Higgs Searches at the Tevatron

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OUTLINE

1. Light (105- 130 GeV) SM Higgs
   (a) Production Cross-sections for h, Vh at $\sqrt{s}$ =2.0 TeV.
   (b) New Combined Limit
   (c) $Wh \to \ell\nu b\bar{b}$ Searches
   (d) $Zh \to \ell\bar{\ell}b\bar{b}$ Searches
   (e) $Zh \to \nu\bar{\nu}b\bar{b}$ Searches
   (f) $Vh \to q\bar{q}b\bar{b}$ Searches
2. Heavy (130- 180 GeV) SM Higgs
   (a) The Branching Ratio $h \to W^+W^-$.
   (b) Direct h Production, with $h \to W^+W^-$.
   (c) $Wh \to W^+W^-W^\pm$: Same-Sign Dileptons
3. Run 1 SUSY/non-SM Higgs Searches
   (a) Neutral MSSM Higgs Produced with QCD $b\bar{b}$
   (b) Top Decay to Charged Higgs in $\tau + b$ channel
   (c) Top Decay to Charged Higgs in $\ell + \tau$ channel
   (d) Indirect limits on $t \to Hb$ from $\ell\bar{\ell}$ and ℓ+jets
   (e) Bosophilic Higgs: H, $VH \to \gamma\gamma + X$.
   (f) SWHG Projections for Run II
4. Run II: New Capabilities and Uncertainties
   (a) The Accelerator Schedule
   (b) Upgraded Detectors: CDF++ and DØ++.
   (c) Silicon Vertex Trackers (SVT) - triggering on $Z^0 \to b\bar{b}$.
5. Conclusions

INTRODUCTION

LIGHT SM HIGGS ($M_h < 130$ GeV)

Cross-sections for SM Higgs production. (M. Spira)

M_h (GeV)	σ_h (fb)	σ_{Wh} (fb)	σ_{Zh} (fb)	σ_{ttH}^{LO} (fb)
100	1170	308	173	6.3
110	900	224	128	4.8
120	704	165	97	3.7
130	558	124	74	2.9
140	448	94	57	2.2

Branching Ratios (M. Spira):

M_h (GeV)	$BR_{b\bar{b}}$	$BR_{\tau\tau}$	$BR_{W^+W^-}$	$BR_{\gamma\gamma}$
100	81%	8%	1%	0.15%
110	77%	8%	5%	0.19%
120	68%	7%	13%	0.22%
130	53%	5%	29%	0.22%
140	34%	4%	49%	0.19%

▷Individual Signatures are a Product of σ and $B.R.$

Event Rates: Some Examples As Introduction:

Assume $m_h = 120$ GeV, 20 fb^{-1} *per detector*:

- $\underline{Wh \to \ell\nu b\bar{b}}$

$$
\begin{aligned}
165\ fb \times\ 20\ \mathrm{fb}^{-1} &= 3300\ Wh \text{ events produced.}\\
\times\ 0.68 &= 2240\ Wb\bar{b} \text{ events produced.}\\
\text{OR } \times 0.07 &= 224\ W\tau\bar{\tau} \text{ events produced.}\\
\times 2/9 &= 500\ \ell\nu b\bar{b} \text{ events produced.}\\
\text{OR } \times 2/9 &= 50\ \ell\nu\tau\bar{\tau} \text{ events produced.}
\end{aligned}
$$

- $\underline{Zh \to \nu\bar{\nu}b\bar{b}}$

$$
\begin{aligned}
97\ fb \times\ 20\ \mathrm{fb}^{-1} &= 1940\ Zh \text{ events produced.}\\
\times\ 0.68 &= 1320\ Zb\bar{b} \text{ events produced.}\\
\text{OR } \times 0.07 &= 136\ Z\tau\bar{\tau} \text{ events produced.}\\
\times\ 0.2 &= 260\ \nu\bar{\nu}b\bar{b} \text{ events produced.}\\
\text{OR } \times 0.2 &= 27\ \nu\bar{\nu}\tau\bar{\tau} \text{ events produced.}
\end{aligned}
$$

- $\underline{t\bar{t}h \to WWb\bar{b}h \to \ell\nu jjb\bar{b}b\bar{b}}$

$$
\begin{aligned}
3.7\ fb \times\ 20\ \mathrm{fb}^{-1} &= 74\ t\bar{t}h \text{ events produced.}\\
\times\ 0.68 &= 50\ WWb\bar{b}b\bar{b} \text{ events produced.}
\end{aligned}
$$

(N.B. LO calculation- probably 20-35% higher).

<u>Compare to Top Quark Discovery:</u>

$\int \mathcal{L}dt = 67$ pb$^{-1} \times$ 6 pb $=$ 400 $t\bar{t}$ events.

New Detectors have >> $\times 2$ in Acceptance$\times$Effic$\times$Resol

Evidence Paper Was at 20 pb^{-1}, or 120 events

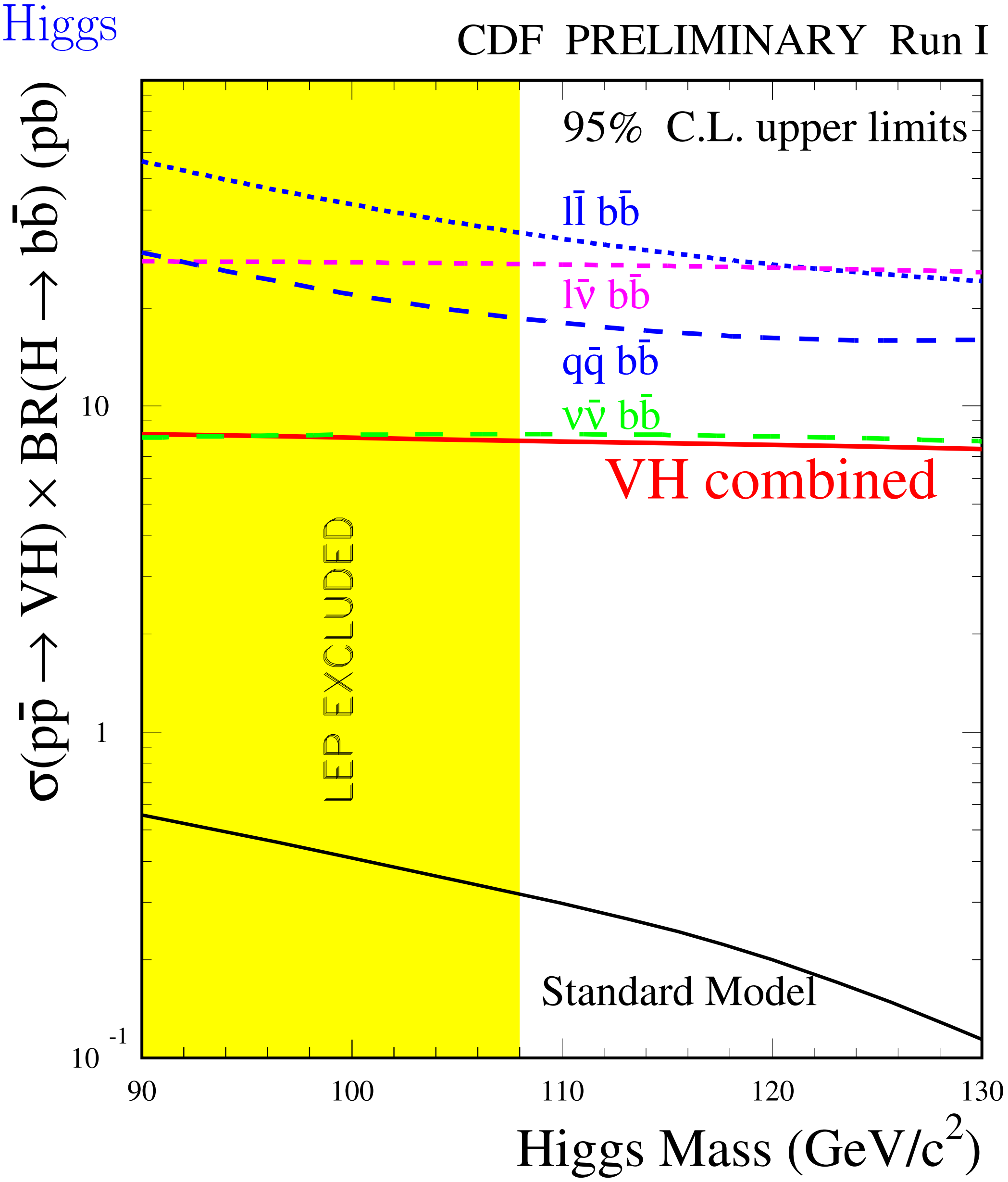
$\triangleright$Given $\int \mathcal{L}dt$, Key Question is Signal to Backgrounds:

W/Z+LIGHT HIGGS: RUN 1 ANALYSES

▷Both CDF and D0 have looked for associated production, Vh

Production	Decay	CDF Reference	D0 Reference
Wh	$\ell\nu b\bar{b}$	PRL 79, 3819 (1997)	P. Tamburello (ICHEP96)
Vh	$jjb\bar{b}$	PRL 81, 5748 (1998)	————-
Zh	$\nu\nu b\bar{b}$	PRL in preparation	Lepton-Photon 97
Zh	$\ell\bar{\ell}b\bar{b}$	PRL in preparation	————-

NEW RESULT: Combined CDF Vh Searches For a Light SM Higgs



▷Summarize These In Turn, One in Some Detail

CDF Analysis of $W^{\pm}h \to (e^{\pm}\nu_e \text{ or } \mu^{\pm}\nu_{\mu})$

Event Selection:

1. A central ($|\eta| < 1$) electron or muon with $\mathrm{E_T} > 20$ GeV
2. Missing transverse energy ($\not{E}_t$) > 20 GeV
3. Two jets, found with a cone size of $R = 0.4$ in $\eta - \phi$ space, with $\mathrm{E_T} > 15$ GeV and $|\eta| < 2.0$

Event Anti-Selection:

1. Remove Z candidates:
2. Remove top quark dilepton candidates:

B-tagging:

Use the same algorithms as used in the top discovery: a silicon-vertex detector displaced vertexing algorithm (SECVTX), and a soft-lepton algorithm (SLT), modified by adding a requirement that the track have a displaced impact parameter (increases the purity).

1. Require at least one jet to be tagged by SECVTX.
2. Single-tag analysis: the second jet must not be tagged
3. Double-tag analysis: the 2nd jet is tagged either by SECVTX or SLT.

Efficiencies/Acceptance:

Accept $\times$Effic $\times \mathrm{BR}_{\mathrm{W}^{\pm} \to l^{\pm}\nu} \times \mathrm{BR}_{h \to b\bar{b}} \simeq 0.003$ for double-tags,

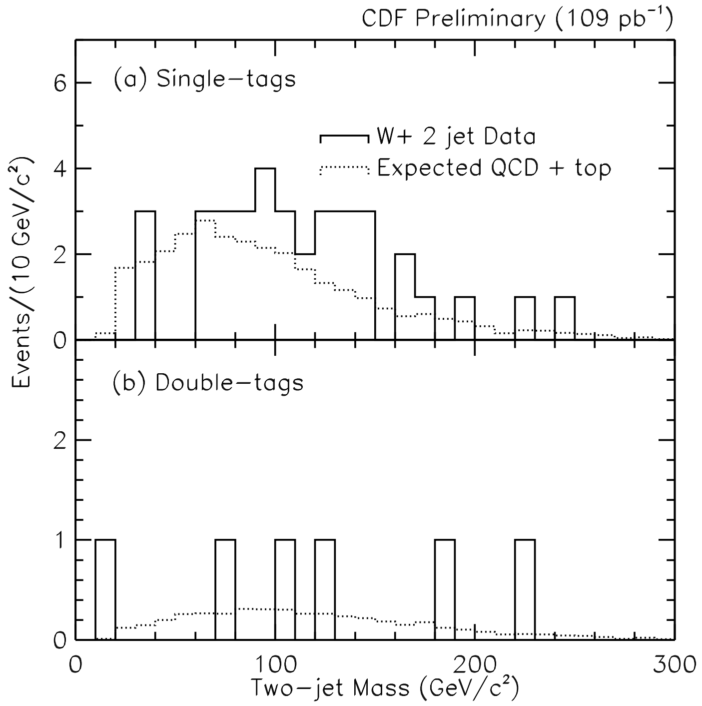
at $M_h = 110$ GeV (grows with mass).

SM Backgrounds to $Wh \to \ell\nu b\bar{b}$:

	W+1 jet	W+2 jet	W+3 jet	W+ $\geq$4 jet
Before tagging	10 135	1 527	232	67
Events with single tag				
QCD	65 ± 13	22.4 ± 4.5	4.9 ± 1.1	1.4 ± 0.4
top	2.2 ± 0.7	7.2 ± 1.4	11.0 ± 1.7	11.6 ± 3.0
QCD + top	67 ± 13	30 ± 5	16 ± 2	13 ± 3
Obs. (e+jets)	36	22	4	5
Obs. (μ+jets)	30	14	7	7
Events with double tag				
QCD	0	1.6 ± 0.4	0.3 ± 0.1	0.15 ± 0.03
top	0	1.4 ± 0.4	3.3 ± 0.5	5.0 ± 1.1
QCD + top	0	3.0 ± 0.6	3.6 ± 0.6	5.2 ± 1.1
Obs.(e+jets)	0	2	3	2
Obs.(μ+jets)	0	4	3	0

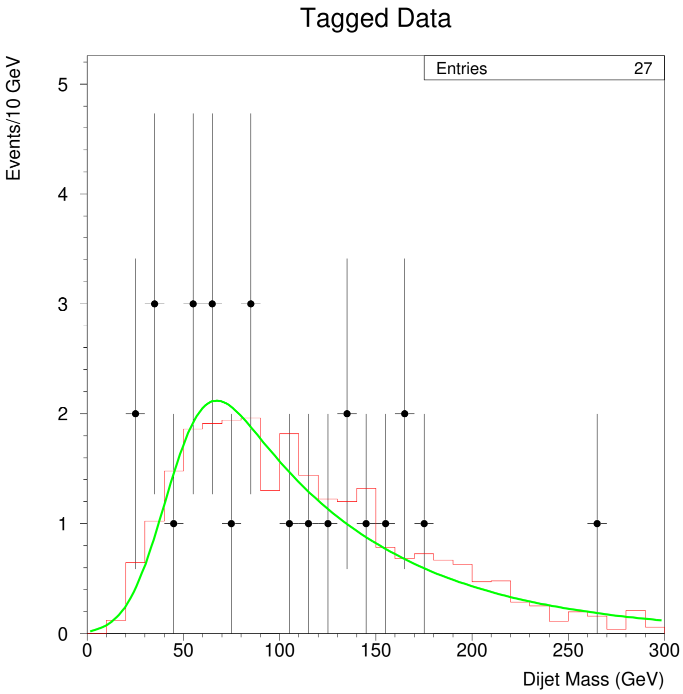
Table 1: The predicted numbers of tagged $W+$ n jet events from QCD backgrounds ($Wb\bar{b}$, $Wc\bar{c}$, mistags, Wc and other small backgrounds) and top production ($t\bar{t}$ and single top) and the number of events observed.

CDF and D0 Measured Dijet Mass Distributions



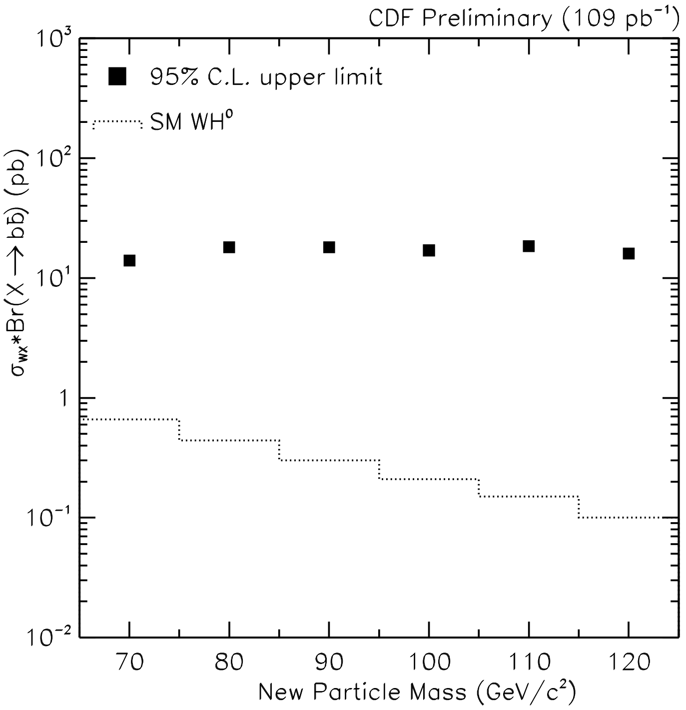
CDF Single+Double Tag

Dijet Masses



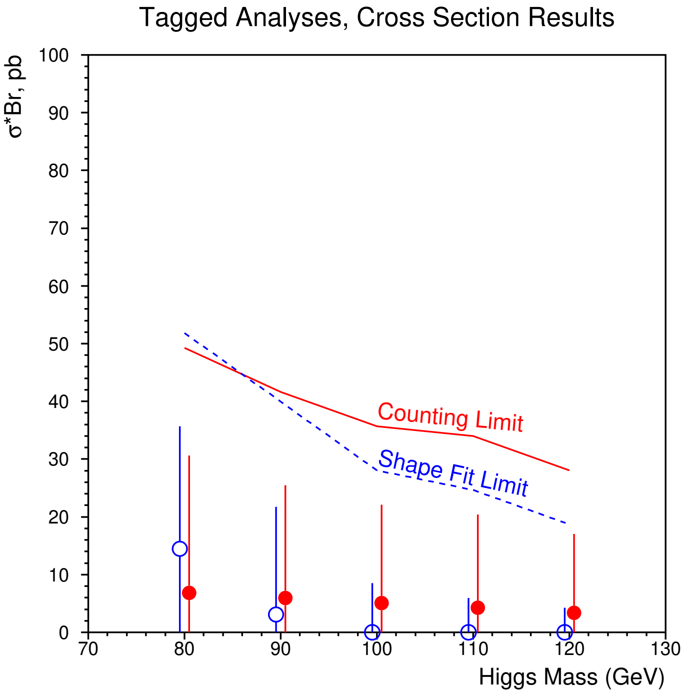
D0 Single Tag Dijet Masses

CDF and D0 Limit Plots



CDF 95% C.L. Limit and

SM Cross Section



D0 95% C.L. Limit and

Best-Fit Cross Section

CDF Analysis of $Zh \to \nu\bar{\nu}b\bar{b}$ (0.086 fb^{-1})

(Reminder: Cross-section×BR: $M_h = 110$: 20 fb; $M_h = 130$: 7.8 fb)

Event Selection:

1. Missing transverse energy trigger ($\not{E}_t^{Trig}$) > 35 GeV
2. Missing transverse energy $\not{E}_t > 40$ GeV
3. Two *or* 3 jets, found with a cone size of $R = 0.4$ in $\eta - \phi$ space, with $E_T > 15$ GeV and $|\eta| < 2.0$
4. $\Delta\phi_{j_1 j_2} < 2.6$; $\Delta\phi_{j\not{E}_t} > 1.0$ $\forall$ jets with $E_T > 8$ GeV and $|\eta| < 2.4$.

Event Anti-Selection:

Remove leptonic W and Z candidates, including tau's, by removing events with (loosely) identified e and μ, or an isolated track.

B-tagging:

Use two algorithms: a silicon-vertex detector displaced-vertexing algorithm (SECVTX), and a jet-probability algorithm ($P < 0.05$).

1. Require at least one jet to be tagged by SECVTX.
2. Single-tag analysis: the second jet must not be tagged
3. Double-tag analysis: the second jet is tagged either by SECVTX or JETPRB.

Efficiencies/Acceptance:

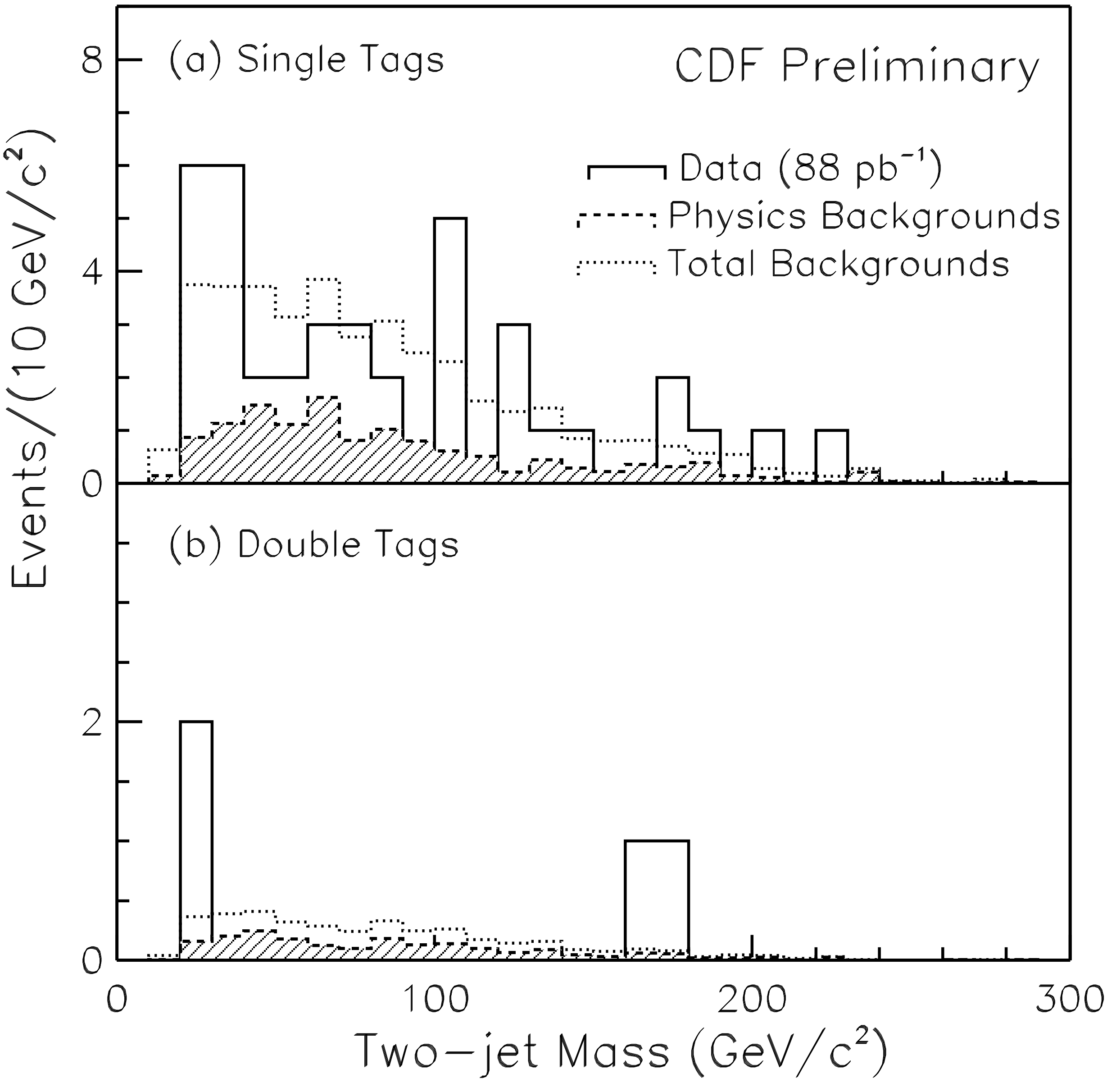
Accept×Effic×BR($Z \to \nu\bar{\nu}$)×BR($h \to b\bar{b}$) $\simeq 0.0033 \pm .0007$ for double-tags, $M_h = 110$ GeV (grows with mass).

SM Backgrounds to $Z \to \nu\bar{\nu}$:

Process	Events Expected
QCD (jet production, inc. $b\bar{b}$):	1.9 ± 0.4 Events
W/Z+ heavy flavor:	1.0 ± 0.2 Events
Top:	0.8 ± 0.2 Events
WZ and ZZ:	0.17 ± 0.04 Events
Total Background:	3.9 ± 0.6 Events

$Zh \to \nu\bar{\nu}b\bar{b}$;CDF: 0.086 fb^{-1}(Continued)

CDF Measured Dijet Mass Distributions



▷Find 4 Events with 2 Tagged Jets (3.9±0.6 Expected)

▷Best Channel So Far In Terms of Sensitivity

CDF Analysis of $Zh \to \ell\ell b\bar{b}$

(Reminder: Cross-section×BR: $M_h = 110$: 6.6 fb; $M_h = 130$: 2.6 fb)

Builds on work in $Zh \to \nu\bar{\nu}b\bar{b}$ channel.

Event Selection:

1. A 'tight' central ($|\eta| < 1$) e or μ, $\mathrm{p_T} > 20$ GeV
2. A 'loose' e or μ, $\mathrm{E_T^e} > 10$, $\mathrm{p_T^\mu} > 10$ (μ ID) or 20 (no μ ID); e^+e^-, $\mu^+\mu^-$.
3. $76 < M_{\ell\ell} < 106$ GeV
4. $\not{E}_t < 50$ GeV (to get rid of Top).
5. Two *or* 3 jets, cone $R = 0.4$ in $\eta - \phi$; $\mathrm{E_T} > 15$ GeV and $|\eta| < 2.0$

B-tagging:

1. Require at least one jet to be tagged by SECVTX.
2. Single-tag analysis: the second jet must not be tagged
3. Double-tag analysis: the second jet is tagged either by SECVTX or JETPRB.

Efficiencies/Acceptance:

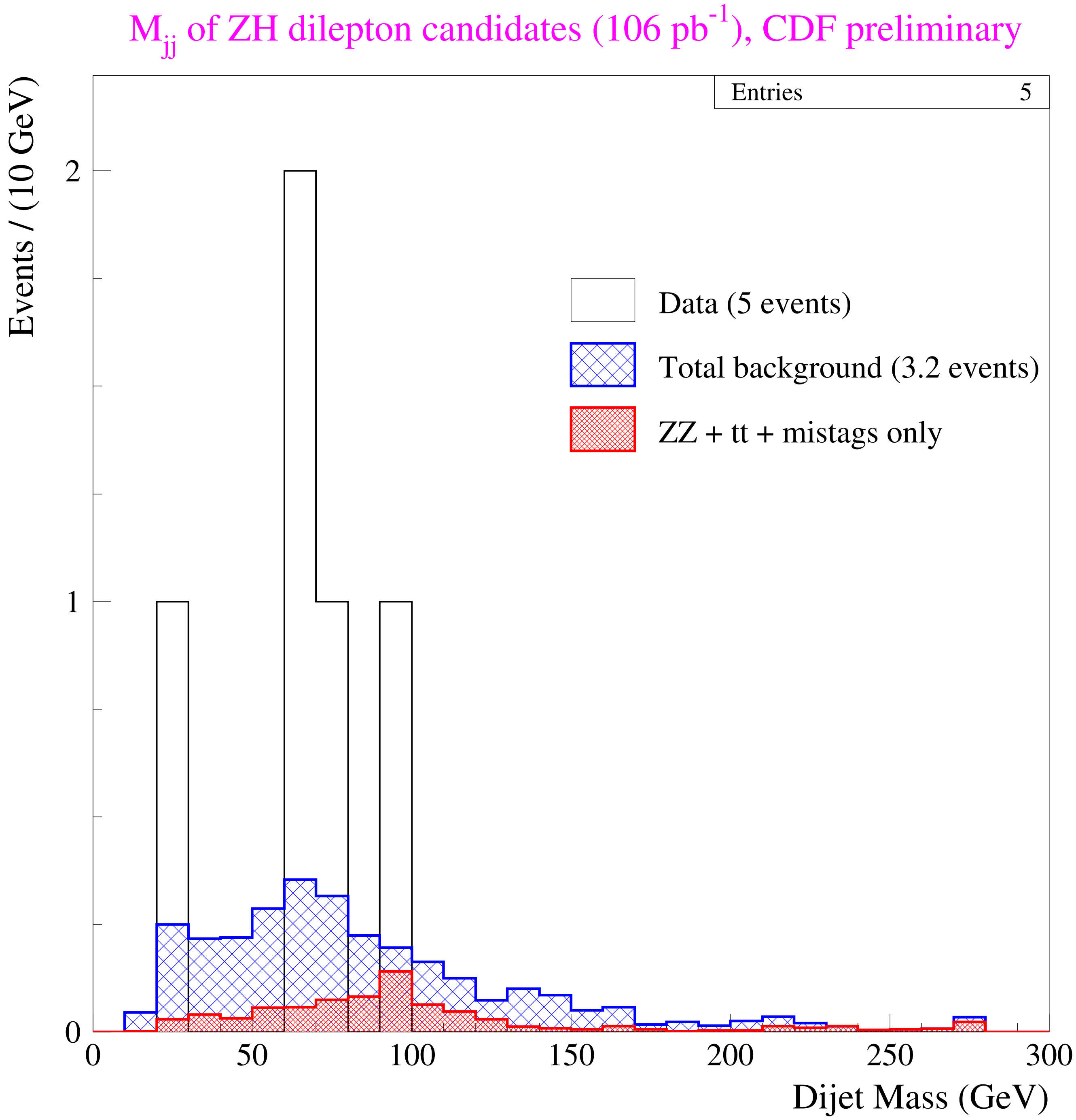
Accept×Effic×BR($Z \to \nu\bar{\nu}$)×BR($h \to b\bar{b}$) $\simeq 0.0046 \pm .0009$

for single+double-tags, $M_h = 110$ GeV (grows with mass).

SM Backgrounds to $hZ \to \ell\bar{\ell}$ (0.1106 fb^{-1}):

$Zb\bar{b}$:	1.7 ± 0.7 Events
$Z+$ Mistag:	0.65 ± 0.13 Events
$Zc\bar{c}$:	0.32 ± 0.13 Events
WZ and ZZ:	0.19 ± 0.06 Events
$Zc\bar{s}$:	0.17 ± 0.10 Events
Top: ($t\bar{t}$):	0.13 ± 0.04 Events
Single Top:	0.0 ± 0.0 Events
Total Bkgd (Single+Double Tag):	3.2 ± 0.7 Events (ee =2.05, $\mu\mu$ =1.13)

CDF Measured Dijet Mass Distributions in $Zh \to \ell\bar{\ell}b\bar{b}$



▷Find 5 Events with 2 Tagged Jets, Versus 3.2±0.7 Expected Background.

▷Adds ~30% to $Zh \to \nu\bar{\nu}b\bar{b}$ Channel Sensitivity for $M_h = 110$ GeV

.

CDF Analysis of $Vh \to Vh \to jjb\bar{b}$ (.091 fb^{-1})

(Reminder: Cross-section×BR: $M_h = 110$: 115 fb for $W^{\pm}h$, 70 fb for Z^0h;

$M_h = 130$: 44 fb for $W^{\pm}h$, 27.4 for Z^0h)

▷$V \equiv W$ or Z^0: Big Branching Ratios For $V \to q\bar{q}$.

Event Selection:

1. Four *or* more jets, found with a cone size of $R = 0.4$ in $\eta - \phi$ space, with $\mathrm{E_T} > 15$ GeV and $|\eta| < 2.1$
2. At least two jets of the 4 highest $\mathrm{E_T}$ tagged by SECVTX.
3. $\mathrm{p_T}(b\bar{b}) \geq 50$ GeV.

Efficiencies/Acceptance:

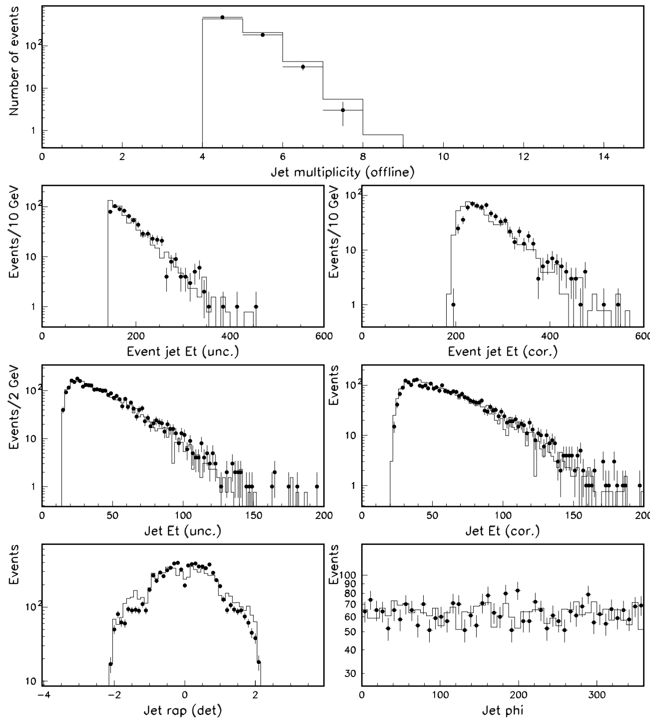
1. $\epsilon_{doubletag} \simeq 14.5\%$
2. $\epsilon_{\mathrm{p_T}^{b\bar{b}}>50} \simeq 75\%$
3. Accept.×Effic×BR$(Z \to \nu\bar{\nu})$×BR$(h \to b\bar{b}) \simeq 0.015 \pm .006$ for $M_h = 110$ GeV (grows to be 2.2% at $M_h = 140$).

SM Backgrounds:

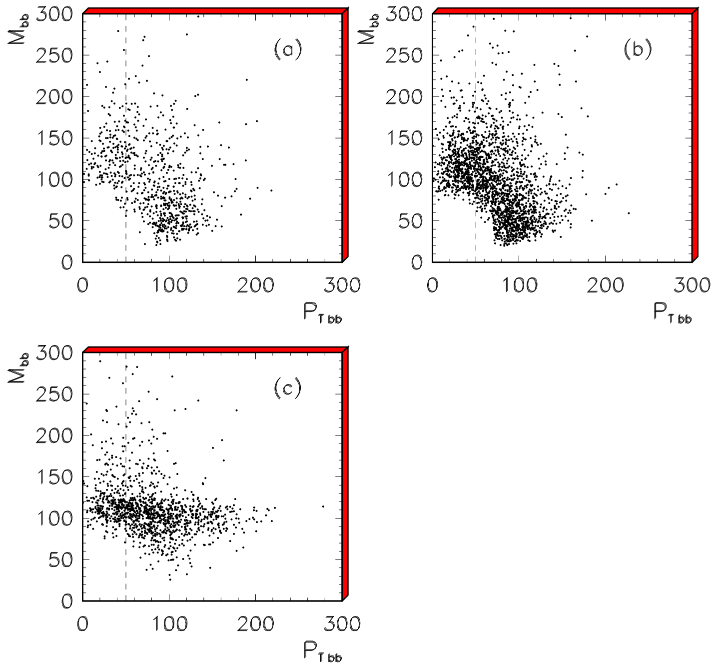
Background Shapes are from MC; the dominant QCD background is from a fit; the others are normalized to data.

Process	Expected	From Fit To Data
QCD (from fit to data)	———-	474 ± 27 Events
Fake tags	89 ± 11 Events	83 ± 11 Events
Top ($t\bar{t}$):	26 ± 7 Events	22 ± 7 Events
$Z \to b\bar{b}, c\bar{c}$+jets:	17 ± 4 Events	15 ± 4 Events
W$b\bar{b}$,W$c\bar{c}$ (not fit):	1.2 ± 0.4 Events	———-
Z$b\bar{b}$,Z$c\bar{c}$ (not fit):	0.7 ± 0.3 Events	———-
Total Background:	———-	596 ± 30 Events

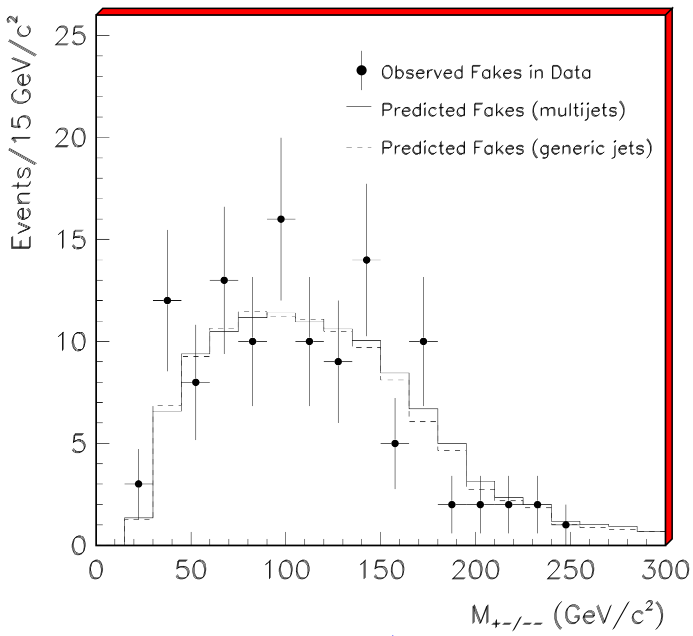
$Vh \to q\bar{q}b\bar{b}$; CDF: 0.091 fb^{-1}(Continued)



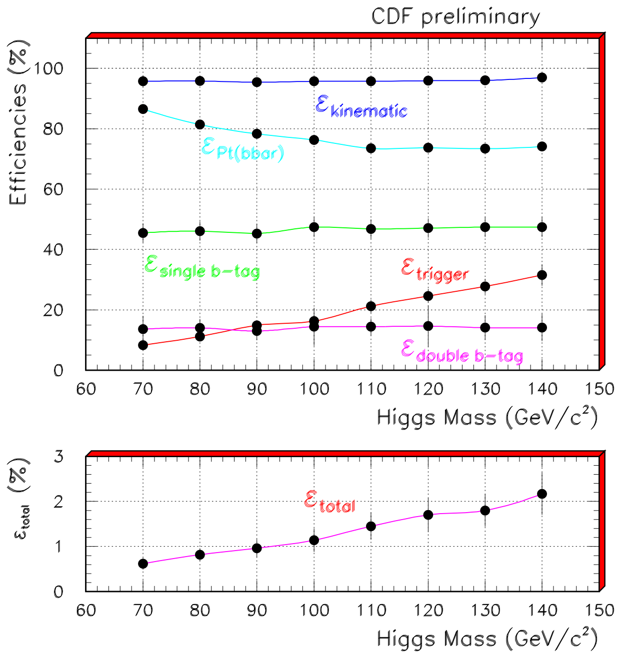
Jet Data/MC Comparison



a)Data; b)$b\bar{b}c\bar{c}$; c) Vh



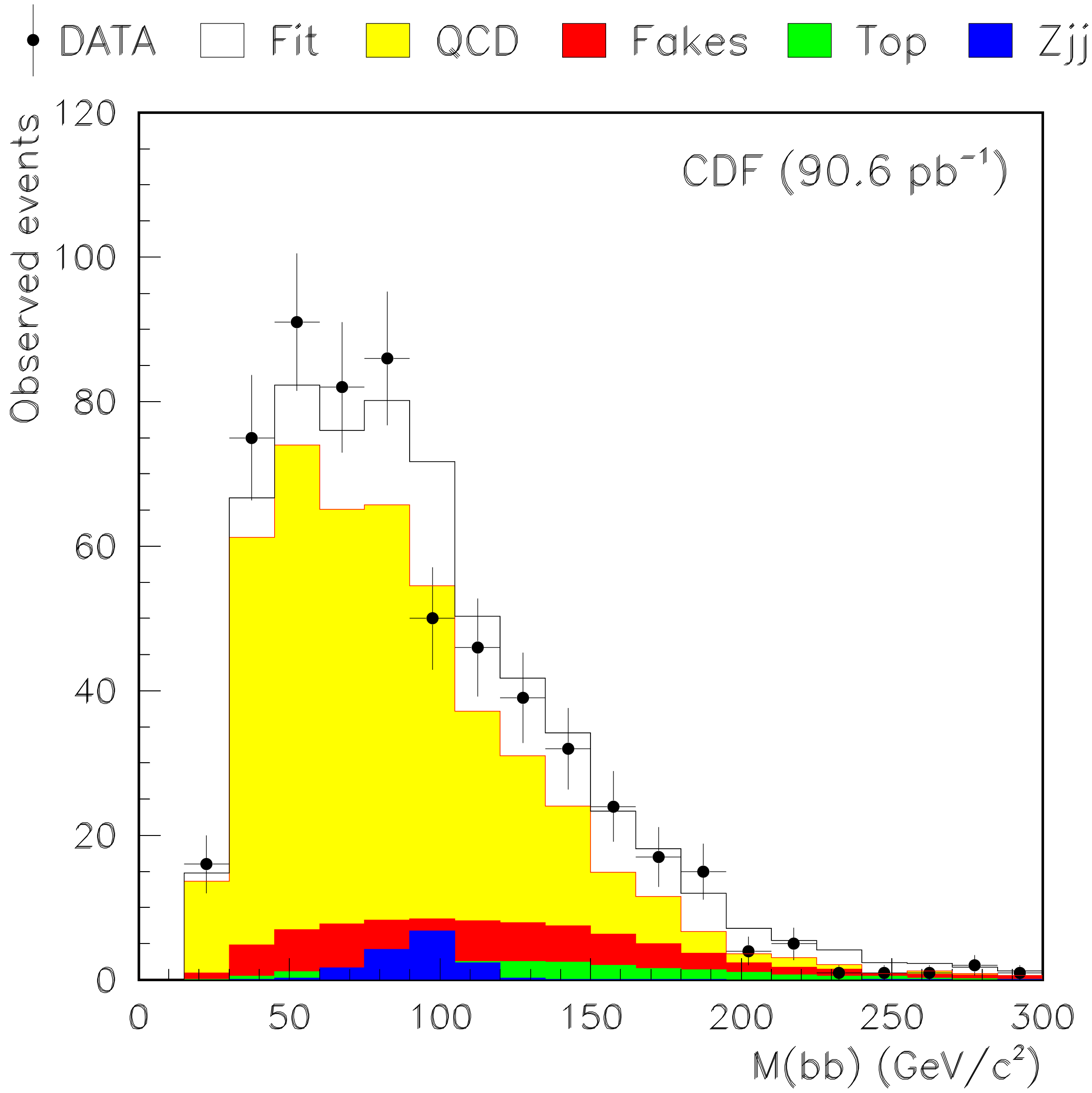
Observed/Predicted Fakes



Efficiencies

$Vh \rightarrow q\bar{q}b\bar{b}$; CDF: 0.091 fb^{-1}(Continued)

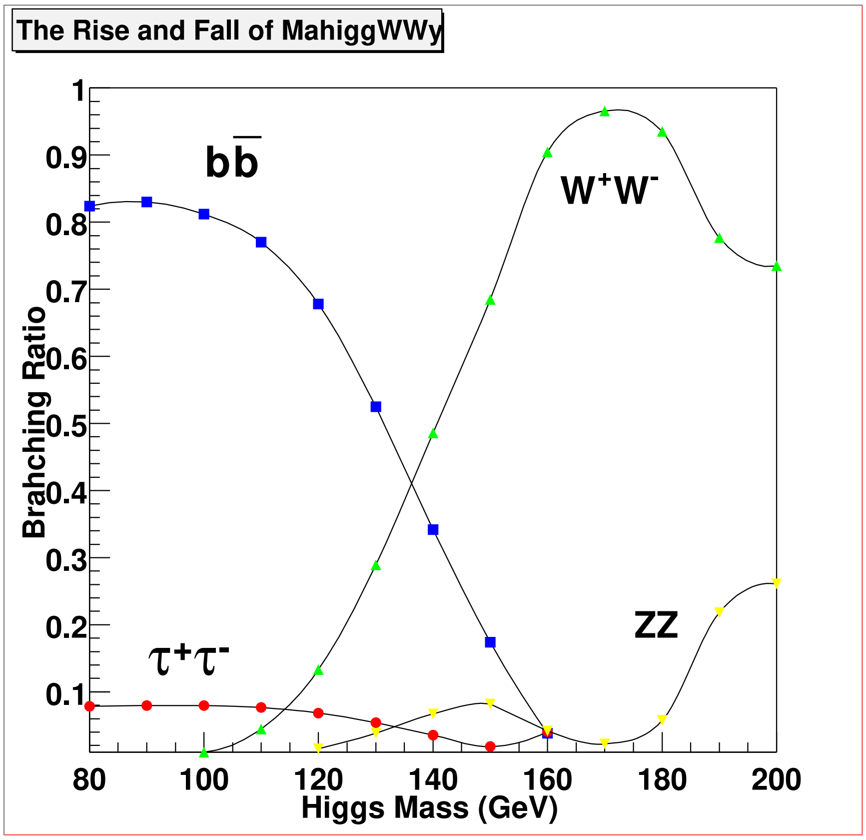
▷Fit for Higgs Signal On Top of Backgrounds



▷Good Fit (With No Higgs Contribution $M_h > 80$ GeV

HEAVY HIGGS ($M_h > 130$ GeV)

▷BR FOR $h \to W^+W^-$ RISES AS $M_H \to 2M_W$.



M_H (GeV)	BR_{WW}	BR_{ZZ}
130	29%	4%
150	69%	8%
170	97%	2%
190	78%	22%

▷TWO DOMINANT PRODUCTION MECHANISMS:

M_H (GeV)	σ_H (fb)	$\sigma_{WH(ZH)}$ (fb)	$\sigma_H \cdot BR_{WW}$	$\sigma_{WH(ZH)} \cdot BR_{WW}$
130	558	124 (74)	162	36 (3)
150	364	72 (44)	251	50 (4)
170	247	43 (27)	240	42 (-)
190	172	27 (17)	134	20 (4)

HEAVY HIGGS to DILEPTONS ($h \to WW$)

$e\mu, ee, \mu\mu + \not{E}_t$ channel

▷h→ WW allows use of $gg \to h \to WW$ cross-section.

▷BR $W^{\pm} \to e^{\pm}\nu = 1/9$, so $e\mu$ is 2/81, ee, $\mu\mu$ are 1/81.

▷BACKGROUNDS (after leptonic BR's):

1. WW: 500 fb
2. $t\bar{t}$: 320 fb
3. $Z^0 \to \tau^+\tau^-$: 220 fb
4. WZ, fake leptons, etc....

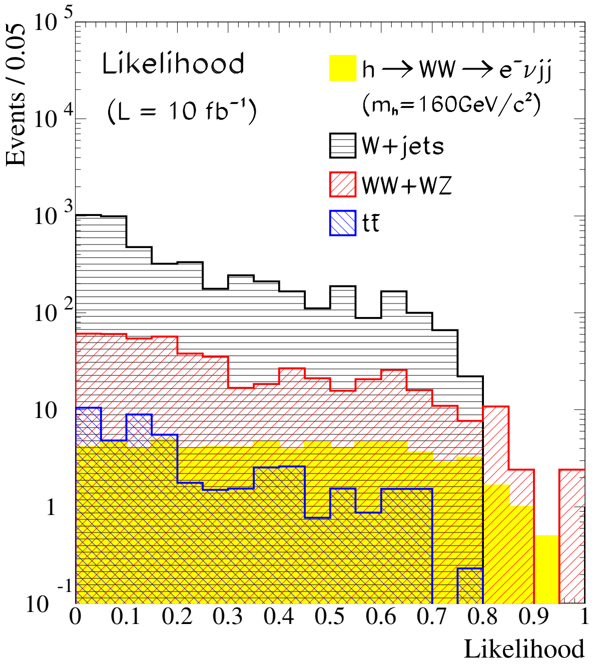
to be compared with the signal of 18 fb.

▷In 10 fb^{-1}per detector, make 180 signal events, but backgd is large, and is *very* similar in signature (WW).

Preliminary look (Han, Lucotte, Schmitt, Turcot, Zhang; Higgs):

M_h [GeV]	140	150	160	170	180	190
signal [fb]	3.9	4.4	5.2	4.8	3.6	2.5
effic. [%]	35	34	38	39	36	37
	WW	$t\bar{t}$	$\tau^+\tau^-$	WZ	ZZ	W+fake
bckgrnds [fb]	130	13	0	4.4	2.4	18

▷Han *et al.* make a likelihood out of kinematic variables;

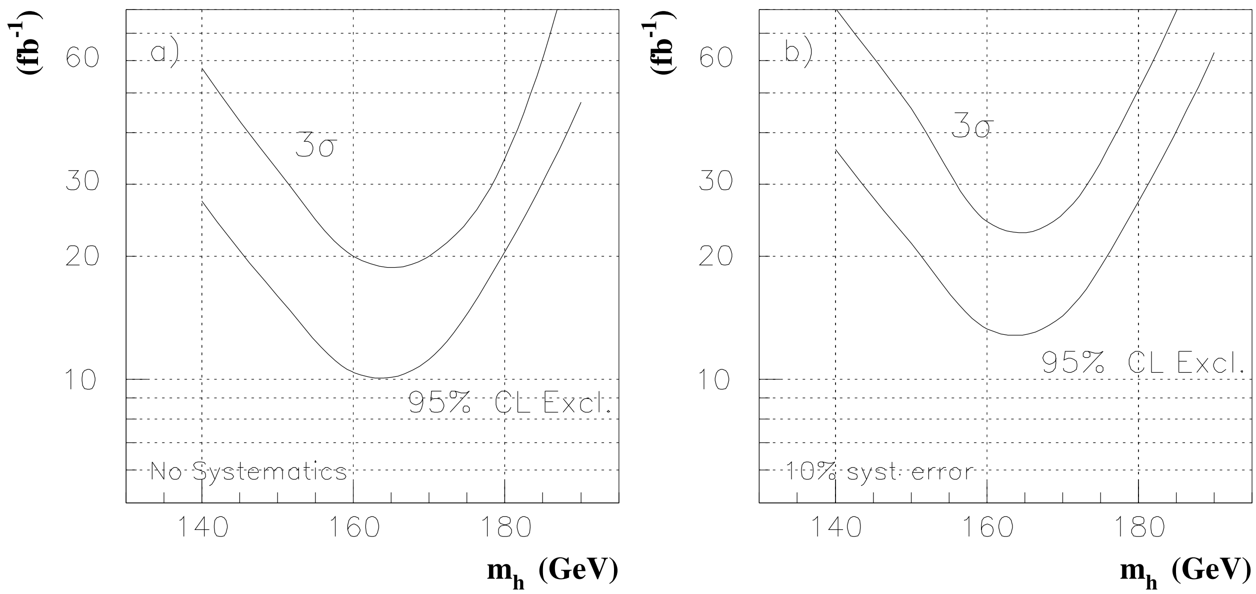


HEAVY HIGGS ($M_h > 130$ GeV) Dilepton Channel (Continued)

M_h [GeV]	140	150	160	170	180	190
$gg \to h$ [fb]	2.2	2.4	1.3	0.93	0.85	0.73
associated VH [fb]	0.26	0.31	0.13	0.09	0.06	0.06
VV fusion [fb]	0.12	0.12	0.09	0.06	0.05	0.05
signal sum [fb]	2.6	2.8	1.5	1.1	0.96	0.83
SM bckgrnds [fb]	39	27	4.1	2.3	3.8	7.0
fake $j \to e$ [fb]	5.1	3.4	0.34	0.15	0.08	0.45
bckgrnds sum [fb]	44	30	4.4	2.4	3.8	7.5
S/B [%]	5.8	9.4	34	45	25	11
$S/\sqrt{B}$ [30 fb^{-1}]	2.1	2.8	3.9	3.8	2.7	1.7

Table 2: Summary table for $h \to WW \to \ell\ell$ signal for $M_h = 140 - 190$ GeV and various SM backgrounds after the kinematical cuts and the likelihood cut

Han et al. Plot 3-σ and 95% C.L. Limits



▷Looks hard: requires accelerator to exceed goals:
▷Lots of work to be done (other channels)...
▷Will show reach when combined with Wh below...

HEAVY HIGGS: Wh to $W^+W^-W^\pm$

▷h→ WW allows use of $Wh \to WWW$ at substantial numbers of events produced. Take 20 fb^{-1}recorded per detector as a benchmark.

▷hW cross section is (arguably) large:
Tabulate number of dilepton events from $hW \to W^+W^-W^\pm$ *per detector* in 20 fb^{-1}versus M_h :

M_h	$\sigma_{W^+W^-W^\pm}$	$N_{W^+W^-W^\pm}$	$N_{\geq 1e,\mu}$	$N_{\geq 2e,\mu}$
130	36 fb	720 Events	380 Events	106 Events
150	50 fb	1000 Events	530 Events	150 Events
170	42 fb	840 Events	440 Events	120 Events
190	20 fb	400 Events	210 Events	60 Events

▷Rates are substantial- all a question of background rejection and resulting efficiency.

▷BACKGROUNDS (after leptonic BR's):

1. Tribosons: $WWW(6fb), WWZ(5fb), WZZ(1.1fb), ZZZ(.05fb)$;
2. W+Drell-Yan$\ell\bar{\ell}$: $W(Z/\gamma^*)jj, , Z(Z/\gamma^*)jj$:
3. Top: $t\bar{t} \to \ell\nu jjb\bar{b}$: 1925 fb
4. Fakes: $Wjj \to \ell\nu jj, Zjj \to \ell\nu jj$, with jet faking a lepton: 100 pb $\times$ (Fake Rate $\equiv F_k$). Run 1 DØ $F_k \sim 10^{-4}$) would give 10 fb.

▷There are a number of possible signatures: For example, a preliminary study from the Run II Higgs Working Gp.:

SS Dileptons: $e^{\pm}\mu^{\pm}, e^{\pm}+e^{\pm}, \mu^{\pm}\mu^{\pm} + \not{E}_t$ channel

Preliminary look:

(Han, Turcot, Zhang; hep-ph/9812275): Han, Lucotte, Schmitt, Turcot, Zhang; SHWG Report):

▷EVENT SELECTION

1. Leptons: 2 Isolated e or μ with $p_T > 10$ GeV, $|\eta| < 1.5$; $\Delta R(\ell j) > 0.3$, $m_{ll} > 10$ GeV, non-coplanar and non-collinear;
2. Jets: $n_{jet} \geq$ 2 jets with $E_T > 15$, $|\eta| < 3.0$;
3. Missing Et: $\not{E}_t > 10$ GeV;
4. WZ rejection: J_1 in $|\eta| < 1.5$, J_2 in $|\eta| < 2.0$;
5. Top rejection: J_3 has $E_T < 30$ GeV;
6. Top,b rejection: no b-tagged jet among above;
7. Tau rejection: J_1 has > 2 tracks;
8. W,Z rejection: Sum $Et_{jets} > 150$ GeV;
9. Misc.: $m_{jj} < 110$ GeV.
10. Spin 0 vs Spin 1: cos(lepton pair, leading lepton)$\equiv \cos\theta^*_{\ell_1} < 0.95$

▷RESULTS of Han et al:

M_h [GeV]	120	130	140	150	160	170	180	190	200
signal sum [fb]	0.093	0.20	0.34	0.52	0.45	0.38	0.29	0.20	0.16
background channels	WZ	ZZ	WW	$t\bar{t}$	VVV	$t\bar{t}V$	W/Z+fake	Sum	
σ [fb]	0.27	0.06	0.01	0.15	0.07	0.02	0.26	0.83	
S/B [%]	11	24	41	63	54	46	35	24	19
$S/\sqrt{B}$ [30 fb^{-1}]	0.56	1.2	2.0	3.1	2.7	2.3	1.7	1.3	0.96

▷At 30 fb^{-1} **recorded** the results of Han et al. barely get to 3-σ.

Projections of Reach for a SM Higgs in Run II:

▷Work of Higgs Working Group (Carena, Conway, Haber, Hobbs et al)

▷The Problem Is That It Is a Big Extrapolation:

M_h [GeV]	110	130
95% C.L. Limit [fb]	7800	7400
SM CrossSection [fb]	250	100
Ratio Limit/SM	31	74

Note- 20 fb^{-1}/detector is >200 times the Run I exposure.

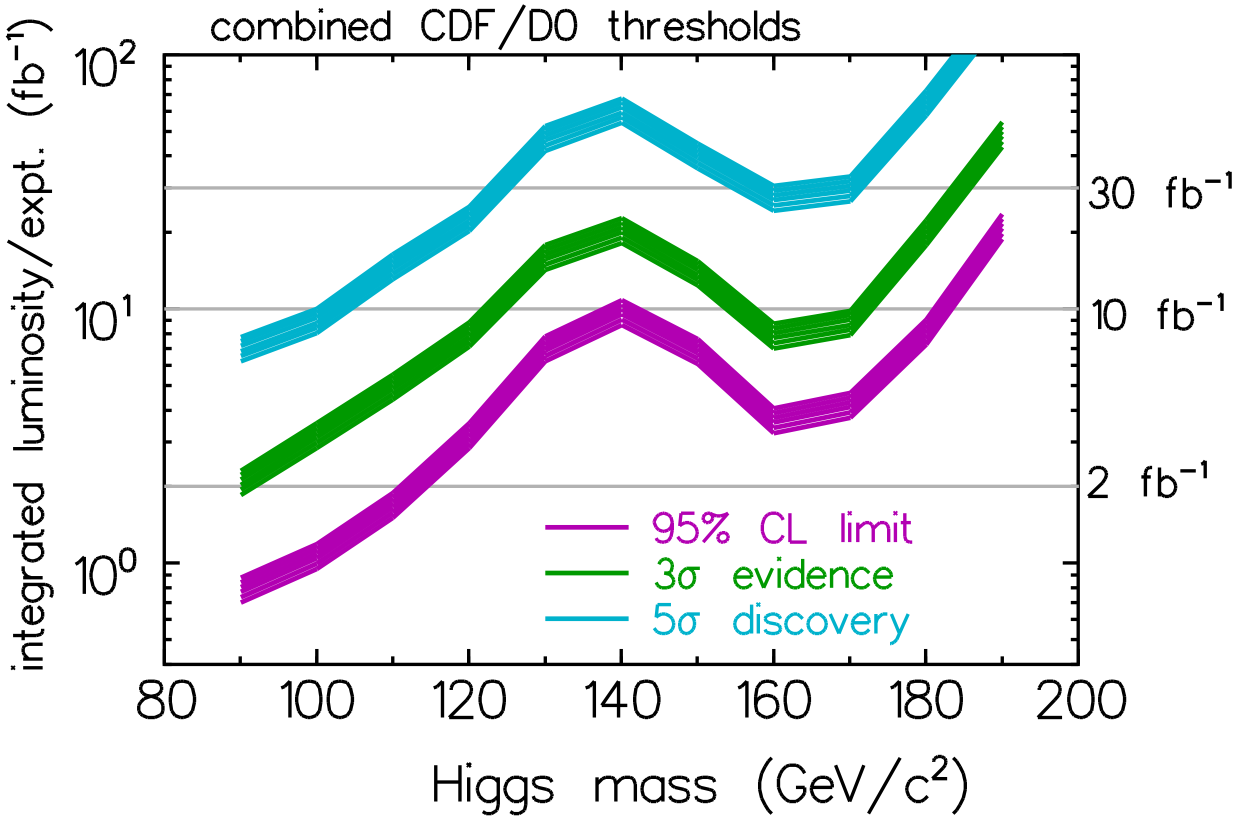
▷Key Unknowns (besides the Big One):

- Accelerator Performance (Has been much better than advertised)
- Detector Performance (Has been better than advertised, but..)
- Laboratory Schedule (Has been much different from advertised)
- Physics Backgrounds (Work in Progress)

▷Summary

1. Light Higgs: Four Channels:
   (a) $Wh \to \ell\nu b\bar{b}$,
   (b) $Zh \to \nu\bar{\nu}b\bar{b}$,
   (c) $Zh \to \ell\ell b\bar{b}$,
   (d) $Vh \to q\bar{q}b\bar{b}$.
2. Heavy Higgs: Two Channels:
   (a) $W^{\pm}h \to W^+W^-W^{\pm} \to \ell^{\pm}\ell^{\pm}jjX$,
   (b) $gg \to h \to WW \to \ell^+\ell^-\nu\bar{\nu}$.

Combine NN analysis described in HWG Report; both experiments:



▷Lower edge of Band is Best Estimate

▷Band Extends Upward 30% For Systematics

▷These are all 'Toy' Analyses: (Proper Simulation In Progress)

▷HWG Concludes Can Exclude SM Higgs at 95% CL For All Masses Up to 180 GeV with $\sim$ 10 fb^{-1}.

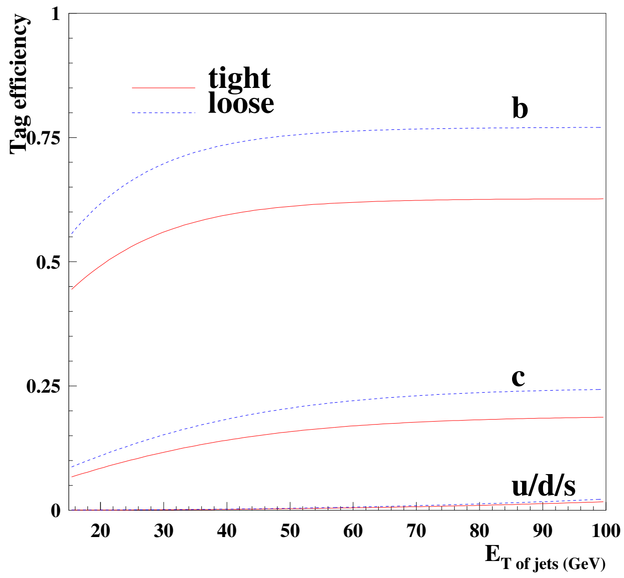
▷Can 'Discover' at $> 3\sigma$ For All Masses with 20 fb^{-1}.

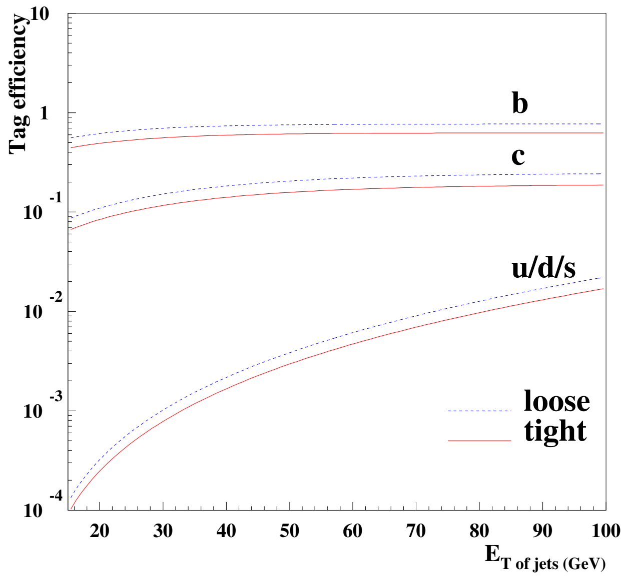
▷Can Discover at $> 5\sigma$ For $M_h \simeq 125$ GeV with 30 fb^{-1}.

Questions:

Question 1. B-Tagging Effiency:

Estimated (For Now) Using CDF Run 1 Efficiency Per Taggable Jet, And Using MC Run 2 Acceptance.





▷This is (probably) quite conservative.

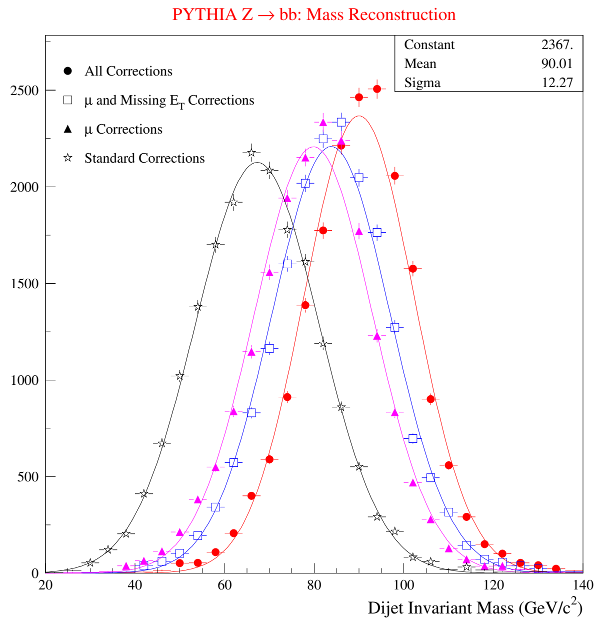
1. Better SVX (5 Double-sided +L00 vs 4 Single-sided)
2. 3D vs 2D Vertex Reconstruction
3. Better Outer Tracking
4. Much Better Vertexing in z (along the beam)
5. Better Impact Parameter Resolution ($6 \oplus 19/p_T$ vs $20 \oplus 26/p_T$
6. SVT Trigger: Allows Calibration On $Z^0 \rightarrow b\bar{b}$
7. But $|\eta| < 2.0$ May be Optimistic
8. But More Material: Multiple Scattering, Secondaries, May Give Pattern Recognition Problems (CDF, and esp. DØ).

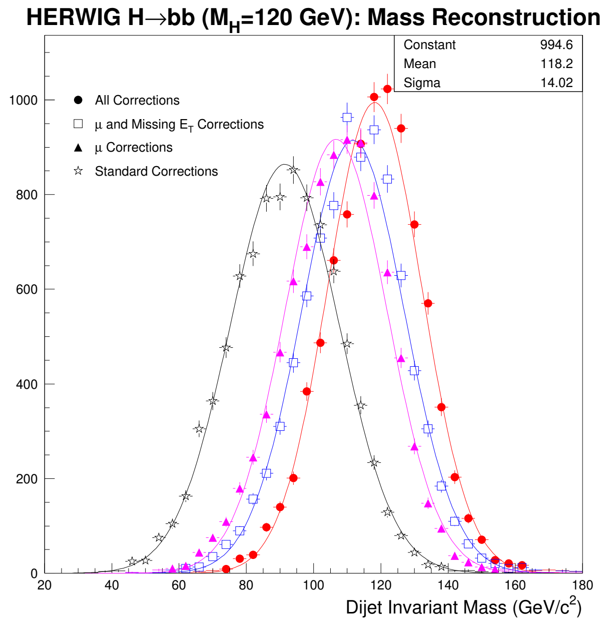
▷Note: Tagging Efficiency Enters As a Power (Square Or Higher, Depending on Signature): $0.6 \rightarrow 0.8$ would gain ≥ 1.8

Question 2. Mass Resolution in $b\bar{b}$:

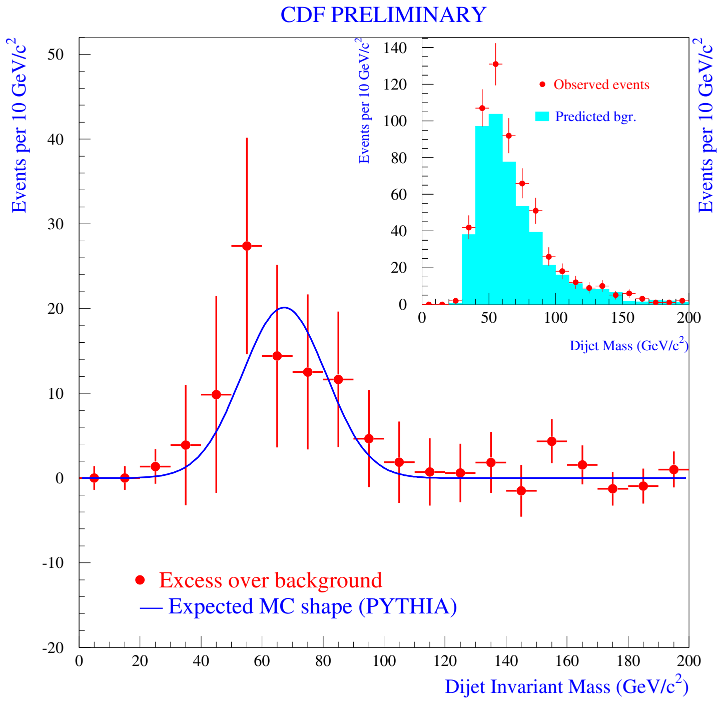
- ▷HWG studies have assumed 10% in $\Delta M/M^2$.
- ▷Not conservative, but not (yet) crazy.
- ▷CDF has data to study this with from $Z^0 \to b\bar{b}$.

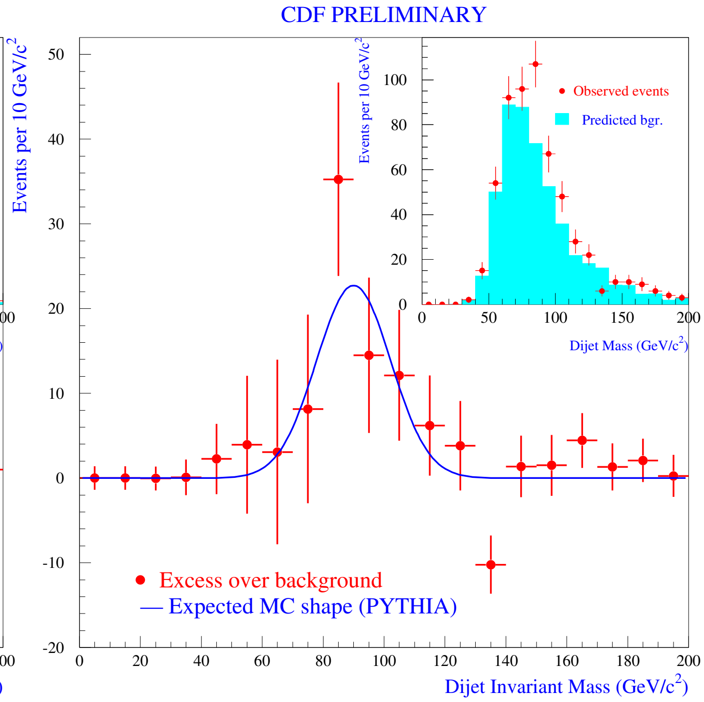
Can Use Higgs-Specific Jet Corrections:





▷Check on CDF $Z^0 \to b\bar{b}$:

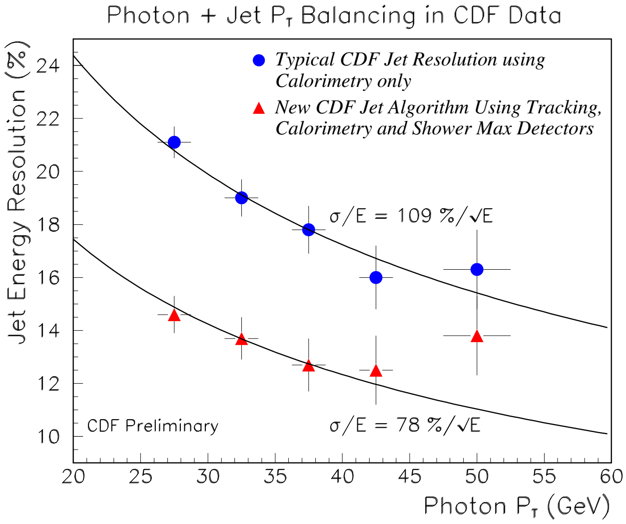




BEFORE AFTER

Question 2. Mass Resolution in $b\bar{b}$:-Continued

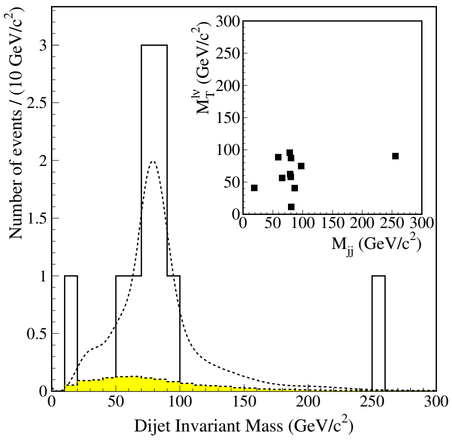
▷But Also Can Have (Much!) Smarter Jet Algorithms



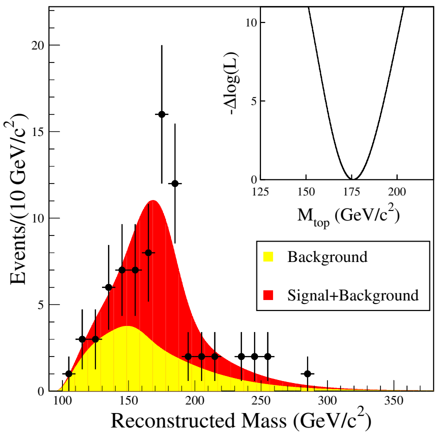
▷Question: Is 10% Reasonable? Honest Answer- We Do Not Know Yet. Need Real Detector Simulations, Calibration Data.

▷One New Important Ingredient: SVT Allows Triggering on $Z^0 \to b\bar{b}$. Allows Calibration at $M_{b\bar{b}} = 90 GeV$!

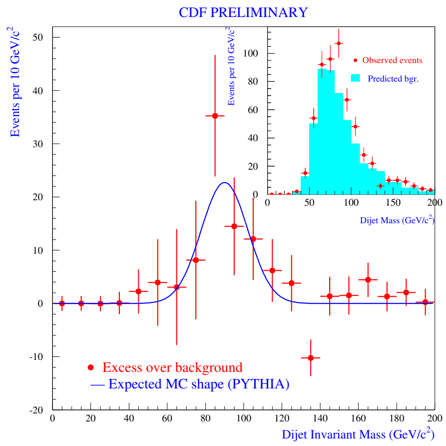
▷Last Comment: Core of Jet Resolution Is Observed To Be Better Than Expected:



$W \to jj$



Top Mass



$Z^0 \to b\bar{b}$

▷May Be Coincidence: Need Data.

Run 1 Searches for Non- SM Higgs

▷Summary

- $b\bar{b}\phi \to b\bar{b}b\bar{b}$, $\phi = h, H, A$
- $V\phi \to b\bar{b}$, $\phi = h, H$
- $\phi \to \tau\bar{\tau}$, $\phi = H, A$
- $t \to H^+b$- Direct
- $t \to H^+b$- Indirect
- $H^+H^- \to t\bar{t}b\bar{b}$

▷Will Discuss First One in Some Detail

▷Will Skip Indirect Searches for the Charged Higgs- Both CDF and D0 Have Made Them

▷Will Discuss Direct Searches for Top Decay into the Charged Higgs Briefly

▷$\phi \to \tau\bar{\tau}$, $\phi = H, A$ Is Being Explored

CDF Analysis of $b\bar{b}\phi \to b\bar{b}b\bar{b}$ (.091 fb^{-1})

▷Very Similar to Search for SM Higgs in $Vh \to q\bar{q}b\bar{b}$

▷Exploits Enhancement at Large $\tan\beta$.

Event Selection:

1. Four *or* more jets, found with a cone size of $R = 0.4$ in $\eta - \phi$ space, with $E_T > 15$ GeV and $|\eta| < 2.4$
2. At least three jets of the 4 highest E_T tagged by SECVTX.
3. A M_h-Dependent E_T Cut on the 3 highest E_T jets.
4. $\Delta\phi > 1.9$ For the 2 Highest E_T B-tagged Jets.
5. Mass window cut on $(M_{12} + M_{12})/2$.

Efficiency

Typical Efficiencies Range from 0.2 to 0.6% for $90 < M_h < 300$ GeV.

SM Backgrounds:

Background Shapes are from MC; the dominant QCD background is from a fit to double-tagged events; the others are normalized to data.

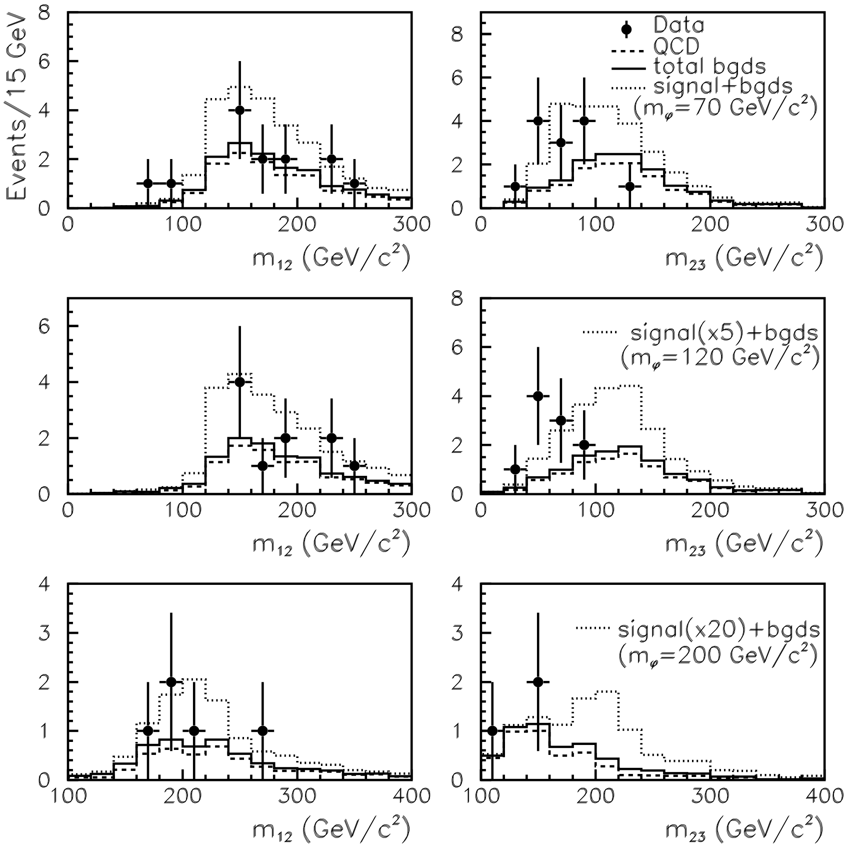
Process	$M_h = 90$	$M_h = 120$	$M_h = 150$
QCD (from fit to data)	2.2±0.6	2.2±0.6	0.7±0.4
Top ($t\bar{t}$):	0.7±0.2	0.7±0.2	0.6±0.2
Fake triple tags	0.5±1.2	0.3±0.9	0.1±0.7
$Zb\bar{b}$,$Zc\bar{c}$:	0.37±0.02	0.29±0.02	0.12±0.02
$Wb\bar{b}$,$Wc\bar{c}$:	0.09±0.06	0.07±0.06	0.03±0.05
Total Events:	3.8±1.3	3.5±1.1	1.5±0.8

$b\bar{b}\phi \rightarrow b\bar{b}b\bar{b}$; CDF: 0.087 fb^{-1}(Continued)

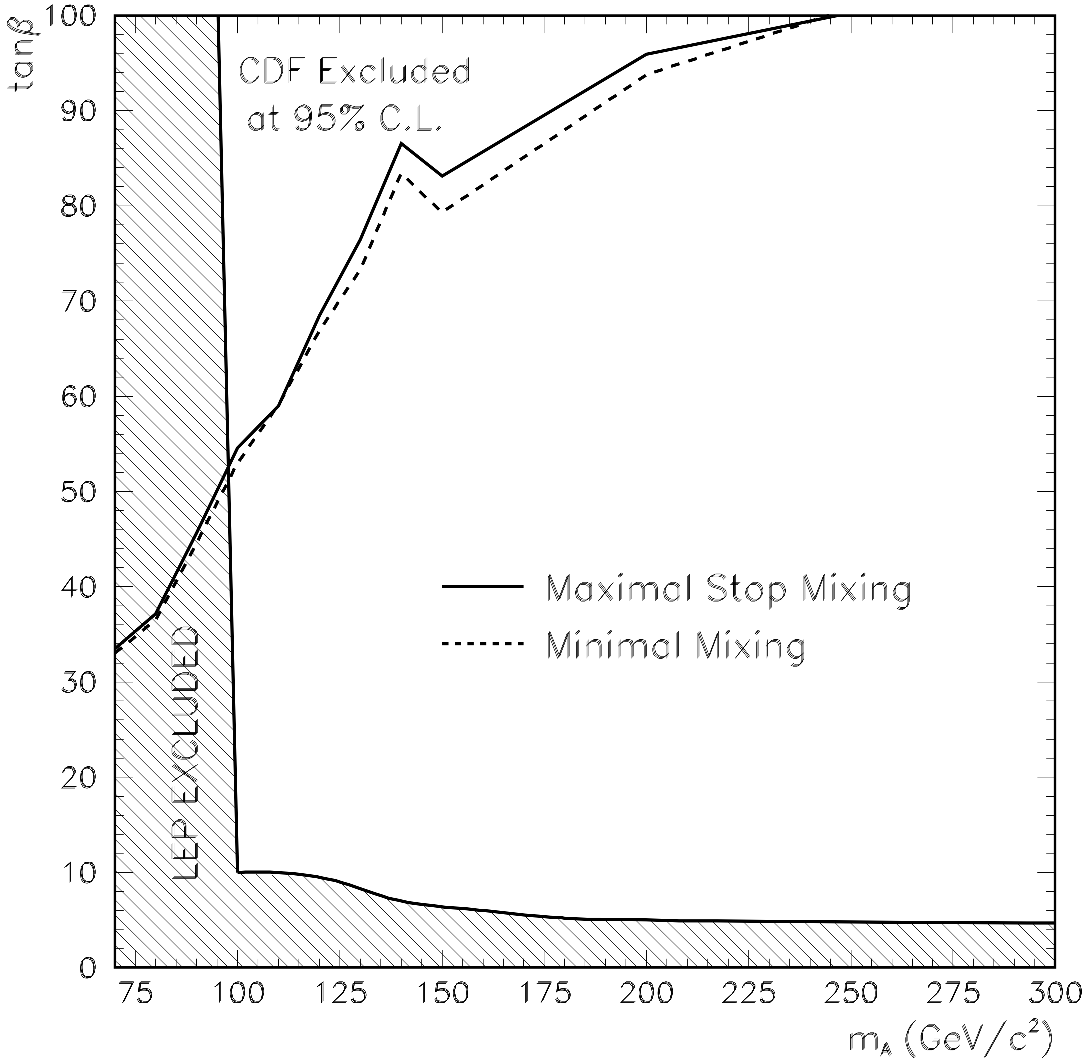
Comparison With Data:

m_ϕ (GeV)	Observed Events	Expected Background	Acceptance (%)	N_{signal} (95% C.L.)	$\sigma \times \mathcal{BR}$ (pb, 95% C.L.)
90	3	3.8 ± 1.3	0.23 ± 0.04	5.8	27.1
110	2	3.7 ± 1.1	0.25 ± 0.04	4.8	20.7
130	1	2.6 ± 0.9	0.28 ± 0.05	4.1	15.8
150	0	1.5 ± 0.8	0.30 ± 0.05	3.2	11.5
200	0	1.2 ± 0.7	0.41 ± 0.07	3.2	8.5
250	0	1.0 ± 0.7	0.47 ± 0.08	3.2	7.5

Comparison of Dijet Mass Distributions:



Limits in the M_A-$\tan\beta$ Plane:



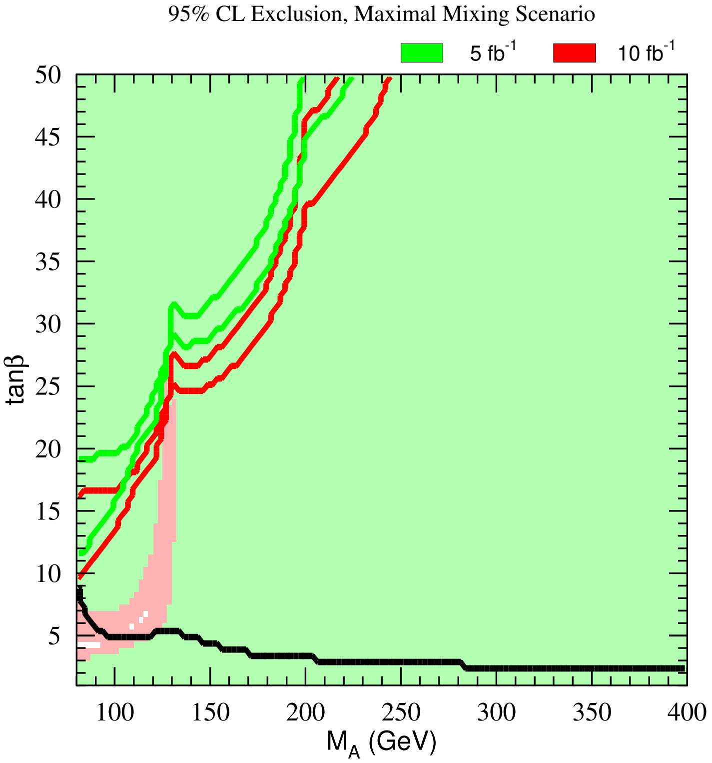
▷Can See the Effect of the $\tan\beta$ Enhancement: Exclusion is at Large $\tan\beta$.

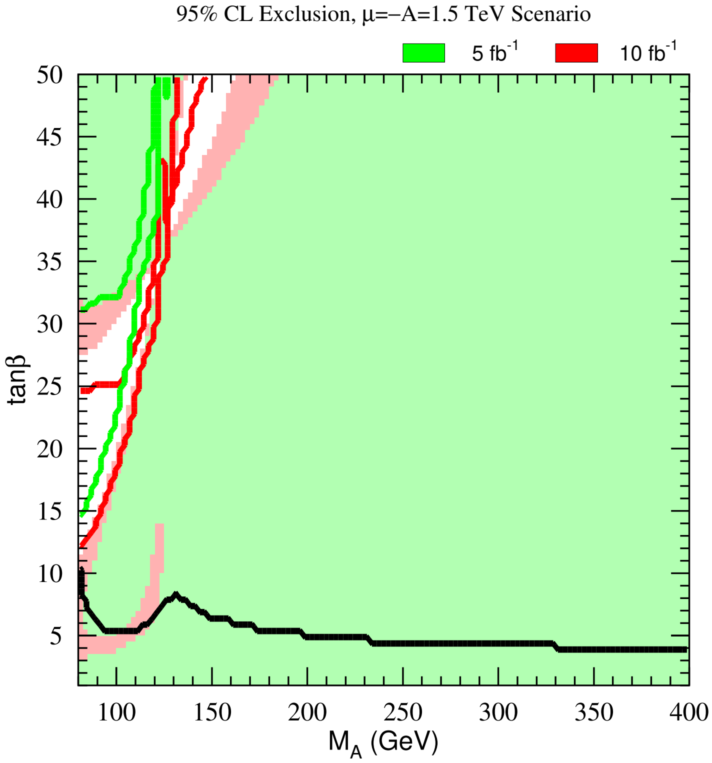
▷Consequence Is We Gain Only as the Sqrt In Area With Luminosity

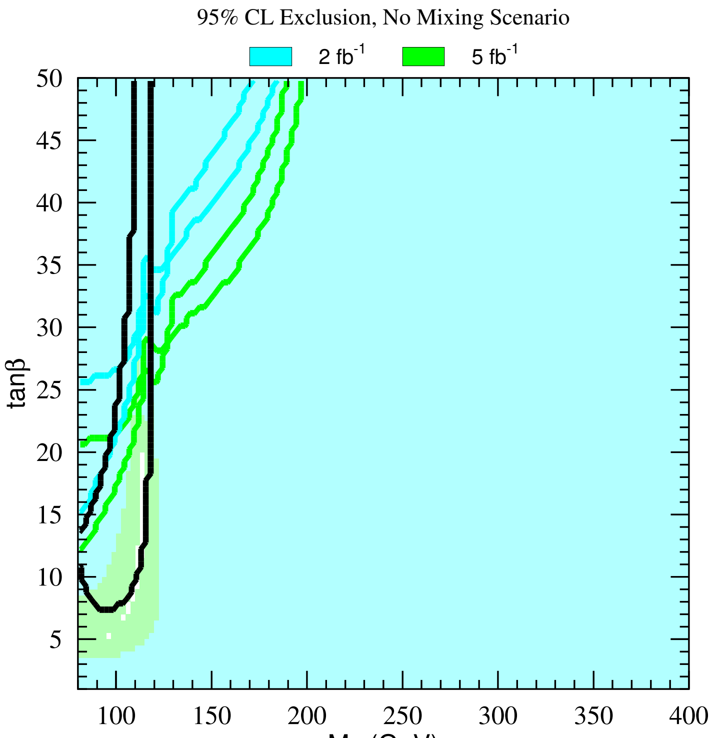
Projections of Reach for MSSM Higgs in Run II:

(Carena, Haber, Mrenna, Wagner)

▷Combine 2 Channels: Solid: $q\bar{q} \to V\phi$, $\phi \to b\bar{b}$, $(\phi = h/A, H/A)$, and Lines: $gg, q\bar{q} \to b\bar{b}\phi$, $(\phi = h/A, H/A)$







95% Exclusion

a) Maximal Mixing

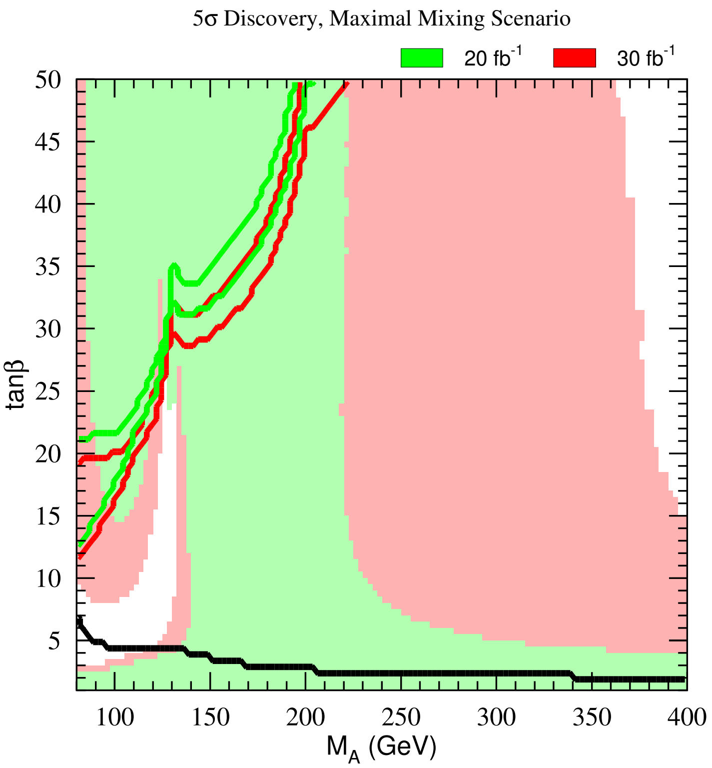
b)'Supressed $V\phi \to Vb\bar{b}$'

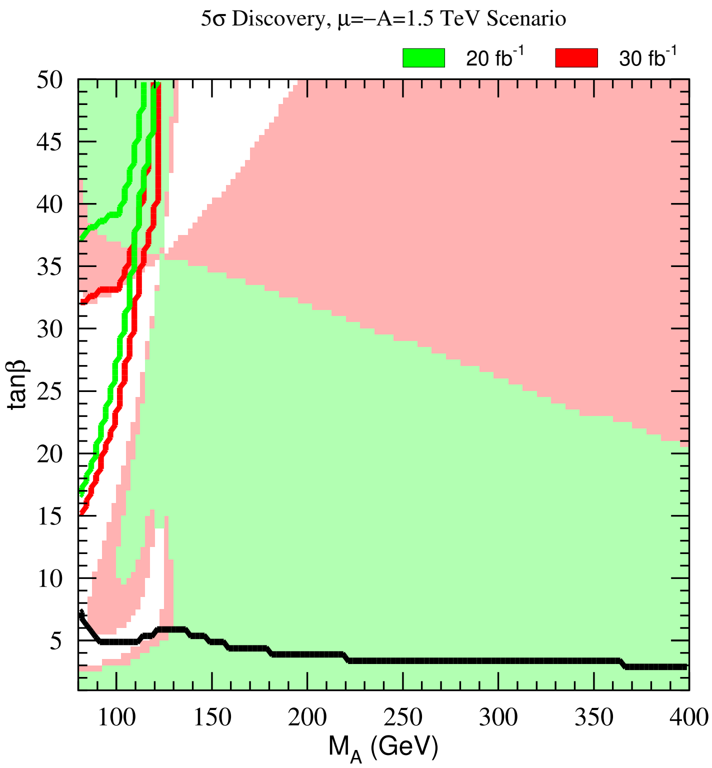
c) No Mixing

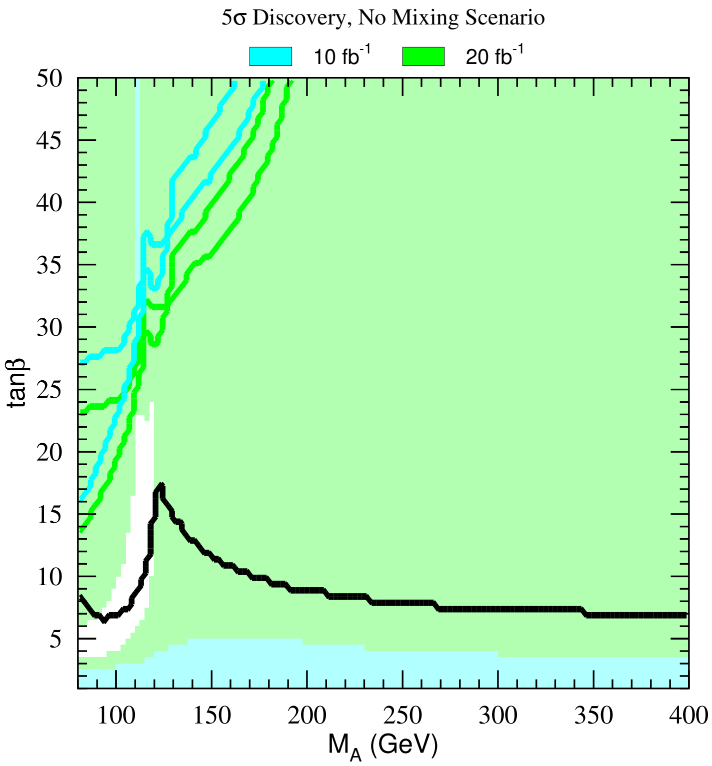
Combined 5σ HWG Discovery Summary Plots

(Carena, Haber, Mrenna, Wagner)

$\triangleright$Combine 2 Channels: Solid: $q\bar{q} \to V\phi$, $\phi \to b\bar{b}$, ($\phi = h/A, H/A$), and Lines: $gg, q\bar{q} \to b\bar{b}\phi$, ($\phi = h/A, H/A$)







5σ Discovery

a) Maximal Mixing

b)'Supressed $V\phi \to Vb\bar{b}$'

c) No Mixing

LONGER TERM PROSPECTS

(quoted from Steve Holmes, Accel. Div., Fall 1999)

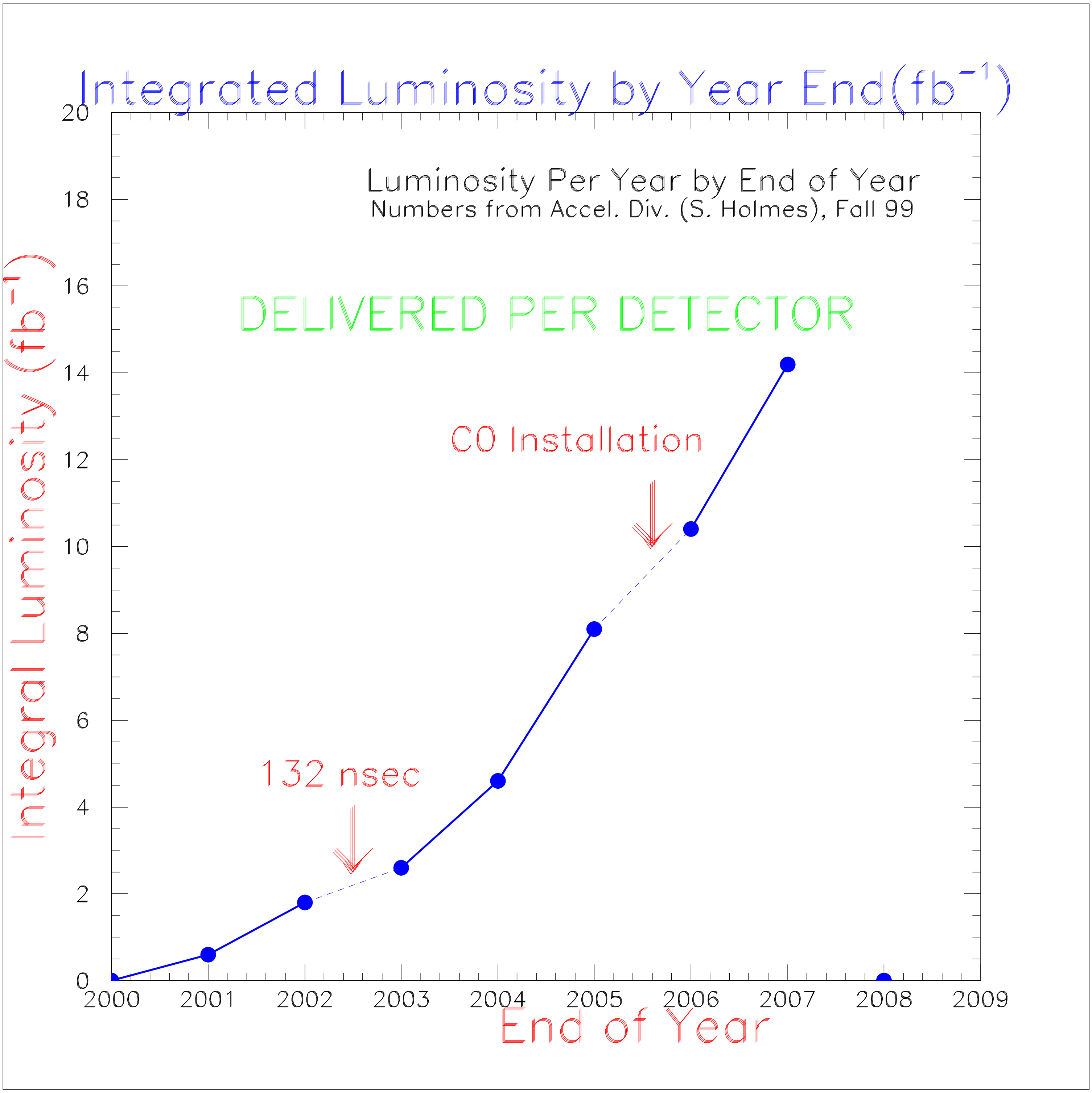
The initial Run II goal is achievement of a luminosity of $\sim 1\times10^{32}$ cm^{-2}sec^{-1}, with 2 fb^{-1}delivered to each detector by the end of 2002.

Further performance enhancements would be based upon:

- Improved antiproton availability
- Electron cooling
- Slip-stacking
- Liquid lithium lens
- Aperture improvements
- Controlling the antiproton (long-range) beam-beam interaction.
- Electron beam compensation

Possible Accumulation of Luminosity in the pre-LHC Era:

Year	Project/Goal	Accumulated Luminosity
2001	Main Injector and Recycler	0.6 fb^{-1}
2002	Initiate antiproton recycling	1.2 fb^{-1}
2003	6 month shutdown to install e-cool, 132 nsec, and other intensity improvements	0.8 fb^{-1}
2004	Achieve 2×10^{32}	2.0 fb^{-1}
2005	Achieve 3×10^{32}	3.5 fb^{-1}
2006	Achieve 5×10^{32}	2.3 fb^{-1}
	6 month shutdown to install C-0.	
2007	Achieve 5×10^{32}	3.8 fb^{-1}
TOTAL		15 fb^{-1}


Integrated Luminosity by Year End(fb^{-1})
Luminosity Per Year by End of Year
Numbers from Accel. Div. (S. Holmes), Fall 99
DELIVERED PER DETECTOR
C0 Installation
132 nsec
Integral Luminosity (fb^{-1})
End of Year
0
2
4
6
8
10
12
14
16
18
20
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009

Is the Fermilab Schedule Realistic and Optimal For Higgs Discovery?

Scheduled 6-Month Shutdowns May Be Unrealistically Short

Scheduled Shutdowns May Be Not Optimally Placed:

- Top Discovery Paradigm a Good One:
  Run for 1/3 of Total, Look, and Then Run Blind for 2/3. Take 20 fb^{-1}as Total: Implies Run for 7 fb^{-1}Before First Major Shutdown (If Possible).
- First Shutdown Should Encompass Major Accelerator Upgrades, Silicon Replacement
- No Major (Scheduled) Shutdowns in 2nd Part of Run (the 2/3).

Is the Following Impossible?

(Really Pushing For a Sensational Fermilab Discovery): Consider As A Goal the Following: (Assume 1.5 ×seconds per year)

Year	Project/Goal	Lum/Yr	Total Lum
2001	Main Injector and Recycler	0.6 fb^{-1}	0.6 fb^{-1}
2002	Initiate antiproton recycling	1.2 fb^{-1}	1.8 fb^{-1}
2003	Achieve 2×10^{32}	2.0 fb^{-1}	3.8 fb^{-1}
2004	Achieve 3×10^{32}	3.5 fb^{-1}	7.3 fb^{-1}
2005	6 month shutdown to install e-cool, 132 nsec, and other intensity improvements	0.8 fb^{-1}	8.1 fb^{-1}
2006	Achieve 5×10^{32}	5.0 fb^{-1}	13.1 fb^{-1}
2007	Achieve 10×10^{32}	10.1 fb^{-1}	23.1 fb^{-1}
2008	Achieve 20×10^{32}	20.1 fb^{-1}	43.1 fb^{-1}
TOTAL		43.1 fb^{-1}	

Are There Higher Priorities? What Are the Realities Standing in the Way?

CONCLUSIONS

1. The HWG results indicate that a SM Higgs with mass < 125 GeV can be ruled out at 95% confidence with 5 fb^{-1}, and can be discovered at 5σ with 30 fb^{-1}.

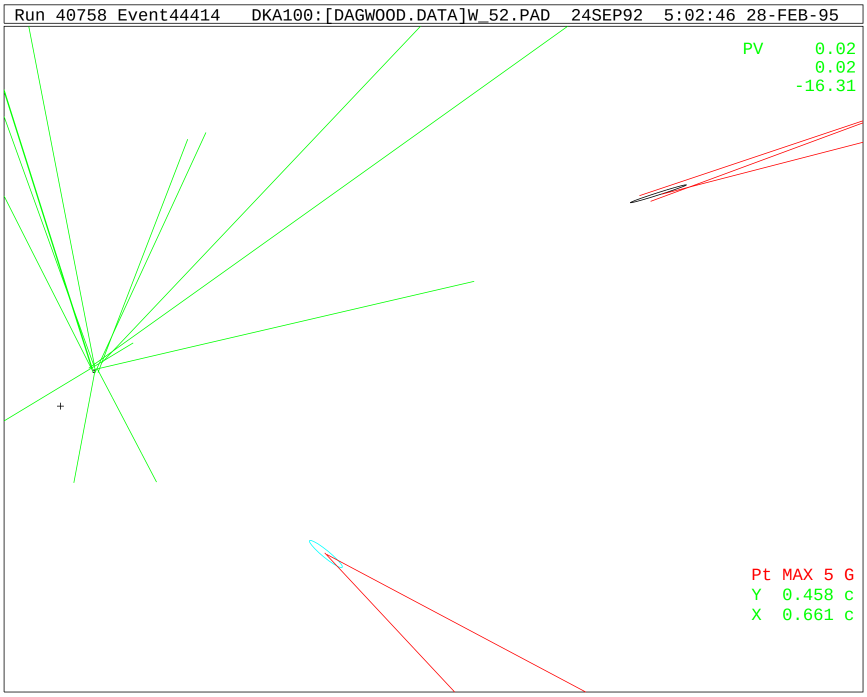
2. Similarly the HWG study indicates that with 5 fb^{-1}, a large part of the MSSM parameter space can be ruled out at 95% C.L.; discovery requires $>$ 20-30 fb^{-1}.

3. There are many channels with experimentally accessible signatures that produce as many events in 20 fb^{-1}as we had for the top quark discovery. The new detectors have twice the geometric acceptance, much better b-tagging, and new triggering capabilities that should allow calibration on $Z^0 \to b\bar{b}$.

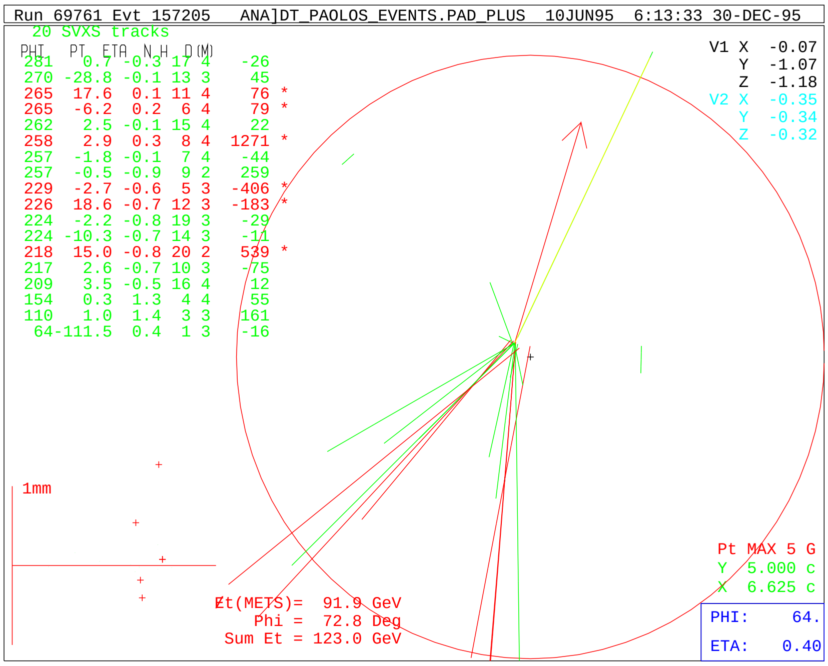
4. Background rejection with adequate acceptance is a key question. Detailed MC work with accurate detector simulations is in progress for both new detectors.

5. Biggest uncertainties are the detector, accelerator and Lab management performances: all 3 are new.

'Typical B-tagged Events (sic)- Data'



$$t\bar{t} \rightarrow W^+W^-b\bar{b}$$



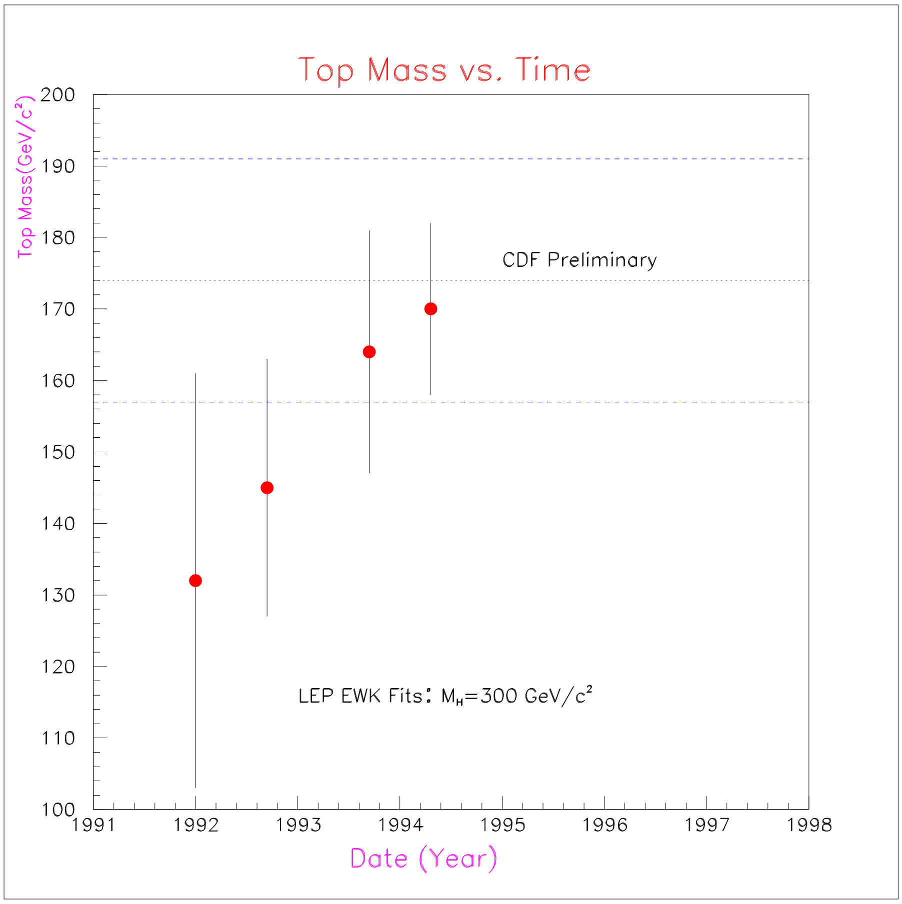
$W^{\pm} \rightarrow \mu^{\pm}\nu + b\bar{b}$: Silicon Vertex Detector Showing 2 B-Vertices

Answers wrt QCD Background in $hZ \to \nu\bar{\nu}$:

- The QCD background in the CDF analysis was determined from data and not Monte Carlo. We used dijet samples and a $\not{E}_t$ control sample to determine tag rate in the latter is the same as in the former when $\not{E}_t$ doesn't lie along jet directions. Both single and double tag rates determined as function of number of tracks.
- The Run II HWG draft report left out the QCD background, as pointed out by ATLAS. While CDF measured it in the Run 1 analysis, it's very hard to extrapolate to the 100-times larger sample for Run II and beyond, as only have Monte Carlo, and the background is way out on the tails and is very sensitive to detector and theretical details (see below).
- The ATLAS MC estimate predicted 30 events for the CDF Run 1 analysis, where a total (background) of 4 was seen. I don't understand the discrepancy: may be related to double-counting processes, and possibly to the angular distribution of the b-bbar system in gluon splitting (S. Mrenna is, as always, the expert- really need a talk from him on this subject).
- From the $Zh \to \nu\bar{\nu}b\bar{b}$ channel, extrapolating the CDF Run I analysis, the HWG has estimated that the QCD bkgd is equal to the other total backgds. The plots shown take this into account. Folks are working to make this (difficult) prediction more robust. However, we really need data to do this right.

'Answer to 'Finding the Top Was Easy: We Told You Where to Look'

1. Historically Inaccurate: CDF Analysis Was Optimized At Previous CDF Lower Limit, Not Heavy Top.
2. LEP Predicted Mass Rose During Run I (After Cuts Were Set):
3. Data Were What Did It (Paper received April 1994) Sorry.



Comment: LEP Mass Was Calculated With Arbitrarily Chosen $M_h = 300$ GeV; We Knew (and I Said) Should Have Used 2-Parameter Fit Top Mass (100 GeV Higgs Lowers EWK Prediction with $1\sigma = 20$ GeV). Uncertainty Was Consequently So Large To Be Meaningless In Any Case.

Answer to Questions on the Parameters For the MSSM Carena et al Study:

Table 3: Description of the values of the MSSM parameters for the benchmark scenarios considered in this report. In all cases, the gaugino mass parameter has been taken to be $M_2 = 200$ GeV.

	Mass parameters [TeV]					(GeV)
Benchmark	μ	$X_t \equiv A_t - \mu \cot\beta$	A_b	M_S	$M_{\tilde{g}}$	m_h^{max}
Maximal Mixing	-0.2	$\sqrt{6}$	A_t	1.0	1.0	129
No Mixing	-0.2	0	A_t	1.0	1.0	115
Suppressed $V\phi \to Vb\bar{b}$	1.5	$-1.5(1+\cot\beta)$	0	1.0	1.0	120

Quote: 'Table 3 defines the set of benchmark parameters for the relevant supersymmetric parameters that govern the Higgs radiative corrections. These include the supersymmetric Higgs mass parameter μ, the third generation squark mixing parameters, A_t and A_b, the average top-squark mass parameter M_S and the gluino mass $M_{\tilde{g}}$. The maximal mixing benchmark scenario, as the name suggests, is defined as the one in which the squark mixing parameters are such that they maximize the value for the lightest CP-even Higgs boson mass for fixed values of the m_A, $\tan\beta$ and M_S. In contrast, in the no mixing scenario, the parameters μ and A_t are chosen such that the combination $X_t \equiv A_t - \mu \cot\beta$ vanishes. In this limit, the value of the lightest CP-even Higgs boson is at its minimum for fixed values of the m_A, $\tan\beta$ and M_S.
However, a scan through the MSSM parameters away from the maximal squark mixing point reveals regions of parameter space in which the CP-even neutral Higgs boson with Standard-Model-like couplings to VV has suppressed couplings to $b\bar{b}$. Benchmark scenario denoted by Suppressed $V\phi \to Vb\bar{b}$ production in table 3 is an example of this behavior. The regions of strongly suppressed BR($\phi \to b\bar{b}$) correspond to a suppressed $Hb\bar{b}$ coupling at lower m_A and a suppressed $hb\bar{b}$ coupling at larger m_A. In particular, the suppression for large $\tan\beta$ extends to relatively large values of m_A, indicating a delay in the onset of the decoupling limit (where the $hb\bar{b}$ coupling approaches the Standard Model value). This is the case when one of the Higgs bosons becomes mostly Φ_u^0, with no coupling to down-type quarks except those induced by SUSY-breaking effects. Such a Higgs boson has SM–like couplings to the W, Z and t, but vanishing couplings to $b\bar{b}$ and $\tau^+\tau^-$. The necessary condition for this limit to arise is explained in section I.C. From the analytic formula, it can be deduced that large values of $|A_t|$ (perhaps A_b), $|\mu|$ and $\tan\beta$ are needed.
Finally, we distinguish between the two scenarios labeled "suppressed $\phi b\bar{b}$ couplings" and "enhanced $Ab\bar{b}$ production" in table 3. In both cases, the sign of $A_t\mu$ is negative; the two cases are distinguished by the sign of μ (in the convention where the gluino mass parameter is positive). If $\mu > 0$ one finds that the $Ab\bar{b}$ corrections, while for $\mu < 0$ the $Ab\bar{b}$ coupling is enhanced.' (end-quote)

D0 Search for $VH \to \gamma\gamma$:

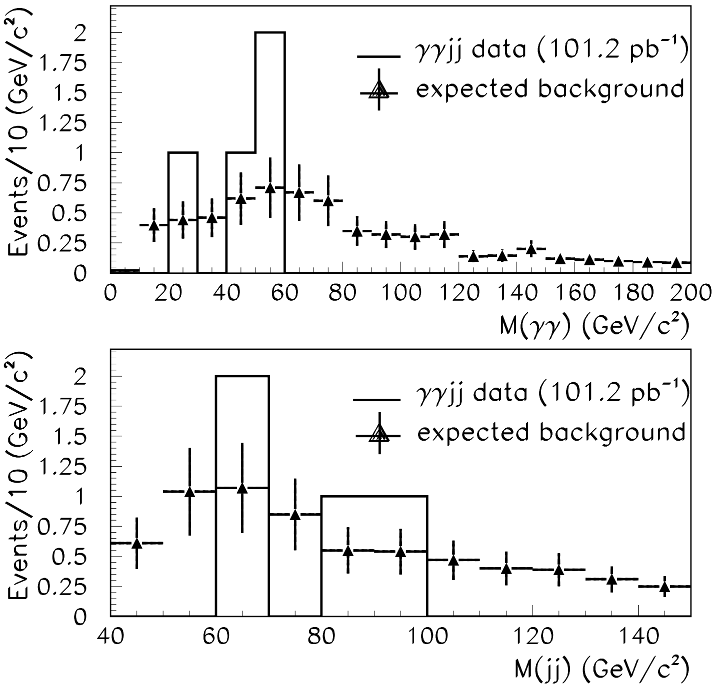
▷Much too small in SM, But Large In Models with Suppressed Couplings to Fermions ('Bosophilic' Higgs)

Photon Selection

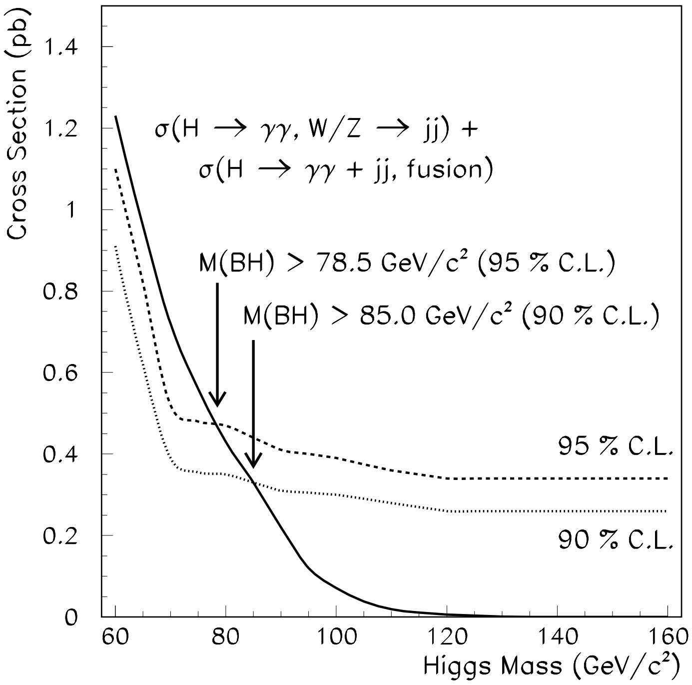
2 Photons, $|\eta < 1.1|$ or $|1.5| < \eta < 2.25|$,
$E_T^1 > 30$, $E_T^2 > 18$

W or Z Selection

2 Jets $E_T^1 > 30$, $E_T^2 > 15$, $40 < M_{jj} < 150$



Dijet Mass Spectrum



Cross-Section Limit

CDF Search for $VH \to \gamma\gamma$:

▷Much too small in SM, But Large In Models with Suppressed Couplings to Fermions ('Bosophilic' Higgs)

Photon Selection

2 Photons, $|\eta < 1.0|$

$E_T > 20$

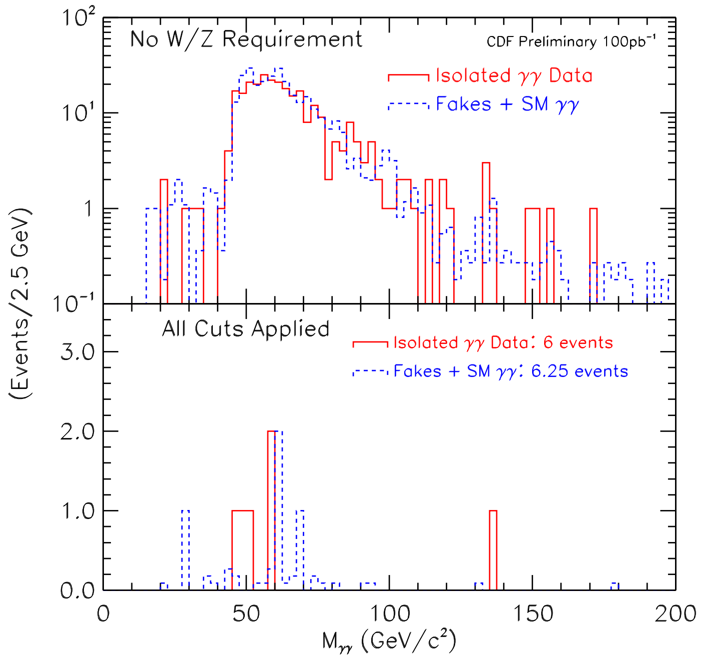
W or Z Selection

e or μ, $p_T > 20$ *or*

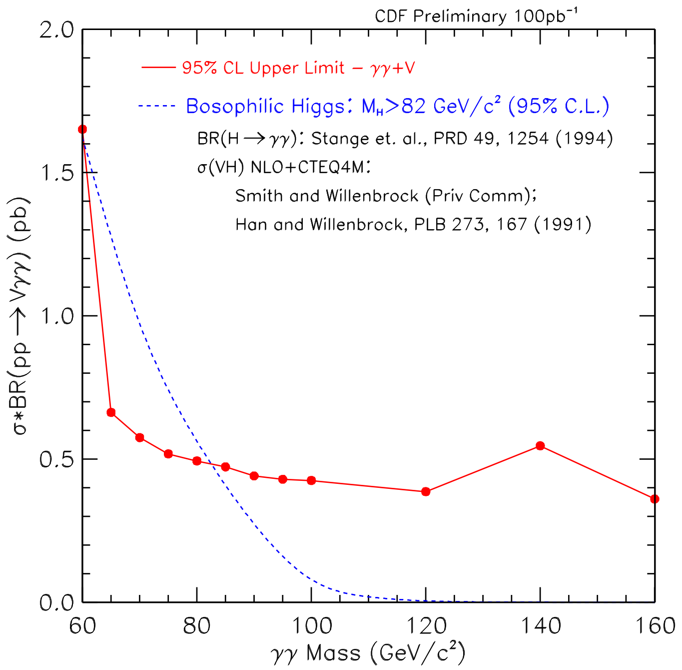
$\not{E}_t > 20$ *or*

2 Jets $E_T > 15$,

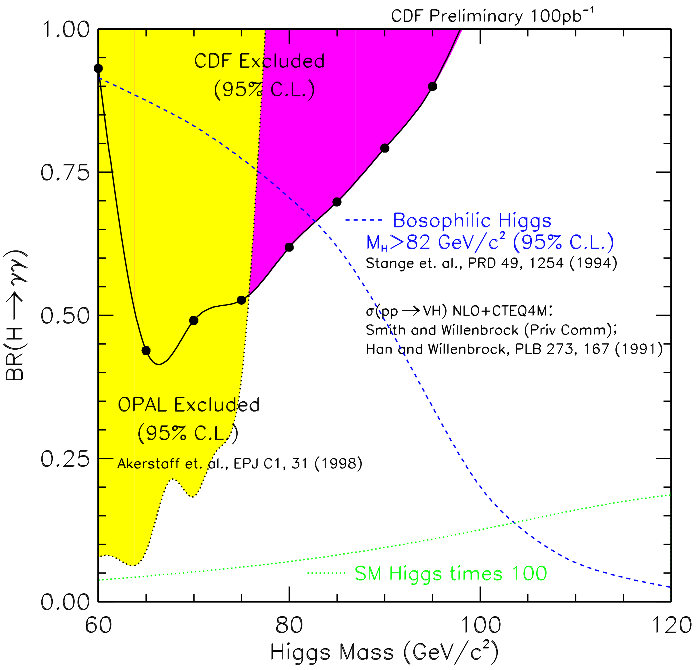
$40 < M_{jj} < 130$



Dijet Mass Spectrum



Cross-Section· BR Limit



Branching Ratio Limit