Search for a Charged Higgs Boson in Single Top Quark Production at DØ

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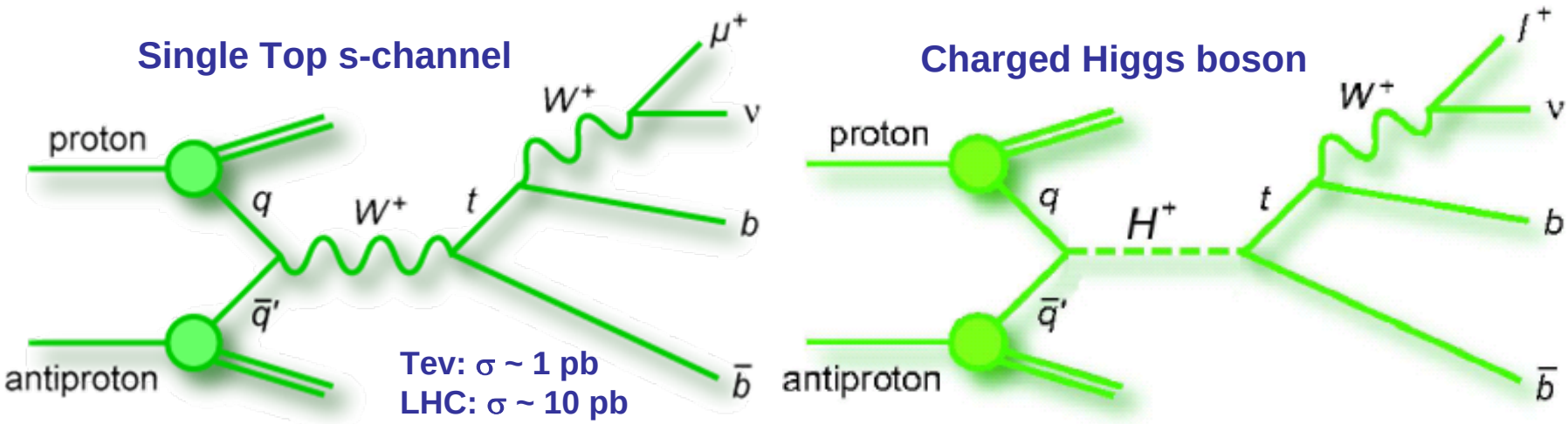
On Behalf of the DØ Collaboration

Physics Motivation



Discovery of charged Higgs boson is an unambiguous evidence for new physics

- **No "charged" Higgs boson in standard model**
- **Identical final state as s-channel single top quark electroweak production (Phys. Rev. Lett. 98,181802(2007))**

Theoretical Background

Extension of SM Higgs

- **Two-Higgs Doublet Model (2HDM)**

$$\phi_1 = \begin{pmatrix} 0 \\ v_1 \end{pmatrix} \qquad \phi_2 = \begin{pmatrix} 0 \\ v_2 \end{pmatrix} \qquad \tan\beta = \frac{v_1}{v_2}$$

- **Leads to five physical Higgs bosons: two neutral scalars h^0 and H^0, one neutral pseudoscalar A^0 and two charged scalars H^+, H^-**
- **2HDMs differentiated by strategies used to avoid FCNC**
  - Type-I: One doublet gives mass to all quarks and leptons
  - Type-II: One doublet gives mass to up-type quarks and neutrinos; Other doublet gives mass to down-type quarks and charged leptons (e.g. MSSM)
  - Type-III: Two doublets contribute to mass of quarks and leptons, ξ **is the top-charm mixing parameter** [H.-J. He and C.-P. Yuan, PRL 83 (1999) 28]

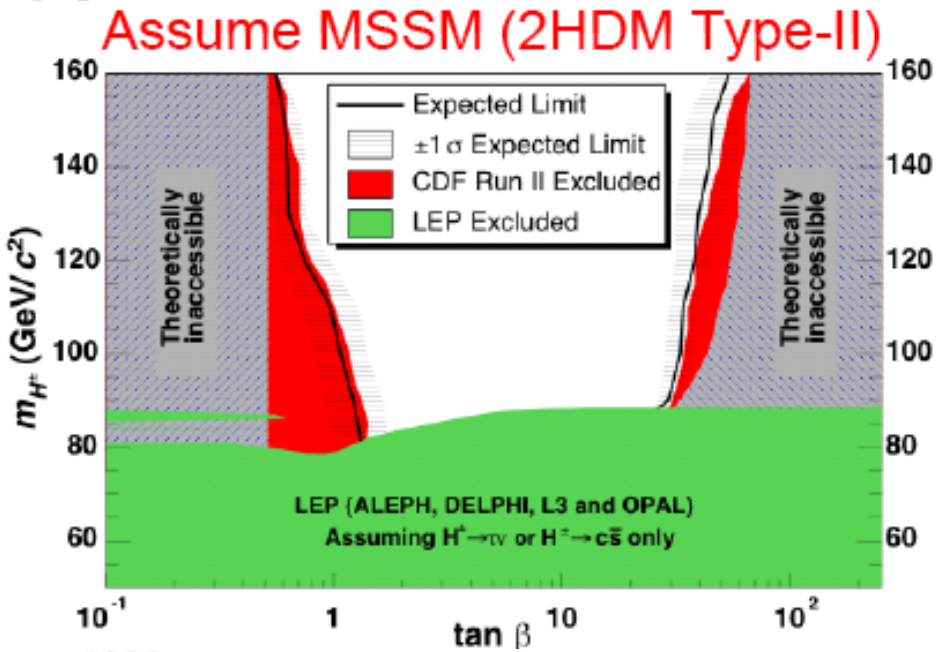
Existing Constraints on H^+ 2HDM Type-II

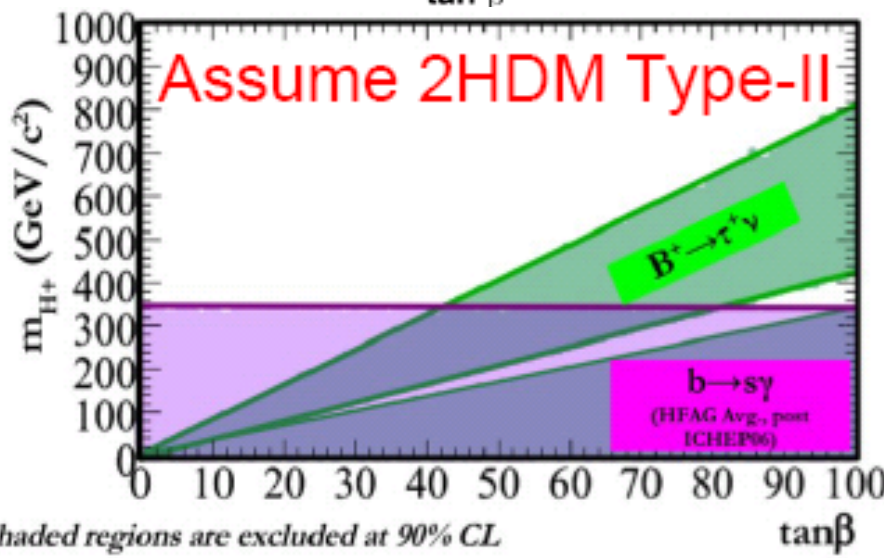
Direct search: $m_{H+} < m_{top}$

- LEP
  - $e^+e^- \rightarrow H^+H^-$
  - Limited by WW bkg
- Tevatron
  - $p\bar{p} \rightarrow \bar{t}t$ and $t \rightarrow H^+b$

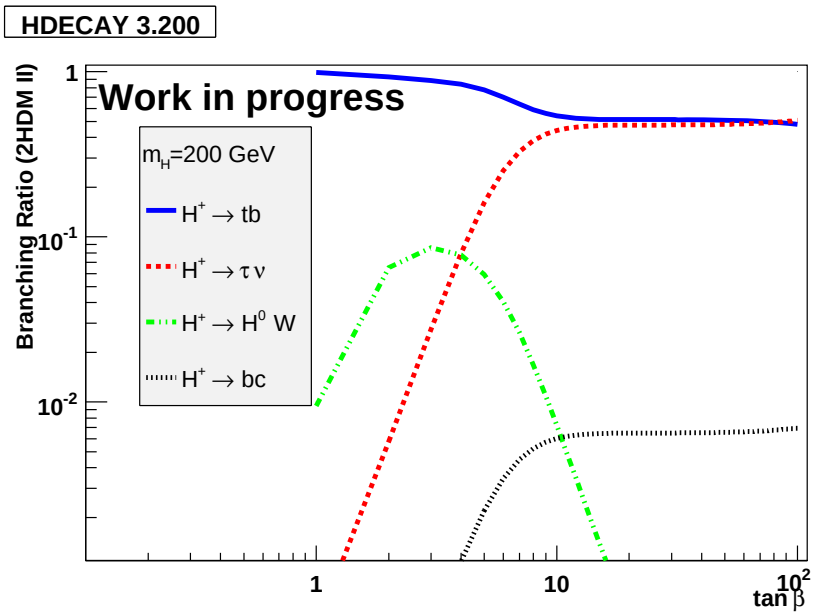
Indirect search

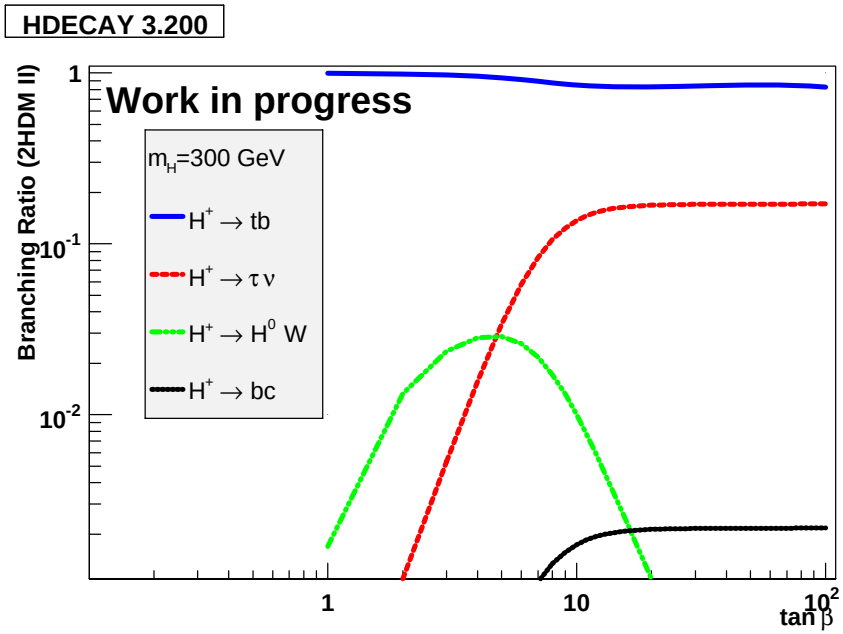
- B-factories
- H^+ loop contributions to
  - $b \rightarrow s\,\gamma$
  - $B^+ \rightarrow \tau^+\nu$
- Assume absence of other sources of new physics at electroweak scale





Direct Search for Heavy H^+ at DØ





First direct search for heavy H^+ via $q\bar{q} \to H^+ \to t\bar{b}$

- **tb decay channel dominates for large region of parameter space (above plots: m_{H+} = 200, 300 GeV in 2HDM Type-II)**
- **For the first time explore a "heavy" charged Higgs mass region $m_{H+} > m_{top}$**
- **Use the same selection of single top quark events in 0.9 fb^{-1} DØ "single top evidence" analysis**

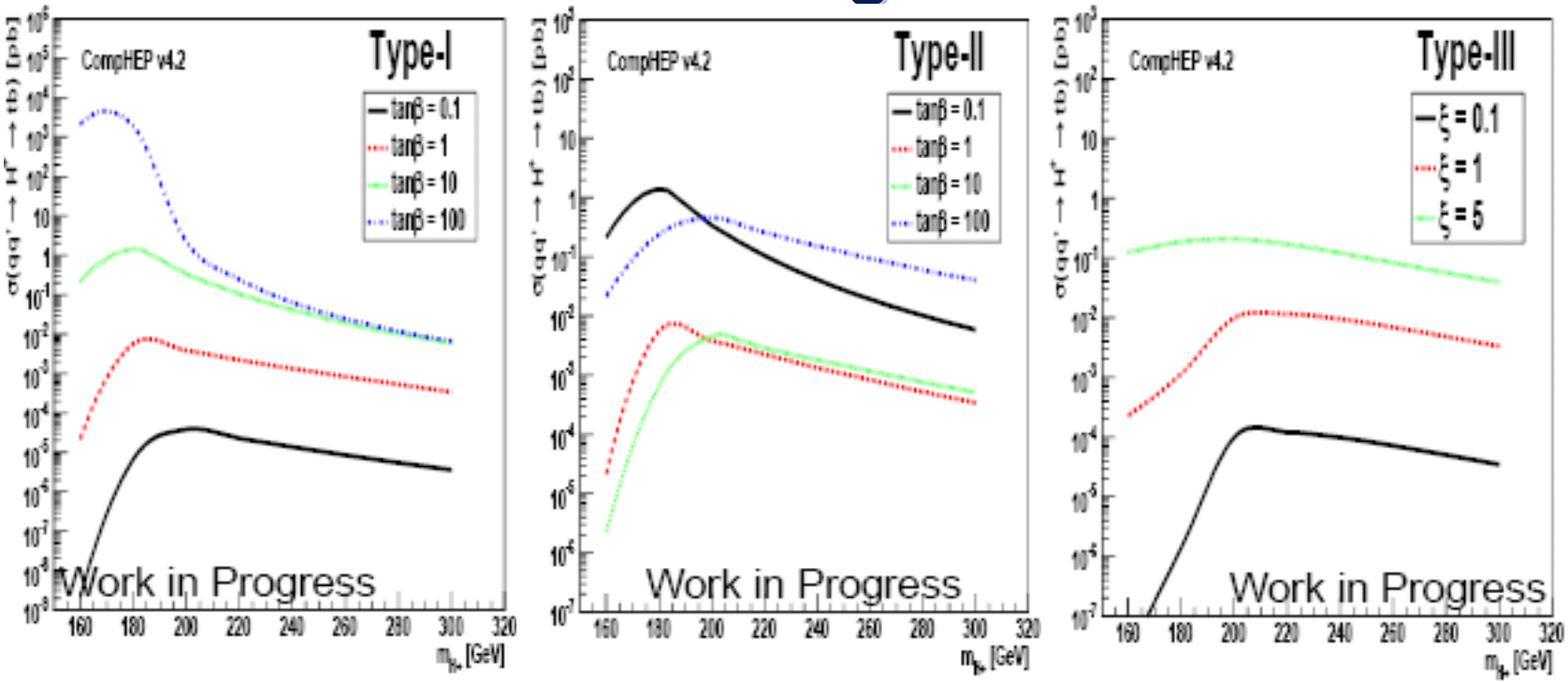
Signal Modeling

- Use CompHEP to simulate $p\bar{p} \rightarrow H^+ \rightarrow t\bar{b}$

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

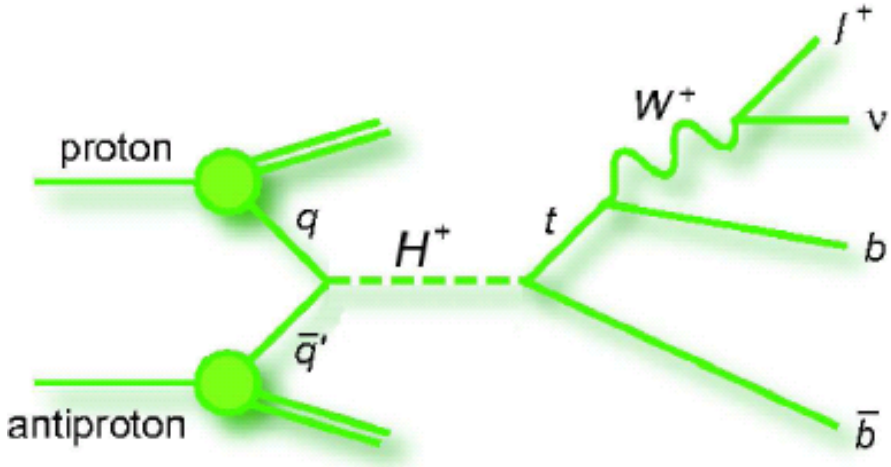
- To be as model independent as possible, produced left-handed samples with $g_L^{ij} = 1, g_R^{ij} = 0$ and right-handed samples with $g_L^{ij} = 0, g_R^{ij} = 1$, combine them in different proportions to simulate a desired 2HDM with a predetermined polarization
  - Type-I: proportion is equal (1:1) for all tanβ
  - Type-II: proportion varies with tanβ
    - For tanβ > 10, right-handed coupling dominates so that the fraction of left-handed sample < 10^{-5}
    - For tanβ < 0.1, left-handed coupling dominates so that the fraction of right-handed sample < 10^{-5}
    - For 0.1 < tanβ < 10, the fractions are in transition: special case is 1:1 when tanβ = 1
  - Type-III: right-handed coupling dominates, the fraction of left-handed sample < 10^{-5} for all ξ
- Mixture of left- and right-handed samples does not take into account interference term ~ $g_L g_R$
  - Analysis not sensitive to small change in kinematics

CompHEP H^+ Cross Sections Times Branching Fraction



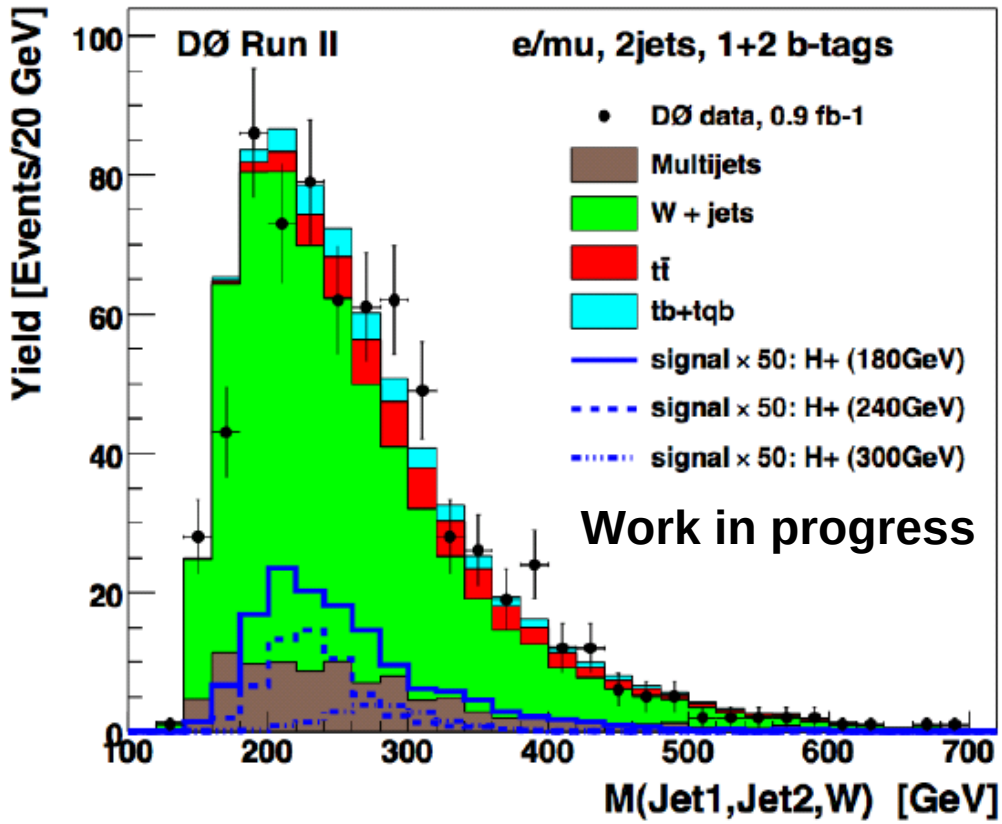
- **H^+ production cross section times branching fraction calculated with CompHEP generator vs. m_{H+} via $q\bar{q} \to H^+ \to t\bar{b}$**
- **Cross sections can be sizable: σxß ~ 10 pb (Type-I), ~ 0.5 pb (Type-II) with tanβ = 100 , ~ 0.1 pb (Type-III) with ξ = 5**
- **Cross section decreases with m_{H+} due to the limited amount of energy in the CM**
- **Produced samples for m_{H+} = 180, 200, 220, 240, 260, 280, 300 GeV**

Event Selection



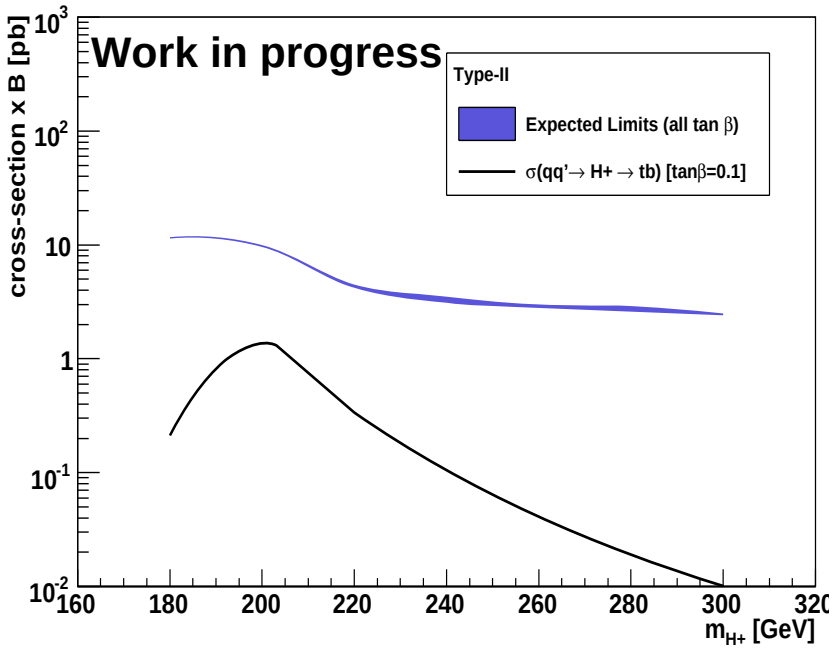
- Same event selection of the "single top evidence" analysis
- One isolated electron or muon
  - Electron p_T > 15 GeV, | η | < 1.1
  - Muon p_T > 18 GeV, | η | < 2.0
- Missing transverse energy > 15 GeV
- Exactly two jets (best signal/background ratio)
  - Leading jet p_T > 25 GeV, | η | < 2.5
  - Second Leading jet p_T > 20 GeV, | η | < 3.4
- At least one b-tagged jet

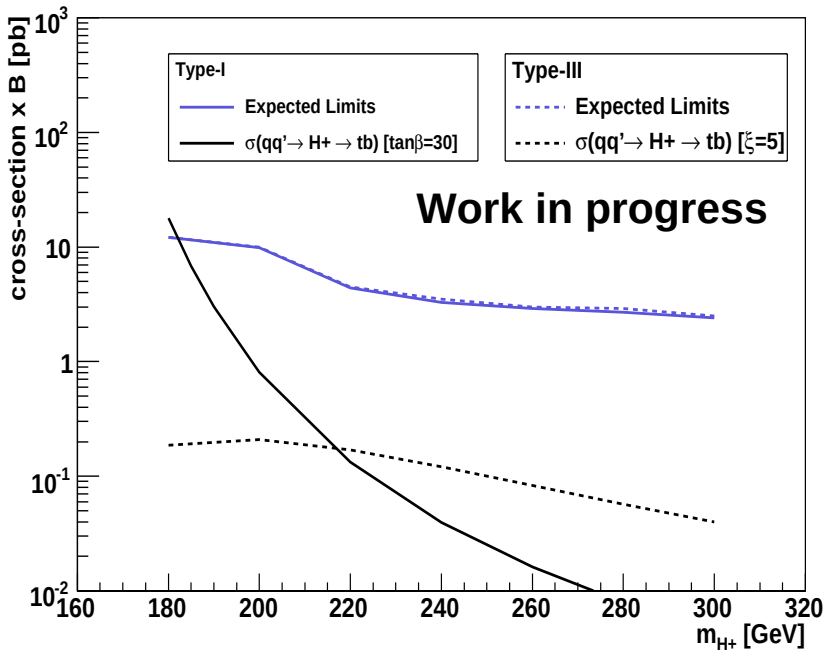
$H^+ \to t\bar{b}$ Reconstructed Invariant Mass



- **Reconstructed invariant mass (j1, j2, W) showed to be the single most sensitive variable**
  - **electron-channel and muon-channel combined, with one or two-btags**
  - **Signal: Type-III model for m_{H+} = 180, 240,300 GeV (scaled by 50)**
- **Used to construct binned likelihood function**

Expected Cross Section Limits





- **Used binned likelihood method with Bayesian statistics to calculate 95% C.L. upper limits on the signal production cross section times branching fraction of $H^+ \to t\bar{b}$**
- **Left: Type-II expected limits with predicted cross section for tanβ = 0.1**
- **Right: Type-I and III expected limits with the predicted cross sections for tanβ = 100 and ξ = 5 respectively**
- **Take into account all systematics and correlations**

Model Parameter Constraints

- **Compare expected cross-section of different models to observed limits to constraint model parameter space** (results coming soon)
  - **Require charged Higgs width ≤ detector resolution**
  - **Exclusion region for 2HDM Type-I**
  - **For Type-II, not sensitive enough to exclude regions of tanβ < 100**
  - **For Type-III, H^+ width depends quadratically on ξ, limits the ability to exclude regions in m_{H+} and ξ parameter space**

Summary

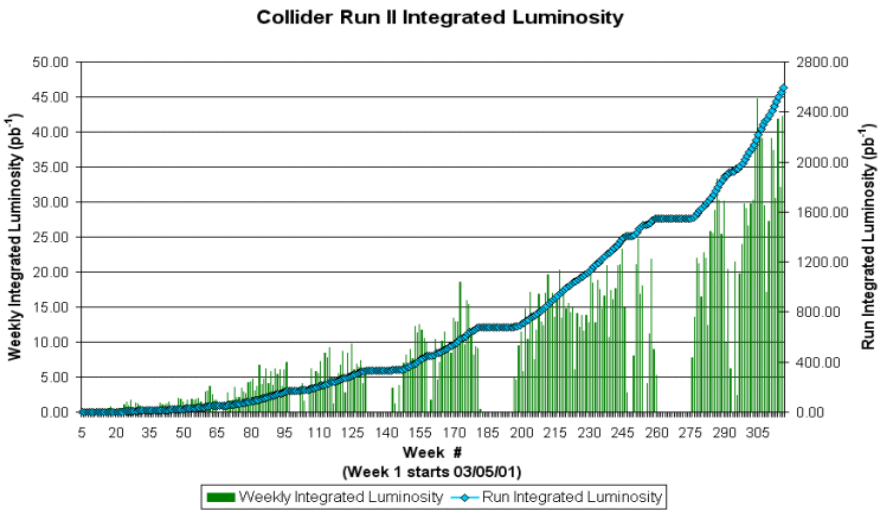
First search for charged Higgs decaying to *tb* final state

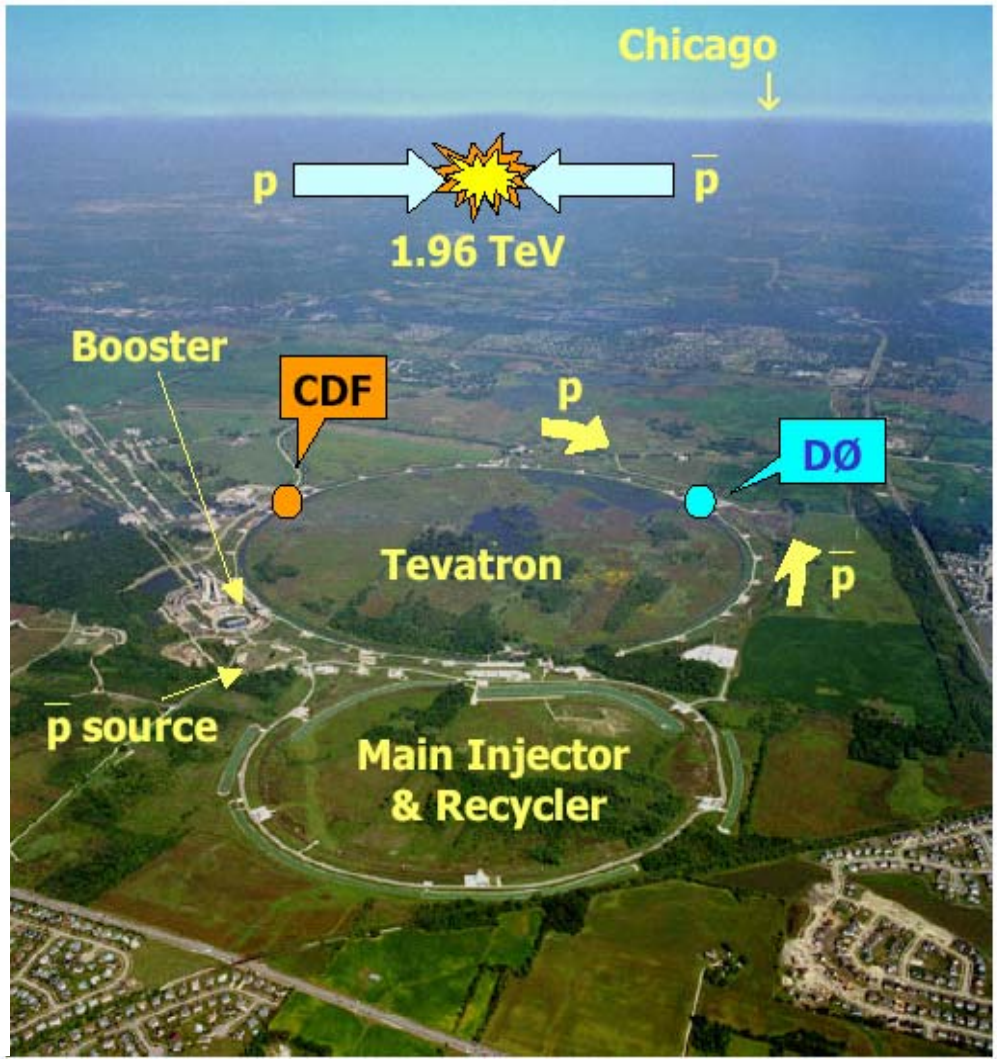
- **No evidence for the existence of a heavy charged Higgs bosons has been found**
- **Upper limits set on the production cross section times $H^+ \to t\bar{b}$ branching fraction for Type-I, II and III 2HDMs**
- **Exclusion region of parameter space for 2HDM Type-I**
- **Expect increased sensitivity from future analysis and a larger data set**

Backup Slides

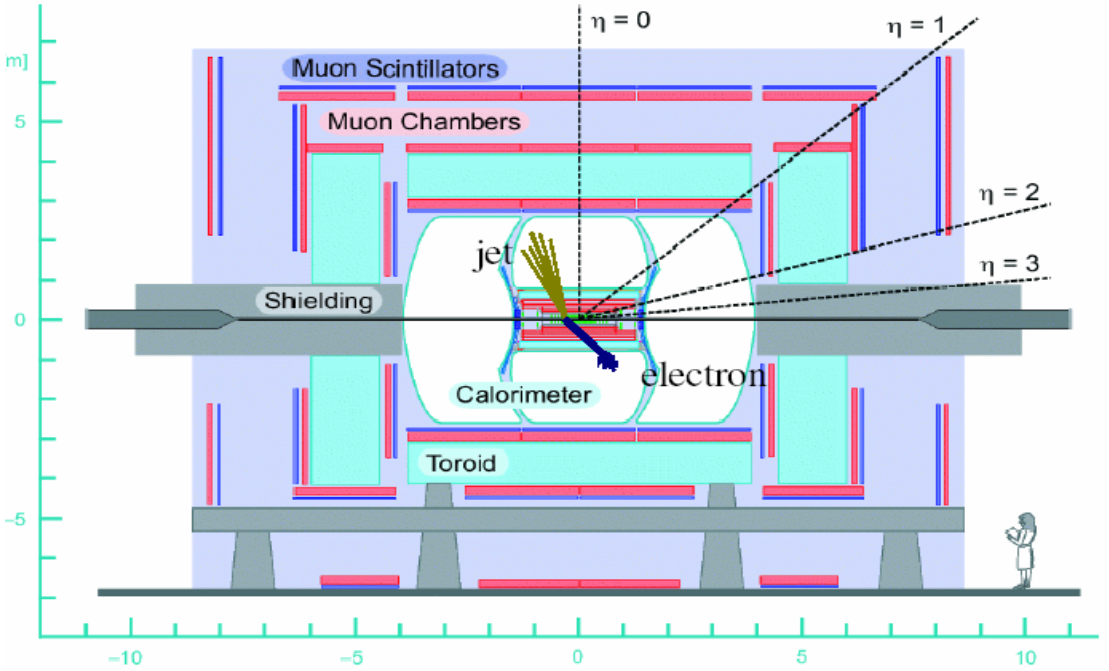
The Fermilab Tevatron

- Highest energy accelerator currently in operation
- Experiments at D0 and CDF
- Data delivered: >3fb^{-1}
  - **Goal of RunII is 4-9fb^{-1}**





The D0 Experiment



Tracking

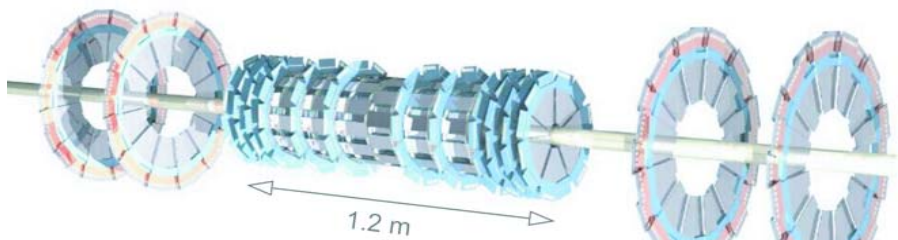
- Silicon + fiber tracker
- 2T magnetic field solenoid
- Pre-shower detectors

Calorimeter

- Liquid argon (EM+HAD)

Muon system

- Wire chambers
- 1.8 T iron toroid



Silicon Tracker

Systematics

Unique for this analyses

	H^+ signal		Background	
	1 b-tag	2 b-tag	1 b-tag	2 b-tag
Components for Normalization				
Initial state parton contribution	10.0	10.0	—	—
Luminosity[a]	6.1	6.1	6.1	6.1
cross section[a]	16	16	15.0–18.0	15.0–18.0
branching fraction[a]	1.0	1.0	1.0	1.0
Matrix method[b]	—	—	18.2–20.7	26.5–27.6
Primary vertex[a]	2.4–3.0	2.4–3.0	2.4–3.0	2.4–3.0
Lepton ID[a]	5.5–7.4	5.5–7.4	5.5–7.4	5.5–7.4
Jet ID[a]	1.5	1.5	1.5	1.5
Jet fragmentation[a]	5.0	5.0	5.0–7.0	5.0–7.0
Trigger[a]	3.0–6.0	3.0–6.0	3.0–6.0	3.0–6.0
Components for Normalization and Shape				
Jet energy scale[a]	1.5–10.3	0.6–10.7	0.3–20.1	0.8–19.7
Flavor-dependent TRFs[c]	1.1–3.2	11.8–13.2	1.8–7.5	12.0–16.1
Statistics	0.4–0.7	0.4–1.2		

Same as for single top MC

[a]Does not apply for W+jets or multijets backgrounds
[b]Applies only for W+jets and multijets backgrounds
[c]Does not apply for multijets background

Evaluated using +/- 1 σ