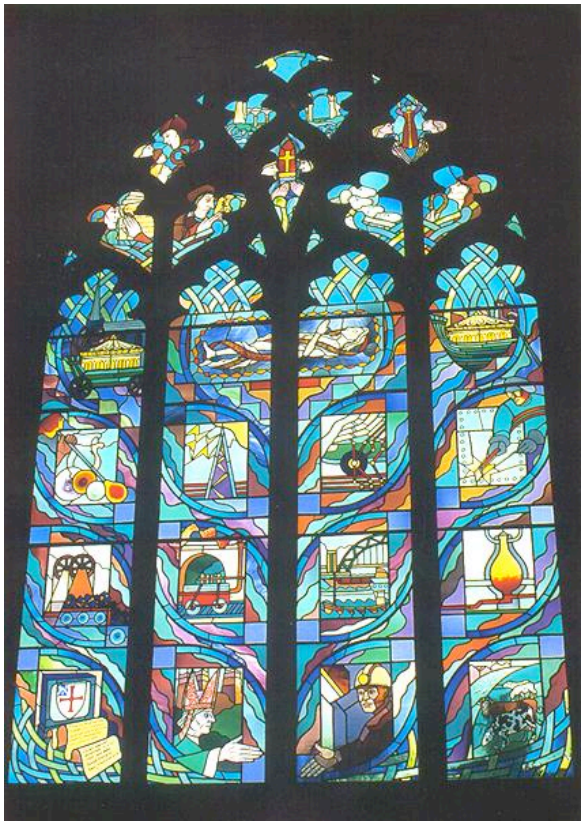
Searches for Higgs Bosons in the MSSM at CDF



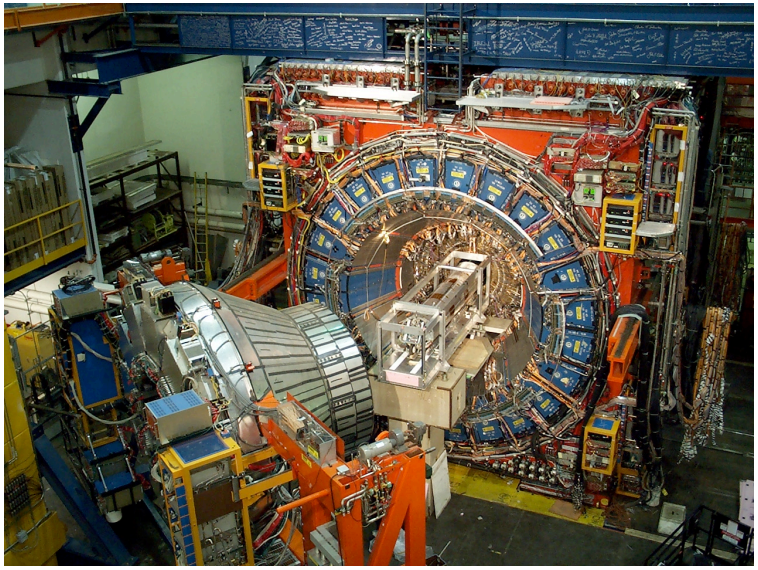
B. Heinemann

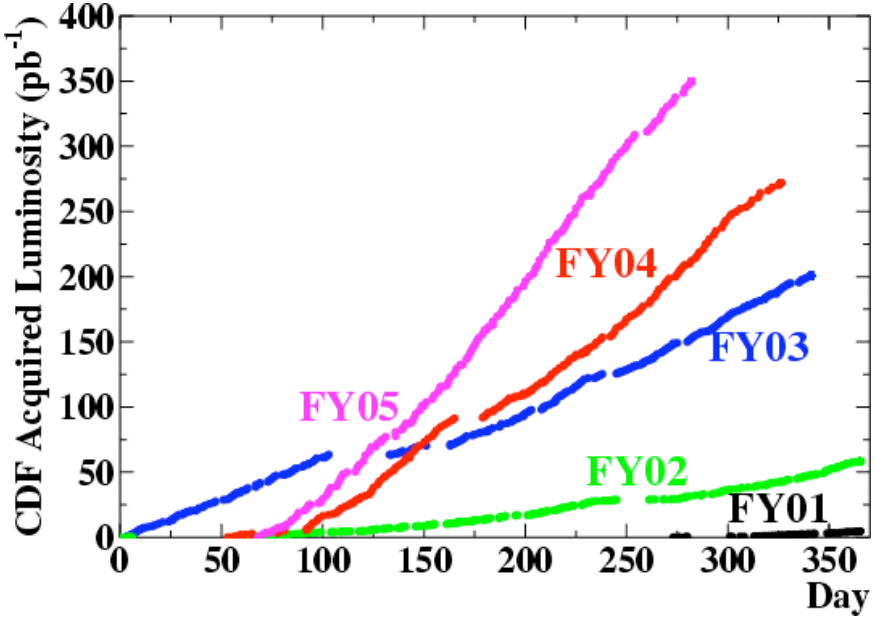
University of Liverpool

SUSY'05, Durham, July 2005

The Tevatron and CDF

- Tevatron:
  - pp at $\sqrt{s}$=1.96 TeV
- CDF:
  - Multi-purpose detector
- Luminosity:
  - 1100 pb^{-1} delivered by Tevatron to CDF
  - 200–300 pb^{-1} analysed for this talk





Higgs in the MSSM

- **Minimal Supersymmetric Standard Model:**
  - **2 Higgs-Fields: Parameter $\tan\beta = \langle H_d^0 \rangle / \langle H_u^0 \rangle$**
  - **5 Higgs bosons: h, H, A, $H^\pm$**

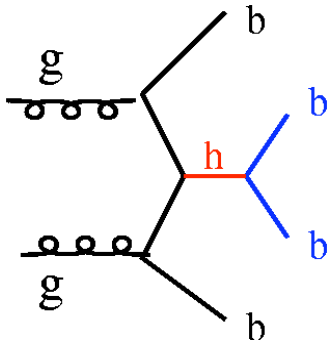
- **Neutral Higgs Boson:**
  - **A, H, h: if light decay to bb or $\tau\tau$**
  - **Here: $\tau\tau$ decay mode**

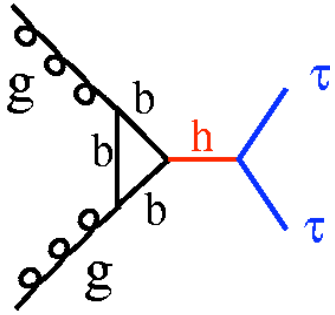
- **Charged Higgs Boson:**
  - **Search in top decays: $t \to H^\pm b$**
  - **$H^\pm \to \tau\nu$ or $H^\pm \to cs$ or $H^\pm \to Wbb$**

•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)

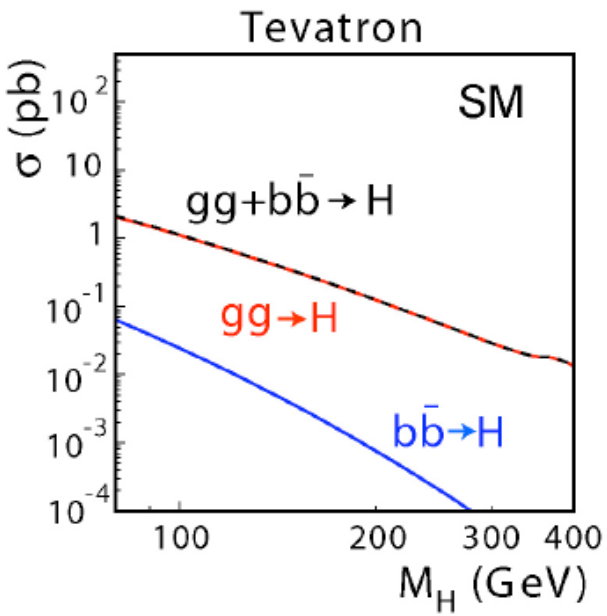
NEUTRAL MSSM HIGGS

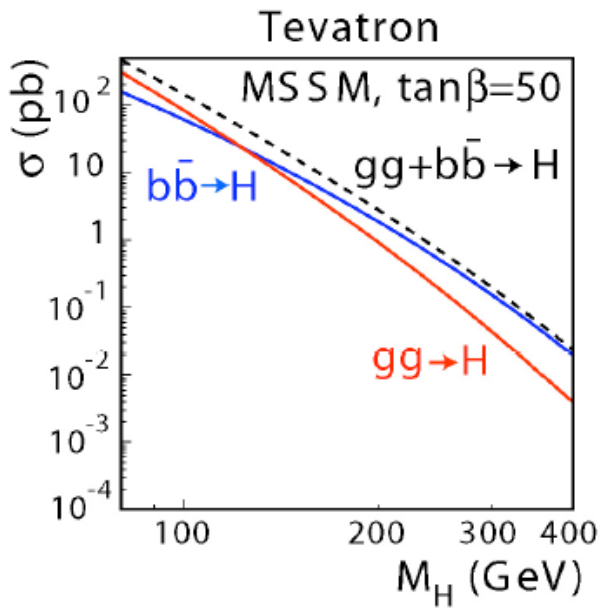
- **High tanβ:**
  - **A degenerate in mass with h or H**
  - **Cross sections enhanced with tan$^2\beta$ due to enhanced coupling to down-type quarks**
  - **Decay into either $\tau\tau$ or bb:**
    - **BR(A $\rightarrow\tau\tau$) ≈ 10%, BR(A$\rightarrow$ bb) ≈ 90%**
    - **Exact values depend on SUSY parameter space**
- **Experimentally:**
  - **pp $\rightarrow$ Ab+X $\rightarrow$ bbb+X**
  - **pp $\rightarrow$ A+X $\rightarrow$ $\tau\tau$ +X**
- **Production mechanisms:**
  - **gg $\rightarrow$ A**
  - **bb $\rightarrow$ A**



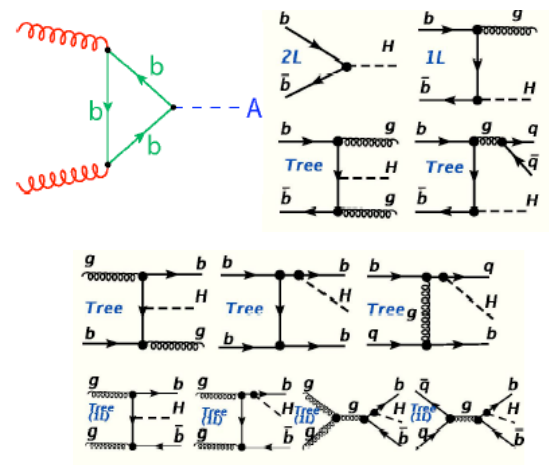


PRODUCTION: SM VS MSSM





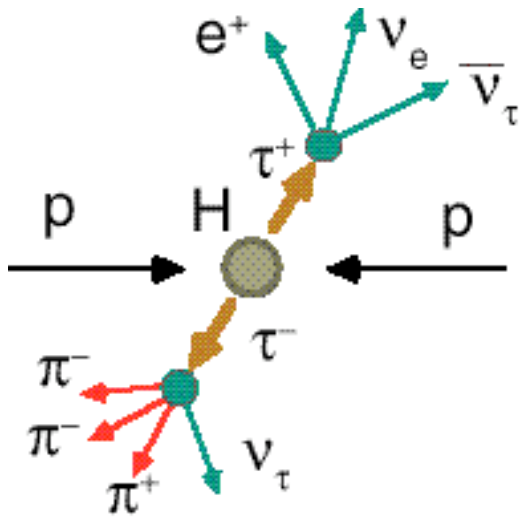
Some diagrams:

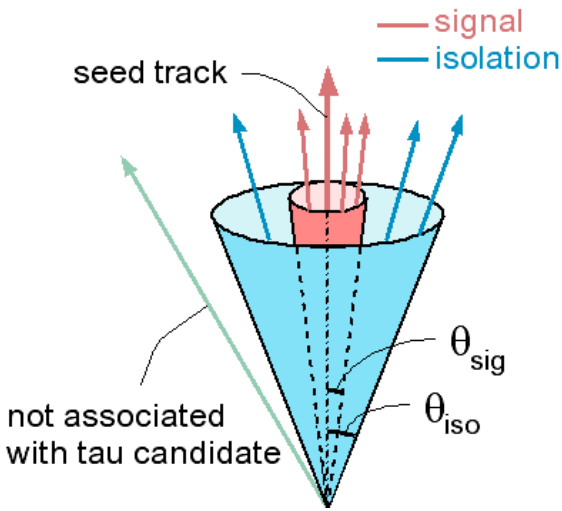


- **Cross section enhanced w.r.t. SM by ~tan²β**
- **Cross sections for bb–>Φ and gg–>Φ similar:**
  - **gg→Φ**
    - **Calculated at NLO with HIGLU (M. Spira)**
  - **bb→Φ**
    - **SM production calculated at NNLO (R. Harlander, W. Kilgore)**
    - **MSSM Higgs coupling to bb and ττ calculated with FeynHiggs (S. Heinemeyer, W.Hollik, G. Weiglein)**

Neutral Higgs: Tau-Selection

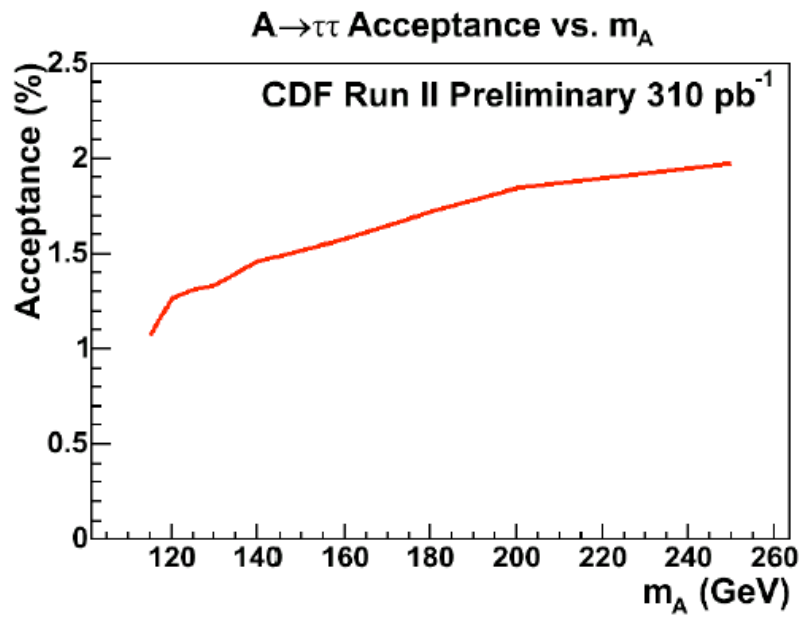
- **Select h->$\tau\,\tau$:**
  - **One τ decays to e or μ**
  - **One τ decays to hadrons**
- **Trigger:**
  - **e or μ with p_T>8 GeV**
  - **Track with p_T>5 GeV**
- **Offline:**
  - **e or μ with p_T>10 GeV**
  - **Hadronic τ:**
    - **Narrow Jet with low multiplicity**
    - **1 or 3 tracks in 10 cone**
    - **No tracks between 10 and 30**
    - **Low π^0 multiplicity**
    - **Mass<1.8 GeV**
- **Kinematic cuts against background**

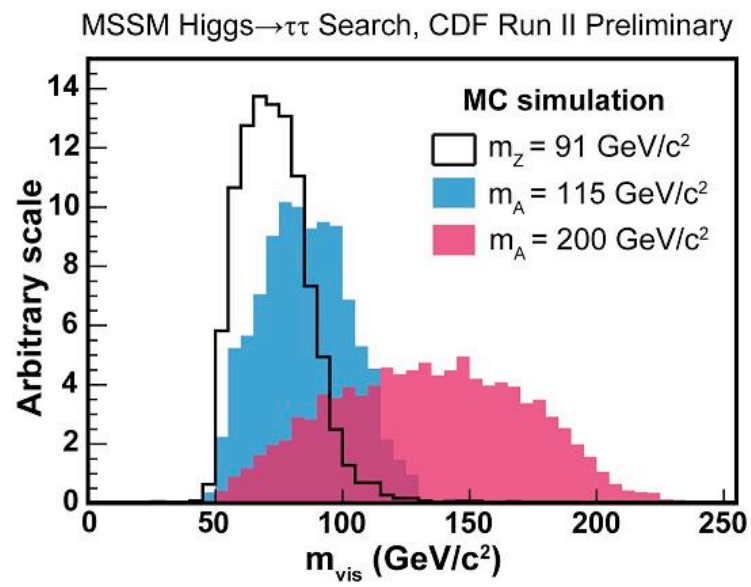




Neutral Higgs: Selection

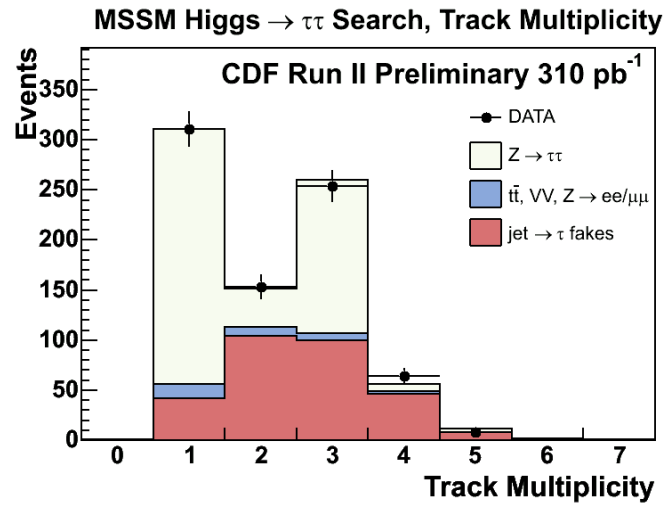
- Acceptance for Higgs about 1–2%
- Main background:
  - Drell–Yan $\tau\tau$
  - Separate kinematically
- No full mass reconstruction possible:
  - Form mass like quantity: $m_{vis}=m(\tau,e/\mu,E_T)$
  - Good separation between signal and background
- Fit mass distribution to maximise sensitivity



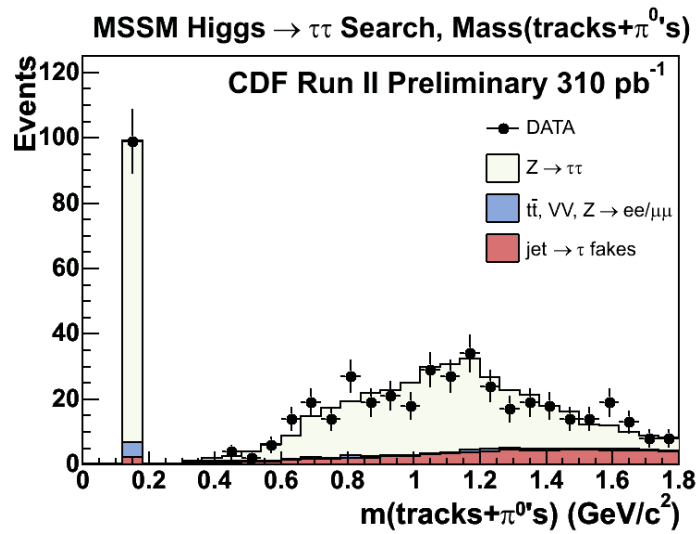


Neutral Higgs: Data vs SM

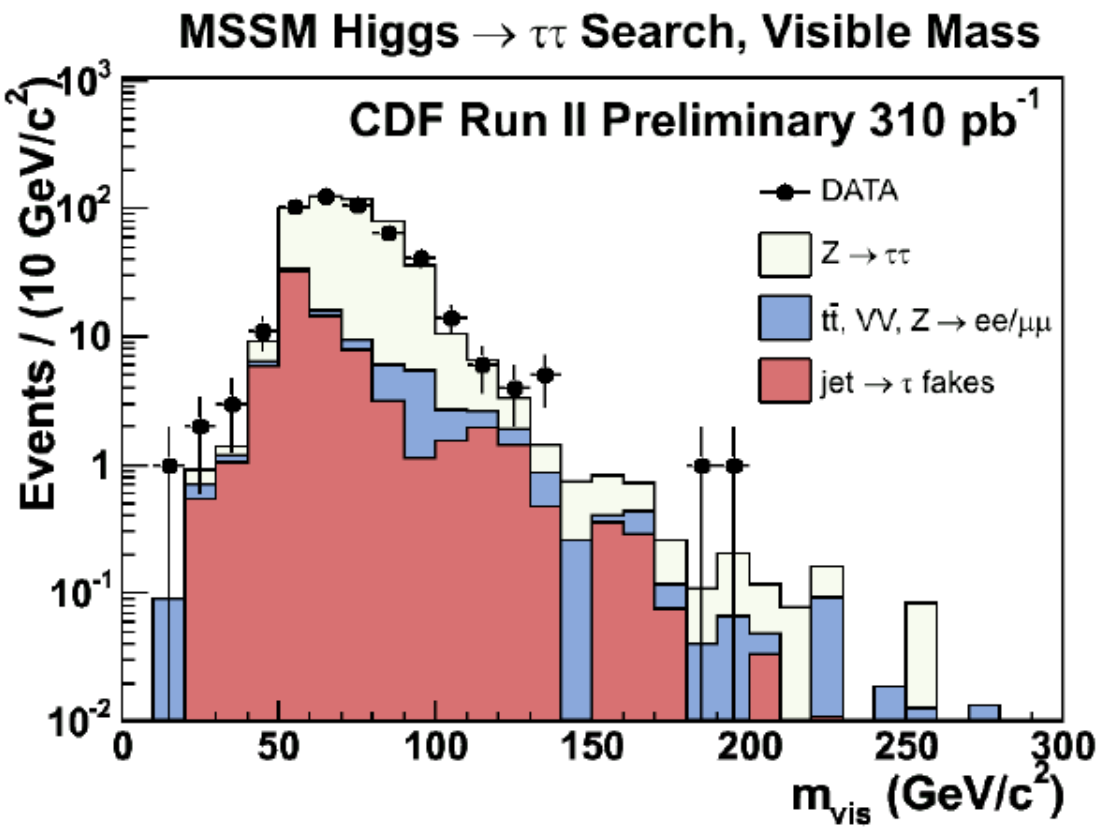
source	$\tau_e\tau_h$	$\tau_\mu\tau_h$	$\tau_e\tau_h + \tau_\mu\tau_h$
$Z \to \tau\tau$	217.2±3.9±12.7	187.3±3.6±11.9	404.5±5.3±23.2
$Z \to \ell\ell$	5.9±0.5±0.3	8.4±0.8±0.5	14.3±0.9±0.8
tt, VV	1.0±0.1±0.1	0.9±0.1±0.1	1.9±0.1±0.1
jet→τ fakes	44.6±0.1±8.9	30.8±0.2±6.2	75.4±0.2±15.1
Predicted bg	268.7±3.9±15.5	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
- Now let's look at the mass!

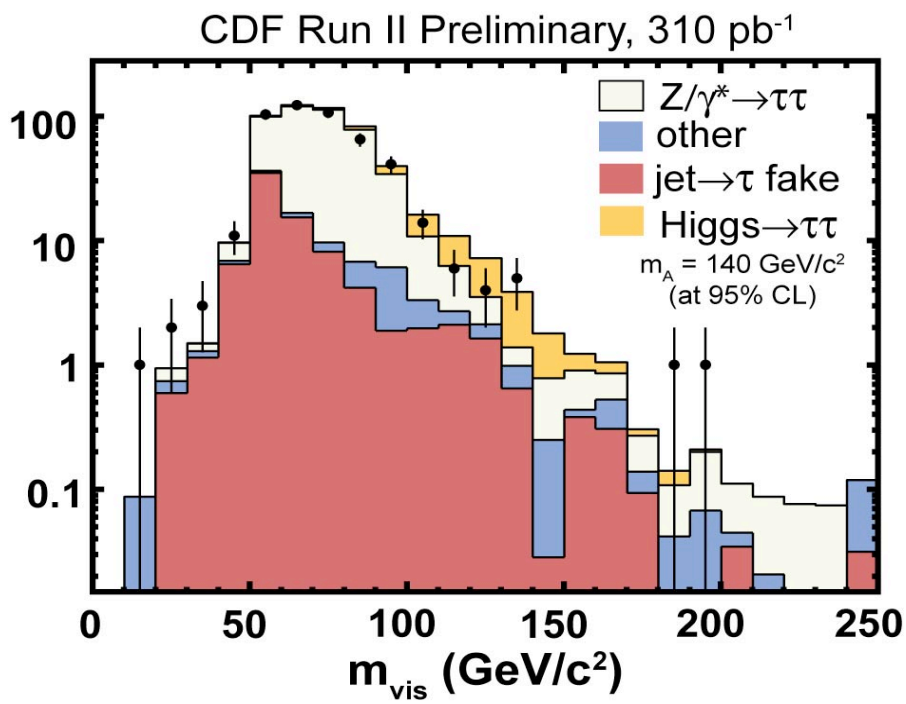


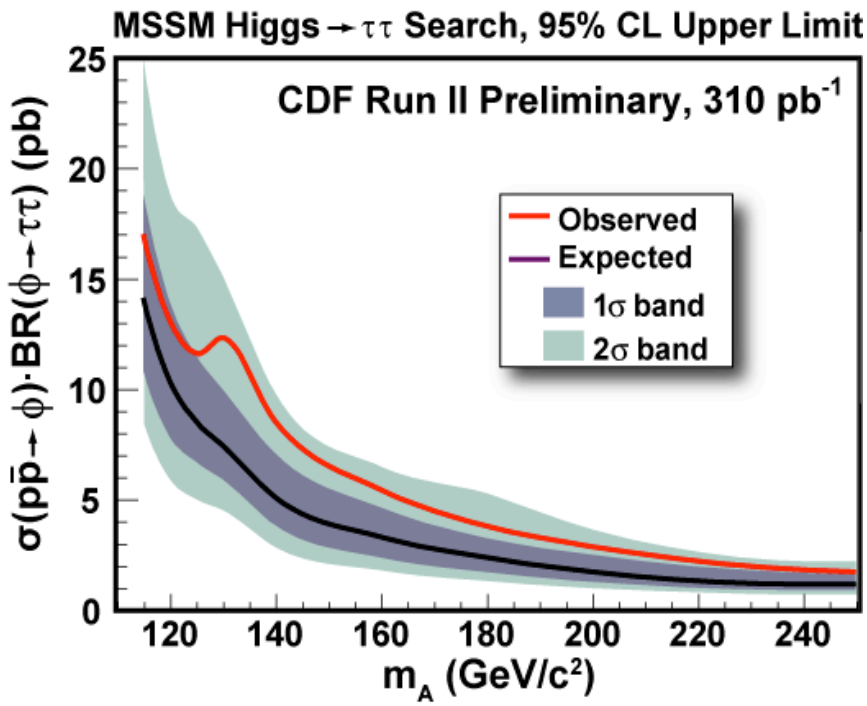
Neutral Higgs: Mass Distribution



- Good Agreement with Expectation
- A few events at High mass:
  - M>120 GeV: 8.4±0.9 expected, 11 observed
- Fit mass distribution for Signal

Neutral Higgs: Mass Distribution





- 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 "benchmark scenarios"

MSSM Higgs: Interpretation

- At tree level cross section and BR depends only on 2 parameters:
  - $\tan\beta$ and m_A
- However, due to rad. Corrections dependence on other parameters:
  - Higgsino mixing μ
  - Stop mixing: $X_t=(A_t-\mu\cot\beta)$
- Use 3 benchmark scenarios (hep-ph/0202167, hep-ph/9912223):
  - No mixing and max. mixing
  - Max. mixing with positive and negative μ

M. Carena, S. Heinemeyer, C.E.M. Wagner, G. Weiglein (hep-ph/0202167)

- **m_h^{max}: $\mu=\pm200$ GeV, $X_t=2\ M_{SUSY}$**
- **No-mixing: $\mu=\pm200$ GeV, $X_t=0$**

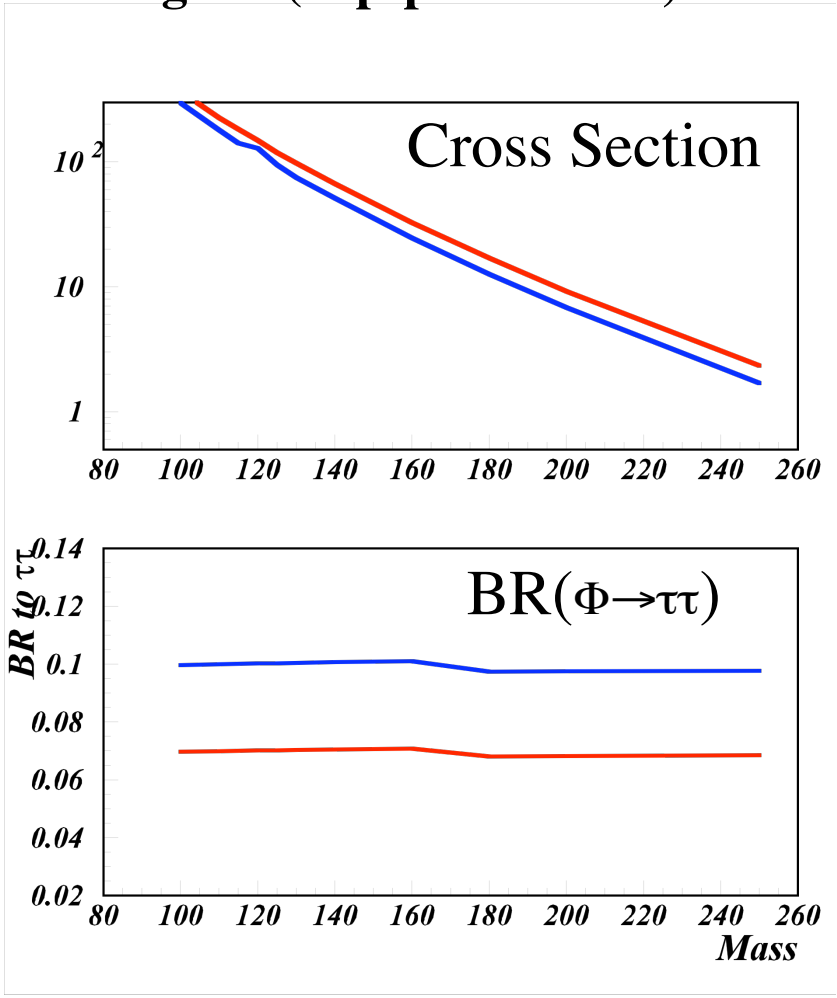
BENCHMARK SCENARIOS

M. Carena, S. Heinemeyer, C.E.M. Wagner, G. Weiglein (hep-ph/0202167)

- **Common parameters:**
  - M_{SUSY}=1 TeV
  - M_2=200 GeV
  - A_b=A_t
  - M(g)=0.8 M_{SUSY}
- **4 scenarios:**

1. No-mixing: μ = +200 GeV, X_t=0
2. No moxing: μ = -200 GeV, X_t=0
3. m_h^{max}: μ = +200 GeV, X_t=2 M_{SUSY}
4. m_h^{max}: μ = -200 GeV, X_t=2 M_{SUSY}

- **Dependence of σ and BR:**
  - Cross section larger for μ<0
  - BR($\Phi\to\tau\tau$) larger for μ >0
  - BR($\Phi\to bb$) larger for μ <0



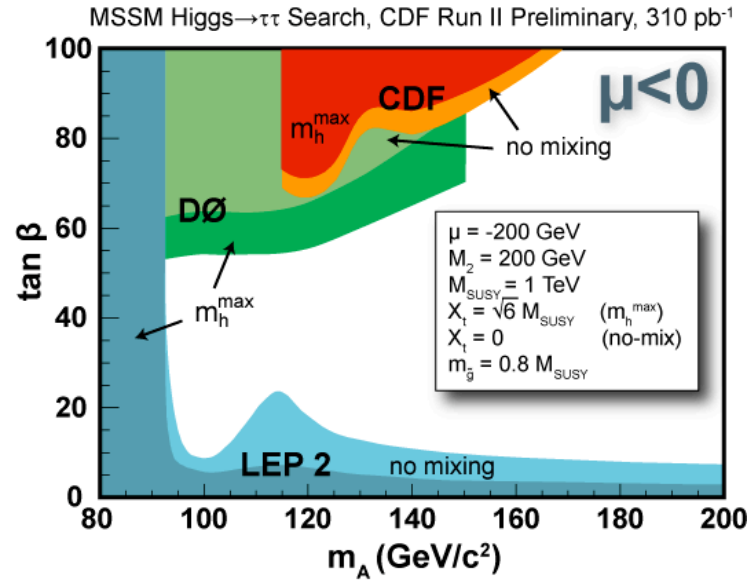
Bottom Yukawa coupling:

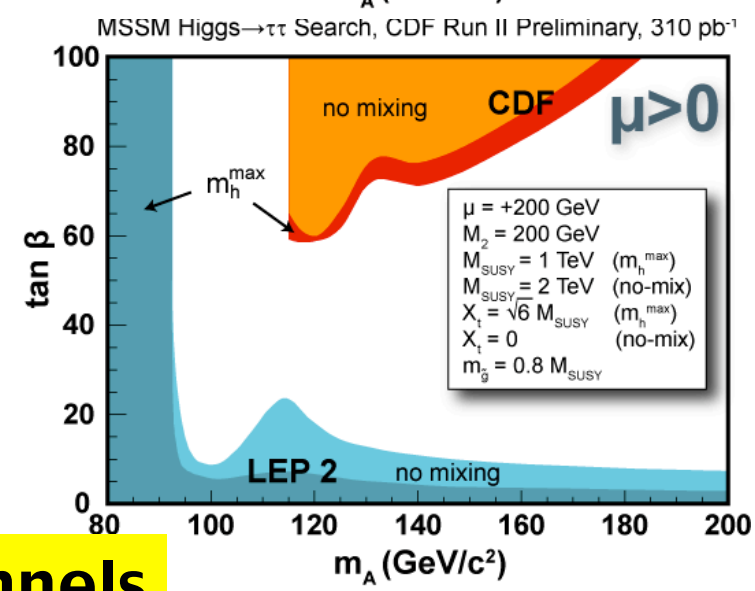
$$y_b \sim \frac{m_b}{1+\Delta_b}, \qquad \Delta_b \sim \mu \tan\beta\, m_{\tilde{g}}\, \alpha_s\, I(m^2_{\tilde{b}_1}, m^2_{\tilde{b}_2}, m^2_{\tilde{g}})$$

Neutral Higgs: Results

- **pp → bA+X→bbb+X (DØ)**
  - Best sensitivity for $\mu<0$
  - Lower sensitivity for $\mu>0$

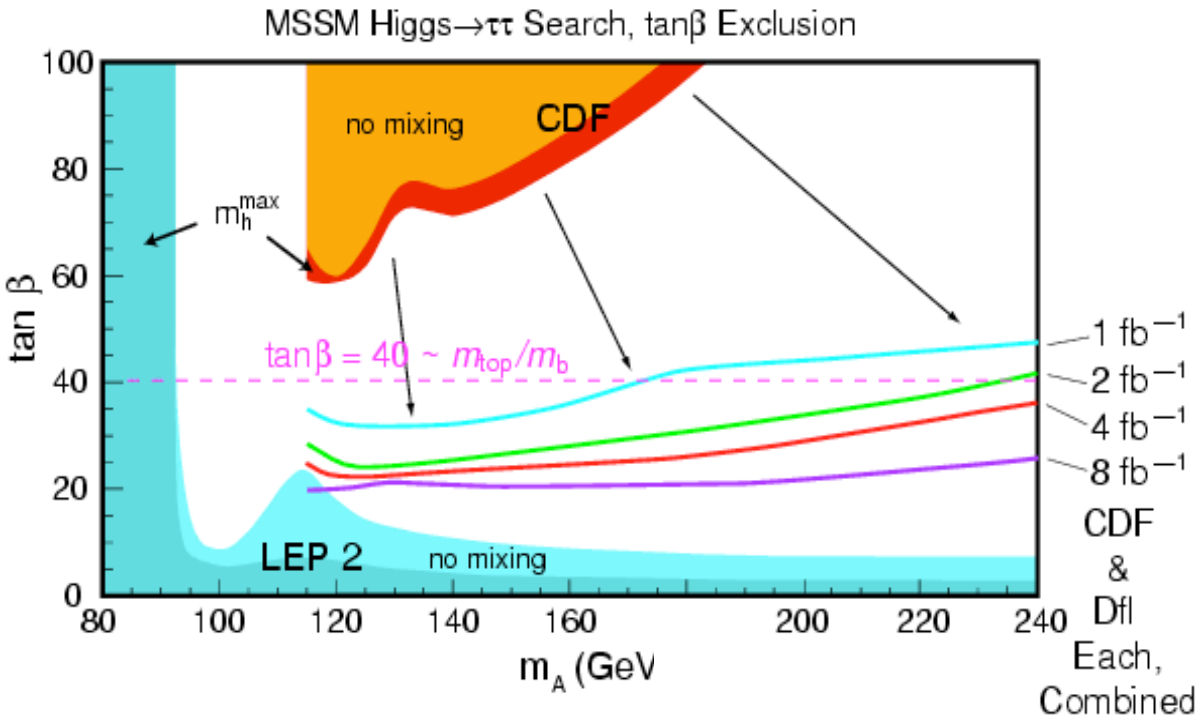
- **pp → A+X→ ττ+X (CDF)**
  - Sensitive for $\mu>0$ and $\mu<0$
  - Best sensitivity for $\mu>0$



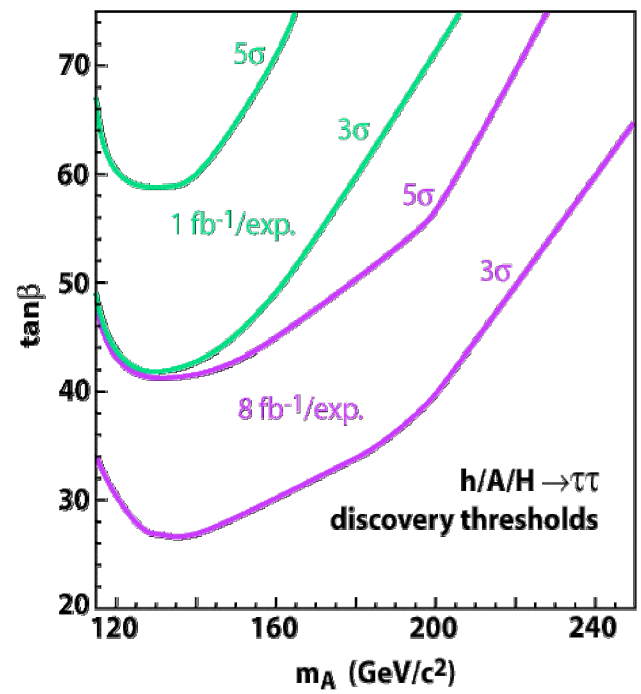


Nice complementarity of both channels

Neutral Higgs: Future



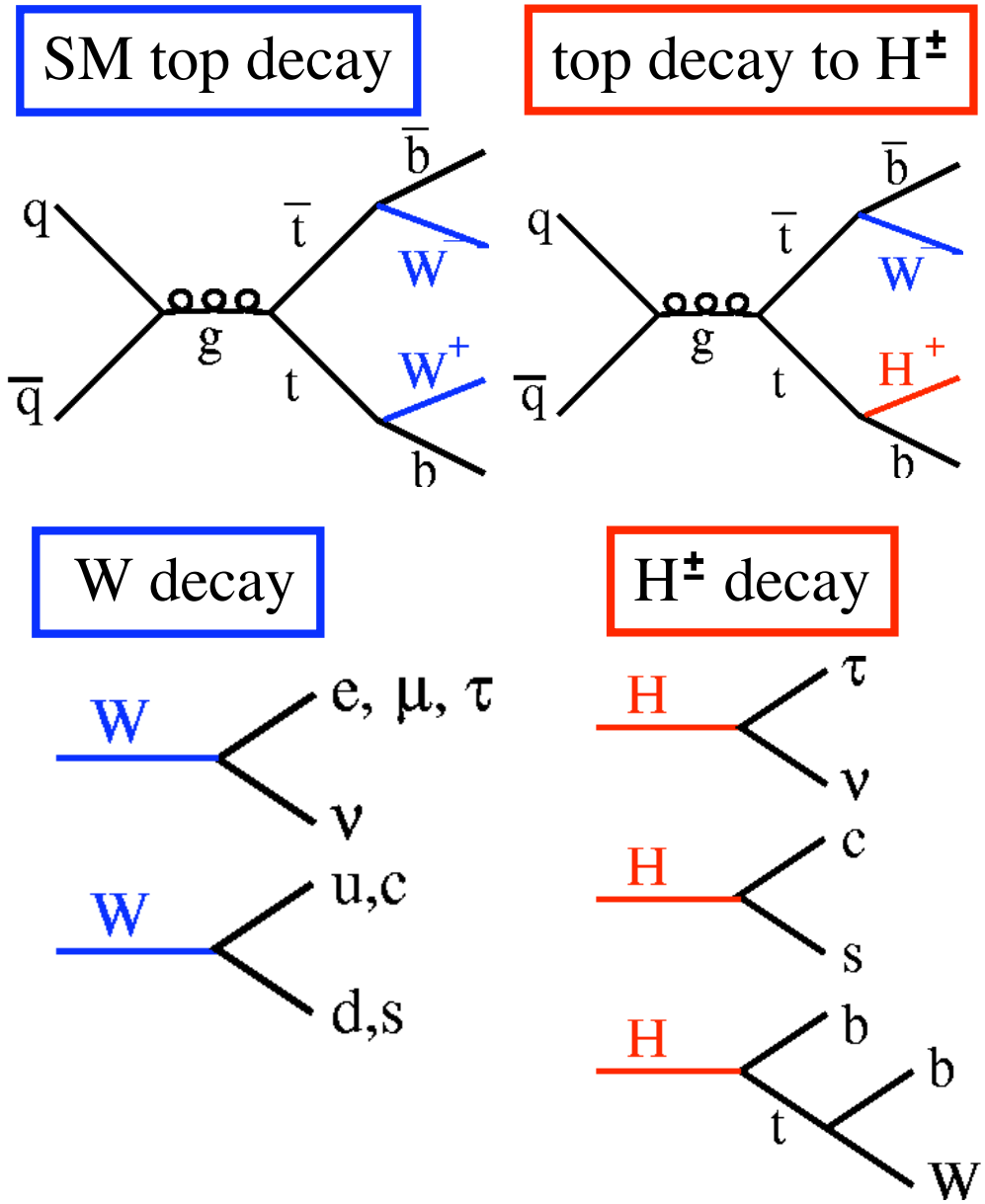
Discovery?



- **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**
- **Discovery potential for masses up to 200 GeV/c^2**

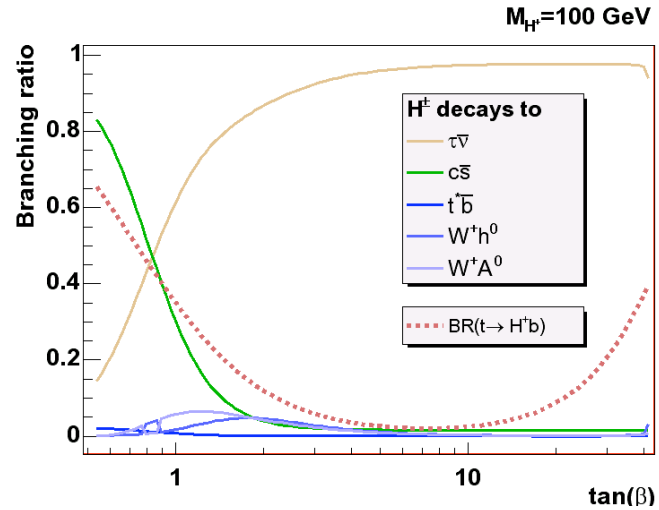
Charged Higgs

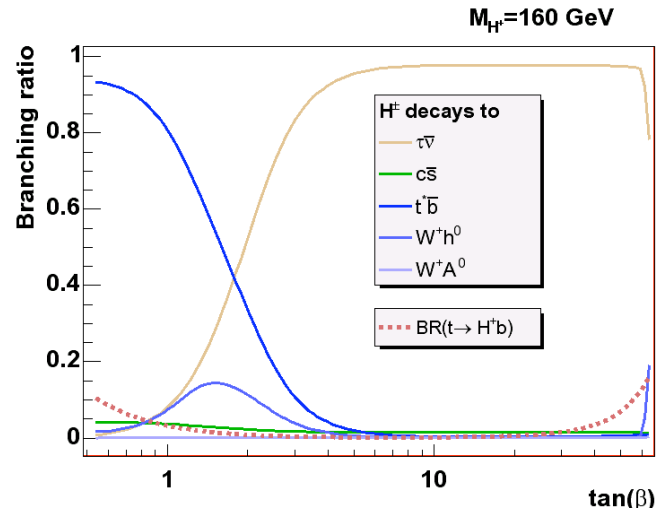
- **SM Top decay:**
  - BR(t->Wb)>99%
- **If m(H±)<m(top):**
  - Top decays to H±b
  - H± decays not like W
- **Constrain charged Higgs by interpreting top cross section measurements:**
  - Dilepton+jj+X
  - Lepton+τ+jj+X
  - Lepton+1b+jjj+X
  - Lepton+2b+jj+X



$H^{\pm}$ Branching Ratios

- Decays:
  - H->τν
  - H->cs
  - H->t*b->Wbb
  - H->Wh->Wbb
- Dependence on
  - Tanβ
  - Mass of $H^{\pm}$
- Largest dependence at low and large tanβ



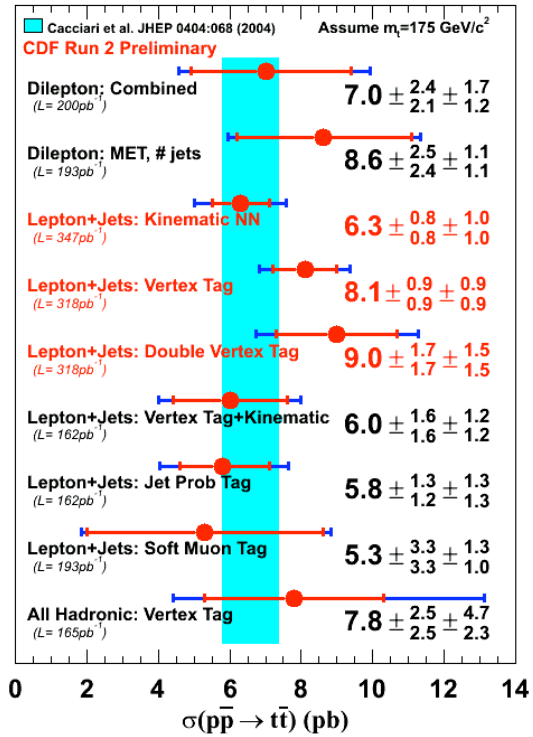


Data vs Standard Model

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

	Observed	Non-top Background	Top+BG
2 e/μ+2 jets	13	2.7±0.7	10.9±1.4
e/μ+τ+2 jets	2	1.3±0.2	2.4 ±0.3
e/μ+4 jets (=1 b-tag)	49	20.3±2.5	54 ±???
e/μ+4 jets (≥2 b-tags)	8	0.9±0.2	10 ±???

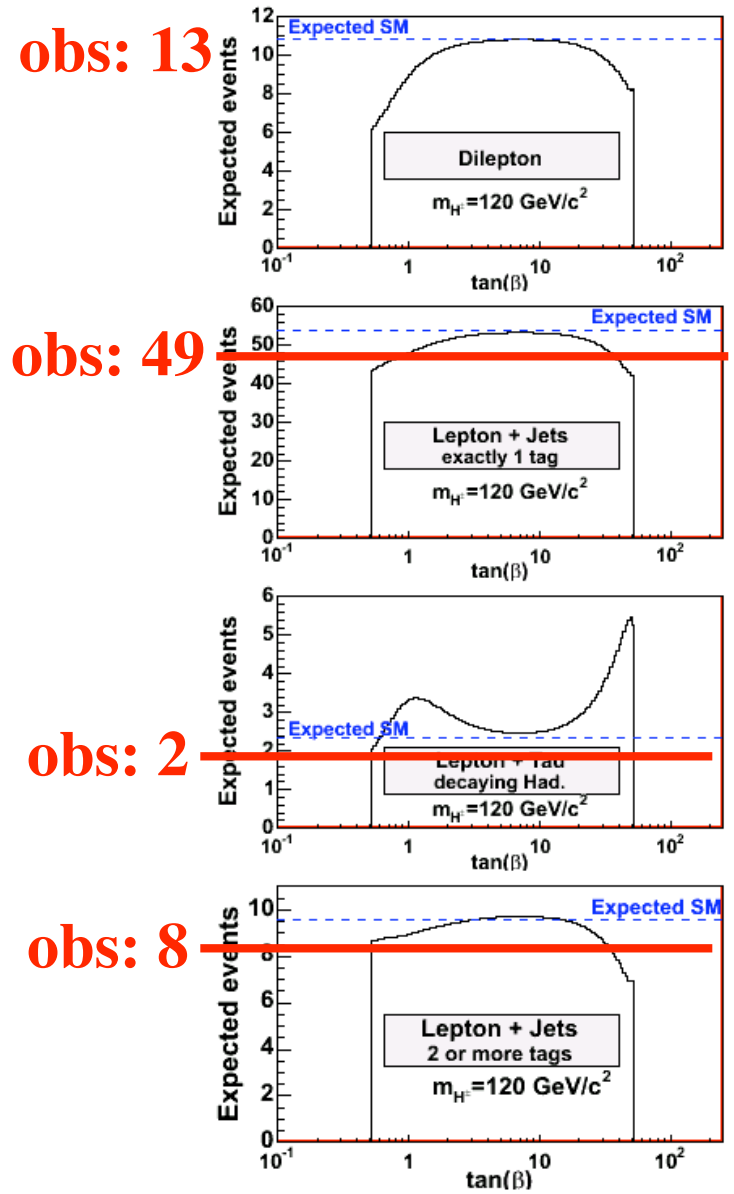
Latest CDF results



- **Data agree with SM top decay**
- **Place limits on Higgs production**

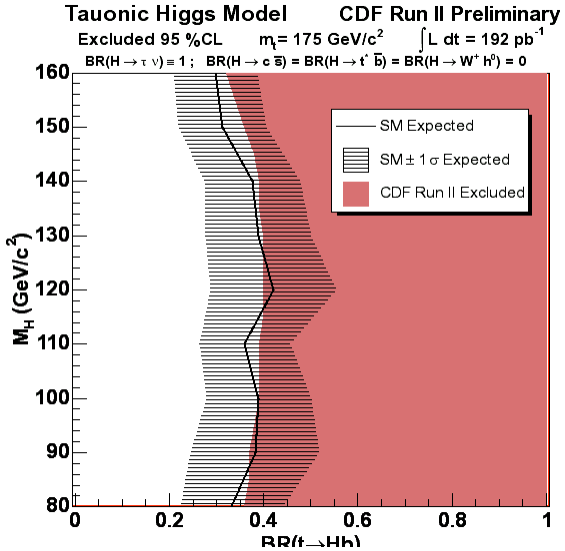
Expected Events

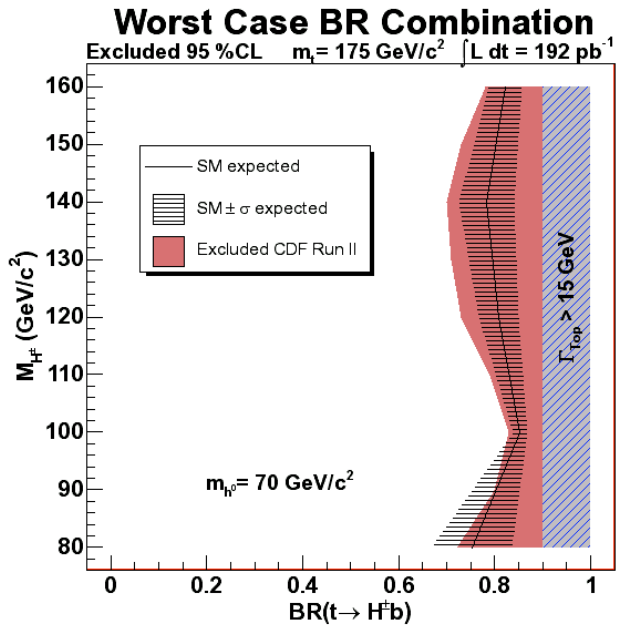
- Example scenario at Higgs mass: m_h=120 GeV/c^2
- Number of expected events changes depending on tanβ
  - E.g. enhancement of tau's at large tanβ
  - E.g. reduction of other channels at small and large tanβ
- By using all channels we get optimal sensitivity



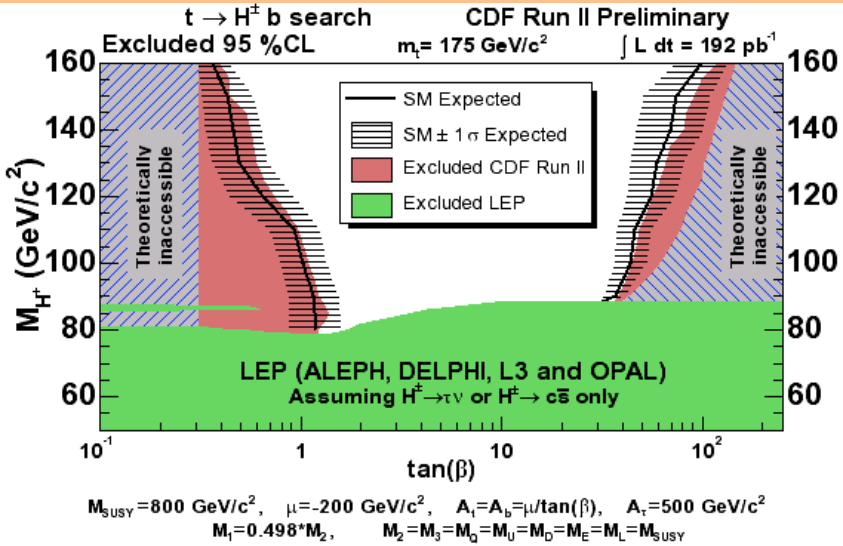
Model independent Limits

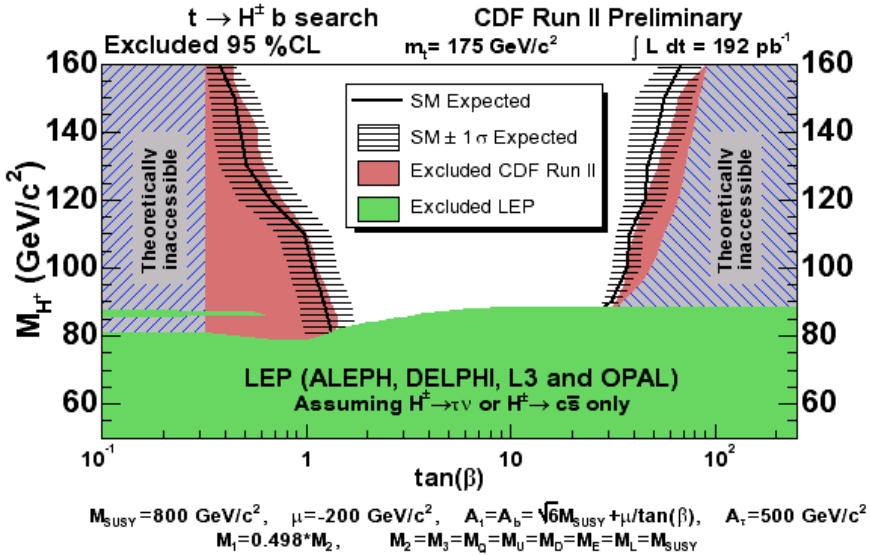
- Reduce dependence on SUSY parameter space
- tauonic model:
  - BR(H->$\tau\nu$)=100%
- Worst case:
  - Take always the combination of BR's which gives the least sensitivity
  - Conservative
- Place limits on BR($H^{\pm}$->tb):
  - < 40% for tauonic model
  - < 80% for worst case





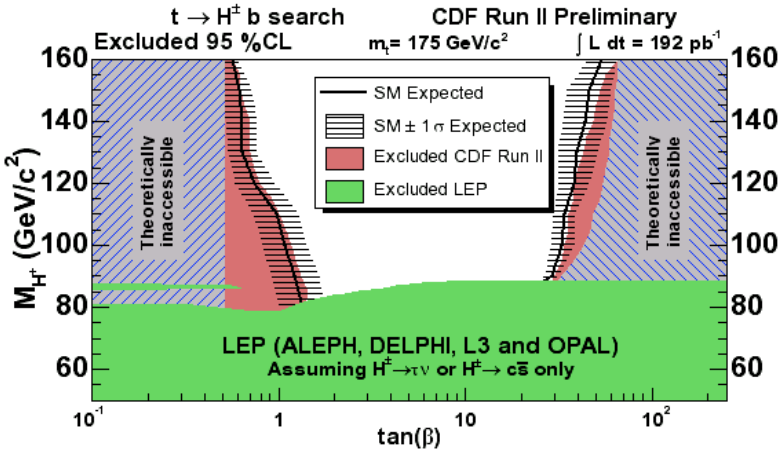
Charged Higgs: Results



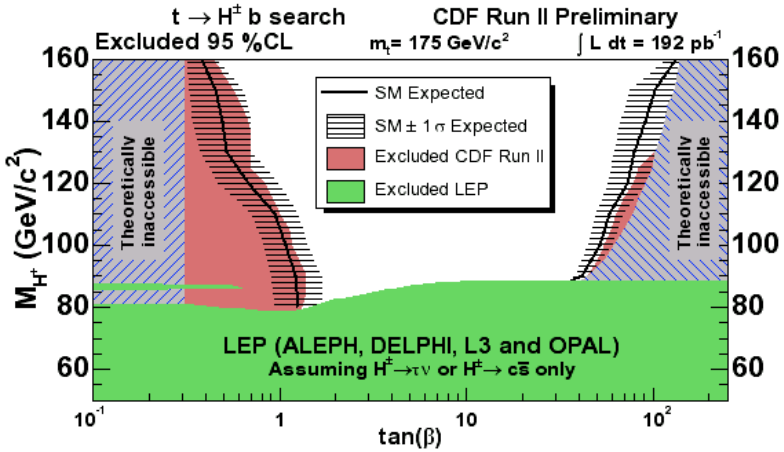


- **Same benchmark models as for neutral Higgs search:**
  - **Hep-ph/0202167: M. Carena, S. Heinemeyer, C.E.M. Wagner, G.Weiglein**
  - **Use CPsuperH for signal prediction**
- **Probing tanβ values around 40 already**
  - **Only used 200 pb^{-1} => large improvements in future**
  - **Experimental limits agree with ecpected limits**
  - **"Theoretically inaccessible" = CPsuperH not happy**

More Benchmark Models



M_{SUSY}=1000 GeV/c^2, μ=-500 GeV/c^2, A_t=A_b=2000 GeV/c^2, A_τ=500 GeV/c^2
M_1=0.498*M_2, M_2=M_3=M_Q=M_U=M_D=M_E=M_L=M_{SUSY}



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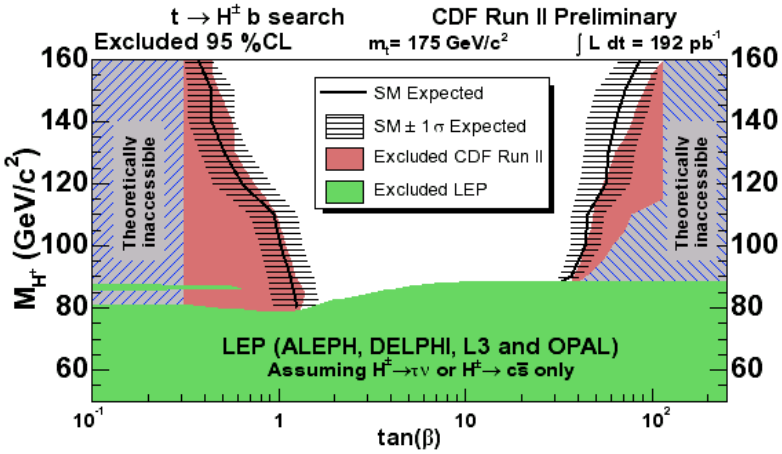

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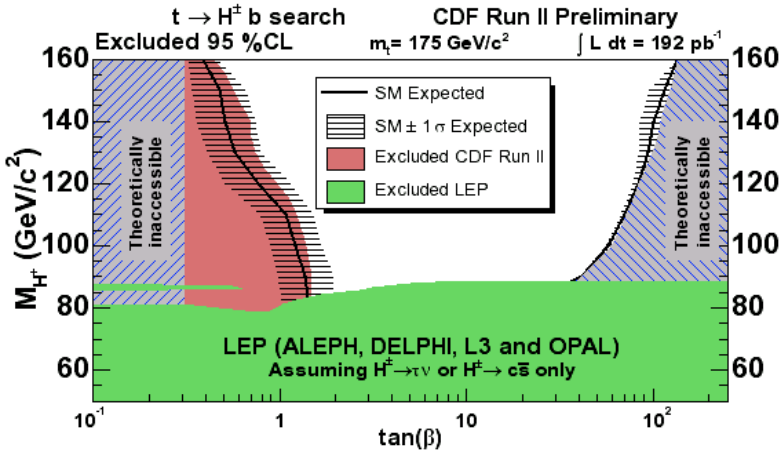


M_{SUSY}=1000 GeV/c^2, μ=500 GeV/c^2, A_t=A_b=2800 GeV/c^2, A_τ=500 GeV/c^2
M_1=0.498*M_2, M_2=M_3=M_Q=M_U=M_D=M_E=M_L=M_{SUSY}

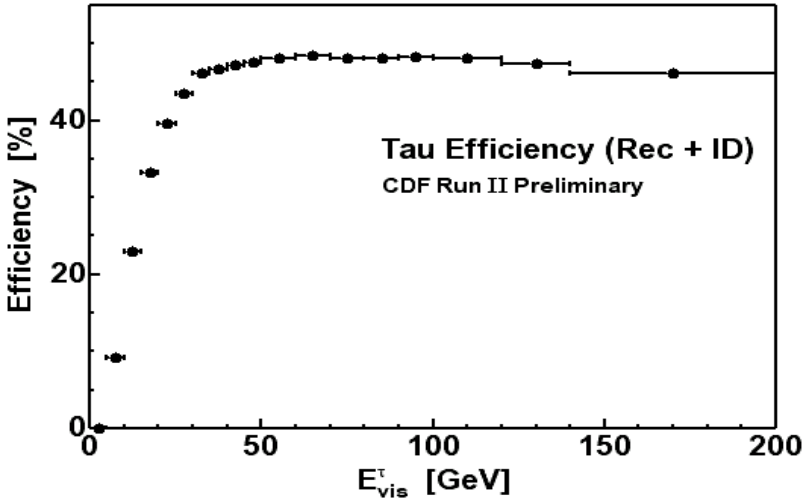
Conclusions and Outlook

- Search for high mass di-tau production :
  - Intepreted in MSSM: h/H/A->tautau
  - 1st limits in this channel in tanb vs m(A) plane
  - Slight excess around m(A)=130 GeV/c2
  - Bright perspectives for the future
- First search for charged Higgs in top production
  - Data agree with SM
  - Data probe new virgin parameter space
  - Large improvements expected with improved statistics

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