Top physics at CDF

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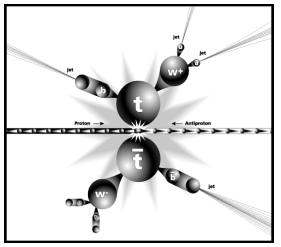
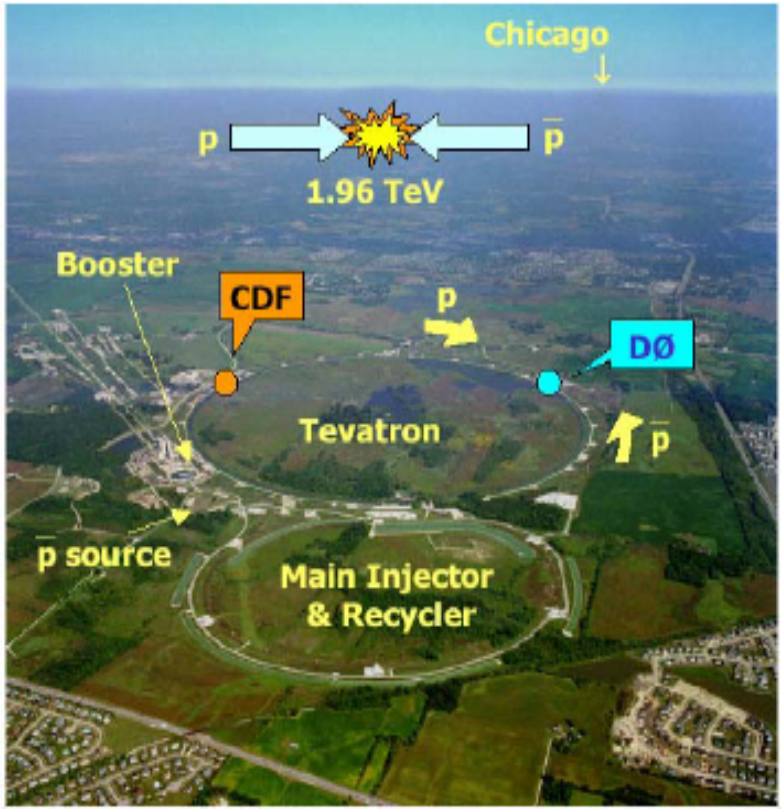
(CDF Collaboration)

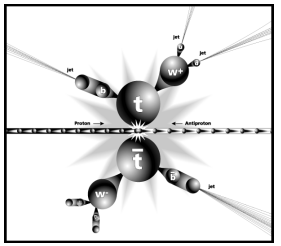
Outline

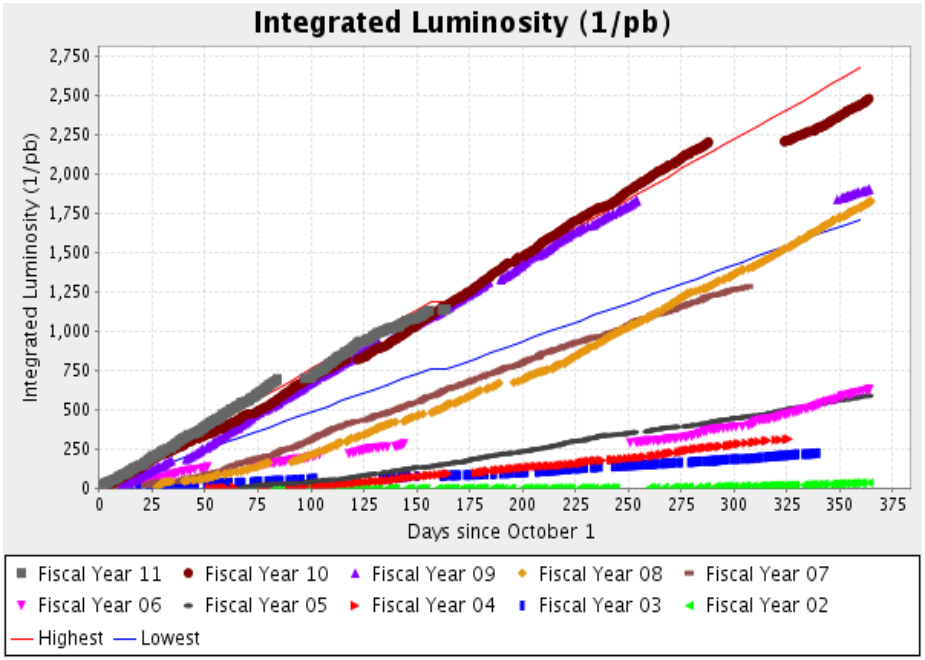


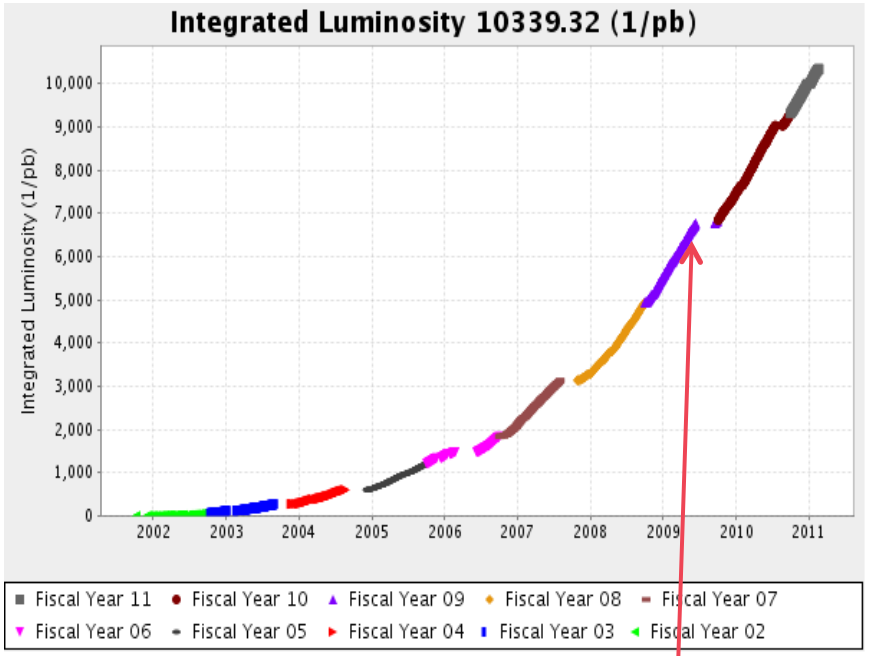
- **Introduction**
  - Tevatron and its current status: Winter 2011 – O(2000) top events are analyzed - very clean samples if SVX b-vertex found (better two)
  - Top quark is special
  - Production and decay modes at the Tevatron
- **Top Mass**
  - Reconstruction Techniques, Systematic Uncertainties
  - What mass is measured?
  - Top events for JE calibration/resolution
- **Is it really SM top?**
  - A_{FB}
  - Properties
- **Summary**



Current Tevatron Luminosity



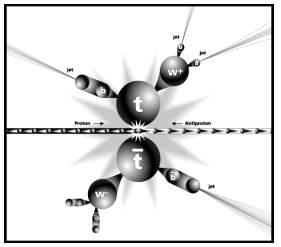


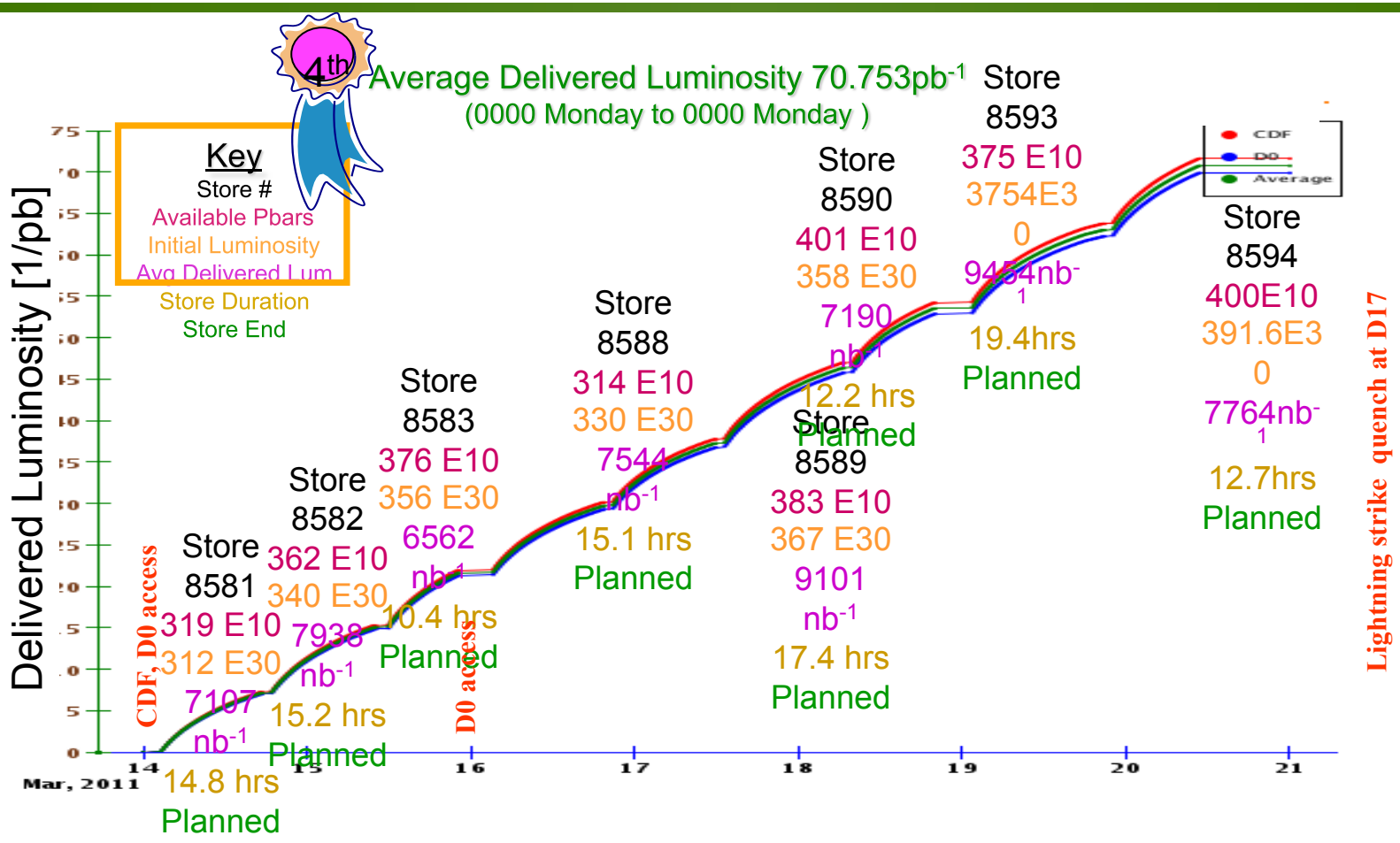


You are here

- Tevatron Winter 2011: 10 fb^{-1}
- CDF& DØ: ~9 fb^{-1} on tapes
- Until Sep. 2011: Tevatron ~ 11 fb^{-1} ; Detectors: ~10 fb^{-1}

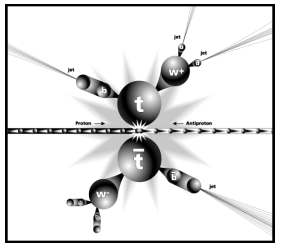
March 2011 week



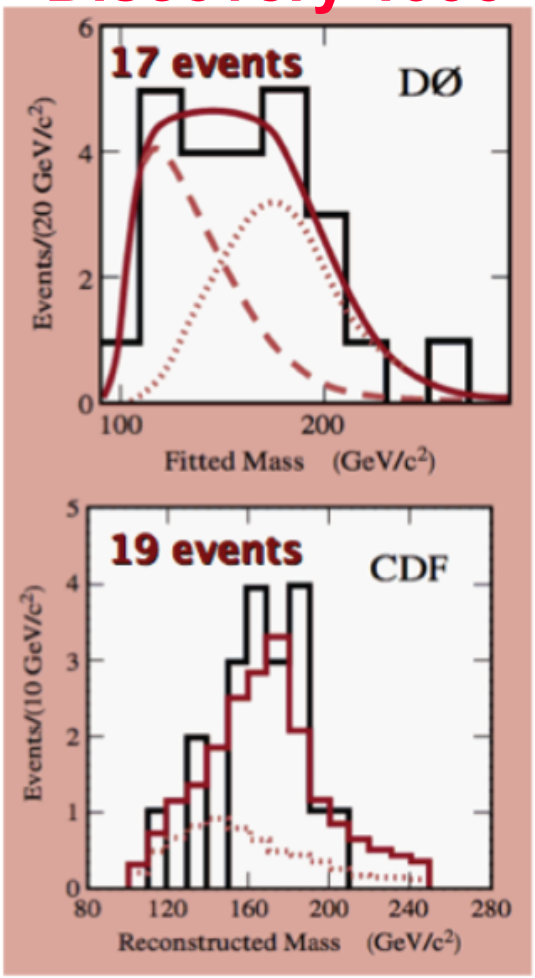


Best weeks ~ 70 pb^{-1}

Top quark

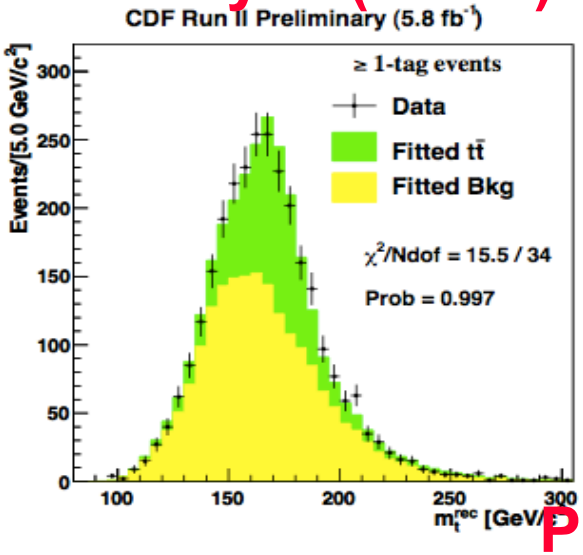


Discovery 1995

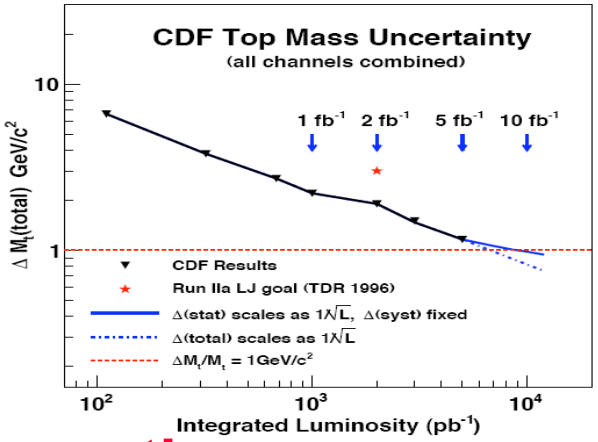


1995, CDF and DØ experiments, Fermilab

Today~O(2x10³)



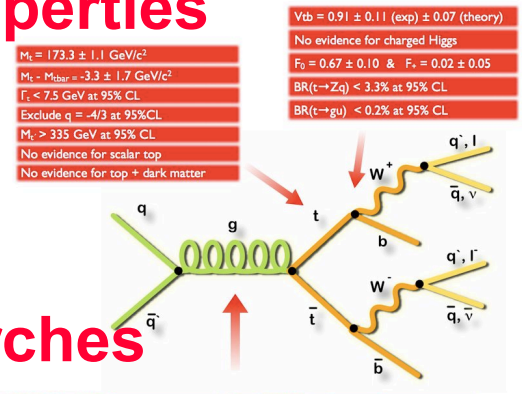
Precision measurement



New phenomena?

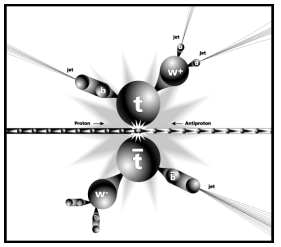
Hints, excesses

Properties

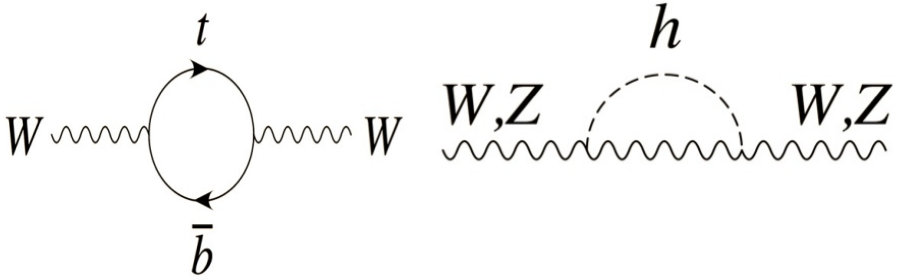


Searches

Why measure the t quark mass?



- The top quark mass is a fundamental parameter of SM – indirect determination: 5.5%, SM consystensy check
- Top and W mass measurements constrain the mass of the Higgs Boson

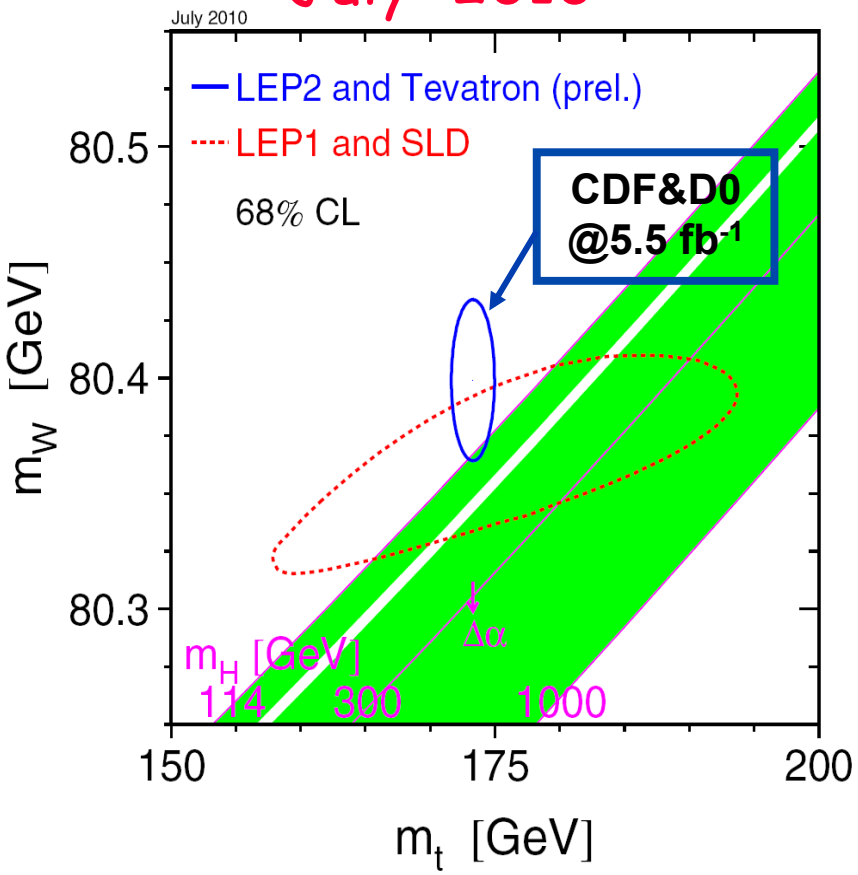


- Top is the only fermion with a mass on the order of the EW symmetry breaking scale
  - M_{top} ~ VEV of the Higgs field – special role of the top quark?

$$M_{top} \approx M_{gold\ atom}$$

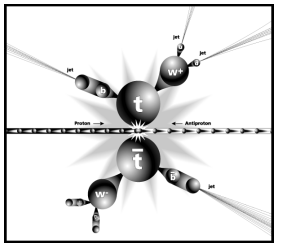
- The result can be used for future detector calibrations

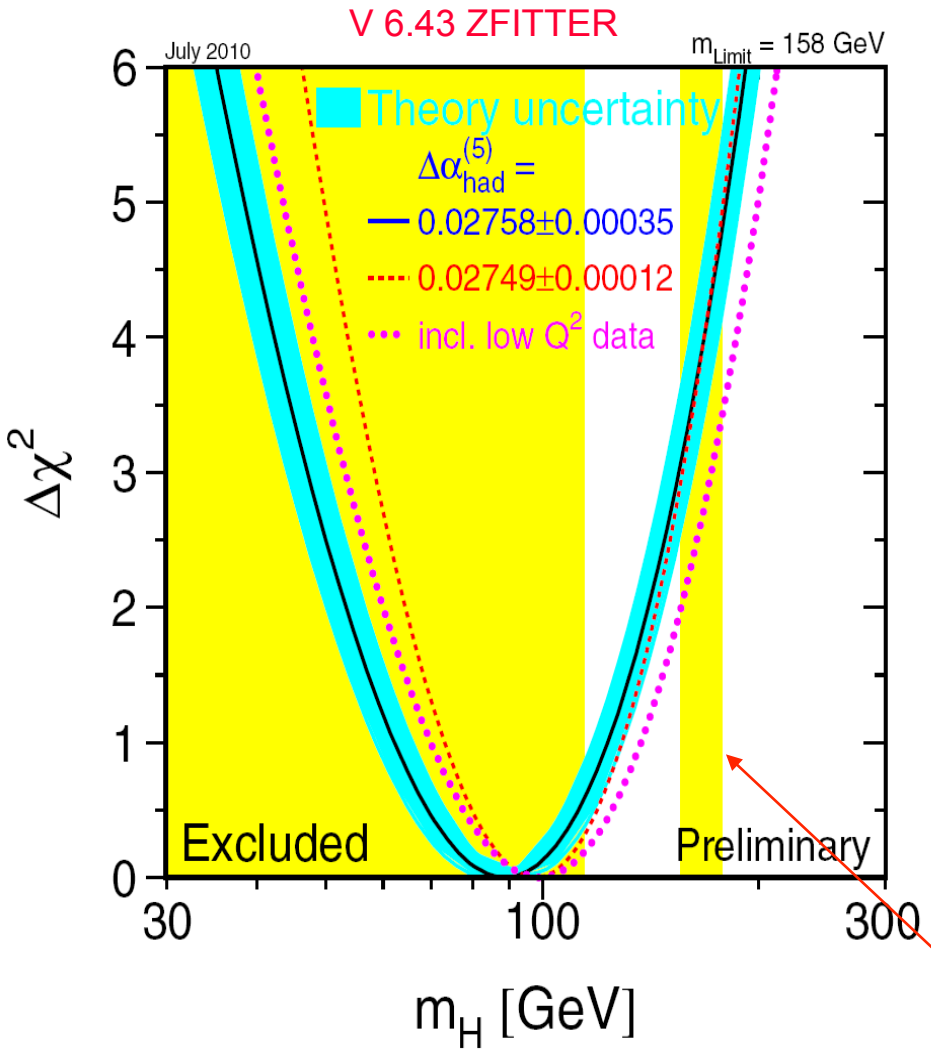
July 2010



Improved W mass measurements is critical

Summer 2010: Higgs limit





New world average

m_t = 173.1 ± 1.1 GeV/c^2

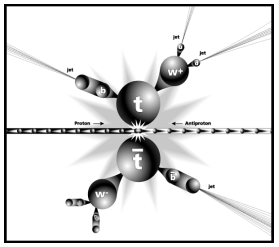
m_{top} = 178.0 ± 4.3 GeV/c^2
m_H = 114^{+60}_{-38} GeV 2004
m_H < 260 GeV @ 95%C.L.

Δm_{top} = 0.6% $\Delta m_{H(limit)}$ = 60%

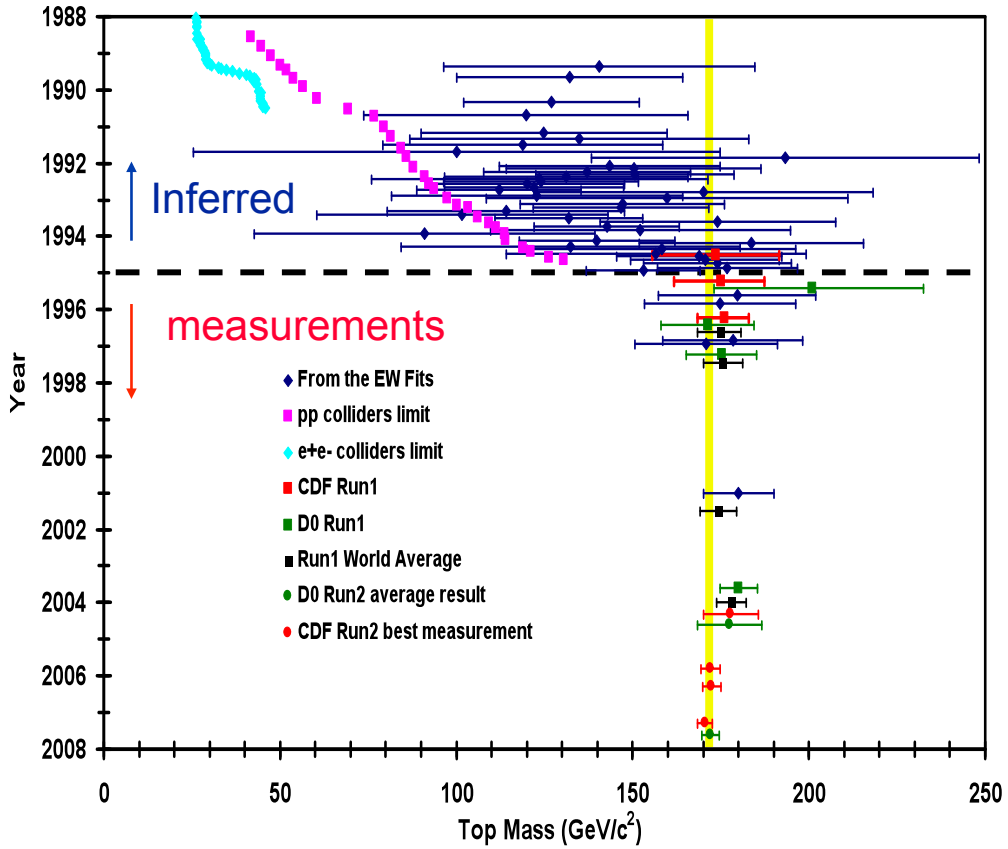
m_{top} = 173.1 ± 1.1 GeV/c^2
m_H = 89^{+35}_{-26} GeV 2010
m_H < 157 GeV @ 95% C.L.

TeV excluded-Winter 2011

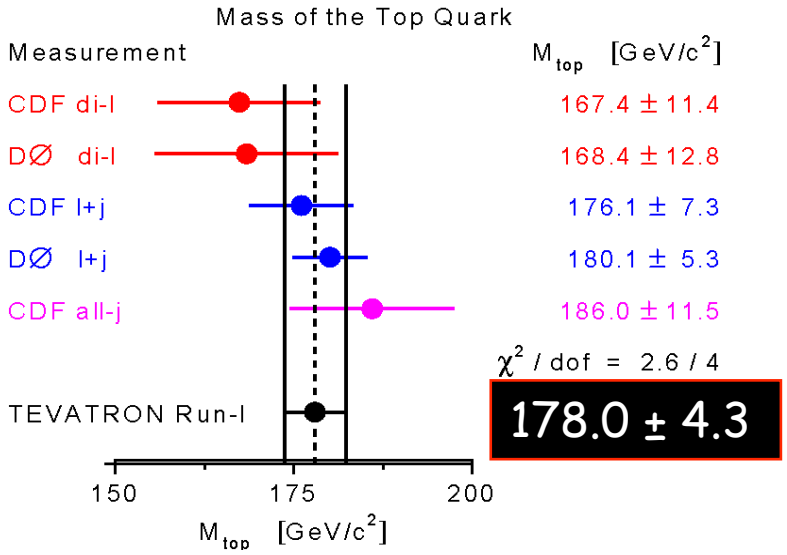
Mass - History



Top mass history

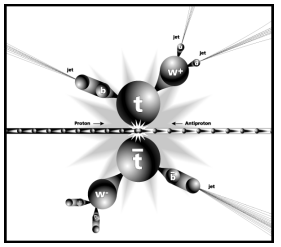


- Run1 analysis on the sample of ~100 pb^{-1} collected by CDF and DØ
  - Lepton + jets data
  - Matrix Element type analysis technique *Nature* 429, **638-642** (2004)



The summary of EW fits (up to 1995) is from: hep-ph/9704332

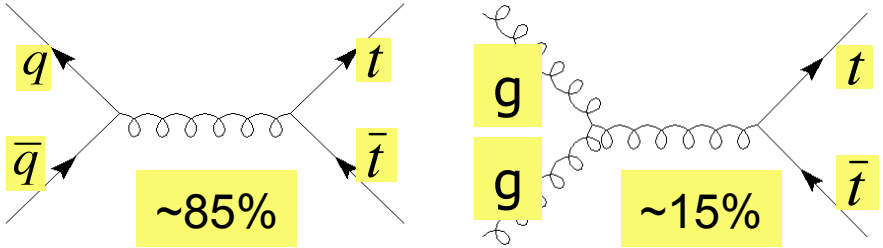
Production and decay modes



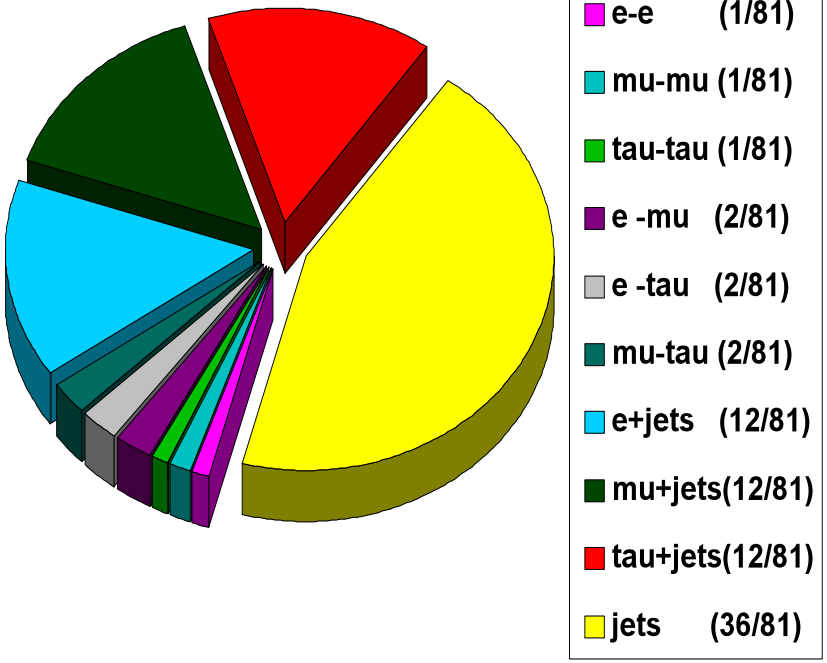
- Tevatron production
  - $q\bar{q}$ annihilation (85%) + gluon fusion(15%
- Since the top lifetime

  $\tau_{top} \sim 10^{-24} < \tau_{qcd} \sim 10^{-23}$

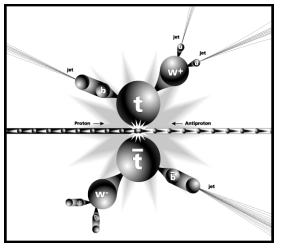
the top quark decays before hadronizing!



- Different final states 3^4 (assuming e,μ,τ and jets)
- BP(t →Wb) ≅100 %
  - Both W's decay via W→ℓ ν
    - ℓ ν ℓ νbb - DILEPTON, S/B = 1/1
  - One W decays via W →ℓ ν
    - ℓ ν qq bb - LEPTON+JETS, S/B = ¼
    - ℓ ν qq bb - MET+JETS, S/B = 1/10
  - Both W's decay via W →qq'
    - qq qq bb - ALL HADRONIC, S/B = 1/100

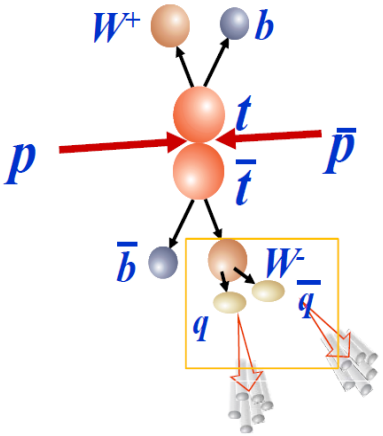


Top kinematics



- Lepton + Jets – (2 CF)
  - 4 jets from one W and two b quarks → 12 jet-parton permutations x 2 neutrino P_z solutions = 24 combinations
  - Use b-tagging to reduce permutations:
    - **1 b-tag: 12 solutions**
    - **2 b-tags: 4 solutions – golden sample**
- Dilepton
  - Two neutrinos → unconstrained system – (-1 CF)
- All Hadronic – 120 combinations (3 CF)

Particles	Unknowns
t's	7
X	2
W's	6
b's	0
q's	0
l	0
ν	3
Total	18



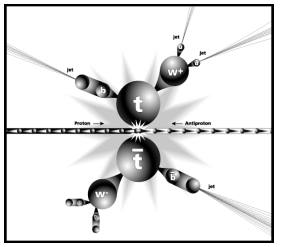
5 vertices

$m_{lν}=m_W$

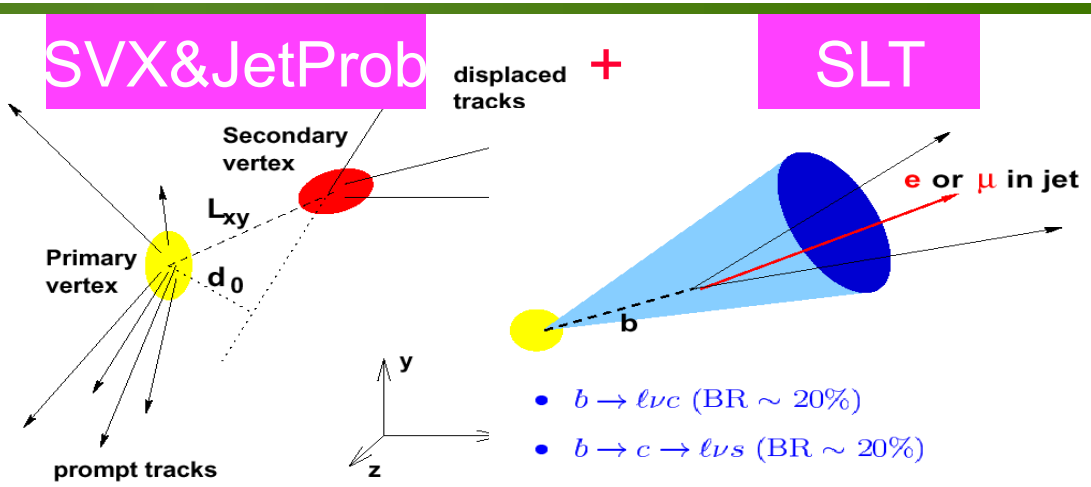
$m_{jj}=m_W$

$m_{t1}=m_{t2}$

b-tagging

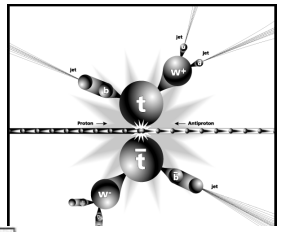


- b tagging improve signal to background ratio significantly
  - 40% eff. with 0.5% mistag rate
  - 60% eff. for ttbar (>=1btag)



Sample	Di-lepton (e,μ)	Lepton+jets (e,μ)	All Hadronic NN selection
0-b-tags S/B	1:1	1:4	1:20
1-b-tags S/B	4:1	4:1	1:5
2-b-tags S/B	20:1	20:1	1:1
Events in 1 fb^{-1} ($\geq$ 1 b-tag)	25	180	150 (2 b-tags)

Top Mass Reconstruction Techniques

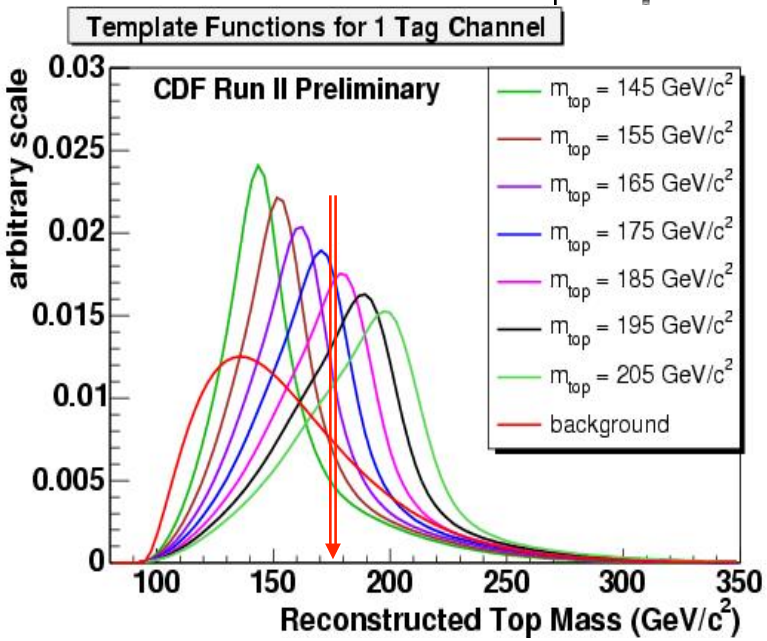


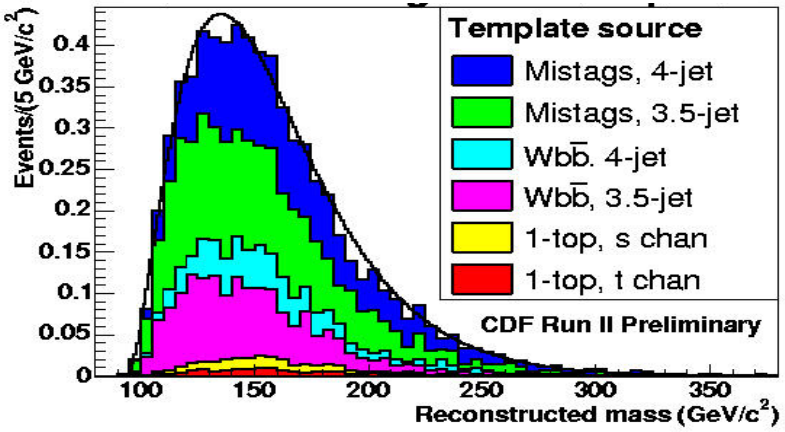
- Template method – data are compared with signal and background
- Example:
  - Reconstruct invariant top mass in each event.
    - **Compute χ^2 as follows:**

$$\chi^2 = \Sigma_{i=\ell,4jets}\frac{(p_T^{i,fit}-p_T^{i,meas})^2}{\sigma_i{}^2} + \Sigma_{j=x,y}\frac{(p_j^{UE,fit}-p_j^{UE,meas})^2}{\sigma_j{}^2} + \frac{(M_{jj}-M_W)^2}{\Gamma_W^2} + \frac{(M_{\ell\nu}-M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj}-M_t)^2}{\Gamma_t^2} + \frac{(M_{b\ell\nu}-M_t)^2}{\Gamma_t^2}.$$

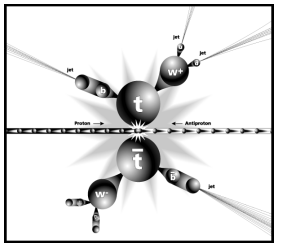
    - **Use kinematic constraints**
    - **Minimize with M_t as a free parameter**
  - Create templates (Prob. Density Functions):
    - **plot M_t for the minimal χ^2 and create p.d.f s**
      - ✓ **signal distributions for different simulated top masses - HERWIG, PYTHIA**
      - ✓ **background distributions – ALPGEN,data**
  - Using the PDFs perform LH shape analysis to obtain the most probable value from the data

$$L_{shape} = \prod_{i=data}\prod_{ev.}\left((1-x_b)f_s(M_t^i, M_{top}) + x_b f_b(M_t^i)\right)$$





Top Mass Reconstruction (cont.)



- Calculate the probability per event
- Examples: DØ & CDF ME analyses
  - using maximal event information, e.g. it takes into account event-by-event resolution effects

Dalitz, R. H. & Goldstein, G. R., Proc. R. Soc. *Lond. A* **445**, 2803 (1999)

K. Kondo, *J.Phys. Soc.* **57**, 4126 (1988) (Dynamical Likelihood Method)

Probability density per event

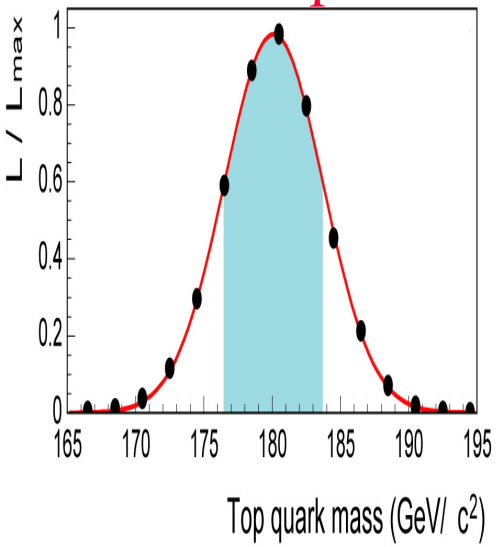
ttbar matrix element

$$L^i(M_{top}) = \sum_{I_t}\sum_{I_s}\int \frac{2\pi^4}{Flux} \underbrace{F(z_a, z_b) f(p_T)}_{\text{PDFs}} |M|^2 \, w(I_t, \mathbf{x} \,|\, \mathbf{y}; M_{top}) d\mathbf{x}$$

Sum over all possible parton states

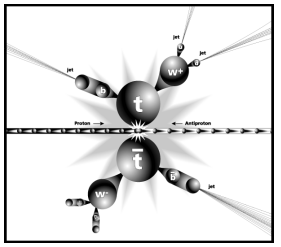
Transfer function: the probability for a measured variable ***x*** to arise from a parton level variables ***y*** ***(energy resolution, etc…)***

Example

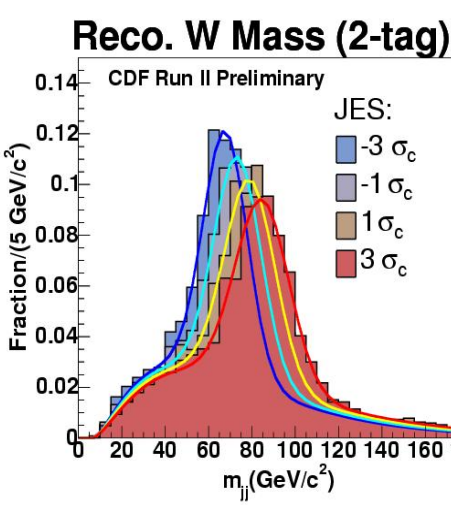


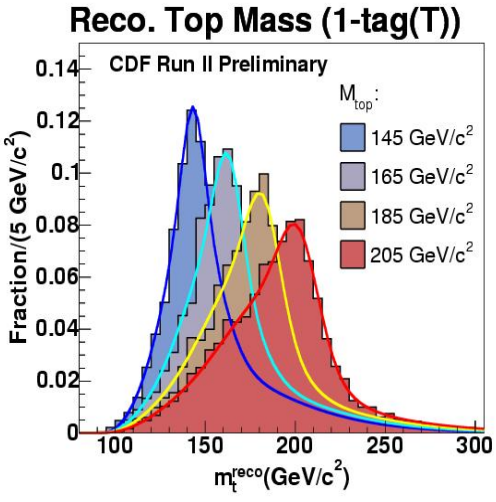
- Sum over all 12 permutations of jets and neutrino solutions
- Background process ME's are (or not) explicitly included in the likelihood
- Top mass: $\Pi_i P^i(M_{top})$

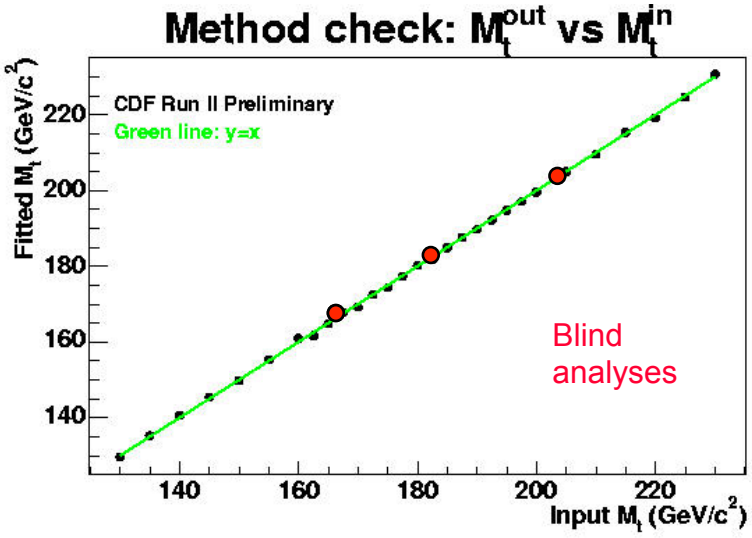
CDF: Template method ≥1 b tag



- Selection criteria
  - one e or μ with p_T > 20 GeV/c
  - 4 jets with E_T > 15 GeV for single tag
  - In case of 2 tags: 4th jet with E_T > 8 GeV
  - missing E_T > 20 GeV
- SVX tag
  - 977 SVX-tagged *tt* candidates & 4.8 fb^{-1}
  - 165.8 ±57.4 estimated background





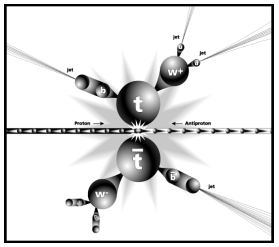


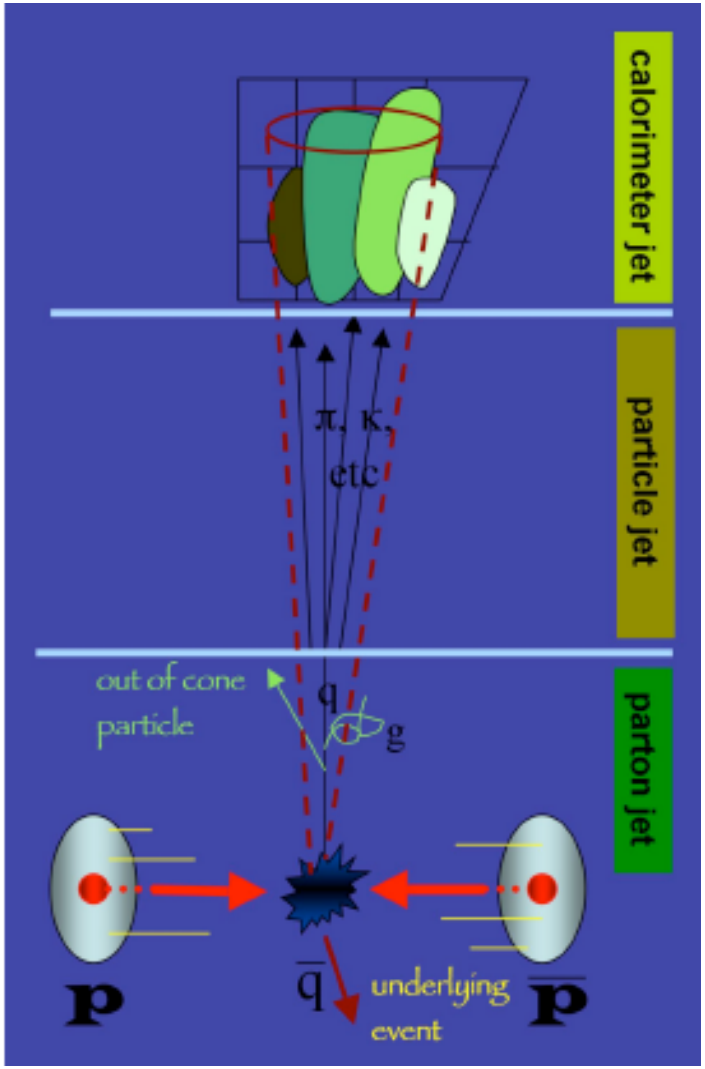
$$\chi^2 = \Sigma_{i=\ell,4jets}\frac{(p_T^{i,fit}-p_T^{i,meas})^2}{\sigma_i^2} + \Sigma_{j=x,y}\frac{(U_j^{fit}-U_j^{meas})^2}{\sigma_j^2} + \frac{(M_{jj}-M_W)^2}{\Gamma_W^2} + \frac{(M_{\ell\nu}-M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj}-m_t^{reco})^2}{\Gamma_t^2} + \frac{(M_{b\ell\nu}-m_t^{reco})^2}{\Gamma_t^2}$$

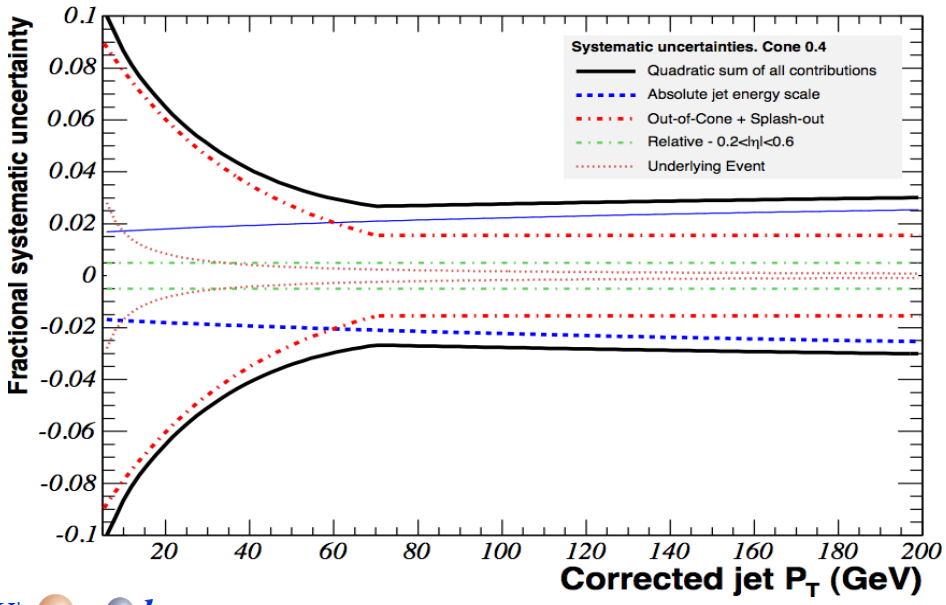
$$P(\vec{x}; M_{top}, \Delta JES)$$

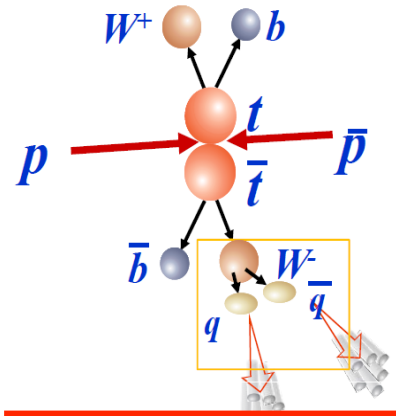
$\vec{x}$ sensitive to Mtop (and JES)

Jet energy scale ♪







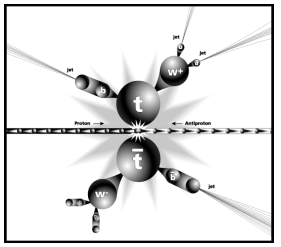


Lepton+jets : 0.5 GeV/c²

Dilepton : 2.2 GeV/c²

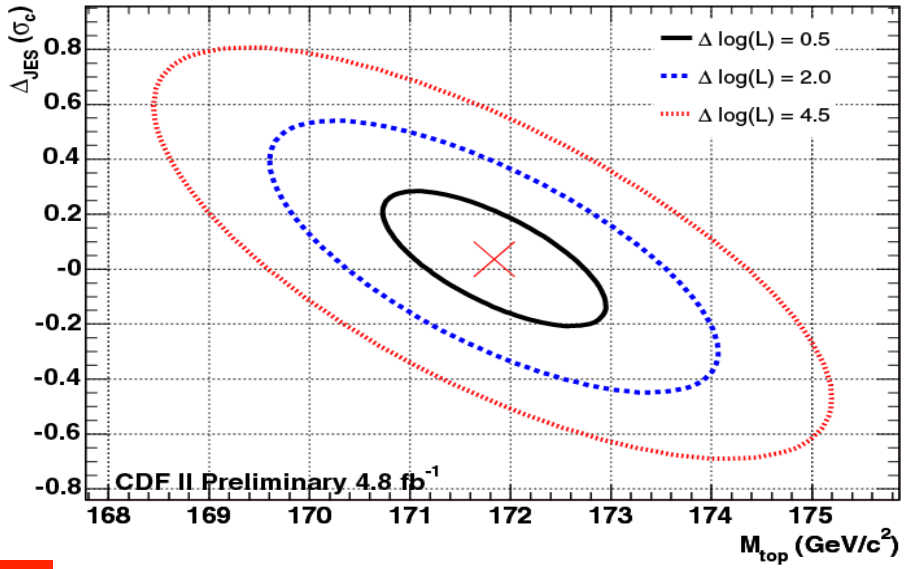
In situ JES calibration ♪

Template method – cont.



- 5.6 fb^{-1} data – Lepton+jets(LJ) Dilepton(DIL)
  - We use MET+jet triggered muon for LJ candidate (30% increasing of acceptance)
  - Chi2(<9) cut was applied for LJ
  - LJ (b-tagged), DIL(pretag)
- Simultaneously use LJ+DIL
- Fully three dimensional PDF using three observables in LJ
  - m_t^{reco}, w_{jj}, $m_t^{reco(2)}$
  - $m_t^{reco(2)}$ is kinematic fit output from different permutation
- W mass is used to calibrate the JES

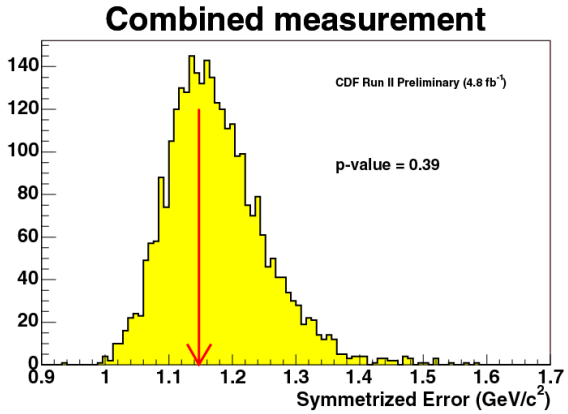
M_{top}^{DIL} = 170.6 ± 2.0(stat) ± 3.1 (syst) GeV/c^2



NEW!

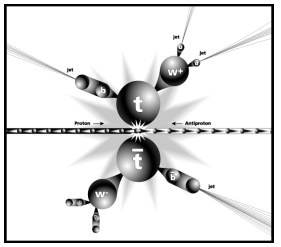
Combined l+jet & Dilepton New Result

M_{top} = 171.9 ±1.1 (stat+JES) ±0.9 (sys) GeV/c^2

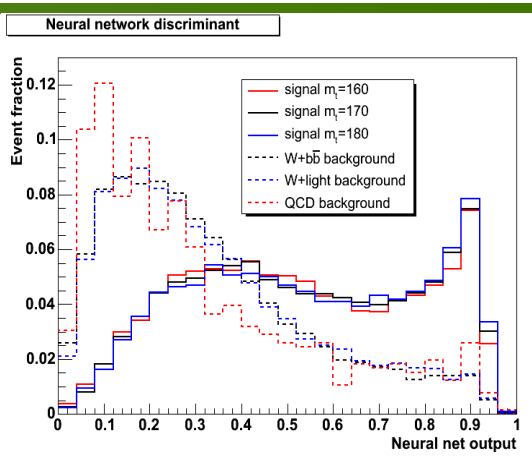


~ 40% of the systematic error comes from the residual jet energy scale

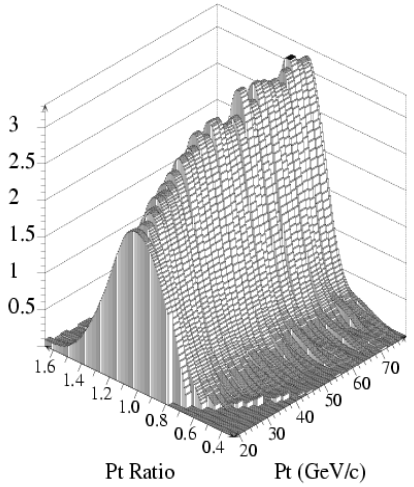
Lepton+jets, ME♪



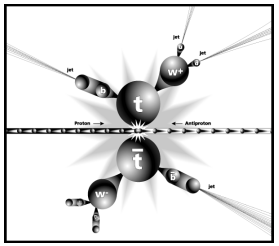
- 5.8 fb^{-1} data – 1070 events
  - CDF increased the muon acceptance by adding MET +jets trigger (30% more events)
  - Additional NN based selection
- Transfer function was parameterized by eta and jet mass for b-jet and light jet
- *In situ* JES calibration
- The method integrates over 19 variables – special integration procedure
- **This is the most precise top quark measurement to date♪**

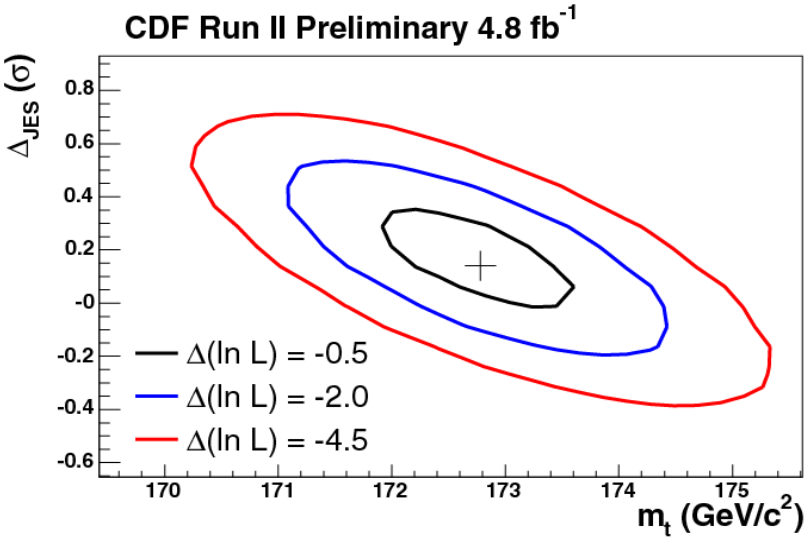


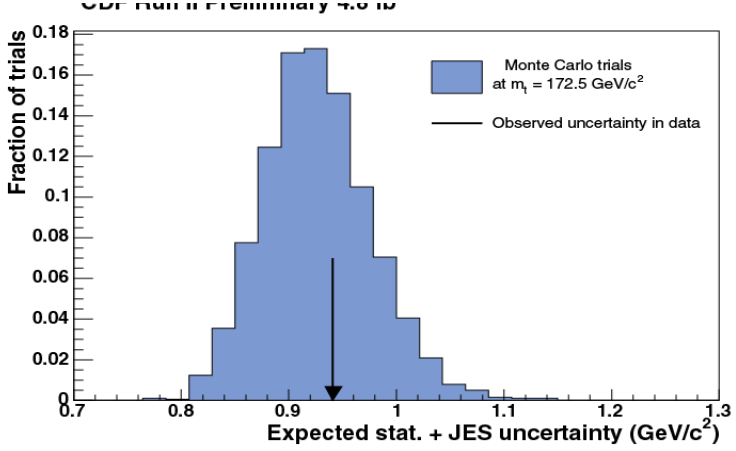
Transfer Function

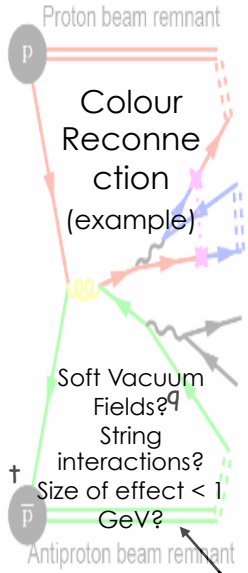


Lepton+jets: ME, cont.







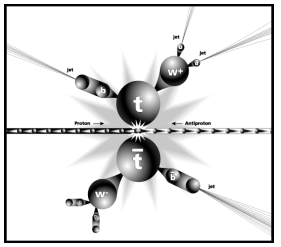


- JES is still the dominant systematic uncertainty
- Color Reconnection takes 2nd place

Systematic Uncertainties	ΔM_{top} (GeV/c²)
Calibration	0.11
MC Generator	0.25
ISR and FSR	0.15
Residual JES	0.49
b-JES	0.26
Lepton Pt	0.14
MHA	0.10
PDFs	0.14
Bkg Modeling	0.33
Gluon Fraction	0.03
Color Reconnection	0.37
Total	**0.84**

M_{top} = 173.0 ±0.7 (stat) ±0.6(JES) ±0.8 (syst) GeV/c²

CDF dilepton channel, template



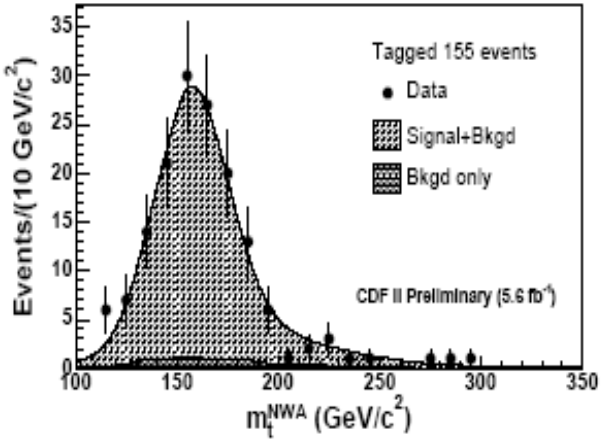
- 5.6 fb^{-1} data, template method
- Two observables taking into account correlation
  - m_t ν weighting and m_{T2}
- Interesting observable m_{T2}
  - Transverse mass with two missing particles
  - Introduced for mass measurement of New physics particles which have two missing particles

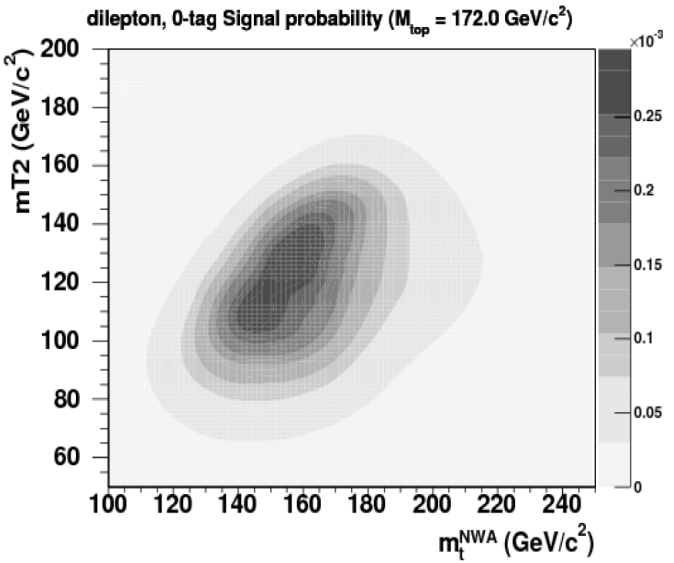
    A. Barr *et. al.*, J.Phys.G 29 (2003) 2343
  - For first time m_{T2} is used in real data

    Phys.Rev.D 81 (2010) 031102

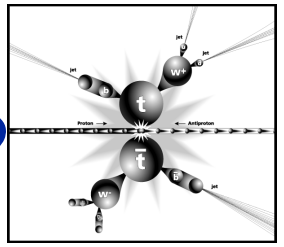
New

M_{top} = 170.3 ±1.9 (stat) ±3.1(syst) GeV/c^2

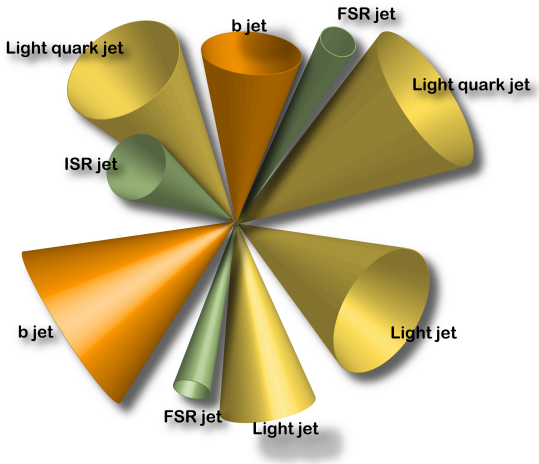


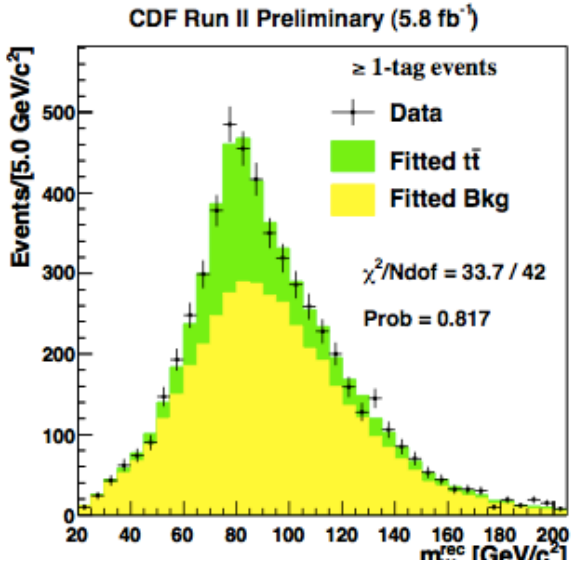


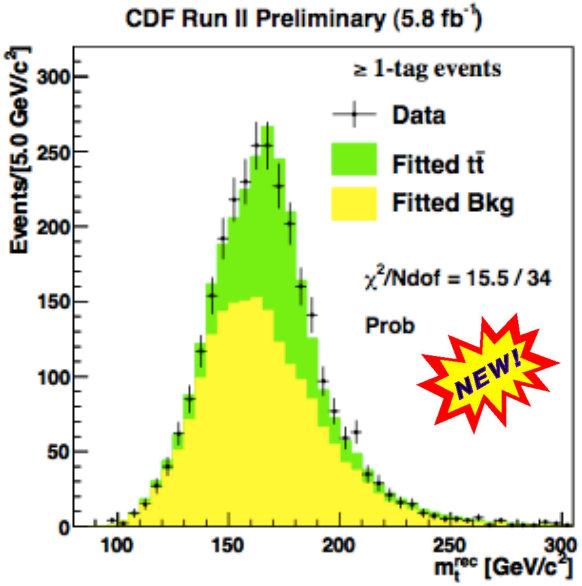
Mtop measurement in tt→bbqqq♪



- 5.8 fb^{-1} date, template method
- Two dimensional template
  - Reconstructed top mass and di-jet mass from W boson decay
- NN discrimination to reduce dominant QCD backgrounds
  - Jet shape to discriminate gluon jet from quark jet
  - 1btag S:B=1:4
  - 2btag S:B=1:1
- Fully reconstruct the kinematics so to reconstruct the top quark mass

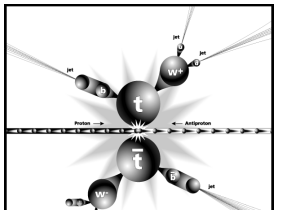


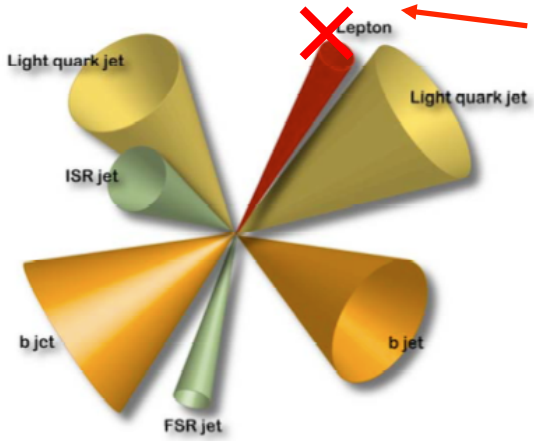




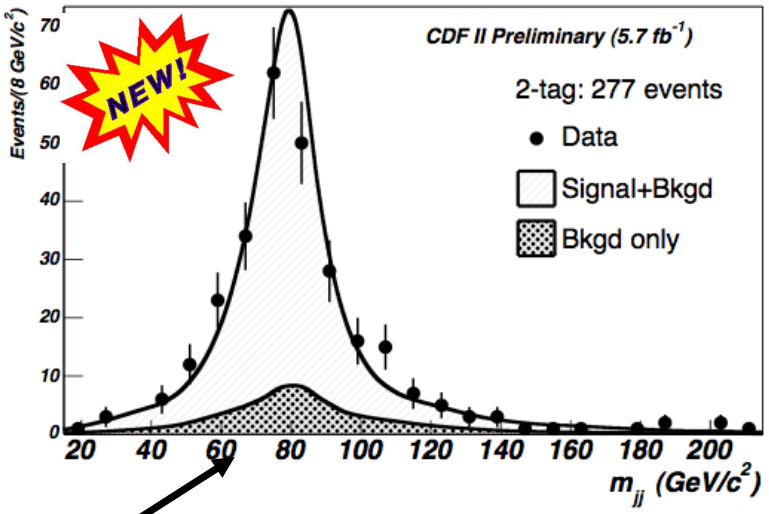
M_{top} = 172.5 ±1.7 (stat) ±1.2(syst) GeV/c^2

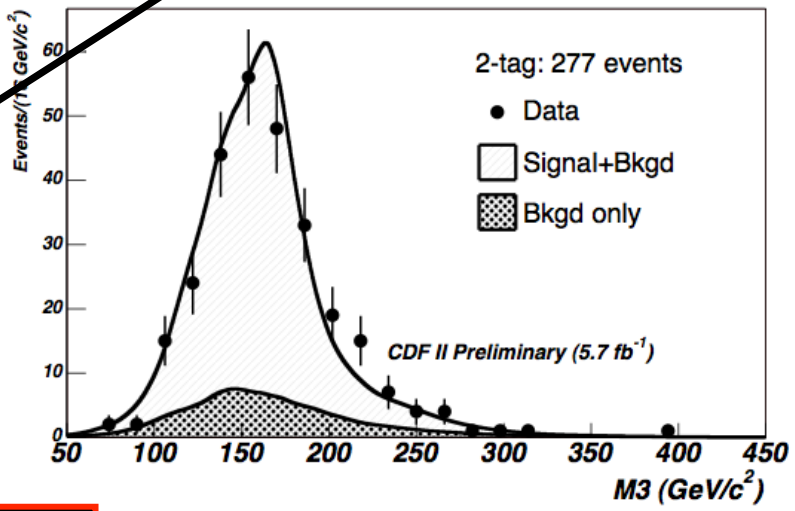
M_{top} measurement in $tt \rightarrow bbqq\not{E}_T$





- Limited lepton ID mostly due to limited detector coverage
- But ttbar events have striking kinematics, and you can still reconstruct one W and one top in this sample

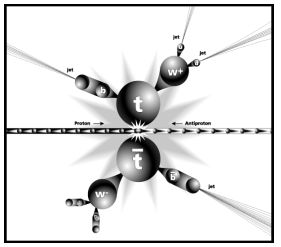




- Choose dijet pair with closest to W mass to measure jet energy scale
- Reconstruct one of the two decaying top to measure the top quark mass!

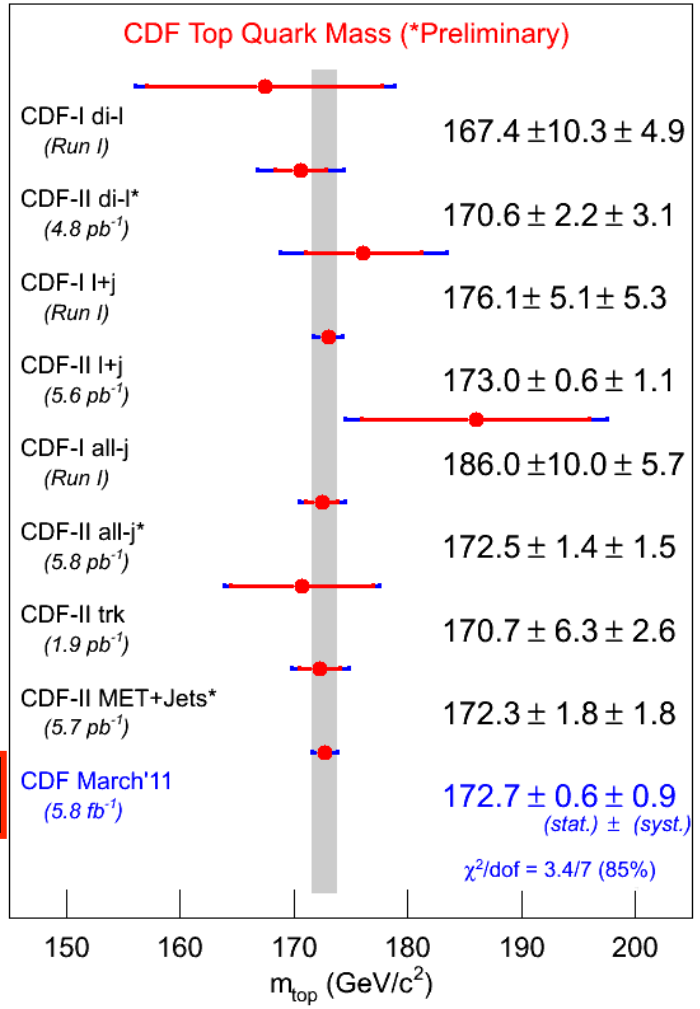
M_{top} = 172.7 ±1.7 (stat) ±1.2(syst) GeV/c^2

Combination – Winter 2011

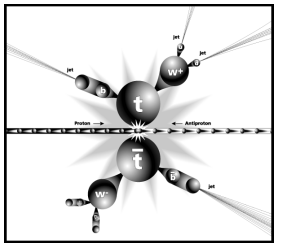


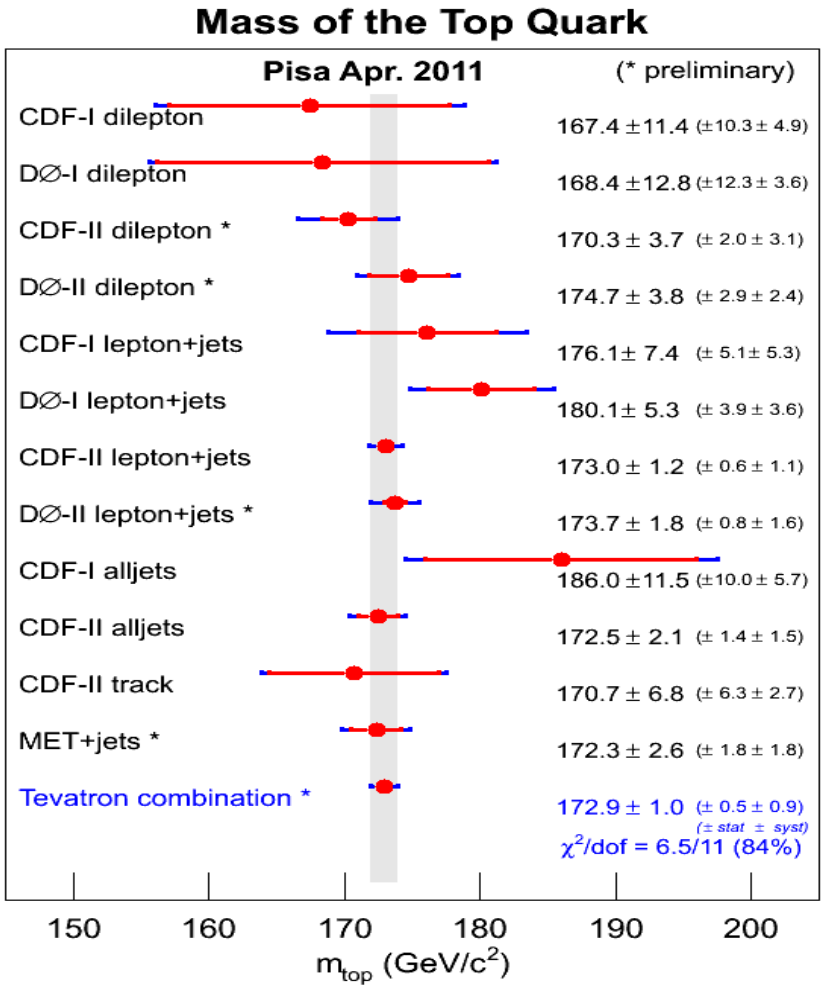
- Combining results obtained in different datasets
  - consistency between 8 analyses
    - **Independent datasets, ~ 2000 top events analyszed!**
    - **with different techniques**
  - robustness
    - **affected by different systematic sources**
    - **W mass to measure jet energy scale**
- Separate channels consistent with each other at >20% level
- $\Delta M_{top}/M_{top}$ = 0.63%

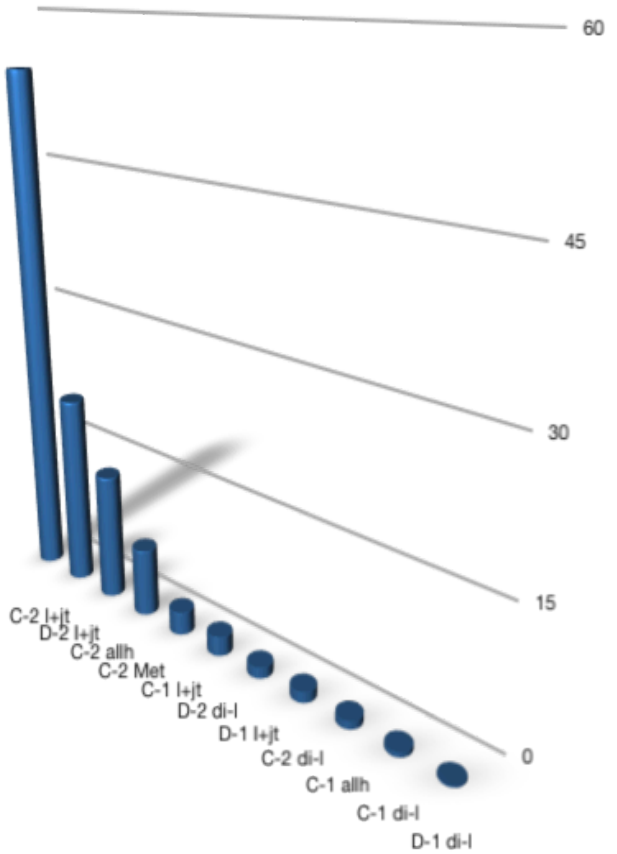
M_{top} = 172.7 ±1.1 (stat+syst) GeV/c^2



CDF&DØ Combination – Pisa 2011*

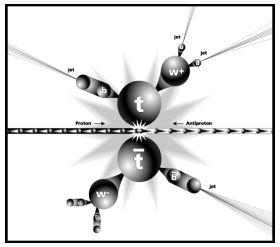




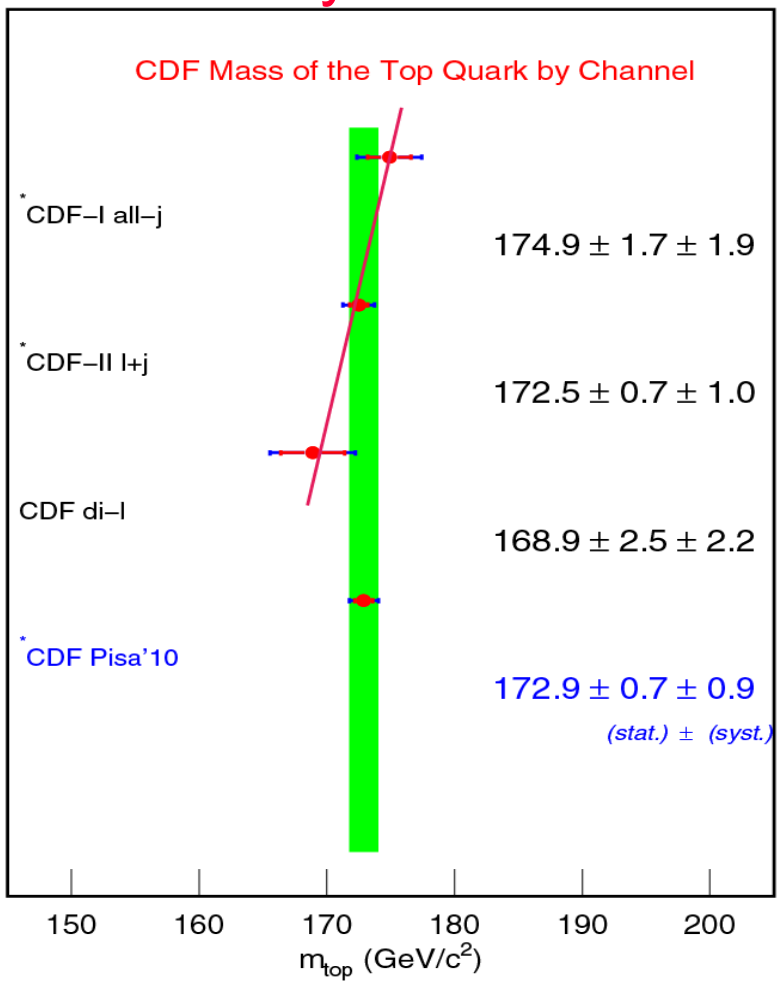


*Unofficial

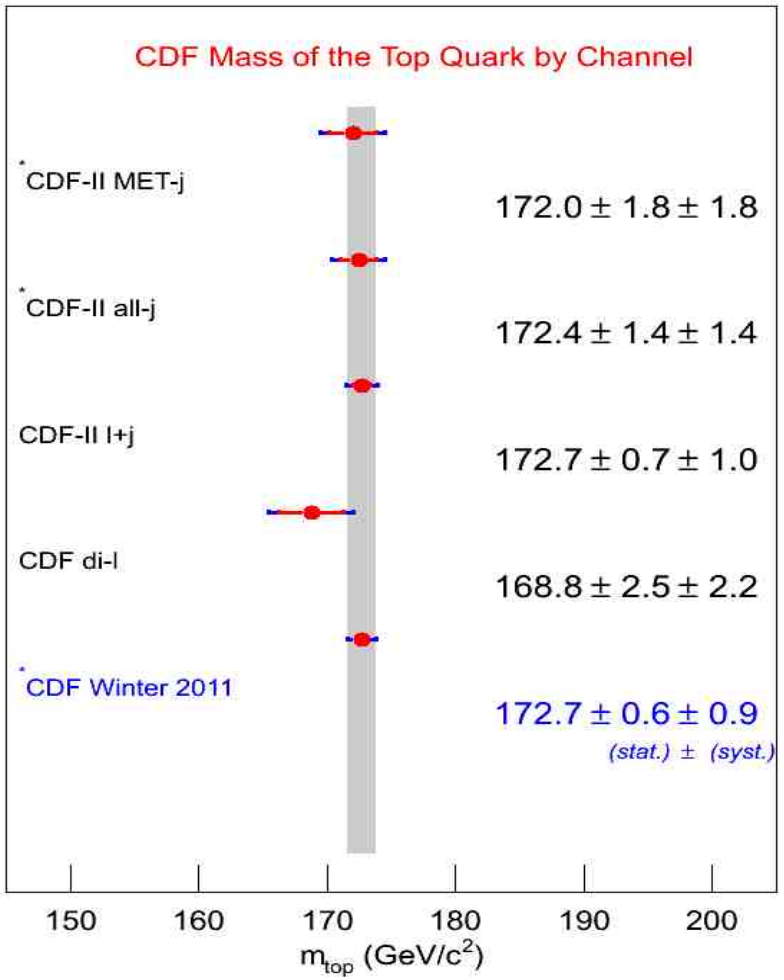
Different channels



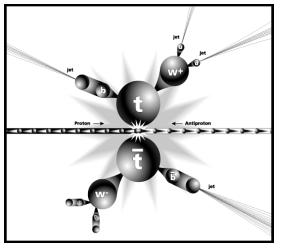
July 2010



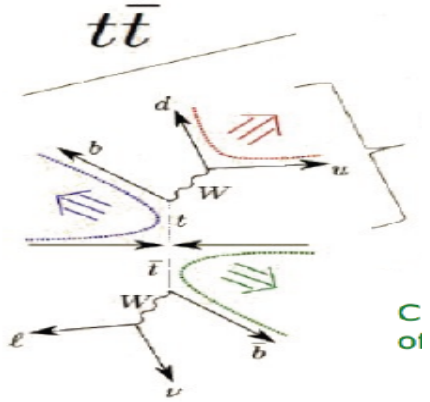
Winter 2011

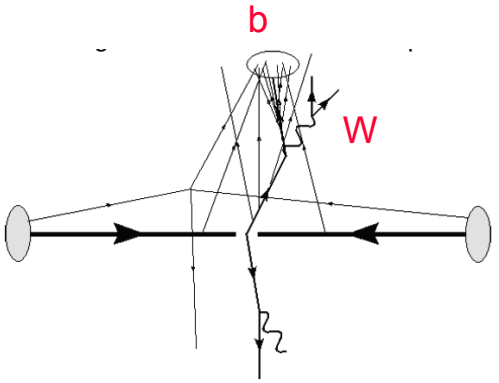


Why is top mass interpretation non-trivial?

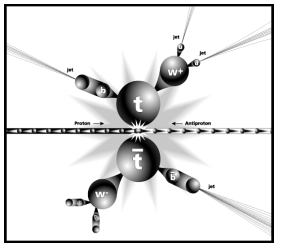


- Confinement
  - Top mass cannot be defined as electron mass
  - Any colored particle is not an asymptotic state is confined on a timescale ~ 10^{-23} s
- Decay
  - top decays to fast to hadronize: $\tau \sim 10^{-24}$ s
  - but its decay products hadronize: t→bW→bjj, and b is color-connected to the rest of the event
- Produce in hadron collision: ISR and underlying event
- Mass depends on QCD renormalization scheme





What mass we measure?



- Parameter to LL parton shower generators? Moreover, what means the input to the MC generators e.g. Pythia, Herwig?
- Common heavy quark mass definitions
  - Pole mass-$p^2=m^2$ – unphysical top being a free parton

$$\longrightarrow = \frac{i}{\not{p} - m + i\epsilon}$$

  - $\overline{\text{MS}}$ running mass (short distance mass)– the divergences are subtracted; It is the most commonly used subtraction scheme

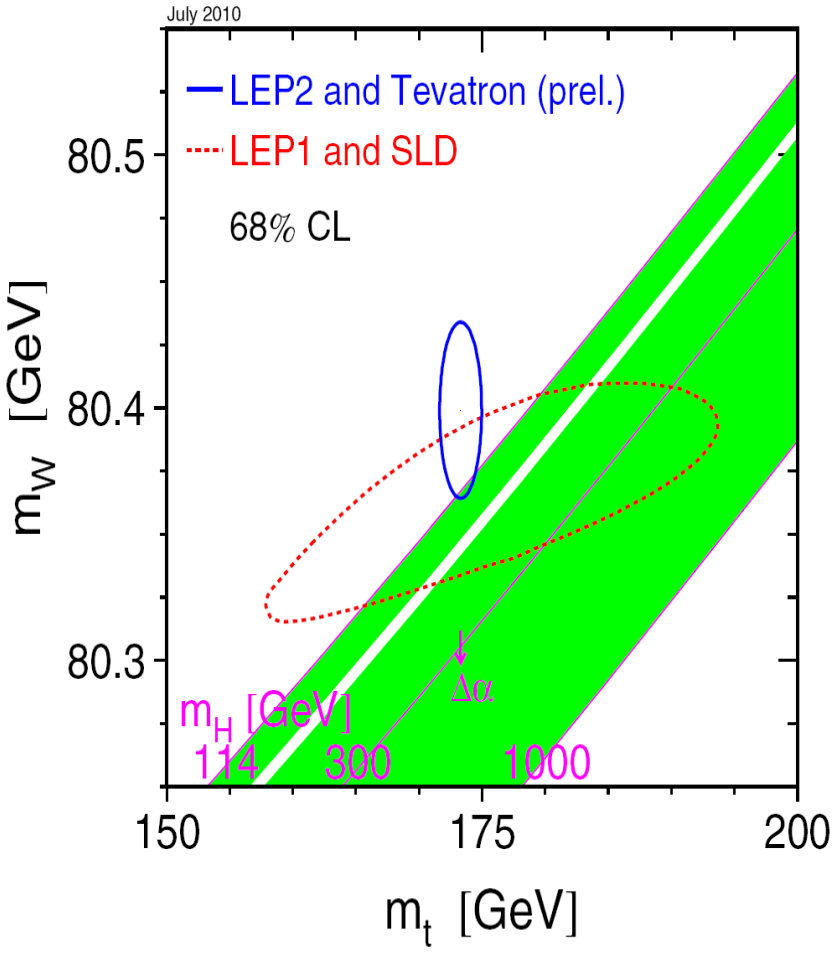
$$\overline{\text{MS}} = m - \delta m$$

- What is measured experimentally? Pole mass –no, parton shower does not evolve the top perturbatively to infinite long distance, stops at some scale Q_0
- Conclusion: top mass is scheme-dependent MC generator parameter. It is connected to the pole mass:

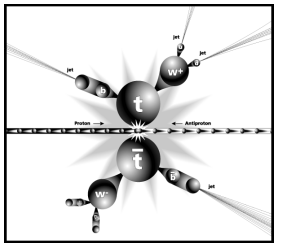
$$M_{pole} = M_{exp} \pm 1.\ (exp) + (2 \pm 1(scheme))\ GeV/c^2$$

- More info about this discussion (M. Seymour): http://agenda.hep.manchester.ac.uk/getFile.py/access?resId=0&materialId=slides&confId=2498

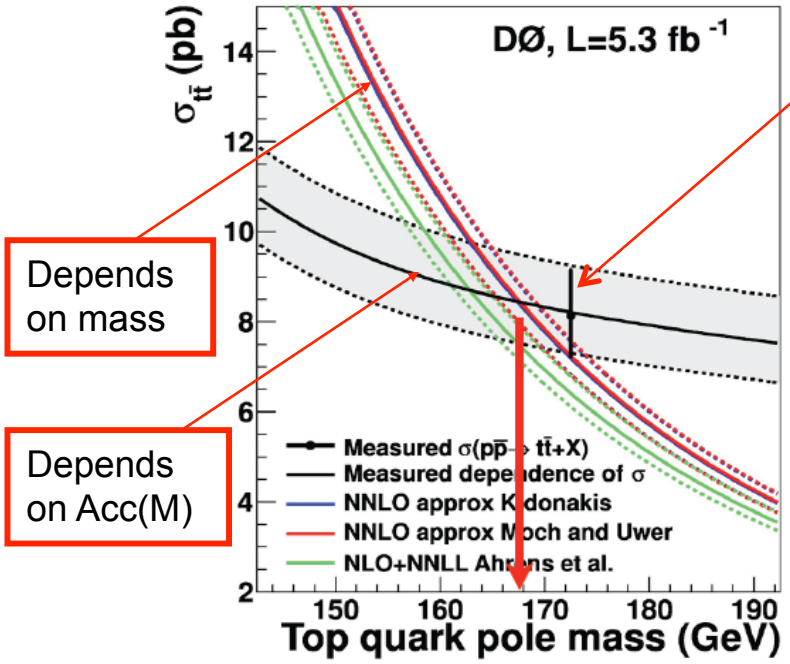
- A.Hoang *et al.*, PRL 101(2008)151602 [arXiv:0803.4214]



Top Cross Section and Mass

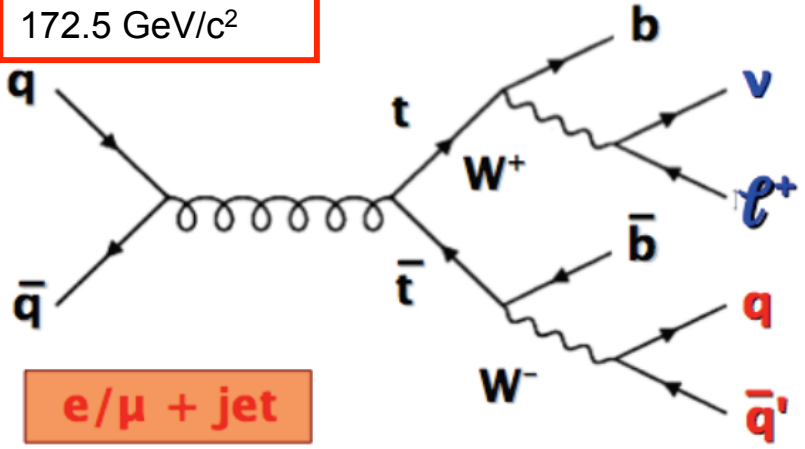


Measurement at 172.5 GeV/c^2



Depends on mass

Depends on Acc(M)



e/μ + jet

5.3 fb^{-1}

NEW!

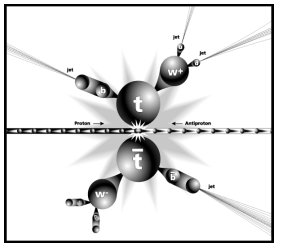
POLE mass: ±3.1%

$$m_t^{pole} = 167.5^{+5.4}_{-4.9}\ GeV$$

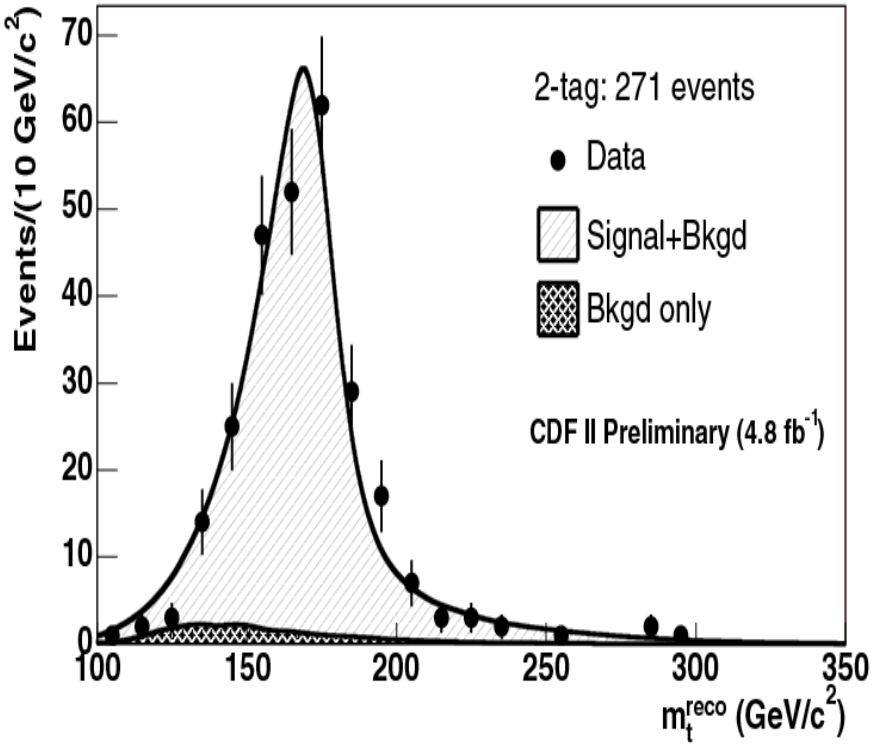
$\overline{MS}$ mass: ±3.0%

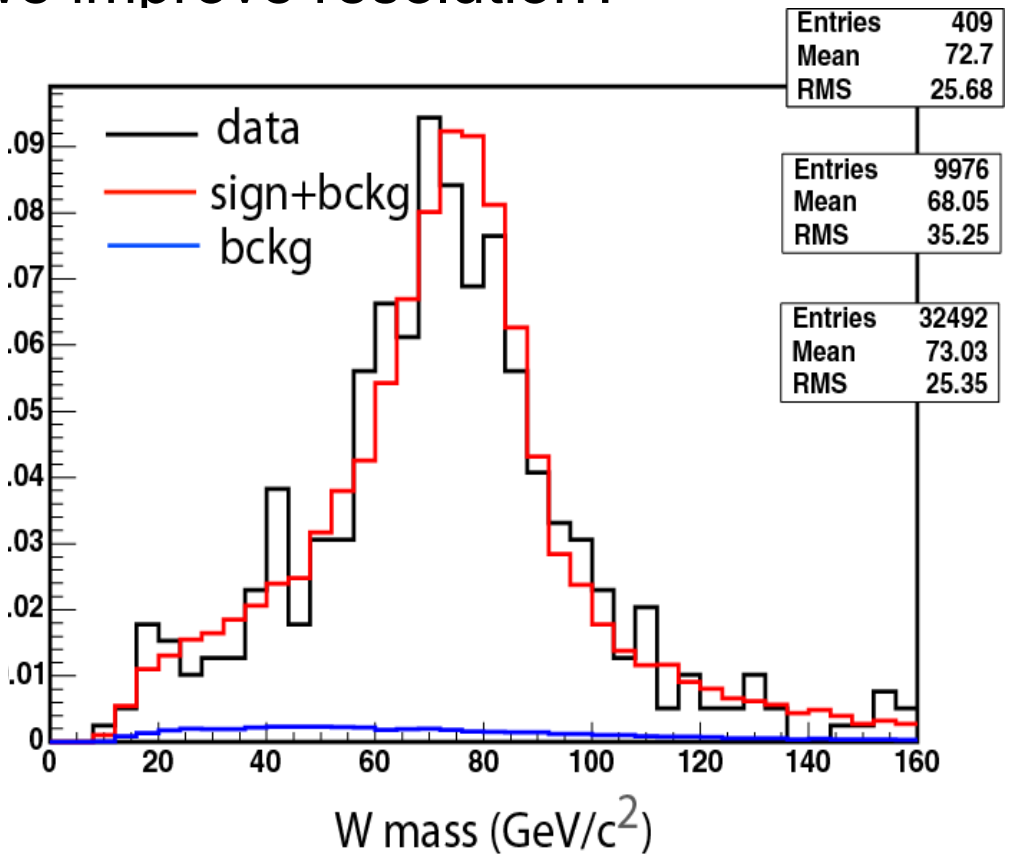
$$m_t^{\overline{MS}} = 159.9^{+5.1}_{-4.4}\ GeV$$

W-mass from double tag events

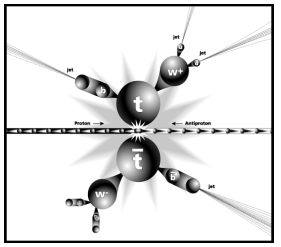


- Usually, for calibration we need clean samples
  - ttbar double tagged events is a good start, S/B = 20/1
  - We get the scale – can we improve resolution?





Top events for calibration

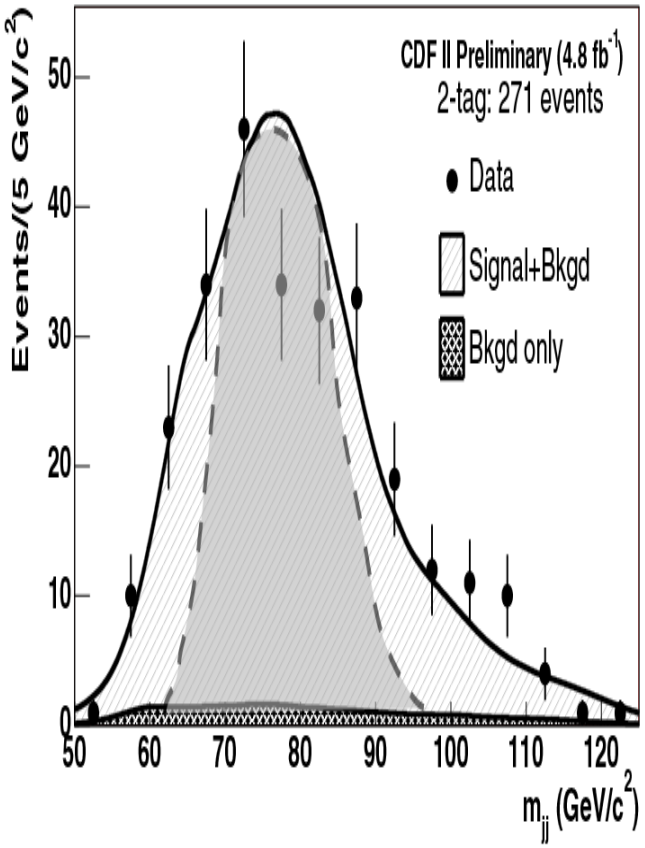


- Good modeling of the light quark jet scale
- Di-jet resolution – minimizing the following χ^2

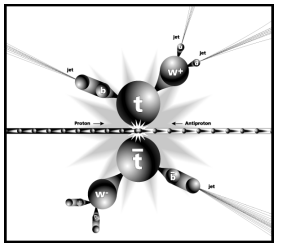
$$\chi^2 = \frac{(E_{j1} - E'_{j1})^2}{\Delta E_{j1}^2} + \frac{(E_{j2} - E'_{j2})^2}{\Delta E_{j2}^2} + \frac{(M(j'_1, j'_2) - M_W)^2}{\Gamma_W^2}$$

$$k_1 = \frac{E'_{j1}}{E_{j1}}; k_2 = \frac{E'_{j2}}{E_{j2}}$$

- We have ~ 350 double SVX events ~ 700 jets.
- One can look at the dependence of *k vs* different jet characteristics, e.g. E_T, η, jet charge fraction and etc.
- If dependence is found => correction function could be implemented



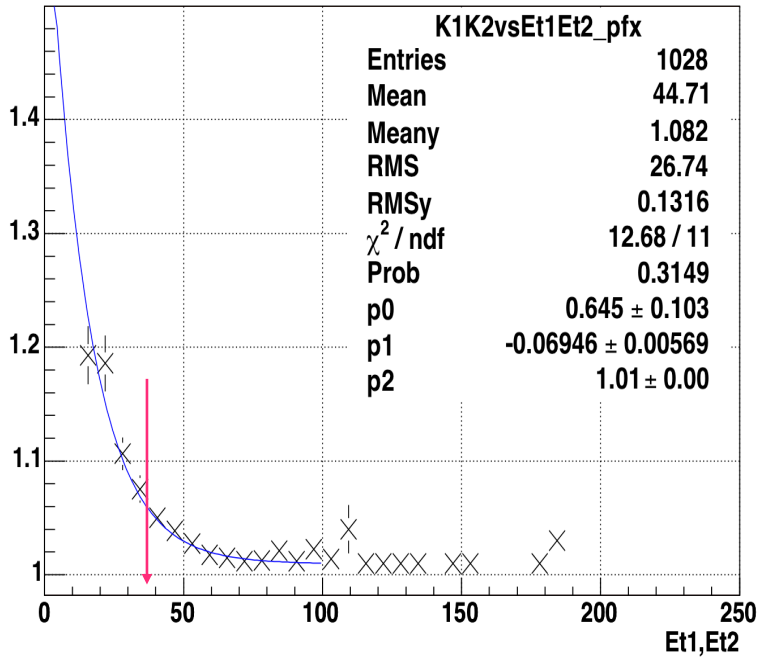
Result from W mass

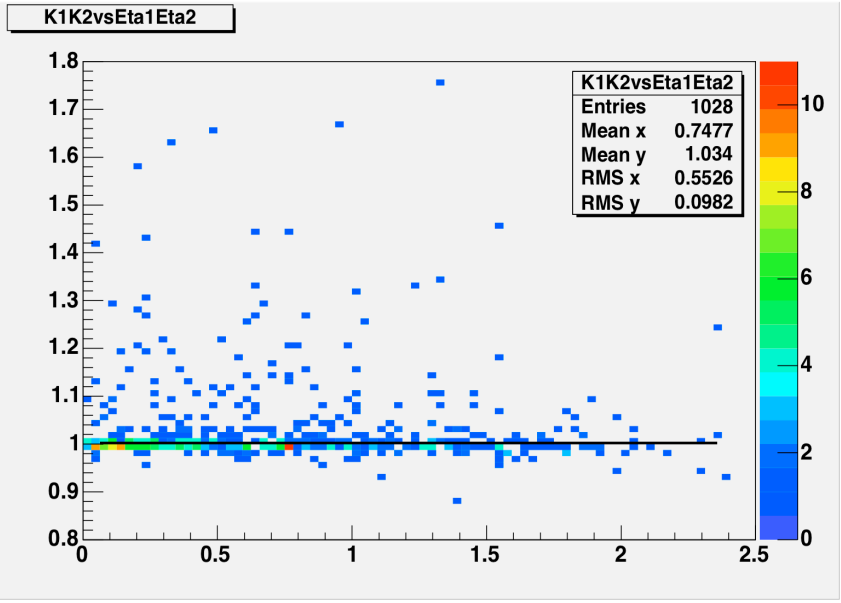


Below 35 GeV the jet energy is largely underestimated.

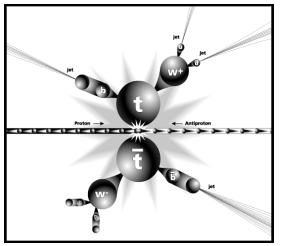
All jets are corrected to level 7

K1K2vsEt1Et2

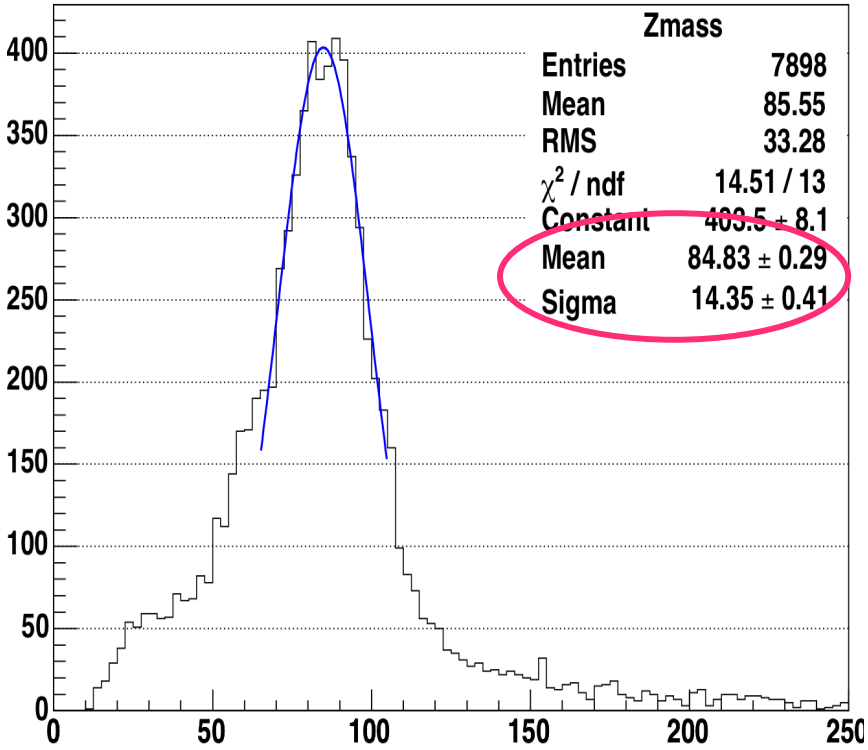




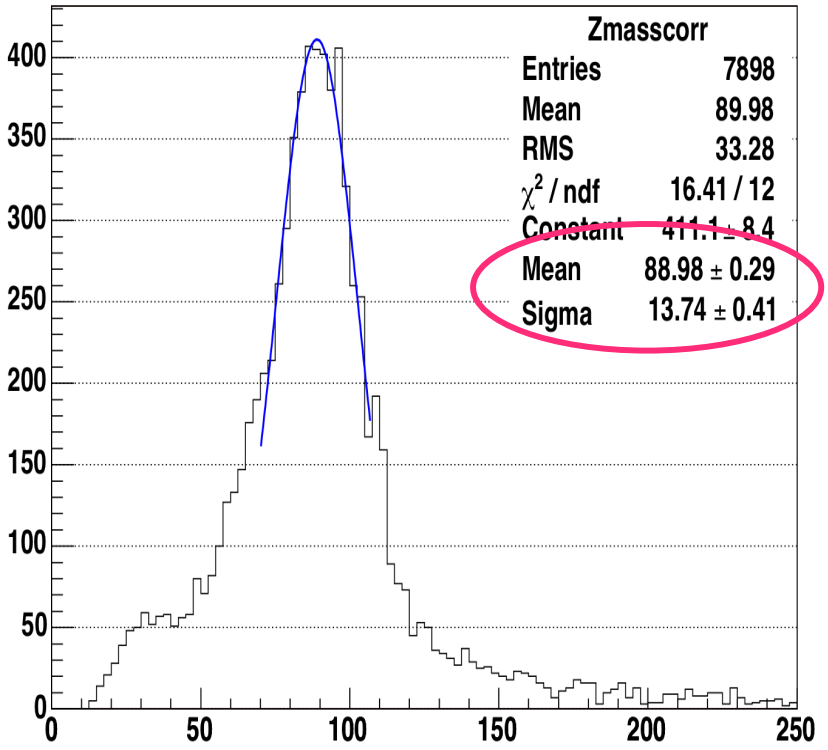
Check on the WZ MC



Zjj mass

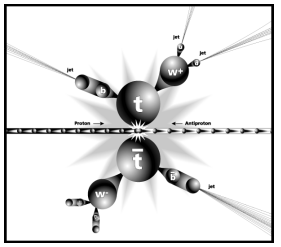


Zjj mass corr



ΔM/M improvement ~ 9%

b-jet JES & resolution

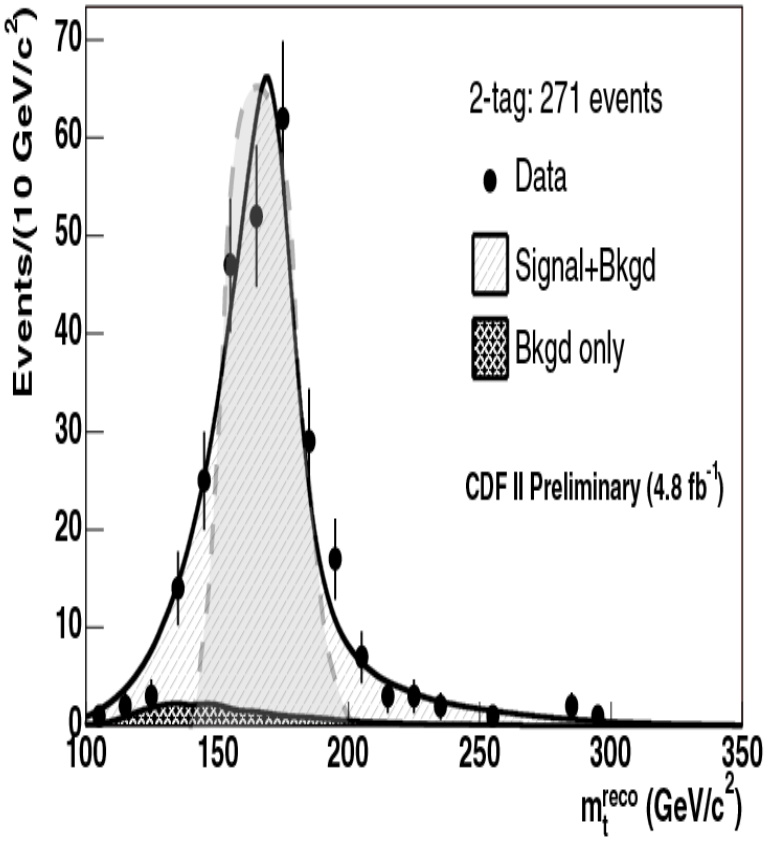


- Top mass interpretation - it is not clear if can be directly transferred from Tevatron to LHC
- Minimizing the tri-jet invariant mass

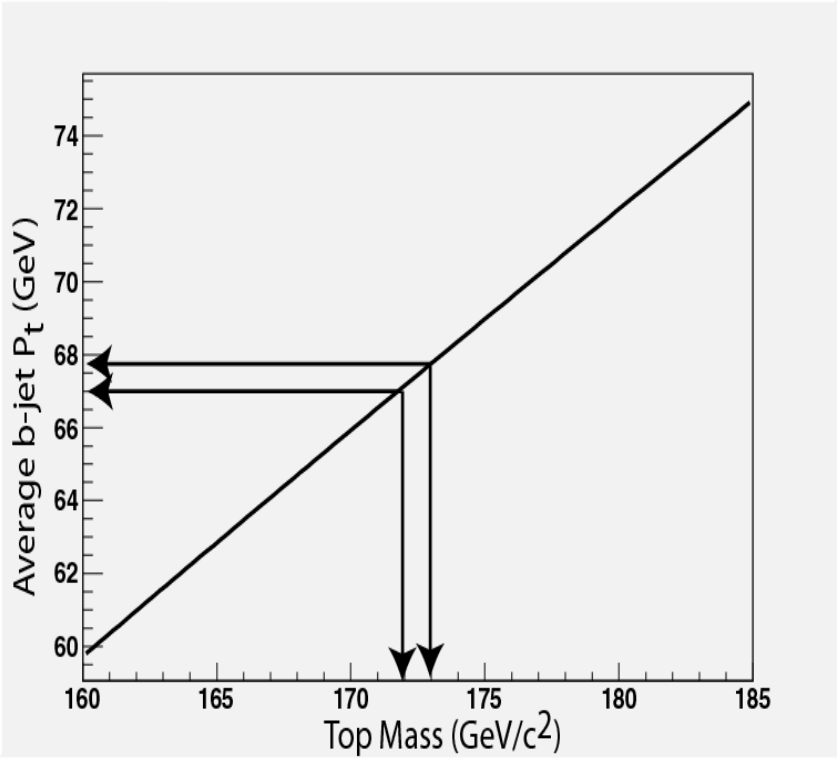
$$\chi^2 = \frac{(E_{j1} - E'_{j1})^2}{\Delta E_{j1}^2} + \frac{(E_{j2} - E'_{j2})^2}{\Delta E_{j2}^2} + \frac{(E_b - E'_b)^2}{\Delta E_{j2}^2} + \frac{(M(j'_1, j'_2) - M_W)^2}{\Gamma_W^2} + \frac{(M(j'_1, j'_2, j'_b) - M_t)^2}{\Gamma_t^2}$$

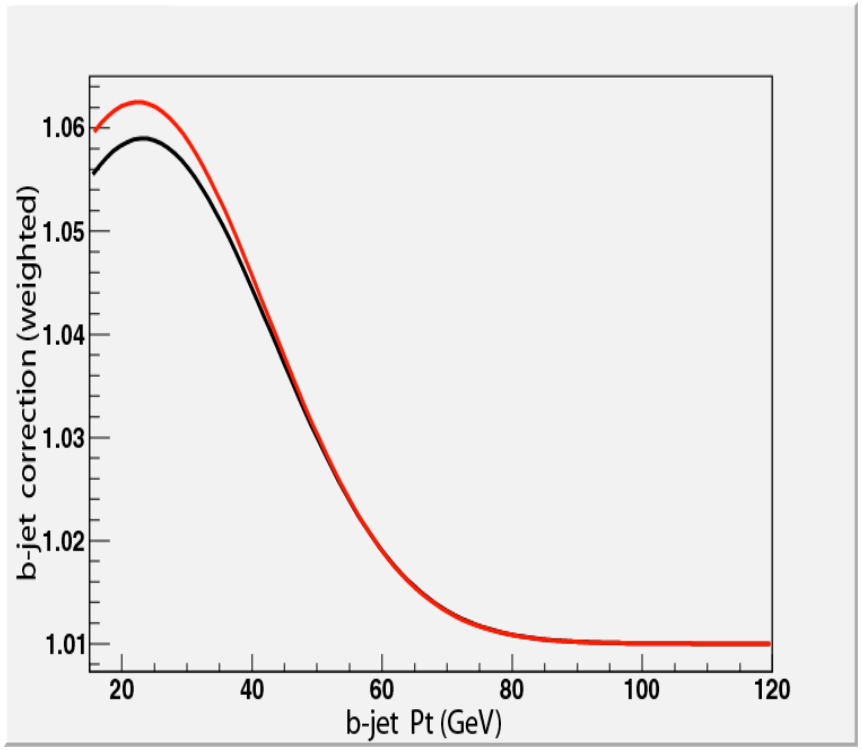
$$k_b = \frac{E'_b}{E_b}$$

- Even if the absolute scale maybe not easy to get, k_b vs E_b and eta of b-jet is a good tests
- Still in progress

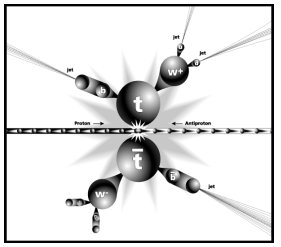


B-jet calibration and top mass





Top Properties: Production



$V_{tb} = 0.91 \pm 0.11$ (exp) ± 0.07 (theory)

No evidence for charged Higgs

$F_0 = 0.67 \pm 0.10$ & $F_+ = 0.02 \pm 0.05$

$BR(t \to Zq) < 3.3\%$ at 95% CL

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$M_t - M_{tbar} = -3.3 \pm 1.7$ GeV/c^2

$\Gamma_t < 7.5$ GeV at 95% CL

Exclude q = -4/3 at 95%CL

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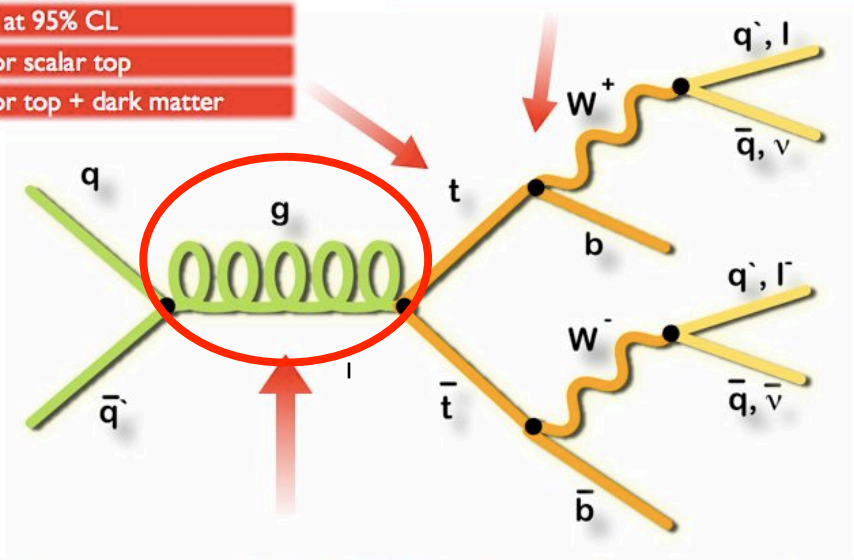

$M_{Z'} > 900$ GeV at 95% CL

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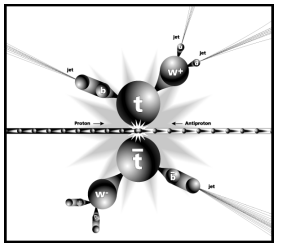
$F_{gg} = 0.07\ ^{+0.15}_{-0.07}$ (stat+sys)

$A_{fb} = 15\text{-}40\%$ (parton level)

Spin Correlations $\kappa = 0.6 \pm 0.5_{stat} \pm 0.2_{sys}$

A_{FB} Production Asymmetry

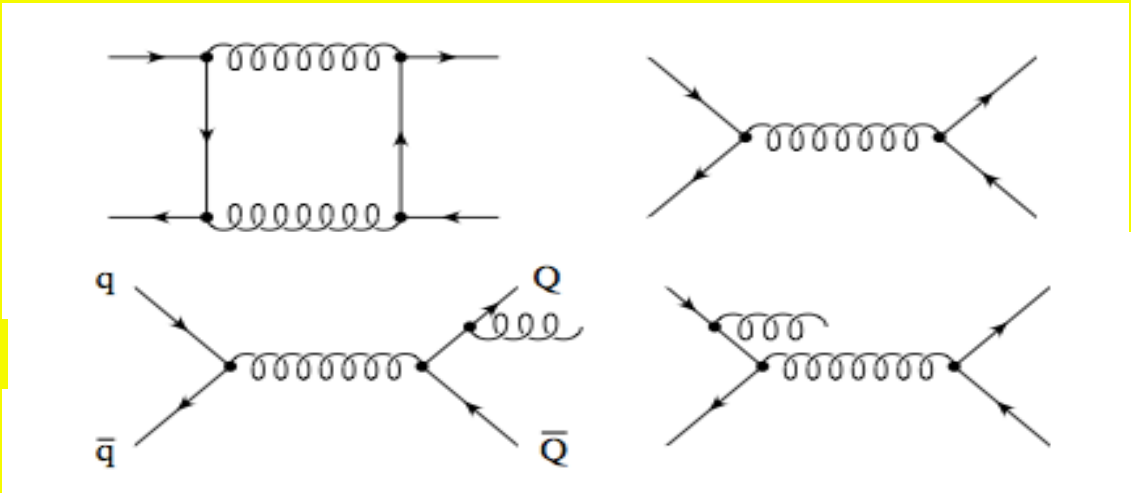


- LO QCD collision – charge-symmetric
- NLO QCD predicts small asymmetry from qqbar → ttbar, about 5%
- A ppbar collider is best suited to study the forward backward asymmetry of top quark production
- Several exotic ttbar production modes generate A_{FB} through the interference with SM, “Axigluons”, Z’
- Only Tevatron, LHC initial state is symmetric

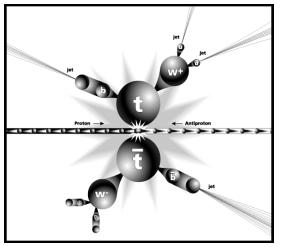
$$A_{fb} = \frac{N_t(y_t > 0) - N_t(y_t < 0)}{N_t(y_t > 0) + N_t(y_t < 0)}$$

between box and Born diagram

between ttj states

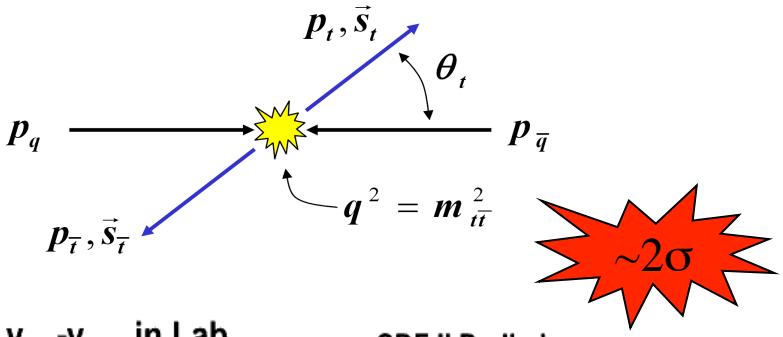


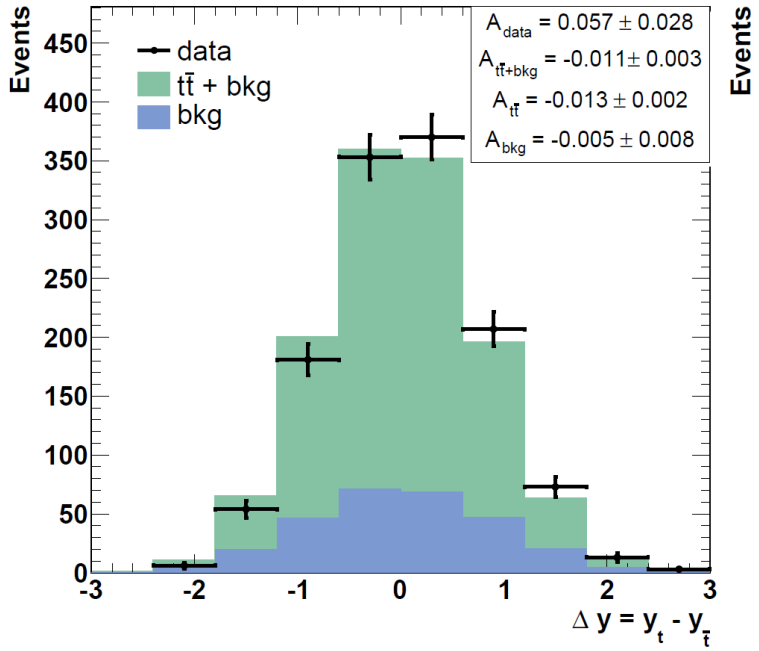
A_{FB}

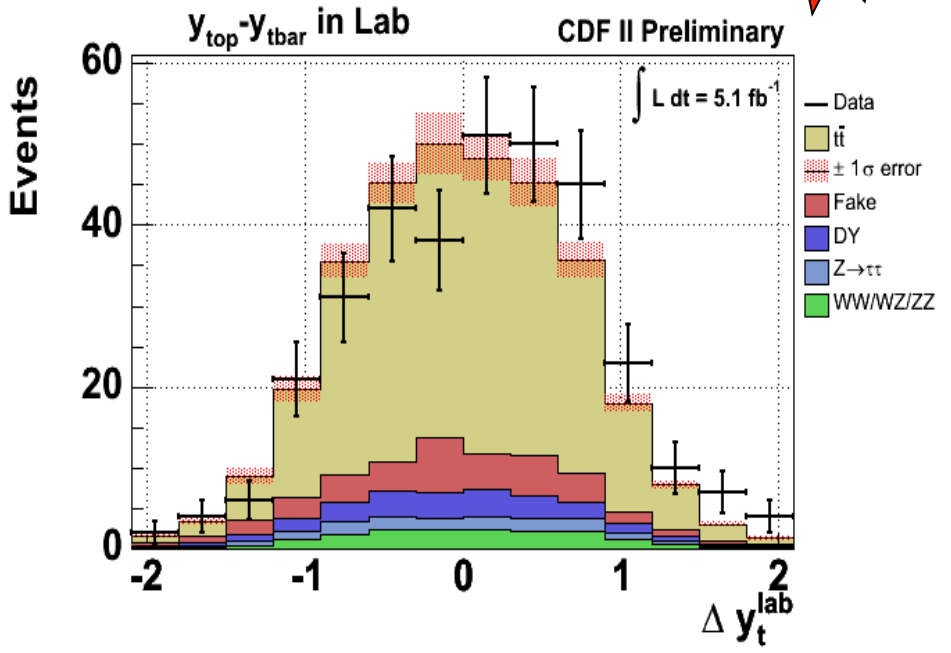


- CDF and DØ see 2σ discrepancy in lepton+jets mode
- CDF sees in dilepton too

NEW!



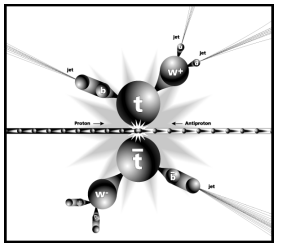




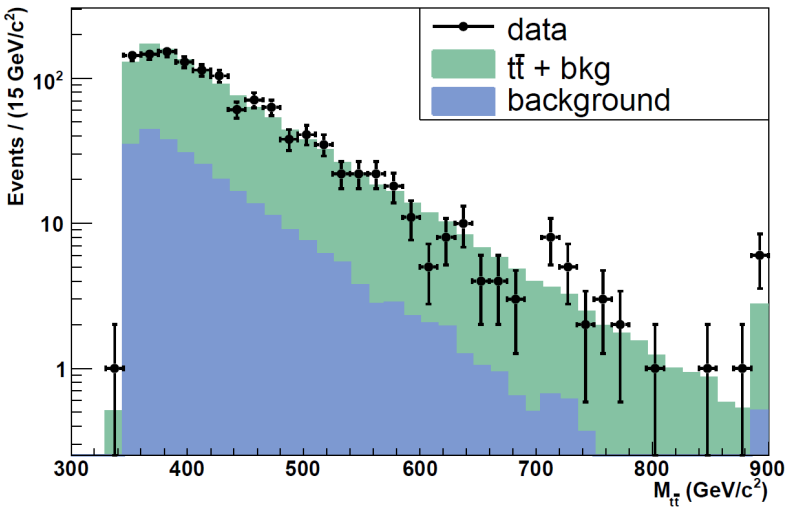
A_{FB} = 0.15 ±0.05 (stat+syst)

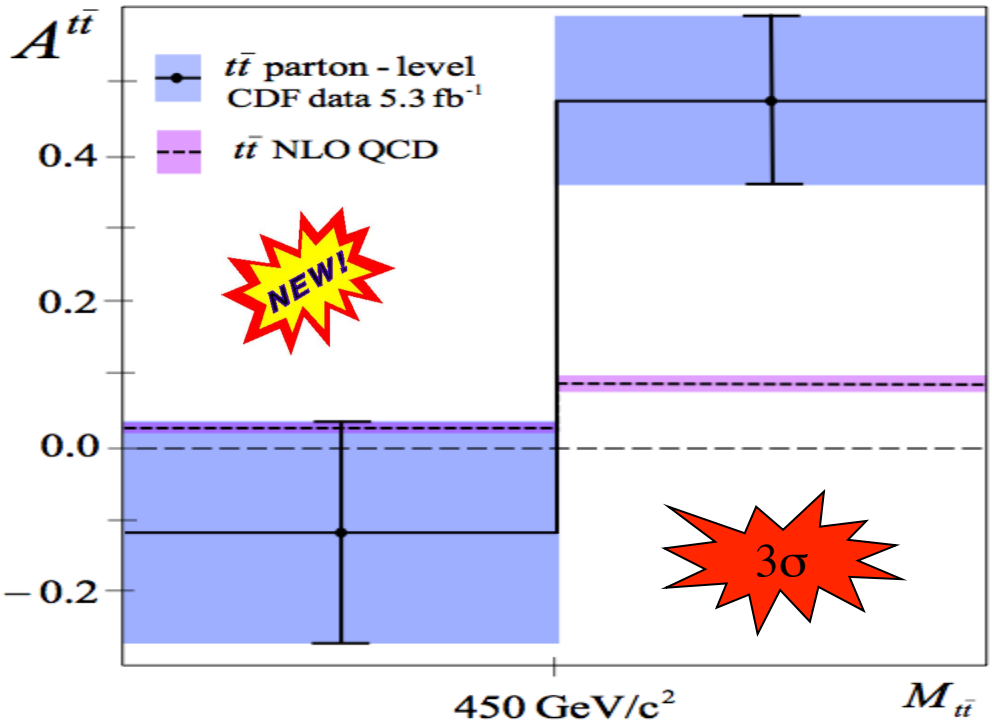
A_{FB} = 0.42 ±0.16 (stat+syst)

A_{FB} vs M($t\bar{t}$)



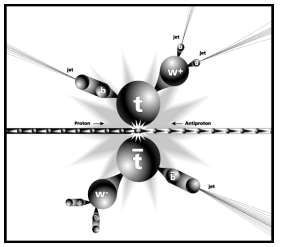
- Can imagine many scenarios where A_{FB} depends on M($t\bar{t}$)
- More than 3σ effect
- New models
  - Total σ in good agreement with SM
  - dσ/dMtt in good agreement with SM





Implies large Q^2 dependence

Top Properties: Top



M_t = 173.3 ± 1.1 GeV/c^2

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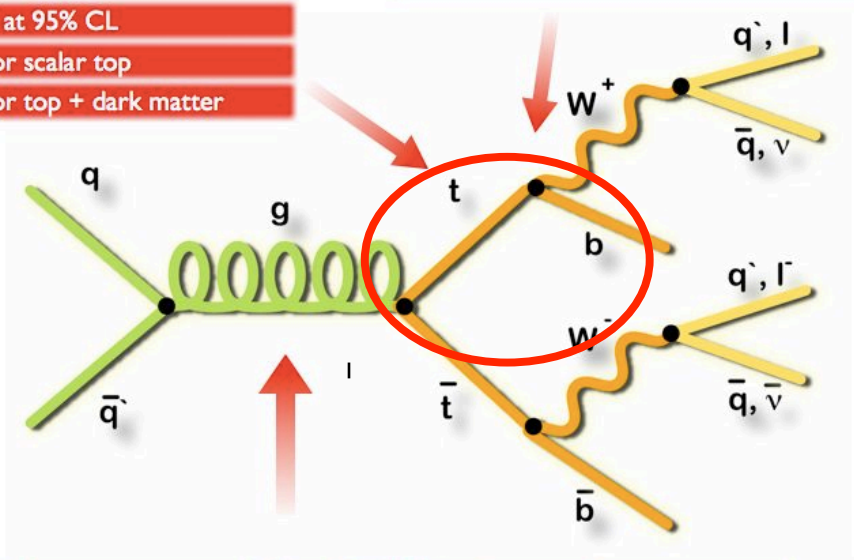

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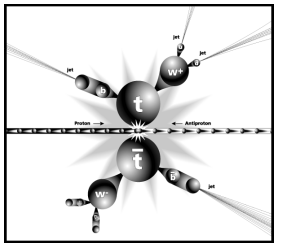
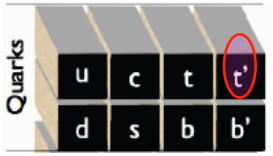
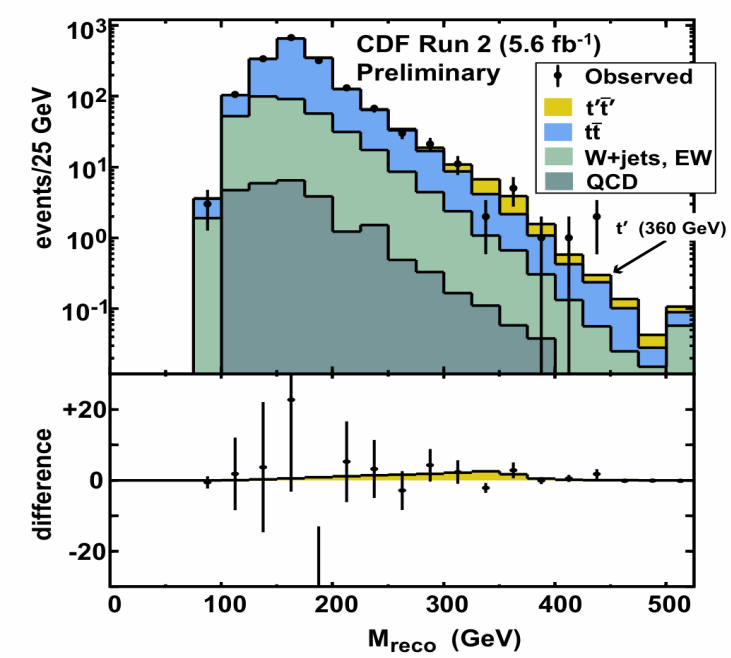
Spin Correlations $\kappa = 0.6 \pm 0.5_{stat} \pm 0.2_{sys}$

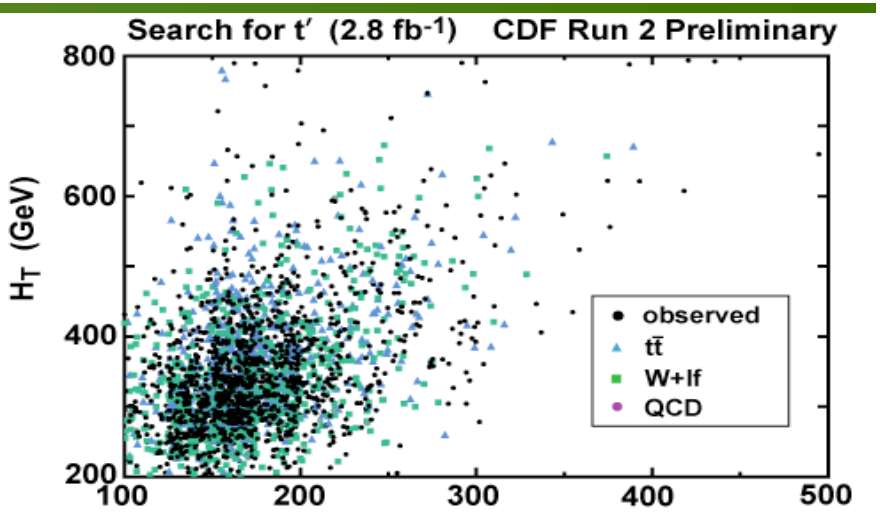
Fourth generation top-like quark search

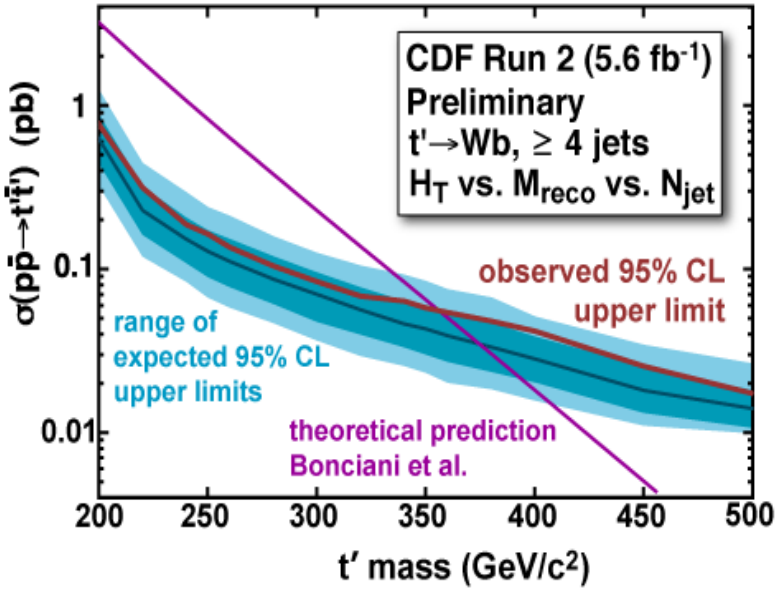


- Theoretical motivation – forth generation up-type quark
- Events selection – pre-tag l +jets >= 4 jets



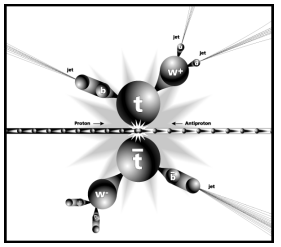






m(t`) > 358 GeV/c^2 at 95% CL

Spin Correlation



- Top quark decays before hadronization – spin information is preserved

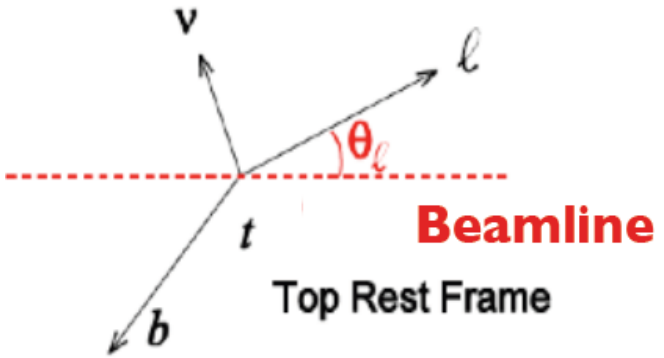
SM prediction

$$\kappa = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\uparrow\downarrow} - N_{\downarrow\uparrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow}} \approx 0.78$$

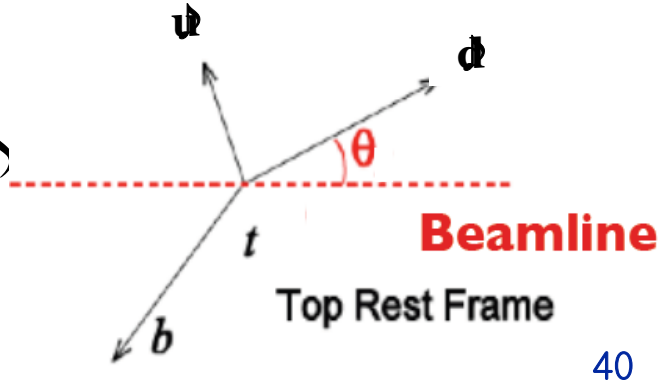
- κ is related with angles of decay products

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_1 d\cos\theta_2} = \frac{1-\kappa\cos\theta_1\cos\theta_2}{4}$$

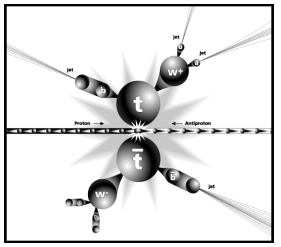
- where



or



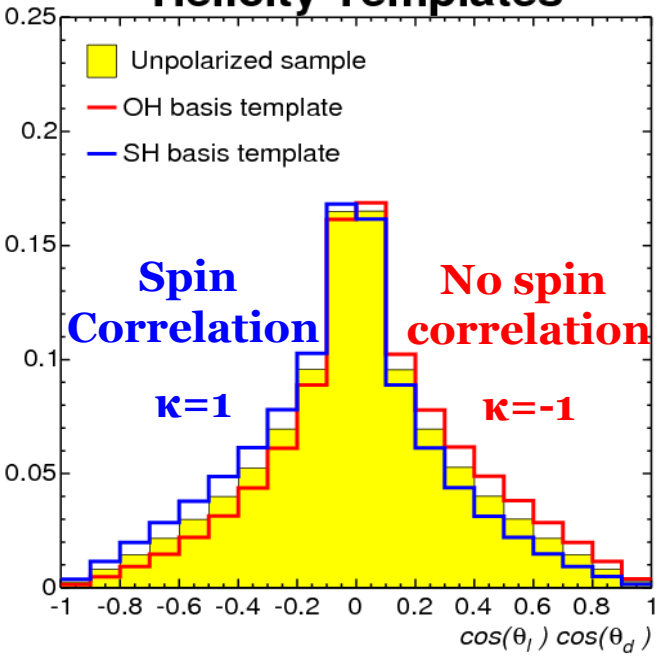
Spin Correlation



- Spin information of top quark passed to decay products

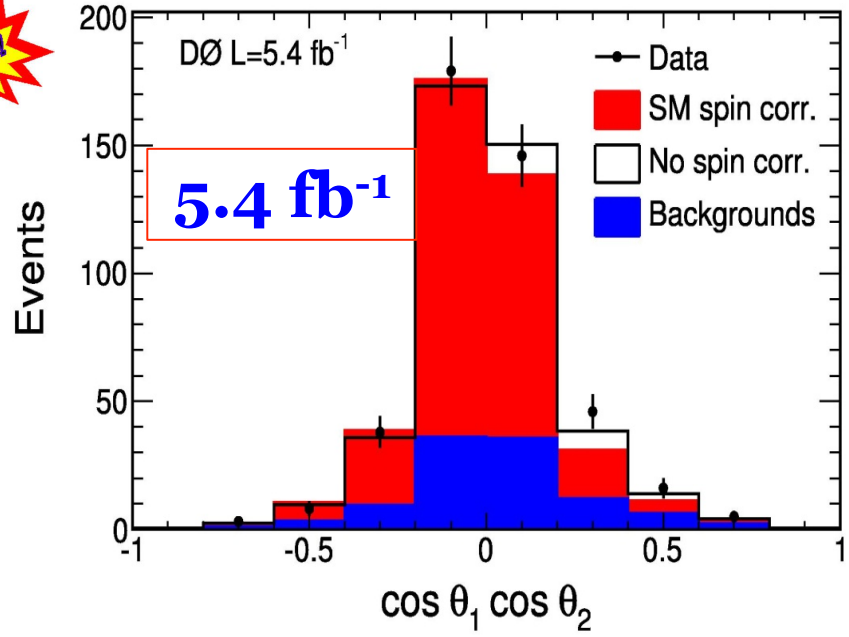
$K_{SM} \approx 0.78$

Helicity Templates



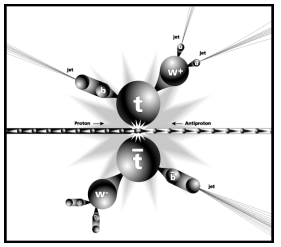
NEW!

Dilepton



K_{SM} = 0.21 ±0.40 (stat+syst)

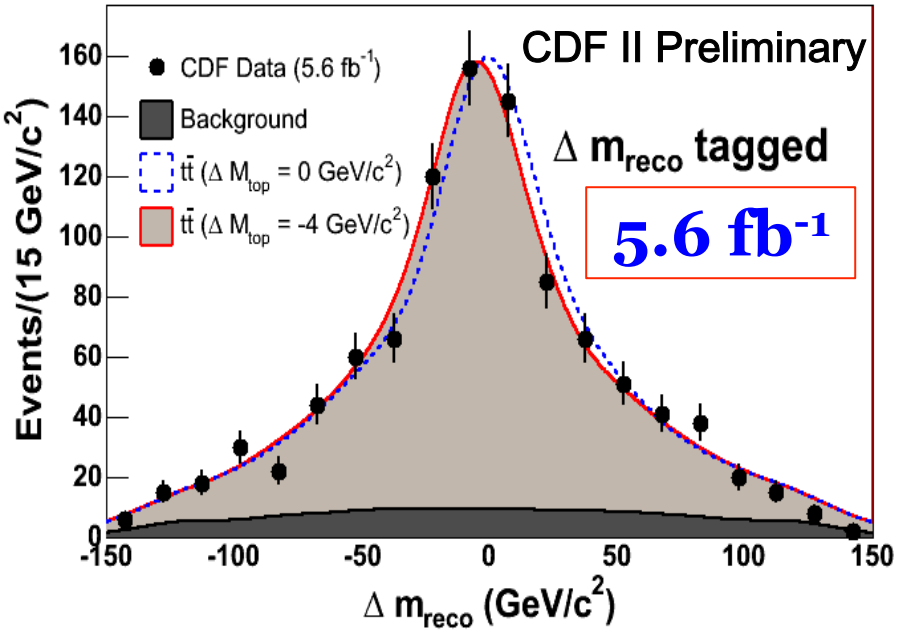
t and $\bar{t}$ mass difference



- CPT is conserved, ΔM_{top} should be zero
- We break this assumption and measure the ΔM_{top}
- We use similar technique to mass measurements♪

NEW!

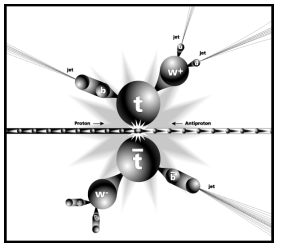
Lepton+Jets



$$\chi^2 = \Sigma_{i=\ell,4jets}\frac{(p_T^{i,fit}-p_T^{i,meas})^2}{\sigma_i^2} + \Sigma_{j=x,y}\frac{(U_j^{fit}-U_j^{meas})^2}{\sigma_j^2}$$
$$+ \frac{(M_{jj}-M_W)^2}{\Gamma_W^2} + \frac{(M_{\ell\nu}-M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj}-(172.5+dM_{reco}/2))^2}{\Gamma_t^2} + \frac{(M_{b\ell\nu}-(172.5-dM_{reco}/2))^2}{\Gamma_t^2}$$

ΔM_{top} = -3.3 ±1.4 (stat) ±1.0(syst) GeV/c^2

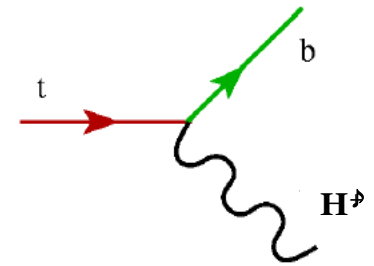
Why top quark width ?♪



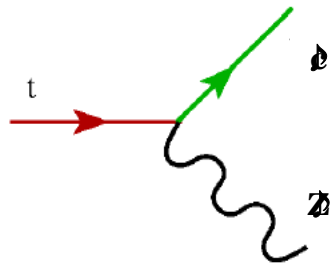
- It is intrinsic parameter of SM
  - Very precise estimation using NLO calculation (~1% precision)

$$\Gamma_t = \Gamma_t^0\left(1-\frac{M_W^2}{m_t^2}\right)^2\left(1+2\frac{M_W^2}{m_t^2}\right)\left[1-\frac{2\alpha_s}{3\pi}\left(\frac{2\pi^2}{3}-\frac{5}{2}\right)\right]$$

  - 1.3 GeV at M_{top} = 172.5 GeV/c^2
- Deviation from SM indicate new physics
  - Charged Higgs decay, FCNC, and other exotic models



top quark decay



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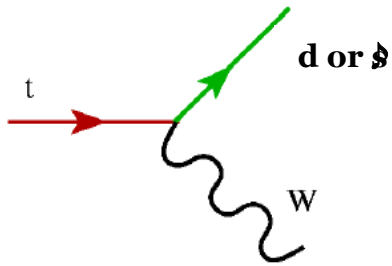
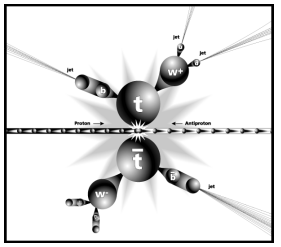
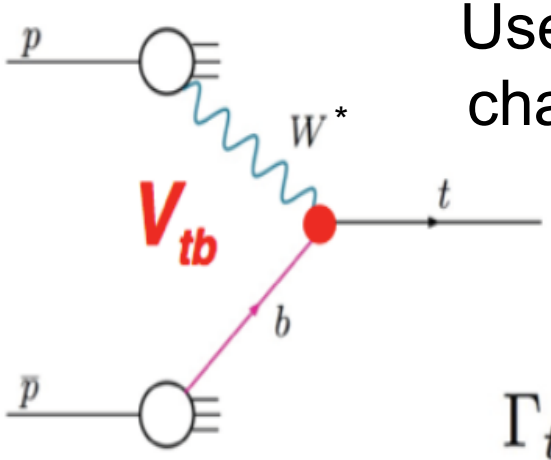


top quark decay

- And top quark life time♪ $\tau = \frac{\hbar}{\Gamma}$

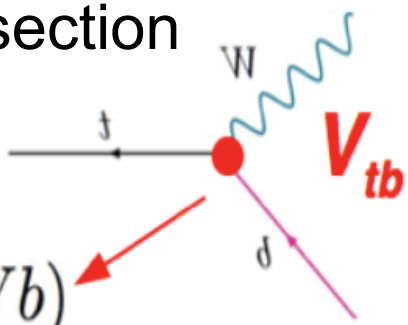
Top quark width





Use SM single top t-channel cross section

♪



$$\Gamma_t = \frac{\Gamma(t \to Wb)}{\mathcal{B}(t \to Wb)}$$

$\Gamma(t \to Wb)$ ← $t\bar{t}$ production

assume that coupling in top production and decay is the same

Γ_{top} = 1.3 GeV @SM

Indirect measurement

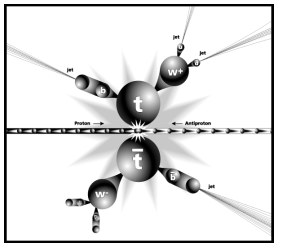
$\Gamma_{top} = 1.99\ ^{+0.65}_{-0.55}$ GeV

Direct measurement

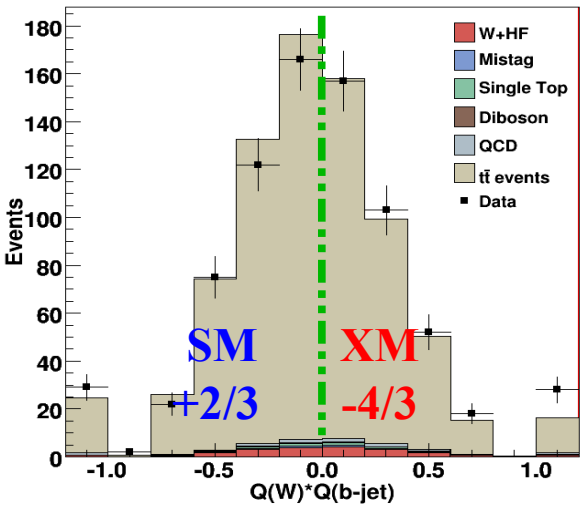
$\Gamma_{top} < 7.4$ GeV @95 CL

$\tau_{top} = 3.3\ ^{+1.3}_{-0.9}\ 10^{-25}$ sec $< \tau^{had.}$

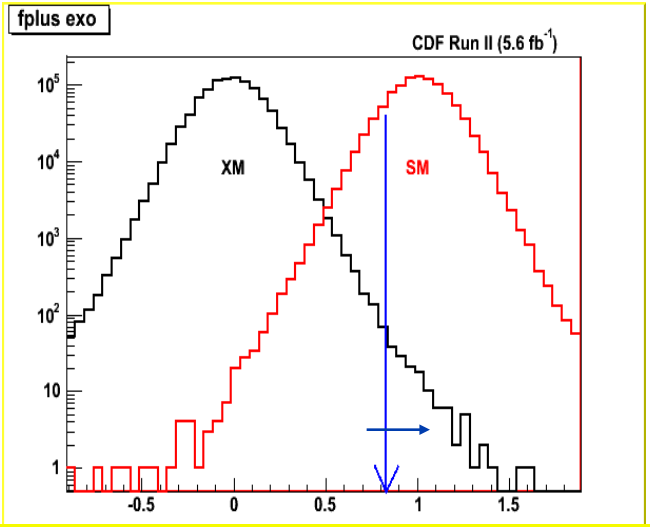
Top Charge



- Lepton + jets events with two b tags
- Use kinematic fit in to choose best combination of W^+b and W^-b
- Flavor tag *b* jets using soft leptons or jet charge
- Compare probabilities for Q=+2/3 vs. -4/3 solutions



NEW!



$$Q_{b-jet} = \frac{\sum_i q_i \cdot (\vec{p}_i \cdot \hat{a})^x}{\sum_i (\vec{p}_i \cdot \hat{a})^x}$$

x = weighting factor

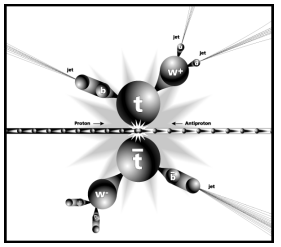
$\hat{a}$ = jet axis

$\vec{p}_i$ = track momentum

Compare to MC trials
Consistent with SM at 13% CL
Only 0.014% of trials for XM have fit metric >0.83

Exclude Q_{top} = -4/3 @ 95 % CL

Top Properties: Decay



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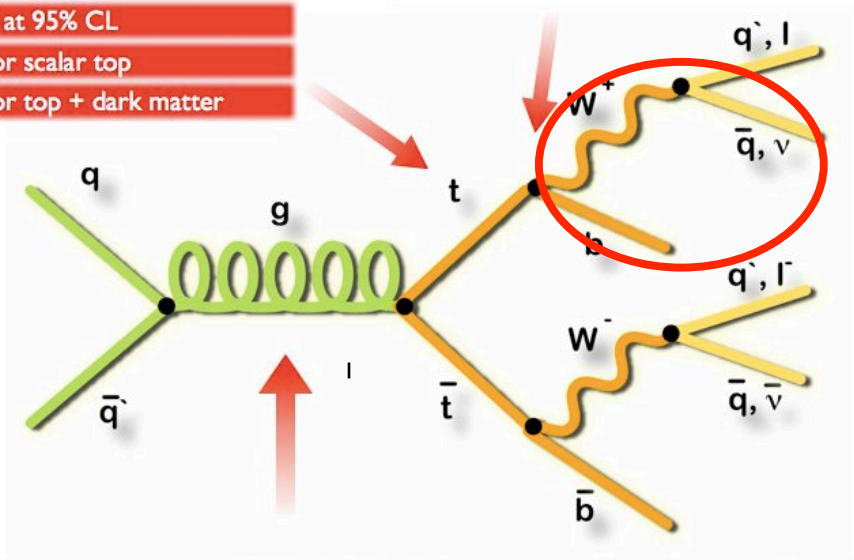

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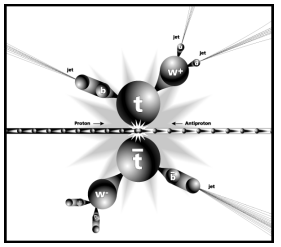
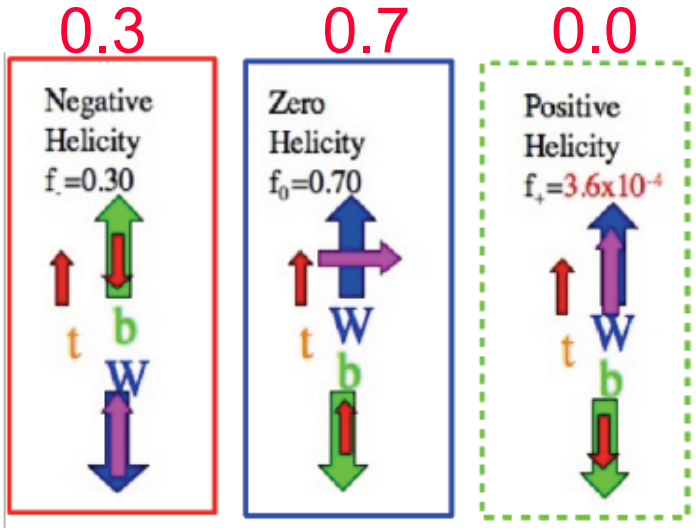
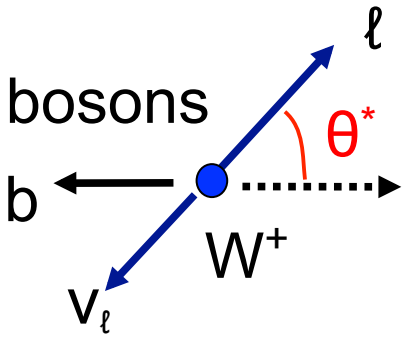
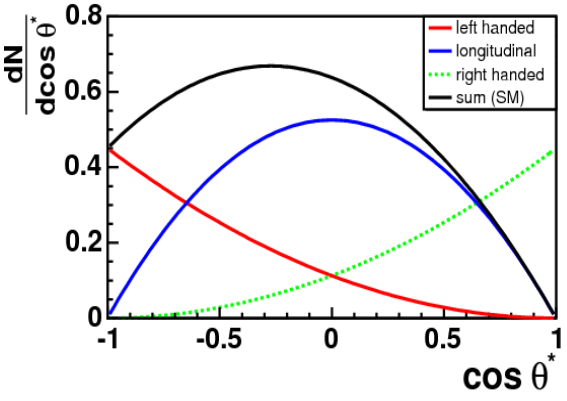
W Helicity



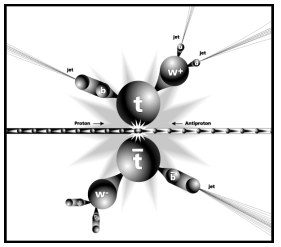
- The SM top decays via EW interaction
  - Top decays as a bare quark ⇒ spin information transferred to final state particles
- V-A coupling predict
  - f_0 = 0.7 (longitudinal polarization)
  - f_+ = 0 (right handed polarization)
  - f_- = 0.3 (left handed polarization)
- Measuring the fraction of longitudinally polarized W bosons
  - Reconstructed cosθ*



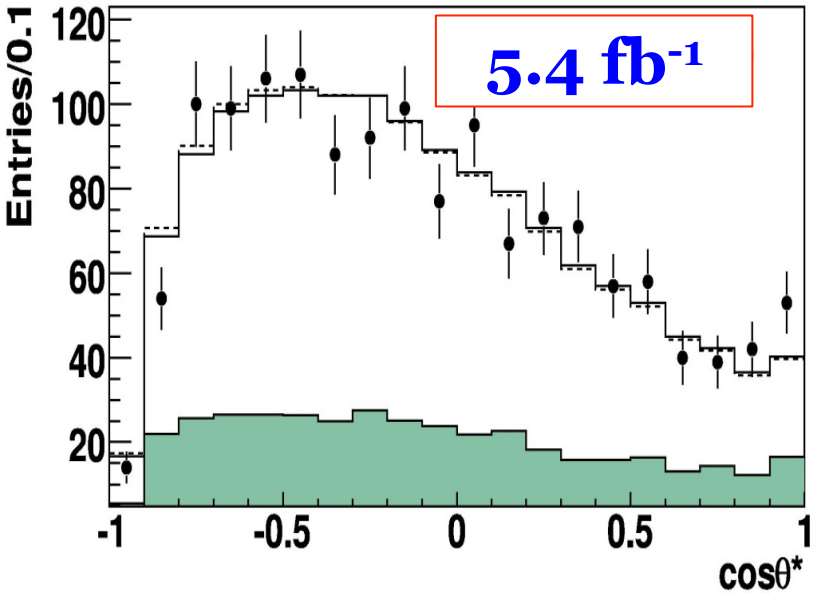




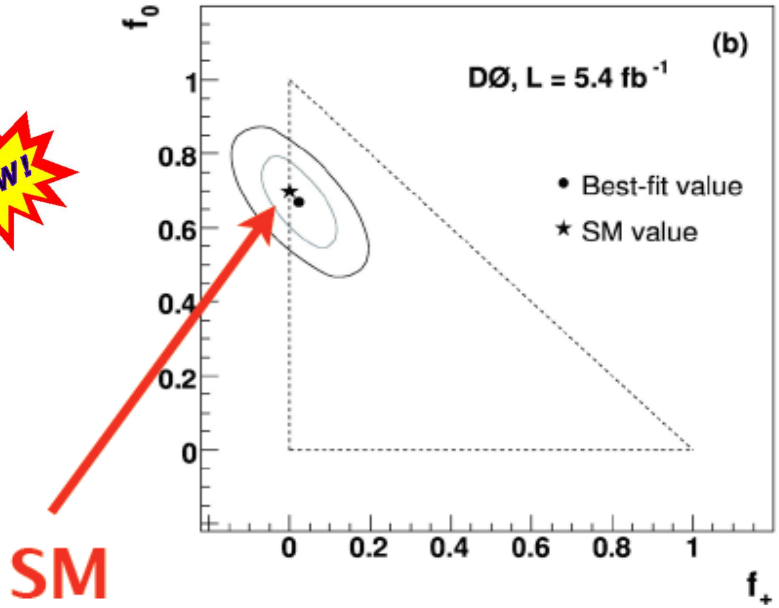
W Helicity



Lepton+Jets & Dilepton



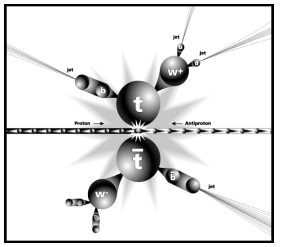
NEW!



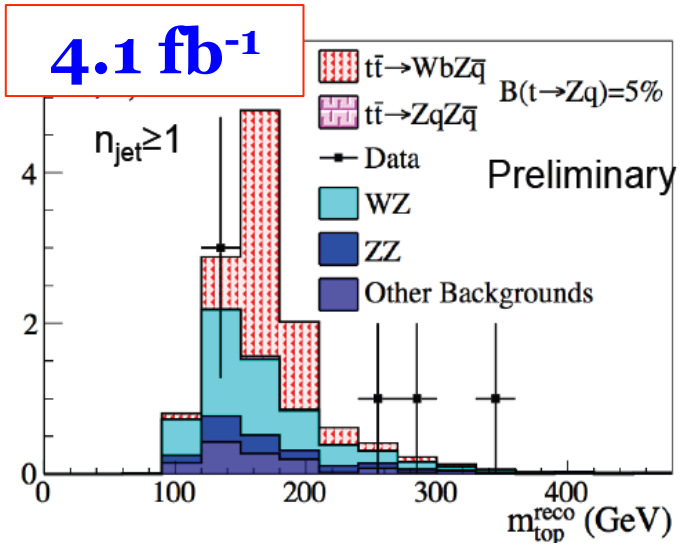
$f_+ = 0.02 \pm 0.05$
$f_0 = 0.67 \pm 0.10$

Consistent with SM @ 98% level

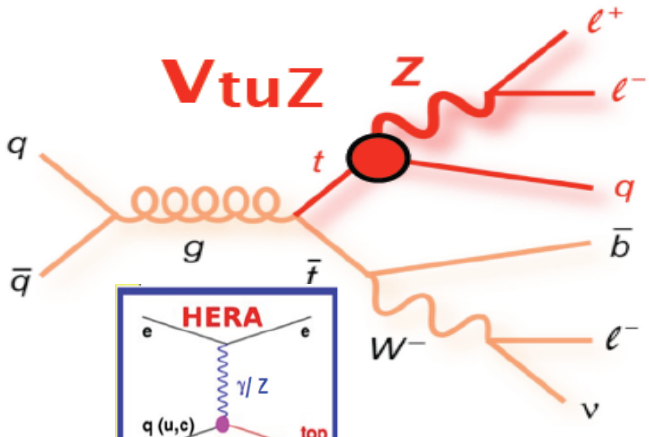
Flavor Changing Neutral Current (FCNC)

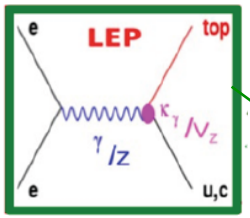


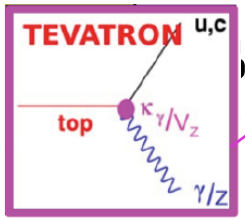
- Top FCNC is extremely small in SM O(10^{-14})
- Beyond SM : up to O(10^{-4})
- Any signal = new physics

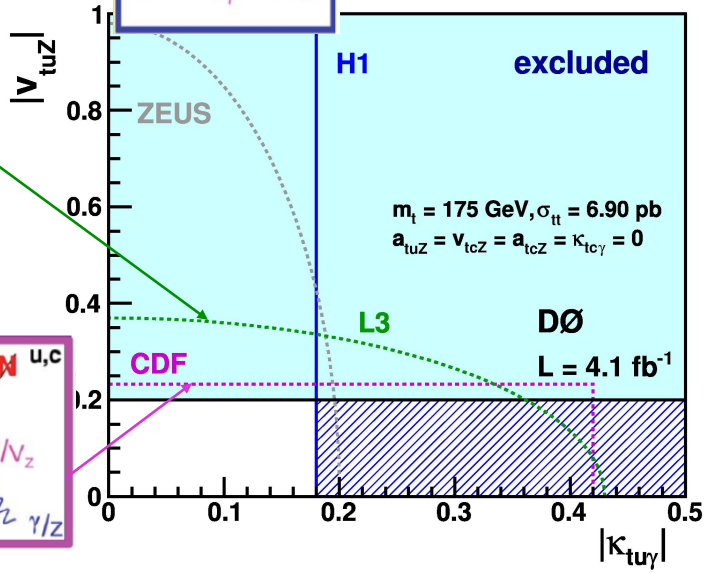


Br(t→Zq)<3.3% @ 95%

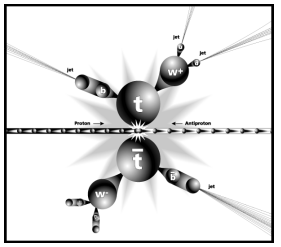






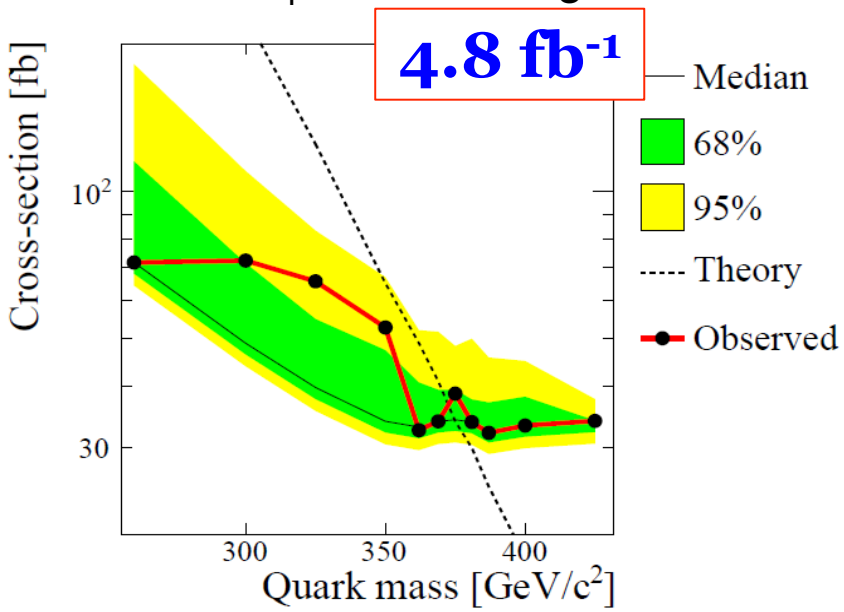


b' and exotic t'



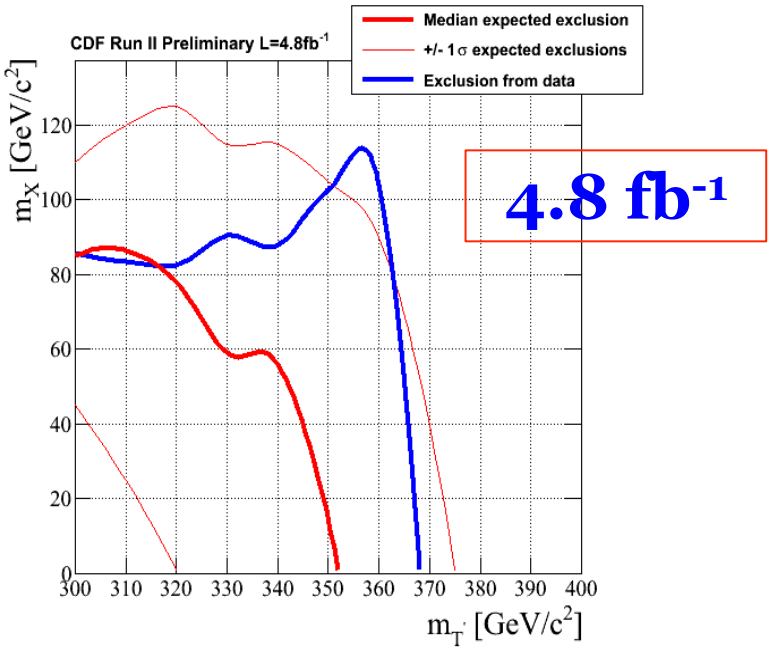
- 100% b'→Wt, so four W and two b final state
  - Very energetic and large jet multiplicities
  - We use H_T to extract signal

NEW!



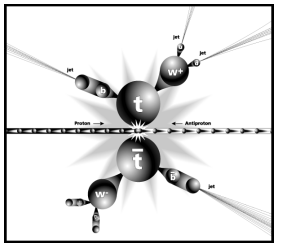
$m_{b'} > 372$ GeV @ 95% CL

- 100% t'→tX where X is invisible (dark matter candidate)
  - Use transverse W mass

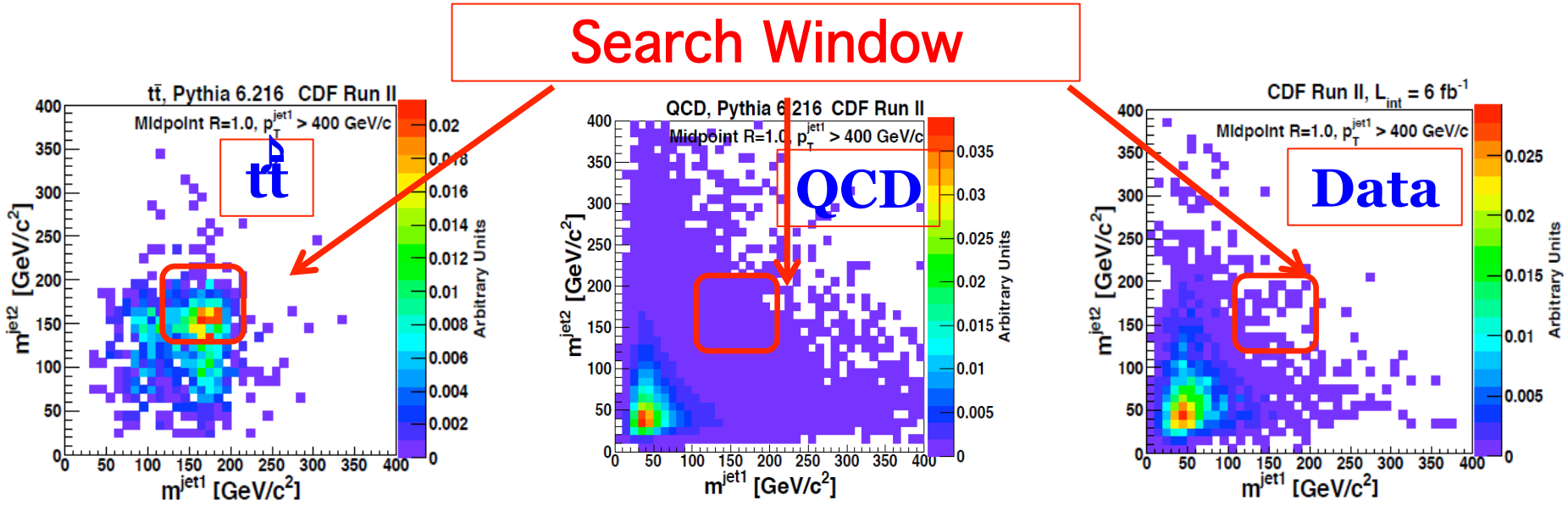


$m_{t'} < 360$ GeV@ 95% CL for $m_X < 80$ GeV

Boosted Top search



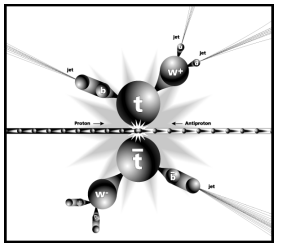
- Search for massive top-jets in high p_T inclusive jet sample
  - p_T > 400 GeV, 130GeV<m_{jet}<210GeV
  - Interesting to test pertubative QCD at high P_T region
  - Resonance productions enhance the boosted tops



Expected : N_{tt}=5±1 N_{QCD}=44±15 **Observed : N_{data} = 58**

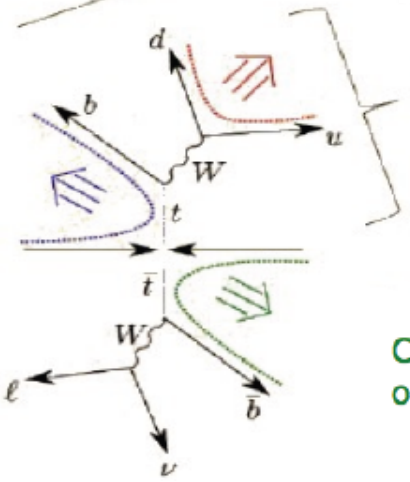
$\sigma_{t\bar{t}}$ (p_T>400 GeV) < 40 fb @ 95% CL

Color flow in top events



colour flow

$t\bar{t}$



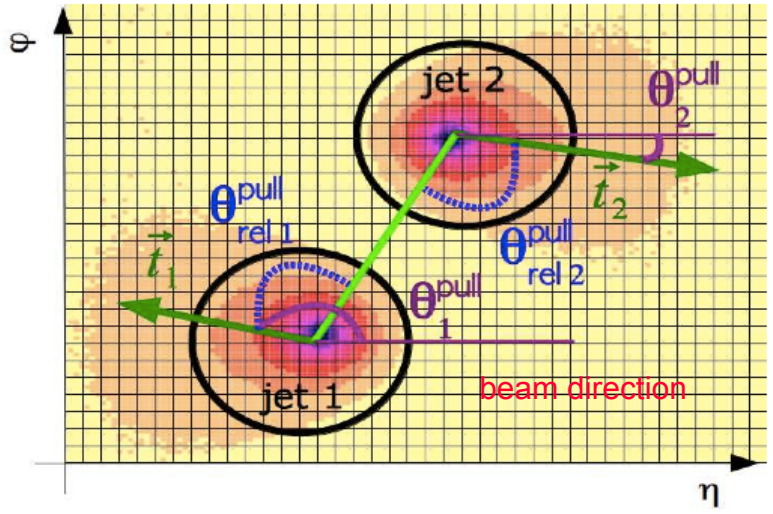
Clean color-singlet jet pair

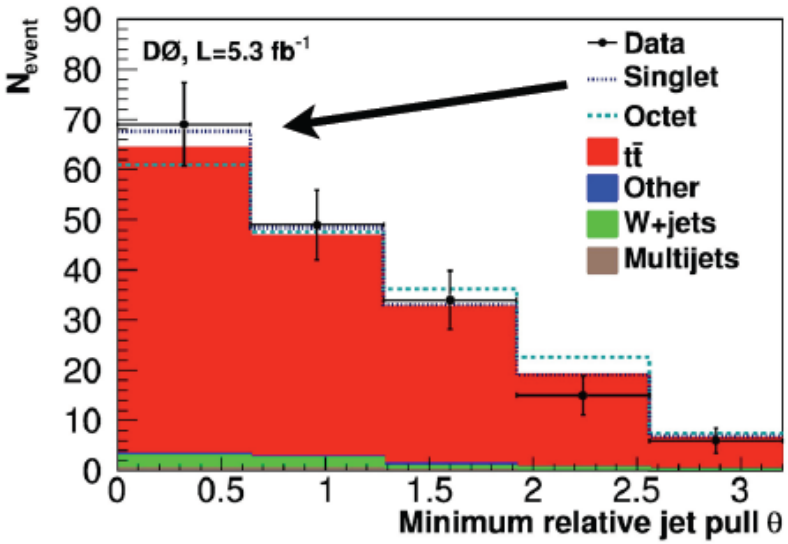
Clean sample of W → jj

$$\vec{t} = \sum_{cells,i} \vec{t}_{cell,i} \,/\, E_T^{jet}$$

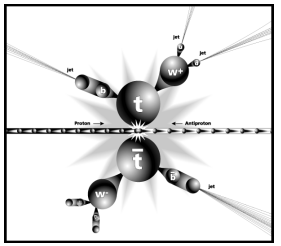
$$\vec{t}_{cell,i} = E_T^{cell} \vec{r}_{cell}$$

$$\vec{r}_{cell} = (\eta_d^{cell} - \eta_d^{jet}, \varphi_d^{cell} - \varphi_d^{jet})$$





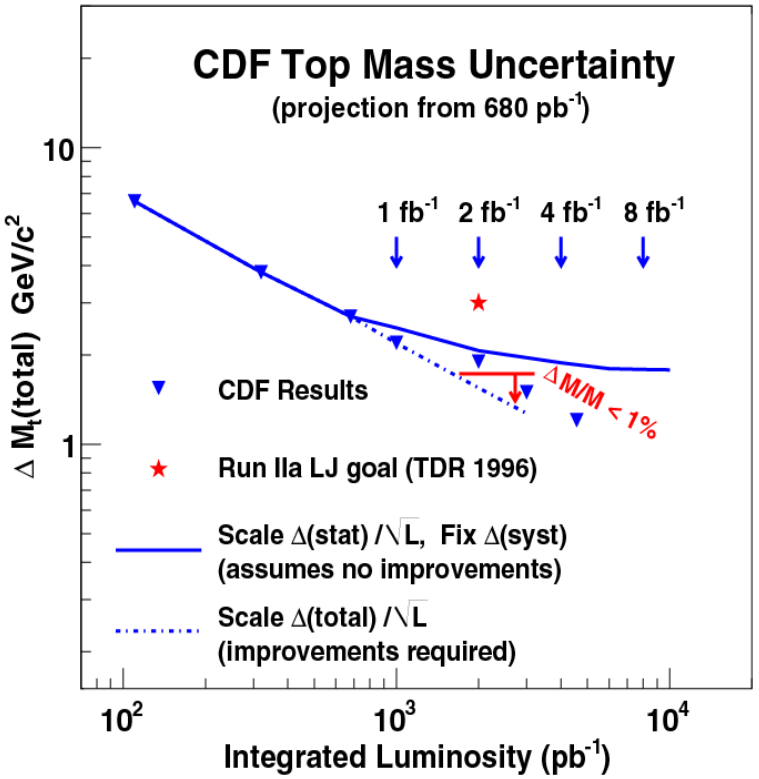
Conclusion



- Tevatron top program is rich of new results – Winter 2011
  - CDF and DØ continue to perform detailed study of top quark
- Tevatron top physics is an era of the precision measurements –systematically limited
  - ~2,000 top events are obtained
- New results from ~ 2 more data are coming.
- With the LHC era coming, Tevatron will still play an important role:
  - some Tevatron measurements - its mass! - have broad impact to our field, and will be a long standing legacy
  - others such as charge asymmetry, spin correlations are complementary to the LHC program
- Study of forward-backward asymmetry of top events shows discrepancy with current NLO QCD prediction. Waiting for NNLO calculation + new data.
- More info in the CDF and DØ public web-pages:

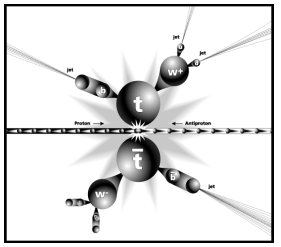
http://www-cdf.fnal.gov/physics/new/top/top.html

http://www-d0.fnal.gov/Run2Physics/WWW/results/top.htm



Stay tuned!

Thank You!



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

$M_t - M_{tbar} = -3.3 \pm 1.7$ GeV/c^2

$\Gamma_t < 7.5$ GeV at 95% CL

Exclude q = -4/3 at 95%CL

$M_{t'} > 335$ GeV at 95% CL

No evidence for scalar top

No evidence for top + dark matter

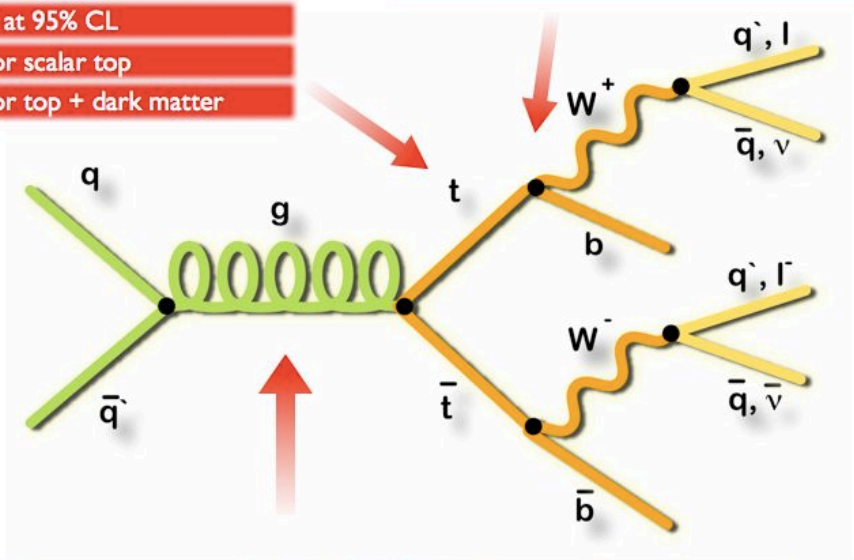
$V_{tb} = 0.91 \pm 0.11$ (exp) ± 0.07 (theory)

No evidence for charged Higgs

$F_0 = 0.67 \pm 0.10$ & $F_+ = 0.02 \pm 0.05$

BR(t→Zq) < 3.3% at 95% CL

BR(t→gu) < 0.2% at 95% CL



$M_{Z'} > 900$ GeV at 95% CL

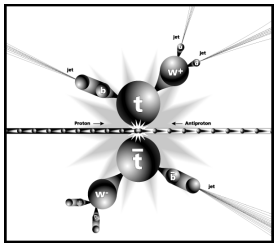
$M_{W'} > 800$ GeV at 95% CL

$M_{b'} > 372$ GeV at 95% CL

$F_{gg} = 0.07\ ^{+0.15}_{-0.07}$ (stat+sys)

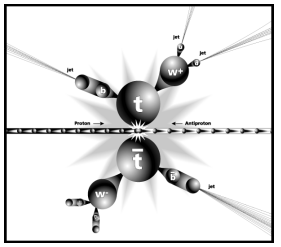
$A_{fb} = 15\text{-}40\%$ (parton level)

Spin Correlations $\kappa = 0.6 \pm 0.5_{stat} \pm 0.2_{sys}$

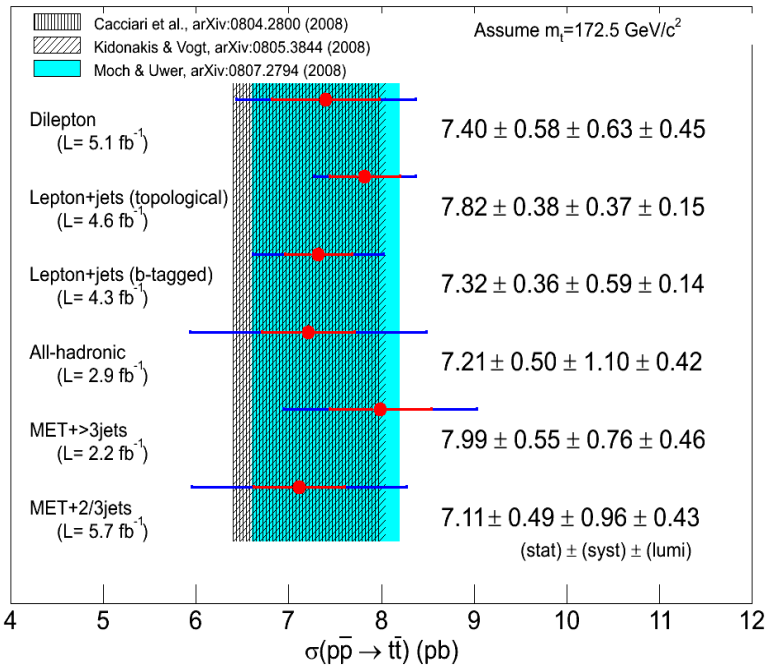


Backup Slides

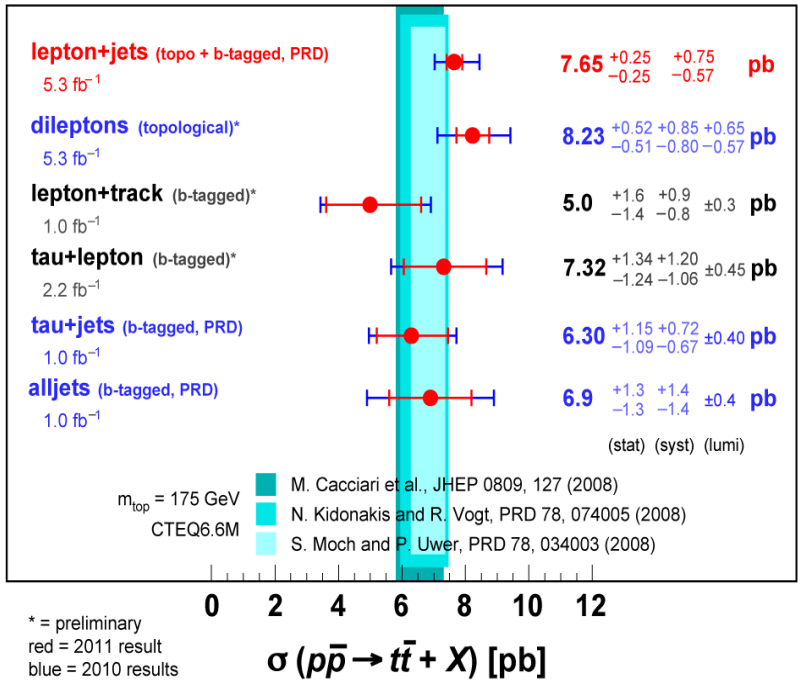
$t\bar{t}$ cross section



σ_{tt}^{SM}=7.5 pb @ M_{top} = 172.5GeV/c^2



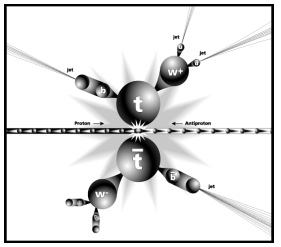
σ_{tt}^{SM}=6.7 pb @ M_{top} = 175 GeV/c^2

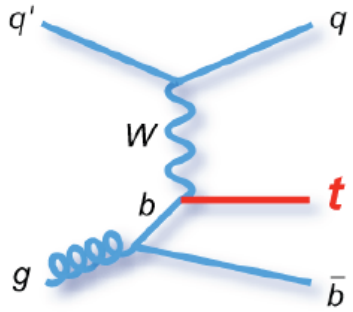


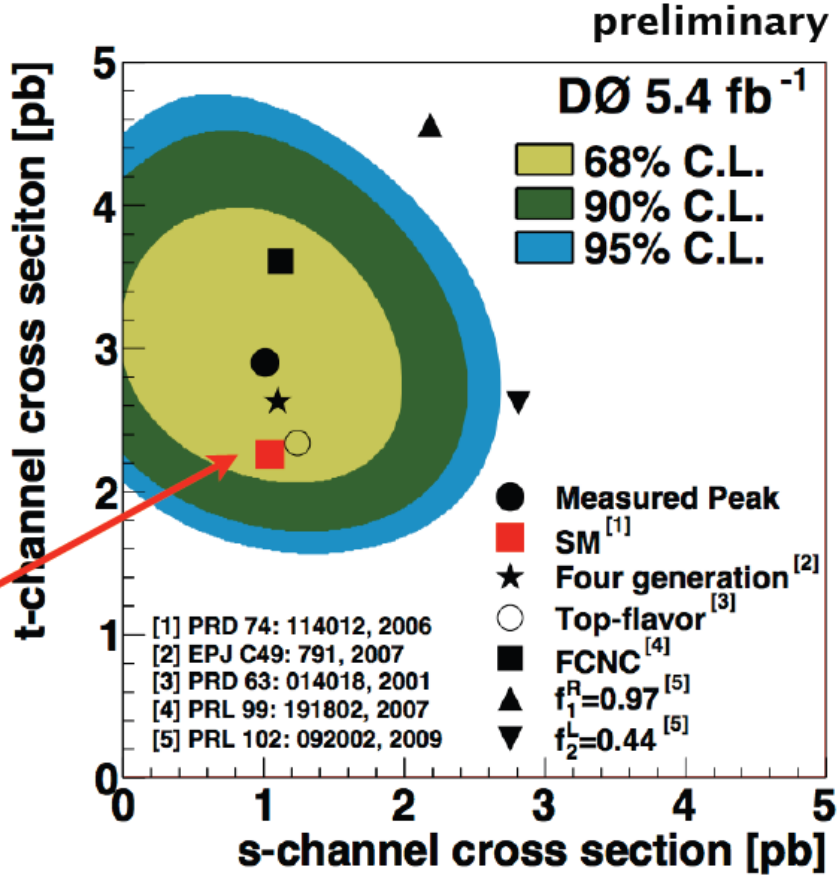
All results are consistent with Standard Model

Systematic limited measurements

Single top

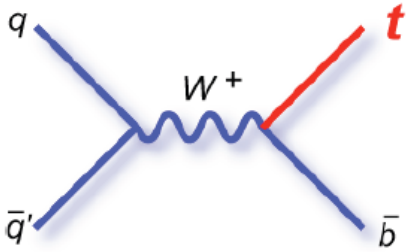






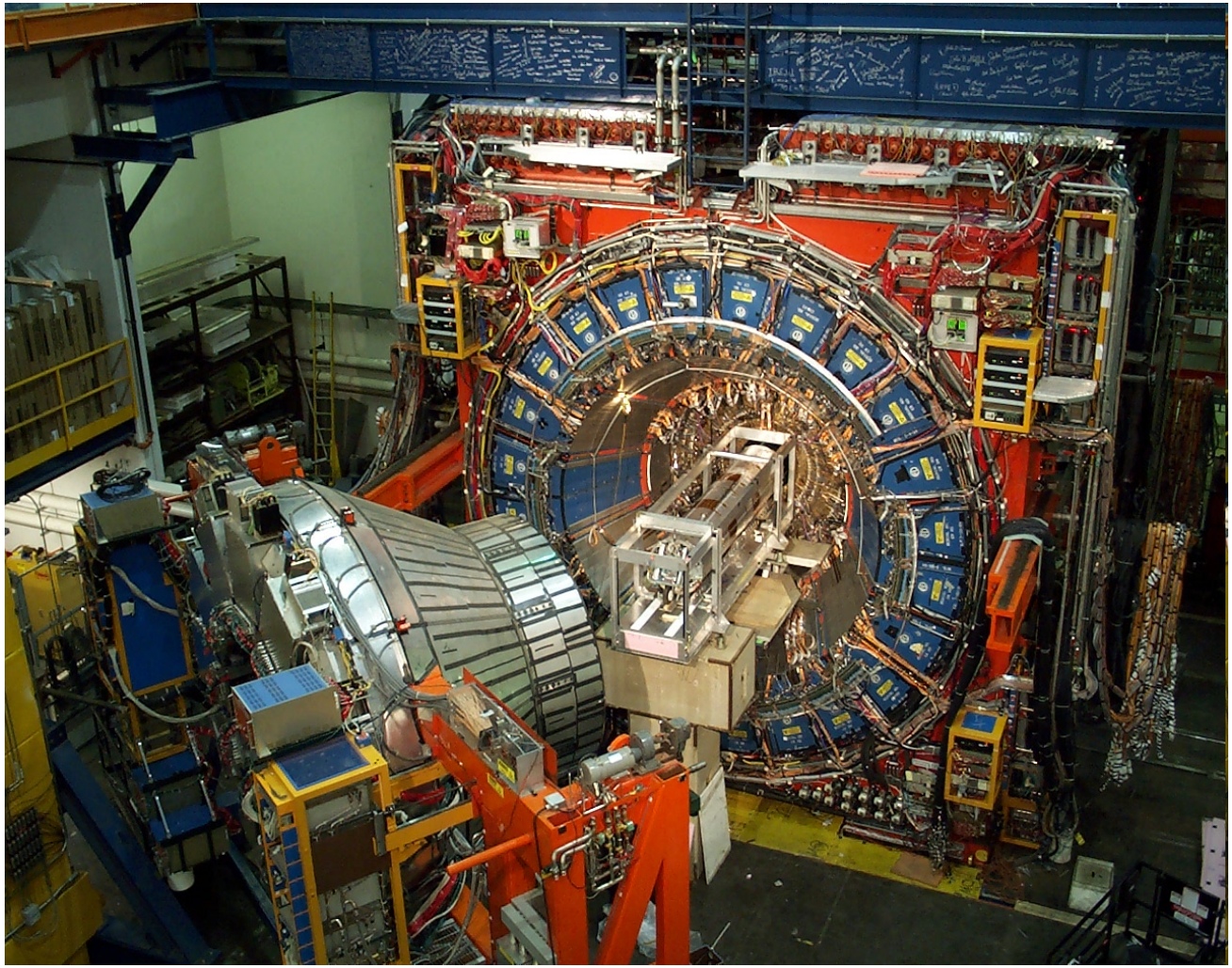
5.4 fb^{-1}

SM



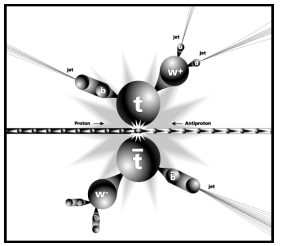
good agreement with Standard Model

CDF experiment



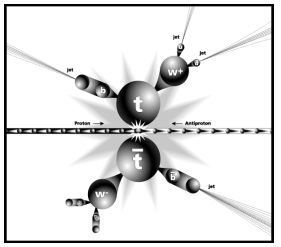
507 physicists from14 countries

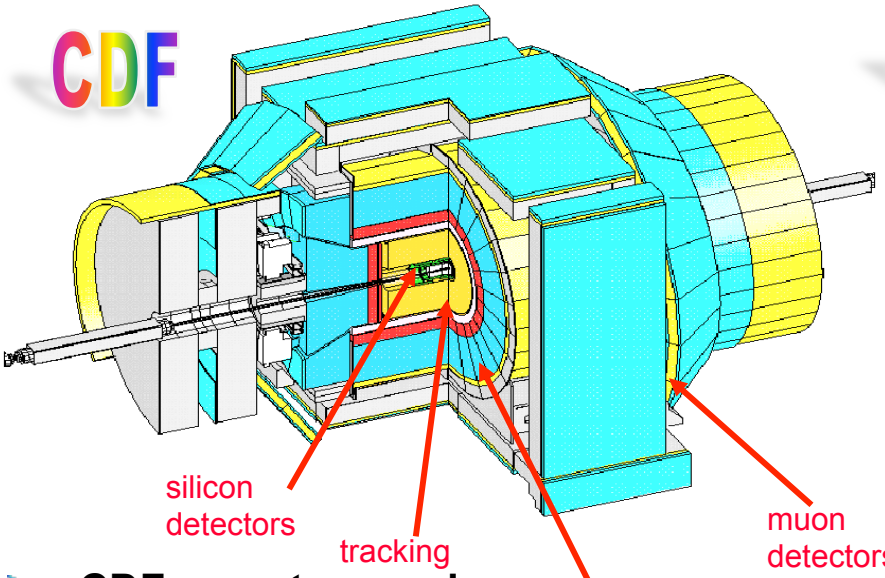
DØ experiment

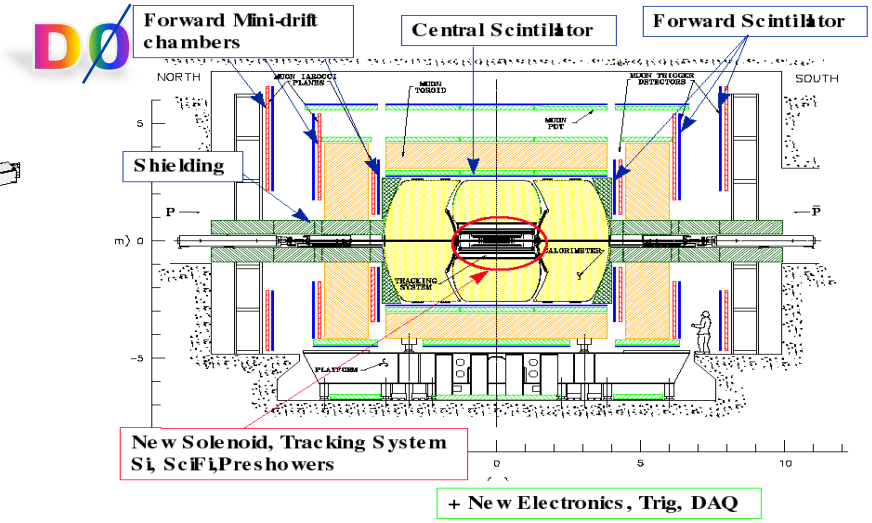


487 physicists from 20 countries

CDF & DØ







CDF recent upgrades

- Improved photon detection
  - **EM calorimeter: timing readout added**
  - **Central preshower: wire chambers replaced with the scintillation tiles**
- DAQ upgrade
  - **to match the trigger: 20MB/sec -> 60 MB/sec**

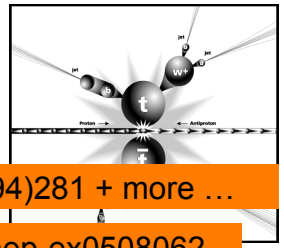
DØ recent upgrades

- Silicon detector: new layer at R~17mm – coming in summer 2005
- fiber tracker electronics - **improving tracking at high luminosities**

CDF & DØ: trigger upgrade to run at high luminosity

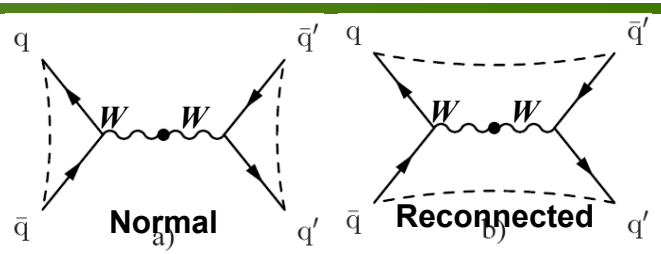
30KHz(L1)/1KHz(L2)/100Hz(L3)

Color Reconnections



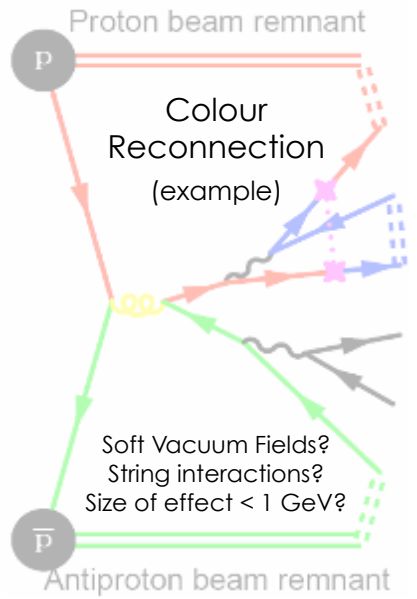
94)281 + more …

OPAL, Phys.Lett.B453(1999)153 & **OPAL**, hep-ex0508062



- Searched for at LEP
  - Major source of W mass uncertainty
  - Most aggressive scenarios excluded
  - But effect still largely uncertain $P_{reconnect} \sim 10\%$
- Prompted by CDF data and Rick Field's studies to reconsider.

  What do we know?
  - Non-trivial initial QCD vacuum
  - A lot more colour flowing around, not least in the UE
  - String-string interactions? String coalescence?
  - Collective hadronization effects?
  - More prominent in hadron-hadron collisions?
  - What is $\langle p_T \rangle (N_{ch})$ telling us?
  - What (else) is RHIC, Tevatron telling us?
  - *Implications for Top mass? Implications for LHC?*



From P.Skands

Sandhoff + PS, in Les Houches '05 SMH Proceedings, hep-ph/0604120