Recent Results on Top and Higgs at Tevatron

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On behalf of the CDF and DØ Collaborations

KEK Theory Meeting on Particle Physics Phenomenology

Feb/18-20 at KEK 4th building 1F, Seminar Hall

Top Quark Physics

Mainly on top decay, $t\bar{t}$ production mechanism, and related

Top Quark

- Heaviest elementary particle
  - play a special role in EWSB?
  - provides new test ground on Standard Model
    - Direct access to bare quark

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

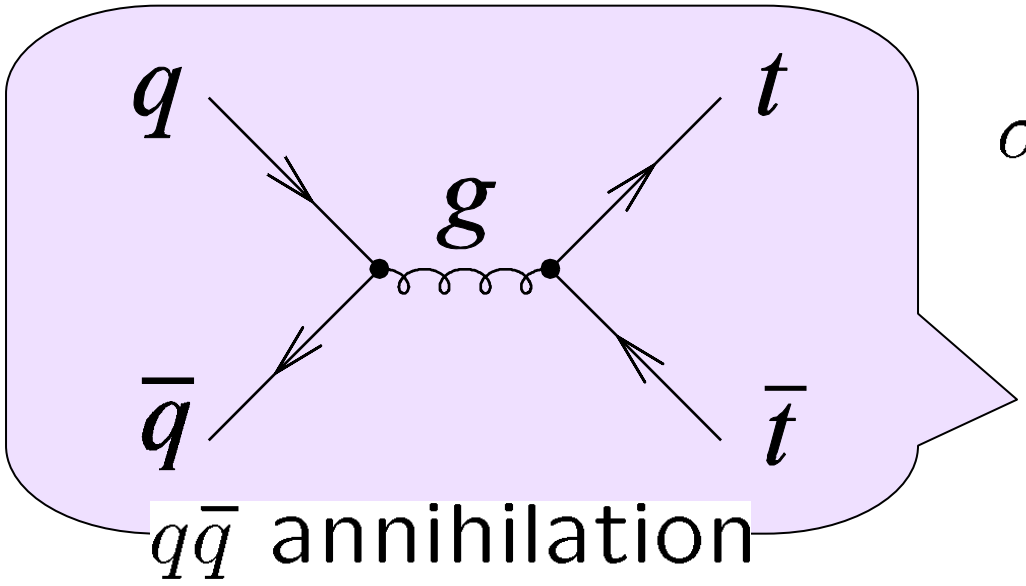
Top quark decays before hadronization

Decays as a naked quark

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

$t\bar{t}$ Production at Tevtron

$p\bar{p}$ collision @ $\sqrt{s} = 1.96\,\mathrm{TeV}$



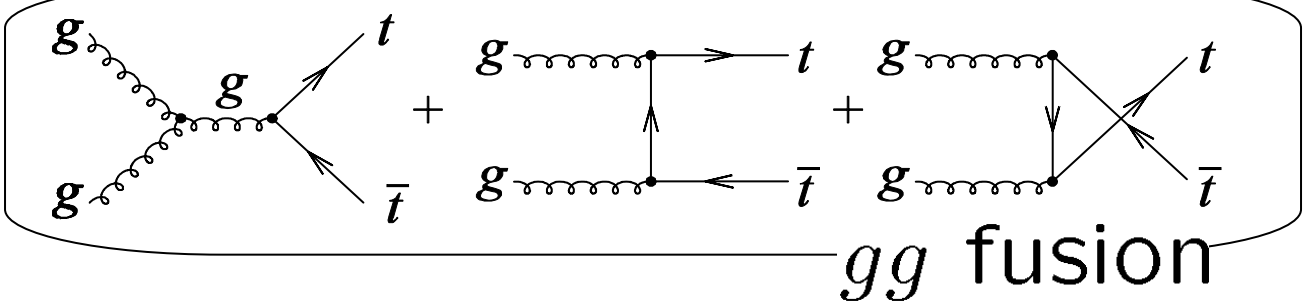
$q\bar{q}$ annihilation

$$\sigma = 7.4^{+0.5}_{-0.7}\ \mathrm{pb}$$

(NLO, $M_t = 172.5\mathrm{GeV}$)

Dominant process at Tevatron

10%~20%



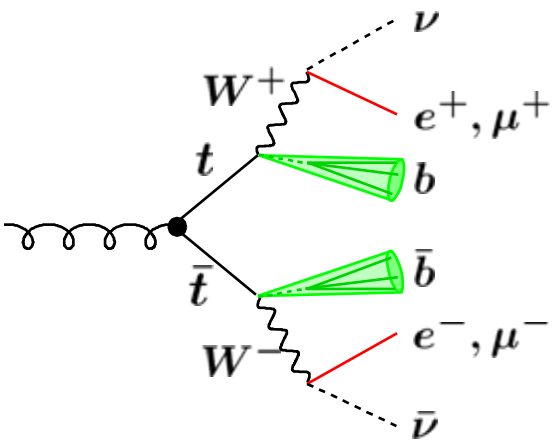
gg fusion

Large ambiguity from PDF uncertainties

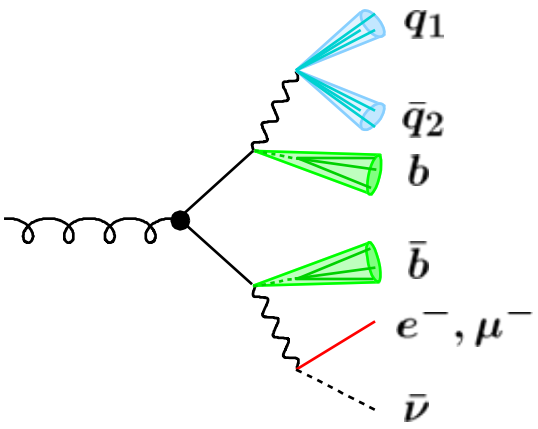
$t\bar{t}$ Signiture

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

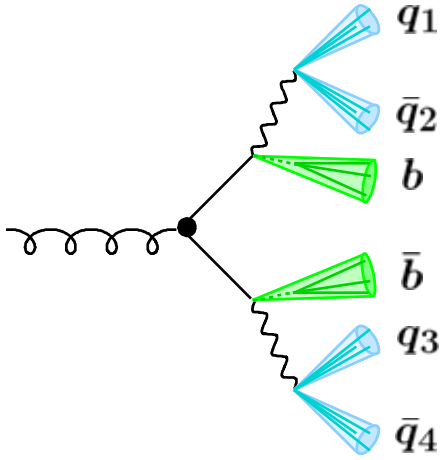
$$V = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$



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



Lepton+Jet
- 1 lepton
- 4 jet(2 *b*-jet)
- MET



All Hadronic
- 6 jet(2 *b*-jet)

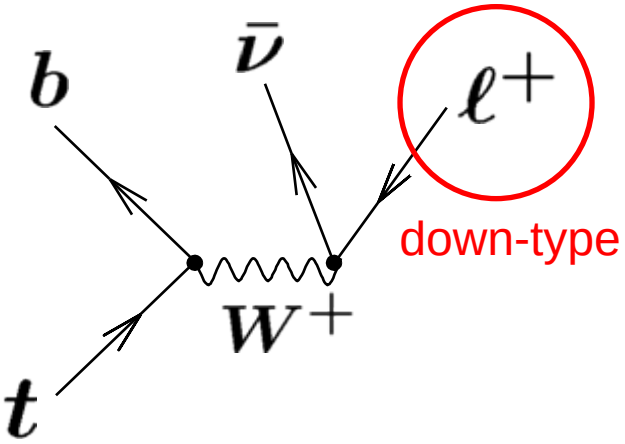
Categorize ttbar events into 3 decay types according to W decay mode

Top Quark Decay $(V-A)$

$$t \to Wb \to \ell\nu b$$

$$|\mathcal{M}|^2 \propto (p_\nu \cdot p_b)\{p_\ell \cdot (p_t + m_t s_t)\}$$

$s_t \equiv (0, \hat{s})$ top spin polarization vector in top rest flame



- top quark decays before losing polarization
- V-A coupling
  - flight direction of down-type fermion from W carries 100% spin information of parent top quark

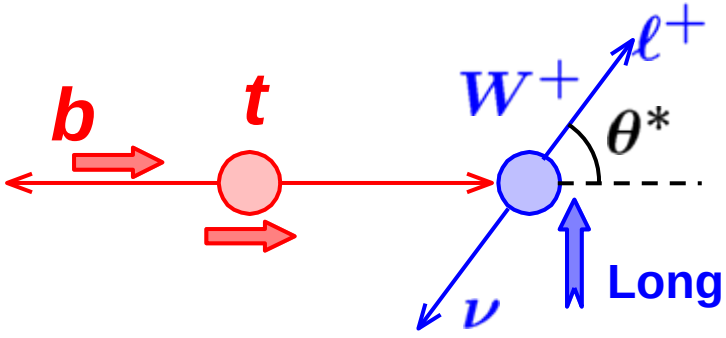
can "see" top quark spin at its production

W Helicity in $t \to Wb$ decay

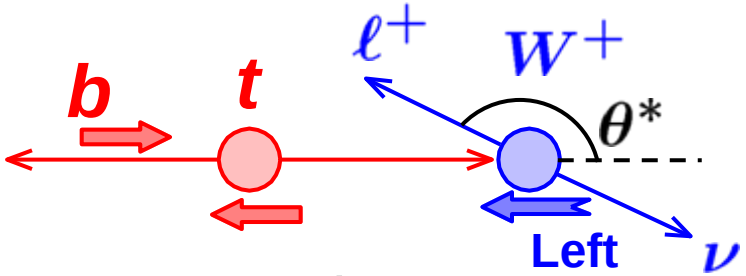
$$|\mathcal{M}|^2 \propto (p_\nu \cdot p_b)(p_\ell \cdot p_t)$$
$$\simeq \tfrac{1}{4}(m_t^2 - m_{\ell b}^2 - m_W^2)(m_{\ell b}^2 + m_W^2)$$
$$\propto \frac{m_t^2}{m_W^2}(1 - \cos^2\theta^*) + (1 - \cos\theta^*)^2$$

$$\cos\theta^* = \frac{2m_{\ell b}^2}{m_t^2 - m_W^2} - 1$$

- Information on Wtb Vertex
  - Really W boson?
  - Really V-A?



$t \to bW_{\text{Long}}$



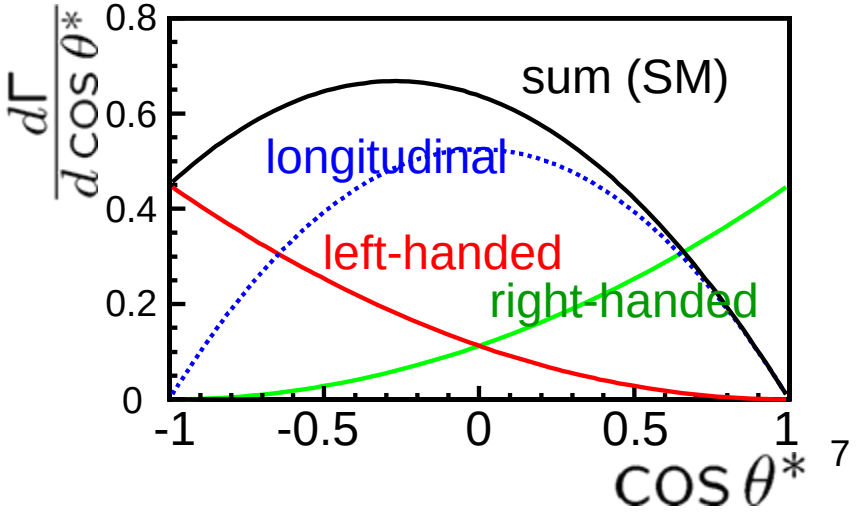
$t \to bW_{\text{Left}}$

In SM

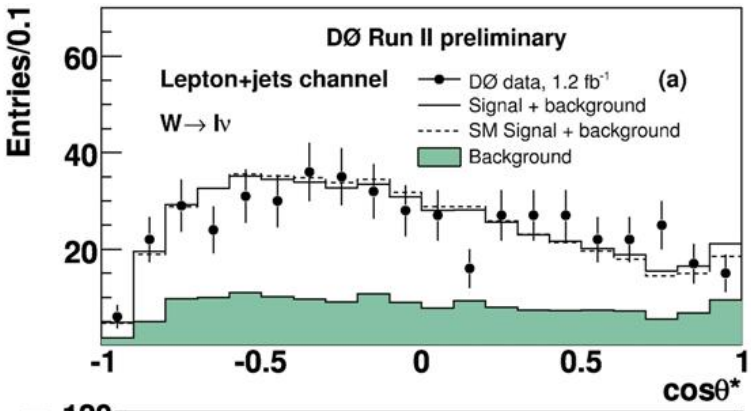
f_+ (right-handed) = 0

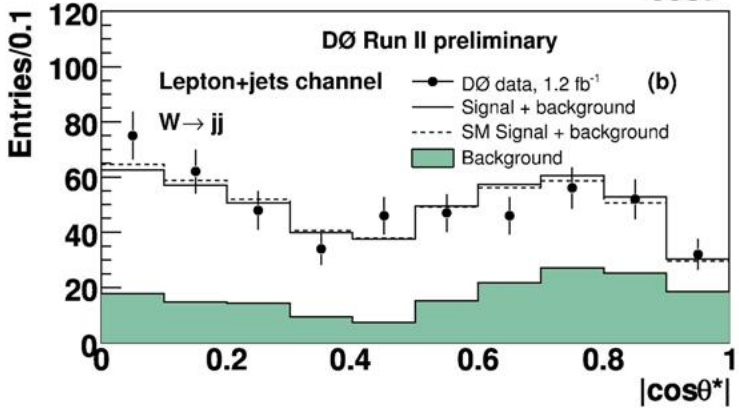
f_0 (longitudinal) = 0.70

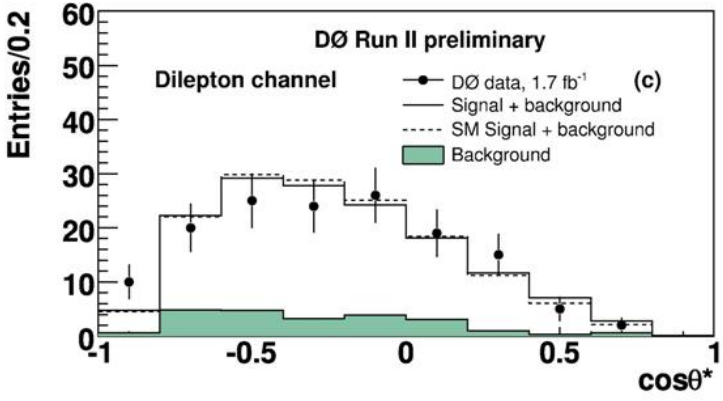
f_- (left-handed) = 0.30



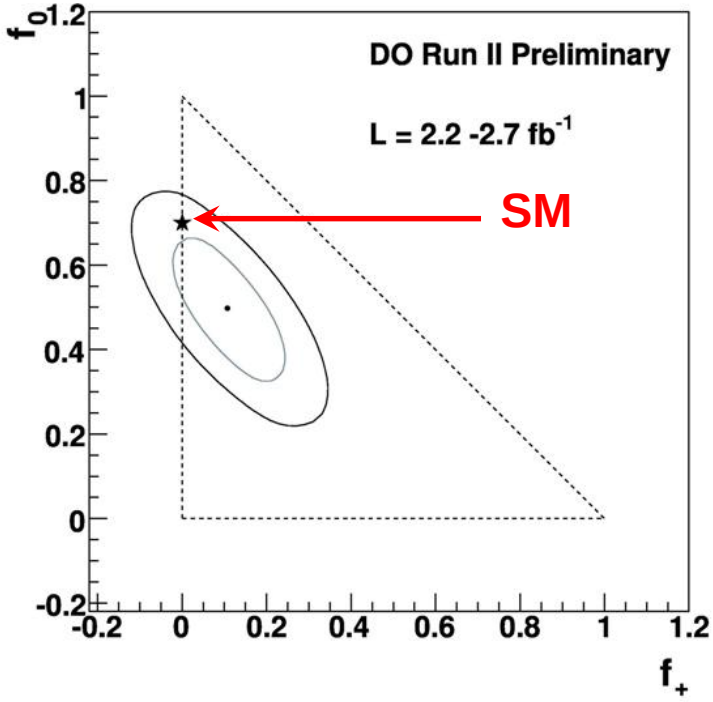
W Helicity Measurement (DØ)







Measure f_0 and f_+ simultaneously



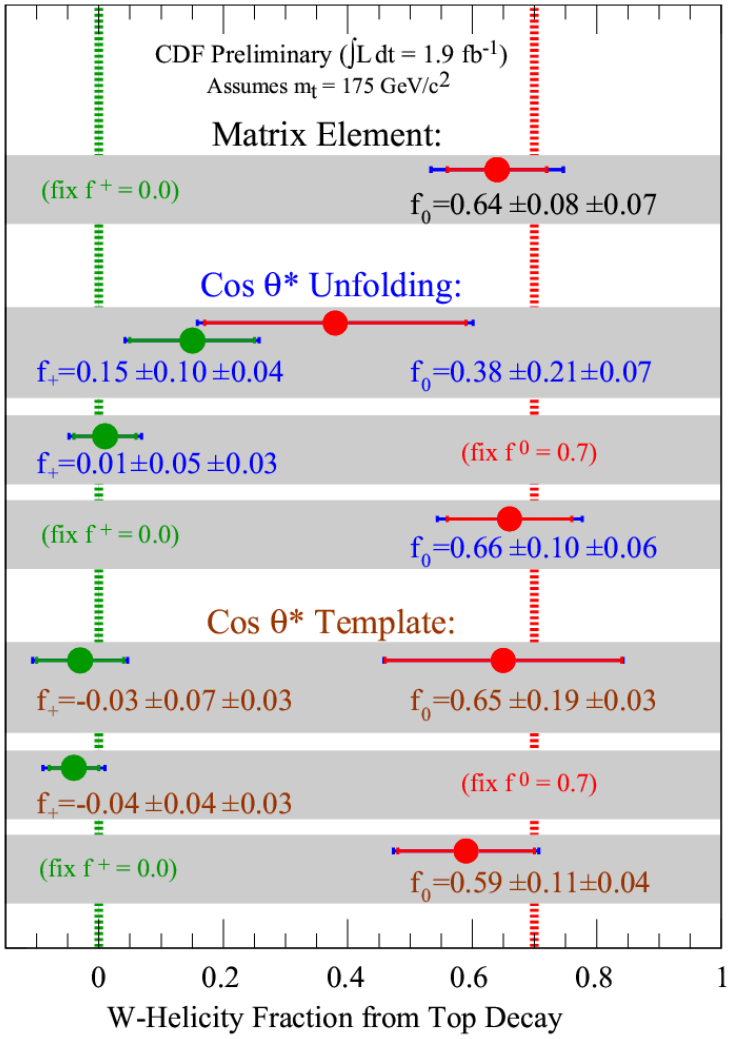
DØ ℓ+Jets and dilepton $\mathcal{L} = 2.7$ fb^{-1}

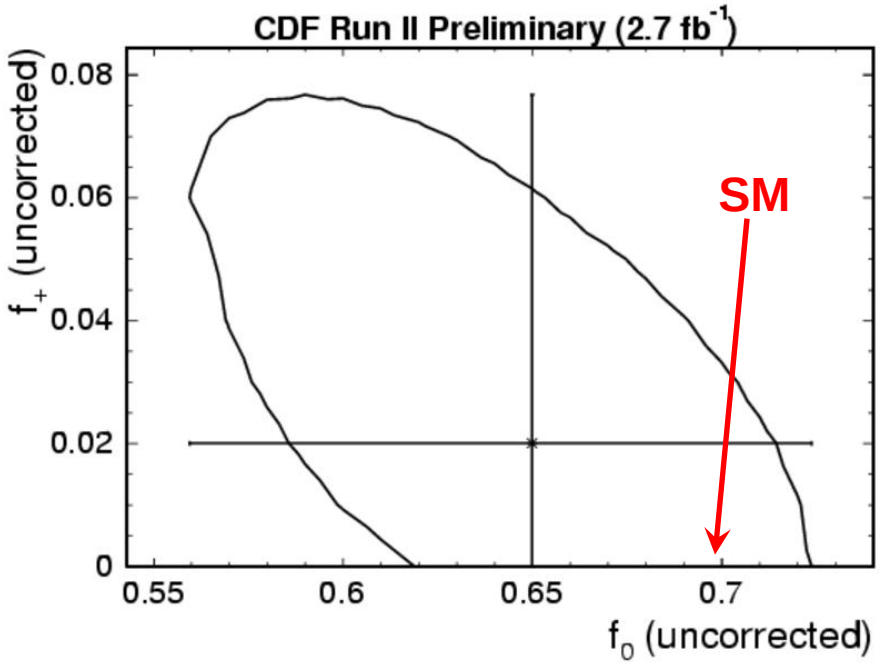
$f_0 = 0.490 \pm 0.106(\text{stat}) \pm 0.085(\text{syst})$

$f_+ = 0.110 \pm 0.059(\text{stat}) \pm 0.052(\text{syst})$

Consistent with SM at 23% CL

W Helicity Measurement (CDF)





Measure f_0 and f_+ simultaneously

CDF ℓ+Jets $\mathcal{L} = 2.7$ fb^{-1}

$f_0 = 0.88 \pm 0.11(\text{stat}) \pm 0.06(\text{syst})$

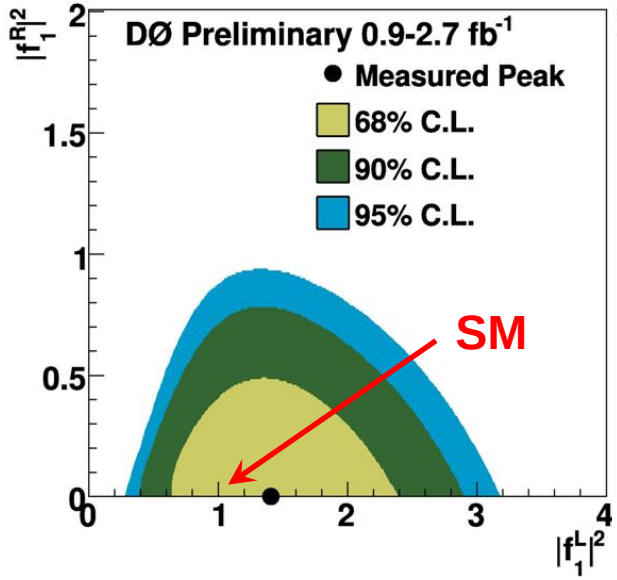
$f_+ = -0.15 \pm 0.07(\text{stat}) \pm 0.06(\text{syst})$

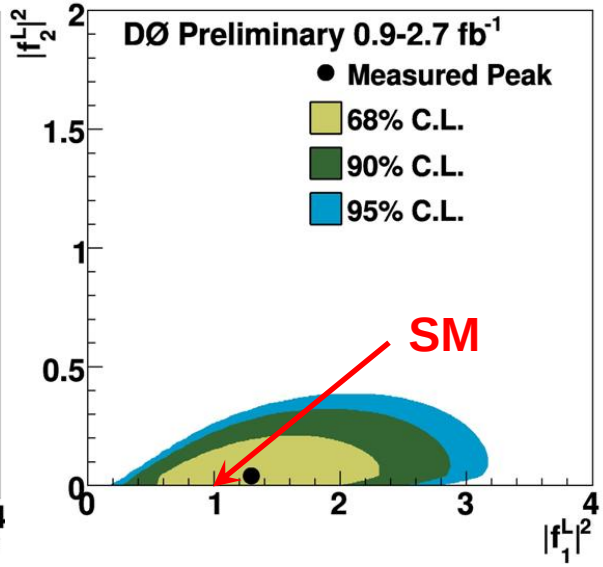
Search for anomalous couplings in $t \to Wb$

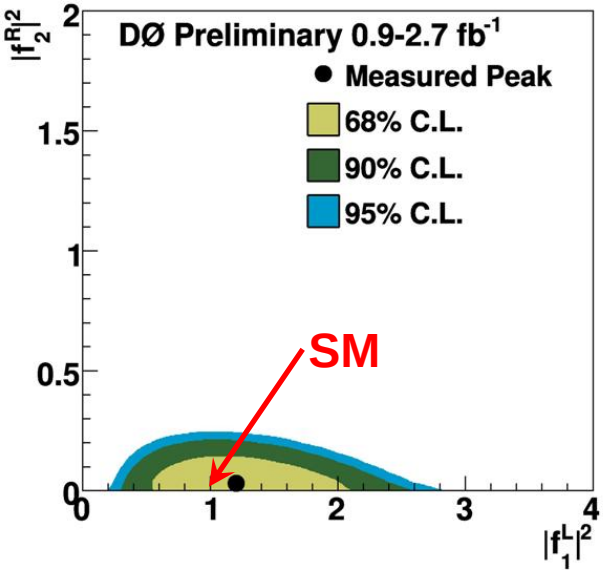
- General Lagrangian for Wtb vertex

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

In SM, $f_1^L = 1$, and $f_1^R = f_2^L = f_2^R = 0$





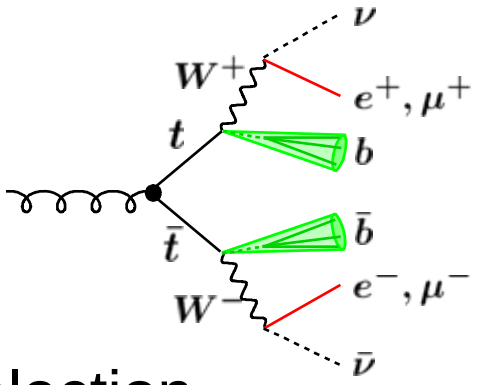


CDF and DØ results support V-A coupling on Wtb vertex so far

$t\bar{t}$ Production at Tevatron

- Cross-section
- Forward backward asymmetry
- Spin-spin correlations

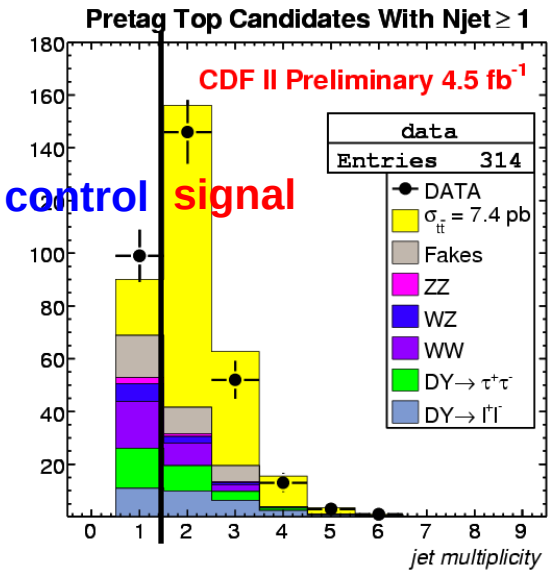
$t\bar{t}$ Cross-section (dilepton)



Selection

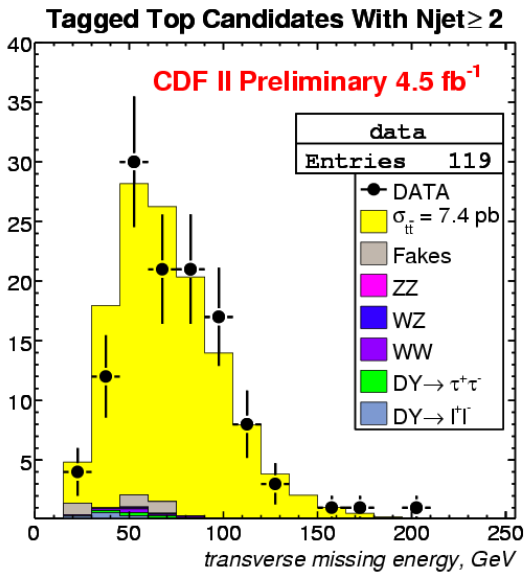
- 2 lepton
- MET
- Z veto
- ≥2 jets
- (*b*-tag)

Pre-tag



N_{jet}

≥1*b*-tag

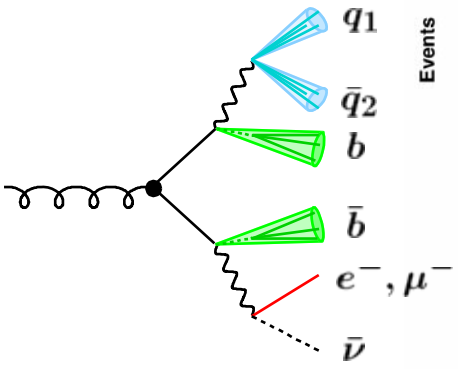


$\not\!\!E_{\text{T}}$

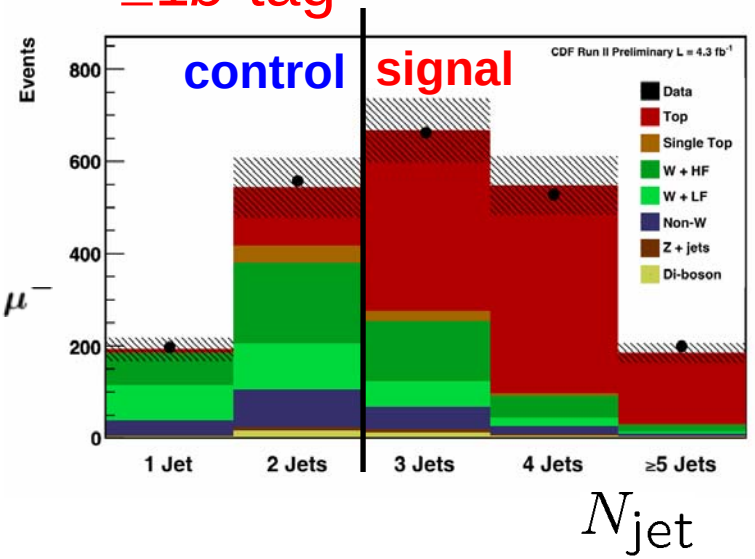
$$\sigma_{\text{pretag}} = 6.56 \pm 0.65(\text{stat}) \pm 0.41(\text{syst}) \pm 0.38(\text{lumi}) \text{ pb}$$

$$\sigma_{\text{tag}} = 7.27 \pm 0.71(\text{stat}) \pm 0.46(\text{syst}) \pm 0.42(\text{lumi}) \text{ pb}$$

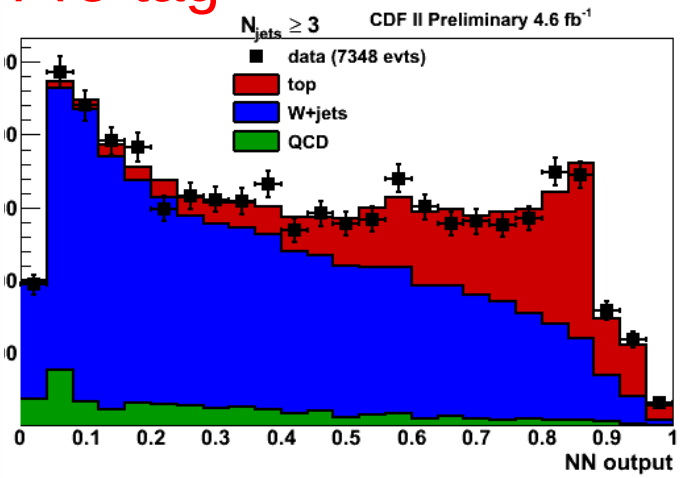
$t\bar{t}$ Cross-section (ℓ+jets)



≥1*b*-tag



Pre-tag



topological Neural Network

Selection

- 1 lepton
- MET
- ≥3 jets
- (*b*-tag)

No uncertainty from luminosity

- Used measured and theoretical Z cross-section

$$\sigma_{t\bar{t}} = \frac{\sigma_{t\bar{t}}^{\mathrm{meas}}}{\sigma_Z^{\mathrm{meas}}} \cdot \sigma_Z^{\mathrm{theory}}$$

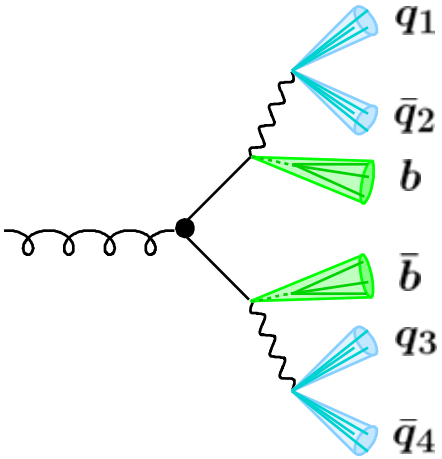
Luminosities are cancelled out here

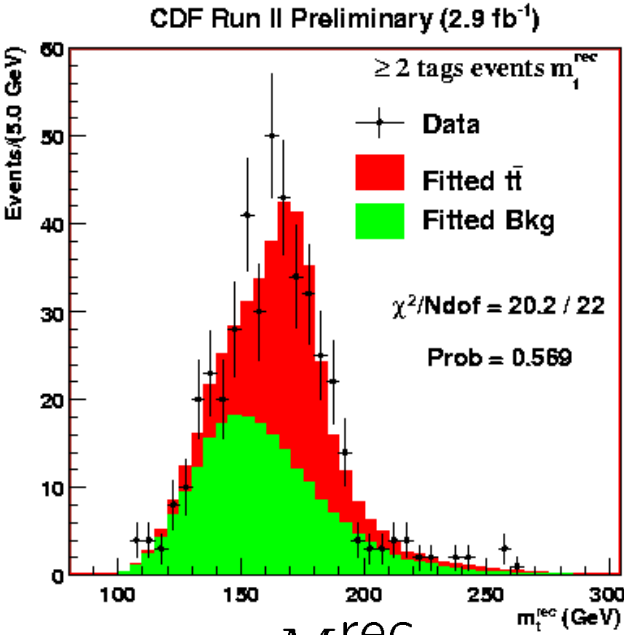
$$\sigma_{b-\mathrm{tag}} = 7.14 \pm 0.35(\mathrm{stat}) \pm 0.58(\mathrm{syst}) \pm 0.14(\mathrm{theory})\ \mathrm{pb}$$

$$\sigma_{\mathrm{pretag}} = 7.63 \pm 0.37(\mathrm{stat}) \pm 0.35(\mathrm{syst}) \pm 0.15(\mathrm{theory})\ \mathrm{pb}$$

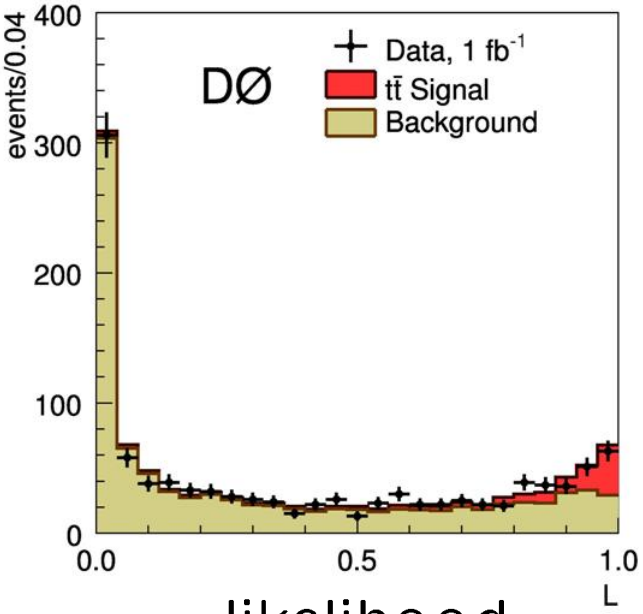
- The total uncertainty is decreased by ~10%

$t\bar{t}$ Cross-section (All hadronic)





M_t^{rec}



likelihood

Selection
- ≥ 6 jet
- ≥ 2 *b*-tag

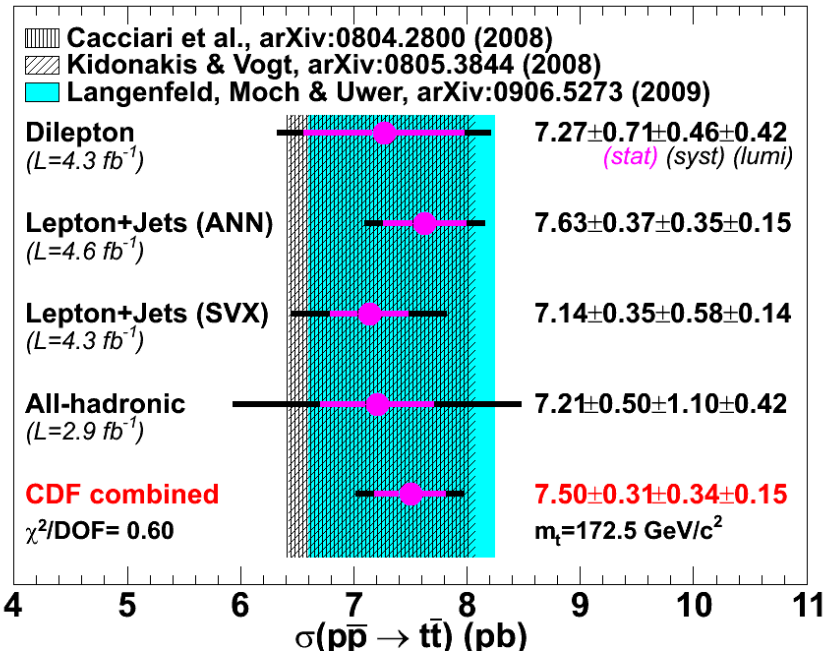
CDF ($\mathcal{L} = 2.9$ fb^{-1}, $M_t = 172.5$ GeV)

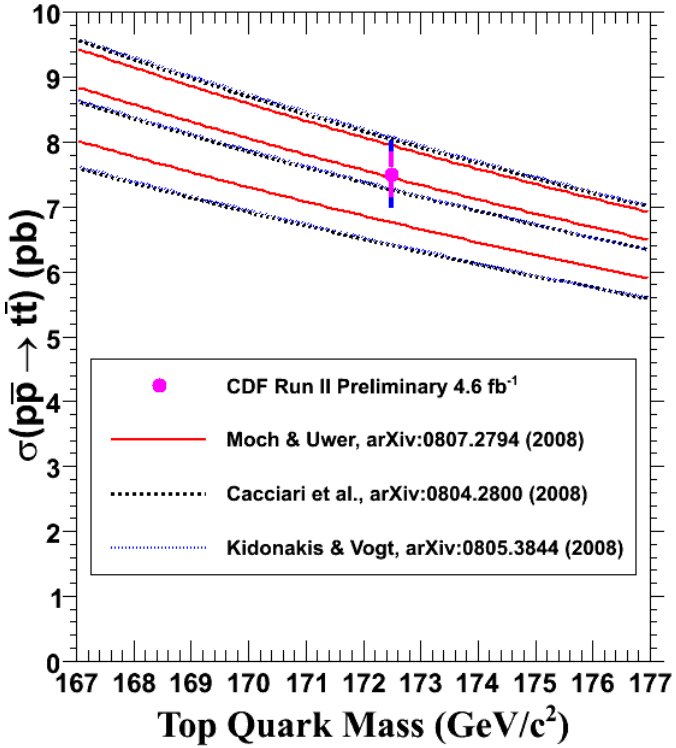
$\sigma = 7.2 \pm 0.5(\mathrm{stat}) \pm 1.1(\mathrm{syst}) \pm 0.4(\mathrm{lumi})$ pb

DØ($\mathcal{L} = 1$ fb^{-1}, $M_t = 175$ GeV)

$\sigma = 6.9 \pm 1.3(\mathrm{stat}) \pm 1.4(\mathrm{syst}) \pm 0.4(\mathrm{lumi})$ pb

$t\bar{t}$ Cross-section (CDF combind)





CDF(4.6 fb^{-1}): $\sigma_{t\bar{t}} = 7.50 \pm 0.31(\text{stat}) \pm 0.34(\text{sys}) \pm 0.15(\text{theory})$ pb

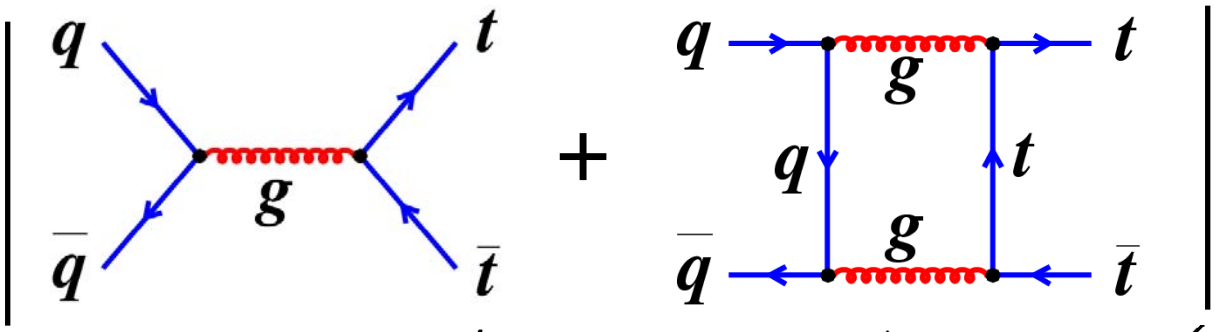
- Now better than theoretical uncertainties
- Cross-sections of all categories (dilepton, lepton+jets, and all-hadronic) as well as w/i and w/o b-tag are consistent with SM

Consistent with Br(t→Wb)~100%

$t\bar{t}$ Foward Backward Asymmetry

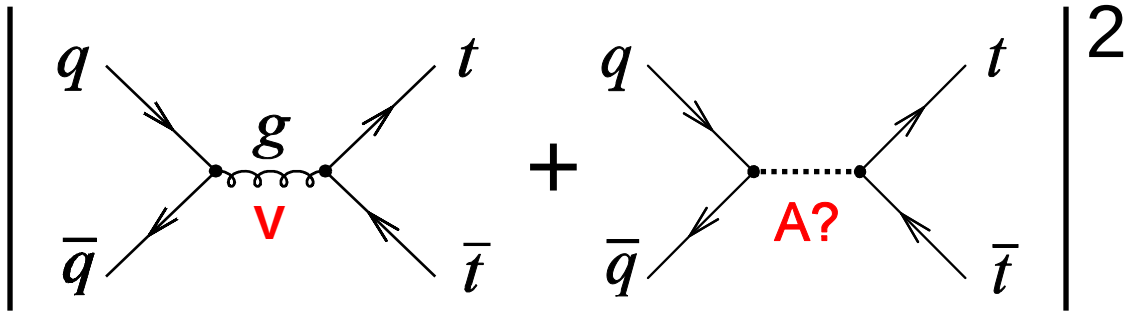
NLO prediction: Interference between LO and NLO

$$|\mathcal{M}|^2 \propto \left| \right|^2$$

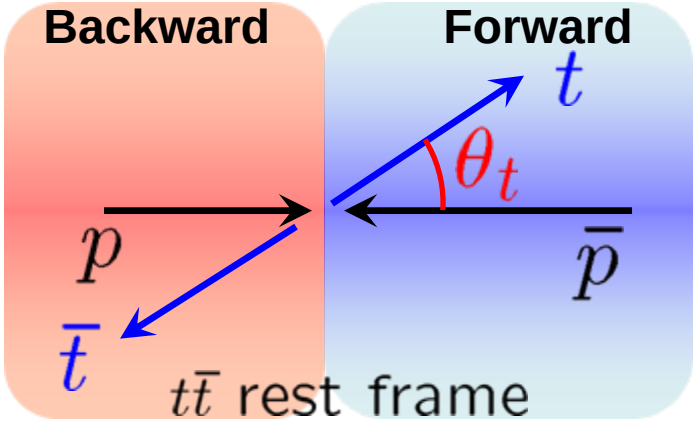


$$A_{fb} = 0.05 \pm 0.015 \text{ (NLO)}$$

Also presence of new physics could make asymmetry



$t\bar{t}$ Forward Backward Asymmetry

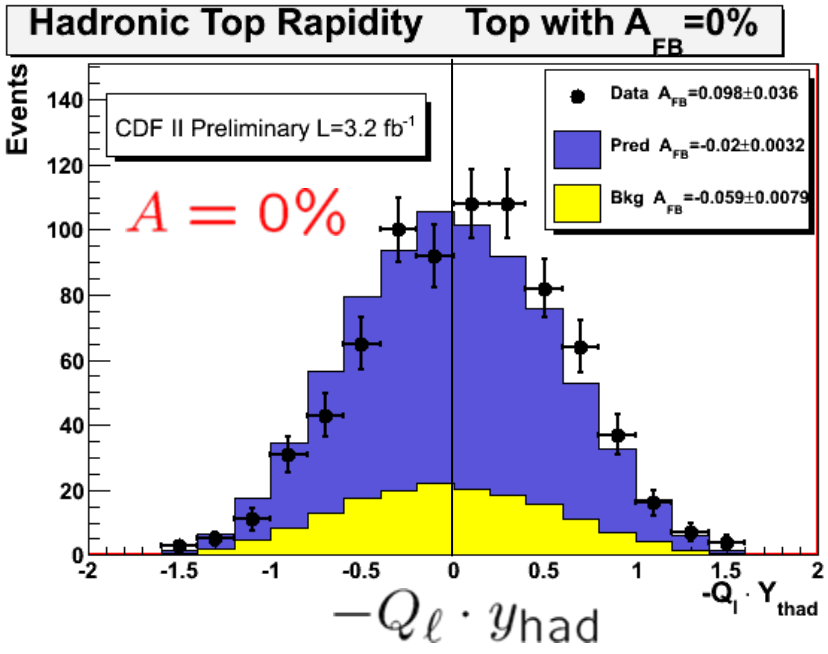


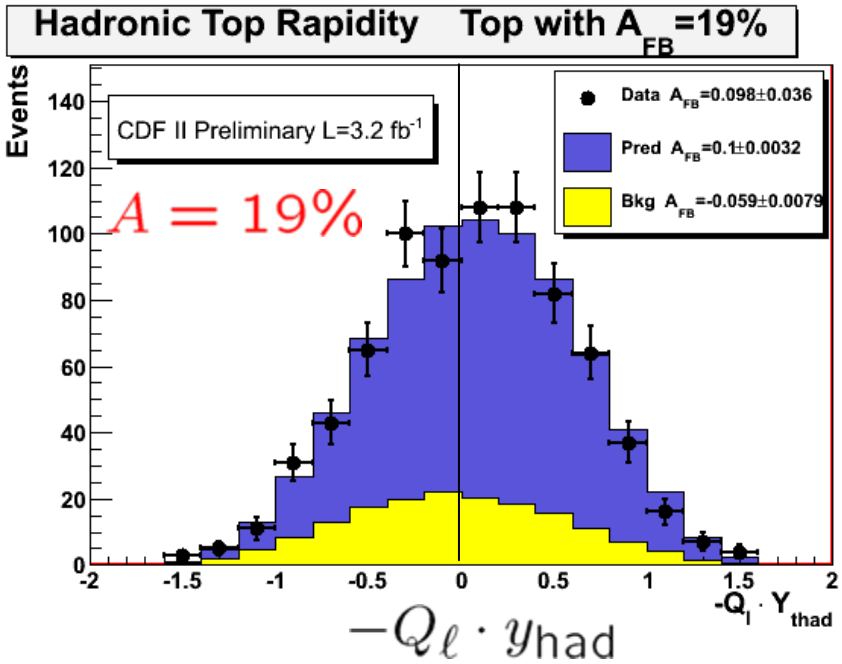
$$A_{\text{fb}} = \frac{F - B}{F + B}$$

$$\text{F} : \cos\theta_t > 0$$

$$\text{B} : \cos\theta_t < 0$$

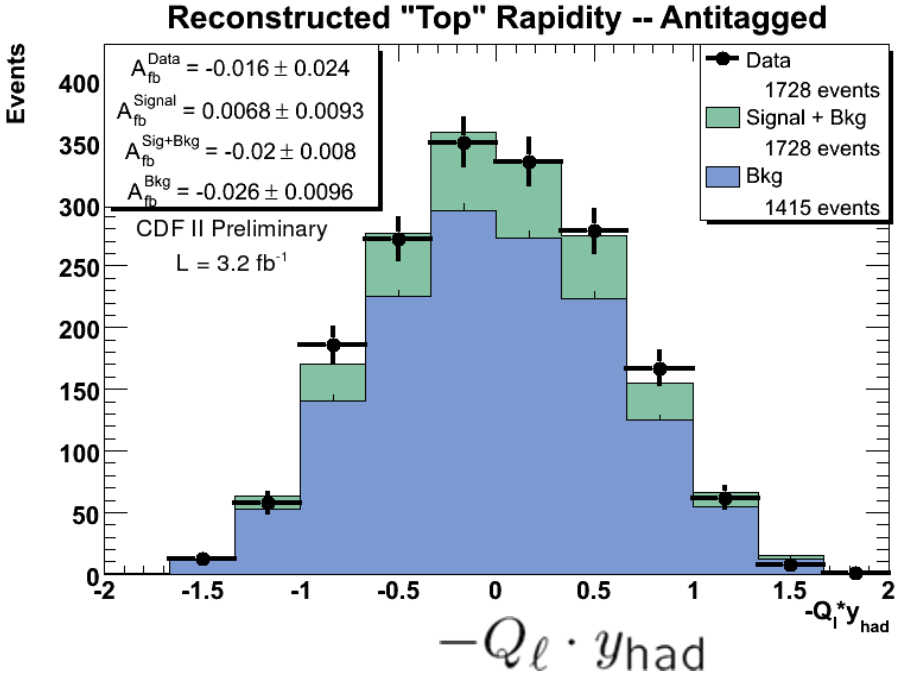
CDF $\mathcal{L} = 3.2$ fb^{-1}, ℓ + jets (b-tag)





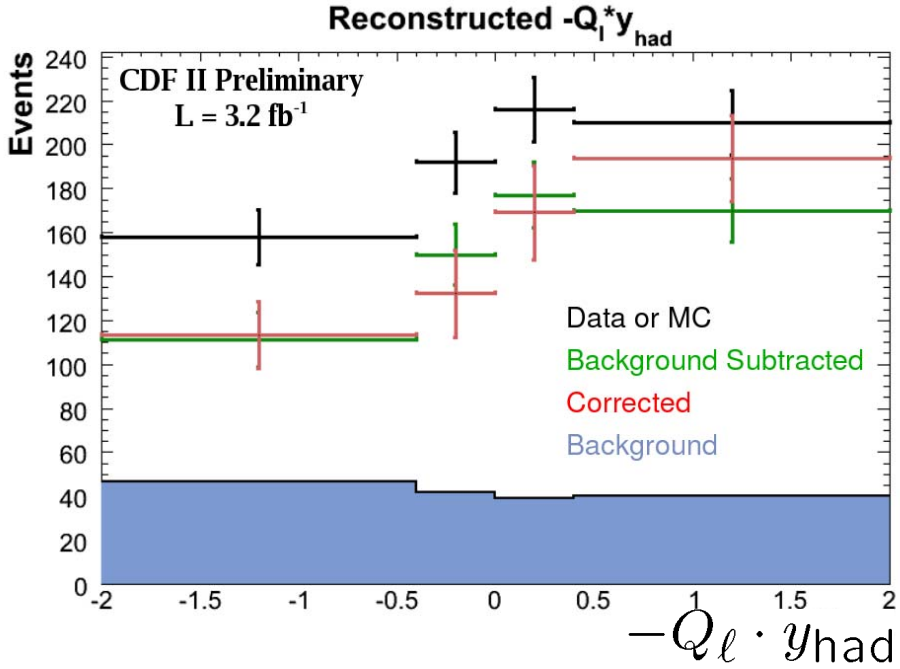
$t\bar{t}$ Forward Backward Asymmetry

ℓ + jets (anti b-tag)



Check background shape

Unfolding



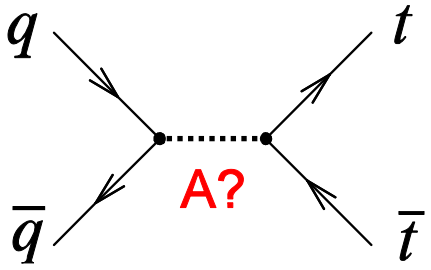
Correct acceptance + smearing (event migration)

CDF(3.2 fb^{-1}): $A_{\mathrm{fb}} = 0.193 \pm 0.065(\mathrm{stat}) \pm 0.024(\mathrm{sys})$

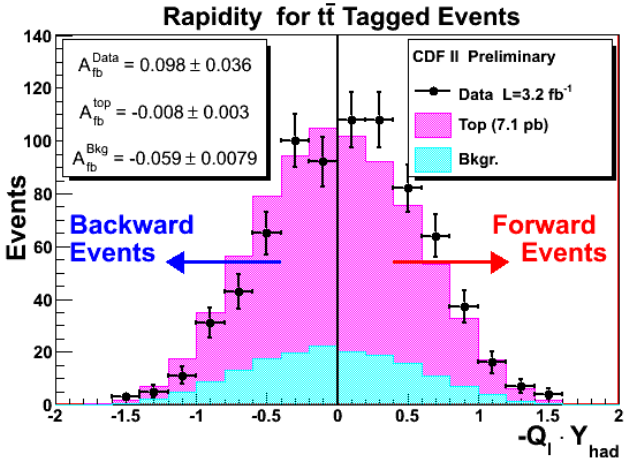
2 sigma away from $A_{\mathrm{fb}} = 0.05 \pm 0.015$ (NLO)

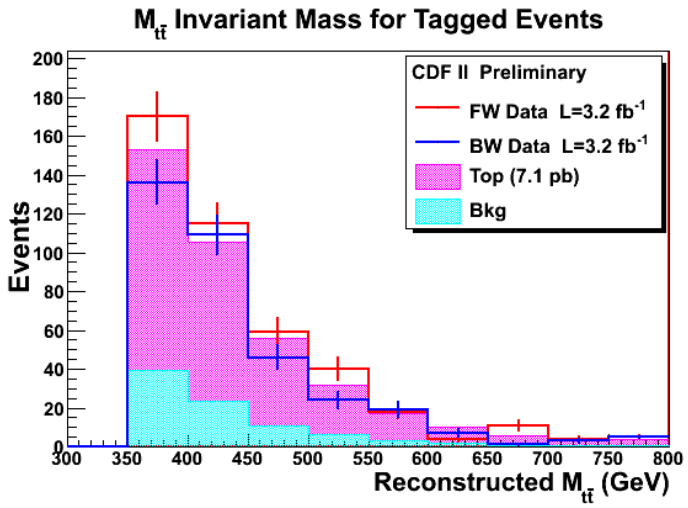
DØ(1 fb^{-1}): $A_{\mathrm{fb}}^{\mathrm{raw}} = 0.12 \pm 0.08(\mathrm{stat}) \pm 0.01(\mathrm{sys})$

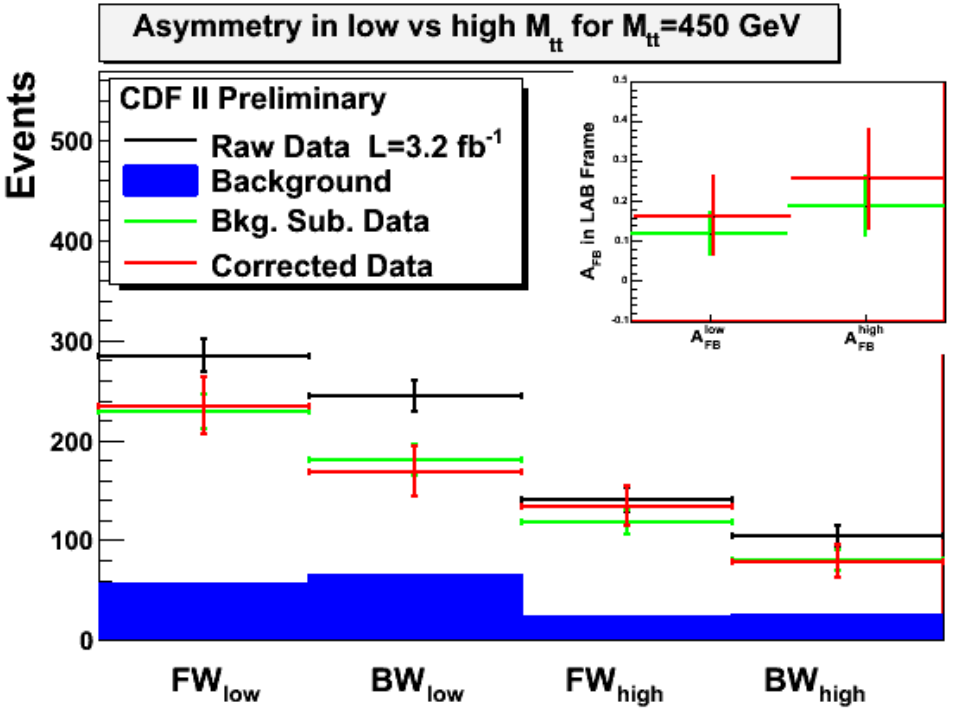
$t\bar{t}$ Forward Backward Asymmetry ($M_{t\bar{t}}$ scan)



- If a new particle (such as Z') would cause asymmetry, asymmetry will rise above the mass

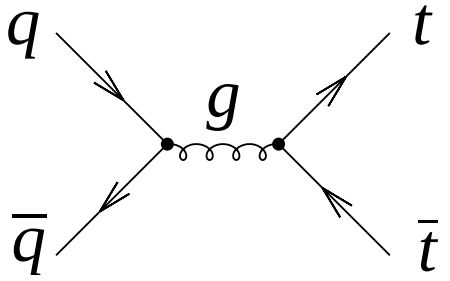




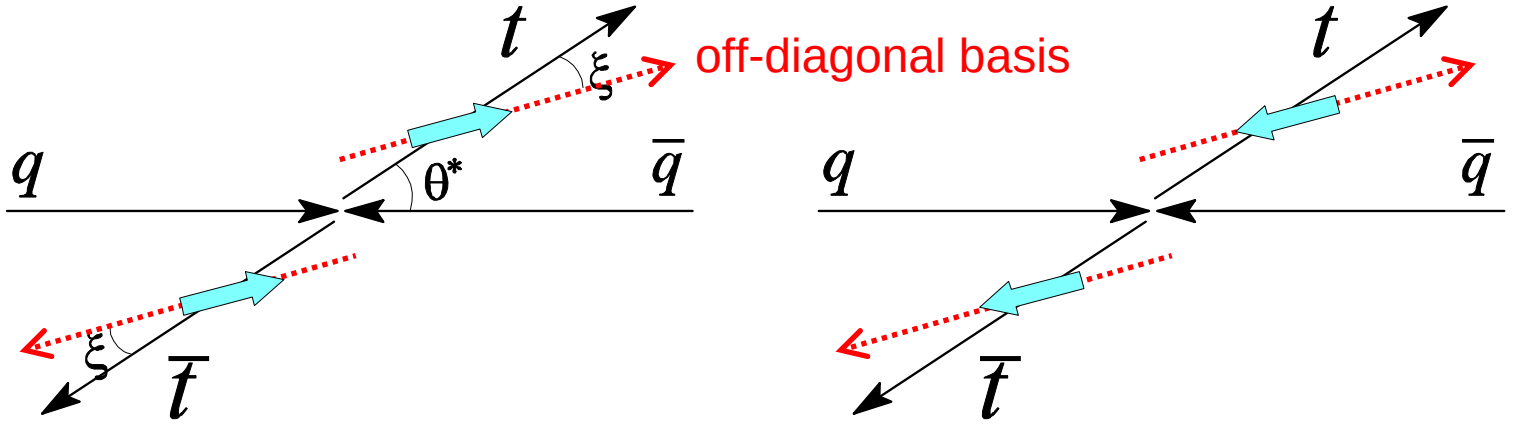


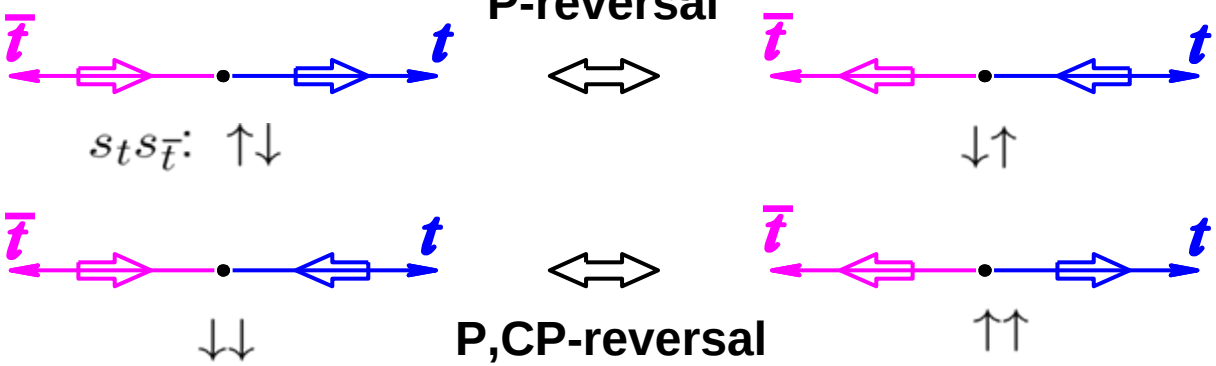
Spin Correlation at $t\bar{t}$ Production

- Top quark decays before losing its polariztion
  - We can see top quark spin at its production
- $t\bar{t}$ production via $q\bar{q}$ annihilation
  - 100% spin correlation in off-diagonal basis



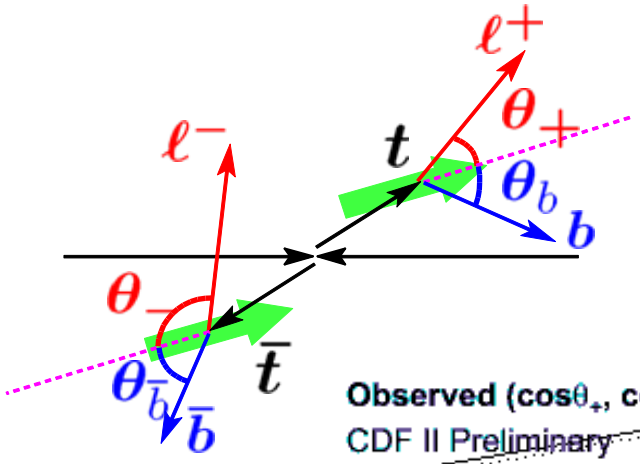
$q\bar{q}$ annihilation



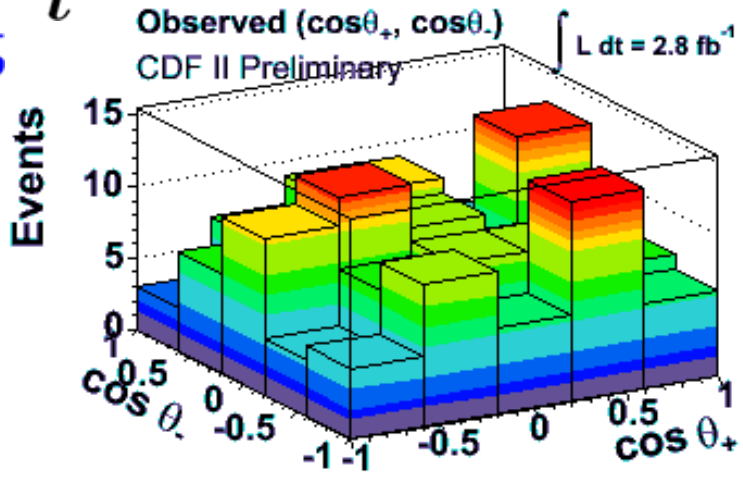


New test ground for P/CP at $t\bar{t}$ production

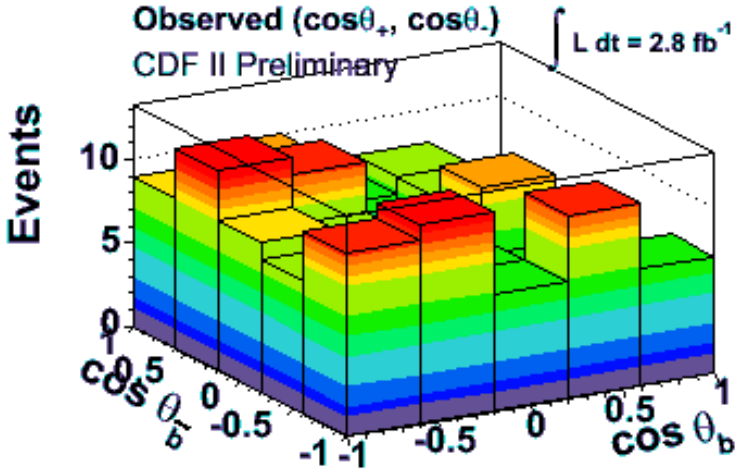
Spin Correlation at $t\bar{t}$ Production



$\kappa \sim 0.78$ (NLO prediction)



$(\cos\theta_+,\ \cos\theta_-)$

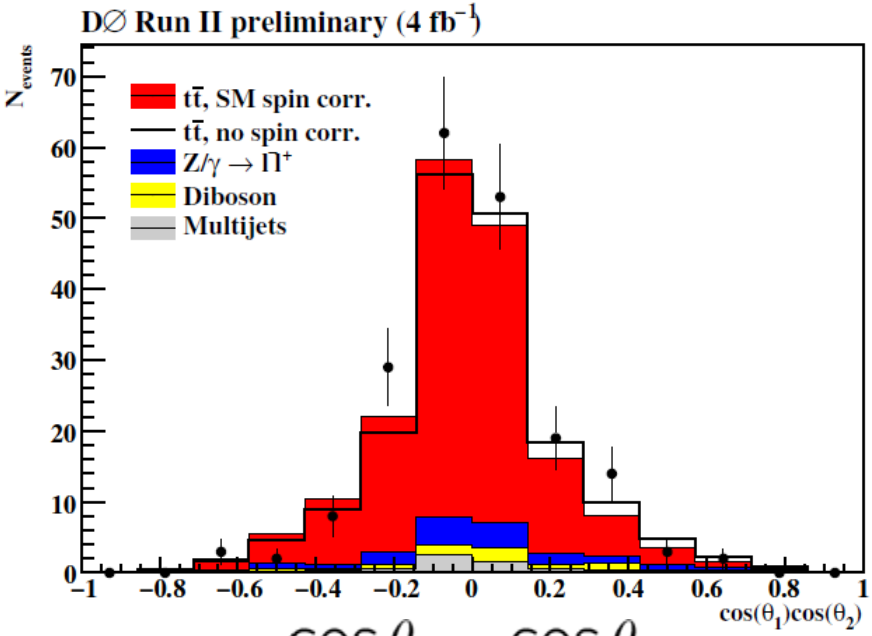


$(\cos\theta_b,\ \cos\theta_{\bar{b}})$

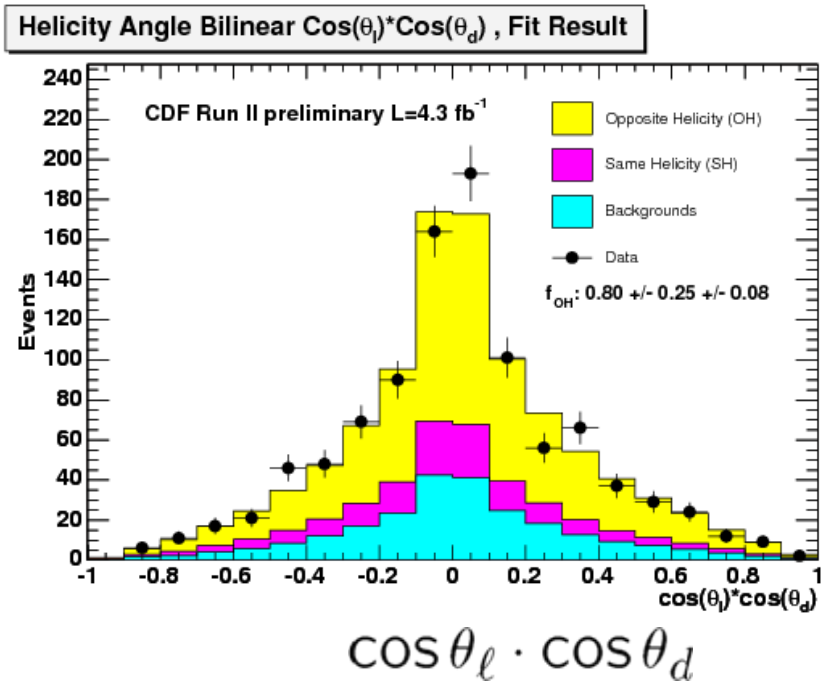
$-0.455 < \kappa < 0.865$ (68% C.L.)

CDF dilepton ($\mathcal{L} = 2.8$ fb^{-1}, $M_t = 175$ GeV, off-diagonal)

Spin Correlation (CDF ℓ+jets, DØ dilepton)



$\cos\theta_{\ell 1} \cdot \cos\theta_{\ell 2}$



$\cos\theta_{\ell} \cdot \cos\theta_{d}$

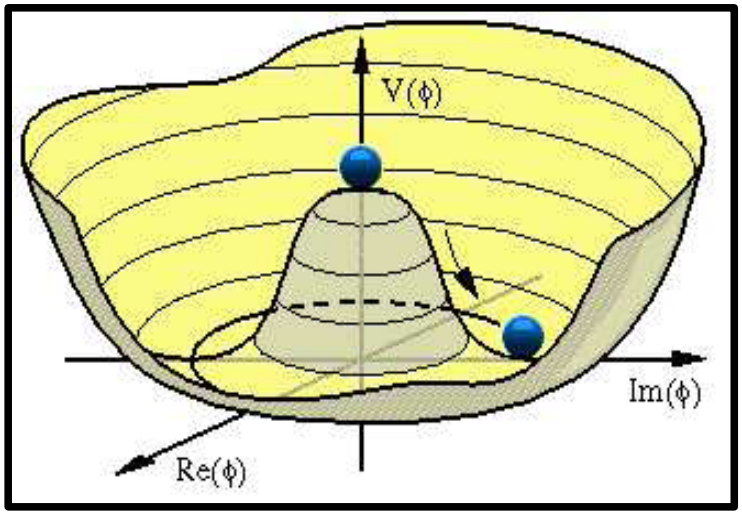
DØ dilepton ($\mathcal{L} = 4.2$ fb^{-1})

$$\kappa(\text{beam}) = -0.17^{+0.64}_{-0.53}$$

CDF ℓ+jets ($\mathcal{L} = 4.3$ fb^{-1})

$$\kappa(\text{helicity}) = 0.60 \pm 0.50(\text{stat}) \pm 0.16(\text{sys})$$

SM Higgs Search



Higgs Cross-section and BR

Low mass Higgs region:

$m_H < 135$ GeV/c^2

H → bb dominant decay.

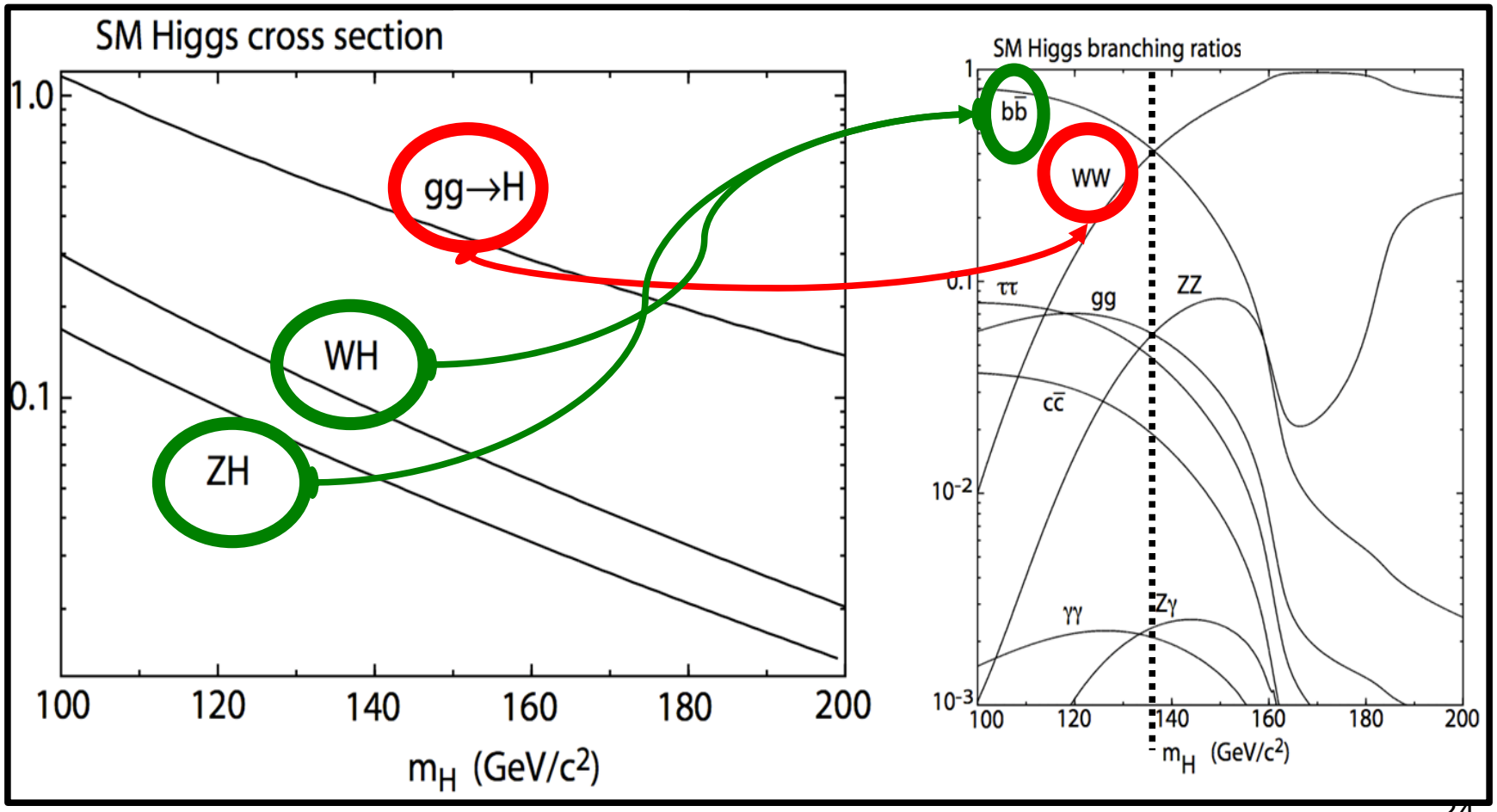
Search for associated W/Z production.

High mass Higgs region:

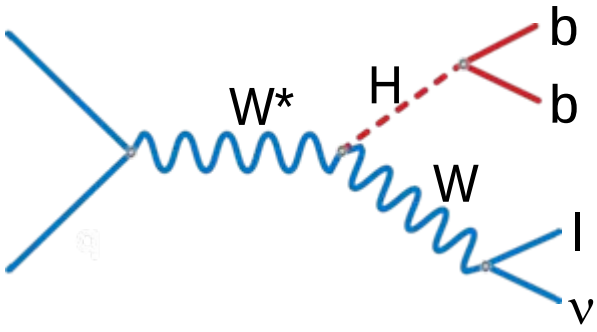
$m_H > 135$ GeV/c^2

H → WW dominant decay.

Gluon fusion production search (gg → H).

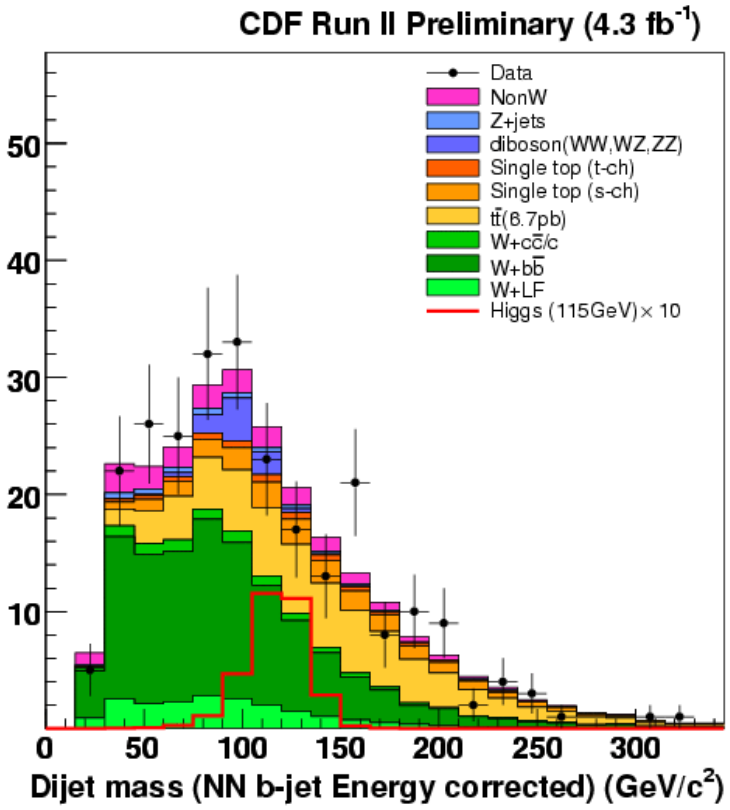


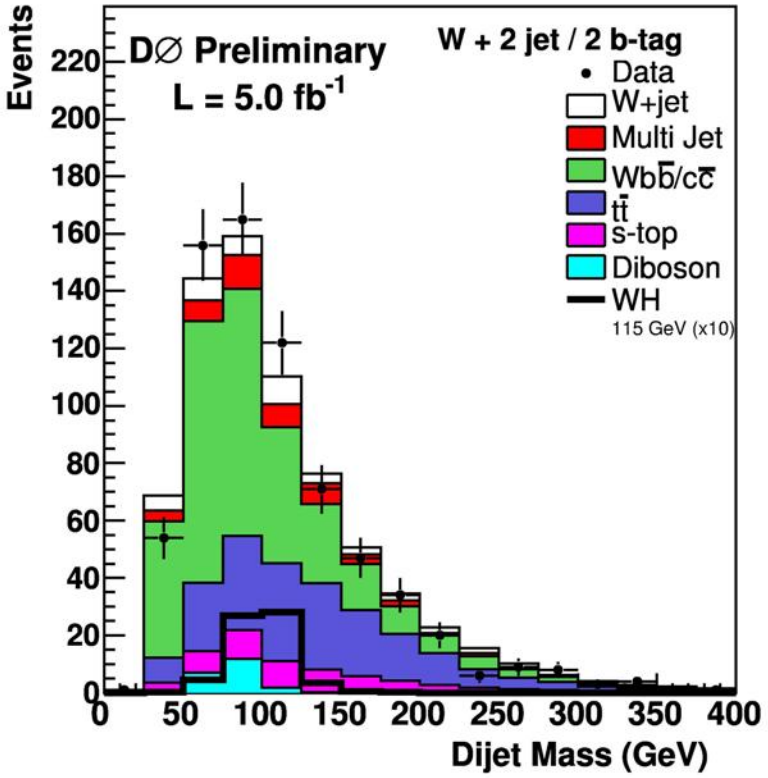
$WH \to \ell\nu bb$



$1\ell + \not\!\!E_T + 2b$ jets

- Most sensitive channel at low mass
- Bkg: W+bb, W+cc, W+qq, ttbar, ...

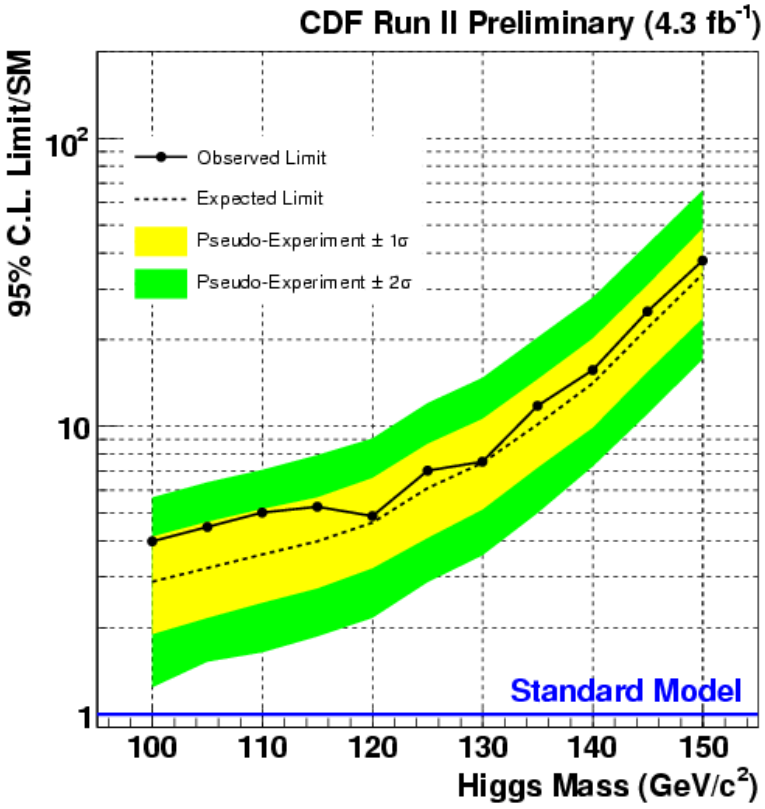




$WH \rightarrow \ell\nu bb$

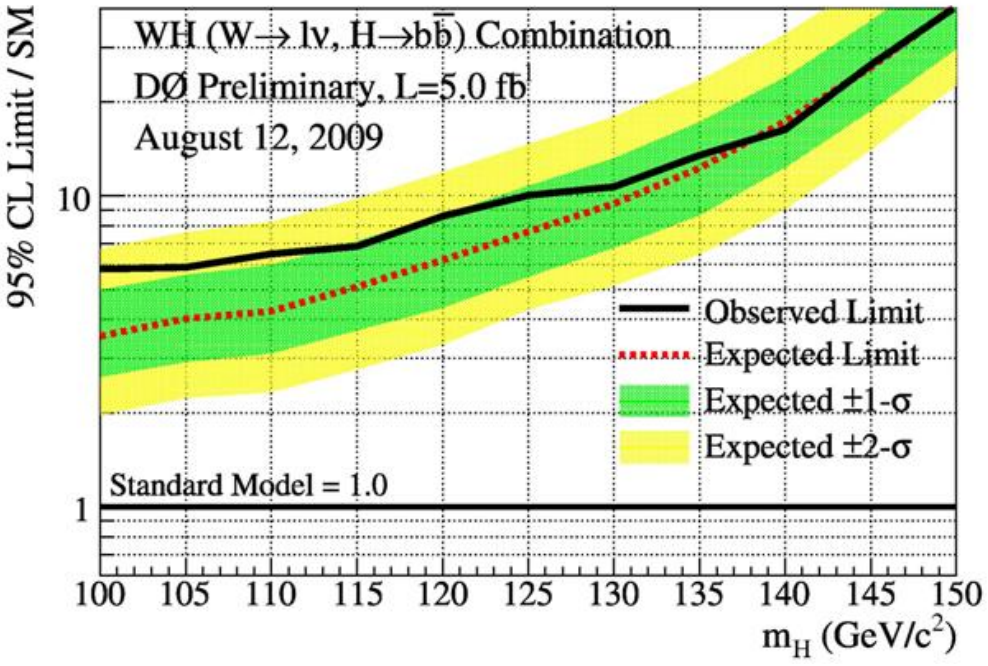
CDF:

- Limit/SM<4.0 @115 GeV

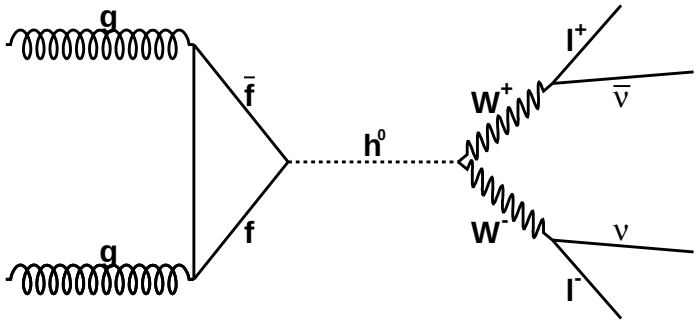


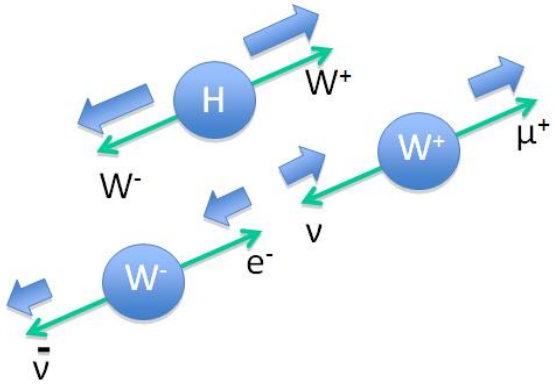
DØ:

- Limit/SM < 6.9 @115 GeV

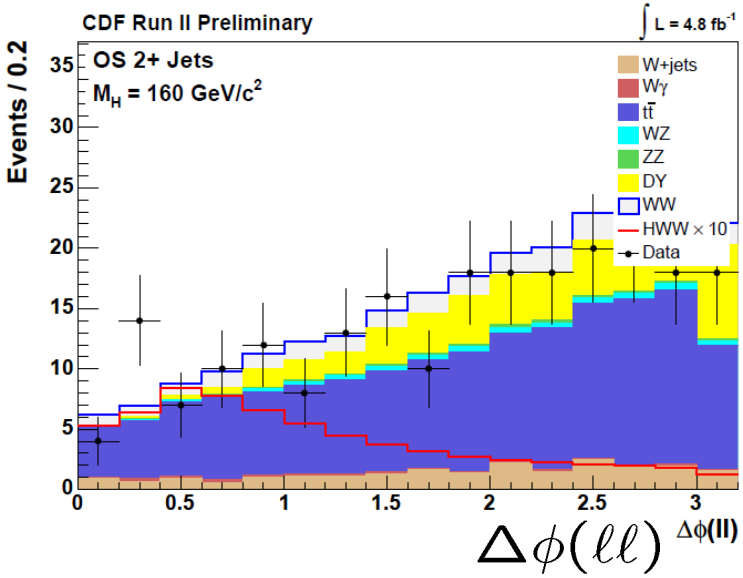


$H \to W^+W^- \to \ell^+\nu\ell^-\bar{\nu}$

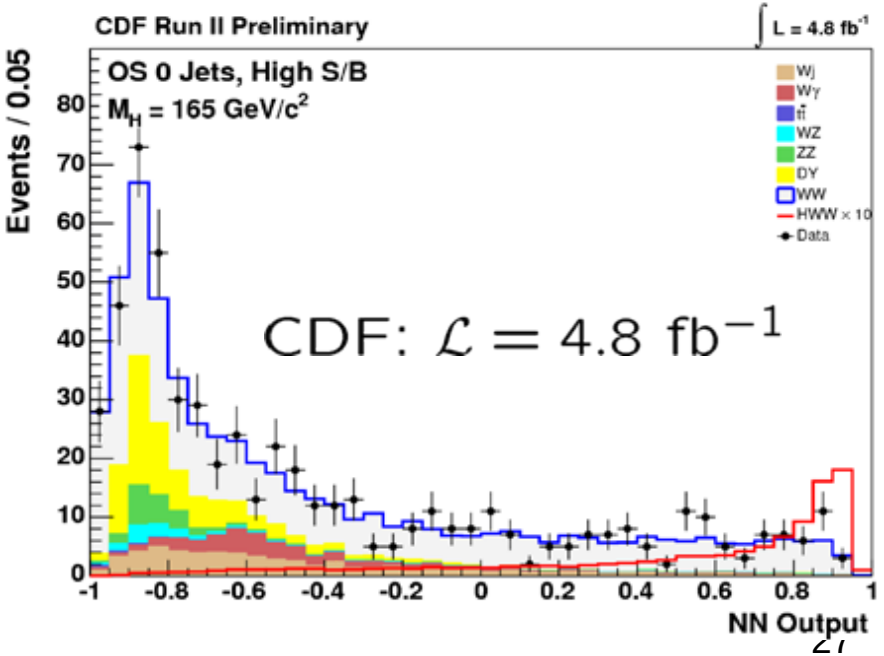




- 2 opposite sign leptons + MET
- WW from spin 0 higgs
  - leptons tend to same direction
  - $\triangle\phi$ is best discriminant

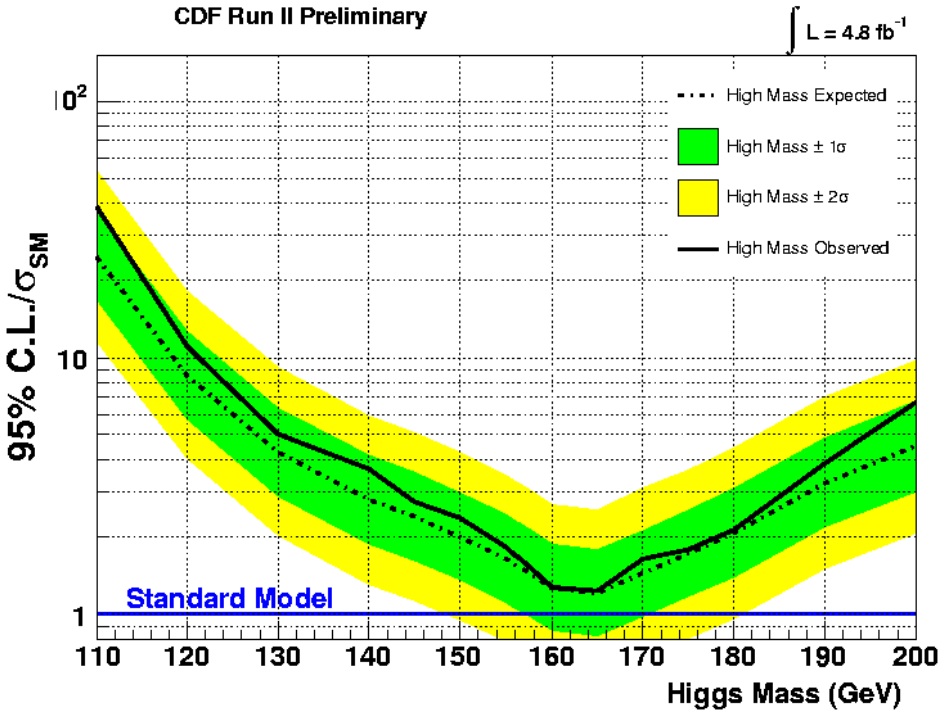


- Neural network technique



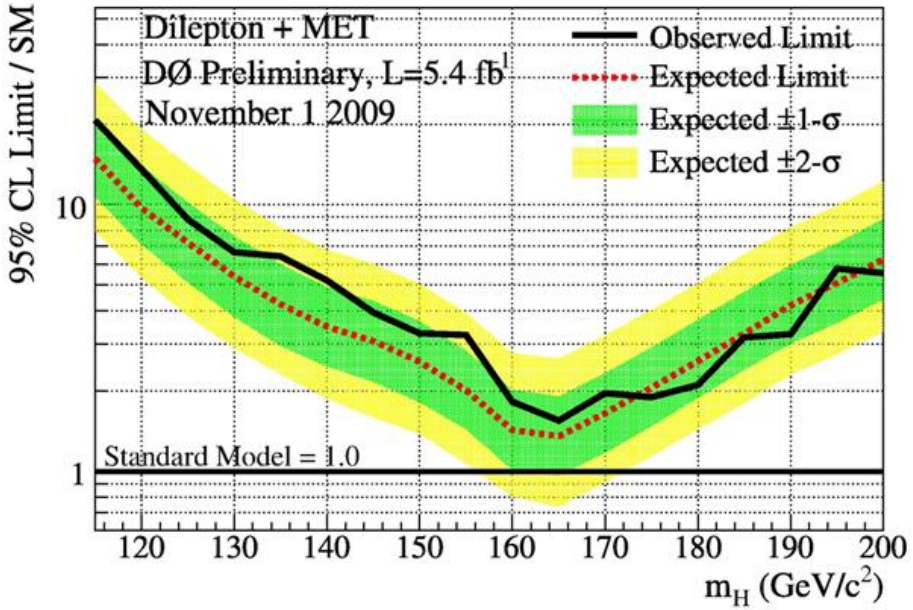
$H \to WW,\ WH \to WWW$

CDF: $\mathcal{L} = 4.8\ \mathrm{fb}^{-1}$



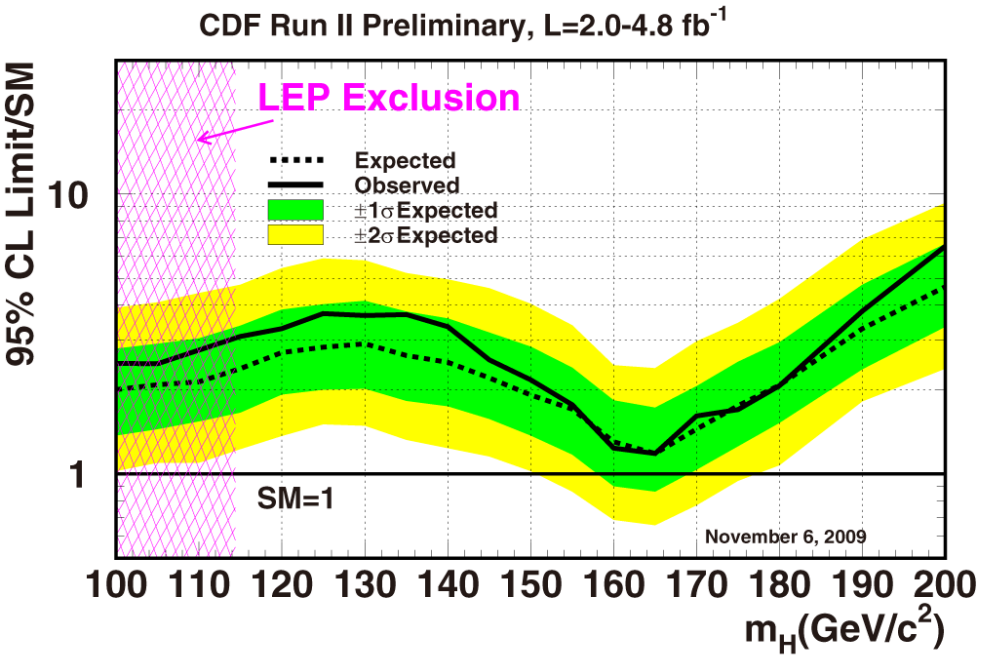
- Also search for same sign leptons for WH $\to$WWW* $\to l^{\pm} l^{\pm} X$
- Limit: <1.23 x SM @ M_H=165 GeV

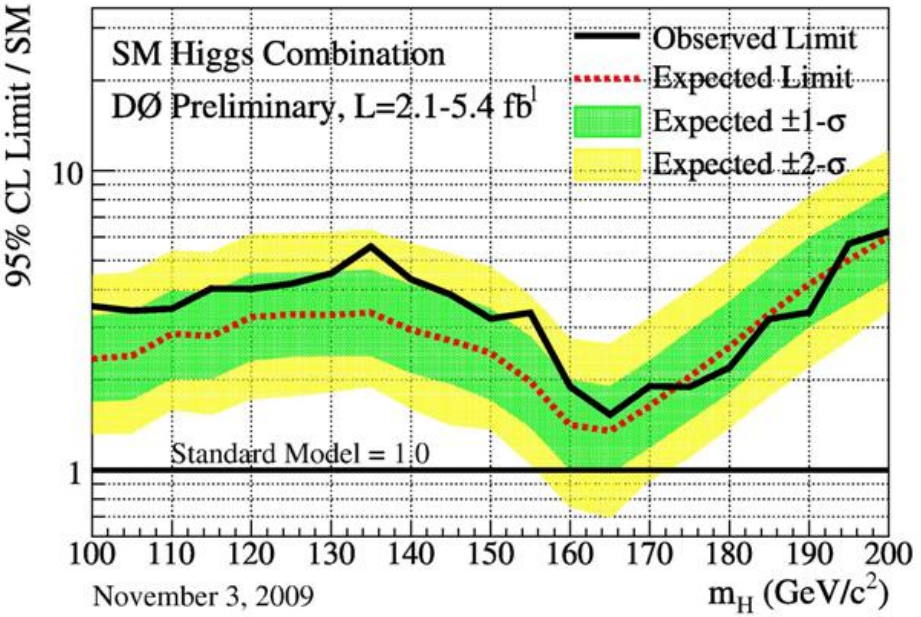
DØ: $\mathcal{L} = 5.4\ \mathrm{fb}^{-1}$



- Limit: <1.55 x SM @ M_H=165 GeV

Combined Limits





CDF:

Included channels

- WH -> lnbb (4.3 fb-1)
- VH -> MET + bb (3.6 fb-1)
- ZH -> bb (4.1 fb-1)
- VH, VBF, ggH
  -> 2 jets + tau tau (2.0 fb-1)
- VH -> 2 jets + bb (2.0 fb-1)
- ggH -> WW* ((4.8 fb-1)
- VH -> VWW* (4.8 fb-1)

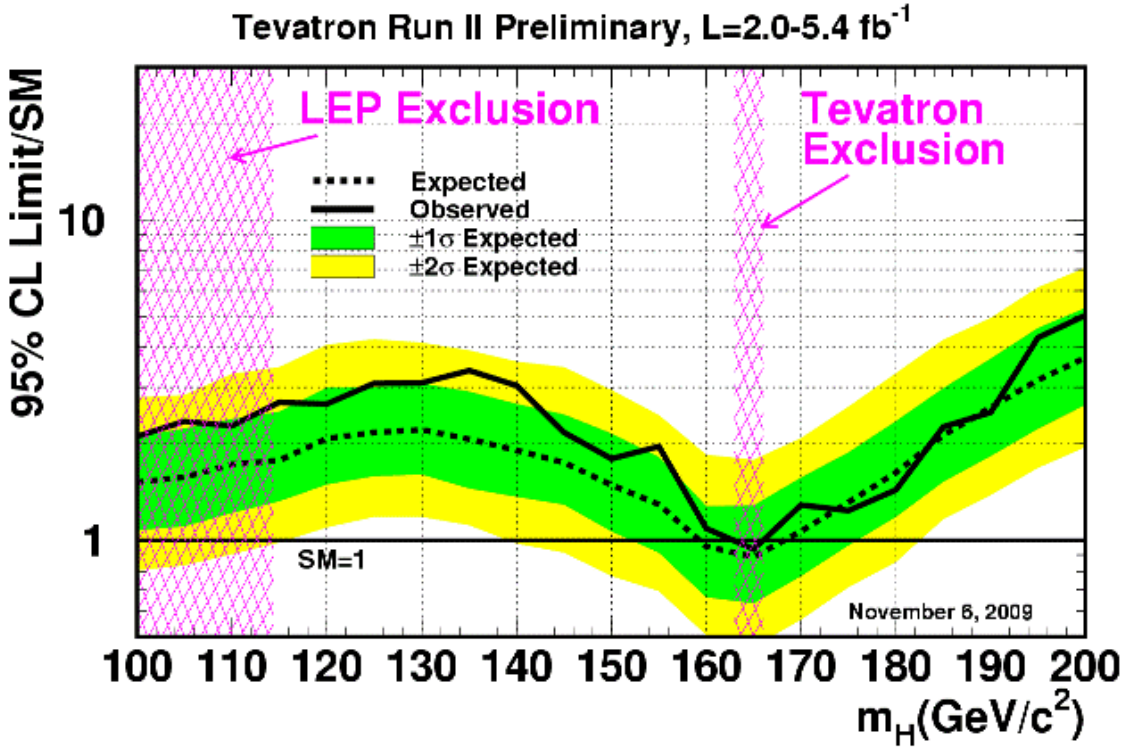
DZero:

Included channels

- WH -> lnbb (5.0 fb-1)
- XH -> tau tau bb/qq tau tau (4.9 fb-1)
- ZH -> nu nu bb (5.2 fb-1)
- ZH -> llbb (4.2 fb-1)
- WH -> WWW* (3.6 fb-1)
- H -> WW* (5.4 fb-1)
- H -> gamma gamma(4.2 fb-1)
- ttH -> ttbb (2.1 fb-1)

Higgs Exclusion @ Tevatron

CDF+DZero combination



CDF + DØ combined :

Observed limit at MH = 115 GeV/c^2 : 2.70 x SM
Excluded mass range at 95% C.L. : 163 - 166 GeV/c^2

Summary

- Top quark properties are consistent with SM so far.
- Top quark properties are being measured more and more precisely, not to overlook any hint of new physics.

- We are sensitive to a Higgs of 160 GeV/c^2.
- Low mass Higgs is also being within range.

- Stay tune for interesting results with $\gtrsim$ 5 fb^{-1} in 2010!