Charged Higgs Searches with DØ

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Outline

- Overview
- DØ Detector
- Large mass $H^+ \to t\bar{b}$
- Ratio method—Lepton plus jets and DiLepton
- Global search—Multiple channels
- Summary

Overview

- No evidence restricts SM to a single Higgs doublet;
- Simplest extension add a second Higgs doublet;
  - Required by SuSy models;
- Additional doublet introduces 4 additional degrees of freedom leading to 4 new scalars (total of 5 scalar particles);
  - 2 Charged, 2 CP even, 1 CP odd (CP conserving model)
- Generic models (require no FCNC & $\rho \approx 1$)
  - Type I—fermions couple to a single double;
  - Type II—Up-type fermions couple to one double, Down-type to other doublet (*required by SUSY*);
  - Type III—fermions couple to both doublets [1];

Overview

- Effective Lagrangian for H^+ quark couplings

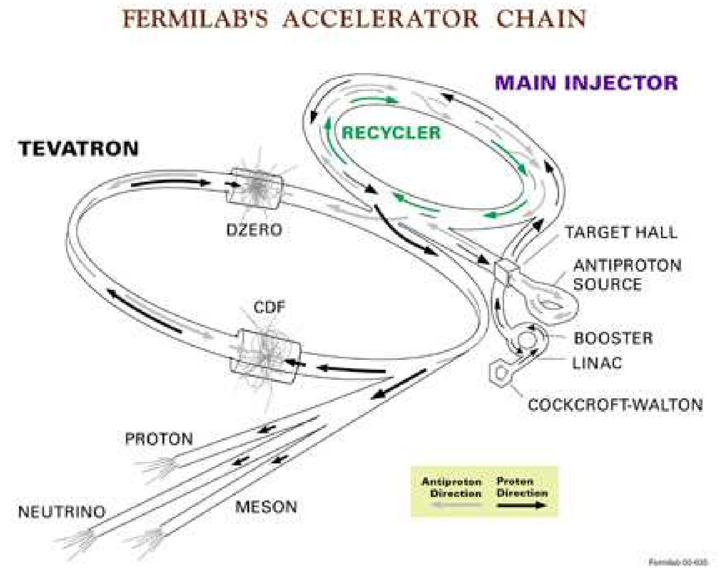
$$\mathcal{L} = \frac{g_w}{2\sqrt{2}} H^+ \bar{f}_i \left[g_L^{ij} \left(1 - \gamma^5\right) + g_R^{ij} \left(1 + \gamma^5\right) \right] f_j$$

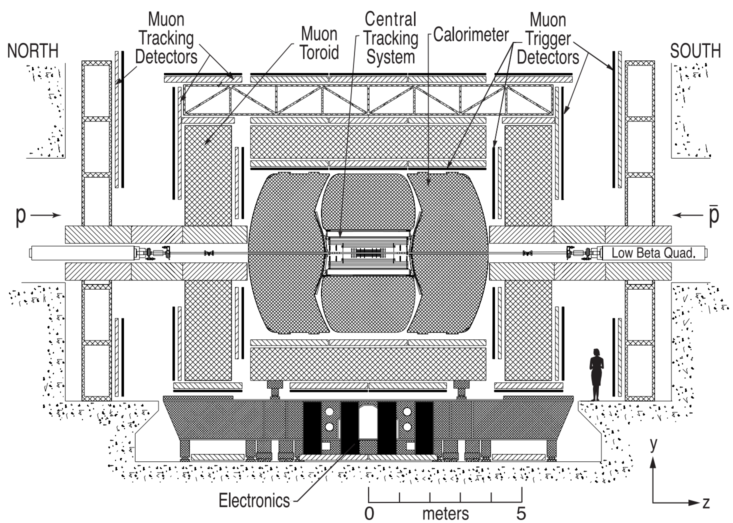
- Couplings q up-type quark, q' down-type quark:

Model	g_L^{ij}	g_R^{ij}
Type I	$-V_{ij} \frac{m_i}{M_W} \tan\beta$	$V_{ij} \frac{m_j}{M_W} \tan\beta$
Type II	$V_{ij} \frac{m_i}{M_W} \cot\beta$	$V_{ij} \frac{m_j}{M_W} \tan\beta$
Type III	$V_{ik} \left(\xi_{kj}^U \frac{\sqrt{2 m_k m_j}}{v} \right)$	$\left(\xi_{ik}^D \frac{\sqrt{2 m_i m_k}}{v} \right) V_{kj}$

- Searches are based on large coupling to t-quark
- Low mass ($m_{H^\pm} < m_t$) search use large τ coupling

DØ Detector

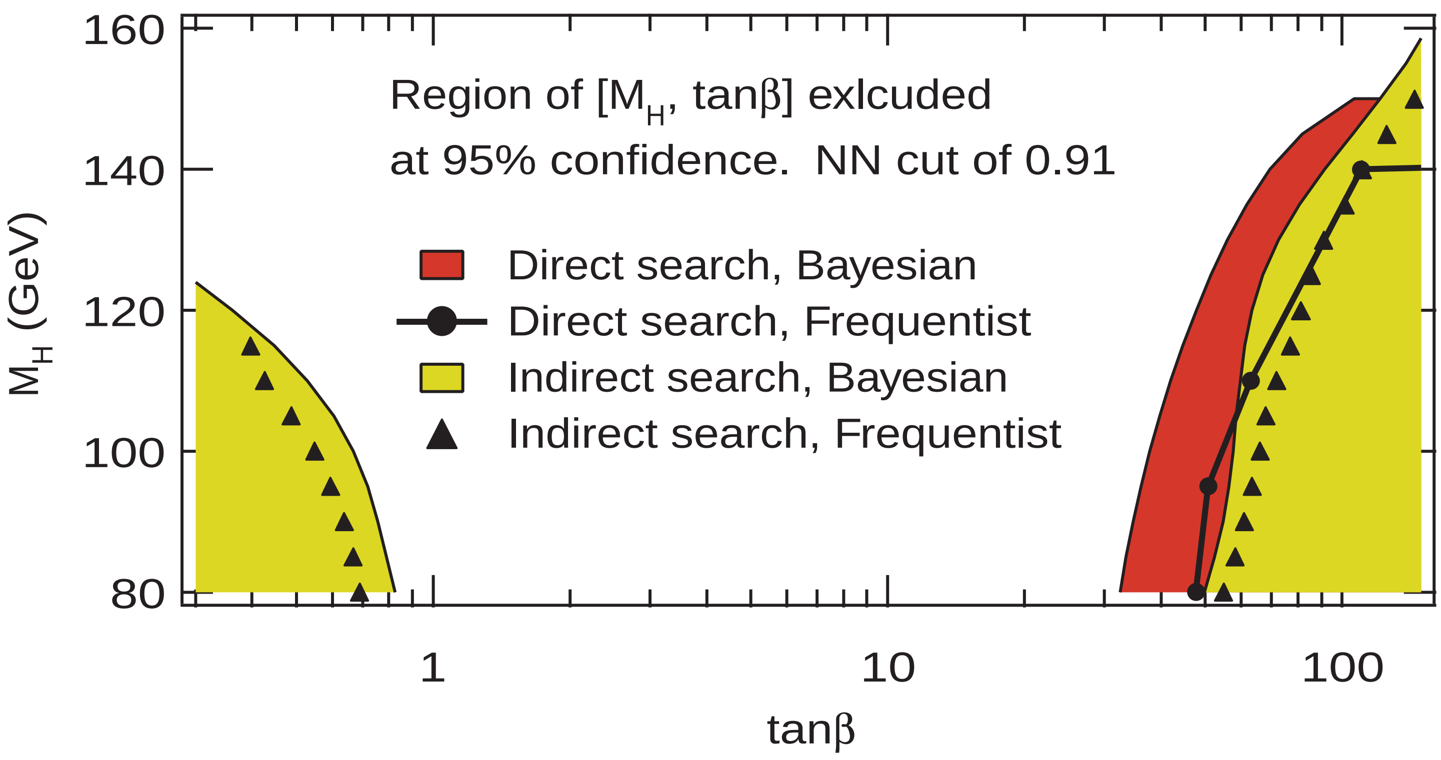




- Tevatron
  - $p\bar{p}$ @ $\sqrt{s} = 1.96$ TeV
  - $\int \mathcal{L}\, dt \approx 1$ fb^{-1} ≈ 4.2 fb^{-1}
- DØ Detector
  - Central Tracker
    - Silicon microstrips
    - Scintillating fiber tracker
    - 2 T solonoidal magnet
  - Calorimeter
    - Cranium Liquid Argon
    - $|\eta \leq 4$
  - Muon Spectrometer
    - Wire chambers
    - Scintillation counters
    - 1.8 T Toroidal magnet

Run I Limits

- $p\bar{p}$ @ $\sqrt{s} = 1.8$ TeV
- $\int \mathcal{L}\, dt \approx 60$ pb^{-1}
- Limit [2] context of type II 2 Higgs Doublet Model (LO)



High Mass Search

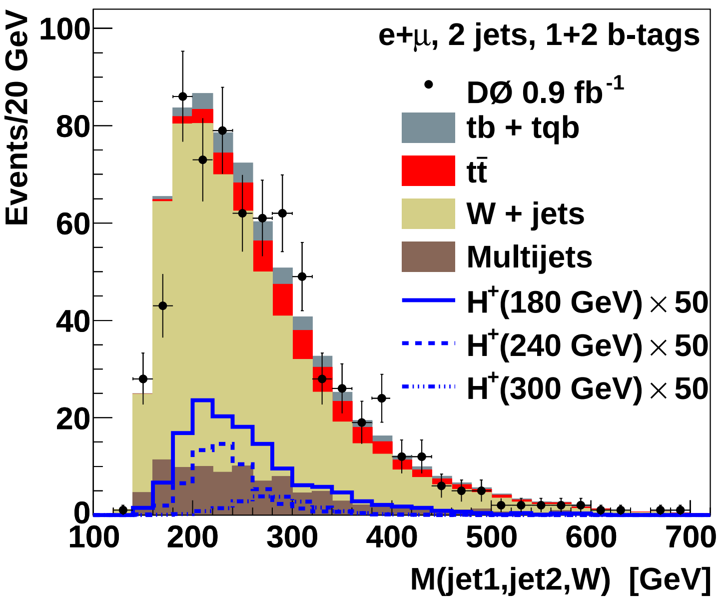
Outline

- Search for $q\bar{q}' \rightarrow H^+ \rightarrow t\bar{b} \rightarrow W^+b\bar{b} \rightarrow \ell^+\nu_\ell b\bar{b}$ [3]
  - 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
    - Require H^+ decay width be less than $t\bar{b}$ mass resolution $\delta M_{tb} \approx \mathcal{O}(10)$ GeV

Discriminant

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

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



Models

Fraction of left and right handed chiral states for different models and values of $\tan\beta$

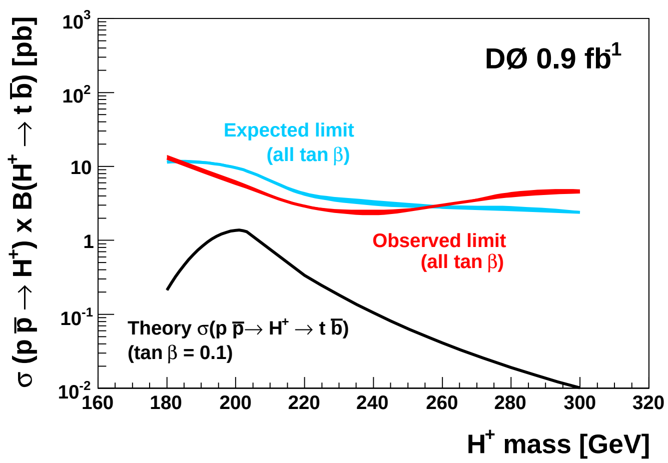
		$\tan\beta < 0.1$	$\tan\beta = 1$	$\tan\beta = 5$	$\tan\beta > 10$
2HDM (I)	Left	0.5	0.5	0.5	0.5
	Right	0.5	0.5	0.5	0.5
2HDM (II)	Left	0.99999	0.5	0.002	0.00001
	Right	0.00001	0.5	0.998	0.99999
2HDM (III)	Left	0.0			
	Right	1.0			

Terms with same color give same upper limit on $\sigma \times \mathrm{BR}$

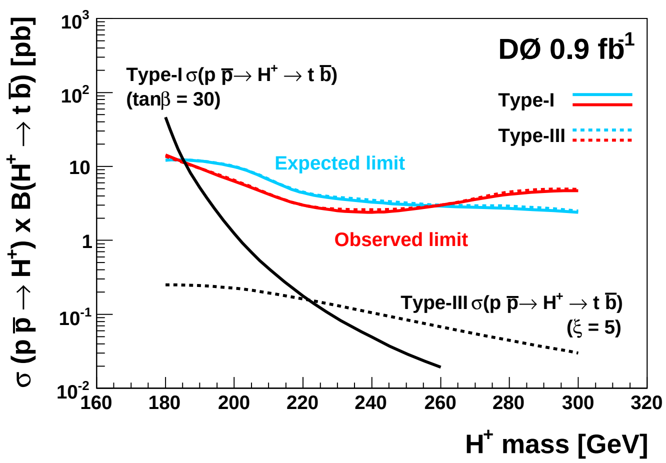
Limits

- 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

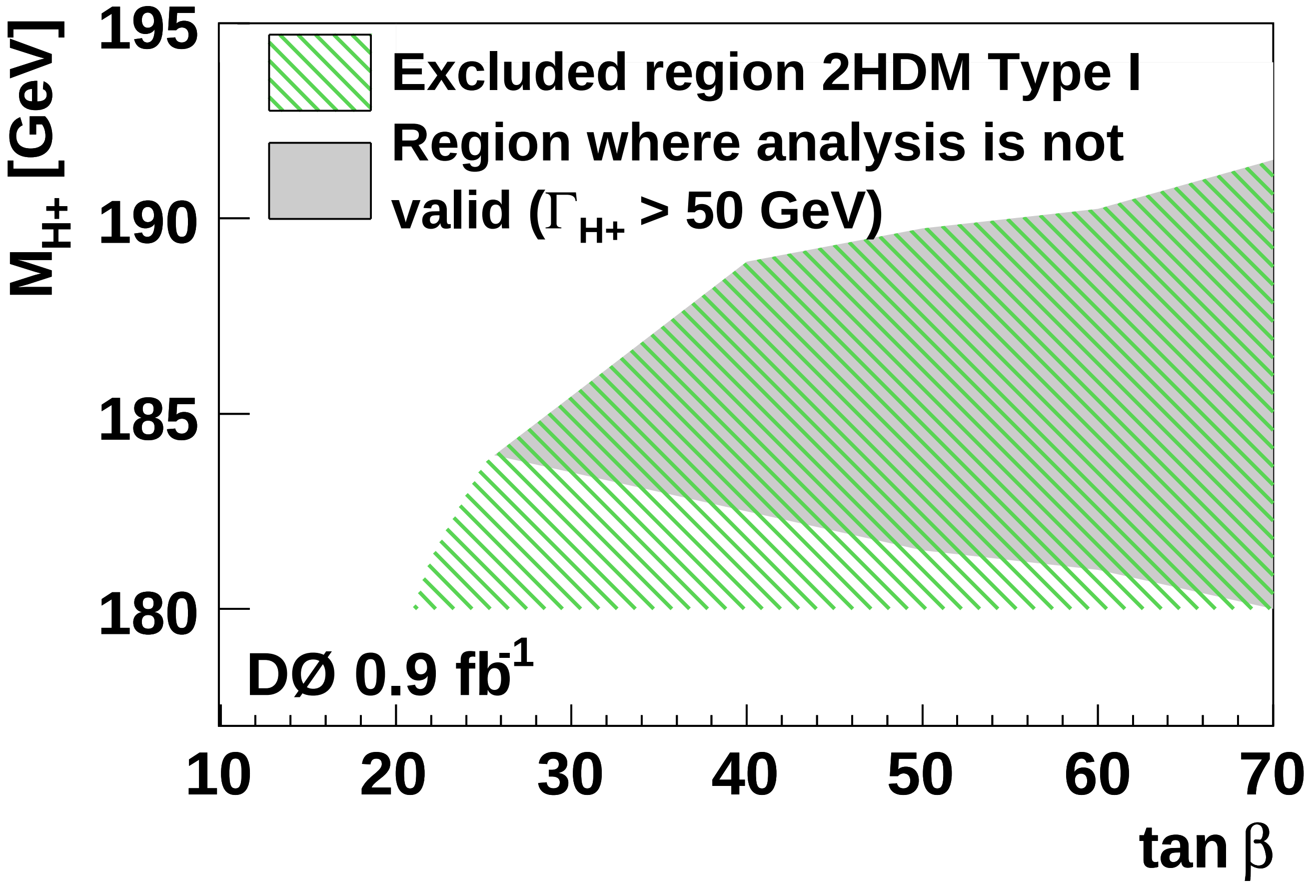


Type I & III



Exclusion

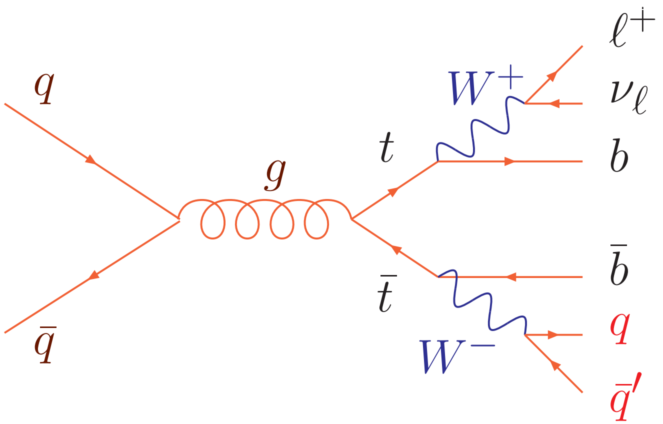
Only Type I model has an exclusion region.

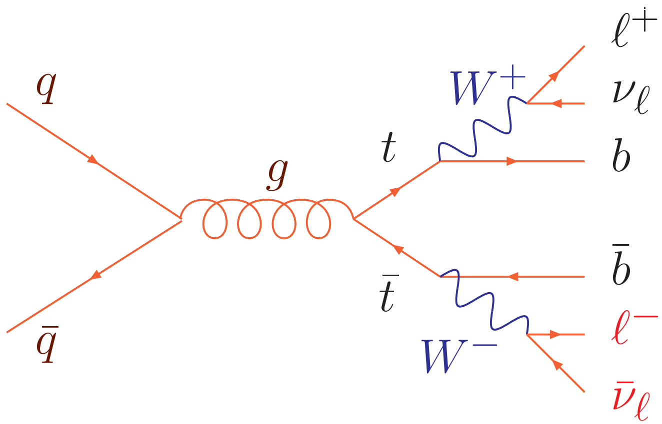


Ratio Method

Outline I

- Consider the following SM t-quark production and decay processes

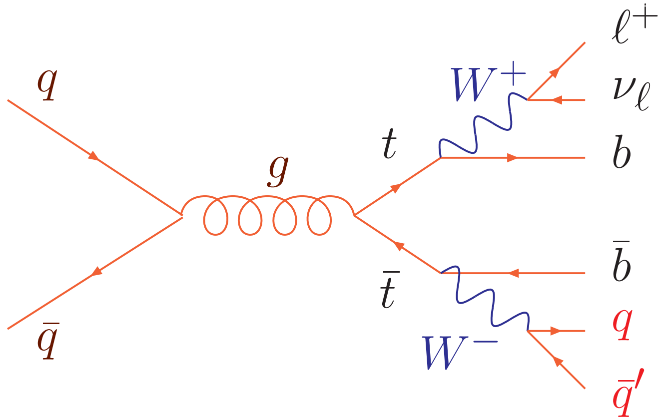


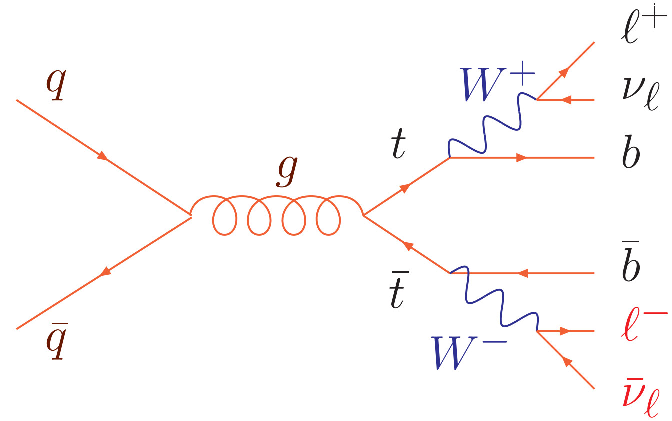


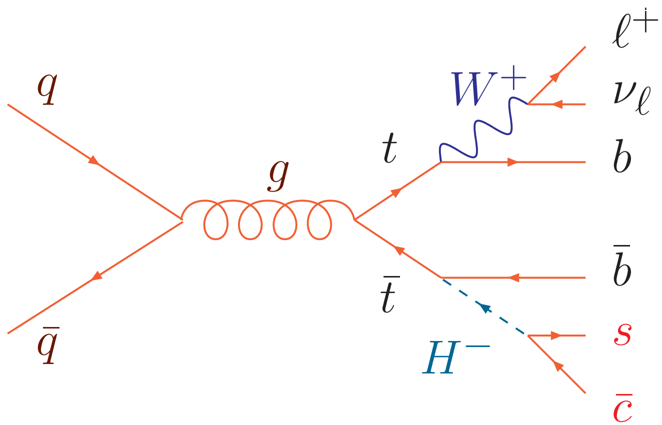
- $\sigma(p\bar{p} \rightarrow t\bar{t})$ can be measured using either $p\bar{p} \rightarrow \ell^\pm + jets$ or $p\bar{p} \rightarrow \ell^\pm \ell^\mp + jets$ assuming SM Branching Ratios
  - ❖ Define $R_\sigma = \frac{\sigma(t\bar{t})_{\ell+jets}}{\sigma(t\bar{t})_{\ell\ell}}$ in SM this is equals 1

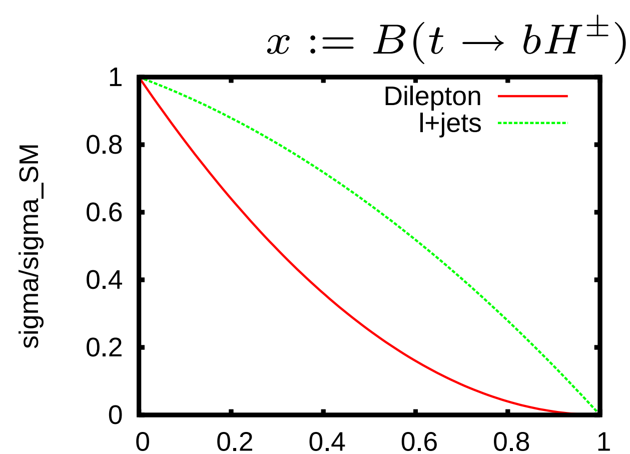
Outline II

- Consider the following SM t-quark production and decay processes and add a non-SM process









$R_\sigma \neq 1$ for this example $R_\sigma > 1$

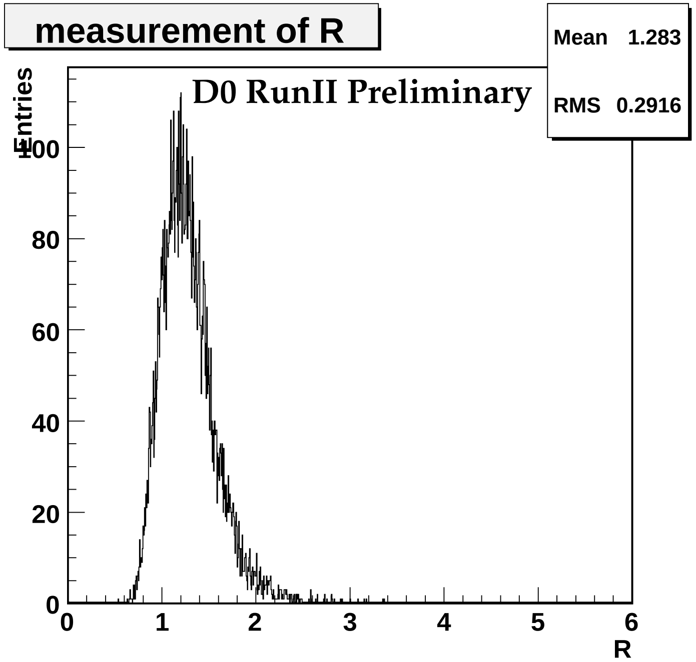
Determination of Cross Section Ratio I

- Use $\int \mathcal{L}\, dt \approx 0.9$ fb^{-1} $\ell+\text{jets}$ and ≈ 1.0 fb^{-1} dilepton data sets
- Perform ensemble test to determine uncertainties
  - Account for correlations between channels
  - Luminosity errors cancel

R_σ ensemble distribution

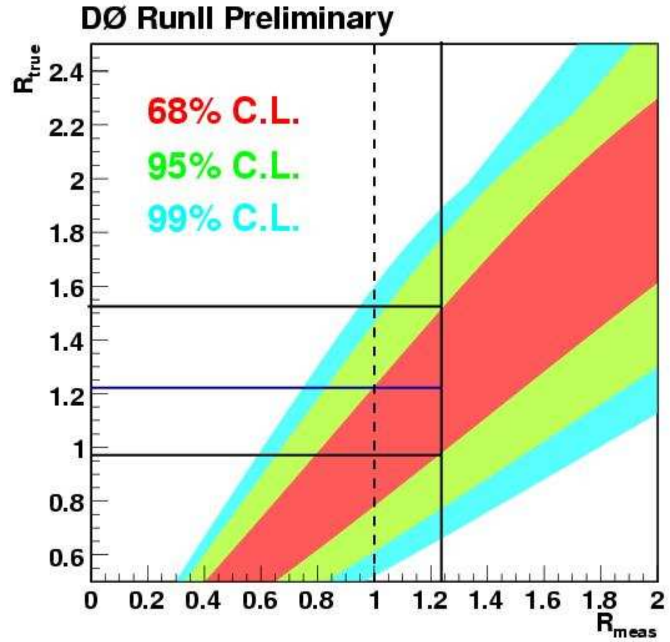
Use 4-jet channel only in $\ell+\text{jets}$ to decrease effect of dilepton contribution to few percent

10000 ensembles, numbers drawn from Poisson distribution



Determination of Cross Section Ratio II

- Derive relation between $R_\sigma^{measured}$ and R_σ^{true}
- Vary $\sigma_{t\bar{t}}^{\ell+jets}$ 6 to 15 pb
- 10000 pseudo-experiments per point (0.5 pb steps)



- Use Feldman-Cousins [4] to interpret result

$R_\sigma = 1.21 \pm 0.27$ (68% confidence interval)

Branching Ratio Limit I

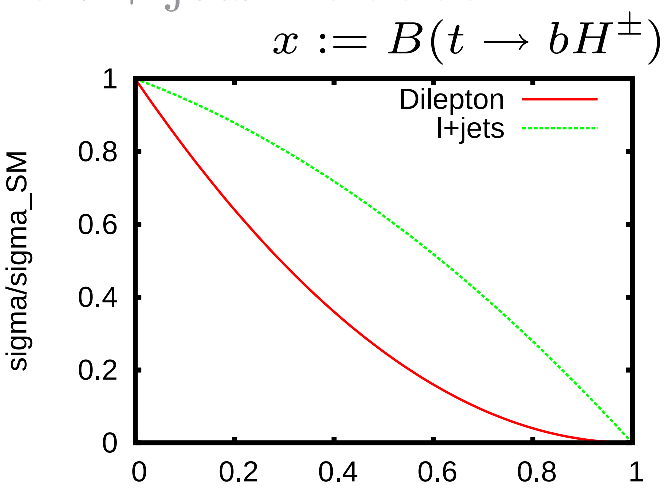
- Our assumptions (model)
  - $M_{H^\pm} = 80$ GeV
  - $\mathrm{B}(H^\pm \to cs) = 1$
  - DiLepton: $\mathrm{B}(t \to W^\pm b) = 1$
  - $\ell + jets$: $t \to H^\pm b$ or $t \to W^\pm b$

$$R_\sigma = 1 + \frac{x}{(1-x)\,\mathrm{B}(W^\pm \to q\bar{q})} \qquad x = \mathrm{B}(t \to bH^\pm)$$

Feedthrough from dilepton to $\ell + \mathrm{jets}$ included

σ/σ_{SM} vs $x = \mathrm{B}(t \to H^\pm b)$

σ includes $t \to H^\pm b$



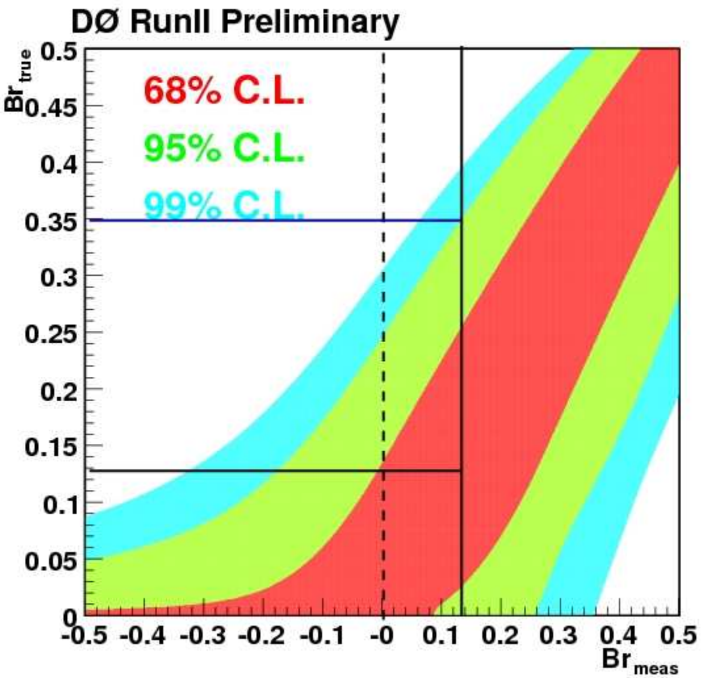
Branching Ratio Limit II

Interpret using Feldman-Cousins

- $\mathrm{B}(t \to H^{\pm}b) = 0.13 \pm 0.12$
- Expected limit $(95\%\mathrm{CL})$

  $\mathrm{B}(t \to H^{\pm}b) < 0.25$
- Measured limit $(95\%\mathrm{CL})$

  $\mathrm{B}(t \to H^{\pm}b) < 0.35$

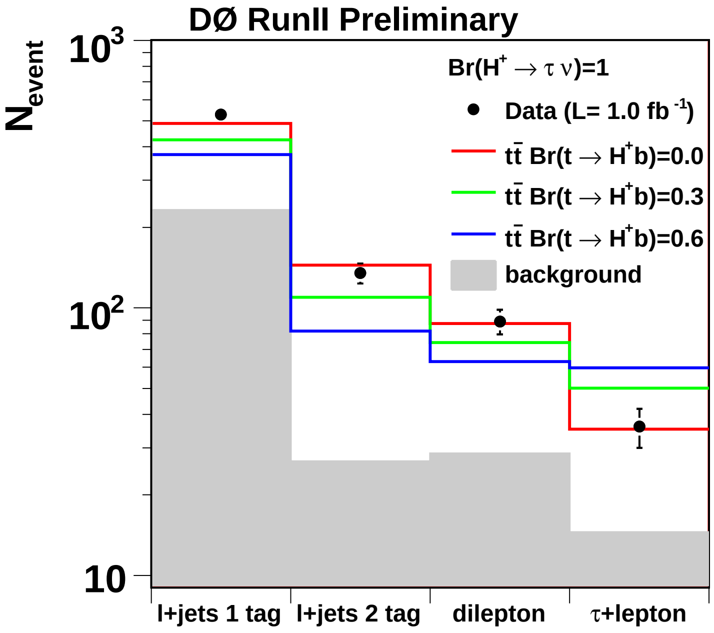


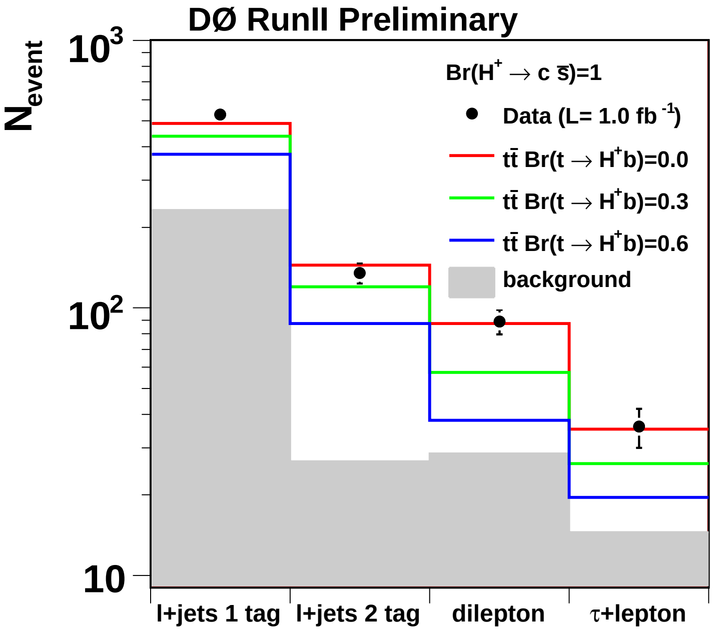
Global Fit

Outline

Combine top cross section analysis

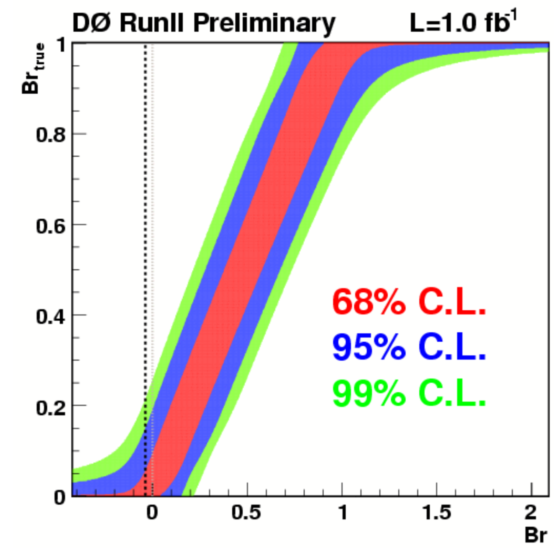
- Includes DiLepton $\ell + \text{jets}$ and $\tau + \ell$ (lepton refers to $e^{\pm}$ and $\mu^{\pm}$ only, can come from τ decay.)
- Consider only tauonic decays ($H^+ \to \tau^+ + \nu_\tau$) and leptophobic decays ($H^+ \to c\bar{s}$) with $M_{H^\pm} < m_t$ decays



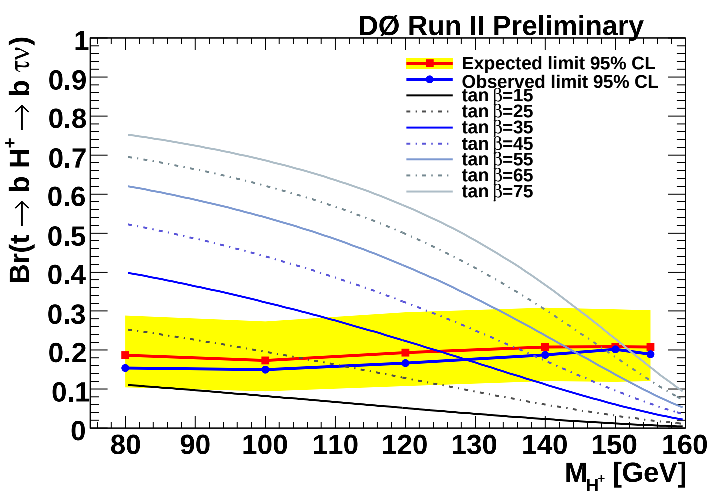


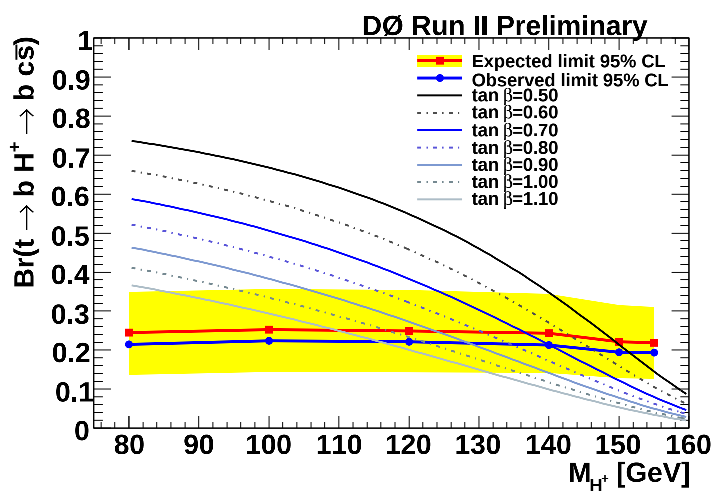
Limits

Feldman-Cousins CL bands for $\mathrm{Br}(t \to H^+ b)$. $M_{H^\pm} = 80$ GeV and tauonic model



Leading order type II 2HDM

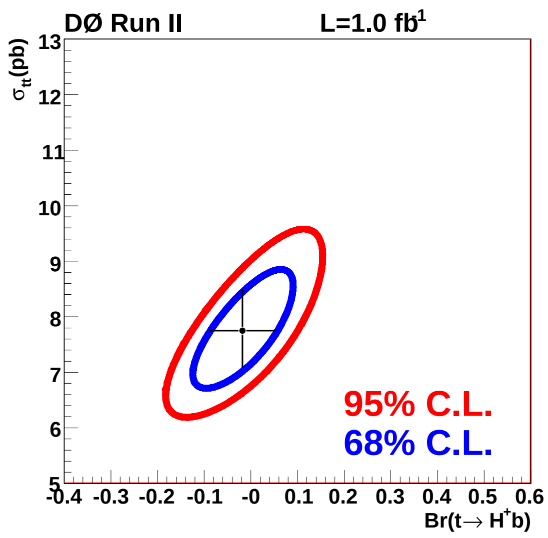


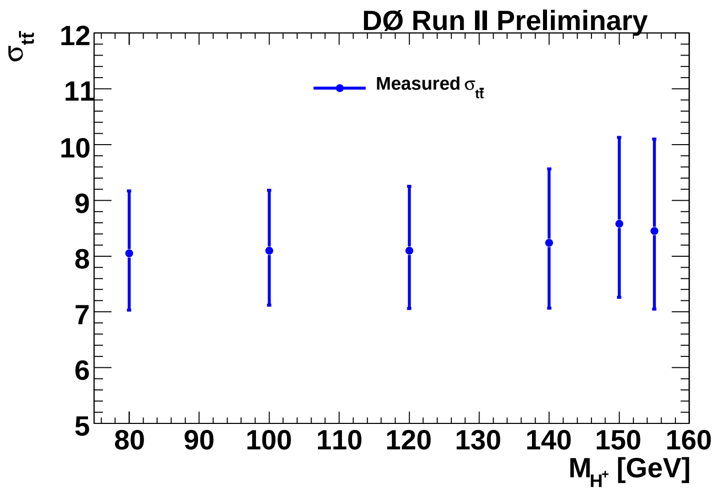


Simultaneous Fit

Simultaneous fit to cross section and $\mathrm{B}(t \to H^+ b)$

- Limit independent of theoretical assumption on $\sigma_{t\bar{t}}$
- Limit not affected by large $\sigma_{t\bar{t}}$ uncertainty
- Luminosity uncertainty absorbed into $\sigma_{t\bar{t}}$
- Fit using tauonic mode only (shown for $M_{H^\pm} = 80$ GeV)



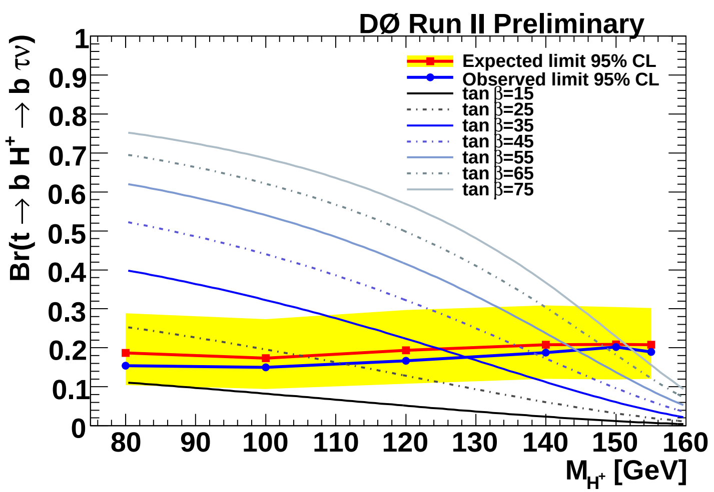


2-d Fit Limits

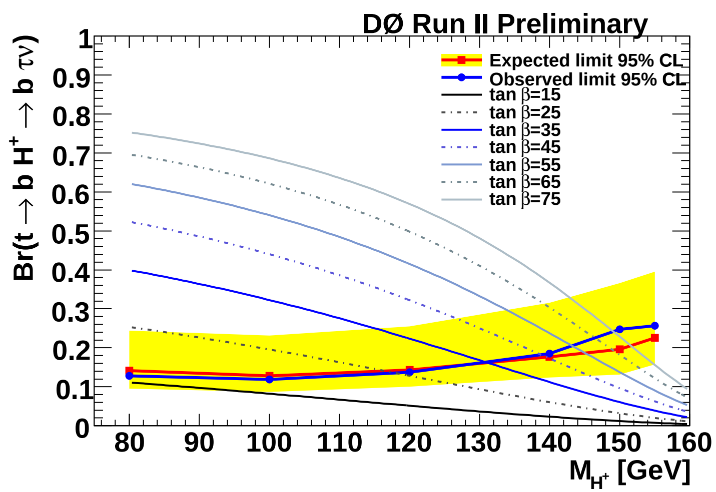
Simultaneous fit to cross section and $\mathrm{B}(t \rightarrow H^+ b)$

30% improvement in limit at low $M_{H^\pm}$

1-d Fit

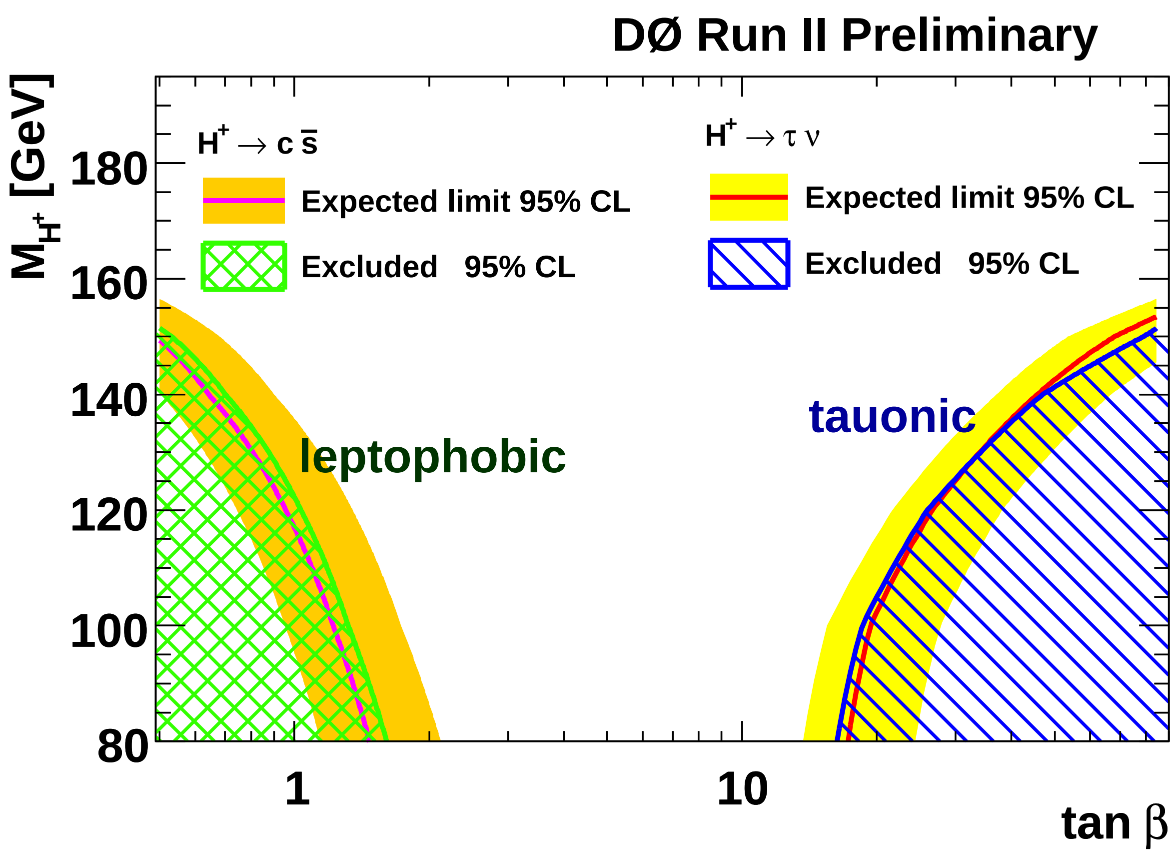


2-d fit



Exclusion

Set exclusion limits on type II 2HDM leading order calculation



Summary

- DØ has set limits on $H^{\pm}$ production
- $M_{H^{\pm}} > m_t$ in context of Type I, II, III models using single top data with exclusion only in type I (limits for others)
- $M_{H^{\pm}} < m_t$ several techniques to search for evidence
  - Ratio method $\mathrm{B}(t \to H^{\pm}b) < 0.35$
  - Global fit $\mathrm{B}(t \to H^{\pm}b) \lesssim 0.2$
- Other analysis in progress

References

[1] H.-J. He and C.-P. Yuan, Phys. Rev. Lett. **83**, 28 (1999).

[2] B. Abbott *et al.* (D0 Collaboration), Phys. Rev. Lett. **82**, 4975 (1999); V.M. Abazov *et al.* (D0 Collaboration), Phys. Rev. Lett. **88**, 151803 (2002).

[3] V.M. Abazov *et al.* (D0 Collaboration), Submitted to Phys. Rev. Lett.

[4] G. Feldman and R. Cousins, Phys. Rev. D **57**, 3873 (1998).