Standard Model Higgs Boson Searches with CDF

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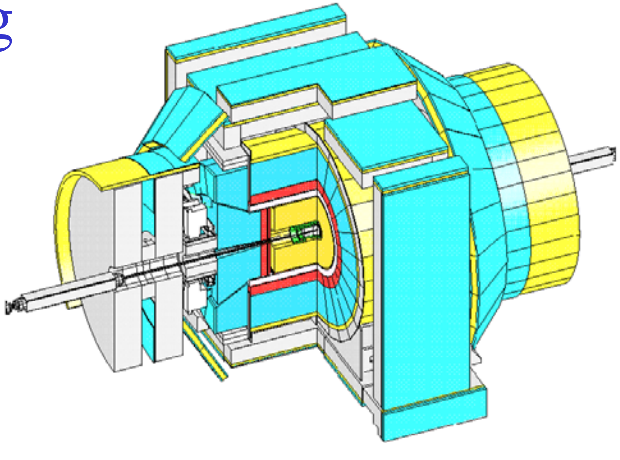
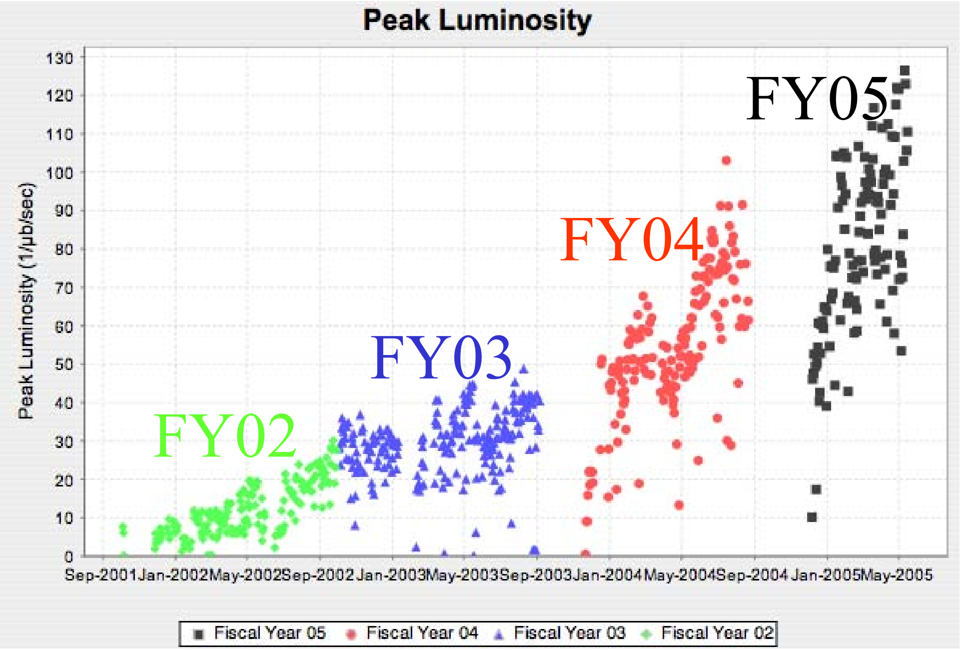
for the CDF Collaboration

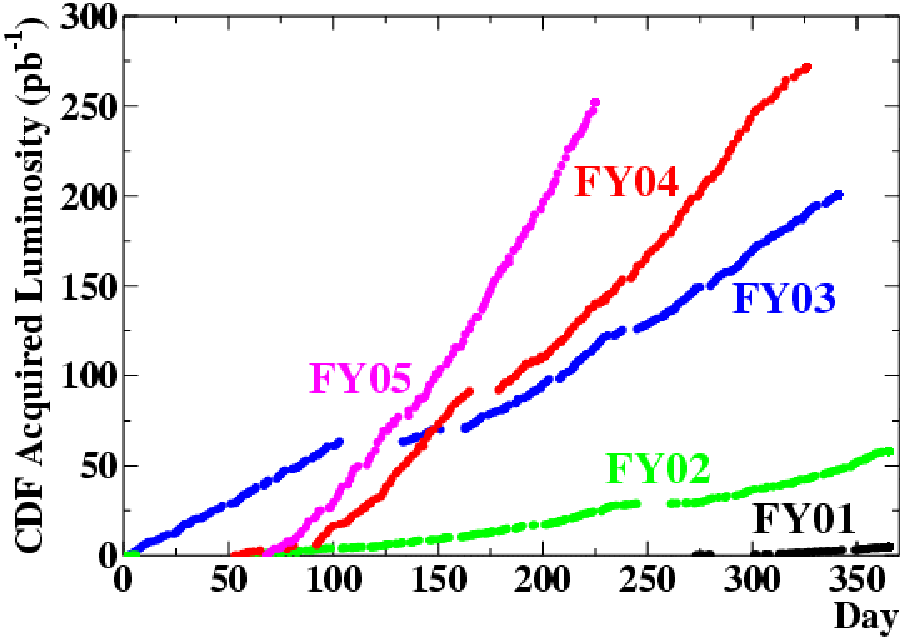
- Tevatron Status and Upgrades
- CDF Detector
- Searches for Higgsstrahlung
- Searches for $H \rightarrow W^+W^-$



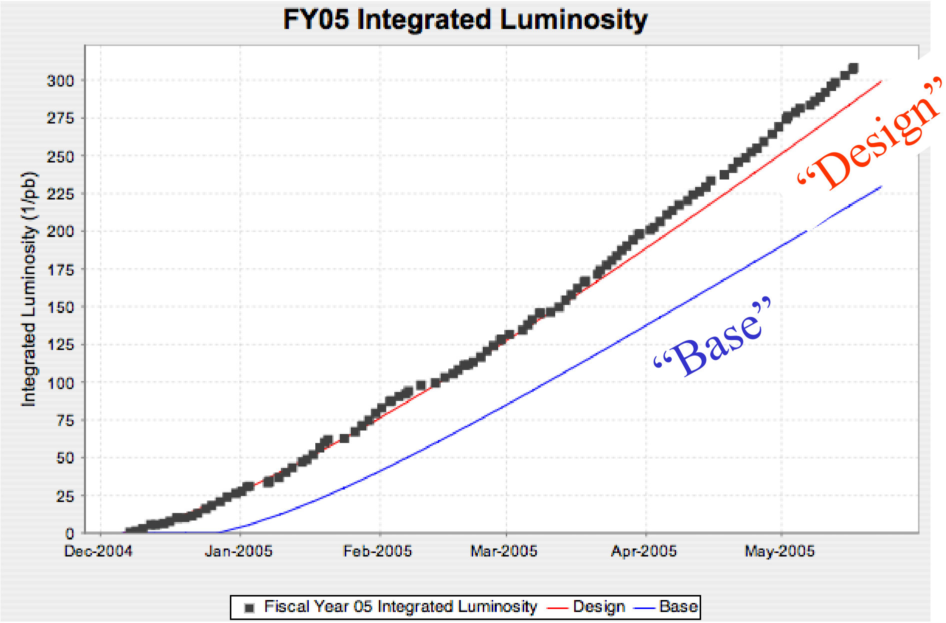
Tevatron Luminosity Steadily Increasing

- Increased antiproton production rate
  - More protons on target
  - Slip-Stacking
  - Mixed Recycler/Accumulator shots
- Increased efficiency of transfers
- Increased reliability of Tevatron operation

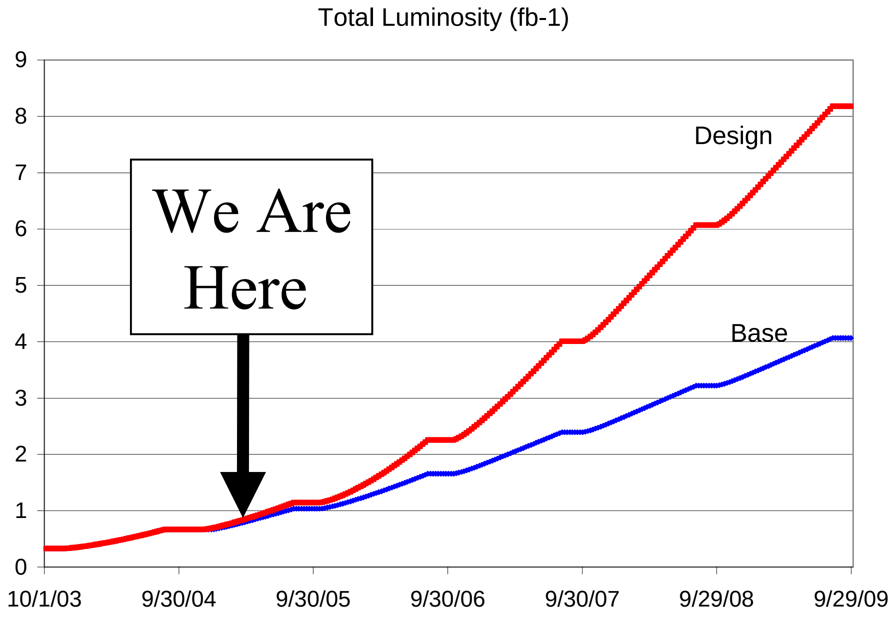




We’re on the Design Luminosity Track



But still a long road ahead to get to 8 fb^{-1}

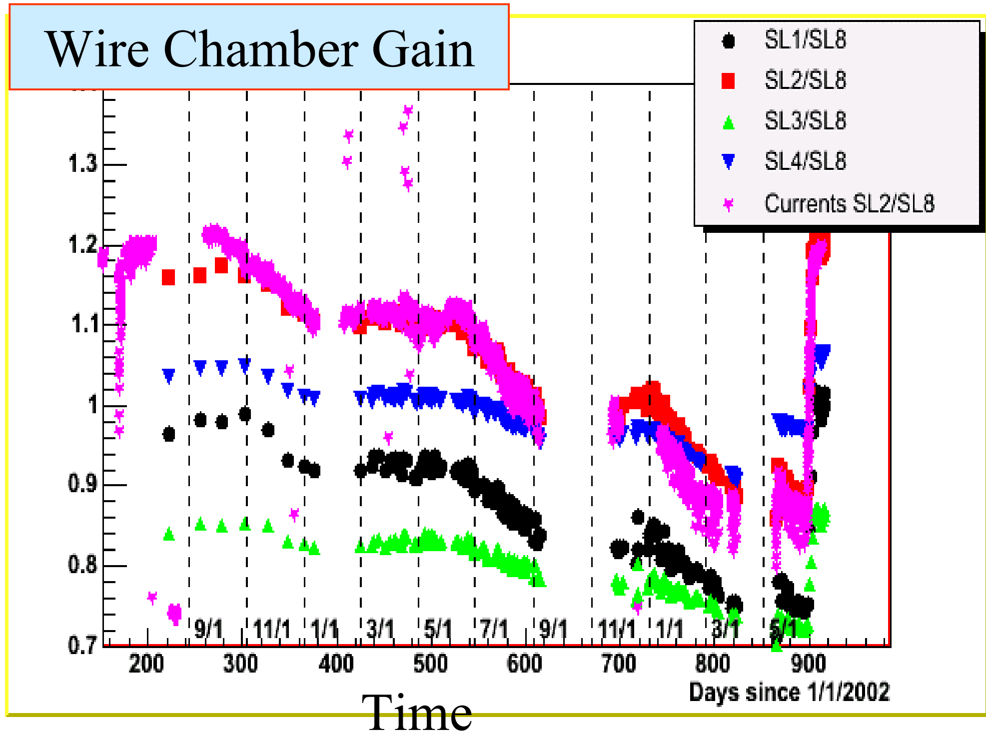


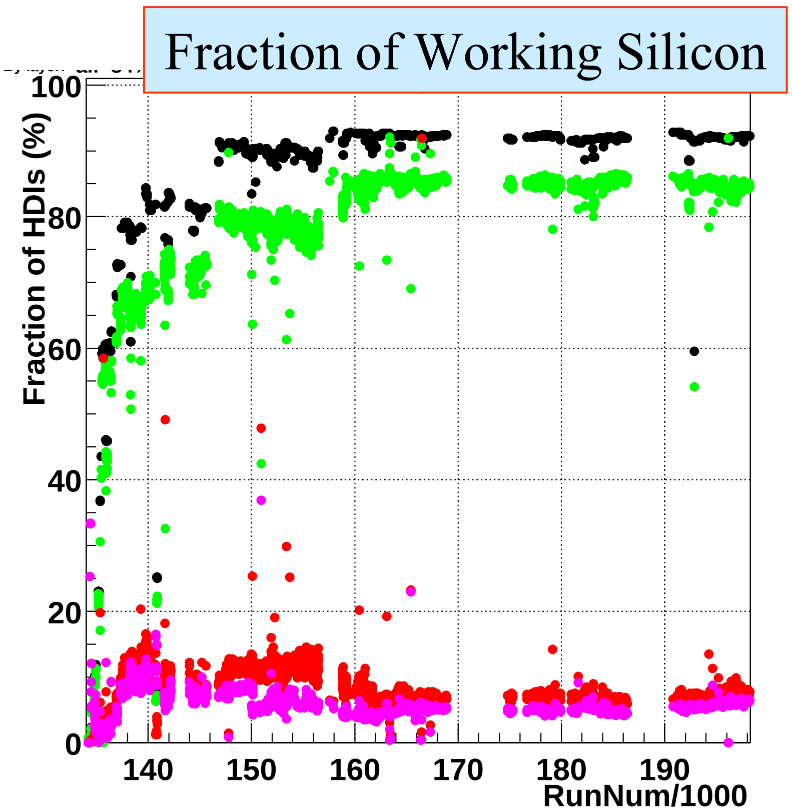
Future Improvements:

- Electron Cooling of antiproton beam in Main Injector

Detector Stability -- Wire Chamber and Silicon

Wire chamber gain deteriorated with increased integrated luminosity in 2004.
Cured with oxygen therapy.
O_2 prevents aging in 2005.

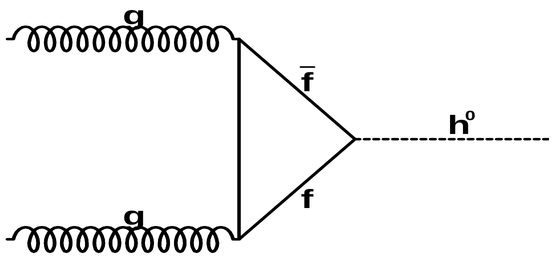




Beam incidents (abort kicker prefires) current concern. Leads to damage in silicon detector. So far, very little damage.

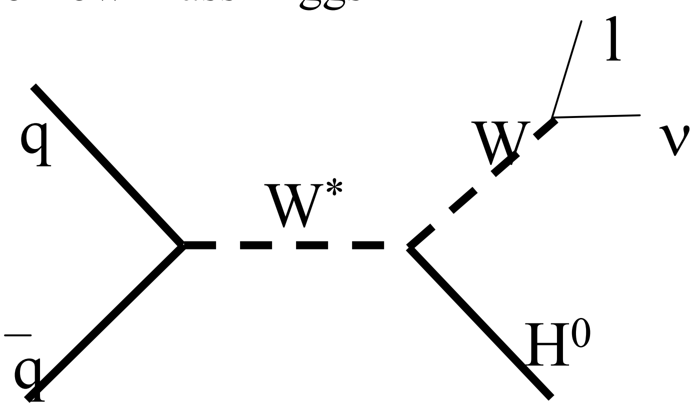
Black: powered; Green: good; Red: bad, Pink: error rate

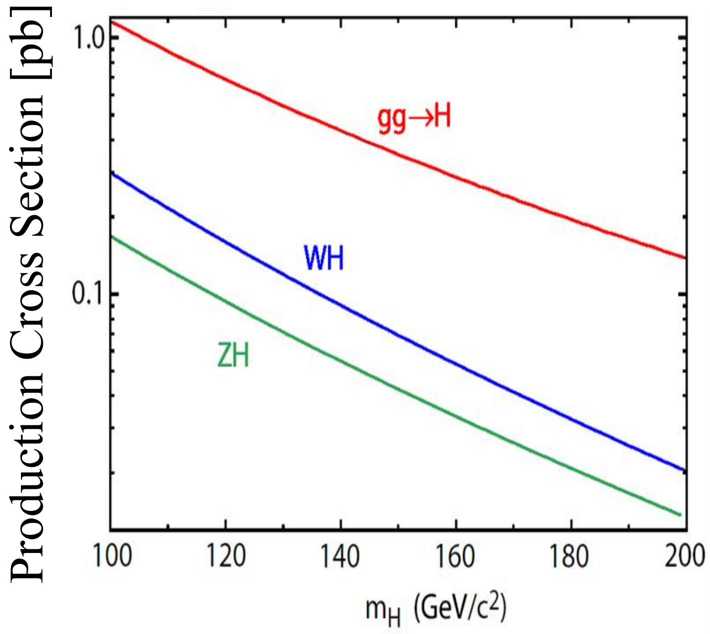
Standard Model Higgs Production Mechanisms



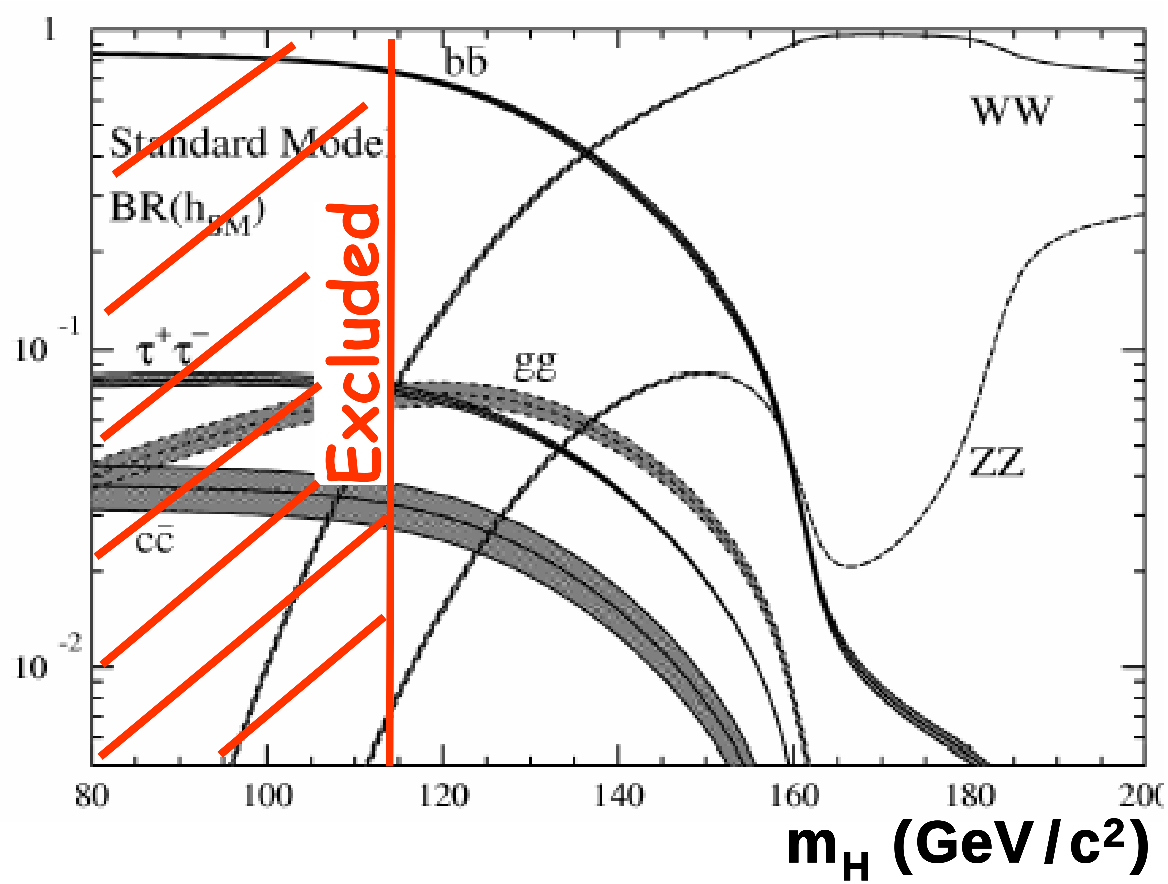
Gluon fusion process dominant in SM.
Difficult to separate from backgrounds.

"Higgsstrahlung" -- Gauge Boson can be W or Z. Distinctive Lepton signatures and b-tagging for low-mass Higgs





Standard Model Higgs Decay Modes



m_H<114.4 GeV
Excluded

114.4 < m_H<135 GeV
H→b-bbar dominates

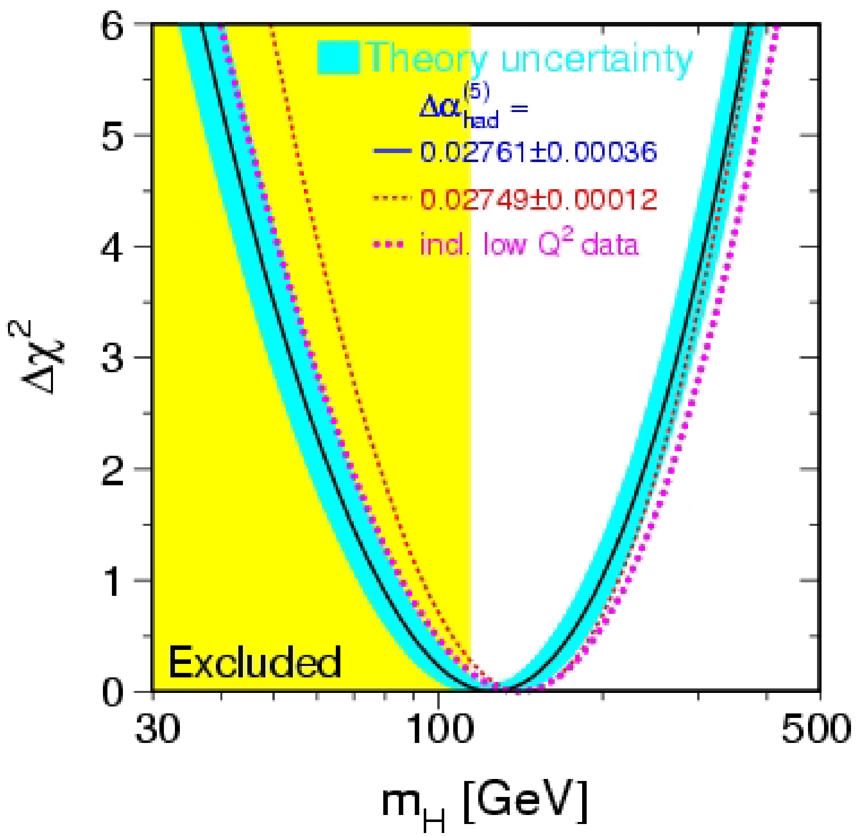
m_H>135 GeV
H →W^+W^- dominates

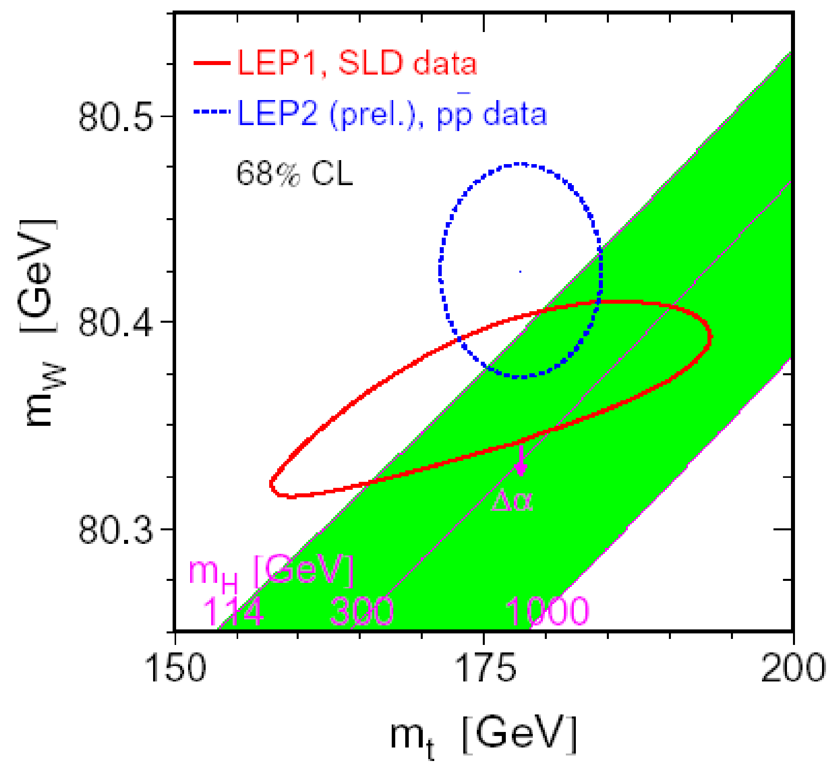
Channels are identified by production and decay mode

Some Guidance from SM EW Fits

Latest Blueband SM Fit (Winter '05)

(m_t=178 GeV)





$$m_H = 126^{+73}_{-48}\ \text{GeV}$$

$$m_H \leq 280\ \text{GeV at 95\% CL}$$

m_H prediction from SM fit is very sensitive to m_{top}, m_W measurements!

SM Channels with $H^0 \rightarrow b\bar{b}$

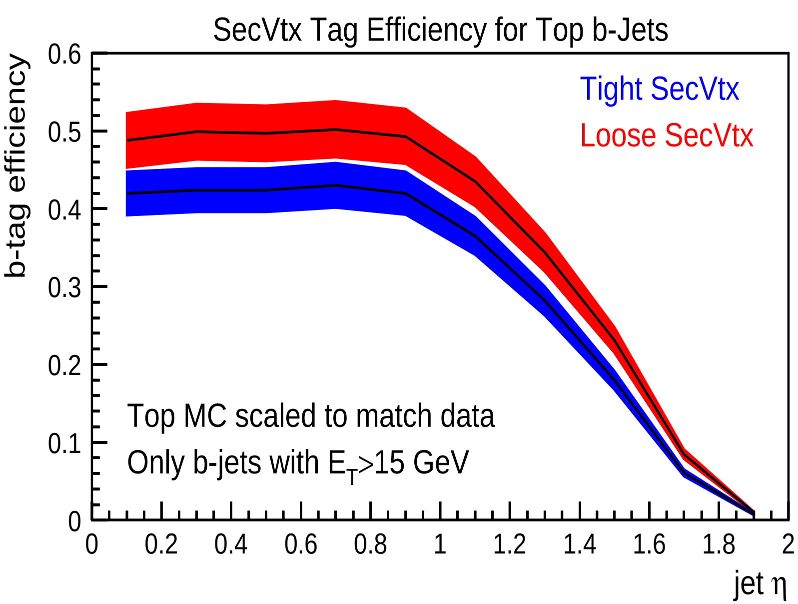
- $W^{\pm}H^0 \rightarrow \ell^{\pm}\nu b\bar{b}$
  - Needs High-efficiency, high-purity b-tagging
  - Needs Lepton identification + Missing E_T reconstruction
  - Needs Dijet Mass Resolution
  - Backgrounds: $Wb\bar{b},\ W + 2\ \text{partons} + \text{fake tag},\ t,\ t\bar{t},\ \text{non}-W$
- $Z^0H^0 \rightarrow \nu\bar{\nu}b\bar{b}$
  - Needs High-Efficiency, high-purity b-tagging
  - Needs Missing-E_T reconstruction
  - Needs Dijet Mass Resolution
  - Has acceptance for $W^{\pm}H^0 \rightarrow \ell^{\pm}\nu b\bar{b}$ with a missing lepton
  - Backgrounds: $QCD,\ Z^0b\bar{b},\ Z + 2\ \text{partons} + \text{fake tag},\ t,\ t\bar{t}$
- $Z^0H^0 \rightarrow \ell^+\ell^-b\bar{b}$
  - Low Backgrounds! Z sample is very clean
  - Needs High-Efficiency, high-purity b-tagging
  - Needs Dijet Mass Resolution
  - Backgrounds: $Z^0b\bar{b},\ Z + 2\ \text{partons} + \text{fake tag}$

SM Channels with $H^0 \to W^+W^-$

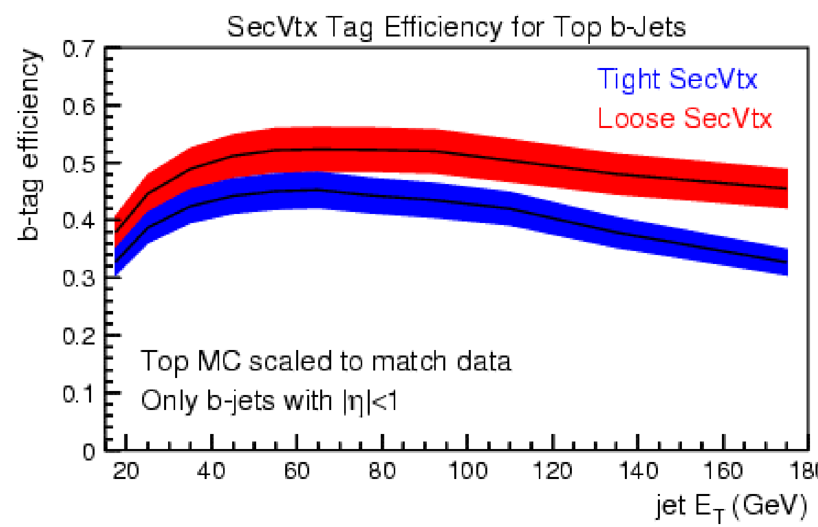
- $gg \to H^0 \to W^+W^-$
  - Seek opposite-sign dileptons, (e or μ) and Missing E_T
  - Main Background: 12 pb of SM W^+W^- production.
    Also: WZ, ZZ, $Z \to l^+l^-$
- $W^\pm H^0 \to W^\pm W^+ W^-$
  - Seek like-sign dileptons -- much lower background!
  - Main background: Leptonically Decaying W, Z+ converted photon or other fake lepton. WZ, ZZ
  - Also sensitive to $Z^0 H^0 \to Z^0 W^+ W^-$

B-tag efficiency

- s/b tradeoff: Leptons & Missing E_T are distinctive; real backgrounds have two b quarks. Single-tag is enough. Future: Combine single and double-tag analyses, do a tight-loose tag.
- Jet-probability tags are available but not yet used in Higgs analyses -- more complication for estimating mistags



Mistag rates typically ~0.5% for displaced vertex tags

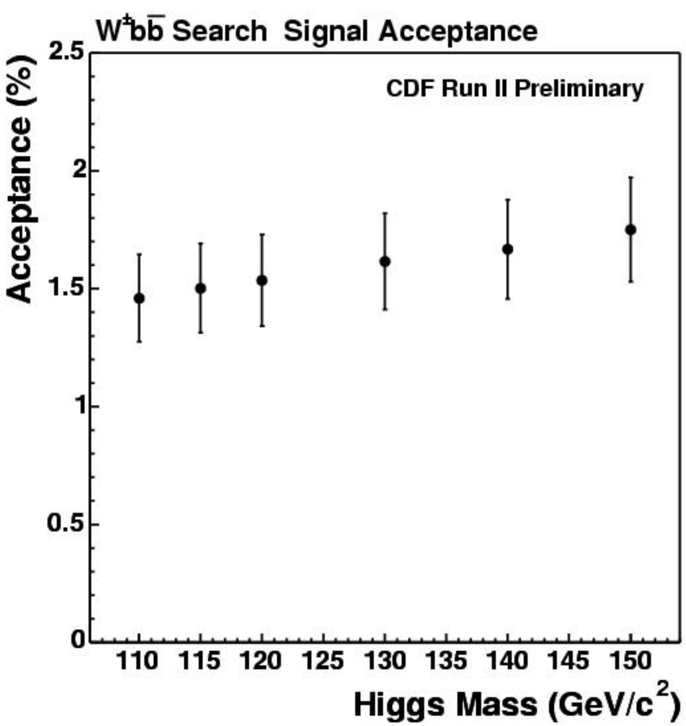


$W^{\pm}H^{0} \rightarrow \ell^{\pm}\nu b\bar{b}$ Selection

Isolated Central electron or muon (Et > 20 GeV)
Rejection of Z^0, photon conversions, cosmic rays

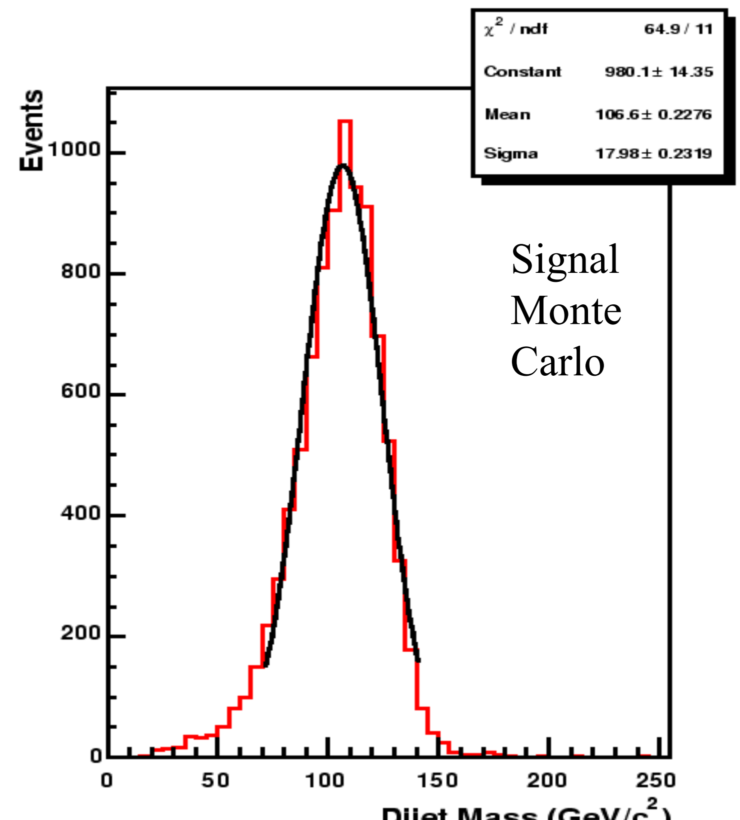
Missing E_T > 20 GeV
Two jets with E_T>15 GeV, |η|<2
At least one Displaced Vertex b-tag

Dijet mass resolution for this analysis: 18% (jet cone size=0.4, unsophisticated m_{jj})



Acceptance for ZH not yet included

Br(W→lν) is part of acceptance; Br(H→bb) is not.



CDF sees Z→bb decays in Run 2

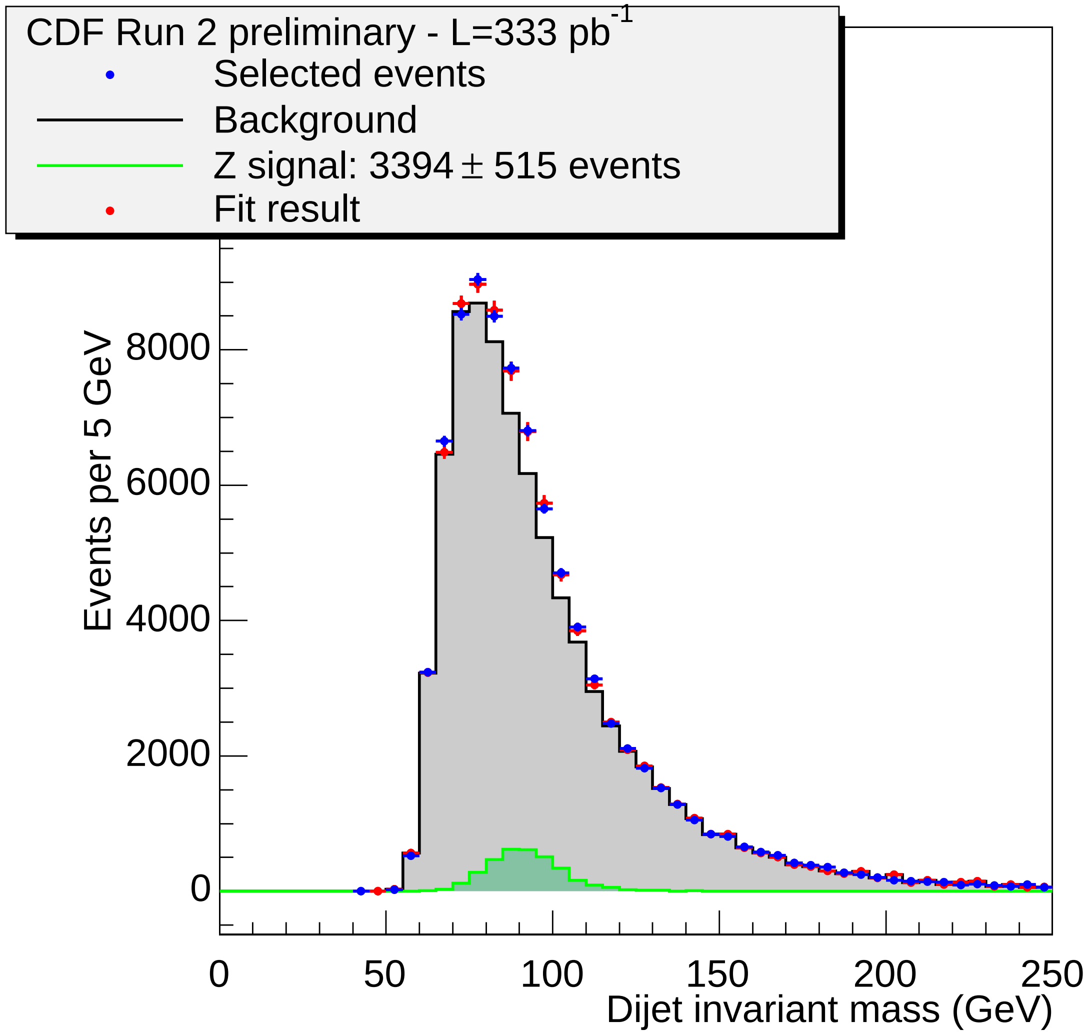
Double b-tagged events with no extra jets and a back-to-back topology are the signal-enriched sample: E_t^3<10 GeV, $\Delta\Phi_{12}$>3

Among 85,784 selected events CDF finds 3400±500 Z→bb decays

- signal size ok
- resolution as expected
- jet energy scale ok!

This is a proof that we are in business with small S/N jet resonances!

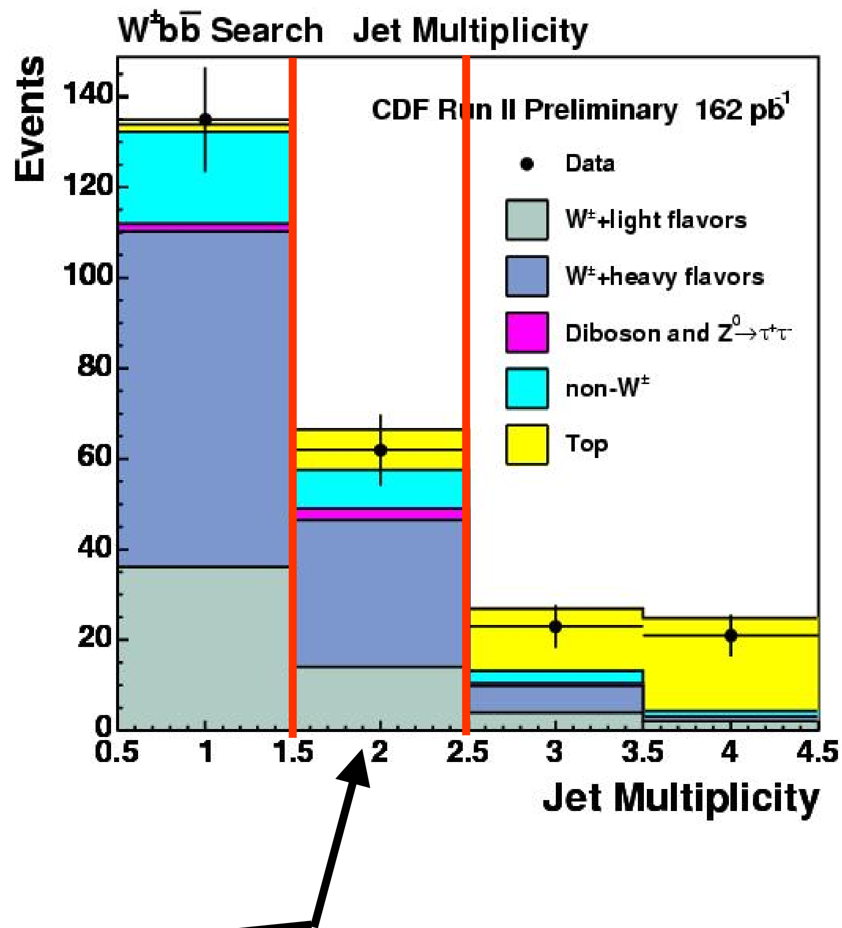
CDF expects to stringently constrain the b-jet energy scale with this dataset



$W^{\pm}H^{0} \rightarrow \ell^{\pm}\nu b\bar{b}$ Background Estimations and Data

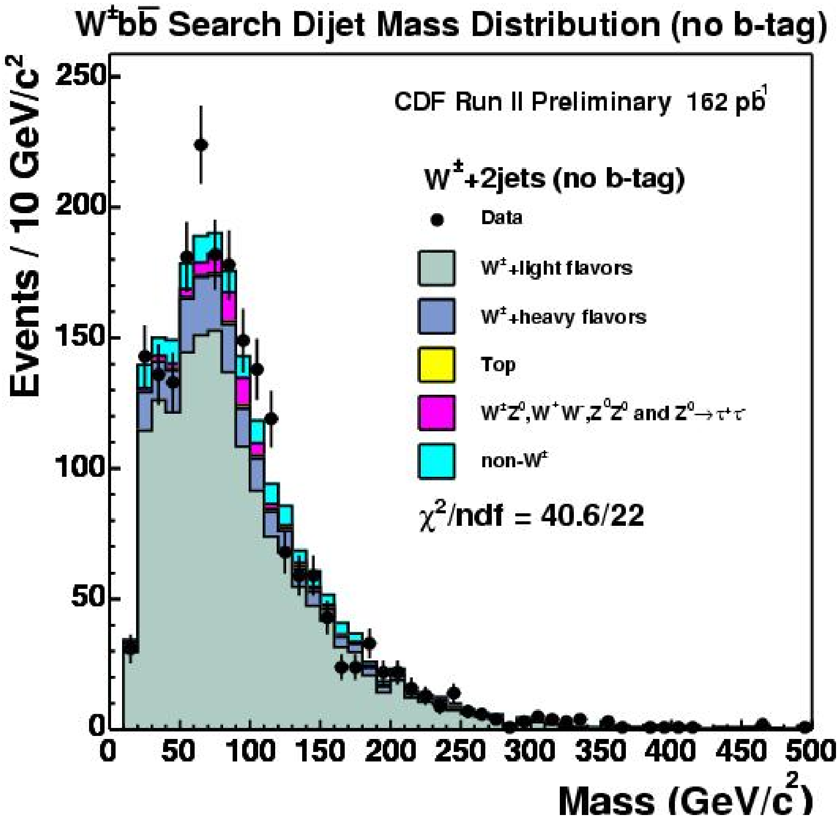
$$\int \mathcal{L}dt = 162 \text{ pb}^{-1}$$

Category	Events
Events before Tagging	2072
W+LF	14.1±2.6
W+HF	32.4 ± 6.5
WW/ZZ/WZ/Z→$\tau^+\tau^-$	2.5 ± 0.6
non-W	8.5 ± 1.2
top	8.9 ± 1.1
total Backgrounds	66.5 ± 9.0
Observed Postive tags	62



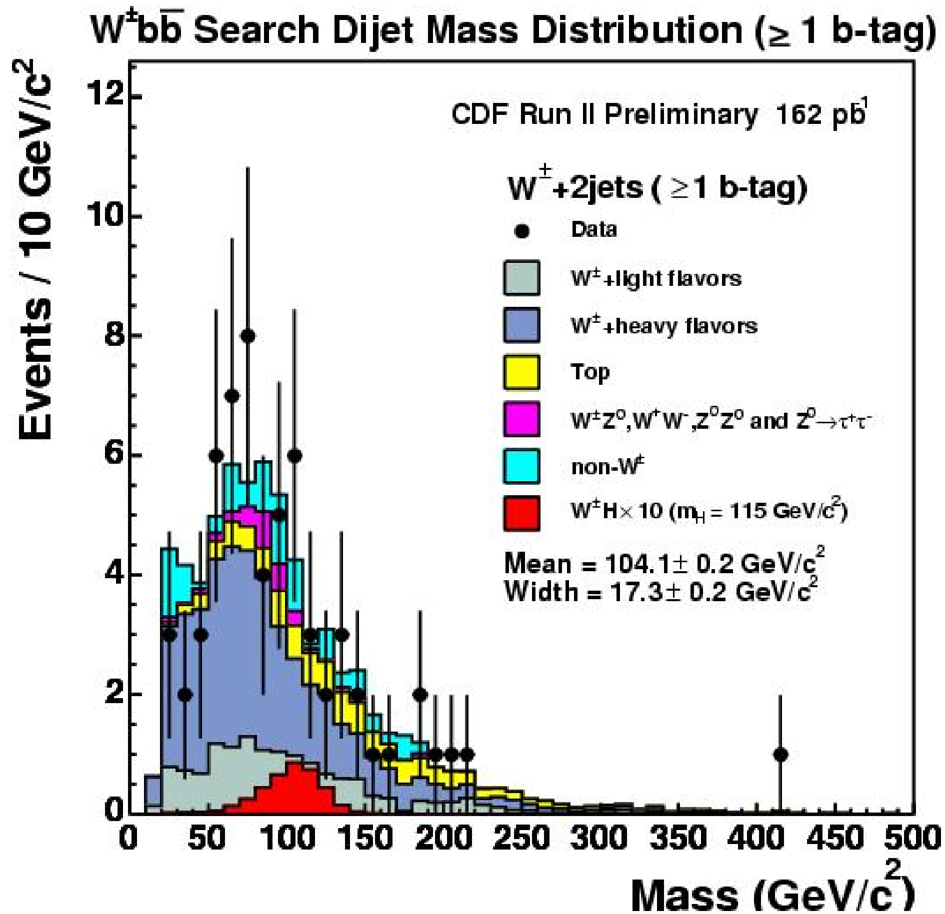
Data are well modeled for all jet multiplicities

Reconstructed Dijet Mass in the $W^{\pm}H^{0} \rightarrow \ell^{\pm}\nu b\bar{b}$ Channel

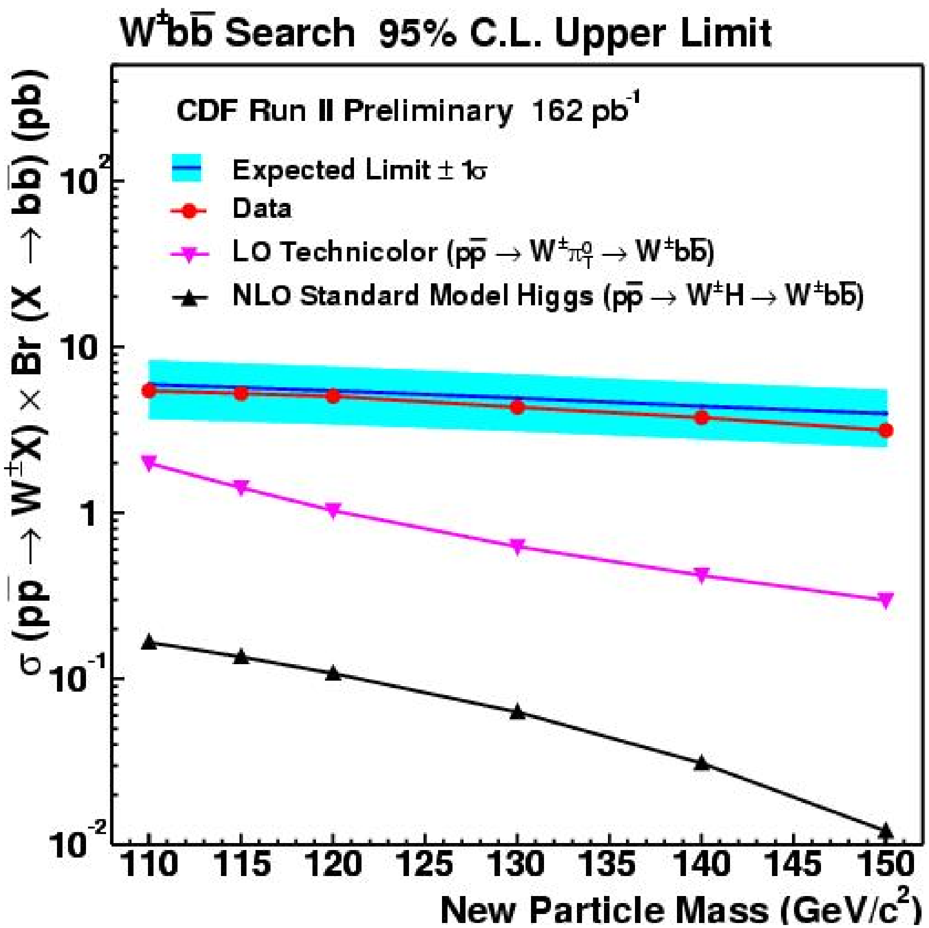


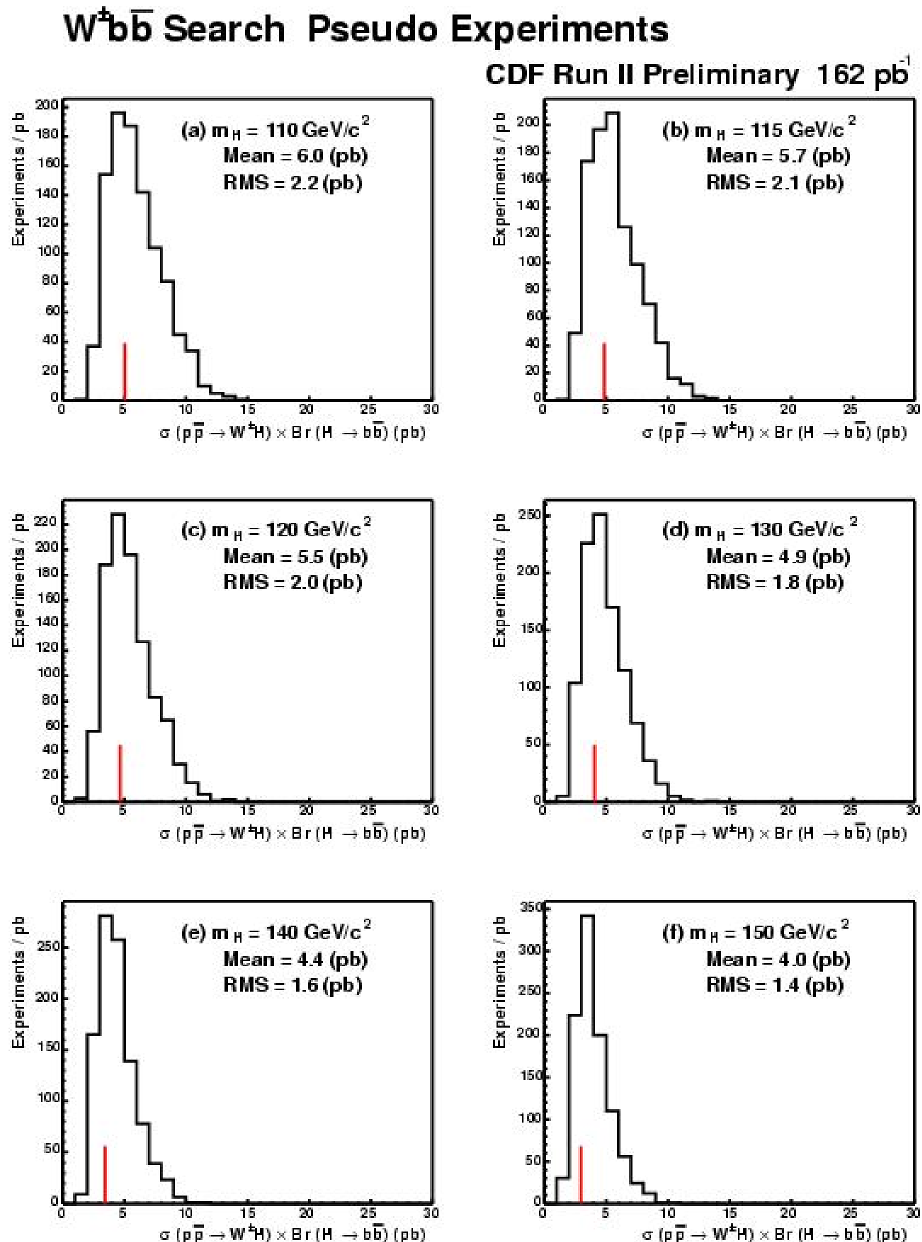
Before b-tagging

After B-tagging



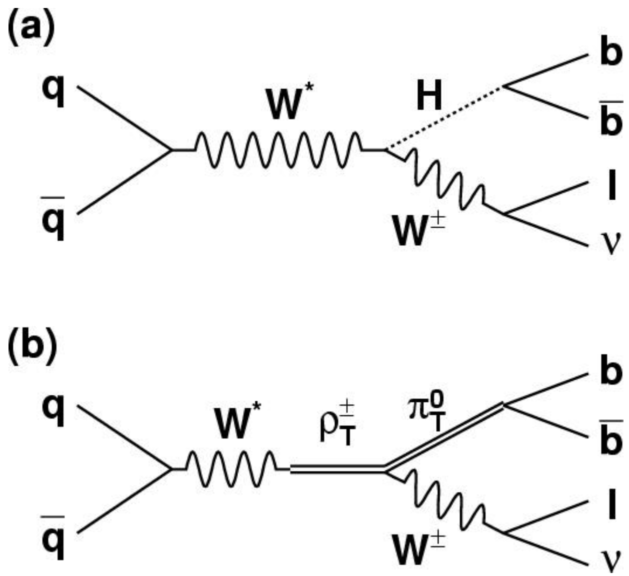
Cross-Section Limits are Close to Expectations for $\int \mathcal{L}dt = 162\ \mathrm{pb}^{-1}$

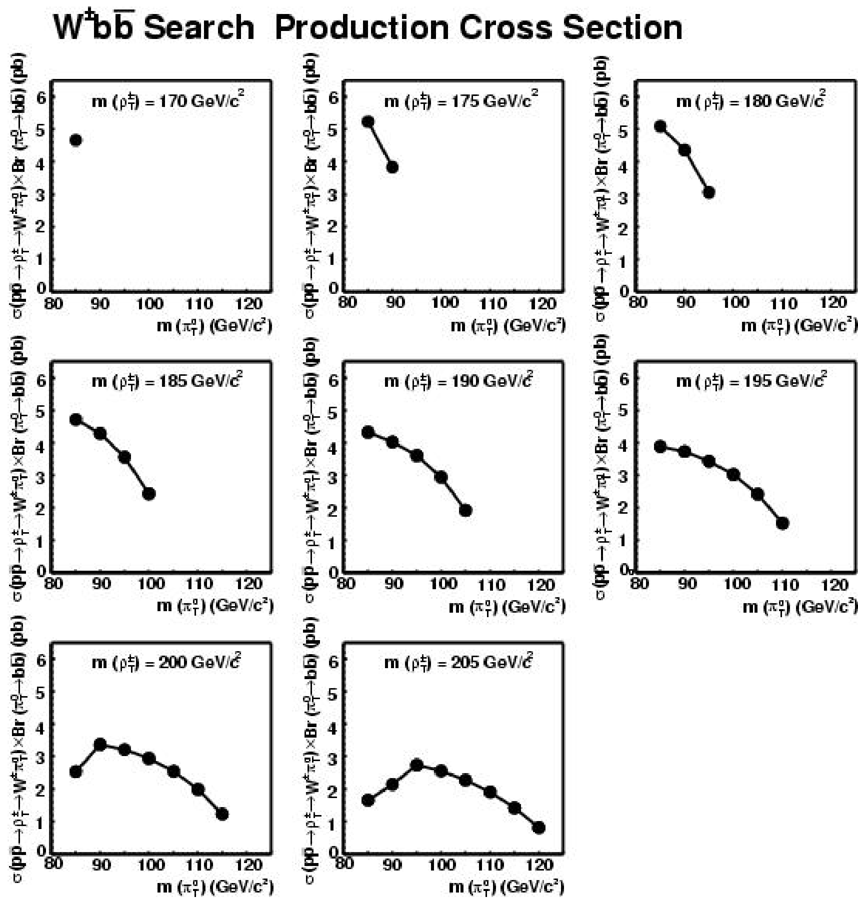




Small Change to Analysis Allows Search for Technicolor Bosons

Same Final State: lνbb

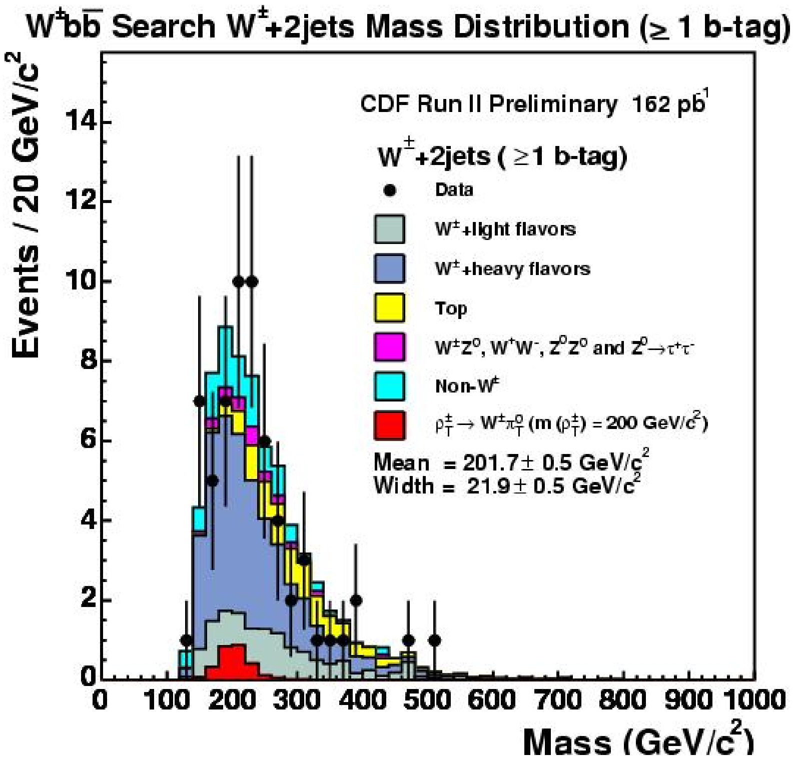


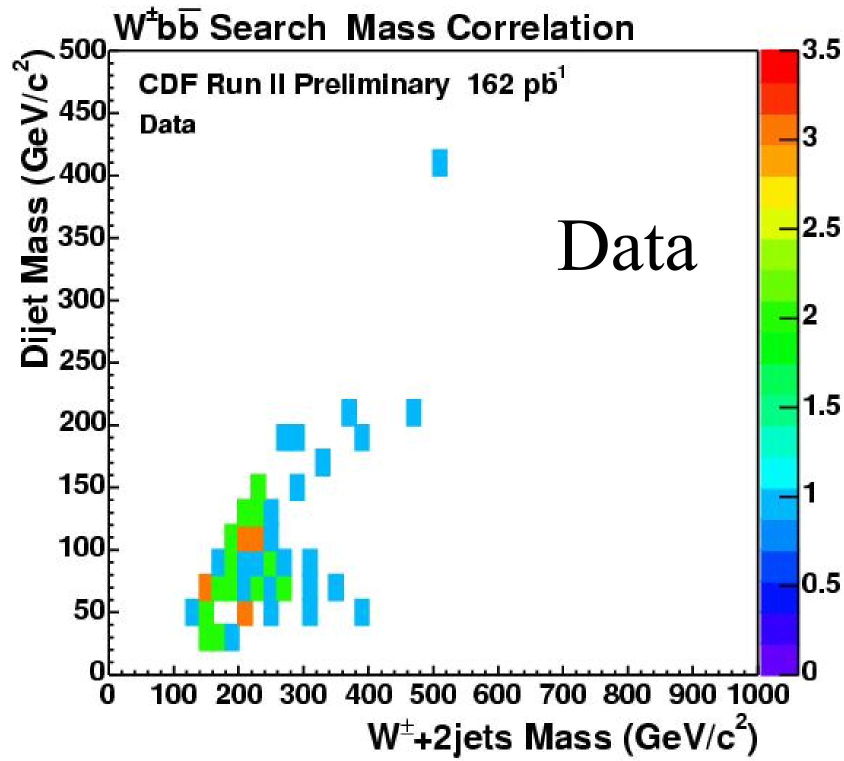


To search for technirho, compute M(Wbb):

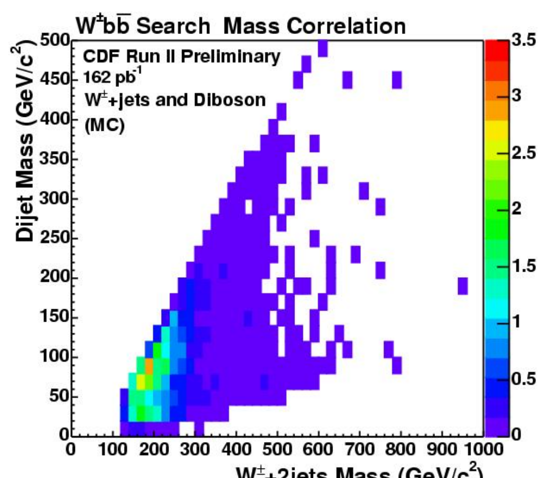
Need Neutrino p_Z (have p_T=Missing E_T). Can solve (2-fold ambig.) assuming $M(l\nu)=M_W$

Reconstructed Wbb Mass and Dijet Mass

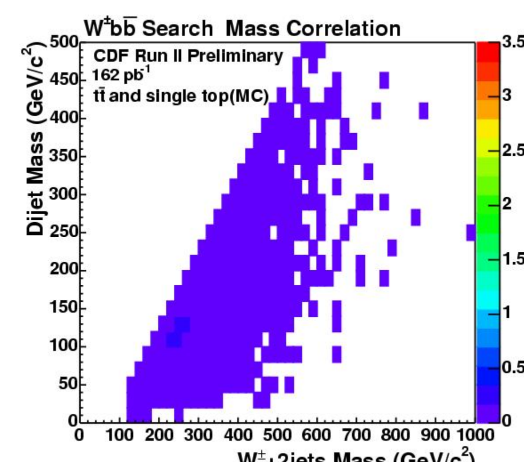




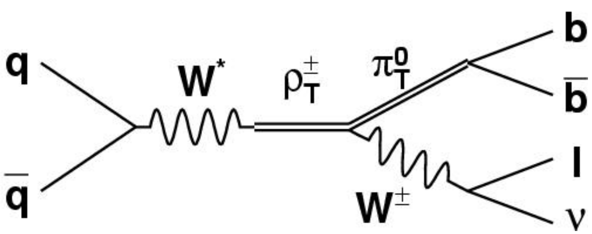
W+jets
+Diboson
Background

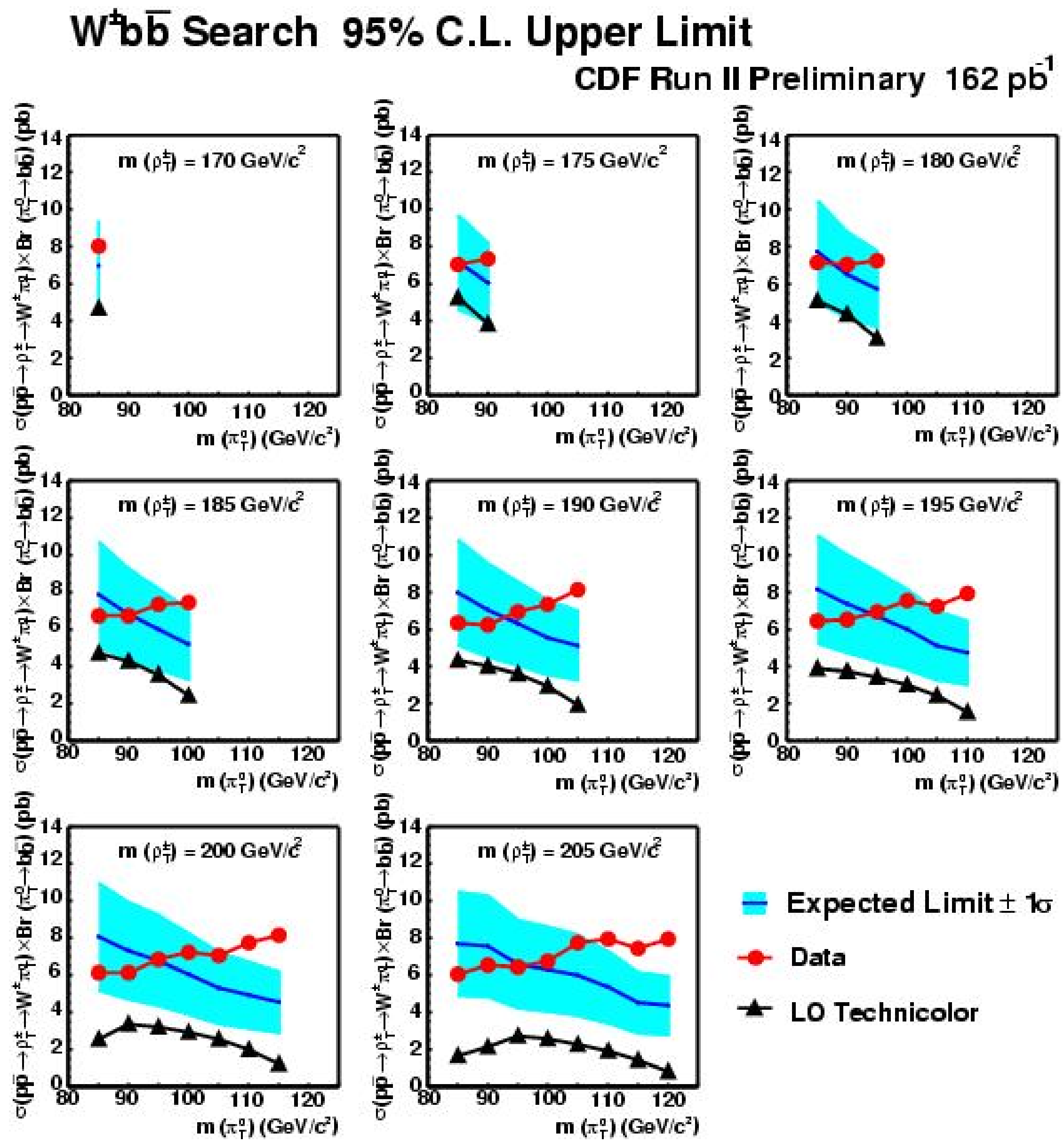


top
Background

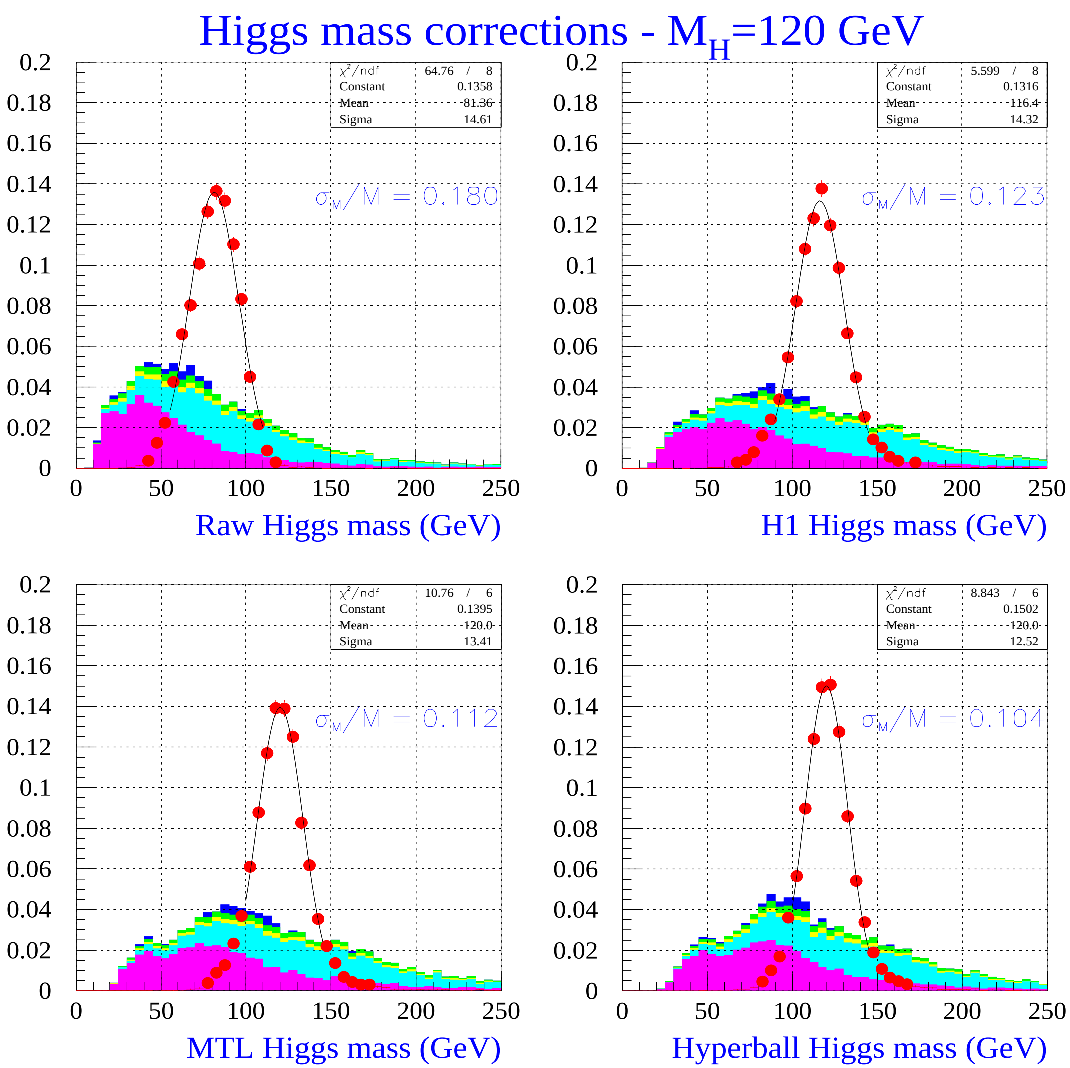


Limits on W-technipion Associated Production For Various Technirho Masses





Roadmap For Higher Sensitivity

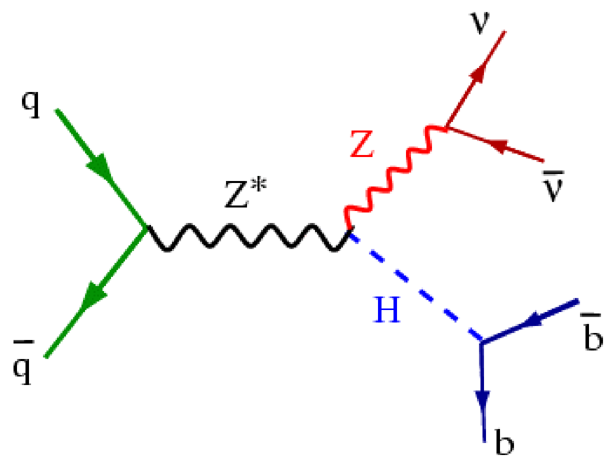


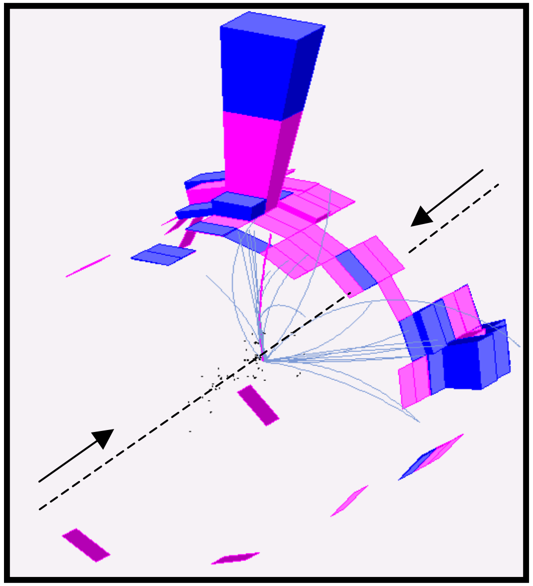
- Improve dijet mass resolution
  - Jet cone size of 1.0
  - Associate tracks+ Clusters
  - B-specific adjustments
  - Advanced techniques
- Understand Backgrounds
  - More control samples
- Improve b-tag acceptance (forward b-tagging still in progress)
- Add more data (in progress)

$Z^0 H^0 \rightarrow \nu\bar{\nu}b\bar{b}$ Search

- Analysis is still blind -- working on backgrounds in control regions

- Select events with
  - two jets
  - at least 1 b-tag
  - Missing E_T>40 GeV





Signal MC Event

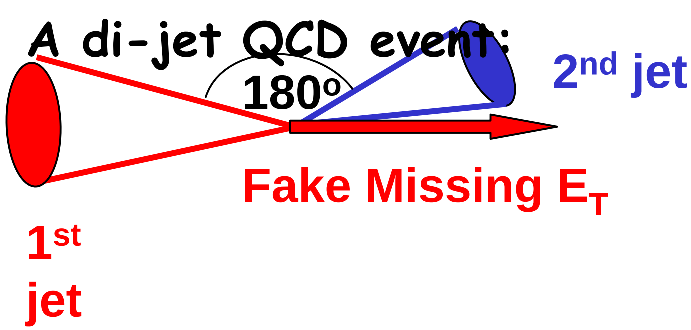
Significant Backgrounds:

QCD (b-bbar+fake missing E_t)

Zbb

ZZ (possibly irreducible)

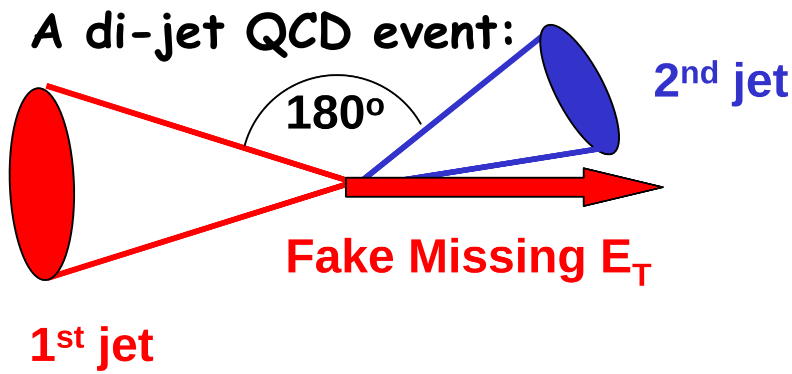
top



Background control regions:

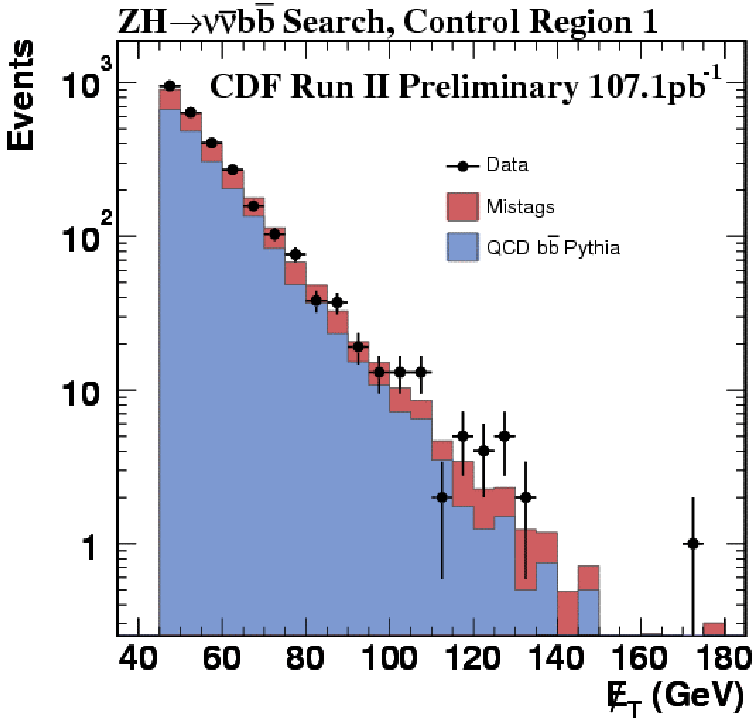
1) Small ΔΦ between Missing E_T and Jet 2 (selects QCD events)
2) Events with an energetic, isolated lepton (has Top, Electroweak backgrounds)

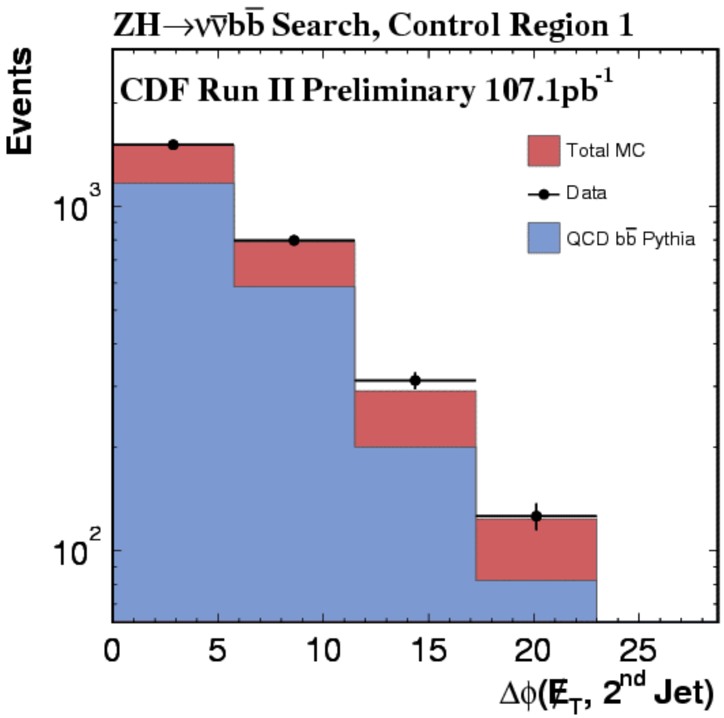
Check Pythia's QCD Modeling in Events where Missing E_T Is Close to a Jet



Mistags estimated from data.

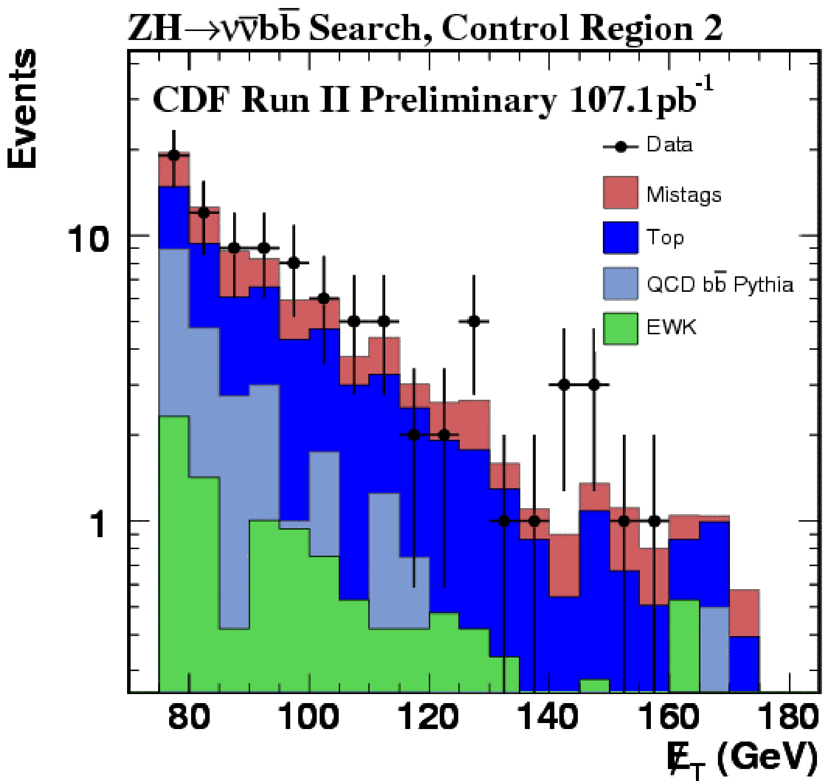
Only shapes compared-- Total prediction scaled to the data

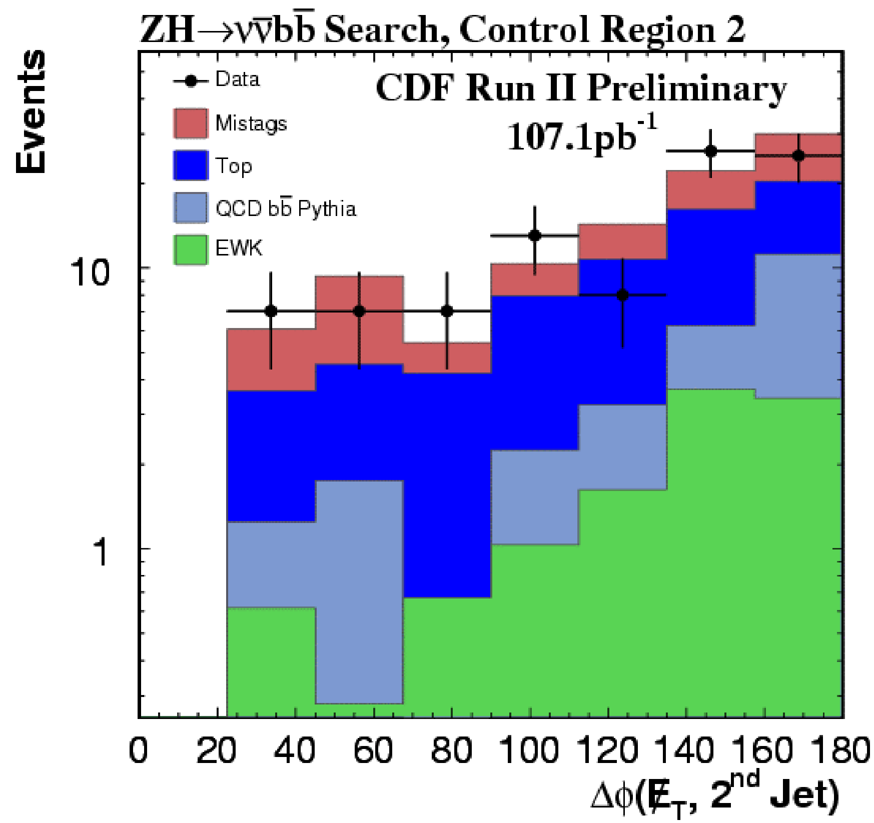




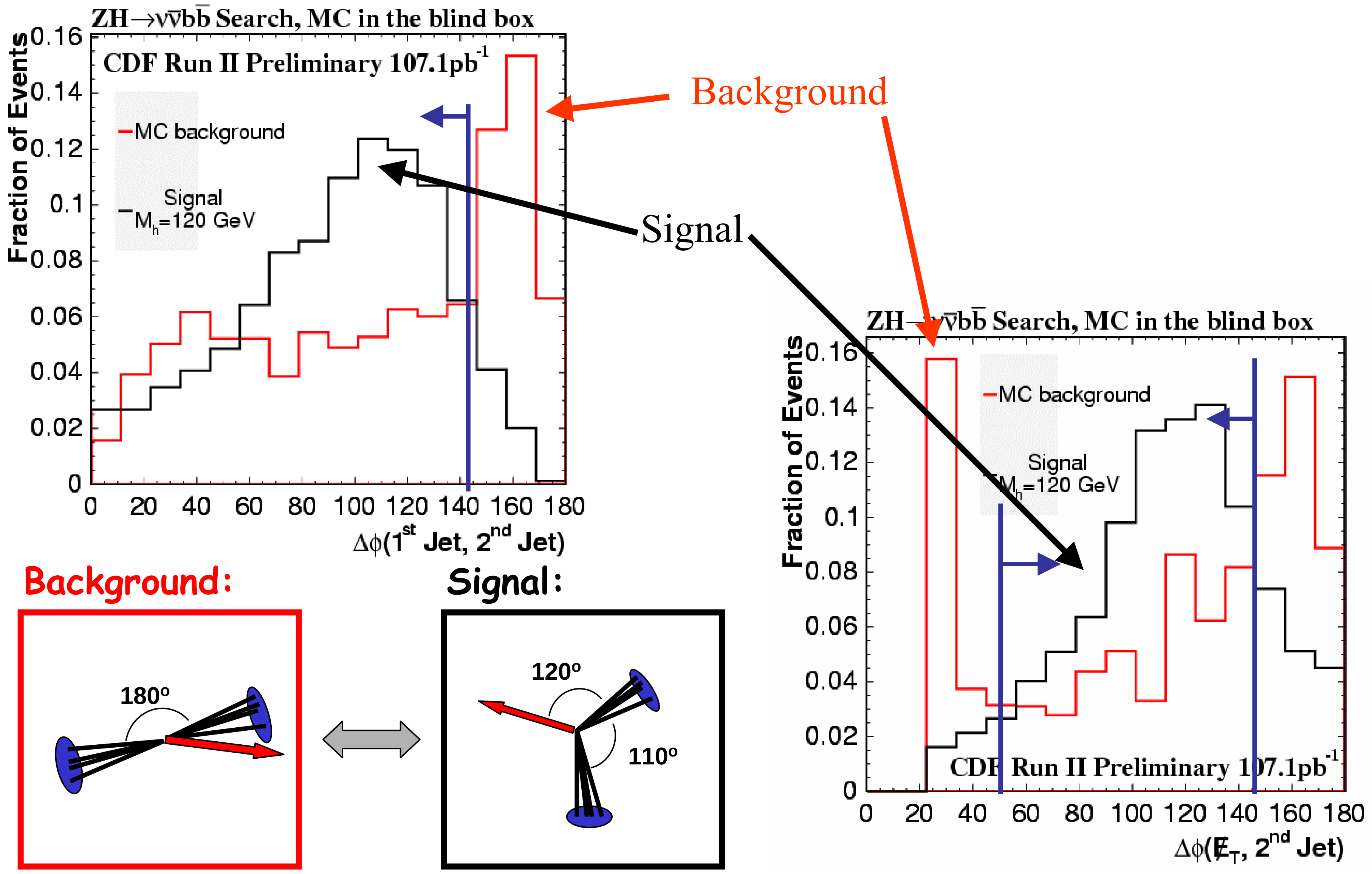
Checking Top and Electroweak Backgrounds in Events with a Lepton

Some QCD present in this sample too -- normalization confirmed.





$Z^0 H^0 \rightarrow \nu\bar{\nu}b\bar{b}$ Selection Cut Optimizations



Extrapolating CDF's Run I νvbb Performance

- Run I analysis (single tag) -- best of

  The Higgssgrahlung chanels

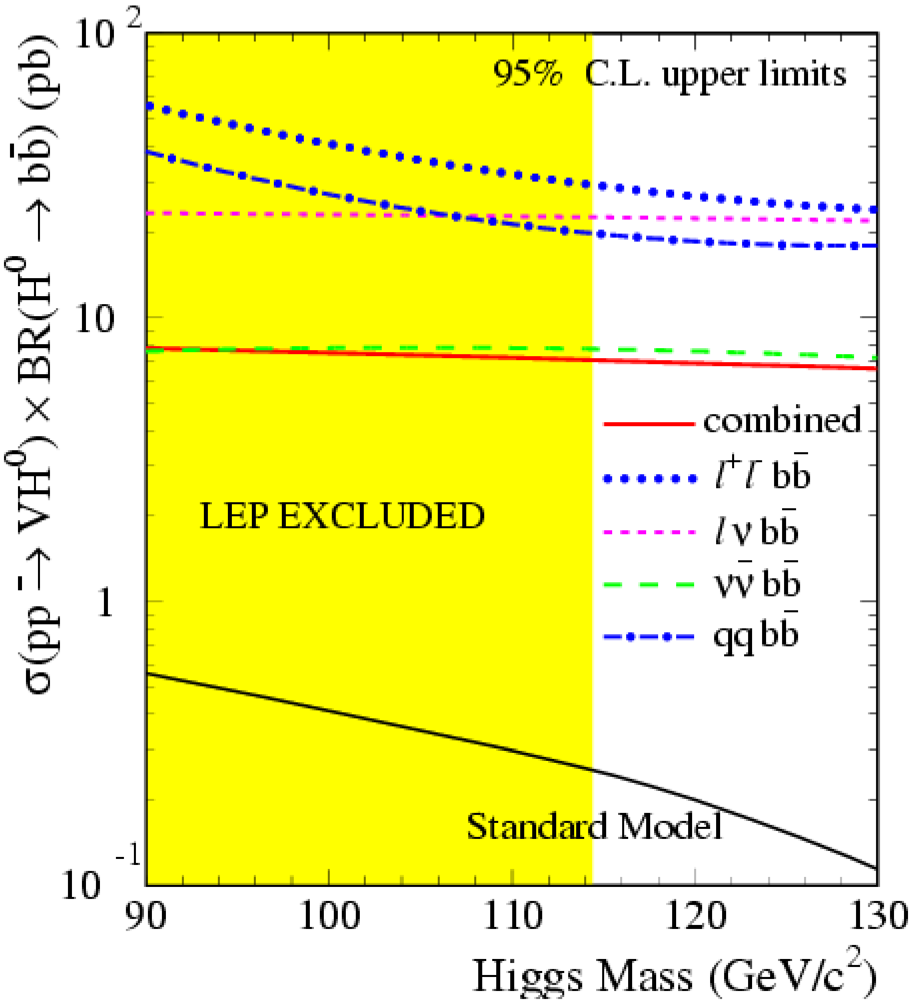
  - Used 88 pb^{-1} luminosity
  - Observed: 40 events
  - Expected: 39 ± 4 events
  - 95% C.L. on $\sigma_{ZH} * Br$: 8.0 pb

- Run II Expectations based on Run I's

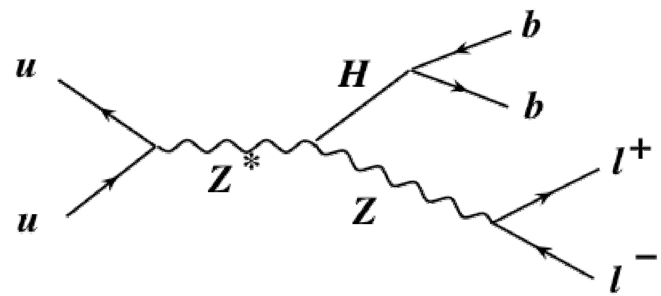
  ννbb analysis

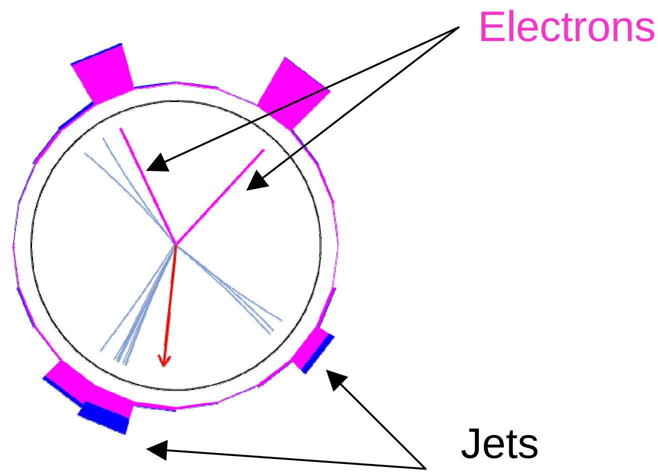
  - For 350 pb^{-1} data
  - $\sigma_{ZH} * Br < \sim 4.3$ pb

Dijet mass resolution ideas apply to this channel too!



Getting Started with $Z^0 H^0 \to \ell^+ \ell^- b\bar{b}$

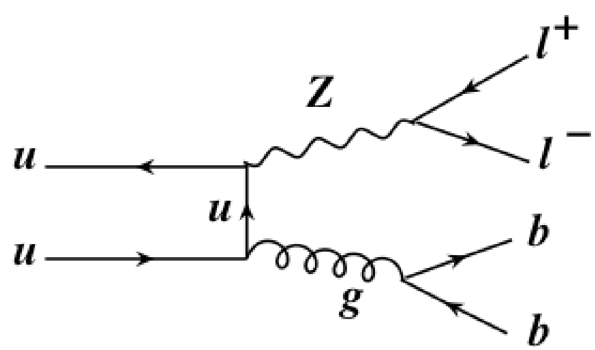




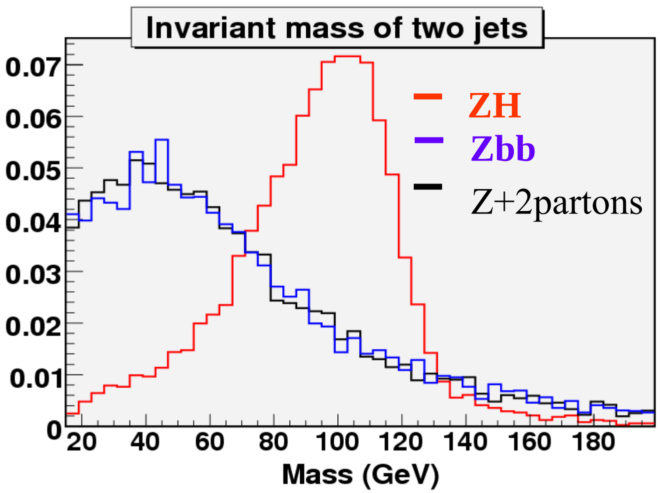
- Selection:
  - $Z^0 \to e^+e^-$ or $\mu^+\mu^-$
  - 2 or 3 jets, at least one b-tag
  - Low Missing E_T

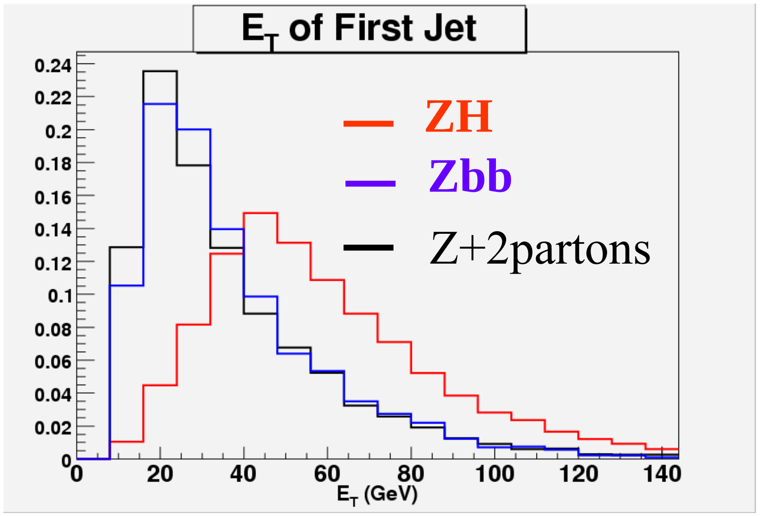
Most of Background: Z^0bb
(Zcc and Zc and Z+LF also there)

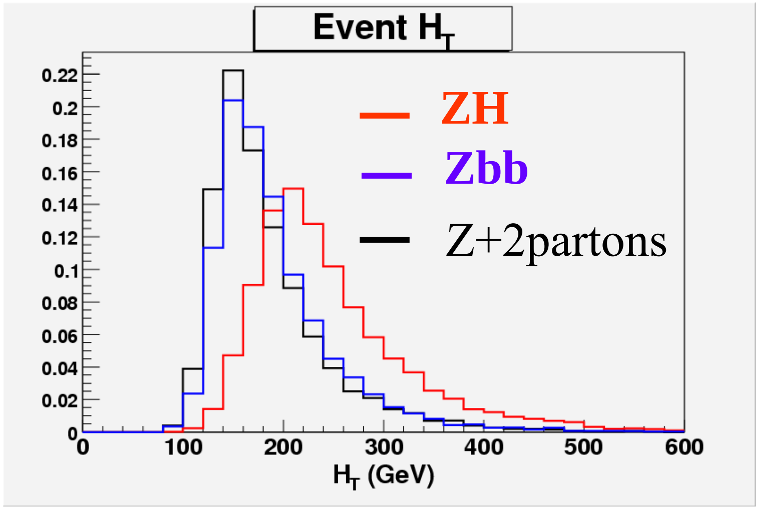
Background: 3 events/100 pb^{-1}
Signal: 0.03 events/100 pb^{-1}

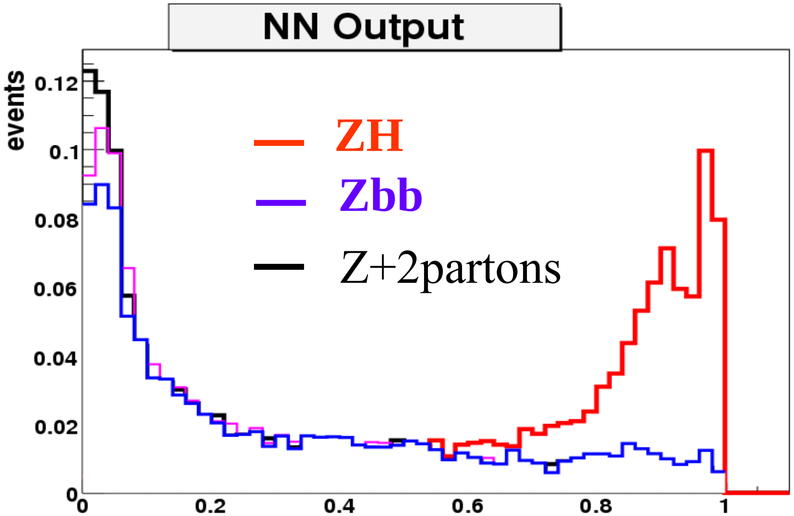


Additional Discrimination Power in the $Z^0 H^0 \rightarrow \ell^+ \ell^- b\bar{b}$ Channel

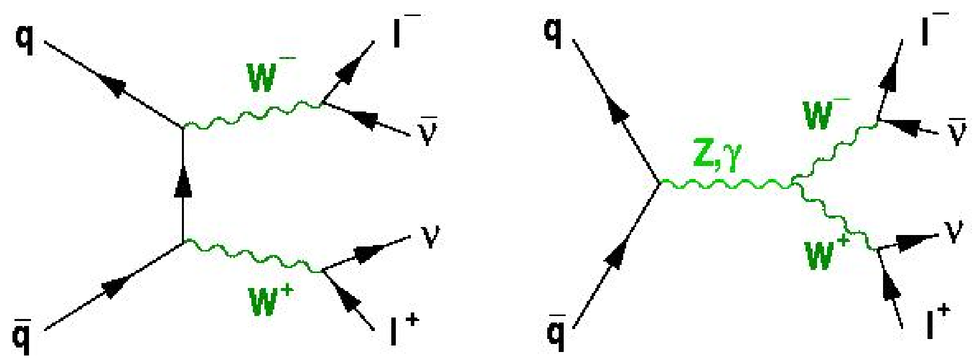






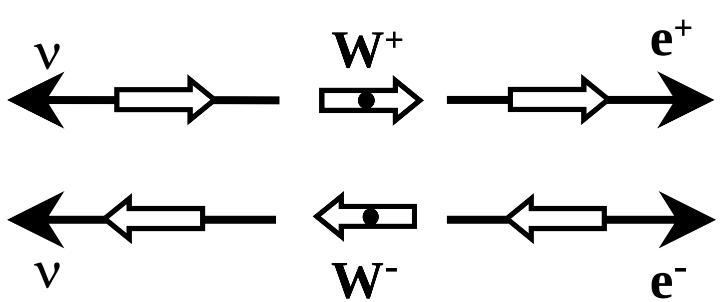


The $gg \to H \to W^+W^-$ Channel



Main Background:
SM W^+W^- production:
Same final state.

Interference is not too much due to narrow Higgs width and zero spin

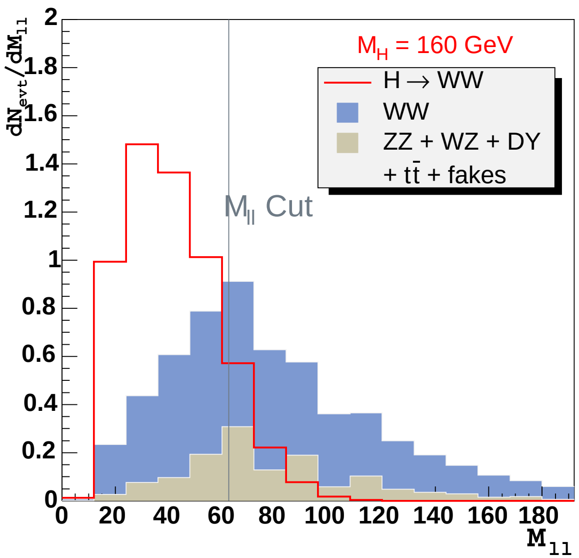


Leptons are emitted together preferentially in Higgs events.

The $gg \to H \to W^+W^-$ Channel Selection

- Two leptons, Each with E_T>20 GeV
- Jet Veto to remove t-tbar
- Missing E_T>25 GeV
- Z veto
- $m_{ll}<m_H/2$ -- note: background depends on test mass
- Acceptance is ~0.4% [including $Br^2(W\to l\nu)$] for m_H>160 GeV

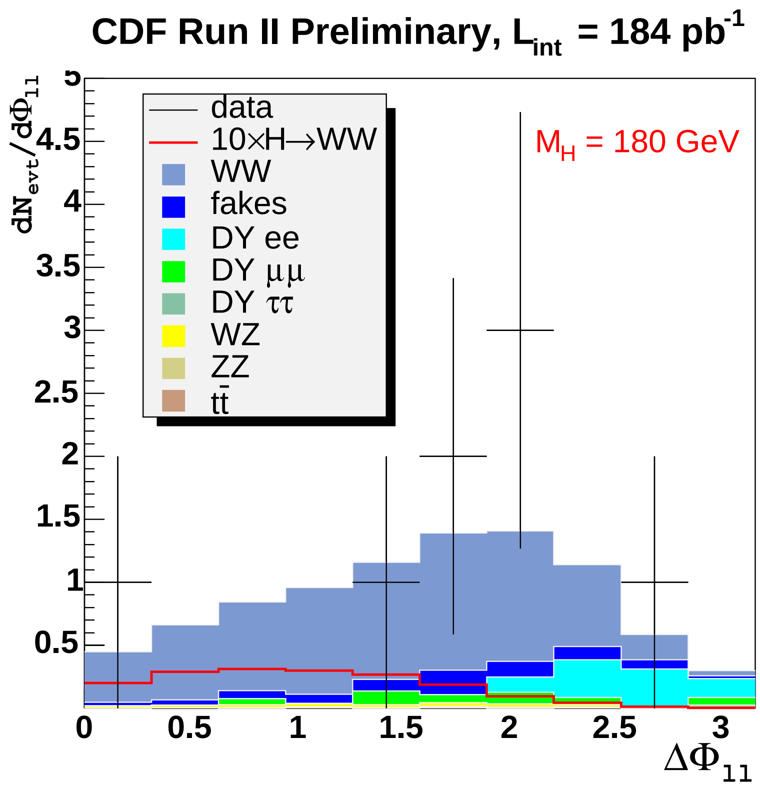
$$m_H = 180\ \mathrm{GeV},\quad \int \mathcal{L}dt = 184\ \mathrm{pb}^{-1}$$

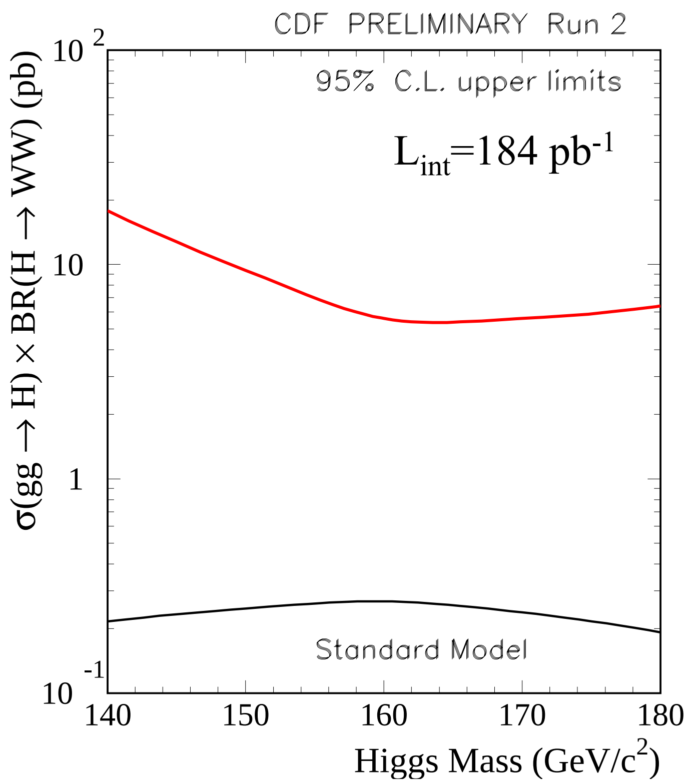


Category	Events
WW	6.49 ± 0.76
Drell-Yan+WZ+ZZ+top	1.59 ± 0.48
Misid'd Leptons	0.81 ± 0.25
Total BG	8.90 ± 0.98
$H\to W^+W^-$	0.17 ± 0.02
Observed	8

$gg \to H \to W^+W^-$ Dilepton Angle and Limits

Likelihood calculation performed on all bins of $\Delta\Phi_{ll}$





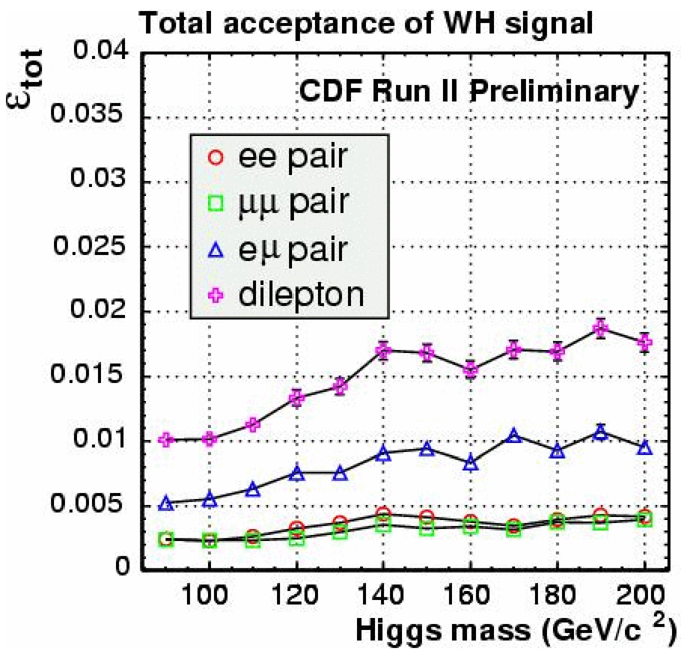
Analysis being upgraded to include more data and optimize cuts for Higgs search.

Search For $W^{\pm}H^0 \rightarrow W^{\pm}W^{+}W^{-}$

- Like-sign dilepton selection (“1”=more energetic lepton, “2”=less energetic)

  - $p_{T,1}$>20 GeV, $p_{T,2}$>6 GeV
  - reject conversions, cosmics, Z→leptons

  - Signal region: $p_{T,2}$>16 GeV, $p_{T,12} = |\vec{p}_{T,1} + \vec{p}_{T,2}| > 35$ GeV
    for m_H<160 GeV. Harden $p_{T,2}$ cut to 18 GeV for m_H>160 GeV



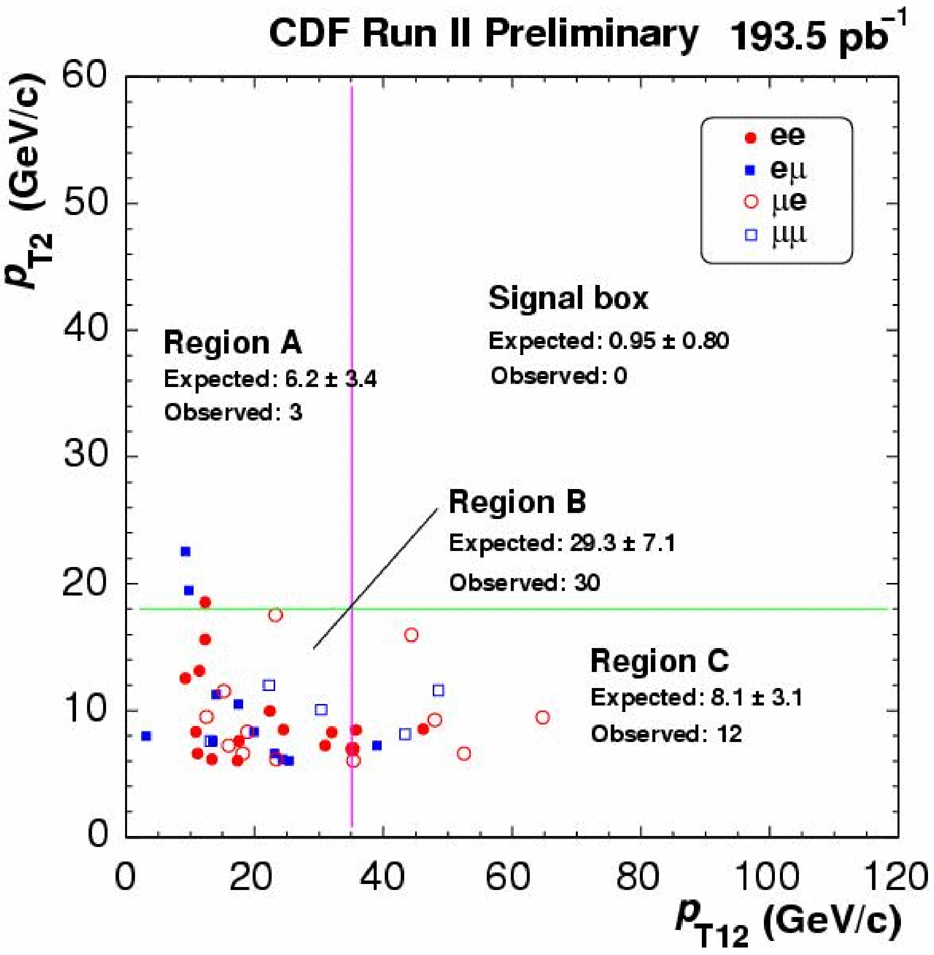
Acceptance includes W branching fractions

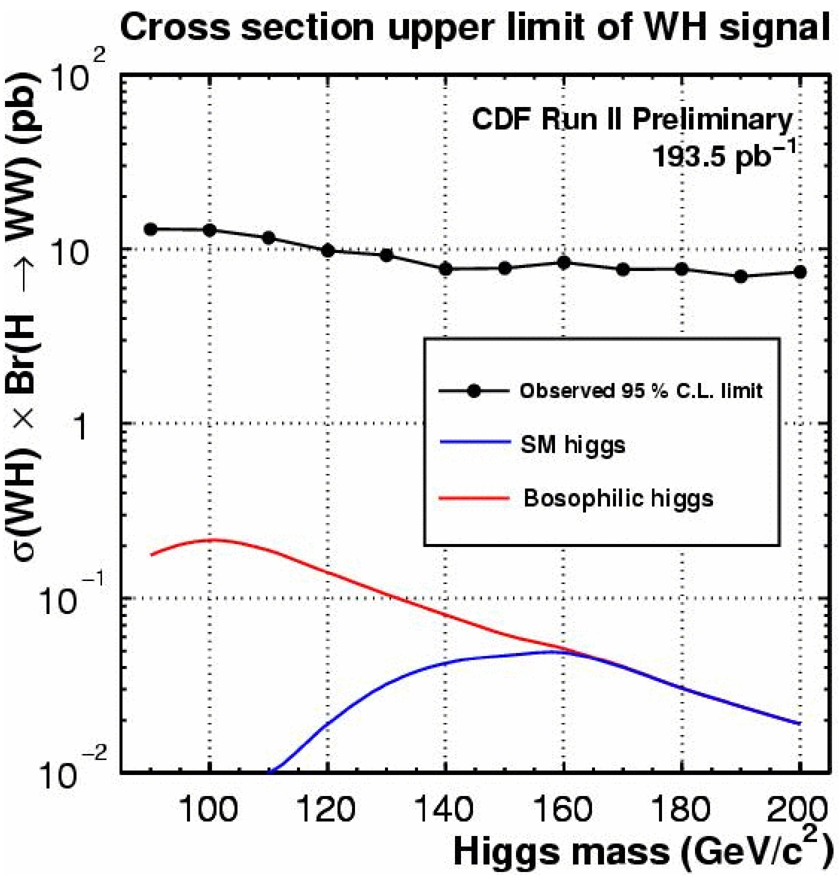
Category	Events in 193.5 pb^{-1}
Conversions	0.61 ± 0.61
Fake Leptons	0.12 ± 0.01
Other sources*	0.22 ± 0.10
Total background	0.95 ± 0.64
Data	0

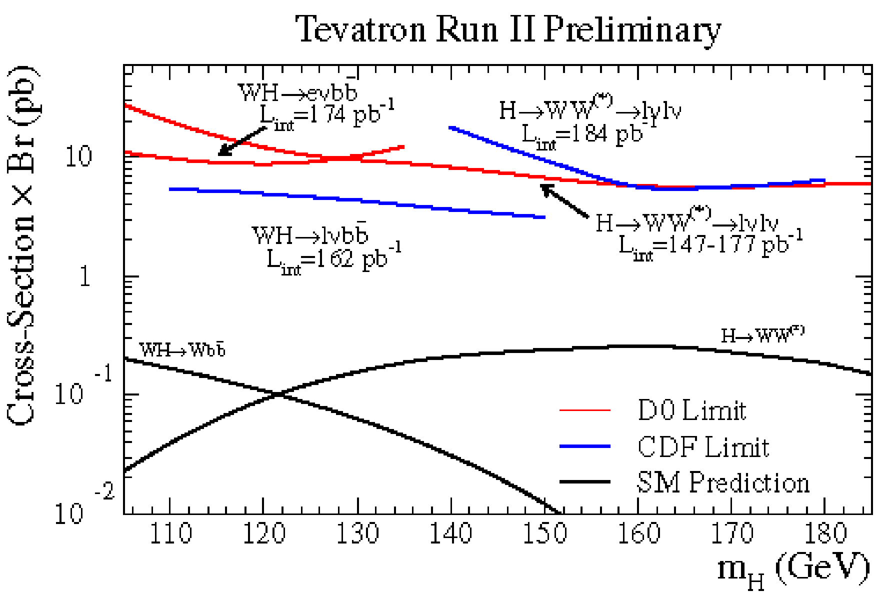
*Other backgrounds: Diboson, top, Wqq

SM WH signal: 0.03 events (m_H=160 GeV)

$W^{\pm}H^0 \to W^{\pm}W^{+}W^{-}$ Data and Limits







We Are Here

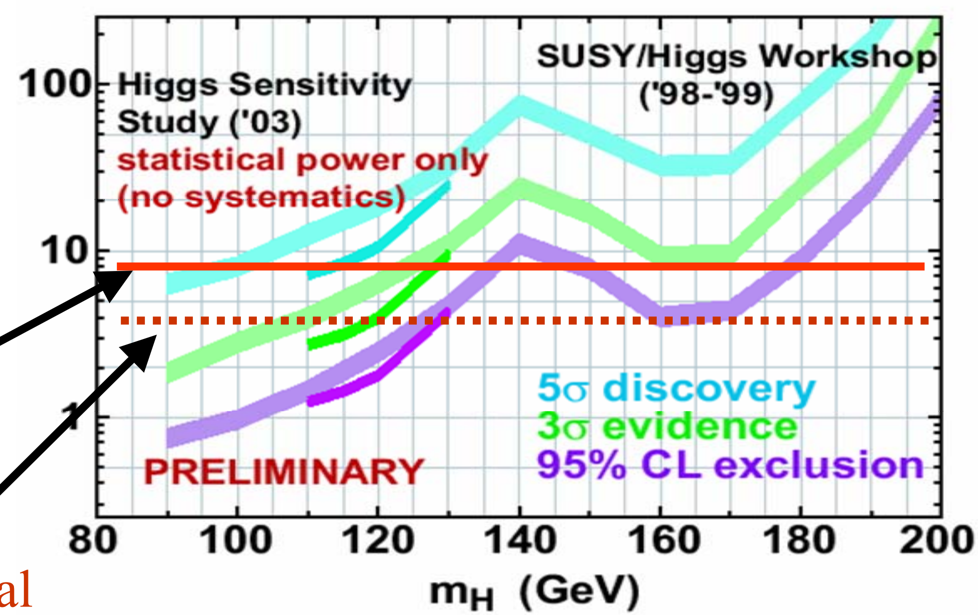
- Updated analyses with 300 pb^{-1} targeting summer conferences in progress.
- SUSY Higgs searches also active -- new tau result imminent.

We have the tools to get here!

"Design" Lumi Goal

"Base" Lumi Goal

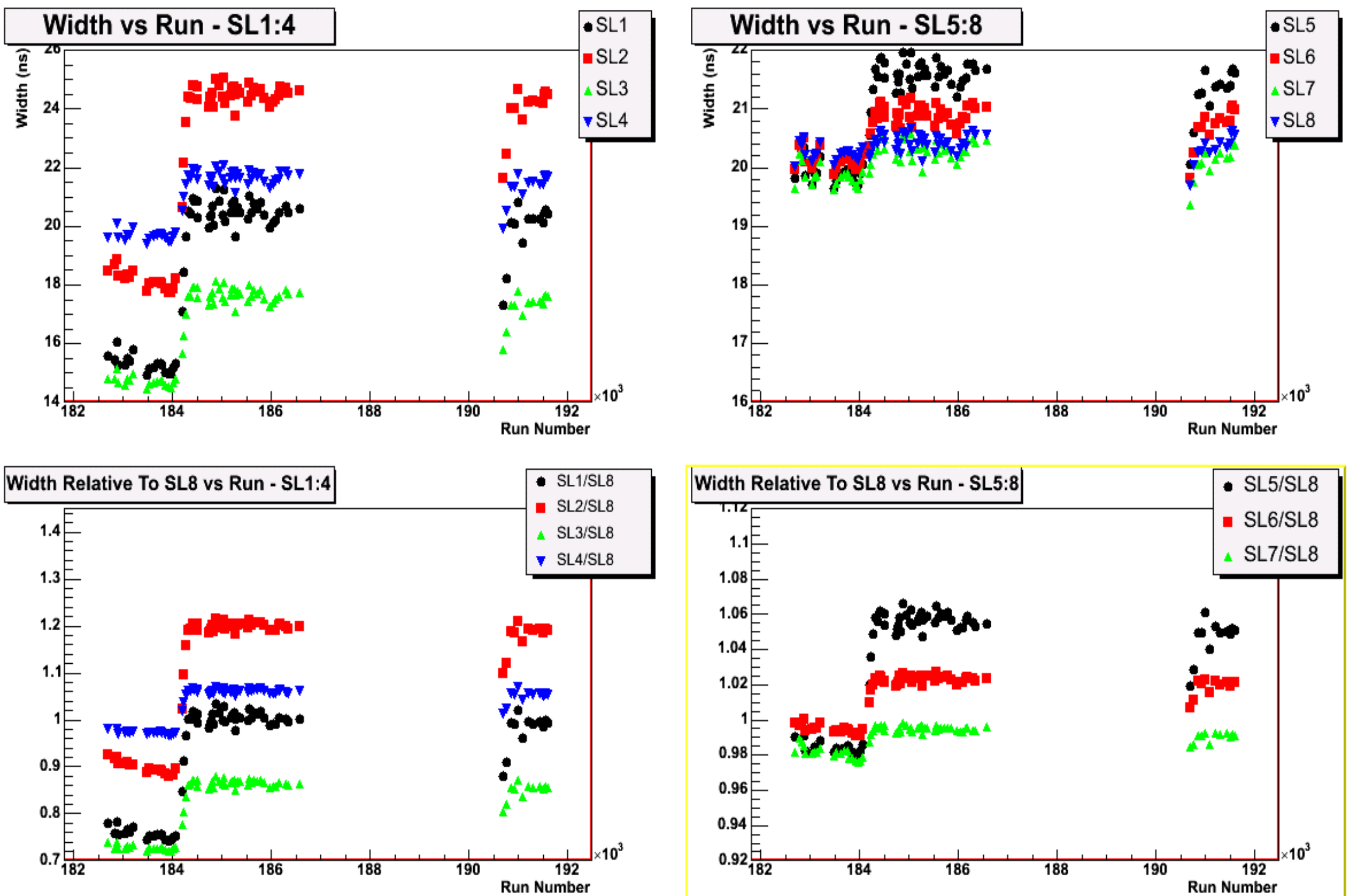
3σ evidence possible over significant preferred range of m_H



Fermilab-PUB-03/320-E

Backup Slides

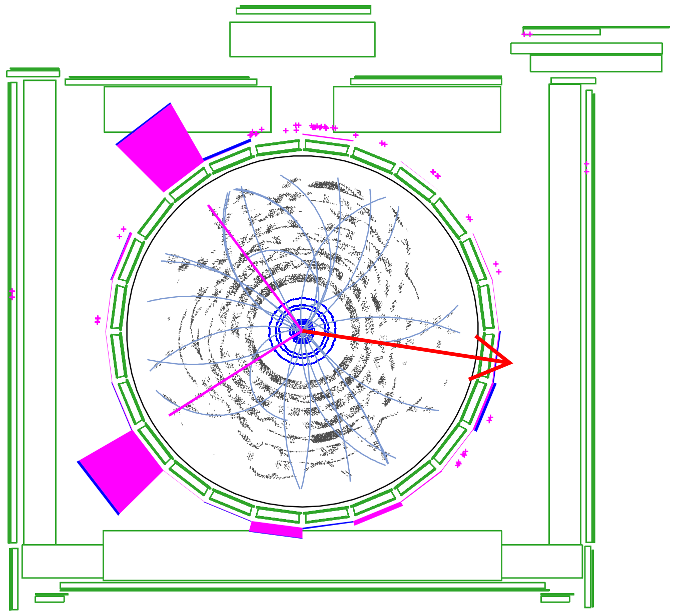
COT Performance in 2005 -- Aging Controlled



The $gg \to H \to W^+W^-$ Channel

Higgs mass (GeV)	140	150	160	170	180
cross-section(gg --> h^0) (pb)	0.45	0.36	0.30	0.25	0.21
branching ratio(H --> WW)	0.48	0.68	0.90	0.97	0.94
integrated luminosity (pb^{-1})	184 +/- 11	184 +/- 11	184 +/- 11	184 +/- 11	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
candidate data (event)	2	2	3	7	8
95% CL limit - counting (pb)	18.4	9.8	6.2	8.2	8.8
expected limit - delta phi (pb)	18.1	9.8	6.0	7.4	8.0
95% CL limit - delta phi (pb)	17.8	9.4	5.6	5.6	6.4

WW→eeνν candidate

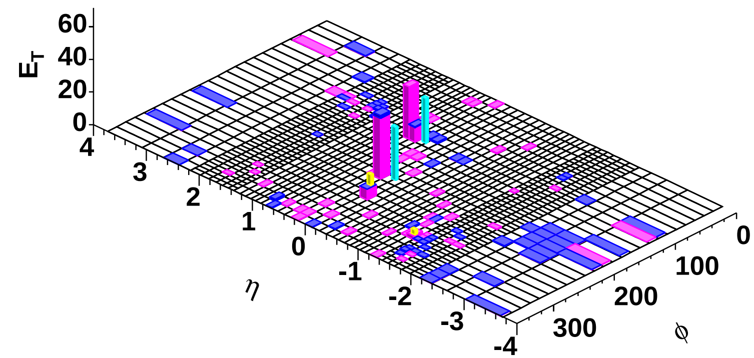


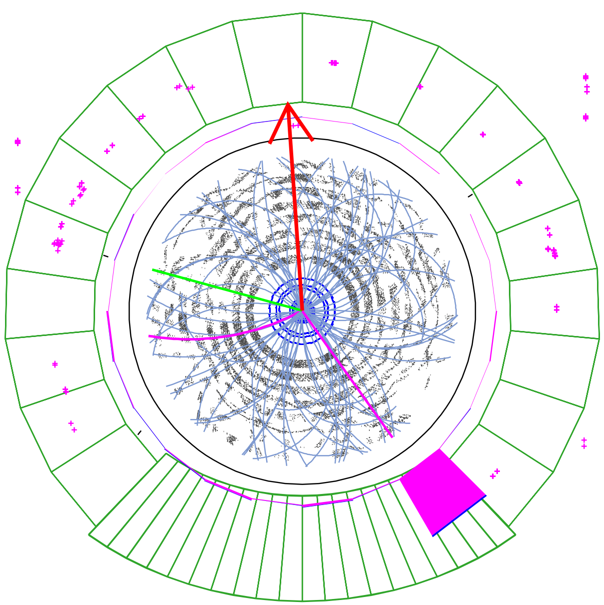
Run 162838 Event 627050 : $WW \to e^+\nu_e e^-\bar{\nu}_e$ **Candidate**

$p_T(e^+) = 48.0$ GeV/c; $p_T(e^-) = 38.2$ GeV/c; $M_{e^+e^-} = 61.4$ GeV

$\not{E}_T = 61.4$ GeV; $\Phi(\not{E}_T) = 6.1$

$\Delta\Phi(\not{E}_T, \text{lepton}) = 2.4$; $\Delta\Phi(e^+, e^-) = 1.5$;   Opening-Angle$(e^+, e^-)$=1.5



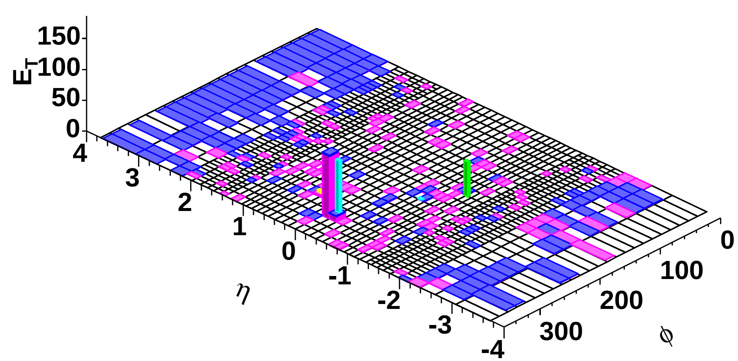


Run 162175 Event 1550545 : $WW \to e^+\nu_e \mu^-\bar{\nu}_\mu$ **Candidate**

$p_T(e) = 112.7$ GeV/c; $p_T(\mu) = 57.0$ GeV/c; $M_{e\mu} = 165.6$ GeV

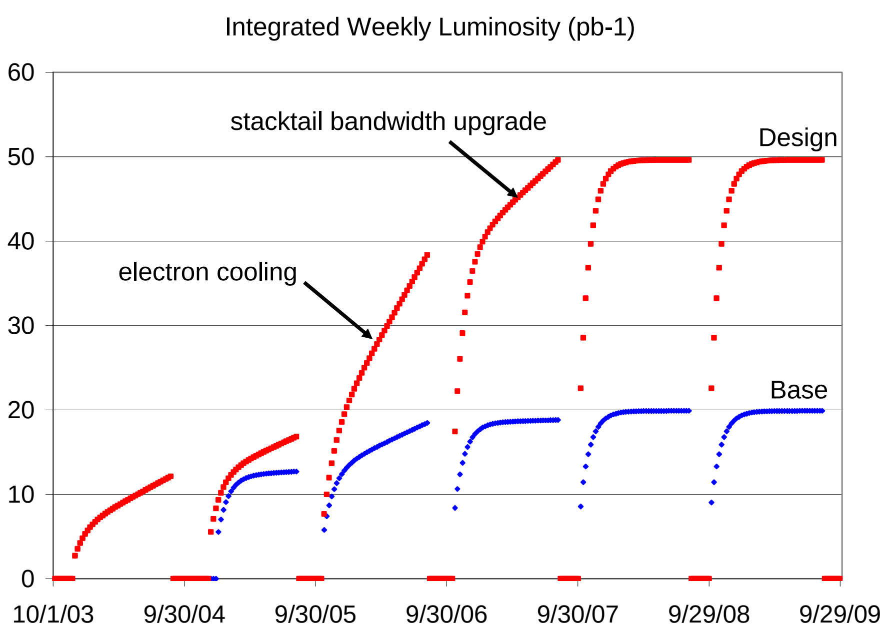
$\not{E}_T = 86.8$ GeV; $\Phi(\not{E}_T) = 1.6$

$\Delta\Phi(\not{E}_T, \text{lepton}) = 1.2$; $\Delta\Phi(e, \mu) = 2.4$;   Opening-Angle(e^+, e^-)=1.9

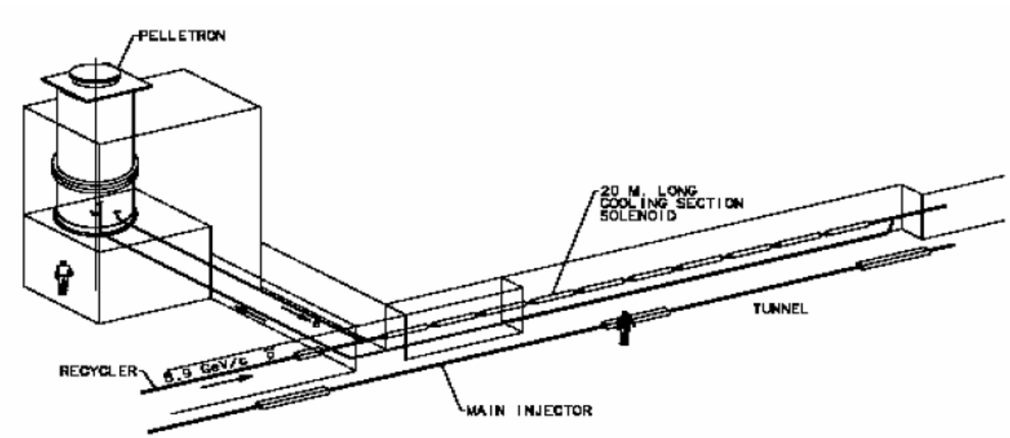


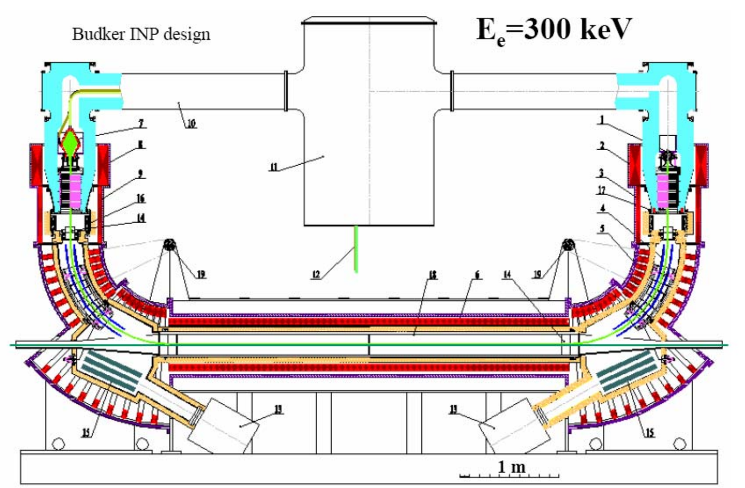
WW→eμνν candidate

Projections with Electron Cooling of Antiprotons in Main Injector



On schedule to cool antiprotons in September 2005



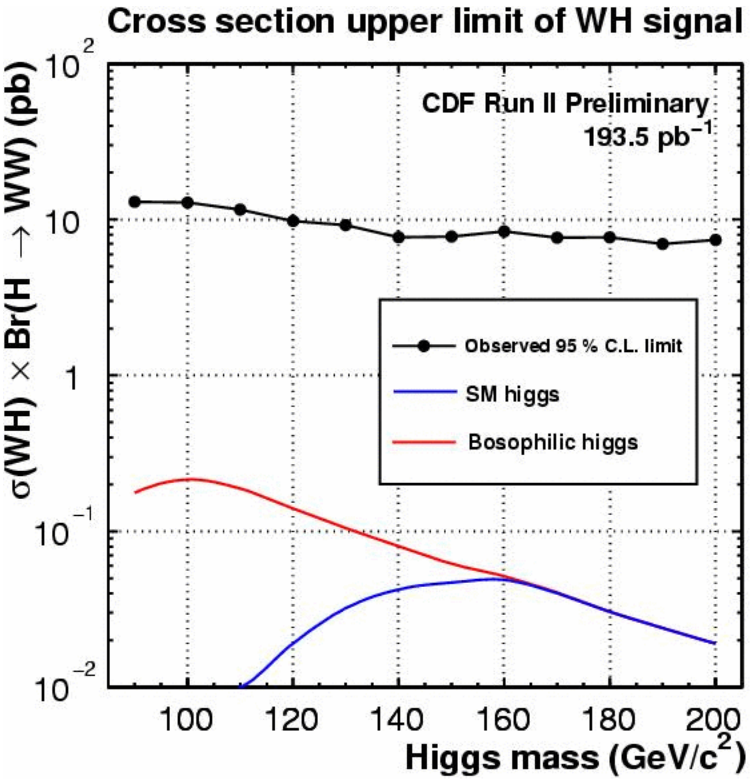


· electron gun; 2- main "gun solenoid"; 4 - electrostatic deflectors;
- toroidal solenoid; 6 - main solenoid; 7 - collector; 8 - collector solenoid; 11 - main HV rectifier; 12 - collector cooling system.

Like-Sign Dilepton Search is also Sensitive to $Z^0 H^0 \rightarrow Z^0 W^+ W^-$

(in spite of Z^0 veto -- second lepton can be lost)

For comparison -- Just WH



W or Z+WW