Search for the Higgs boson in the $\gamma\gamma$ final state at the Tevatron

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On behalf of the CDF and DØ collaborations

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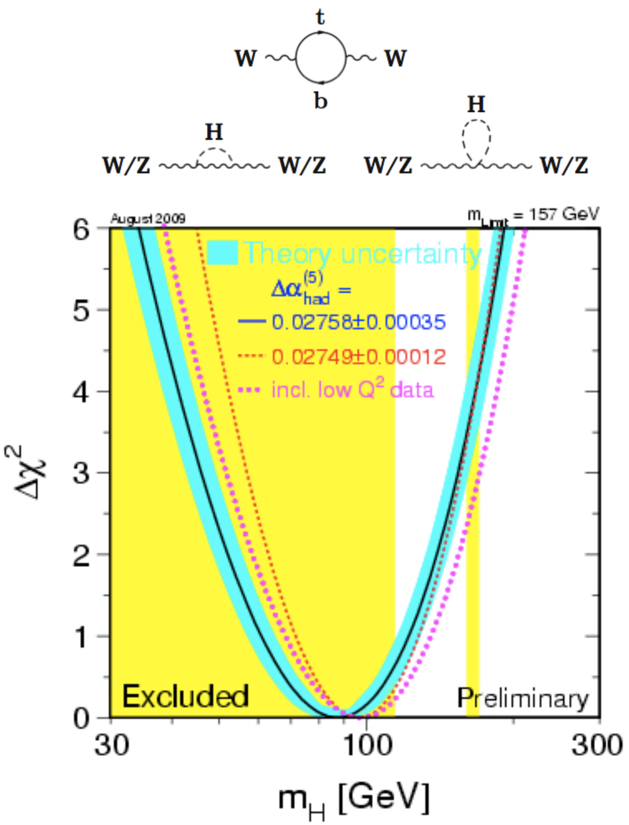
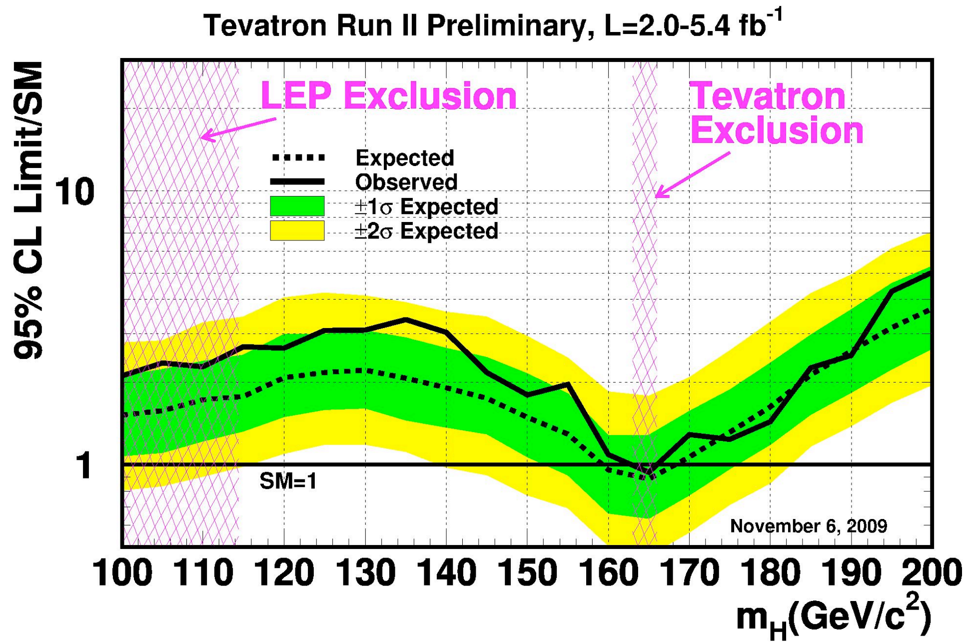
Stalking the Higgs



Combined Tevatron result 2009

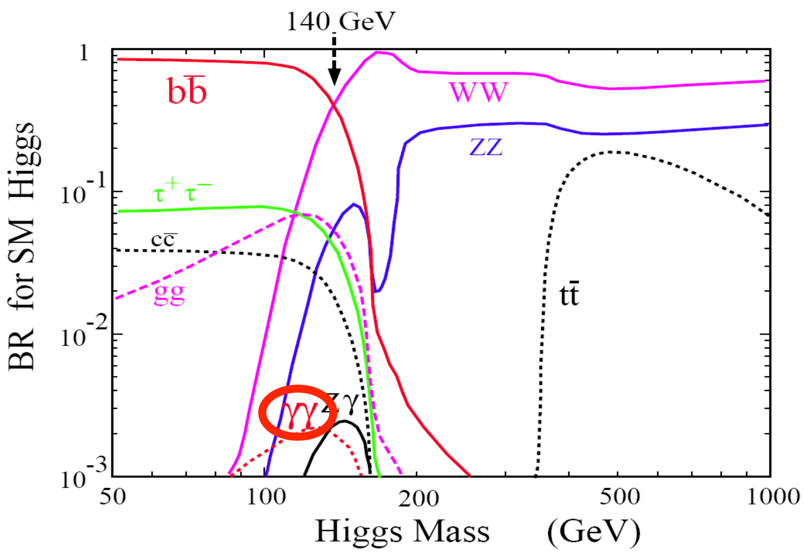


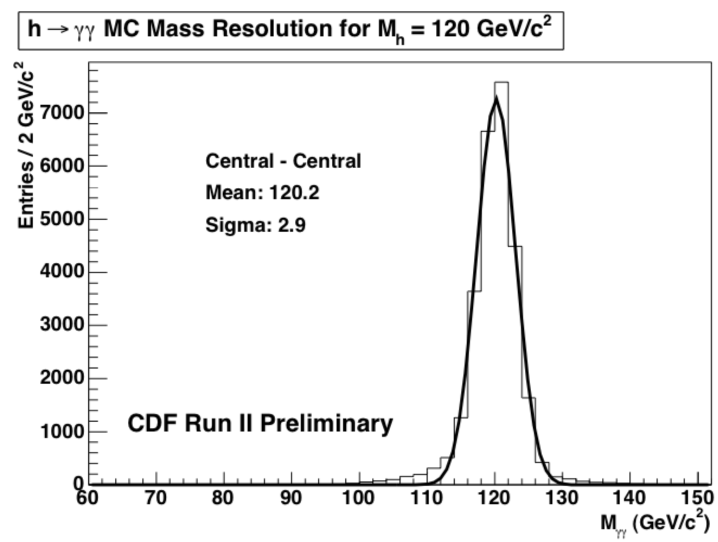
If the SM is correct, a light Higgs boson is around the corner!

Investigate different production mechanisms and a large number of final states to scan the whole mass range allowed at the Tevatron

Why search for H → γγ at the Tevatron?

Within the SM, small BR (~0.2%) results in very small production rate
⇒ Compensate with much better mass resolution compared to dijet final states





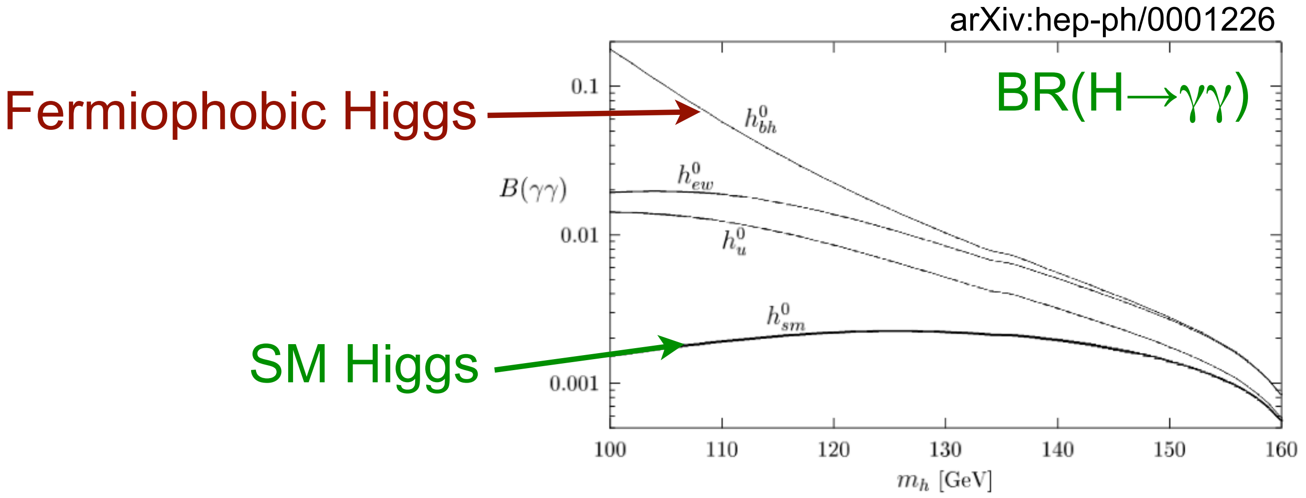
H → γγ provides important additional sensitivity especially in the difficult intermediate mass region ~130 GeV

Forerunner to similar search at the LHC

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

Beyond the SM, significant enhancements to the production rate possible:

- New particles affecting the loop-mediated Hgg or H$\gamma\gamma$ couplings
- Increased BR(H$\rightarrow\gamma\gamma$) in models with modified Higgs couplings to fermions
- Fermiophobic example: suppressed couplings to all fermions



Fermiophobic models can be probed with H $\rightarrow \gamma\gamma$ at the Tevatron

In general, this search can probe for any narrow resonance decaying into di-photons in a quasi-model independent way

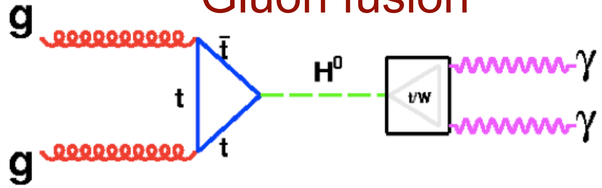
H → γγ search at the Tevatron

Perform search as model-independent as possible

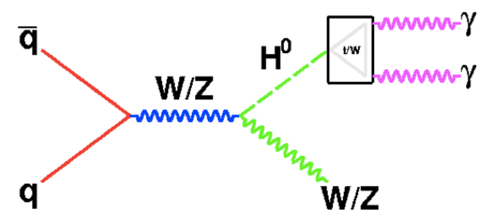
- Inclusive event selection
- Use only di-photon mass observable, look for bump in deeply falling spectrum
- Signal acceptance/sensitivity basically independent of production mechanism

For the Standard Model Higgs:

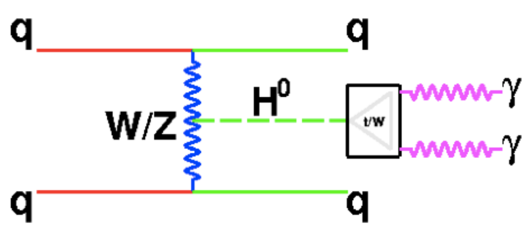
Gluon fusion



Associated production



Vector boson fusion

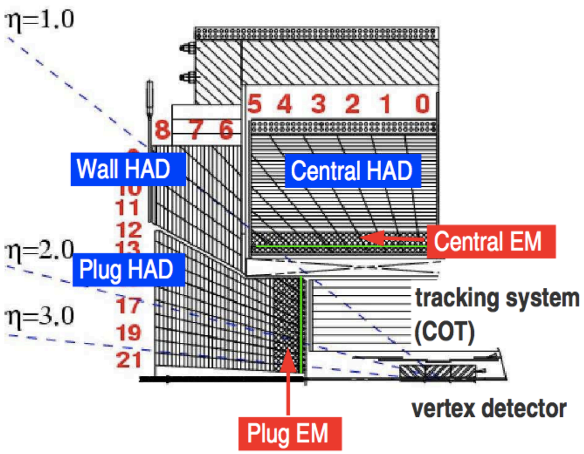


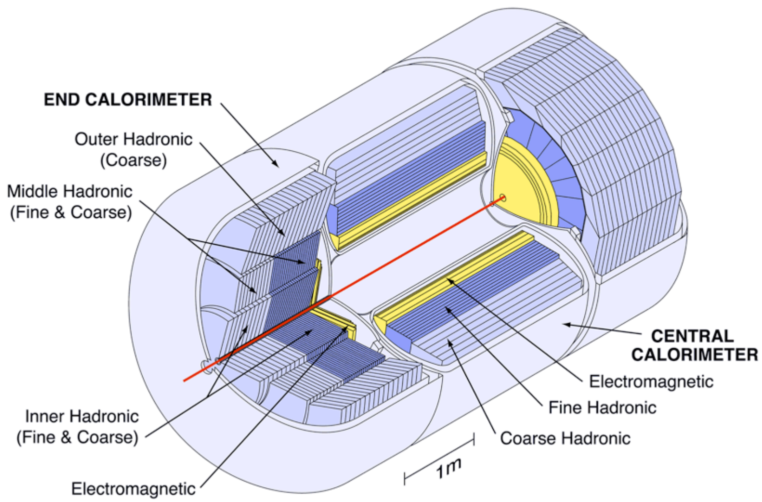
Add ~30% more signal

Relevant aspects for this search:

- Calorimeter resolution
- Photon identification
- Background model (data driven techniques)

CDF and DØ calorimeters





Central/Wall (|η|<1.2) and Plug calorimeters

- Scintillating tile with lead as absorber material in EM section
- Coarse granularity: ~800 towers
- Nearly no noise
- EM resolution:
  $\sigma/E = 13.5\% / \sqrt{E} \oplus 1.5\%$
  (in central)

Central (|η|<1.1) and forward calorimeters

- Liquid Argon with mostly uranium as absorber
- Fine granularity: ~50K cells
- EM resolution:
  $\sigma/E = 21\% / \sqrt{E} \oplus 2.0\%$
  (at normal incidence)

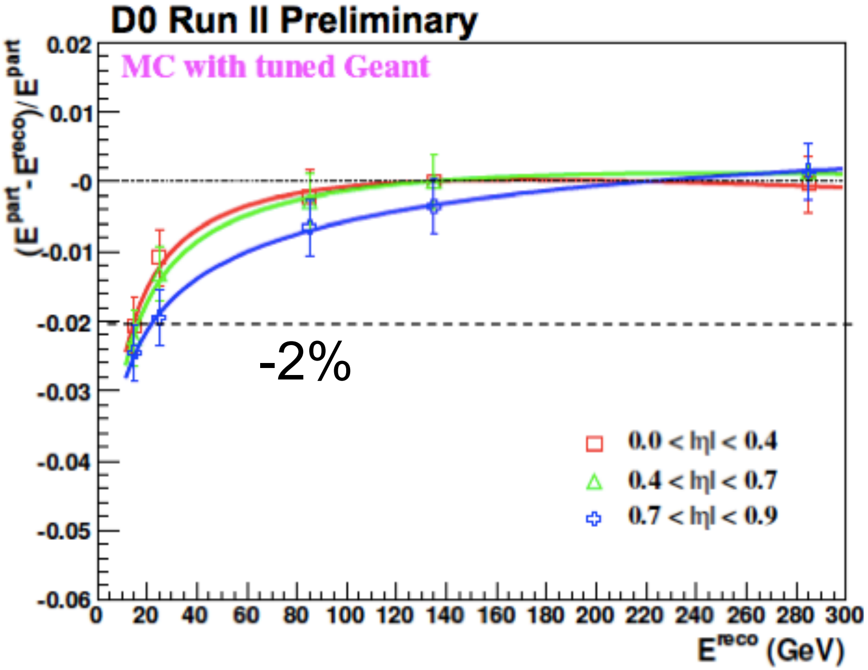
Both calorimeters calibrated regularly with special triggered data

Photon energy scale and resolution

DØ example: the presence of additional dead material (non-uniformly distributed) with the Run II upgrade leads to:

- Shower maximum in frontal CAL layers
- Significant dependence of EM response and resolution on the particle energy and incident angle
- Different energy-loss corrections between electrons and photons

Energy-loss corrections measured in $Z \rightarrow ee$ events. Propagated to different energy scales and photons with tuned GEANT simulation



Systematic uncertainties:

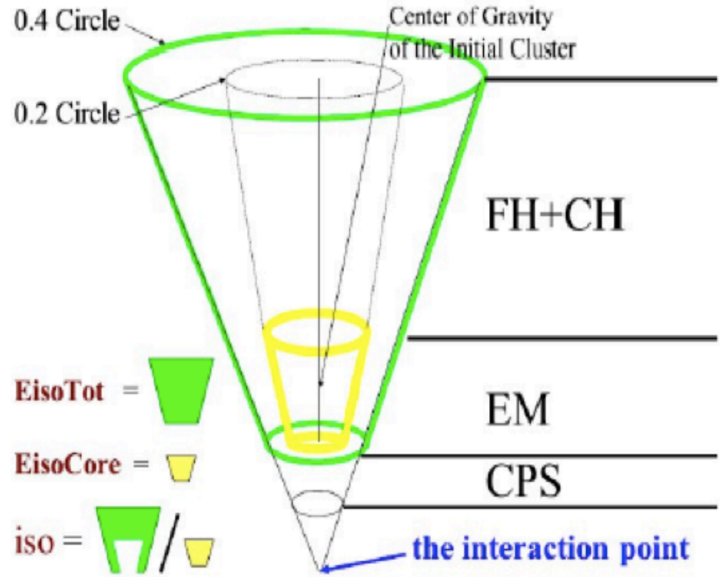
- Energy scale: ±0.5%
- Energy resolution: ±5% in constant term

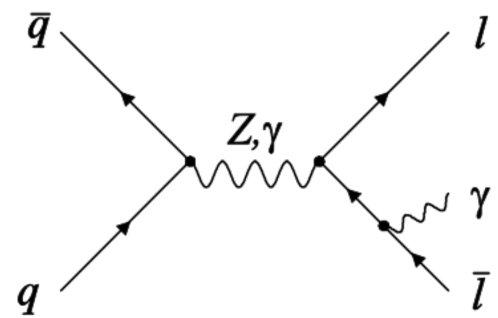
Photon identification: basic selection

Both experiments select photons from EM clusters with the following criteria:

- High EM fraction / cluster in shower maximum detector
- Isolated in the calorimeter
- Isolated in the tracker
- Transverse shower profile consistent with EM object
- No associated track / no pattern of hits consistent with electrons

Differences between data and simulation calibrated using photons from radiative Z decays ($Z \to ll\gamma$) and $Z \to ee$





Photon identification: Neural Network

DØ: Further improve photon purity with a five variable NN

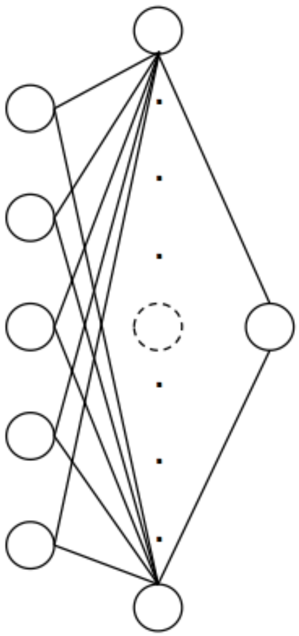
Tracker isolation ($p_T^{\Sigma trk}$)

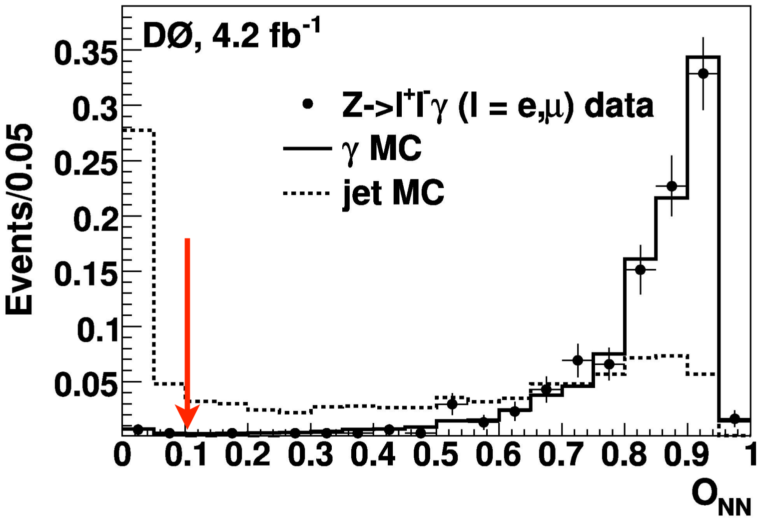
Number of EM1 cells within R<0.2

Number of EM1 cells 0.2<R<0.4

Number of pre-shower clusters R<0.1

Energy-weighted width of energy deposition in the pre-shower detector





Trained using QCD $\gamma\gamma$ and di-jet MC. Performance verified with $Z \rightarrow ll\gamma$ data events - excellent agreement between data and MC

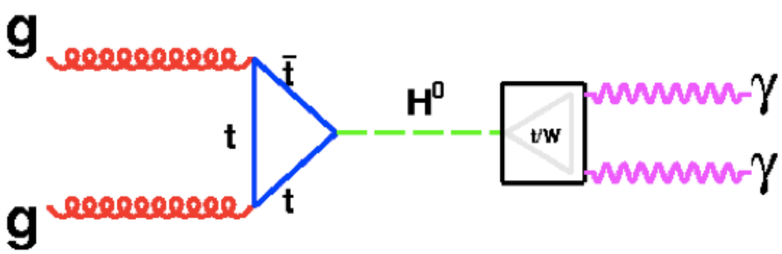
Require NN>0.1 (almost 100% efficient for photons while rejecting 50% misidentified jets)

Event selection

Data collected with a suite of calorimeter only triggers:

- Di-EM triggers (p_T thresholds vary within 12-25 GeV)
- Single photon triggers with high p_T threshold 50/70 GeV (CDF only)
- Trigger efficiency after offline selection ~100%

Require primary vertex within the acceptance of the tracking detectors



Two photons candidates:

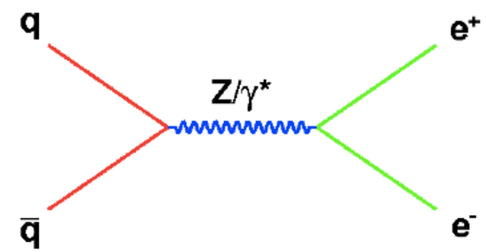
- In central calorimeters (away from module boundaries)
- p_T > 15 / 25 GeV (CDF / DØ)
- $M_{\gamma\gamma}$ > 30 / 60 GeV (CDF / DØ)

Main backgrounds

Reducible backgrounds:

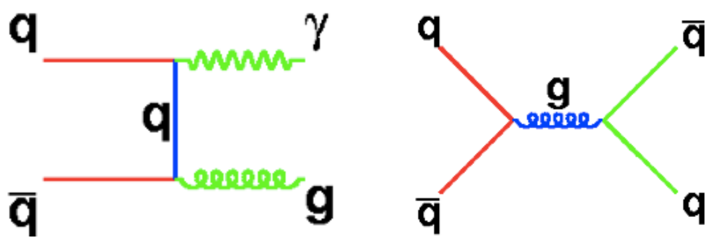
Electrons misidentified as photons: $Z/\gamma^* \rightarrow ee$

Estimated using MC normalized to NNLO theoretical cross section



Jets misidentified as photons: di-jet and γ+jet

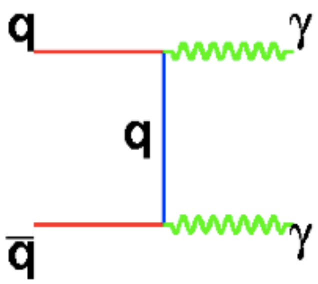
Normalization and shape estimated from data



Irreducible background:

Direct QCD di-photon production

Normalization and shape estimated from data using sideband fitting method



In the CDF analysis the sum of all backgrounds is taken from an inclusive sideband fitting method

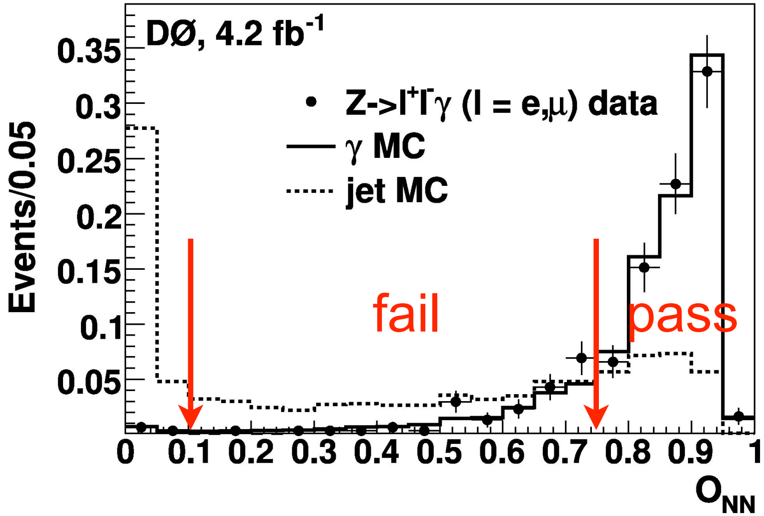
Di-jet / γ+jet background modeling

4x4 Matrix Method:

Use efficiency of a tighter cut (NN>0.75) to classify the events in 4 categories

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

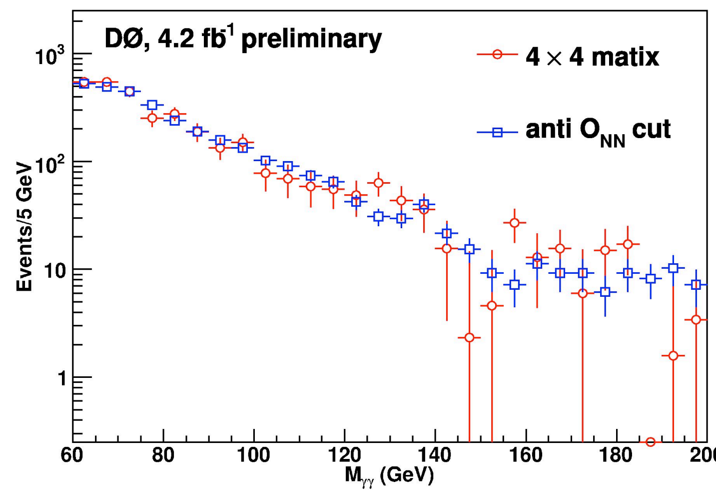
Both photons fail
Leading fail, trailing passes
Leading passes, trailing fails
Both photons pass



Solve linear equation with photon and jet efficiencies to obtain Njj+Nγj+Njγ

Inverse-NN Method:

Invert NN (0.1) cut for one photon candidate to obtain enriched non-γγ sample from data



Di-jet / γ+jet background modeling

4x4 Matrix Method: For normalization

Use efficiency of a tighter cut (NN>0.75) to classify the events in 4 categories

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

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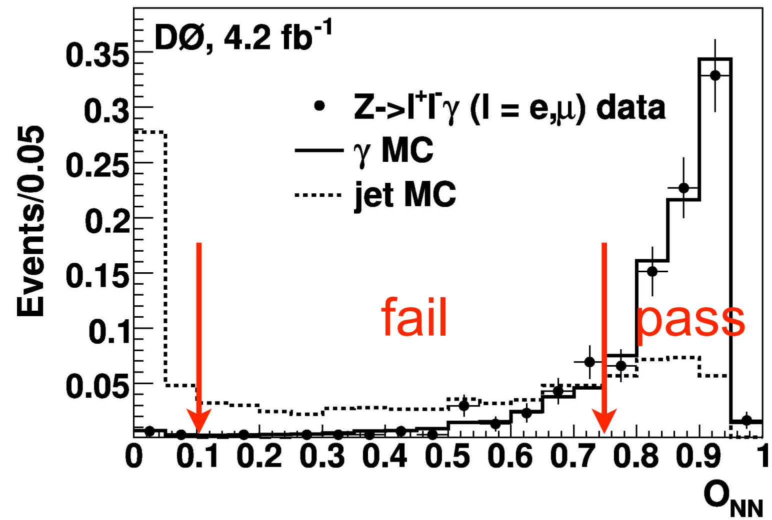
Leading fail, trailing passes

Leading passes, trailing fails

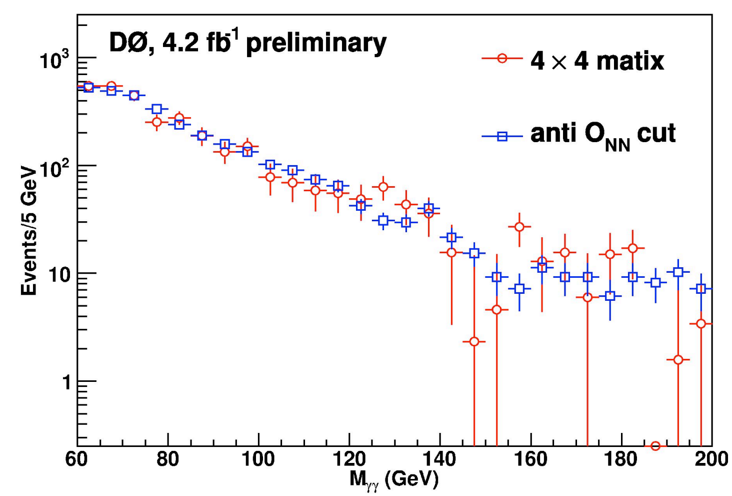
Both photons pass



Solve linear equation with photon and jet efficiencies to obtain Njj+Nγj+Njγ

Inverse-NN Method: For shape

Invert NN (0.1) cut for one photon candidate to obtain enriched non-γγ sample from data



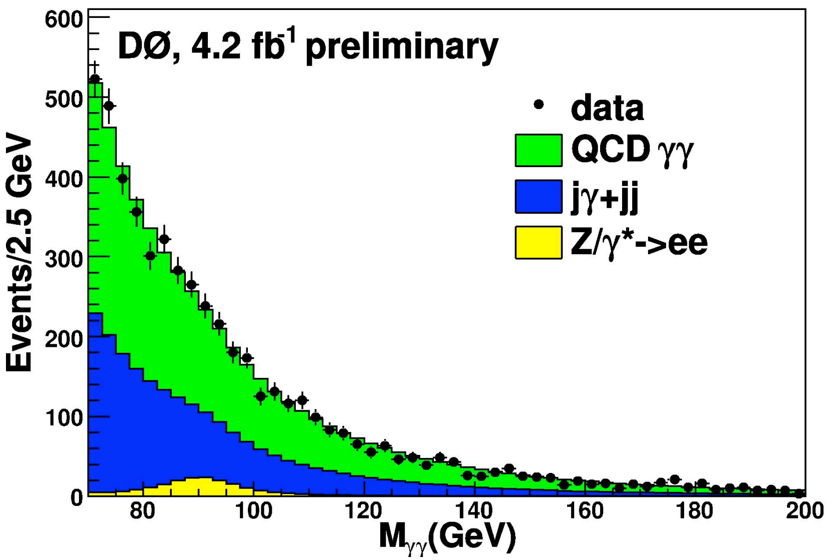
Direct di-photon production

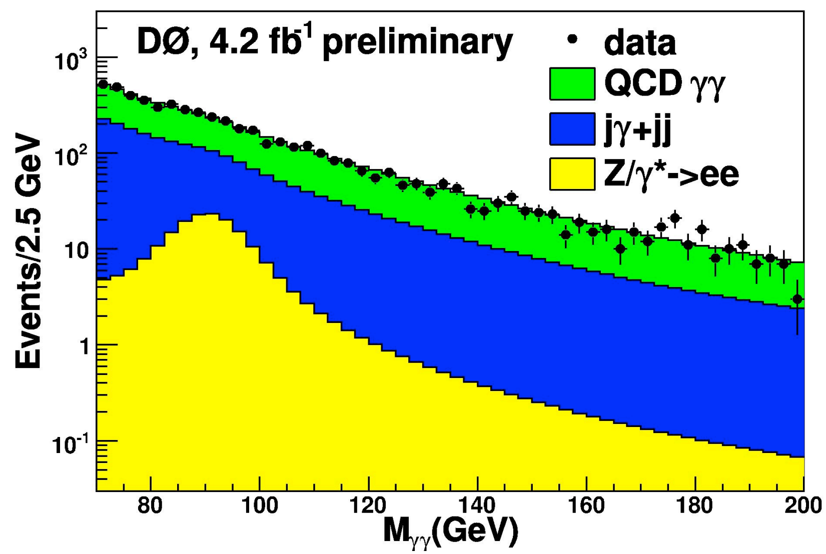
Challenging to predict theoretically. Estimated from sideband fitting in data after subtraction of the reducible backgrounds

Fitting range is [70,200] GeV, excluding the signal region, defined to be interval $m_H \pm 15$ GeV

Choice of fitting function validated on PYTHIA reweighted to DIPHOX (NLO)

$$f(M_{diem}) = \exp(p_0 \cdot M_{diem}^2 + p_1 \cdot M_{diem} + p_2)$$





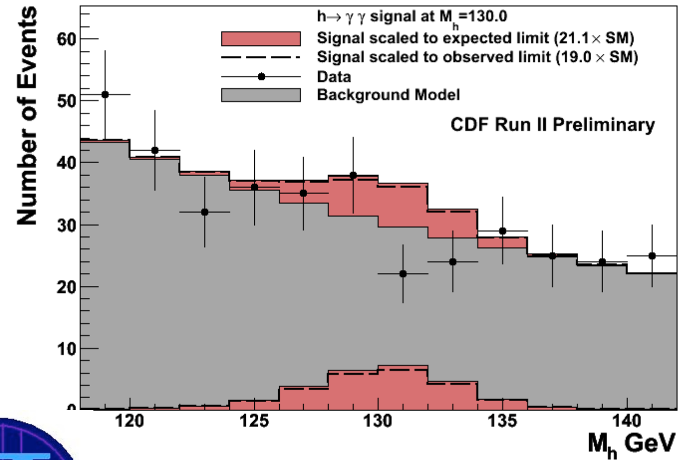
Systematic uncertainties

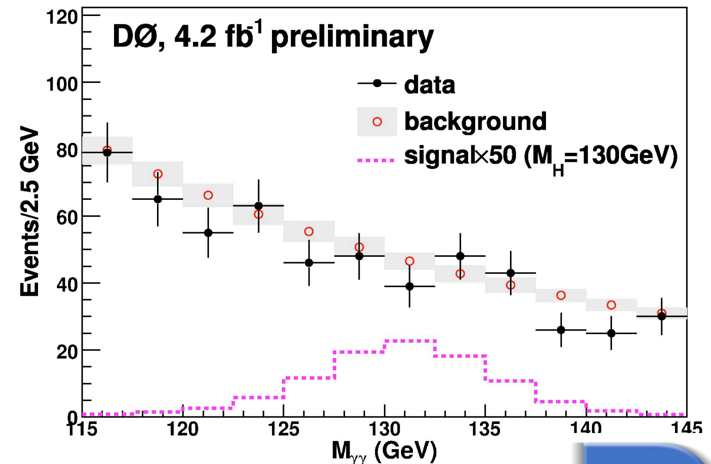
Systematic uncertainties affecting the normalization and shape of the $M\gamma\gamma$ spectrum are estimated for both signal and backgrounds

source	uncertainty
luminosity	6.1%
trigger	0.1%
PDF for $h \to \gamma\gamma$ acceptance	1.7% - 2.2%
electron misidentification efficiency	19.0%
$Z/\gamma^*(ee)$ cross section	3.9%
photon identification efficiency	6.8%
background subtraction	shape
photon energy scale	shape

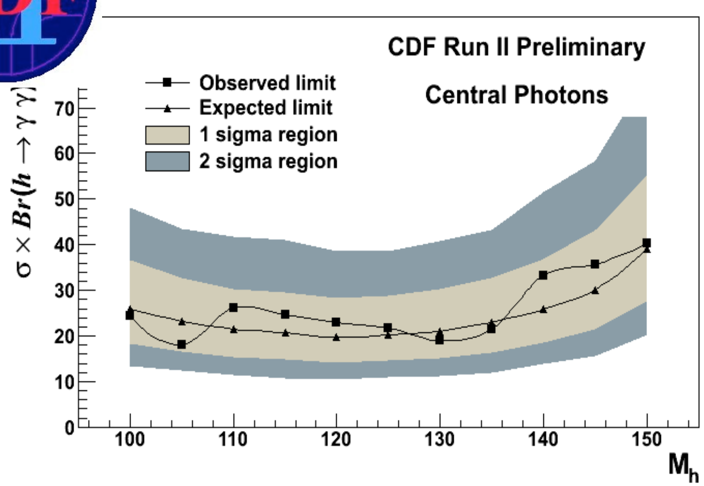
Systematic uncertainties have small effect of limits, final sensitivity completely driven by statistics

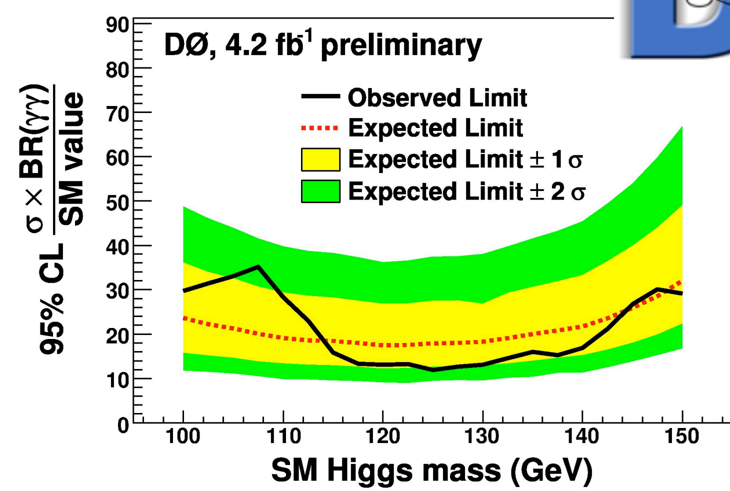
SM Higgs limits





Limits for h→γγ (5.4 fb-1)



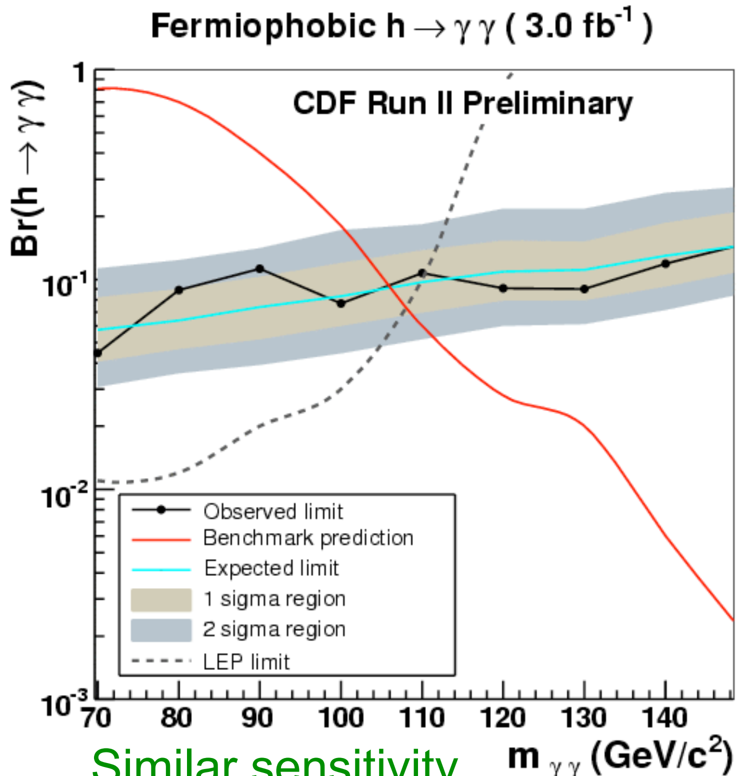


The Mγγ spectrum in the search region is used to derive limits, which are a factor of ~20 above the SM expectation for m_H = 100 ~ 140 GeV

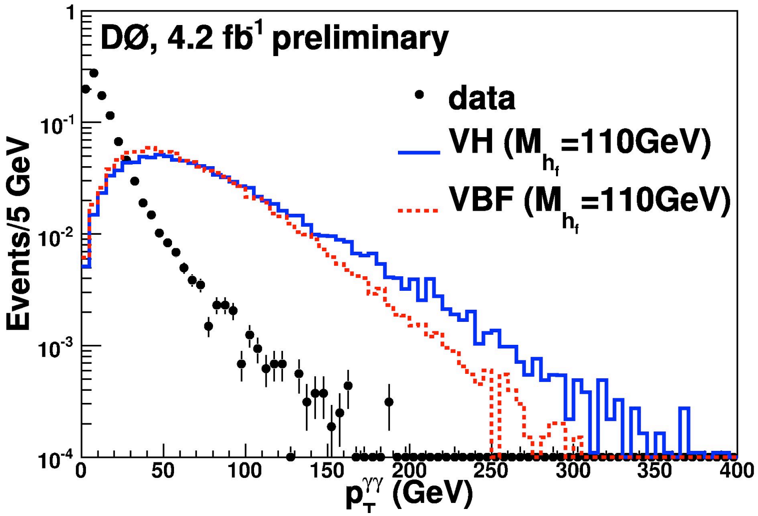
Fermiophobic Higgs limits

Large enhancement to BR($H \to \gamma\gamma$)

Gluon-fusion mechanism absent. Significant Higgs recoil in VH and VBF production



Similar sensitivity for DØ analysis



Similar to SM analysis, but require large di-photon p_T:

$p_T(\gamma\gamma)$ > 75 / 35 GeV (CDF / DØ)

Within Fermiophobic scenario, exclude m_H>106 GeV

Probing BR beyond kinematic reach of LEP

Conclusions

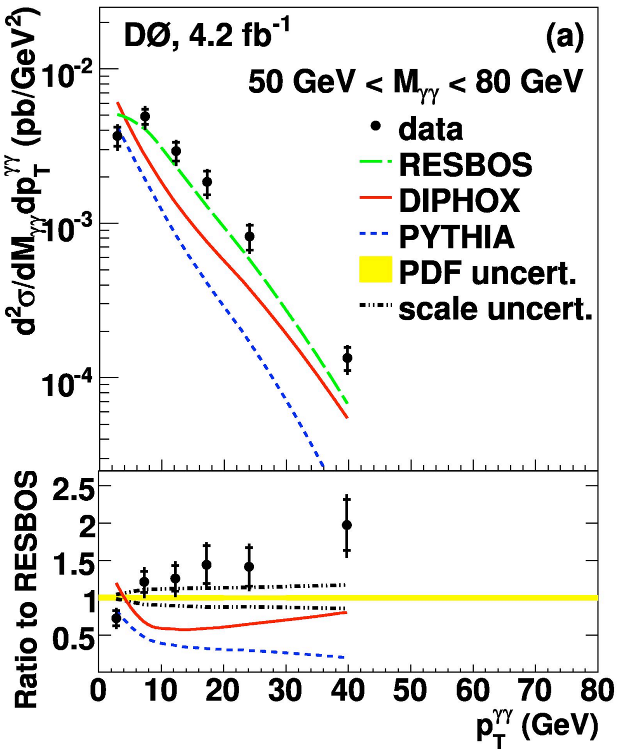
SM Higgs:

Due to the good mass resolution for di-photons, $H \rightarrow \gamma\gamma$ search adds ~5% sensitivity to Tevatron's SM Higgs combination

- Especially important for the difficult intermediate mass region ~130 GeV

Expect main improvements from multivariate analysis

- Di-photon differential cross-section measurements at the Tevatron tell how well the theory works and how to reweight the MC



Fermiophobic Higgs:

Both Tevatron experiments have better sensitivity than any single LEP experiment

- Next round of results likely to exceed combined LEP result

Limits on BR($H \rightarrow \gamma\gamma$) probing new territory beyond kinematic reach of LEP