Top quak mass measurement at Tevatron

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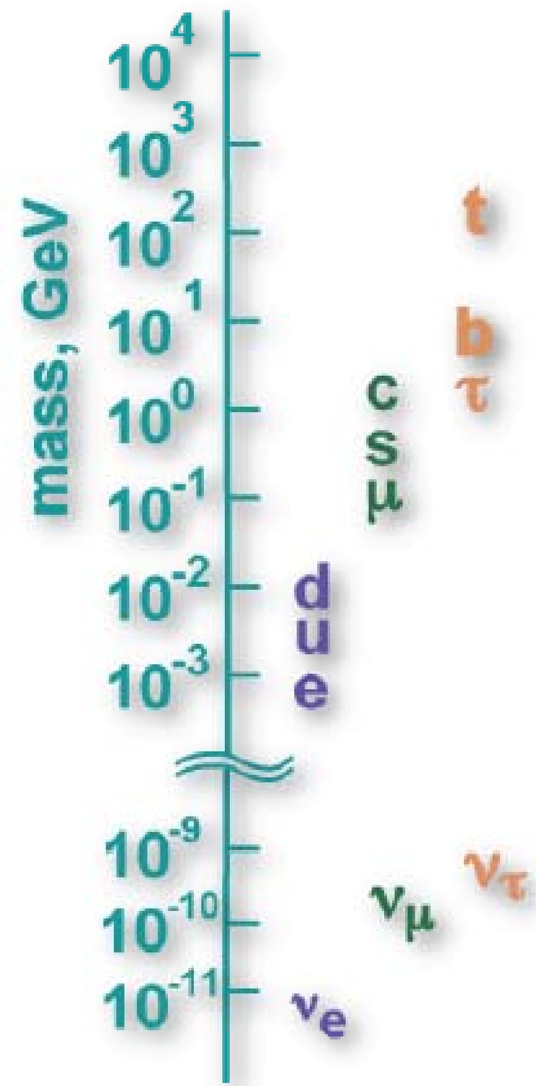
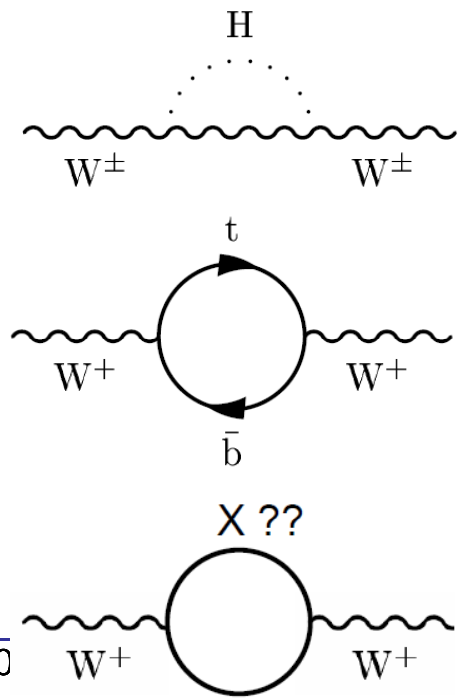
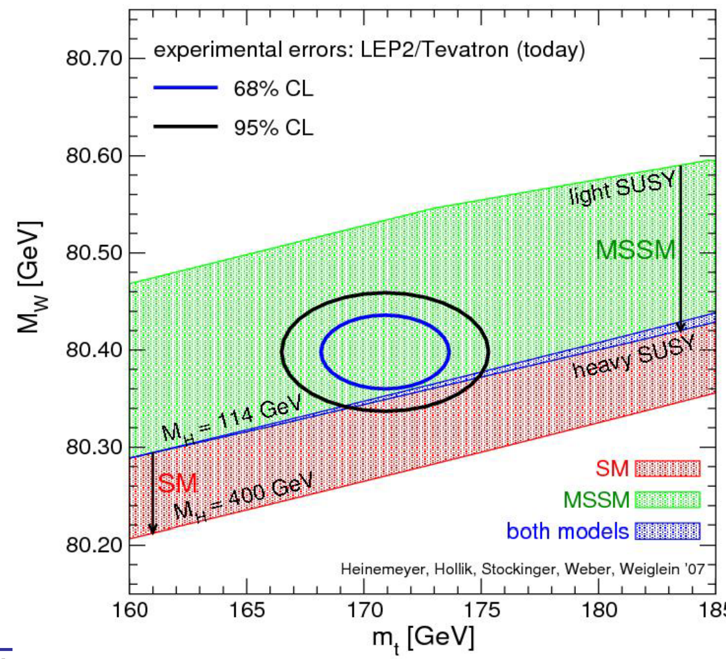
On behalf of the CDF and D0 collaboration

Top quark



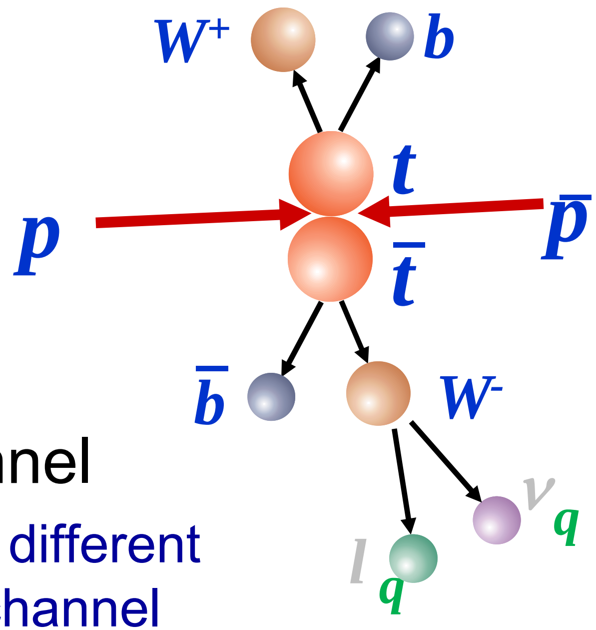
- Top quark is the heaviest known elementary particle
- Top quark mass is not predicted by SM
- Can constrain SM Higgs boson mass
  - ❖ Important contribution in radiative correction of W
  - ❖ Important test of SM

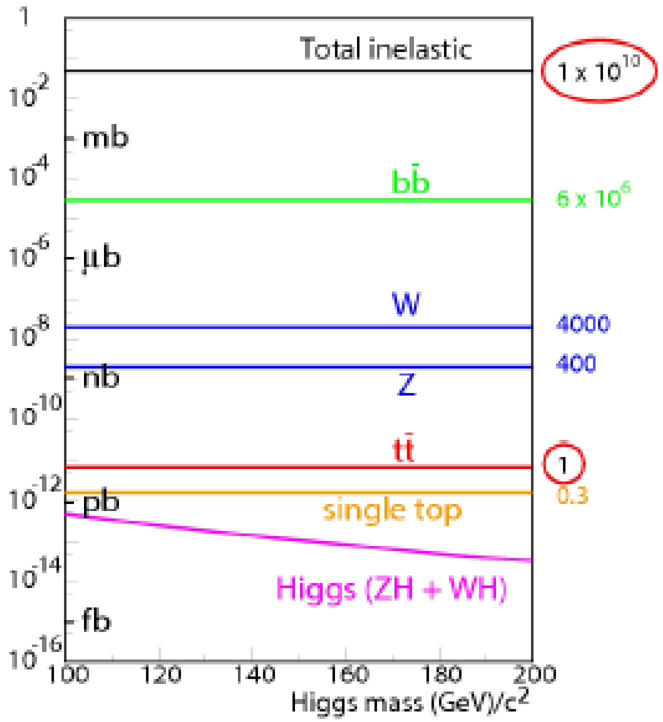




Top quark decay

- 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%)





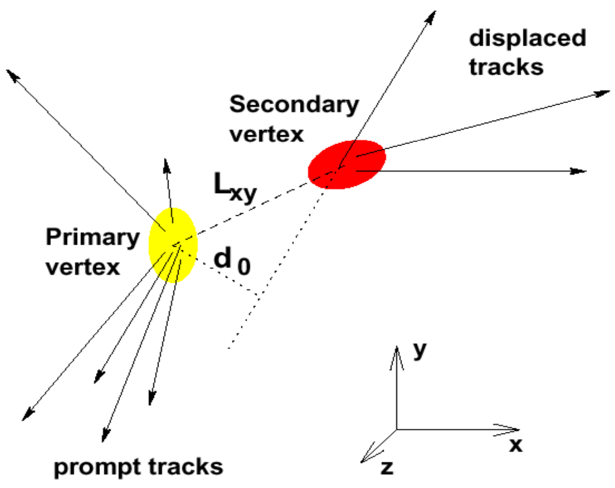
Important to look all channel

- ❖ 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

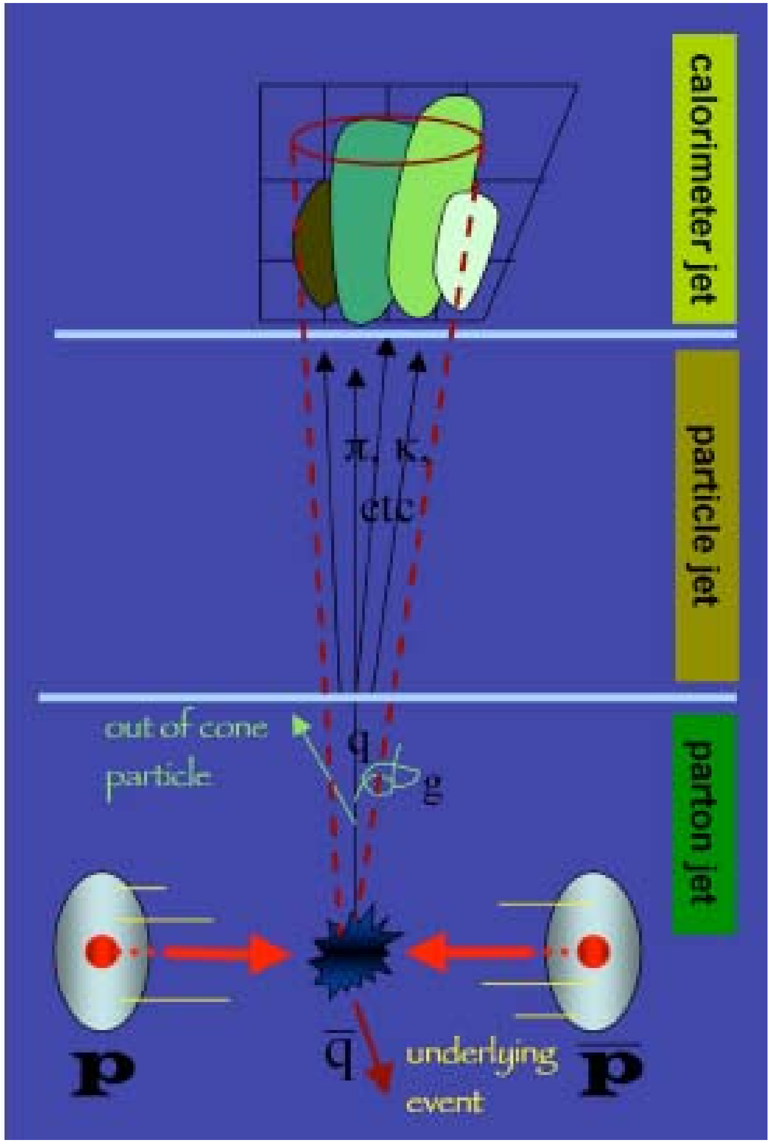
b-tagging

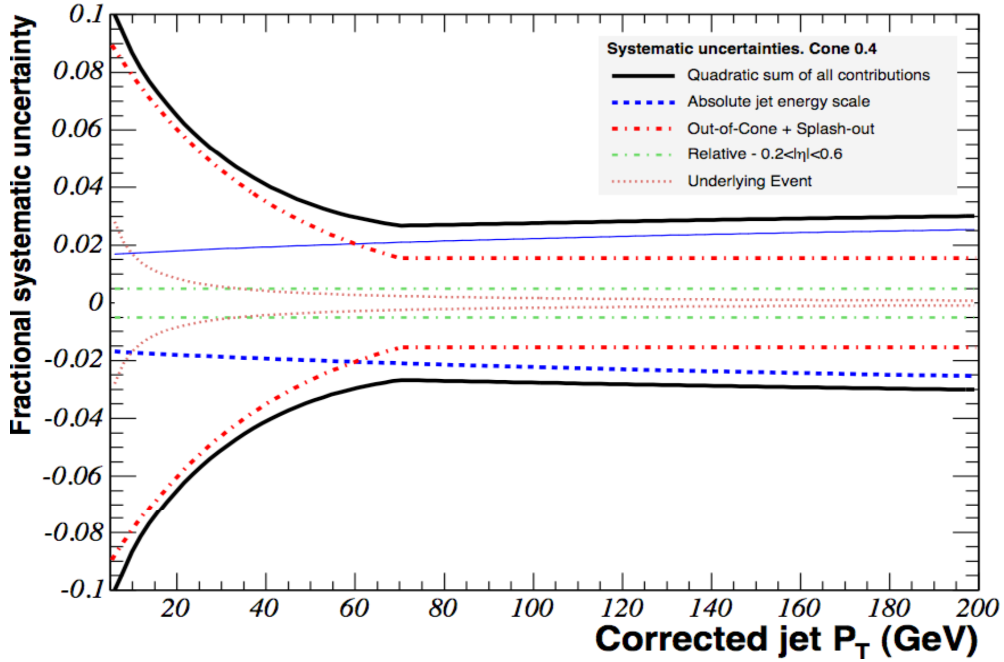


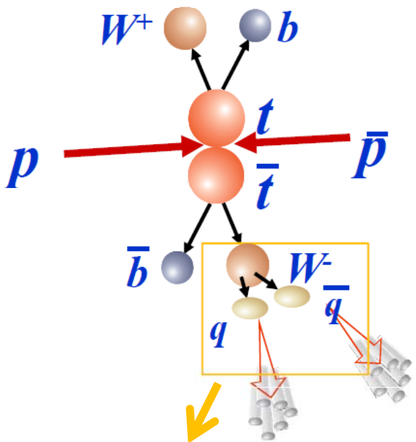
- B hadron can be identified by long displacement
- b tagging reduce # of jet-to-parton assign.
  - Ex) lepton+jets channel
  - 24 (0-btags), 6(1-btags), 2(2-btags)
- b tagging improve signal to background ratio significantly – 40% effi., 0.5% fake

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

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

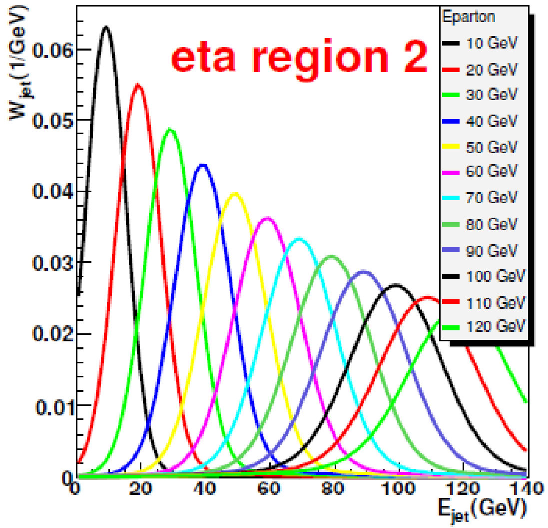
ttbar Matrix element

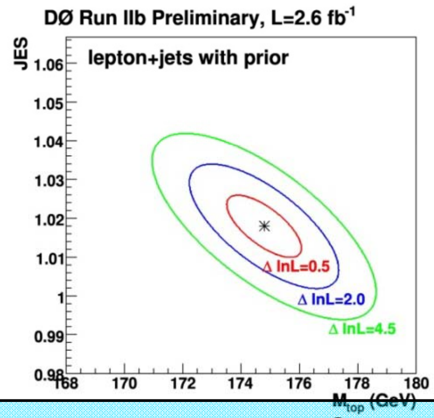
Parton distribution function

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

D0 lepton+jets , ME

- 3.6 fb^{-1} , 817 data events
- NN based b-tagging to increase efficiency
- Transfer function was estimated for four different eta region for b-jet, light jet, and lepton
- We modeled background only using W+jets ME
- 24 different permutations were summed by taking into account b-tagging information
- *In situ* JES calibration

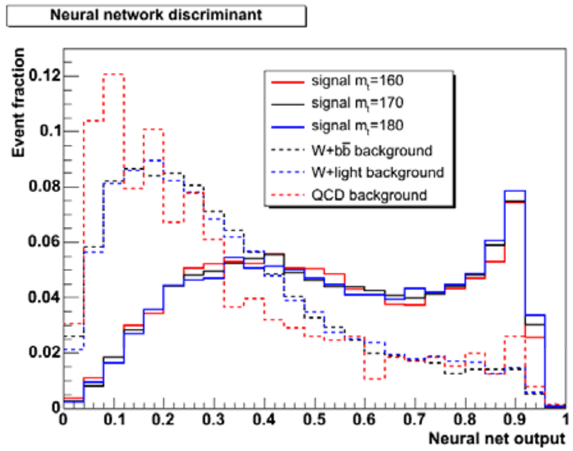




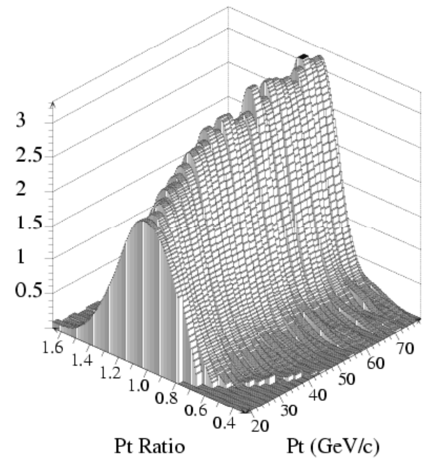
173.7 $\pm$ 0.8 (stat) $\pm$ 1.6 (JES+syst) GeV/c^2
=173.7 $\pm$ 1.8 GeV/c^2

CDF lepton+jets, ME

- 4.8 fb^{-1} data – 1070 events
  - ❖ We increase 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



- This is the most precise top quark measurement to date

$$172.8 \pm 0.7(stat) \pm 0.6(JES) \pm 0.8(syst)\ GeV/c^2$$
$$=172.8 \pm 1.3\ GeV/c^2$$

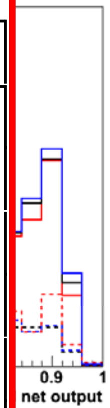
New

CDF lepton+jets, ME

- 4.8 fb⁻
  - We
    MET
  - Add
- Transf
  eta an
- *In situ*
- This is
  measu

CDF Run II Preliminary, 4.8 fb^{-1}

Systematic source	Systematic uncertainty (GeV/c^2)
Calibration	0.11
MC generator	0.25
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	0.33
Gluon fraction	0.03
Color reconnection	0.37
Total	0.84

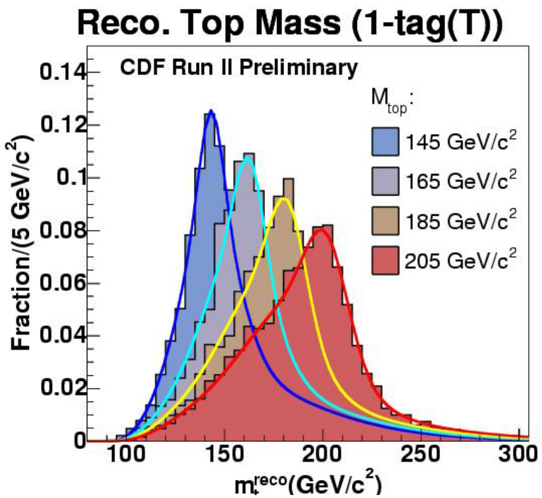


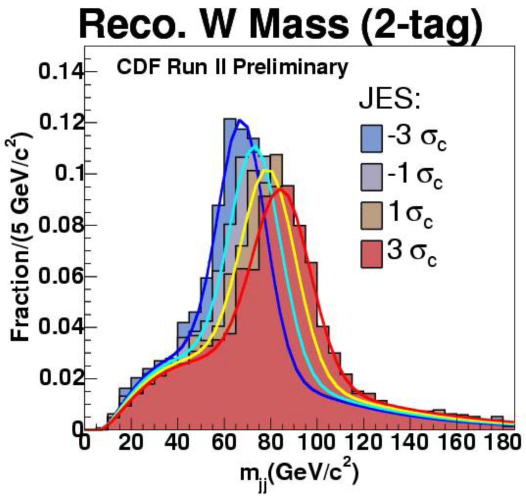
Pt Ratio
Pt (GeV/c)

$172.8 \pm 0.7(\text{stat}) \pm 0.6(\text{JES}) \pm 0.8(\text{syst})$ GeV/c^2
$= 172.8 \pm 1.3$ GeV/c^2

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





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

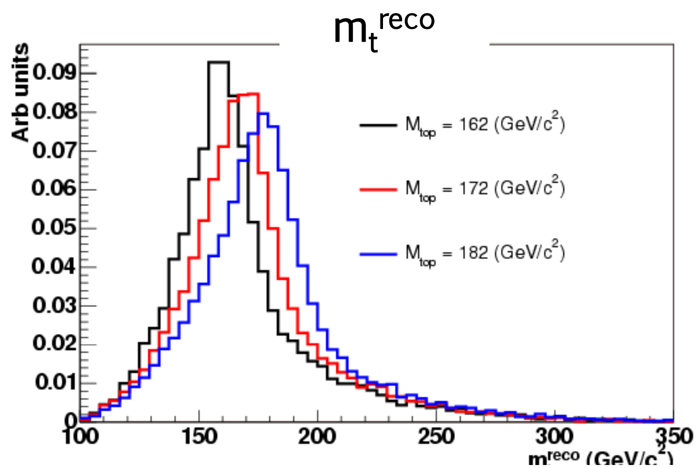
Event reconstruction in the lepton+jets

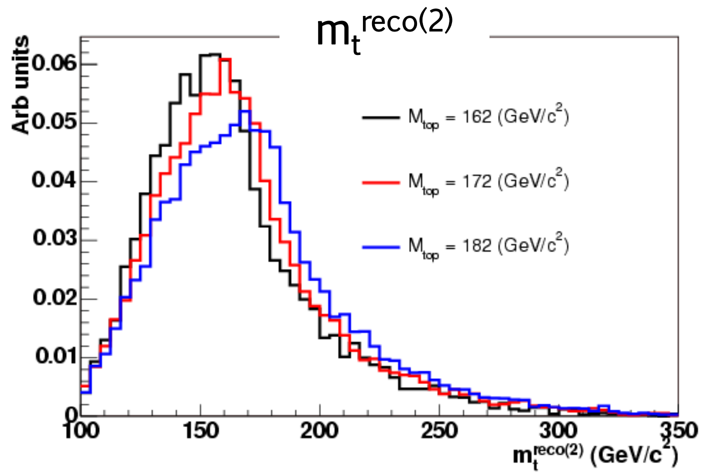
$$\chi^2 = \Sigma_{i=\ell,4jets} \frac{(p_T^{i,fit} - p_T^{i,meas})^2}{\sigma_i^2} + \Sigma_{j=x,y} \frac{(U_j^{fit} - U_j^{meas})^2}{\sigma_j^2} + \frac{(M_{jj} - M_W)^2}{\Gamma_W^2} + \frac{(M_{\ell\nu} - M_W)^2}{\Gamma_W^2} + \frac{(M_{bjj} - m_t^{\rm reco})^2}{\Gamma_t^2} + \frac{(M_{b\ell\nu} -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

- Construct likelihood based on probabilities

New CDF lepton+jets and dilepton, Template

- 4.8 fb^{-1} data – 977 Leopton+jets(LJ)
  344 Dilepton(DIL)
  - ❖ Chi2(<9) cut was applied for LJ
- Simultaneously use LJ+DIL
- Fully three dimensional PDF using three observables in LJ
  - ❖ 3rd observables is reconstructed mass using kinematic fit with different combinatoric of jet to parton assignment (2nd best fit)
- LJ only measurement
  - ❖ 172.0 ± 1.5 GeV/c^2
  - ❖ Complement technique, consistent result

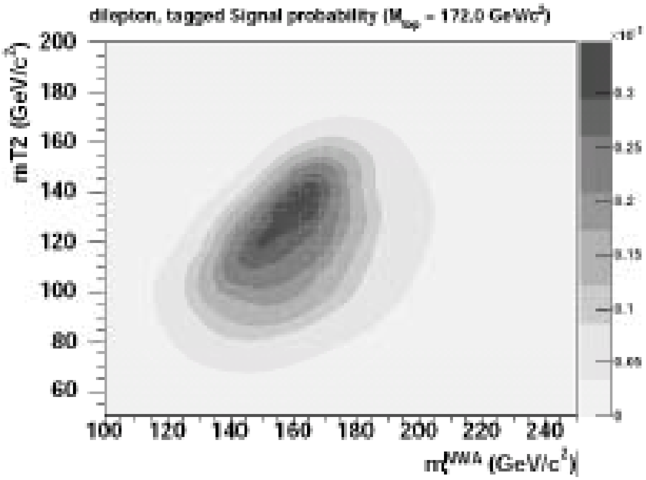




171.9 ± 0.8 (stat) $\pm$ 0.8(JES) $\pm$ 0.9(syst) GeV/c^2
=171.9 ± 1.5 GeV/c^2

CDF dilepton channel, template

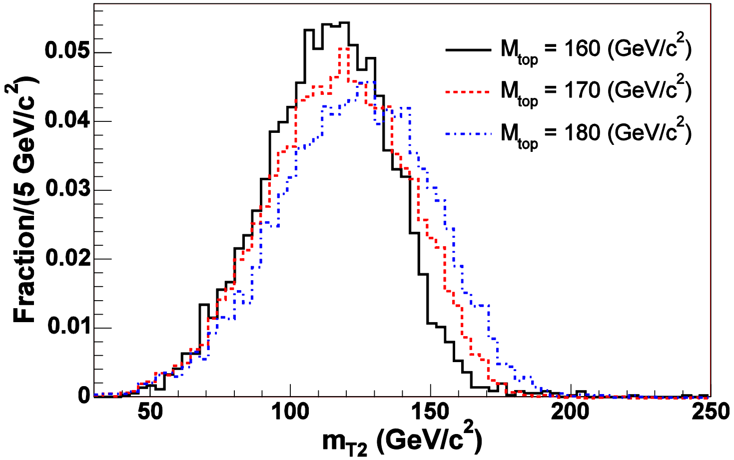
- Two observables taking into account correlation
  - Reconstructed mass and m_{T2}



- 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
  - We firstly use m_{T2} in real data

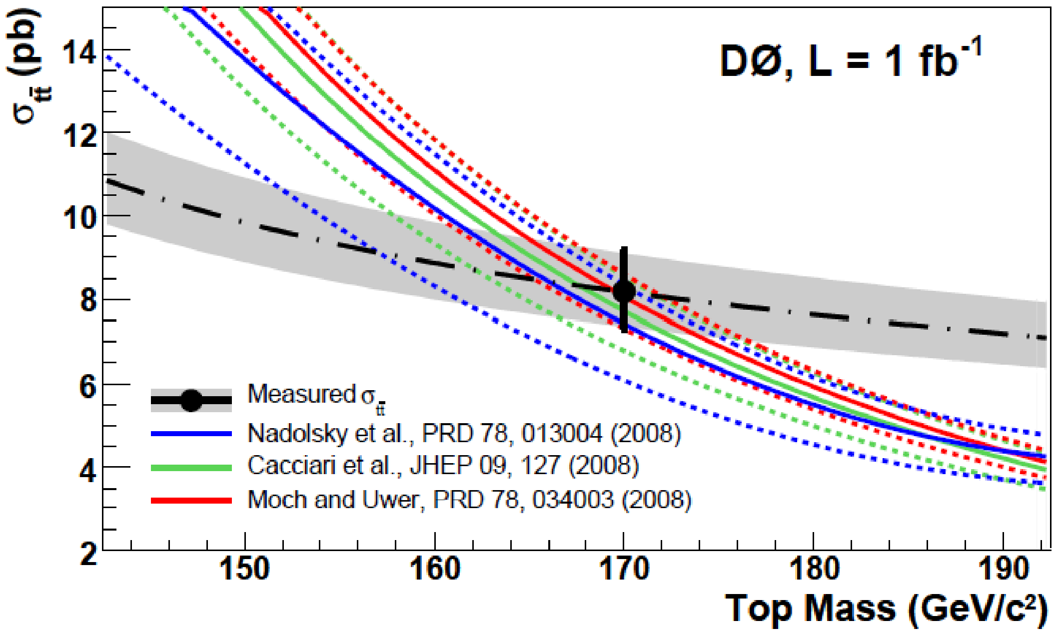
    Phys.Rev.D 81 (2010) 031102



$$170.6 \pm 2.2\ (\text{stat}) \pm 3.1\ (\text{syst})\ \text{GeV}/c^2$$
$$= 170.6 \pm 3.8\ \text{GeV}/c^2$$

Top mass from cross section

- Top quark cross section measurement constraints top quark mass with taking into account theoretical calculation
  PRD 80 (2009) 071102



NLO : $165.5^{+6.1}_{-5.9}$ (PRD 78 (2008) 013004)

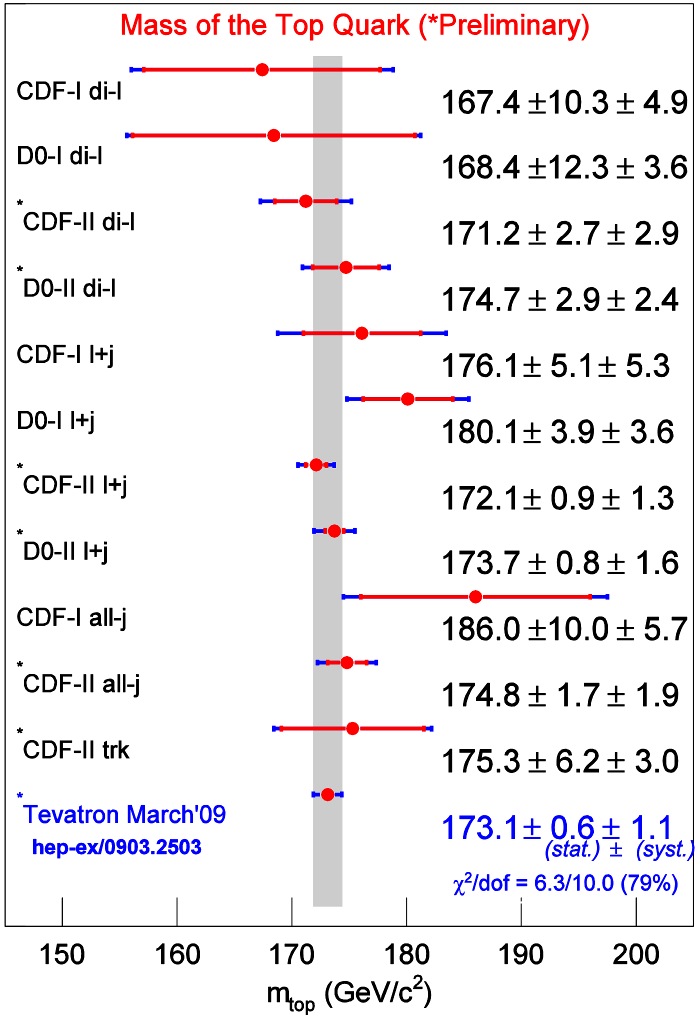
NLO+NLL : $167.5^{+5.8}_{-5.6}$ (JHEP 09 (2008) 127)

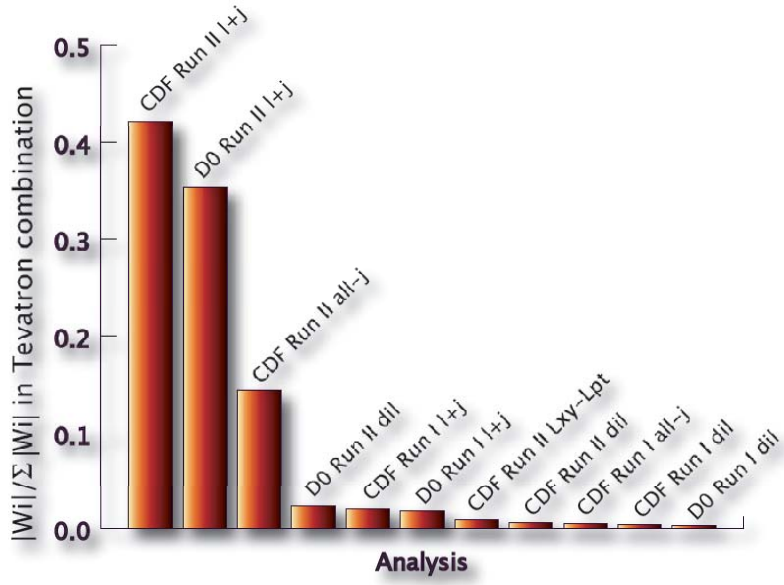
NLLO(approx.) : $169.1^{+5.9}_{-5.2}$ (PRD (2008) 074005)

NLLO (approx.) : $168.2^{+5.9}_{-5.4}$ (PLB 360 (1995) 47)

Complement technique, consistent result

Combination





$m_{top} = 173.1 \pm 1.3\ \mathrm{GeV}/c^2$

New measurements

CDF LJ (ME) $= 172.8 \pm 1.3\ \mathrm{GeV}/c^2$

CDF LJ (TM) $= 172.1 \pm 1.5\ \mathrm{GeV}/c^2$

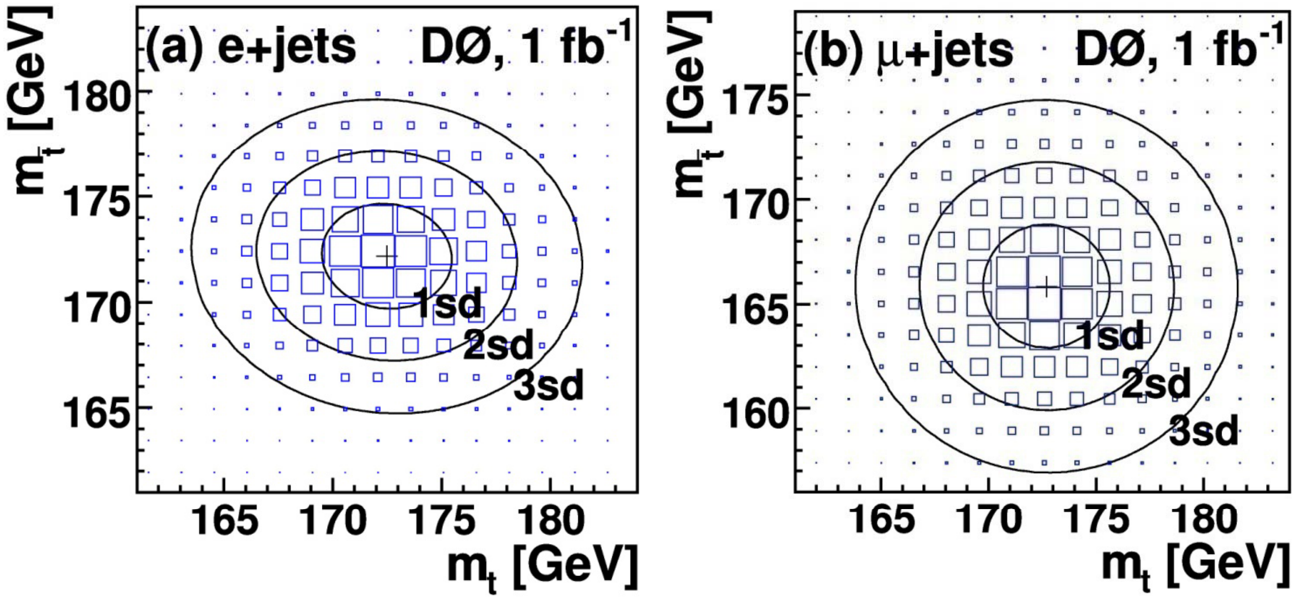
CDF DIL(TM) $= 170.6 \pm 3.8\ \mathrm{GeV}/c^2$

D0 top-antitop mass difference

- 1 fb^{-1} modified matrix element
  - $P(\vec{x}; M_t, M_{\bar{t}})$ instead of $P(\vec{x}; M_{top}, JES)$

- Test of CPT violation in the top sector
  - First time in the quark and high mass

PRL 103 (2009) 132001



$\Delta M = 3.8 \pm 3.7$ GeV/c^2

Good agreement with SM

Limited by statistics

Will be updated with more data

Conclusion

- 0.75% precision in world average (a year ago)

$$m_{top} = 173.1 \pm 1.3\ \mathrm{GeV}/c^2$$

- 0.75% precision by single measurement (now)

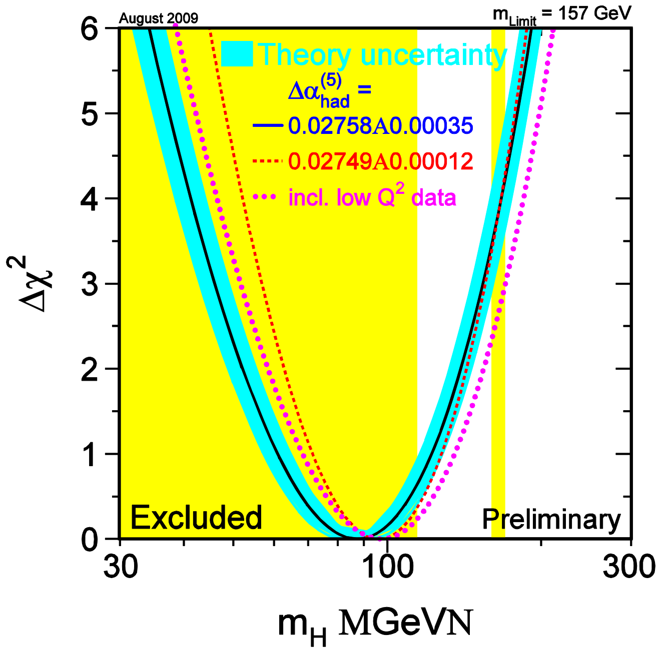
$$m_{top} = 172.8 \pm 1.3\ \mathrm{GeV}/c^2$$

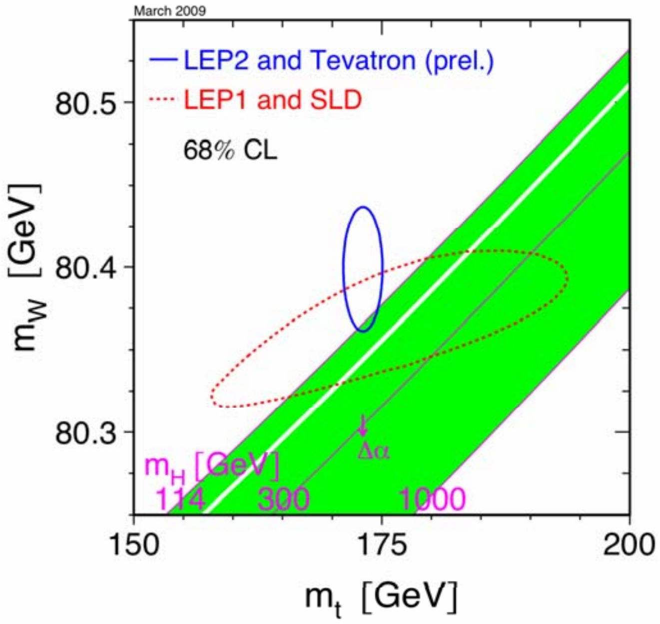
- We may have new measurement from LHC (next year)
  - However Tevatron will have the most precise measurement for a while

Backup

Global EWK fit and Higgs constraints

LEPEWWG, arXiv:0911.2604 [hep-ex]





Not include new measurements

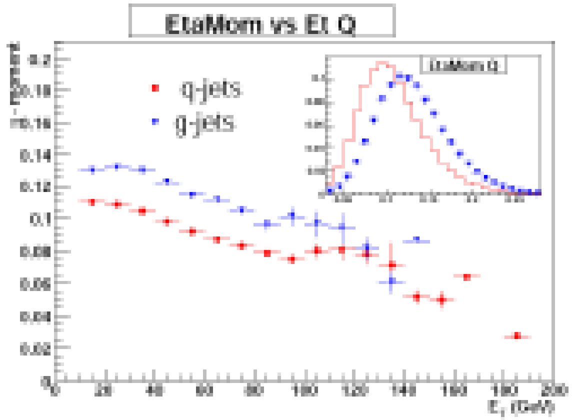
$$m_H = 87^{+35}_{-26}\ \mathrm{GeV/c^2} \qquad m_H < 157\ \mathrm{GeV/c^2}\ (95\%\ \mathrm{CL})$$

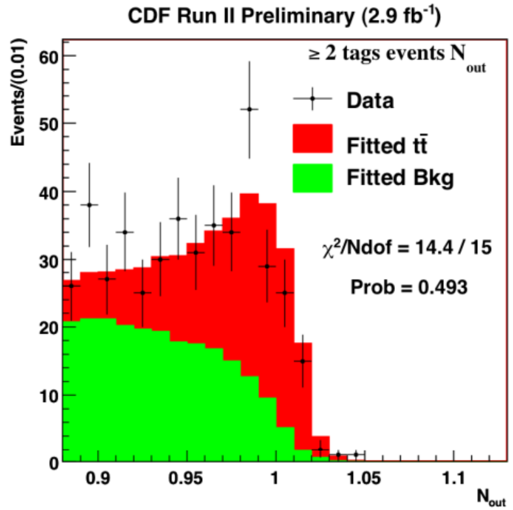
$$m_H < 187\ \mathrm{GeV/c^2}\ (95\%\ \mathrm{CL})$$

With direct limit from LEPII

CDF all hadronic channel

- 2.9 fb^{-1} date, template method
- Two dimensional template
  - ❖ Reconstructed top mass and dijet 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 (3452 candidates)
  - ❖ 2btag S:B=1:1 (441 candidates)

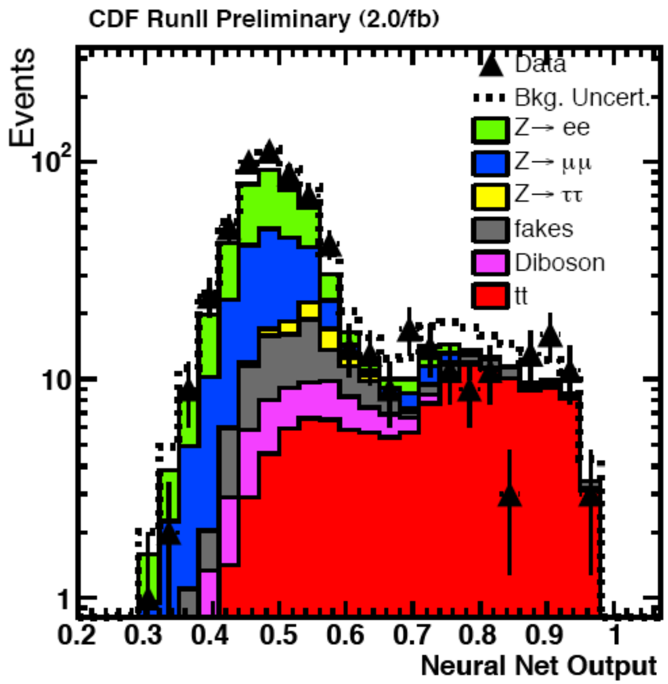


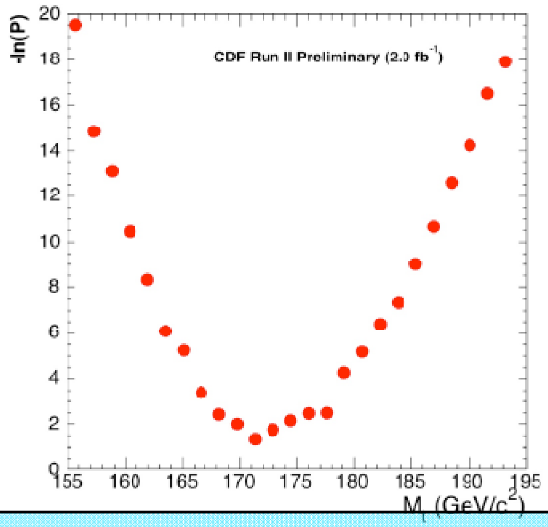


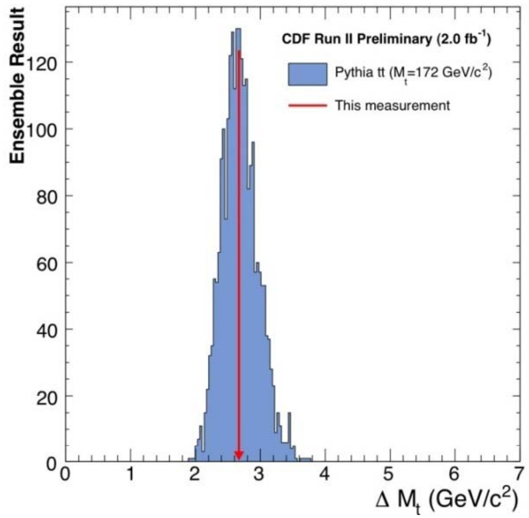
$$174.8 \pm 1.7 \text{ (stat)} \pm 1.9 \text{ (JES+syst) GeV}/c^2$$
$$=174.8 \pm 2.7 \text{ GeV}/c^2$$

CDF dilepton channel, ME

- 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







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

$= 171.2 \pm 4.0\ \text{GeV}/c^2$

D0 dilepton channel

- We have two b-jets, two lepton, and two neutrino
  - Underconstraint system

- Event reconstruction to build template is challenging

  Neutrino weighting

  Integrate over expected neutrino eta distribution to obtain a probability for certain top mass

  Matrix weighting

- 1.0 fb^{-1} , template method
  - 174.7±4.4(stat)±2.0(syst) GeV/c^2

- Matrix element calculation
  - Integrate over unknown neutrino momentum

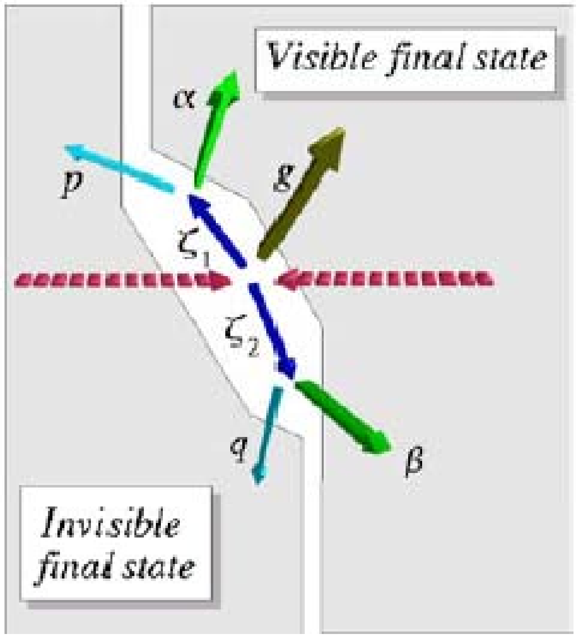
- We use Z to tau tau +jets for background modeling

- 3.6 fb^{-1} , ME, Only use eμ events
  - 174.8±3.3(stat)±2.6(syst) GeV/c^2

174.7± 2.9 (stat) ± 2.4 (syst) GeV/c^2
=174.7 ± 3.8 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



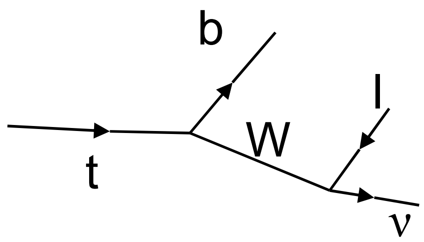
- Top dilepton channel have exactly same final state

$$m_{T2} = \min[\max(m_{T(1)}, m_{T(2)})]$$
$$q_T + p_T = \text{missing } p_T$$

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

m_t^{NWA}

- Leptonical decay of top
  - t->blν
  - We measure b and lepton but don't know neutrino
    - 4 unknown
  - Known parameter
    - W mass, neutrino mass (2 unknown)
  - If we assume the top quark mass and neutrino eta direction, we can measure neutrino x,y momentum
  - Same thing happen for the other leg
- Getting weight using measured missing transverse energy



$$\begin{aligned} B &\equiv 2b\nu &= m_t^2 - m_W^2 - m_b^2 - 2b\ell \\ L &\equiv 2\ell\nu &= m_W^2 - m_\ell^2 - m_\nu^2 \\ & &= m_W^2 - m_\ell^2 \end{aligned}$$

$$w_i = exp(-\frac{(\not{E}_x - P_x^\nu - P_x^{\bar{\nu}})^2}{2\sigma_x^2}) \cdot exp(-\frac{(\not{E}_y - P_y^\nu - P_y^{\bar{\nu}})^2}{2\sigma_y^2})$$

$$w_i = w_i(m_{top}, \eta_1^\nu, \eta_2^\nu)$$

m_t^{NWA}

- Some over neutrino rapidities

$$W(m_t) = \int d\eta_1 \int d\eta_2 P(\eta_1) P(\eta_2) \sum_j \sum_i w(m_t)_{i,j}$$

- We have maximum weight m_t as reconstructed mass (m_t^{NWA})
- We scan mt with 3GeV size and then decrease the step size upto 0.15GeV near the peak
- We have gaussian fit in the near of peak to get m_t continuously