

Search for Non-SM Higgs at the Tevatron



Richard Hughes
The Ohio State University

Representing the
CDF & D0
Collaborations

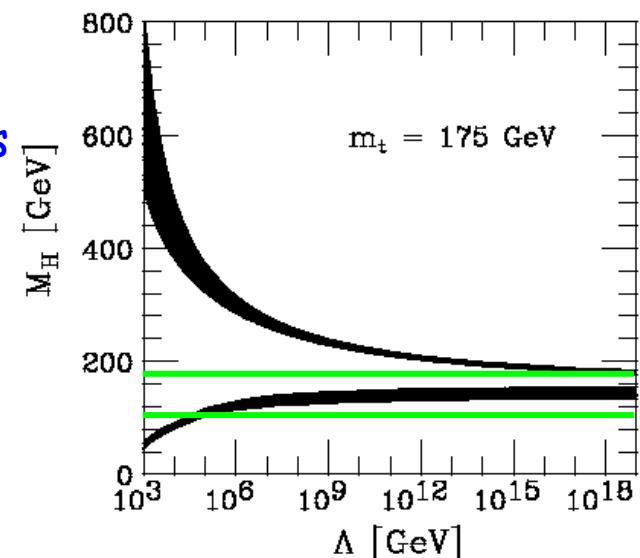
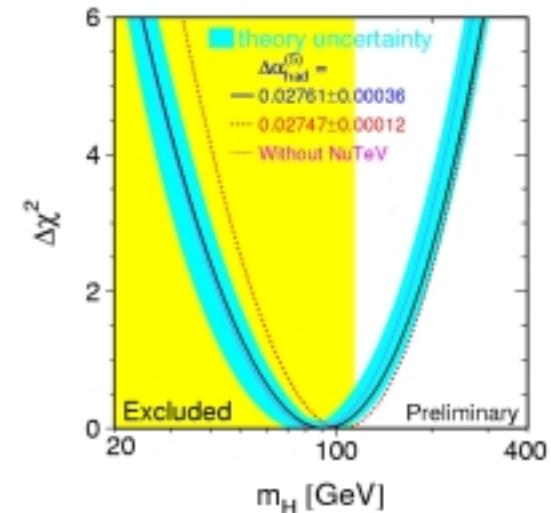
QCD and Hadronic
Interactions
Moriond 2004





Introduction

- SM Higgs: one model of EWSB
 - Gives mass to particles through H couplings
- Bounds on Higgs Mass
 - EWK Experimental Fits: $m_H < 193 \text{ GeV}/c^2$
 - Direct Searches (LEP): $m_H > 114.4 \text{ GeV}/c^2$ (95%CL)
- MSSM: one solution to hierarchy problem
 - m_H receives corrections $\sim m_{\text{Planck}}^2$
 - Needs fine-tuned parameters for $m_H \sim 100 \text{ GeV}$
 - Supersymmetry: symmetry between fermions, bosons \rightarrow cancellations occur naturally
 - Two Higgs doublets are needed to generate mass for "up" and "down" type quarks, as well as charged leptons



Higgs Beyond the Standard Model



- MSSM
 - 5 physical Higgs:
 - Two CP-even scalars: h (lighter, SM-like), H (heavier)
 - ❖ Searches for h like SM searches....
 - CP-odd scalar: A (\sim mass H)
 - Charged Higgs pair: H^\pm (\sim mass H, A)
 - At tree-level, two free parameters
 - Ratio of vacuum expectation values:
$$\tan \beta = \frac{v_u}{v_d}$$
 - One higgs mass $m_{H^\pm}^2 = m_A^2 + m_W^2$
- Other Models
 - Left-Right Symmetric: Doubly Charged Higgs
 - SM extensions that suppress fermi couplings
 - Fermiphobic Higgs
 - TopColor Higgs
- This talk will focus on new results from CDF and D0
 - H^{++}/H^{--} , bh/bbh (at large $\tan\beta$), and searches for $H \rightarrow \gamma\gamma$

Higgs Masses in MSSM



$$\left. \begin{array}{l} m_H \geq m_h^{\max} \\ m_{H^\pm} \geq m_A \\ m_A \equiv m_h \text{ or } m_H \end{array} \right\} \text{for all } m_A, \tan \beta$$

if $m_A < m_h^{\max}$

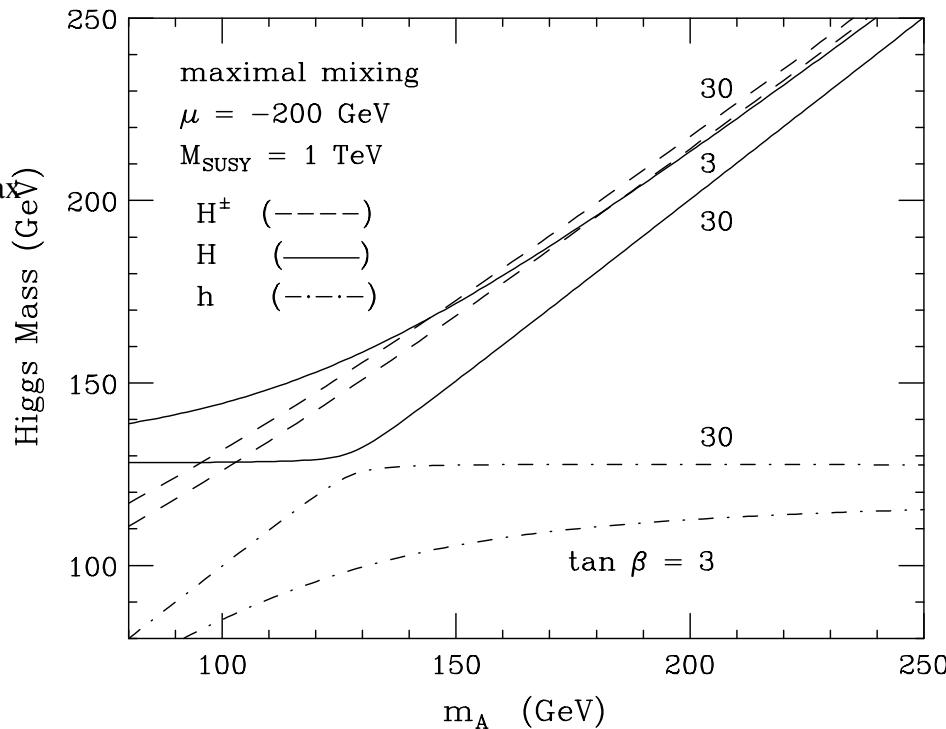
then $m_h \cong m_A$

and $m_H \cong m_h^{\max}$

if $m_A > m_h^{\max}$

then $m_h \cong m_h^{\max}$

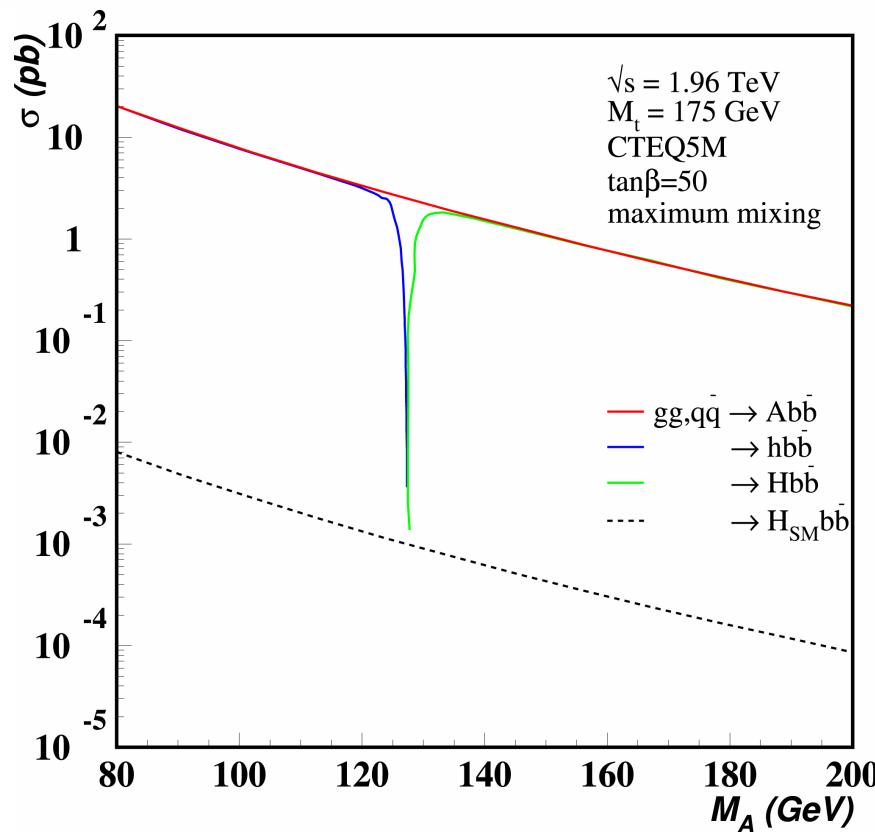
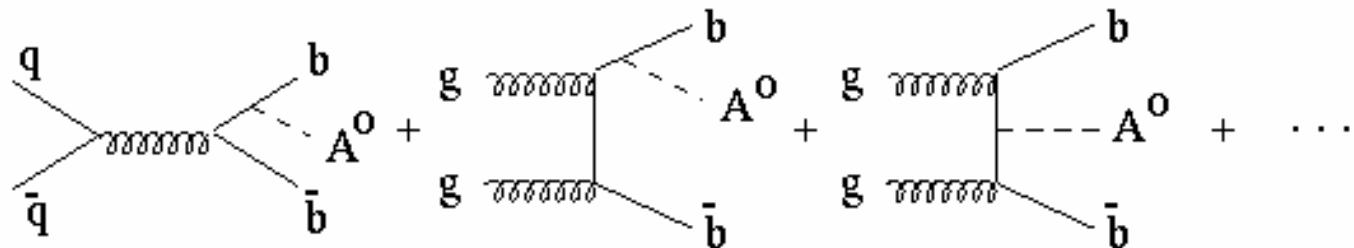
and $m_H \cong m_A$



$m_h \leq m_h^{\max}$
where $m_h^{\max} \cong 130$ GeV

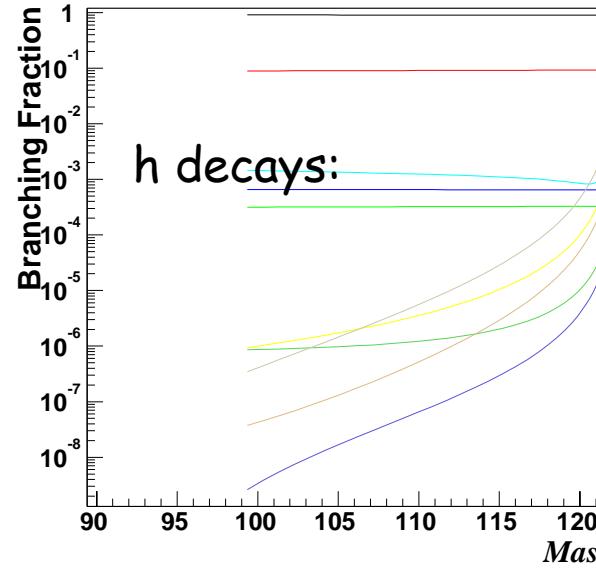


MSSM Higgs Production



Large enhancement of rates over $H_{SM} bb$

MSSM Higgs Decays



Decay Modes:
 bb
 $\tau^+\tau^-$
 $\mu^+\mu^-$
 ss
 cc
 gg
 $Z\gamma$
 $Z\gamma$
 W^+W^-
 ZZ
 hh
 AA
 $Z\Lambda$

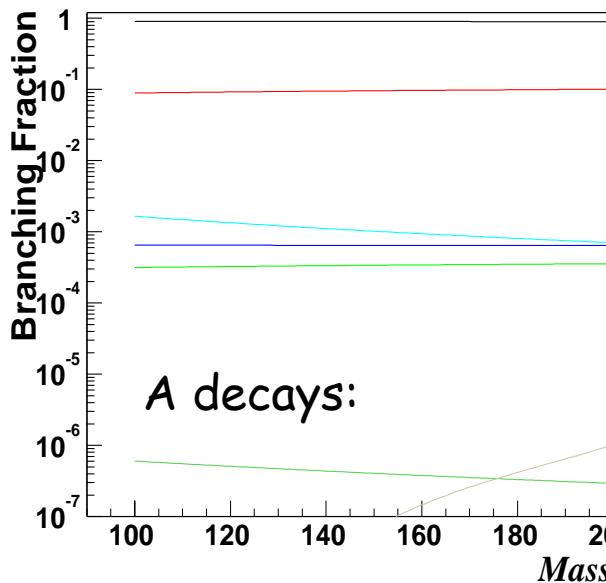
Summary

$h/H/A \rightarrow bb \sim 90\%$

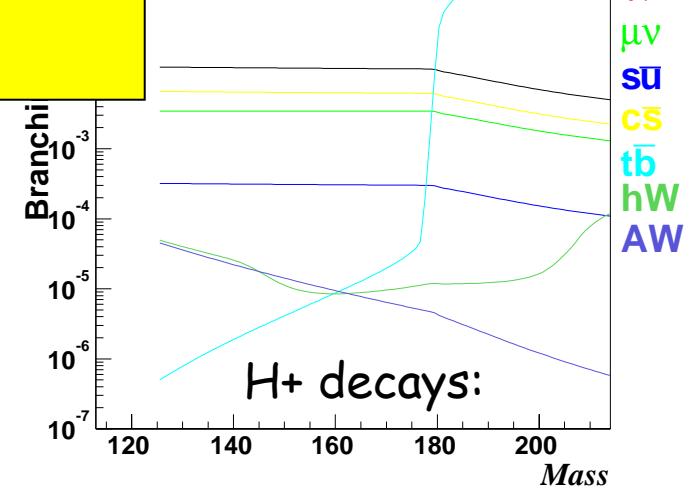
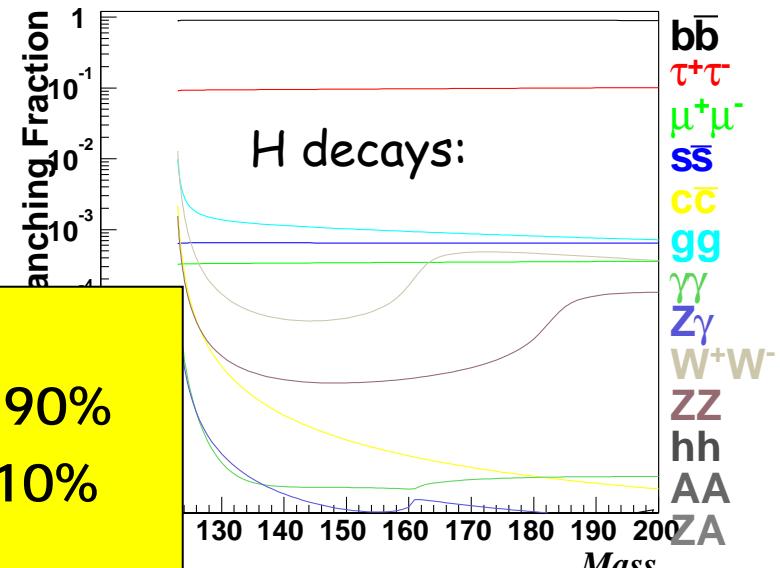
$h/H/A \rightarrow tt \sim 10\%$

$H^+ \rightarrow \tau\nu \sim 100\%$
 $(\tan\beta > 1)$

M. Spira
 HDECAY



Decay Modes:
 bb
 $\tau^+\tau^-$
 $\mu^+\mu^-$
 ss
 cc
 gg
 $Z\gamma$
 $Z\gamma$
 W^+W^-
 ZZ
 hh
 AA
 $Z\Lambda$



DØ Search for Neutral Higgs in MSSM (1)

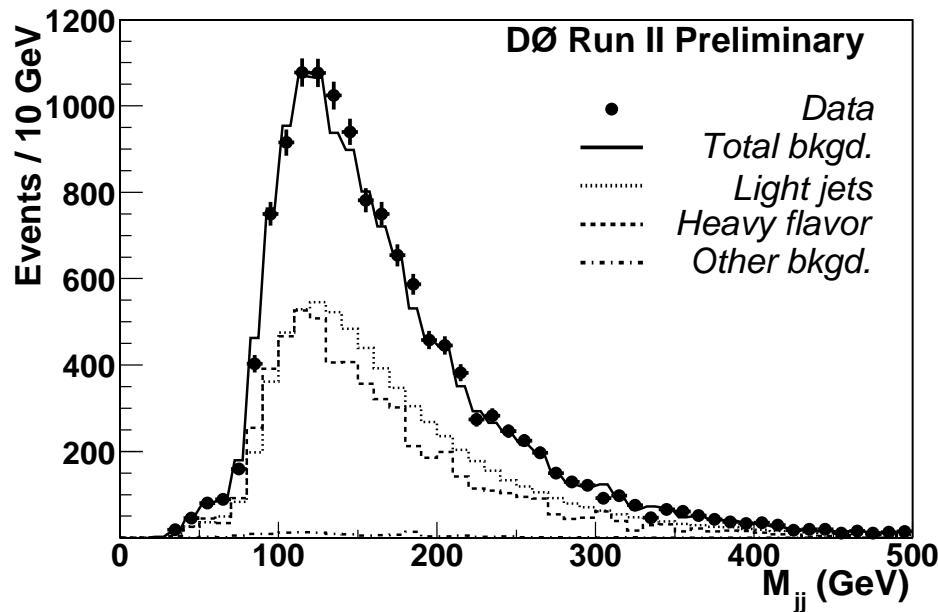


- Use NLO calculations or production of A and h/H
 - Don't distinguish between A and h/H
 - Assume A doubles cross section (of sum of h/H)
 - Assume cross sections scale with $\tan^2\beta$
- Event selection:
 - Use a multi-jet trigger ($L \sim 130 \text{ pb}^{-1}$)
 - Require 3 or 4 jets with $E_T > 15 \text{ GeV}$
 - ≥ 3 b-tag (displaced vertex)
 - ET cuts on 2 leading jets varied with m_h
 - $\sim 40 \text{ GeV}$ at $m_h = 100$ to $\sim 60 \text{ GeV}$ at $m_h = 150$
 - $\text{BR} \times \text{Accept}$
 - $\sim 0.2 - 0.6\%$ ($\text{njmin}=4$; $100 < m_h < 150 \text{ GeV}$)
 - $\sim 0.5 - 1.5\%$ ($\text{njmin}=3$; $100 < m_h < 150 \text{ GeV}$)
- Backgrounds: from double b-tagged data sample

DØ Search for Neutral Higgs in MSSM (2)



The double b-tagged data with 4 or more jets, showing the composition of various sources.

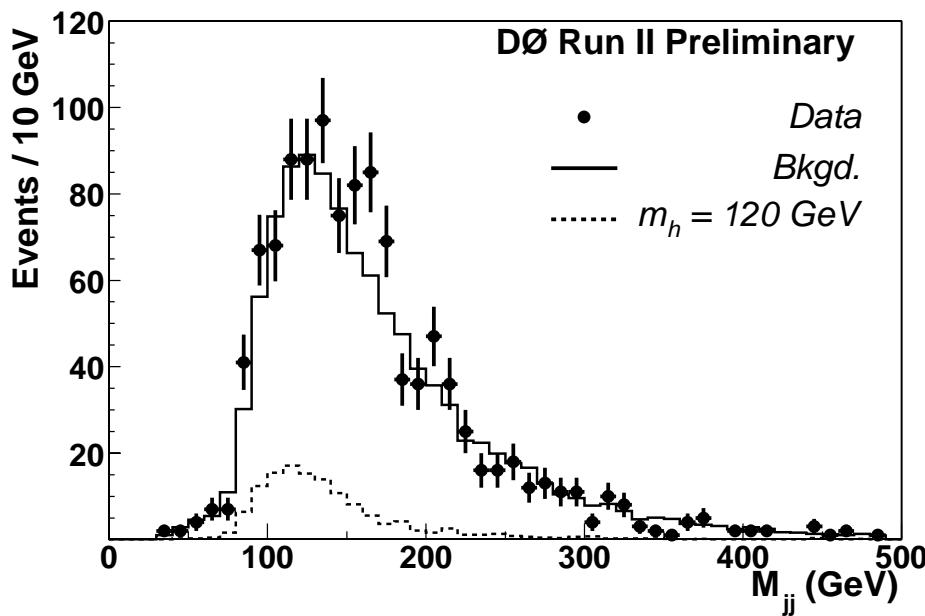


- We have derived the composition of the double b-tagged data, from which the triple b-tagged data background was derived. The double b-tagged data with 4 or more jets is shown in the first figure below.
- SVX Extra Loose b-tagging was applied, and events were kept which had 3 or more tags.
- The shape of the triple b-tagged background was estimated from the double b-tagged background and extrapolated using a tag-rate-function derived on the full multi-jet data sample. This background shape was then normalized to the triple b-tagged data outside a 1σ signal window determined for each Higgs mass.

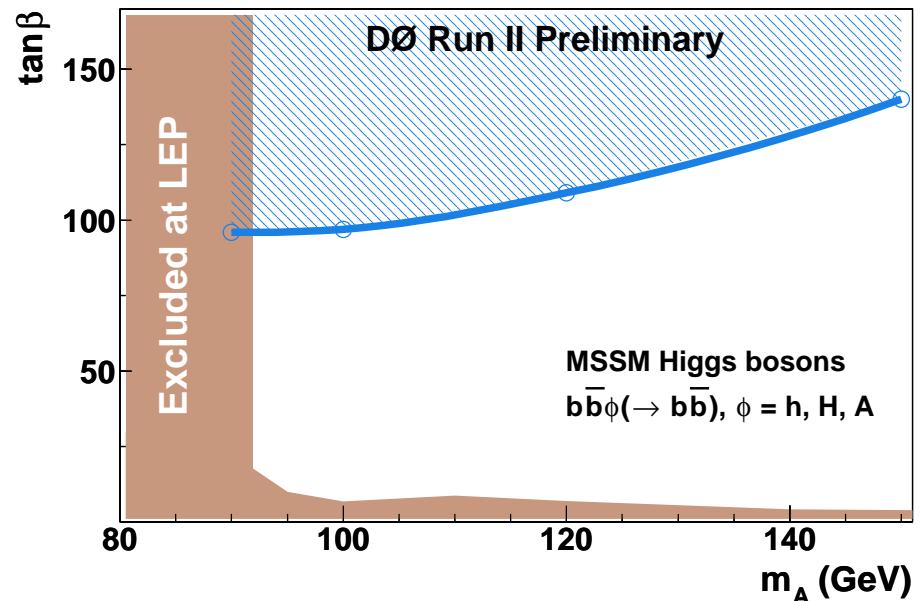
DØ Search for Neutral Higgs in MSSM (3)



An example of the excluded signal and normalized background for a Higgs mass of 120 GeV (at $\tan \beta \sim 110$), compared to the data



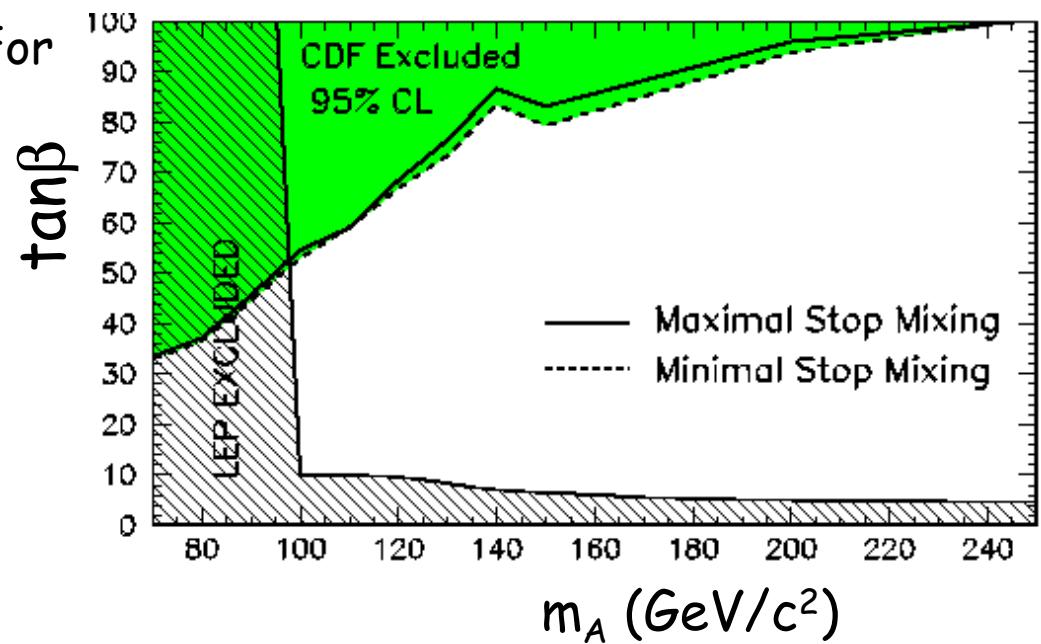
In the absence of an observed signal, limits have been set in the $\tan \beta$ vs. m_A plane



Run I CDF Neutral Higgs in MSSM



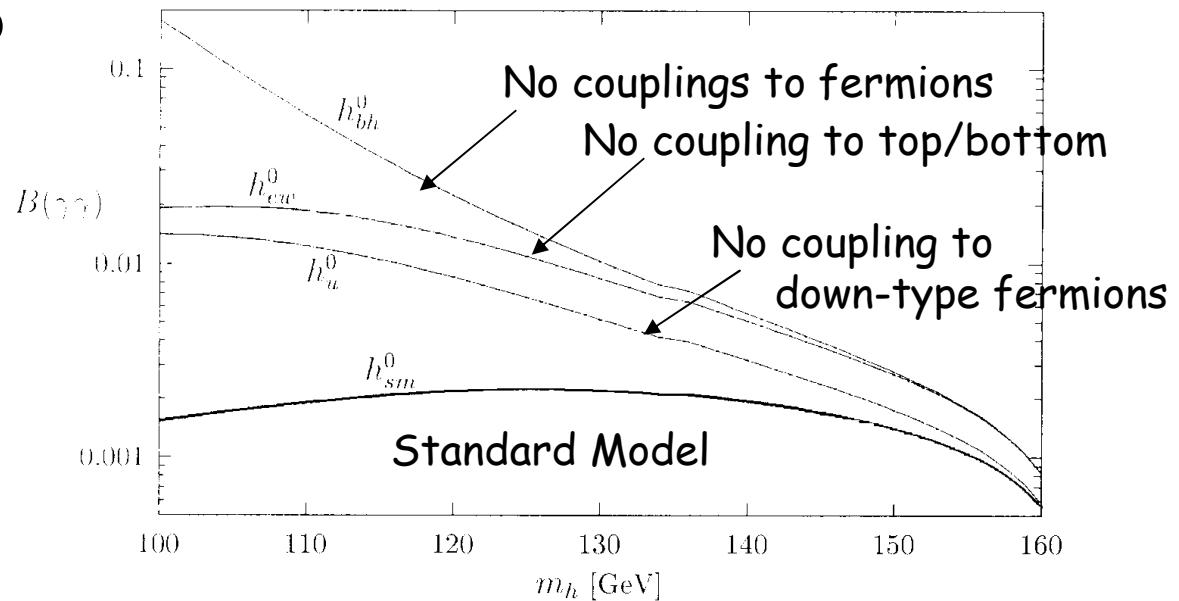
- Event selection:
 - 4-jets + $\Sigma ET > 125$ GeV trigger ($L \sim 91$ pb $^{-1}$)
 - ≥ 3 b-tag (displaced vertex)
 - $\Delta\phi_{bb} > 1.9$
 - m_j dependent cuts optimized for max. expected signif.:
 - ET cuts on jets
 - mass window 1-3s
- $BR \times \text{Accept} \sim 0.2 - 0.6\%$ ($70 < m_j < 300$ GeV)
- Backgrounds: QCD, W/Z+jets, ttbar
- For $m_j = 70$ GeV hypothesis, observe
 - 5 events, expect 4.6 ± 1.4





Search for Higgs Decays to γ Pairs

- In the Standard Model, Higgs bosons decay into gamma pairs with a very small branching ratio ($10^{-3} - 10^{-4}$) at the Tevatron.
- However many extensions of the SM allow enhanced gamma pair decay rate of Higgs largely due to suppressed coupling to fermions.
 - Fermiphobic Higgs
 - Topcolor Higgs

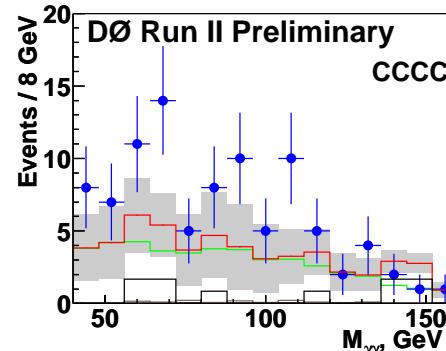


Mrenna, Wells, PRD63 (2001)

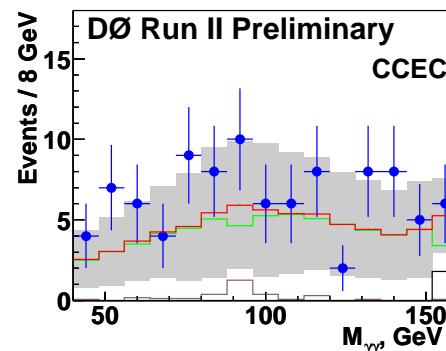
DØ Search for $H \rightarrow \gamma\gamma$ (1)



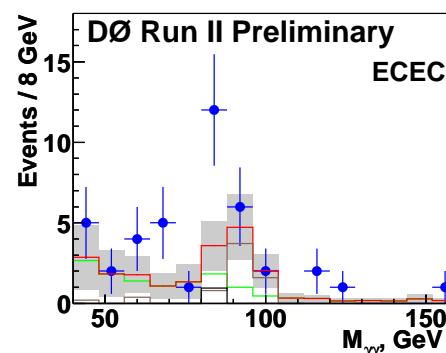
- The analysis is based on the data collected from April 2002 to September 2003. The integrated luminosity used in the analysis is $191^{+13} \text{ pb}^{-1}$.
- Event Selection Criteria:
 - Two isolated EM objects with $\text{ET} > 25 \text{ GeV}$ and no associated track.
 - CC: central calorimeter
 - EC: end calorimeter
 - pT of diphoton system $> 35 \text{ GeV}$.



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



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

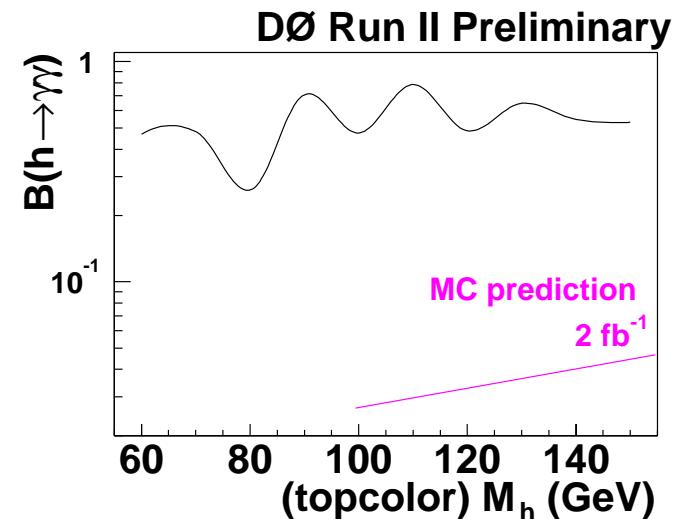
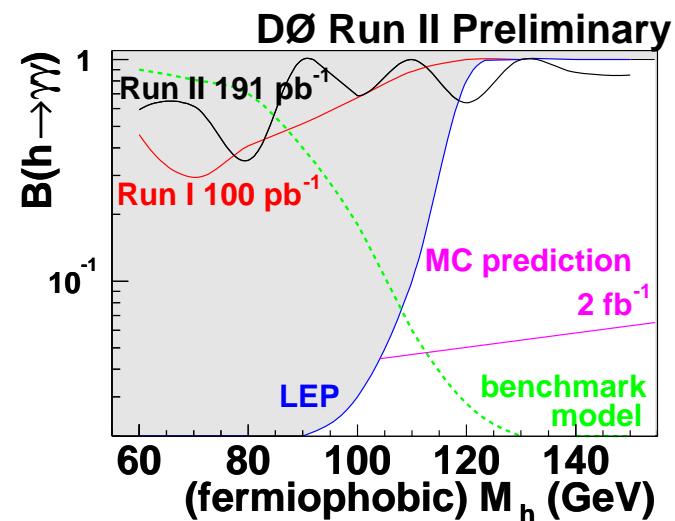


data = 41.0
bkgd = 20.8 ± 10.4
QCD = 13.1 ± 10.0
DY = 6.7 ± 3.0
 $\gamma\gamma = 1.0 \pm 0.1$



DØ Search for $H \rightarrow \gamma\gamma$ (2)

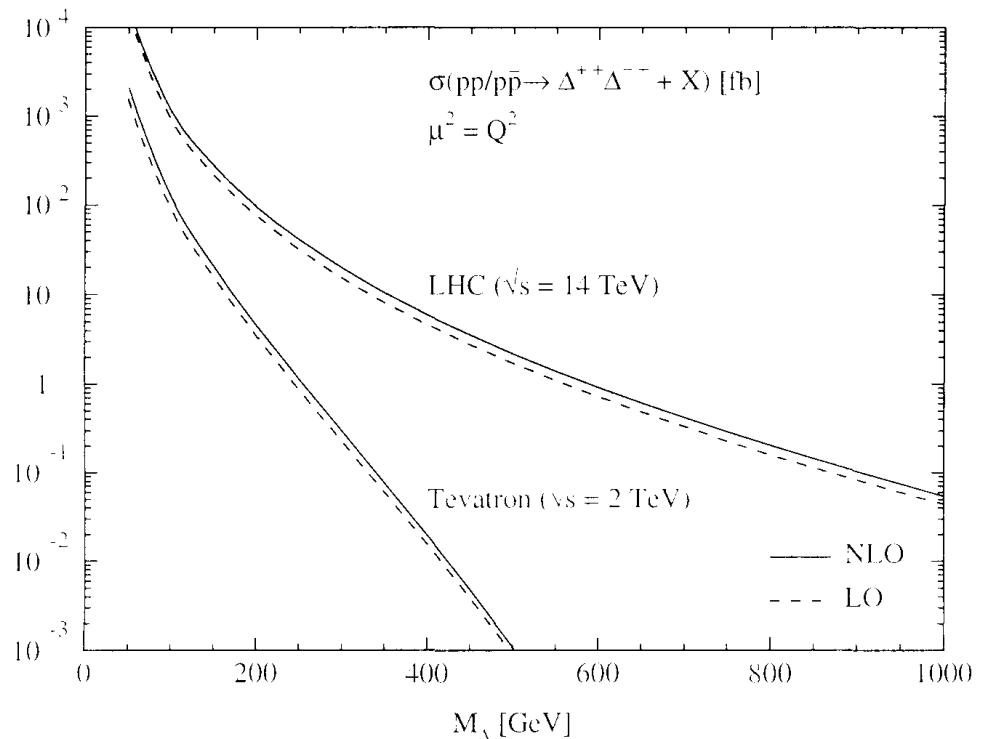
- A counting experiment is then performed, using an optimized sliding mass window for higgs masses 60-150 GeV
 - Window varies from ~6 GeV ($m_h=60$ GeV) to ~10GeV ($m_h=150$ GeV)
- Then derive an upper 95% CL limit on the diphoton branching ratio as a function of Higgs mass for Fermiphobic and Topcolor Higgs scenarios.
 - Use CC-CC and CC-EC events for this



Doubly Charged Higgs (H^{++}/H^{--})



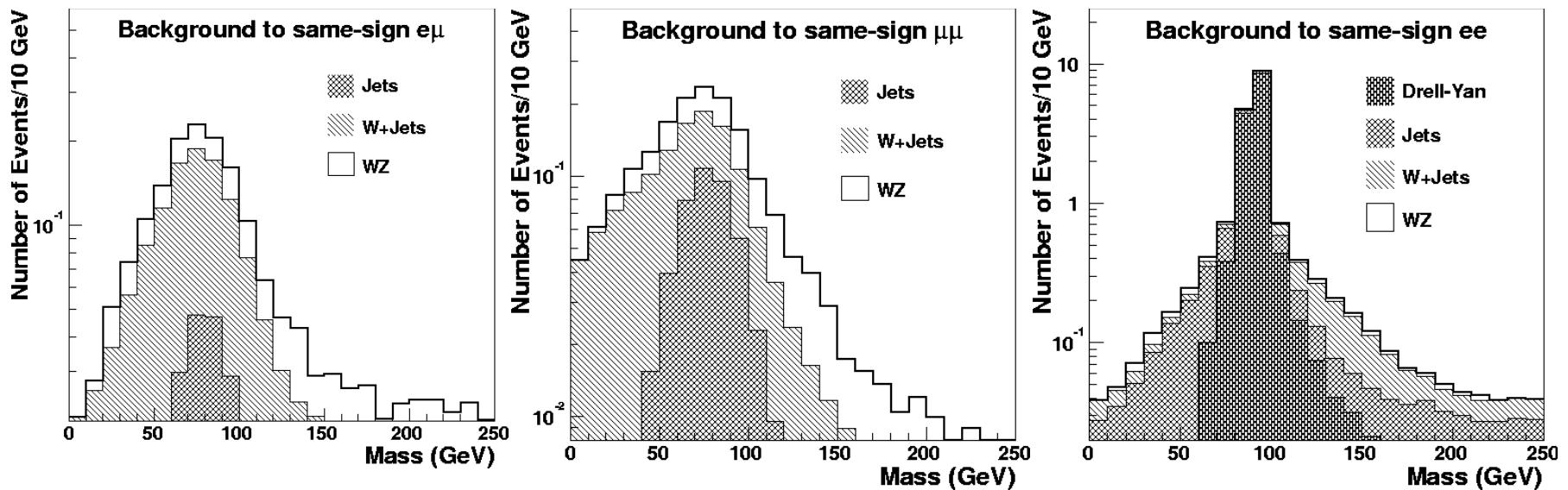
- Predicted by left-right (LR) symmetric models
- SUSY LR models: low mass:
 - $100 \text{ GeV} < M(H^{++}) < 1 \text{ TeV}$
- Signature: energetic like sign dileptons
 - $ee, e\mu, \mu\mu$
- Strategy:
 - compare expected background with data, then derive limits as a function of mass
 - Use mass window $\sim 10\% M(H^{++})$



CDF H⁺⁺ Search (1)



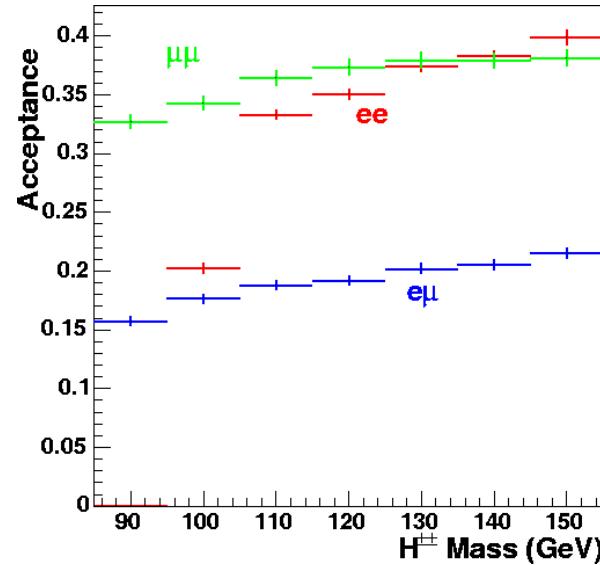
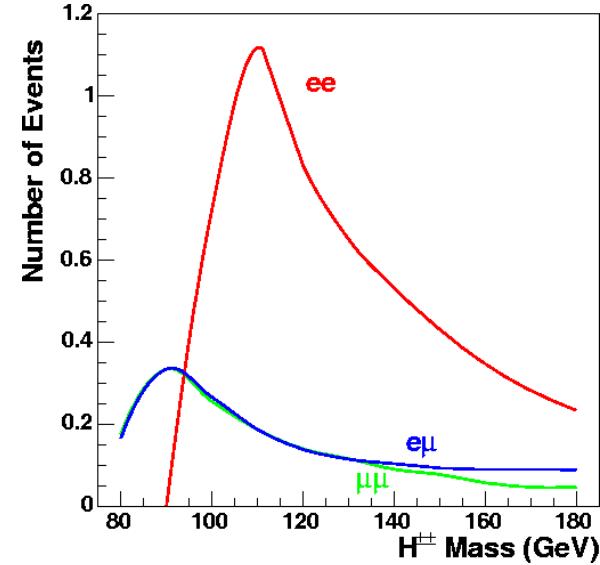
- Low mass (ee/eμ/μμ: <80 GeV)
 - Obs 1 event (ee, 70GeV)
 - background: $\sim 3.4 \pm 0.8$ evt
- High Mass: (ee: 100-300GeV; eμ/μμ: 80-300GeV)
 - Obs 0 events
 - background: $\sim 3.9 \pm 1.2$ evt



CDF H⁺⁺ Search (2)



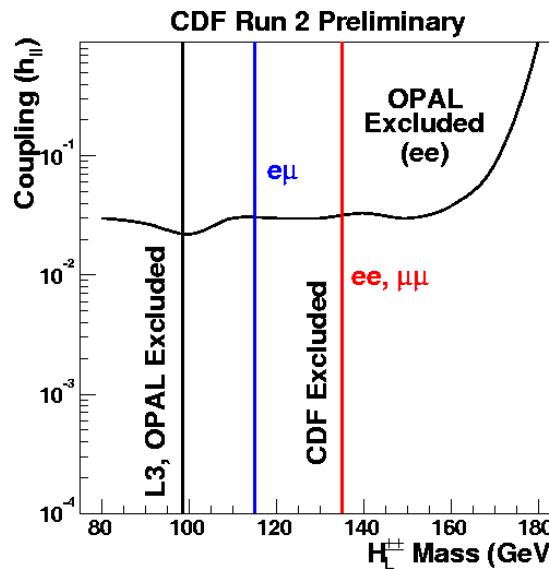
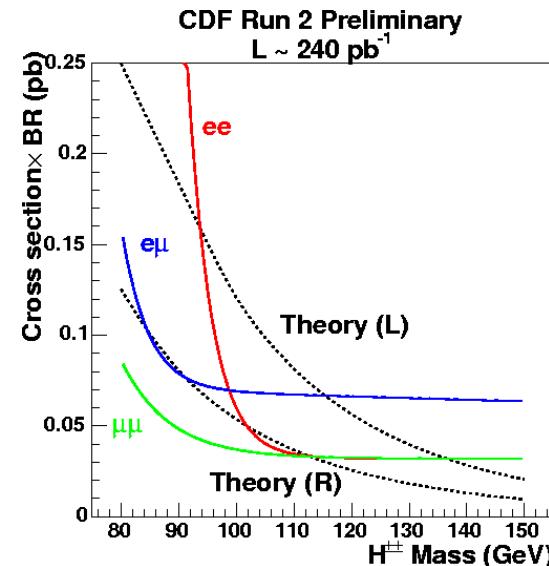
- As a function of doubly-charged Higgs mass, the background rises as the mass increases away from the low-mass cut-off due to the increasing search window size. At high masses, the background falls steadily.
- We estimate the total acceptance for the pair-production of doubly-charged Higgs particles using the PYTHIA event generator and a GEANT-based detector simulation.



CDF H[±] Search (3)



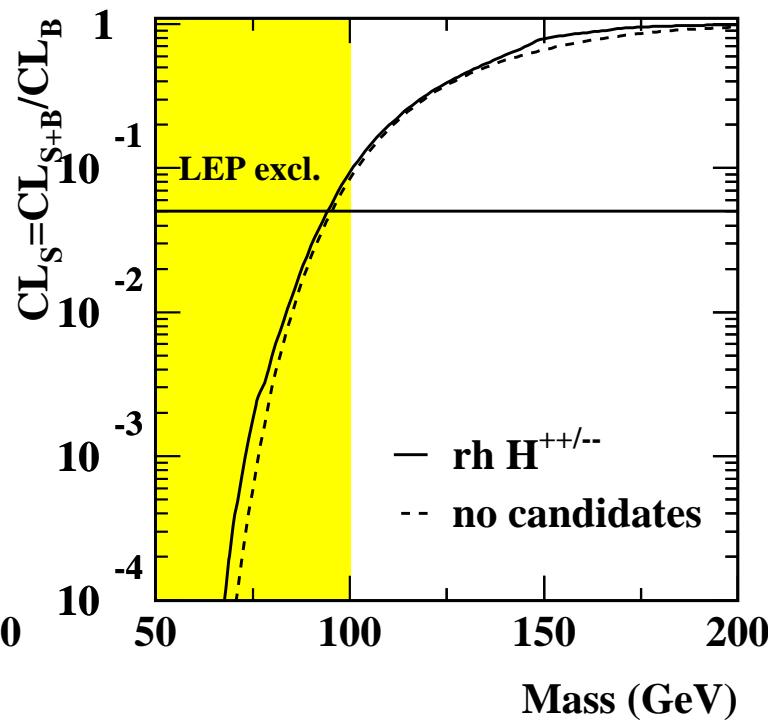
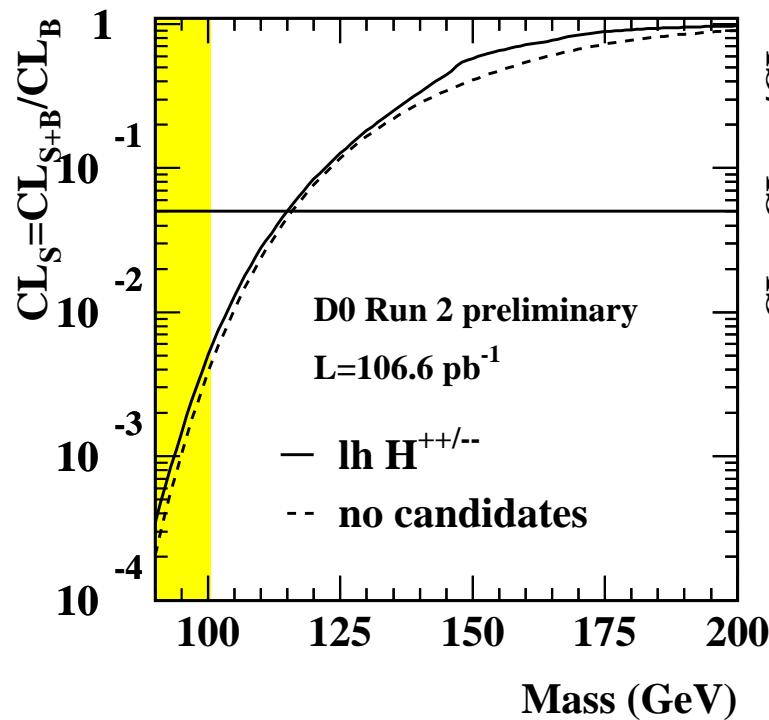
- In the search region, CDF observes 0 events. These results provide a 95% confidence level cross section limit for pair-production of doubly-charged particles.
- current world limits in the doubly-charged Higgs mass versus lepton coupling plane:



DØ H⁺⁺ Search



- Search assumes the H⁺⁺/-- decay branching ratio to like-sign muons to be 100%.
- Confidence level of the signal as a function of the H⁺⁺ mass, for the left- and right-handed Higgs bosons



Summary/Conclusions

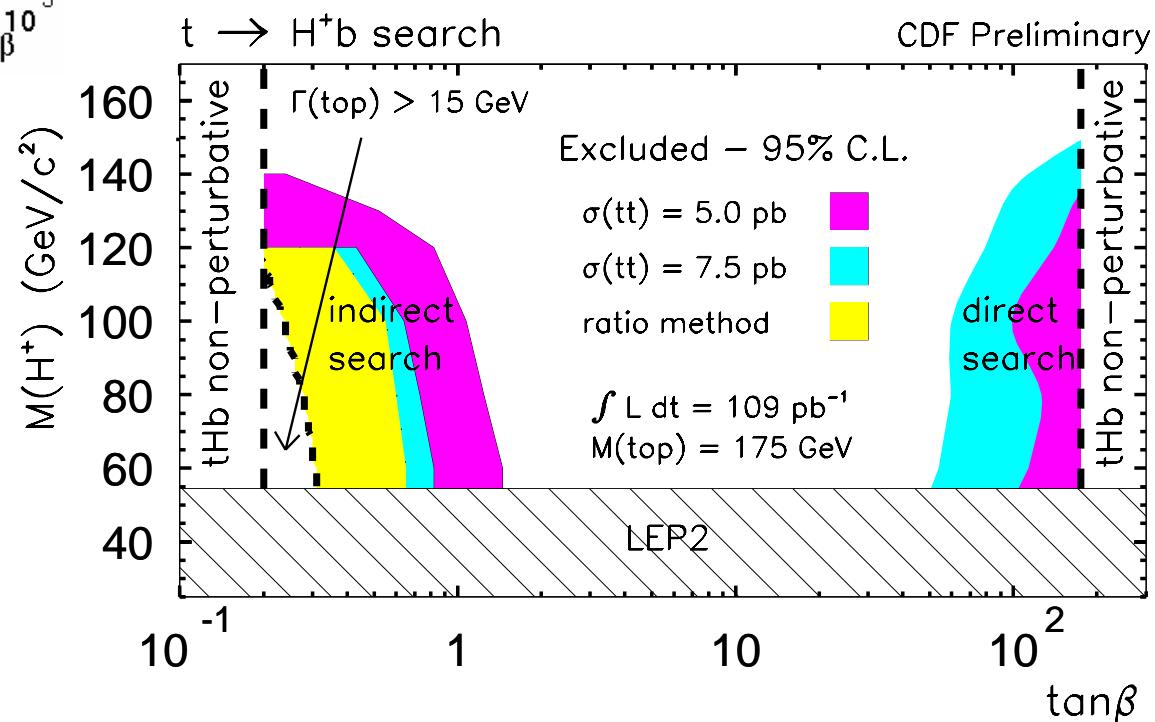
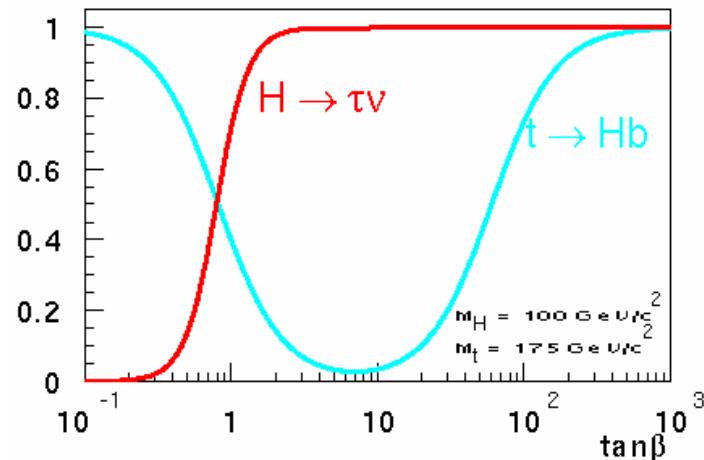


- CDF and DØ are actively exploring many possibilities in the area of non-Standard Model Higgs searches
- Newest results include:
 - DØ Search for Neutral Higgs in MSSM:
 - ❑ excludes A and h/H for masses 90-150 GeV/c² at high tan β ($>\sim 100$)
 - CDF H⁺⁺ Search:
 - ❑ Limits 135, 135, 115 GeV/c² for exclusive $H_L^{\pm\pm}$ decays to ee, $\mu\mu$, e μ
 - ❑ Limits 110 GeV/c² for exclusive $H_R^{\pm\pm}$ decays to $\mu\mu$
 - DØ Search for $H \rightarrow \gamma\gamma$:
 - ❑ Limits are set for the Branching Ratio vs Mass for both Fermiphobic and TopColor models
- Stay tuned for more in the near future!



Additional Slides

Run I CDF H⁺ Search



DØ H⁺⁺ Search (1)



- search assume the H⁺⁺/-- decay branching ratio to like-sign muons to be 100%.
- Muon ID and analysis requirements
- Make data quality requirements based on official good run lists
- Select di-muon trigger events
- Have muon identification requirements based on:
 - Track segments reconstructed in the muon system, isolation from significant energy deposition in the calorimeter and an associated track from the central tracking system. The muon momentum is taken as the central track momentum
- Muons are required to have $pT > 15$ GeV and $|\eta| < 2$

Dimuon mass spectra at various steps of the event selection procedure

