Top quark Production and Properties

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Workshop on Deep Inelastic Scattering 2007

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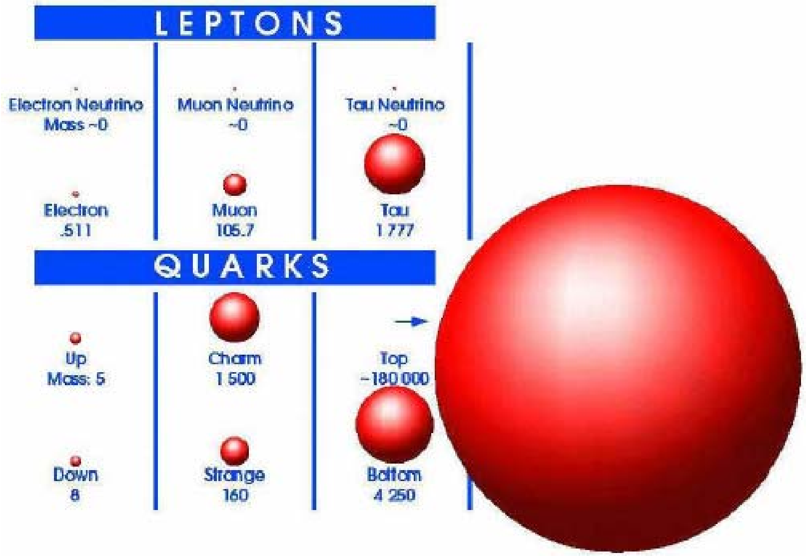
Outline

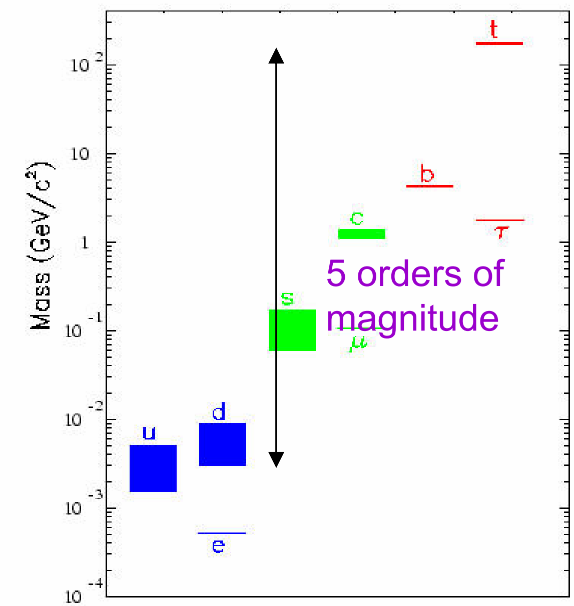
- Motivation
- Introduction to top production and decay
- Measurements of Top quark pair production cross section
  - Assume SM production and decay
- Studies of Top quark pair production mechanisms
  - Is the SM correct?
- Studies of Top quark production properties
  - Top Charge
- Conclusions and Outlook

Note: Top mass and decay properties and Single top production included in talks by J. Wagner and S. Jabeen, respectively.

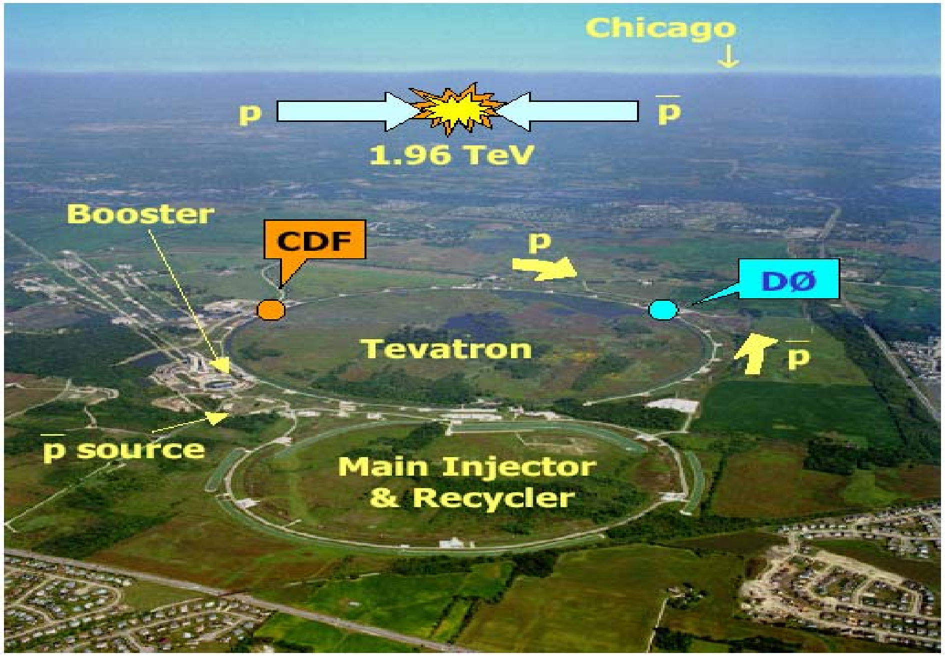
Why study the Top Quark?

- Predicted by the SM and Discovered in 1995 by CDF and DØ
  - **m_t ~ 170 GeV vs m_b~ 5 GeV**
- Top-Higgs Yukawa coupling $\lambda_t \approx 1$
  - **may help identify the mechanism of EWSB and mass generation.**
  - **may serve as a window to new physics that might couple preferentially to top.**
- Until now, we knew very little about top
  - **Indirect constraints from low energy data, or statistically limited direct measurements from the Tevatron**
    - **Plenty of room for new Physics**
  - **Even if we find no surprises, precision top measurements will allow for stringent tests of the SM.**



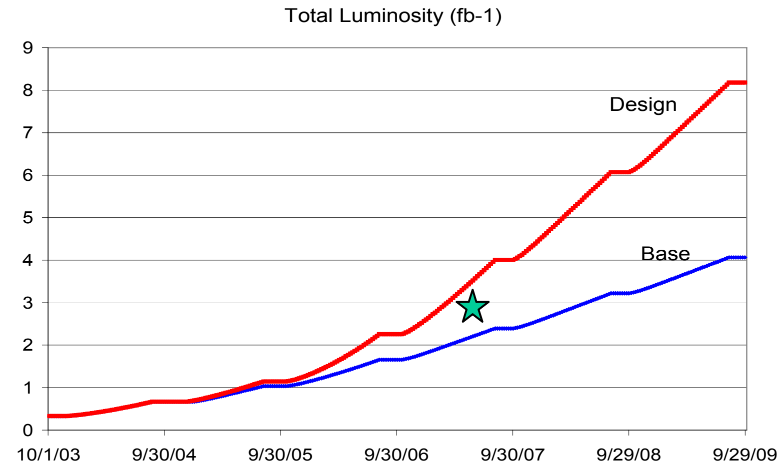


The Fermilab Tevatron



- Highest-energy accelerator currently in operation
  - **Only place where Top quarks can be produced**
- Data delivered >2fb^{-1}
  - **expect 4fb^{-1} by end of 2007**

	Run I	Run IIa	**Run IIb**
Bunches in Turn	6×6	36×36	**36×36**
$\sqrt{s}$ (TeV)	1.8	1.96	**1.96**
Peak L ($cm^{-2}s^{-1}$)	1.6×10^{30}	9×10^{31}	**3×10^{32}**
$\int Ldt$ (pb^{-1}/week)	3	17	**50**
Bunch crossing (ns)	3500	396	**396**
Interactions/ crossing	2.5	2.3	**8**

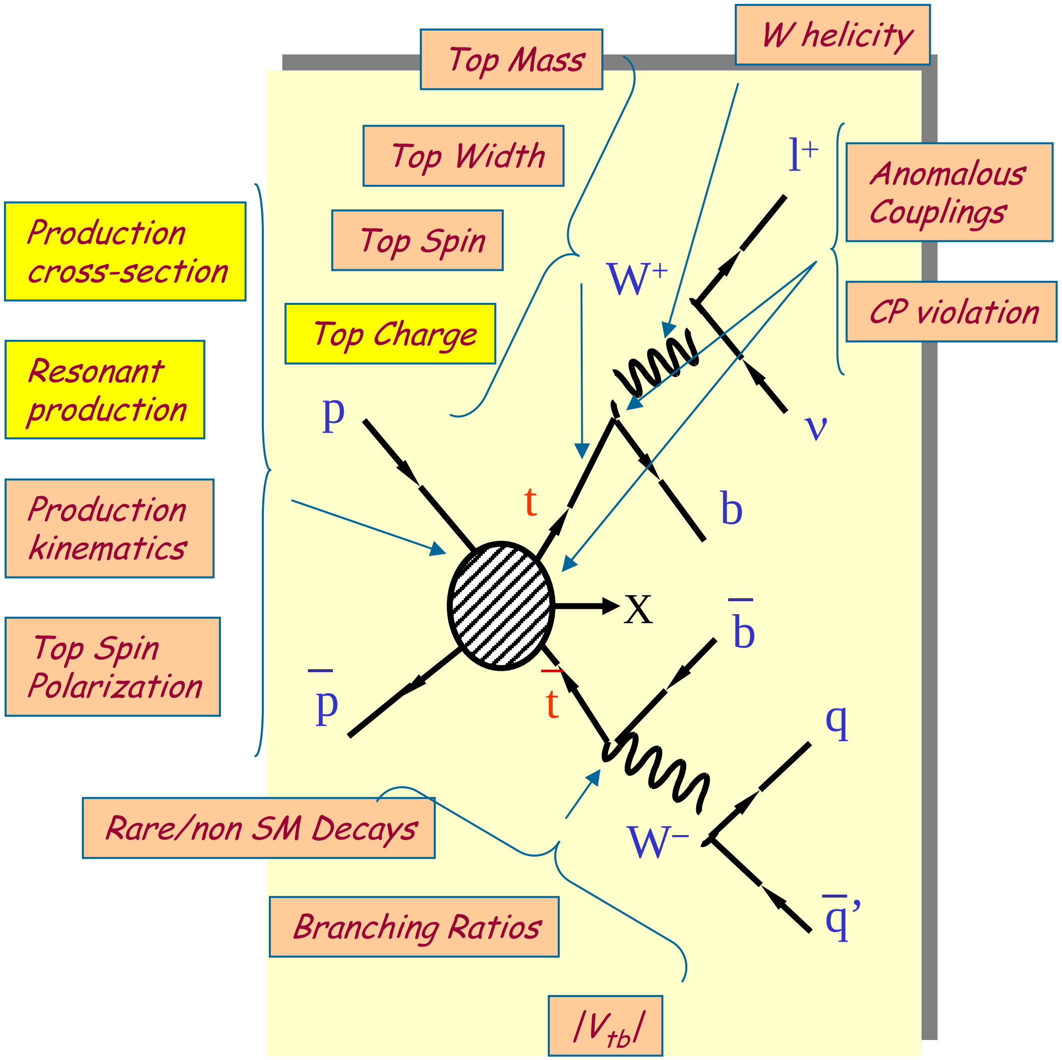


Results based on ~1fb^{-1}

Cecilia Gerber (UIC)

Understanding the Top quark

- Tevatron Run I
  - Dataset: 100pb^{-1}
  - top mass and x-sec statistics-limited
- Tevatron Run IIA
  - Dataset: 1000pb^{-1}
  - top mass and x-sec systematics-limited
  - Precise measurements of top properties possible for the first time
    - Is the Top really the Standard Model Top?

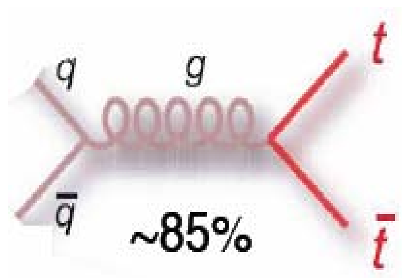


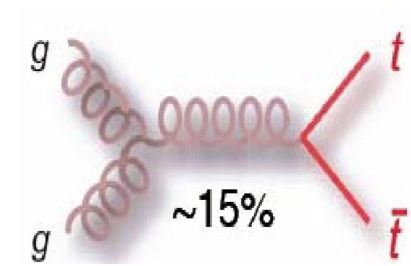
Top Quark Production at the Tevatron

- Top quarks are mainly produced in pairs, via the strong interaction

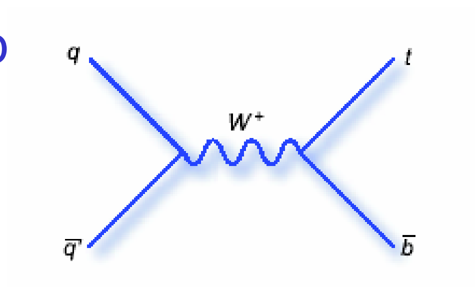
σ_{tt}=6.8±0.6 pb (Kidonakis, Vogt)
σ_{tt}=6.7+0.7-0.9 pb (Cacciari et al.)

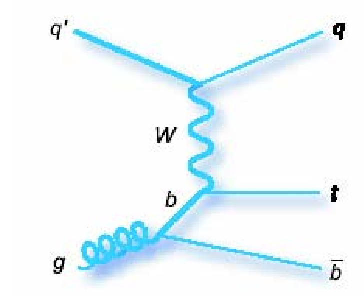
(Calculated for top mass = 175 GeV)





- Recent evidence for EW Single Top production observed at DØ
  - **Experimentally challenging due to large W+jets background in lower jet multiplicities than pair production**





***s*-channel**

σ = 0.88 ± 0.11 pb

***t*-channel**

σ = 1.98 ± 0.25 pb

DØ result accepted by PRL

σ = 4.8 ± 1.3 pb

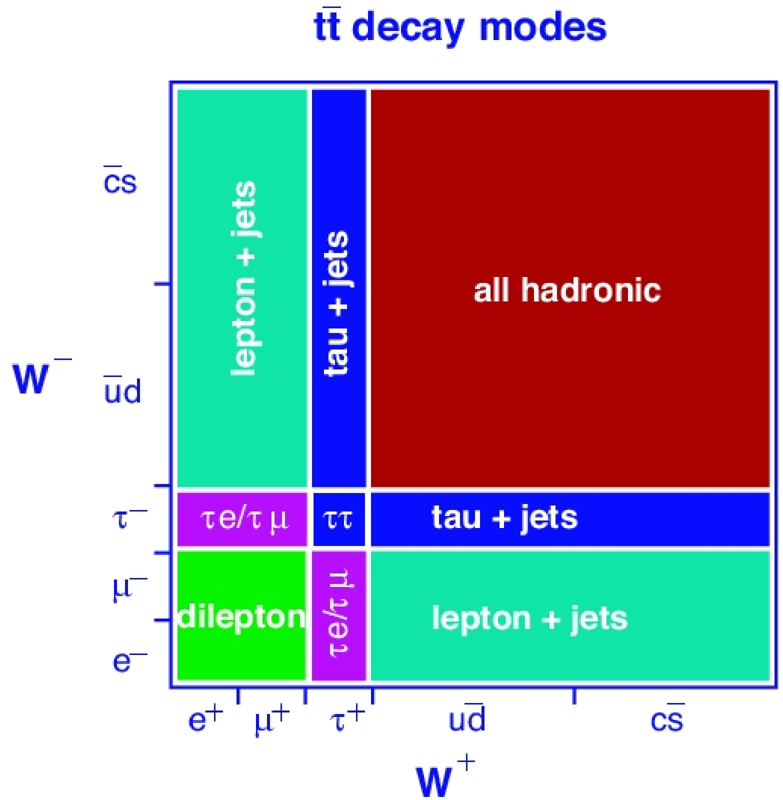
Significance = 3.5 σ

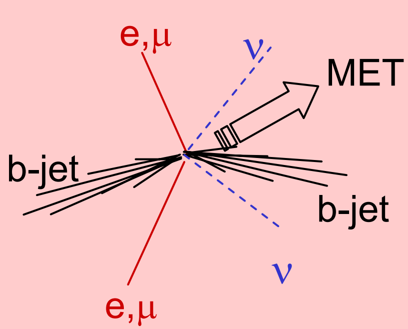
Associated production tW too small at the Tevatron

see talk by Shabnam Jabeen

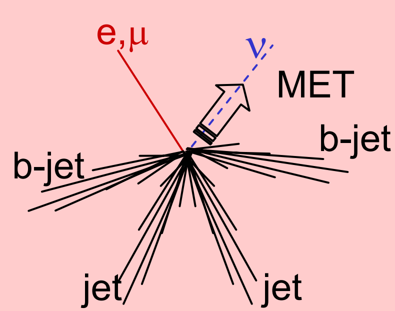
Top Quark Decay

- $m_t > m_W + m_b \Rightarrow$
  dominant 2-body decay $t \rightarrow Wb$
- Assuming unitarity of 3-generation CKM matrix $\Rightarrow$ $B(t \rightarrow Wb) \sim 100\%$
- $\Gamma_t^{SM} \approx 1.4$ GeV at $m_t = 175$ GeV
  - Top decays before top-flavored hadrons or $t\bar{t}$-quarkonium bound states can form
  - Top spin and kinematics is transferred to the final state

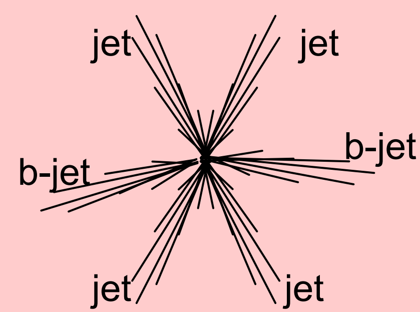




Dilepton
(BR~5%, low bckg)



Lepton+jets
(BR~30%, moderate bckg)



All-hadronic
(BR~46%, huge bckg)

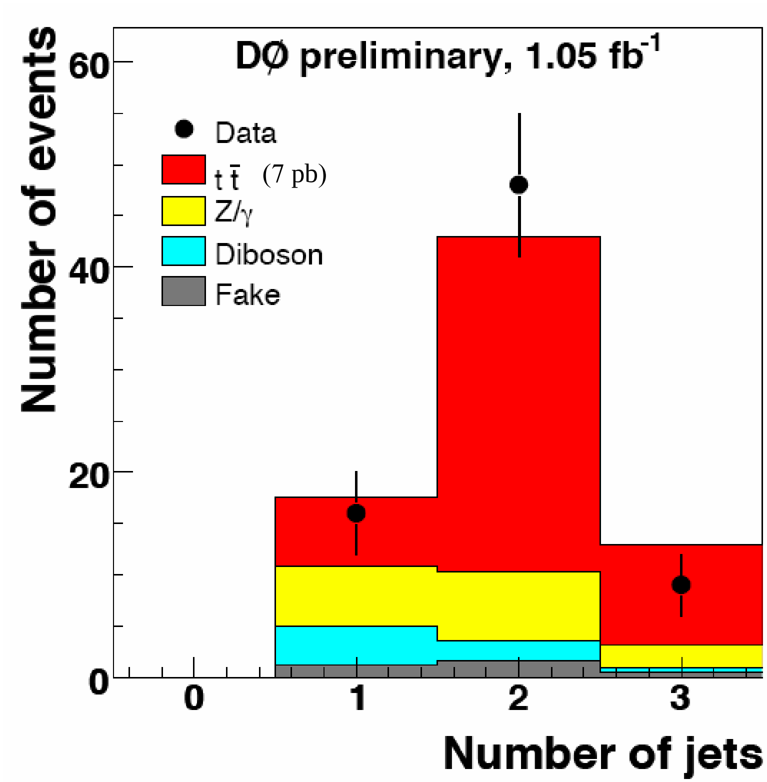
Top Quark Pair Production Cross Section

- Test of pQCD at high Q^2
- Sensitive to new physics - Expect higher x-sec if resonant or non-SM production occurs
  - **Measure in different channels**
  - **Measure with different techniques**
    - **b-tagging method assumes $Br(t \to Wb)=1$**
    - **Kinematic fit methods are free of this assumption**
- Provides sample composition for other top properties measurements
- Gives input for searches for which top events are a dominant background.

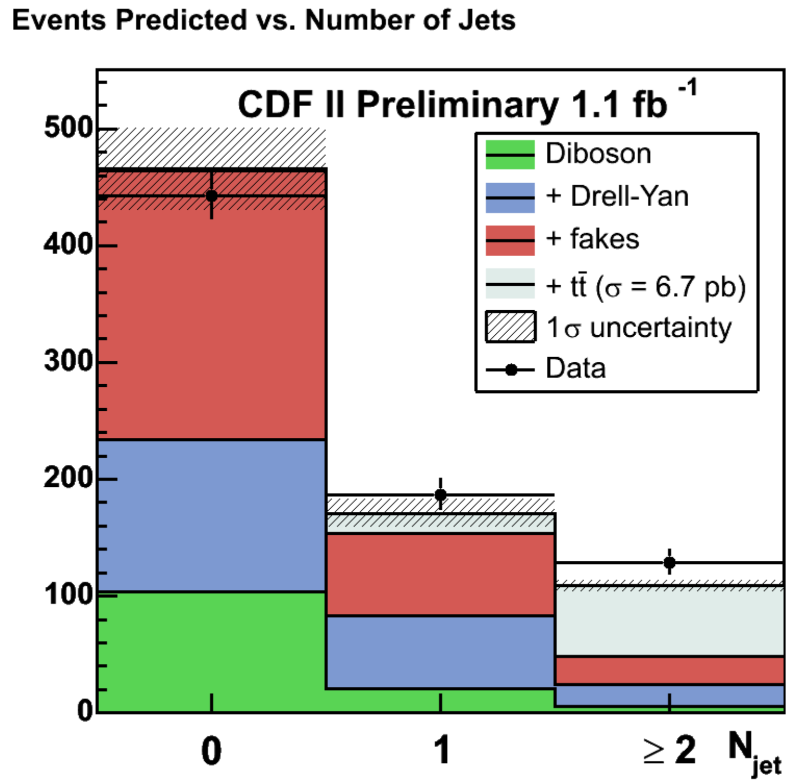
- New results available for:
  - **Dilepton (ee, eμ, $\mu\mu$) DØ**
    - **Opposite sign leptons**
    - **≥1 jet for eμ**
    - **≥2 jets for ee and $\mu\mu$**
  - **Lepton + track CDF**
    - **Increase acceptance by requiring 1 lepton + 1 isolated track (opposite charge)**
    - **≥2 jets**
  - **Lepton + jets DØ**
    - **1 isolated lepton (e or μ)**
    - **b-tagged, ≥3 jets**
    - **Kinematic, ≥4 jets**
  - **All channels require significant Missing E_T**

Cross Section Results (1)

Dileptons



Lepton + Track



$\sigma_{tt} = 6.8^{+1.2}_{-1.1}$ (stat) $^{+0.9}_{-0.8}$ (syst) ± 0.4 (lumi) pb

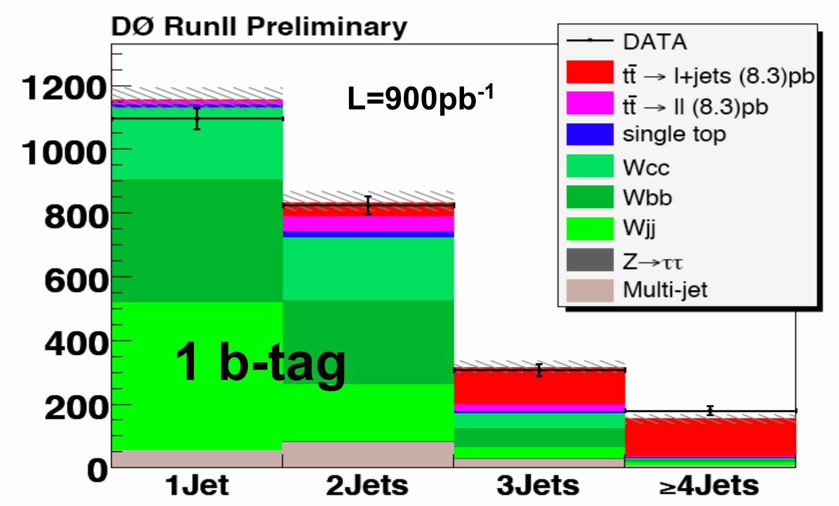
$\sigma_{tt} = 9.0 \pm 1.3$(stat) ± 0.5(sys) ± 0.5(lumi) pb

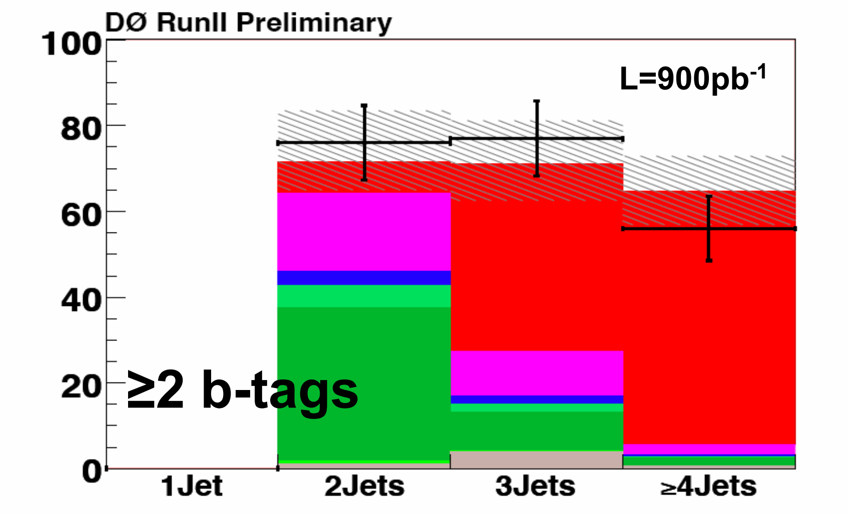
$\delta\sigma/\sigma = 22\%$ **(excluding luminosity)**

$\delta\sigma/\sigma = 15\%$ **(excluding luminosity)**

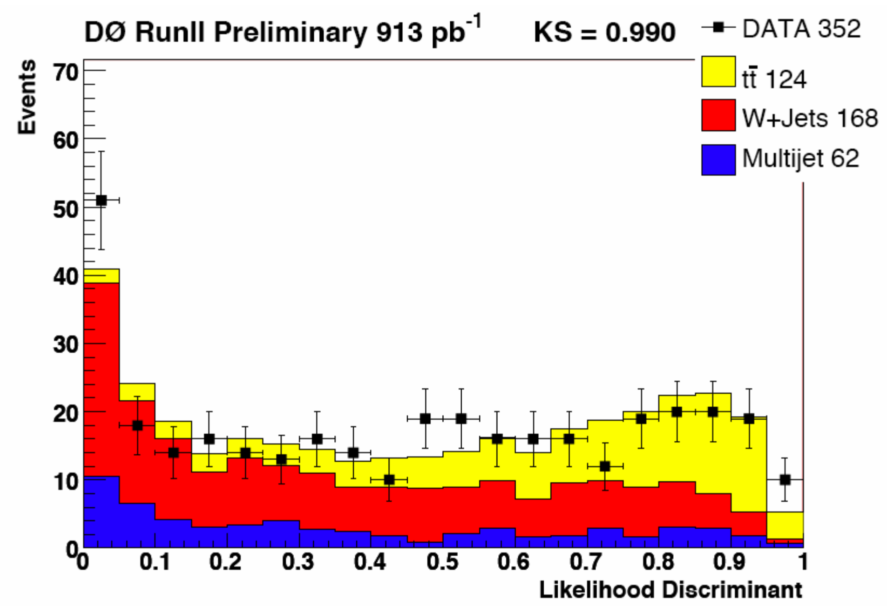
Cross Section Results (2)

(1) l+jets with b-tagging





(2) l+jets kinematic



(1) $\sigma_{tt} = 8.3\ ^{+0.6}_{-0.5}(\text{stat})\ ^{+0.9}_{-1.0}(\text{syst}) \pm 0.5\ (\text{lumi})$ pb

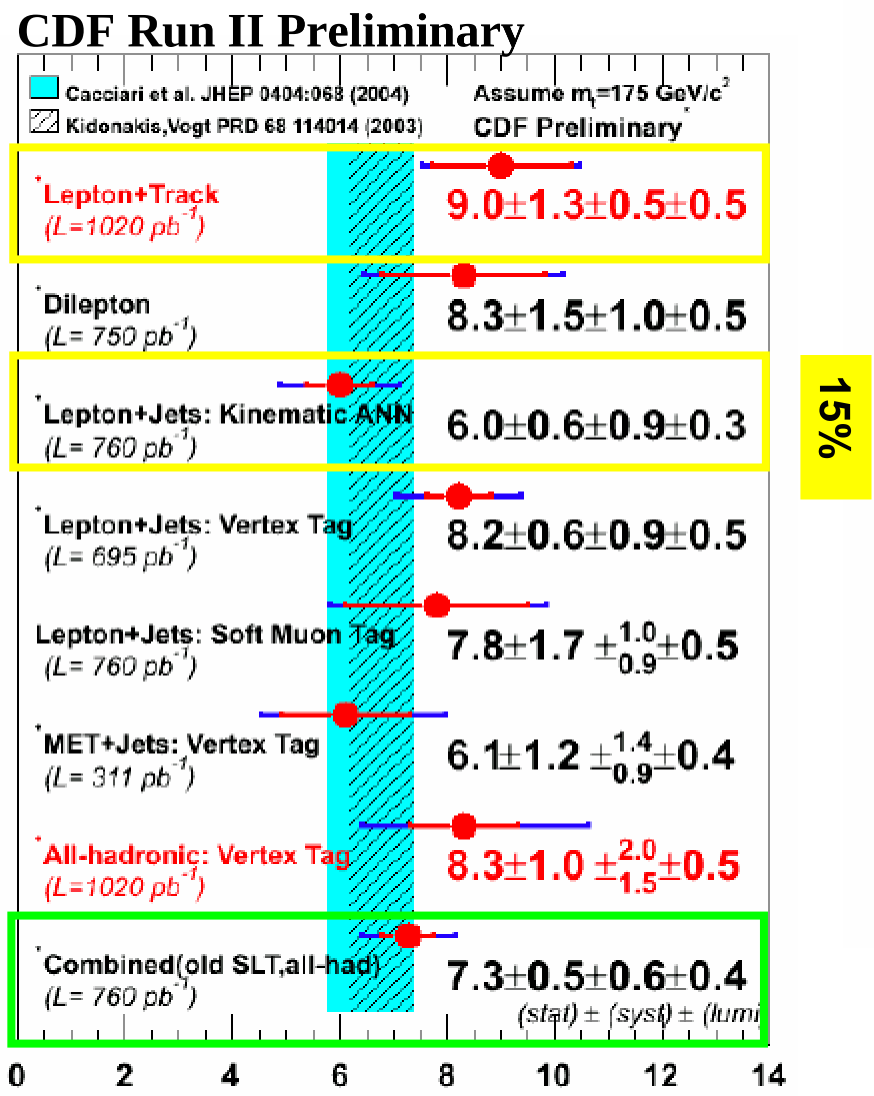
(2) $\sigma_{tt} = 6.3^{+0.9}_{-0.8}\ (\text{stat}) \pm 0.7\ (\text{syst}) \pm 0.4\ (\text{lumi})$ pb

(3) Published result 425 pb-1 PRD D 74, 112004

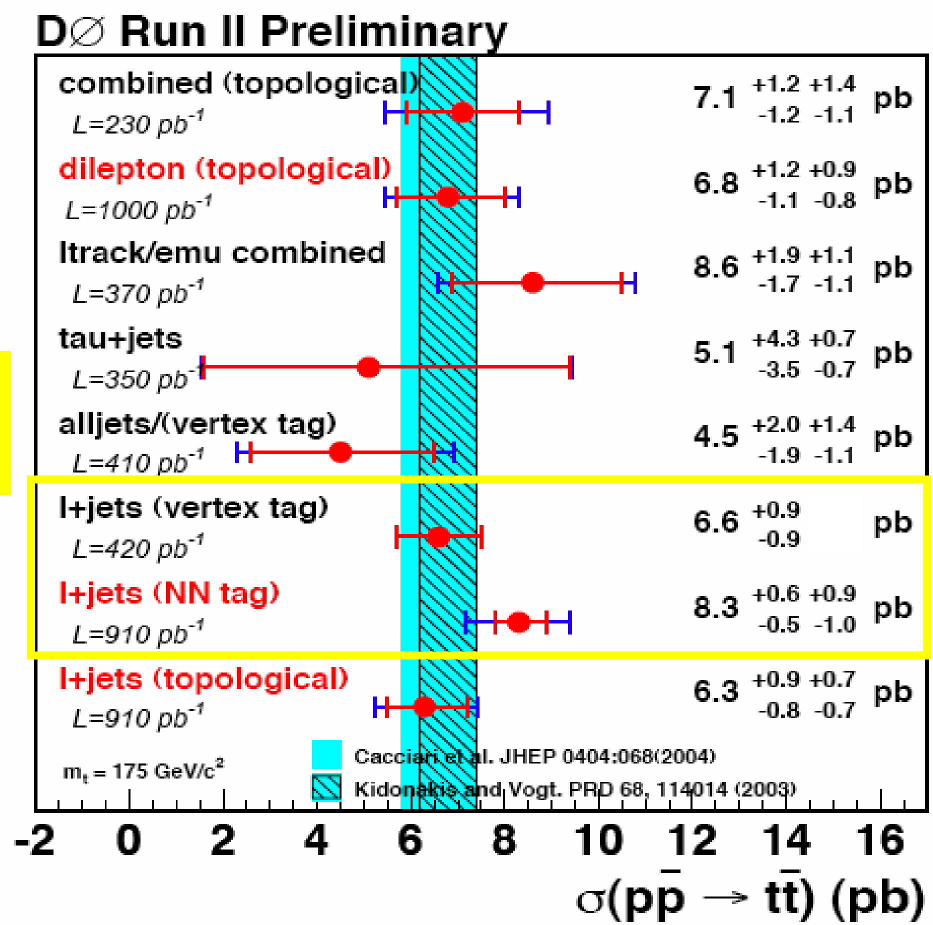
$\sigma_{tt} = 6.6 \pm 0.9\ (\text{stat+syst}) \pm 0.4\ (\text{lumi})$ pb

$\delta\sigma/\sigma =$ (1): 15%; (2)19%; (3) 14%

Cross Section Summary



Fall 2006 combination



Experimental results reaching theoretical precision of ~12%

Expect ~10% with 2fb^{-1}

Top Quark Pair Production Mechanism (1)

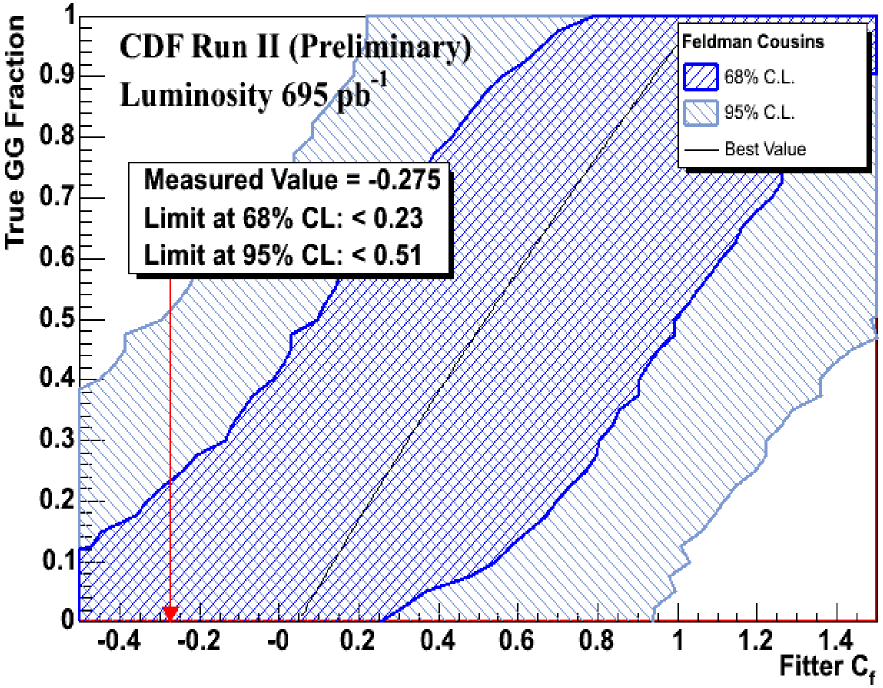
- NLO Theoretical predictions have large uncertainties:
  - **$q\bar{q}$ annihilation: 0.85±0.5**
  - **gluon fusion: 0.15±0.5**
- Top quark decays before hadronization
  - **Different production processes retain their kinematic characteristics in the final state**

Method 1:

Build a NN using 2 production and 6 decay variables & generate templates for $q\bar{q}$, gg and W+jets

Simulate Top samples with different fractions of gg & fit samples to the templates.

Output of fit is mapped to the known gg content of the samples.



Red line is NN fit obtained from data

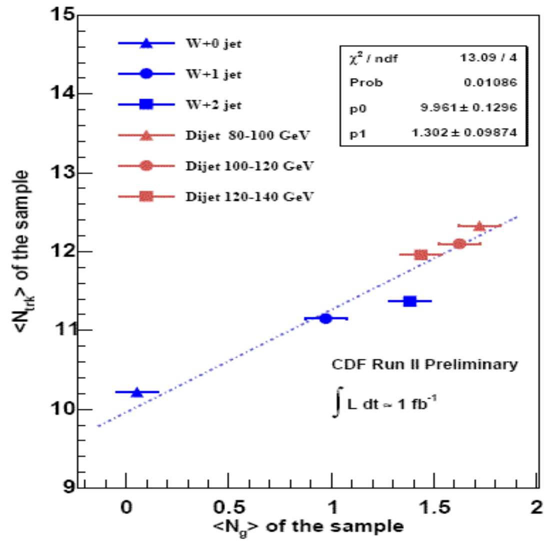
$$\frac{\sigma(gg \to t\bar{t})}{\sigma(p\bar{p} \to t\bar{t})} < 0.51 \quad 95\% \text{ C.L.}$$

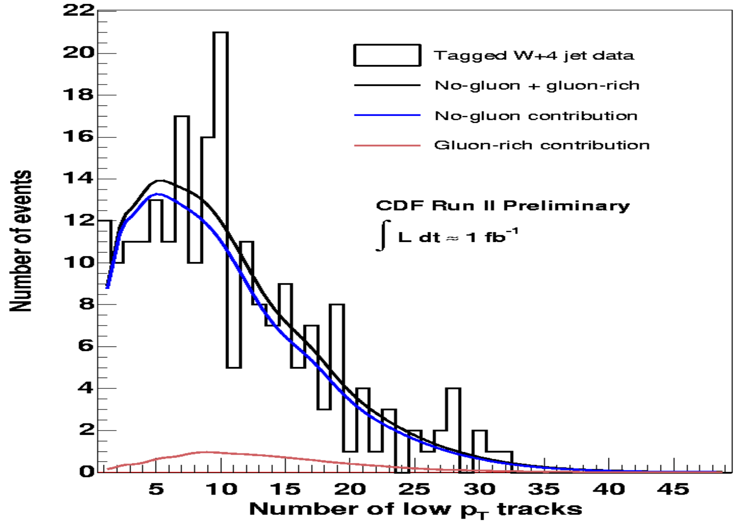
Top Quark Pair Production Mechanism (2)

Method 2:

- **Multiplicity of low p_T tracks correlated with number of gluons**
  - **Calibrate average number of tracks in collider data with gluon content in sample as predicted by MC**
  - **Obtain track multiplicity templates from data**
    - **W+0jets (no-gluon)**
    - **dijet events (gluon-rich)**
  - **Measure the gluon-rich fraction of tagged W+4 jets events by fitting the track multiplicity to the templates.**
  - **Extract the gluon-rich fraction of $t\bar{t}$ events using the known fractions of top and W+jets events in the sample.**

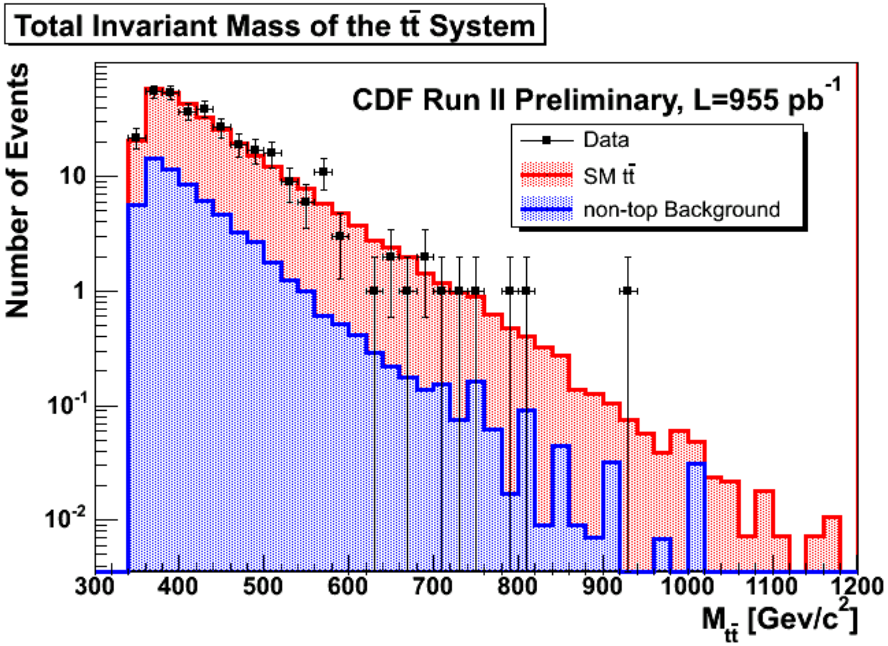
$$\frac{\sigma(gg \to t\bar{t})}{\sigma(p\bar{p} \to t\bar{t})} = 0.01 \pm 0.16(stat) \pm 0.07(syst)$$

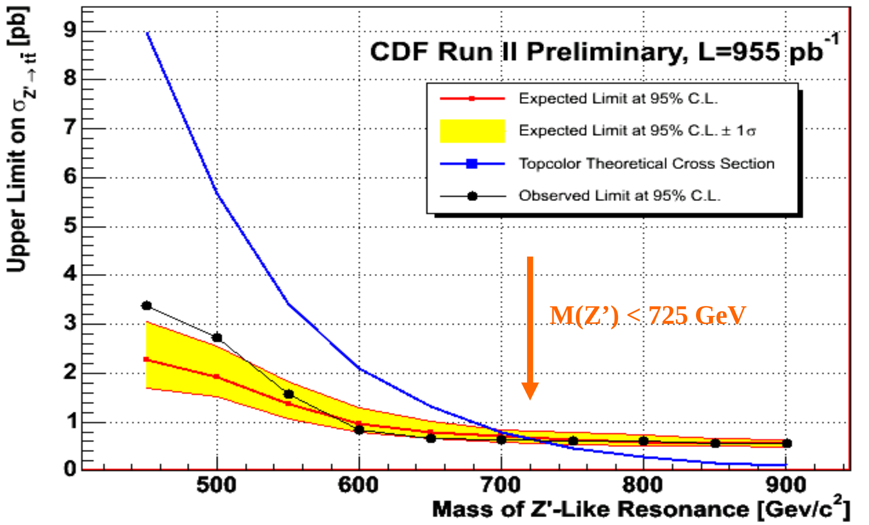




Search for $t\bar{t}$ Resonances

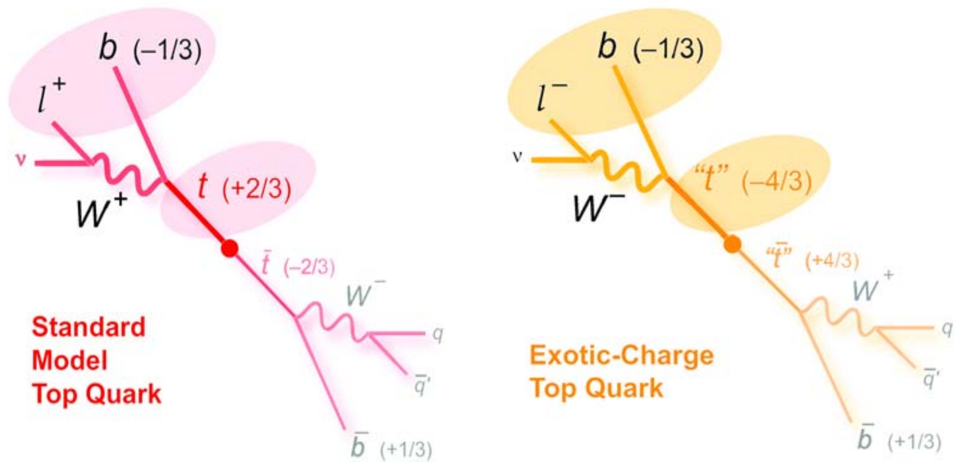
- Top pairs could be produced by the decay of a heavy particle into a $t\bar{t}$ pair: $X \rightarrow t\bar{t}$
- Study invariant mass spectrum of the l+jets b-tagged data sample and compare with SM predictions
  - **Spectrum is consistent with the SM expectations and shows no evidence for additional resonant production mechanisms**
- Model resonant $t\bar{t}$ production by a narrow heavy neutral boson
  - **Set model-dependent limits on resonant production**
    - **Topcolor leptophobic Z' excluded with M(Z') < 725 GeV**





Top Quark Charge (1)

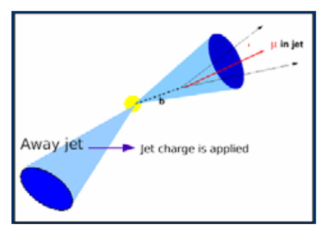
- Fundamental property of particle
  - **has not been determined yet**
- One possible scenario
  D. Chang et al, Phys Rev D59, 091503 (1999):
  - **The discovered top quark is an exotic quark of charge - 4e/3**
  - **The top quark with charge 2e/3, mass 270GeV not observed yet**
  - **Model accounts for precision Z data (including R_b and A_{FB}^b)**

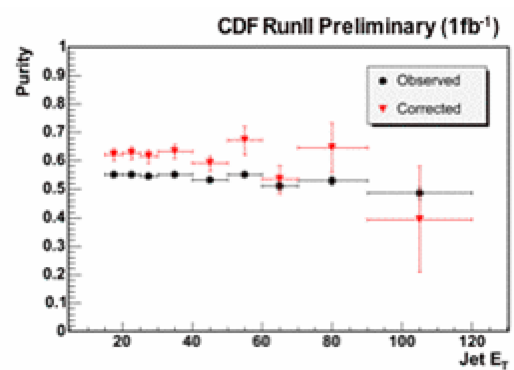


Analysis technique:

W charge from charge of lepton
Associate lepton with b-jet using constrained kinematic fit for l+jets double tagged & M²(lb) for dilepton tagged events
b charge obtained from momentum-weighted sum of charged tracks associated to b-jet, calibrated on data

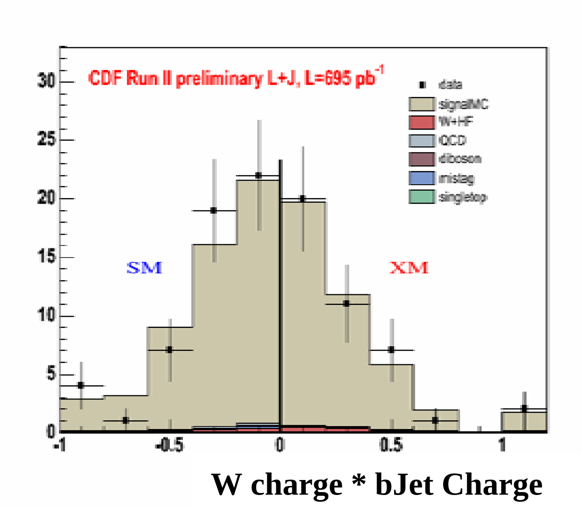
Jet Charge Calibration



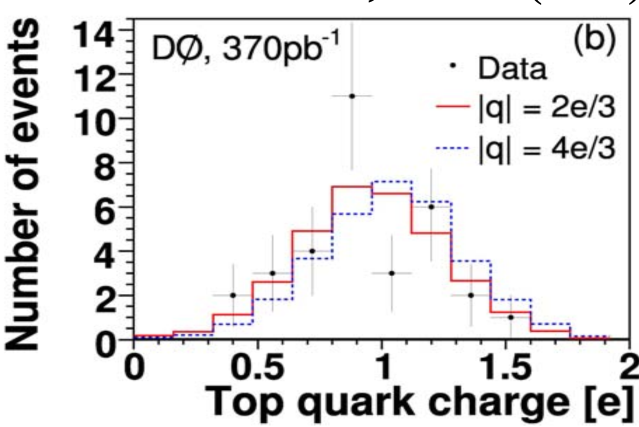


Select $b\bar{b}$ dijet events
Muon gives “true” charge
Measure charge in away-jet
~ 60% correct assignment

Top Quark Charge (2)



PRL **98,** 041801 (2007)



CDF:

Use Hypothesis testing with Null Hypothesis "SM is correct" & define a-priori probability of incorrectly rejecting SM to 0.01

If measured p-value is <0.01, exclude SM at 99% C.L.

If exotic model (XM) is true, 81% of all p-values are below 0.01. Measured p-value 0.35 (>0.01) ⇒ XM excluded at 81% C.L.

DØ:

Likelihood ratio test

Measured p-value = 0.078 (probability of obtaining measured value if the sample has 100% XM tops is 7.8%) ⇒ XM excluded up to max 92.2% C.L.

- C.L. Not directly comparable -

CDF: Measured p-value using DØ's method is 0.002 ⇒ XM excluded at max 99.8% C.L.

Bayes Factor (odds of SM vs XM) = 8.54 (CDF), 4.3(D0)

"Strong" "Positive"

Both CDF & DØ Data strongly favor the SM over XM

Conclusions and Outlook

- Entering a new era of precision top properties measurements
  - **Cross section measurements soon to reach precision of theoretical predictions**
  - **Comparisons across channels and methods interesting**
- Series of new top properties measurements becoming available with larger samples
  - **Production mechanisms**
  - **Top charge**

STILL NO SIGN OF NEW PHYSICS

Expect results based on 2fb^{-1} by Summer

Expect to have collected 4fb^{-1} by the end of 2007.