Direct di-γ Production @ Tevatron

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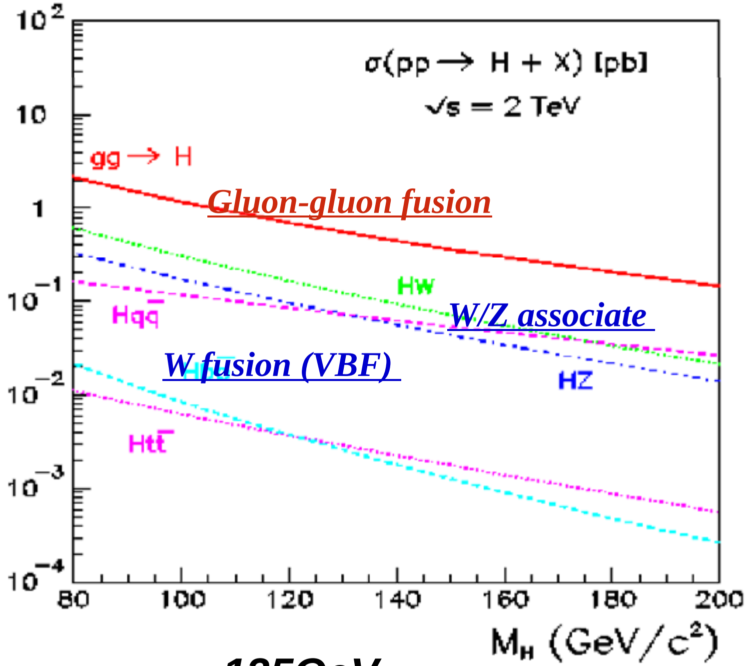
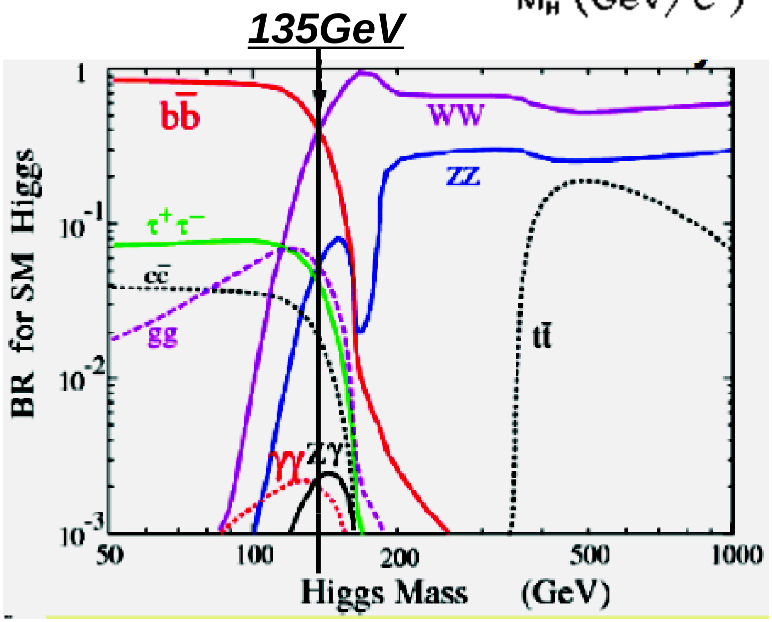
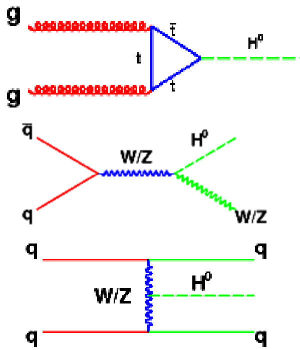
On behalf of the CDF & DØ Collaborations

1[st] motivation: SM Higgs search@Tevatron

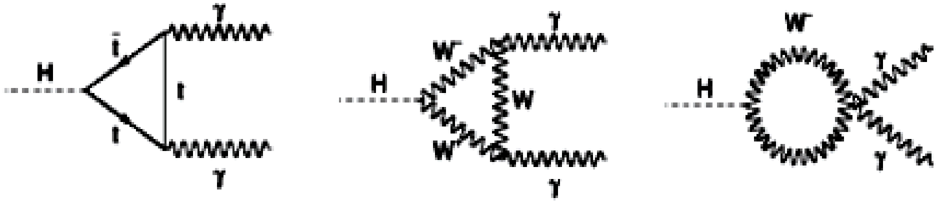




- Production
  1. Gluon-gluon fusion gg→H
  2. W/Z associate qq→W/Z+H
  3. W fusion (VBF) qq→qq+H



- Searching for ***light*** Higgs(~130GeV)
  - "inaccessible" gg→H→bb, S/B(QCD) ~ 10^{-9}
  - "common" qqbar→W(lν)/Z(ll,νν) + H(bb)
  - "extra" gg→H→γγ , with Br(H→γγ) ~ **0.2**%

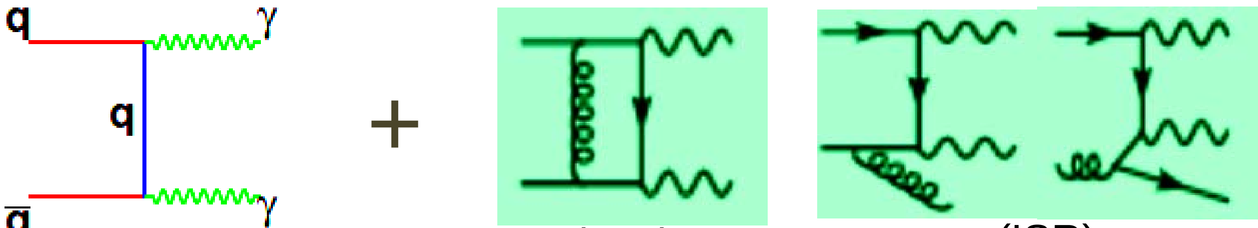


Direct photon pair production at **O(1)fb**

SM prediction on direct diphoton production

➢Quark annihilation:

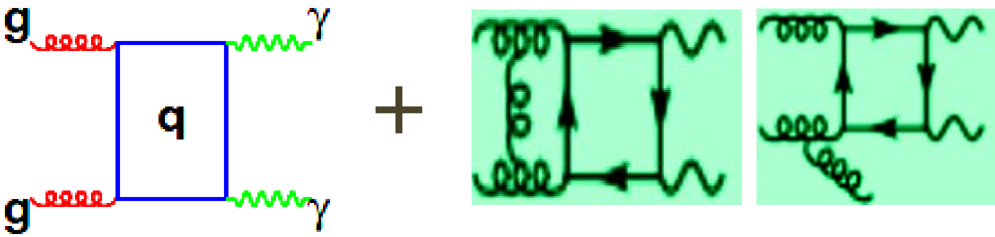
LO (α^2_{EM}): NLO ($\alpha_s\alpha^2_{EM}$): virtual + real emission → infra-safe

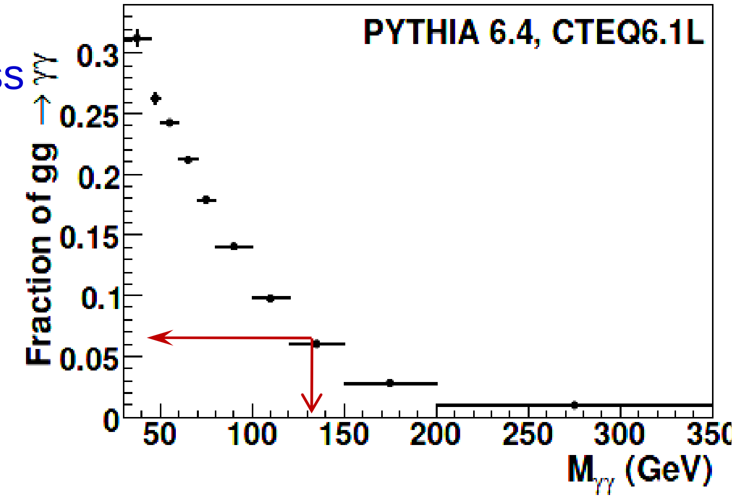


(Box) (ISR)

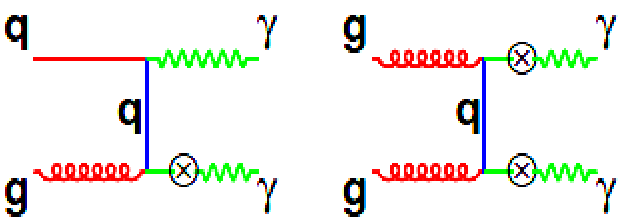
➢Gluon fusion:

LO ($\alpha^2_s\alpha^2_{EM}$): gluon PDF density enhancement at low mass





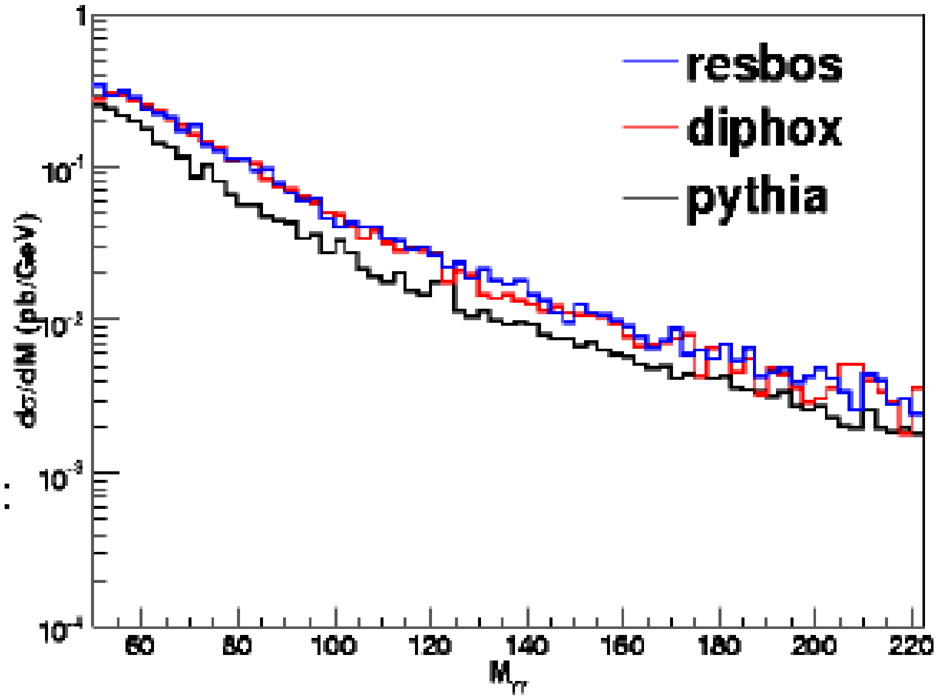
➢Single photon fragmentation:



- Factorize singularity of γ radiated from final quark
- Suppressed by photon isolation + $p_T(\gamma\gamma)<M(\gamma\gamma)$

2^{nd} motivation: precise test of QCD predictions

- RESBOS, *Phys. Rev. D 76, 013009 (2007)* :
  - \+ Quark Scattering qqbar→$\gamma\gamma$ and Gluon Fusion gg→$\gamma\gamma$ up to ***NLO***
  - \+ Fragmentation at LO, with additional NLO approximation
  - \+ Resummation of soft/collinear terms of initial gluons up to all orders, cancelling divergence at NLO as $p_T(\gamma\gamma)\to 0$



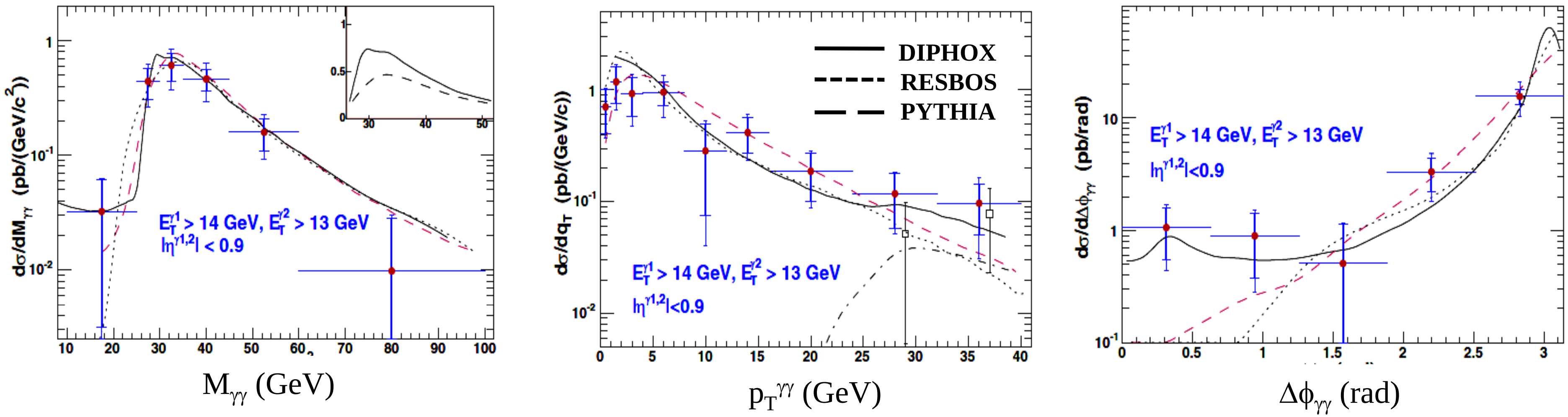
- DIPHOX, *Eur. Phys. J. C 16, 311 (2000)* :
  - \+ qqbar→$\gamma\gamma$ up to **NLO** + gg→$\gamma\gamma$ at LO
  - \+ Fragmentation up to ***NLO***
  - \+ asymmetry di-photon $p_T(\gamma 1) > p_T(\gamma 2)$

- PYTHIA, *Comp. Phys. Comm. 135, 238(2001)* :
  - \+ qqbar→$\gamma\gamma$ and gg→$\gamma\gamma$ at LO
  - \+ Resummation via parton shower

CDF results

➢ First di-γ measurement @ Tevatron: 207pb^{-1}, *PRL 95, 022003 (2005)*

$p_T(\gamma 1)>14GeV$, $p_T(\gamma 2)>13GeV$; $|\eta_{1,2}|<0.9$; $E_T^{iso}<1GeV$



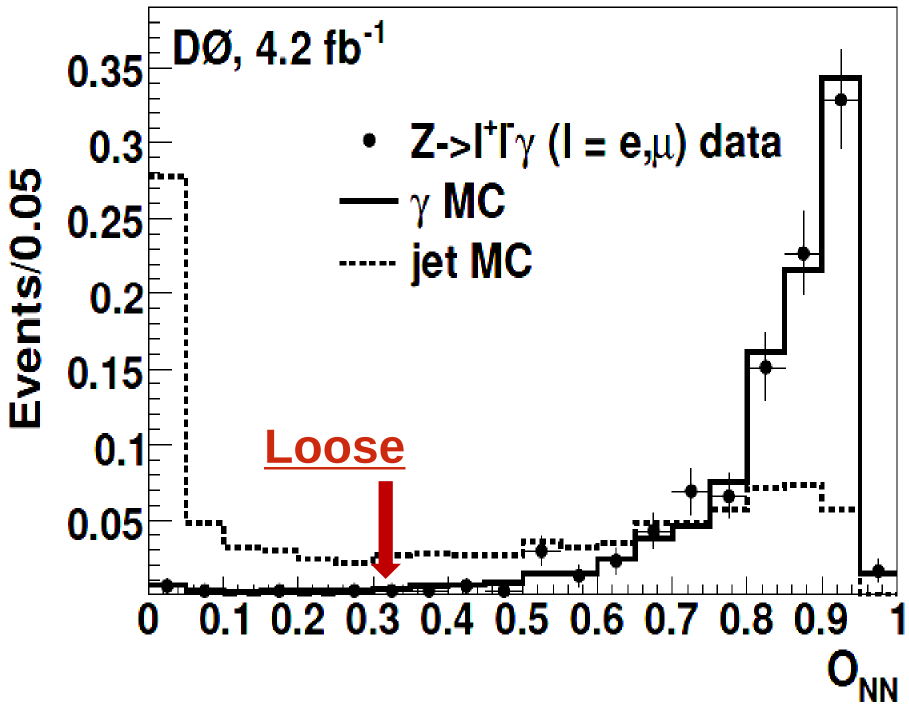
Reasonable agreements between data and QCD predictions in different region :

- Low p_T $(\gamma\gamma)$~0GeV and $\Delta\phi\sim\pi$, DIPHOX unstable due to the lack of resummation
- Bump of $p_T(\gamma\gamma)$~30GeV dominated by events of $\Delta\phi<\pi/2$ and $p_T(\gamma\gamma)>M(\gamma\gamma)$, described in DIPHOX as final state radiation + Fragmentation on the same quark

$$g + g \rightarrow q_1 + q_2^{'} \rightarrow q_1 + q(Frag)\gamma$$

D0 di-photon measurement

- D0 analysis based on 4.2fb^{-1} data:
  - $p_T(\gamma 1)$>21GeV, $p_T(\gamma 2)$>20GeV, $|\eta_{1,2}|<0.9$, dR(1,2)>0.4
  - Isolation requirement(jet and Fragmentation) + track veto(electron)
  - $p_T(\gamma\gamma)<M(\gamma\gamma)$ → remove Fragmentation, reduce theoretical uncertainty
  - Neutral Network discriminator O_{NN} to separate γ from EM-like jet



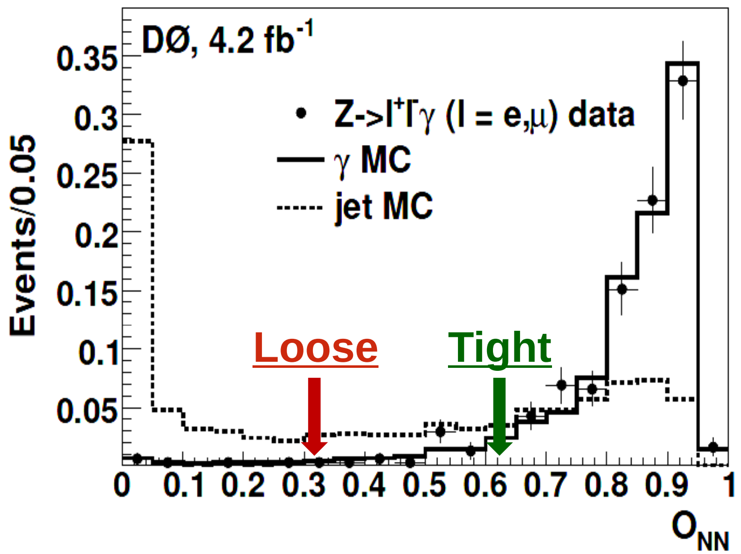
Background composition

➢ Electron misidentified in Drell-Yan $Z/\gamma^* \rightarrow ee$:

- Estimated with GEANT simulation, normalized up to NNLO and $4.2 fb^{-1}$

➢ Jet-misidentified in *γ+jet* and *jet+jet* :

- Split data($Z \rightarrow ee$ deducted) into 4 groups based on tighter $O_{NN} \rightarrow$ normalization



\+ Npp : both pass
\+ Npf : leading passes, trailing fails
\+ Nfp : vice-versa
\+ Nff : both fail

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

4×4 γ/j O_{NN}>0.6 efficiency matrix

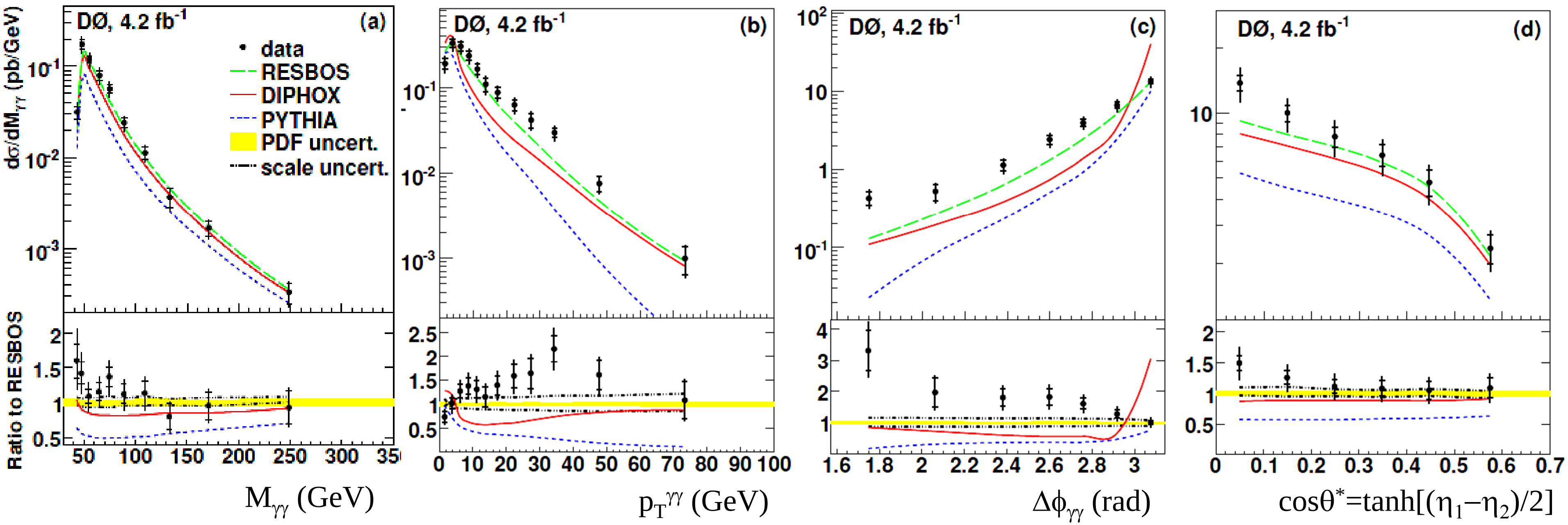
$$E = \begin{pmatrix} (1-\epsilon_{j1})(1-\epsilon_{j2}) & (1-\epsilon_{j1})(1-\epsilon_{\gamma2}) & (1-\epsilon_{\gamma1})(1-\epsilon_{j2}) & (1-\epsilon_{\gamma1})(1-\epsilon_{\gamma2}) \\ (1-\epsilon_{j1})\epsilon_{j2} & (1-\epsilon_{j1})\epsilon_{\gamma2} & (1-\epsilon_{\gamma1})\epsilon_{j2} & (1-\epsilon_{\gamma1})\epsilon_{\gamma2} \\ \epsilon_{j1}(1-\epsilon_{j2}) & \epsilon_{j1}(1-\epsilon_{\gamma2}) & \epsilon_{\gamma1}(1-\epsilon_{j2}) & \epsilon_{\gamma1}(1-\epsilon_{\gamma2}) \\ \epsilon_{j1}\epsilon_{j2} & \epsilon_{j1}\epsilon_{\gamma2} & \epsilon_{\gamma1}\epsilon_{j2} & \epsilon_{\gamma1}\epsilon_{\gamma2} \end{pmatrix}$$

- Line shapes estimated by reversing O_{NN}<0.1

Differential cross section

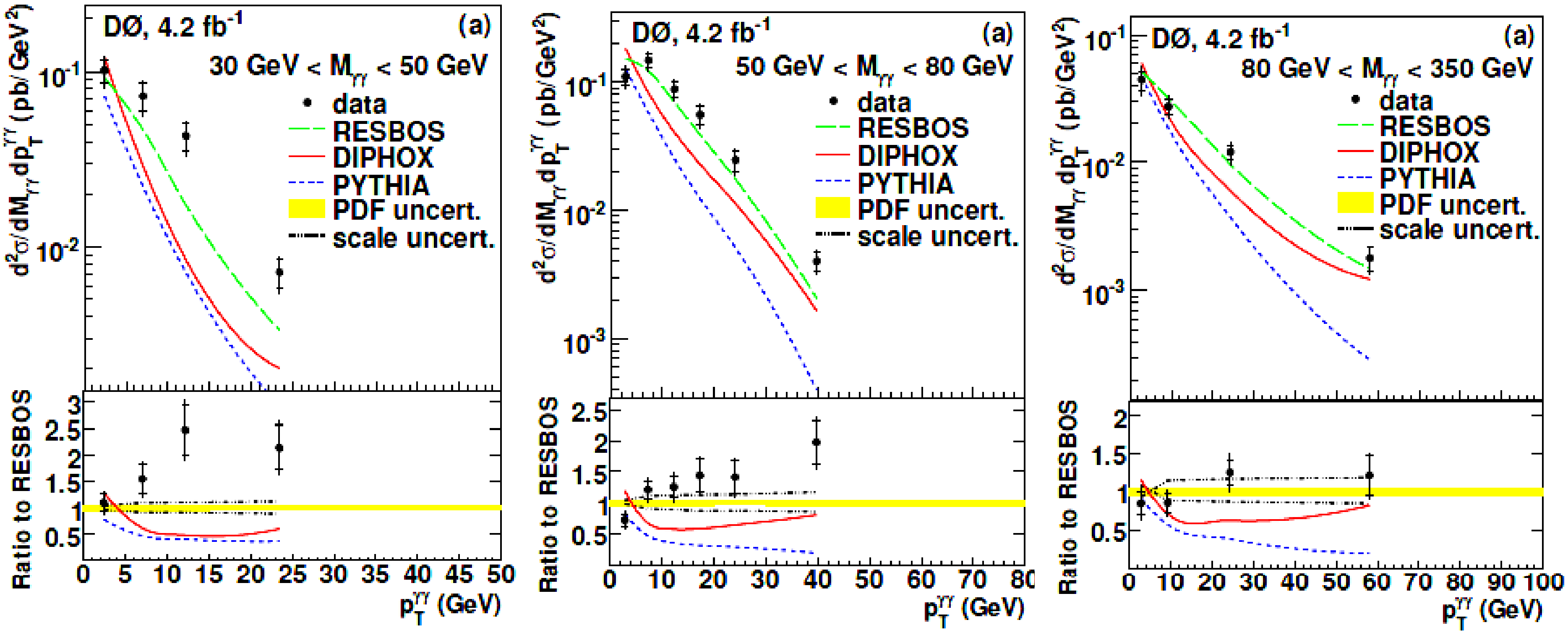
- Theoretical predictions:
  - \+ RESBOS and DIPHOX, with CTEQ6.6M, $\mu_R=\mu_F=\mu_f=M\gamma\gamma$
  - \+ PYTHIA 6.420 with CTEQ5L

- Data.vs.MC comparison:

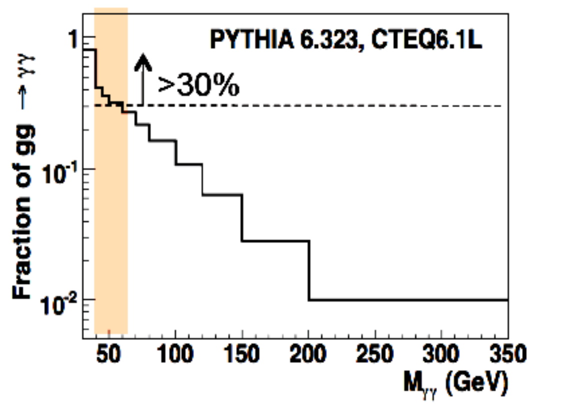


- RESBOS with resummation demonstrates better agreement with data
- data shows harder $p_T(\gamma\gamma)$ and excess in low $\Delta\phi$ $(\gamma\gamma)$

- Double-differential cross section: $\frac{d^2\sigma}{dM_{\gamma\gamma}dp_T^{\gamma\gamma}}$



- The $p_T(\gamma\gamma)$ inconsistence occurs in $M_{\gamma\gamma}$< 50GeV region, where the gluon fusion is significant. NNLO correction to gg→$\gamma\gamma$ at low mass?



- $\frac{d^2\sigma}{dM_{\gamma\gamma}d\Delta\phi_{\gamma\gamma}}$ distributions tell the same story

Systematic uncertainty

- Dominated by uncertainty of di-photon purity, ~10-15%, followed by luminosity ~ 6%

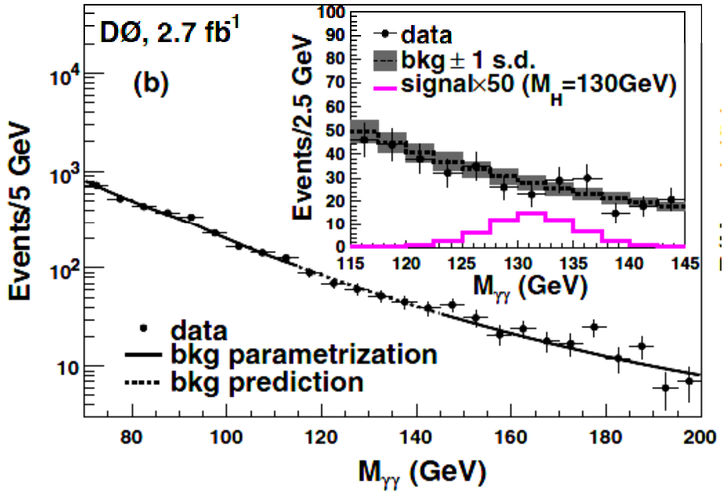
$M_{\gamma\gamma}$ (GeV)	$\langle M_{\gamma\gamma}\rangle$ (GeV)	$d\sigma/dM_{\gamma\gamma}$ (pb/GeV)			
		Data	δ_{stat} (%)	δ_{syst} (%)	RESBOS
30 – 45	43.0	3.11×10^{-2}	15	$+26/-29$	1.94×10^{-2}
45 – 50	47.6	1.74×10^{-1}	11	$+19/-19$	1.22×10^{-1}
50 – 60	54.7	1.19×10^{-1}	10	$+18/-17$	1.09×10^{-1}
60 – 70	64.6	7.89×10^{-2}	11	$+18/-16$	6.82×10^{-2}
70 – 80	74.6	5.61×10^{-2}	10	$+17/-15$	4.09×10^{-2}
80 – 100	88.6	2.39×10^{-2}	12	$+16/-15$	2.13×10^{-2}
100 – 120	108.9	1.12×10^{-2}	15	$+16/-14$	0.98×10^{-2}
120 – 150	132.9	3.65×10^{-3}	23	$+16/-14$	4.52×10^{-3}
150 – 200	170.7	1.67×10^{-3}	20	$+16/-14$	1.74×10^{-3}
200 – 350	248.8	3.30×10^{-4}	26	$+16/-14$	3.53×10^{-4}

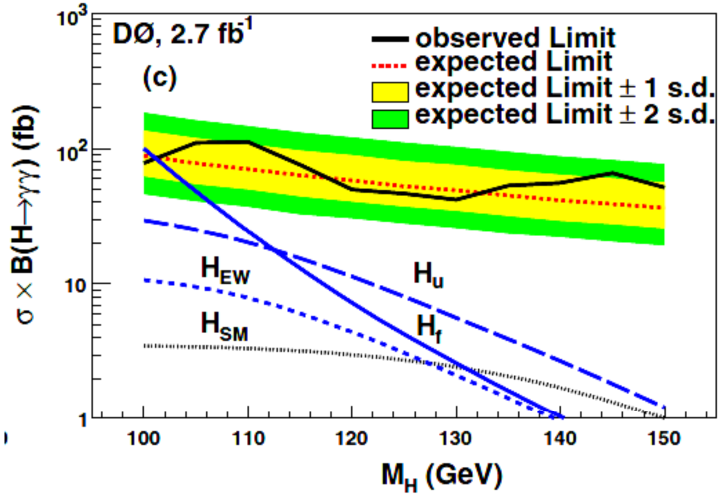
- the accuracy is around O(1)fb, statistics are close to systematic

Impact on Higgs search

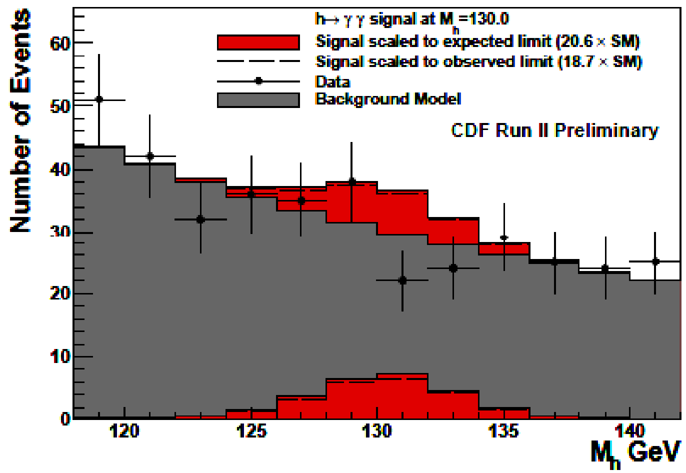
- Reducible background (Z→ee, γ+j, jj)subtracted, sideband fitting into signal region
- Combine all signal channels (gg→H, W/Z+H, VBF) to increase sensitivity

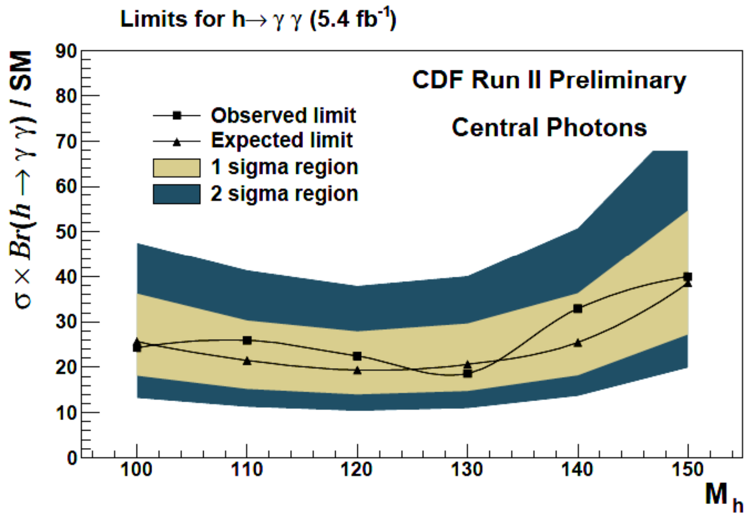
D0:





CDF:





Summary

➢ Direct di-γ production at Tevatron has been studied both by CDF and D0

➢Data are compared with theoretical predictions, RESBOS, DIPHOX and PYTHIA. None of these calculations provides full description of data in all kinematic regions.

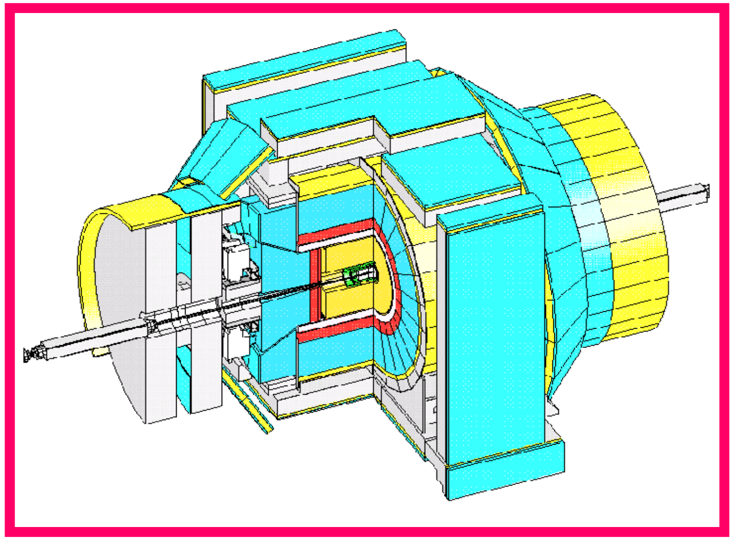
- DIPHOX treats the Fragmentation better; impose $p_T(\gamma\gamma)<M(\gamma\gamma)$ would reduce the discrepancy to RESBOS;

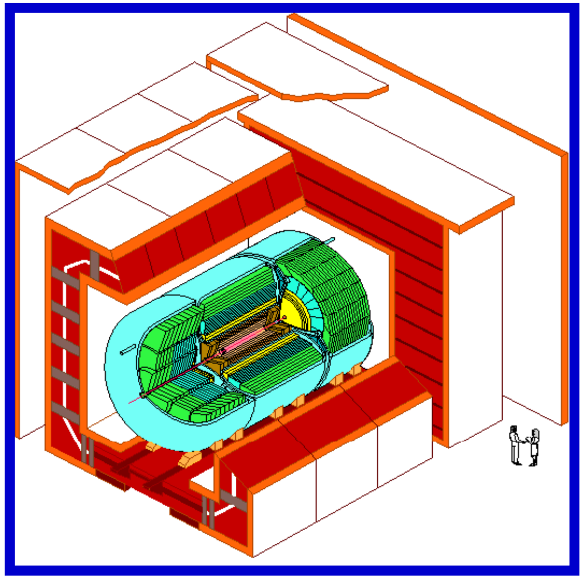
- RESBOS, with NLO gg→$\gamma\gamma$, gives the best agreement with data; hints the need of NNLO corrections for low mass region (<50GeV)

➢ Provide extra the sensitivity to SM Higgs search in the most interested mass region ~130GeV

Backup Slides

CDF & DØ

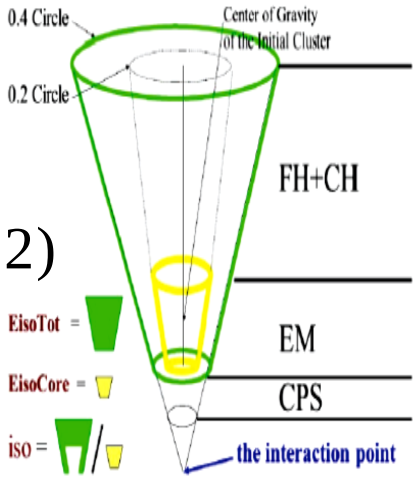




- Calorimeter : fine granularity and good energy resolution
  - CDF : $\Delta\eta \times \Delta\phi \sim 0.1 \times 0.26$
  - D0 : $\Delta\eta \times \Delta\phi \sim 0.1 \times 0.1$

Isolation requirement to suppress fragmentation

$$E_T^{iso} = \sum_{dR<0.4} E_T^i - E_T^{\gamma}(0.2)$$



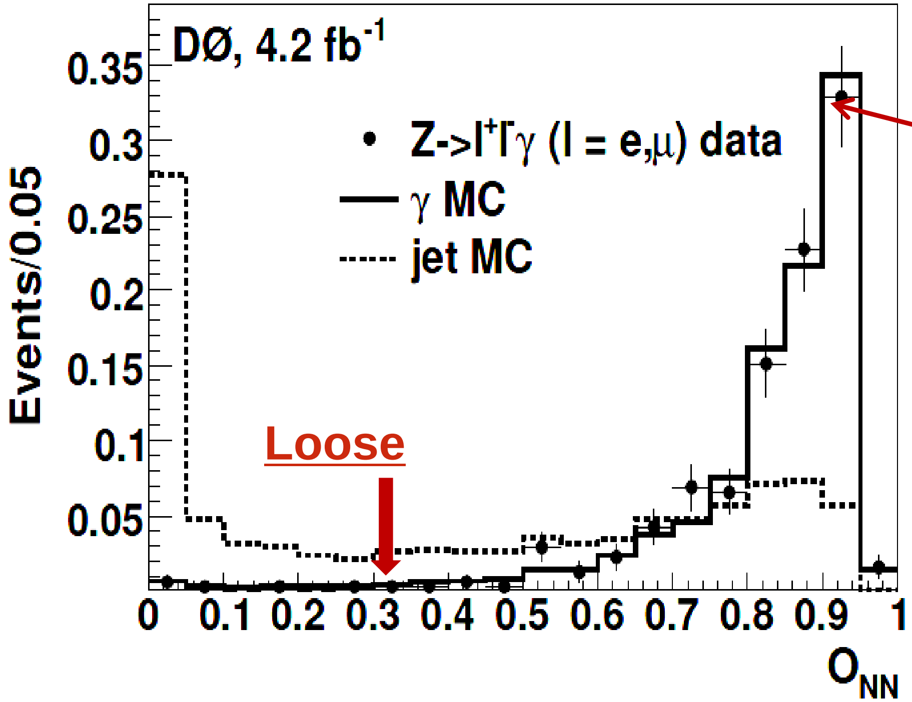
- Preshower: to distinguish γ vs. neutral jets
  - D0 : lead + scintillating strip Central Preshower (CPS)
  - CDF : Preshower detector + shower maximal CES

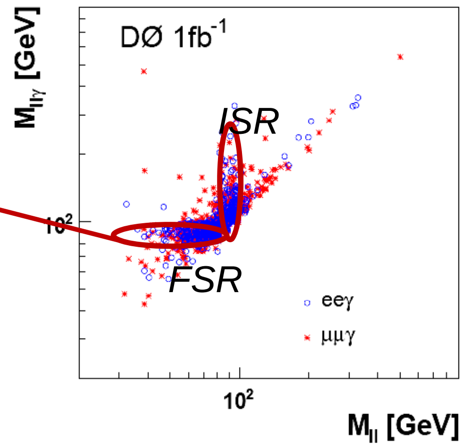
Shower shape difference between single γ and multi-γ from neutral hadron (e.g. $\pi^0 \rightarrow \gamma\gamma$)

+ Input : Preshower & Calorimeter shower shapes + tracker activities

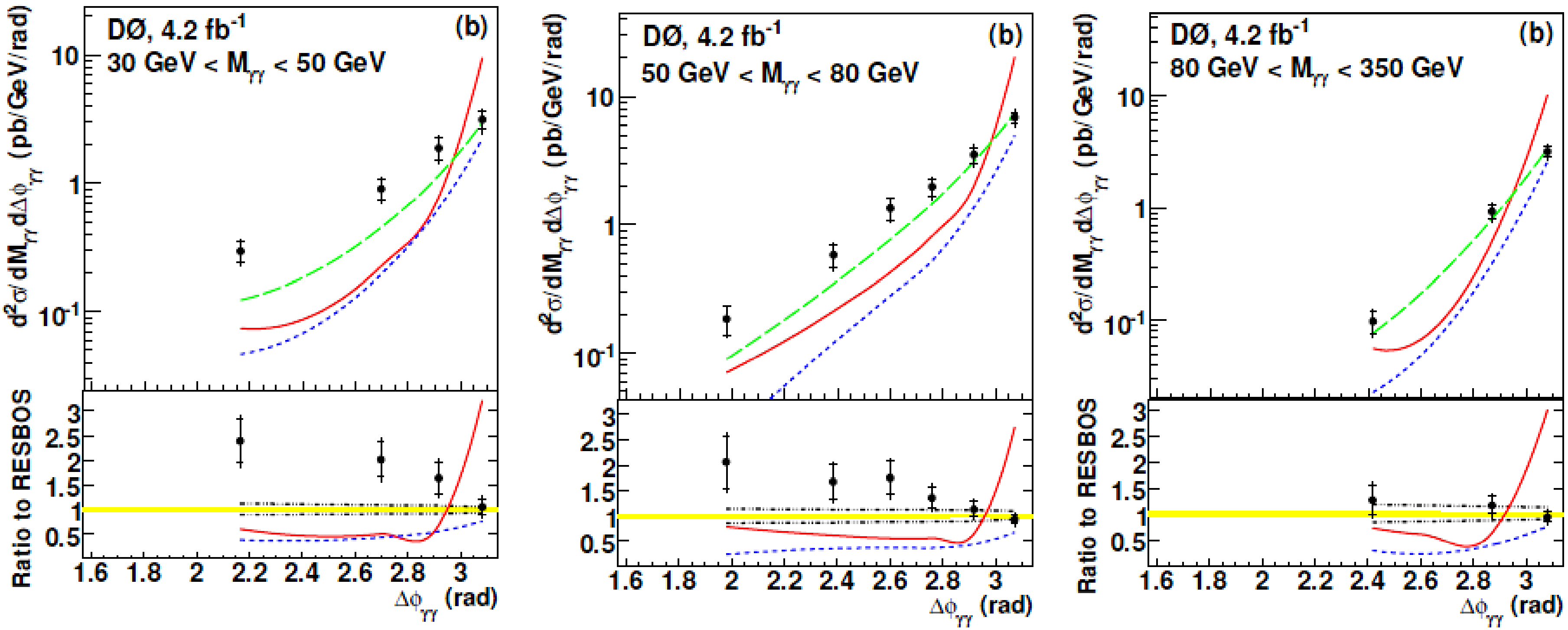
+ Training : MC EM-like jet vs. γ

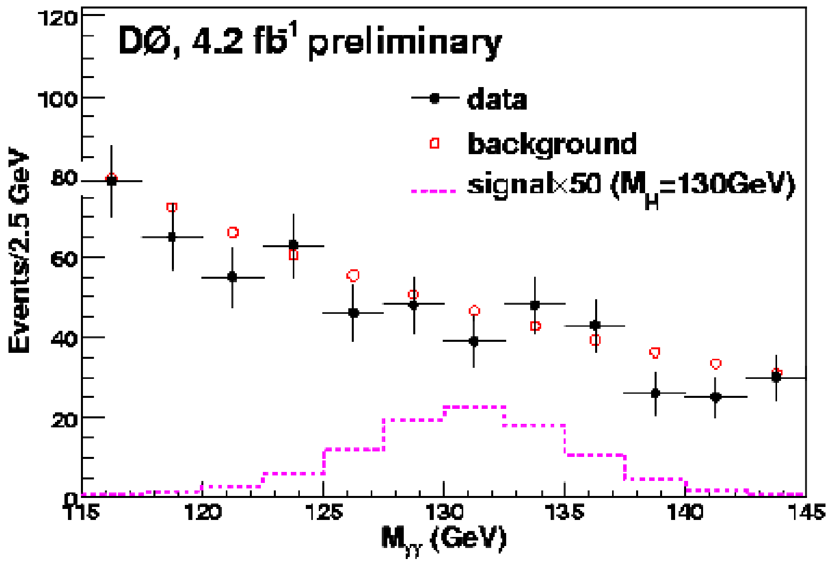
+ Validation : data Z→llγ FSR

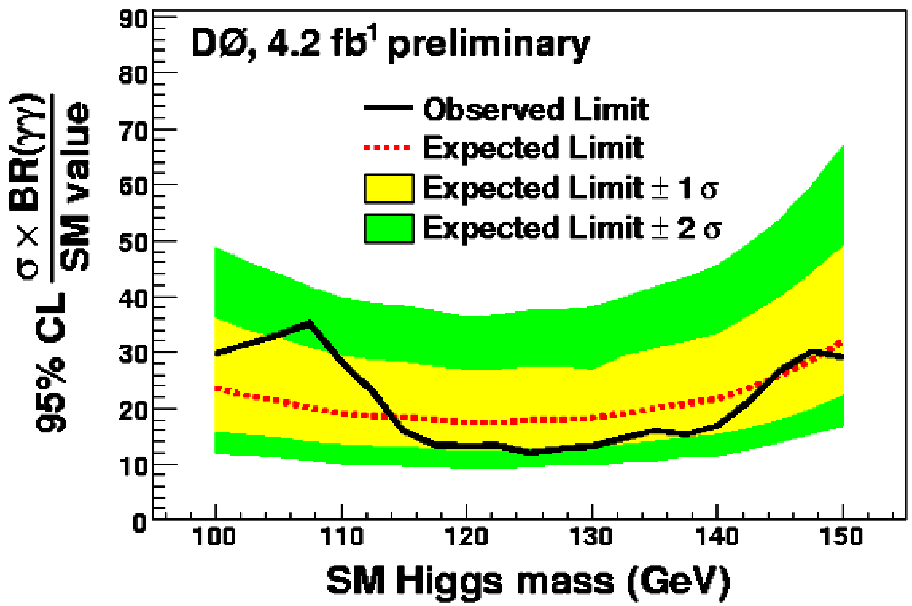




➢ Double-differential cross section: $\dfrac{d^2\sigma}{dM_{\gamma\gamma}\,d\Delta\phi_{\gamma\gamma}}$




DØ, 4.2 fb-1 preliminary
data
background
signal×50 (MH=130GeV)
Events/2.5 GeV
Mγγ (GeV)


DØ, 4.2 fb-1 preliminary
Observed Limit
Expected Limit
Expected Limit ± 1 σ
Expected Limit ± 2 σ
95% CL σ × BR(γγ) / SM value
SM Higgs mass (GeV)