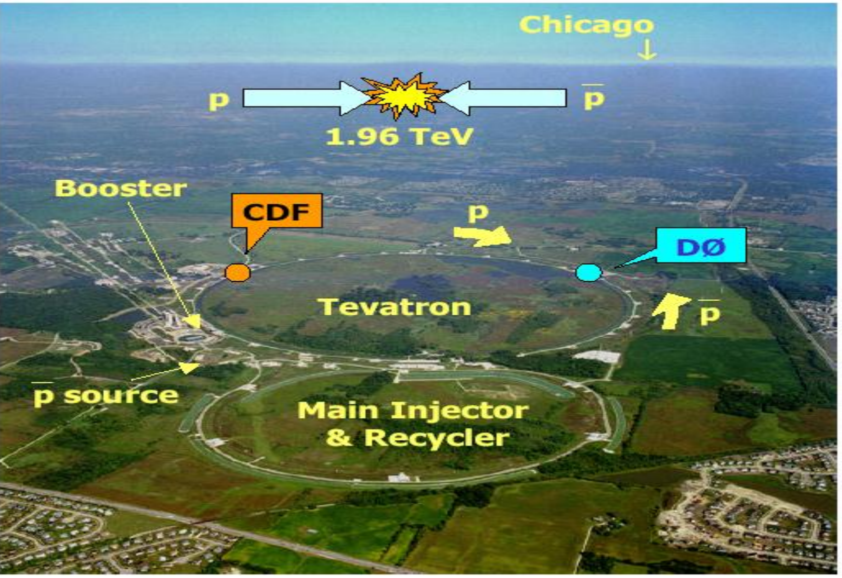
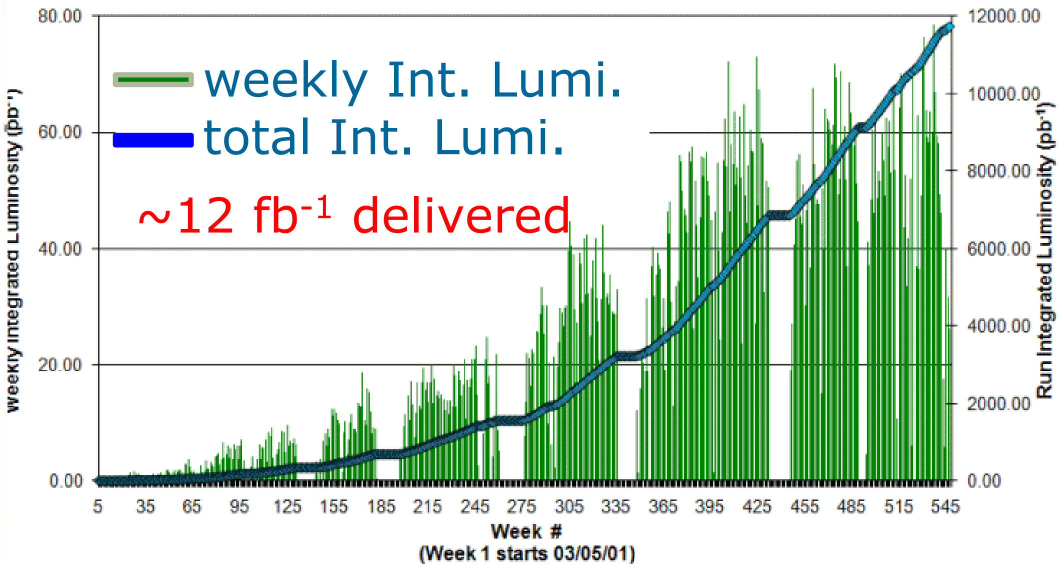
Electroweak and Top Results from the Tevatron

Junji Naganoma (Waseda University)
on behalf of the CDF and D0 collaborations

XLI International Symposium on Multiparticle Dynamics
Sept. 29th, 2011

Tevatron RunII





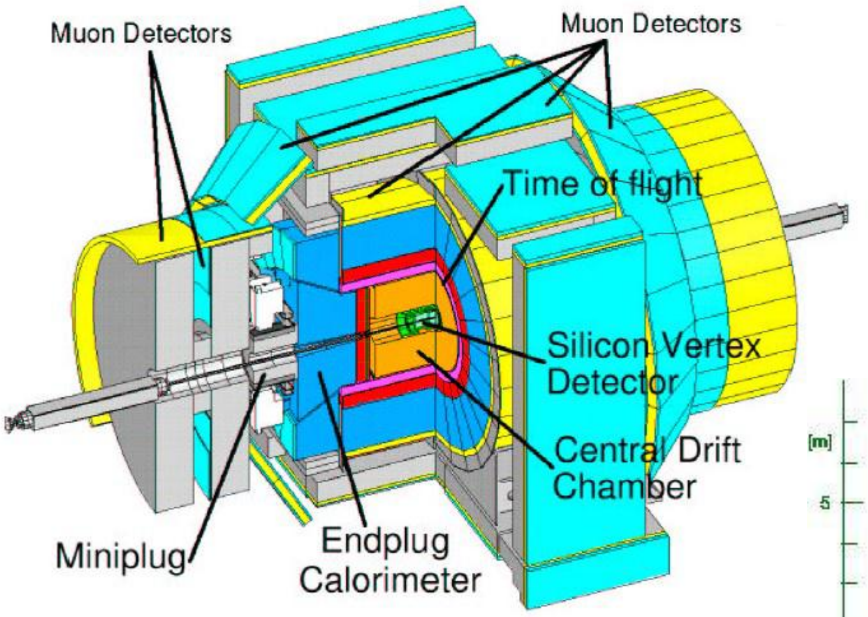
Proton-antiproton collider
C.M. Energy: 1.96 TeV

36 bunch crossings
396 ns bunch spacing
Peak luminosity: 4×10^{32} $cm^{-2}s^{-1}$
Started on March 2001
End on September 30

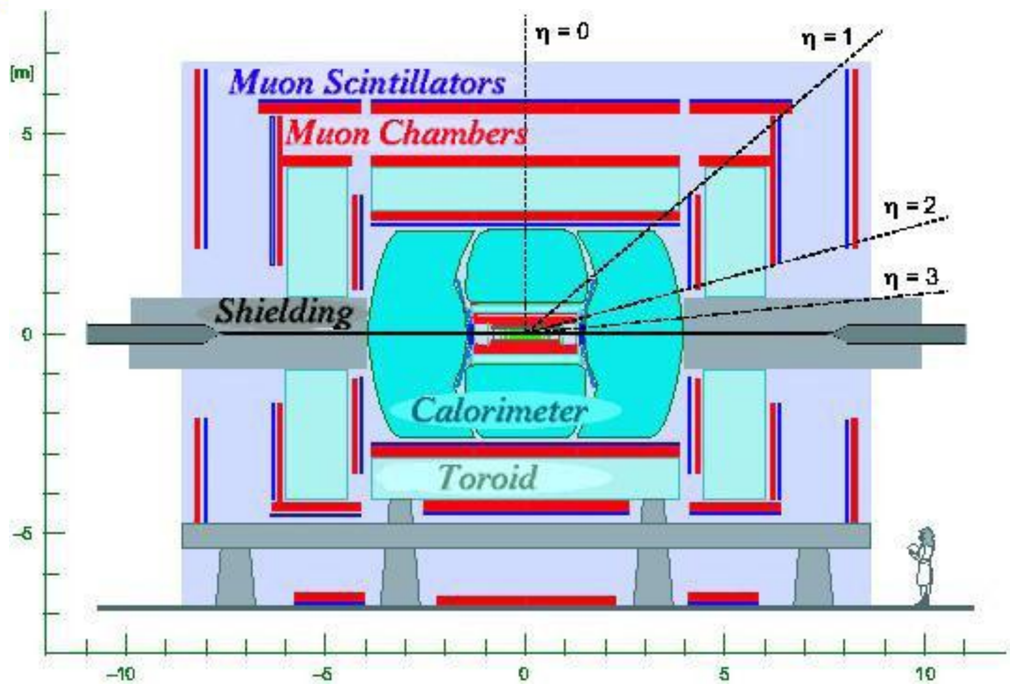
~10 fb^{-1} available for analysis for both experiments at the end of data taking.

CDF and D0 Detectors

CDF II Detector



D0 Detector RunII



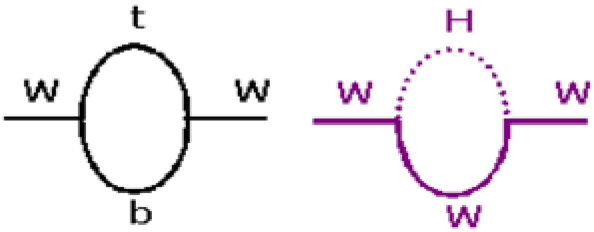
Both are well understood though >10 years operations

W Boson and Top Quark Mass

- Top quark mass is free parameter in SM.
- SM predicts only relation between W and other experimental observables.

$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G_F}}\frac{1}{\sin\theta_W\sqrt{1-\Delta r}}$$

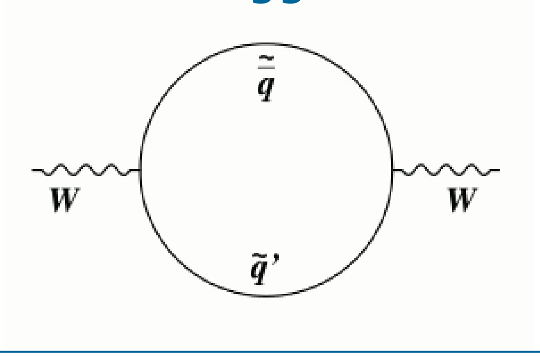
- Radiative corrections (Δr) depend on M_t^2 and $\log M_H$ through diagrams like:



Precise measurement of M_W and M_t constrain SM Higgs mass.

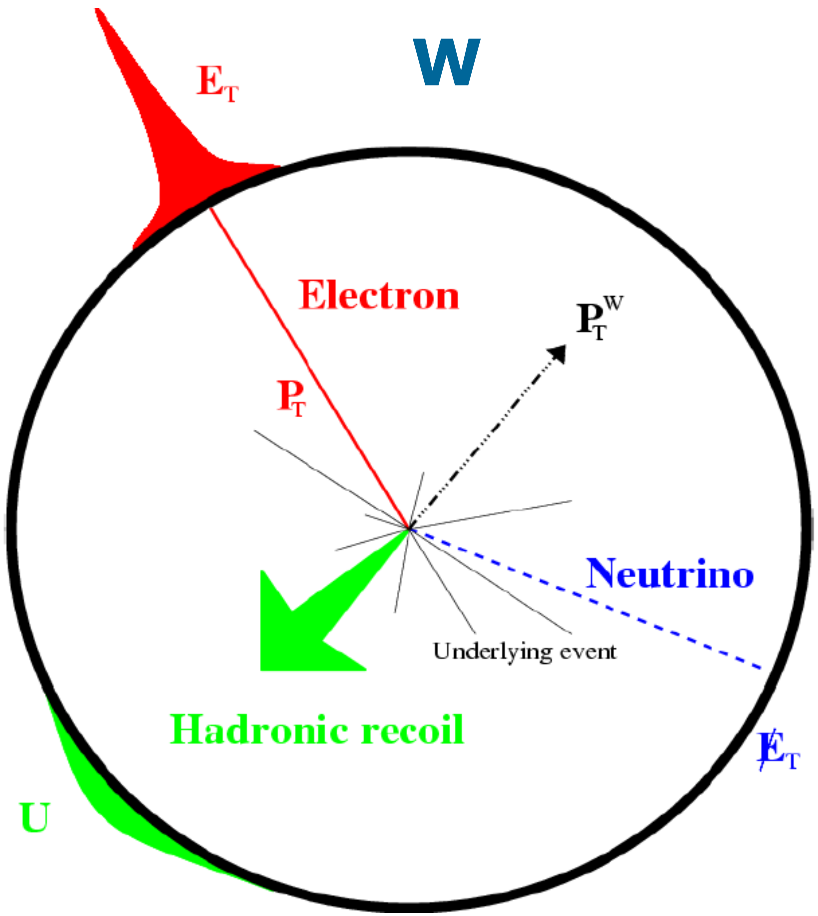
- $\Delta Mw \approx 0.006\Delta Mt$ for equal contribution to the Higgs mass uncertainty

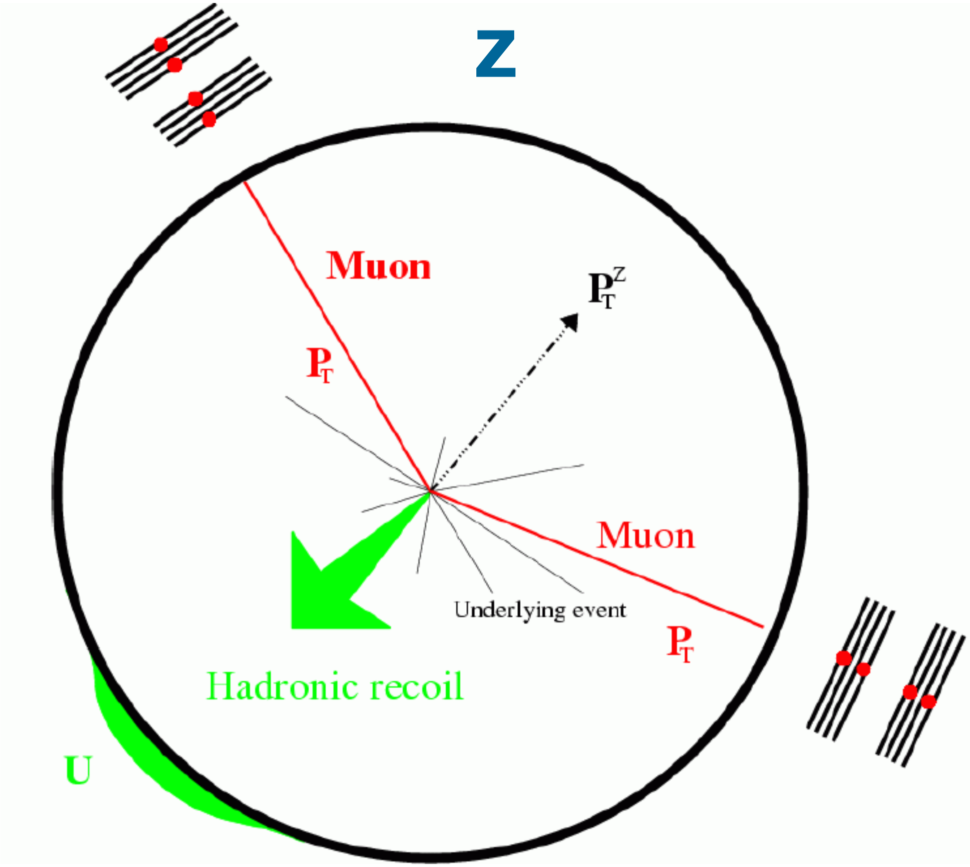
- e.g. SUSY can also contribute to Δr.



W(Z) Signature in Detector

Isolated, high pT lepton, missing transverse momentum in W event





Typically small hadronic activities.

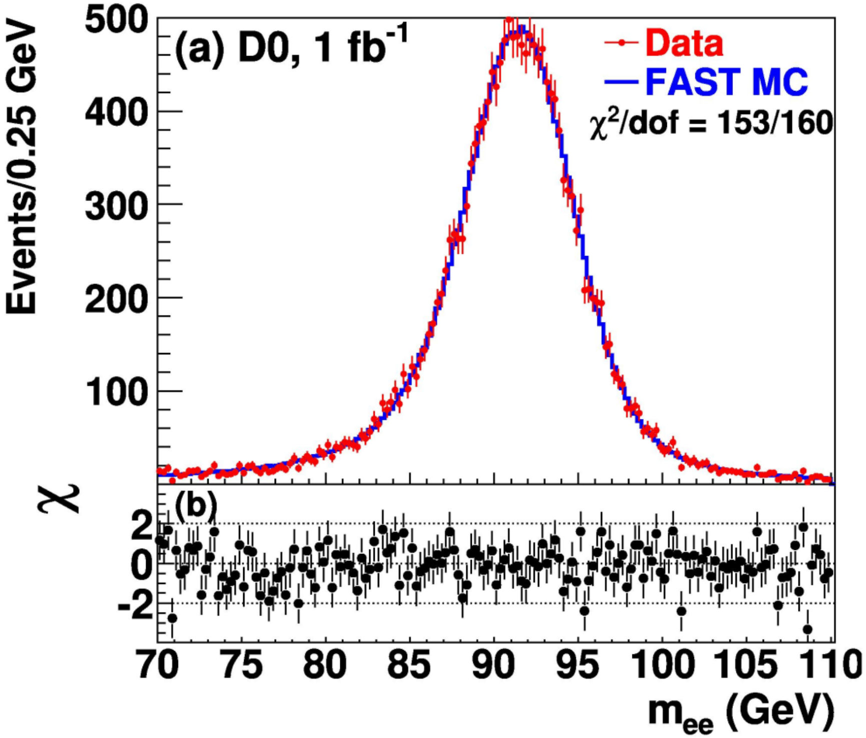
Z event provides excellent control sample. (M_Z&Γ_Z: high precision at LEP)

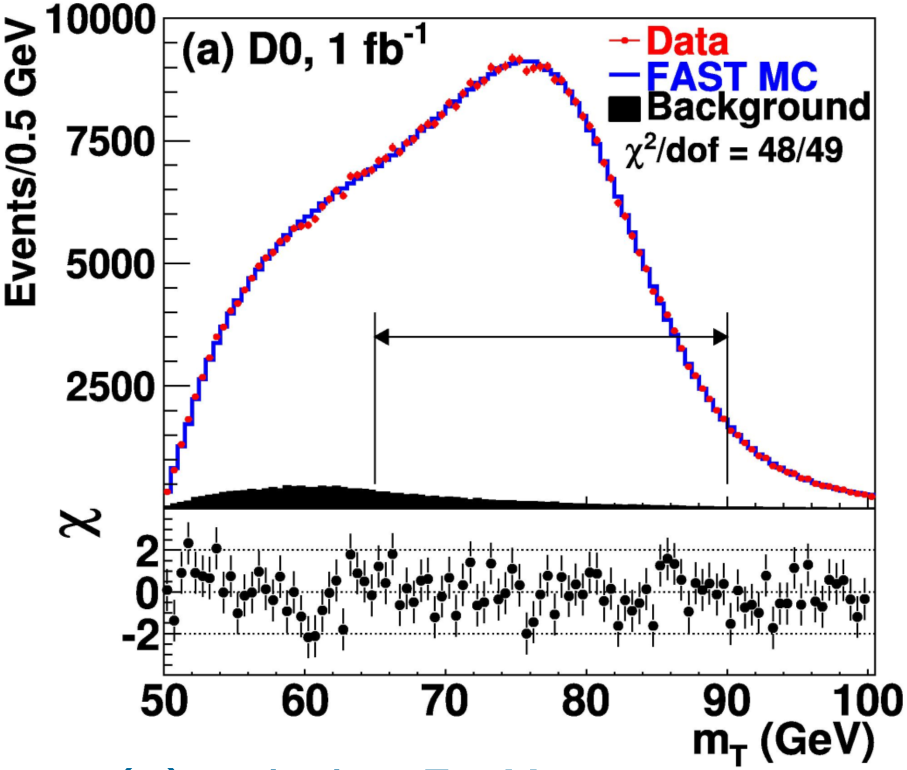
W Mass Measurement (D0)

Electron energy calibration from ~19k $Z \rightarrow ee$ events.

PRL103,141801(2009) **1fb^{-1}**

~500k $W \rightarrow e\nu$ events.





W mass from template fitting. Combine $p_T(e)$, missing E_T, M_T.

$$M_W = 80.401 \pm 0.021\ (\text{stat.}) \pm 0.038\ (\text{syst.})\ \text{GeV}$$

World best single measurement (~0.05% precision)

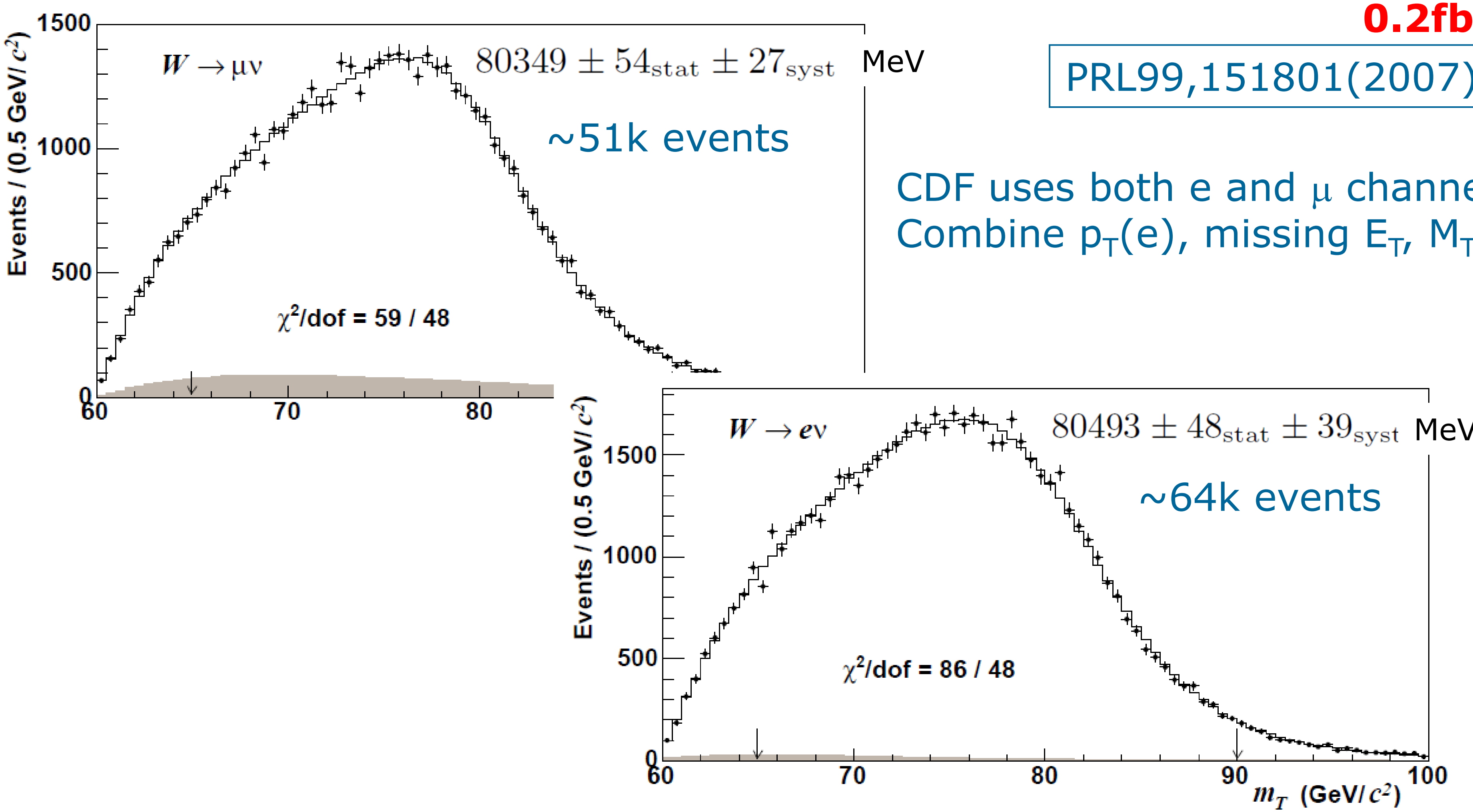
Dominant syst. is energy calibration: can be improved with more data.

W Mass Measurement (CDF)

0.2fb^{-1}

PRL99,151801(2007)

CDF uses both e and μ channel
Combine p_T(e), missing E_T, M_T

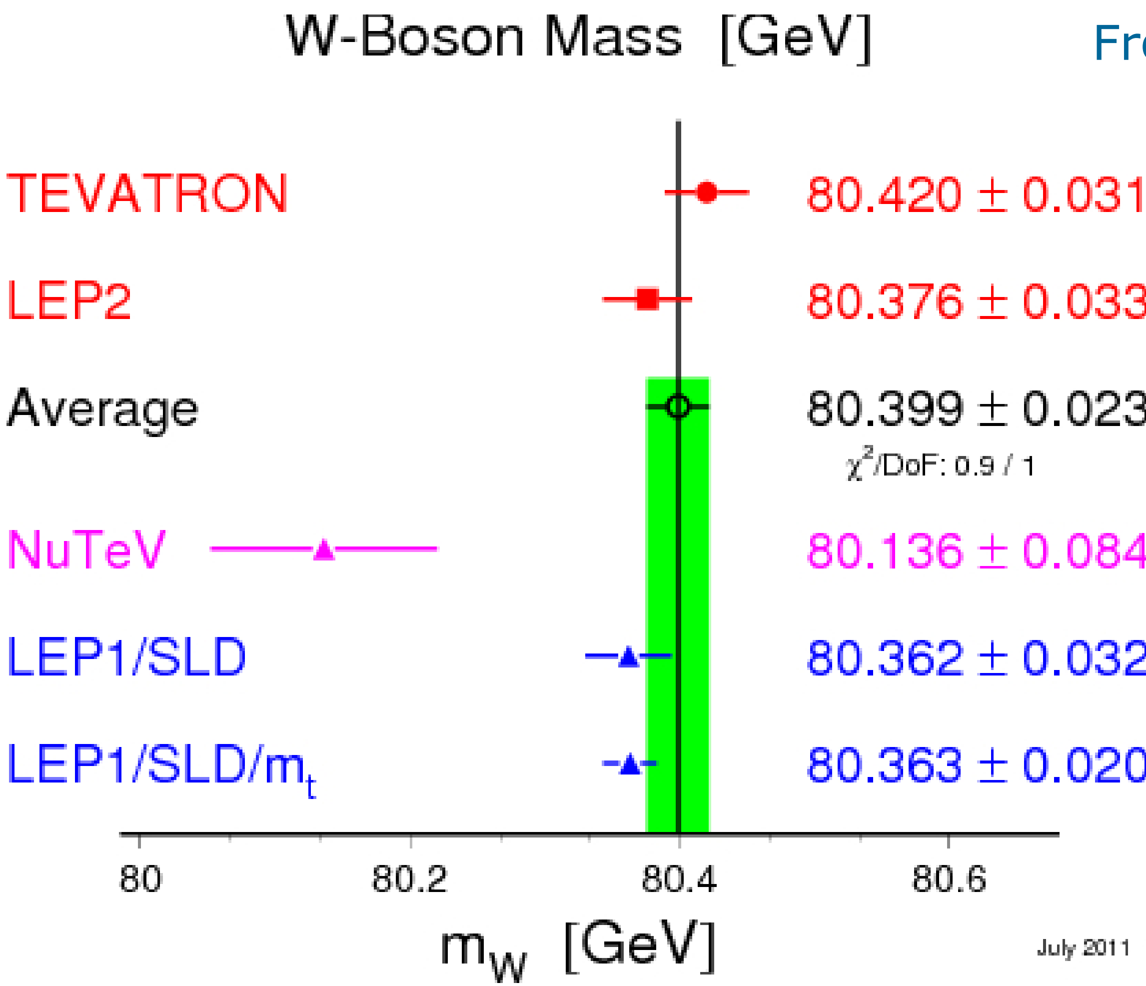


M_W = 80.413 ± 0.034 (stat.) ± 0.034 (syst.) GeV

~0.06% precision: aiming for ΔM_W=25MeV.

W Mass Measurement Comparison

From LEPEWWG



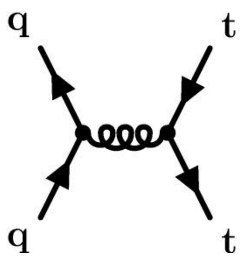
M_W = 80.399 ± 0.023 GeV

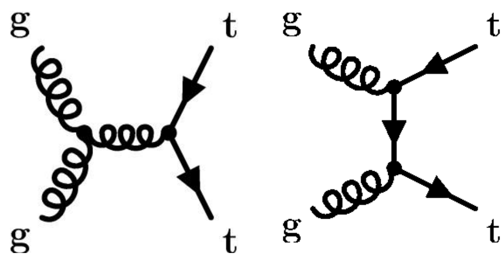
Tevatron has worlds best measurement so far.

Top Quark Pair Signature

quark-antiquark annihilation

gluon-gluon fusion

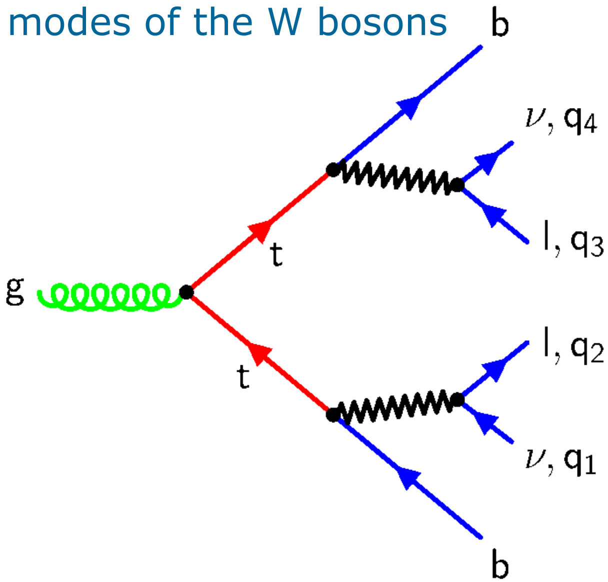




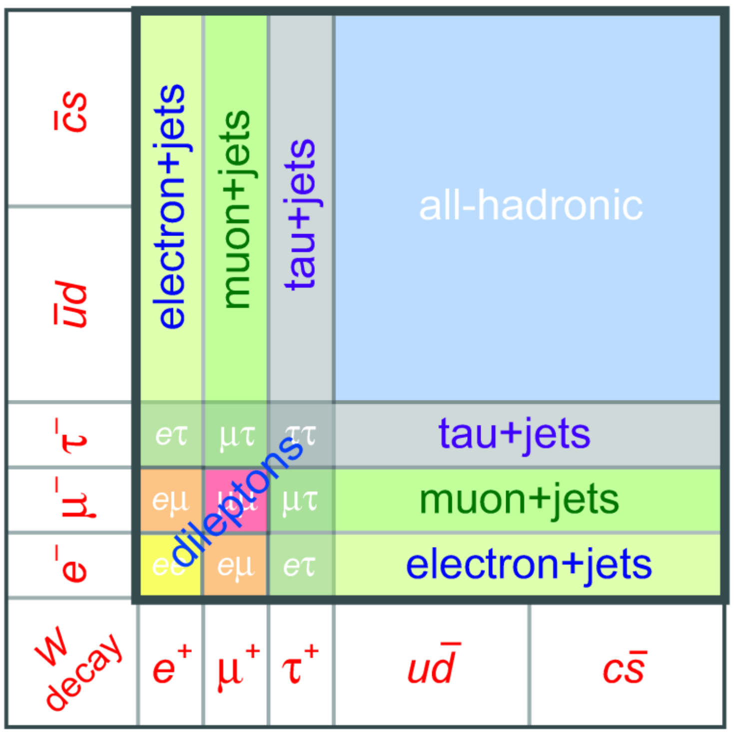
~85%

~15% : @ Tevatron

classification according to the decay modes of the W bosons



Top Pair Decay Channels



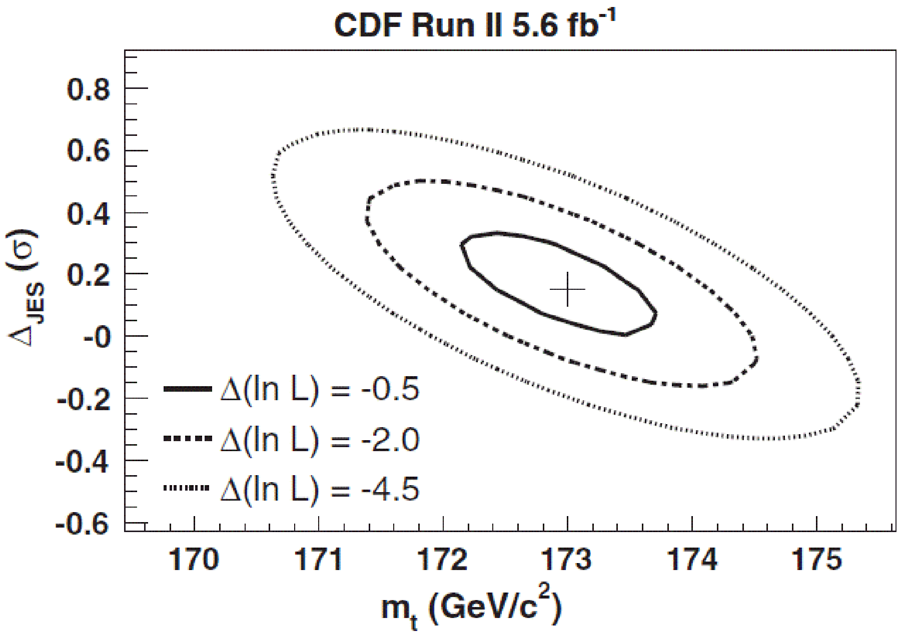
lepton (e, μ) + jets channel = "golden channel"

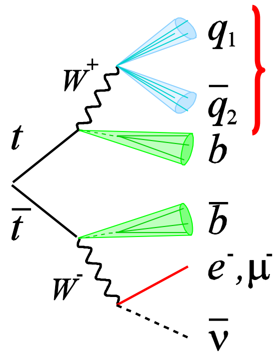
- Large branching fraction
- Manageable background
- Full reconstruction possible

Top Mass Measurement in ℓ+jets (CDF)

PRL105,252001(2010) **5.6fb^{-1}**

- CDF ℓ+jets channel
  - $e,\mu+\geq$4jets, ≥1b-tag
  - 1016(1b-tag), 247(≥2b-tag)
- Matrix element method
- in-situ JES calibration
  - $L_i(\vec{y}\,|\,m_t,\Delta_{\mathrm{JES}})$ for each event
  - $L(m_t,\Delta_{\mathrm{JES}}) = \prod_i L_i(\vec{y}\,|\,m_t,\Delta_{\mathrm{JES}})$



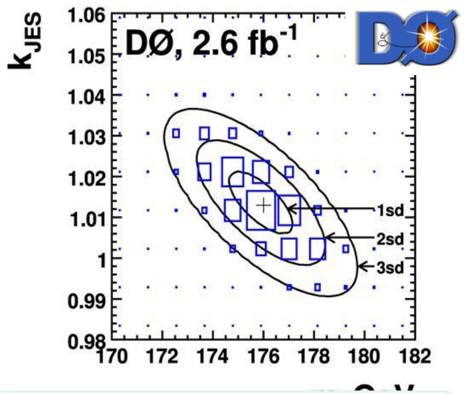


$$M_t = 173.0 \pm 0.7_{stat} \pm 0.6_{JES} \pm 0.9_{syst}\ \mathrm{GeV}$$
$$= 173.0 \pm 1.2\ \mathrm{GeV}$$

$\Delta m_t/m_t \sim 0.7\%$

World best single measurement

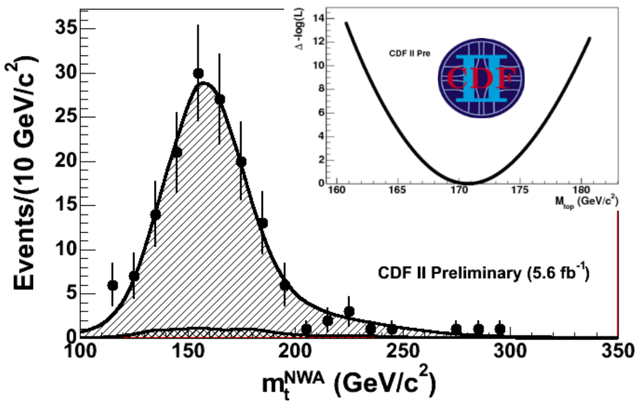
Top Mass Measurements at Tevatron



- DØ, **3.6fb^{-1}**
- ℓ+jets
- Matrix element
- in-situ JES calib.

$m_t = 174.9 \pm 1.5$ GeV

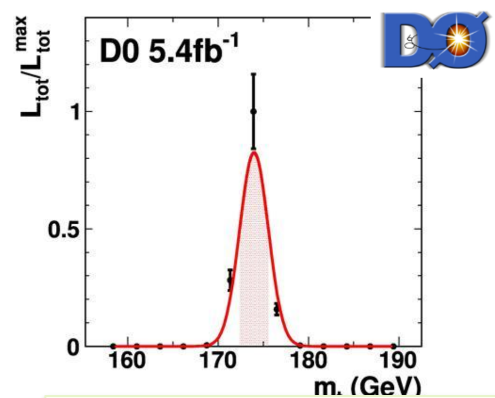
PRD84,032004(2011)



- CDF, **5.6fb^{-1}**
- dilepton
- Assume $\eta_{\nu,\bar{\nu}}$ (NWA)

$m_t = 170.3 \pm 3.7$ GeV

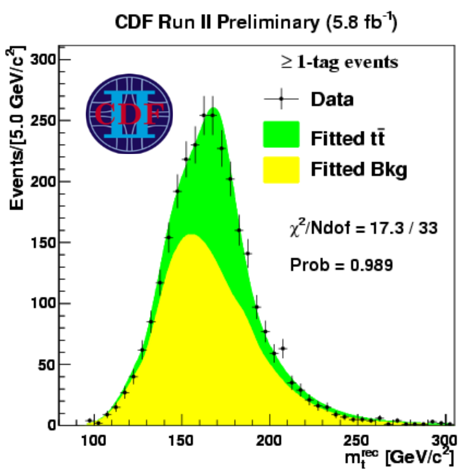
PRD83,111101R(2011)



- DØ, **5.4fb^{-1}**
- dilepton
- Matrix element

$m_t = 174.0 \pm 3.0$ GeV

arXiv:1105.0320



- CDF, **5.8fb^{-1}**
- All-hadronic
- Kinematic fit + Template method
- in-situ JES calib.

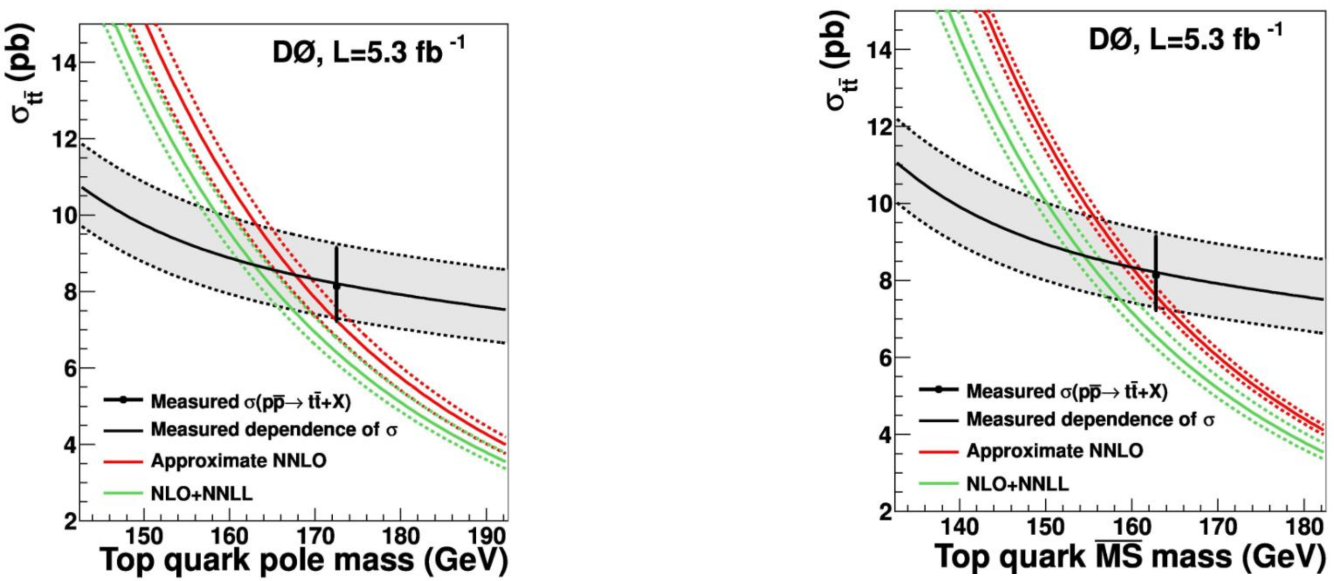
$m_t = 172.5 \pm 2.0$ GeV

CDF: 10456

What top mass did we measure?

arXiv:1104.2887 **5.3fb^{-1}**

- m_t defined in $t\bar{t}$ MC
  - relate to pole mass or $\overline{\mathrm{MS}}$ mass scheme?
- Extract well-defined m_t from $\sigma_{t\bar{t}}$ measurement in DØ ℓ+jets channel

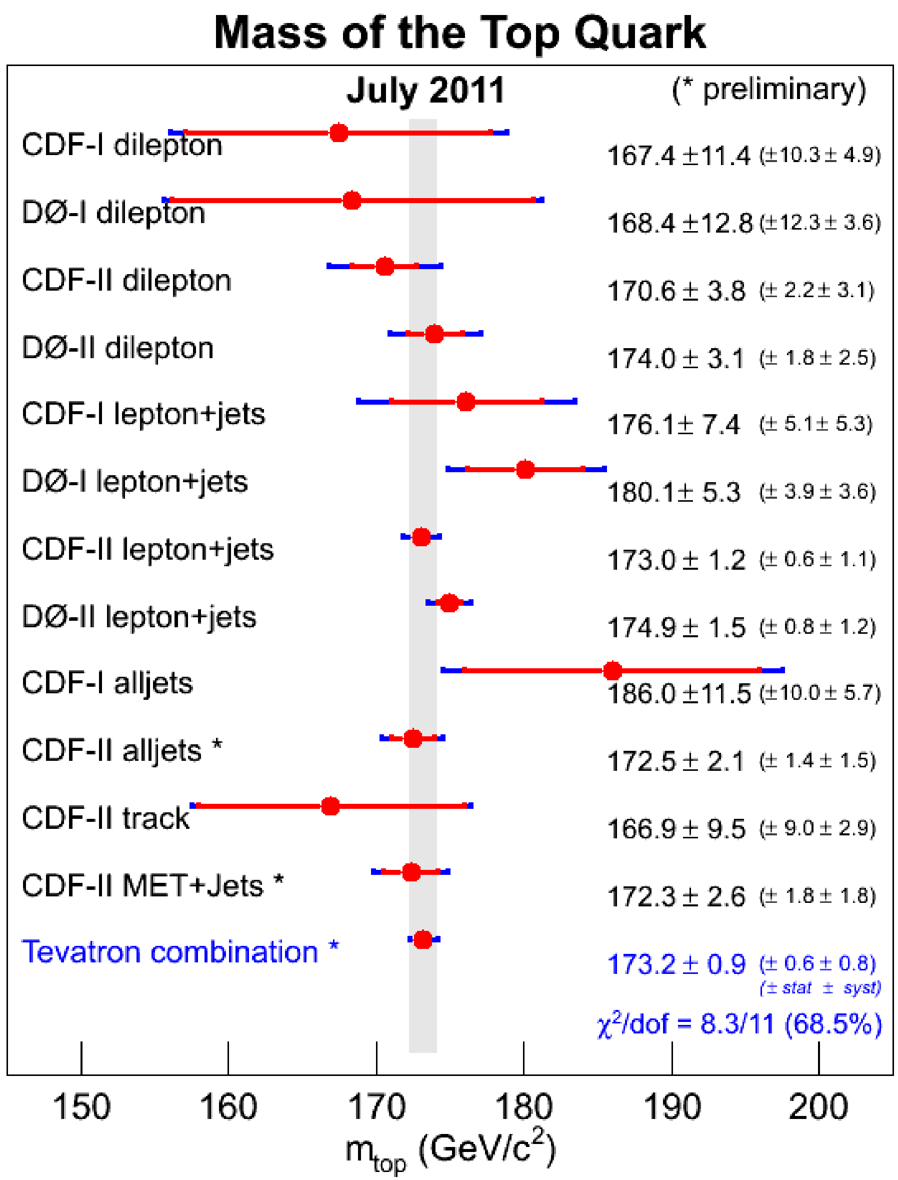


$m_t^{\mathrm{pole}} = 166.7^{+5.2}_{-4.5}$ GeV
Approx. NNLO

$m_t^{\overline{\mathrm{MS}}} = 160.0^{+4.8}_{-4.3}$ GeV
Approx. NNLO

Tevatron average m_t is more consistent with m_t^{pole}

Top Quark Mass: Tevatron Combination



3.6 – 5.8 fb $^{-1}$

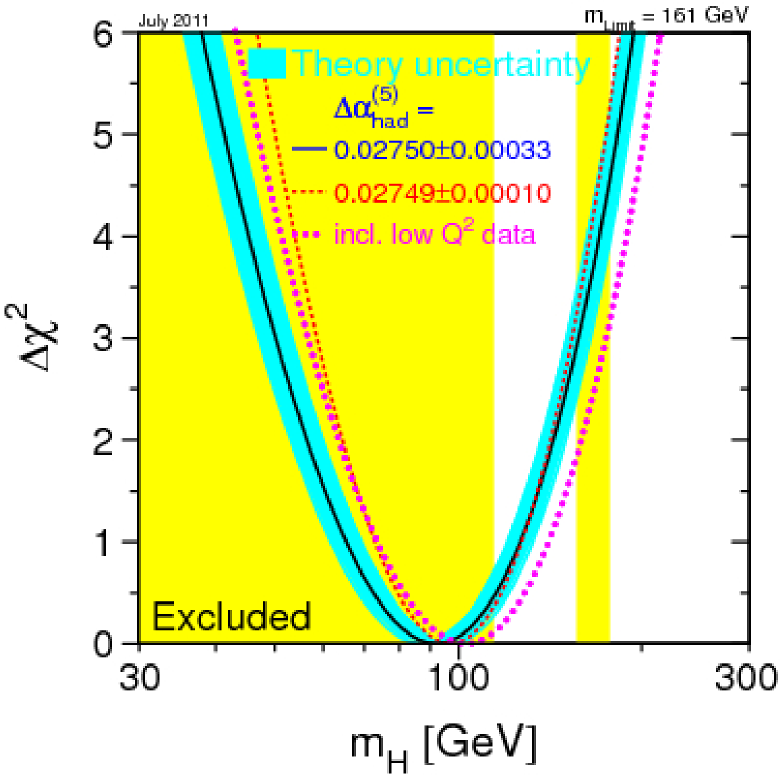
$$M_t = 173.2 \pm 0.9 \text{ GeV}$$

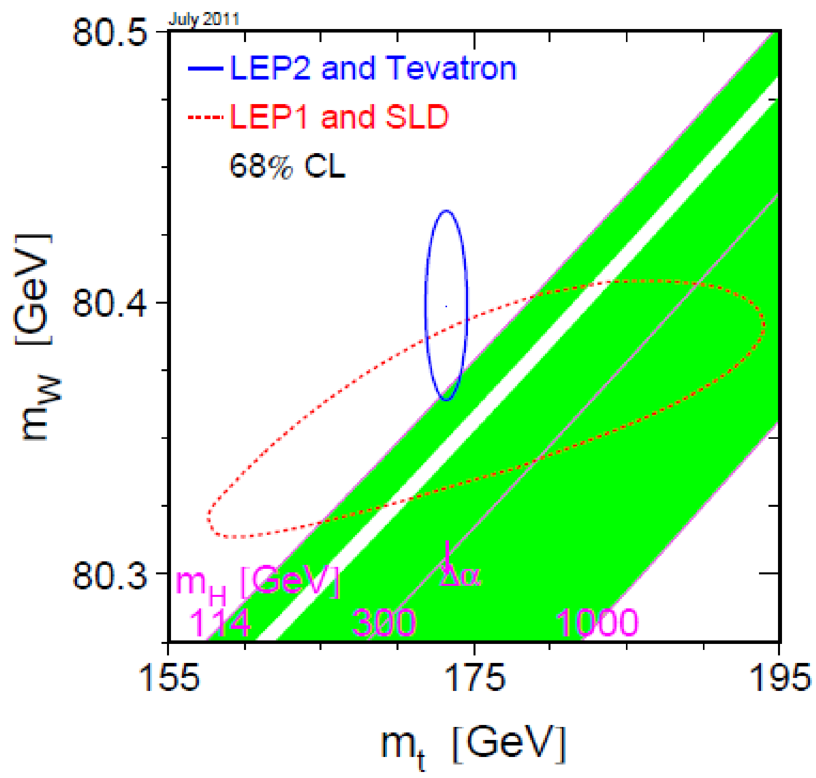
ΔMt < 1 GeV

ΔMt/Mt ~ 0.5%

Constraint on Higgs Mass

From LEPEWWG





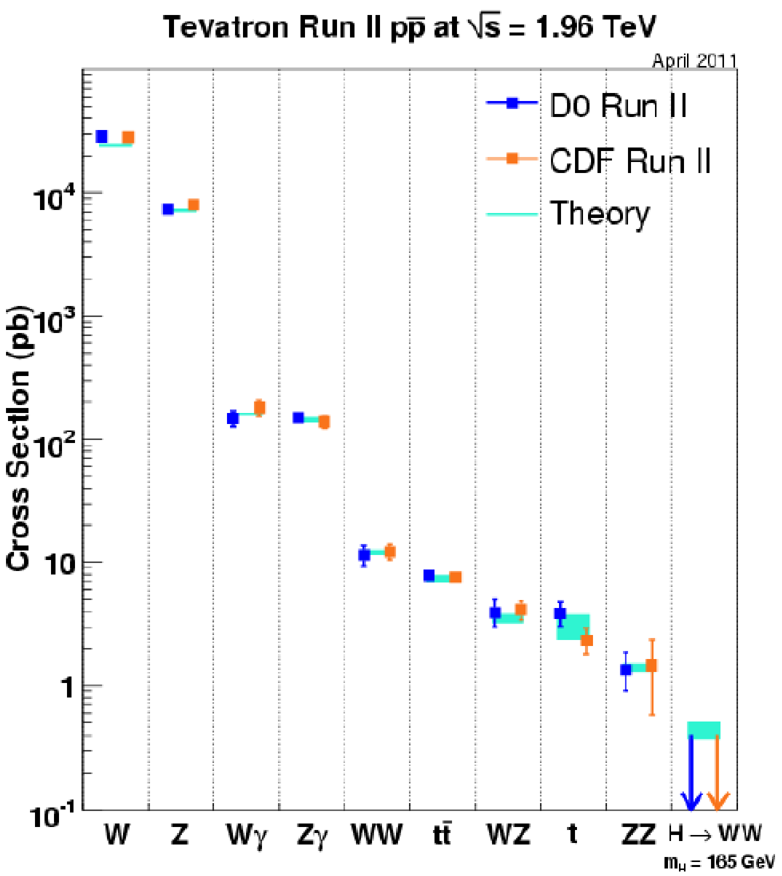
$$m_{\mathrm{H}} = 92^{+34}_{-26}\ \mathrm{GeV}\ (68\%\mathrm{CL})$$

or

$$< 161\ \mathrm{GeV} \quad (95\%\mathrm{CL})$$

Di-Boson Measurement

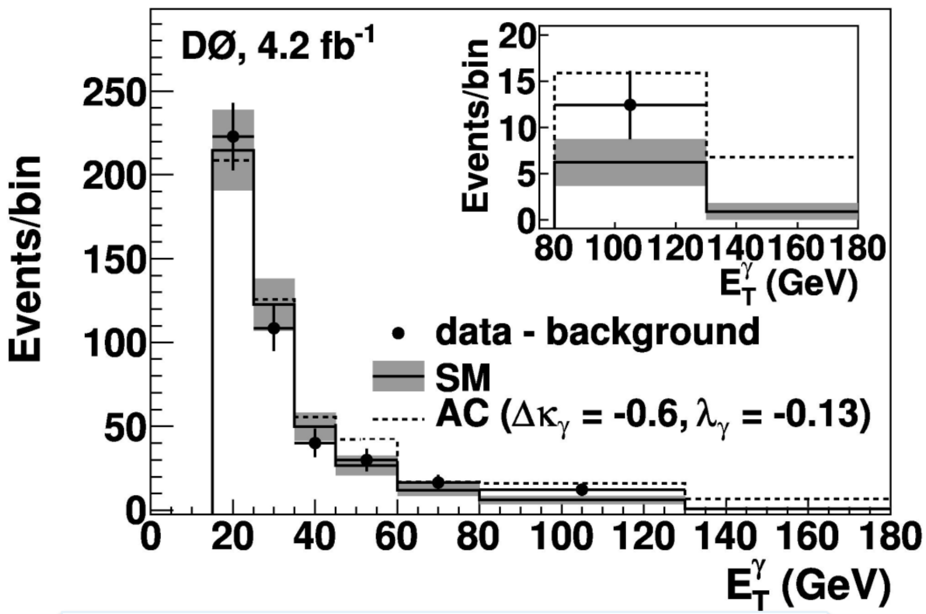
- SM vertices
  - $\gamma/Z \rightarrow WW$
  - $W \rightarrow WZ$
  - $W \rightarrow W\gamma$
- SM forbidden
  - ZZ
  - $Z\gamma$



- Couplings predicted by SM
  - Look for deviations: $\Rightarrow$ SUSY, little Higgs, …

Wγ, Zγ Cross Sections

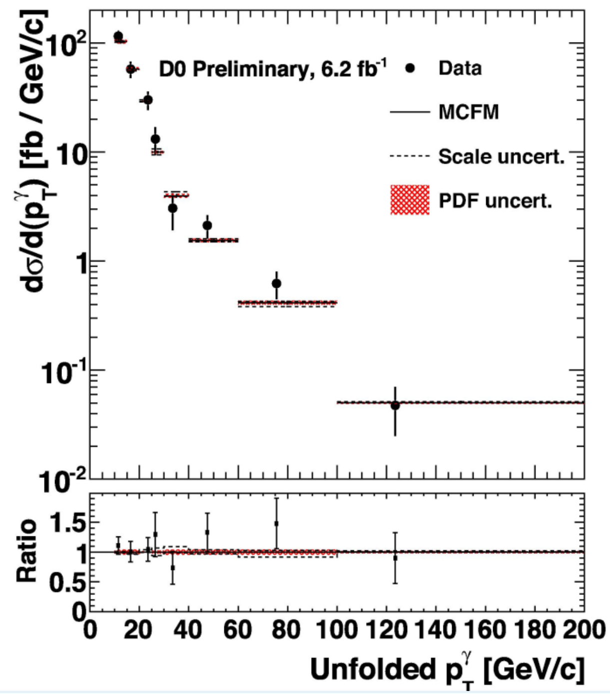
Wγ (lνγ)



- DØ, **4.2 fb^{-1}**
- **σ×Br = 15.8 ± 1.4 pb**
- SM(pred.) : 16.0 ± 0.4 pb

arXiv:1109.4432

Zγ (μμγ)



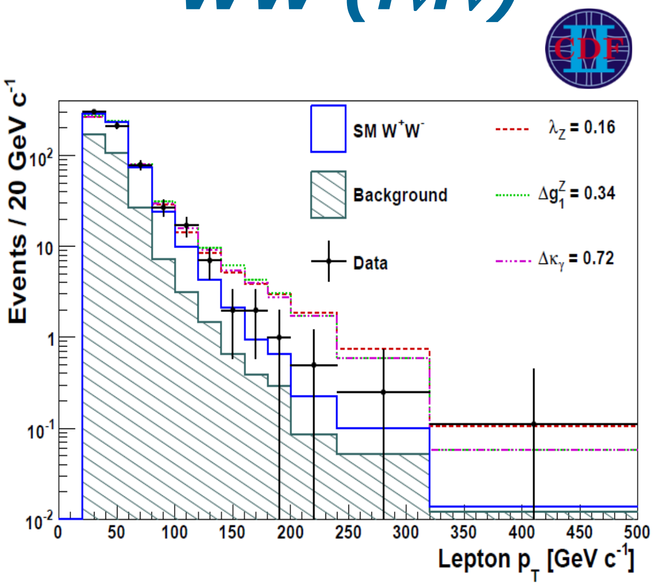
- DØ, **6.2 fb^{-1}**
- **σ×Br = 1.16 ± 0.1 pb**
- SM(pred.) : 1.10 ± 0.03 pb

D0 6240-CONF

Total & differential cross sections are in good agreement with SM.

WW,WZ,ZZ Cross Sections

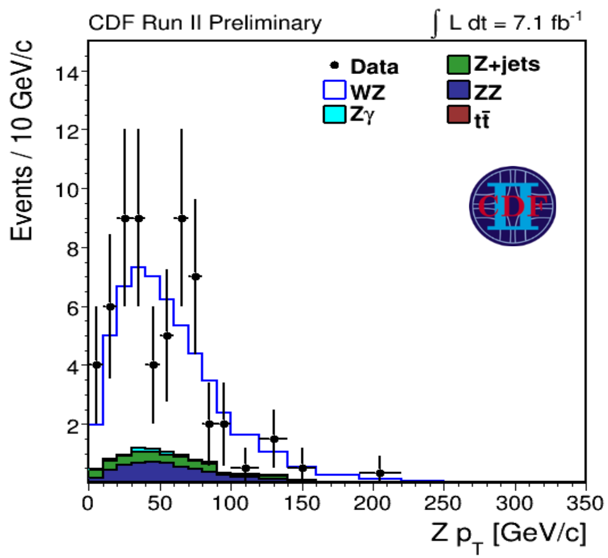
WW ($l\nu l\nu$)



- CDF, **4.2 fb^{-1}**
- **σ= 12.1 ± 1.7 pb**
- SM(pred.) : 11.7 ± 0.7 pb

PRL104,201801(2010)

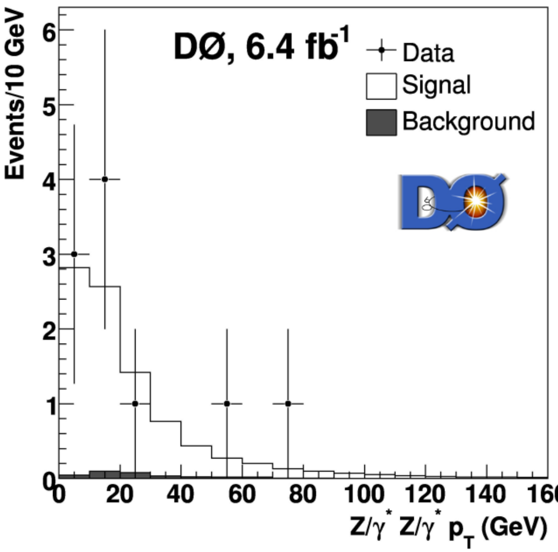
WZ ($l\nu ll$)



- CDF, **7.1 fb^{-1}**
- **σ = 3.9 ± 0.8 pb**
- SM(pred.) : 3.5 ± 0.2 pb

CDF 10176

ZZ ($llll, ll\nu\nu$)



- DØ, **6.4 fb^{-1}**
- **σ = 1.4 ± 0.4 pb**
- SM(pred.) : 1.4 ± 0.1 pb

PRD84,011103(2011)

Total & differential cross sections are in good agreement with SM.

Top Quark Properties

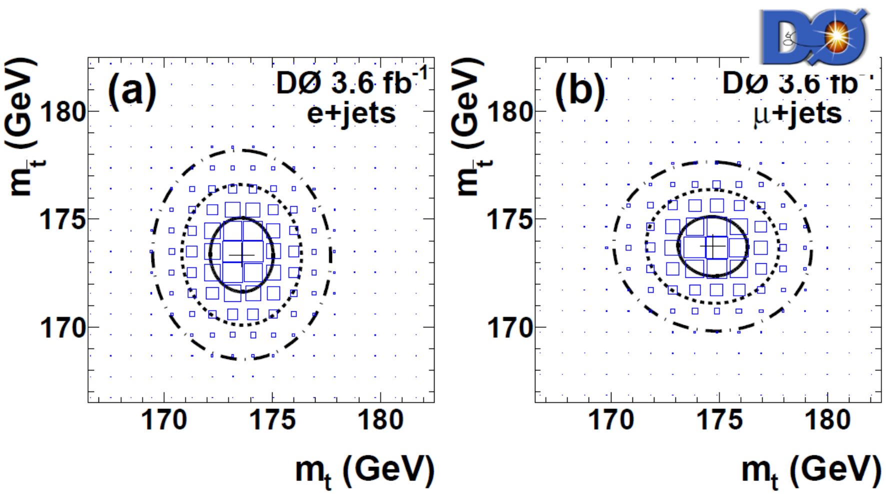
- Mt is close to EWSB scale
  $\lambda_t = \sqrt{2} m_t / v \sim 1$
- Top decays before hadronization
  $\Gamma_t \sim 1.4\ \mathrm{GeV} \gg \Lambda_{QCD} \sim 200\ \mathrm{MeV}$
  $\rightarrow$ direct access to bare quark

- Decay
  - Br(t→Wb)
  - Br(t→Zq)
  - Charged Higgs search
  - W helicity
  - Color flow
- Production & Decay
  - Spin correlation
- Intrinsic
  - Mass
    (already covered)
  - $m_t - m_{\bar{t}}$ difference
  - Width
  - Charge
- Production
  - Cross section
  - Forward-backward Asymmetry
    (covered by M.Takahashi)
  - Resonance search

m_t-$m_{\bar{t}}$ Difference

- If CPT is conserved, particle and antiparticle must have the same mass.
- Top quark decays before hadronization.
  → Top quark is the only quark with which we cant test this directory.

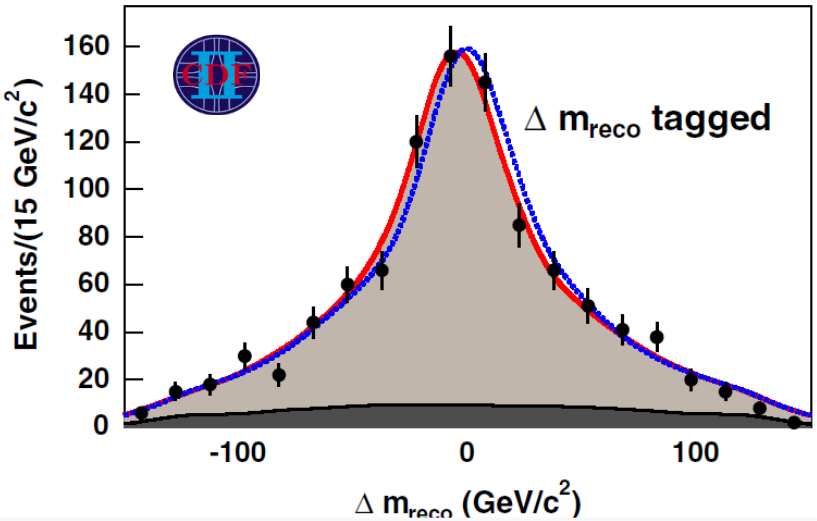
- DØ ℓ+jet channel
- Matrix element method **$3.6fb^{-1}$**



$$\Delta m_t = 0.8 \pm 1.8 \pm 0.5 \text{ GeV}$$

arXiv:1106.2063

- CDF, ℓ+jets channel
- template method **$5.6fb^{-1}$**



$$\Delta m_t = -3.3 \pm 1.4 \pm 1.0 \text{ GeV}$$

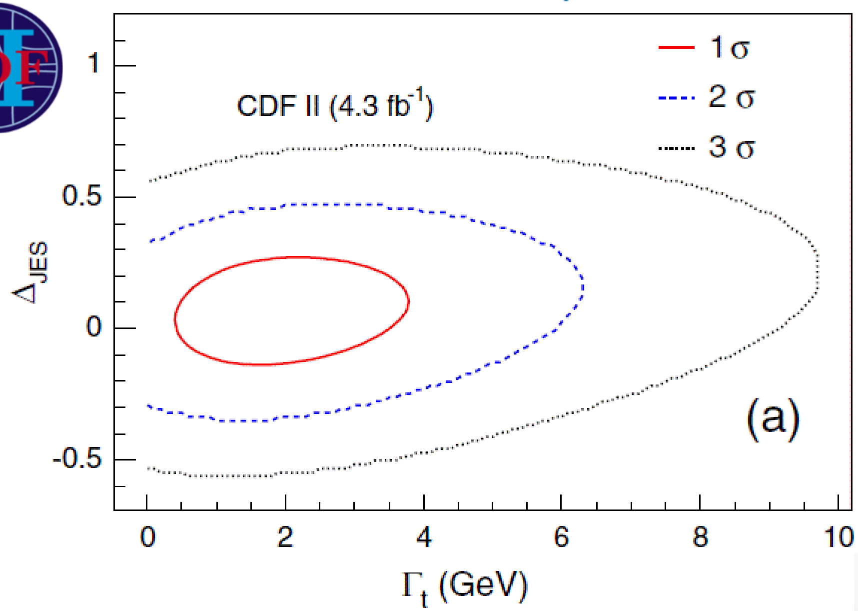
PRL106,152001(2011)

Consistent with $m_t = m_{\bar{t}}$

Top Quark Width

- In SM, t→ Wb is dominant: $\Gamma_t \sim \Gamma(t \to Wb) \sim 1.4\ \mathrm{GeV}$
- If unknown decay channel contributes, larger Γ_t will be observed.

- CDF, ℓ+jet channel
- From m_t^{rec} distribution
- Kinematic fit + Template Method

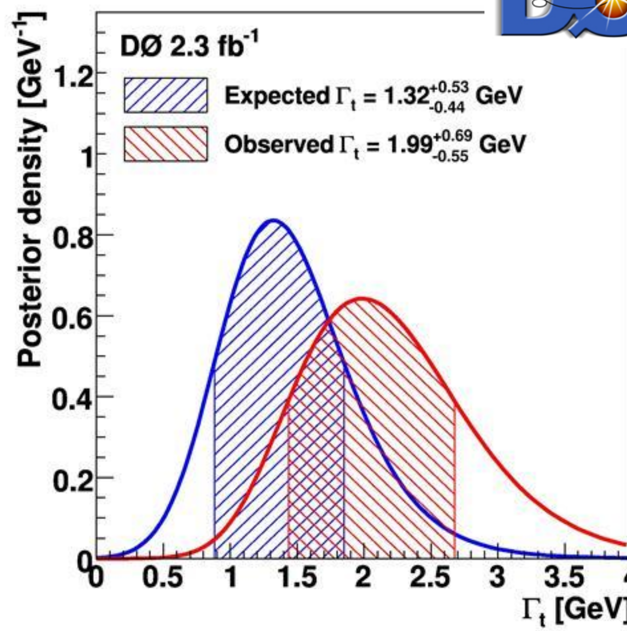


$\Gamma_t < 7.6\ \mathrm{GeV}$ **at 95%CL**

$0.3 < \Gamma_t < 4.4\ \mathrm{GeV}$ **at 68%CL**

PRL105,232003(2010) **4.3fb-1**

- Extraction from $\sigma_{t-\mathrm{channel}}$ (L=2.3fb-1) and $\mathrm{Br}(t \to Wb)$ (L=0.9fb-1)



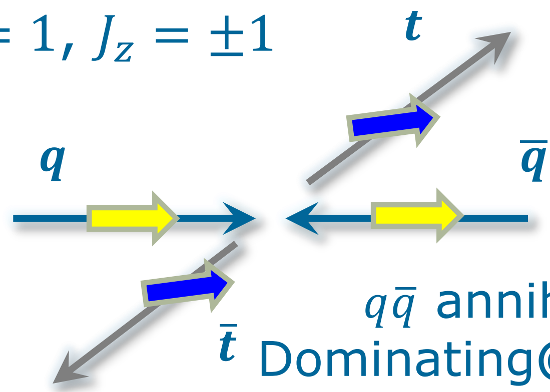
$\Gamma_t = 1.99^{+0.69}_{-0.55}\ \mathrm{GeV}$

PRL106,022001(2011) **2.3fb-1**

Spin Correlation

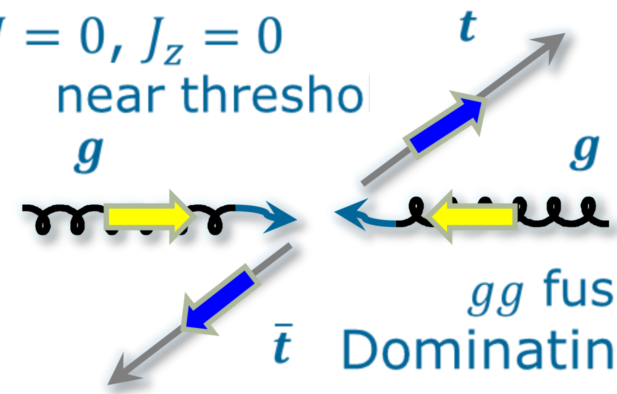
- Top and anti-top spins are correlated at production
  - in different ways at Tevatron and LHC
- Top quark decays before losing polarization
  - Spin correlation can be measured as angular correlations of decay products: $d\sigma \propto 1 - C\cos\theta_{+}\cos\theta_{-}$

$J = 1,\ J_z = \pm 1$



$q\bar{q}$ annihilation
Dominating**@Tevatron**

$J = 0,\ J_z = 0$
near thresho

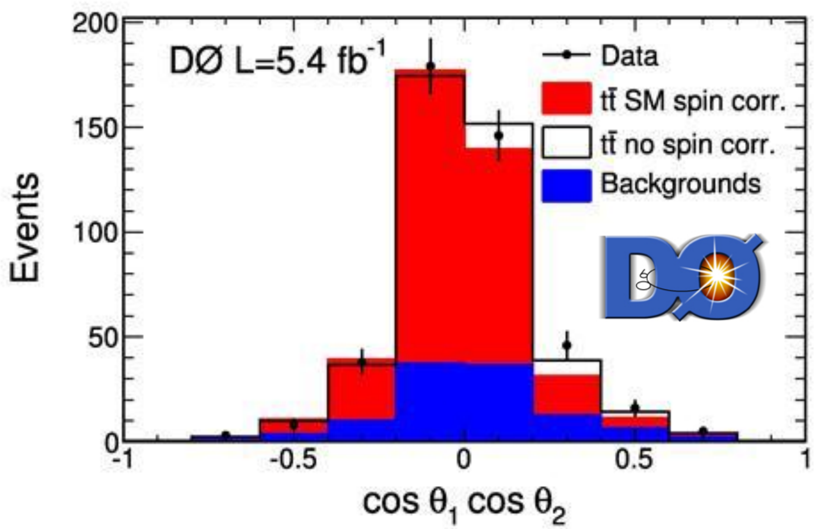


gg fusion
Dominating**@LHC**

- Experimental verification of
  top decaying before losing polarization
- Sensitive to anomalous coupling at $t\bar{t}$ produc

Spin Correlation Measurement

- DØ, dilepton channel (441evt)
- Use lepton flight directions in top rest frame
- Neutrino weighting method + Template fit extract C_{beam}



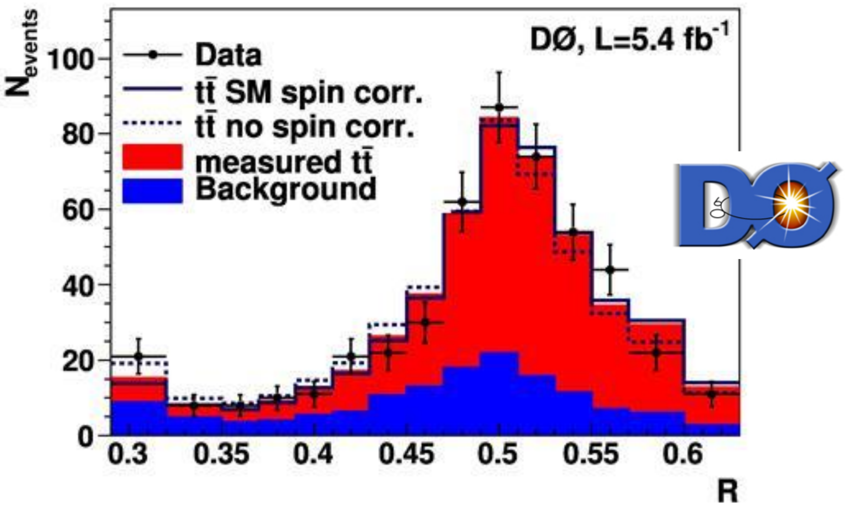
Correlation coefficient in beamline basis

$$C_{\text{beam}} = 0.10 \pm 0.45$$

PLB702,16(2011) **5.4fb^{-1}**

SM pred.: $C_{\text{beam}} \sim 0.78$

- DØ, dilepton channel (485evt)
- Matrix element method
  - f: fraction of SM spin corr.
    - f=1: SM spin corr.
    - f=0: No corr.



$$f^{SM} = 0.74^{+0.40}_{-0.41}$$

Exclude f=0 (no spin corr) at 97.7% CL

Corresponding to $C_{\text{beam}} = 0.57 \pm 0.31$

PRL107,032001(2011) **5.4fb^{-1}**

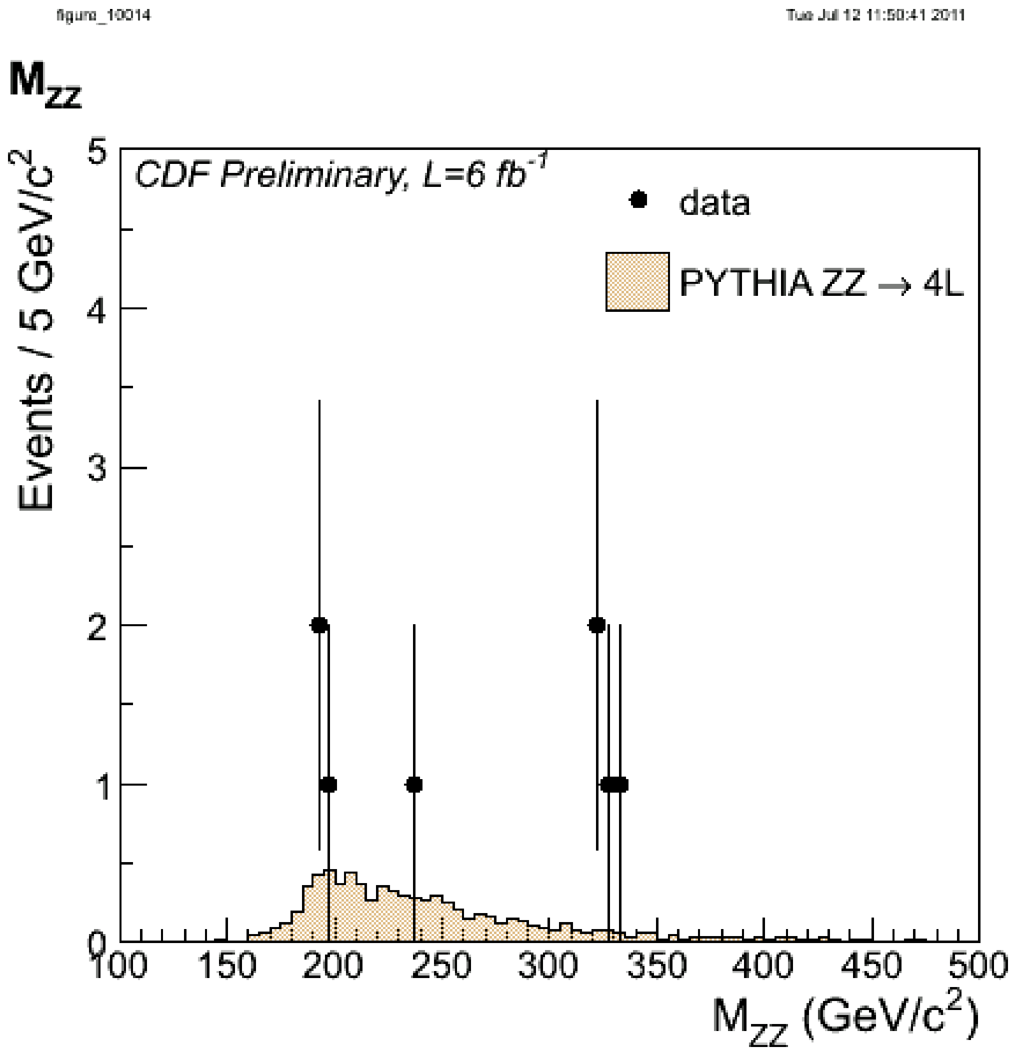
Consistent with SM, but statistically limited

Summary

- W boson & top masses have been measured in great precision at the Tevatron.
- Various measurements on EW and top quark properties have been performed.
  results are consistent with SM so far.
- Continue precise measurements not to overlook any hint of new physics.

Backup

CDF ZZ Resonance Search



Two Breakthroughs in Top Mass Measurements

Matrix Element Method

- Use information on leptons and jets maximally

Observables

$$L_i(M_t; y) = N \frac{d\sigma}{d\Phi}(y; M_t)$$

$$L(M_t) = \prod_i L_i(M_t)$$

Matrix element with a given top mass gives p.d.f. of observables

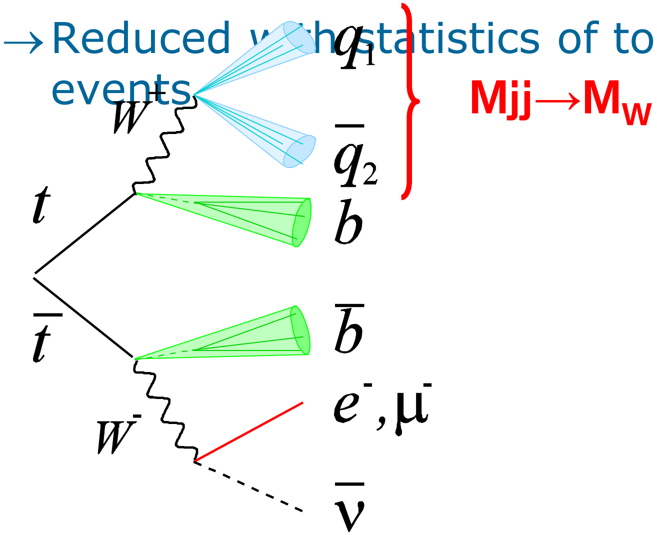
⇩

Likelihood function of top mass for a given set of observables

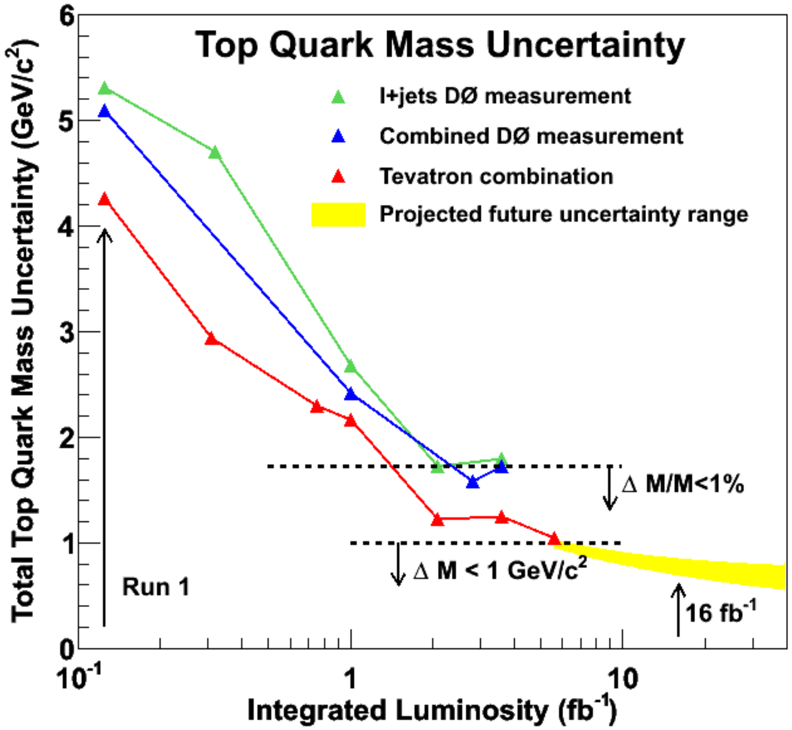
in-situ W→jj JES calib.

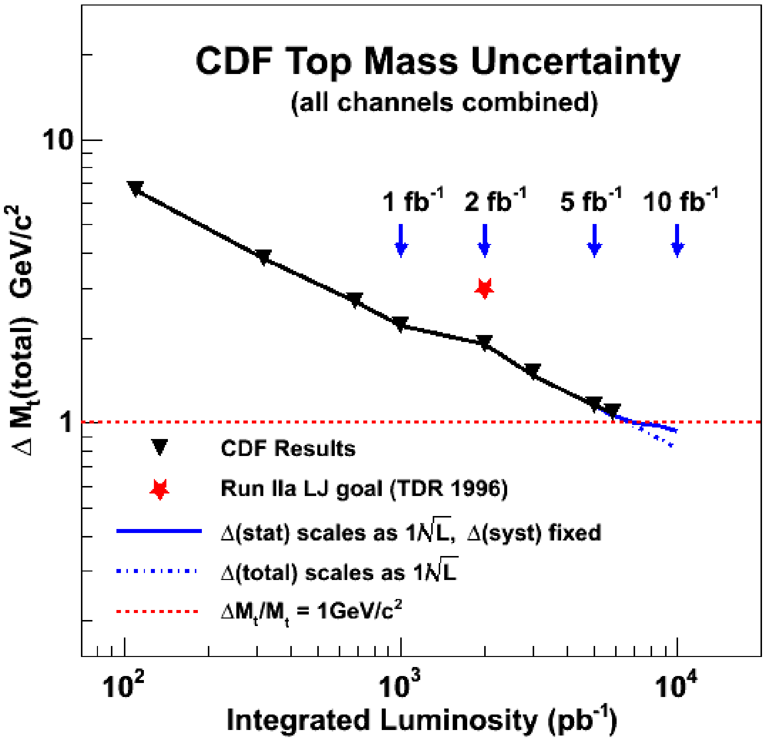
- JES (jet energy scale) calibration using di-jet invariant mass from W
- Incorporate JES into likelihood function
  - $L(M_t) \rightarrow L(M_t, JES)$
  - Turn JES systematics into statistics

→Reduced with statistics of top events



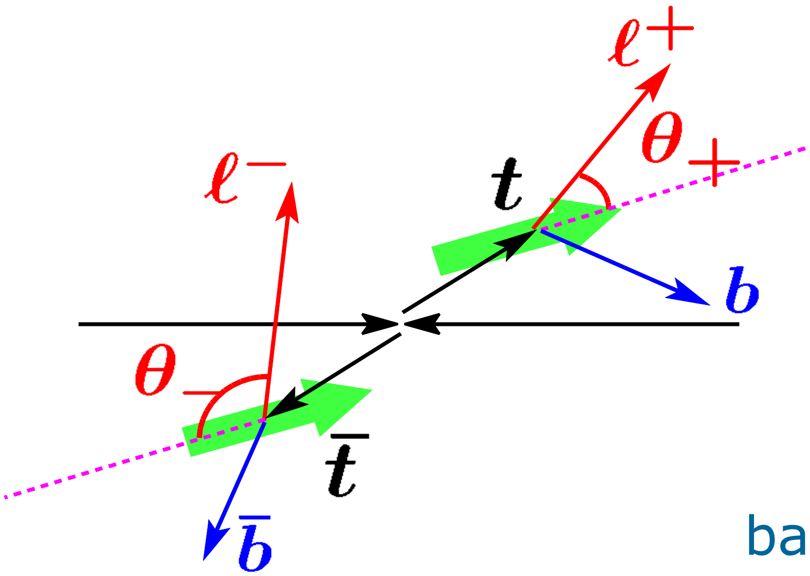
Δm_t History at Tevatron





- Systematics also reduced by $1/\sqrt{L}$ by continuous efforts

c_{base}: spin-spin correlation coefficient



$$c_{\text{base}} \equiv \frac{N_{\uparrow\downarrow} + N_{\downarrow\uparrow} - N_{\uparrow\uparrow} - N_{\downarrow\downarrow}}{N_{\uparrow\downarrow} + N_{\downarrow\uparrow} + N_{\uparrow\uparrow} + N_{\downarrow\downarrow}}$$

base: quantization axis for top and anti-to
off-diagonal, beam, helicity, …

$$\rightarrow \frac{1}{\sigma}\frac{\mathrm{d}^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1 + C_{\text{base}}\cos\theta_+\cos\theta_-}{4}$$