Top quak mass and width measurement from CDF Detector

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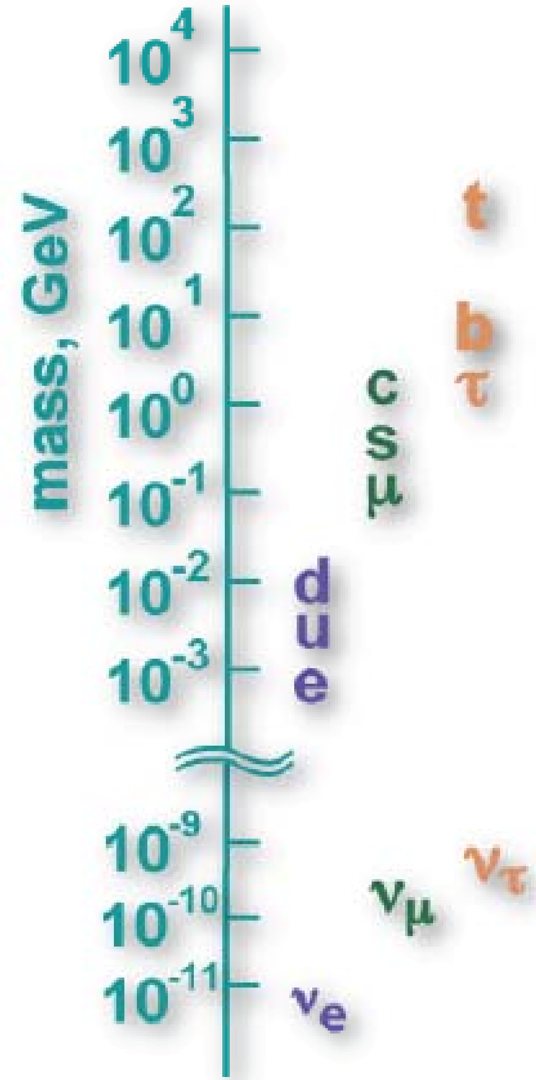
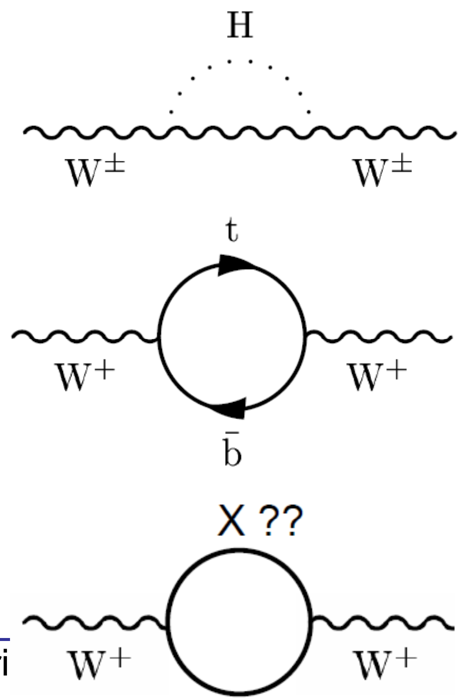
On behalf of the CDF collaboration

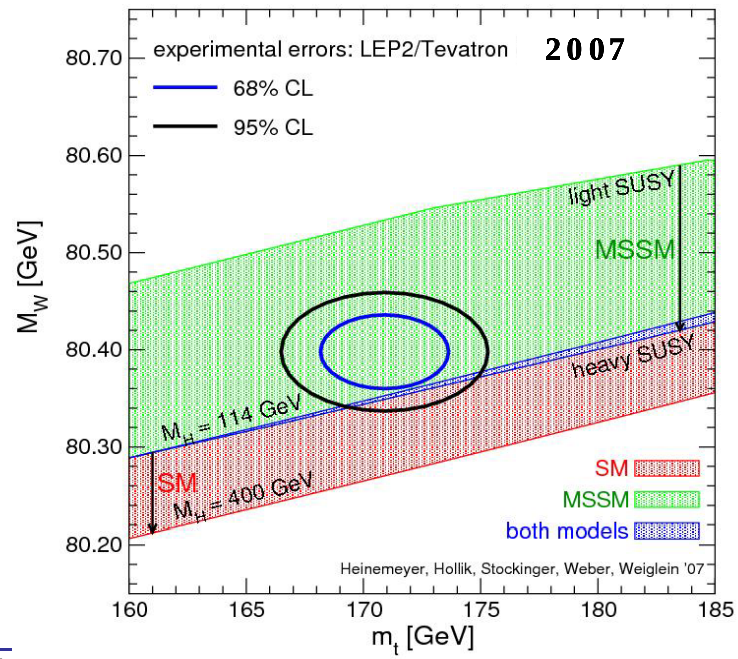
The 35th International Conference on High Energy Physics

Top quark mass



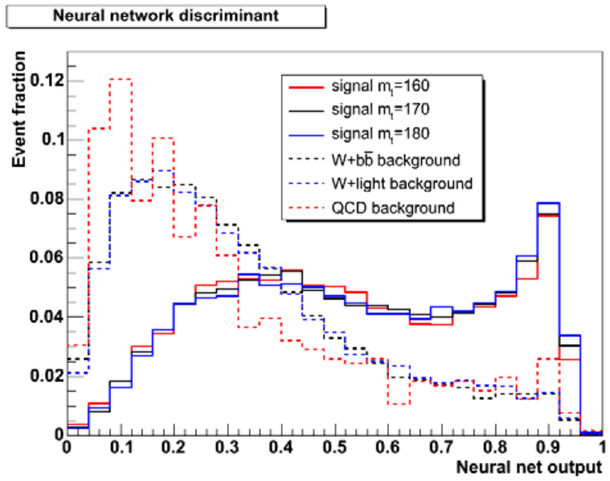
- Top quark is the heaviest known elementary particle
- Top quark mass is not predicted by SM
- Can constrain SM Higgs boson mass
  - Important contribution in radiative correction of W
  - Important test of SM

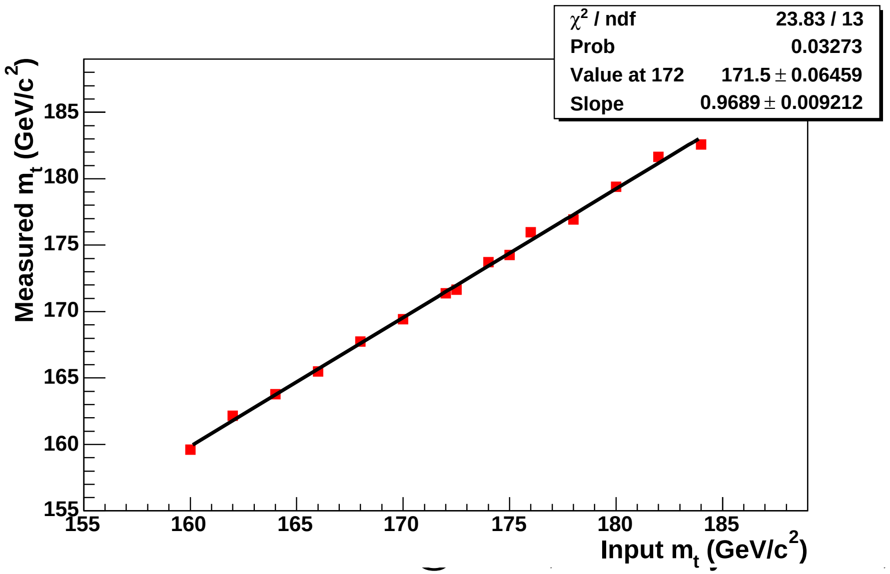


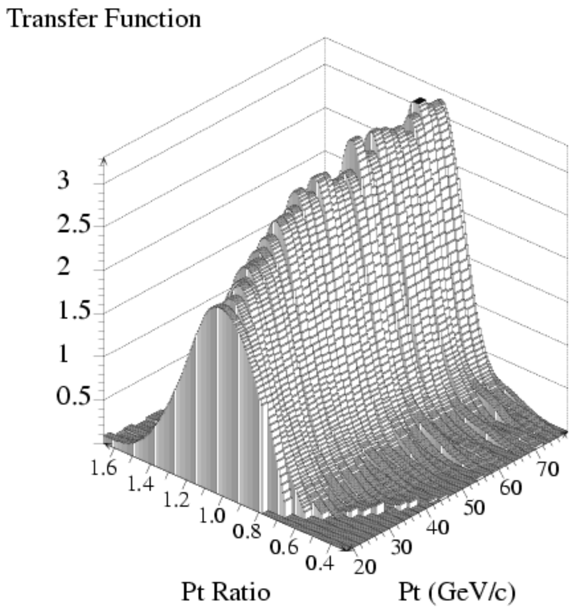


Lepton+Jets channel, Matrix Element

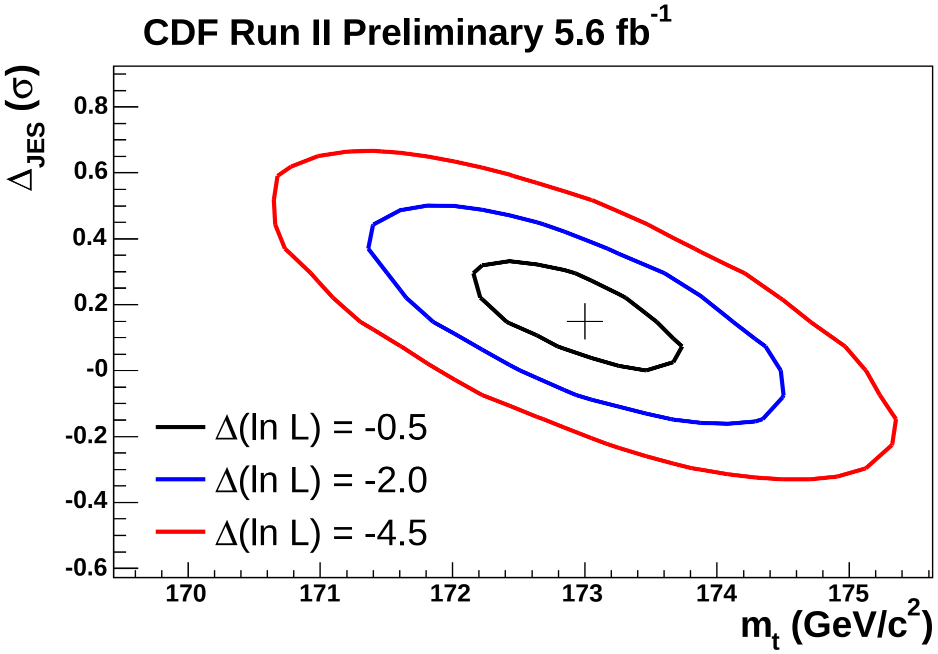
- 5.6 fb^{-1} data – 1263 events
  - ❖ We have additional NN based selection beside topology based selection
- Transfer function was parameterized by eta and jet mass for b-jet and light jet
- *In situ* JES calibration
- MC Pseudo experiments to calibrate machinery

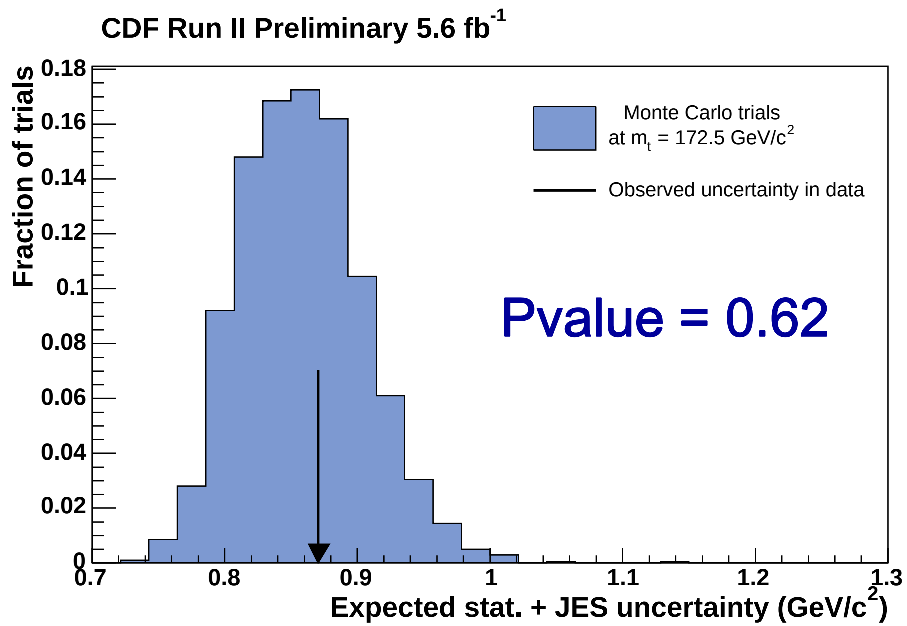






Result





This is the best individual top mass measurement in the world to date

$$173.0 \pm 0.7(\text{stat}) \pm 0.6(\text{JES}) \pm 0.9(\text{syst})\ \text{GeV}/c^2$$
$$= 173.0 \pm 1.2\ \text{GeV}/c^2$$

Systematic Uncertainties

CDF Run II Preliminary, 5.6 fb^{-1}

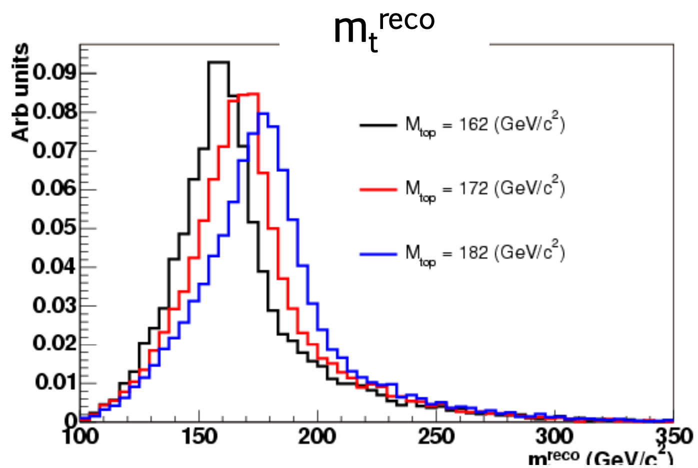
Systematic source	Systematic uncertainty (GeV/c^2)
Calibration	0.10
MC generator	0.37
ISR and FSR	0.15
Residual JES	0.49
b-JES	0.26
Lepton P_T	0.14
Multiple hadron interactions	0.10
PDFs	0.14
Background modeling	0.34
Color reconnection	0.37
Total	0.88

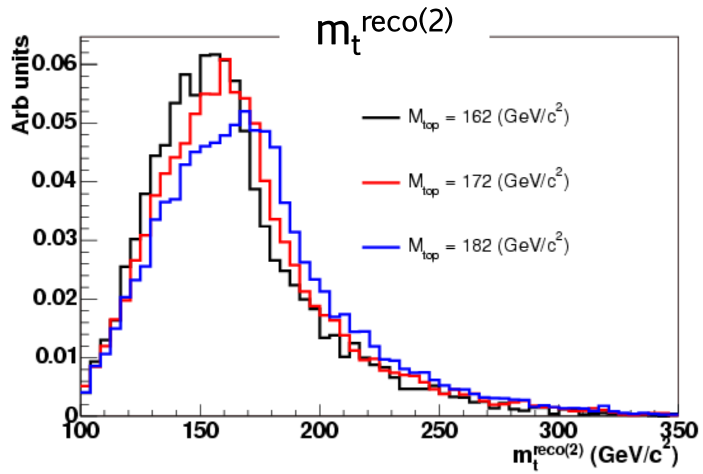
$173.0 \pm 0.7(\text{stat}) \pm 0.6(\text{JES}) \pm 0.9(\text{syst})$ GeV/c^2

$= 173.0 \pm 1.2$ GeV/c^2

Lepton+jets and Dilepton, Template Method

- 4.8 fb^{-1} data – 977 Lepton+jets(LJ)
  344 Dilepton(DIL)
- Fully three dimensional PDF using three observables in LJ
  - ❖ 3rd observables is reconstructed mass using kinematic fit with different combination of jet to parton assignment (2nd best fit)
- LJ only measurement
  - ❖ 172.0 ± 1.5 GeV/c^2
  - ❖ Complement technique, consistent result





- Simultaneously use LJ+DIL

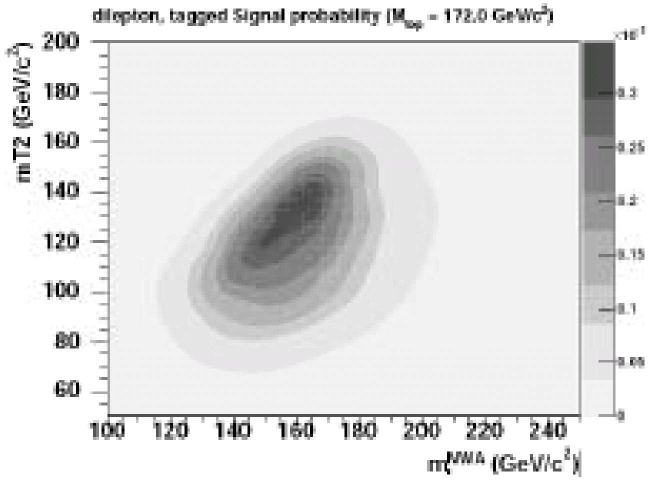
$$171.9 \pm 0.8\,(\text{stat}) \pm 0.8\,(\text{JES}) \pm 0.9\,(\text{syst})\ GeV/c^2$$
$$=171.9 \pm 1.5\ GeV/c^2$$

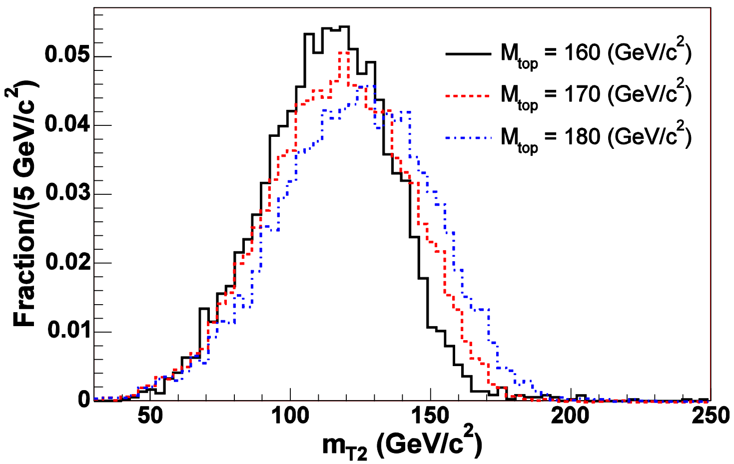
Continue – Dilepton channel alone

- Two observables taking into account correlation
  - Reconstructed mass and m_{T2}
- Interesting observable m_{T2}
  - Quantity of transverse mass in two missing particle system
  - Originally introduced to measure the mass of new physics particles

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

    Phys.Rev.D 81 (2010) 031102





LJ : 172.0 ± 1.5 GeV/c^2

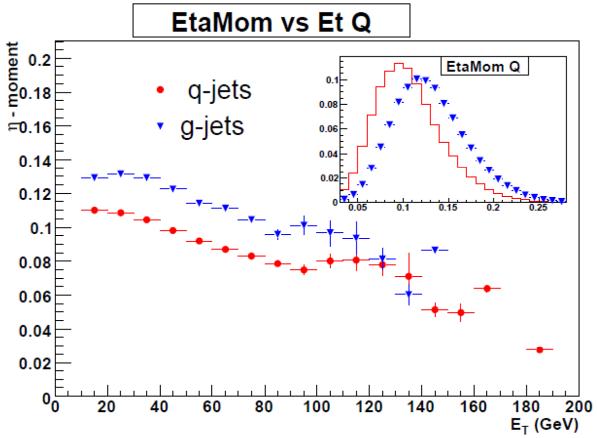
170.6 ± 2.2 (stat) ± 3.1 (syst) GeV/c^2
=170.6 ± 3.8 GeV/c^2

All jets channel, Template Method

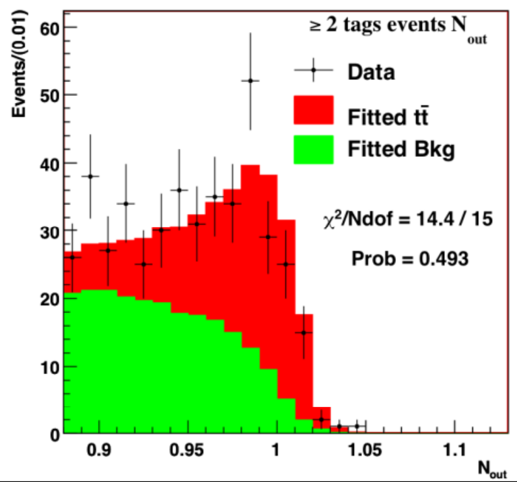
- 2.9 fb^{-1} date, template method
- Two dimensional template
  - Reconstructed top mass and reconstructed dijet mass
- NN discrimination to reduce dominant QCD backgrounds
  - Jet shape to discriminate gluon jet from quark jet

$$M_\eta \equiv \sqrt{\sum_{towers} \frac{E_T^{tower}}{E_T^{jet}} \eta^2_{tower} - \eta^2_{jet}}$$

  - 1btag S:B=1:4 (3452 candidates)
  - 2btag S:B=1:1 (441 candidates)

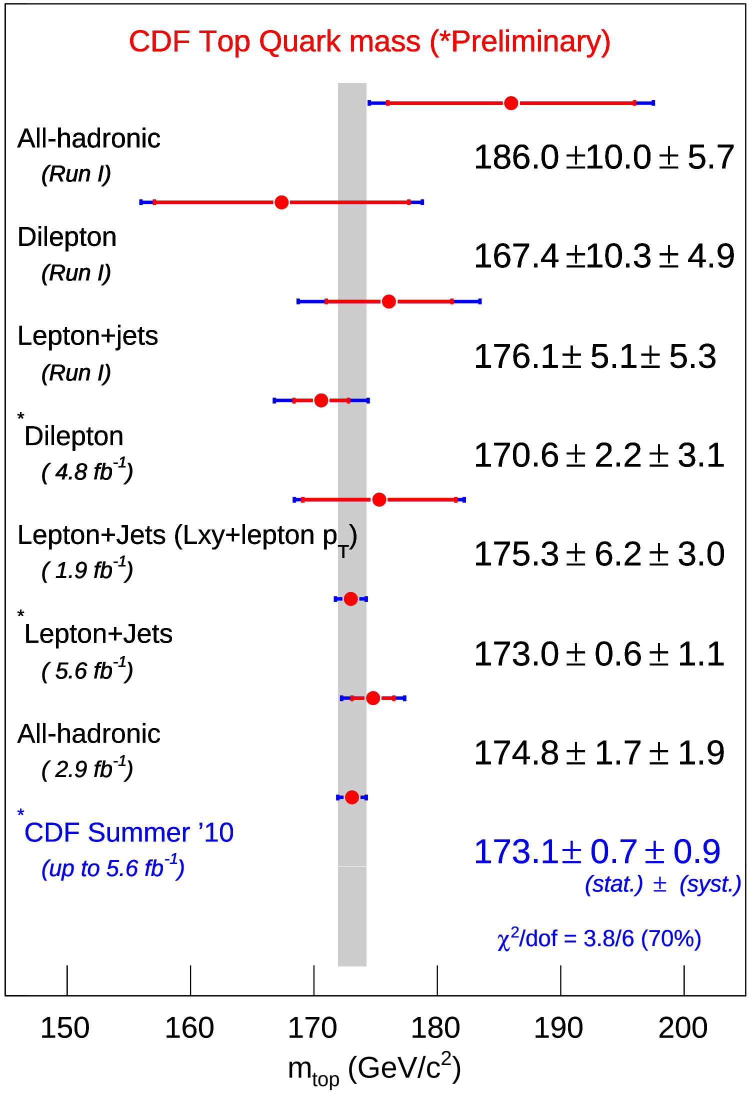


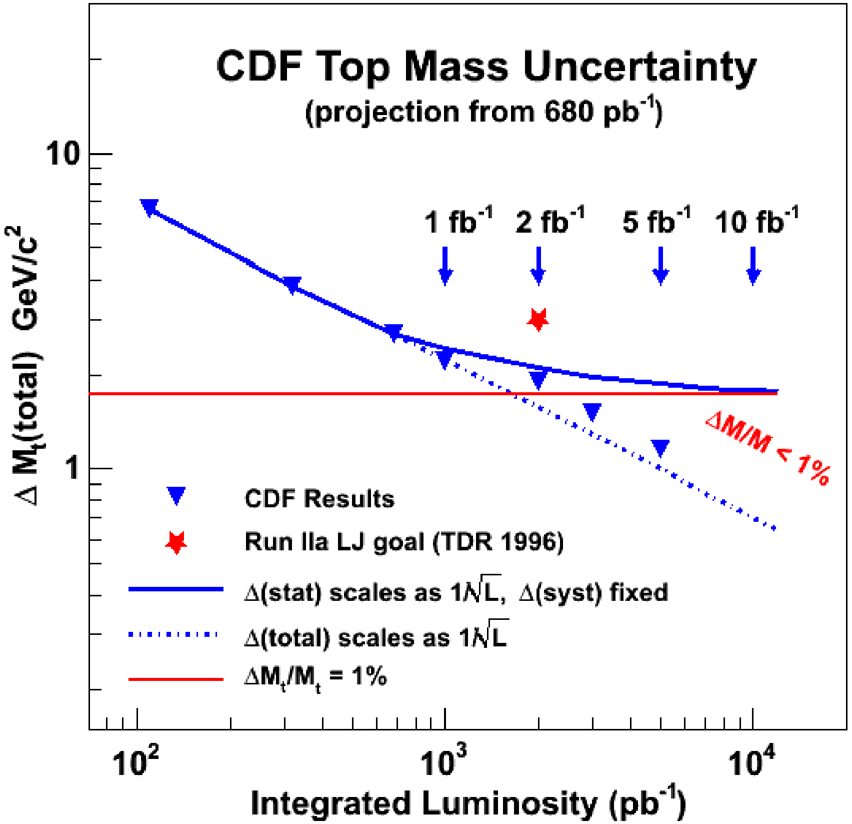
CDF Run II Preliminary (2.9 fb^{-1})



174.8 ± 1.7 (stat) ± 1.9 (JES+syst) GeV/c^2
=174.8 ± 2.7 GeV/c^2

CDF Combination and future

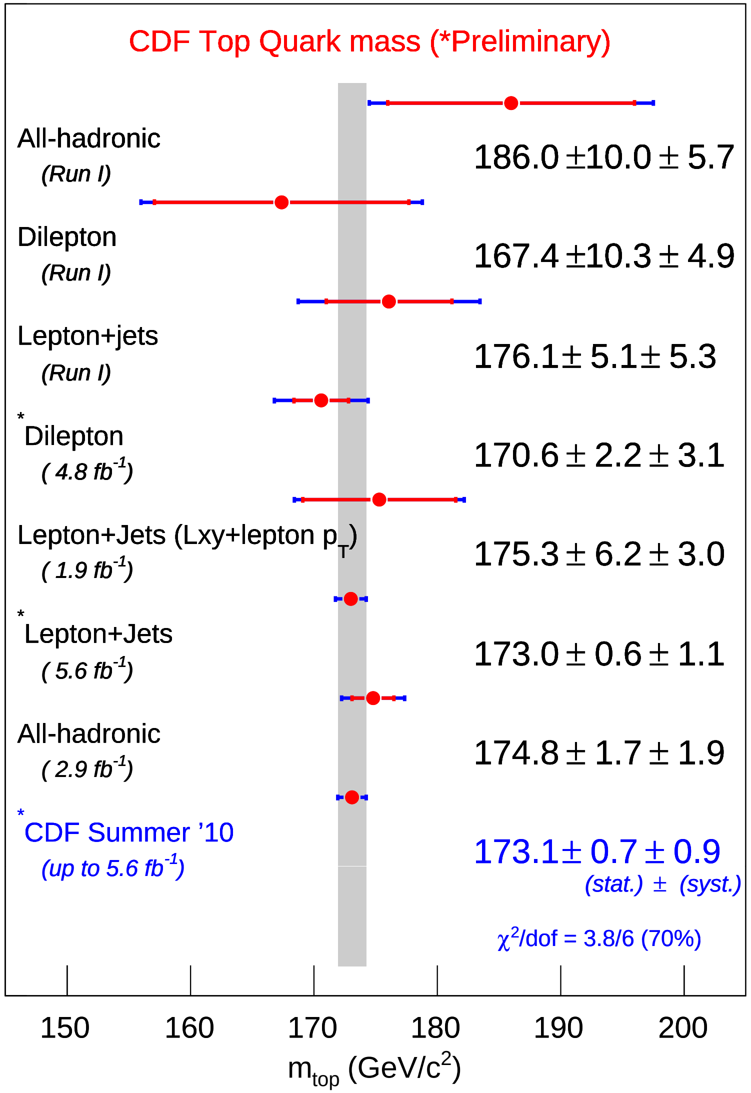


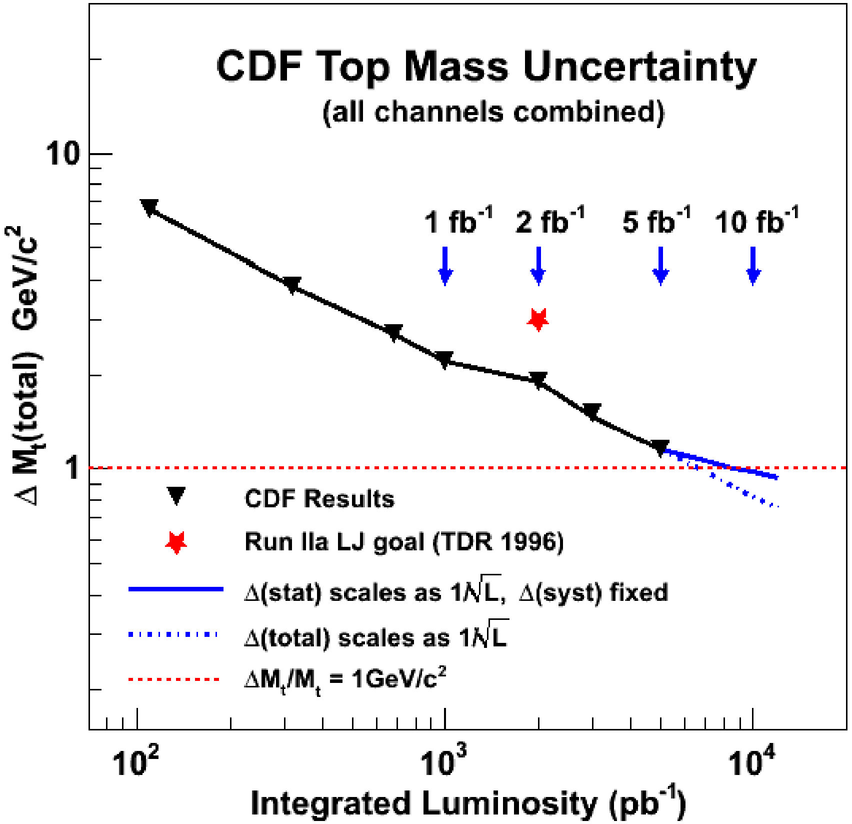


- Better than luminosity increase
- Current precision = 1.2 GeV/c^2

~0.67 %

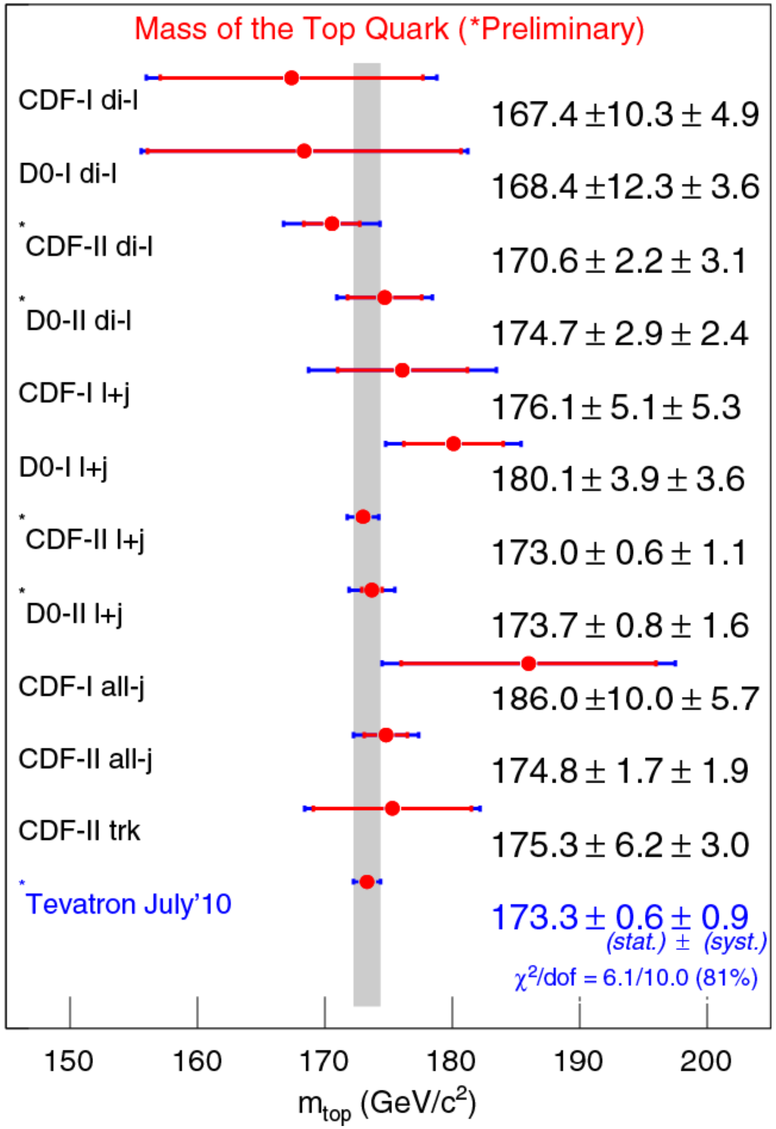
CDF Combination and future

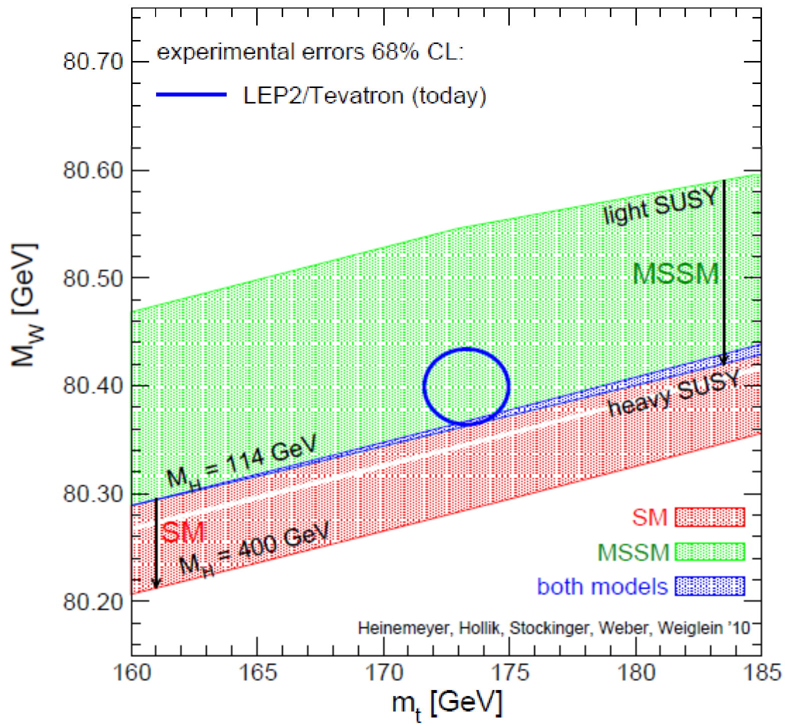




- $1\,\mathrm{GeV}/c^2$ precision might be possible without any improvement at $10\ \mathrm{fb}^{-1}$

Tevatron Combination





World average = 173.3 $\pm$ 1.1 GeV/c^2

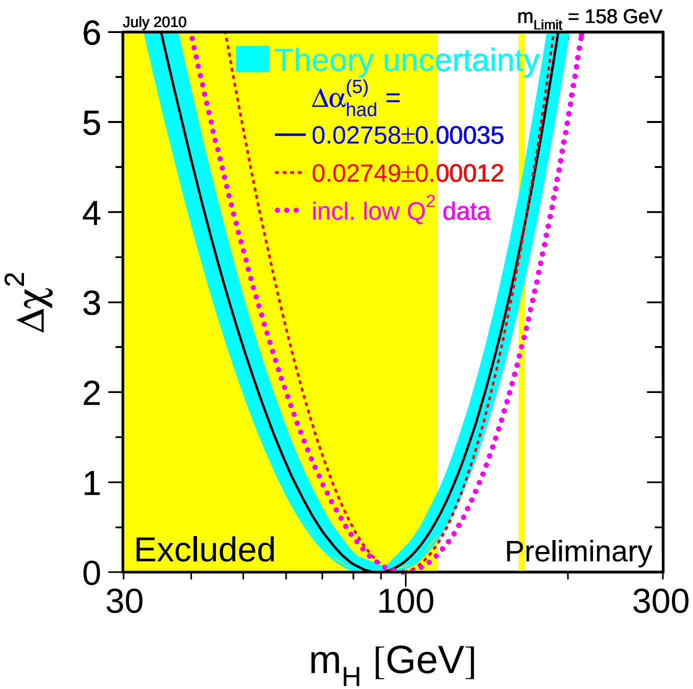
~0.61 % Precision

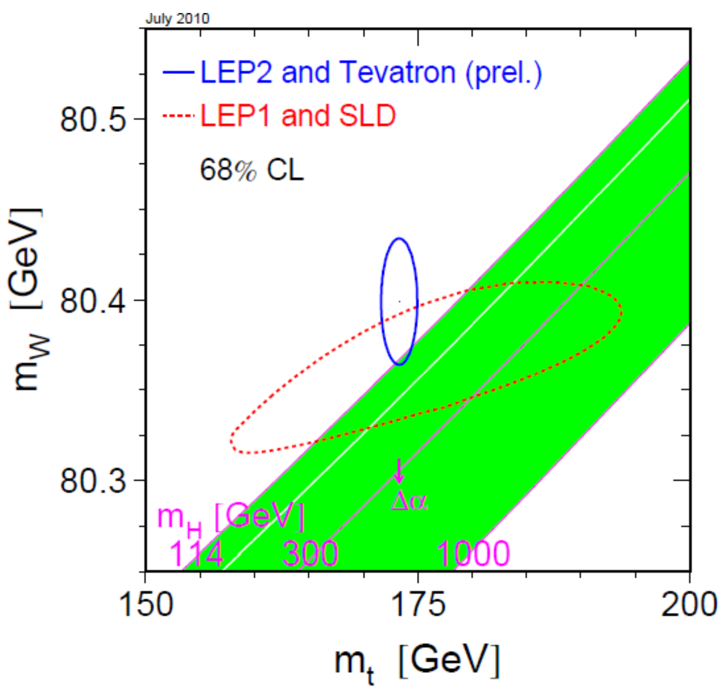
All results are consistent each others

Global EWK fit and Higgs constraints

LEP Electron Weak Working Group July 2010 Update

http://lepewwg.web.cern.ch/LEPEWWG/





$$m_H = 89^{+35}_{-26}\ \text{GeV/c}^2 \qquad m_H < 158\ \text{GeV/c}^2\ (95\%\ \text{CL})$$

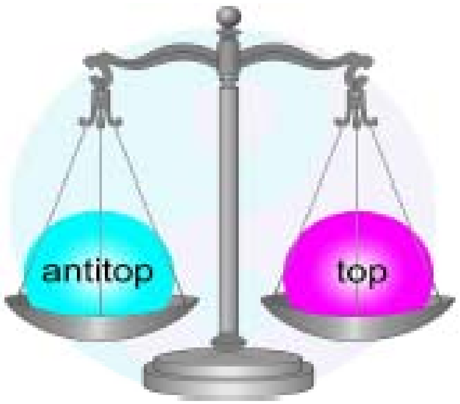
$$m_H < 185\ \text{GeV/c}^2\ (95\%\ \text{CL})$$

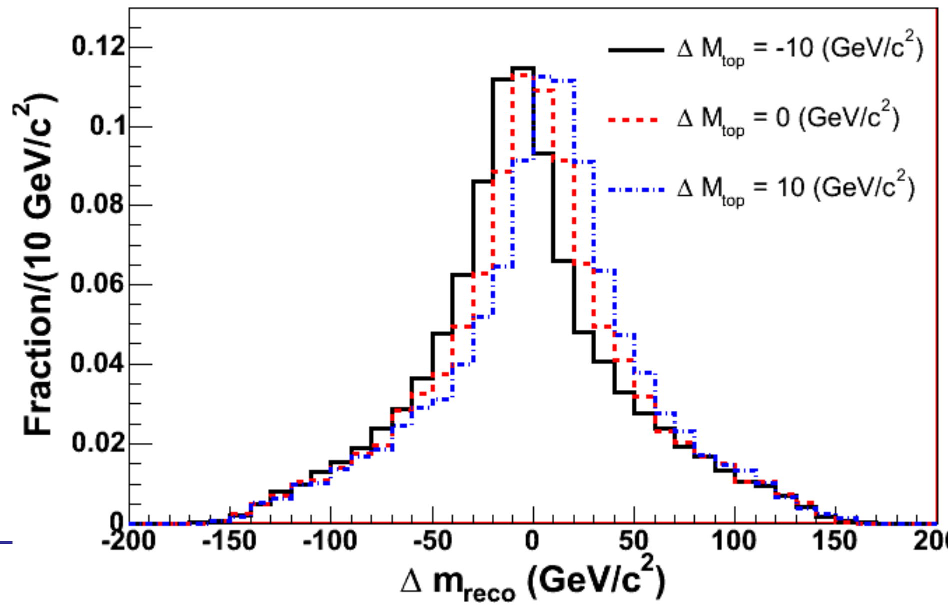
With direct limit from LEPII

Is top mass same with anti top quark?

- Measured top mass precision allows us to test the mass difference top and anti-top quark
- Good test of possible CPT violation
  - CPT violation has not very well tested on bare quarks
  - Most of test was done for relatively low mass particles
  - D0 1fb^{-1} measurement using ME technique

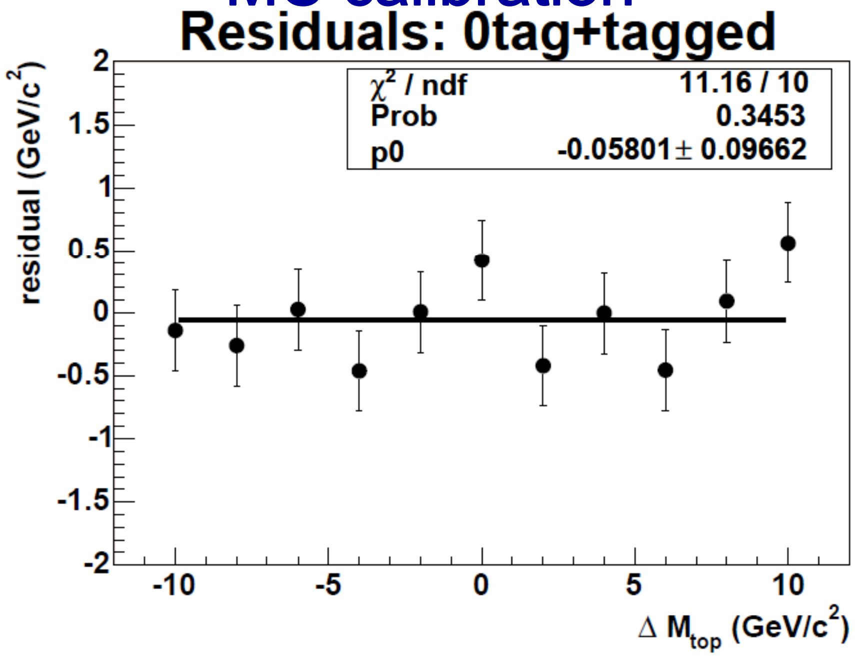
    $\Delta M = 3.8 \pm 3.7$ GeV/c^2
- We use template technique in the lepton+jets channel



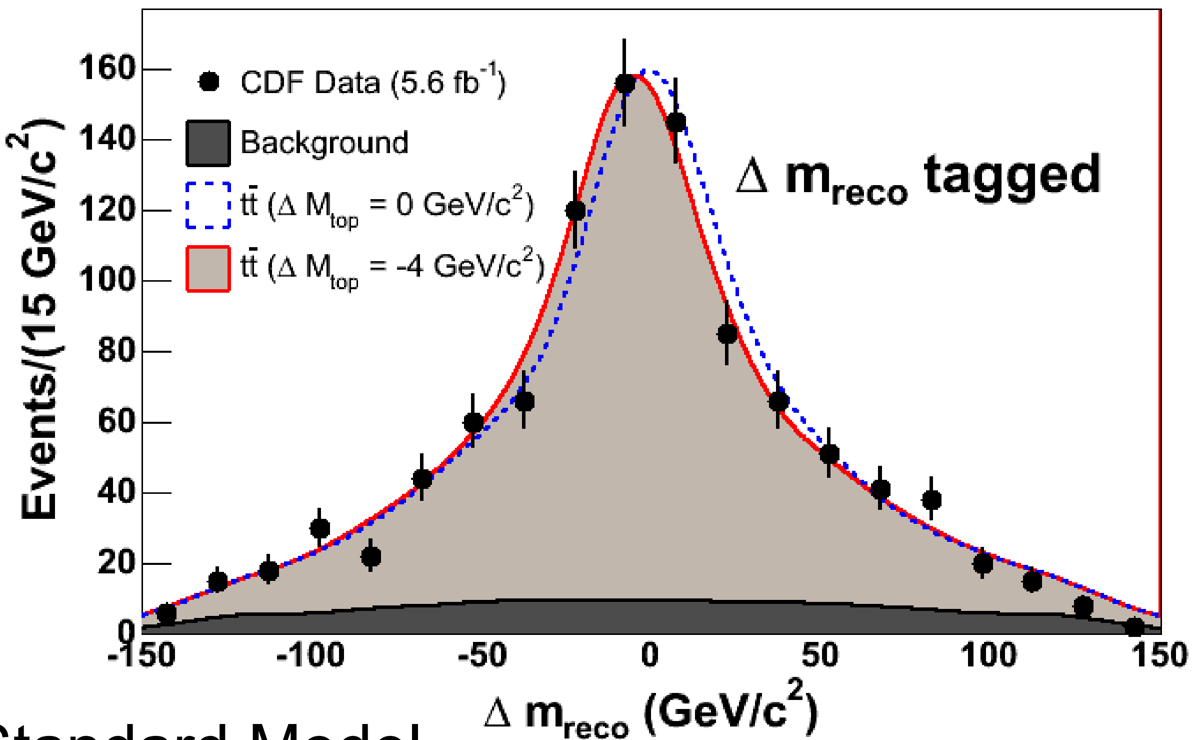


Results

MC calibration



CDF II Preliminary



- ~ 2σ deviation from Standard Model

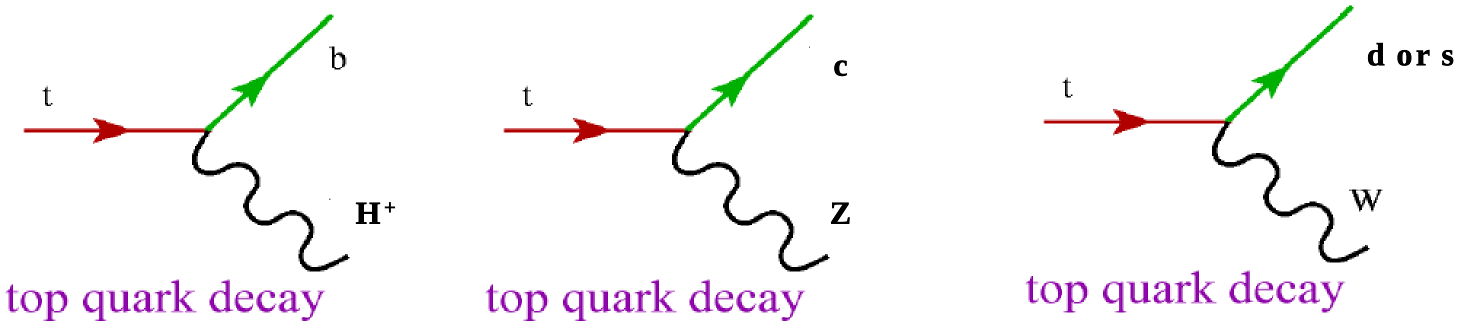
$$-3.3 \pm 1.4\ (\text{stat}) \pm 1.0\ (\text{syst})\ \text{GeV}/c^2$$
$$= -3.3 \pm 1.7\ \text{GeV}/c^2$$

Why top quark width ?

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

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

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

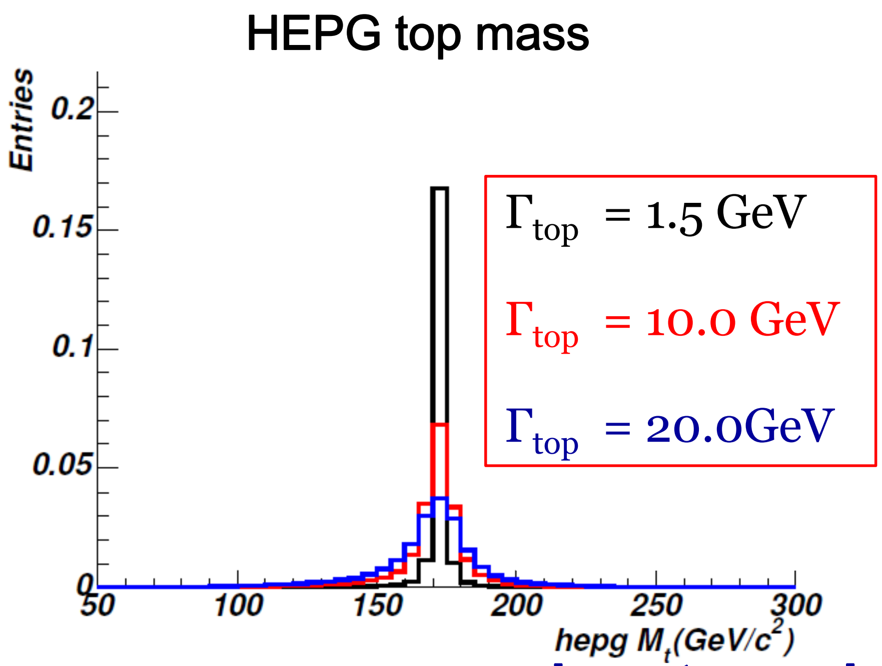


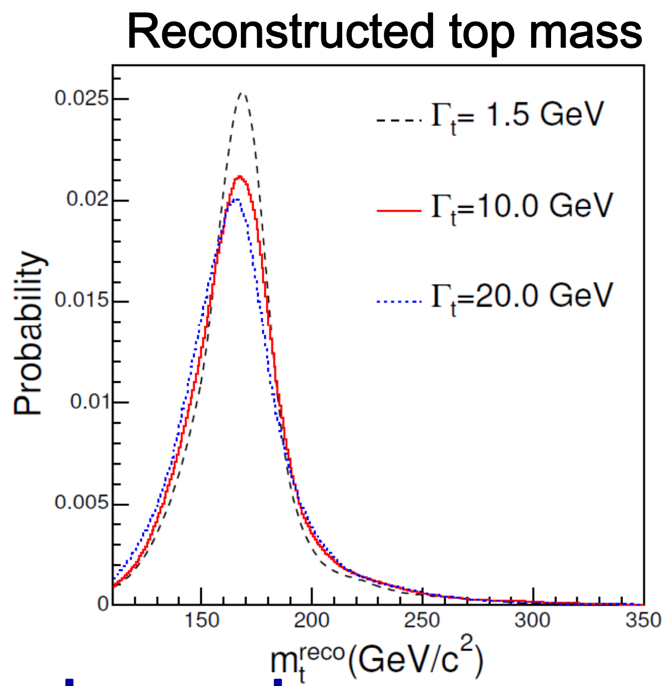
- Resolving Top quark life time

$$\tau = \frac{\hbar}{\Gamma}$$

Short life time (decay before hadronization)

How we can extract top width?

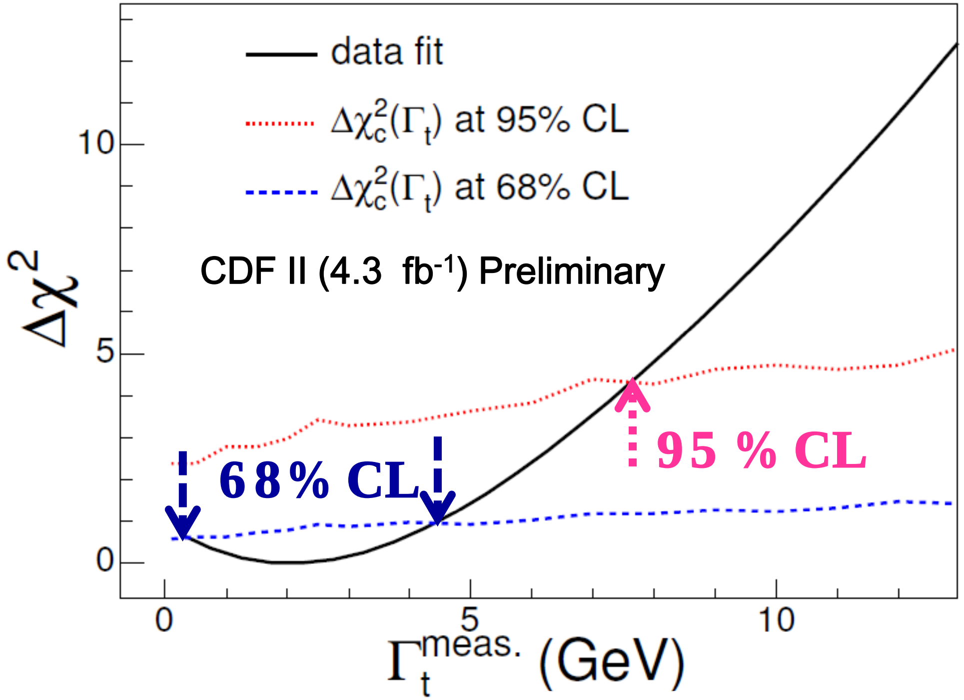




Lepton+Jets channel

- Top width can make different shape of reconstructed top quark mass (RMS)
- After detector response, the effects were smeared but still we have information about top quark width

Results



- *In situ* JES calibration using 2D template (m_t^{reco}, W_{jj})
- First direct lower bound (68% CL) was set

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

$$0.3 < \Gamma_{top} < 4.4 \text{ GeV @ } 68\% \text{ CL}$$

$$1.5\ e^{-25}\ s < \tau_{top} < 2.2\ e^{-24}\ s < \tau_{had.} \approx 3.3\ e^{-24}\ s$$

Conclusion

- 0.67% (0.61%) precision of top quark mass from CDF(Tevatron)

$$M_{top} = 173.1 \pm 1.2 \text{ GeV}/c^2 \text{ ,CDF Comb.}$$

$$M_{top} = 173.3 \pm 1.1 \text{ GeV}/c^2 \text{ ,Tevatron Comb.}$$

- 1% resolving and observing approximately 2σ deviation (but, still consistent) of the mass difference from CDF

$$\Delta M_{top} = -3.3 \pm 1.7 \text{ GeV}/c^2$$

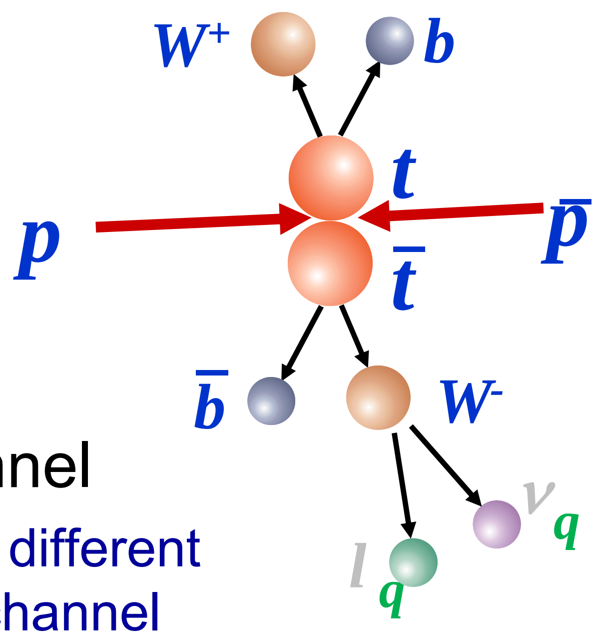
- First direct lower bound of top quark width from CDF

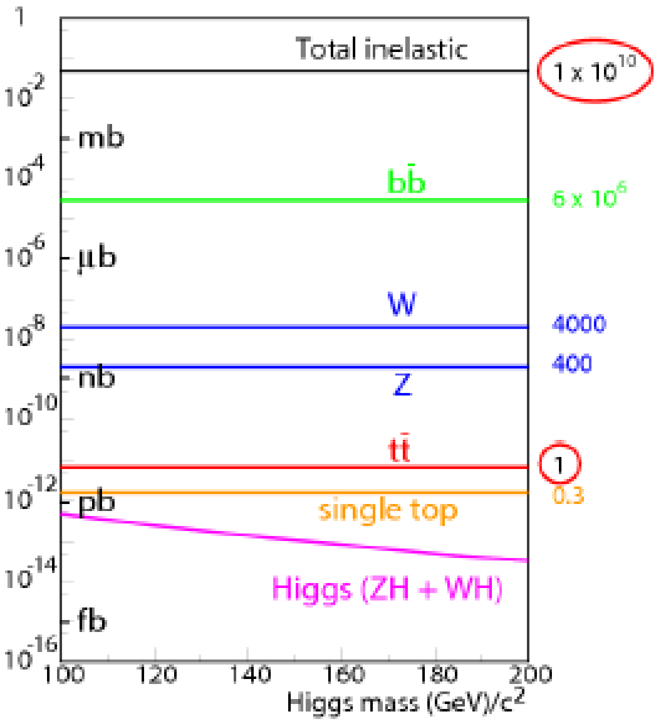
$$0.3 < \Gamma_{top} < 4.4 \text{ GeV @ 68\% CL}$$

Backup

Top quark decay

- Pair production is predominated
- ~100% decay to W boson plus b quark
- Decay topologies rely on the decay of W boson
  - ❖ two jet (70%) or lepton and neutrino (30%)





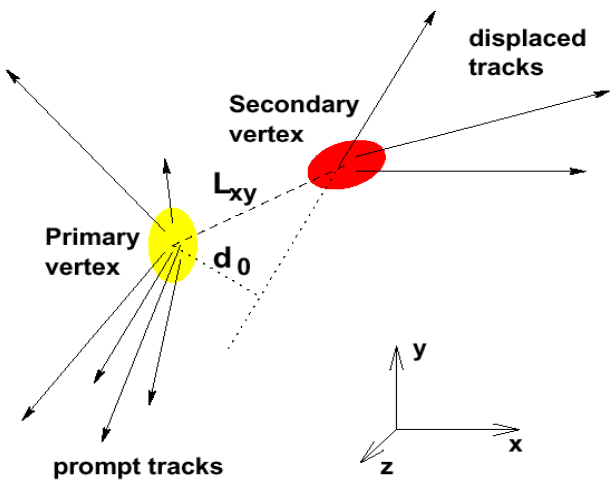
Important to look all channel

- ❖ New physics would make different phenomena for different channel

Challenge for mass measurement

- ❖ Up to six jet - Jet energy scale , jets to parton assignment
- ❖ Up to two neutino – Missing energy – Event reconstruction
- ❖ Large QCD backgrounds

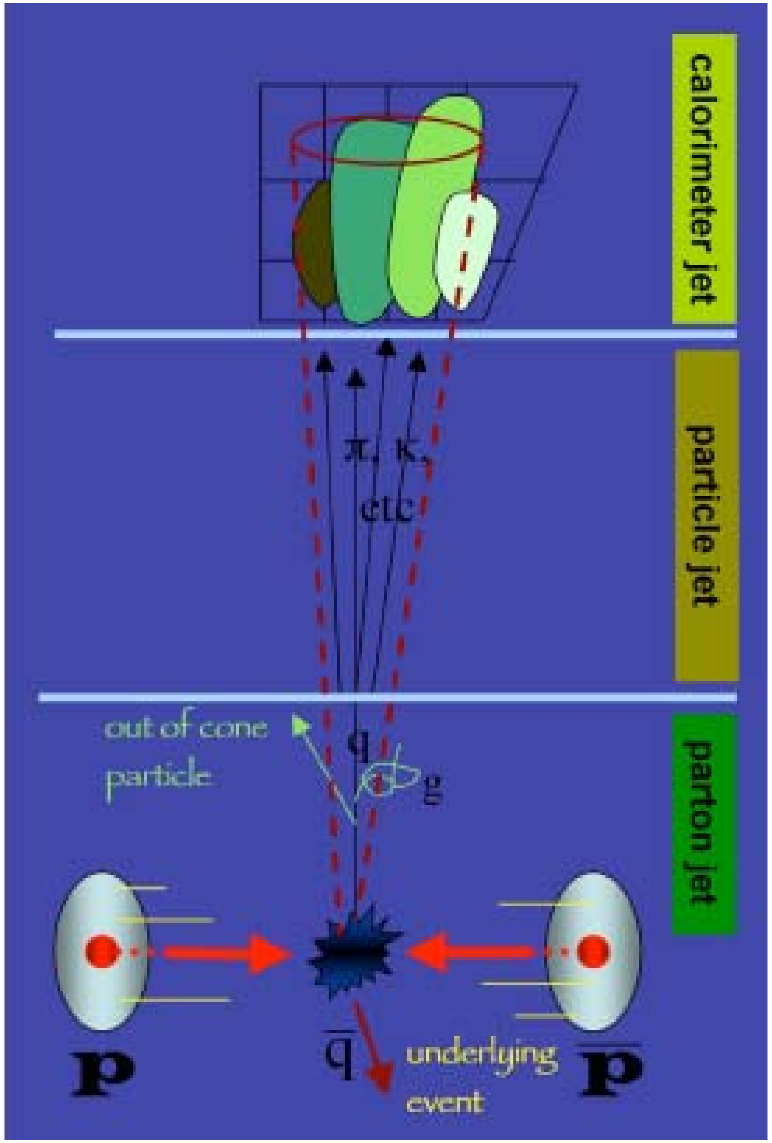
b-tagging

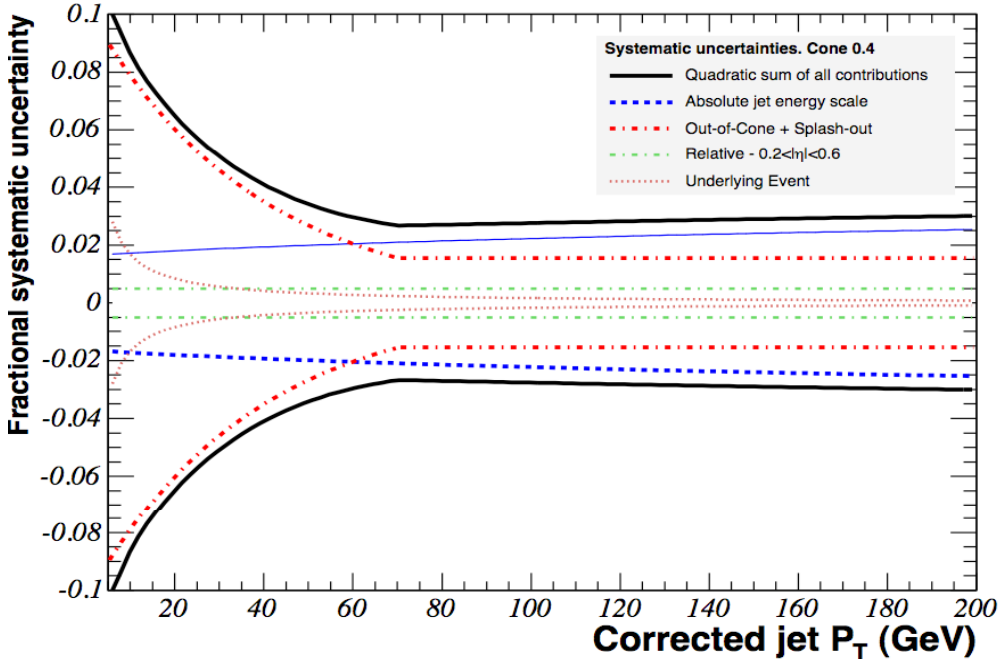


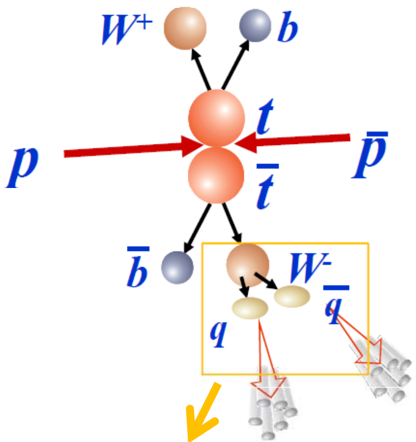
- B hadron can be identified by long displacement
- b tagging reduce # of jet-to-parton assign.
  - Ex) lepton+jets channel
  - 24 (0-btags), 6(1-btags), 2(2-btags)
- b tagging improve signal to background ratio significantly – 40% effi., 0.5% fake

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)

Jet energy scale







Measured JES uncertainty

Lepton+jets : 1.0 GeV/c^2

Dilepton : 2.9 GeV/c^2

(CDF 4.8 fb^{-1}, template method)

In situ JES calibration

Measurement technique (Matrix element technique)

- Try to extract as much information as possible from every event using theoretical prediction for ttbar production and decay
- Integrate over unknown parton energies given a measured jet energy
- For each event, we calculate probability to be ttbar with certain mass M_{top} (also JES)

Transfer function between parton and detector response

$$P(\vec{x}; M_{top}, JES) \propto \int ME \times TF \times PDF$$

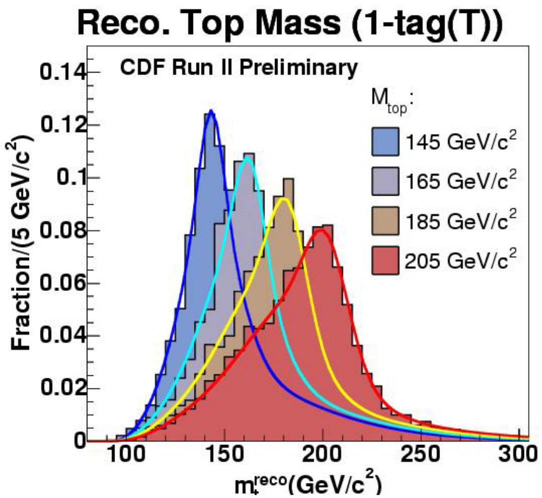
ttbar Matrix element

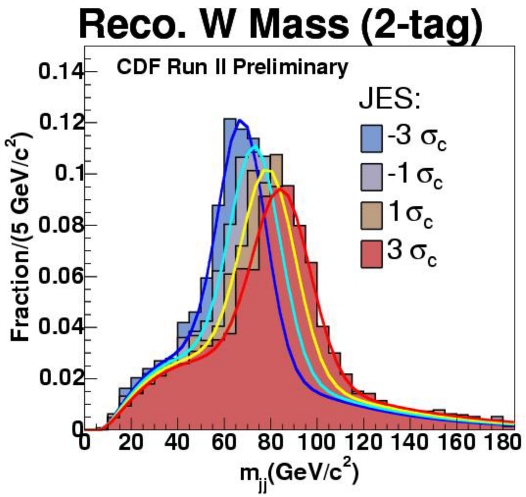
Parton distribution function

- Background probability is also calculated using background matrix element
- Perform the likelihood fit using event probability

Measurement technique (template method)

- Identify variables $\vec{x}$ sensitive to M_{top} (or JES)
- Using MC, generate signal distribution of $\vec{x}$ as a function of M_{top} (or JES)
- Parametrize templates in terms of probability density function then assign the probability for certain mass and JES





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

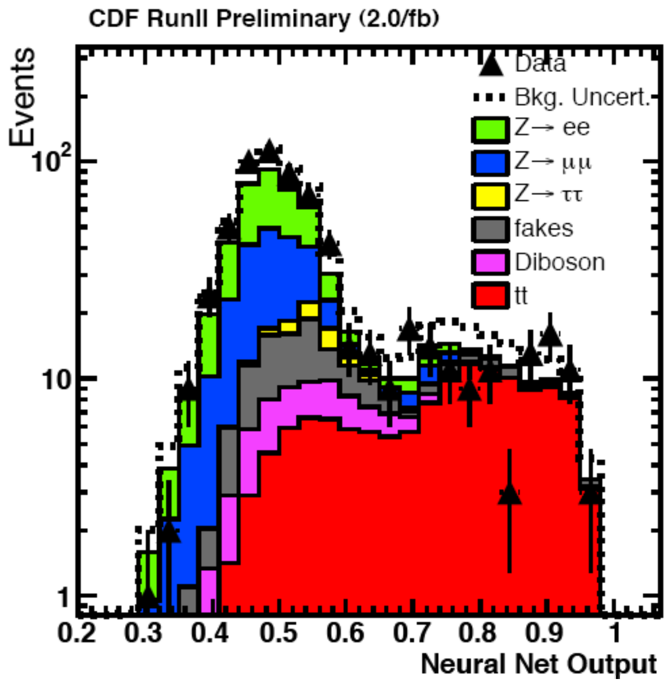
Event reconstruction in the lepton+jets

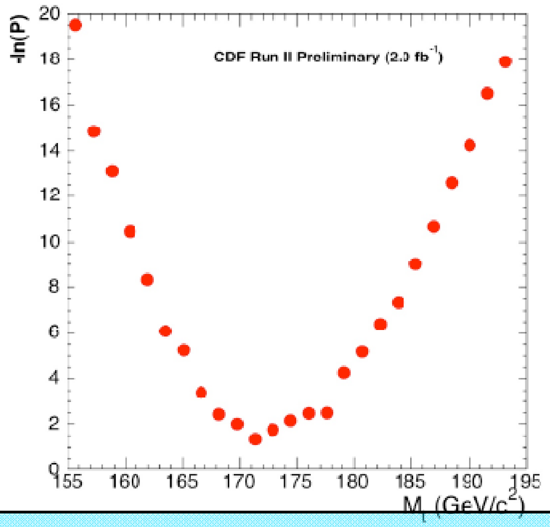
$$\chi^2 = \Sigma_{i=\ell,4jets} \frac{(p_T^{i,fit} - p_T^{i,meas})^2}{\sigma_i^2} + \Sigma_{j=x,y} \frac{(U_j^{fit} - U_j^{meas})^2}{\sigma_j^2} + \frac{(M_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(M_{\ell\nu} - M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj} - m_t^{\rm reco})^2}{\Gamma_t^2} + \frac{(M_{b\ell\nu} -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

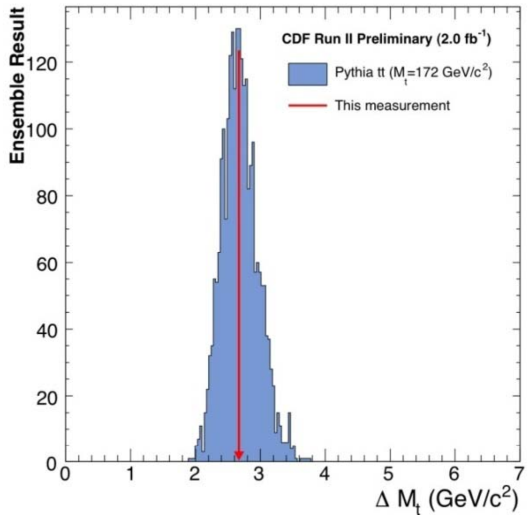
- Construct likelihood based on probabilities

Dilepton channel, Matrix Element

- 2.0 fb^{-1} data, Matrix element method
- Event selection was optimized for top quark mass measurement using NN
- More sensitive analysis than template method



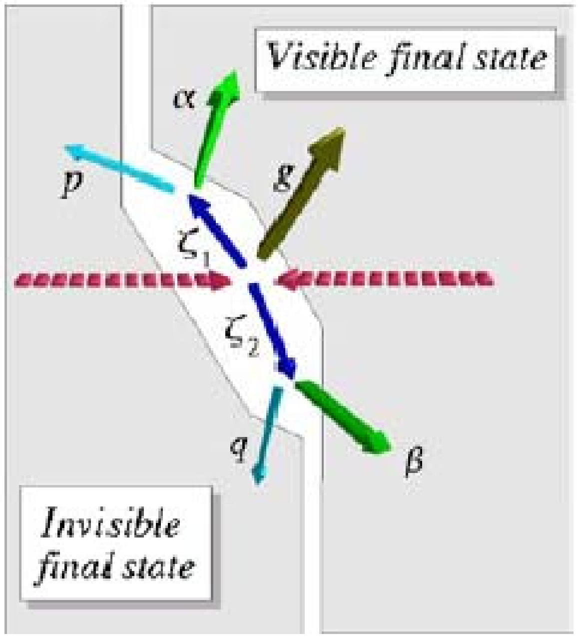




$$171.2 \pm 2.7\ (\text{stat}) \pm 2.9\ (\text{syst})\ \text{GeV}/c^2$$
$$=171.2 \pm 4.0\ \text{GeV}/c^2$$

m_{T2}

- Introduced to measure the mass of new physics particle)
  - Most of new physics predict long-live stable particle – dark matter candidate
  - We expect missing particle at the final state
  - If we consider pair production of new physics particle, it will have two missing particle



- Top dilepton channel have exactly same final state

$$m_{T2} = \min[\max(m_{T(1)}, m_{T(2)})]$$

$$q_T + p_T = \text{missing } p_T$$

Alan Barr, Christopher Lester and Phil Stephens
J. Phys. G: Nucl. Part. Phys. 29 (2003) 2343–2363

Event Reconstruction

- We modified nominal kinematic fitter to get mass difference

$$\chi^2 = \Sigma_{i=\ell,4jets}\frac{(p_T^{i,fit}-p_T^{i,meas})^2}{\sigma_i^2} + \Sigma_{j=x,y}\frac{(U_j^{fit}-U_j^{meas})^2}{\sigma_j^2}$$

$$+ \frac{(M_{jj}-M_W)^2}{\Gamma_W^2} + \frac{(M_{\ell\nu}-M_W)^2}{\Gamma_W^2}$$

$$+ \frac{(M_{bjj}-(172.5+dM_{reco}/2))^2}{\Gamma_t^2} + \frac{(M_{b\ell\nu}-(172.5-dM_{reco}/2))^2}{\Gamma_t^2}$$

$$\Delta m_{\mathrm{reco}} = -Q_{lepton} \times dM_{reco}$$

- This variable is corresponding to top quark mass minus anti-top quark mass in reconstruction level