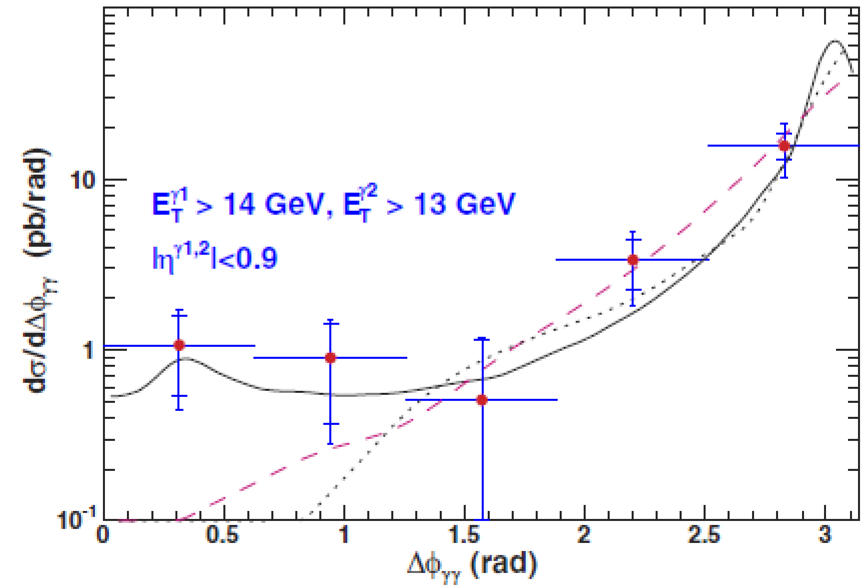


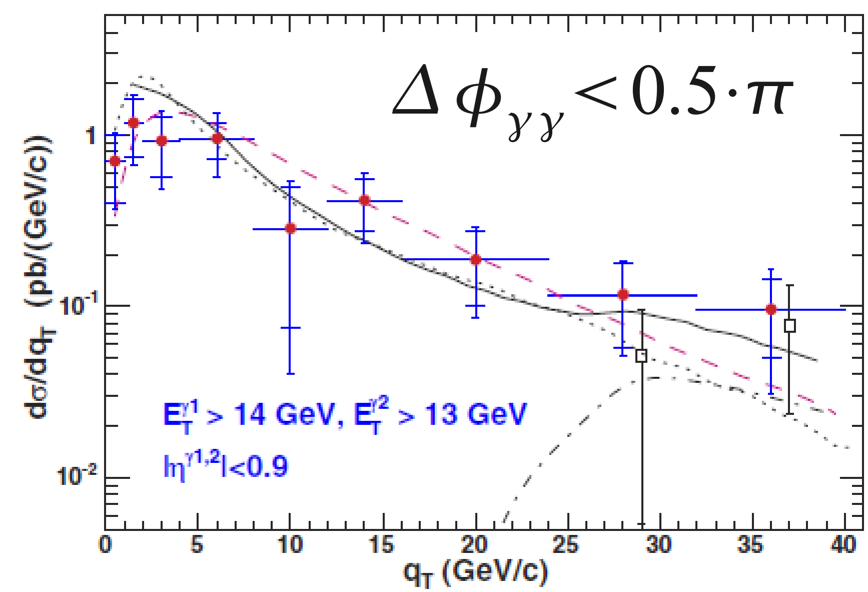
back-up

Previous Tevatron results

- CDF 207 pb^{-1} (PRL 95, 022003 (2005))





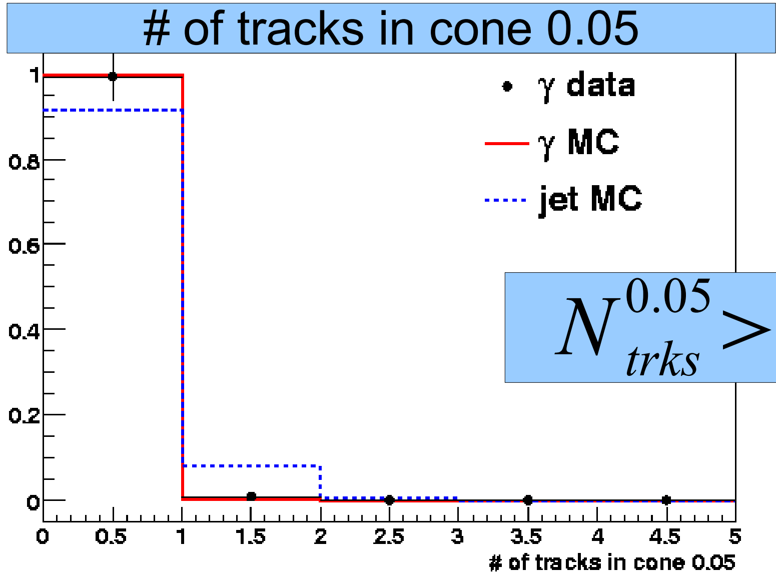


Resbos: dashed line

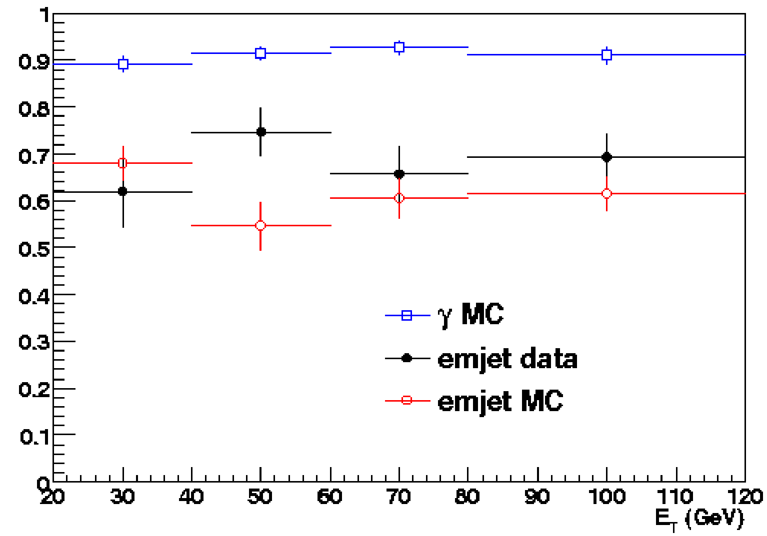
Diphox: solid line

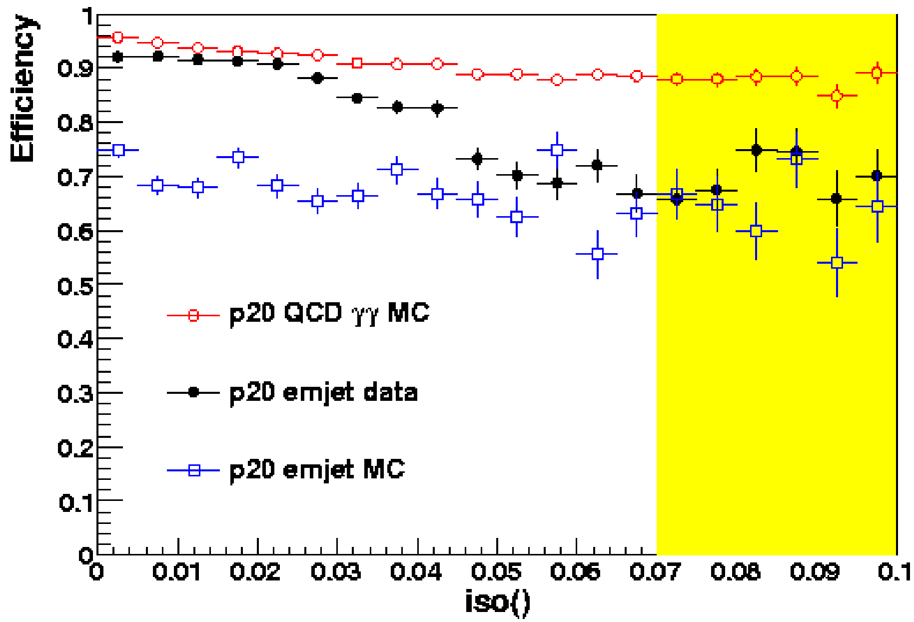
Pythia: dot-dashed line

Validate jet ANN > 0.6 efficiency from data



$$N^{0.05}_{trks} > 0$$





Conservatively, we assign 10% uncertainty.

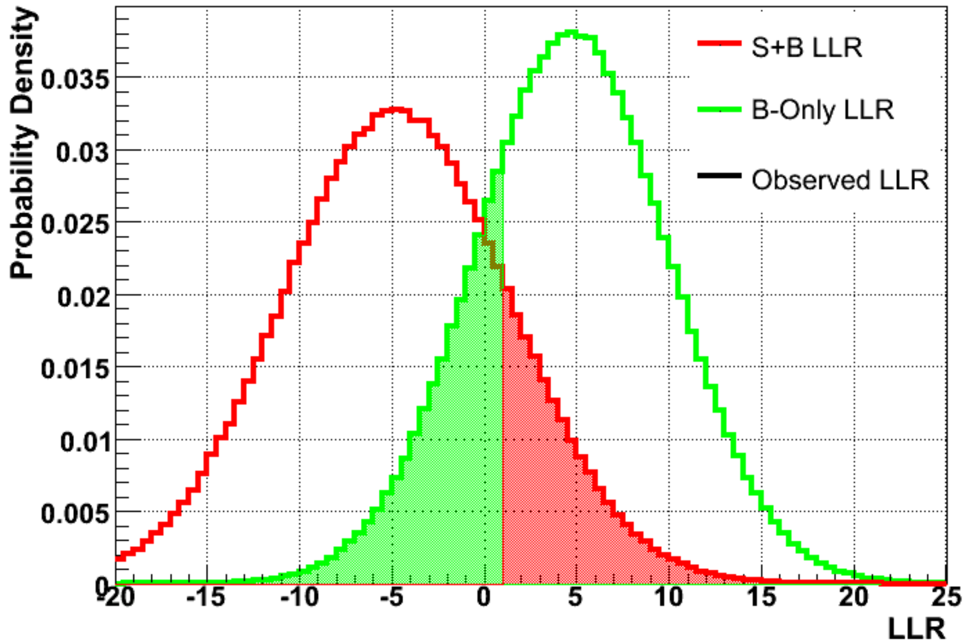
CL Limits calculation

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

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

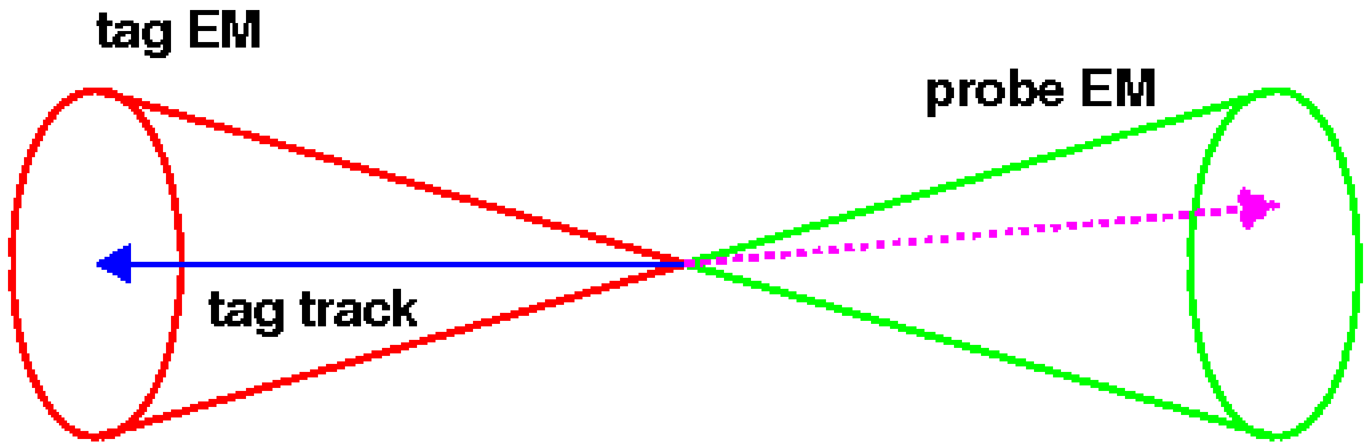
$$Q = \prod_{all\ bins} Q_i \quad (7.16)$$

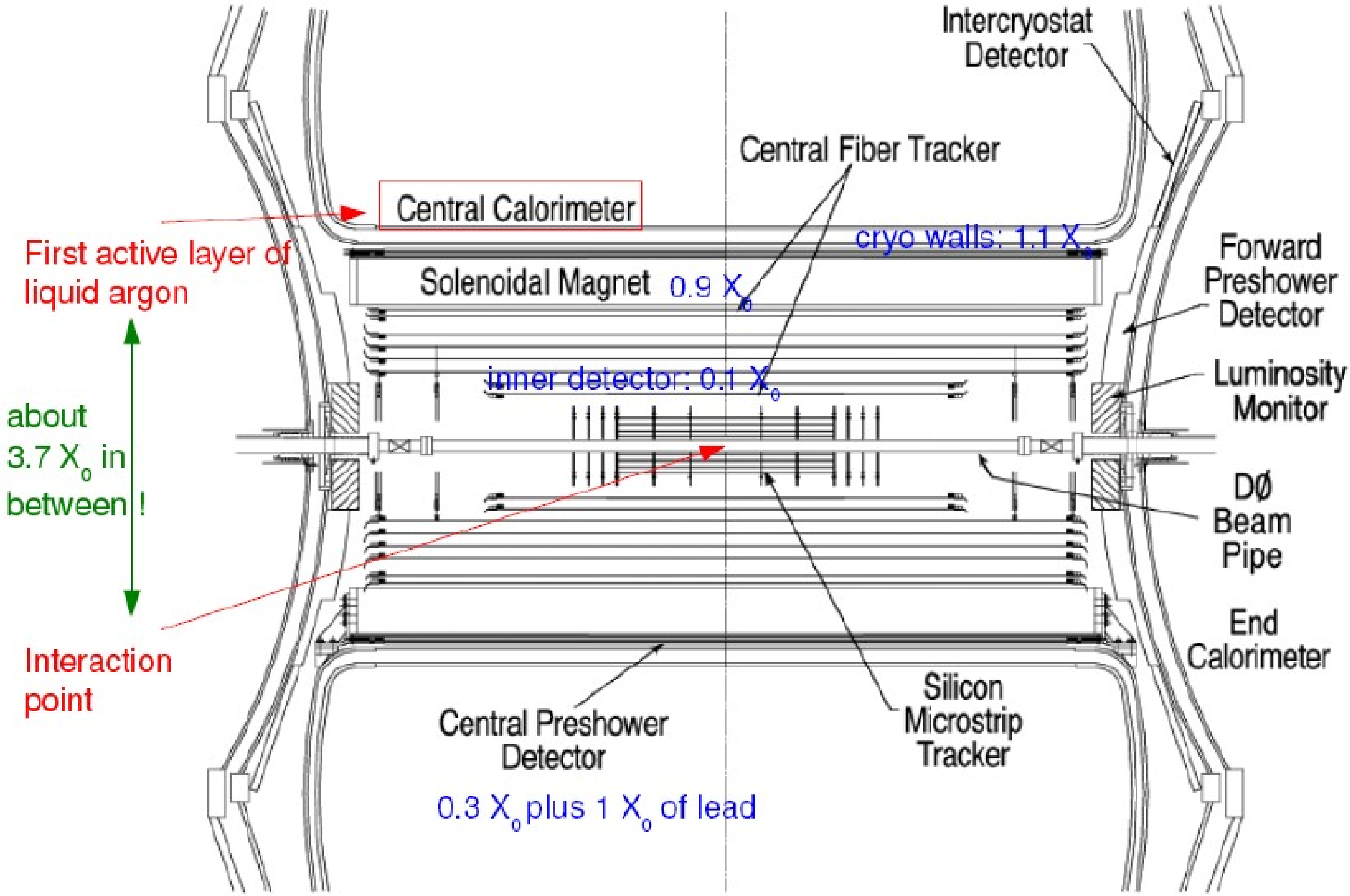
Probability distribution function (p.d.f) of the -2lnQ variable under the background-only and signal+background hypotheses can be obtained from the Poisson sampling.



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

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


tag EM
probe EM
tag track


Intercryostat Detector
Central Fiber Tracker
Central Calorimeter
First active layer of liquid argon
cryo walls: 1.1 X_0
Solenoidal Magnet
0.9 X_0
Forward Preshower Detector
inner detector: 0.1 X_0
Luminosity Monitor
about 3.7 X_0 in between !
DØ Beam Pipe
End Calorimeter
Interaction point
Central Preshower Detector
Silicon Microstrip Tracker
0.3 X_0 plus 1 X_0 of lead