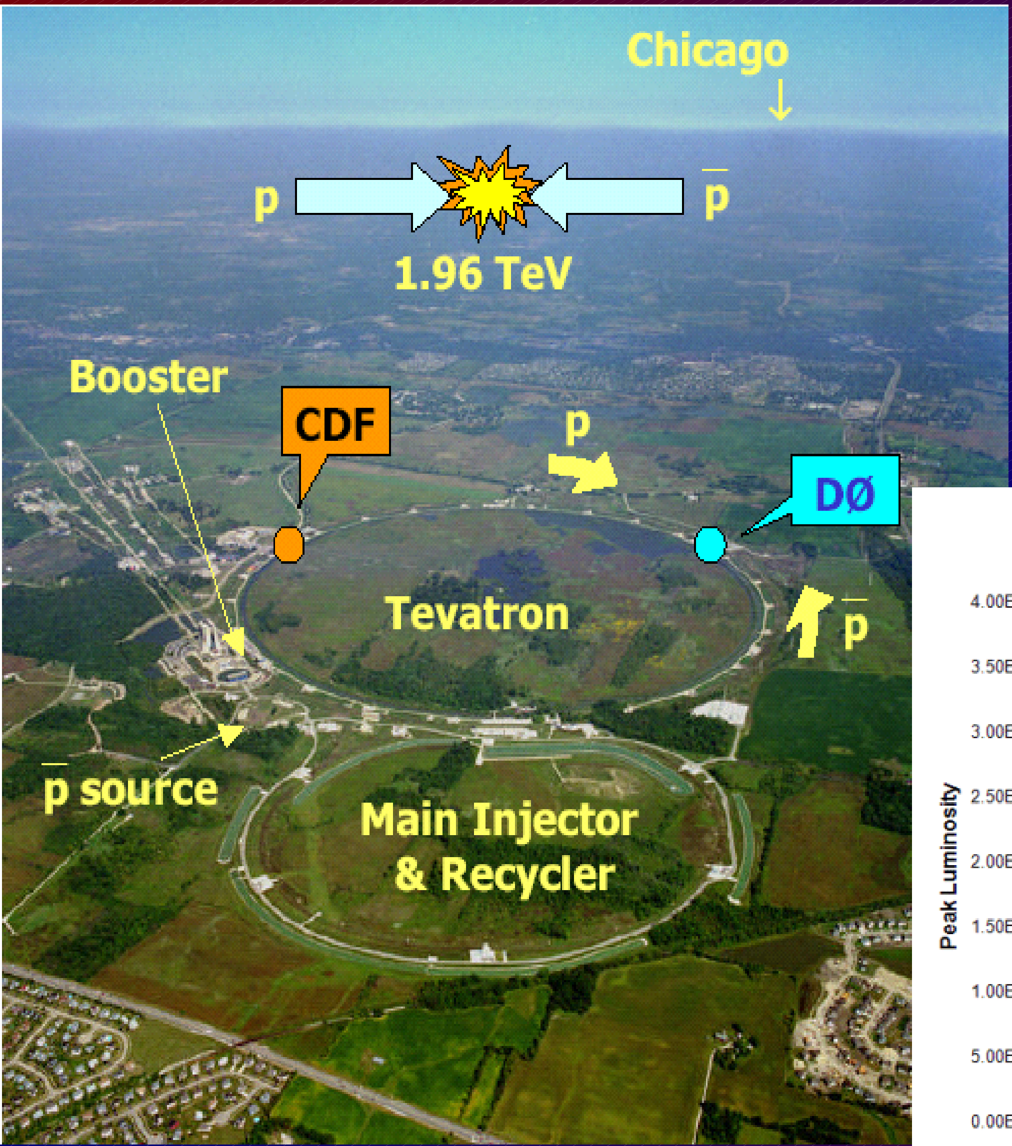
Top, W and Z: rassegna sperimentale - risultati recenti da Tevatron-

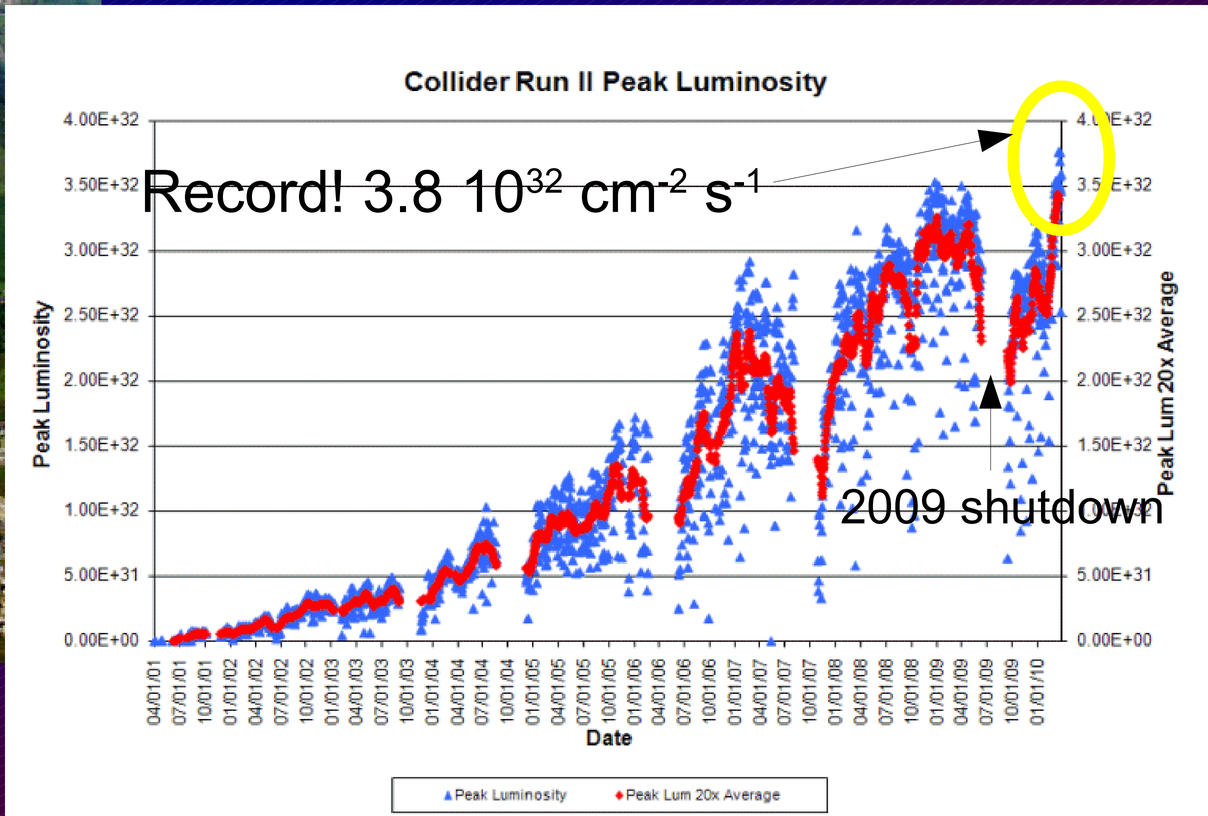
Silvia Amerio
INFN Padova

IFAE 2010 – Roma – 7-9 Aprile

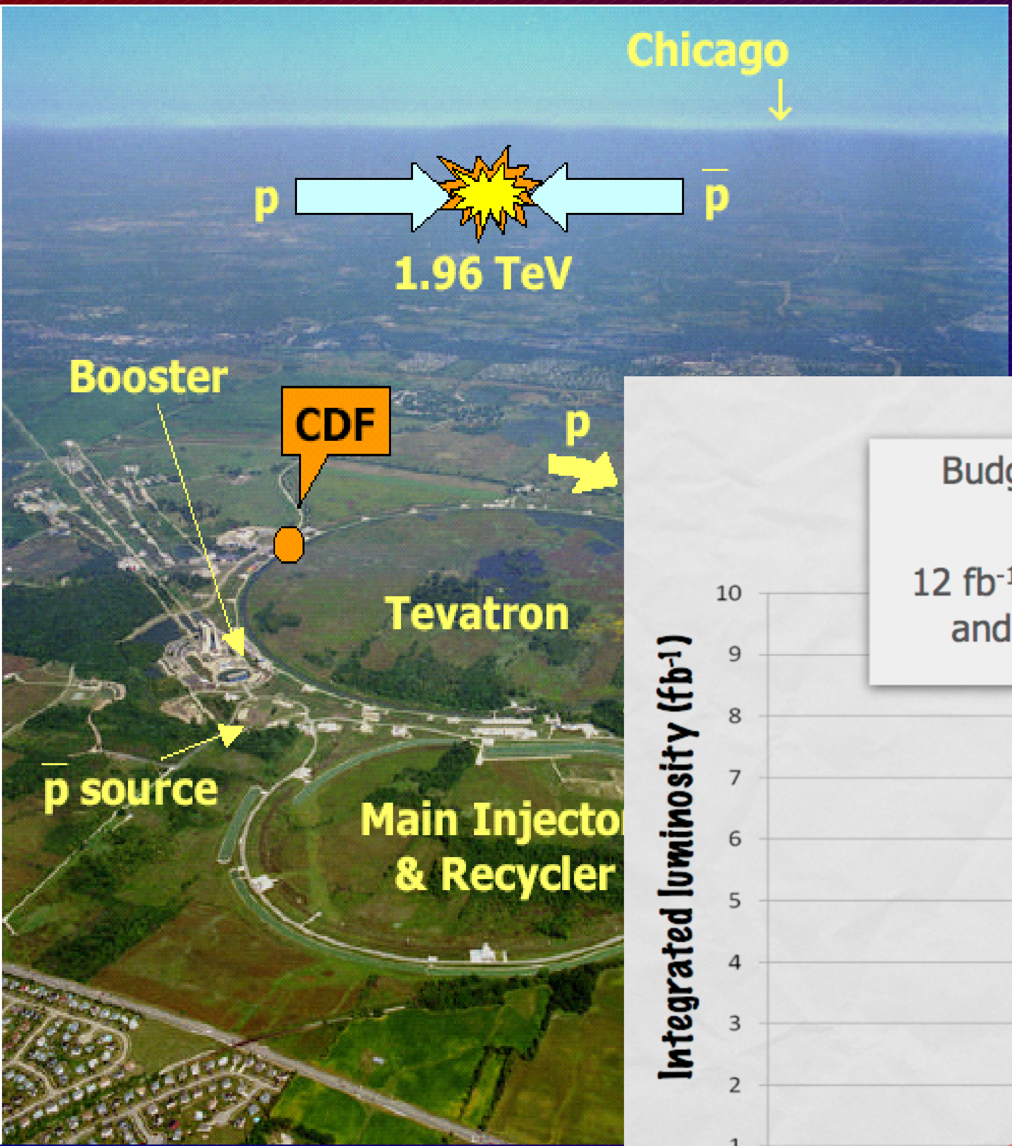
Tevatron



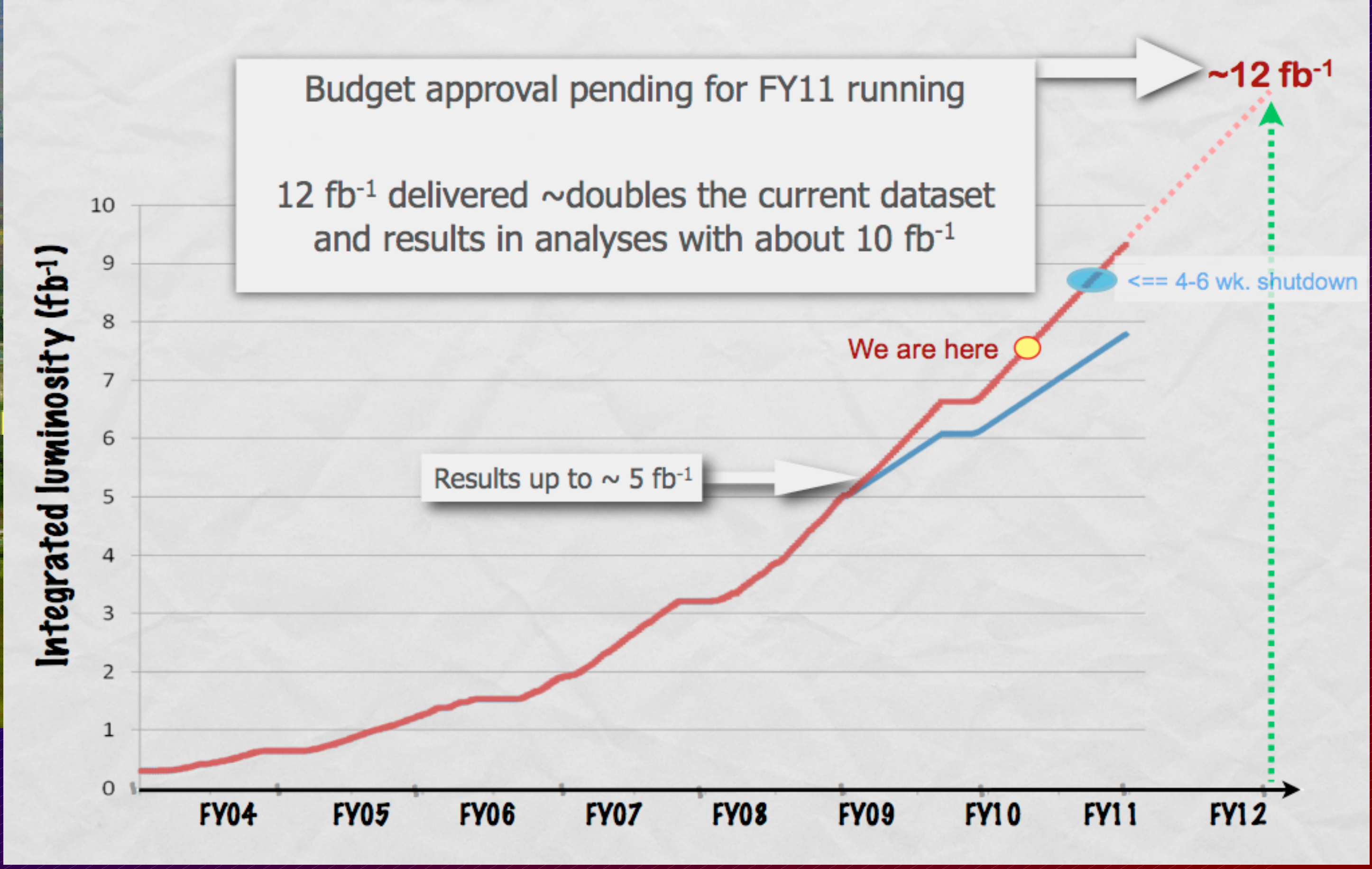
- Circumference 6.2 km
- Run I (1987-1995)
- Run II (since 2001)
- Surpassed design luminosity



Tevatron

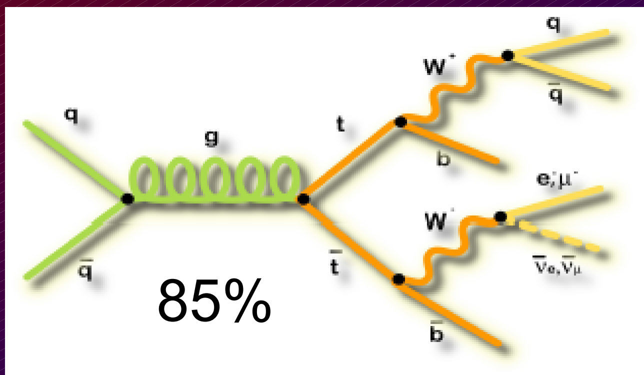


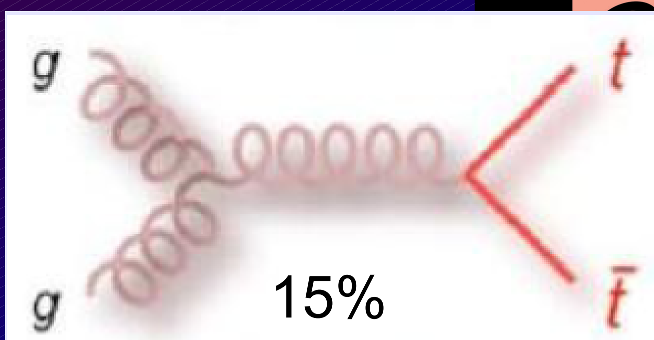
- **7.5 fb^{-1}** of data on tape
- Results in this talk with data up to **5 fb^{-1}**



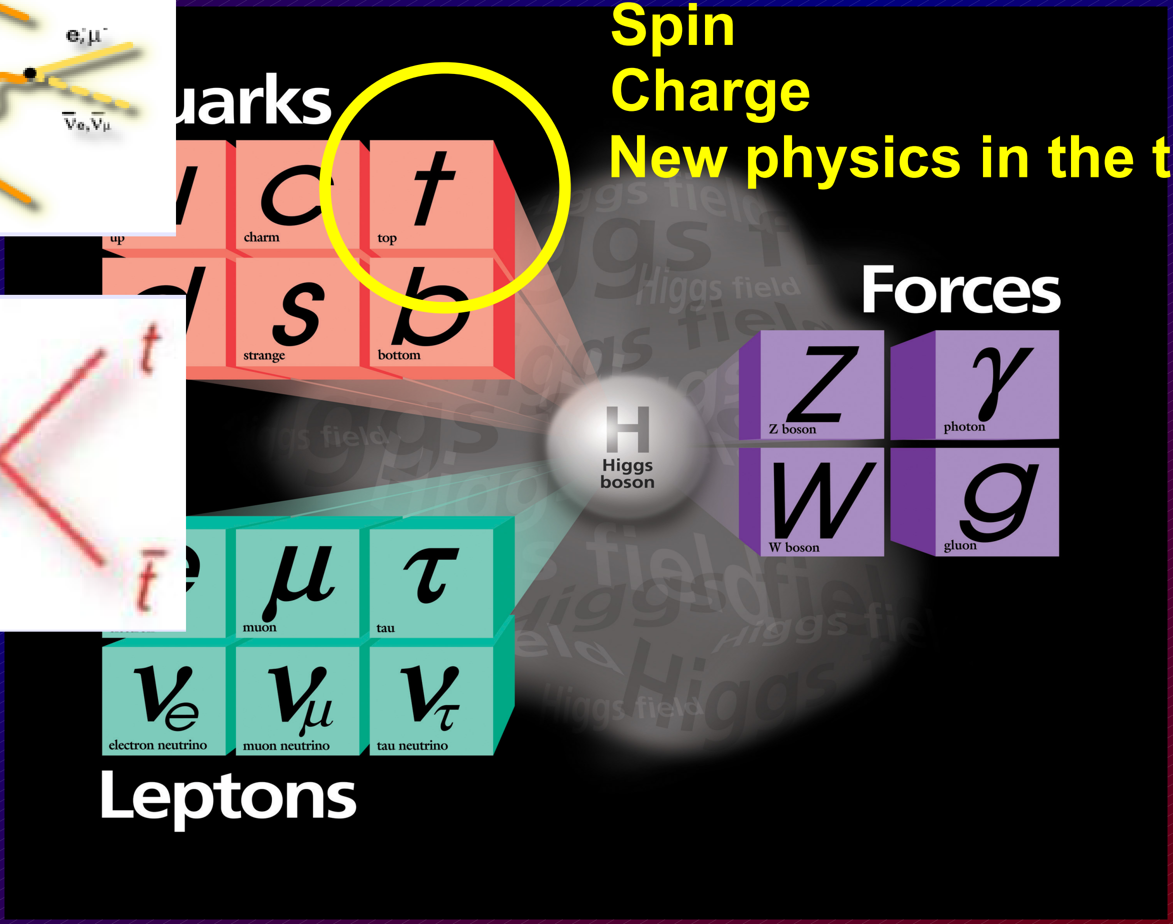
Top

- Heaviest quark
- Discovered at Tevatron in 1995
- At Tevatron mainly produced through qq annihilation
- t→ Wb, no hadronization: its properties can be measured directly





Mass
Spin
Charge
New physics in the top sector



Top mass : summary of the results

Tevatron (March 2009):

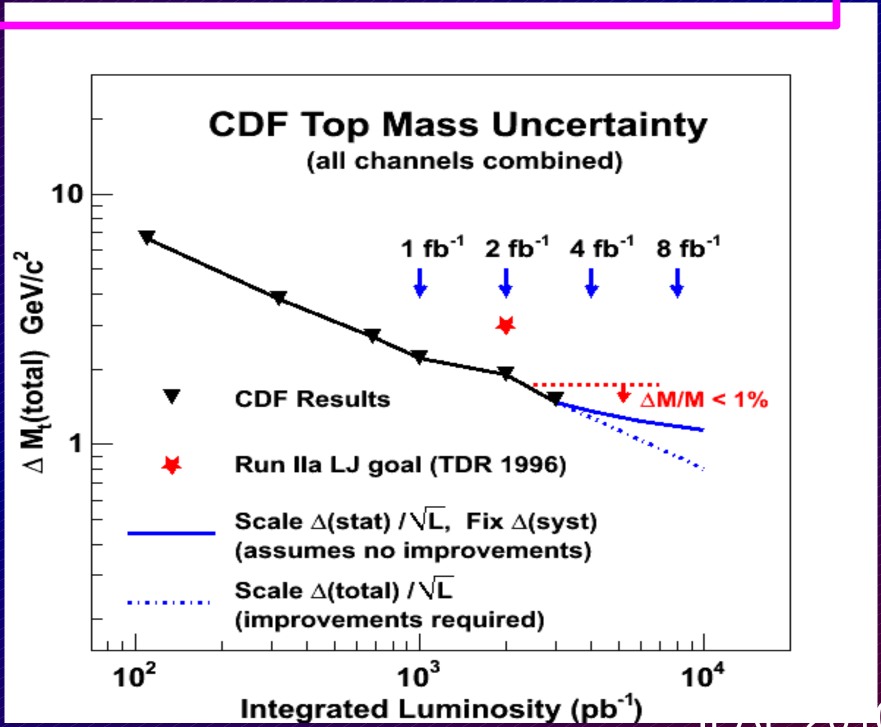
M_{top} = 173.1 ± 0.6 (stat) ± 1.1 (syst) GeV/c^2

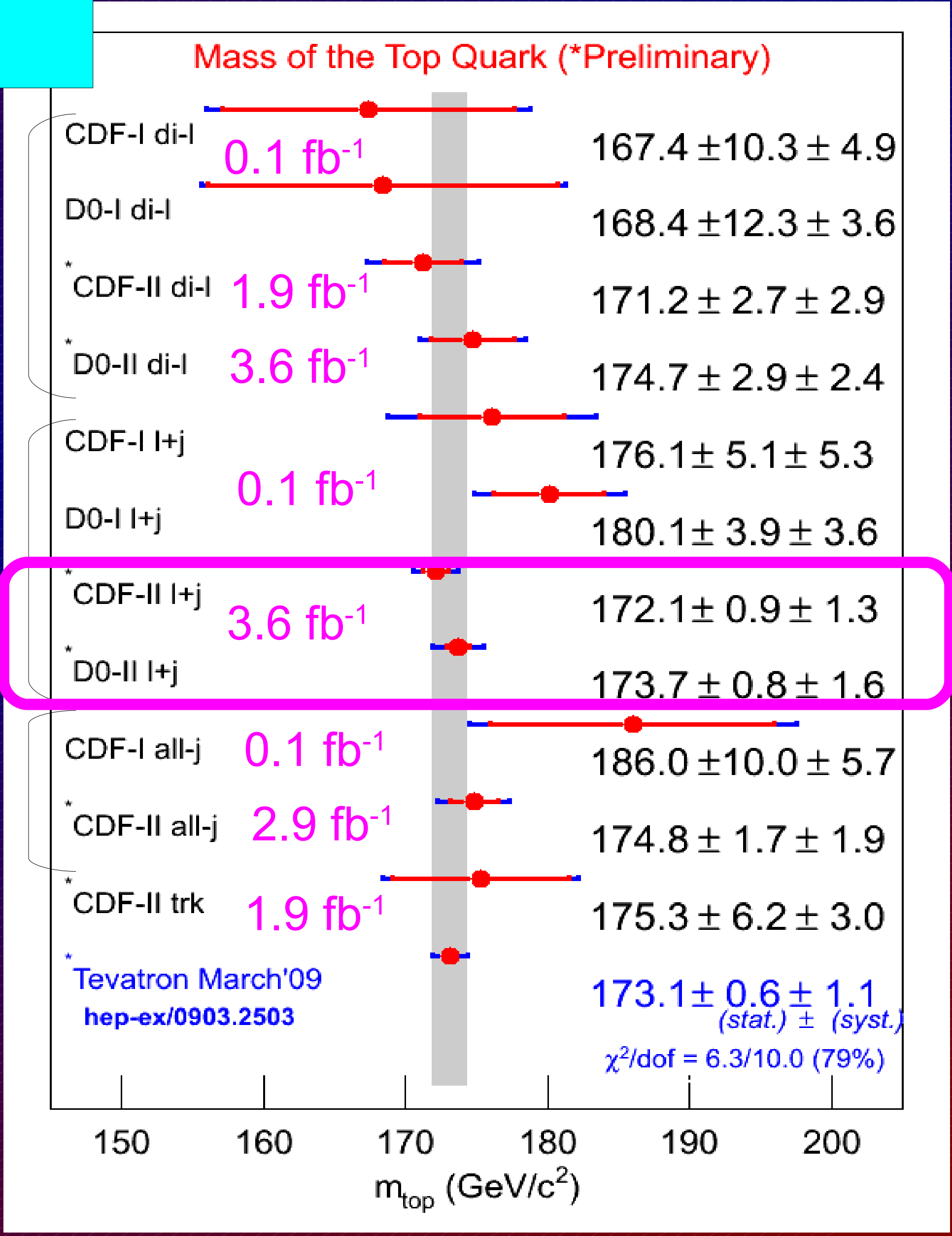
= 173.1 ± 1.3 (stat + syst) GeV/c^2

Δm/m < 1%

Uncertainty dominated by systematic error: joint CDF/D0 effort to better understand systematic sources

Single experiment top quark mass precision reaching 1 GeV





Top mass at CDF

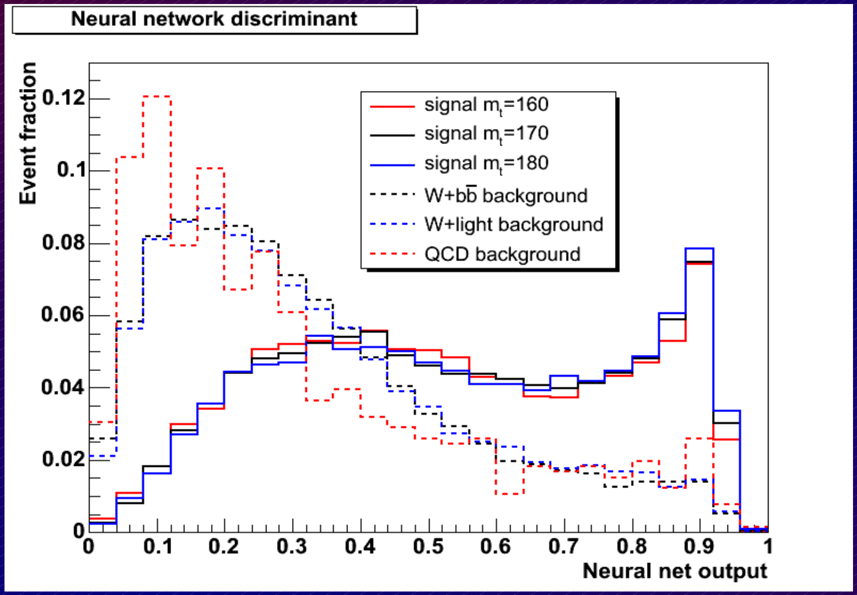
L = 4.8 fb^{-1}

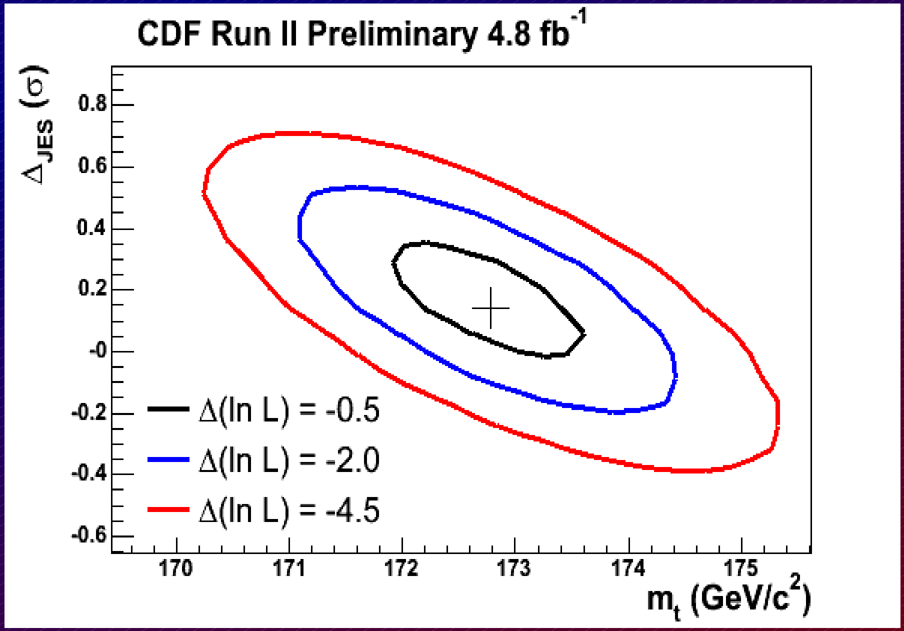
Lepton+Jets with the *Matrix Element Method* & **Neural Network discriminant** to distinguish signal from background.

b-tagging algorithm, **increased muon acceptance**

2D likelihood $L = \Pi Pevt(M_{top}, \mathbf{JES}, f_{top}(M_{top}, JES))$

In situ calibration of the JES using the W mass





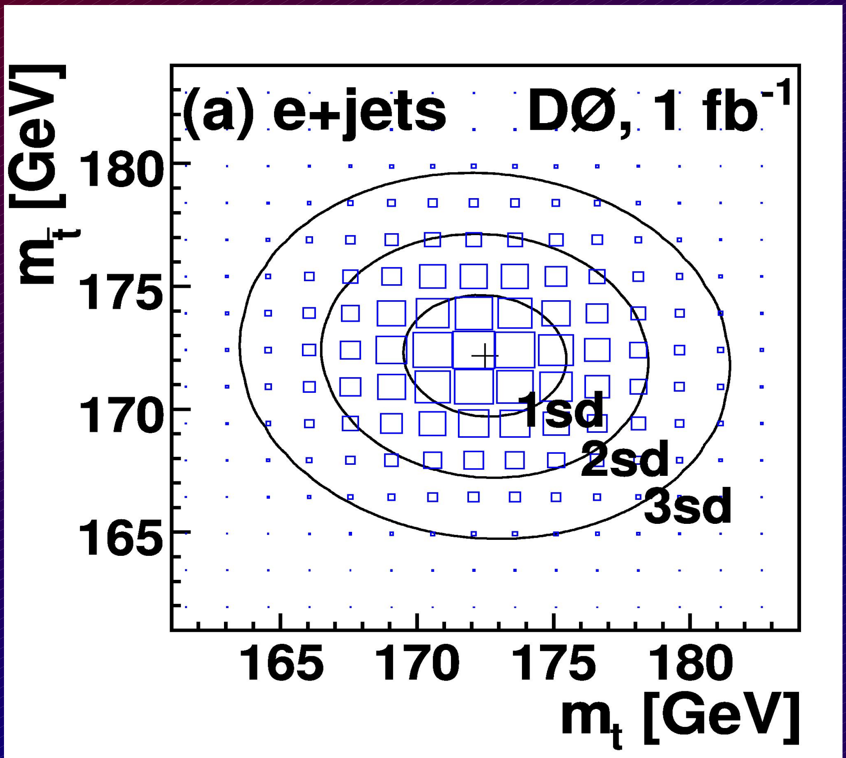
This is the most precise measurement ever done.

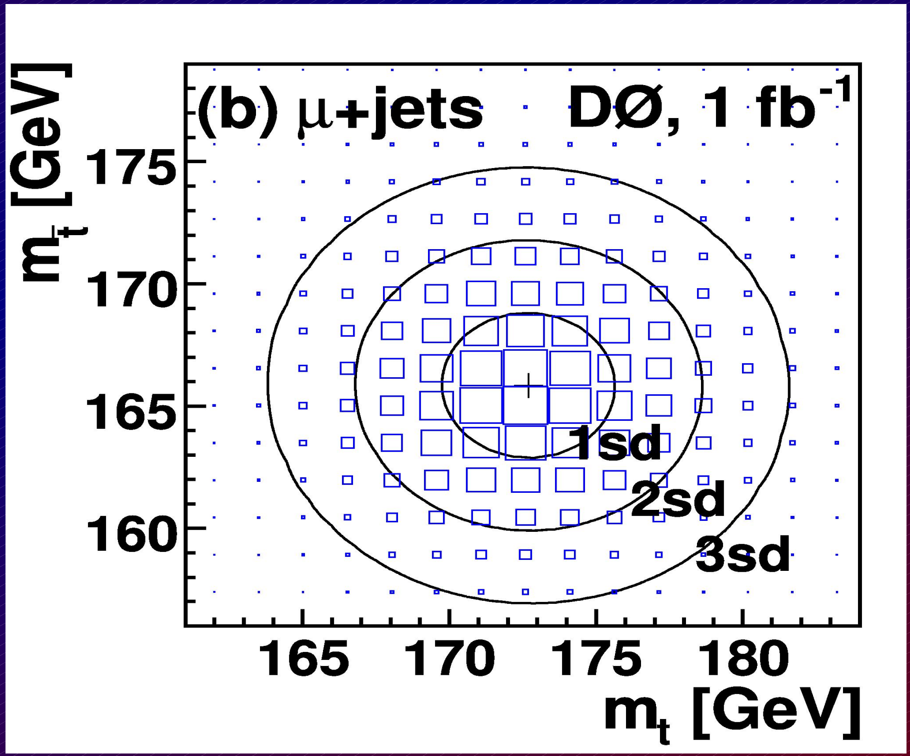
M_{top} = 172.8 ± 0.7 (stat) ± 0.6 (JES) ± 0.8 (syst) GeV/c^2 = 172.8 ± 1.3 (total) GeV/c^2

Top – anti top mass difference

Particles and antiparticles have the same mass: test of CPT invariance.
Measured with matrix element method in lepton + jets events

L = 1 fb^{-1}





First time measured for a "bare quark"
Consistent with SM expectations

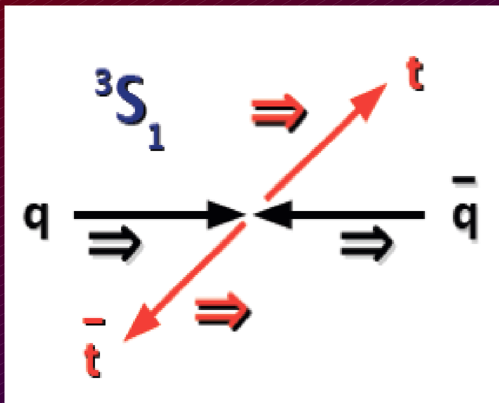
PRL 103, 132001 (2009)

$\Delta M_{top} = 3.8 \pm 3.7$ GeV/c^2

Statistics limited

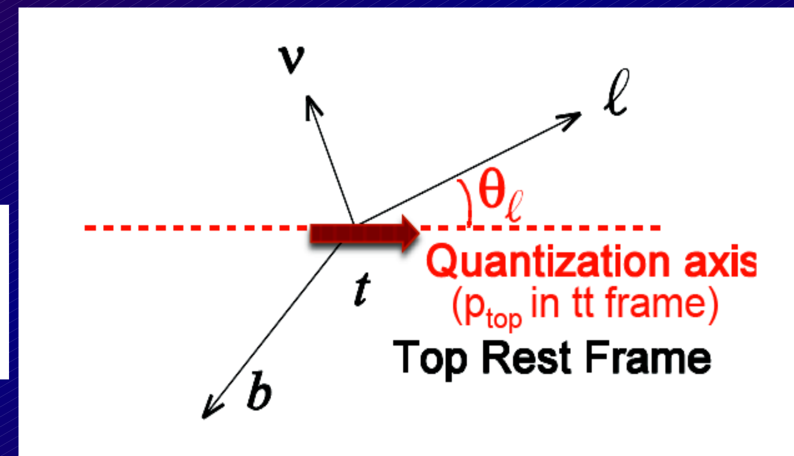
Top antitop spin correlations

Top short lifetime → spin correlations at ttbar production can be observed
New production mechanisms could modify SM characteristic spin correlations



We measure the spin correlation coefficient k

$$\kappa = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\uparrow\downarrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\uparrow\downarrow)}$$

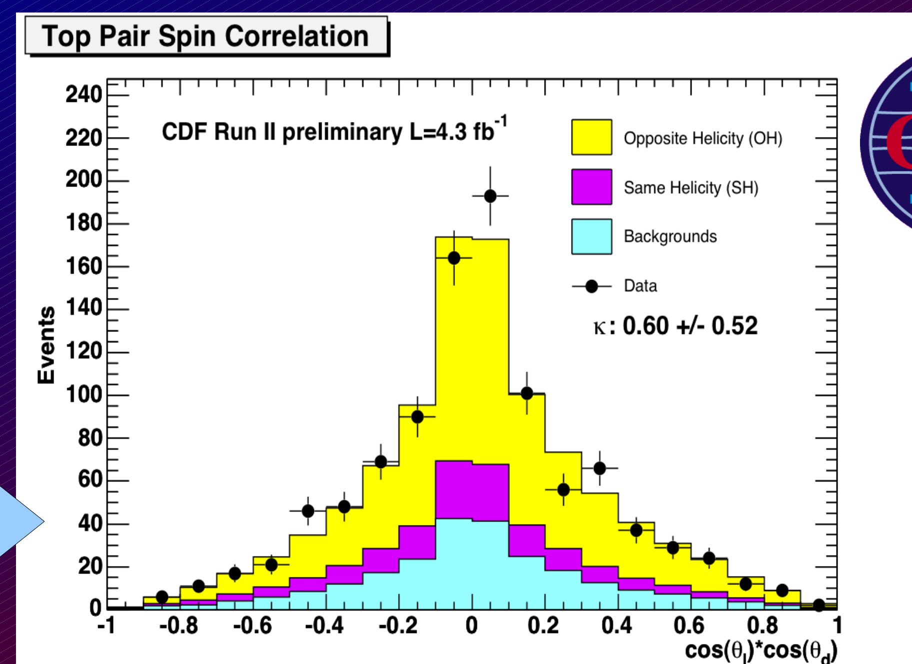


L = 4.3 fb^{-1}

Lepton + jets channel

Helicity Axis
k(SM) = 0.40

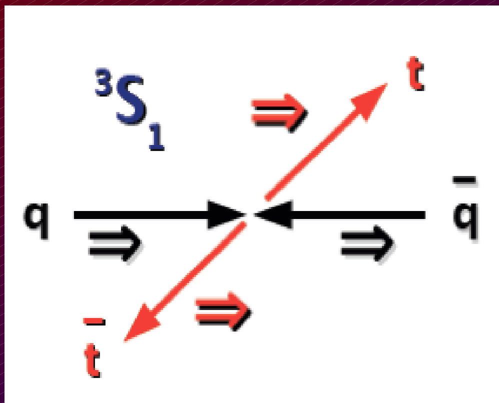
Opposite helicity fraction f_0 fitting $\cos(\theta_d)\cos(\theta_b)$ and $\cos(\theta_l)\cos(\theta_d)$ to Same and Opposite helicity and bgnd templates



K= 0.60 ± 0.50 (stat) ± 0.16 (syst)

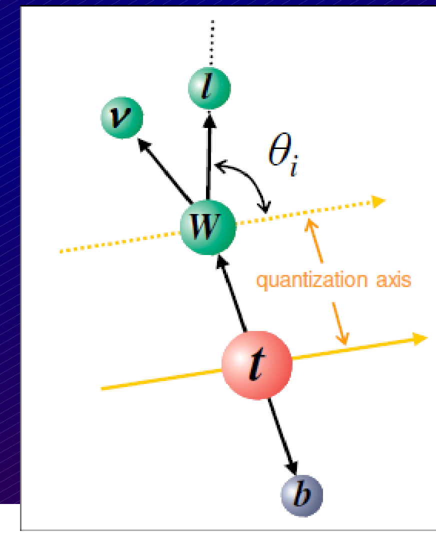
Top antitop spin correlations

Top short lifetime → spin correlations at ttbar production can be observed
New production mechanisms could modify SM characteristic spin correlations



We measure the spin correlation coefficient k

$$\kappa = \frac{N(\uparrow\uparrow)+N(\downarrow\downarrow)-N(\uparrow\downarrow)-N(\uparrow\downarrow)}{N(\uparrow\uparrow)+N(\downarrow\downarrow)+N(\uparrow\downarrow)+N(\uparrow\downarrow)}$$

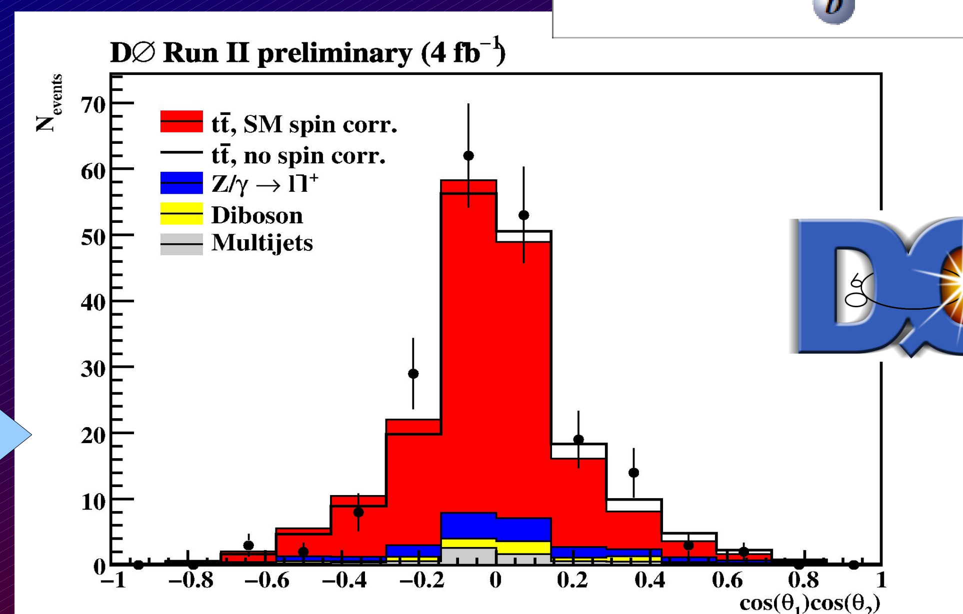


L = 4.2 fb^{-1}

Dilepton channel

Beam Axis
K(SM) = 0.8

k obtained fitting $\cos(\theta_1)\cos(\theta_2)$ to templates w/ different k input values

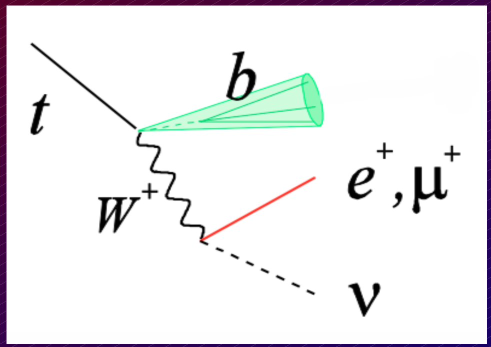


K= -0.17 - 0.65 + 0.53 (stat+syst)

Top Quark Charge

SM → top quark has charge + 2/3 and decays in W^+b
4th generation scenario -> the observed top quark is a non-SM particle with charge 4/3

L = 2.7 fb^{-1}

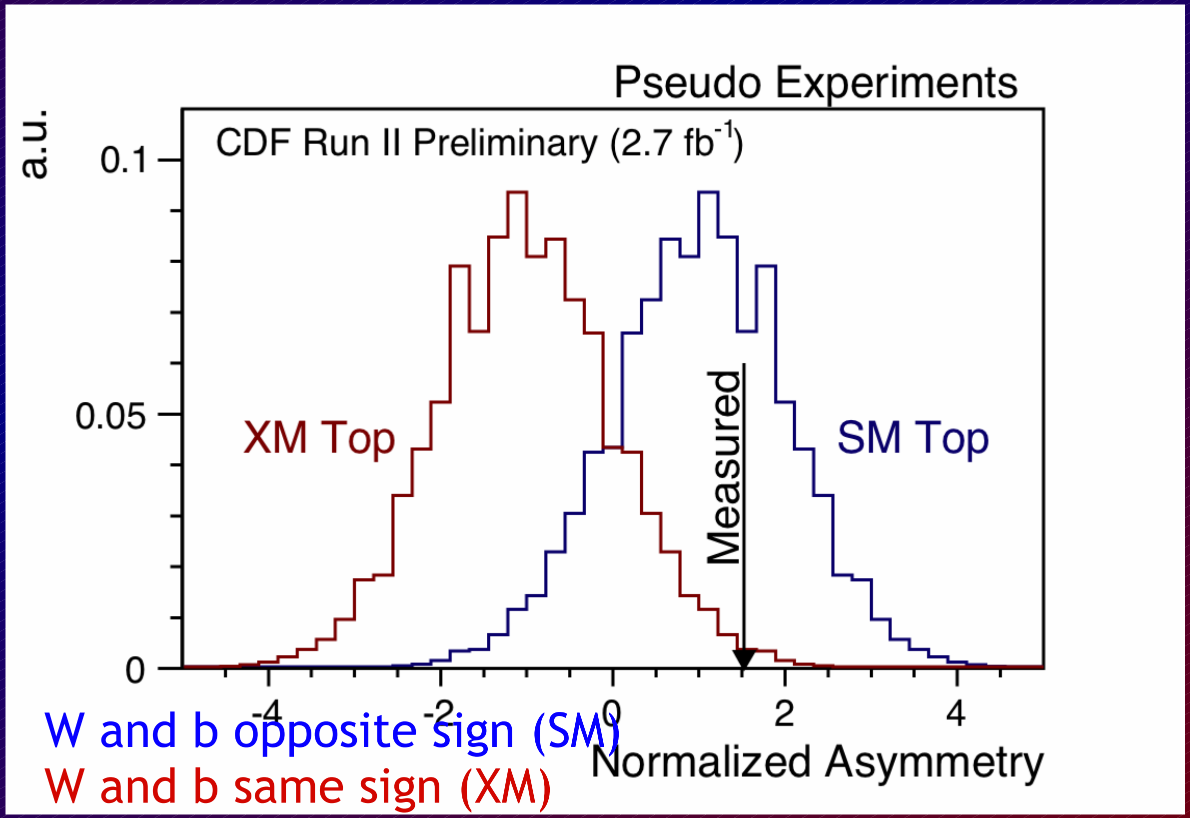


Lepton + jets channel

1) Identify 2 b-jets
   - **Secondary vertex tagger**
   - **Soft lepton tagger**

2) Associate the b-jet to the hadronic/leptonic W
   - **Kinematic fitter**

3) Determine the flavor of the leptonic b
   - **Soft lepton tagger**



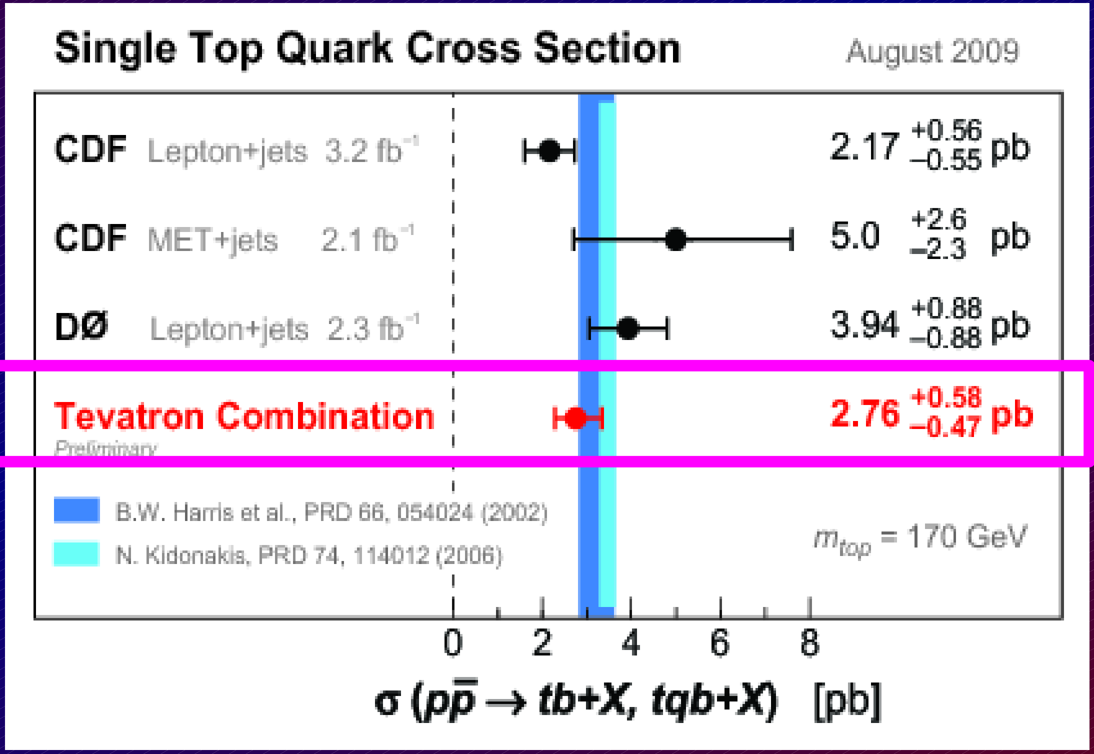
Excludes Q_{top} = 4/3 at 95% C.L.

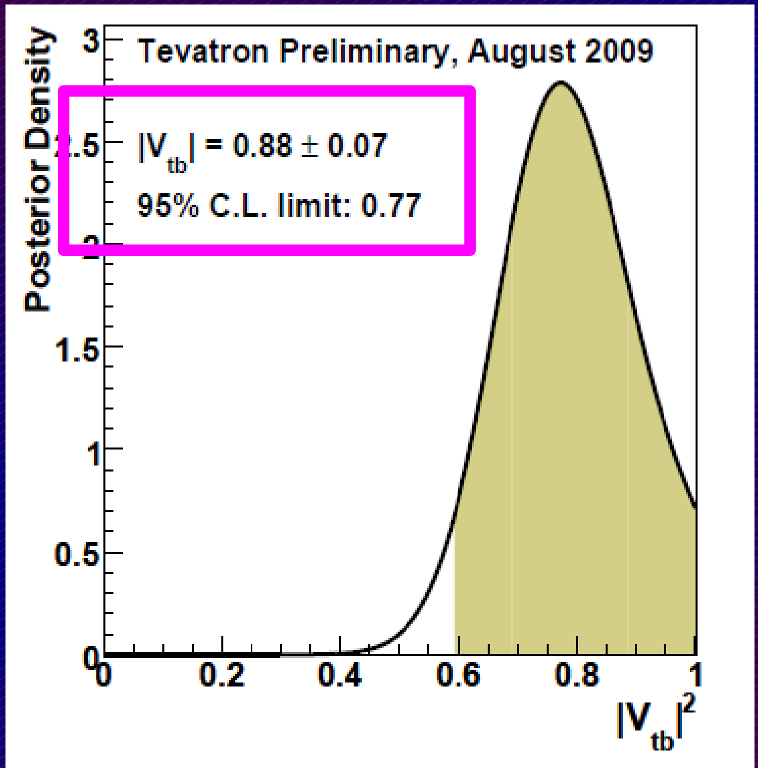
Single top: Tevatron combination

Very challenging measurement: small cross section and large backgrounds.

Need for sophisticated multivariate techniques (NN, BDT, ME, LL)

CDF and D0 observe single top at 5 σ level (compatible at 1.6 σ with each other)





Combined cross section uncertainty from 22% to 19%

Combined V_{tb} uncertainty from 14% (CDF) and 11% (D0) to 8%

Top quark width

Top short lifetime → large width
For M_{top} = 175 GeV, Γ = 1.5 GeV

Deviations from prediction can signal contributions from decays to non SM particles ($t \to H^{+}b$)

First indirect and most precise determination of the top quark width.

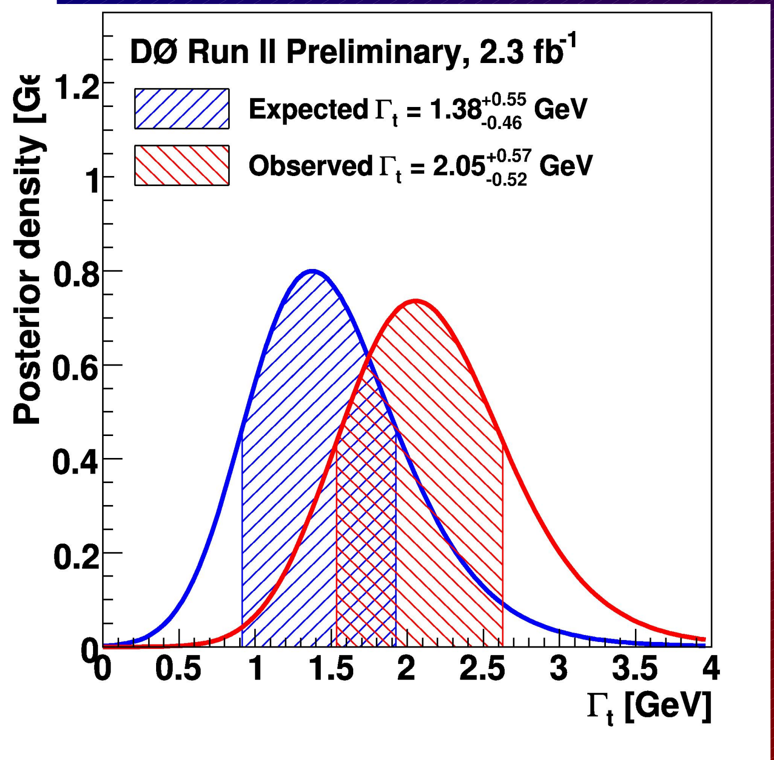
$3.14^{+0.94}_{-0.80}$ pb (D0)

Γ_{SM} = 1.26 GeV
σ_{SM} = 2.15 ±0.24 pb

$$\Gamma_t = \frac{\sigma(t\text{-channel}) \frac{\Gamma(t \to Wb)_{SM}}{\sigma(t\text{-channel})_{SM}}}{\mathcal{B}(t \to Wb)}$$

$$R = \frac{\mathcal{B}(t \to Wb)}{\mathcal{B}(t \to Wq)} = 0.962^{+0.068}_{-0.066}(\text{stat})\ ^{+0.064}_{-0.052}(\text{syst})$$

$\Gamma_t = 2.05\ ^{+0.57}_{-0.52}$ **GeV**

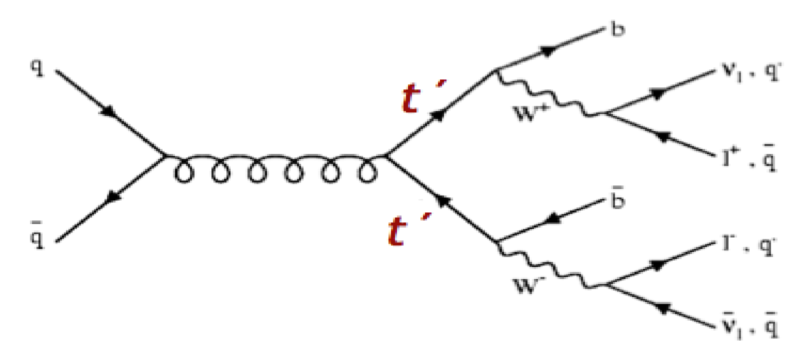


Search for new physics: heavy t'

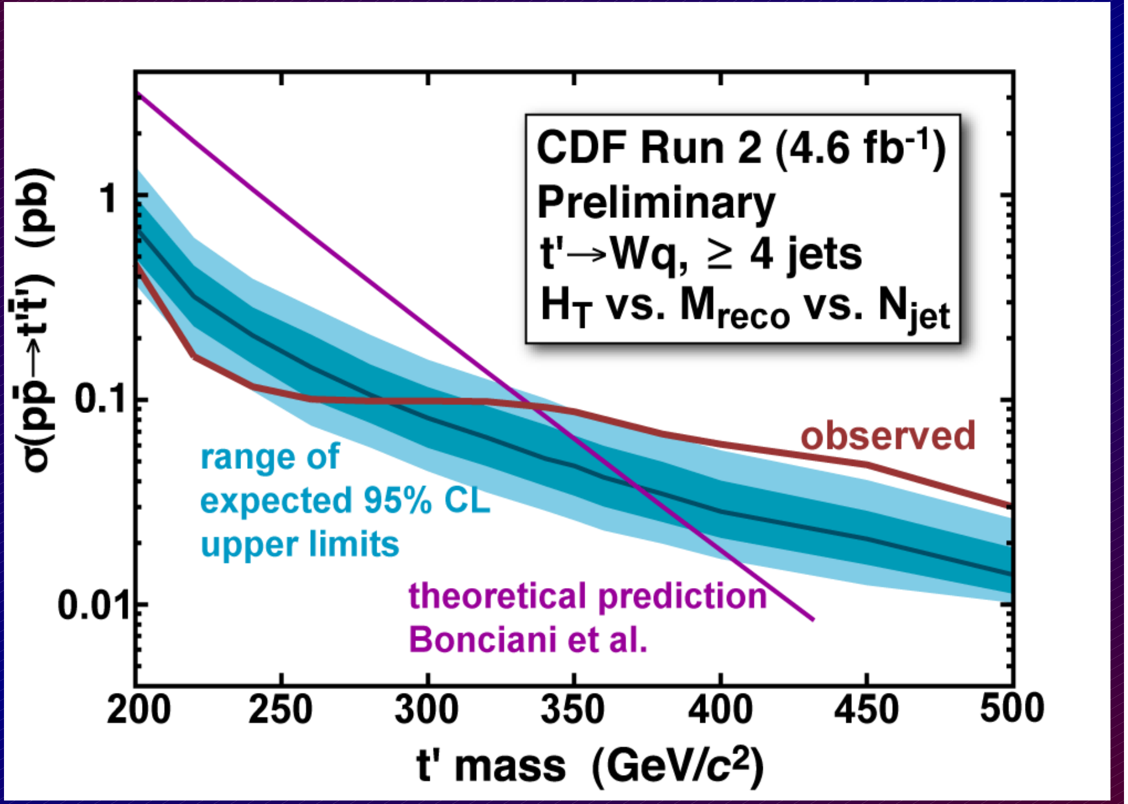
L = 4.6 fb^{-1}

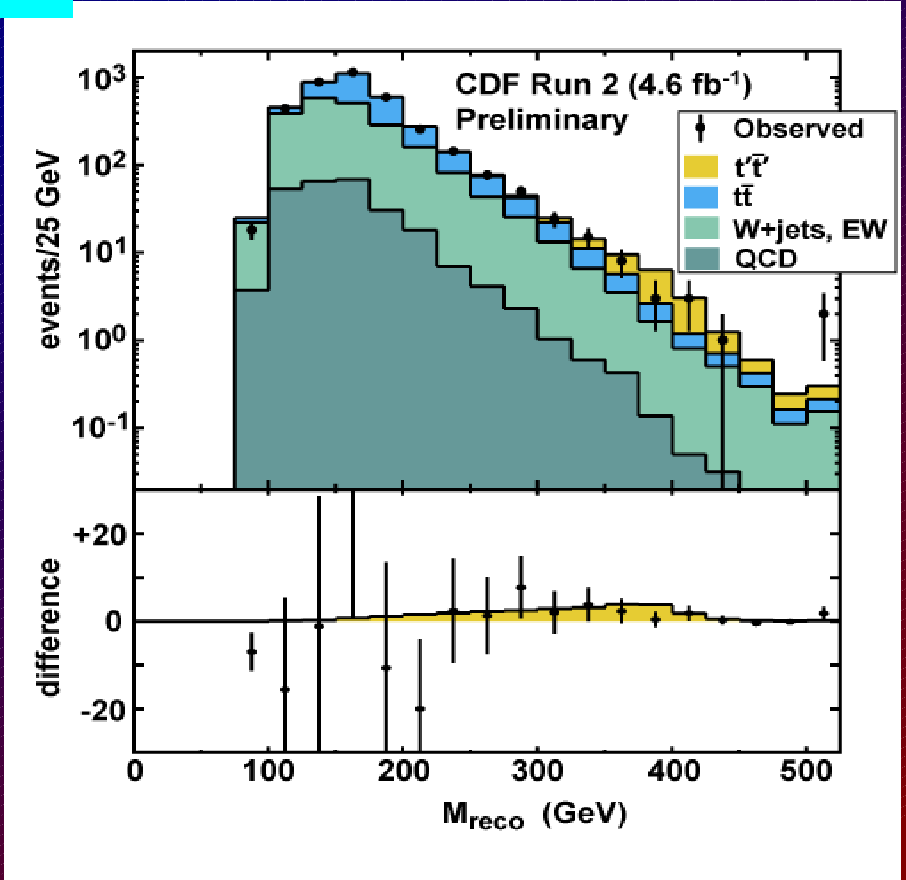
Heavy t' production *suggested in 4th generation models and Little Higgs models*

Search for t' t' in Lepton + Jets events
2D fit on (H_T, M_{Reco}) distribution



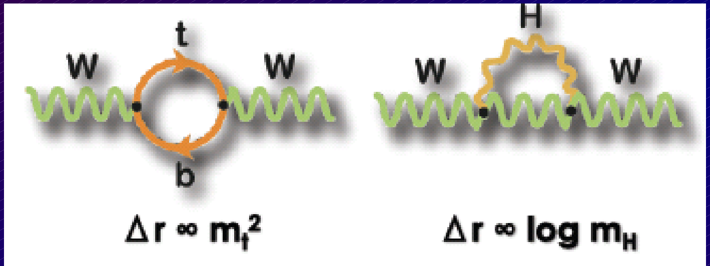
Excluded $M_{t'}$ < 335 GeV/c^2 at 95% CL.

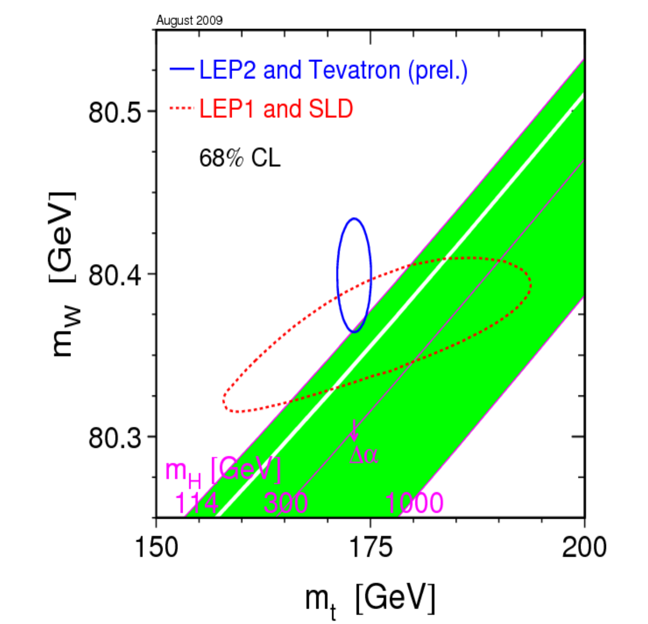


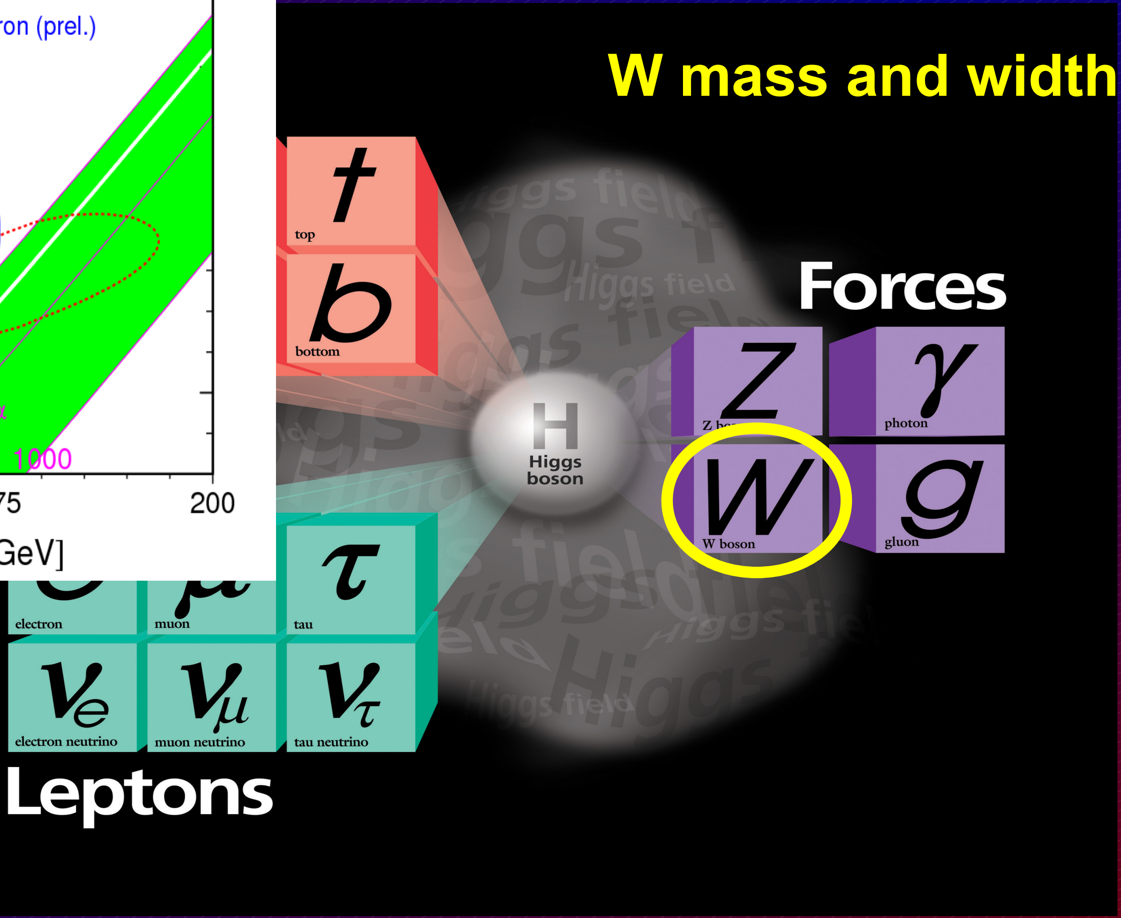


W

- Precise M_W measurement helps to tighten the constraints on the SM Higgs boson mass
- W width tests the SM







W mass

L = 1 fb^{-1}

World's best result from D0

Mw = 80.402 ± 0.043 GeV

W mass extracted from transverse variables by means of fit to templates with varying input M_W

$$M_T = \sqrt{2 p_T^e \, p_T^\nu (1 - \cos\phi_{e\nu})}$$

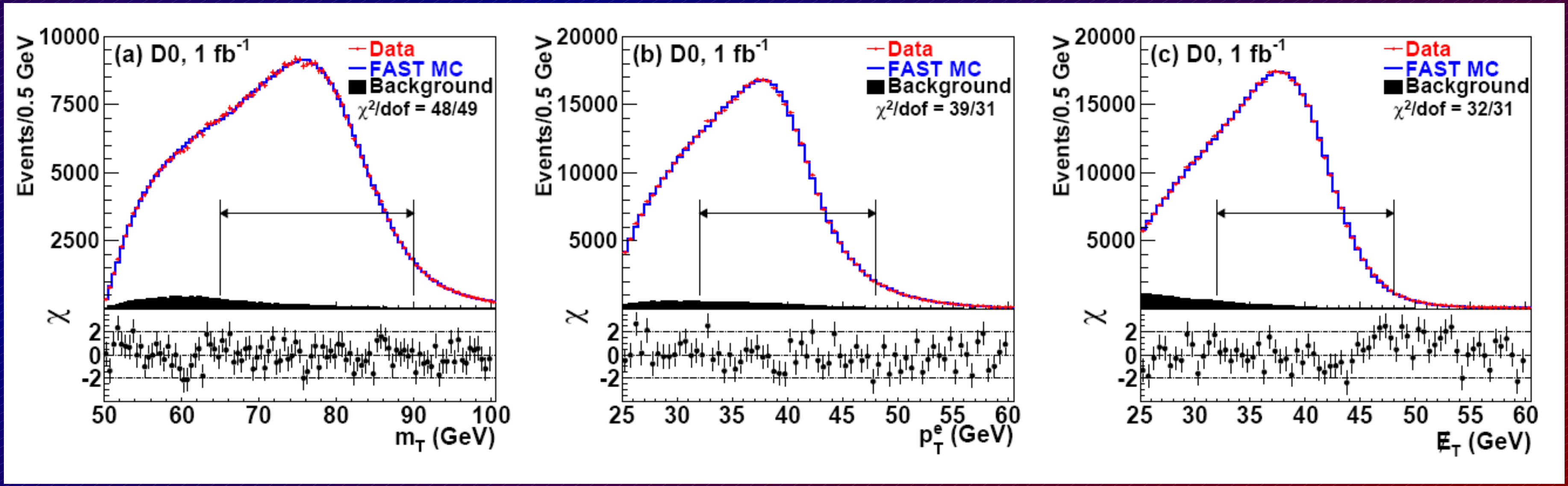
$$p_T^e \qquad p_T^\nu \left(\not{E}_T = \left| \vec{p}_T^{\,e} + \vec{p}_T^{\,recoil} \right| \right)$$

It requires *precise measure of lepton momentum and hadronic recoil*

It uses *Z→ee events for calibration*

Main systematics:

- Electron energy scale
- Parton Density Functions



W mass

World's average = 80.399 ± 0.023 GeV/c^2
Tevatron's average = 80.376 ± 0.031 GeV/c^2

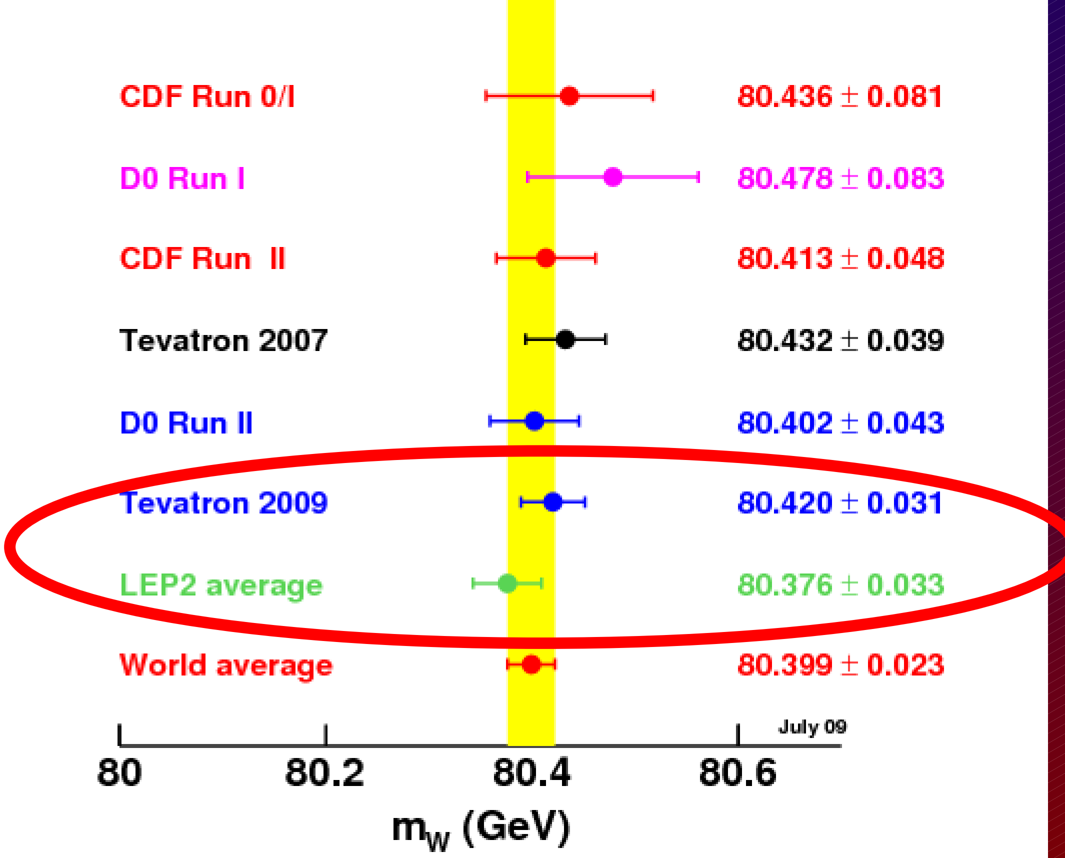
Prospects: more data are being analyzed by CDF (2.4 fb^{-1}) and D0 (4.4 fb^{-1})

Effort to reduce systematic errors:

- Higher Z → ll statistics will reduce electron energy scale uncertainty
- Measurements (*W charge asymmetry, Z rapidity*) to reduce PDF uncertainty.

Tevatron expects total uncertainty < 25 MeV

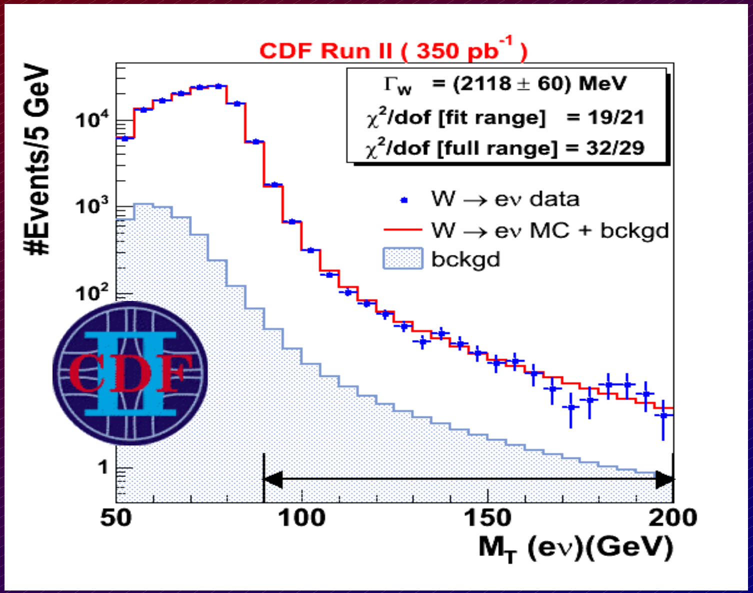
Tevatron combination more precise than LEP direct measurement

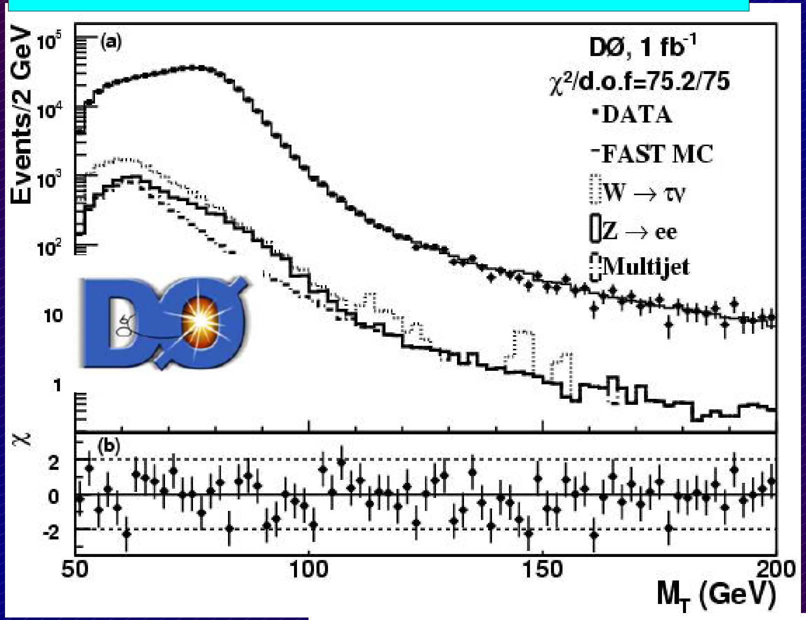


W width

Powerful test of Standard Model
Measured by a fit to the high-end tail of the transverse mass peak

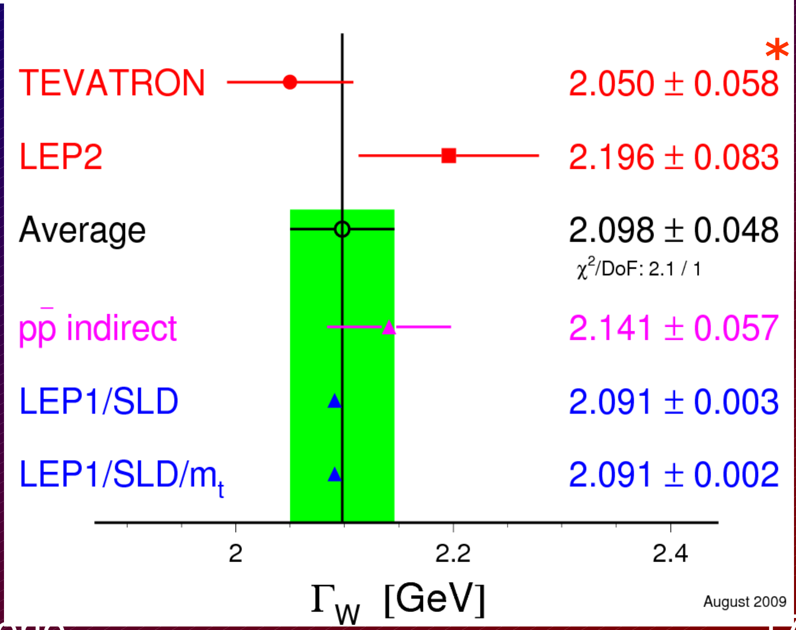
$\Gamma w = 2.034 \pm 0.072$ GeV/c^2





$\Gamma w^{SM} = 2.091 \pm 0.002$ GeV/c^2

$\Gamma w = 2.032 \pm 0.073$ GeV/c^2



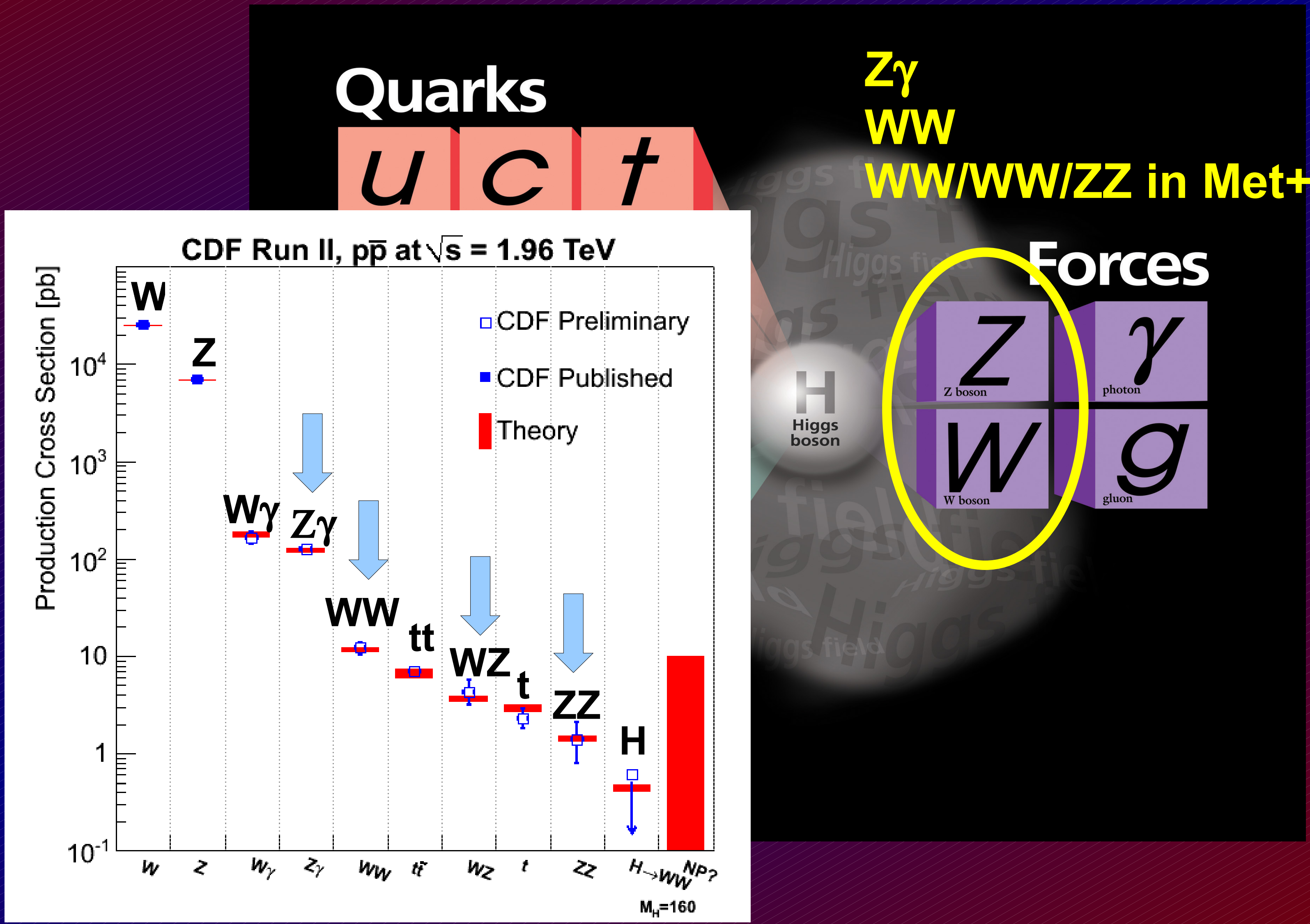
Tevatron average doesn't include the new D0 result → 10 MeV expected improvement.

Tevatron (and CDF/D0 separately) measurement more precise than LEP!

Diboson

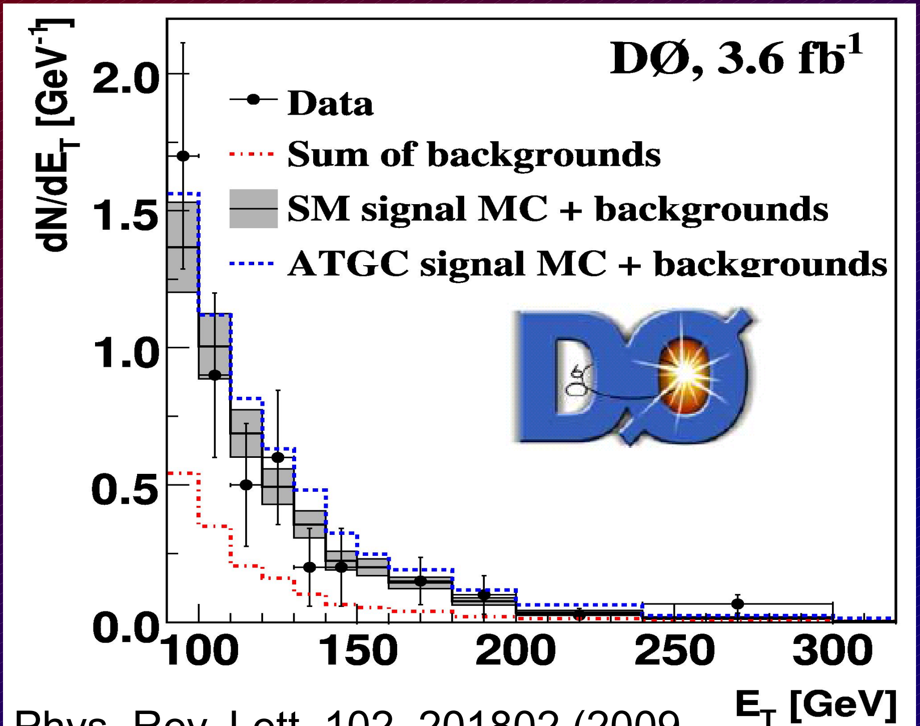
Tests of the self-interactions of the gauge bosons
Deviations from SM production cross section could indicate new physics
Background to many Higgs searches

Zγ
WW
WW/WW/ZZ in Met+jets



Zγ

Sensitive to aTGC ZZγ and Zγγ
Background to NP and Higgs searches



Phys. Rev. Lett. 102, 201802 (2009

D0: $Z \to \nu\nu$ **L = 3.6 fb^{-1}**

First observation at Tevatron (5.1 σ)

σ = 32 ± 9 (stat+syst) ± 2 (lumi) fb (Et$_\gamma$ > 90 GeV)

SM: σ = 39 ± 4 fb

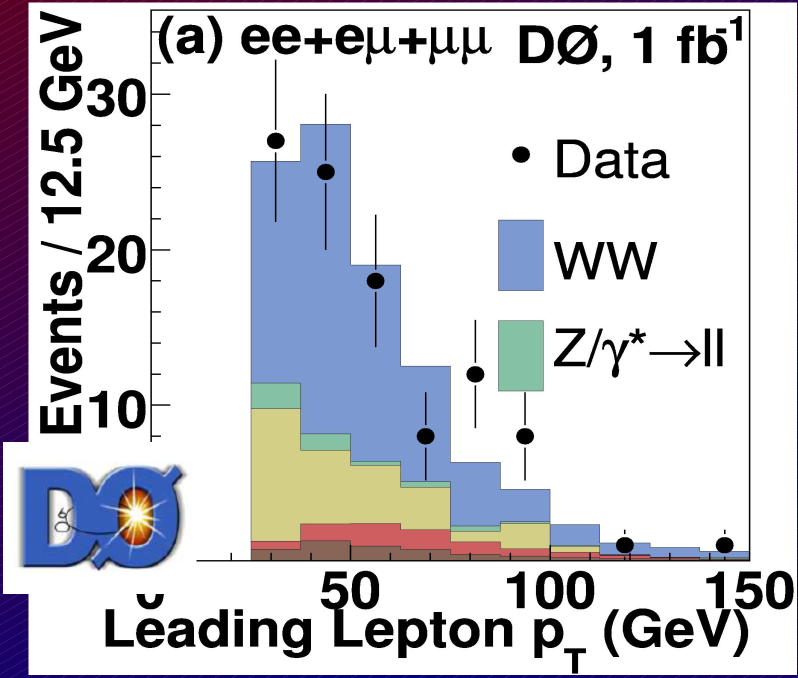
95% CL limits
$|h_{30}^{\gamma}| < 0.033$, $|h_{40}^{\gamma}| < 0.0017$,
$|h_{30}^{Z}| < 0.033$, $|h_{40}^{\gamma}| < 0.0017$

WW

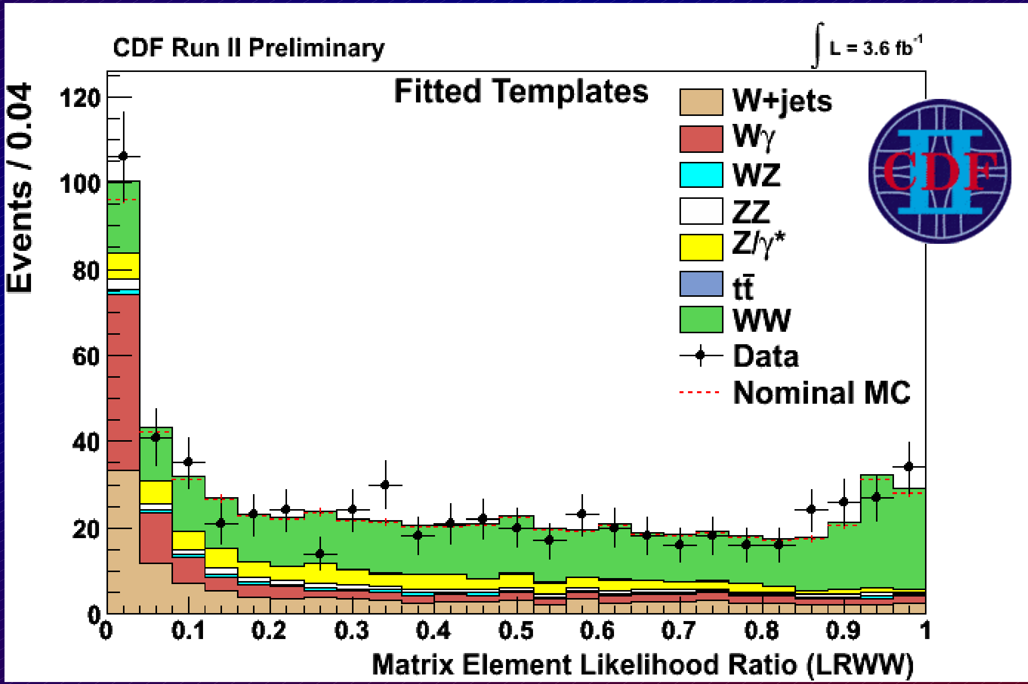
Primary background for H → WW
Look for anomalous TGC (WWγ and WWZ)

At Tevatron, first measured in **WW → lνlν**: clean signature and high statistic in the final state

SM: σ^{NLO} (pp →WW) = 11.7 ± 0.7 pb



PRL 103:191801, 2009 **L = 1 fb^{-1}**



Submitted to PRL, arXiv:0912.4500v1 **L = 3.6 fb^{-1}**

σ(pp→WW) = 11.5 ± 2.1 (stat+syst) ± 0.7 (lumi) pb

σ(pp→WW) = 12.1 ± 0.9 (stat) $^{+1.6}_{-1.4}$ (syst) pb

Combined limits on anomalous ZWW & γWW TGC

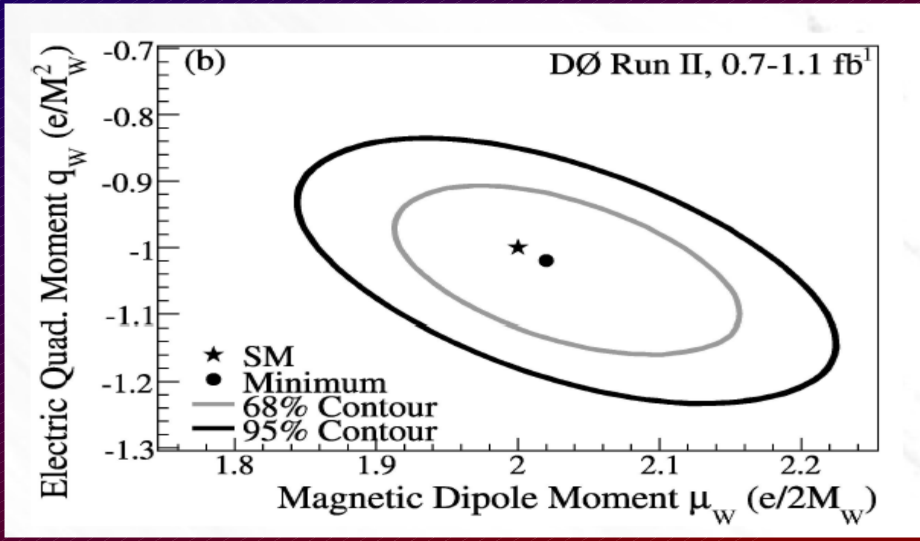
Process	Sensitive to	Discrim. Var.	Data Used
Wg → lvg	WWg	Photon Et	0.7 /fb
WW → lvlv	WWg, WWZ	Lepton Ets	1 /fb
WZ → lvll	WWZ	Z Pt	1 /fb
W(W/Z) → lvjj	WWg, WWZ	W/Z (dijet) Pt	1.1 /fb

Results respecting $SU(2)_L \otimes U(1)_Y$ symmetry			
Parameter	Minimum	68% C.L.	95% C.L.
$\Delta\kappa_\gamma$	0.07	$[-0.13, 0.23]$	$[-0.29, 0.38]$
Δg_1^Z	0.05	$[-0.01, 0.11]$	$[-0.07, 0.16]$
λ	0.00	$[-0.04, 0.05]$	$[-0.08, 0.08]$
μ_W	2.02	$[1.93, 2.10]$	$[1.86, 2.16]$
q_W	-1.00	$[-1.09, -0.91]$	$[-1.16, -0.84]$
Results for equal-couplings			
Parameter	Minimum	68% C.L.	95% C.L.
$\Delta\kappa$	0.03	$[-0.04, 0.11]$	$[-0.11, 0.18]$
λ	0.00	$[-0.05, 0.05]$	$[-0.08, 0.08]$
μ_W	2.02	$[1.94, 2.09]$	$[1.88, 2.15]$
q_W	-1.02	$[-1.09, -0.94]$	$[-1.16, -0.87]$

First high statistic combination of limits across different diboson productions at Tevatron

Most stringent results on aTGC couplings and W magnetic dipole and electric quadrupole moment from hadronic collisions.

Future: Combination of CDF and D0 data with $5fb^{-1}$ each will improve sensitivity to be competitive with LEP



WW/WZ/ZZ with *jets* in the final state

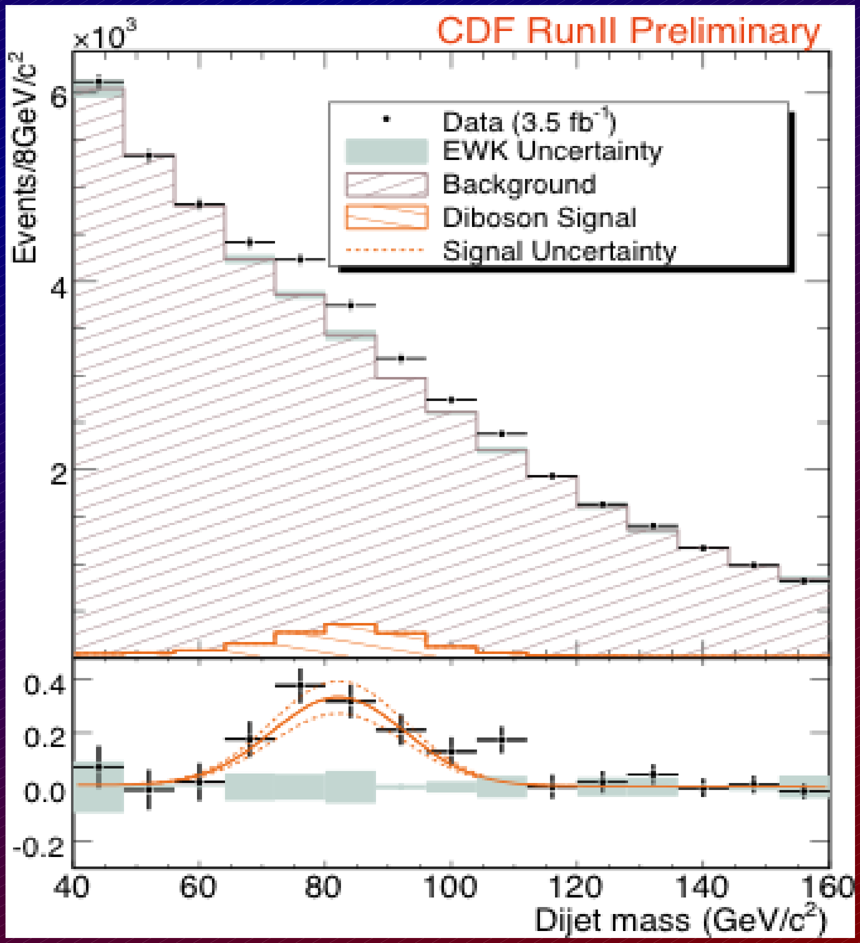
Look for **neutrinos (missing energy) and jets** in the final state

→ sensitive to lνqq and ννqq

→ acceptance on WW/WZ/ZZ

L = 3.5 fb^{-1}

1516 ± 239 (stat) ± 144 (syst)
5.3 σ significance



First observation at a hadron collider

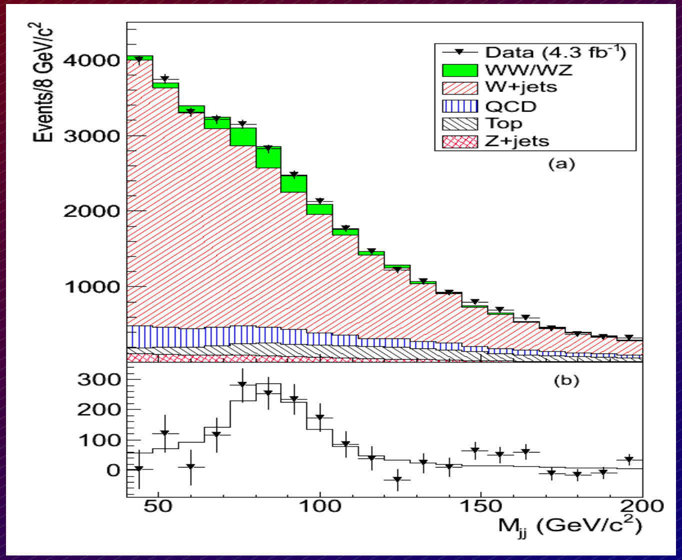
σ (pp→ vv) = 18.0 ± 2.8 (stat) ± 2.4 (syst) ± 1.1 (lumi) pb

SM: σ (pp →VV) = 16.8 ± 0.5 pb

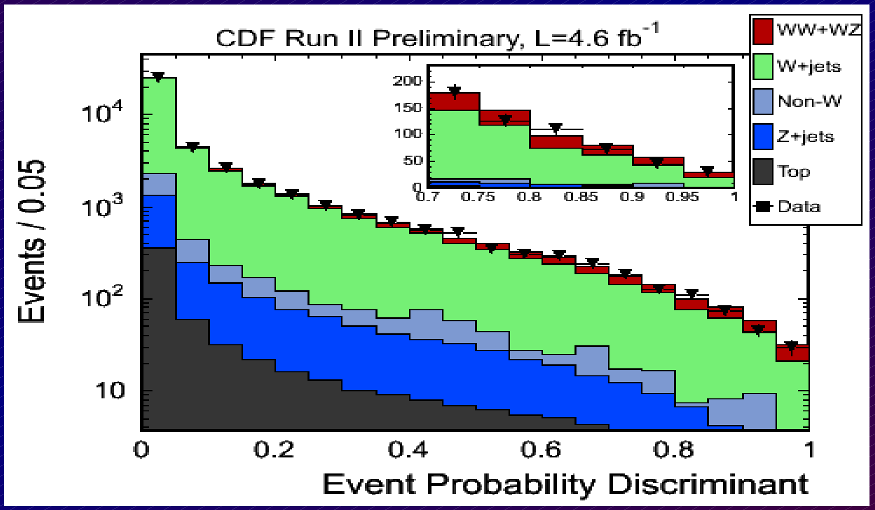
WW-WZ → lνjj

First observation

Fit to the dijet invariant mass



Matrix element technique

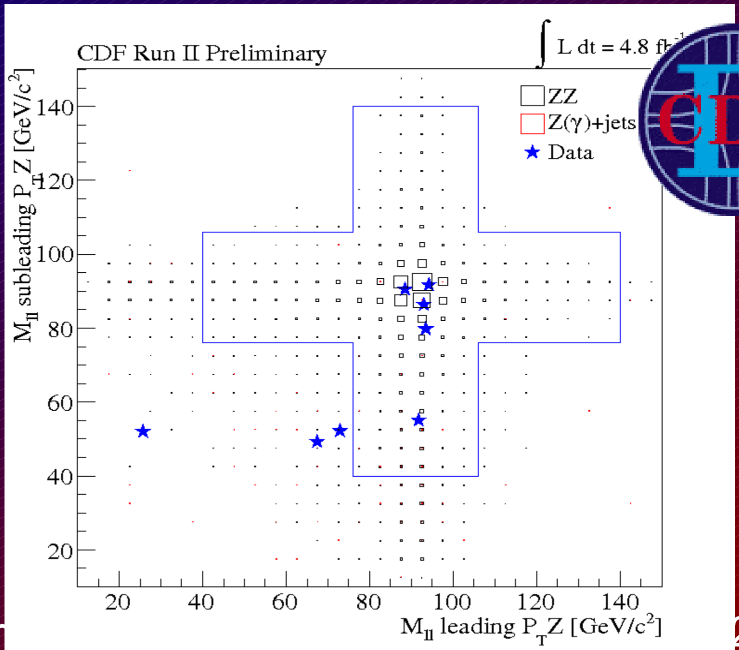


ZZ → 4l

First observation at CDF

5 events observed

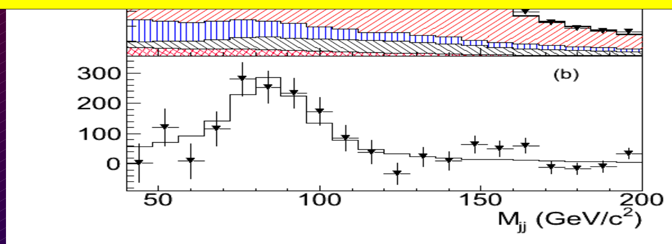
5.70 σ significance

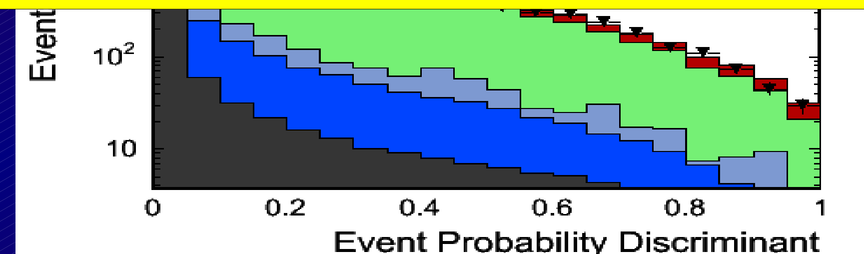


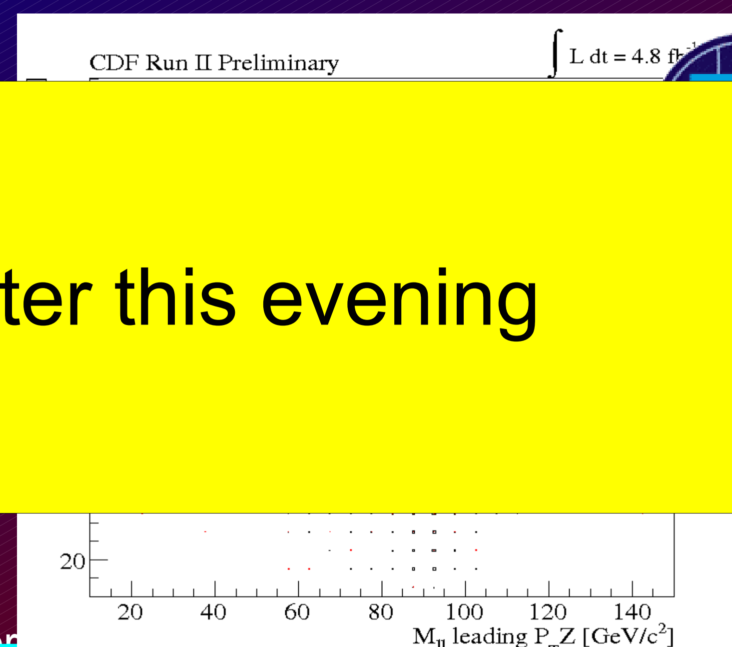
WW-WZ→ lνjj

First observation

See Viviana Cavaliere's talk tomorrow afternoon







See Matteo Bauce's poster this evening

5.70 σ significance

Summary

Tevatron is producing high quality physics more than ever!

- Both detectors are well understood, Sophisticated analysis techniques, Join effort of CDF and D0

High precision measurements to constrain the Standard Model:

- **Top mass know with a precision less than 1 %**
  - Tevatron should reach 1GeV error
- **W mass combination more precise than LEP average**
  - < 25 MeV error achievable by Tevatron

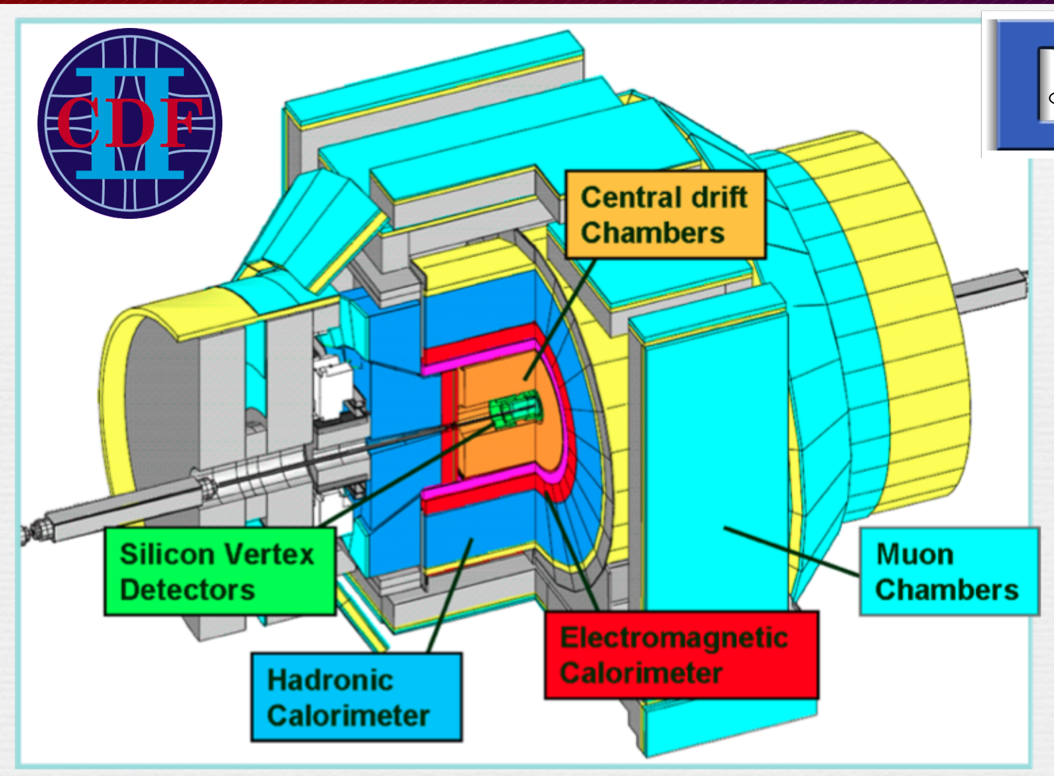
New diboson signatures explored → experimental reach expanded

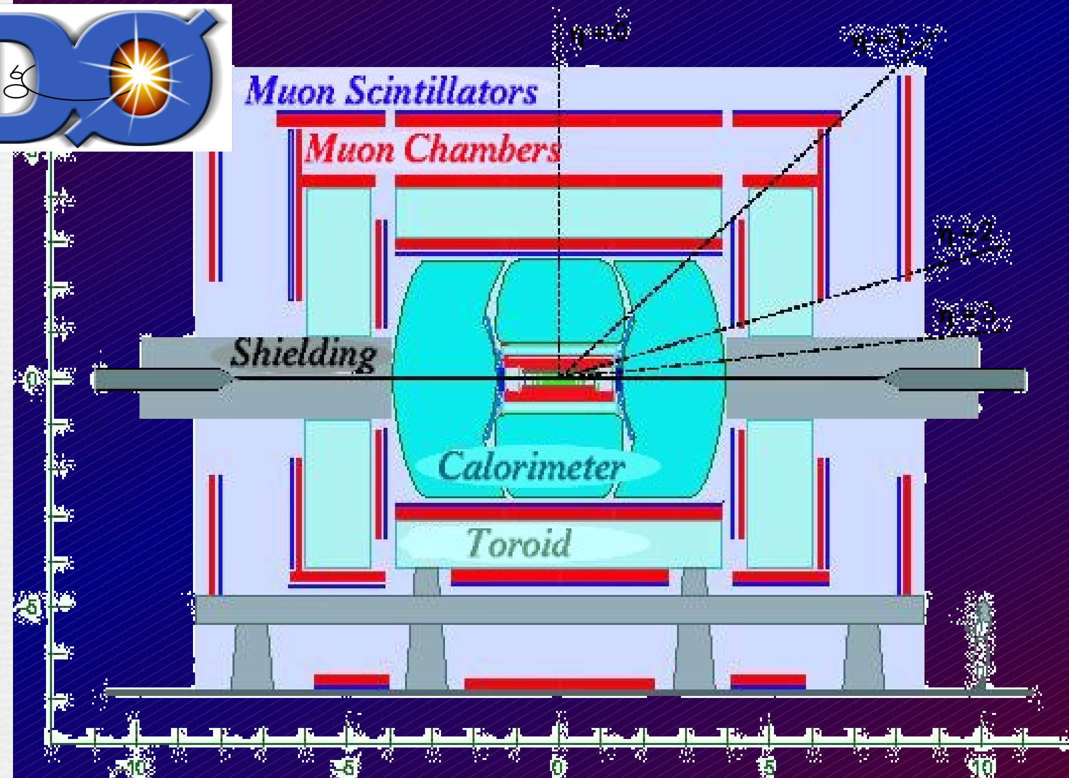
Top and EW physics will play an important role at early LHC:

- **LHC top factory**, top fundamental tool for b-tagging, JES calibrations and bgnd to many analysis
- In 10fb^{-1} of data, ~ **4 10^{7} W events** in each channel → can reach 1 MeV of statistical sensitivity
- **Increased sensitivity on aTGC** (increased luminosity and diboson cross section)

BACKUP

CDF & D0 detectors



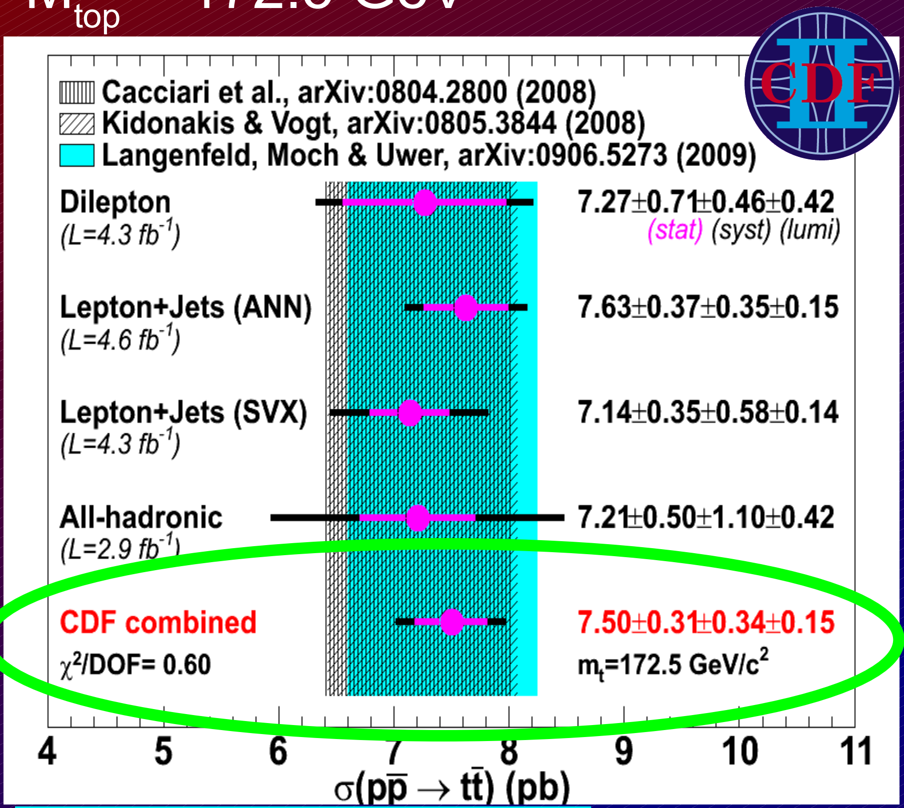


- Silicon tracking
- Large radius drift chamber (r=1.4m)
- 1.4 T solenoid
- Projective calorimetry (|η| < 3.5)
- Muon chambers (|η| < 1.0)
- Particle identification
- Silicon Vertex Trigger

- Silicon tracking Outer fiber tracker (r=0.5m)
- 2.0 T solenoid
- Hermetic calorimetry (|η| < 4)
- Muon chambers (|η| < 2.0)
- New trigger and more silicon in Summer 2006 (Run2b)

Top cross section: combinations

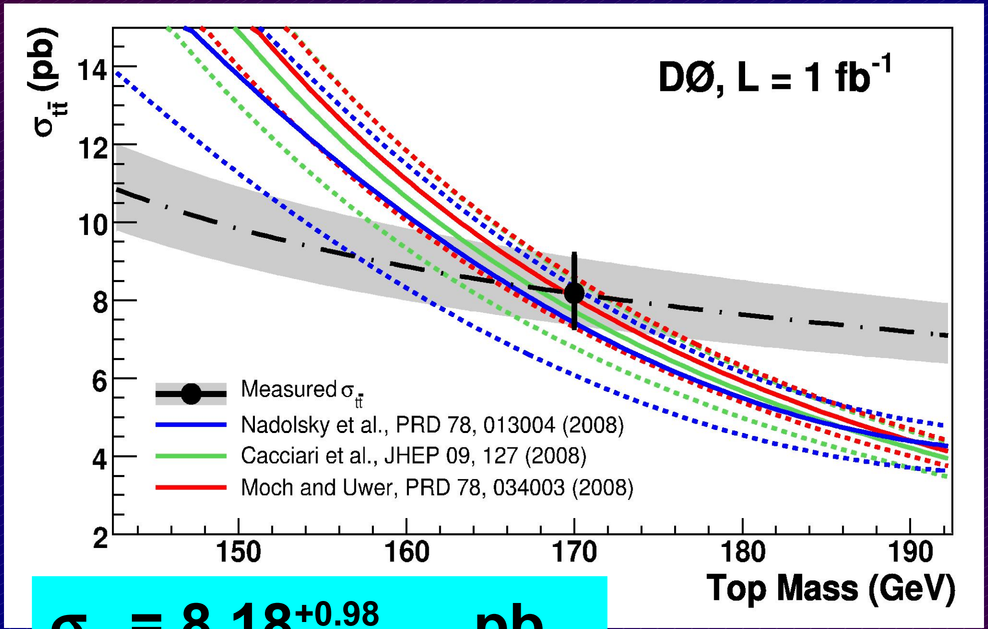
M_{top} = 172.5 GeV



σ_{tt} = 7.50 ± 0.48 pb

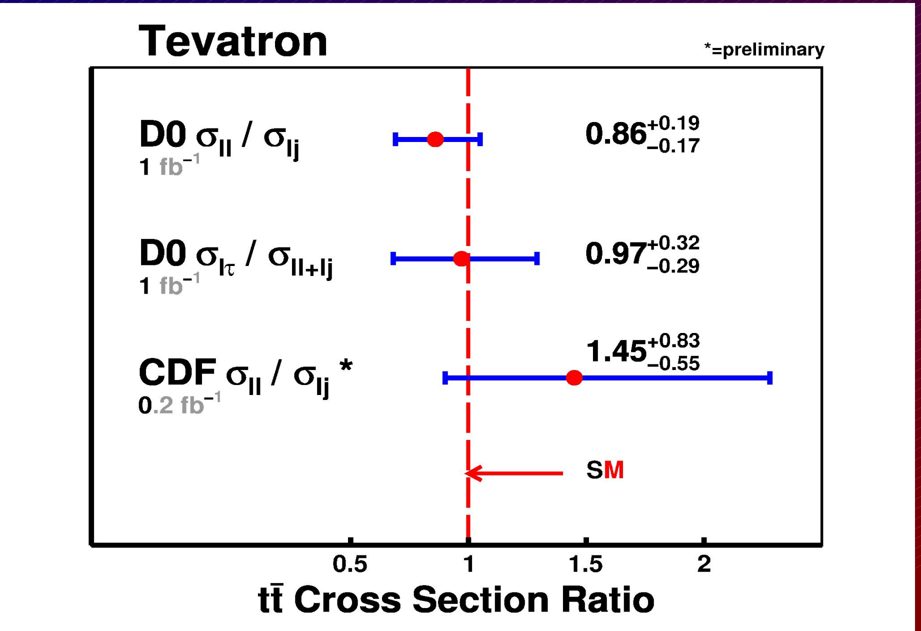
All measurements compatible with each other and with SM.

6.4% of uncertainty

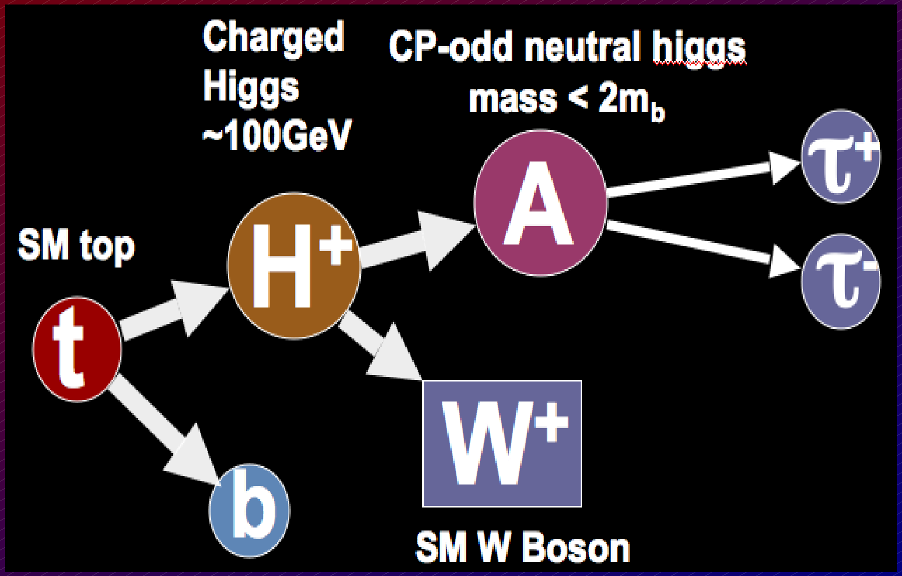


$\sigma_{tt} = 8.18^{+0.98}_{-0.87}$ pb

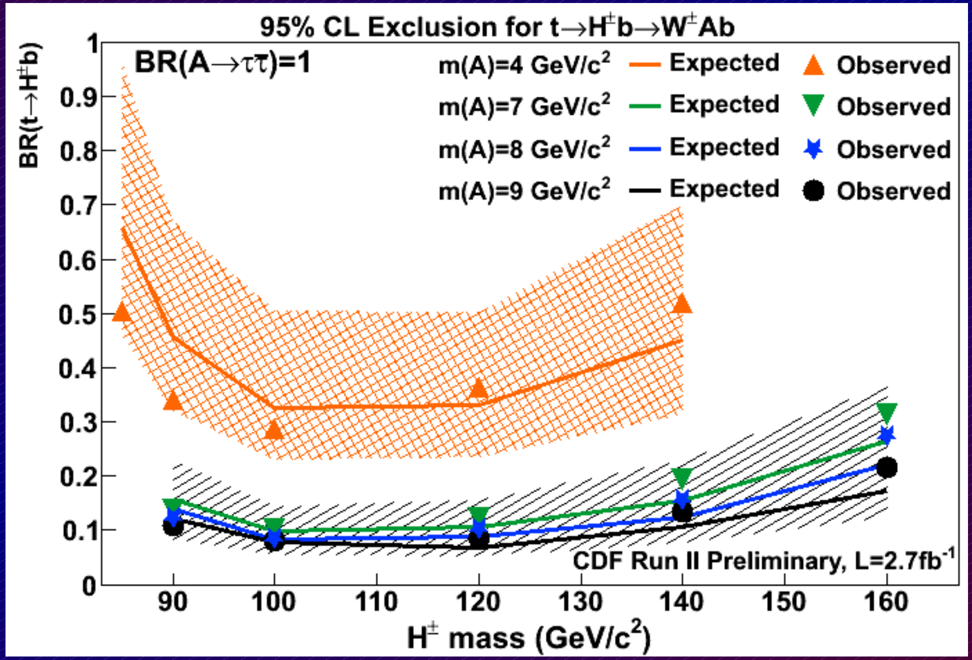
Combined l+jets, dilepton and l+t

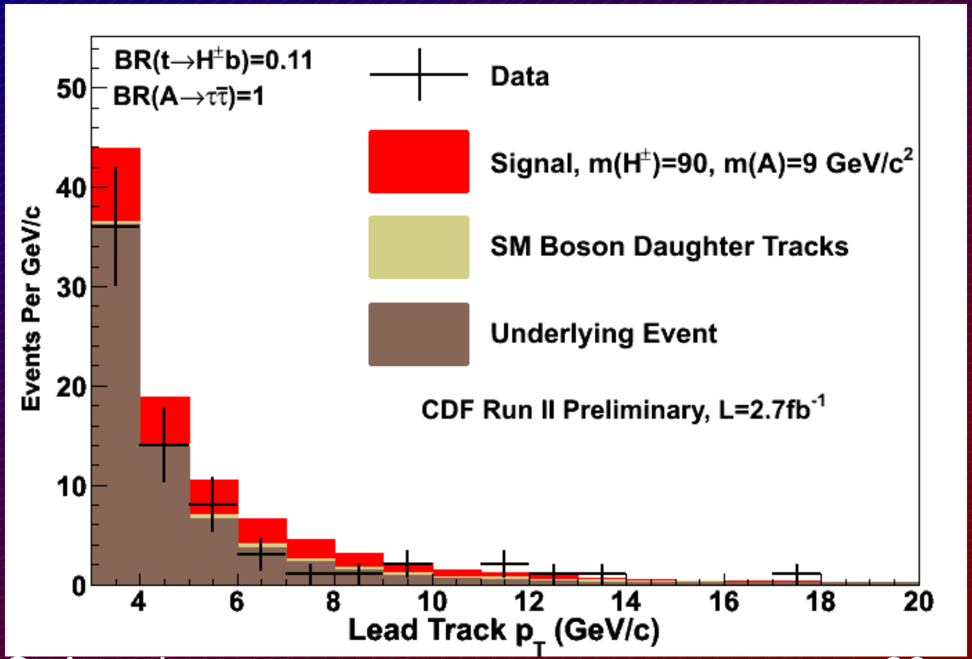


Search for new physics: NSSM Higgs

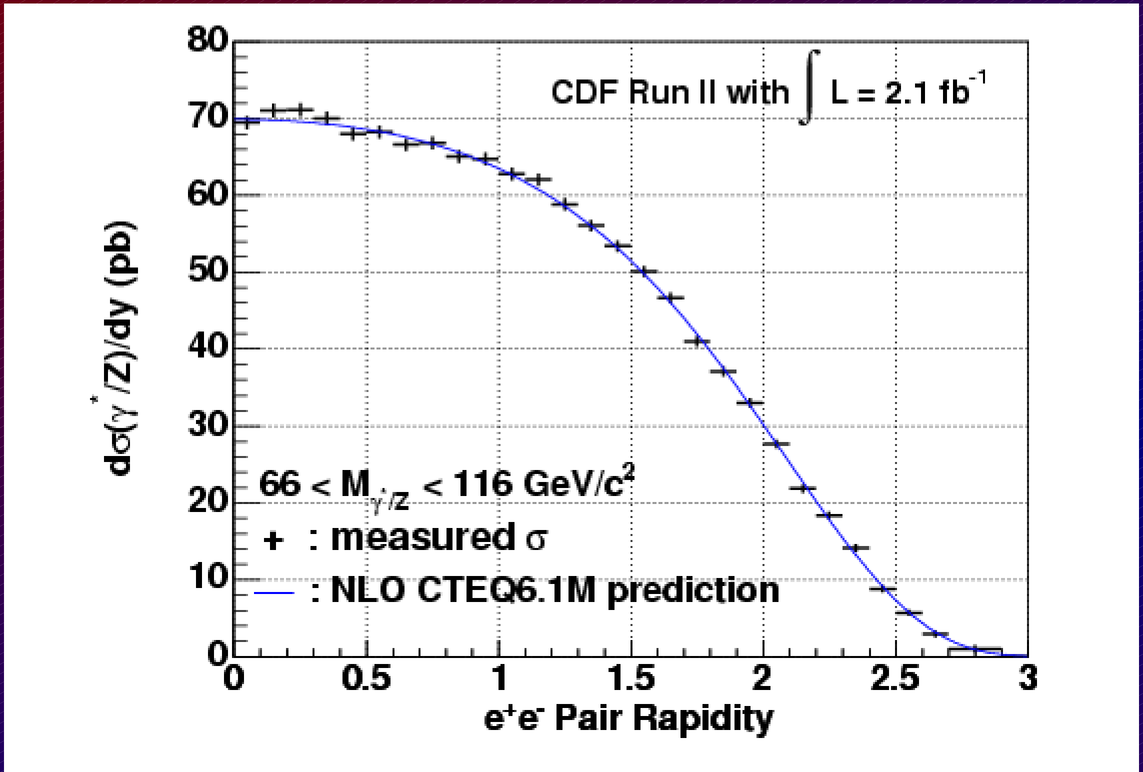


- If a charged higgs of around ~100GeV/c^2 exists, then the branching ratio of top to charged higgs may be LARGE (as high as 10 to 40%)
- This search assumes $m_A < 2m_b$, a region in parameter space not yet experimentally excluded
- Taus should leave low pT isolated tracks in top events





Z rapidity



dσ/dy distribution of Z/γ* -> e+e-.

No PDF or luminosity uncertainty included in data.

NLO calculation with NLO CTEQ6.1M PDF theory prediction compared to data.

Theory prediction scaled to total cross section from data.

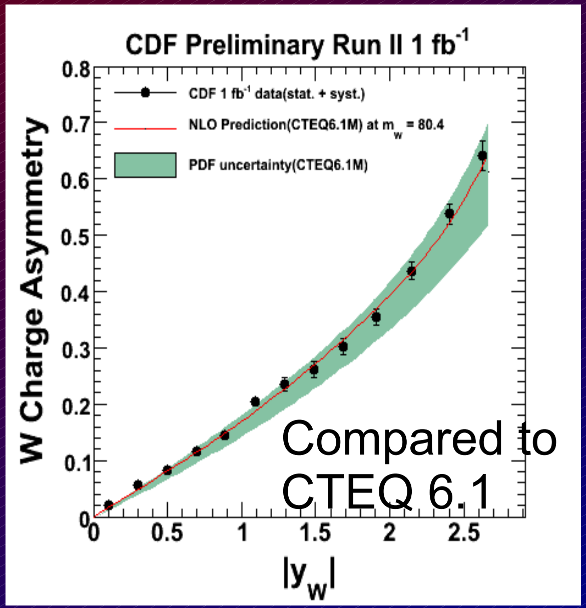
L = 2.1 fb^{-1}

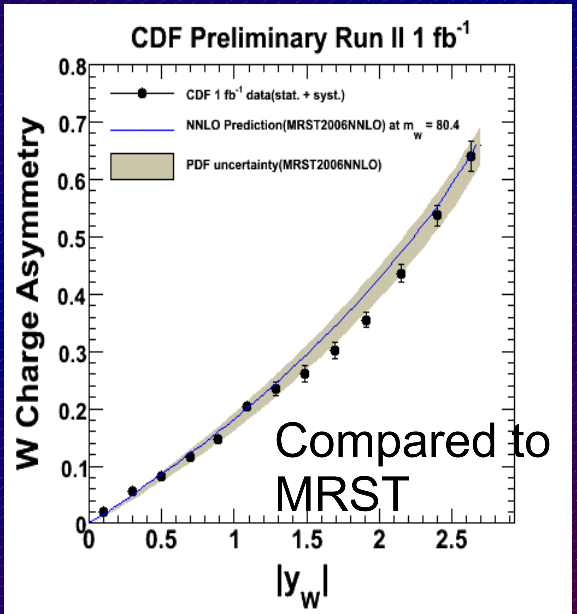
$Z \rightarrow ee$

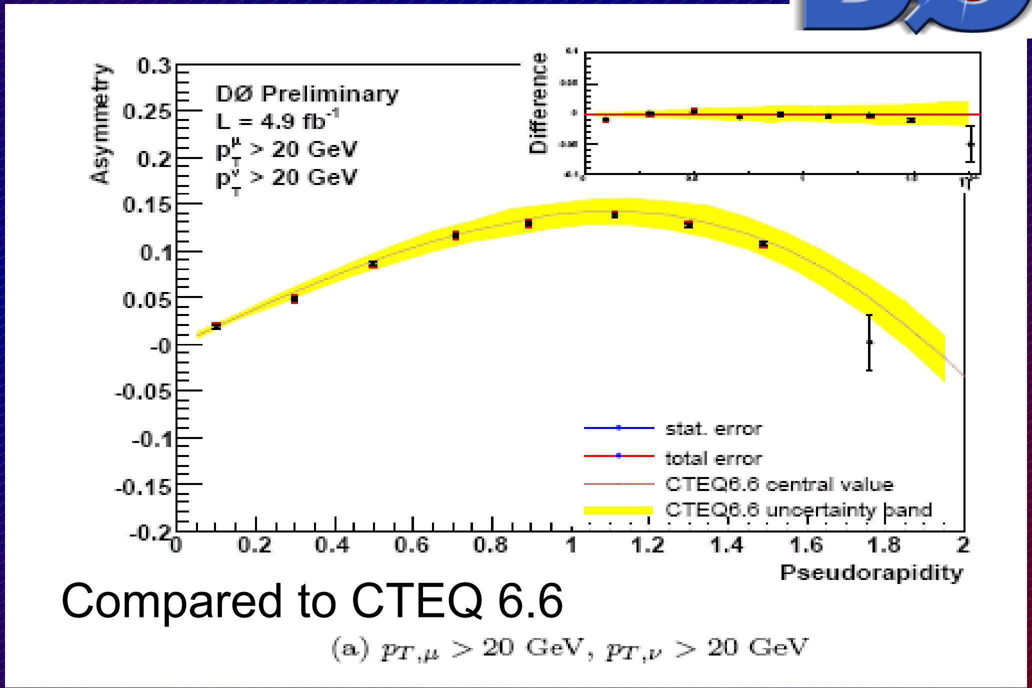
Good agreement between theory and experiment.

W charge asymmetry

W± charge asymmetry sensitive to the fractional momentum difference between u and d quarks → it helps constraining the PDFs

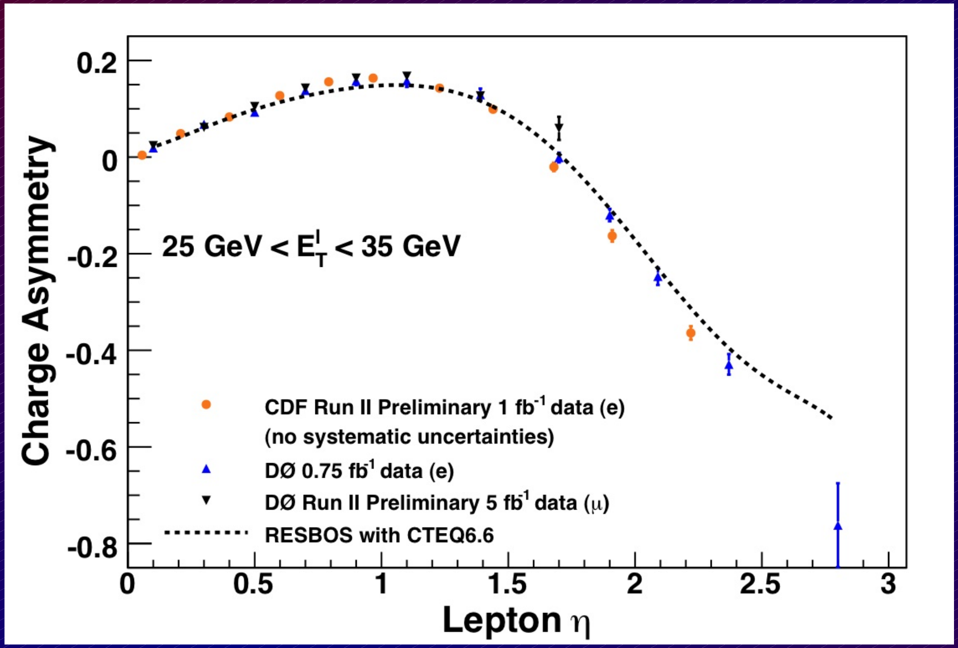


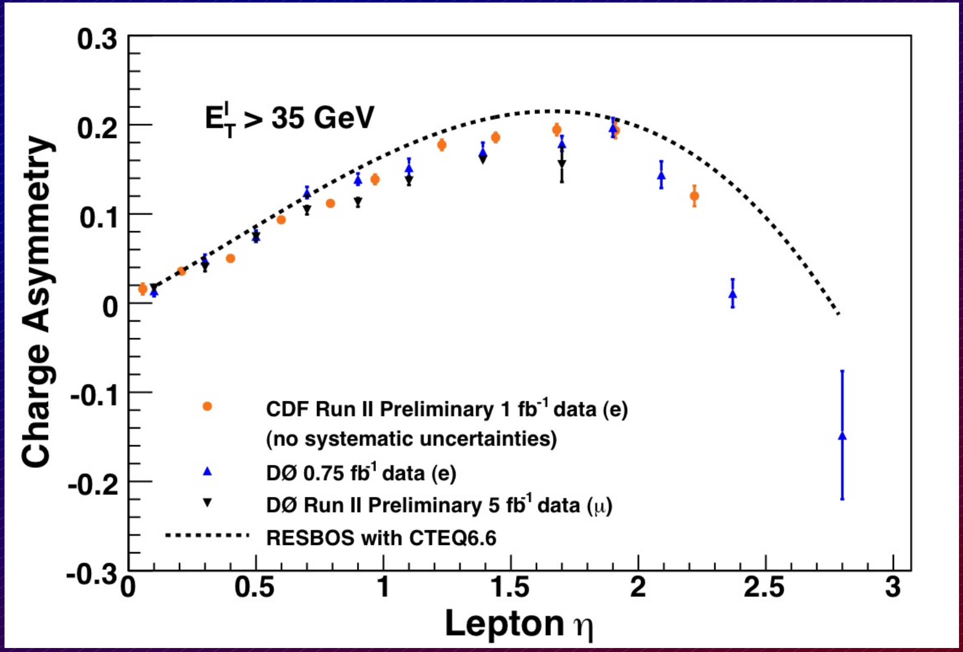




W charge asymmetry

Recent: comparison between CDF and D0 asymmetries
- 2 lepton Pt bins
- Comparison w/ CTEQ6.6 only





- Good agreement between the two experiments
- Discrepancy with PDF at high pt → under investigation

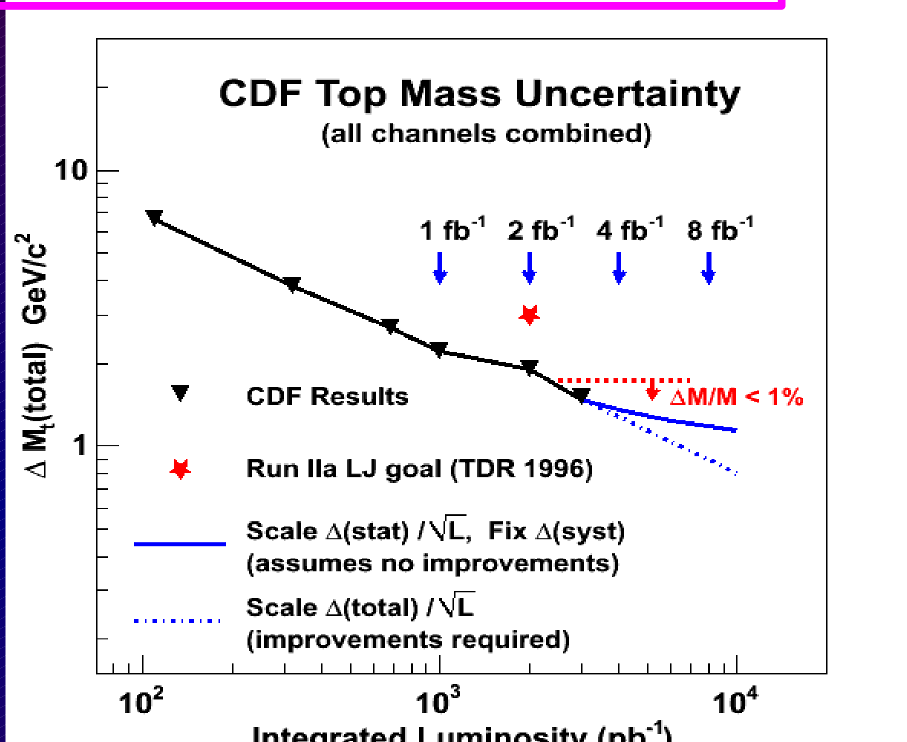
Top mass projections

Joint effort of CDF and D0 to improve the knowledge of the systematics

Systematics uncertainties are comparable; main sources should be *reduced with larger statistics*

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



Single experiment top quark mass precision reaching 1 GeV

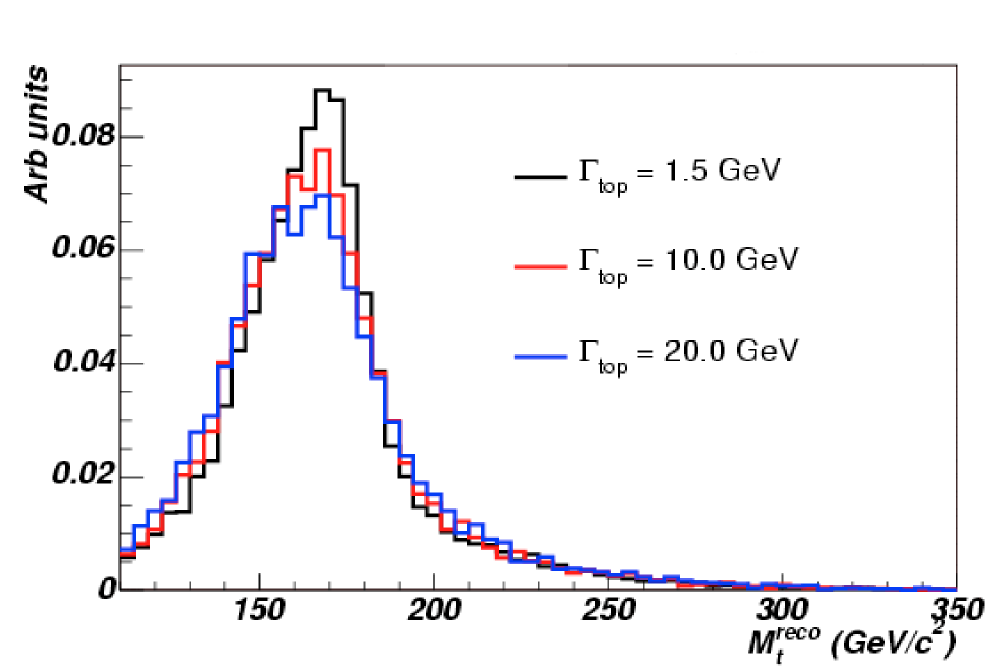
Top quark width

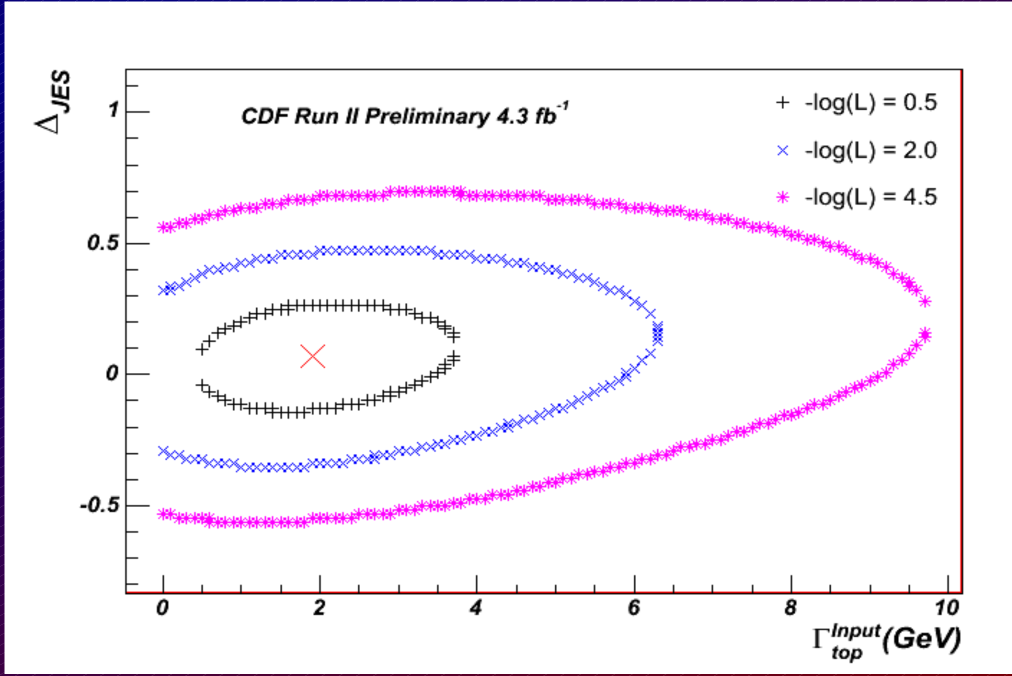
Top short lifetime → large width
For M_{top} = 175 GeV, Γ = 1.5 GeV

Deviations from prediction can signal contributions from decays to non SM particles ($t \rightarrow H^+ b$)

Lepton + jets channel
Template method with W->jj in situ calibration

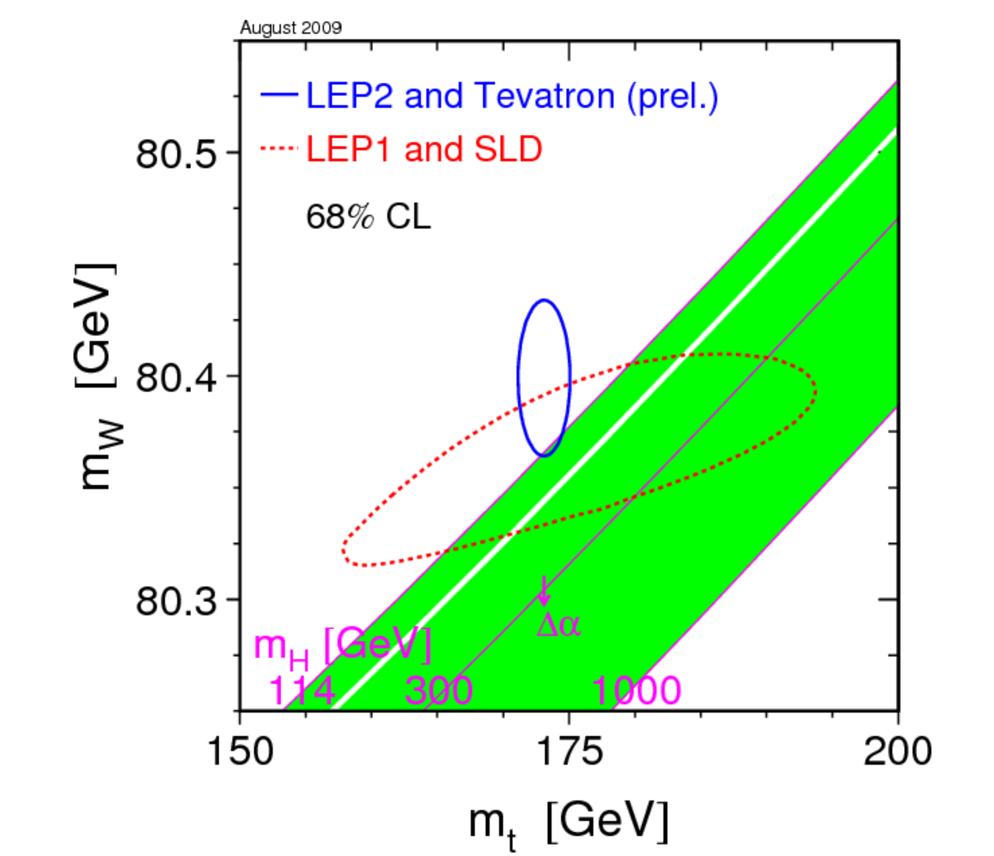
L = 4.3 fb^{-1}

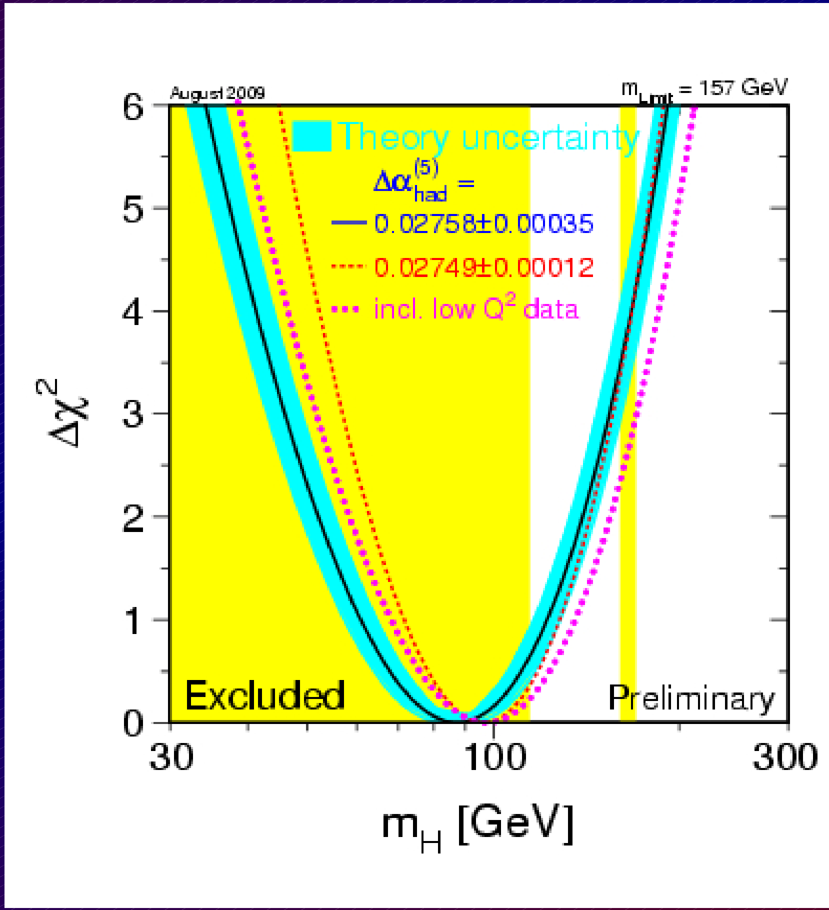




Γ_{top} < 7.5 GeV at 95% C.L.

Impact on Higgs





M_{top} vs M_W favor a low mass Higgs

$M_H = 87^{+35}_{-26}$ GeV (68% CL)

M_H < 157 GeV at 95% CL

Including LEP limit M_H < 186 GeV at 95% CL