Recent Results from the Tevatron

Charged Higgs 2010 Uppsala

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Outline

Overview

- Tevatron zeros in on SM Higgs boson.
  - 95% CL exclusion $100 < m_h < 109$ GeV and $158 < m_h < 175$ GeV (LEP $m_h < 114$ GeV)
- No evidence restricts SM to a single Higgs doublet;
- Simplest extension add a second Higgs doublet;
  - Required by MSSM;
- Additional doublet adds 4 degrees of freedom leading to 4 new spin zero bosons (5 total h^0, H^0, A^0, $H^{\pm}$);
- Generic models (require no FCNC at LO & $\rho \approx 1$)
  - Type I—fermions couple to a single doublet;
  - Type II—Up-type fermions couple to one doublet, Down-type to other doublet (*required by MSSM*);
  - Type III—fermions couple to both doublets
- Analysis are based on large tH^+b coupling.

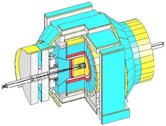
Overview
Tevatron Results

- Tevatron charged Higgs ($H^{\pm}$) results:
  - Published: Run II 6, Run I 6; Preliminary Run II 1.
    - Run I 6 D0 2 CDF 4
    - Run II 6+1 D0 4 CDF 2+1
    - 5 results on H^{++} also, will not be discussed D0 2 CDF 3
  - Covered mass range: 60 to 300 GeV.
  - Techniques:
    - Indirect: Deviations from SM branching ratios.
    - Direct: Search for mass resonance.
  - $H^{\pm}$ decay modes $M_{H^{\pm}} < m_t + m_b$, $M_{H^{\pm}} > m_t + m_b$:
    - $H^{\pm} \to \tau\nu_{\tau}$ $\quad H^{\pm} \to cs$ $\quad H^{\pm} \to t^{*}b \to W^{\pm}\bar{b}b$

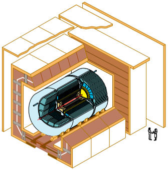
      $H^{\pm} \to A^{0}W^{\pm}$ $\quad H^{\pm} \to h^{0}W^{\pm}$ $\quad H^{\pm} \to tb$

Tevatron

$p\bar{p}$ $\sqrt{s} = 1.96$ TeV $\int \mathcal{L}dt \gtrsim 8$ fb^{-1}



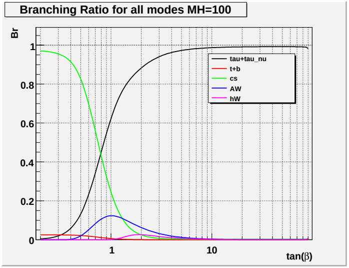
CDF

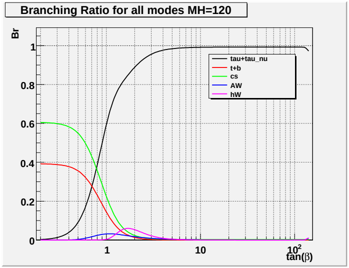


DØ

Indirect Search
Overview

- Analysis are based on type 2 models
  - Concentrate on $m_{H^\pm} < m_t + m_b$
  - Search for: $H^\pm \to \tau\nu_\tau$ $H^\pm \to cs$ $H^\pm \to h^0W^\pm$ $H^\pm \to A^0W^\pm$ $H^\pm \to t^*b \to W^\pm\bar{b}b$

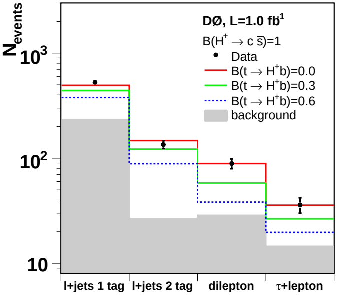


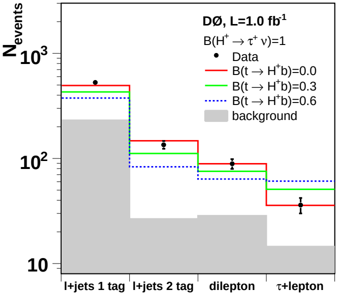


FeynHiggs m_h^{max}

Indirect Search
Overview

- Search for deviations from SM branching ratios.
  - N_{events} will increase/decrease depending on channel.
    - $H^{\pm} \to \tau\nu_{\tau}$ Increase final states with τ decrease final states with e, μ, all-hadronic.
    - $H^{\pm} \to cs$ Increase all-hadronic final states decrease final states with leptons.





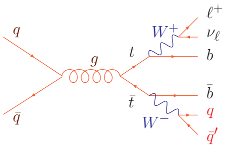
DØ Ratio Method

Technique Overview 1

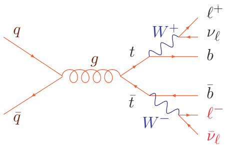
- Measure cross section ratios
  - Cross section measurement

$$\sigma_{t\bar{t}}^{\text{exp}} = \frac{\left[\sigma_{t\bar{t}} \cdot \text{B}(t\bar{t} \to X)\right]_{\text{exp}}}{\left[\text{B}(t\bar{t} \to X)\right]_{\text{SM}}} = \sigma_{t\bar{t}}$$

$$\sum_X \text{B}(t\bar{t} \to W^{\pm}b \to X) = 1$$



$\ell + \text{jets}$



$\ell + \ell$

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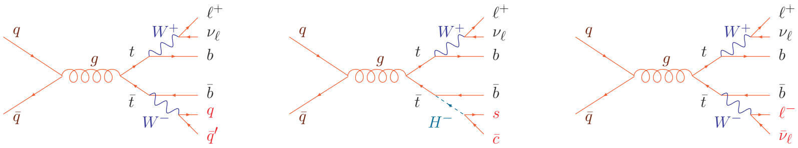
$$\sum_X \text{B}(t\bar{t} \to W^{\pm}b \to X) + \sum_X \text{B}(t\bar{t} \to H^{\pm}b \to X) = 1$$



ℓ + jets $\ell + \ell$

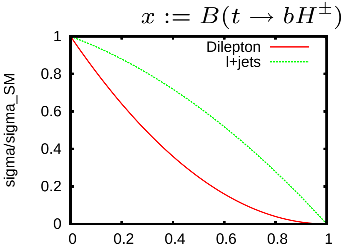
DØ Ratio Method

Technique Overview 2

- If ratio does not equal 1, can imply new physics.
- Assume leptophobic $H^{\pm}$ small tan β
  - $H^{\pm} \rightarrow cs \quad \Rightarrow \quad \sigma^{\ell\ell}/\sigma^{\ell j} < 1 \qquad (\ell = e \text{ or } \mu)$
- Tauonic $H^{\pm}$ model large tan β
  - $H^{\pm} \rightarrow \tau\nu_{\tau} \quad \Rightarrow \quad \sigma^{\tau+\ell}/\sigma^{\ell\ell\text{-}\ell j} > 1$
- $\sigma_{\text{meas}}/\sigma_{\text{SM}}$ vs. $B(t \rightarrow H^{\pm}b)$

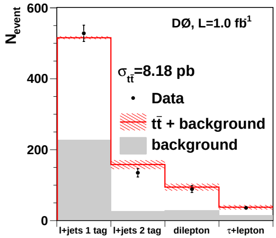
  $B(H^{\pm} \rightarrow cs) = 1$

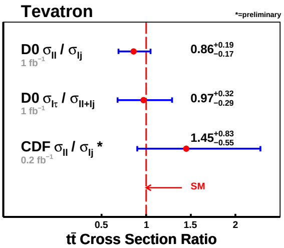
  σ_{meas} assuming SM BR



DØ Ratio Method
Results 1

- Ratios computed using pseudodata data sets for numerator and denominator.
  - Decay channels are exclusive.
  - Account for correlations in systematic uncertainties.
  - Account for misidentified decay channels.

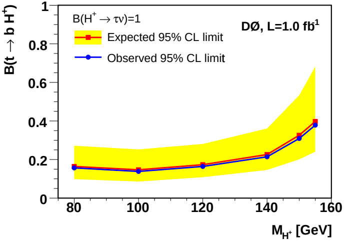


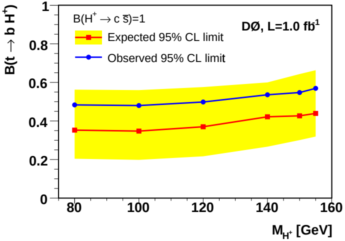


DØ Ratio Method

Results 2

- Two models assumed B($H^\pm \to \tau\nu_\tau$) $= 1$ and B($H^\pm \to cs$) $= 1$.
  - Calculate efficiencies for different B($t \to H^\pm b$)).
  - Limit set using Feldman Cousins frequentist approach.





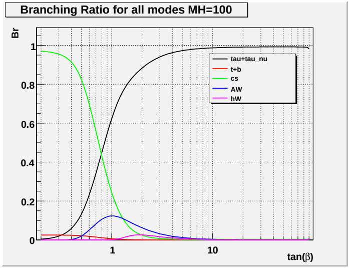
Phys. Rev. D 80, 071102(R) (2009) DØ

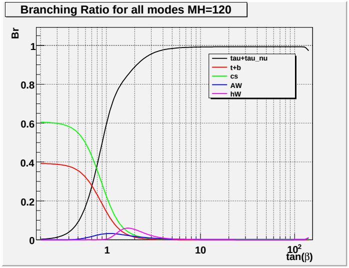
CDF MSSM

- Analysis based on MSSM using CPsuperH calculation.
- Covers entire tan β range.

$H^\pm \to \tau\nu_\tau$ $H^\pm \to cs$ $H^\pm \to t^*b \to W^\pm \bar{b}b$

$H^\pm \to A^0W^\pm$ $H^\pm \to h^0W^\pm$



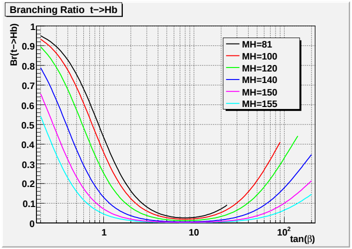


FeynHiggs m_h^{max}

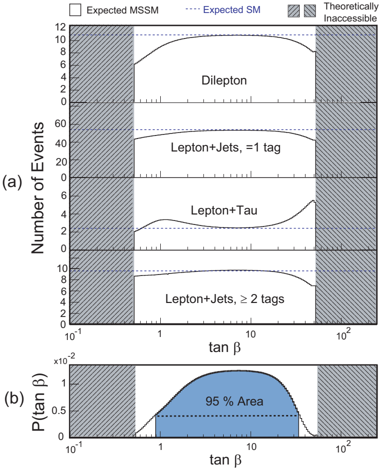
CDF MSSM

- $\int Ldt = 193 \text{ pb}^{-1}$
- Covers full tan β range
- Expected number of events SM, MSSM (2HDM)
- Exclusion based on CPsuperH
- Bayesian limit

$t \rightarrow H^{\pm} b$



FeynHiggs



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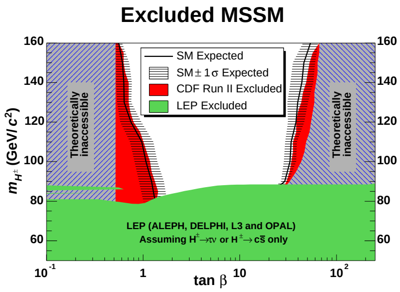
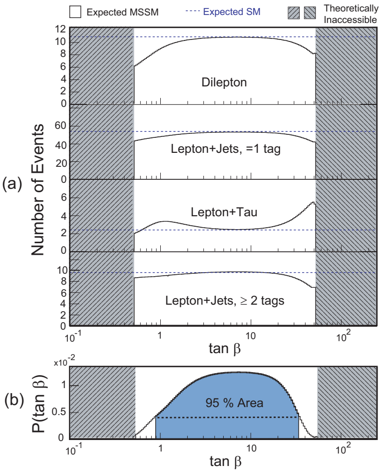




Phys. Rev. Lett 96, 042003 CDF

DØ Topological Search

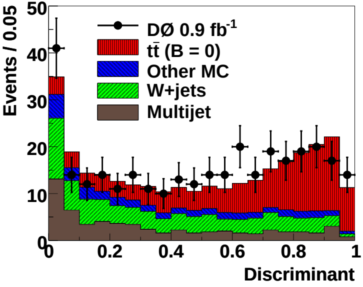
Results 1

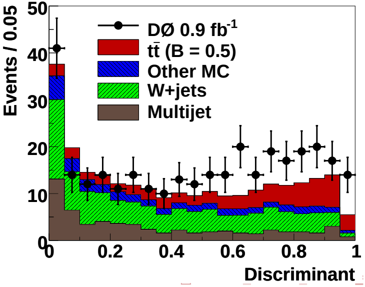
- Based on $t\bar{t} \to \ell +$ jets cross section measurement.

  Phys. Rev. Lett. **100** 192004 (2008) DØ

- Assume B$(H^{\pm} \to \tau\nu_{\tau}) = 1$
- Discriminant (**x** kinematic variables)

$$\mathcal{D}(\mathbf{x}) = \frac{P(\mathbf{x}|\mathcal{S})}{P(\mathbf{x}|\mathcal{S}) + P(\mathbf{x}|\mathcal{B})}$$

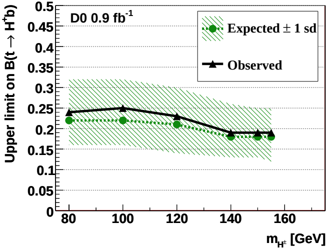


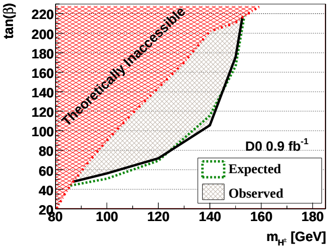


DØ Topological Search

Results 2

- Limits assume B$(t \to \tau\nu_\tau) = 1$
- Use modified frequentist approach
- Exclusion regions based on m_h^{max} scenario FeynHiggs



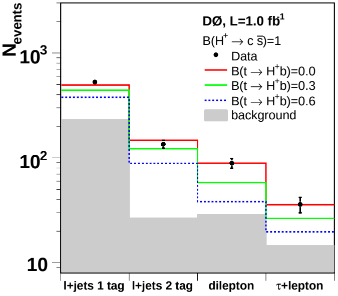


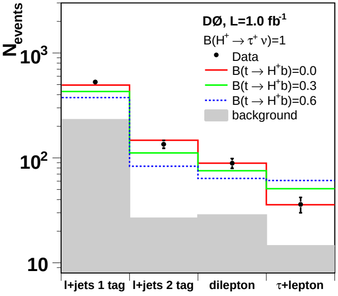
Phys. Rev. D 80, 051107(R) (2009) DØ

DØ Global Fit
Overview

- Limits based on previously measured final states.
  - $t\bar{t} \to \ell^{\pm} + \text{jets}$, $t\bar{t} \to \ell^{\pm} + \ell^{\mp}$, $t\bar{t} \to \tau^{\pm} + \ell^{\mp}$
- Limits for B$(H^{\pm} \to \tau\nu_{\tau}) = 1$, B$(H^{\pm} \to cs) = 1$, and B$(H^{\pm} \to \tau\nu_{\tau})$ + B$(H^{\pm} \to cs) = 1$

$$M_{H^{\pm}} = 80 \text{ GeV}$$

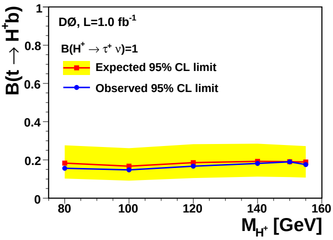




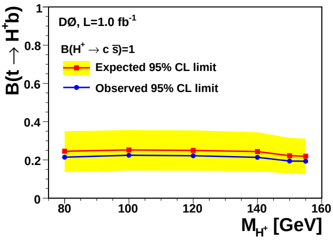
DØ Global Fit
Tauonic and Leptophobic Limits

- Limits assume SM $\sigma_{t\bar{t}}$
  - Data is split into 14 subchannels
  - Channels are statistically independent.

$\mathrm{B}(H^{\pm} \rightarrow \tau\nu_{\tau}) = 1$



$\mathrm{B}(H^{\pm} \rightarrow cs) = 1$

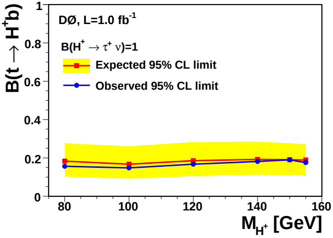


DØ Global Fit

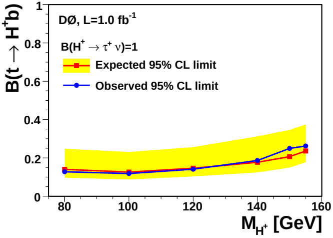
Tauonic Simultaneous Fit

- Measure $\sigma_{t\bar{t}}$ and B($t \to H^{\pm}b$) simultaneously
  - Reduces systematics: $\sigma_{t\bar{t}}^{\text{theory}}$, Luminosity, ...
  - Requires small correlation between fitted quantities
    - holds for tauonic $M_{H^{\pm}} \leq 130$ GeV, does not for Leptophobic
    - Fitted $\sigma_{t\bar{t}}$ flat with $M_{H^{\pm}}$
  - Improves sensitivity for $M_{H^{\pm}} < 140$ GeV by $> 20\%$

Fixed $\sigma_{t\bar{t}}$



Fit $\sigma_{t\bar{t}}$



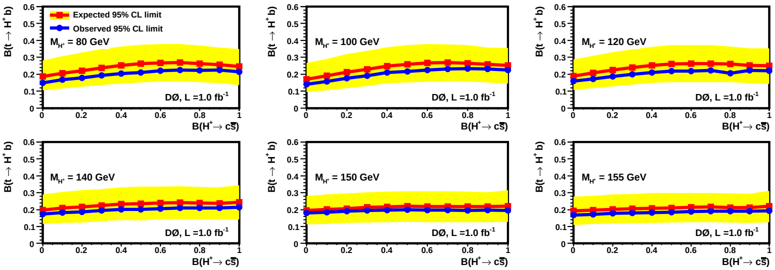
Phys. Lett. B **682** 278 (2009) DØ

DØ Global Fit

Tauonic + Leptophobic Limits

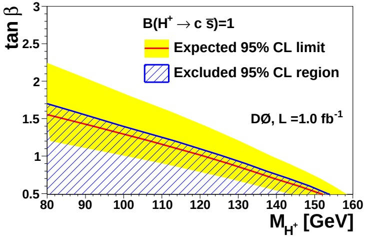
- Limits assume SM $\sigma_{t\bar{t}}$
  - Data is split into 14 subchannels
  - Channels are statistically independent.

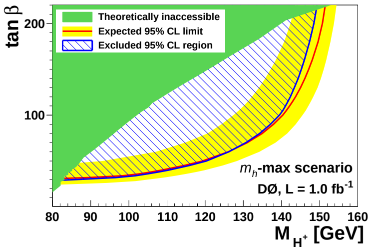
$$B(H^{\pm} \to \tau\nu_{\tau}) + B(H^{\pm} \to cs) = 1$$

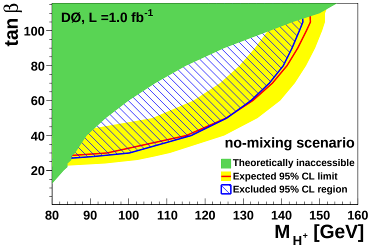


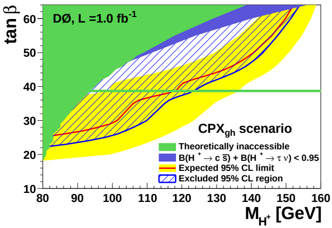
DØ Global Fit

Exclusion





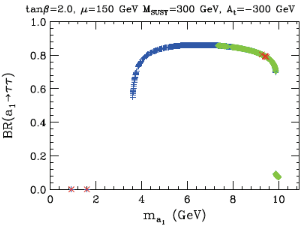


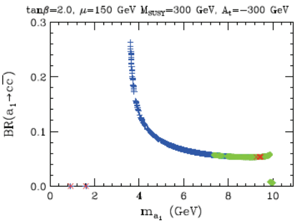


CDF NMSSM A^0 and $H^\pm$

Overview

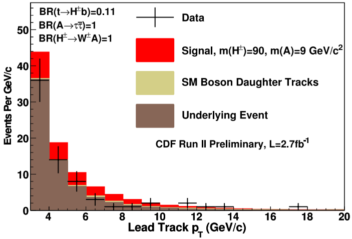
- NMSSM contains additional singlet superfield relative to MSSM $\Rightarrow$ additional CP-even and CP-odd Higgs bosons.
- $m_{A^0} < 2m_b$ not ruled out and $\tan\beta \lessapprox 2.5$ in NMSSM within Tevatron reach.
  - $m_{H^\pm} \approx 100$ GeV $\Rightarrow$ B$(H^\pm \to W^\pm A^0) > 0.5$
  - $0.4 < \tan\beta < 1 \Rightarrow 0.1 <$ B$(t \to H^\pm b) < 0.4$
  - B$(A^0 \to \tau^+\tau^-) = 1 \Rightarrow$ low p_T isolated tracks
    $t \to W^\pm b\ \tau^+\tau^-$

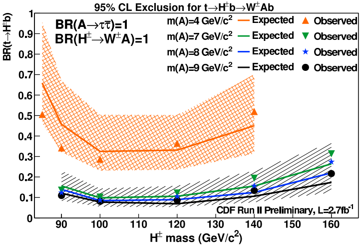




CDF NMSSM A^0 and $H^\pm$

- Uses 2.7 fb^{-1}, $\sigma(t\bar{t})/\sigma(Z/\gamma^*)$ measurement ($t\bar{t} \to \ell +$ jets).
- $t \to H^\pm b \to W^\pm A^0 b$ with $B(A^0 \to \tau^+\tau^-) = 1$.
- Assume:
  - $m_{H^\pm} \approx 100$ GeV
  - $m_{A^0} < 2m_b$
- The τ lepton identified as a single track



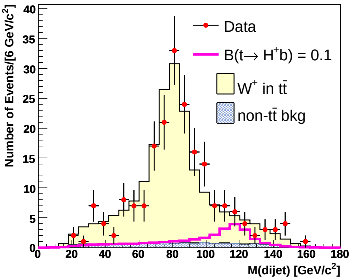


CDF Note 10104 & Phys. Rev. Lett. **105**, 012001 (2010)

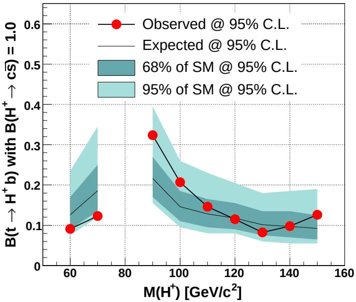
CDF Direct

- Data: $\ell^{\pm} +$ jets mass measurement w/2 b-tags (2.7 fb^{-1})
- Search for 2nd peak in dijet mass spectrum ($W^{\pm}$ and $H^{\pm}$)
- Assume $B(H^{\pm} \to cs) = 1$
  - For $M_{H^{\pm}} < M_W$ assume generic scalar $t \to X^{\pm}(ud)b$

Dijet Mass Spectrum



95% CL Limit 2.2 fb^{-1}



Phys. Rev. Lett. 103, 101803 (2009) CDF

DØ Large Mass

Outline

- Search for $q\bar{q}' \to H^+ \to t\bar{b} \to W^+ b\bar{b} \to \ell^+ \nu_\ell b\bar{b}$
  - Same final state as "Single top" s-channel analysis;
  - Use "Single top" data set with $\int L\,dt \approx 0.9$ fb^{-1};
  - Use CompHEP to general H^+ MC samples
    - H^+ masses 180, 200, 220, 240, 260, 280, 300 GeV
    - Generate pure chiral states, then mix to get appropriate model
    - Effective Lagrangian for H^+ quark couplings

$$\mathcal{L} = \frac{g_W}{2\sqrt{2}} H^+ \bar{f}_i \left[g_L^{ij} \left(1 - \gamma^5\right) + g_R^{ij} \left(1 + \gamma^5\right)\right] f_j$$

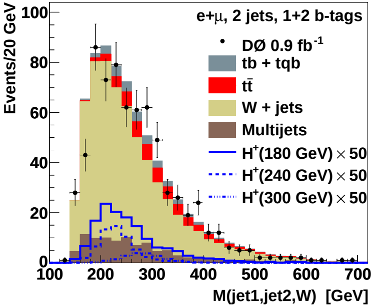
    - Require H^+ decay width be less than $t\bar{b}$ mass resolution $\delta M_{tb} \approx \mathcal{O}(10)$ GeV

DØ High Mass

Discriminant

- M_{tb} used as discriminant to select $H^{\pm}$ events
  - Selected smallest p_z for ν in M_W calculation

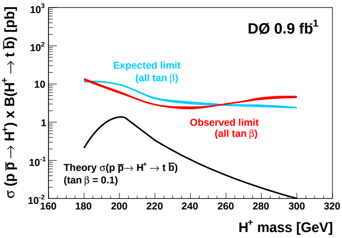
$H^{\pm}$ mass distributions for Type III model



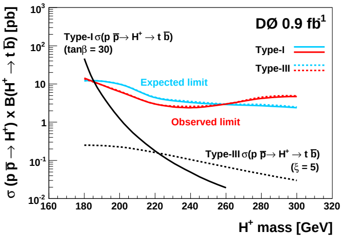
DØ High Mass
Limits

- Limits for Type II and III above expected cross section (under the assumption that $\Gamma_{H^\pm}$ is comparable to detector resolution).
- Can exclude region in $M_{H^\pm}$ $\tan\beta$ space for type I model.

Type II



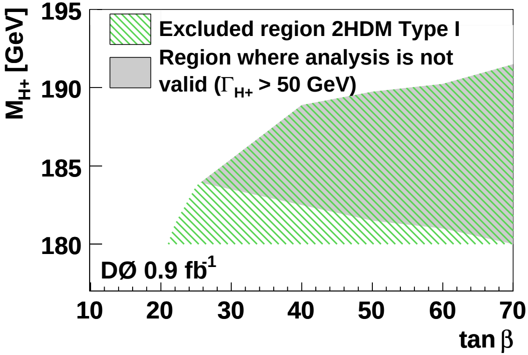
Type I & III



DØ High Mass

Exclusion

Only Type I model has an exclusion region.



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Summary

- Searches in the context of 2HDM
- In the mass range 60 to 300 GeV
- Various decay modes considered

  $H^\pm \to \tau\nu_\tau$ $\quad H^\pm \to cs$ $\quad H^\pm \to t^*b \to W^\pm \bar{b}b$

  $H^\pm \to tb$ $\quad H^\pm \to A^0W^\pm$ $\quad H^\pm \to h^0W^\pm$
- For $M_{H^\pm} < m_t + m_b$ $\mathrm{B}(t \to H^\pm b) \lessapprox 20\%$
- For $M_{H^\pm} > 180$ GeV $\sigma(p\bar{p} \to H^\pm) \cdot \mathrm{B}(H^\pm \to tb) \lessapprox 10$ pb
- Experiments will use larger data sets and add more channels.
- If Tevatron runs through 2014, can accumulate $\approx 17\ \mathrm{fb}^{-1}$
  - Improve limits by a factor of up to ≈ 4