Prospects for Discovering a Light Higgs at the Tevatron in Run2

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FERMILAB/CDF

La Thuile '01

Outline

- **Introduction:**
  - the Standard Model Higgs
  - production at the Tevatron
  - Higgs decays
- **SM Higgs searches**
  - SM Higgs
  - Impact of the Upgrades
    - CDF
    - DØ
  - Combined Channel Results
- **MSSM Higgs**
- **Tevatron: long-term luminosity goals**
- **Summary**

Acknowledgements:

Tevatron Higgs Working Group

or HWG

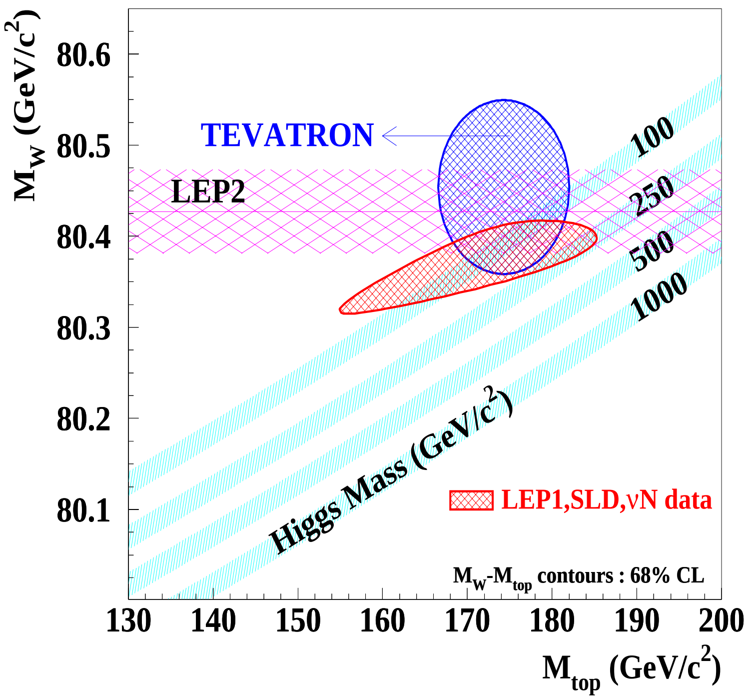
Final report:
http:/fnth37.fnal.gov/higgs.hml

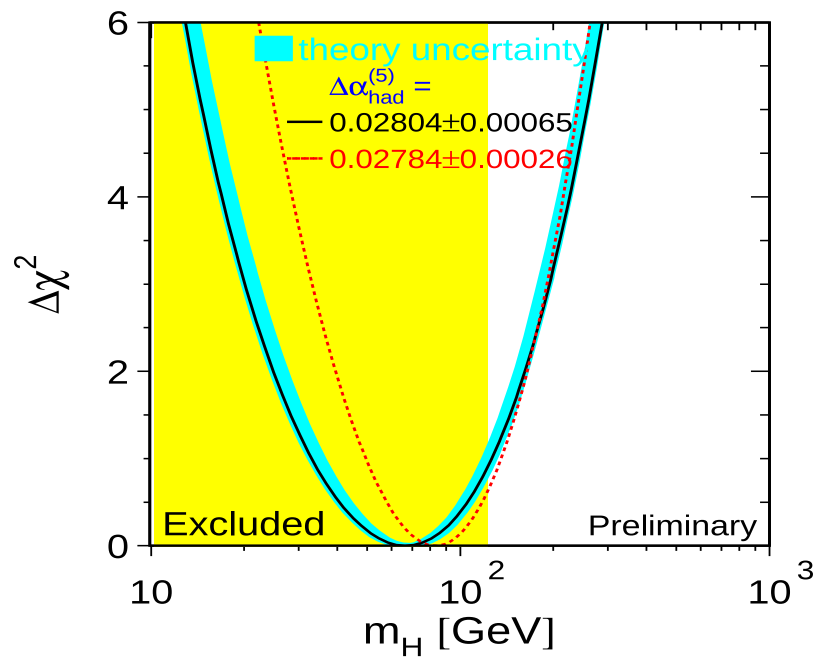
The Standard Model Higgs

- The Standard Model is a very successful theory of elementary particles and their interaction at energies of O(100 GeV)
- Precision tests of the electroweak theory show impressive consistency with the Standard Model, no signs of any deviations
- The underlying dynamics responsible for electroweak symmetry breaking is still unknown.
- The simplest possible dynamics for electroweak symmetry breaking predicts the existence of one scalar boson (Higgs) with unknown mass M_H (free parameter).
  - $\ln M_H \propto f(m_t, \Delta M_W)$

Current Status of the Higgs Searches

- Indirect search via precision measurements
  - Data seem to prefer low mass Higgs: M_H<170 GeV at 95 % CL
- The direct search at LEP-200:
  - M_H>113.5 GeV/c^2 at 95 % CL or 2.9σ excess for M_H =115 GeV/c^2
- Is it within reach in Tevatron Run II?

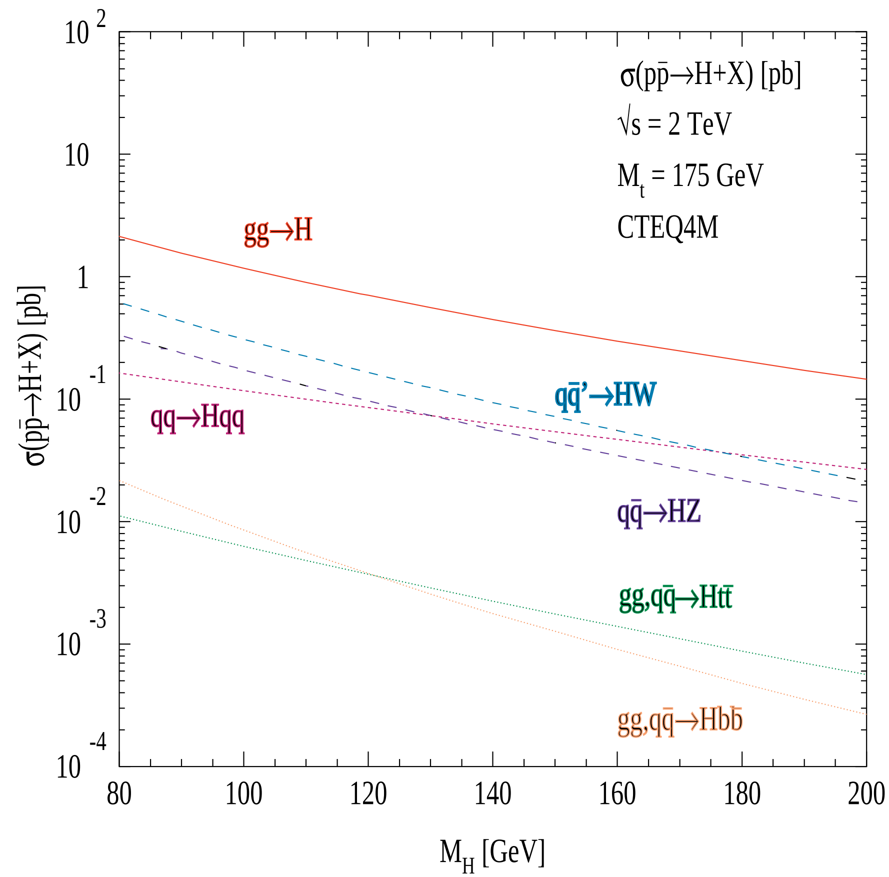




SM Higgs Production at Tevatron

- gg$\rightarrow$H dominates over all mass ranges, but backgrounds are largest
- WH, ZH modes provide straightforward trigger, smaller backgrounds
- H$t\bar{t}$ mode has distinct signature
- SUSY enhances some cross-sections...

M.Spira, hep-hp/9810289



Higgs BR (M_H<130) GeV)

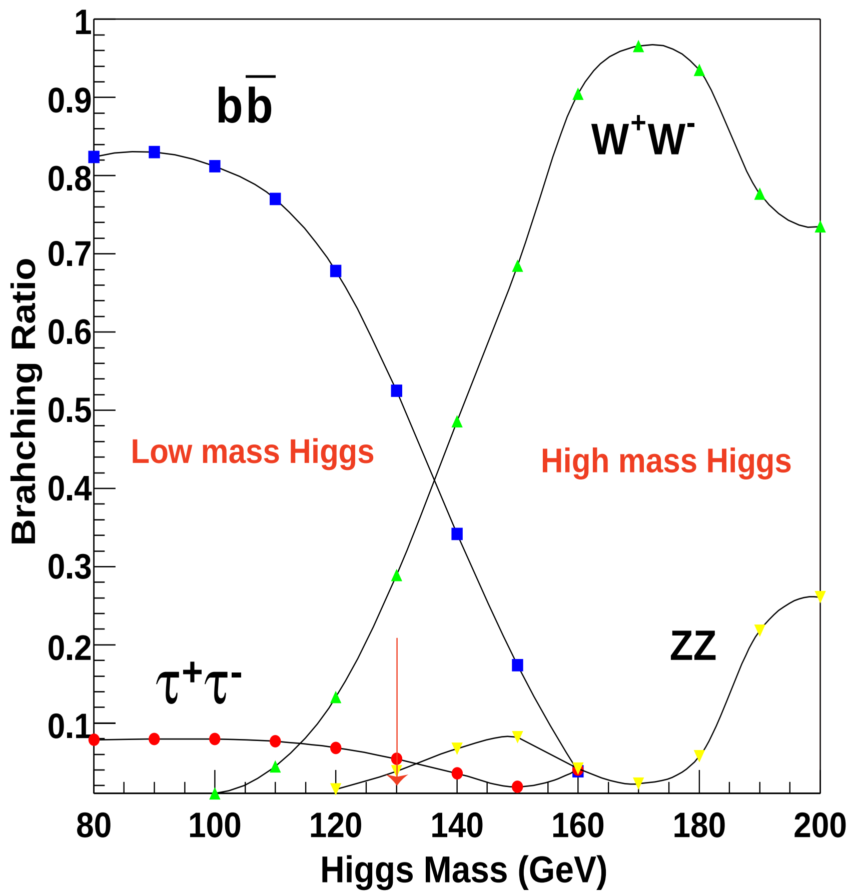
- M_H<130 GeV/c^2 "low mass Higgs"
  - Most promising modes are:

$$q\bar{q}' \to VH \ \ where$$
$$V \to \ell\nu, \nu\bar{\nu}, \ell^+\ell^-, q\bar{q} \ and \ \ H \to b\bar{b}$$

  - good b-tagging, jet resolution, lepton ID and coverage are the key for success

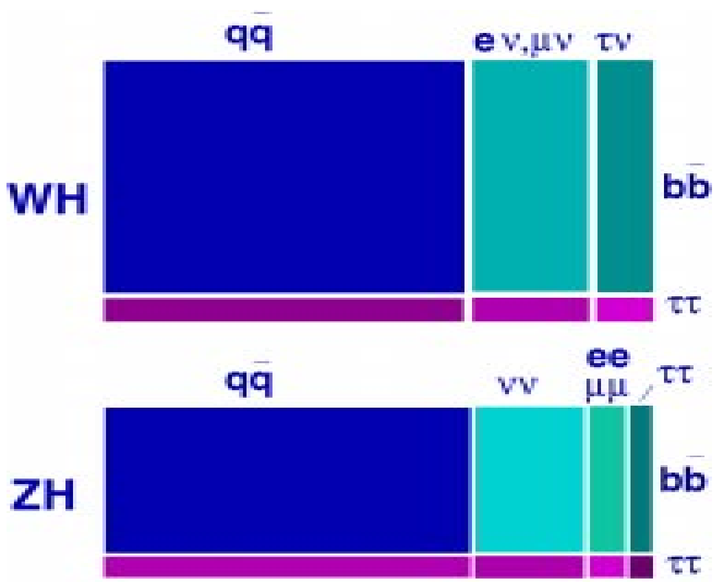
- M_H>130 GeV/c^2 "high mass Higgs"

$$gg \to H \to VV \quad where$$
$$VV \to \ell^+\ell^-\nu\bar{\nu},$$
$$q\bar{q}' \to VH \to VVV \quad where$$
$$VVV \to \ell^\pm\ell^\pm q\bar{q}'X \ , \ell^\pm\ell^\pm\ell^\mp X$$



Event Rates: Example

- Assume M_H ~120 GeV/c^2, WH/ZH final states are



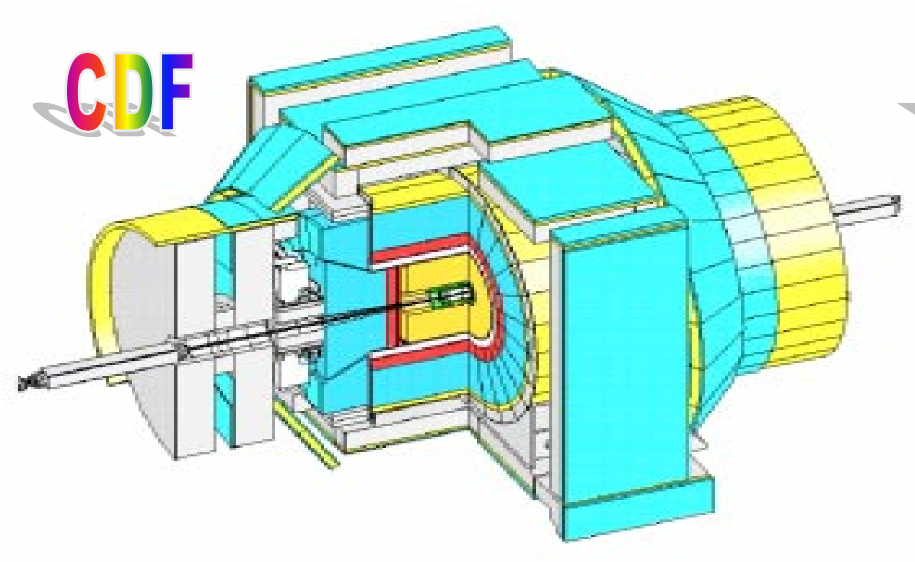
- and assume 15 fb^{-1} luminosity per detector

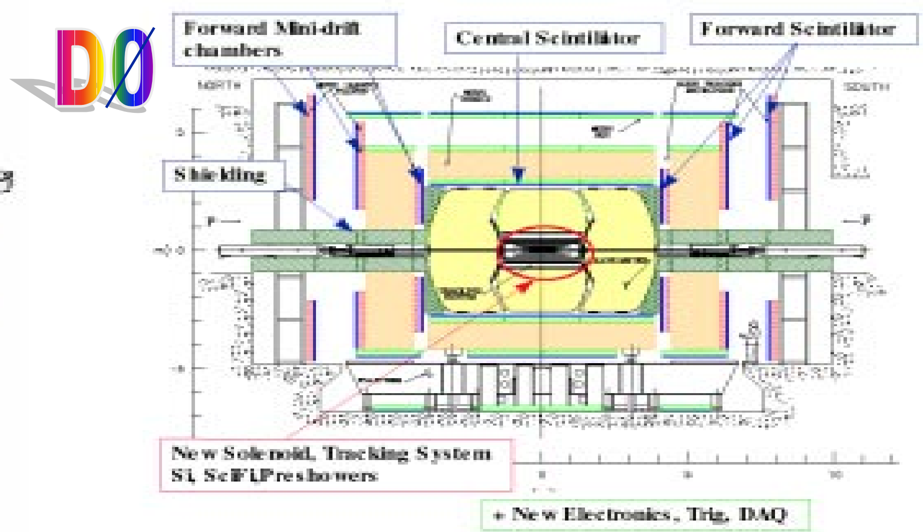
Process	WH	Wbb Wττ	lνbb lνττ
Events	165 fb x 15 fb^{-1} = 2475	x 0.68 = 1650 x 0.07 = 168	x 0.296 = 500 x 0.296 = 50

Process	ZH	Zbb Zττ	ννbb ννττ
Events	97 fb x 15 fb^{-1} = 1455	x 0.68 = 990 x 0.07 = 181	x 0.2 = 195 x 0.2 = 21

- Compare to top quark discovery: 67 pb^{-1} x 5 pb = 335 tt events.
- New detectors (CDF & DØ) have more than twice better (Acceptance)x(Efficiency)x(Resolution)

CDF and DØ Run II Detectors





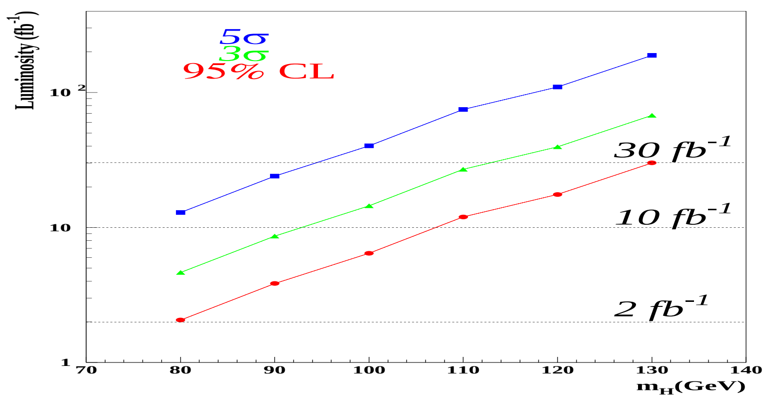
- CDF Run II upgrades
  - new front-end, DAQ and trigger electronics
  - trigger
    - ✔ new L1 tracking trigger
    - ✔ new L2 secondary vertex trigger
  - new time of flight system
  - new silicon vertex detector
    - ✔ 7 layers, $|\eta|<2$
  - new central tracker drift chamber
    - ✔ $N_{axial}=N_{stereo}=48$, $\Delta p_t/p_t<0.001p_t$
  - new plug calorimeter
  - large muon system coverage

- DØ Run II upgrades
  - new trigger and DAQ electronics
  - entirely new tracking system
    - ✔ 2T super conductor solenoid
    - ✔ barrel silicon detector
    - ✔ 8 layers of scintilating fiber tracker
    - ✔ preshower detector
  - improved muon spectrometer

Low Mass Higgs: $l\nu b\bar{b}$

E.Barberis et al., Report of the Tevatron HWG

- Typical selection
  - inclusive high-p_t lepton trigger
  - central e(μ) with $E_T(p_t)$>20 GeV
  - $\not{E}_T$>20 GeV
  - two b-tagged jets($E_T \geq 15$ GeV, $|\eta| \leq 2.0$): one tight b-tag and one loose tag (example soft lepton tag, SLT)
  - veto:
    - ✔ additional leptons with E_T>10 GeV
    - ✔ extra jets with p_t>30 GeV and $|\eta|$<2.5
    - ✔ more than one extra jet with p_t<30 GeV and $|\eta|$<2.5
- Main backgrounds: $Wb\bar{b}$, $t\bar{t}$, WZ, tb

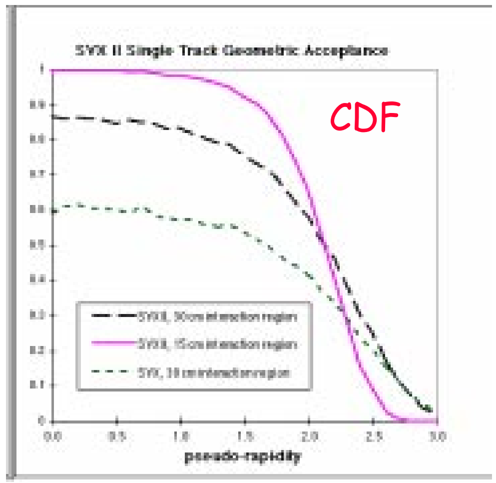


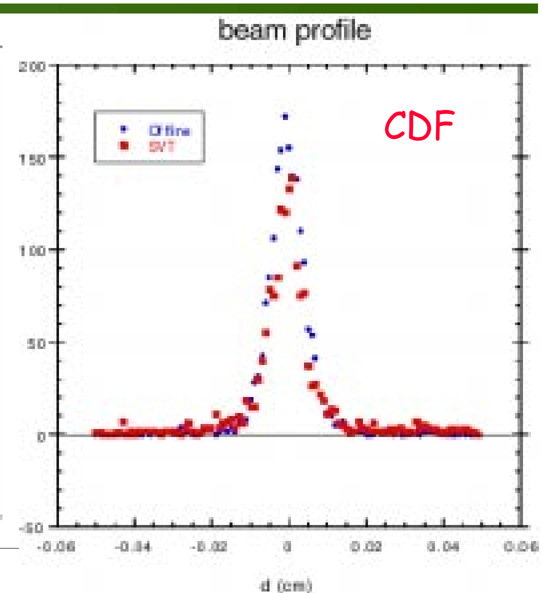
M_H (GeV/c^2)	100	110	120	130
Signal events(S)	8	5	4	3
Wbbbar	36	29	25	19
WZ	9	6	4	2
ttbar	16	15	20	22
Single top	7	7	9	9
Total Background(B)	68	57	58	52
$S/\sqrt{B}$	0.9	0.7	0.6	0.4

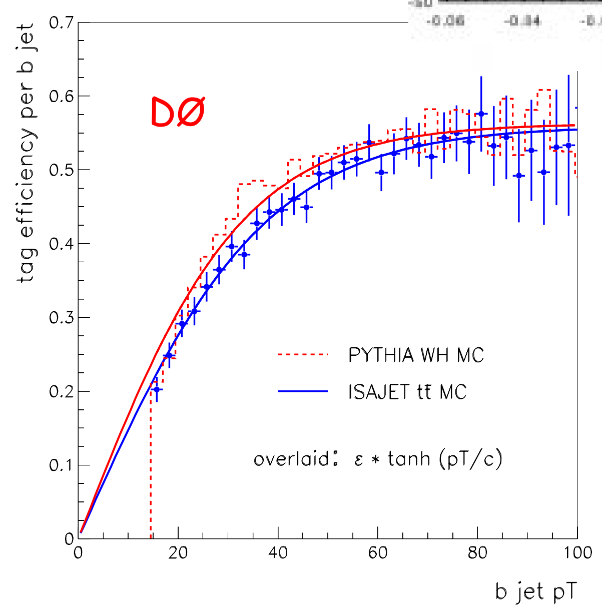
Signal and background events in 1 fb^{-1}

b-tagging in Run II

- B-tagging is very important in the low mass Higgs search: $H \to b\bar{b}$
- CDF:
  - 3D vertex reconstruction
  - better impact parameter resolution comparing to Run I $(6\oplus 19/p_t)$
  - SVT trigger: allows calibration on $Z \to b\bar{b}$
- DØ:(M. Roco)
  - new silicon detector: 6 barells



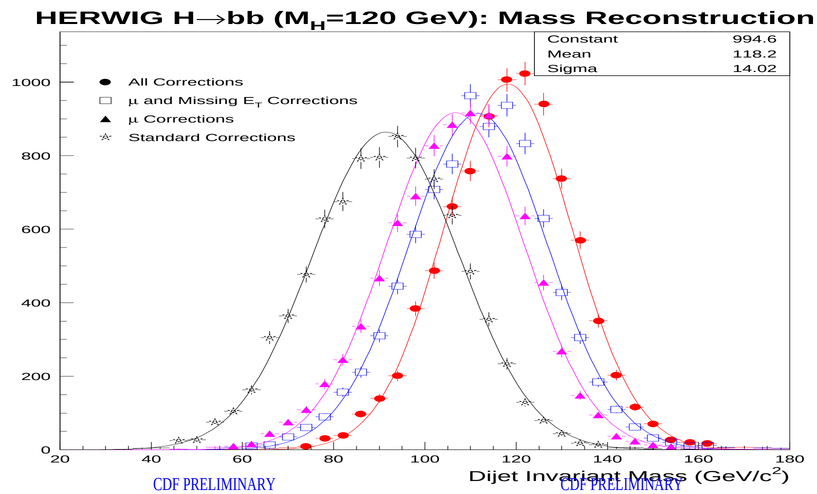


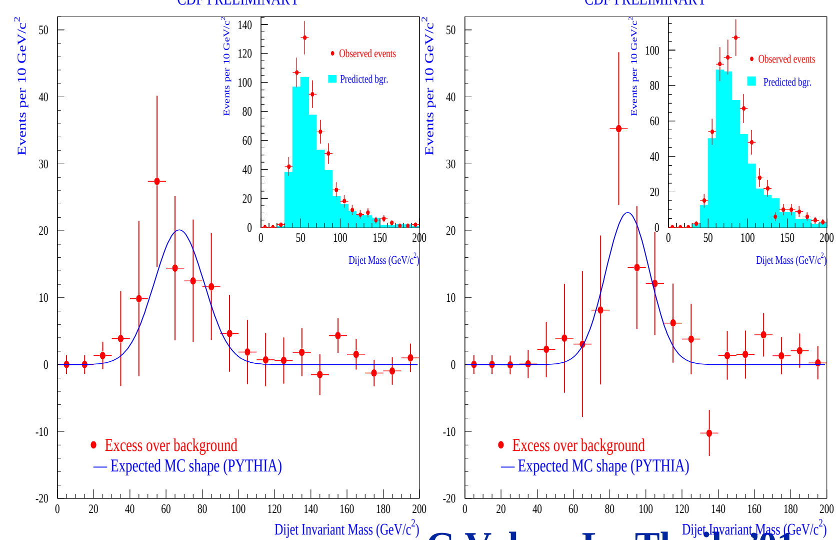


Mass resolution in $b\bar{b}$

- The $b\bar{b}$ mass resolution is crucial in the establishment of a signal
  - MC study of $b\bar{b}$ events collected via inclusive muon trigger. Applied specific jet corrections:
    - ✔ the muon momentum
    - ✔ $\not{E}$ projection along each jet
    - ✔ jet charge fraction
- Check these corrections on Run I CDF data
  - the improvement in the real $Z \to b\bar{b}$ data is as predicted by MC

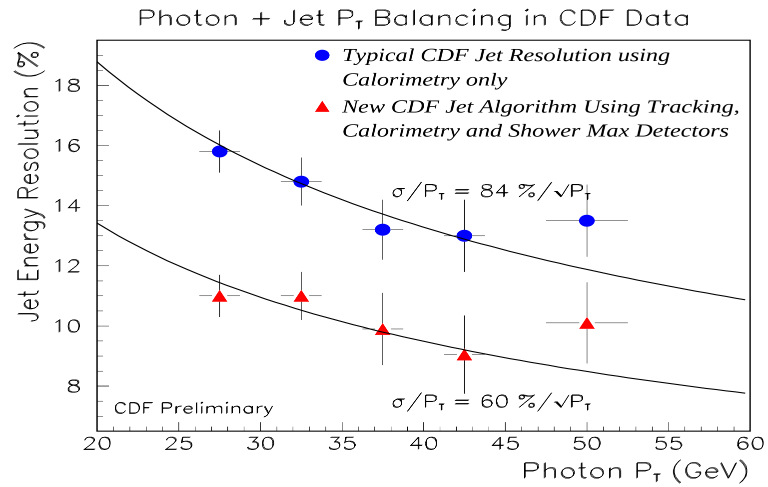
S. Kulman, S.Lami, R. Snihur, T. Dorigo, A. Ribon



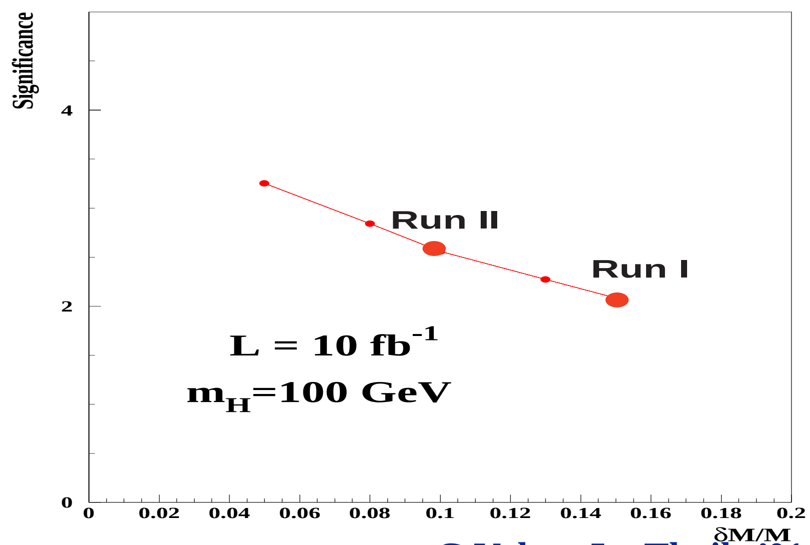


Jet-Jet Mass Resolution in Run II

- Using more information can improve jet resolution:
  - standard jet algorithm uses only calorimeter information
  - adding tracking + shower detector information improves energy resolution by 24%/$\sqrt{P_T}$



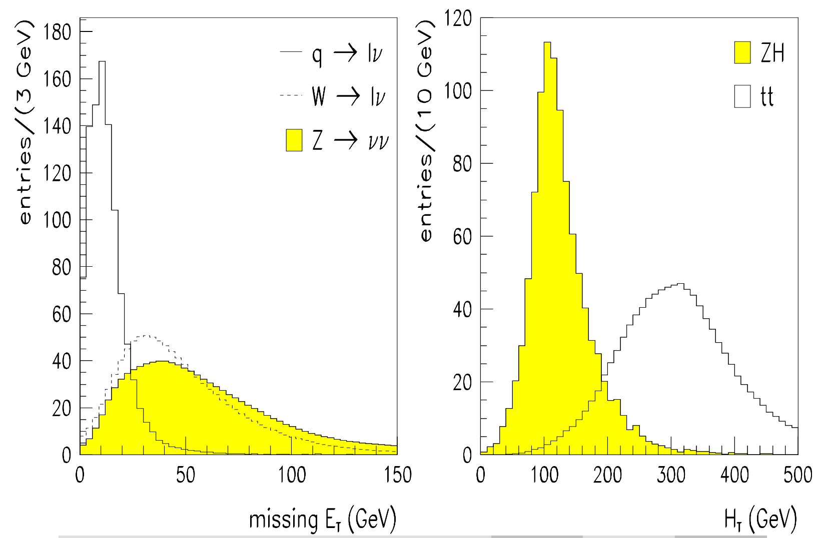
- If the dijet mass resolution can improve to 10%, then a gain in significance is almost 25%



Low Mass Higgs: $\nu\bar{\nu}b\bar{b}$

- Typical selection
  - $\not{E}_T$ + jets trigger
  - $\not{E}_T$>35 GeV
  - two b-tagged jets: one tight b-tag and one loose tag (SLT)
  - $\delta\phi(\not{E}_T$,closest jet)>0.5
  - scalar sum of the hadronic energy H_T<175 GeV (reject the $t\bar{t}$ background)
  - veto:
    - ✔ no extra jets
    - ✔ reject events with one or more isolated leptons with p_t>8 GeV
- Main backgrounds: QCD, $Zb\bar{b}$, ZZ, $t\bar{t}$, WZ, tb

P.Bhat et al., Report of the Tevatron HWG



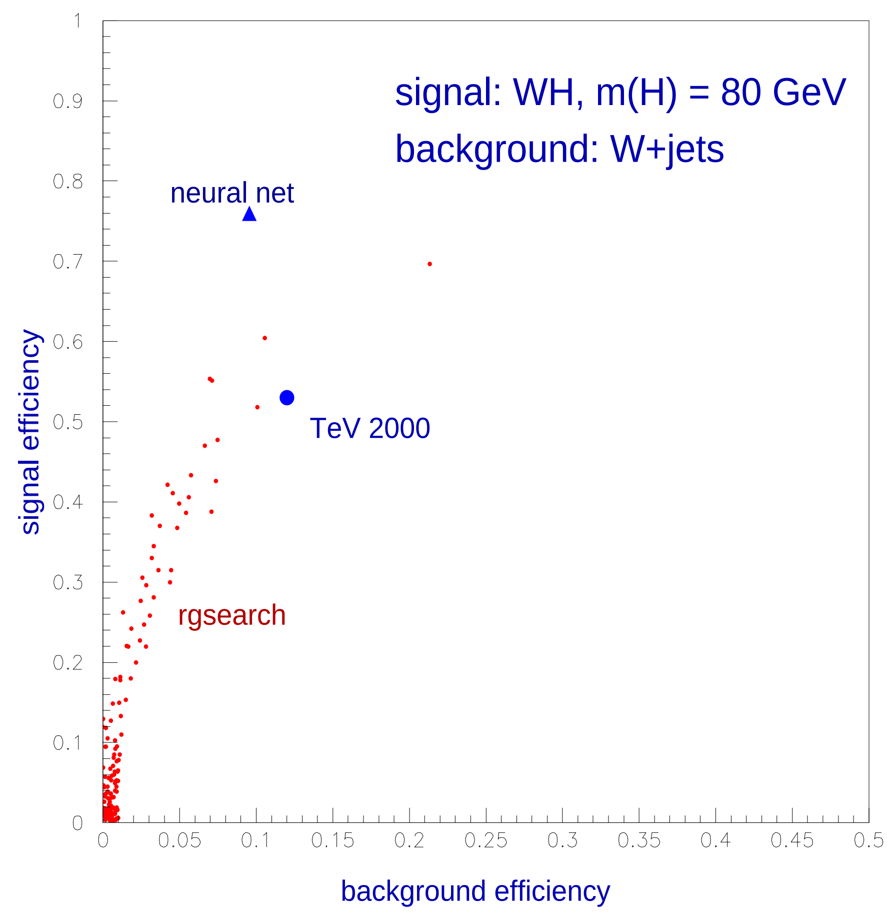
M_H (GeV/c^2)	100	110	120	130
Signal events (S)	6.7	4.6	3.2	2.1
Zbb	6.3	5.6	4.6	3.5
W bb	7.1	6.7	5.4	4.2
ZZ	6.0	2.9	0.2	0.0
W Z	5.1	2.7	0.2	0.0
tt	4.7	4.7	4.3	3.5
Single top	5.4	5.3	4.7	3.8
Total Background (B)	34.6	27.9	19.4	15.0
S/√B	1.1	0.9	0.7	0.5

Signal and background events in 1 fb^{-1} (do not include generic $b\bar{b}$ production processes)

Study of the Selection Optimization

- DØ: neural network (NN) selection (P.Bhat, R. Gilmartin and H.Prosper)
- Example: expected number of $\not{E}_T b\bar{b}$ signal and background events in 1 fb^{-1} for various M_H assuming 10% $b\bar{b}$ mass resolution in case of NN(**red**) and traditional techniques (**black)**

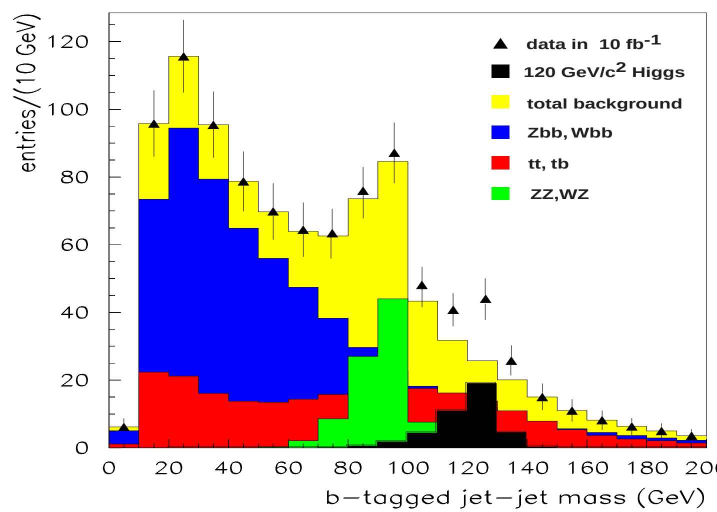
M_H (GeV/c²)	110	120	130
ZH	3.5 (2.8)	2.8 (1.9)	2.2 (1.3)
WH	2.8 (1.8)	2.0 (1.3)	1.7 (0.8)
Signal	6.3 (4.6)	4.7 (3.2)	2.1 (3.9)
Background	27.7 (27.9)	22.4 (19.4)	23.6 (15.0)



Low Mass Higgs: $l^+l^-b\bar{b}$

- Typical selection
  - inclusive lepton trigger
  - at least two opposite sign leptons (ee,μμ) with $E_T(p_t)$>10 GeV
  - M_Z -10<M_{ll} <M_Z+10 GeV/c^2
  - two b-tagged jets: one tight b-tag and one loose tag (example soft lepton tag, SLT)
  - scalar sum of the hadronic energy H_T<175 GeV (reject the $t\bar{t}$ background)
  - veto:
    - ✔ no extra jets
- Main backgrounds: $Zb\bar{b}$, $t\bar{t}$, ZZ, tb

P.Bhat et al., Report of the Tevatron HWG



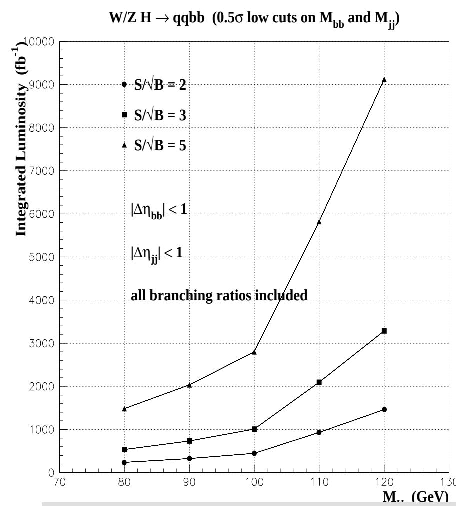
M_H (GeV/c^2)	100	110	120	130
Signal events(S)	1.2	0.9	0.6	0.4
Zbbbar	1.4	1.2	1.0	0.8
ZZ	1.6	0.8	0.1	0.0
ttbar	1.3	1.2	1.2	1.1
Total Background(B)	4.3	3.2	2.3	1.9
S/√B	0.6	0.5	0.4	0.3

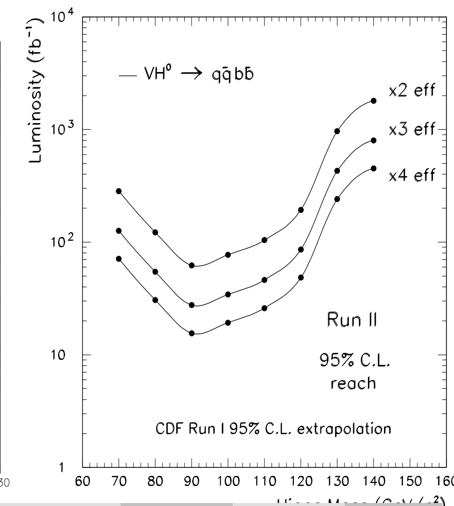
Signal and background events in 1 fb^{-1}

Low Mass Higgs: $qq'b\bar{b}$

- Typical selection
  - multijet trigger
  - $N_{jets}>4$, $E_T>15$ GeV, $|\eta| \leq 2.0$
  - two b-tagged jets, $c \geq 15$ GeV, $|\eta| \leq 2.0$
  - $|\Delta\eta_{bb}| \leq 1$, $|\Delta\eta_{jj}| \leq 1$
  - $M_{jj} \geq M_{w(z)} - \sigma(M_{jj})$
  - $M_{b\bar{b}} \geq M_H - \sigma(M_{b\bar{b}})$
- Main backgrounds: huge QCD, $t\bar{t}$, Zjj, $W/Zb\bar{b}$
- CDF improvements:
  - higher b-tagging efficiency
  - special multijet trigger for associated Higgs production: 3 jets, uneven E_T cuts and lower ΣE_T threshold

A.Goussiou et al., Report of the Tevatron HWG

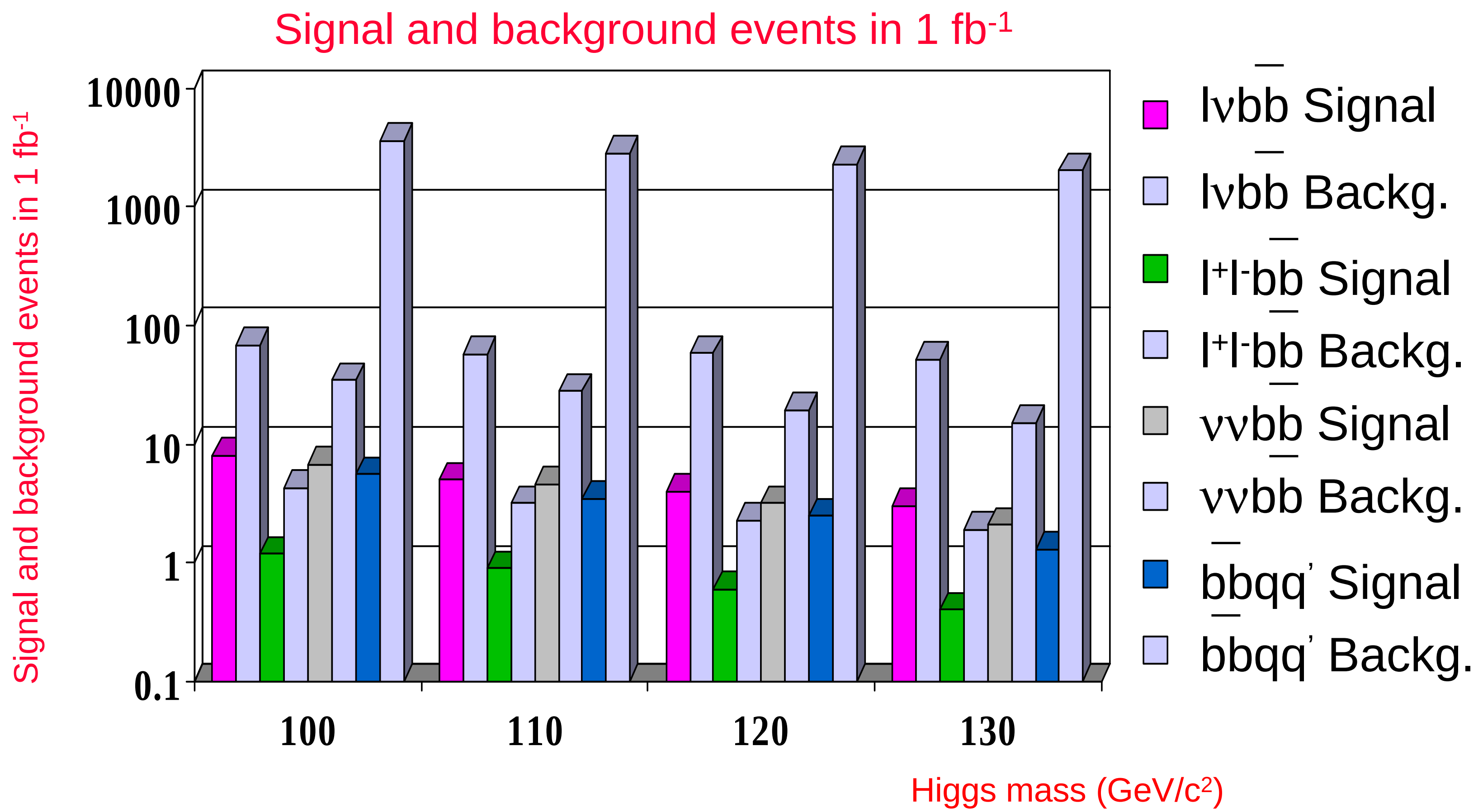




M_H (GeV/c^2)	100	110	120	130
Signal events(S)	5.6	3.5	2.5	1.3
Total Background(B)	3600	2800	2300	2000
$S/\sqrt{B}$	0.09	0.07	0.05	0.03

Signal and background events in 1 fb^{-1}

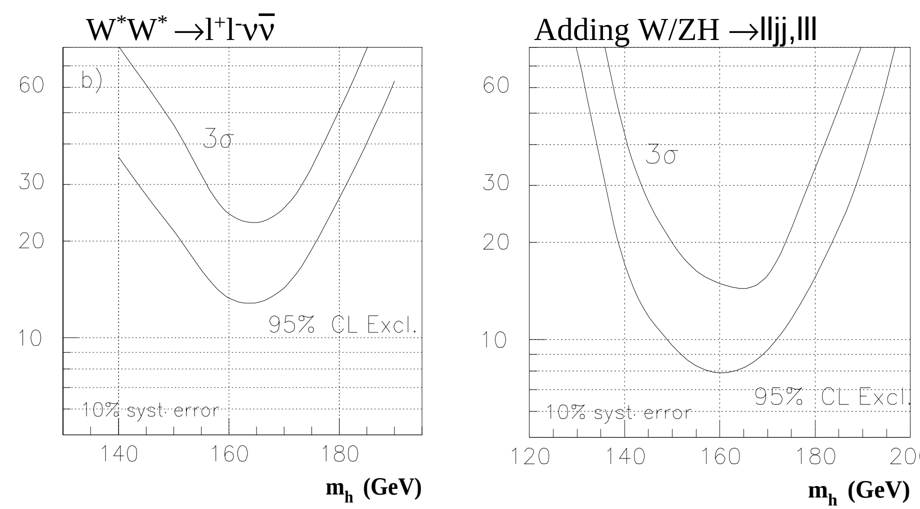
Low Mass SM Higgs: Summary



High Mass Higgs: WW^*, $W\,WW^*$, $Z\,WW^*$

- Focus on $gg \to H \to W^*W^* \to l^+l^-\nu\bar{\nu}$
  - trigger: two high p_t central e or μ
  - angular cuts to remove $\tau\tau$ background
  - veto: events with high E_T jets, or b-tags
  - main backgrounds: WW, $t\bar{t}$
- Add $q\bar{q} \to W(Z)H \to W(Z)W^*W^* \to lllX$ (trilepton) mode
  - special cuts, expect 1 event, 0.5 background at 20 fb^{-1} (M_H =150 GeV/c^2) $S/\sqrt{B} = 1.4$
  - main backgrounds: WZ,ZZ
- $q\bar{q} \to W(Z)H \to W(Z)W^*W^* \to l^{\pm}l^{\pm}jjX$
  - same sign leptons, two jets with E_T>15 GeV, $\not{E}_T$>10 GeV
  - veto: no b-tagged jets
  - main backgrounds: WZ,ZZ,$t\bar{t}$
- Looks very hard to do, Tevatron must exceed its present goals

T.Han et al., Report of the Tevatron HWG

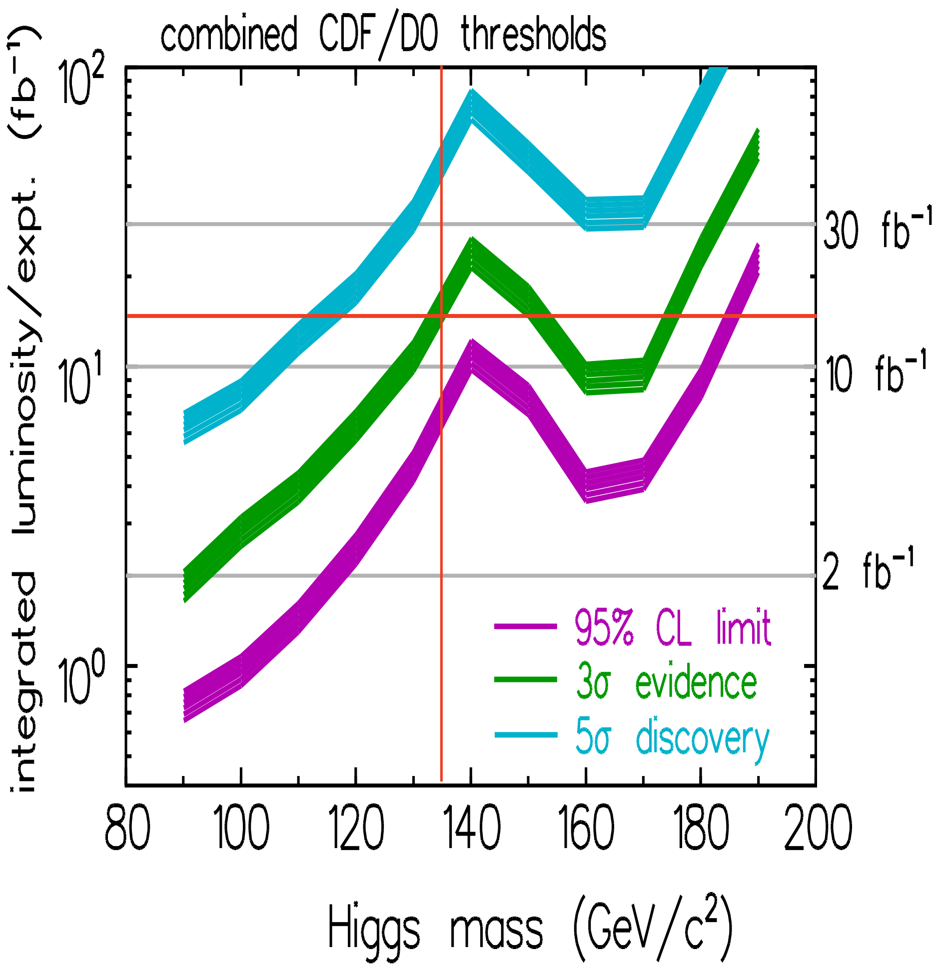


Channel	Rates	Higgs mass (GeV/c^2) 140	150	160	170	180
	S	2.6	2.8	1.5	1.1	1.0
$l^+ l^- \nu\nu$	B	44.0	30.0	4.4	2.4	3.8
	$S/\sqrt{B}$	0.39	0.51	0.71	0.71	0.51
	S	0.29	0.36	0.41	0.38	0.26
$l^{\pm} l^{\pm} jj$	B	0.58	0.58	0.58	0.58	0.58
	$S/\sqrt{B}$	0.38	0.47	0.54	0.50	0.34

Signal and background events in 1 fb^{-1}

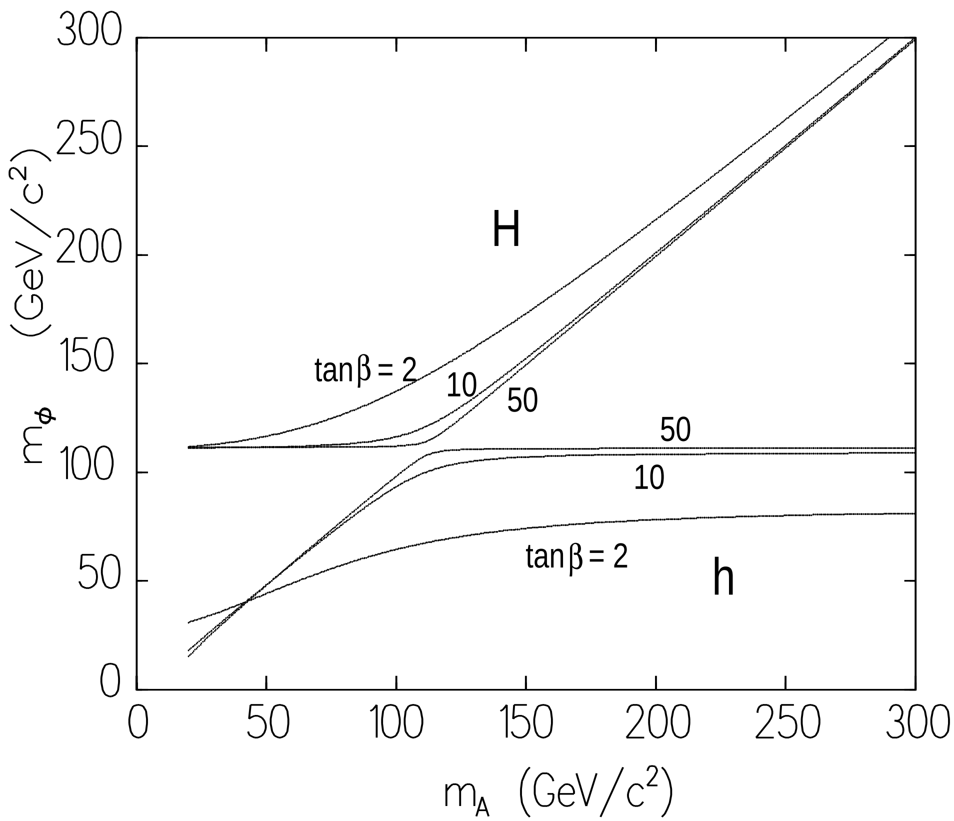
Combined Channels Thresholds

- Bayesian combination method - two experiments (CDF and DØ)
- Band extends upward 30% as an indication of the uncertainties in:
  - b-tagging efficiency
  - mass resolution
  - background rate
  - systematic effects
- These curves are from parameterized simulation (SWH) developed by HWG. We expect to improve on it because:
  - 3D silicon vertexes
  - SVT triggering



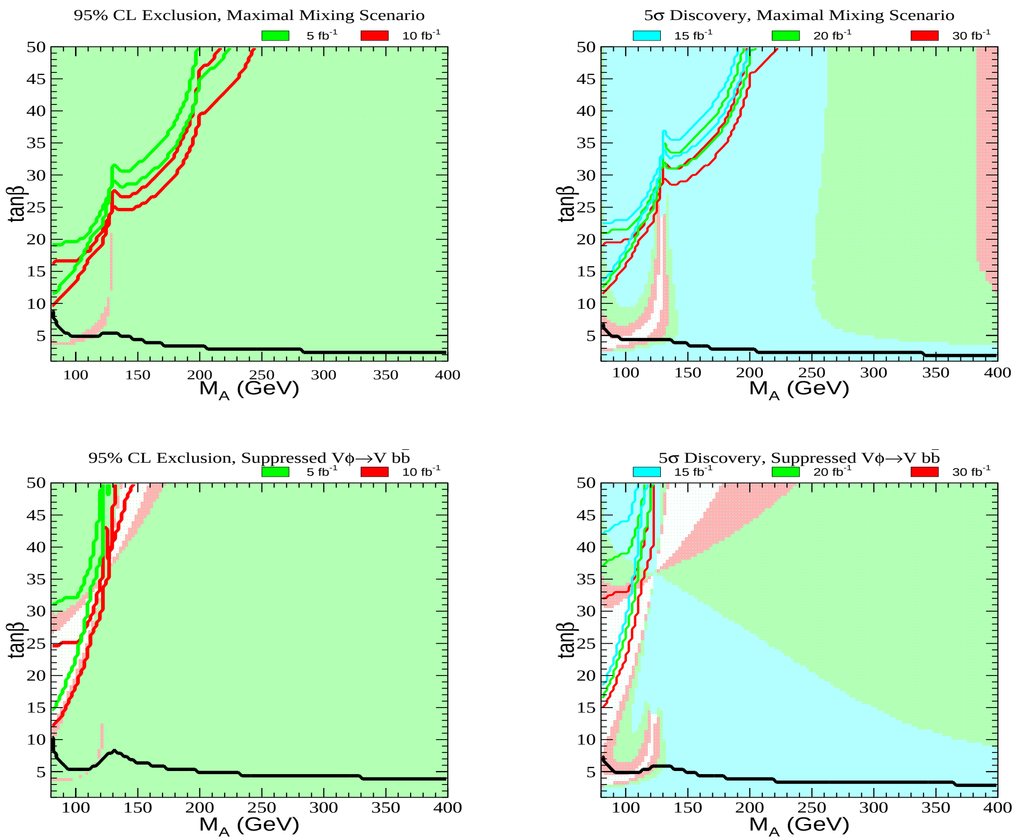
SUSY Higgs (MSSM)

- Focus: the Higgs sector of the minimal supersymmetric model (MSSM)
  - SM with a second Higgs doublet
  - supersymmetric partners
- MSSM has five Higgs bosons: h,A,H,$H^{\pm}$
- Masses are governed by two parameters: M_A and $\tan\beta \equiv v_2/v_1$
- Production of $V\phi$ (ϕ=h,H) can be SM like. We can apply SM Higgs search to MSSM parameter space
- At large tanβ the $b\bar{b}A$ and $b\bar{b}\phi$ production is enhanced (M.Roco et al., Report of the Tevatron HWG)
  - search signatures: $b\bar{b}b\bar{b}$



MSSM Higgs in Run II

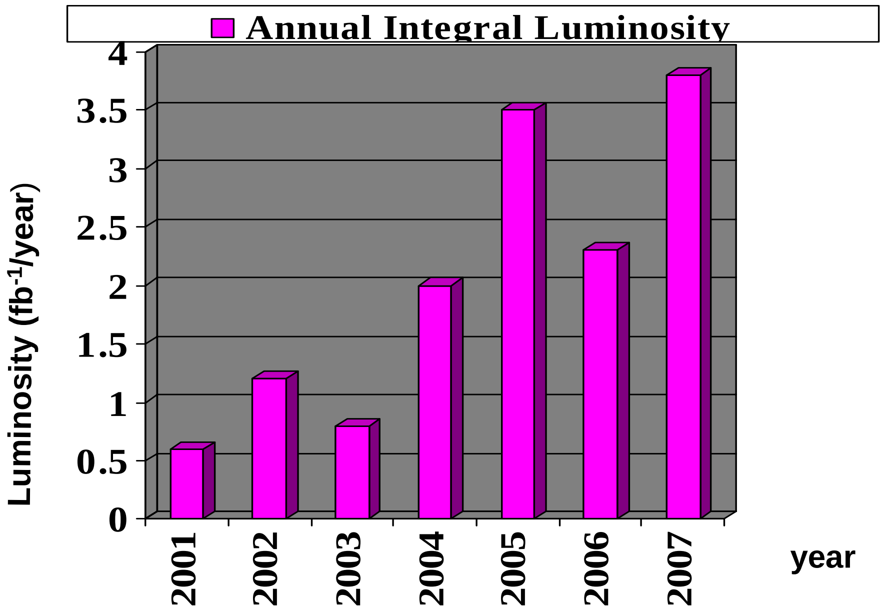
T.Carena, H.E.Haber, S.Mrena and C.E.M.Wagner,
Report of the Tevatron HWG



- Assumption:
  - m_{stop} = 1TeV
  - shaded regions: Vϕ (ϕ=h,H)
  - solid lines: $b\bar{b}\phi$,A
  - left plots: 95 CL exclusion regions
  - right plots: 5σ discovery regions
  - top two plots: maximal mixing in top squark sector
  - lower two plots: particular choice of top squark mixing, which makes a dificult region at large tanβ

Fermilab Long-Term Luminosity Goals

- The initial Run II goal is to achieve a luminosity of ~ 1×10^{32} cm^{-2} sec^{-1}
  - 2 fb^{-1} delivered to each detector, CDF and DØ
- Future accelerator performance would be based upon:
  - electron cooling
  - improved antiproton availability
  - liquid lithium antiproton lens
  - aperture improvements
  - controlling the $p\bar{p}$ beam-beam interaction



Run	Dates	Integrated Lumi (fb^{-1})
I	1993-1996	0.1
IIa	2001-2003	~2
IIb	2004-2007	~15

Long Term Prospects

Possible Accumulation of luminosity before LHC era….

Year	Goal	Luminosity
‘01	Main injector and recycler	0.6 fb^{-1}
‘02	Start antiproton recycling	1.2 fb^{-1}
‘03	6 month shutdown; install e-cool, 132 nsec and etc.	0.8 fb^{-1}
‘04	$L= 2x10^{32}$	2.0 fb^{-1}
‘05	$L = 3x10^{32}$	3.5 fb^{-1}
‘06	$L = 5x10^{32}$, 6 month shutdown to install C-0	2.3 fb^{-1}
‘07	$L= 5x10^{32}$	3.8 fb^{-1}
TOTAL		15.0 fb^{-1} /per exp.

Summary

- The HWG results indicate that a SM Higgs with M_H<190 GeV/c^2 can be excluded at 95% CL with 15 fb^{-1}, and can be discovered at 5σ with M_H<120 GeV/c^2. The actual CDF/DØ detectors might be also do better than HWG simulation.
- There is no single, "golden" discovery channel like we had for the top quark: combining all channels, CDF and DØ results, is crucial!
- To make 3σ evidence or 5σ discovery of a higgs signal at the Tevatron, all the following factors are essential:
  - more luminosity > 15 fb^{-1}
  - significant improvement over Run I
    - ✔ much better b-taging, 3D
    - ✔ dijet and $b\bar{b}$ mass resolution
    - ✔ more efficient triggers, possible calibration on $Z \to b\bar{b}$
    - ✔ improved background estimates and cuts, employing new analysis methods, e.g neural nets …
- The upgraded Tevatron, with assumption above could place tight limits on the MSSM Higgs sector (a good chance for discovery exist, if it is present) before LHC era.