Top Quark Properties

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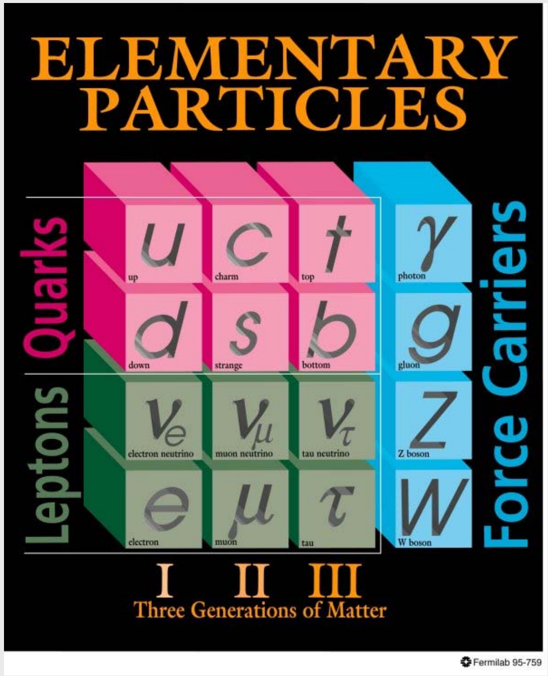
Outline

- Introduction
- Exploring top properties
  - Top quark mass
  - Other top properties with ttbar sample
    - Forward backward asymmetry
    - Differential cross section
    - W helicity
  - Search for beyond the Standard Model (SM) physics
    - Search for ttbar resonance, massive gluon, FCNC, stop, t′, H^+, W′, Wtb anomalous couplings
- Summary and prospects

Top Quark Physics

- Existence required by the SM
  - Spin 1/2 fermion,   charge +2/3
  - Weak-isospin partner of the bottom quark
- Discovered ~12 years ago at Tevatron
- Mass surprisingly large ⇒ ~40x heavier than the bottom quark
  - Only SM fermion with mass at the EW scale



As Top-quark is heavy:

- **Top decays before hadronization:** Γ~1.4 GeV >>Λ_{QCD}
  - **Provide a unique opportunity to study a "bare" quark**
- Currently only produced at Tevatron ⇒ somewhat “rare”

Why Study Top Properties?

Try to address some of the questions:

- Why is top so heavy ? Is top related to the EWSB mechanism? (PRD 59, 075003 (1999); PRD 65, 055006 (2002))
- Is it the SM top?
- Search for beyond SM physics:
  - Does top decay into new particles? couple via new interactions?

Pair production

- *Cross section (F. Déliot's talk)*
- *Production mechanism*
- **Differential cross section**
- **Searchs: ttbar resonance, FCNC, scalar top, t′**

Characteristics

- **Mass**
- *Charge*
- *Life-time, Spin, ...*

DECAY

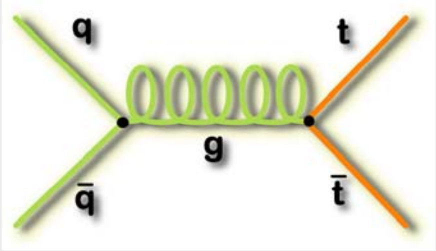
- **W helicity**
- **Charged Higgs**
- *Anomalous couplings*

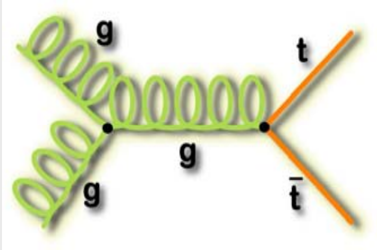
EW-single top

- *Cross section (F. Déliot's talk)*
- **W′ search**
- **Anomalous Wtb coupling**

Producing Top Quarks

- At hadron colliders
  - Predominantly pair produced via strong interaction
  - Electro-weak single top production





Tevatron	~85%	~15%
LHC	~13%	~87%

Tevatron Run II

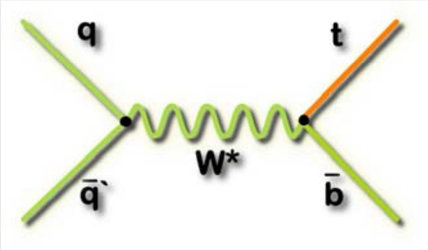
Proton-antiproton collider (2001-20xx)

$\sqrt{s}$ = 1.96 TeV

σ_{tt} = ~7.6 pb at m_{top}=171 GeV/c^2

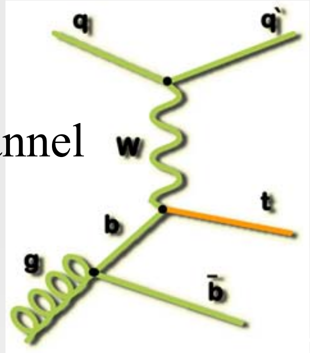
$\sigma_{single\ top}$ = ~2.9 pb at m_{top} = 175 GeV/c^2

Experiments: CDF, D0



s channel

t channel



Large Hadron Collider (LHC)

Proton-proton collider (2008-20xx)

$\sqrt{s}$ = 14 TeV

σ_{tt} = ~908 pb at m_{top} = 171 GeV/c^2

$\sigma_{single\ top}$ = ~315 pb at m_{top} = 175 GeV/c^2

Experiments: ATLAS, CMS

Tevatron: $\sigma_{s\text{-}channel}$=0.9 pb, $\sigma_{t\text{-}channel}$=2.0 pb

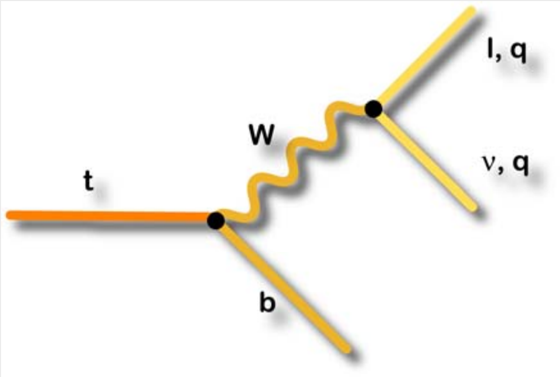
LHC: $\sigma_{s\text{-}channel}$=10.6 pb, $\sigma_{t\text{-}channel}$=247 pb, $\sigma_{associatedW}$=62 pb

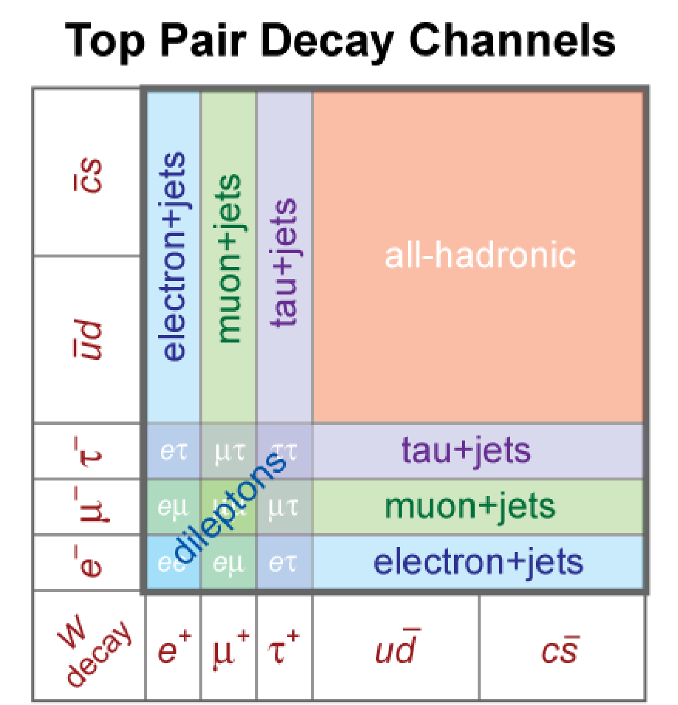
Top Decay

- In the SM: Br($t \rightarrow Wb$) ~ 100%

Top pair decay channels classified by W decays

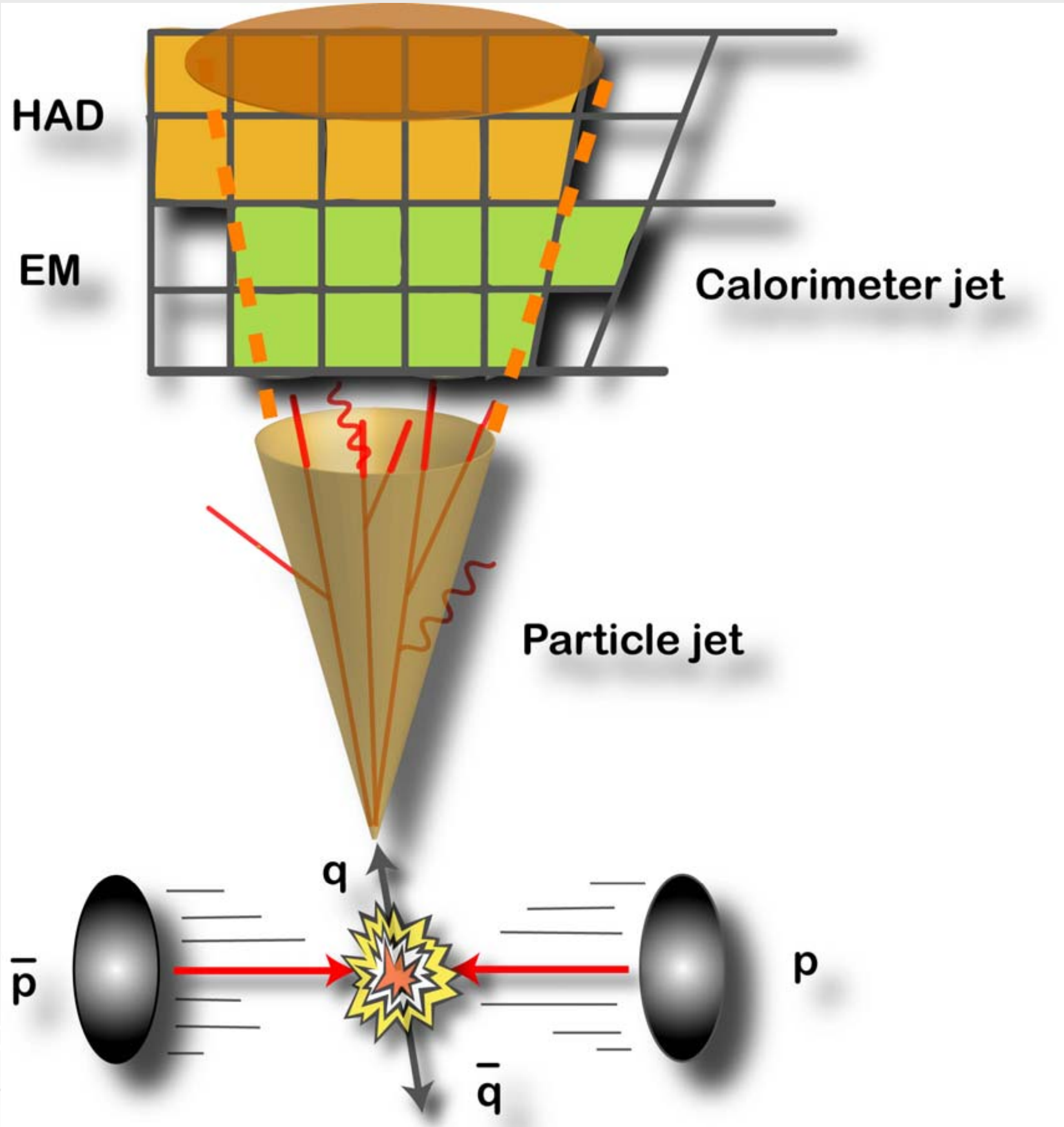
- **Dilepton:** $l\nu l\nu bb$
  - Experimental signature: 2 high-P_T e's or μ's, 2 high-E_T jets, large missing E_T *(for l = e, μ or τ decaying leptonically)*
  - Low background
- **Lepton+jets:** $l\nu qqbb$
  - Experimental signature: 1 high-P_T e or μ, 4 jets (2 b's), large missing E_T *(for l = e, μ or τ decaying leptonically)*
  - Medium background
- **All-hadronic:** $qqqqbb$
  - Experimental signature: 6 jets (2 b's)
  - Large background



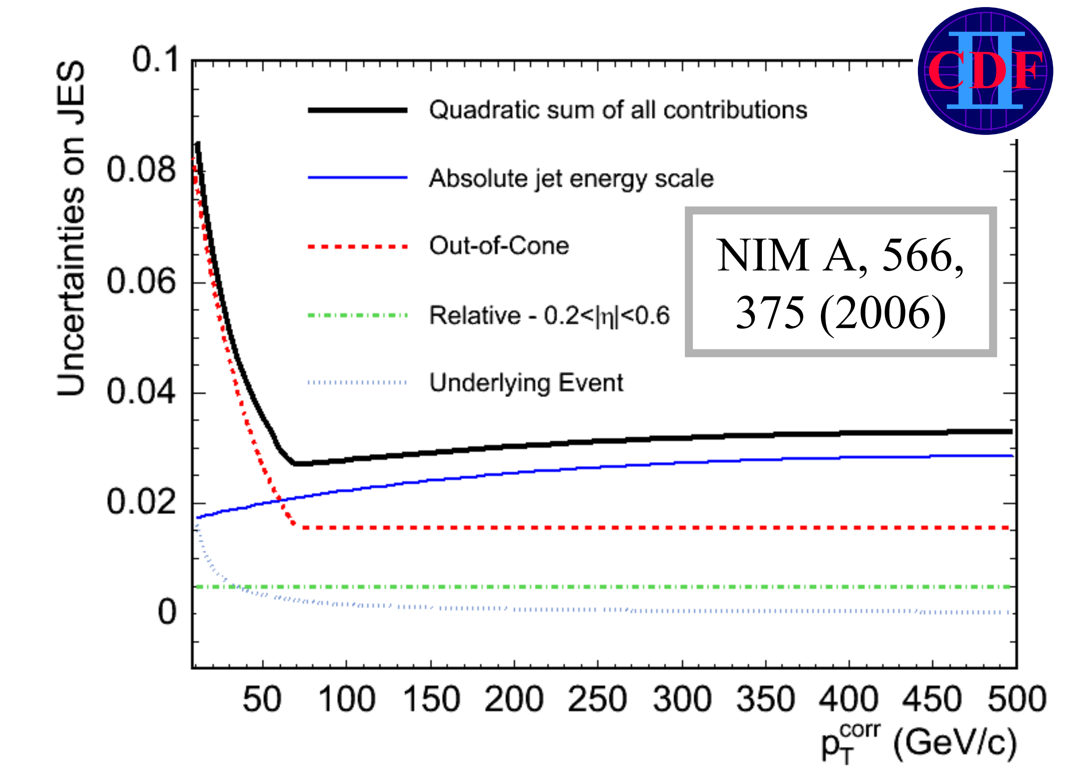


Jet Energy Scale

- **Jet energy scale (JES)**
  - Determine the energy of the quarks produced in the hard scattered
  - We use the Monte Carlo and data to derive the jet energy scale
- **Jet energy scale uncertainties**
  - Differences between data and Monte Carlo from all these effects



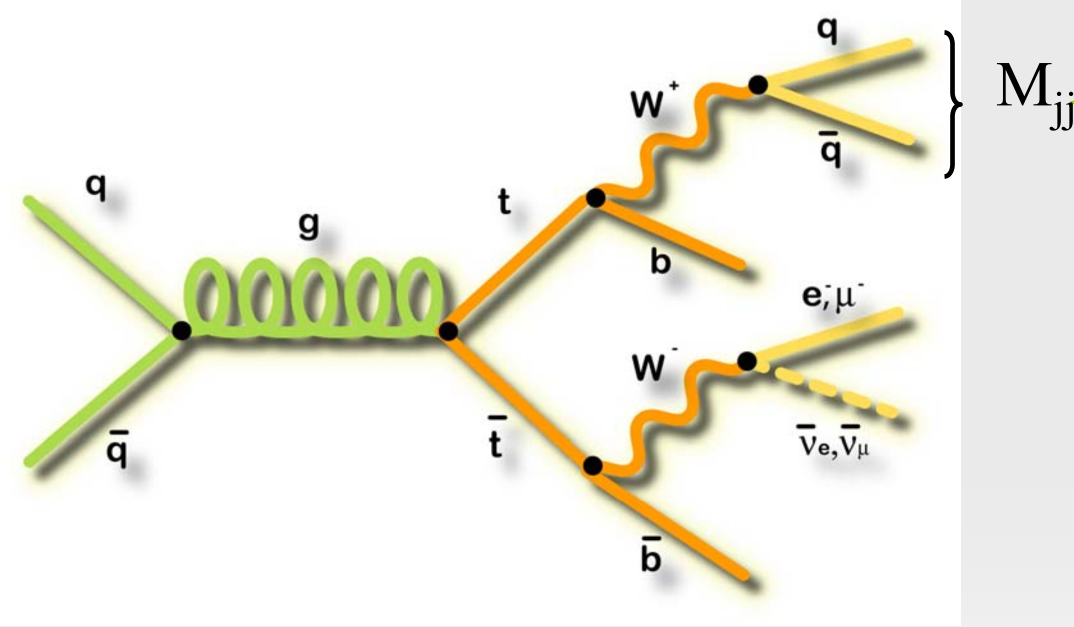
Jet Energy Scale Uncertainties



• Uncertainty on JES ⇒ About 3% systematic uncertainty on Top mass measurement when convoluted with ttbar p_T spectrum

In-situ Measurement of JES

- Additionally, we use W→jj mass resonance (M_{jj}) to measure the jet energy scale (JES) uncertainty



Constrain the invariant mass of the non-b-tagged jets to be 80.4 GeV/c^2

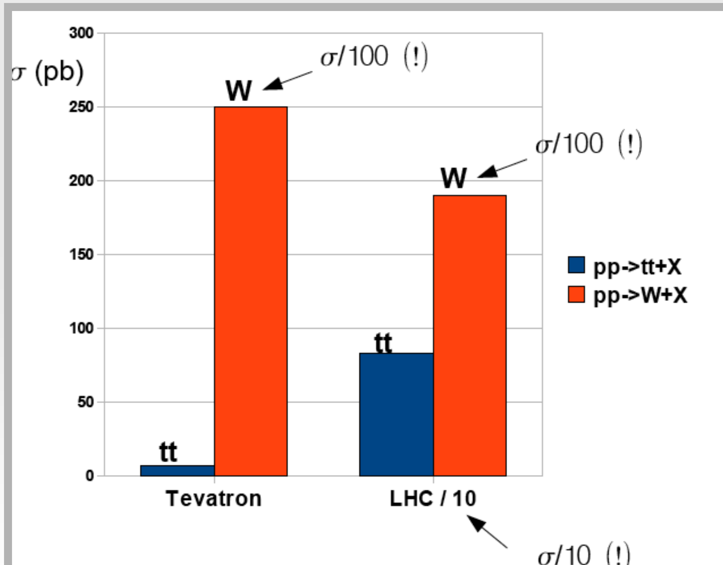
Measurement of JES scales directly with statistics!

Signal-to-Background Ratio (S/B)

- b-jet identification provides significant background suppression
- Dilepton channel: Manageable S/B even without b-tagging
- Lepton+Jets channel: Good S/B after b-tagging
  - Remaining dominant background from W+jets
- All-hadronic channel suffers from huge QCD background
  - S/B ~1/1000 at trigger level
  - Needs additional effort for background suppression
    - Neural network (NN) based event selection has been used

S/B at Tevatron	Dilepton	Lepton+Jets	All-hadronic (After NN Selection)
0 b-tag	1:1	~1:4	~1:20
1 b-tag	20:1	4:1	1:5
2 b-tags		20:1	1:2

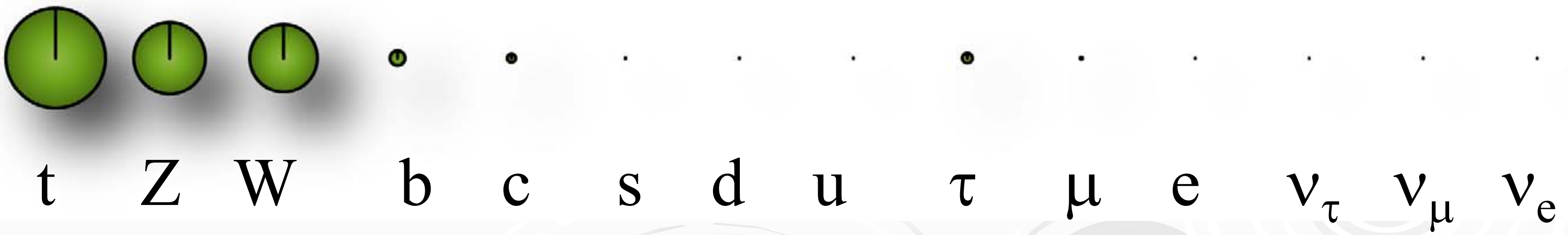
Most top properties analyses use relatively clean event sample



Tevatron VS LHC

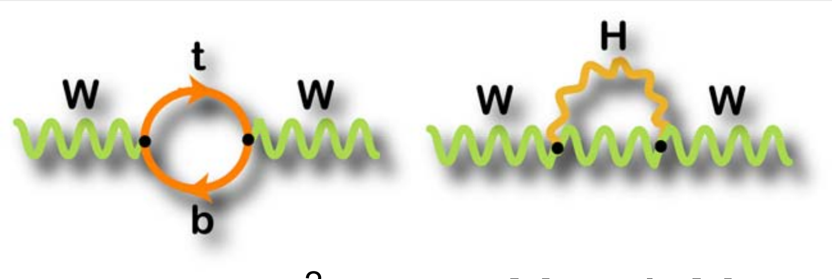
Top Mass

Particle Masses



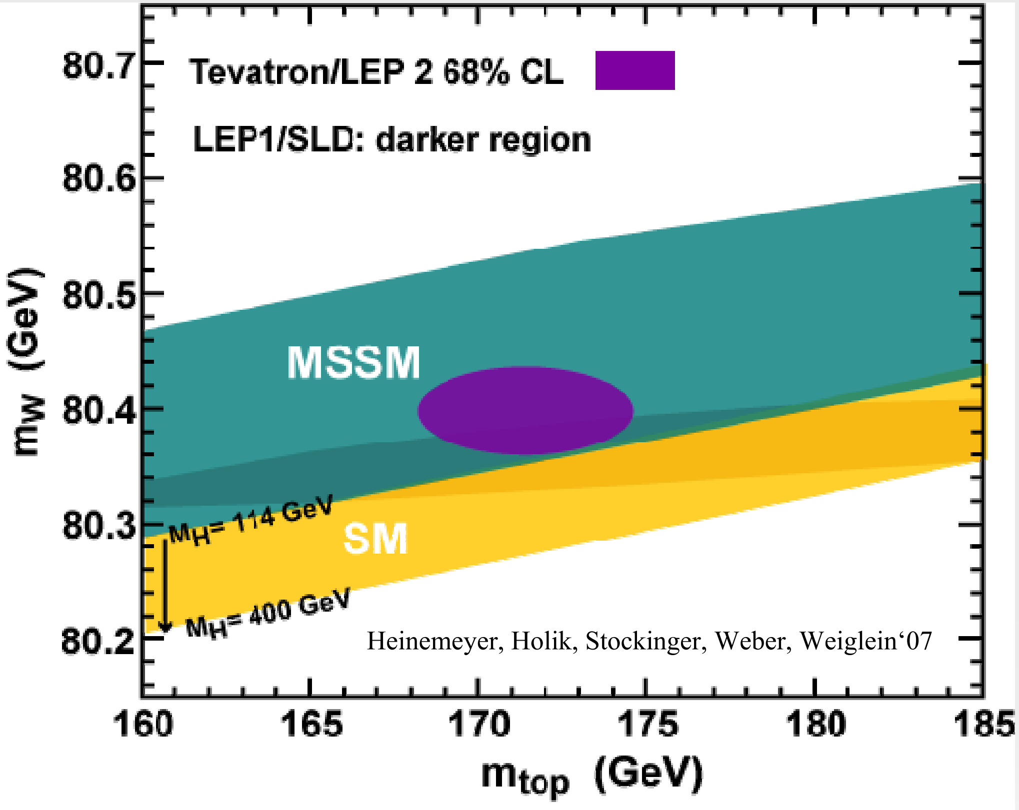
Why measure the Top Quark Mass?

- Related to standard model observables and parameters through **loop diagrams**
- Consistency checks of SM parameters



$\Delta M_W \propto M_{top}^2$ $\Delta M_W \propto \ln M_H$

- Precision measurements of the M_{top} (and M_W) allow prediction of the M_{Higgs}
- Constraint on Higgs mass can point to physics beyond the standard model



Top Mass at Tevatron

- Robust program of top quark mass measurements
- Many measurements in all the different channels → **consistency**
- Different methods of extraction with different sensitivity → **confidence**
- Combine all channels and all methods → **precision**

Measurement Techniques

- Template Method
  - Select observables sensitive to top mass
  - Build templates from signal MC and background distributions in the chosen observable
  - Fit template to data

- Event-by-Event likelihood
  - For each event determine likelihood as a function of top mass
  - Multiply event probabilities to obtain joint likelihood $\Rightarrow$ extract the most likely value

- Common procedures:
  - Calibrate and validate the technique with data-size pseudo-experiments
    - Check and/or correct for biases
    - Check pull width, expected sensitivity …

Template Analysis: Dilepton and Lepton+Jets

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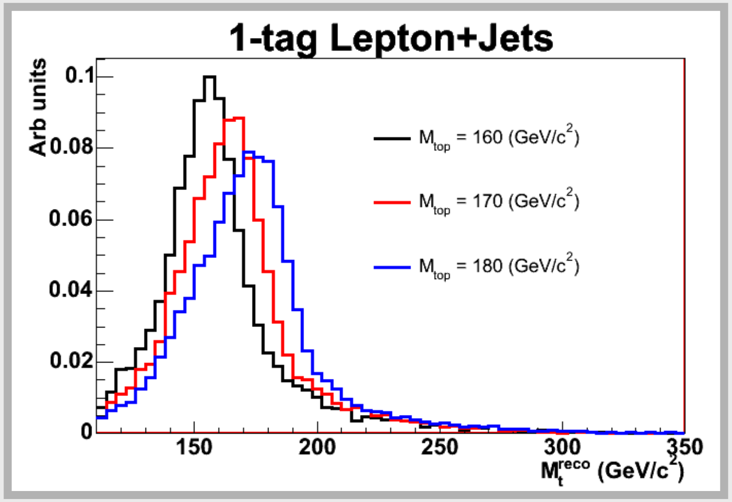
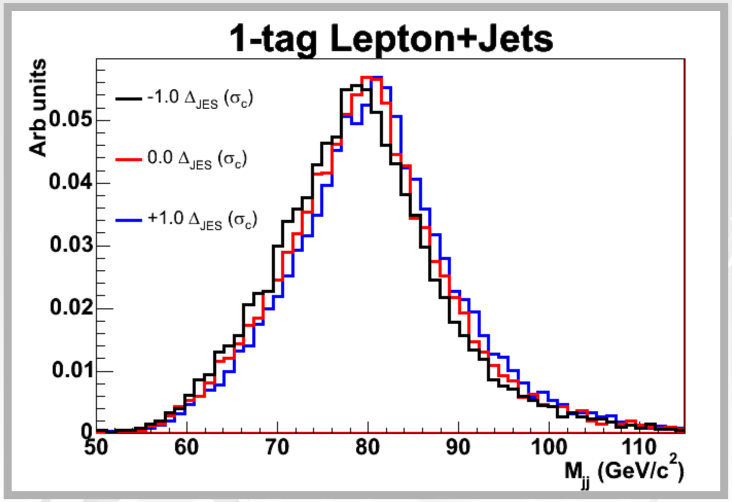
- Simultaneous measurement of top mass
  - Lepton+Jets:
    - Select events with ≥4 jets and ≥1 b-tag
    - 344 selected events
  - Dilepton:
    - Select events with ≥2 jets and ≥0 b-tag
    - 144 selected events
- 2D templates in each channel:
  - Reconstructed top mass
  - Lepton+Jets : ΔJES
  - Dilepton: $H_T = \Sigma(E_{T,jets}+E_{T,lep}+E_{T,missing})$
- The JES from the Lepton+Jets channel naturally applied to the Dilepton channel





Template Analysis: Top Mass Reconstruction in Lepton+Jets

- Minimize a χ^2 describing the over constrained kinematics of Lepton+Jets channel

Constraints on measured Lepton and Jet momenta

Constraints on un-clustered Energy

$$\chi^2 = \sum_{i=\ell,4\,jets} \frac{\left(p_T^{i,fit} - p_T^{i,meas}\right)^2}{\sigma_i^2} + \sum_{j=x,y} \frac{\left(U_j^{fit} - U_j^{meas}\right)^2}{\sigma_j^2}$$
$$+ \frac{\left(M_{jj} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(M_{\ell\nu} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(M_{bjj} - m_t^{reco}\right)^2}{\Gamma_t^2} + \frac{\left(M_{b\ell\nu} - m_t^{reco}\right)^2}{\Gamma_t^2}$$

W Mass Constraints

Top mass Constraints

- Select one permutation based on χ^2:
  - Require consistency with identified b-jet assignments

Template Analysis: Top Mass Reconstruction in Dilepton

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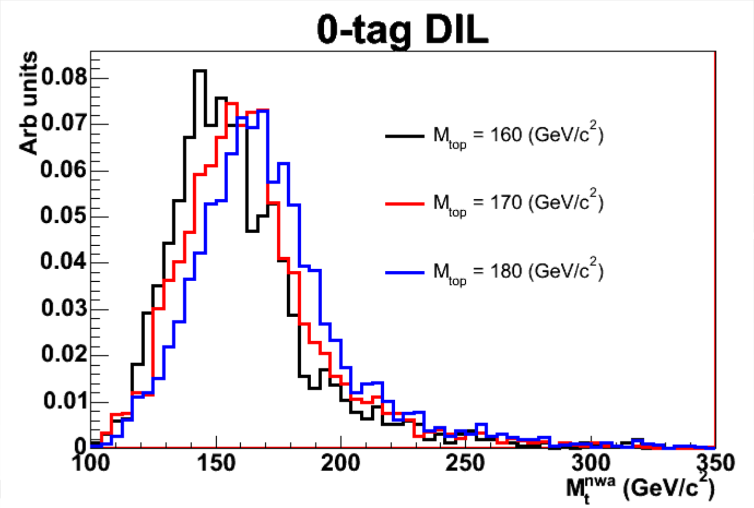
- Under-constraint kinematics due to two neutrinos
- Use Neutrino Weighting Algorithm (NWA)
  - Scan potential top masses and ν rapidities (η) and solve for ν's
  - Compare each combination of ν solution to measured missing E_T

$$w^{\nu}(M_t) = \exp\left(\frac{-\left(\not{E}_x^{calc} - \not{E}_x^{obs}\right)^2}{2\sigma_{\not{E}_x}^2}\right)\exp\left(\frac{-\left(\not{E}_y^{calc} - \not{E}_y^{obs}\right)^2}{2\sigma_{\not{E}_y}^2}\right)$$

- Integrate over η of the ν's, obtaining total weight for different top mass hypothesis
  - Reconstructed top mass ⇒ Mass hypothesis with largest weight



Method Validation

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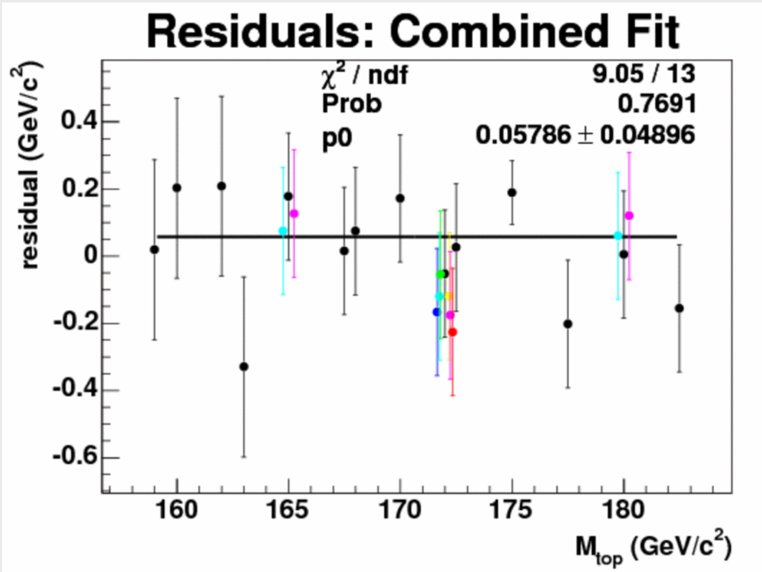
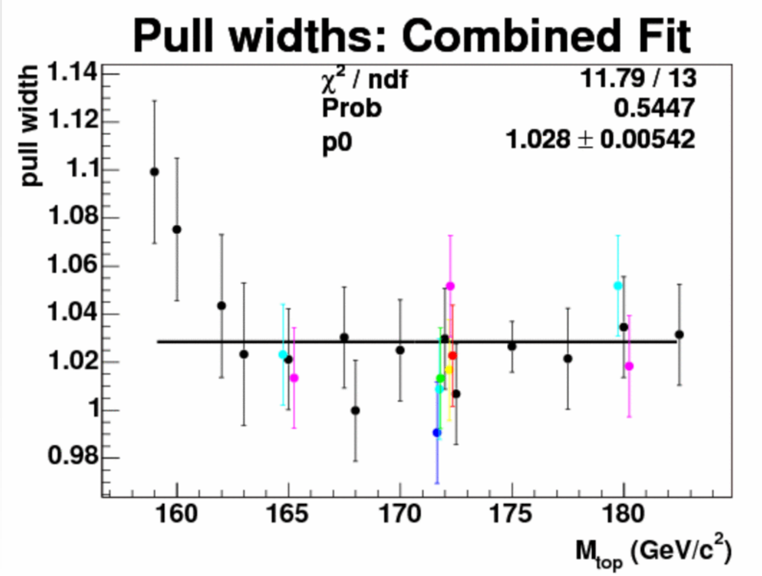
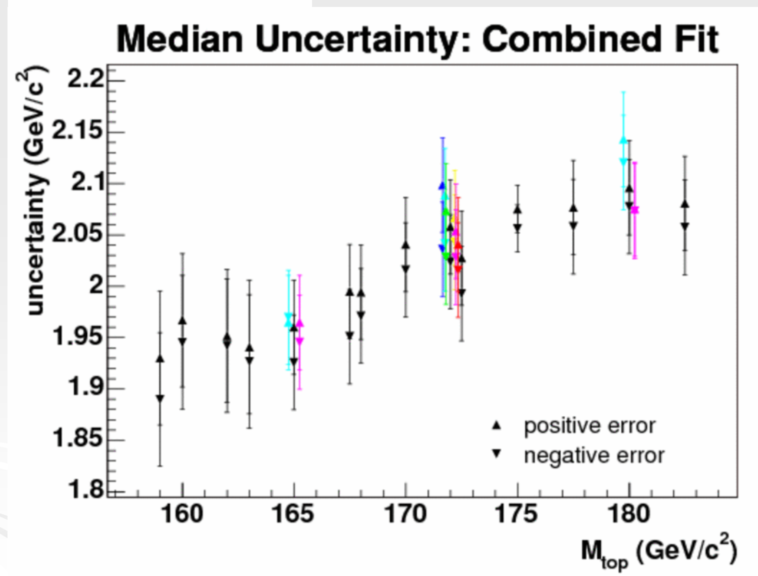


- ΔJES= 0.0
- ΔJES=-1.4
- ΔJES=-1.0
- ΔJES=-0.8
- ΔJES= 0.8
- ΔJES= 1.0
- ΔJES= 1.4

Extensive checks and validation of the method performed





Template Analysis: Data Fit

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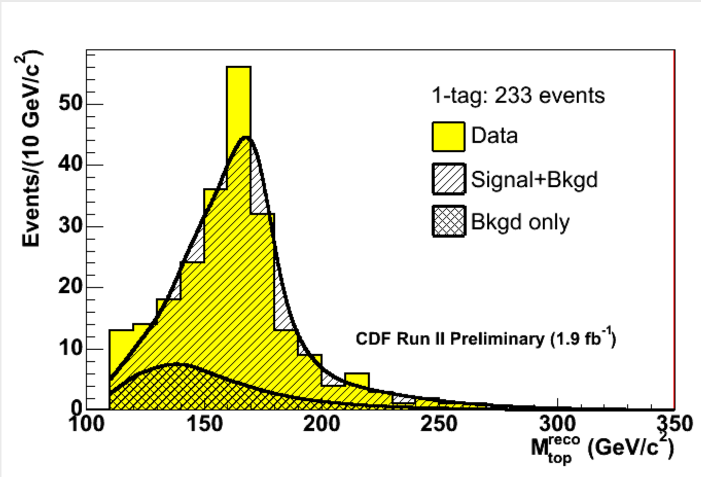
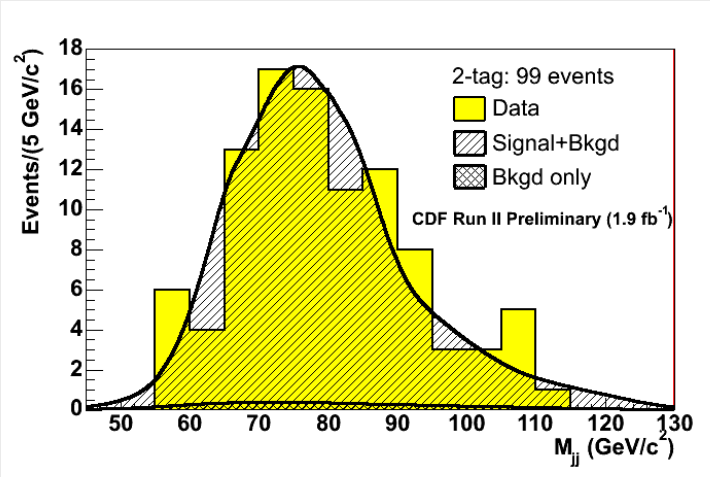
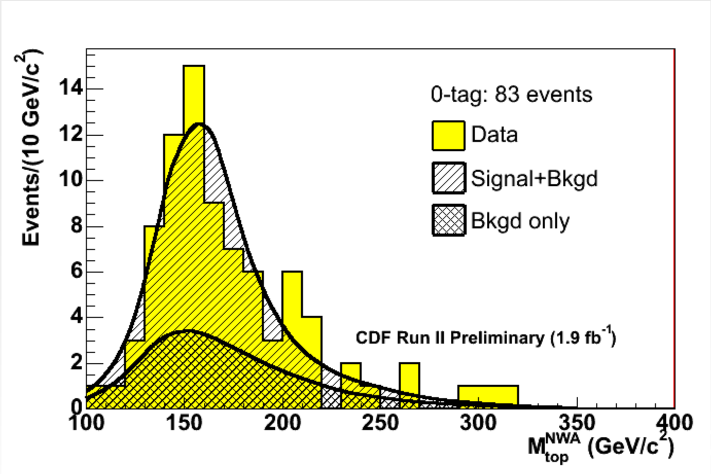


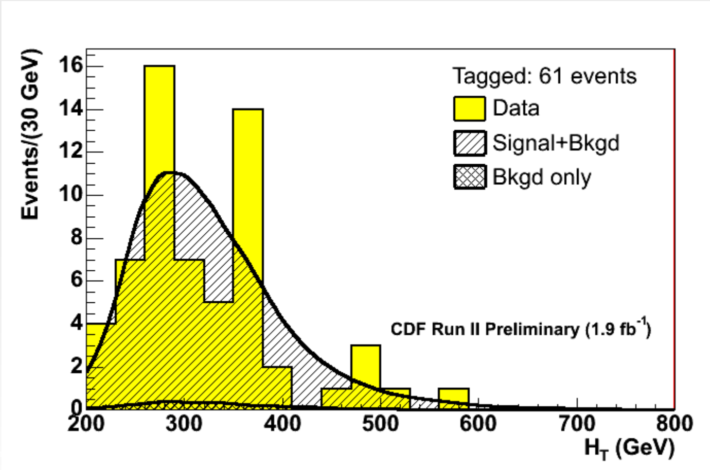
M_{reco}, Lepton+Jets, 1 b-tag



M_{jj}, Lepton+Jets, 2 b-tags



M_{reco}, Dilepton, 0 b-tag



H_T, Dilepton, 1 b-tag

Template Analysis: Measured Top Mass

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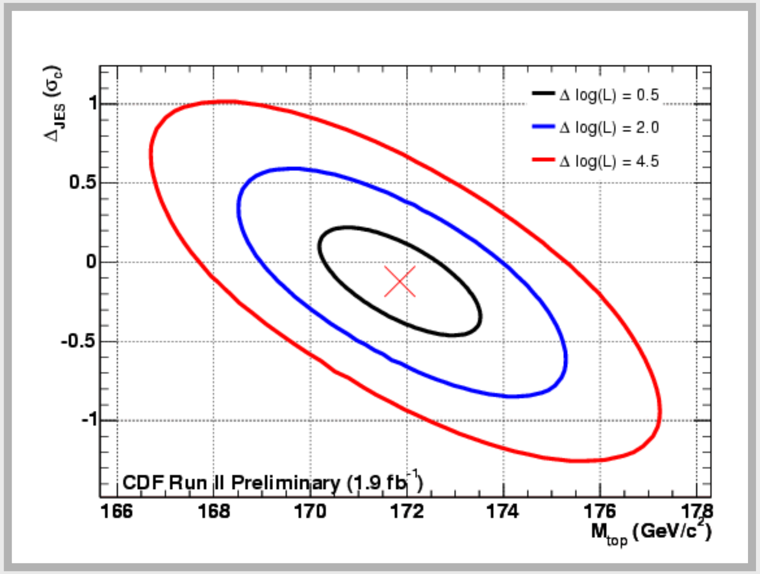


- **Combined fit result:**

171.9 ± 1.7 (stat.+JES) ± 1.0 (syst) GeV/c^2

- ***Lepton+Jets only result:***

171.8 ± 1.9 (stat.+JES) ± 1.0 (syst) GeV/c^2

- ***Dilepton only result:***

171.6 $^{+3.4}_{-3.2}$ (stat.) ± 3.8 (syst) GeV/c^2

Syst. (GeV/c^2)	LJ	DIL	Comb
b-JES	0.6	0.5	0.6
Residual JES	0.5	3.5	0.5
ISR	0.3	0.4	0.4
FSR	0.2	0.5	0.2
PDFs	0.3	0.5	0.3
Generator	0.2	0.8	0.2
LJ Bkg Shape	0.2	0.0	0.2
DIL Bkg Shape	0.0	0.4	0.1
MC statistics	0.1	0.2	0.1
Lept energy scale	0.1	0.4	0.1
pileup	0.1	0.1	0.1
gg fraction	0.0	0.2	0.0
Total	1.0	3.8	1.0

Event-by-Event Likelihood Matrix Element Method: Lepton+Jets

- For each event build a signal and background probabilities
- For a set of measured variable x:

$d^n\sigma$ is the differential cross section: LO Matrix element

W(x,y) is the probability that a parton level set of variables ***y*** will be measured as a set of variables ***x*** **(parton level corrections)**

$$\overline{P}_{signal}(x; M_{top}, JES) = \frac{1}{\sigma}\int d^n\sigma(y; M_{top})\underline{dq_1 dq_2 f(q_1) f(q_2)}W(JES, x, y)$$

f(q) is the probability distribution that a parton will have a momentum ***q***

- All permutations and neutrino solutions are taken into account
- Lepton momenta and all angles are considered well measured

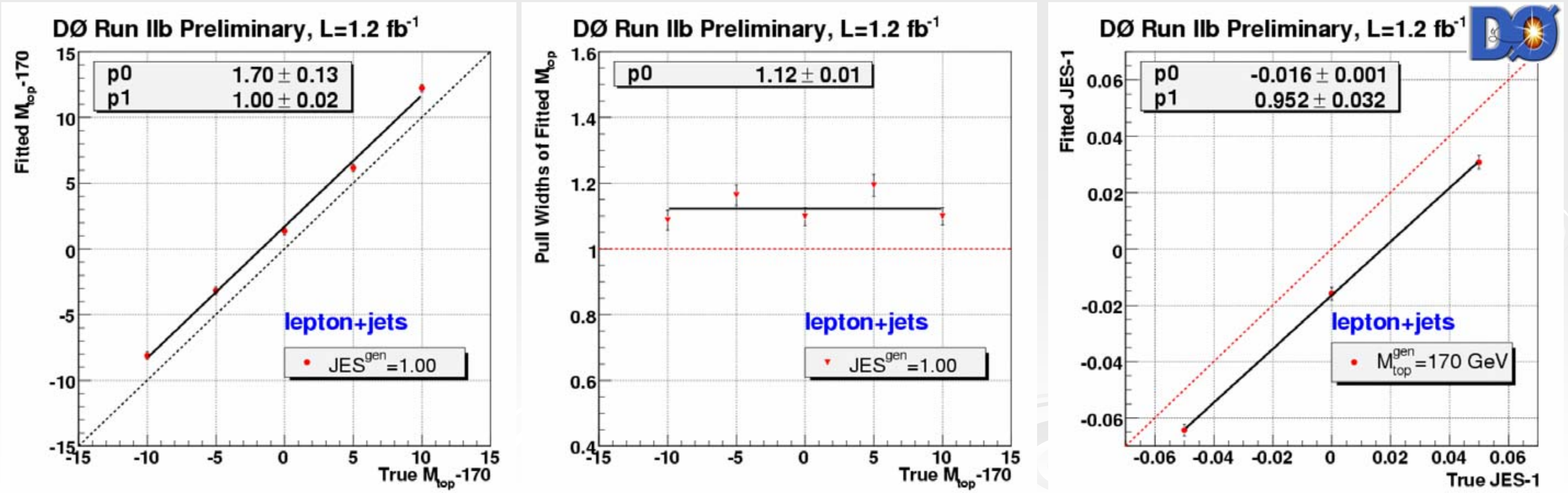
Matrix Element Method: Lepton+Jets

- Maximize likelihood and simultaneously determines M_{top} and JES

Signal fraction

$$L(C_s, M_{top}, JES) \propto \prod_{i=1}^{Nevents} (C_s P_{signal,i}(M_{top}, JES) + (1 - C_s) P_{background,i}(JES))$$

- Calibration against simulation



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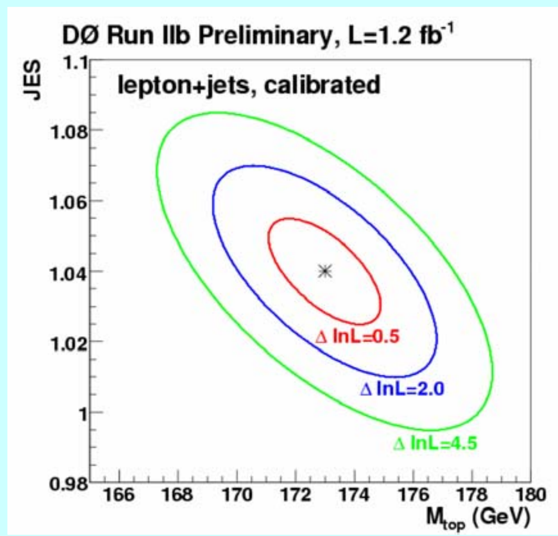
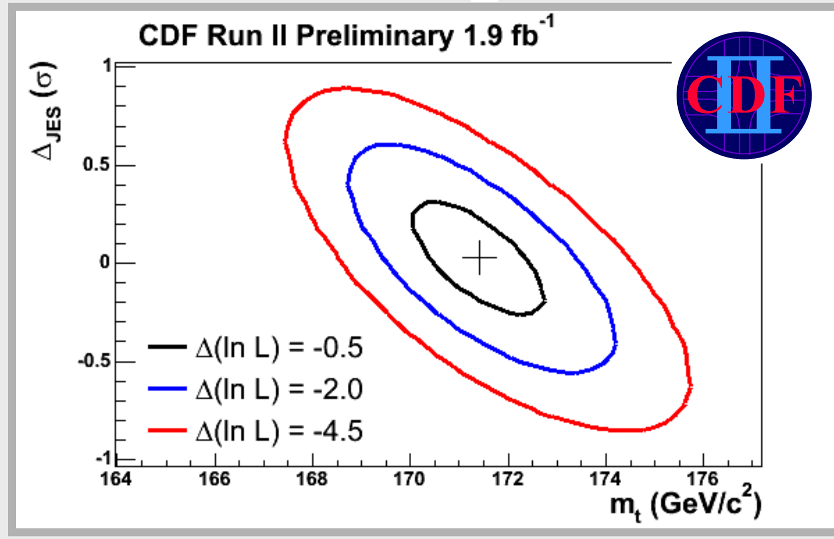
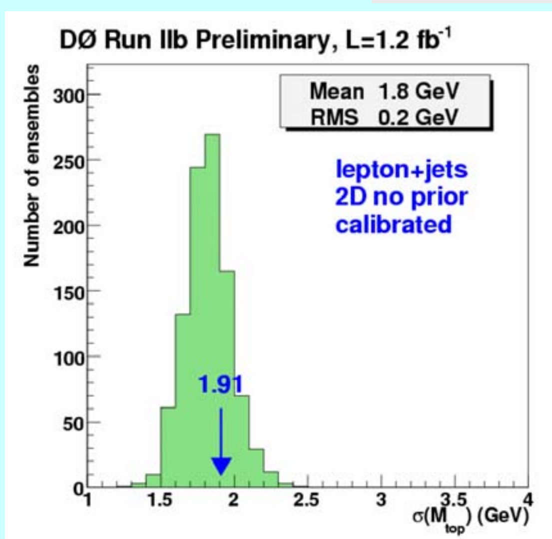
Matrix Element: Measured Top Mass





171.4 ± 1.1(stat) ± 1.0(JES) ± 1.0(syst) GeV/c²

D0 Plots corresponds to 2nd 1 fb-1. Combined result:

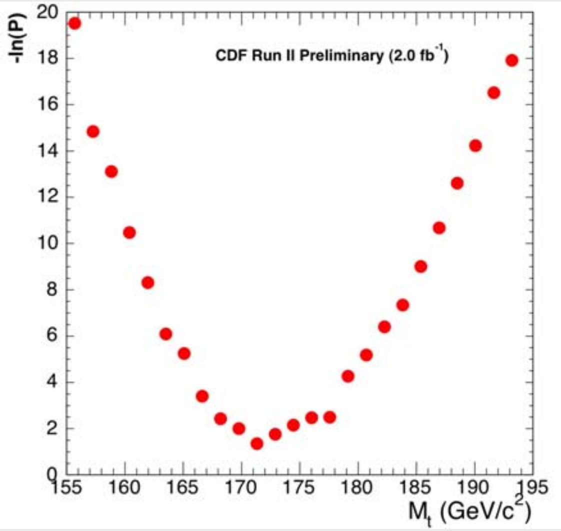


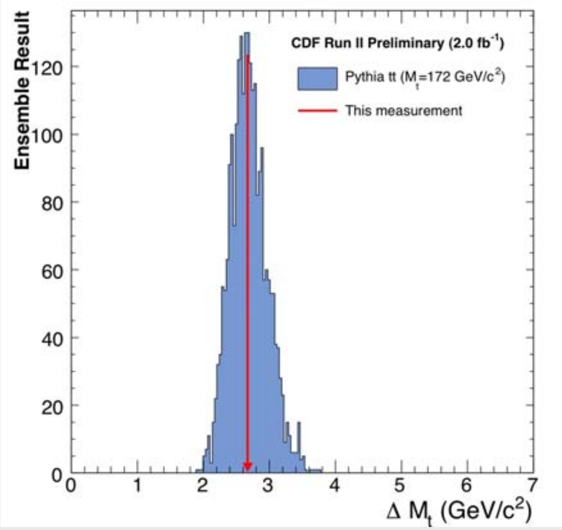
172.2±1.1(stat)±1.6(JES+syst) GeV/c²

- *Most precise CDF and D0 Top mass measurements from single channels*
- Major sources of systematics:
  - Radiation, residual JES, b-JES, modeling, generator …
  - No single source dominates total systematics

2 fb^{-1}

Matrix Element Method: Dilepton





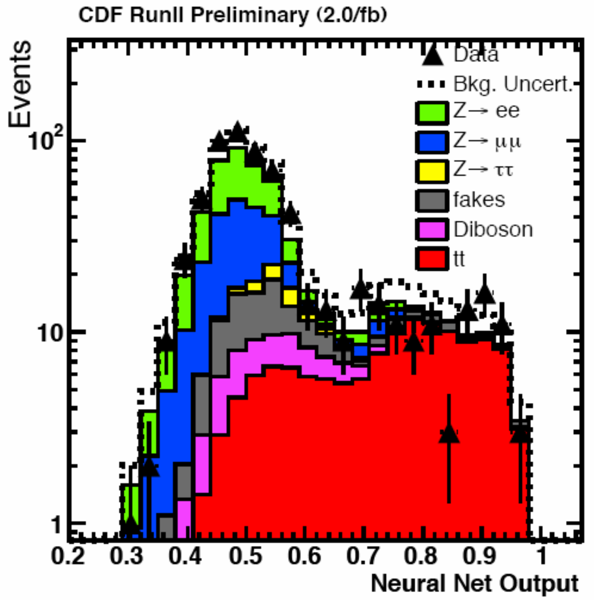
Sources of Systematics	δm_{top} (GeV/c^2)
JES	2.5
Other	1.5
Total	2.9

171.2 ± 2.7 (stat.) ± 2.9 (syst.) GeV/c^2

- Most sensitive analysis in Dilepton channel
- Comparable statistical and systematic uncertainties
- Optimized event selection for sensitivity
  - Use NeuroEvolution method

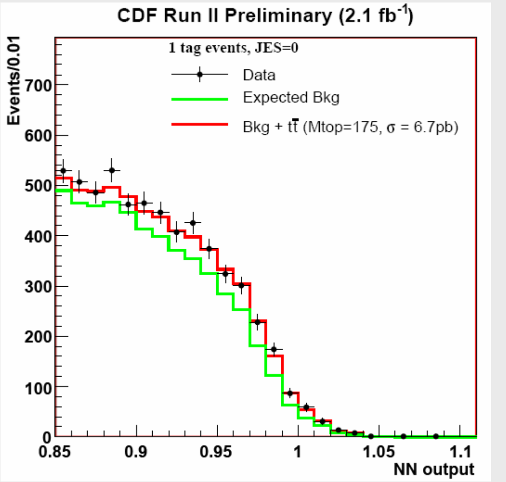
(K. Stanley and R. Miikkulainen, Evolutionary Computation 10(2) 99-127, 2002)

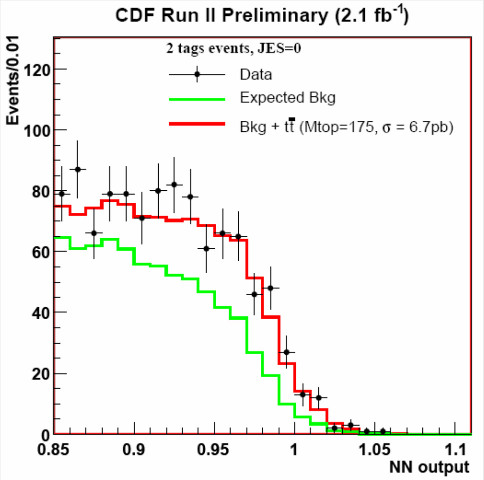
  - Method capable of evolving Neural Network's topology in addition to its weights.



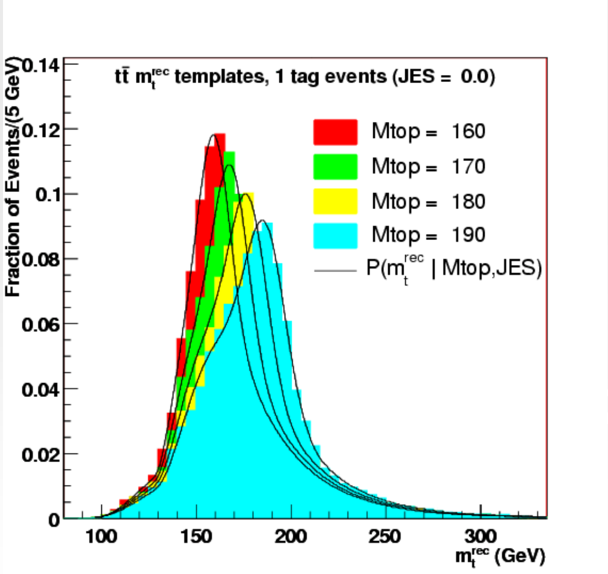
Template: All Hadronic

- Suffers from huge QCD background
  - Apply neural net (NN) kinematical selection
  - Require ≥1 b-tag
- Use kinematic fitter to reconstruct top mass
  - χ^2: constrain 2 dijet masses to the W mass, 2 triplet masses to be equal, and 6 terms representing the jet JES.
- Select permutation with min χ^2
  - requiring consistency with identified b-jet assignments





Require NN output > 0.91



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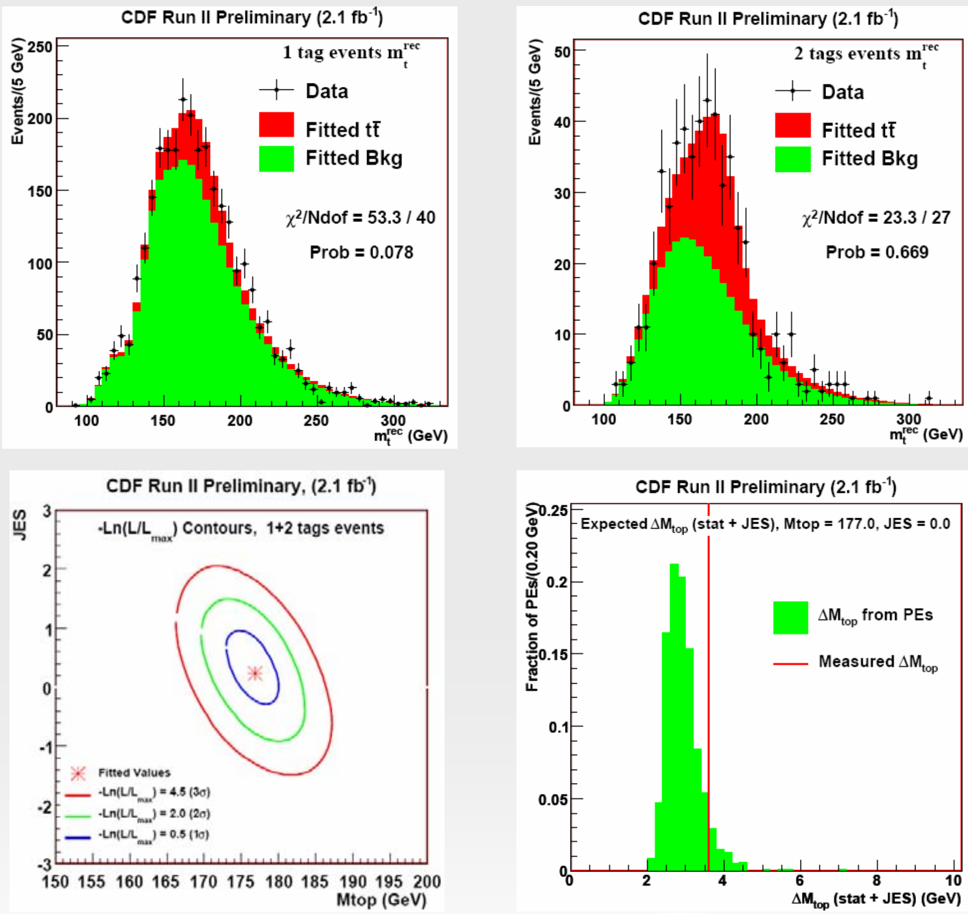
All Hadronic : Measured Top Mass

- Likelihood fit extracts top mass and JES



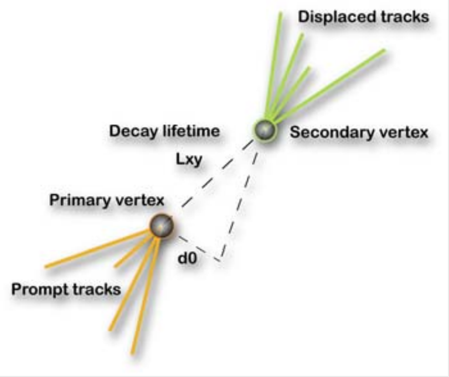
Source	GeV/c2
Residual JES	0.8
b-JES	0.6
SF E_T Dependence	0.4
Radiation	0.3
PDFs	0.4
Generator	0.5
Bkg. Template	**1.0**
Signal Template	0.3
Method related	0.4
Total	1.7

176.9 ± 3.8 (stat+JES) ± 1.7 (syst) GeV/c^2

2 fb^{-1}

Different Methods: Lepton P_T and L2d

- Use single variables sensitive to top mass
  - L2d/L_{xy}: B hadron decay length $\propto$ b-jet boost $\propto$ M_{top}
  - Lepton transverse momentum
- Relies on tracking, less JES dependence
  - Uncorrelated with other measurements



CDF Run II Preliminary (1.9 fb^{-1})

Measured Top Mass (GeV/c^2)

Combined : 175.3±6.2(stat)±3.0(syst)

L2d : $176.7^{+10.0}_{-8.9}$(stat)±3.4(syst)

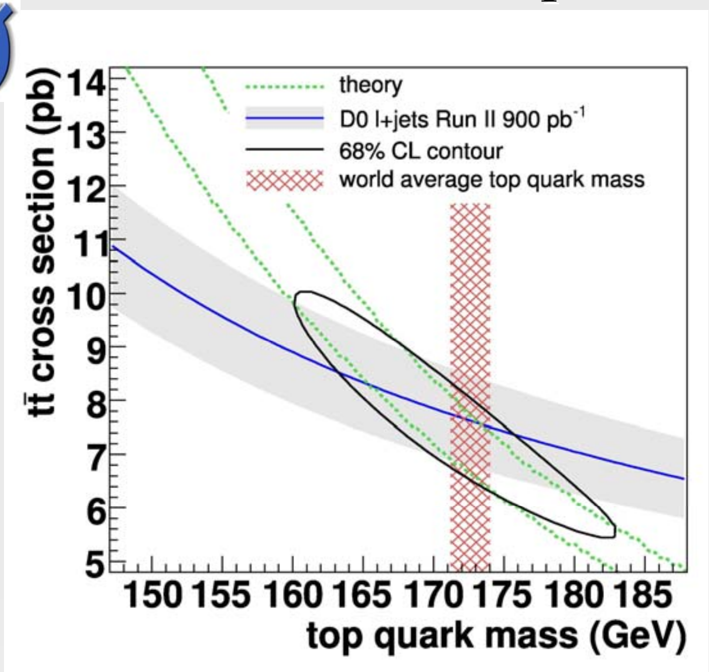
Lepton P_T : $173.5^{+8.9}_{-9.1}$(stat)±4.2(syst)

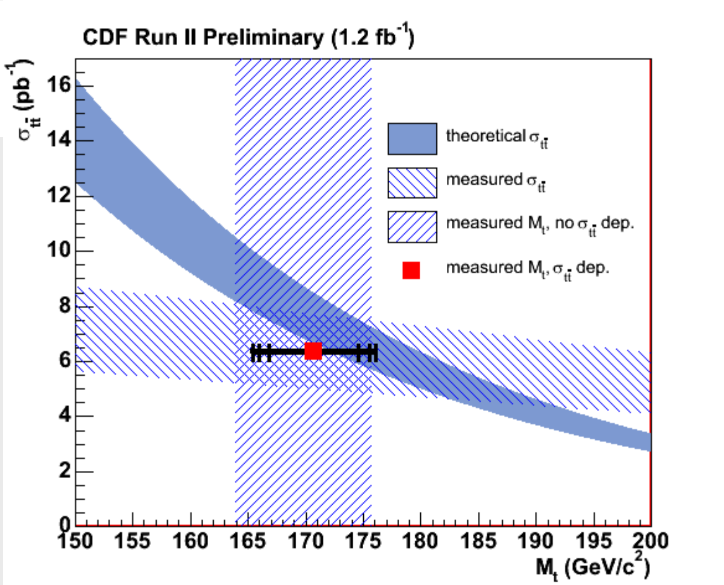
Syst. (GeV/c^2)	L2d	LepPt	Comb
Radiation	0.9	2.3	1.5
PDFs	0.3	0.6	0.5
Generator	0.7	1.2	0.6
L2d SF	2.9	0	1.4
LepPt Scale	0	2.3	1.1
Bkg. Shape	1.0	2.3	1.6
Out-of-cone JES	1.0	0.3	0.6
Total	3.4	4.2	3.0

- Statistically limited at Tevatron
- Relatively large systematic uncertainty from sources like radiation, generator, modeling ⇒ work in progress

Cross-section and Mass

- Explore the cross section and mass dependence for top mass measurement or improving sensitivity





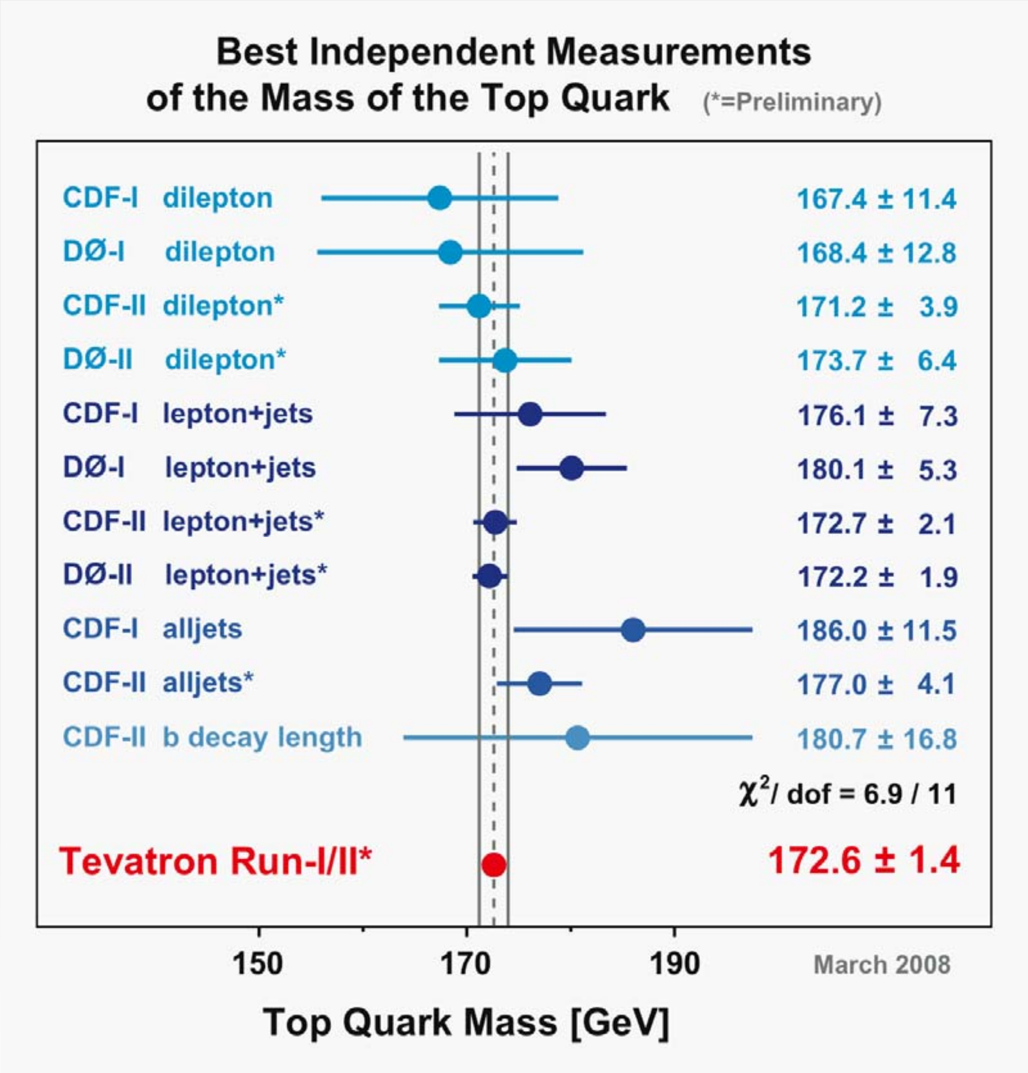
Determine top mass by comparing measured ttbar cross section with best theoretical calculations *(Details in F. Déliot's talk)*

Top mass = 170 ± 7 GeV/c^2

For Dilepton analysis: Apply additional constrain using theoretical ttbar cross section with kinematic information

Top mass = $170.7^{+4.2}_{-3.9}$ (stat) ± 2.6 (syst) ± 2.4 (theory) GeV/c^2

Combination of Top Mass Results



- Combine Run I measurements with most recent Run II measurements
- Take into account the statistical and systematic uncertainties and their correlations (NIM A270 (1988) 110, NIM A500 (2003) 391)
- Combined top mass

  172.6±1.4 GeV/c^2

  $\chi 2$/ndof 6.9/11 $\Rightarrow$ 81% prob

  - Good agreement among all input measurements
- Top mass known with relative precision of 0.8%

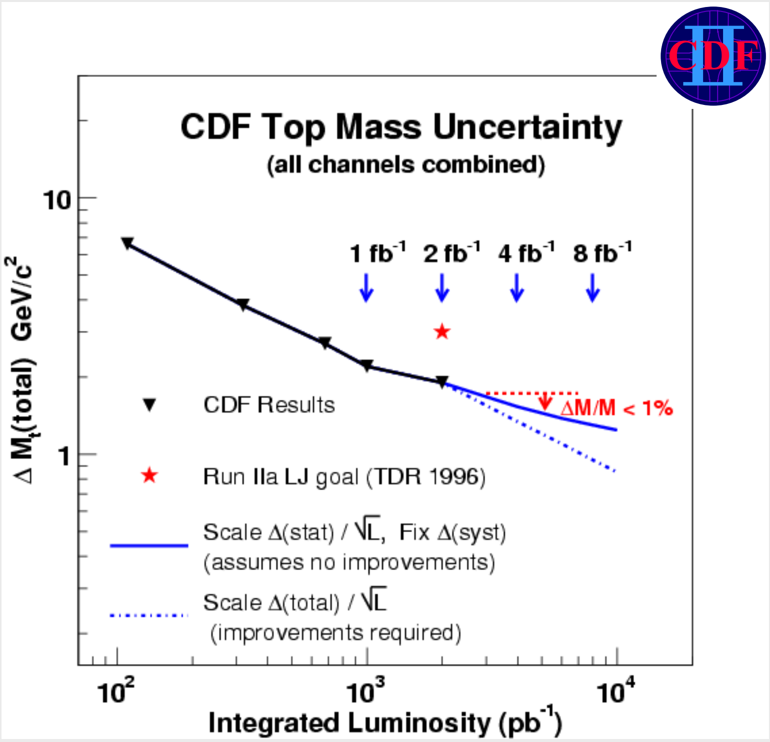
δM_{top}

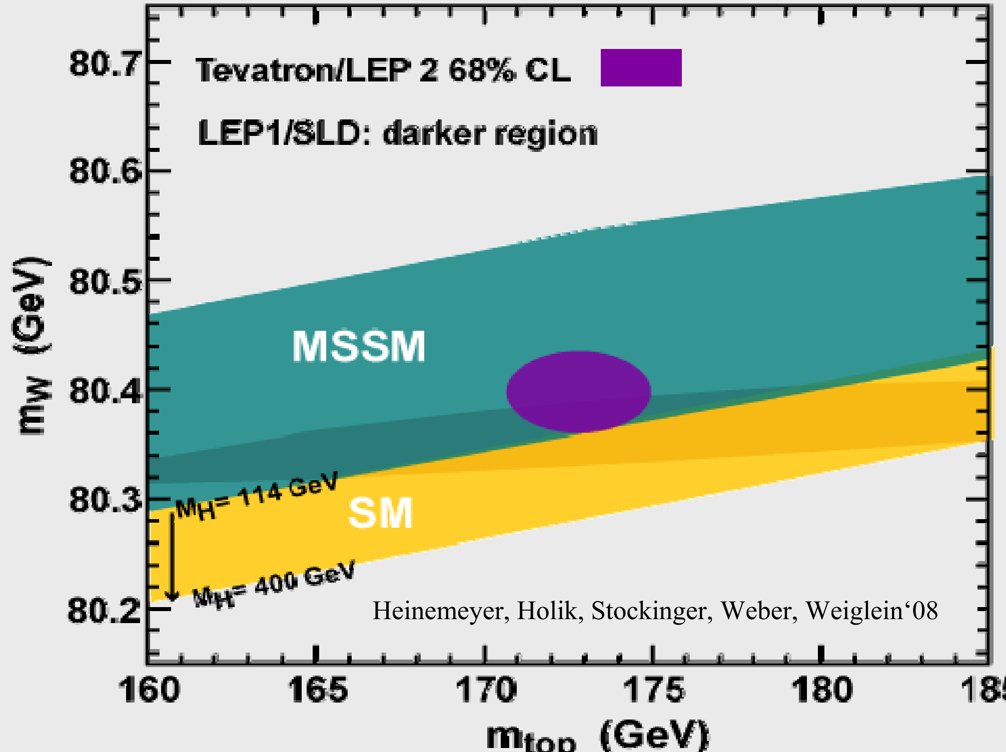
- Top mass measurements are becoming systematic dominated
- In channel/analysis not using in-situ JES $\Rightarrow$ Systematics dominated by the uncertainty on parton energies (JES)
- Other sources arise from the assumptions employed to infer M_{top}

Statistical and systematical sensitivities by channel

δM_{top} per CDF/D0 Analysis with ~2 fb^{-1}	Statistical *(Including in-situ JES for LJ& All-Had)* (GeV/c^2)	JES (DIL) OR Residual JES (LJ and All-Had) (GeV/c^2)	Other Systematics (GeV/c^2)
Dilepton	~2.7	~2.5	~1.5
Lepton+Jets	~1.5	~0.6	~0.8
All Jets	~3.8	~1.0	~1.4

Prospects : Top Mass At Tevatron





- The combined CDF and D0 top mass measurement is at <1% precision
  - Surpassed Run II goal for δM_{top} ~3 GeV
- Improving constraint on the SM Higgs boson
  - Pushing the SM to it's boundary

Prospects : Top Mass At Tevatron (Cont')

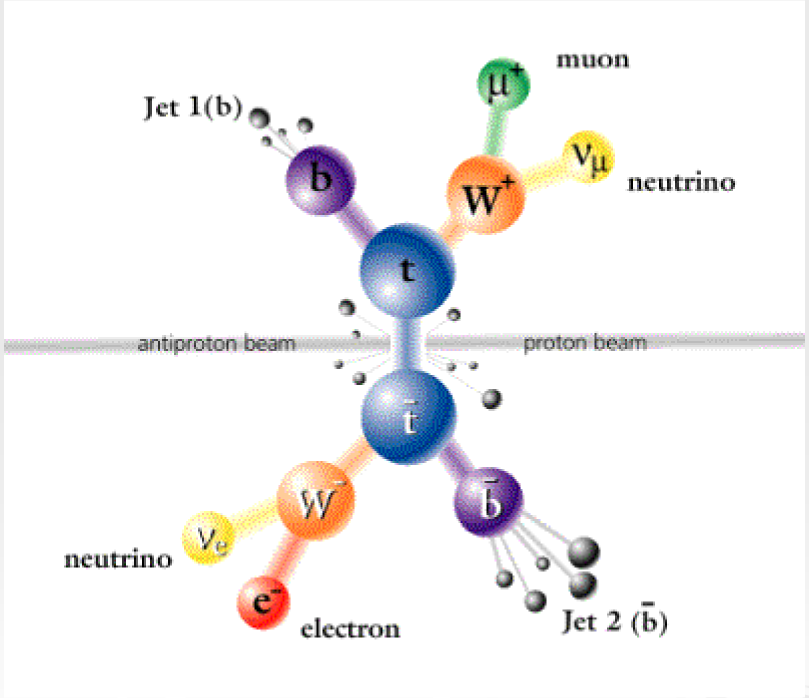
- Working toward the final systematic uncertainties on Top mass measurement

Are we missing anything? Are all possible sources properly accounted for?

Work in progress:

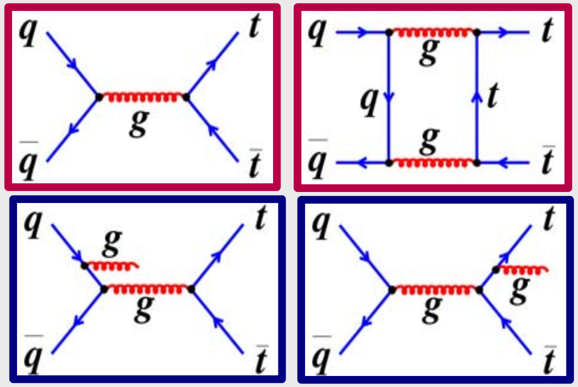
- Color reconnection
  - Estimating effect on Top mass measurement using theory models (P. Skands and D. Wicke, hep-ph/0703081v2)
- Revisiting various sources of systematics
  - Better understanding
  - Possibly avoid double counting and over estimation

Other Properties with ttbar Sample



Forward Backward Asymmetry (A_{fb}) in Top Pair Production

- Asymmetry caused by interference of ME amplitudes for same final state
- The SM predictions:
  - In ttbar frame: $A_{fb}^{ttbar} = (4\text{-}7)\%$ in NLO (arXiv:0709.1652)
  - In ppbar frame (A_{fb}^{ttbar}) : reduced by ~30% relative to A_{fb}^{ttbar}



- Can be significantly enhanced in different BSM models:
  - Z'-like states with parity violating coupling (PLB 387, 113 (1996)), theories with chiral color (PLB 190, 157 (1987), PLB 200, 211(1988))
- A_{fb} measured in both the ttbar rest frame and the lab rest frame

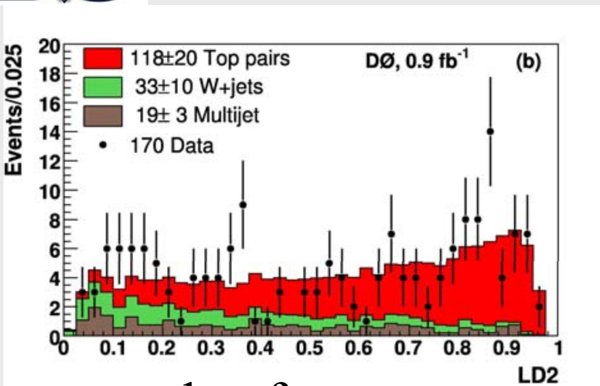
$$A_{fb}^{t\bar{t}} = \frac{N(\Delta Y > 0) - N(\Delta Y < 0)}{N(\Delta Y > 0) + N(\Delta Y < 0)}$$

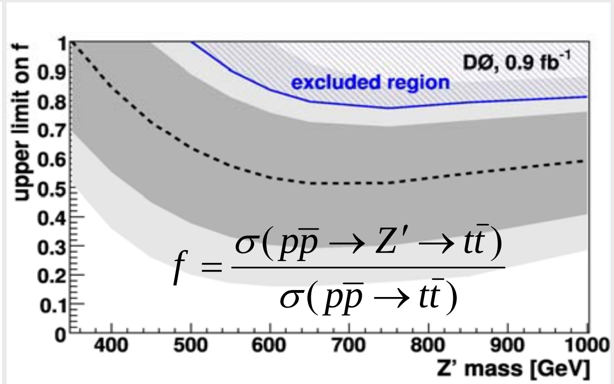
$$\Delta Y = -Q_\ell . (Y_{t,leptonic} - Y_{t,hadronic})$$

$$A_{fb}^{p\bar{p}} = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)}$$

$$\cos\theta = -Q_\ell . \cos\theta(t_{hadronic}, Beam_{proton})$$

A_{fb} Measurements





ttbar frame

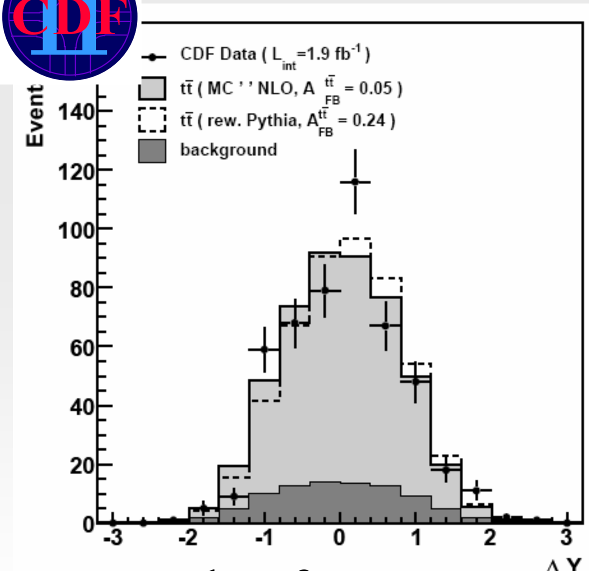
D0 Measurements

(*PRL 100, 142002 (2008)*)

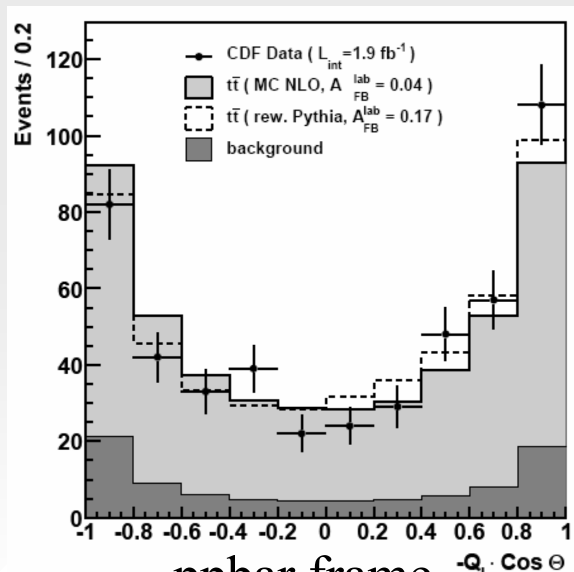
$A_{fb}^{uncorrected}$ =

0.12±0.08 (stat) ± 0.01(syst)

- Set constrain on leptophobic Z' production



ttbar frame



ppbar frame

CDF Measurements (submitted to PRL)

- Apply unfolding to go from reconstructed to parton level

A_{fb}^{tt} =

0.24± 0.13(stat) ± 0.04(syst)

A_{fb}^{pp} =

0.17± 0.07(stat) ± 0.04(syst)

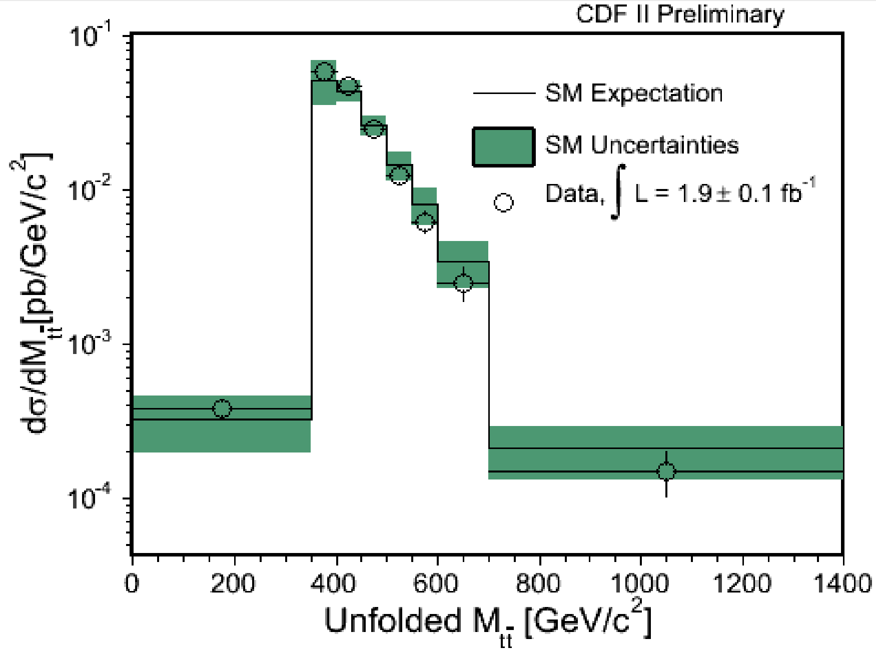
- Consistent with SM expectation

2 fb^{-1}

Measurement of the ttbar Differential Cross Section $d\sigma/dM_{ttbar}$

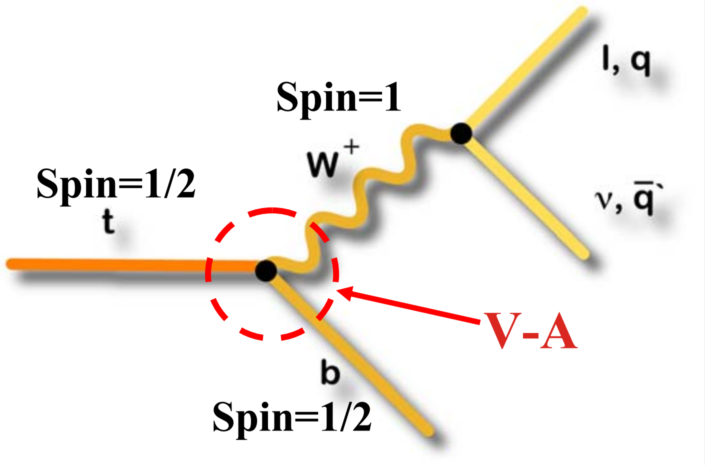
- In BSM models new gauge interactions can produce massive particles which may strongly couple to top quark (PRD 49, 4454 (1994), hep-ph/07122355V1)
  - Can produce resonances in the ttbar invariant mass (M_{ttbar}) distribution
  - Or may interfere with the SM and modify the shape of M_{ttbar}

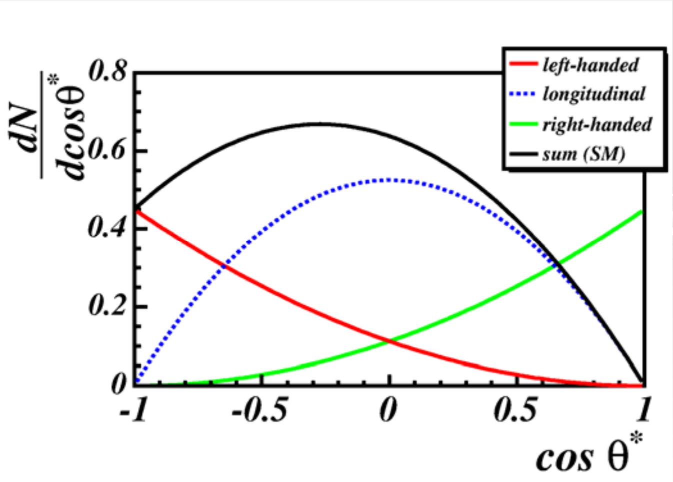
- Measure top pair cross-section in bins of M_{ttbar} for Lepton+Jets events
  - Correct the reconstructed invariant mass distribution to back to true distribution
- Check consistency with the SM
  - Put more emphasis on the tail of the distribution
- Data consistent with SM



W Helicity: tbW coupling

- The SM top decays via EW interaction: Br($t \rightarrow bW$)~100%
  - Top decays as a bare quark ⇒ spin info transferred to final states
- Possible W helicities:
  - J•P = 0: longitudinal
  - J•P = -1: left-handed
  - J•P = +1: right-handed
- V-A coupling in the SM ⇒
  - longitudinal fraction f_0 ~70%
  - left-handed fraction f_- ~30%
  - right-handed fraction f_+ ~0%
- The SM prediction modified in various new physics models
  - PRD 45, 124 (1992); PRL 38, 1252 (1977); J. Phys. G26, 99 (2000); PRD 62, 011702 (2000); PRD 65, 053002 (2002).





- Recent measurements use cosθ* :

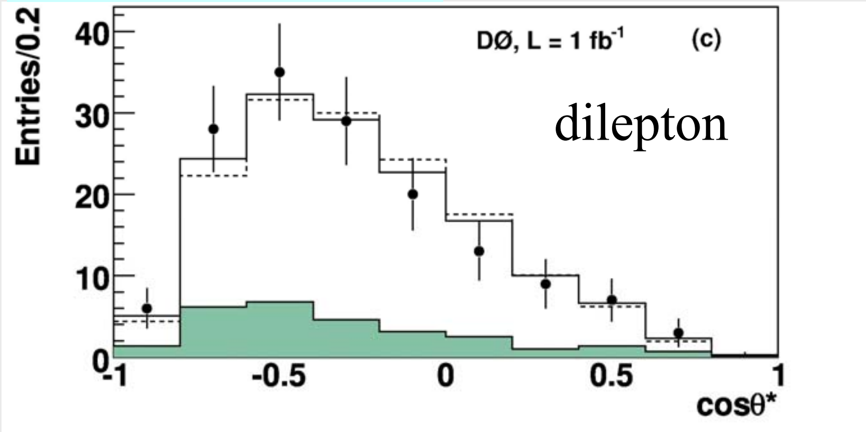
Angle between lepton and b in W rest frame.

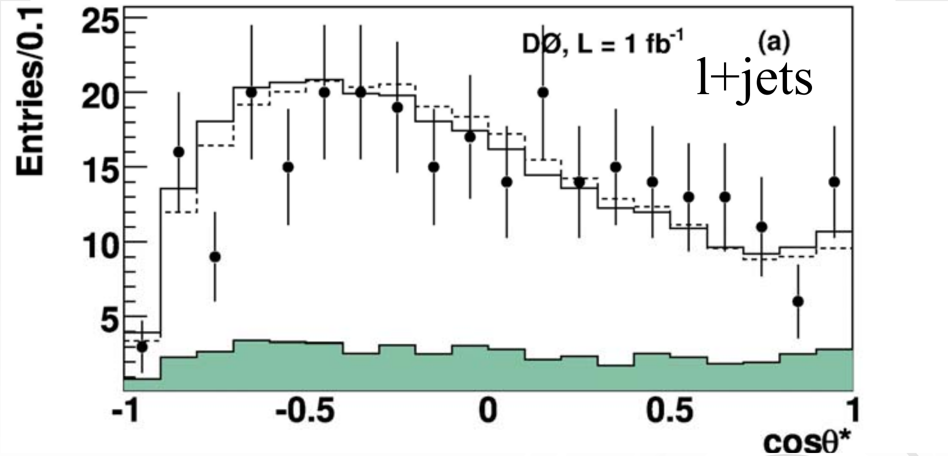
$1\ fb^{-1}$

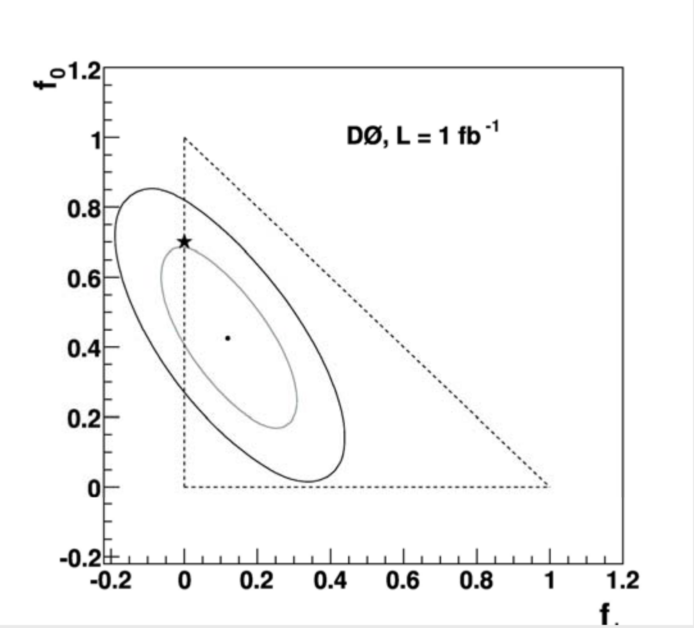
W Helicity Measurements

- Template based analysis using cosθ*
  - Reconstruct ttbar decay using event kinematics

PRL 100, 062004 (2008)





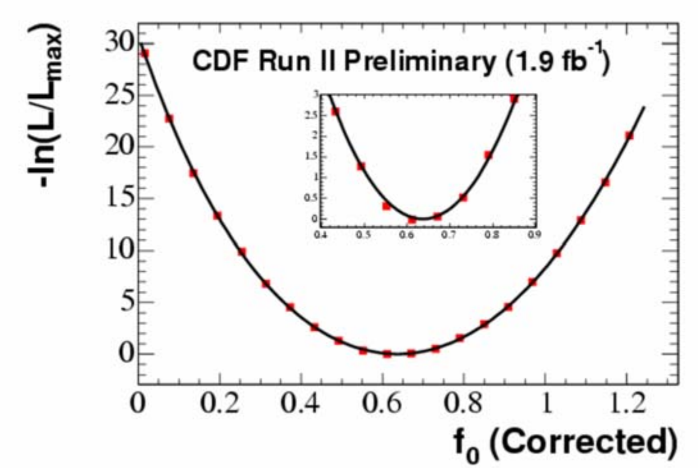


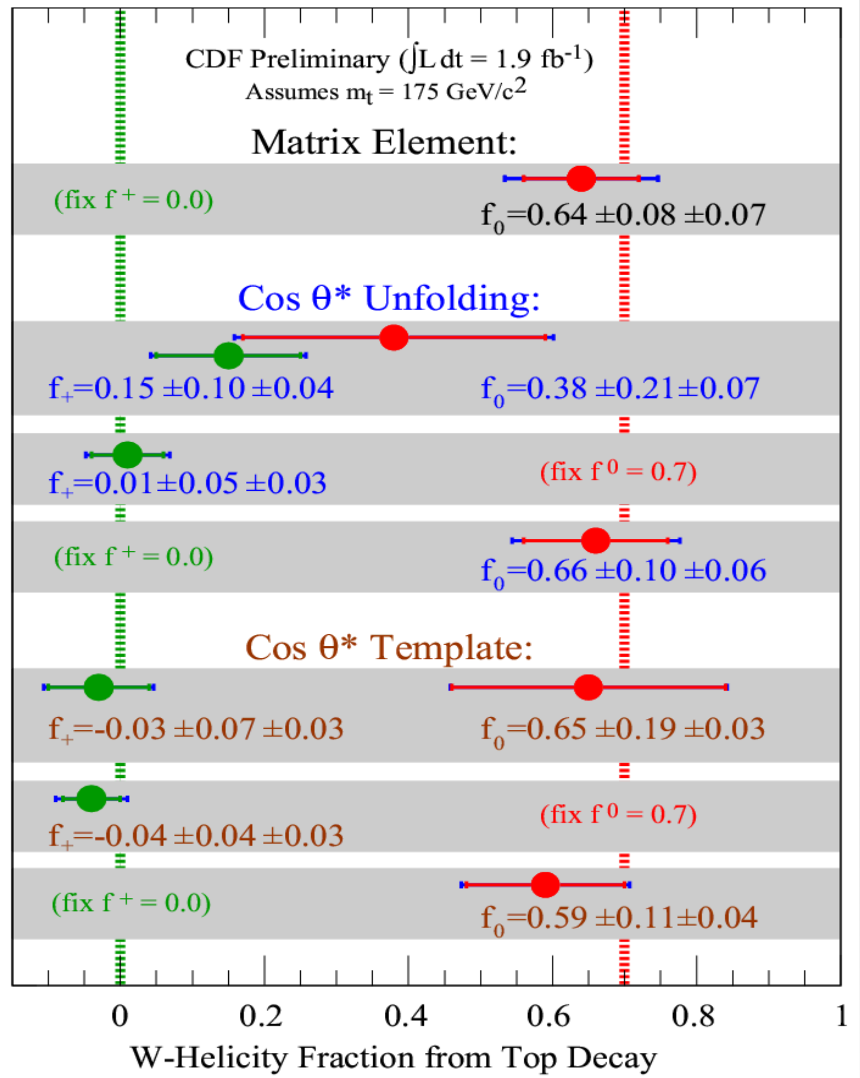
- Simultaneously measure f_0 and f_+
  - $f_0 = 0.42 \pm 0.17(\text{stat}) \pm 0.10(\text{syst})$
  - $f_+ = 0.12 \pm 0.09(\text{stat}) \pm 0.05(\text{syst})$
- Fix $f_+=0$
  - $f_0=0.62\pm0.09\ (\text{stat}) \pm 0.05\ (\text{syst})$
- Fix $f_0=0.7$
  - $f_+ = -0.00\pm0.05\ (\text{stat})\pm0.05(\text{syst})$
- Consistent with SM expectation

W Helicity Measurements

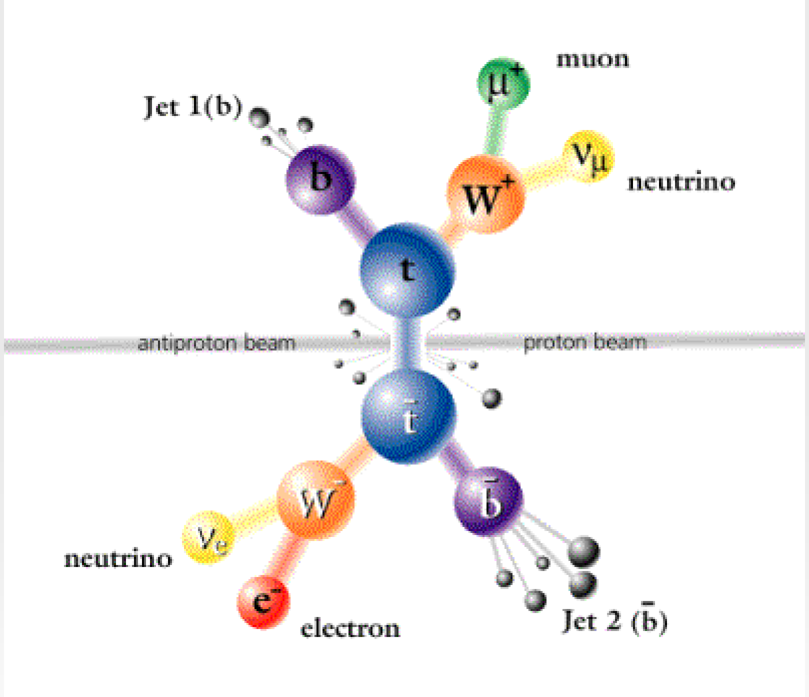
2 fb^{-1}

- Template method
  - Simultaneously measure f_0 and f_+
  - Measure f_0 assuming fixed f_+=0.0
  - Measure f_+ assuming fixed f_0=0.7
- Using a matrix element-based technique
  - Likelihood based on differential cross-sections of ttbar and dominant background
  - Measure f_0 assuming fixed f_+=0.0





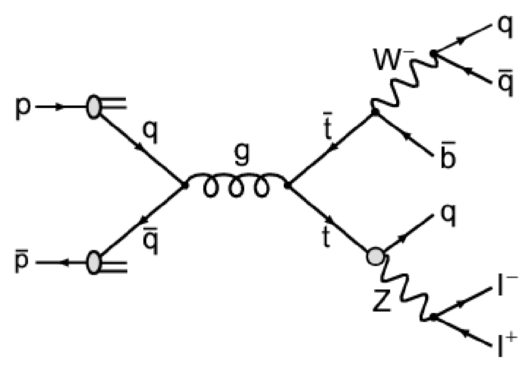
Search for Beyond the SM Physics With ttbar Sample



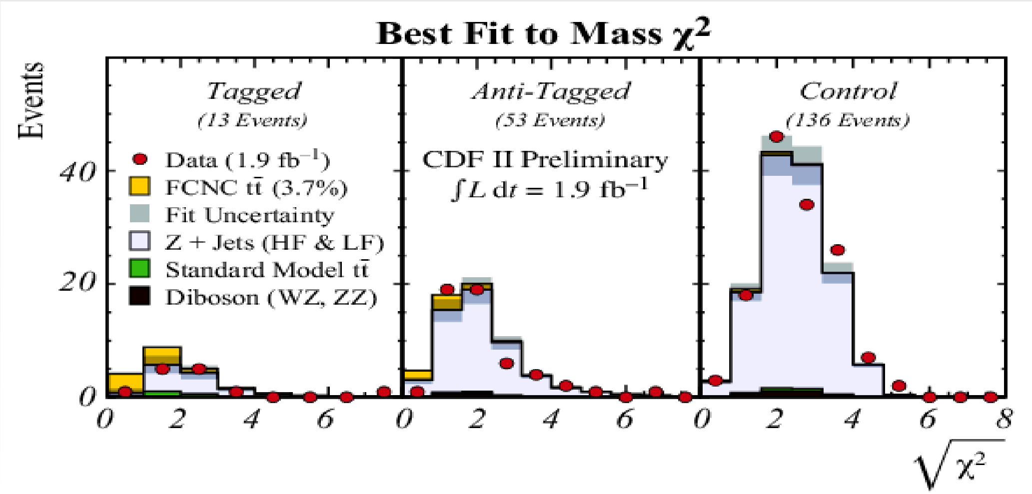
FCNC Search

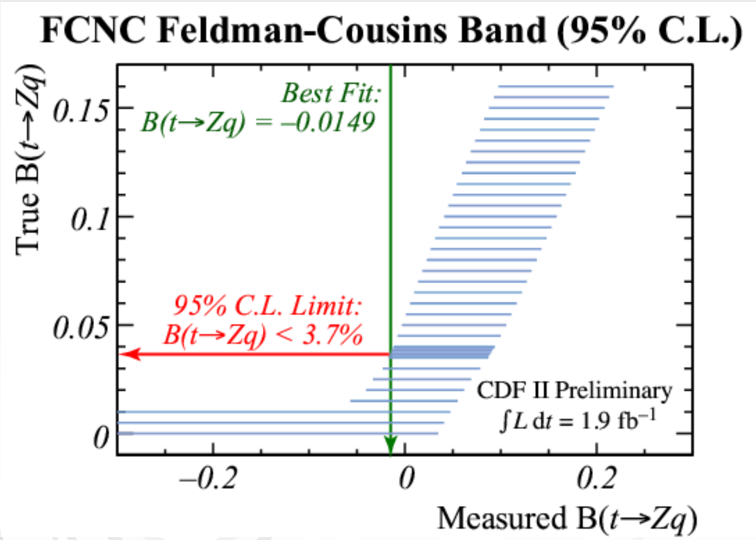
2 fb^{-1}

- Search for Flavor Changing Neutral Current (FCNC) process $t \rightarrow Zq$
  - Highly suppressed in SM : $O(10^{-14})$
  - Different new physics models predict much higher rate, up to $O(10^{-4})$
- Select $Z(\rightarrow ee/\ \mu\mu)+\geq 4$ Jets
  - Fit to a mass χ^2
  - Separate events 0 b-tag and $\geq$1 b-tag events



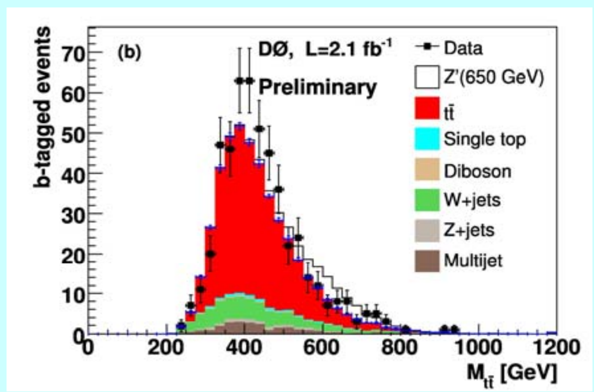
$$\chi^2 = \left(\frac{m_{W,\mathrm{rec}} - m_W}{\sigma_W}\right)^2 + \left(\frac{m_{t\rightarrow Wb,\mathrm{rec}} - m_t}{\sigma_{t\rightarrow Wb}}\right)^2 + \left(\frac{m_{t\rightarrow Zq,\mathrm{rec}} - m_t}{\sigma_{t\rightarrow Zq}}\right)^2$$



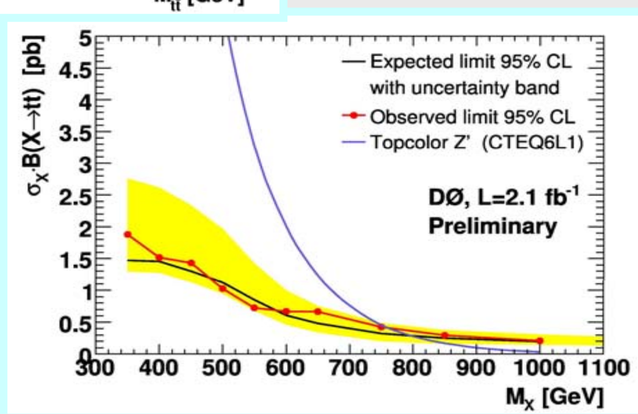


Resonant ttbar Production

- Various BSM theories predict resonant ttbar production from the decays of massive Z-like bosons: Topcolor (PRD49, 4454, 1994) , KK gluon excitation in RS model (hep-ph/0701166)

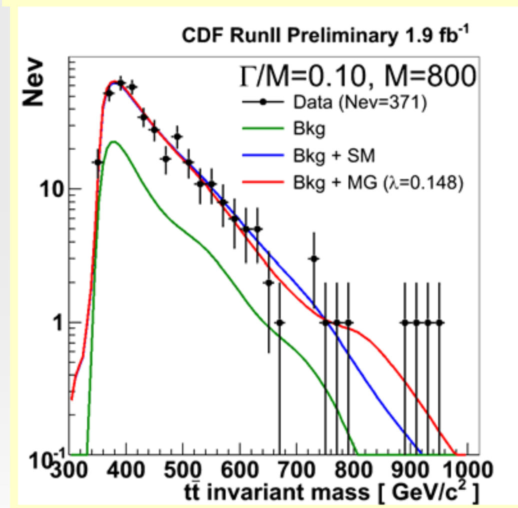


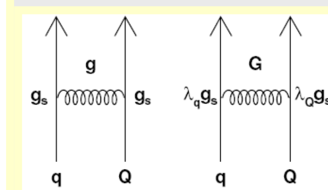
Exclude $M_{Z'}$<760 GeV/C^2 at 95% CL in Topcolor model



M_{tt} (GeV): Lepton+Jets

- Search for "massive gluon" decaying to ttbar pair (PRD 49, 4454 (1994))
  - The SM qqbar→ttbar and qqbar→G→ttbar interfere
- Scan mass and width of massive gluon to extract the coupling strength





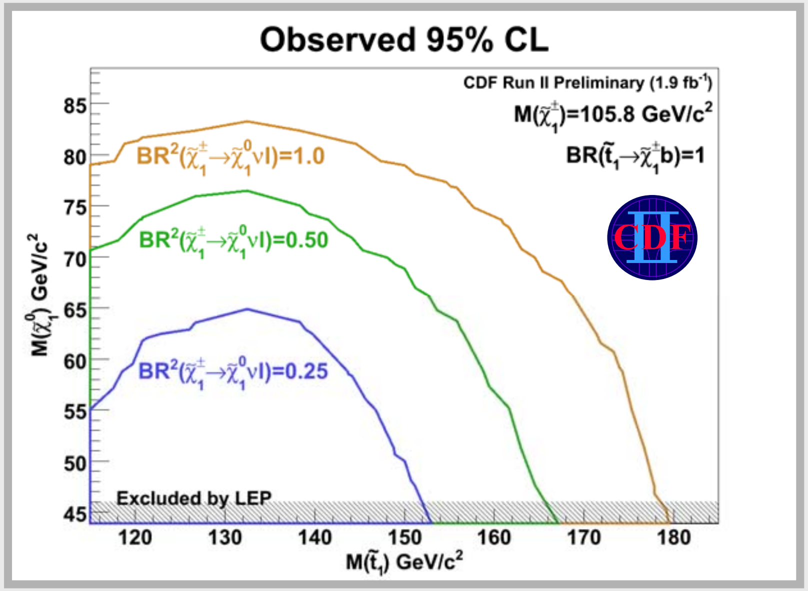
Data consistent with the SM

Search For Pair Production of Stop

- Search for

$$\boxed{\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm} \rightarrow b\tilde{\chi}_1^{0}\ell\,\nu}$$

- Very similar event signature as SM ttbar decays ⇒ can be hiding in Tevatron data

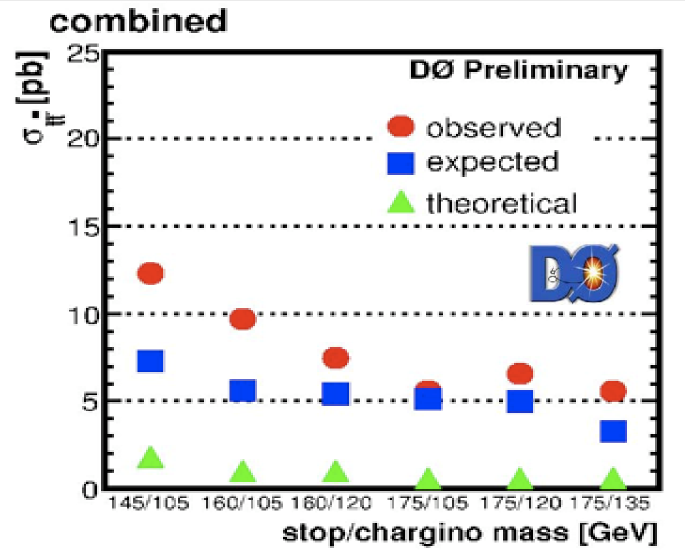


$\tilde{\chi}_1^0$ is the LSP, and $\tilde{q}, \tilde{\ell}, \tilde{\nu}$ are heavy

$m_{\tilde{t}_1} \lesssim m_t$

$m_{\tilde{\chi}_1^+} < m_{\tilde{t}_1} - m_b$

- Assume BR(stop→b and chargino)=100%
- Search in dilepton (CDF) and lepton+jets (D0) final states.
  - No evidence for stop quark pair production observed

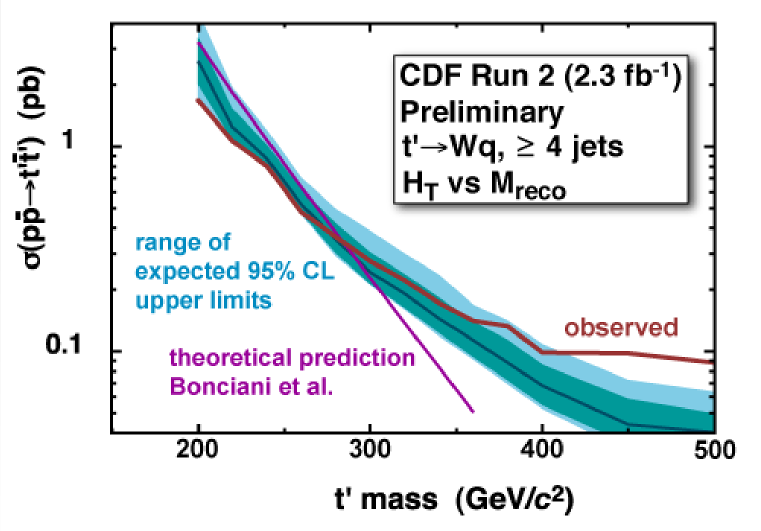


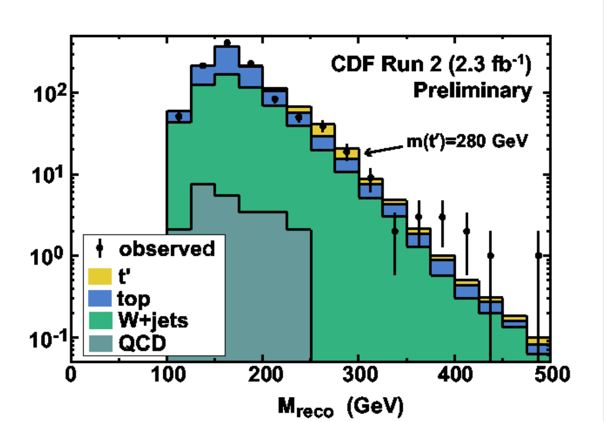
Search for Heavy Top t'→Wq

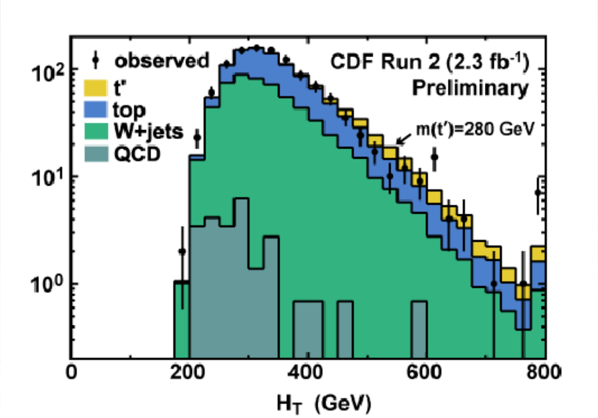
2.3 fb^{-1}

- Motivated in various BSM: Little Higgs model with t-parity, "Beautiful Mirrors" model
- EWK precision data don't exclude fourth generation.

- Use Lepton+Jets final state
- Two-variable search:
  - Reconstructed top mass
  - H_T (total transverse energy)



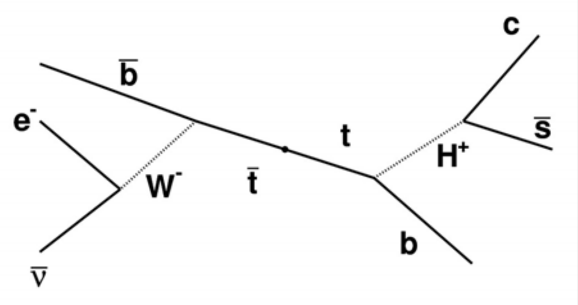


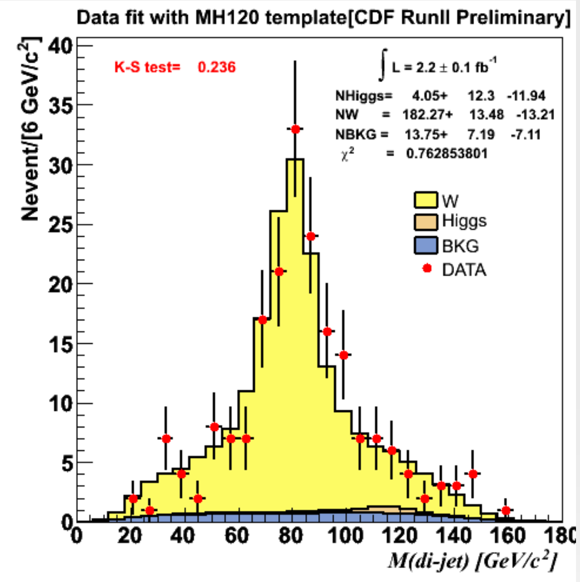


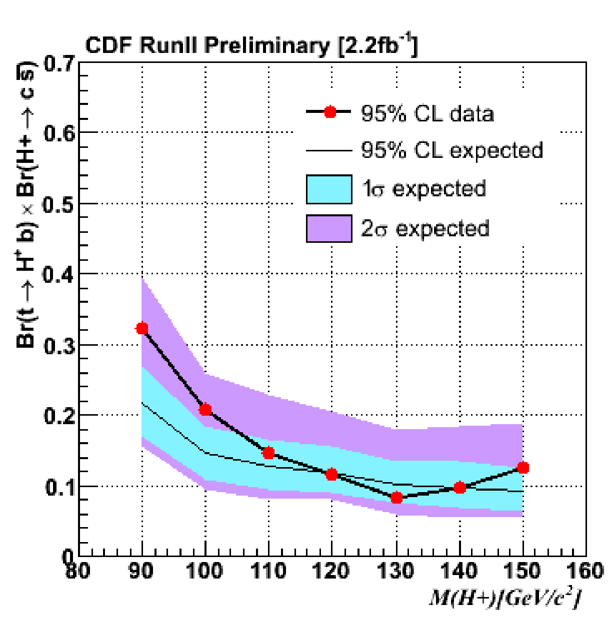
Charged Higgs Searches

2.2 fb^{-1}

- Search for $H^+ \to cs$
  - In the MSSM, predicted for charged Higgs in low tan β around unity.
  - Assume BR($H^+ \to cs$) = 1

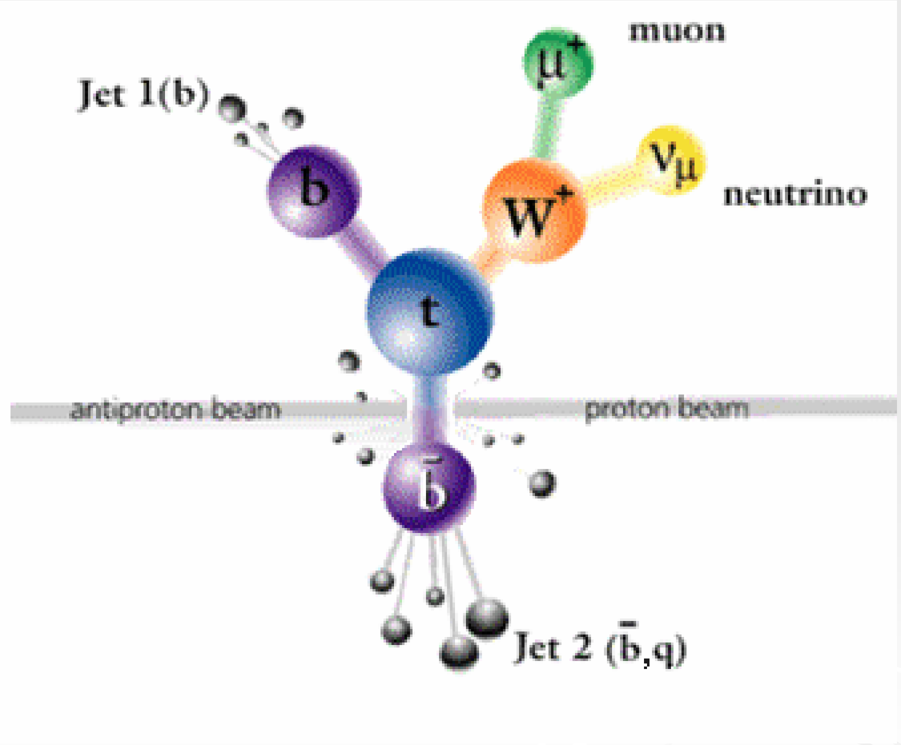


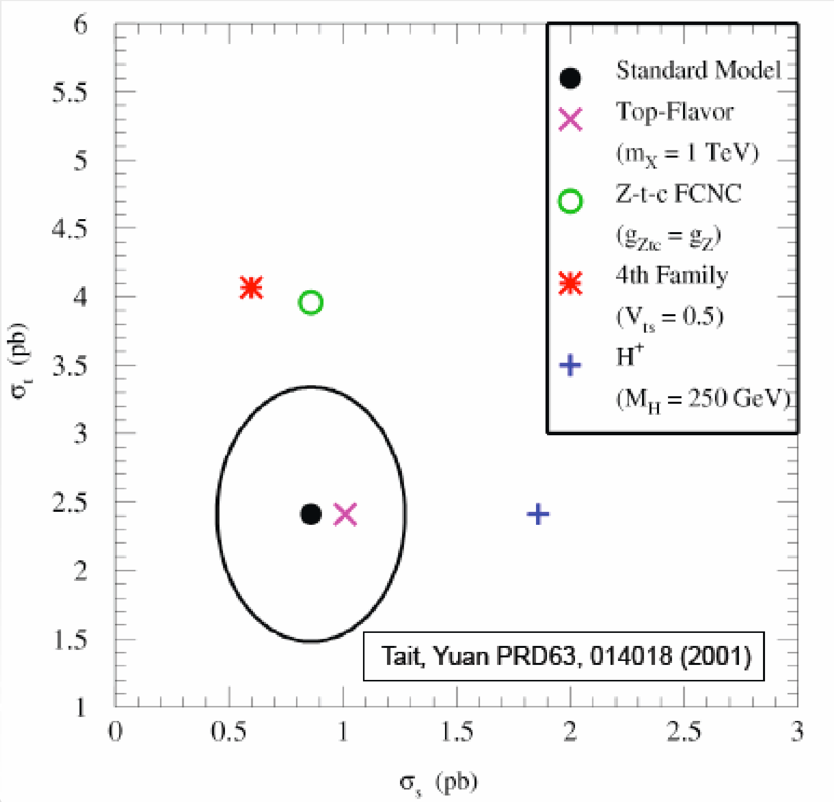




- Template fit to the dijet invariant mass in Lepton+Jets channel
  - No evidence for H^+ signal in data

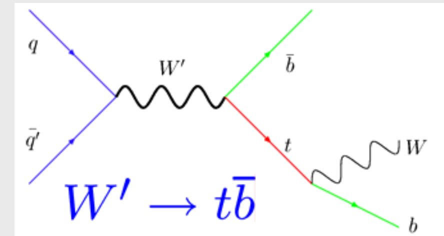
Search for Beyond the SM Physics With Single Top Sample



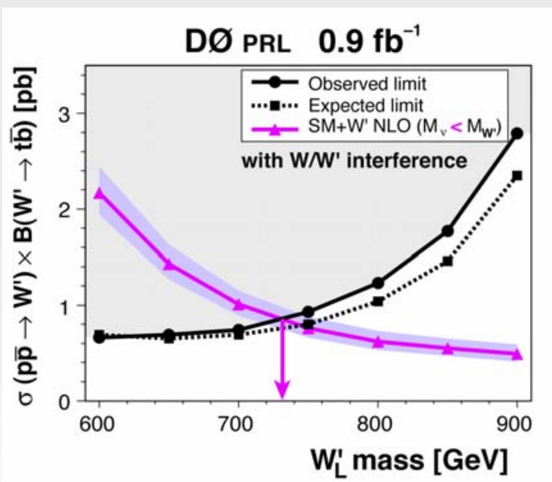


W'-like Resonances

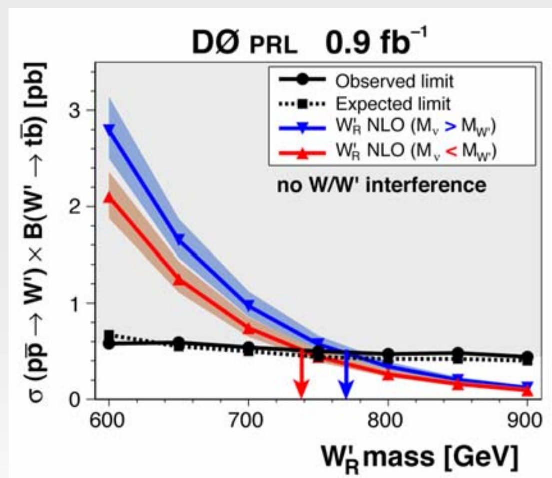
- Many theories predicts W′ : massive W-like boson (PRD 10, 275 (1974); PRD 11, 566 (1975); PLB 385, 304 (1996) etc.)



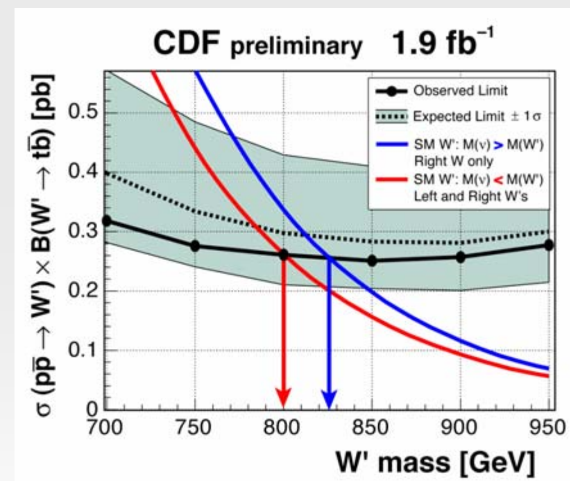
- Search for resonant tb production: W′ →tb
    - LH couplings: D0 include interference with SM W in the signal model
    - RH couplings: decay to $\nu_R l$/qq depending on mass of ν_R
- **Set 95% exclusion limits on W′ production and it's coupling to fermion**



$$M_{W'_L} > 731 \quad GeV/c^2$$



$$M_{W'_R} > 739 \quad GeV/c^2, \quad M_{W'_R} > M_{\nu_R}$$
$$M_{W'_R} > 768 \quad GeV/c^2, \quad M_{W'_R} < M_{\nu_R}$$



$$M_{W'_R} > 800 \quad GeV/c^2, \quad M_{W'_R} > M_{\nu_R}$$
$$M_{W'_R} > 820 \quad GeV/c^2, \quad M_{W'_R} < M_{\nu_R}$$

Anomalous Wtb Coupling in Single Top Production

0.9 fb^{-1}

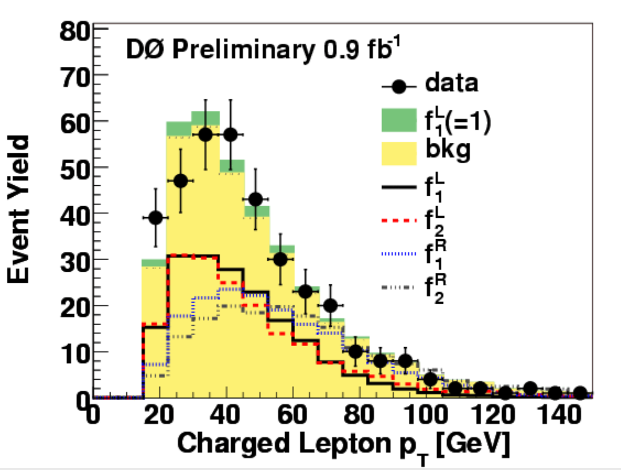
- Assume single top production proceeds exclusively through W exchange, $|V_{td}|^2+|V_{ts}|^2 << |V_{tb}|^2$ and CP conversation.

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

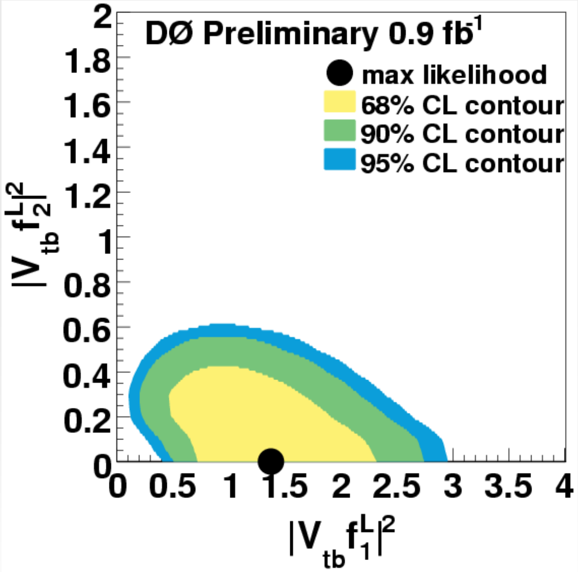
$$In \quad the \quad SM \quad f_1^L = 1, \quad f_2^L = f_1^R = f_2^R = 0$$

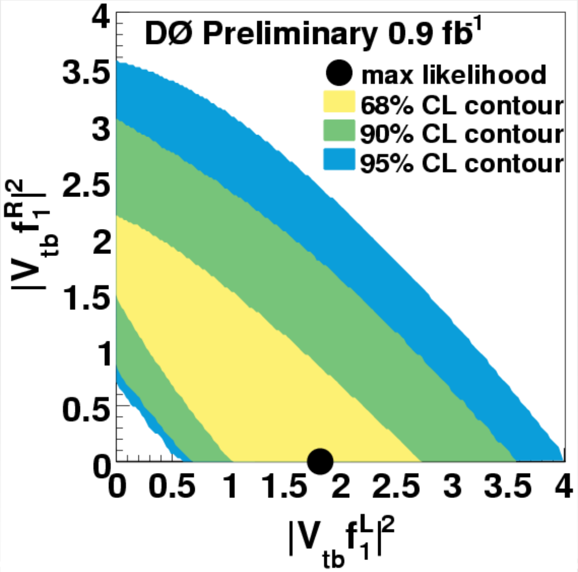
- Look at two couplings at a time, assuming other two as negligible
  - Allow the SM coupling f_1^L and any one of the three non-SM couplings
    - Three cases considered: (L_1,L_2), (L_1,R_1), (L_1,R_2)
- Use single top selection with boosted decision tree (BDT)
  - Described in previous talk
- Use lepton P_T to distinguish signals with different couplings
  - All the BDT variables used in the single top search are also used

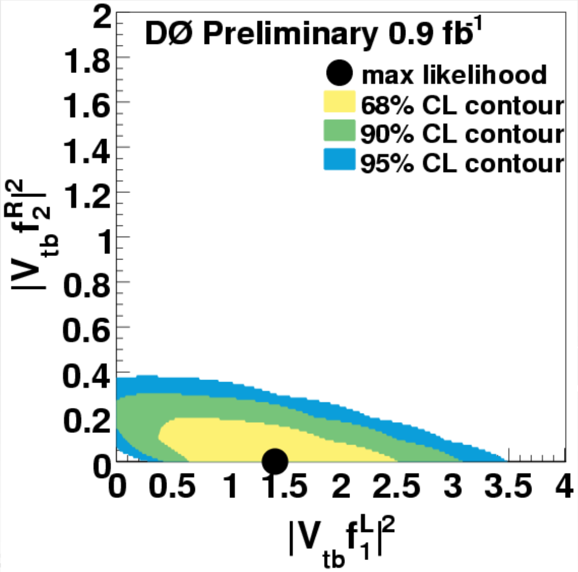
Anomalous Wtb Coupling (cont')



Scenario	Cross Section	Coupling
(L_1, L_2)	$4.4^{+2.3}_{-2.5}$ pb	$\lvert V_{tb} f_1^L \rvert^2 = 1.4^{+0.6}_{-0.5}$
		$\lvert V_{tb} f_2^L \rvert^2 < 0.5$ at 95% C.L.
(L_1, R_1)	$5.2^{+2.6}_{-3.5}$ pb	$\lvert V_{tb} f_1^L \rvert^2 = 1.8^{+1.0}_{-1.3}$
		$\lvert V_{tb} f_1^R \rvert^2 < 2.5$ at 95% C.L.
(L_1, R_2)	$4.5^{+2.2}_{-2.2}$ pb	$\lvert V_{tb} f_1^L \rvert^2 = 1.4^{+0.9}_{-0.8}$
		$\lvert V_{tb} f_2^R \rvert^2 < 0.3$ at 95% C.L.







Data favors the SM coupling

Summary and Outlook

- Top quark properties are currently being studied at Tevatron
  - Top mass measured in different final states and using different methods
    - Mass measured to 0.8% precision
    - Good consistency among all measurements
  - Other properties of top quark are studied and new physics searches are performed using top sample
    - Almost all the measurements are limited by statistics at present
  - Increasing data from Tevatron will further help reveal the true nature of top quark $\Rightarrow$ **Expect 6-8 fb^{-1} by the end of Run II**
- LHC will open up a new era of Top quark physics $\Rightarrow$ Top factory
  - Top is a standard candle, tool for calibrating JES, b-tagging
  - All the properties measurements and new physics searches would enter a new level of precision and sensitivity
    - Understanding of systematic uncertainties would become crucial
- Tevatron's top physics program and understanding of systematic effects will continue to play a significant role for years to come