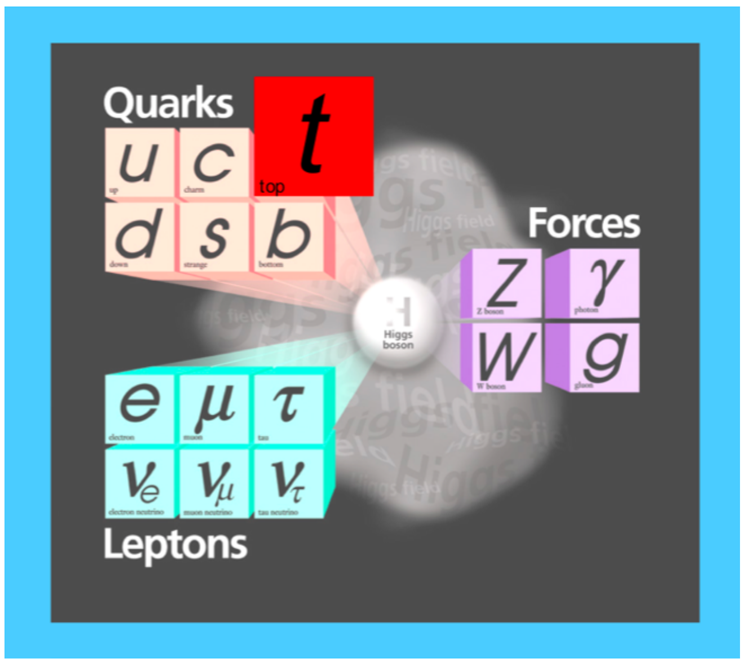
The Tevatron top legacy: from precision measurements to new physics smoking gun?



Fabrizio Margaroli
PURDUE UNIVERSITY

The top quark is special

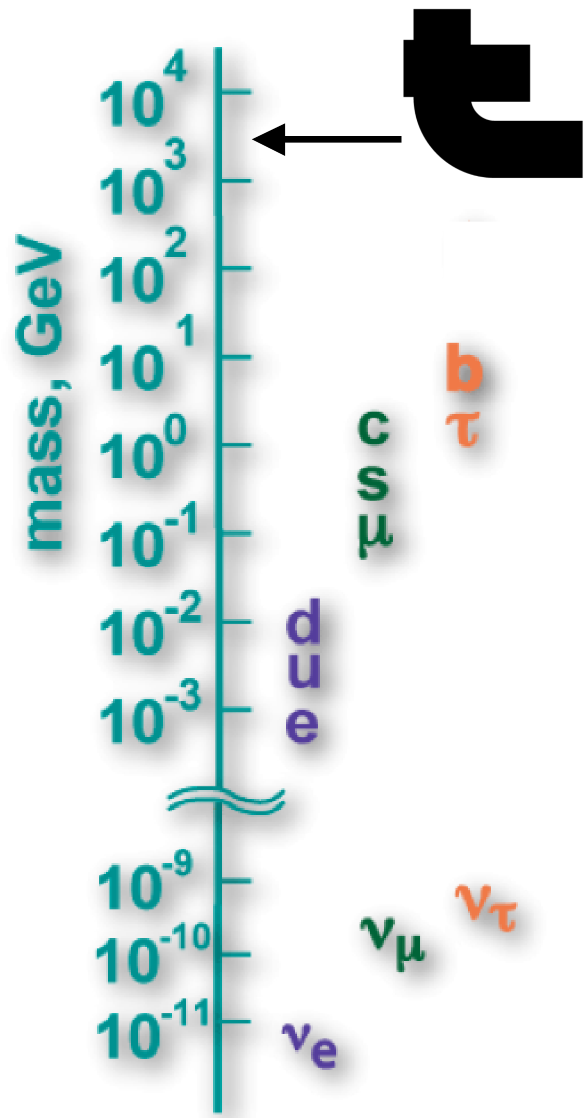
- Top was discovered at Fermilab in 1995
- Its mass much larger than any other fermion
- Using the latest Tevatron-averaged M_{top} arXiv:1007.3178

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

- 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

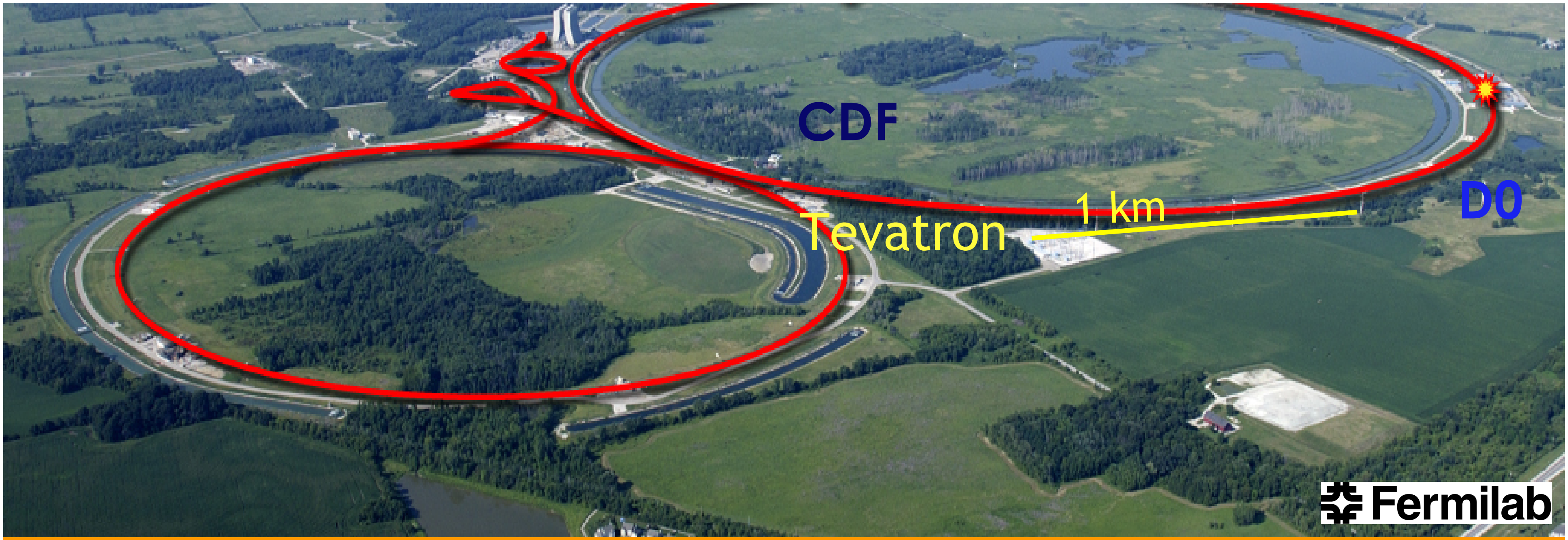
→ $O(10^3)$ of top events analyzed, $O(10^4)$ by the end of the Tevatron



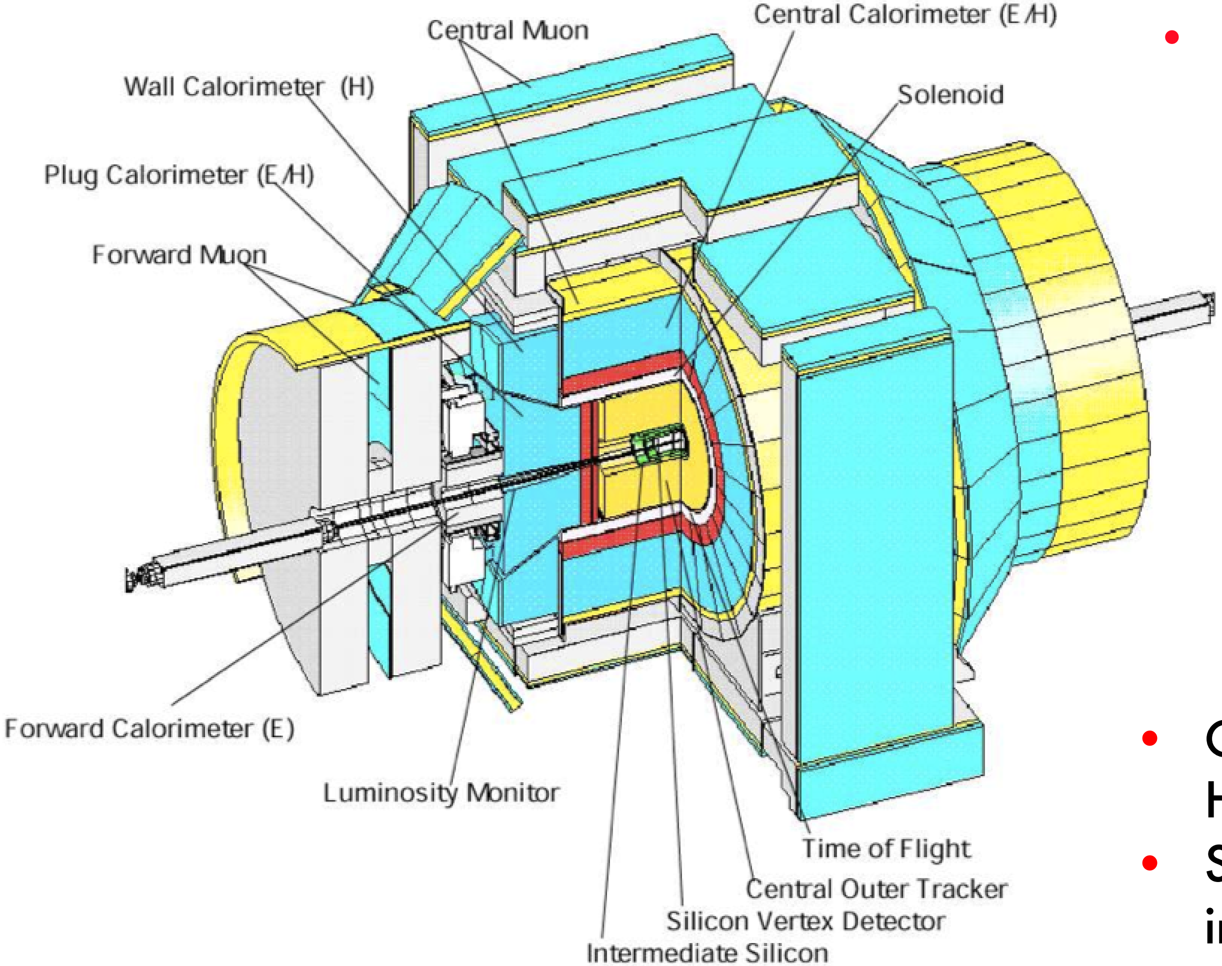
Where?

- 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: $2.5 fb^{-1}$ per year
  - Two multi-purpose, well-understood detectors CDF and D0

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



The CDF II detector



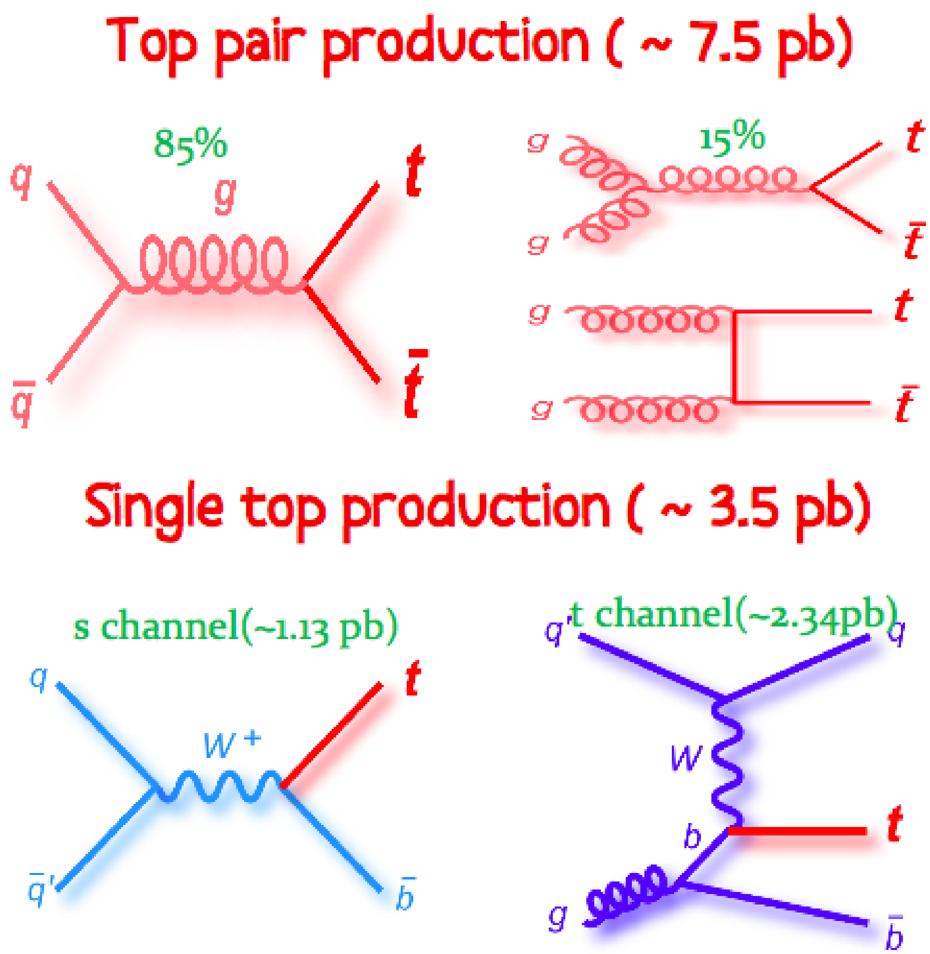
- Tracking:
  - Silicon tracker allows precision vertex detection $|\eta|<2$
  - Drift chamber $|\eta|<1$ measures charged particle P_T

- Calorimeter split in EM and HAD devices $|\eta|<3.6$
- Shower maximum detector in EM cal

- Muon chamber outside calorimeter coverage $|\eta|<1.5$

All important for top physics!

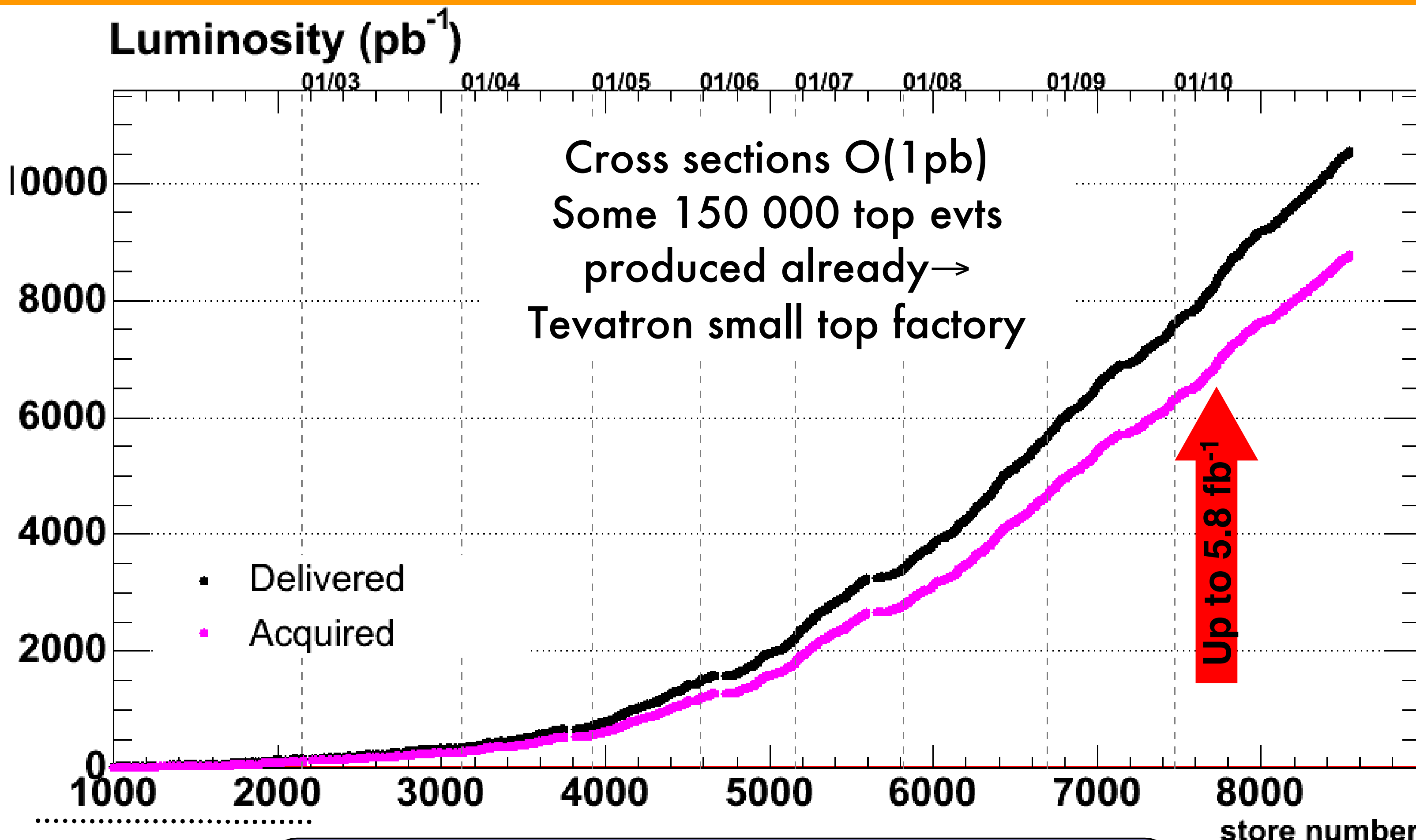
Top quark production



- Proportions inverted at 7TeV LHC
- Ttbar cross section 20 times larger at LHC

- T-channel xsec 30 times larger at LHC
- S-channel xsec increases very little at LHC (while backgrounds do much more)

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

CDF top physics in the LHC era

- *Precision phyiscs in the top sector*
  - **A precision on M_{top} below 1GeV is achievable**. Crucial to constrain the Higgs boson mass but also new physics, and to calibrate LHC detectors!
  - **A precision on V_{tb} below 5% is achievable**. Chance to discover new physics

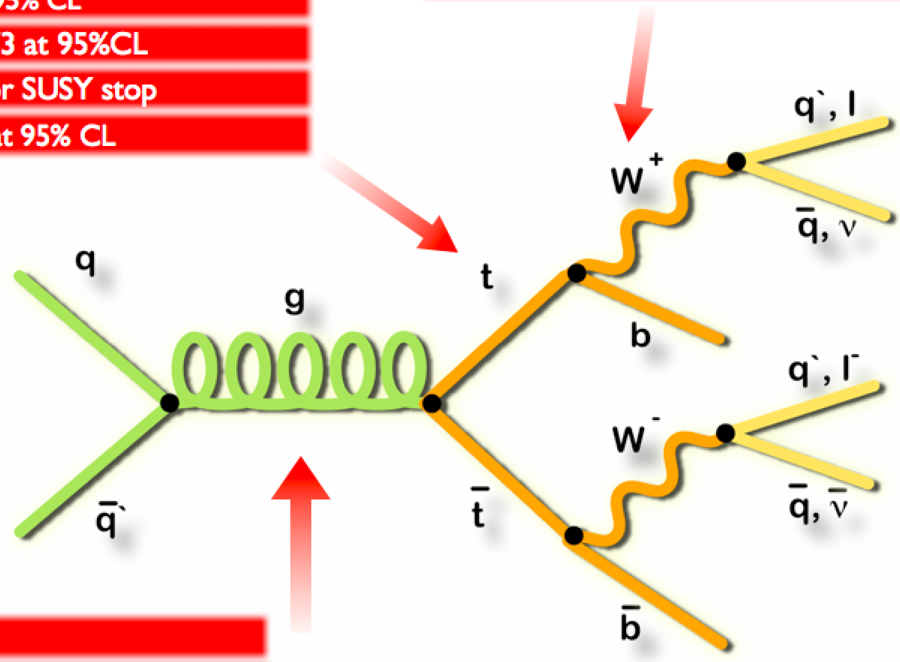
- *Complementarity with the LHC program*
  - **Forward backward asymmetry** will need a lot of data and different phase space at LHC. Similar for spin correlation (but it's hard at the Tevatron too)
  - **Single top s-channel** has favorable S/B ratio at the Tevatron

- *Any sign for new physics in the top quark signature?*
  - **Anomalously large forward backward asymmetry!**
  - Stringest exclusions **fo 4th generation of quarks (t',b')**
  - sensitive to leptophobic **exotic bosons (W'→tb,Z' →tt)** up to 1 TeV
  - probing presence of **SUSY charged Higgs, axigluons**, etc.etc.

What we know about top quarks

- $M_t = 173.3 \pm 1.1$ 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
- No evidence for SUSY stop
- $M_{t'} > 335$ GeV at 95% CL

- Vtb = 0.91 ± 0.11 (exp) ± 0.07 (theory)
- No evidence for charged Higgs
- $BR(t \rightarrow Zq) < 3.7\%$ at 95% CL
- $F_0 = 0.62 \pm 0.11$ & $F_+ = -0.04 \pm 0.05$



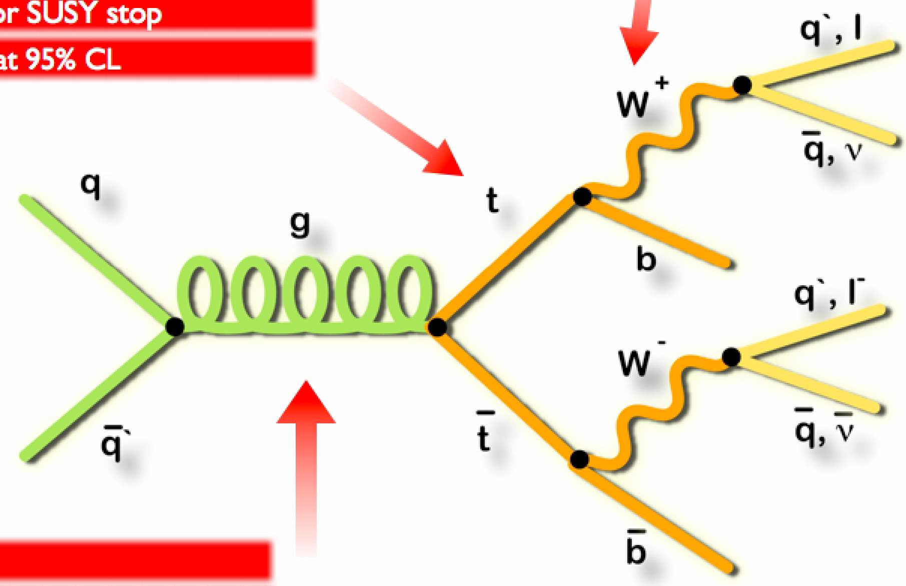
- $\sigma_{ttbar} = 7.5 \pm 0.5$ pb
- $\sigma_{singletop} = 2.8 + 0.5$ pb
- $\sigma_{ttbar+j} = 1.6 \pm 0.5_{sys}$ pb
- $M_{Z'} > 900$ GeV at 95% CL
- $M_{W'} > 800$ GeV at 95% CL
- $M_{b'} > 372$ GeV at 95% CL

- $F_{gg} = 0.07\ ^{+0.15}_{-0.07}$ (stat+sys)
- $A_{fb} = 0.475 \pm 0.114$
- Spin Correlations $\kappa = 0.6 \pm 0.5_{stat} \pm 0.2_{sys}$

What we know about top quarks

$M_t = 173.3 \pm 1.1$ 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
No evidence for SUSY stop
$M_{t'} > 335$ GeV at 95% CL

Vtb = 0.91 ± 0.11 (exp) ± 0.07 (theory)
No evidence for charged Higgs
BR($t \to Zq$) < 3.7% at 95% CL
$F_0 = 0.62 \pm 0.11$ & $F_+ = -0.04 \pm 0.05$

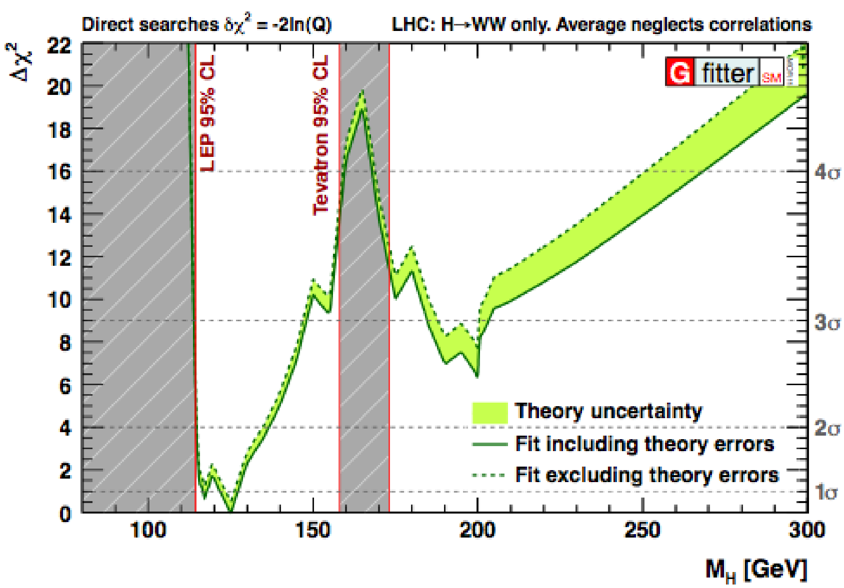


$\sigma_{ttbar} = 7.5 \pm 0.5$ pb
$\sigma_{singletop} = 2.8 + 0.5$ pb
$\sigma_{ttbar+j} = 1.6 \pm 0.5_{sys}$ pb
$M_{Z'} > 900$ GeV at 95% CL
$M_{W'} > 800$ GeV at 95% CL
$M_{b'} > 372$ GeV at 95% CL

$F_{gg} = 0.07\ ^{+0.15}_{-0.07}$ (stat+sys)
$A_{fb} = 0.475 \pm 0.114$
Spin Correlations $\kappa = 0.6 \pm 0.5_{stat} \pm 0.2_{sys}$

From top to Higgs

Direct searches and indirect constraints - *top quark mass* and W mass especially - point to a relatively light Higgs boson



M_Z [GeV]	91.1875 ± 0.0021
Γ_Z [GeV]	2.4952 ± 0.0023
σ^0_{had} [nb]	41.540 ± 0.037
R^0_ℓ	20.767 ± 0.025
$A^{0,\ell}_{\mathrm{FB}}$	0.0171 ± 0.0010
A_ℓ $^{(\star)}$	0.1499 ± 0.0018
A_c	0.670 ± 0.027
A_b	0.923 ± 0.020
$A^{0,c}_{\mathrm{FB}}$	0.0707 ± 0.0035
$A^{0,b}_{\mathrm{FB}}$	0.0992 ± 0.0016
R^0_c	0.1721 ± 0.0030
R^0_b	0.21629 ± 0.00066
$\sin^2\theta^\ell_{\mathrm{eff}}(Q_{\mathrm{FB}})$	0.2324 ± 0.0012
M_H [GeV] $^{(\circ)}$	Likelihood ratios
M_W [GeV]	80.399 ± 0.023
Γ_W [GeV]	2.085 ± 0.042
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$
m_t [GeV]	173.3 ± 1.1
$\Delta\alpha^{(5)}_{\mathrm{had}}(M_Z^2)$ $^{(\dagger\triangle)}$	2749 ± 10
$\alpha_s(M_Z^2)$	–

LEP & SLC

LEP & Tevatron & LHC

Tevatron

Latest fit (Moriond 2011): $M_H = 120^{+8}_{-5}$ GeV/c²
95% interval: {115,137} GeV/c²

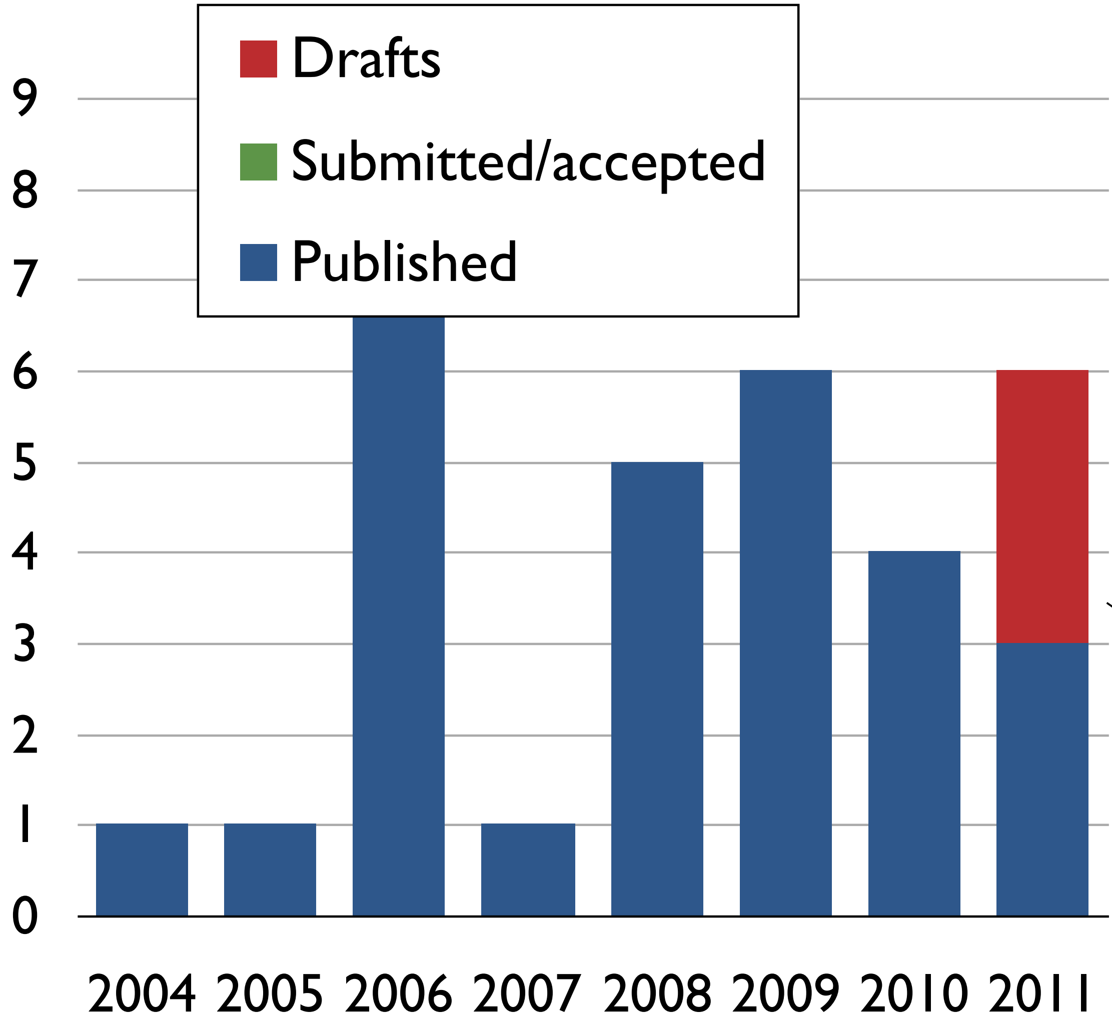
Pair production decay signatures

Potential to analyze more than 15 000 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

Top quark mass at CDF



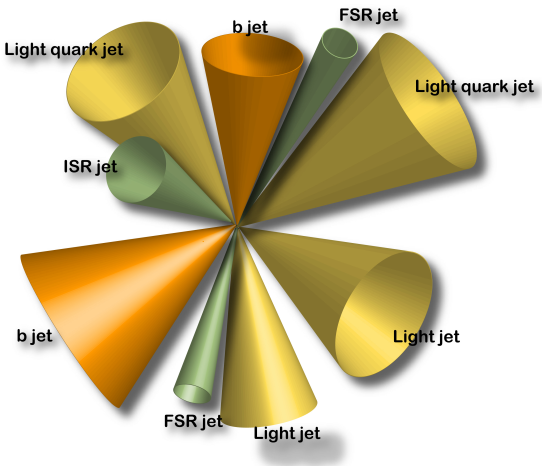
M_{top} measurement represents the crowning of the top quark studies.
The related publications constitute 35% of the top group publication output

True CDF legacy

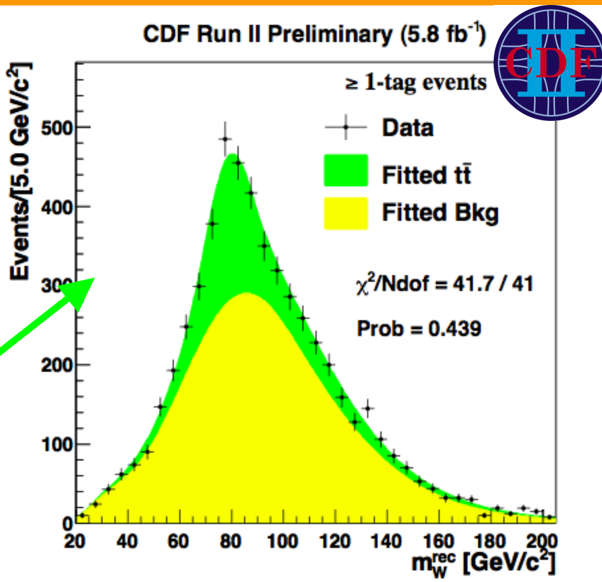
More than 1250 citations!

And still improving…

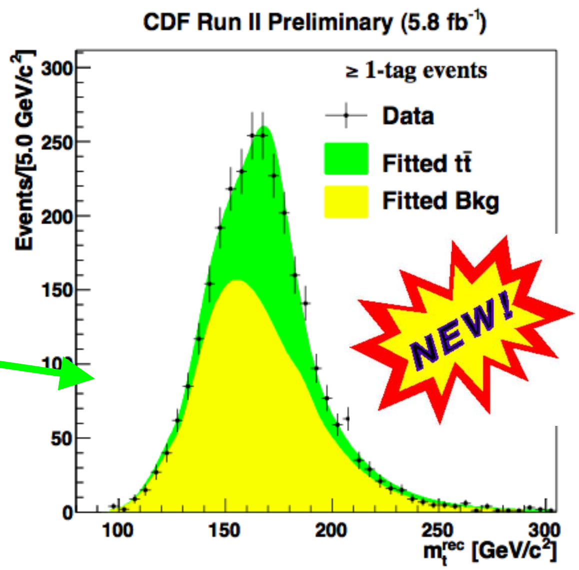
M_{top} measurement in $t\bar{t}\rightarrow bbqqqq$



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

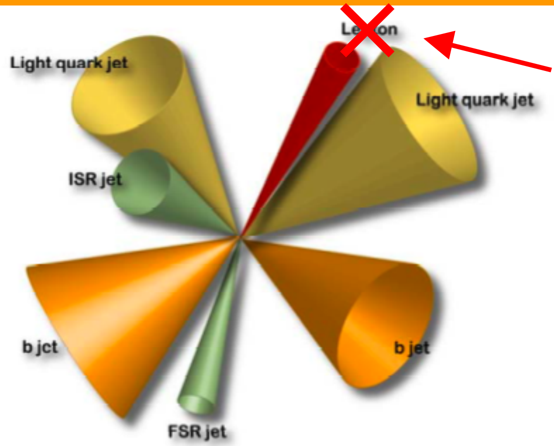


- Jet energy scale is the largest syst uncertainty: use $W\rightarrow qq$ decays to constrain it in situ
- Fully reconstruct the kinematics so to reconstruct the top quark mass



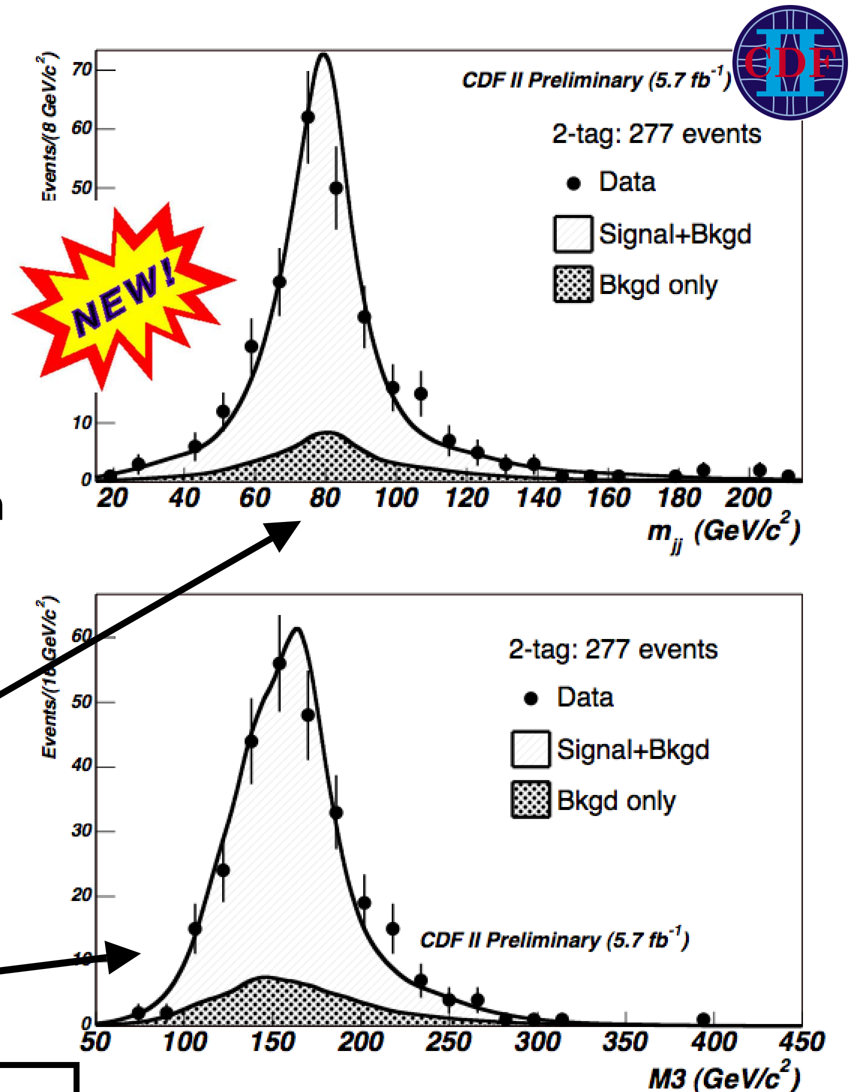
M_{top}= 172.5 ± 1.7 (stat.+JES) ± 1.2 (syst.) GeV/c^2

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 fully reconstruct one top in this sample



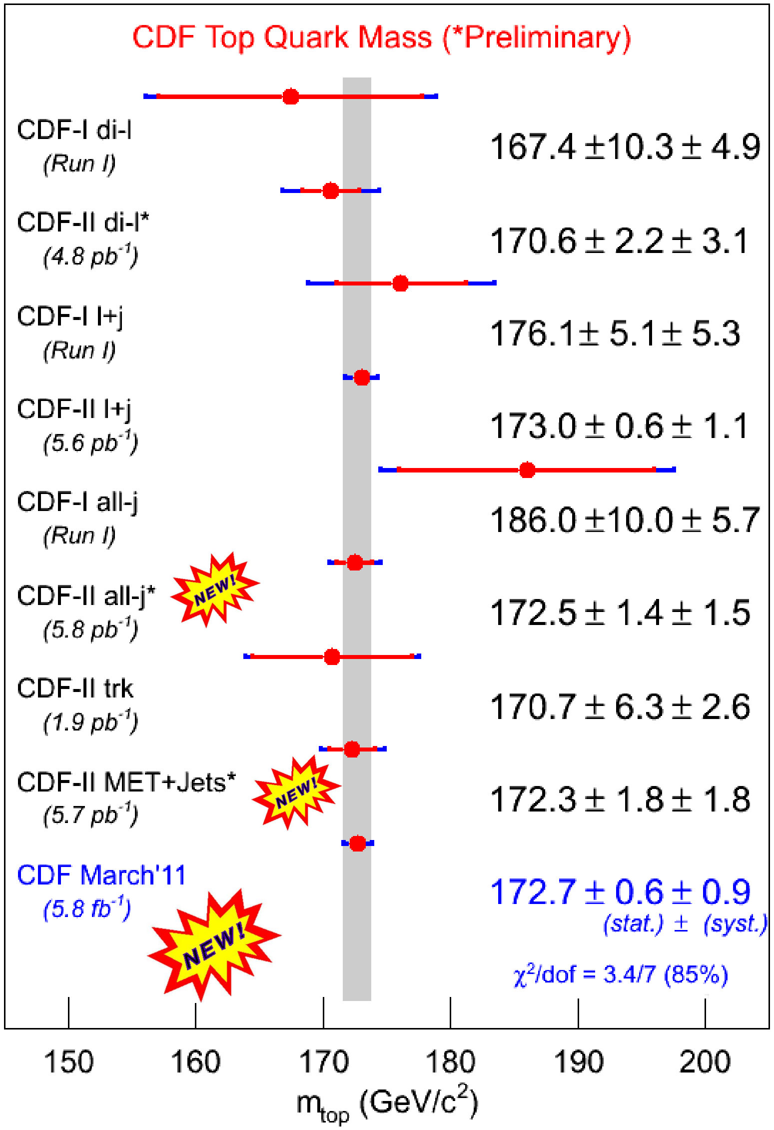
- Choose dijet pair with closest to W mass to measure jet energy scale
- Reconstruct one of the two decaying top to measure the top quark mass!

$\boxed{M_{top} = 172.3 \pm 2.4\ (\text{stat.+JES}) \pm 1.0\ (\text{syst.})\ \text{GeV}/c^2}$

CDF M_{top} combination

Combining results obtained

- in different datasets
  - consistency between 8 analyses
  - Indepent 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

As sensitive as 2010 Tevatron average!

Direct measurements from D0

- By Moriond QCD, D0 updated the Mtop measurements in the lepton+jets and dilepton channels using matrix element technique

$$P_{sig}(x;m_{top},JES) = \frac{1}{\blacklozenge_{obs}(m_{top})} \times \int \boxed{dq_1\, dq_2 f(q_1) f(q_2)} \boxed{\frac{(2\pi)^4 \left|M(y,m_{top})\right|^2}{4\sqrt{(q_1 \cdot q_2 - m_1 m_2}}} \boxed{d\blacklozenge_6\, W(y,x,JES)}$$

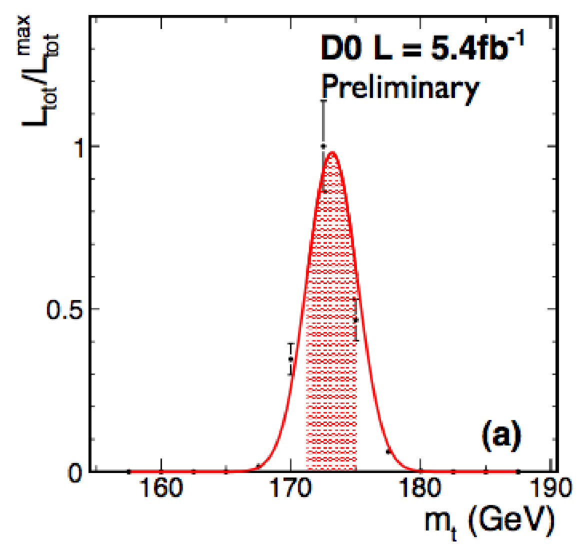
Parton densities | LO matrix element | Transfer functions

- Ljets: reduced systematics, new transfer functions

M_{top}= 174.9 ± 0.8 (stat) ± 1.3 (syst.) GeV/c^2

- Dilepton: more data

M_{top}= 173.6 ± 1.8 (stat) ± 2.6 (syst.) GeV/c^2



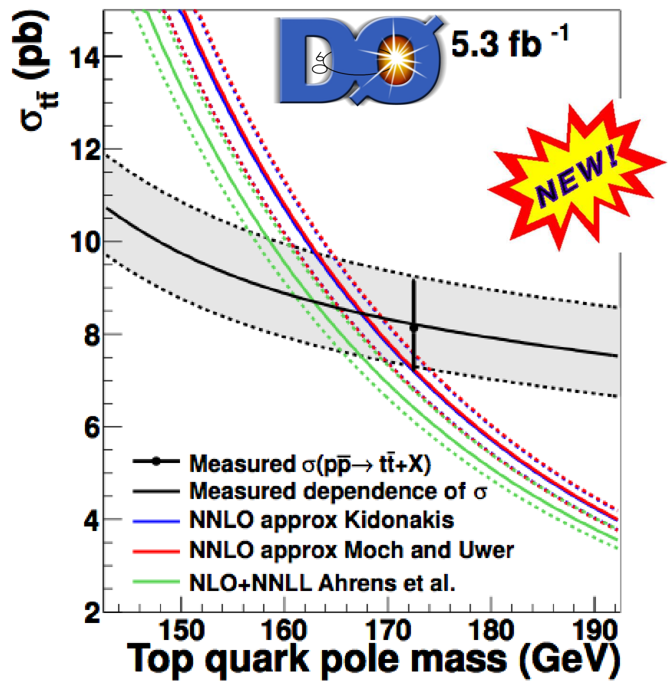
Tevatron has already 4 new precision measurements,
Will soon update the world's average!

Indirect measurement from D0

- Q. what is the M_{top} we are measuring?A. The Monte Carlo 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

Similar result from ATLAS
ATLAS-CONF-2011-054

*using Moch and Uwer

What we know about top quarks

$M_t = 173.3 \pm 1.1$ 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

No evidence for SUSY stop

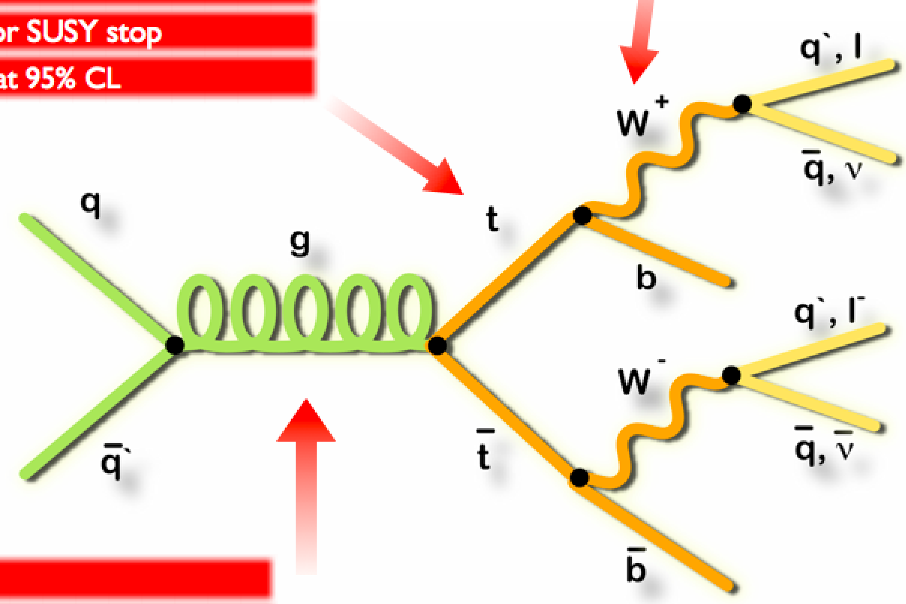
$M_{t'} > 335$ GeV at 95% CL

$V_{tb} = 0.91 \pm 0.11$ (exp) ± 0.07 (theory)

No evidence for charged Higgs

$BR(t \rightarrow Zq) < 3.7\%$ at 95% CL

$F_0 = 0.62 \pm 0.11$ & $F_+ = -0.04 \pm 0.05$



$\sigma_{ttbar} = 7.5 \pm 0.5$ pb

$\sigma_{singletop} = 2.8 + 0.5$ pb

$\sigma_{ttbar+j} = 1.6 \pm 0.5_{sys}$ pb

$M_{Z'} > 900$ GeV at 95% CL

$M_{W'} > 800$ GeV at 95% CL

$M_{b'} > 372$ GeV at 95% CL

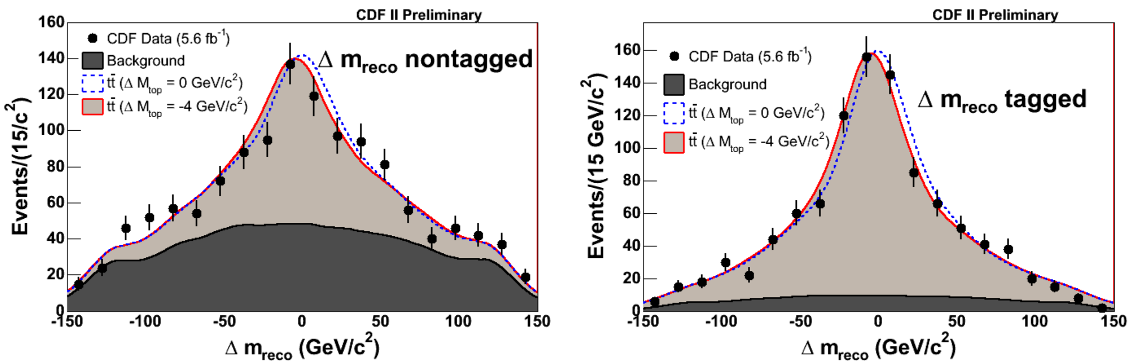
$F_{gg} = 0.07^{+0.15}_{-0.07}$ (stat+sys)

$A_{fb} = 0.475 \pm 0.114$

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

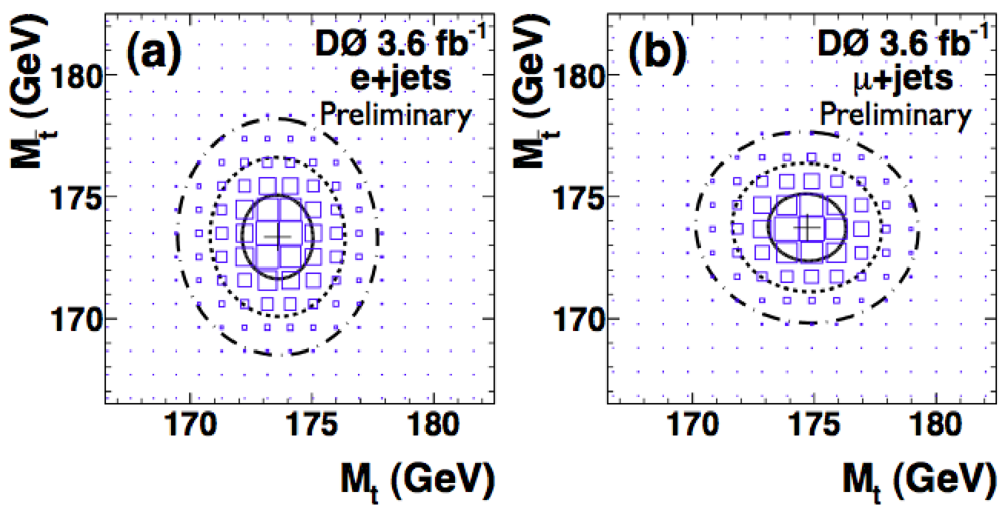
Top-antitop mass difference

Test of CPT
violation



arXiv:1103.2782
Accepted by PRL

ΔM_{top}= -3.3 ± 1.4(stat) ± 1.0(syst) GeV/c^2



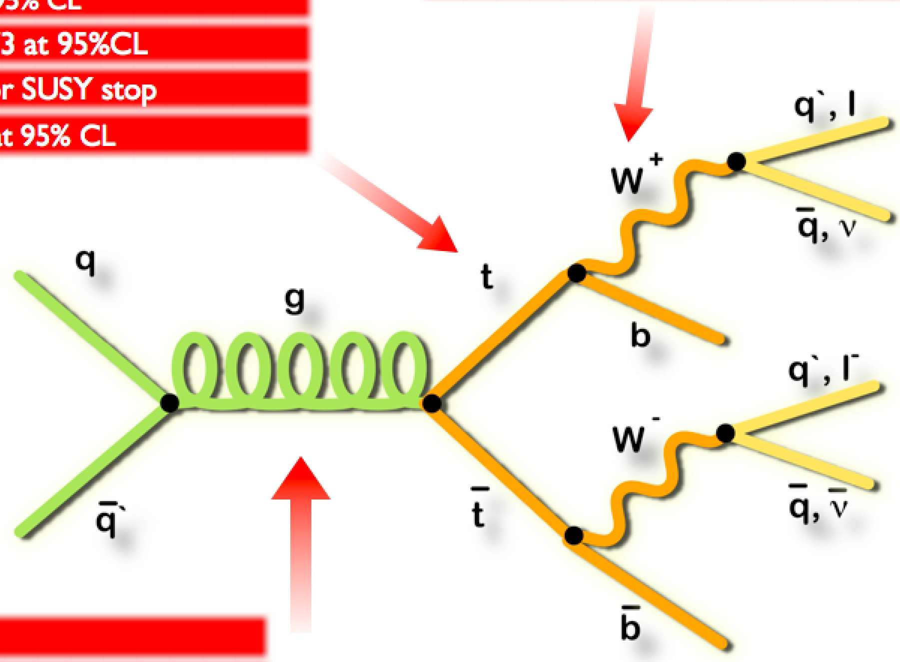
Update of PRL 103, 132001
with three times the data

ΔM_{top}= +0.8 ± 1.8(stat) ± 0.8(syst) GeV/c^2

What we know about top quarks

$V_{tb} = 0.91 \pm 0.11$ (exp) ± 0.07 (theory)
No evidence for charged Higgs
$BR(t \rightarrow Zq) < 3.7\%$ at 95% CL
$F_0 = 0.62 \pm 0.11$ & $F_+ = -0.04 \pm 0.05$

$M_t = 173.3 \pm 1.1$ 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
No evidence for SUSY stop
$M_{t'} > 335$ GeV at 95% CL



$\sigma_{ttbar} = 7.5 \pm 0.5$ pb
$\sigma_{singletop} = 2.8 + 0.5$ pb
$\sigma_{ttbar+j} = 1.6 \pm 0.5_{sys}$ pb
$M_{Z'} > 900$ 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)
$A_{fb} = 0.475 \pm 0.114$
Spin Correlations $\kappa = 0.6 \pm 0.5_{stat} \pm 0.2_{sys}$

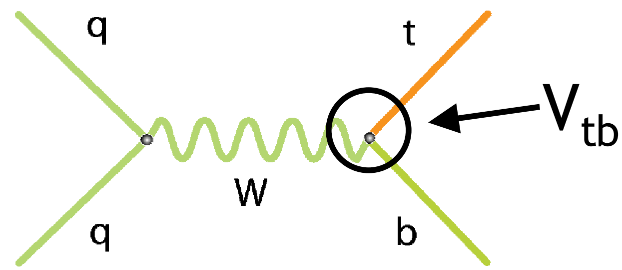
Why measure Single Top?

- Access to the W-t-b vertex
  - probe V-A structure
  - access to top quark spin
- Allows measurement of CKM matrix element $|V_{tb}|$:
  - Is there a 4th generation ?
  - Does unitarity hold ?

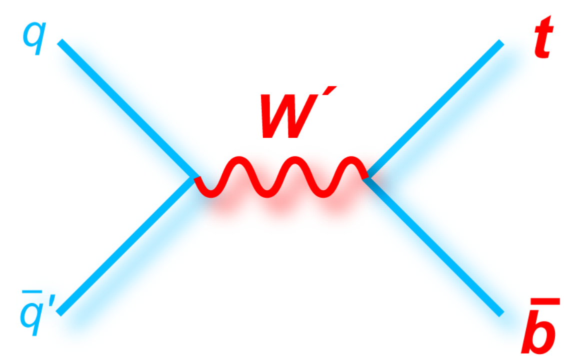
$$|V_{ub}|^2 + |V_{cb}|^2 + |V_{tb}|^2 \stackrel{?}{=} 1$$

J. Alwall et. al., “Is $|V_{tb}| \sim 1$?”
Eur. Phys. J. C49 791-801 (2007).

- t- and s-channel sensitive to (different) BSM physics
  - FCNC
  - Extra gauge bosons (W′, W_{kk})

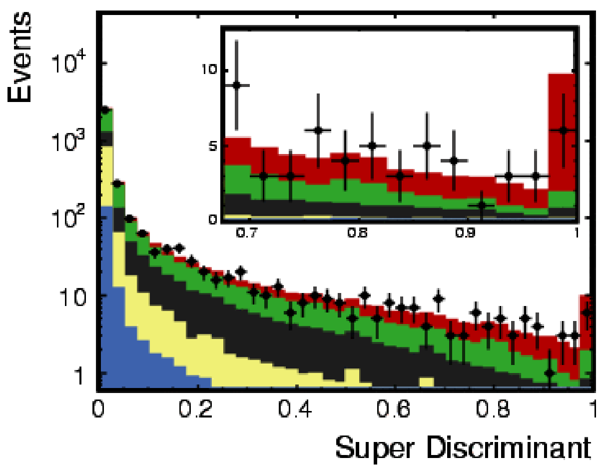


$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{uX}? \\ V_{cd} & V_{cs} & V_{cb} & V_{cX}? \\ V_{td} & V_{ts} & V_{tb} & V_{tX}? \\ V_{Yd}? & V_{Ys}? & V_{Yt}? & V_{YX}? \end{pmatrix}$$

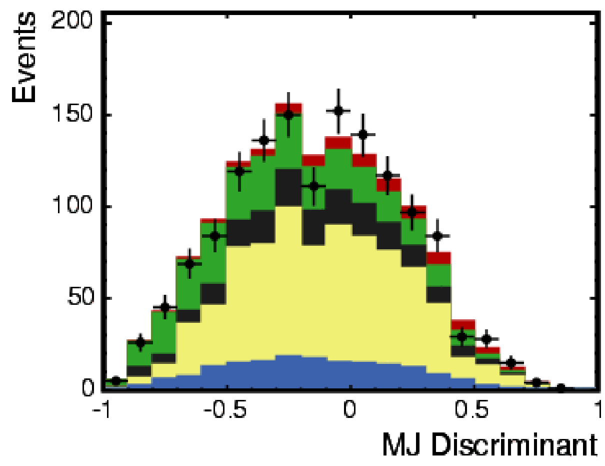


A 5.5fb^{-1} result

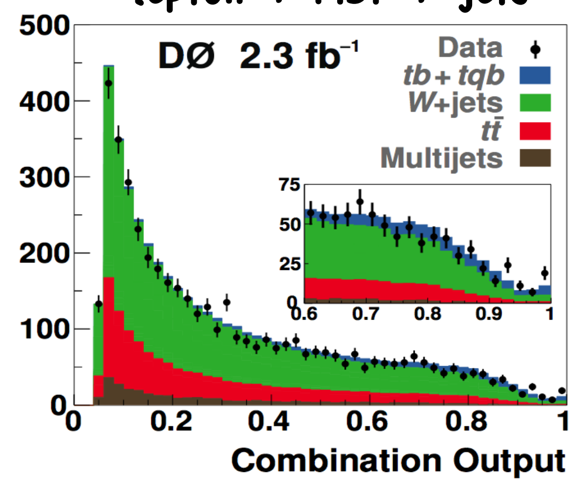
lepton + MET + jets

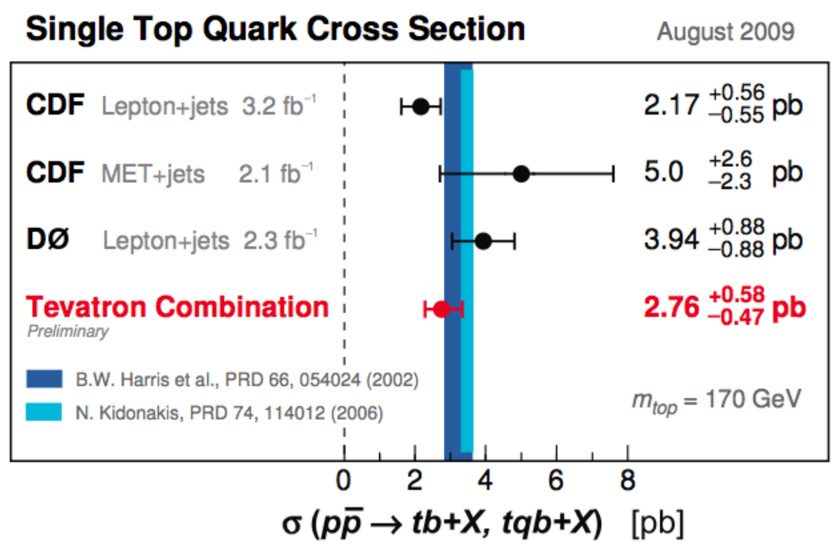


MET + jets



lepton + MET + jets





Important to have a result in a different signature (and in both experiments) to increase confidence

Crucial to combine them to increase precision

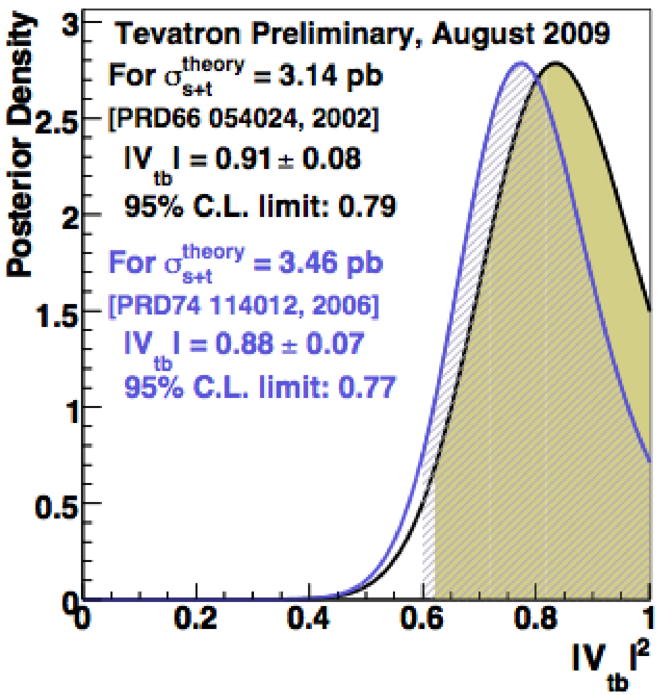
arXiv:0908.2171

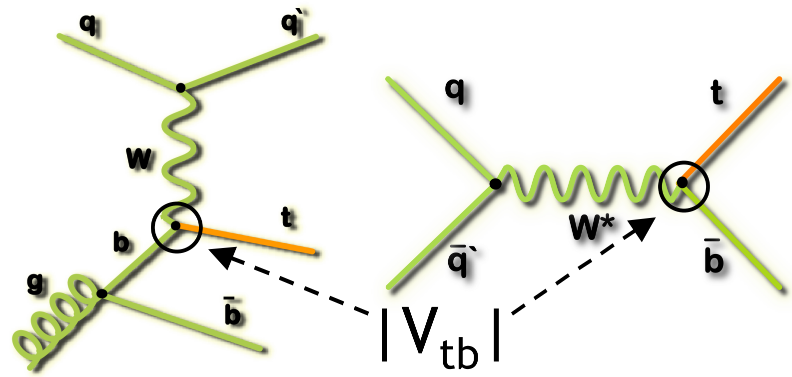
20% better than single experiment determination

Direct $|V_{tb}|$ Measurement

- Using cross section result measure $|V_{tb}|$
- Assume Standard Model (V-A) coupling
- and $|V_{tb}| >> |V_{ts}|, |V_{td}|$
- (from BR($t \rightarrow Wb$) measurements)

$$|V_{tb,meas}|^2 = \frac{\sigma_{meas}}{\sigma_{SM}} \cdot |V_{tb,SM}|^2$$





Tevatron combined fit:

$|V_{tb}|>0.79$ at 95% C.L.

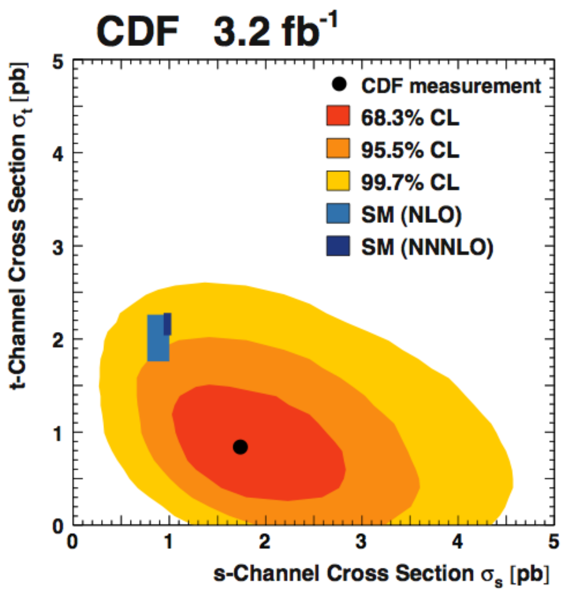
$|V_{tb}|= 0.91 \pm 0.08$ (exp+theor)

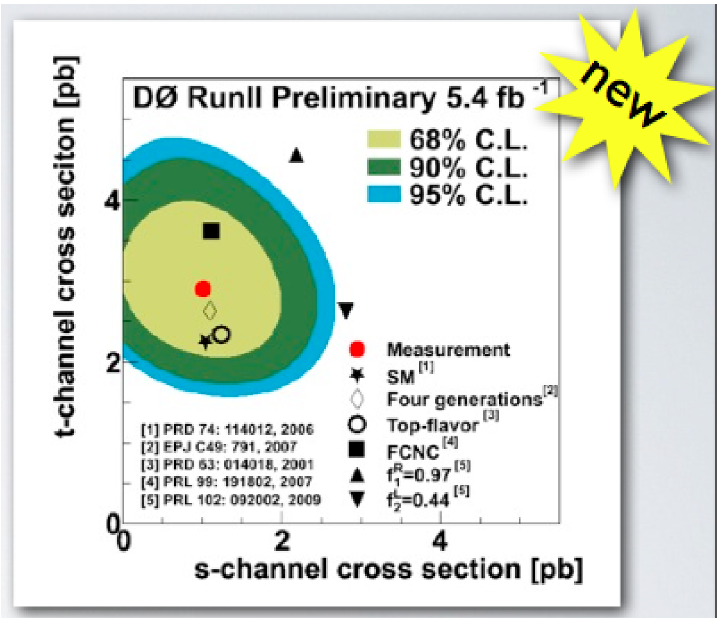
Combination increases precision from 13% to 9% on V_{tb}

arXiv:0908.2171

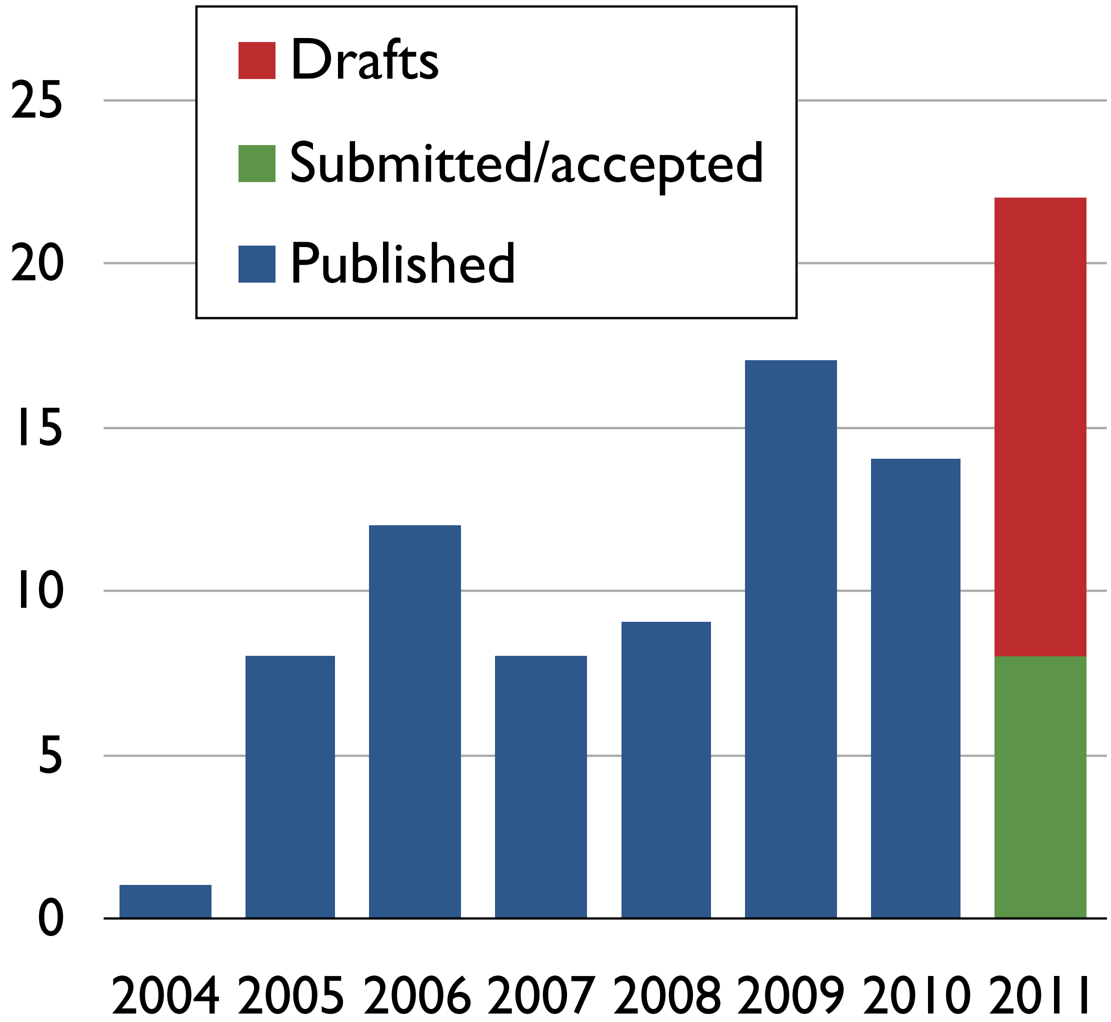
s- vs t-channel

- The two observation analyses measured combined single top quark cross section, assuming SM ratio between s and t
- This ratio is modified in several new physics scenarios
  - for example in models with additional quark generations,
  - new heavy bosons (like the one that explain the anomalous forward backward asymmetry :)
  - anomalous top quark couplings



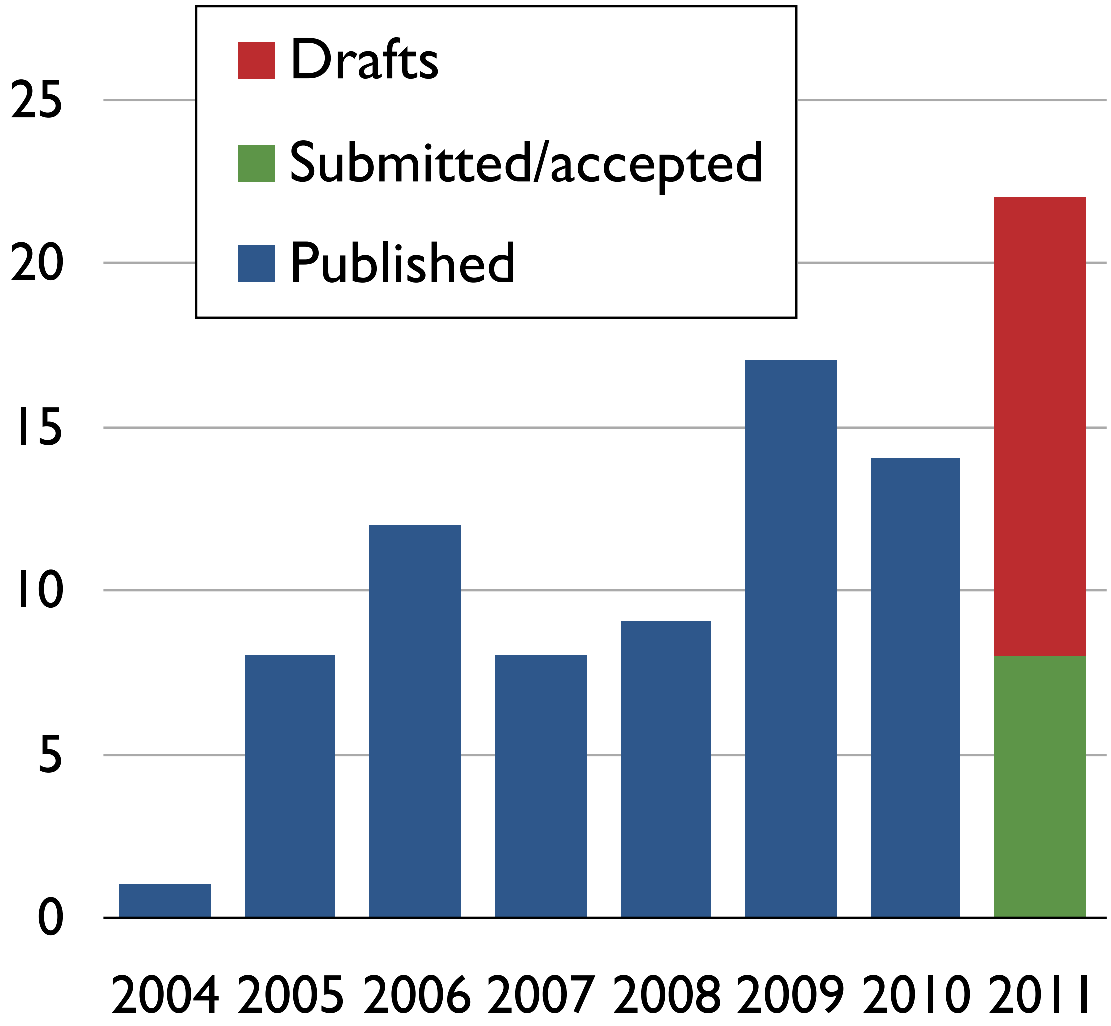


CDF Top physics group in numbers



84 publications in RunII
73 in peer-reviewed papers
11 combinations
8 topcite 50+
7 topcite 100+

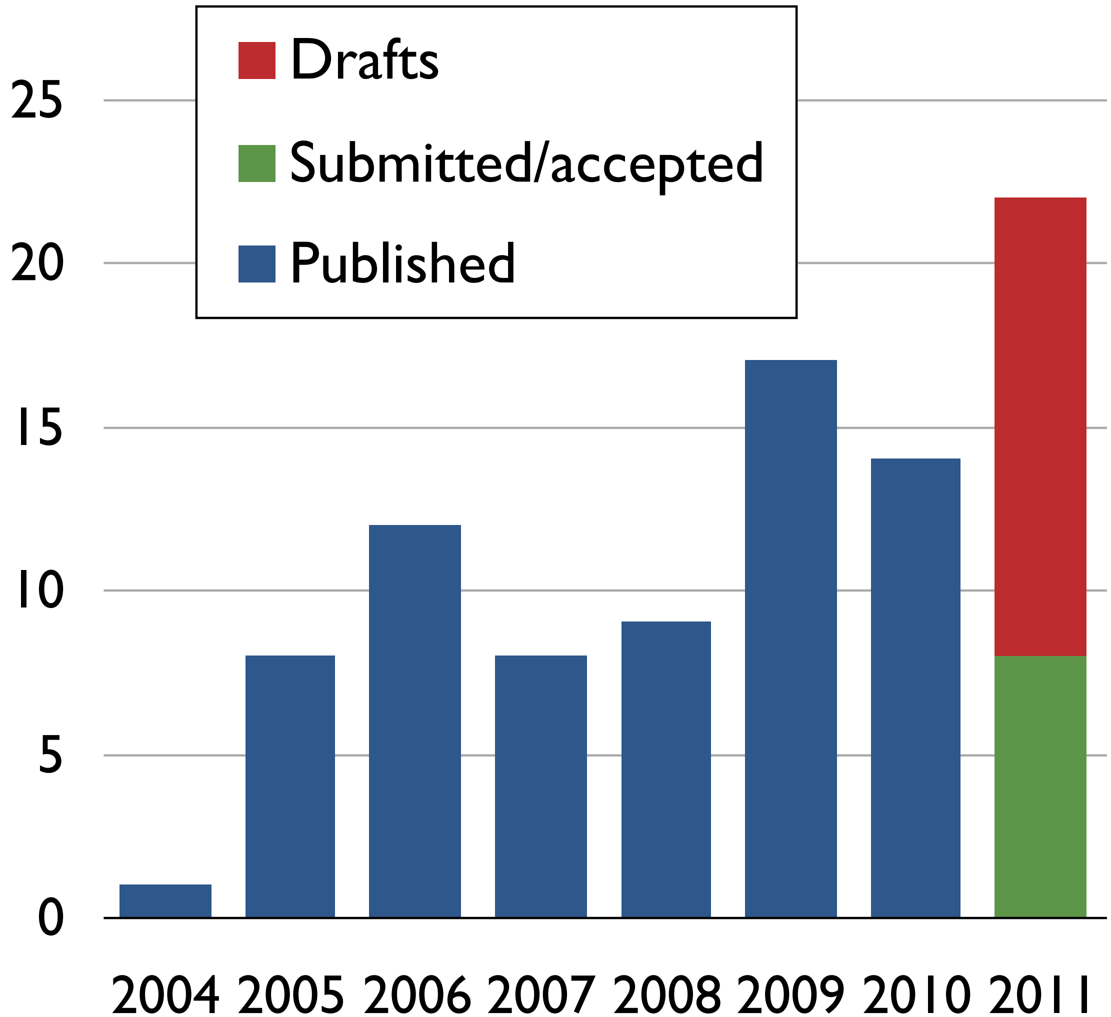
CDF Top physics in numbers



84 publications in RunII
73 in peer-reviewed papers
11 combinations
8 topcite 50+
7 topcite 100+

2011 will be the most productive year for top phsyics at CDF!

CDF Top physics in numbers



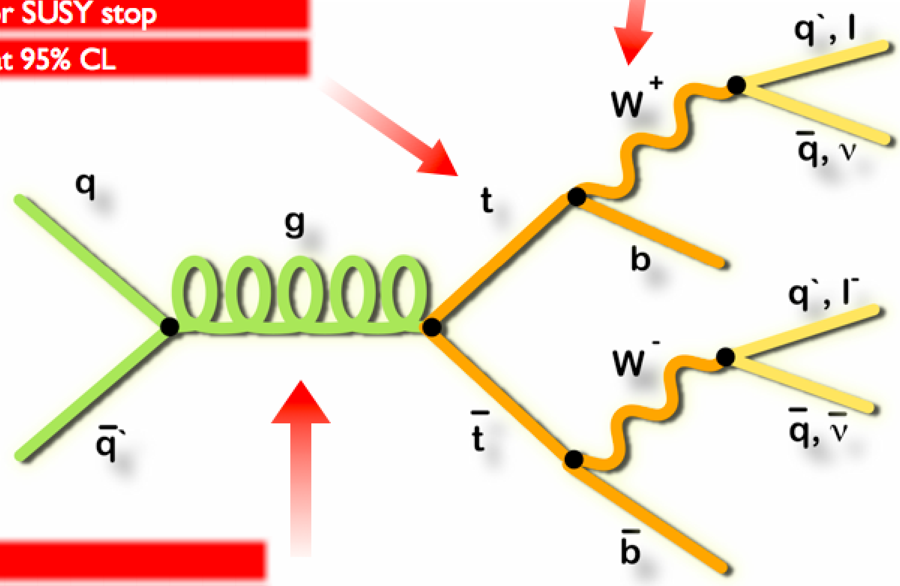
84 publications in RunII
73 in peer-reviewed papers
11 combinations
8 topcite 50+
7 topcite 100+

I picked two major breakthrough (M_{top} and single top). A lot of physics done, everything SM so far. Then came 2011...

What we *don't know* about top

- $M_t = 173.3 \pm 1.1$ 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
- No evidence for SUSY stop
- $M_{t'} > 335$ GeV at 95% CL

- Vtb = 0.91 ± 0.11 (exp) ± 0.07 (theory)
- No evidence for charged Higgs
- BR($t \rightarrow Zq$) < 3.7% at 95% CL
- $F_0 = 0.62 \pm 0.11$ & $F_+ = -0.04 \pm 0.05$



- $\sigma_{ttbar} = 7.5 \pm 0.5$ pb
- $\sigma_{singletop} = 2.8 + 0.5$ pb
- $\sigma_{ttbar+j} = 1.6 \pm 0.5_{sys}$ pb
- $M_{Z'} > 900$ 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)
- $A_{fb} = 0.475 \pm 0.114$
- Spin Correlations $\kappa = 0.6 \pm 0.5_{stat} \pm 0.2_{sys}$

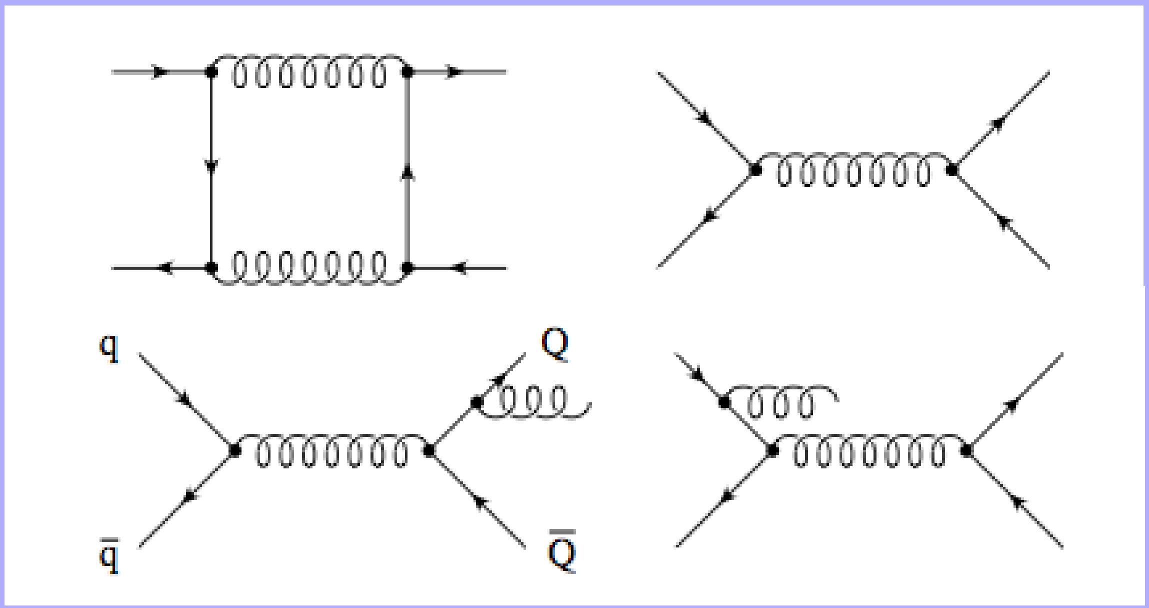
!

C asymmetry in ttbar production

- LO collision is charge-symmetric
- NLO produces asymmetry through interference

between box and Born diagram

between ttj states

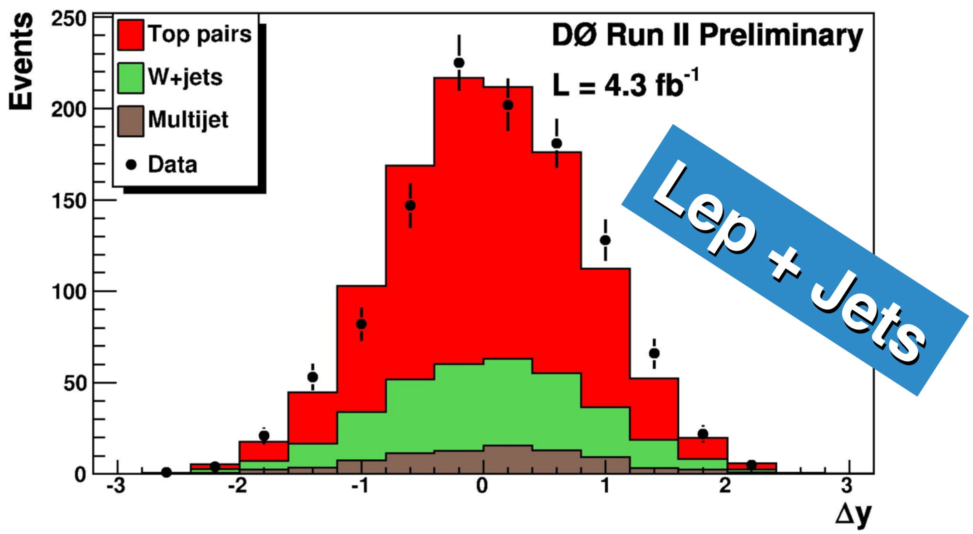


- Net result is a positive asymmetry of about 5%
- Several exotic ttbar production modes generate at tree-level a larger C through the interference with SM qq → tt.

Experimental determination(1)

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%



$$A_{FB}^{SM} = 1 \pm 1.5\ \%$$

vs

$$A_{FB}^{D0} = 8.0 \pm 4\ \%$$

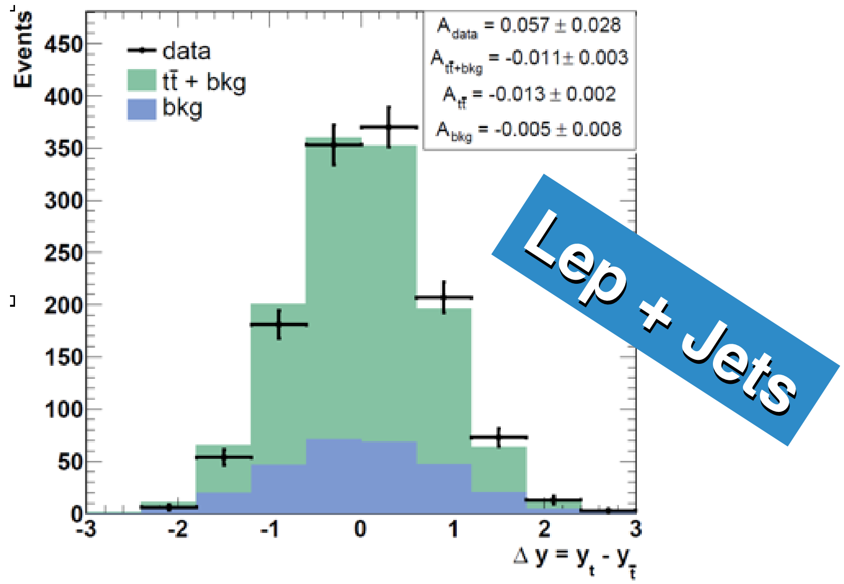
2σ

*reconstruction level

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%



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

vs

$$A_{FB}^{CDF} = 15.0 \pm 5\ \%$$

hep-ex/1101.0034

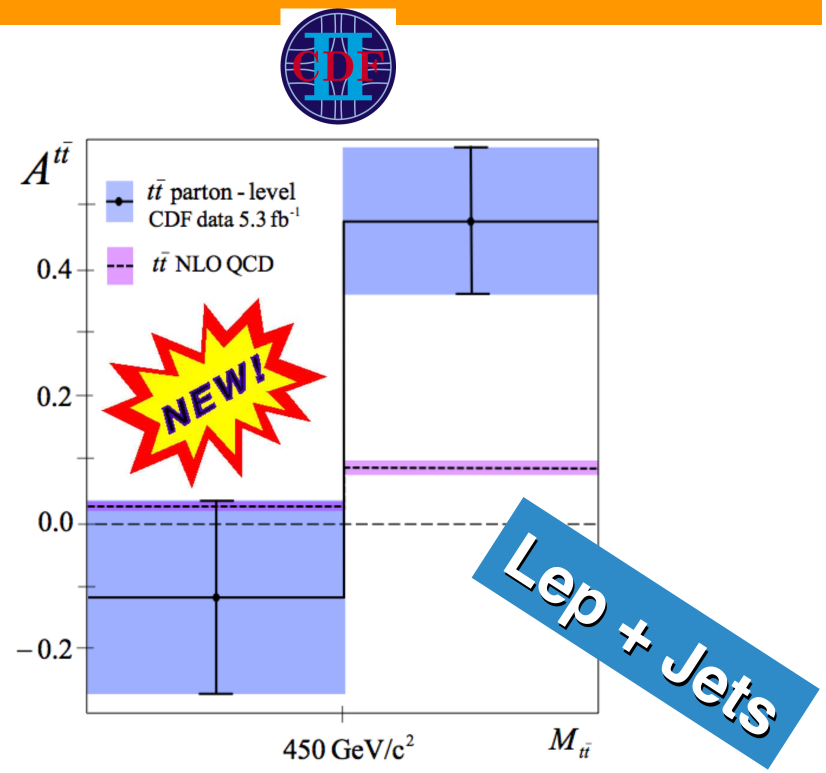
2σ

*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 ± 1.3 %

vs

A_{FB}^{CDF} = 48 ± 11 %

hep-ex/1101.0034

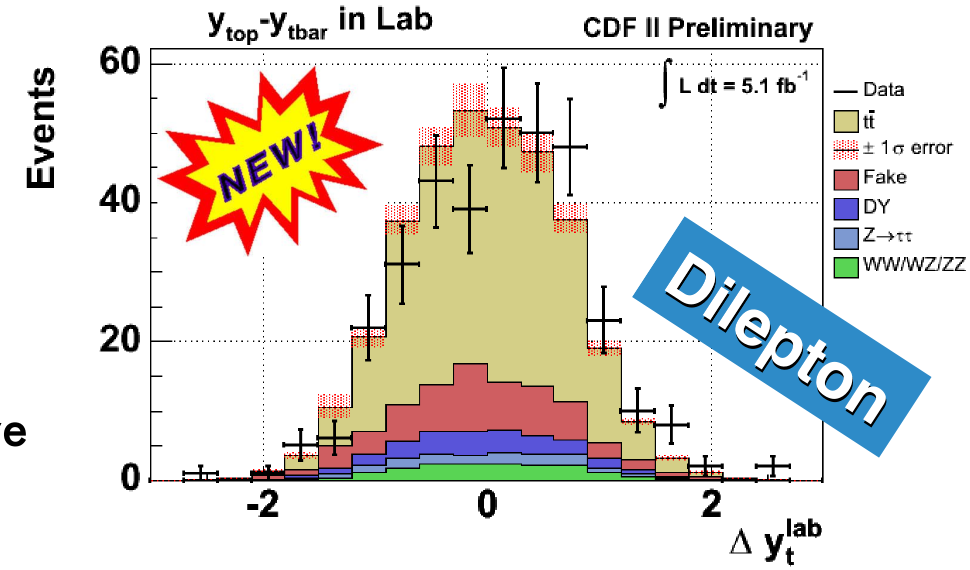
>3σ

*parton level

Experimental determination(3)

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 ± 1.5 %

vs

A_{FB}^{CDF} = 42 ± 16%

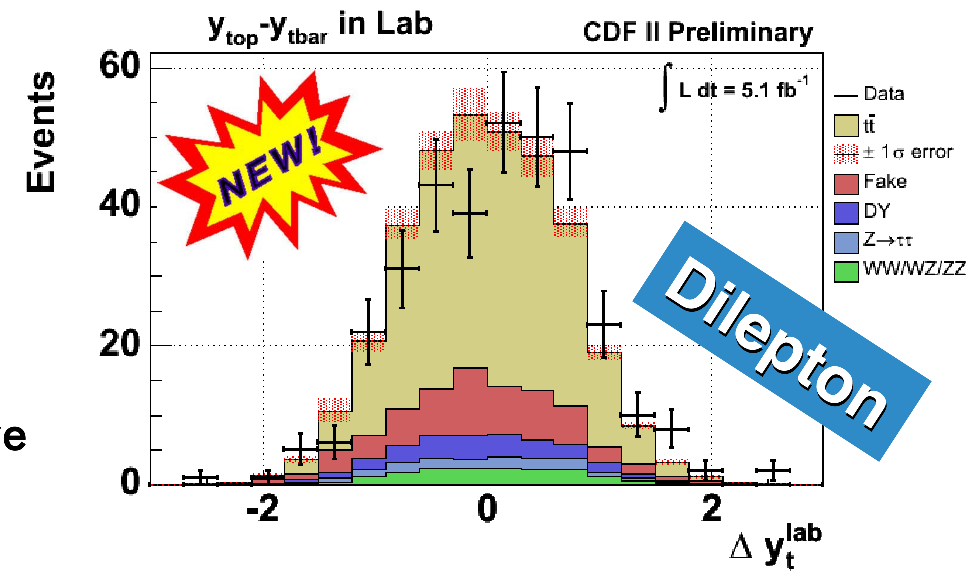
*parton level

2.3σ

Experimental determination(3)

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



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

vs

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

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

16y later, top is again in the press

DiscoveryNews

HIGGS CAN RUN, BUT IT CAN'T HIDE

But the Higgs isn't the only game in town for the LHC and Tevatron physicists. A paper recently appeared on the arXiv announcing mounting evidence for a potential new particle that nobody was really looking for in the first place. The smoking gun is in the directions that top quarks and their counterparts, antiquarks, travel after a collision; theory predicts that the particles should show a preference for one direction in particular 5% of the time.

However, both the CDF ... particles showed a pre... showing a preference f... (greater than 450 GeV)...

It's not the Higgs, acc... of behavior. The most ... escape detection by th... with its higher energies ... weeks or months.

So if the Higgs keeps ... signs of new physics.

ars technica

Tevatron: top quarks may indicate new particle, need for new physics

Even as it's slated for retirement, Fermilab's Tevatron particle collider may be providing its successor, the Large Hadron Collider, with directions to some new physics. Recently, researchers with the Tevatron's CDF detector started discussing results that they submitted to the arXiv at the end of last year. The draft paper suggests tha... odd asymme... surprise: it's ...

Like many o... background ... antitop quark... we're familia... travel in the ... but the Teva... appeared to ...

symmetry breaking — A joint Fermilab/SLAC publication — VOLUME 08 ISSU... FEBRUAR... VIEW CURRENT IS...

Interesting effect at the Te...

March 18, 2011 | 9:00 am

Scientists at the Large Hadron Collid... discovering a new particle, accordin... experiments at Fermilab's Tevatron.

Judging by its behavior, it's not the H...

Scientists are finding signs of new ph... particle Fermilab physicists discover... quark.

When top quarks and their anti-partic... in particle collisions at the Tevatron, ... which they fly. Theory predicts that th... direction slightly over the other, trave... the time more.

However, in studies by the DZero col... collaboration, the particles seemed t... backward. This month, the CDF colla...

They also recently released a study i... time in collisions above a certain ene...

"It's really challenging for us to const... the subject at the Rencontres de Mor...

Scientists think the cause of the unex... enough to go undetected by the Teva... weeks from collecting enough data to find it.

ScienceNews — MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC

:: ATOM & COSMOS :: GENES & CELLS :: MOLECU... :: BODY & BRAIN :: HUMANS :: SCIENC... :: EARTH :: LIFE :: OTHER T... :: ENVIRONMENT :: MATTER & ENERGY :: SCIENC...

HOME / NEWS / FEATURES / BLOGS / COLUMNS / DEPARTMENTS / RSS FEEDS / E-MAIL ALERTS

Home / News / Article

Remodeling the standard model

Fermilab findings suggest new elementary particle may soon emerge

By Ron Cowen

Web edition : Friday, April 1st, 2011

the world's most powerful atom smasher, ... from finding a new elementary particle — a ...re — recent studies suggest.

...p quark, the heaviest of the six quarks, ... building blocks of nature. Top quarks ...en they are produced during proton-...wer-energy particle accelerator, the ...via, Ill. Compared with what the standard ...edicts, these quarks fly off too often in the ...n and not enough in the antiproton

...rst reported in 2008, but the results could ... recent report, using additional data, boosts ...ys Dan Amidei of the University of Michigan ... the Tevatron's CDF experiment. For ...electron volts, 45 percent of the top quarks ... proton beam while only 9 percent are ...nd colleagues reported online January 3 at ..., the team reported additional evidence of ...ectional preference after examining the ...by a different set of particle interactions.

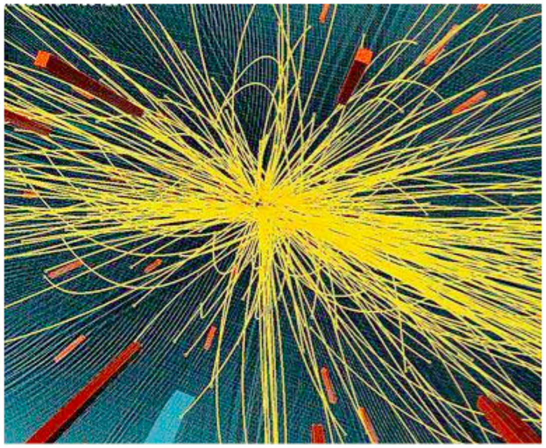
...ercent chance that the top quark's ...nce is a fluke, Amidei notes. Although that

la Repubblica — GIOVEDÌ 7 APRILE 2011 — 42

R2 LA SCIENZA — PER SAPERNE DI PIÙ www.fnal.gov

La scoperta in un laboratorio americano "Una materia sconosciuta, è un mistero"

L'ultimo giallo nella fisica "È la nuova particella di Dio?"

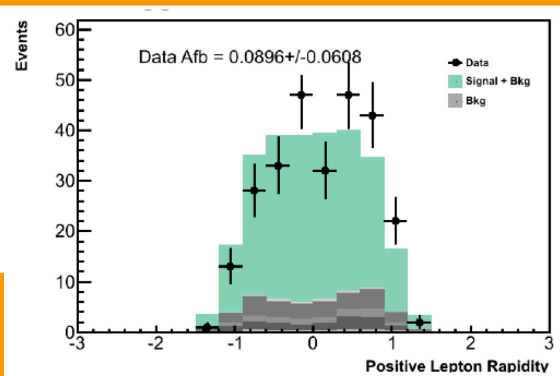


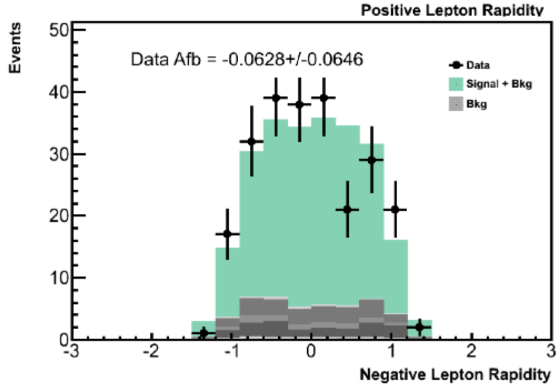
ELENA DUSI

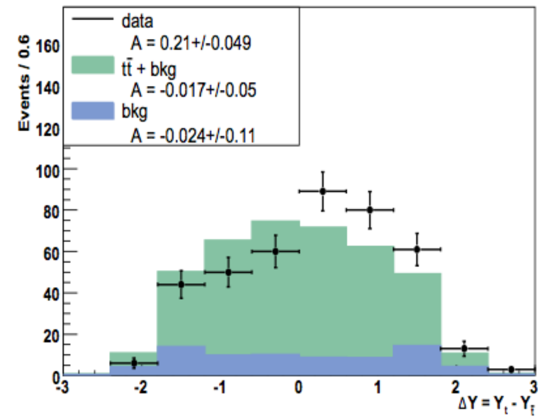
«C... osa abbia-mo di fronte a noi è un mistero. Si tratta di qualcosa al di là della fisica nota. Potrebbe essere un nuovo ingrediente della materia, o una nuova forza». Giovanni Punzi è a capo di un gruppo di fisici in buona parte italiani al laboratorio Fermilab di Chicago. «Abbiamo misurato un fenomeno nuovo nel nostro acceleratore di protoni e antiprotoni. I dati sono inatte-sa di conferma, ma dalle collisioni è nato un evento che non riusciamo a spiegarci se non con la presenza di una particella totalmente nuova». Tra i frammenti delle collisioni che avvengono a energie estreme e velocità prossime alla luce, i fisici si aspettano di "catturare" lo sfuggente bosone di Higgs: la cosiddetta particella di Dio, prevista alla fine degli anni '70 dai fisici teorici (in particolare dall'inglese Peter Higgs) e inseguita in vari esperimenti nel mondo. La sua presenza è fondamentale per spiegare come mai la materia

From lepton rapidity to top rapidity

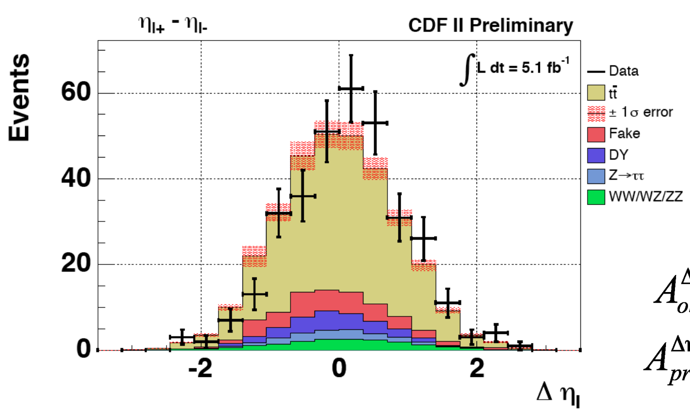
Leptons





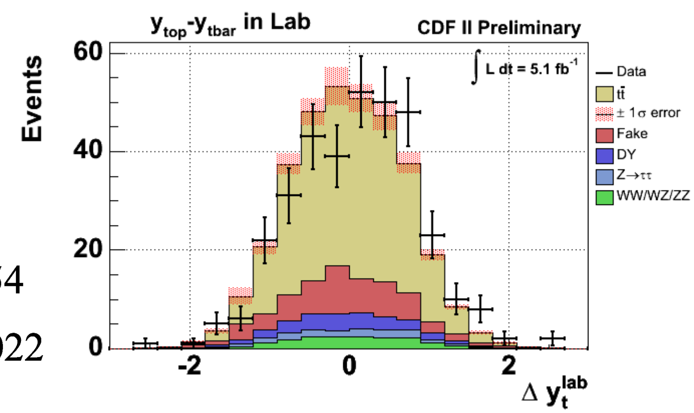


Top quarks

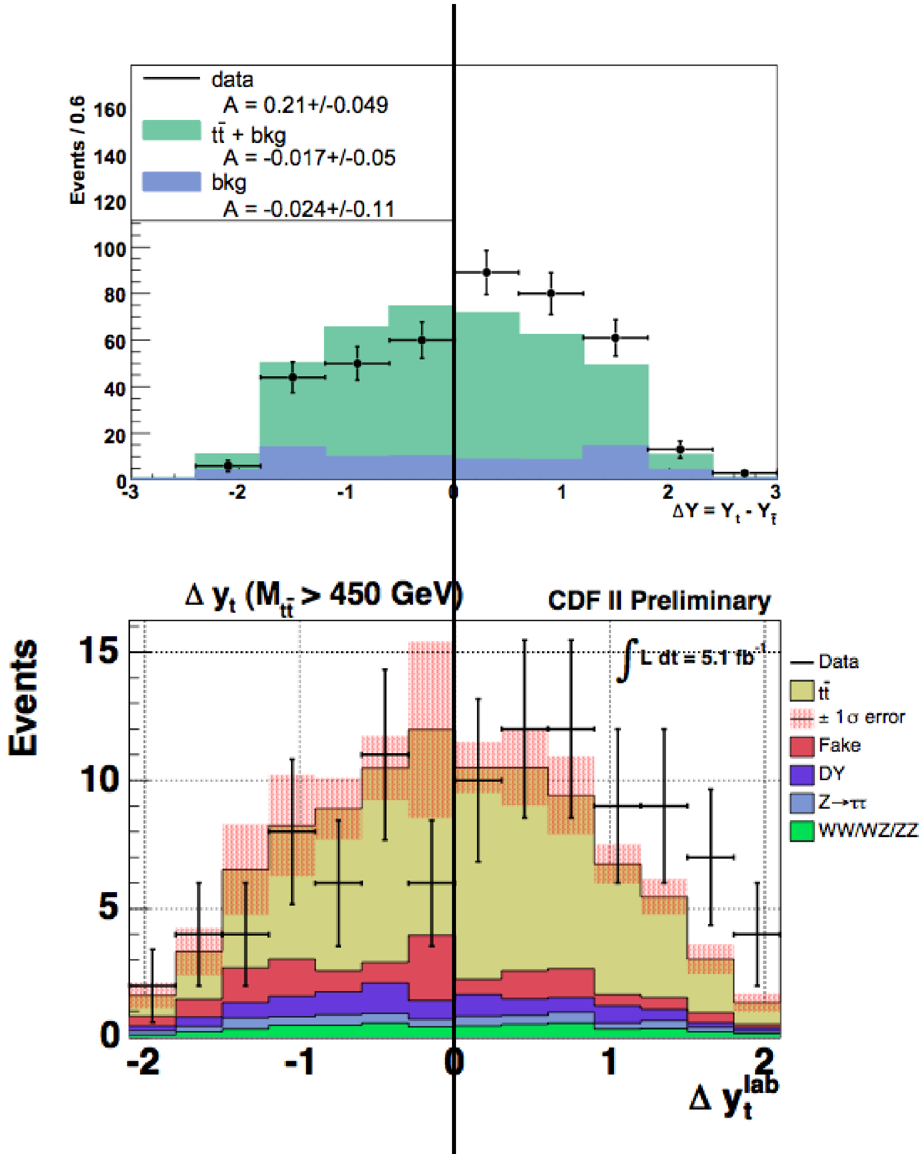


$$A_{obs}^{\Delta\eta_l} = 0.138 \pm 0.054$$

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



The high mass asymmetry



Here a 3 sigma effect, plus a 2 sigma effect…

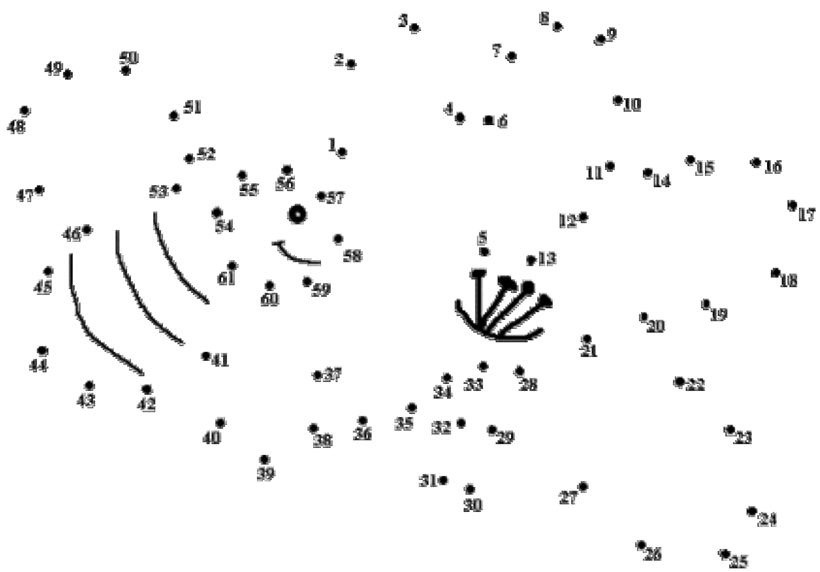
How bad can the theoretical predictions be?

- asymmetry appears only at NLO (so in a way, the theoretical computations are just leading order)
- Approx NNLO in agreement with NLO
- Full NNLO prediction will take time! about a year
- Before that, as experimentalists we need to get ourselves busy

Let's play the phenomenologist

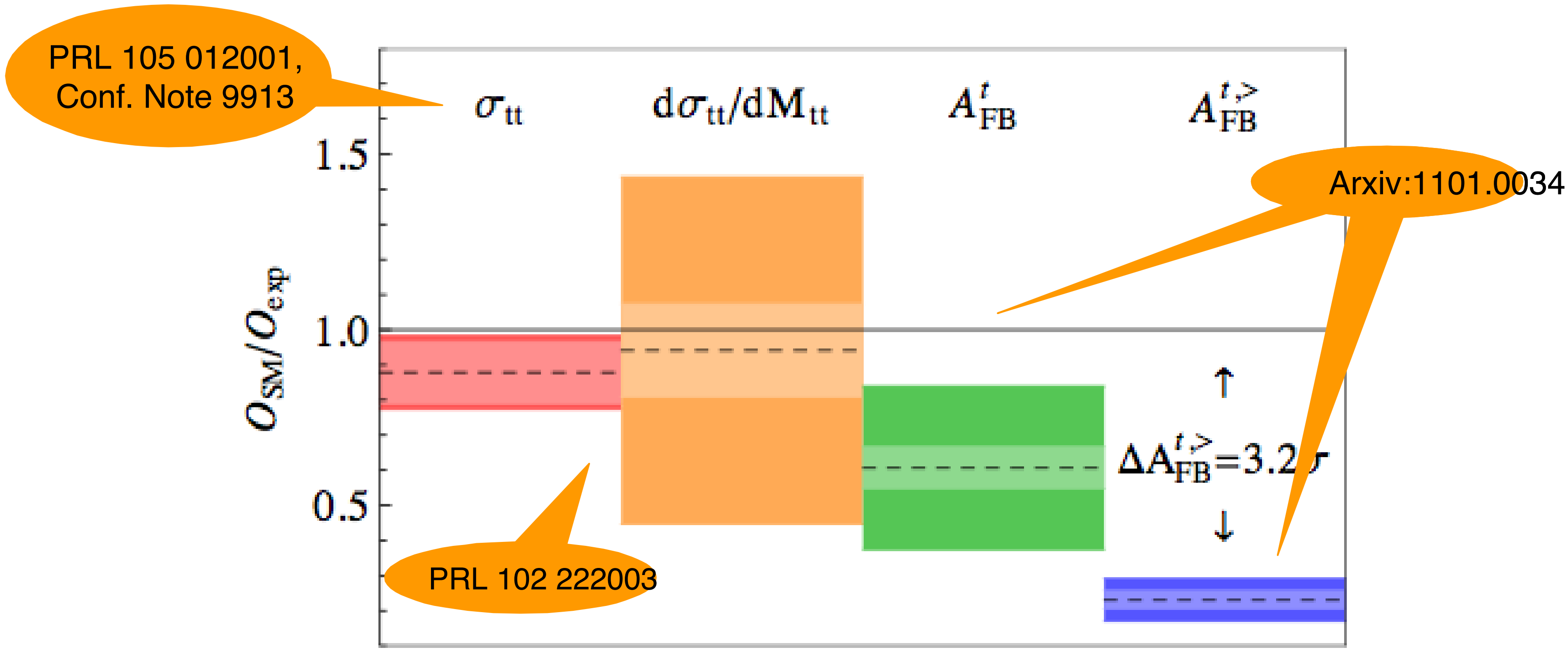
While we wait for NNLO computations to be completed, we can entertain ourselves in two possible ways

1) Increase precision on AFB measurements (more CDF data, D0 measurements)
2) Test the new physics scenarios that are in hand at Tevatron energy that could explain the large AFB



Connect the dots!

SM top prediction vs CDF data



Asymmetric observables lie significantly below the measurement.

Standard deviations δO_{SM} and δO_{exp} added in quadrature.

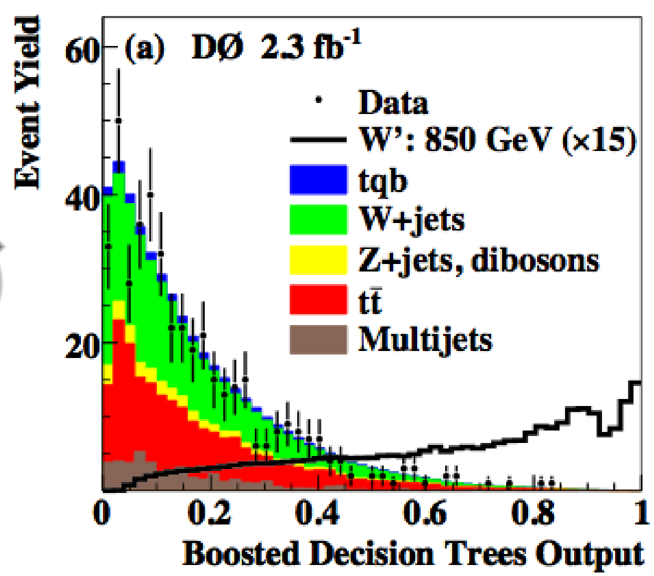
Apparently no strong constraints from B physics...

From S.Westhof Moriond EWK talk

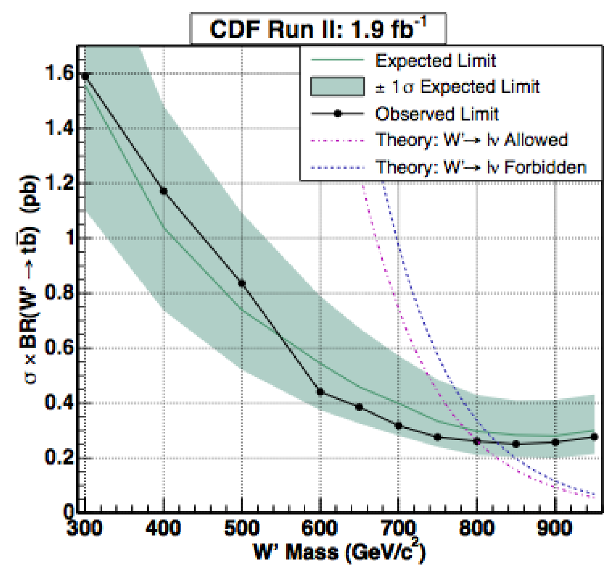
Is this an a heavy W'?

- W' that couples preferentially to top quarks, should also decay to top (and bottom) if heavy enough
- Same signature of s-channel single top production (difficult at the LHC) for the direct search for W'to tb

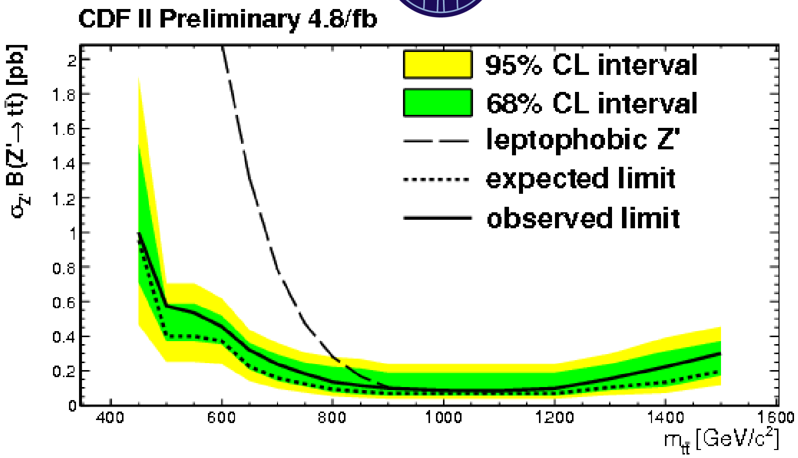
Arxiv:1101.0806



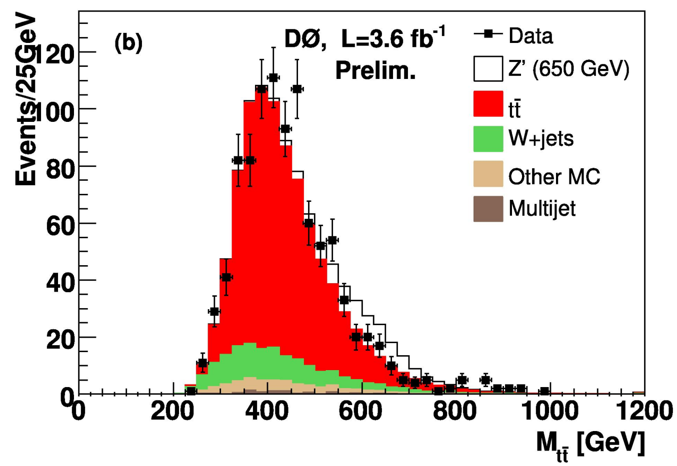
PRL 103, 041801 (2009)



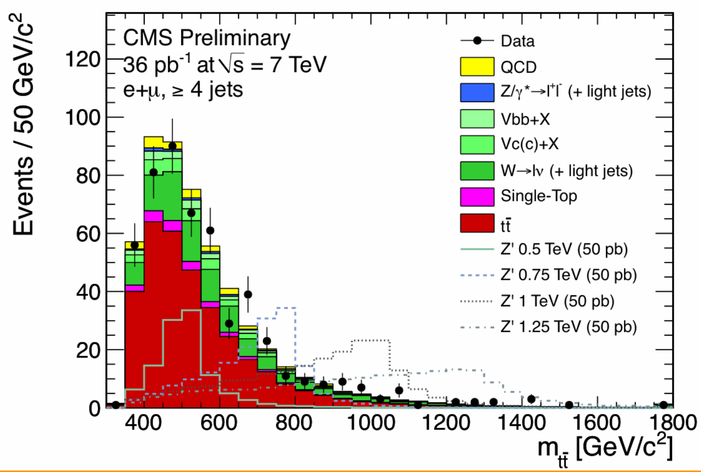
Or a axigluon/heavy Z′?



Z′<900GeV excluded at 95%CL



Z′<820GeV excluded at 95%CL



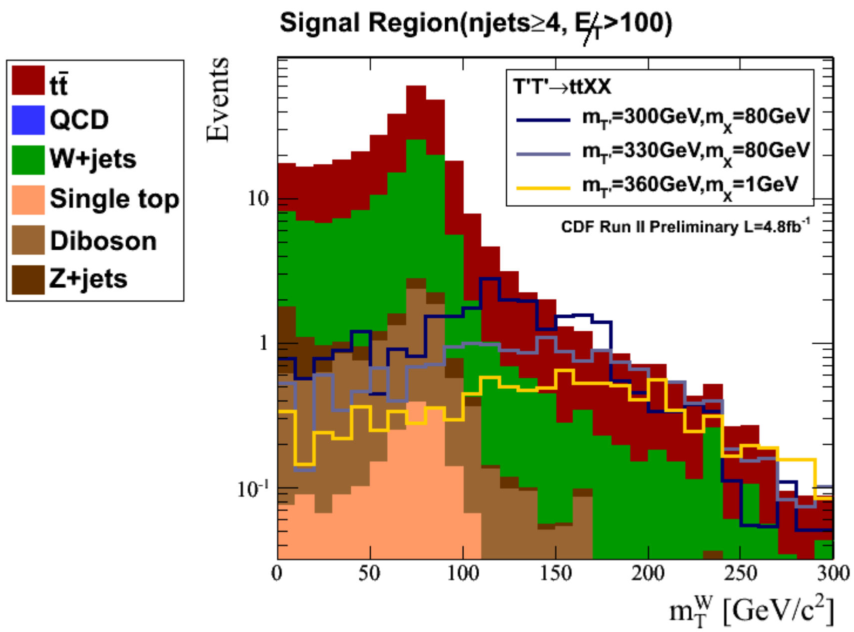
No sign of narrow width resonances

NEW!

Or SUSY-like?

- It has been argued that stop -> top + chi can lead to a significant enhancement of the forward-backward asymmetry in ttbar production at the Tevatron.

- A similar search (but with fermionic hypothesis) done by CDF in the lnu+many jets channel Arxiv:1103.2482



- SUSY signature some 10 times smaller. But the MET+many jets signature is supposed to be much more sensitive (negligible physics background)

- Similar search (less sensitive) by ATLAS ATLAS-CONF-2011-036

Is it a <u>*light*</u> W'/Z' instead? (part1)

PHYSICAL REVIEW D **81,** 015004 (2010)

Top quark forward-backward asymmetry from new t-channel physics

Sunghoon Jung,[1] Hitoshi Murayama,[2,3,4] Aaron Pierce,[1] and James D. Wells[1,5]
[1]*Michigan Center for Theoretical Physics, University of Michigan, Ann Arbor, Michigan 48109, USA*
[2]*Department of Physics, University of California, Berkeley, California 94720, USA*
[3]*Theoretical Physics Group, LBNL, Berkeley, California 94720, USA*
[4]*IPMU, University of Tokyo, 5-1-5 Kashiwa-no-ha, Kashiwa, Japan 277-8568*
[5]*CERN Theoretical Physics (PH-TH), CH-1211 Geneva 23, Switzerland*
(Received 30 July 2009; revised manuscript received 19 October 2009; published 7 January 2010)

Motivated by recent measurements of the top quark forward-backward asymmetry at the Tevatron, we study how t-channel new physics can contribute to a large value. We concentrate on a theory with an Abelian gauge boson that possesses flavor changing couplings between up and top quarks but satisfies flavor physics constraints. Collider constraints are strong, but can be accommodated with the aid of small flavor-diagonal couplings. We find that $M_{Z'} \approx 160$ GeV can yield a total lab-frame asymmetry of $\sim$18% without conflicting with other observables. There are implications for future collider searches, including exotic top quark decays, like-sign top quark production, and detailed measurements of the top production cross section. An alternate model with a gauged non-Abelian flavor symmetry has similar phenomenology, but lacks the like-sign top signal.

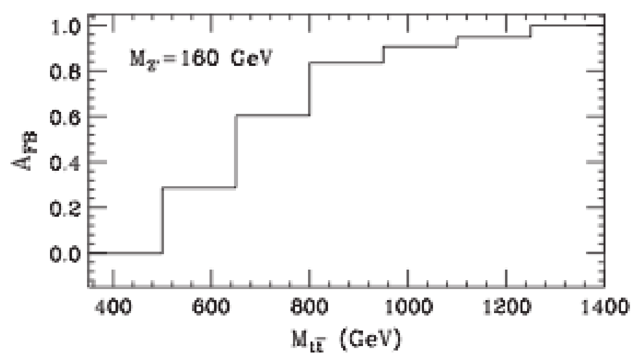
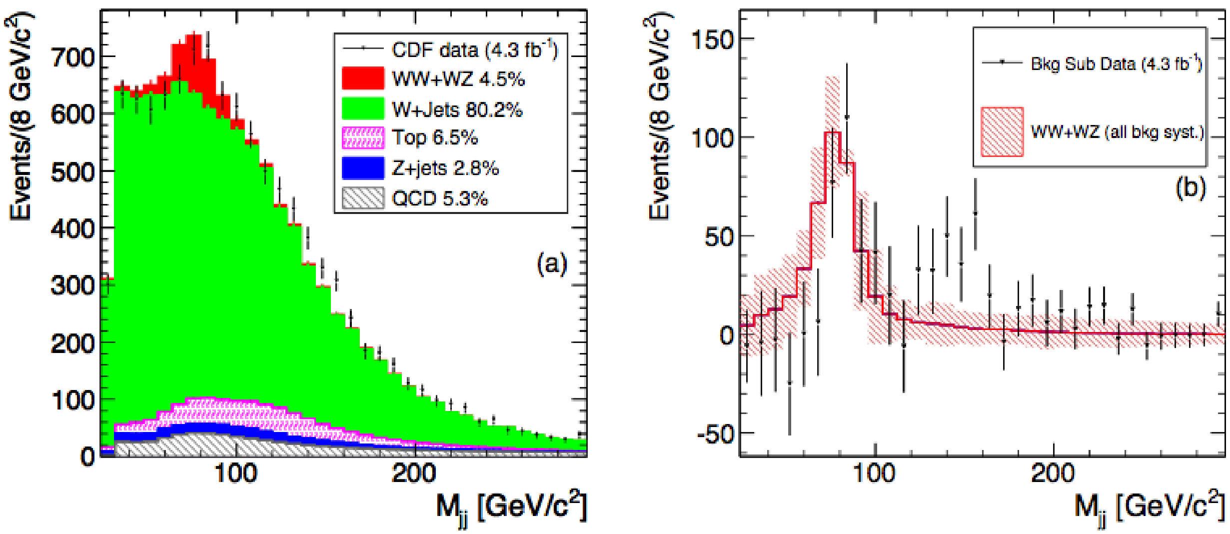


FIG. 1. A^t_{FB} as a function of $\sqrt{\hat{s}} = M_{t\bar{t}}$ for $M_{Z'} = 160$ GeV.

Is it a *light* W'/Z' instead? (part2)

- Z' with uZ't coupling that has also uZ'u coupling. Direct search Z'→uu very difficult due to huge background. Search performed only by UA2, weak limits that can be evaded
- CDF has a similar analysis that stems from the observation of dibosons in lνqq sample. An excess is seen and investigated

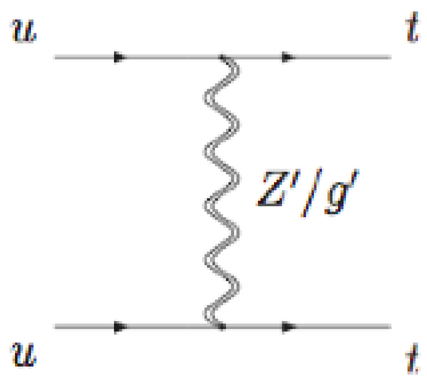


Appeared yesterday arXiv:1104.0699

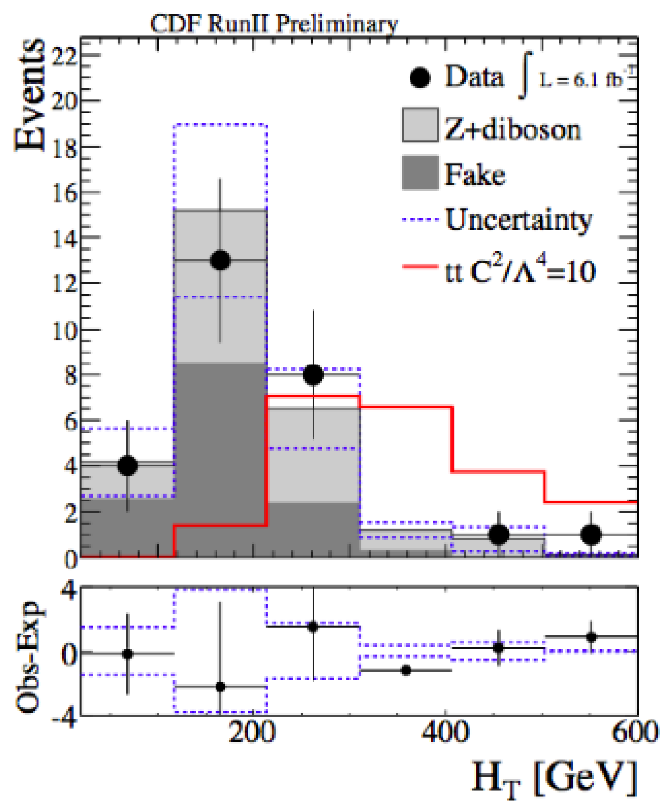
- Significance of the excess is 3 sigma. Need to hear a word from D0!

Is it a *light* Z′ instead? (part3)

- A t-channel exchange of Z′ should produce abundant same sign top pairs



Freshly approved search for such a signature.
No signs here as well…



Summary

- Sixteen years after its discovery, the knowledge of the top quark has greatly expanded thanks to the large Tevaron dataset
  - extensive measurements of top quark intrinsic properties, study of its production and decay. Lots of physics but all SM :(

- We are into LHC era, and Tevatron still playing 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 unique/complementary to the LHC program

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. Lots of physics but all SM :(

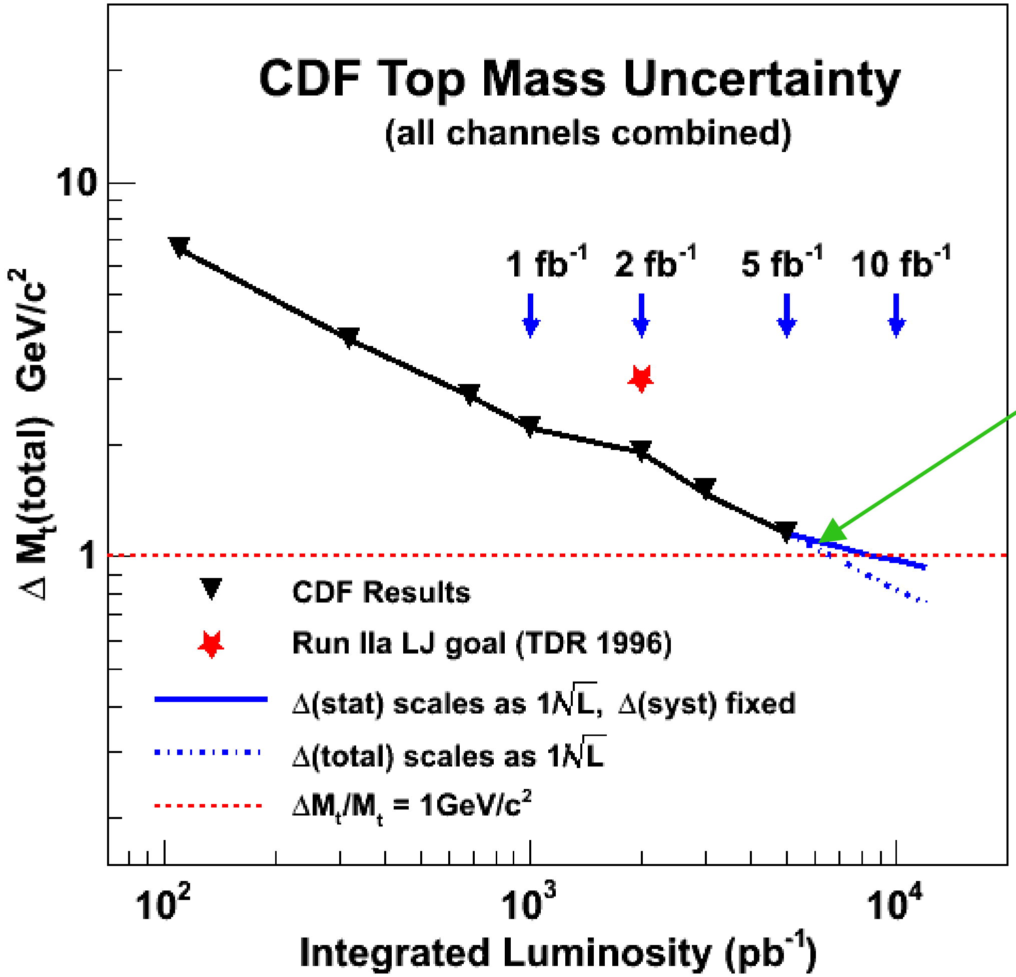
- We are into LHC era, and Tevatron still playing an important role:
  - some Tevatron measurements - its mass! - have broad impact to our field, and will be a long standing legacy
  - others such as charge asymmetry, spin correlations are unique/complementary to the LHC program

- Study of forward-backward asymmetry of top events shows first significant discrepancy with SM. Is "the bumpt" the cause?A close collaboration between theorists, and experimentalists from Tevatron and LHC will *very* soon clear the fog!

Stay tuned!

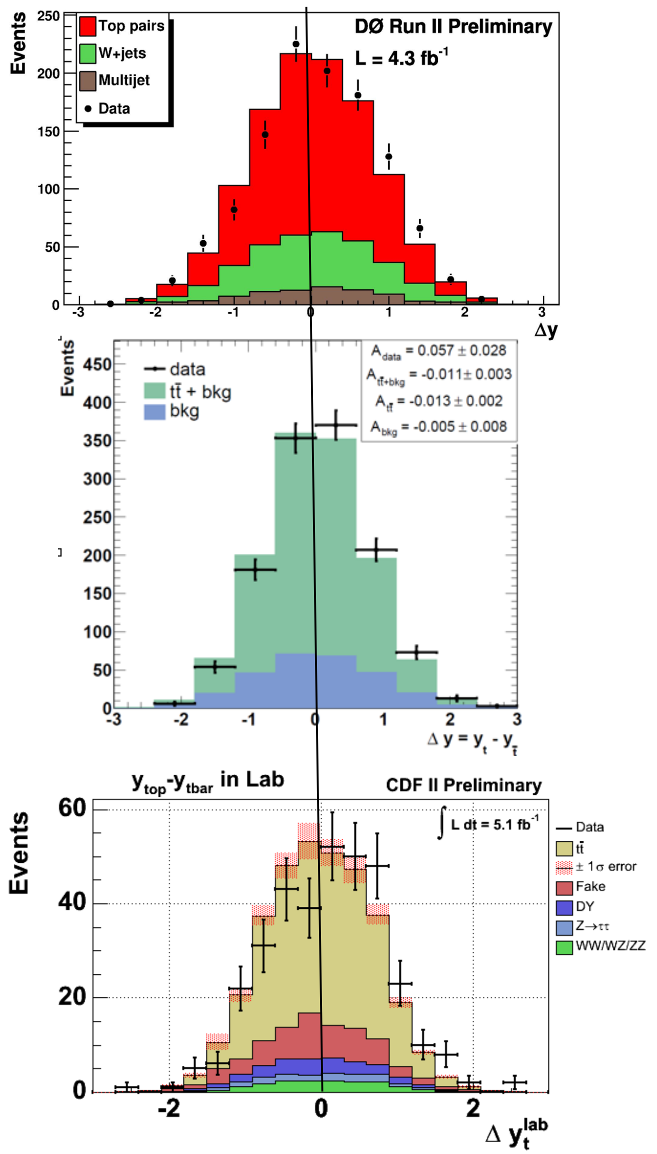
Backup

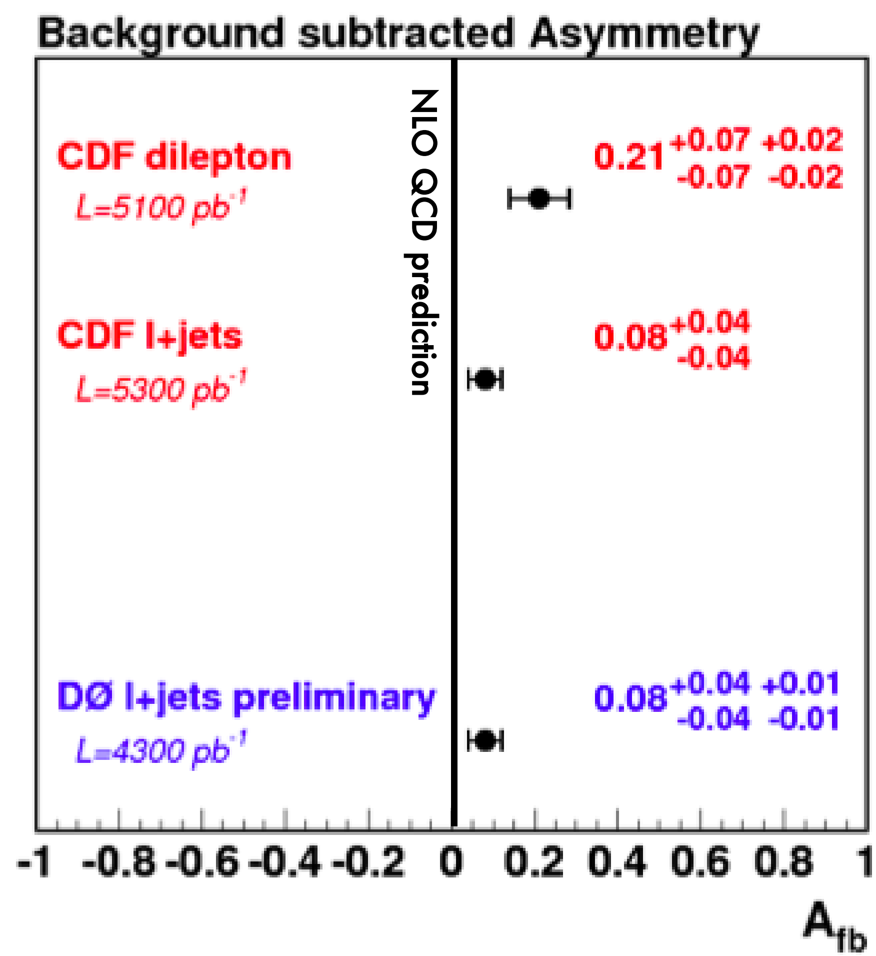
M_{top}: where we stand



Combination shown at Moriond

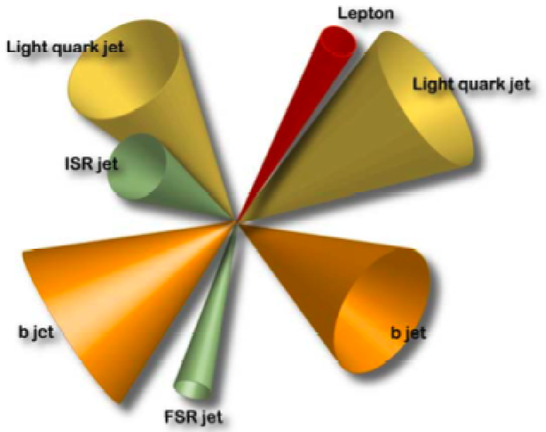
The inclusive asymmetry





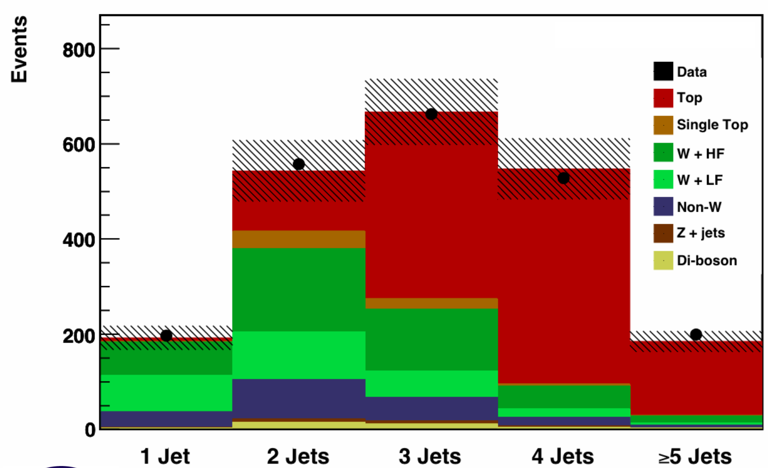
Three independent 2 sigma effects, same sided

No multivariate

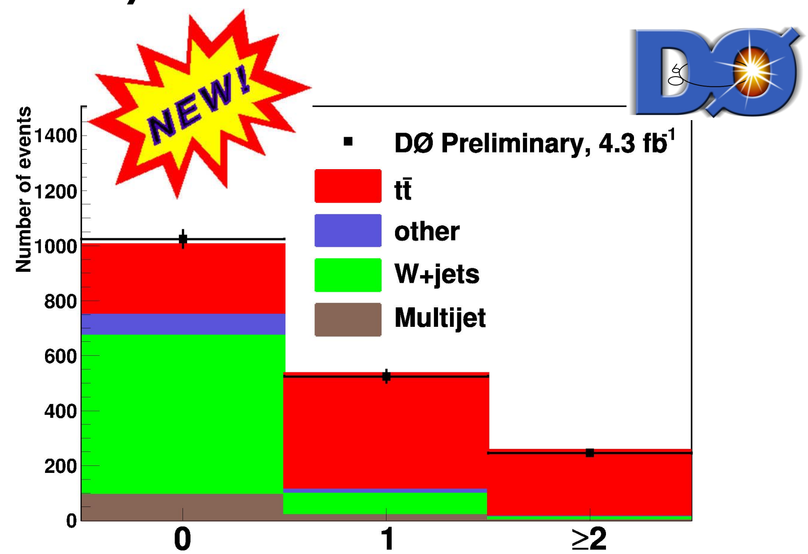


Counting experiment after background understanding:

- 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



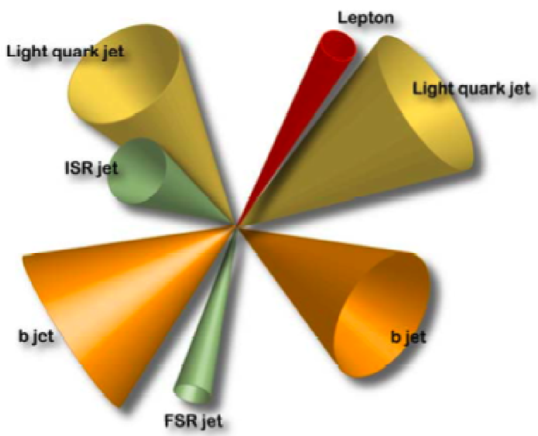
PRL 105 012001 (2010)



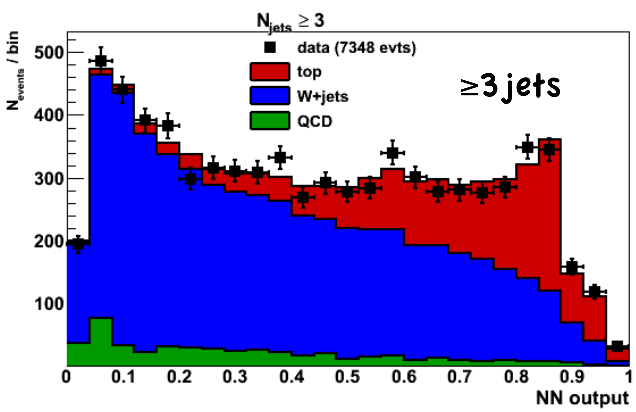
D0 (L=4.3fb^{-1}): $\sigma_{t\bar{t}}$ = 7.93 ± 0.98 (stat+syst+lumi) pb

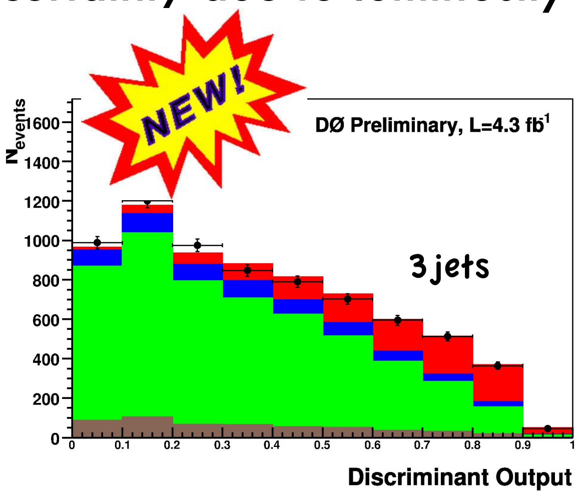
CDF(L=4.3fb^{-1}): $\sigma_{t\bar{t}}$ = 7.32 ± 0.71 (stat+syst+theory) pb

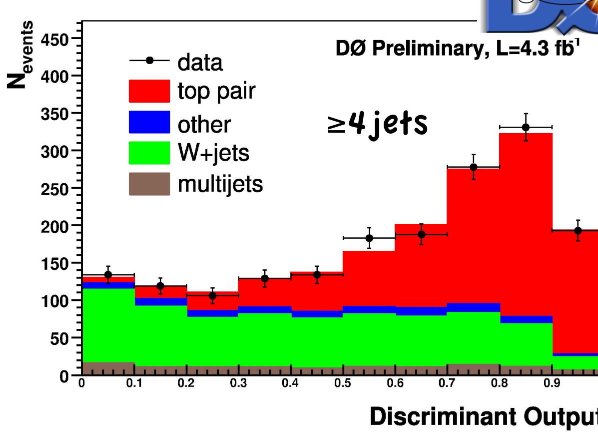
With multivariate



- 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→ll with the same trigger and use the theoretical Z cross section to remove the uncertainty due to luminosity measurement





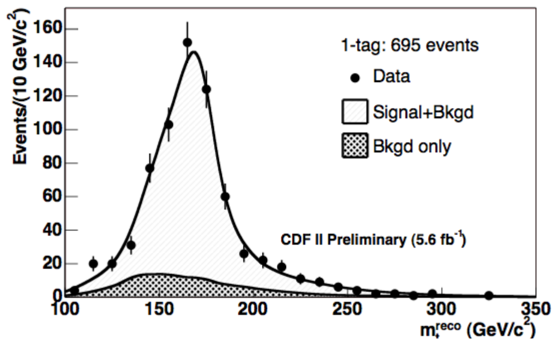


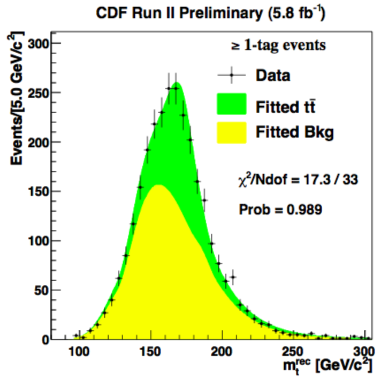
PRL 105 012001 (2010)

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

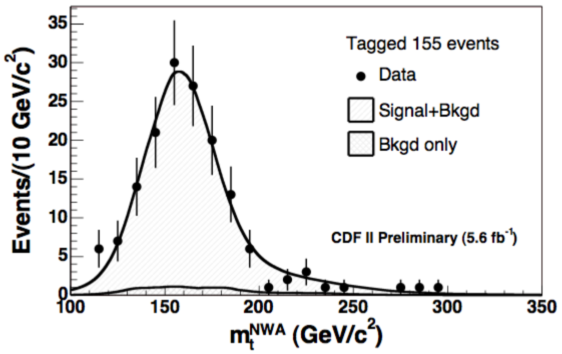
CDF(L=4.6fb^{-1}): σ_{tt} = 7.82 ± 0.55 (stat+syst+theory) pb

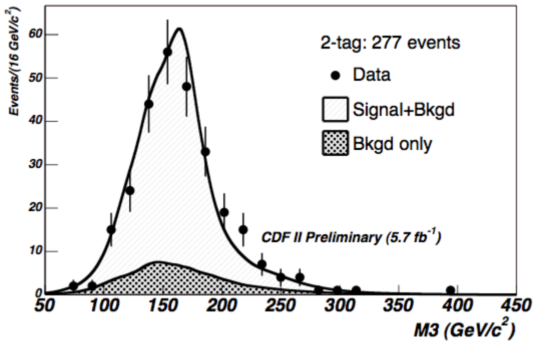
Thousands of top events analyzed



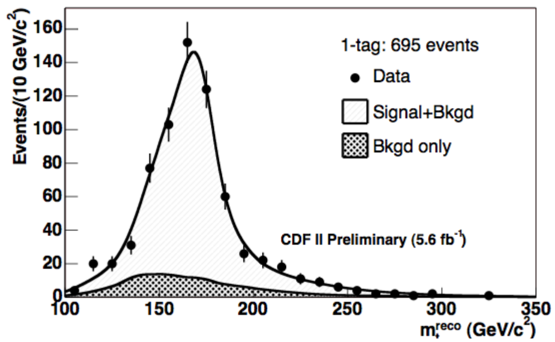


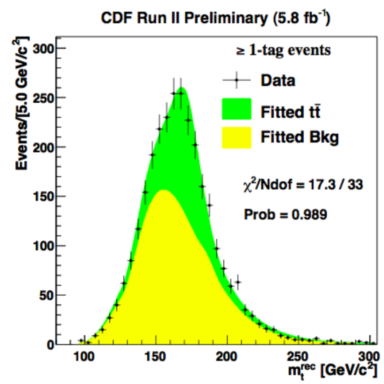
- Study all decay modes

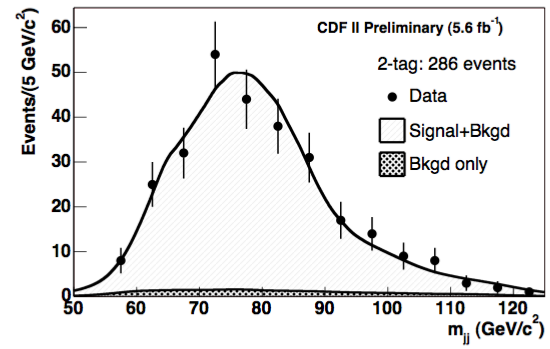


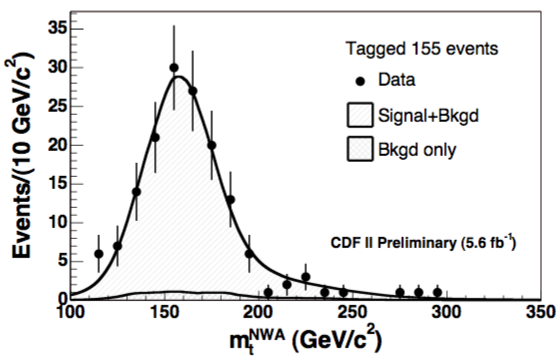


Thousands of top events analyzed

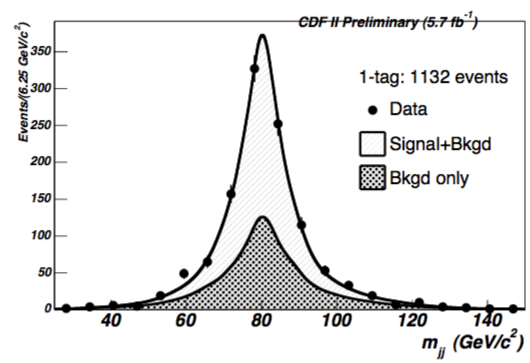


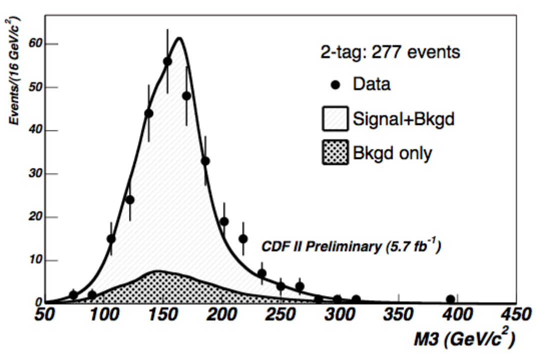


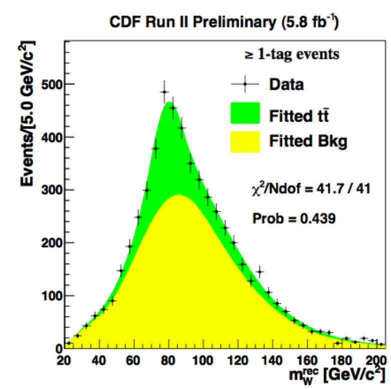




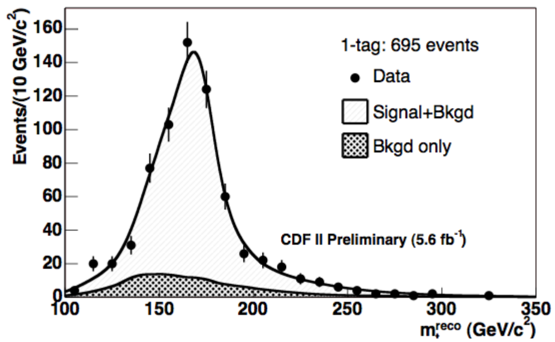
- Study all decay modes
- Utilize all hadronic W to measure the jet energy scale

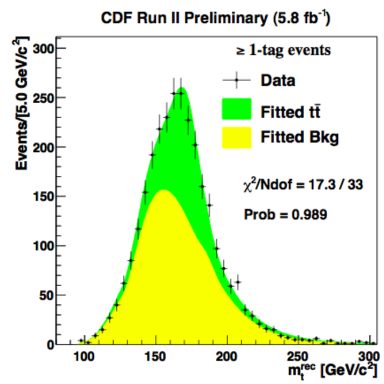


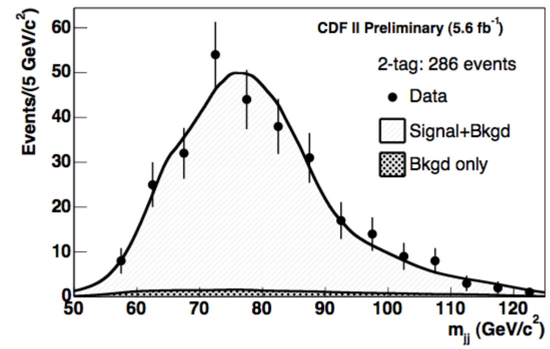


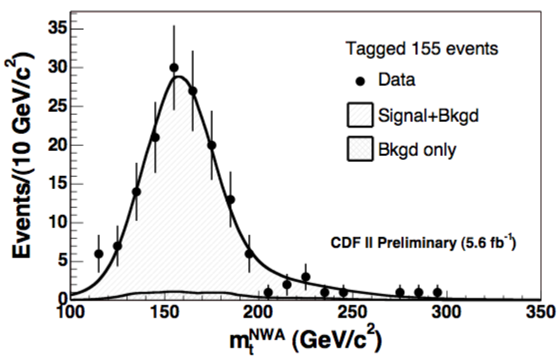


Thousands of top events analyzed

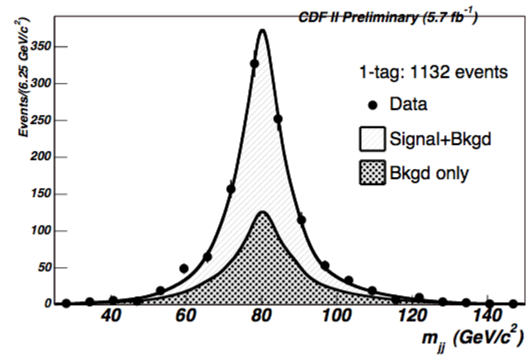


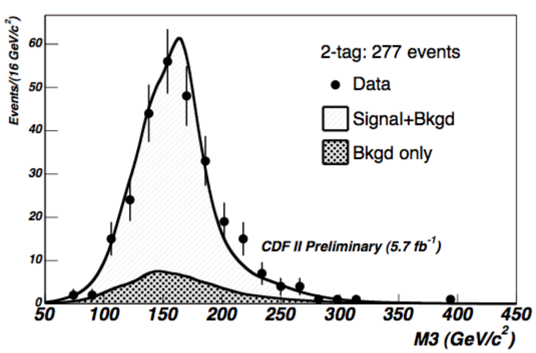


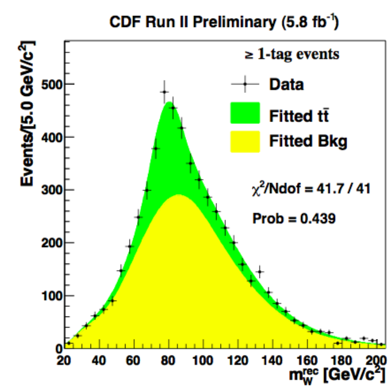




- Study all decay modes
- Utilize all hadronic W to measure the jet energy scale
- Measure the top-antitop difference and top width

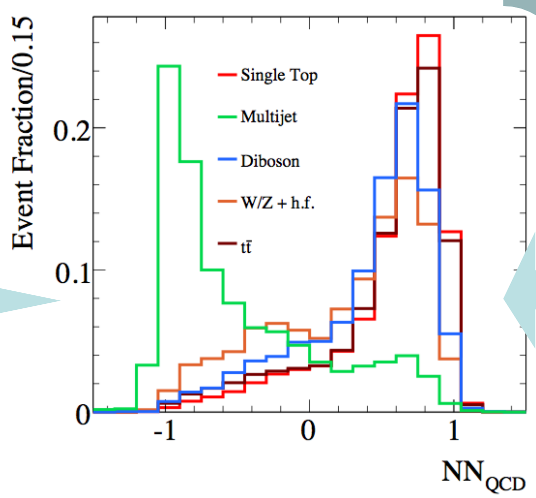






Single top observation at CDF

- Observing electroweak production of single top quarks crucial goal for CDF:
- I first used the MET+(b)jets signature to recover non-reconstructed electrons/muons - sample rich in τs. Adds 50% acceptance per fb^{-1}
- MET+jets much harder than l+MET+jets:
  - less objects in the final state → more backgrounds
  - impossible to reconstruct top resonance
- Required state-of-the-art QCD understanding and rejection through several innovative techinques:
  - Rejection of QCD using kin. and topology, and MET from tracker in NN
  - Precise data-driven modeling for QCD
- Now other searches in the same signature are benefitting from all of the above:
  - dibosons, SUSY quark and gluinos
  - low mass Higgs searches - see later

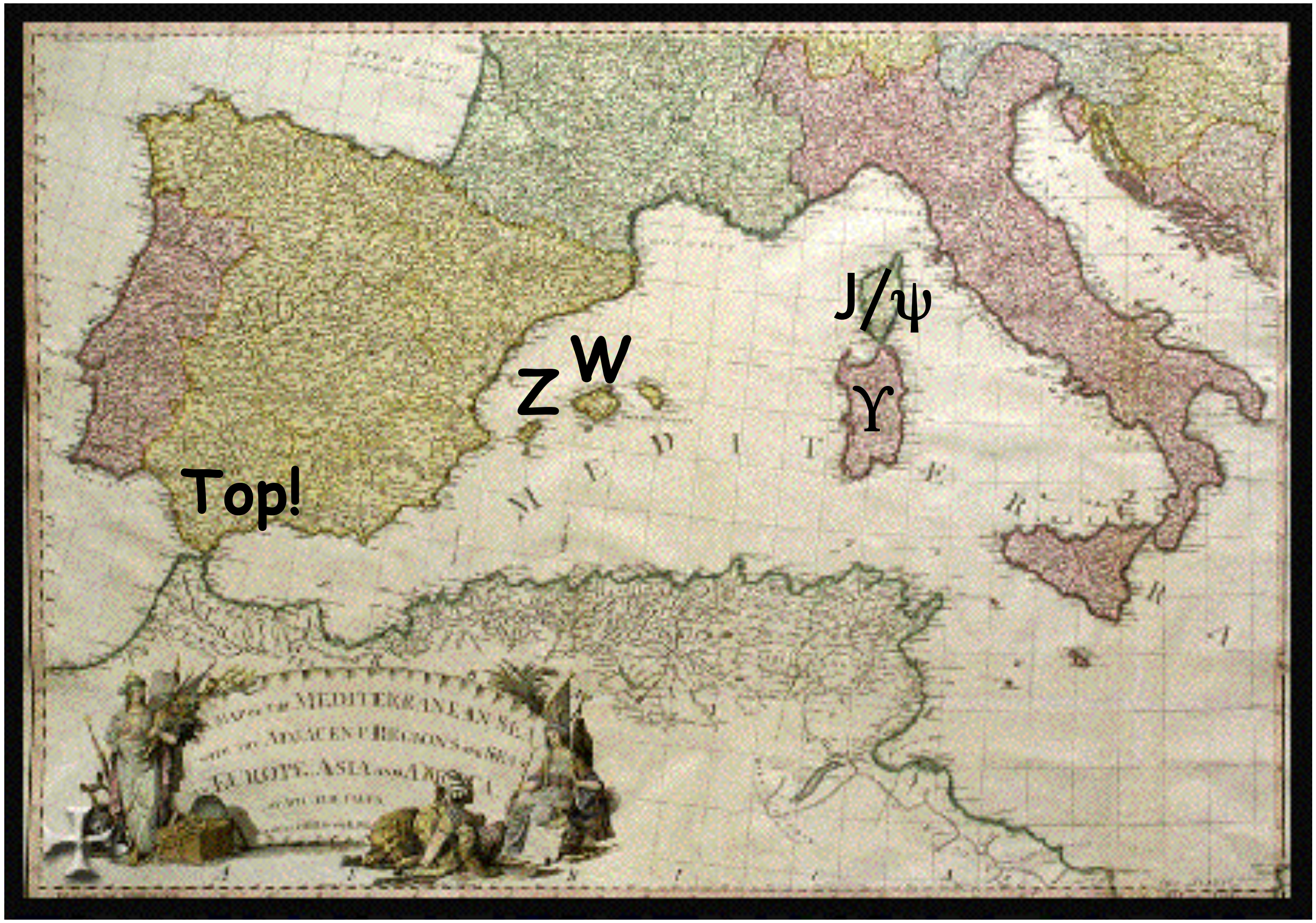


arXiv:1001.4577, submitted to PRD

The experimentalist view

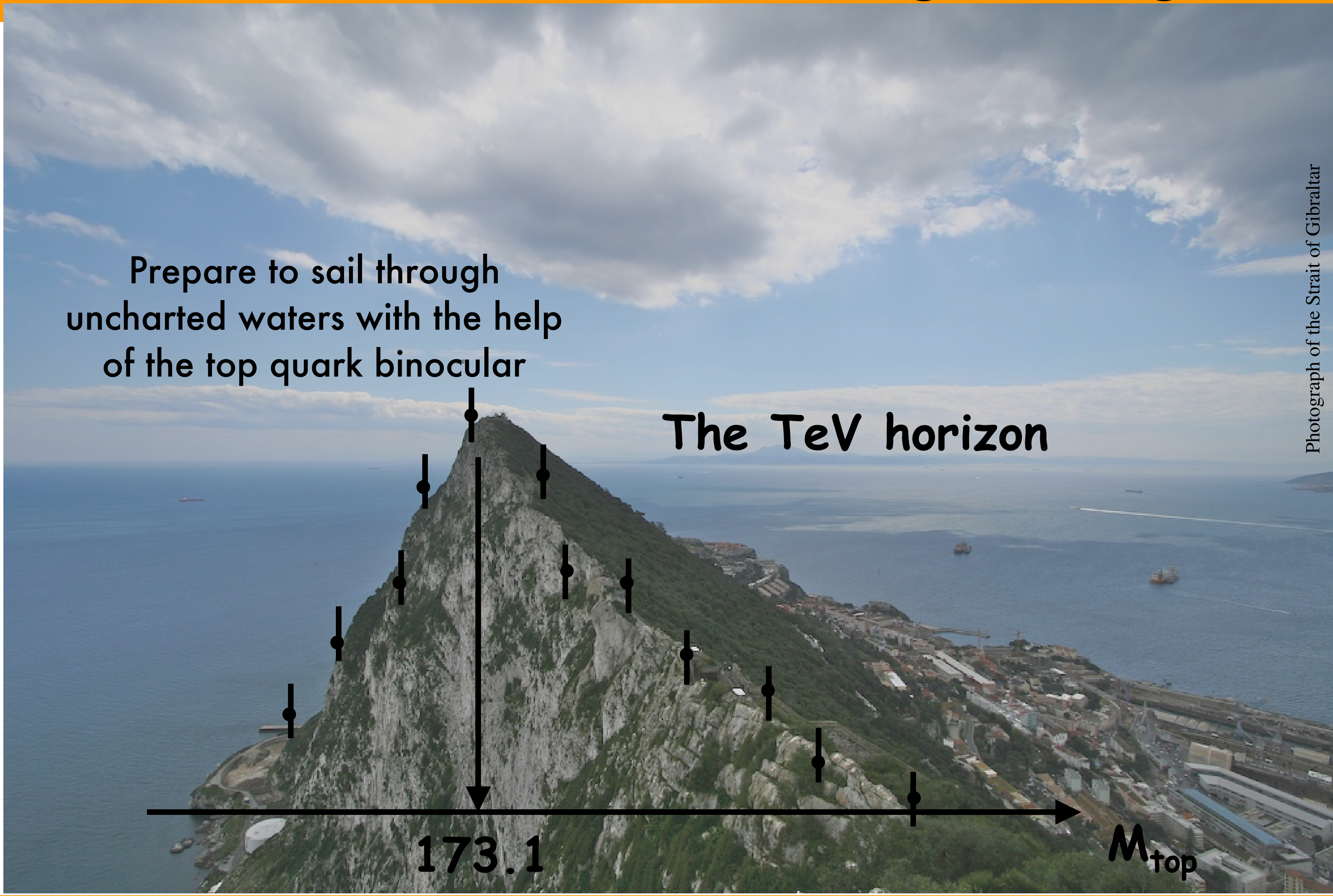
What lies aftter the
pillars of Hercules ?

Nec plus ultra?
Or Antlantis?



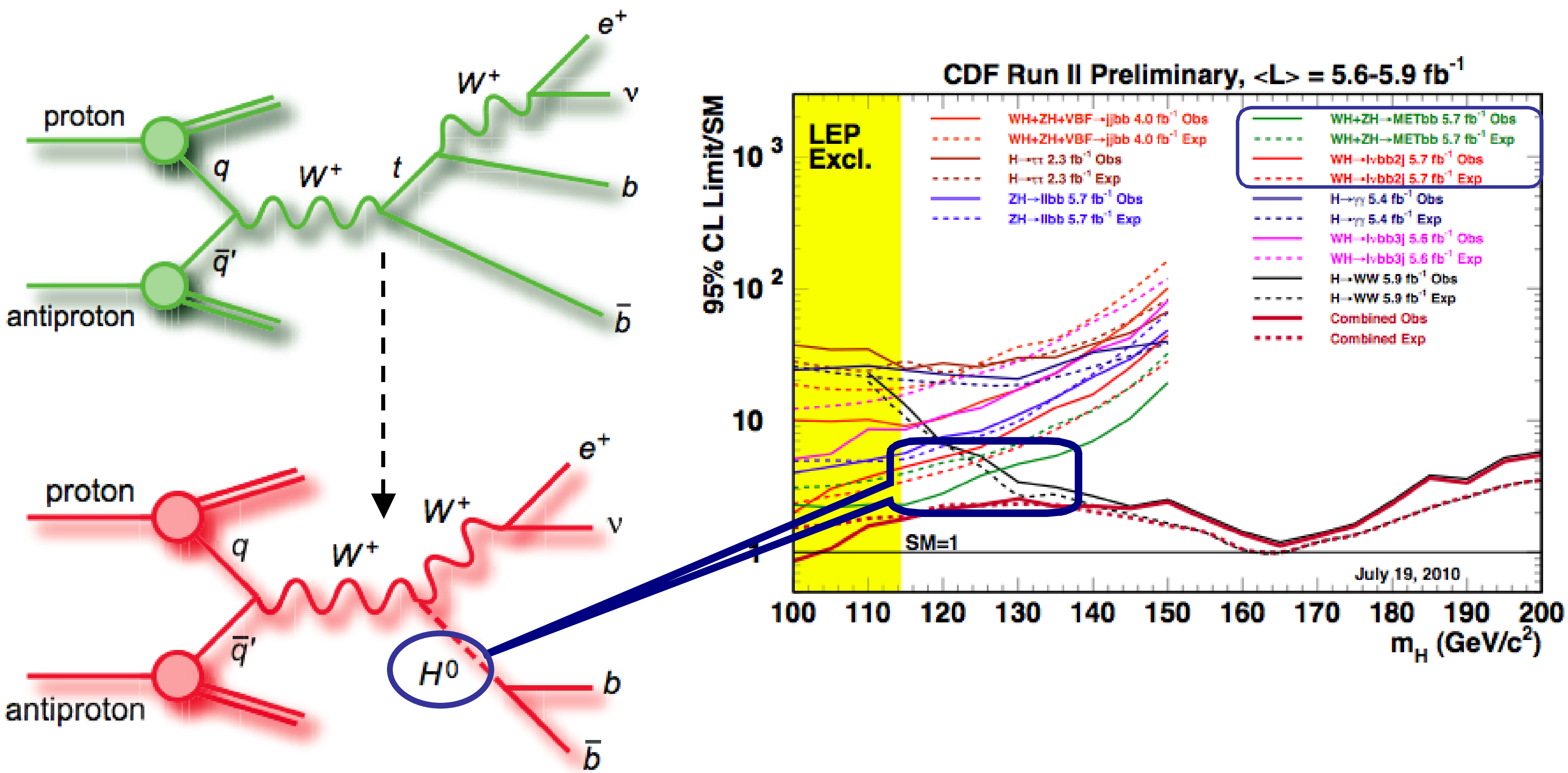
The knowledge of the top quark will ultimately guide us into the unknown

The end - a new beginning?



Why measure Single Top (2)?

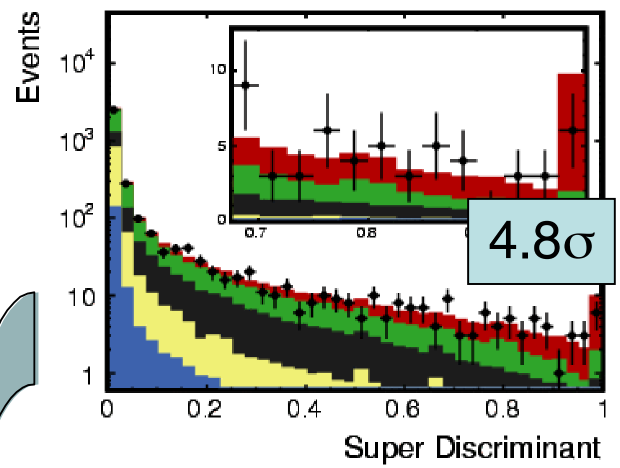
- Background to most sensitive low mass Higgs searches at Tevatron!
- σ_{WH} ~ 1/10 $\sigma_{Singletop}$



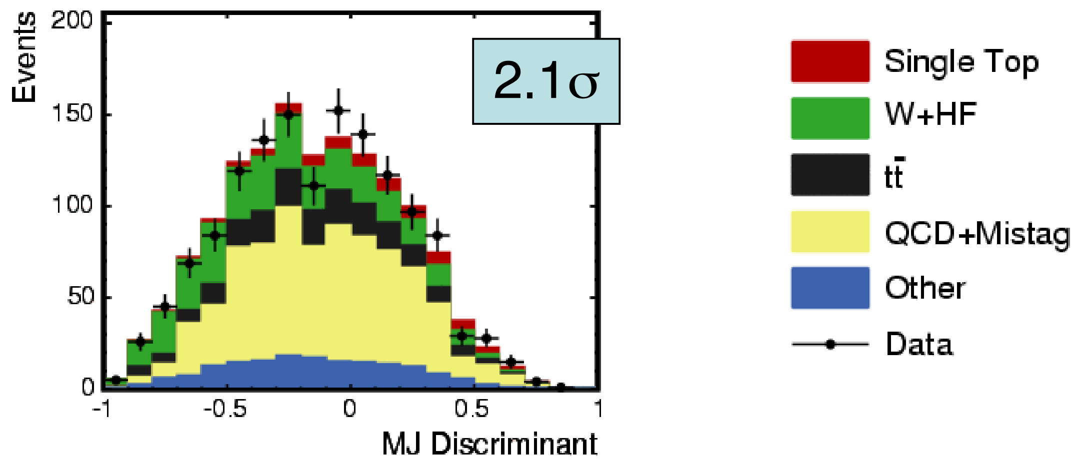
- Today's signal, tomorrow's background!

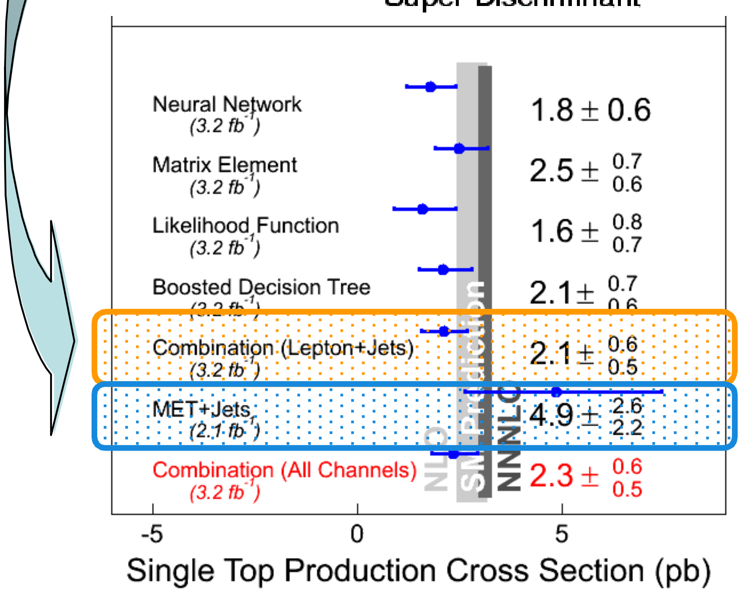
CDF results and combination

lepton + MET + jets



MET + jets





Highly correlated analyses (identical dataset)
historically observed deficit of signal

+

Completely independent analysis
(100% independent data, partly
different sytematics)

=

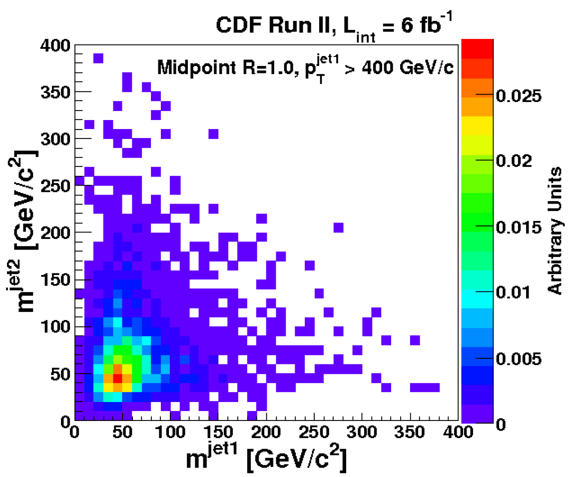
5σ Observation!

Phys. Rev. Lett. 103, 092002 (2009)

Or a axigluon/heavy Z'? (part 2)

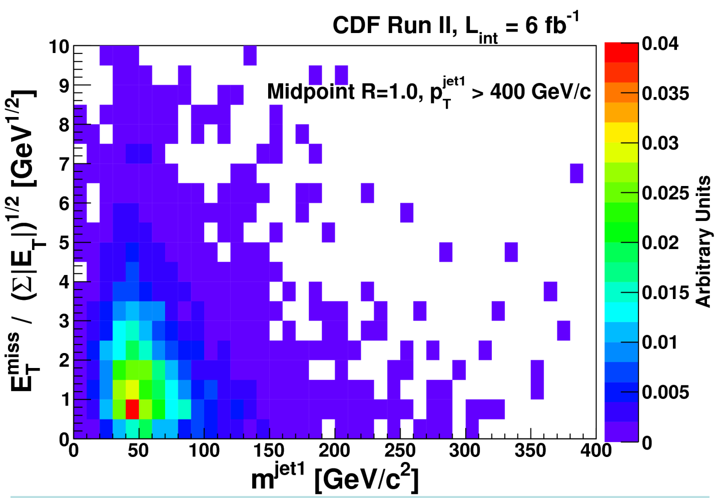
- Study boosted top → Probe NLO QCD/understand boosted jets/search for NP
  - Cross section for SM ttbar with Pt(top) ≥ 400GeV is a handful of fb
- direct identification of the W decay and the b quark unfeasible
- jet has mass close to Mtop → very different from jets from q/g

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

Not enough time...

V_{tb} = 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) < … % at 95% CL

BR(t→… % at 95% CL

$M_t = 173.3 \pm 1.1$ 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

…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

$M_{Z'} > 900$ GeV at 95% CL

$M_{W'} > 800$ GeV at 95% CL

$M_{b'} > 372$ GeV at 95% CL

$F_{gg} = 0.07\ ^{+0.15}_{-0.07}$ (…at+sys)

A_{fb} = 15-40% (parton level)

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

Statistics 101

The 3 sigma evidence, 5 sigma observation is an arbitrary standard that was set to minimize the rate of false discoveries at the time where our business was considered large: O(100) people per collaboration, 1nb^{-1} of data

HEP increased exponentially since then in both amount of experimenters and data and thus distributions we look at. It's always best to translate "sigmas" in p-value and then use your own judgement.

Please keep in mind: sigmas are not a linear scale!!!

- 1 sigma 1 sided = 16%
- 2 sigma 1 sided = 2.3%
- 3 sigma 1 sided = 0.14%
- 4 sigma 1 sided = 0.003%
- 5 sigma 1 sided = 0.00002%

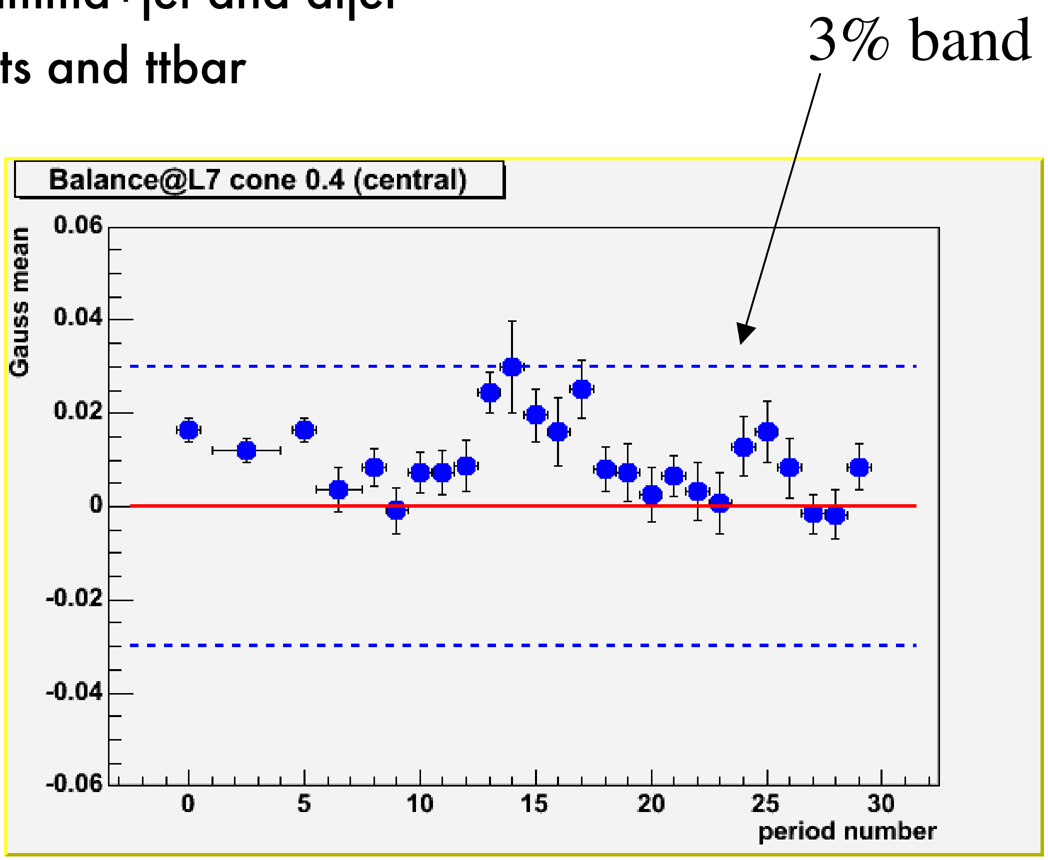
1 order of magnitude less likely per each sigma

2 orders of magnitude(!) less likely per each sigma

On “the bump” and the JES

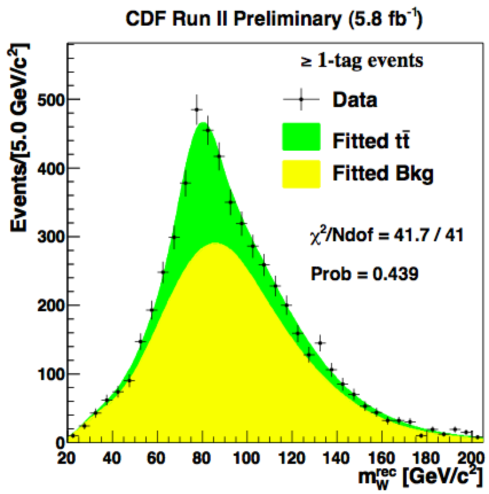
- JES is a complex business, but (as with every systematic) one where you learn fast with new data. In other words, JES can be
  - 10% before you get collisions: test-beam, single particle response)
  - 5% months later: first gamma+jet and dijet
  - 2% one year later: Z+jets and ttbar

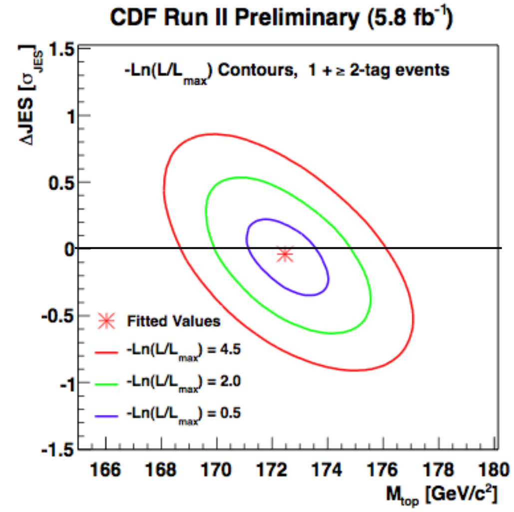
- JES validated period-by-period using gamma+jet events(mixture of quark and gluon jets)
- Shown here is Pt(gamma)-Pt(jet)/Pt(gamma)

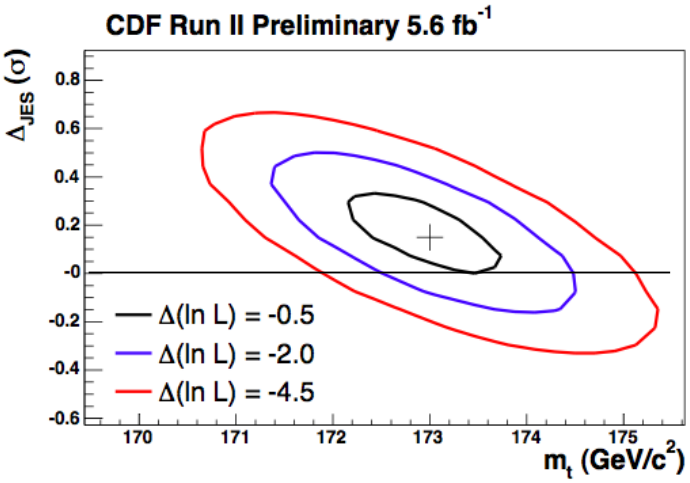


JES from ttbar events

- Pure samples of light quark jets
- About 5000 hadronic Ws, from three different ttbar decay modes, all right on the spot!
- JES for light quarks cab be summarized as 0.5+-1%





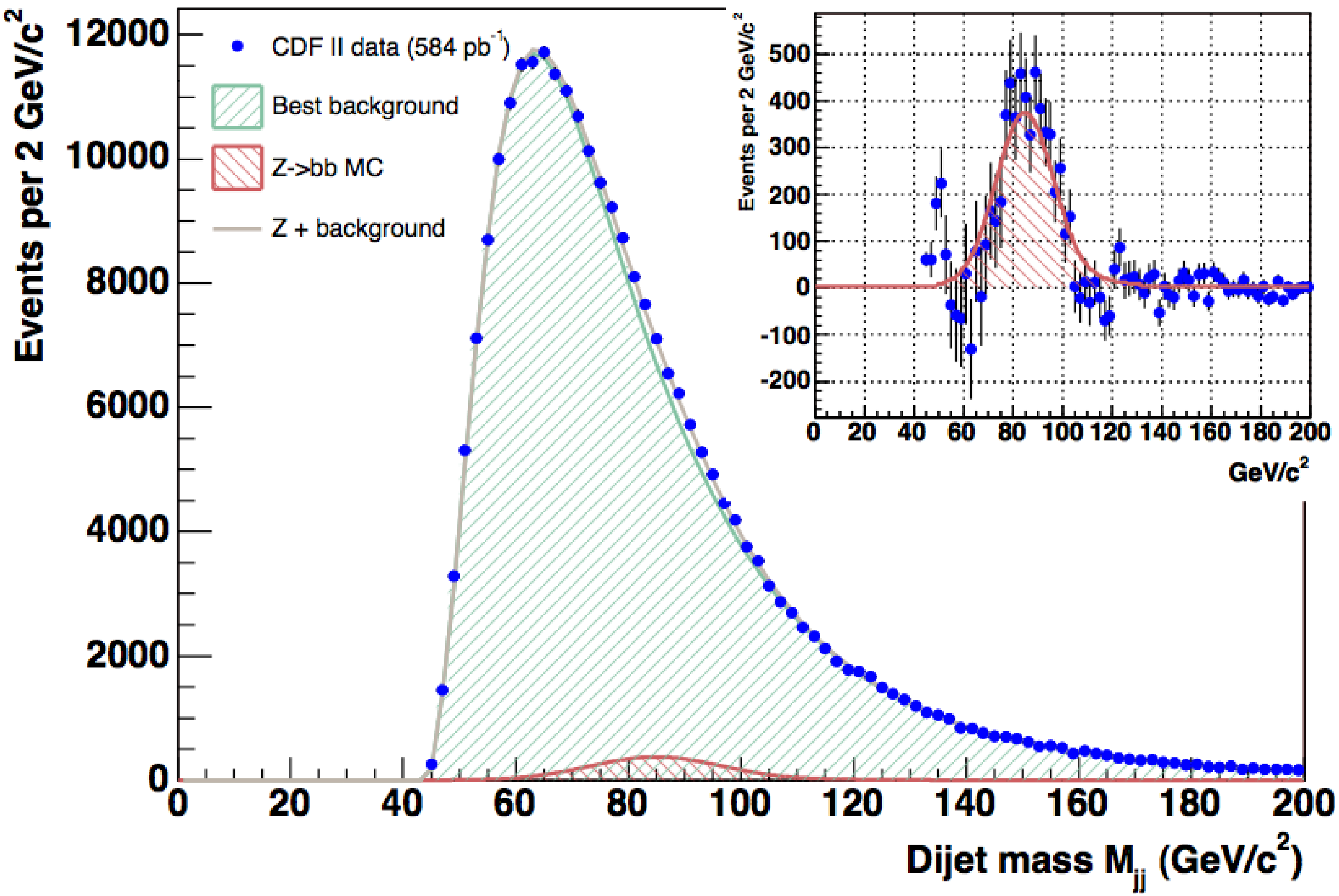


+ more…

- JES for light quarks cab be summarized as 0.5+-1%

More plots/infos
on http://www-cdf.fnal.gov/physics/new/top/public_mass.html

JES from Z→bb



CDF II data (584 pb⁻¹)
Best background
Z->bb MC
Z + background
Events per 2 GeV/c²
Dijet mass Mjj (GeV/c²)
Events per 2 GeV/c²
GeV/c²