Searches for Non-SM Higgs Bosons at the Tevatron

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for the CDF & DØ Collaborations

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Higgs Beyond the Standard Model

- **Unlikely that only broken symmetry is Electroweak symmetry**
  - Even without new symmetries a new Higgs triplet is required to obtain Majorana neutrinos

- **Non-SM Higgs searches at the Tevatron focus on a few scenarios**
  - Supersymmetric Higgs particles (5 Higgs's in MSSM)
  - Higgs triplets inspired by see-saw and L-R symmetric theories
  - Fermiophobic Higgs

- **Many promising signatures:**
  - **MSSM**: $H^0 \to \tau\tau$, $bb(H^0 \to bb)$, $tt \to W^{\pm}bH^{\mp}b$ ←
  - **LRSM**: $H^{\pm\pm}H^{\mp\mp} \to l^{\pm}l'^{\pm}l^{\mp}l'^{\mp}$
  - **Fermiophobic**: $H^0 \to \gamma\gamma$

J. Naganoma's talk

Supersymmetric Higgs

- **MSSM requires two complex doublets**
  - One couples to up-type fermions, the other to down-type fermions
  - Ratio of vacuum-expectation-values is "tanβ" parameter

- **Eight degrees of freedom**
  - Three go to $W^{\pm}$ and Z^0 masses
  - Five physical scalars: three neutral (h^0, H^0, A^0) and two charged ($H^{\pm}$)

- **Properties determined by pseudoscalar mass (m_A) and tanβ**
  - Typically $m_h < m_A < m_H$ and $m_{H^{\pm}} \sim m_A$
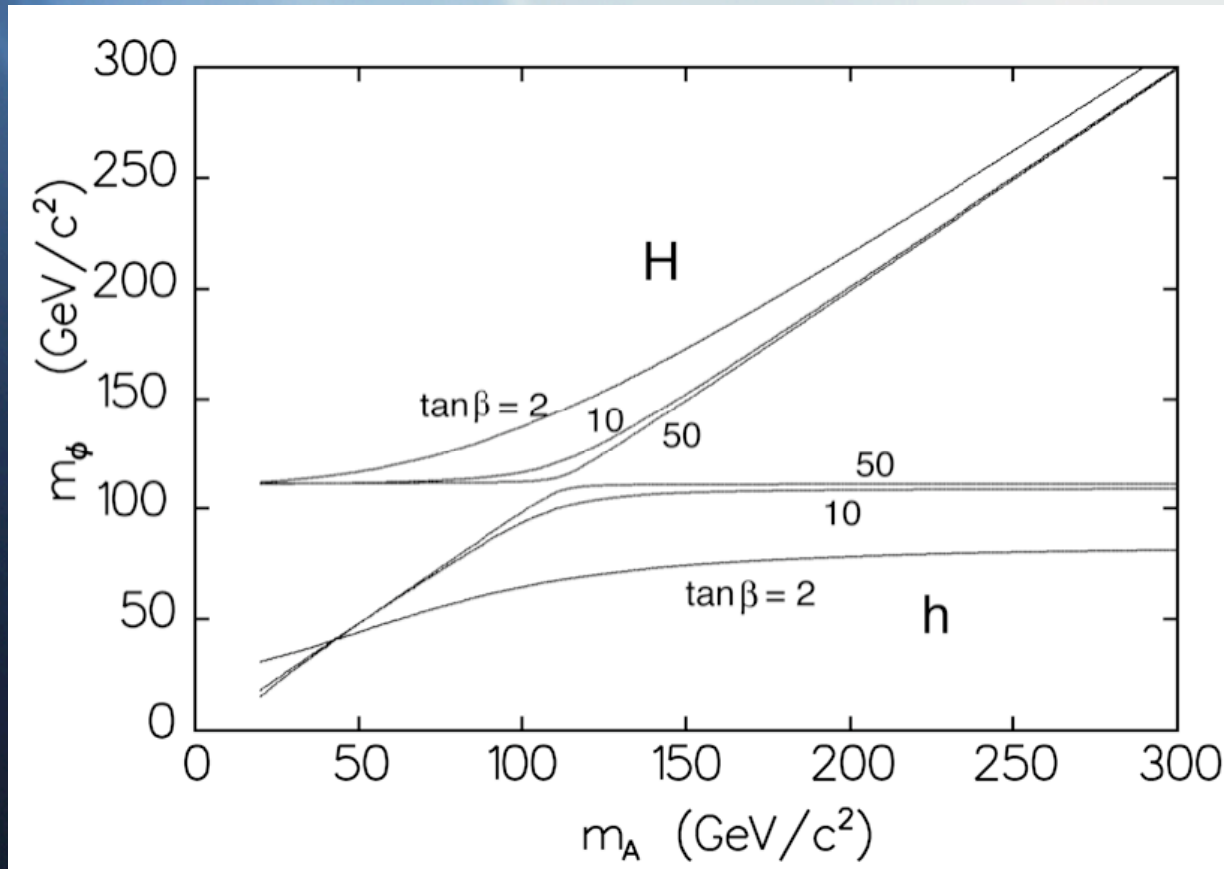 - For tanβ ~ 1, light Higgs h is SM Higgs

Higgs at High tanβ

- **Down-type fermion processes enhanced by tan²β**
  - Tevatron cross sections can increase from O(pb) to O(100 pb)
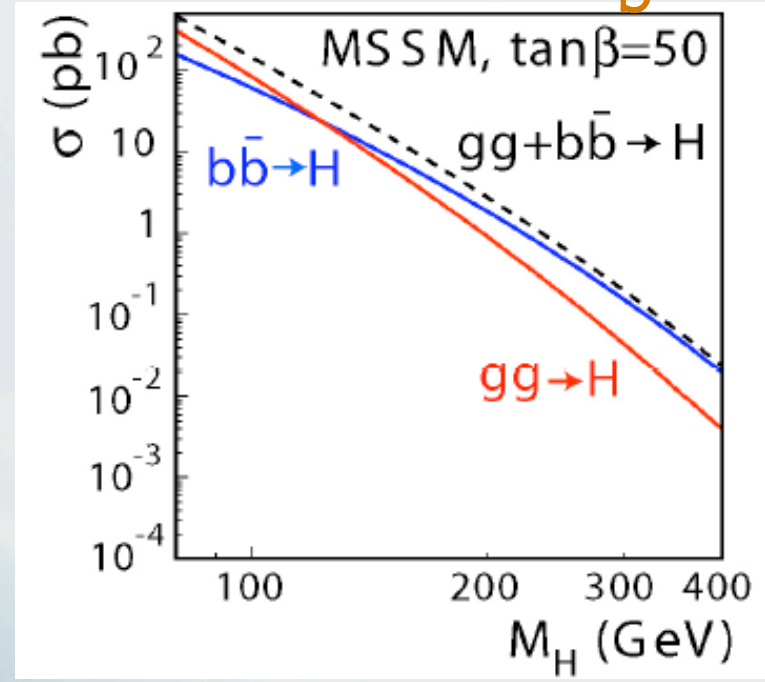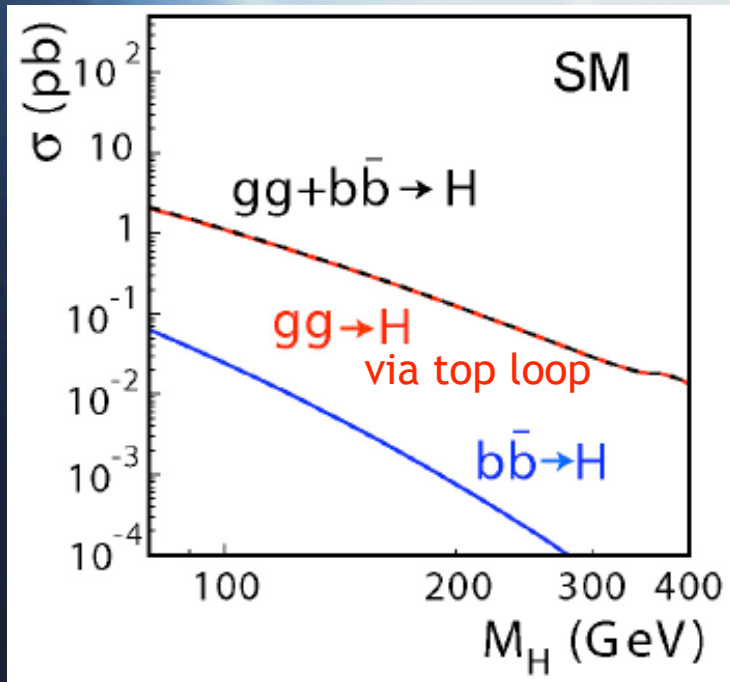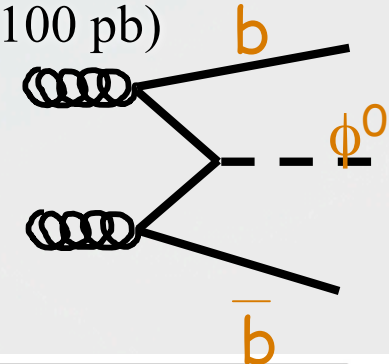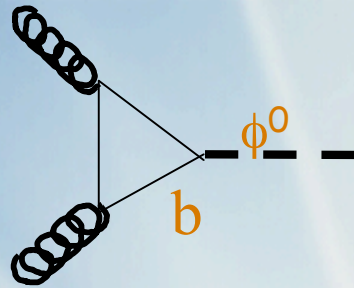
Higgs at High tanβ

Degeneracy occurs at high tanβ between A and h ($m \lesssim 100$ GeV) or H ($m \gtrsim 100$ GeV)
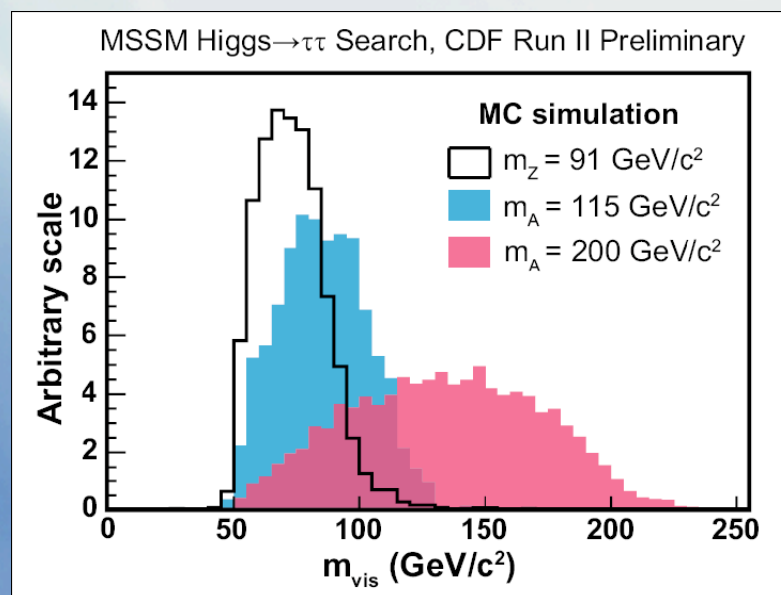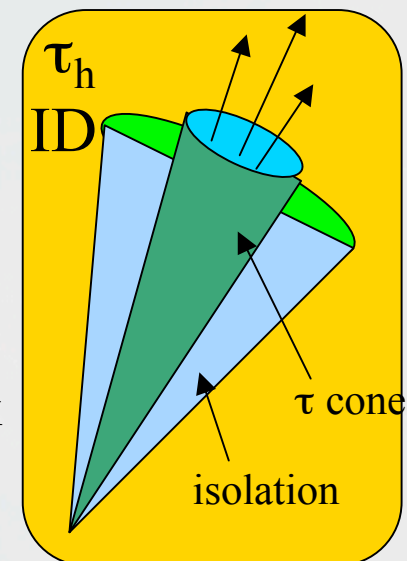
Non-degenerate scalar is SM-like

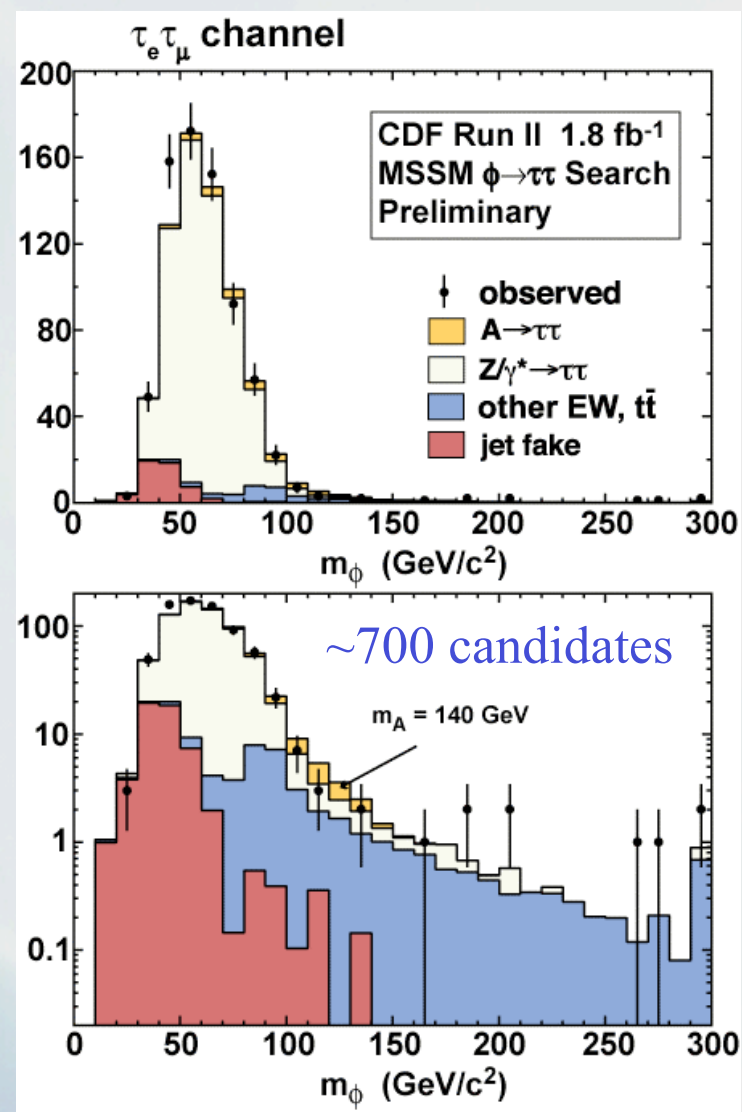High tanβ: Higgs decays dominantly to bb(90%) and $\tau\tau$(10%)

Almost no BR to WW

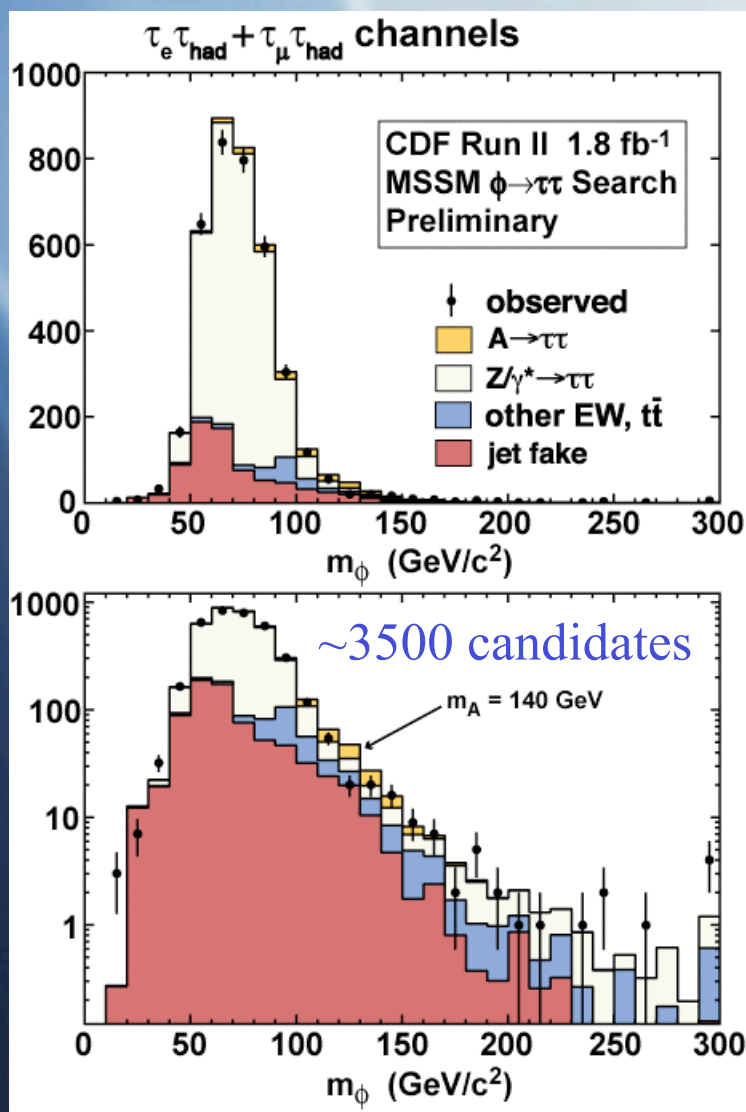# CDF Search for Higgs → ττ

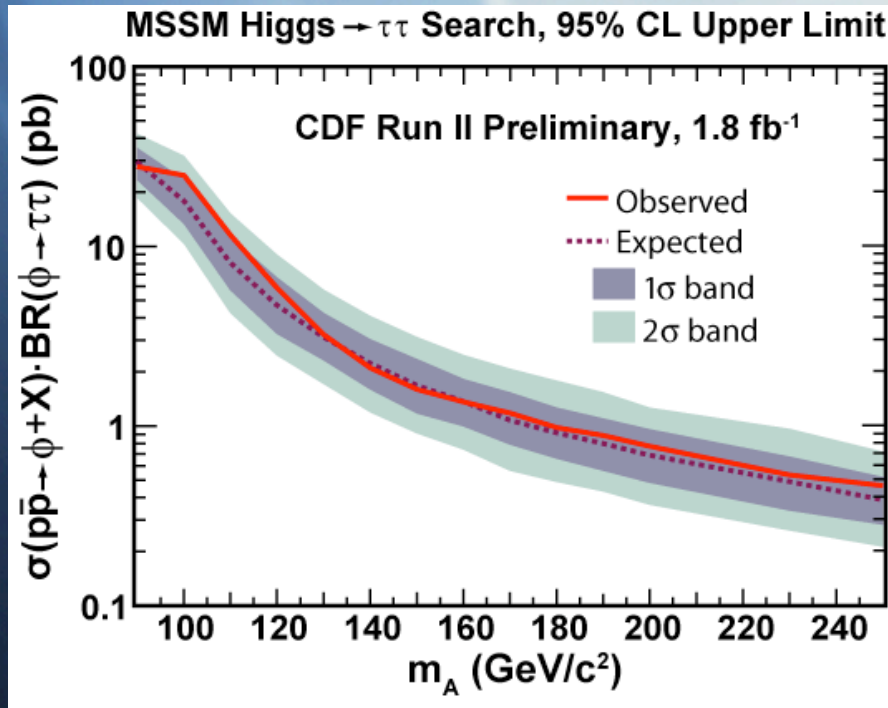- **Analysis hinges on tau reconstruction**
  - Tau identification: Reduce dijet and W+jet backgrounds
    - *No energy in region surrounding tau cone (isolation)*
    - *Track counting and charge assignment*

  - Tau energy resolution: Maximize significance of mass peak
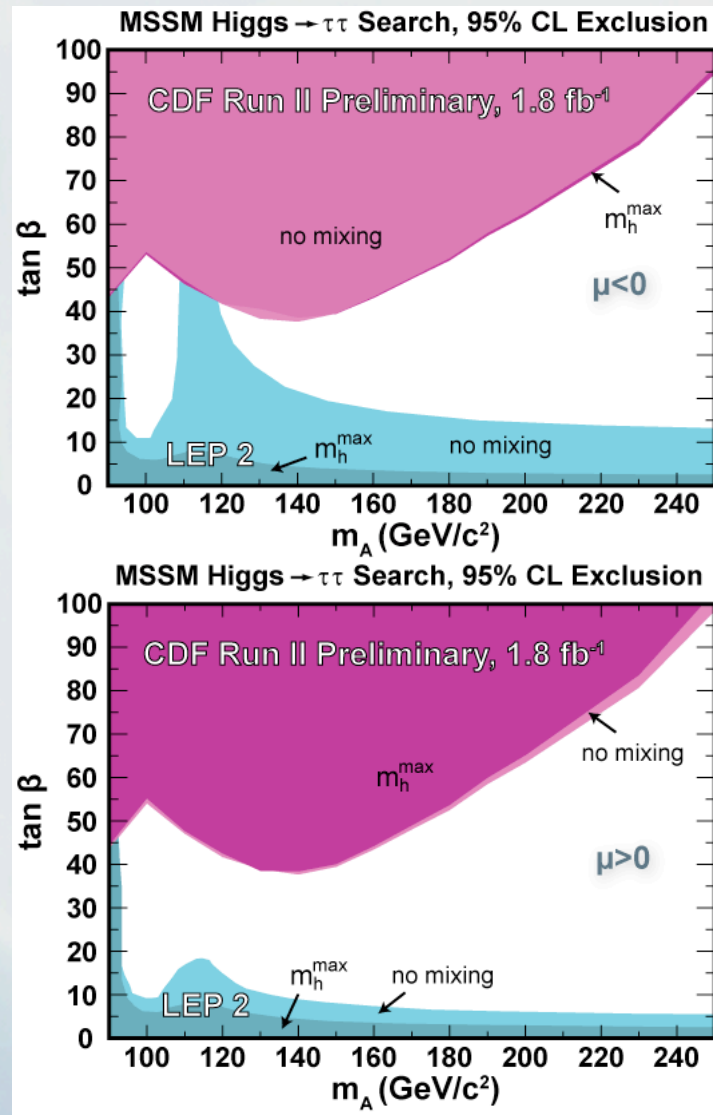   - *Combine track momentum and EM calorimeter energy*

MSSM Higgs→ττ Search, CDF Run II Preliminary

MC simulation
- m_Z = 91 GeV/c²
- m_A = 115 GeV/c²
- m_A = 200 GeV/c²

Arbitrary scale

m_{vis} (GeV/c²)

CDF Search for Higgs → ττ

CDF Search for Higgs → ττ

**Data consistent
with background**

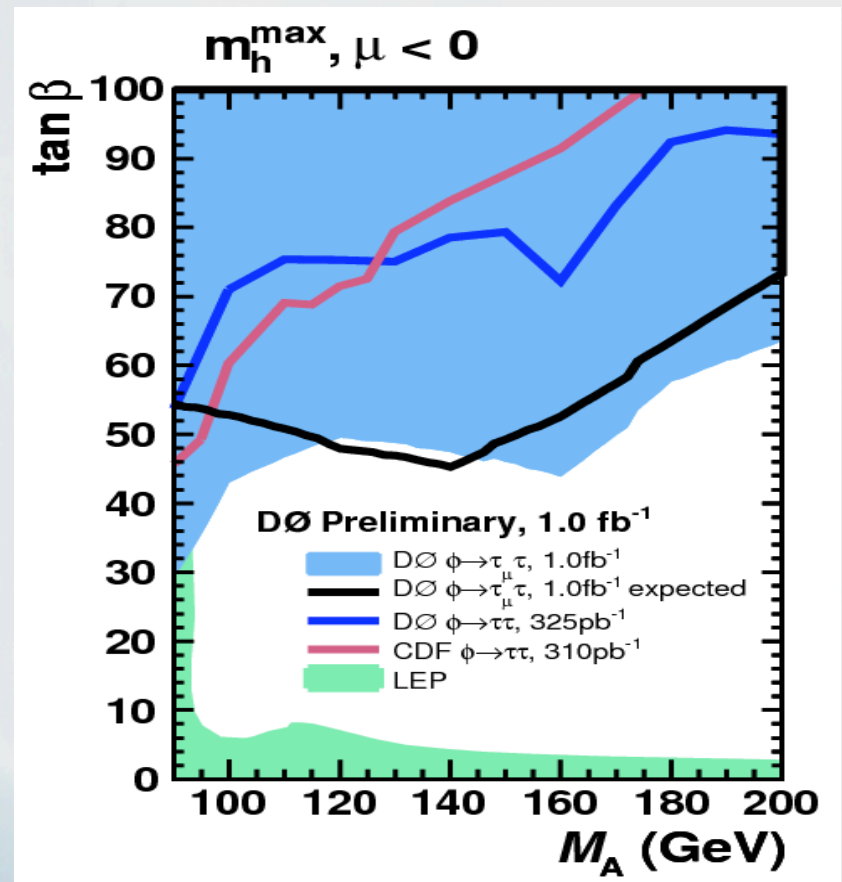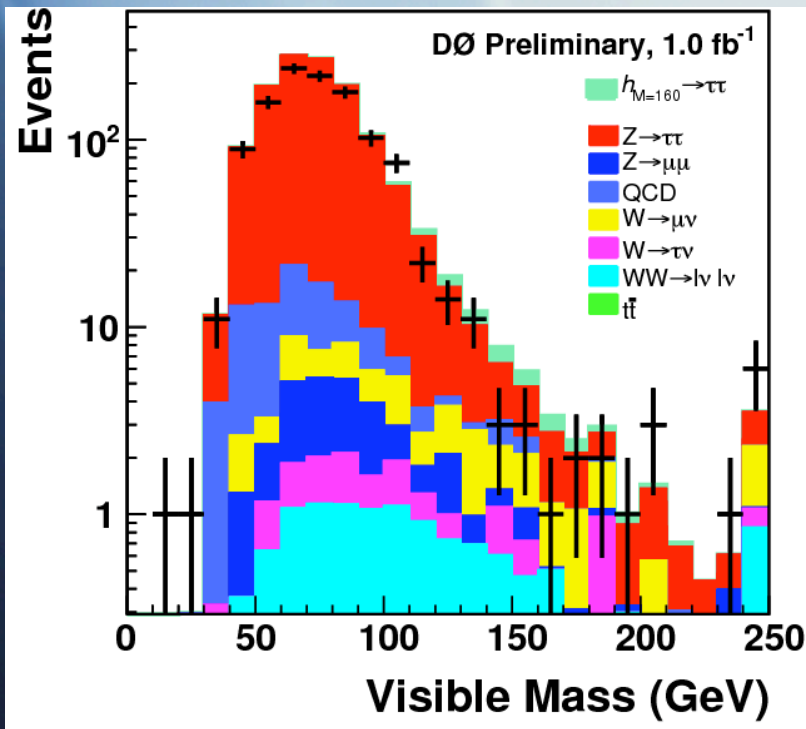**Tau reconstruction
improvements ongoing**

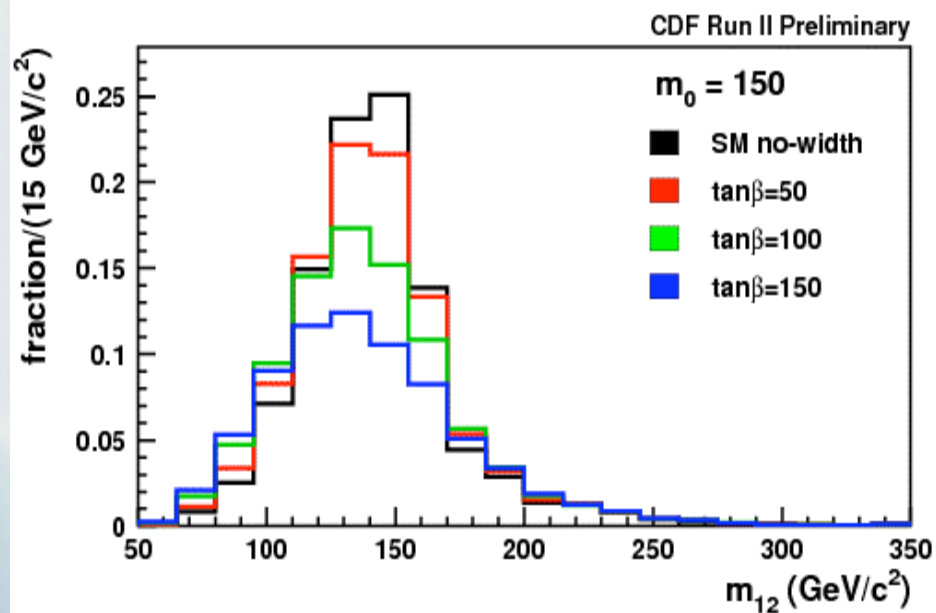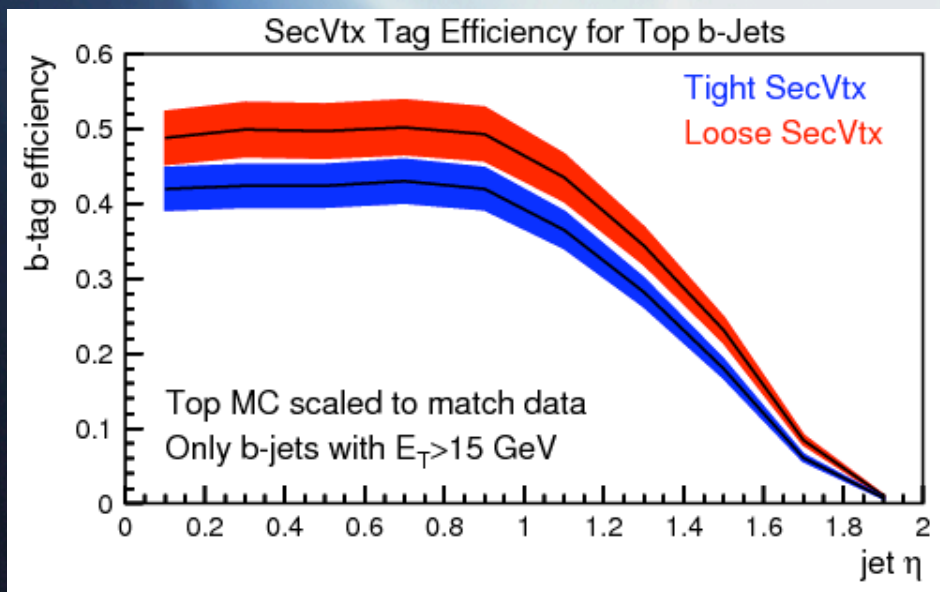# DØ Search for Higgs → ττ

Use neural network for tau identification
**Search for peaks in mass reconstructed from visible tau decay products**

Also search for $b(H \to \tau\tau)$
Updating with all tau decays

CDF Search for $bbH \rightarrow bbbb$

- **Analysis hinges on *b* reconstruction (akin to low-mass SM Higgs)**
  - *b*-jet identification: Reduce light-flavor jet backgrounds
    - *Require 3 b-tagged jets*

  - *b*-jet energy resolution: Maximize significance of leading jets' mass peak
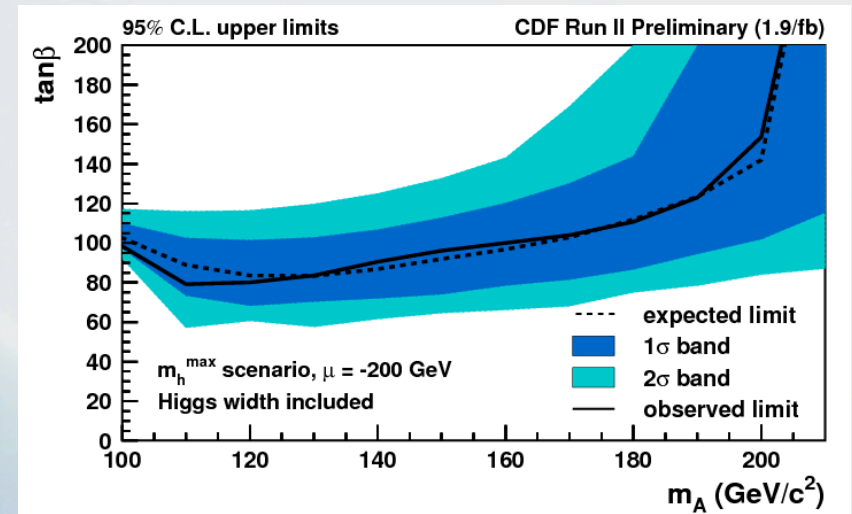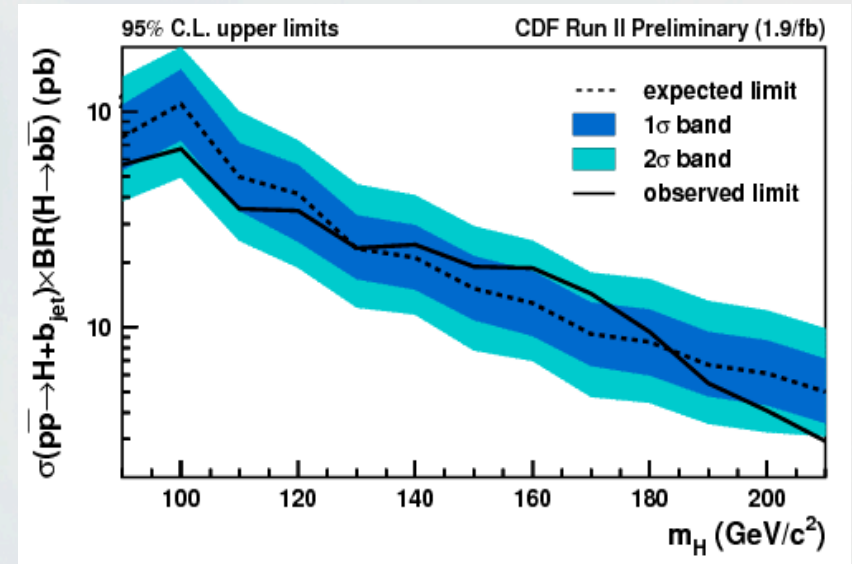   - *Less important at highest tanβ due to intrinsic Higgs width*
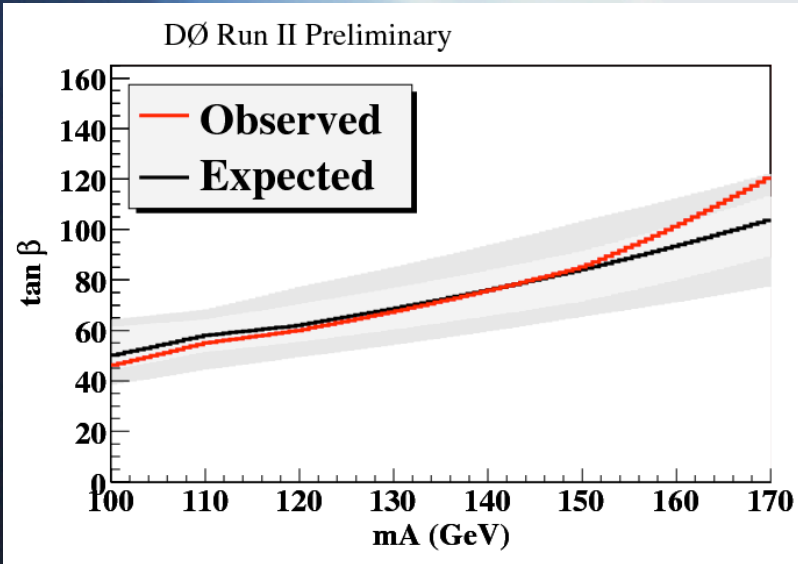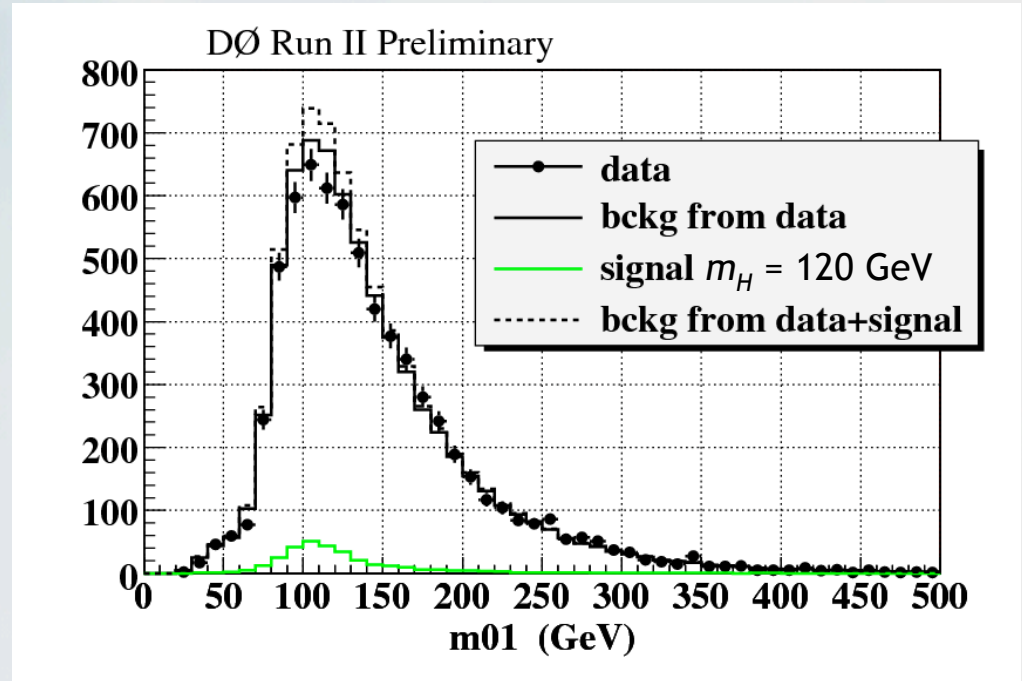
CDF Search for $bbH \rightarrow bbbb$
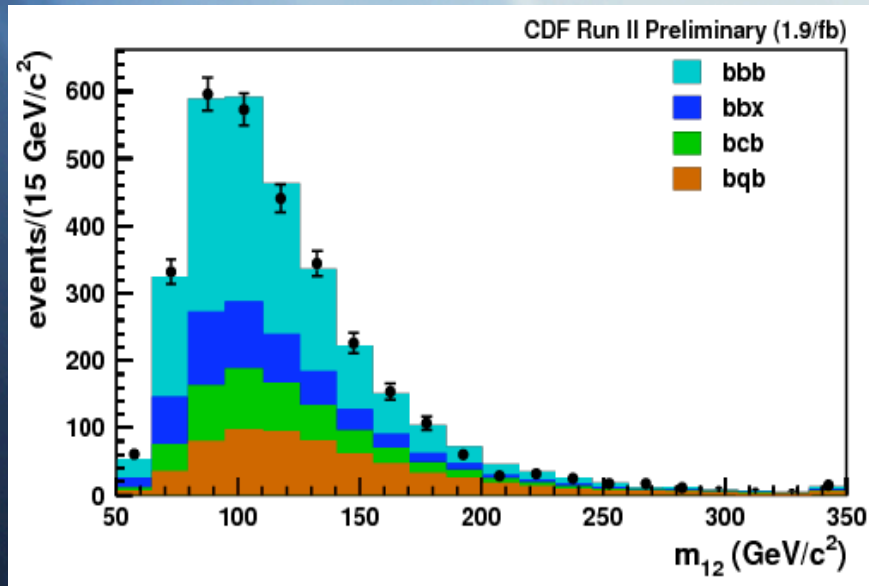
Data consistent with background

Working on reducing background systematics

Chris Hays, DIS 2008

DØ Search for $bbH \rightarrow bbbb$
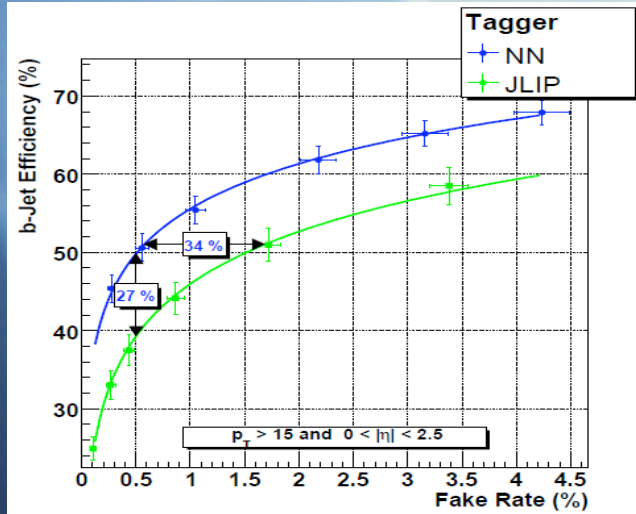
Predict background using a 2-tag data sideband region

Data consistent with prediction

Higgs Triplets

- **Higgs $SU(2)_R$ triplet provides see-saw mechanism**
  - Occurs naturally in left-right symmetric models
  - H^0 has large vacuum-expectation-value ($v_R \sim 10^{11}$ GeV) and couples to $v_R v_R$
  - Mass matrix has small Dirac term $\sim m_l$ and eigenvalues $\sim m_l/v_R$ m_l v_R
  - $H^\pm$ couples to $l^\pm v$ and $H^{\pm\pm}$ couples to $l^\pm l^\pm$ 0 m_l
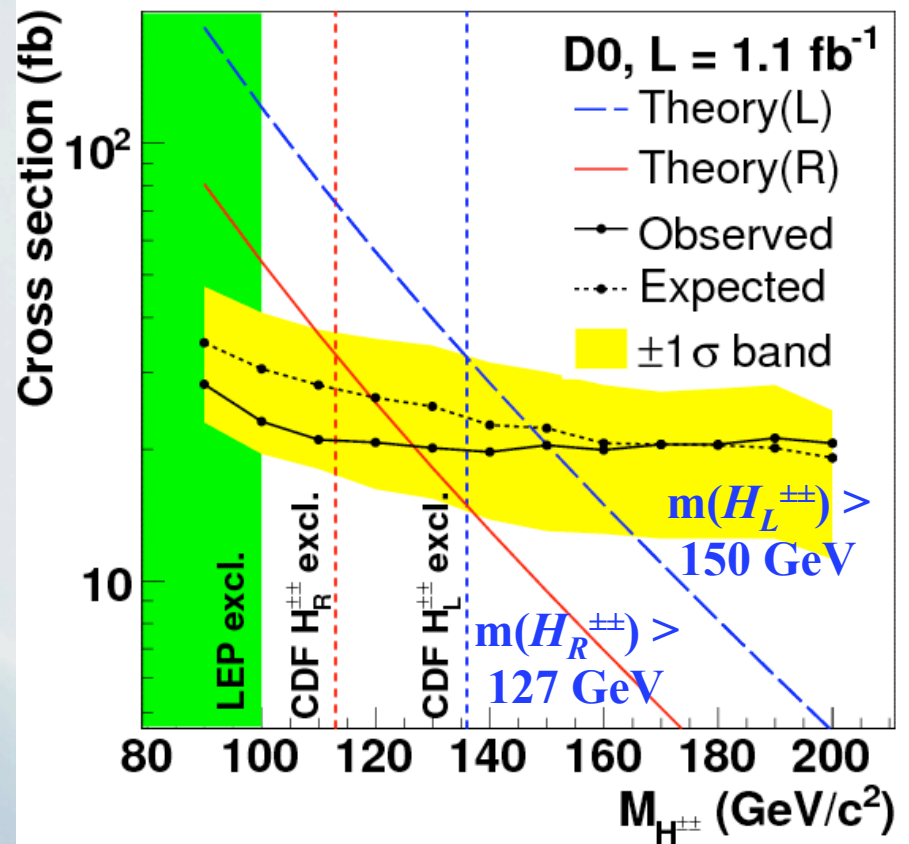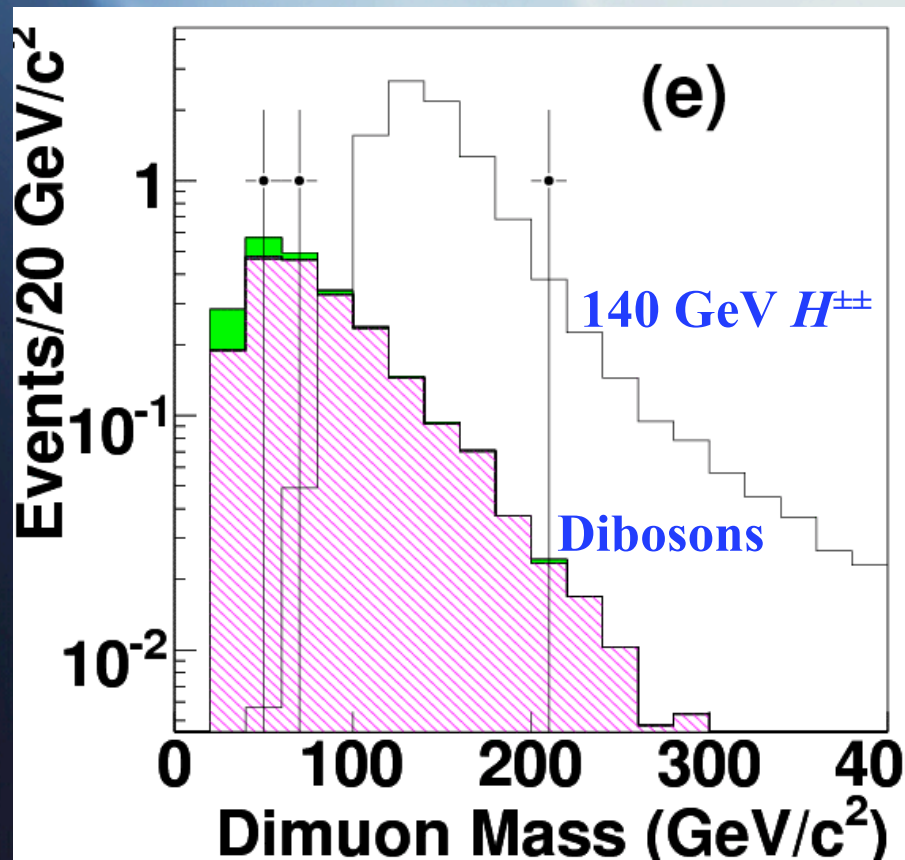 - Supersymmetric LRSM can have O(100 GeV) Higgs triplets

- **Doubly charged Higgs pair-produced at the Tevatron**
  - Single production possible but highly suppressed
  - Signature of mass peak in like-charge leptons has small background

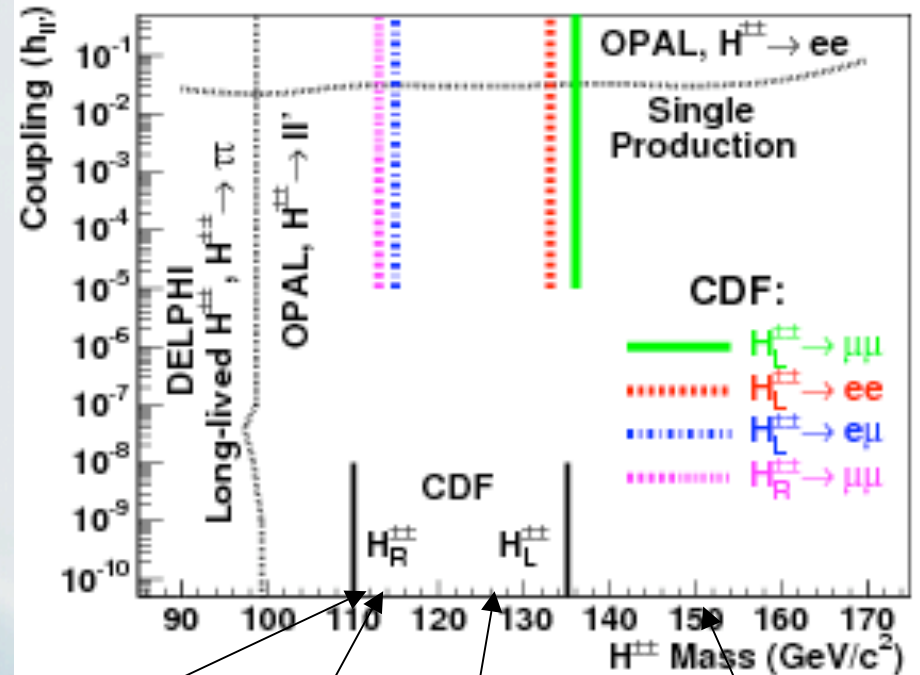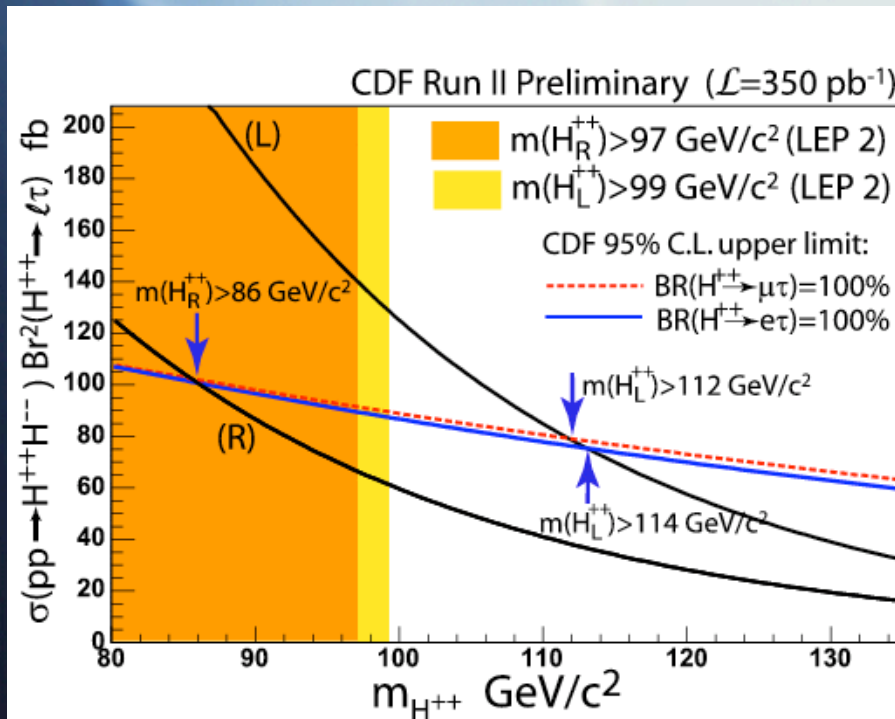- **Indirect constraints: couplings $\lesssim 0.1$ for $m_H \sim 100$ GeV**

DØ Search for Doubly Charged Higgs

- **Require 3 muons**
  - Plot same-sign muon mass

CDF Searches for Doubly Charged Higgs

- **Search all *ll'* final states except ττ**
  - Also search for long-lived doubly charged Higgs

$H_L^{\pm\pm} \to \mu\tau$

$H_L^{\pm\pm} \to e\tau$

$DØ\ H_R^{\pm\pm} \to \mu\mu$

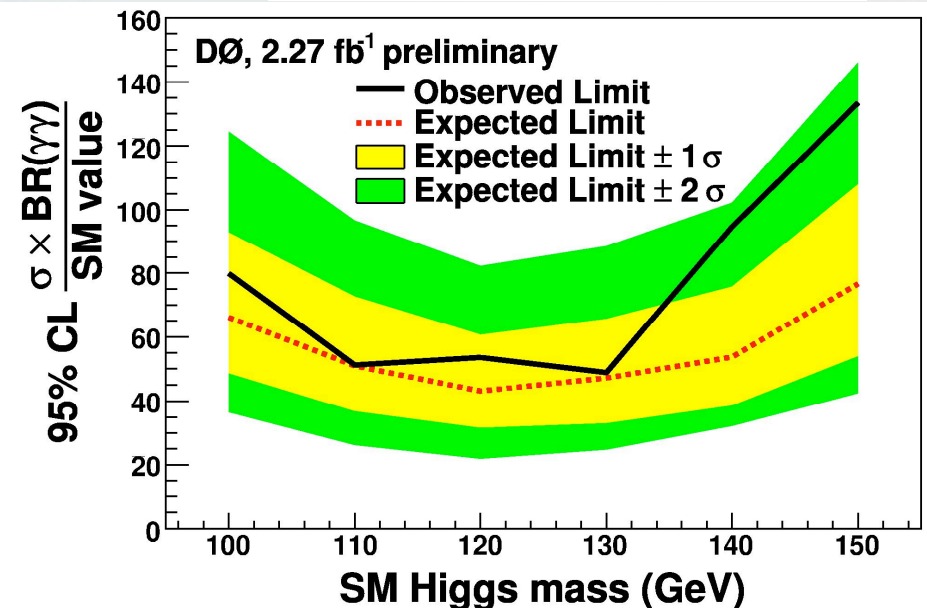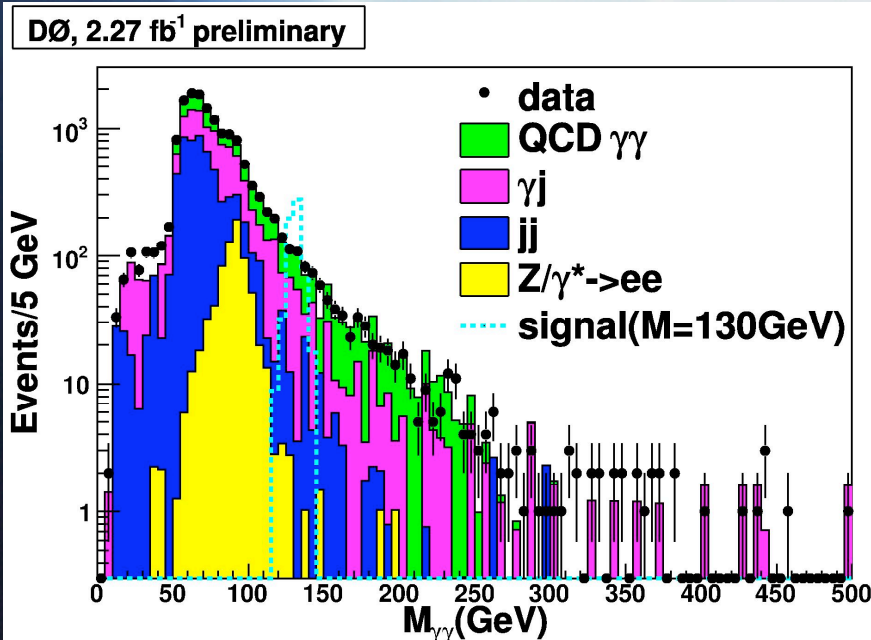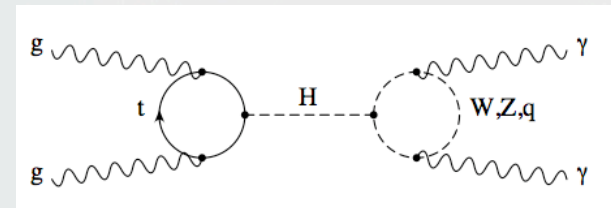$DØ\ H_L^{\pm\pm} \to \mu\mu$

DØ Search for Fermiophobic Higgs

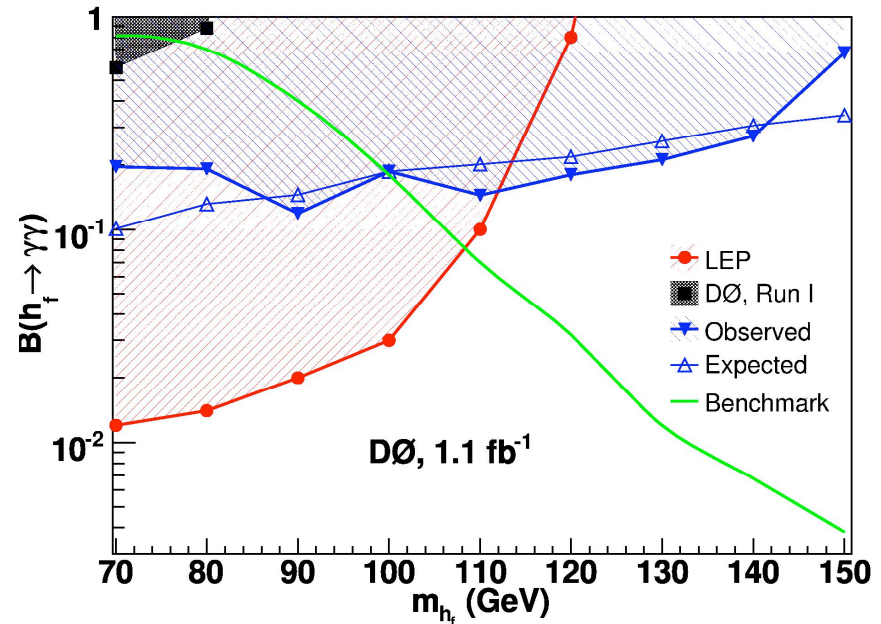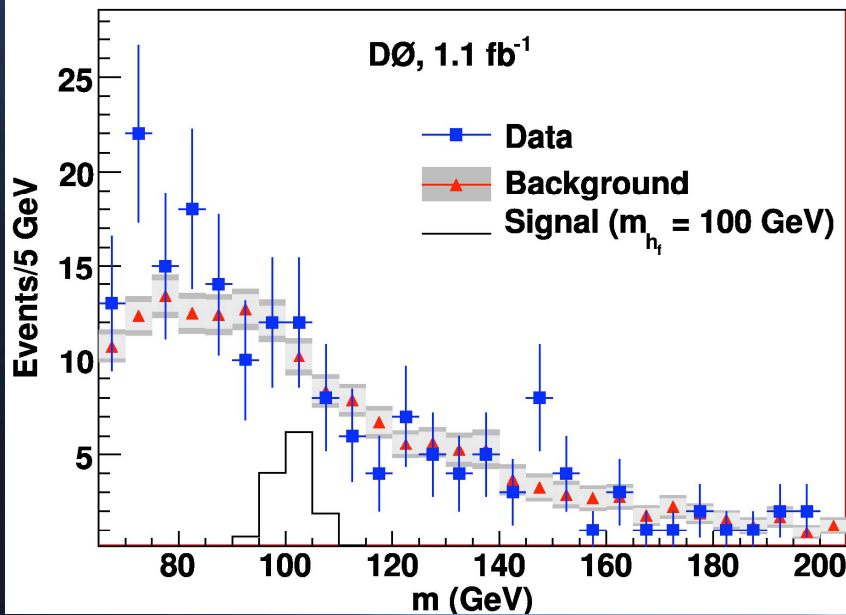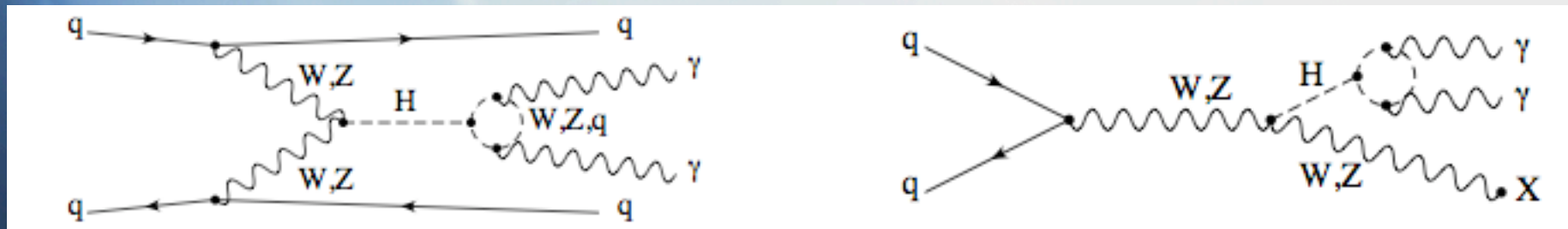- **H → γγ enhanced in fermiophobic models**
  - DØ searches for fermiophobic Higgs produced via gluon fusion, vector-boson fusion, and associated production
    - *Use neural network for photon identification*

Gluon fusion search:

DØ Search for Fermiophobic Higgs

Vector boson fusion/associated production search:
require diphoton system to have p_T > 35 GeV

Summary

- **Higgs physics does not end with the SM Higgs boson**
  - Electroweak symmetry may not even be broken by SM Higgs!

- **Tevatron exploring many possibilities for Higgs beyond the SM**
  - Supersymmetric Higgs
  - Higgs triplets
  - Fermiophobic Higgs

- **More than one Higgs could be awaiting discovery in the Tevatron data!**