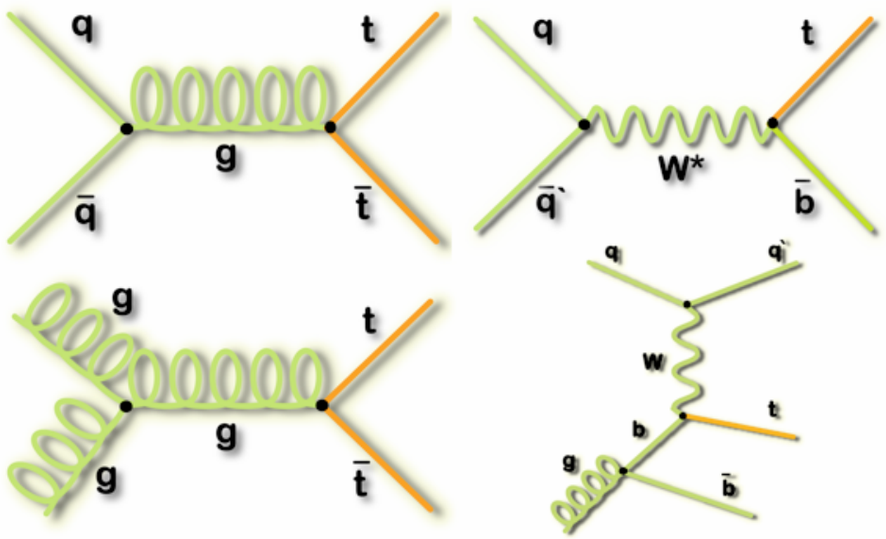
Top Physics at CDF

Tom Schwarz
University of California - Davis
On behalf of the CDF Experiment

SUSY 2010 Bonn, Germany

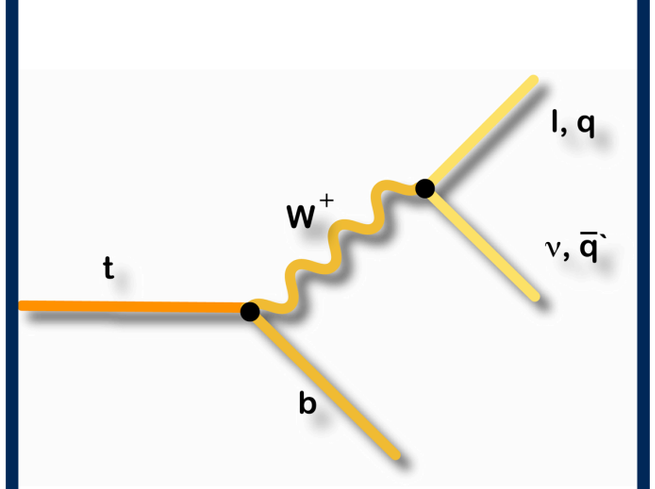
Top Physics at the Tevatron

How is Top Produced



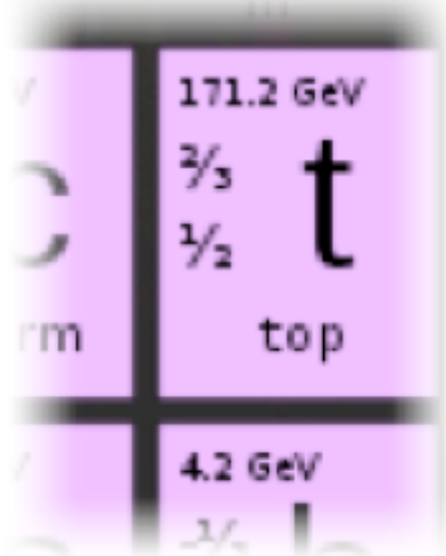
- **Strong Force**
  $\sigma_{tt} \sim 7.5$ pb
- **Electroweak**
  $\sigma_{s+t} \sim 3$ pb

How Does Top Decay



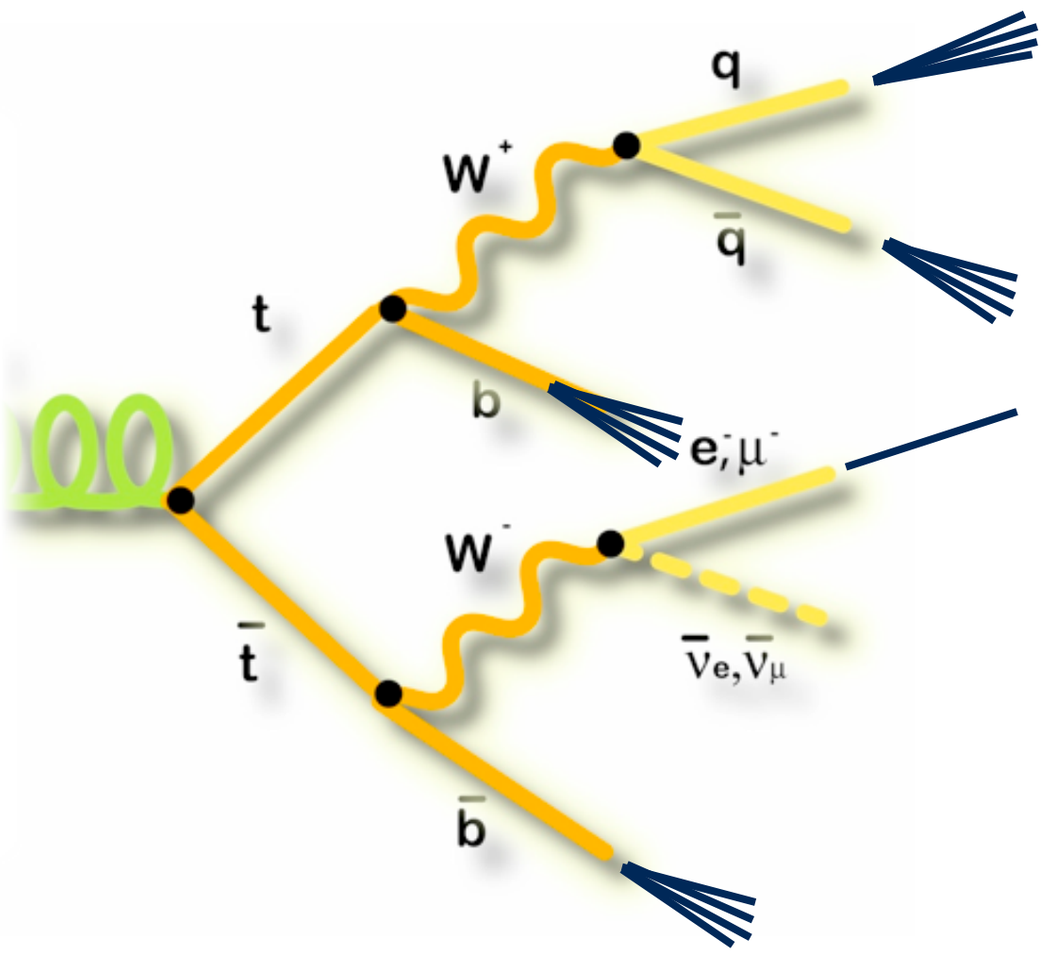
- **V-A**
  $F_0 \sim 0.7$, $F_+ \sim 0$
- $V_{TB} \sim 1$

What are Top's Intrinsic Properties

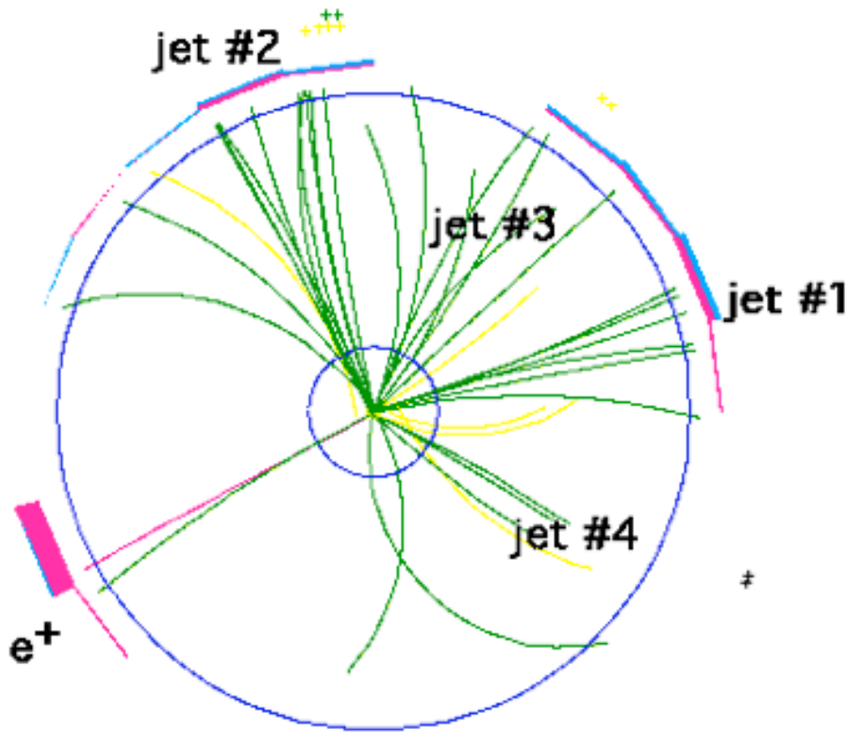


- **Mass**
- **Width** $\Gamma_t \sim 1.3$ GeV
- **Spin** 1/2
- **Charge** +2/3

What does Top look like?

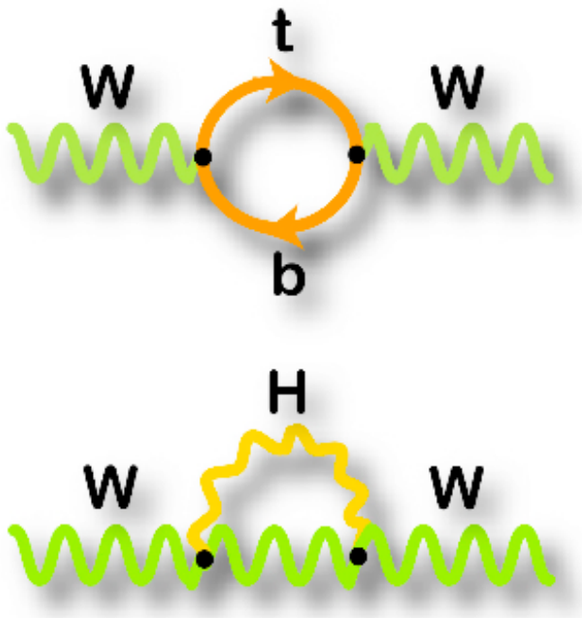


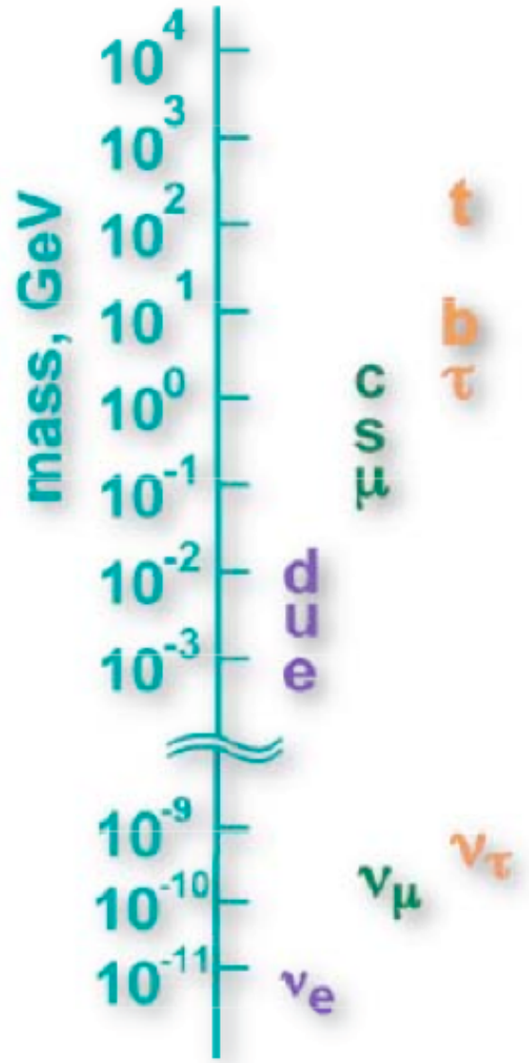
- ~ 4 jets
- A single high energy lepton
- Large Missing Energy



Top Mass

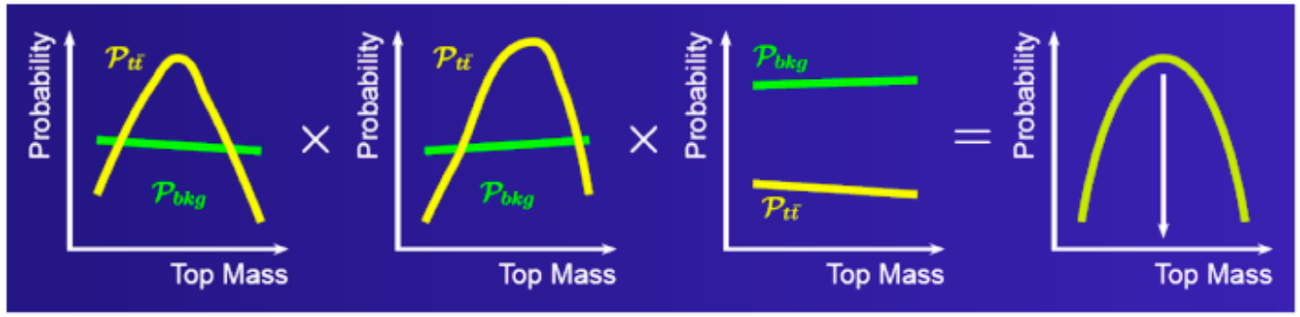
- **Free parameter in the SM**
- **Combined with the measured W mass constrains the mass of the Higgs through radiative corrections**

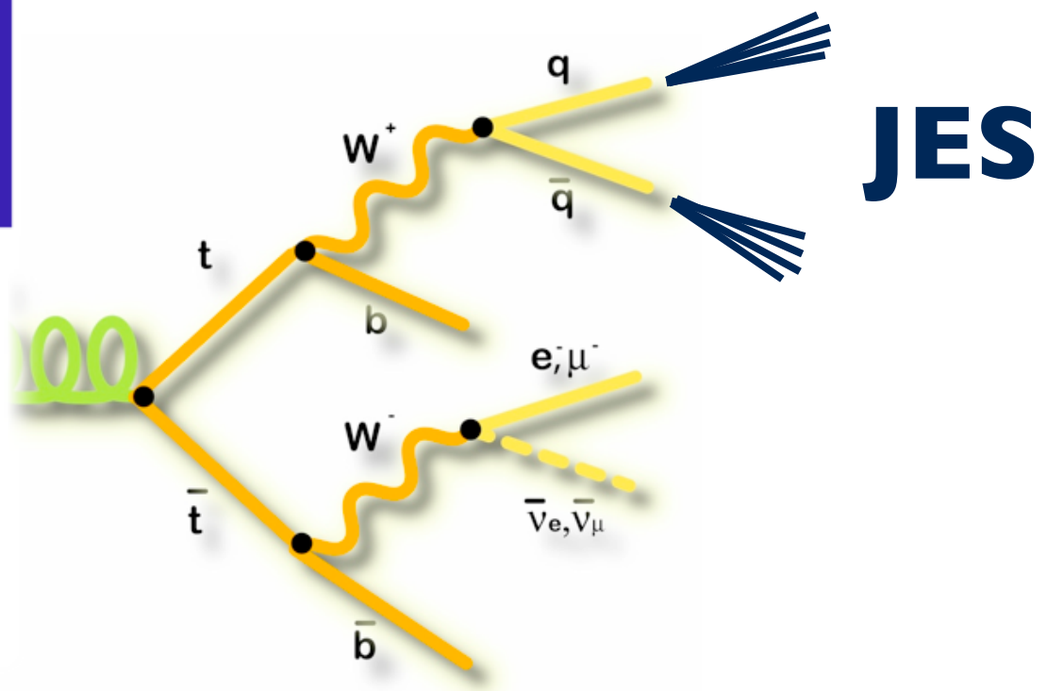




Top Mass

- **Matrix Element Technique: The probability of being signal or background is calculated per event as a function of M_t**





JES

- **Multiply event probabilities to extract the most likely mass**

- **Jet Energy Scale is reduced by measuring from hadronic W decays**

$M_t = 173.0 \pm 0.9_{stat+JES} \pm 0.9_{sys}$ GeV/c^2

$\Delta M / M \sim 0.7$ %

5.6 fb^{-1}

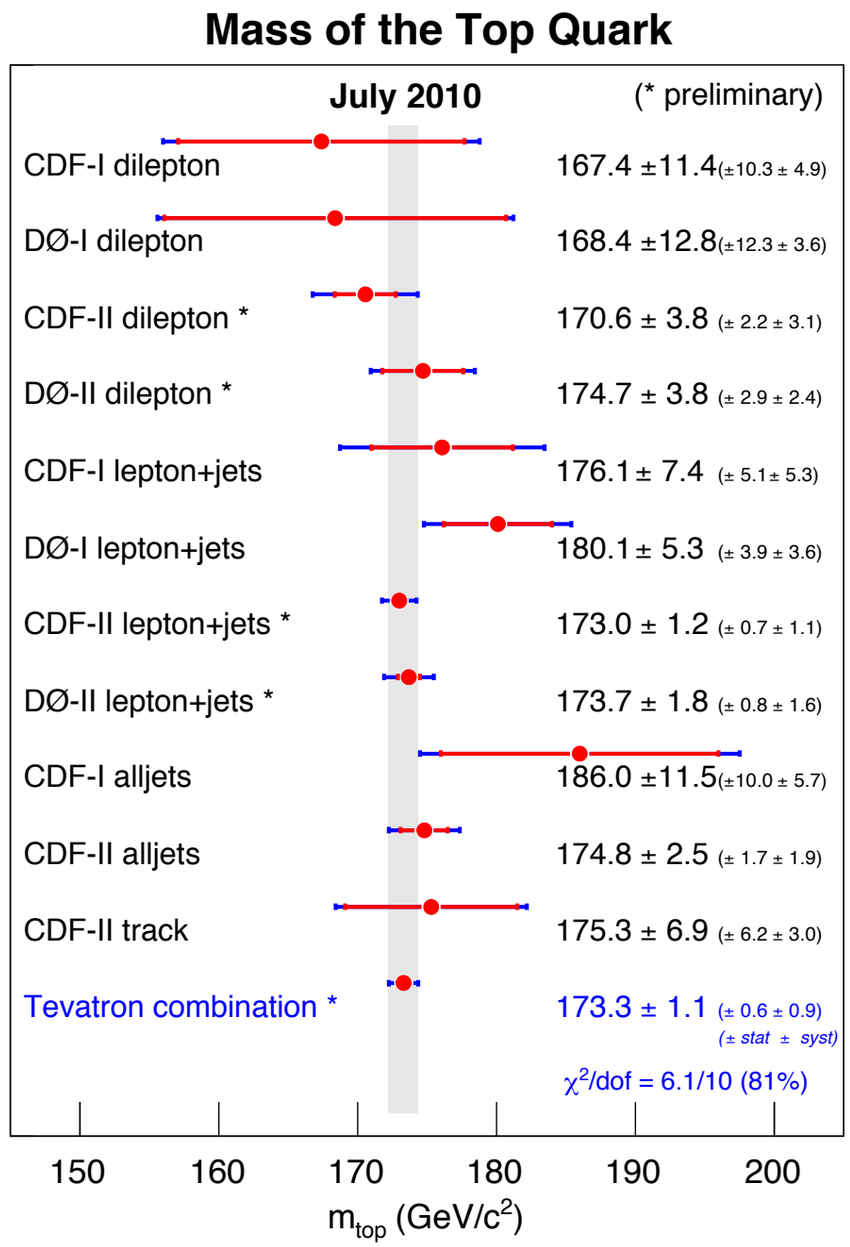
Top Mass Combination

- **Tevatron Combination updated this July - includes 11 results**
- **Statistical Uncertainty on Jet Energy Scale is largest systematics (~ 0.46 GeV)**
- **Good agreement across both experiments and channels**

$$M_t = 173.3 \pm 1.1 \text{ GeV}/c^2$$

$$\Delta M / M \sim 0.6\ \%$$

up to 5.6 fb^{-1}

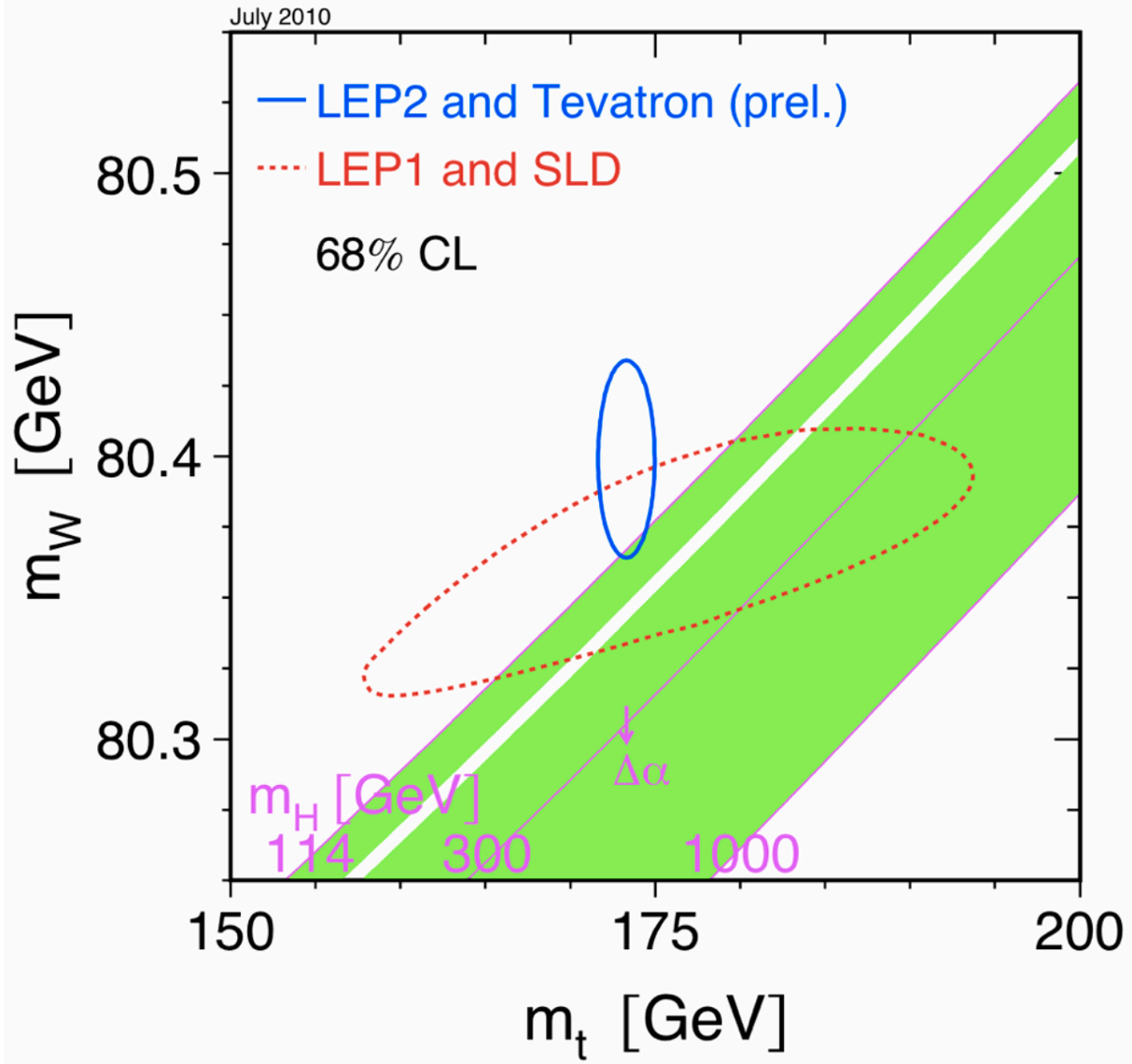


Back to the Higgs

Electroweak Fit

$M_H = 89^{+35}_{-26}$ GeV

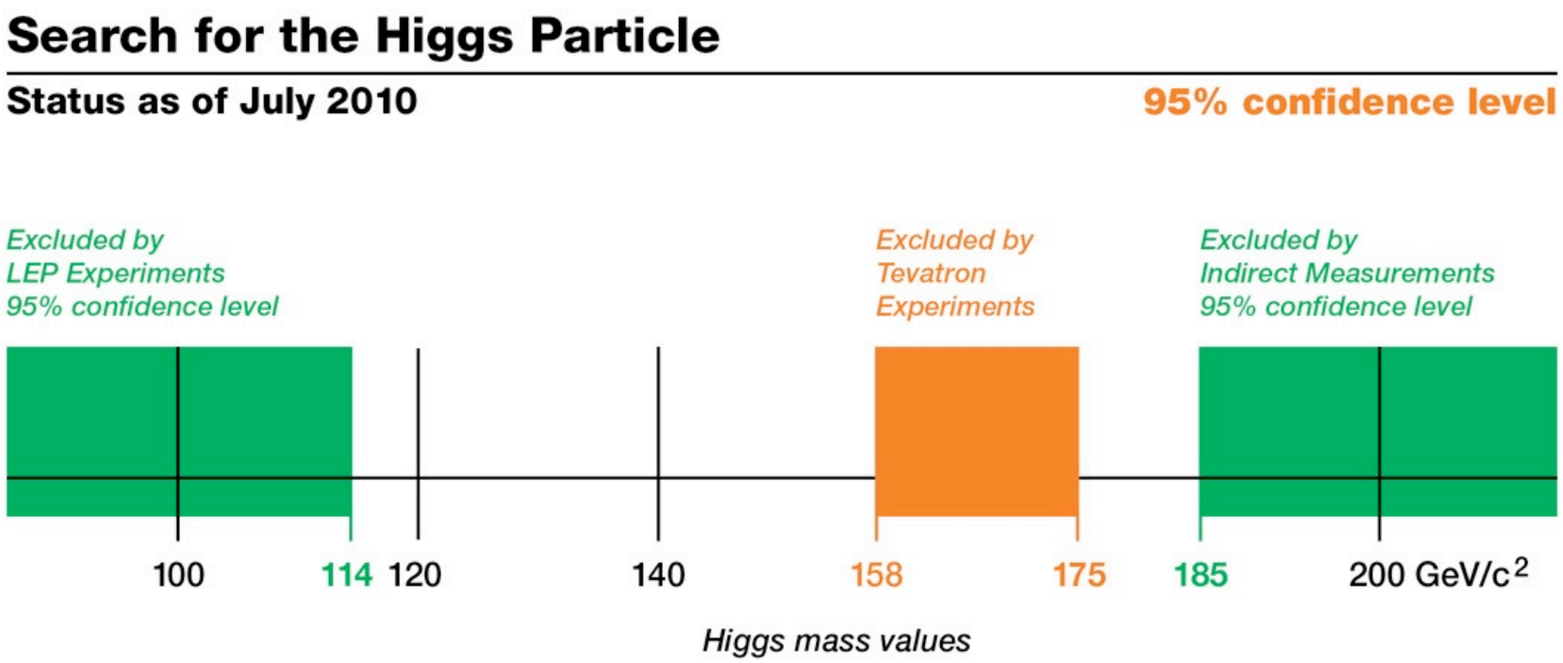
$M_H < 158$ GeV @ 95% CL



Back to the Higgs

Including LEP
Direct Search Limit

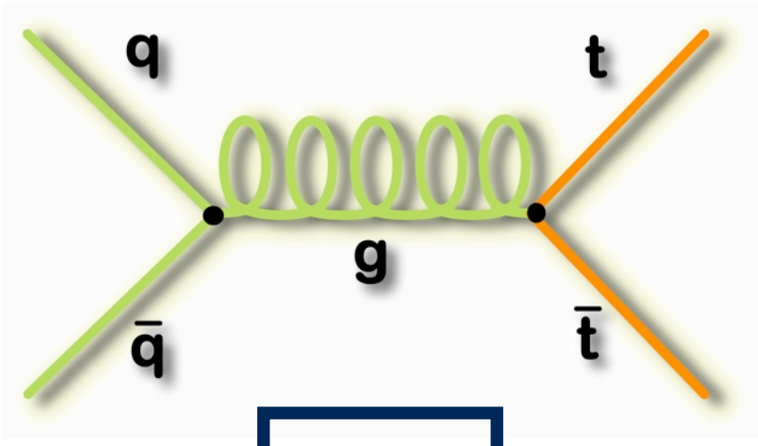
M_H < 185 GeV @ 95% CL



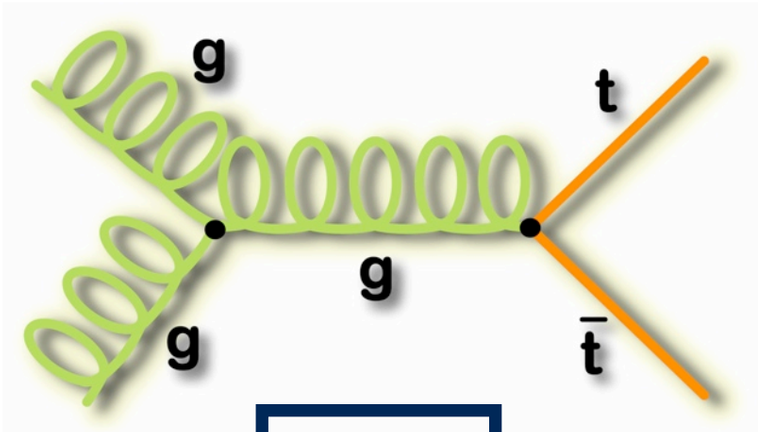
$t\bar{t}$ Cross Section

- **Testing perturbative QCD at high energy**
- **New production mechanisms may appear as an enhancement (or deficit) in the rate of production**

$$\sigma_{tt}^{SM} = 7.5 \text{ pb}$$

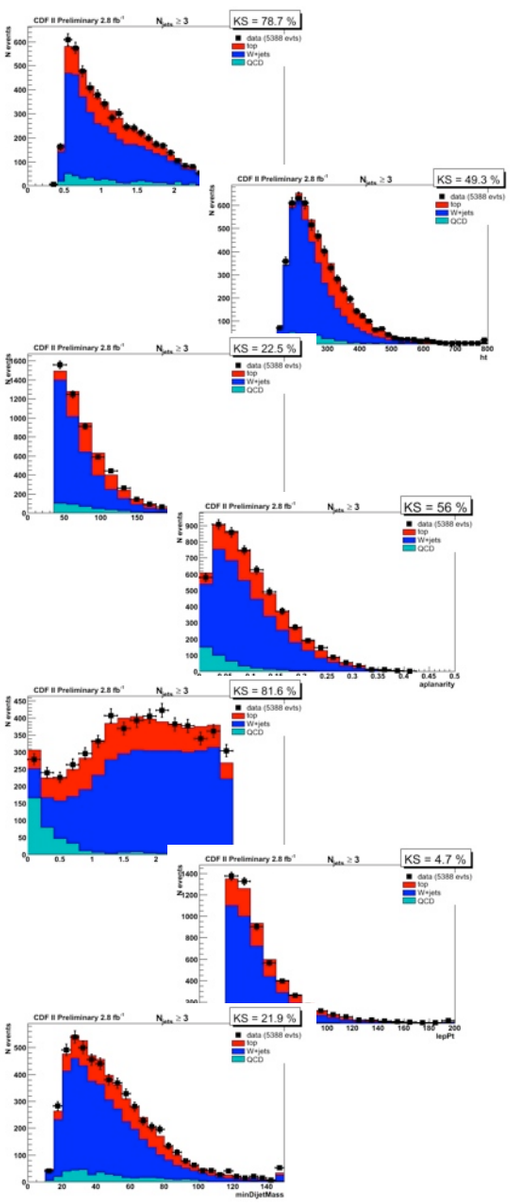


85 %

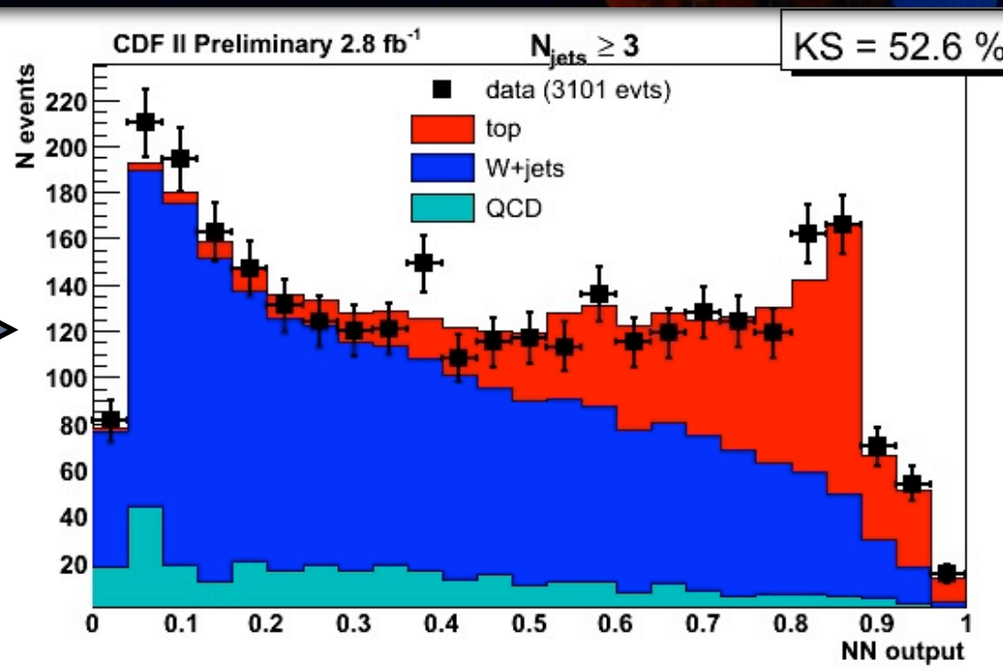


15 %

$t\bar{t}$ Cross Section

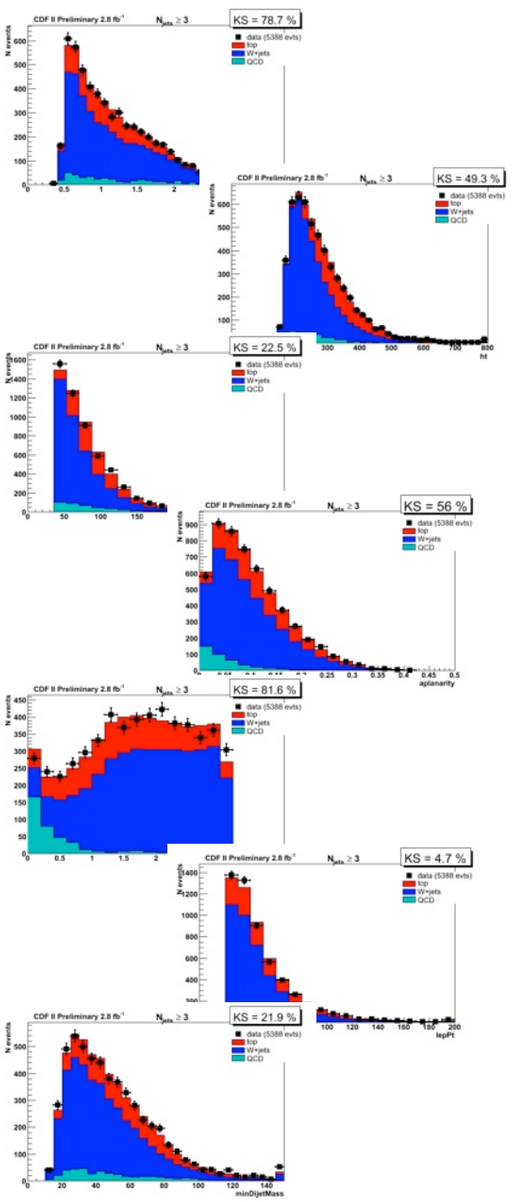


Neural Network

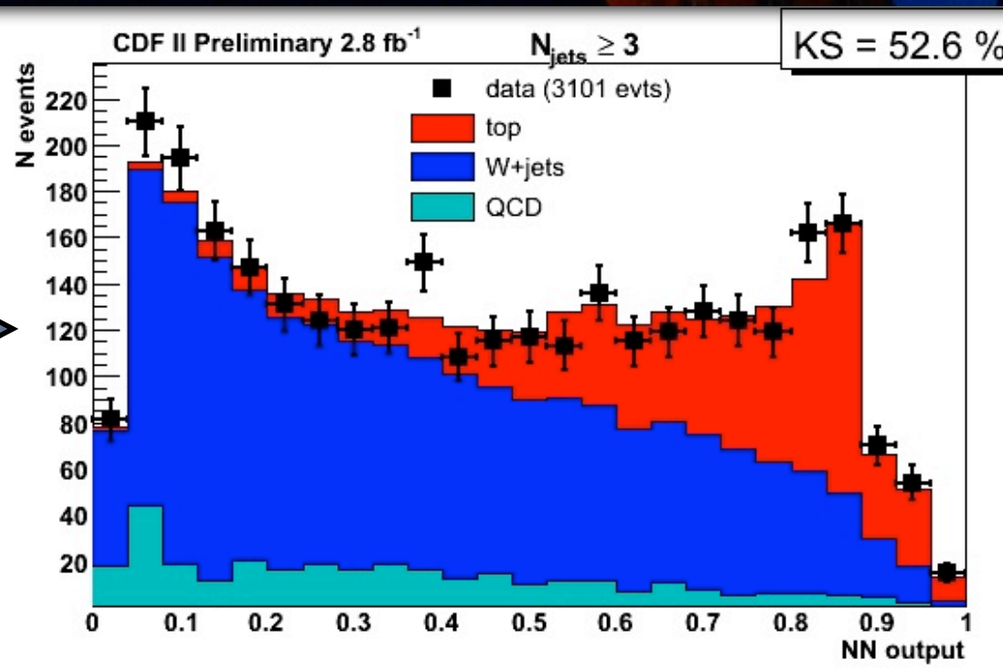


- **Identify top events through kinematics using a Neural Net, trained to distinguish signal from background**
- **Fit signal/background templates to data**
- **Measured relative to Z cross section to reduce uncertainty from measured luminosity**

$t\bar{t}$ Cross Section



Neural Network



$\sigma_{tt} = 7.82 \pm 0.54_{stat+sys}$ pb

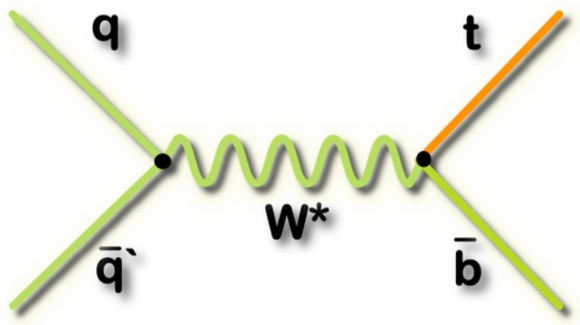
@ $M_t = 172.5$ GeV/c^2

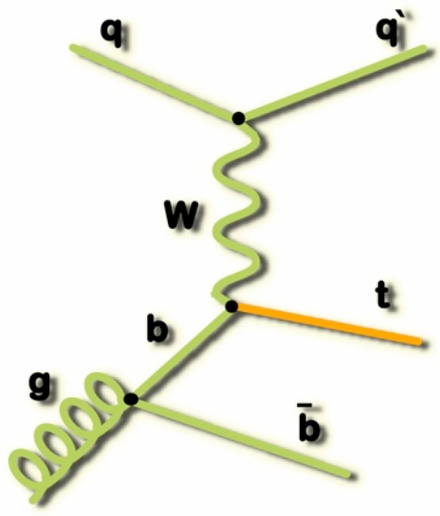
4.6 fb^{-1}

$$\frac{\Delta\sigma}{\sigma} = 7\,\%$$

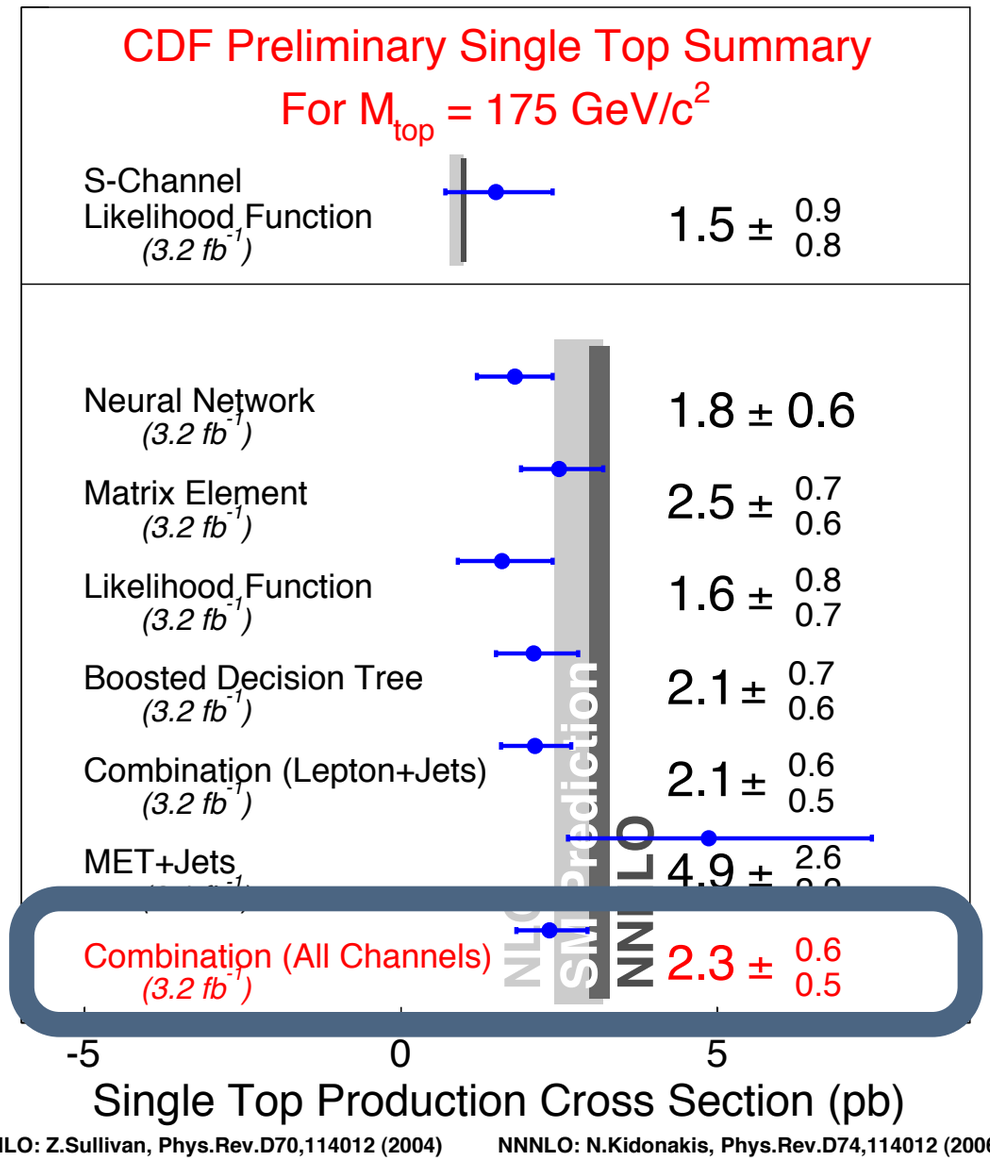
$\sigma_{tt}^{SM} = 7.5$ pb

Electroweak Production





$\sigma_{s+t}^{SM} = 2.9$ pb



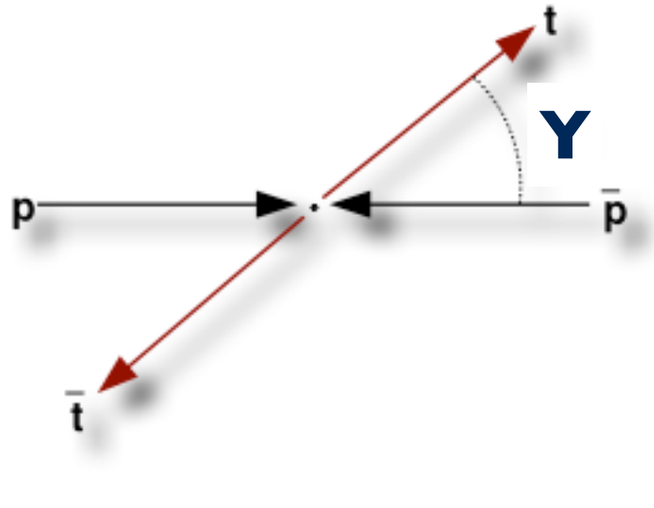
NLO: Z.Sullivan, Phys.Rev.D70,114012 (2004) NNNLO: N.Kidonakis, Phys.Rev.D74,114012 (2006)

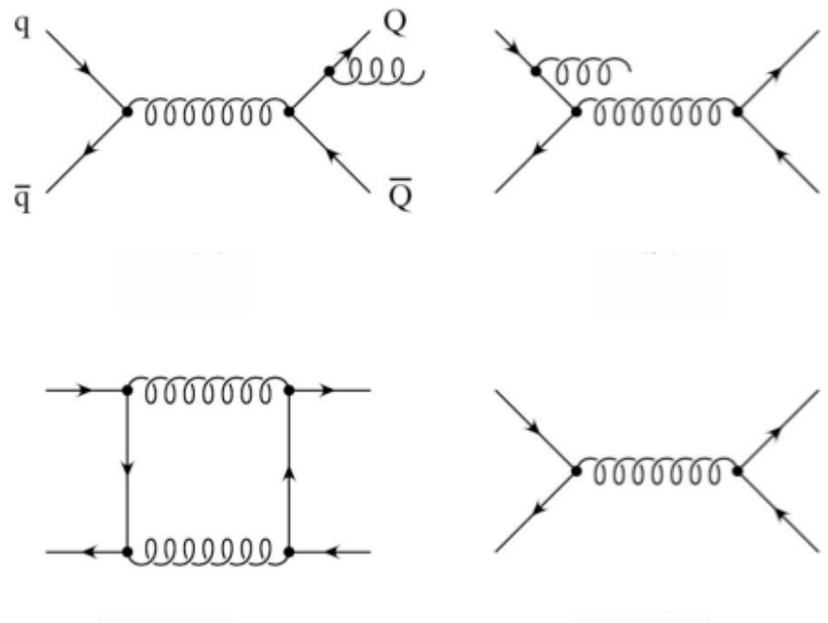
Forward Backward Asymmetry

- **Test of discrete symmetries of the strong interaction at high energy**
- **Tevatron is special: $p\bar{p}$ collider**
- **NLO QCD predicts small asymmetry from $q\bar{q}\rightarrow t\bar{t}$**

$$A_{FB} = \frac{N_{Y>0} - N_{Y<0}}{N_{Y>0} + N_{Y<0}} \approx 5\%$$

- **Ideally suited to discover new big gluons with axial vector coupling**

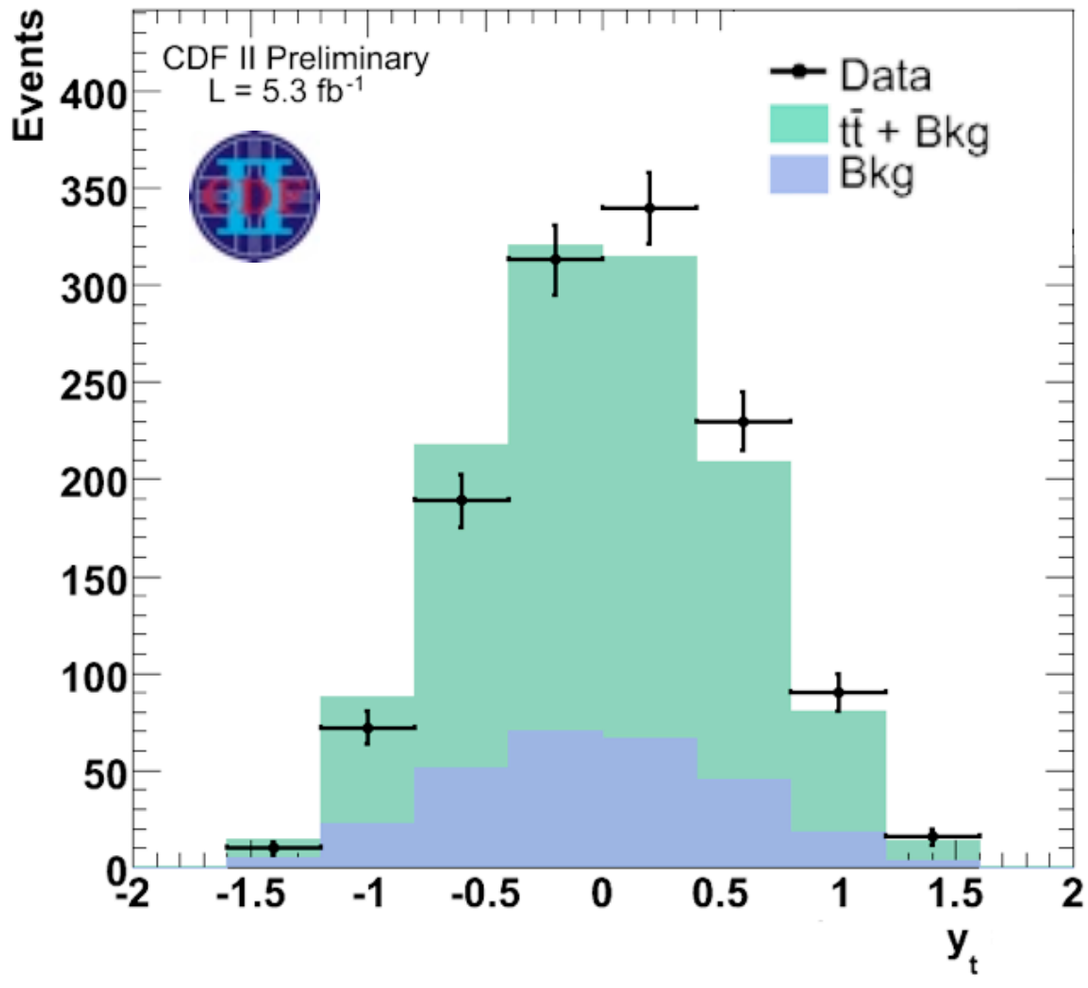




Top Quark A_{FB}

- **Reconstruct the top and anti-top direction from their decay products observed in the detector**

- **Correct for backgrounds, acceptance, and mis-reconstructed angles**



3σ

$A_{FB} = 15 \pm 5_{stat+sys}$ %

5.3 fb^{-1}

$A_{FB}^{SM} = 5.0 \pm 1.5$ %

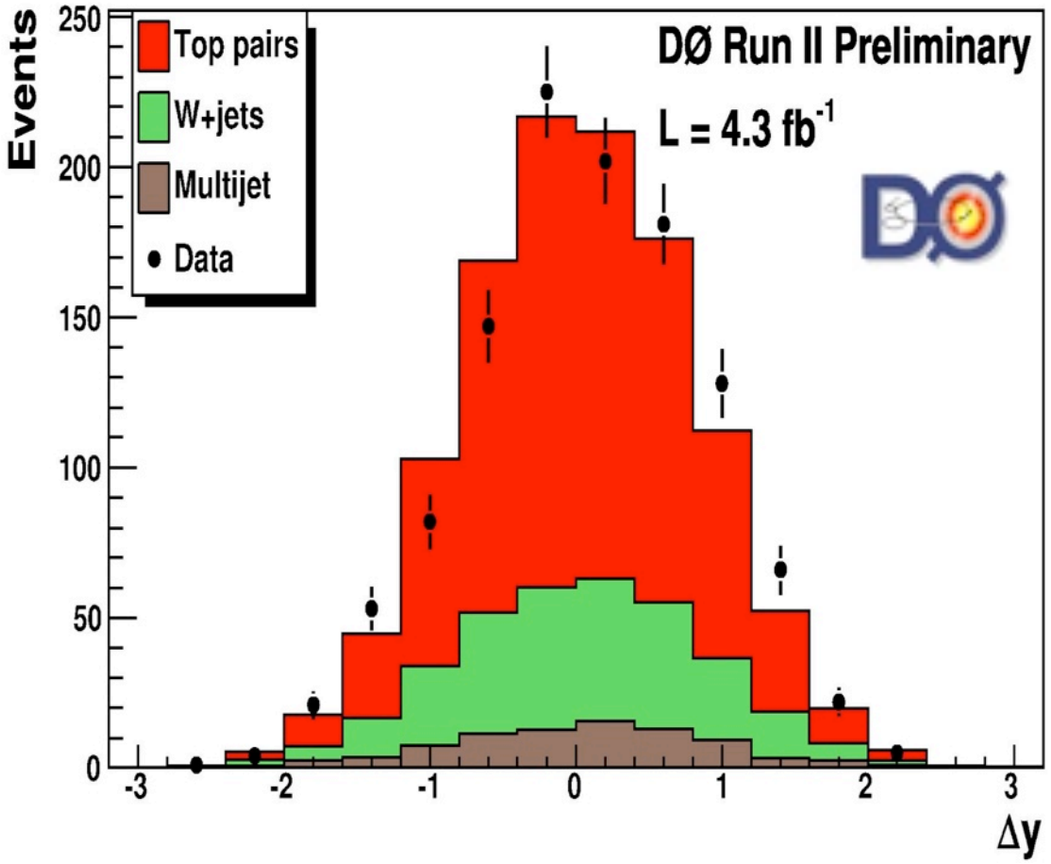
Top Quark A_{FB}

- **D0 corrects for backgrounds only and compares the result to the SM as seen by the detector**

$A_{FB}^{data-bkg} = 8 \pm 4_{stat+sys}$ %

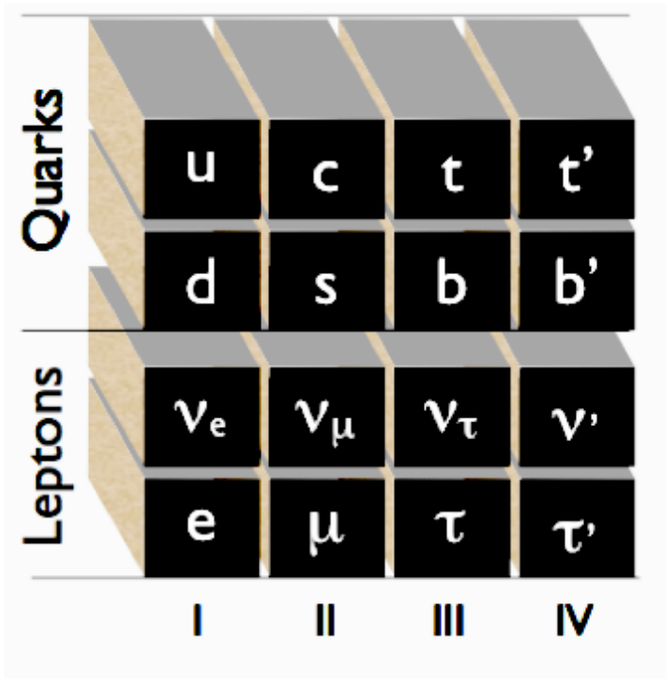
4.3 fb^{-1}

$A_{FB}^{mc@nlo} = 1^{+2.0}_{-1.0}$ %



Searching for a 4th Generation

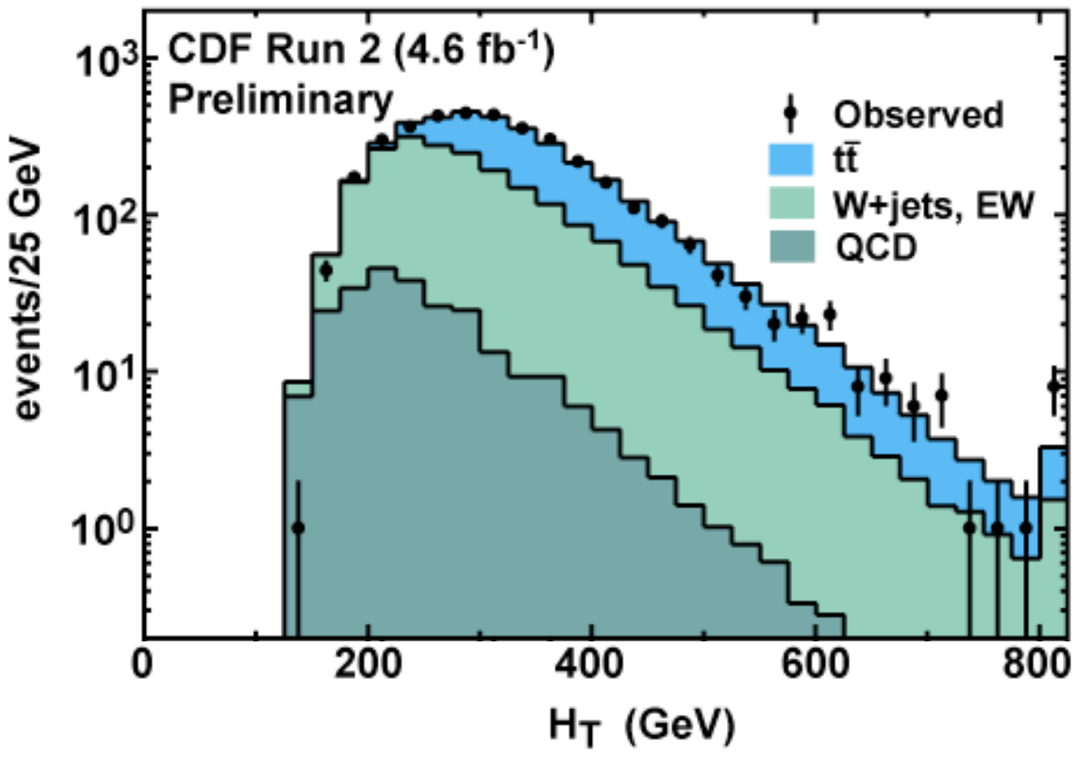
- **Why are there only 3 generations?**
- **No theoretical reason, only experiment**
  - ***Electroweak Constraints***
  - ***Flavor Physics Measurements***
  - ***Direct Searches***

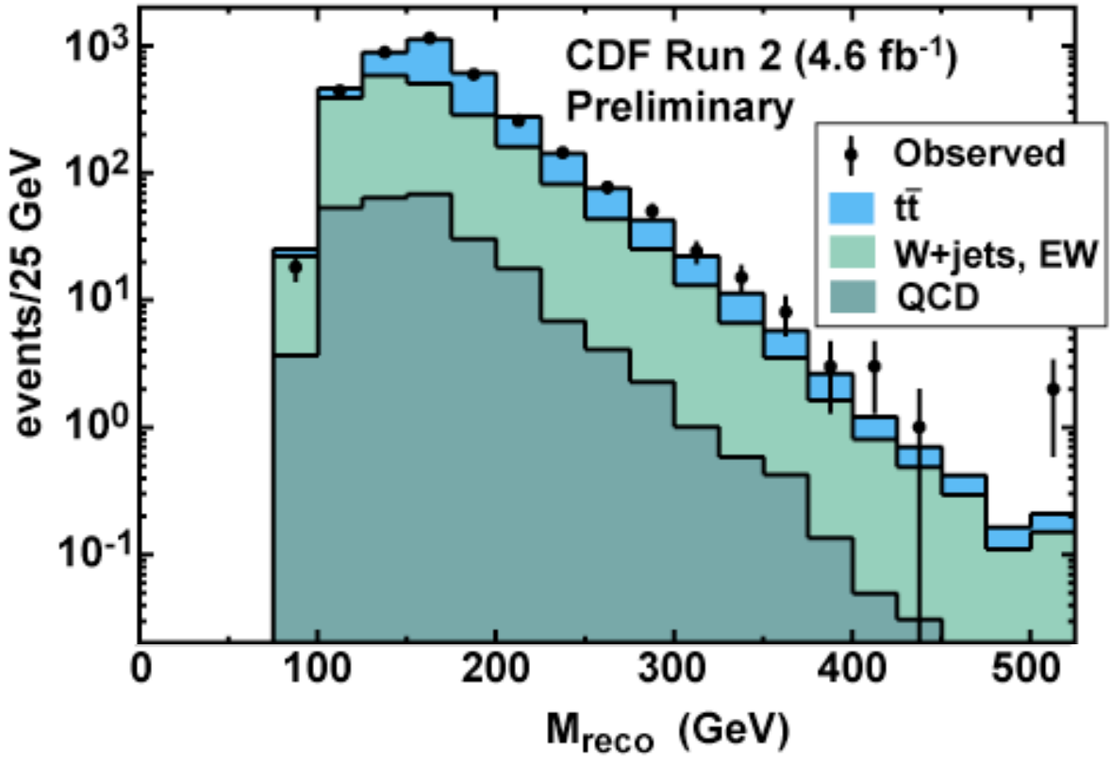


- **Tevatron explores phase space beyond these limits**

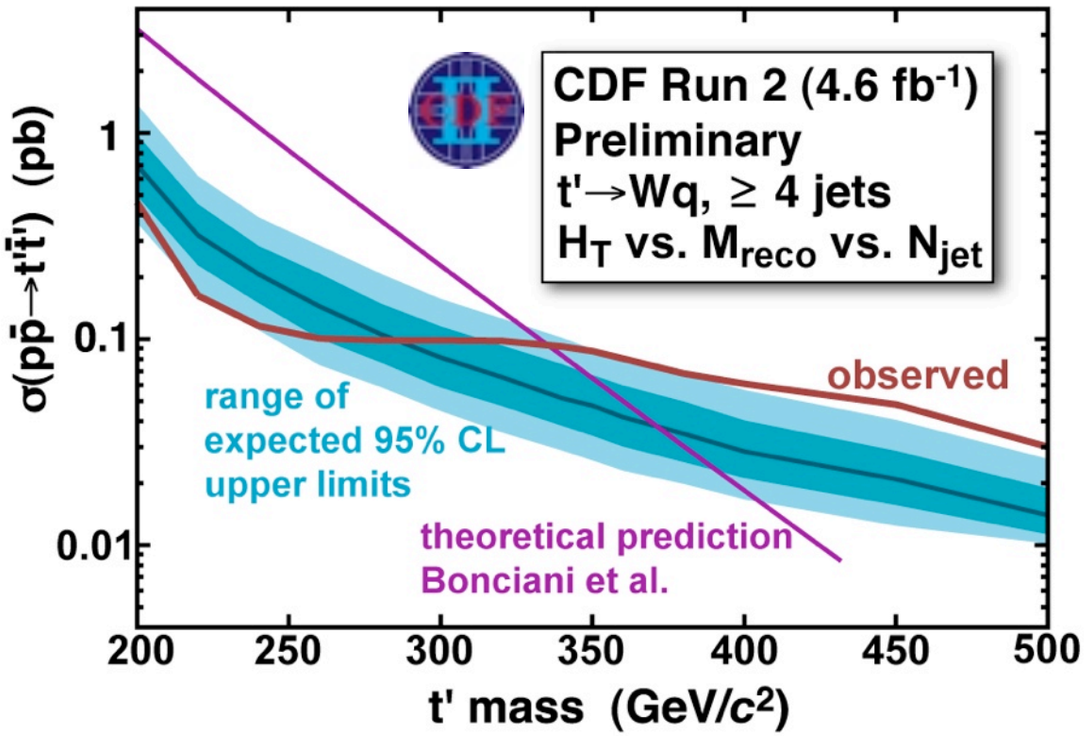
Searching for t´

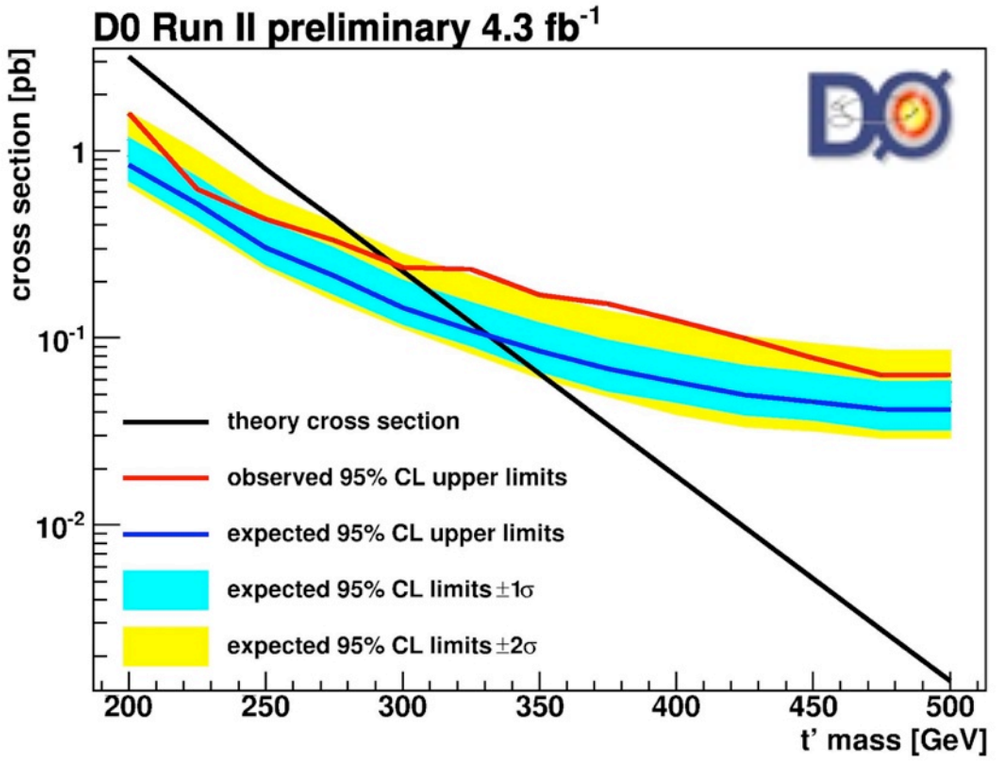
- **Experimentally we treat t´ as just a more massive top quark (t´ → Wq)**
- **Use reconstructed t´ mass and the scalar sum of the transverse energy in the event (H_T)**





Searching for t´





$M_{t´}$ < 335 GeV @ 95 % CL

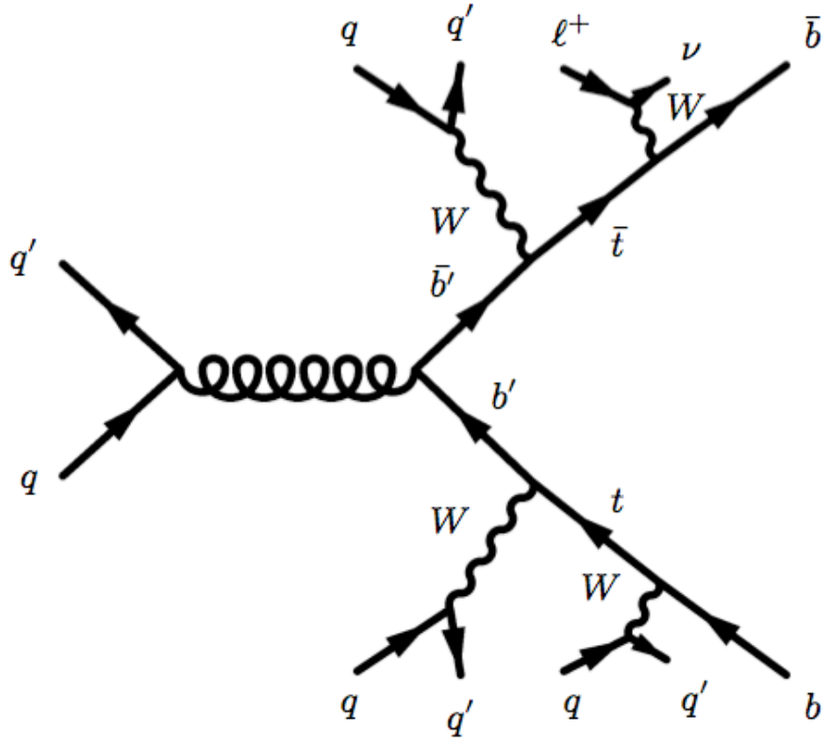
4.6 fb^{-1}

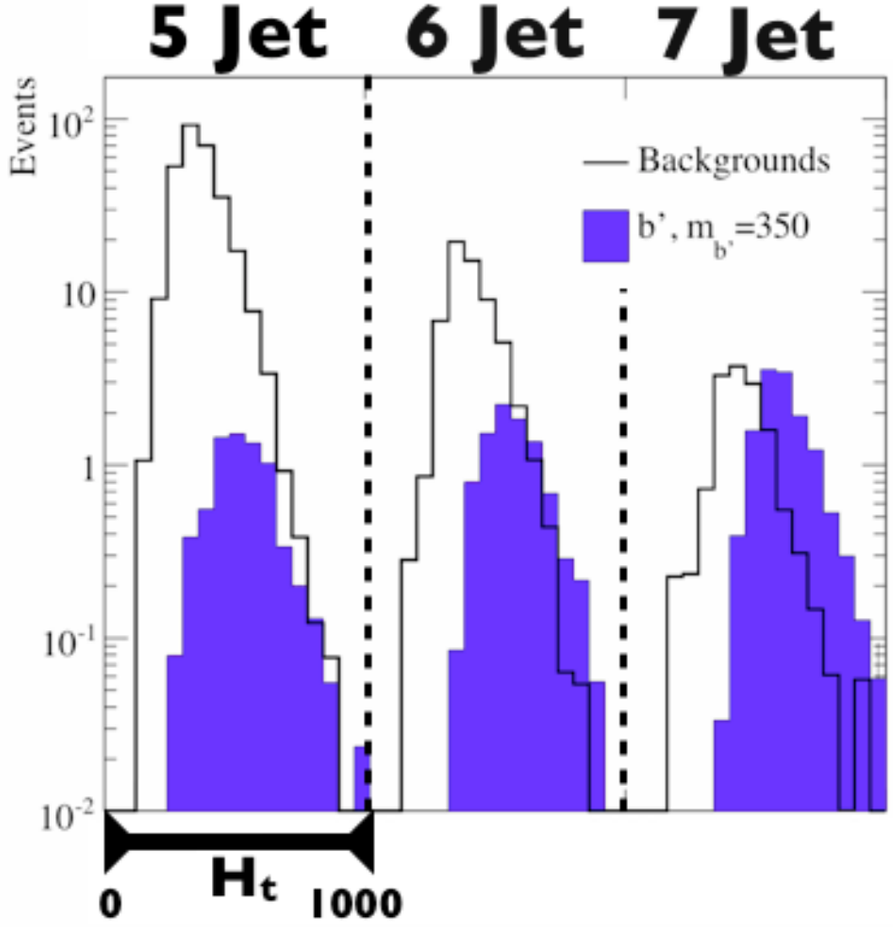
$M_{t´}$ < 296 GeV @ 95 % CL

4.3 fb^{-1}

Searching for b´

- **Similarly, we can search for b´ → tW**
- **Signature is very energetic, jetty events: search in high H_T, high jet multiplicity**
- **Largest background is $t\bar{t}$+jets**





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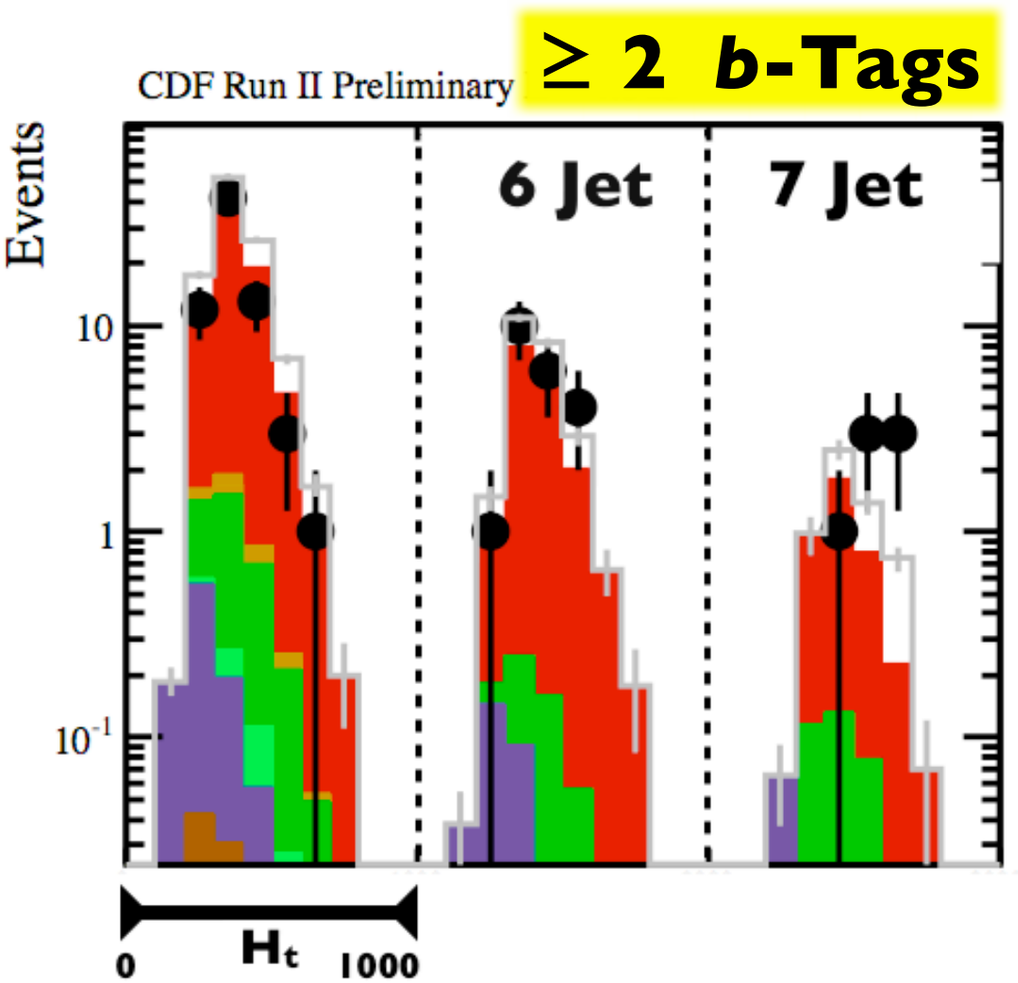
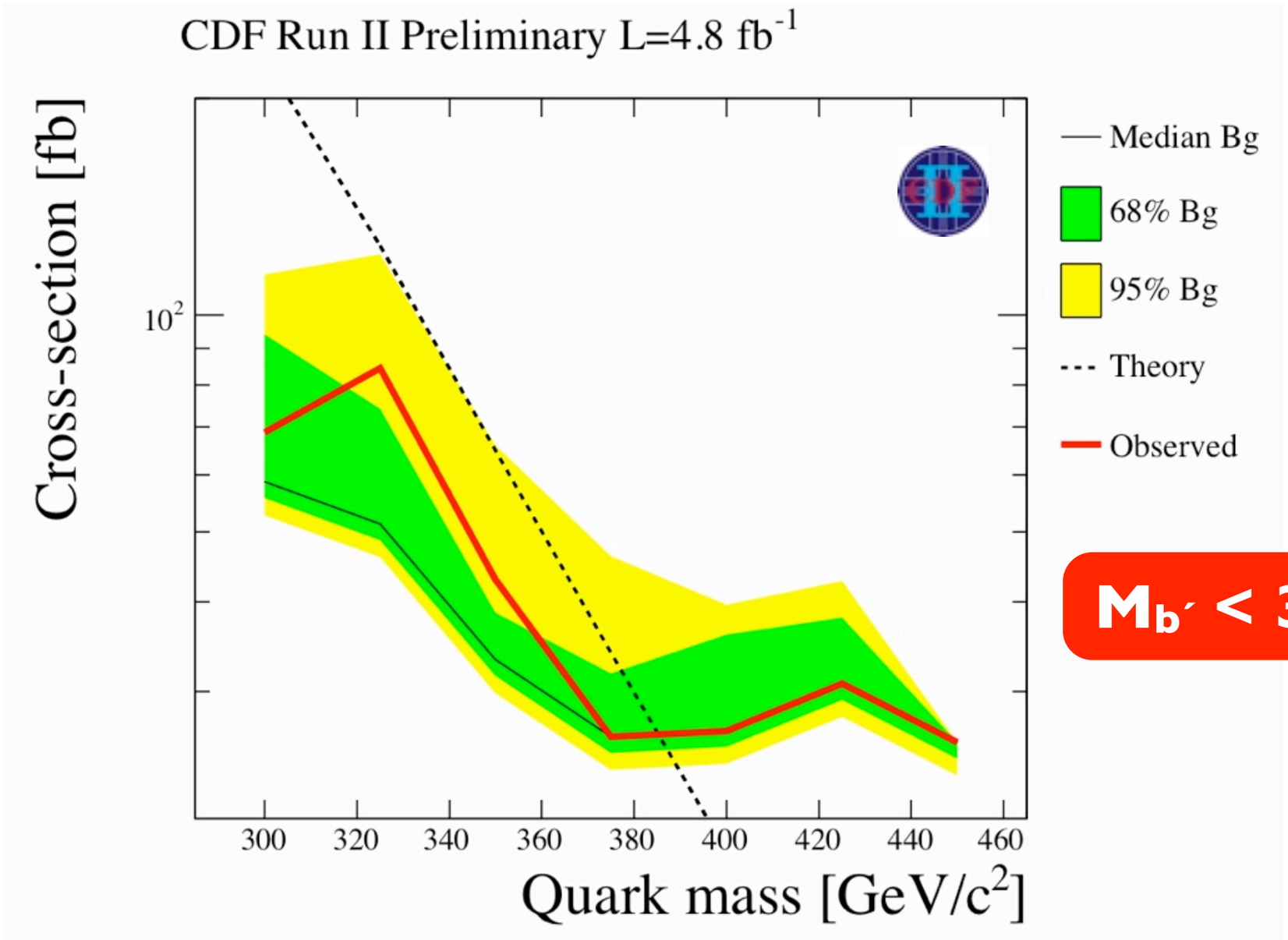


Searching for b´

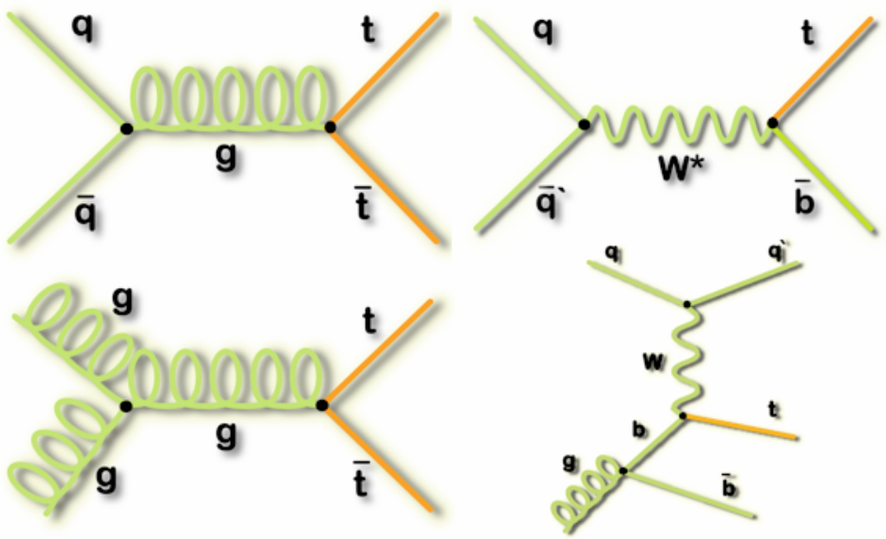


$M_{b´}$ < 385 GeV @ 95 % CL

~ 5 fb^{-1}

Top Physics at the Tevatron

How is Top Produced



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  $\sigma_{tt} \sim 7.5$ pb
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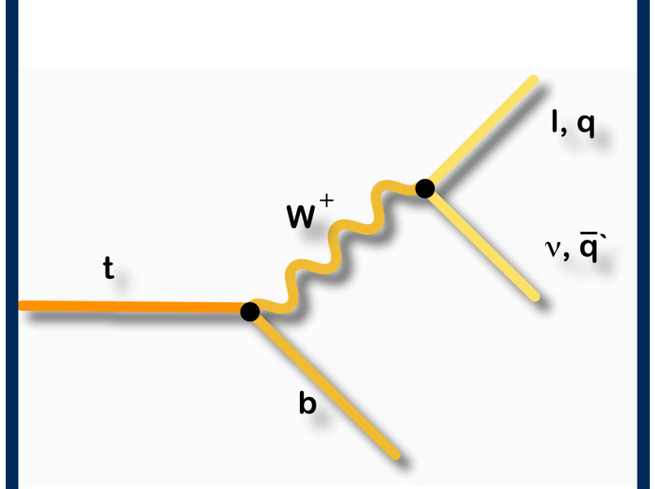
  $\sigma_{s+t} \sim 3$ pb

How Does Top Decay



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  $F_0 \sim 0.7$, $F_+ \sim 0$
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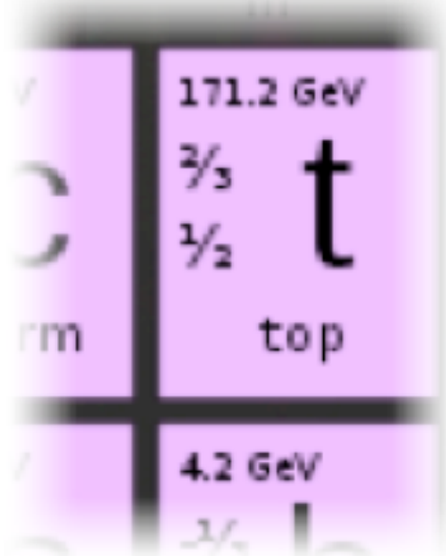
What are Top's Intrinsic Properties

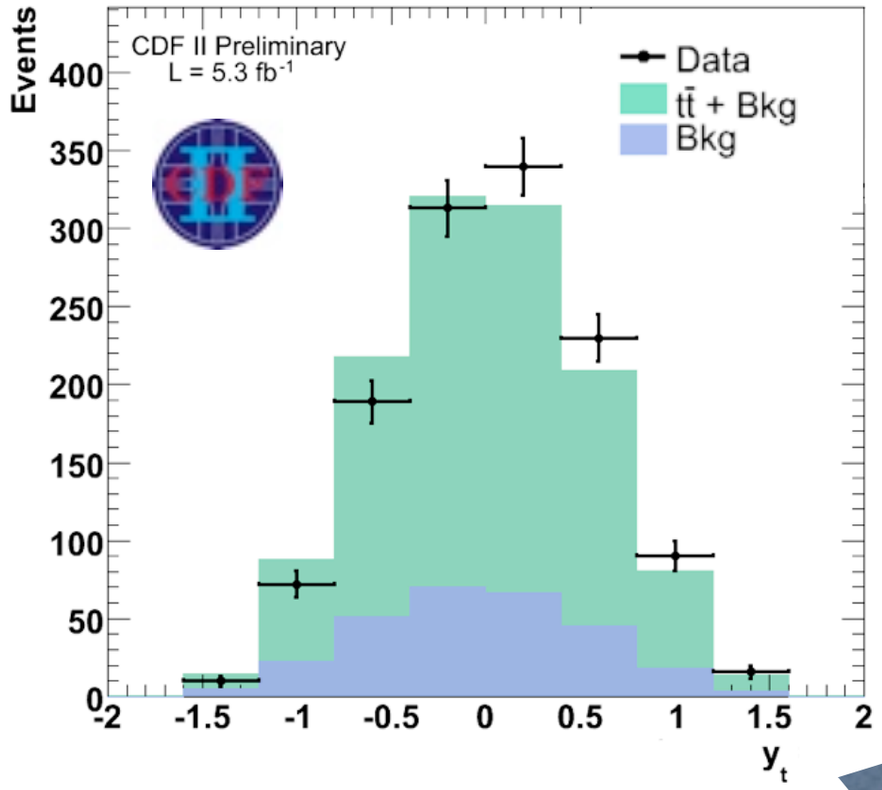


- **Mass**
- **Width** $\Gamma_t \sim 1.3$ GeV
- **Spin** 1/2
- **Charge** +2/3

Top Physics at the Tevatron

How is Top Produced	How Does Top Decay	What are Top's Intrinsic Properties
σ_{tt} = 7.50 δ ~ 6 %	F_0 = 0.88 δ ~ 10 %	M_t =173.3 δ ~ 0.6 %
σ_{s+t} = 2.8 δ ~ 19 %	F_+ = -0.15 δ ~ 10 %	Γ_t = 2.1 δ ~ 25 %
σ_t = 3.1 δ ~ 30 %	V_{tb} = 0.88 δ ~ 9 %	κ = 0.7 sig ~ 1 σ
		q ≠ -4/3 @ 95%CL
• Strong Force σ_{tt} ~ 7.5 pb • Electroweak σ_{s+t} ~ 3 pb	• V-A F_0 ~ 0.7 , F_+ ~ 0 • V_{TB} ~ 1	• Mass • Width Γ_t ~ 1.3 GeV • Spin 1/2 • Charge +2/3

Maybe a Surprise?



3σ

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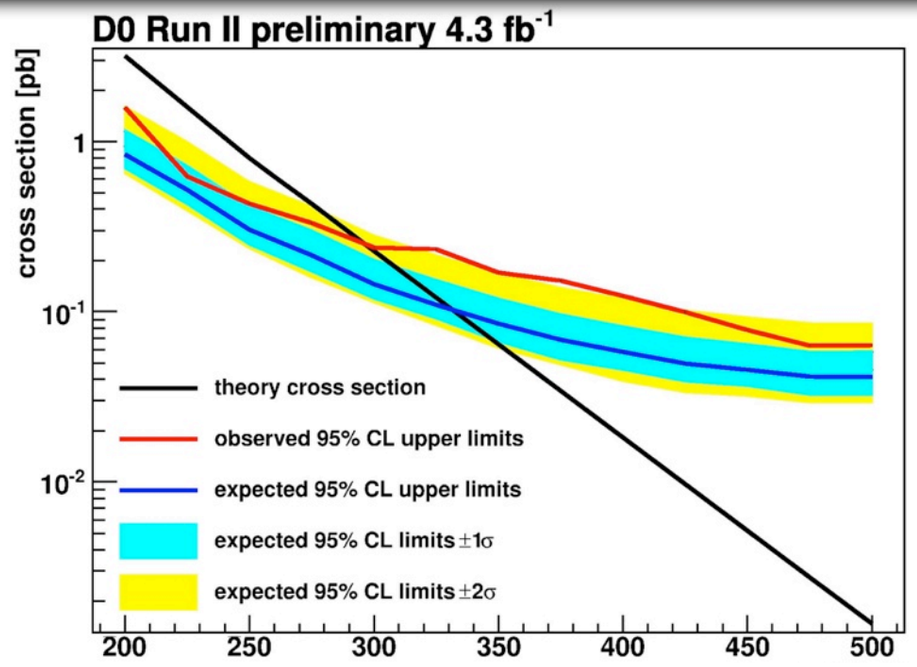
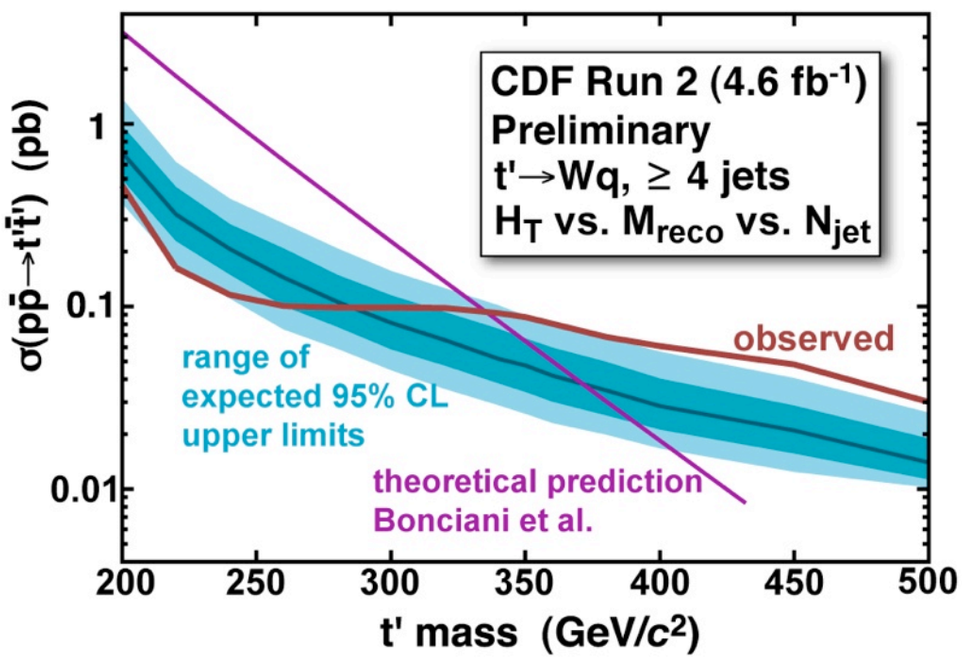
5.3 fb^{-1}

$A_{FB}^{SM} = 5.0 \pm 1.5$ %





Conclusion and the Future

- **Precision top physics a reality at the Tevatron**
  - 1000's of Top Events are now being used in analysis

- **Most measurements statistically limited and use a 3rd of the possible final Tevatron dataset (~ 12 fb^{-1})**

- **Working closely with our colleagues at D0 on combining results from several measurements -** ***Mass, Cross Section, W-helicity, Spin Correlations, t´***

- **Searches are now a very active part of our program (~30% of new results). If something is there, we intend to find it!**

Backup

Spin Correlations

- **Top decays before hadronization - spin information passed to decay products**

- **SM predicts top pairs produced mostly in opposite-spin states at the Tevatron**

$$\kappa = \frac{\mathbf{N}_{\downarrow\uparrow} + \mathbf{N}_{\uparrow\downarrow} - \mathbf{N}_{\uparrow\uparrow} - \mathbf{N}_{\downarrow\downarrow}}{\mathbf{N}_{\downarrow\uparrow} + \mathbf{N}_{\uparrow\downarrow} + \mathbf{N}_{\uparrow\uparrow} + \mathbf{N}_{\downarrow\downarrow}} \approx \mathbf{0.78}$$

- **Several effects probed: spin, width, qq/gg production**

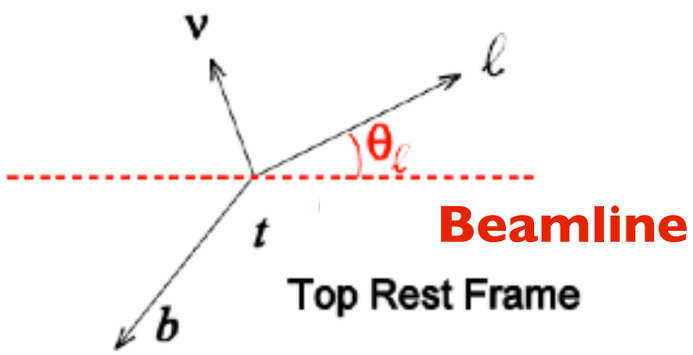
Spin Correlations

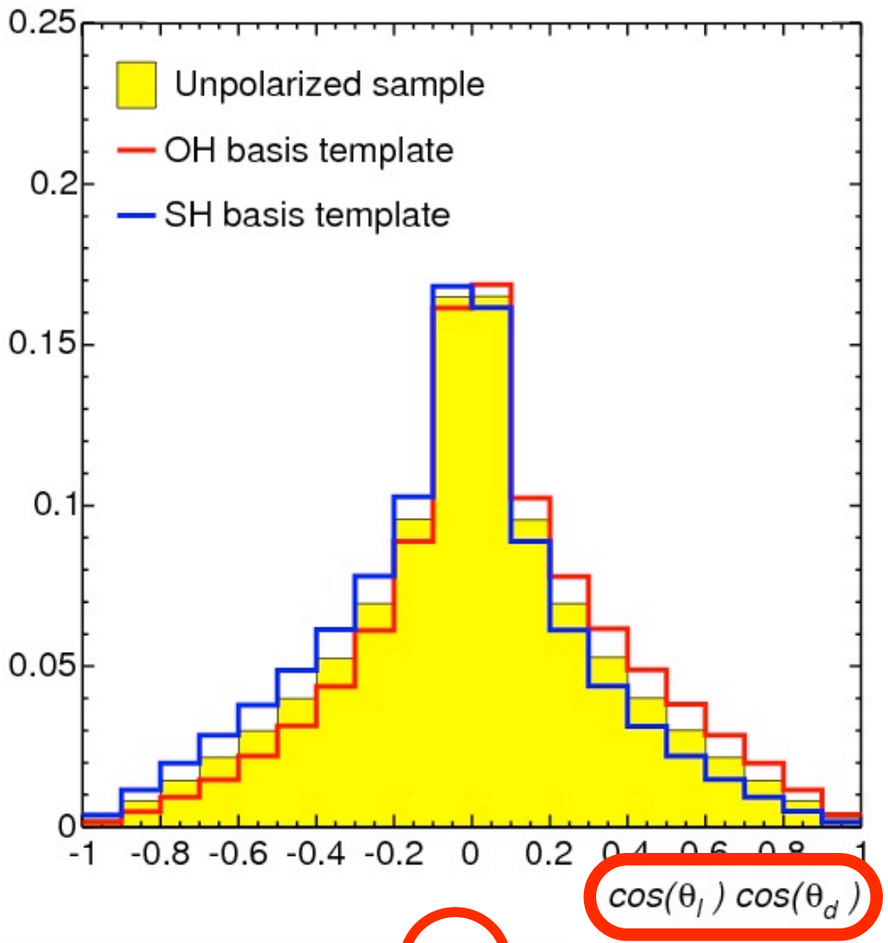
$$\kappa = \frac{\mathbf{N_{\downarrow\uparrow} + N_{\uparrow\downarrow} - N_{\uparrow\uparrow} - N_{\downarrow\downarrow}}}{\mathbf{N_{\downarrow\uparrow} + N_{\uparrow\downarrow} + N_{\uparrow\uparrow} + N_{\downarrow\downarrow}}}$$

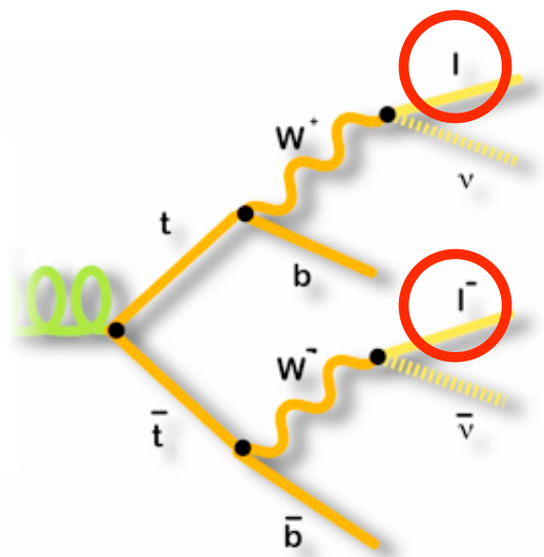
- **κ related to decay products angle through:**

$$\frac{1}{\sigma}\frac{\mathbf{d^2\sigma}}{\mathbf{dcos\theta^+ dcos\theta^-}} = \frac{\mathbf{1 + \kappa\, cos\theta^+ cos\theta^-}}{\mathbf{4}}$$

- **where**







Dileptons

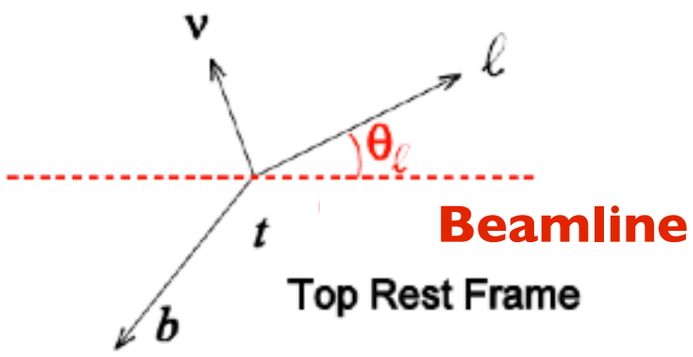
Spin Correlations

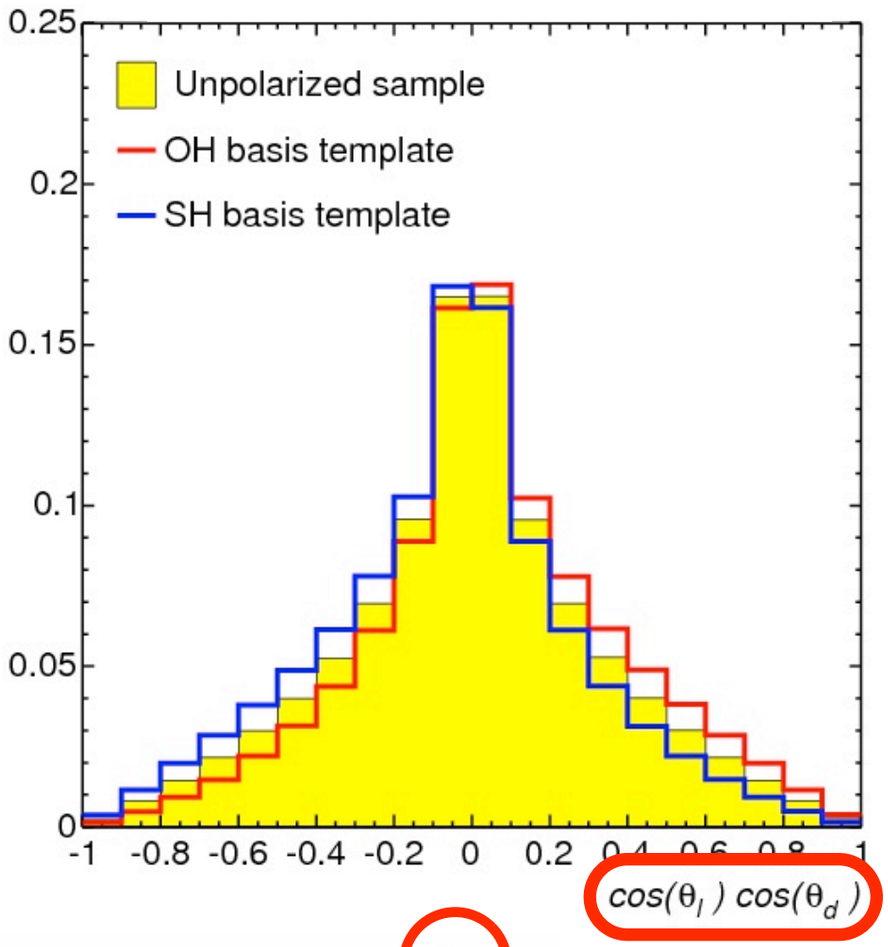
$$\kappa = \frac{\mathbf{N_{\downarrow\uparrow} + N_{\uparrow\downarrow} - N_{\uparrow\uparrow} - N_{\downarrow\downarrow}}}{\mathbf{N_{\downarrow\uparrow} + N_{\uparrow\downarrow} + N_{\uparrow\uparrow} + N_{\downarrow\downarrow}}}$$

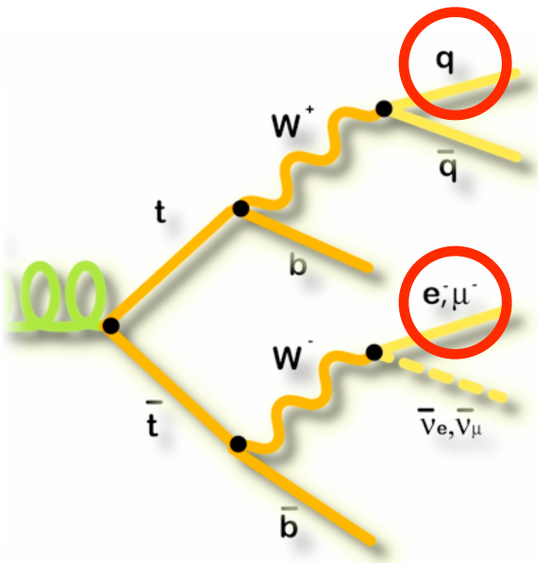
- **κ related to decay products angle through:**

$$\frac{1}{\sigma}\frac{\mathbf{d^2\sigma}}{\mathbf{dcos\theta^+ dcos\theta^-}} = \frac{\mathbf{1 + \kappa\, cos\theta^+ cos\theta^-}}{\mathbf{4}}$$

- **where**







Lep+Jets

Spin Correlations

$K^{sm} = 0.78$

Lepton+Jets Channel

$\kappa = 0.7 \pm 0.6_{stat} \pm 0.3_{syst}$

5 fb^{-1}

Di-lepton Channel

$\kappa = 0.3^{+0.6}_{-0.8}$

3 fb^{-1}