cHarged 2006

Searches for Charged Higgs at CDF II

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(on behalf of the CDF collaboration)

Outline :

- *Introduction*
- *Single Channel search*
- *Multi-channel search*
    - *Results for Tevatron*
    - *Expectation for LHC*
- *Ongoing analyses*
- *Summary*

Introduction

Electroweak Symmetry Breaking

- **Standard Model (SM) : 1 Higgs doublet**
  - EWSB → One Higgs boson, $h^{0(SM)}$
  - Decays to bb , $\tau\tau$, etc.

- **Natural Next step : Models with 2 Higgs Doublets (2HDM)**
  - EWSB → 5 Higgs bosons (h^0,H^0,A,$H^\pm$)
  - h^0, H^0 → bb, $\tau\tau$, gg, W^+W^-, ZZ, cc
  - A→ bb, $\tau\tau$, gg, Zh^0, tt
  - H^+→tb, $\tau\nu$, cs, W^+h^0, W^+A

direct evidence of physics beyond SM

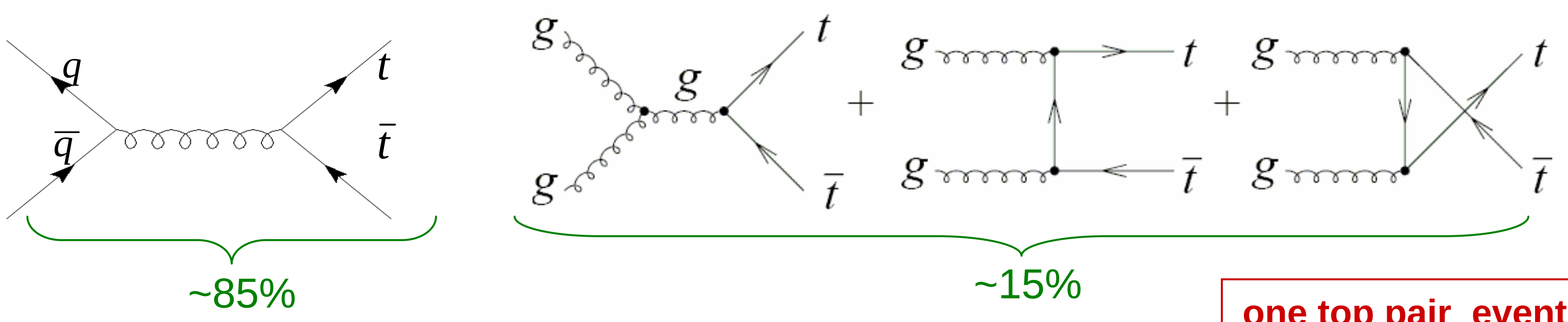
- **Top**
  - Large mass suggest it plays an important role
  - Fermion to which coupling to Higgs is most important, $y_t=M_t/v \approx 1$.

Top and Higgs bosons are the main characters in EWSB

- **What can be said about Top and charged Higgs production?**

Top quark production and decay

- **Produced in pairs via the strong interactions**



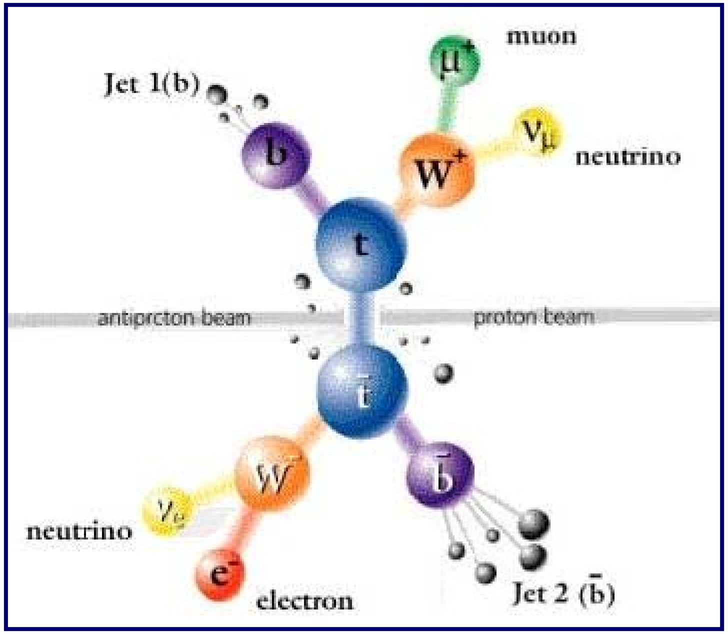
one top pair event every 10^{10} inelastic collisions

$$\sigma(\bar{p}p \to t\bar{t}\ @\ M_{top} = 175 GeV, \sqrt{s} = 1.96\ \mathrm{TeV}) \approx 6.7\ \mathrm{pb}$$

Other mechanisms of production possible, but not yet observed.

- **Decay:**
  - In the SM BR($t \to W^+ b$)>0.99 @95 C.L.

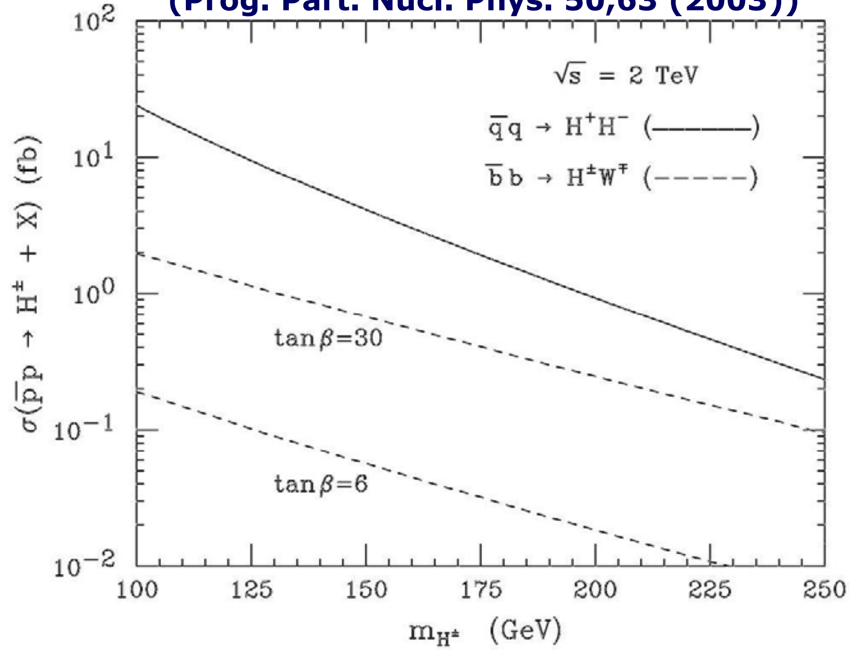
BR($t \to H^+ b$)= ??



Charged Higgs Production

- **Direct C.H. Production**
  - $\sqrt{s}$=2 TeV : $q\bar{q} \rightarrow H^+H^-$
  - Very small production rate
  - Signature hard to distinguish

(Prog. Part. Nucl. Phys. 50,63 (2003))



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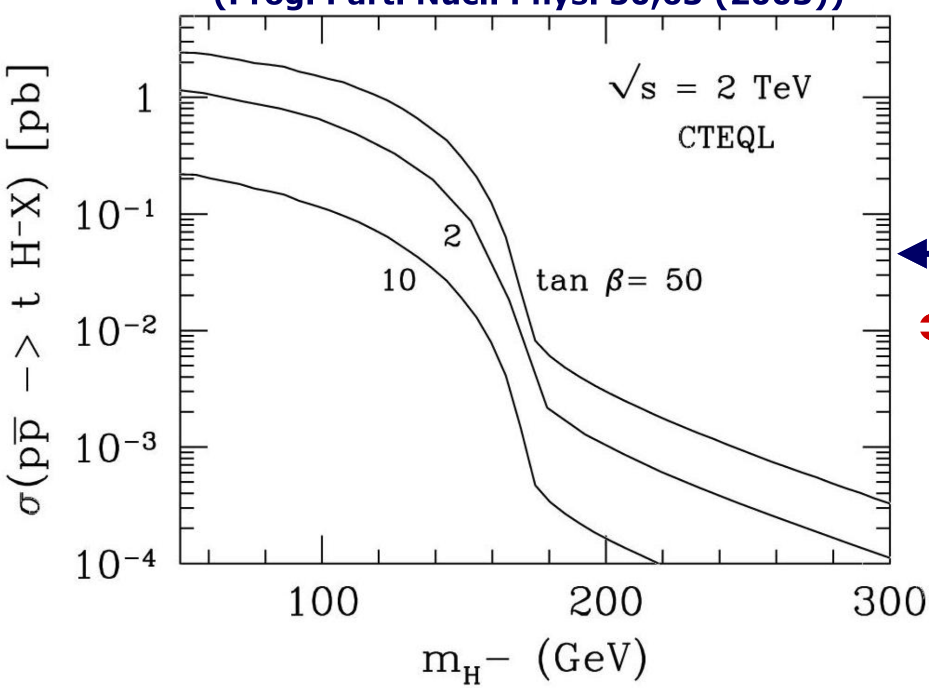


- **Indirect C.H. Production**
  - $\sqrt{s}$=2 TeV : top associated
    - If $m_{top} > m_H + m_b$ from tt decays
    - If $m_{top} < m_H$ with associated top
  - **Maybe Large production rates !**
    - **compare with ~6.7 pb**
  - **Clean signature !**

Single-channel search *(335 pb^{-1})*

Anomalous tau production in tt events

$(t\bar{t},\ t \rightarrow H^{+}b,\ H^{+} \rightarrow \tau\nu)$

Event Selection

- **One high p_T electron or muon (trigger)**
  - E_T>20 GeV
- **At least two jets.**
  - Leading jet E_T>25 GeV, other jet E_T>15 GeV
  - Cone radius $R=(\eta^2+\phi^2)^{1/2}$ > 0.4
- **At least one jet identified as a b-jet.**
  - Efficiency in $t\underline{t}$: 48 %
  - Displaced vertex
- **Missing transverse energy, E_T> 20 GeV.**
- **Scalar sum of all objects, H_T > 205 GeV.**
- **Exactly one hadronically decaying Tau lepton.**
  - Tau-jet likelihood > 0.65

Tau-jet likelihood

- Hadronic Tau candidates distinguished in 4 types

Tau Type	No. of tracks	No. of π^0 s
Type1	1	0
Type2	1	≥ 1
Type3	3	≥ 0
Type4	2	≥ 0

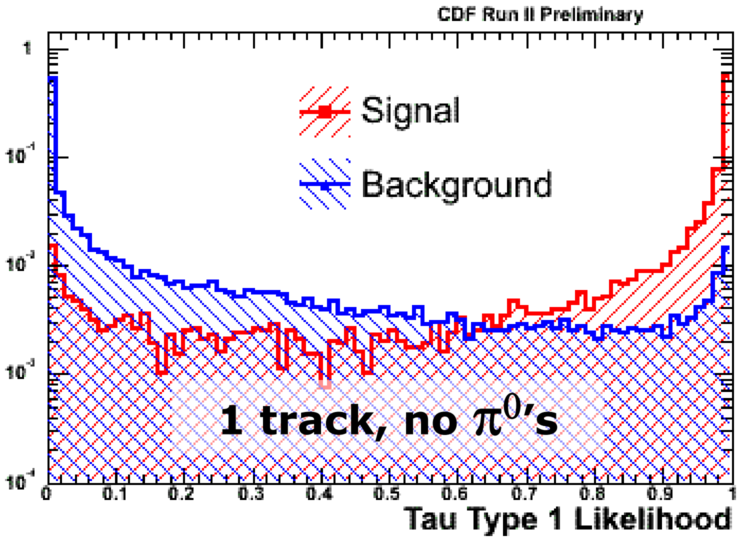
- One Likelihood per type. Based on variables characterizing a tau
  - Tracking and calorimeter isolation
  - Ratios of track P_T
  - Maximum d_0 significance

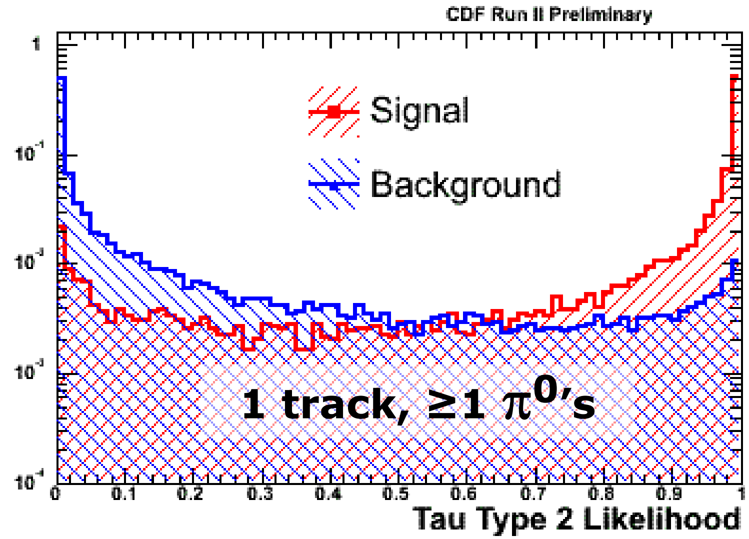
$$\mathcal{L} = \frac{\prod_i^N \mathbf{P}_S^i(x_i)}{\prod_i^N \mathbf{P}_S^i(x_i) + \prod_i^N \mathbf{P}_B^i(x_i)}$$

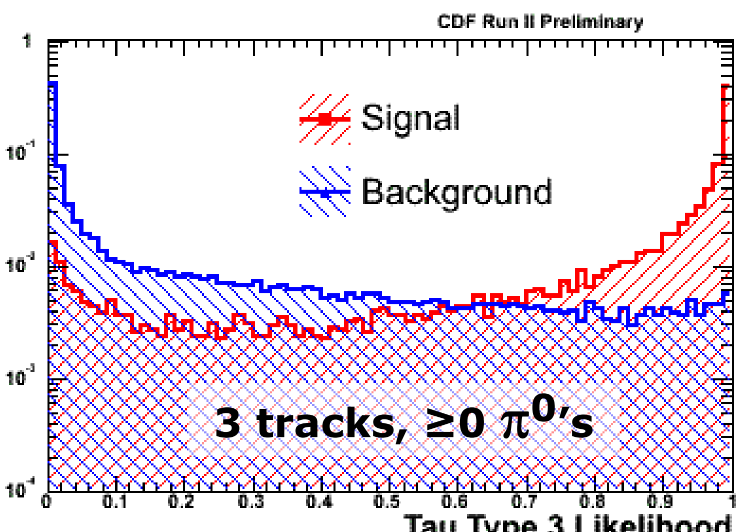
where $\mathbf{P}_s$ ($\mathbf{P}_B$) is the signal (background) probability for variable i.

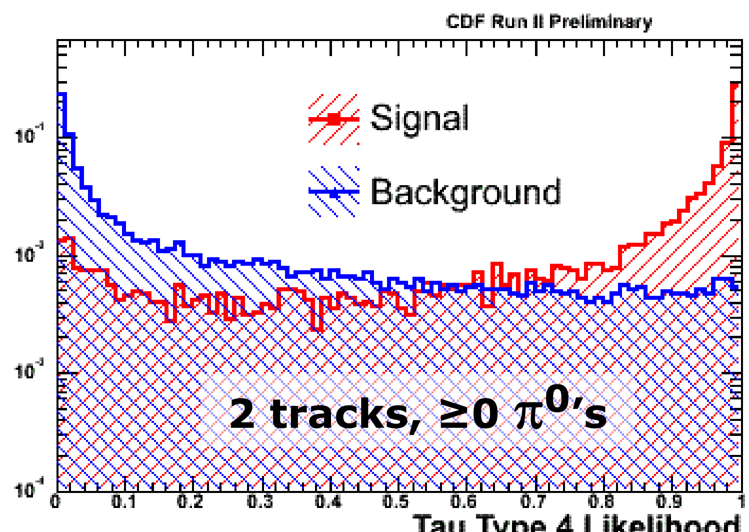
Tau-jet likelihood fitter

Signal : $t\bar{t}$ Monte Carlo.
Background: jet-triggered data









Results

Systematic uncertainties

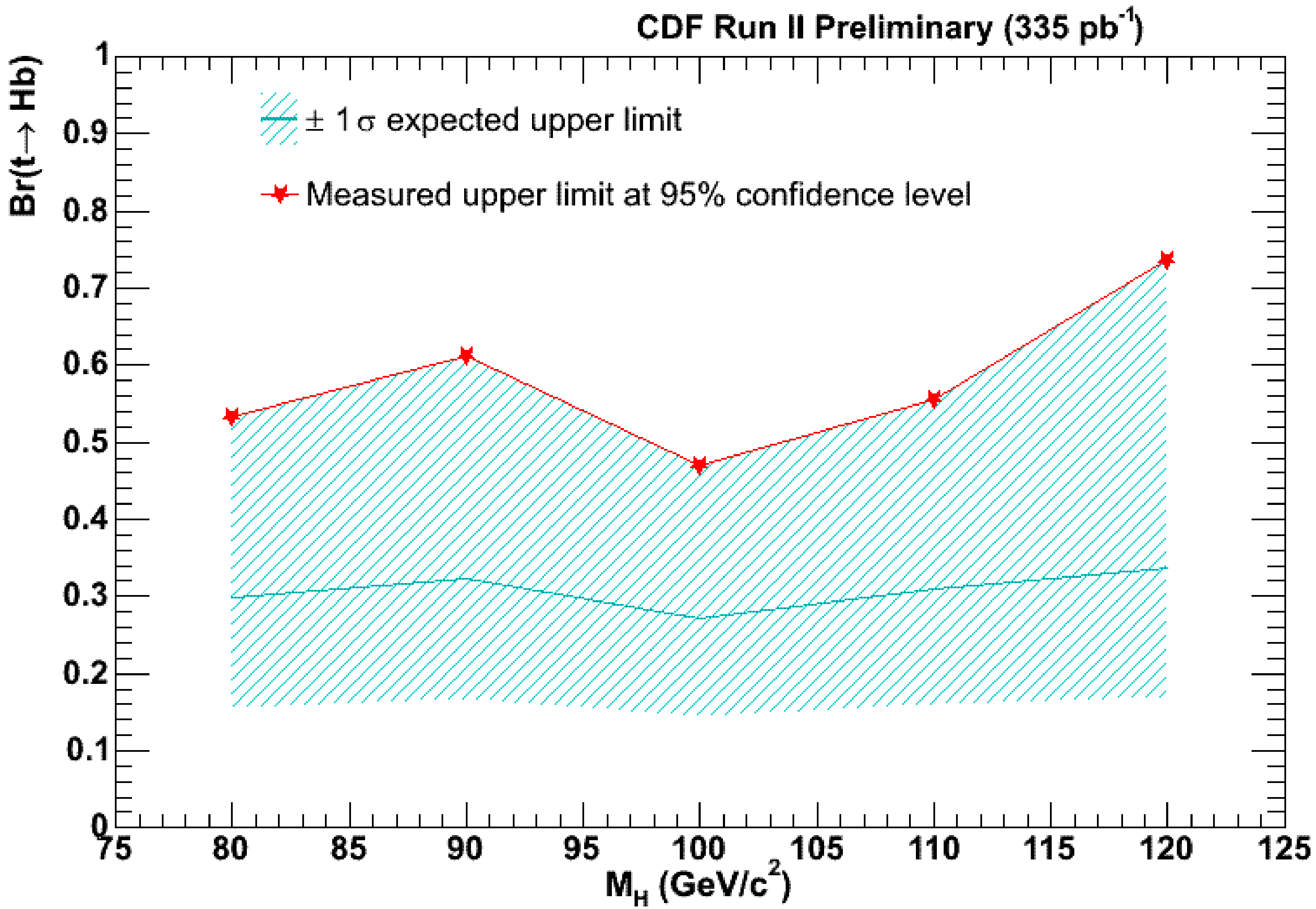
Source	Relative Error
jet$\to\tau$ misidentification	20%
Tau identification	15%
b-jet identification	7%
jet$\to b$-jet misidentification	11%
Jet energy scale	5%
Lepton identification	2%

Results

	Electron, Tau	Muon, Tau	All
$t\bar{t}\to\tau$	1.22 ± 0.22	0.85 ± 0.15	2.07 ± 0.37
fake τ,b-jet	0.65 ± 0.14	1.10 ± 0.22	1.74 ± 0.36
Other	0.03 ± 0.03	0.02 ± 0.02	0.06 ± 0.06
Total	1.90 ± 0.26	1.97 ± 0.27	3.88 ± 0.52
Data	4	2	6
Prob.	0.13	0.58	0.20

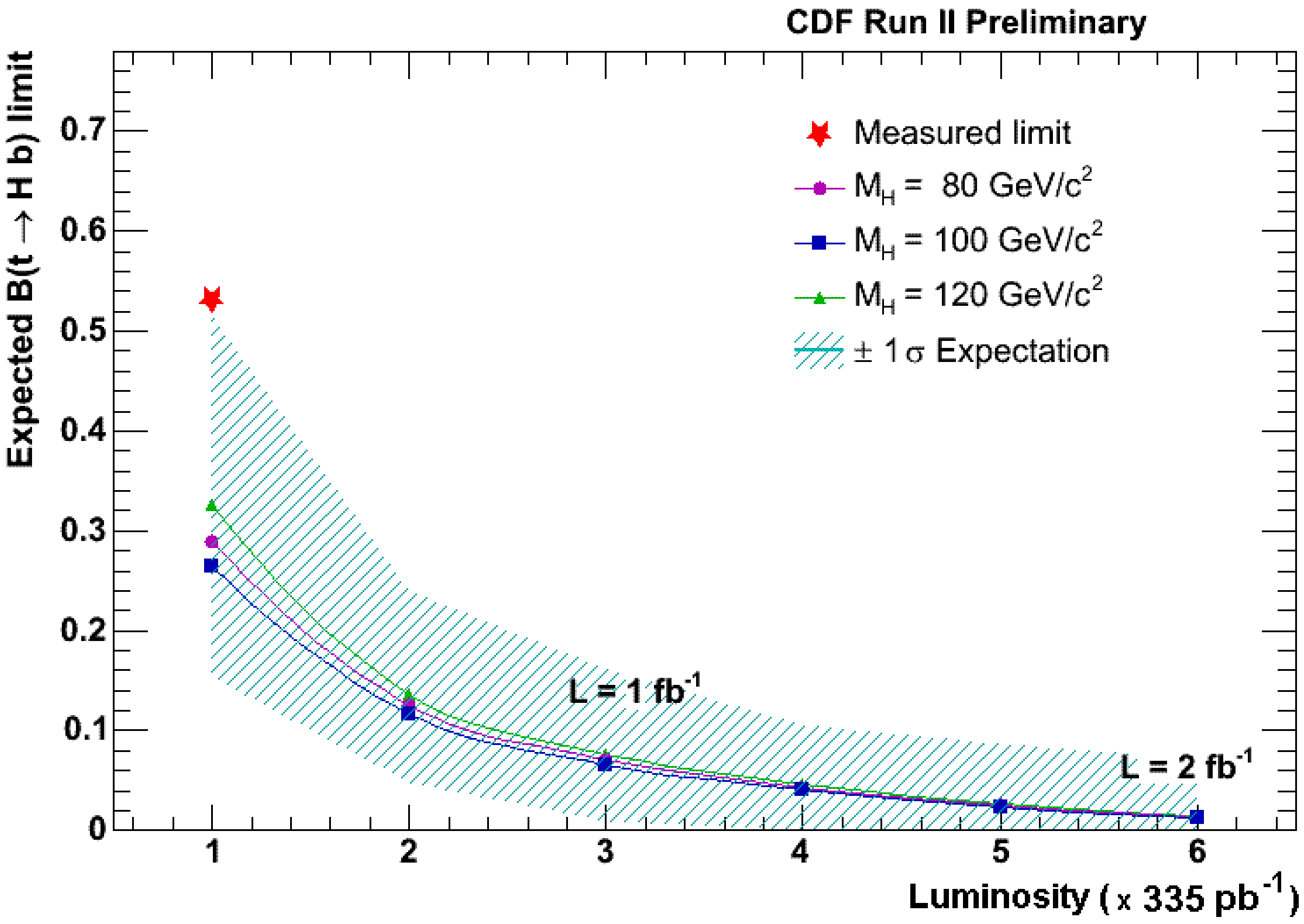
Results

- In terms of BR($t \rightarrow H^+b$) Vs. mH^+, assuming σ_{tt} = 6.7 pb.



Expected limit Vs. Luminosity

- Expected limits on BR(t→H⁺b) Vs. Lum.



Multi-channel search *(200 pb^{-1})*

PRL 96, 042003 (2006)

$t\underline{t}$, $t \to H^{+}b$, $H^{+} \to c\underline{s}$, $t^{*}\underline{b}$, Wh^{0}, $\underline{\tau}\nu$

Charged Higgs Decays Considered

- Assume that top decays either to W^+b or H^+b
  - $t \rightarrow W^+b$
  - $t \rightarrow H^+b$

$$BR(t \rightarrow W^+b) \equiv 1 - BR(t \rightarrow H^+b)$$

- Assume that the Higgs decays only as follows :
  - $H^+ \rightarrow c\underline{s}$
  - $H^+ \rightarrow \underline{\tau}\nu$
  - $H^+ \rightarrow t^*\underline{b}$
  - $H^+ \rightarrow W^+h^0$

$$BR(H^+ \rightarrow \tau\upsilon) \equiv 1 - BR(H^+ \rightarrow c\bar{s}) - BR(H^+ \rightarrow t^*b) - BR(H^+ \rightarrow W^+h^0)$$

- We further consider the h^0 decays to bb
  - $h^0 \rightarrow b\underline{b}$

$$BR(h^0 \rightarrow b\bar{b})$$

- **Summary :** For each top quark we consider 5 possible decays modes

B_1. $t \rightarrow W^+b$

B_2. $t \rightarrow H^+b \rightarrow csb$

B_3. $t \rightarrow H^+b \rightarrow \tau\nu b$

B_4. $t \rightarrow H^+b \rightarrow t^*Bb$

B_5. $t \rightarrow H^+b \rightarrow W^+h^0b \rightarrow W^+bbb$

The BR to each (B_i) can be predicted from these 5 indep. BR's

The Narrow Width Approximation (NWA) is implicit.

Search Strategy

Look at the relative rates of events in different $t\underline{t}$ decay channels

- **Take advantage of existent cross section analyses**
  - Lepton+Jets (1, and 2 or more tags) — Phys. Rev. **D**71,052003
  - Lepton+Tau — Phys. Lett. **B**639, 172 (2006)
  - Dilepton — PRL. **93**, 142001 (2004)

- **If $H^{\pm}$ is present, and $t \rightarrow H^{+}b$, what do we expect ?**
  - If **$BR(H^{+} \rightarrow \underline{\tau}\nu) \sim 1$**:
    - Lepton+tau will see an excess w.r.t. SM expectations.
    - Dilepton and Lepton+jets will show a deficit.
  - If **$BR(H^{+} \rightarrow c\underline{s}) \sim 1$** :
    - All channels would see a deficit. All hadronic channel will see an excess.
  - Similar considerations for other H^{+} decays.

Analysis Technique

Model : Top and $H^{\pm}$ production

→

#events in search channels

→

Comparison to data

→

Limits on model

Results

Presented for three types of model:

- The MSSM
- The tauonic Higgs model
- The Higgs BR independent model.

Results: MSSM , Choice of Benchmarks

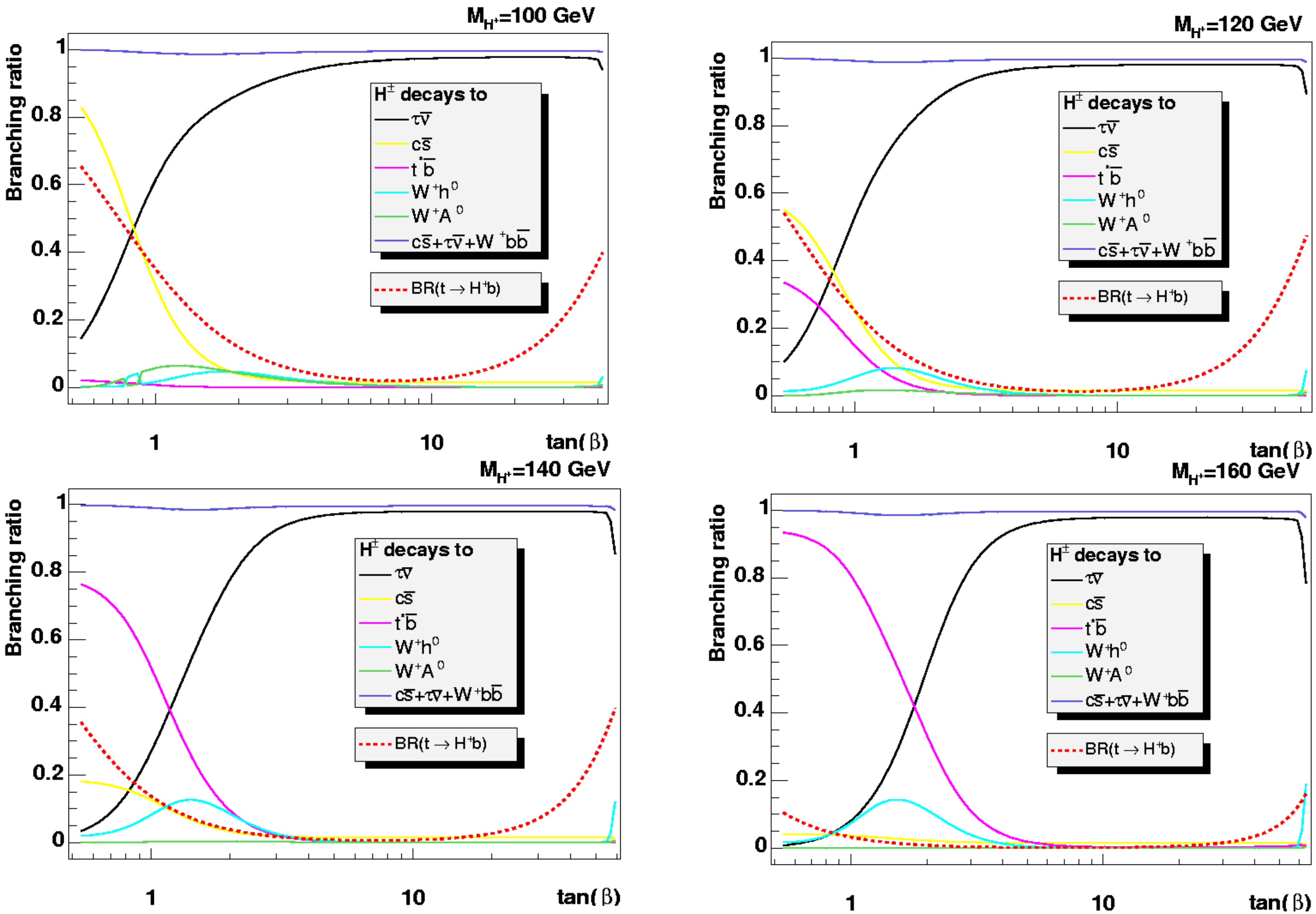
Using Phenomenological MSSM; 14 params for the 3rd generation.

	μ (GeV)	At(GeV)	Rest of parameters (GeV)
B1	**-500**	**2000**	**M2=M3=MQ=MU=MD=1 TeV**
B2	**-500**	**-500**	**M1=0.4978*M2, ML=ME= 1 TeV**
B3	**500**	**500**	**Ab=At, Atau=500 GeV**
B4	**500**	**2800**	
B5(Minimal)	**-200**	**μ/tan(β)**	**MQ=MU=MD=1 TeV, M2=M3=200**
B6(Maximal)	**-200**	**2450GeV + μ/tan(β)**	**ME=ML=MQ, At=Ab, Atau=500**

- **B1 and B2 value of μ=-500 GeV, large BR($t \to H^+ b$) at large tan(b)**
  - Difference is At, that is chosen so as to maximize (B1) and minimize (B2) the mass of the h^0 in the tan(b) ~1 region.
- **B3 and B4 value of μ=+500 GeV, small BR(t→H+b) at large tan(b)**
  - Difference is At, that is chosen so as to maximize (B4) and minimize (B3) the mass of the h^0 in the tan(b) ~1 region.
- **B5 and B6 are the minimal and maximal stop mixing scenarios used at LEP. They minimize and maximize the mass of the h^0 at every point in tan(b).**

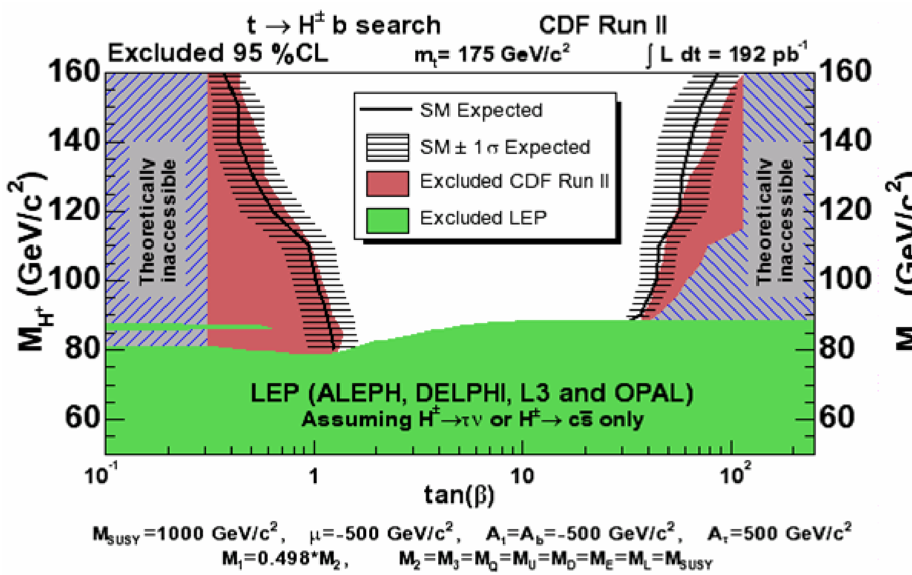
Results: MSSM , BR Predictions

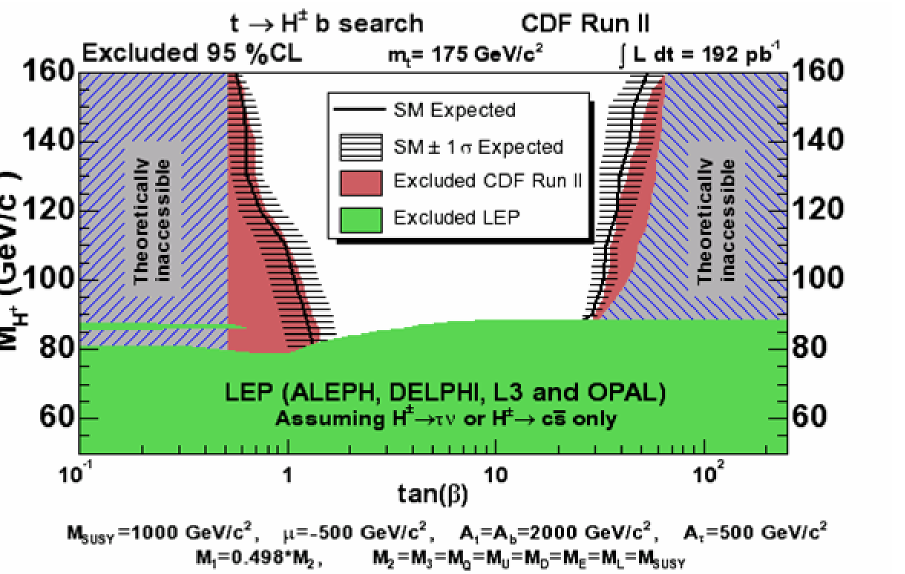
- **CPsuperH (hep-ph/0307373) predicts the Higgs BR's. For Bench #1 :**



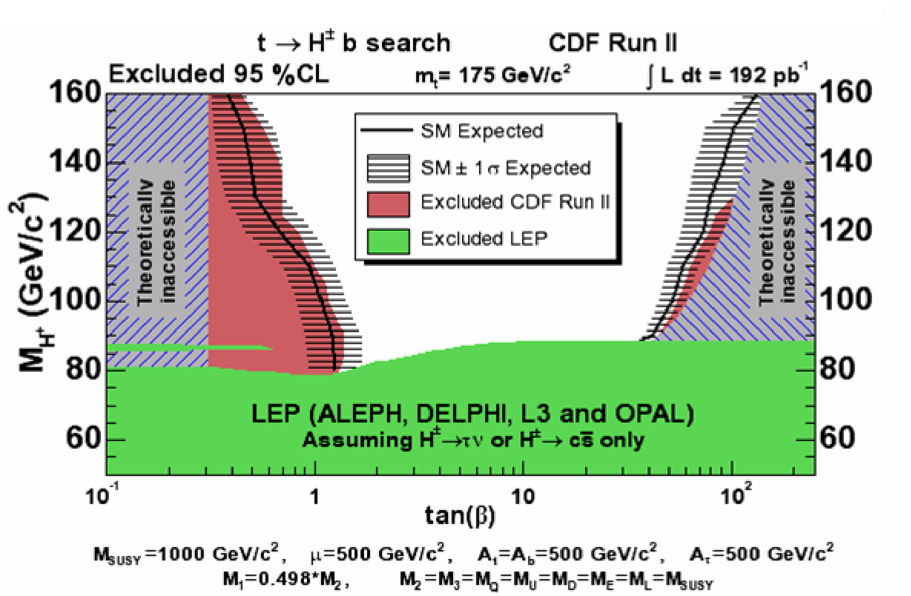
Results: MSSM, Benchmarks 1 to 4

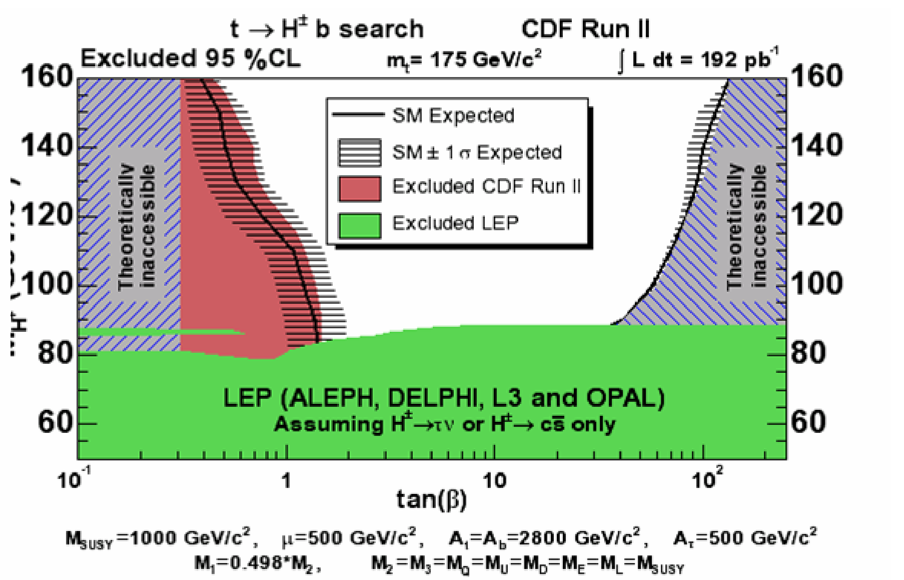
μ=-500 GeV





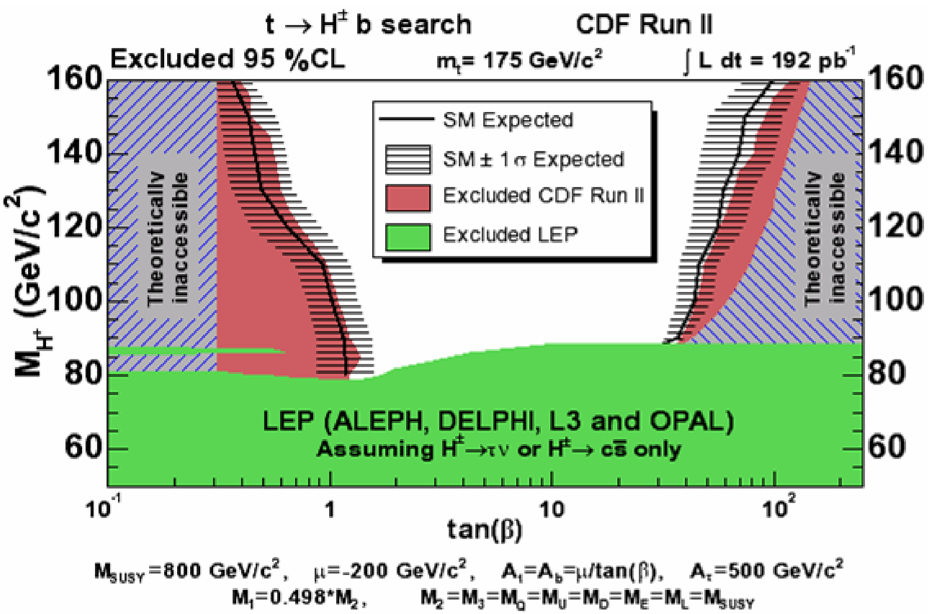
μ=500 GeV



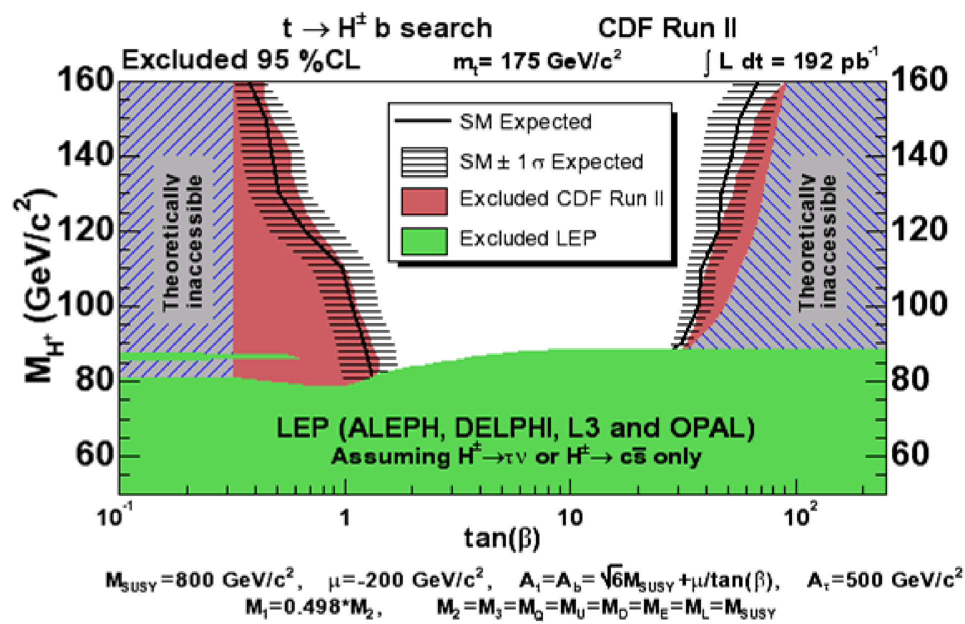


Results: MSSM, Benchmark 5 and 6

Minimal stop Mixing



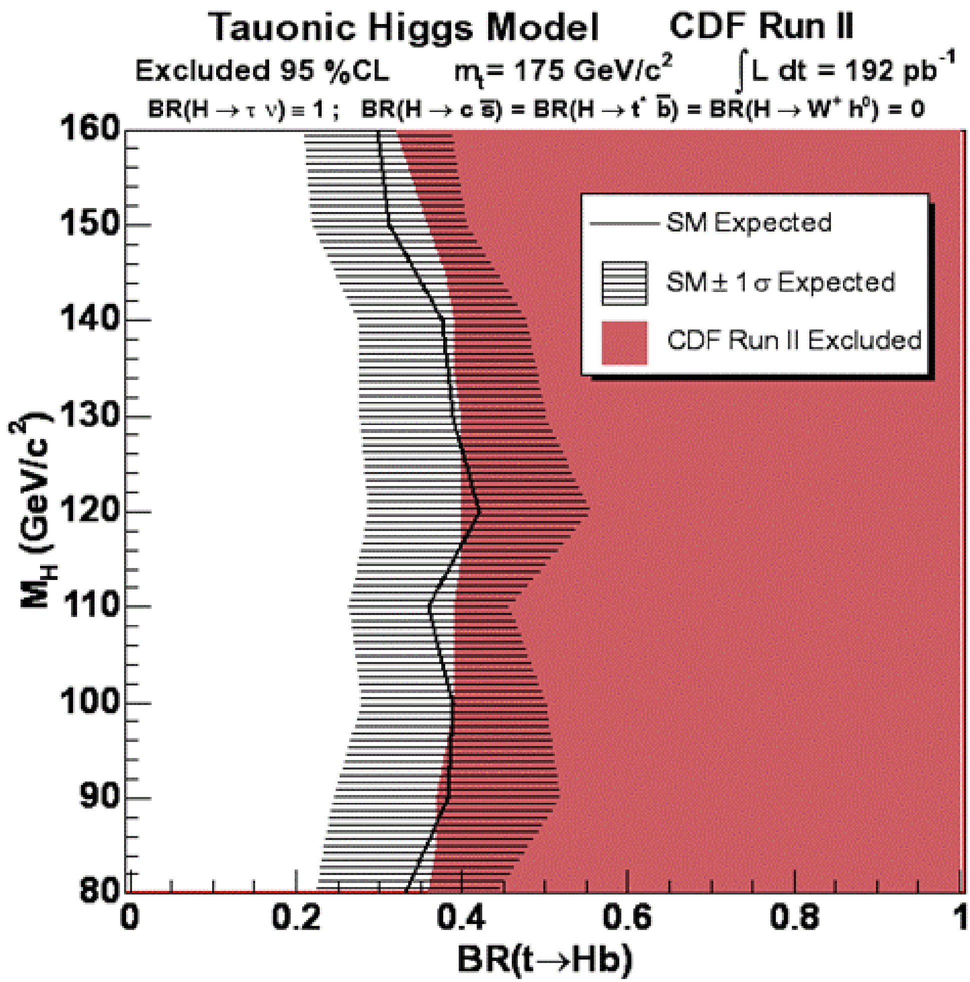
Maximal stop mixing



Clearly, these benchmarks were not designed for the charged Higgs search in ttbar decay products.

Results: Tauonic Higgs Model ($H^+ \rightarrow \tau\nu$)

- **Set** BR($H^+ \rightarrow cs$)≡ BR($H^+ \rightarrow t^*b$) ≡ BR($H^+ \rightarrow Wh^0$) ≡0. **Limits directly on BR($t \rightarrow H^+b$)**

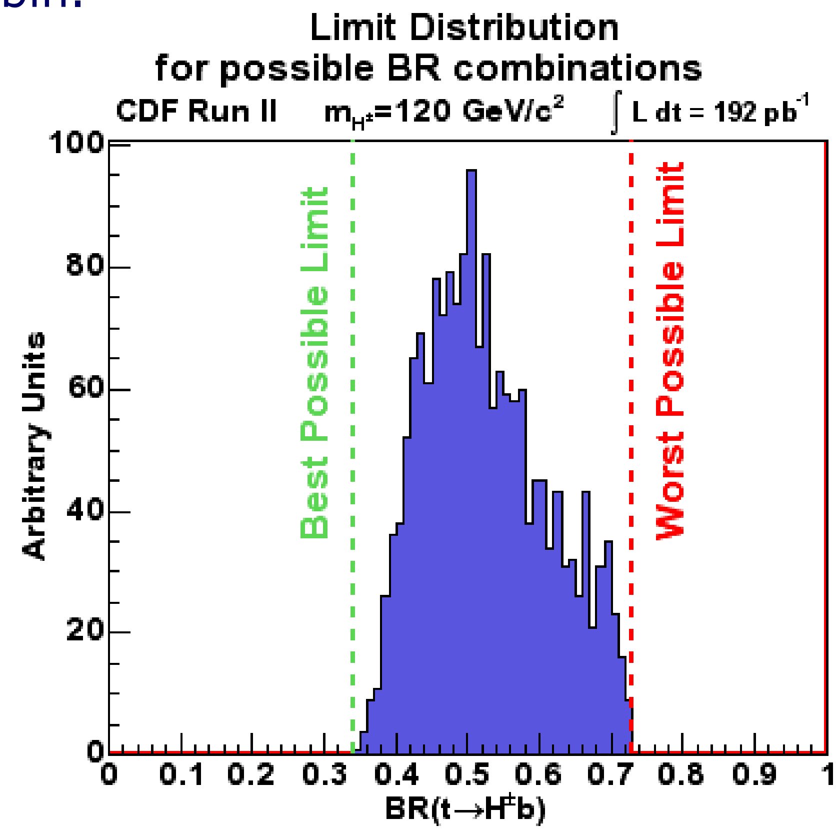


BR($t \rightarrow H^{\pm}b$)<0.4 @95%CL for **80 GeV<mH$^{\pm}$<160 GeV**!

Results: Higgs BR independent

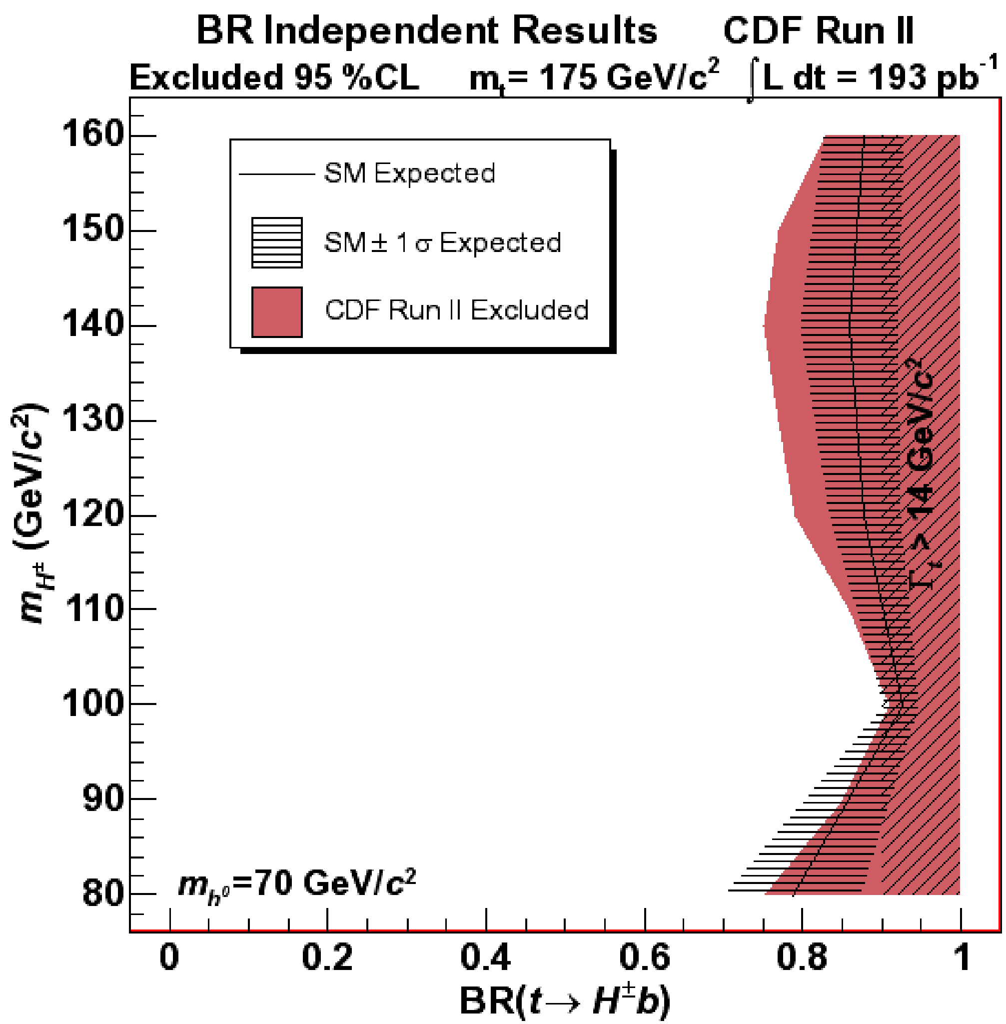
- **Scan over all BR combinations and take the worst limit:**
  - Slice the BR($H^+ \rightarrow cs$, t^*b, W^+h^0) in bins of 0.05 (21 bins each,1771 total)
  - Limit on BR($t \rightarrow H^+b$) for each bin.

Limit distribution
for $mH^{\pm}=120$ GeV/c^2



95%CL limits on BR($t \rightarrow H^+b$) ranging from 0.34 to 0.73

Results: Higgs BR independent



BR(t→H⁺b)<0.9 @95%CL for **80 GeV<mH±<160 GeV**!

- ✓ **Results obtained in the context of three different models.**

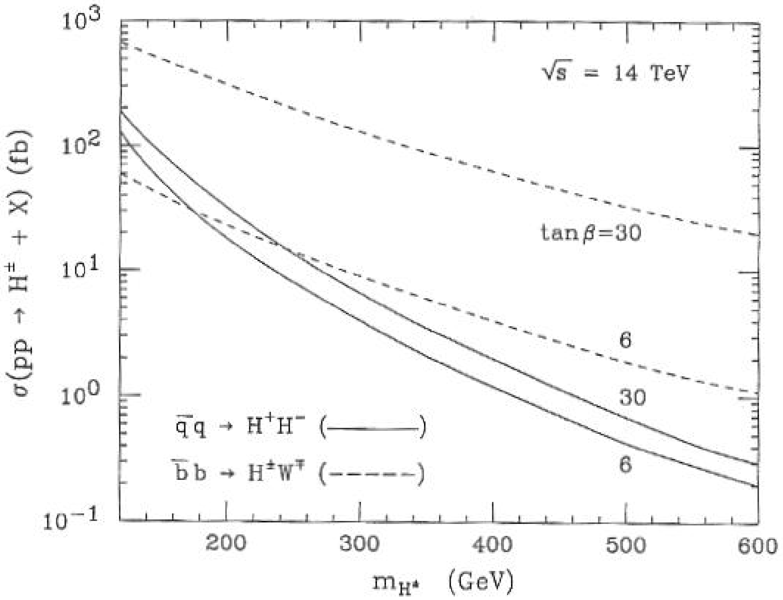
What is expected for the future ?

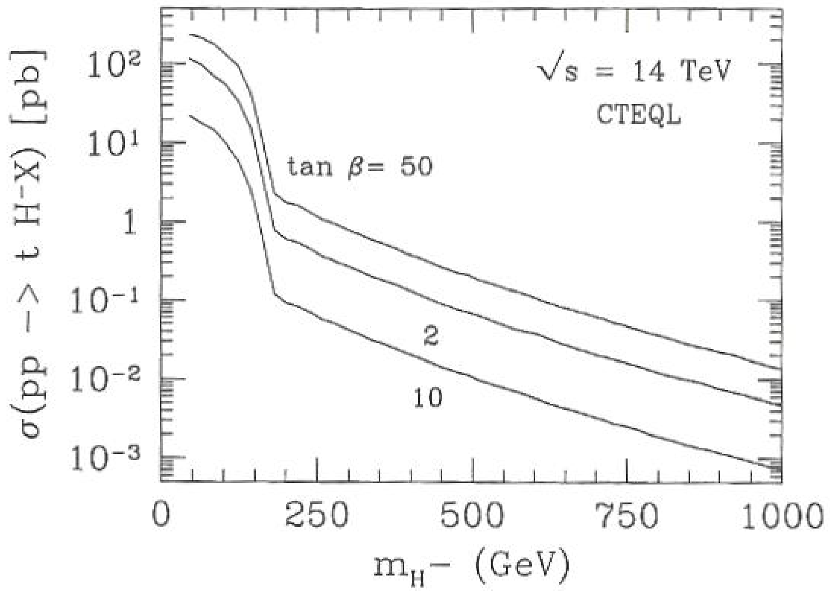
The Future, LHC

The Future : H^+ Production at LHC

$m_{H+} < m_{Top} - m_b$

Main source : tt,t→H⁺b
Well behind : qq→H⁺H⁻
bb→H⁺W⁻





$m_{H+} > m_{Top} - m_b$

Main source : gg,qq→tbH⁻
Well behind : qq(gg)→H⁺H⁻
bb→H⁺W-

Again, H^+ stronger signal comes associated with a top quark.
Strongest signal if $m_H < m_{Top} - m_b$

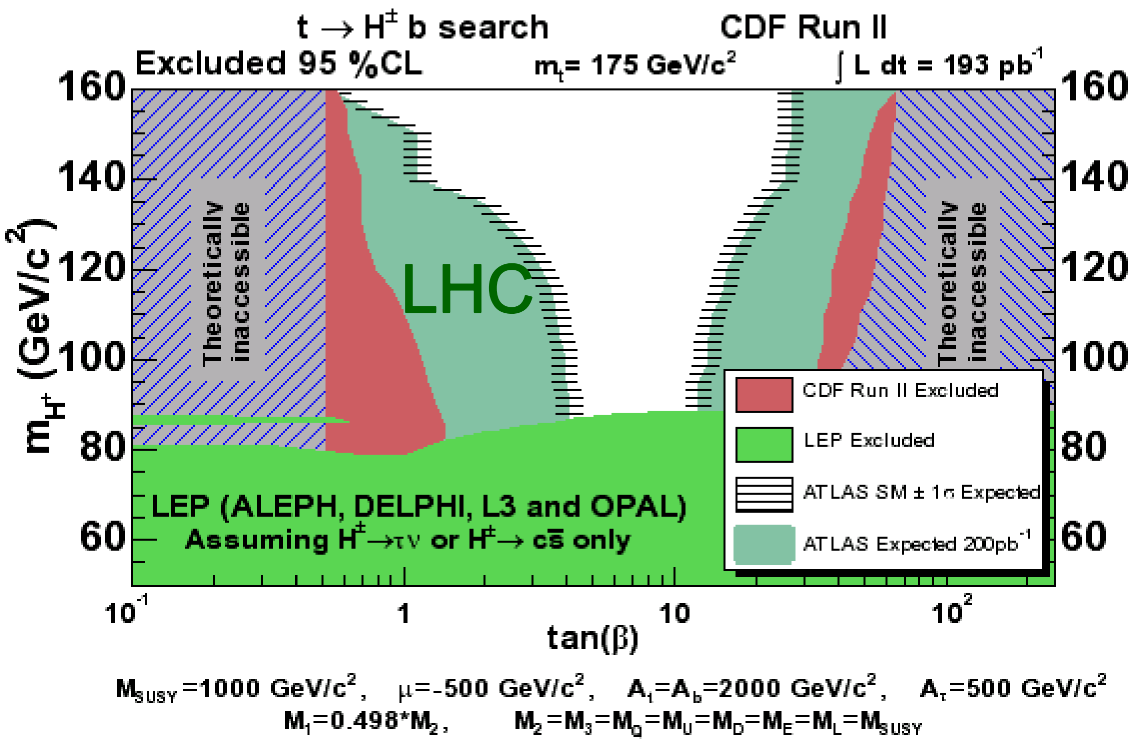
The Future : *LHC tt Production*

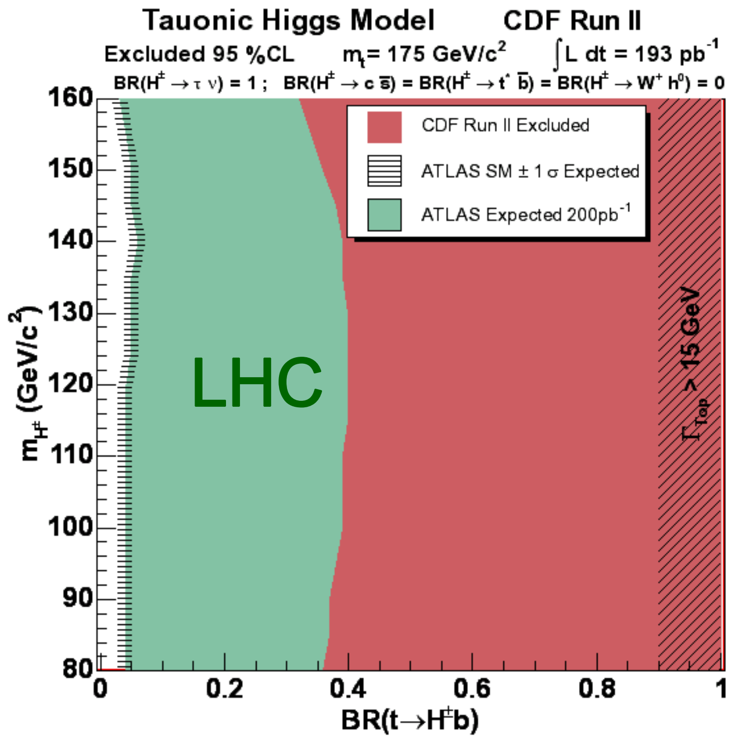
- **From Tevatron : tt channels to first order as expected from SM. Either :**
  - H^+ does not exist, or it is not between 80 GeV and 160 GeV
  - the top rarely decays to H^+
  - H^+ decays are significantly shared between decay modes.
- **Expect the same at LHC !**
- **Projections for Atlas(hep-ph/0403021) in 200 pb-1**
  - Use only 200 pb-1 to compare to the TeV results
  - At LHC this is only 1 week of nominal luminosity data taking !
  - Prod. Rate σ_{tt}~633 pb. **WOW!**

Channel (L≡e,μ)	S/B	#tt expected	#Background
Dilepton	10	1600	160
L+Jets (1^+ Tag)	28	5280	185
L+Jets (2^+ Tag)	78 WOW-WOW!	1740	22
L+tau$_{had}$	10	290	29

Use these numbers to calculate raw estimates for the limits on Charged Higgs.

The Future : *LHC Limits on Charged Higgs*



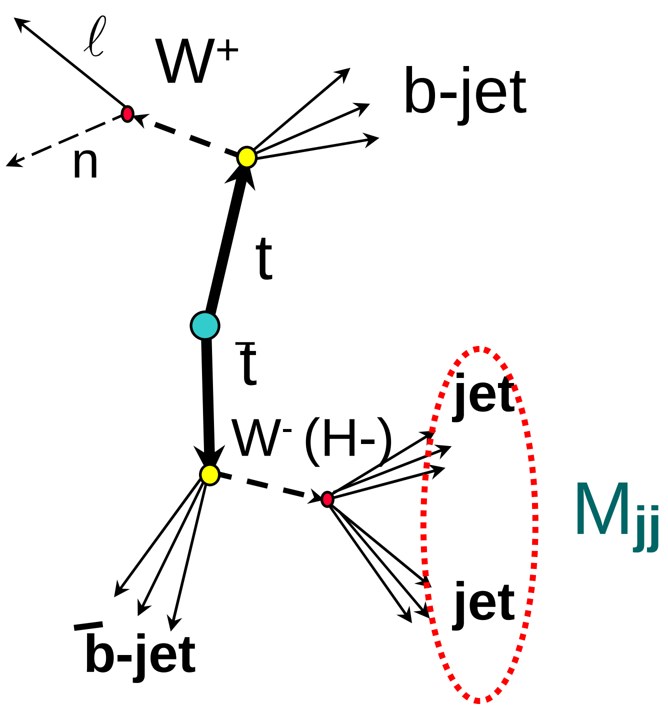


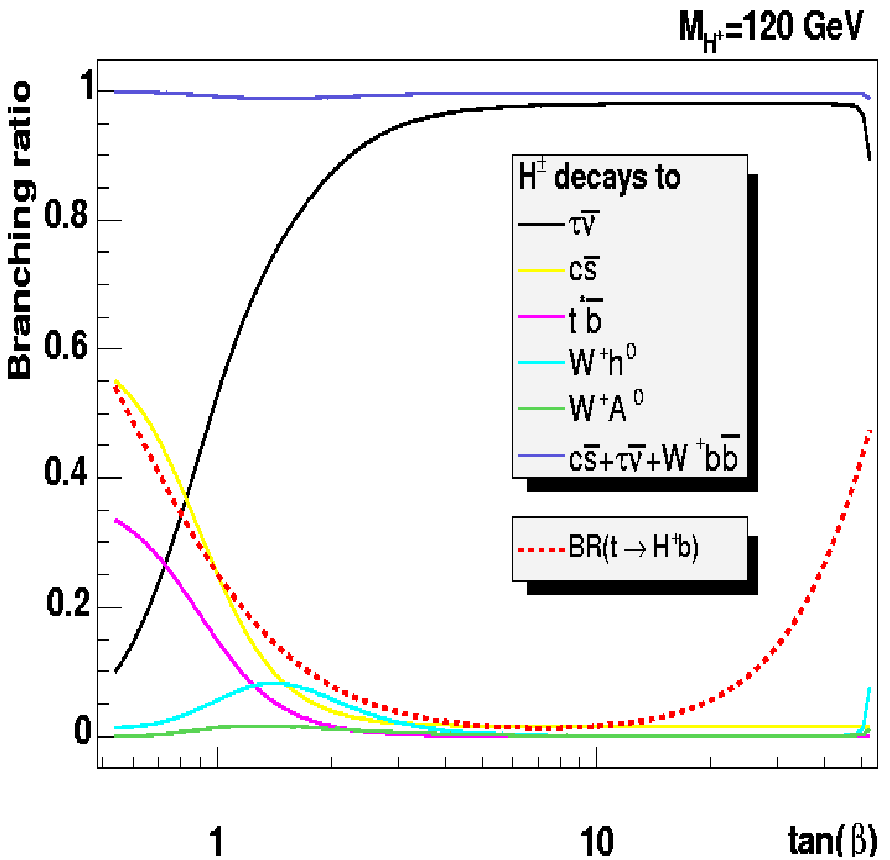
Large exclusion region promptly obtained
Note the small uncertainties

Other ongoing analyses

Search for $H^+ \rightarrow c\underline{s}$ in top decays

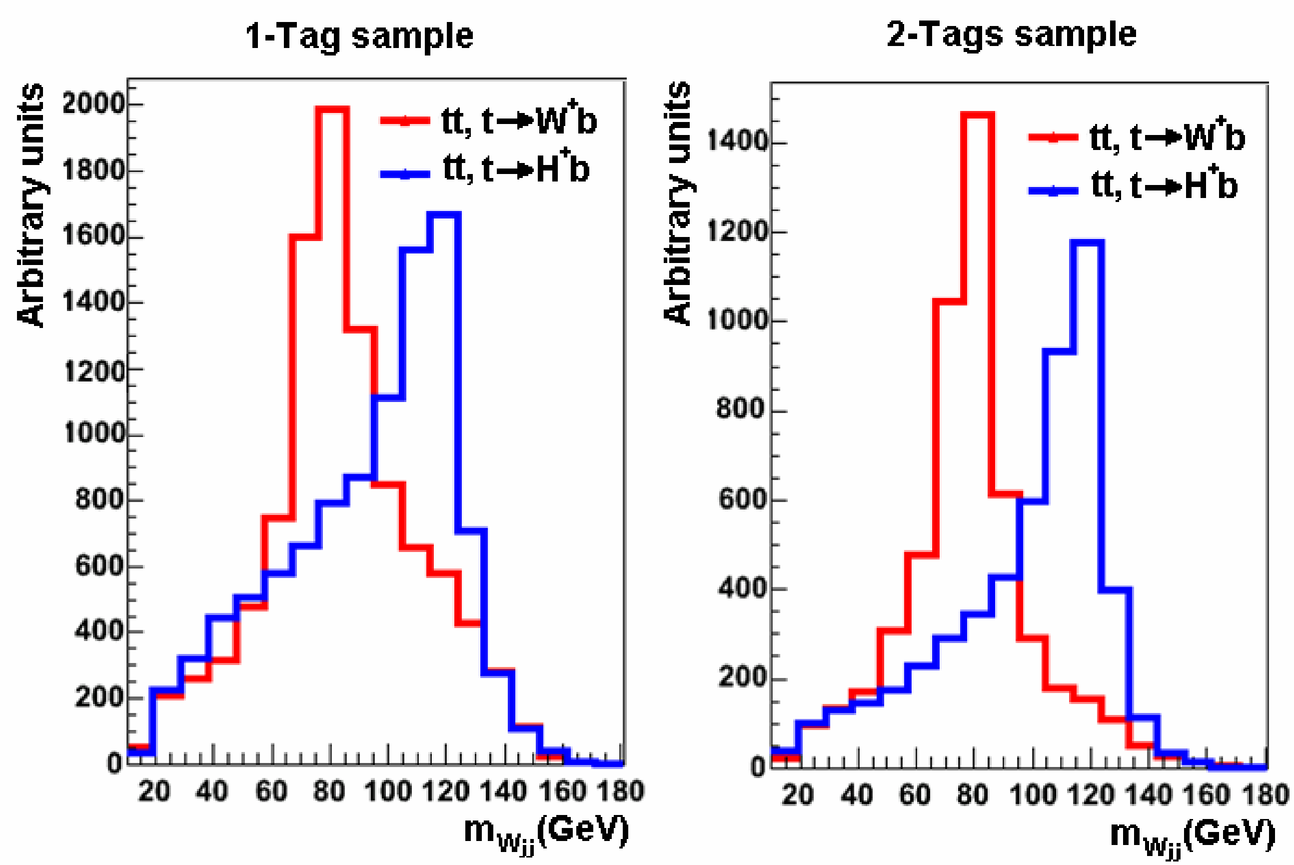
- **Strategy :** look for a second bump in W mass distribution
- Search for $H^+ \rightarrow c\underline{s}$, or generic charged particle decay into two jets
- In MSSM : $H^+ \rightarrow c\underline{s}$ happens at low tan(β), low mH±





Kinematic Fitter

- Kinematic Fitter: $mW_{l\nu}$=80.4, $m_t=m_{\bar{t}}$=175 GeV, **mW_{jj} is left unconstrained**
- Charged Higgs Signal Pythia MC: 1M events, m_t=175 GeV, m_{H+}=120 GeV/c^2, tan(β)=1, BR($H^{\pm}\rightarrow cs$)=1



Summary

Summary

- **$H^+ \rightarrow \tau\nu$ analysis**
  - Improved Hadronic tau sensitivity by using jet-tau likelihood fitter.
  - Results stricter that previous results using only that channel.

- **$H^+ \rightarrow c\bar{s}$ analysis**
  - Brand new. Still to understand shapes for signal, ttbar, and W+jets
  - Shape of the charged Higgs signals look promising!
  - Look for publication early next year.

- **Multi-channel analysis**
  - Radiative corrections included to the best of our knowledge.
  - Benchmark parameters developed specifically for the charged Higgs search.
  - **Best limits to date!** See PRL **96**, 042003 (2006)
  - Promising results expected at the LHC!

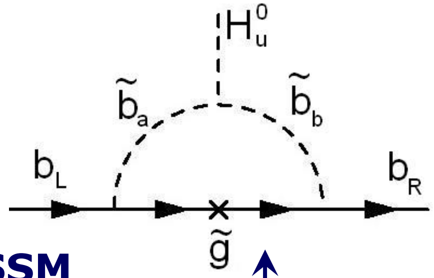
CDF is thoroughly searching for the charged Higgs boson

Thank you very much.

Correction to bottom Yukawa coupling

Effective Lagrangian :

$$h_b H_d^0 b\overline{b} + \underbrace{\Delta h_b H_u^0 b\overline{b}}$$



- **This term is forbidden at tree-level MSSM**
- **Δh_b dynamically generated at one-loop level**

- **Relation between the bottom mass and its Yukawa coupling changes:**

$$m_b = v_1 h_b \rightarrow m_b = v_1 h_b + v_2 \Delta h_b = v_1 h_b (1 + \Delta h_b \tan(\beta)) = v_1 h_b (1 + \Delta m_b)$$

- **Mass of b well known, this induces a change in effective Yukawa coupling that affects the whole multiplet**
  Thus, the Yukawa coupling of charged Higgs to top and bottom is modified:
  Whenever a m_b is brought from Yukawa coupling replace as follows

$$m_b \rightarrow \frac{m_b}{1 + \Delta m_b}$$

Δm_b = Loops from : gluino-sbottom, charged Higgsino-stop,
charged Wino-stop, neutral Wino-sbottom

See Nucl. Phys. B577,88 (2000) for more details.

Anal.

Number of Expected Events

- Dilepton, lepton+jets ≡1 and ≥2 tags, lepton+tau XS analyses (XSA)

Includes Luminosity

$$\mu_{XSA}^{\exp} = N_{XSA}^{back} + \sigma \;\; \varepsilon_{tt,XSA}$$

Anal.

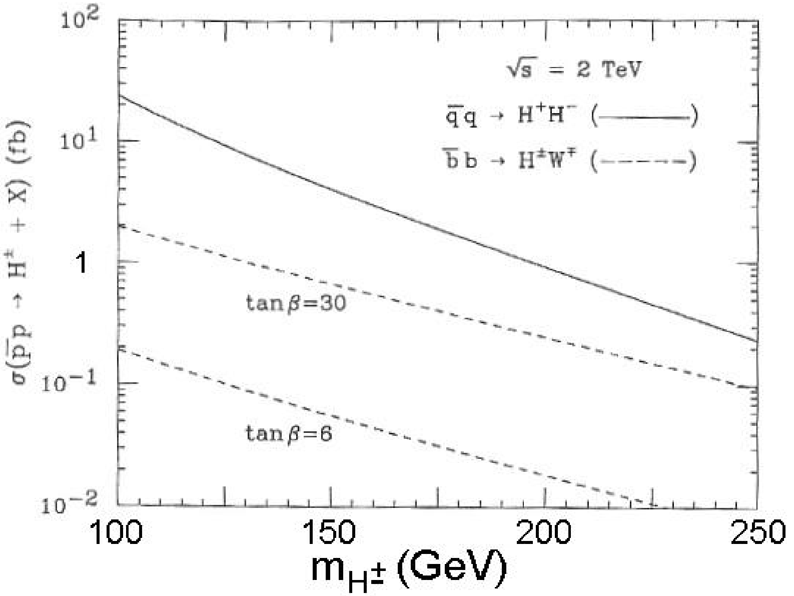
Number of Expected Events, N^{back}

- Dilepton, lepton+jets ≡1 and ≥2 tags, lepton+tau XS analyses (XSA)

$$\mu_{XSA}^{\exp} = \underbrace{N_{XSA}^{back}}_{} + \sigma \;\; \varepsilon_{tt,XSA}$$

Taken from the cross section measurement

- **Assume non-SM backgrounds to be negligible**
  - $pp \to Wh^{0(MSSM)}$ **< σ(Wh^0_{SM}) < 0.2 pb**
  - $pp \to Zh^{0(MSSM)}$ **< σ(Zh^0_{SM}) < 0.1 pb**
  - $pp \to H^+H^-$
  - $pp \to W^+H^-$
  - H^+ production via decay of heavy SUSY particles. ***Ignored here.***



Number of Expected Events, σ

- *Dilepton, lepton+jets ≡1 and ≥2 tags, lepton+tau XS analyses (XSA)*

$$\mu_{XSA}^{\exp} = N_{XSA}^{back} + \underbrace{\sigma} \, \varepsilon_{tt,XSA}$$

Use the theoretical production cross section σ^{theo}=(6.7±0.7)pb, hep-ph0303085

- **Assume that introduction of the Higgs sector do not change the production rate.**

Anal.

Number of Expected Events, B_i's

- Dilepton, lepton+jets ≡1 and ≥2 tags, lepton+tau XS analyses (XSA)

$$\mu_{XSA}^{\exp} = N_{XSA}^{back} + \sigma \underbrace{\varepsilon_{tt,XSA}}$$

$$\varepsilon_{tt,XSA} = \sum_{i,j=1}^{5} \underbrace{B_i B_j} \; \varepsilon_{i,j\ \mathrm{XSA}}\left(\Gamma_{top}, \Gamma_{Higgs}, m_{H^\pm}, m_{h^0}\right)$$

B_i (B_j) : Branching fractions of top (anti-top) decay mode

Total efficiency calculated from top and anti-top branching ratio decay modes.

- **Recall that the B_i's are calculated assuming the Narrow Width Approximation is valid. The analysis is limited to regions in which the widths of top and Higgs are each below 15 GeV.**

Number of Expected Events, $\varepsilon_{i,j\ XSA}$

- Dilepton, lepton+jets ≡1 and ≥2 tags, lepton+tau XS analyses (XSA)

$$\mu_{XSA}^{\exp} = N_{XSA}^{back} + \sigma \underbrace{\varepsilon_{tt,XSA}}$$

$$\varepsilon_{tt,XSA} = \sum_{i,j=1}^{5} B_i B_j \underbrace{\varepsilon_{i,j\ \mathrm{XSA}}}\left(\Gamma_{top}, \Gamma_{Higgs}, m_{H^\pm}, m_{h^0}\right)$$

→ Mode-specific efficiency

Mode-specific efficiency determined given (Γ_{top}, Γ_{Higgs}, $mH^{\pm}$, mh^{0})

- **It is the efficiency of the tt event with modes *i, j* given the mass of the charged Higgs and the mass of the neutral Higgs h^0.**
- **It takes into account corrections due to large width of the top and Higgs.**

Present limits

- **LEP:** **Direct search; $mH^{\pm} > 78.6$ GeV @ 95 % CL, irrespective of tan(b). Combined ALEPH, DELPHI, L3 and OPAL collaborations.**

- **CLEO:** **Indirect limit; measurement of b->sγ decay rate results in $mH^{\pm} > (244 + 63/\tan(b)^{1.3})$ GeV assuming 2HDM only. Can be circumvented in SUSY.**

- **Tevatron:** **Run I, results in the (mH,tan(b)) plane :**
  - CDF : Direct search in $t \to H^{+}b \to \tau\nu b$.
  - CDF & D0 : indirect searches using the "Lepton+Jets" (+"Dilepton" (+"Dilepton" for CDF) analyses using leading order calculations in similar to this studies.
  - D0 : analysis using NN.

Top and Higgs Widths

Widths grow with phase space and couplings :

Couplings :

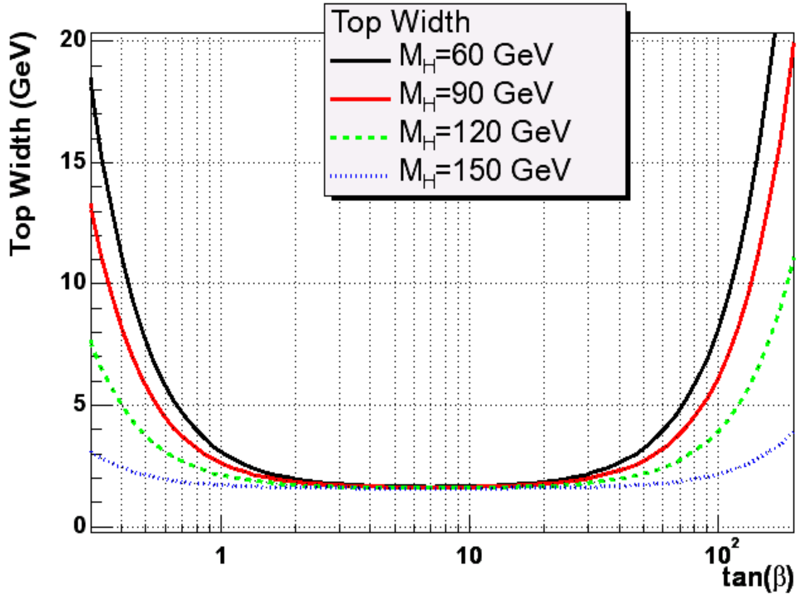
t->Hb coupling get large at high and low tanbeta.

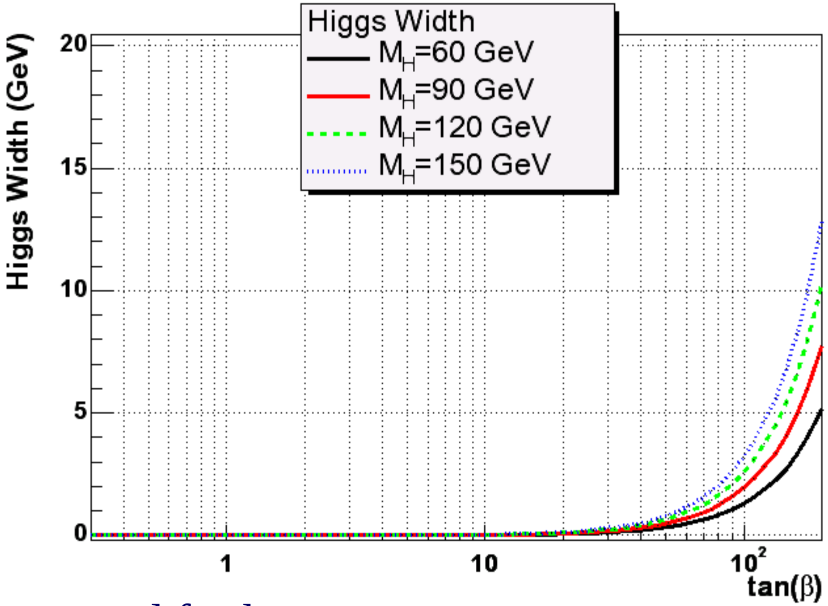
H->$\tau\nu$ grows with tan(β)^2.

Phase space :

High m_H ; low Γ_{top} high Γ_H

Low m_H ; high Γ_{top} low Γ_H





Higgs width correction, high tanbeta region, accounted for here.

Top width correction accounted too.

Note that it decreases with mHiggs.

Fairly symmetrical below 15 GeV. **Don't expect and don't see much change in eff.**

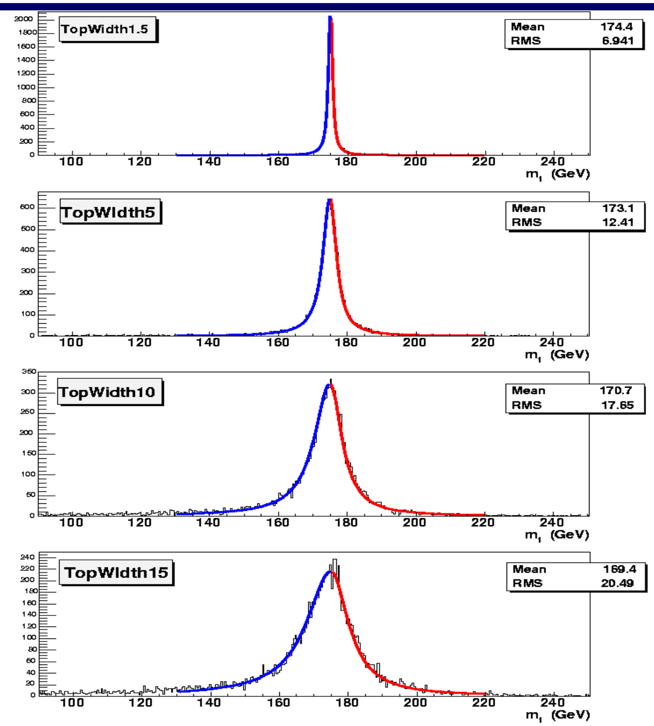
Anal.

Width Corrections, quantitatively

Width correction taken into account when doing :

$$\varepsilon_k^{MC}\left(\Gamma_{top},\Gamma_{Higgs},m_{H^\pm},m_{h^0}\right) = \int_0^\infty W^t(m'_{top},\Gamma_{top})\left(\int_0^\infty \varepsilon_k^{rawMC}(m'_{top},m'_{H^\pm},m_{h^0})W^H(m_{H^\pm},m'_{H^\pm},\Gamma_{Higgs})dm'_{H^\pm}\right)dm'_{top}$$

W^t(175,wT) for diff wT



ε_k^{rawMC} wrt m_{top}=175	tt→WbWb m_{top} (GeV) 165	175	185
Dilep	**0.94**	≡1	**1.12**
LJets1+	**0.96**	≡1	**1.1**
LTauH	**0.93**	≡1	**1.09**

After corrections

$\varepsilon_k^{MC}(wT,...)$ wrt Γtop = 1.4	tt-->WbWb Γtop(GeV) 1.4	**5**	**10**	**15**
LJets1+	≡1	1.002	1.003	1.005

Width corrections are very small, although we still take them into account.

Anal.

Removal of Overlap Between XS'

- **Separate the lepton+jets into exactly 1 tag and 2 or more tags**
- **Signal Overlap between lepton+jets and dilepton ?**
  - No. Lepton+jets has a dilepton veto
- **Signal Overlap between XSA and lepton+tau, given by**
  - $F_{XSA} \equiv$ # events passing both XSA and lepton+tau / # events passing XSA

in (%)	mH±=120 GeV		
$t\bar{t} \to bB$ +	$F_{Dilepton}$	$F_{l+jets\ 1\ Tag}$	$F_{l+jets\ \geq 2\ Tags}$
WW (SM)	0.1±0.1	1.1±0.2	1.5±0.4
$HW \to \tau\nu$ W	0.2±0.2	8.7±0.4	10.1±0.9
$HH \to \tau\nu\tau\nu$	1.1±0.7	12±1	15±2

~1% for SM

up to 15% if Higgs is present

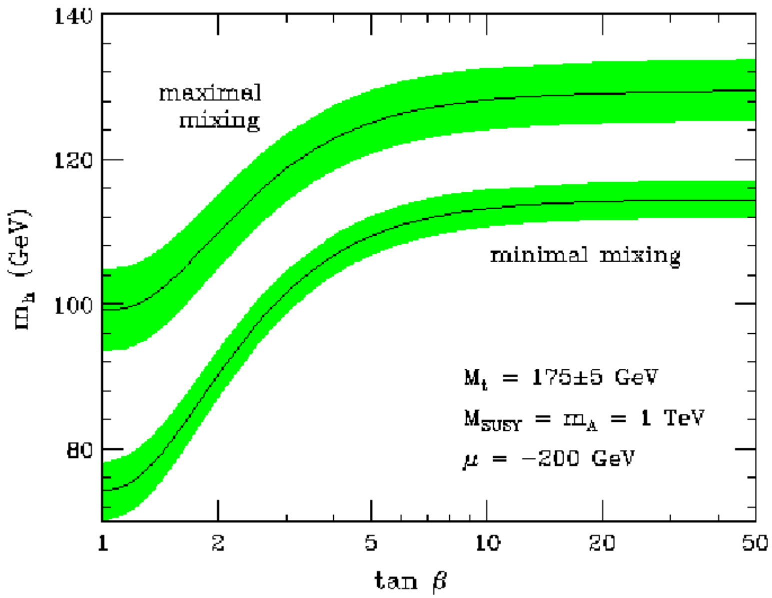
- **Strategy :**
  - Implement a lepton+tau veto cut in the lepton+jets and dilepton XS's.
  - Recalculate signal (and background) efficiencies

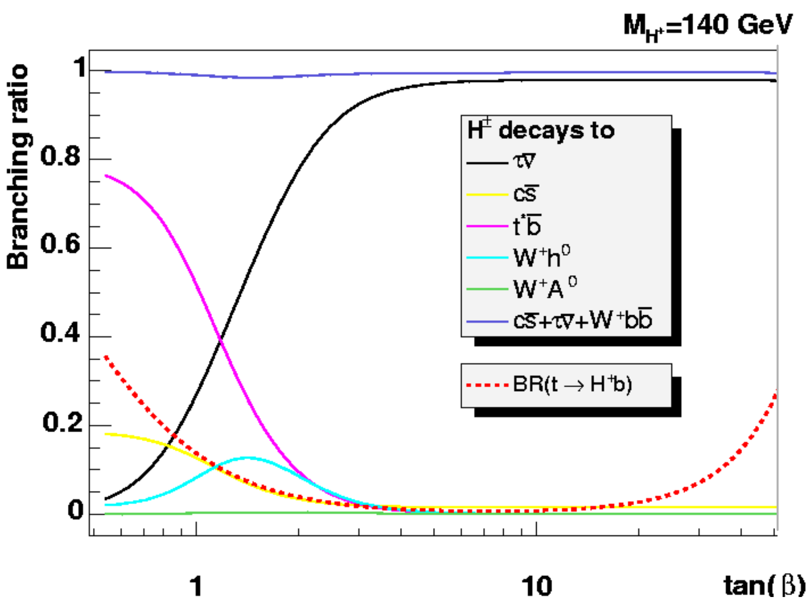
Results: MSSM

- **Several parameterizations of MSSM**
  - General MSSM :
    - intergenerational mixing.
    - Complex phases.
    - 105 input parameters in addition to the SM ones.
  - Phenomenological MSSM :
    - Soft SUSY breaking parameters are real. No new sources of CP violation.
    - Matrices for sfermions and trilinear couplings are diagonal. No FCNC at tree level.
    - Masses and trilinear couplings of 1st and 2nd generation are equal.
    - 22 input parameters. Down to 14 if only third generation needed.
  - GUT-constrained MSSM (mSUGRA)
    - Unification of gaugino masses.
    - Universal scalar masses.
    - Universal trilinear coupling.
    - 4 and a half parameters.
- **We use the Phenomenological MSSM (pMSSM), with 14 parameters.**
- **Use different sets of pMSSM parameters (or benchmark scenarios)**

Results: MSSM , Choice of Benchmarks

- **LEP benchmarks revisited**
  - Maximal and minimal stop mixing scenarios.
  - Maximize and minimize the mass of the h^0 as a function of tan(b).
  - All parameters except **At** fixed. **At** is chosen so as to maximize or minimize m_h^0

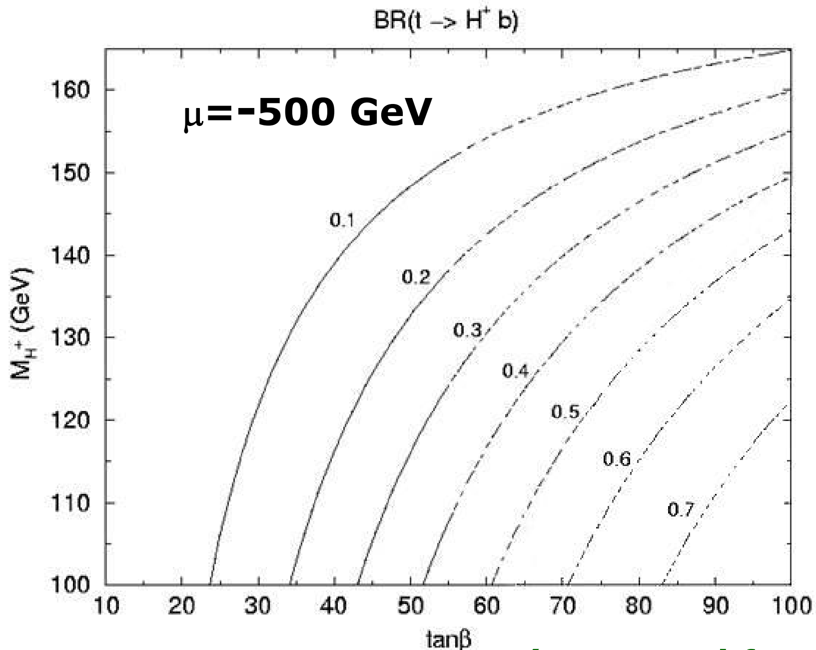


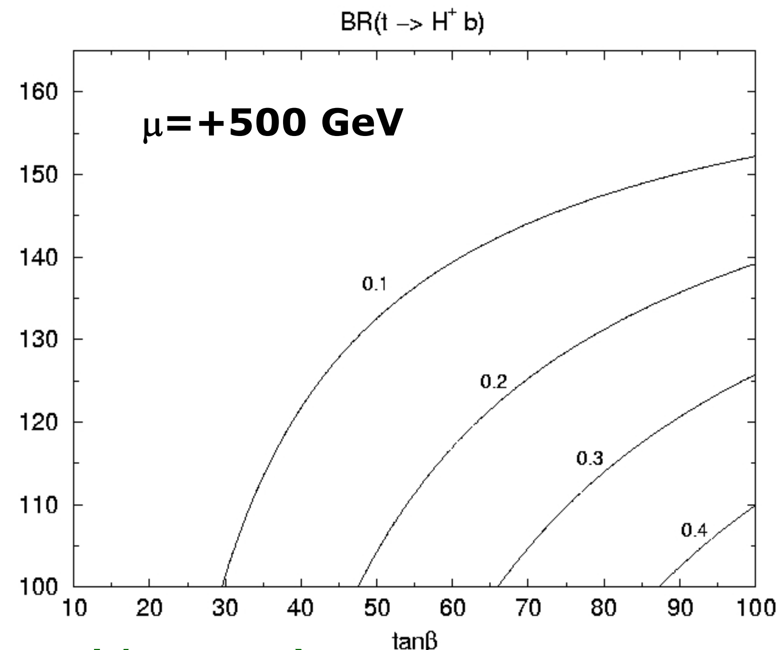


- **The decay $H^+ \rightarrow W^+h^0$ larger around tan(b)≈1**
  - $\Gamma(H \rightarrow \tau\nu, cs, t^*b)$ is bigger at lower and higher tan(b) values
  - Maximization or minimization of the h^0 mass useful at tan(b)≈1

Results: MSSM , Choice of Benchmarks

- **BR(t→H⁺b) strongly depends on the MSSM parameter μ**





(extracted from hep-ph/9912516)

  - **Problem :** Previous calculations developed in the large tan(b) approx.

- **Recalculated to all ranges of tan(b). CDF note 7348 (R. Eusebi, M. Carena)**
- **Summary from the last two slides :**
  - μ has strong effects in the BR($t \to H^+ b$) predictions at high tan(b)
  - At has strong effects in BR($H^+ \to W^+ h^0$) at tan(b)≈1.

Results: MSSM , Choice of Benchmarks

	μ (GeV)	At(GeV)	Rest of parameters (GeV)
B1	**-500**	**2000**	**M2=M3=MQ=MU=MD=1 TeV**
B2	**-500**	**-500**	**M1=0.4978*M2, ML=ME= 1 TeV**
B3	**500**	**500**	**Ab=At, Atau=500 GeV**
B4	**500**	**2800**	
B5(Minimal)	**-200**	**μ/tan(β)**	**MQ=MU=MD=1 TeV, M2=M3=200**
B6(Maximal)	**-200**	**2450GeV + μ/tan(β)**	**ME=ML=MQ, At=Ab, Atau=500**

- **B1 and B2 value of μ=-500 GeV, large BR($t \to H^+ b$) at large tan(b)**
  - Difference is At, that is chosen so as to maximize (B1) and minimize (B2) the mass of the h^0 in the tan(b) ~1 region.
- **B3 and B4 value of μ=+500 GeV, small BR($t \to H+b$) at large tan(b)**
  - Difference is At, that is chosen so as to maximize (B4) and minimize (B3) the mass of the h^0 in the tan(b) ~1 region.
- **B5 and B6 are the minimal and maximal stop mixing scenarios used at LEP. They minimize and maximize the mass of the h^0 at every point in tan(b).**

Results: Higgs BR independent

- **Scan over all BR combinations and take the worst limit:**
  - Slice the Higgs BR($H^+ \rightarrow c\underline{s}$, t^*b, W^+h^0) in bins of 0.05. (21 bins each,1771 total)
  - In each bin scan $a \equiv BR(t \rightarrow H^+b)$ from 0 to 0.9 evaluating the posterior.
    - In each point in scan : $BR(h^0 \rightarrow b\underline{b}) \equiv 0.9$, Γ_{Higgs} = 1 GeV, $\Gamma_{top} = 1.4/(1-BR(t \rightarrow Hb))$

flat between 0 and 1

$$P(\alpha, | n_{ll}, n_{lj1}, n_{l\tau}, n_{lj2+}) = \frac{L(n_{ll}, n_{lj1}, n_{l\tau}, n_{l\tau 2+} | \alpha)\ \pi(\alpha)}{\int L(n_{ll}, n_{lj1}, n_{l\tau}, n_{l\tau 2+} | \alpha')\ \pi(\alpha')\pi d\alpha'}$$

    - Integrate the posterior and obtain the 95% CL
  - Repeat for all bins and take worst limit.
  - Repeat for different charged Higgs masses

Results in the (mH,BR(t→Hb)) plane