Recent Results from Tevatron

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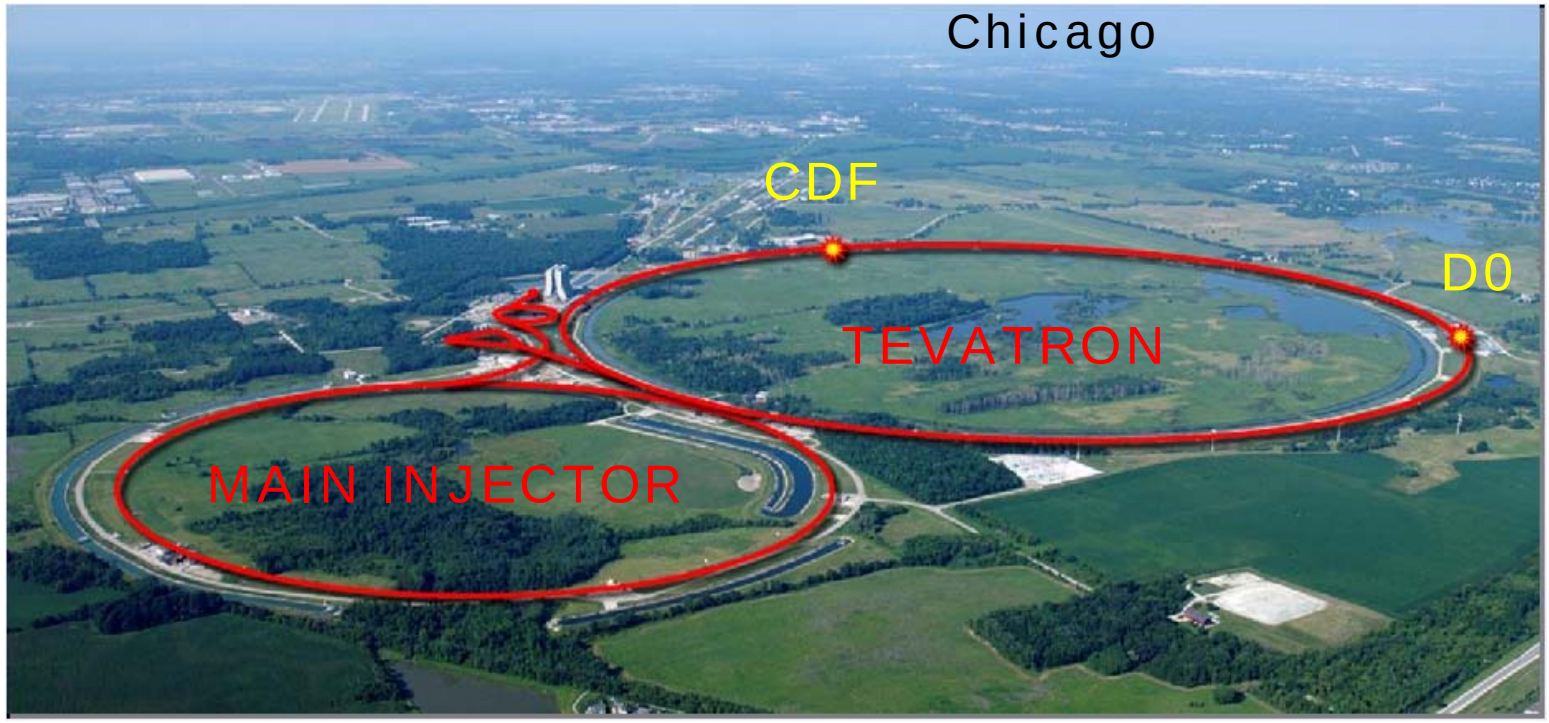
for CDF and DØ Collaborations

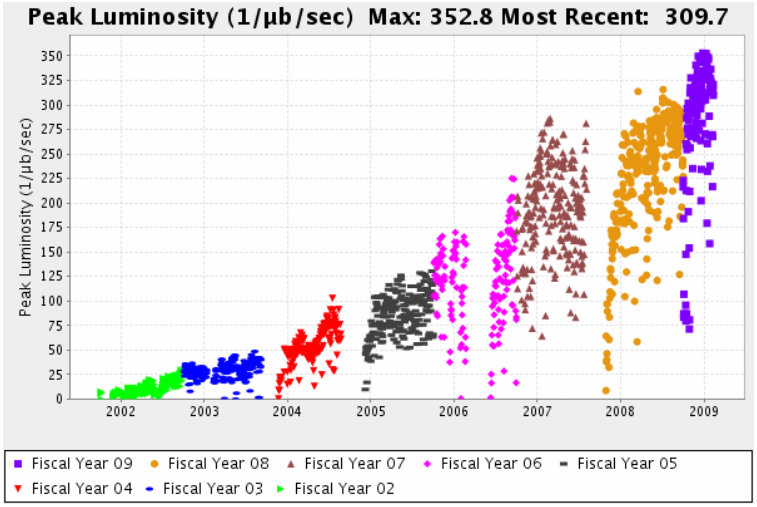
Tevatron Run II

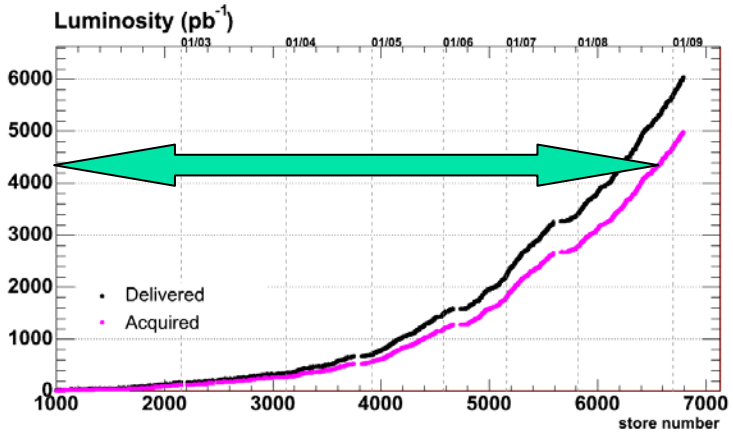


- The world's highest-energy particle collider, so far.
- Proton-antiproton collisions at s = 1.96 TeV
- Tevatron is performing really well: delivered 6 fb^{-1}
  - 7~8 fb^{-1} expected by the end of 2009. (8~9 fb^{-1} if run in FY10)

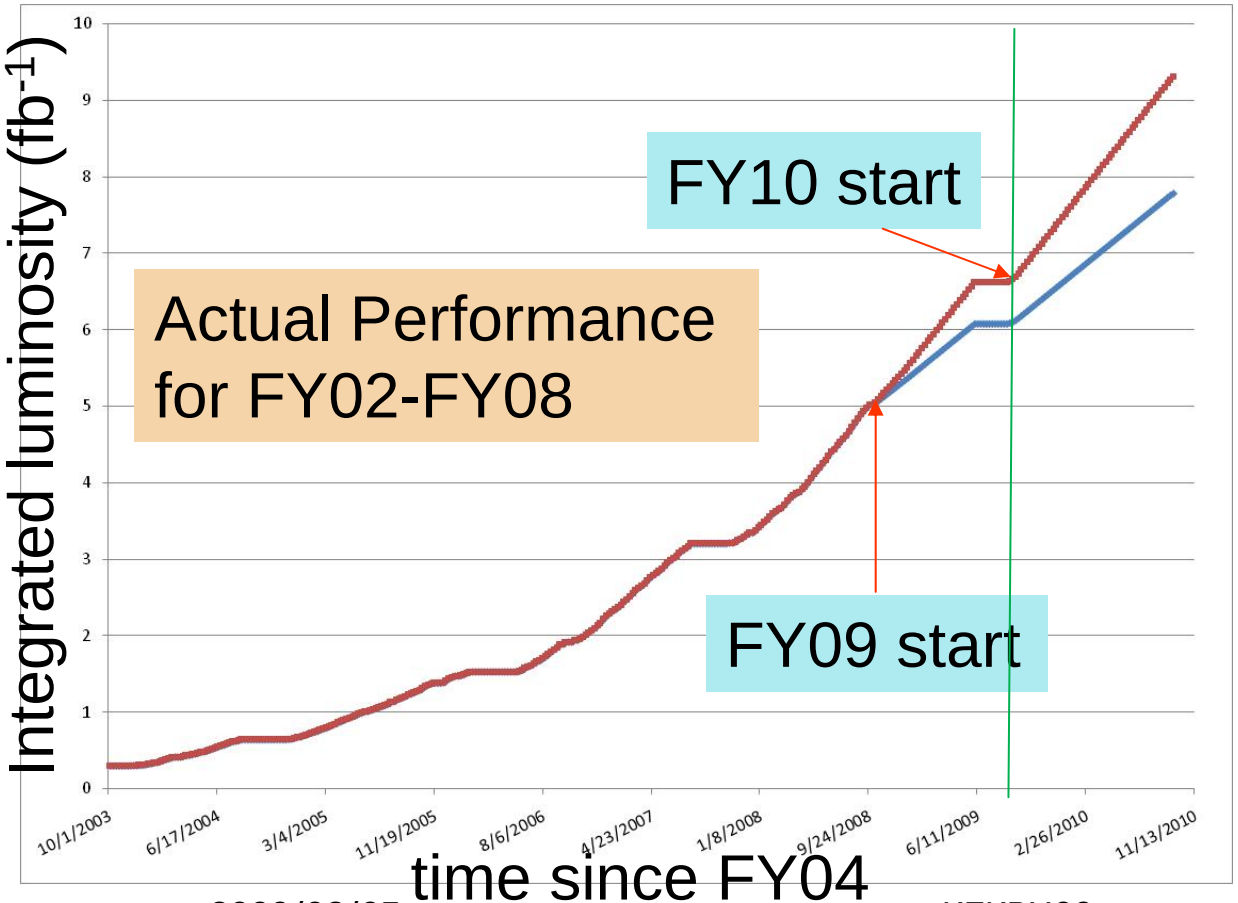
Tevatron Status

- Continually establishing new records!
  - Peak luminosity
    ~3.5×10^{32} cm^{-2} s^{-1}
  - Weekly integrated luminosity
    78 pb^{-1}
  - Annual integrated luminosity
    1.8 fb^{-1} (US FY2008)
  - Avarage pbar accumulation rate
    - 21×10^{10} pbar/ hour
- Very stable operation
  - Maximizing integrated luminosity
  - 10 weeks shutdown in 2009 summer





Tevatron Prospects



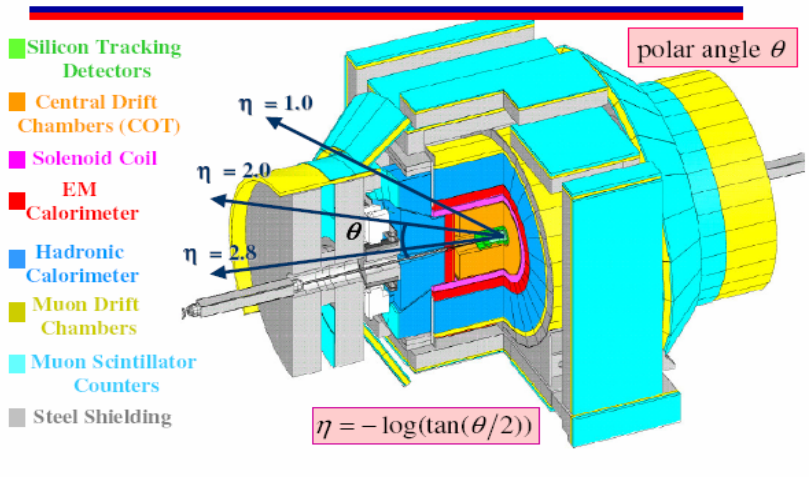
Updated Feb 2009

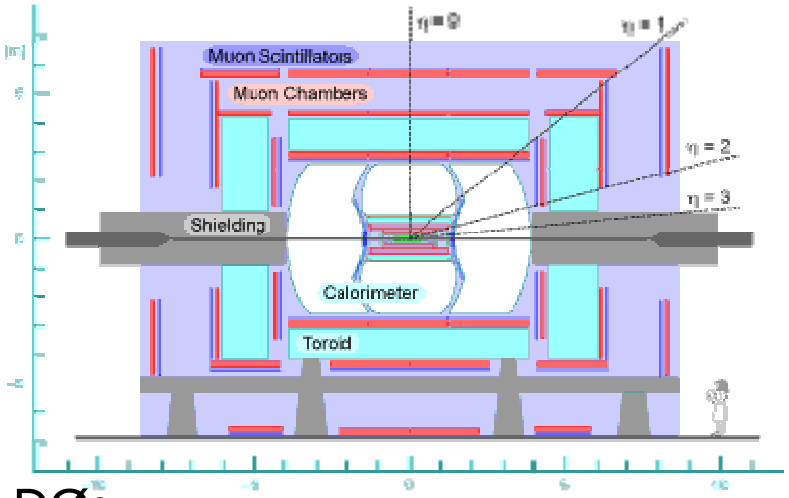
9.32 fb^{-1}

7.78 fb^{-1}

- Highest Int. Lum
- Lowest Int. Lum
- FY2010
  - FNAL plans to run (if budget allows) and CDF/DØ are ready.
  - Another ~2 fb^{-1}, total ~9 fb^{-1}

CDF/DØ Detectors

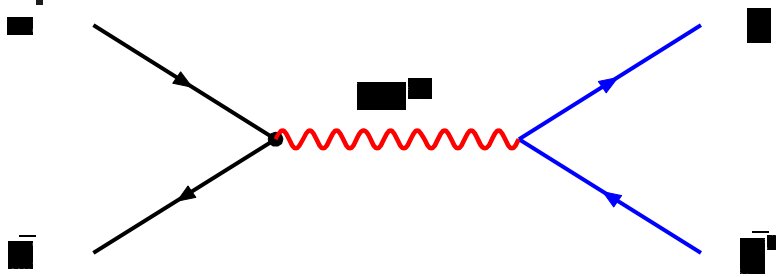




- CDF:
  - 8 layer silicon vertex detector
  - 8 super layer drift chamber
  - 1.4T solenoid
  - Good particle identification (K, π)
  - Central/Wall/Plug calorimeters
  - Scintillator+drift chamber muon detectors
- DØ:
  - 8 layer silicon vertex detector
  - 16 layers scintillating fibers
  - 2T solenoid
  - Central/Endcap calorimenters
  - 1.8T toroid
  - 3 layer muon scintillator + drift tubes (Extended muon coverage)

Electroweak Physics

W Boson Mass



- Use $e\nu$ and $\mu\nu$ modes.
- ν's not directly measured, inferred from missing transverse momentum.

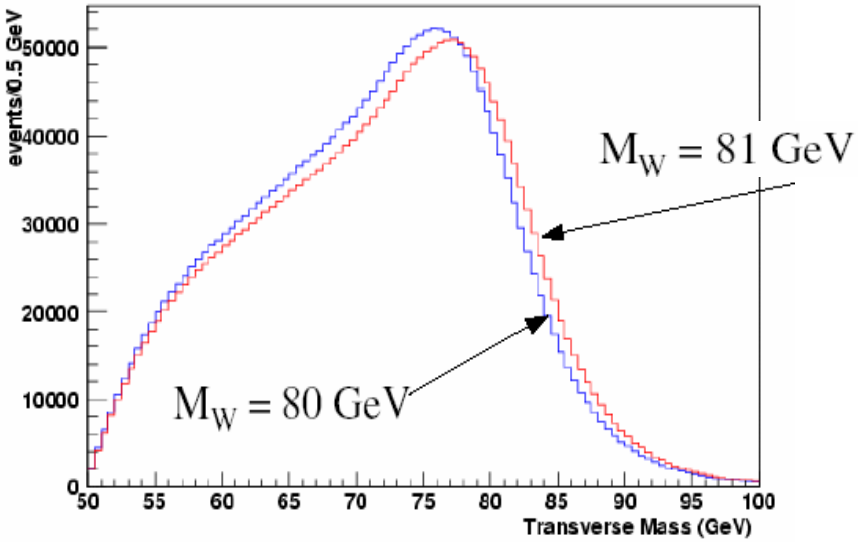
Neutrino longitudinal momentum not known.

form transverse mass :

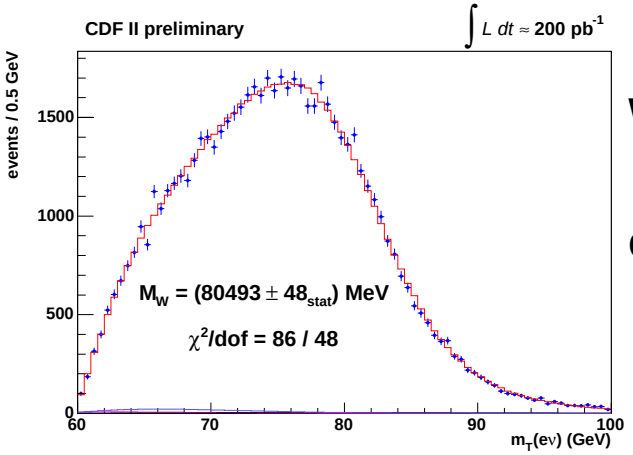
$$M_T^2 \equiv 2\, p_T^\ell\, p_T^\nu\, (1 - \cos\Delta\phi)$$

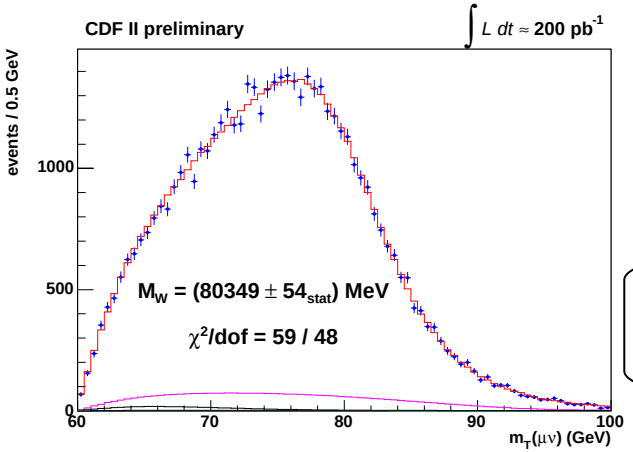
Muon momenta from tracking.

Electron energy from calorimeter.



W Mass Measurement (CDF)



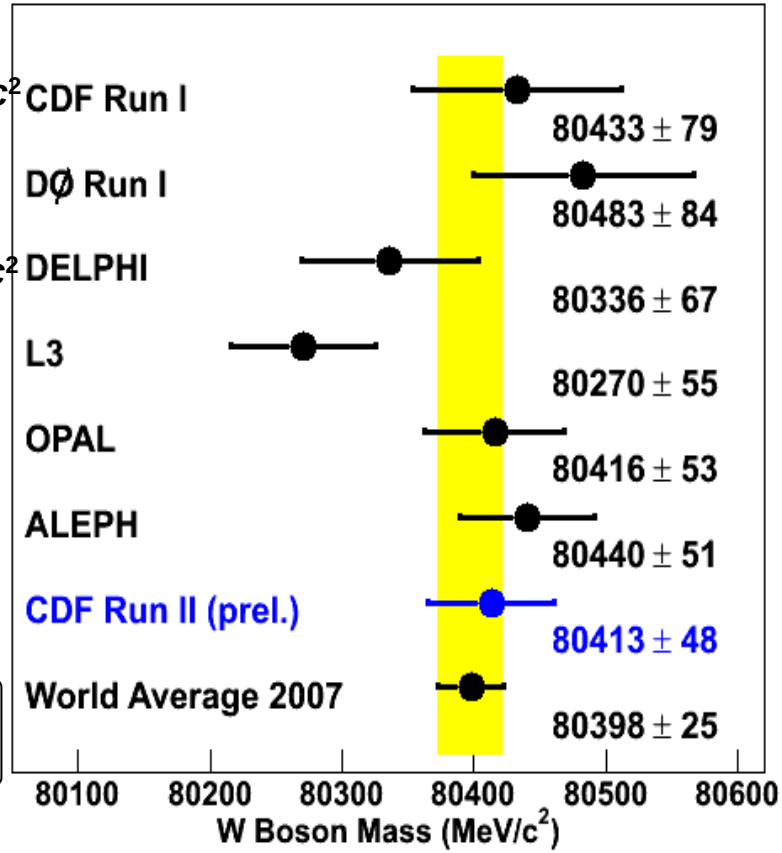


World average:
$M_W = 80.398 \pm 0.025$ GeV/c^2

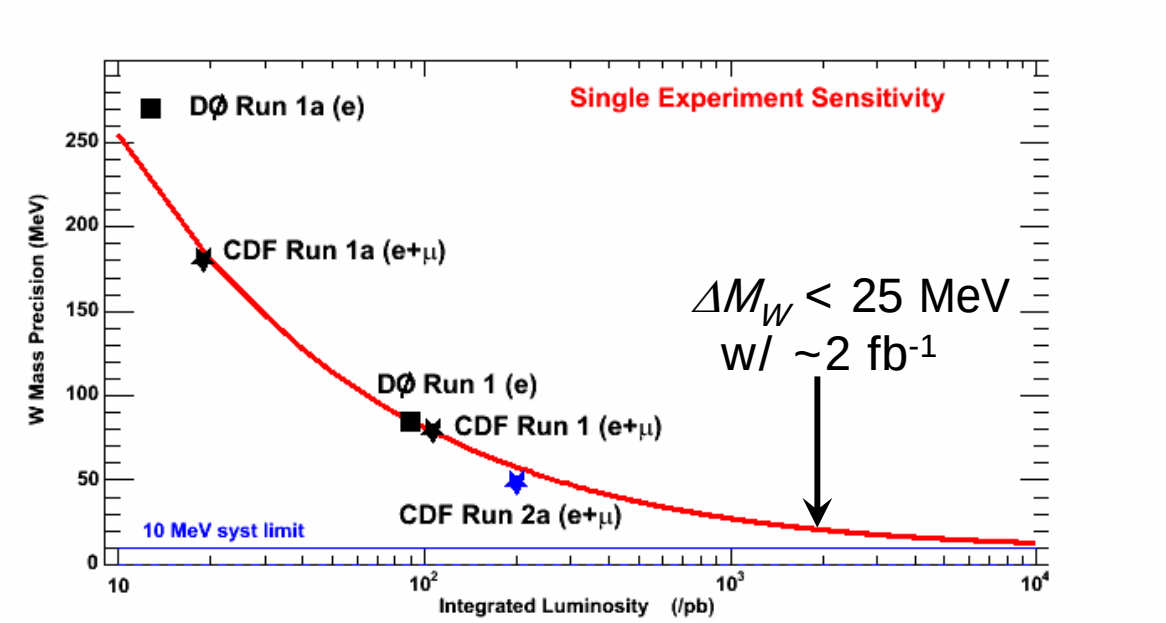
CDF ($\int L$=200 pb^{-1}):
$M_W = 80.413 \pm 0.034$ (stat)
± 0.034 (syst) GeV/c^2
$\Delta M_W = 0.048$ GeV/c^2

[Phys. Rev. Lett. **99**, 151801 (2007), Phys. Rev. D **77**, 112001 (2008)]

Single most precise measurement!

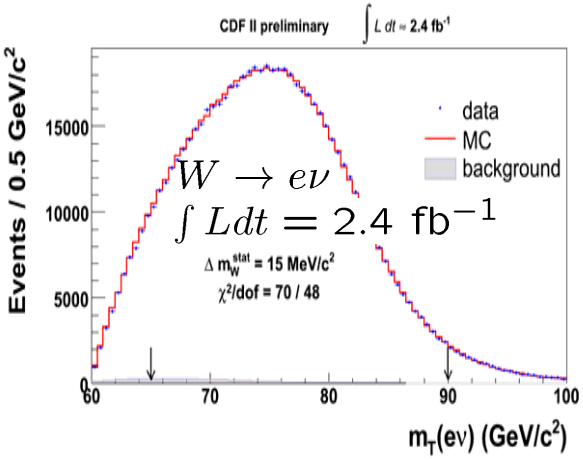


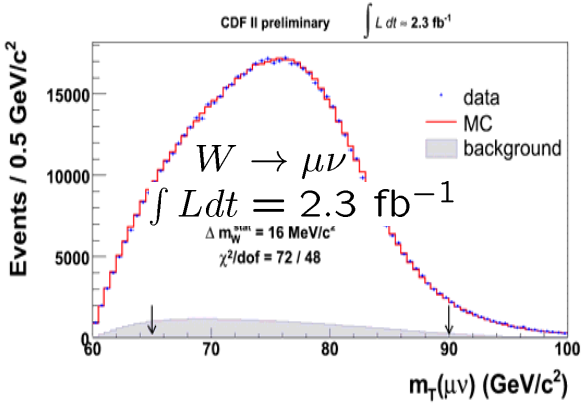
W Mass Projections



$W \to e\nu$	Δm_W^{stat}
published (200pb^{-1})	48 MeV/c^2
expected (2.4fb^{-1})	14 MeV/c^2
fit (2.4fb^{-1})	15 MeV/c^2

$W \to \mu\nu$	Δm_W^{stat}
published (200pb^{-1})	54 MeV/c^2
expected (2.3fb^{-1})	16 MeV/c^2
fit (2.3fb^{-1})	16 MeV/c^2



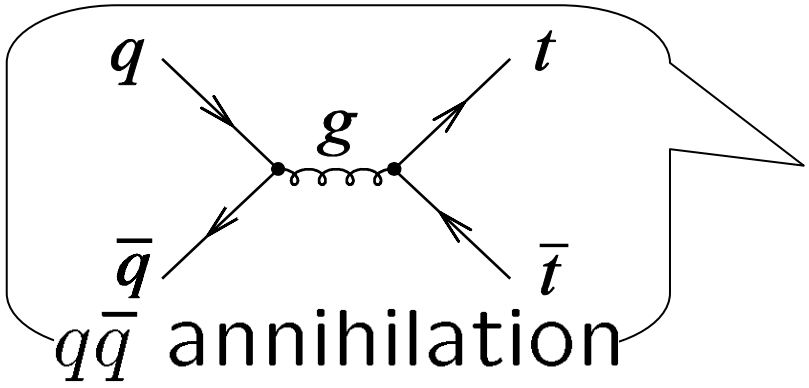


Top Quark Physics

Top Pair Production

$p\bar{p}$ collision @ $\sqrt{s} = 1.96\text{TeV}$ $\quad \sigma = 6.8 \pm 0.8$ pb

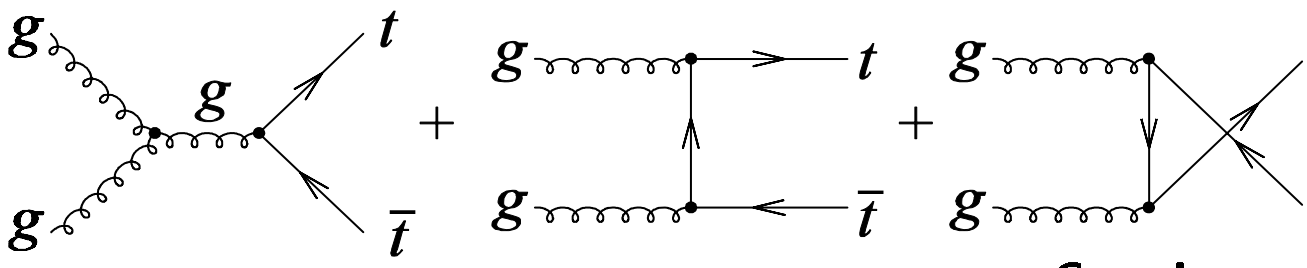
(NLO, $M_t = 175\text{GeV}$)



$q\bar{q}$ annihilation

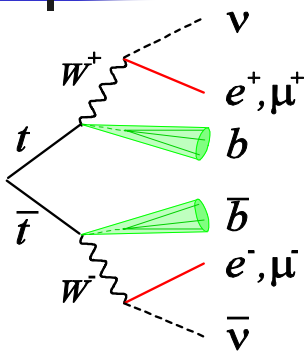
Dominant process

10%~20%



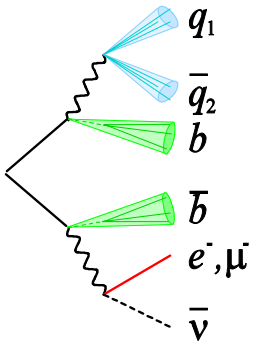
gg fusion

Top Pair Signature



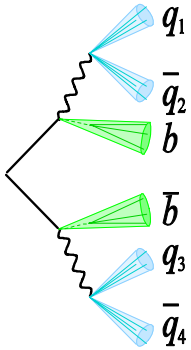
Dilepton

- 2 lepton
- 2 *b*-jet
- MET



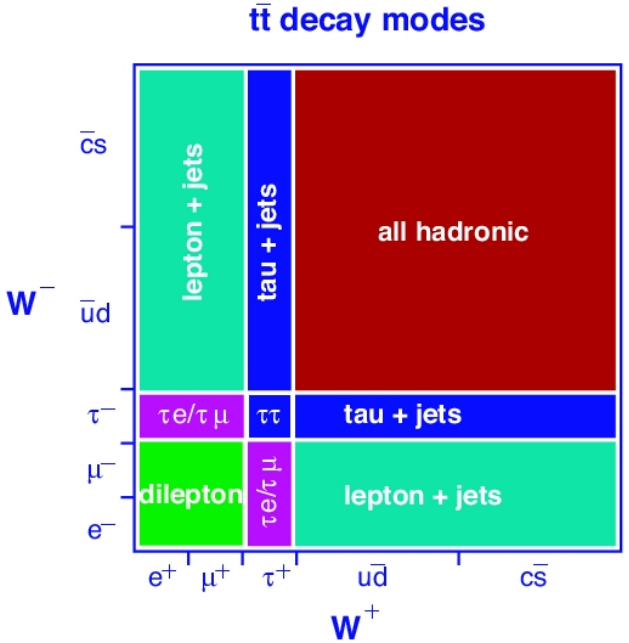
Lepton+Jet

- 1 lepton
- 4 jet (2 *b*-jet)
- MET



All Hadronic

- 6 jet (2 *b*-jet)



$$\Gamma^{-1} \approx (1.5\,\mathrm{GeV})^{-1} << \Lambda_{\mathrm{QCD}}^{-1} \sim (200\,\mathrm{MeV})^{-1}$$

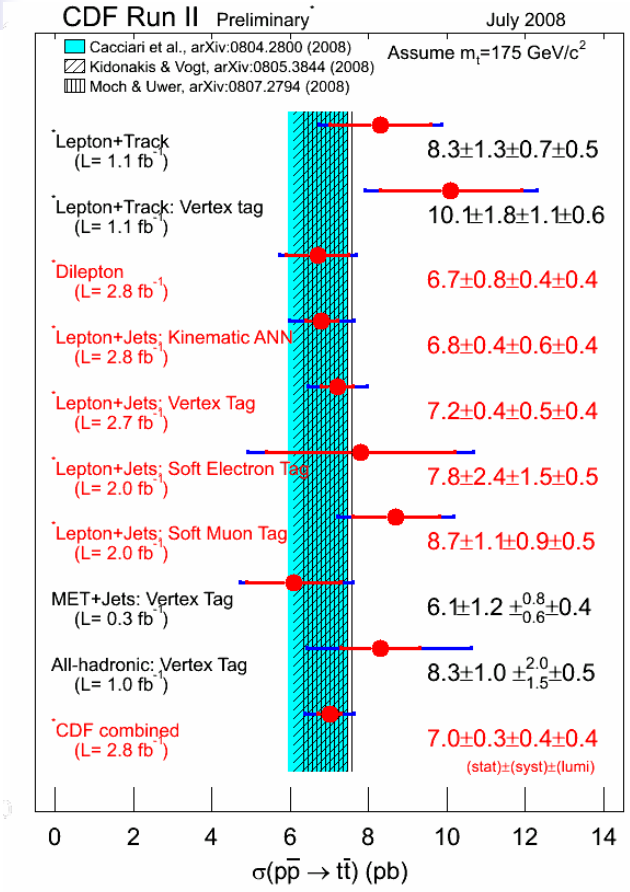
Top quark decays as a naked quark

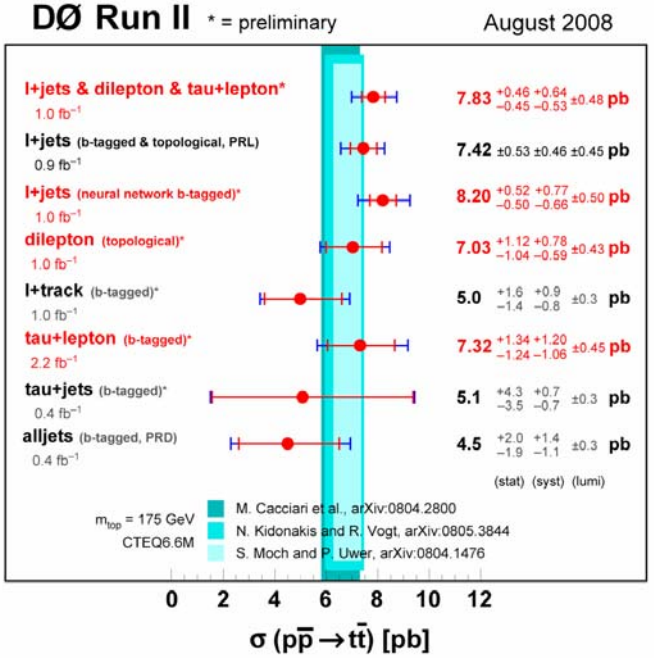
➔ Information on spin polarization and momentum is directly transferred to decay products

$$Br(t \to W^+ b) \sim 100\%$$

Categorize ttbar events into 3 decay types according to *W* decay mode

Top Pair Production Cross Section

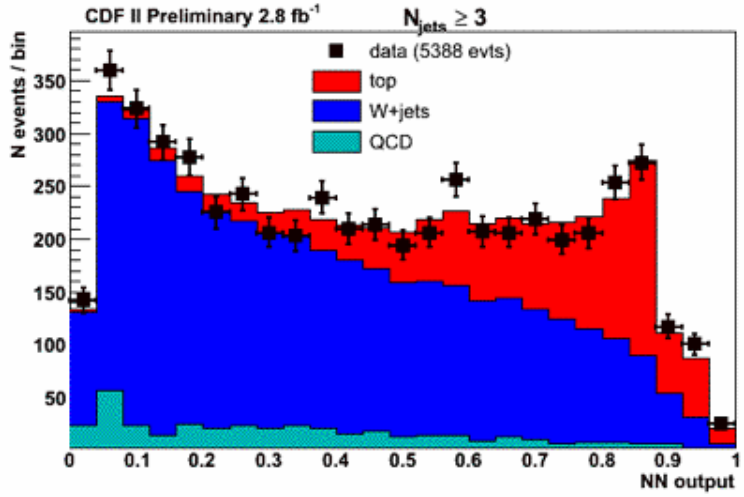


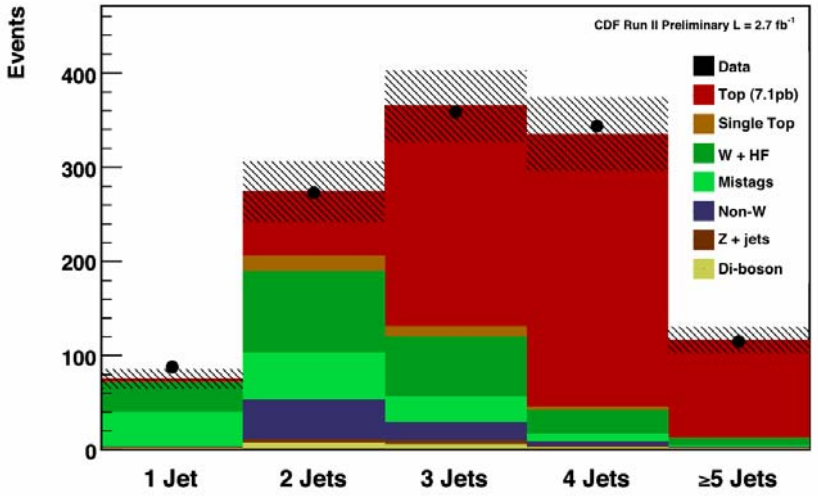


- Now better than theoretical uncertainties
- Luminosity is dominant source of uncertainty

$$\mathrm{CDF}(2.8\ \mathrm{fb}^{-1}):\ \sigma_{t\bar{t}} = 7.0 \pm 0.3(\mathrm{stat}) \pm 0.4(\mathrm{sys}) \pm 0.40(\mathrm{lumi})\ \mathrm{pb}$$

Ratio of Top Pair to Z Boson Cross Section (CDF)





$$\begin{cases}\sigma_{t\bar{t}} = 6.97^{+0.42}_{-0.41}(\text{stat})^{+0.40}_{-0.42}(\text{syst}) \pm 0.40(\text{lumi})\ \text{pb} \\ \sigma_Z = 253.27 \pm 1.01(\text{stat})^{+4.4}_{-4.6}(\text{syst})^{+16.63}_{-13.71}(\text{lumi})\ \text{pb}\end{cases}$$

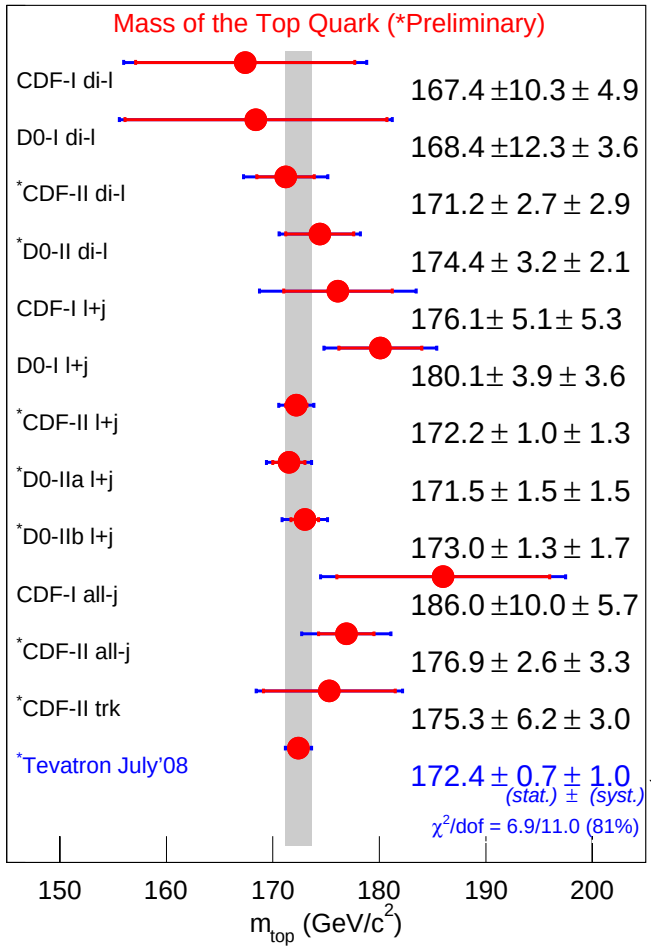
$$\begin{cases}\sigma_{t\bar{t}} = 7.1 \pm 0.4(\text{stat}) \pm 0.6(\text{syst}) \pm 0.4(\text{lumi})\ \text{pb} \\ \sigma_Z = 253.5 \pm 1.1(\text{stat}) \pm 4.5(\text{syst}) \pm 14.9(\text{lumi})\ \text{pb}\end{cases}$$

$$\sigma_{t\bar{t}} = 6.89 \pm 0.41(\text{stat})^{+0.41}_{-0.37}(\text{syst}) \pm 0.14(\text{theo})$$

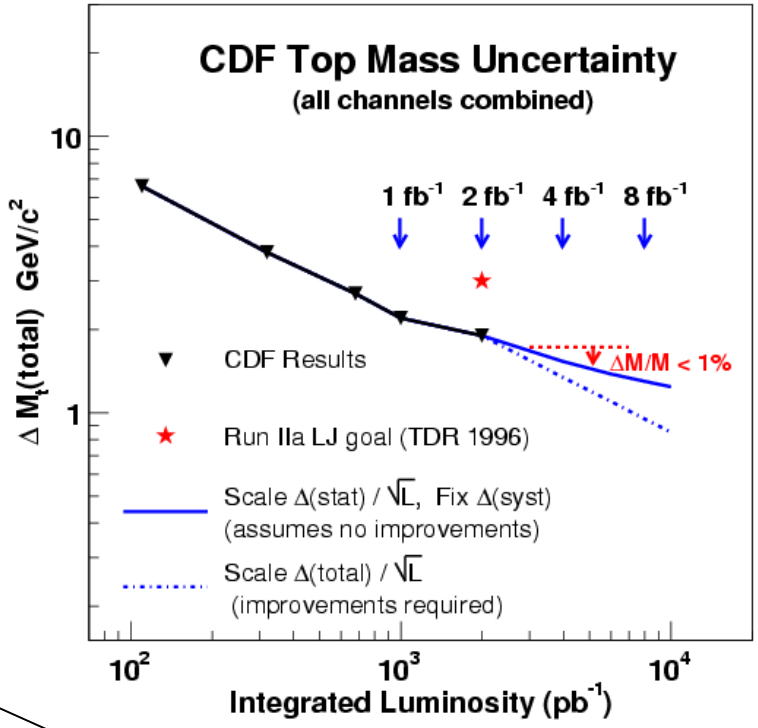
$$\sigma_{t\bar{t}} = 7.0 \pm 0.4(\text{stat}) \pm 0.6(\text{syst}) \pm 0.1(\text{theo})$$

- Taking the ratio of the top pair to the Z cross sections, the total uncertainty is decreased by ~10%.

Top Quark Mass



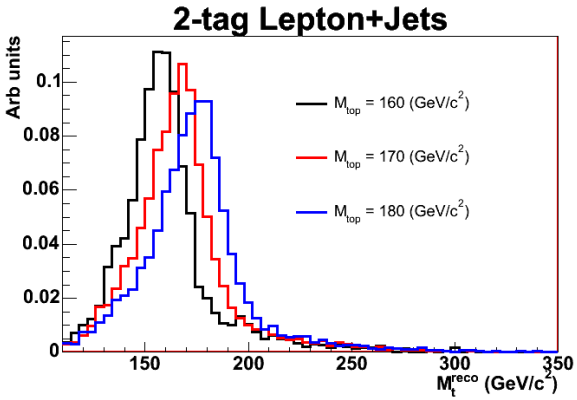
Goal before Run-II started :
3 GeV/c^2 with 2 fb^{-1}

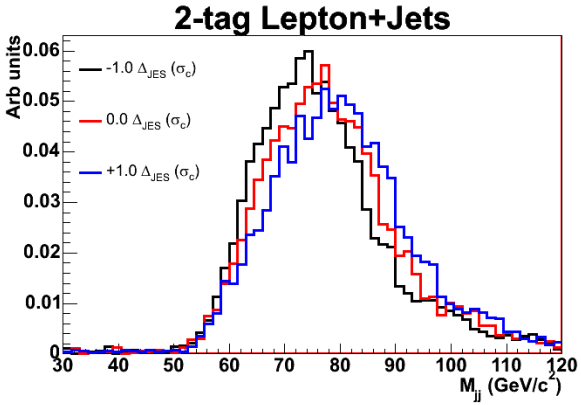


Now better than 1%

Top Mass Measurement (CDF)

- Template Method (Lepton+jets / Dilepton)

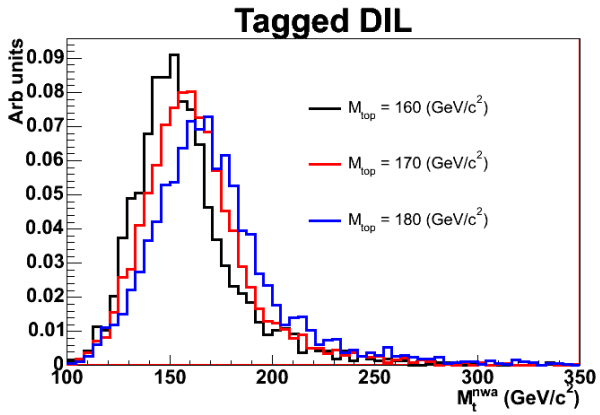


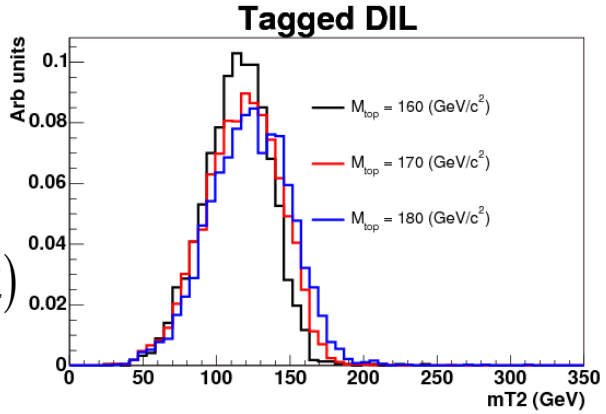


- Lepton+jets
  - Event-by-event m_{top}^{reco} from χ^2 fitter
  - Utilize m_{jj} for *in situ* JES calibration
- Dilepton
  - Neutrino Weighting Algorithm
  - m_{T2}

$$m_T^{\,2} = m_{b\lambda}^{\,2} + m_\nu^{\,2} + 2\left(E_T^{b\lambda}E_T^{\nu} - \mathbf{p}_T^{b\lambda}\cdot\mathbf{p}_T^{\nu}\right)$$

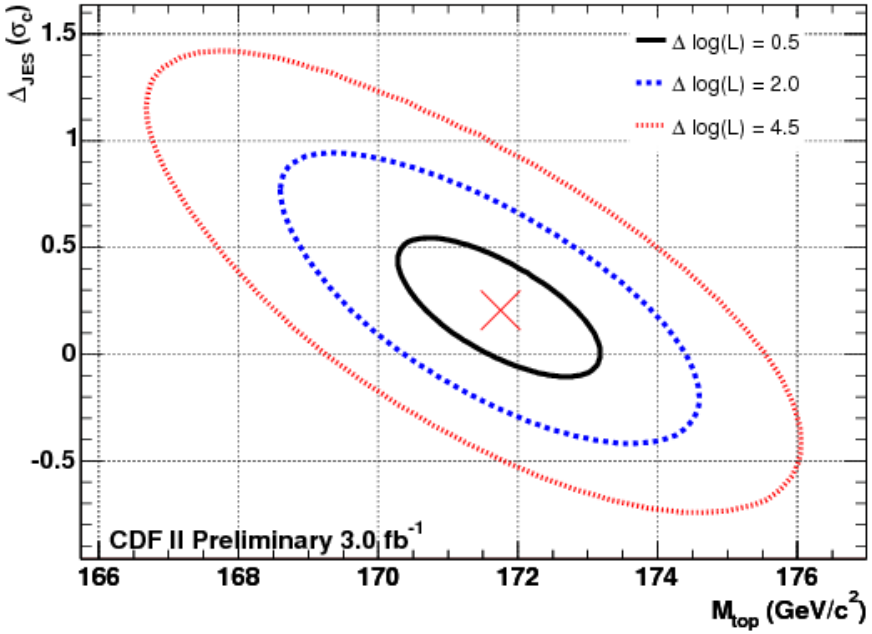
$$m_{T2} \equiv \min\left[\max\left\{m_T^{(1)}, m_T^{(2)}\right\}\right]$$



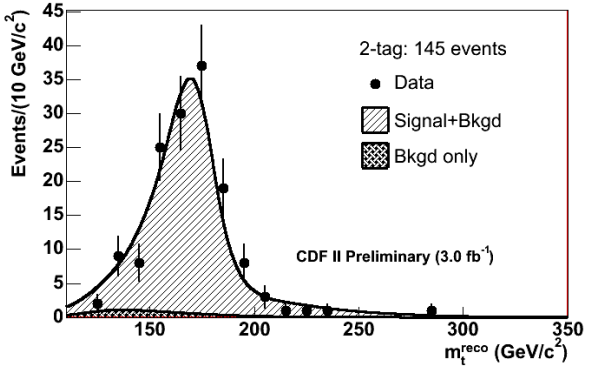


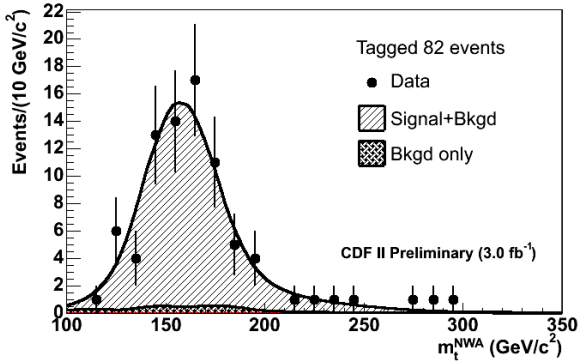
Top Mass Measurement (CDF)

- Template Method (Lepton+jets / Dilepton)



3.0 fb^{-1}



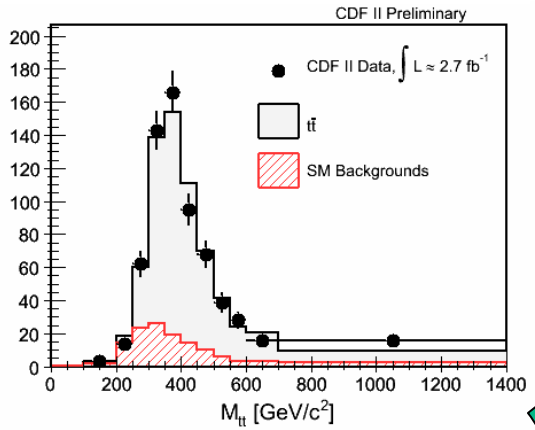


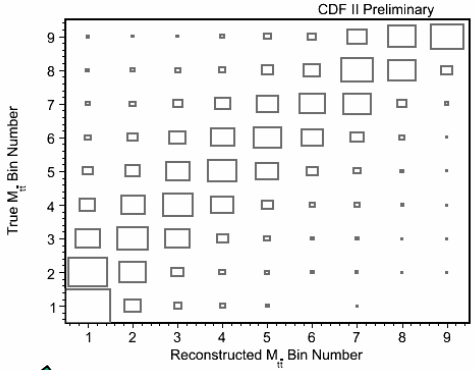
$$M_{\text{top}} = 171.8 \pm 1.5(\text{stat} + \text{JES}) \pm 1.1(\text{syst})\ \text{GeV}/c^2$$

ttbar Differential Cross Section, $d\sigma/dM_{ttbar}$ (CDF)

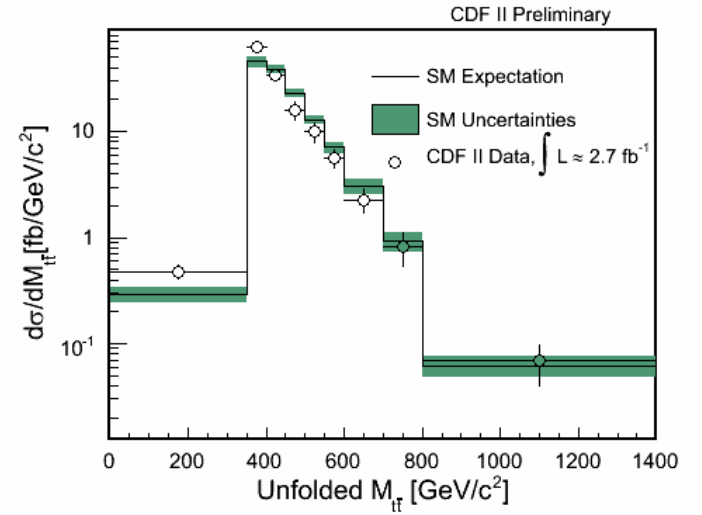
2.7 fb^{-1}

No evidence of inconsistency with SM

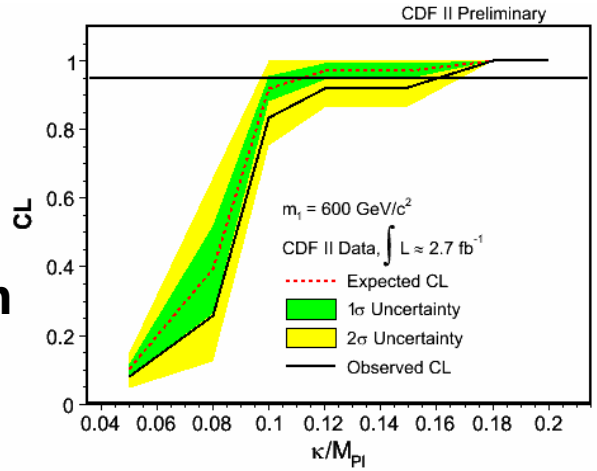




Singular Value Decomposition (SVD) of the response matrix

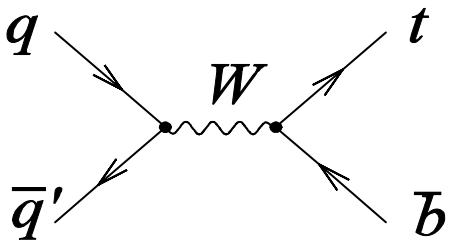


Randall-Sundrum Model Graviton

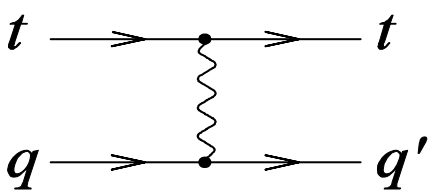


$\kappa/M_{Pl} > 0.16$ at the 95% CL

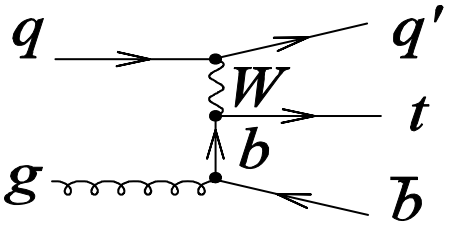
Single Top Production



S-channel



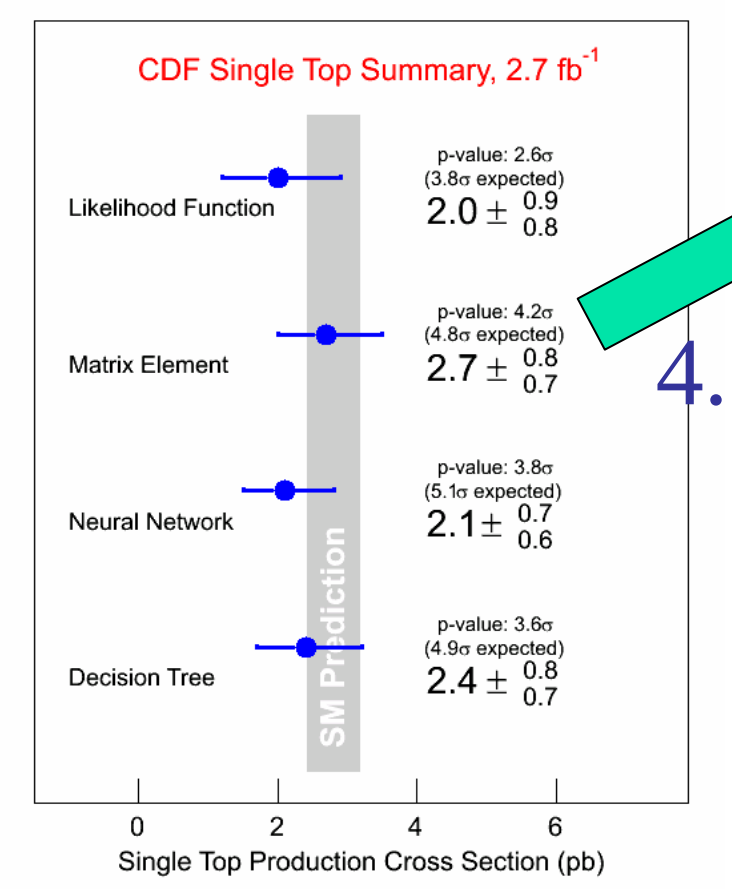
t-channel



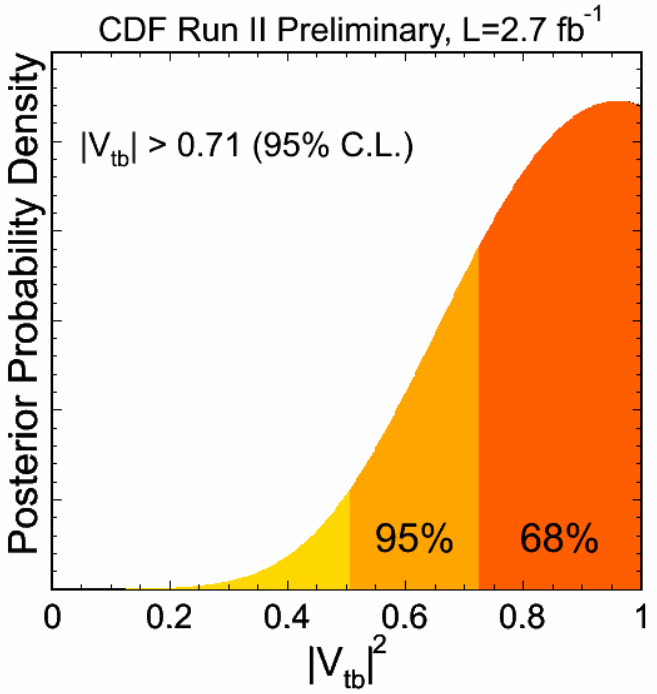
$$\sigma = 2.9 \pm 0.4 \text{ pb}$$
$$(M_t = 175\text{GeV})$$

- Cross section $\propto |V_{tb}|^2$
  - No need to assume unitarity of CKM matrix nor three generations of quarks
    - On the assumption of CKM unitarity: $V_{tb} = 0.99$
    - 3 generations: Can be derived from Br($t \to Wb$)
- Important to understand bkg of *WH* event for low mass Higgs ($m_H < 130$ GeV)
  - Benchmark of Higgs search in *WH*
    - $\sigma(WH)$: σ(Single Top) ~ 1 : 10

Single Top Cross Section (CDF)



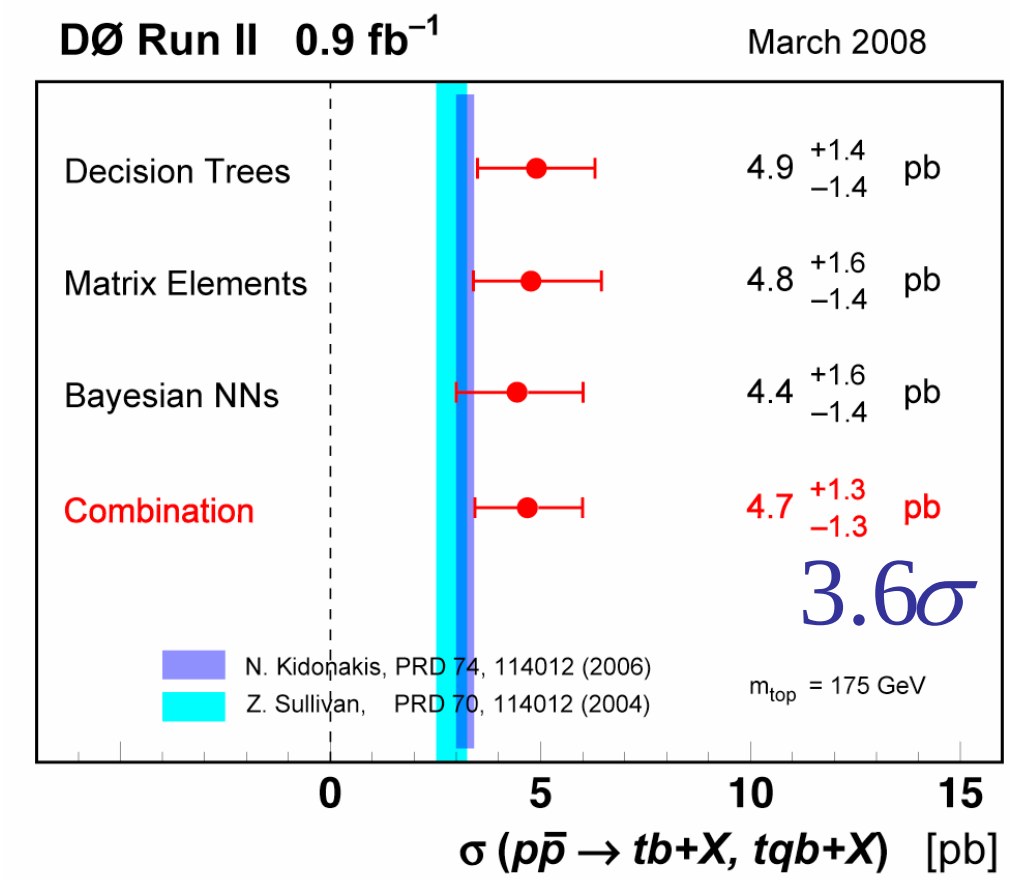
4.2σ

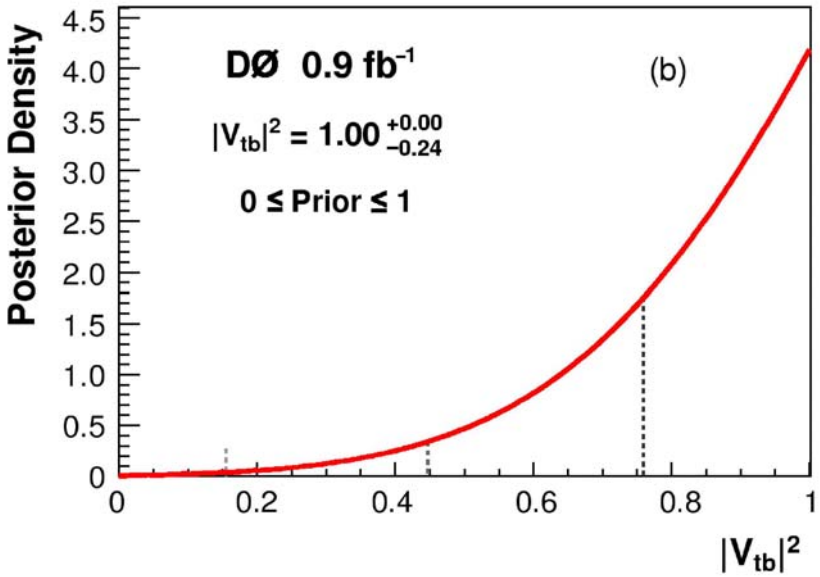


$$|V_{tb}| = 0.97 \pm 0.13(\text{exp}) \pm 0.07(\text{theo})$$

$$|V_{tb}| > 0.71 \ @95\% \text{ C.L.}$$

Single Top Cross Section (DØ)



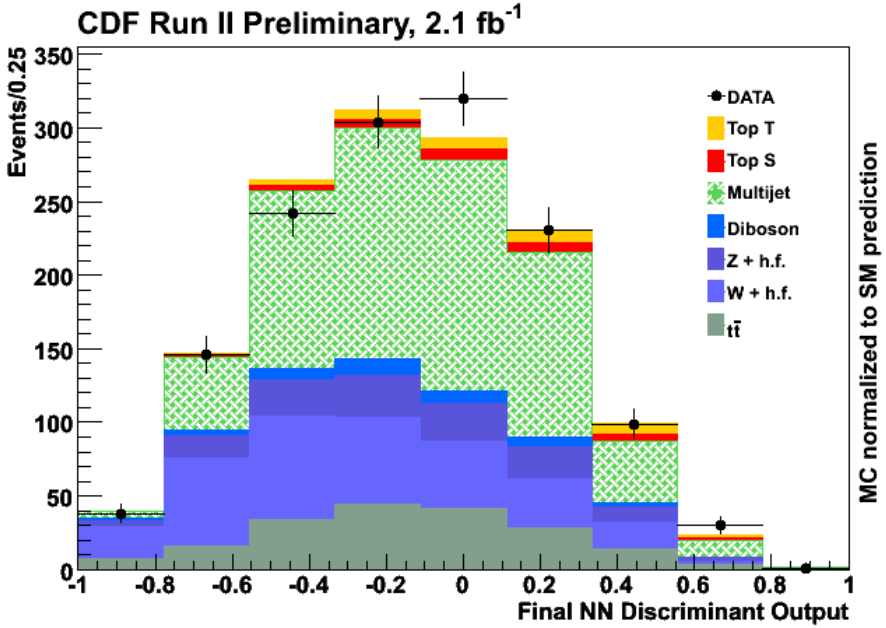


$$|V_{tb}| = 1.00^{+0.00}_{-0.12}$$

$$|V_{tb}| > 0.68 \ @95\% \text{ C.L.}$$

New Channel for Single Top (CDF)

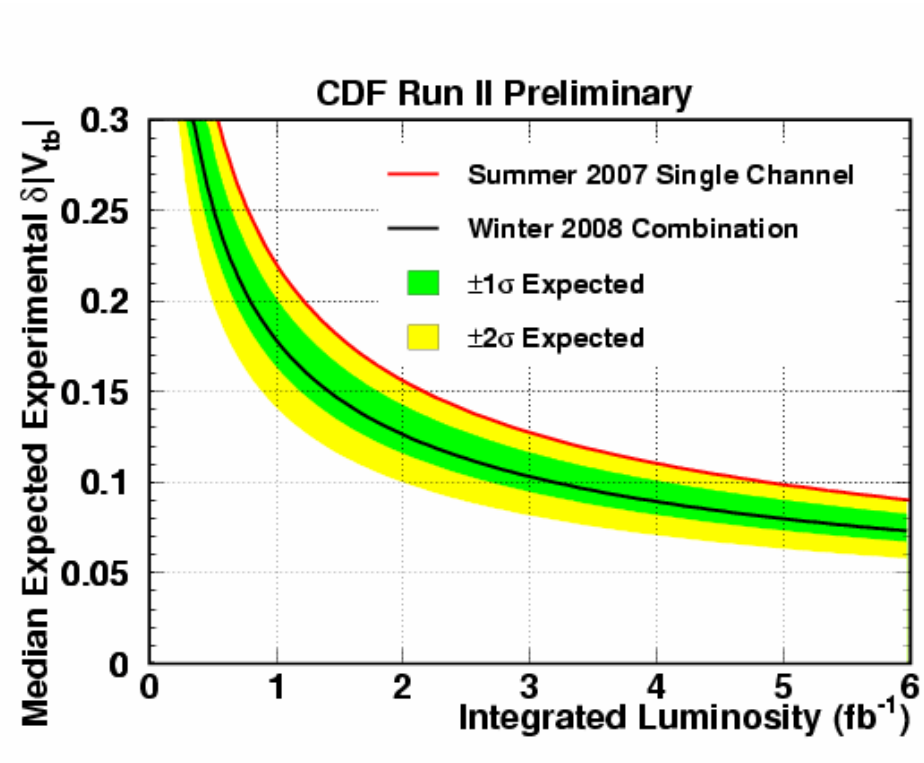
- MET + jets (2.1 fb^{-1})
  - Leptonic decays with hadronic τ and e/μ not fiducial
  - Performing orthogonal channel gives extra information
    - Contribute to the combination of single top cross section



$$\sigma = 4.9^{+2.5}_{-2.2}\ \text{pb}$$

Significance: 2.1σ
(Expected: 1.4σ)

Single Top Prospects



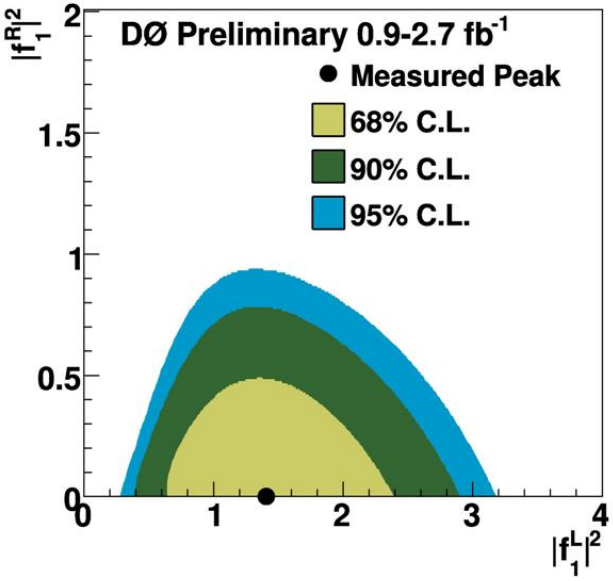
- Expected uncertainty on V_{tb} as a function of $\int L dt$
- Uncertainties arise from:
  - Experiment
  - Cross-section dependence on M_{top}
  - Factorization and renormalization scales
  - Parton distribution functions
  - α_s

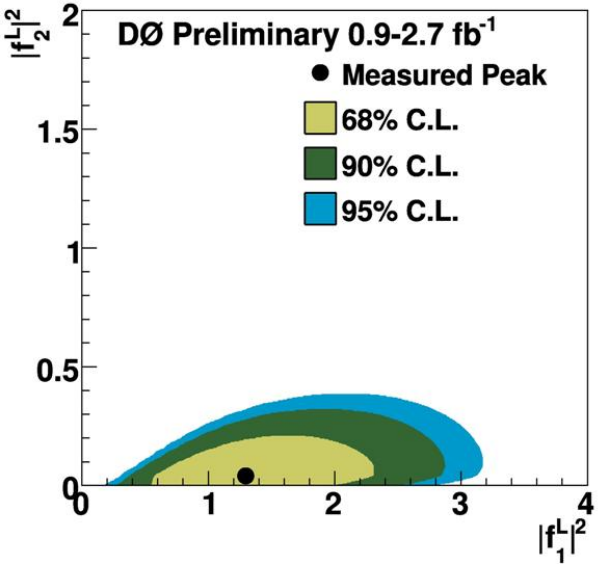
Anomalous Top Couplings (DØ)

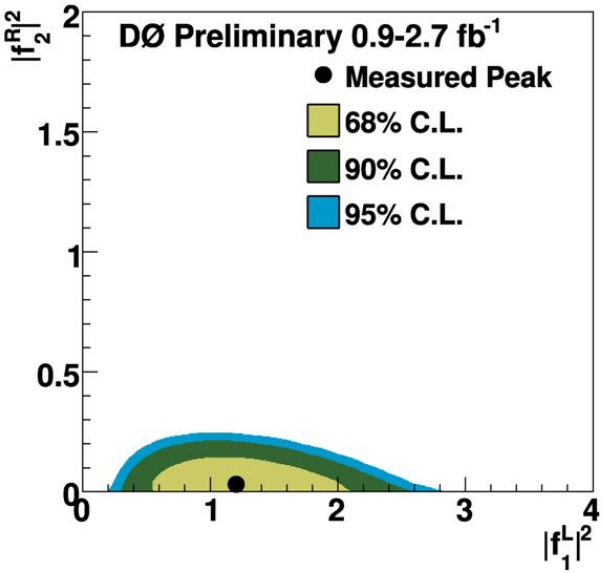
W Helicity
+
Single Top

$$M = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}(f_1^L P_L + f_1^R P_R)tW_{\mu}^{-}$$
$$- \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}V_{tb}}{M_W}(f_2^L P_L + f_2^R P_R)tW_{\mu}^{-} + h.c.$$

In the standard model, $f_1^L = 1$, and $f_1^R = f_2^L = f_2^R = 0$



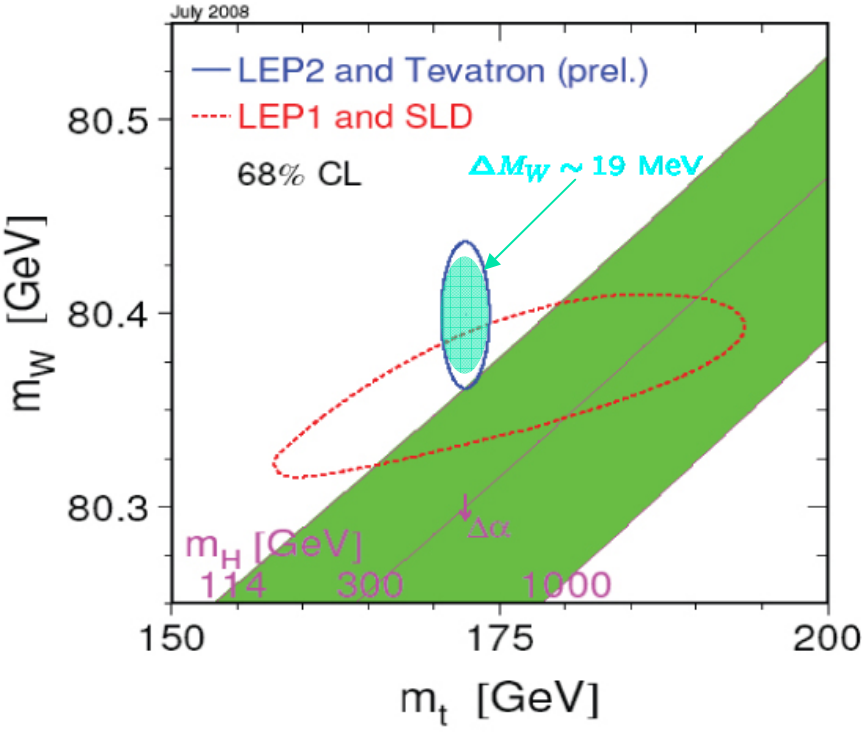


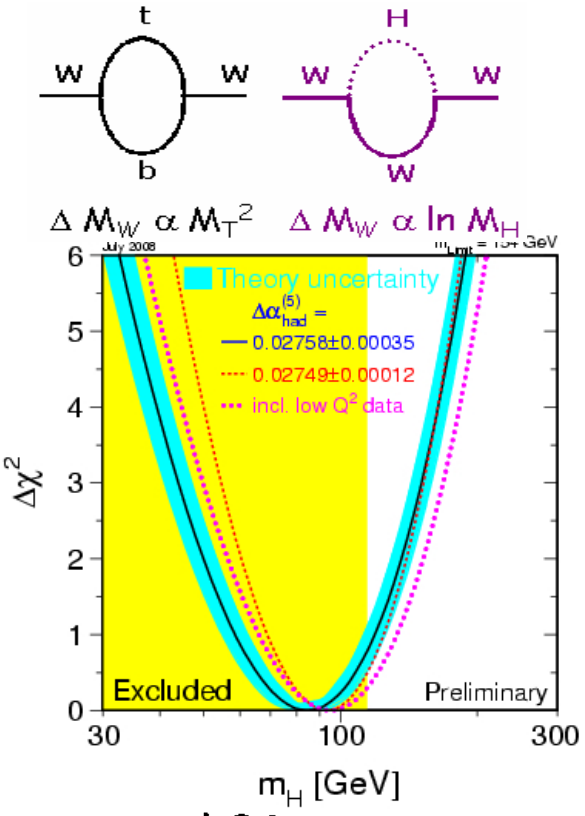


Higgs Search

Indirect Limits on Higgs

$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_F}(1+\Delta r)$$

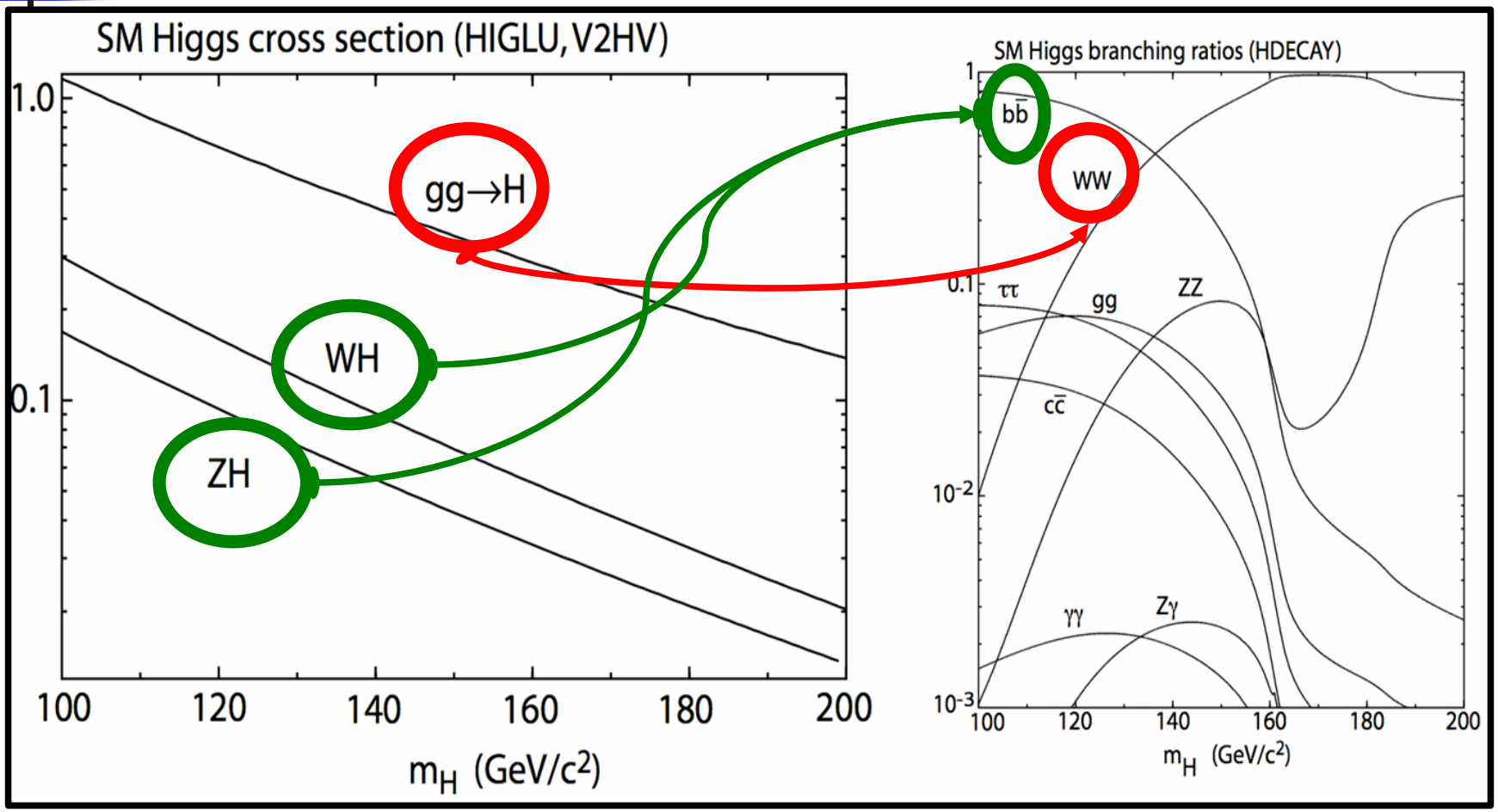




$$m_H = 84^{+34}_{-26}\ \text{GeV}/c^2 \quad (68\%\ \text{CL})$$

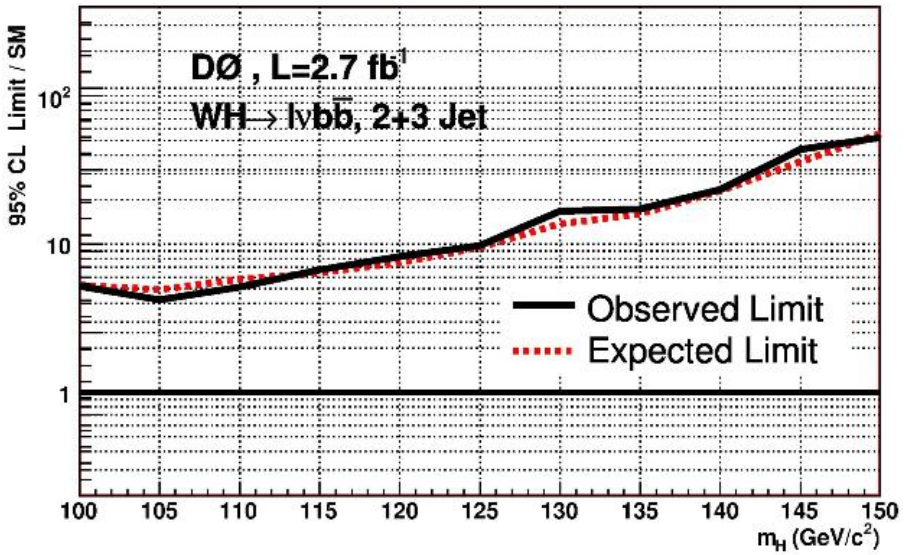
$$m_H < 154\ \text{GeV}/c^2 \quad (95\%\ \text{CL})$$

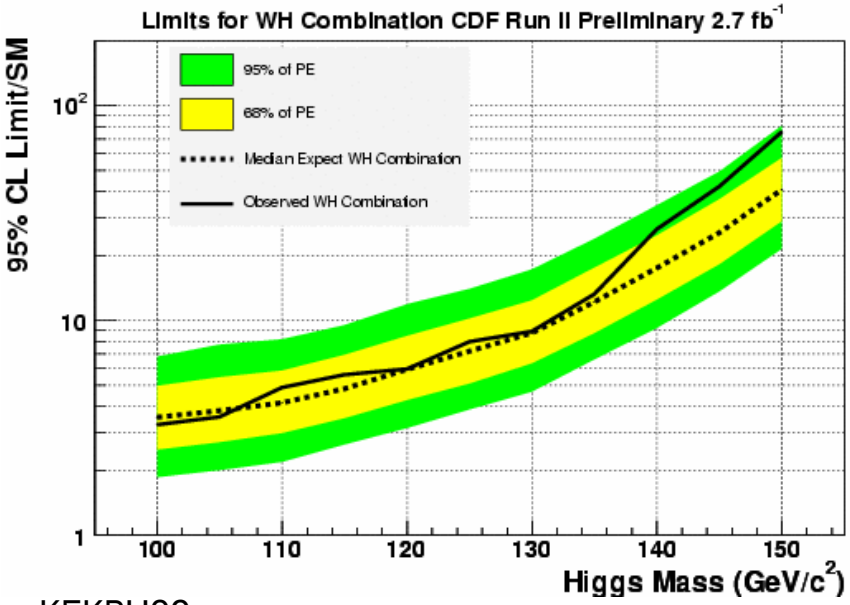
Higgs Cross Section and Branching Ratio



$WH \rightarrow l\nu bb$ (CDF & DØ)

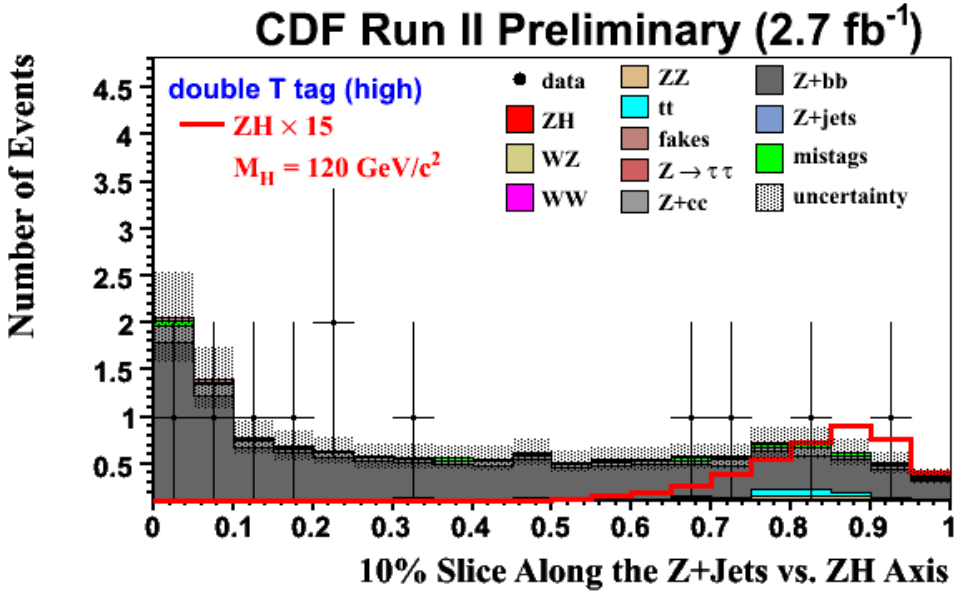
- DØ:
  - Updated on Feb 5, 2009
  - Limit/SM < 6.7 @115 GeV/c^2
- CDF:
  - Updated on Nov 7, 2008
  - Combined result of NN and ME+BDT
  - Improved by 15%

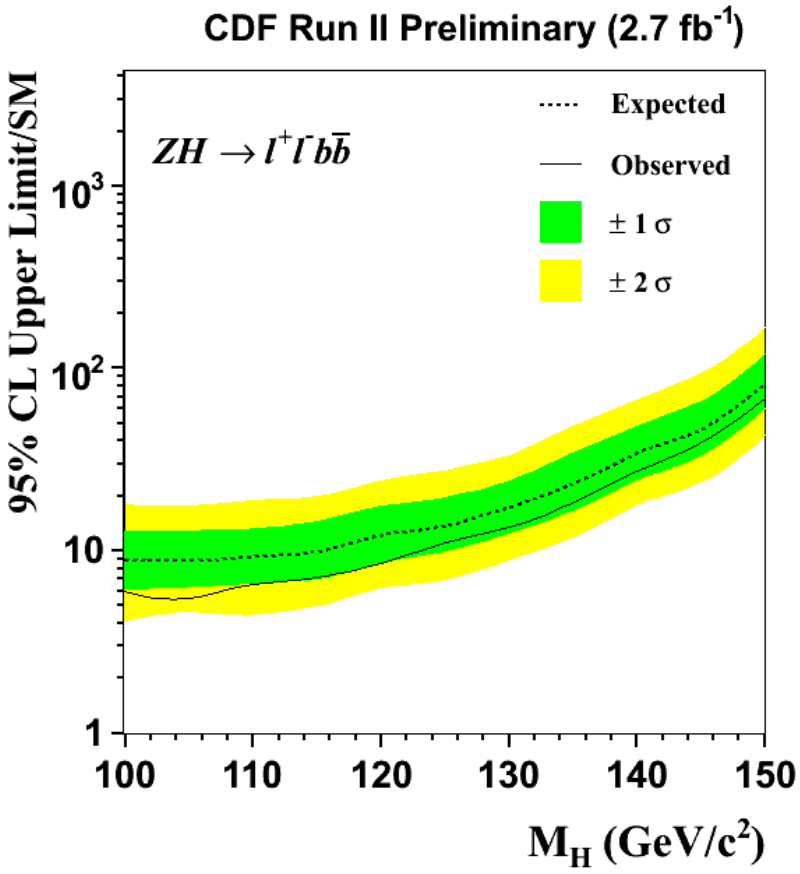




$ZH \rightarrow llbb$ (CDF)

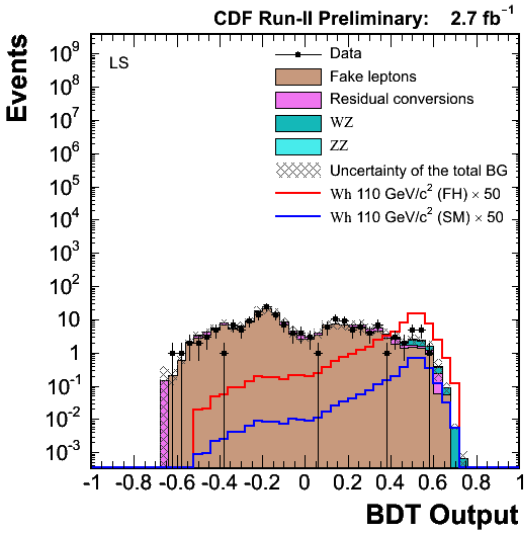
- Looser *b*-jet identification
- 2D Neural Net
- Improve dijet mass resolution with MET projection technique

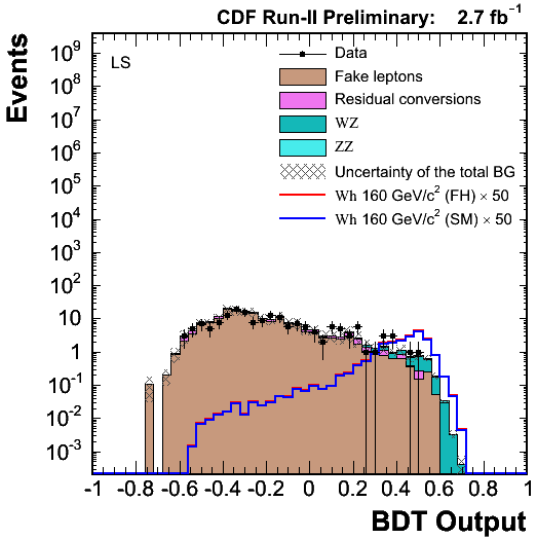


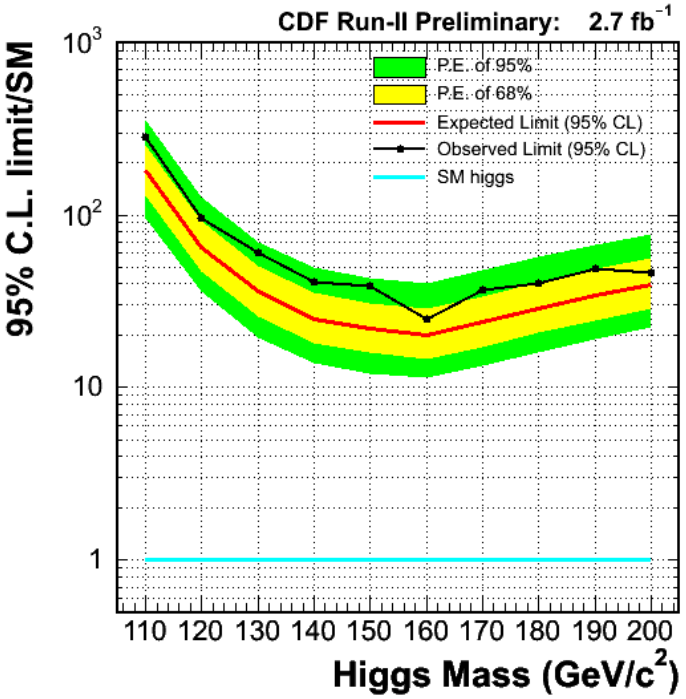


$WH \rightarrow WWW^*$ (CDF)

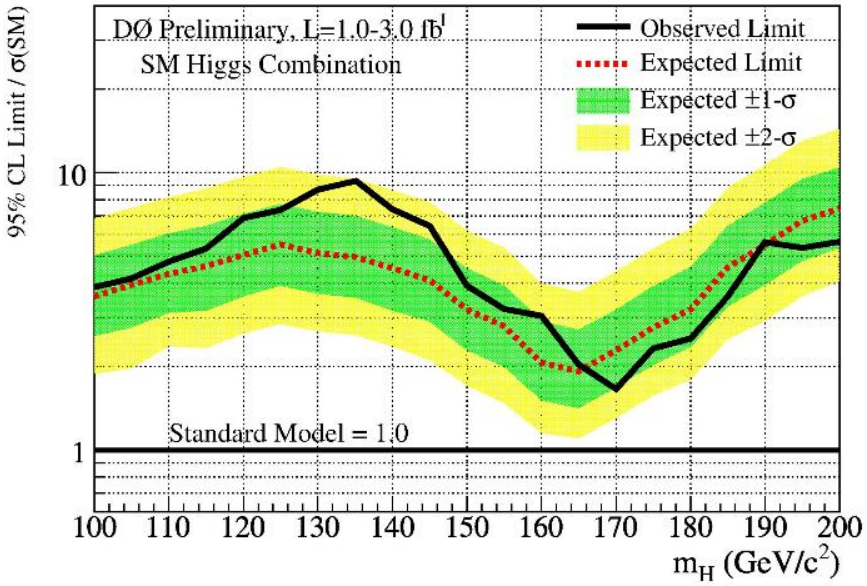
- 2 like-sign leptons using Boosted Decision Tree discriminant



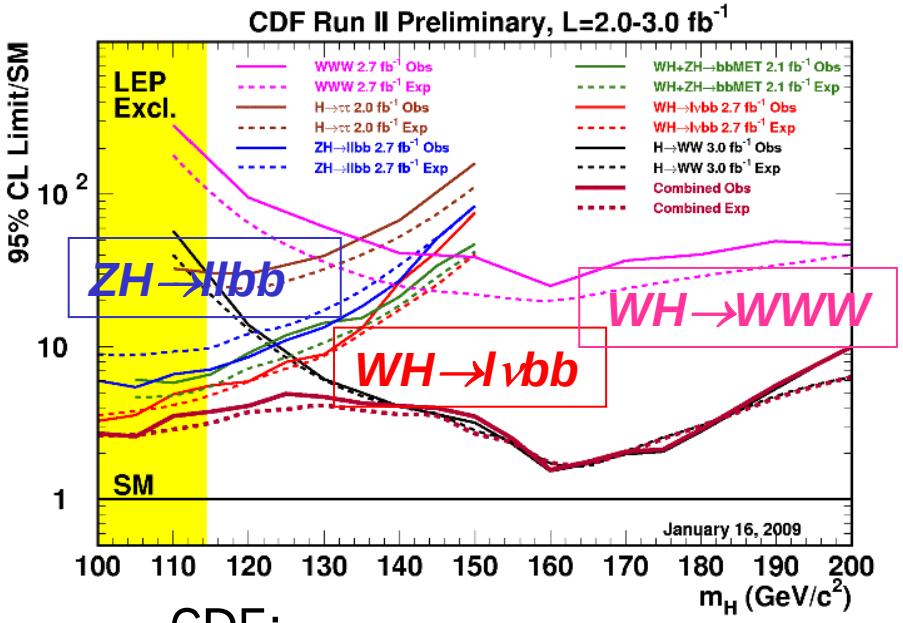




Combined Limits on Higgs (CDF & DØ)



- DØ:
  - Updated on Aug 2, 2008
  - New *WH→lνbb* result NOT included

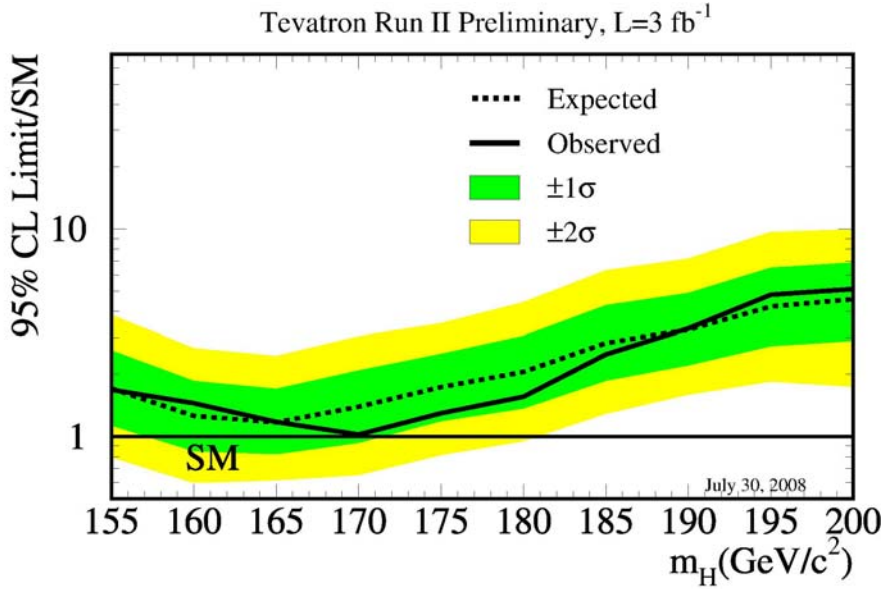


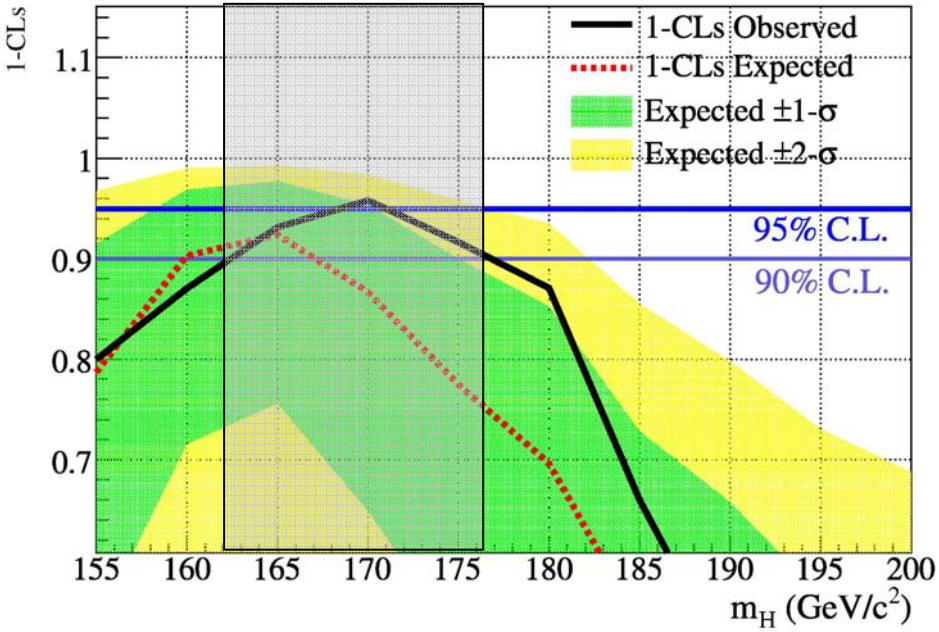
- CDF:
  - Updated on Jan 16, 2009
  - Updates since last summer
    - *WH→lνbb*
    - *WH→WWW*
    - *ZH→llbb*

Higgs Exclusion (CDF & DØ)

CDF+DØ combination

Updated on Jul 30, 2008



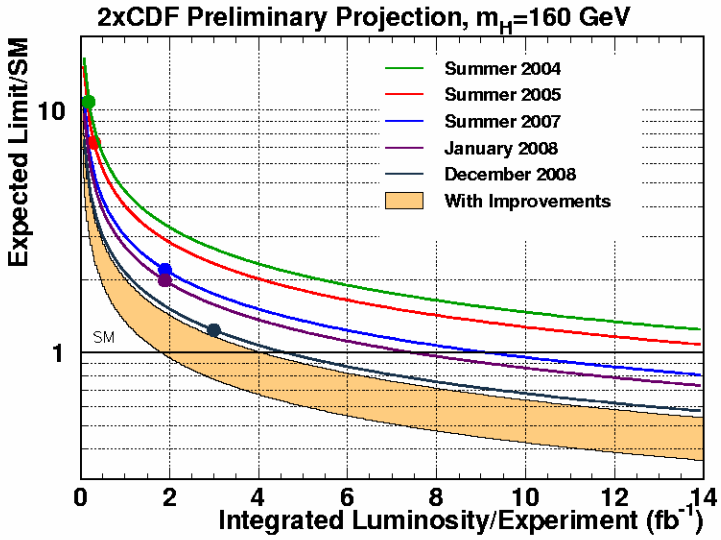


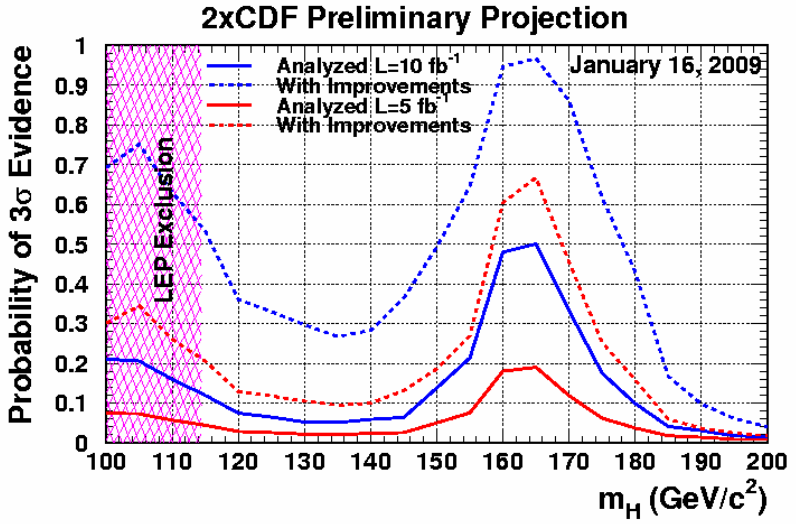
CDF + D0 combined :

$m_H = 170\ \mathrm{GeV}/c^2$ excluded (95%)

- One mass point, 170 GeV, excluded @ 95% C.L.
- 15 GeV window [162 : 177] excluded @ 90% C.L.

Projections of Higgs Search





- CDF+DØ projections assuming they perform the same
- Possible improvements:
  - Acceptance, Analysis method, jet/MET resolutions, etc.
- Good possibility to see 3σ evidence to a Higgs of 160 GeV/c^2

Summary

- Tevatron is operating well. Better than ever!
  - CDF and DØ experiments are ready to run for FY2010. $\int L dt \sim 9$ fb^{-1} is expected.
- Top quark properties are being measured more and more precisely. Mass precision is now less than 1%.
  - Top quark properties are consistent with SM so far.
- We are sensitive to Higgs of 160 GeV/c^2.
- Stay tuned for interesting results from Tevatron with more than ~3 fb^{-1} data in 2009!
  - New top mass combination
  - Single top search
  - Updated Higgs limit
  - New results in EW, B, Exotic, QCD, …