Tevatron:
Top quark production and properties

Veronica Sorin

Michigan State University

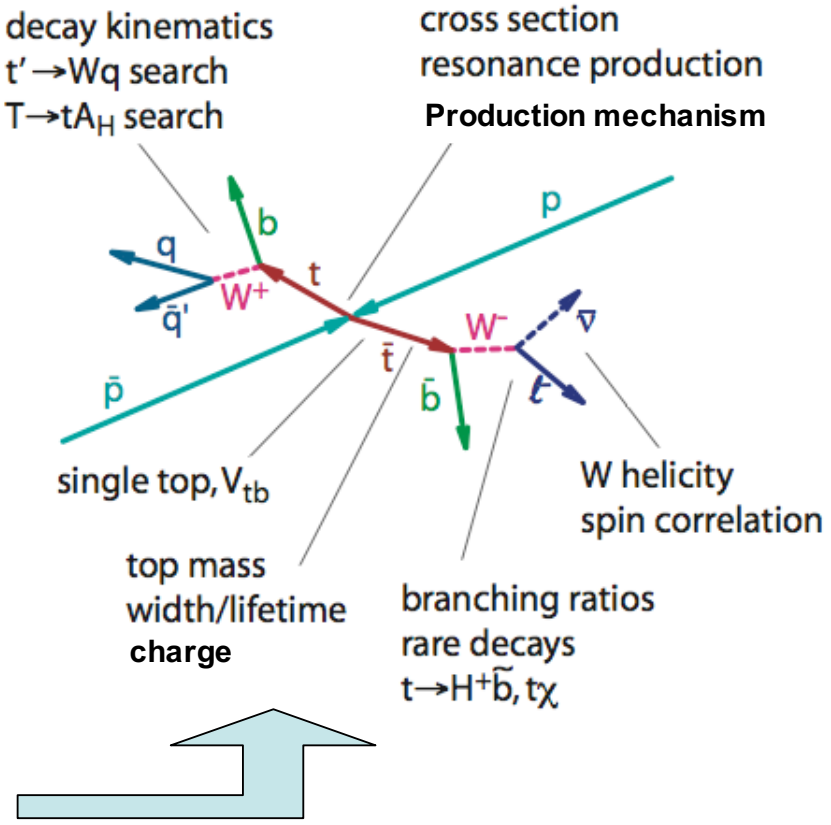
For the CDF and D0 Collaborations

Rencontres de Moriond EWK 2007

Top Physics

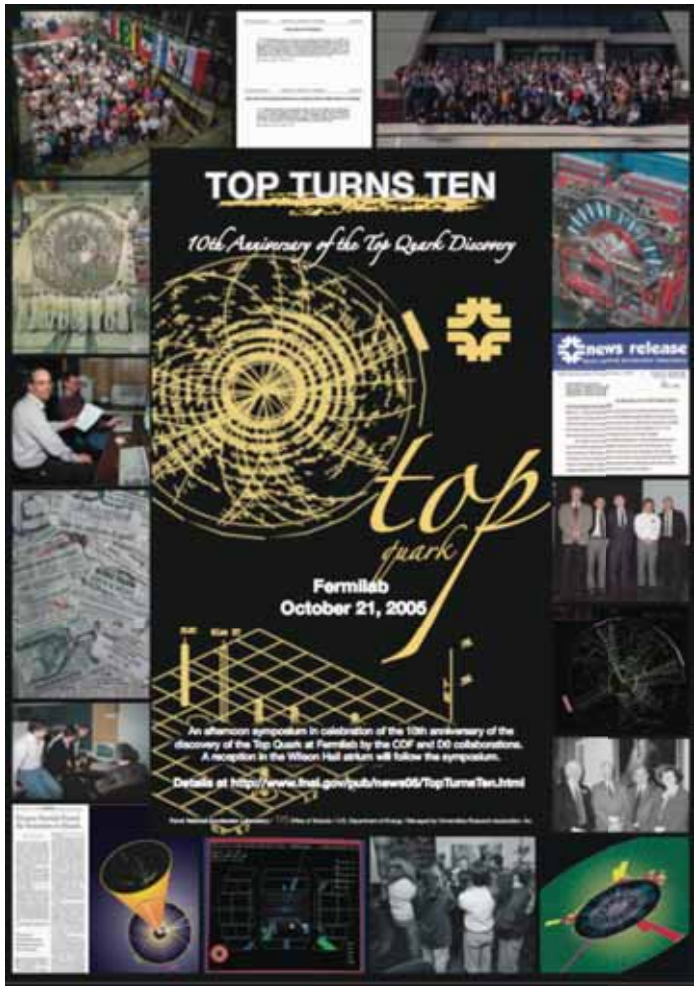
- Large Top mass
  - Special role in Electro Weak Symmetry Breaking?
- Is it SM top?
  - Need precision measurements of top properties
- Tevatron the only place to study top until into the LHC era.

Very rich top physics program at Tevatron



Top Physics Today

Tevatron doing well, more than 2 fb^{-1} on tape
Today's results up to $1fb^{-1}$



Final Run 1 analyses

~$110pb^{-1}$

~ 30 events per experiment

Today's presentation
factor 10 more data

Although still an
experimental challenge:

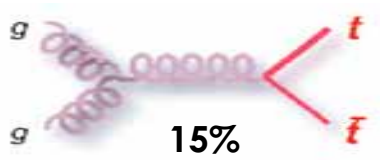
One top pair each 10^{10} inelastic collisions at $\sqrt{s}$ = 1.96 TeV

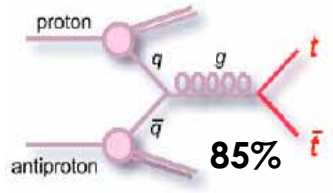
Entering a Precision Era in Run 2!

Outline

Top Pair Production

- Cross Section Measurements
- Production Mechanism
- Anomalous Production





Resonance Production

$$p\bar{p} \rightarrow X^0 \rightarrow t\bar{t}$$

Top Decay

In SM t→Wb ~ 100%

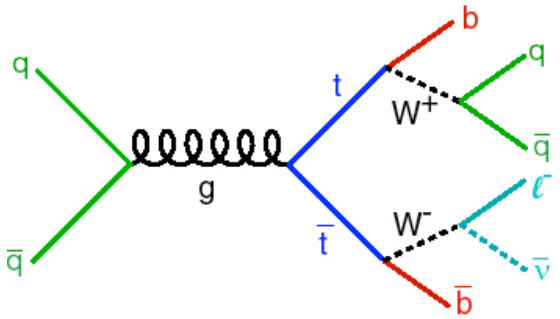
W helicity: Examine nature tWb vertex

Top Charge:

Is it top or an exotic quark?

- (EWK single top production : see talks by Stelzer and Garcia-Bellido)
- (Top Mass: see talk by E. Barberis)

Top Signatures



Measurements perform in distinct channels, classified based on W decays

Dilepton: Both W's decay via W→lν (l=e or μ, 5%)
Lepton+jets: One W decays via W→lν (30%)
All hadronic: Both W's decay via W →qq (45%)
Tauonic: 1 or both W decaying via W->tau ν (20%)

Signatures:
depend on decay channel
- High p_T lepton (> 20 GeV)
- Large missing E_T (> 20GeV)
- High E_T jets (>15GeV)
  - 2 b-jets

Main Backgrounds
W+jets, Diboson, DY,
QCD multi-jets

To reduce Background,
identify jets containing a b quark :
reconstruct displaced vertices
•Efficiency per jet ~ 50%
•False tag ~0.5%
Other methods, like soft lepton taggers

Is Top Produced as Expected?

Pair Production Cross Section

- Test QCD in high Q^2 regime
- Deviations from SM expectations could indicate non-SM productions mechanisms
- or new physics in the top sample

$$\sigma_{t\bar{t}} = \frac{N_{\text{observed}} - N_{\text{background}}}{A \cdot \varepsilon \cdot \int \mathcal{L}\, dt}$$

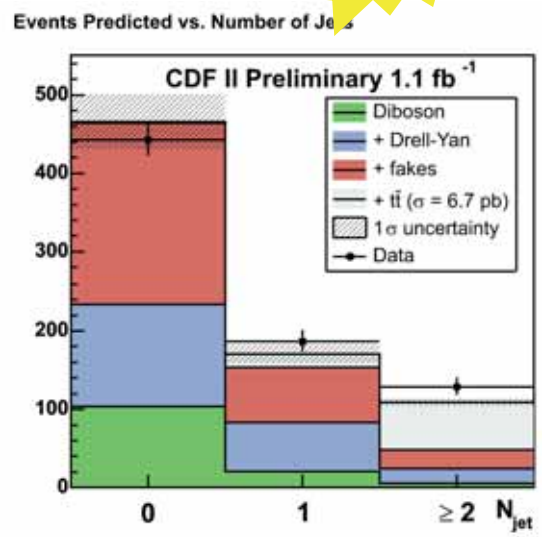
- Measure in different final states:
  - different sensitivity to new physics
- Use complementary techniques :
  - "counting" vs shape fit
- Provides sample composition for other top properties measurements
- ttbar is background for searches

NLO Theoretical Prediction

$$\sigma(\bar{p}p \to t\bar{t} \,@\, M_{top} = 175 GeV) \approx 6.7 \pm 0.8 \text{ pb}$$

Kidonakis et al. PRD 68 114014
Cacciari et al. JHEP 0404:068

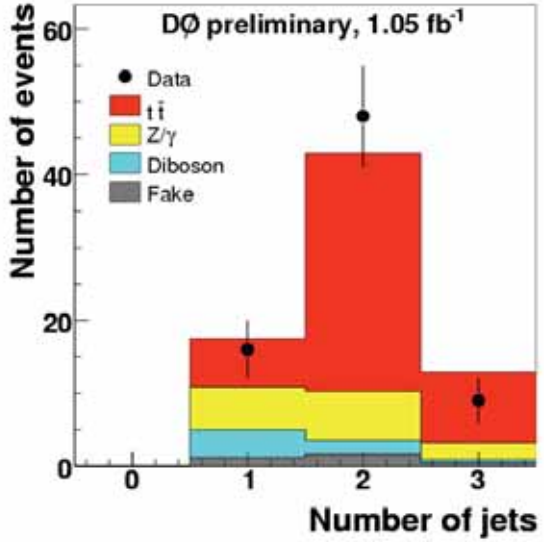
New Pair Production Cross Section



Lepton+Track
opposite-sign
with ≥2 jets

$\sigma_{t\bar{t}} = 9.0 \pm 1.3\ (stat) \pm 0.5\ (syst) \pm 0.5\ (lum)$ pb

b-tagged result coming soon !

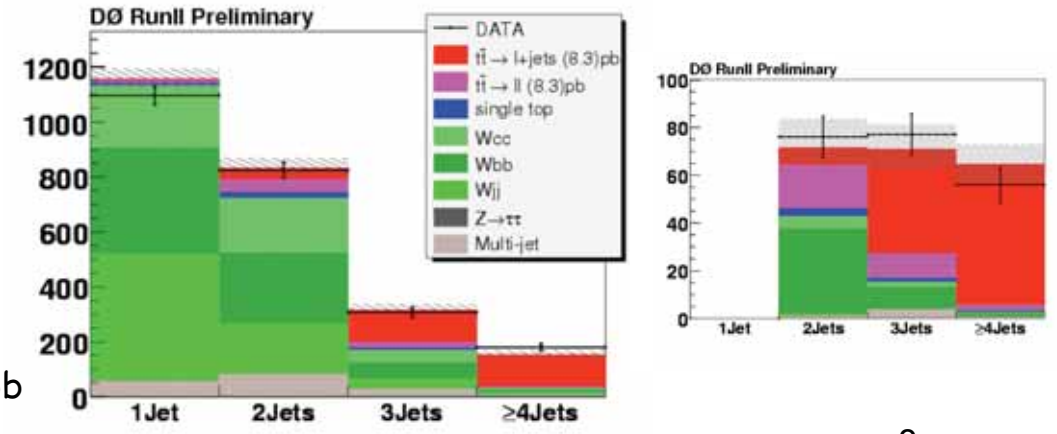


Dilepton
opposite-sign
with ≥1 jets for
eμ and ≥2
jets for others

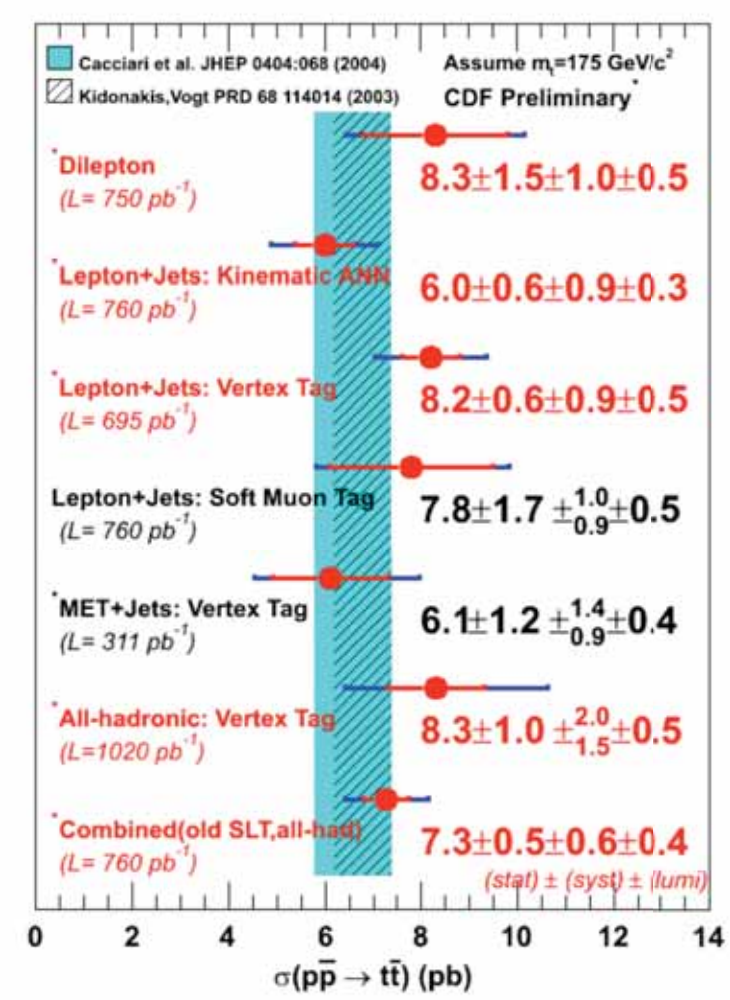
$\sigma_{t\bar{t}} = 6.8\ ^{+1.2}_{-1.1}\ (stat)\ ^{+0.9}_{-0.8}\ (syst) \pm 0.4\ (lum)$ pb

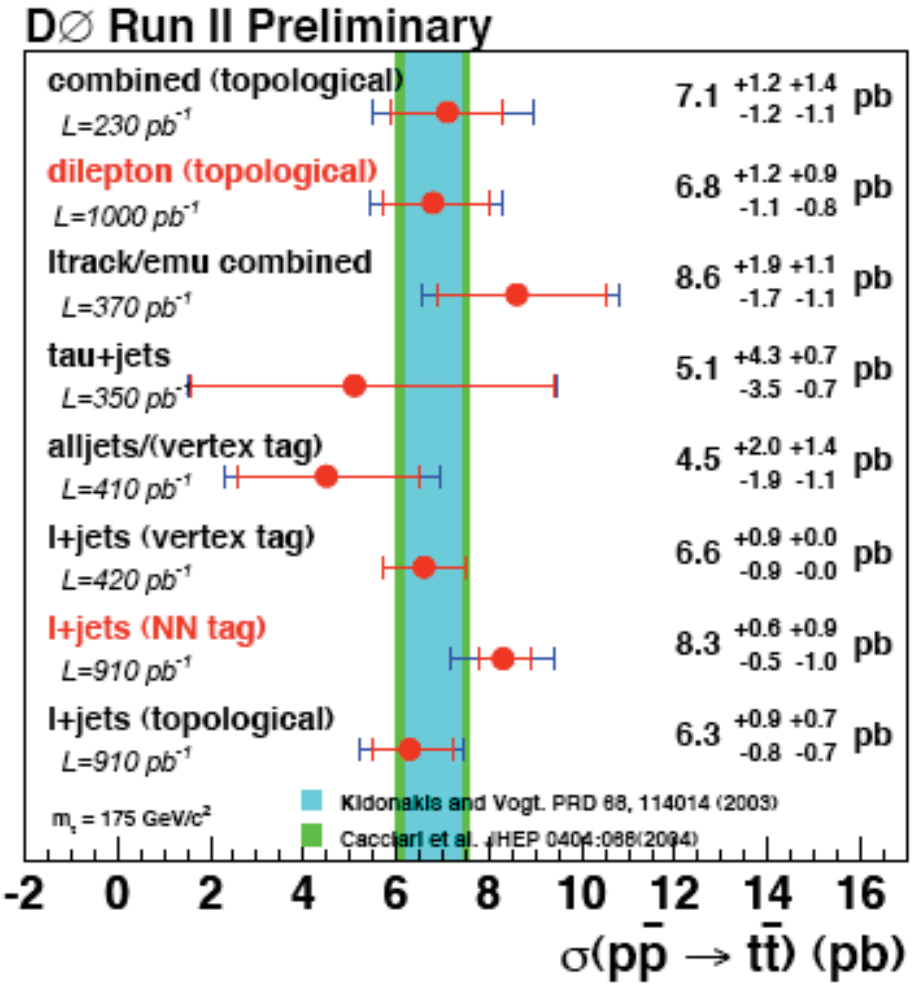
Lepton+Jets
L+J events, with NN b-tagger
3 or ≥4 jets , 1 or 2 tags

$\sigma_{t\bar{t}} = 8.3\ ^{+0.6}_{-0.5}\ (stat)\ ^{+0.9}_{-1.0}\ (syst) \pm 0.5\ (lum)$ pb



Top-Pair Cross Section Summary





No surprises yet…

Expect 10% uncertainty/experiment with 2fb^{-1}

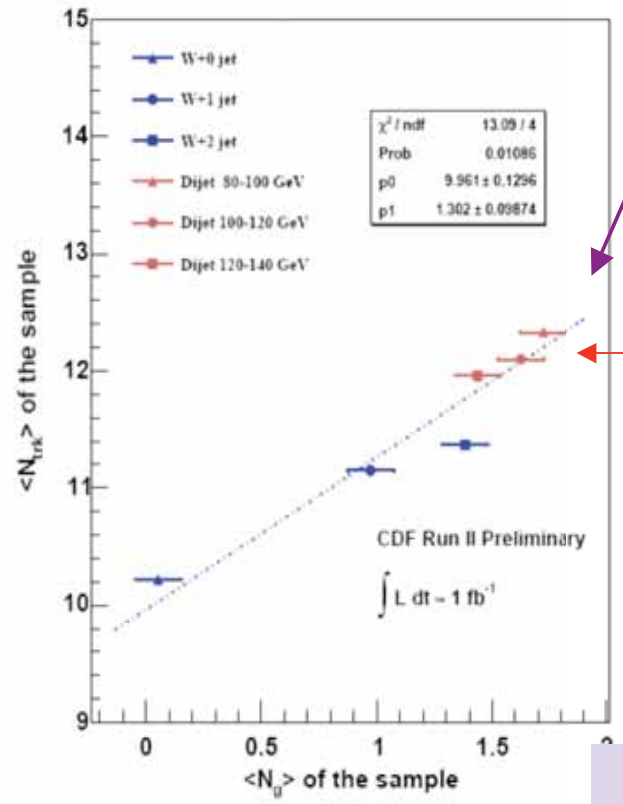
Production Mechanism

At Tevatron: 85% qq annihilation, 15% gg fusion

Measure ratio of gg/qq top pair production

- **Test pQCD and sensitive to new physics**

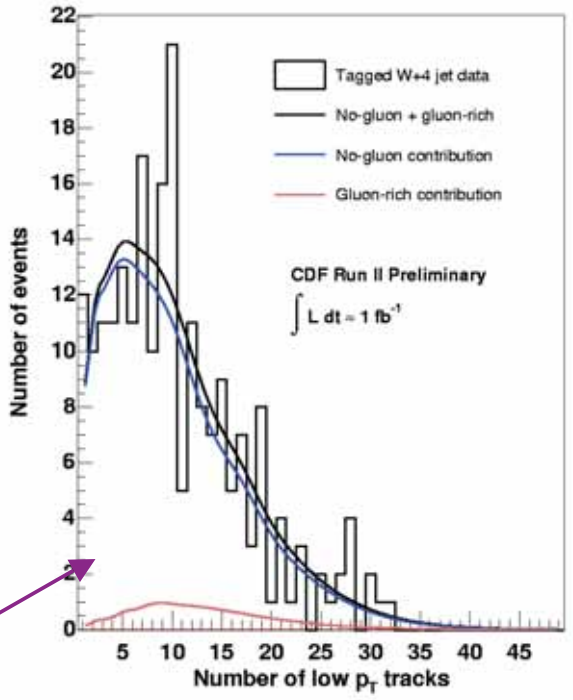
Use number of low p_T tracks as discriminator



Calibrate $\langle N_{trk} \rangle$ vs $\langle N_g \rangle$ in W+Jets and Dijet data

Higher density in gluon-rich events

Fit tagged W+4 jets data to gluon-rich and no-gluon templates

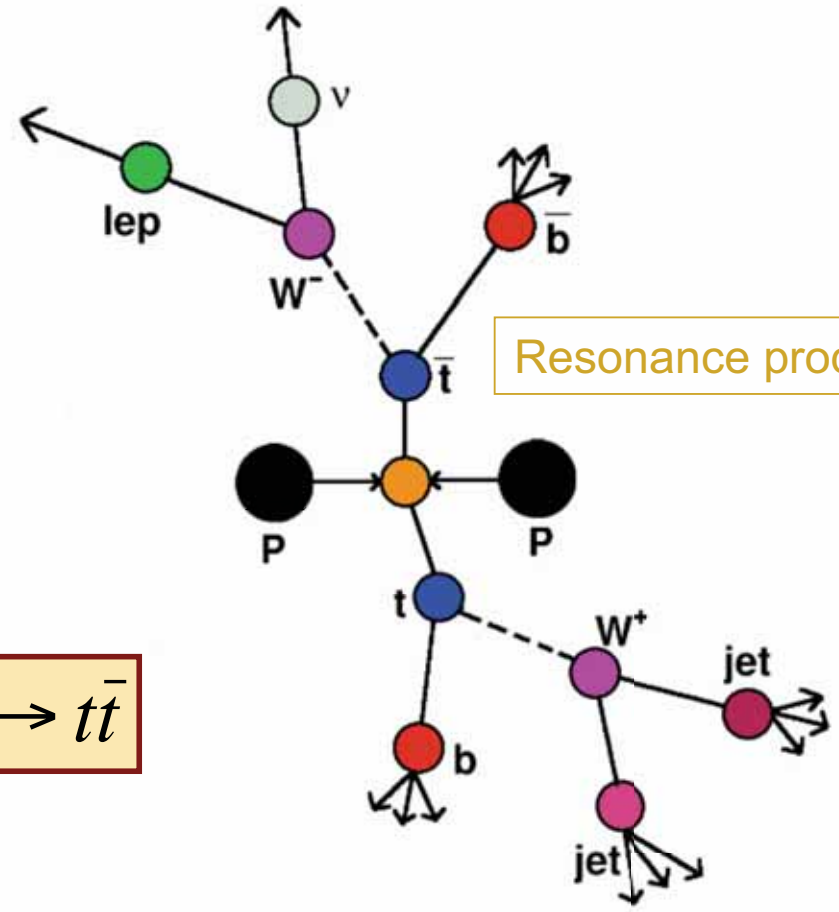


$$\frac{\sigma(gg \to t\bar{t})}{\sigma(p\bar{p} \to t\bar{t})} = 0.01 \pm 0.16(stat) \pm 0.07(syst)$$

Is Top Produced as Expected?

Heavy resonance decaying to *ttbar?*

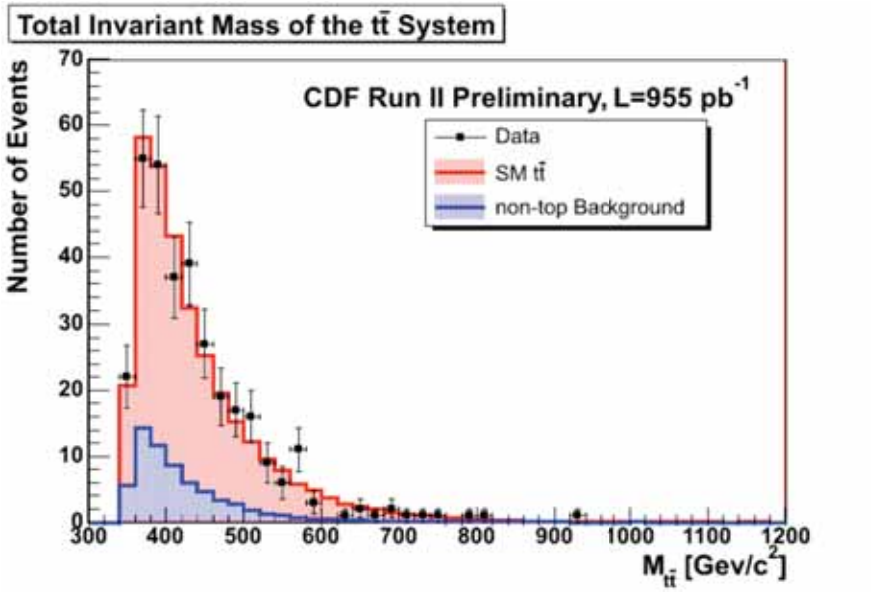
$$p\bar{p} \rightarrow X^0 \rightarrow t\bar{t}$$

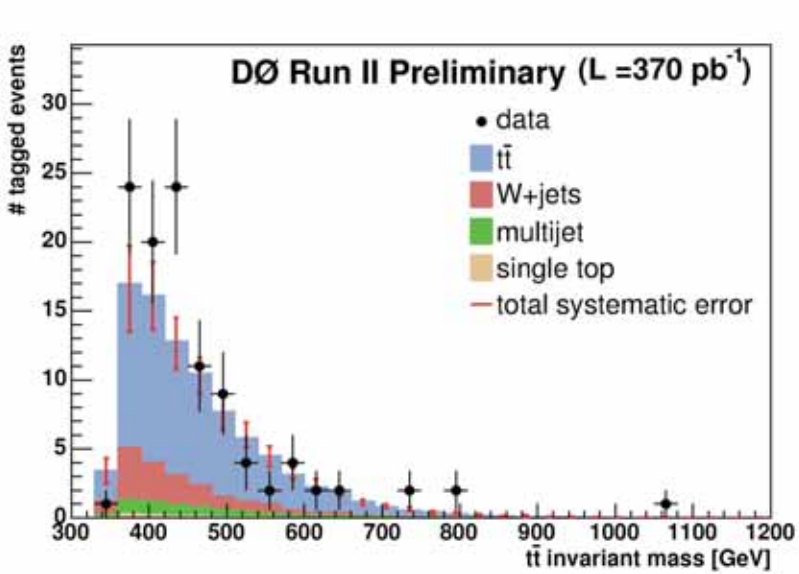


Resonances decaying to top pairs

Look at the invariant mass of t-tbar system

Compare with Standard Model expectations.





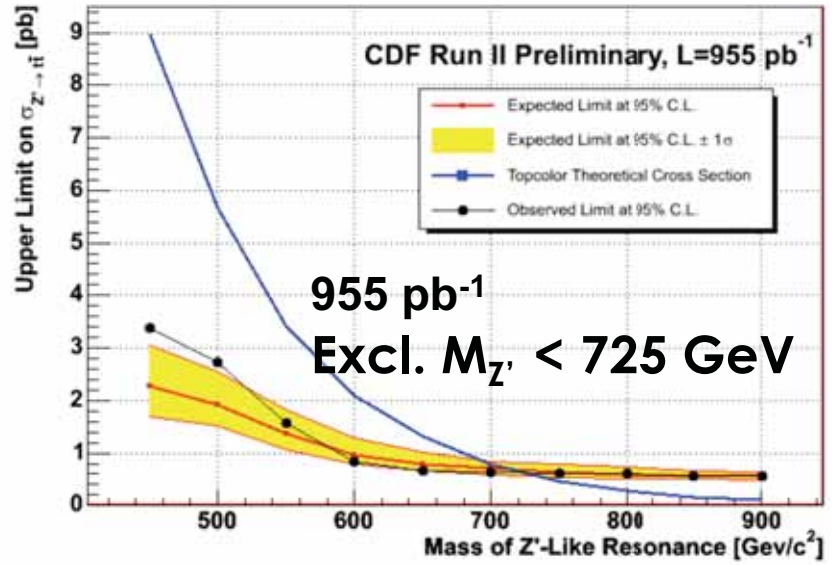
Reconstructed using constrained kinematic fit

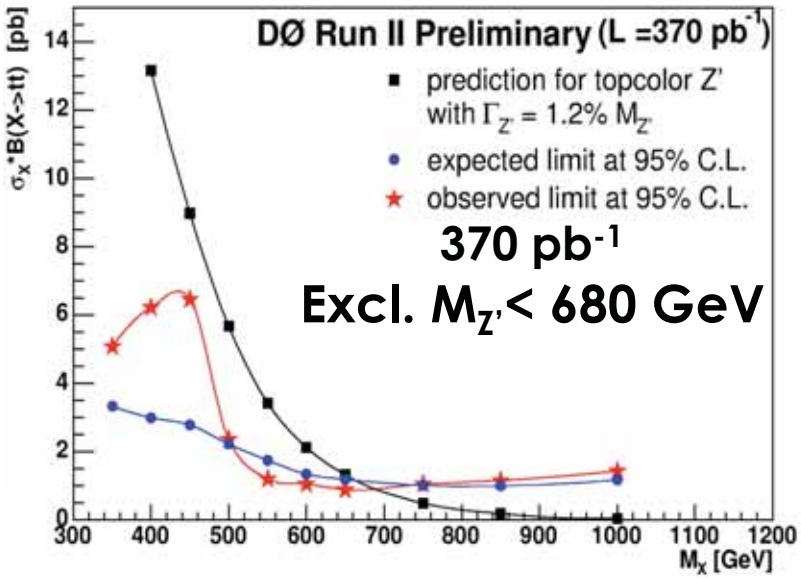
Lepton+Jets with ≥4 jets and ≥1 b-tag

Resonances decaying to top pairs

Add signal of new physics, such as a narrow-width heavy resonance.

Derive 95% limit on $\sigma_X \cdot BR(X \rightarrow ttbar)$





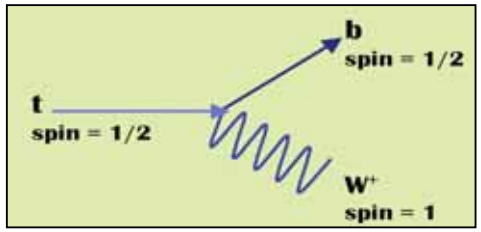
Data consistent with SM

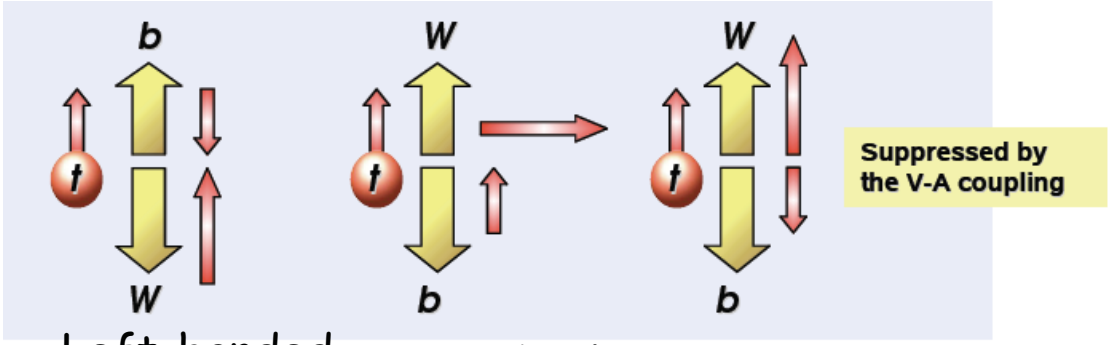
Exclude leptophobic Z' with $M_{Z'} < 725$ GeV

Top Decay: examine tWb vertex

Top quark Decay: W Helicity

Within SM, top decays via weak interaction → V-A coupling





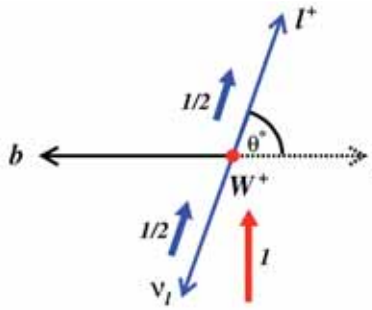
Left-handed $F_- \sim 0.3$

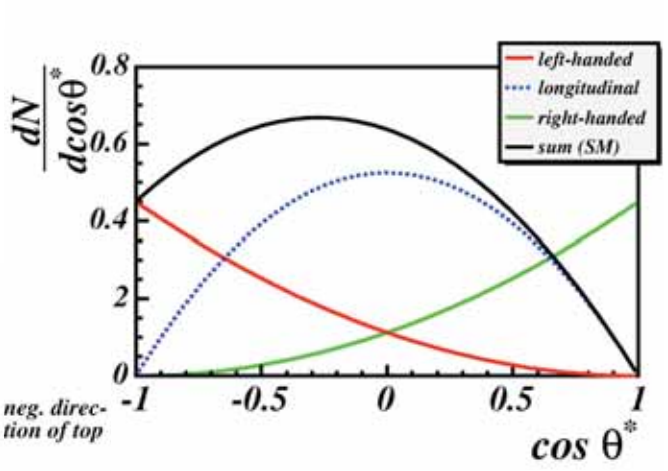
Longitudinal $F_0 \sim 0.7$

Right-handed $F_+ \sim 0$

Measure fractions using variables sensitive to angular distributions of W decay products:

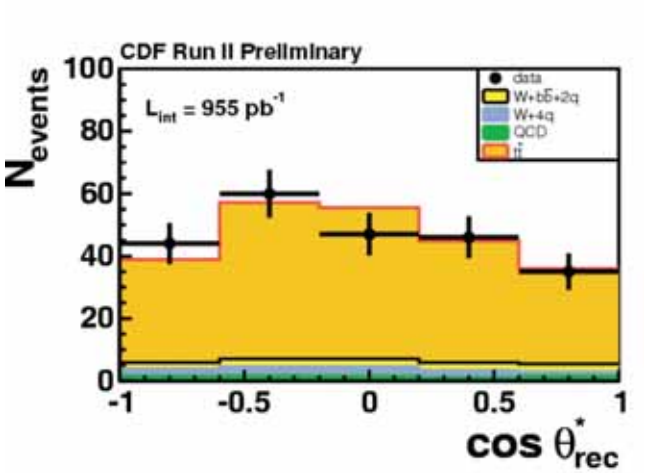
- $\cos(\theta^*)$
- M^2_{lb}
- Lepton p_T





W helicity measurements

1fb^{-1}, Lepton + Jets ≥1 b-tag



F_0 = 0.59 ± 0.12(stat) ± 0.07(syst) (Fix F_+ = 0)
F_+ = -0.03 ± 0.06(stat) ± 0.04(syst) (Fix F_0 = 0.7)
F_+ < 0.1 @ 95% CL

Results statistically limited
Consistency with SM predictions

370pb^{-1}, Dilepton and L+J

F_+ = 0.056 ±0.08(stat)±0.057(syst)
F_+ < 0.23 @ 95% CL

PRD **75**, 031102 (2007)

700pb^{-1}, Dilepton and L+J (1 or 2 tags)

Using M^2_{lb}

F_+ = -0.02 ± 0.07
F_+ < 0.09 @ 95% CL

PRL **98**, 072001 (2007)

Top Charge

Is it Top?: Top Charge

In SM t → Wb, but is it
our sample consistent with:
W^+b : SM Top with charge +2/3
or
W^-b : an exotic quark of -4/3

D. Change et al. PRD 59, 091503 m_t~270GeV

Analysis Strategy:

- Charge of W (lepton charge)
- Pairing between W and b
- Flavor of b-jet
  - JQ algorithm: momentum weighted sum of charged tracks associated to b-jet
    Calibrated in double tagged dijet events

New

Top Charge (II)

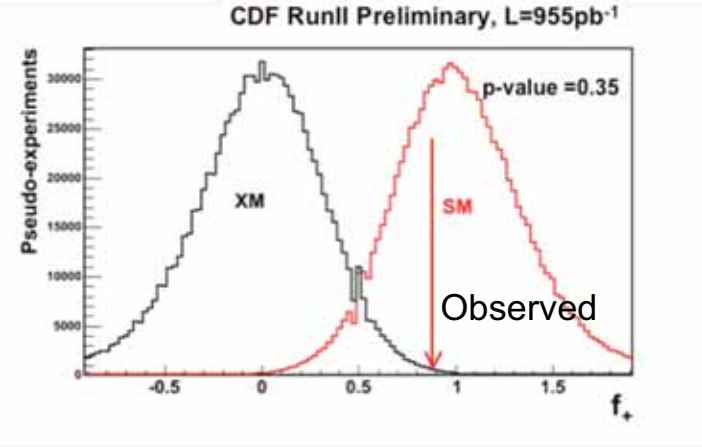
955pb^{-1} Dilepton (tagged) and
695pb^{-1} L+J (double tagged)

Counting Experiment
Find Number of pairs SM like (W^+b)
and eXotic Model (W^-b) like.

Pairing:
- In Dil, using Mlb^2 as discriminant
- In L+J, constrained kinematic fitter

Jet Flavor:
- b-jet if JQ<0, bbar if JQ >0

If either Exotic or SM
Using Profile Likelihood,
f+ : fraction of SM



Require 99%CL for SM ⇒
Define a-priori Prob of incorrectly rejecting the SM : α = 0.01 (1%)
Prob of rejecting the SM if XM is true:
Power of test β (at α= 1%) = 81%

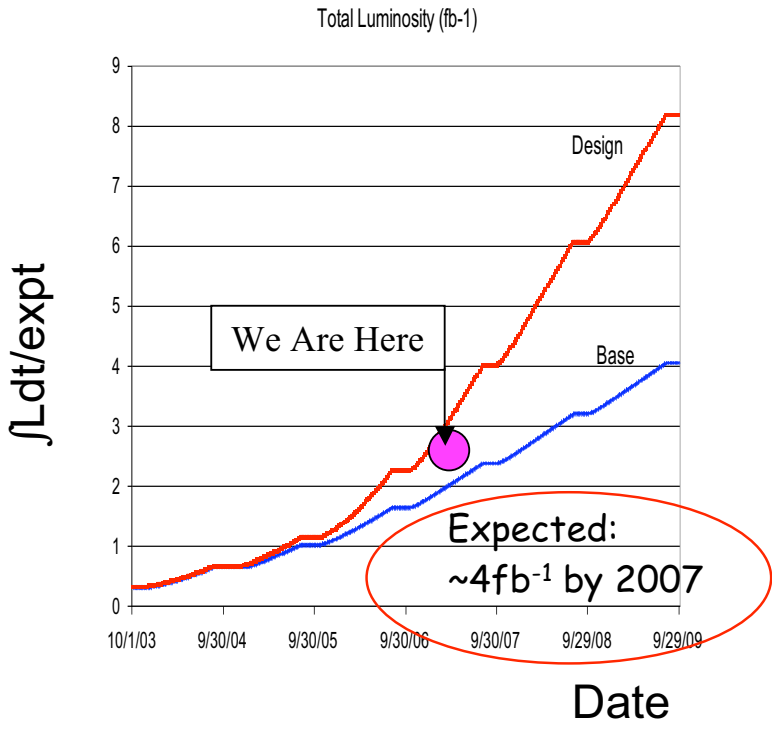
Observed 62 SM and 48 XM pairs

f+= 0.88, p-value = 0.35
-> p > α : Consistent with SM
Reject XM with 81% CL

Summary

- Top Cross Section consistent with SM :
  - ➢expect to be measured to <10% with 2fb^{-1}
  - ➢meaningful comparison among channels coming soon !
- Top Properties so far consistent with SM:
  - ➢ still statistically limited
  - ➢ on-going effort to optimally utilize data and control systematics
  - ➢So far no evidence for new physics

Tevatron , CDF and D0 doing very well
Expected 2fb^{-1} results by summer.
Stay tuned !

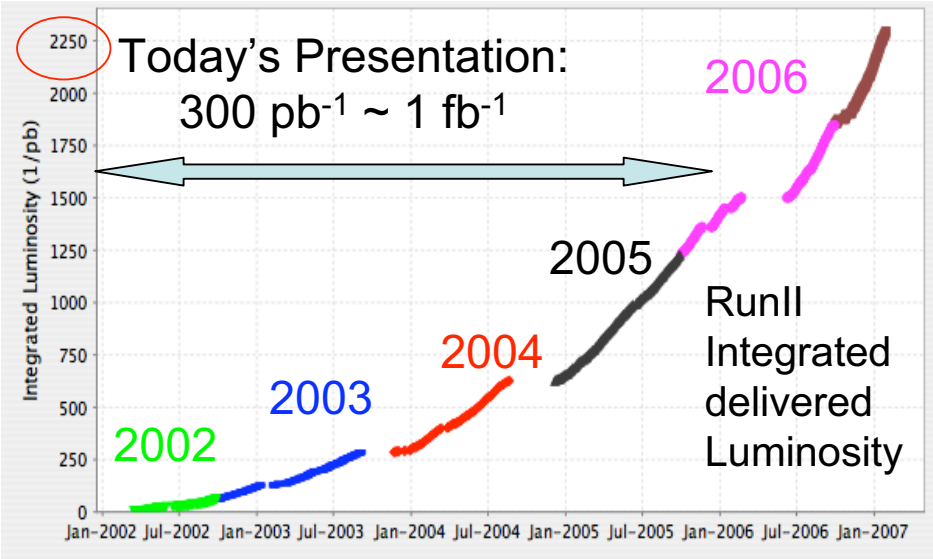


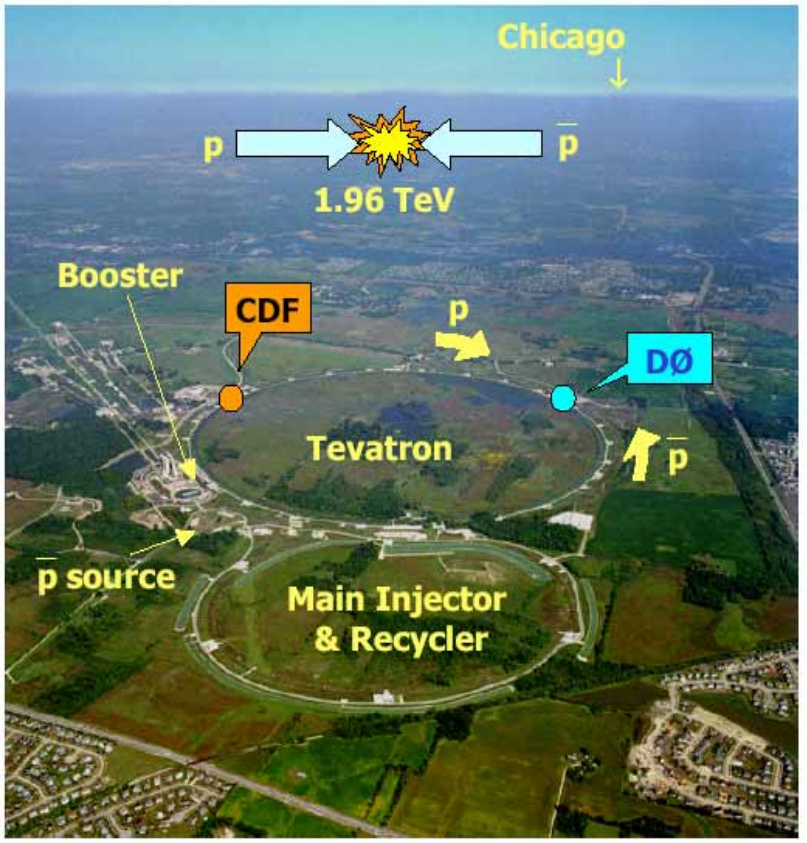
http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html
http://www-cdf.fnal.gov/physics/new/top/top.html

Back-up Slides

TEVATRON

- RunII $\sqrt{s}$ = 1.96 TeV
- Peak luminosity record:
  2.8×10^{32} cm^{-2} s^{-1}
- Integrated luminosity
  - Weekly record:
    40 pb^{-1} /week/expt
  - Total delivered: ~2.5 fb^{-1} /expt.
  - Total recorded: ~2. fb-1 /expt





Expect ~4fb^{-1} by end this year!

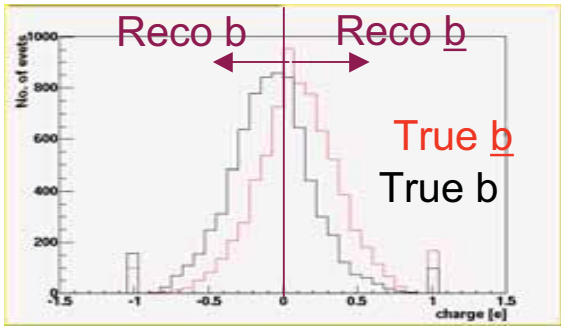
Top Charge

New

$955pb^{-1}$ Dilepton (tagged) and
$695pb^{-1}$ L+J (double tagged)

Counting Experiment
Find Number of pairs SM like (W^+b) and eXotic Model (W^-b) like.

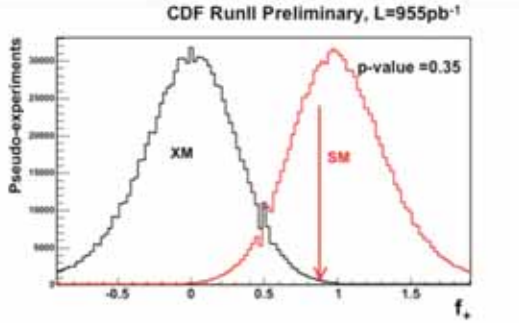
Pairing:
In Dil, using Mlb^2 as discriminant
In L+J, constrained kinematic fitter



If either Exotic or SM:
Using Profile Likelihood,
f+ : fraction of SM

Decide a-priori
α= 1%

(Prob of incorrectly rejecting the SM)

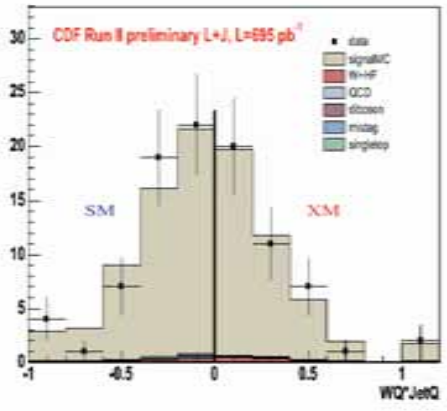


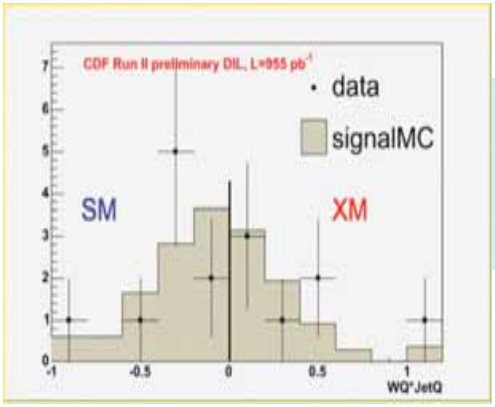
Power of test β (at α 1%) = 81%

(prob of rejecting the SM if XM is true)

(Sensitivity approx to compare with D0 : 99.8%)

Observed 62 SM and 48 XM pairs

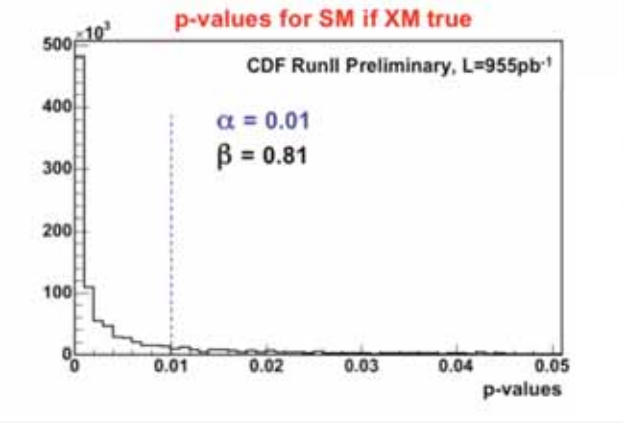


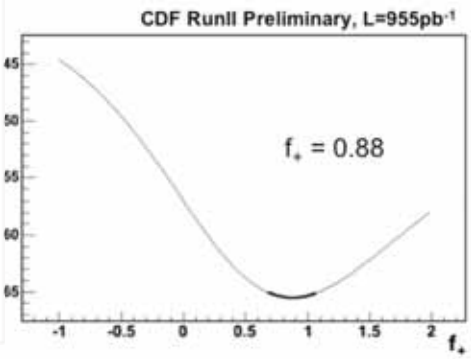


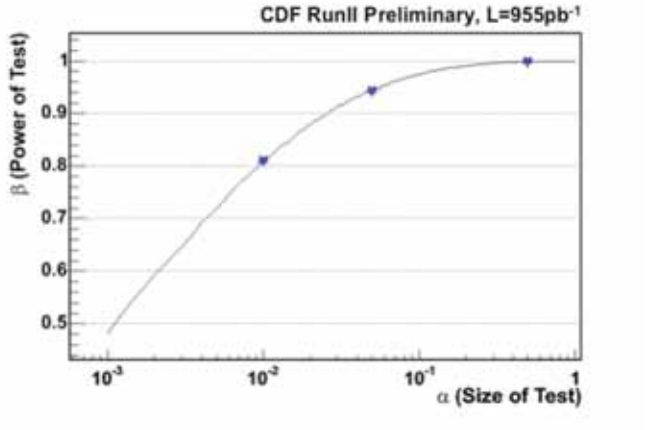
f+= 0.88, p-value = 0.35
-> p > alpha: Consistent with SM
Reject XM with 81% CL

Bayes Factor: 2ln(BF)=8.5
data favors strongly the SM hypothesis over the exotic.

Top Charge



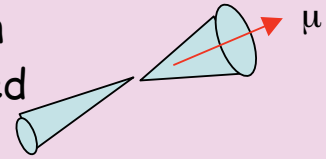




Flavor Tagging

JQ algorithm: momentum weighted sum of charged tracks associated to b-jet

Calibrated in double tagged dijet events



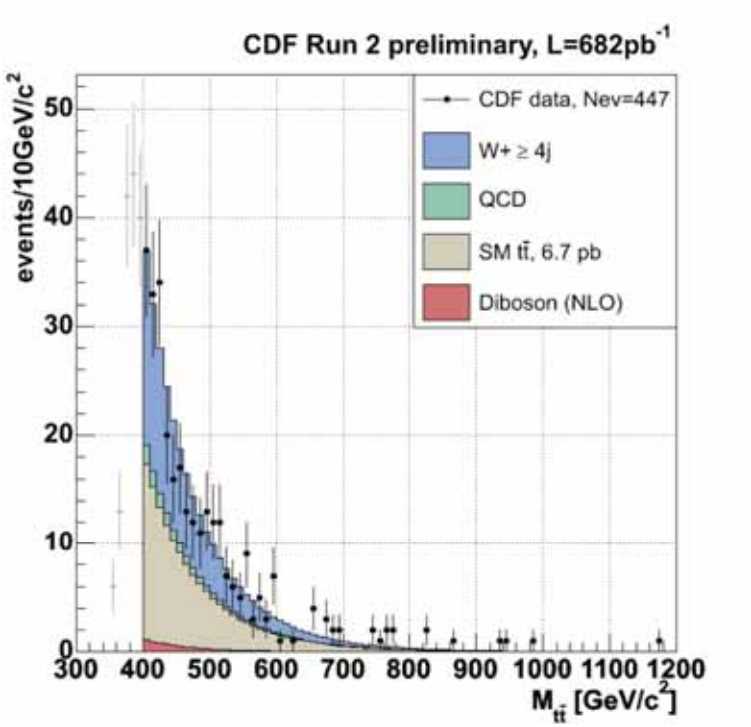
requiring a soft muon

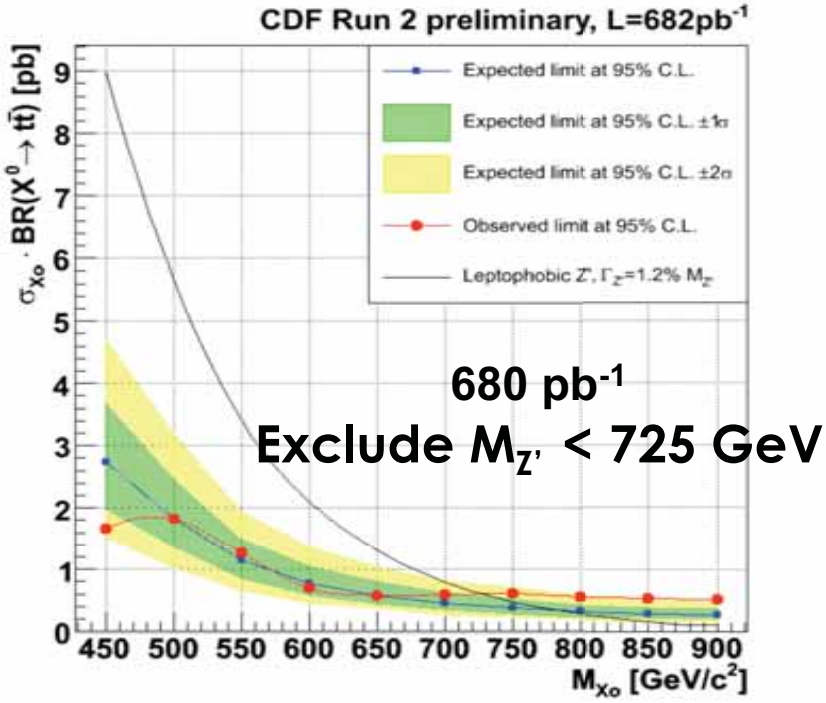
Correct for B-mixing, b → c → μ

Resonances decaying to top pairs

Lepton+Jets with ≥4 jets

Reconstructed matrix element technique





680 pb^{-1}

Exclude M$_{Z'}$ < 725 GeV

M$_{ttbar}$ spectrum consistent with SM

W helicity Measurement

Using M^2_{lb} : 700pb^{-1}, DIL and L+J (1 or 2 b-tag)