Search for Higgs at CDF

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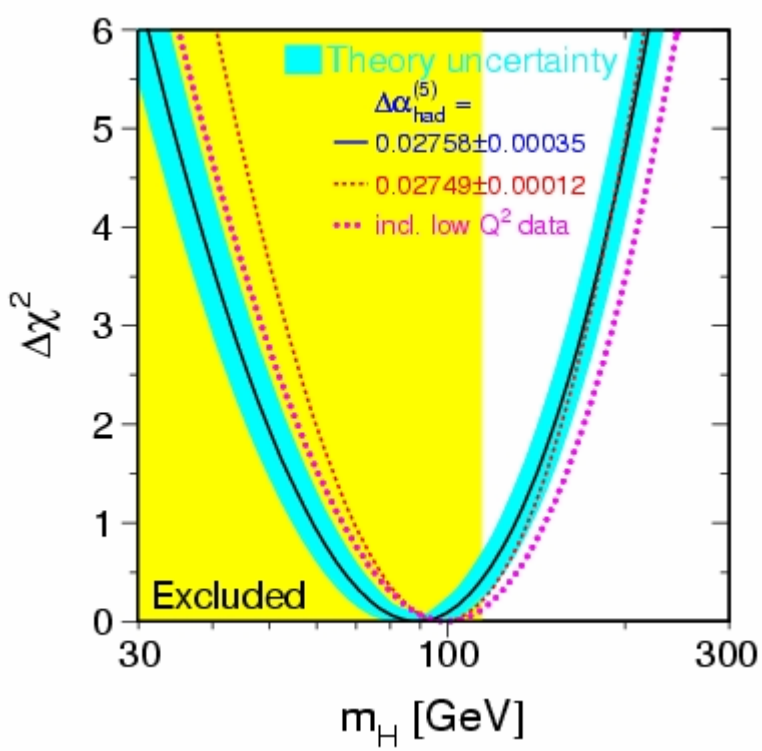
Introduction

- Test the hypothesis of spontaneous electroweak symmetry breaking

- Standard Model Higgs
  - Single scalar: spin 0, charge 0
  - Generate masses of W, Z and fermions

- Other possibilities
  - MSSM, L/R Symmetric Model, Little Higgs: h, H, A, H^+, H^- , H^{++}, H^{--}

Precision SM EW fits combined with 114.4 GeV direct search bound: 114.4 - 207 GeV



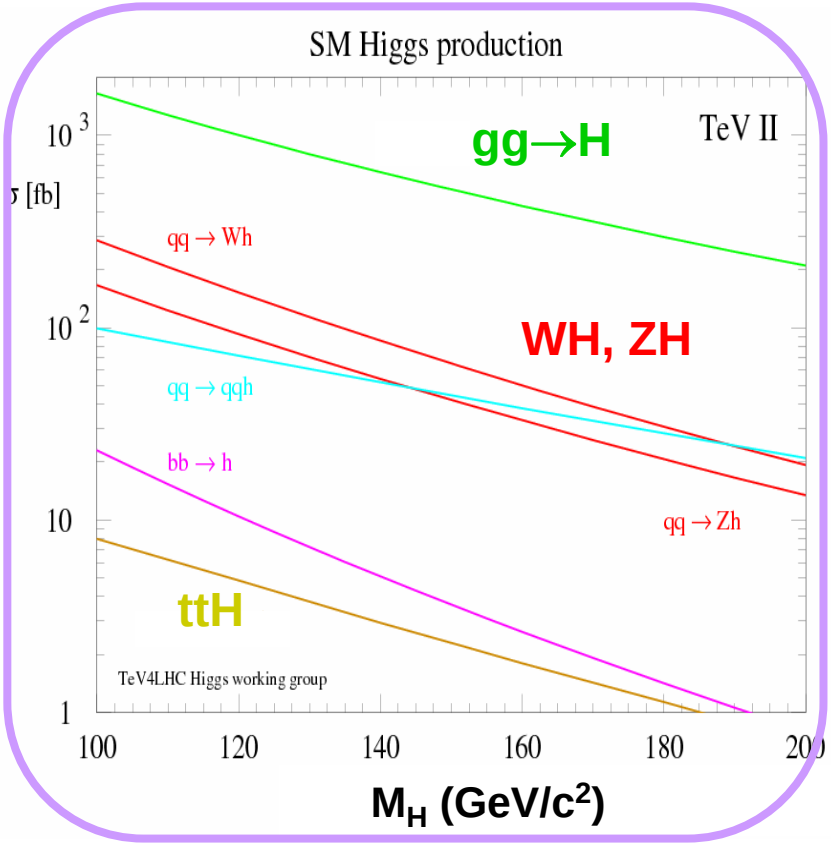
Higgs Search at CDF

- In this talk, new results from CDF
  - Standard Model Higgs
    - $H \rightarrow W^+W^- \rightarrow l\nu\, l\nu$
    - $WH \rightarrow l\nu bb$
    - $ttH \rightarrow l\nu bbbbjj$
  - Doubly Charged Higgs (L/R Symmetric Model)
    - $H^{++}H^{--} \rightarrow l\tau l\tau$ (Lepton Flavor Violation)

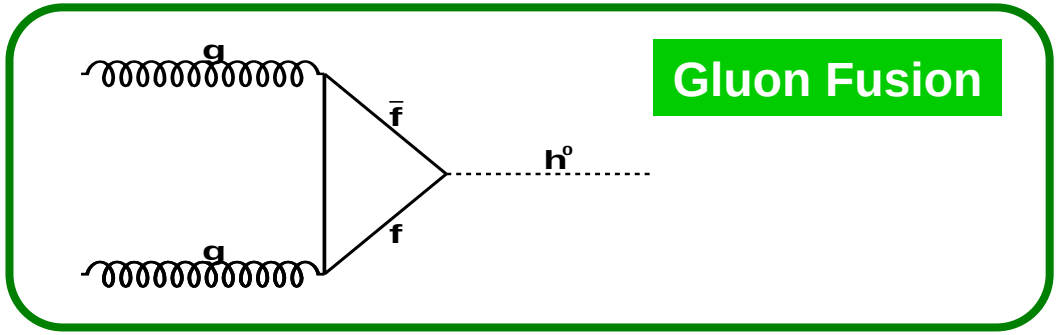
$l = e, \mu$

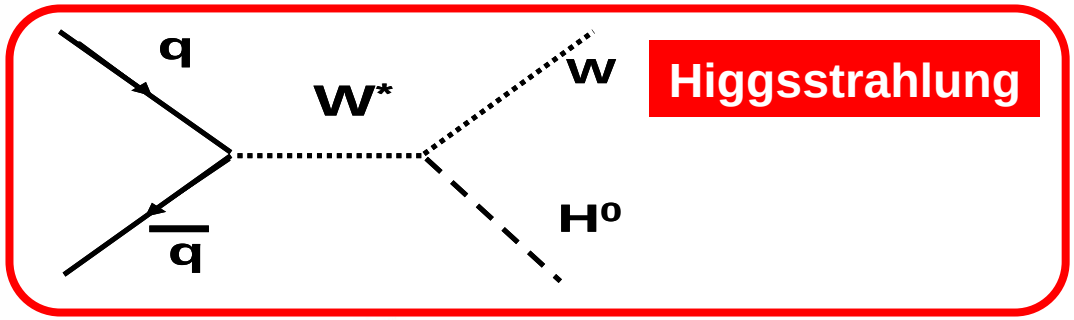
- See K. Lannon's talk for MSSM Higgs $t \rightarrow b\, H^+$ search
- See A. Anastassov's talk for searches of $H \rightarrow \tau\tau$, $ZH \rightarrow \nu\nu bb$, $WH \rightarrow WWW$

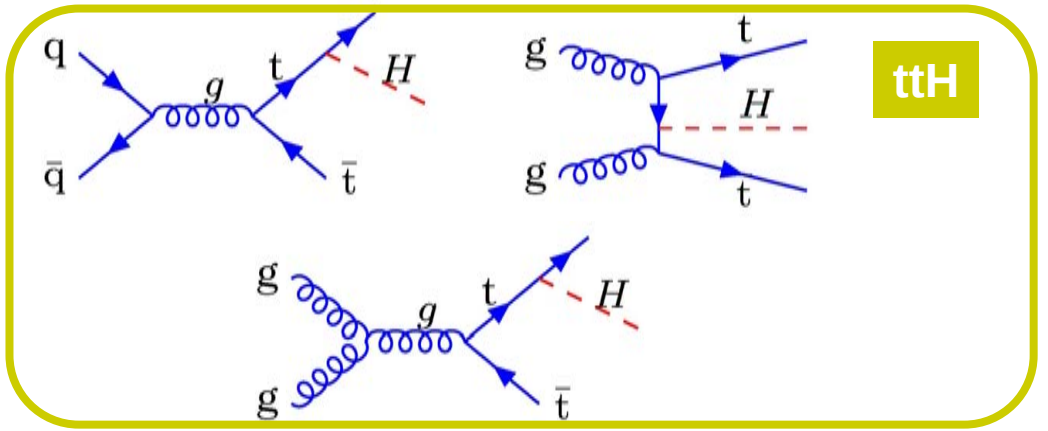
SM Higgs Production & Decays



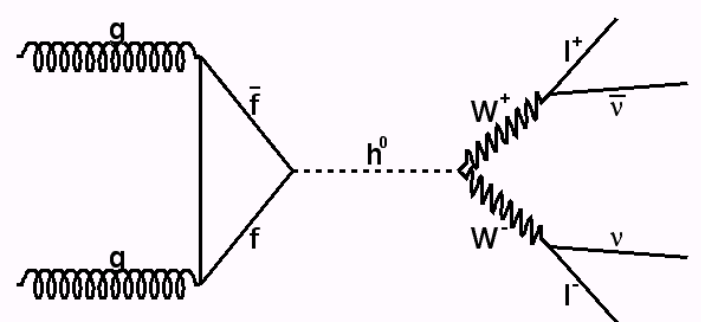
Dominant modes:
H→bb for m_H<130 GeV
H→WW for m_H>130 GeV



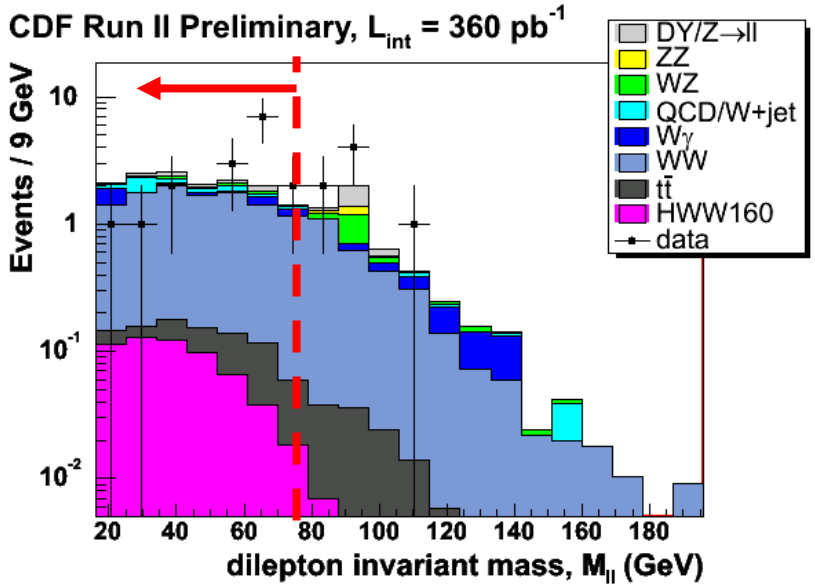




$gg \to H \to WW^{(*)} \to \ell^+\ell^-\nu\bar{\nu}$



Submitted to PRL



- Dileptons are aligned due to the scalar nature of Higgs
  - Small M_{ll}, $\Delta\phi_{ll}$, and large missing Et
  - Different from SM WW background

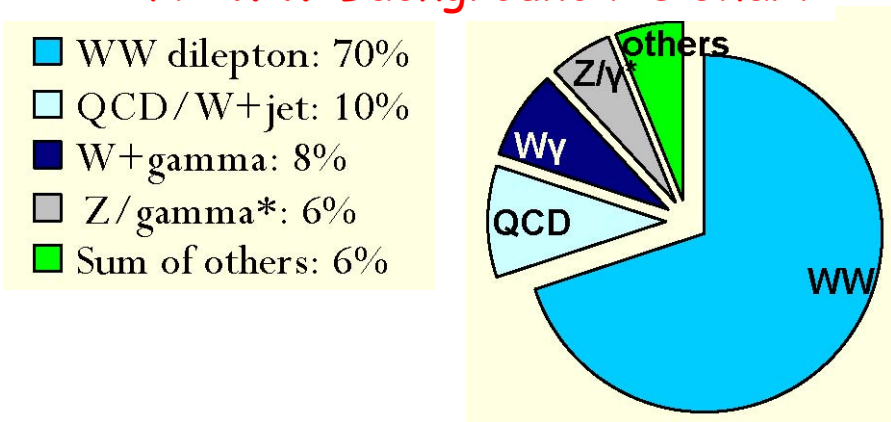
Event Selection

- Two opposite-sign isolated leptons: $P_{T,1}$>20 GeV, $P_{T,2}$>10 GeV
- Missing $E_T > M_H/4$ GeV (reduce Drell-Yan)
- $16 < M_{ll} < M_H/2 - 5$ GeV (reduce diboson, ccbar or bbbar resonances)
- Njet =0, or Njet =1 if E_T < 55 GeV or Njet =2 if E_T < 40 GeV (reduce ttbar)
- If missing Et < 50 GeV, $\Delta\phi$(missing Et-lepton (jet)) > 20 degrees (reduce $Z \to \tau\tau$)
- $P_{T,1}$ + $P_{T,2}$ + missing Et < M_H (reduce diboson)
- Acceptance X Efficiency = 3.0% – 6.5%

$gg \to H \to WW^{(*)} \to \ell^+\ell^-\nu\bar{\nu}$

(SM) source	Expectation (M_H=160 GeV)
WW	9.79 ± 1.03
WZ	0.37 ± 0.05
ZZ	0.04 ± 0.01
Drell-Yan ee	0.76 ± 0.19
ttbar	0.35 ± 0.04
Wγ	1.14 ± 0.08
fakes	1.33 ± 0.67
total bg	**13.78 ± 1.25**
HWW	**0.58 ± 0.04**
data	**16**

H->WW Background Pie Chart



- Physics background estimated with MC
- Fakes estimated by applying the fake rate from the inclusive jet data to W+jet sample

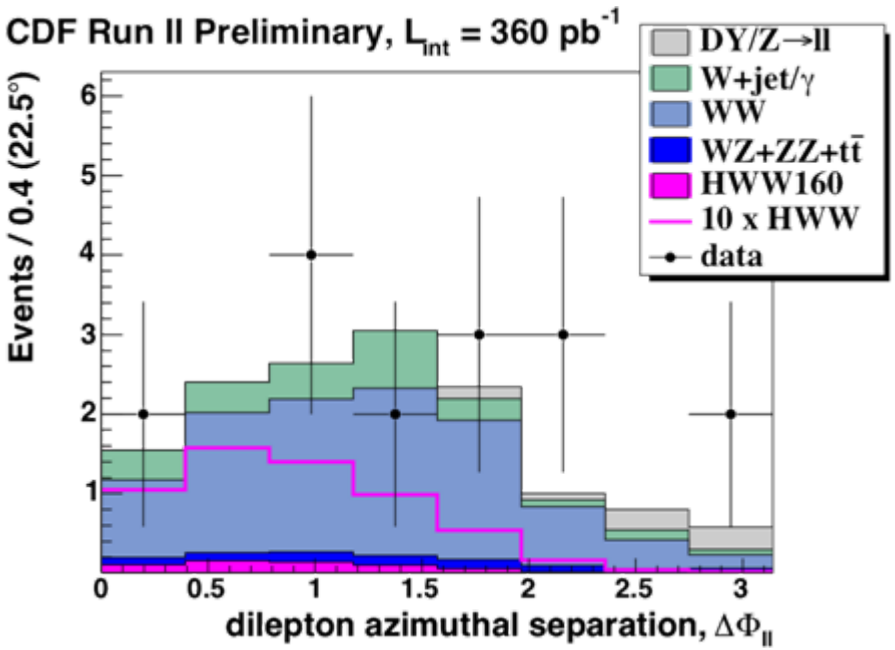
$gg \to H \to WW^{(*)} \to \ell^+\ell^-\nu\bar{\nu}$

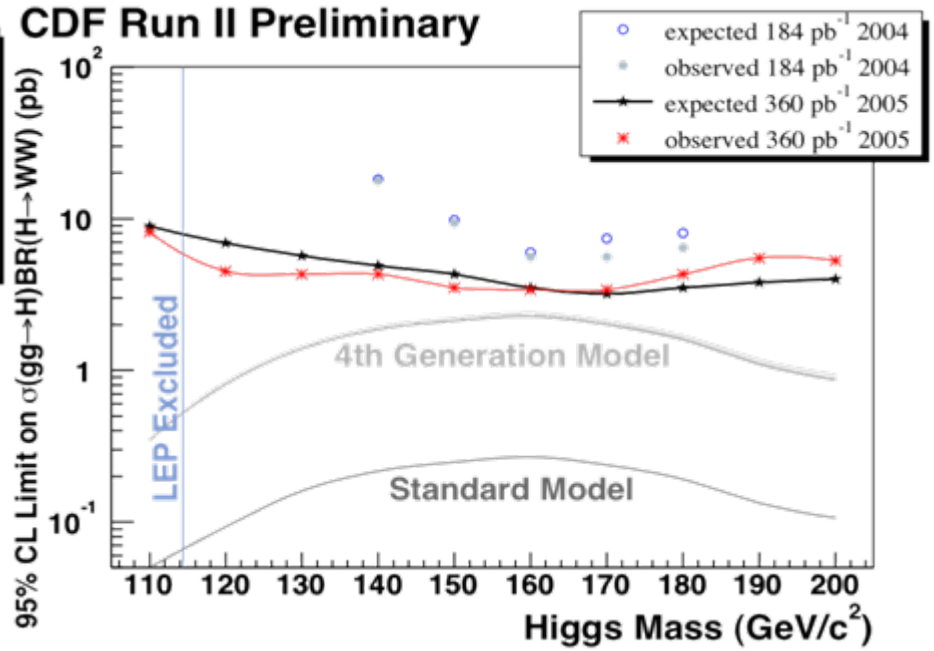
Use binned likelihood to compare the $\Delta\phi_{ll}$ of data against the SM prediction

For $M_H = 160\ \mathrm{GeV}/c^2$,

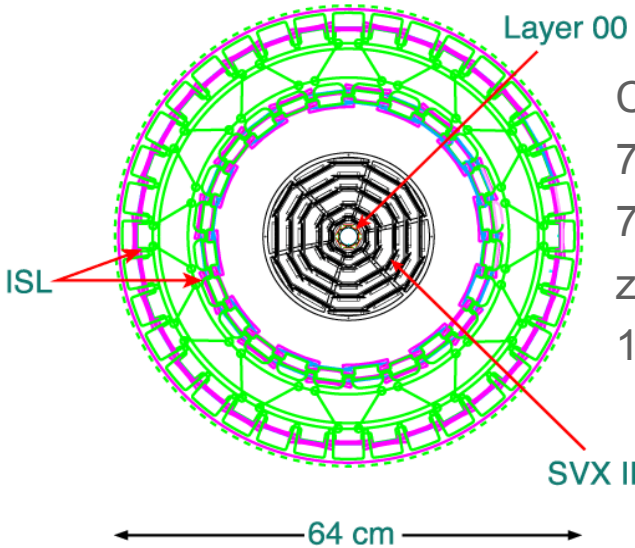
$\sigma(gg \to H) \times \mathrm{B}(H \to WW) < 3.2\ \mathrm{pb}$

$\int \mathrm{L}\, dt = 360 \pm 22\ pb^{-1}$

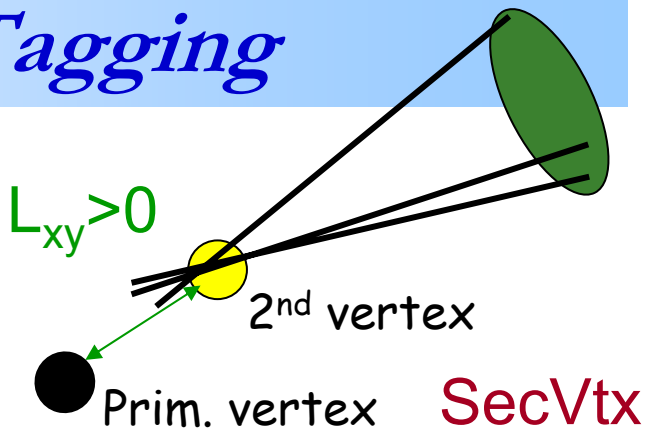




Secondary Vertex Tagging

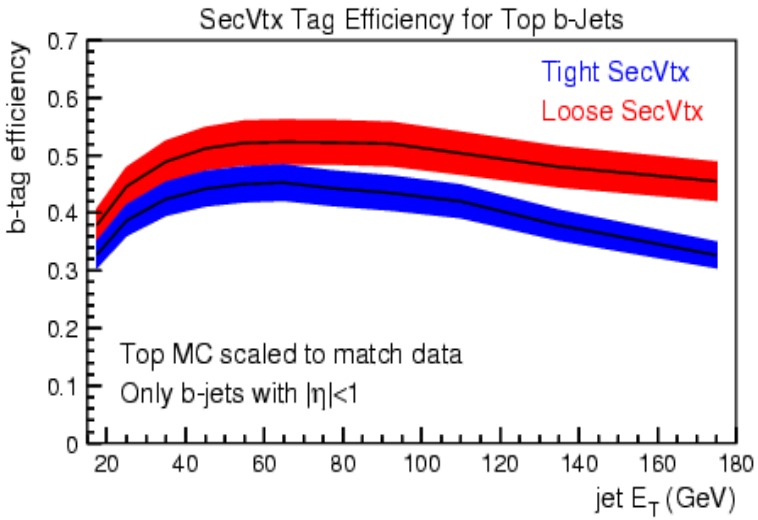


CDF Run II Silicon:
7-8 silicon layers
722,432 channels
z^{max} = 45 cm, $|\eta|^{max}$ = 2
1.3 < *r* < 30 cm



- **tag jet if decay length $L_{xy}/\sigma_{Lxy} > 7$**
- **L_{xy} > 0 : positive tag**
- **L_{xy} < 0 : negative tag**

SecVtx b-tag efficiency data/MC scale factor is the dominant systematic uncertainties of low mass Higgs analysis.

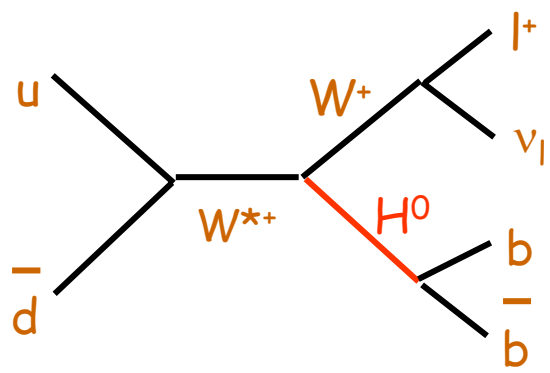


L_{xy}< 0 used to estimate mistag rate

Mistag rates of SecVtx ~ 0.5% for light-flavor jets.

$W^+H \to \ell^+\nu_\ell b\bar{b}$

X2.2 data, Neural Network b-tag

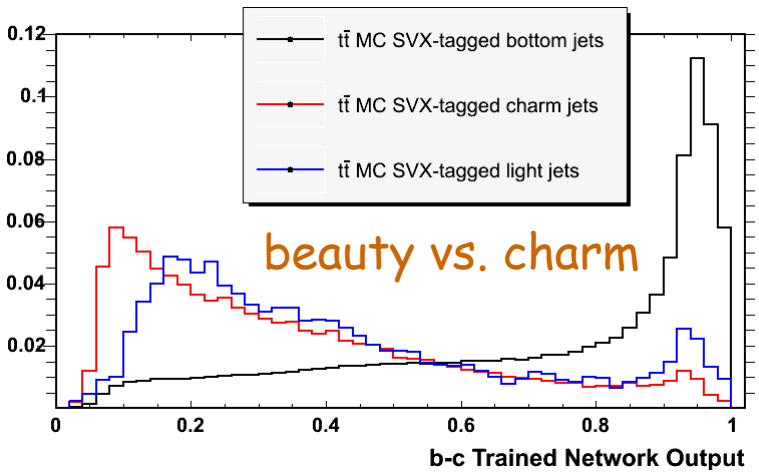


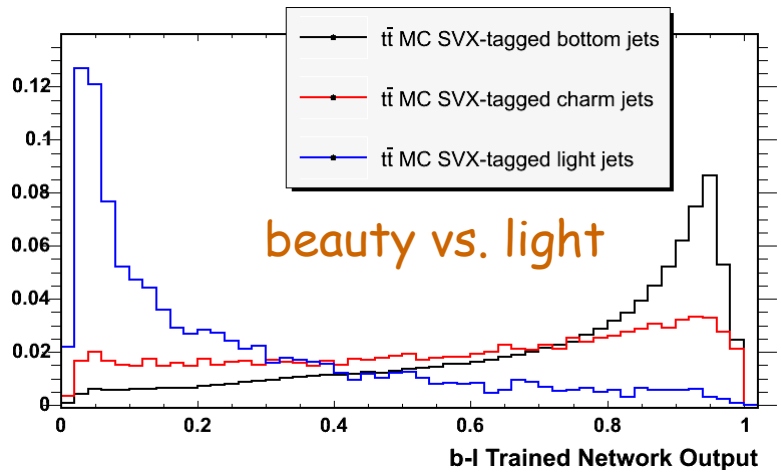
Event Selection

- One central isolated lepton with E_T > 20 GeV
- Large Missing E_T (> 20 GeV)
- 2 jets (E_T > 15 GeV, $|\eta|$<2.0)
- = 2 jets tagged by SecVtx
- or = 1 jet tagged by SecVtx and NN
- Veto Z and ttbar diplepton events
- Acceptance x Efficiency=1.3%-1.5% and 0.5-0.6%

NN Trained on SecVtx Tagged Events

NN b-tag keeps 90% of b jets, and rejects 50% of c jets, 65% of light-flavor jets





$W^+H \to \ell^+\nu_\ell b\bar{b}$

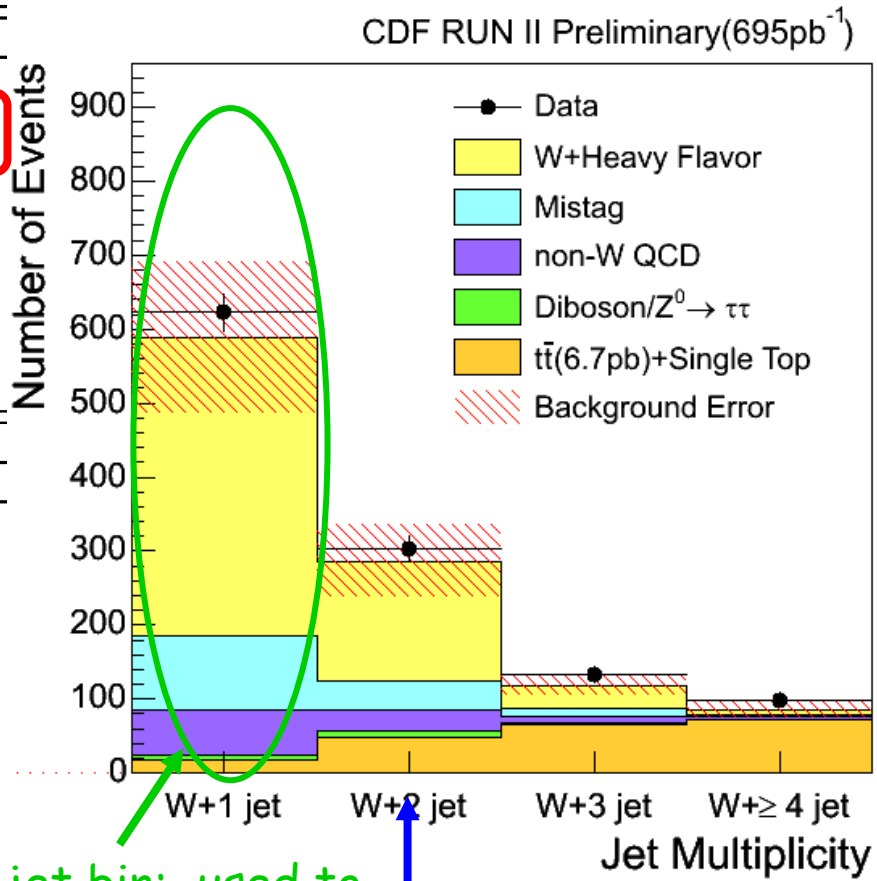
= 1 jet tagged by SecVtx and NN

Jet Multiplicity	w/o NN tag	w/ NN tag
Before b-tagging	10647	10647
Mistag	119.4 ± 19.4	41.8 ± 9.0
$Wb\bar{b}$	130.4 ± 44.6	120.2 ± 41.1
$Wc\bar{c}$	48.9 ± 16.7	33.7 ± 11.5
Wc	47.4 ± 12.4	25.0 ± 6.5
$t\bar{t}$(6.7pb)	43.1 ± 7.3	37.8 ± 6.4
Single Top	22.7 ± 2.4	20.1 ± 2.1
Diboson/$Z^0 \to \tau\tau$	17.0 ± 2.5	10.6 ± 1.7
non-W QCD	44.4 ± 7.7	29.5 ± 5.1
Total Background	473.4 ± 66.9	318.8 ± 54.7
Observed($\geq$1tag)	514	332

= 2 jets tagged by SecVtx

Mistag	3.1 ± 0.5
$Wb\bar{b}$	14.8 ± 5.3
$Wc\bar{c}$	0.2 ± 0.1
Wc	0.0 ± 0.0
$t\bar{t}$(6.7pb)	7.5 ± 1.3
Single Top	3.0 ± 0.3
Diboson/$Z^0 \to \tau\tau$	0.8 ± 0.2
non-W QCD	1.0 ± 0.2
Total Background	30.6 ± 5.6
Observed($\geq$2tag)	29

= 1 jet tagged by SecVtx and NN



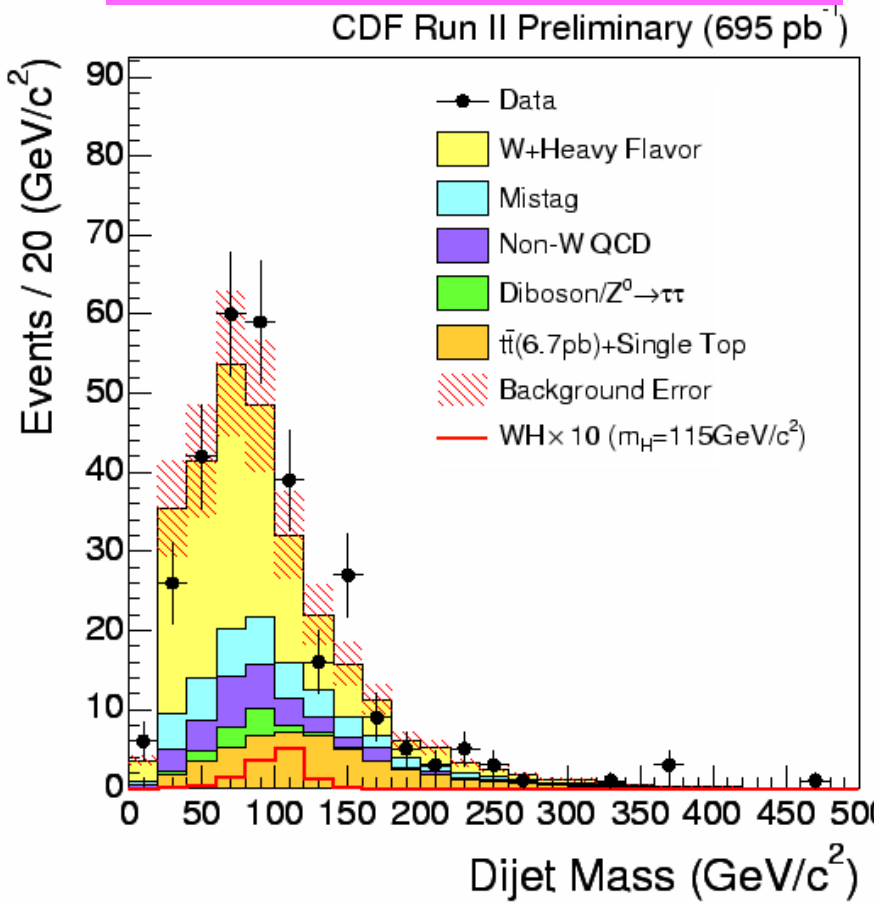
1-jet bin: used to normalize HF fraction

signal region

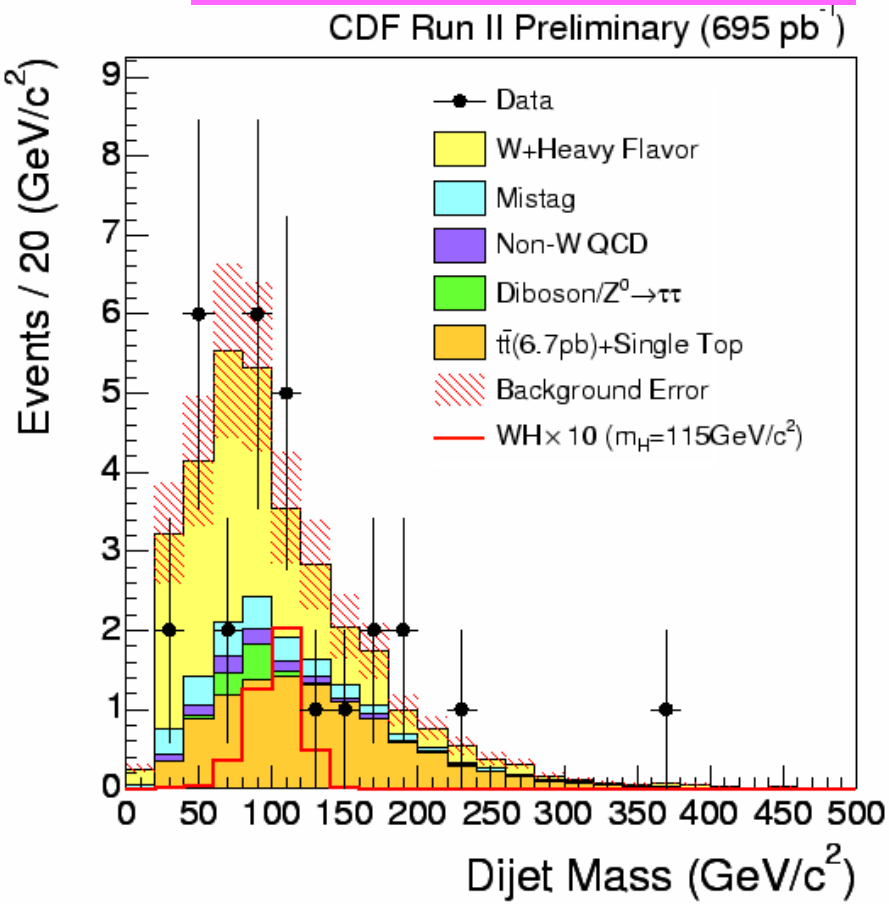
$W^+H \to \ell^+\nu_\ell b\bar{b}$

Use binned likelihood to compare the dijet mass distribution

= 1 jet tagged by SecVtx and NN

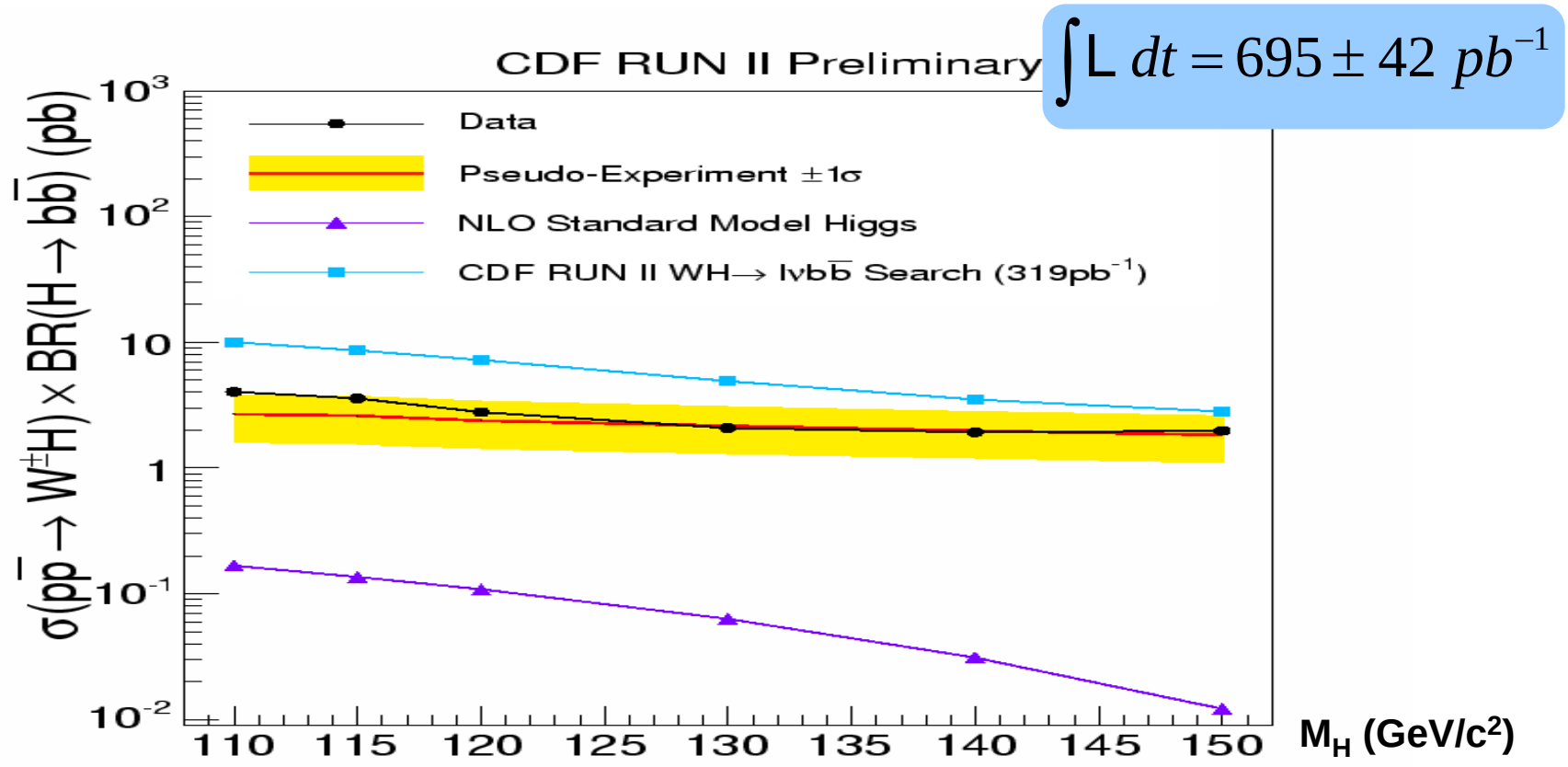


= 2 jets tagged by SecVtx



$W^+H \to \ell^+\nu_\ell b\bar{b}$

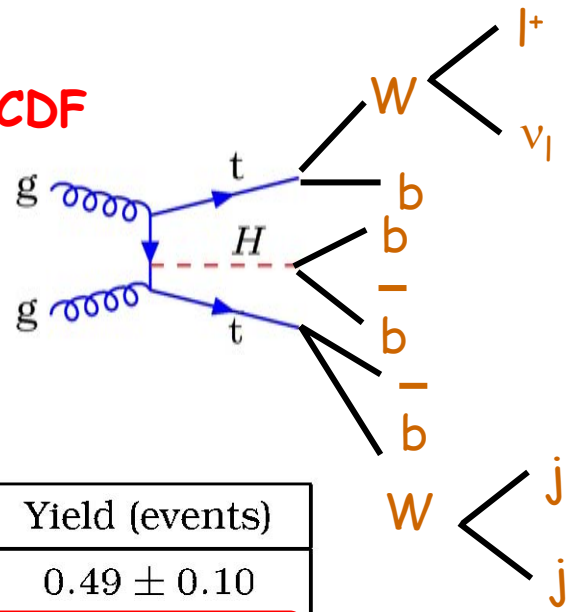
For $M_H = 115\ \text{GeV}/c^2$, $\sigma(p\bar{p} \to W^{\pm}H) \times B(H \to b\bar{b}) < 3.6$ pb



Combining limit from 1+2 tagged events increased sensitivity by 20% (compared to ≥ 1 tag)

$t\bar{t}H \rightarrow W^+W^-b\bar{b}\,b\bar{b} \rightarrow \ell^+\nu_\ell jjb\bar{b}\,b\bar{b}$

New! First time at CDF



- Event Selection
  - One isolated lepton with E_T or pt > 20 GeV in $|\eta|<1.0$
  - Missing E_T > 10 GeV
  - ≥ 5 jets (E_T > 15 GeV, $|\eta|<2.0$)
  - Veto events with Z
  - ≥ 3 jets tagged by SecVtx
  - Acceptance X Efficiency= 1.9%-2.6%
- Signal region blinded when evaluating background components
- Observed 1 event in data

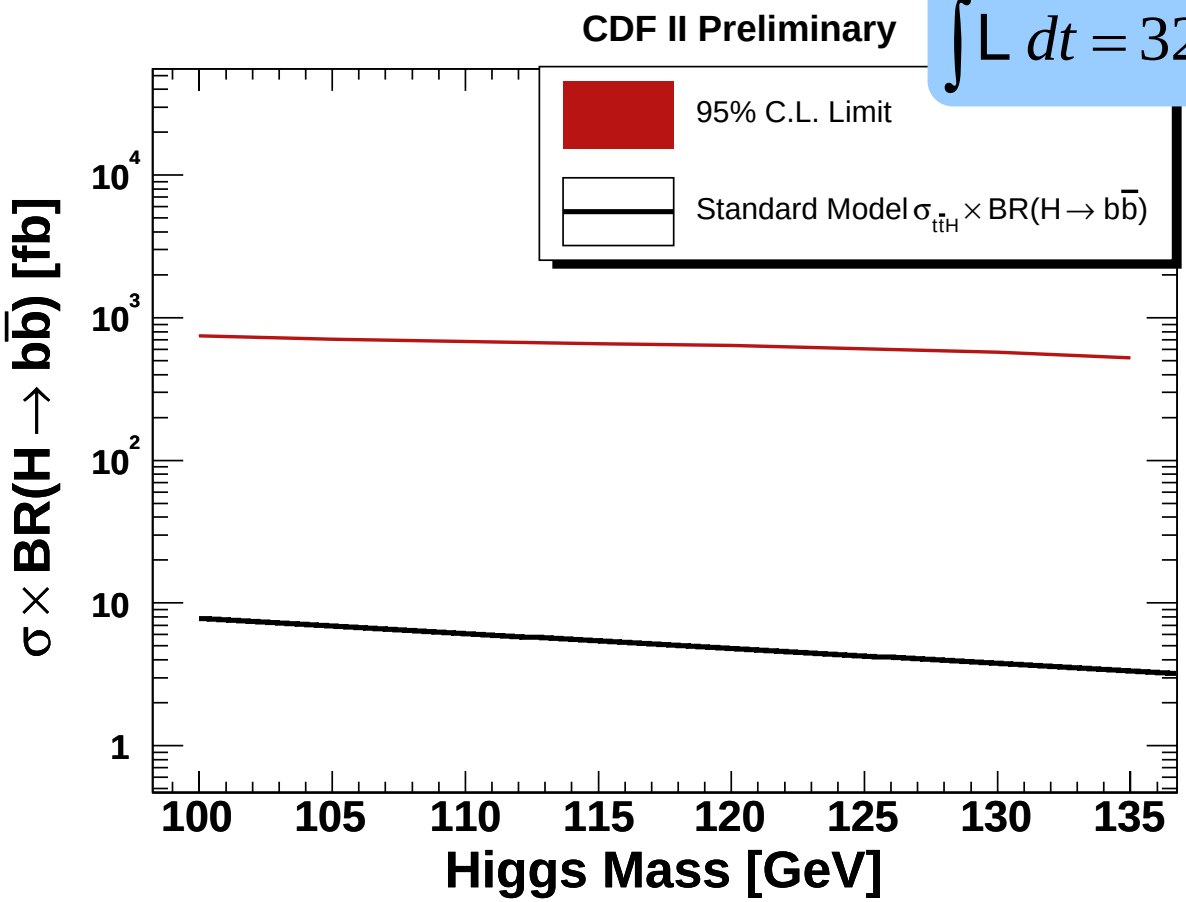
Source	Yield (events)
Mistag	0.49 ± 0.10
Irreducible	0.36 ± 0.07
QCD	0.04 ± 0.04
Total Background	0.89 ± 0.12
Signal ($m_H = 115$ GeV)	0.024 ± 0.005

$t\bar{t}b\bar{b}, t\bar{t}c\bar{c}$

$t\bar{t}H \rightarrow W^+W^-b\bar{b}\,b\bar{b} \rightarrow \ell^+\nu_\ell jjb\bar{b}\,b\bar{b}$

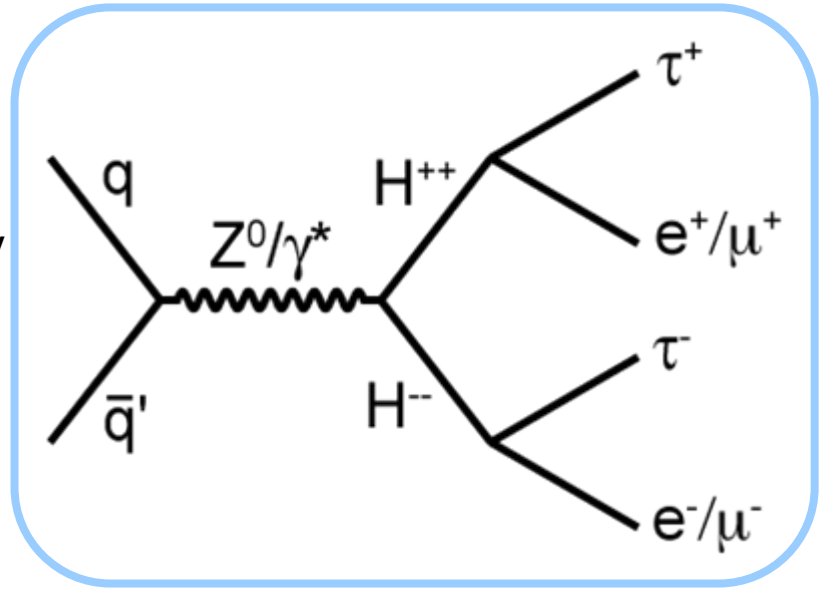
For $M_H = 115\ \mathrm{GeV}/c^2$, $\sigma(p\bar{p} \rightarrow t\bar{t}H) \times B(H \rightarrow b\bar{b}) < 660$ fb

$\int L\,dt = 320 \pm 19\ pb^{-1}$



Doubly Charged Higgs

- Left/Right Symmetric Model
  - Predicts none-zero neutrino mass
  - Drell-Yan like H^{++} pair production
  - At mass below 160 GeV/c^2, decay primarily to charged leptons without flavor restriction
  - H^{++}_L (H^{++}_R) couples exclusively to left (right)-handed particles



- Existing limits
  - LEP: $m(H^{++}_L) > 99$ GeV/c^2, $m(H^{++}_R) > 97$ GeV/c^2
  - CDF: $m(H^{++}_L) > 133$ (ee), 136 ($\mu\mu$), 115 ($e\mu$) GeV/c^2, $m(H^{++}_R) > 113$ ($\mu\mu$) GeV/c^2

CDF Collaboration, PRL 93, 221802 (2004)

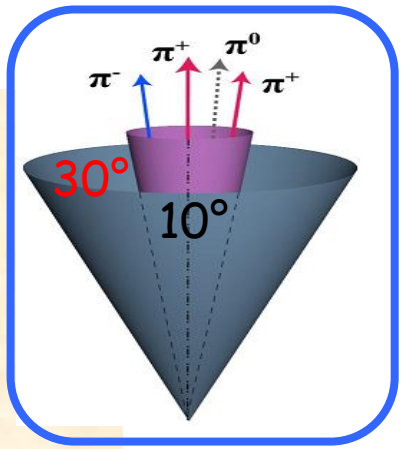
- Assume 100% BR for each channel

$H^{++}H^{--} \rightarrow e^{+}\tau^{+}e^{-}\tau^{-}, \mu^{+}\tau^{+}\mu^{-}\tau^{-}$

- Event Selection
  - 3 or 4 isolated leptons
  - eτ (μτ) channel
    - 1 central electron (muon) E_T > 20 GeV
    - 1 tau E_T > 15 GeV in |η|<1.0
    - 1 tau E_T > 10 GeV in |η|<1.3 (1 ILC)
    - 1 ILC for 4-lepton final state
  - 3-lepton
    - ∑Pt(lep) + missing Et > 190 GeV
    - 30 < M_{OS}, 30 < M_{LS} < 125 GeV/c^2
    - Veto Z, Zγ
  - 4-lepton
    - ∑Pt(lep) + missing Et > 100 GeV
    - Veto Z, Zγ
  - Acceptance X Efficiency 8%-14%

New! First time at CDF

ILC: isolated track system with 1 or 3 tracks, sum Pt > 8 GeV/c, seed track Pt > 6 GeV/c



Reconstruction of τ:

Double Cone algorithm
- Energy from trks and π^0'
- Isolation veto (trk, π^0)

Hadronic system
- m_{had}< 1.8 GeV
- N_{trk} = 1,3 ; charge = ±1

Electron candidates included

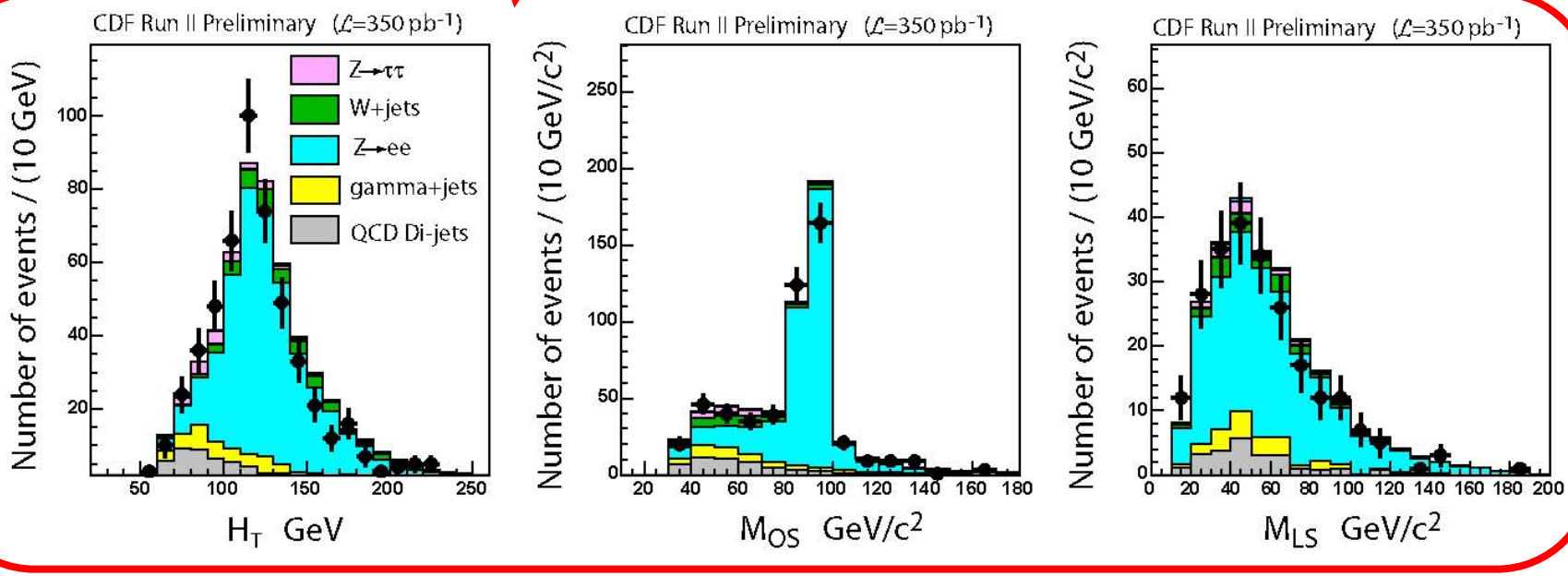
$H^{++}H^{--} \rightarrow e^+\tau^+e^-\tau^-, \mu^+\tau^+\mu^-\tau^-$

6 control regions to X-check the background prediction: eτ

Region	Definition	N Expected	N Observed
Loose Selection	Isolated Ele, Unisolated Tau/LTC	518	516
QCD	Met<25, Z-Veto	169	162
W+Jet-Like	Met>30, Z-Veto	195(After Scaling W MC)	202
Z-Like	Fails Z-Veto	313	326
Low-Ht	All Cuts But Ht	6.82	6
BOX	Passes Analysis	0.25	0

3-lepton background
- Z + jet (68%)
- Diboson (27%)
- ttbar (5%)
- QCD, γ + jet (<1%)

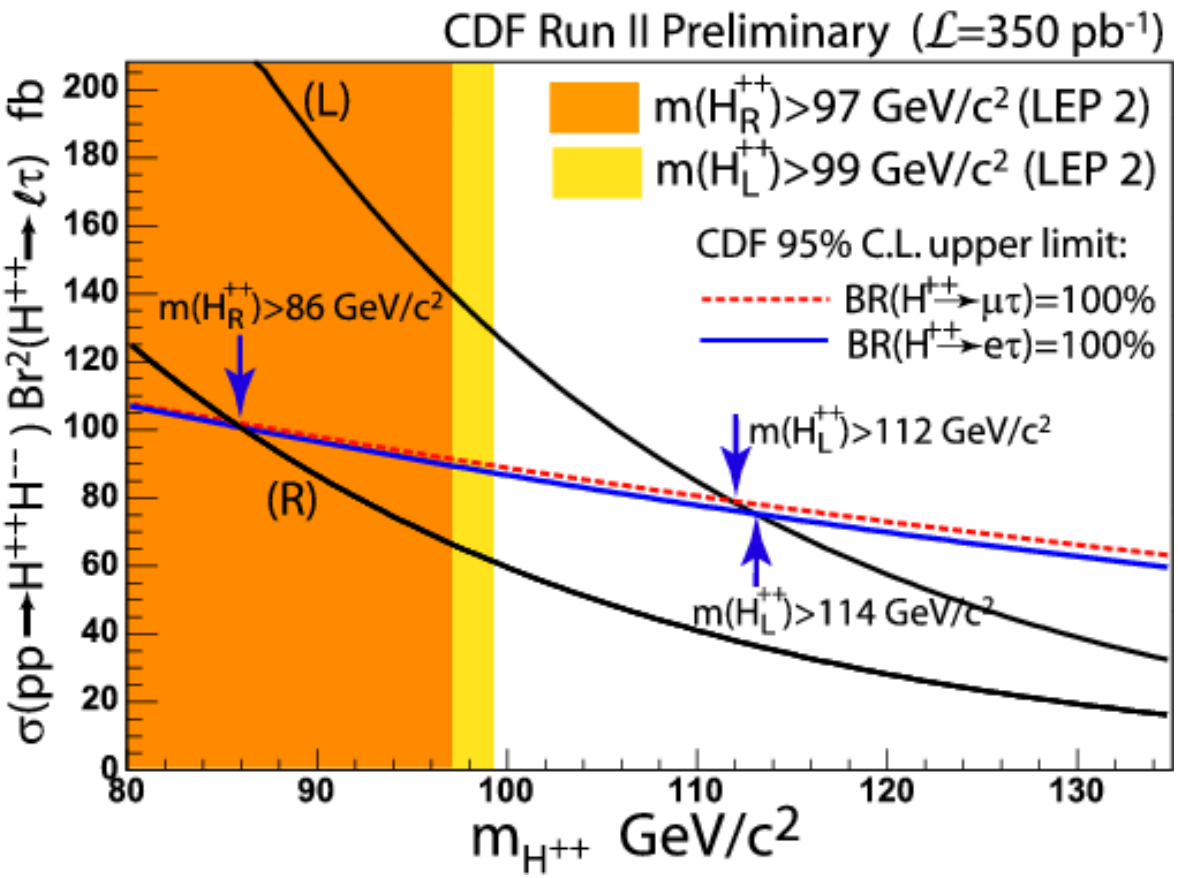
4-lepton background
- ZZ* (~100%)



$H^{++}H^{--} \rightarrow e^+\tau^+e^-\tau^-, \mu^+\tau^+\mu^-\tau^-$

$$\int L\,dt = 350 \pm 21\ pb^{-1}(e\tau),$$
$$= 322 \pm 19\ pb^{-1}(\mu\tau)$$

3-lepton		
	Data	Bkg
eτ	0	0.24 +/- 0.27
μτ	0	0.27 +/- 0.13
4-lepton		
eτ	0	0.04 +/- 0.05
μτ	0	0.14 +/- 0.05



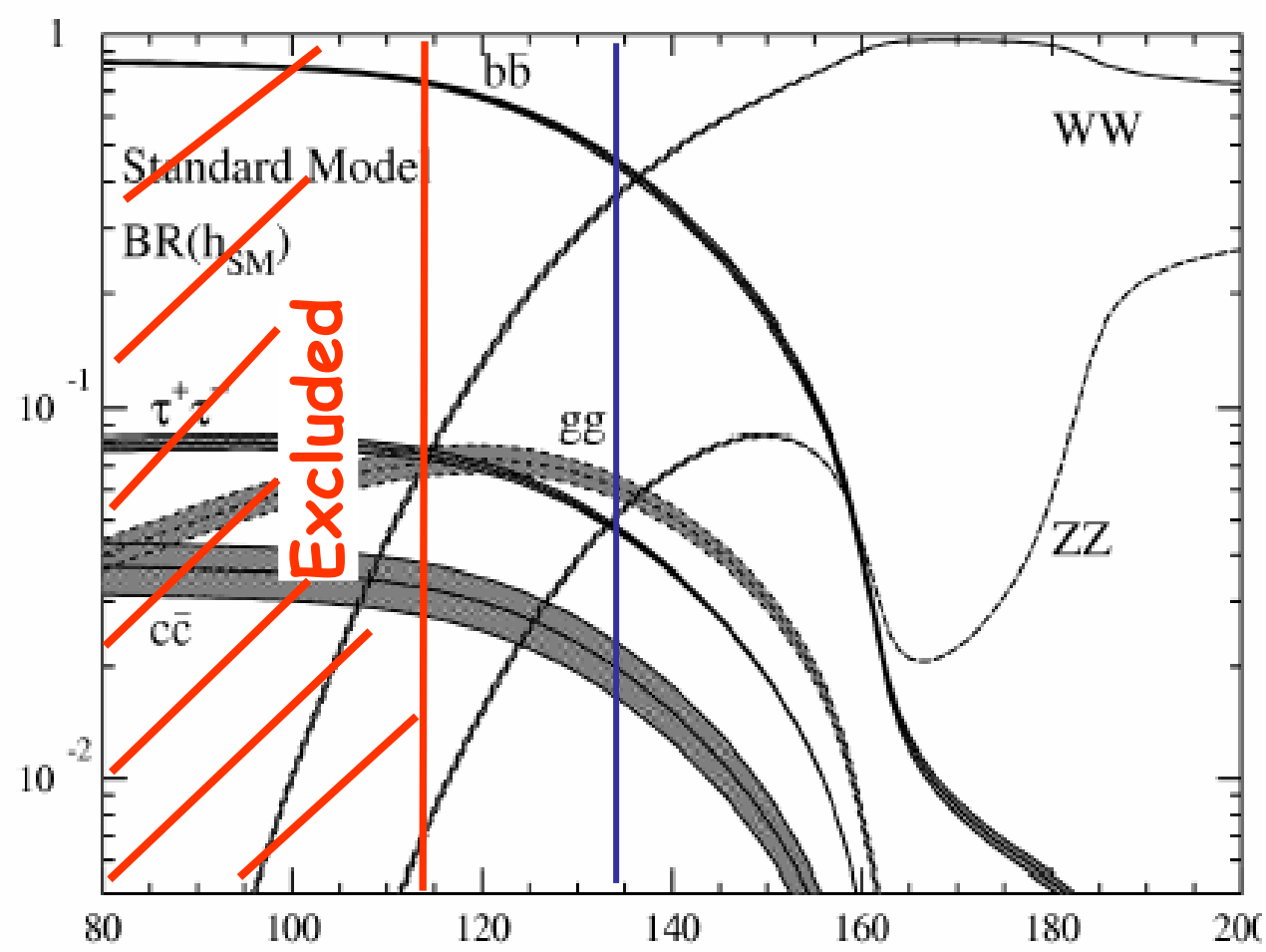
$$M_H > 113.6\ \text{GeV}/c^2(e\tau), 112.1\ \text{GeV}/c^2(\mu\tau)$$

Summary and Outlook

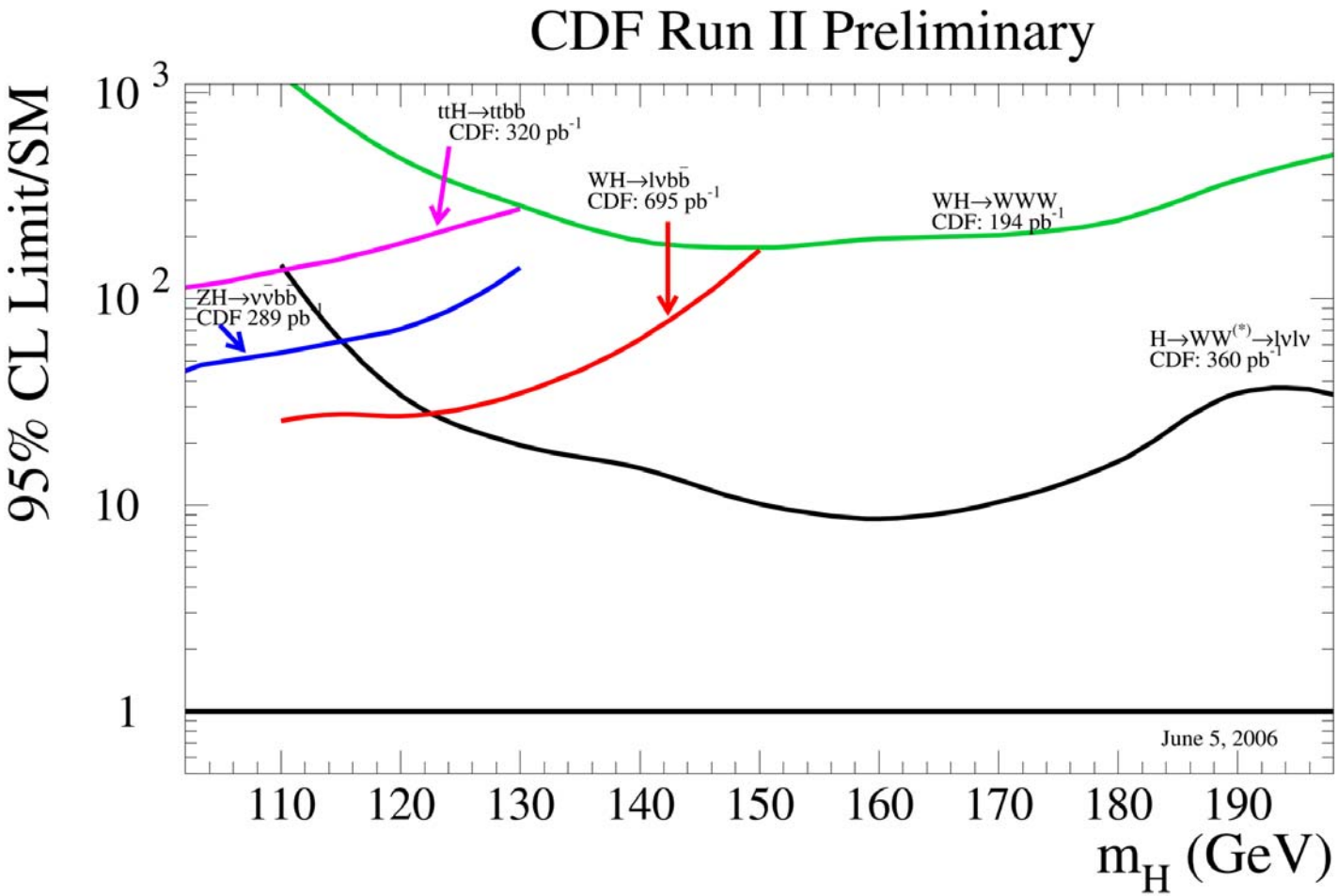
- CDF has searched for both SM and non-SM Higgs using 320~695 pb^{-1} of data
- Started using more advanced analysis techniques, such as Neural Network b-tagging
- No signal found in the analyzed data
- Several analyses work in progress
- Most of the data are yet to come. Stay tuned!

Backup Slides

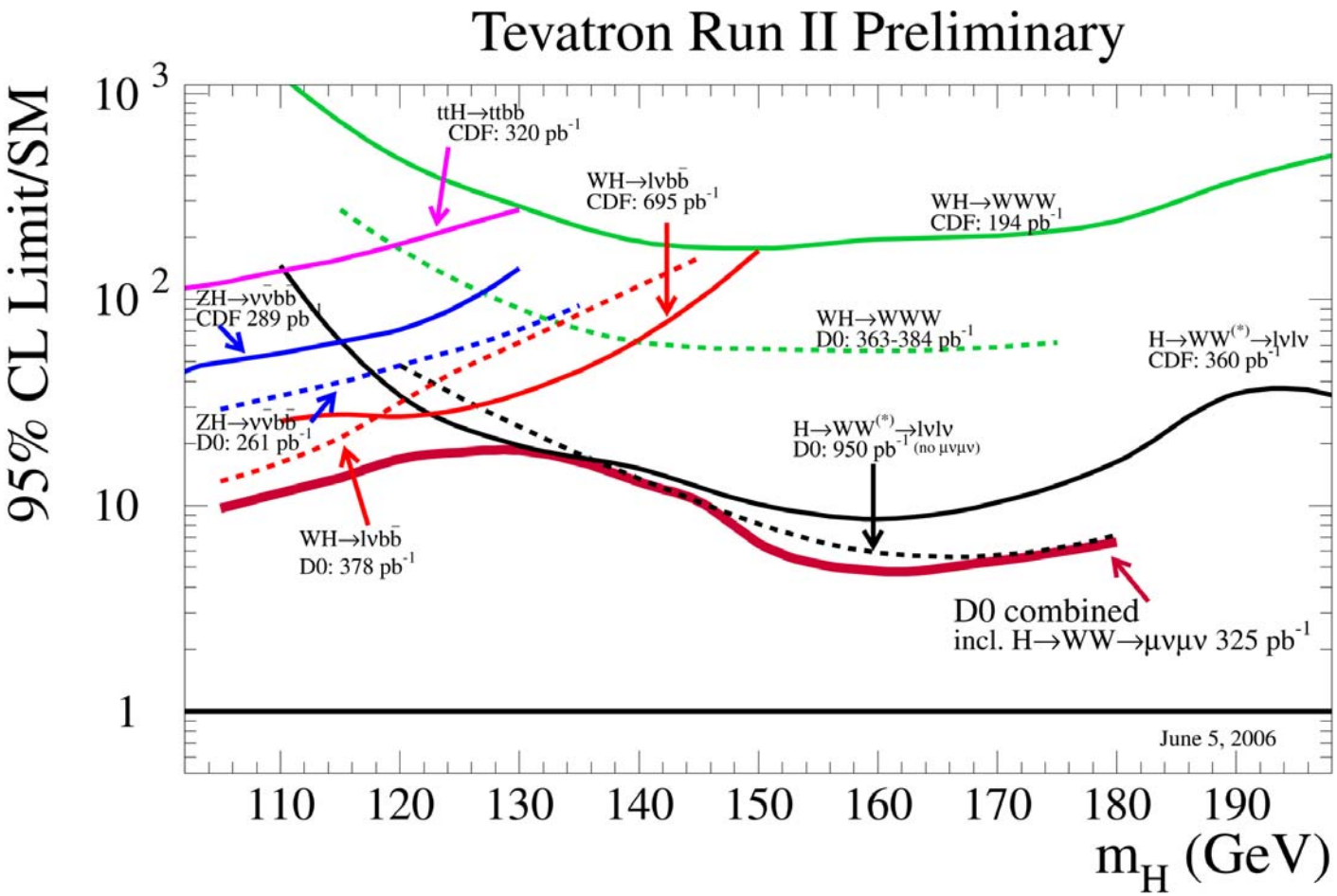
Standard Model Higgs Decay Modes



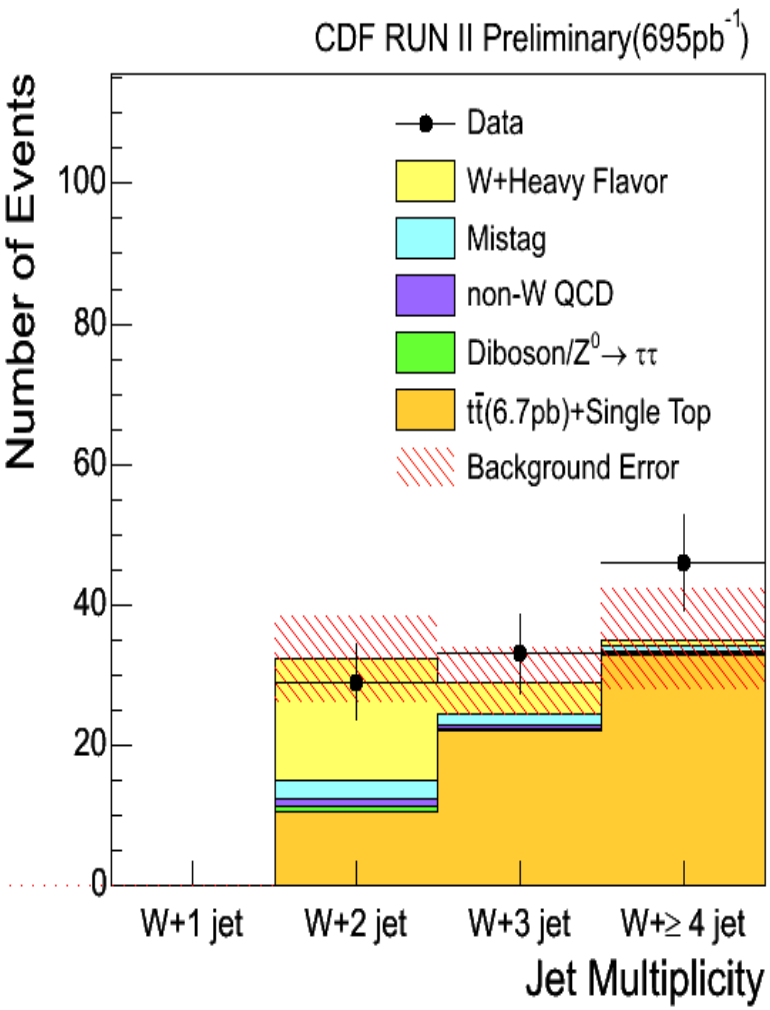
All CDF Standard Model Higgs Results

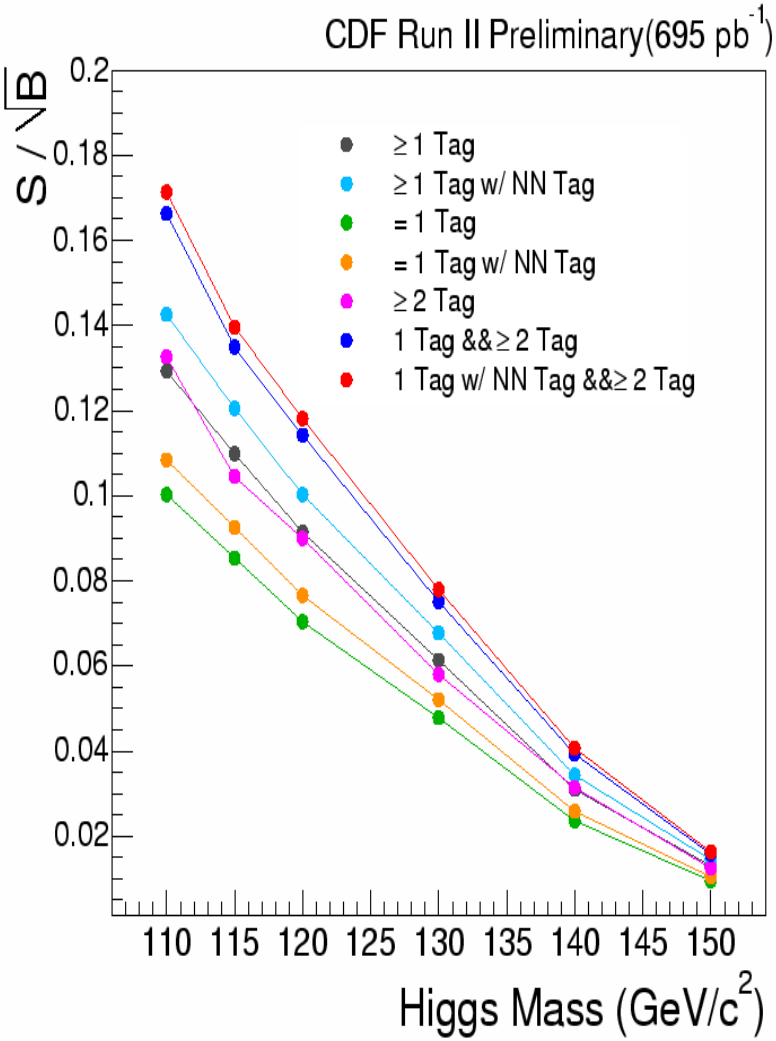


All CDF & D0 SM HiggsResults



$W^+H \to \ell^+\nu_\ell b\bar{b}$





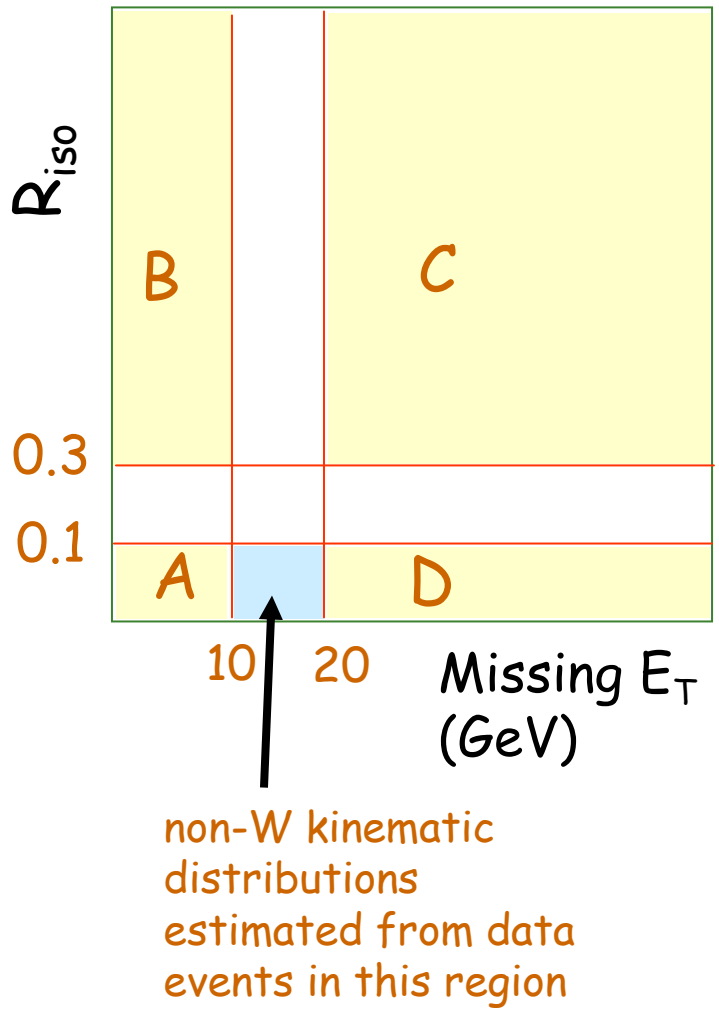
Non-W Backgrounds in WH→lνbb

- CDF: Estimated with – Missing E_T vs. R_{iso}

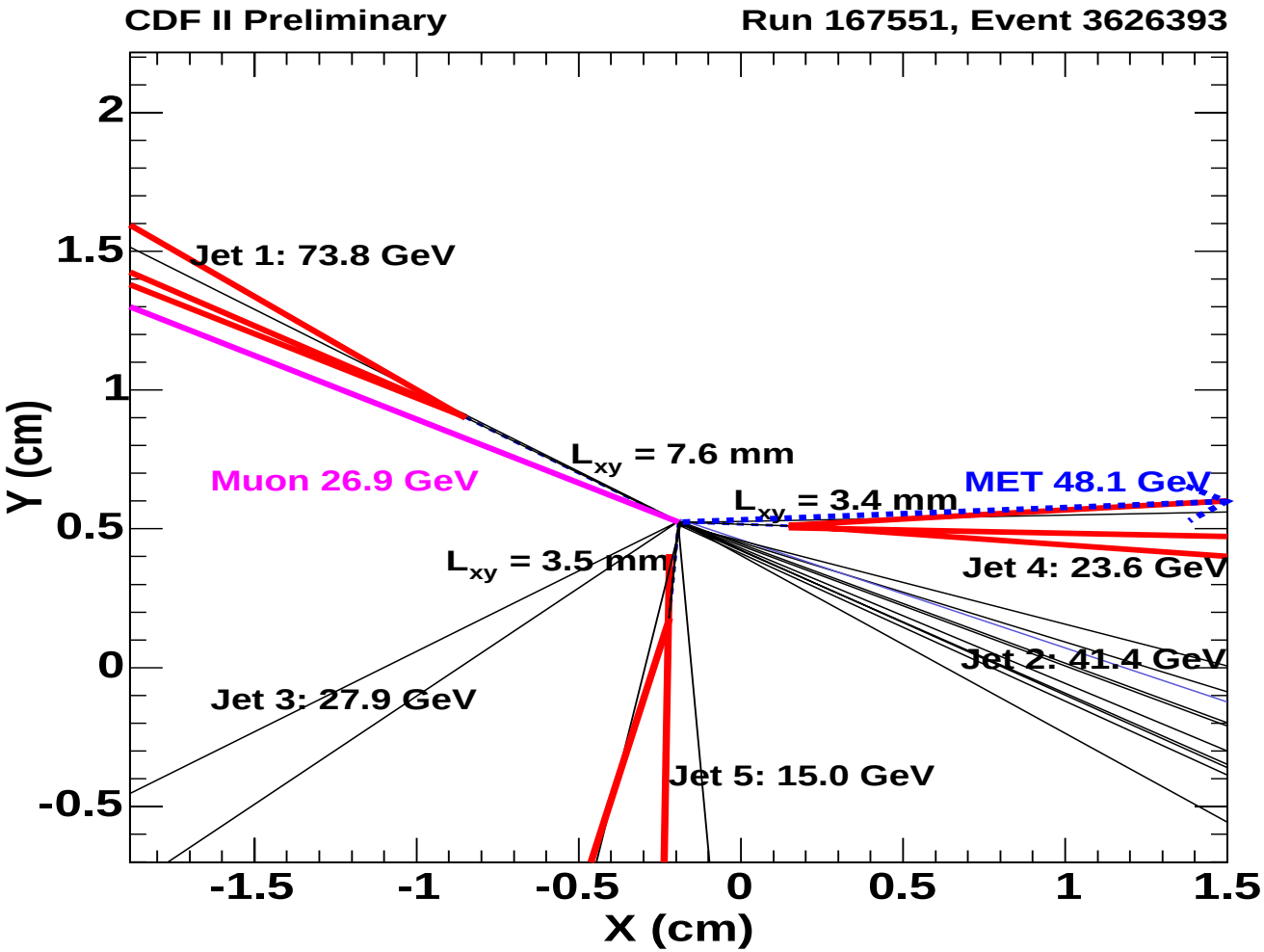
R_{iso}=[Energy inside cone of size 0.4 around lepton] / [Energy of lepton]

Non-W background is assumed to have uncorrelated R_{iso} and E_T

Non-W: D= C*(A/B) (after correcting for signal in the background samples)



$t\bar{t}H \rightarrow W^+W^-b\bar{b}b\bar{b} \rightarrow \ell^+\nu_\ell jjb\bar{b}b\bar{b}$



$H^{++}H^{--} \rightarrow e^{+}\tau^{+}e^{-}\tau^{-}, \mu^{+}\tau^{+}\mu^{-}\tau^{-}$

One interesting event which failed Mos cut, 1μ, 2τ
Exp bkg 0.5 +/- 0.7 Most likely W+ jet