Top-antitop production and top properties at CDF

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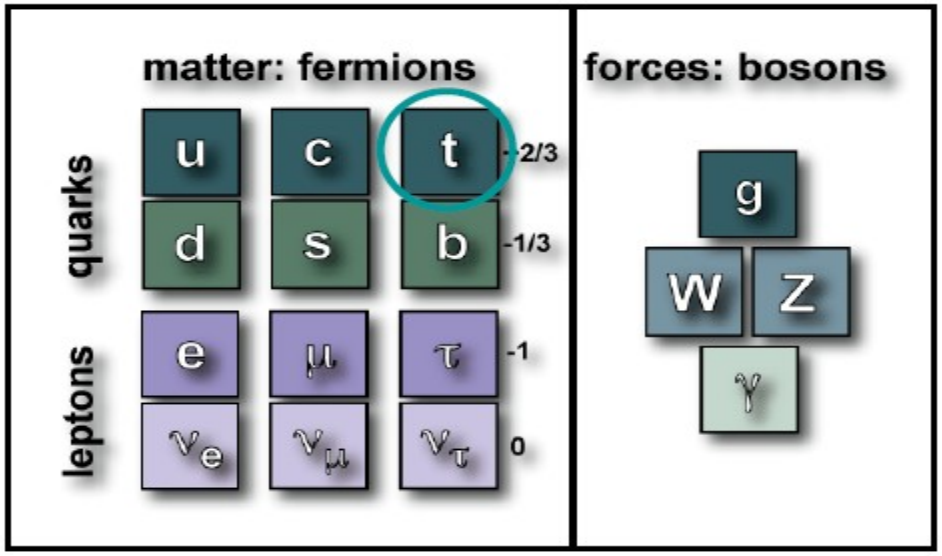
(on behalf of the CDF collaboration)

SM benchmarks 2011, Zeuthen

Outline

- Introduction
- Top quark exploration
  - Cross-section
  - Mass
  - Properties: production, intrinsic, decay
- Summary and prospects

Introduction

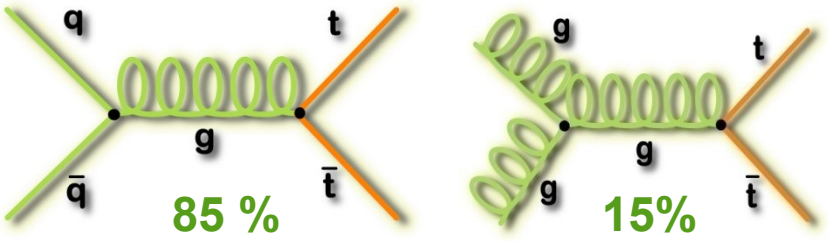


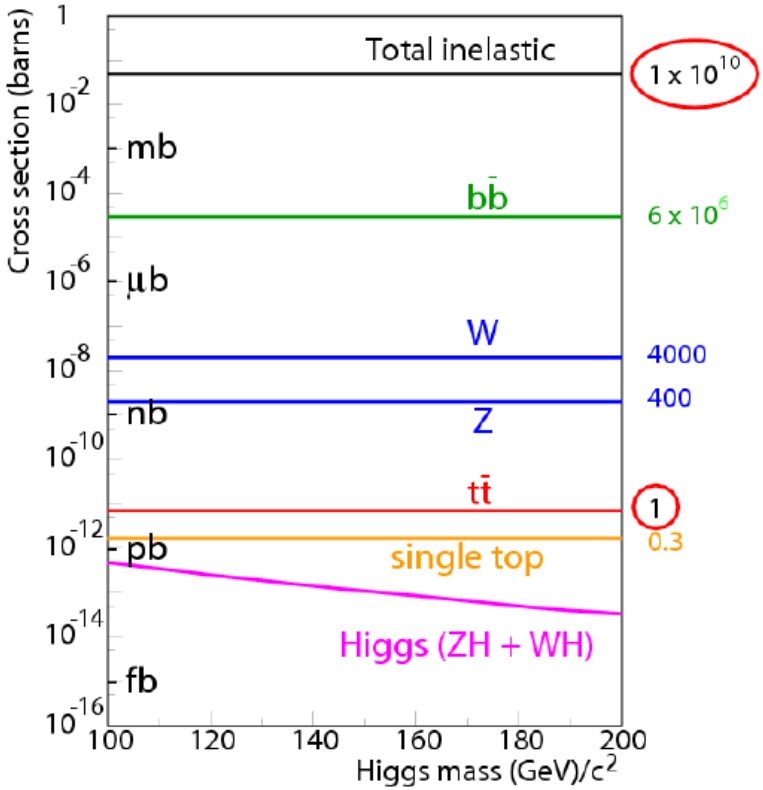
- Top quark finalize 3rd fermion generation
- Determine nature of 'top quark' experimentally
- Try to address some of the questions:
  - Is it the SM top?
  - Is top related to the EWSB mechanism?
  - Decay into new particles?
  - Couple via new interactions?

Top quark production at Tevatron

According Standard Model:

- predominantly pair produced via strong interaction
  - $\sigma = 7.45^{+0.72}_{-0.63}$ pb (m_{TOP}=172.5 GeV)
- EW single top production possible (m_{TOP}=175 GeV)
  - s-channel: $\sigma = 0.88 \pm 0.11$ pb
  - t-channel: $\sigma = 1.98 \pm 0.25$ pb

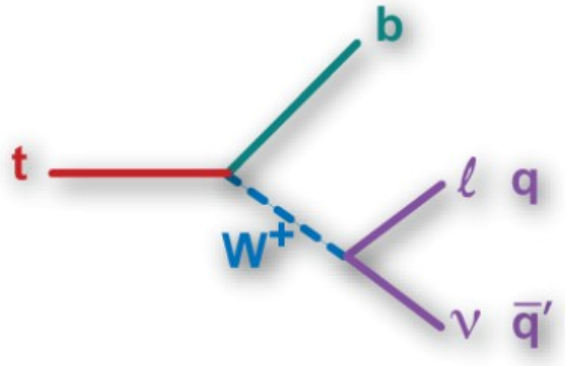


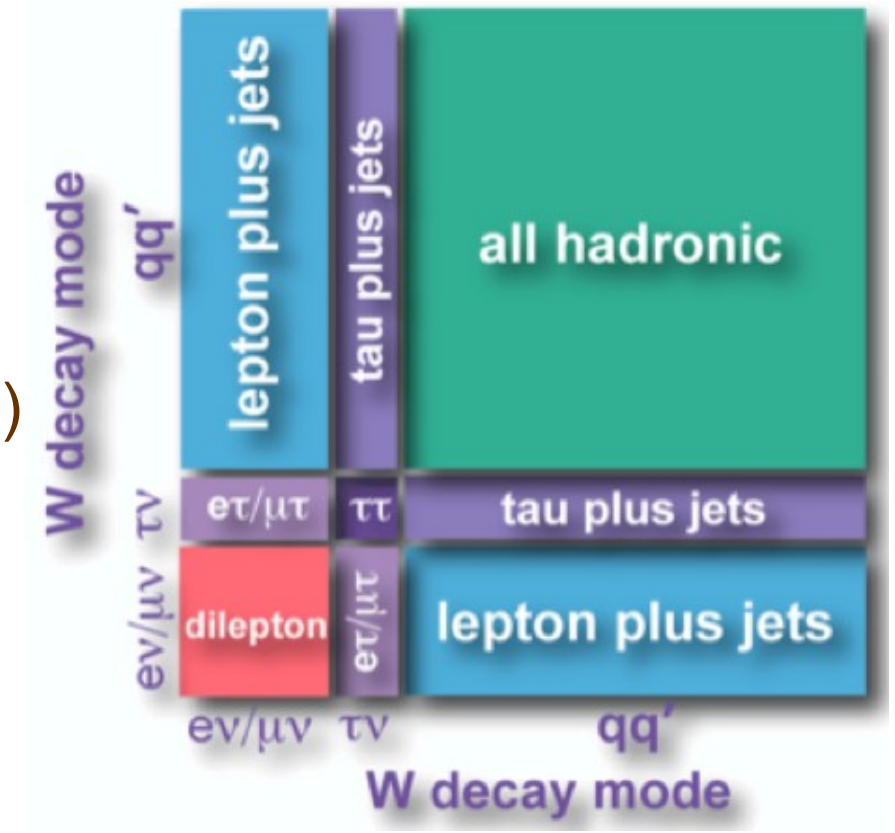


Top quark decay

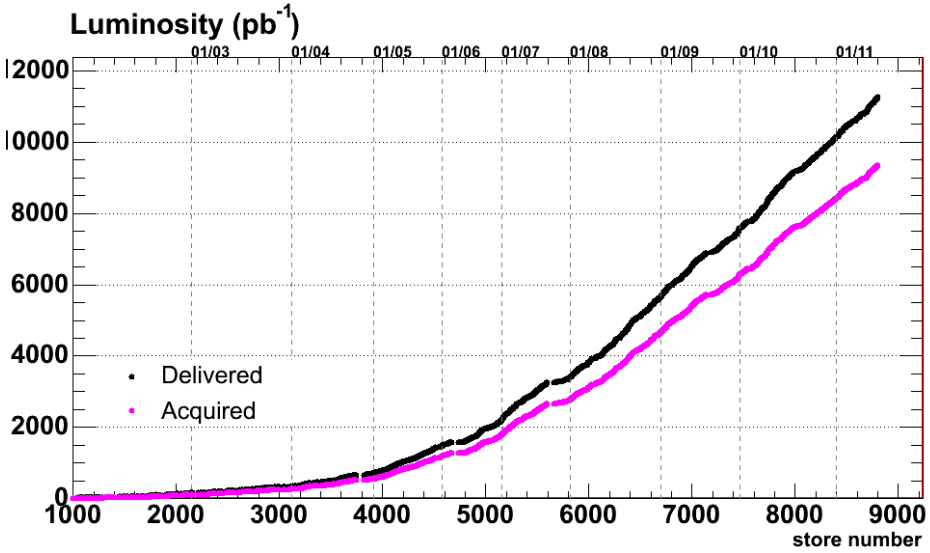
According Standard Model:

- Almost exclusively (>99%) into W and b quark
- $t\bar{t}$ decay channels:
  - Dilepton (e,μ): *lνlνbb*
  - Lepton+jets : *lνqqbb*
  - All-hadronic: *qqqqbb*
- Note: hadronic taus (missing E_T+jets signature)





CDF experiment



CDF Run II (2001-2011) : $\sqrt{s}$ = 1.96 TeV

- Luminosity:
  - Delivered ~ 11 fb^{-1}
  - Recorded ~ 9 fb^{-1}
  - Used in presented analyses: up to 6 fb^{-1}
- Selected $t\bar{t}$ events in presented dataset:
  - Dilepton: ~250
  - Lepton+jets: ~1200
  - All-hadronic: ~1400

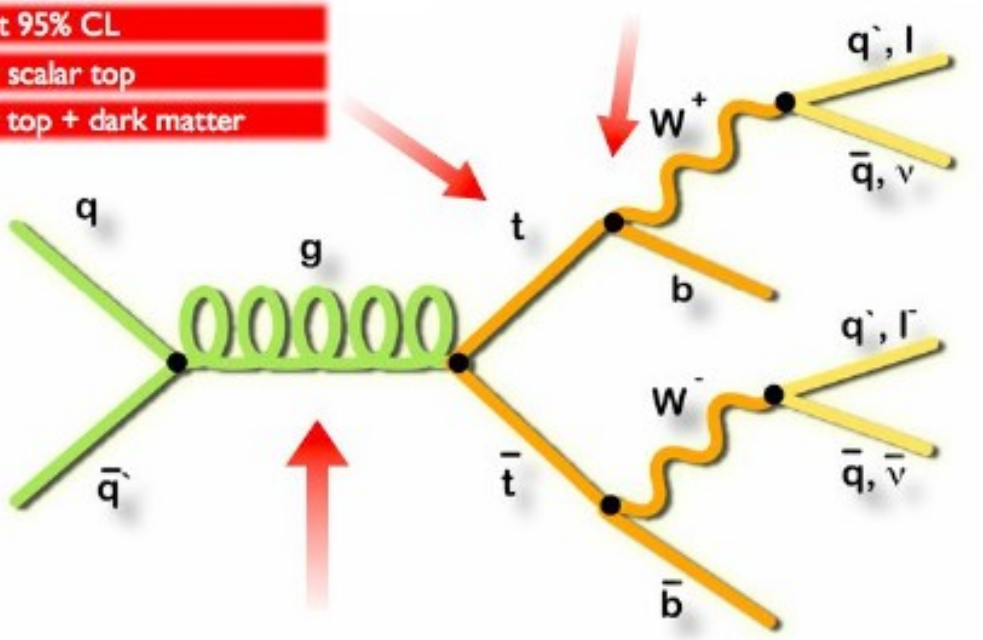
What we can learn about top

Intrinsic properties

- $M_t = 173.3 \pm 1.1$ 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

Decay properties

- $V_{tb} = 0.91 \pm 0.11$ (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)
- $A_{fb} = 15$-40% (parton level)
- Spin Correlations $\kappa = 0.6 \pm 0.5_{stat} \pm 0.2_{sys}$

Production properties

What we can learn about top

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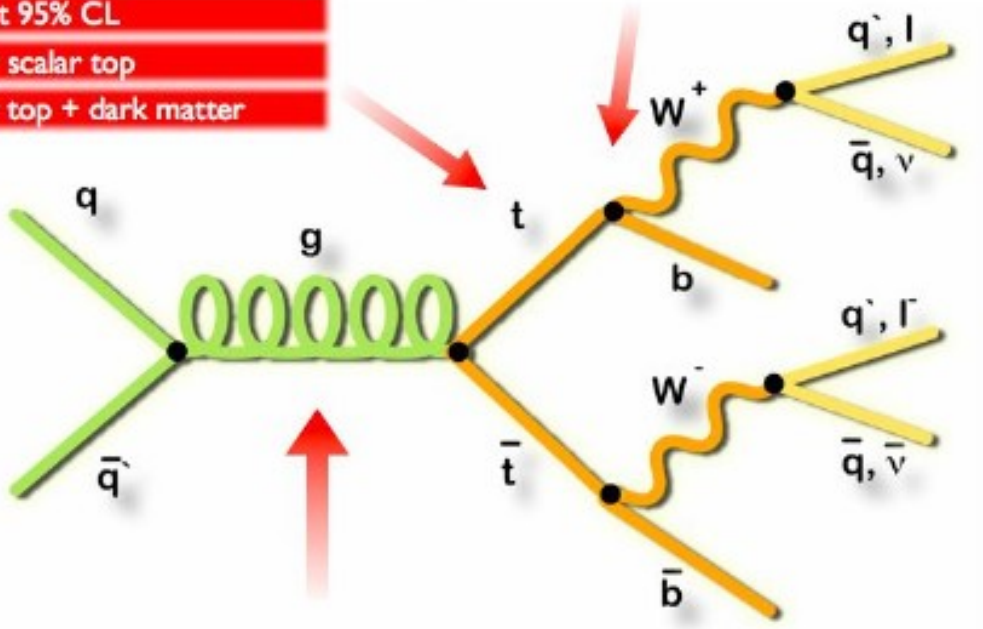

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- A_{fb} = 15-40% (parton level)
- Spin Correlations κ = 0.6 ± 0.5_{stat} ± 0.2_{sys}

Production properties

Top pair production cross-section

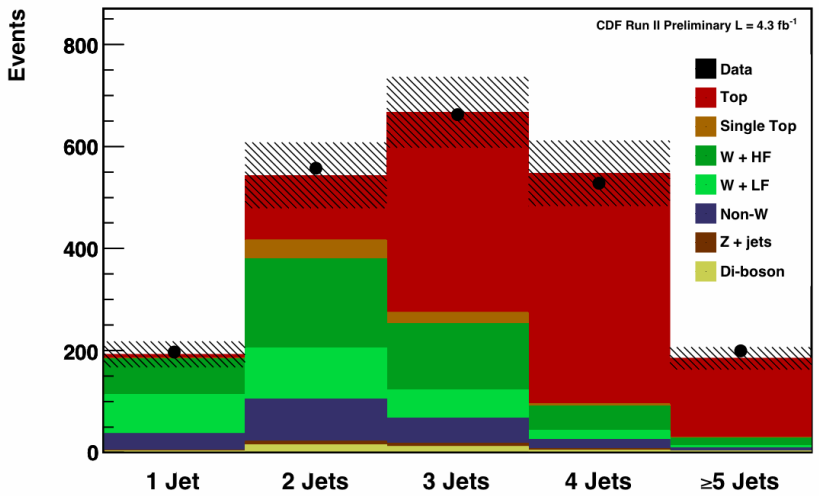
- Precise test of QCD in very high Q^2 regime
- Interest lately because of important background for various searches (Higgs, 4^{th} generation, SUSY)
- Anomalies in the $t\bar{t}$ rate would indicate:
  - presence of resonances → high cross section
  - new top decay channels → low cross section

→ measure cross sections in various $t\bar{t}$ final states

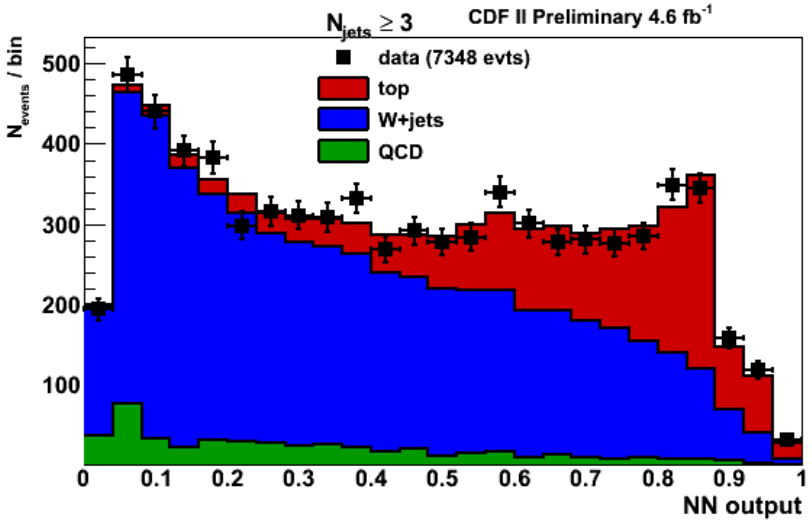
Top pair production: lepton+jets channel

- Most precise result from single channel
- Two complementary methods
  - One is using b-jet identification algorithm
  - Other is a topological method (no b-tag)
- Normalizing with respect to Z/gamma* cross section

  → reduce uncertainty from luminosity determination



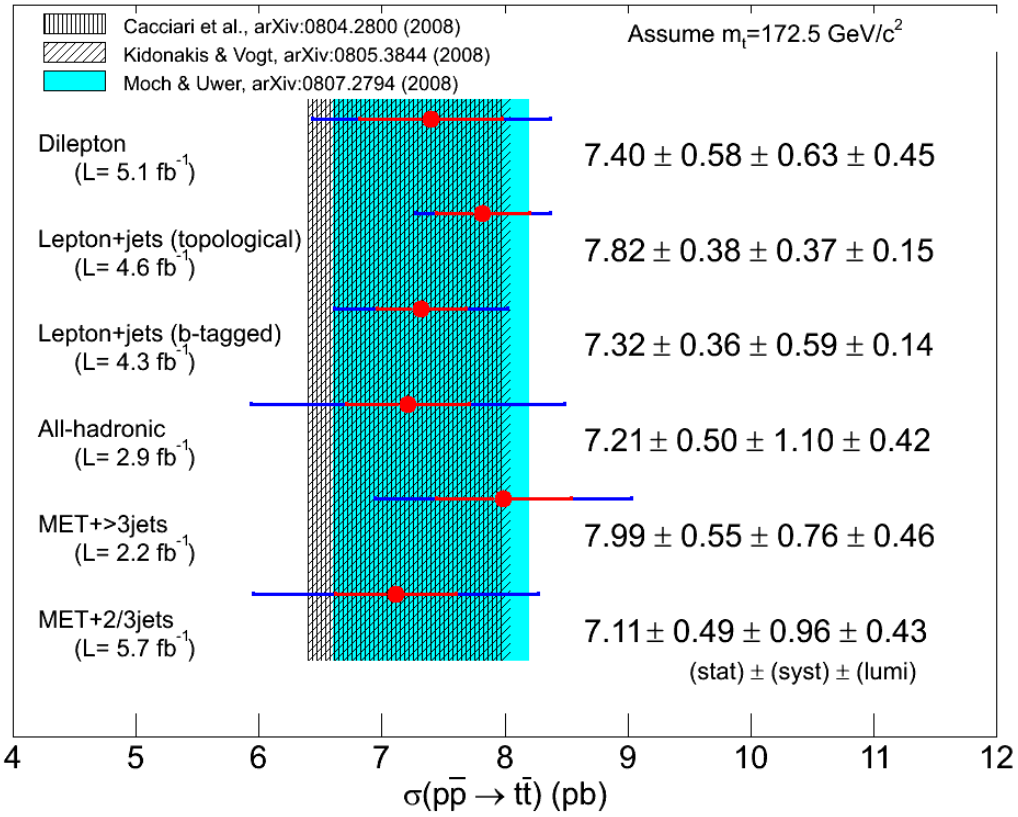
$\sigma = 7.32 \pm 0.36$ (stat) ± 0.59 (syst) ± 0.14 (theory) pb



$\sigma = 7.82 \pm 0.38$ (stat) ± 0.37 (syst) ± 0.15 (theory) pb

Combined result (m_{top} = 172.5 GeV): $\sigma = 7.70 \pm 0.52$ pb (6.8%)

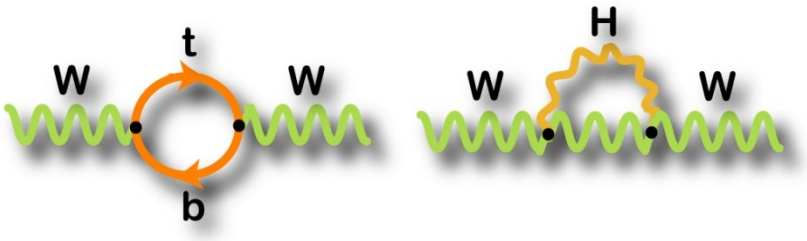
Top pair production: summary

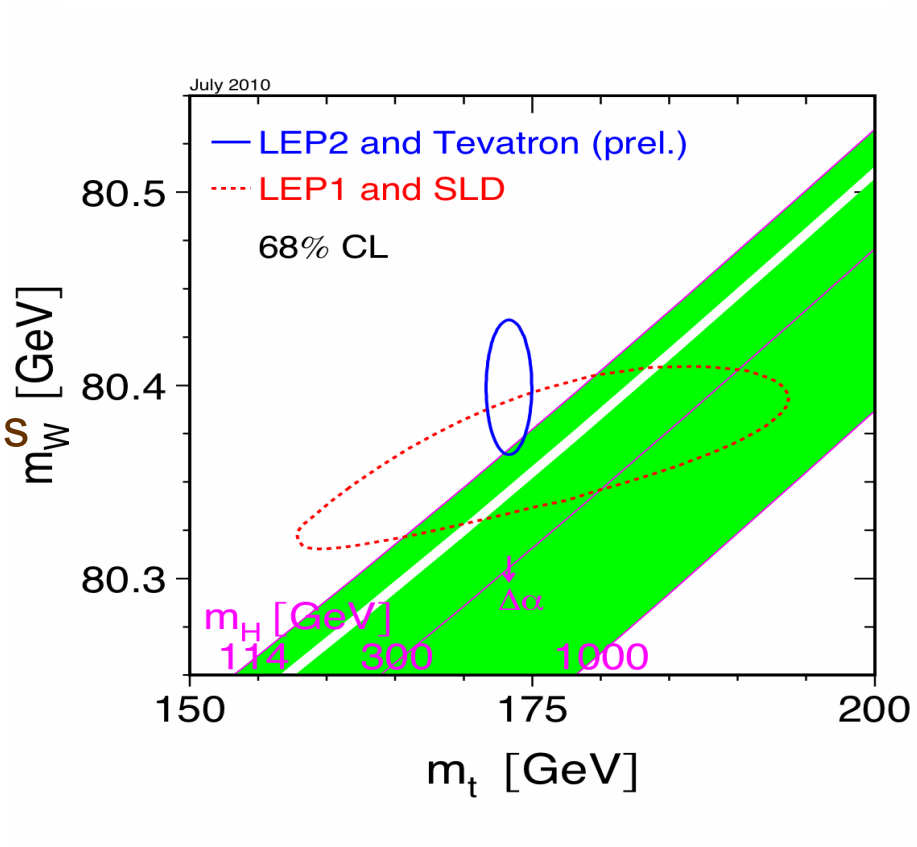


- Consistent results across channels
- Excellent agreement with the theory

Top quark mass

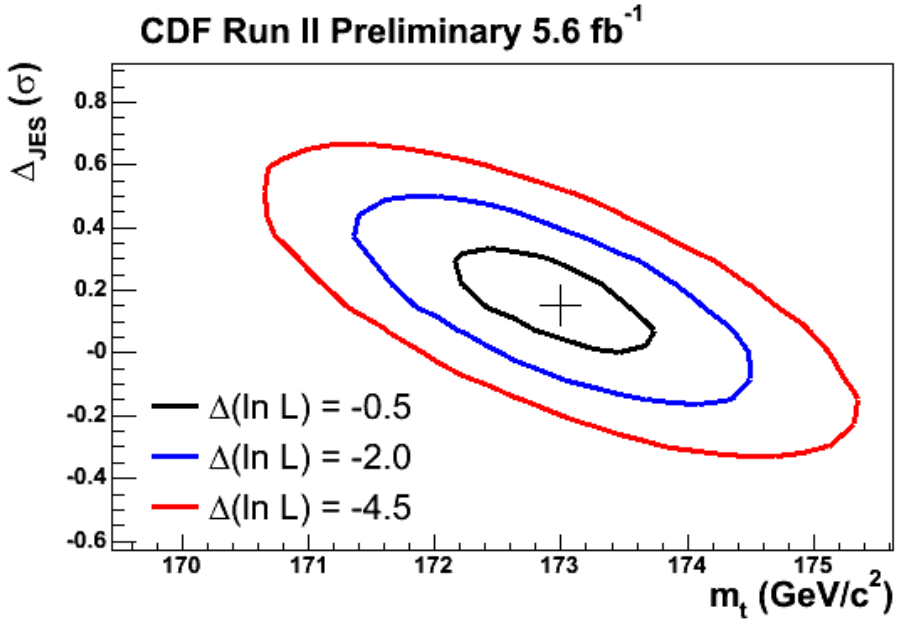
- Fundamental parameter of SM
- related to SM observables and parameters through loop diagrams → consistency checks of SM parameters
- Precise measurement of m_{top} (and m_W) allow prediction of m_{higgs}
- Typically two classes of methods:
  - **Template** – compare sensitive variable between data and MC simulations
  - **matrix-element (ME)** – event-by-event probability according production matrix element





Top mass: lepton+jets channel

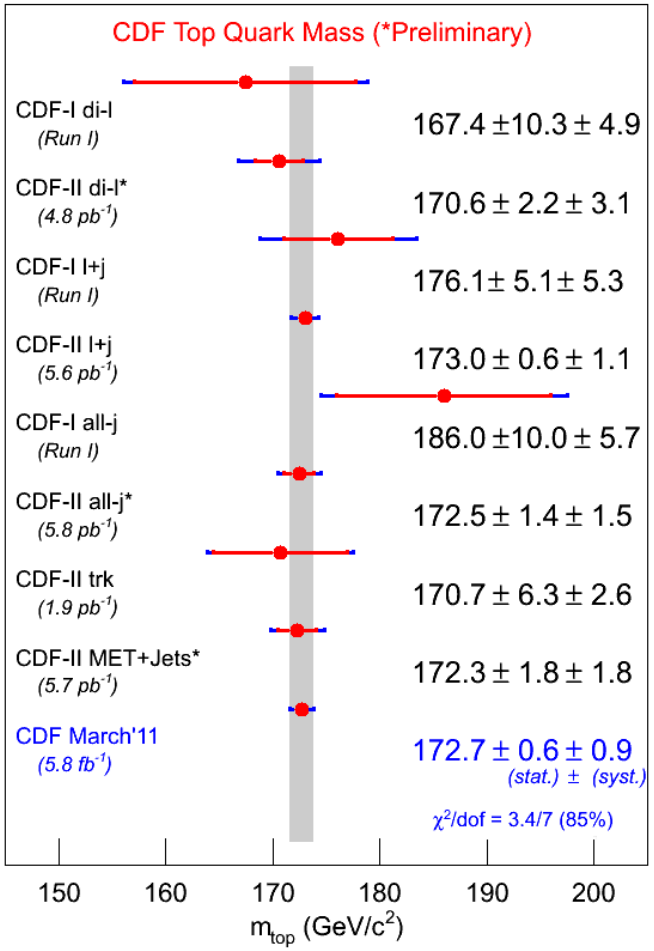
- **Most precise top mass measurements from single channel**
- NN to distinguish between signal and background
- event-by-event likelihood based on leading order $t\bar{t}$ matrix-element
- In-situ jet enery scale (JES) calibration



$$m_{top} = 173.0 \pm 0.7\ (stat) \pm 0.6\ (JES) \pm 0.9\ (syst)\ GeV$$

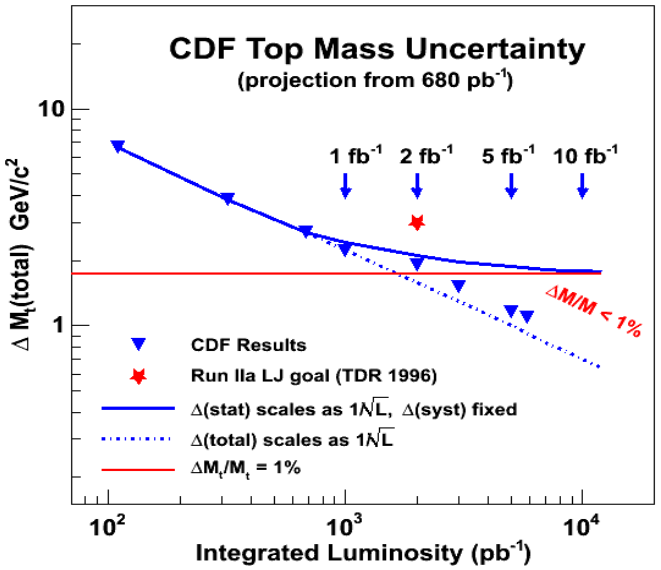
$$\Delta\ m_{top} = 1.2\ GeV$$

Top mass: combination



- Largest systematics: JES
- CDF expectation: $\Delta m_{top} < 1$ GeV

Source	Δm_{top} (GeV)
jet energy scale:	0.61
ttbar modeling:	0.59
background:	0.23
lepton energy scale:	0.10
miscellaneous:	0.14
Systematic:	0.89
Statistical:	0.56



CDF Win'11:

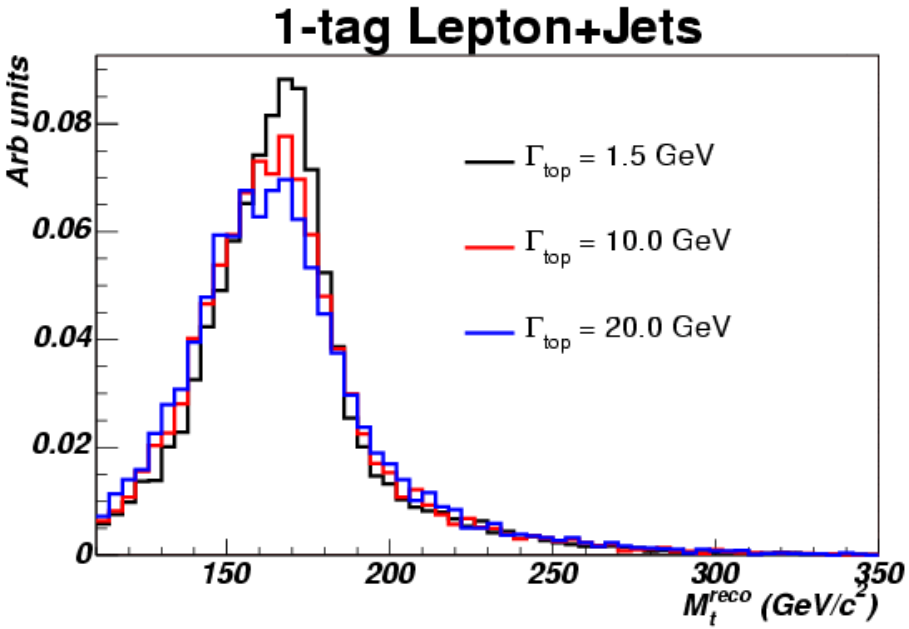
172.7 ± 1.1 GeV (0.63%)

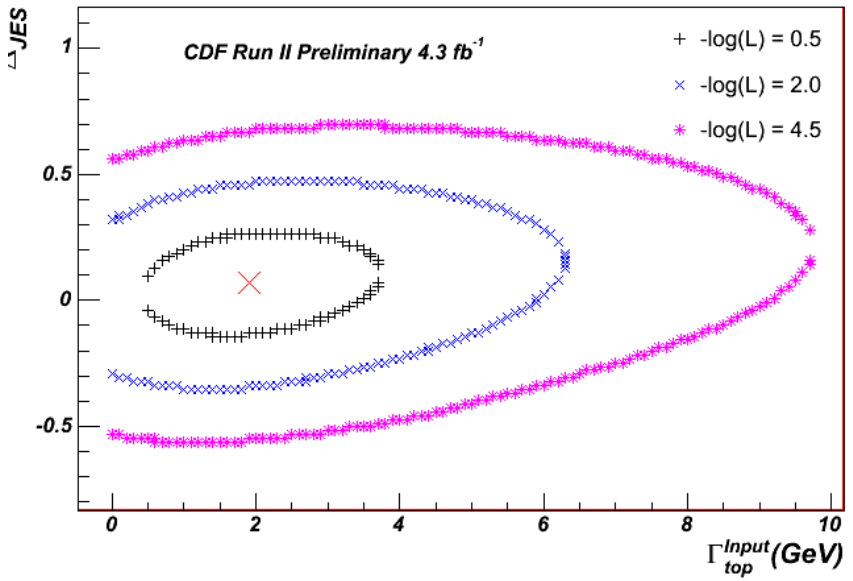
CDF+D0 Sum'10:

173.3 ± 1.1 GeV (0.61%)

Top quark width

- Large mass → decay fast
- Known precisely from theory: 1.3 GeV (for m_{top}=172.5 GeV)
- Deviations from SM could indicate unexpected top decays
  - Charged Higgs, FCNC, etc.
- template method with in-situ JES calibration
- Direct measurement:
  - **Γ(top) < 7.6 GeV @ 95 C.L.** → τ(top) > 8.7 x10^{-26} s @ 95% C.L.

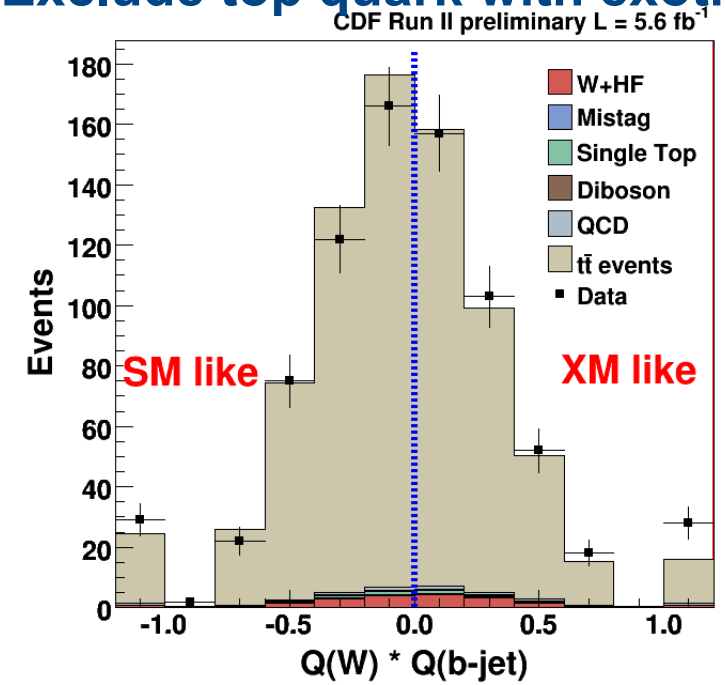


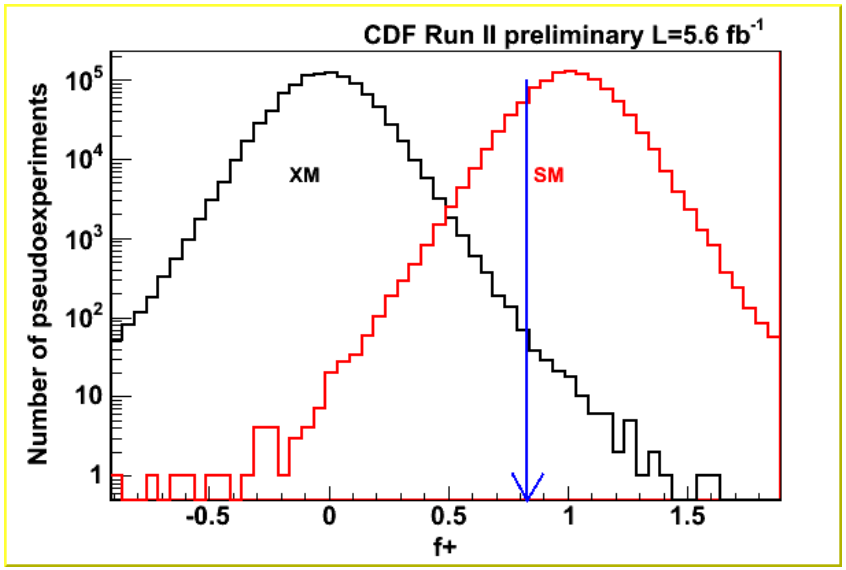


Top quark charge

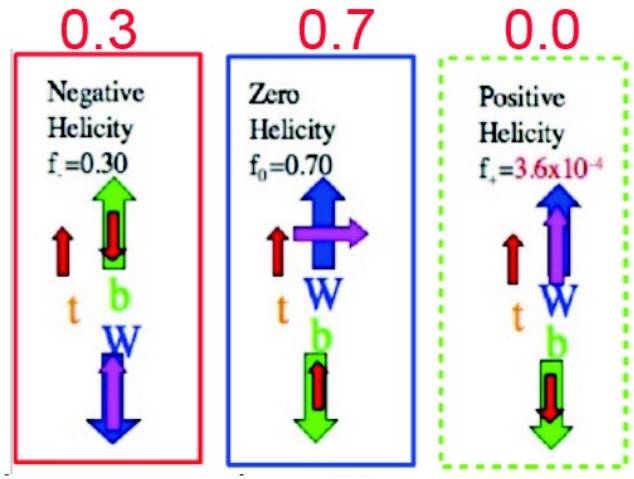
- Decide between 2 hypothesis : +2/3 and -4/3 charge
- It requires:
  - W charge: identify with lepton charge
  - Jet charge: p_T weighted sum of track charges
  - Jet – lepton pairing: top mass constraint
- Data favors very strongly SM over exotic (XM) hypothesis:

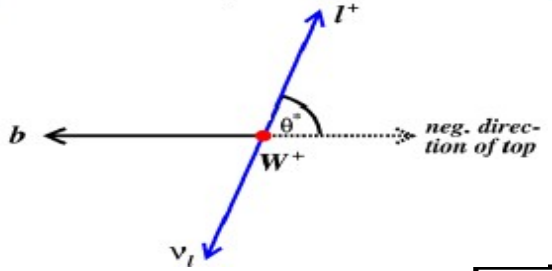
  $p_{SM} = 0.13$ $p_{XM} = 1.4 \times 10^{-4}$
- **Exclude top quark with exotic charge -4/3 with 95% C.L**

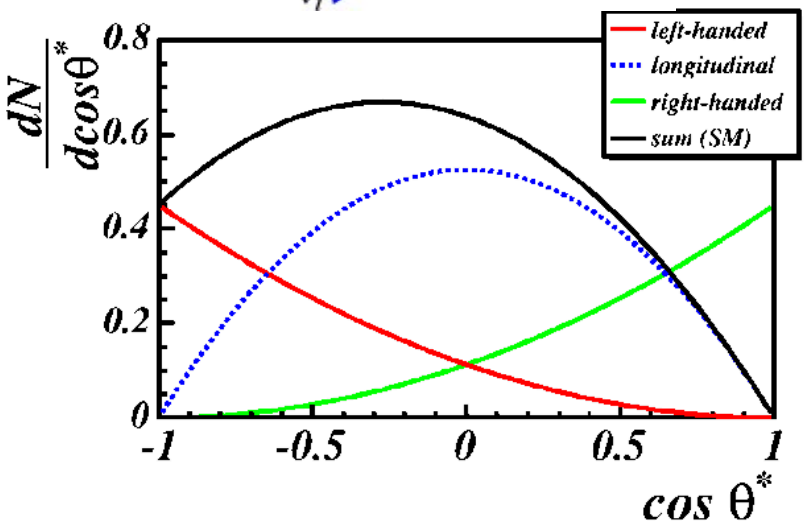




Polarization of W from top decay







Dilepton channel (5.1 fb^{-1}):

- 1D fits:

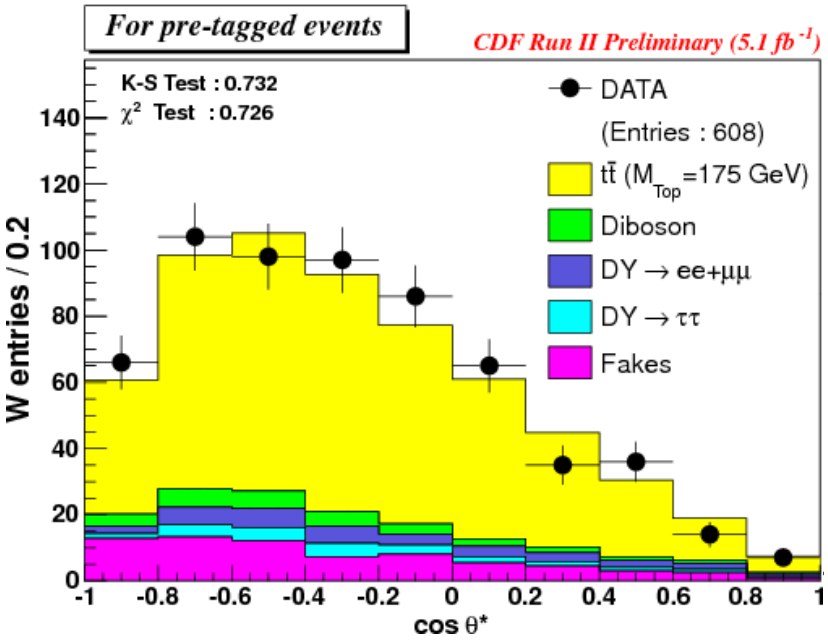
  $f_0 = 0.60 \pm 0.09(stat) \pm 0.06\ (syst)$

  $f_+ = -0.06 \pm 0.04\ (stat) \pm 0.03\ (syst)$

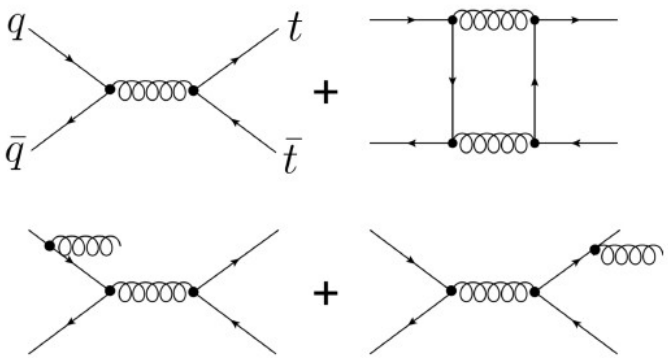
- Simultaneous fit of f_0 and f_+:

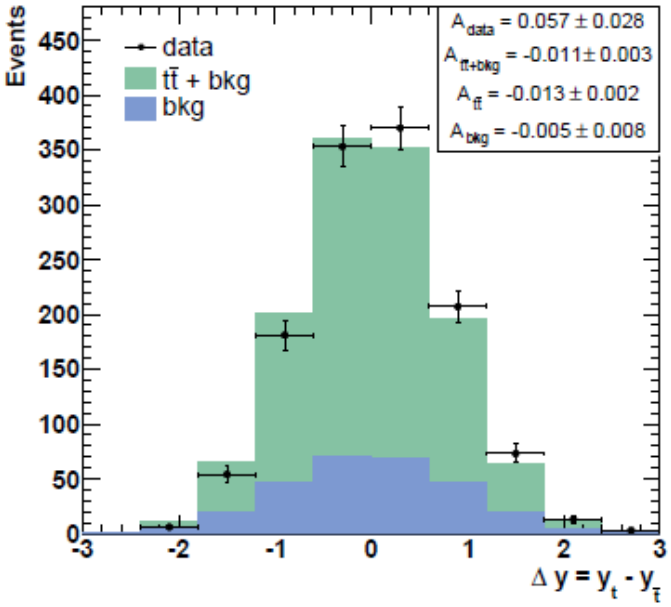
  $f_0 = 0.73\ ^{+0.18}_{-0.17}\ (stat) \pm 0.06\ (syst)$

  $f_+ = -0.08 \pm 0.09\ (stat) \pm 0.03\ (syst)$



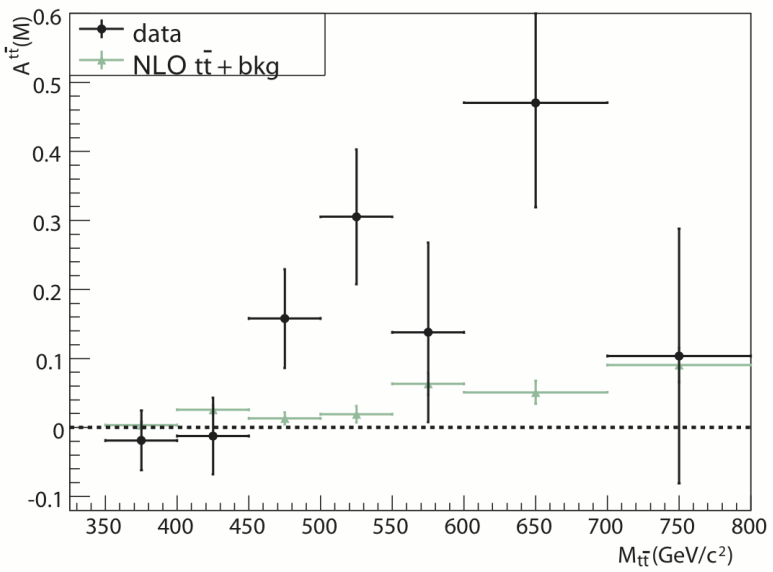
Forward backward asymmetry in top pairs





- caused by interference of amplitudes
- SM prediction (QCD at NLO) :
  $A^{FB}_{t\bar{t}} = 0.058 \pm 0.009$
- Significantly enhanced in BSM models:
  - Z'-like with parity violating coupling
  - chiral color theories
- l+jets channel
  $A^{FB}_{t\bar{t}} = 0.158 \pm 0.074$ (stat + syst)
- Found strong dependence on $m_{t\bar{t}}$:

  $A^{FB}_{t\bar{t}}$ ($m_{t\bar{t}} > 450$ GeV) = 0.48 ± 0.11
  - 3.4σ above the SM prediction (8.8 ± 1.3) in high $m_{t\bar{t}}$ region

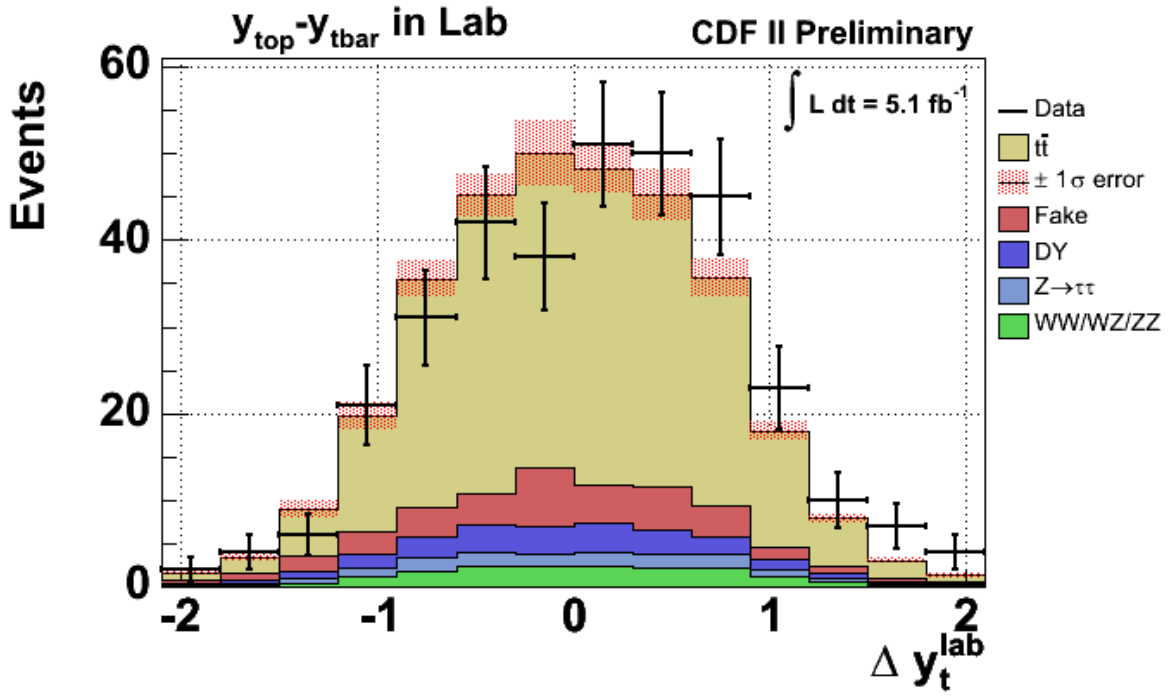


Forward backward asymmetry in top pairs

- **Dilepton channel:**

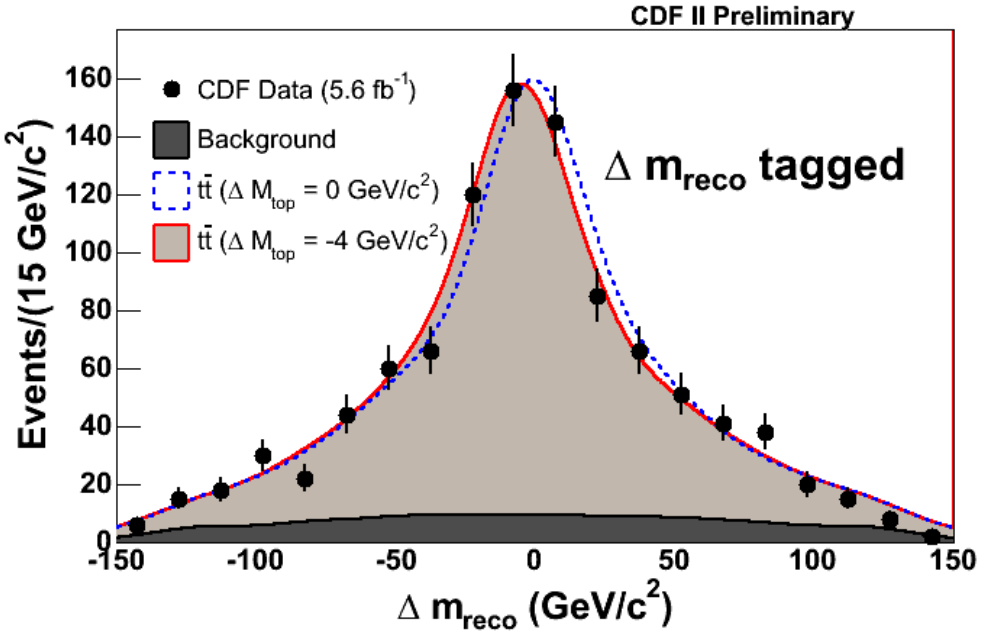
$$A^{FB}_{t} = 0.42 \pm 0.15 \text{ (stat)} \pm 0.05 \text{ (syst)}$$

- 2.3 σ from the SM (0.06 +- 0.01)
- DIL channel adds evidence
- Twice more data in each Tevatron experiment!



Top – antitop mass difference

- If CPT conserved: $\Delta m_{top} = 0$ GeV
- The method same as in top mass measurement but allows for mass difference



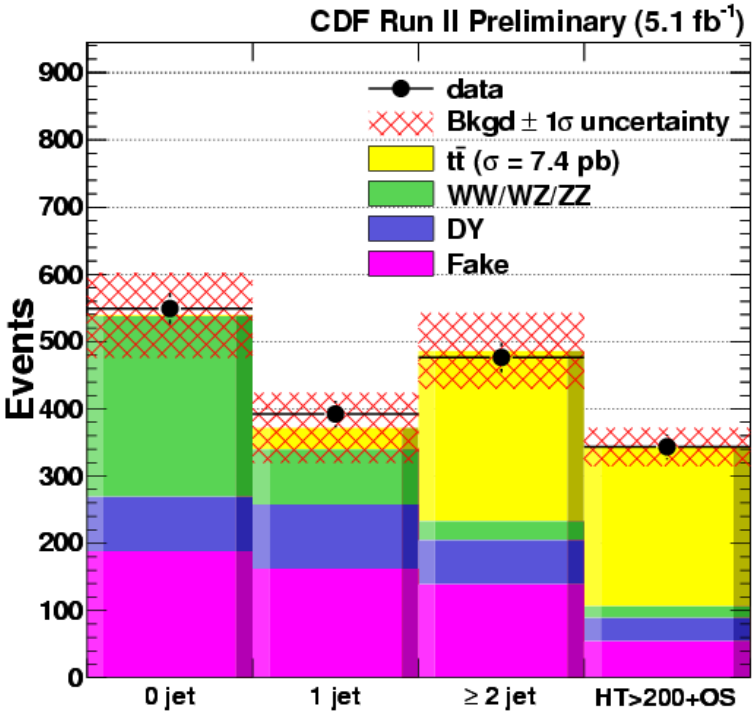
Δm_{top} = -3.3 ± 1.4(stat.) ± 1.0 (syst.) GeV
= -3.3 ± 1.7 GeV

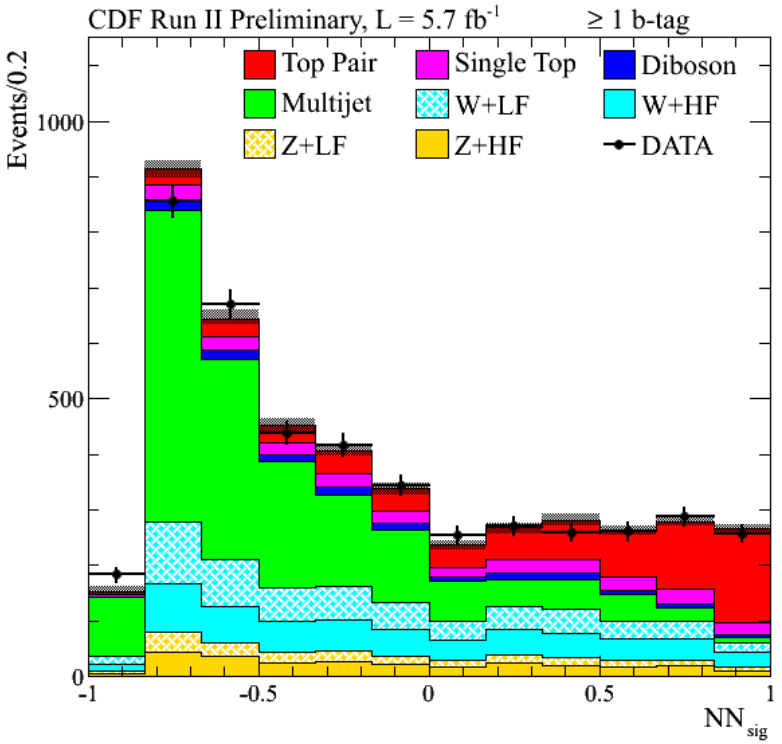
Summary and prospects

- CDF has a robust program of top quark measurements
  - using different methods → confidence
  - measurements in different channels → consistency
  - combining channels and methods → precision
- $t\bar{t}$ cross-section and top mass measurement already limited by systematics
- Most of the property measurements limited by statistics
- A few latest results show tension with Standard Model

BACKUP

Top pair production: other channels





Dilepton channel:

- simple counting experiment
- Both pre-tag and b-tag results

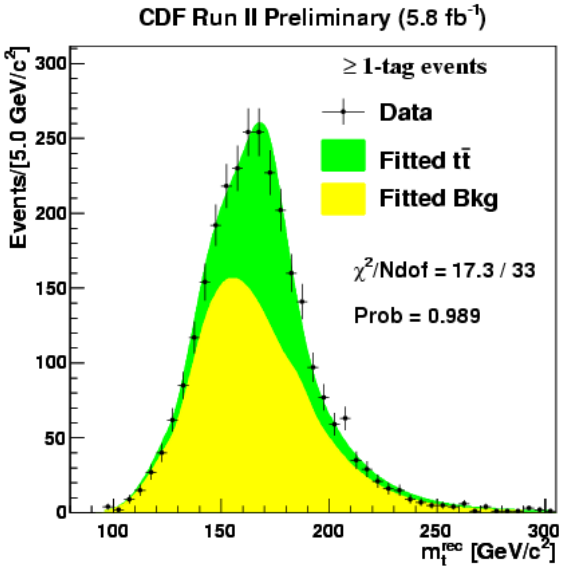
σ (0-tag) = 7.40 ± 0.97 (stat+syst) pb

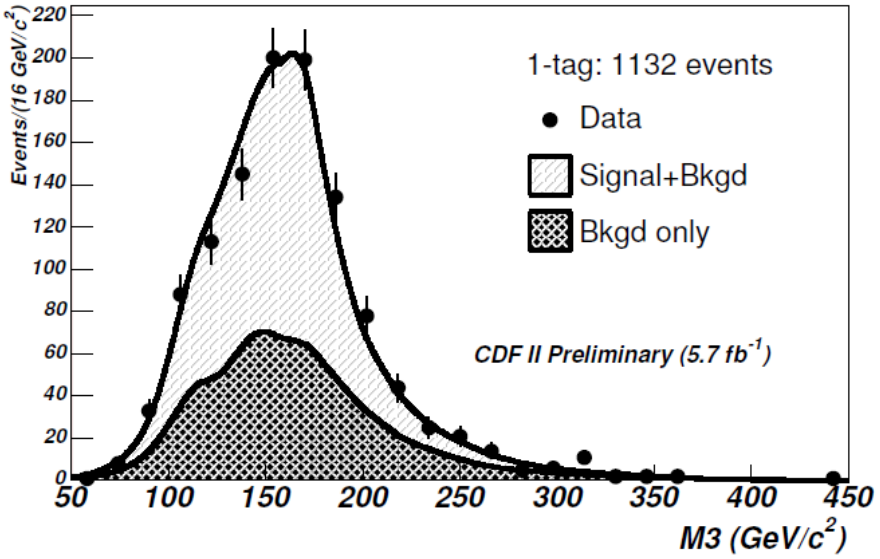
MET+jets channel:

- Background to Higgs search
- Mostly lepton+jet events
- Use NN to supress QCD and other backgrounds

$\sigma = 7.12\ ^{+1.20}_{-1.12}$ (stat + syst) pb

Top mass: other channels





All-hadronic channel

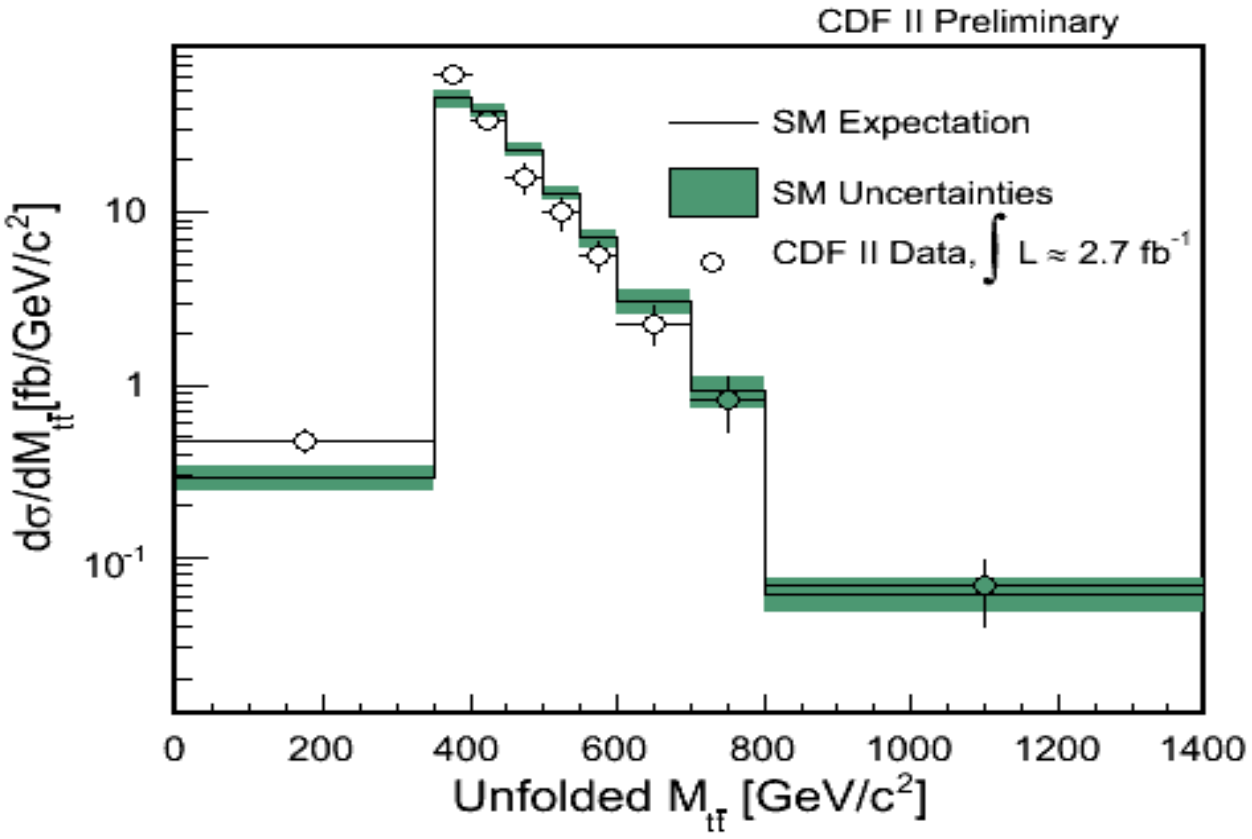
MET+jets channel (for the 1st time!)

Both measurements:

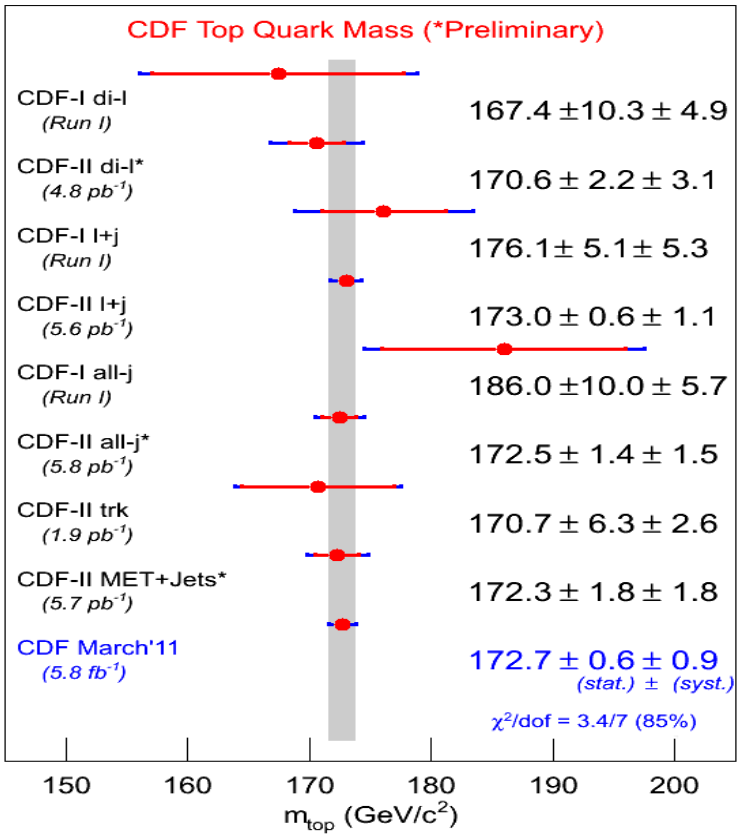
- NN selection and b-tagging
- In-situ JES calibration
- Template method: m(jj) and m_{top} (all-had); M3, M3', m(jj) (MET+jets)

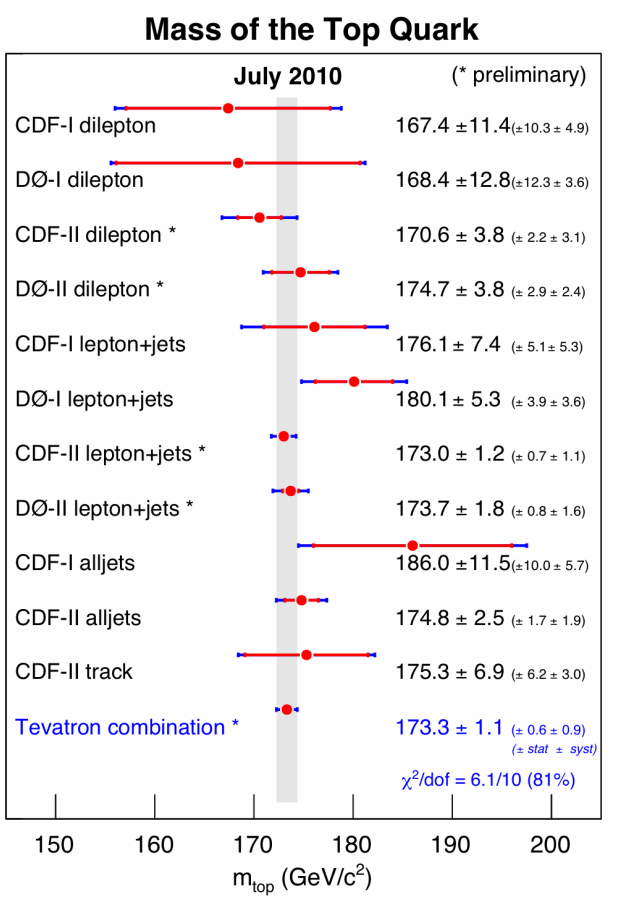
m_{top}=172.5 ± 1.4(stat.) ± 1.5(syst) **m_{top}=172.3 ± 1.8(stat.) ± 1.8(syst)**

Differential cross-section



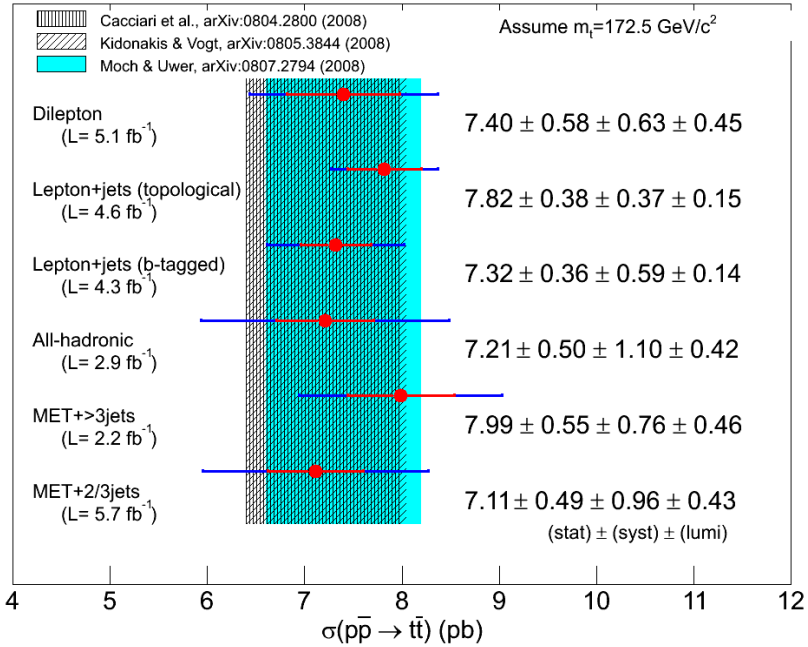
Top mass: CDF & Tevatron

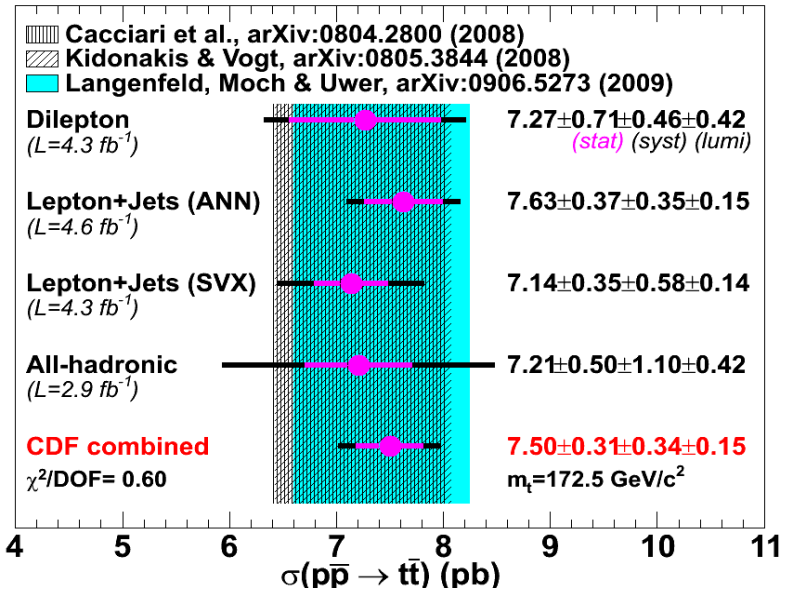




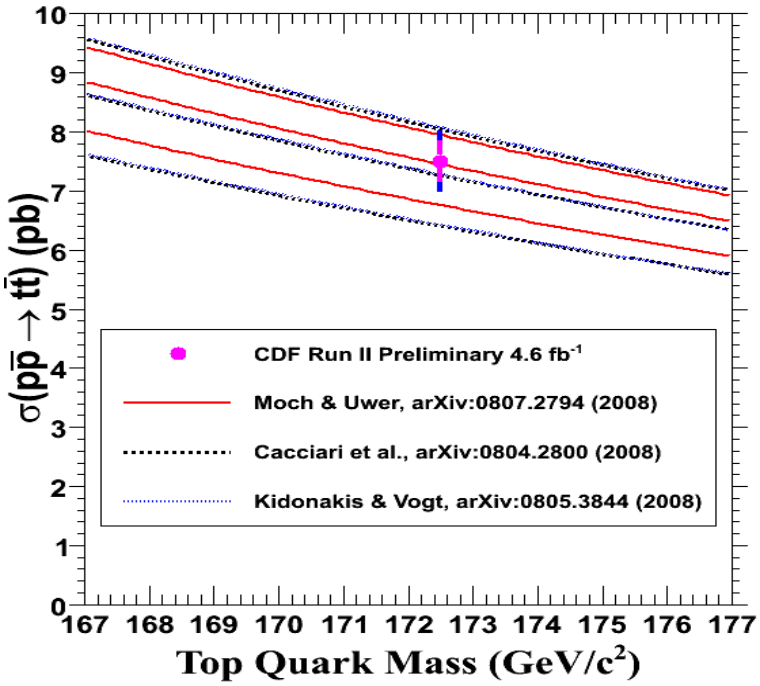
- CDF Sum'10: 173.13 ± 1.16 [0.67 (stat) ± 0.95 (syst)] GeV (0.67%)
- Tevatron Sum'10: 173.32 +- 1.06 [0.56 (stat) +- 0.89 (syst)] GeV(0.61%)
- CDF Win '11: 172.70 ± 1.09 [0.63(stat) ± 0.89(syst)] GeV (0.63%)

Top pair production: summary

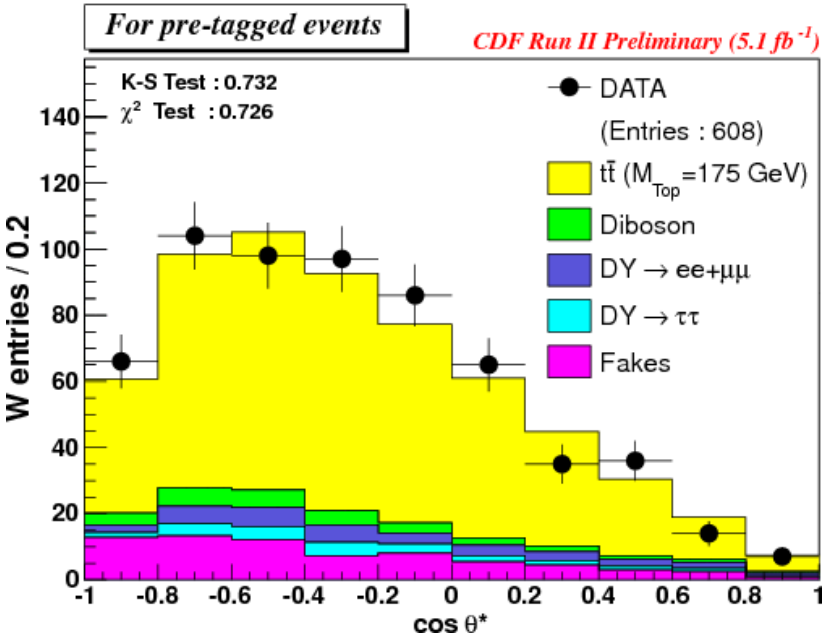


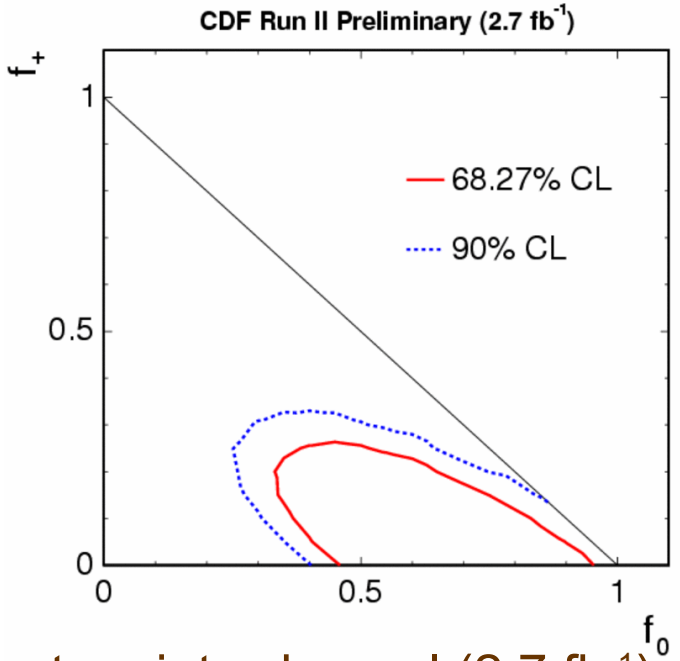


- **DIL channel updated since last combination**
- MET+jets channel not in combination
- Combined CDF result: 7.50 +- 0.48 pb (6.4 %)
- Consistent results, excelent agreement with theory



Polarization of W from top decay: results





Dilepton channel (5.1 fb^{-1}):

- 1D fits:

  $f_0 = 0.60 \pm 0.09(\text{stat}) \pm 0.06\ (\text{syst})$

  $f_+ = -0.06 \pm 0.04(\text{stat}) \pm 0.03\ (\text{syst})$

- Simultaneous fit of f_0 and f_+:
  - $f_0 = 0.73\ ^{+0.18}_{-0.17}\ (\text{stat}) \pm 0.06\ (\text{syst})$
  - $f_+ = -0.08 \pm 0.09\ (\text{stat}) \pm 0.03\ (\text{syst})$

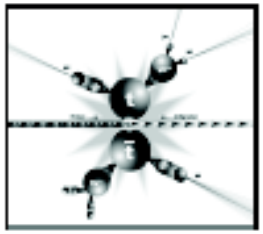
lepton+jets channel (2.7 fb^{-1}):

- Probabilities according ME
- Model independent measurement of f_0 and f_+:

  $f_0 = 0.88 \pm 0.11\ (\text{stat}) \pm 0.06\ (\text{syst})$

  $f_+ = -0.15 \pm 0.07\ (\text{stat}) \pm 0.06\ (\text{syst})$

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

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

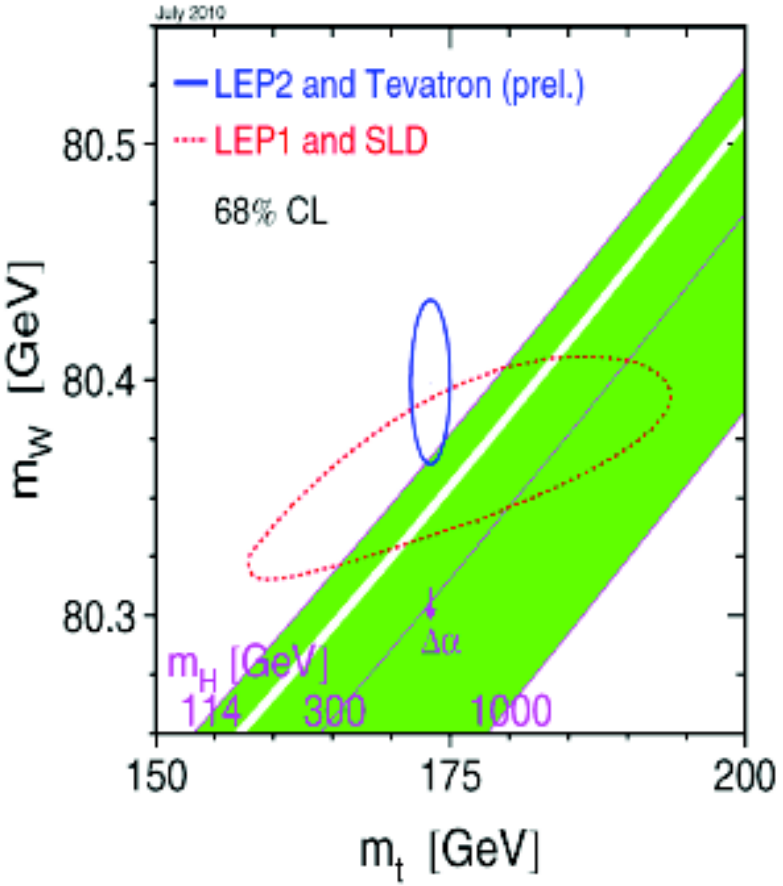
  - $\overline{\text{MS}}$ running mass (short distance mass)– the divergences are subtracted; It is the most commonly used subtraction scheme

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

- 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]

Taken from G.Velev's talk at Workshop on jet spectrosopy, Pisa 2011