Higgs Discovery Prospects at the TeVatron Run II

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I. Higgs Phenomenology at the TeVatron

II. Tools for Higgs Search

III. Run II expectations for main Channels

Conclusion

Higgs Phenomenology at the TeVatron

Theoretical Constraints on the SM Higgs

Unitarity

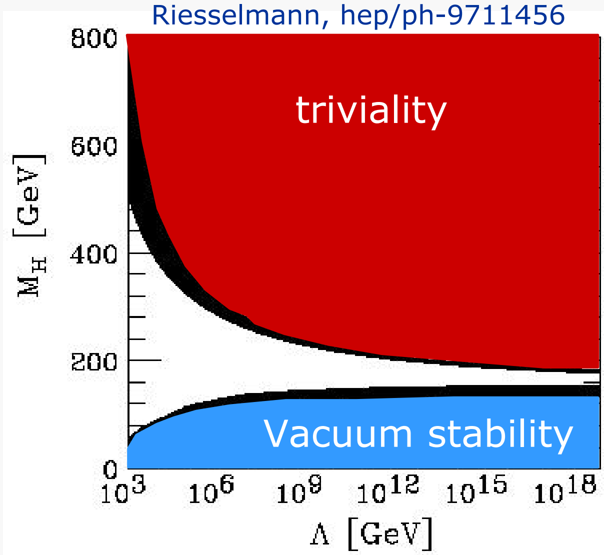
Boson scattering

$\sigma(V_L V_L \to V_L V_L)$ diverge

$\to$ Compensation via Higgs

Unitarity implies:

$m_H \leq (2\sqrt{2}\pi / G_F)^{1/2} \leq 700$ GeV/c^2



Triviality

RGE equation $\lambda(\Lambda)$:

$\lambda > 1$ for $\Lambda \sim \Lambda_L$(landau)

$\lambda < 1$ valid up to $\lambda(\Lambda_L) \to \infty$

$m_H < 8\pi^2 v^2 / 3 \log(\Lambda^2/v^2)$

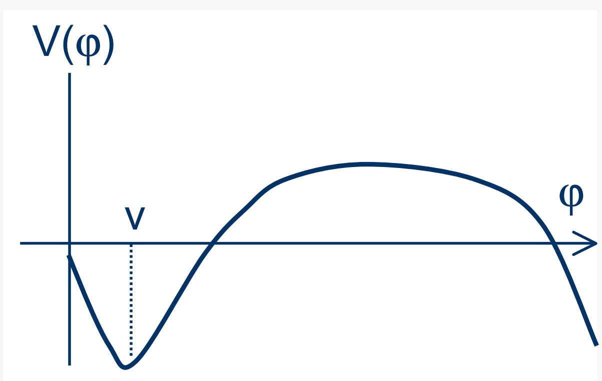
Vacuum Stability

$V(\varphi)$ has an abolute minimum

$\partial V(\varphi) / \partial\varphi > 0$

$\Leftrightarrow \lambda(\Lambda) > 0$

$\Leftrightarrow m_H(\Lambda) > M_{min}$



$m_H > 52$ GeV/c^2 @ Λ=1TeV

Experimental constraints on the SM Higgs

Direct Search

– LEP Channels:

$e^+e^- \to HZ$

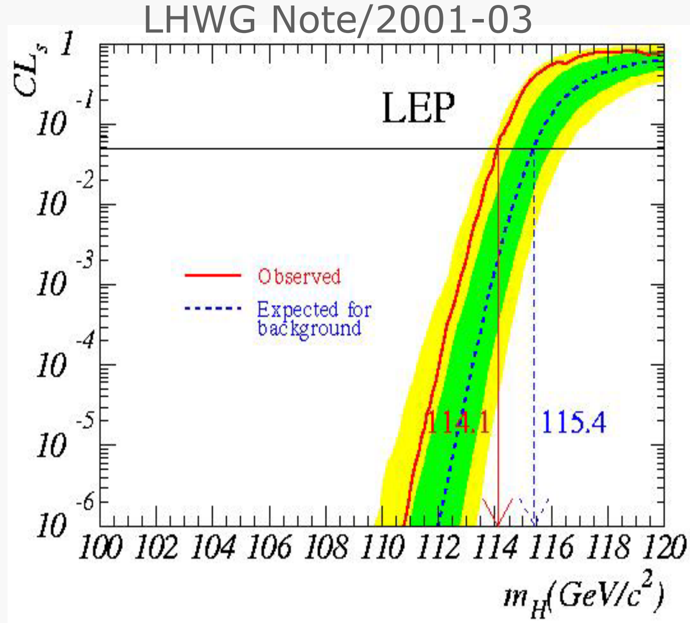
$ZH \to b\bar{b}\, l\bar{l}$

$ZH \to b\bar{b}\, q\bar{q}$

Exclusion @ 95% CL: $m_H > 114.1$ GeV/c²

Higgs Candidates $m_H \approx 115$ GeV/c²

LHWG Note/2001-03



Indirect Search

– Precision Measurements

m_Z , m_W , m_t

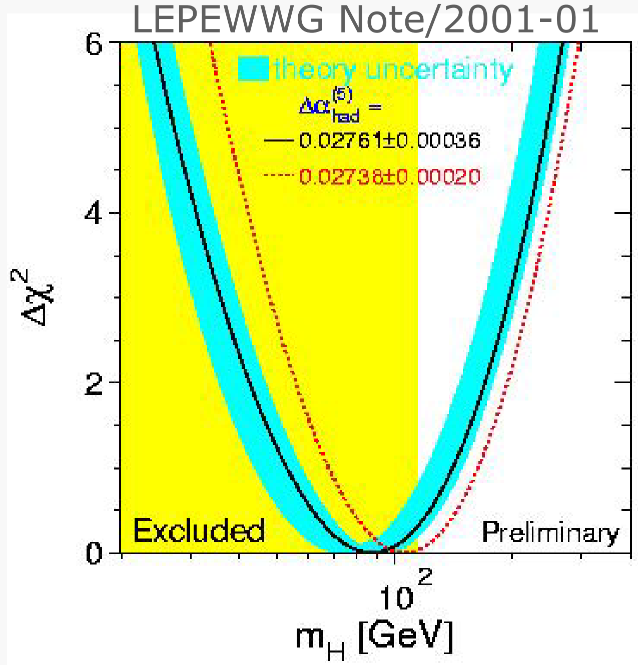
$\sin^2\theta_W$, α_{EM}

– Prediction within SM:

m_H , χ^2

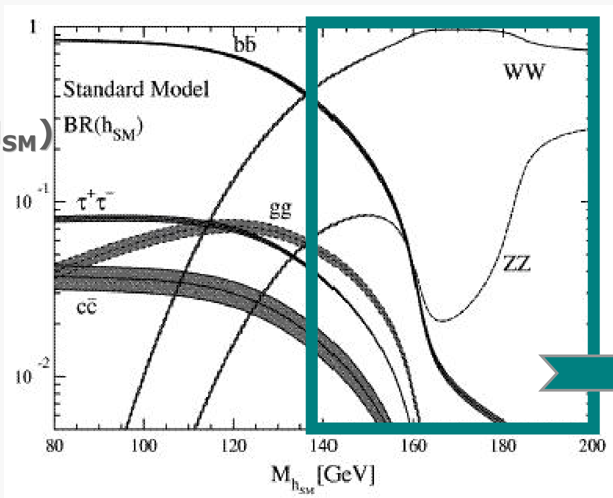
Light Higgs Favored $m_H < 300$ GeV/c²

LEPEWWG Note/2001-01



SM Higgs Production at the TeVatron

Decay Modes



m_H<135 GeV
- $H\to bb$ ~ 90 - 45%
- $H\to\tau^+\tau^-$ ~ 8%
- $H\to gg$ ~ 3 - 8%

m_h>135 GeV
- $H\to WW^*$
  - $\to l^+l^-\nu\nu$ (~4.5%)
  - $\to l\nu qq'$ (l = e,μ)

Production Modes

$p\bar{p}$ ($\to$ gg) $\to H_{SM}$

~ 1000 evts / fb^{-1}

- $p\bar{p}\to b\bar{b},\tau\tau$ <135GeV
- $p\bar{p}\to WW^*$ >135GeV

$p\bar{p}$ ($\to q\bar{q}'\to V^*$) $\to VH_{SM}$

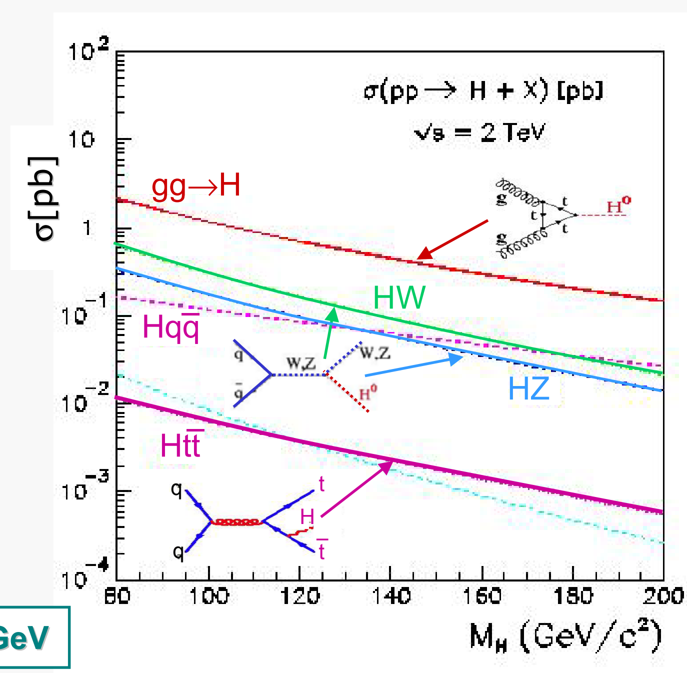
~ 200 evts / fb^{-1}

- $p\bar{p}\to V\ b\bar{b}$ <135GeV
- $p\bar{p}\to V\ WW^*$ >135GeV

$p\bar{p}\to t\bar{t}H_{SM}$

~ 2-5 evts / fb^{-1}

- $p\bar{p}\to WbWb\ b\bar{b}$ <135GeV
- $p\bar{p}\to WW^*WW\ b\bar{b}$ >135GeV



Theoretical Constraints on MSSM Higgses

Tree Level

2 main free parameters:

- $\tan\beta = v_u/v_d$
- m_A (or m_H , m_h)

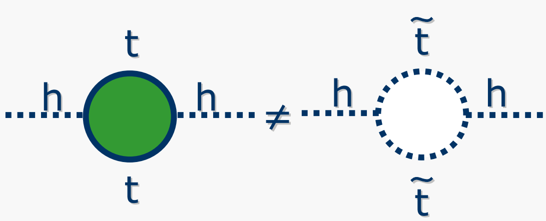
$$m_{H\pm}^2 = m_W^2 + m_A^2$$

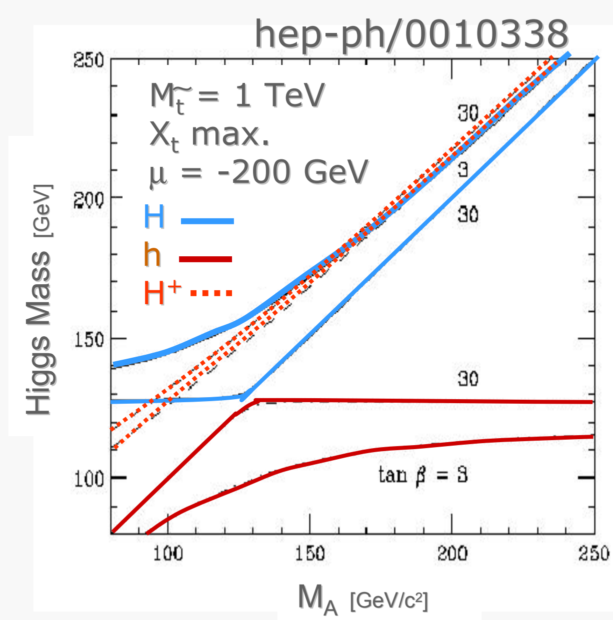
$$m_{H,h}^2 = \tfrac{1}{2}\left(m_A^2 + m_Z^2 \pm \sqrt{(m_A^2+m_Z^2) - 4m_Z^2 m_A^2 \cos^2 2\beta}\right)$$

Higher Orders

\+ 3 parameters:

- $M_{\tilde{t}}$ = stop Mass
- $X_{\tilde{t}}$ = stop Mixing
- μ = Higgs Mass





SUSY is broken: $M_{\tilde{t}} \neq m_t$

$$m_h^2 \leq m_Z^2 + \frac{3g^2 m_t^4}{8\pi^2 m_W^2}\left[\ln\left(\frac{M_{\tilde{t}}^2}{m_t^2}\right) + X_t^2\left(1 - \frac{X_t^2}{12}\right)\right]$$

0 if $M_{\tilde{t}} = m_t$

Increases with X_t

Experimental Constraints on neutral MSSM Higgses

Direct Search

LEP Channels

- $e^-e^+ \to Zh$
- $e^-e^+ \to hA$

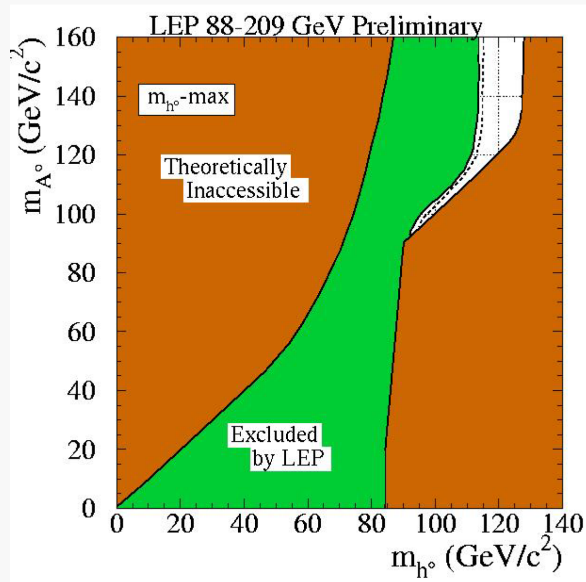
Luminosity L = 870 pb^{-1}

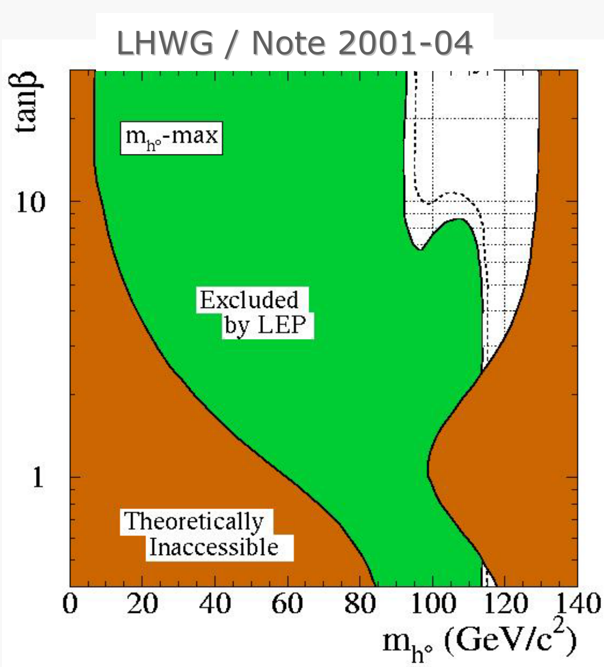
Energy $\sqrt{s}$ = 200-209 GeV

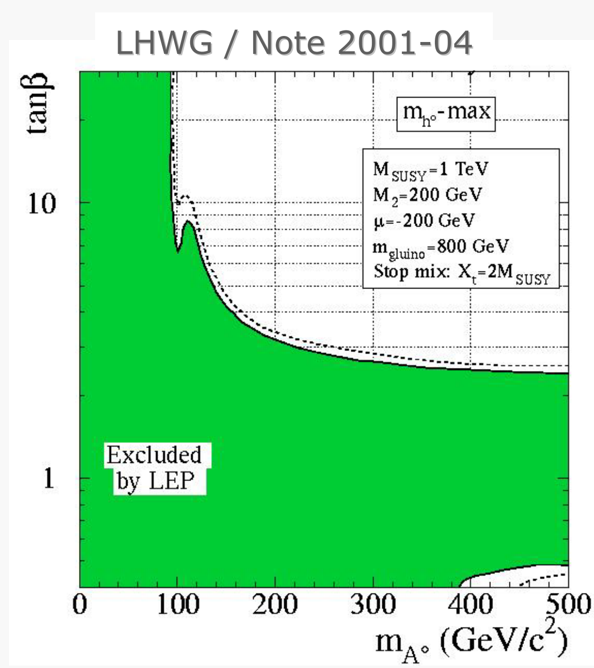
Scenario :

Maximal Mixing $(\tilde{t}_1,\tilde{t}_2)$

$\to$ most conservative







$m_h \geq 90.1$ GeV/c^2

$m_A \geq 91.0$ GeV/c^2 @ 95% CL

Phenomenology of h/H/A at the TeVatron (tanβ=6)

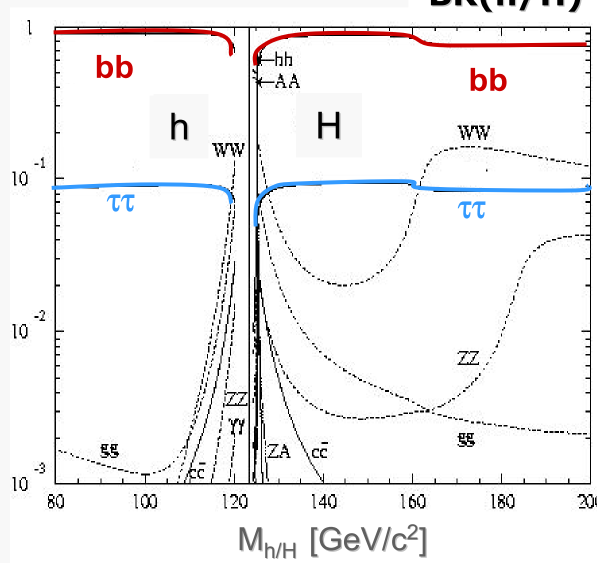
Decay Modes:

Light Higgs:

- $BR(b\bar{b}) > 90\%$
- $BR(\tau^+\tau^-) < 8\%$

Heavy Higgs:

- $g_{H/Abb} \propto \tan\beta$
- $BR(b\bar{b}) > 80\%$
- $BR(\tau^+\tau^-) < 8\%$
- $BR(W^+W^-) < 12\%$



Production Modes:

Light Higgs:

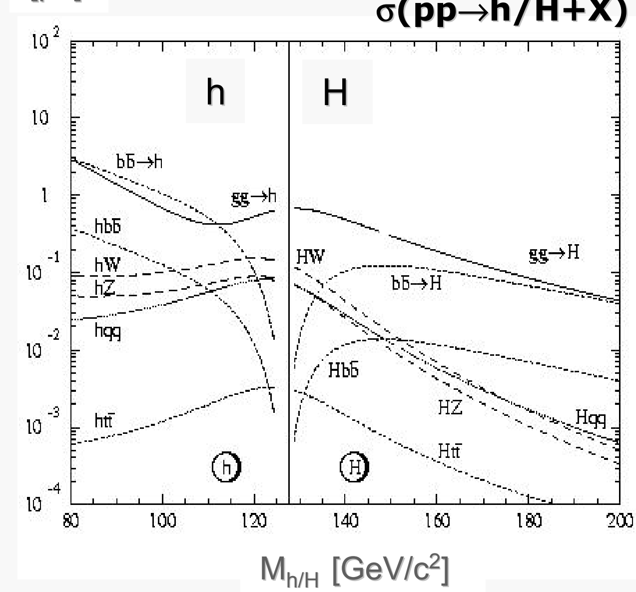
- $\sigma(p\bar{p} \to Wh) \sim 0.15$ pb

⇨ SM-like analysis

Heavy Higgs:

- $\sigma(p\bar{p} \to A/Hb\bar{b}) \sim 10$ fb

  ⇒ 4b 's final state



⇨ <u>tanβ=6:</u>
- Light Higgs h: SM-like analysis
- Heavy Higgs A/H: 4 b's final states

Phenomenology of h/H/A at the TeVatron (tanβ=30)

Decay Modes:

Couplings:

- $g_{Abb} \propto \tan\beta$

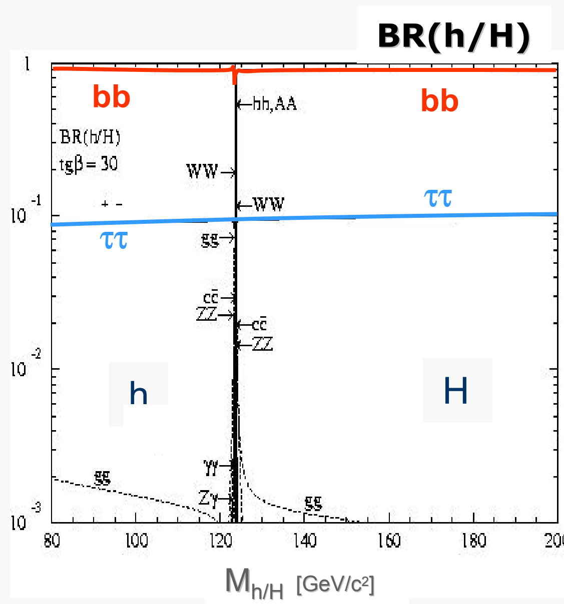
Higgs h/A:

- $BR(b\bar{b}) > 90\%$
- $BR(\tau^+\tau^-) < 8\%$

Heavy Higgs H:

- $BR(b\bar{b}) > 90\%$
- $BR(\tau^+\tau^-) < 10\%$

⇨ H→WW closed !



Production Modes:

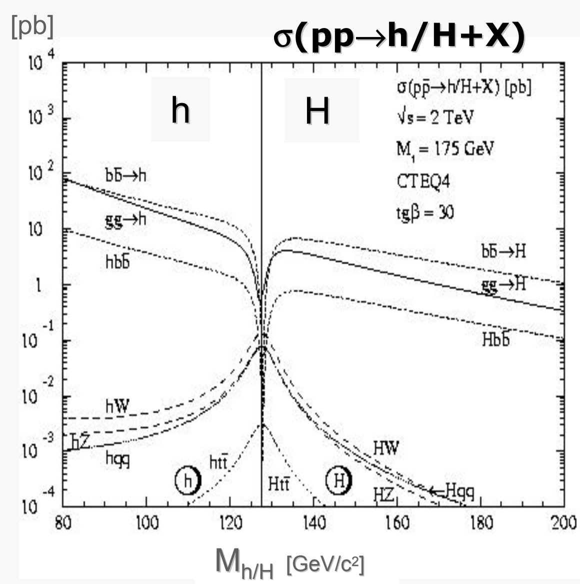
Standard channels "out":

- $\sigma(Wh)/\sigma(WH_{SM}) < 0.1$

⇨ WH closed !

Only available channels:

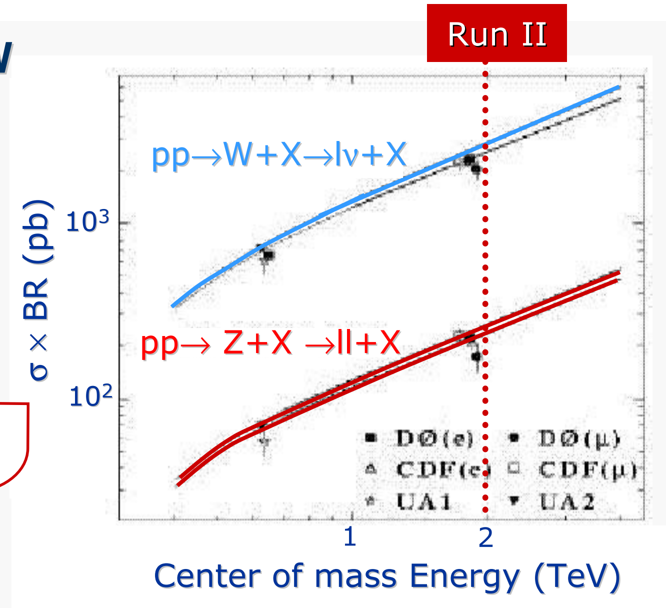
- $\sigma(A/hb\bar{b} \to b\bar{b}b\bar{b})$~1-10 pb
- $\sigma(Hb\bar{b} \to b\bar{b}b\bar{b})$~0.1-1pb



➡ tanβ=30: – Standard channels not relevant for h/A/H
– 4 b's final states analysis

SM Backgrounds to Higgs Search

Main Backgrounds to H →bb/WW



QCD bb:

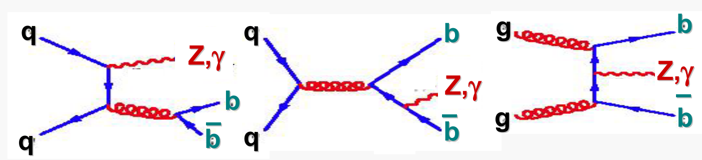
- $\sigma_{bb} \approx 100\ \mu b$
- factor 10^8 vs signal

Boson Production:

- W+X: σ ~ 7 nb
- Z+X : σ ~ 0.2 nb

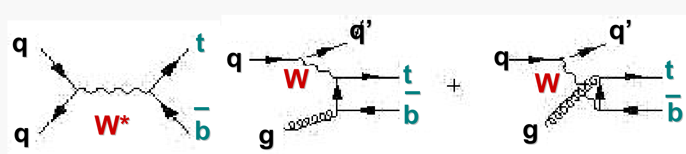
- Wbb: σ ~ 8060 fb
- Zbb : σ ~ 5290 fb

($60 < m_{bb} < 160$ GeV)



Top quark Production:

- pp→tt: σ ~ 8 pb
- single t: σ ~ fb



Di-boson

- WW: σ ~ 24 pb
- ZZ+WZ : σ ~ 1.2 pb

Still large uncertainty in the theoretical prediction for both Signals + Backgrounds (NLO/LO):

Large K factors (1.3-1.8) + effects on $d\sigma / dm_{bb}$

Tools for Higgs Search

Strategy and Tools for Higgs Search

Low Mass Analysis

$pp \to WH \to l\nu bb$

$pp \to ZH \to \nu\nu bb$

$pp \to ttH \to WbWb\ bb$

- Triggers:
  - Lepton, mE_T
  - Displaced Vertex
- b-tagging:
  - b-tagging efficiency
  - mistag rate
- Jet Energy & Resolution:
  - M_{bb} resolution

$Z \to bb$ Control Sample

High Mass Analysis

$H \to WW^*, WWW^*$

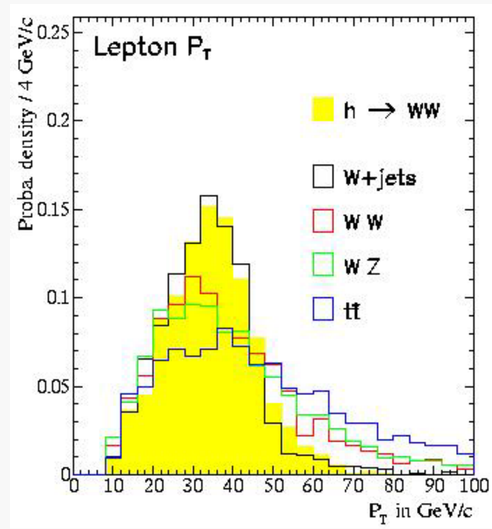
$pp \to ttH \to WbWb\ WW^*$

- Triggers:
  - Lepton, mE_T
- Lepton ID
- E_T, mE_T, angles resolution

Lepton trigger for Higgs Searches

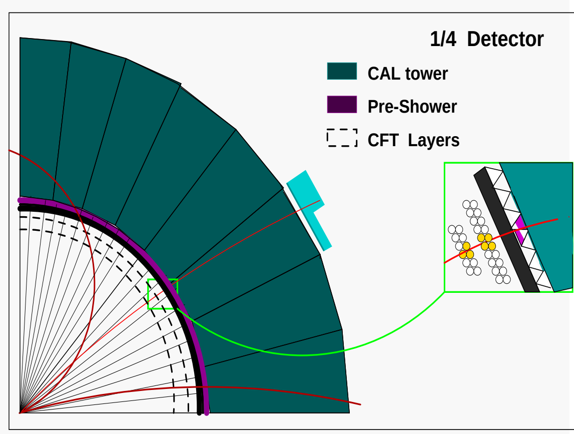
Motivation & goals

- Huge QCD Background:
  - $\sigma_{dijets} \approx 43$ mbarn
- Specific triggers:
  - Soft Lepton for b-tagging
    $b \to l\nu + X$ and $b \to J/\psi(\to ll) + X$
  - High p_T leptons & mE_T
    $H \to W^*W^*, Z^*Z^*$ w $W \to l\nu$, $Z \to ll$



New Trigger Design

- New Architecture:
  - Fast & pipelined electronics
  - Band width: L1= 10-50 kHz
  - Correlations at L1
- Lowered Thresholds:
  [ee] $p_T(e) > 2.5$ GeV/c
  [μμ] $p_T(\mu) > 1.5$ GeV/c
  [μ] $p_T(\mu) > 4.0$ GeV/c
- Missing E_T triggers:
  missing E_T resolution ~7-10GeV



- Triggers to be tested with 1st data
- effects of mbias, pile-up, to be assessed

b trigger for Higgs Searches

Principles

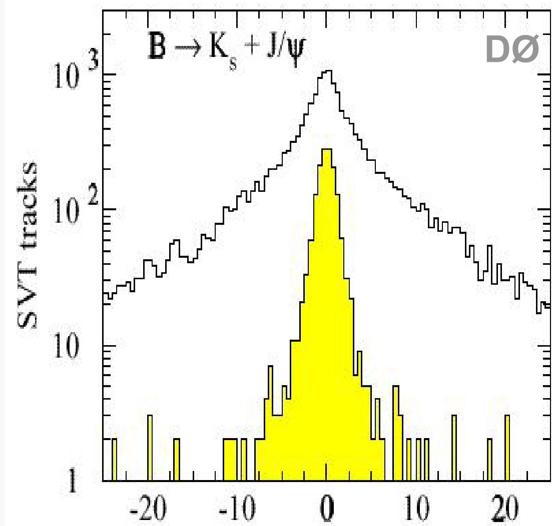
b decays within few ~mm

- Soft Lepton from b

⇒ High Impact parameter tracks

Specific Triggers for run II:

- Inclusive muon trigger
- L2 selection with high d_0/σ_{d0}



d_0/σ_{d0}

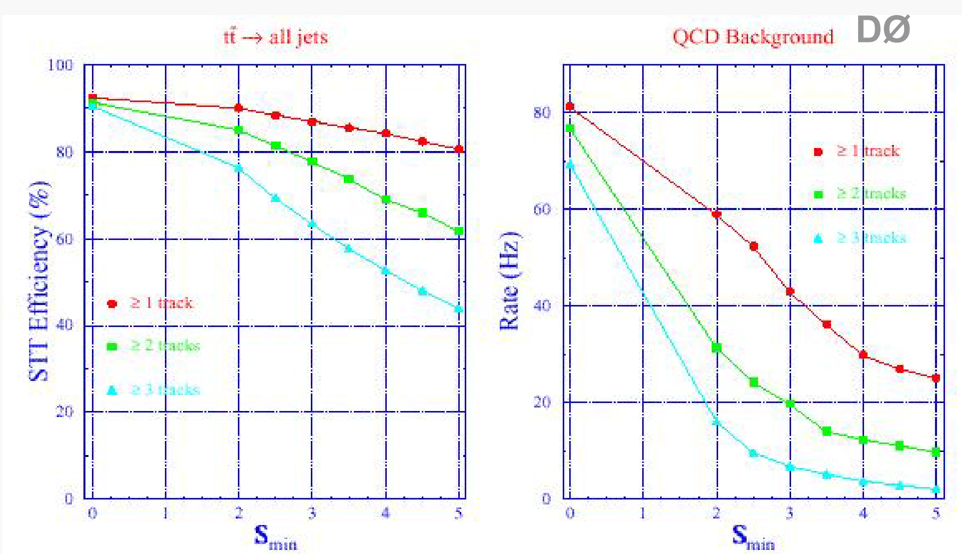
Performances

Trigger on ZH→ννbb:

efficiency ε ~ 80%

Trigger on Z→bb

efficiency ε ~ 20% vs rates ~20 Hz

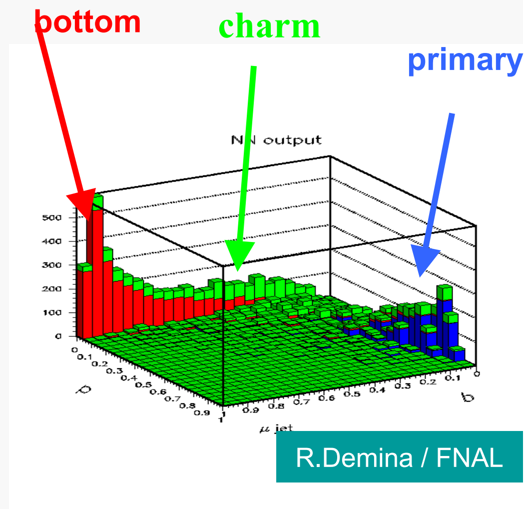


⇒ 50,000 Z→bb /exp./2 fb^{-1}

b-tagging for Higgs Search

b-jet Tagging

- “Multi-tag” approach developped:
  - Soft Lepton from b $\rightarrow l\nu X$
  - High Impact parameter tracks
  - Secondary Vertices: $|L_{xy}| / \sigma_{xy}$
- b/c separation:
  - LifeTime
  - Vertex Mass
  - Kinematics, topology
- Optimization w/ Likelihood & Nnet
  - Tight / Loose taggers



Performances

Estimates w/ SHW parametrization:

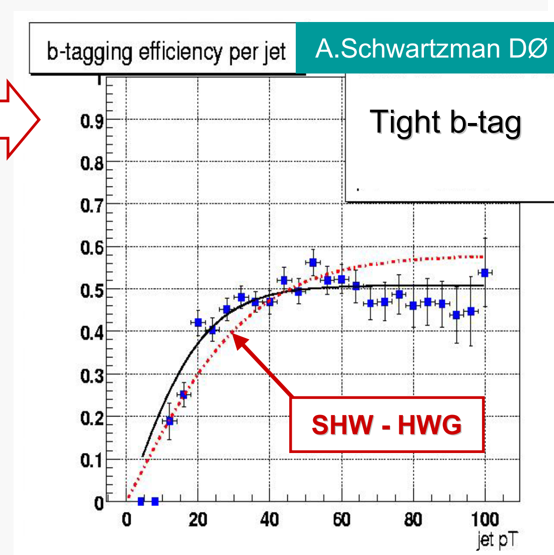
- Checks in progress

Tagging Efficiency & mistag:

- b-jet: ε_{1b} ~ 50% (tight)
- c-jet: ε_{1b} ~ 13%
- light jet: ε_{1b}~0.7%

Tagging for WH$\rightarrow$lvbb

$\varepsilon_{1\text{-btag}}$ ~ 70%



Numerous progresses made / still to be made
Use of likelihood & NNet being tested & implemented

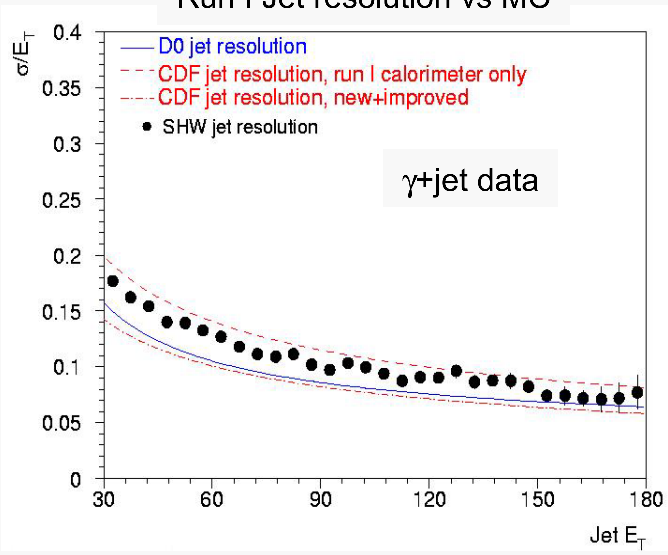
Mass resolution and Z→b$\bar{b}$ sample

Jet E_T resolution

Run I data:

- σ/E ~75%/√E (DØ)
  σ/E ~78%/√E (CDF)

Run I Jet resolution vs MC



Run II:

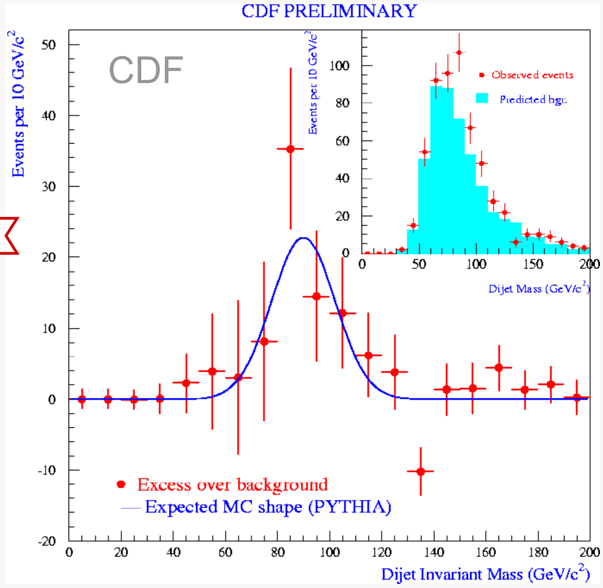
- More challenging (materials, mbias etc.)
- Improve energy scale (20 x more γ+jet)
- Use Track+Calorimeter (CDF: 30% better)

M resolution with Z→bb

Run I (CDF):

- Inclusive muon sample
- Corrections for b→l

⇒ S ~50 evts / 0.1 fb^{-1}
15% resolution in M_{bb}



Run II:

- Specific Zbb triggers:
  Muon: 500 evts / fb^{-1}
  Vertex: 50,000 evts / fb^{-1}

– Improvements needed* to reach σ/M ~10%

Main Channels in Higgs Search

The $WH \to l\nu b\bar{b}$ Channel

Signal Selection

Pre-selection:

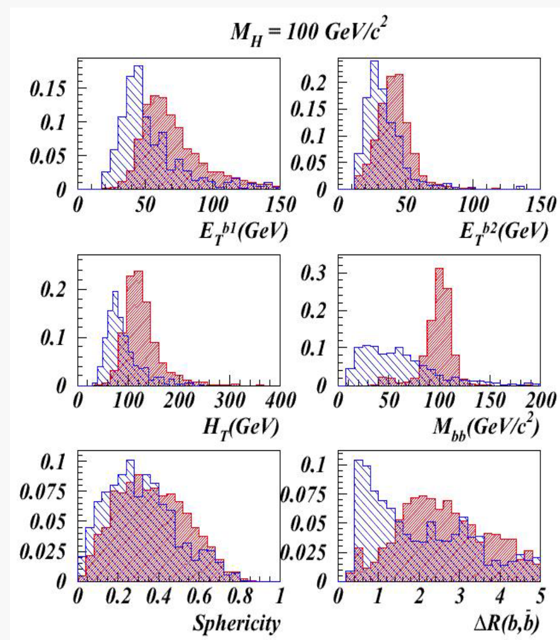
- High p_T lepton, mE_T
- 2 b-tagged jets

Discriminant Variables:

- Lepton: E_T^l et η^l et mE_T
- Energy E_t^b, M_{bb} ($=m_H \pm 2\sigma_m$)
- Total jet Energy H_T
- Sphericity

Dominant backgrounds:

- Wbb, tt, single top, WZ



Expectations

Key parameters:

- b tagging efficiency & mistag
- Knowledge of Wbb background
- M(bb) resolution (σ_M/M ~10%)

1 fb^{-1}	m_H GeV	110	120	130
	Signal	5.0	3.7	2.2
Cuts	ε x BR	2.3%	2.3%	1.9%
	S/√B	0.72	0.53	0.35
NNet	S/√B	1.1	0.87	0.55

– S ~ 4 / fb^{-1}
– S/B ~ 10%

The $ZH \rightarrow \nu\bar{\nu}b\bar{b}$ Channel

Selection

Pre-selection:

- High mE_T + 2 b-tagged jets

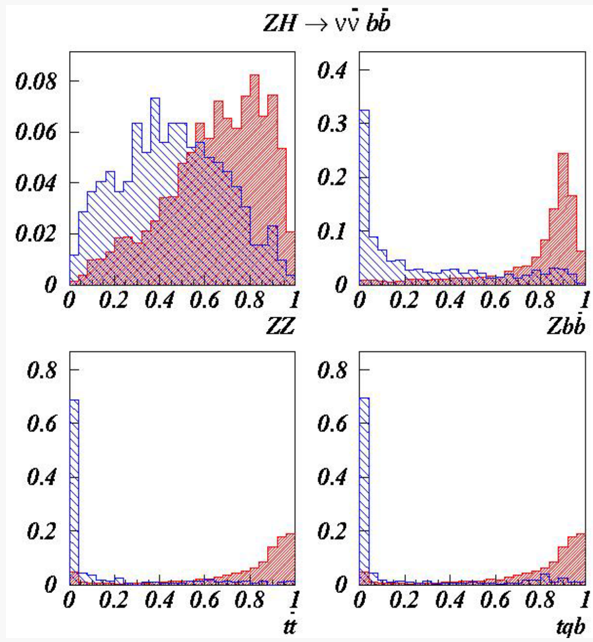
Discriminant Variables:

- E_T^b et mE_T
- M_{bb} (=$m_H \pm 2\sigma_m$)
- Total jet energy H_T
- Sphericity , Centrality
- $\Delta\Phi(mE_T,jet)>0.5$

Dominant Backgrounds:

- QCD bb, Zbb, tt

From Data only !!



Expected performance

Key parameters:

- b-tagging & σ_M/M Resolution (~10%)
- Reliable estimates for QCD bb+mE_T & Zbb

1 fb^{-1}

	m_H GeV	110	120	130
Cuts	Signal	2.7	1.7	0.9
	ε x BR	2.1%	1.7%	1.2%
	$S/\sqrt{B}$	0.84	0.59	0.38
NNet	$S/\sqrt{B}$	**0.90**	**0.73**	**0.53**

S ~ 2 evts / fb^{-1}
S/B ~ 15%
M_H distribution

The ZH→$l^+l^-b\bar{b}$ Channel

Selection

Pre-selection:

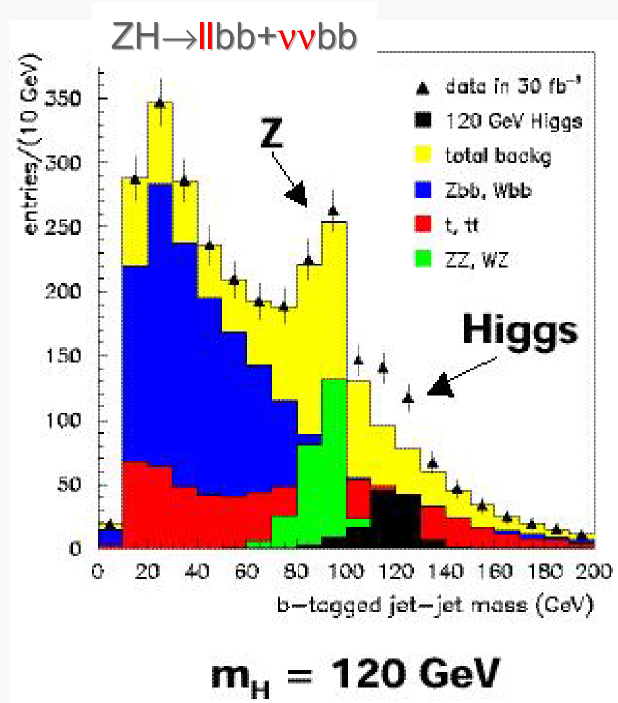
- 2 high p_T lepton
- 2 b-tagged jets

Discriminant variables:

- Energy E_t^b , E_T^l
- M(ll) & M(bb)
- Total jet Energy H_T
- ΔR(l,b)

Dominant Backgrounds:

- ZZ, Zbb, Wbb



Expected performance

Key parameters:

- b-tagging and σ_M/M Resolution (~10%)
- Reliable estimates for Zbb

1 fb^{-1}	m_H GeV	110	120	130
Cuts	Signal	0.9	0.6	0.4
	S/√B	0.5	0.4	0.3
NNet	**S/√B**	**0.6**	**0.5**	**0.4**

⇒

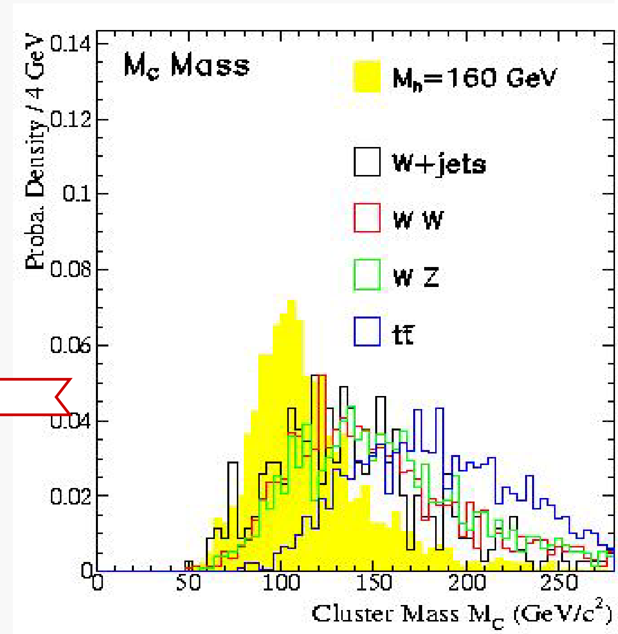
S ~ 0.5 / fb^{-1}
S/B ~ 30-45%
M_H distribution

The $H \to W^*W^* \to l^+ l^- \nu\bar{\nu}$ Channel

Selection

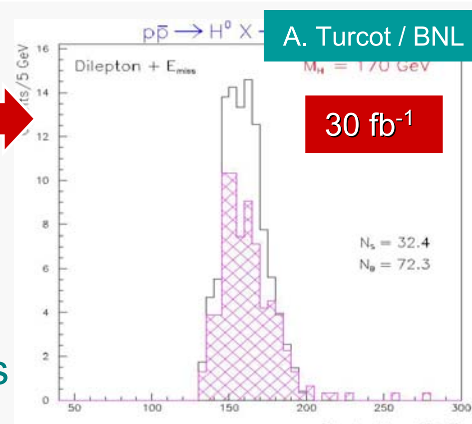
Discriminant Variables:

- 2 high p_T lepton, high $\not{E}_T$
- Spin correlation $h \to WW^*$
  $\Phi(ll)$,$\theta(ll)$
- $M_T(ll\not{E}_T)$, $p_T(ll)$ (vs $\tau^+\tau^-$)
- Cluster Mass: (vs WW)
  $M_C = \sqrt{p_T^2(ll) + M_T^2(ll)} + \not{E}_T$



Dominant backgrounds:

- $W^+W^- \to l^+l^-\nu\bar{\nu}$
- W+fake, $t\bar{t} \to l^+l^-\nu\bar{\nu}b\bar{b}$



Expectated Performance

Key parameters:

- Reliable estimates for WW,W+jets
- Counting experiment !

1 fb^{-1}	150	160	170	180
Signal	2.8	1.5	1.1	1.0
S/B(%)	10%	34%	45%	25%
S/√B	0.5	0.7	0.7	0.5

S ~ 1-3 / fb^{-1}
S/B ~ 10-45%

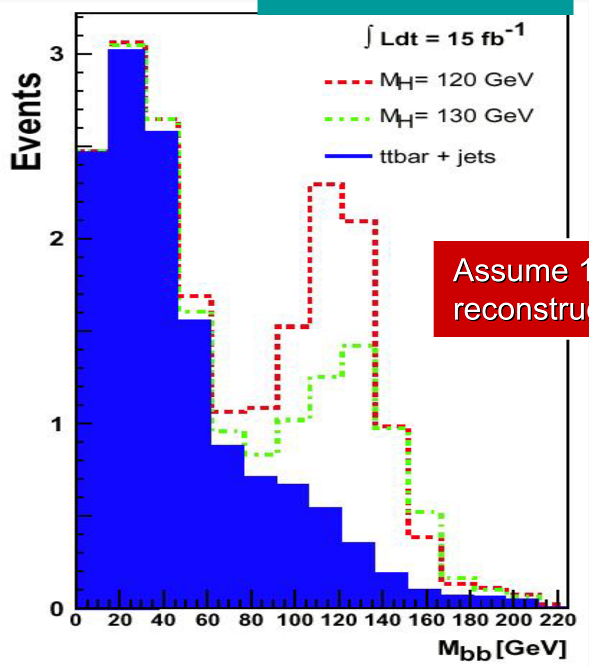
Channel: pp$\rightarrow$ tt H$\rightarrow$WbWb bb

Selection

Discriminant Variables:

- $\geq$ 1 high p_T lepton+mE_T
- 4 high E_T jets + 2 jets
  $\rightarrow$ reconstruct tt
- 3 b-tags (vs tt+jets)
- Mbb once tt jets id !

J.Incandela et al. / CDF



Assume 1 Top reconstructed

Dominant backgrounds:

Backgrounds	$\sigma\times$BR [fb]
tt+jj (ΔRjj>0.4)	1030
tt+bb	27
tt+Z(bb)	1.5
W(lv)Z(bb)+jj	10.4

Expected Performance

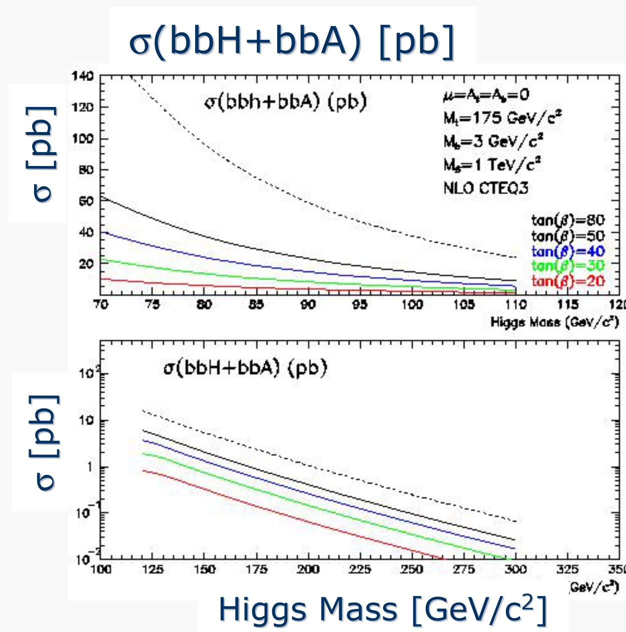
Key Parameters:

- btagging & mistag: ε_b~60% ε_c~25% ε_{uds}~0.5%
- Top products Grouping efficiency (many combinations)
- Add H$\rightarrow$WW* channels (more difficult)
- Reliable NLO calculations

See S. Dittmaier, L. Reina

S ~ 0.5 / fb^{-1}
S/B ~ 50%

MSSM Higgs: $p\bar{p} \to b\bar{b}\varphi \to b\bar{b}b\bar{b}$ $(\varphi = h,H,A)$



Selection

- Discriminant Variables:
  - 4 b-jets: (≥ 3 b-tags)
  - $E_T(j)$ cuts as $f(m_\varphi)$
  - Topology $\Delta\Phi(bb)$
- Dominant Backgrounds
  - QCD (bb/cc), Z/Wjj, tt

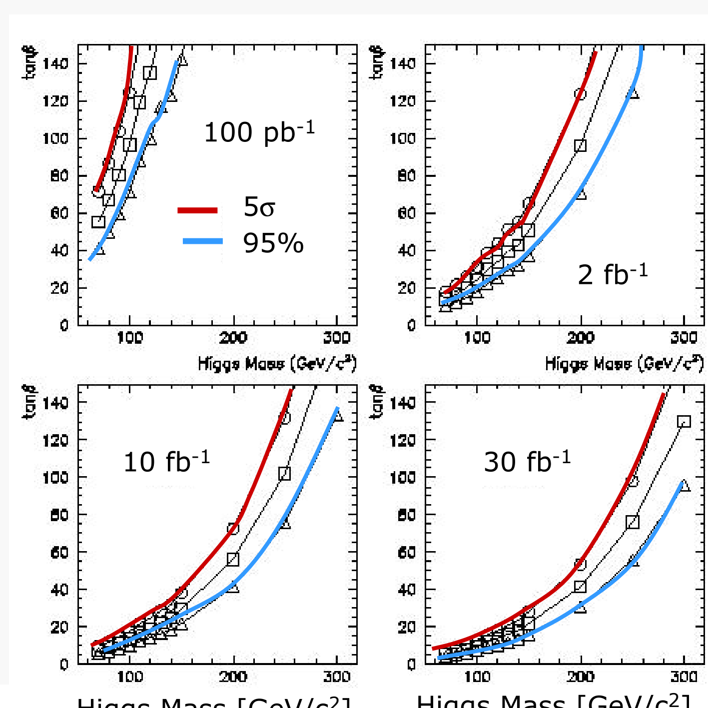
Fonds	σ×BR [pb]
qq,gg →bbbb	2.40
pp → Zbb	0.49
pp → W(jj)bb	2.11
pp → bbjj	1610.8

Expected Performance

Key parameters:

- σ_M/M Resolution
- Reliable estimates for Backgrounds

– Sensitivity for M_A to 125GeV with 2fb^{-1}
– Stringent Constraints in $(m_A, \tan\beta)$ plane

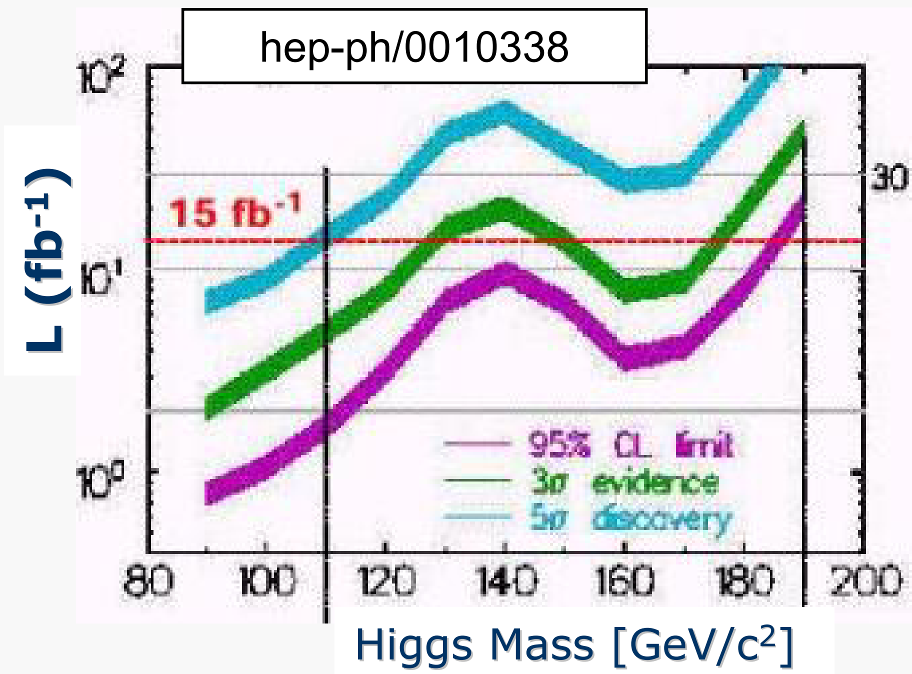


Conclusion & Perspectives

Neutral (SM) Higgs

Needed luminosity to get 95% exclusion / discovery:

- Assuming 10% M_{bb} resolution, NNet analysis for $H \rightarrow bb$
- Bands represent 30% effect in M_{bb}, ε_b, backgds



New Channel: ttH

– looks promising : ~15% reduction in luminosity threshold for discovery at 120 GeV

MSSM Higgses

– Accessible with 4 b's final states and Charged Higgs

Still a lot of work ahead of us. Progress needed:
– on M_{bb} resolution (energy flow)
– on b-tagging & trigger
– on theoretical calculation (bckgd)
...But data are flowing in...and could bring suprises

....What about m_H = 115 GeV ?

If Higgs is indeed here:

- Signal Evidence requires
  - ~5 fb^{-1} with 3 standard evidence (2004-5)

- Expected number of events
  - per experiment with 15 fb^{-1} (2007)

J.Womersley. / DØ

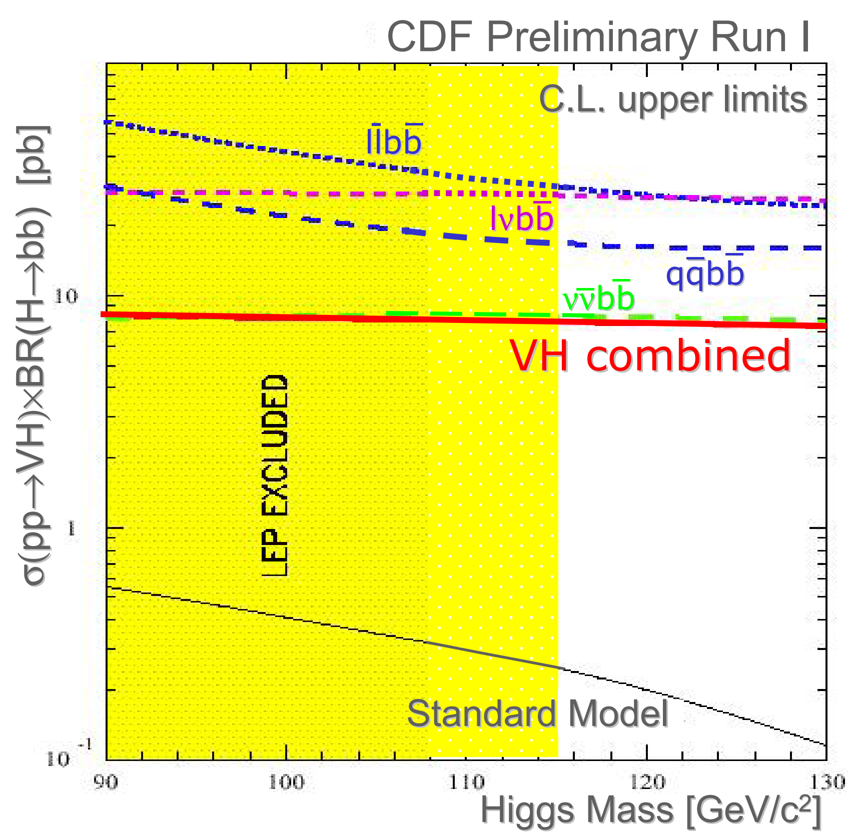
Mode	Signal	Background	$S/\sqrt{B}$
lνbb	92	450	4.3
ννbb	90	880	3.0
llbb	10	44	1.5

- If we do see something, we need to measure:
  - its Mass
  - Its production cross-section
  - Can we see $H \rightarrow \tau\tau$ (BR ~ 8%) ?
  - Can we see $H \rightarrow W^*W^*$ (BR ~ 5%) ?

If Higgs is not here:

- we can exclude a m_H = 115 GeV Higgs
  - at 95% CL with 2 fb^{-1} (2003)

Higgs Search at the TeVatron Run 1



TeVatron au Run I : ~110 pb^{-1}

Défaut d'un facteur ~ 30-80 en sensibilité !

Updates & References

Higgs Search at the TeVatron:

- Htt : J. Goldstein et al., FERMILAB-PUB-00/146-T
- « QCD Corrections to ttH production », L. Reina, FNAL Workshop, May 2001
- « NLO QCD corrections to ttH production », S. Dittmaier

Backgournds to TeVatron Higgs production

K. Ellis , J. Campbell, S. Veseli

hep-ph/9810489, hep-ph/9905386, hep-ph/0006404