Limits on charged Higgs using $t\underline{t}$ cross section measurements

with an eye on LHC

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Higgs Sector in MSSM

- MSSM Higgs sector: Type II 2HDM. E.S.B =>5 Higgs bosons (h^0, H^0, A^0, $H^\pm$)

  Myriad of new decay channels :

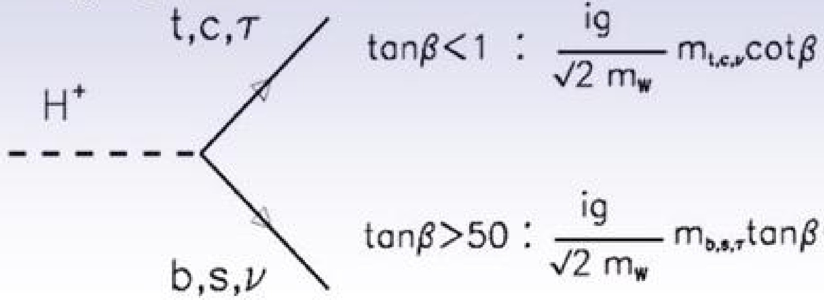
  - $h^0, H^0 \rightarrow b\bar{b}, \tau^+\tau^-, gg, W^+W^-, ZZ, c\bar{c}$
  - $A \rightarrow b\bar{b}, \tau^+\tau^-, gg, Zh, t\bar{t}$
  - $H^+ \rightarrow t\bar{b}, \tau^+\nu, c\bar{s}, c\bar{b}, W^+h, W^+A$

  Direct searches are aimed to specific decay channels.

  Indirect searches can exclude parameter space by combination of channels

- At tree level (mH^+, $\tan(\beta)$) determines the decays modes for top and $H^\pm$

H+ couplings to Fermions :



$$\tan\beta<1 \; : \; \frac{ig}{\sqrt{2}\, m_W} m_{t,c,\nu}\cot\beta$$

$$\tan\beta>50 \; : \; \frac{ig}{\sqrt{2}\, m_W} m_{b,s,\tau}\tan\beta$$

Main decay modes for 80GeV$<m_H<m_{Top}$			
Top	$t \rightarrow W b$	Higgs	$H \rightarrow c\bar{s}$
	$t \rightarrow H b$		$H \rightarrow \tau\nu$
			$H \rightarrow Wb\bar{b}$

Large H^+tb coupling when $\tan(\beta) \le 0.3$ or $\tan(\beta) \ge 175$!!

- MSSM in its general form has more than 100 parameters.

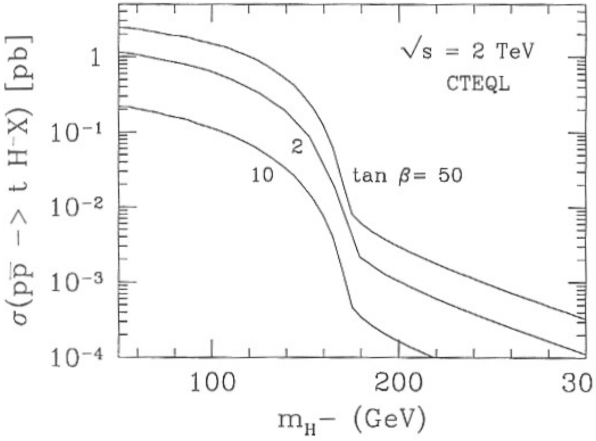
  Luckily, most of them have no consequence on the Higgs phenomenology

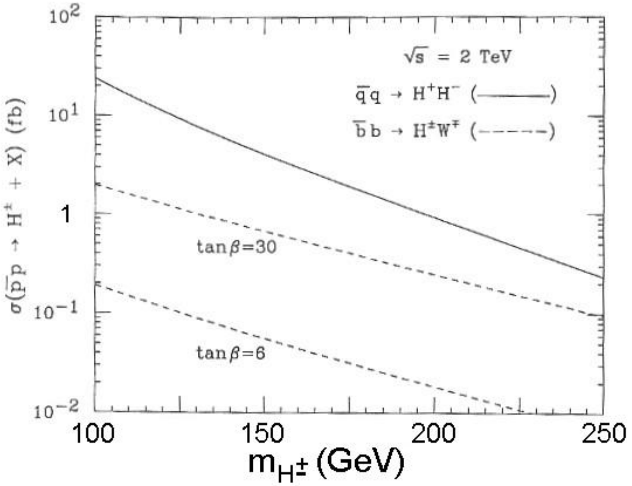
SM + MSSM Higgs sector

New channels contributions

- pp$\rightarrow t\underline{t} \rightarrow H^+$ +X $\sigma(t\underline{t}) = 6.7+0.7$
- pp$\rightarrow tH^+$
- pp$\rightarrow Wh^0$ $< \sigma(Wh^0_{SM}) < 0.2$
- pp$\rightarrow Zh^0$ $< \sigma(Zh^0_{SM}) < 0.1$
- pp$\rightarrow H^+H^-$
- pp$\rightarrow W^+H^-$
- H^+ production via decay of heavy SUSY particles. *Ignored here.*

The production cross section of these new backgrounds is generally small compared to that of $t\underline{t}$.





Tevatron : $H^\pm$ production from $t\underline{t}$ via t->$H^\pm$b, competes with t->Wb

How likely is this scenario, given the measured cross sections?

Present limits

- **LEP :** Direct search; $M_H > 78.6$ GeV/c2 @ 95 % CL, irrespective of tan(β). Combined result from ALEPH, DELPHI, L3 and OPAL collaborations.

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

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

We will compare our results to all the LEP and Tevatron results at the result section of this talk.

New top decay channels

- For each top quark we have 4 possible decay modes

1) t→Wb 2) t→Hb->τνb 3) t→Hb→t*bb→Wbbb 4) t→Hb→csb

- Take advantage of "***Dilepton***", "***Lepton + jets***" *and* "***Lepton*** + τ_{Had}" *XS's*
- The number of expected candidates N^{exp}, for a given m_{H+}, in each XS is

$$N^{\exp} = \underbrace{N^{back}}_{\text{from XS meas.}} + \sigma \quad \varepsilon_{tt} \int L dt \longrightarrow \text{~193 pb}^{-1}$$

from XS meas.

σ^{theo}**=(6.7±0.7)pb**

hep-ph 0303085

from MC

$$\varepsilon_{tt} = \sum_{i,j=1}^{4} \varepsilon_{i,j} \underbrace{B_i B_j}$$

Branching fractions of each decay mode

$\varepsilon_{t\underline{t}} = \varepsilon_{t\underline{t}}(\{B_i\})$ Need to get the B_i to find $\varepsilon_{t\underline{t}}$

- Then compare N^{obs} to N^{exp} <u>for all cross section measurements</u>
- Repeat for different m_{H+}

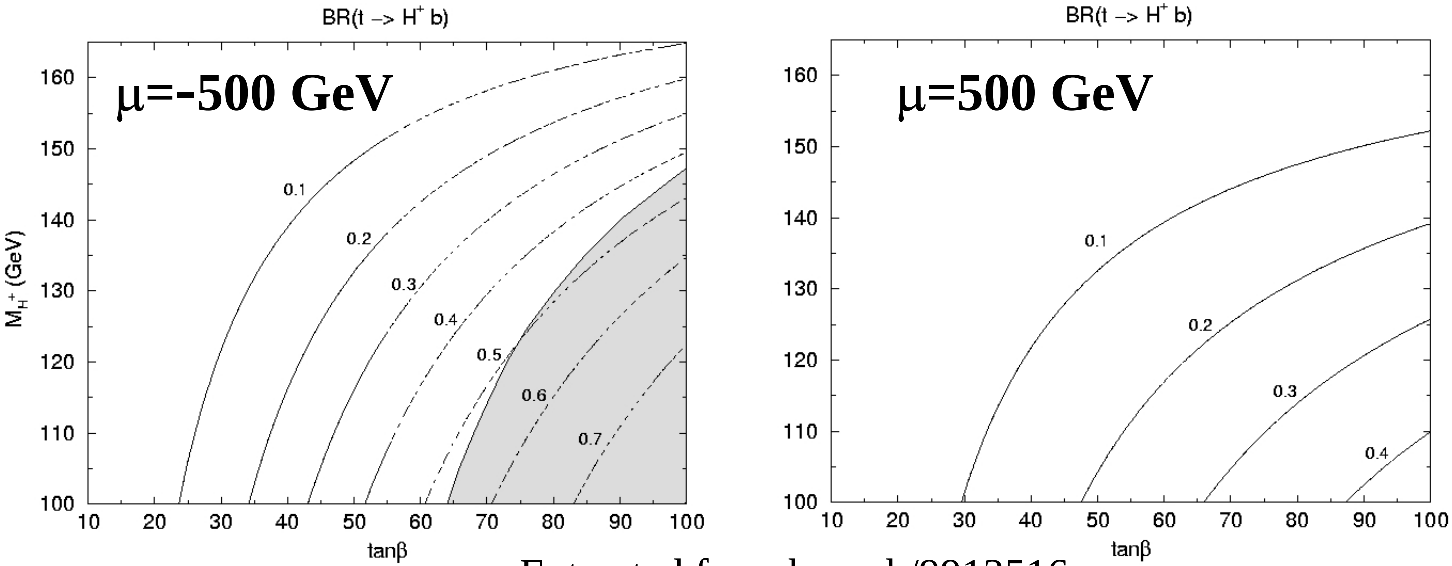
(Different assumptions taken in this equation.)

Branching Ratios from ME : (aka Model Dependent)

Question : Where do we get the BR's from?

Answer: We can get BR's from ME calculations.

Caveat: *Loop corrections are large and model dependent.*



Extracted from hep-ph/9912516.

D0's tree level result from Run I can be "tuned out" by choice of μ.

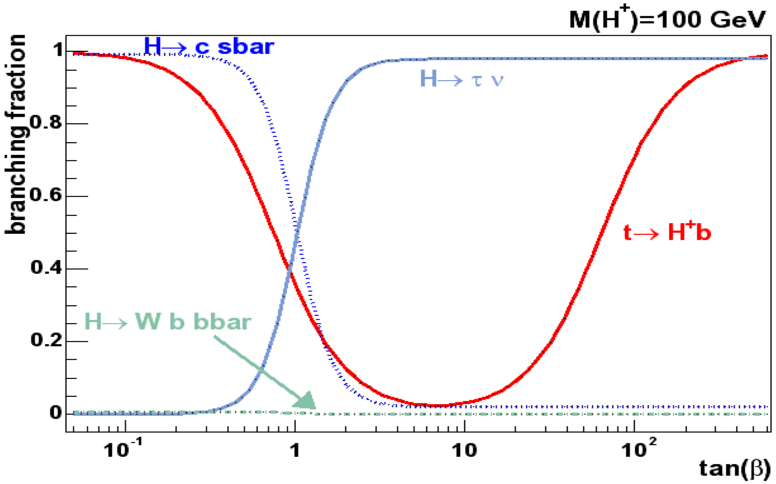
In the next version (coming soon) we use :

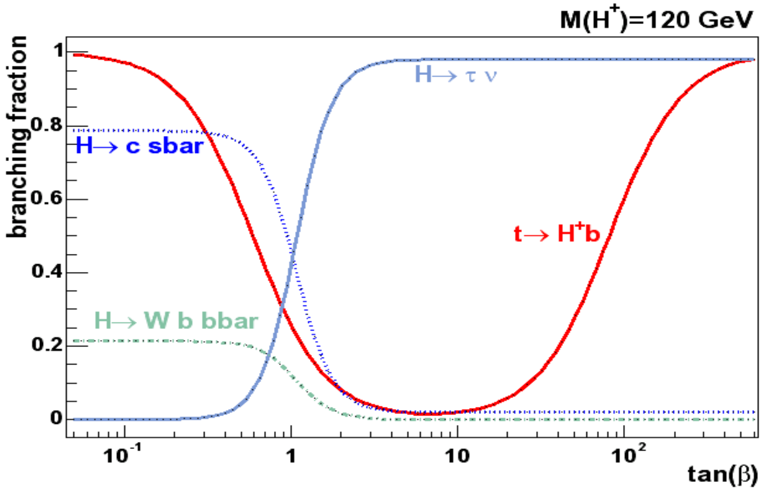
✓the BR(t->H^+b) with full loop corrections.
(Calculated with the help of M. Carena and C. Wagner.)

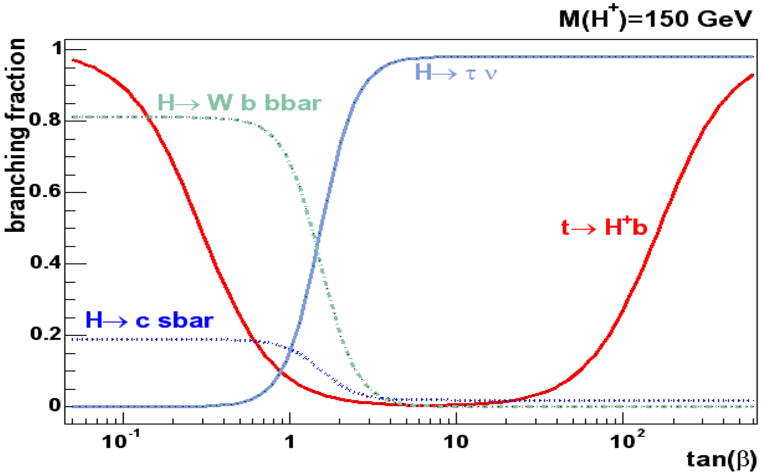
✓the BR($H^+ \rightarrow$xx) taken from HDecay

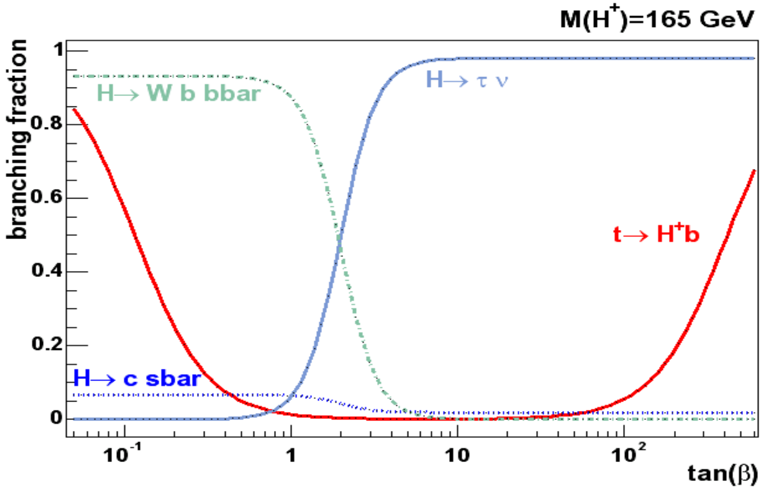
Today : ***I will show tree level results to compare with previous analyzes***

Model Dependent :
Tree level branching fractions in MSSM









Model dependent : SUSY, width corrections

Width-related corrections to eff. Widths grow with phase space and couplings.

Couplings :

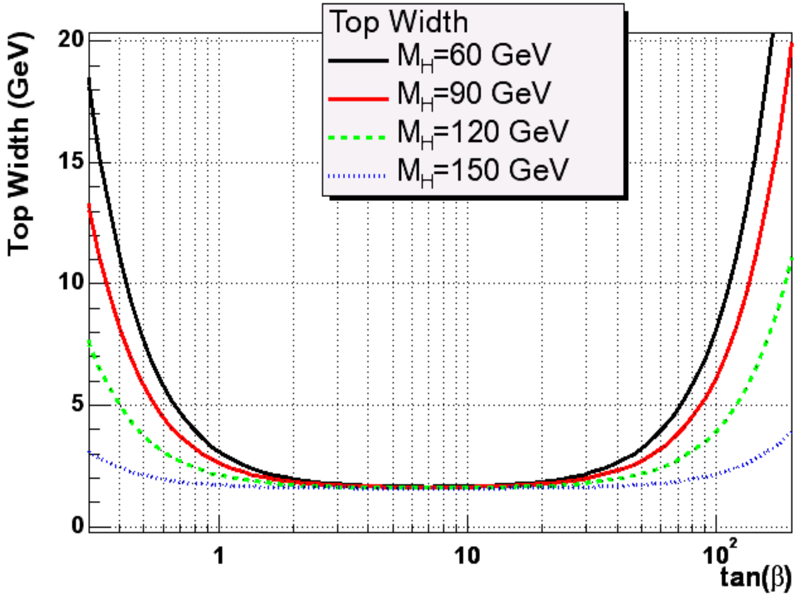
t->Hb coupling get large at high and low tanbeta.

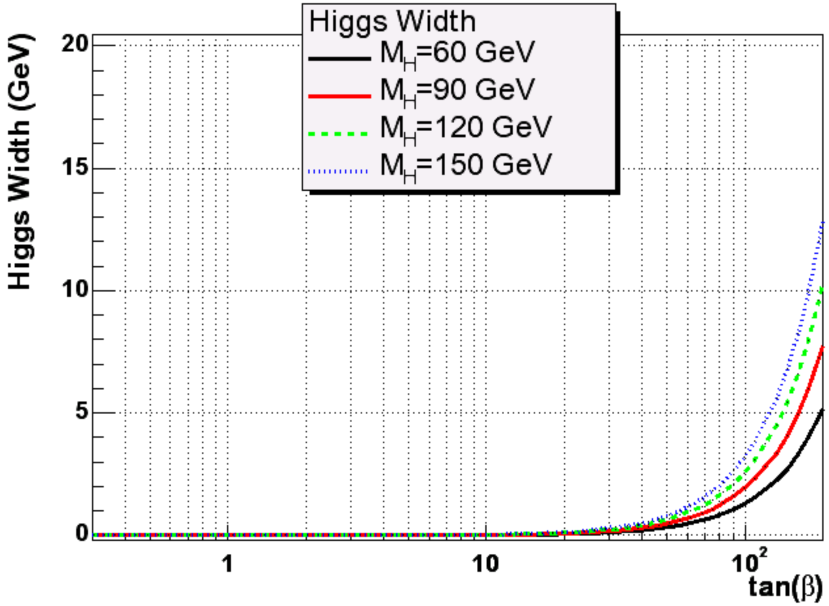
H->τν grows with $\tan^2(\beta)$.

Phase space :

High m_H ; low Γ_{top} high Γ_H

Low m_H ; high Γ_{top} low Γ_H





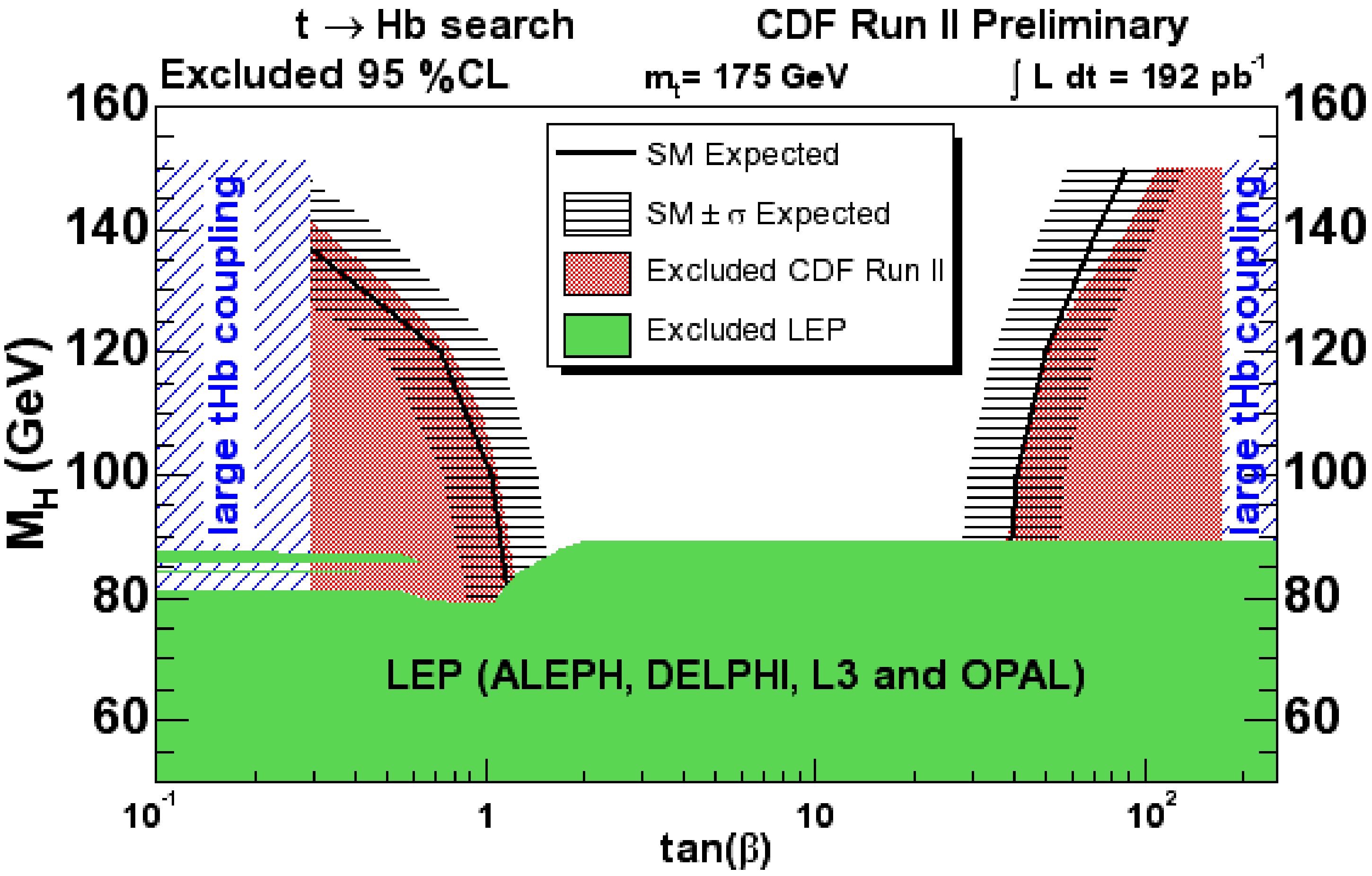
Higgs width correction, high tanbeta region, ***accounted for here.***

Top width correction (convoluted with PDF) ***accounted too***.

Note that it decreases with mHiggs.

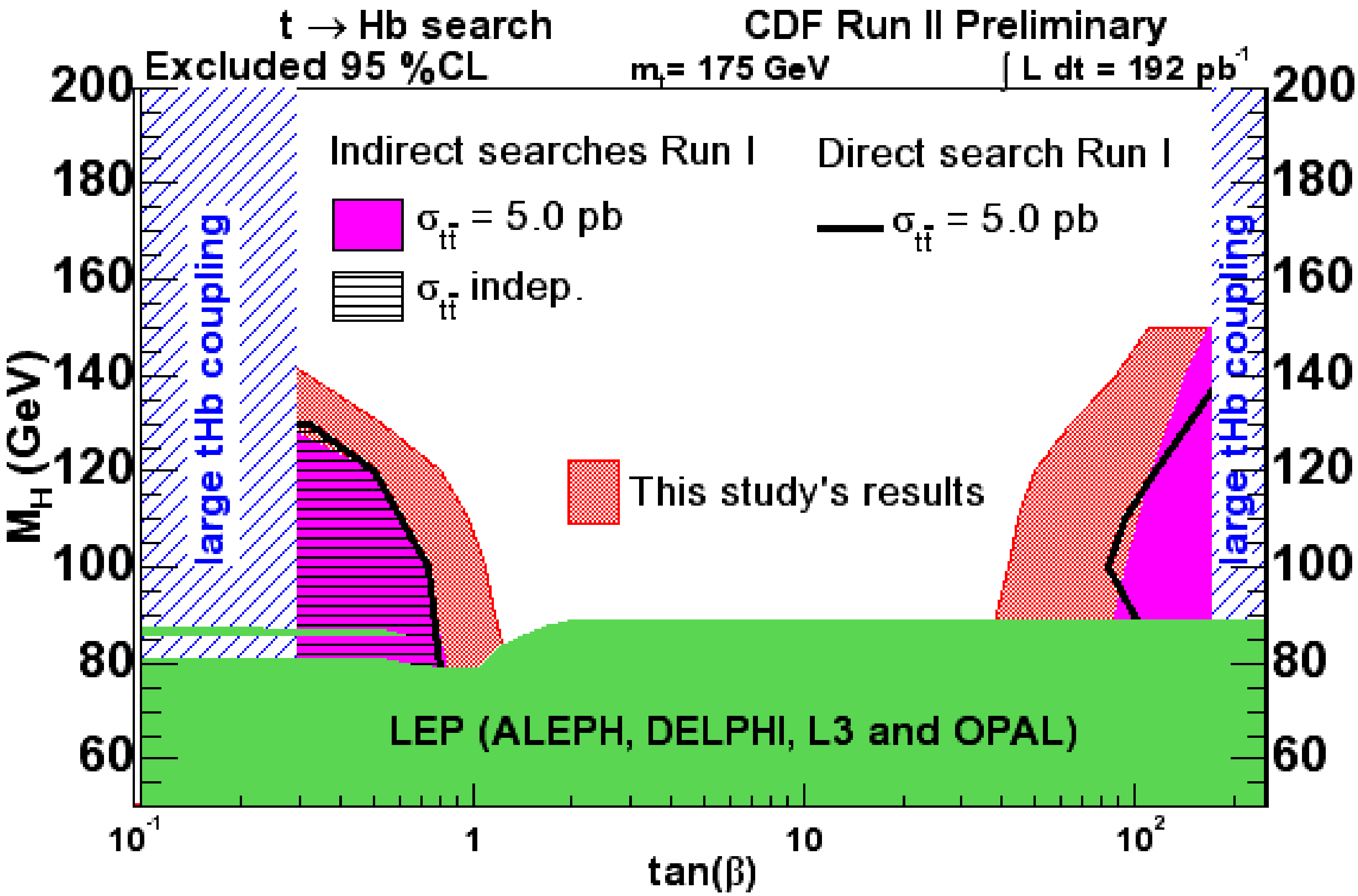
Fairly symmetrical below 15 GeV. Don't expect and don’t see much change in eff.

Tree level MSSM results



Expected and observed limits in good agreement at low tan(β).
High tan(β) region shows a gap consistent with SM.

Tree level MSSM comparison to Run I results



Model Independent

- **Can we get a measurement of BR(t→Hb) regardless of the BR(H→xx) ?**

  Caveat: *Limits may not be as strong as with a specific model.*

- **Parameter set :**

$$\beta = BR(H^+ \to c\bar{s})$$

$$\alpha = BR(t \to H^+ b) \quad \gamma = BR(H^+ \to Wb\bar{b})$$

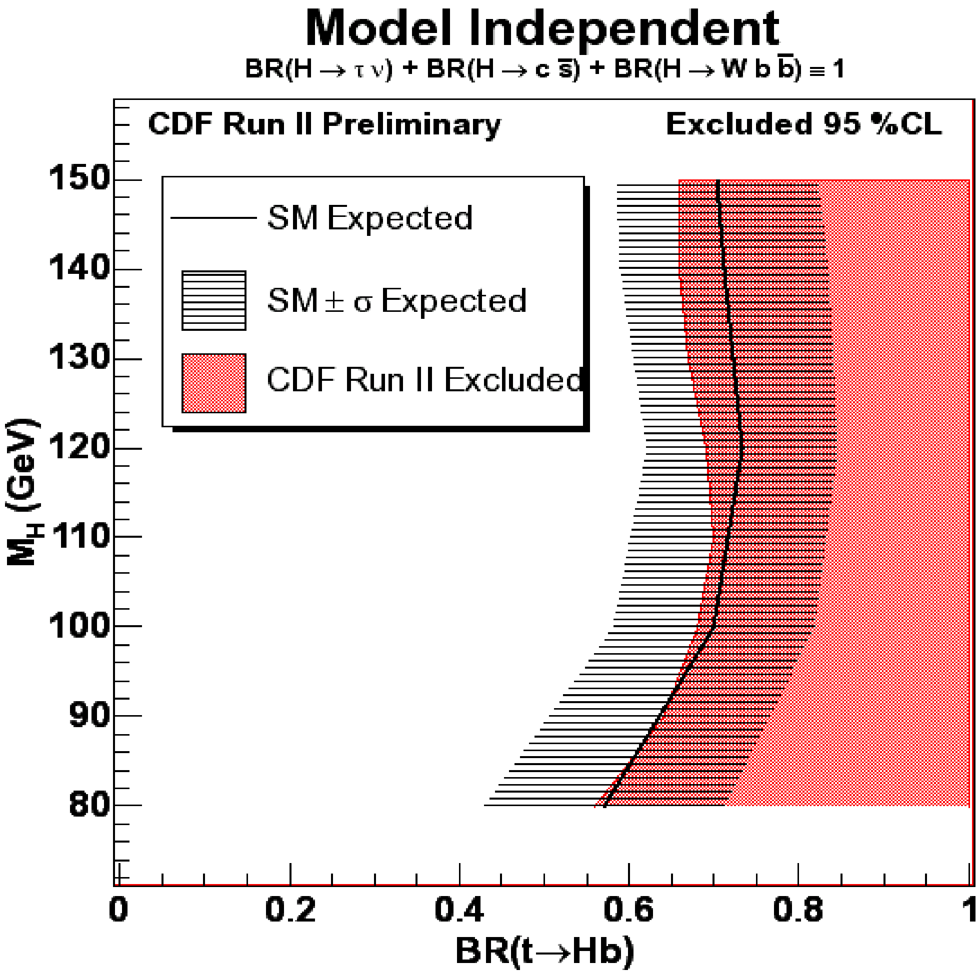
$$\delta \equiv BR(H^+ \to \bar{\tau}\upsilon) \equiv 1 - \beta - \gamma$$

- **Probability of the diff BR's given the obtained number of candidates :**

$$P\left(\alpha, | n_{ll}, n_{lj}, n_{l\tau}\right) = \frac{\int_0^1 d\beta' \int_0^{1-\beta'} d\gamma' \; L\left(n_{ll}, n_{lj}, n_{l\tau} \,|\, \alpha, \beta', \gamma'\right) \, \pi(\alpha)\pi(\beta')\pi(\gamma')}{\iiint L\left(n_{ll}, n_{lj}, n_{l\tau} \,|\, \alpha', \beta', \gamma'\right) \, \pi(\alpha')\pi(\beta'')\pi(\gamma') d\alpha' d\beta' d\gamma'}$$

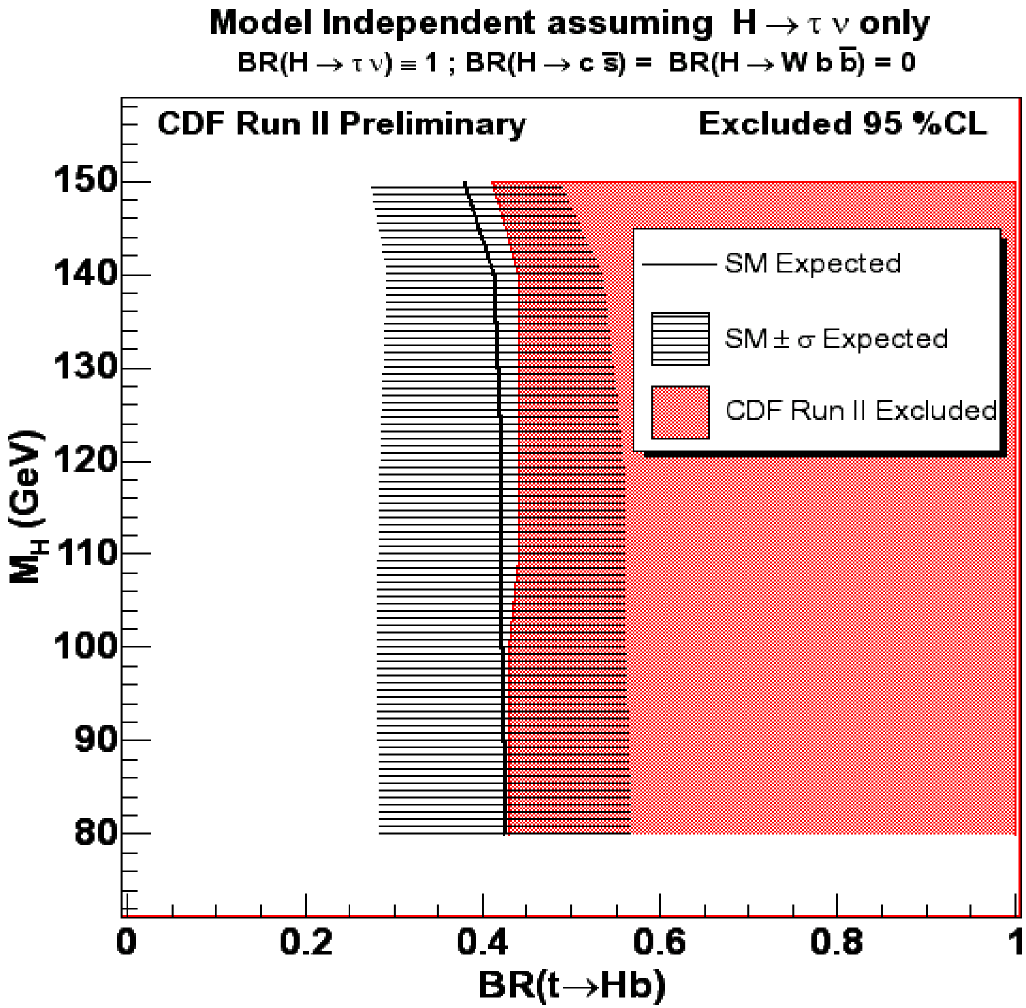
$\pi(\alpha),\pi(\beta),\pi(\gamma)$ are the prior probability densities in the branching ratios. We take them uniform in this model independent study.

Model Independent results



Limit does not depend on the model's loop corrections to the BR's !!

Model Independent results



Limit does not depend on the model's loop corrections to the BR's !!

What about LHC ?

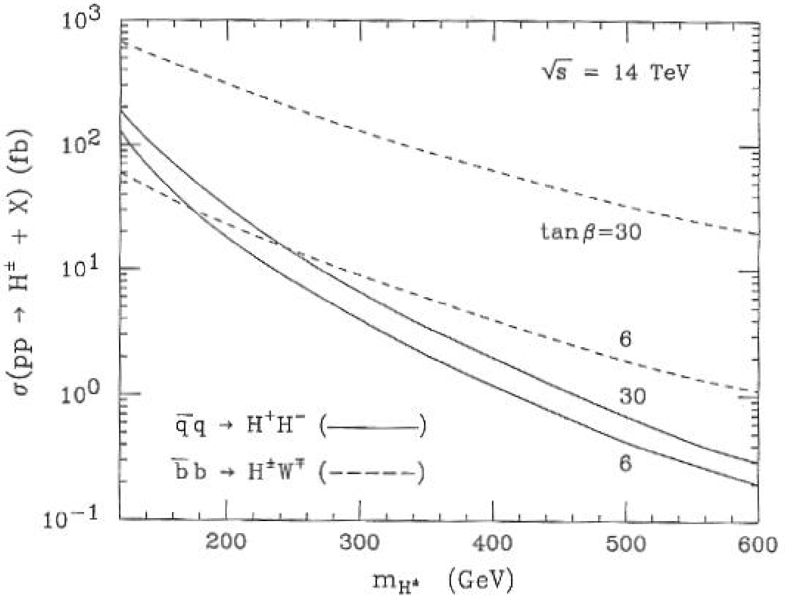
H^+ production at LHC

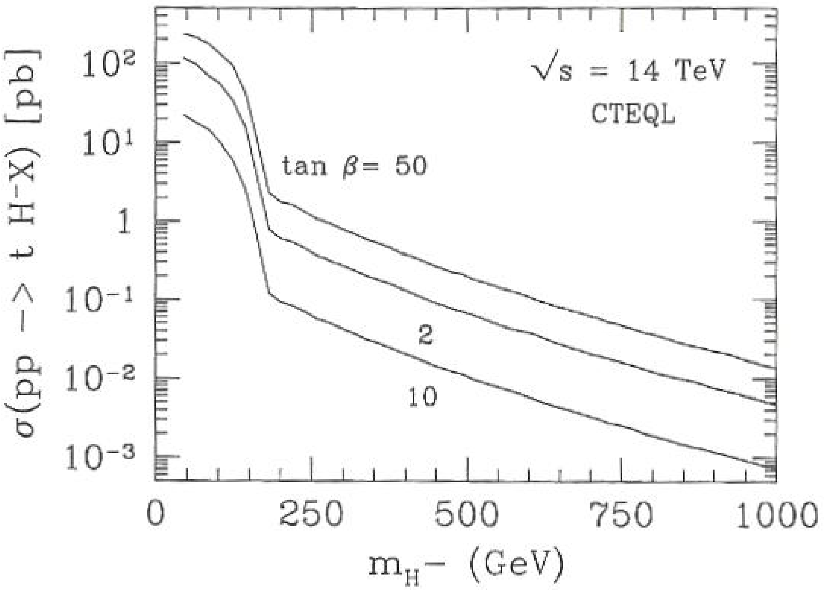
$m_{H+}<m_{Top}-m_b$

Main source : $t\underline{t}$,t→H^+b

Well behind :qq→H^+H^-

bb→H^+W^-





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

Main source :gg,q$\underline{q}$→t$\underline{b}$$H^-$

Well behind :q$\underline{q}$(gg)→H^+H^-

b$\underline{b}$→H^+W-

H^+ stronger signal comes associated with a top quark.

Strongest signal if $m_H<m_{Top}-m_b$

LHC Analyzes

Analyzes at LHC likely to start with :

(See F.Gianotti and M.Mangano.October 13 2004, Napoli)

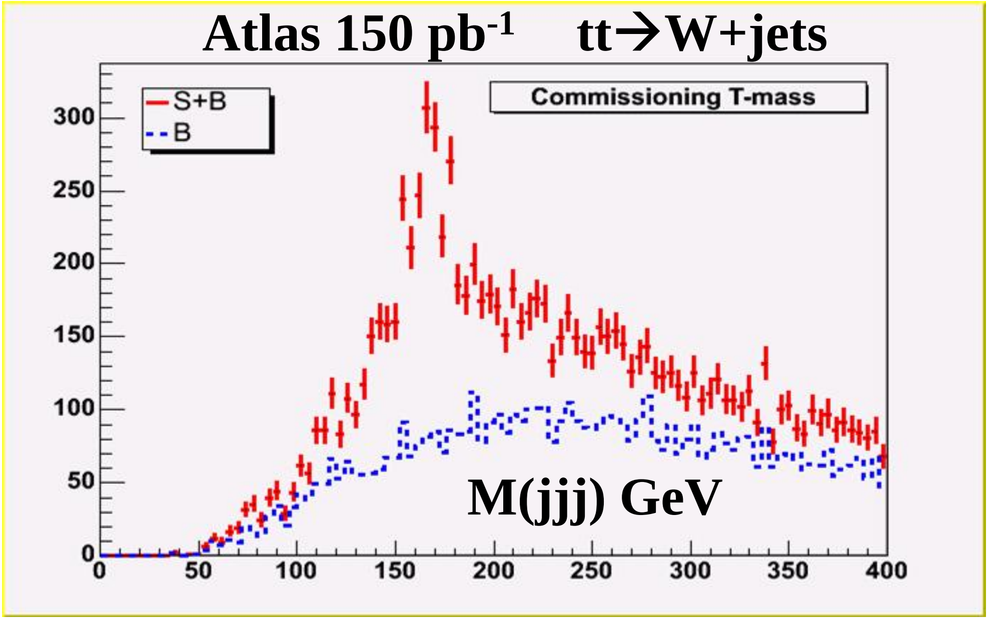
1. W cross section
2. DY cross section
3. Top pair cross section

↔

- **Test of QCD to NNLO : pot. accuracy ~2%**
- **Luminosity monitor**
- **Probe of PDF’s**

- Use lepton+jets channels
- isolated e,μ. P_t>20 GeV
- exactly four jets
- no kinematic fit
- no b-tagging
- Cross section to ~20%

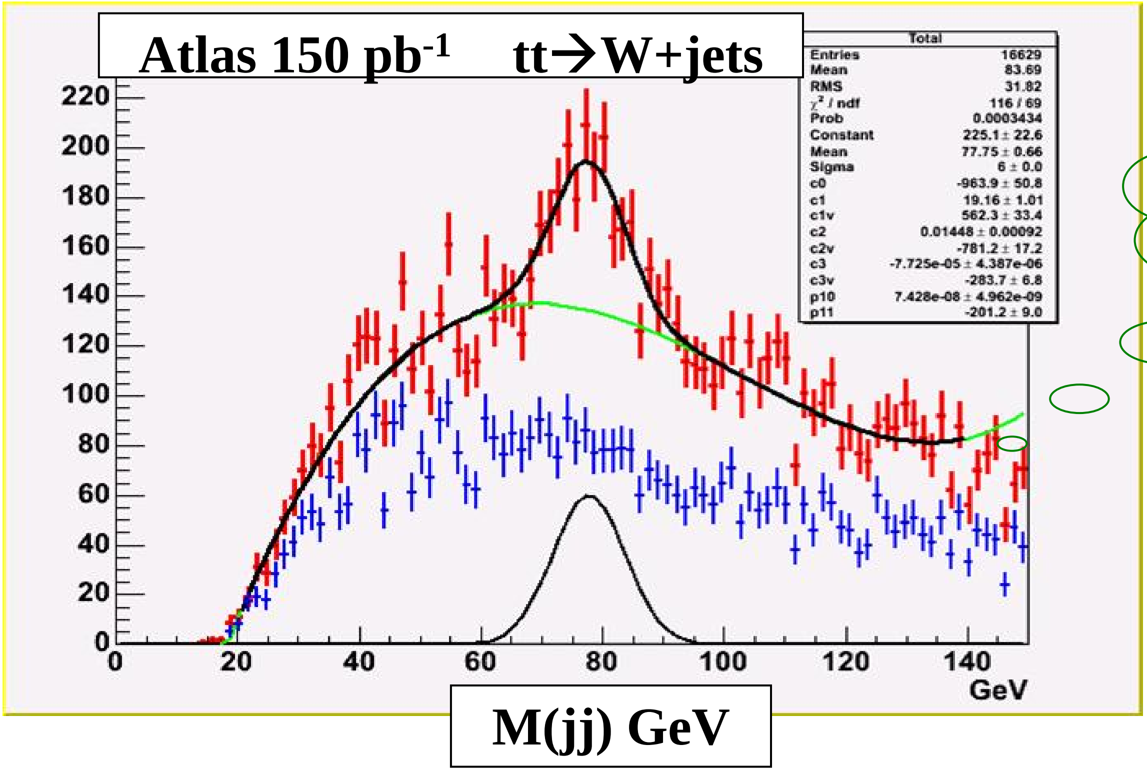
Atlas 150 pb^{-1} tt→W+jets



Top pair production cross section analyzes at early stages with very simple selection cuts.

LHC $t\underline{t}$ production

- From Tevatron we know there isn't much difference between $t\underline{t}$ XS's.
  - →Either : H^+ is not between 80 GeV and m_{Top}, the top rarely decays to H^+, or the H^+ decays are significantly shared between decay modes. Expect the same at LHC.



$H^+ \to \tau\nu$ wouldn't show here

With 150 pb^{-1} direct searches like M(jj) may not be enough to "see" the Higgs mass bump.

LHC t$\underline{t}$ production

$\sigma(pp \rightarrow tt)_{theo}$ = 833±83 (assume 10% error) WOW! @10 fb^{-1}/year

In Atlas specifically (hep-ph/0403021)

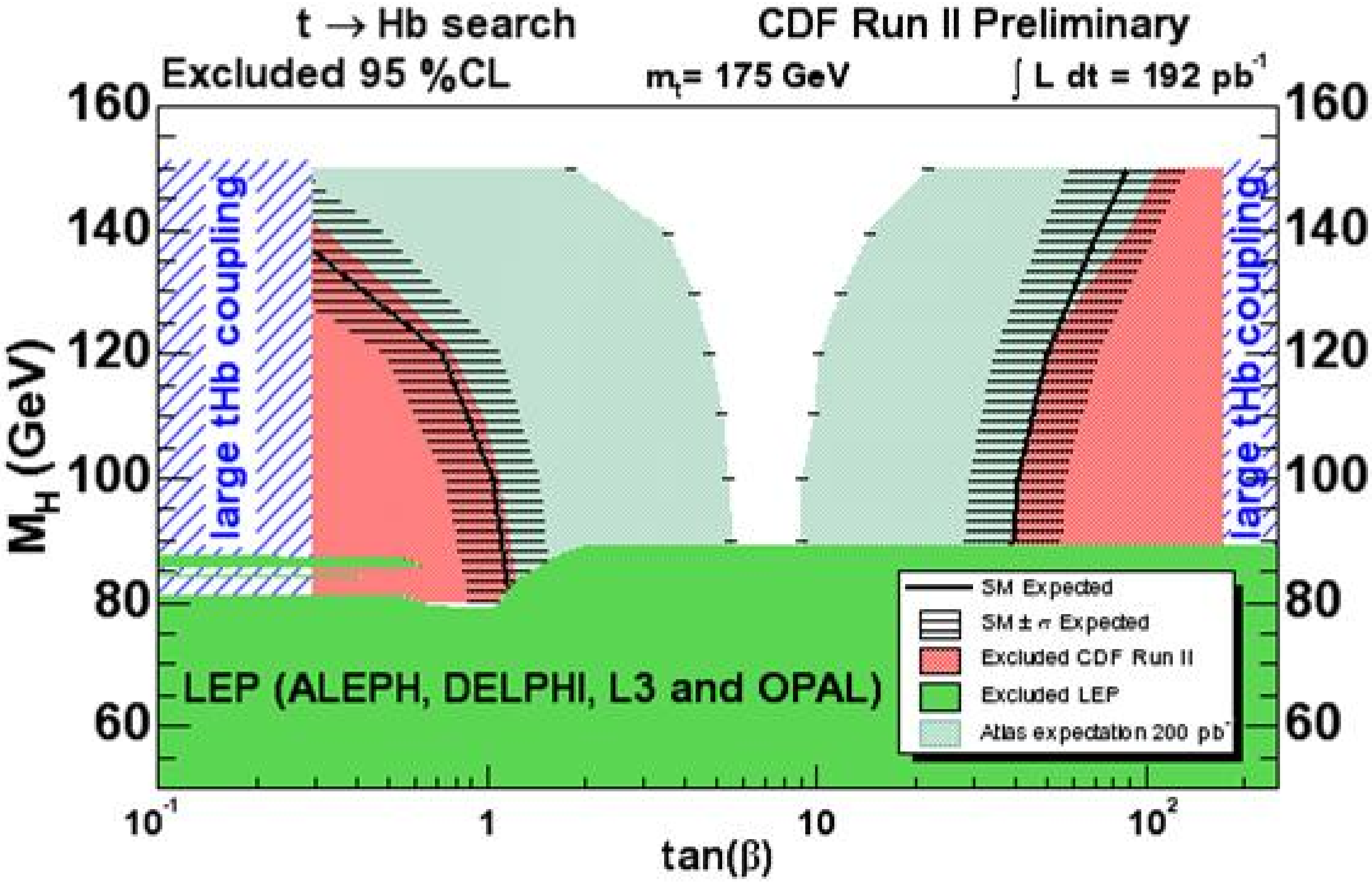
Channel (L≡e,μ)	**S/B**	**#t$\underline{t}$ expected in 200 pb^{-1}**	**#Background in 200 pb^{-1}**
Dilepton	10	1600	160
L+Jets (1^+ Tag)	28	5280	185
L+Jets (2^+ Tag)	78 WOW-WOW!	1740	22
L+τ_{had}	10	290	29

Time needed to understand tracker & b-tags

Very large signal to background ratios

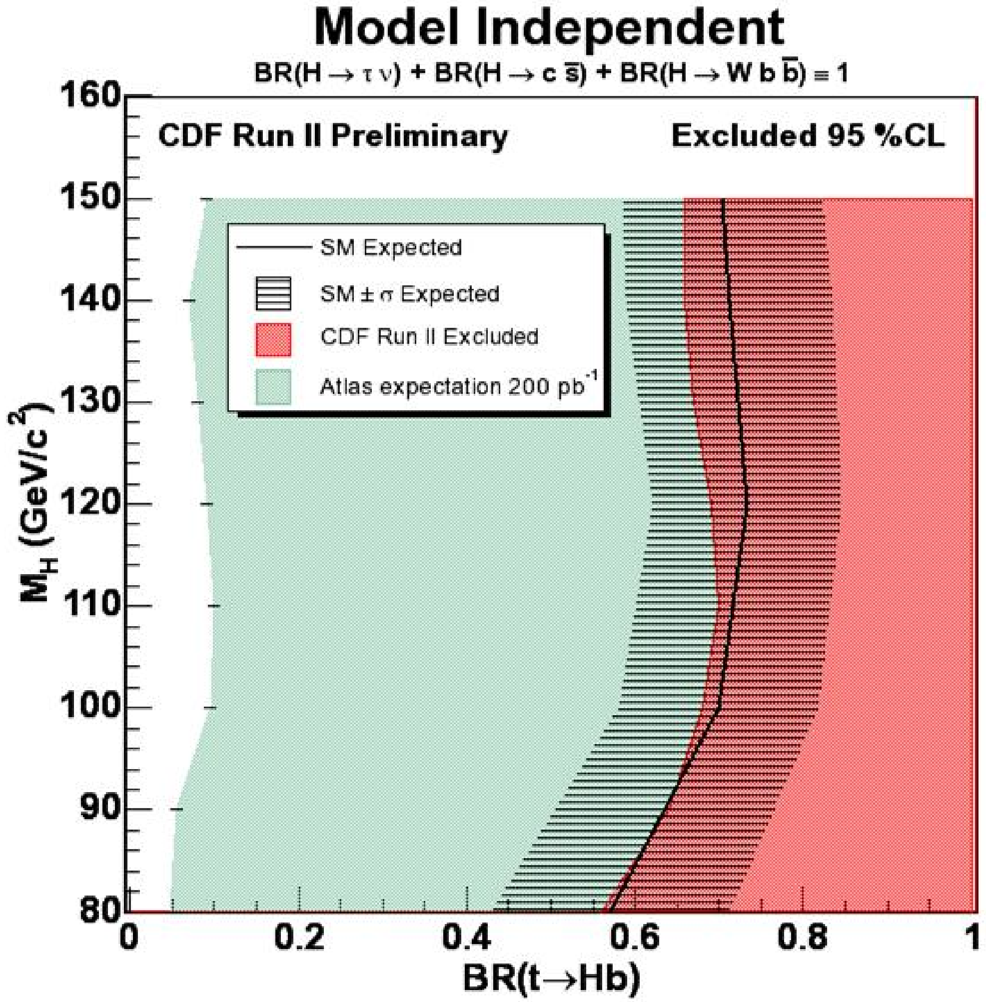
Use these numbers to calculate <u>raw</u> estimates for the limits on Charged Higgs.

LHC Limits on Charged Higgs



Large exclusion region promptly obtained
Note the small uncertainties

LHC Limits on Charged Higgs



Large exclusion region promptly obtained

Conclusions

CDF search for charged Higgs :

✓Assuming leading order calculations we set limits in the $(m_H,\tan(\beta))$ plane.

-Our limits are competitive, surpassing limits set by previous studies under the same assumptions.

✓We are currently finishing the analysis with full loop corrections, (QCD, SUSY-QCD and SUSY-EW) using the formulae that represent the best of the present knowledge.

✓We've set limits to BR(t➔Hb) in a model independent fashion.

✓We have already improved the method, extending the reach of exclusion limits.

✓Get a second "bless" and Paper will follow.

LHC :

✓Charged Higgs production mostly associated with a top.

✓This type of analysis can be done in the early days of data-taking.

✓Large exclusion limits can be obtained in a week of nominal luminosity operation.

✓The diversity of channels the Higgs can decay to makes this analysis more compelling in the beginning. Use it to decide where to look ?

✓With larger quantities of data a straightforward combination of direct analysis exclusion limits may provide stronger limits.

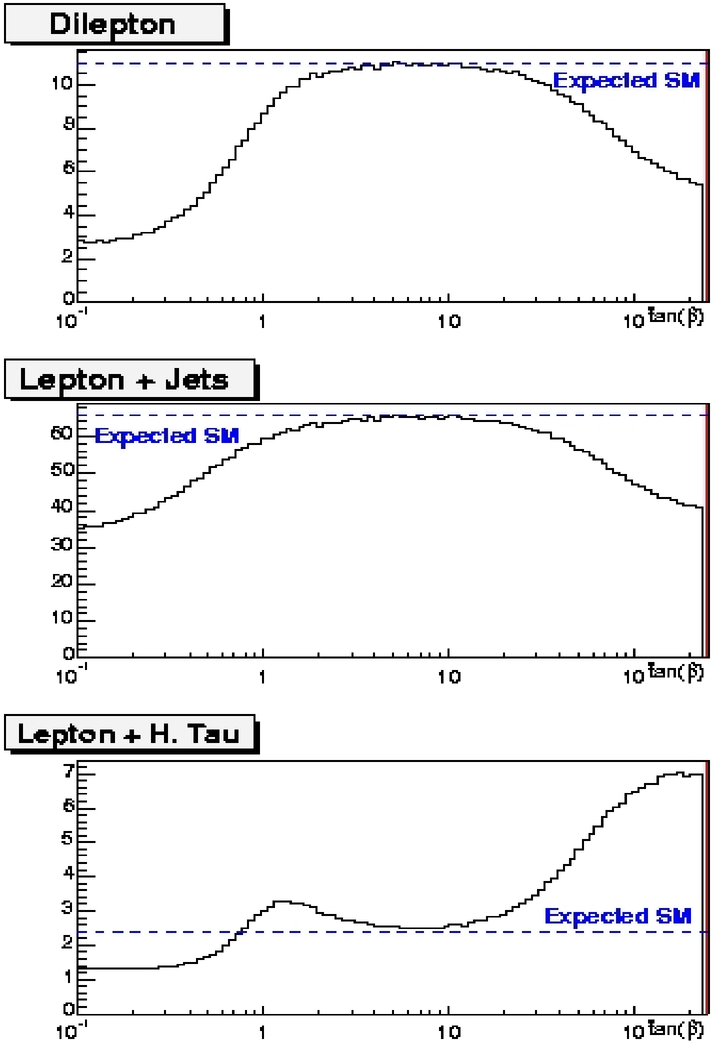
Backup slides

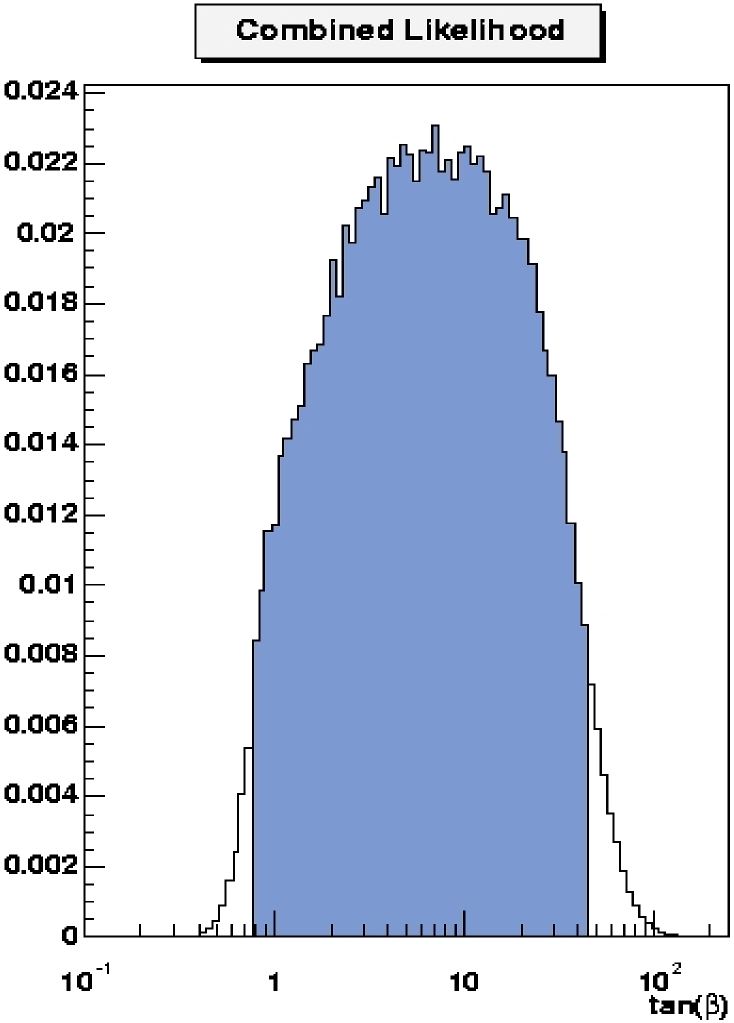
Implicit assumptions on the method

There are four important assumptions implicitly made in the last equation :

1. The tt production cross section is not affected by the inclusion of the MSSM.
   Needs further checking. We know it is affected by Γ_{top}
2. Idem for the background in each XS measurements.
   Can be checked for a specific MSSM parameter set.
3. Other H^+ decays, besides the three mentioned, have negligible branching ratios.
   True for large fraction of MSSM parameter space.
4. The efficiencies $\varepsilon_{i,j}$ do not depend in MSSM parameters.
   This can be shown by analyzing the MSSM coupling constants.

Model dependent : SUSY, expected limits





Sensitivity

Model Independent : P(t->Hb)

- Assuming the theoretical $\sigma^{\tau\tau}=(6.7\pm0.7)\ \text{pb}^{-1}$ we'd expect :
  - 11 events in the Dilepton channel .
  - 66 events in the L+Jets channel.
  - 2 events in the L+Hadronic Tau channel.

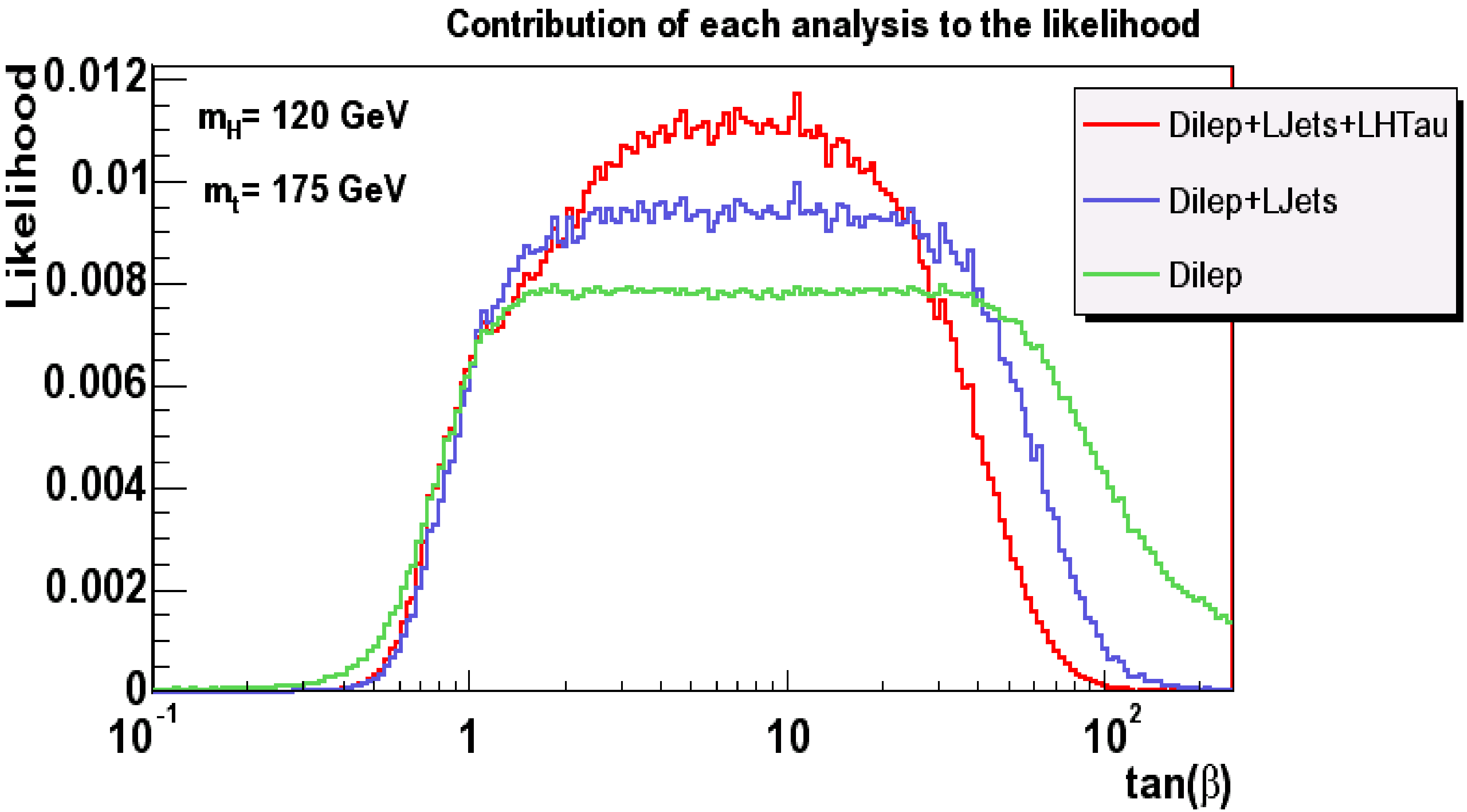
- Calculate L(11,66,2|α,β,γ) for all α,β,γ (Eq. slide 9)

- Calculate the P(α|11,66,2) by integrating Eq. in slide 11

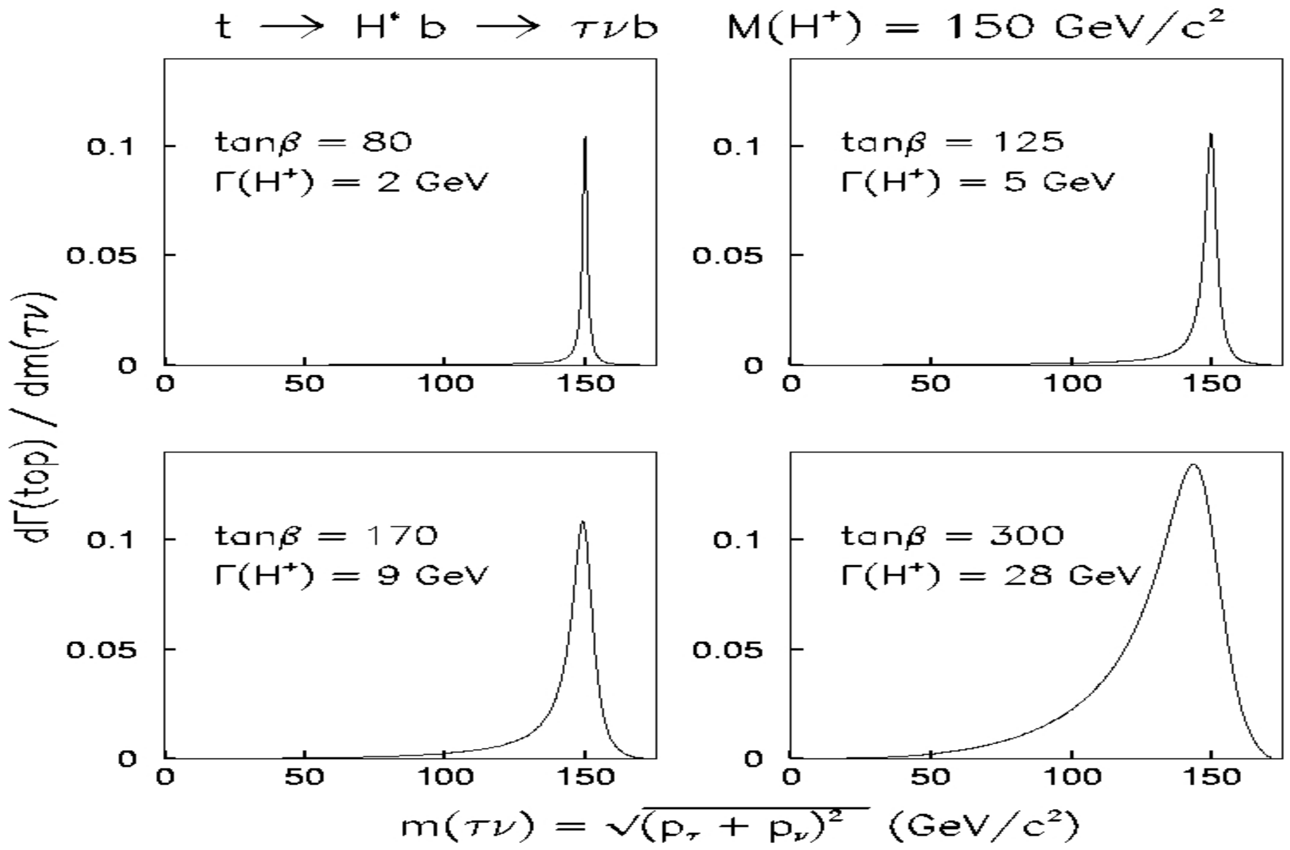
$$P\left(\alpha,|\,n_{ll},n_{lj},n_{l\tau}\right)=\frac{\int_0^1 d\beta' \int_0^{1-\beta'} d\gamma'\ L\left(n_{ll},n_{lj},n_{l\tau}\,|\,\alpha,\beta',\gamma'\right)\,\pi(\alpha)\pi(\beta')\pi(\gamma')}{\iiint L\left(n_{ll},n_{lj},n_{l\tau}\,|\,\alpha',\beta',\gamma'\right)\,\pi(\alpha')\pi(\beta'')\pi(\gamma')\,d\alpha' d\beta' d\gamma'}$$

- Get the 95 % CL on P(α|11,66,2)

Likelihood, analyses contributions



Model dependent : SUSY H+ width corrections



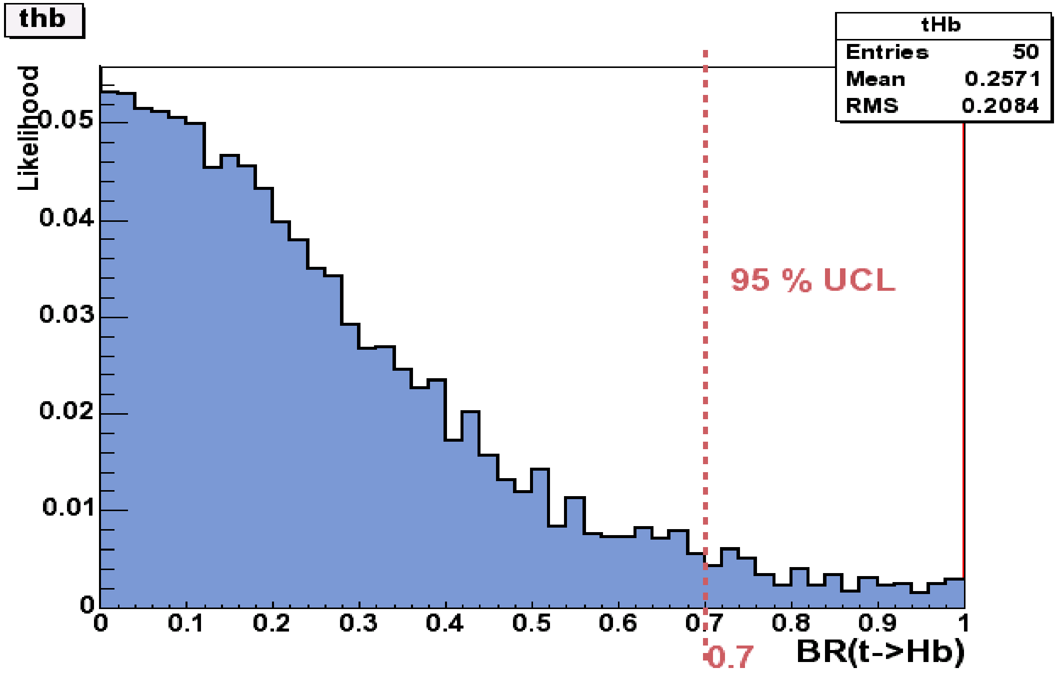
The final efficiency is calculated by :

$$\varepsilon(mH_0) = \int_0^\infty \varepsilon(mH')\, WF(mH', mH_0)\, dm H'$$

provided the Width Function is normalized

Model Independent : P(t->Hb) sensitivity

- For M_H = 120 GeV, assuming SM production only we'd expect 11,66 and 2 candidates in the "***Dilep***", "***L+Jets***" and "***L+τ_{Had}***" XS'
- We obtain for P(α|11,66,2):



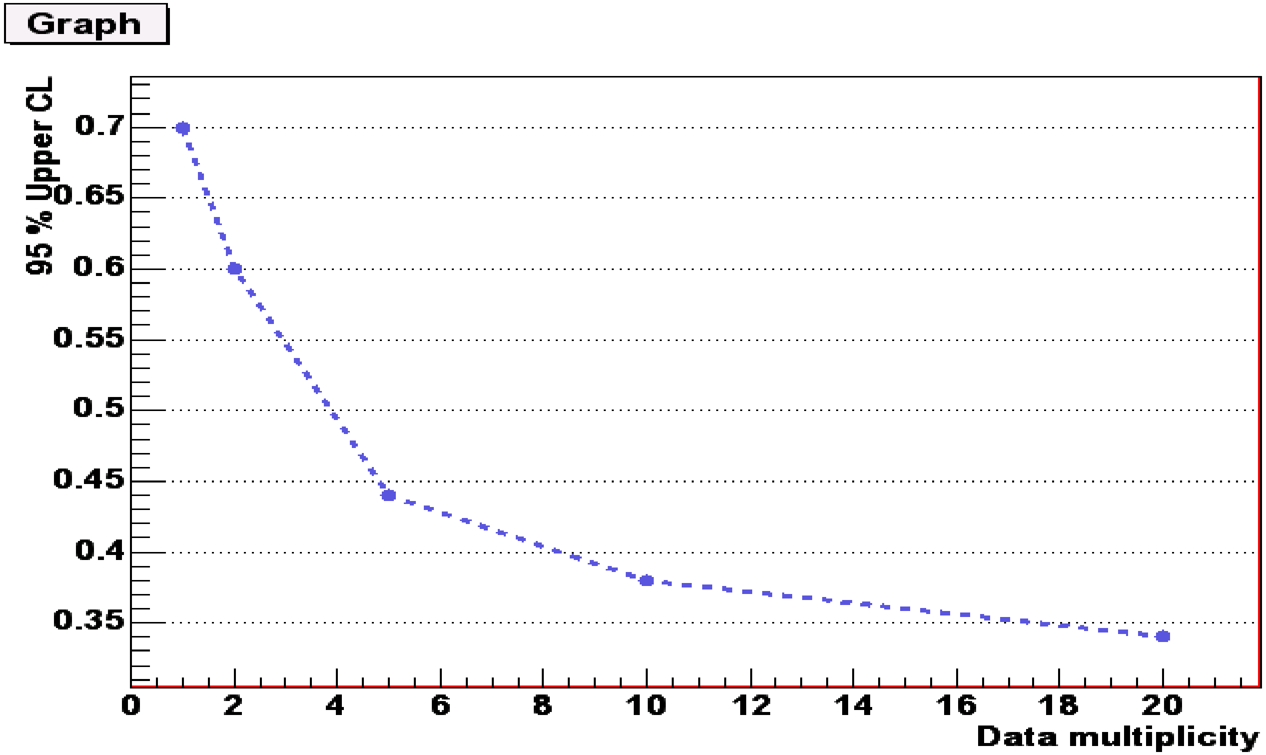
From that **BR(t→Hb)**<0.70 @ 95% CL

Weak limit, but consider the HUGE variable phase space we have.

- ***With 5 times the current luminosity we can set a limit below 0.44 at 95%CL***

Model Independent : P(t->Hb) sensitivity

Find P(α) for mH = 120 GeV and different data multiplicities:

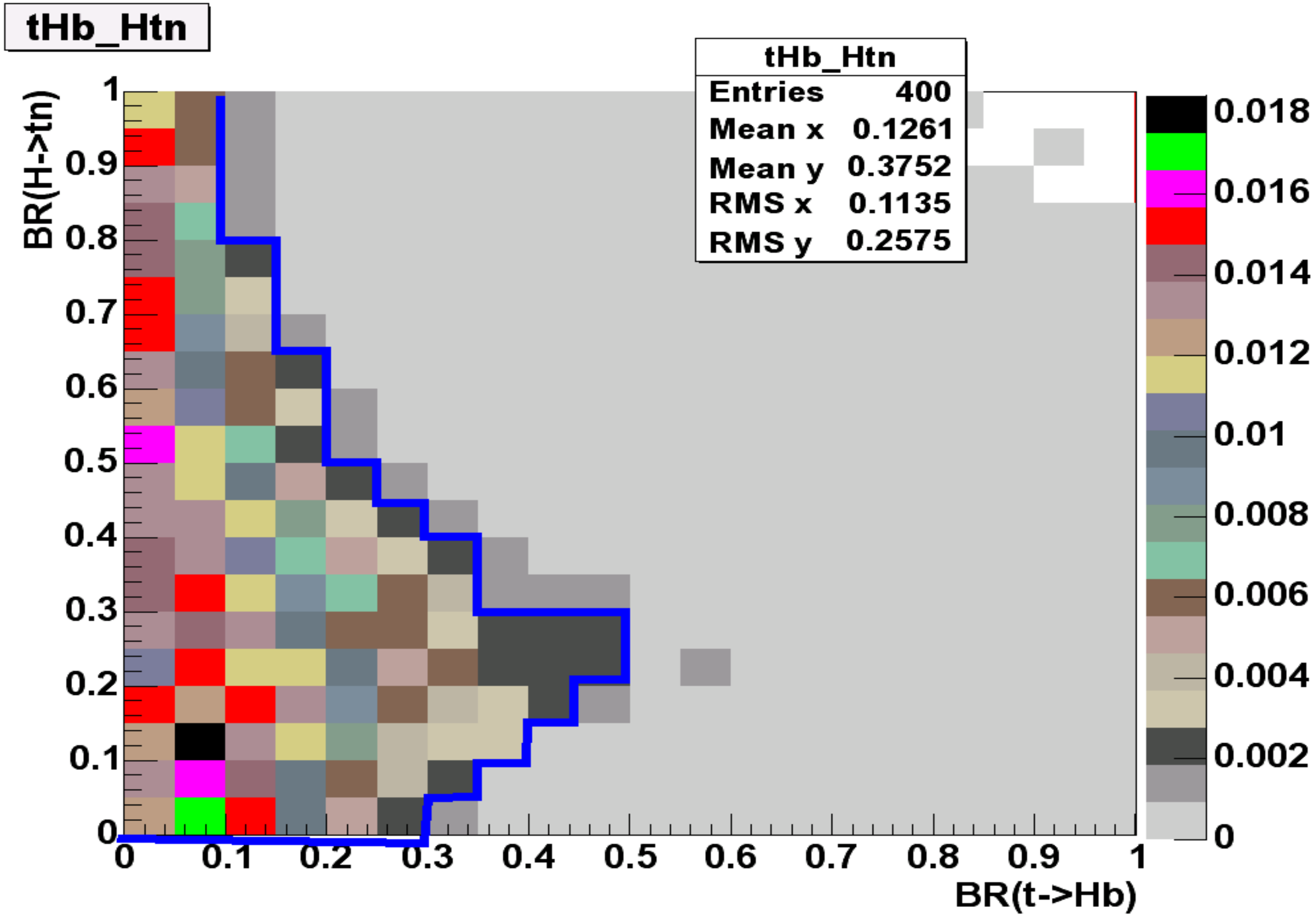


The 95%UCL evolution with data amount.

•Limits get stricter, note that with 5 times the current luminosity we should be able to put a limit below 0.44 at 95%CL. No assumptions about H^+ decays used.

Model Independent : BR(t->Hb) Vs BR(H->tau nu)

Likelihood in the BR(t->Hb), BR(H->Tau nu) plane. mHiggs = 120 GeV



Likelihood in bayesian statistics

- In general we use the same calculation in both models, only difference is the set of parameters ρ.
- Probability of parameters given the obtained number of candidates :

$$P\left(\rho \mid n_{ll}, n_{lj}, n_{l\tau}\right) = \frac{L\left(n_{ll}, n_{lj}, n_{l\tau} \mid \rho\right)\ \pi(\rho)}{\int_P L\left(n_{ll}, n_{lj}, n_{l\tau} \mid \rho'\right)\ \pi(\rho')d\rho'}$$

Where L is the likelihood and π(ρ) is the prior probability density in the parameters. In general we will take flat priors.

- L can be written as :

$$L\left(n_{ll}, n_{lj}, n_{l\tau} \mid \rho\right) =$$

$$= \frac{1}{N} \int_0^\infty \int_0^\infty \cdots \int_0^\infty \prod_{XS=ll}^{l\tau} \left\{ \frac{\mu_{XS}'^{\,n_{XS}} e^{-\mu'_{XS}}}{n_{XS}!} G\left(\varepsilon'_{XS}, \varepsilon_{XS}\right) G\left(b'_{XS}, b_{XS}\right) d\varepsilon'_{XS}\, db'_{XS} \right\}$$

and the μ's are :

$$\mu_{XS}^{tt} = b_{XS} + L\sigma_{tt}^{prod} \varepsilon_{XS}(\rho)$$

Likelihood evaluation

- Evaluate the likelihood using MC integration.

$$L\left(n_{ll}, n_{lj}, n_{l\tau} \mid \rho\right) \cong \frac{1}{N}\sum_{n=1}^{N} \frac{\mu_{ll}'^{\,n_{ll}} e^{-\mu_{ll}'}}{n_{ll}!} \times \frac{\mu_{lj}'^{\,n_{lj}} e^{-\mu_{lj}'}}{n_{lj}!} \times \frac{\mu_{l\tau}'^{\,n_{l\tau}} e^{-\mu_{l\tau}'}}{n_{l\tau}!}$$

- In each element of the sum the independent numbers are allow to vary within its errors. The errors in the correlated numbers are then calculated. With all numbers at hand the three different μ's are calculated :

$$\mu_{XS}^{tt} = b_{XS} + L\,\sigma_{tt}^{prod}\,\varepsilon_{XS}(\rho) \quad \mathrm{XS} = \{\mathrm{Dilep},\ \mathrm{LJets},\ \mathrm{LTauH}\}$$

- The product of the Poisson's is computed and added to average. This procedure take naturally into account all correlations. See CDF note 7151 for details.