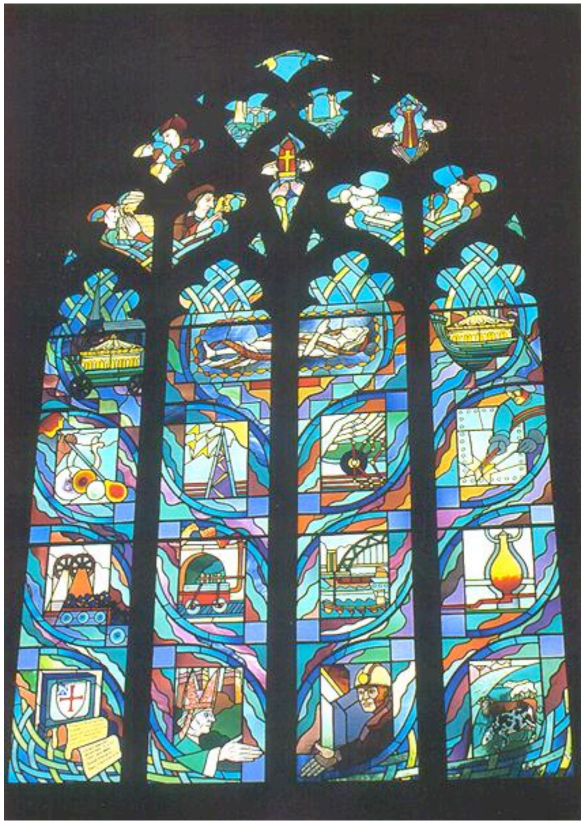
Searches for Higgs Bosons in the MSSM at CDF



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HAEC OTIA FIAT LUX FOVENT STUDIA

THE ROYAL SOCIETY

SUSY'05, Durham, July 2005

Higgs in the MSSM

- **Minimal Supersymmetric Standard Model:**
  - 2 Higgs-Fields: Parameter $\tan\beta = \langle H_u \rangle / \langle H_d \rangle$
  - 5 Higgs bosons: h, H, A, $H^{\pm}$

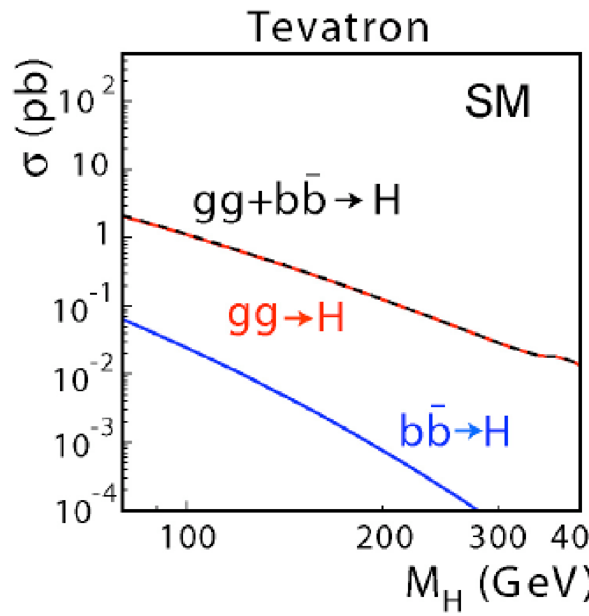
- **Neutral Higgs Boson:**
  - Φ = A, H, h: decays to $b\bar{b}$ or $\tau\tau$
  - This talk: $\tau\tau$ decay mode

- **Charged Higgs Boson:**
  - Search in top decays: $t \to H^{\pm}\bar{b}$
  - $H^{\pm} \to \tau\nu$ or $H^{\pm} \to cs$ or $H^{\pm} \to Wbb$

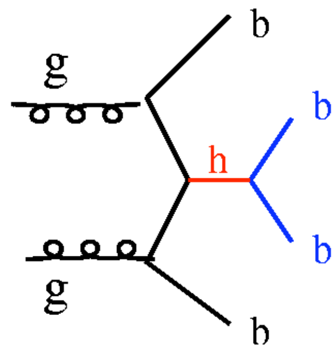
•C. Balazs, J.L.Diaz-Cruz, H.J.He, T.Tait and C.P. Yuan, PRD 59, 055016 (1999)
•M.Carena, S.Mrenna and C.Wagner, PRD 60, 075010 (1999)
•M.Carena, S.Mrenna and C.Wagner, PRD 62, 055008 (2000)

Neutral MSSM Higgs

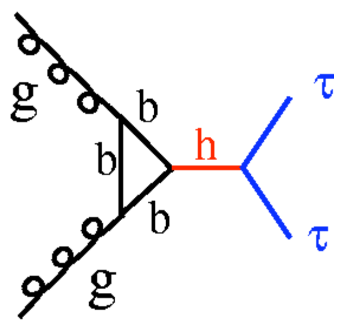
- **High tanβ:**
  - A degenerate in mass with h or H
  - Cross sections enhanced with $\tan^2\beta$ due to enhanced coupling to down-type quarks
  - Decay into either $\tau\tau$ or bb for mA<300 GeV:
    - BR(A $\rightarrow \tau\tau$) ≈ 10%, BR(A$\rightarrow b\bar{b}$) ≈ 90%
    - Exact values depend on SUSY parameters

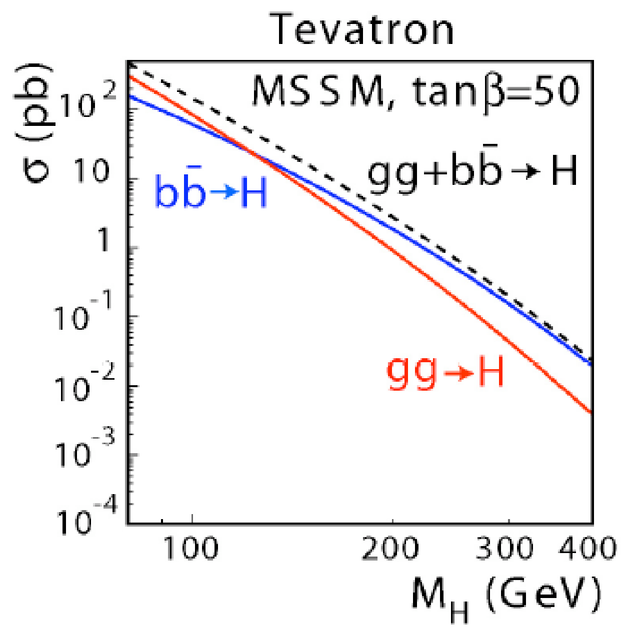


- **Production mechanisms:**
  - $b\bar{b} \rightarrow$ A/h/H
  - gg $\rightarrow$ A/h/H



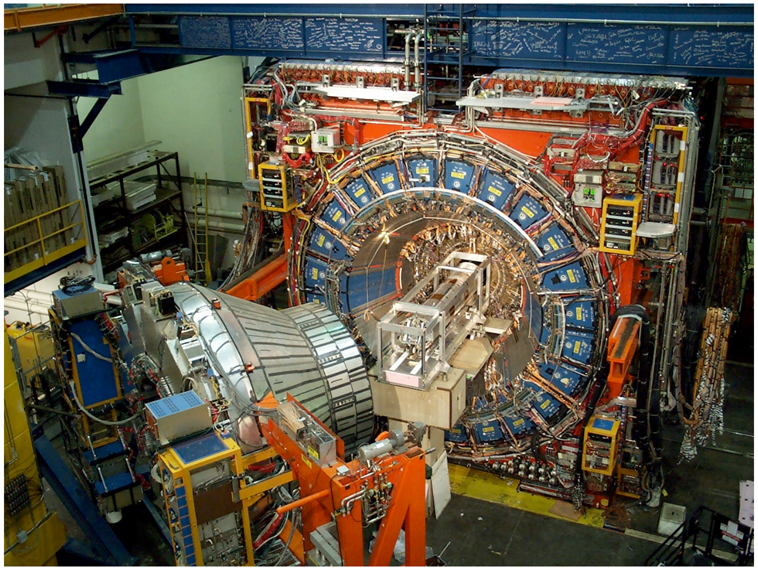
- **Experimentally:**
  - $p\bar{p} \rightarrow \Phi$b+X $\rightarrow b\bar{b}$b+X
  - $p\bar{p} \rightarrow \Phi$+X $\rightarrow \tau\tau$ +X

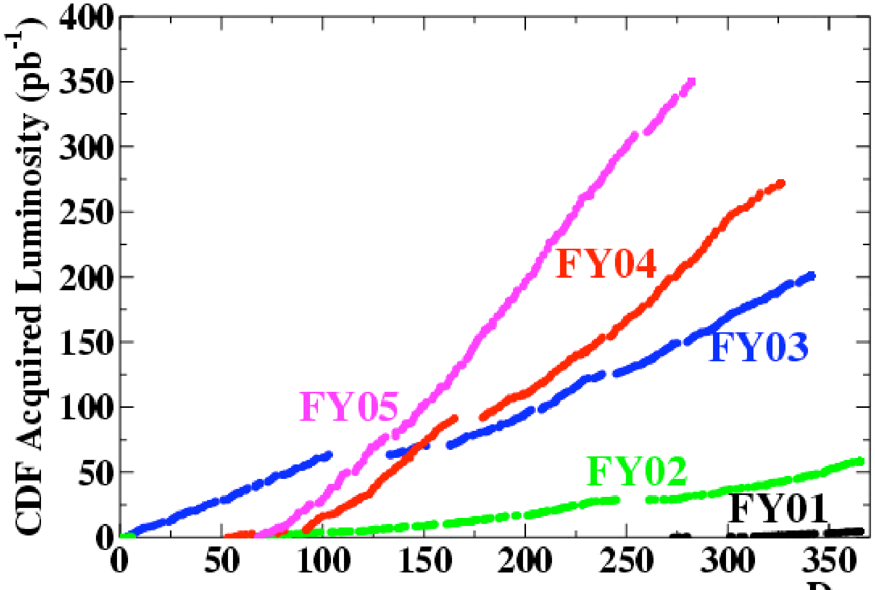




The Tevatron and CDF

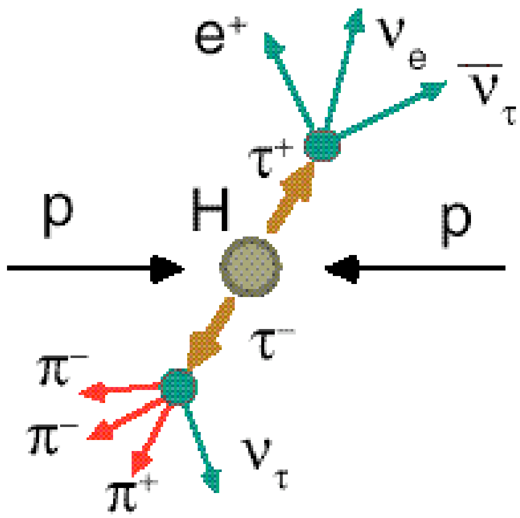
- **Tevatron:**
  - $p\bar{p}$ at $\sqrt{s}$=1.96 TeV
- **CDF:**
  - Multi-purpose detector
    - Tracking
    - Calorimetry
    - Muon systems
    - Time-of-flight
- **Luminosity:**
  - $\int Ldt$=1.1 fb^{-1} delivered by Tevatron to CDF
  - 200-300 pb^{-1} analysed for this talk

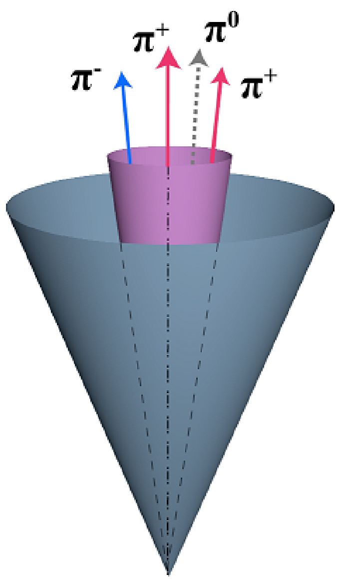




Neutral Higgs: Tau-Selection

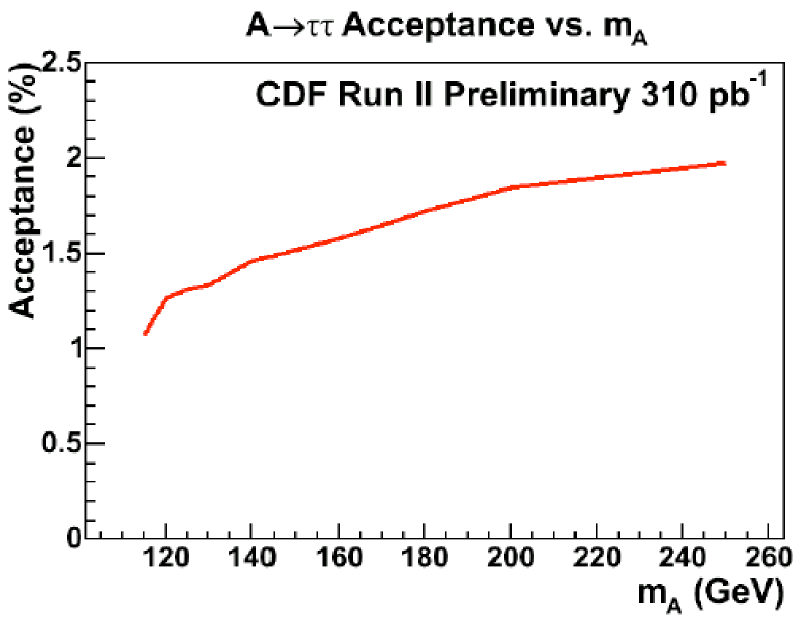
- Select $\tau\,\tau$ Events:
  - One τ decays to e or μ
  - One τ decays to hadrons
- Require:
  - e or μ with p_T>10 GeV
  - Hadronic τ:
    - Narrow Jet with low multiplicity
    - 1 or 3 tracks in 10° cone
    - No tracks between 10° and 30°:
      - Cone size descreasing with increasing energy
    - Low π^0 multiplicity
    - Mass<1.8 GeV
- Kinematic cuts against background:
  - W+jets

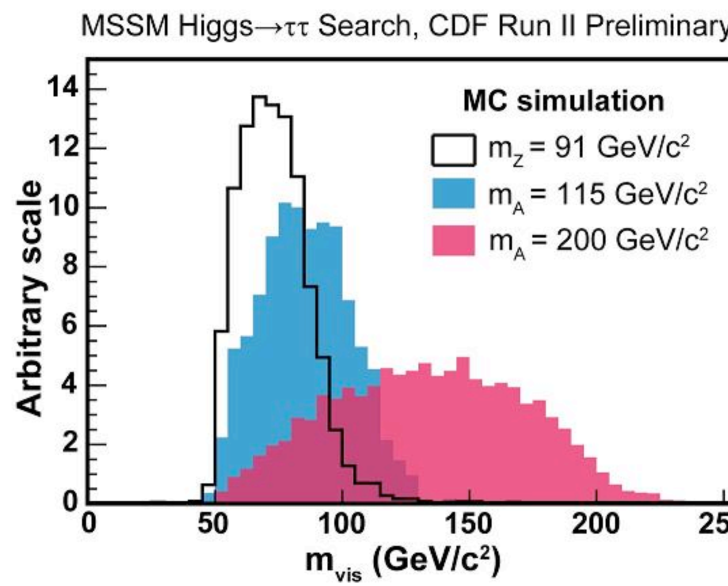




Acceptance and Mass

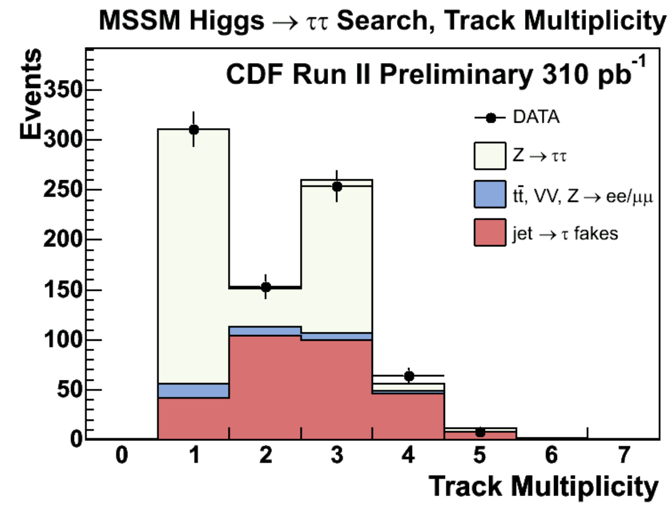
- Acceptance for Higgs about 1–2%
- Main background:
  - Drell-Yan $\tau\tau$
  - Indistinguishable signature => Separate kinematically
- No full mass reconstruction possible for low Higgs p_T:
  - Form mass like quantity: $m_{vis}=m(\tau,e/\mu,\not{E}_T)$
  - Good separation between signal and background

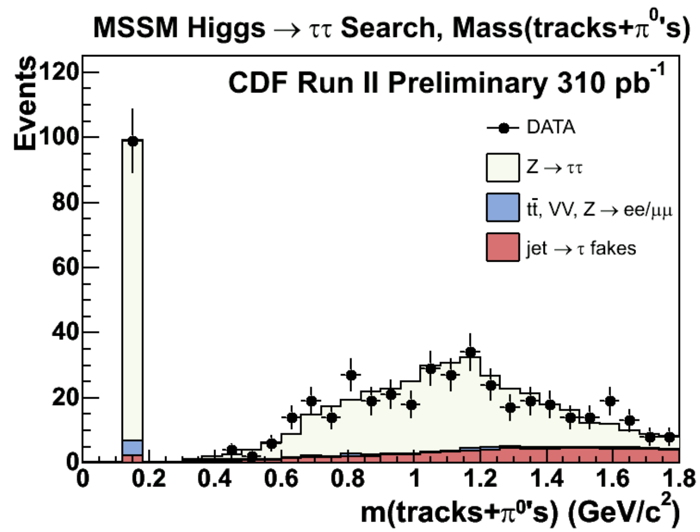




Neutral Higgs: Data vs SM

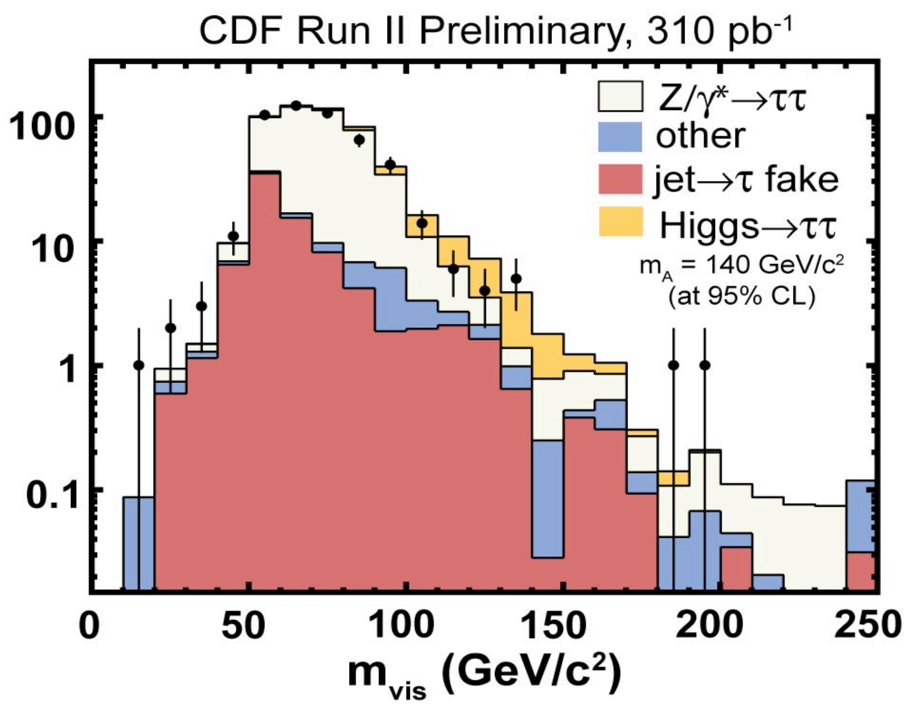
source	$\tau_e\tau_h$	$\tau_\mu\tau_h$	$\tau_e\tau_h + \tau_\mu\tau_h$
$Z \to \tau\tau$	217.2±3.9±12.7	187.3±3.6±11.9	404.5±5.3±23.2
$Z \to \ell\ell$	5.9±0.5±0.3	8.4±0.8±0.5	14.3±0.9±0.8
tt, VV	1.0±0.1±0.1	0.9±0.1±0.1	1.9±0.1±0.1
jet→τ fakes	44.6±0.1±8.9	30.8±0.2±6.2	75.4±0.2±15.1
Predicted bg	268.7±3.9±15.5	227.3±3.7±13.4	496.1±5.4±27.7
Observed Events	260	227	487

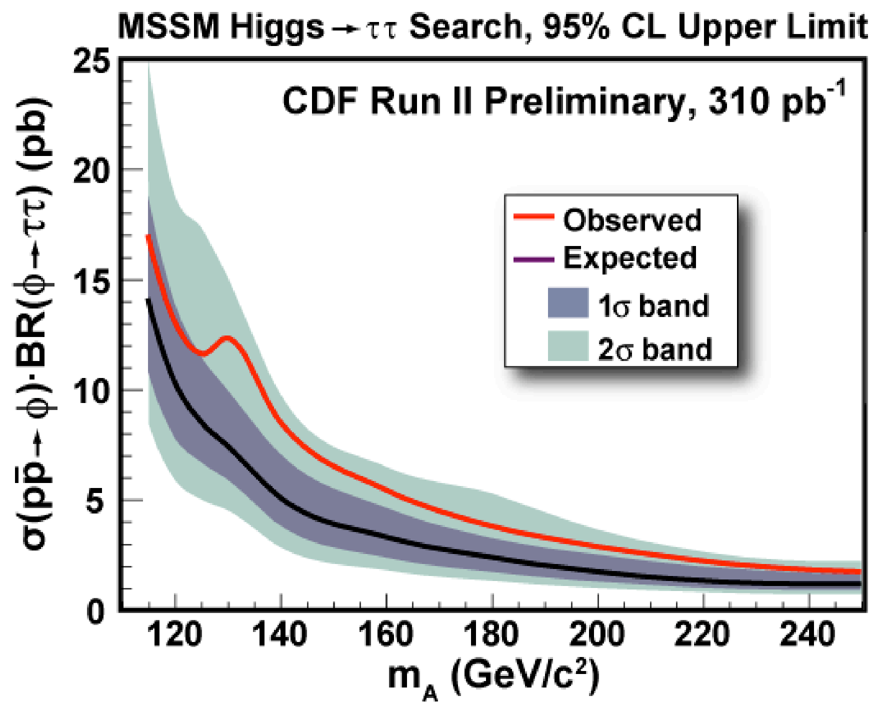




- **Good overall agreement of data with Standard Model prediction**
- **One and three prong decays of tau clearly visible**

Neutral Higgs: Mass Distribution





- **Data mass distribution agrees with SM expectation:**
  - M>120 GeV: 8.4±0.9 expected, 11 observed
- **Fit mass distribution for Higgs Signal**
  - Exclude signals at 95% C.L.
  - Upper limit on cross section times branching ratio
  - Can be compared to ANY model
- **We interpret in MSSM benchmark scenarios**

MSSM Higgs: Interpretation

- At tree level cross section and BR depend only on 2 parameters:
  - $\tan\beta$ and m_A
- Radiative Corrections => dependence on other parameters:
  - Higgsino mixing μ
  - Stop mixing: $X_t=(A_t-\mu\cot\beta)$
- Use 4 benchmark scenarios:
  - No mixing ($X_t=0$) and max. mixing ($X_t=2\ M_{SUSY}$)
  - Positive $\mu=+200$ GeV and negative $\mu=-200$ GeV
  - Common parameters:
    - $M_{SUSY}=1$ TeV, $M_2=200$ GeV, $A_b=A_t$, $M(g)=0.8\ M_{SUSY}$
  - M. Carena, S. Heinemeyer, C.E.M. Wagner, G. Weiglein (hep-ph/0202167, hep-ph/9912223)

Cross Section Calculation

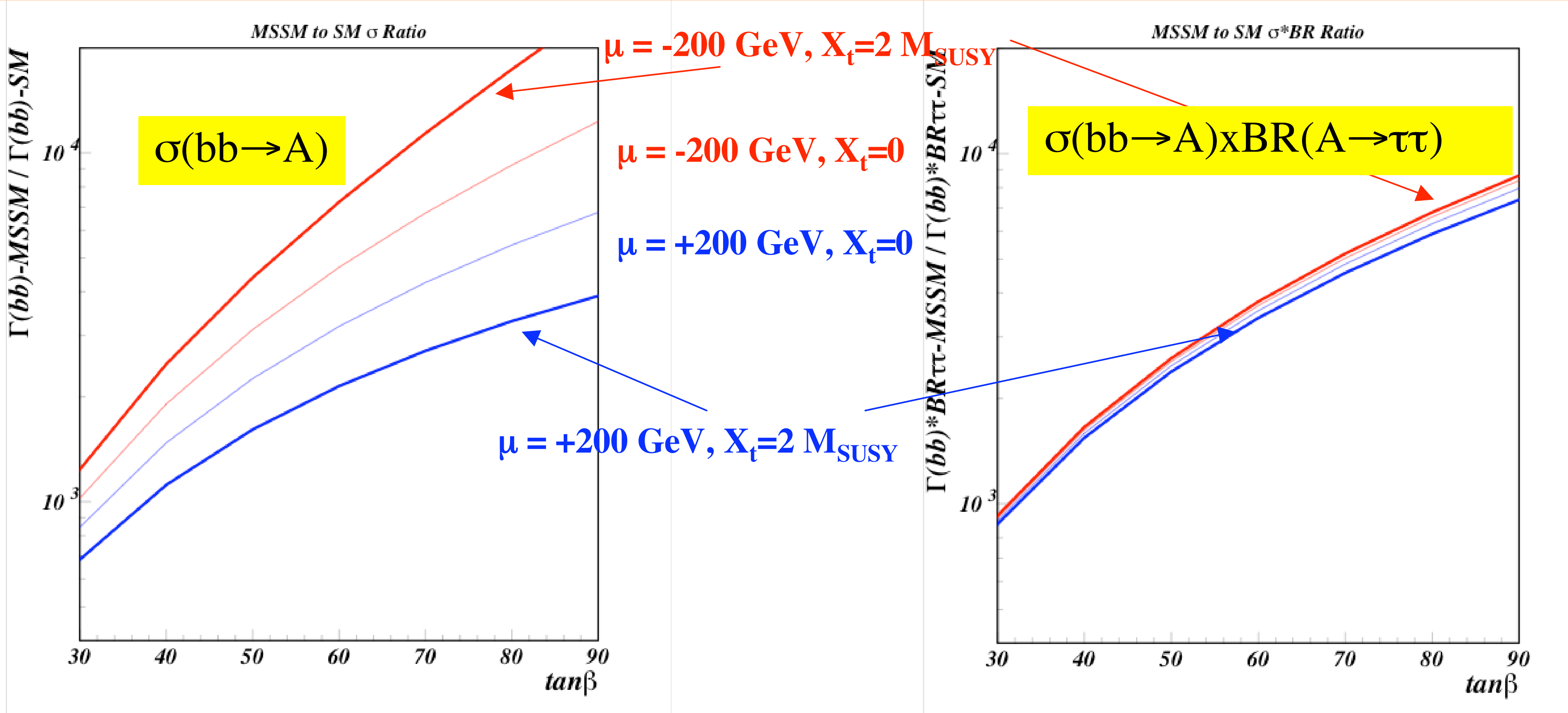
- $gg \to \Phi$
  - MSSM production calculated at NLO with `HIGLU` (*M. Spira*)

- $b\bar{b} \to \Phi$
  - SM production calculated at NNLO (*R. Harlander, W. Kilgore*)

- MSSM Higgs coupling to bb and $\tau\tau$ calculated:
  - `FeynHiggs` (*S. Heinemeyer, W.Hollik, G. Weiglein*)
  - Branching ratio to $\tau\tau$ for bb $\to \Phi$ and gg $\to \Phi$
  - Enhancement factor for $b\bar{b} \to \Phi$
    - only applied to bb $\to \Phi$ (not available for gg $\to \Phi$ yet)

- A,h,H all calculated separately:
  - Added whenever two masses are within Δm<5 GeV of A :
    - A+h or A+H or A+h+H

Ratio of MSSM to SM



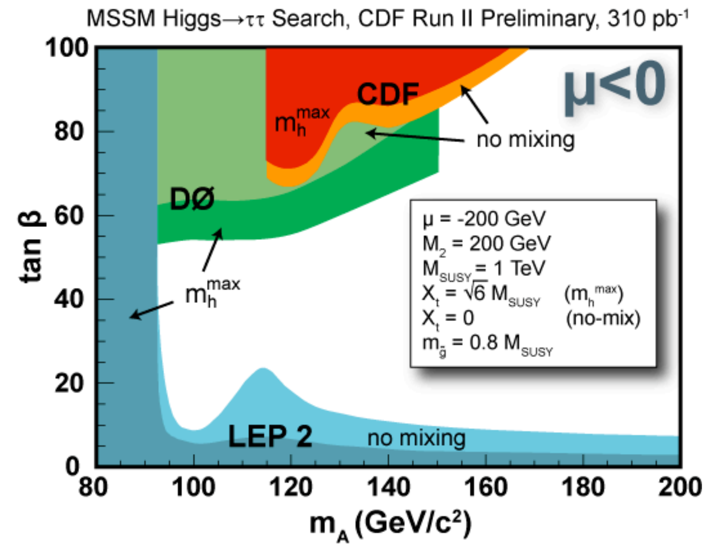
- **Dependence of σ and BR due to bottom Yukawa coupling:**

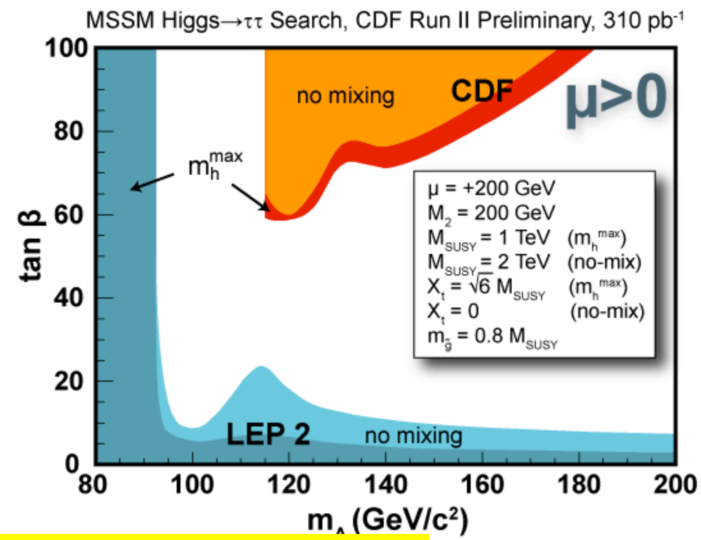
$$y_b \sim \frac{m_b}{1+\Delta_b}, \qquad \Delta_b \sim \mu \tan\beta \, m_{\tilde{g}} \, \alpha_s \, I(m^2_{\tilde{b}_1}, m^2_{\tilde{b}_2}, m^2_{\tilde{g}})$$

  - Cross section changes by factor 3
  - Cross section times branching ratio nearly the same for all cases
  - No Δm_b corrections available for gg –>H production: assume correction 0 for now

Neutral Higgs: Results

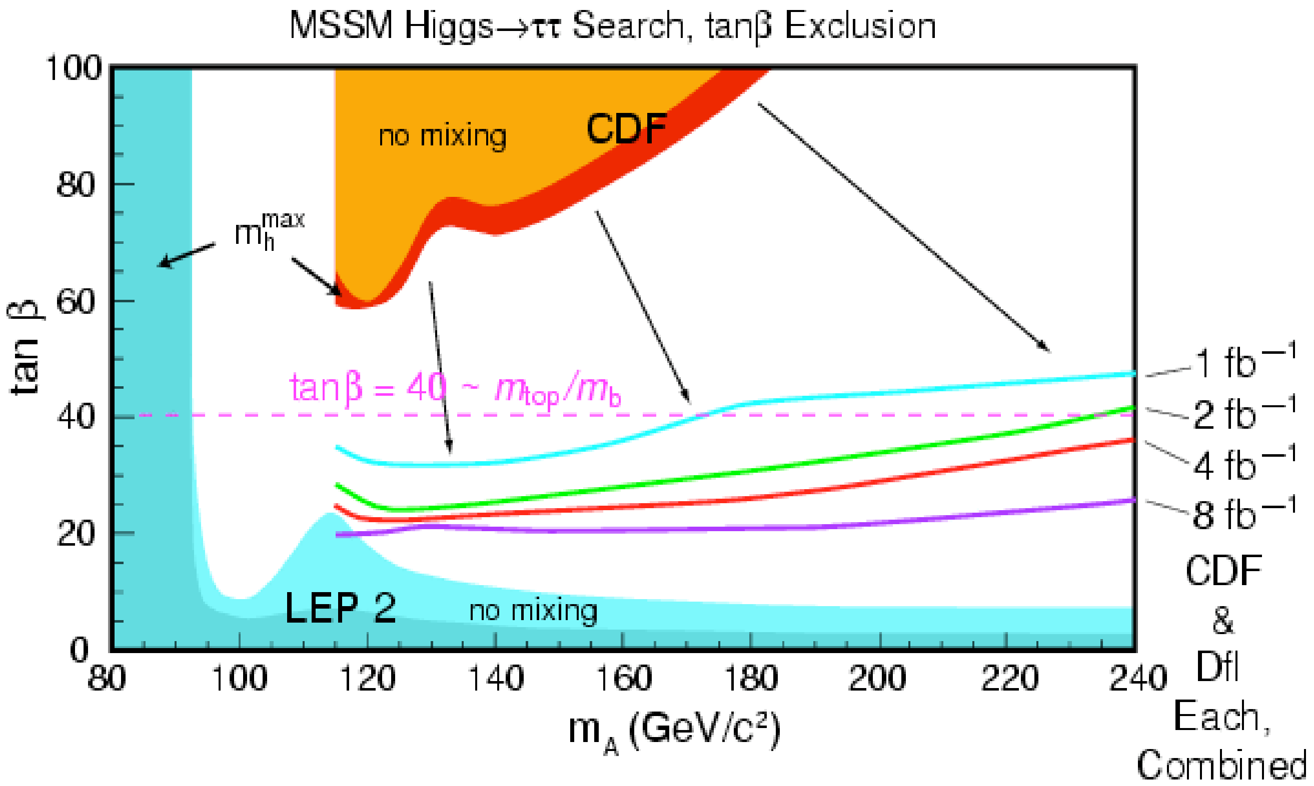
- **$p\bar{p} \rightarrow bA+X \rightarrow bbb+X$ (DØ)**
  - Best sensitivity for $\mu<0$
  - Lower sensitivity for $\mu>0$
- **$p\bar{p} \rightarrow A+X \rightarrow \tau\tau+X$ (CDF)**
  - Sensitivity similar for
    - Min. and max. mixing
    - $\mu>0$ and $\mu<0$
- **Future improvements**
  - Extend to m_A=90 GeV/c^2
  - Use $A \rightarrow \tau_h\tau_h$ and $A \rightarrow \tau_e\tau_\mu$
  - Use more luminosity
  - Use full mass reconstruction:
    - Possible for large Higgs p_T
  - Analyse $pp \rightarrow bA+X \rightarrow \tau\tau b+X$
  - Improve interpretation, e.g. vs μ and m_A





Nice complementarity of channels:
different sensitivities to radiative corrections

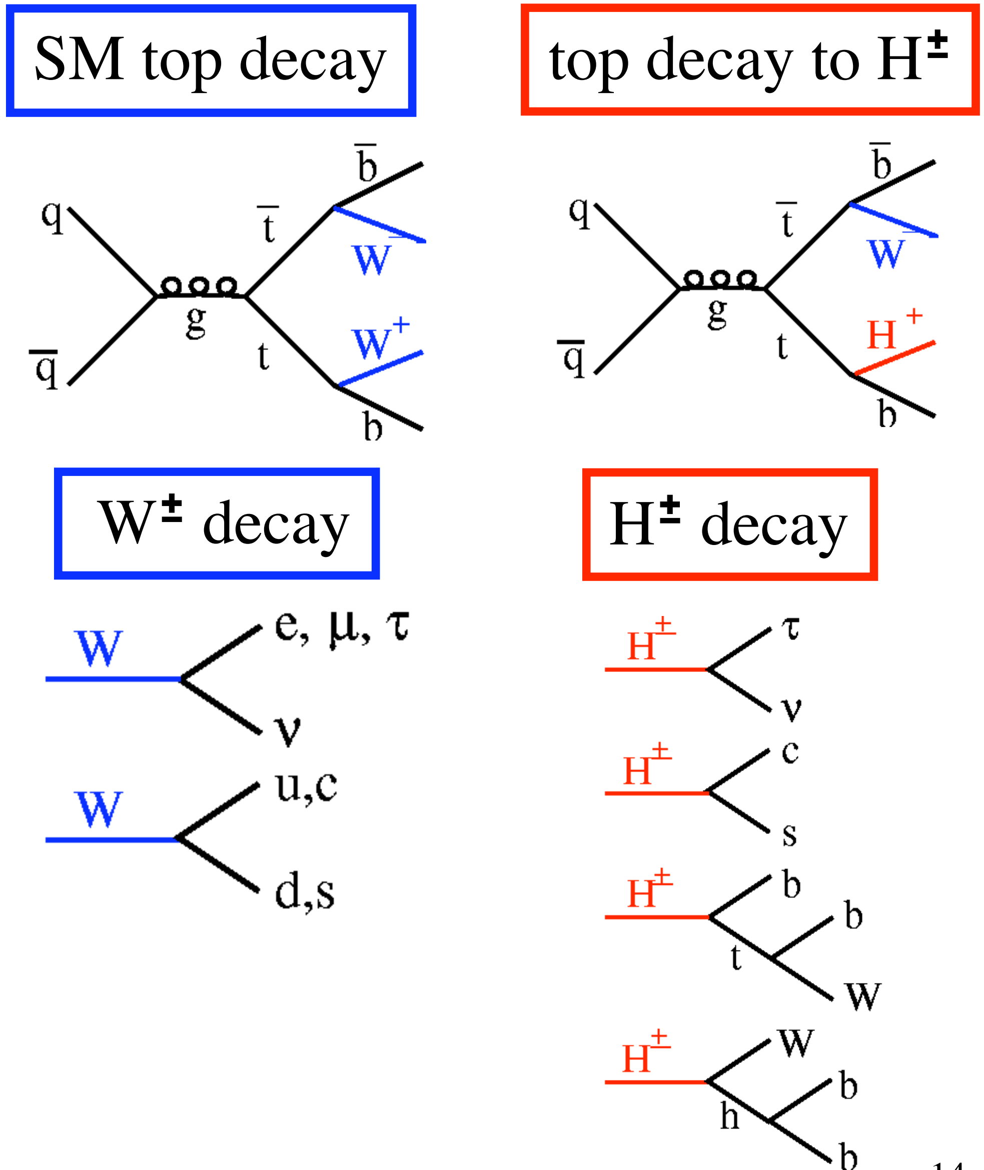
NEUTRAL HIGGS: FUTURE



- **Sensitivity for D0 and CDF data combined**
- **probe values down to tanβ=20 for m_A≈140 GeV/c2**
- **tanβ=40≈m_{top}/m_b reached for m_A<240 GeV/c^2**

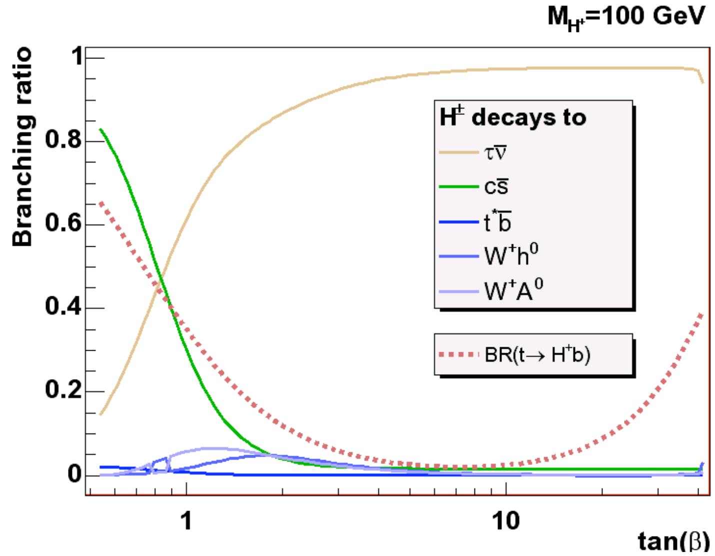
Charged Higgs

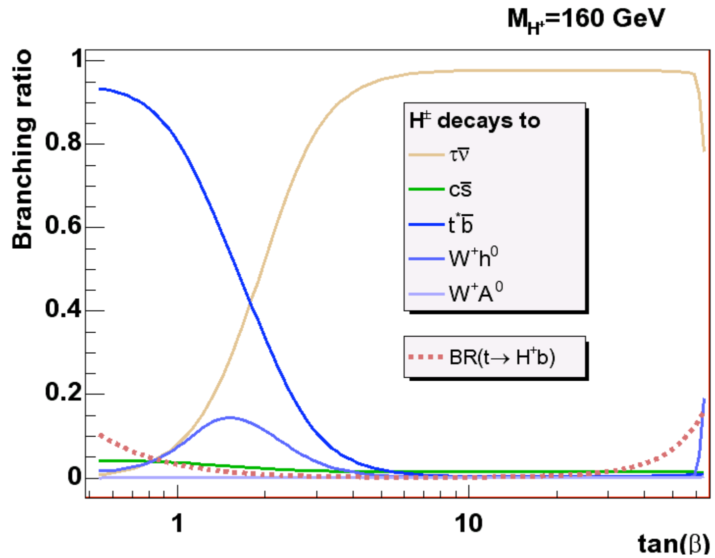
- SM Top decay:
  - BR(t->Wb)≈100%
- If m(H±)<m(top):
  - Top decays to H±b
  - H± decays different to W±
- top cross section analyses sensitive to H± production:
  - Dilepton+jj+X
  - Lepton+τ+jj+X
  - Lepton+1b+jjj+X
  - Lepton+2b+jj+X



$H^\pm$ Branching Ratios

- **BR($t \to H^\pm b$):**
  - Large at low and high tanβ
- **$H^\pm$ Decays:**
  - $H^\pm \to \tau\nu$
  - $H^\pm \to cs$
  - $H^\pm \to t^*b \to Wbb$
  - $H^\pm \to Wh \to Wbb$
- **$H^\pm$ BR depends on**
  - Tanβ
  - Mass of $H^\pm$
- **Difference to $t \to W^\pm b$:**
  - Less leptonic decays at low tanβ
  - More tau decays at high tanβ



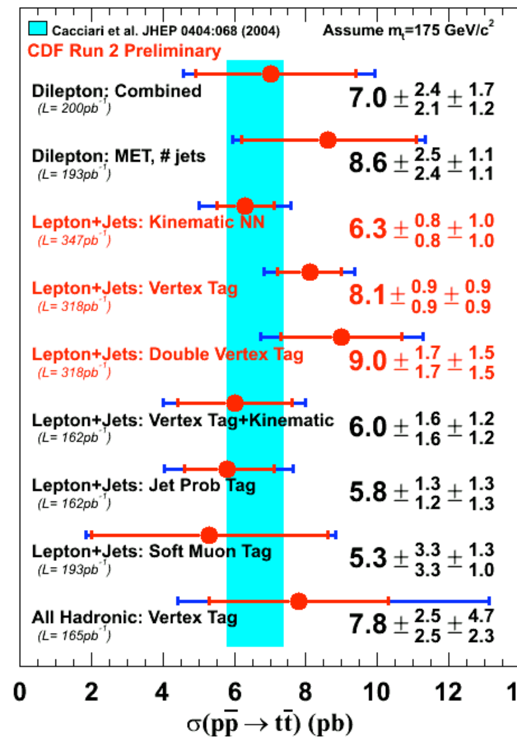


DATA VS STANDARD MODEL

4 analyses used for $H^{\pm}$ search result: $\int L dt = 162\text{–}194\ pb^{-1}$

	Observed	Top+BG
2 e/μ+2 jets	13	11
e/μ+τ+2 jets	2	2
e/μ+4 jets (=1 b-tag)	49	54
e/μ+4 jets (≥2 b-tags)	8	10

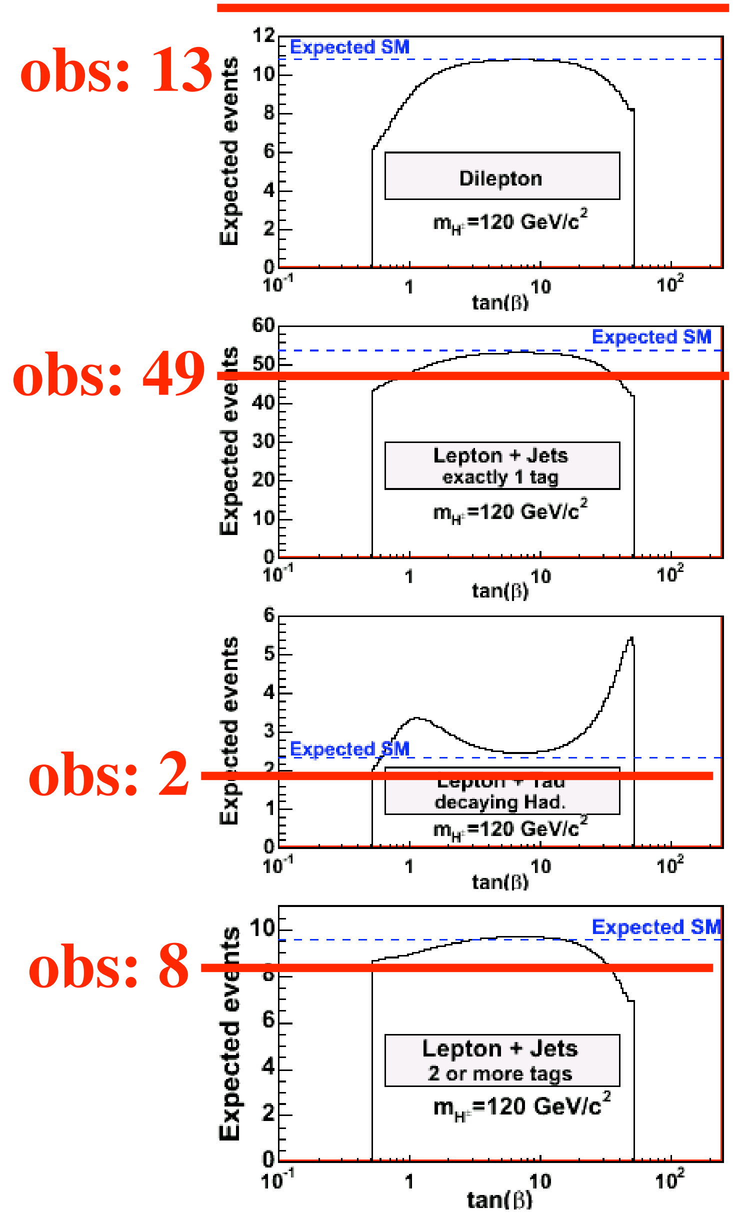
Latest CDF results



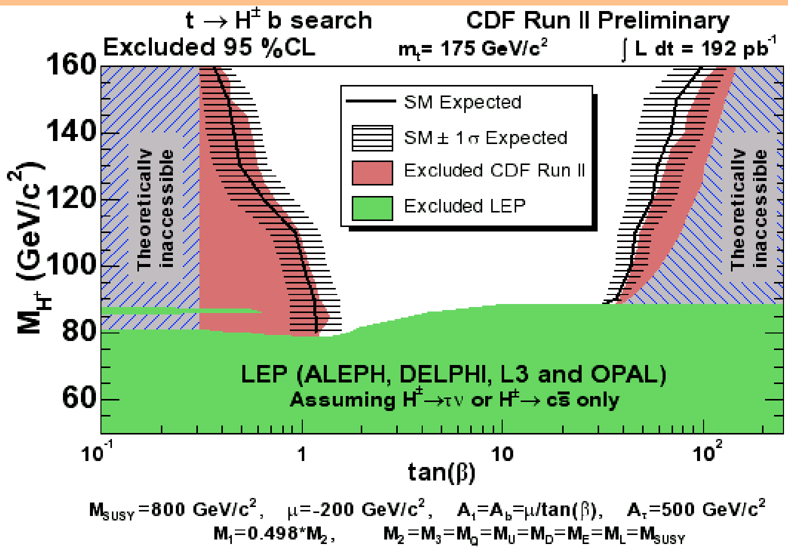
- **Data agree with SM top decay**

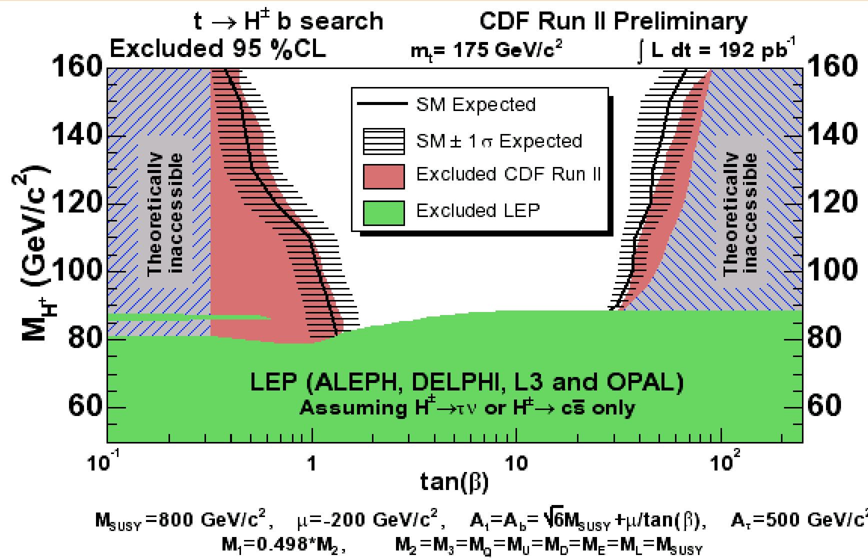
Expected Events

- Example at for m_h=120 GeV/c^2
- Number of expected events changes depending on tanβ
  - E.g. enhancement of tau's at large tanβ
  - E.g. reduction of other channels at small and large tanβ
- By using all channels we get optimal sensitivity:
  - All-hadronic and tau+b+jets will improve sensitivity in future



Charged Higgs: Results

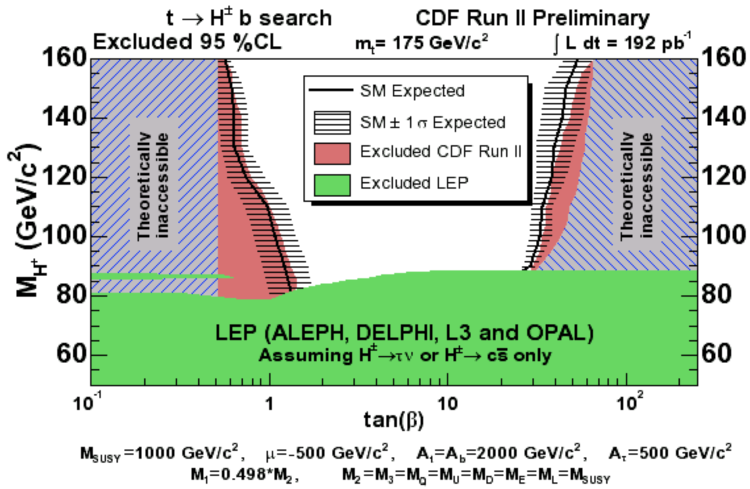


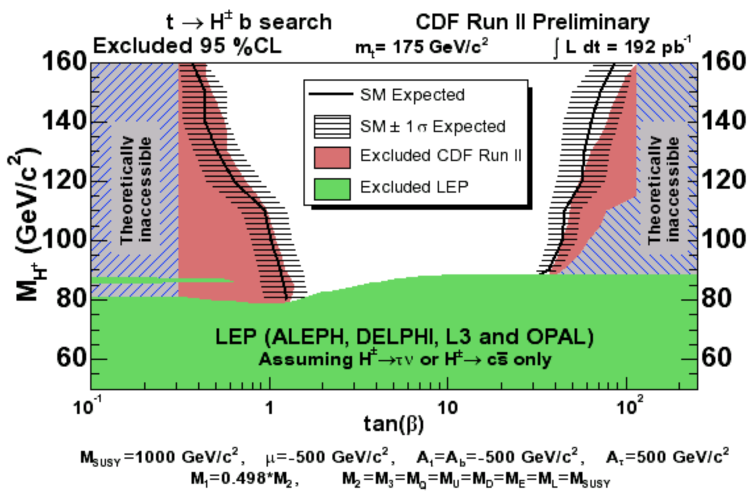


- **Same benchmark models as for neutral Higgs search:**
  - **hep-ph/9912223 : M. Carena, S. Heinemeyer, C.E.M. Wagner, G.Weiglein (μ<0)**
  - **Use `CPsuperH` (*M. Carena et al.*) for signal prediction:**
    - **"Theoretically inaccessible" = CPsuperH finds theory inconsistent**
- **Probing small and large tanβ values:**
  - **Only used 200 pb^{-1} => large improvements in future**
  - **Experimental limits agree with expected limits**
  - **No major difference between these two model scenarios**

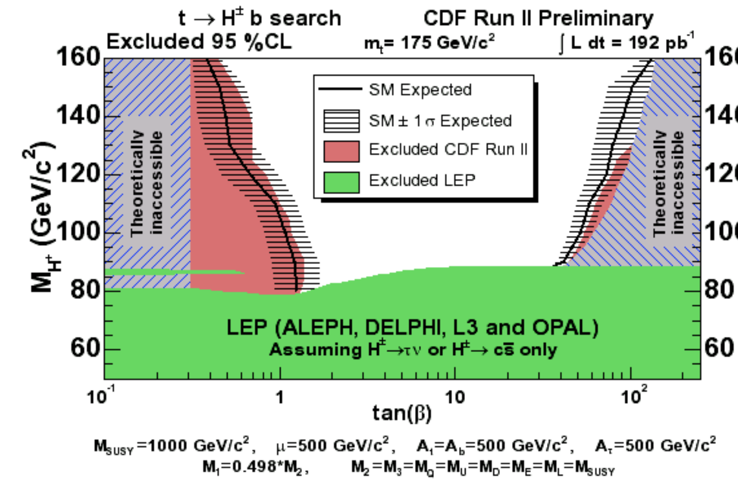
More Benchmark Models

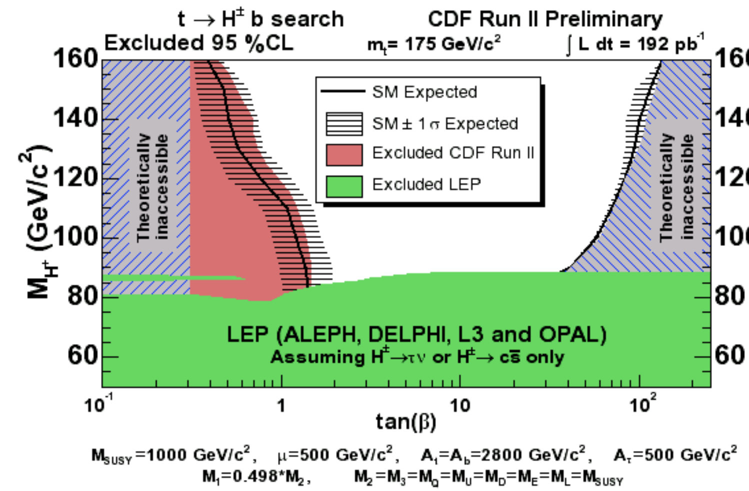
$\mu = -500$ GeV





$\mu = +500$ GeV

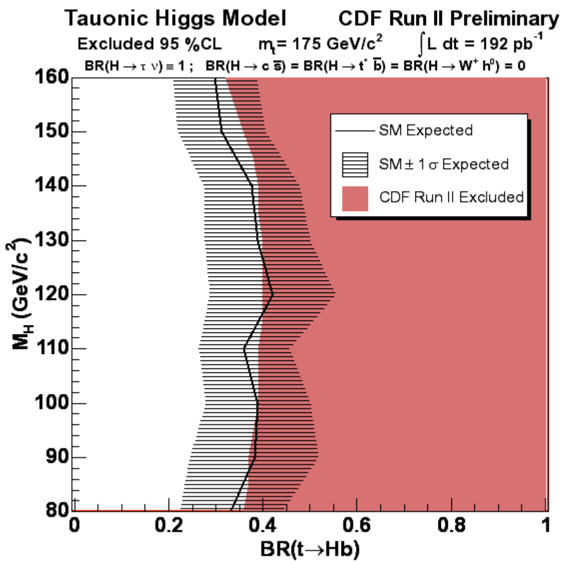


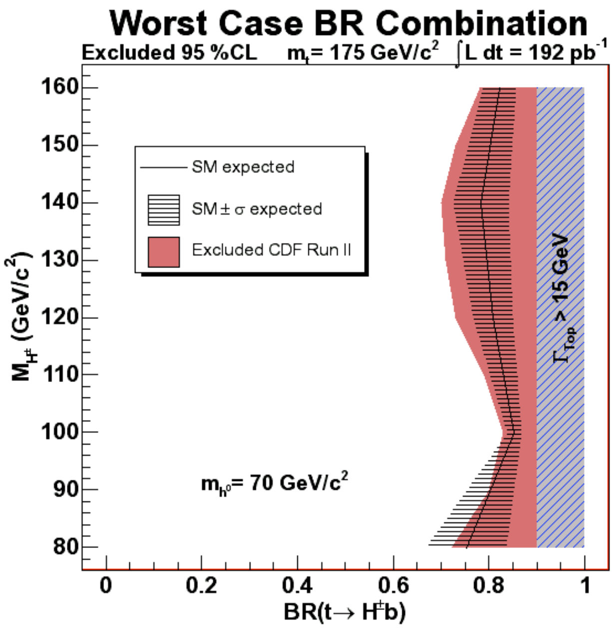


Sensitivity depends on radiative corrections: μ and A_t

"MODEL INDEPENDENT" LIMITS

- Reduce dependence on SUSY parameter space
- "tauonic" model:
  - BR($H^{\pm}\rightarrow\tau\nu$)=100%
- "Worst case BR" model:
  - Take always the combination of BR's which gives the least sensitivity
  - Conservative
- Place limits on BR($H^{\pm}\rightarrow tb$):
  - < 40% for tauonic model
  - < 80% for worst case

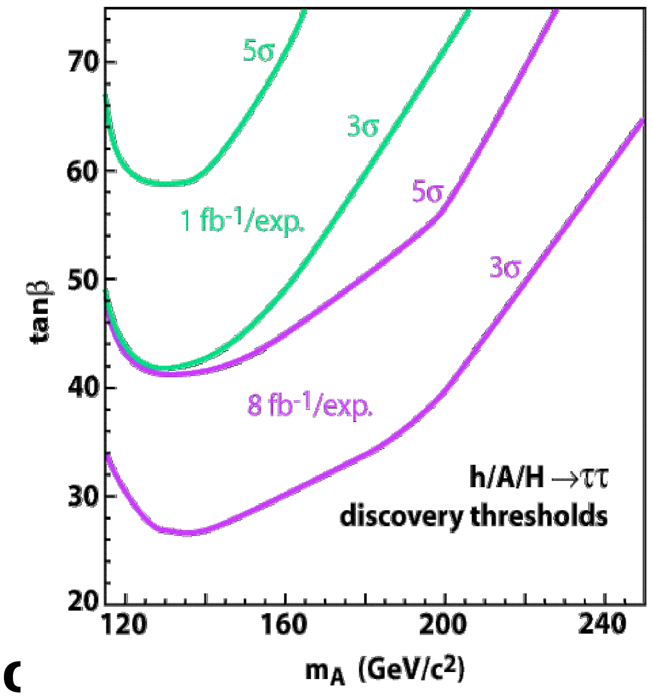




Conclusions and Outlook

- Tevatron provided ∫Ldt>1 fb^{-1}
  - CDF takes data efficiently
- No sign of Higgs boson yet
- Search for high mass di-tau production (L≈320 pb^{-1}):
  - Intepreted in MSSM: h/H/A→ττ
  - 1st limits in this channel in tanβ vs m_A plane
- Search for charged Higgs in top quark decays (L≈200 pb^{-1})
  - Model independent and model specific interpretations

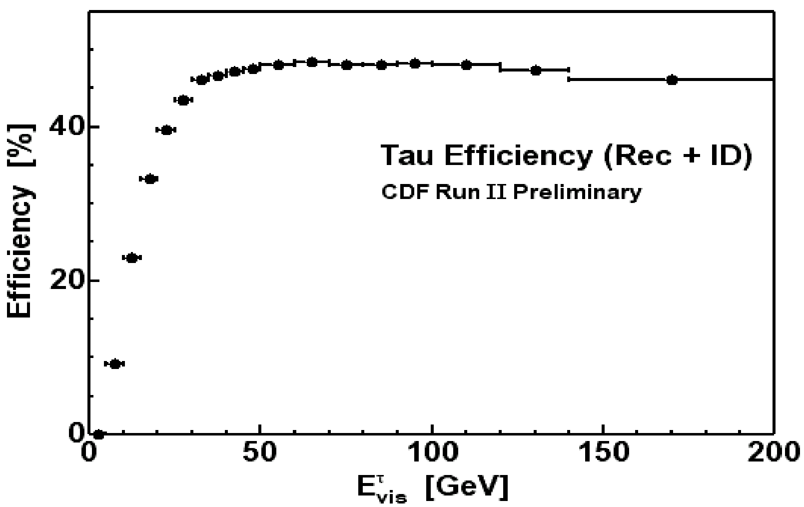
Discovery or Evidence by 2006 or 2009 ?



Will we see the Higgs before the LHC?

BACKUP

Tau Selection



Systematic Uncertainties

source	uncertainty (%)
Electron ID	1.3
Muon ID	4.4
Tau ID	3.5
Electron Trigger	1.9
Muon Trigger	1.0
Tau Trigger	1.0
jet$\rightarrow\tau$ fakes rate	20
Event Cuts	1.8
PDF (Higgs)	5.7
PDF (Z)	3.0
σxBr(Z $\rightarrow$ll)	2.1
Luminosity	6.0