Top Results from the Tevatron

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for the CDF and D0 Collaborations

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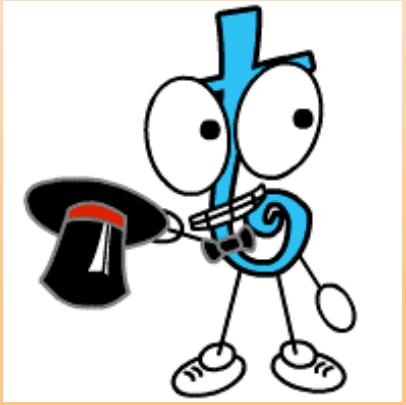
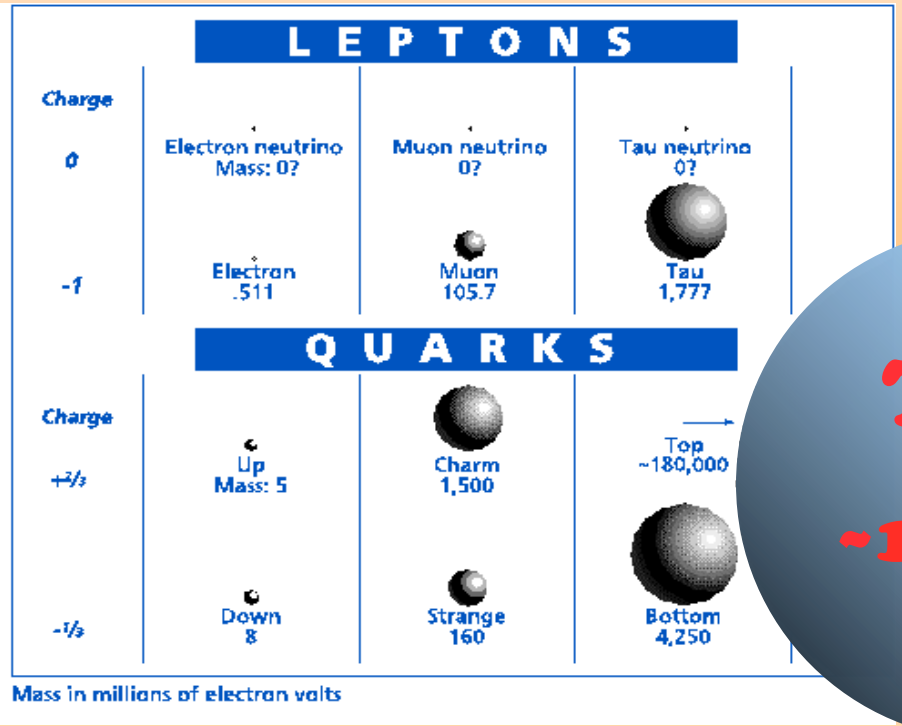
Top Quark

- Discovered in 1995 at Tevatron
- Youngest member of the quark family
- “Last brick” to the Standard Model



- Not a surprising discovery: b-quark requires isospin partner, however …

Why is the top quark so special …



- Unexpectedly huge mass
- Comparable to gold nucleus

TOP

~175 GeV

$$y_t = \frac{\sqrt{2}m_t}{v} \approx 1$$

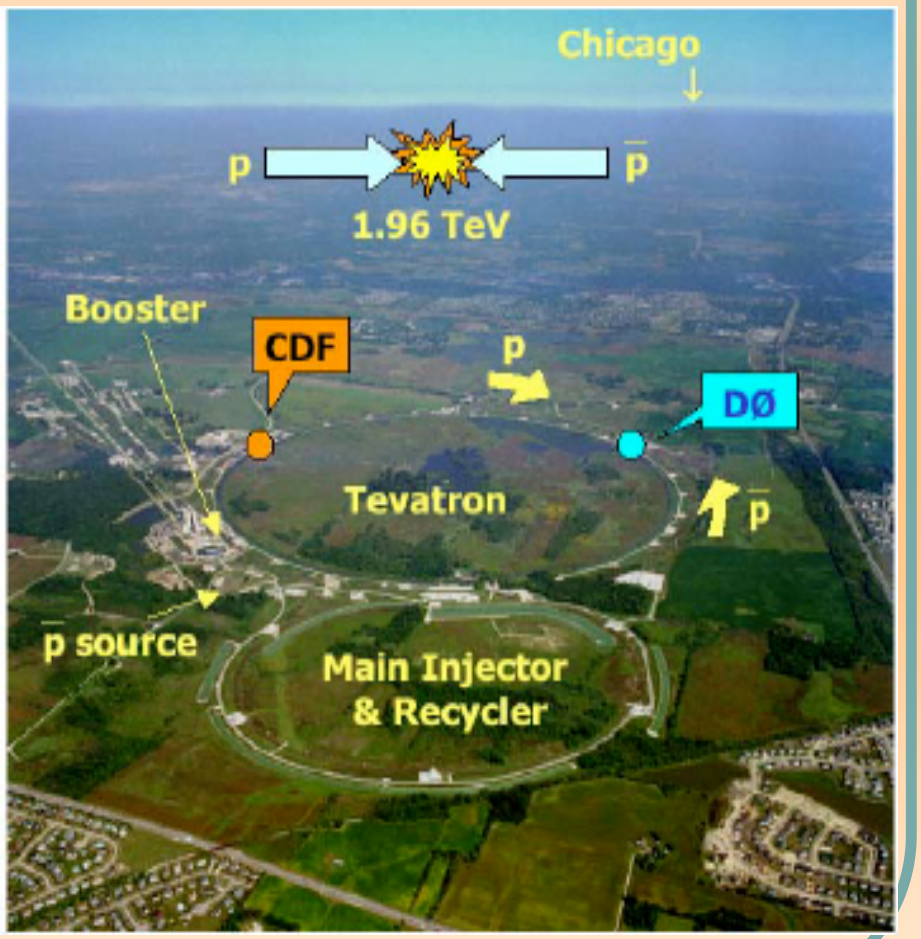
- Special role in the dynamics of EWSB ?
- Serves as a probe of BSM physics

$$\tau_{top} \sim 10^{-24}\,\mathrm{s}\,,\ \Gamma^{-1} \approx (1.5\,\mathrm{GeV})^{-1} << \Lambda_{QCD}^{-1} \sim (200\,\mathrm{MeV})^{-1}$$

- Decays before hadronizing
- Passes momentum and spin info to its decay products

Tevatron Collider

- Currently the world's only top quark production machine
- Operating at world's highest particle energy collisions
- Two multi-purpose detectors
- Run I (1992-1996)
  - $\sqrt{s}$ = 1.8 TeV
  - Integrated Lum ~110 pb^{-1}
  - Top Discovery!
- Run II (2001-present)
  - $\sqrt{s}$ = 1.96 TeV
  - 30% higher ttbar cross section



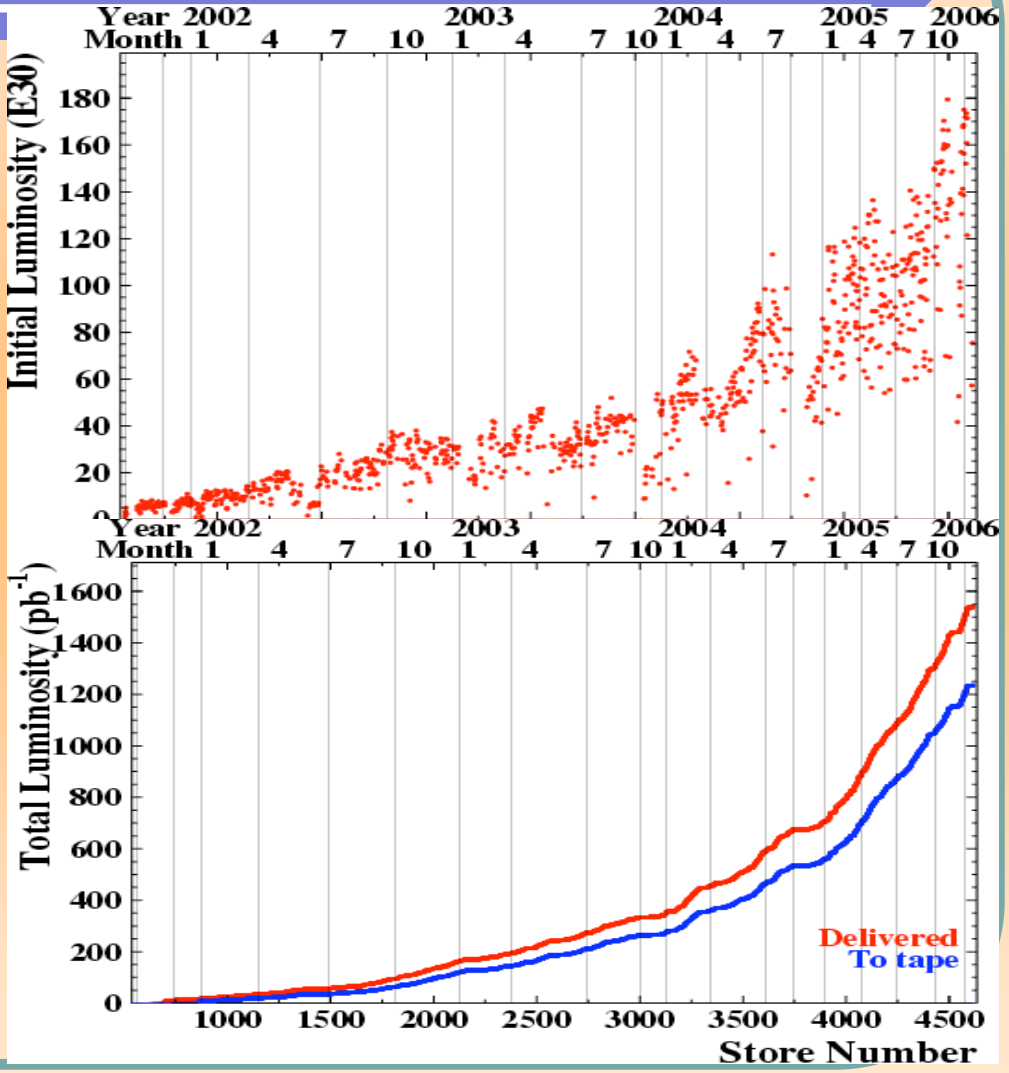
Luminosity in Run 2

Record initial Luminosity
1.8×10^{32} $cm^{-2}s^{-1}$
(11/10/2005)

Expect 2.5×10^{32} $cm^{-2}s^{-1}$ next year

On tape ~1.2 fb^{-1}

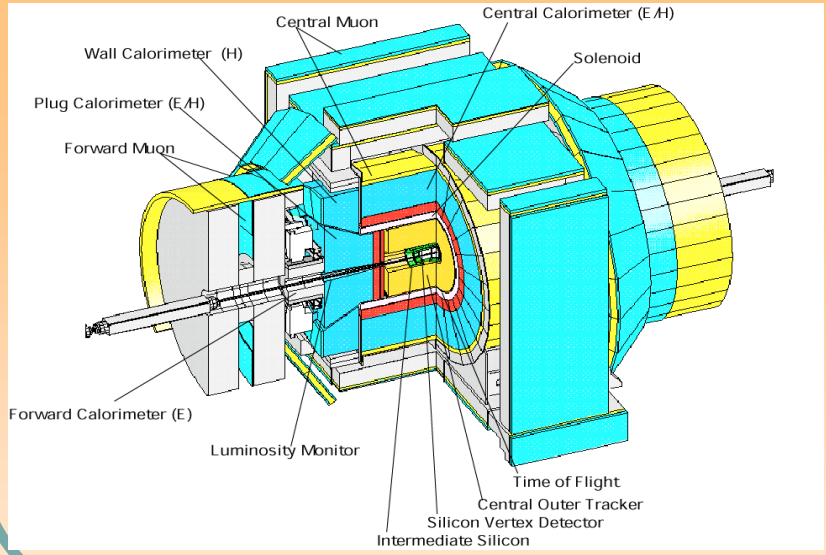
- New results with up to Sep 2005 (~760 pb-1)
  x7 of Run I !
- Some of analyses presented here use up to Sep 2004 (~360 pb-1)

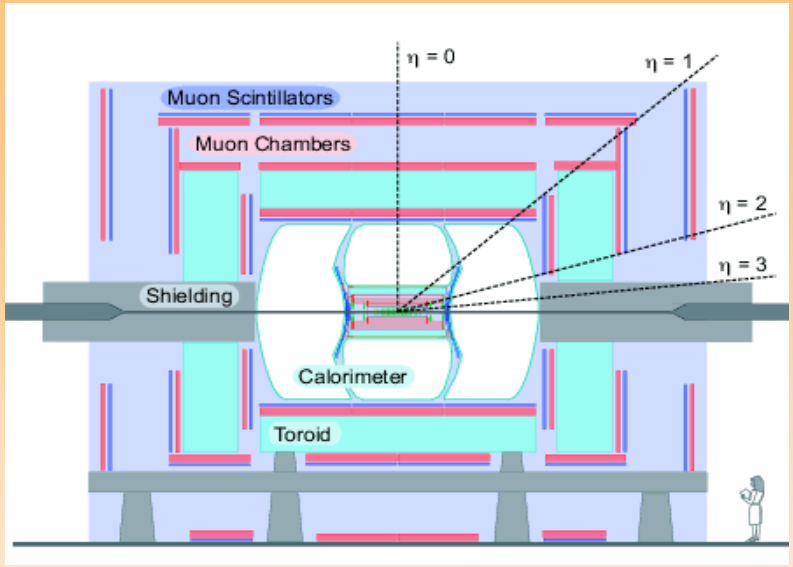


Tevatron Detectors

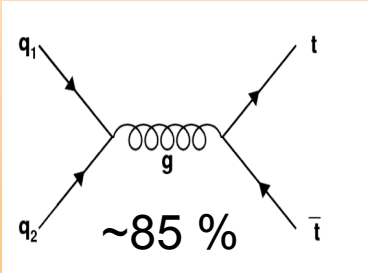
- Inner Silicon Precision Tracking
- Tracking Chambers
- Solenoid
- EM and HAD calorimeters
- Muon Detectors

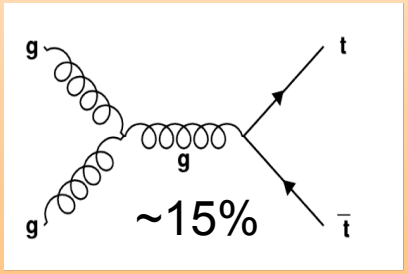
All crucial for top physics!





Top Quark Production

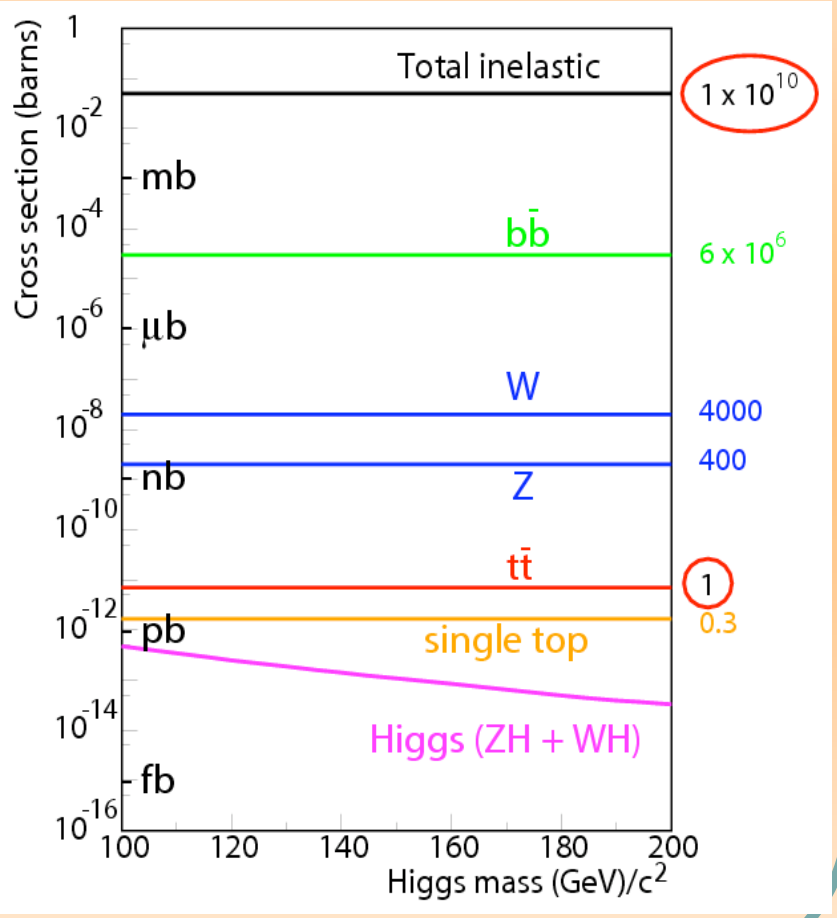




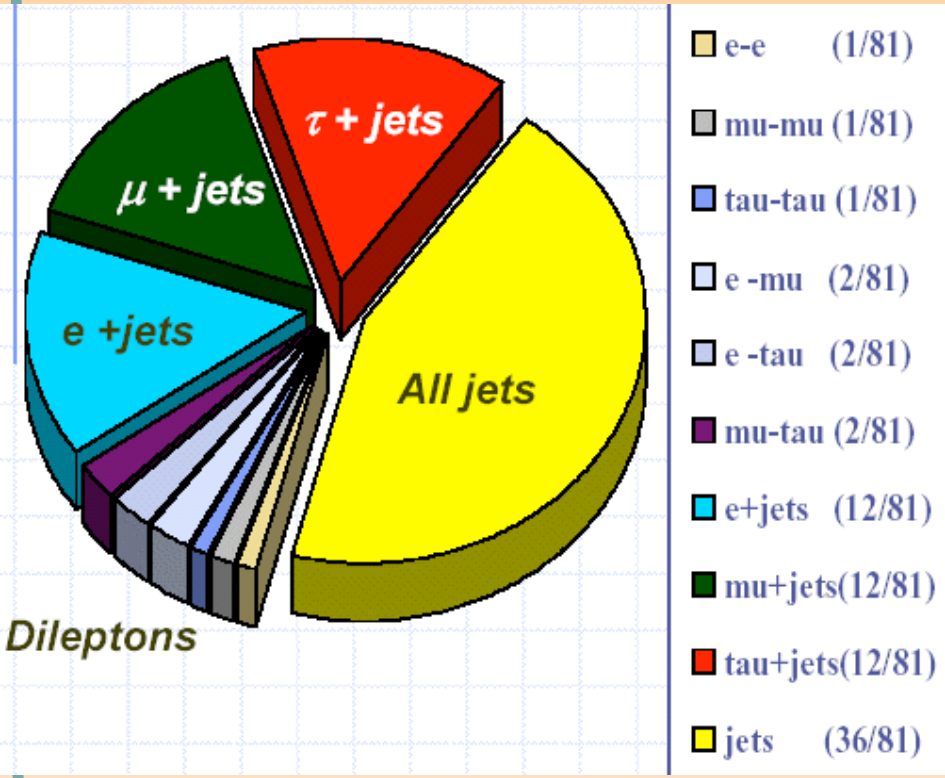
- Within SM
- $\sigma_{tt} = 6.7 \pm^{0.7}_{0.9}$ pb @ m_{top} = 175 GeV

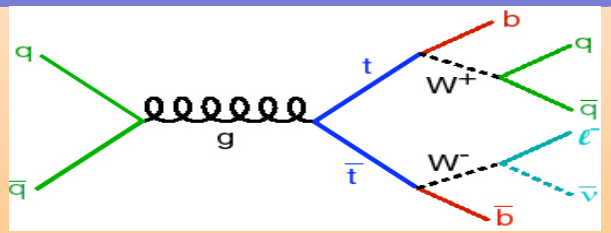
Cacciari et al. JHEP 0404:068(2004)
Kidonakis,Vogt PRD 68 114014(2003)

- One top pair every 10^{10} inelastic collisions
- Produced ~15000 top pairs so far



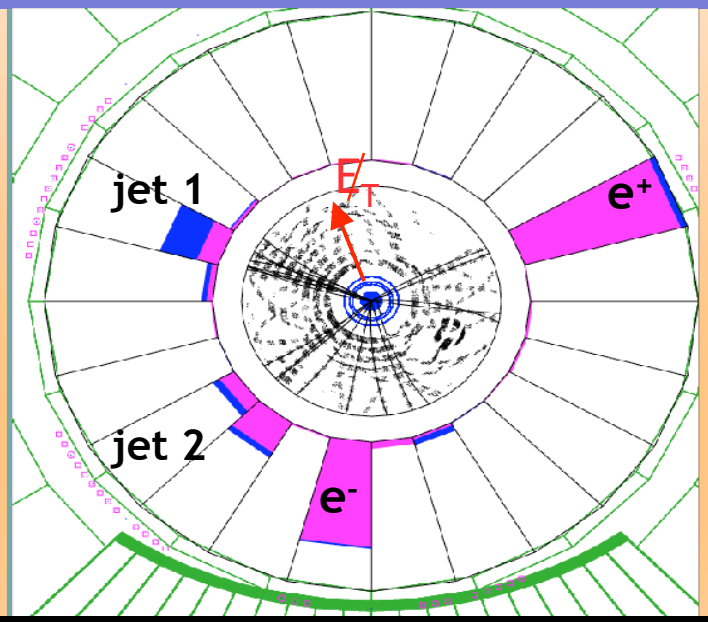
Top Quark Decay

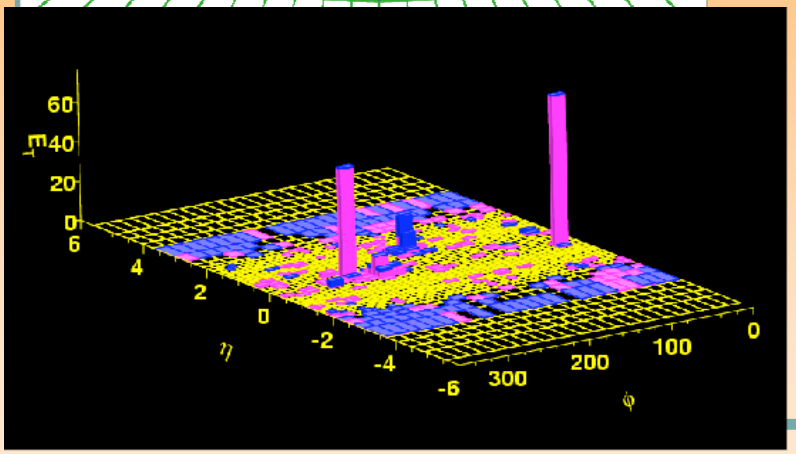




- ***t → Wb***
- Events classified by *W* decay
  - *"Lepton [e,μ] + jets" (30%)*
    - ***tt → blνbqq'***
  - *"Dilepton [e,μ]" (5%)*
    - ***tt → blνblν***
  - *"All jets" (44%)*
    - ***tt → bqq'bqq'***
  - ***"Tau + X" (21%)***

Detecting the Top





- Signal:
  - Triggering on lepton
  - High missing transverse energy ($\not{E}_T$)
  - High E_T jets, central and spherical
  - Two b-jets (displaced vertex)
- Background:
  - W+jets:
    - dominant in leptonic modes
    - fakes the second lepton
  - Drell-Yan(dileptons): no $\not{E}_T$
  - QCD: huge in HAD mode

Production Cross Section Measurements

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bgd}}{\varepsilon_{t\bar{t}} \cdot \int Ldt}$$

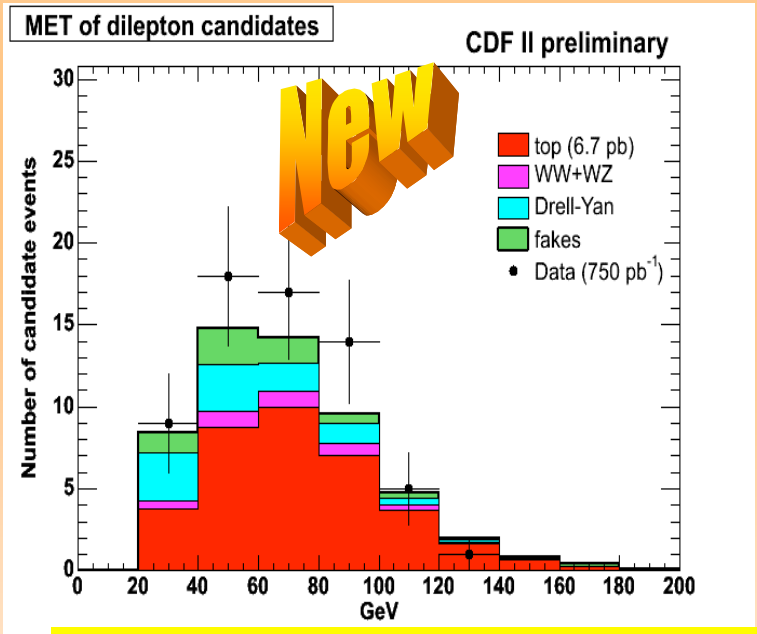
- Testing non-standard model top production mechanisms
- Top sample might contain an admixture of exotic processes

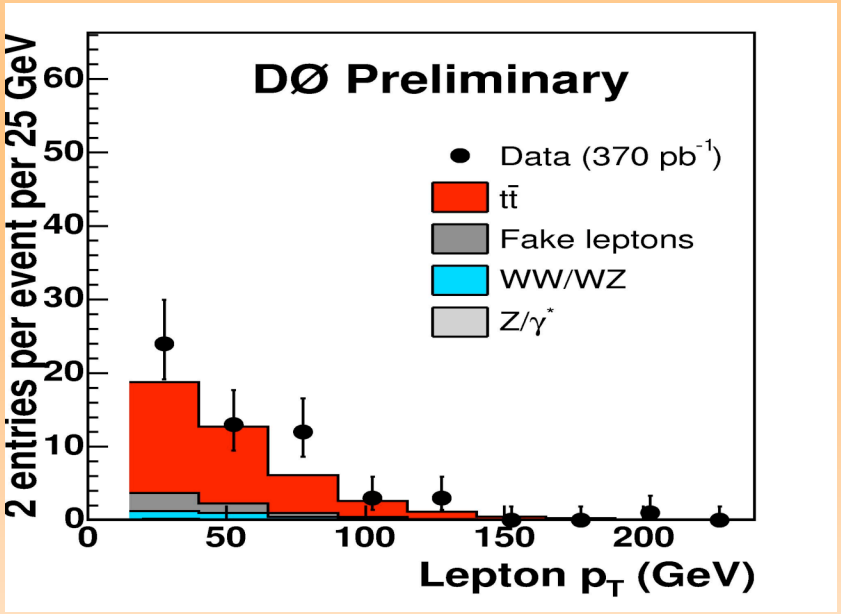
Cross Section in Dilepton channel

L =750 pb^{-1}

	obs	expected
ee	12	14.3 ± 2.2
μμ	24	16.1 ± 2.4
eμ	28	25.0 ± 1.5

	obs	expected
ee	5	4.5 ± 0.5
μμ	2	3.8 ± 0.5
eμ	21	15.8 ± 2.8



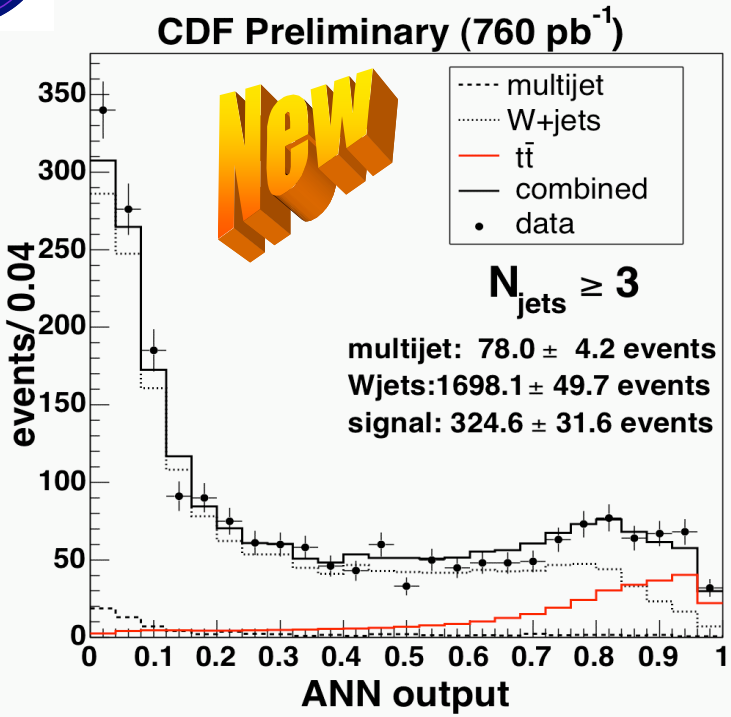


σ (tt) = 8.3 ± 1.5 (stat) ± 1.0 (syst) ± 0.5 (lumi) pb

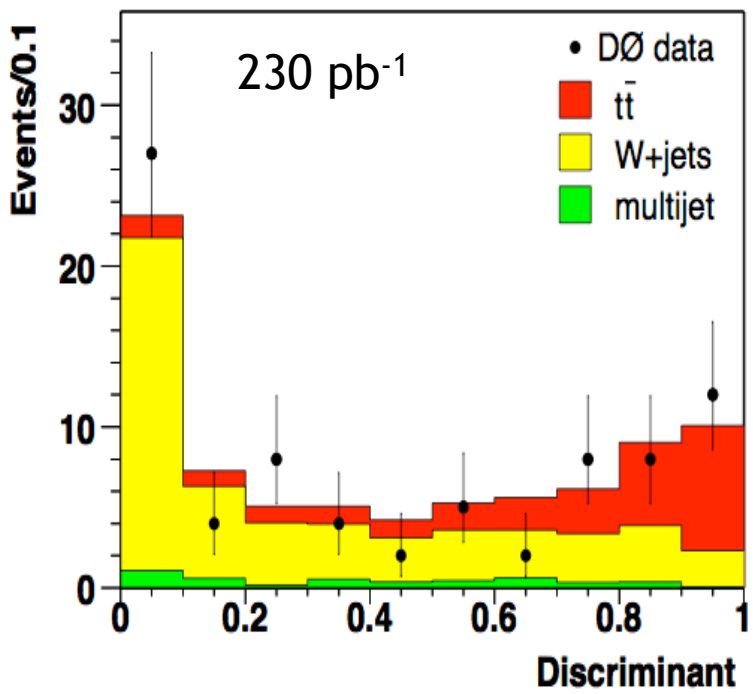
σ (tt) = 8.6 ± 2.3 (stat) ± 1.1 (syst) ± 0.6 (lumi) pb

Lepton+jets cross section

- Topological/kinematical analyses:
- Neural Network (CDF) / Likelihood Discriminant(D0)

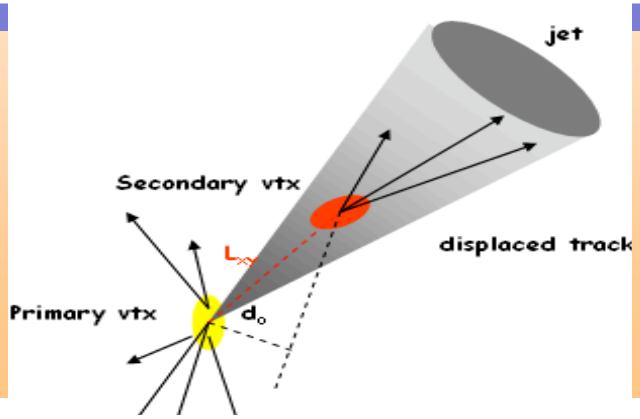


σ (tt) = 6.0 ± 0.6 (stat) ± 0.9 (syst) pb



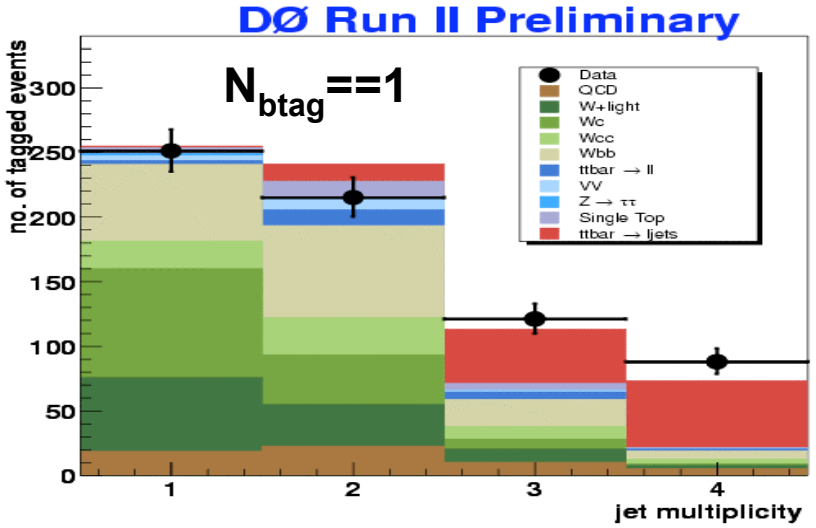
σ (tt) = 6.7 ± 1.4 (stat) ± 1.4 (syst) pb

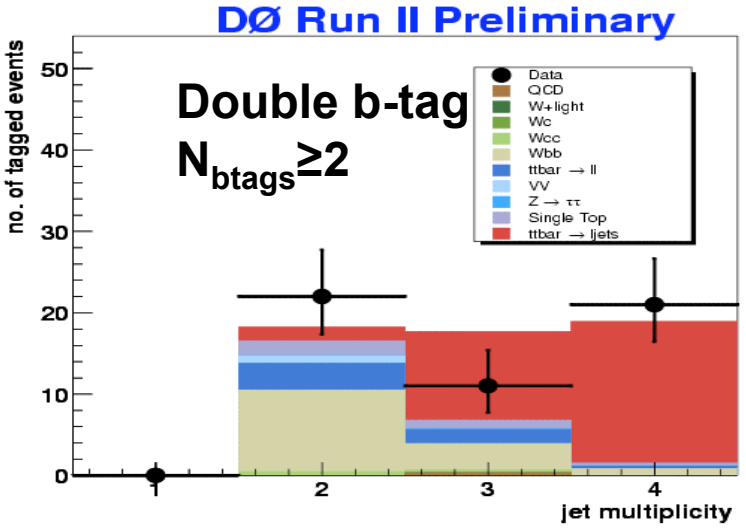
Lepton + Jets with b-tagging



- B-jets are tagged by finding displaced vertex within a jet
- B-quark lifetime $c\tau$ ~ 450 μm
- Reduces backgrounds, increases purity of ttbar

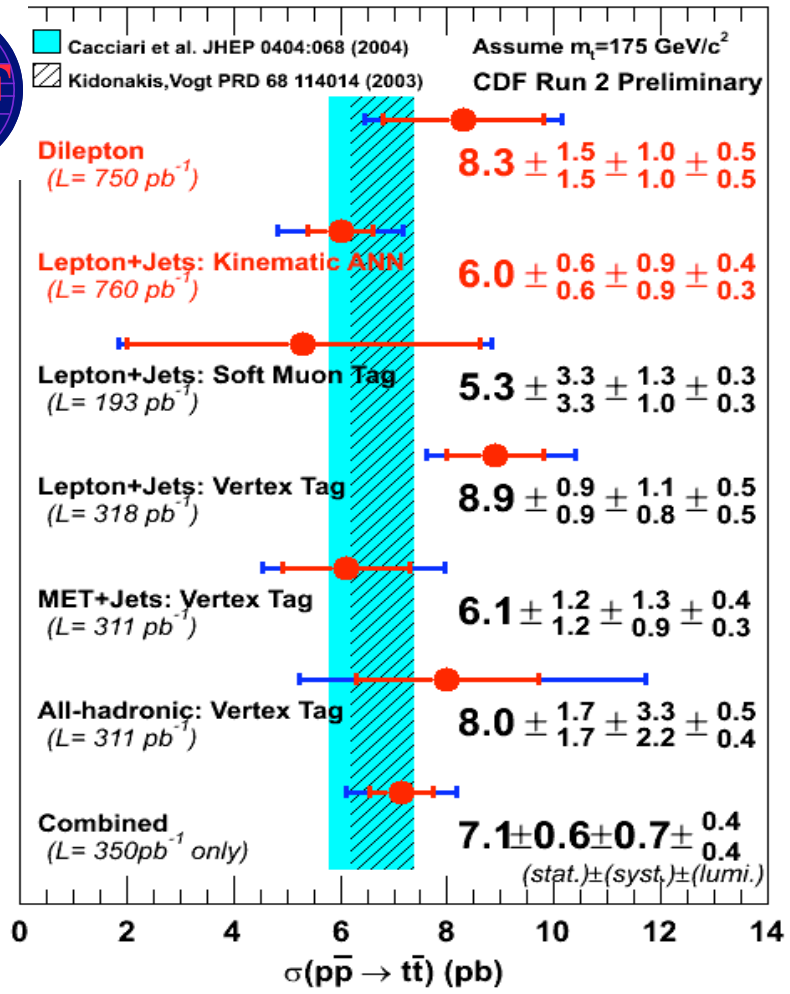
$L = 365\,\text{pb}^{-1}$

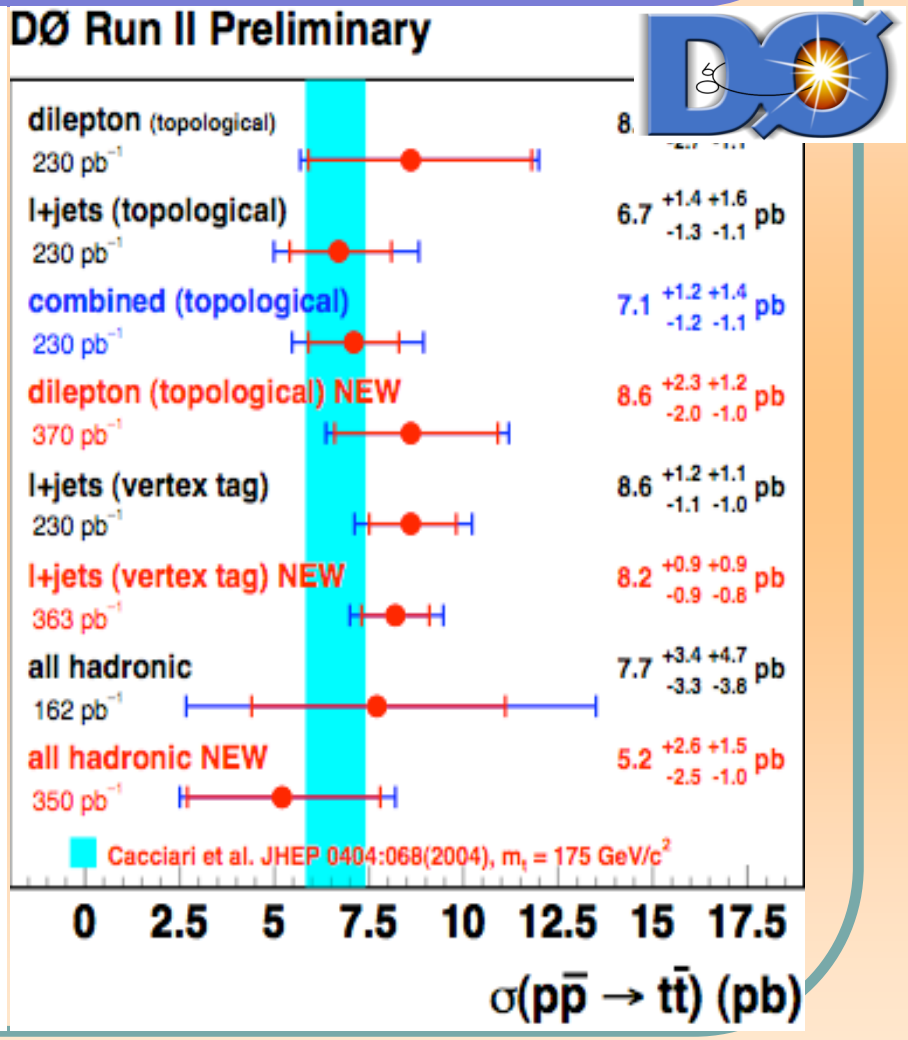




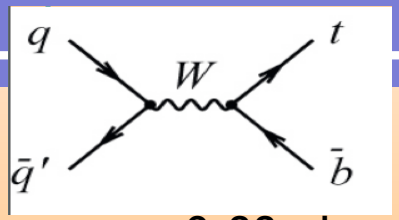
$$\sigma(t\bar{t}) = 8.1 \pm 0.9(\text{stat}) \pm^{0.9}_{0.8} (\text{syst}) \pm 0.5(\text{lumi})\,\text{pb}$$

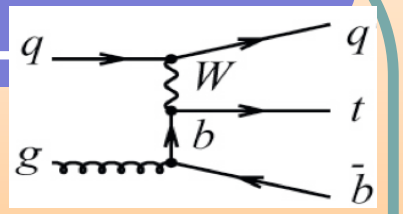
Top Quark Pair Production: Summary





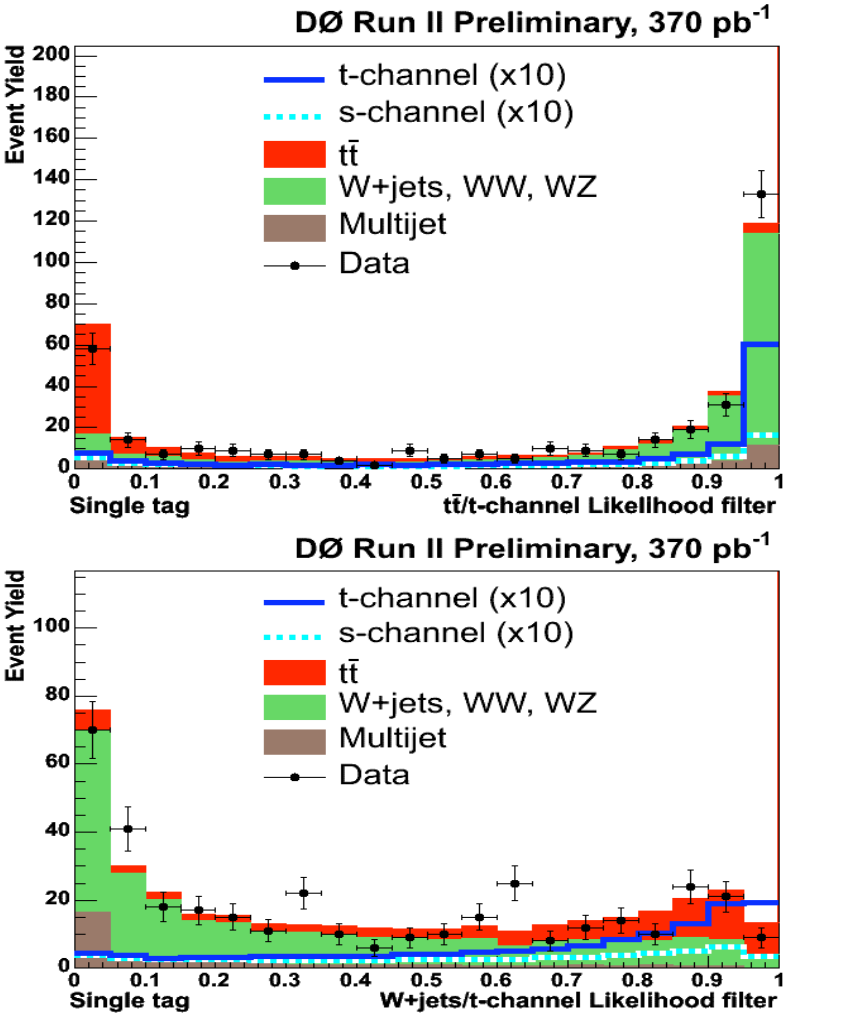
Single Top Search

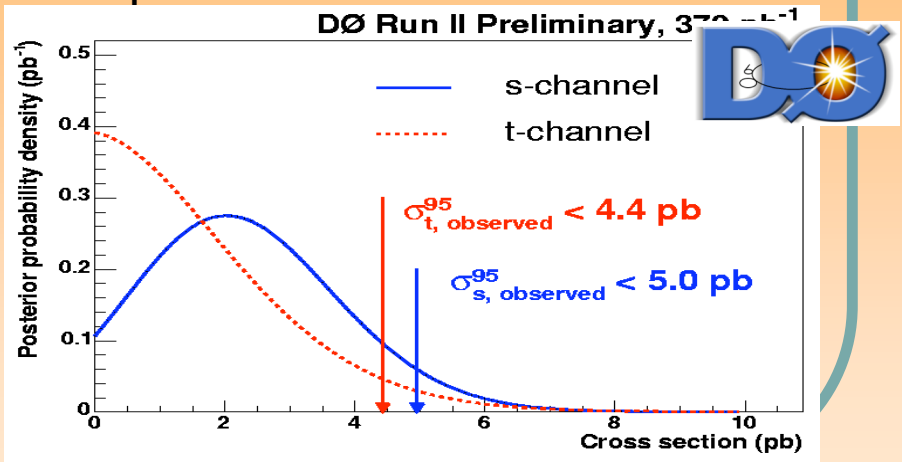




- σ_s = 0.88 pb; σ_t = 1.98 pb; (~$|V_{tb}|$)

  Harris et al PRD 66 054024(2002)
- Lepton + jets, ≥1 b-tag
- Overwhelming W+jets backgrounds
- Dedicated 2D Likelihood fitter
- Best world's upper limits so far
- Expect 3σ evidence with 2fb-1

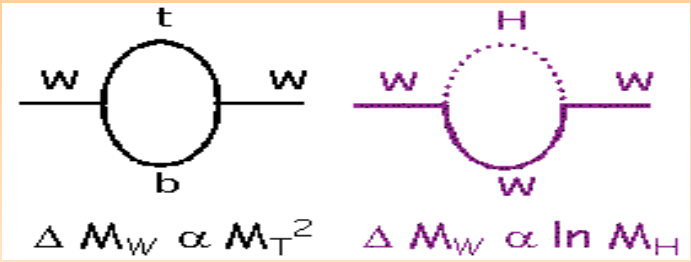


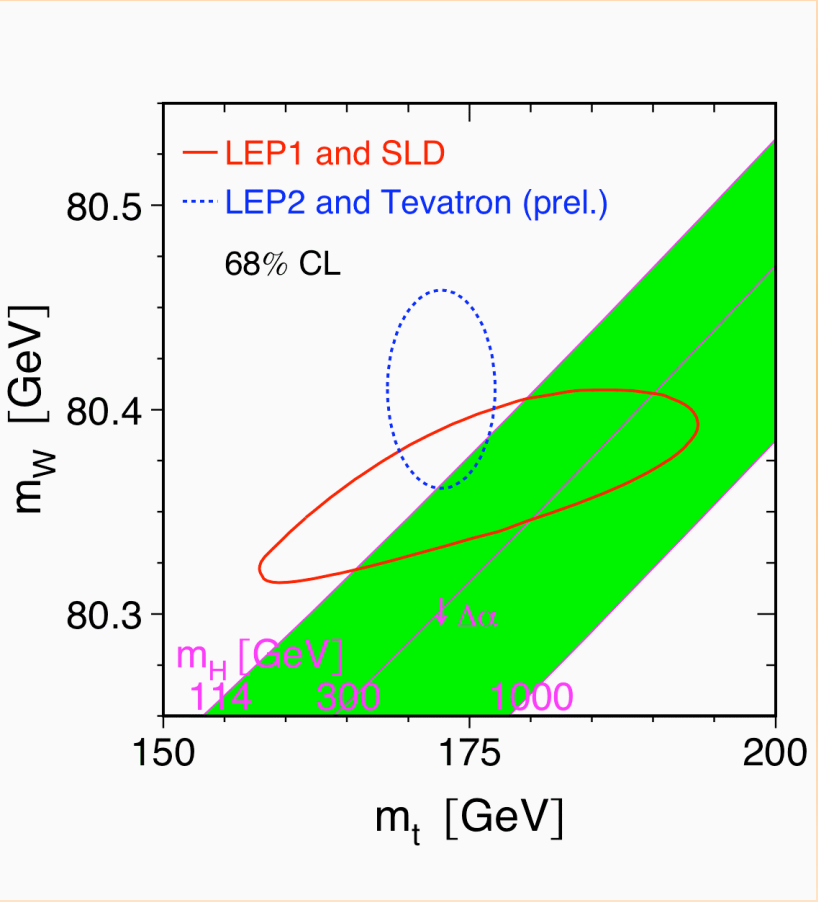


Top Mass Measurements

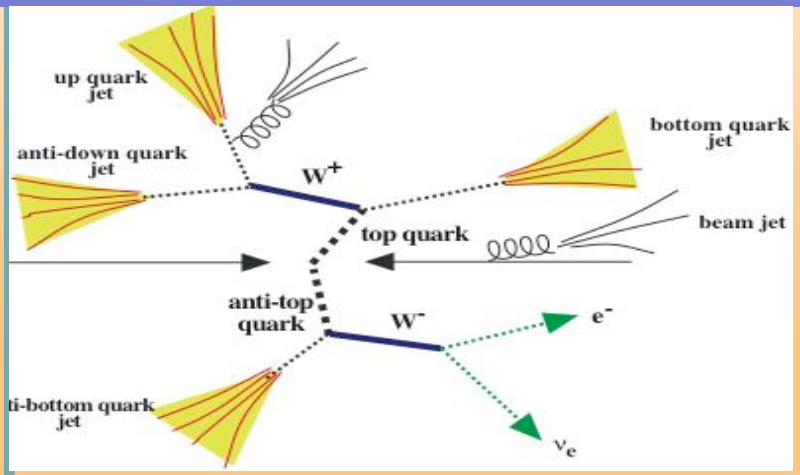
Top mass relation to Higgs

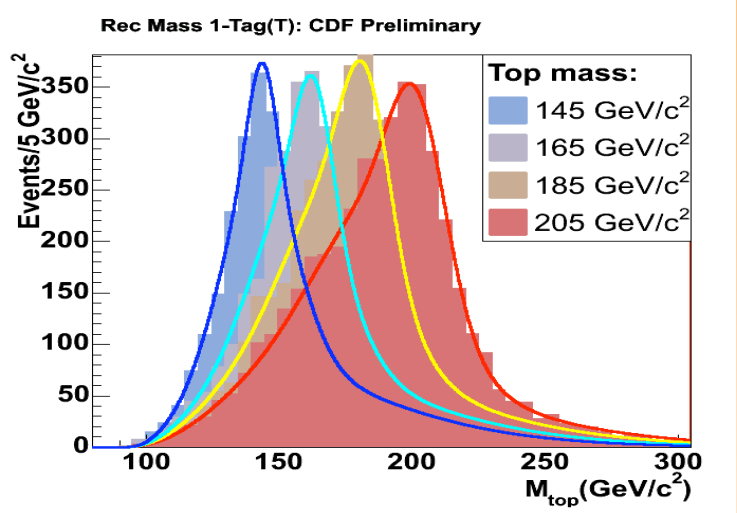
- Top quark mass is a fundamental parameter of SM
- Radiative corrections to SM predictions dominated by top mass
- Together with W mass places a constraint on Higgs mass





CDF Lepton+jets



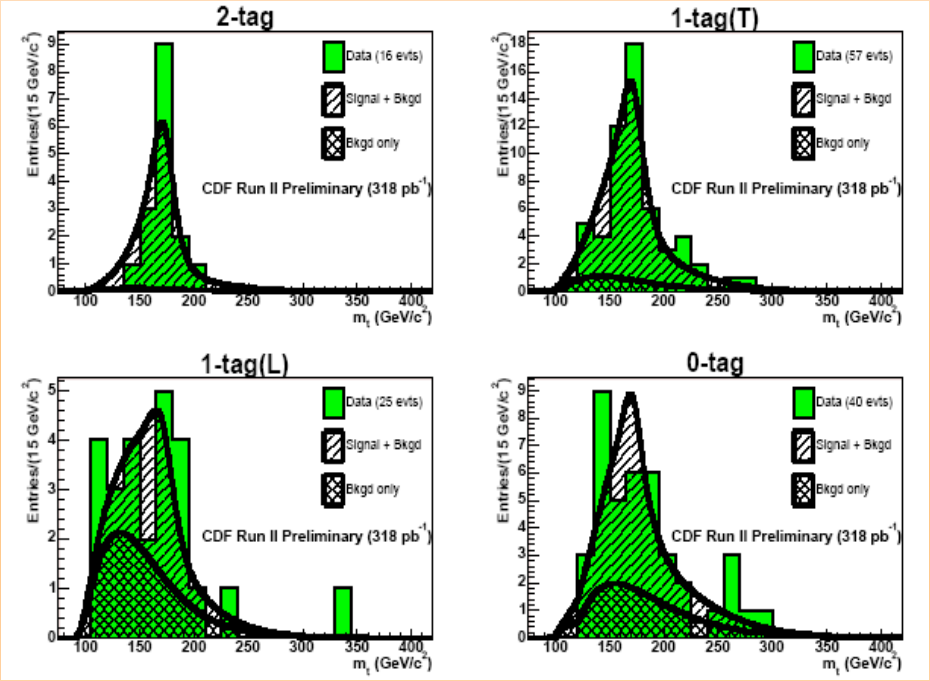


- Constrain $m(jj) = m_W$, $m(\ell\upsilon) = m_W$ and $m(\ell\upsilon b) = m(jjb)$
  - 24 possibilities for 0 b-tags
  - 12 possibilities for 1 b-tag
  - 4 possibilities for 2 b-tags
- Select configuration with best χ^2 fit -> obtain M_{reco}

- 2005 New: Jet Energy Calibration in situ
- Simultaneous fit to invariant mass of W->jj
- Global factor used to correct energies of jet
- Reduces systematic uncertainty

CDF M_{top} Measurement in Lepton+Jets

- Up to date the best single measurement in the world!
- Better than Tevatron Run I average
- Will be shortly updated with ~750 pb^{-1}



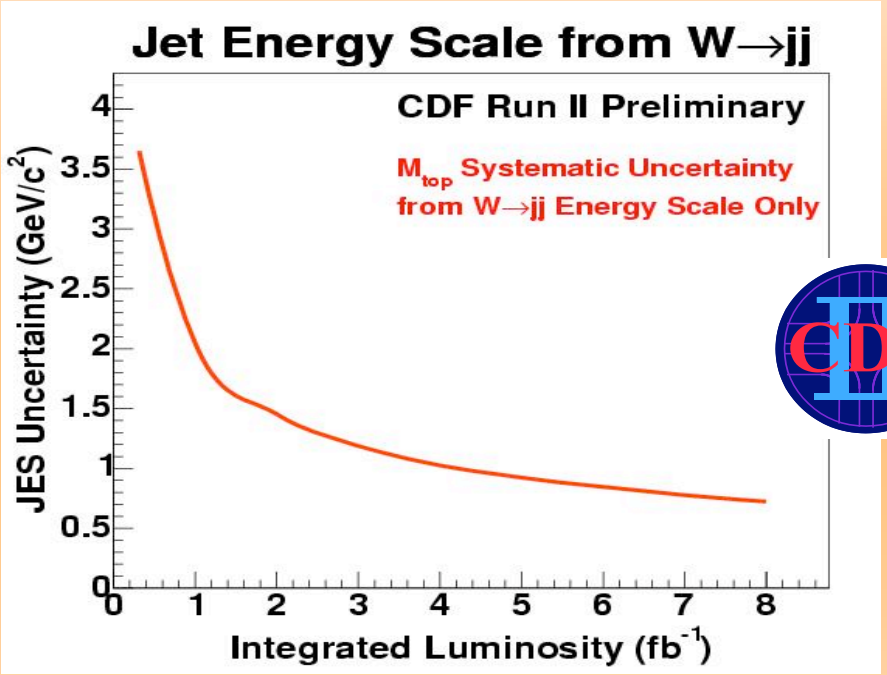
$$m_{top} = 173.5 \pm^{2.7}_{2.6} (\text{stat}) \pm 2.5(\text{JES}) \pm 1.3(\text{syst}) \text{GeV}/c^2$$

$$\Delta\text{JES} = -0.10 \pm^{0.78}_{0.80} \sigma(\text{a priori})$$

PRD: hep-ex/0510048
PRL: hep-ex/0510049
(accepted)

Future Projection

Systematic Source	Uncertainty (GeV/c^2)
Radiation	0.7
Model	0.7
b-jet	0.6
Method	0.6
PDF	0.3
Total	1.3
Jet Energy	2.5



- Expect significant reduction in JES uncertainty with more data
- Turning JES systematic into a statistical uncertainty

DO Matrix Element Technique

Made best single measurement in Run I

- Form probability for each event:

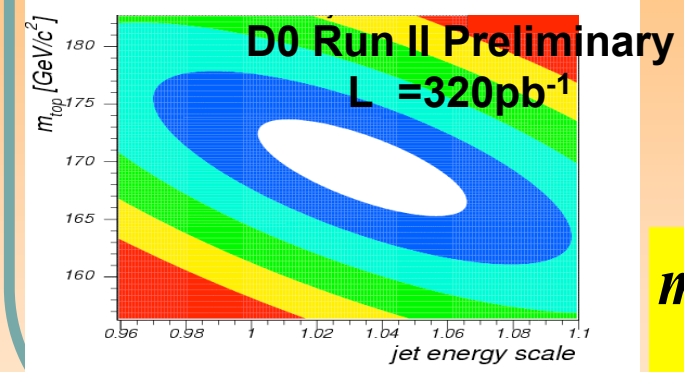
$$P(x;M_{top}) = \frac{1}{\sigma}\int d^n\sigma(y;M_{top})\,dq_1\,dq_2\,f(q_1)\,f(q_2)\,W(x,y)$$

f(q): parton density functions

$d^n\sigma$: LO Matrix element

W(x,y): transfer function between jet and parton momenta

- Consider all permutations
- Maximize Likelihood: $\Pi_i\ P^i\ (x;M_{top})$



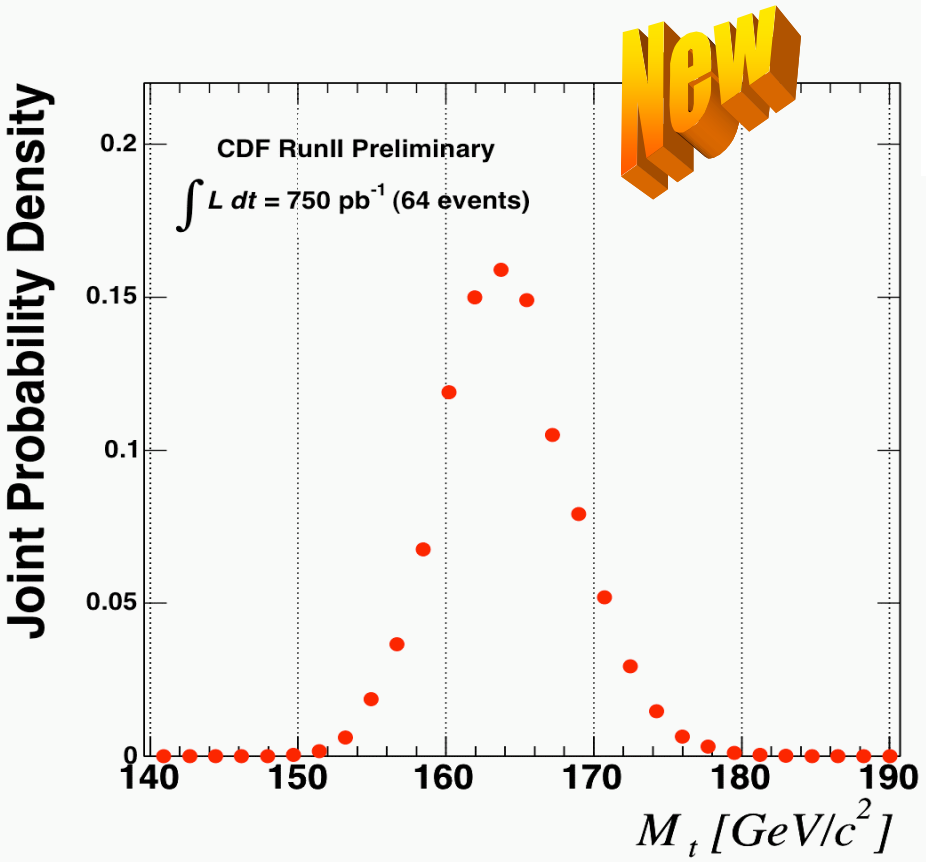
- Use LO ME for ttbar and W+jets
- Run II Improvements: W->jj energy calibration
- No a priori energy determination

$$m_{top} = 169.5 \pm 3.0_{(stat)} \pm 3.2_{(JES)} \pm 1.7_{(syst)}\ GeV/c^2$$

$$JES = 1.034 \pm 0.034$$

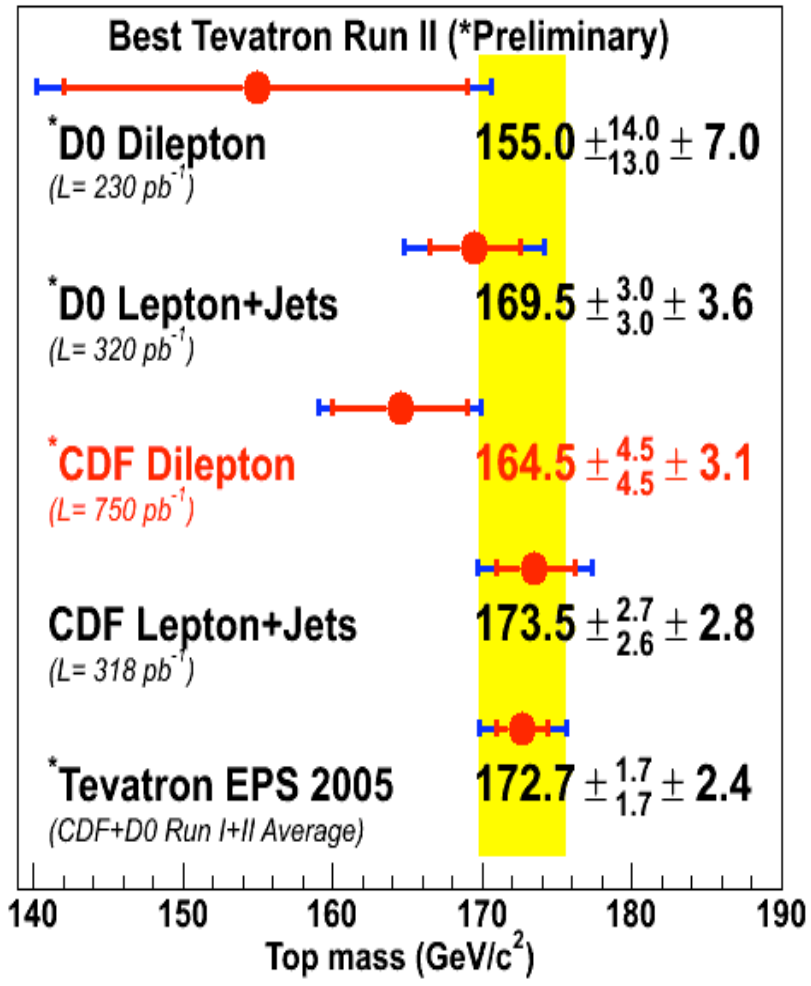
CDF Dilepton Matrix Element M_{top} Measurement (750 pb^{-1})

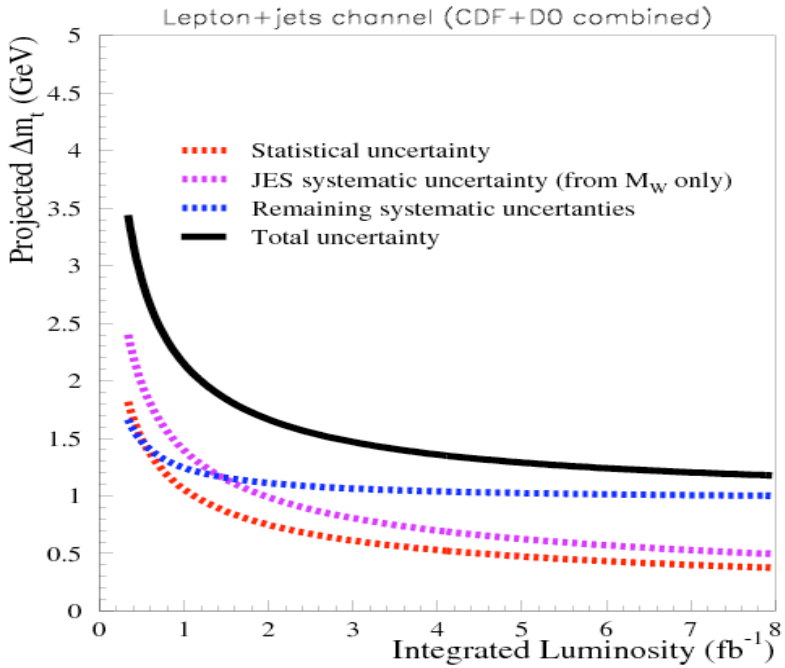
- DIL mode:
  - Reduced combinatorics
  - Only two possible parton-jet assignments
  - Unconstrained kinematics: two neutrinos in the final state
- Background LO Matrix Element treatment
- Best single measurement in Dilepton channel!



$$m_{top} = 164.5 \pm 4.5\ (\text{stat}) \pm 3.1\ (\text{syst})\ \text{GeV}/c^2$$

Top Mass: Summary





- Expect to get down to 1.5 GeV total uncertainty on top mass

Searches for ttbar Resonances

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

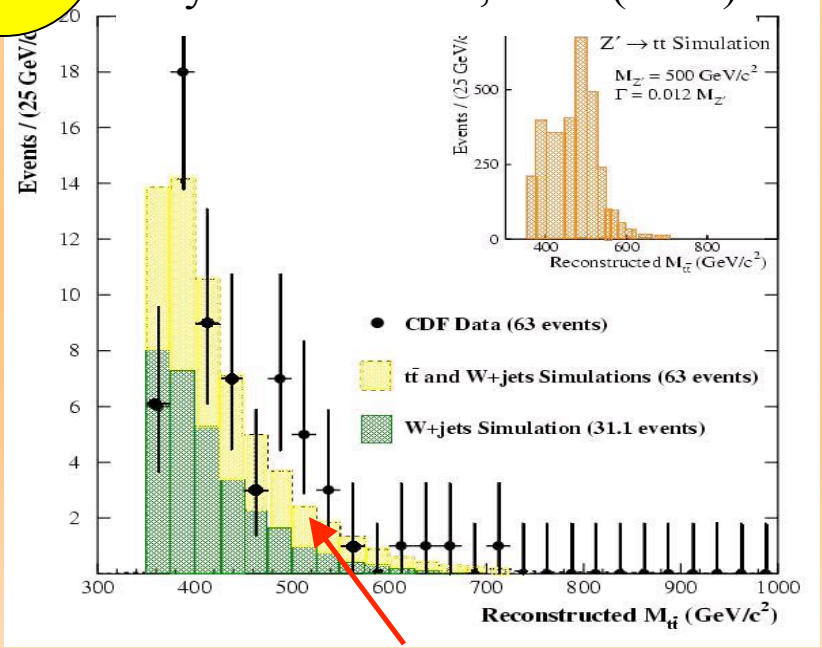
- Various exotic models predict the existence of particles decaying to ttbar: Topcolor-Assisted Technicolor
  - (Hill, Phys Lett. B345, 483 (1995); Hill and Parke Phys. Rev. D49, 4454 (1994))
- Extends technicolor models and attempts to explain EWSB by introducing a new strong interaction
- Predicts new massive bosons “topgluons” and a topcolor Z’

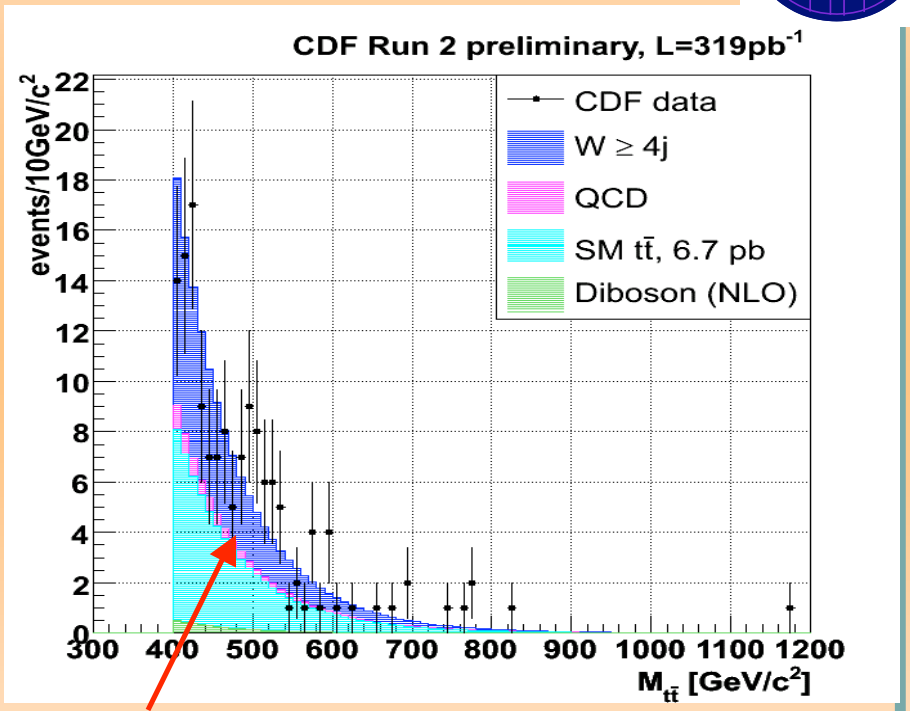
History: Previous Measurements

CDF Run 1

- Lepton + jets:

Phys.Rev.Lett. 85, 2062 (2000)





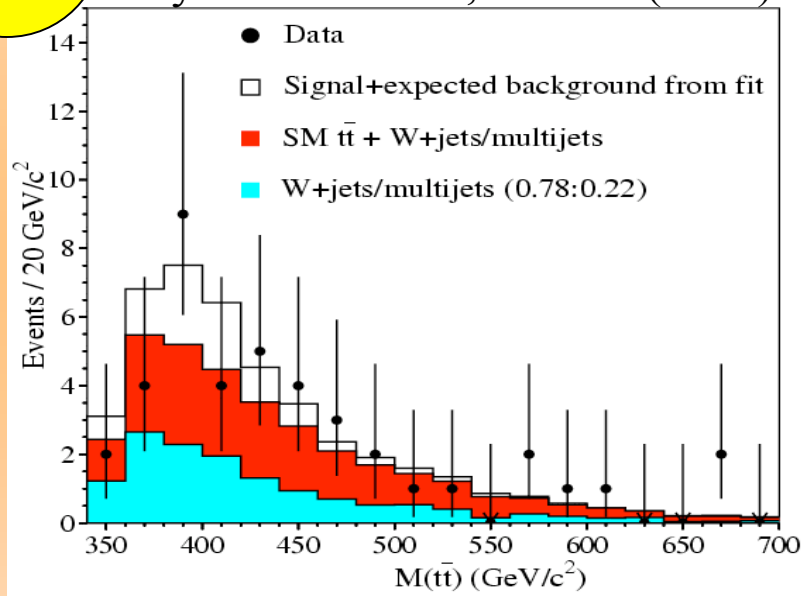
- Observed quite intriguing excess around 500 GeV
- Had a similar although smaller excess in Run 1

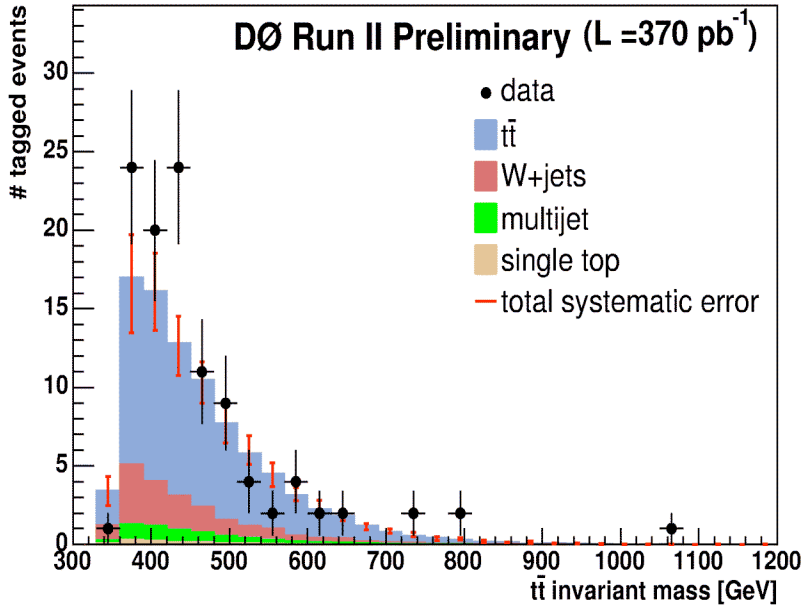
D0 searches

D0 Run 1

- Lepton + jets:

Phys.Rev.Lett. 92, 221804 (2004)

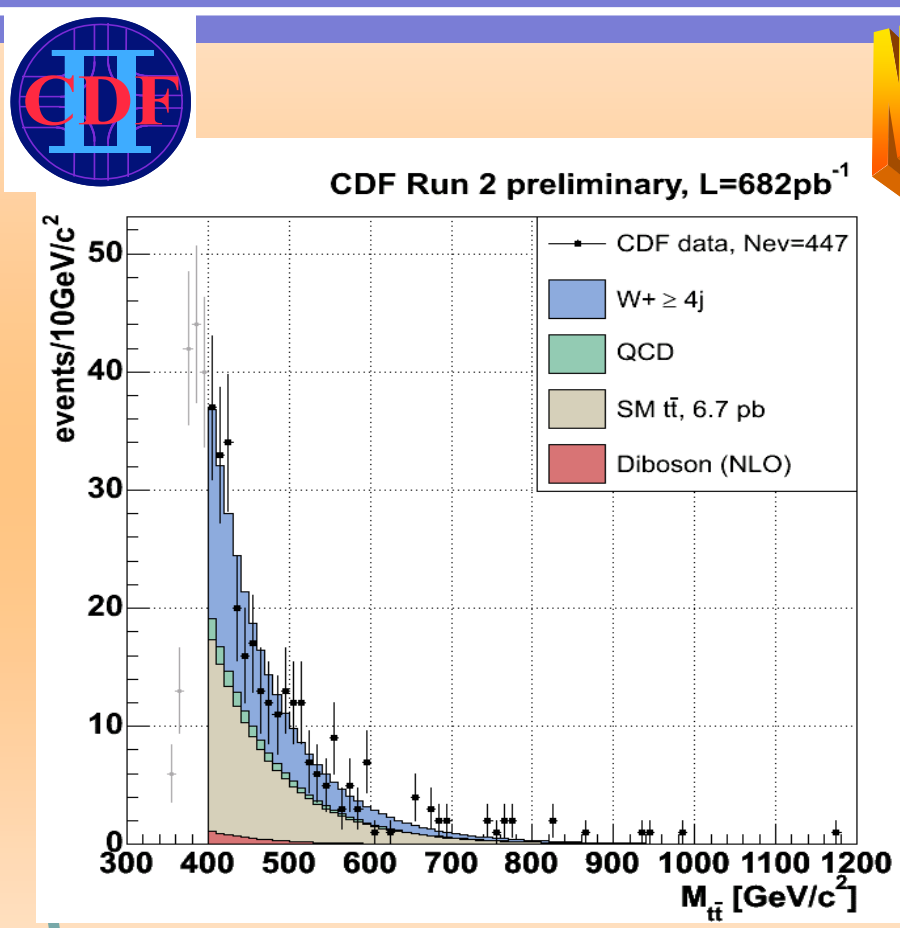


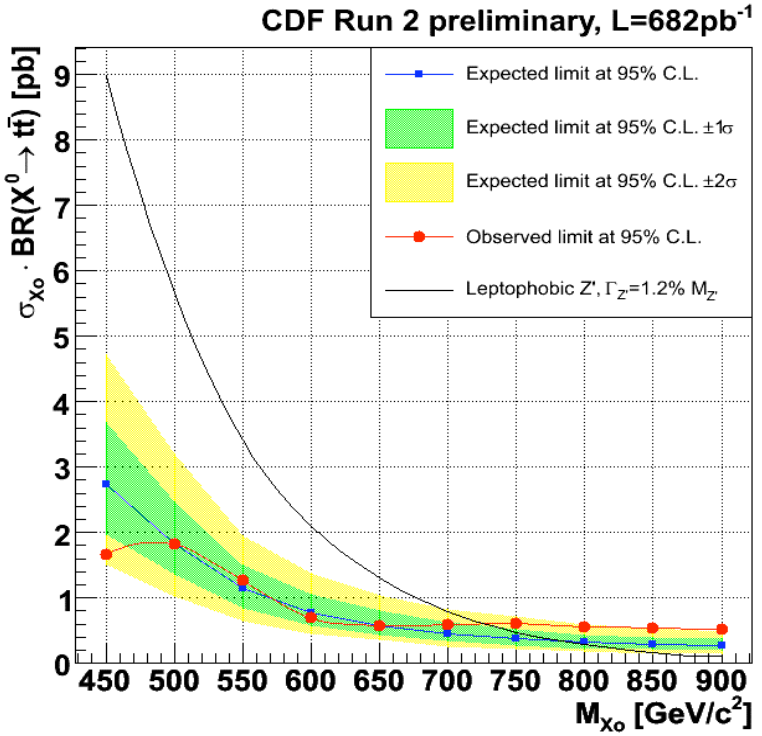


- No similar anomaly seen in D0 data

Excluded with 95%CL
$M_{Z'} < 680$ GeV
($\Gamma_{Z'} = 0.012 M_{Z'}$)

Latest CDF measurement (682pb^{-1})





- Alas! With about twice more data the excess has washed out!

Top Quark Properties

- I will cover only the latest measurements:
  - Top Charge
  - Top lifetime
  - New heavy top in the top sample?

Top Charge

- Is it the Standard Model top ?
- W.-F. Chang et al.,Phys. Rev. D 59, 091503 (1999), (hep-ph/9810531) proposes an exotic doublet of quarks $(Q1, Q4)_R$ with charges (-1/3,-4/3) and M ~ 175 GeV
- Right-handed b quark mixes with the isospin +1/2 component
- while M_{top} ~ 274 GeV escaped detection
- q = -4/3 is consistent with EW data, new b-couplings improve the EW fit (E. Ma et al. , hep-ph/9909537)

Top Quark Charge Measurement

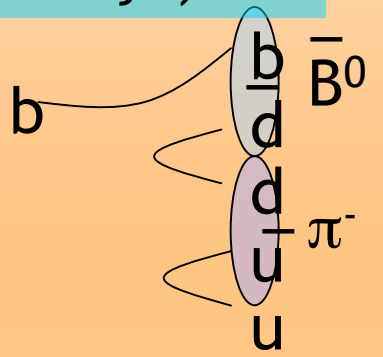
Lepton+jets, double b-tag events
Determine:

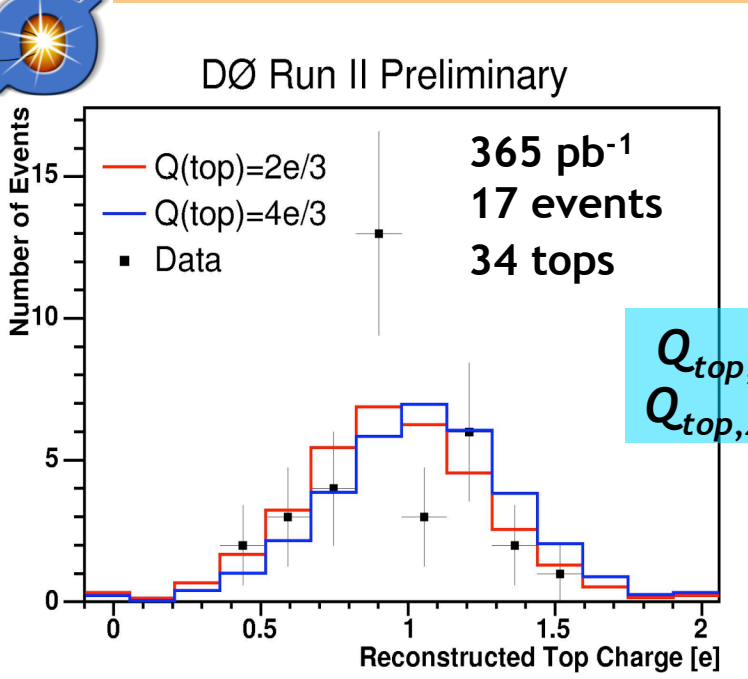
- charge of W (lepton)
- pairing between W and b (χ^2 fit)
- flavor of b-jet

Jet Charge:

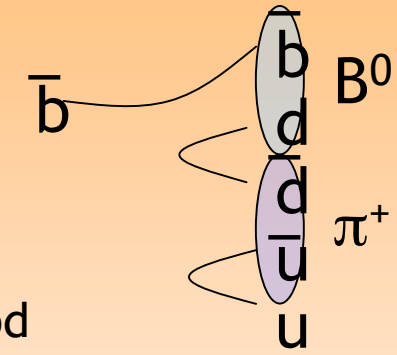
$$Q_{jet} = \Sigma q_i \, p_{Ti}^{0.6} / \Sigma \, p_{Ti}^{0.6}$$

(sum over tracks within a jet)





$$Q_{top,1} = | \, q_l + q_{,b(l)} \, |$$
$$Q_{top,2} = | \, - q_l + q_{,b(j)} \, |$$



Perform likelihood ratio test

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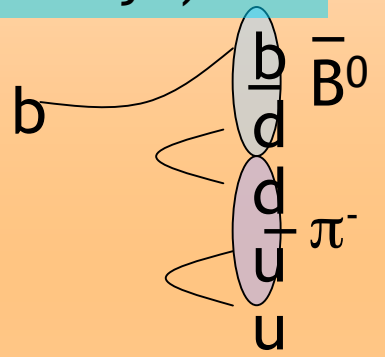

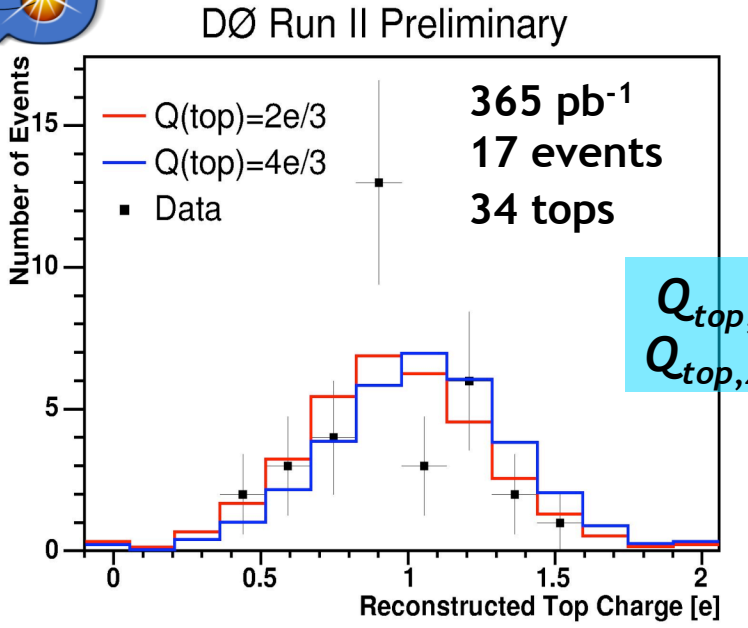

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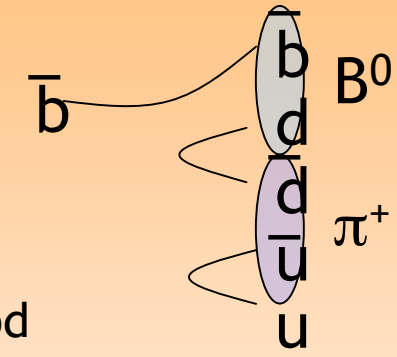


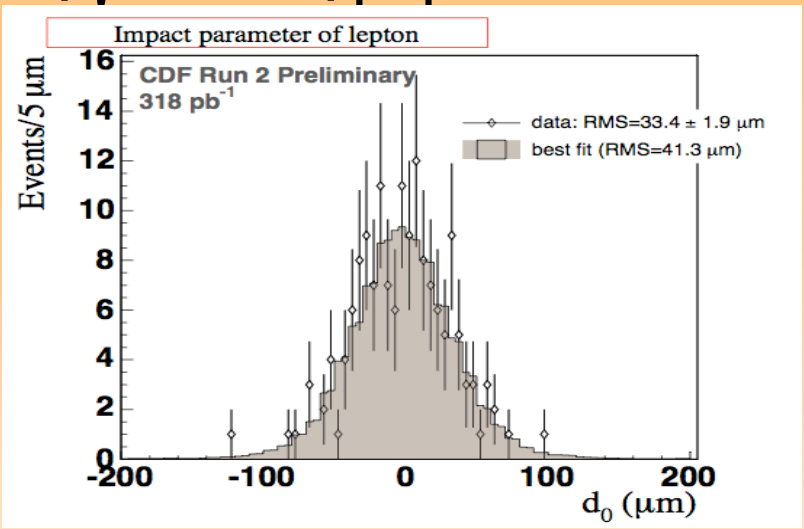
Perform likelihood ratio test:

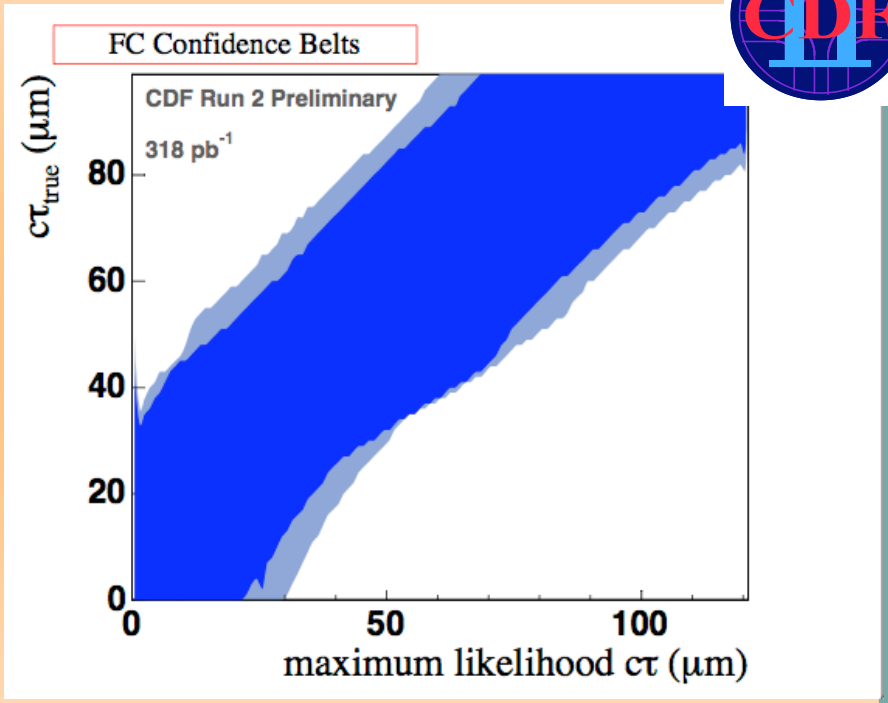
Excluded Q=4/3 with 94%CL

Top Lifetime

- Within the SM τ_{top} ~10^{-24} s
- Long-lived top?
- Use d_0-lepton impact parameter with respect to beamline
- Determine detector resolution from

Z^0/γ -> $e^+e^-/\mu^+\mu^-$





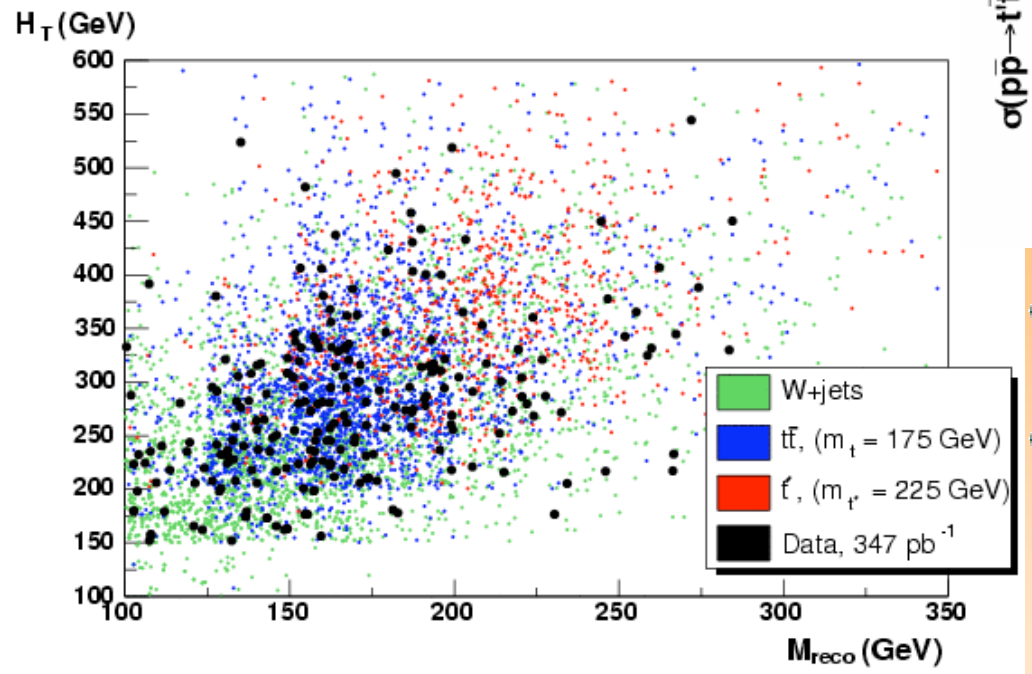
$c\tau < 52.5$ μm with 95% CL

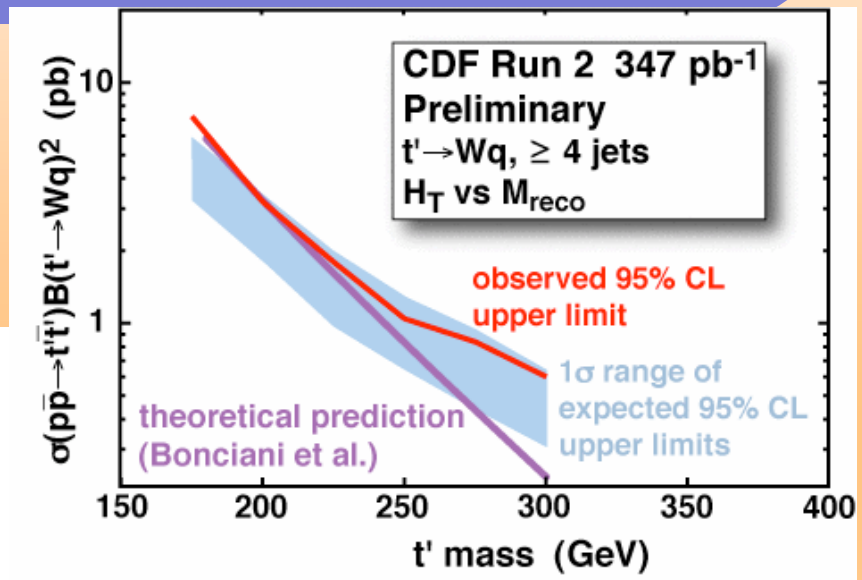
Fit combination of signal/BG templates to the data: lepton+jets with >=1 b-tag

New Heavy Particles Decaying to Wq?

- Can be a fourth generation up-type quark
  He/Polonsky/Su (hep-ph/0102144)
  a generic 4th chiral generation is consistent with EWK data; accommodates a heavy Higgs (500 GeV) without any other new physics
- "Beautiful Mirrors" model
  Wagner et al (hep-ph/ 0109097)
  predicts a new heavy up-type quark decaying to Wb; naturally accomodates the LEP b forward-backward asymmetry results
- From the precision EWK data the mass splitting between a t' and a b' quark is relatively small. Therefore if $M_{t'} < M_{b'} + M_W$: t' -> W b(q) (promptly)
- CDF Search in Lepton + jets channel: 2D-fit with
  - H_T = sum of transverse momenta of all objects in the event
  - M_{reco} from χ^2-fit

Search for t'->Wq





- Set a limit on 4th generation up-type quark pair production
- Data did not cooperate well

Excluded t'
$196 < m_{t'} < 207$ GeV

Conclusions

- Future is now! We are taking and analyzing Tevatron data
- Many other analyses utilizing datasets of integrated luminosity ~700 pb^{-1} are being finalized
- Results will be presented at the forthcoming Winter conferences
- Stay tuned for 1fb^{-1} results at the Summer conferences (x10 of Run I)
- No evidence for the top quark being non-Standard Model so far
- More precise measurements of the top mass (~1.5 GeV uncertainty) and other quantities coming soon