Status of CDF's Run II Higgs Searches

Tom Junk

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- Detector and Data sets
- Search for Higgsstrahlung: $W^+H \rightarrow \ell^+\nu_\ell b\bar{b}$
- Search for Higgs decays to W^+W^-
- Search for MSSM Higgs decays to $\tau^+\tau^-$
- Search for Doubly-Charged Higgs bosons
  - Unstable
  - Long-Lived

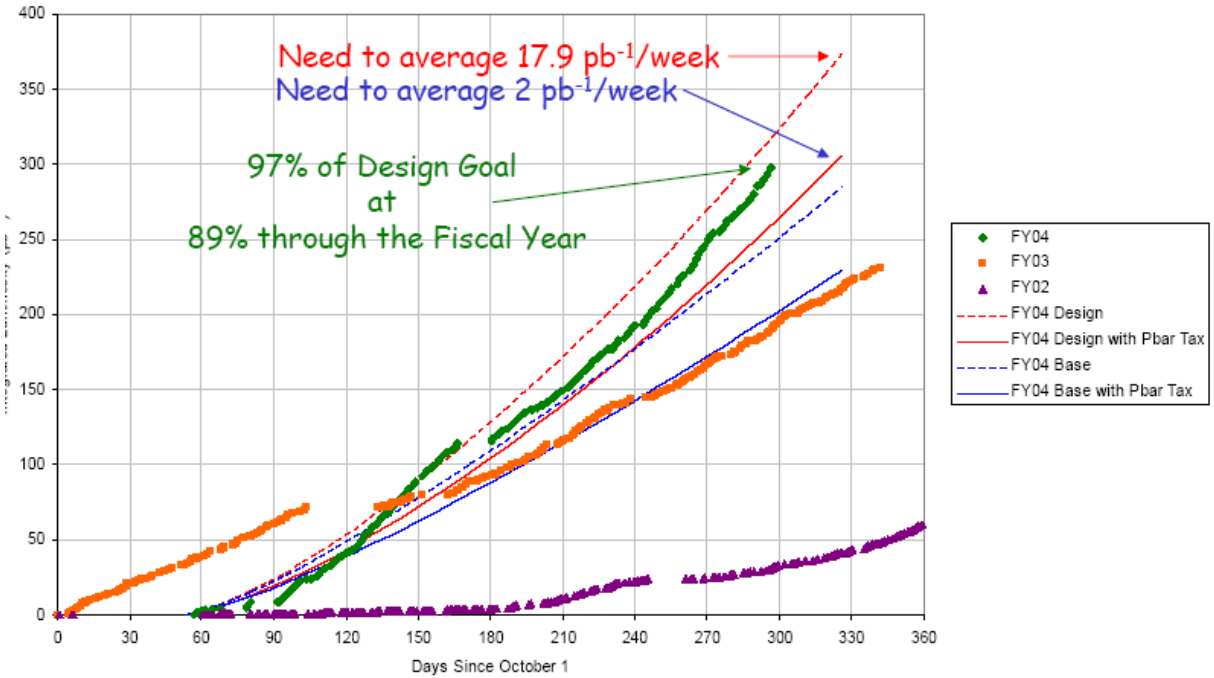
These and other results are available at

http://www-cdf.fnal.gov/physics/PublicResults.html

Tevatron: Exceeding Design Goals

Lots of improvements:

- Recycler now used to accumulate antiprotons
- Main injector -- bunches lengthened, slip-stacking, transfers improved
- Tevatron -- improved alignment and low-beta optics



Best Peak Luminosity:
103×10^{30} cm^{-2}sec^{-1}

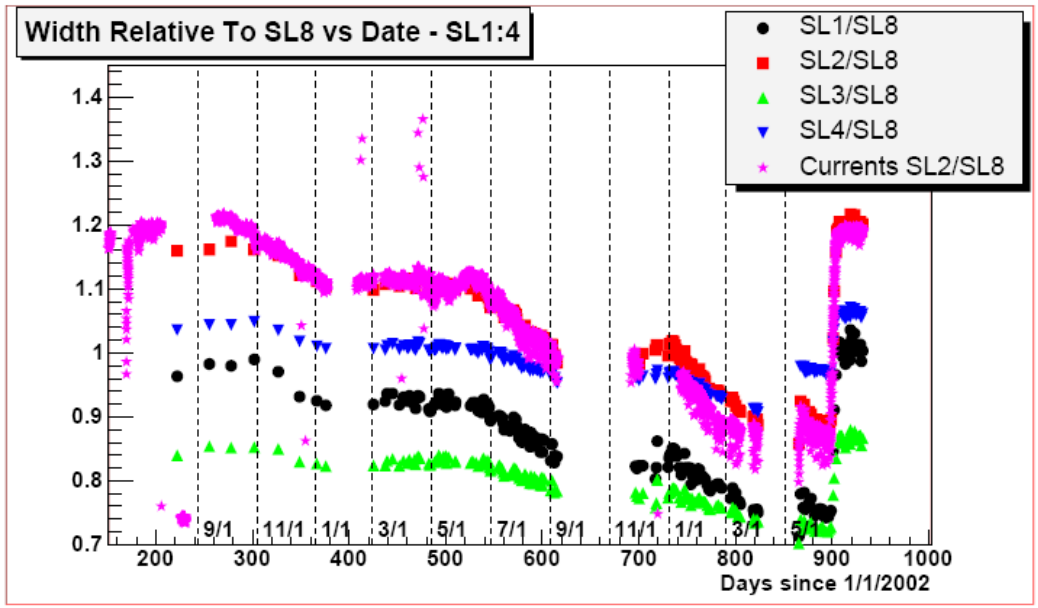
Achieving 4 fb^{-1} by end FY '09 should be a "slam dunk"

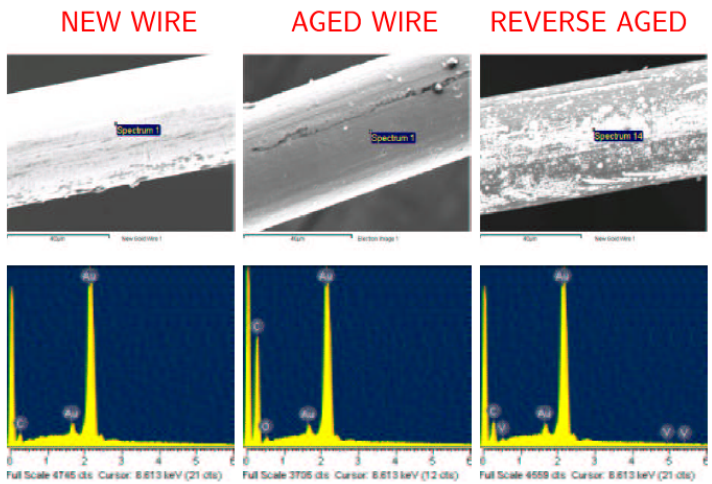
8 fb^{-1} "could be possible"

-- Dave McGinnis

Detector Performance

- Gaseous tracking chamber COT: wire aging problem seen in 2003-2004
- hydrocarbon residue detected on sense wires where gain had been falling
- addition of air (probably the oxygen) reverses the aging
- Chamber gains back go pre-aged status
- Voltages reduced on inner superlayers from February to May 2004





Run 2 Data Sets

Different amounts of integrated luminosity used for each analysis due to different requirements on detector functioning.

$W^+H \rightarrow \ell^+\nu_\ell b\bar{b}$	162 pb^{-1}
$gg \rightarrow H \rightarrow W^+W^-$	184 pb^{-1}
$H \rightarrow \tau^+\tau^-$ in the MSSM	195 pb^{-1}
Promptly-Decaying $H^{++/--}$	240 pb^{-1}
Long-Lived $H^{++/--}$	200 pb^{-1}

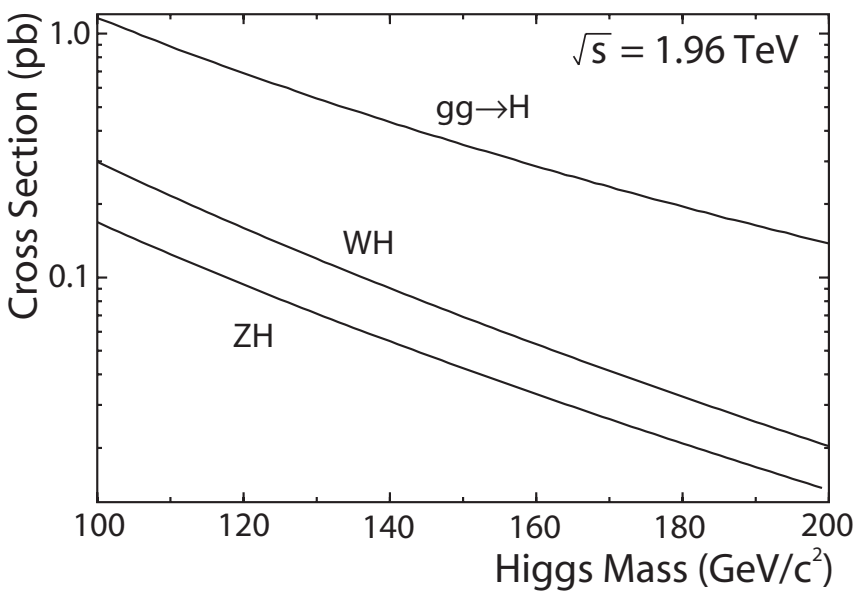
$$\sqrt{s} = 1.96\,\text{TeV}$$

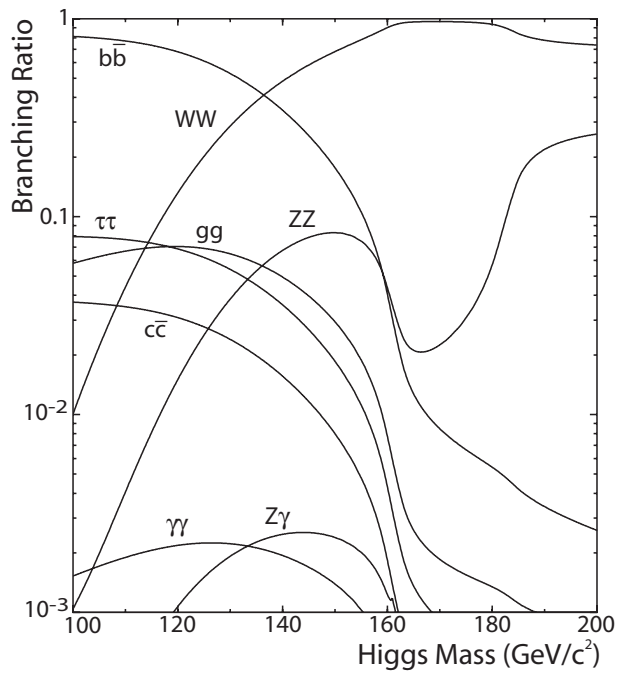
SM Higgs Production and Decay

$gg \to H \to b\bar{b}$ is the dominant process for 115 GeV<m_H<135 GeV but there is too much dijet background.

$q\bar{q} \to WH \to \ell\nu b\bar{b}$ and $q\bar{q} \to ZH \to \nu\bar{\nu}b\bar{b}$ Higgsstrahlung has less background

$gg \to H \to W^+W^-$ is promising for higher-mass Higgs bosons



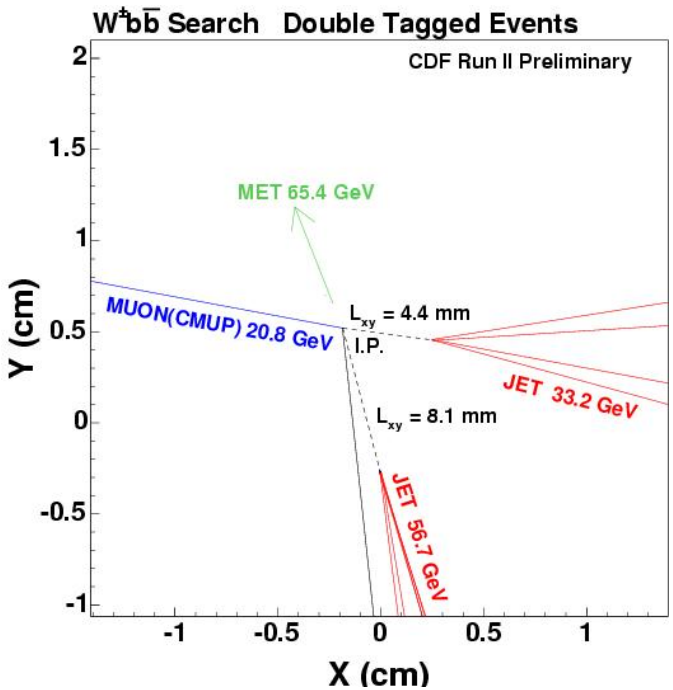


Search for $W^+H \rightarrow \ell^+\nu_\ell b\bar{b}$

Event Selection:

- Require lepton (e or μ) with $p_T > 20$ GeV
- Missing $E_T > 20$ GeV
- Dilepton veto, Z^0 veto
- Two jets, each with $E_T > 15$ GeV and $|\eta| < 2$
- One jet B-tagged with a displaced vertex
  need highly efficient, pure b-tagging with large angular acceptance

- Use M_{bb} distribution to extract limit
  need excellent M_{bb} resolution

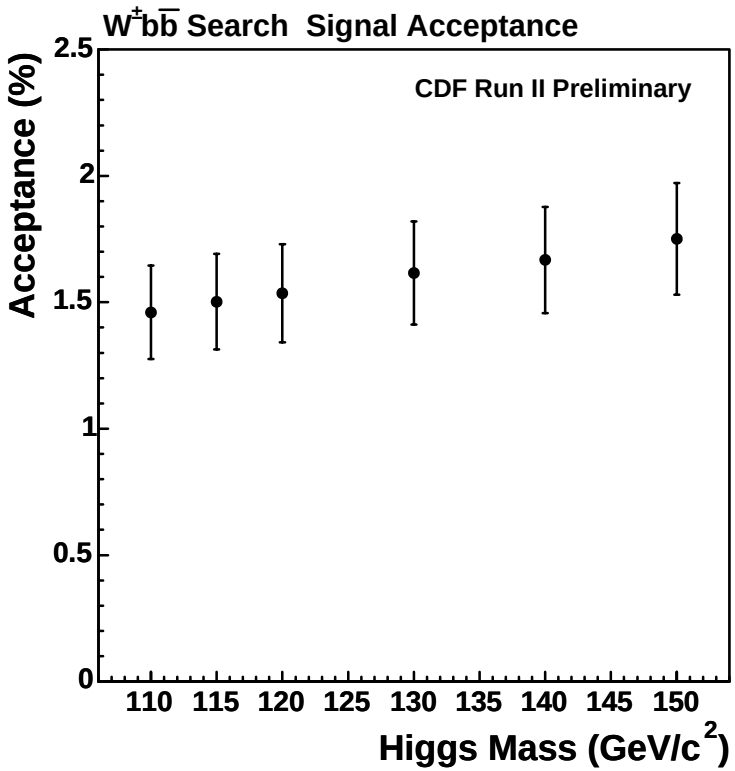


Performance: b-tag $\varepsilon_b \sim 53\%$ (in t-tbar events)

$\varepsilon_c \sim 3\%$ $\varepsilon_{uds,g} < 1\%$

M_{bb} resolution: 16% (now) 10% is achievable

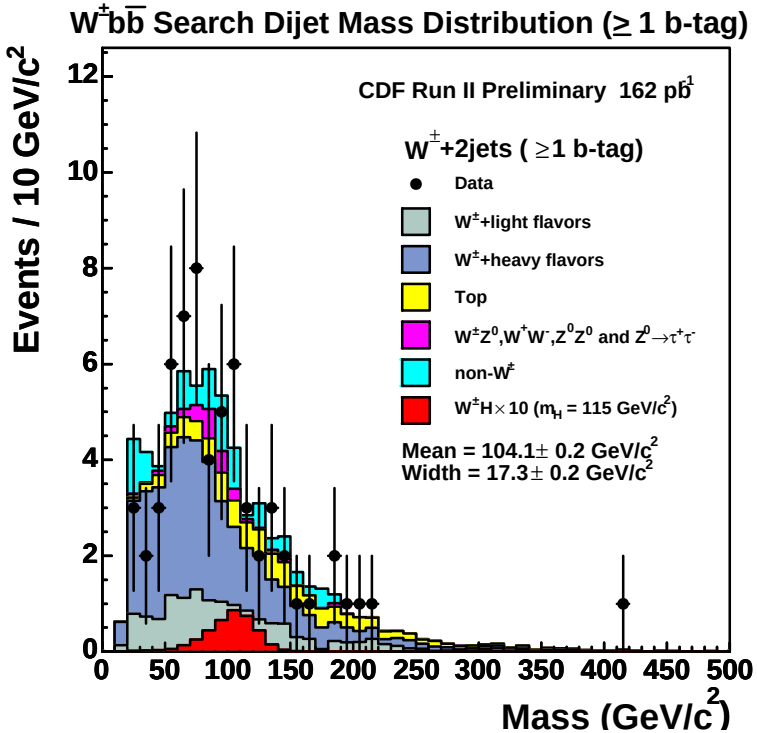
Signal Acceptance, Background and Data Counts

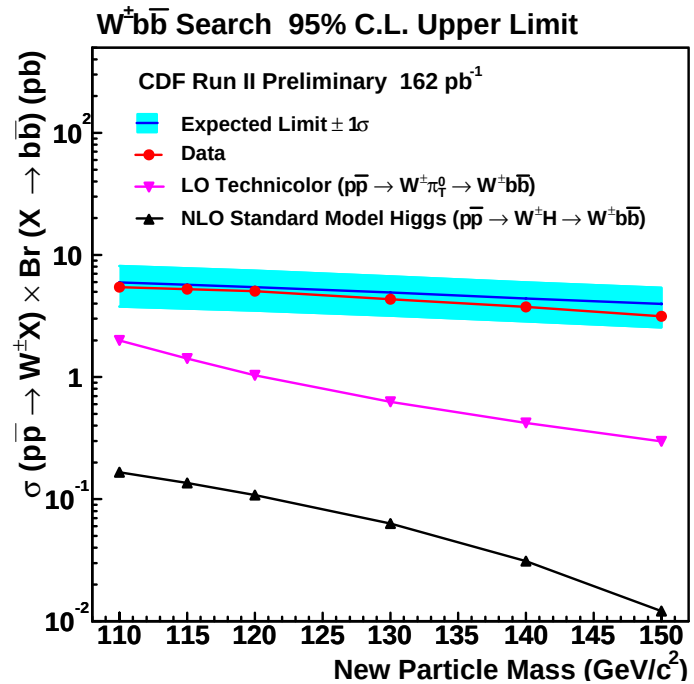


Acceptance includes leptonic branching ratios of the W, but not Br(H→$b\bar{b}$)

Background Source	Events in 162 pb^{-1}
W+light flavor	14.1 ± 2.6
$W + b\bar{b}$	19.1 ± 5.8
$W + c\bar{c}$	6.8 ± 2.2
$W + c$	6.5 ± 1.8
Diboson+Z→$\tau^+\tau^-$	2.5 ± 0.6
QCD	8.5 ± 1.2
$t\bar{t}$	5.1 ± 1.0
$t\bar{b}$	3.8 ± 0.5
Total Background	66.5 ± 9.0
Observed Data	62

$W^+H \to \ell^+\nu_\ell b\bar{b}$ limit using the M_{bb} Distribution



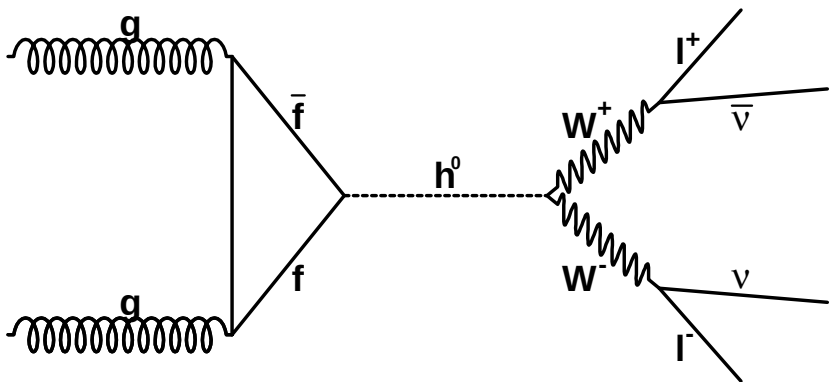


Techni-rho model also tested

Lots of improvement possible:

- Better M_{bb} resolution (now: calorimeter only. Add tracks!)
- Extend b-tagging acceptance, efficiency.
- Additional kinematic variables
- Add ννbb channel

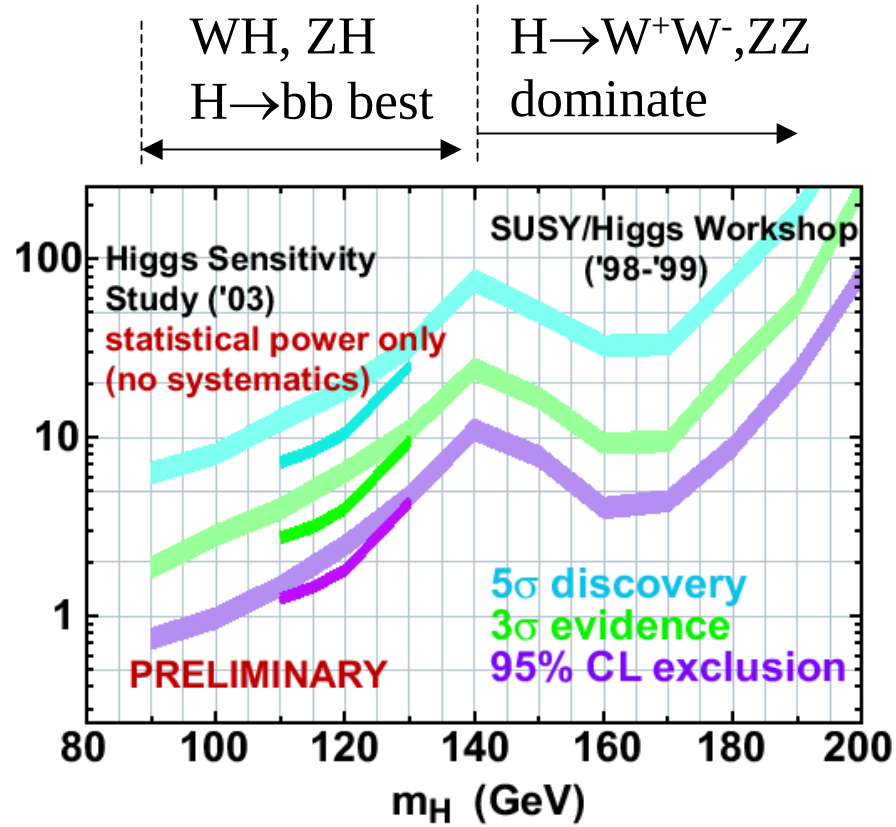
Search for $gg \to H \to W^+W^-$



ℓ = e, μ

Low Backgrounds, mainly W^+W^-, with some $W^{\pm}Z$, DY, and fake leptons

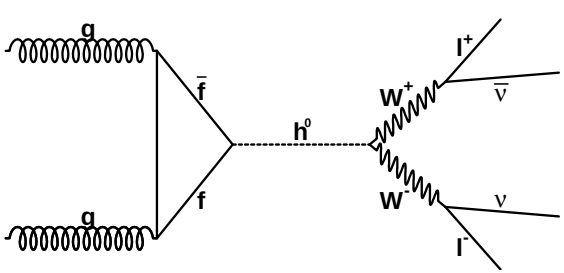
Analysis similar to W^+W^- selection



$gg \to H \to W^+W^-$ Event Selection

Select events with:

- Two leptons, each with $E_T > 20$ GeV, opposite charge
- No jets with $E_T > 15$ GeV and $|\eta| < 2.5$
- $\not{E}_T > 25$ GeV
- If $\not{E}_T < 50$ GeV, then require $\Delta\varphi_{\ell(jet),\not{E}_T} < 20^\circ$
- Z^0 Veto: Reject 76 GeV $< M_{ee,\mu\mu} <$ 106 GeV unless $\not{E}_T / \sqrt{\not{E}_T} > 3$
- Test-mass-dependent cut: $M_{\ell\ell} < M_H/2$



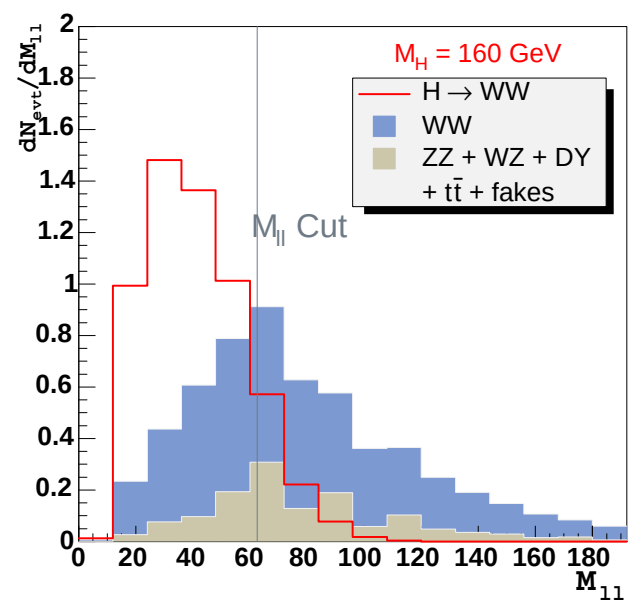
H has spin zero

↓

W spins are anticorrelated

↓

Leptons have low invariant mass (small opening angle) compared to SM W^+W^- background



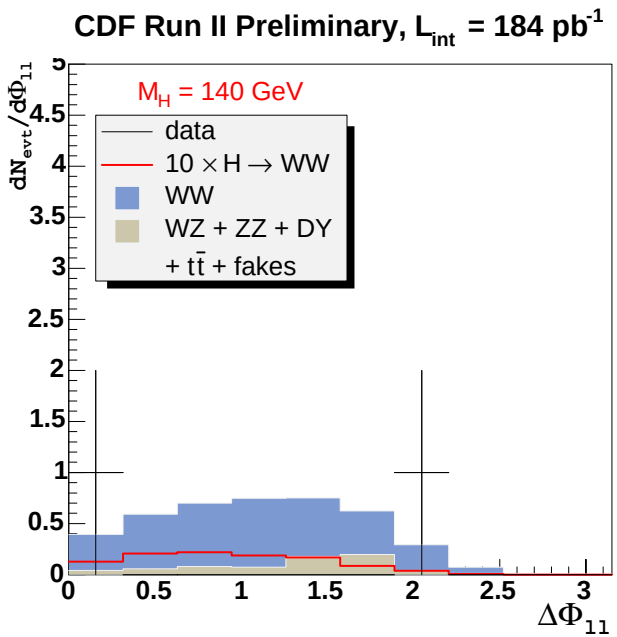
$gg \to H \to W^+W^-$ Event Counts and Expectation in 184 pb^{-1}

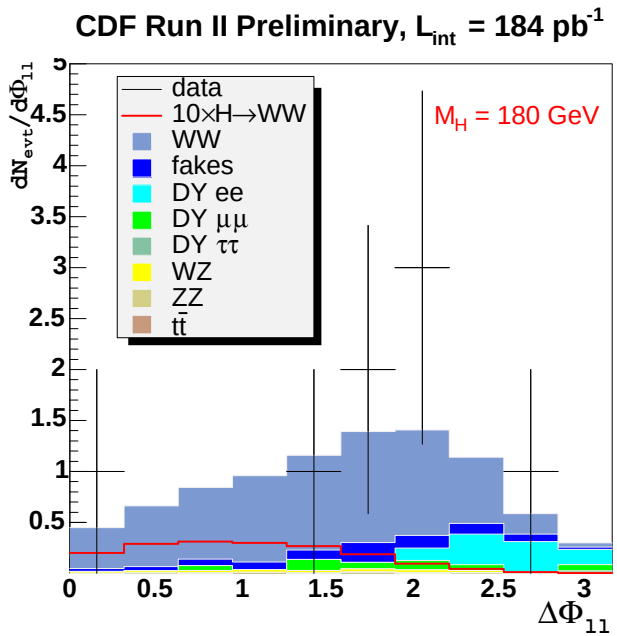
M_H assumed	140 GeV	150 GeV	160 GeV	170 GeV	180 GeV
Acceptance (%)	0.124±0.012	0.228±0.023	0.402±0.040	0.476±0.048	0.449±0.045
Expected Signal events	0.10±0.01	0.15±0.02	0.22±0.03	0.22±0.03	0.22±0.03
WW	3.51±0.41	3.82±0.45	4.45±0.52	5.38±0.63	6.49±0.76
All other bkg (WZ,ZZ,fakes, DY,ttbar)	0.68±0.16	0.90±0.24	1.34±0.35	1.91±0.47	2.40±0.55
total bg	4.19±0.45	4.72±0.52	5.79±0.64	7.29±0.81	8.90±0.98
data	2	2	3	7	8

Using the $\Delta\varphi_{\ell\ell}$ Distribution

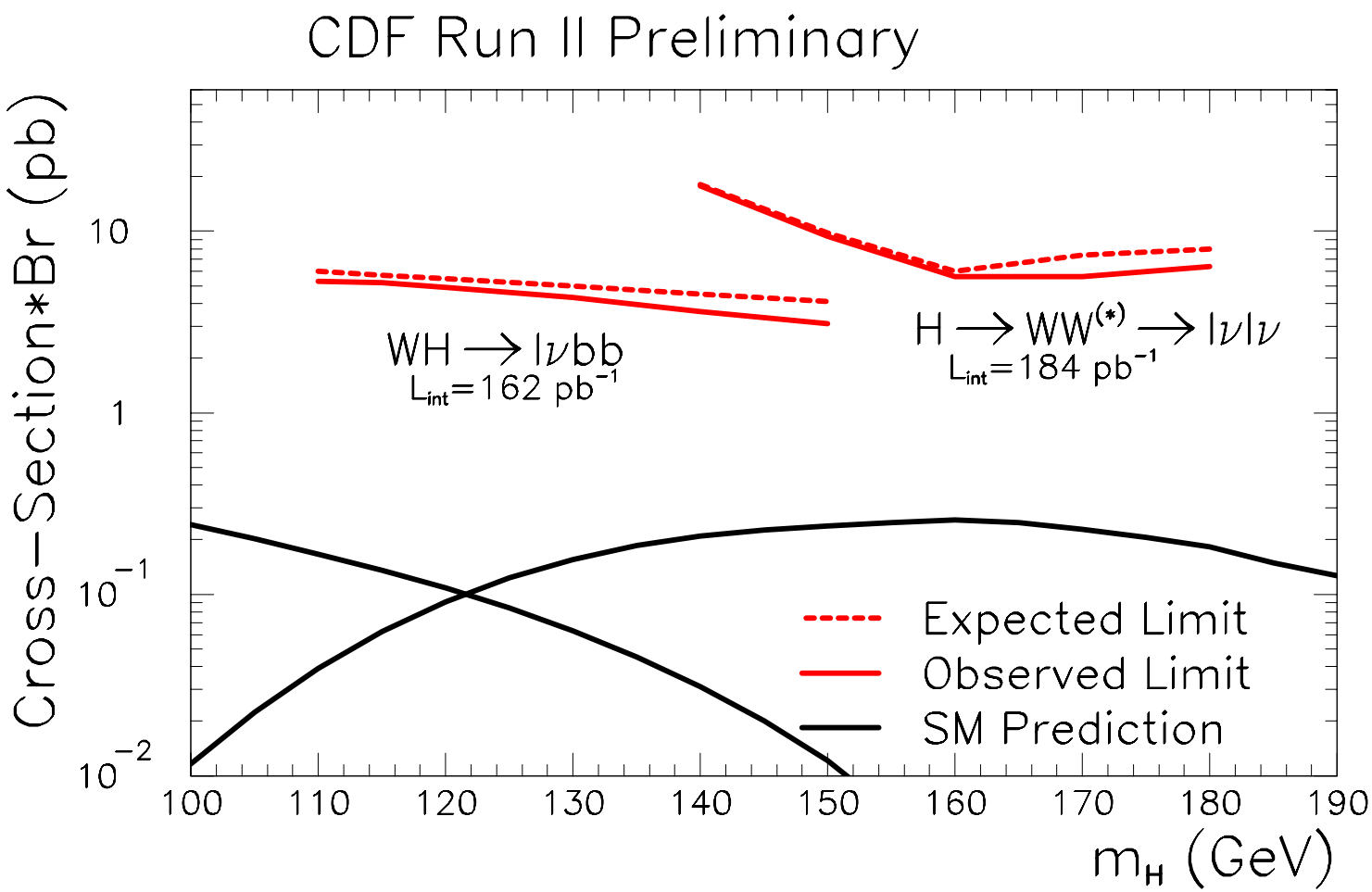
Signal, background, and candidates depend on Higgs boson mass hypothesis

$\Delta\varphi_{\ell\ell}$ Distribution used to extract limit (Bayesian)

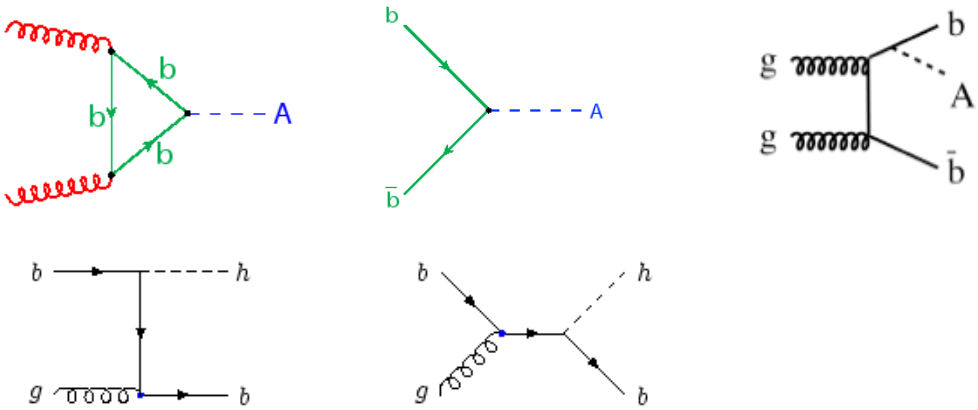




Current SM Higgs Limit Summary



High-tanβ H,A Production



$$p\bar{p} \rightarrow h / A + X$$

includes all of these processes.

Cross-section proportional to $\tan^2\beta$ for these processes

See: hep-ph/0406152

bbA→bbbb : High backgrounds, difficult trigger. Analysis in preparation

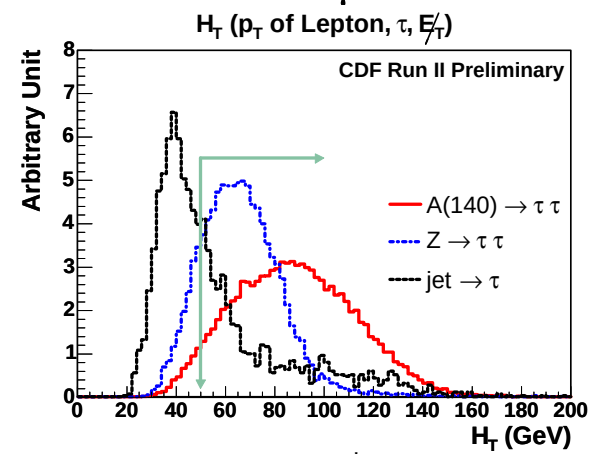
A→ττ: triggers implemented, lower background. Analysis described here.
No b-jet requirement.

Br(H→ττ) ~ 8% at large tanβ

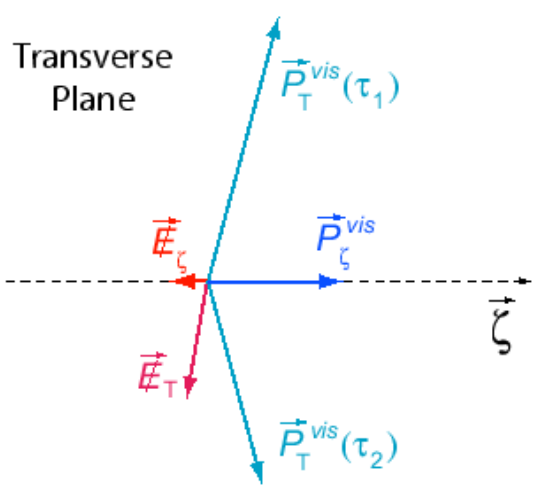
Search for $H \to \tau^+\tau^-$ in the MSSM

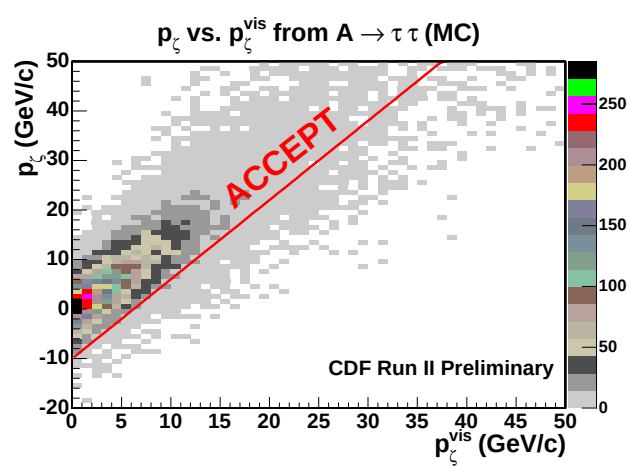
Event selection:

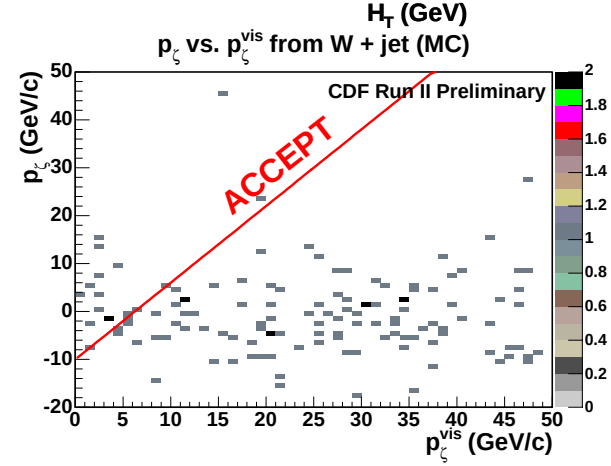
- Require one hadronically-decaying τ and one $\tau \to e\nu\nu$ or $\tau \to \mu\nu\nu$ in the event
- $H_T \equiv |p_T^{\ell}| + |p_T^{\tau}| + |\not{E}_T| > 50\,\text{GeV}$



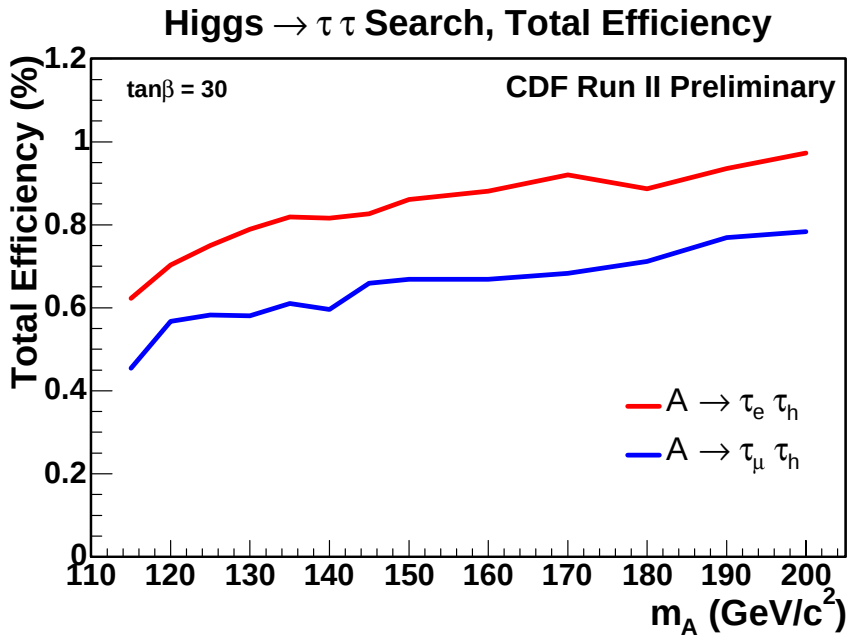
- And a clever "ζ cut"

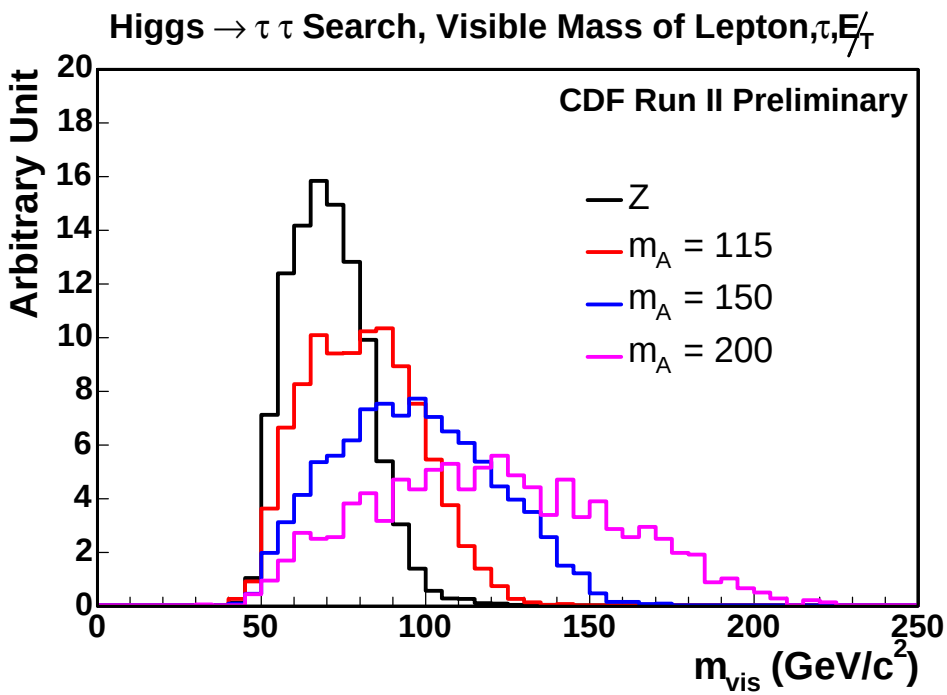






$H,A \rightarrow \tau^+\tau^-$ Acceptance and M_{vis} Resolution

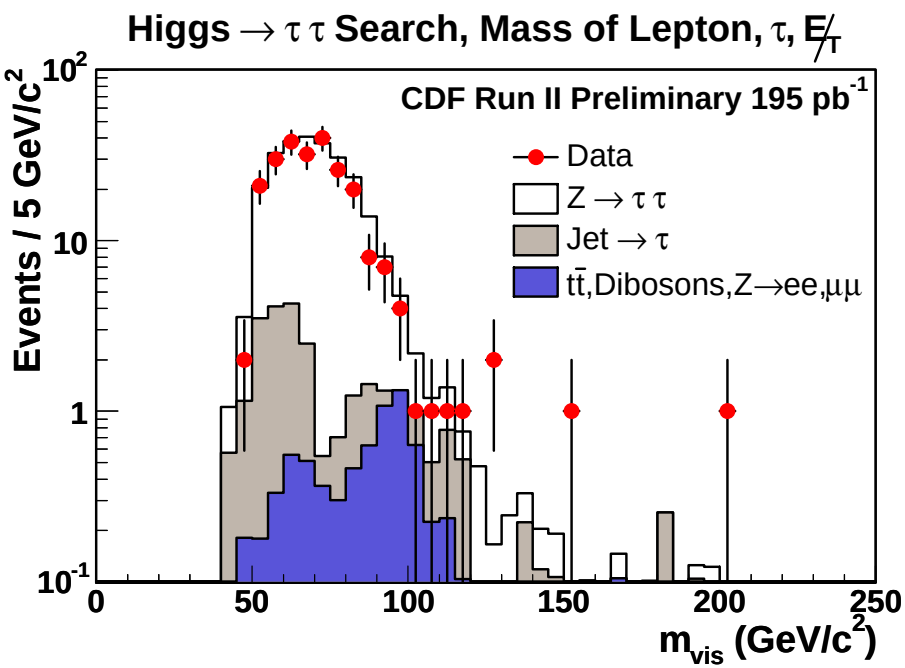


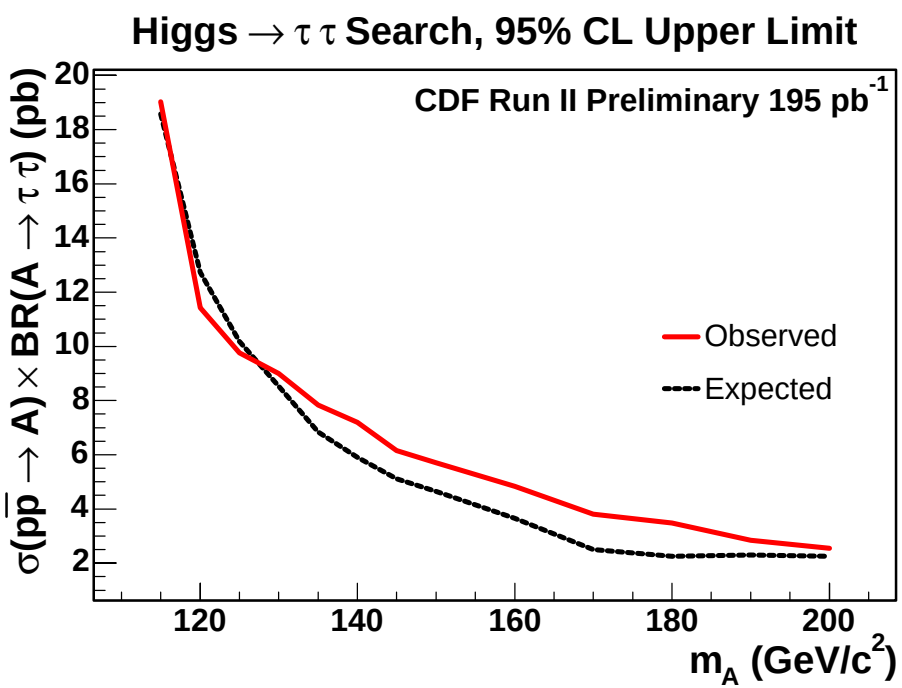


Selected Events, Backgrounds, and Limit

$$\int L dt = 195\,\mathrm{pb}^{-1}$$

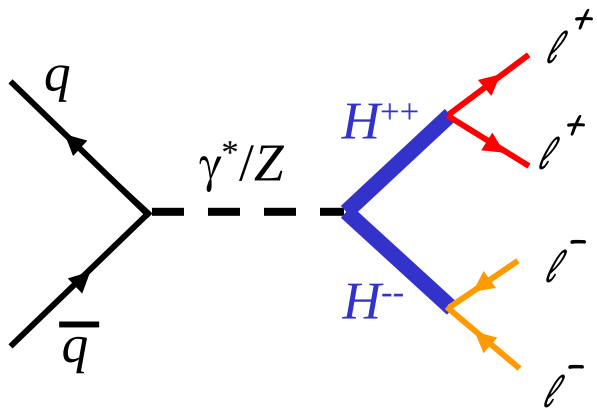
	$\tau_h\tau_e$	$\tau_h\tau_\mu$	Combined
$Z \to \tau\tau$	132.3 ± 17.1	104.1 ± 13.3	236.4 ± 29.5
$Z \to ll$	1.8 ± 0.2	4.9 ± 0.4	6.7 ± 0.6
$t\bar{t}, VV$	0.7 ± 0.1	0.8 ± 0.1	1.5 ± 0.1
$jet \to \tau$	12.0 ± 3.6	7.0 ± 2.1	19.0 ± 5.7
Total predicted	146.8 ± 17.5	116.8 ± 13.5	263.6 ± 30.1
Data	133	103	236



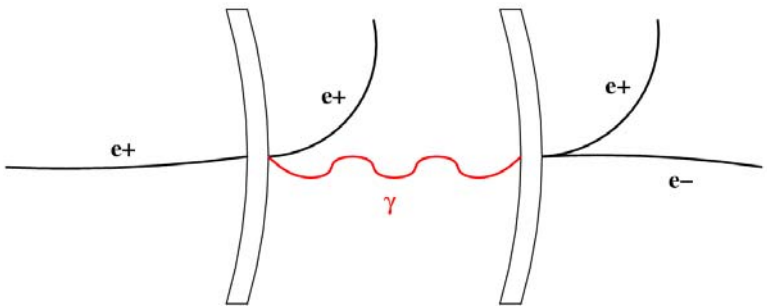


Search for Unstable $H^{++/--}$

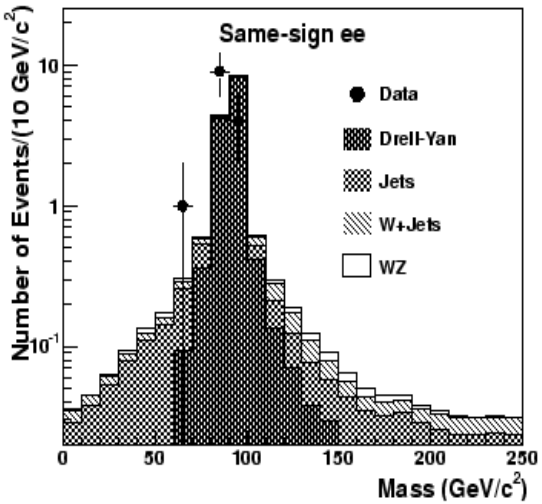
- Predicted by Left-Right Symmetric models, and other models with Higgs triplets

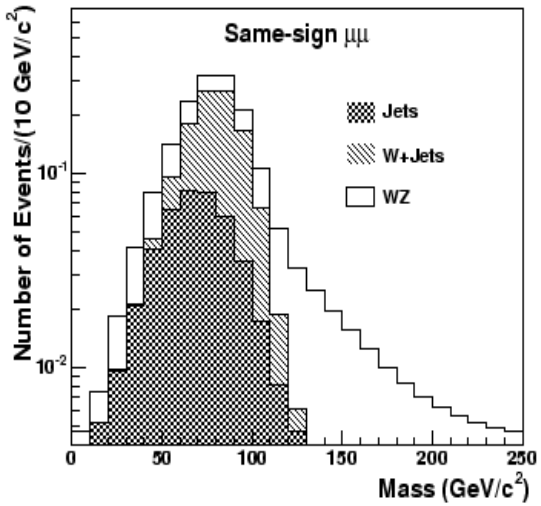


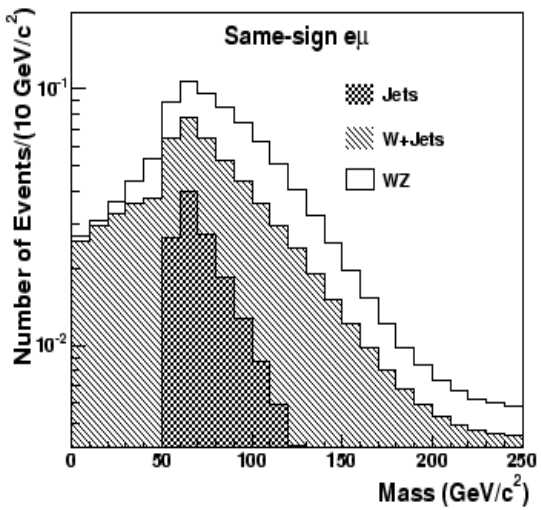
- Very prominent signature: Like-sign dileptons
- Search strategy -- look for Like-sign dileptons with $m_{\ell\ell}$ within the experimental resolution of the test mass
- Backgrounds: Z/γ^* with converting bremsstrahlung ("tridents"), WZ, W+jets (fake leptons)

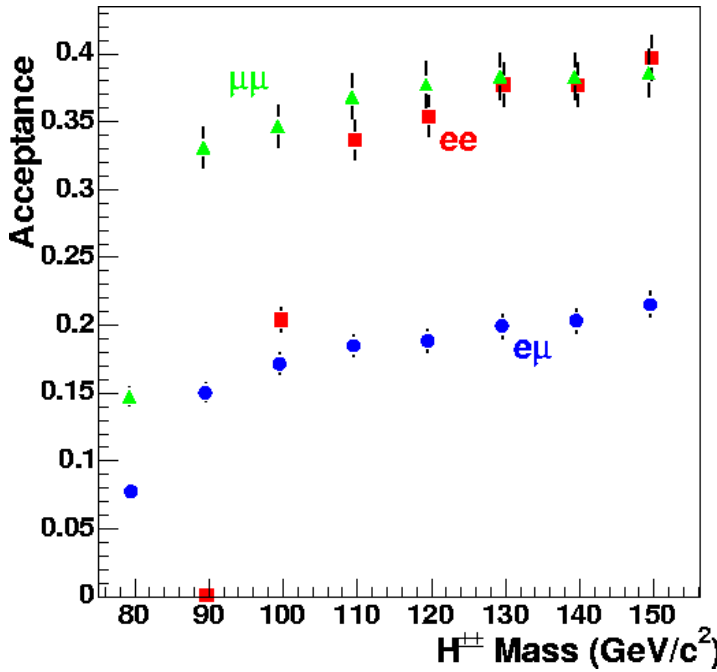


Backgrounds and Acceptance
$H^{++/--} \rightarrow$ Like-Sign Dileptons

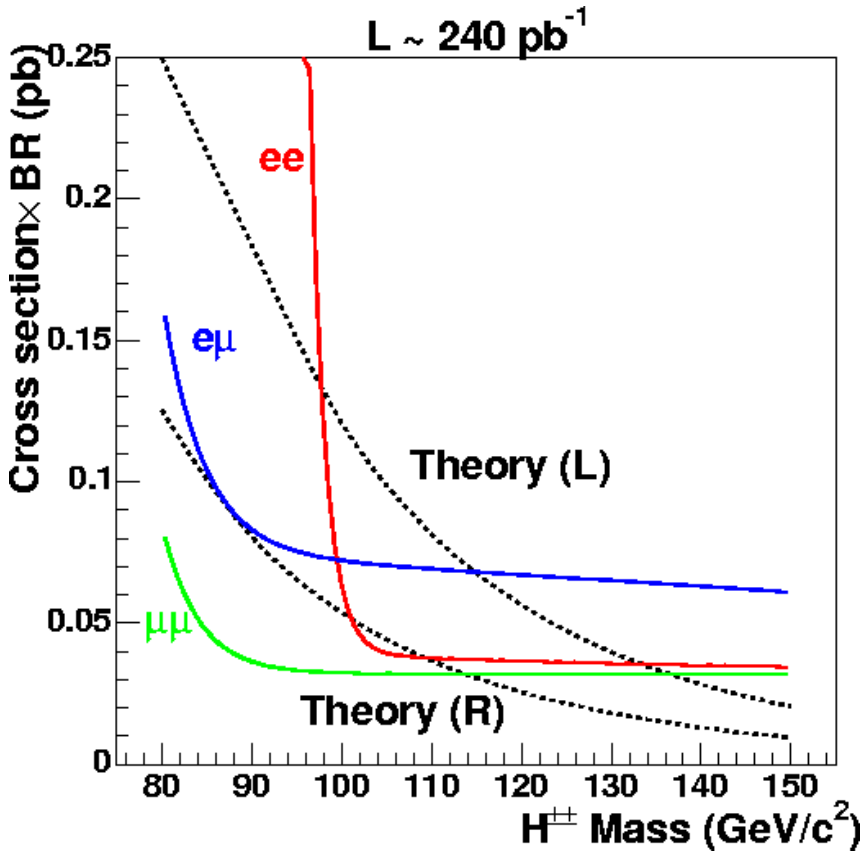


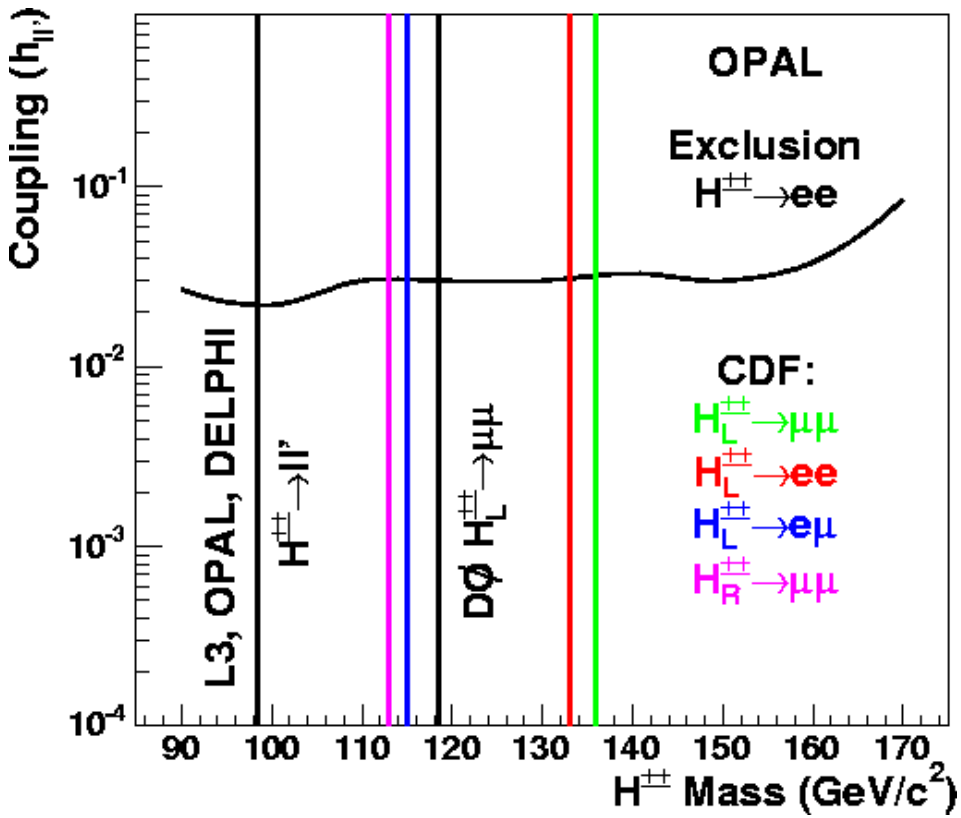






Unstable $H^{++/--}$ Limits





Search for Long-Lived $H^{++}H^{--}$

Signature: (pair-produced $H^{++}H^{--}$)

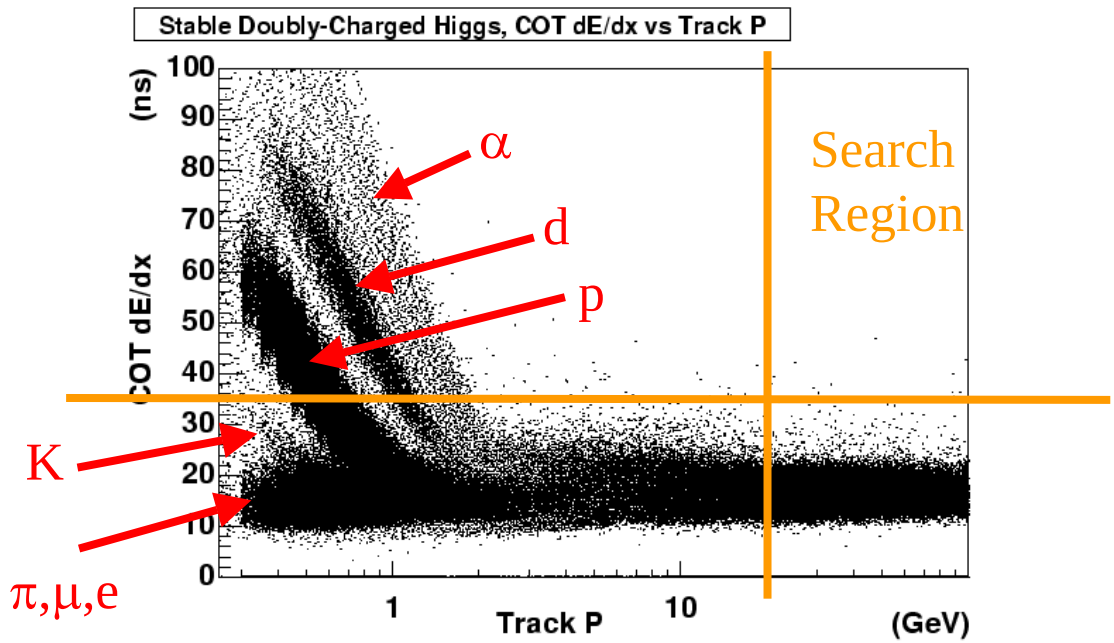
- Two heavily-ionized tracks in the gas tracking chamber (COT)
- Penetrate calorimeters and muon chambers to leave "muon" stubs

Require a "muon" with "p_T" >20 GeV and another track with p_T>20 GeV

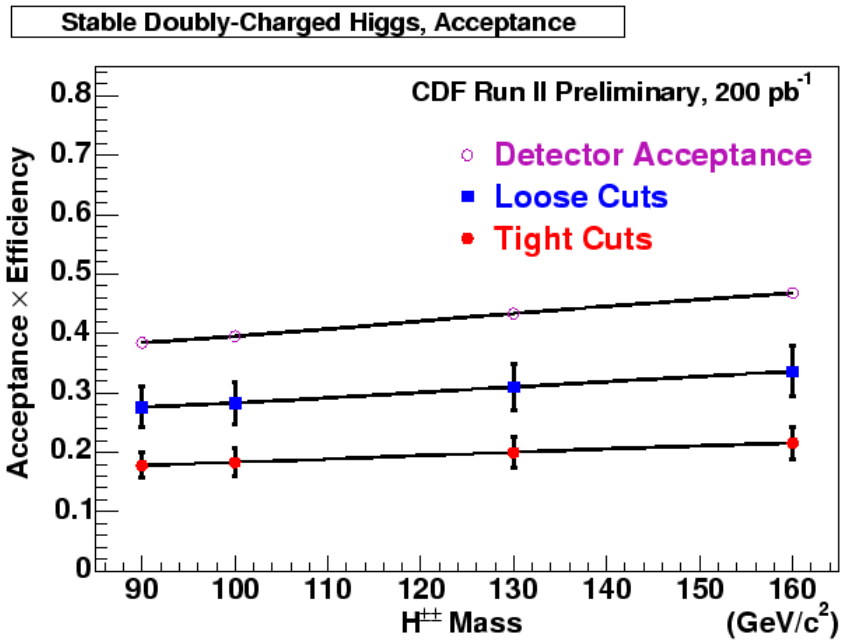
dE/dx is measured with pulse widths in the COT.

A track is "heavily ionizing" if the average pulse width is at least 35 ns.

Need two such tracks in an event.



Long-Lived $H^{++/--}$ Acceptances and Backgrounds



CDF Run II Preliminary, 200 pb^{-1}

Background Source	Loose Search	Tight Search
$Z \to \mu\mu$	$< 10^{-6}$	$< 10^{-12}$
$Z \to ee$	$< 10^{-6}$	$< 10^{-7}$
$Z \to \tau\tau$	$< 10^{-9}$	$< 10^{-9}$
Jet Misidentified	$< 10^{-5}$	$< 10^{-6}$
Total Background	$< 10^{-5}$	$< 10^{-6}$
Data Candidates	0	0

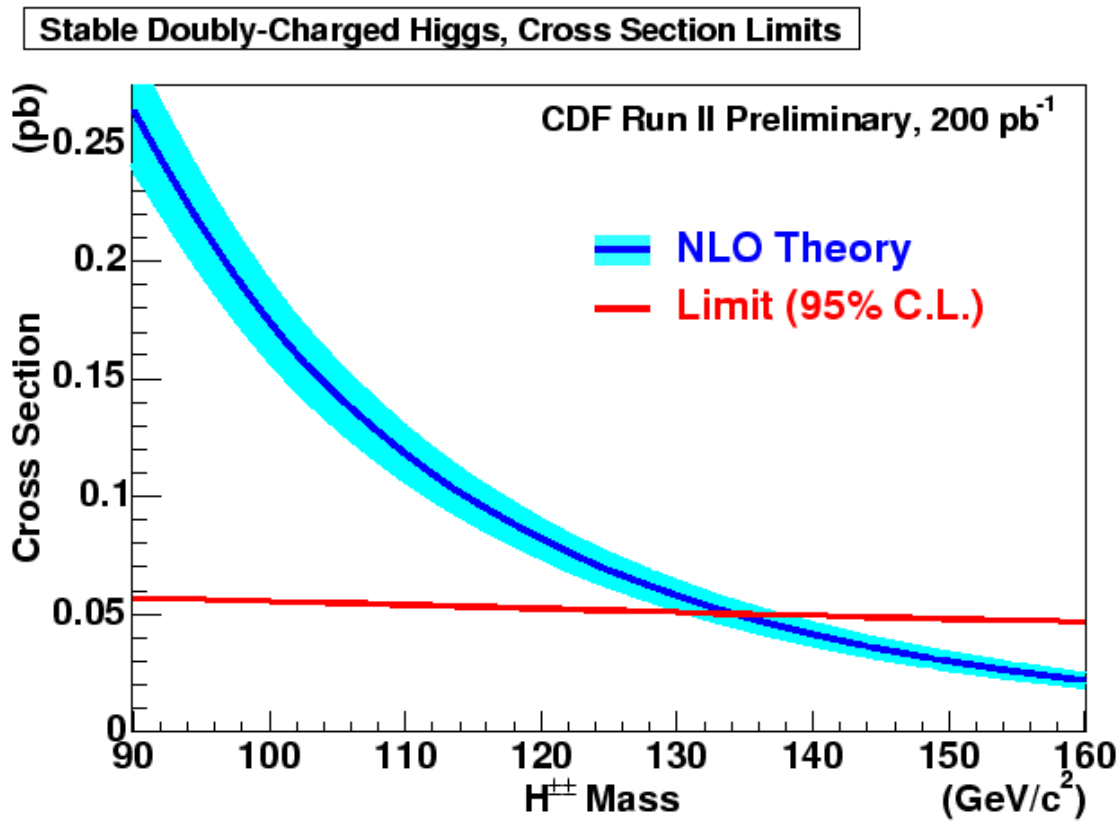
Almost zero background!

"Tight" cuts include minimum requirments on ECAL and HCAL energy deposits (highly ionizing in the calorimeter too, to reject muons)

Long-Lived $H^{++/--}$ Limits

With backgrounds nearly zero, additional cuts and use of m_{rec} do not help -- just count events.

Mass limit:
134 GeV



Summary

The Tevatron is beginning to perform well.

CDF has exciting new searches using the Run 2 data

- Higgsstrahlung: $W^+H \rightarrow \ell^+\nu_\ell b\bar{b}$
- High mass $gg \rightarrow H \rightarrow W^+W^-$
- $H \rightarrow \tau^+\tau^-$ in the MSSM
- Promptly-Decaying $H^{++/--}$
- Long-Lived $H^{++/--}$

But:

Many more channels/signatures to be added to the list

Improvements in selection and discriminant variables are needed. There are many ideas already!

Backup Slides Follow

Sensitivity to Higgsstrahlung

Three Channels Considered:

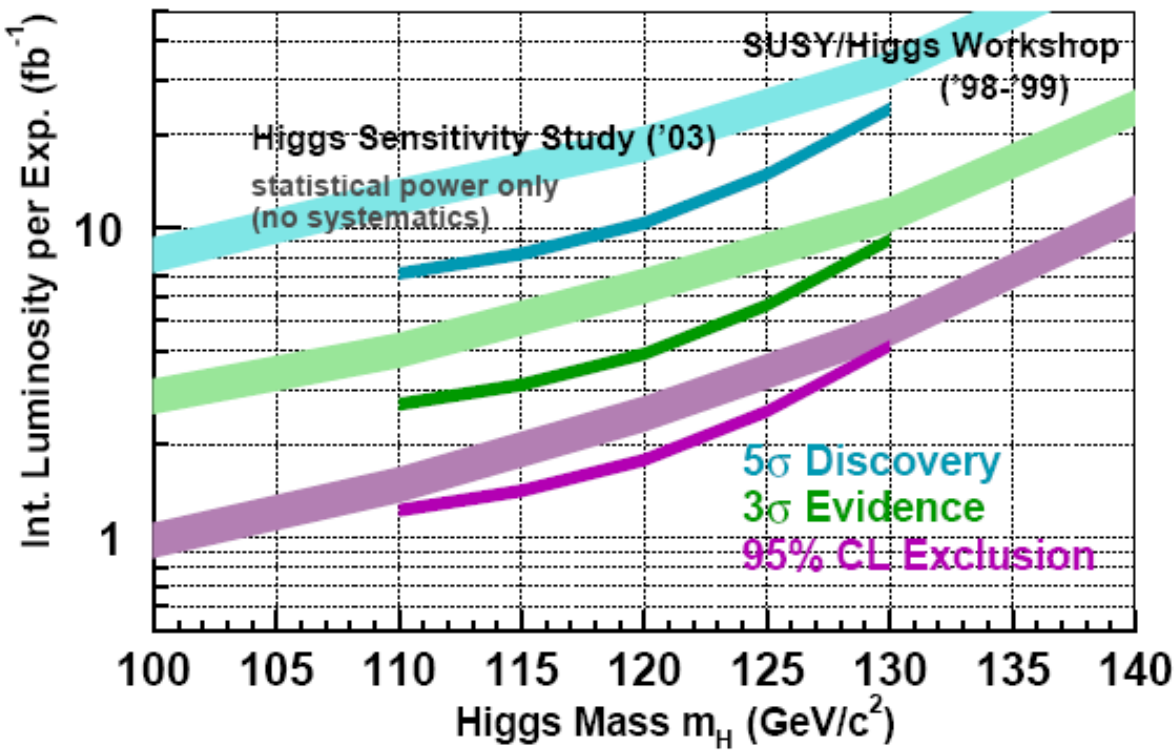
$$W^+H \to \ell^+\nu_\ell b\bar{b}\ (+\text{c.c.})$$

$$ZH \to \nu\bar{\nu}b\bar{b}$$

$$ZH \to \ell^+\ell^- b\bar{b}$$

Combined CDF+D0 sensitivity.

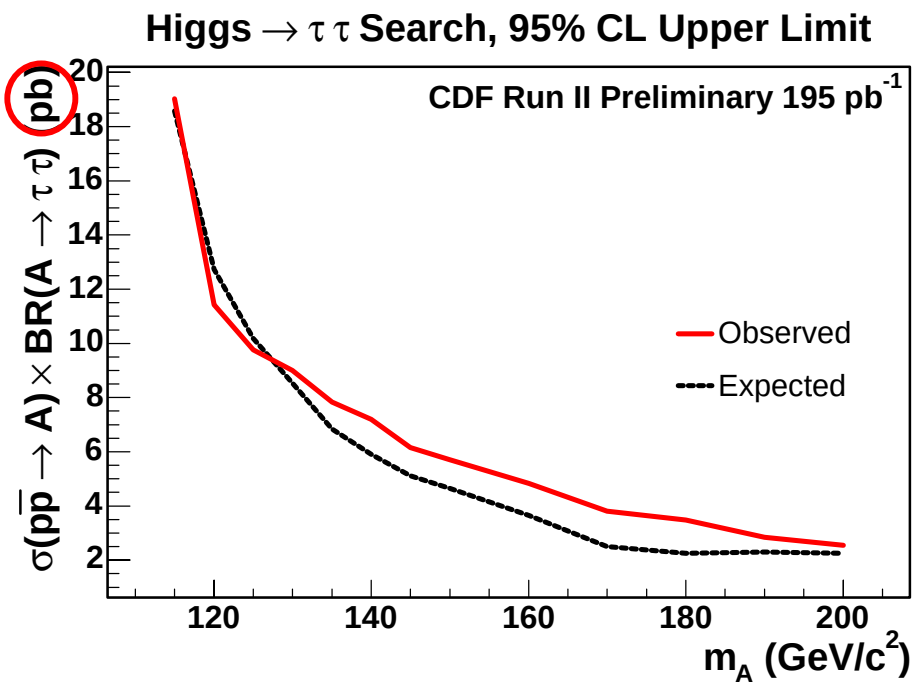
Luminosity is per experiment.



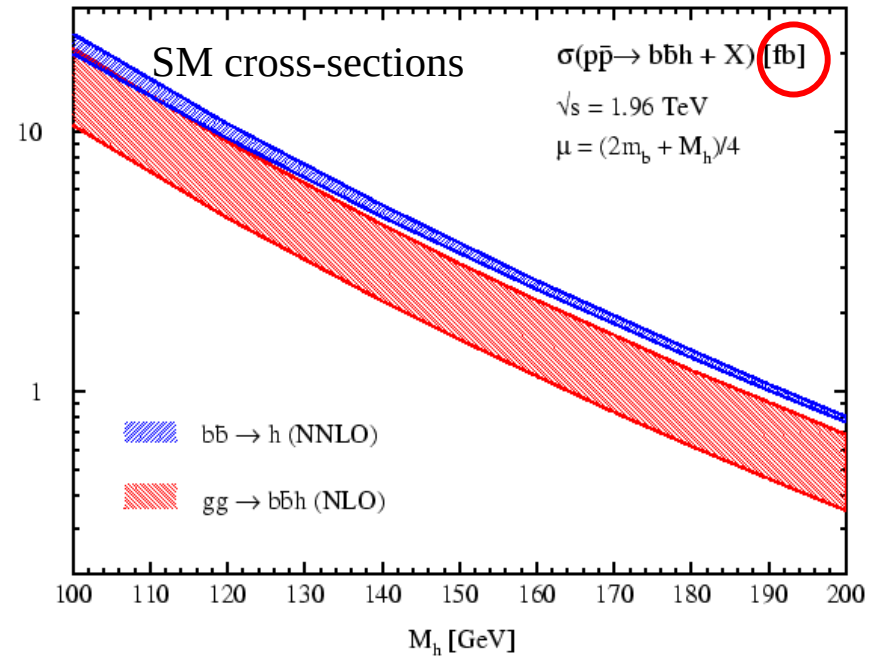
$gg \to H \to W^+W^-$ Event Counts and Expectation in 184 pb^{-1}

M_H assumed	140 GeV	150 GeV	160 GeV	170 GeV	180 GeV
M_{ll} cut (GeV)	55.0	57.5	62.5	70.0	80.0
DY ee	0.0000±0.0000	0.1501±0.1569	0.4201±0.2756	0.7202±0.3912	0.8703±0.4448
DY μμ	0.1676±0.1073	0.1676±0.1073	0.2160±0.1217	0.3229±0.1576	0.4270±0.1878
DYττ	0.0052±0.0027	0.0074±0.0033	0.0140±0.0052	0.0219±0.0074	0.0263±0.0082
ttbar	0.0083±0.0052	0.0083±0.0052	0.0083±0.0052	0.0111±0.0061	0.0172±0.0081
ZZ	0.0224±0.0025	0.0252±0.0028	0.0312±0.0032	0.0428±0.0041	0.0639±0.0058
WZ	0.0832±0.0087	0.0963±0.0098	0.1187±0.0115	0.1462±0.0135	0.1844±0.0164
WW	3.5048±0.4099	3.8170±0.4463	4.4496±0.5201	5.3799±0.6285	6.4922±0.7583
fakes	0.3970±0.1225	0.4500±0.1398	0.5300±0.1638	0.6460±0.1946	0.8140±0.2529
total bg	4.1885±0.4495	4.7219±0.5177	5.7878±0.6447	7.2910±0.8146	8.8952±0.9759
HWW	0.1042±0.0122	0.1553±0.0182	0.2241±0.0262	0.2200±0.0258	0.1716±0.0201
S/sqrt(S+B)	0.0503	0.0703	0.0914	0.0803	0.0570
data	2	2	3	7	8

Comparison with SUSY Expectation



Inclusive: no requirement on observation of b jets



From hep-ph/0406152

SM cross-section needs to be multiplied by $\tan^2\beta$ and BR($h\to\tau\tau$).

$\tan\beta$ ~200 needed

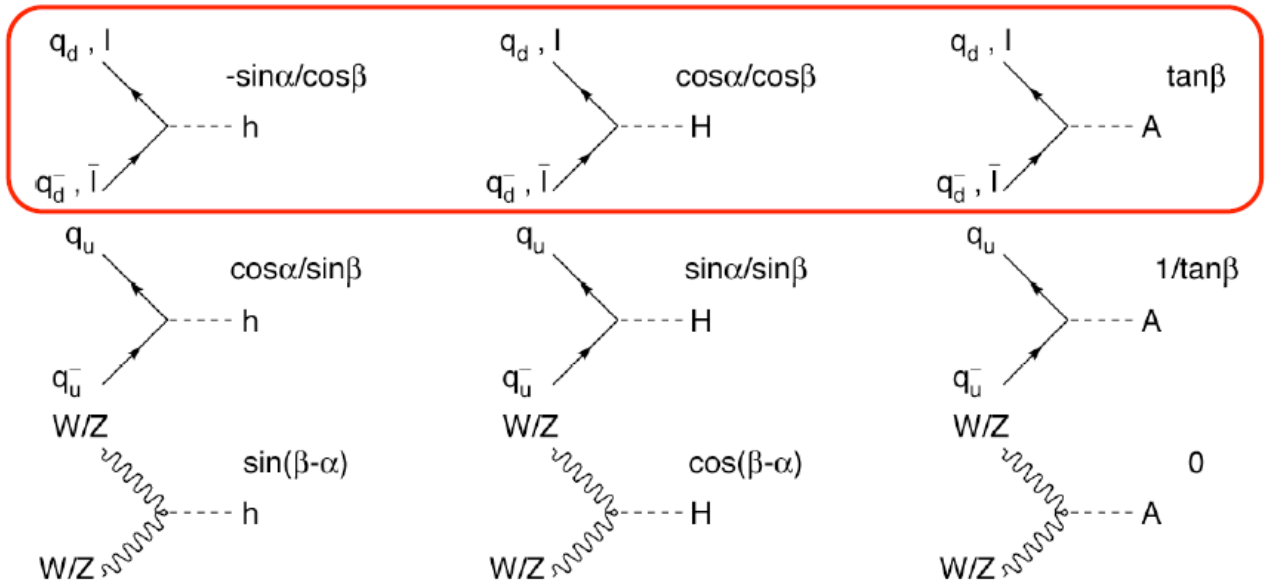
MSSM H Couplings

Couplings of Higgs bosons to:

down-type quarks and charged leptons

up-type quarks

gauge bosons



Top row gives production cross-sections proportional to $\tan^2\beta$