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

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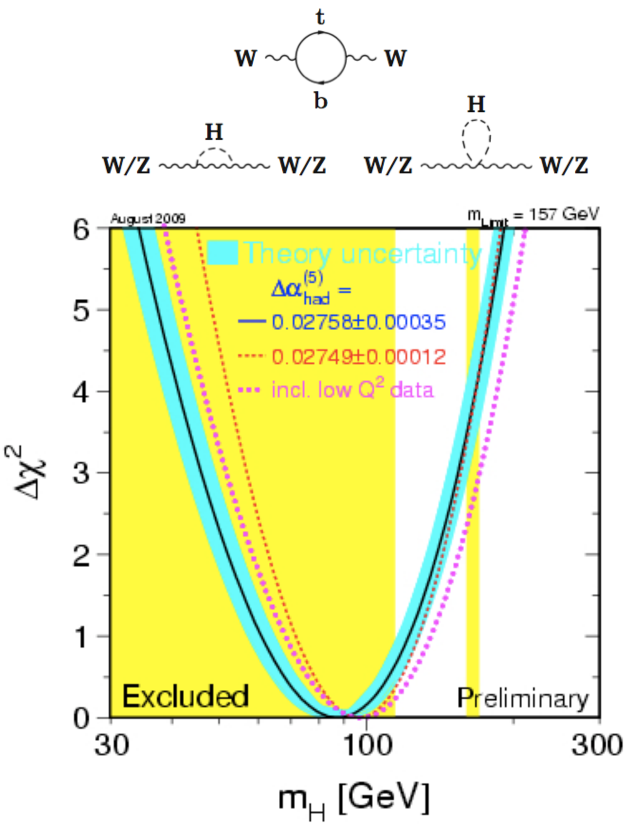
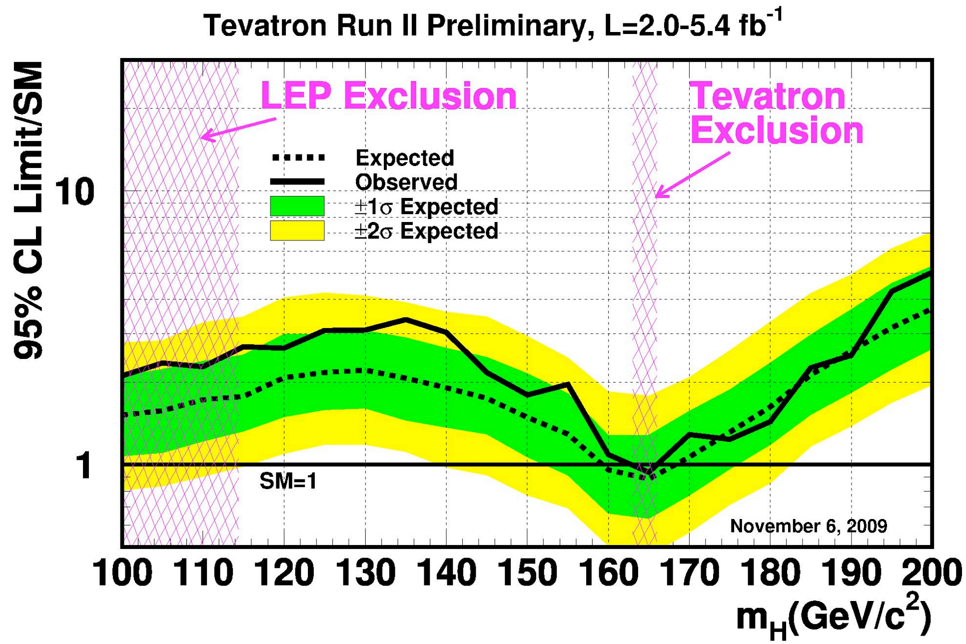
CDF II

DØ

Stalking the Higgs



Combined Tevatron result 2009

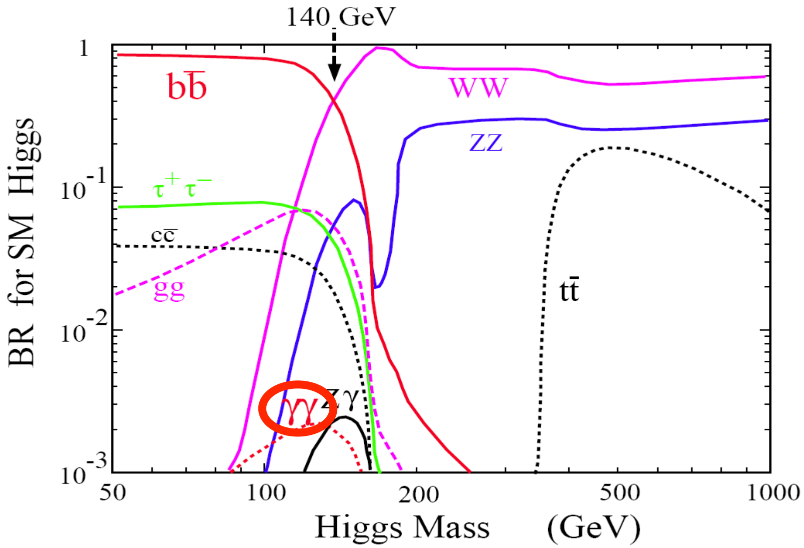


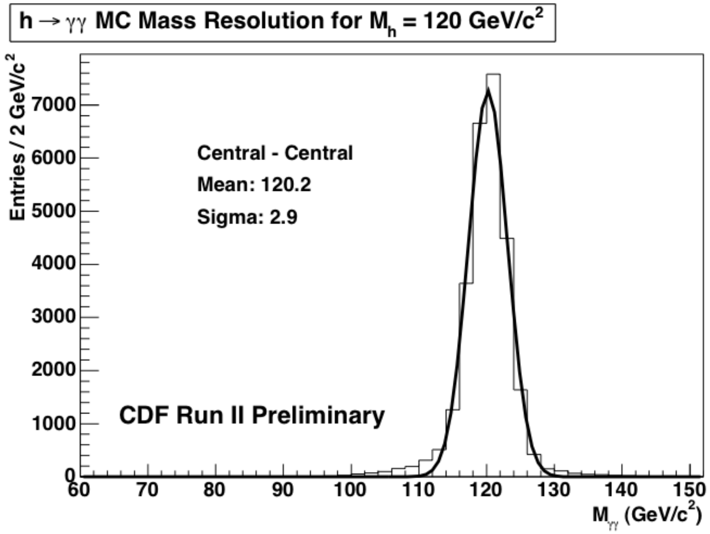
If the SM is correct, a light Higgs boson is around the corner!

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





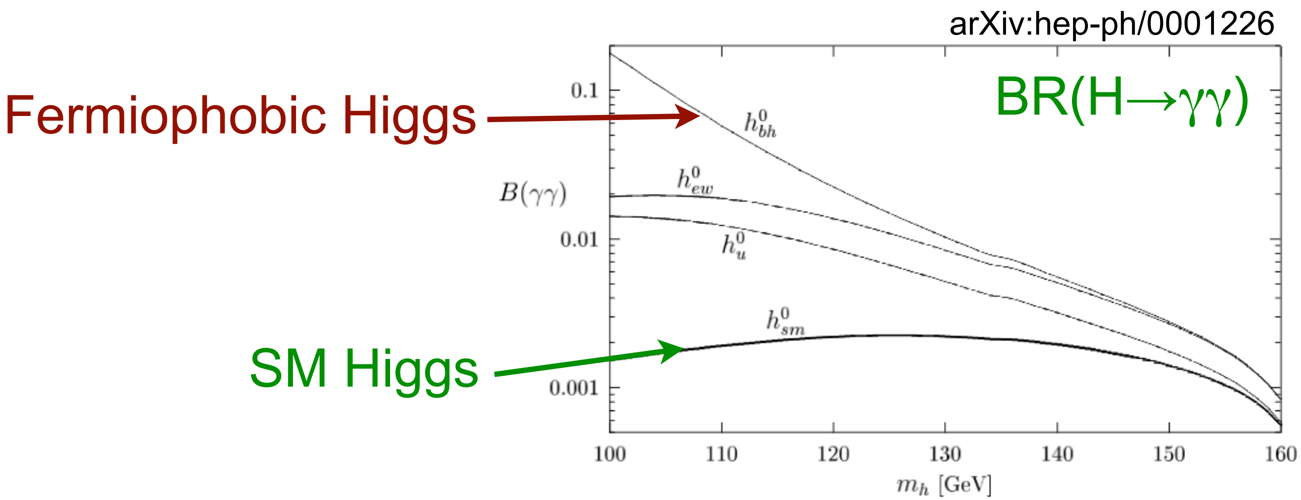
H → γγ provides important additional sensitivity especially in the difficult intermediate mass region ~130 GeV

Forerunner to similar search at the LHC

Why search for H → γγ at the Tevatron?

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

- New particles affecting the loop-mediated Hgg or Hγγ couplings
- Increased BR(H→γγ) in models with modified Higgs couplings to fermions
- Fermiophobic example: suppressed couplings to all fermions



Fermiophobic models can be probed with H → γγ at the Tevatron

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

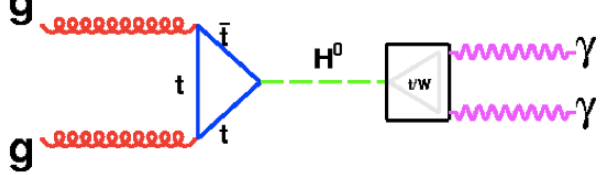
H → γγ search at the Tevatron

Perform search as model-independent as possible

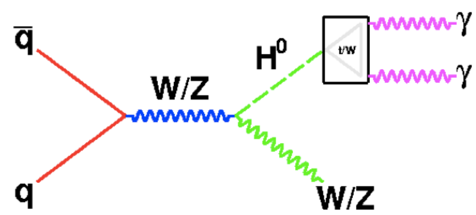
- Inclusive event selection
- Use only di-photon mass observable, look for bump in deeply falling spectrum
- Signal acceptance/sensitivity basically independent of production mechanism

For the Standard Model Higgs:

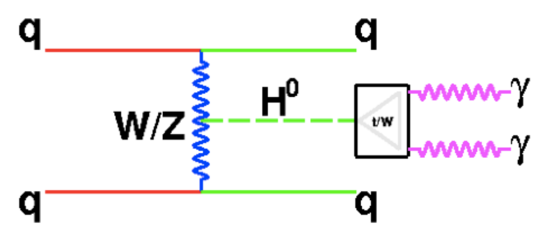
Gluon fusion



Associated production



Vector boson fusion

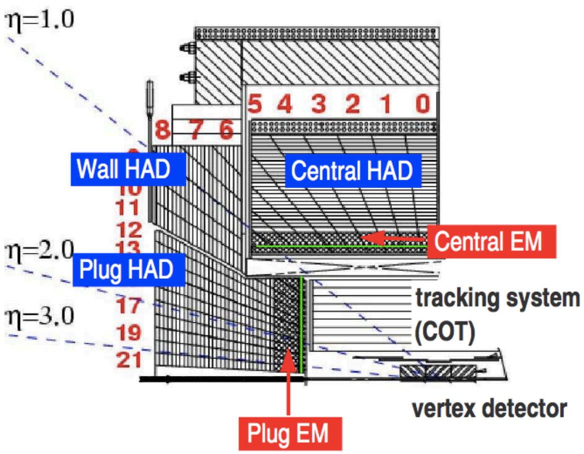


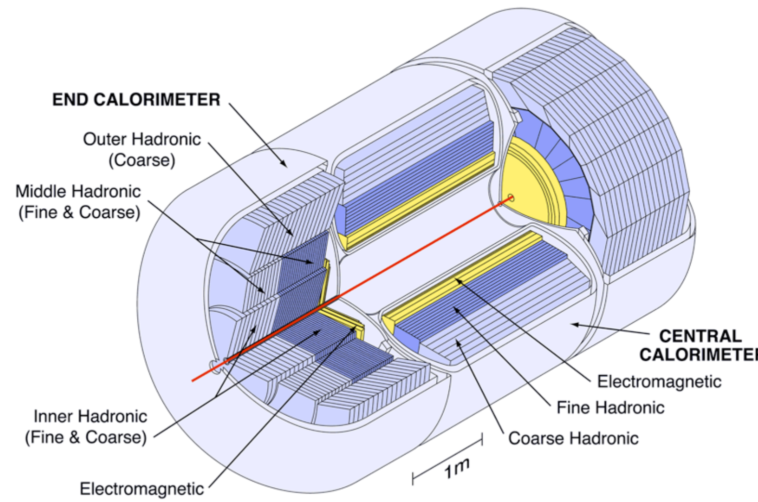
Add ~30% more signal

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)

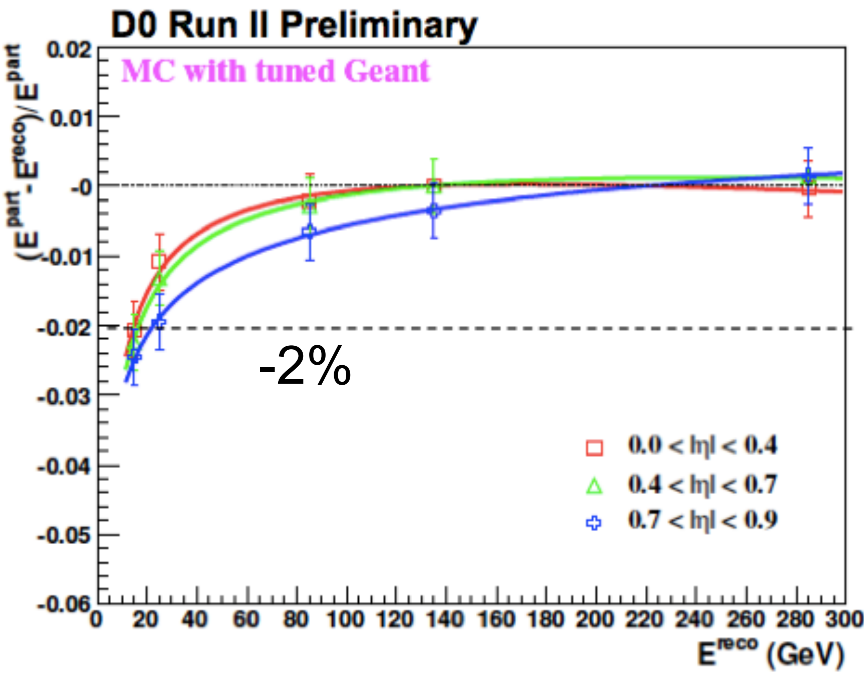
Both calorimeters calibrated regularly with special triggered data

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:

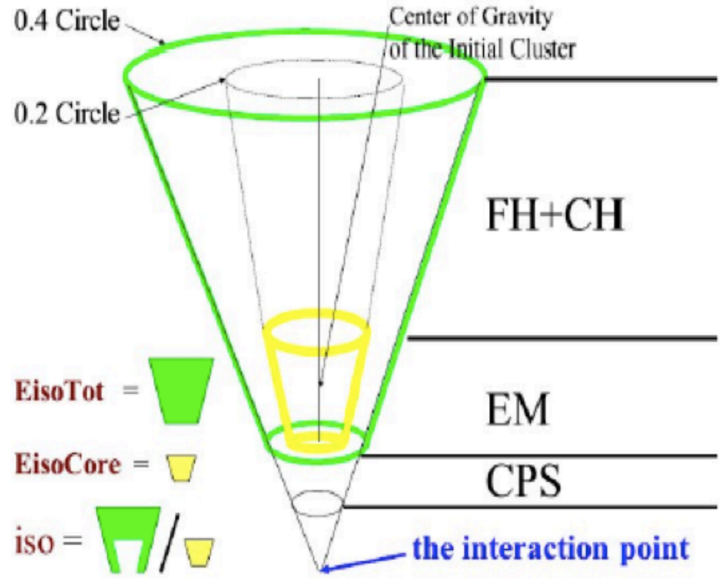
- Energy scale: ±0.5%
- Energy resolution: ±5% in constant term

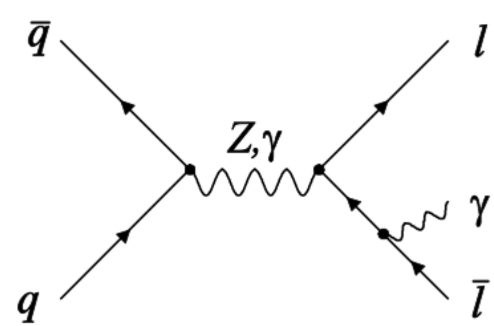
Photon identification: basic selection

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 ($Z \rightarrow ll\gamma$) and $Z \rightarrow ee$





Photon identification: Neural Network

DØ: Further improve photon purity with a five variable NN

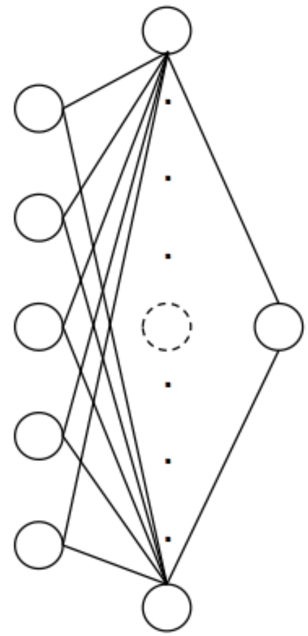
Tracker isolation ($p_T^{sum,trk}$)

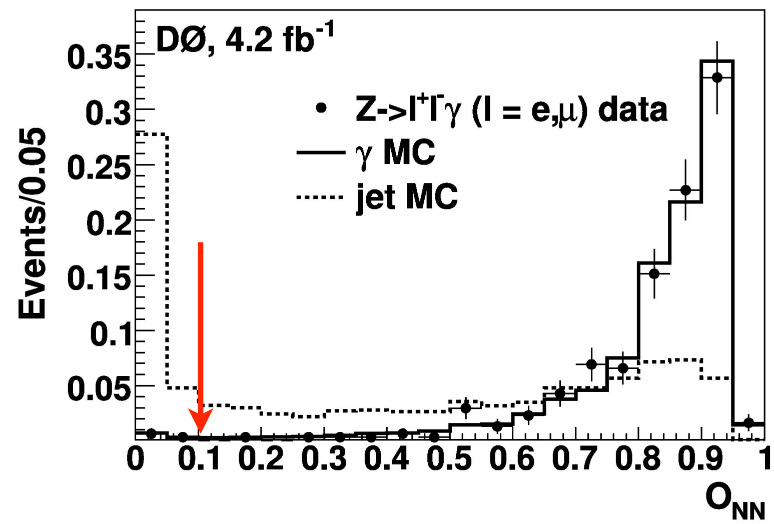
Number of EM1 cells within R<0.2

Number of EM1 cells within 0.2<R<0.4

Number CPS clusters within R<0.1

Squared-energy-weighted width of energy deposition in the CPS





Trained using QCD γγ and di-jet MC. Performance verified with Z → llγ data events - excellent agreement between data and MC

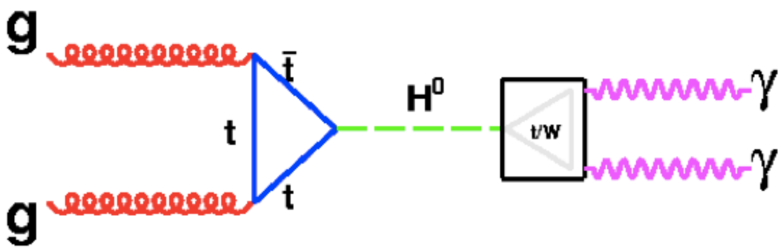
Require NN>0.1 (almost 100% efficient for photons while rejecting 50% misidentified jets)

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:

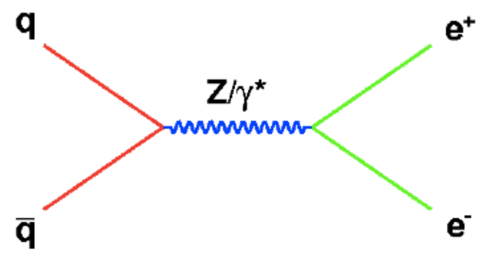
- In central calorimeters (away from module boundaries)
- $p_T > 15$ / 25 GeV (CDF / DØ)
- $M_{\gamma\gamma} > 30$ / 60 GeV (CDF / DØ)

Main backgrounds

Reducible backgrounds:

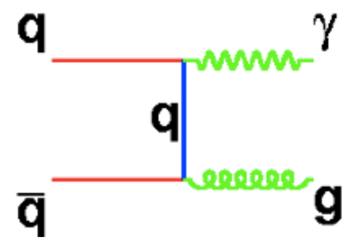
Electrons misidentified as photons: $Z/\gamma^* \to ee$

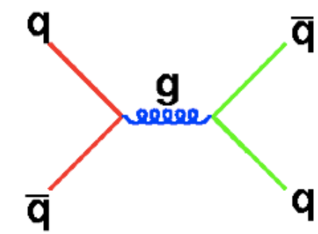
Estimated using MC normalized to NNLO theoretical cross section and with suitable data/MC scale factors to correct selection efficiencies



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

Normalization and shape estimated directly from data using photon NN information

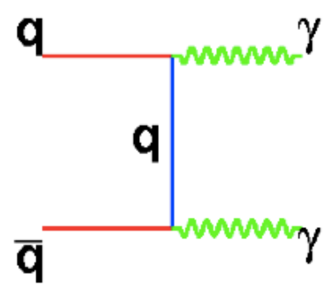




Irreducible background:

Direct QCD di-photon production

Normalization and shape estimated directly 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

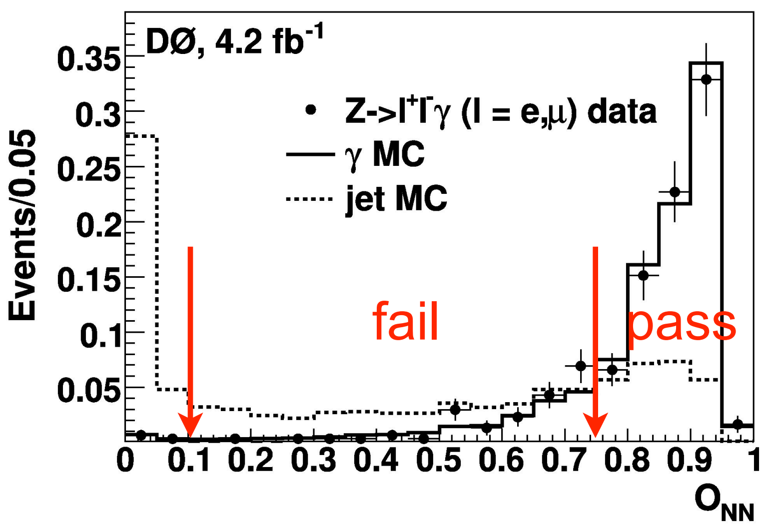
$$\begin{pmatrix} w_{jj} \\ w_{j\gamma} \\ w_{\gamma j} \\ w_{\gamma\gamma} \end{pmatrix} = E^{-1} \times \begin{pmatrix} w_{ff} \\ w_{fp} \\ w_{pf} \\ w_{pp} \end{pmatrix}$$

Both photons fail

Leading fail, trailing passes

Leading passes, trailing fails

Both photons pass

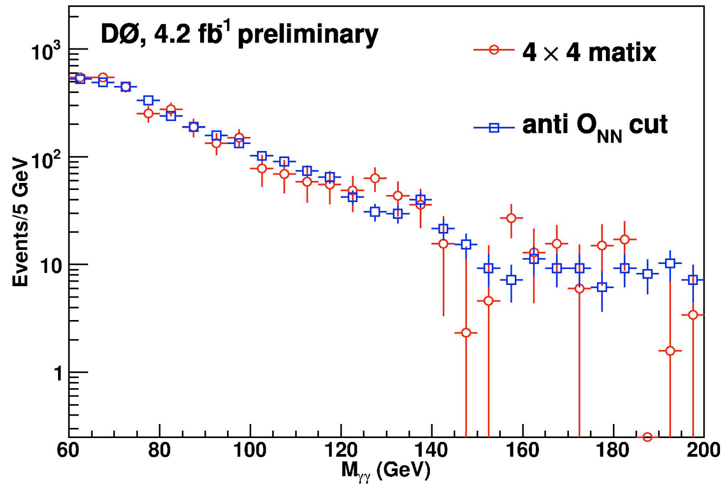


Solve linear equation with photon and jet efficiencies to obtain Njj+Nγj+Njγ

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

Take normalization from 4x4 Matrix Method, shape from Inverse-NN Method (but smoothen statistical fluctuations)

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



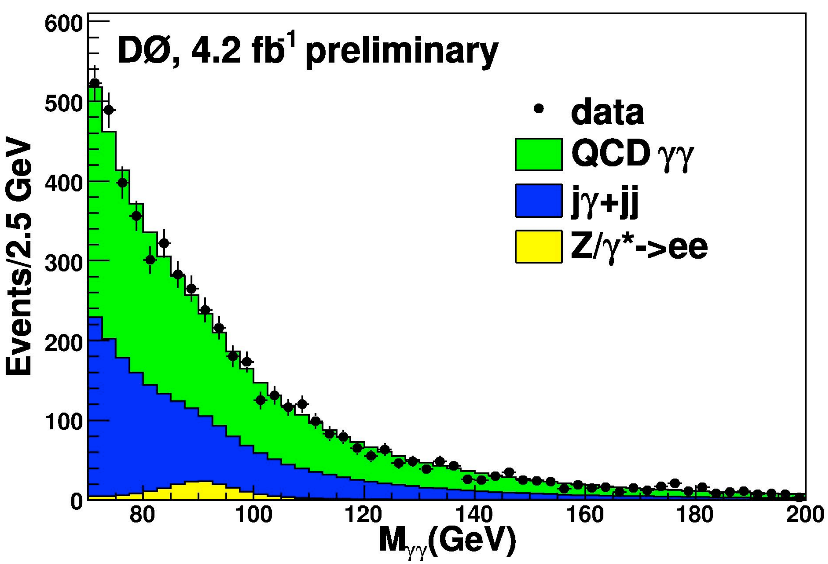
Direct di-photon production

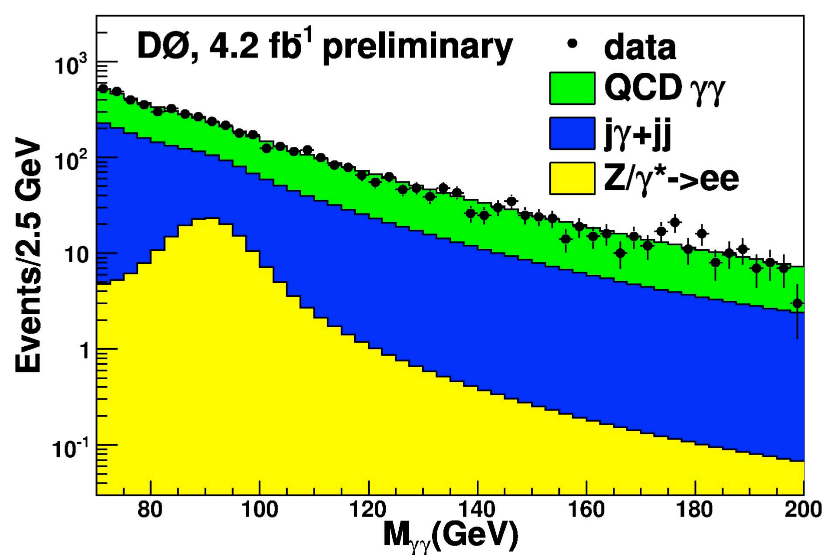
Challenging to predict theoretically. DDP background estimated from sideband fitting in data after subtraction of the reducible backgrounds

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)

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





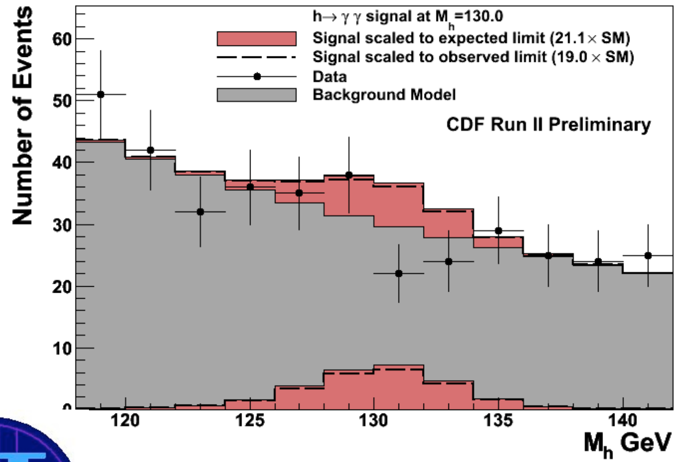
Systematic uncertainties

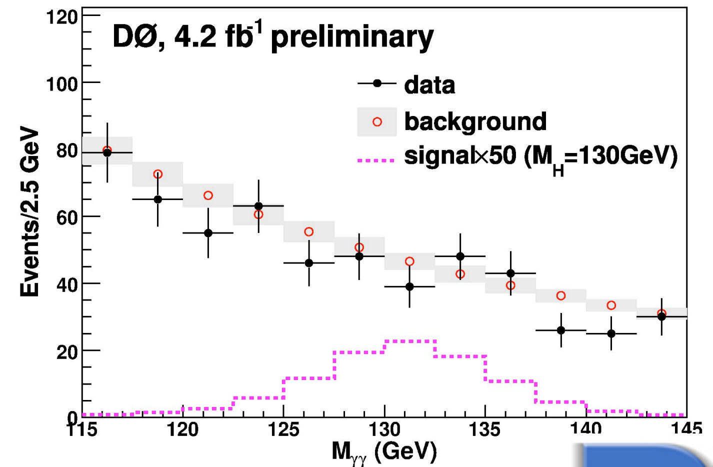
Systematic uncertainties affecting the normalization and shape of the Mγγ spectrum are estimated for both signal and backgrounds

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/γ^*(ee) cross section	3.9%
photon identification efficiency	6.8%
background subtraction	shape
photon energy scale	shape

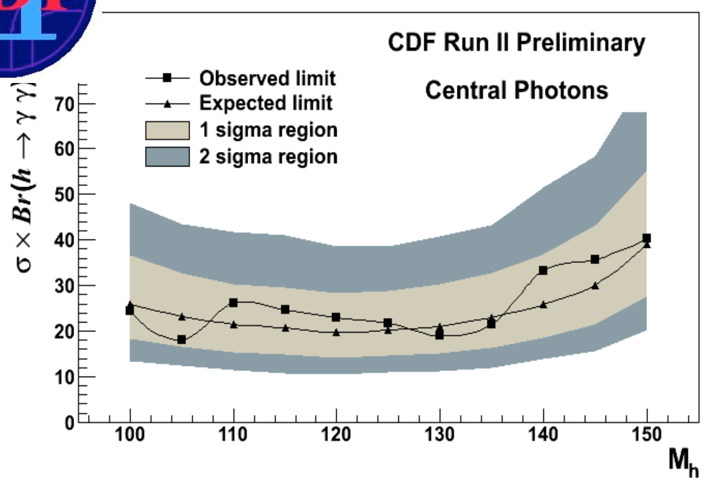
Uncertainties effecting the $Z/\gamma^* \to$ ee background are propagated to the estimation of the γ+jet and di-jet contribution, together with the NN>0.75 selection efficiency. All these effect further the shape and normalization of the DDP background contribution

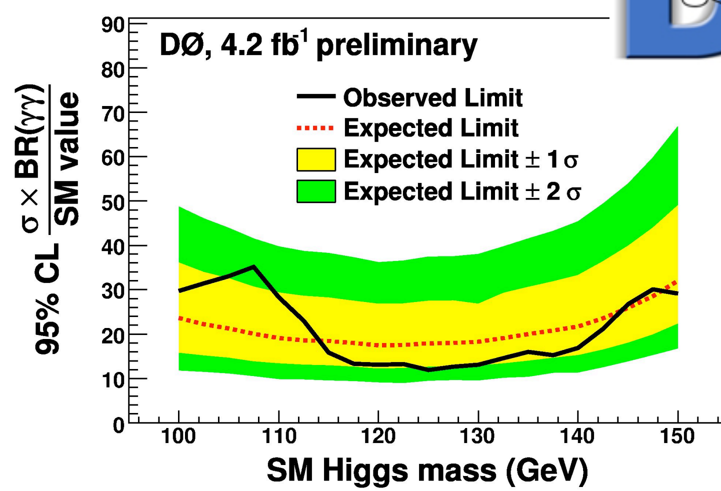
SM Higgs limits





Limits for h→ γ γ (5.4 fb^{-1})



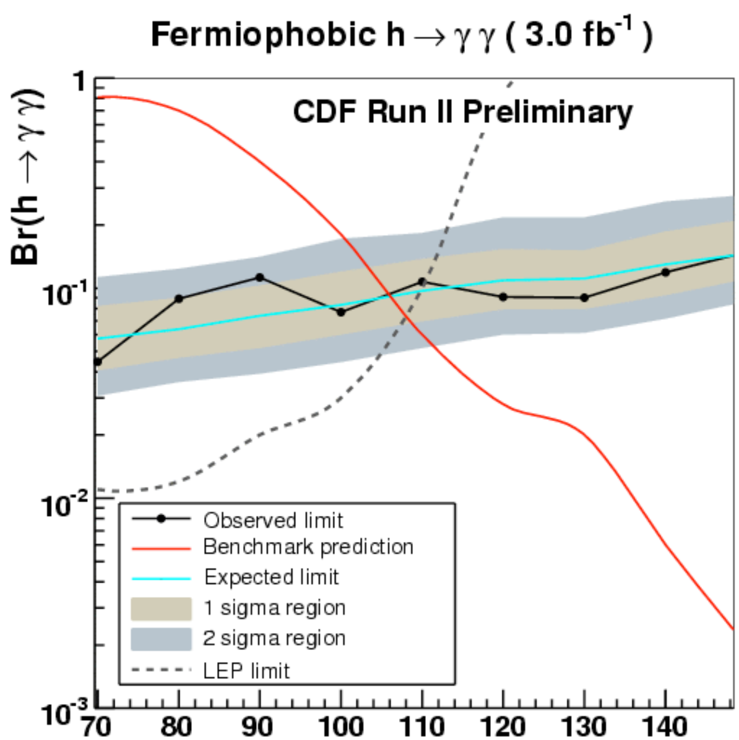


The Mγγ spectrum in the search region is used to derive limits, which are a factor of ~20 above the SM expectation for m_H = 100 ~ 140 GeV

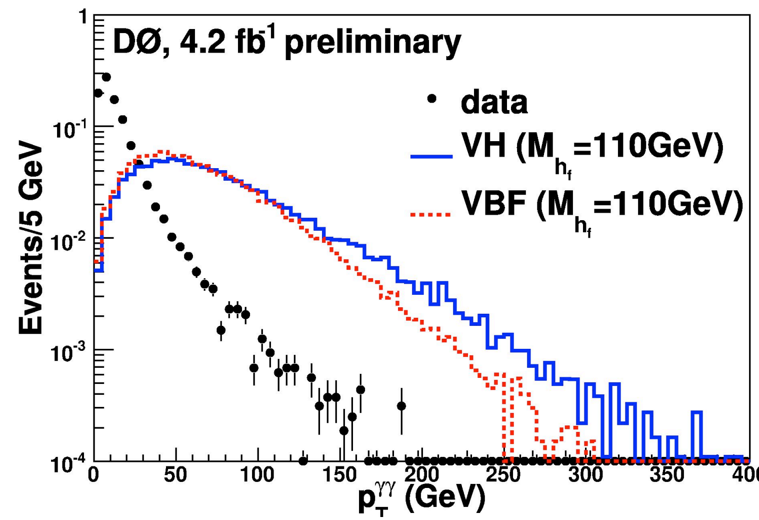
Fermiophobic Higgs limits

Large enhancement to B(H→γγ)

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

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 additional variables in a 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