Search for a SM Higgs boson in the diphoton final state at CDF

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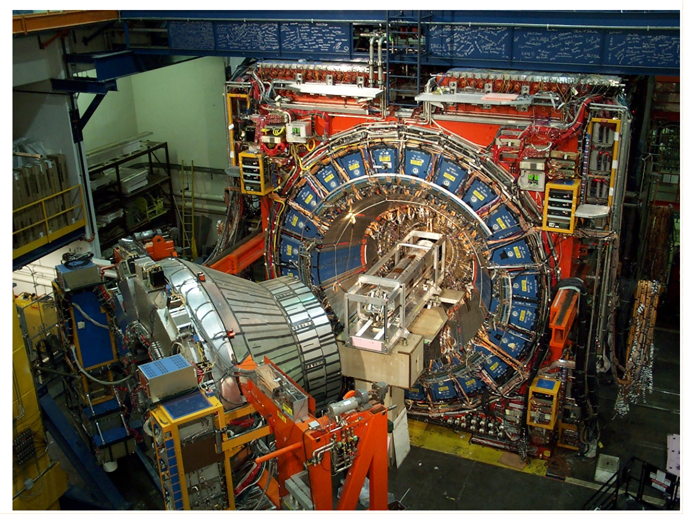
On behalf of the CDF Collaboration

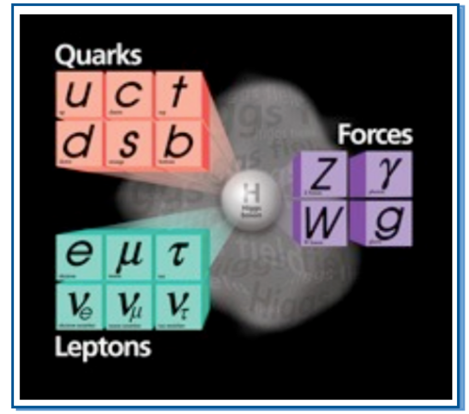
UVA Particle Physics Seminar Series
April 20, 2011
Charlottesville, VA



Outline

- Introduction
- Higgs Searches at the Tevatron
- Motivation for H→$\gamma\gamma$
- Tevatron and CDF
- Photon Identification
- Background Model
- Results
- Summary

The Standard Model



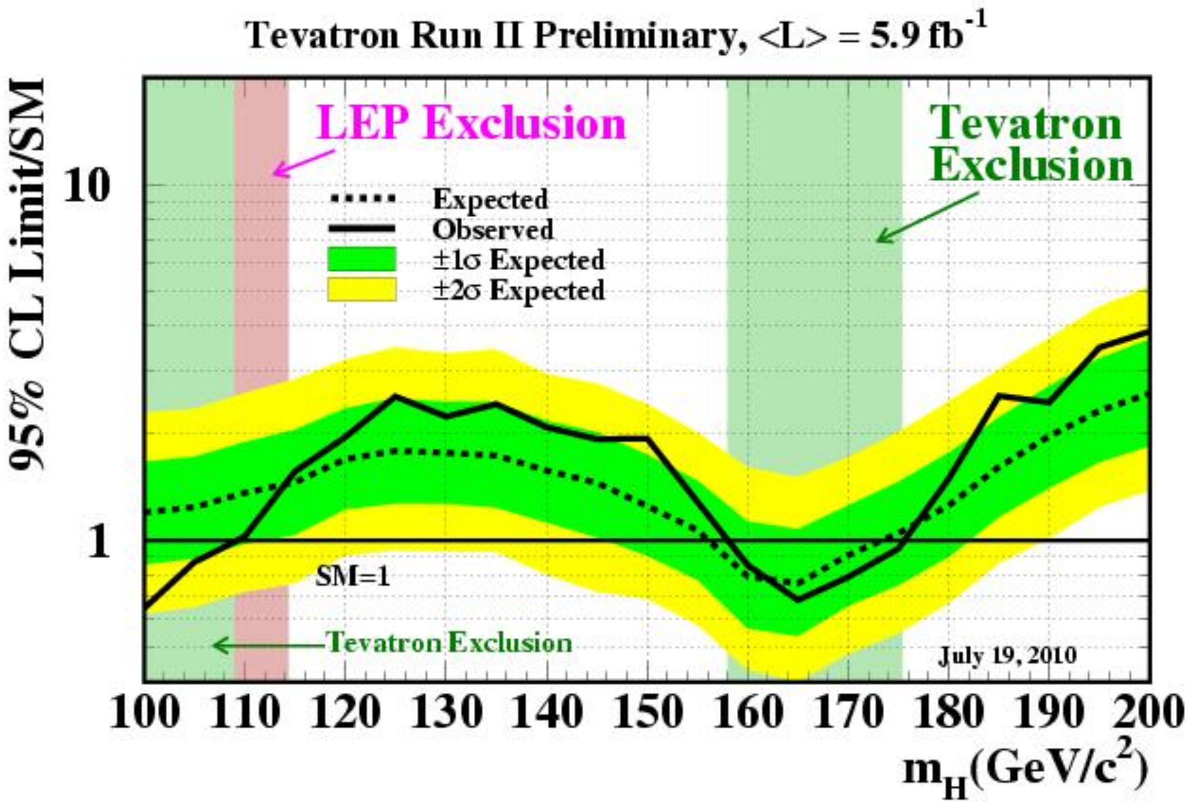
- The Standard Model
  - Describes the fundamental constituents of matter and the interactions between them
  - Has had tremendous success in explaining a wide variety of experimental results
  - Yet still considered incomplete
  - Says nothing about the masses of particles!
  - The Higgs mechanism was theorized in the 1960's…
- Through the "Higgs Mechanism"
  - The W and Z bosons acquire large masses, yet the photon remains massless
  - The masses of quarks and leptons are also generated
  - Predicts the existence of a single, scalar Higgs Boson… that has not been observed in nature

The SM Higgs Boson

- Higgs mechanism generates mass of particles… yet reveals no hint of what the Higgs boson mass is
- If the Higgs boson exists it must be determined experimentally
- What we know so far:
  - From direct searches at LEP II: $m_H > 114$ GeV/c^2 @ 95% CL
  - From indirect electroweak precision measurements (involving top quark mass, W boson mass): $m_H < 186$ GeV/c^2 @ 95% CL
  - Probing the range $100 < m_H < 200$ GeV/c^2 is crucial!
  - This is exactly the range where the Tevatron is sensitive…
  - The most recent Tevatron exclusion region is between 158 – 173 GeV/c^2 @ 95% CL

Status of Higgs Search at the Tevatron

for Low and High Mass Combination (July 2010)



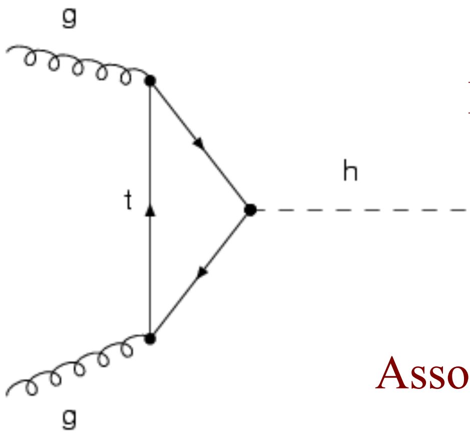
- Upper limits shown on the number of Higgs bosons produced with 95% CL, with ~5.9 fb^{-1} of data
- These limits are shown relative to the SM prediction for comparison
- Expected limit based on background models. Observed limit based on data.
- 1*SM implies that we would be able to exclude a Higgs boson with a 95% confidence level
- 2*SM means that we would be able to exclude a Higgs boson if it were produced at a rate twice what the SM predicts

There is a lot of work being done still to extend this exclusion region, so stayed tuned!

SM Higgs production at the Tevatron

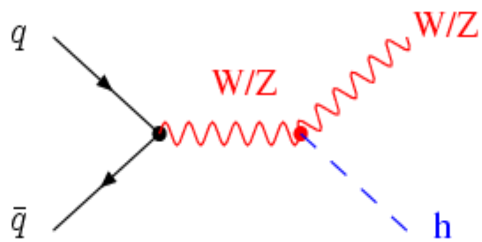
- The Higgs is produced only rarely:
  - In one out of every 10^{12} collisions
  - That's about 2 Higgs bosons produced each week
- How is the Higgs produced?

SM Higgs production at the Tevatron

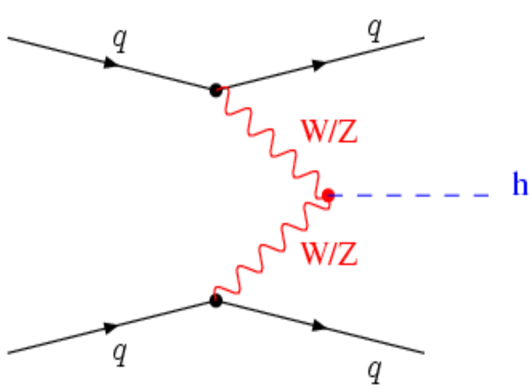


Direct Production
(Gluon Fusion)

Associated Production



Vector Boson Fusion



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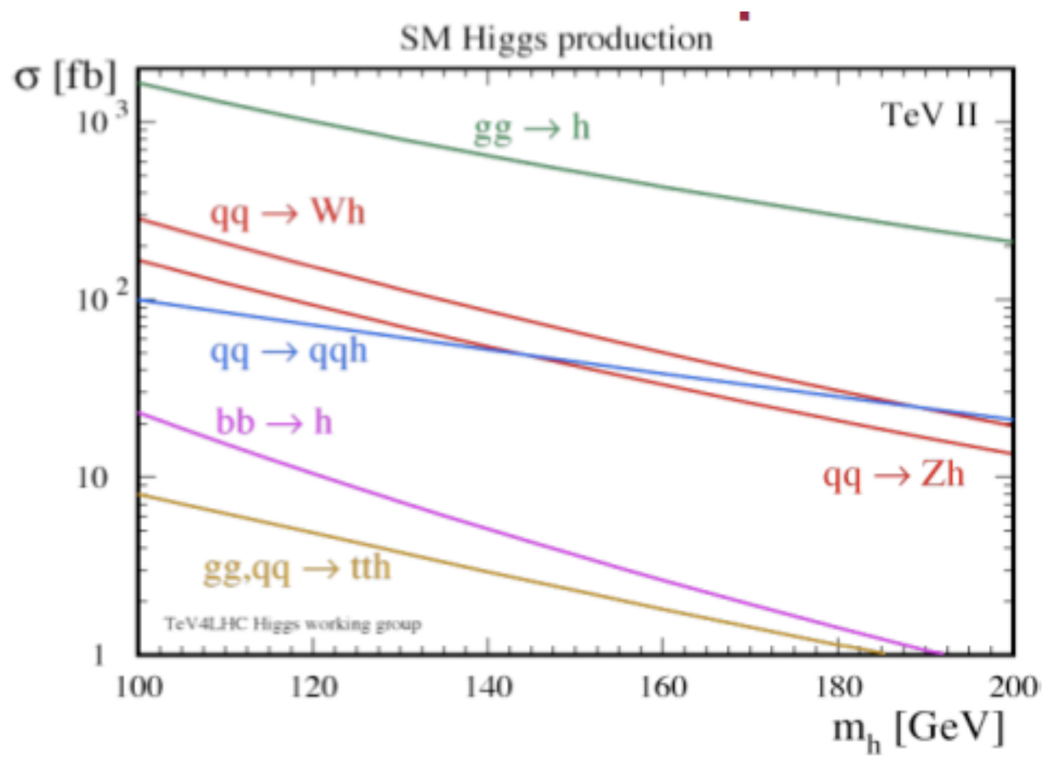
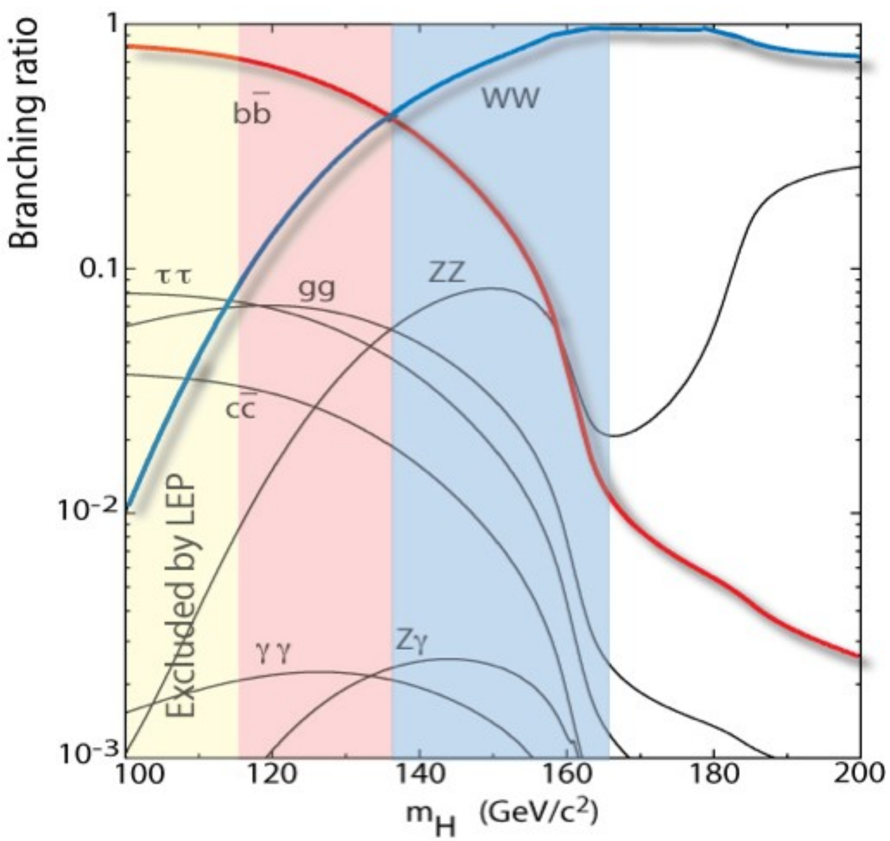


SM Higgs Decay

Since the mass of the Higgs boson is unknown, we seek the Higgs through various search channels in order to maximize the chance of finding it.

Some channels are sensitive to a Higgs boson at low mass. Others are sensitive at high mass.



High mass Higgs

- $m_H > 135$ GeV/c^2
- Main decay mode is $H \rightarrow W^+W^-$
  - Main channel to help exclude masses between ~160-175 GeV/c^2

Low mass Higgs

- $m_H < 135$ GeV/c^2
- Main decay mode is $H \rightarrow bb$
  - $gg \rightarrow H \rightarrow bb$ is overwhelmed by multijet background events
  - So this main channel relies on associative production (WH/ZH)
- Secondary channels:
  - $H \rightarrow \tau\tau$
  - $H \rightarrow \gamma\gamma$

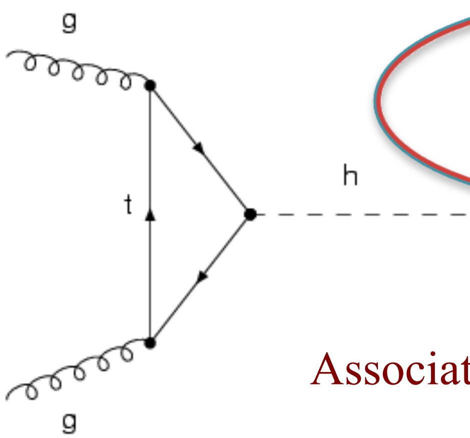
Inclusion of Secondary Channels

- In general, no single channel able to exclude or give evidence for the Higgs, so combination needed
- For last year's combination secondary low mass channels had sensitivities ~ 20xSM >> Combo
- Individually, contribute perhaps a few percent
- Together, however, the channels shown at the right have a limit of ~8xSM…

- *Combination of the secondary channels is like a primary channel!*

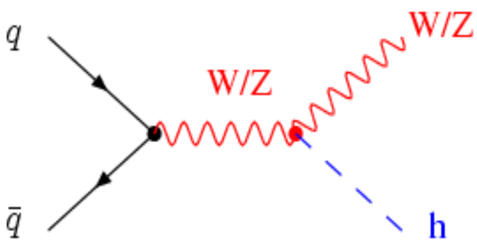
Analysis	L (fb^{-1}) Analyzed	Expected Sensitivity @MH =115 (xSM)
Tevatron Combo	2.0-5.4	1.78
CDF qqbb	4.0	18
CDF $H \to \tau\tau$	2.3	25
DØ $H \to \tau\tau qq$	4.9	18.8
DØ $WH \to \tau\upsilon bb$	4.0	22.4
DØ $H \to \gamma\gamma$	4.2	18.5
CDF $H \to \gamma\gamma$	5.4	19.4 (@120)

SM H→γγ Search

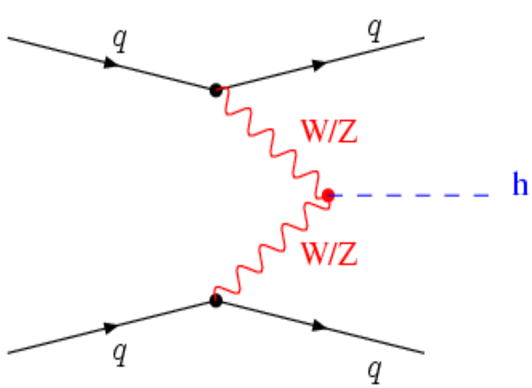


Gluon Fusion:
σ ≈ 1000 fb*

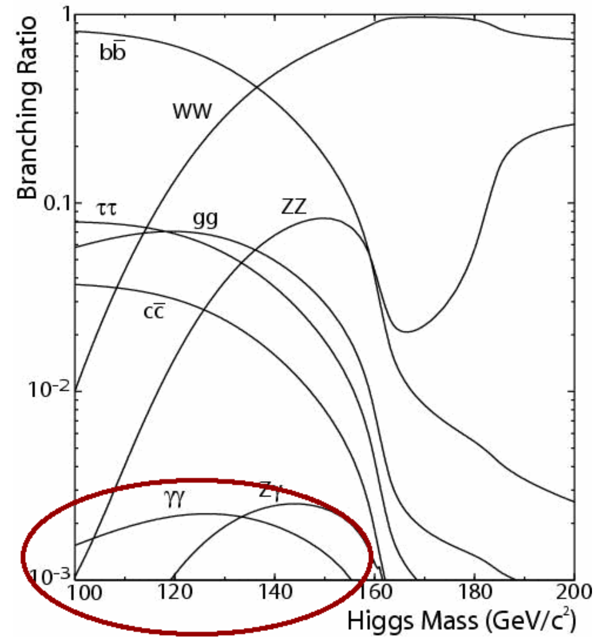
Associated Production:
σ ≈ 225 fb*



Vector Boson Fusion:
σ ≈ 70 fb*



*σ for √s = 1.96 TeV p-pbar collisions and M_h = 120 GeV/c^2



- Overall σ: ~1300 fb: larger overall cross section than bb channels
- Br(h→$\gamma\gamma$) < 0.0025: smaller branching ratio than bb channels
- Low mass search: Focus on 100 – 150 GeV/c^2
- Diphoton signal expectation with 7.0 fb^{-1} of data:

$N = \sigma \bullet L \bullet Br$

$= 1300fb \bullet 7.0fb^{-1} \bullet 0.0025$

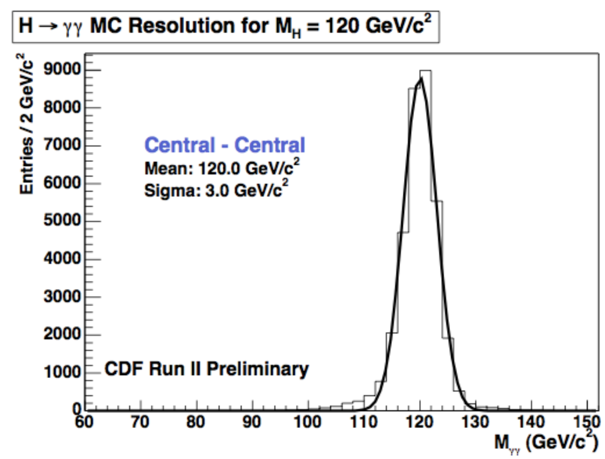
≈ 23 h→γγ events produced in the detector

≈ 5 that would be reconstructed

$H\rightarrow\gamma\gamma$ Search: Motivation

- **Clean Signature**:
  - Photons are easier to identify and reconstruct from detector information than jets that come from b-quarks
  - So larger fraction of $H\rightarrow\gamma\gamma$ events accepted in comparison
  - Also improves the reconstructed mass resolution…
- **Small Mass Resolution**:
  - Limited mainly by energy resolution of electromagnetic (EM) calorimeters which has relatively small uncertainty
  - $\sigma/M_{\gamma\gamma}$ ~ 4x better than that from best jet algorithms used to identify $H\rightarrow$b b-bar
  - The $M_{\gamma\gamma}$ distribution of the data is smooth, so this means we can simply search for a narrow resonance in the data

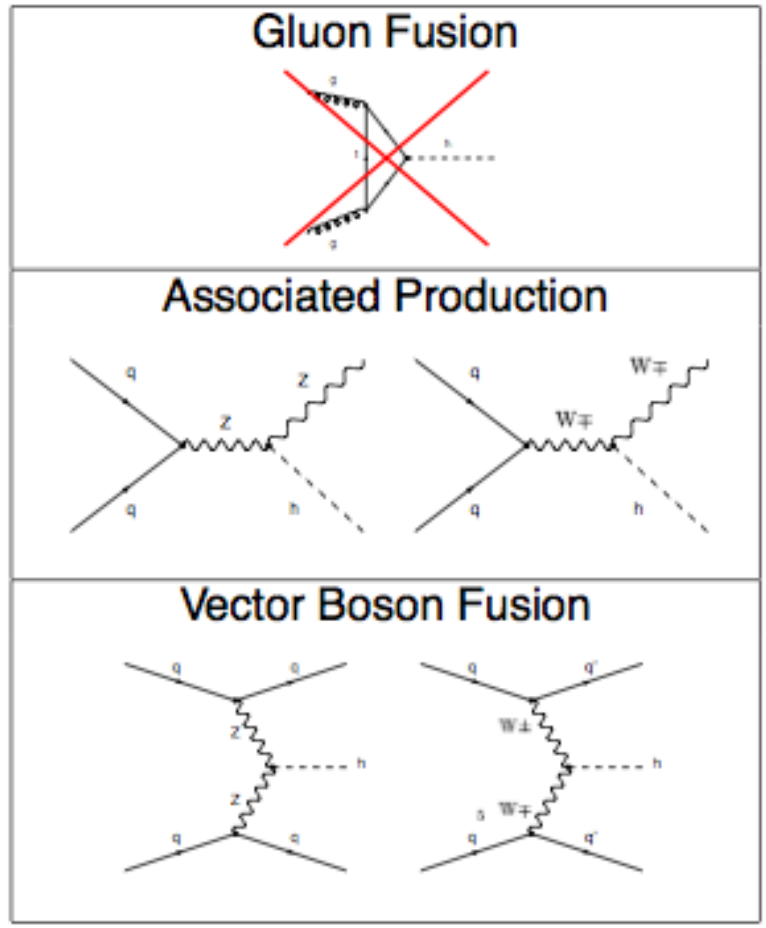
- At the Tevatron, included in Higgs combination
- One of most likely modes for low mass SM Higgs discovery at LHC due to larger backgrounds in b-bbar channel as compared to Tevatron



Also, many beyond SM scenarios include a larger Br($h\rightarrow\gamma\gamma$)…

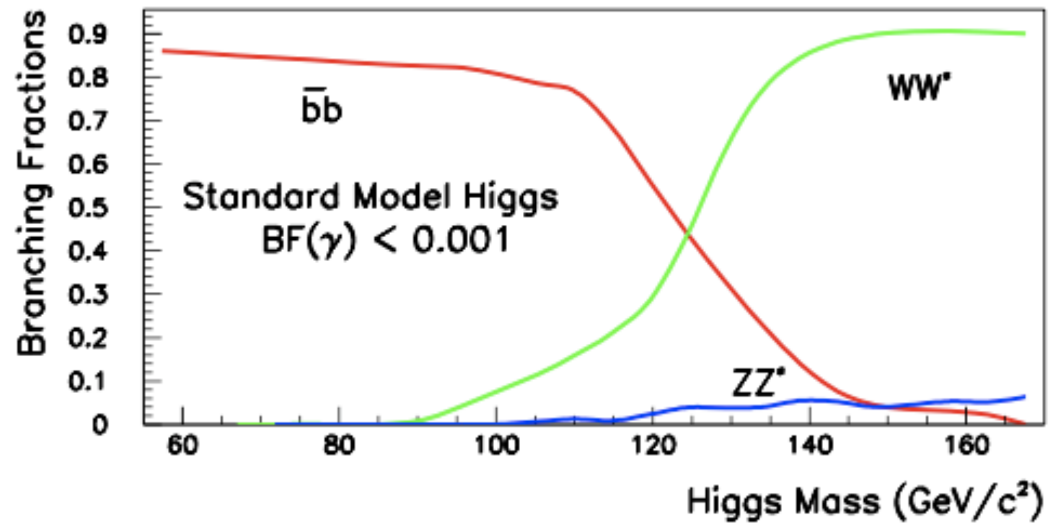
Fermiophobic h→γγ Channel

- In a two-Higgs doublet model extension to the SM:
  - SM production cross section assumed
  - No Higgs coupling to fermions
  - SM Higgs coupling to bosons
    - Br(h→bb) suppressed
    - Br(h→γγ) enhanced for low mass
    - Only WH, ZH, and VBF production (no gg→h)
- Both CDF and DZero have considered this "benchmark" fermiophobic model

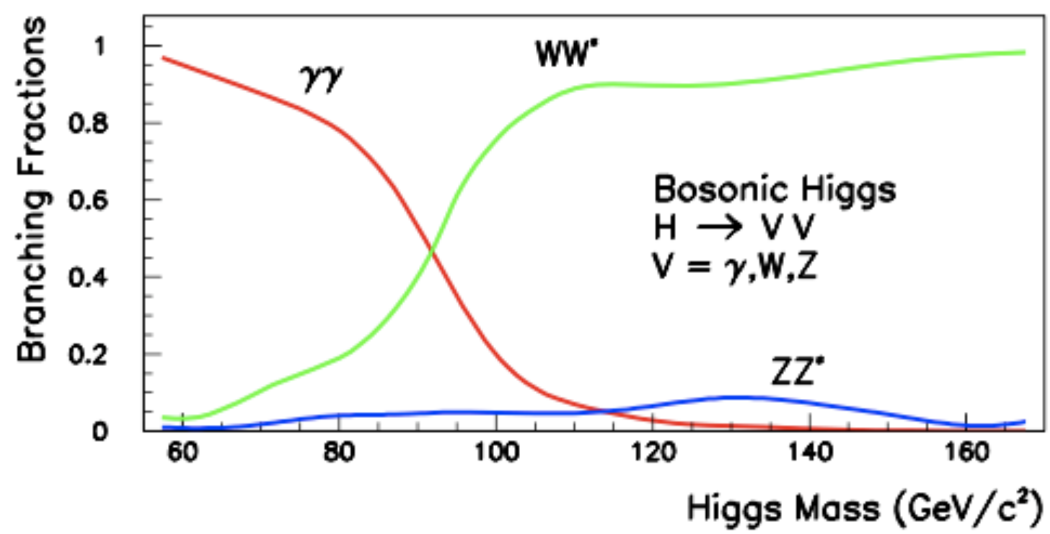


Fermiophobic h→γγ Channel

- SM Br where bb final state dominates at low mass →

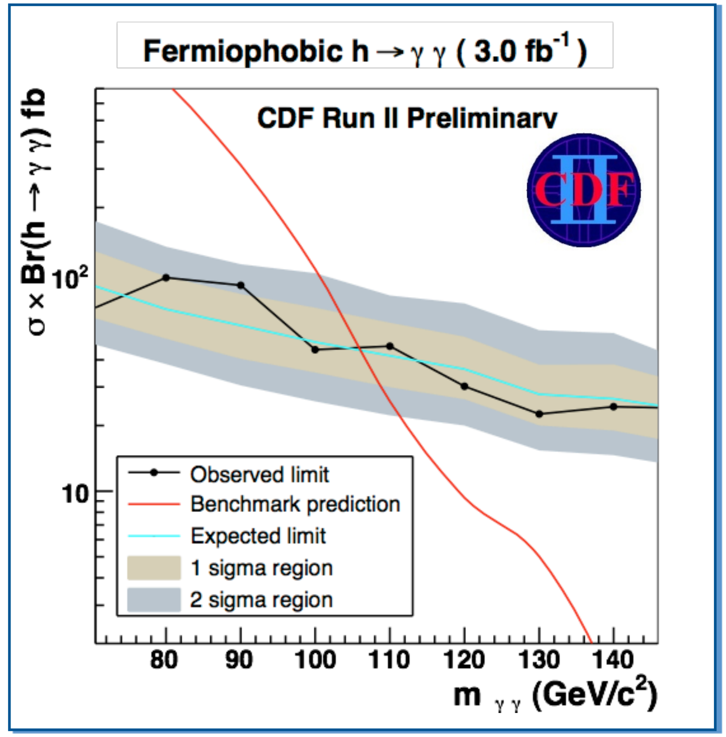


- Diphoton final state becomes primary decay channel at low mass →



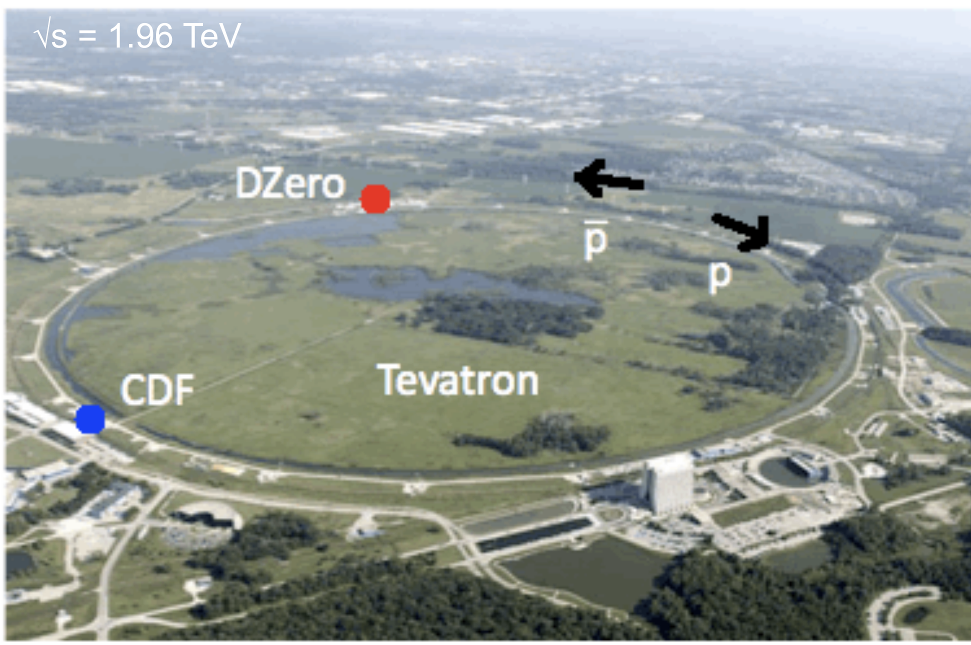
Fermiophobic h→γγ Channel

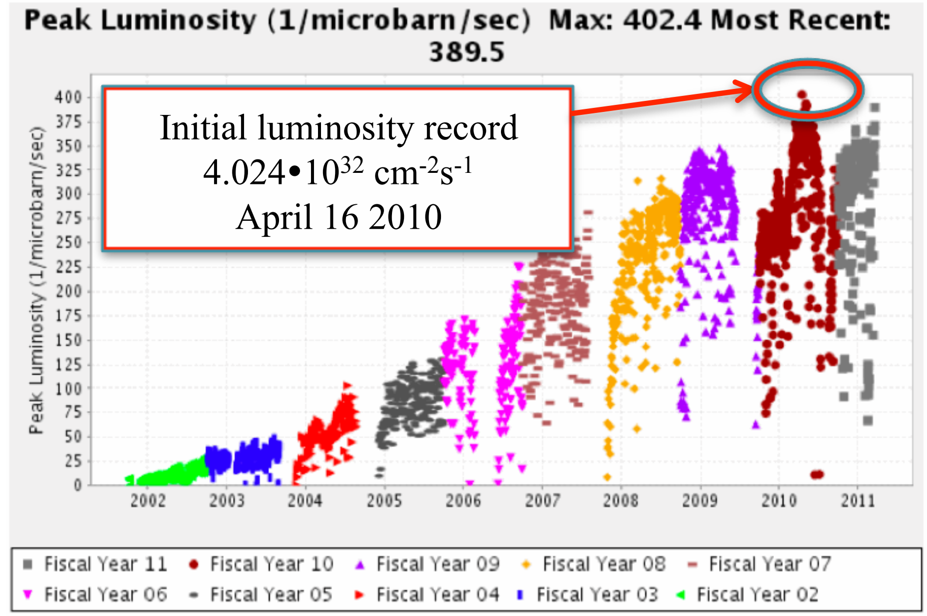
- CDF Result w/ 3.0fb-1
  - Two photons selected and γγ mass distribution searched for resonance
  - No excess observed in data so limits set on Higgs production
  - $M_{\gamma\gamma}$>106 GeV/c^2
- Other limits:
  - $M_{\gamma\gamma}$>109.7 GeV/c^2 by LEP
  - $M_{\gamma\gamma}$>112 GeV/c^2 by Dzero w/ 8.2 fb-1 (March 2011) Currently best limit
- Results presented today are for SM Higgs, but CDF expected to have an updated competitive result for fermiophobic Higgs within the next month!

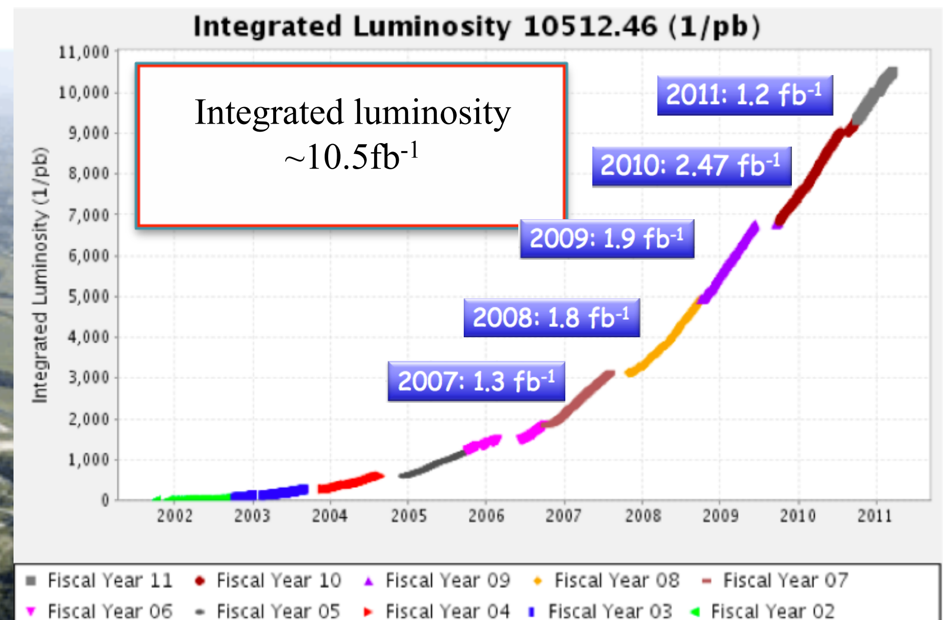


Tevatron

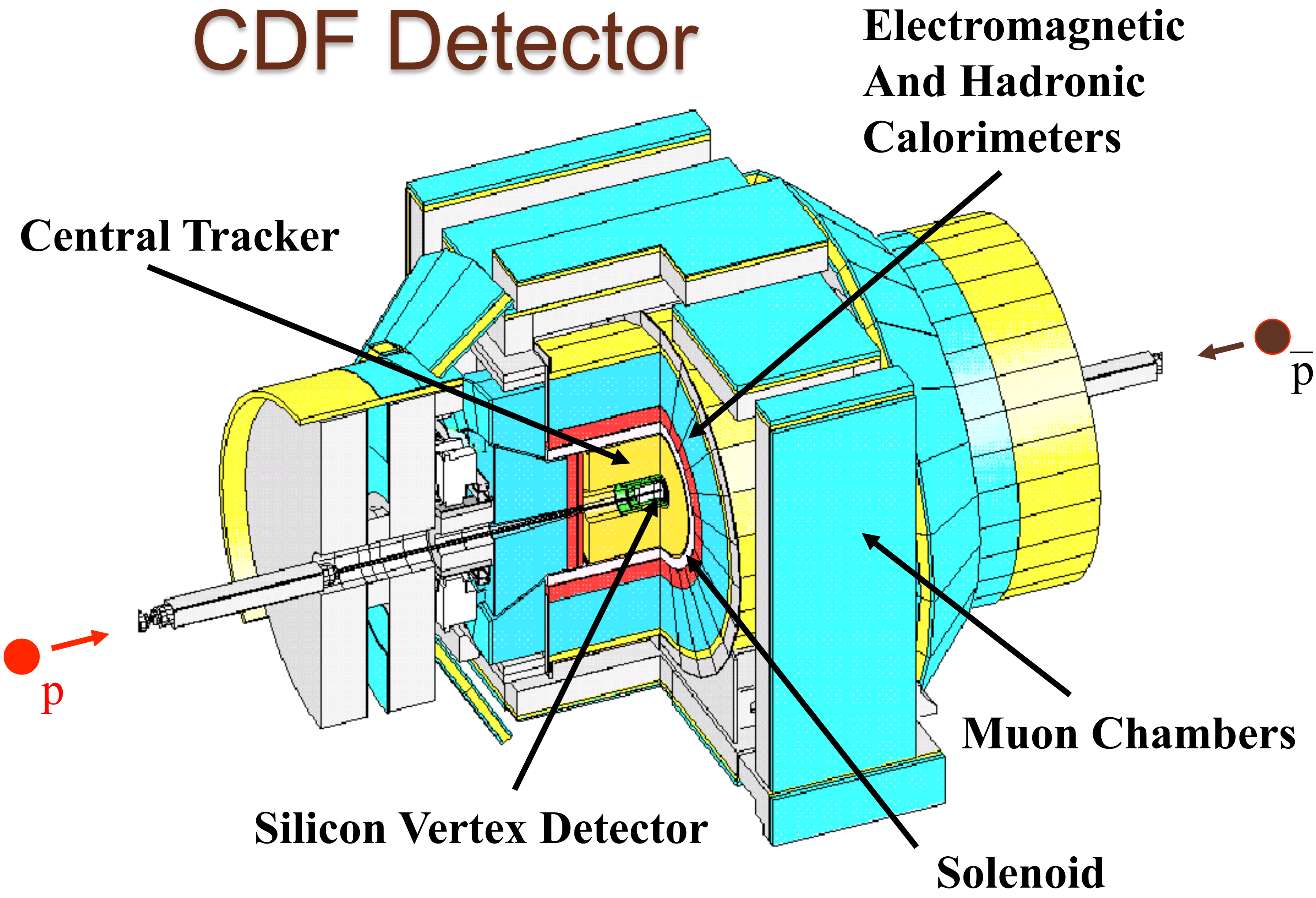
- p-pbar collisions @ $\sqrt{s}$ = 1.96 TeV
- Two interaction points:
  - CDF (Collider Detector at Fermilab)
  - DZero
- Running stable at high instantaneous luminosity
- Delivered per experiment ~ 10.5 fb^{-1} integrated luminosity (on tape ~ 8.7 fb^{-1})
- Total on tape expected to be ~10 fb^{-1} by the time Tevatron shuts down later this year
- Presenting results today for 7.0fb^{-1}







CDF Detector

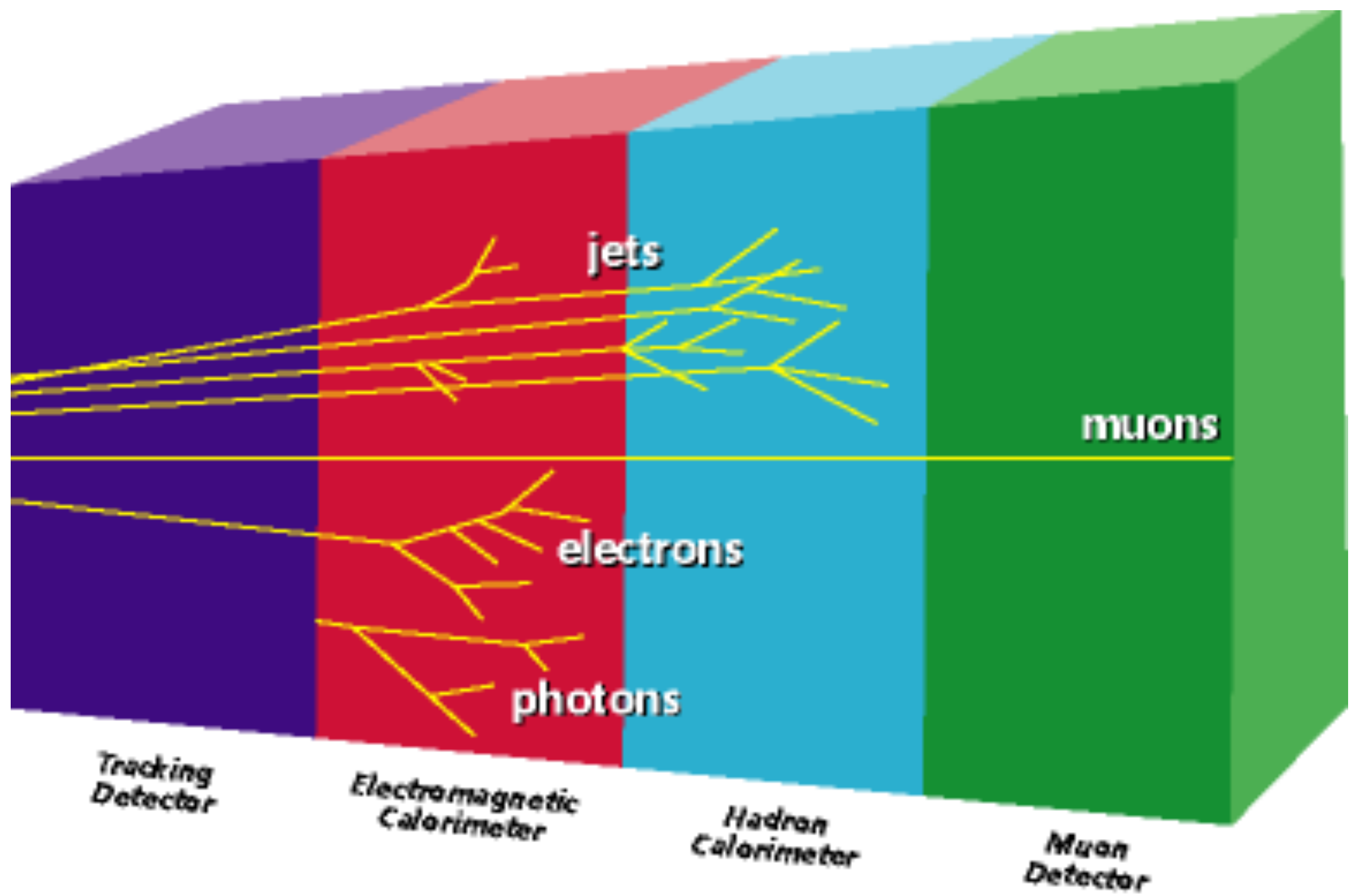


Identifying Particles

Multipurpose detector that observes:

- Electrons
- Photons
- Quark and gluon jets
- Muons

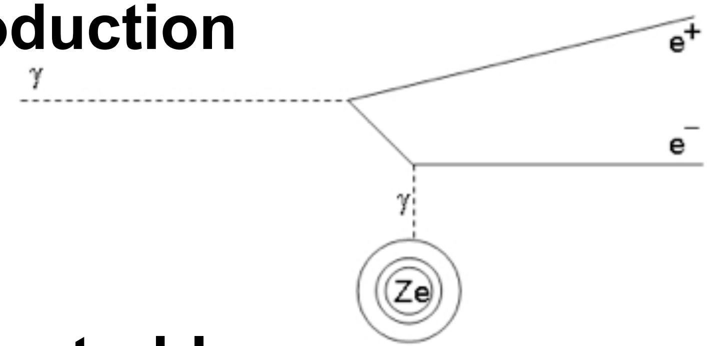
- From these we can reconstruct other particles … like the Higgs boson if it exists!



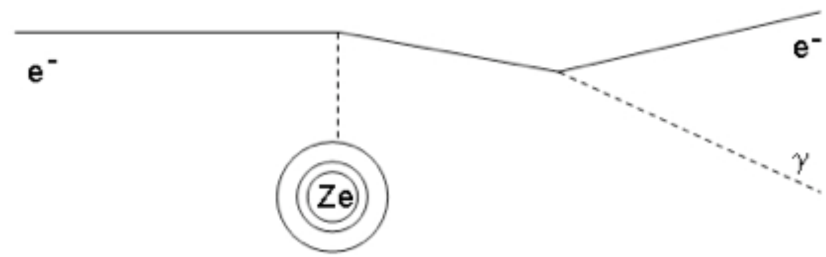
Detection of EM objects

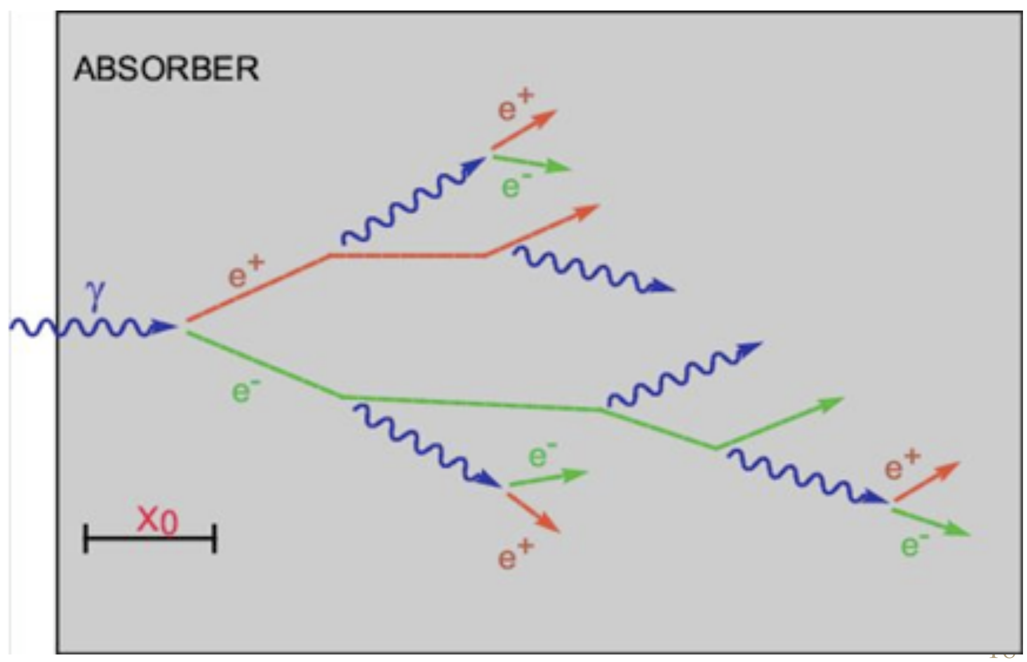
- Electromagnetic calorimeter is made of alternating sheets of lead and scintillator
- **Lead**: causes electromagnetic objects to shower until all energy is absorbed
- **Scintillator**: light emitted as particle passes through material; energy measured using photomultiplier tubes

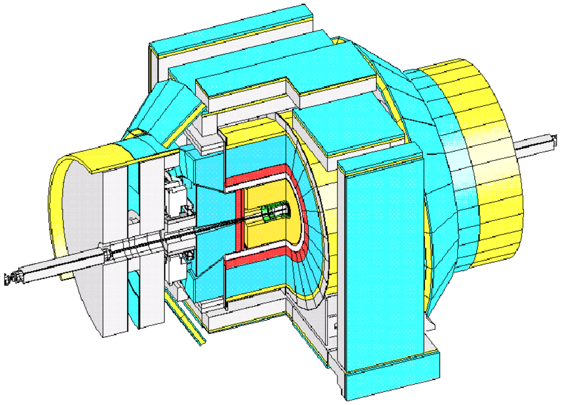
Pair production



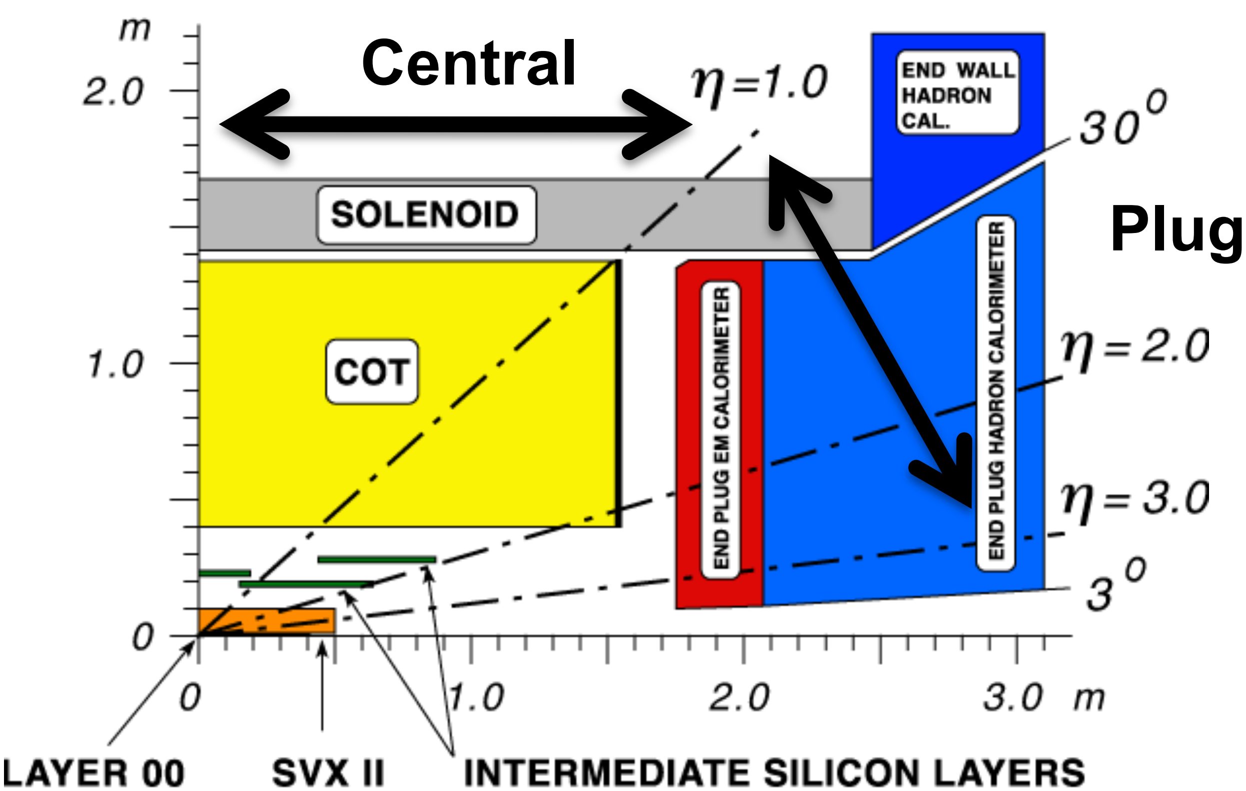
Bremmsstrahlung







Photon Identification



Cross sectional view

- **"Central"**
  - |η|<1.1
  - Use central calorimeters
- **"Plug"**
  - 1.2<|η|<2.8
  - Use forward calorimeters
  - Tracking efficiency lower than in central region
  - Easier to miss a track and reconstruct fake object as a photon
  - Higher backgrounds then for plug photons

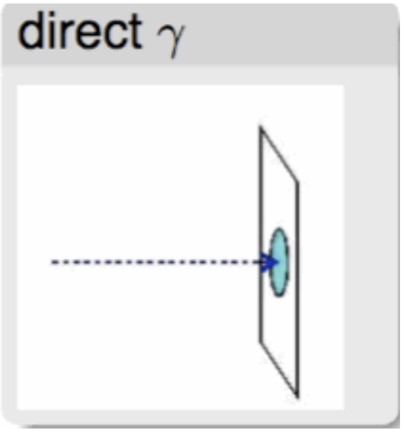
Photon Identification

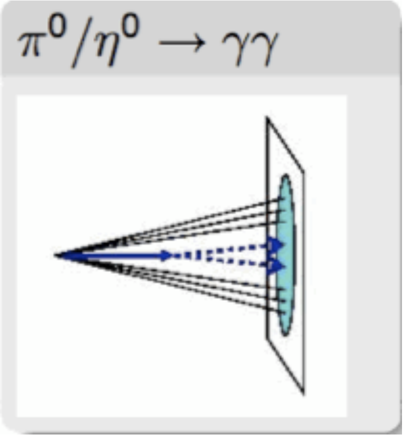
- The types of photons identified for this analysis:
  - Central photons
  - Plug photons
    } "Regular" photons
  - Central photons that converted into an e+e- pair ("conversions")
- This creates 4 categories of diphoton pairs of interest to us:
  - Central-central (CC) → most sensitive
  - Central-plug (CP)
  - Central-central conversion (CC conversion)
  - Plug-central conversion (CP conversion)

Regular Photon Identification

Standard "Cut" Based Selection

- Searching for a prompt (direct) photon:
  - An electromagnetic calorimeter cluster that's isolated and compact
- Basic Selection:
  - Charged electrons and jets have tracks pointing to a calorimeter cluster
    → Require isolation by restrict number of tracks pointing to a cluster or require momentum of such tracks to be insignificant
  - Jets deposit energy in a large region in calorimeters compared to photons
    → Require calorimeter isolation
  - Most jets have more energy in hadronic calorimeter
    → Require minimal fraction of energy to be in hadronic calorimeter
  - π^0 and η mesons decay to $\gamma\gamma$ jets that are colinear and have a different profile in the detector than direct photons
    → Require shape be consistent with that of a prompt photon (shape compared to test beam studies)





Regular Photon Identification

Standard "Cut" Based Selection

- Standard Central ID
  - *Selection used for previous result*

CES X and Z Fiducial (shower max)
HAD/EM $\sim <$ .125 (slides with E_T)
Calorimeter Isolation
χ^2 (CES strips and wires) [a]
N tracks ($\leq$ 1)
Track p_T ($< 1 + 0.005 * E_T$ GeV)
Track Isolation
2nd CES cluster veto

- Standard Plug ID
  - *Selection used for current result*

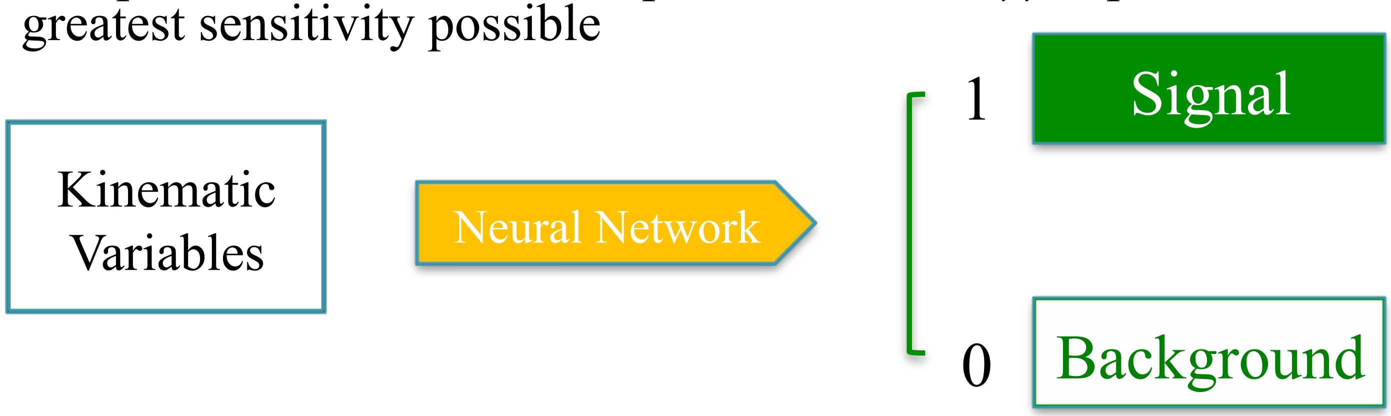
PES Fiducial ($1.2 < \|\eta\| < 2.8$)
HAD/EM
Calorimeter Isolation
PEM χ^2 (3×3)[a]
PES 5x9 (> 0.65) [b]
Track Isolation

A new method developed for central photons (would like to incorporate for plug photons soon)

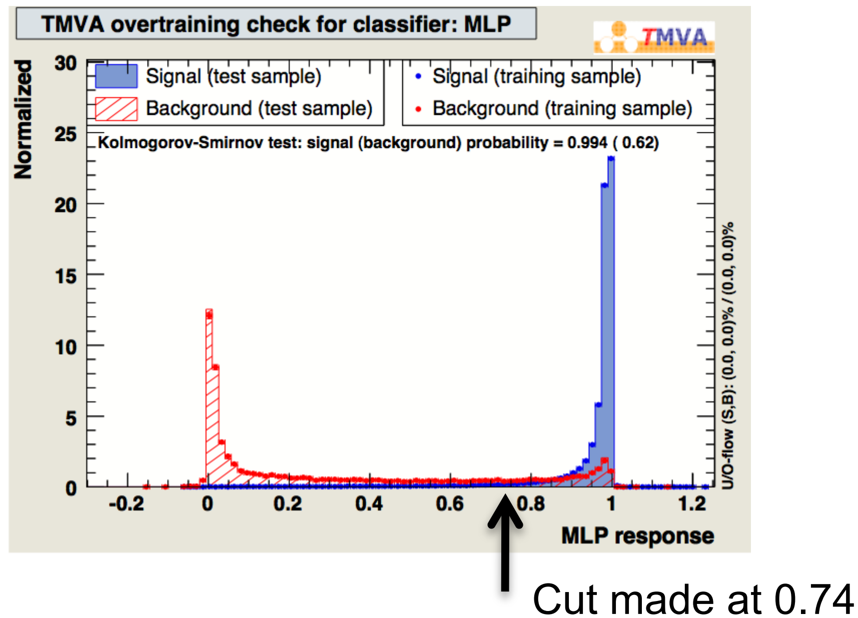
[a]Lateral shower shape compared with test beam
[b]Energy in central 5 strips divided by energy in all 9 strips

Central Photon Identification

- Uses a multivariate tool to better accept true prompt photons (signal) and reject backgrounds such as jets
- "Multivariate" tool considers all input variables combined rather than individually
- In particular we using an artificial neural network (NN)
- Input detector variables mostly from standard variables used in cut-based approach; chosen so that NN output can be used for electrons also
- A single output value
- Cut made on this output value to choose how signal like or background like the candidate photon is
- The particular cut we use is optimized for h→$\gamma\gamma$ to provide the greatest sensitivity possible

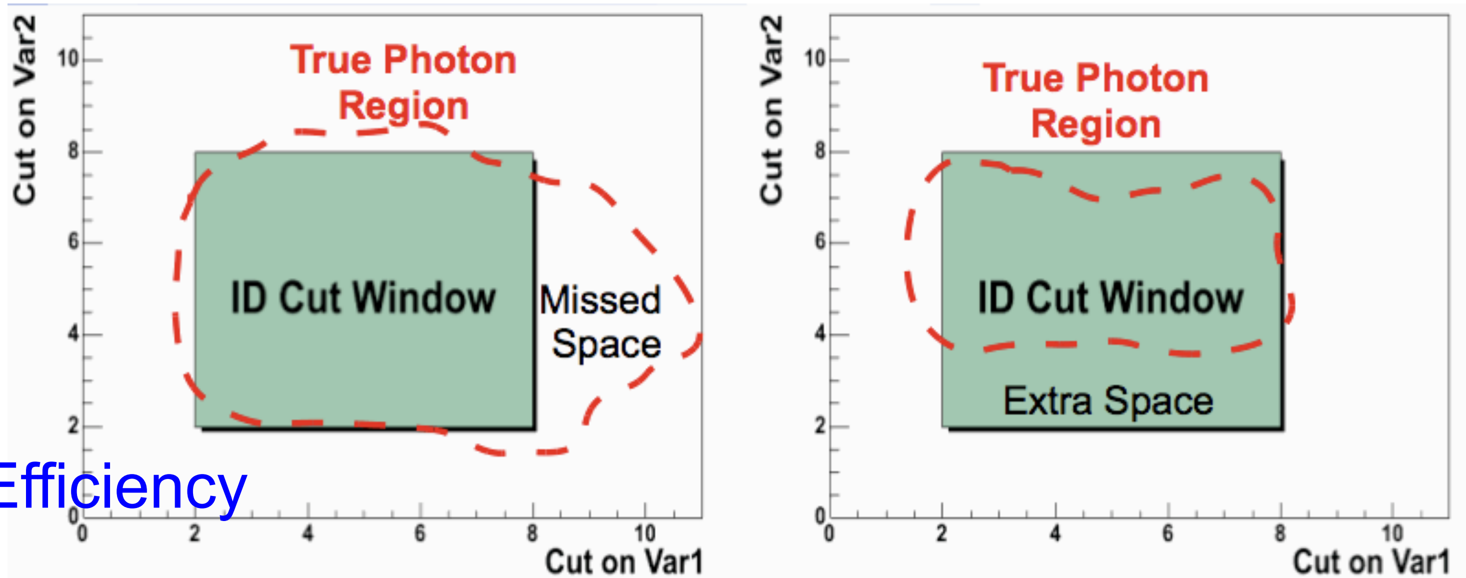


Central Photon Identification



- Implementing this for central photons improves signal acceptance by about 8%
- Provides about 23% more background rejection

Benefits of Multivariate Methods



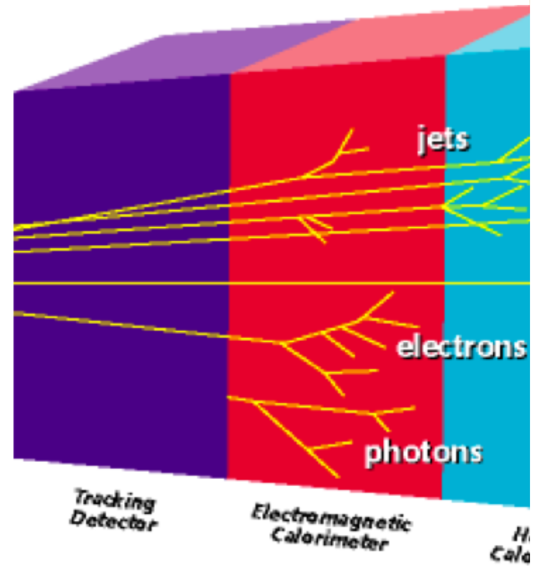
Low Efficiency

High background

- Cut based ID simple and quick to assess, but…
  - Ignores correlations
  - Rectangular parameter space (tight cuts on left, loose on right)
  - Somewhat arbitrary: cuts good and consistent for photons, but exact endpoints often lack real justification
  - Rigid: What if I want a higher purity? Cuts not easily adjusted to allow this.
- Pros for MVA:
  - Does not ignore correlations
  - Can weigh signal-like values of some variables to allow others to vary within a wider range
  - Single output is continuous, so user can choose how signal-like a particle must be to pass as a "true" photon

… MVA methods are more powerful: improves sensitivity for $H \rightarrow \gamma\gamma$ by ~10%

Regular Photon ID Efficiency



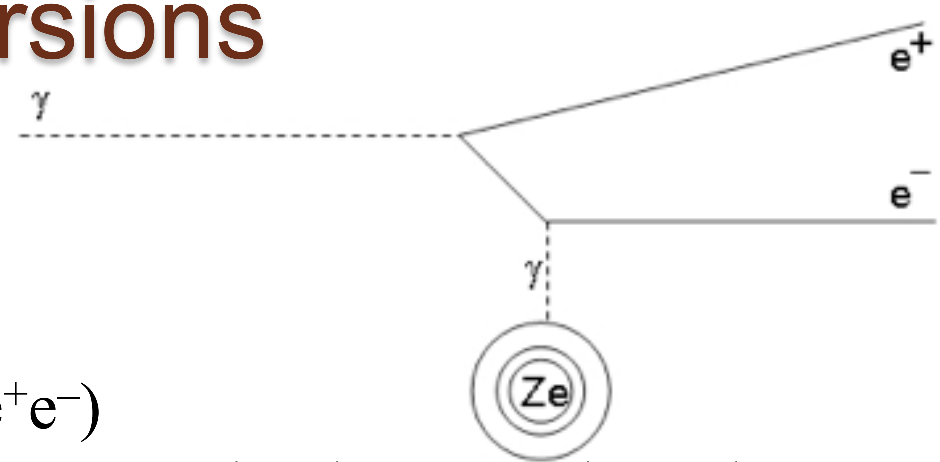
- Higgs signal MC simulated with PYTHIA+CDFsim
- Used to estimate detector acceptance for h→γγ
- If simulation is off, we need to correct our simulation and/or add systematic uncertainties
- Use pure sample of electrons from Z→e+e- decays to determine efficiency of photon selection in data as compared to MC
- Scale factor determined from difference

Regular Photon ID Efficiency

- Scale factor = $\varepsilon_{data}/\varepsilon_{MC}$
  - Use to correct signal acceptance in simulation
  - ~95% central photons
  - ~91% for plug photons
- Systematic Uncertainties:
  - Data taking period dependence
  - Fits/background subtraction
  - Differences between electron vs photon response
- Net uncertainties small
  - ~2% for central
  - ~4.5% for plug

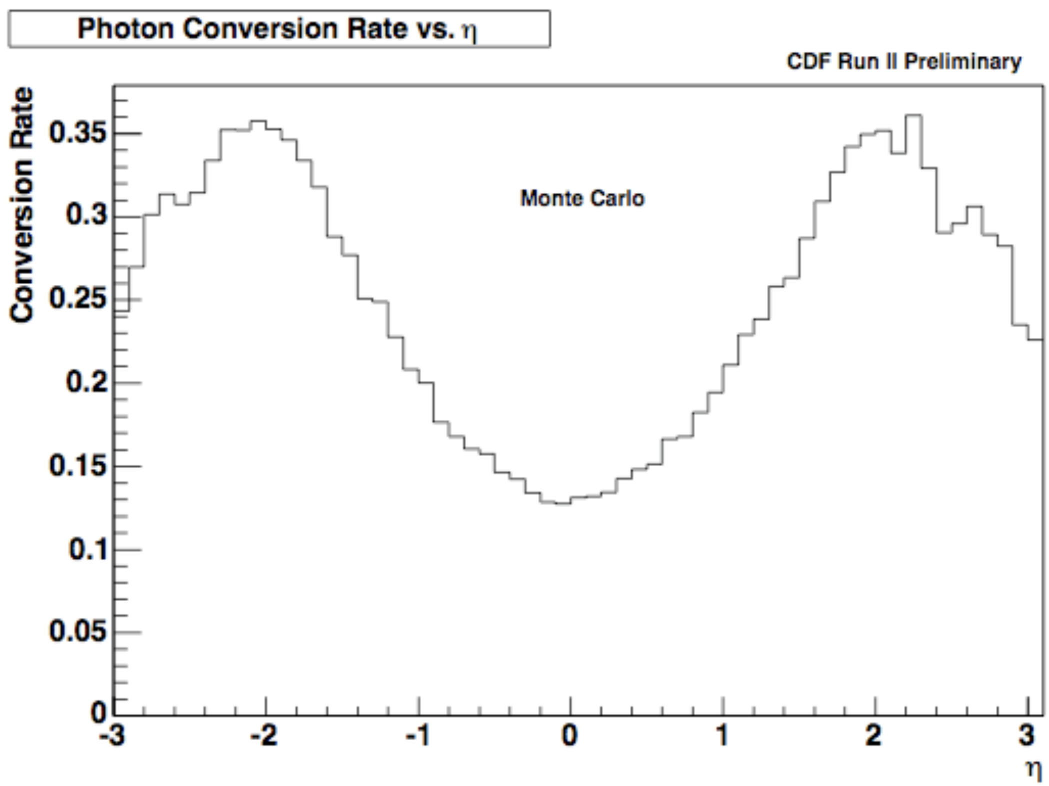
Z→e+e- is a great calibration channel: ensures small uncertainties on ID efficiencies, data-MC scale factor and energy scale!

Photon Conversions



- Electron-positron pair production ($\gamma \rightarrow e^+e^-$)
- The e^+e^- pair are colinear, moving in approximately the same direction
- Doesn't occur in empty space; conservation of momentum would be violated
- Happens in the presence of a nucleus then, which absorbs some of the original photon's momentum
- Nucleus produces an electric field which photon interacts with, producing pair production
- Some events with regular photons lost as they travel through detector material!

Photon Conversions

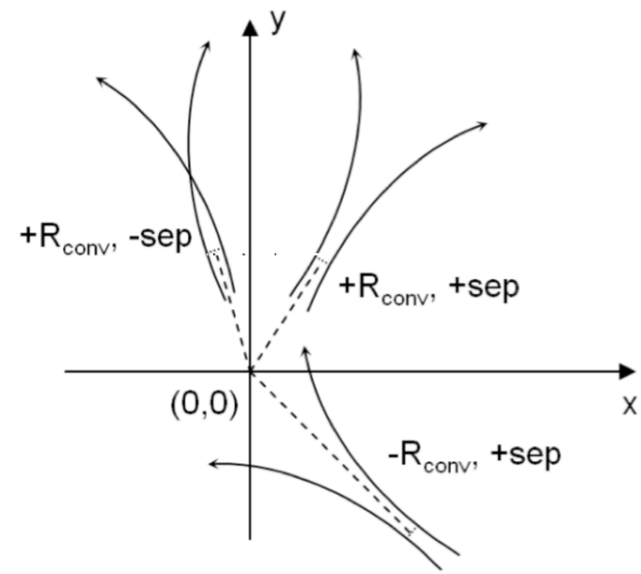


- Conversion probability at CMS* is ~27% for η=0, 50% for η=0.9, and 62% for η=1.4.
- About 70% of their h→γγ events have at least one photon that converts*
- Important for LHC experiments

•* J. Nysten, Nuclear Instruments and Methods in Physics Research A 534 (2004) 194-198

- $\gamma \rightarrow e^+e^-$ probability at CDF:
  - ~15% in central region
  - ~27% in plug region
- We use only central photon conversions due to poorer tracking in plug
- Impact on diphoton analyses:
  - For two central photons (CC), about 26% of events lost
  - For one central and one plug photon (CP), about 15% of events lost
- Inclusion of central conversions adds two new channels to h→γγ search which we call:
  - CC Conversion channel
  - CP Conversion channel

Central Conversion Photon ID



- Main Backgrounds:
  - $\pi^0/\eta \rightarrow \gamma\gamma$ where one photon converts
  - Combinatorics of associating a random track with a primary electron
  - Fake electrons + track
  - Prompt conversions: Dalitz decays $\pi \rightarrow e+e-\gamma$ for small radius
- Searching for prompt conversions
- Oppositely signed tracks
- r-φ separation ("sep") sharply peaked at 0 cm
- Difference in cotθ = Pz/Pt also sharply peaked at 0
- Restrictions on these variables is basic selection
- "tridents" also removed $e+(\gamma \rightarrow e+e-)$
- Other calorimeter variables used to reduce $\pi \rightarrow \gamma\gamma$ events where one photon converts
- Events with small radius of conversion rejected to remove prompt conversions from Dalitz decays

Conversion Photon ID Efficiency

- Used Z decays similar to regular photons
- Except search for Z→e+trident events
- "Trident" is where second leg electron brems a photon which converts to e+e-
- These probed conversions of lower momentum range compared to those from $H \rightarrow \gamma\gamma$
- Use study to obtain an uncertainty rather than apply a scale factor to simulation

Conversion Photon ID Efficiency

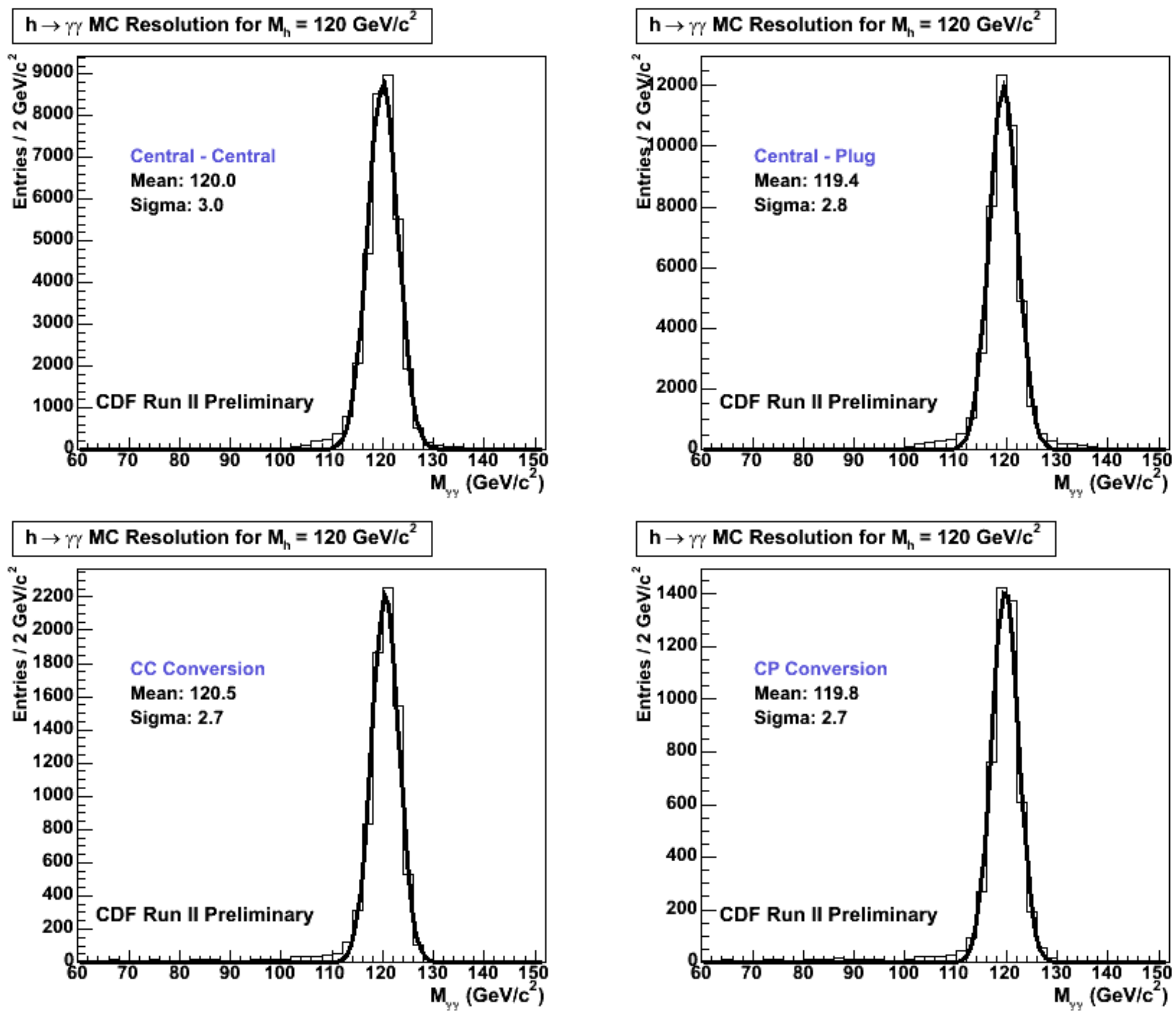
- Identify Z→e+trid events in both data and MC using conversion selection
- Scale resulting MC to luminosity in data ($N \sim \sigma * L * A$) gives a prediction on the amount of data events passed
- Data/MC difference provides uncertainty
- Dependent on uncertainties that exist on Z cross section, luminosity, or trigger efficiency though…
- Remove this dependence by instead calculating in both data and MC the ratio of the number of Z→e+trid to number of Z→e+e- events
- Difference in data and MC gives ~7% uncertainty
- Other studies show that this uncertainty improves for higher momentum photon conversions
- We apply a 7% uncertainty on conversion ID, but consider this conservative for $H \rightarrow \gamma\gamma$

H→γγ Search Method

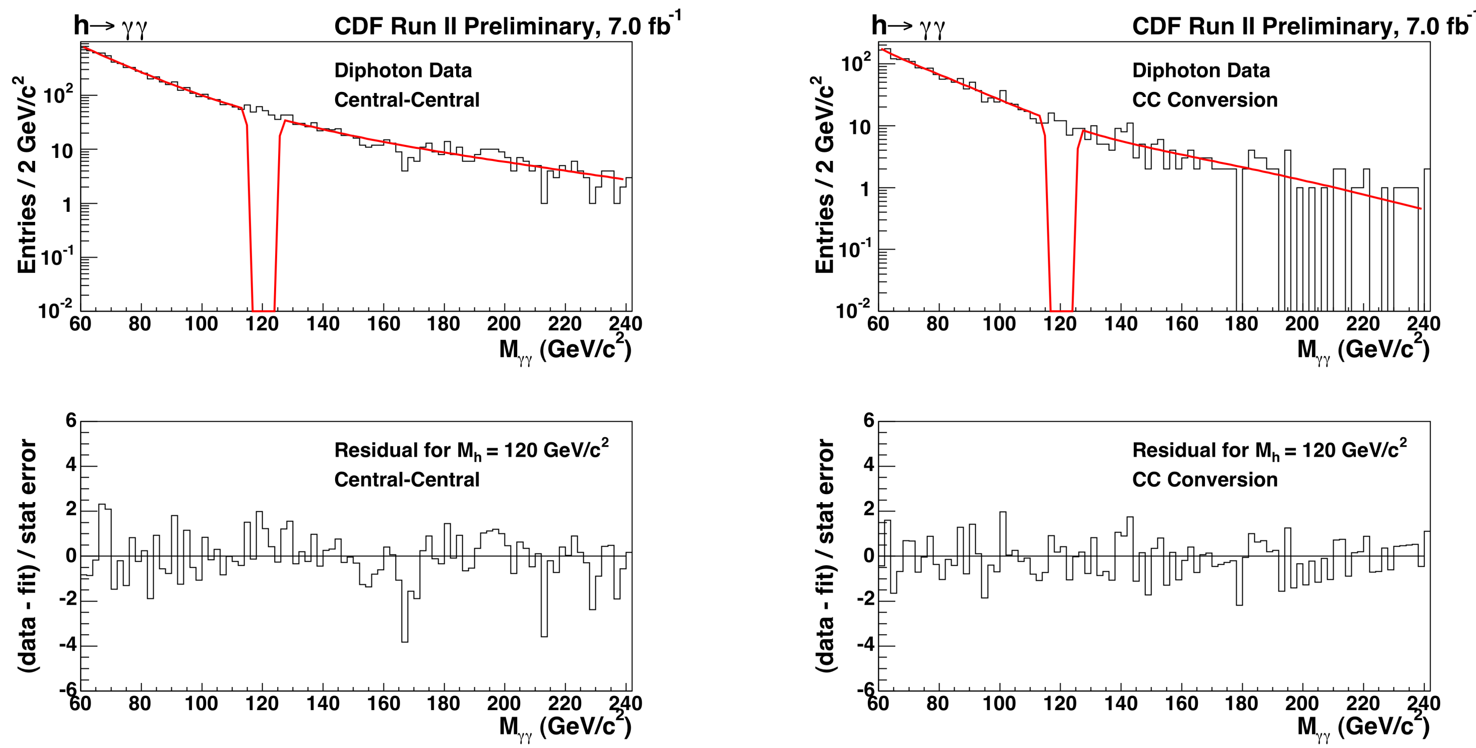
- Event selection
  - Use photon ID as previous described
  - Select two photons w/ P_T > 15 GeV and $M_{\gamma\gamma}$ > 30 GeV/c^2
- Data-driven background model
  - Assume null hypothesis
  - Search for narrow resonance in mass distribution
  - Apply a fit to sideband regions of $M_{\gamma\gamma}$ distribution and interpolate to signal region
  - Fit used as a null hypothesis background model for predicting sensitivity against data for signal
- No significant resonance observed, then set 95% CL limits on σ x Br

Signal Shapes

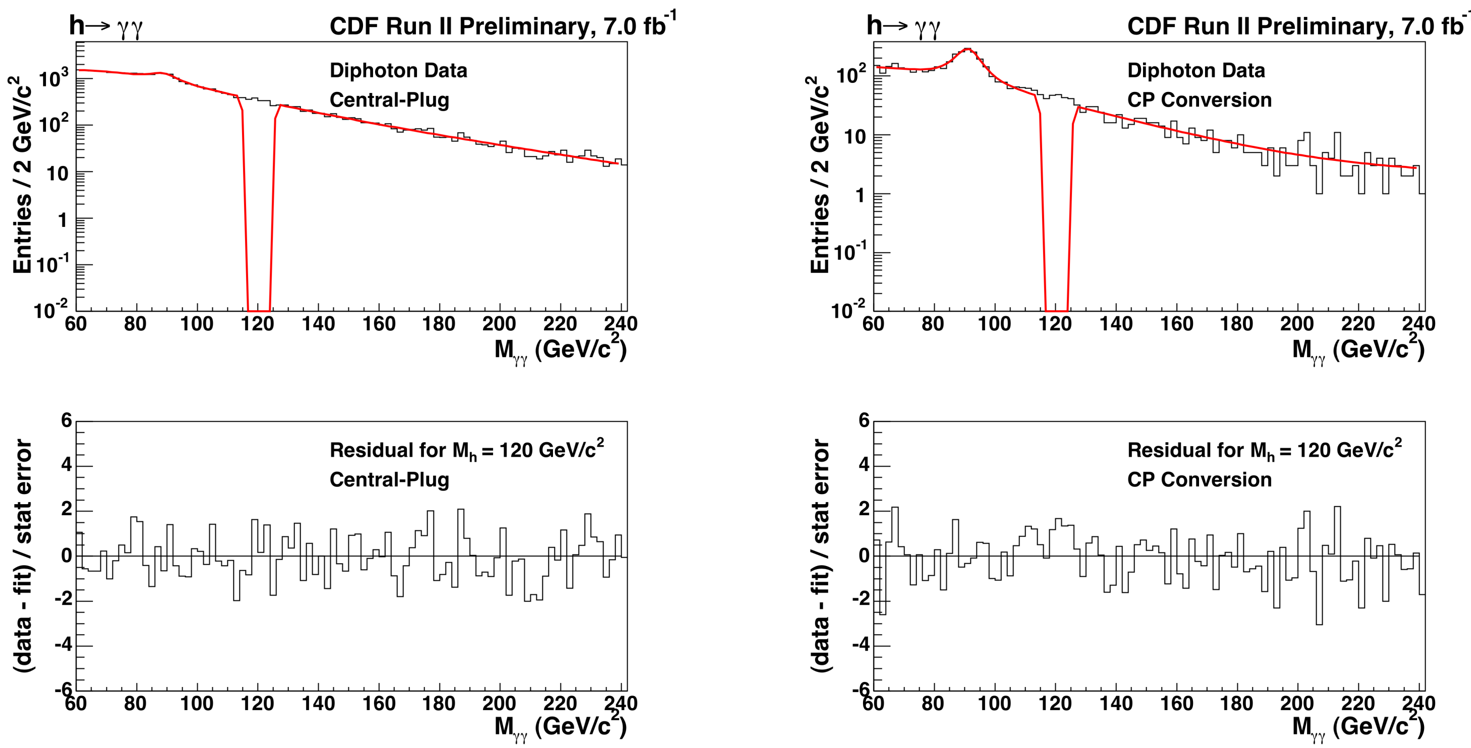
Widths less than a few GeV for each channel



CC and CC Conversion Fits for a 120 GeV Test Mass



CP and CP Conversion Fits for a 120 GeV Test Mass



Background Rate Uncertainty

- Vary parameters of fit within parameter uncertainties to obtain a new test fit
- Compare normalization to standard fit in region of interest (12 GeV around test mass)
- Largest differences from standard retained to determine appropriate background rate uncertainty

Background Rate Uncertainty

Approximate Systematic Errors on Background (%)	
CC	3.5
CP	1.1
CC Conv	7.5
CP Conv	3.5

- Approximate uncertainties per channel shown
- A different value is actually applied for each mass
- Generally speaking, the uncertainty increases for higher mass signal regions due to lower statistics and therefore higher fit variations

Systematic Uncertainties on $H \rightarrow \gamma\gamma$ Signal

CDF Run II Preliminary $\int \mathcal{L} = 7.0\ \text{fb}^{-1}$

	Systematic Errors on Signal (%)			
	CC	CP	CC Conv	CP Conv
Luminosity	6	6	6	6
$\sigma_{ggH}/\sigma_{VH}/\sigma_{VBF}$	14/ 7/ 5	14/ 7/ 5	14/ 7/ 5	14/ 7/ 5
PDF	2	2	2	2
ISR	3	4	2	5
FSR	3	4	2	5
Energy Scale	0.2	0.8	0.1	0.8
Trigger Efficiency	–	–	0.1	0.4
Z Vertex	0.2	0.2	0.2	0.2
Conversion ID	–	–	7	7
Material Uncertainty	0.4	3.0	0.2	3.0
Photon/Electron ID	1.0	2.8	1.0	2.6
Run Dependence	3.0	2.5	1.5	2.0
Data/MC fits	0.4	0.8	1.5	2.0

Event Yields @ 120 GeV

- Includes only 12 GeV signal window around 120 GeV test mass
- CC most sensitive; NN ID adds about 9% gain
- CP adds about 7% gain and CC Conv about 12% gain
- Expect about 5-6 $H \rightarrow \gamma\gamma$ events total

Event Yields at 120 GeV/c^2				
Channel	Signal	Background	Data	S/sqrt(B)
CC	2.2	270.9	308	.13
CP	2.4	2070.9	2075	.054
CC Conv	0.52	66.5	67	.063
CP Conv	0.28	227.7	268	.018

Method used to set limits

The likelihood as a function of cross section:

$$L(\sigma) = \prod_{i=1}^{N_{bins}} \frac{\mu(\sigma)_i^{N_i^d} e^{-\mu(\sigma)_i}}{N_i^d!}$$

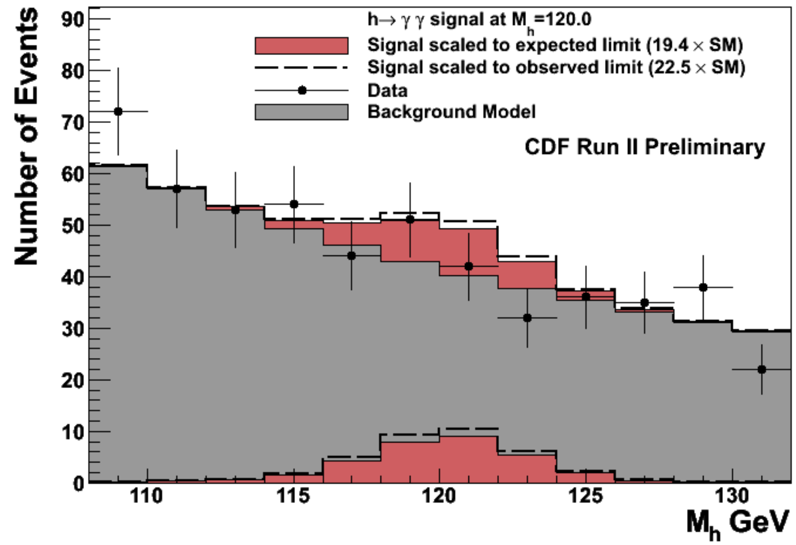
$$\mu(\sigma)_i = A\epsilon\mathcal{L}\sigma N_i^s / N_{tot}^s + N_i^b$$

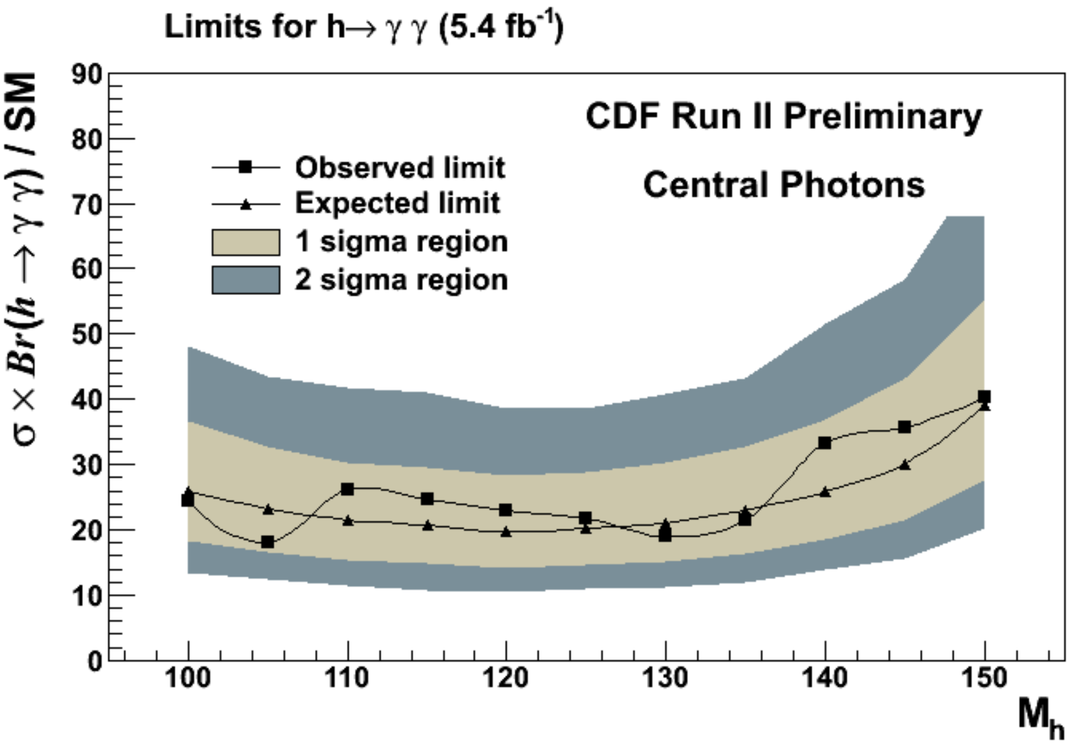
- N_i^d, N_i^b, and N_i^s are the number of data, bkg, and sig events in the i^{th} bin
- A is detector acceptance
- ϵ is ID efficiency
- $\mathcal{L}$ is luminosity
- N_{tot}^s is the total number of signal events passing selection requirements

The 95% confidence limit was obtained by finding the value of σ_{95} for which:

$$\frac{\int_0^{\sigma_{95}} L(\sigma)\, d\sigma}{\int_0^{\infty} L(\sigma)\, d\sigma} = 0.95$$

- Used two central photons from cut-based ID
- 12 GeV/c^2 signal region for each test mass used to set upper limits set on σ • Br relative to SM prediction
- Expected and observed limits in good agreement
- Expected limits of 19.4xSM @ 120 GeV
- Most sensitive for range 110 – 130 GeV/c^2





Previous Limits on $h \rightarrow \gamma\gamma$ at CDF using 5.4fb-1

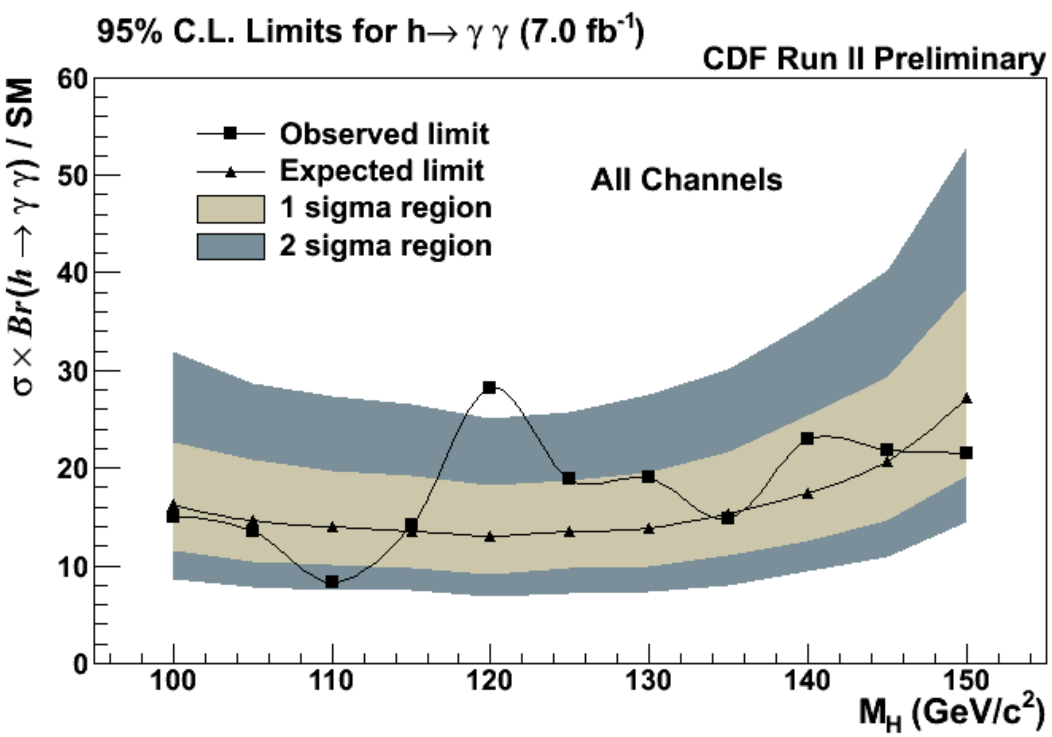
Added to SM Higgs Tevatron combination this past summer

Limits on $h \rightarrow \gamma\gamma$ at CDF using 7.0fb-1

- CC, CP, CC conv, and CP conv combined
- 12 GeV/c^2 signal region for each test mass used to set upper limits set on σ • Br relative to SM prediction
- Expected limit of 13.0xSM @ 120 GeV
- Observed limit outside 2σ band, but reduced to < 2σ after trial factor taken into account
- An improvement of 33% on last result!

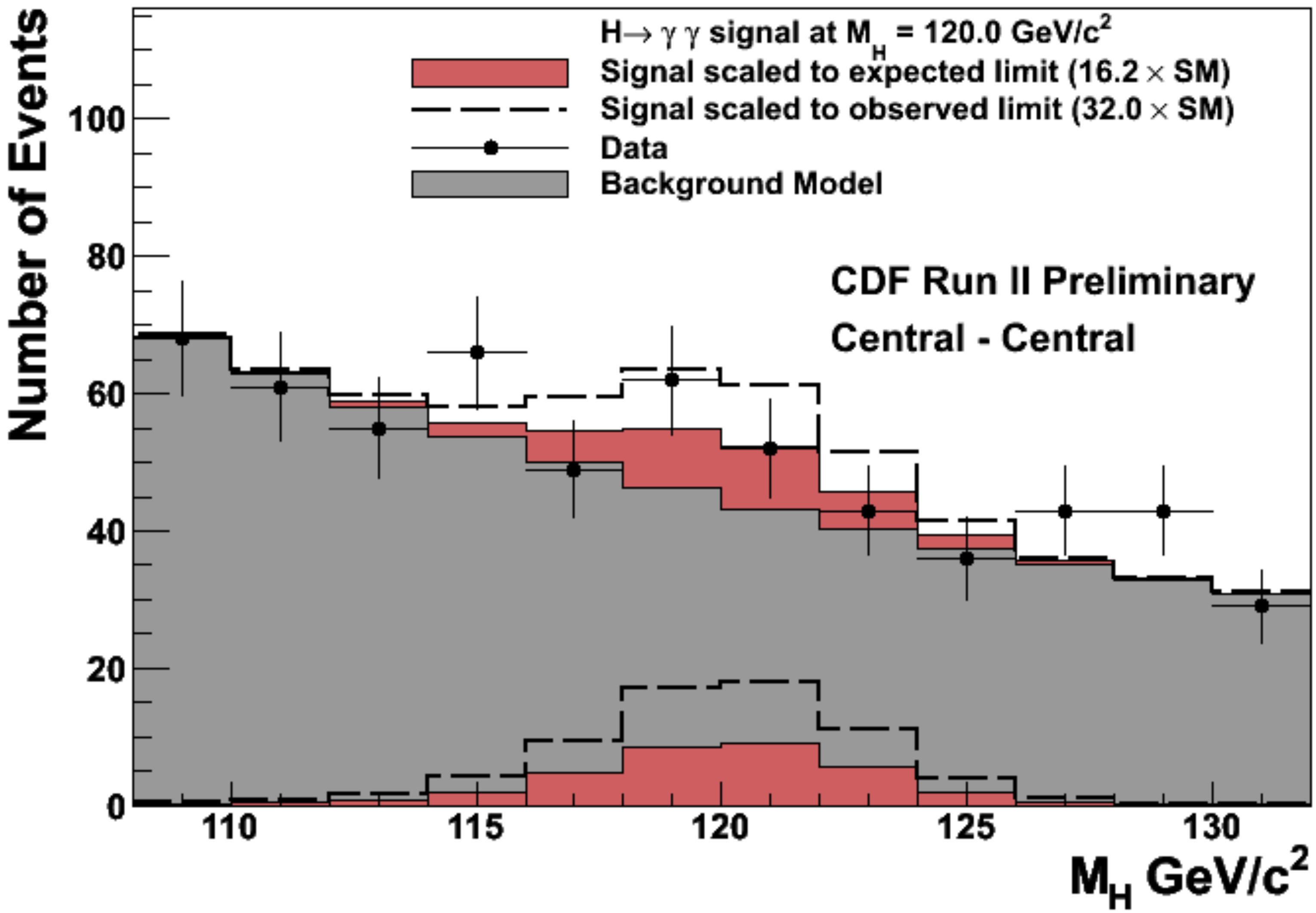
CDF Run II Preliminary $\int \mathcal{L} = 7.0\ \text{fb}^{-1}$

M_H (GeV/c^2)	95% C.L. Limit/σ(SM)$\times B(h \rightarrow \gamma\gamma)$ -2σ	-1σ	Median Exp	+1σ	+2σ	Observed
100	8.7	11.6	16.2	22.7	32.0	14.9
105	7.9	10.5	14.6	20.8	28.6	13.5
110	7.5	10.1	14.0	19.7	27.3	8.3
115	7.5	9.8	13.5	19.2	26.6	14.1
120	6.8	9.2	13.0	18.3	25.1	28.2
125	7.2	9.7	13.5	18.7	25.7	18.8
130	7.4	10.0	13.9	19.6	27.5	19.0
135	8.0	11.0	15.3	21.7	30.1	14.8
140	9.4	12.5	17.5	25.4	34.9	22.9
145	11.0	14.7	20.7	29.3	40.2	21.9
150	14.5	19.2	27.2	38.5	52.9	21.5

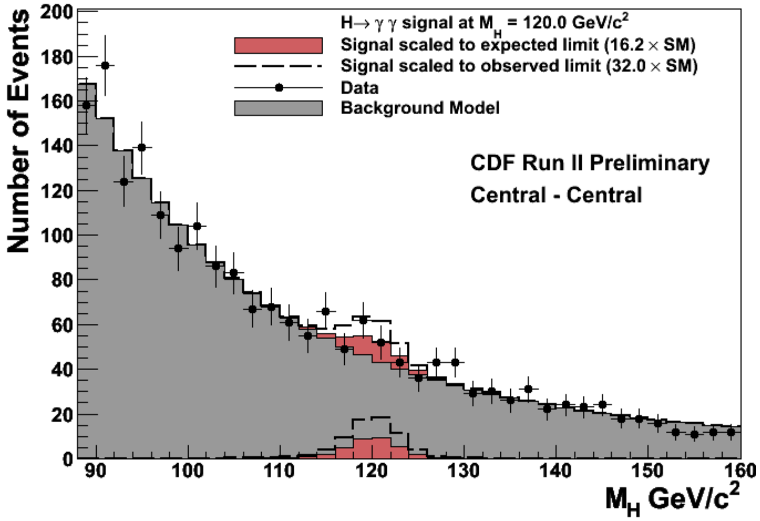


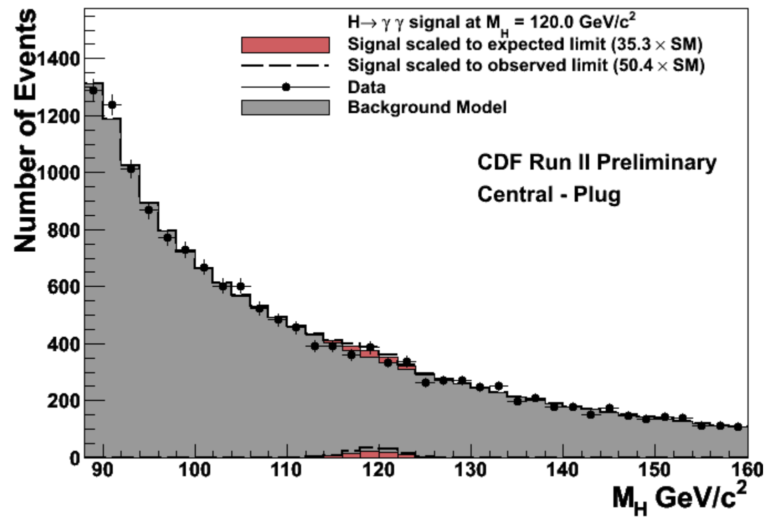
Will be added to SM Higgs Tevatron combination this summer

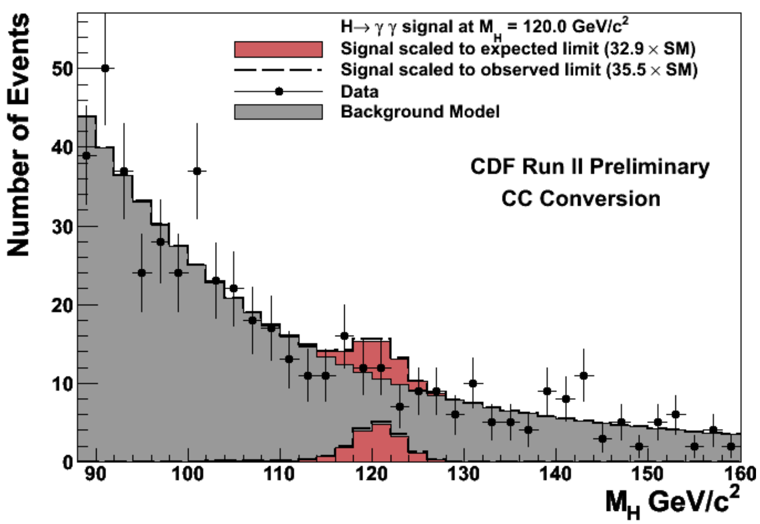
$M_{\gamma\gamma}$ for CC Channel @ 120 GeV

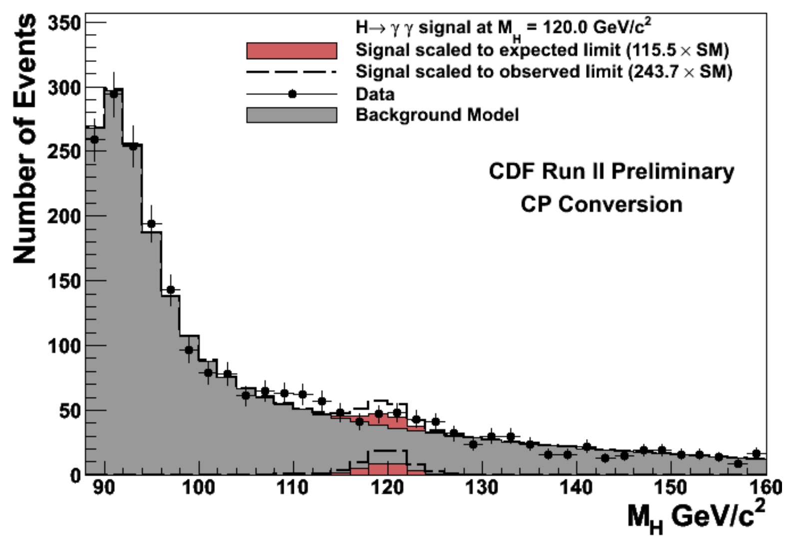


Limits for Individual Channels Alone @ 120 GeV







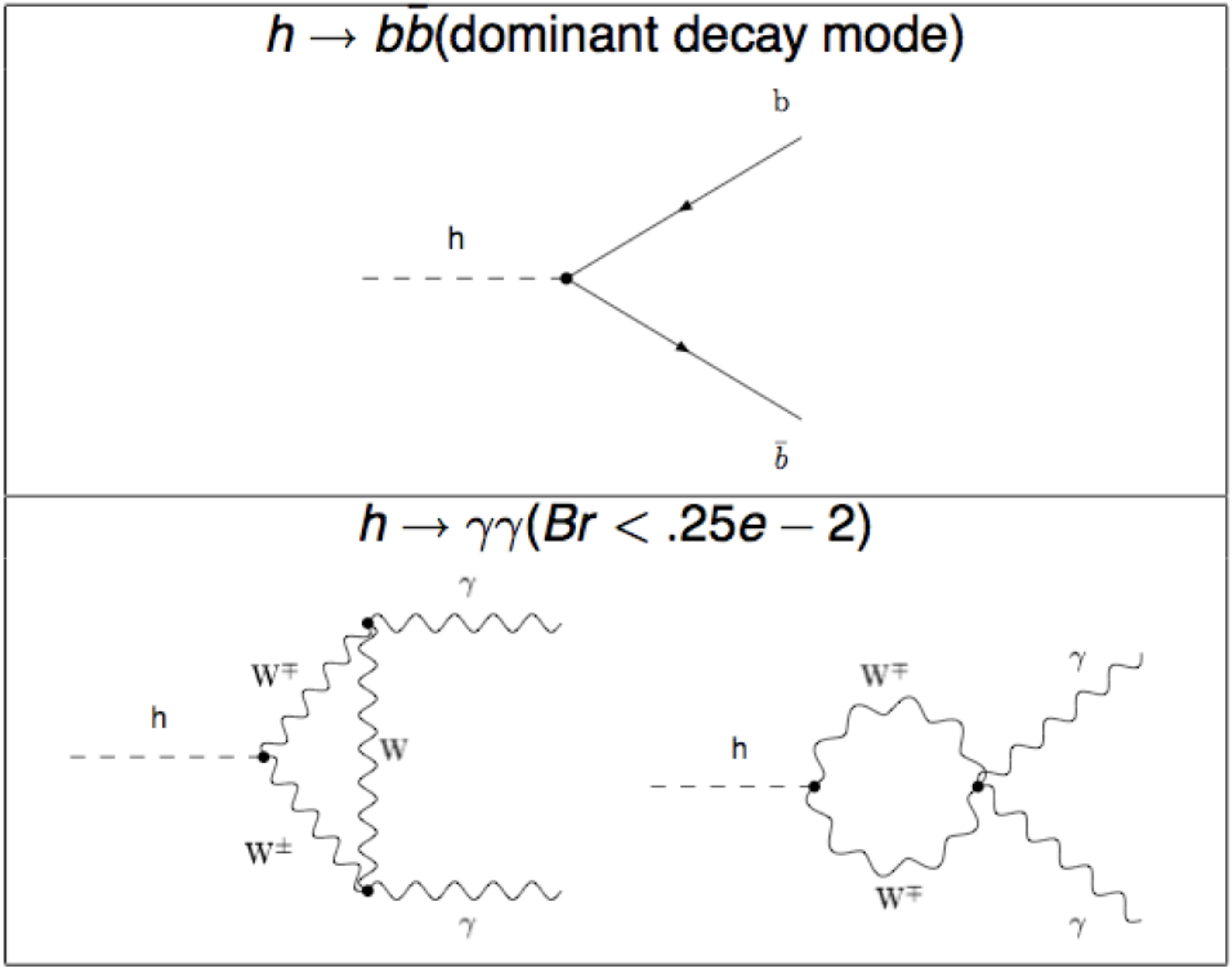


Summary

- Have presented a search for SM Higgs boson in diphoton final state using 7.0fb-1 of data
- Current result improved upon previous methods by incorporating a new central photon ID, adding forward photons, and recovering central conversion photons
- 95% C.L. upper limits on σxBr relative to SM prediction are set between 13 – 28 expected and 8 – 28 observed for 100 – 150 GeV Higgs test masses
- Results improves upon previous analysis by about 33%

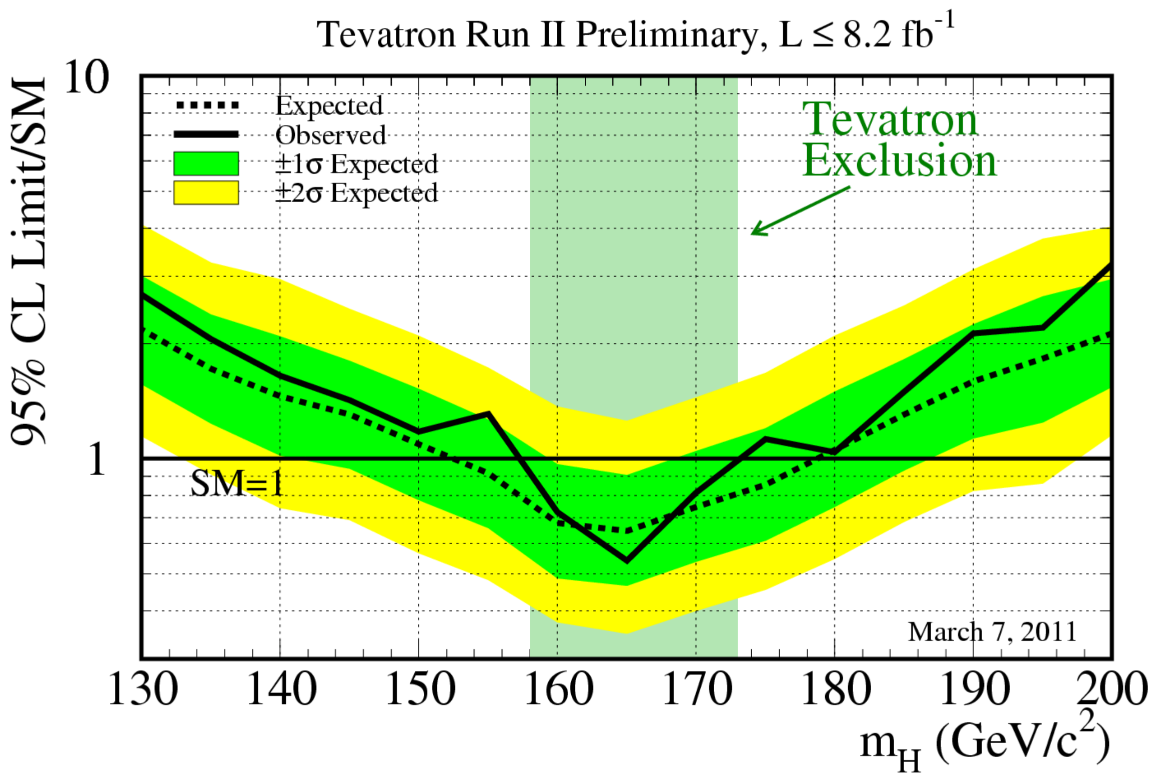
Backup Slides

SM $h \rightarrow \gamma\gamma$ Channel



Status of Higgs Search at the Tevatron

High Mass Combination (March 2011)



- Upper limits shown on the number of Higgs bosons produced with 95% CL, with ~8.2 fb^{-1} of data
- These limits are shown relative to the SM prediction for comparison
- Expected limit based on background models. Observed limit based on data.
- 1*SM implies that we would be able to identify a Higgs boson with a 95% confidence level
- 2*SM means that we would be able to identify a Higgs boson if it were produced at a rate twice what the SM predicts

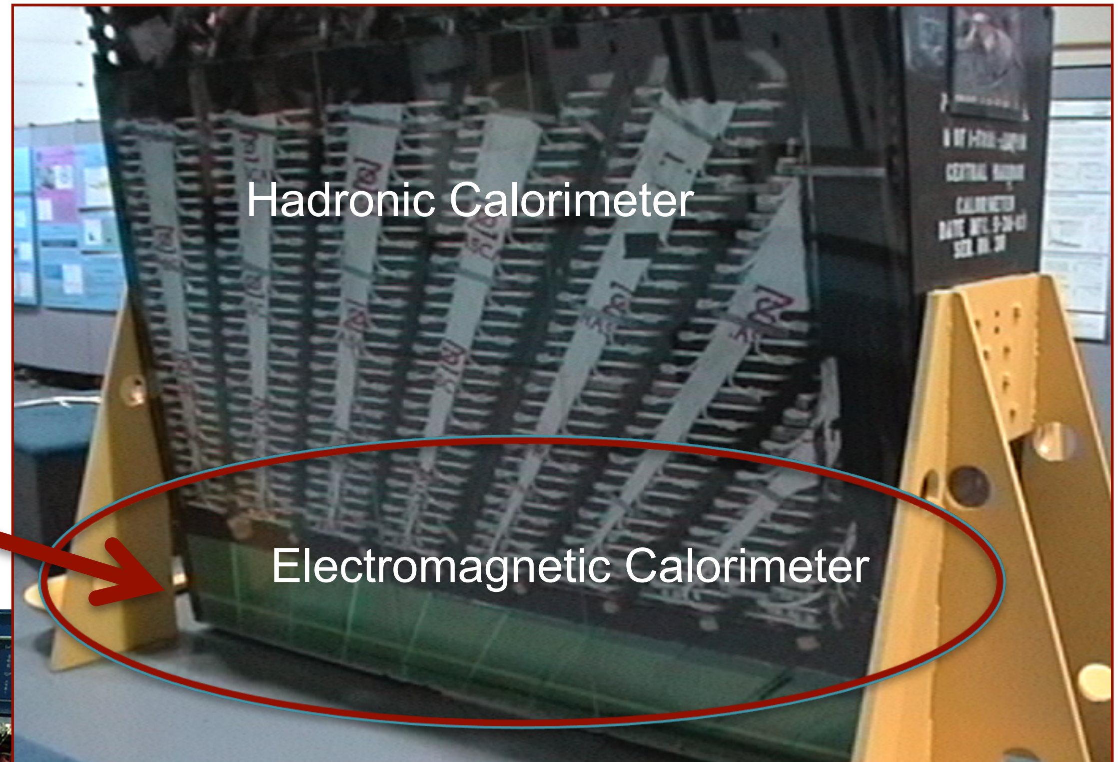
Latest Tevatron Higgs combination for high mass channels only.

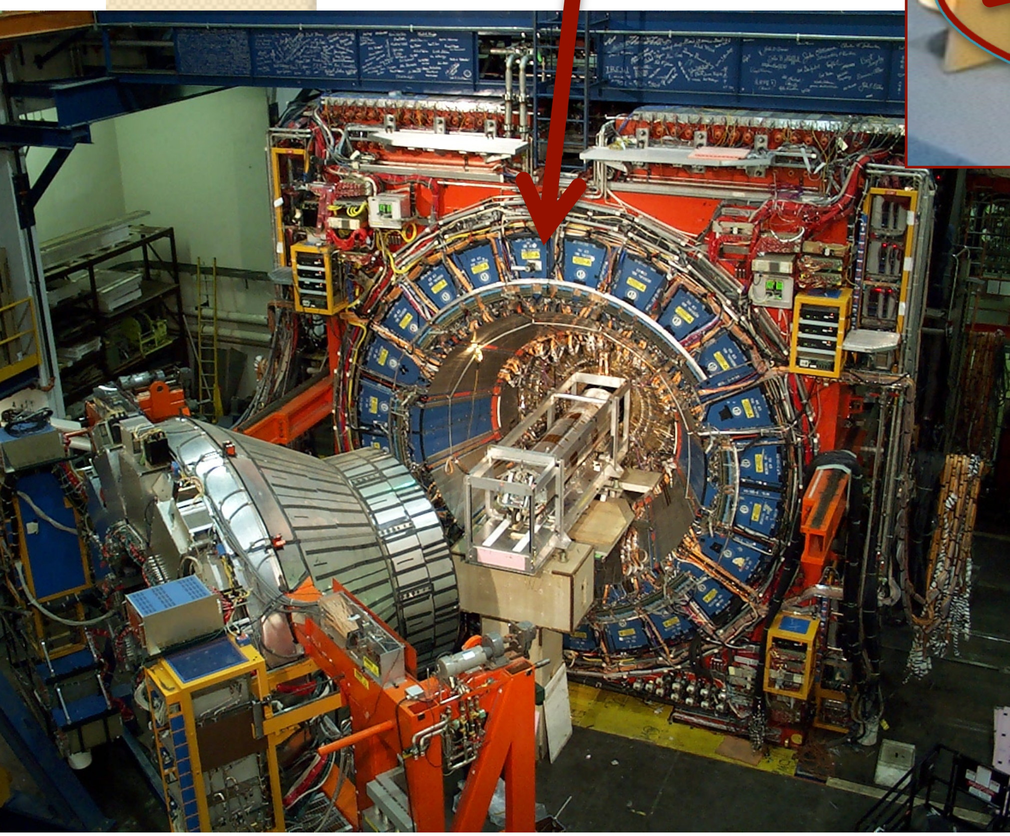
Excluded Higgs masses in region 158 – 173 GeV/c^2

Summary of Conversion ID Selection

For Diphoton Analyses Only	No tight diphoton pair Single tight isolated photon found
Base Conversion Selection	$\eta < 1.05$ NStSeg (NAxSeg) > 1 (1) NStSeg5Hits (NAxSeg5Hits) ≥ 1 (2) Opposite signed tracks $\|sep\| < 0.2$ cm $\|\Delta cot\theta\| < 0.04$ Trident removal
Tighter Conversion Selection	$\|X_{CES}\| > 21.0$ cm and $90.0 < Z_{CES} < 210$ cm (Prim. Ele.) $\|X_{CES}\| > 21.0$ cm and $90.0 < Z_{CES} < 210$ cm (Sec. Ele.) p_T of Sec. Ele. > 1.0 GeV/c Conversion $p_T > 15.0$ GeV/c Had/Em $< 0.055 + 0.00045 \times$Energy $0.1 <$ Conversion $E/P < 1.9$ Conversion Isolation < 2.6 $R_{conv} > 2.0$ cm

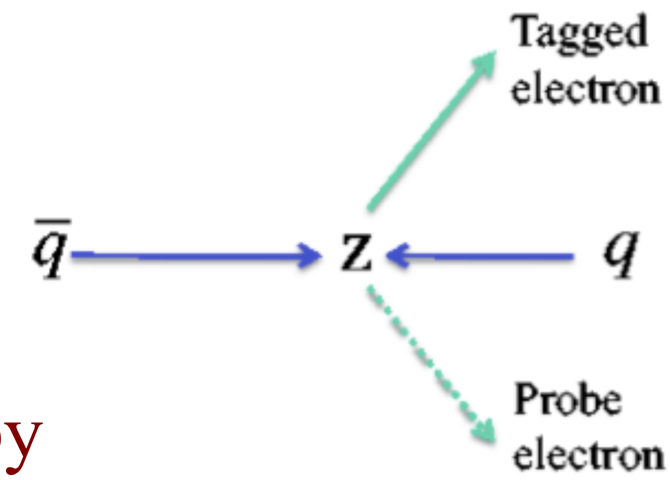
CDF's Central Electromagnetic (EM) Calorimeter





- **CEM** (Central EM calorimeter)
  - Alternating sheets of scintillator and lead shown
  - Great energy resolution: ~13.5%/√E + 2% Better than that of hadronic calorimeter
  - $|\eta| < 1.1$
  - 24 wedges distributed in ϕ
- **EM cluster** defined as localized deposit of energy in one wedge of the CEM
- Results from this analysis use central photons

Regular Photon ID Efficiency



- Pure sample obtained by searching for Z→e+e- decays
- Tag and probe method:
  - "Tag" passes tight requirement in central region
  - Tag of first leg provides high purity for second leg
  - "Probe" passes looser isolated track requirements
  - Add the tighter photon ID requirements to the probe leg to compare data/MC efficiency

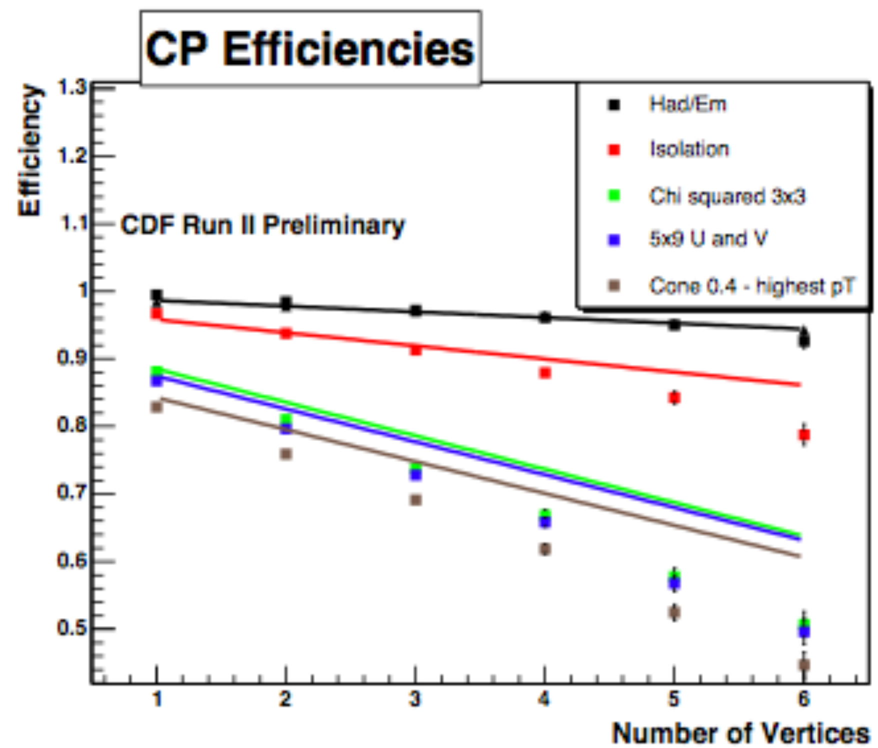
Regular Photon ID Efficiency

- Use $M_{ee} \sim M_Z$ as a constraint from searching for Z→e+e- to remove backgrounds and ensure pure sample to study
- Fits made to mass distributions
- Used to determine N events passing each selection requirement as compared to a loose set of events
- $\varepsilon = N_{cut}/N_{loose}$
- Different for different number n of reconstructed vertices in event
- Take net efficiency as weighed average over n vertices in diphoton data (or MC):

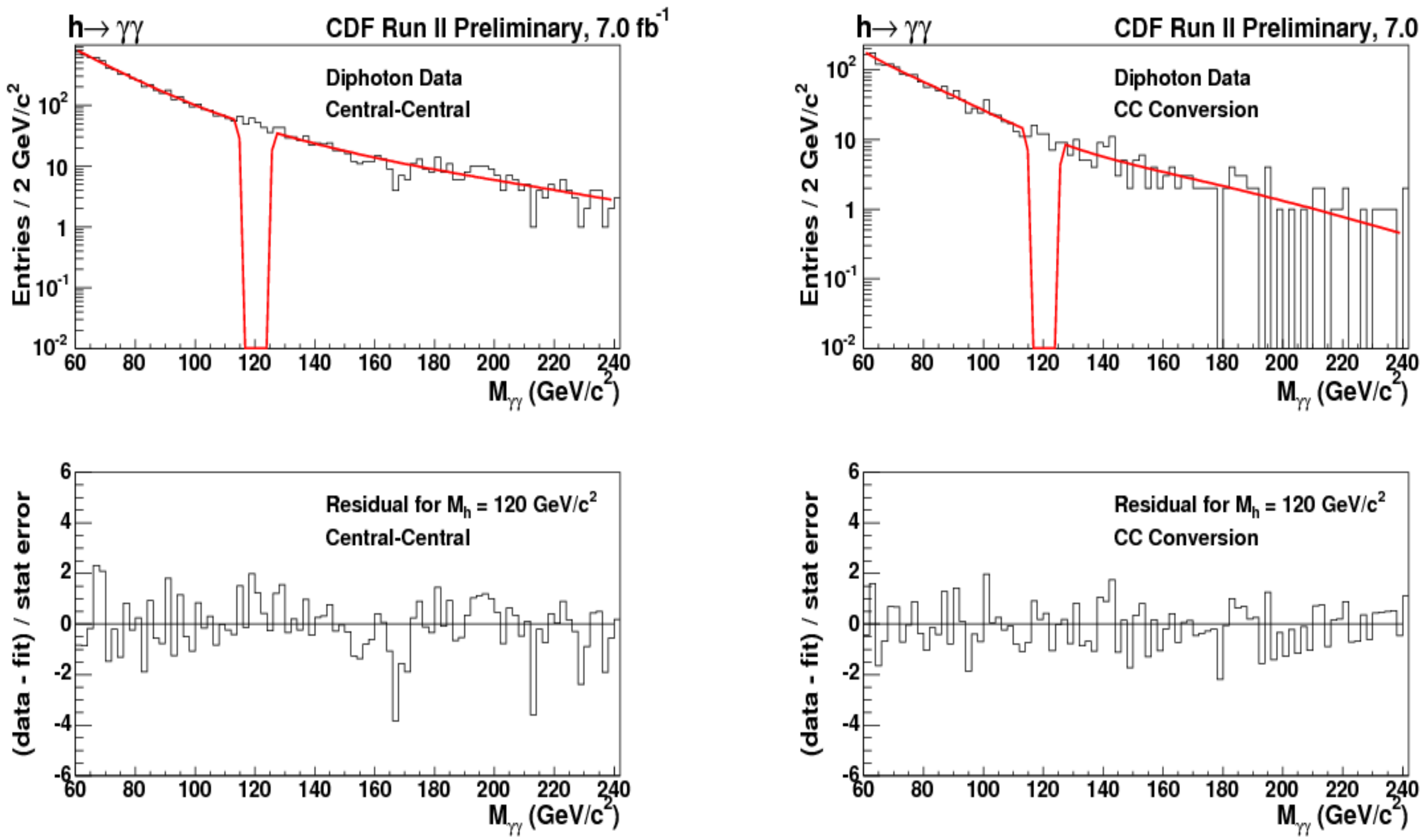
$$\varepsilon = \frac{\sum_n N_n \times \varepsilon_n}{N_{tot}}$$

- N_n is number of events with n reconstructed vertices

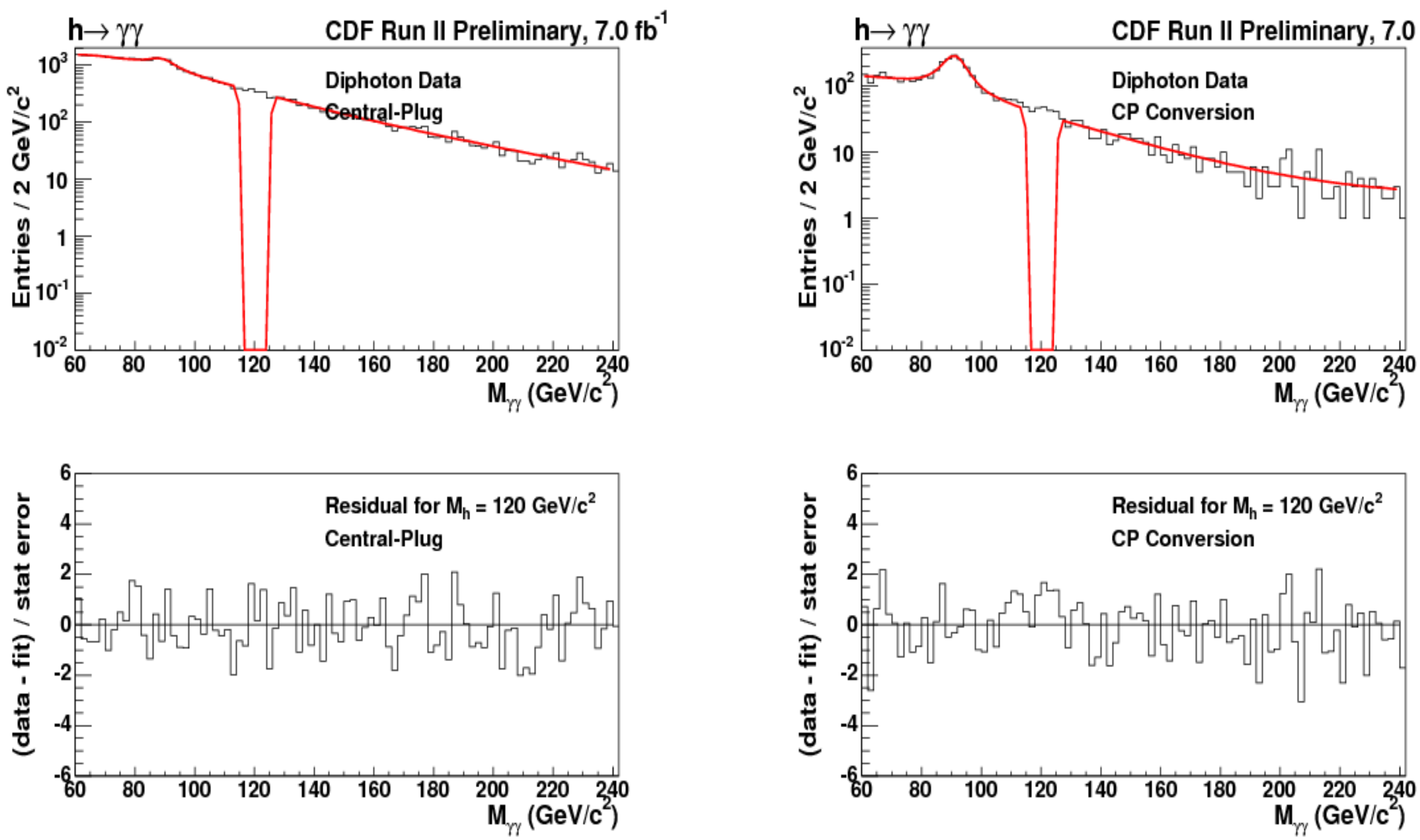
- Plug efficiencies shown
- Same method for central photons



CC and CC Conversion Fits for a 120 GeV Test Mass



CP and CP Conversion Fits for a 120 GeV Test Mass



Limits for Individual Channels Alone @ 120 GeV

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Channel Alone	95% C.L. Limit/σ(SM)$\times B(h \rightarrow \gamma\gamma)$ -2σ	-1σ	Median Exp	+1σ	+2σ	Observed
CC	8.4	11.6	16.2	23.14	32.0	32.0
CP	18.4	24.7	35.3	50.3	67.8	50.4
CC Conv	17.2	23.8	32.9	46.8	66.7	35.5
CP Conv	60.5	81.9	115.5	166.0	229.5	243.7