Search for the Higgs boson in $H \rightarrow \gamma\gamma$ decays in $p\bar{p}$ collisions at 1.96 TeV

Meeting of the Division of Particles and Fields

Providence, RI

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for the D0 and CDF collaborations

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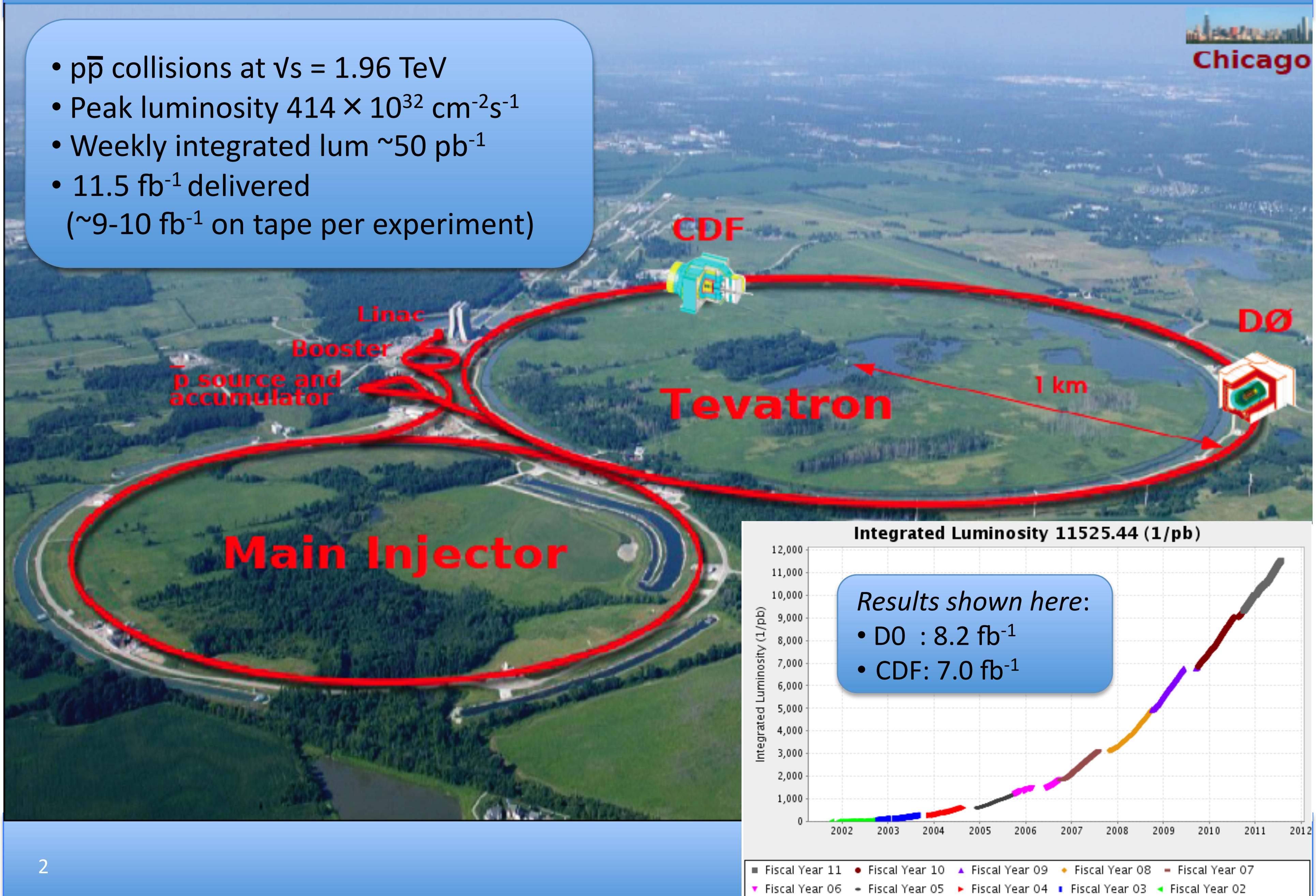
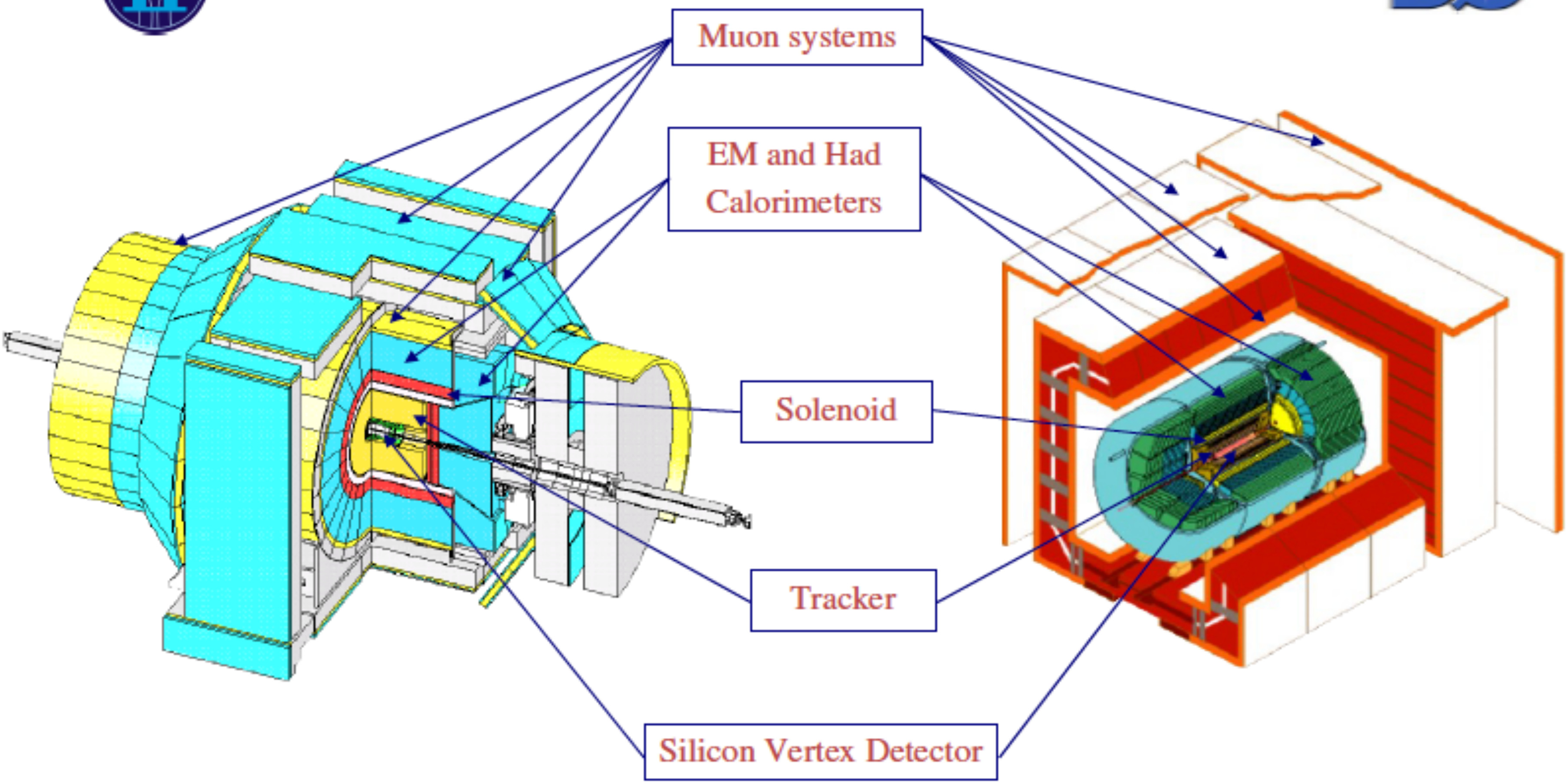
Tevatron

- $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV
- Peak luminosity 414 × 10^{32} $cm^{-2}s^{-1}$
- Weekly integrated lum ~50 pb^{-1}
- 11.5 fb^{-1} delivered
  (~9-10 fb^{-1} on tape per experiment)



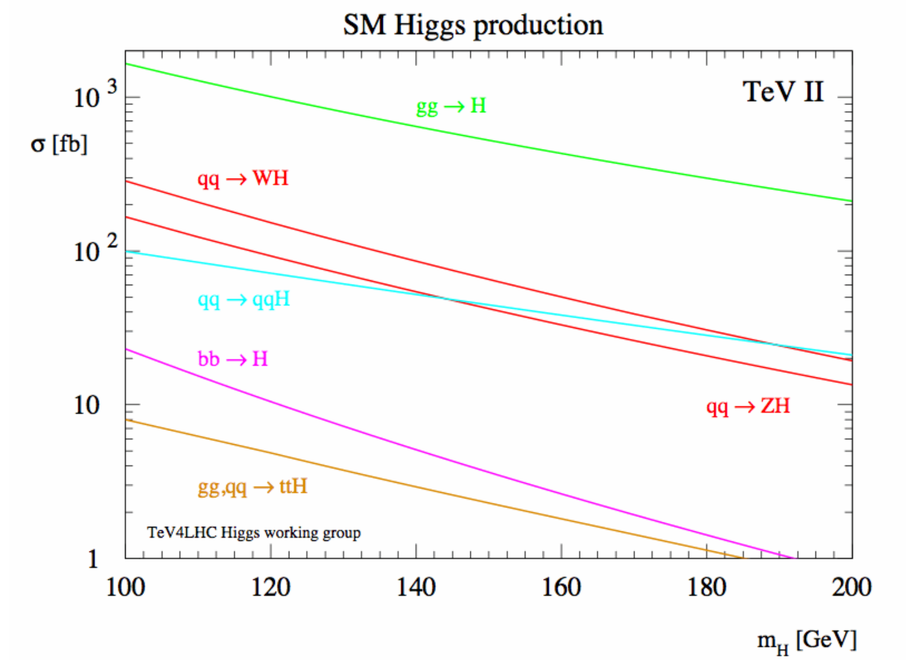
Results shown here:
- D0 : 8.2 fb^{-1}
- CDF: 7.0 fb^{-1}

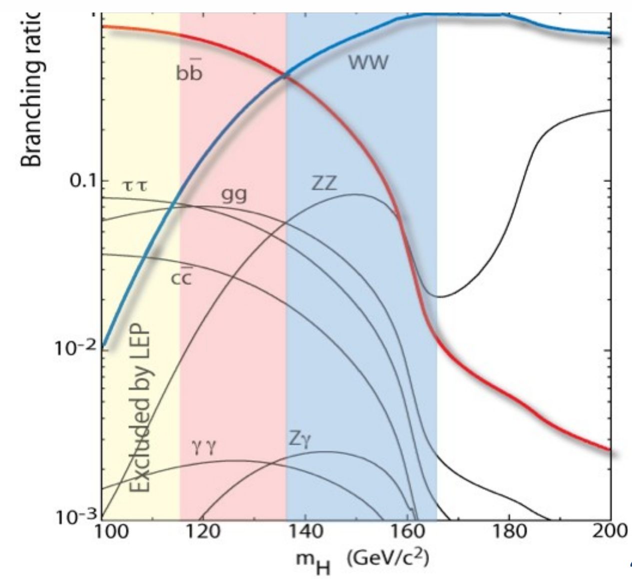
The CDF and the D0 Detectors



Tevatron Higgs Searches

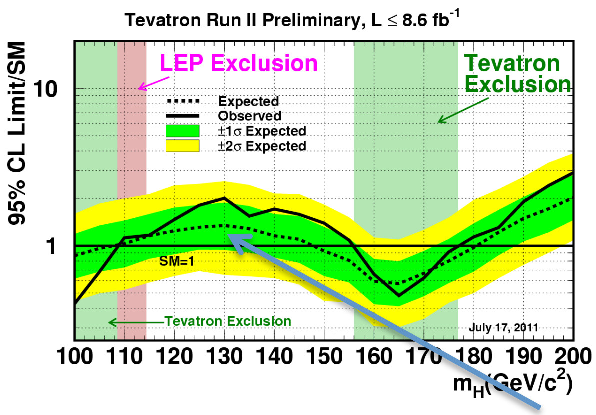
- Higgs Production @ 115 GeV:
  - gg→H ~ 1200 fb
  - $q\bar{q}$→VH ~ 275 fb
  - $q\bar{q}$→$q\bar{q}$H ~ 80 fb
- Search strategy is driven by dominant decay modes
  - H→$b\bar{b}$ for M_H < 135 GeV:
    - gg→H not possible due to large multi-jet background
    - Associated production provides cleaner experimental signatures
  - H→WW for M_H > 135 GeV
    - Leptonic W decays provide cleaner final states
    - Take advantage of more abundant gluon fusion production
- Can improve by using secondary channels like H→γγ
  - *No channel left behind*



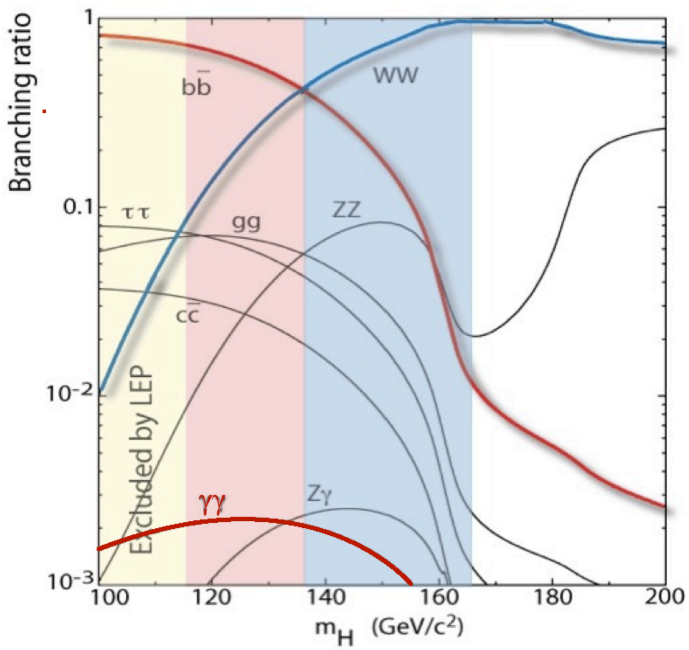


H→γγ Channel

- Limited by branching ratio (Br) ~ 0.2%
- Advantage is clean signature:
  - gg→H signal included along with VH and VBF (~1600 fb @ 115 GeV)
  - Larger signal acceptance compared to $b\bar{b}$ channels
  - Narrow mass resolution: $M_{\gamma\gamma}$ powerful discriminant against backgrounds
- Contributes sensitivity at low mass:
  - Favored region from EWK constraints



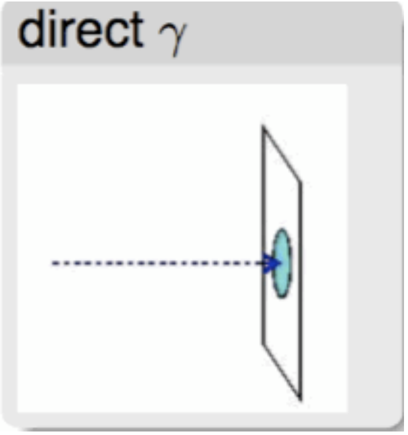
  - Best sensitivity in difficult intermediate mass region at the Tevatron ~ 125 GeV



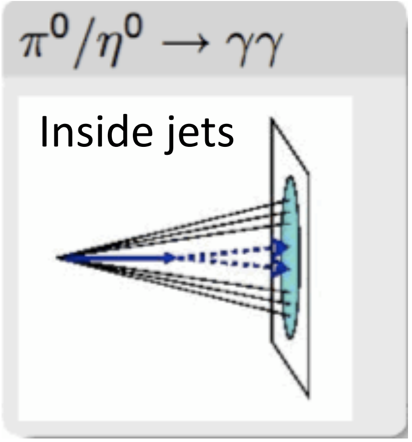
- Many beyond SM scenarios also predict larger Br (described later in talk)
- Favored channel at LHC for low mass Higgs discovery

Basic Photon Identification

- Fake backgrounds:
  - Neutral mesons in jets ($\pi^0/\eta^0 \rightarrow \gamma\gamma$)
  - Electrons faking photons
- Basic direct photon selection:
  - High EM fraction
  - Isolated in the calorimeter
  - No high momentum tracks associated with EM cluster (track isolation/veto)
  - Shower profile consistent with that of a direct photon



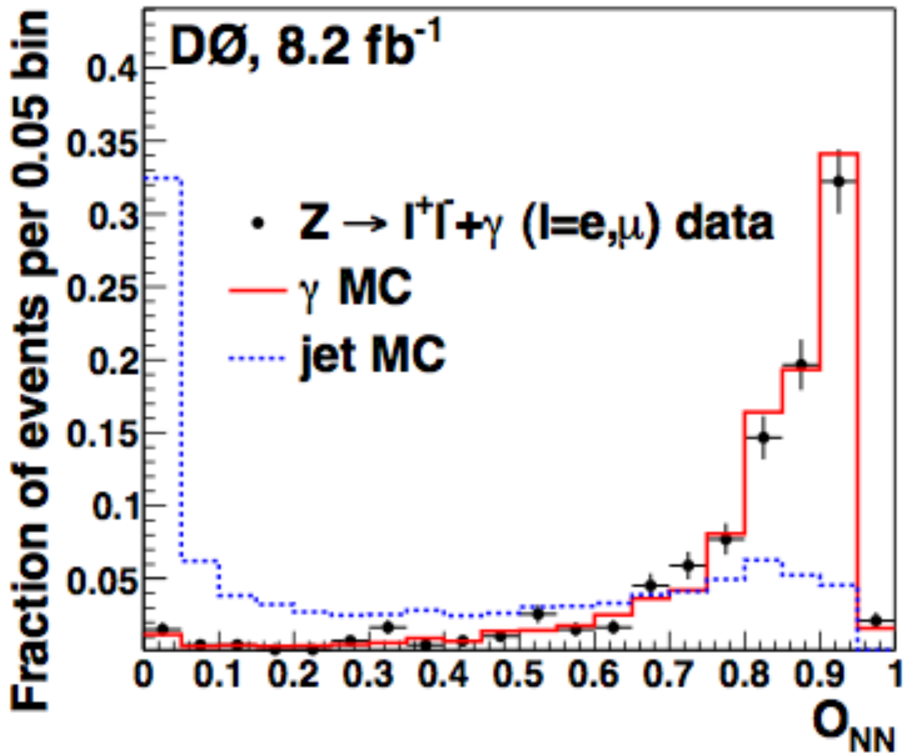
Signal



Background

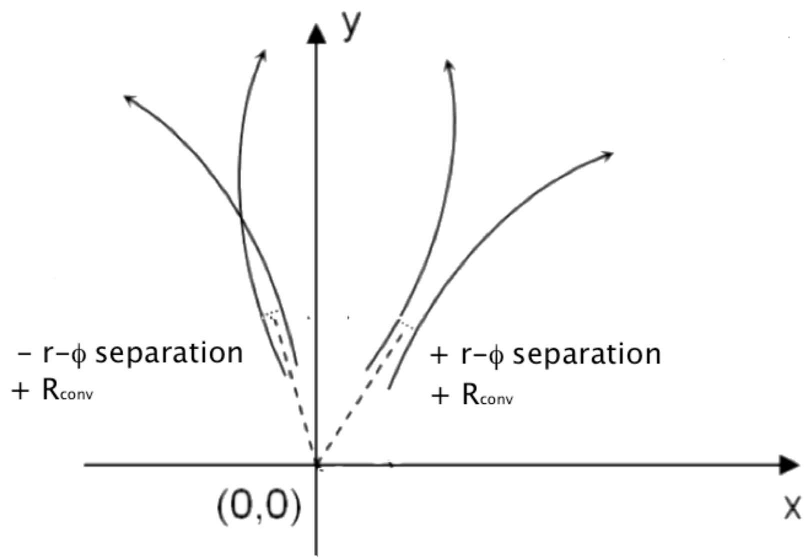
Photon Identification

- $p_T > 25$ GeV
- $|\eta| < 1.1$
- NN discriminant developed to further separate jet background from true photons
- Trained using diphoton and dijet MC samples
- Require NN>0.3
- Efficiency validation:
  - Photon efficiency ~98%, validated using $Z \rightarrow l^+l^-\gamma$, l=e, μ
  - ~40% of jet background rejected, validated using jet data



Photon Identification

- $p_T > 15$ GeV
- Central photons ($|\eta|<1.1$):
  - Use a NN similar to D0
  - Photon efficiency of NN cut ~98%, validated using $Z \rightarrow e^+e^-$
  - 87% of jet background rejected with NN cut
- Forward/"plug" photons ($1.2 < |\eta| < 2.8$)
  - Standard photon ID at CDF
  - Validated with $Z \rightarrow e^+e^-$
- Conversion photons ($\gamma \rightarrow e^+e^-$)
  - $|\eta|<1.1$
  - More material, higher probability of converting
  - 15% probability for $|\eta|<1.1$ at CDF
  - Base selection:
    - Oppositely signed high quality tracks
    - Proximity: r-ϕ sep and $\Delta\cot\theta$ ($\cot\theta = p_z/p_T$)



Diphoton Background Estimation

- SM QCD photons: $\gamma + \gamma$
  - Shape from Sherpa MC
  - Normalization from sideband fits to data after subtracting other backgrounds
- Fake photons:
  - Drell-Yan: $Z/\gamma^* \rightarrow e^+e^-$
    - Modeled using Pythia MC
  - γ + jet and jet+jet
    - Shape from data: NN<0.1 on single or both photons
    - Normalization from data: 4x4 matrix method

- 4x4 matrix method:
  - Exploit different efficiency of tighter cut (NN>0.75) relative to NN>0.3 for photon and jet
  - Per-event weight computed:

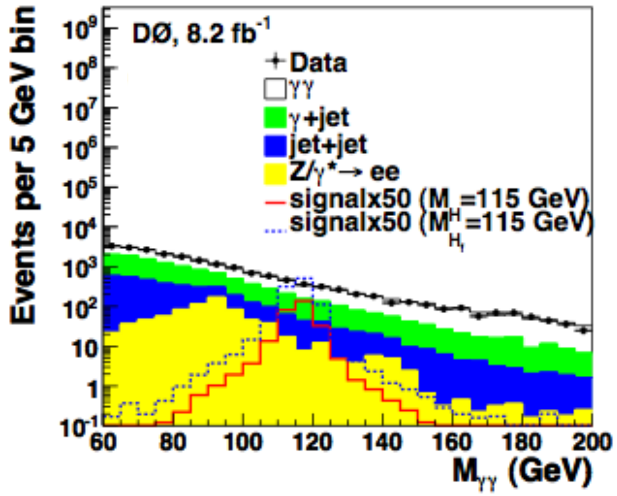
$$\begin{pmatrix} w_{jj} \\ w_{j\gamma} \\ w_{\gamma j} \\ w_{\gamma\gamma} \end{pmatrix} = E^{-1} \times \begin{pmatrix} w_{ff} \\ w_{fp} \\ w_{pf} \\ w_{pp} \end{pmatrix}$$

Both photons fail
Leading fail, trailing passes
Leading passes, trailing fails
Both photons pass

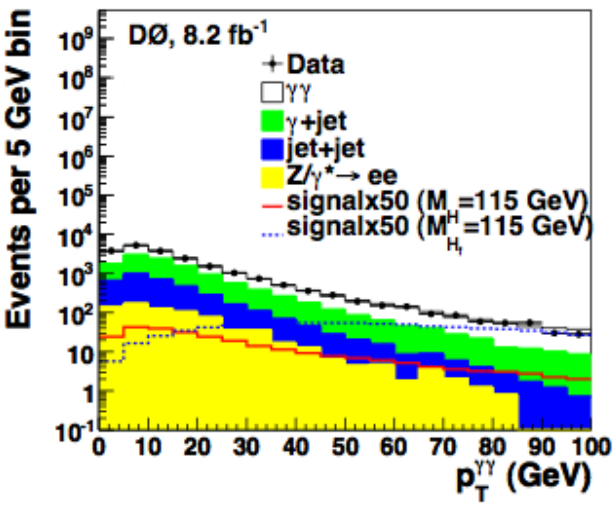
  - 4x4 E matrix derived from photon and jet efficiencies
  - Then, for example,

$$N_{jj} = \sum_{i=1}^{N_{data}} w^i_{jj}$$

Final Discriminants

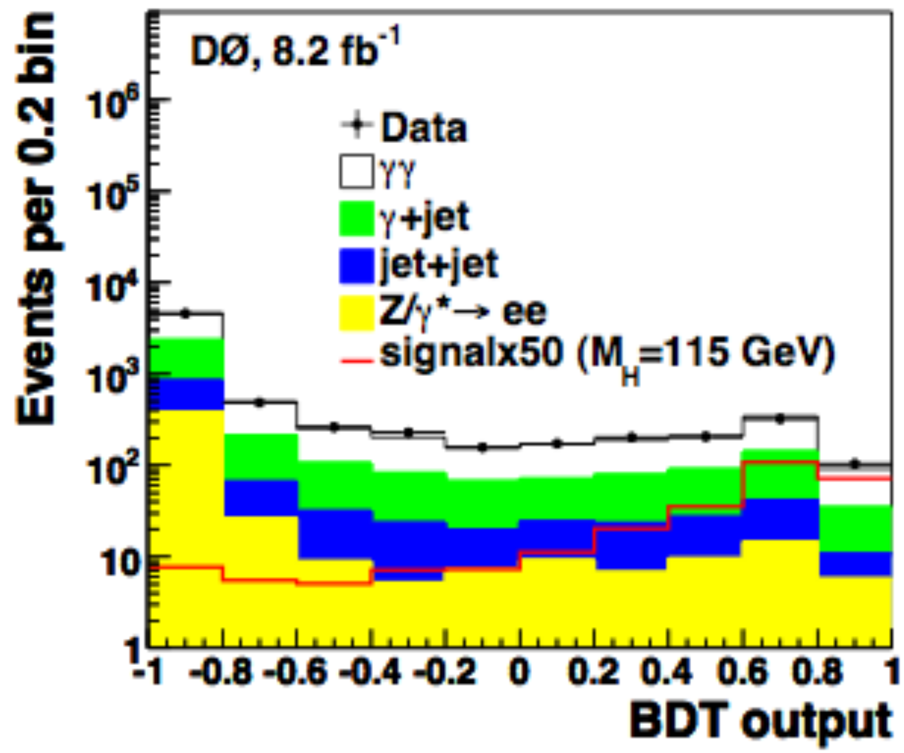


$M_{\gamma\gamma}$



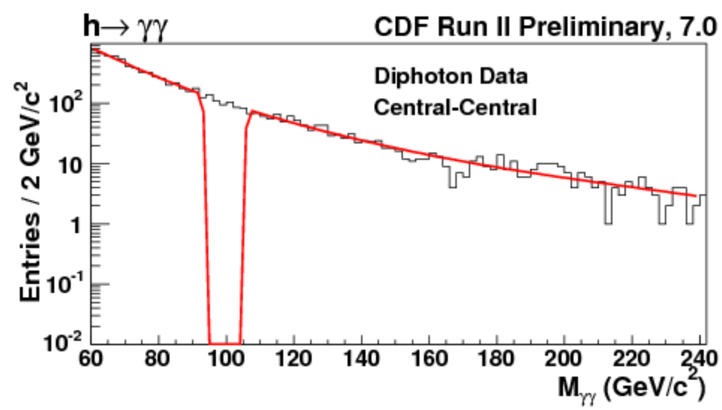
$p_T^{\gamma\gamma}$

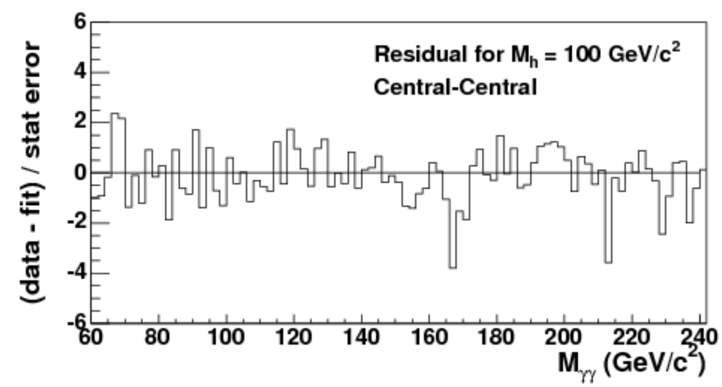
$+ p_T^1 + p_T^2 + \Delta\phi_{\gamma\gamma}$



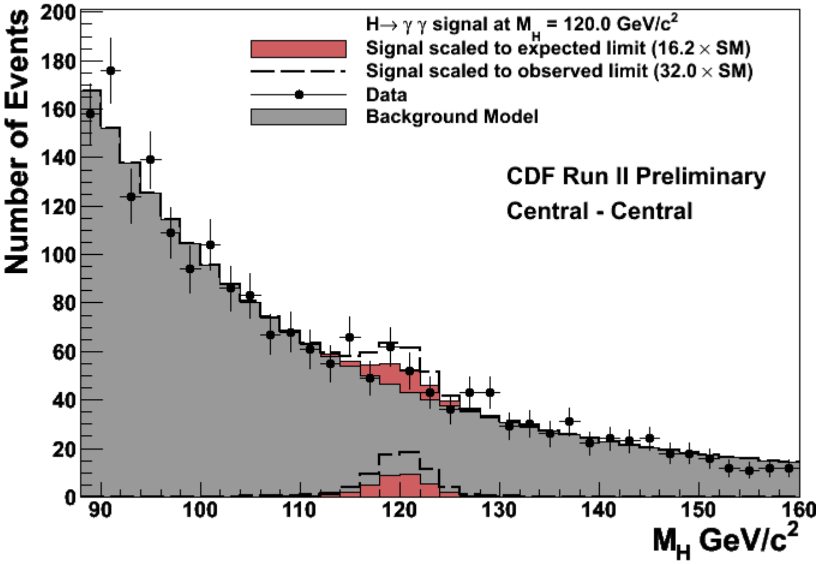
Diphoton Background Estimation

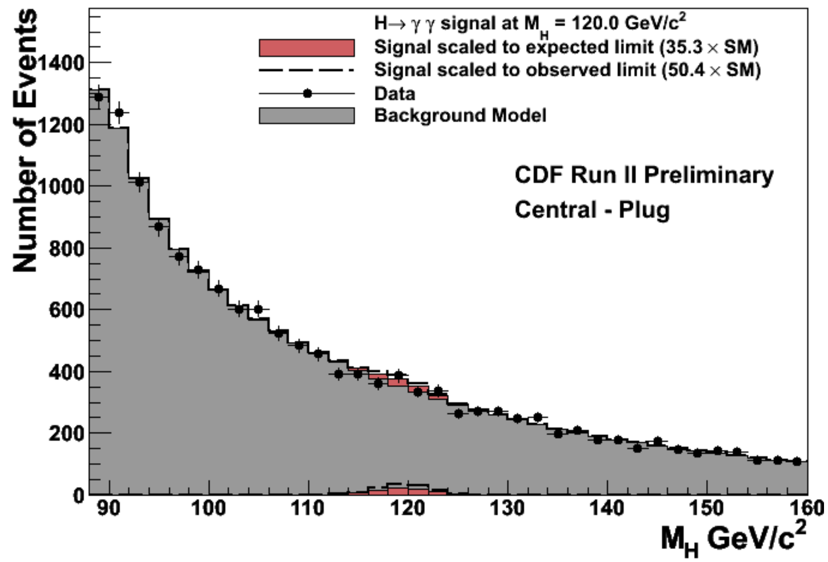
- Diphoton events divided into four categories:
  - Two central photons
  - Central photon + a plug photon
  - Central conversion + central photon
  - Central conversion + plug photon
- Data-driven model
  - Exploit mass resolution of H→γγ (~3 GeV @ 1σ)
  - Make sideband fits to the data excluding 12 GeV signal region
  - Interpolate fits to signal region

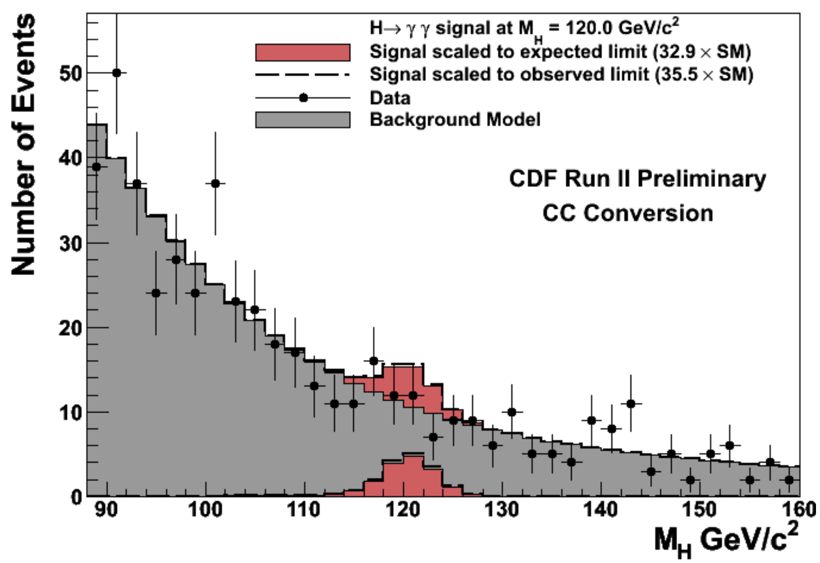


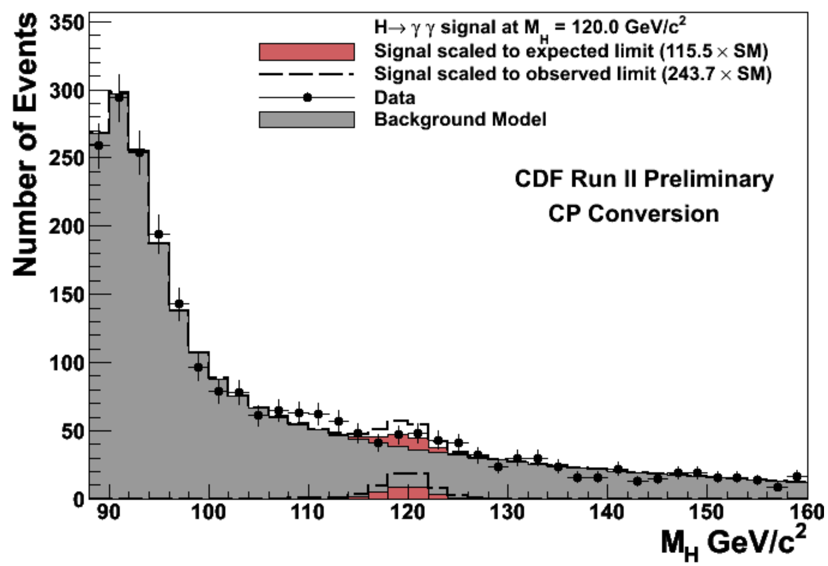


Final Discriminants

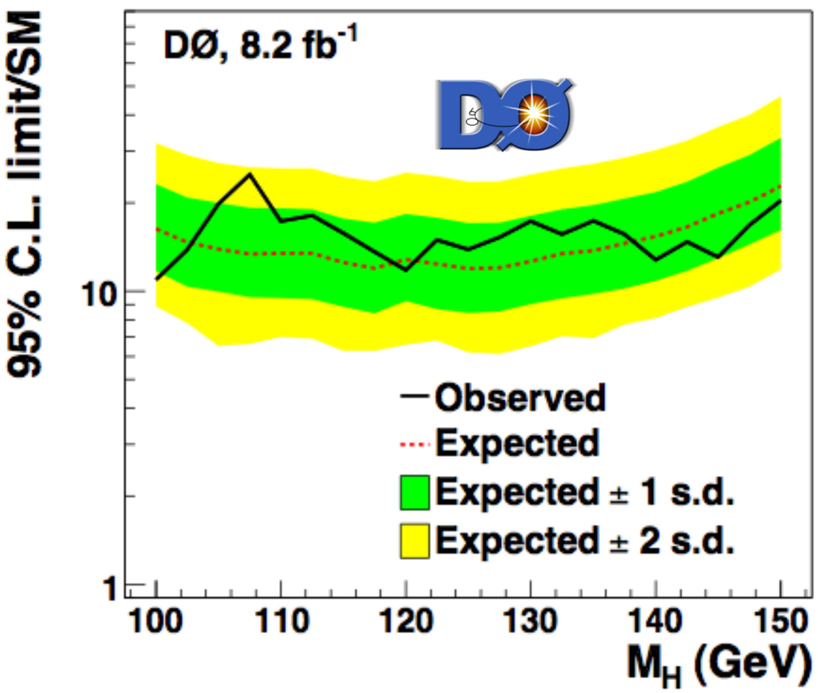


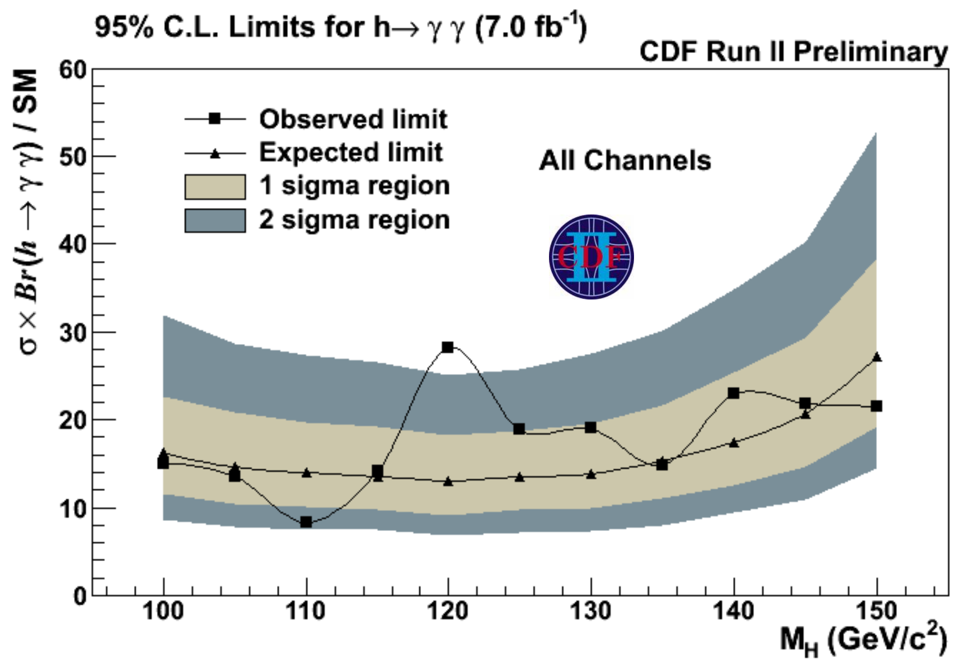






95% C.L. Limits on σ×Br/SM

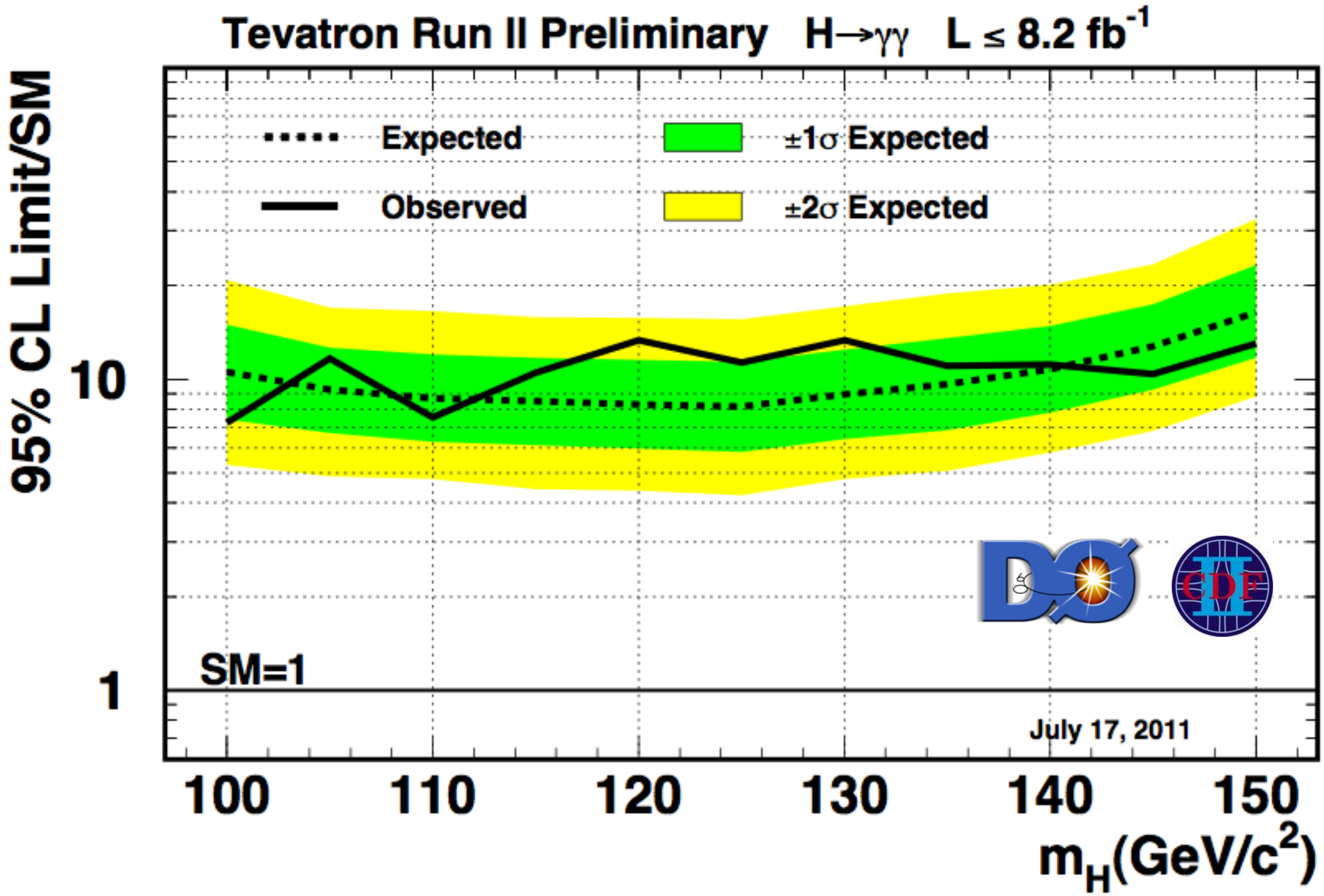




For M_H of 115 GeV	Luminosity	Expected/SM	Observed/SM
D0	8.2 fb^{-1}	12.5	15.8
CDF	7.0 fb^{-1}	13.5	14.1

- CDF observed limit @ 120 below 2σ after trial factor considered
- Similar sensitivities from very different techniques

95% C.L. Limits on σ×Br/SM

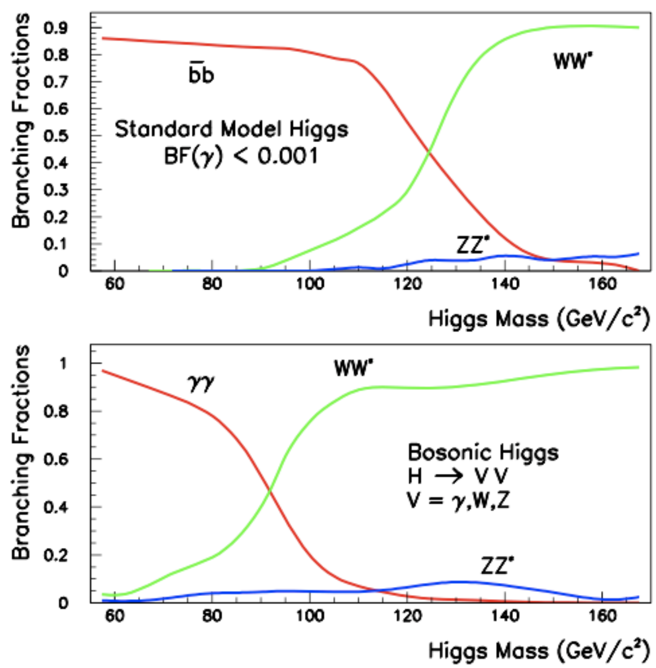


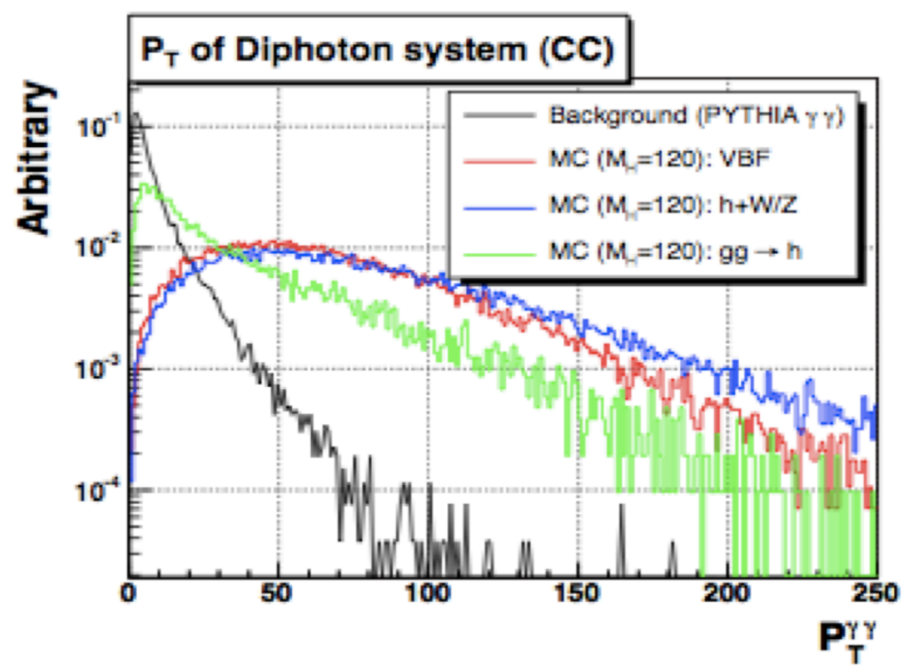
For M_H of 115 GeV	Luminosity	Expected/SM	Observed/SM
Tevatron H→γγ Combo	≤ 8.2 fb^{-1}	8.5	10.5

BSM Higgs to diphoton (Fermiophobic)

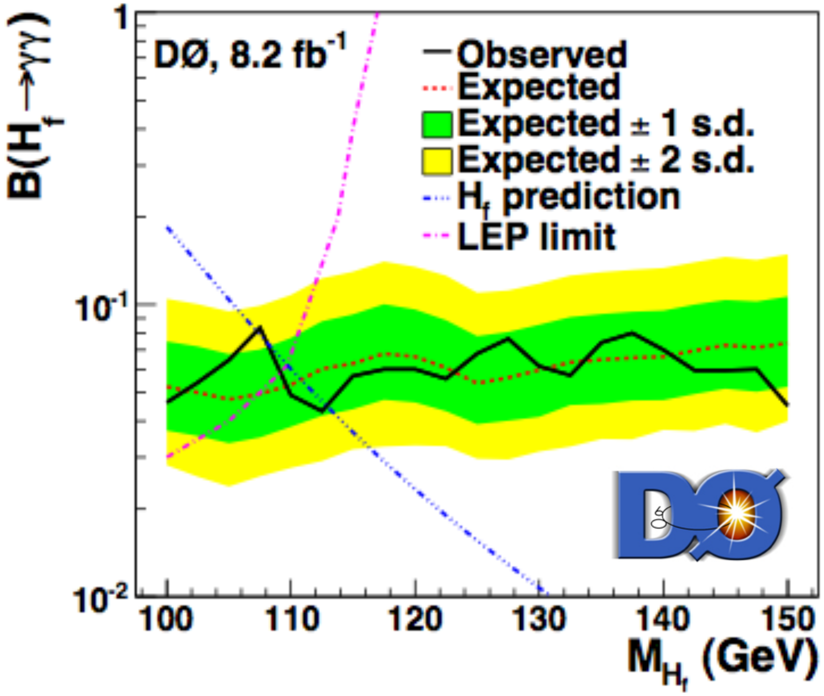
- A "benchmark" fermiophobic Higgs (h_f) model also considered
- A two-Higgs doublet model extension to SM
- Br enhanced significantly relative to SM (about 120x higher @ a mass of 100 GeV)

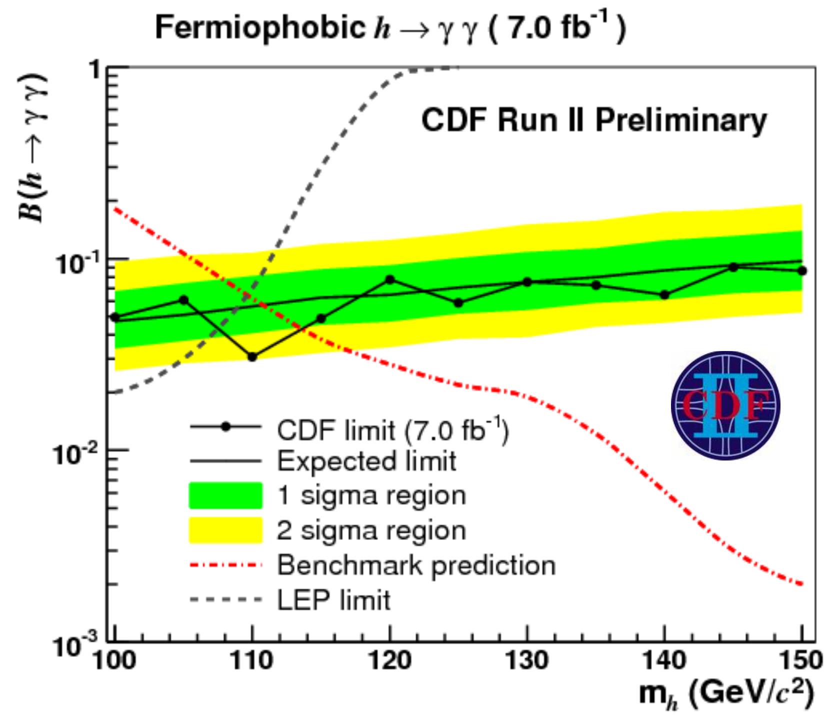
- Assume SM cross sections
- But no $gg \rightarrow h_f$
- Only VH and VBF:
- More sensitive to $p_T^{\gamma\gamma}$
  - CDF splits data into 3 $p_T^{\gamma\gamma}$ bins
  - D0 sensitive to this by using a BDT (separate training for fermiophobic Higgs than for SM)





95% C.L. Limits on Br($h_f \rightarrow \gamma\gamma$)





- Mass exclusions
- LEP exclusion below 109.7 GeV
- *Tevatron experiments place most stringent limits on h_f to date*

	Luminosity	h_f Exclusion @ 95% C.L.
D0	8.2 fb-1	< 112.9 GeV
CDF	7.0 fb-1	< 114 GeV

Conclusions

- SM $H \rightarrow \gamma\gamma$ search
  - D0 and CDF individually set expected limits of ~12-14xSM @ 115 GeV
  - Combined limits ~8xSM @ 115 GeV
  - Individually, have a small contribution to overall Higgs search at Tevatron
  - However, contributes in regions where Tevatron is least sensitive at low mass
  - Together with other less sensitive channels – searches with taus and an all jets search – has sensitivity like that of a primary channel
  - Important role in Tevatron Higgs combination!
- Fermiophobic $h_f \rightarrow \gamma\gamma$ search
  - D0 (CDF) excludes $M_{hf} < 112.9$ (114) GeV
  - These are currently the worlds best limits on $h_f \rightarrow \gamma\gamma$!

Documentation

- D0
  - http://arxiv.org/pdf/1107.4587v1
- CDF
  - SM: http://www-cdf.fnal.gov/physics/new/hdg/Results_files/results/hgamgam_apr11/
  - Fermiophobic: http://www-cdf.fnal.gov/physics/new/hdg/Results_files/results/fermi_hgamgam_may11/