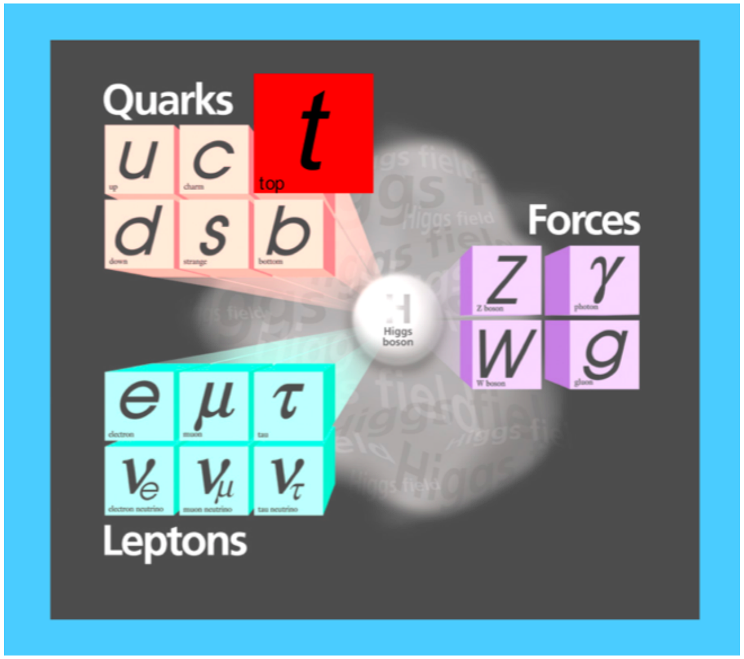
Top quark properties at the Tevatron



Fabrizio Margaroli PURDUE UNIVERSITY
On behalf of CDF and D0 collaboration

The top quark is special

Top was discovered at Fermilab in 1995

Its mass much larger than any other fermion

Using the latest Tevatron-averaged M_{top} arXiv:1007.3178

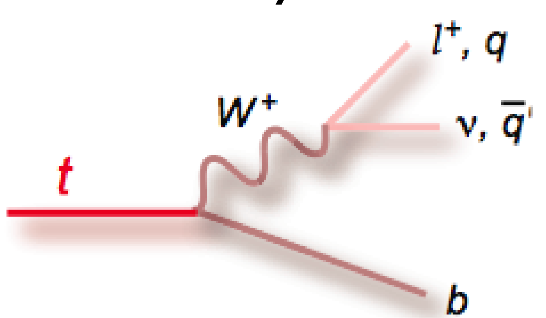
$$L_{\text{Yukawa}} = -\lambda\psi_L\Phi\overline{\psi}_R$$

Yukawa coupling = 0.996±0.006

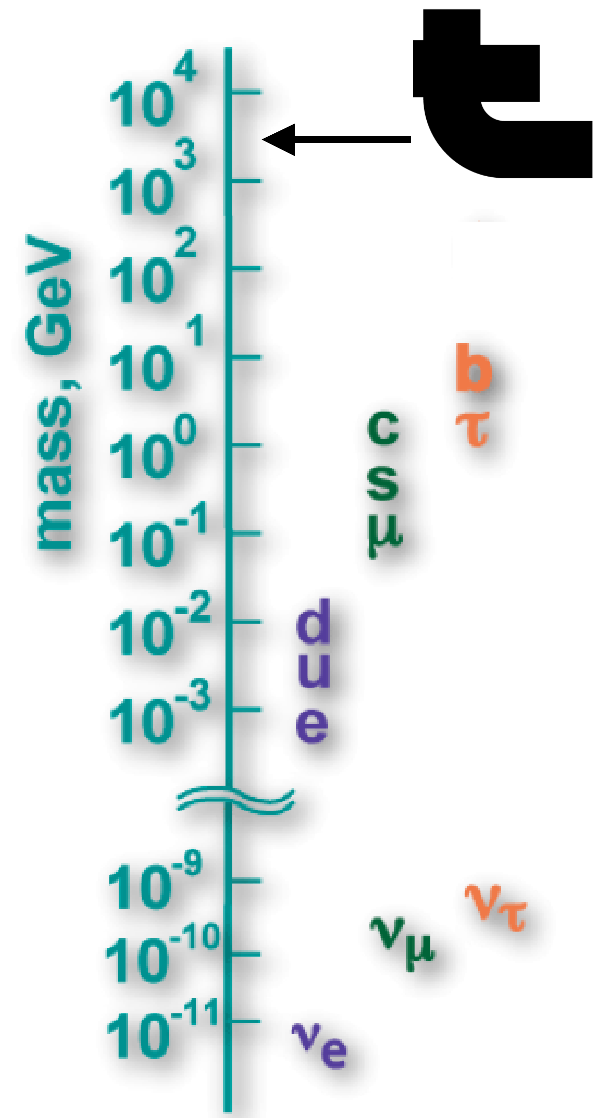
- Only quark with large coupling to Higgs - special role for the top quark?

Lifetime shorter than hadronization time

→ only quark that decays before hadronizing



→ Thousands of top events analyzed, O(10^4) by the end of the Tevatron run!



Is it really the SM 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

- Vtb = 0.91 ± 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
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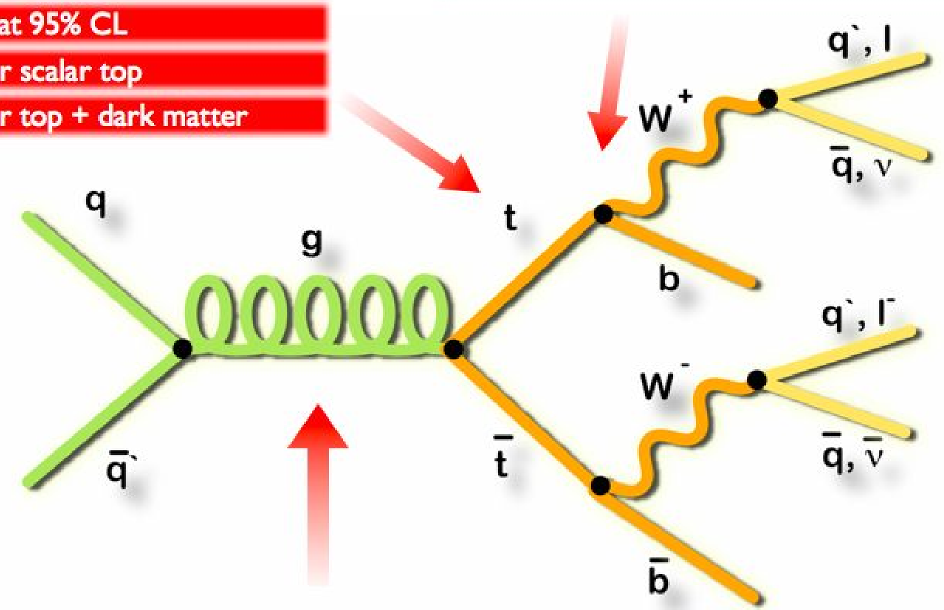
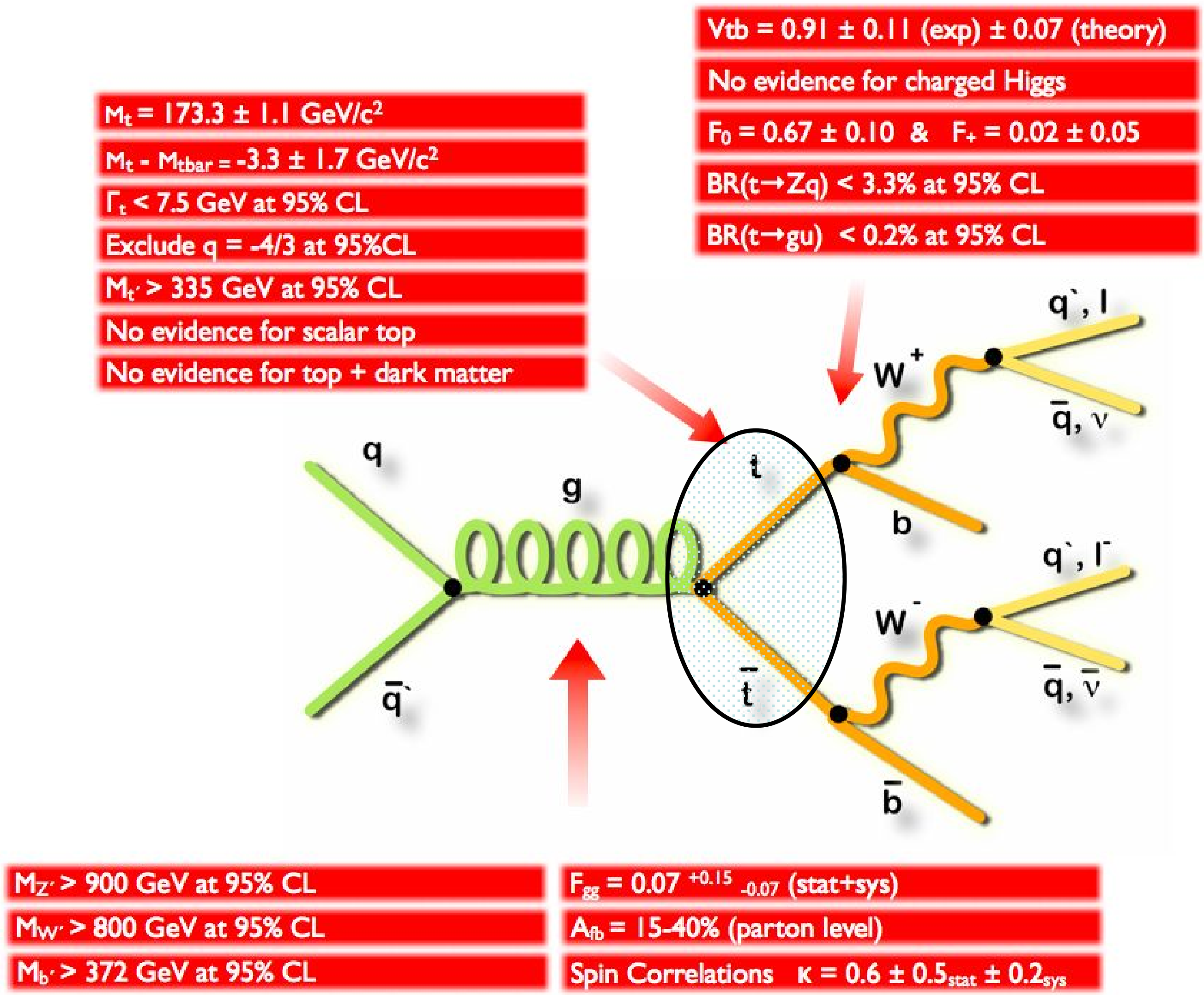


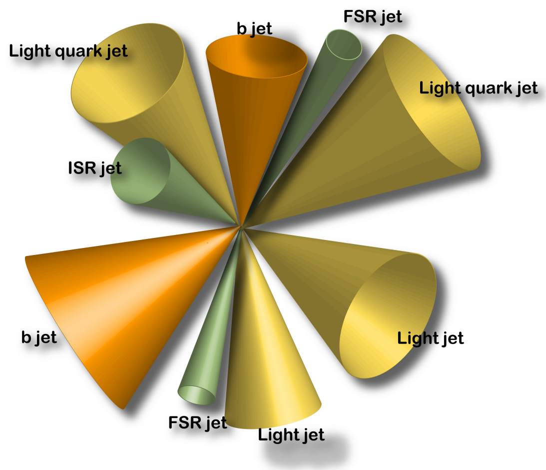
- $M_{Z'} > 900$ GeV at 95% CL
- $M_{W'} > 800$ GeV at 95% CL
- $M_{b'} > 372$ GeV at 95% CL
- $F_{gg} = 0.07^{+0.15}_{-0.07}$ (stat+sys)
- A_{fb} = 15-40% (parton level)
- Spin Correlations $\kappa = 0.6 \pm 0.5_{stat} \pm 0.2_{sys}$

Production properties

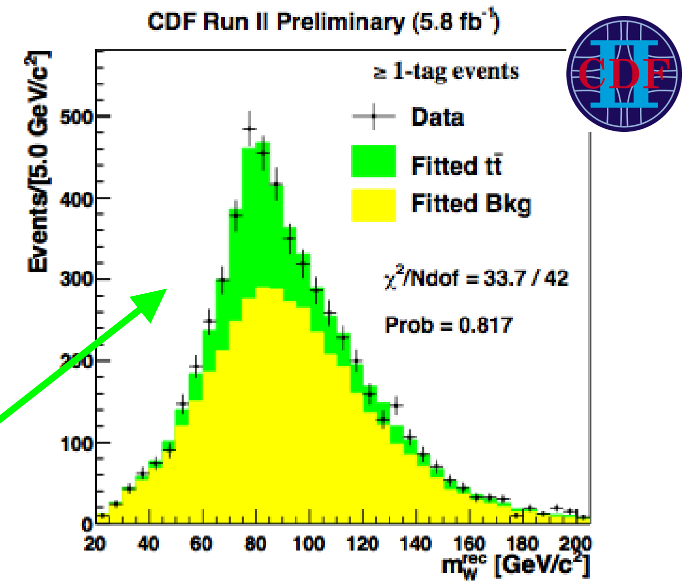
Intrinsic properties



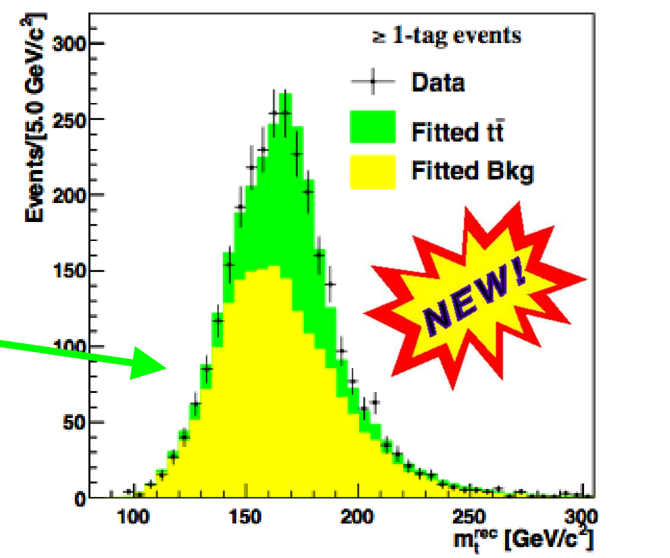
M_{top} measurement in $t\bar{t} \rightarrow bbqqqq$



Use b-tagging and multivariate techniques to isolate the signal from the overwhelming QCD background

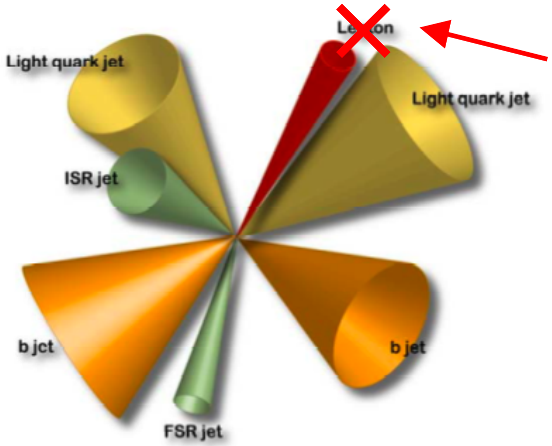


- Jet energy scale is the largest syst uncertainty: use $W \rightarrow qq$ decays to constrain it in situ
- Fully reconstruct the kinematics so to reconstruct the top quark mass



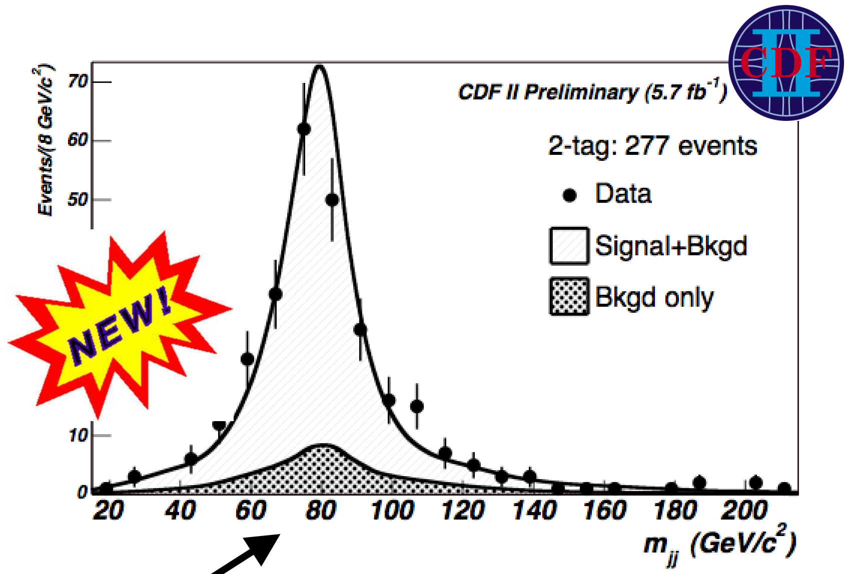
M_{top}= 172.5 +/- 1.7 (stat.+JES) +/- 1.2 (syst.) GeV/c^2

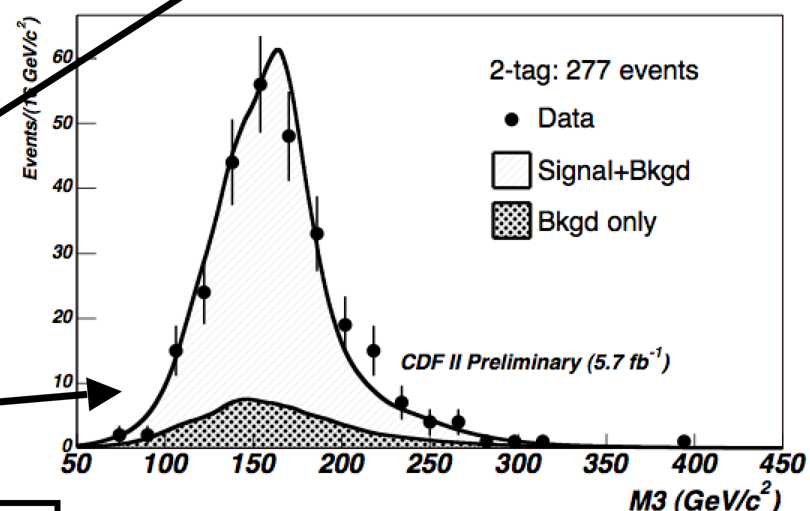
M_{top} measurement in $t\bar{t} \rightarrow bbqq\not{E}_T$



Limited lepton ID mostly due to limited detector coverage

But ttbar events have striking kinematics, and you can still reconstruct one W and one top in this sample





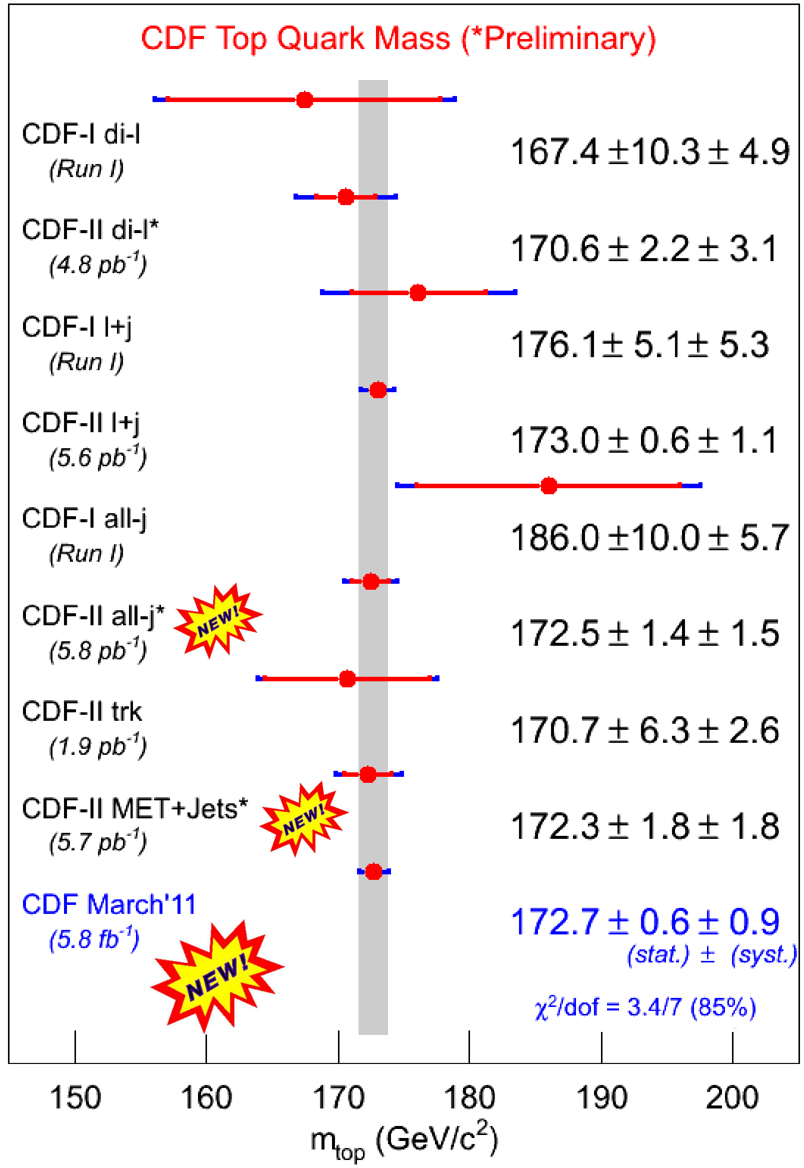
- Choose dijet pair with closest to W mass to measure jet energy scale
- Reconstruct one of the two decaying top to measure the top quark mass!

M_{top}= 172.3 +/- 2.4 (stat.+JES) +/- 1.0 (syst.) GeV/c^2

CDF M_{top} combination

Combining results obtained

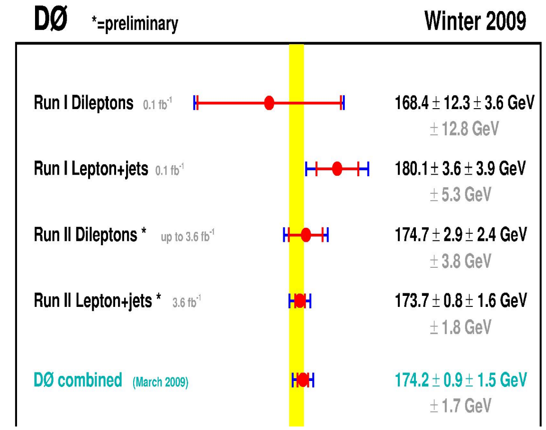
- in different datasets
  - consistency between 8 analyses
  - Independent datasets, about 5000 top pair evts analyzed!
- with different techniques
  - robustness
  - affected by different systematic sources



M_{top}= 172.7 +/- 0.6 (stat) +/- 0.9 (syst.) GeV/c^2

Top mass from D0

D0 measures too top quark mass *directly* in two decay modes



Q. what is the M_{top} we are measuring?A. MC mass

Q. what is the quark mass? A. mass is a renormalization scheme-dependent quantity

General agreement that m(MC) is close to the m(pole)

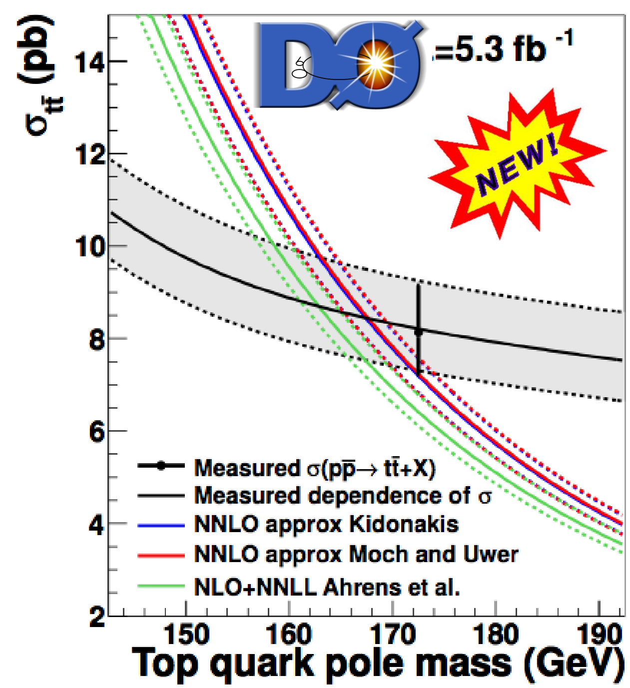
D0 challenges this assumption:

- use D0 σ(ttbar) meas in arxiv:1101.0124 and its dependence on M_{top} in MC
- assume M_{top} in MC is the pole mass
- compare it to NLO computations to measure pole mass $\boxed{M_{top}^{pole} = 167.5\ ^{+5.4}_{-4.9}\ \mathrm{GeV/c^2}}$*

agreement (1 sigma) with Tevatron world average

$\overline{\mathrm{MS}}$ interpretation disfavored

*using Moch and Uwer



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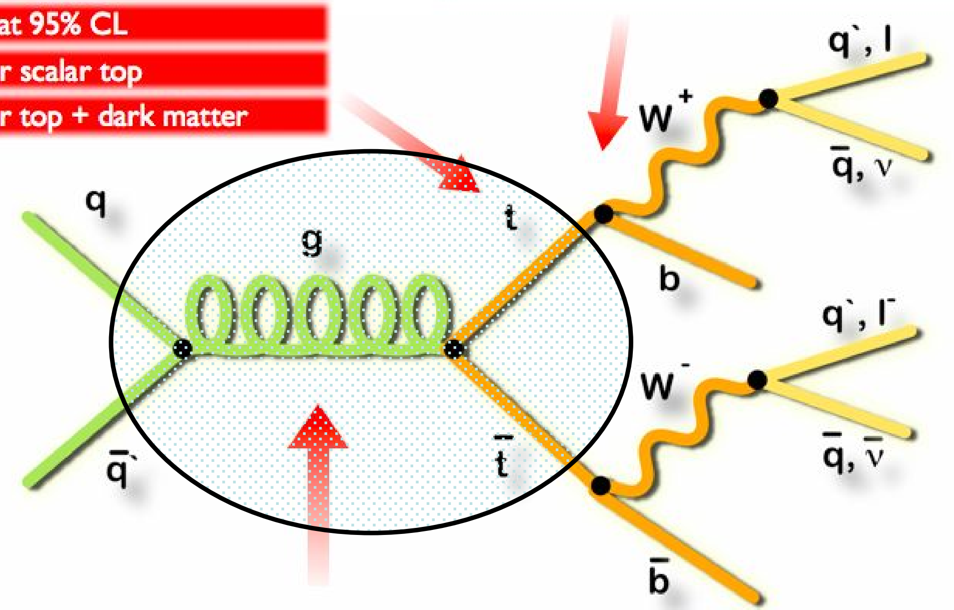

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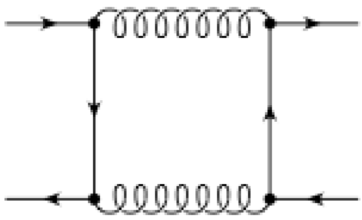
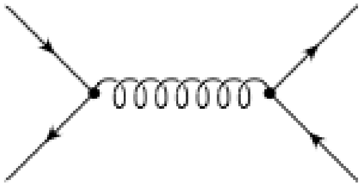
Spin Correlations $\kappa = 0.6 \pm 0.5_{stat} \pm 0.2_{sys}$

Charge asymmetry in top events

A ppbar collider is best suited to study the forward backward asymmetry of top quark production





- NLO QCD predicts small asymmetry from qqbar → ttbar, about 5%

Experimental determination(1)

A ppbar collider is best suited to study the forward backward asymmetry of top quark production

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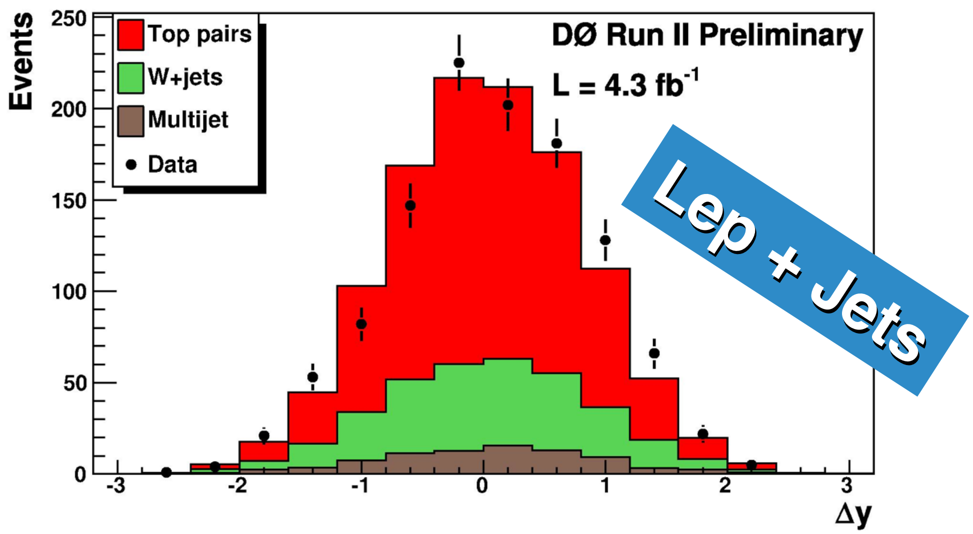


A_{FB}^{SM} = 1 ± 1.5 %

vs

A_{FB}^{D0} = 8.0 ± 4 %

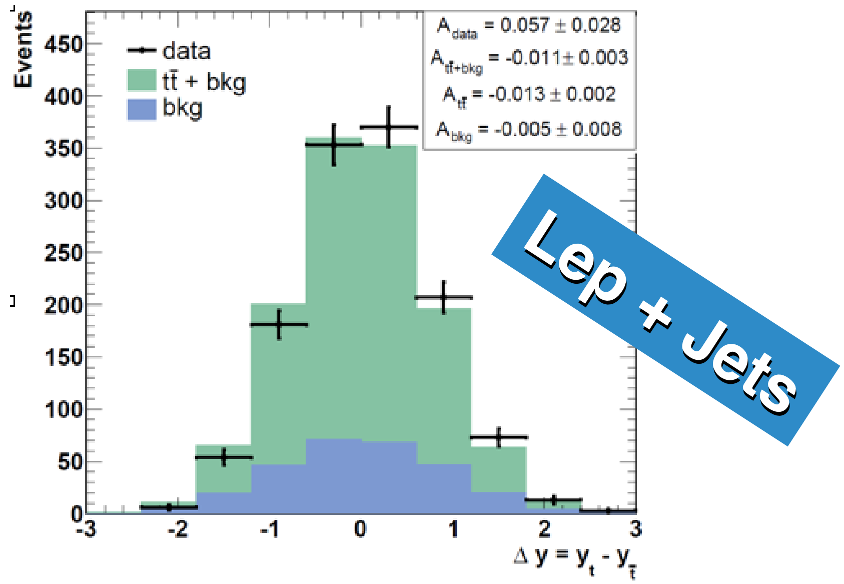
*background subtracted

2σ

Experimental determination(2)

A ppbar collider is best suited to study the forward backward asymmetry of top quark production

- NLO QCD predicts small asymmetry from qqbar → ttbar, about 5%



A_{FB}^{SM} = 5.0 ± 1.5 %

vs

A_{FB}^{CDF} = 15.0 ± 5 %

hep-ex/1101.0034

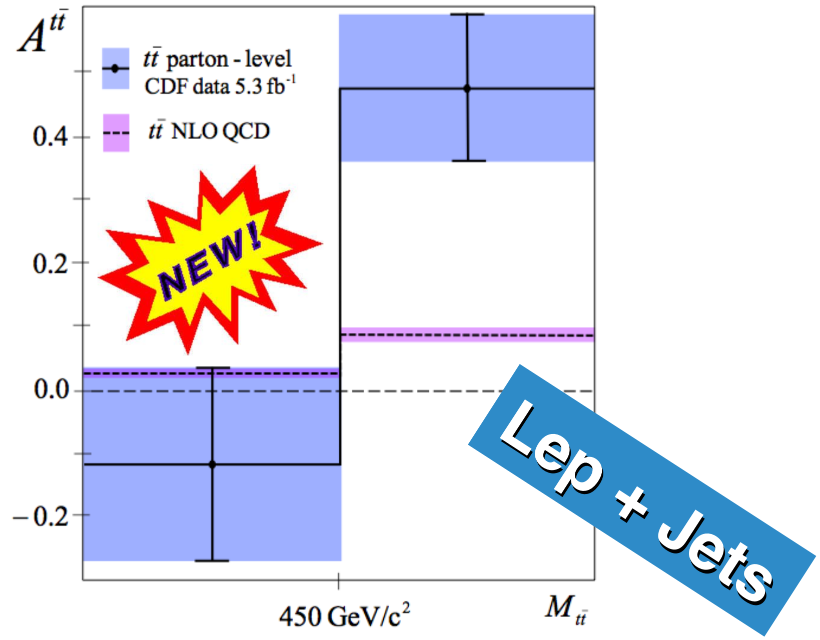
2σ

*parton level

Dependence on Q^2

A ppbar collider is best suited to study the forward backward asymmetry of top quark production

- NLO QCD predicts small asymmetry from qqbar → ttbar, about 5%
- Study of Q^2 dependence - M(ttbar) probes more finely NLO QCD computations. Also, it is a more sensitive probe to new physics



$A_{FB}^{SM} = \;\; 8.8 \pm 1.3\ \%$

vs

$A_{FB}^{CDF} = \;\; 48 \pm 11\ \%$

hep-ex/1101.0034 $>3\sigma$

*parton level

Experimental determination(3)

A ppbar collider is best suited to study the forward backward asymmetry of top quark production

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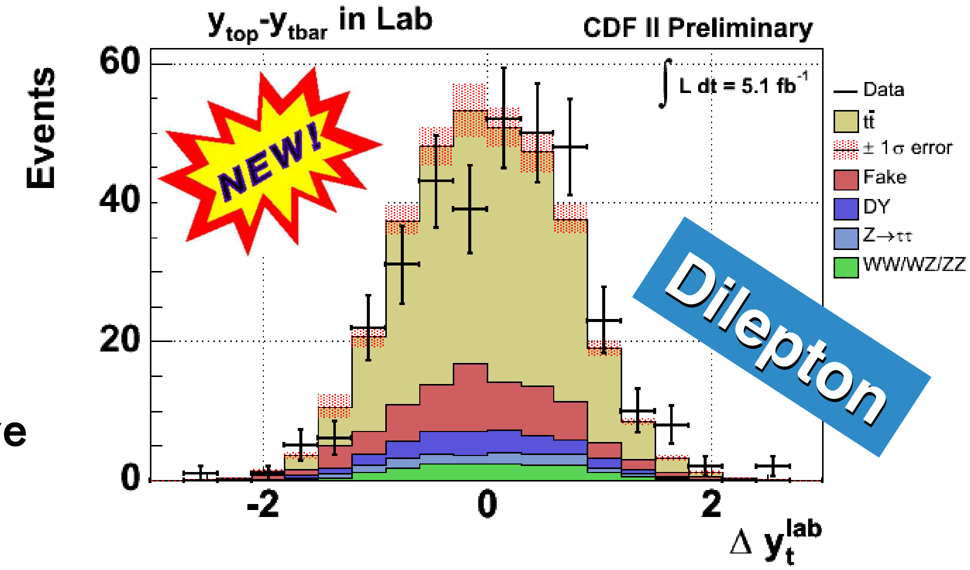


A_{FB}^{SM} = 5.0 ± 1.5 %

vs

A_{FB}^{CDF} = 42 ± 16%

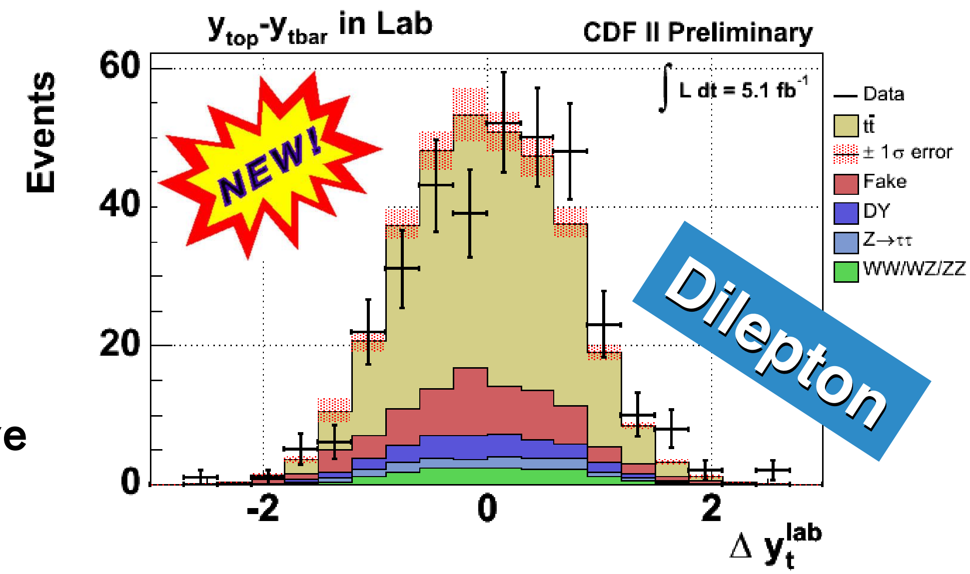
two experiments (CDF D0) to study this effect
two different decay modes at hand
twice the data yet to be analyzed!

*parton level

2.3σ

A ppbar collider is best suited to study the forward backward asymmetry of top quark production

- NLO QCD predicts small asymmetry from qqbar → ttbar, about 5%
- Study of Q^2 dependence - M(ttbar) probes more finely NLO QCD computations. Also, it is a more sensitive probe to new physics
- Model building must contend with precisely measured ttbar xsection and direct searches of exotic resonances decaying to ttbar



$$A_{FB}^{SM} = 5.0 \pm 1.5\ \%$$

vs

$$A_{FB}^{CDF} = 42 \pm 16\%$$

2.3σ

*parton level

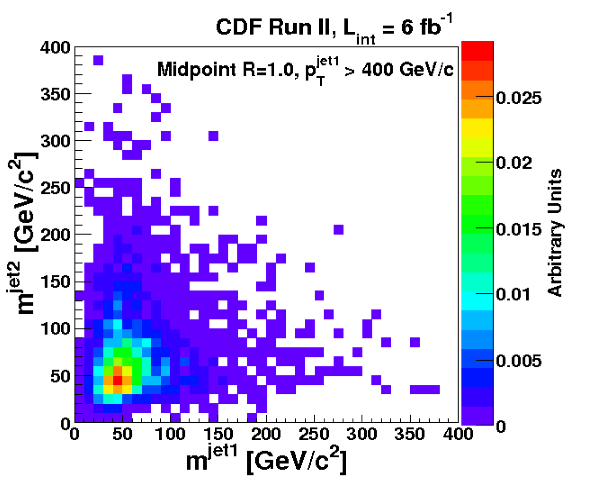
Search for boosted top quarks

Study boosted top → Probe NLO QCD/understand boosted jets/search for NP

Cross section for SM ttbar with Pt(top) ≥ 400GeV is a handful of fb

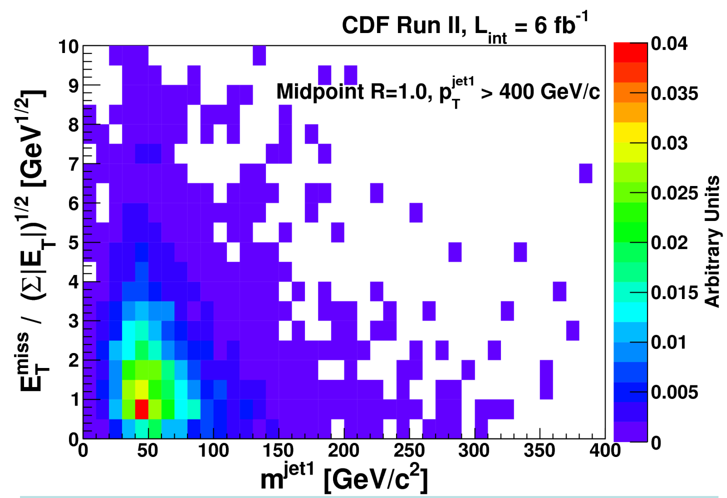
- direct identification of the W decay and the b quark unfeasible
- jet has mass close to Mtop → very different from jets from q/g

all-hadronic decays:
two tops with mass~175



M(Lead jet) vs M(sublead jet)

Lepton+jets decays:
one jet with mass~175, large MET



Lead jet mass vs $\not{E}_T/\sum E_T$)

Set limits on boosted SM ttbar xsec <40 fb @ 95CL

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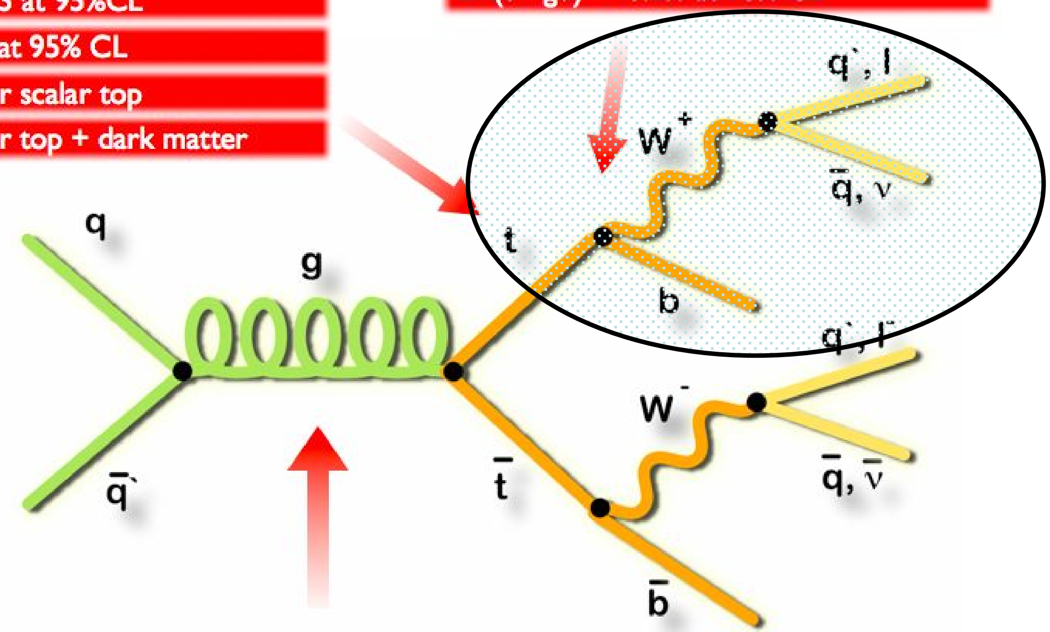

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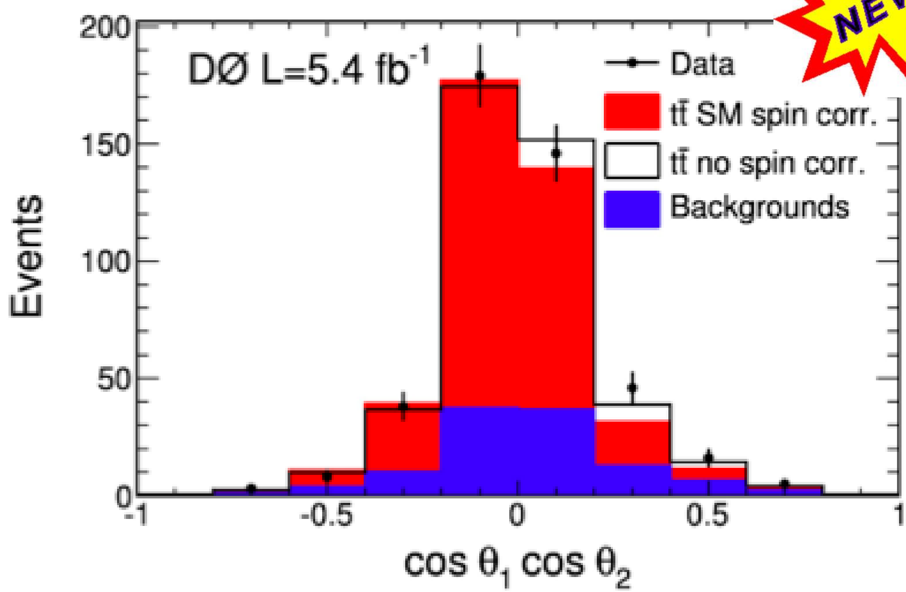
Spin correlation

SM predicts top and antitop spins to be highly correlated

- observable to measure depends on quantization axis

Leptons from W decays are ideal probe for this observable

NEW!



D0 compares data to different correlation hypotheses and finds
C = 0.10+0.45 (stat+syst)

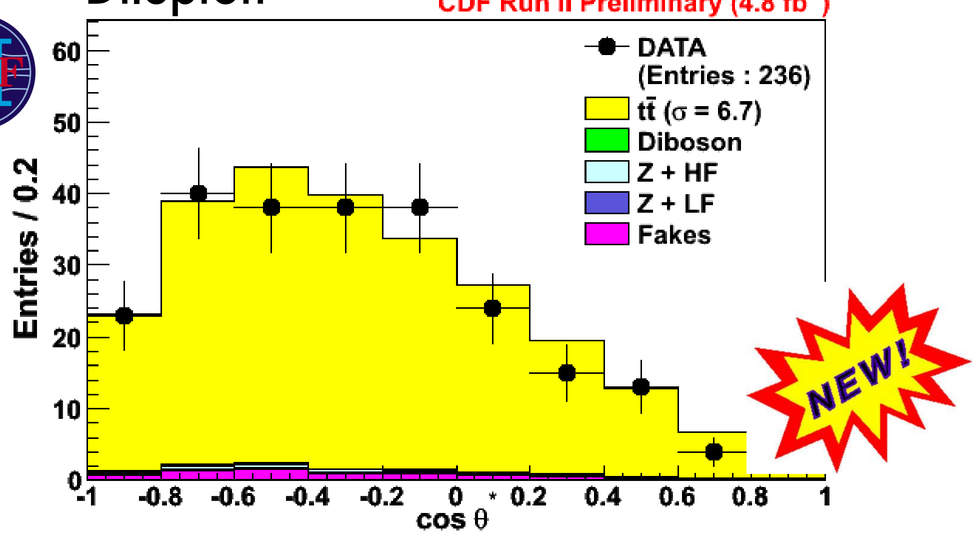
vs correlation predicted by QCD at NLO
C = 0.78+0.03

arxiv:1103.1871

W helicity in top decays

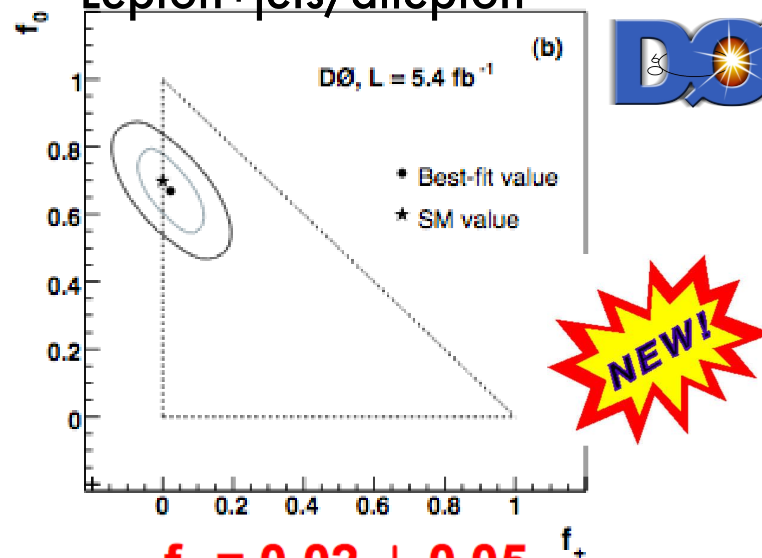
The V-A structure of the weak interaction can be tested by reconstructing the polarization of the W+ boson from top-quark decay.
SM predicts $f_0 = 0.7$ and $f_+ = 0$
In beyond- the-SM scenarios, significant deviations from the SM expectations are possible due to the presence of anomalous couplings

Dilepton



$f_+ = -0.12^{+0.12}_{-0.11}$
$f_0 = 0.78^{+0.20}_{-0.21}$

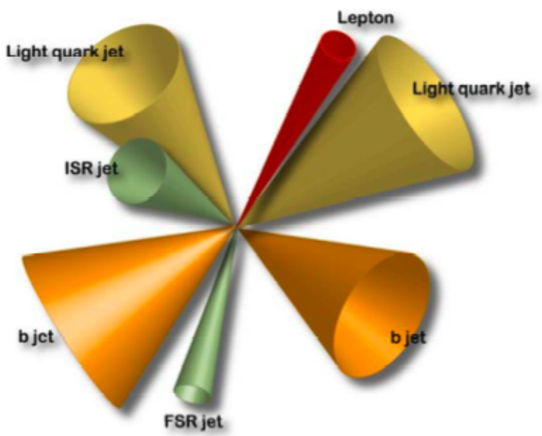
Lepton+jets/dilepton



$f_+ = 0.02 \pm 0.05$
$f_0 = 0.67 \pm 0.10$
arXiv:1011.6549

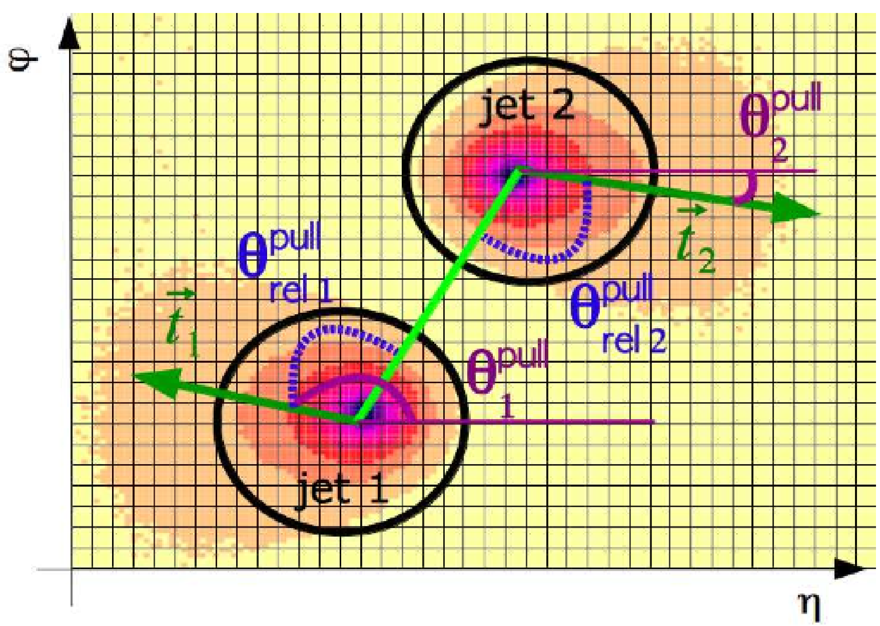
Combination of all Tevatron results ongoing - stay tuned

Study of color flow in ttbar events



Jet pulls have been introduced to discriminate jet pairs originating from color singlets (H→bb) from jet pairs originated from color octects (g→bb)

W from ttbar events are good candidates for this study.



NEW!

Compare SM hypothesis with color-octet "W" hypothesis. Expect fSinglet > 0.277 @ 95% C.L.
Meas fSinglet = 0.56 ± 0.42(stat+syst)

arxiv:1101.0648

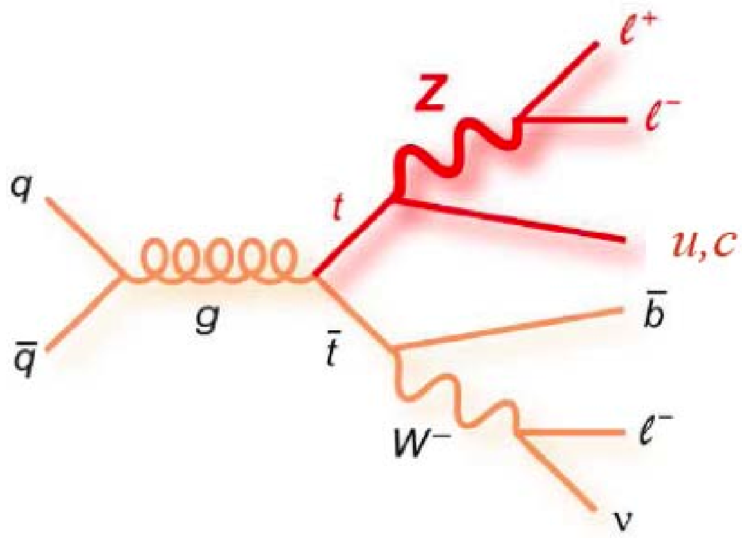
FCNC in ttbar events

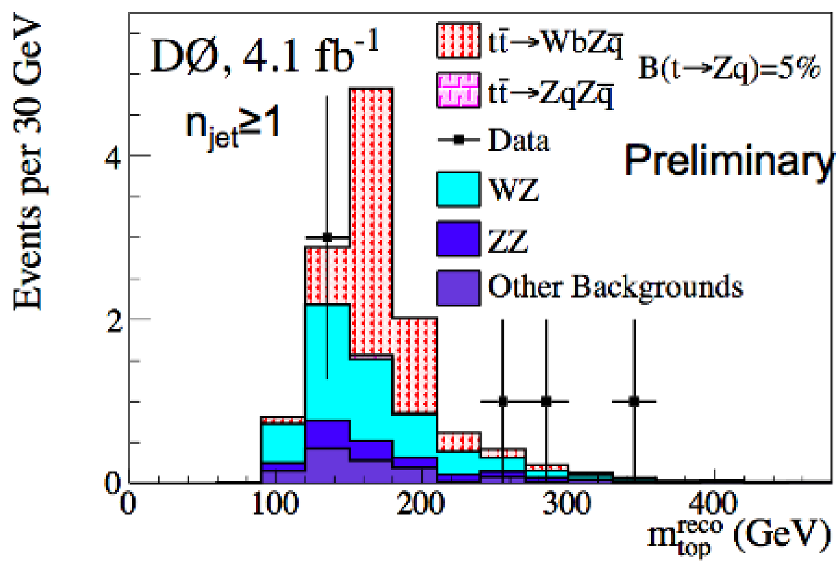
Top FCNC is extremely small in SM ~ $O(10^{-14})$

Beyond SM : up to $O(10^{-4})$

Signature of trileptons, jets and missing ET very striking

Any signal = new physics





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Not enough time...

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…vidence for scalar to…

Many more results!
Check our public web page for full list
www-cdf.fnal.gov/physics/new/top/top.html
www-d0.fnal.gov/Run2Physics/WWW/results/top.htm

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Summary

- Sixteen years after its discovery, the knowledge of the top quark has greatly expanded thanks to the large Tevatron dataset
  - extensive measurements of top quark intrinsic properties, study of its production and decay

- With the LHC era coming, Tevatron will still play an important role:
  - some Tevatron measurements - its mass! - have broad impact to our field, and will be a long standing legacy
  - others such as charge asymmetry, spin correlations are complementary to the LHC program

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- Study of forward-backward asymmetry of top events shows discrepancy with current NLO QCD prediction. Waiting for NNLO calculation. Also, *twice the data already available to soon confirm or disprove the existing excess!*

Stay tuned!

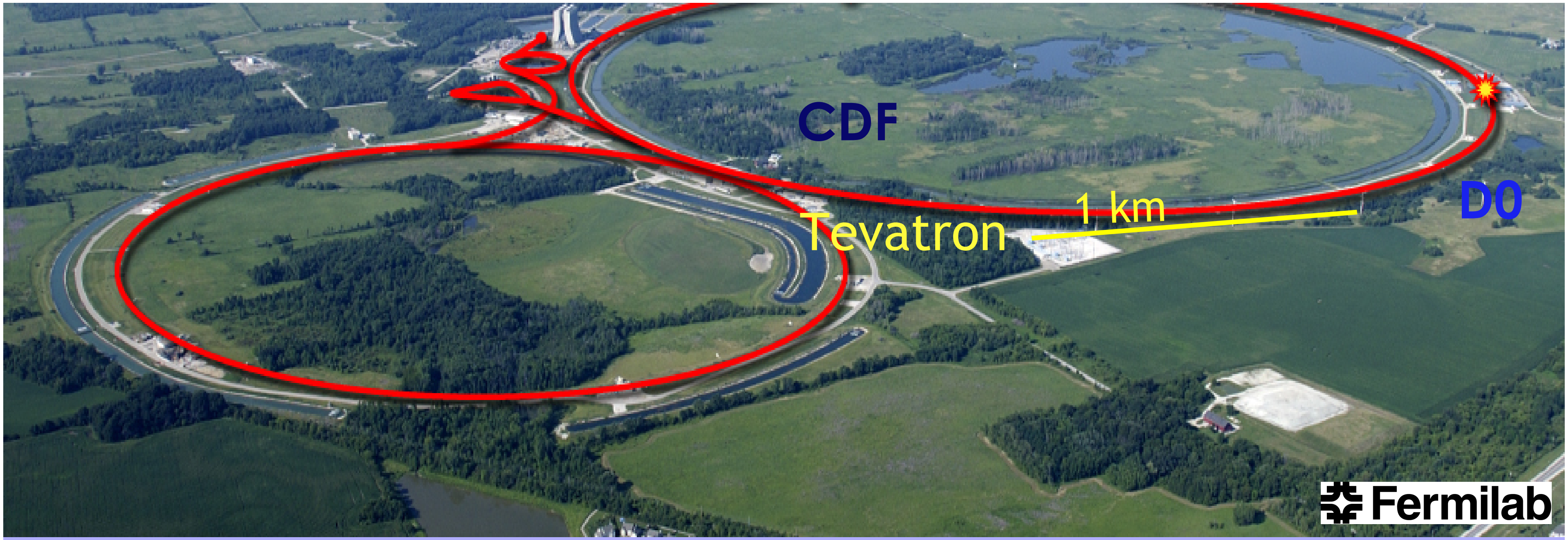
Back-up

Where?

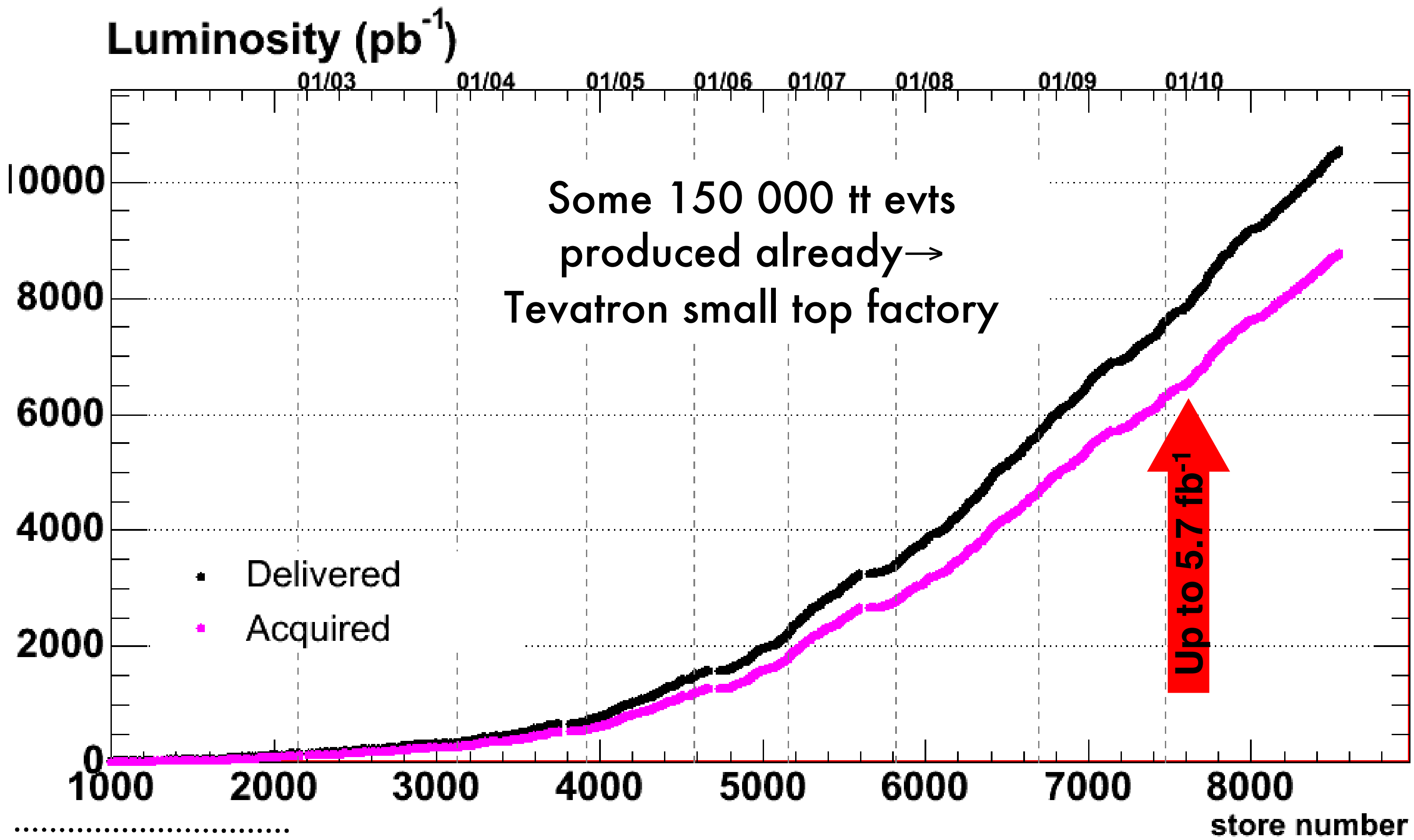
Fermilab's Tevatron Run II $p\bar{p}$ collider at 1.96 TeV, running since year '01. Currently performing very well:

- New record in instantaneous luminosity $4 \cdot 10^{32}$ cm^{-2} s^{-1}
- New record in delivered luminosity: 2.5fb^{-1} per year
- Two multi-purpose, well-understood detectors CDF and D0

Top created in 1 in O(10^{10}) collisions at the Tevatron



How many?



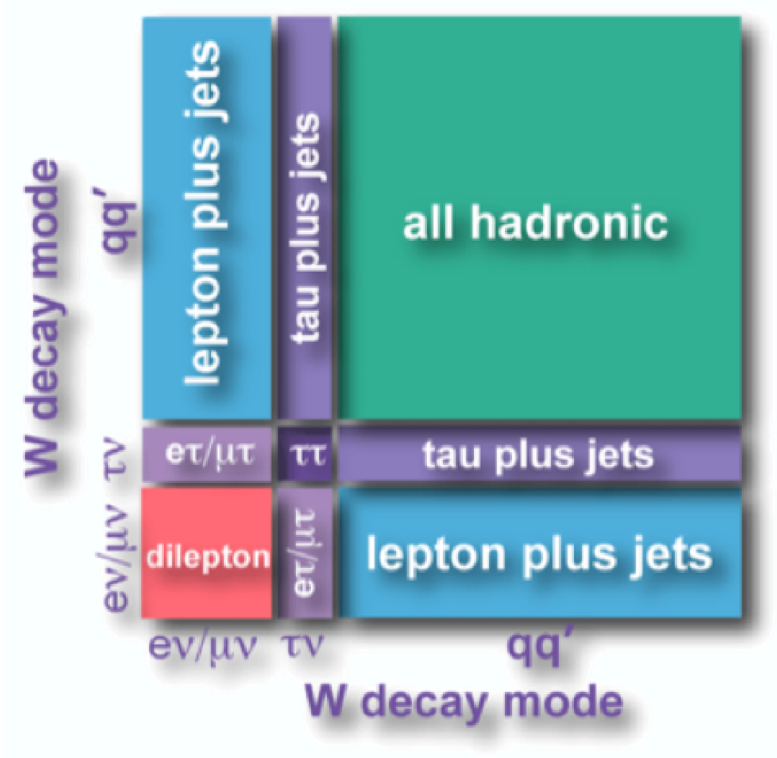
Delivered >10.0 fb^{-1}

Acquired ~9 fb^{-1*} (slightly less w/ silicon)

Almost 6 fb^{-1*} analyzed

*CDF shown here
Similar numbers for D0

Pair production decay signatures



Potential to analyze more than 30 000 top quarks by end 2011

Total acceptance 13%

Lepton+Jets
- large BR(30%)
- good S/B ratio.

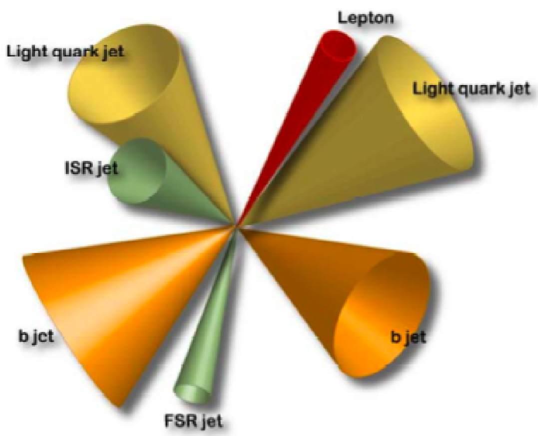
Dileptonic
- Highest S/B
- lowest BR(5%)

All hadronic
- highest BR(44%)
- Very large QCD background

Tau modes
- explicit tau identification

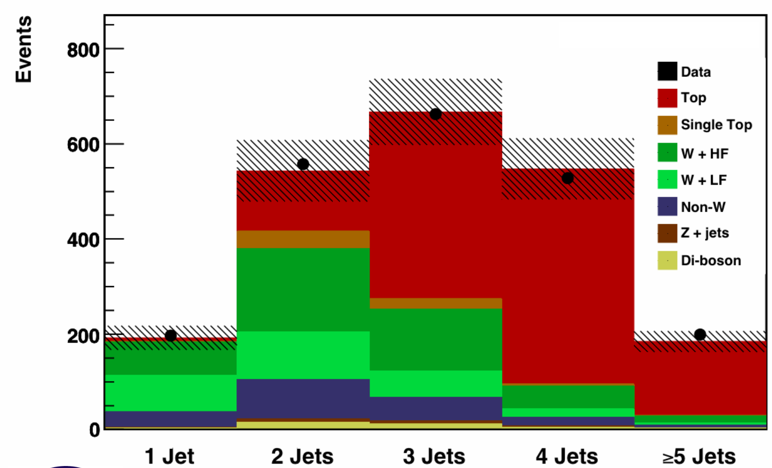
MET + jets
- Lepton+jets and dileptonic decays where electron/muon is not id'ed. Large acceptance to taus

No multivariate

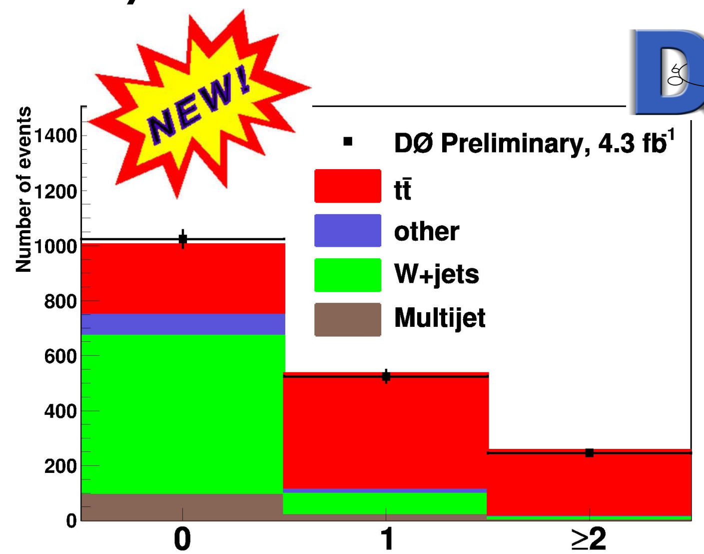


Counting experiment after background understanding:

- W+HF cross section underestimated in the MC: W+HF content measured in data in the 1 or 2 jet event sample
- b-tagging mistag rate measured in data, parametrization applied to W+jets
- CDF measures ratio of ttbar/Z→ll with the same trigger and use the theoretical Z cross section to remove the uncertainty due to luminosity measurement



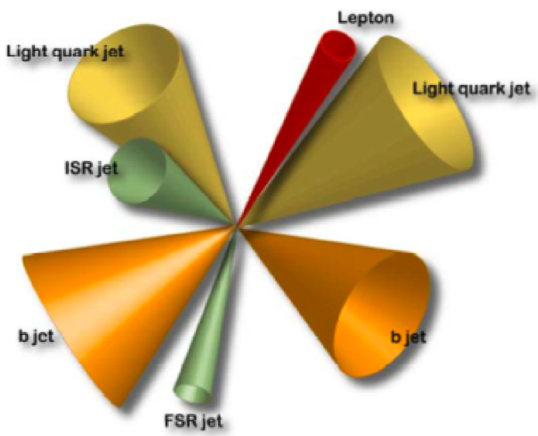
PRL 105 012001 (2010)



D0 (L=4.3fb^{-1}): $\sigma_{t\bar{t}}$ = 7.93 ± 0.98 (stat+syst+lumi) pb

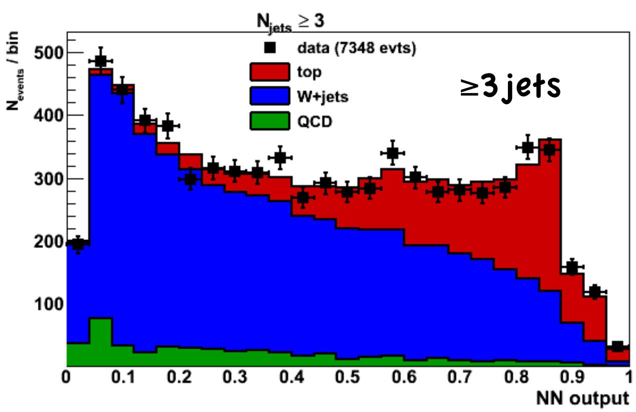
CDF(L=4.3fb^{-1}): $\sigma_{t\bar{t}}$ = 7.32 ± 0.71 (stat+syst+theory) pb

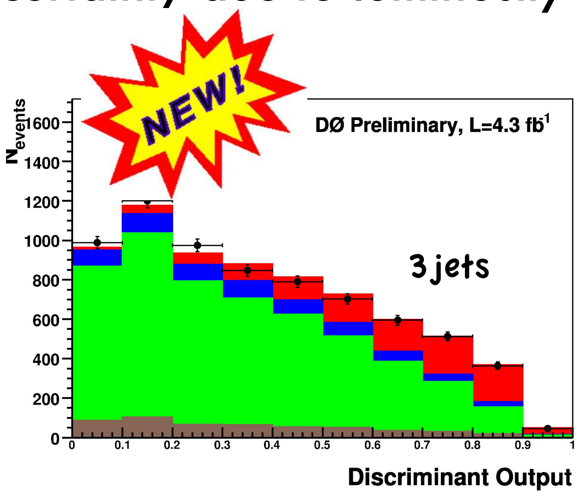
With multivariate

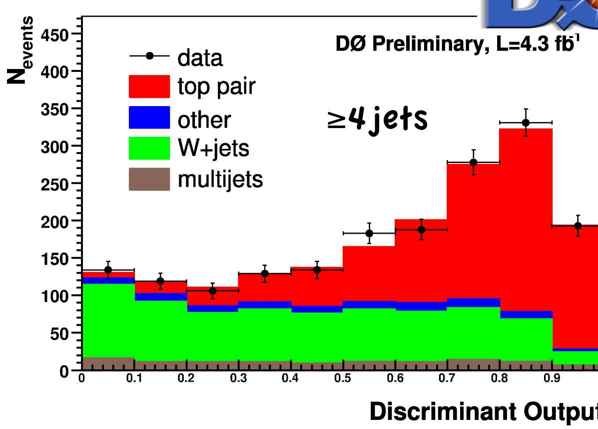


One step further: signal/background discrimination:

- ttbar more energetic, central and isotropic than W+jets
- NN (CDF) or BDT (D0) input variables: Ht, aplanarity, sphericity, etc.
- cross section measurement: template fit of ttbar and W+jets to the discriminant output
- CDF measures ratio of ttbar/$Z \rightarrow ll$ with the same trigger and use the theoretical Z cross section to remove the uncertainty due to luminosity measurement







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D0 (L=4.3fb^{-1}): σ_{tt} = 7.70 ± 0.75 (stat+syst+lumi) pb

CDF(L=4.6fb^{-1}): σ_{tt} = 7.82 ± 0.55 (stat+syst+theory) pb

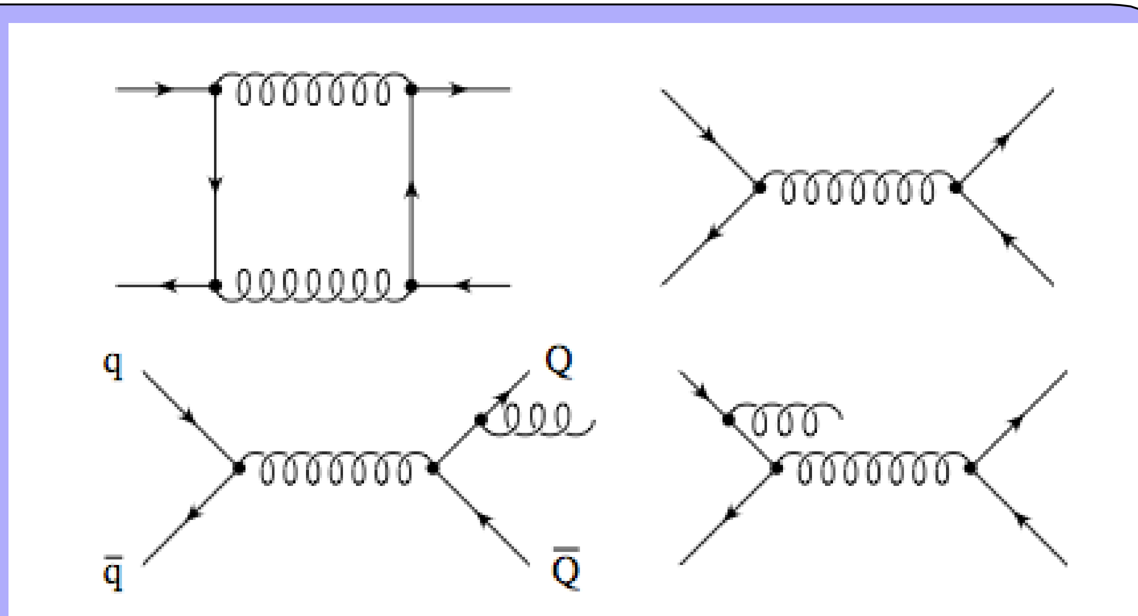
C asymmetry in ttbar production

LO collision is charge-symmetric

NLO produces asymmetry through interference

between box and Born diagram

between ttj states

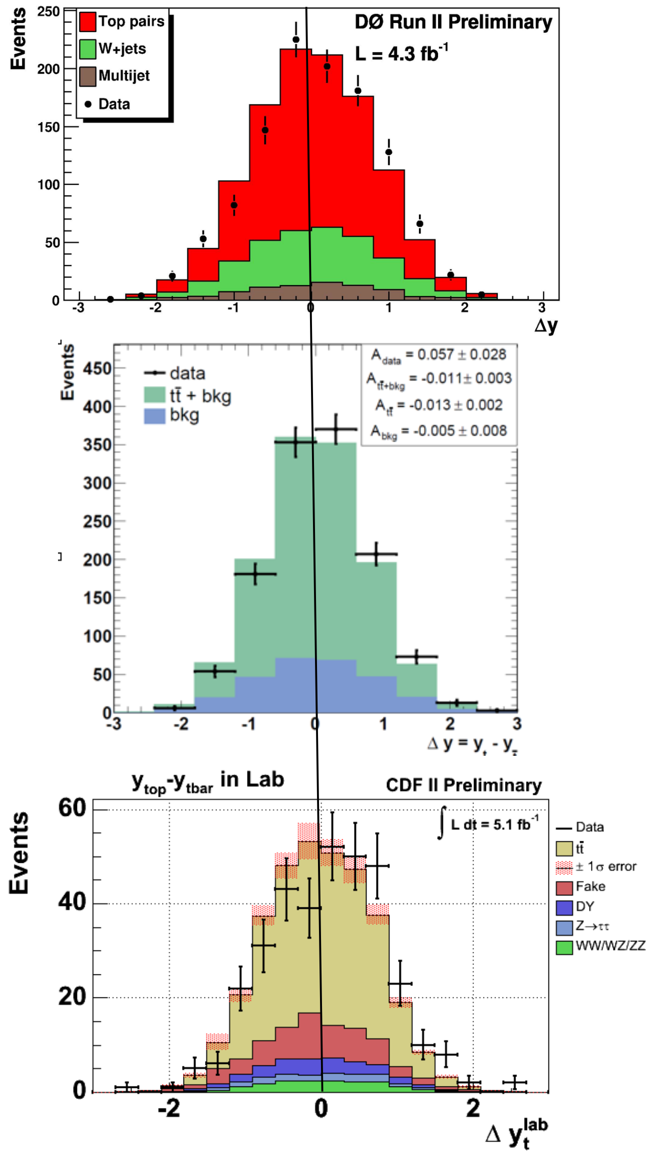


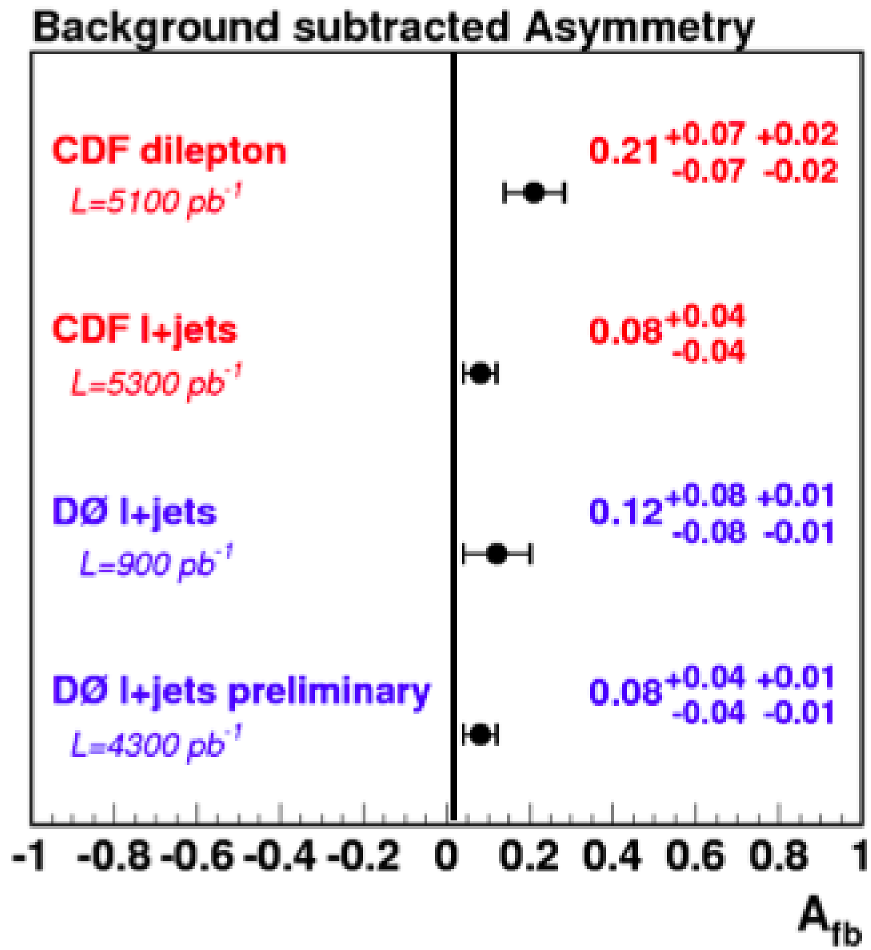
Net result is a positive asymmetry

Several exotic ttbar production modes generate at tree-level a C asymmetry too, through the interference with SM qq → tt.

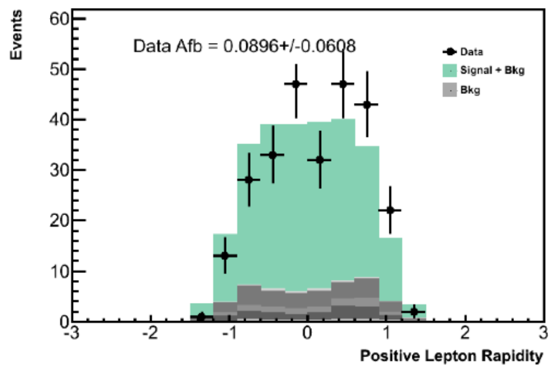
PS gg (LHC) initial state is C-symmetric. Also, no asymmetry to gg → X → tt

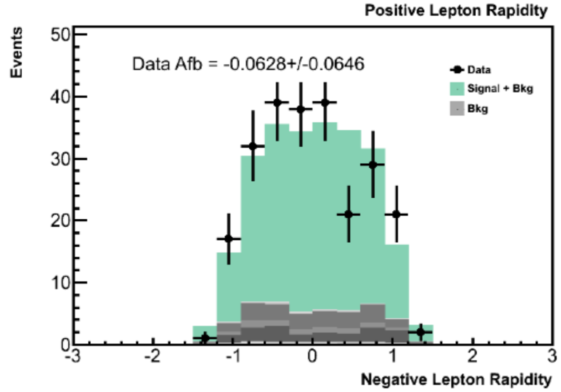
The big picture

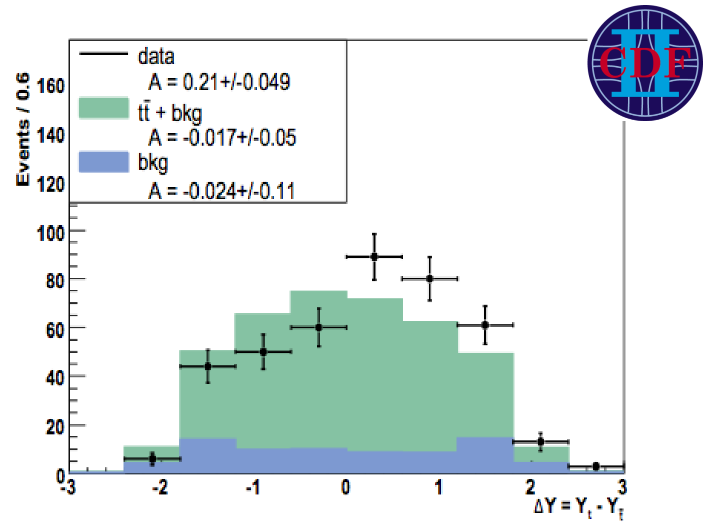


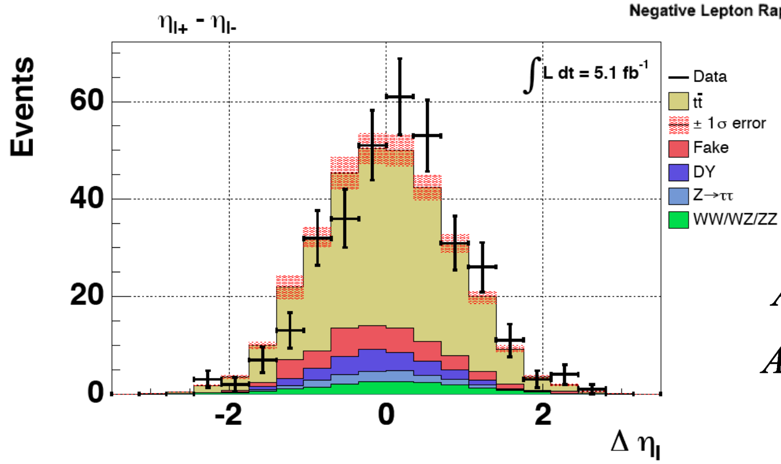


From lepton rapidity to top rapidity



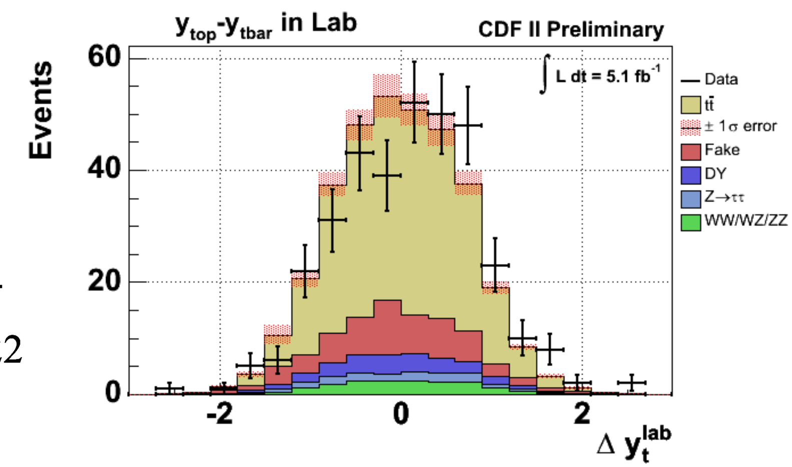




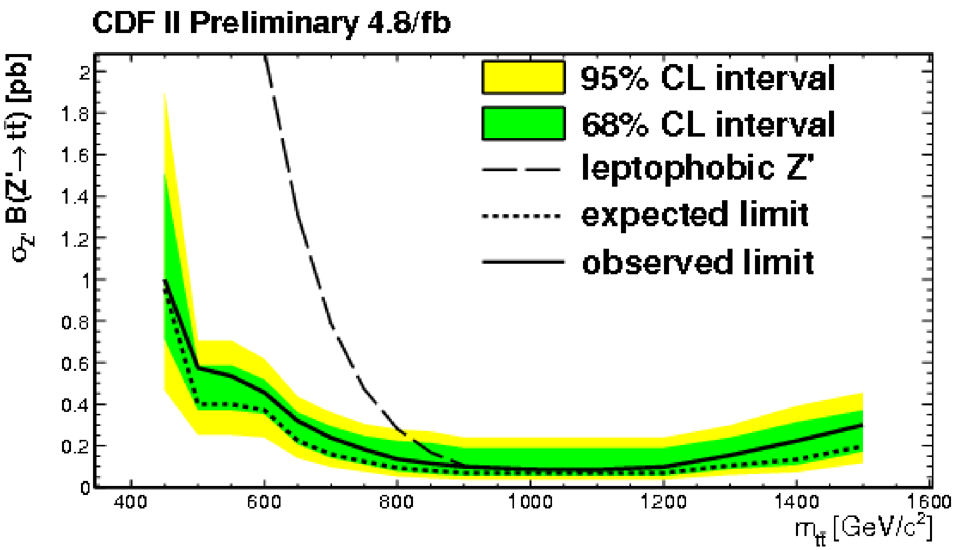


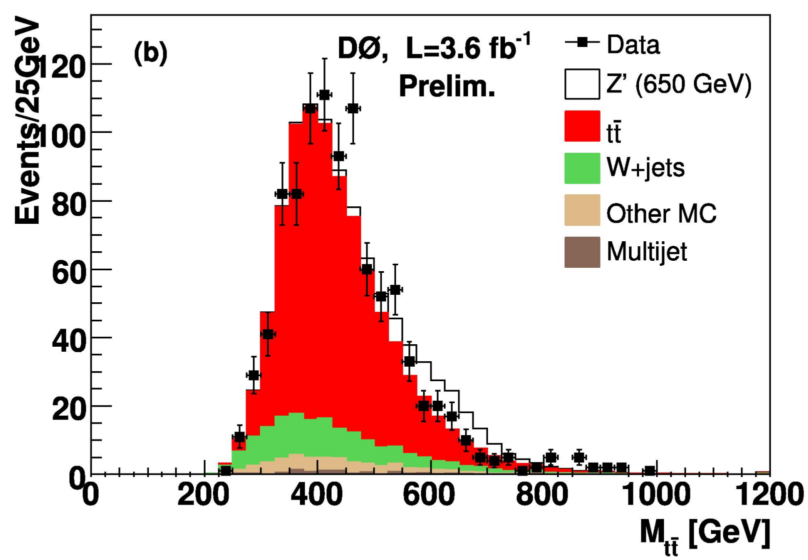
$$A_{obs}^{\Delta\eta_l} = 0.138 \pm 0.054$$

$$A_{pred}^{\Delta\eta_l} = -0.022 \pm 0.022$$



Search for Z′





Z′<900GeV excluded at 95%CL

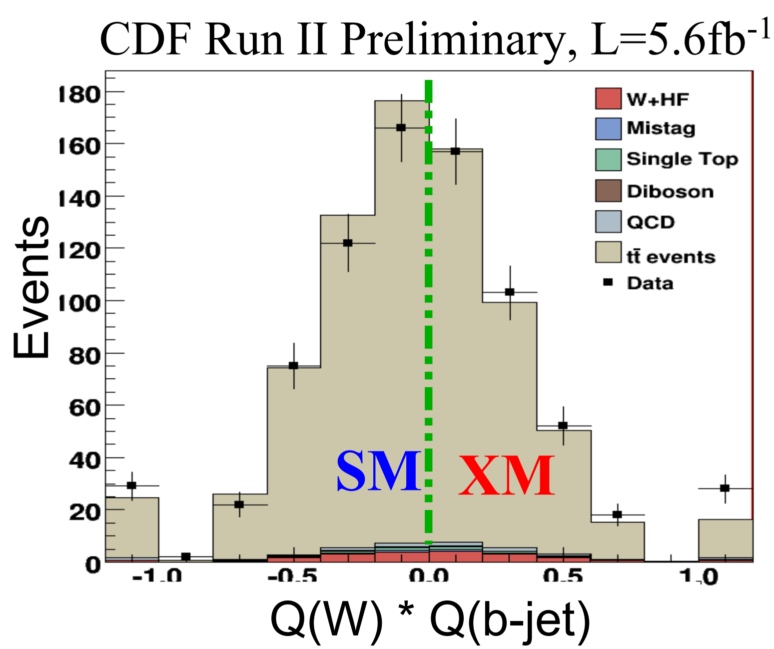
Z′<820GeV excluded at 95%CL

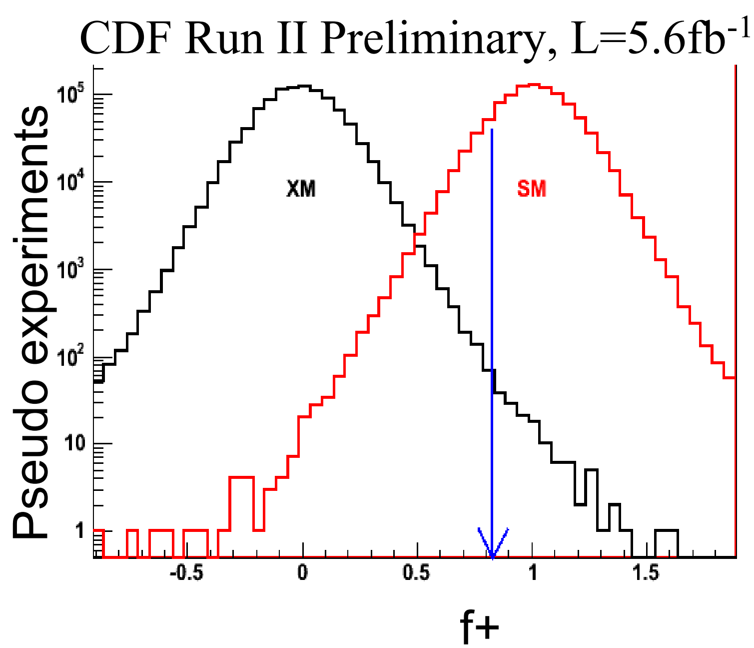
Narrow widht hypothesis in both analyses

Top charge

Select Lepton+Jets events wih 2 b-tagged jets

- kinematically reconstruct the events->choose best combination of Wb pa
- charge of lepton = charge of W boson
- tag the flavor of b-jet by its charge

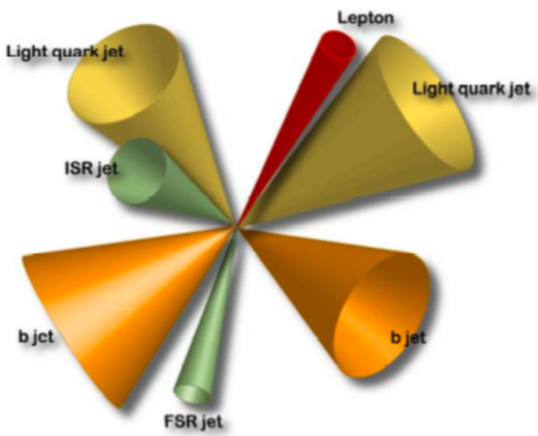




p-value XM = 0.00014

Exclude 4/3 hypothesis with 95% CL

The quest for 4th generation



4th generation long believed to be ruled out.

We now know this is not the case.

- Possible mass range is in the few 100's GeV.
- Large region already covered by CDF/D0
- Exploring several b'/t' decays