SM HIGGS SEARCHES AT THE TEVATRON

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DØ & CDF Collaborations

http://www-cdf.fnal.gov/physics/exotic/exotic.html
http://www-d0.fnal.gov/Run2Physics/higgs/

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Outline

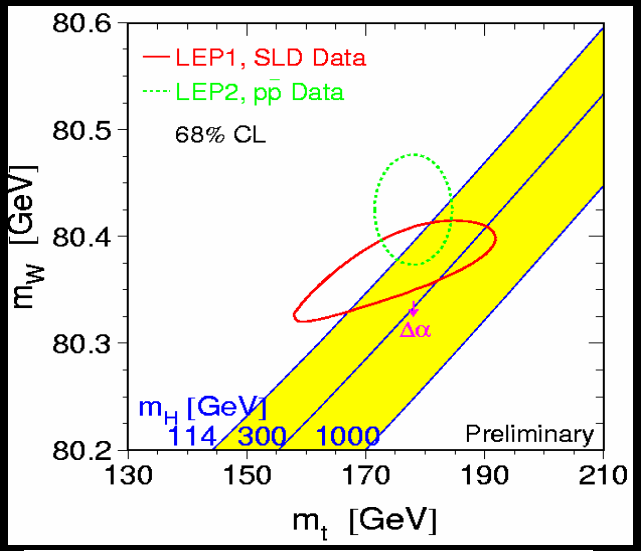
- Introduction
  - EW Constraints on the Higgs Mass
  - Data Samples – Tevatron Run II
  - Strategy for SM Higgs Searches
- Understanding the background processes
  - $Z \rightarrow bb$
  - W+Jets
  - Z+Jets
  - $\sigma(Z+b)/\sigma(Z+jet)$
  - Wbb Production
- Low Mass SM Higgs Searches:
  - WH and ZH Associated Production
- High Mass SM Higgs Searches:
  - $H \rightarrow WW^*$
  - $WH \rightarrow WWW^*$
- Future Prospects & Summary

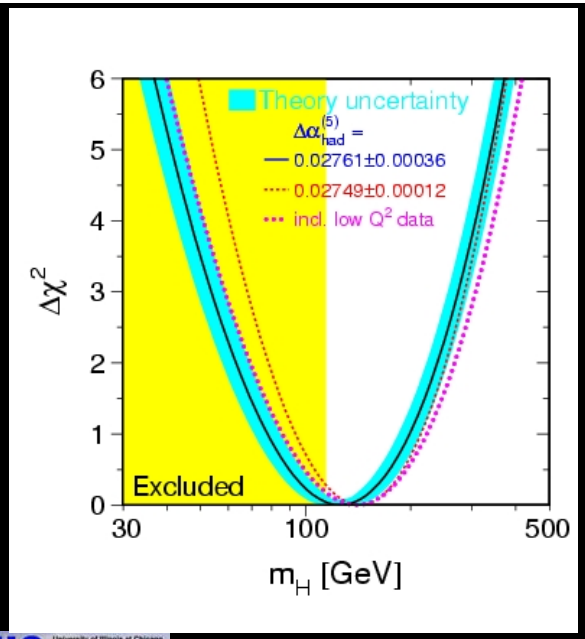
Other Tevatron Higgs Talks:

→ A Search for Fermiophobic Higgs in Multiphoton Final State at DØ - Drew Baden

→ Search for MSSM Higgs Bosons at Tevatron - Anton Anastassov

Guidance from EW Fits

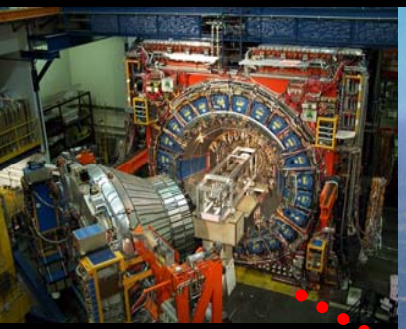


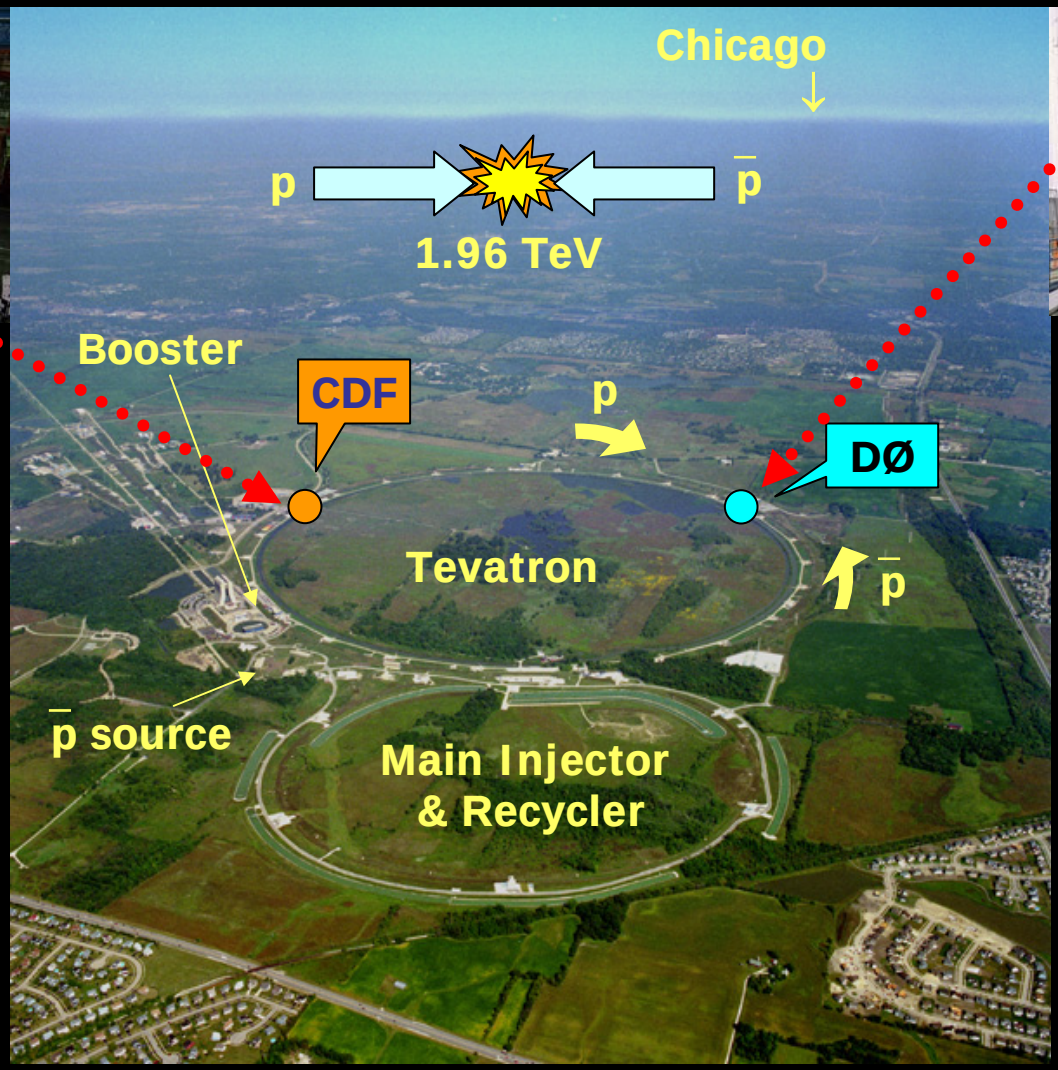


- Direct searches by LEP on SM Higgs Boson:
  - m_H > 114.4 GeV (95% CL)
- Indirect limit from fits to precision EW measurements from LEP-SLC-Tevatron
  - m_H < 280 GeV (95% CL)
  - Expected value: $m_H = 126\ ^{+73}_{-48}$ GeV
- Run II will provide stringent constraints to SM Higgs
  - δM_t < 2.5 GeV per exp (currently 4.3 GeV – Run I combined)
  - δM_W < 30 MeV per exp (currently 59 MeV – Run I combined)

➔ Light Mass Higgs favored

Fermilab TeVatron - RunII





Run I
1992-1996
E_{CM} = 1.8 TeV
~120 pb^{-1}
(0.63 TeV ~600 nb^{-1})

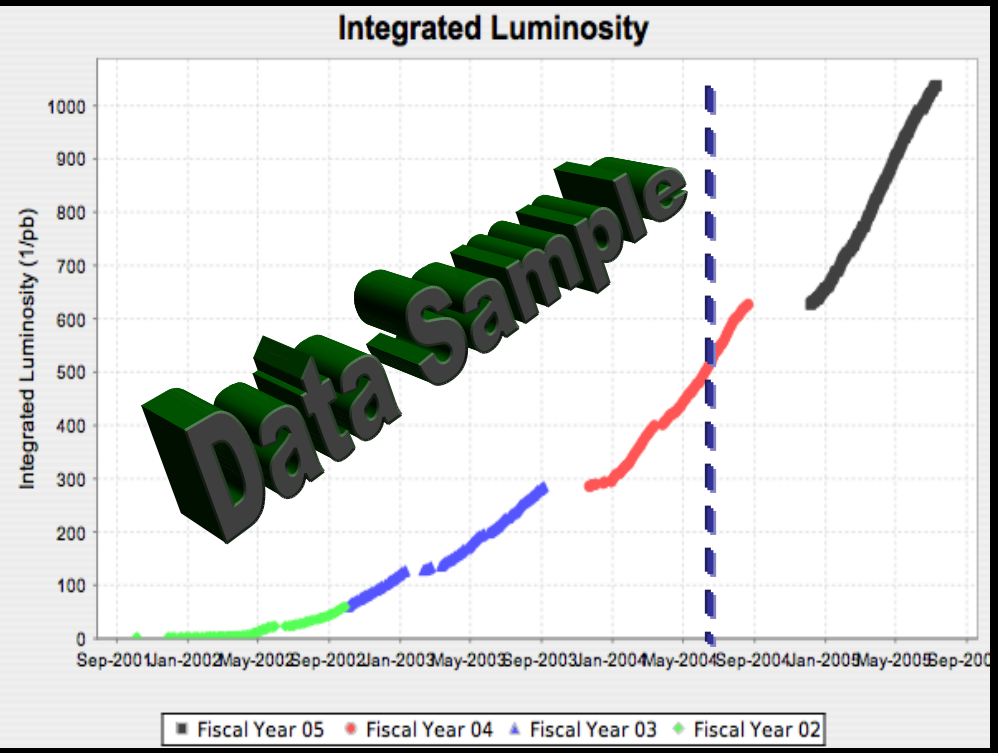
Run IIa
2002-2005
E_{CM} = 1.96 TeV
~ 1.5 fb^{-1}

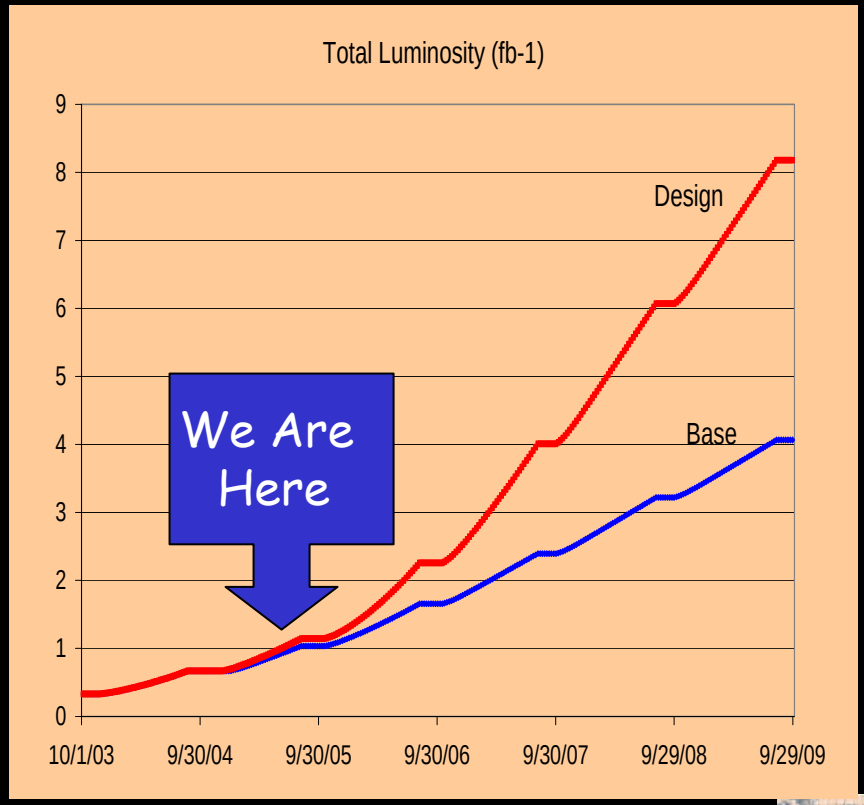
Run IIb
2006-2009
E_{CM} = 1.96 TeV
~4-8 fb^{-1}

Data Sample

- Tevatron performs according to design
  - Record peak luminosity ~ 1.2×10^{32}
  - Record integrated luminosity ~ 21 pb^{-1} / week
- Data samples presented here:
  - 2002-2004 ($\leq$ 400 pb^{-1})
- Detector data collection efficiency 85-90%

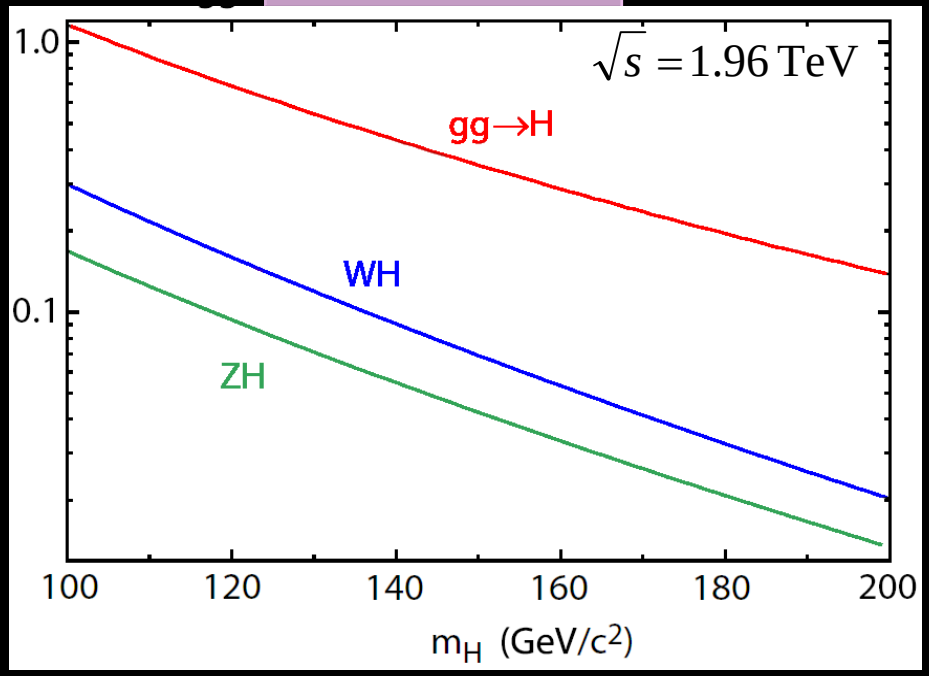
Currently expecting delivered luminosity to each experiment → 4 - 8 fb^{-1} by the end of 2009



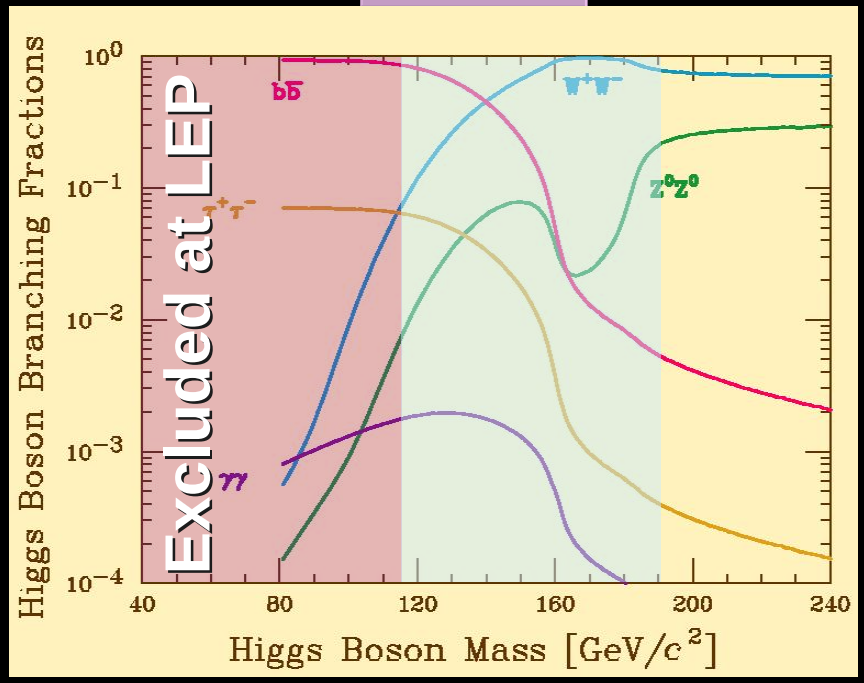


SM Higgs Production and Decay

Production



Decay



Search strategy:

M_H <135 GeV associated production WH and ZH with H→bb decay

Backgrounds: Wbb, Zbb, top…

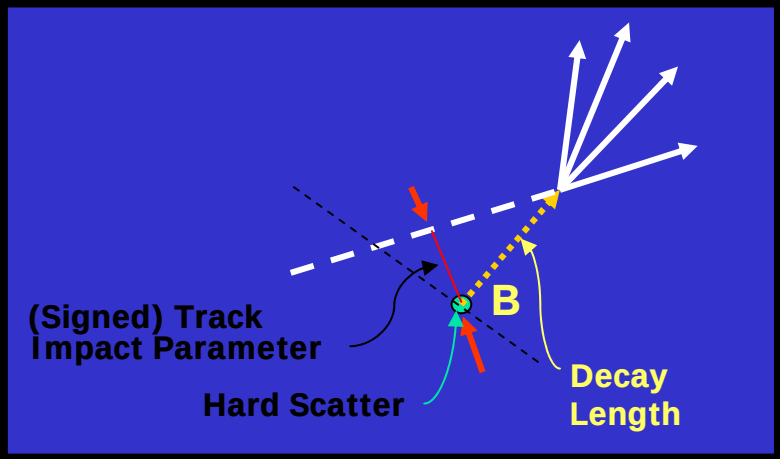
M_H >135 GeV gg →H production with decay to WW*

Backgrounds: electroweak WW production…

Low Mass SM Higgs Searches

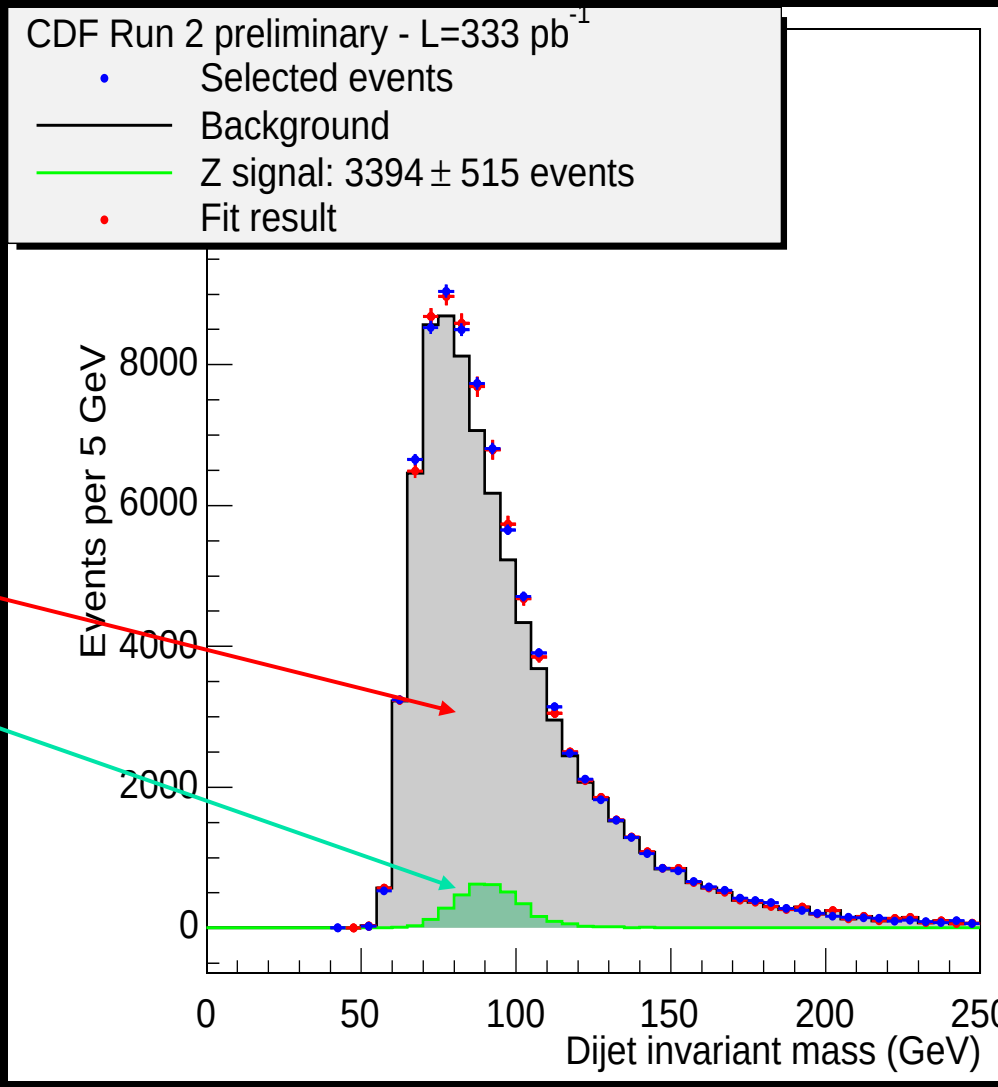
- WH → e(μ)ν +bb
- ZH → ee/μμ/νν + bb
- Measurements rely on
  - b-tagging
  - Lepton identification + Missing-E_T resolution
  - Dijet mass resolution and light/b-jet calibration
    - Z → bb
  - Understanding of backgrounds
    - W/Z + heavy-flavor/light jets
    - QCD

b-tagging
- Based on signed impact parameter resolution
  - Jet Lifetimetime Impact Parameter algorithm
- Based on decay length resolution
  - Secondary Vertex Algorithm



Z → bb (A First Look...)

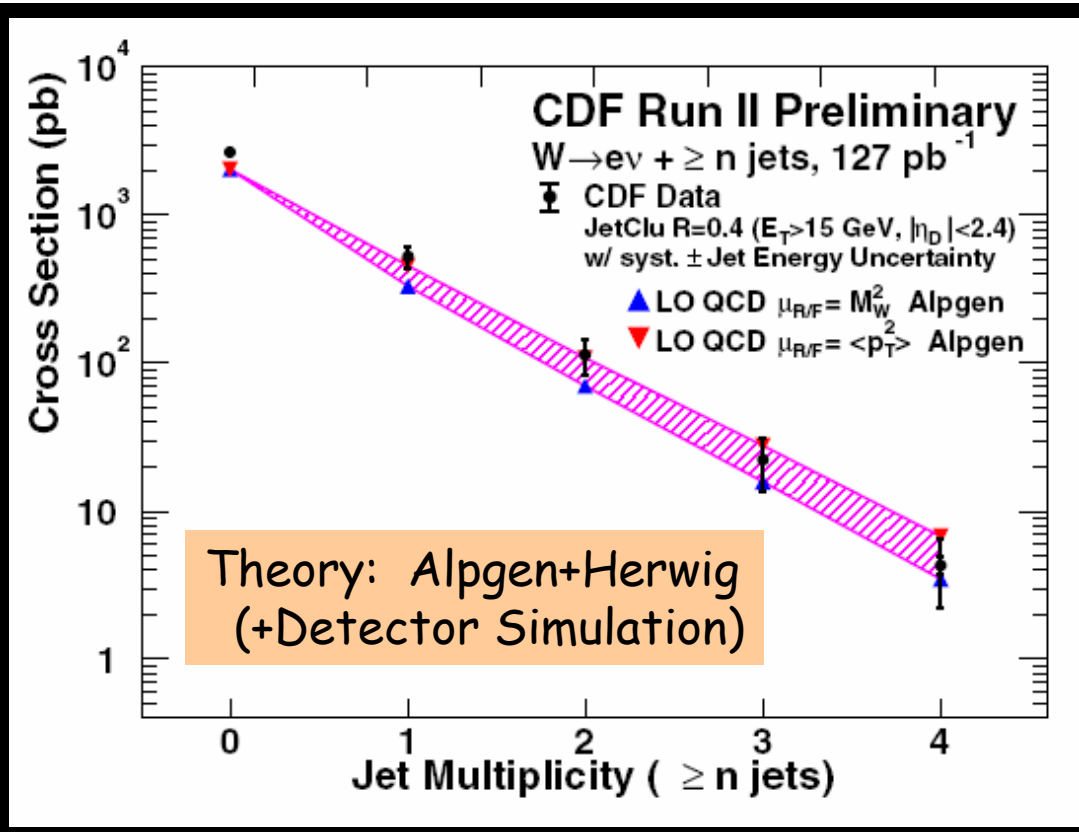
- Dijet invariant mass of ~86K events
  - Only two jets in the events (veto other jets with $E_T > 10$ GeV)
  - Jets must be back-to-back ($\Delta\Phi > 3.0$)
  - Both jets have a secondary vertex b-tag
- The background shape is computed using untagged data passing the same selection
- The Z→bb shape is simulated with PYTHIA
- The two shapes are fit to the data (blue points)
- Fit results are shown in red
- Statistical errors only



$\sigma(W(\rightarrow e\nu) + \geq n$ jets)

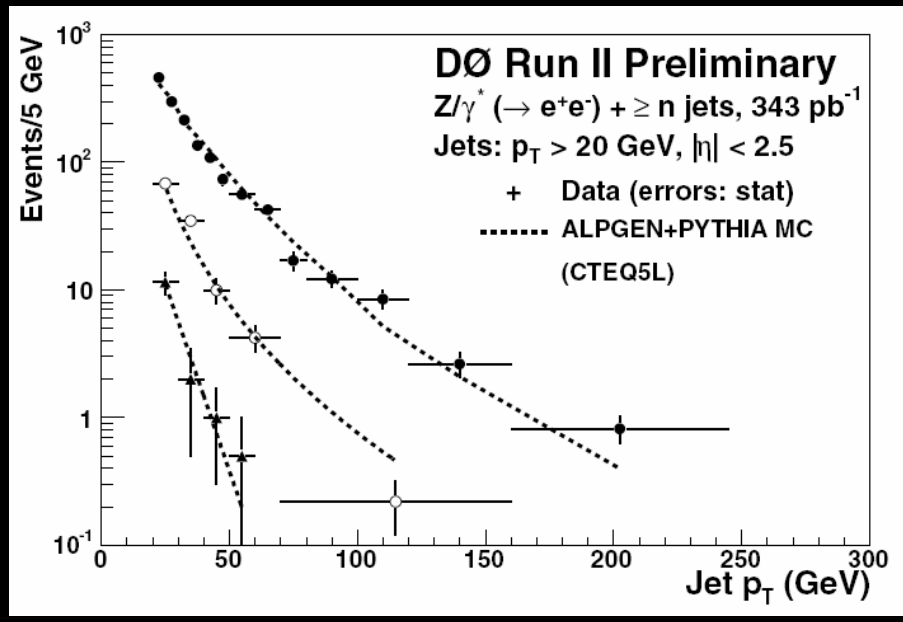
- Based on 127 pb^{-1}
- Jets
  - $E_T > 15$ GeV, $|\eta|<2.4$
  - Cone Alg, $R_{cone} = 0.4$
- Electrons
  - $P_T > 20$ GeV, $|\eta|<1.1$
- W's
  - Missing $E_T > 30$ GeV
  - Veto Z mass region
- Backgrounds (3-40%)
  - QCD
  - $W\rightarrow\tau\nu$, top, Z
  - multiple pp interactions

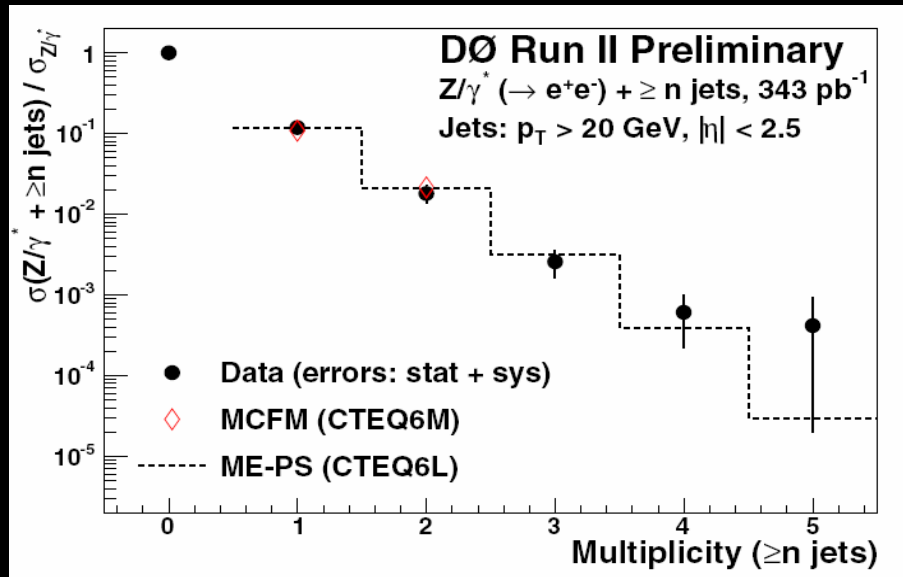
Jet multiplicity	≥ 0	≥ 1	≥ 2	≥ 3	≥ 4	≥ 5	≥ 6
Central	54799± 234	11615± 96	2680± 50	602± 24	145± 12	36± 6	12± 3
syst. Up	—	+1818	+708	+236	+71	+23	+7
syst. Down	—	-1552	-519	-145	-43	-12	-5



$\sigma(Z/\gamma^*(\rightarrow ee) + \geq n \text{ jets})/\sigma_{Z/\gamma^*}$

- Based on 343 pb^{-1}
  - 1,646 Z+jets events
- Selection:
  - Jets
    - $E_T > 20$ GeV, $|\eta|<2.5$
    - Midpoint Alg, $R_{cone} = 0.5$
  - Electrons
    - $P_T > 20$ GeV, $|\eta|<1.1$
  - Z's
    - $75 < M_{ee} < 105$ GeV
- Background (2-5%)





Good agreement with Theory:

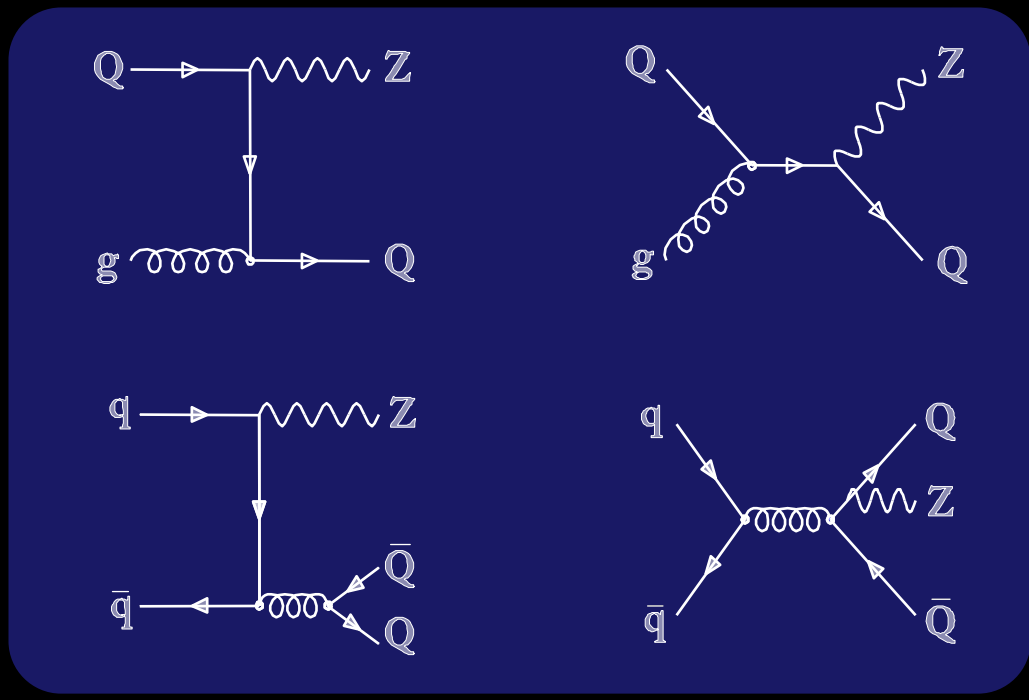
MCFM (NLO up to Z+2 partons)

ME-PS (MADGRAPH + PYTHIA with matching)

$\sigma(Z+b)/\sigma(Z+jet)$ (1)

- Analysis combines $Z \rightarrow ee$ and $\mu\mu$ channels
- Based on 180 pb^{-1}
  - 3,458 Z+jets events
- Jets:
  - $E_T > 20$ GeV, $|\eta|<2.5$
  - Midpoint Alg, $R_{cone} = 0.5$
- 2 Electrons/muons:
  - $P_T > 15$ GeV, $|\eta|<2.5/2.0$
- Z mass cut
  - $80 < M_{ee} < 100$ GeV
  - $65 < M_{\mu\mu} < 115$ GeV

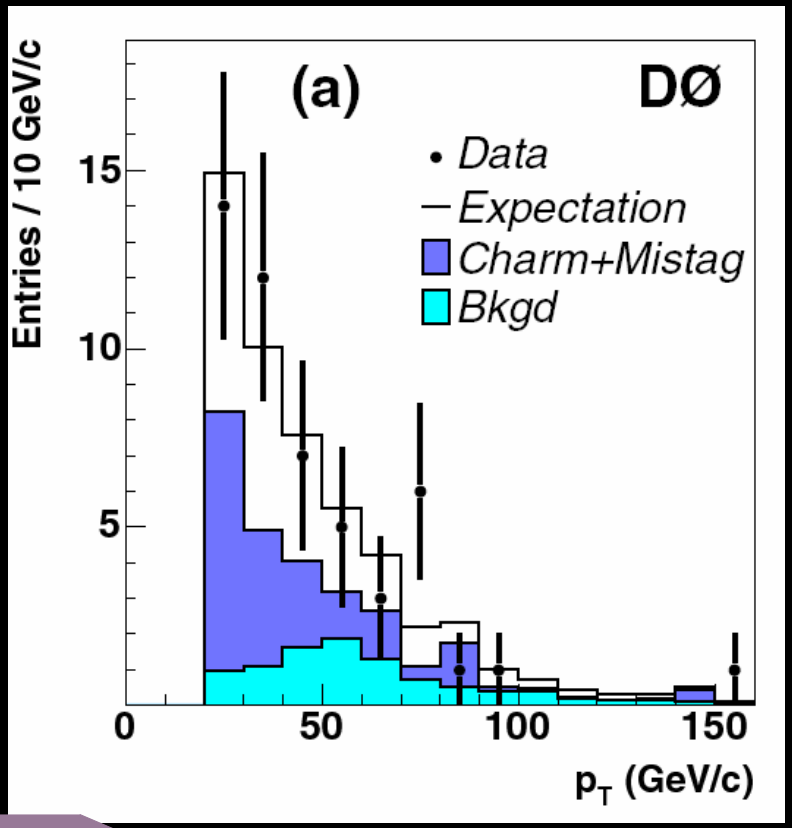
- Z+heavy flavor is background to ZH
- Z+b probes the b-quark PDF
  - b-PDF is important for hb and single-top production



σ(Z+b)/σ(Z+jet) (2)

- Apply sec. vertex b-tag
  - 42 events with ≥1 tag
  - 8.3 events from QCD background
- Disentangle light, c, b-jet contributions
  - Use light and b-tagging efficiency from data
  - c-tagging efficiency from MC and scaled from data/MC difference in b-tagging
  - N_c=1.69N_b from theory
- Measure inclusive ratio to cancel many systematics

p_T Spectrum of b-tagged jets



PRL (94), 161801 (2005)

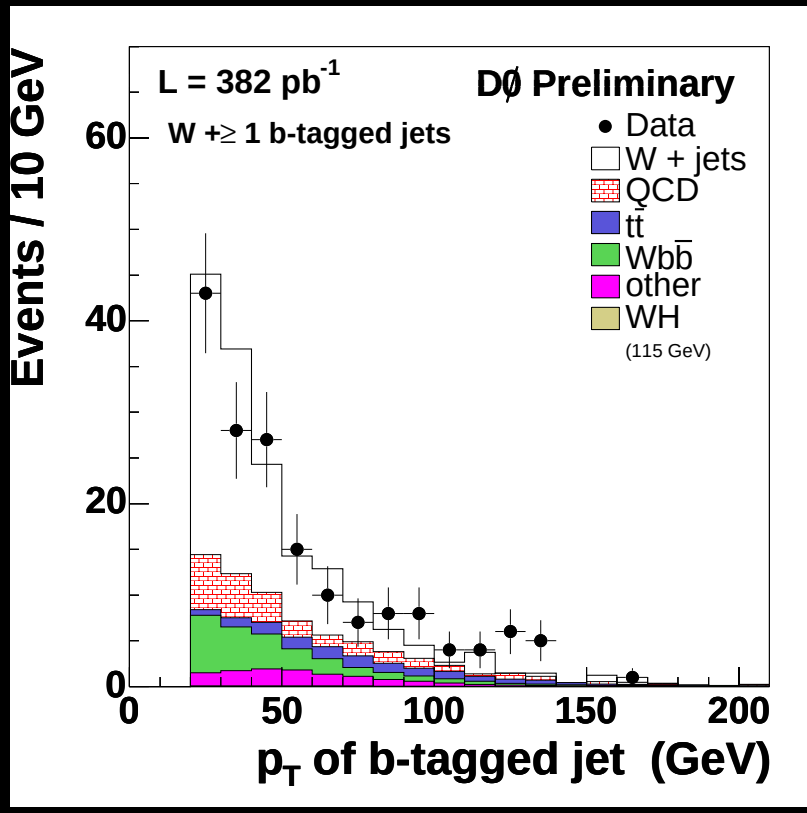
Measurement:
σ(Z+b)/σ(Z+j) = 0.021±0.004(stat)±0.002(sys)
Good agreement with NLO QCD: 0.018

Search for W(eν)bb Production

- Dominant bkgd for WH
- Based on 382 pb^{-1}
- Selection:
  - 2 Jets:
    - $E_T > 20$ GeV, $|\eta|<2.5$
  - 1 electron:
    - $P_T > 20$ GeV, $|\eta|<1.1$
  - Missing ET > 25 GeV

- b-tag:
  - JLIP (Jet Lifetime Probability)
  - 153 events with ≥1 b-tag
  - 13 events with 2 b-tags

Expect	4.29 ± 1.03 Wbb
	0.14 ± 0.03 WH
	5.73 ± 1.45 WZ, tt, W/Z+jets, single top, multijets
Total	10.2 ± 2.4 events
Observe	13

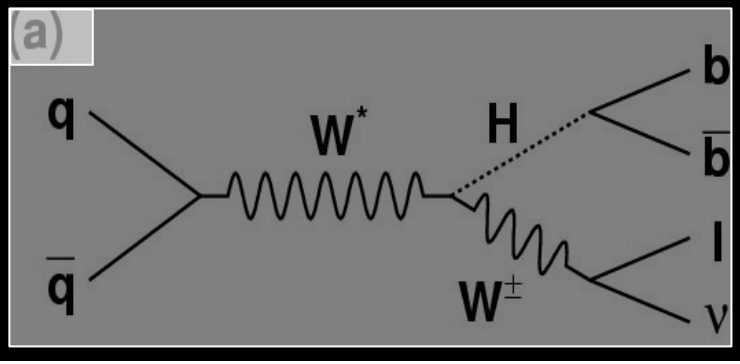


95% CL upper limit:

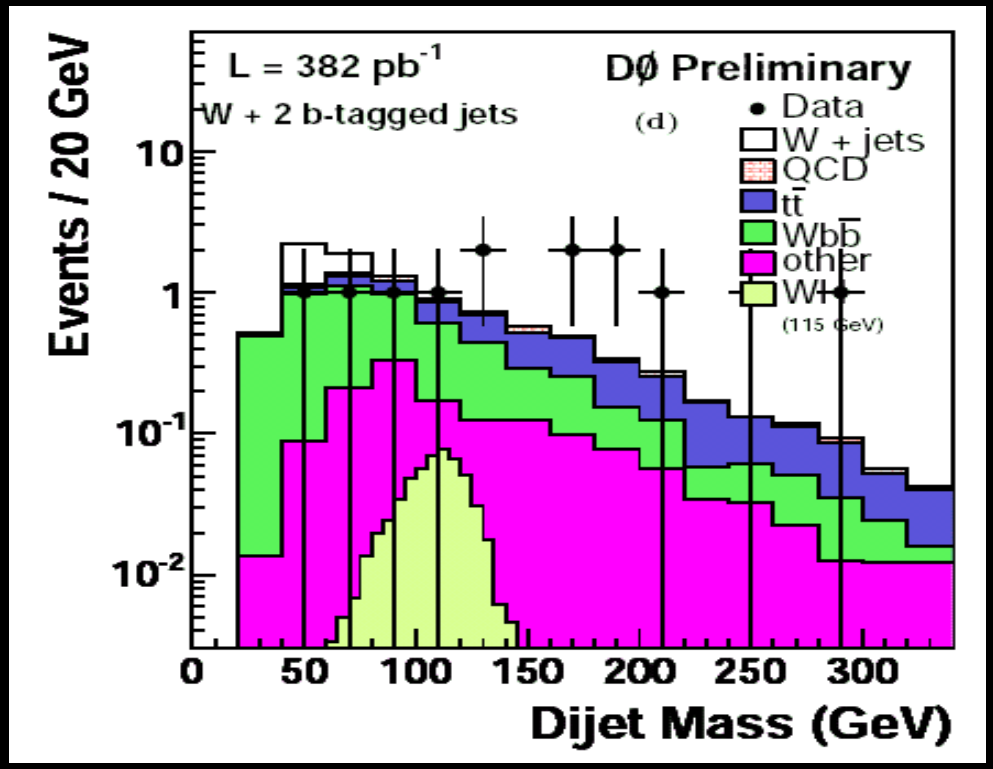
$\sigma(Wbb) < 4.6pb$

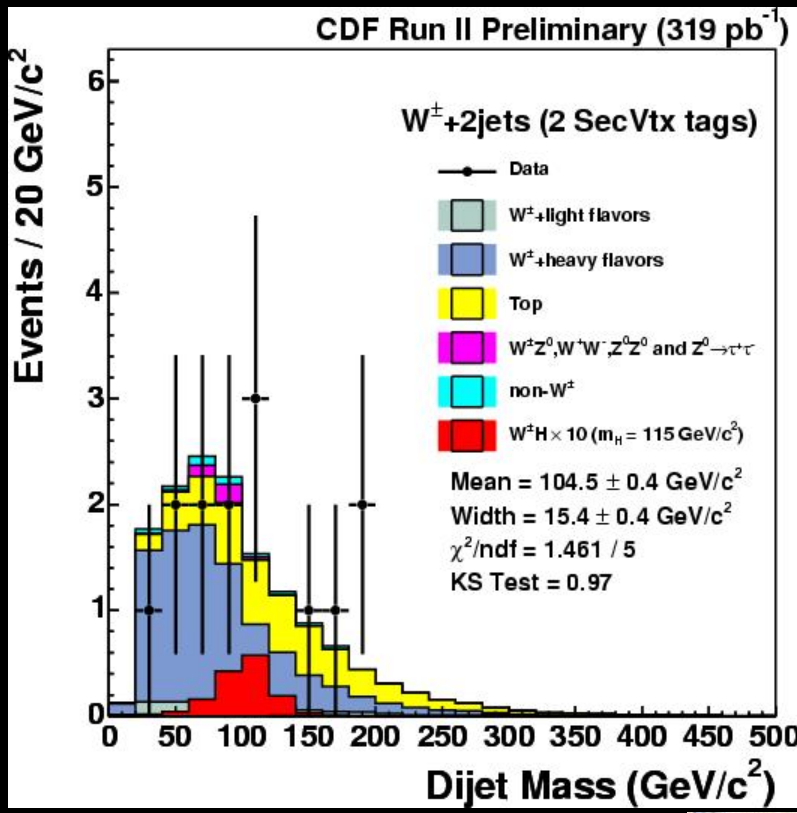
for b-jets with $p_T^b > 20$ GeV, $|\eta_\beta|<2.5$, and $\Delta R_{bb}>0.75$

From Wbb to WH



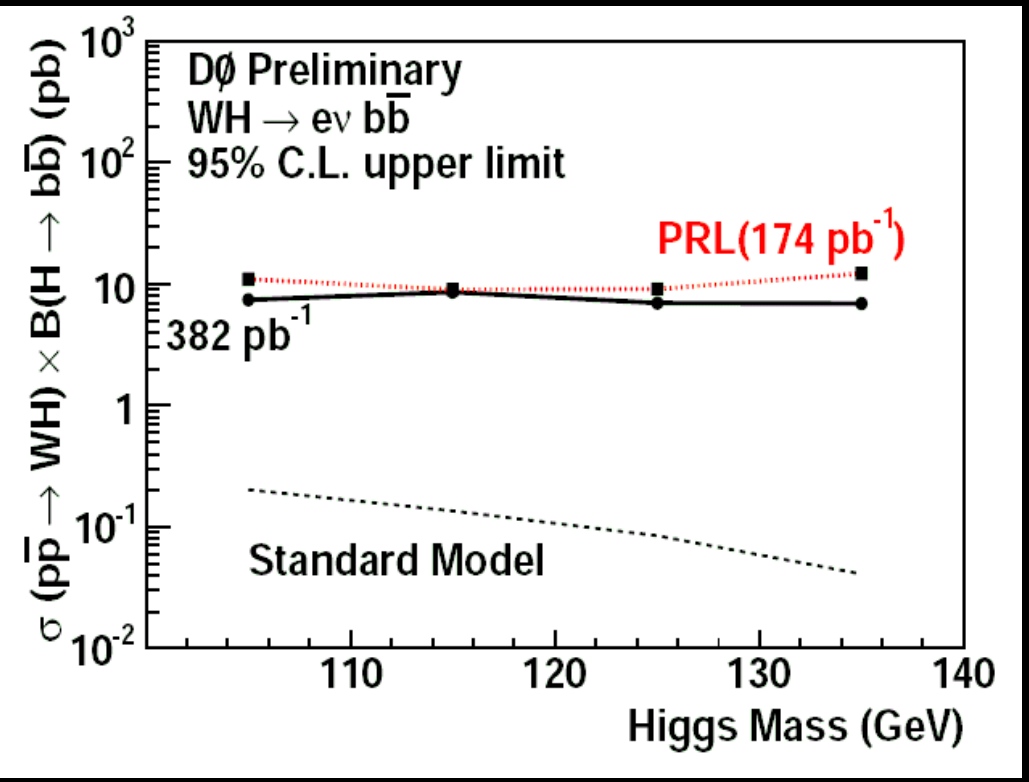
- Based on 319 pb-1
- Selection (**eν and μν channels**):
  - 2 Jets:
    - $E_T > 15$ GeV, $|\eta|<2$
  - 1 electron or muon:
    - $P_T > 20$ GeV, central
  - Missing $E_T > 20$ GeV
  - b-tagging: Secondary Vertex

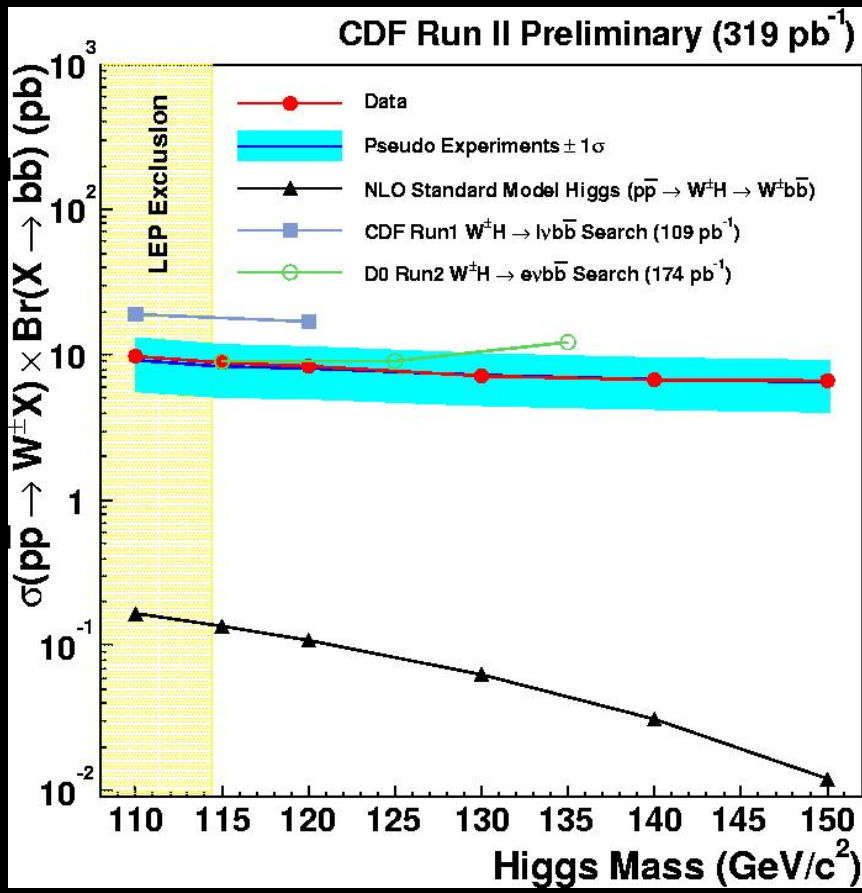




WH Limits

In the absence of a signal, 95% C.L. limits are set on Higgs boson production cross section times branching ratio to b-quarks



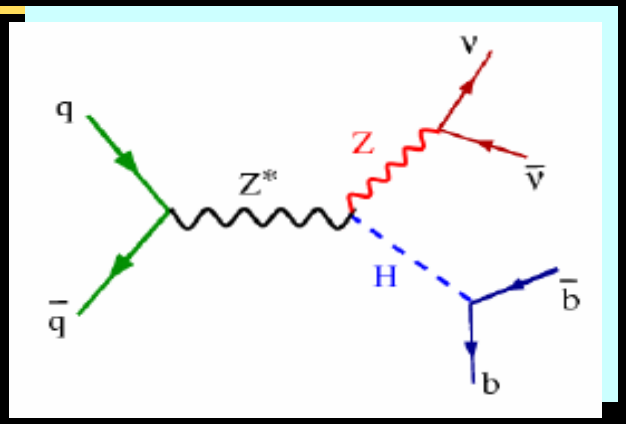


DØ previous Wbb/WH Result – 174 pb^{-1}
PRL (94), 091802 (2005)

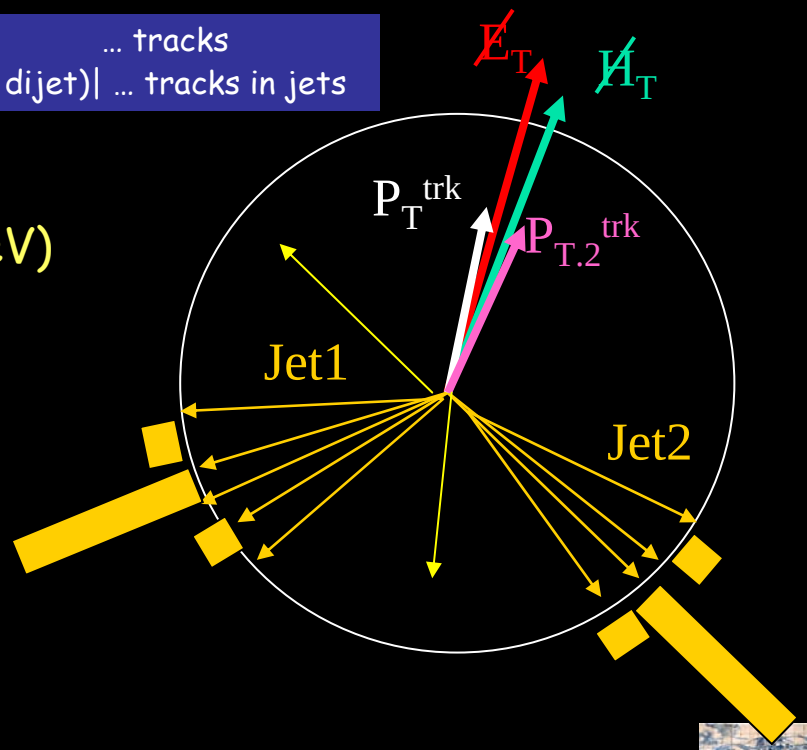
CDF RunI WH Result – ~100 pb^{-1}
PRL (81), 5748 (1998)

$Z(\rightarrow\nu\nu)H(\rightarrow bb)$ Search (1)

- An important channel for low-mass Higgs search
  - Large $B(Z\rightarrow\nu\nu) \sim 20\%$
- Trigger on events with large missing H_T
  - H_T is defined as the magnitude of the vector sum of jets' E_T
- Analysis was based on 261 pb^{-1}
- Selection:
  - 2 Jets:
    - $E_T > 20$ GeV, $|\eta|<2.5$
  - Missing $E_T > 25$ GeV
  - Veto events with isolated tracks ($p_T>8$ GeV)
    - To reject leptons from W/Z
  - $H_T = \Sigma|p_T(\text{jets})| < 200$ GeV
    - To reject tt events
  - Reduce "instrumental" backgrounds
    - Jet acoplanarity $\Delta\phi(\text{dijet}) < 165°$
    - Use various missing energy/momentum variables
    - Form asymmetry variables

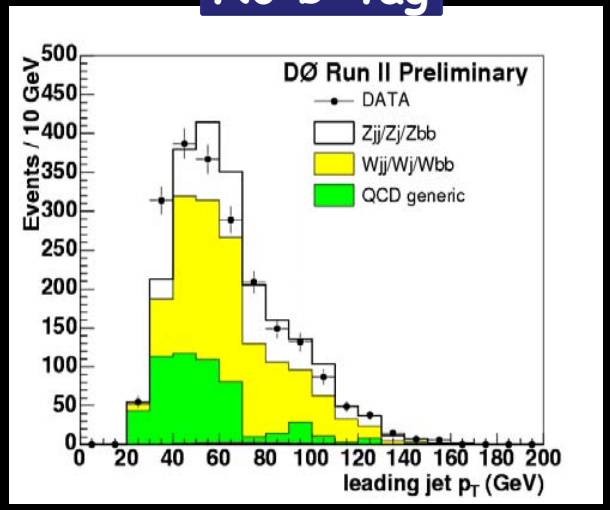


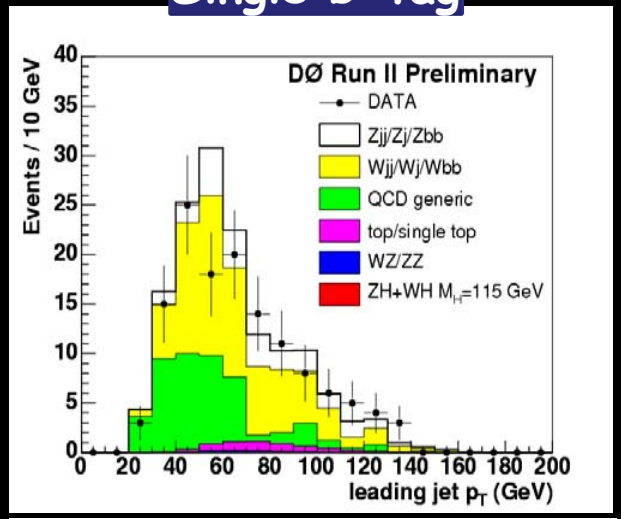
$P_T^{trk} = -|\Sigma p_T(\text{trk})|$ ... tracks
$P_{T,2}^{trk} = -|\Sigma p_T(\text{trk in dijet})|$ ... tracks in jets

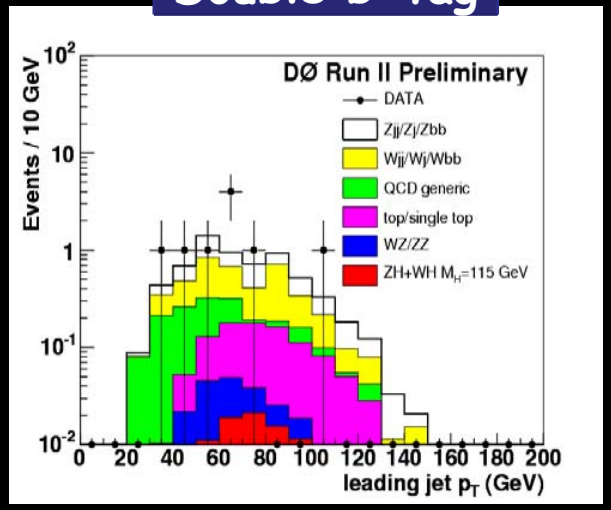


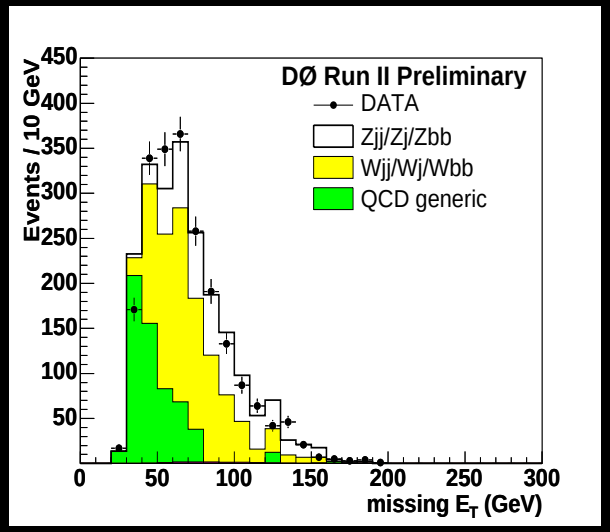
Z(→νν)H(→bb) Search (2)

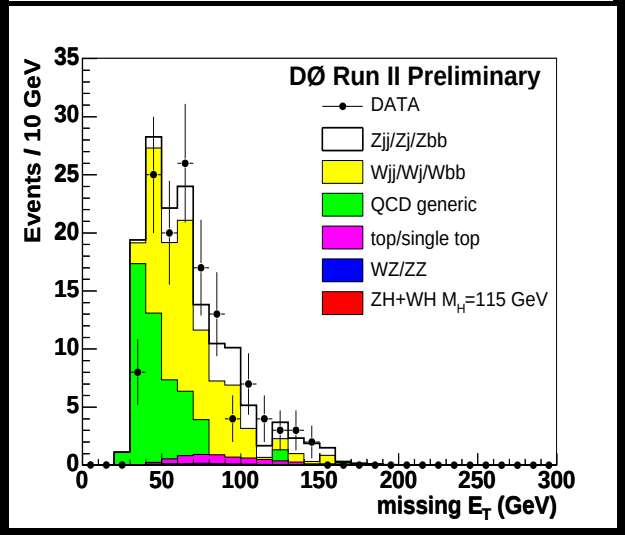
No b-tag | **Single b-tag** | **Double b-tag**

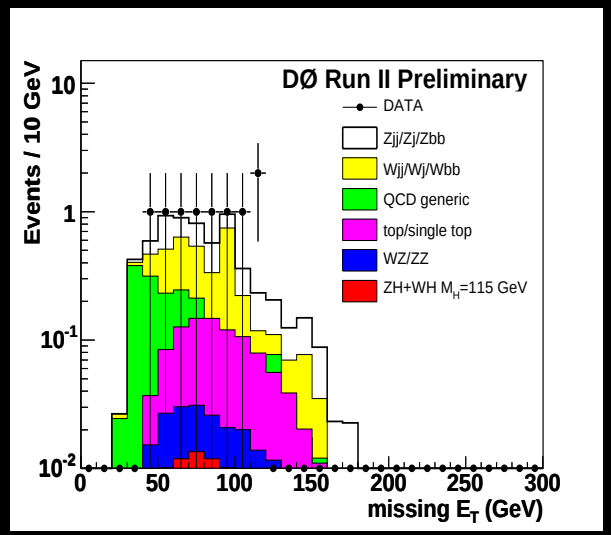








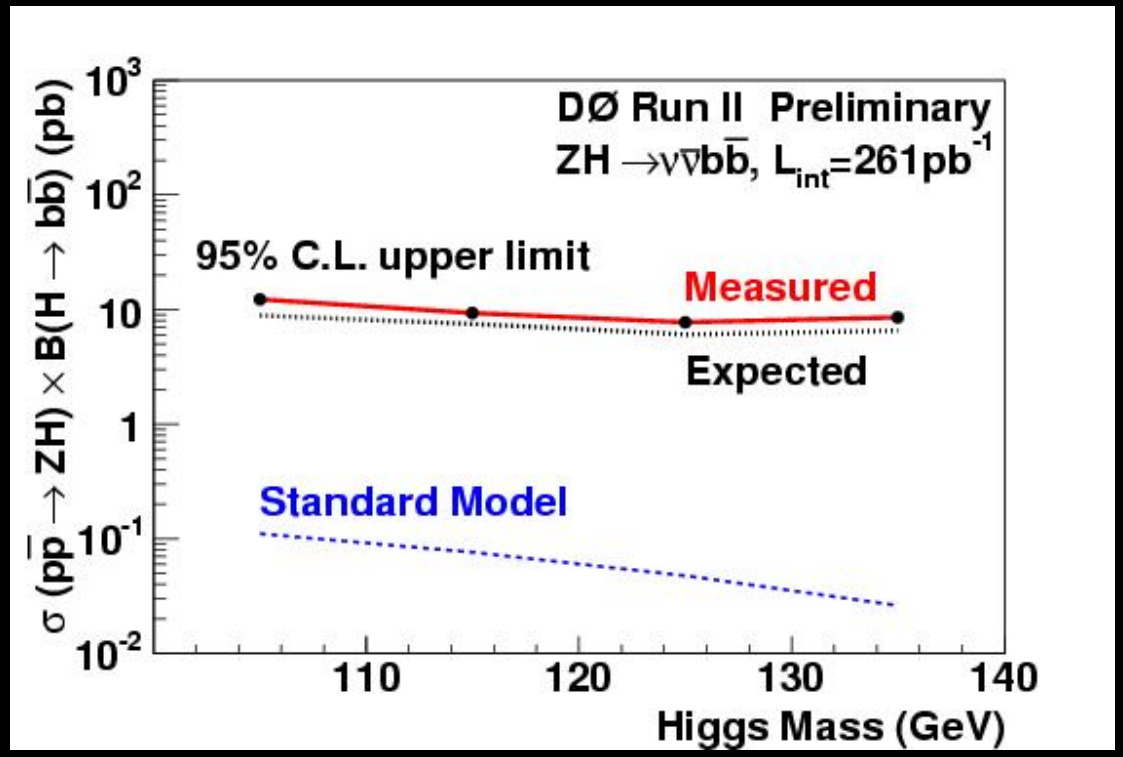




Z(→νν)H(→bb) Search (3)

Mass (GeV) Window	105 [70,120]	115 [80,130]	125 [90,140]	135 [100,150]
Data	4	3	2	2
Acceptance (%)	0.29 ± 0.07	0.33 ± 0.08	0.35 ± 0.09	0.34 ± 0.09
Total bkgd.	2.75 ± 0.88	2.19 ± 0.72	1.93 ± 0.66	1.71 ± 0.57
Expected limit (pb)	8.8	7.5	6.0	6.5
Limit @95% C.L. (pb)	**12.2**	**9.3**	**7.7**	**8.5**

Bkgd. composition (%)	
Wjj/Wbb	32
Zjj/Zbb	31
Instrumental	16
Top	15
WZ/ZZ	6

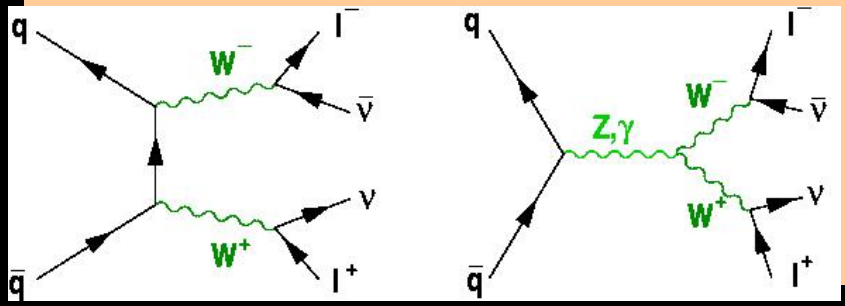


High Mass SM Higgs Searches

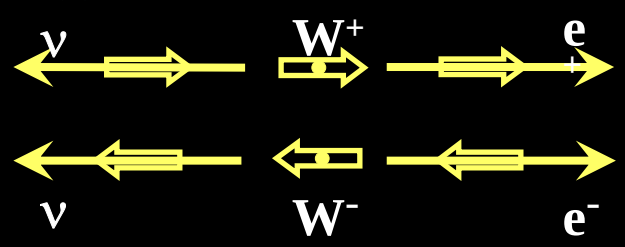
- $gg \rightarrow H \rightarrow WW^* \rightarrow \ell^+\ell^-\nu\nu$
  - $B(H \rightarrow WW^*) > 0.9$ for $m_H > 160$ GeV
- $WH \rightarrow WWW^*$
  - Fermiophobic Higgs
    - High $B(H \rightarrow WW^*)$ for $m_H \geq 100$ GeV
- Measurements rely on
  - Lepton identification + Missing-E_T resolution
  - Understanding of backgrounds
    - W/Z, WW production

$gg \to H \to WW^* \to \ell^+\ell^-\nu\nu$ (1)

- Bkgd: Z/γ^*, WW, ZZ, WZ, tt, W/Z + j, QCD



- Selection:
  - 2 high-p_T leptons + $\not{E}_T$
    - ee, $\mu\mu$, & $e\mu$ combined
  - Veto on
    - Z and energetic jets
  - Low ($<M_H/2$) dilepton inv mass
  - Opening angle between leptons is useful discriminating variable
    - Two leptons tend to move in parallel due to spin correlation of Higgs boson decay products



WW Cross Section Measurements (pb)

DØ: $13.8^{+4.3}_{-3.8}(\text{stat})^{+1.2}_{-0.9}(\text{sys}) \pm 0.9(\text{lum})$ (25 evts)

CDF: $14.6^{+5.8}_{-5.1}(\text{stat})^{+1.8}_{-3.0}(\text{sys}) \pm 0.9(\text{lum})$ (17 evts)

NLO Theory: 12-13.5 pb

CDF: *PRL (94), 211801 (2005)* DØ: *PRL (94), 151801 (2005)*

$gg \rightarrow H \rightarrow WW^* \rightarrow \ell^+\ell^-\nu\nu$ (2)

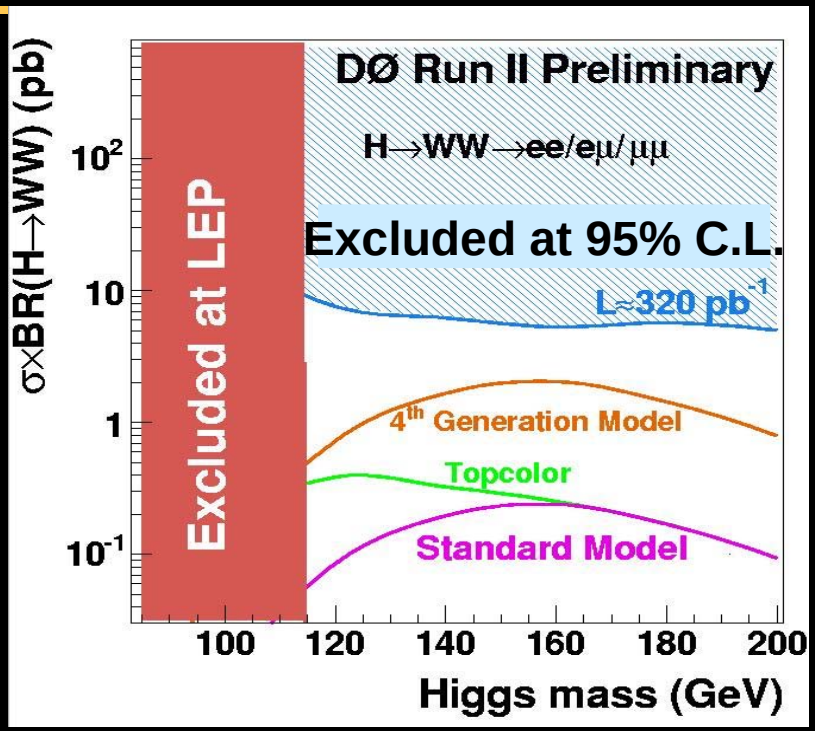
DØ

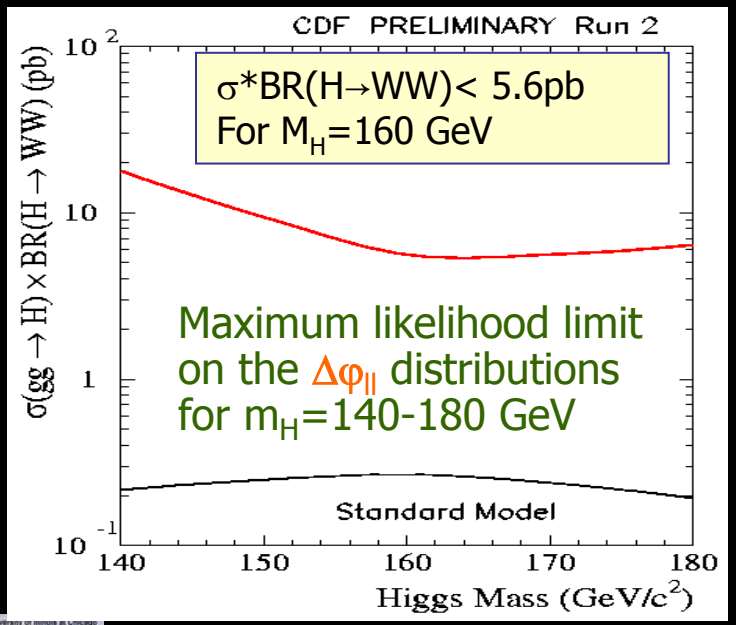
Analysis based on ~320 pb^{-1}

Expected number of events for M_H=160 GeV:

	0.54 ± 0.02	$H \rightarrow WW^*$
	11.7 ± 0.2	Diboson Production
	2.1 ± 0.7	W+jet/γ
	3.3 ± 0.7	Z/γ^*
	0.64 ± 0.1	tt + multijets
Total	17.7 ± 1.0 events	
Observe	20	

σ*BR(H→WW) < 5.7pb
For M_H=160 GeV





CDF

Analysis based on ~200 pb^{-1}

Expected number of events for M_H=160 GeV:

	0.22 ± 0.03	$H \rightarrow WW^*$
	4.45 ± 0.52	WW
	1.34 ± 0.35	Other bkgds
Observe	3	

WH → WWW* (1)

- Search for associated Higgs production with W where the H→WW*
- Selection:
  - 2 like-sign high-p_T leptons
    - Reduce Z→ee bkgd
  - Significant $\not{E}_T$

DØ

Analysis based on ~370 pb^{-1}

Data: 1/3/2 events for ee/eμ/μμ channels

bkgd: 0.70 ± 0.08 for ee

4.32 ± 0.23 for eμ

3.72 ± 0.75 for μμ

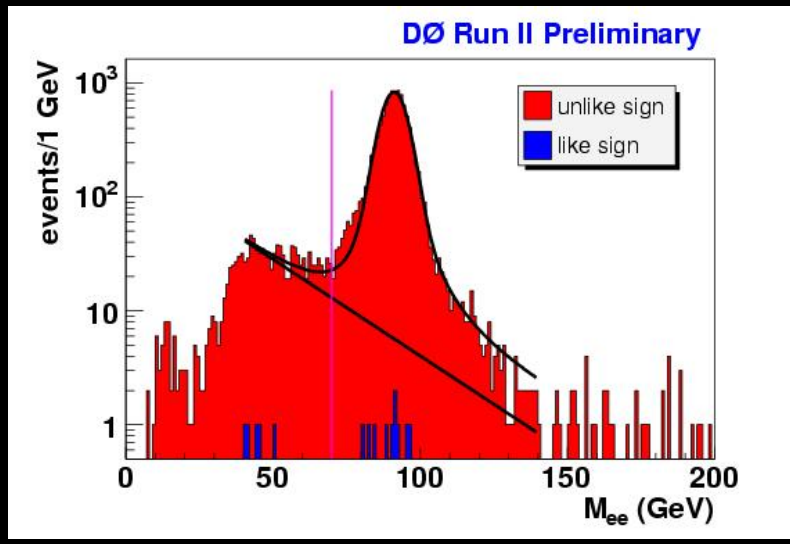
CDF

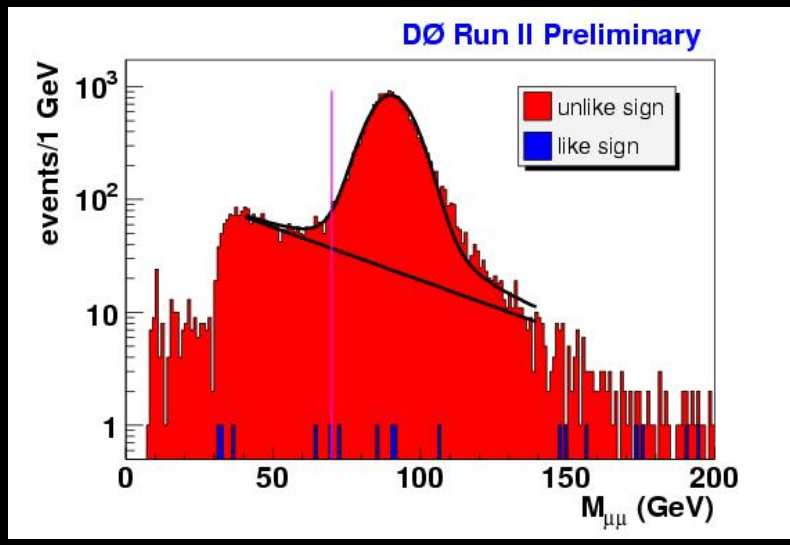
Analysis based on ~190 pb^{-1}

Data: 0 events

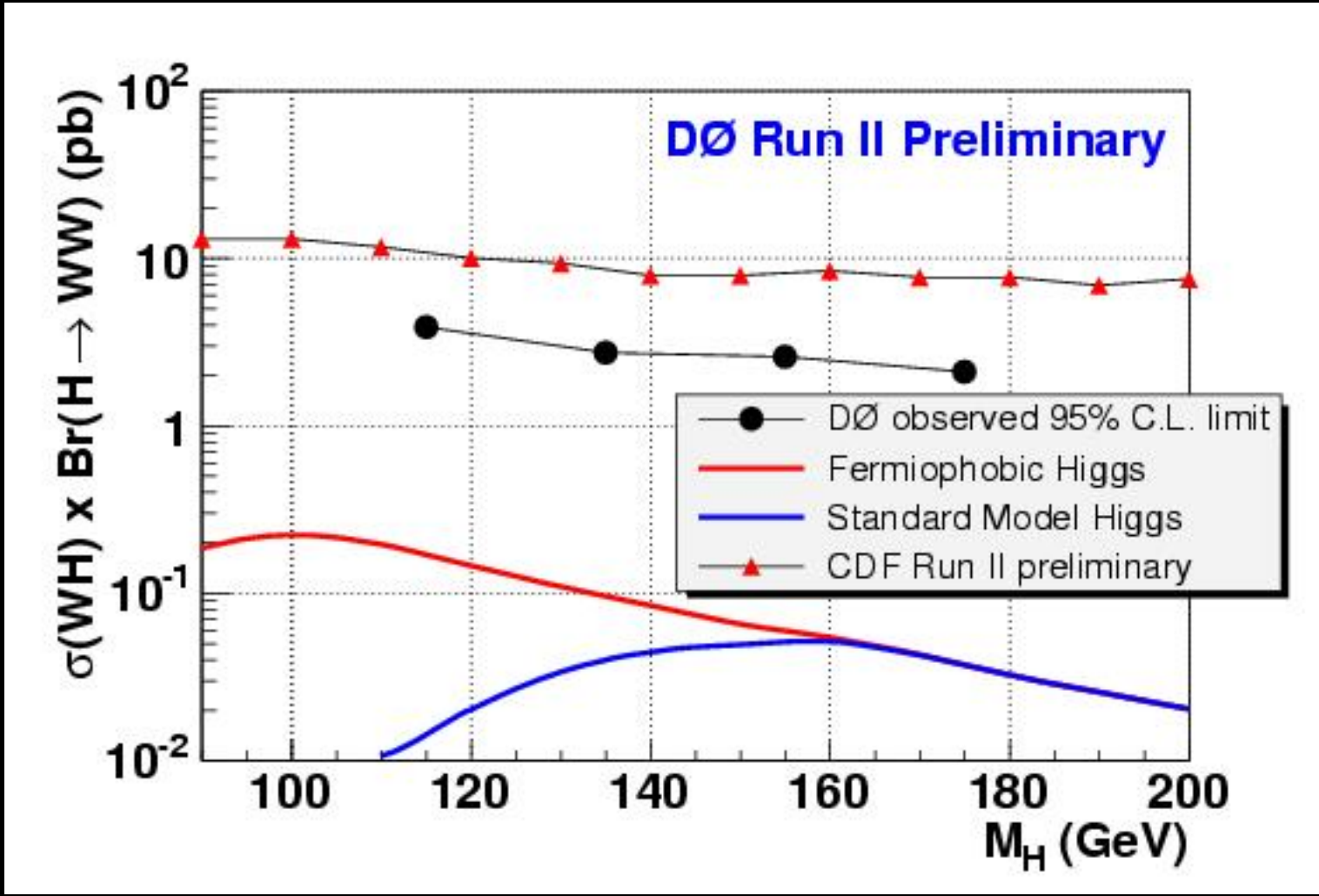
bkgd: 0.95 ± 0.61(stat) ± 0.18(sys)

SM Higgs (160 GeV) expected to be ~0.03 evts

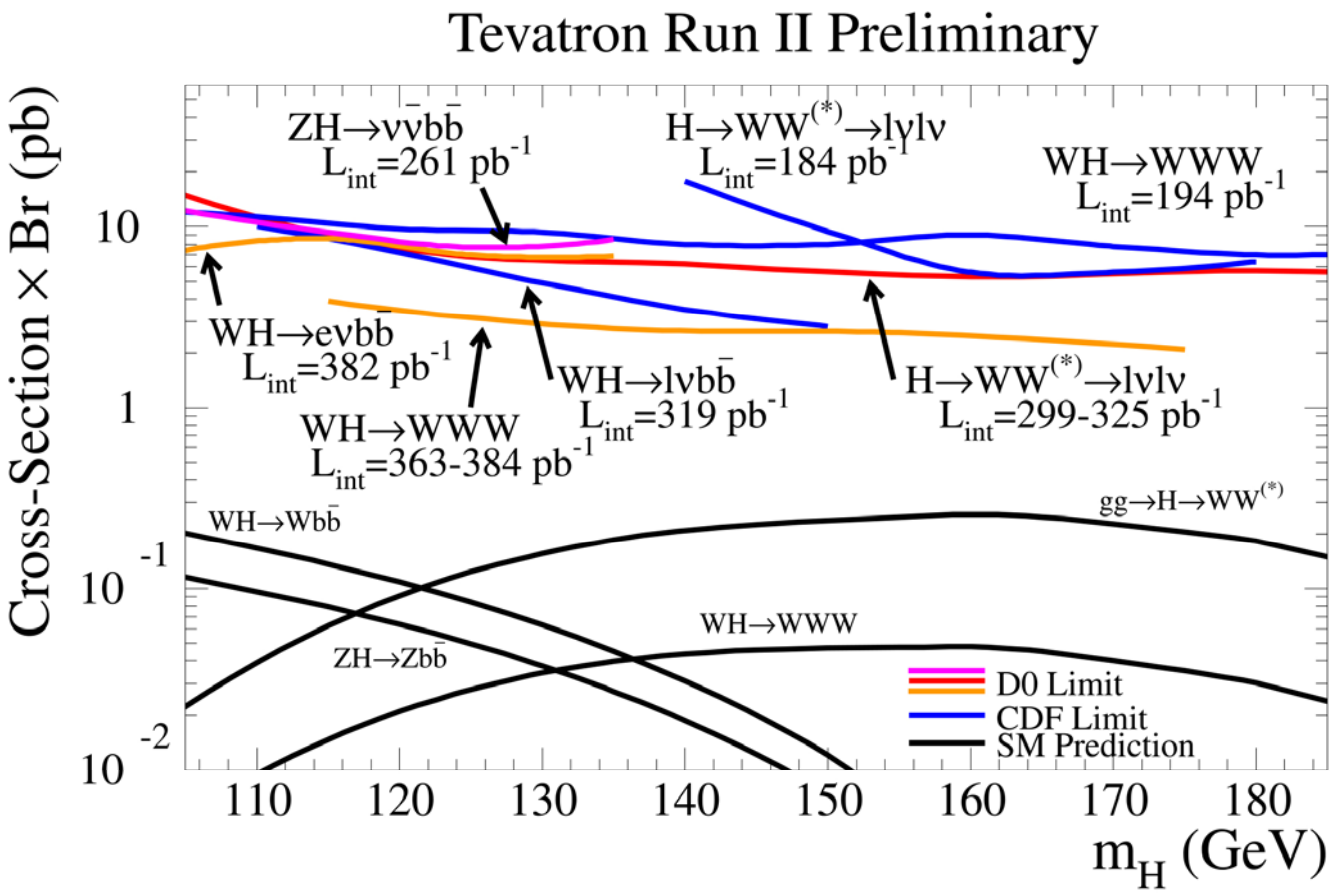




HW → WWW* (2)


DØ Run II Preliminary
σ(WH) x Br(H → WW) (pb)
10^2
10
1
10^{-1}
10^{-2}
100
120
140
160
180
200
M_H (GeV)
DØ observed 95% C.L. limit
Fermiophobic Higgs
Standard Model Higgs
CDF Run II preliminary

Where we Stand Today



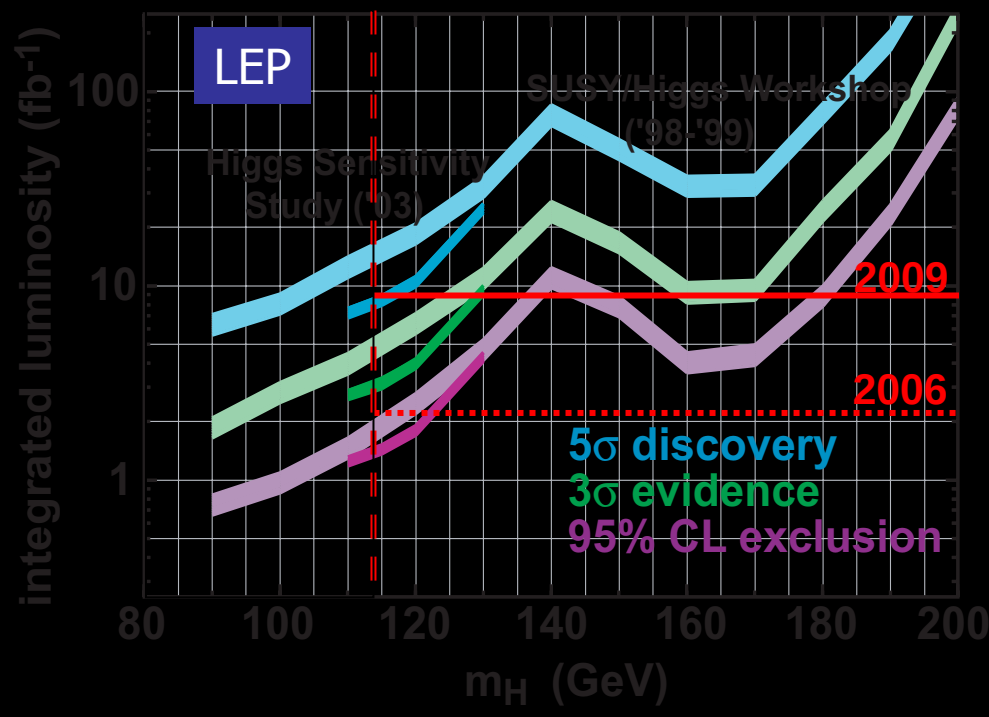
Future Prospects

- Near term: expect at least doubling of analyzed data for Spring '06 conferences
- Long term: reaching 4-8 fb^{-1} by FY09
  - Detector upgrades in late 2005 (Si, trigger)

Tevatron Higgs Sensitivity Group:
Initial Report: hep-ph/0010338 (2000)

Updated in 2003 in the low Higgs mass region: Fermilab-PUB-03/320-E
http://www-d0.fnal.gov/Run2Physics/higgs_sensitivity_study.html

- $WH \rightarrow l\nu bb$
- $ZH \rightarrow \nu\nu bb$
- Improvement due mainly to sophisticated analysis techniques and better detector understanding



Summary

- Tevatron accelerator complex and experiments are performing well
- Higgs searches from $\leq$400 pb^{-1} of Run II data show no deviation from SM bkgd expectations
- Expect improved analyses and limits by Spring '06 based on ~ 1 fb^{-1} of data
- Sensitivity of m_H>114 GeV starts with 2 fb^{-1}
- Exclusion up to m_H ~ 135 GeV with 8 fb^{-1}
- Very exciting short and long term future prospects with a lot of hard work ahead