Neutral Higgs Boson Search at Tevatron

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ICHEP04, Beijing, August 16 2004

- Introduction
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- Recent Run2 Results
  - SM or SM-like Higgs Searches (12-0381(CDF), 12-0382(CDF), 12-0574(D0))
  - MSSM Higgs Searches (12-0378(CDF), 12-0379(CDF), 12-0612(D0))
  - Other Higgs Searches (12-0381(CDF), 12-0608(D0))
- Future Prospects
- Conclusions

Introduction

- Standard Model is an effective theory of particle physics up to the electroweak scale.

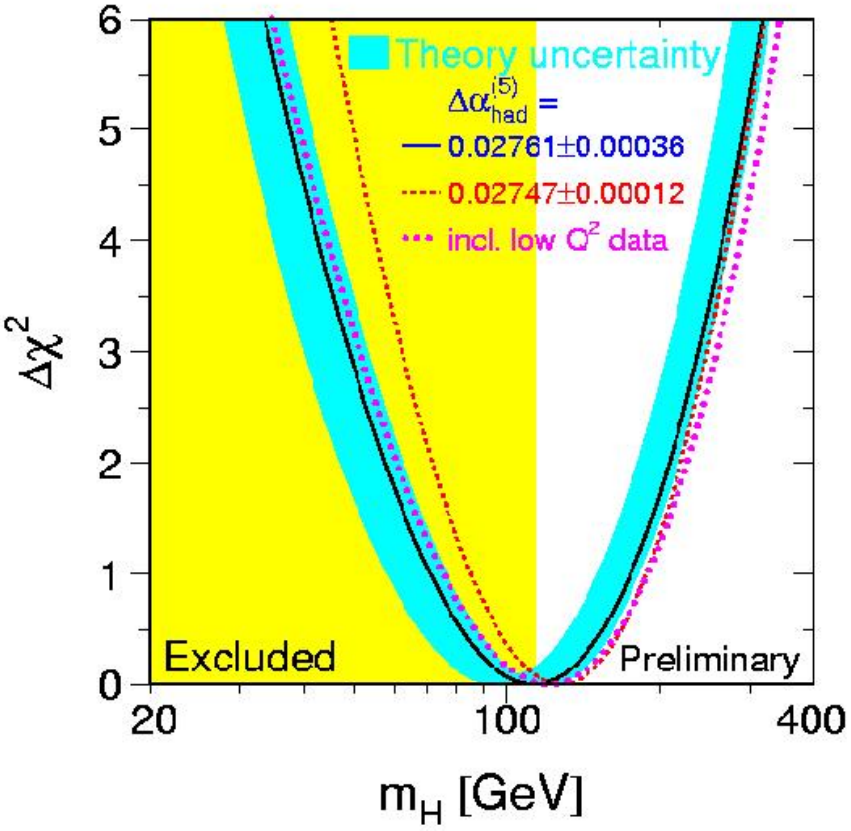
- Precision tests of electroweak theory show no signs of deviation, with extraordinary accuracy.

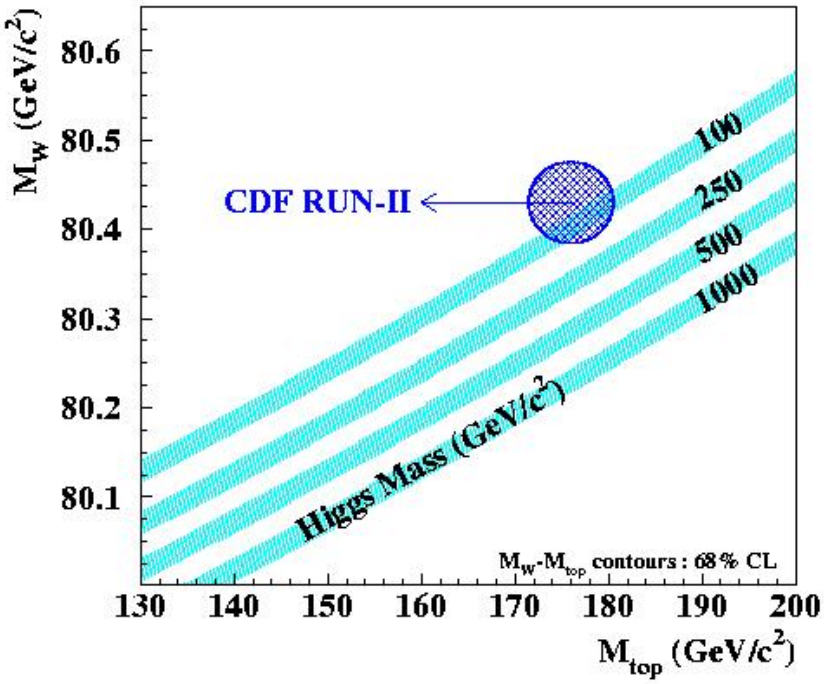
- SM predicts the existence of Higgs boson and requires "new physics" to stabilize the Higgs mass (the hierarchy problem).

- Possible source of new physics
  - SUSY and its variants
  - Extra dimensions
  - Little Higgs ($m_h \approx m_t$, t' and other Higgs at TeV scale)
  - Higgsless ...

- Need experimental inputs for the future direction !

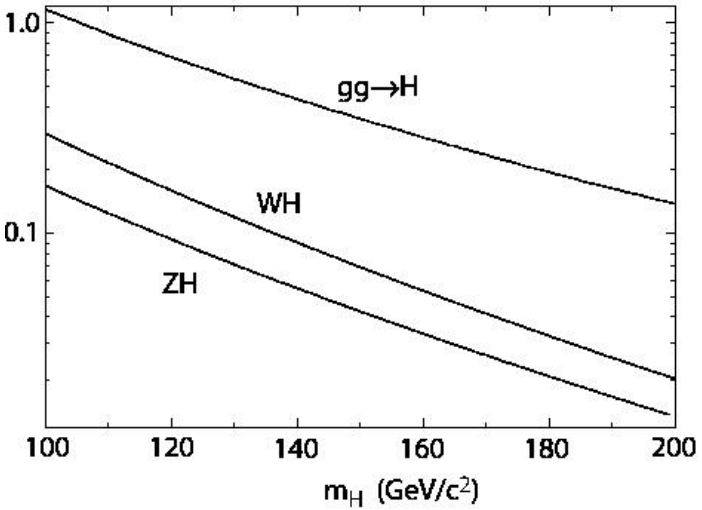
Higgs Mass Limit



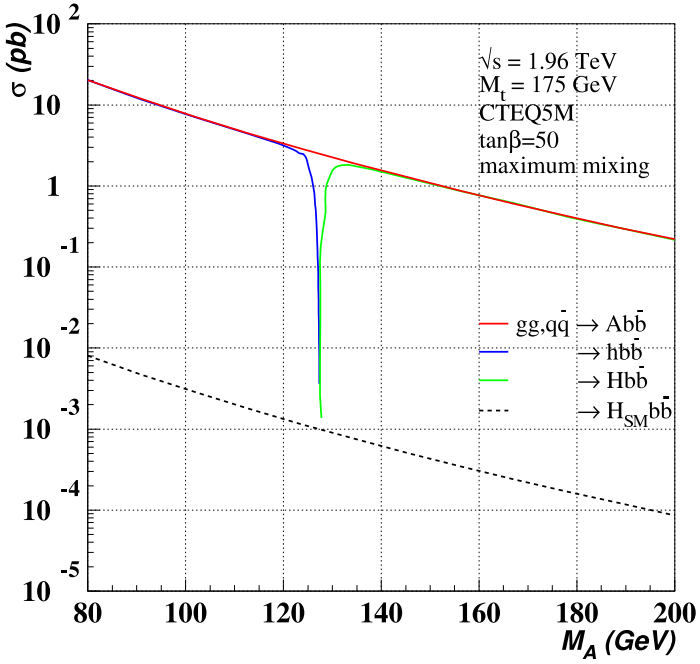


- Global fit to electroweak data with latest $M_{top} = 178.0 \pm 4.3$ GeV/c^2
- Best fit of $M_h = 113^{+62}_{-42}$, or $M_h < 237$ GeV/c^2 at 95% C.L.
- LEP excludes $M_h \leq 114.4$ GeV at 95% C.L.
- Precision measurements of M_{top} and M_W at Run II will provide a stringent test of SM and the Higgs mass.

Higgs Production and Search Strategies



- $M_h < 130$ GeV: $h \to b\bar{b}$
  - Wh, Zh are most accessible, easy to trigger
  - Excellent b-tag efficiency and dijet mass resolution
- $M_h > 130$ GeV: $h \to WW^*$
  - Exploit the large $\sigma(gg \to h)$
  - Identify clean final states with leptons
- Very Challenging...

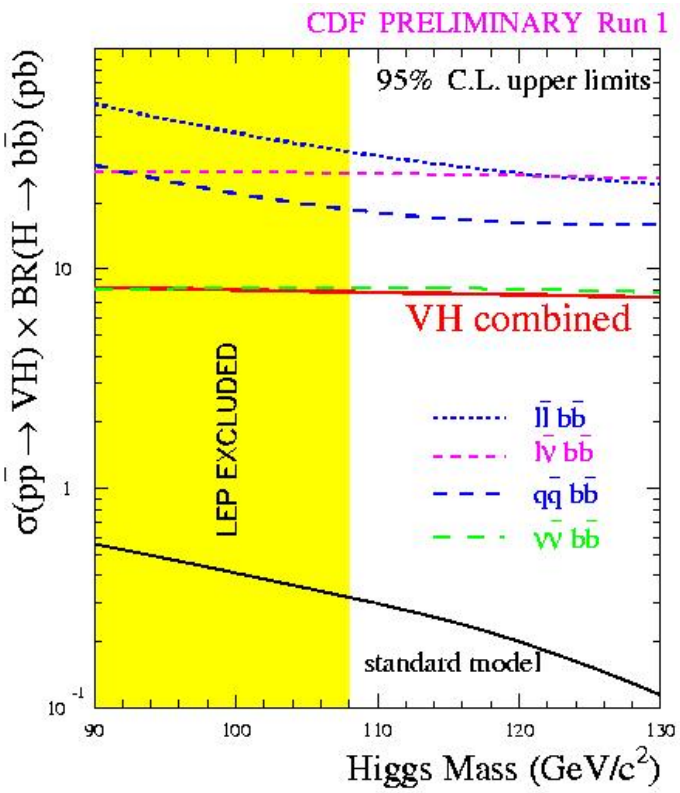


- $b\bar{b}A/b\bar{b}h/b\bar{b}H$ enhanced by $\tan\beta^2$
- Exploit $A \to b\bar{b}, \tau\tau$ with excellent btagging and τ ID.
- Need much less luminosity for discovery compared to SM Higgs !

Higgs Search at Tevatron (Run1)

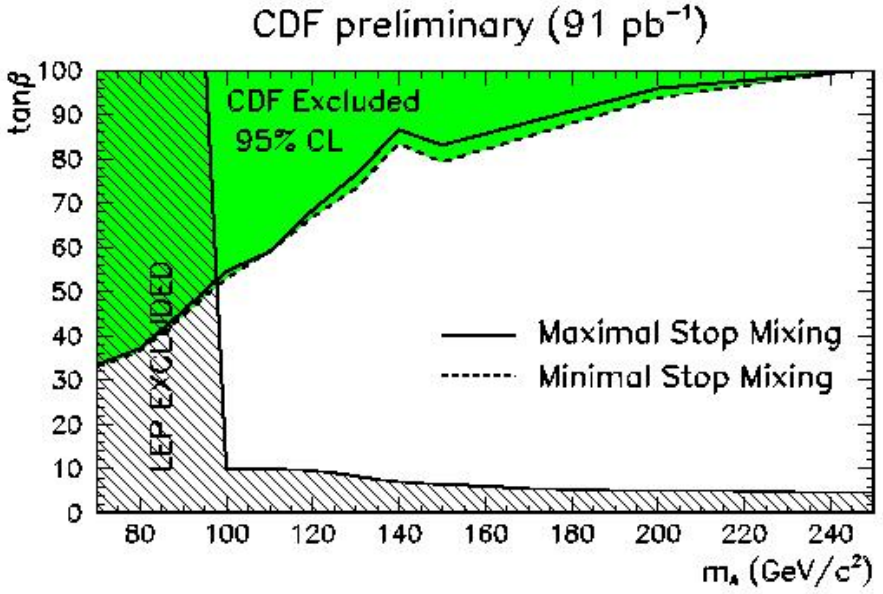
SM Higgs Search

- $Wh \rightarrow (l\nu, q\bar{q}')b\bar{b}$
- $Zh \rightarrow (l^+l^-, \nu\bar{\nu})b\bar{b}$
- set $\sigma_{Vh} \cdot B < 8$ pb at 95% CL



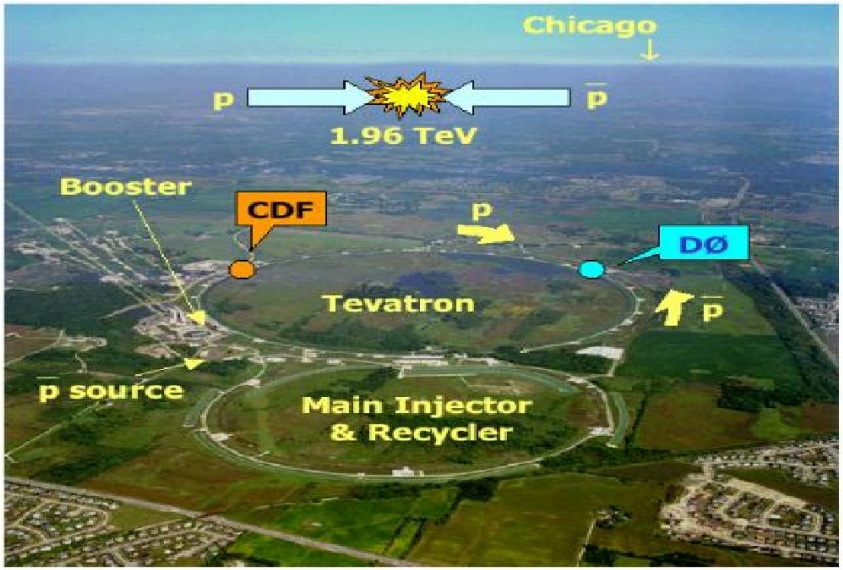
MSSM Higgs Search

- Due to enhancement of $b\bar{b}h/H/A \rightarrow b\bar{b}b\bar{b}$ xsec at large $tan\beta$
- Selecting 3 b-jets from multi-jet sample
- set $tan\beta > 50$ at 95% CL for $m_A = 100$ GeV



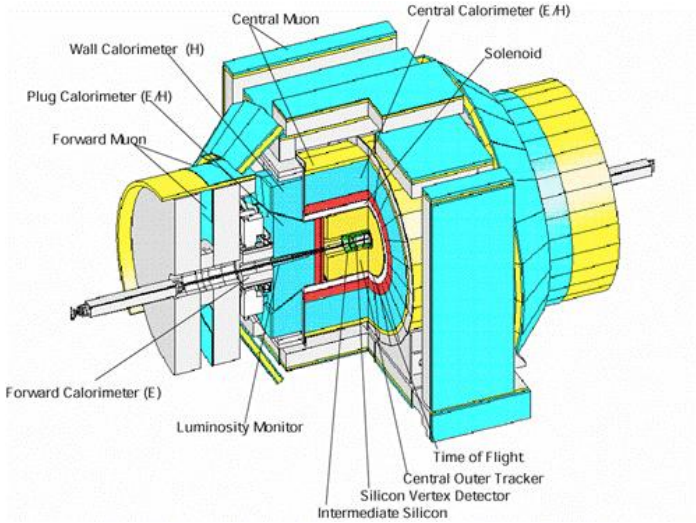
No real sensitivity yet ...

What's New at FermiLab

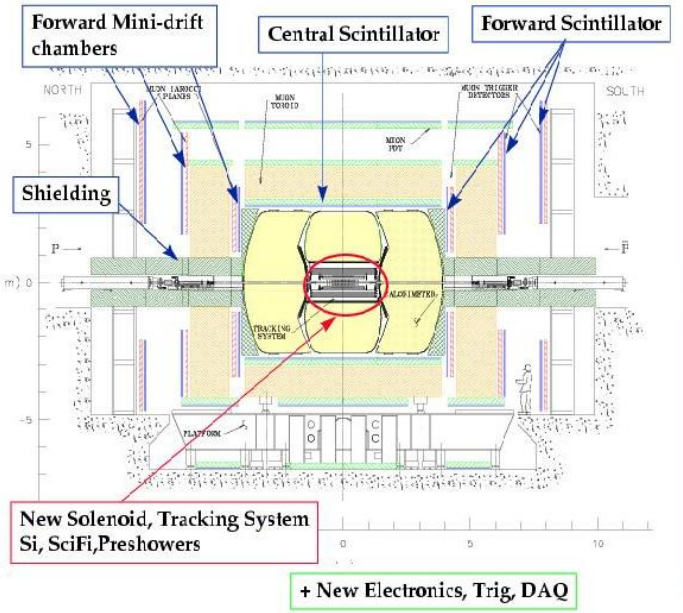


- New main injector(150 GeV proton storage ring)
- New recycler storage ring for pbar accumulation
- Higher energy collisions at 1.96 TeV (1.8 TeV)
- Increased number of p and pbar bunches from 6x6 $\longrightarrow$36x36 (396 ns beam crossing)

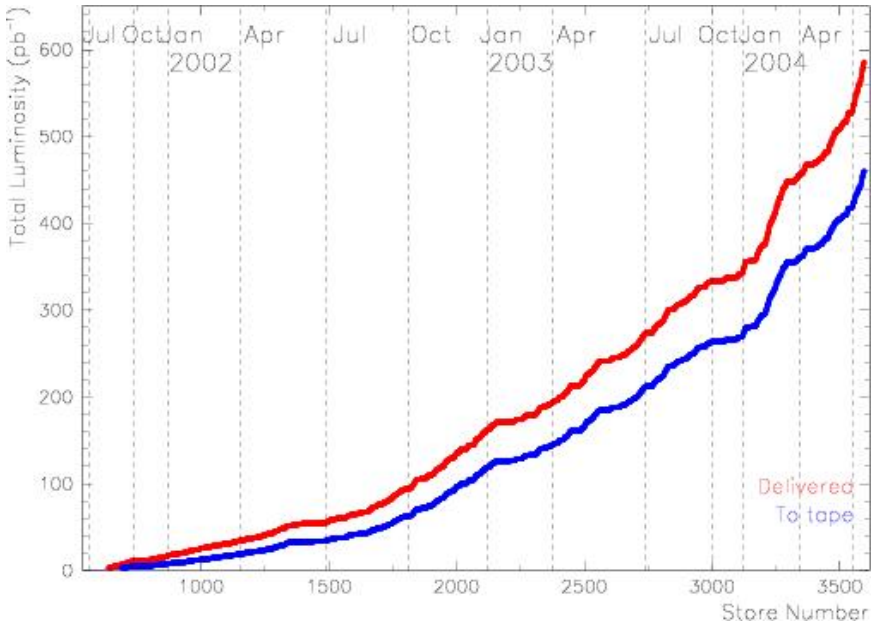
- Upgraded CDF II Detector

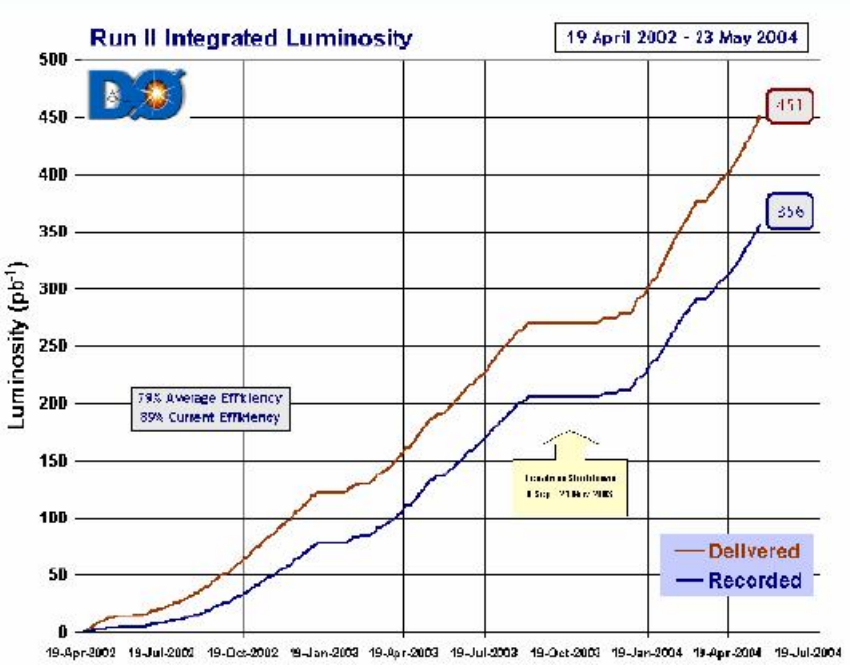


- Upgraded D0 Detector



Run2 Performance





- Tevatron are doing well. The record peak luminosity exceeded $1 \times 10^{32} cm^{-2} s^{-1}$
- CDF/D0 have recorded > 450 pb^{-1} on tape, but the results shown here mostly based on $\approx 200 pb^{-1}$, up to Sept. 2003.
- Anticipate achieving int. luminosity 1 fb^{-1} in 2005
- Total expected int luminosity 4.4-8.6 fb-1 in 2009

Recent Run2 Results

- Re-established the top signal in lepton + jets and dileptons, more importantly, the tools needed for lepton ID, btagging, Jets, and detector simulation.

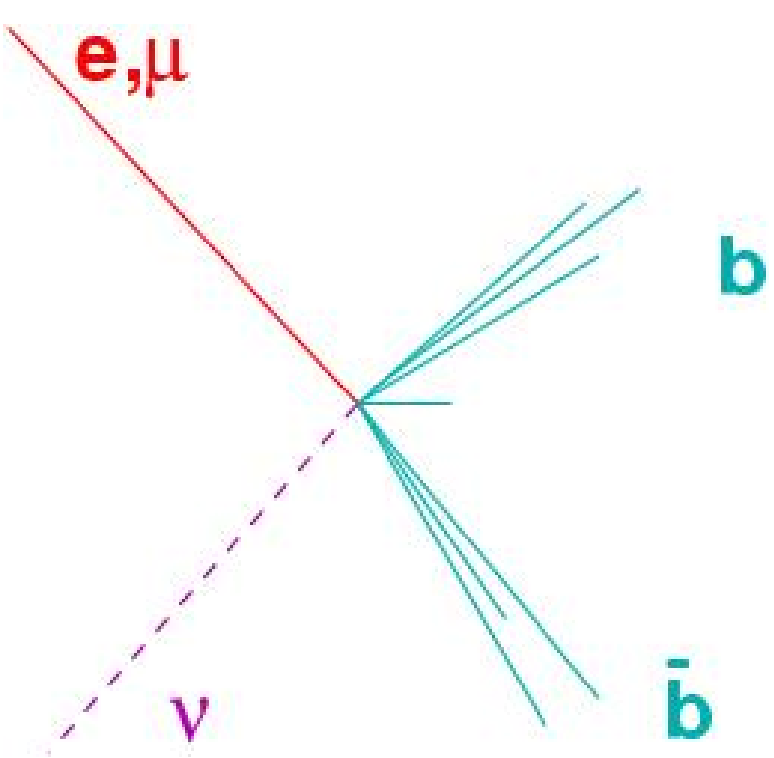
- Higgs searches still at the engineering stage, more interesting results will emerge soon.

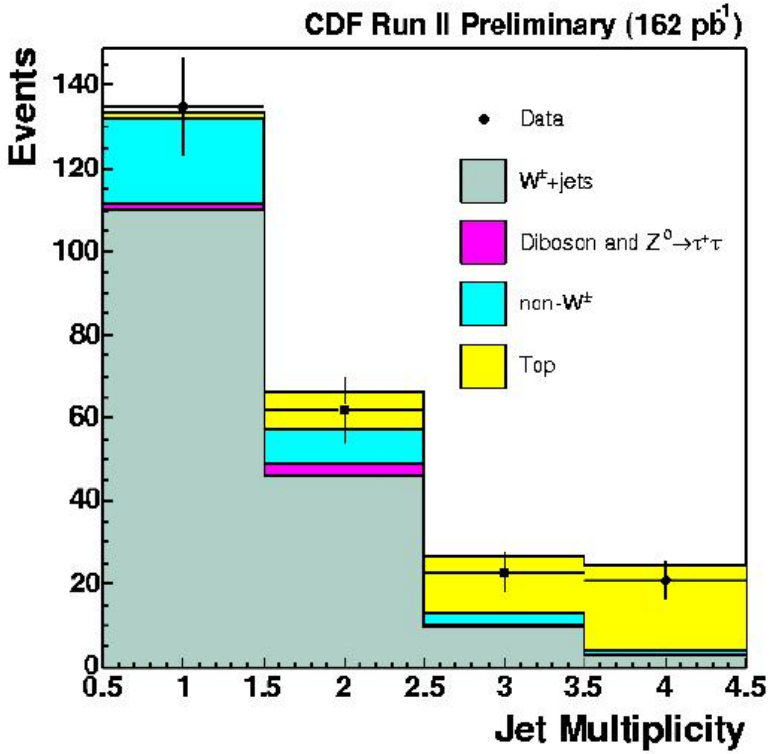
- SM or SM-like Searches – Challenging
  - $Wh \rightarrow l\nu b\bar{b}$, similar to the lepton+jets
  - $Zh \rightarrow \nu\bar{\nu}b\bar{b}$, similar to the met+jets
  - $h \rightarrow WW^*$, similar to the dilepton

- MSSM Searches – Best bet !
  - $A/H/h \rightarrow b\bar{b}, \tau\bar{\tau}$ in multi-jets

- Other Higgs Searches (Technicolor, Fermiphobic, Topcolor)
  - $p\bar{p} \rightarrow \rho_T \rightarrow W\pi_T^0 \rightarrow l\nu b\bar{b}$
  - $h \rightarrow \gamma\gamma$

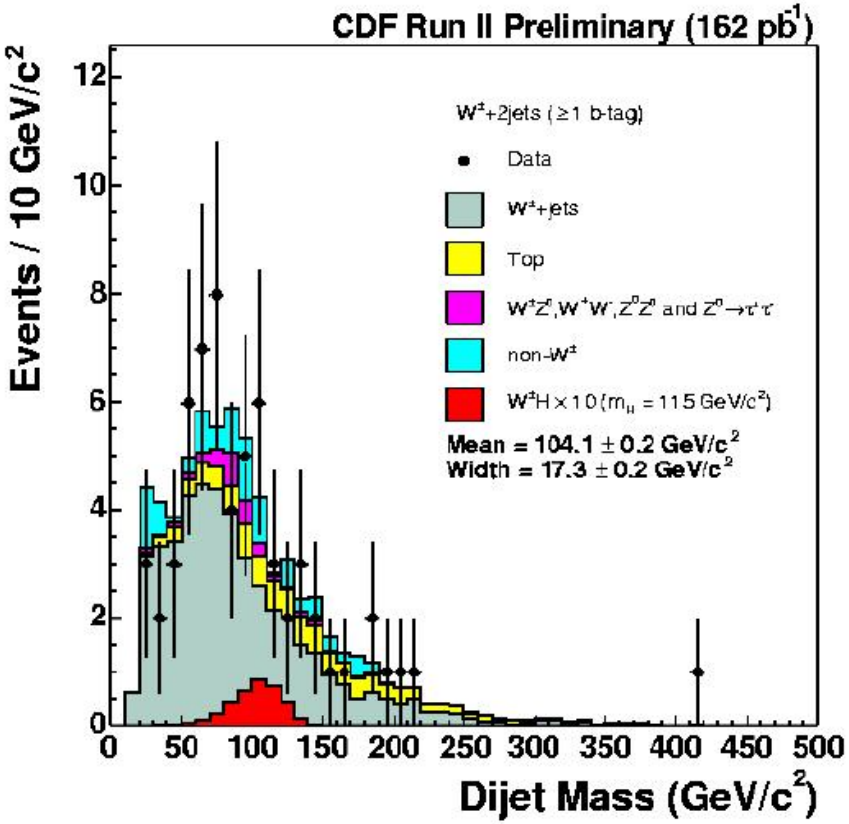
Run2 Search for $Wh \to l\nu b\bar{b}$(CDF)

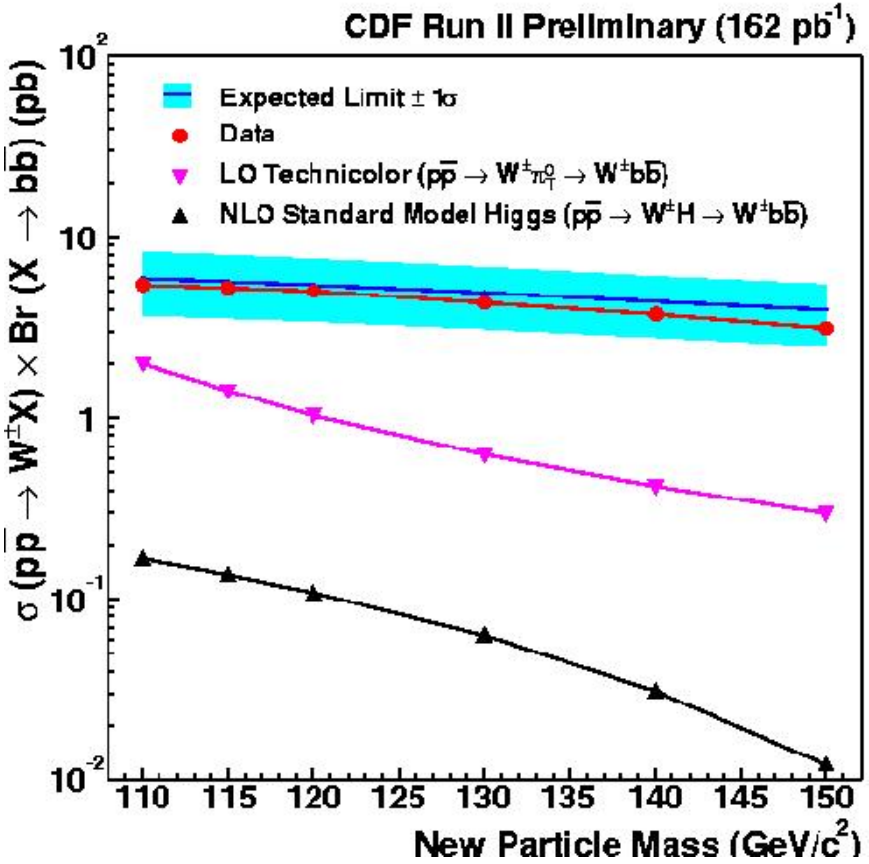




- Event Selections: $P_T(lepton) > 20$, $\not\!\!E_{\rm T} > 20$ GeV, 2jet and one b-tagged.
- Applying extra jet and isolated track veto to reduce $t\bar{t}$
- Events agree with the expectation.

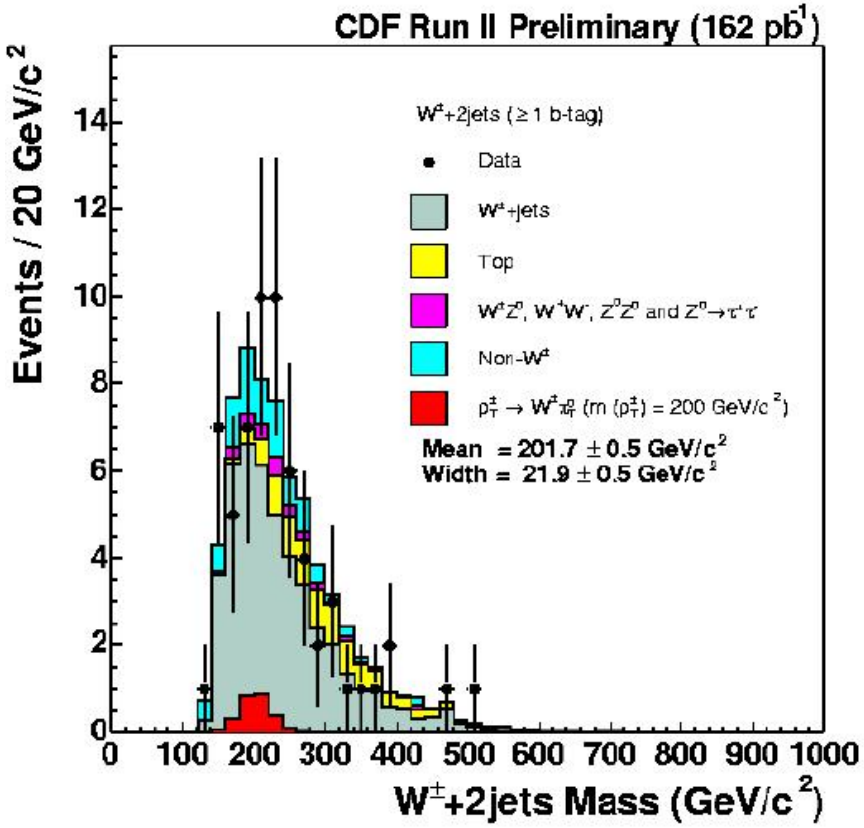
Search for $Wh \to l\nu b\bar{b}$(CDF)

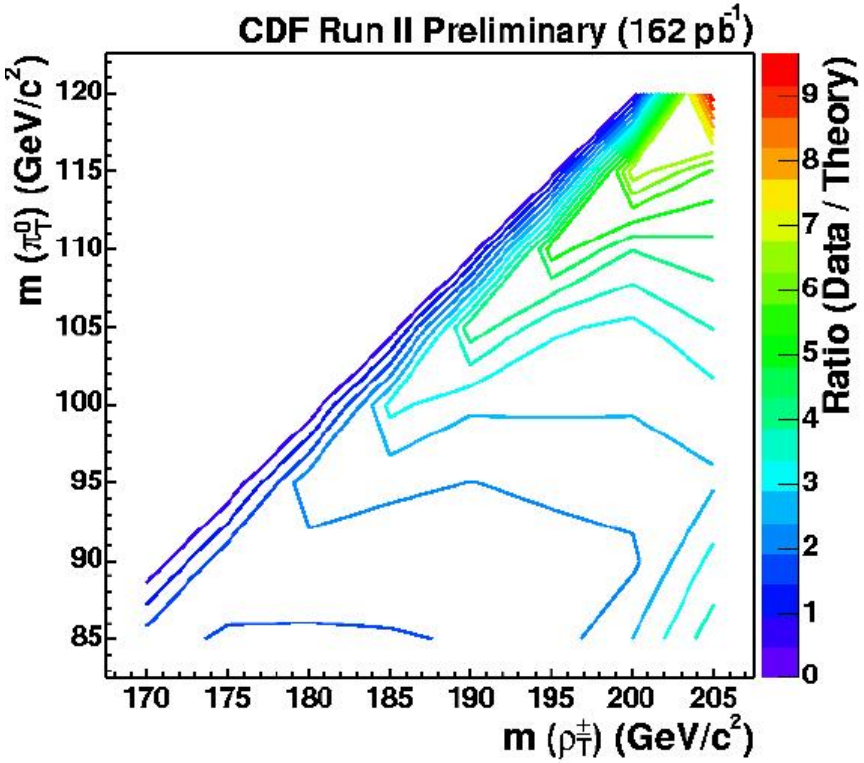




- Set a limit on $\sigma_{Wh} \times B(h \to b\bar{b})$ as a function of Higgs mass
- Not sensitive to SM higgs yet, but getting close to other new physics, such as $p\bar{p} \to \rho_T \to W\pi_T^0$ at a few pb level.

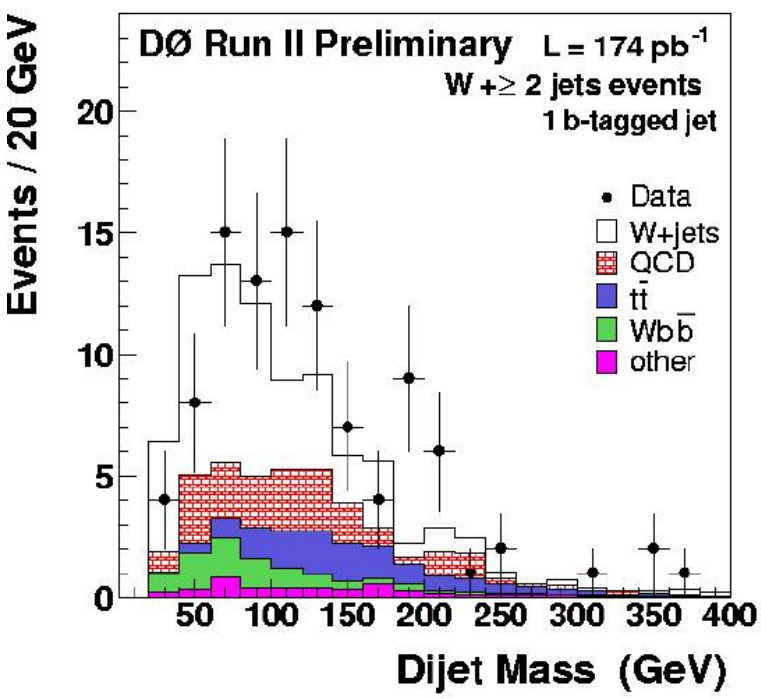
Search for $\rho_T \to W\pi_T^0 \to l\nu b\bar{b}$(CDF)

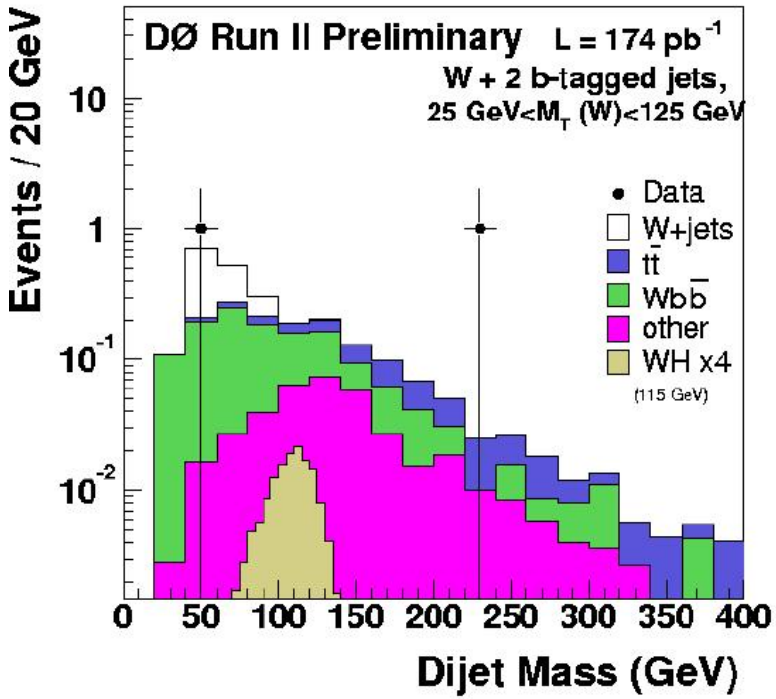




- Reconstruction of ρ_T (W + dijet) Mass by solving P_Z of neutrino with W mass constrain.
- Fitting both $m(\rho_T)$ and $m(\pi_T^0)$ invariant masses.
- No exclusion limit yet, but getting close to some of theoretical cross section for technicolor particle production.

Search for $Wh \to l\nu b\bar{b}$(D0)

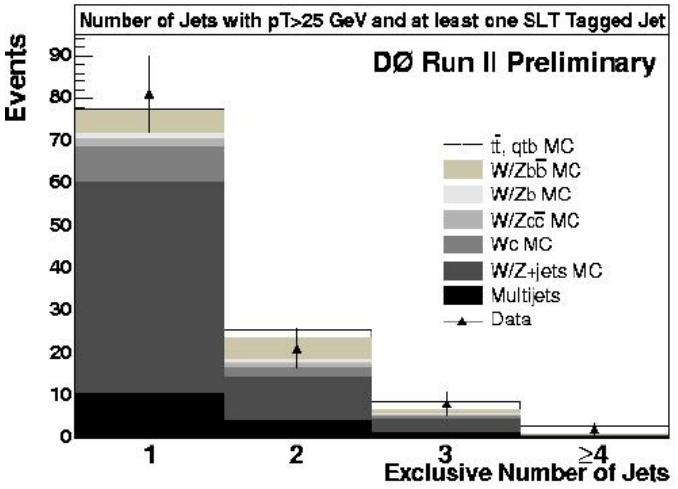


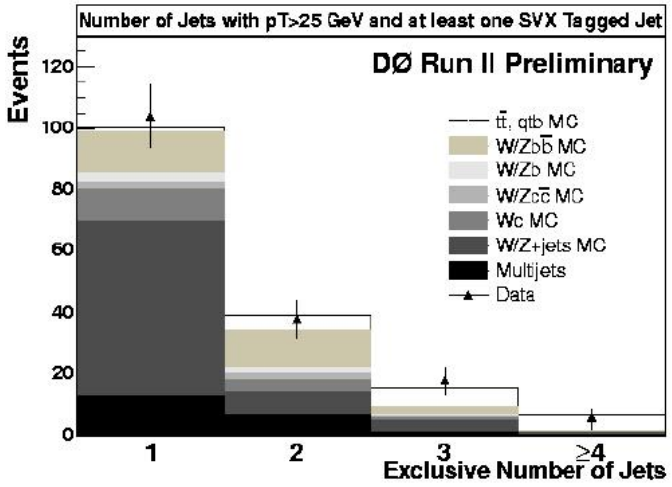


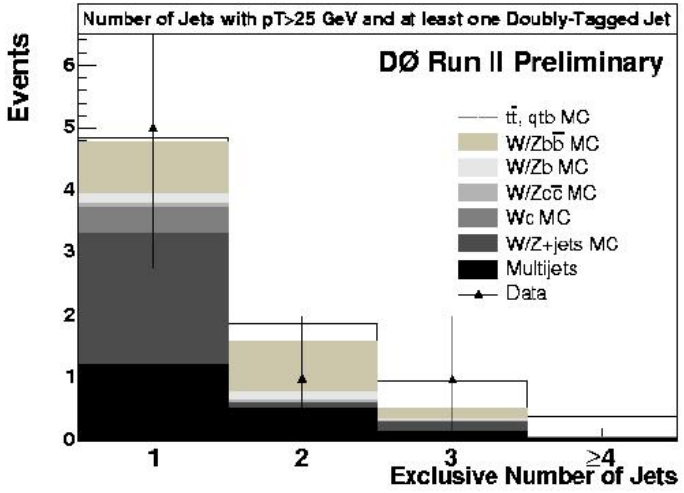
- Select events with W plus two b-tagged jets
- Observe 2 events with expected 2.5 ± 0.7
- set a limit of $\sigma_{Wh} \times B(h \to b\bar{b}) < 12.4$ pb at 95% CL for $m_h = 115$ GeV/c^2.

Search for Anomalous Heavy-Flavor in W+Jets (D0)

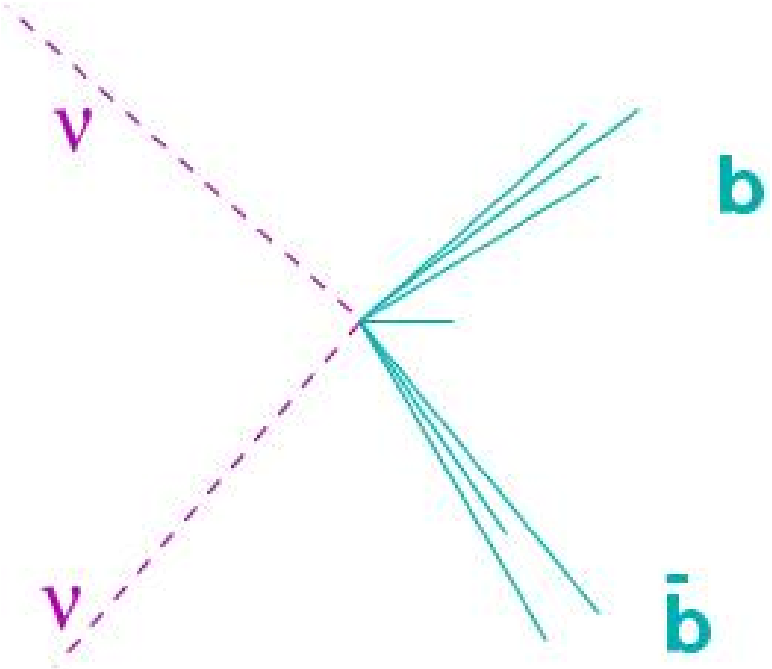
- Selecting events with one high Pt lepton + $\not\!\!E_{\rm T}$ (W+jets)
- Examined for possible b-jets with SVX, SLT or both
- No significant deviation found and set a cross section limit of 25.0 pb and 9.3 pb for anomalous peoduction of $Wb\bar{b}$-like or top-like events.

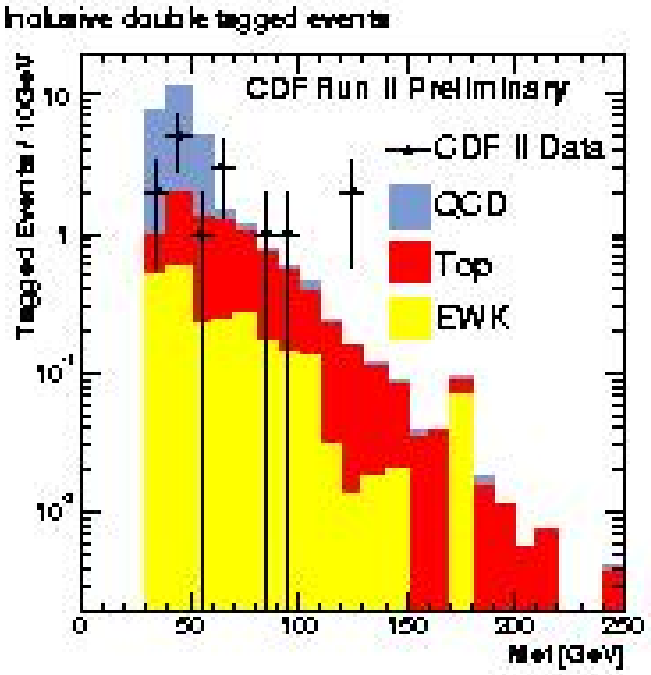






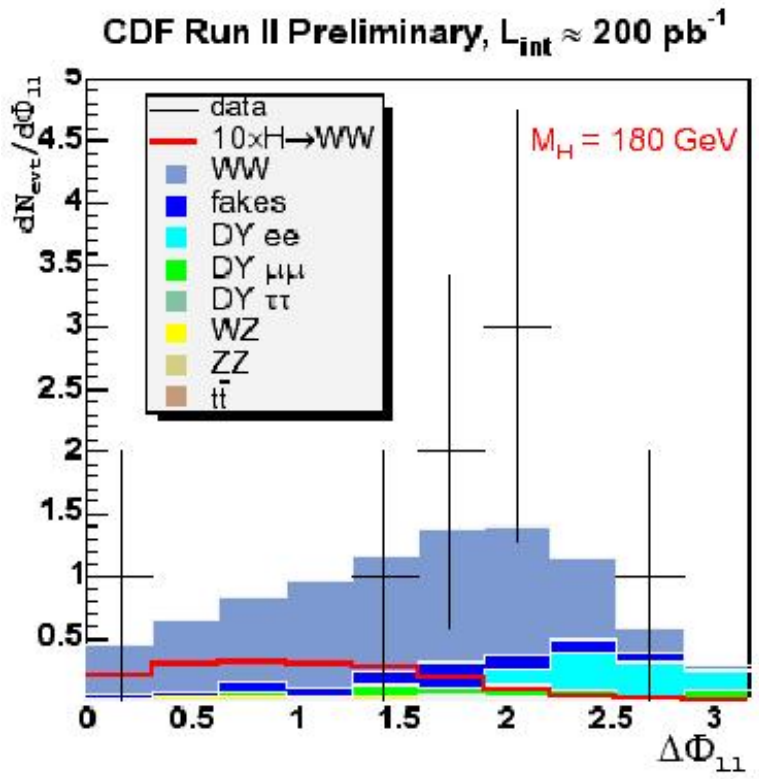
Search for $Zh \to (\nu\bar{\nu}, l^+l^-)b\bar{b}$(CDF)

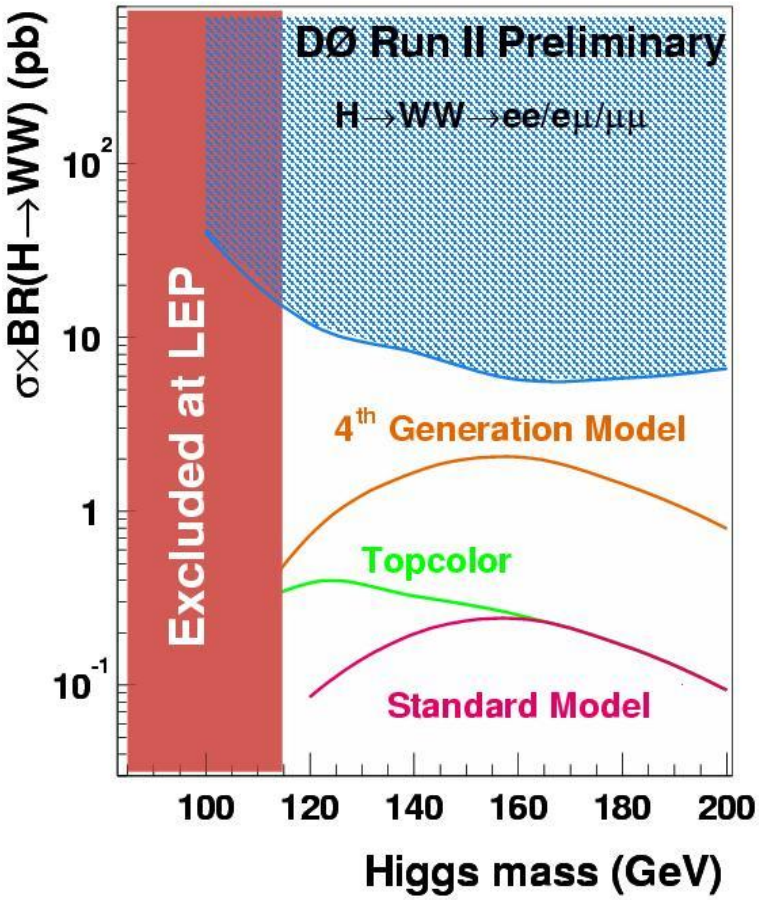




- Select events with large $\not\!\!E_{\rm T}$ and two b-tagged jets, similar to sbottom search ($q\bar{q} \to \tilde{g}\tilde{g} \to b\bar{b}b\bar{b}\chi^0\chi^0$).
- Large dijet backgrounds, but less top contributions
- Key is to understand the QCD background
- Most sensitivity channel! (Limit is in progress)

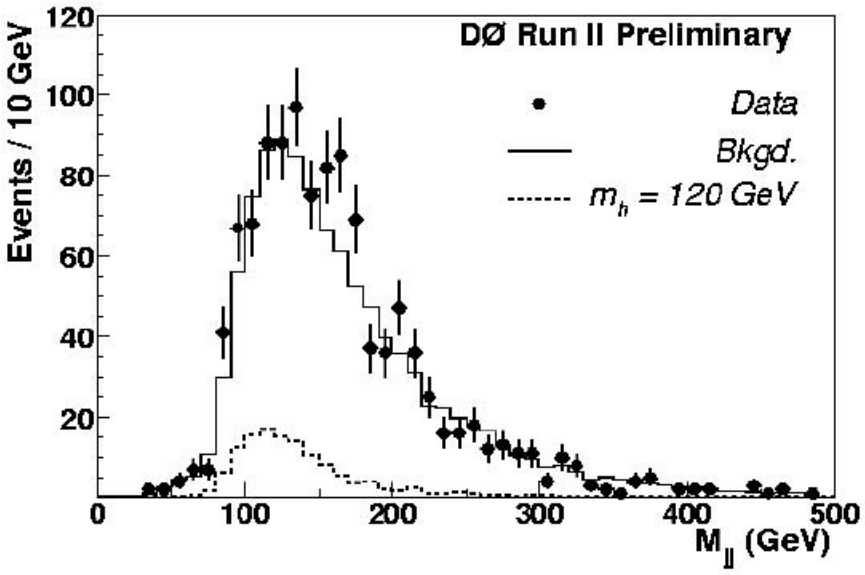
Search for $h \to W^+W^- \to l^+l^-\nu\bar{\nu}$

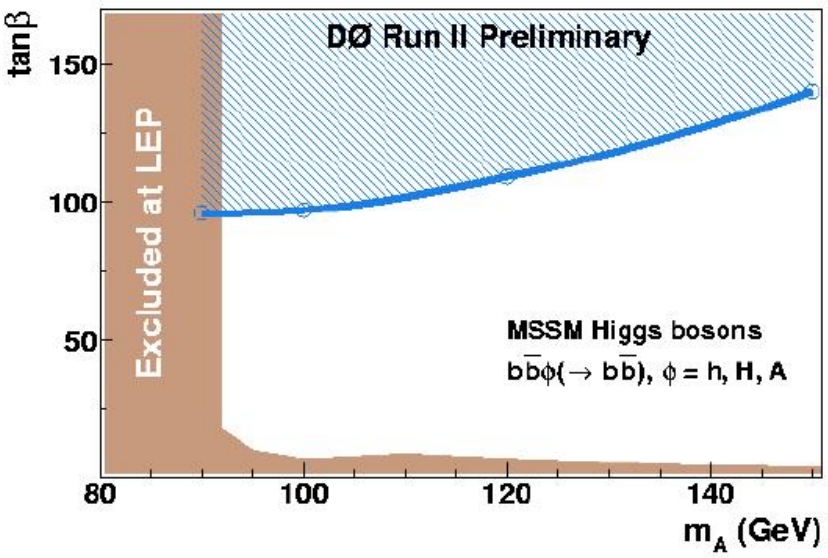




- Take full advantage of large $\sigma(gg \to h)$
- Two high pt isolated lepton (e or μ) + large $\not\!\!E_{\rm T}$
- Major background: W^+W^- production
- Exploit spin correlations of $h \to W^+W^-$
- Both CDF/D0 set a limit $\sigma \times Br < 5.6$ pb at 95% C.L.

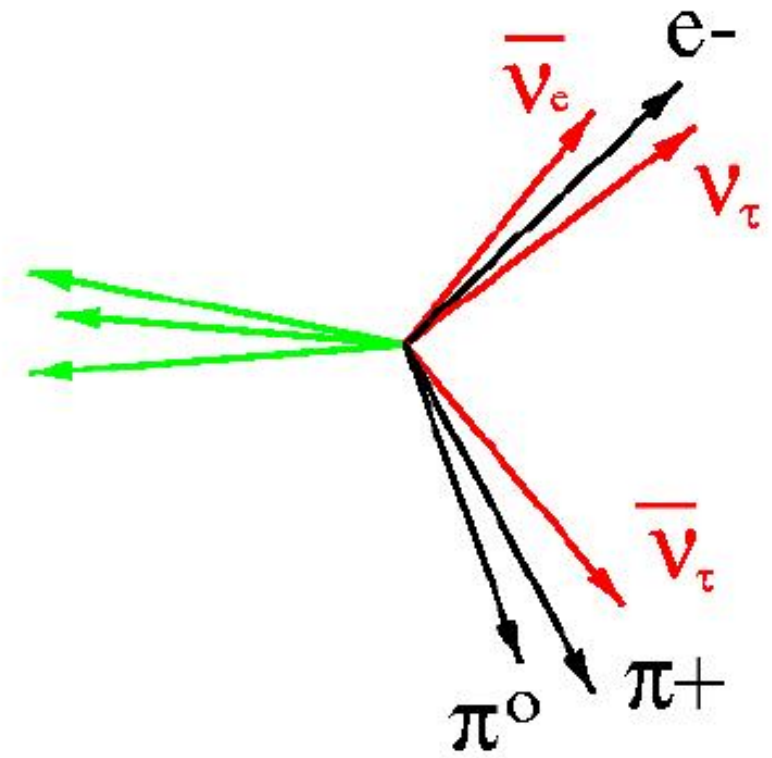
Search for MSSM Higgs: $Ab\bar{b} \rightarrow b\bar{b}b\bar{b}$ (D0)

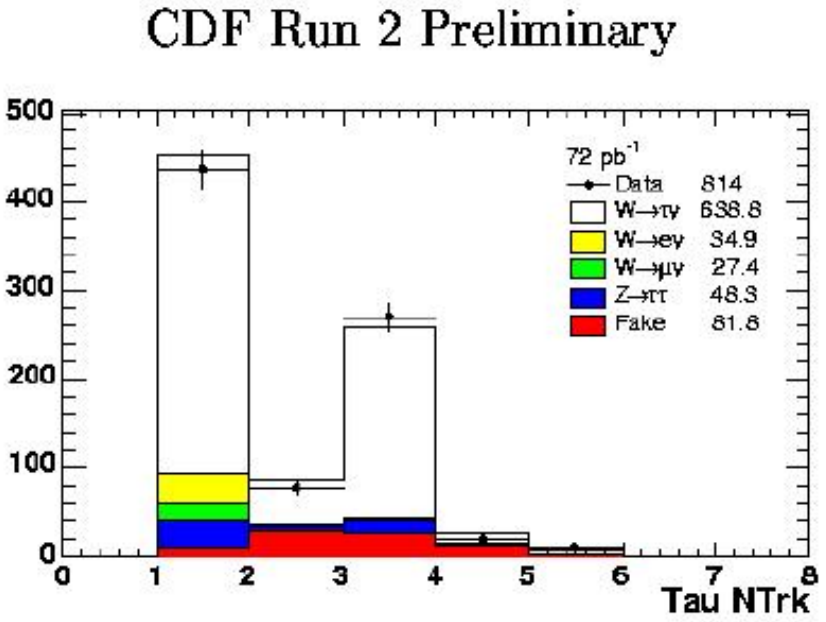




- $b\bar{b}(h/H/A)$ enhanced at large $tan\beta$
- Selecting events on multijet trigger (131 pb^{-1})
- Requiring 4 jets with 3 b-tags
- Invariant mass of the two highest b-tag jets and set a limit on $tan\beta$ vs m_A

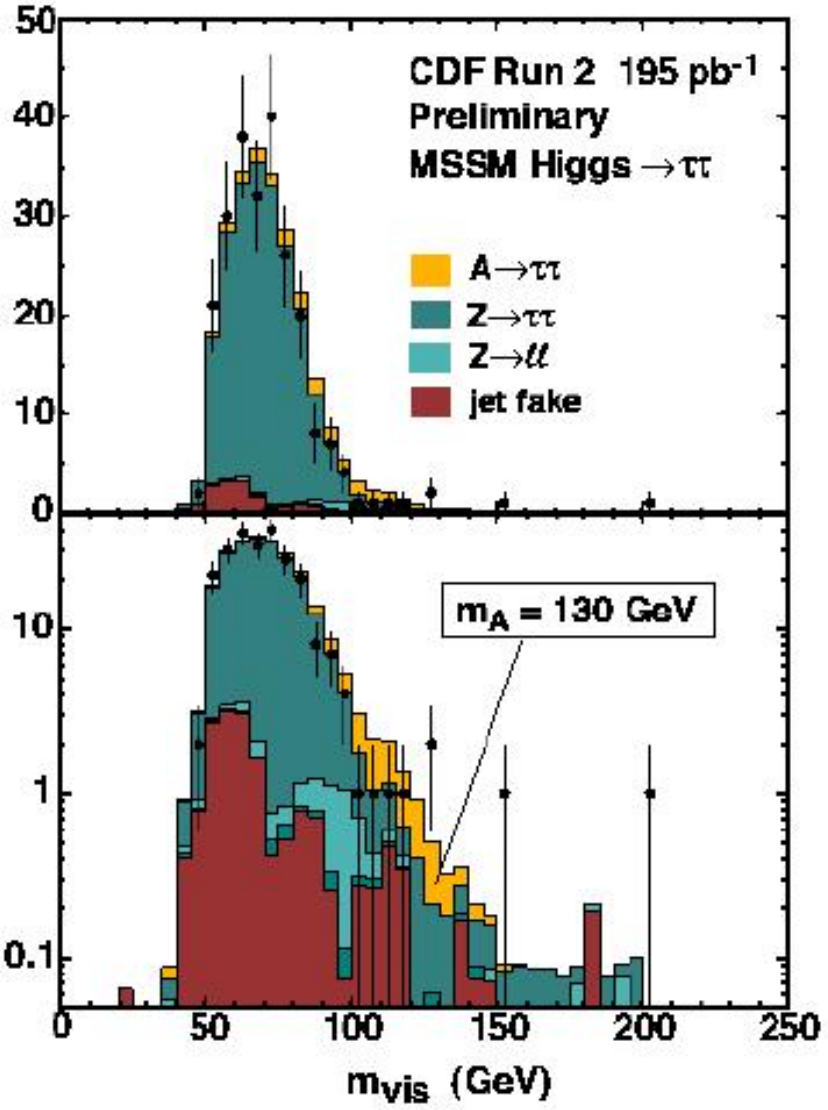
Search for MSSM Higgs:$h/A/H \to \tau^+\tau^-$ (CDF)

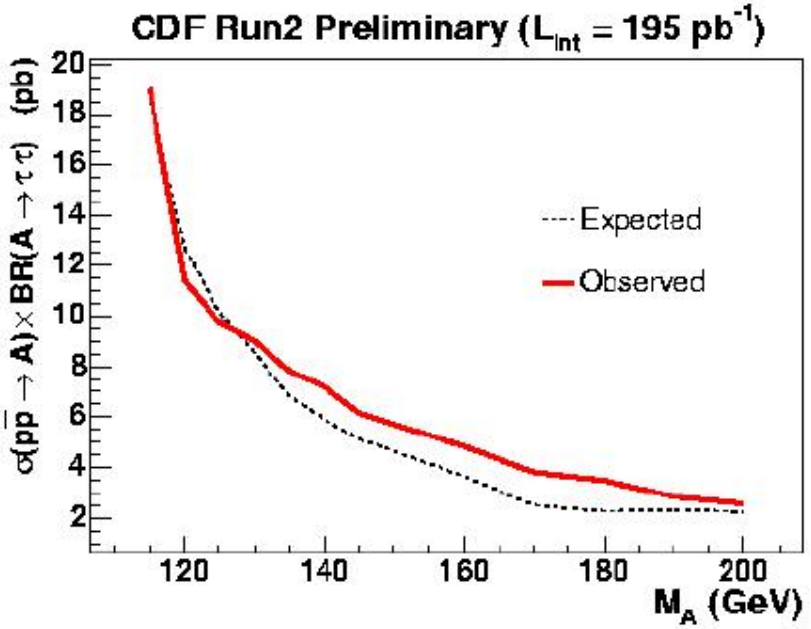




- Take advantage of enhanced xsec at large $tan\beta$
- Selecting ditau in Run2 dedicated "lepton+track" triggers: one leptonic, one hadronic
- Excellent τ ID, cross checked using $W \to \tau\nu$ events

Search for MSSM Higgs:$h/A/H \to \tau^+\tau^-$ (CDF)

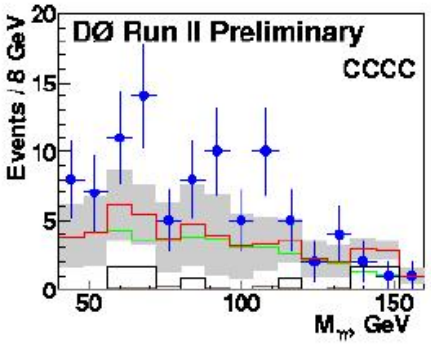




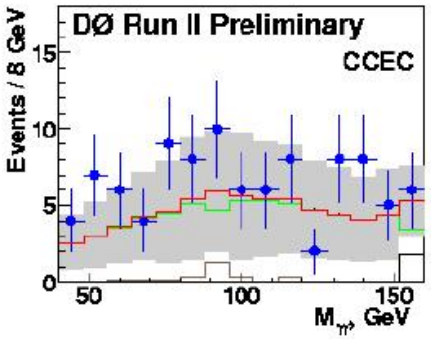
- Reconstructed transverse mass $m(\tau + l + \not{E}_{\rm T})$, $Z \to \tau^+\tau^-$ signal is evident
- Set limit for $\sigma(p\bar{p} \to A) \times B(A \to \tau\tau)$ vs m_A mass!

Search for $h \to \gamma\gamma$ (D0)

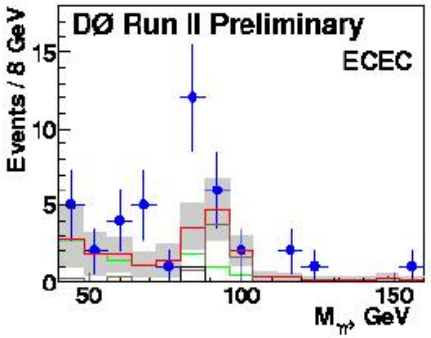
- $B(h \to \gamma\gamma)$ is suppressed in SM, however many extension of SM (Fermiphobic, Topcolor) could enhance the decay.
- Selections:
  - Two isolated photon with $E_T > 25$ GeV
  - P_t of diphoton > 35 GeV to reduce di-jet background



data = 93.0
bkgd = 52.4 +- 28.0
QCD = 42.7 +- 28.0
DY = 1.4 +- 1.3
$\gamma\gamma$ = 8.3 +- 0.6

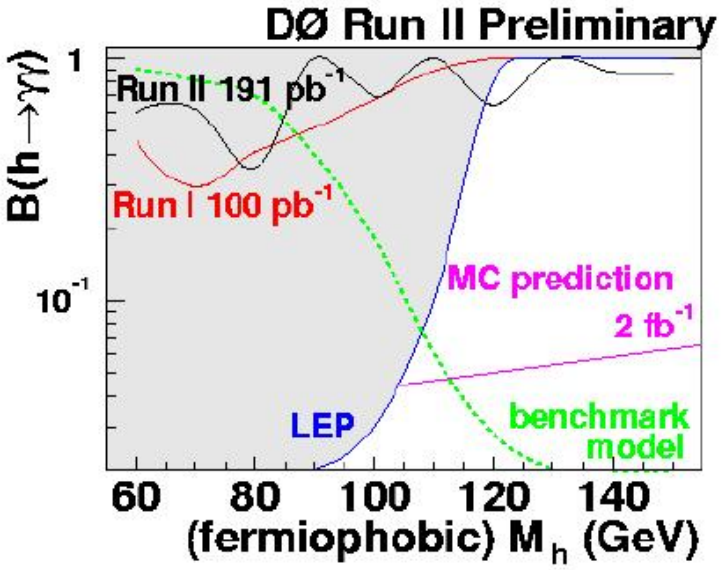


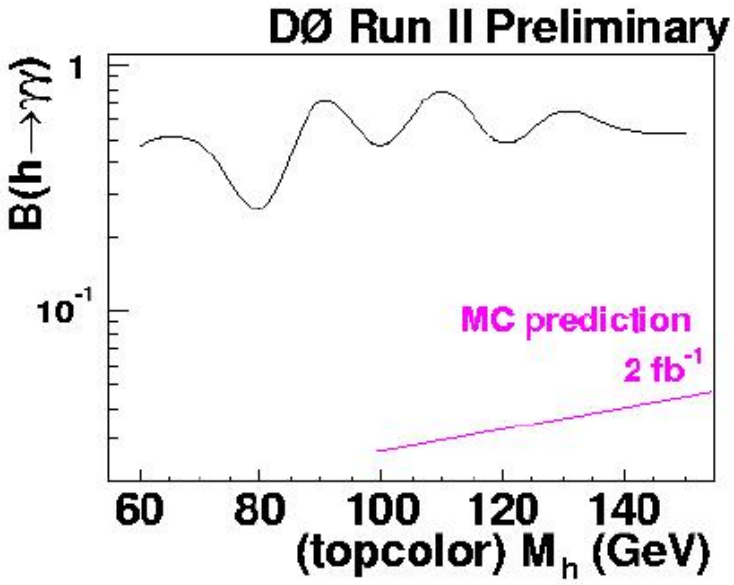
data = 97.0
bkgd = 68.8 +- 45.8
QCD = 64.0 +- 45.7
DY = 3.0 +- 3.0
$\gamma\gamma$ = 1.8 +- 0.1



data = 41.0
bkgd = 20.8 +- 10.4
QCD = 13.1 +- 10.0
DY = 6.7 +- 3.0
$\gamma\gamma$ = 1.0 +- 0.1

Search for $h \to \gamma\gamma$ (D0)

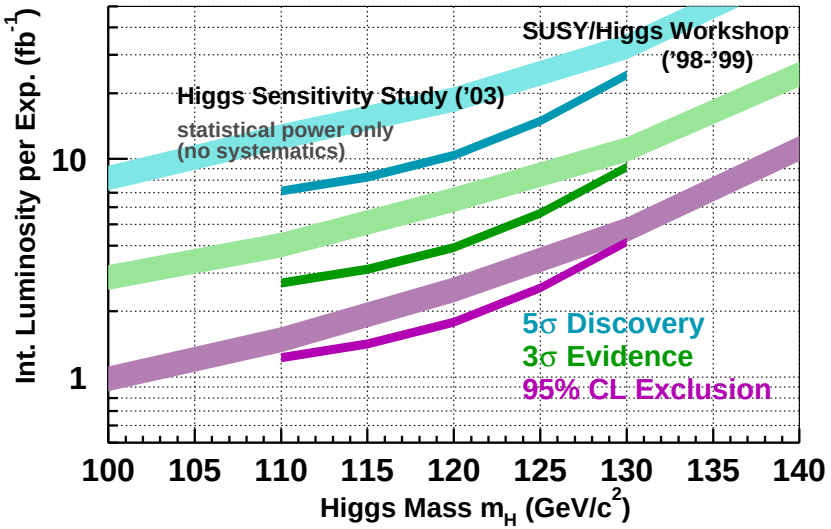


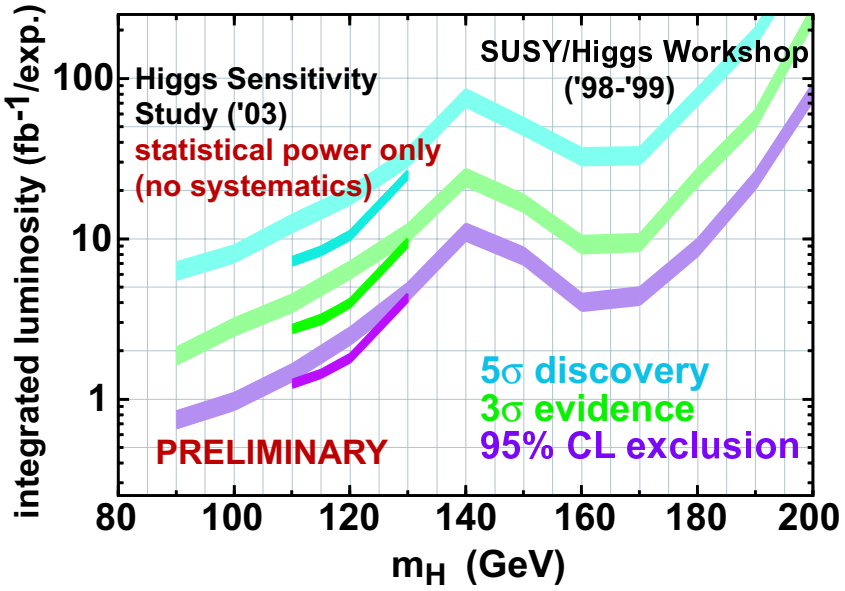


- No excess of events found in diphoton mass.
- Set a limit as a function of Higgs mass in Fermiphobic Higgs and Topcolor Higgs model.

Re-evaluating Higgs Sensitivity CDF + D0

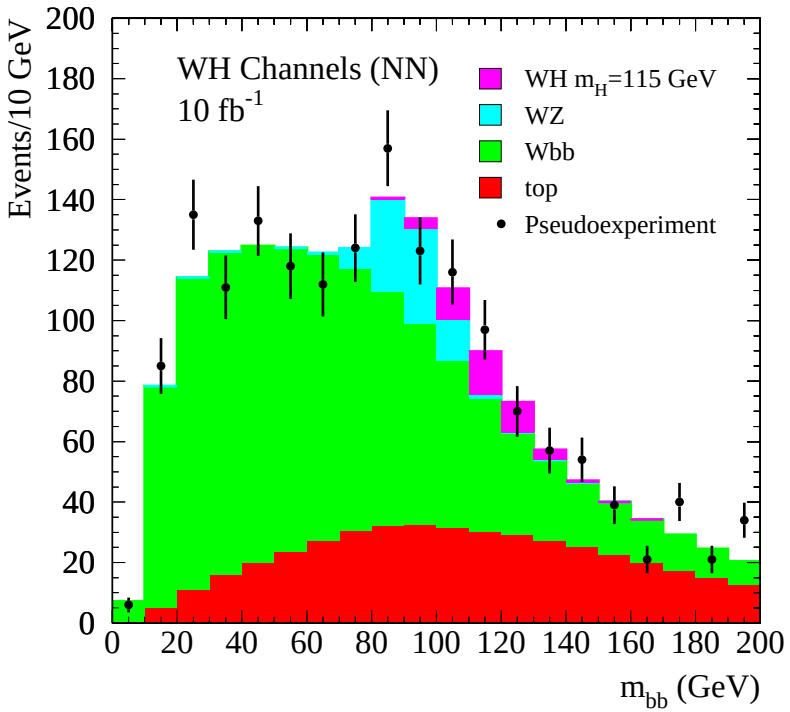
- CDF/D0 were asked by DOE to provide a new estimation of the Higgs Sensitivity based on current Run II detector performances last year (2003).
- Focus on the improvement of detector and analysis techniques (btag efficiency, dijet mass resolution, advanced analysis techniques)
- Finding consistent with SUSY-Higgs Workshop report (1998).

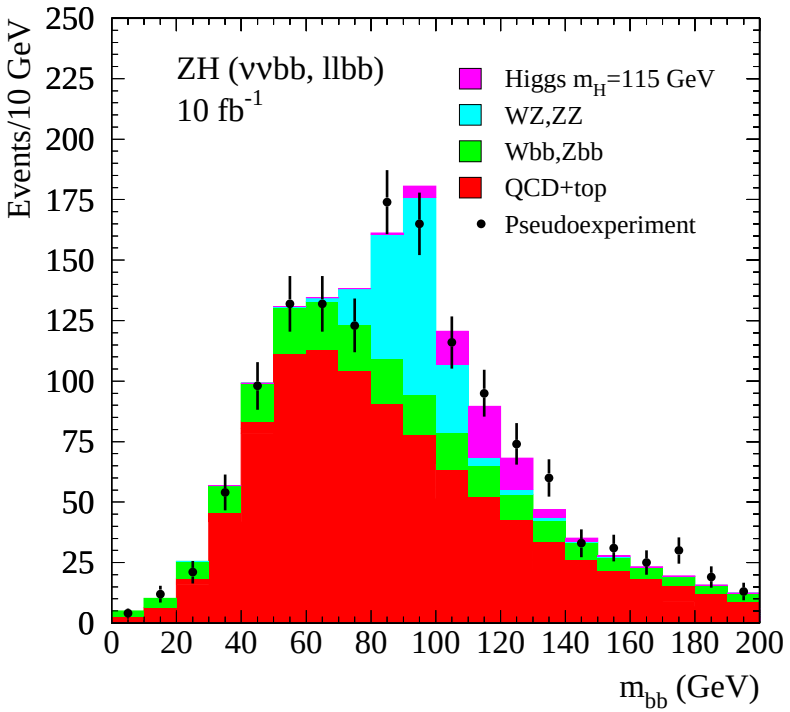




A Pseudo Experiment with Signal (115) and backgrounds

- Fit the dijet mass with signal and background
- Extract the int. luminosity needed for the 95% CL exclusion limit, and 3 σ and 5 σ discovery.



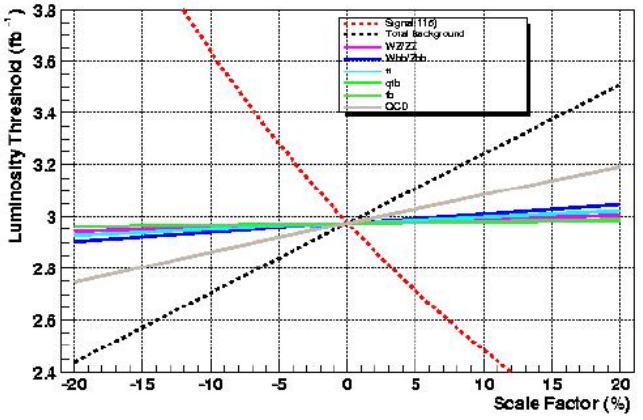


Background Systematic

- Controlling the normalization and shape systematic on each background is crucial.
- Need to fully exploit the potential of Run II and work with MC experts to ensure that physics are well described.
- The understanding of the Higgs sensitivity will improve over time as top discovery during Run I - the final sensitivity was much better than expected.

Observation of WZ and ZZ in $Z \to b\bar{b}$

- Excellent calibration for low mass Higgs($m_h = m_Z$)
- Purely leptonic decays should provide a normalization
- Dijet mass shape constrained from inclusive $Z \to b\bar{b}$ data



Conclusions

- The Higgs boson remains elusive, but discovery may be just around the corner !
- The Tevatron is at the world's energy frontier until the LHC era. Already with 200 pb^{-1}, CDF and D0 have produced many interesting results.
- There is an extremely rich, exciting physics program ahead of us, every time we double the integrated luminosity we open a new window for new physics.
- The Higgs sensitivity will improve over time as we get more data, better understood detector, and getting smarter,but challenging...
- With 5 fb^{-1} data, Tevatron will:
  - Exclude SM or SM-like Higgs mass up to 130 GeV/c^2 at 95% C.L.
  - Have a 3 σ discovery for Higgs mass up to 120 GeV/c^2.
  - Set a stringent limit on MSSM or more exotic Higgs in the parameter space beyond the SM.
- Stay tuned !