# Search for the Standard-Model Higgs Boson in the Decay Channel

$$gg \to H \to WW \to \ell^{+}\nu\ell^{'-}\overline{\nu}(\ell,\ell^{'} = e,\mu)$$

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On behalf of the CDF & D0 collaboration.

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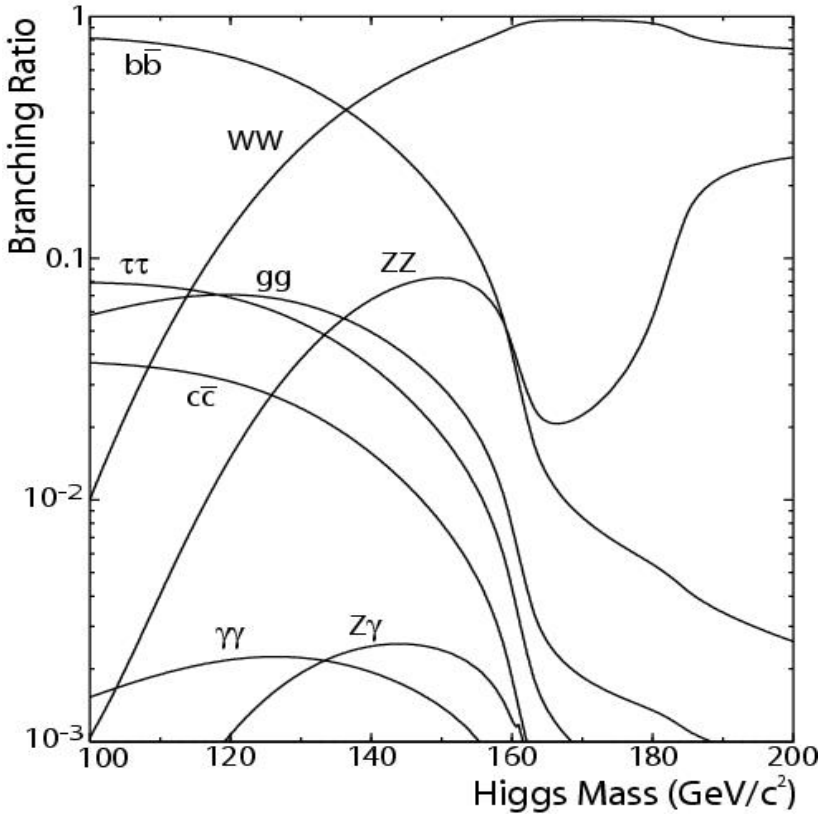
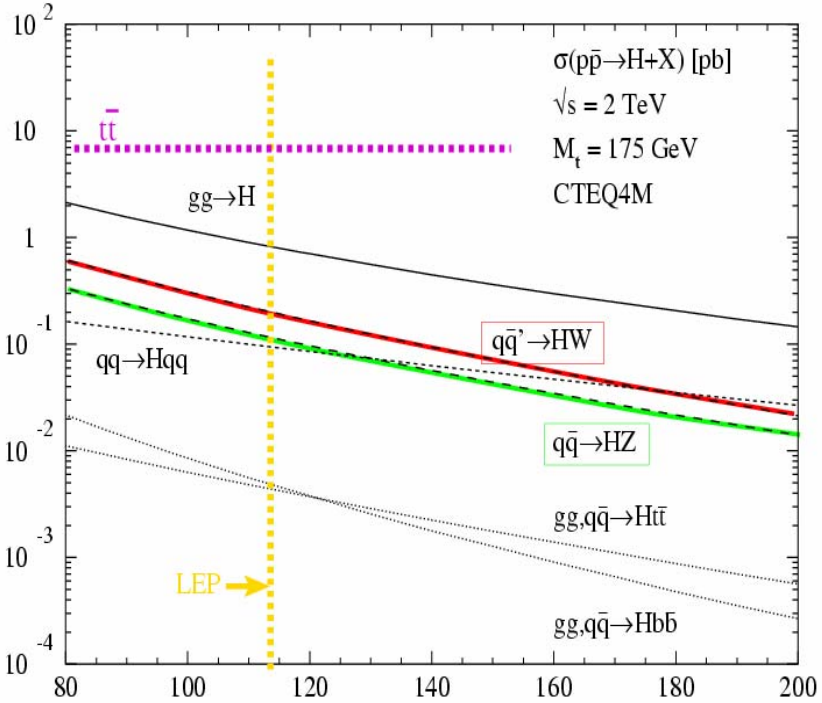
Fermilab 16-18 September 2004

# Introduction



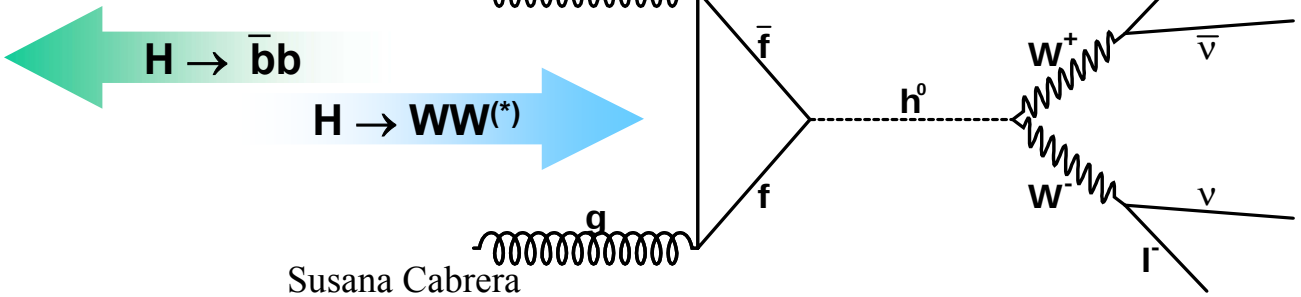




$M_H$ >135 GeV/$c^2$

$gg \rightarrow H \rightarrow WW^{(*)} \rightarrow l^+l^-\nu\nu$

$M_H$ <135 GeV

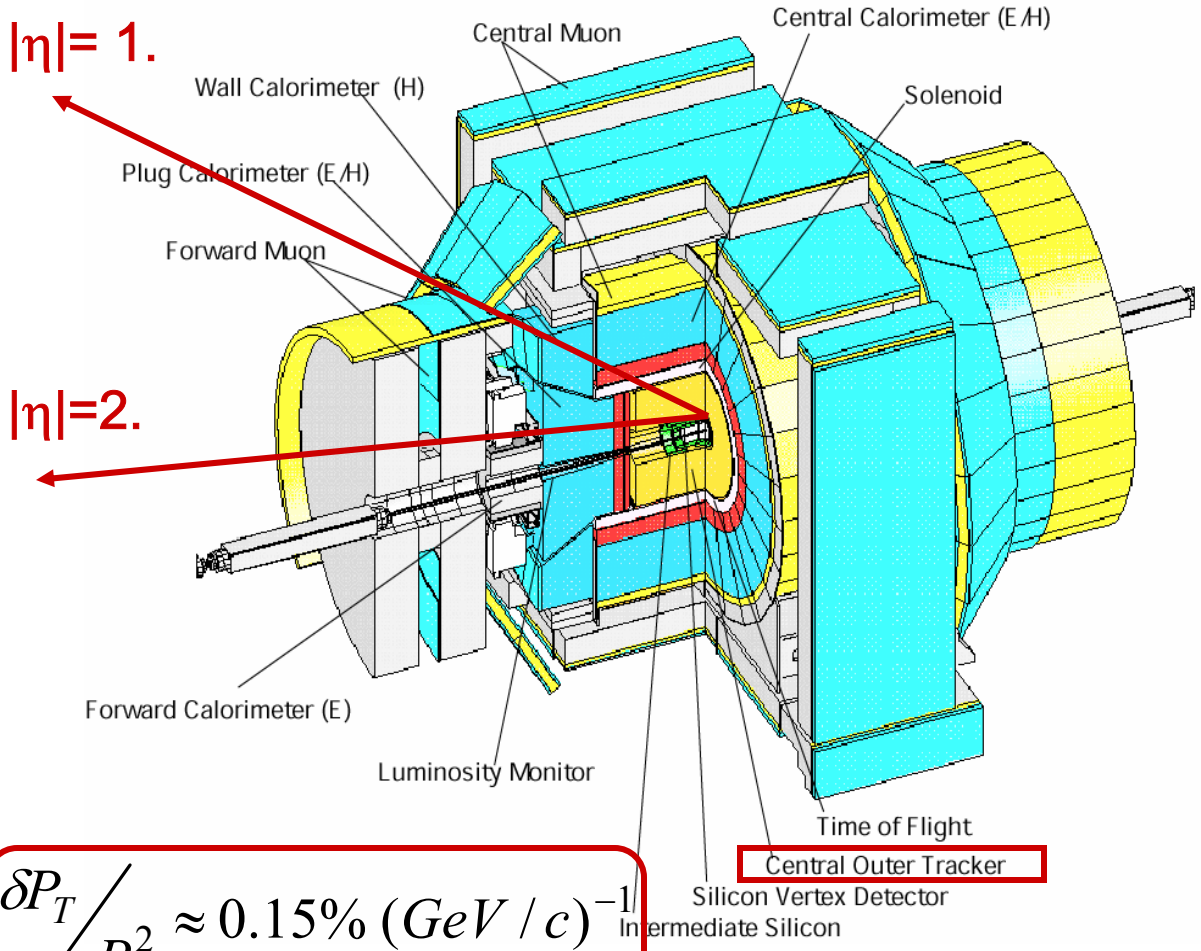
$qq' \rightarrow W/Z+(H \rightarrow bb)$



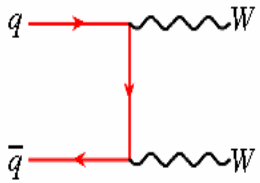
# CDF Run II Detector

From Run I:
- Solenoid
- Central muon system
- Central calorimeter

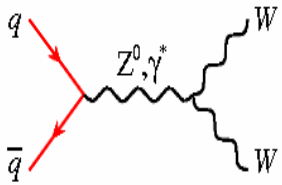
New For Run II:
- Front-end DAQ
- Trigger:Track (L1) and Displaced Track (L2)
- Silicon Tracker (8 Layers) ($|\eta| < 2.0$)
- Central Outer Tracker ($|\eta| < 1.0$)
- Plug Calorimeters ($1.0 < |\eta| < 3.6$)
- Extended Muon Coverage ($|\eta| < 1.5$, gaps filled in)




$$\delta P_T / P_T^2 \approx 0.15\% \, (GeV/c)^{-1}$$




# Starting point: WW cross section




- Two "well-detected" electron/mμons,each with $E_t$ ($P_t$)> 20 GeV.
- Missing $E_t$ > 25 GeV ✂ Zττ,WZ,ZZ
- ΔΦ(missing $E_t$, closest lepton or jet) > 20° for missing $E_t$ < 50 GeV
- Reject 76<$M_{ll}$<106 & missing $E_T$ / Σ$E_T$ <3 ✂ DY
- No jets with $E_t$ > 15 GeV and |η| < 2.5 ✂ top dilepton
- Opposite lepton charge signs, both lepton isolated ✂ Fake lepton background: W+jets
- **Veto cosmics using timing information and track information.**
- **Veto μ from jets (mostly b) using calorimeter-Iso and track-Iso**

Central e: |η|<1.2

Et>20-25 GeV

EM cluster + Drift chamber track,Pt>10 GeV

Plug e: 1.2<|η|<2.0-2.8

EM cluster (+ Silicon track)

Loose μ:

High Pt isolated track pointing to a gap in the μ- coverage |η|<1.2

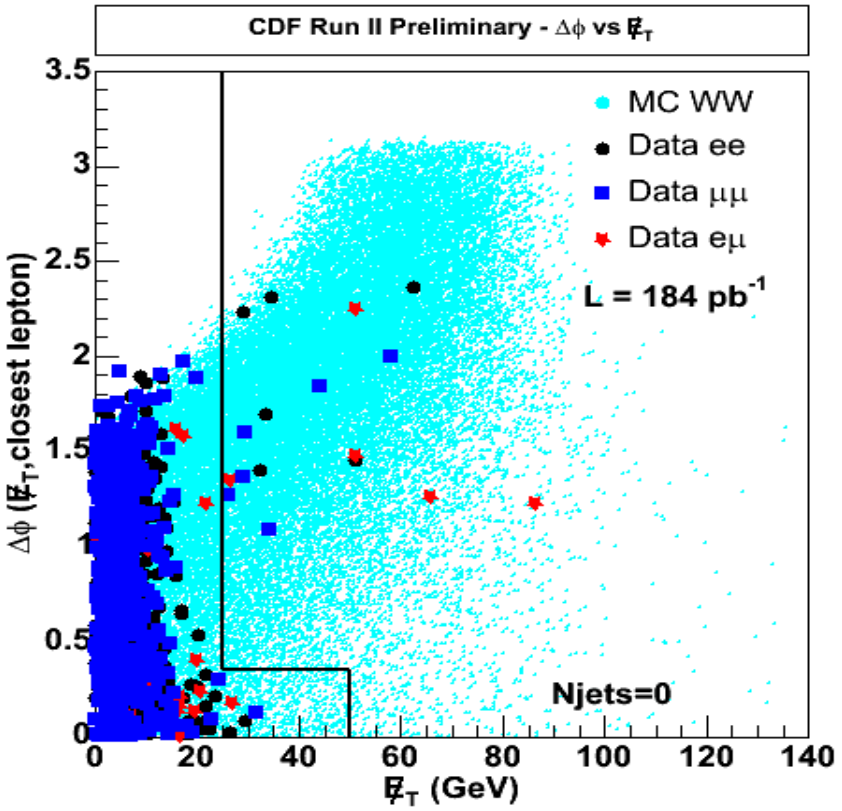
MIP requirements.

Tight μ :

pointing to a μ -stub |η|<1.

# Starting point: WW cross section

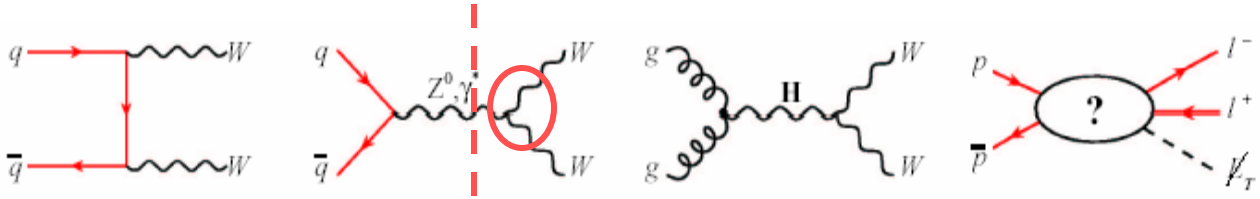
| ~200 pb$^{-1}$ | ll: ee, eμ, μμ |
|---|---|
| WW | 11.3 ±1.3 |
| DY | 1.82 ±0.4 |
| WZ+ZZ | 0.76 ±0.06 |
| Wγ | 1.05±0.19 |
| Fakes | 1.08±0.49 |
| Bkg | 4.77±0.70 |
| WW+Bkg | 16.1±1.6 |
| Data | 17 |




NLO (MFCM, Ellis& Campbell) $\sigma^{WW}$=12.5±0.8 pb

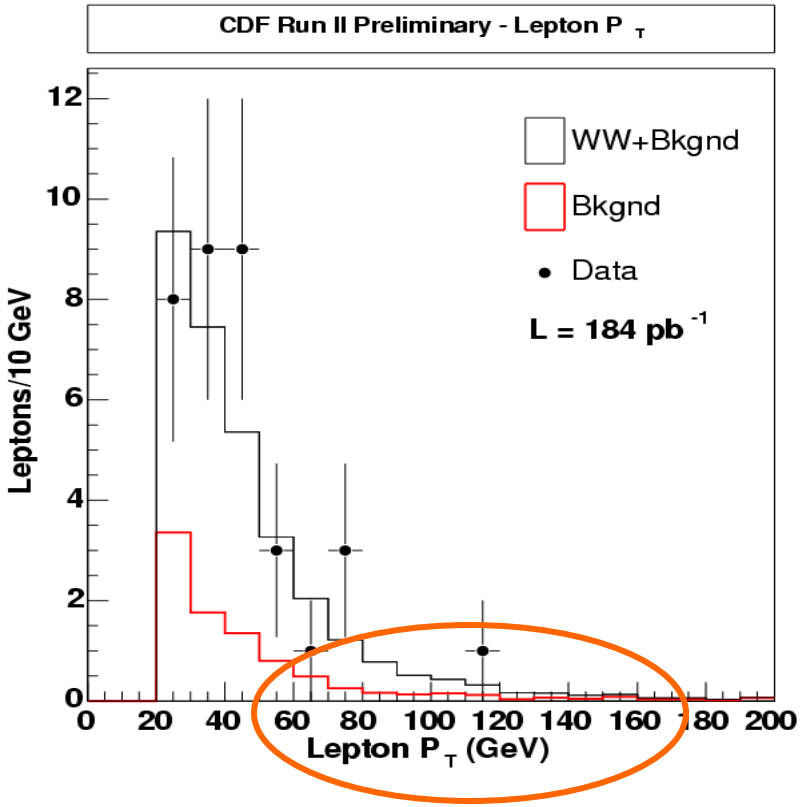
$$\sigma(p\bar{p} \to WW) = 14.3^{+5.6}_{-4.9}(stat) \pm 1.6(syst) \pm 0.9(lum)\ pb$$

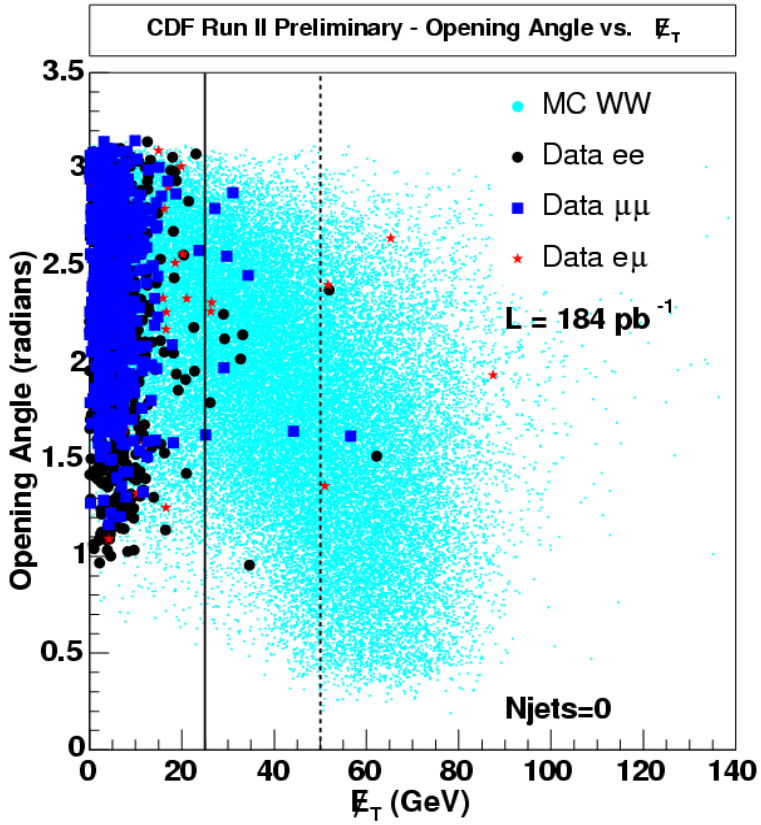
# CDF: WW Beyond SM




**Anoumalous TGC WWZ/WWγ**

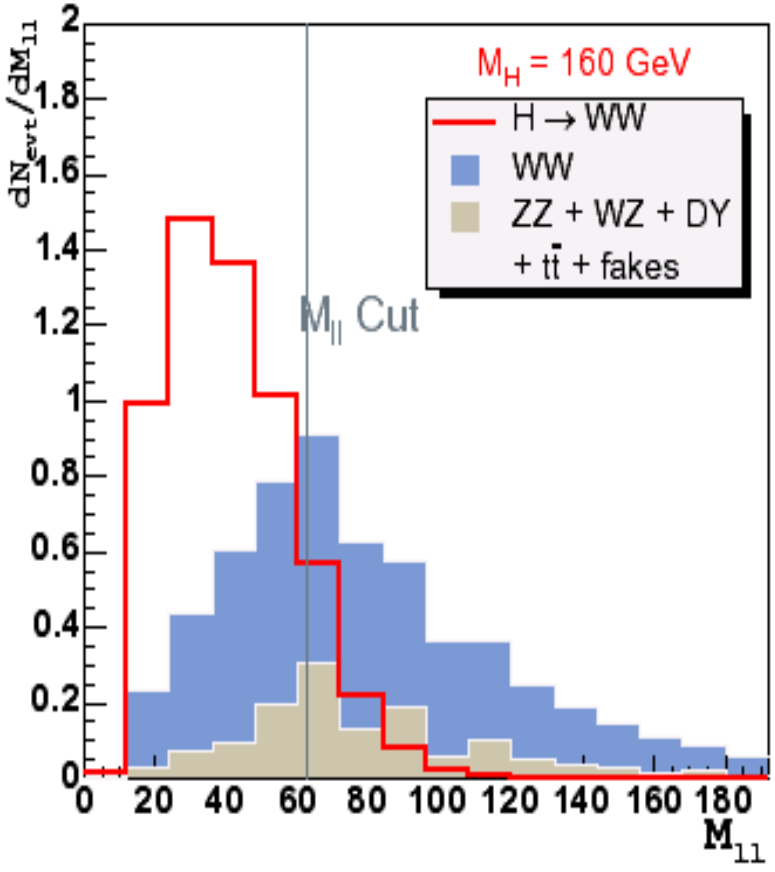
**gg→H→WW 140<$M_H$<180GeV/$c^2$**

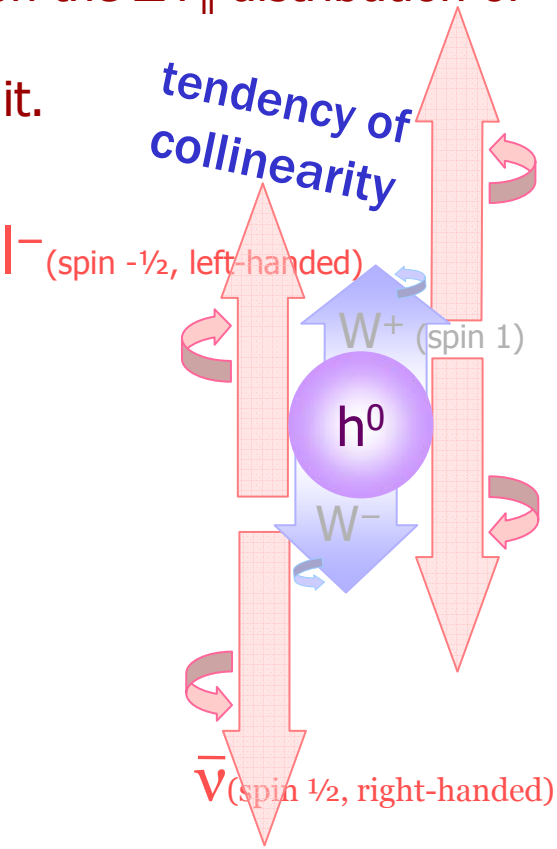


# gg→H→WW* Event Selection

- Kinematic selection from the WW cross section analysis
- ADITIONAL CUTS to separate WW SM production from H→WW
  - Dilepton invariant mass $M_{ll} < ½M_H$
  - Use a binned maximum likelihood method on the $\Delta\Phi_{ll}$ distribution of selected events
  - Extract the 95% CL σ·BR(gg→$h^0$→WW) limit.

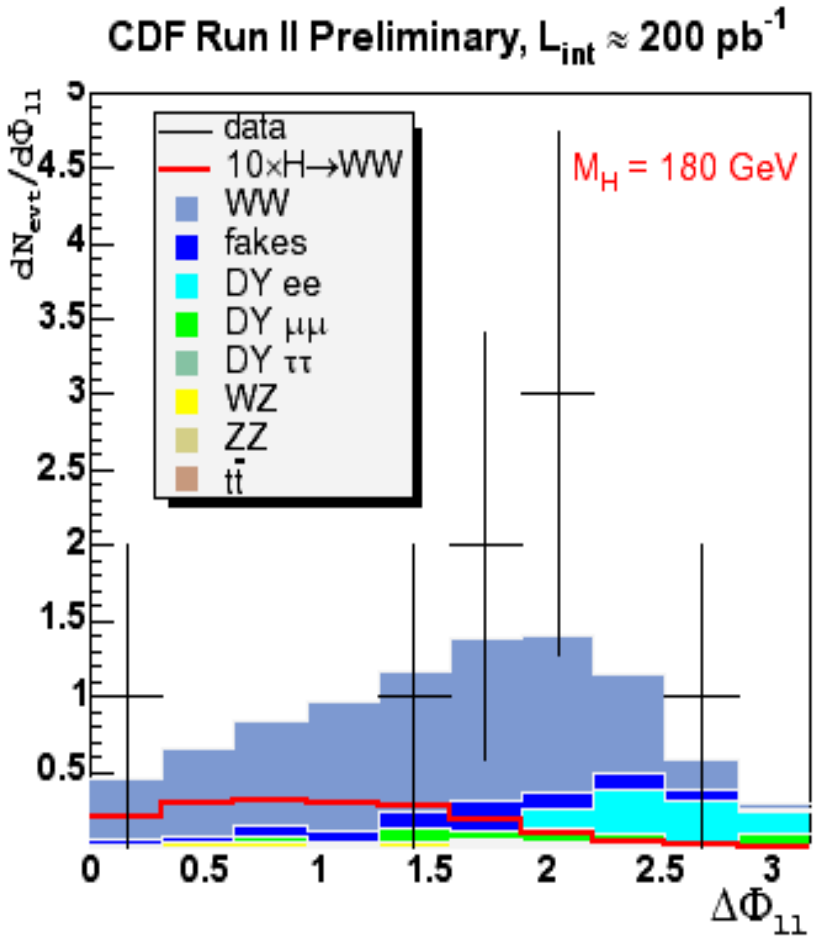



in the rest frame of the higgs boson

# Signal and Background Expectations

| SM $M_H$ (GeV) | 180 |
|---|---|
| $M_{ll}$ cut (GeV) | 80.0 |
| ttbar | 0.02 ± 0.01 |
| ZZ | 0.06 ± 0.01 |
| WZ | 0.18 ± 0.02 |
| DY ττ | 0.03 ± 0.01 |
| DY μμ | 0.43 ± 0.19 |
| DY ee | 0.87 ± 0.44 |
| fakes | 0.81 ± 0.25 |
| WW | 6.49 ± 0.76 |
| total bg | 8.90 ± 0.98 |
| HWW | 0.17 ± 0.02 |
| data | 8 |



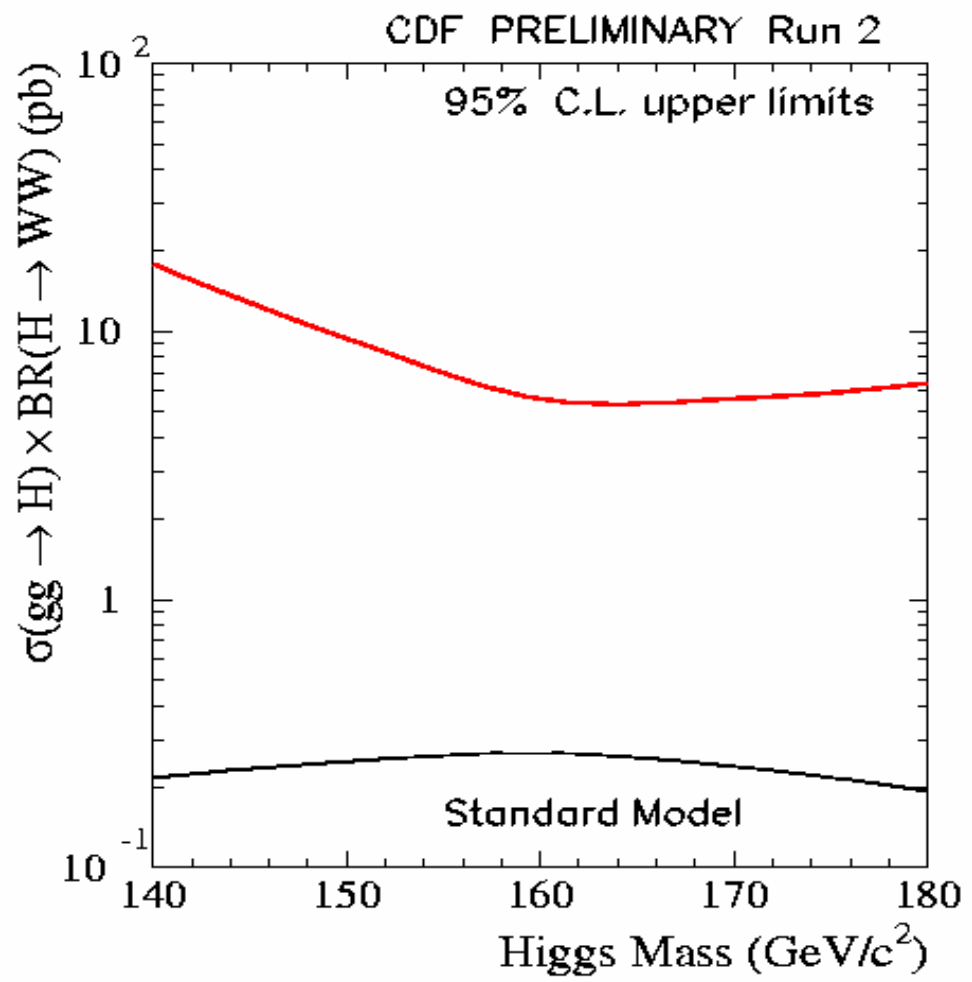
# Limit on σ·BR(gg→H→WW*) as a function of Higgs Mass at √ŝ = 1.96 TeV

CDF Run II Preliminary, $L_{int} \approx 200\ pb^{-1}$

| SM Higgs Mass (GeV) | **140** | **150** | **160** | **170** | **180** |
|---|---|---|---|---|---|
| σ(gg→$h^0$) (pb) | 0.45 | 0.36 | 0.30 | 0.25 | 0.21 |
| BR (H → WW*) | 0.48 | 0.68 | 0.90 | 0.97 | 0.94 |
| Integrated Luminosity ($pb^{-1}$) | 184 ± 11 | | | | |
| Total Acceptance (%) | 0.124±0.012 | 0.228±0.023 | 0.402±0.040 | 0.476±0.048 | 0.449±0.045 |
| Expected Signal (event) | 0.10 ± 0.01 | 0.15 ± 0.02 | 0.22 ± 0.03 | 0.22 ± 0.03 | 0.17 ± 0.02 |
| WW Background (event) | 3.51 ± 0.41 | 3.82 ± 0.45 | 4.45 ± 0.52 | 5.38 ± 0.63 | 6.49 ± 0.76 |
| Other Background (event) | 0.68 ± 0.16 | 0.90 ± 0.24 | 1.34 ± 0.35 | 1.91 ± 0.47 | 2.40 ± 0.55 |
| 95% CL Limit – Counting (pb) | 18.4 | 9.8 | 6.2 | 8.2 | 8.8 |
| Expected Limit – ΔΦ-fitting (pb) | 18.1 | 9.8 | 6.0 | 7.4 | 8.0 |
| 95% CL Limit – ΔΦ-fitting (pb) | **17.8** | **9.4** | **5.6** | **5.6** | **6.4** |

BR(W→lν)² included

# Limit on σ·BR(gg→H→WW*) as a function of Higgs Mass at √ŝ = 1.96 TeV

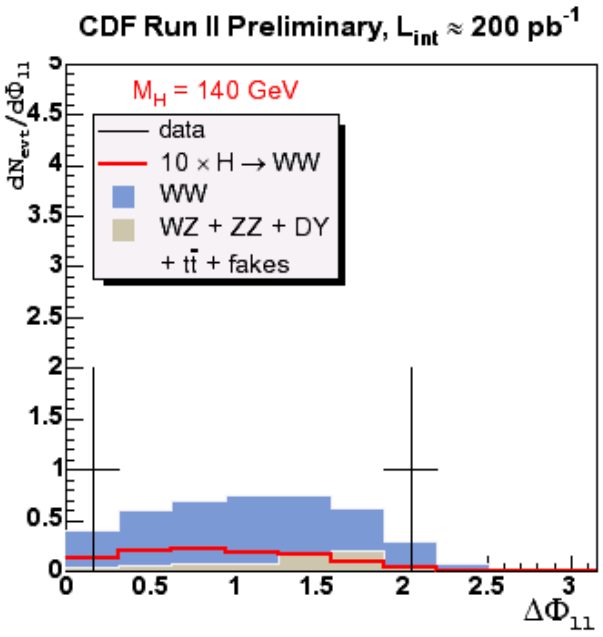


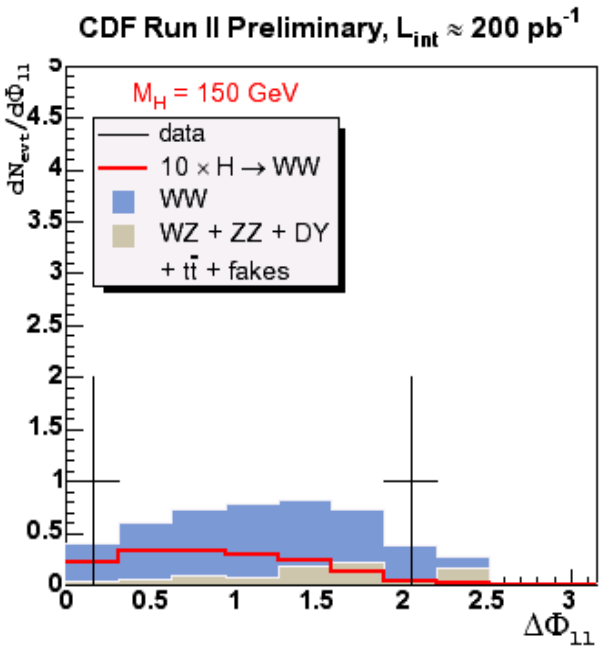

Future plans:

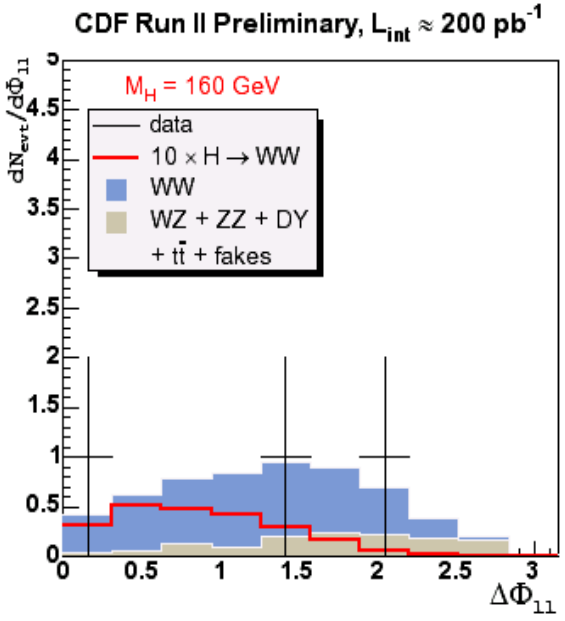
Working on optimization

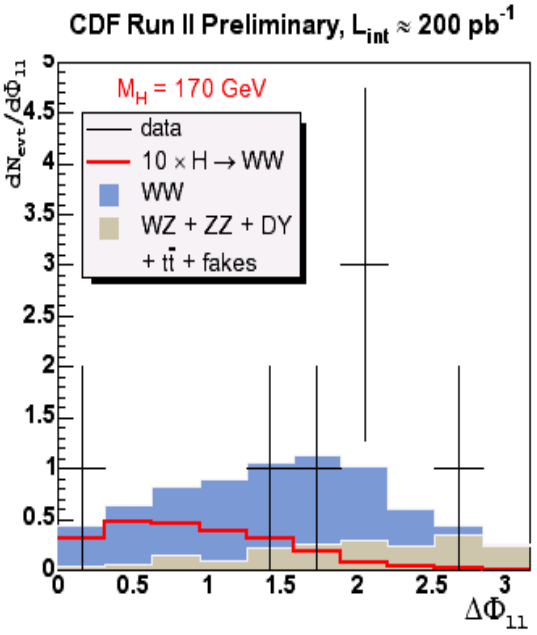
Jet Veto

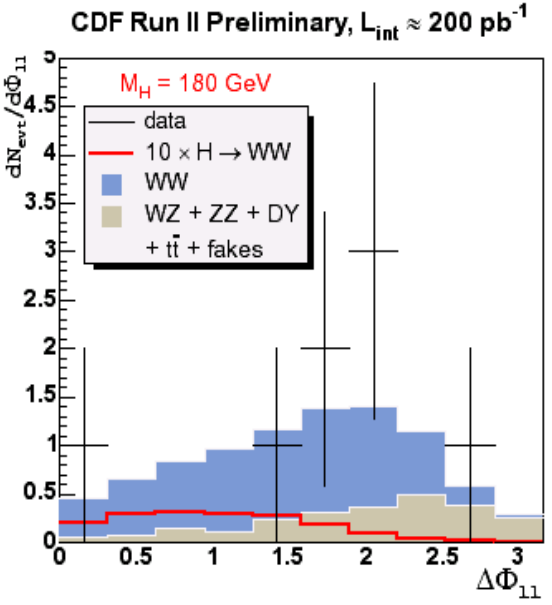
Lowering the Pt of one lepton.


CDF Run II Preliminary, $L_{int} \approx 200\ pb^{-1}$
$M_H$ = 140 GeV
data
10 × H → WW
WW
WZ + ZZ + DY
+ tt̄ + fakes
$dN_{evt}/d\Phi_{11}$
$\Delta\Phi_{11}$


CDF Run II Preliminary, $L_{int} \approx 200\ pb^{-1}$
$M_H$ = 150 GeV
data
10 × H → WW
WW
WZ + ZZ + DY
+ tt̄ + fakes
$dN_{evt}/d\Phi_{11}$
$\Delta\Phi_{11}$


CDF Run II Preliminary, $L_{int} \approx 200\ pb^{-1}$
$M_H$ = 160 GeV
data
10 × H → WW
WW
WZ + ZZ + DY
+ tt̄ + fakes
$dN_{evt}/d\Phi_{11}$
$\Delta\Phi_{11}$


CDF Run II Preliminary, $L_{int} \approx 200\ pb^{-1}$
$M_H$ = 170 GeV
data
10 × H → WW
WW
WZ + ZZ + DY
+ tt̄ + fakes
$dN_{evt}/d\Phi_{11}$
$\Delta\Phi_{11}$

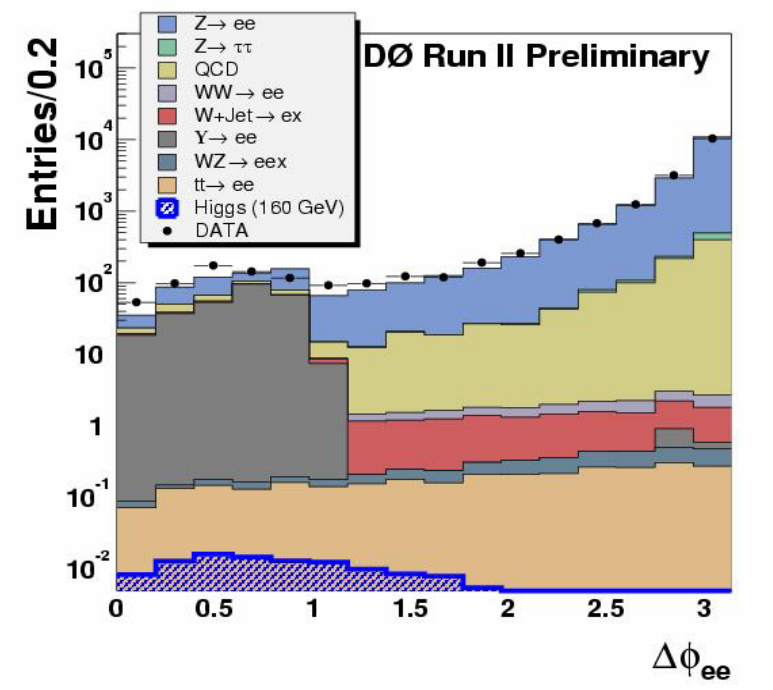

CDF Run II Preliminary, $L_{int} \approx 200\ pb^{-1}$
$M_H$ = 180 GeV
data
10 × H → WW
WW
WZ + ZZ + DY
+ tt̄ + fakes
$dN_{evt}/d\Phi_{11}$
$\Delta\Phi_{11}$

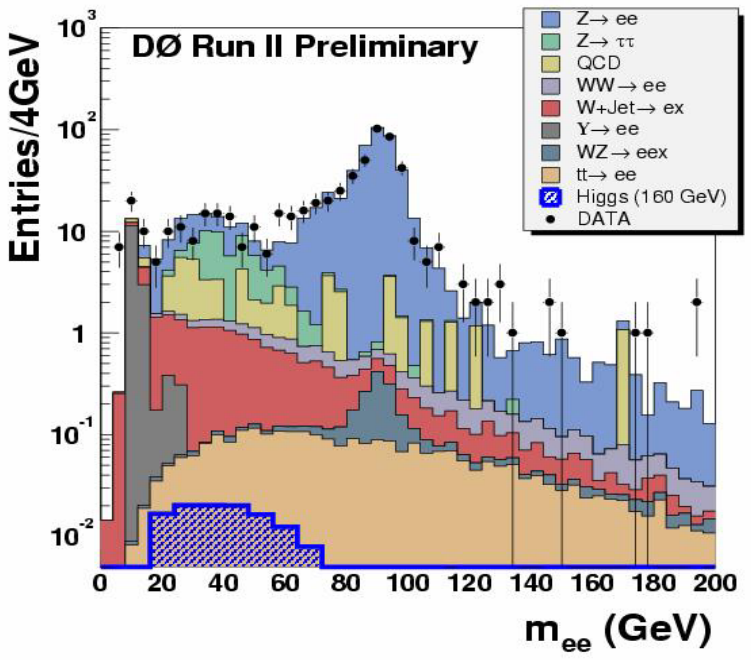
# $gg \rightarrow H \rightarrow WW^*$ Event Selection

- Two leptons with opposite charge:
  - Veto conversions: $N^{SMT}$(trailing e)>2
  - ee channel: $P_t(e_1)>12$ GeV, $P_t(e_2)>8$ GeV
  - eμ channel: $P_t(e)>12$ GeV, $P_t(\mu)>8$GeV
  - μμ channel: $P_t(\mu_1)>20$ GeV, $P_t(\mu_1)>10$ GeV
- Missing $E_t$ >20 GeV  Missing $E_t$ >0.75 •$P_t(\mu_1)$+10 GeV
- To veto dilepton resonances:
  - 12 GeV < $m_{ee}$<80 GeV ✂ $Z \rightarrow ee$, $\Upsilon \rightarrow ee$
  - $m_T^{min}$ > 20 GeV ✂ $Z \rightarrow \tau\tau$
  - $|m_{\mu\mu}-M_Z|$>15 GeV ✂ $Z \rightarrow \mu\mu$ ✂ Z,W+jets…

- $P_t(e_1)$+ $P_t(e_2)$+ Missing $E_t$ >100 GeV $P_t(\mu_1)$+ $P_t(\mu_2)$+ Missing $E_t$ >100 GeV
- Missing Et (scaled) > 15 GeV Missing Et (scaled) > 15 GeV
- $\Delta\phi_{ee}$<1.5 $\Delta\phi_{e\mu}$<1.5 $\Delta\phi_{\mu\mu}$<1.5 ✂ WW and others
- Jet Veto: ✂ top dilepton
  - No jet OR $E_t^{jet1}$<90 GeV OR ($E_t^{jet1}$<50 GeV AND $E_t^{jet1}$<30 GeV )
  - No jet OR $E_t^{jet1}$<90 GeV OR ($E_t^{jet1}$<50 GeV AND $E_t^{jet1}$<30 GeV )
  - No jet OR ($E_t^{jet1}$<60 GeV AND $E_t^{jet1}$<30 GeV )

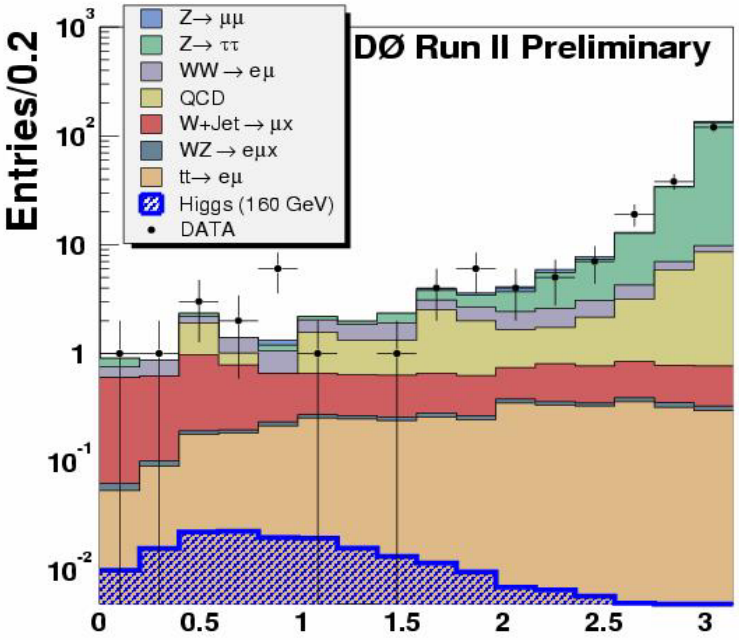
# $gg \rightarrow H \rightarrow WW^{*} \rightarrow ee\nu\nu$

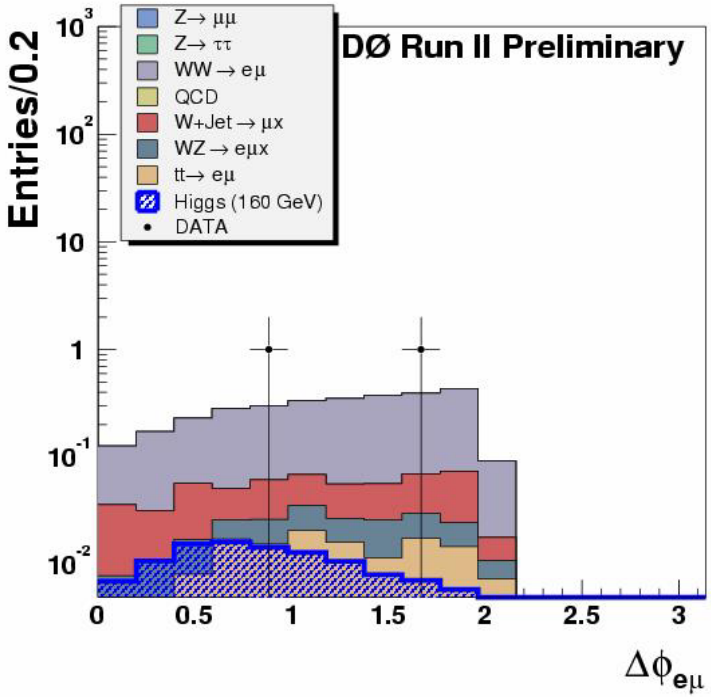



| | |
|---|---|
| $tt \rightarrow be^{+}\nu be^{-}\nu$ | $0.06 \pm 0.01$ |
| $WZ \rightarrow e^{+}e^{-}X$ | $0.04 \pm 0.01$ |
| $\Upsilon \rightarrow e^{+}e^{-}$ | $0.0 \pm 0.01$ |
| W+jets | $1.24 \pm 0.07$ |
| $WW \rightarrow e^{+}\nu e^{-}\nu$ | $1.17 \pm 0.02$ |
| $Z/\gamma^{*} \rightarrow \tau^{+}\tau^{-}$ | $0.0 \pm 0.1$ |
| $Z/\gamma^{*} \rightarrow e^{+}e^{-}$ | $0.1 \pm 0.1$ |
| QCD | $0.0 \pm 0.5$ |
| Total | $2.7 \pm 0.4$ |
| DATA | 2 |

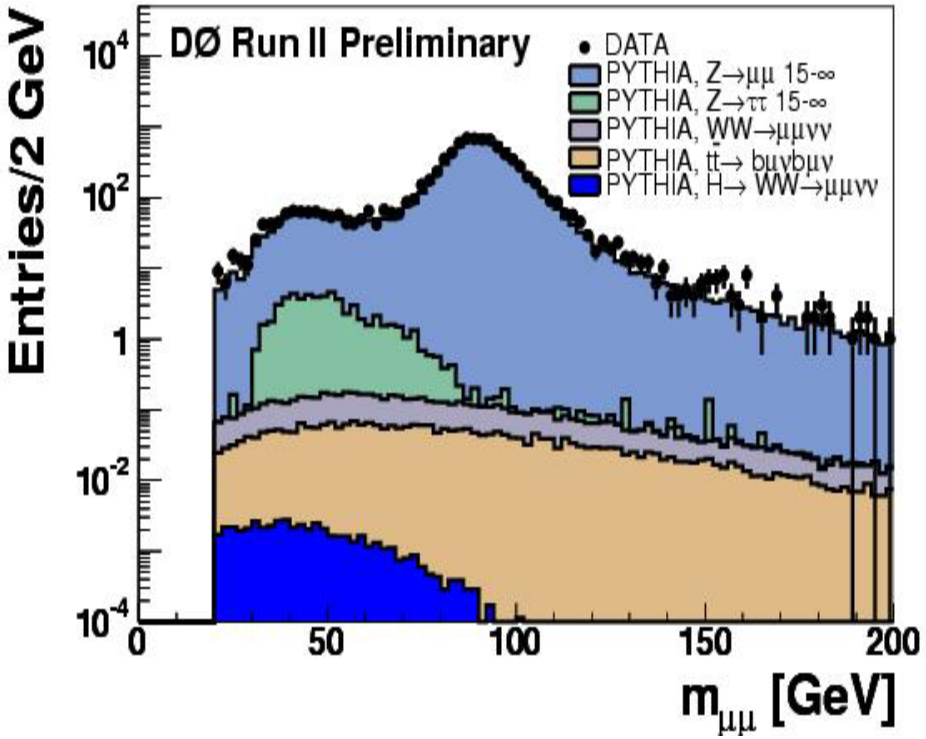
# $gg \rightarrow H \rightarrow WW^{*} \rightarrow e\mu\nu\nu$

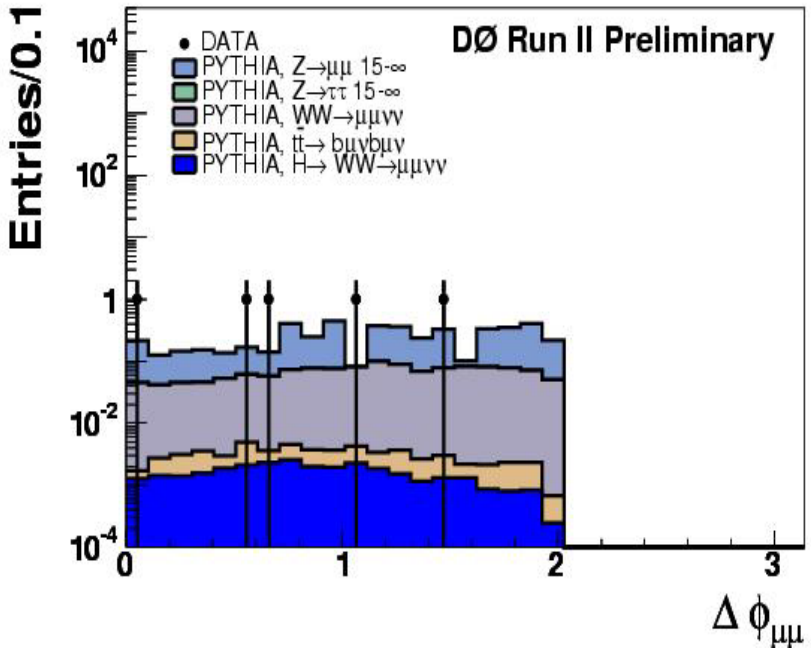



| | |
|---|---|
| $tt \rightarrow be^{\pm}\nu b\mu^{\pm}\nu$ | $0.13 \pm 0.01$ |
| $WZ \rightarrow e^{\pm}\mu^{\pm}+X$ | $0.11 \pm 0.01$ |
| W+jets | $0.34 \pm 0.02$ |
| $WW \rightarrow e^{\pm}\nu\mu^{\pm}\nu$ | $2.51 \pm 0.05$ |
| $Z/\gamma^{*} \rightarrow \tau^{+}\tau^{-}$ | $0.0 \pm 0.1$ |
| $Z/\gamma^{*} \rightarrow \mu^{+}\mu^{-}$ | $0.0 \pm 0.5$ |
| QCD | $0.0 \pm 0.2$ |
| Total | $3.1 \pm 0.3$ |
| DATA | 2 |

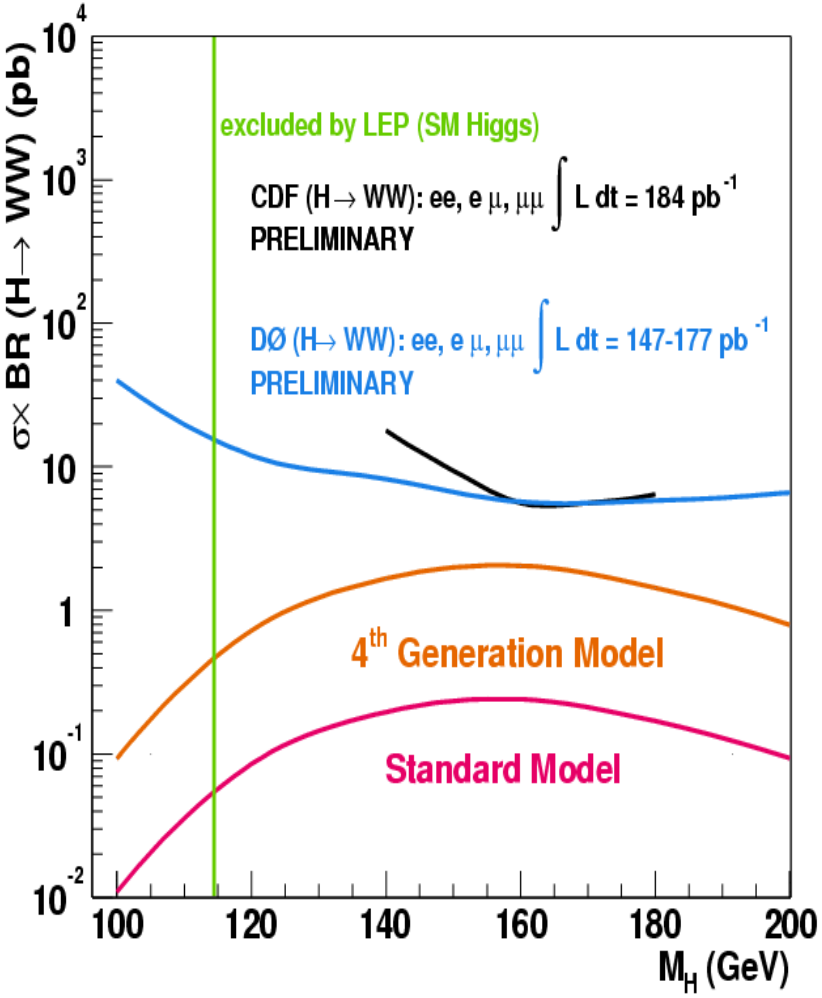
# $gg \rightarrow H \rightarrow WW^{*} \rightarrow \mu\mu\nu\nu$

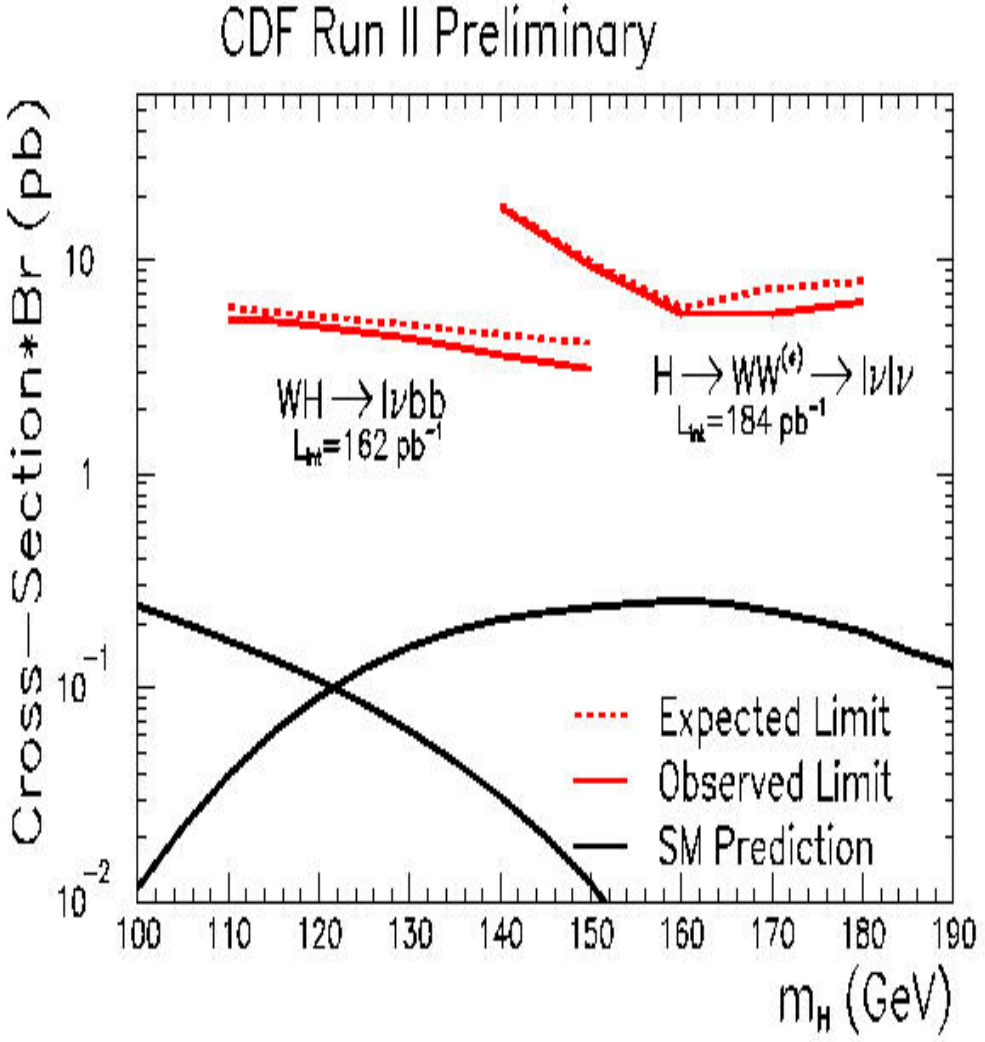



| | |
|---|---|
| $tt \rightarrow b\mu^{+}\nu b\mu^{-}\nu$ | $0.03 \pm 0.003$ |
| QCD W+jets | $0.02 \pm 0.02$ |
| $WW \rightarrow \mu^{+}\nu\mu^{-}\nu$ | $1.28 \pm 0.03$ |
| $Z/\gamma^{*} \rightarrow \tau^{+}\tau^{-}$ | $0. \pm 0.$ |
| $Z/\gamma^{*} \rightarrow \mu^{+}\mu^{-}$ | $3.9 \pm 0.6$ |
| Total | $5.3 \pm 0.6$ |
| DATA | 5 |

# CONCLUSIONS



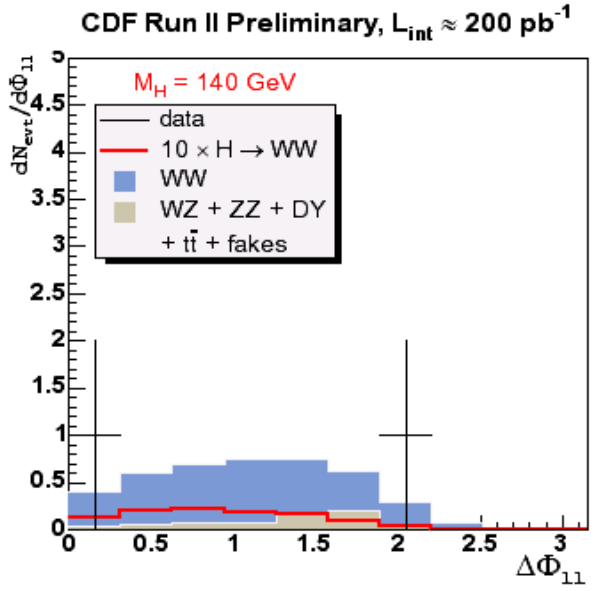
# BACKUP SLIDES

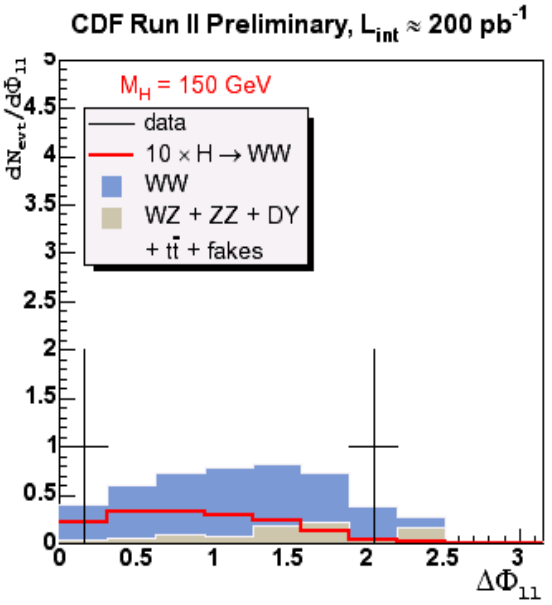
# Signal acceptance

| $M_H$ | $M_{ll}$ Cut (GeV) | ee (%) | eμ (%) | μμ (%) | ee+eμ+μμ (%) |
|---|---|---|---|---|---|
| 140 | 55.0 | 0.030±0.001 | 0.060±0.001 | 0.034±0.001 | 0.124±0.002 |
| 150 | 57.5 | 0.055±0.002 | 0.110±0.002 | 0.063±0.002 | 0.228±0.003 |
| 160 | 62.5 | 0.093±0.002 | 0.196±0.003 | 0.113±0.002 | 0.402±0.004 |
| 170 | 70.0 | 0.115±0.003 | 0.230±0.004 | 0.131±0.003 | 0.476±0.005 |
| 180 | 80.0 | 0.110±0.003 | 0.219±0.003 | 0.119±0.002 | 0.449±0.005 |

TABLE V: Signal efficiencies with statistical error after all cuts for the ee, $e\mu$, and $\mu\mu$ channel for different Higgs masses $m_H$.

| $m_H$ [GeV] | 100 | 120 | 140 | 160 | 180 | 200 |
|---|---|---|---|---|---|---|
| $ee$ | $0.023 \pm 0.002$ | $0.077 \pm 0.003$ | $0.104 \pm 0.003$ | $0.155 \pm 0.004$ | $0.151 \pm 0.004$ | $0.118 \pm 0.003$ |
| $e\mu$ | $0.014 \pm 0.001$ | $0.059 \pm 0.002$ | $0.094 \pm 0.003$ | $0.131 \pm 0.004$ | $0.137 \pm 0.004$ | $0.130 \pm 0.004$ |
| $\mu\mu$ | $0.045 \pm 0.002$ | $0.110 \pm 0.003$ | $0.150 \pm 0.004$ | $0.216 \pm 0.005$ | $0.179 \pm 0.005$ | $0.151 \pm 0.004$ |


CDF Run II Preliminary, $L_{int} \approx 200\ pb^{-1}$
$M_H$ = 140 GeV
data
10 × H → WW
WW
WZ + ZZ + DY
+ $t\bar{t}$ + fakes
$dN_{evt}/d\Phi_{ll}$
$\Delta\Phi_{ll}$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$M_H$ = 150 GeV
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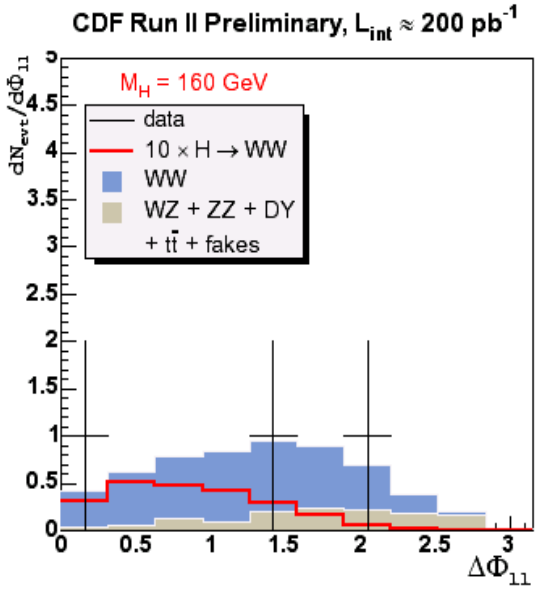
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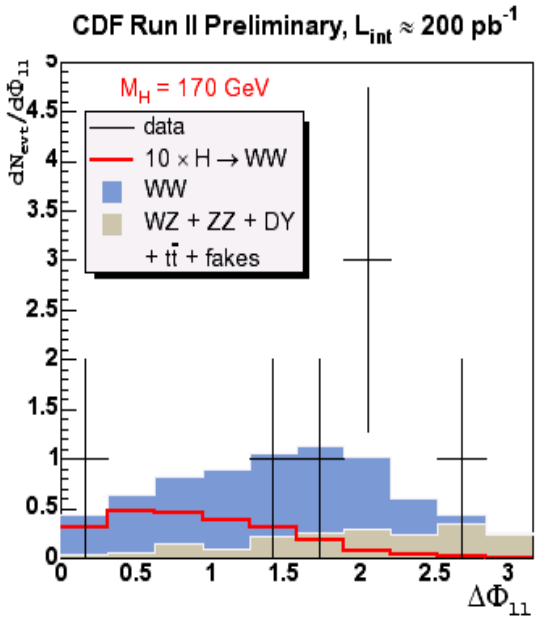
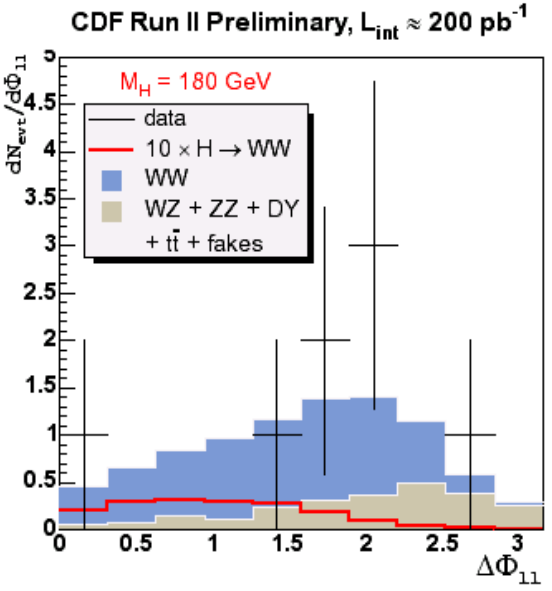
+ $t\bar{t}$ + fakes
$dN_{evt}/d\Phi_{ll}$
$\Delta\Phi_{ll}$


CDF Run II Preliminary, $L_{int} \approx 200\ pb^{-1}$
$M_H$ = 170 GeV
data
10 × H → WW
WW
WZ + ZZ + DY
+ $t\bar{t}$ + fakes
$dN_{evt}/d\Phi_{ll}$
$\Delta\Phi_{ll}$


CDF Run II Preliminary, $L_{int} \approx 200\ pb^{-1}$
$M_H$ = 180 GeV
data
10 × H → WW
WW
WZ + ZZ + DY
+ $t\bar{t}$ + fakes
$dN_{evt}/d\Phi_{ll}$
$\Delta\Phi_{ll}$

| SM Higgs Mass (GeV) | 140 | 150 | 160 | 170 | 180 |
|---|---|---|---|---|---|
| $\sigma(gg \rightarrow h^0)$ (pb) | 0.45 | 0.36 | 0.30 | 0.25 | 0.21 |
| BR ($H \rightarrow WW^*$) | 0.48 | 0.68 | 0.90 | 0.97 | 0.94 |
| Expected Signal (event) | 0.10 ± 0.01 | 0.15 ± 0.02 | 0.22 ± 0.03 | 0.22 ± 0.03 | 0.17 ± 0.02 |
| WW Background (event) | 3.51 ± 0.41 | 3.82 ± 0.45 | 4.45 ± 0.52 | 5.38 ± 0.63 | 6.49 ± 0.76 |
| Other Background (event) | 0.68 ± 0.16 | 0.90 ± 0.24 | 1.34 ± 0.35 | 1.91 ± 0.47 | 2.40 ± 0.55 |
| 95% CL Limit – ΔΦ-fitting (pb) | **17.8** | **9.4** | **5.6** | **5.6** | **6.4** |

TABLE VI: Upper limits on the cross section times branching ratio for $\sigma \times BR(H \rightarrow WW)$ from the ee, $e\mu$, $\mu\mu$ final state and the combination of all three channels for different Higgs masses $m_H$.

| $m_H$ [GeV] | 100 | 120 | 140 | 160 | 180 | 200 |
|---|---|---|---|---|---|---|
| $ee$: limit $\sigma \times BR(H \rightarrow WW)$ [pb] | 102.2 | 29.7 | 21.8 | 14.8 | 15.2 | 19.2 |
| $e\mu$: limit $\sigma \times BR(H \rightarrow WW)$ [pb] | 90.0 | 21.0 | 13.1 | 9.6 | 9.2 | 9.6 |
| $\mu\mu$: limit $\sigma \times BR(H \rightarrow WW)$ [pb] | 86.4 | 35.2 | 25.8 | 17.9 | 21.6 | 25.7 |
| all: limit $\sigma \times BR(H \rightarrow WW)$ [pb] | 40.1 | 12.0 | 8.2 | 5.7 | 5.8 | 6.6 |