Search for Charged Higgs Bosons in $p\bar{p}$ Collisions

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Content

- Introduction
- Search for heavy charged Higgs in the single top mode
- Search for light charged Higgs in the top pair production
- Conclusion and outlook

Two Higgs Doublet Model: 2HDM

- Extend SM by introduction of a second complex doublet
  - two vacuum expectation values v_1 and v_2
  - in total five physical Higgs Bosons: A^0, h^0, H^0, $H^\pm$
- Higgs-Fermion coupling not specified by the model – but avoid FCNC
  - TYPE I: only one Higgs doublet couples to fermions
  - TYPE II: one Higgs doublet couples to up-type fermions, the other to down-type fermions
  - TYPE III: both doublets couple to fermions; additional methods to suppress FCNC (e. g. small mass of 1st and 2nd generation quarks)
- MSSM: Type II 2HDM realized
  - tree level: two independent parameters: m_A and $\tan(\beta)=v_1/v_2$

Charged Higgs and the top quark

Top quark: Fermion with highest mass
→ Fermion with largest coupling to Higgs

Top mass (current world average):

$$172.6 \pm 0.8(stat) \pm 1.1(syst)\,GeV$$

FERMILAB-TM-2403-E

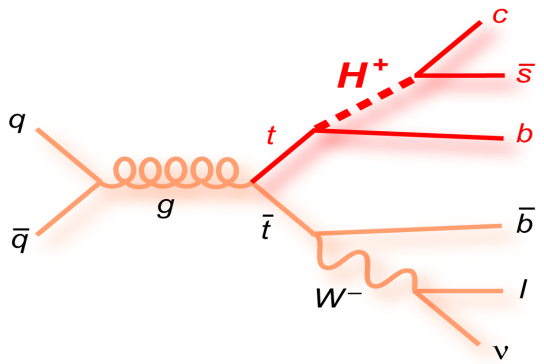
Standard Model: $t \to W^+ b$ 100%

Light $H^\pm$: $m_t > m_{H^\pm}$

decay $t \to H^+ b$

Observable: $Br(t \to H^+ b)$

in top pair production channels

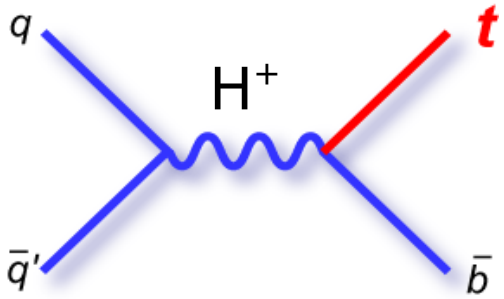


Heavy $H^\pm$: $m_t < m_{H^\pm}$

decay $H^+ \to t\bar{b}$

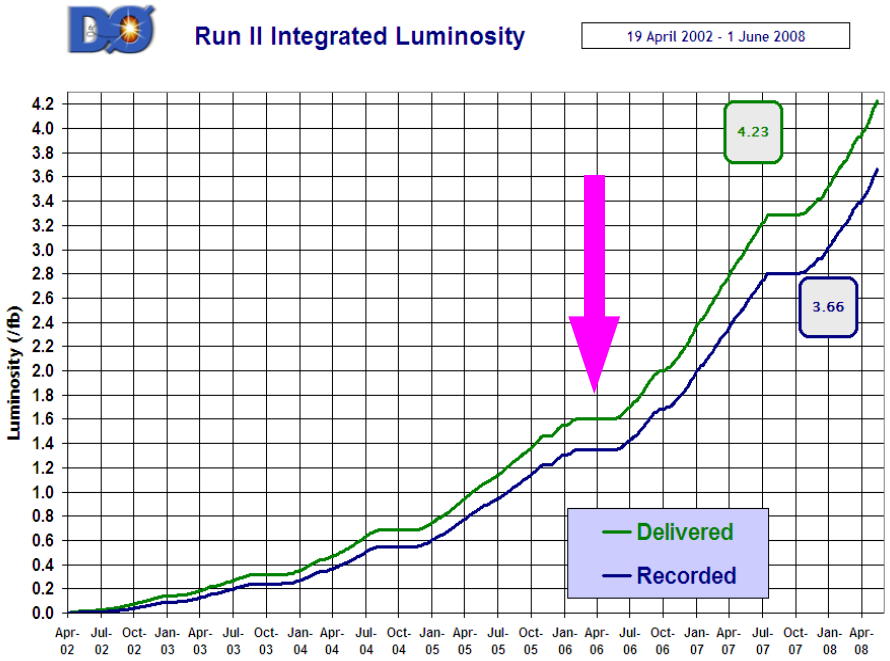
Observable: cross section times $Br(H^+ \to t\bar{b})$

in single top production channels



Fermilab and the TEVATRON

- Tevatron:
  - $p\bar{p}$ acceleration and collisions
  - center of mass energy: 1.96 TeV

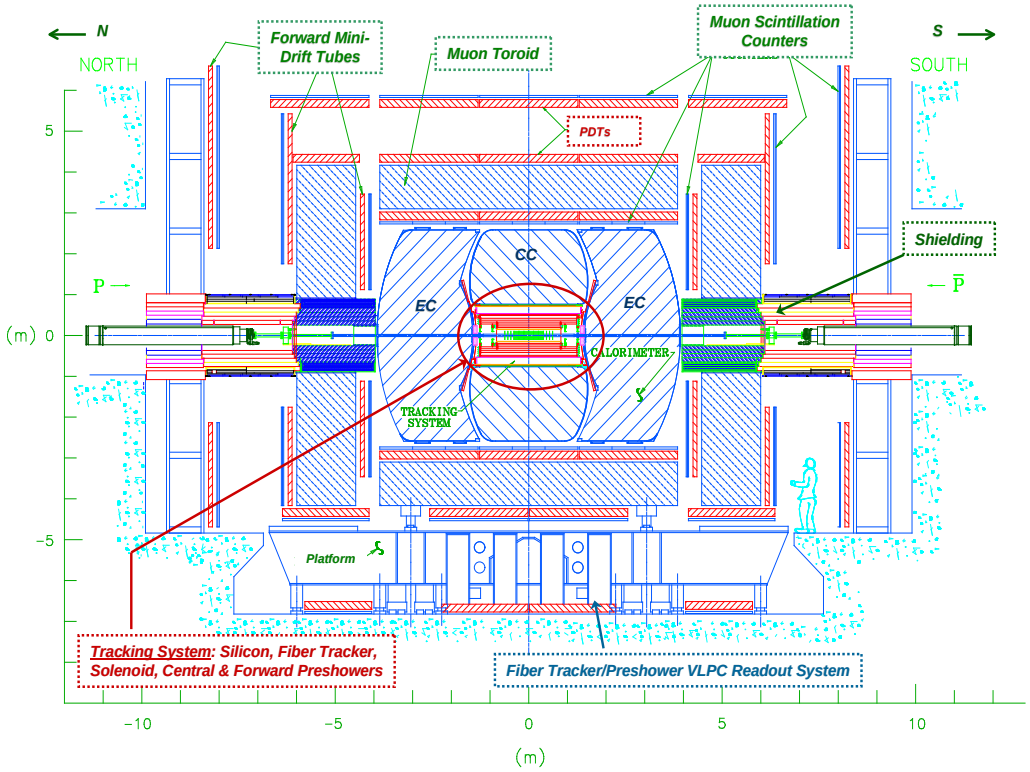


- >4fb^{-1} integrated luminosity delivered
- almost 4fb^{-1} on disk

The D0 detector

- Track detector: SMT and CFT
  - measures tracks of charged particles
- Calorimeter:
  identification and energy measurement of jets and electrons
  - tau identification
- Muon chamber:
  identification and measurement of muons

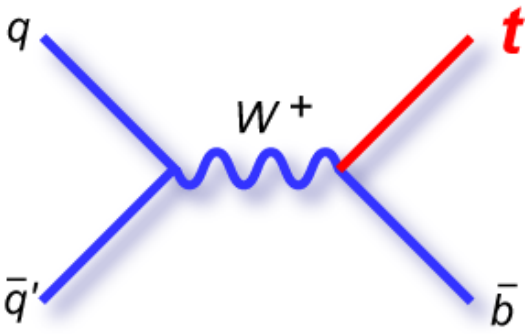
20m x 12m x 12m



Search for high mass charged Higgs bosons

Standard model single top

First evidence of single top reported in 2006

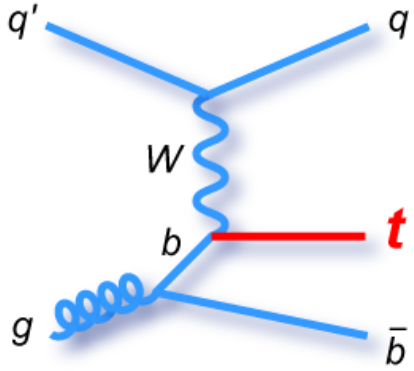


with

$\sigma(tb+X, tbq+X)=4.7\pm1.3$ pb

(3.6 std. dev. significance)

accepted by PRD



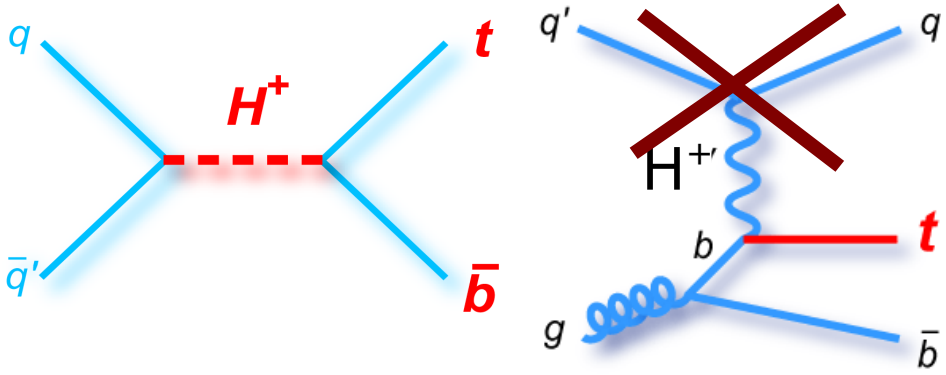
Measurement of the two channels separately

s-channel: $\sigma(tb+X) = 1.0 \pm 0.9$ pb t-channel: $\sigma(tqb+X) = 4.2\ ^{+1.8}_{-1.4}$ pb

- Different sensitivity to new physics
  - W' search
  - anomaleous Wtb couplings
  - FCNC
  - charged Higgs

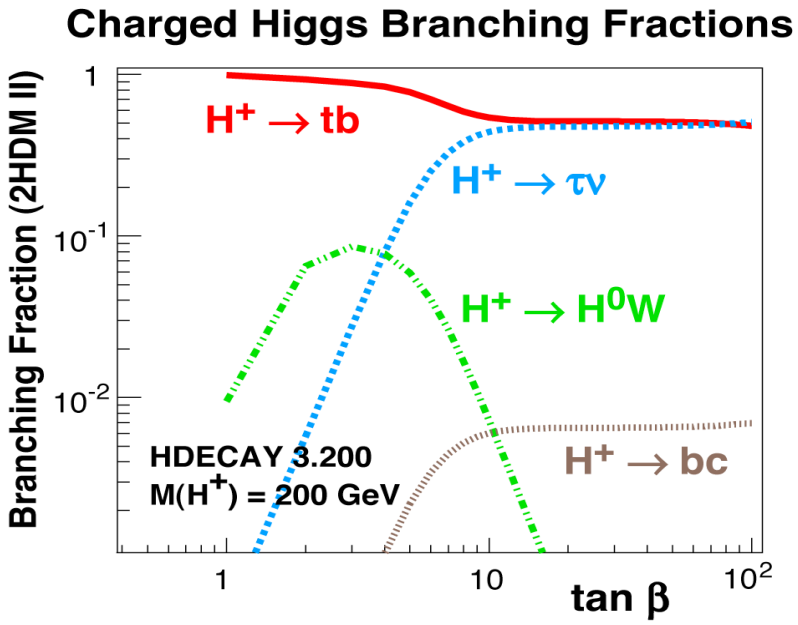
Charged Higgs and single top

- Replace W^+ by H^+
  - Only relevant in s-channel
    - low coupling to light quarks



  - branching fraction $H^+ \to t\bar{b}$ of order unity

- $H^+ \to t\bar{b}$ and $W \to t\bar{b}$ result in same final state

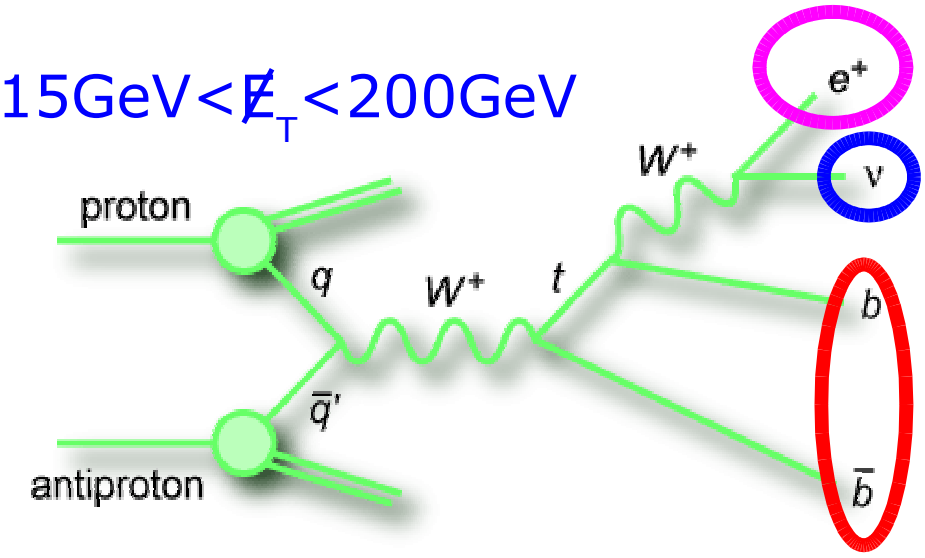


Event selection

- Select events with
  - W boson decaying to leptons
  - 2, 3 and 4 jets
  - s- and t-channel contribute differently to different jet multiplicities

Source	Event Yields in 0.9 fb^{-1} Data Electron+muon, 1tag+2tags combined 2 jets	3 jets	4 jets
tb	16 ± 3	8 ± 2	2 ± 1
tqb	20 ± 4	12 ± 3	4 ± 1
$t\bar{t} \rightarrow ll$	39 ± 9	32 ± 7	11 ± 3
$t\bar{t} \rightarrow l$+jets	20 ± 5	103 ± 25	143 ± 33
$W+b\bar{b}$	261 ± 55	120 ± 24	35 ± 7
$W+c\bar{c}$	151 ± 31	85 ± 17	23 ± 5
$W+jj$	119 ± 25	43 ± 9	12 ± 2
Multijets	95 ± 19	77 ± 15	29 ± 6
Total background	686 ± 41	460 ± 39	253 ± 38
Data	697	455	246

15GeV<$\not\!\!E_T$<200GeV



exactly one isolated lepton:
electron: E_T>15GeV, |η|<1.1
muon: E_T>18GeV, |η|<2.0

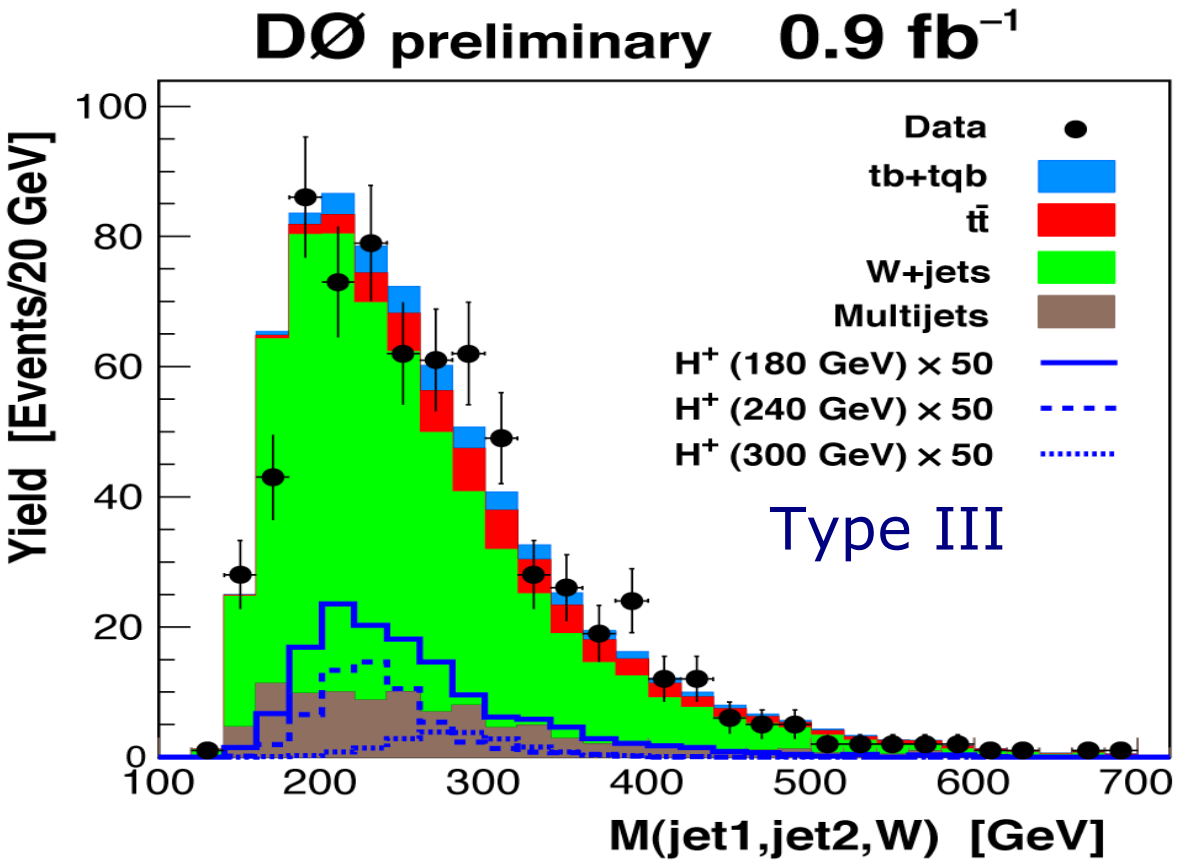
2 jets, 3 jets, 4 jets
≥ 1 jet identified as b-jet

Topological discriminant

- Use the same event selection as for standard model single top search
  - but exactly 2 jets only
- Discrimination:

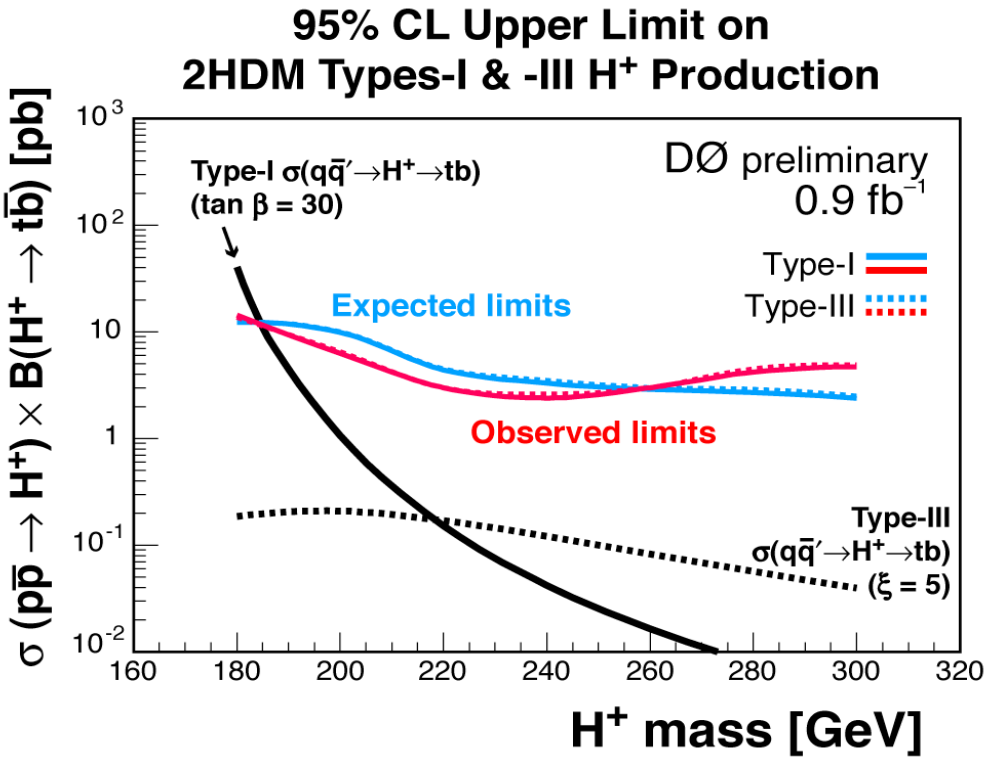
  use $m_{H\pm} > m_t$

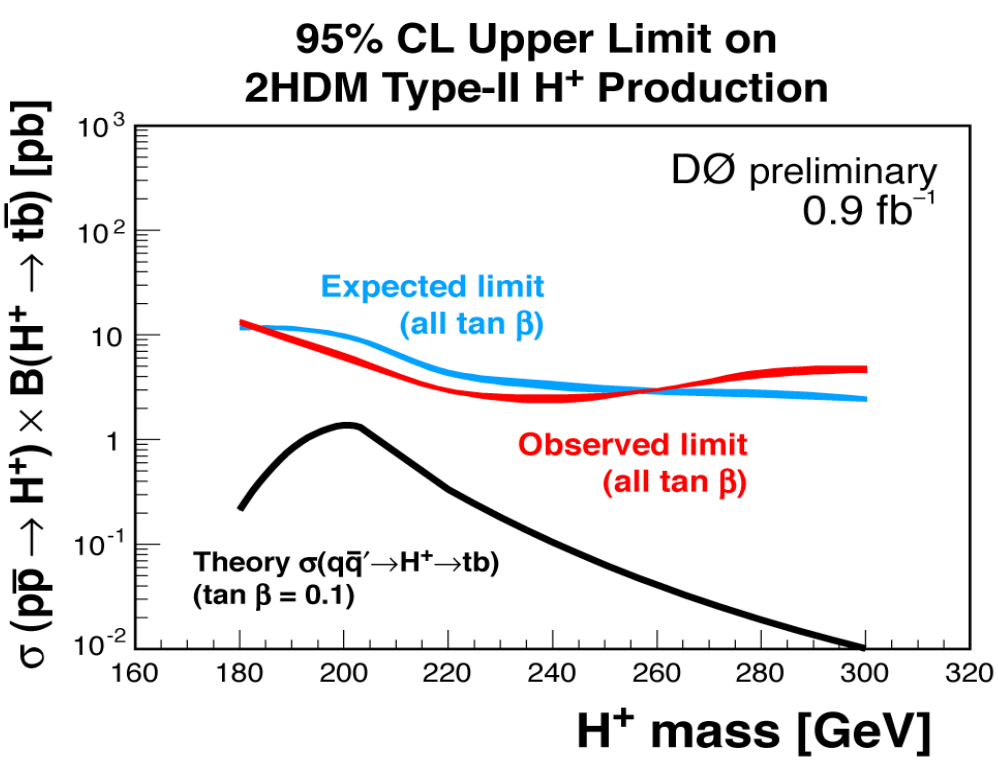
  Binned likelihood in invariant mass M(jet1, jet2, W)
- Simulation of different models by different mixing of left and right handed samples



Limits

- No deviation from SM ⇒ Set limits on $\sigma(p\bar{p}\rightarrow H^{+})xBr(H^{+}\rightarrow t\bar{b})$
- Type I & II: m_{H+} and tan β
- Type III: m_{H+} and ξ (top-charm quark mixing parameter)
- Exclude $180<m_{H+}<184$GeV for $23<\tan\beta<70$ for 2HDM Type I



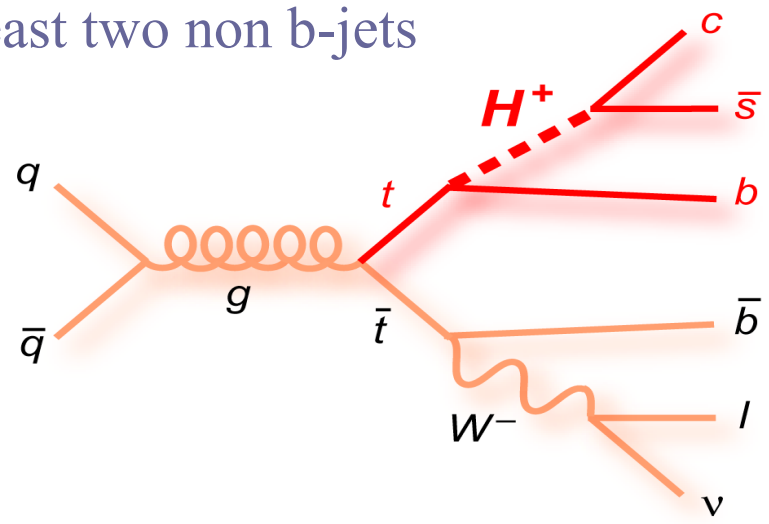


Search for low mass charged Higgs bosons

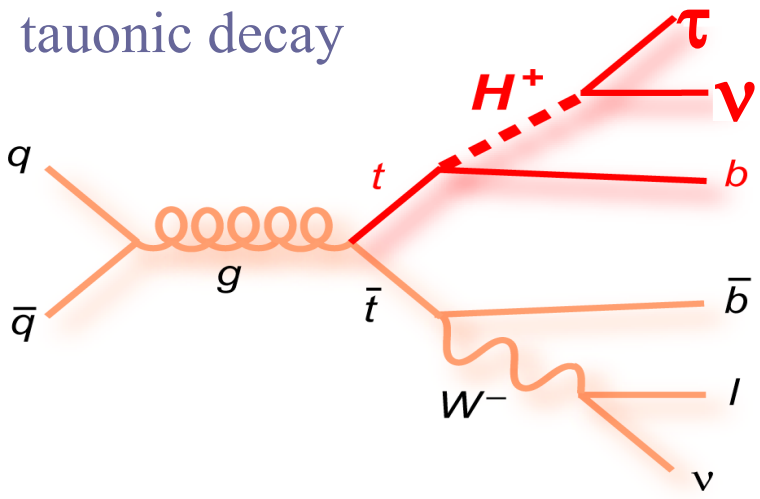
Charged Higgs search in $t\bar{t}$

- Production via 85% $q\bar{q}$ annihilation and 15% gg fusion
- Theoretical cross section: 6.8pb @ top mass of 175GeV
- Decays $t \rightarrow W^+b$ and $t \rightarrow H^+b$ can compete
- Different H^+ decays ----> change of final states

at least two non b-jets

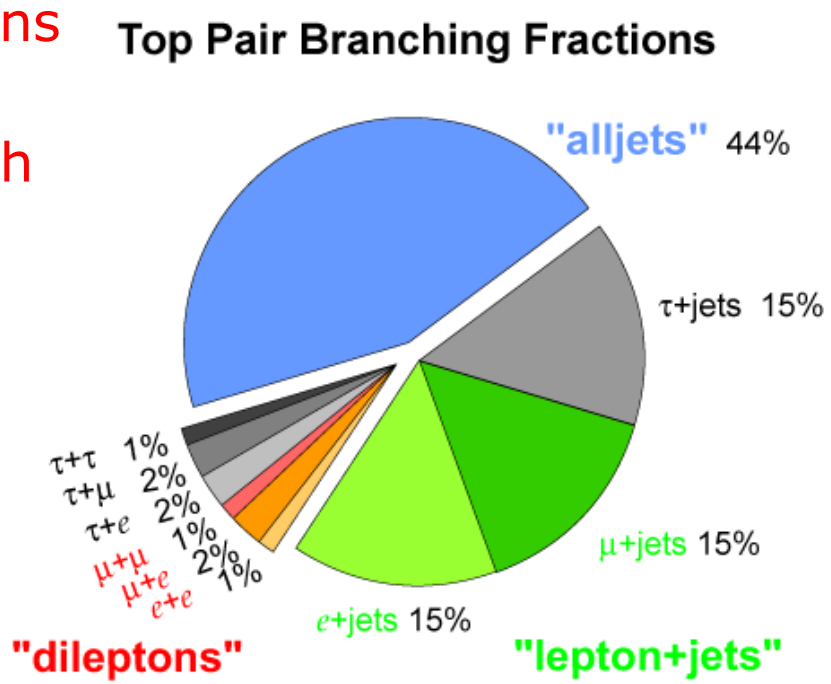


tauonic decay



$t\bar{t}$ decay final states

dilepton:
two isolated leptons
>=2 jets (b jets)
2 neutrinos → high missing E_T



all hadronic:
>= 6 jets
2 b-jets

τ+lepton:
as dilepton
and τ
candidate

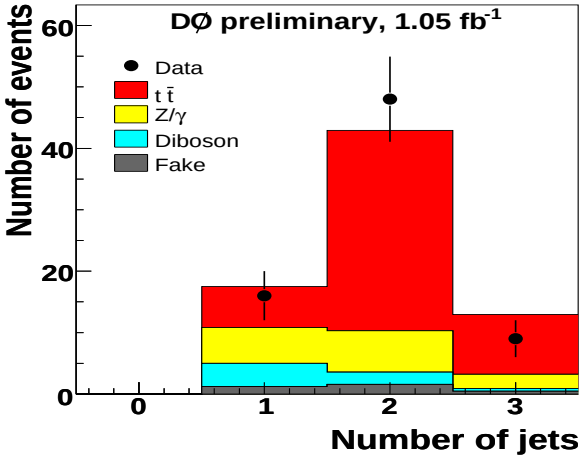
lepton+jets:
exactly one isolated lepton
>=4 jets
2 b-jets
1 neutrino → missing E_T

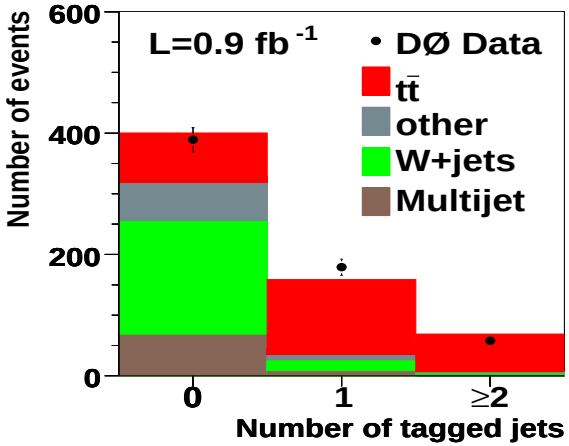
channels classified according to W decay

$t\bar{t}$ cross section

dilepton channel:
leptons give clear signature
-> pure channel
main background Z+jets

$$\sigma_{t\bar{t}} = 6.8^{+1.2}_{-1.1}(stat)^{+0.9}_{-0.8}(syst) \pm 0.4(lumi)\ pb$$





4 jets and more

$t\bar{t}$ cross section with b-tag
in lepton+jets channel:
high statistics
main background W+jets

$$\sigma_{t\bar{t}} = 8.27^{+0.96}_{-0.95}(stat+syst) \pm 0.51(lumi)\ pb$$

Cross section ratio

- New decay modes can change measured $\sigma_{t\bar{t}}$ depending on decay mode
- Calculate cross section ratio

$$R_\sigma = \frac{\sigma\left(p\bar{p}\to t\bar{t}\right)_{ljets}}{\sigma\left(p\bar{p}\to t\bar{t}\right)_{dilepton}}$$

  - all correlations between systematics fully taken into account by performing combined ensemble tests
  - many uncertainties cancel
  - Result:

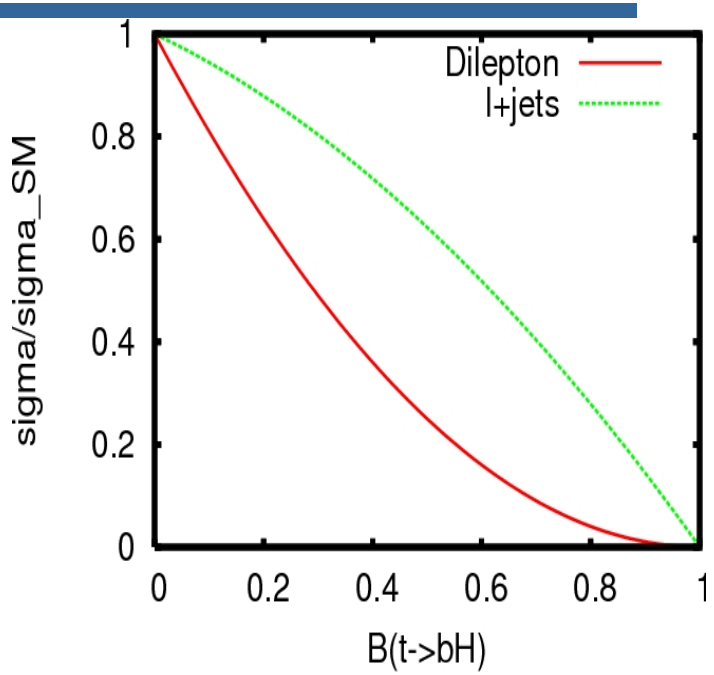
$$R_\sigma = 1.21^{+0.27}_{-0.26}\left(stat+syst\right)$$

in agreement with SM $R_\sigma = 1$

  - CDF: $1/R_\sigma = 1.45^{+0.83}_{-0.55}\left(stat+syst\right)$ (lumi: 200pb^{-1})

Cross section ratio and Br(t $\rightarrow H^+b$)

- dilepton: both W bosons from top decay need to decay leptonically
- l+jets: one W boson decays leptonically, one H^+ hadronically



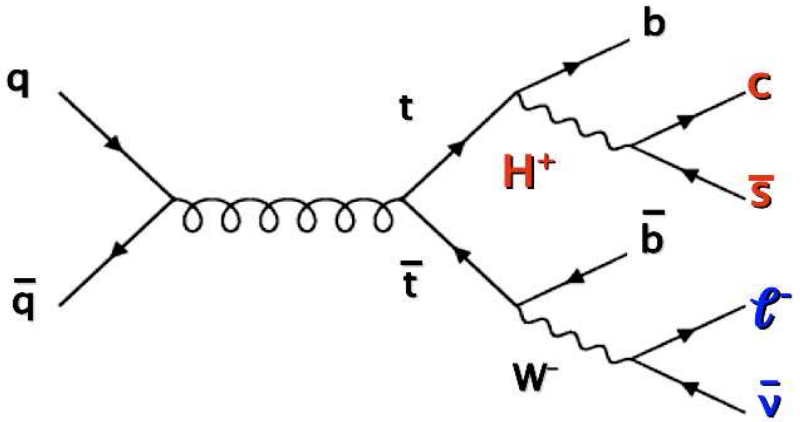
- Cross section ratio can be interpreted in terms of charged Higgs decay

$$R_\sigma = 1 + \frac{Br(t \rightarrow H^+ b)}{(1 - Br(t \rightarrow H^+ b))(Br(W \rightarrow q\bar{q}))}$$

Interpretation: Upper limit on Br(t$\rightarrow H^+$b)

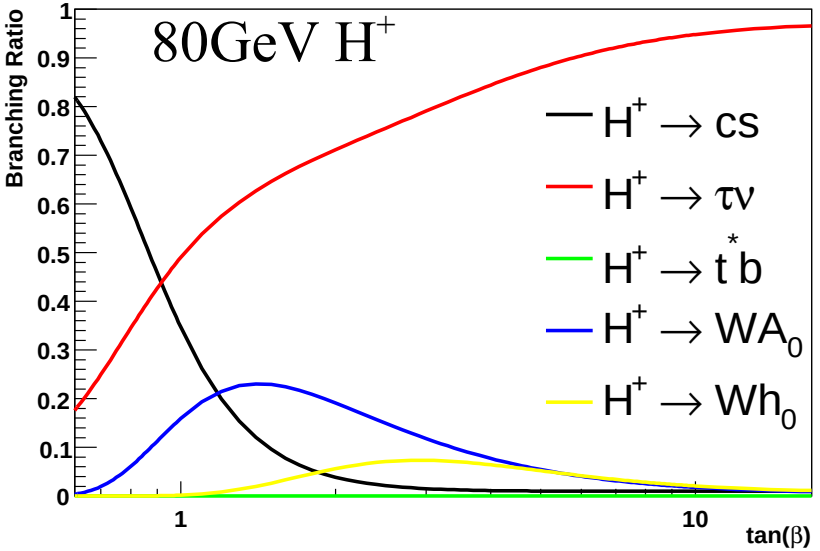
Leptophobic charged Higgs

- Simple model:
  - charged Higgs H^+ with
    - mass ~ W boson mass
    - $Br(H^+ \to c\bar{s}) = 100\%$
    - similar event kinematics for $t \to H^+ b$ and $t \to W^+ b$



- No LEP exclusion of 80GeV H^+
- Interesting at low tan β in MSSM
  - scenarios with large suppression of tauonic decay
- In MHDM models: leptophobic

  charged Higgs at all tan β possible

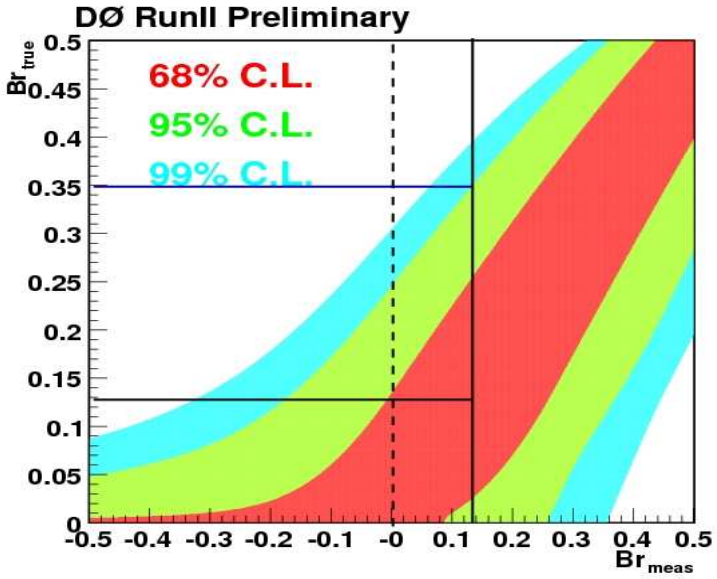


Limits on Br($t \to H^+ b$)

- For hadronically decaying charged Higgs with mass of 80GeV
  - set limit on Br($t \to H^+ b$) with Feldman Cousins method

Measured value:

$B(t \to H^+ b) = 0.13 \pm 0.12$



Observed limit:

$B(t \to H^+ b) < 0.35$ @ 95% C.L.

Expected limit:

$B(t \to H^+ b) < 0.25$ @ 95% C.L.

Conclusion and outlook

- We performed searches for charged Higgs at D0 with about 1fb^{-1} of integrated luminosity
  - in the single top mode (heavy H^+)
    - limits on $\sigma(p\bar{p}\rightarrow H^+)xBr(H^+\rightarrow t\bar{b})$ for Type I, II and III 2HDM models
  - in the top pair production mode (light H^+)
    - Interpretation of cross section ratio gives limits on $Br(t \rightarrow H^+b)$ for simple model
- No deviation from Standard Model yet
- Expected 6-8fb^{-1} of data until end of RunII
  - still a lot of room for new physics!