Experimental results on top physics from hadron machines

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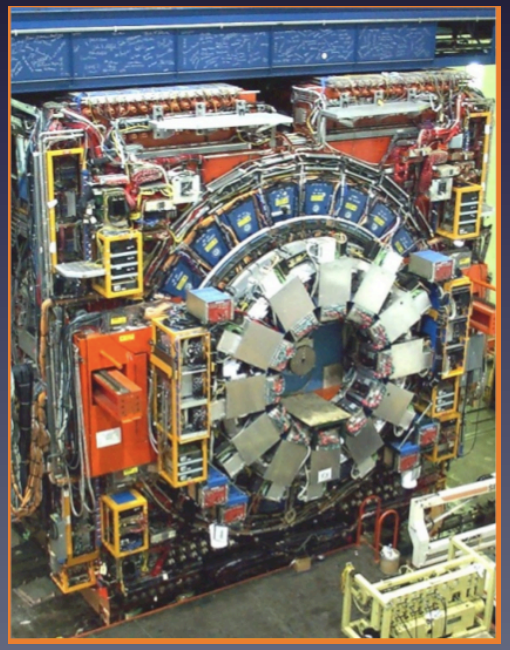
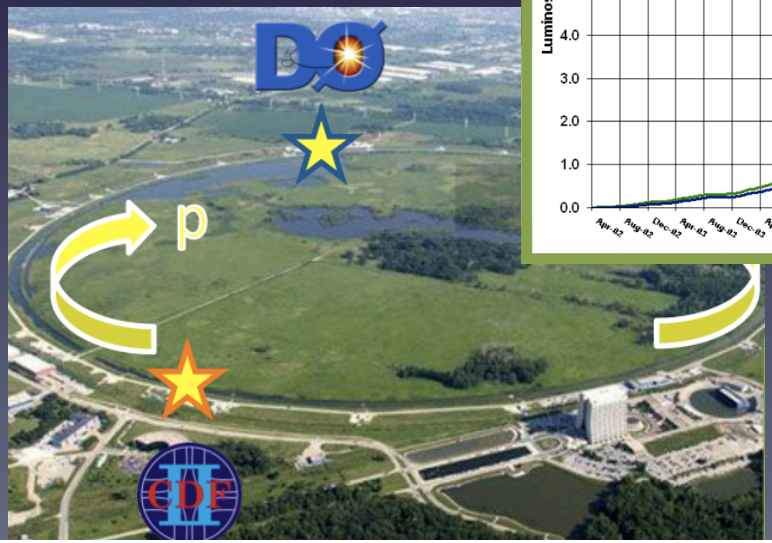
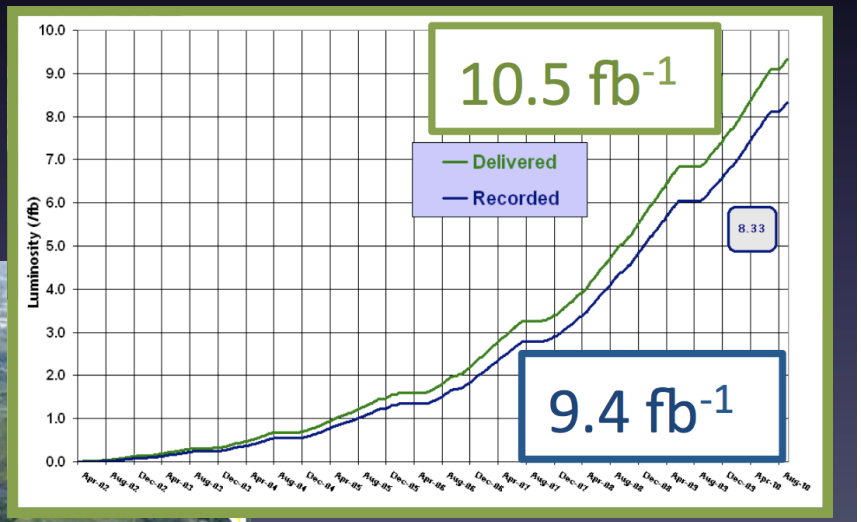
Tevatron status

- p-p collisions at $\sqrt{s}$ = 1.96 TeV
  - Peak luminosity: $4 \cdot 10^{32} cm^{-2} s^{-1}$
  - About **10 fb^{-1}** of data collected
  - > 8 fb^{-1} for data analysis (analysed ≈ 5 fb^{-1})
  - Plan to analyse all data by end of Run II
- **close at the end of 2011**

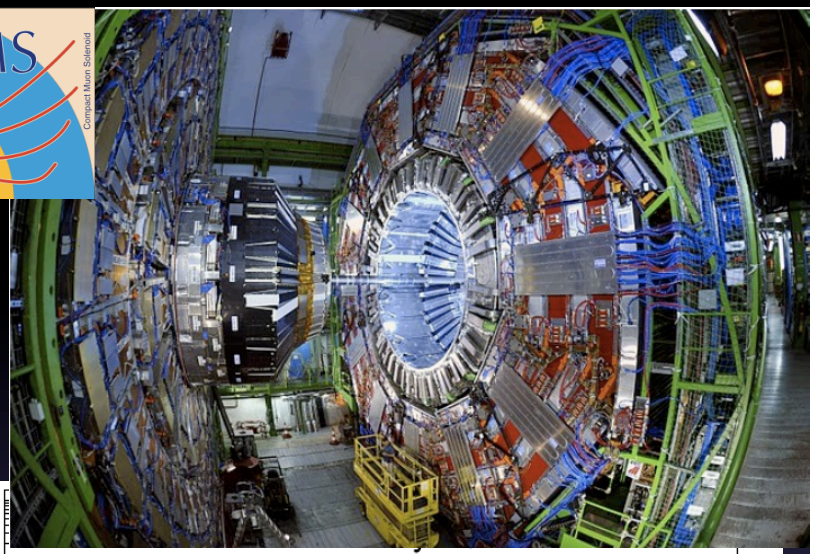


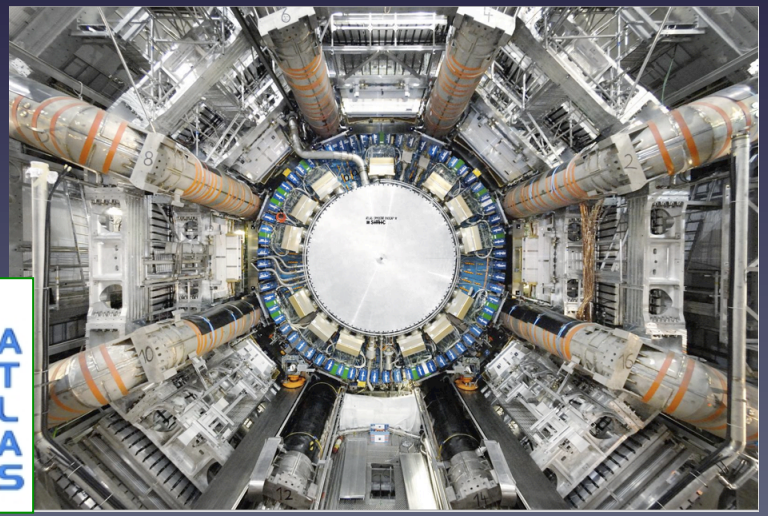


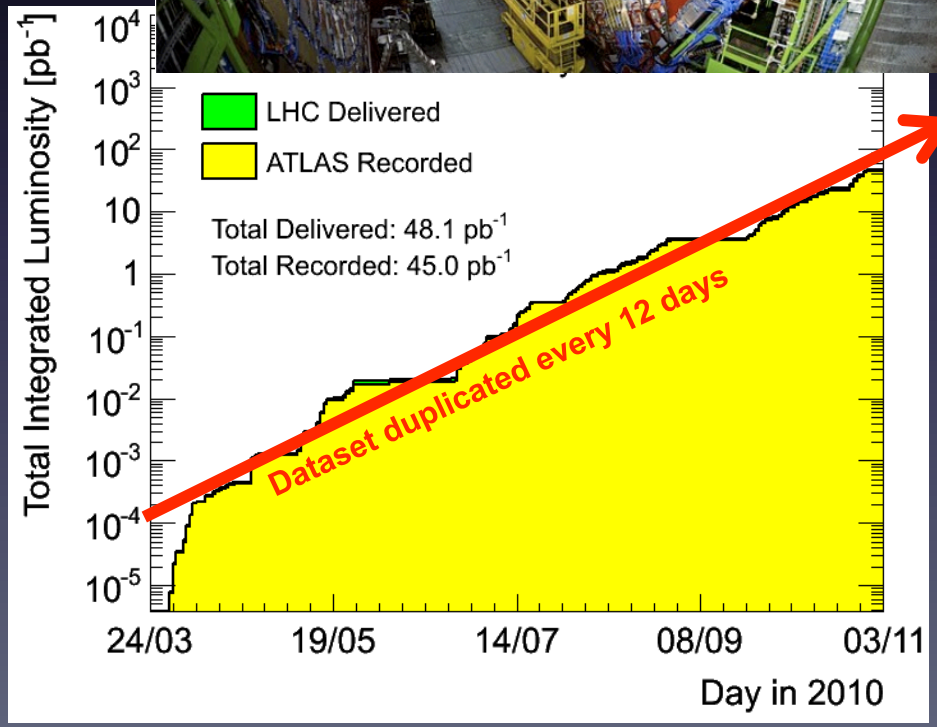


LHC status

- **pp** collisions at **$\sqrt{s}$ = 7 TeV**)
  - Peak luminosity 2.1 x 10^{32} cm^{-2} s^{-1}
  - About **45 pb^{-1}** of data collected
  - Pile-up now up to $<n_{vtx}>$ = 4
  - Single lepton triggers ~35 pb^{-1}
  - Lumi uncertainty down to 3.4%
- Data taking **until end of 2012**

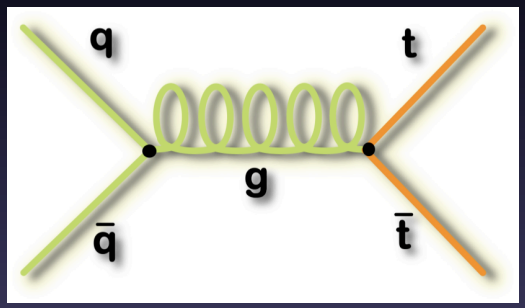


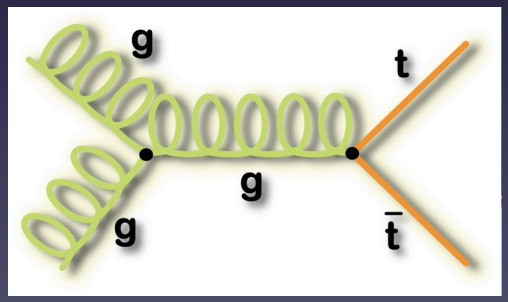




The Top quark

- Weak isospin partner of b-quark
- Spin ½ fermion, charge 2/3
- Produced in pairs via *qq annihilation* or *gg fusion*
- Lifetime ~ $5 \cdot 10^{-25}$ s
- Decays (BR ~ 100%) in Wb





Strong production

Most precise predictions of production cross section by approximate NNLO calculations, precision of 6% to 8%.

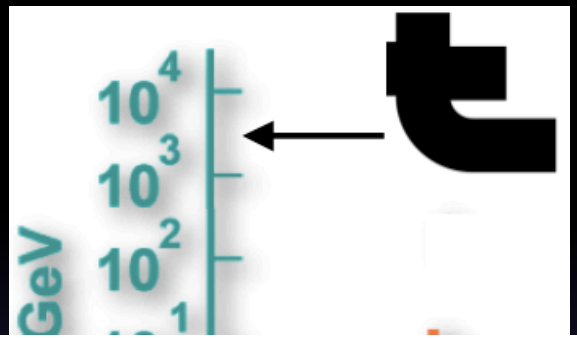
The Top quark is special

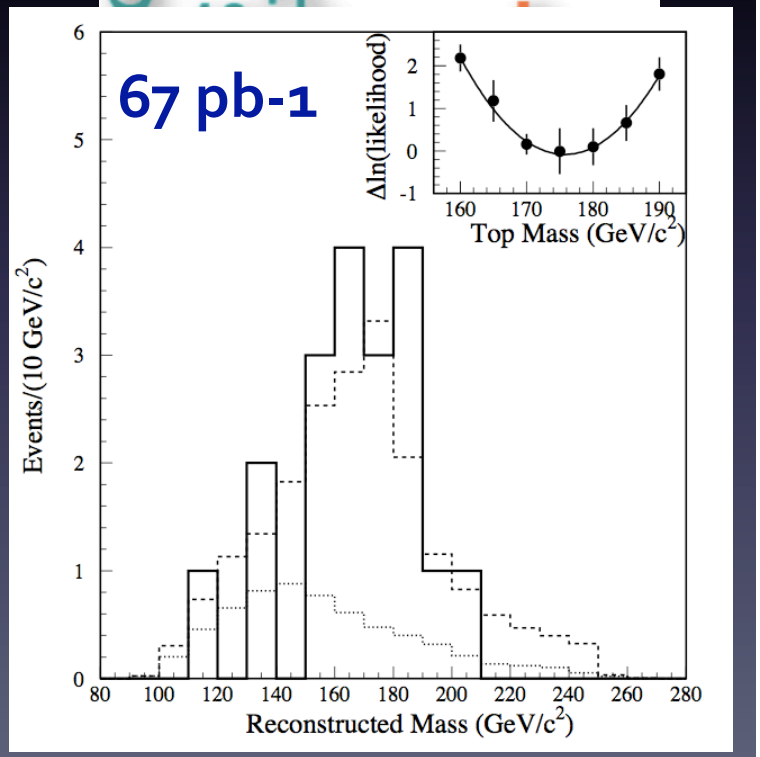
- Top was **discovered** at Fermilab **in 1995**
- Its mass much larger than any other fermion
- Using the latest Tevatron-averaged M_{top}

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

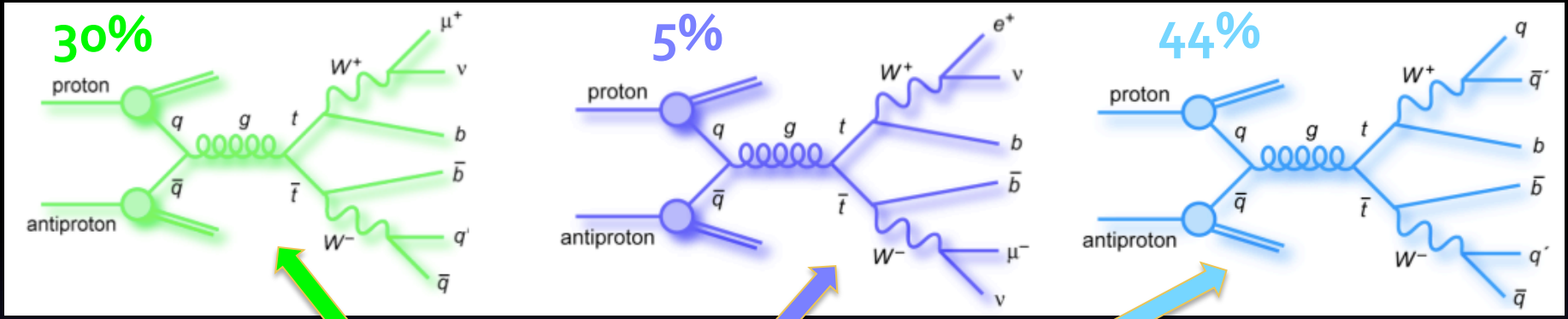
Yukawa coupling = 0.996±0.006

- Only quark with large coupling to Higgs – special role for the top quark?
- Lifetime shorter than hadronization time →only quark that decays before hadronizing





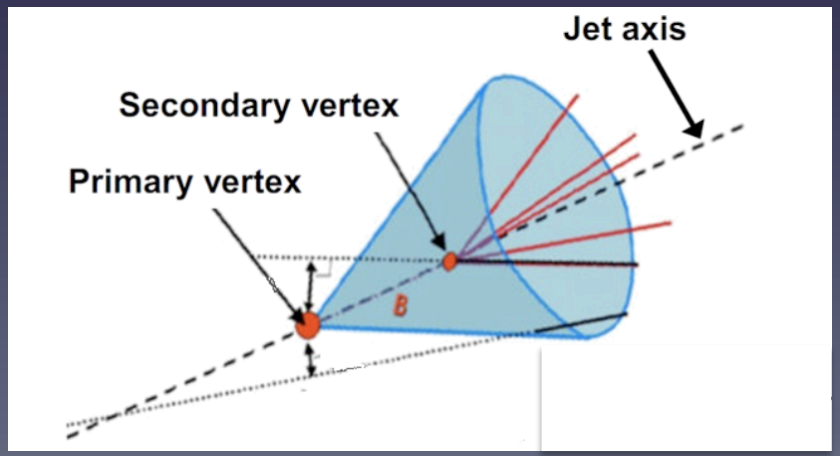
Top decay



lepton+jets: $t\bar{t} \rightarrow lvqq'b\bar{b}$

di-lepton: $t\bar{t} \rightarrow ll'vv'b\bar{b}$

all hadronic: $t\bar{t} \rightarrow qq'q''q'''b\bar{b}$

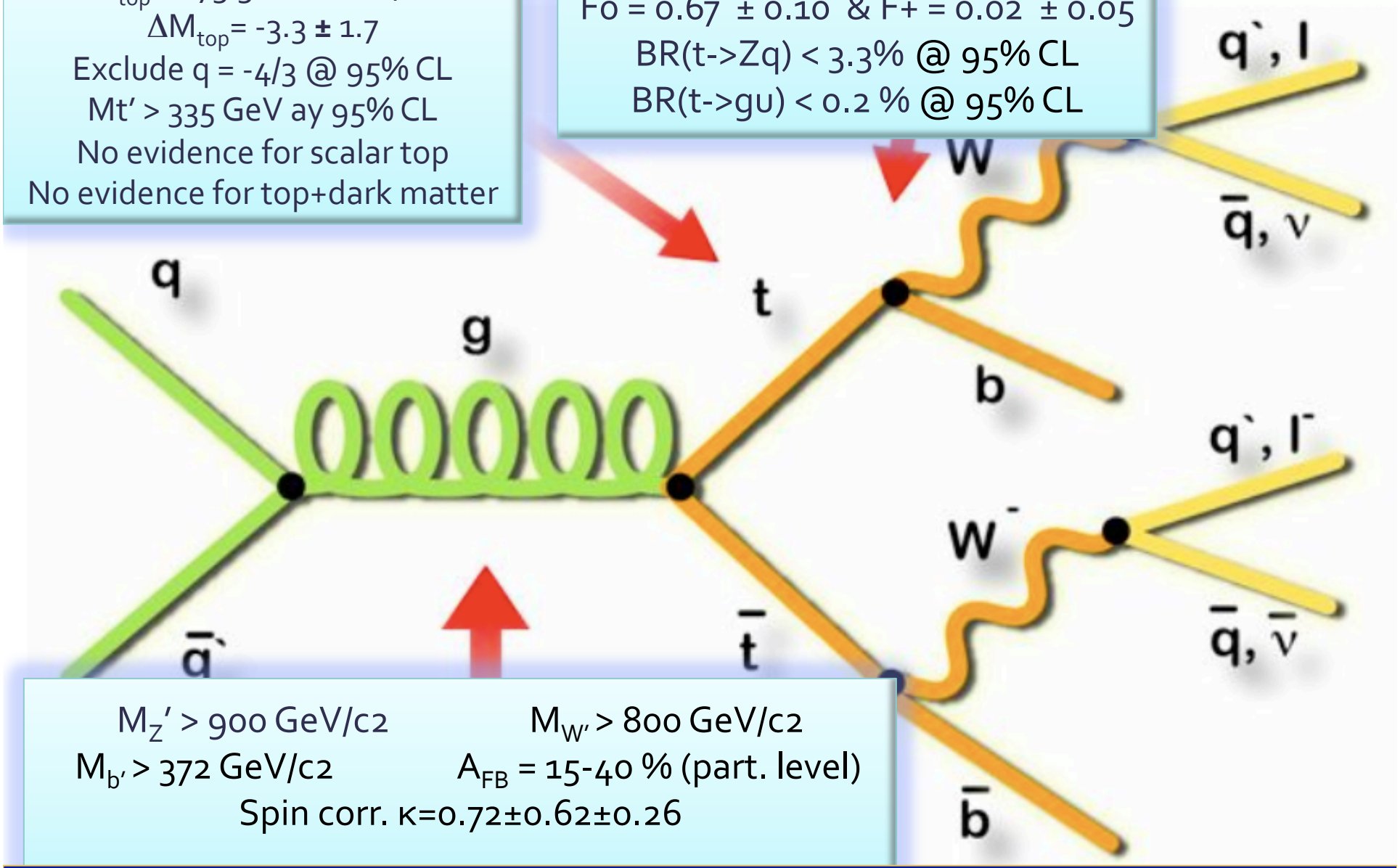


Single Lepton

- **Selection**:
  1 high-Pt leptons
  Missing Et
  At least 4 jets
- **Background**:
  Physics : W+jets (Data)
  Instrumental: multijets, WW/WZ/ZZ (MC)

M_{top} = 173.3 ± 1.1 GeV/c2
ΔM_{top}= -3.3 ± 1.7
Exclude q = -4/3 @ 95% CL
Mt' > 335 GeV ay 95% CL
No evidence for scalar top
No evidence for top+dark matter

V_{tb} = 0.91 ± 0.11 ± 0.07
No evidence for charged Higgs
Fo = 0.67 ± 0.10 & F+ = 0.02 ± 0.05
BR(t->Zq) < 3.3% @ 95% CL
BR(t->gu) < 0.2 % @ 95% CL

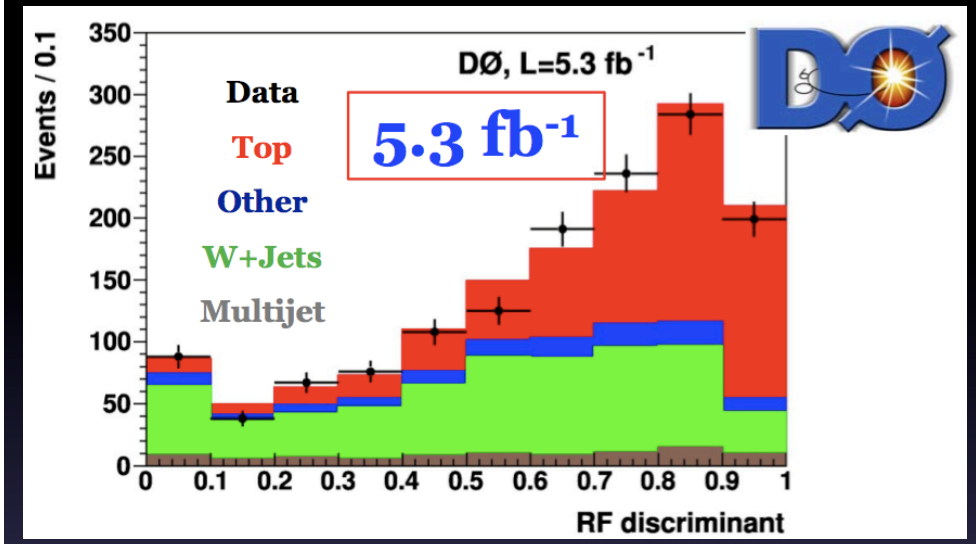


$M_{Z'}$ > 900 GeV/c2
$M_{W'}$ > 800 GeV/c2
$M_{b'}$ > 372 GeV/c2
A_{FB} = 15-40 % (part. level)
Spin corr. κ=0.72±0.62±0.26

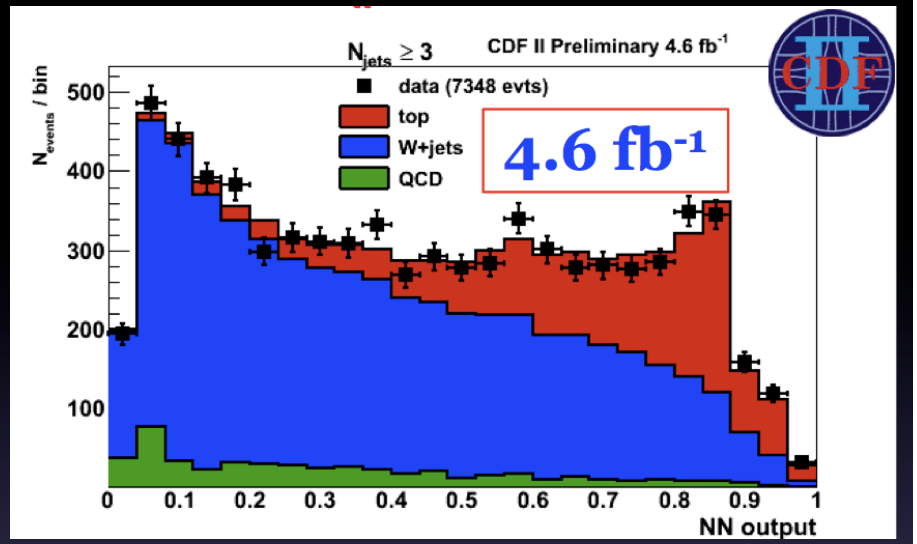
σ_{tt} @ Tevatron

arXiv:1101.0124

PRL 105 (2010) 012001



B-tag lepton + jets



Pre-tag lepton + jets

Assume M_{top} = 172.5 GeV/c^2
Use kinematic info +b-jet identification

$\sigma_{tt} = 7.78^{+0.77}_{-0.64}$ pb
with ± 0.45 lumi. Uncertainty
9% precision

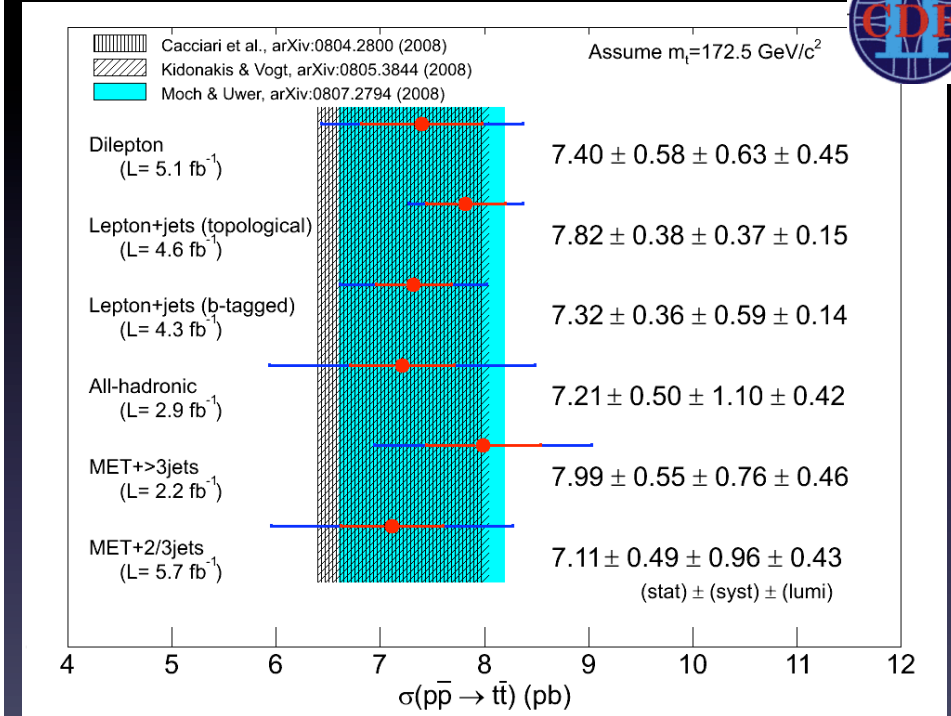
Measure σ_{tt}/σ_z to reduce lumi uncert.
and then multiply theory σ_z

$\sigma_{tt} = 7.82 \pm 0.38(stat) \pm 0.35(sys) \pm 0.15(theory)$ pb =
7.82 ± 0.54 pb -> 7% precision

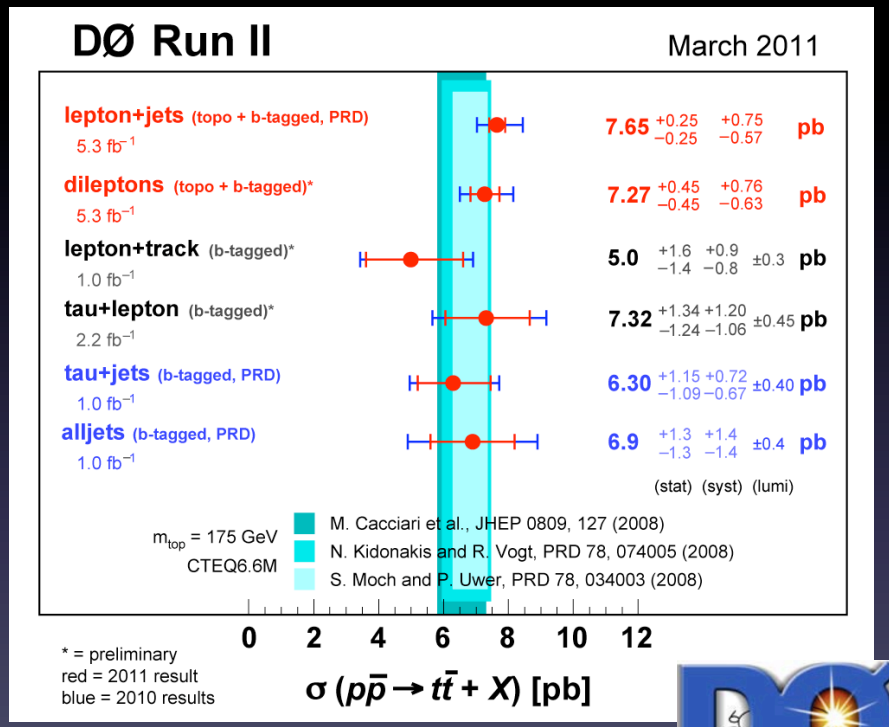
Thousands of top events analyzed, **O(10^4)** by the end of the Tevatron run!

σ_{tt} @ Tevatron

σ_{SM}=7.5 pb@ M= 172.5GeV/c²



σ_{SM}=6.7 pb@ M= 175GeV/c²



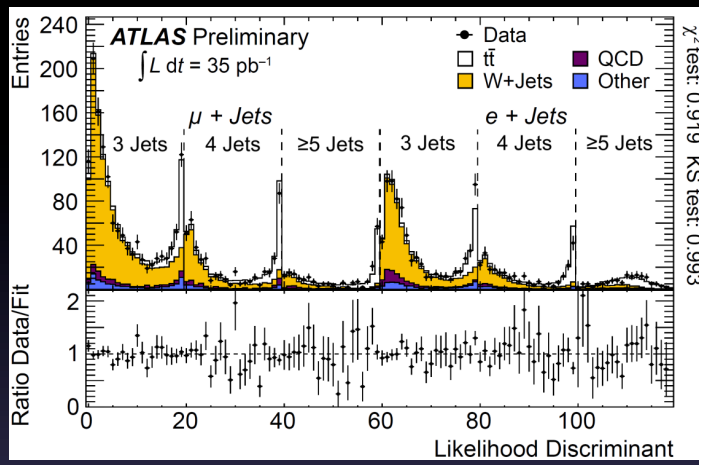
All results are consistent with Standard Model
Systematic limited measurements

σ_{tt} @ LHC

- Multivariate method in 6 channels (3,4,≥5 jets, e/μ)
- Input variables: lepton η, A, $H_{T,3p}$, b-tag weight
- Profile likelihood fit extracts 16 parameters with σ_{tt}
- Main systematics:
  - W+jets HF content (7%)
  - Tagger calibration (7%)

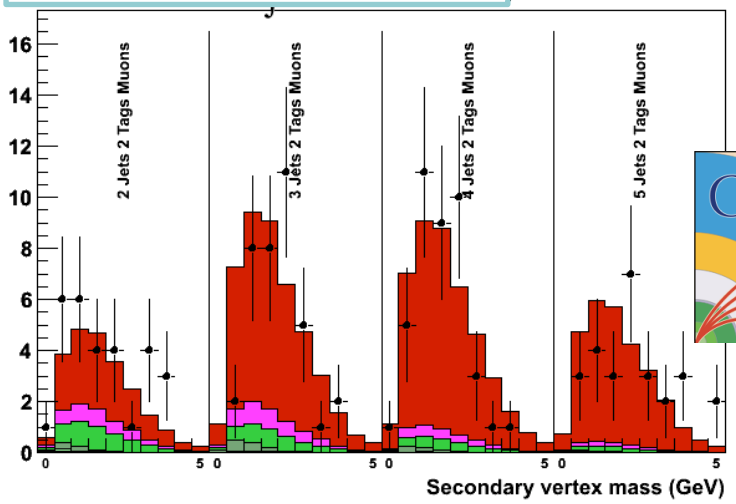
uncert. ~13%

ATLAS-CONF-2011-035



σ_{tt} = 186 ± 10(stat) $^{+21}_{-20}$(syst) ± 6(lumi) pb

CMS-PAS TOP-10-003



σ_{tt} = 150 ± 9 (stat) ± 17 (syst) ± 6(lumi) pb

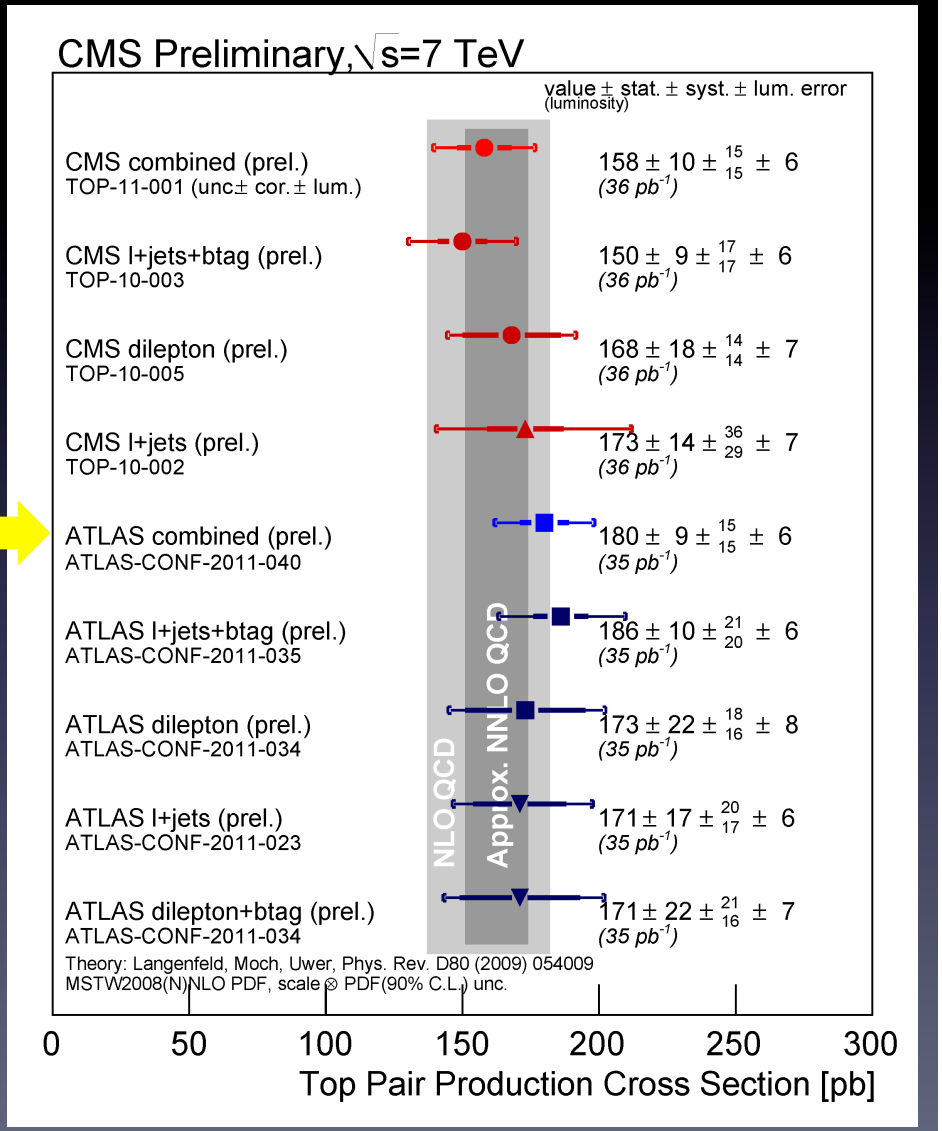
Binned likelihood fit to the secondary vertex mass in the e/μ+jets

- Combine e/μ channels

σ_{tt} combination @ LHC

- Combined dilepton (w/o btag) and single lepton (btag) channels
  - extend 3 channels to 5 channels
  - choose most precise: l+jets with b-tag, dilepton w/o b-tag

δσ = 10%

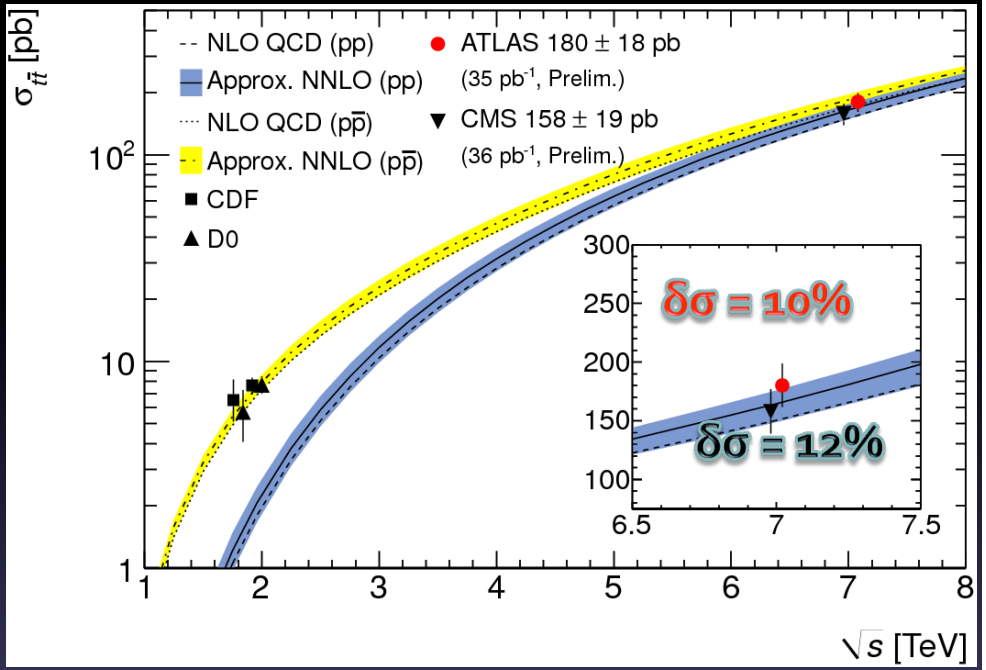


- Statistical uncertainty ~4%
- Systematic uncertainty ~8%
- Luminosity uncertainty ~3%
- Agrees with QCD prediction

SM : 165^{+11}_{-16} pb

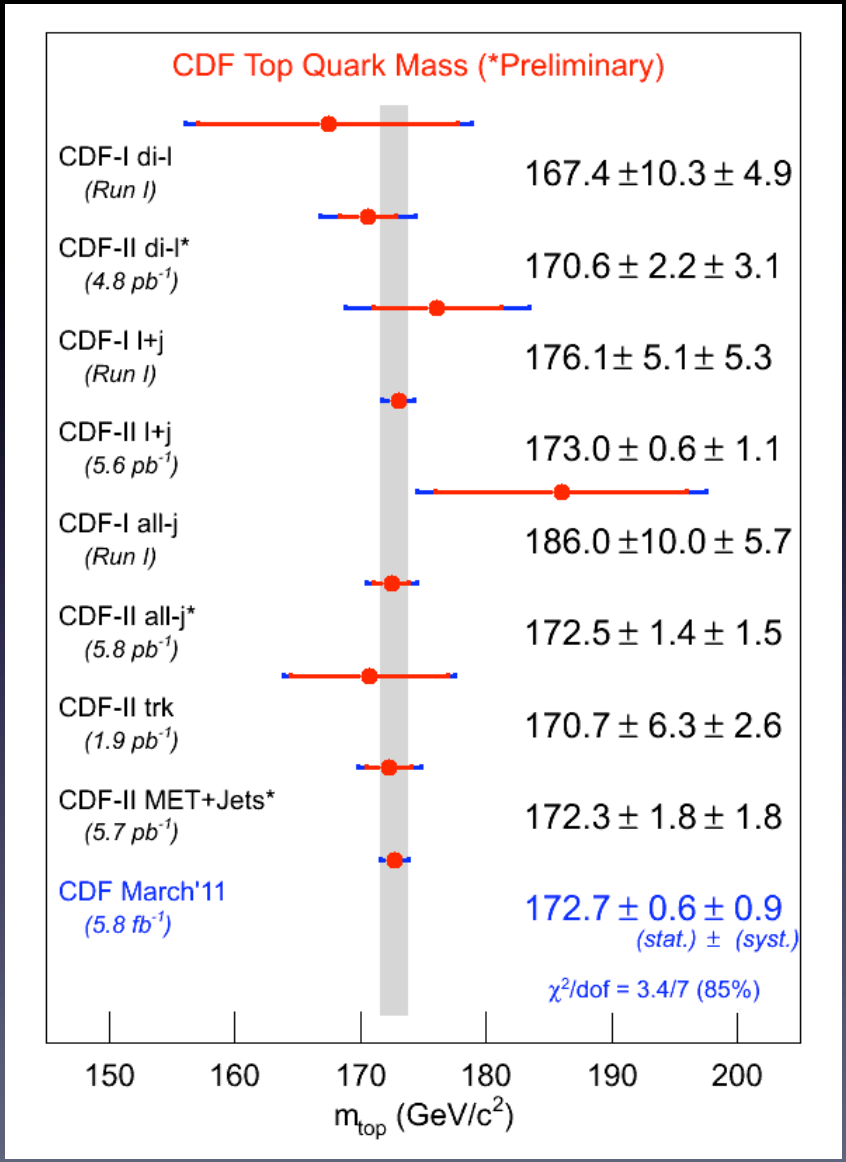
σ_{tt} @ LHC

- The era of top physics at the LHC has just started
  - with only 35 pb^{-1} can already look into production cross-section, mass, single-top and several properties
  - competitive measurements are emerging



- **Statistics limited analysis will become attractive this year**
  - **anticipate ~0.7 fb^{-1} by Summer and >2 fb^{-1} by the end of the year**
- **Focus to reduce systematics**
  - **improve detector understanding; use advanced analysis techniques**

M_{top}@ Tevatron



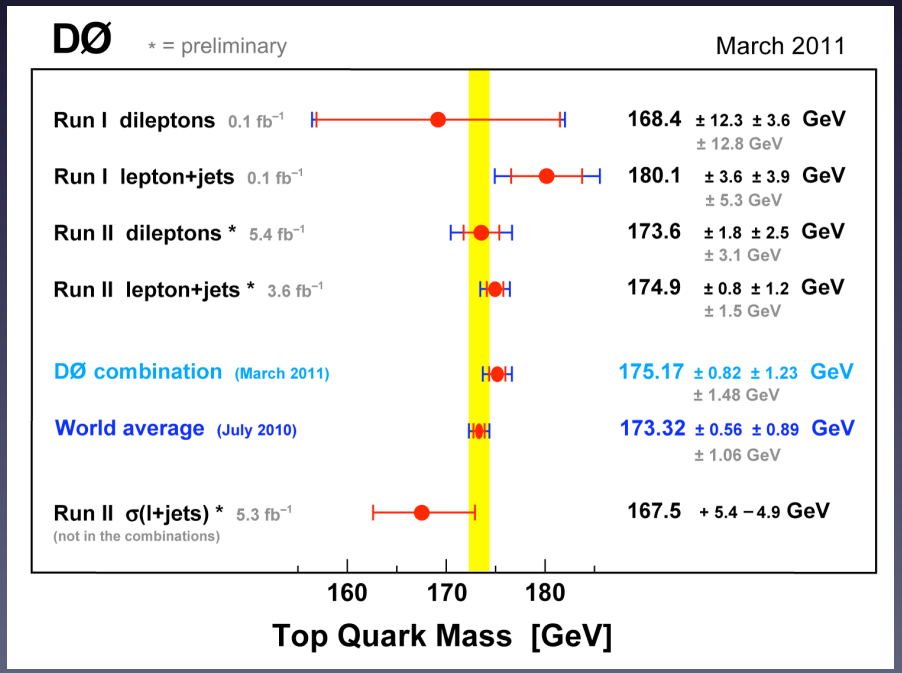
World average = 173.3±1.1 GeV/c2

~0.61 % Precision

Average is to be updated:

CDF all-had, CDF MET+jets (brand new)

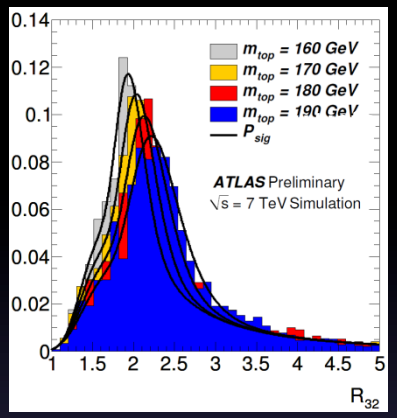
Do l+jets,Do di-lepton are improved!!



M_{top} @ LHC

ATLAS-CONF-2011-033

μ+jets

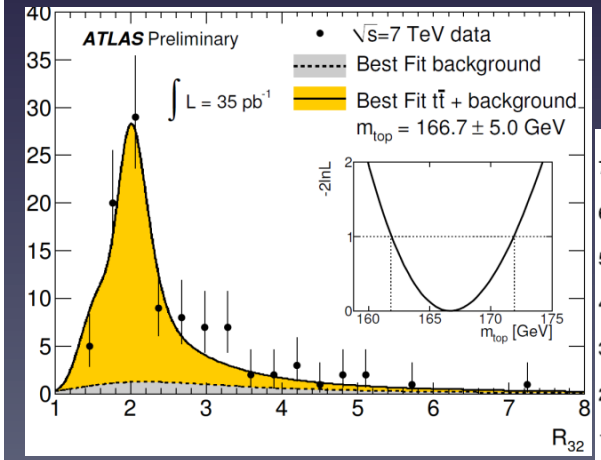


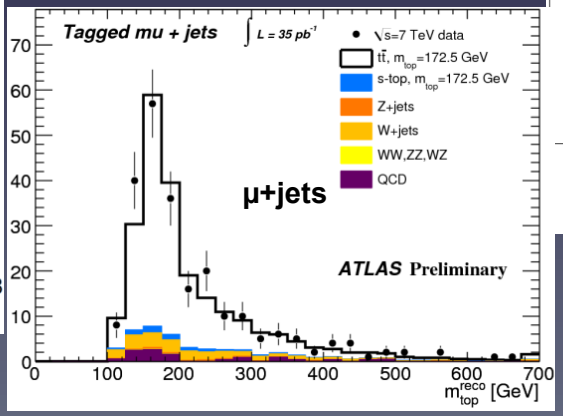
- Single lepton channel (e+ μ)
- Template in $R_{32} = m_{jjb}(t) / m_{jj}(W)$

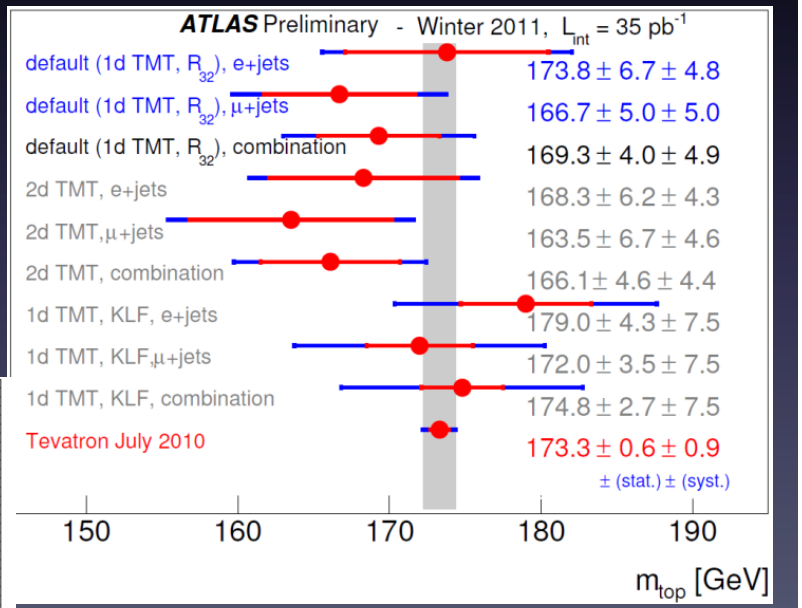
$m_{top} = 169.3 \pm 4.0(stat) \pm 4.9(syst)$ GeV

- Systematics: JES , ISR/FSR
- Cross-checked by
  - kinematic fit templates
  - 2d templates with Jet Scaling Factor

μ+jets

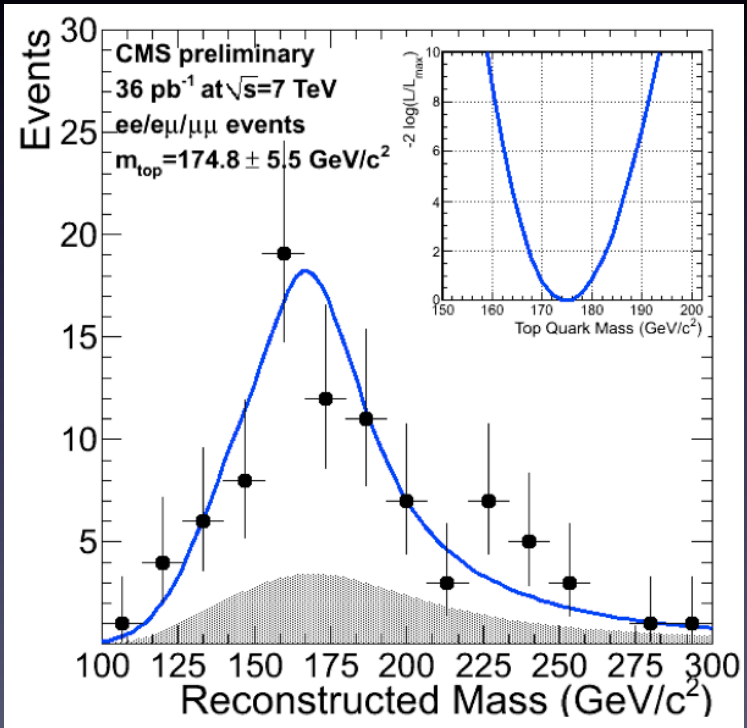


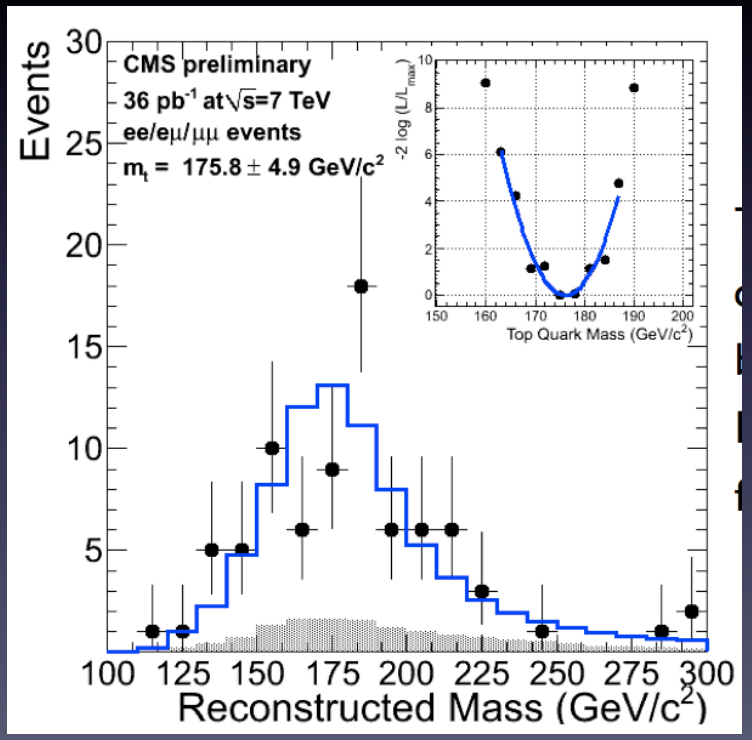




M_{top} @ LHC

- Also studied the **dilepton channel**
- Two analysis techniques based on template fits: fully kinematic analysis (left) and analytical matrix weighting technique (AMWT, right)





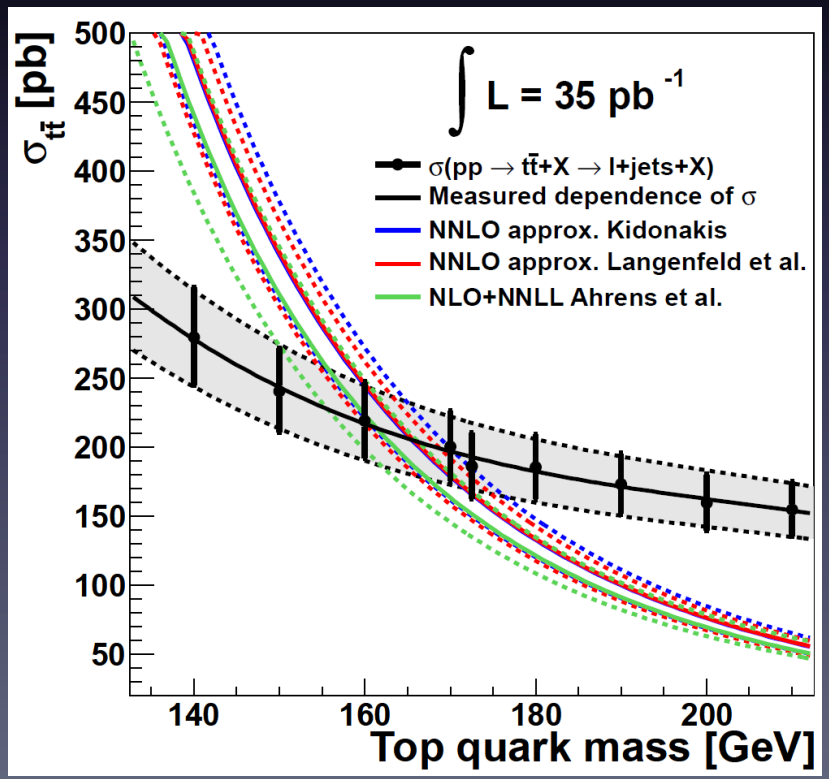
CMS-PAS TOP-10-006

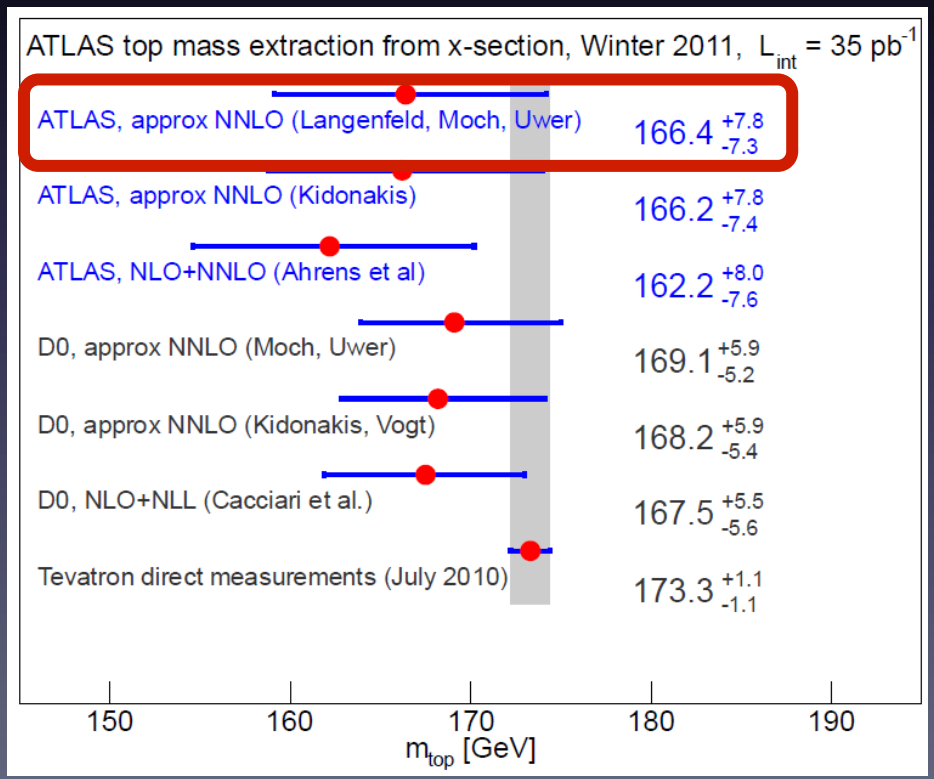
m_{top} = 175.5 ± 4.6 (stat) ± 4.6 (syst) GeV/c²

M_{top} from σ_{tt} @ LHC

ATLAS-CONF-2011-054

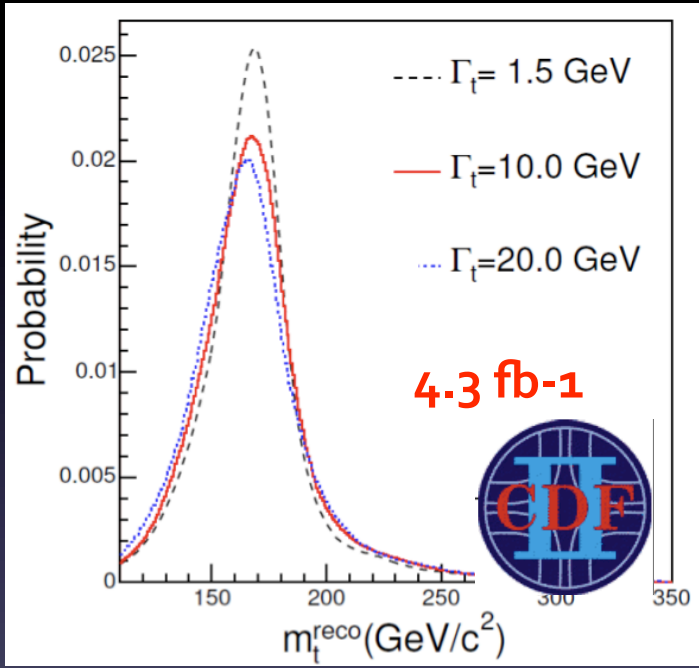
- Use single-lepton with b-tagging cross-section
- Assume constant relative systematic uncertainties
  - verified for 140 and 210 GeV
- Compare with mass-dependent prediction from calculations: extract pole mass





Top width @ Tevatron

Direct measurement



Use recontructed Mt shape

$\Gamma_{top} < 7.4$ GeV @ 95% C.L.
$0.3 < \Gamma_{top} < 4.4$ GeV @ 68% C.L.

PRL 105 (2010) 232003

Indirect measurement

Single top t-channel x-sec
2.3 fb-1

$$\Gamma_t = \frac{\sigma(t-ch)}{Br(t \to bW)} \cdot \frac{\Gamma(t \to bW)_{SM}}{\sigma(t-ch)_{SM}}$$

$\Gamma_{top} = 1.99^{+0.65}_{-0.55}$ GeV
$\tau_{top} = 3.3^{+1.3}_{-0.9} \cdot 10^{-25}$ sec

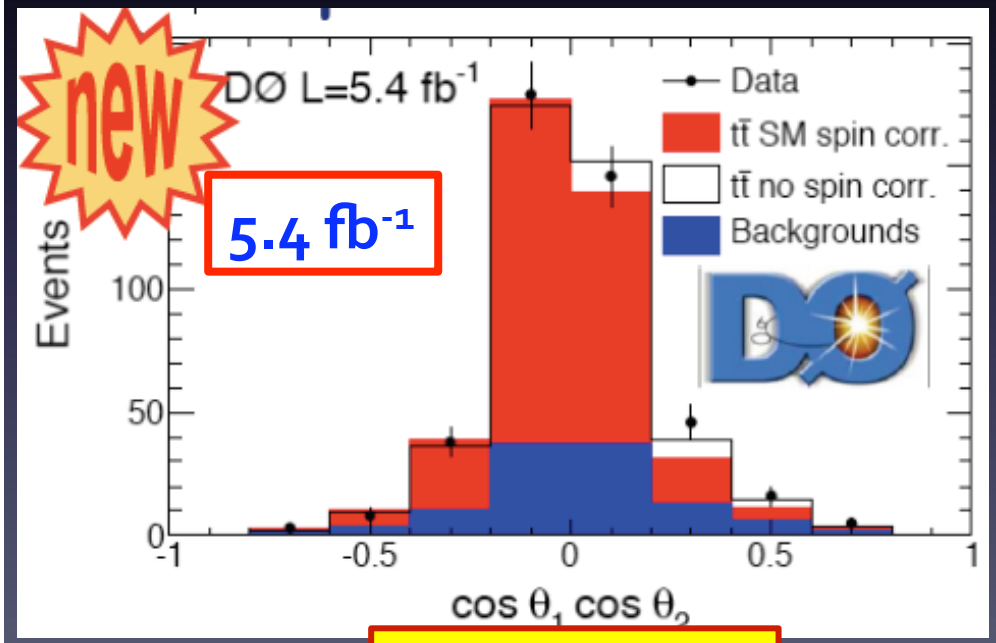
PRL 106 (2010) 022001

In the SM:
$\Gamma_{top} = 1.3$ GeV
@ $M_{tt} = 172.5$ GeV/c^2

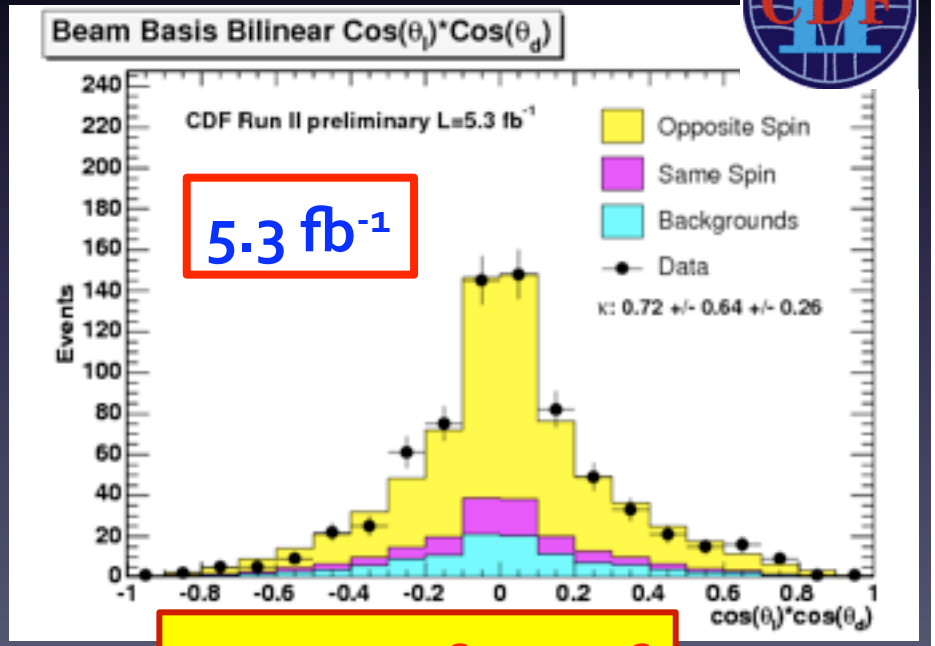
Spin correlation @ Tevatron

Top decays before hadronization – spin information goes to decay products

$$\textbf{SM prediction } \kappa = \frac{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} - N_{\uparrow\downarrow} - N_{\downarrow\uparrow}}{N_{\uparrow\uparrow} + N_{\downarrow\downarrow} + N_{\uparrow\downarrow} + N_{\downarrow\uparrow}} \approx 0.78$$



$K=0.10^{+0.45}_{-0.45}$



$K=0.72\pm0.64\pm0.26$

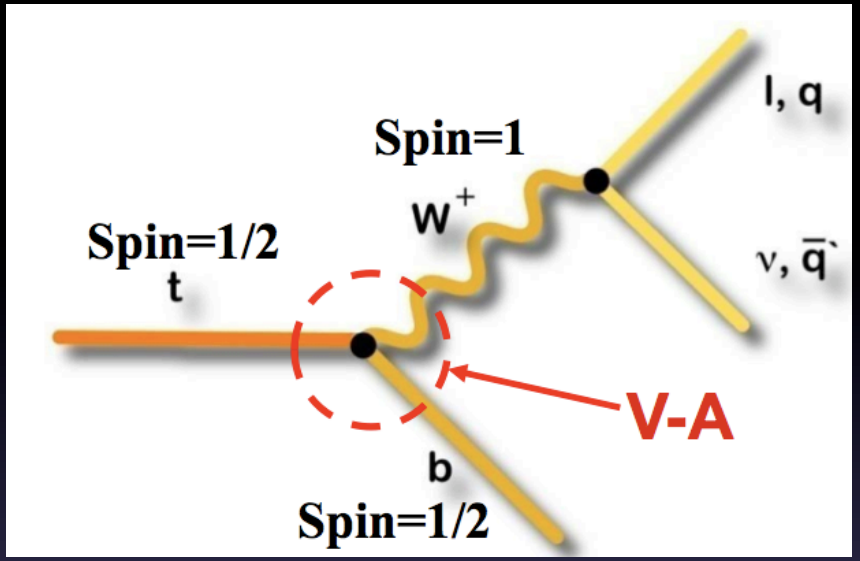
arXiv:1103.1871

CDF Note 10211

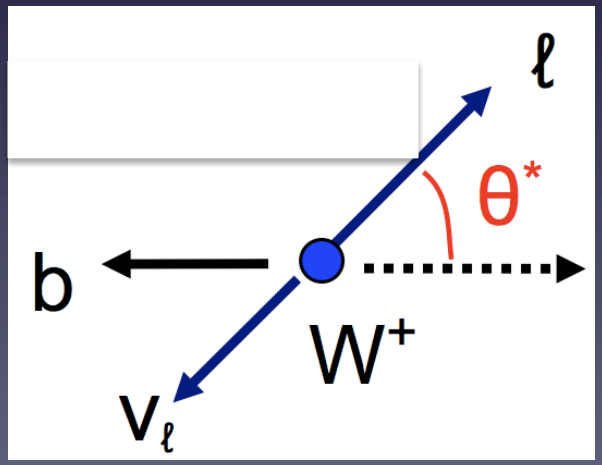
W helicity @ Tevatron

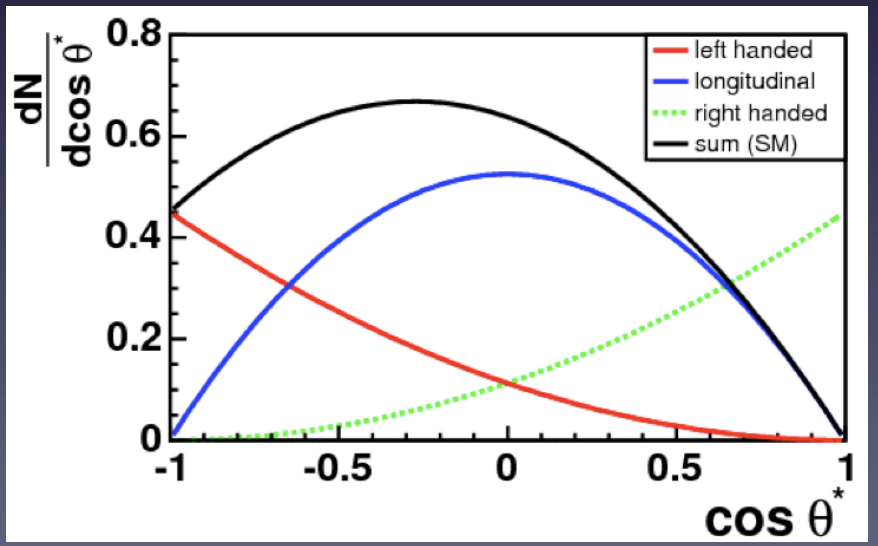
V-A coupling predicts:

f0= 0.7 (long. polarization)
f+= 0 (RH polarization)
f-= 0.3 (LH polarization)

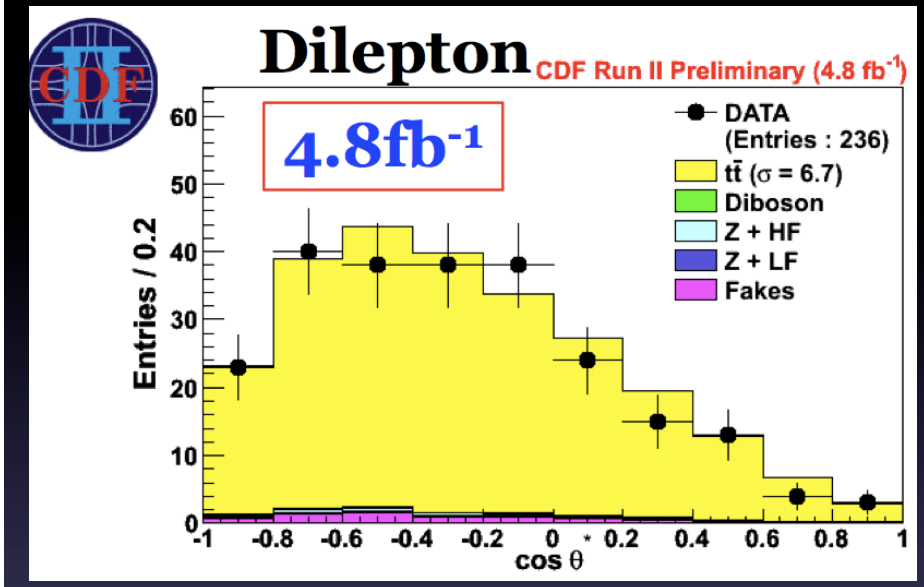


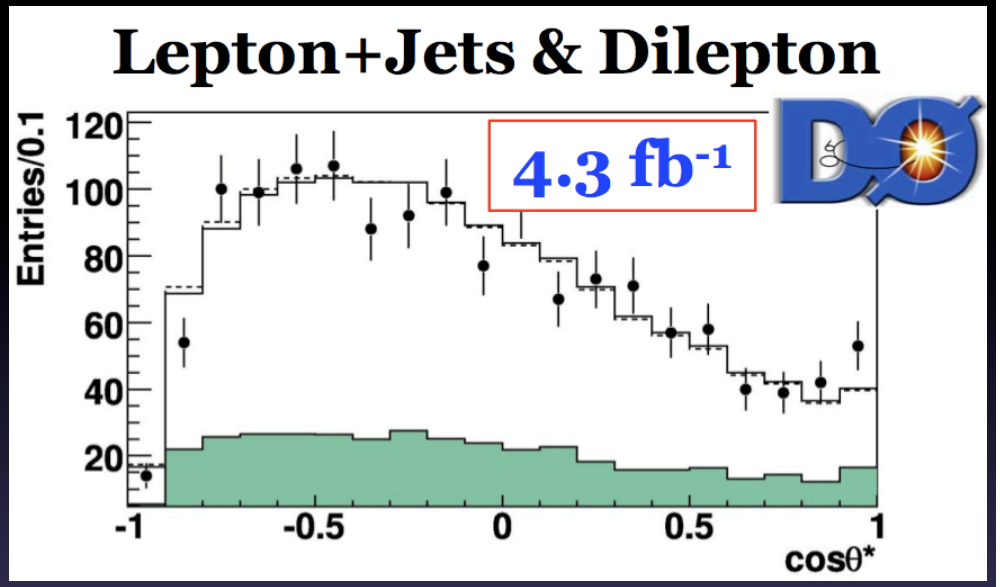
Measuring the W long polarization





W helicity @ Tevatron





$f_+ = -0.12^{+0.12}_{-0.1}$
$f_0 = 0.78^{+0.20}_{-0.21}$

$f_+ = 0.02 \pm 0.05$
$f_0 = 0.67 \pm 0.10$

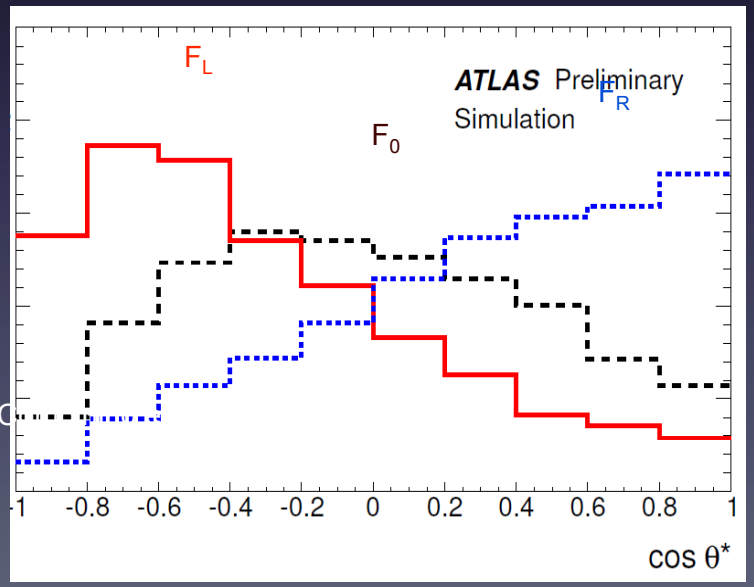
Agreement with SM prediction

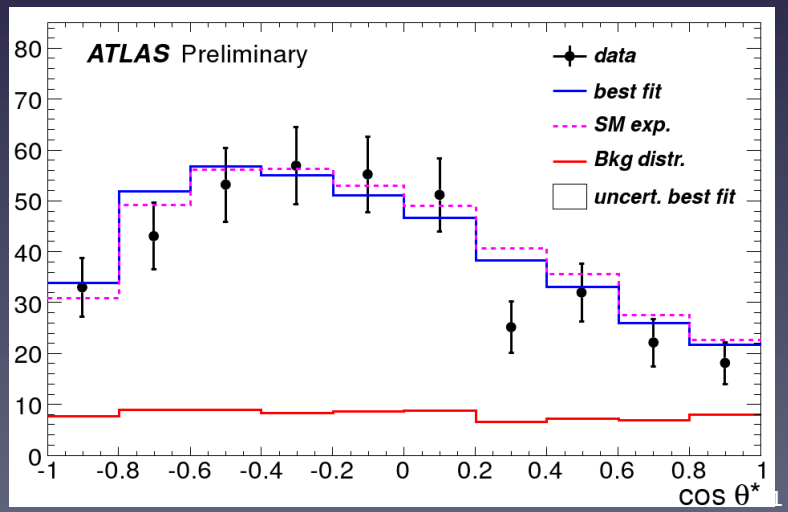
W helicity @ LHC

- Can extract directly from cos θ* or unfold and calculate asymmetry
- Use e+jets and μ+jets channels

ATLAS-CONF-2011-037

	Template method	Asymmetry method
F_L	0.41 ± 0.12	0.36 ± 0.10
F_0	0.59 ± 0.12	0.65 ± 0.15
F_R	Fixed 0	-0.01 ± 0.07





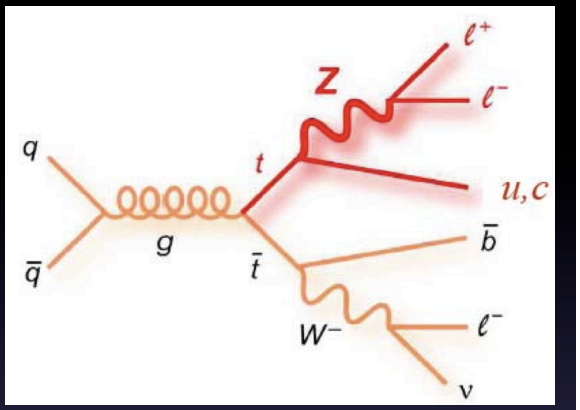
W helicity @ LHC (prospects)

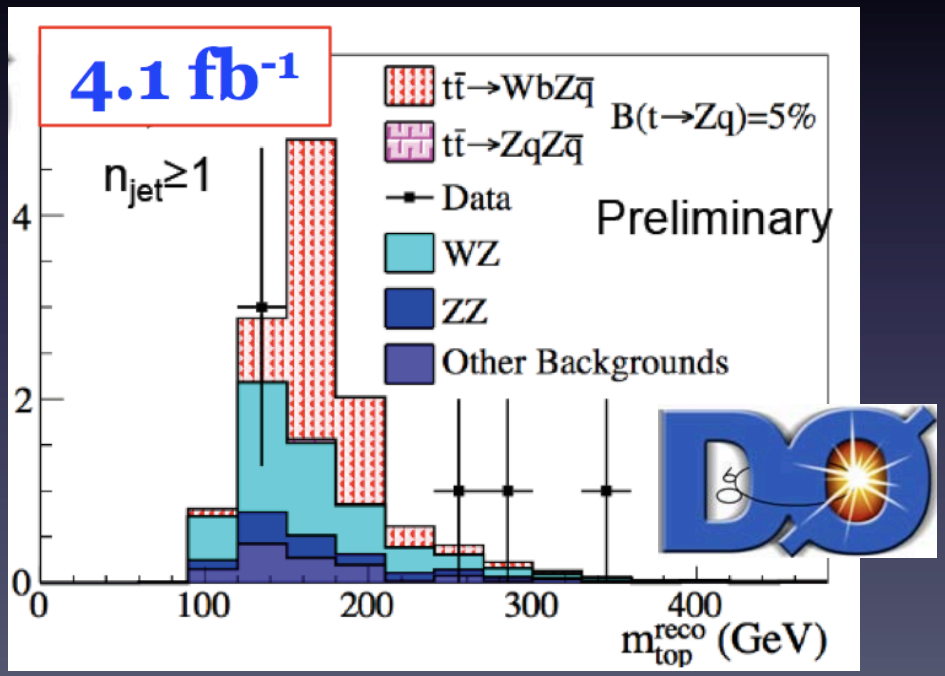
- For L = 0.7 fb^{-1}, $\sqrt{s}$ = 7 TeV, 3500 events in each of the l+jet channel
- Dominant uncertainties : hadronization scheme M_{top}, ISR/FSR.
- Systematics assumed to be the same for both luminosity scenarios.
- W helicity measurement would benefit from increased L

Quantity	Stat. ($\int \mathscr{L} = 1$ fb^{-1})	Stat. ($\int \mathscr{L} = 5$ fb^{-1})	Syst.
e+jets channel:			
f_L	0.03	0.01	0.03
f_0	0.06	0.03	0.02
f_R	0.03	0.01	0.02
μ+jets channel:			
f_L	0.03	0.01	0.03
f_0	0.05	0.02	0.02
f_R	0.03	0.01	0.02

FCNC @ Tevatron

- Top FCNC extremely small in SM ($O(10^{-14})$)
- Beyond SM: up to $O(10^{-4})$
- Any signal = new physics





Br (t->Zq) < 3.3% @ 95% CL

CDF II

1.9 fb-1

- Two lepton channel
- Hadronic decay W

Br (t->Zq) < 3.7% @ 95% CL

PRL 101 (2008) 192002

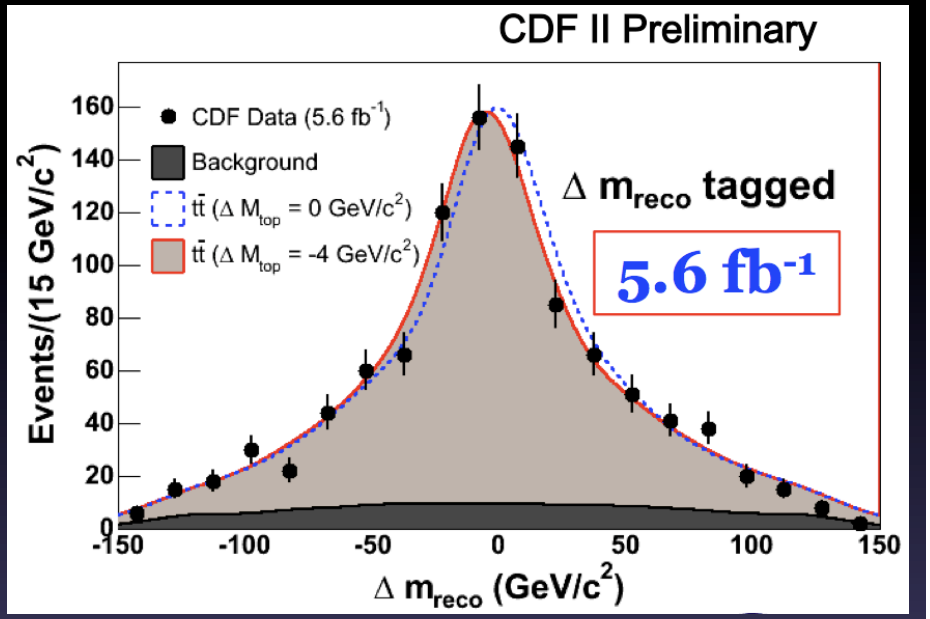
FCNC @ LHC (prospects)

- Expected BR limits from MC at $\sqrt{s}$ = 14 TeV and an integrated luminosity of 1 fb^{-1} , better than current Tevatron limits.
- Simplified model: signal and background cross-sections reduced by a factor of 5 for 7 TeV, the limits will be unchanged for 5 fb^{-1} compared to the numbers for 14 TeV and 1 fb^{-1} (if a discovery is not made).

Quantity	Limit ($\int \mathscr{L} = 1\ \mathrm{fb}^{-1}$)	($\int \mathscr{L} = 5\ \mathrm{fb}^{-1}$)
$BR(\bar{t}t \to bWq\gamma)$	$1.5 \cdot 10^{-3}$	$6.8 \cdot 10^{-4}$
$BR(\bar{t}t \to bWqZ)$	$6.3 \cdot 10^{-3}$	$2.8 \cdot 10^{-3}$
$BR(\bar{t}t \to bWqg)$	$2.7 \cdot 10^{-2}$	$1.2 \cdot 10^{-2}$

ΔM_{top} @ Tevatron

- If CPT is conserved, no ΔM_{top} (SM)
- Break assumption, measure ΔM_{top}
- Similar to M_{top} measurements



Lepton + jets
3.6 fb^{-1}
Matrix element technique

Δm_{top} = 0.8 ± 1.8(stat) ± 0.8(syst) GeVc^2

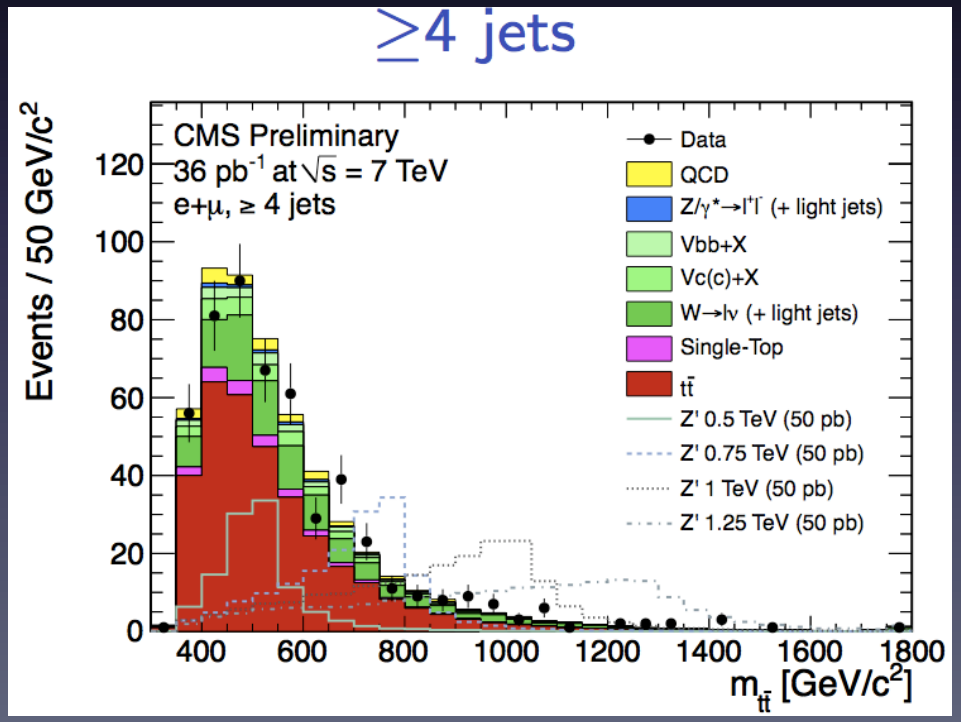
Lepton + jets
Template based technique

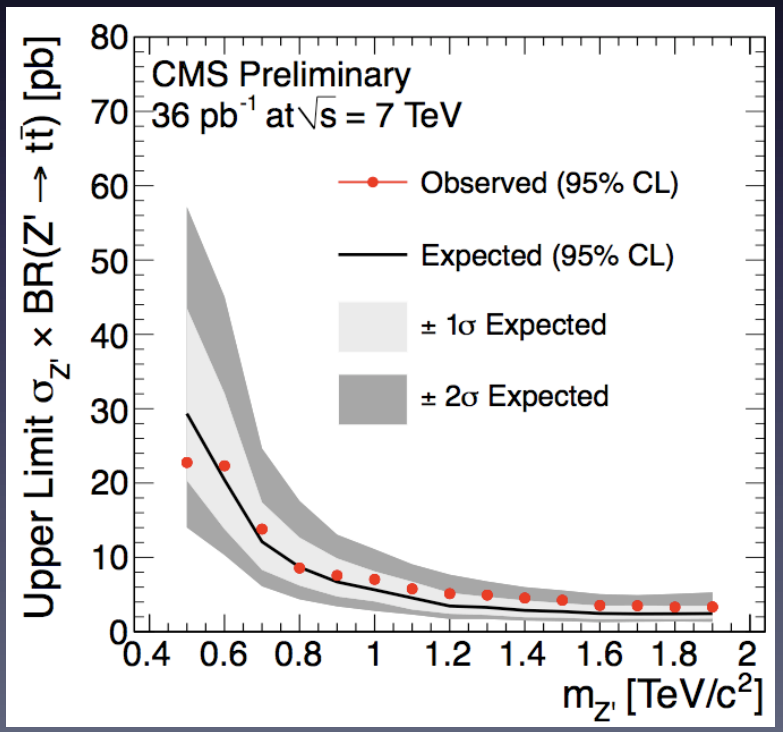
Δm_{top} = -3.3 ± 1.4 (stat) ± 1.0 (sys) =
= -3.3 ± 1.7 GeV/c^2

M_{ttbar} @ LHC

CMS-PASTOP-10-007

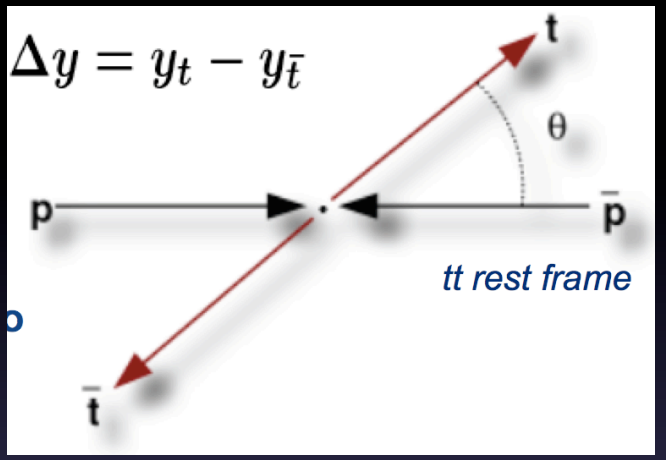
- Search for massive neutral bosons decaying in top pairs
- Narrow topcolor leptophobic resonance excluded for masses < 800 GeV/c^2.
- No significant signal observed in the e/μ + jets channel
- Upper limits on the production cross sec vs the boson mass





A_{FB} @ Tevatron

- In leading order QCD, top production symmetric
- NLO QCD predicts small asymmetry
  - AFB about 5%
- New physics can give rise to a larger asymmetry (Z', W'. axigluons, technicolours…)

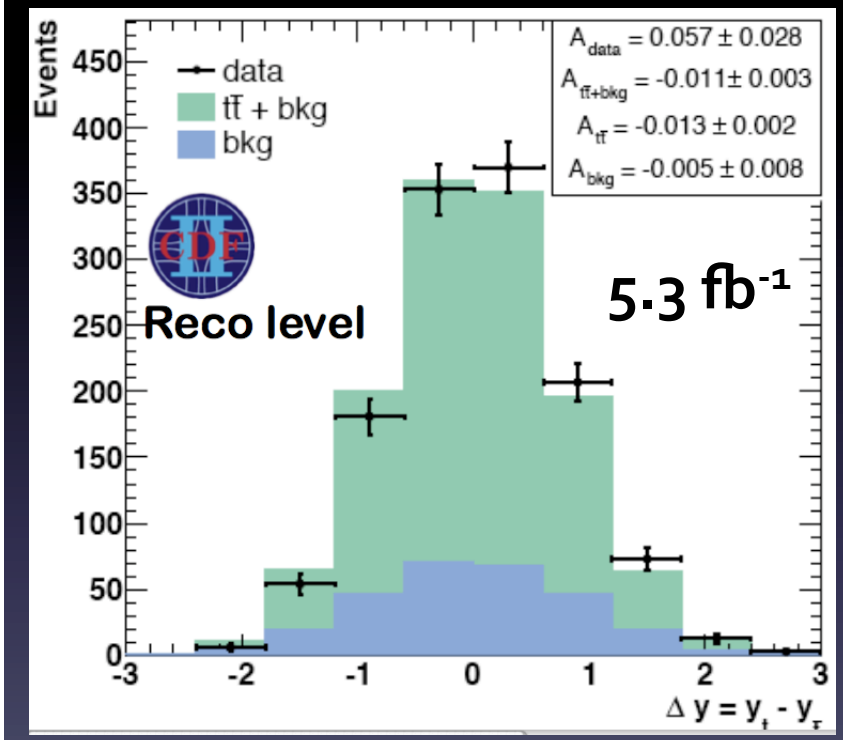


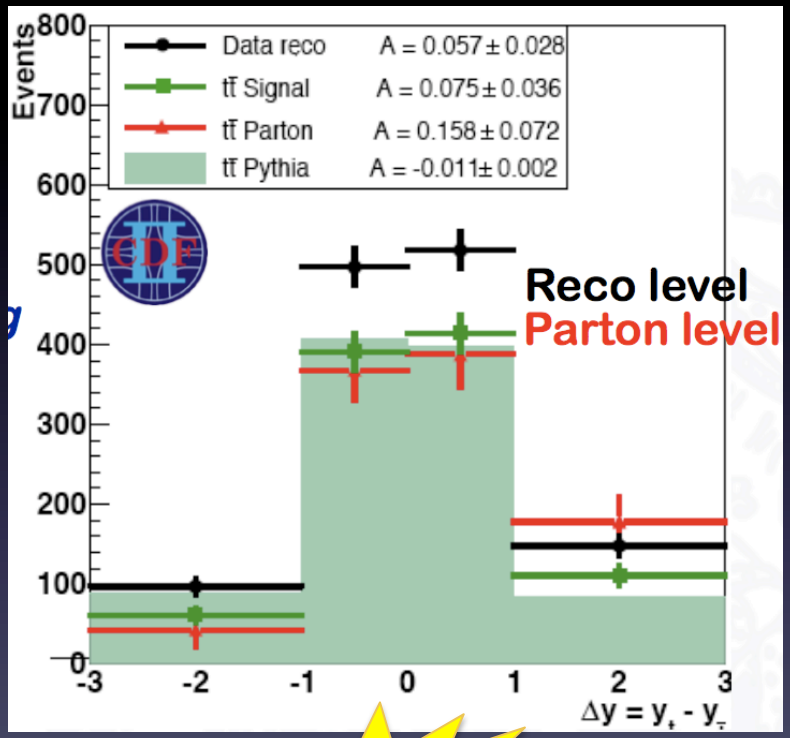
$$A_{FB} = \frac{N_{\cos\Theta>0} - N_{\cos\Theta<0}}{N_{\cos\Theta>0} + N_{\cos\Theta<0}} = \frac{N_{\Delta Y>0} - N_{\Delta Y<0}}{N_{\Delta Y>0} + N_{\Delta Y<0}}$$

A_{FB} @ Tevatron

hep-ex/1101.0034

Lepton + jets



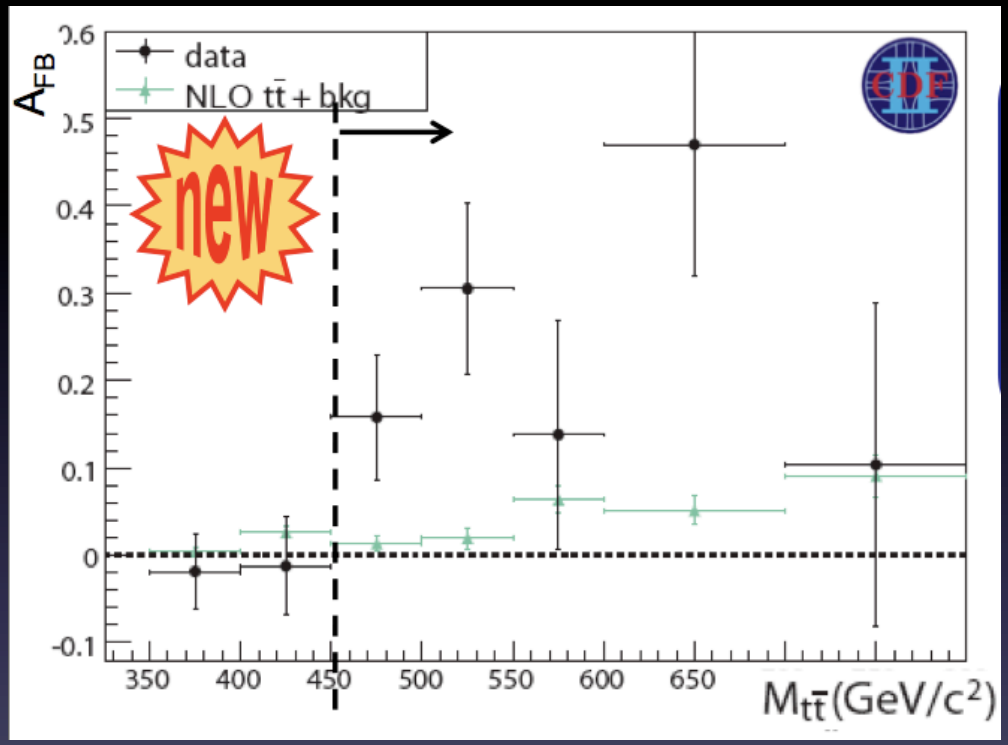


A_{FB} (MC) = 0.058 ± 0.009

A_{FB}(Data) = 0.158 ± 0.074

1.5 σ

A_{FB} @ Tevatron

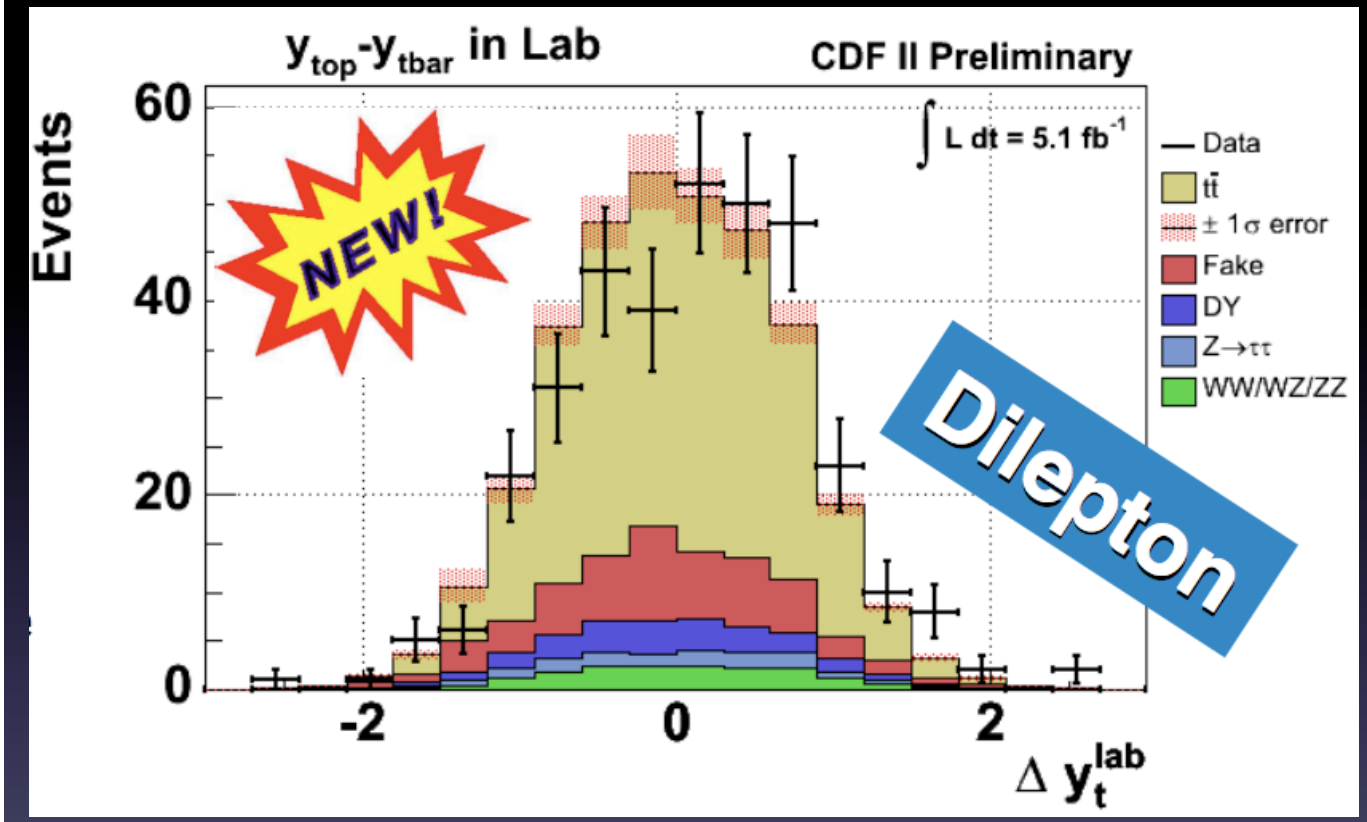


- Look at AFB vs Mtt: study of Q dependence probes better NLO QCD computations. Also, more sensitive to new physics
- New physics? Or SM?
- See talk from Aguilar-Saavedra

>3 σ

selection	$M_{t\bar{t}} < 450$ GeV/c^2	$M_{t\bar{t}} \geq 450$ GeV/c^2
data parton	$-0.116 \pm 0.146 \pm 0.047$	$0.475 \pm 0.101 \pm 0.049$
MCFM	$+0.040 \pm 0.006$	0.088 ± 0.013

A_{FB} @ Tevatron



A_{FB} (MC) = 5.0± 1.5%

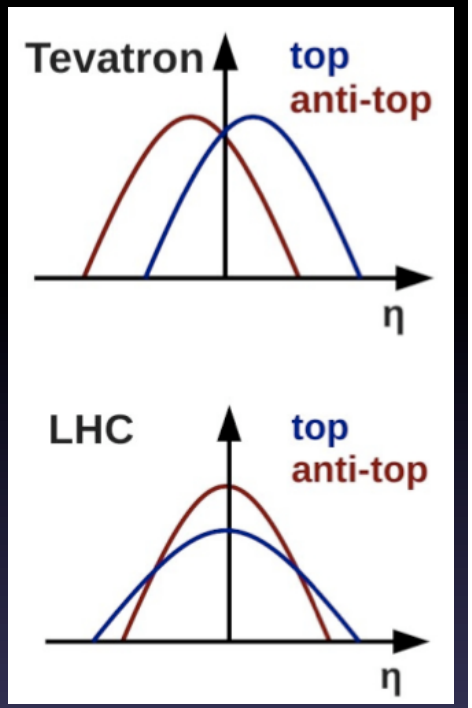
A_{FB}(Data) = 42 ± 16%

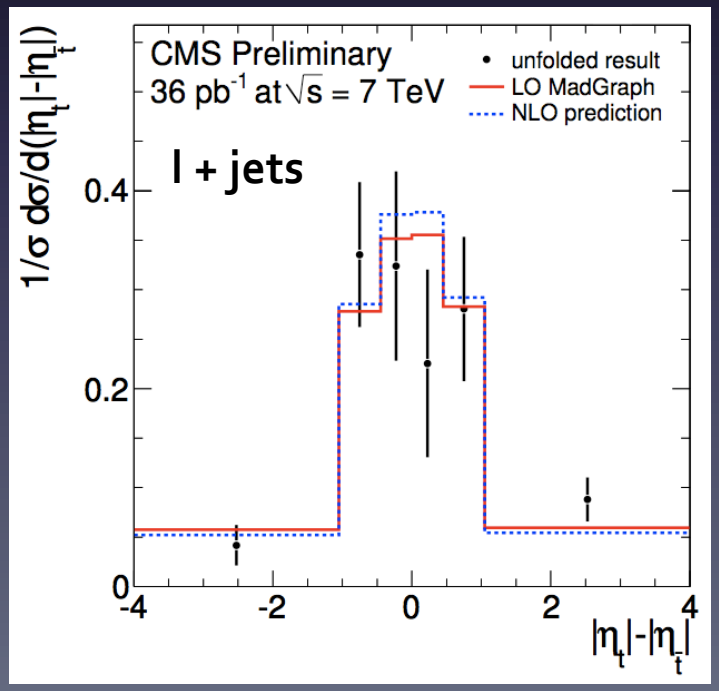
2.3 σ

A_c @ LHC

CMS-PASTOP-10-010

- At Tevatron deviation > 3 σ from SM predicted A_{FB} 5%
- At LHC: Initial state symmetric -> charge asymmetry visible in $|\eta_t| - |\eta_{tbar}|$
- Expected asymmetry small A_c = 0.0130(11) [Ferrario et al.]
- L ≥ 1 fb^{-1} needed to compete with Tevatron



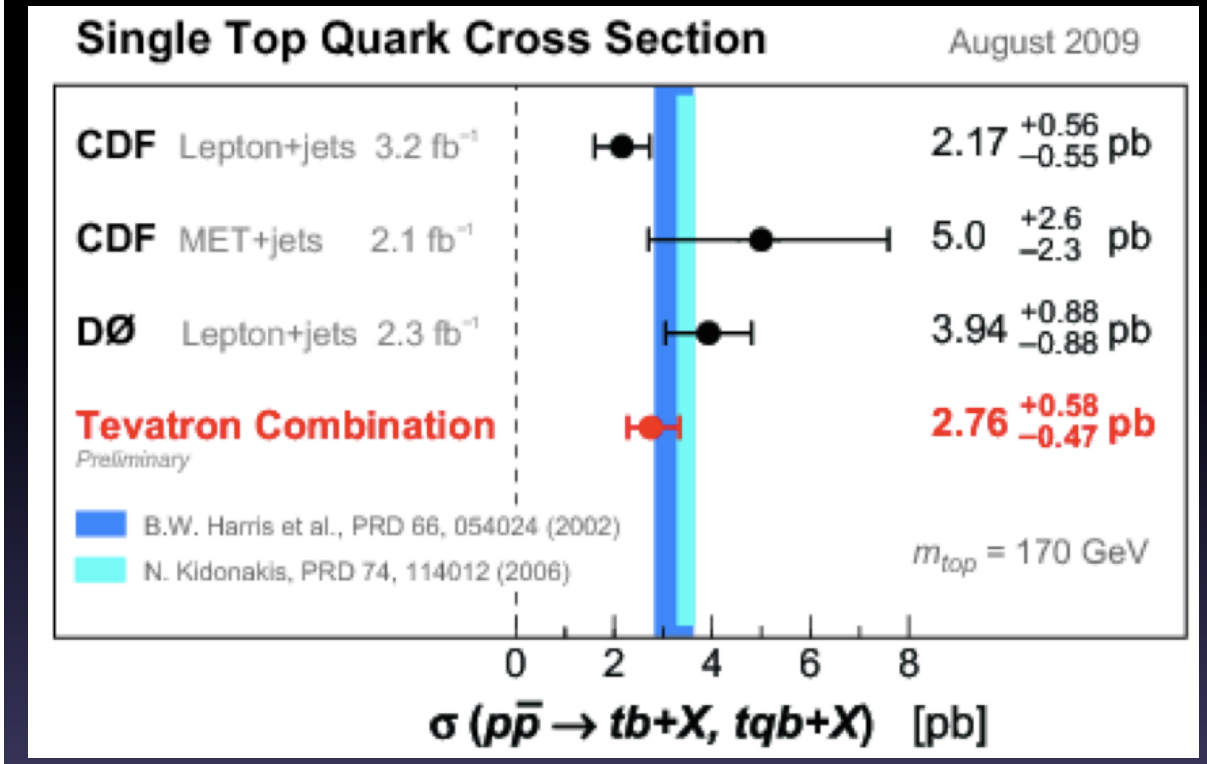


$A_c = (N^+ - N^-)/(N^+ + N^-)$

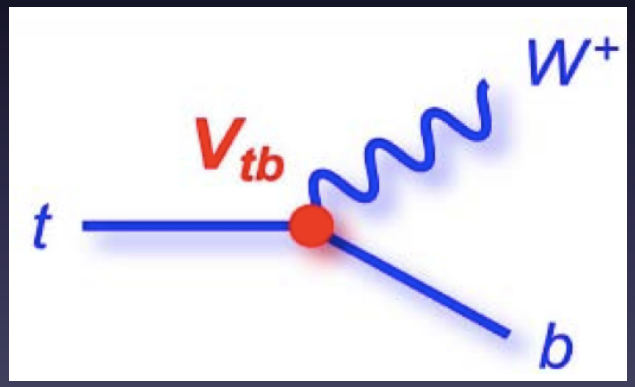
$N^+ = |\eta_t| - |\eta_{tbar}| > 0$

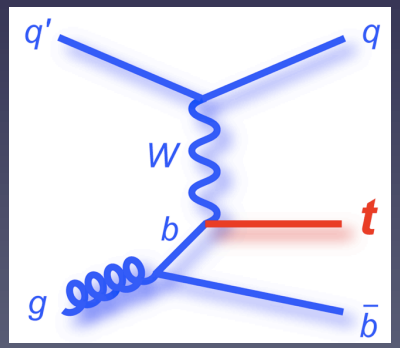
$A_C = 0.060 \pm 0.134(stat.) \pm 0.026(syst.)$

Single top @ Tevatron

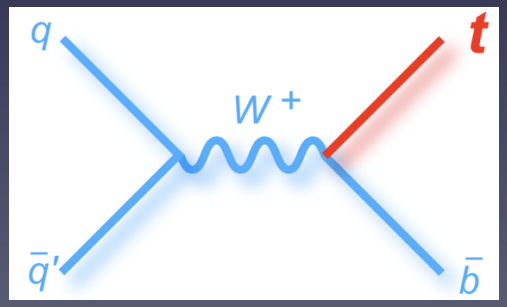


In 2009 first observation





t channel~1 pb



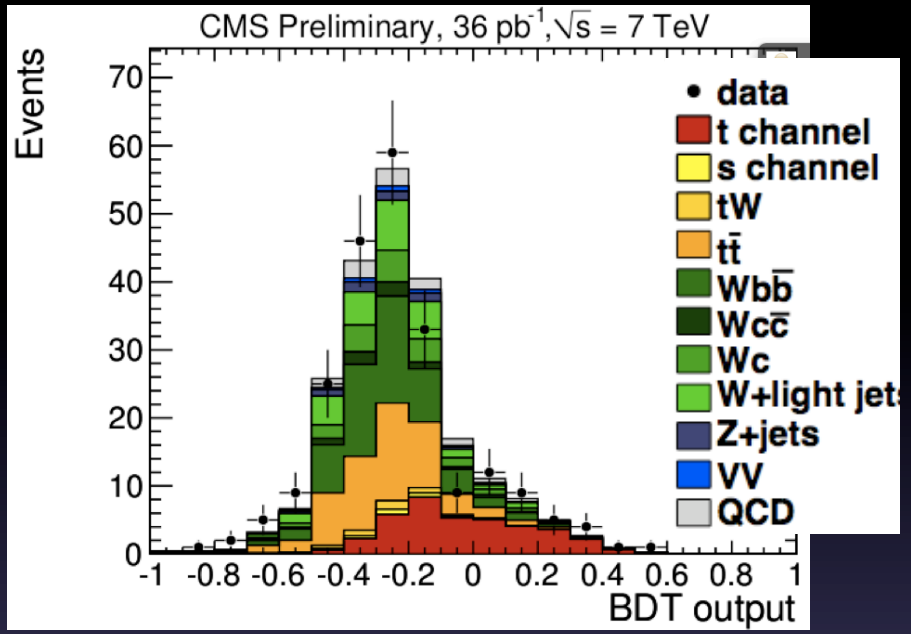
s channel~1 pb

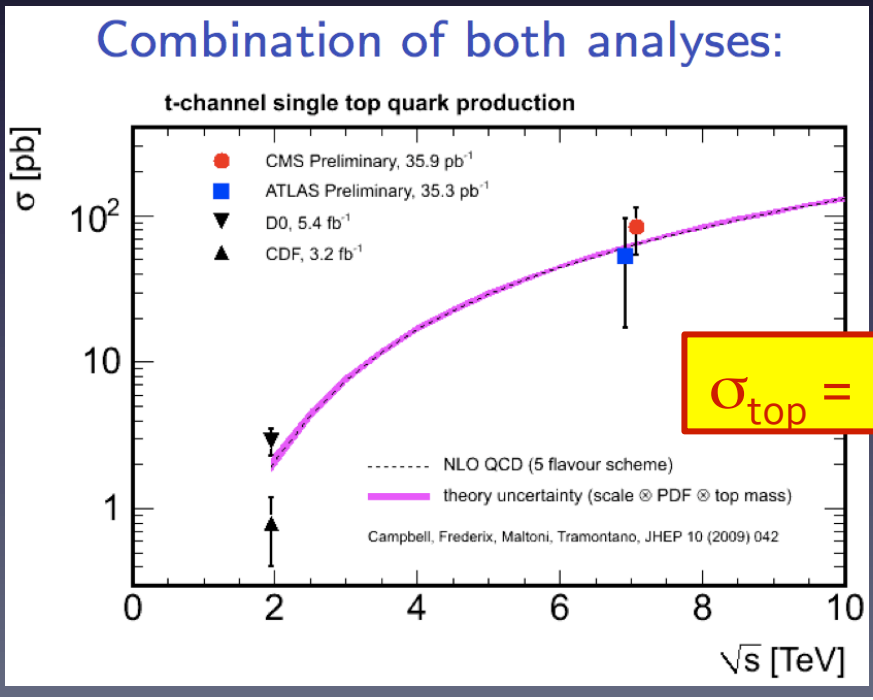
|Vtb| = 0.88 ±0.07
95% C.L. limit : 0.77

Single top @ LHC

- t-channel (66.2 pb)
- Two analyses

A 2D template fit to cos(θ* lj) and |η|j|
A multivariate technique (BDT)





- Both analyses: significance > 3 σ
- Combination

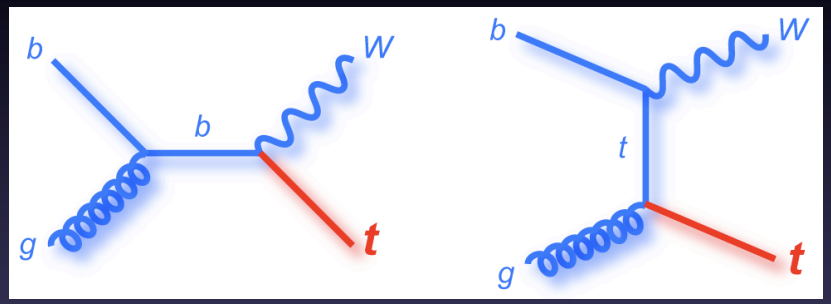
σ_{top} = 83.6 ± 29.8 (stat+syst) ± 3.3 (lum) pb

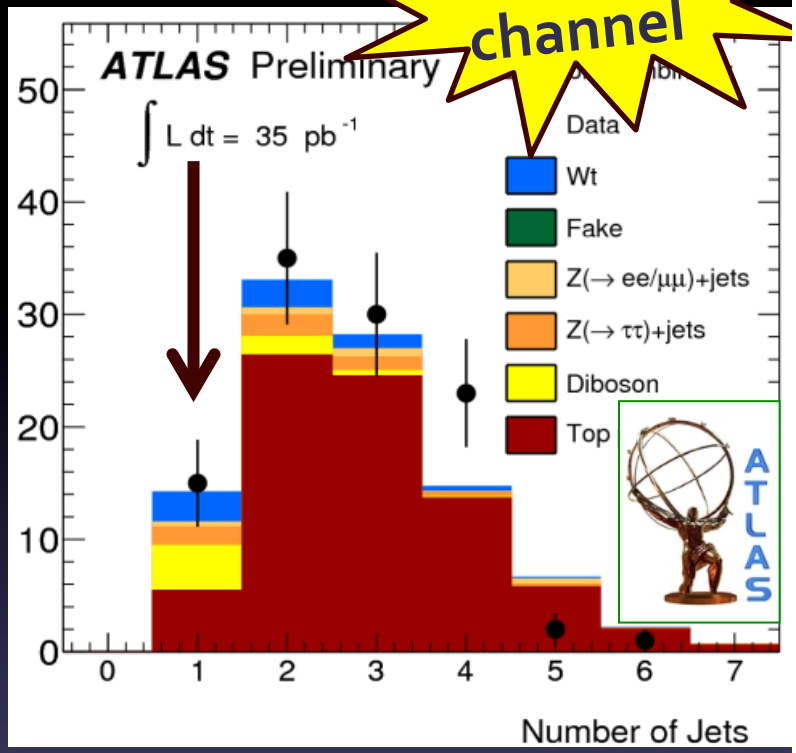
CMS-PAS TOP-10-008

Single top @ LHC

- Wt-channel (14.6 pb): cut-based
  - **l+jets:**
  - **dilepton:**
  - **combine channels, expect $\sigma_{Wt} < 94$ pb**

$\sigma_{Wt} < 158$ pb at 95%





Channel	$\mathscr{A} \times$ BR	$N_t(\int \mathscr{L} = 1\ \mathrm{fb}^{-1})$	$N_t(\int \mathscr{L} = 5\ \mathrm{fb}^{-1})$	S/B
t-ch (CB)	0.47%	310	1550	0.67
t-ch (MVA)	0.22%	150	750	1.13
Wt-ch (CB)	1.32%	190	950	0.08
Wt-ch (MVA)	0.33%	50	250	0.30
s-ch (CB)	0.23%	10	50	0.05
s-ch (MVA)	0.13%	6	30	0.10

6-7 σ
$\Delta\sigma = 13\%$
$\Delta V_{tb} = 7\%$

Conclusions

- **Broad top program at Tevatron**
  - X-sec measured in all possible final states, precision comparable to the theoretical one (7-9%)
  - M_{top} measured with precision < 0.61%
  - Many properties studied
  - Some tension between SM prediction and Tevatron data (A_{FB})
  - About twice the data is available for a closer look!
- **LHC started to explore the top sector**
  - With only 35 pb^{-1} can already look into production cross-section, mass, single-top and several properties
  - Competitive measurements are emerging: cross-section at 10%
  - Next couple of years will be quite interesting!