Status of Top Quark Physics

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Top Quarks at hadron colliders

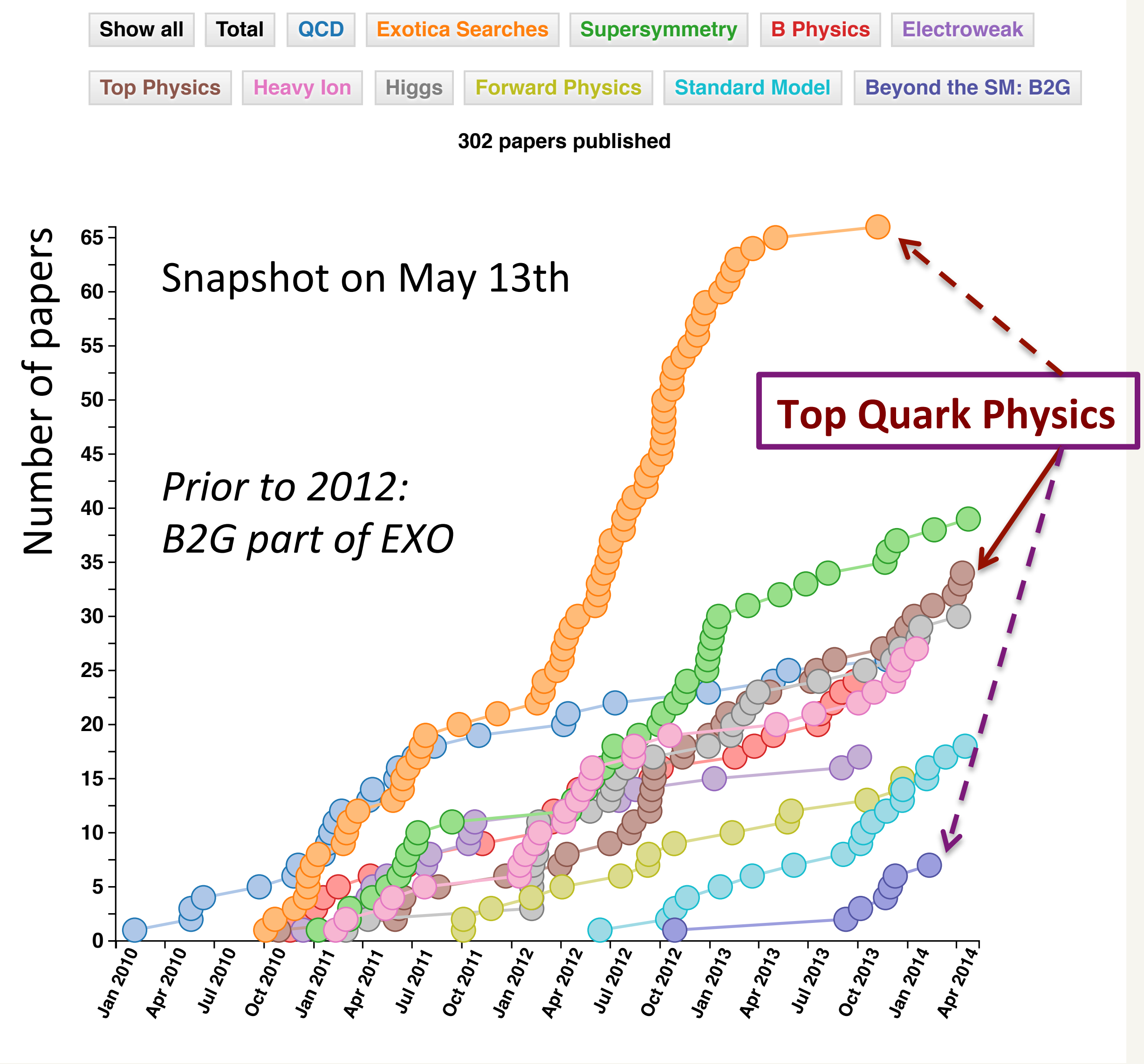
A hot topic at colliders, example from CMS.

Related talks this week:

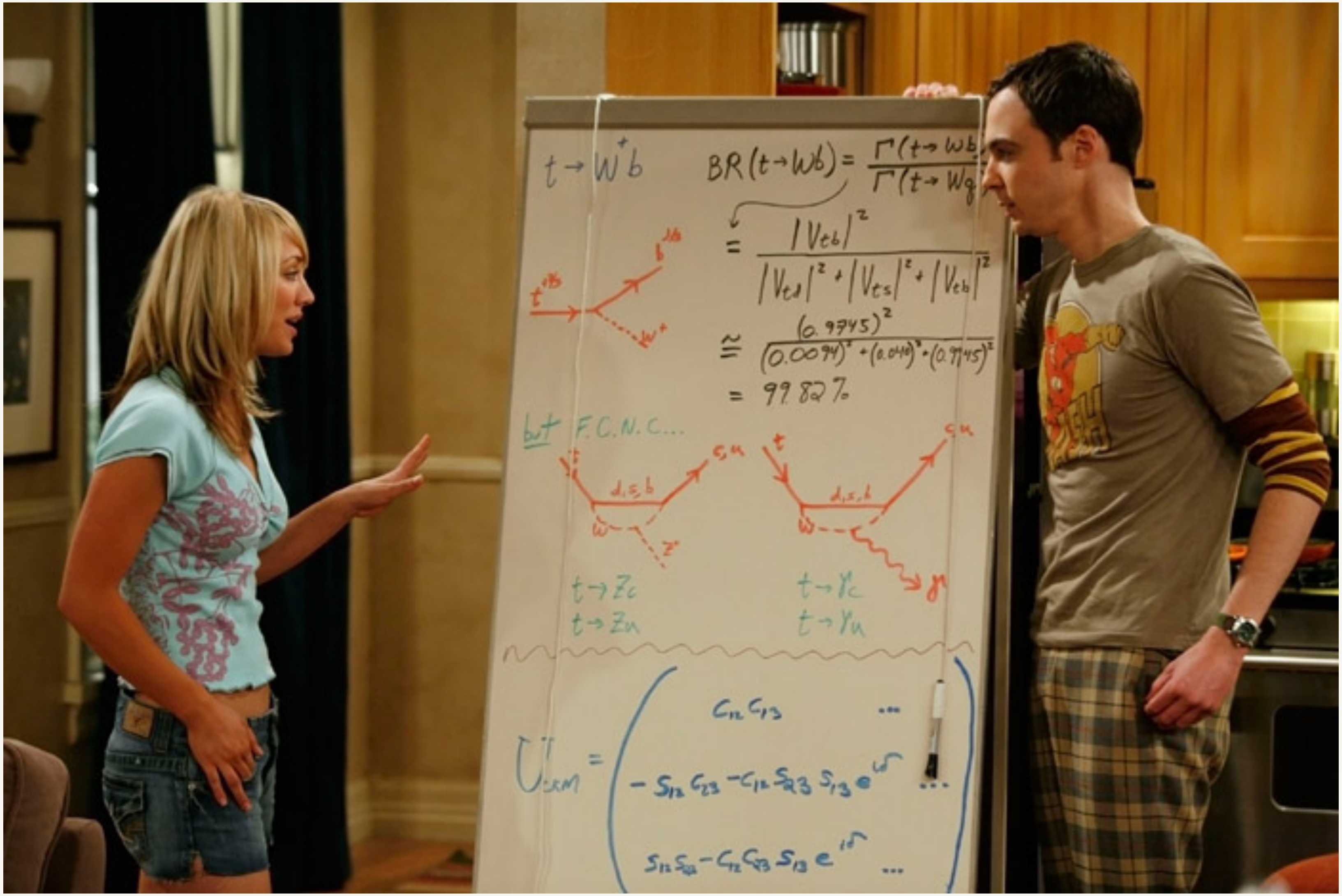
Top Quark Theory – P. Uwer

Searches w. t/b – F. Blekman

9 (!) talks in parallel session

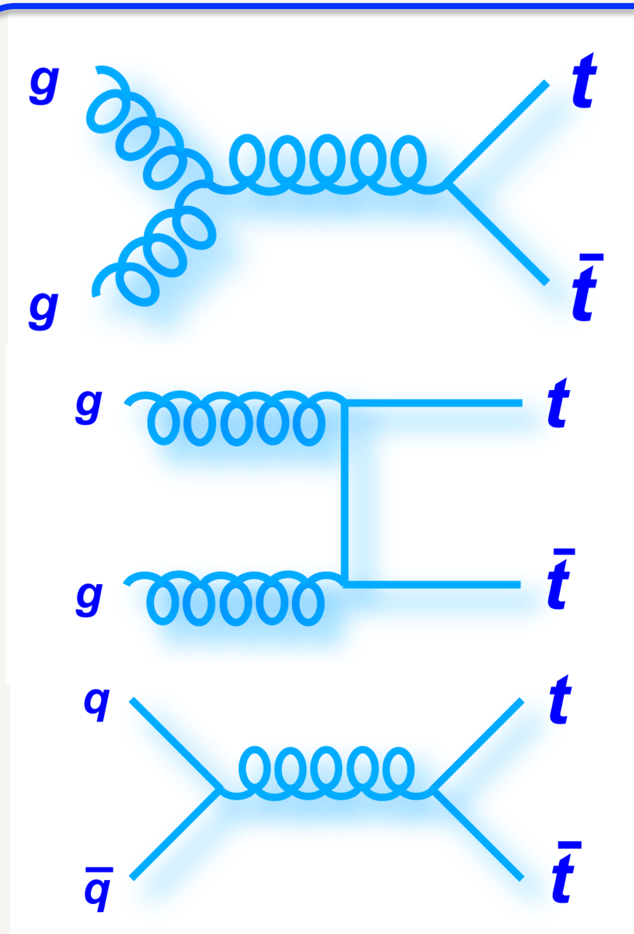


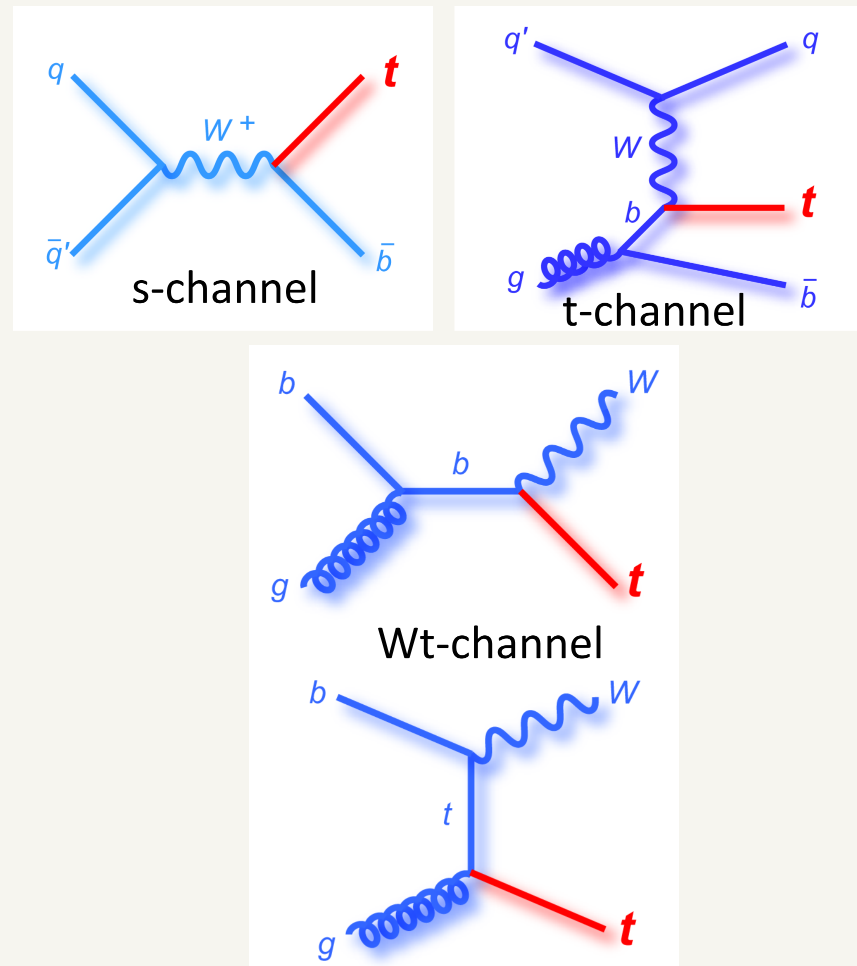
Top Quarks: a hot topic



Top Quarks at hadron colliders

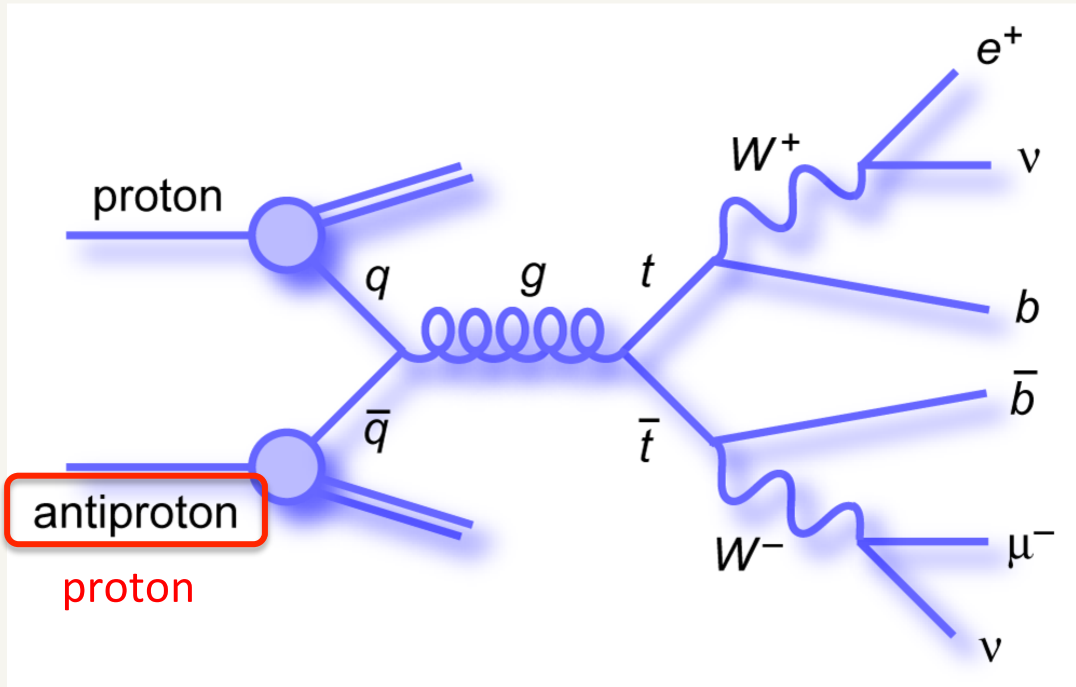
- Both strong and electroweak production

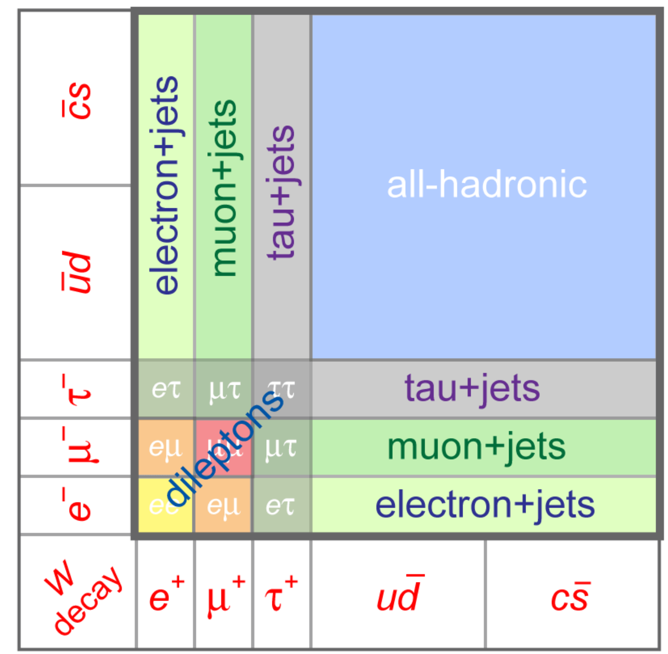




Top Quarks at hadron colliders

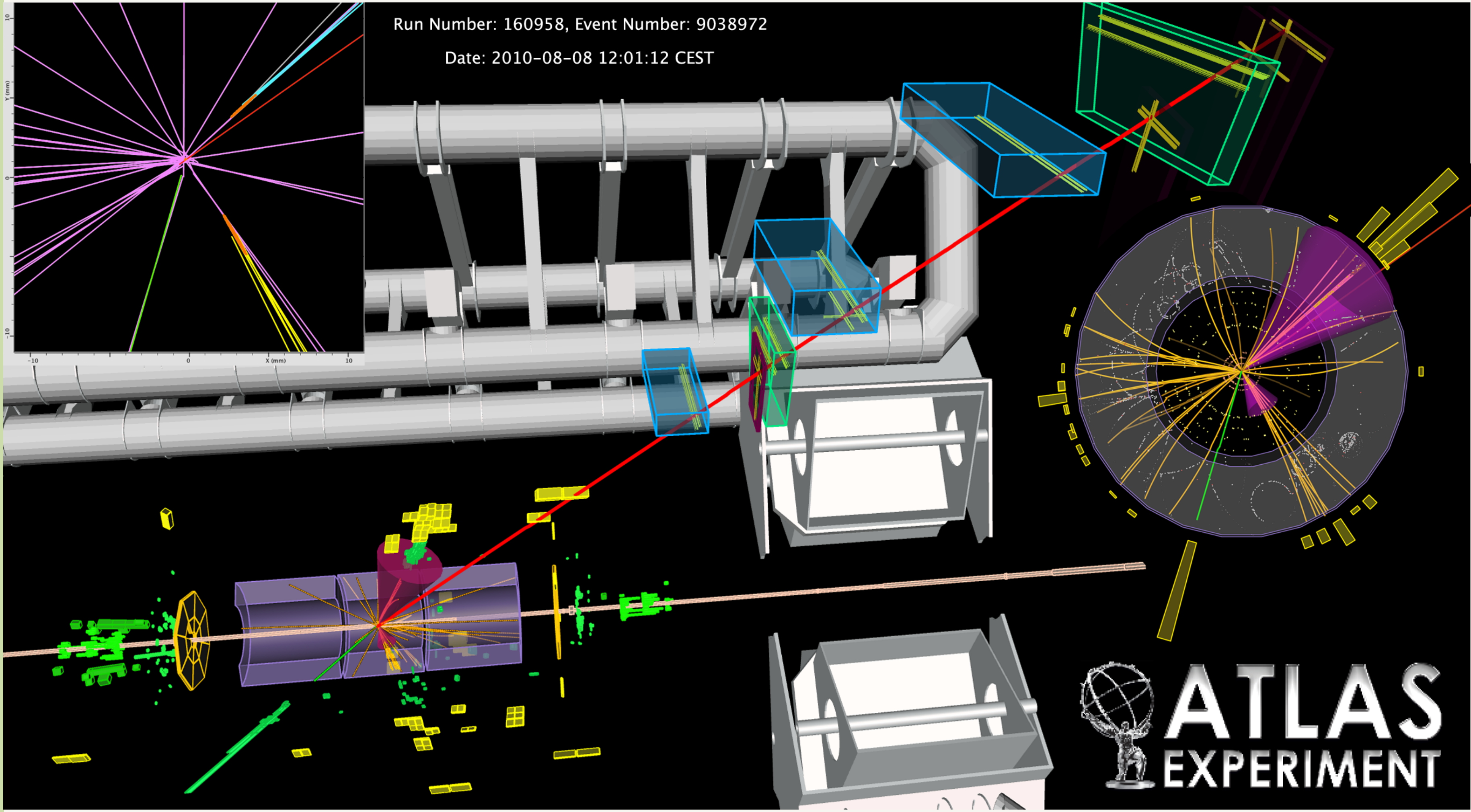
<u>strong</u> pair production





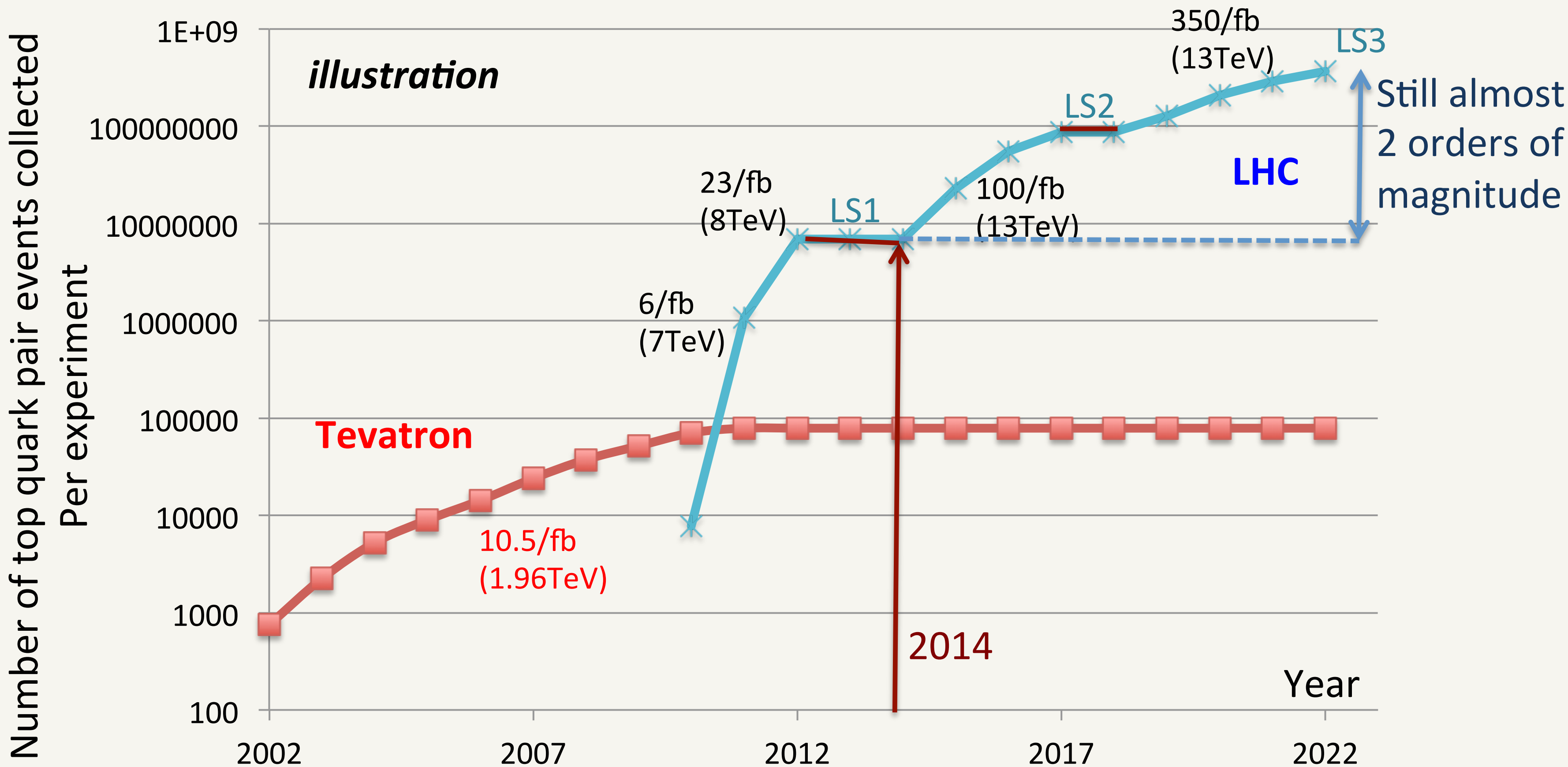
jets, b-jets, charged leptons, neutrino's → need the full functionality of the detector

Observing t → b W at colliders



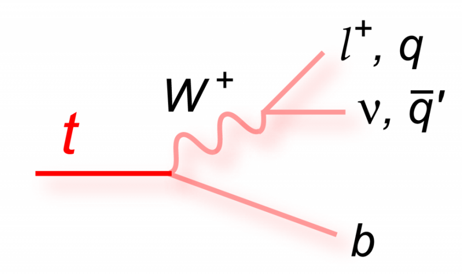
Production at Tevatron and LHC

20 years for almost 6 orders of magnitude → the Top Quark era



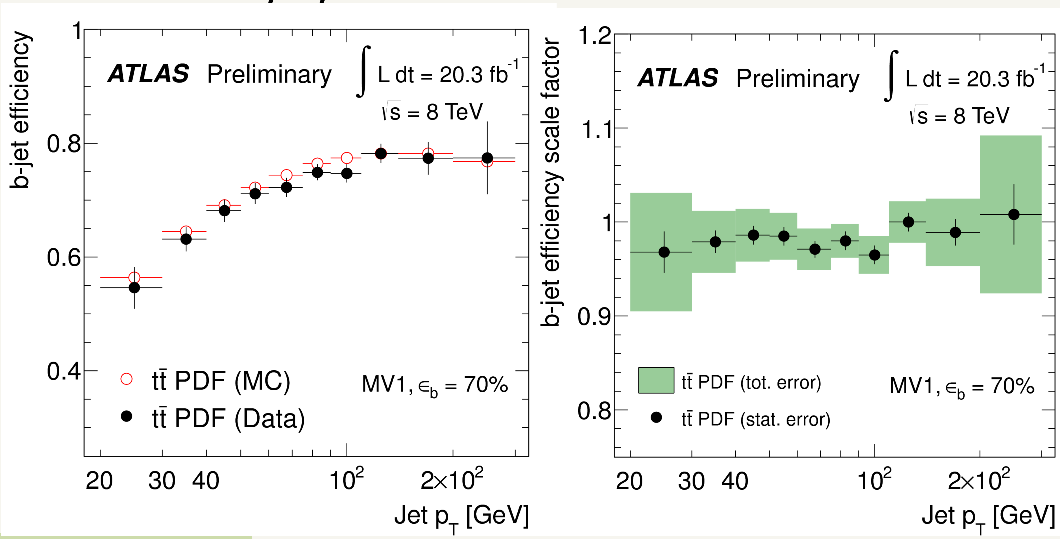
(caveat: assumed 13 TeV collisions with a cross section of 800 pb)

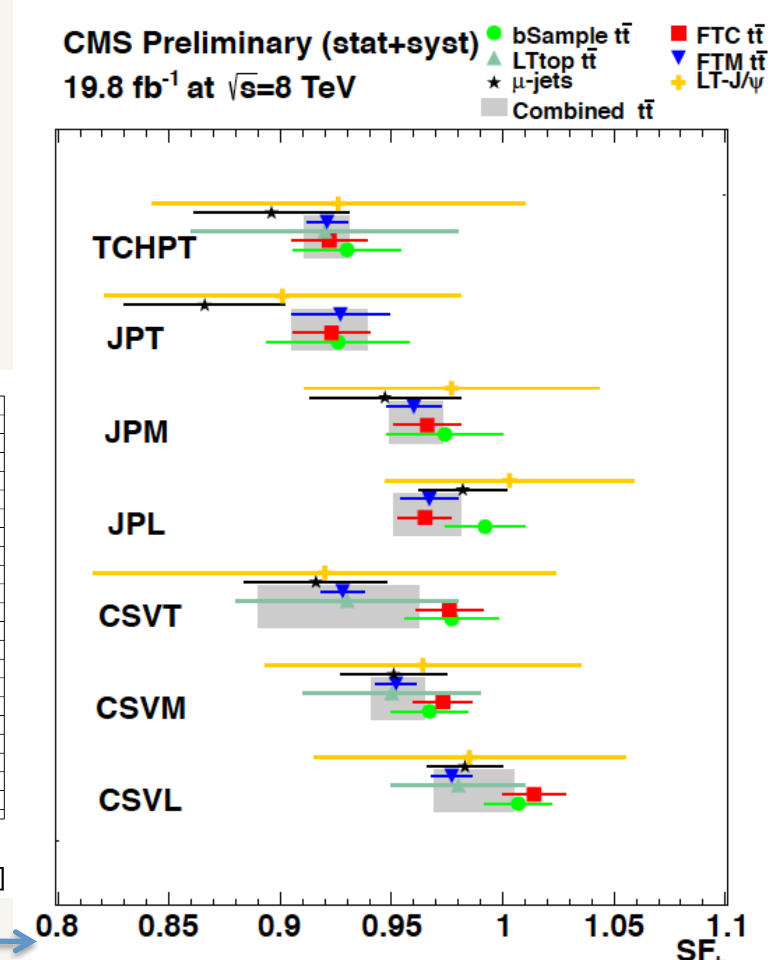
Using t → b W for calibration



Top quark events useful for both the calibration of the Jet Energy Scale as well as the b-tagging performance.

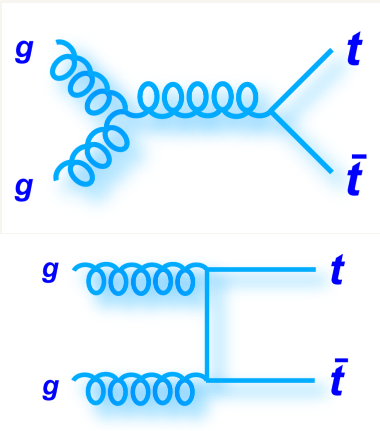
- Di-lepton events in ATLAS, assume $|V_{tb}|=1$
- Likelihood fit on binned histograms of the b-tagging discriminators to extract the b-tagging efficiency (PDF's from simulation)
- Limited by systematic uncertainties

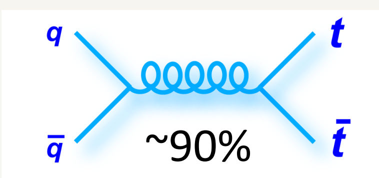


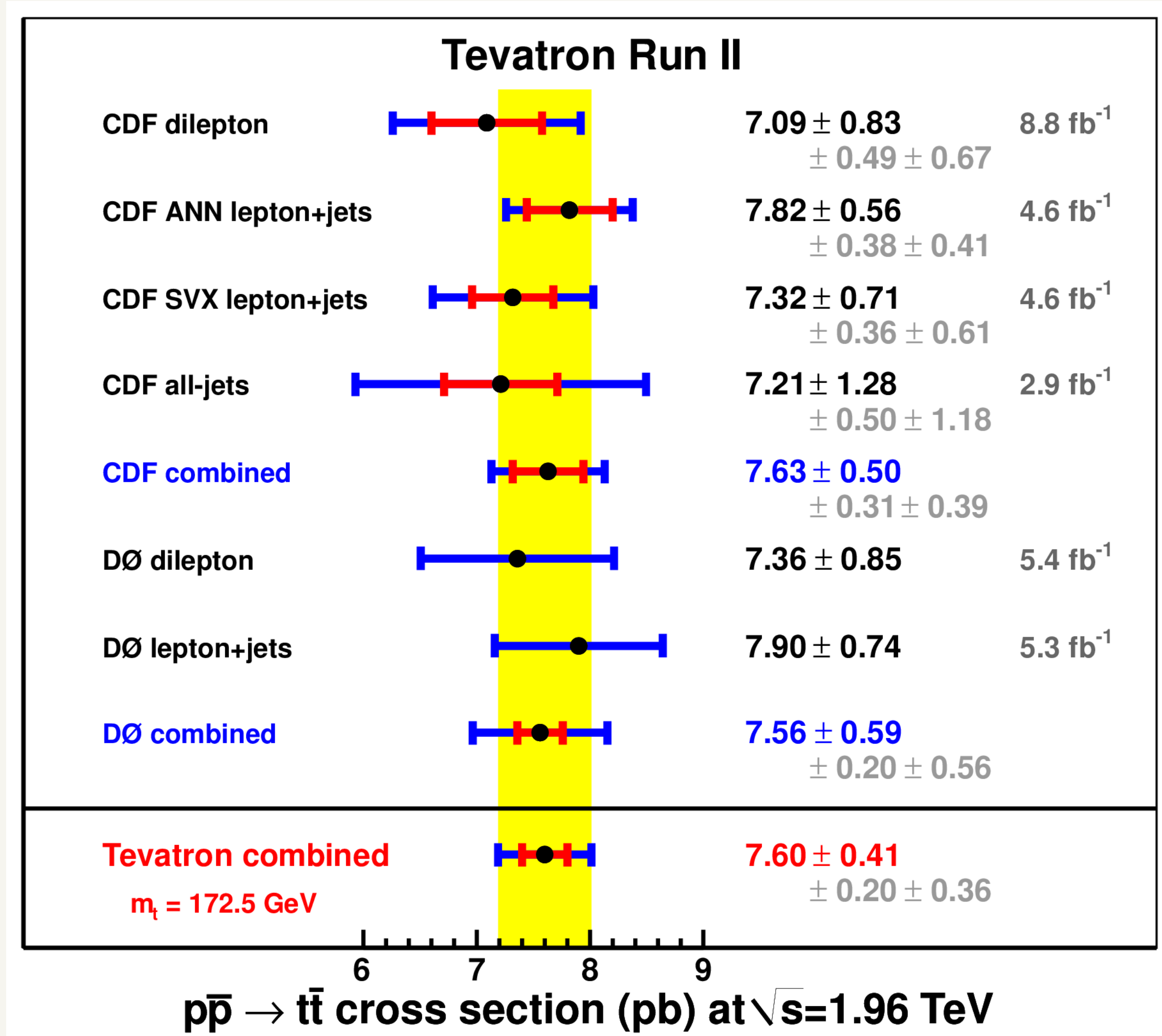


Diversity of methods in CMS →

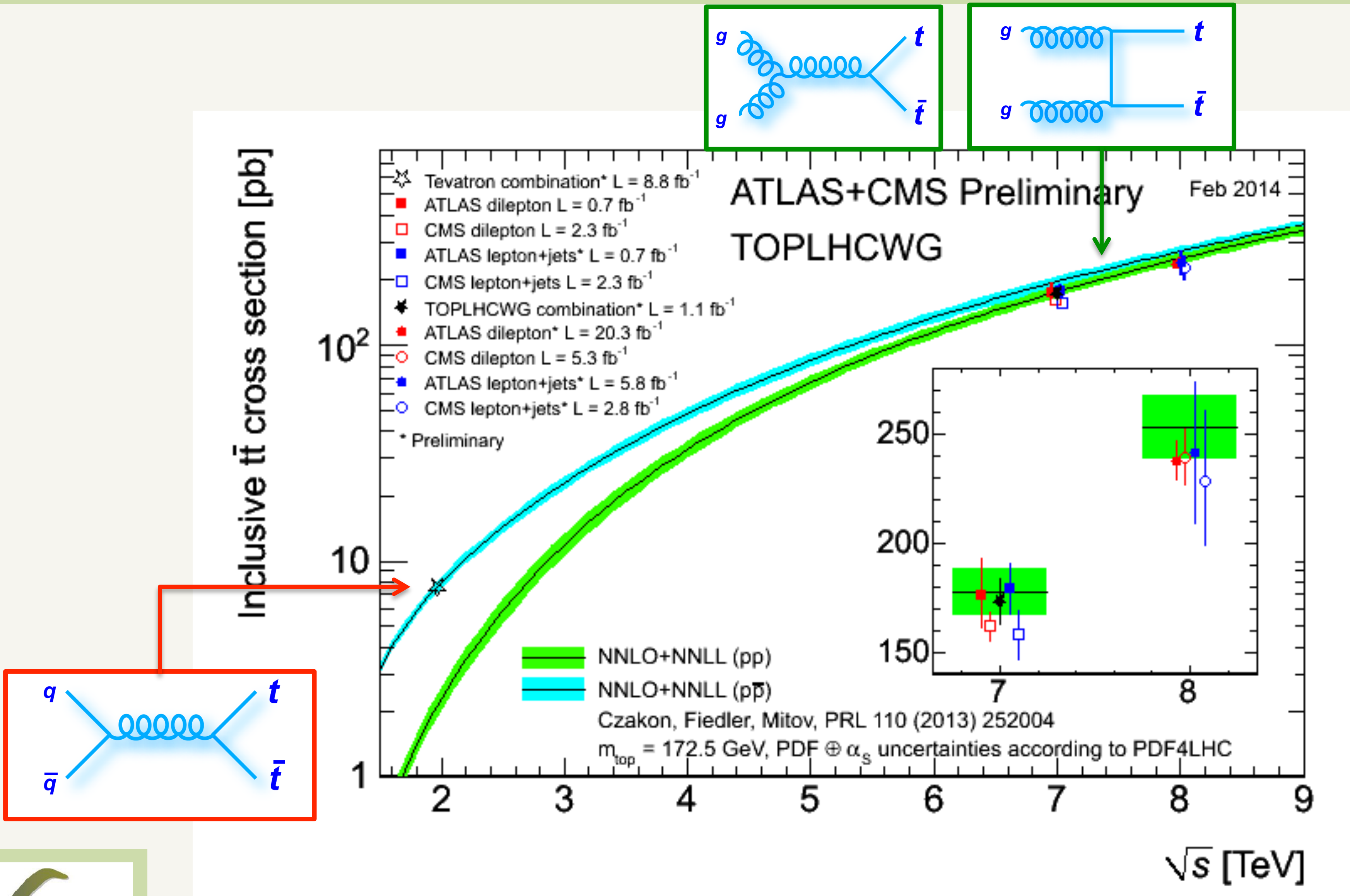
Cross-section – Tevatron







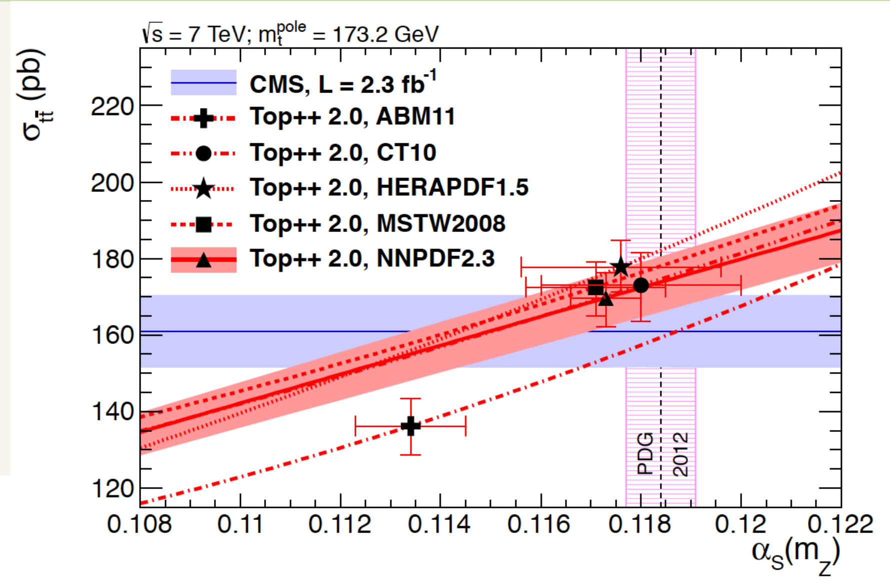
Cross-section – pair production

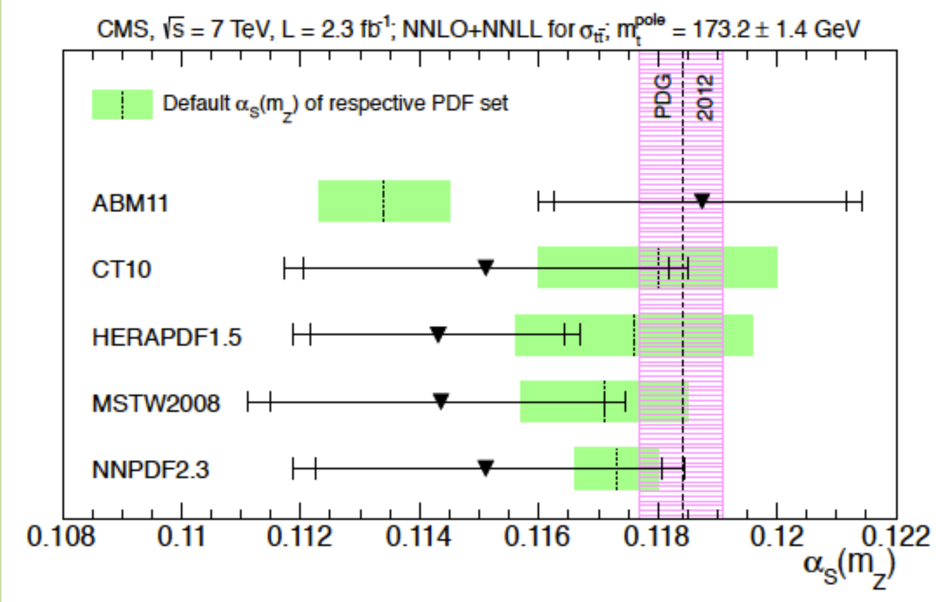


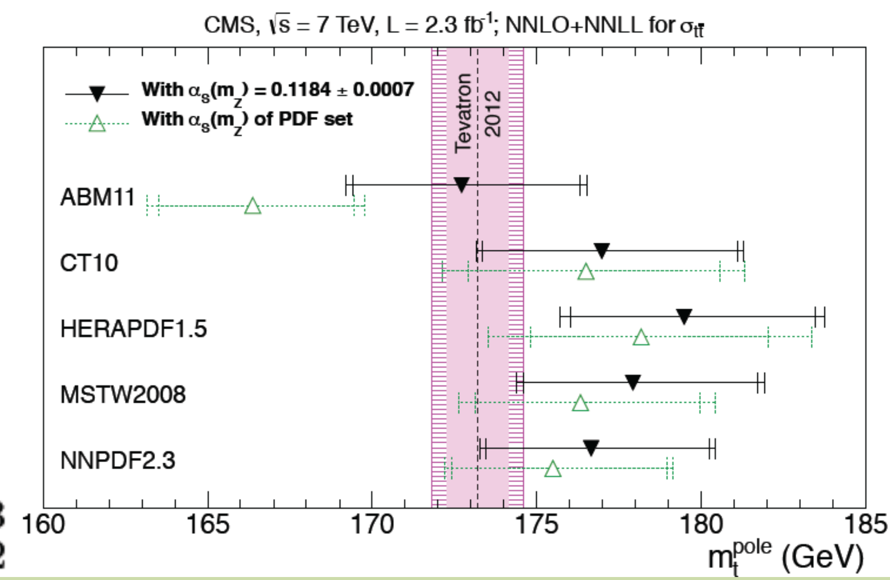
CMS Phys. Lett. B 728 (2013) 496

Cross-section and PDF's

- PDF's from the measured top quark pair cross-sections
- Assume the top quark pole mass to be 173.2 ± 1.4 GeV





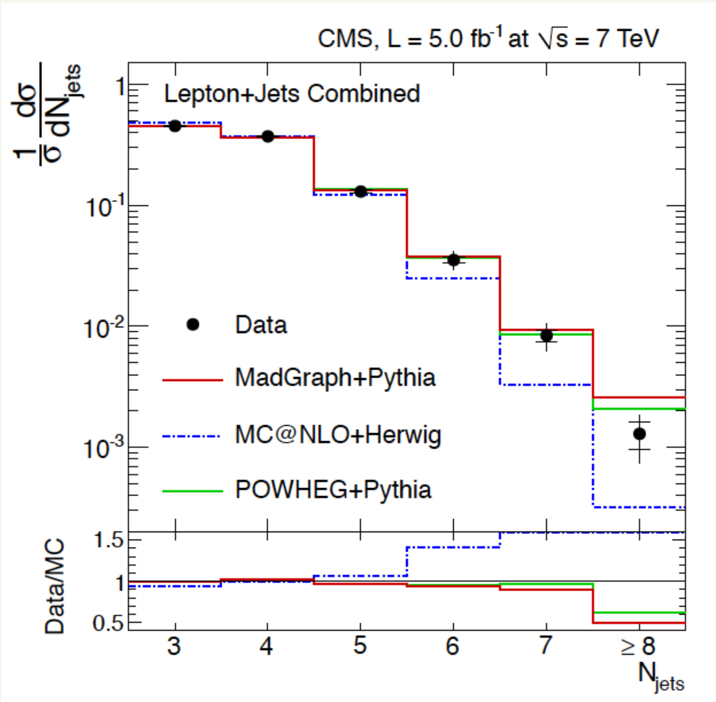


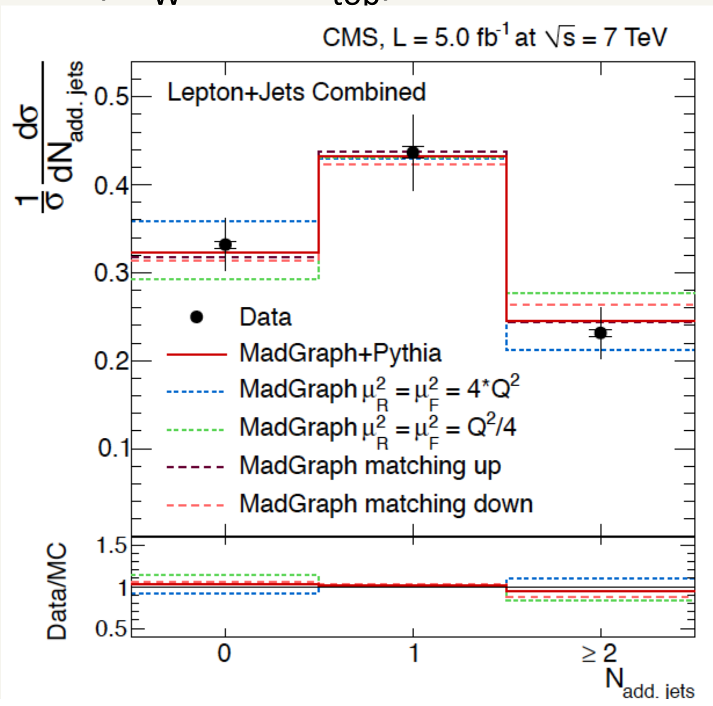
$$\alpha_S(M_Z) = 0.1151^{+0.0033}_{-0.0032}$$

Cross-section – Jet Multiplicity

Differential cross-section as a function of the jet multiplicity (testing higher order QCD and an important background for ttH), measurement in visible phase-space.

The fractions with 0, 1, ≥2 jets are fitted to data histograms of a χ^2 variable including the observed kinematics of the event (m_W and m_{top})





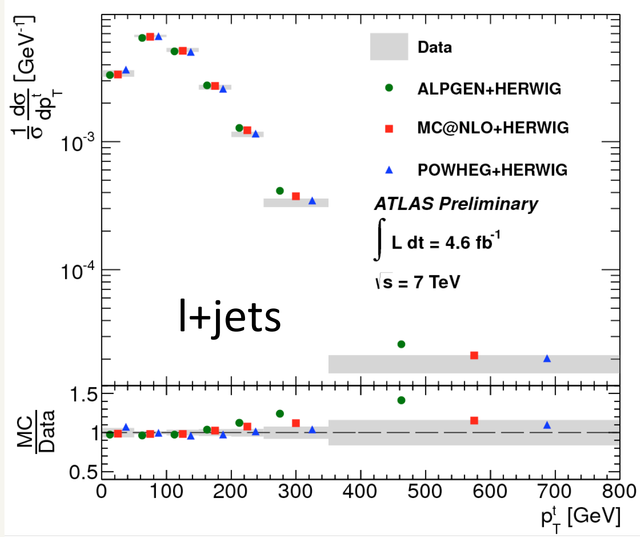
N_{jets}	$1/\sigma\, d\sigma/dN_{add.\ jets}$	Exp. Syst. (%) JES	Exp. Syst. (%) Other	Model Syst. (%) Q^2/Match./Had.	Model Syst. (%) Other	Total (%)
$t\bar{t}$ + 0 add. Jets	0.332	4.2	1.4	7.5	1.6	9.0
$t\bar{t}$ + 1 add. Jet	0.436	0.9	1.0	9.5	1.3	9.8
$t\bar{t}$ + $\geq$2 add. Jets	0.232	7.2	1.5	9.6	2.6	12.5

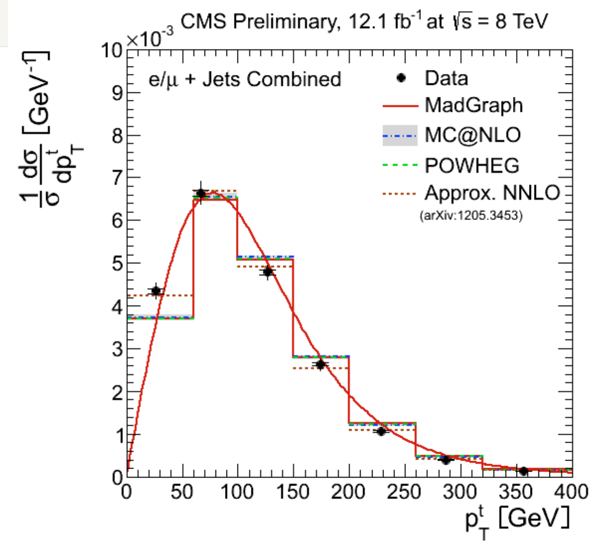
Differential cross-sections

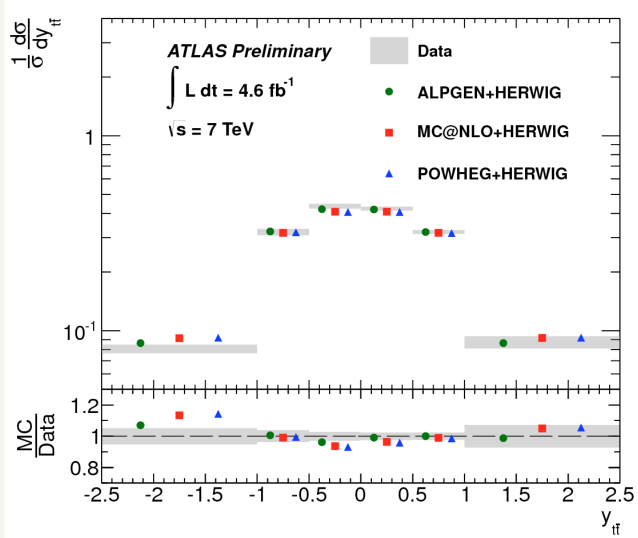
Measured distributions are unfolded to correct for experimental effects.

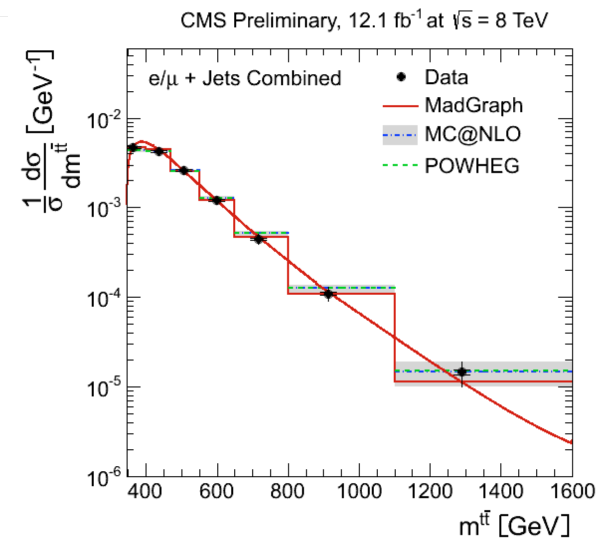
Discrepancies with NLO generators are to be taken into account when estimating systematic uncertainties in measurement/searches.

Important for searches in processes where top quarks appear.



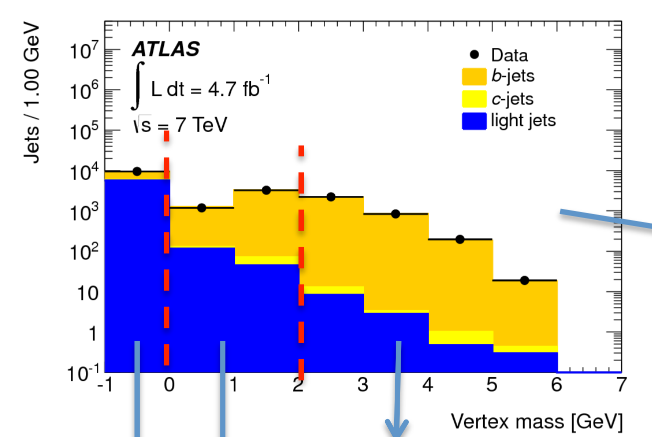






Cross-section – Top and Heavy-Flavour

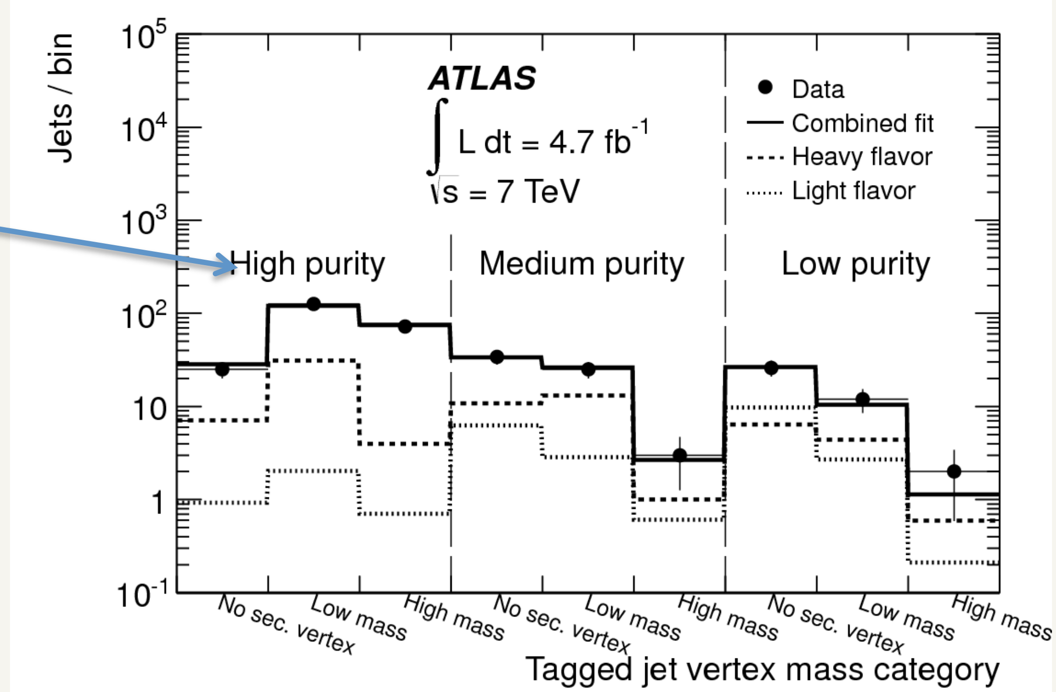
- Top quarks in association with heavy-flavor quarks (b or c) are important background events for several searches, eg. tt+H.
- Selected di-lepton sample with at least 3 b-tagged jets.



High mass

Low mass

No reconstructed secondary vertex



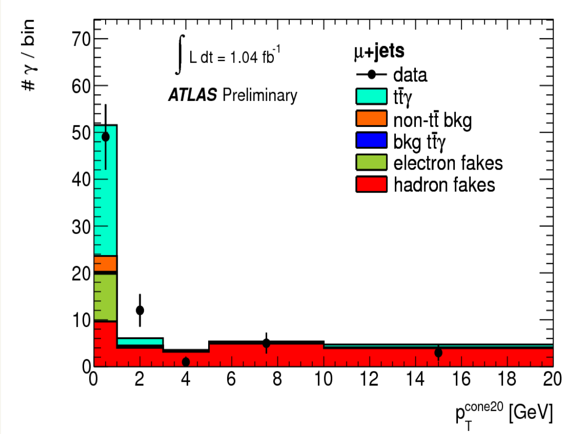
$$R_{\mathrm{HF}} = \frac{\sigma_{\mathrm{fid}}(t\bar{t}+\mathrm{HF})}{\sigma_{\mathrm{fid}}(t\bar{t}+j)}$$

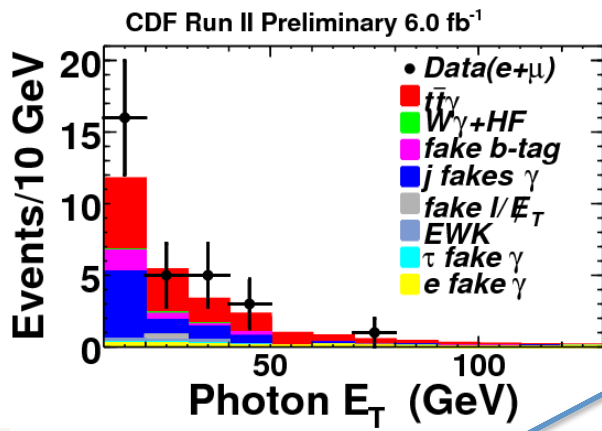
Fitted fraction of Heavy-Flavour is 6.2 ± 1.1(stat) ± 1.8(syst) %.

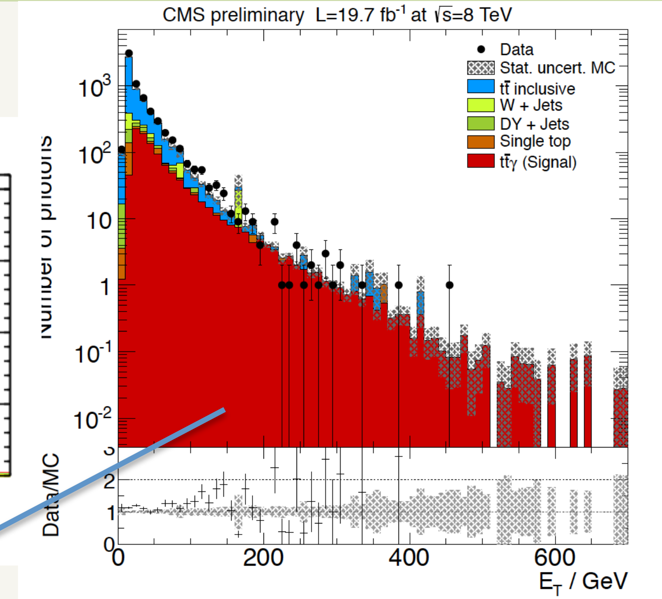
CMS (8 TeV): $\sigma(t\bar{t}b\bar{b})/\sigma(t\bar{t}jj) = 0.023 \pm 0.003(stat.) \pm 0.005(syst.)$ at 20 GeV

Cross-section – associated production

Top quark pairs with a photon







Mis-identification rate of hadronic activity is obtained from side-bands of photon-ID variables in data, after a simulation based reweighing from side-bands to signal region. The purity of correctly identified photons is measured to be 66.7%.

$$R = \sigma_{\bar{t}t+\gamma}/\sigma_{\bar{t}t}$$
$$= (1.07 \pm 0.07(\mathrm{stat.}) \pm 0.27(\mathrm{syst.})) \cdot 10^{-2}$$

modeling bck

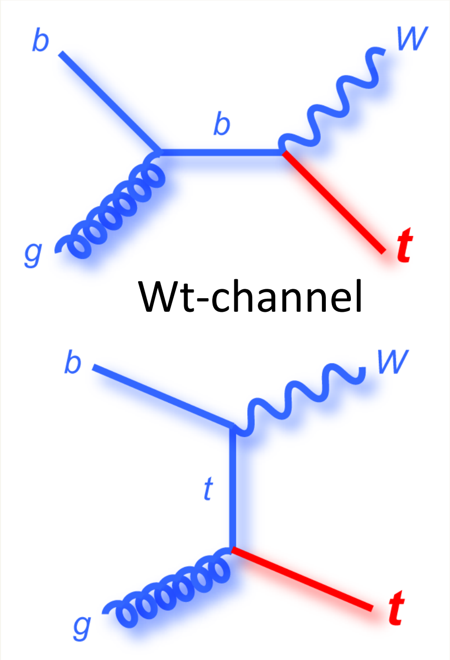
$$\sigma_{t\bar{t}+\gamma} = R \cdot \sigma_{\bar{t}t}^{\mathrm{CMS}}$$
$$= 2.4 \pm 0.2(\mathrm{stat.}) \pm 0.6(\mathrm{syst.})\,\mathrm{pb}$$

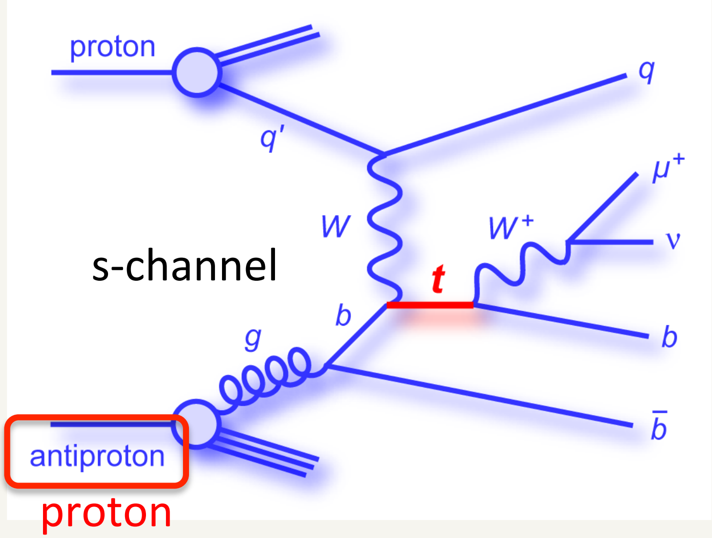
E_T^{photon} > 20 GeV
ΔR(photon, b-quarks) > 0.1

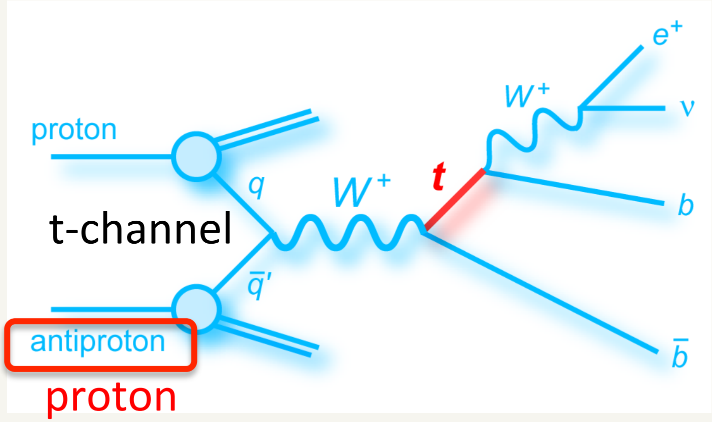
$$\sigma_{\bar{t}t+\gamma}^{SM} = 1.8 \pm 0.5\,\mathrm{pb}$$

Cross-section – single-top production

Electroweak single-top production



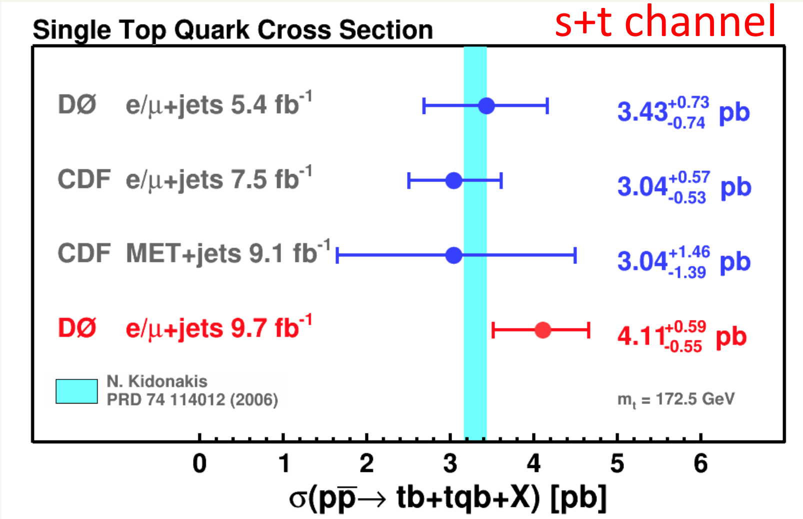


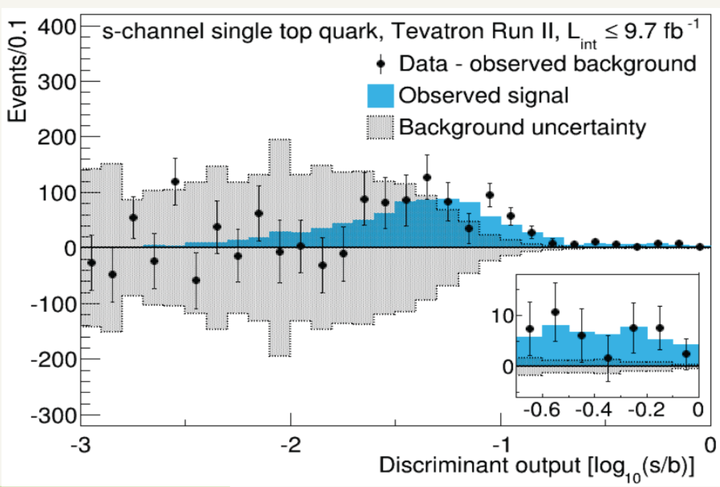


arXiv:1402.5126

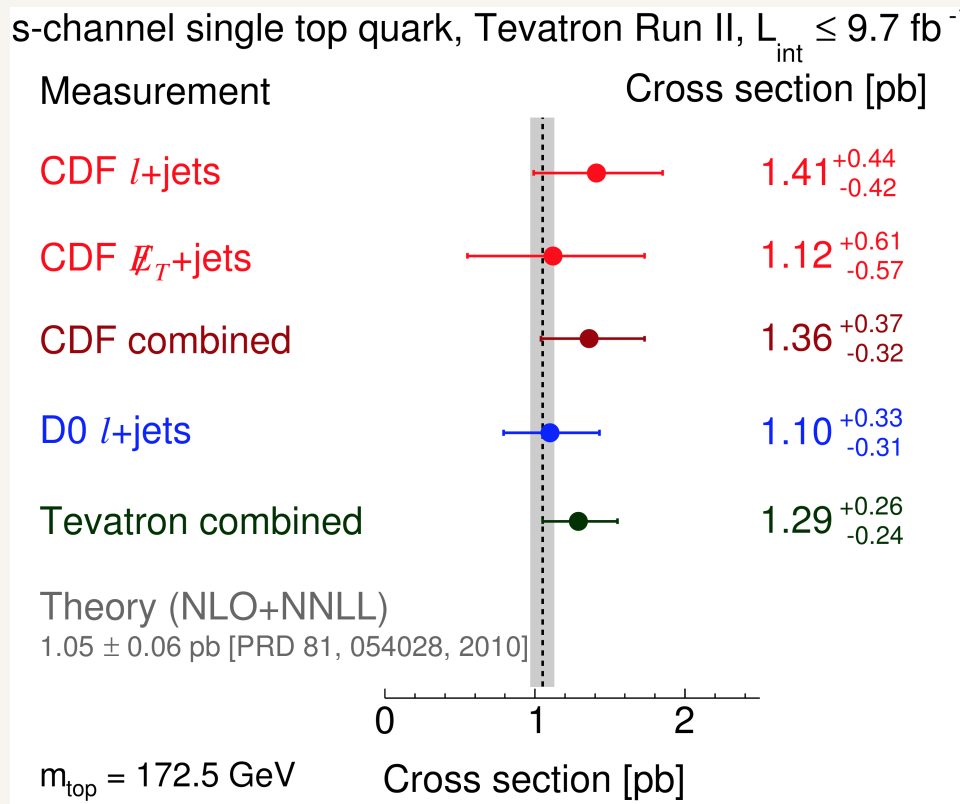
Cross-section – single-top Tevatron

s+t channel





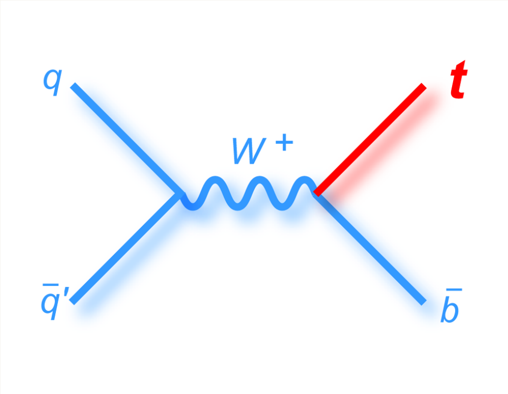
Tevatron's legacy



Observed significance is 6.3 σ

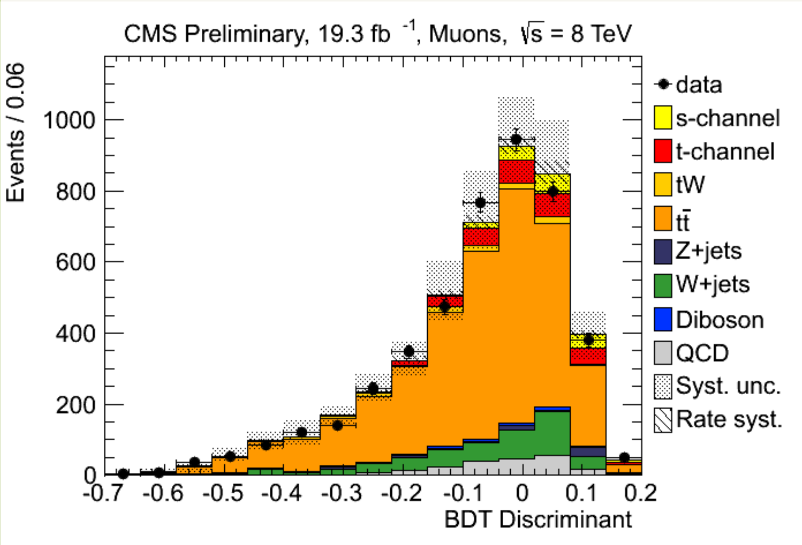
Cross-section – s-channel

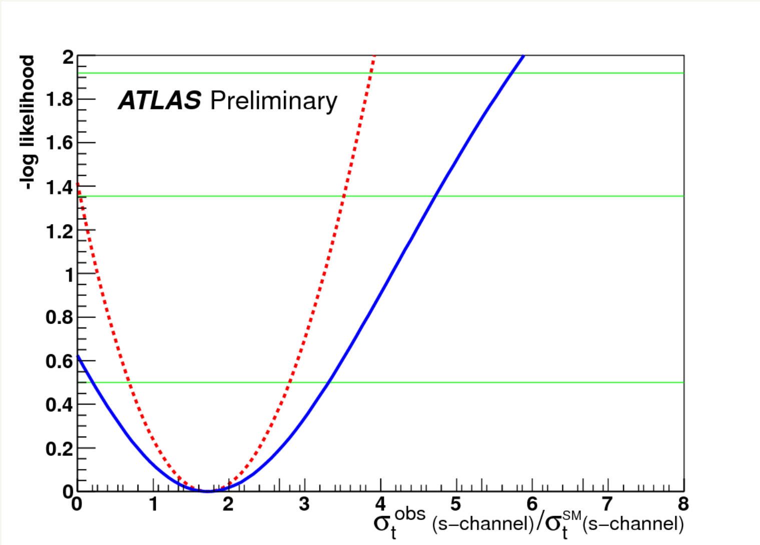
- Multivariate analyses are developed, and sensitivity limited by theoretical uncertainties
- **ATLAS** (7 TeV): $\sigma_{s\text{-}ch} < 26.5$ pb (= 5.8 x σ^{SM})
- **CMS** (8 TeV): $\sigma_{s\text{-}ch} < 11.5$ pb (= 2.1 x σ^{SM})



Assuming signal (σ>0)
(Feldman-Cousins 68% CI)

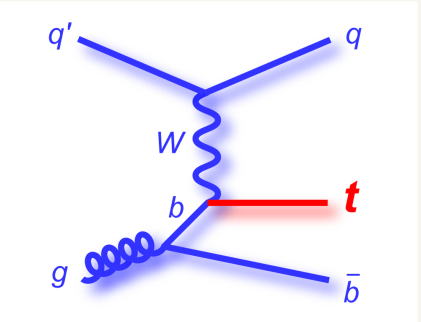
$$\sigma_{s\text{-ch.}} = 5.9^{+8.6}_{-5.1} \text{ pb muon channel}$$
$$\sigma_{s\text{-ch.}} = 6.9^{+8.7}_{-5.7} \text{ pb electron channel}$$
$$\sigma_{s\text{-ch.}} = 6.2^{+8.0}_{-5.1} \text{ pb combined}$$

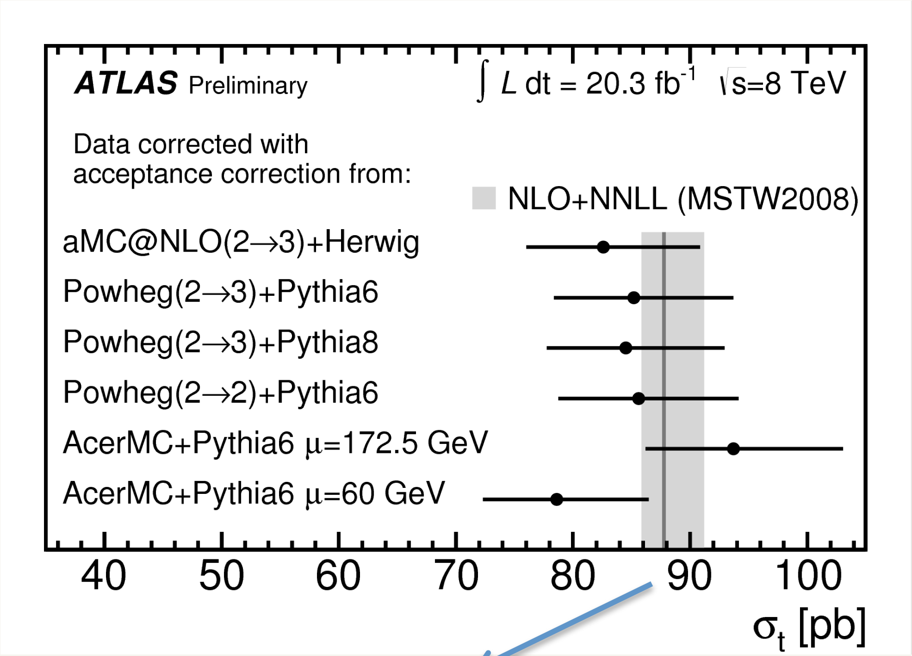


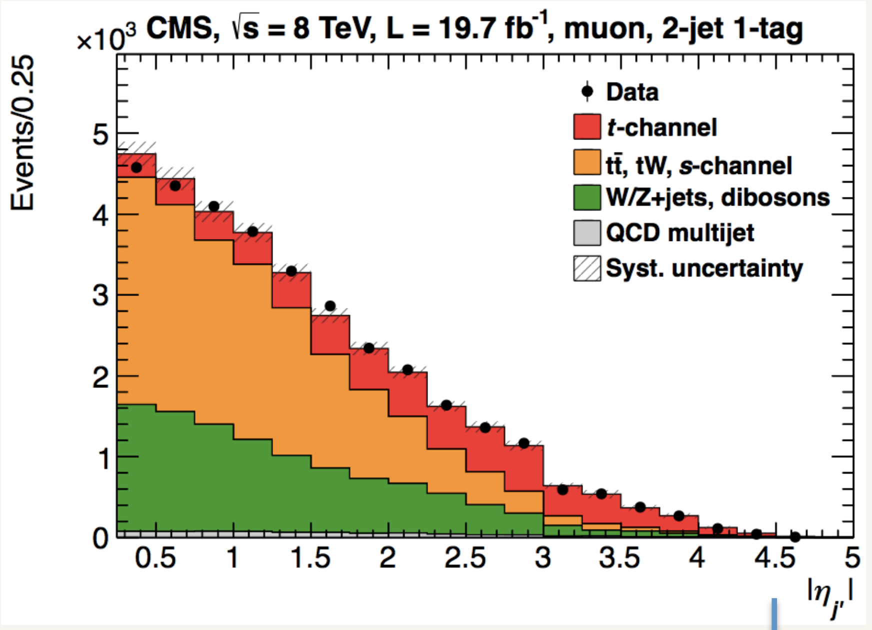


Cross-section – t-channel

- **ATLAS**: Multivariate analyses to measure cross-section in detector acceptance and extrapolate to full phase space
- **CMS**: fitting on $|\eta_j|$ distribution
- Systematic uncertainties dominate







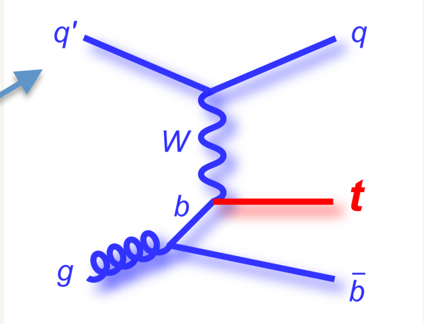
$\sigma_{t\text{-}ch}$ (aMC@NLO + Herwig)= 82.6 ± 1.2(stat) ± 11.4(syst) ± 3.1(PDF) ± 2.3(lumi) pb

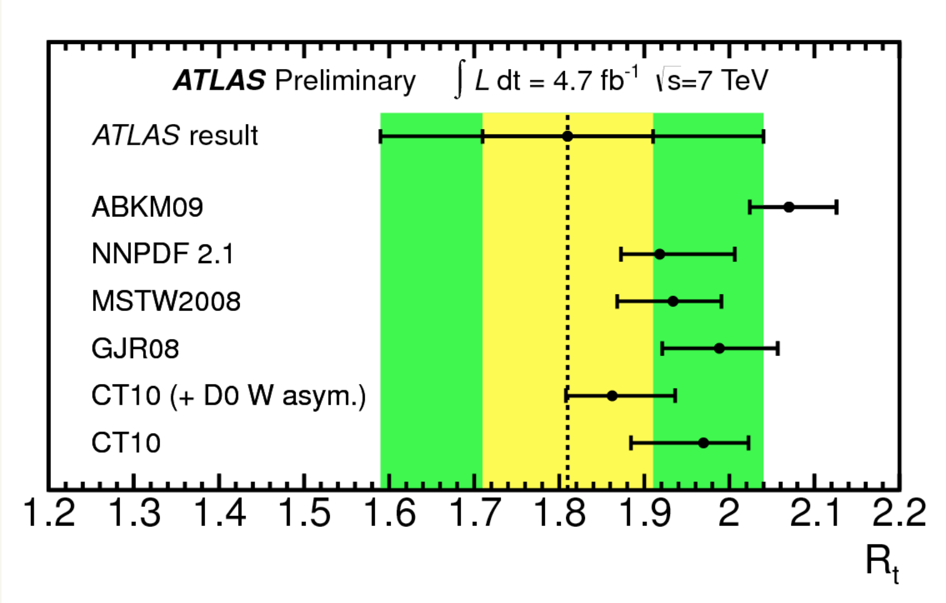
LHC combination to be updated

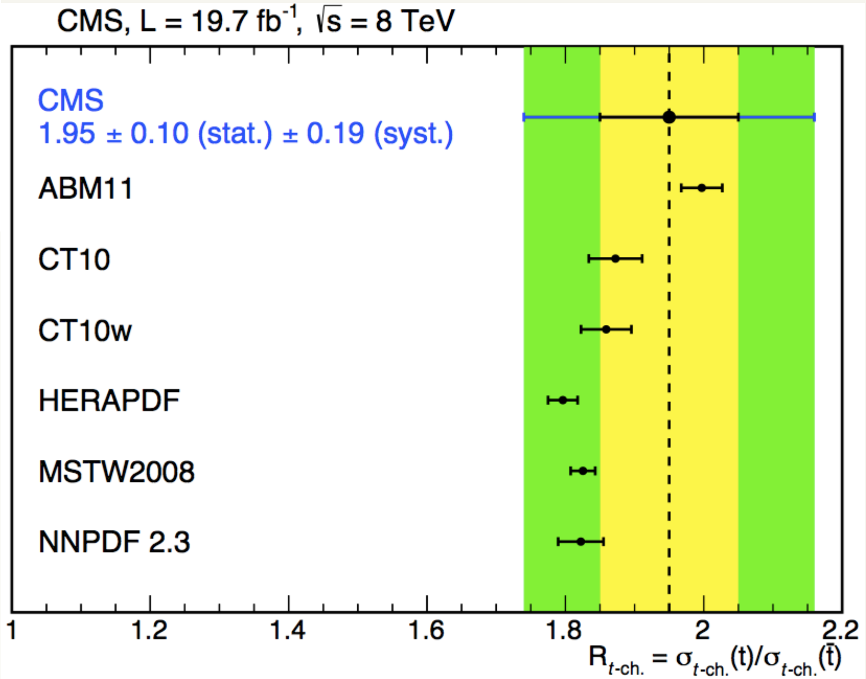
$\sigma_{t\text{-}ch}$ = 83.6 ± 2.3(stat) ± 7.4(syst) pb

Lepton Charge Ratio – t-channel

- Lepton charge ratio is sensitive to PDF models



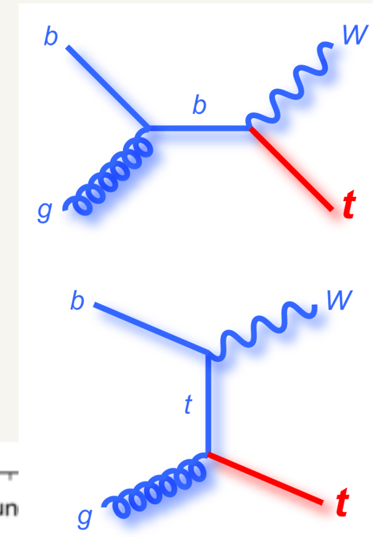


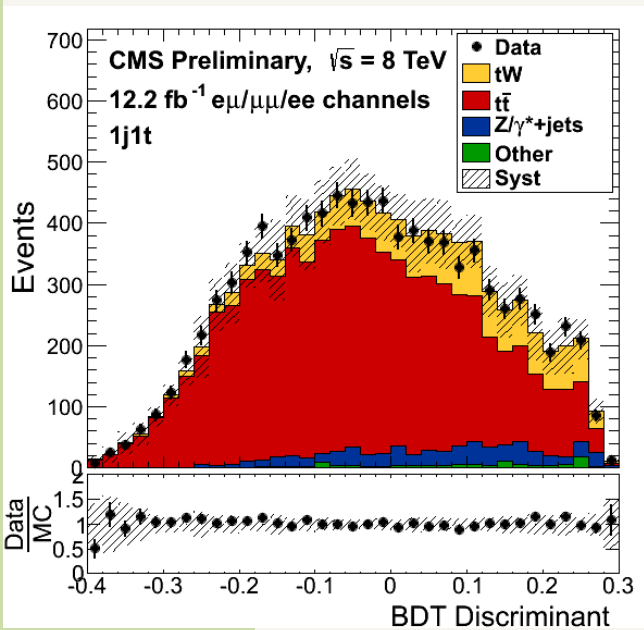


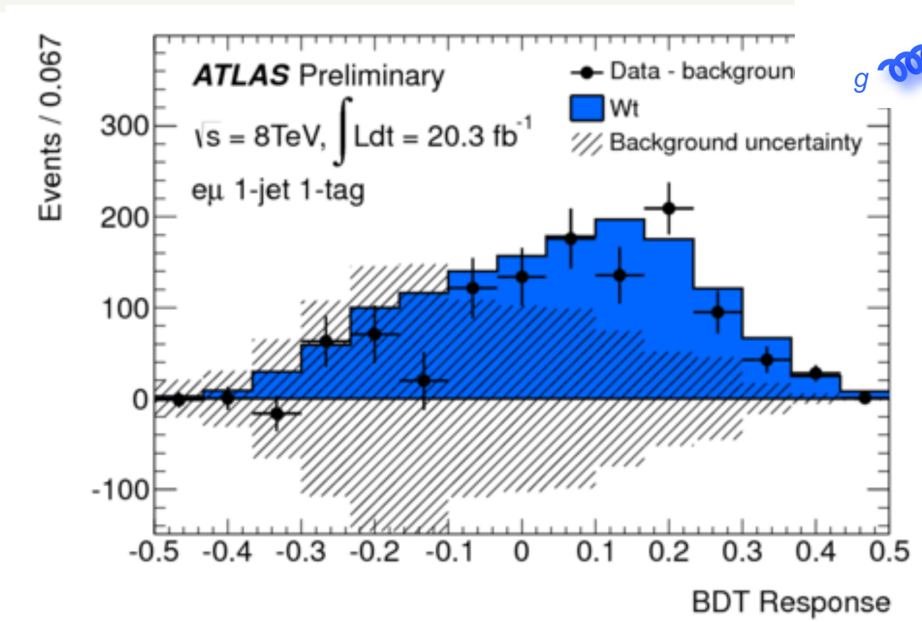
Cross-section – Wt-channel

BDT analyses have observed the Wt-channel at 8 TeV

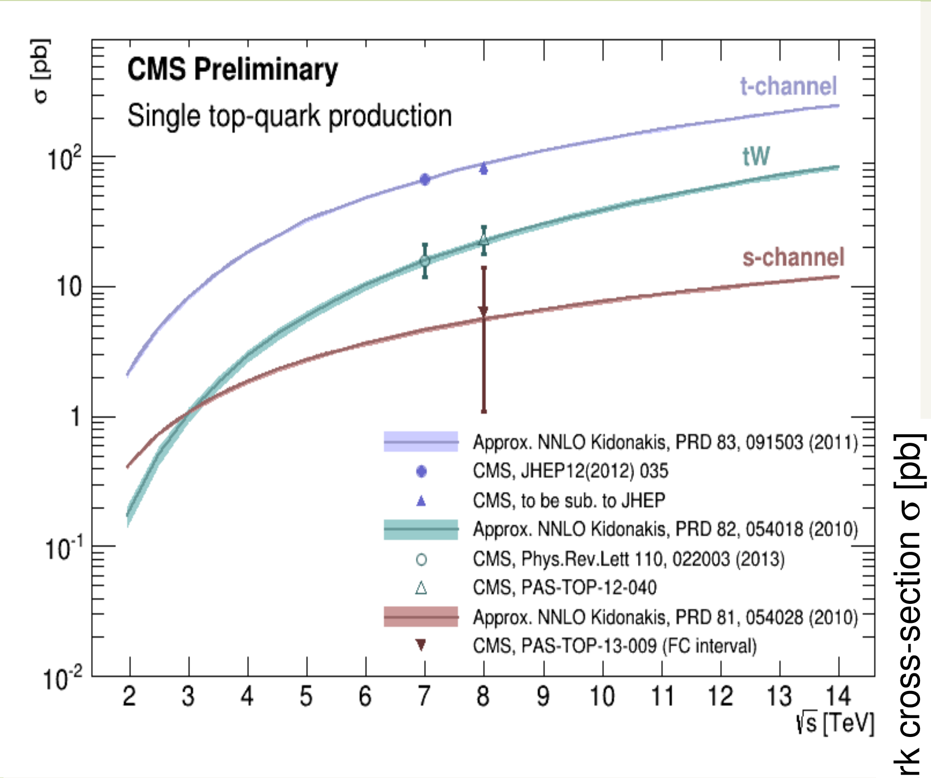
- **CMS** (12.2/fb): $\sigma_{tW} = 23.4^{+5.5}_{-5.4}$ pb
  - (6.1σ obs, 5.4σ exp.)
- **ATLAS** (20.3/fb): $\sigma_{tW} = 27.2 \pm 2.8(\text{stat}) \pm 5.4(\text{syst})$ pb
  - (4.2σ obs, 4.0σ exp.)

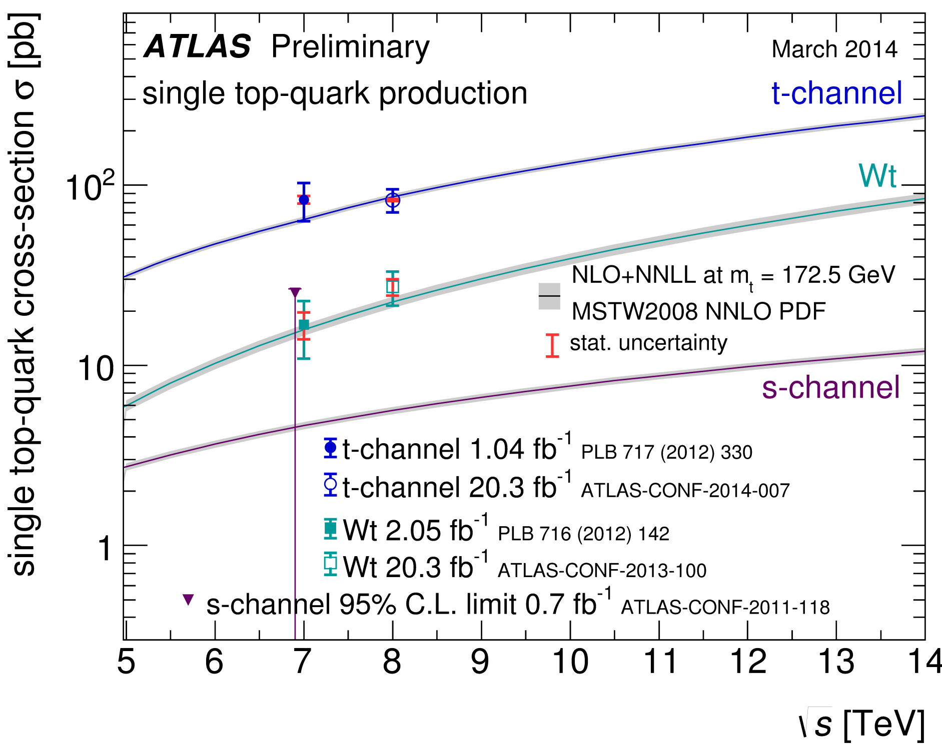






Cross-section – single-top production



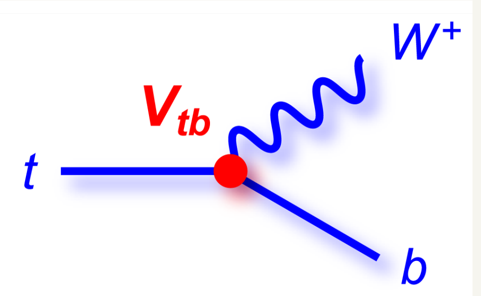


V_{tb} in single-top production

Direct measurement of $|V_{tb}|$, *assuming BR(t→Wb)=1*:

$$|V_{tb}|^2 = \sigma/\sigma_{th}(|V_{tb}|=1)$$

Measurements at 4-5% precision, and limited by the statistical uncertainty and more data will come.



Luca Lista @ Moriond EW 2014

- ATLAS:
  - 7 TeV: $|V_{tb}| = 1.13^{+0.14}_{-0.13}$ (t-ch., 11.9%)
    $|V_{tb}| = 1.03^{+0.16}_{-0.19}$ (tW, 17.0%)
  - 8 TeV: $|V_{tb}| = 0.97 \pm 0.01(\text{stat})^{+0.06}_{-0.07}(\text{syst}) \pm 0.6(\text{gen+PDF})^{+0.02}_{-0.01}(\text{th}) \pm 0.01(\text{lumi})$
    $= 0.97^{+0.09}_{-0.10}$ (t-ch., 9.8%)
    $|V_{tb}| = 1.10 \pm 0.12(\text{exp}) \pm 0.03(\text{th})$ (tW, 11.2%)

NEW

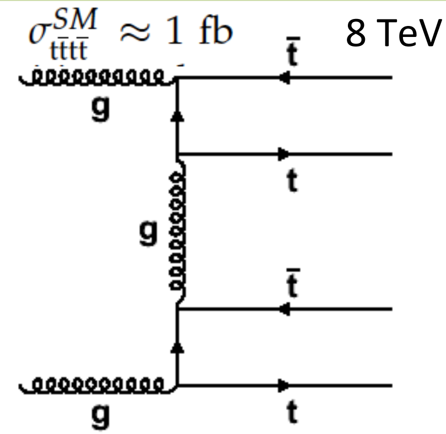
- CMS:
  - 7 TeV: $|V_{tb}| = 1.020 \pm 0.046(\text{exp}) \pm 0.017(\text{th})$ (t-ch. 4.8%)
    $|V_{tb}| = 1.01^{+0.16}_{-0.13}(\text{exp})^{+0.03}_{-0.04}(\text{th})$ (tW, 14.8%)
  - 8 TeV: $|V_{tb}| = 0.979 \pm 0.045(\text{exp}) \pm 0.016(\text{th})$ (t-ch. 4.9%)
    $|V_{tb}| = 1.03 \pm 0.12(\text{exp}) \pm 0.04(\text{th})$ (tW 12.3%)

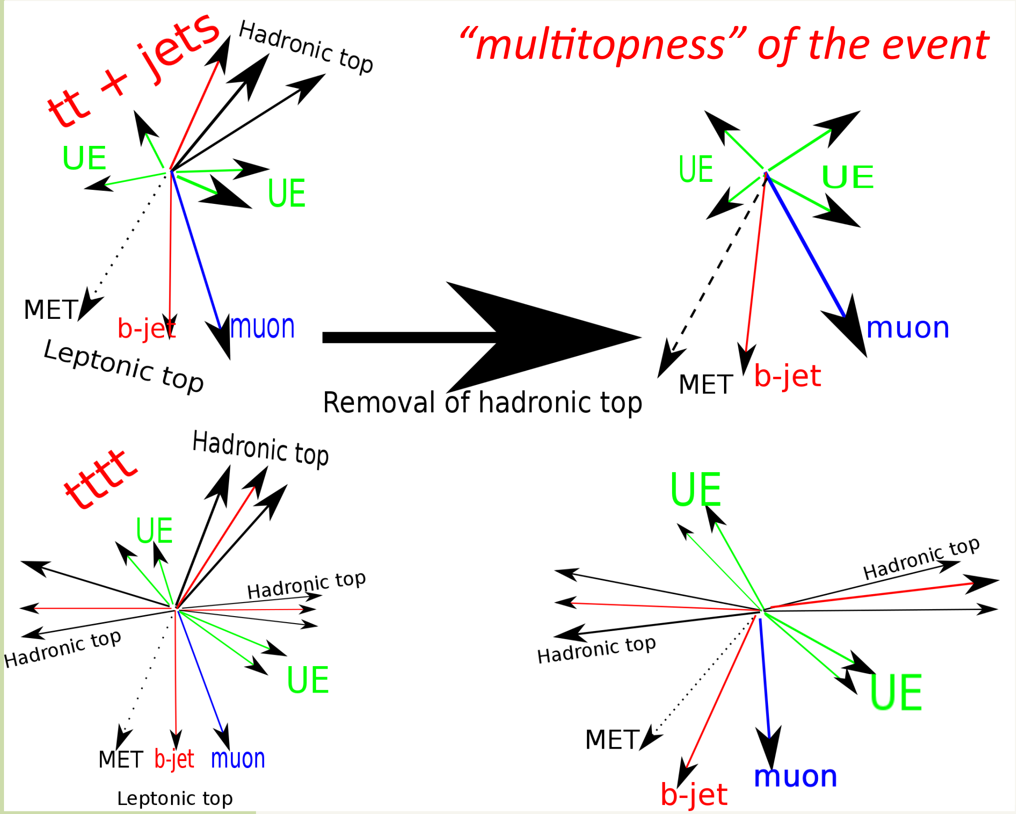
  } $|V_{tb}| = 0.998 \pm 0.038(\text{exp}) \pm 0.016(\text{th})$ (7+8 TeV t-ch., comb.: 4.1%)

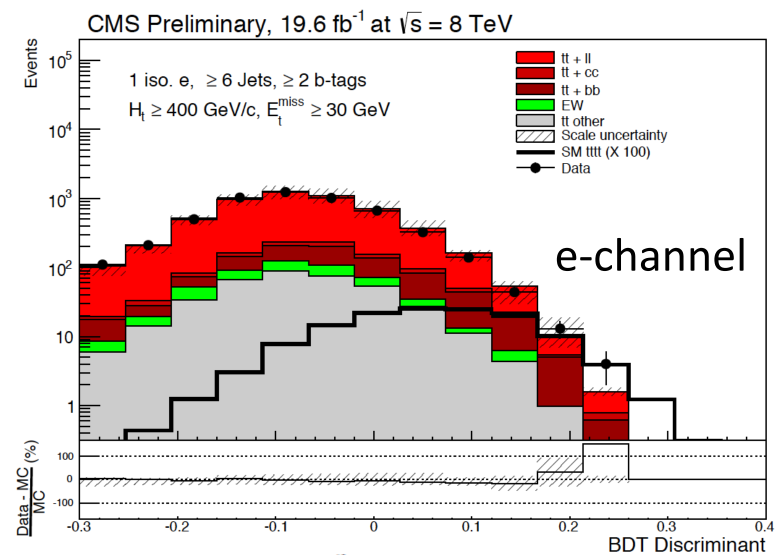
NEW

Cross-section – 4 Top Quarks ?

A combination of kinematic reconstruction and multivariate techniques is used to distinguish between signal and backgrounds.





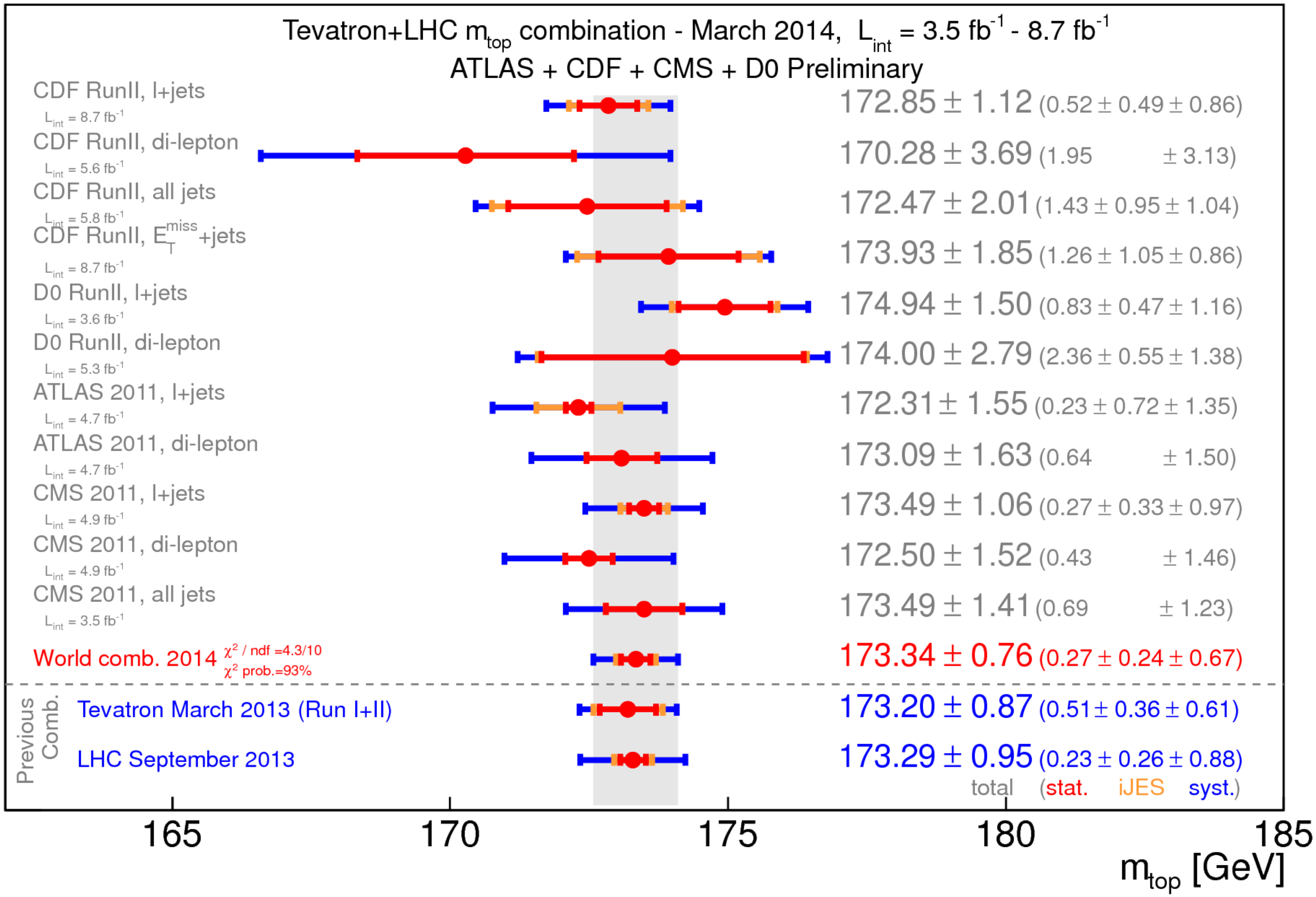


upper limit: $\sigma^{SM}_{t\bar{t}t\bar{t}}$ of 42^{+18}_{-13} fb (expected)

63 fb (observed)

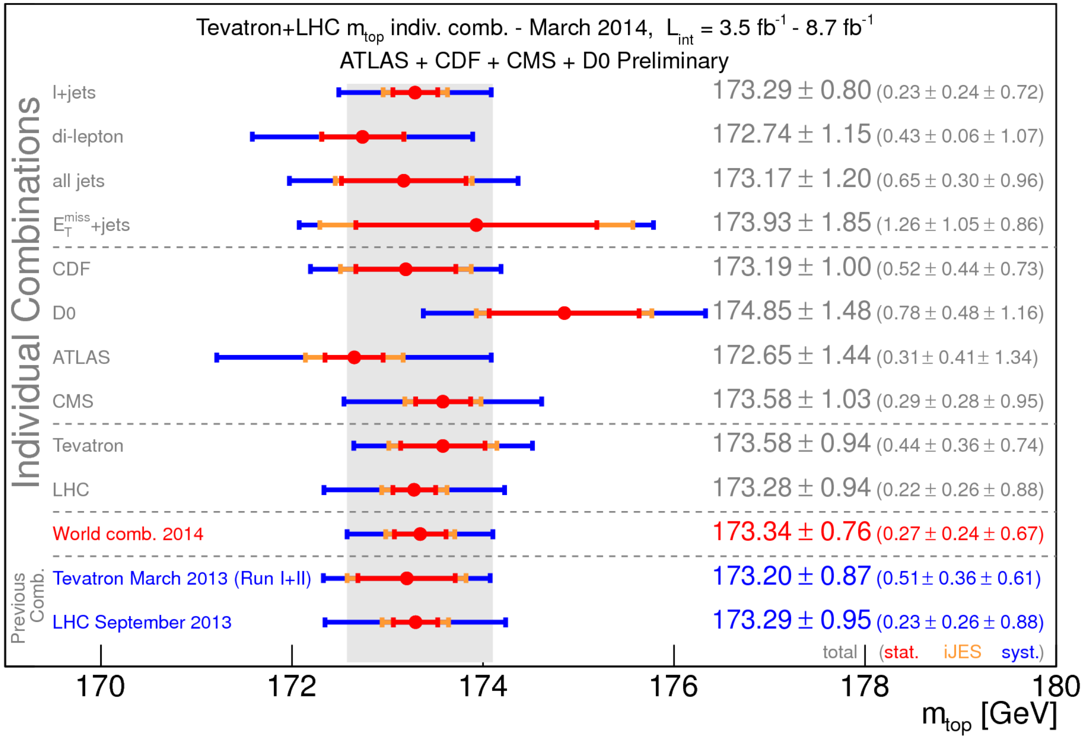
The Top Quark Mass

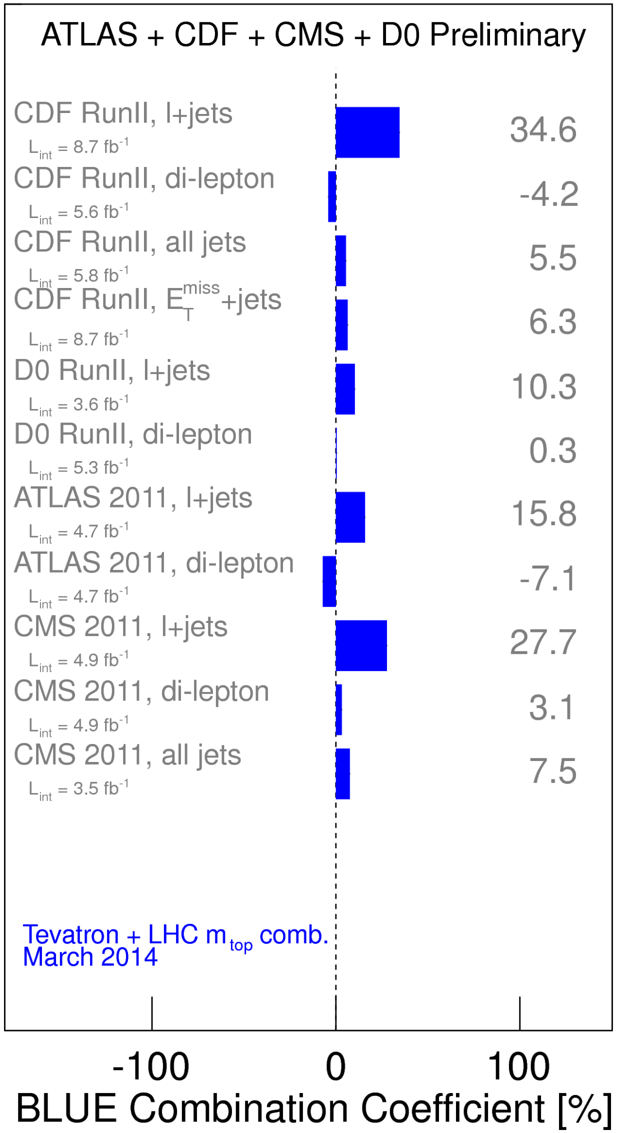
First LHC + Tevatron combination (11 measurements, 93% fit probability)



The Top Quark Mass

- Impact of the different measurements in the BLUE combination
- Comparing decay channels, experiments, colliders

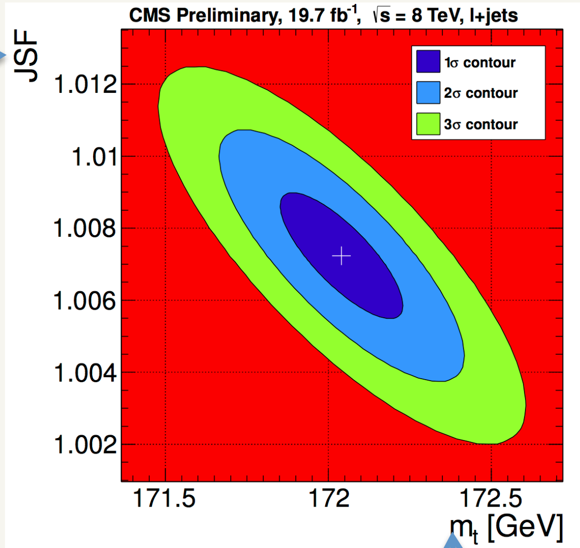


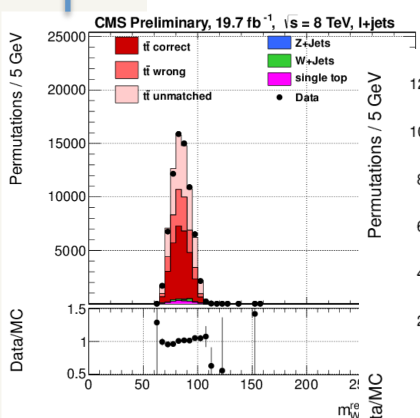


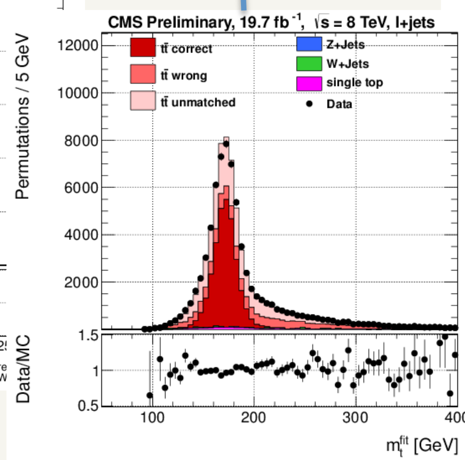
The Top Quark Mass – update CMS

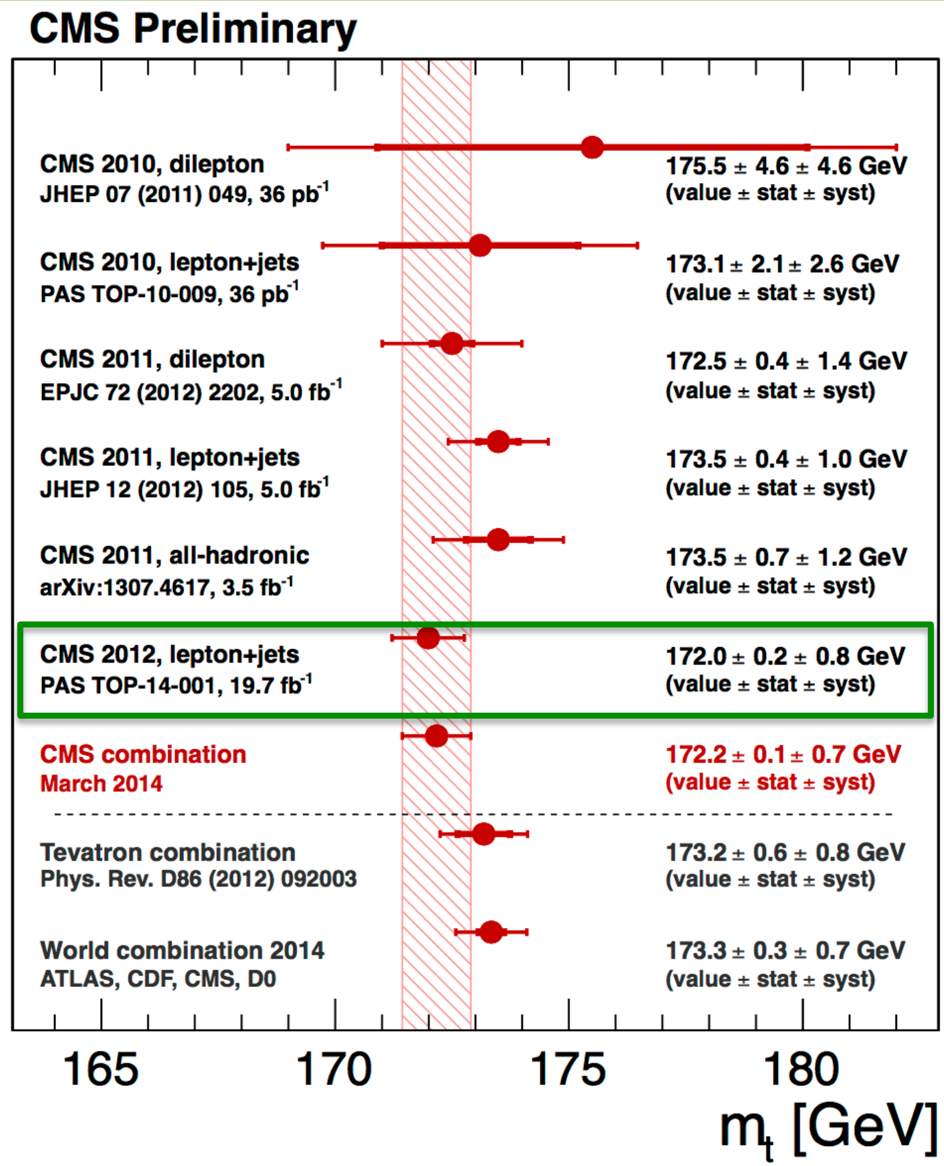
2D measurement with the Jet energy Scale Factor (using kinematic fit)

m_W









CMS TOP-14-001

The Top Quark Mass – update CMS

Measuring the key systematic uncertainties together with the top quark mass improves the precision.

	δm_t^{2D} (GeV)	δJSF	δm_t^{1D} (GeV)
Experimental uncertainties			
Fit calibration	0.10	0.001	0.06
p_T- and η-dependent JES	0.18	0.007	1.17
Lepton energy scale	0.03	<0.001	0.03
MET	0.09	0.001	0.01
Jet energy resolution	0.26	0.004	0.07
b tagging	0.02	<0.001	0.01
Pileup	0.27	0.005	0.17
Non-$t\bar{t}$ background	0.11	0.001	0.01
Modeling of hadronization			
Flavor-dependent JSF	0.41	0.004	0.32
b fragmentation	0.06	0.001	0.04
Semi-leptonic B hadron decays	0.16	<0.001	0.15
Modeling of the hard scattering process			
PDF	0.09	0.001	0.05
Renormalization and factorization scales	0.12±0.13	0.004±0.001	0.25±0.08
ME-PS matching threshold	0.15±0.13	0.003±0.001	0.07±0.08
ME generator	0.23±0.14	0.003±0.001	0.20±0.08
Modeling of non-perturbative QCD			
Underlying event	0.14±0.17	0.002±0.002	0.06±0.10
Color reconnection modeling	0.08±0.15	0.002±0.001	0.07±0.09
Total	0.75	0.012	1.29

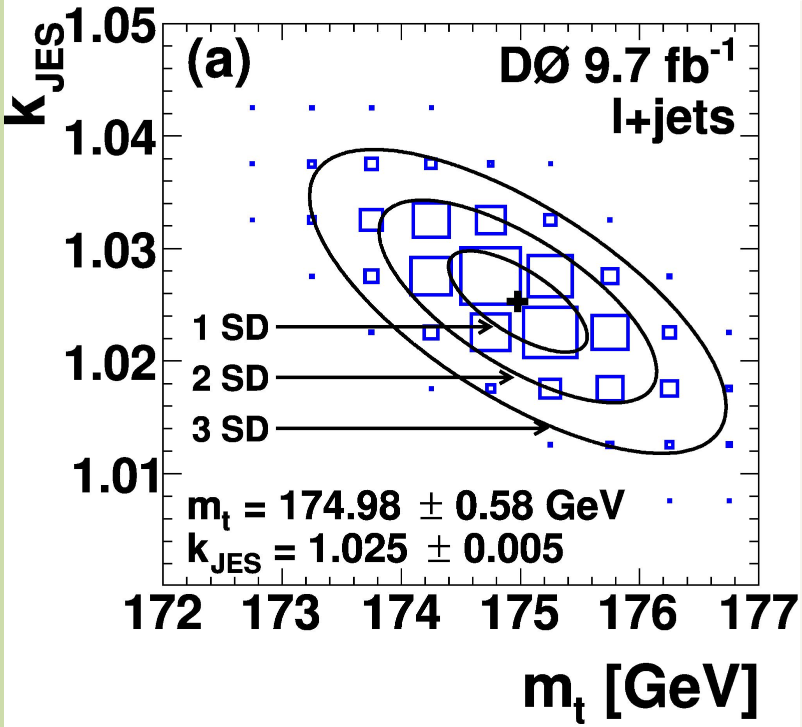
arXiv:1405.1756

The Top Quark Mass – update D0

Applying the Matrix Element technique in the lepton+jet final state on the full Run-II dataset

$$m_t = 174.98 \pm 0.58\,(\text{stat} + \text{JES}) \pm 0.49\,(\text{syst})\ \text{GeV}$$

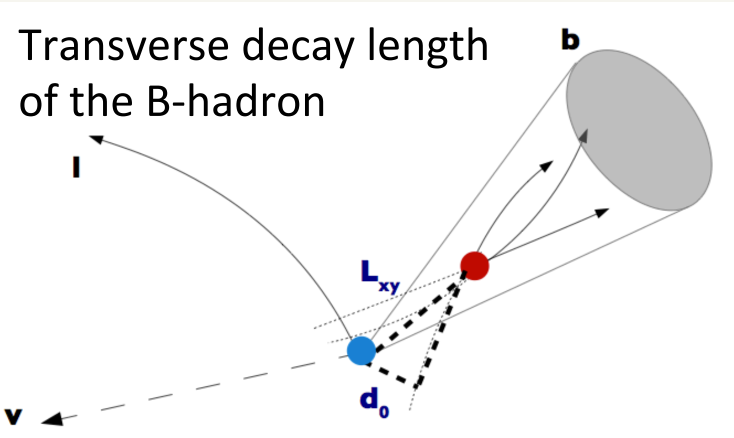
$$m_t = 174.98 \pm 0.76\ \text{GeV},$$

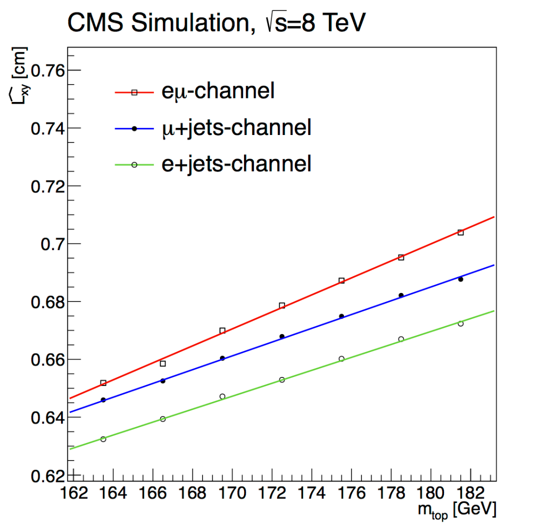


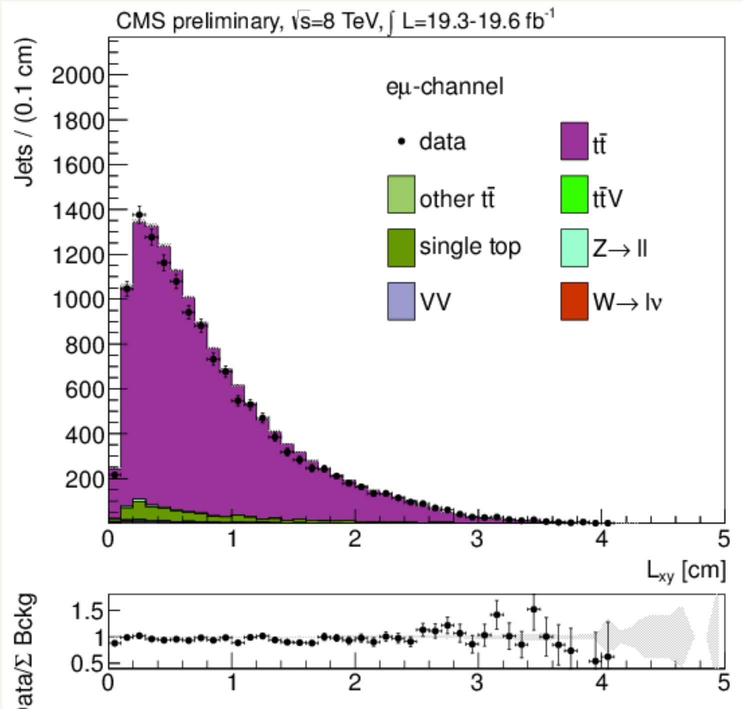
Source of uncertainty	Effect on m_t (GeV)
Signal and background modeling:	
Higher order corrections	+0.15
Initial/final state radiation	±0.09
Hadronization and UE	+0.26
Color reconnection	+0.10
Multiple $p\bar{p}$ interactions	−0.06
Heavy flavor scale factor	±0.06
b-jet modeling	+0.09
PDF uncertainty	±0.11
Detector modeling:	
Residual jet energy scale	±0.21
Flavor-dependent response to jets	±0.16
b tagging	±0.10
Trigger	±0.01
Lepton momentum scale	±0.01
Jet energy resolution	±0.07
Jet ID efficiency	−0.01
Method:	
Modeling of multijet events	+0.04
Signal fraction	±0.08
MC calibration	±0.07
Total systematic uncertainty	±0.49
Total statistical uncertainty	±0.58
Total uncertainty	±0.76

Top Quark Mass - alternatives

example: using the B-hadron lifetime technique (8 TeV)







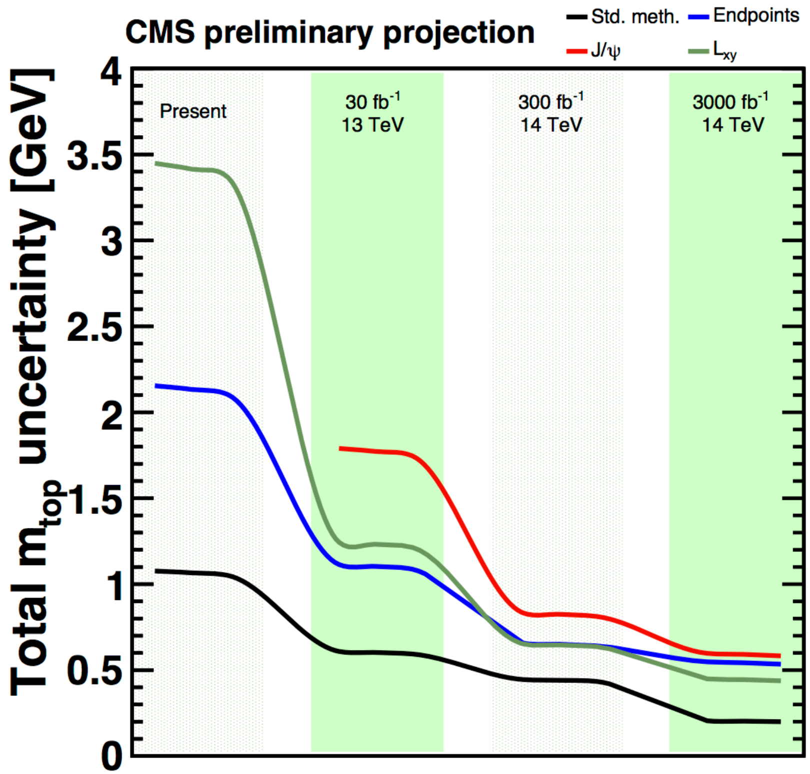
Main uncertainty is the modeling of the top quark p_T

Channel	m_t [GeV]
muon+jets	$173.2 \pm 1.0_{stat} \pm 1.6_{syst} \pm 3.3_{p_T(t)}$
electron+jets	$172.8 \pm 1.0_{stat} \pm 1.7_{syst} \pm 3.1_{p_T(t)}$
electron-muon	$173.7 \pm 2.0_{stat} \pm 1.4_{syst} \pm 2.4_{p_T(t)}$

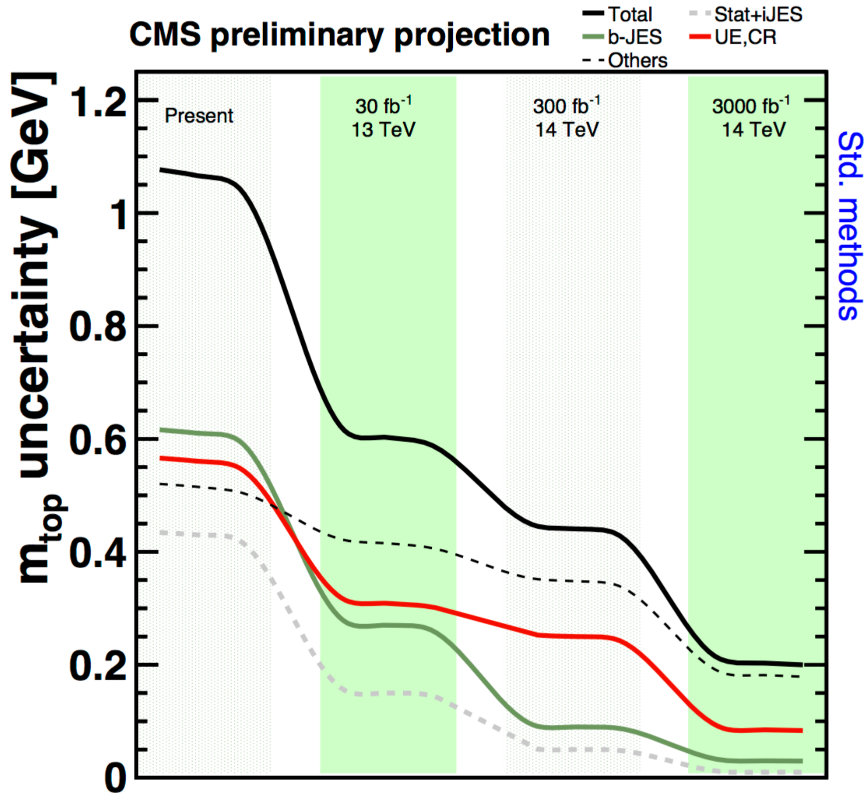
$m_t = 173.5 \pm 1.5_{stat} \pm 1.3_{syst} \pm 2.6_{pt(t)}$ GeV

Top Quark Mass - future

Non-standard methods



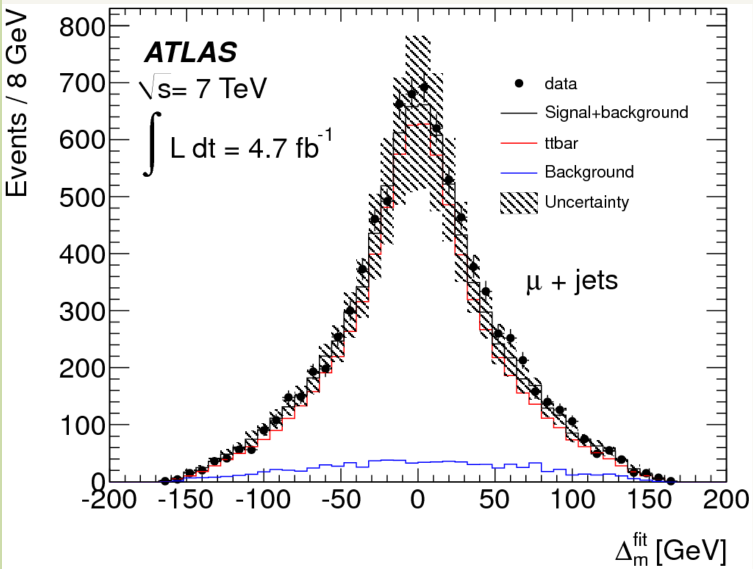
Standard methods

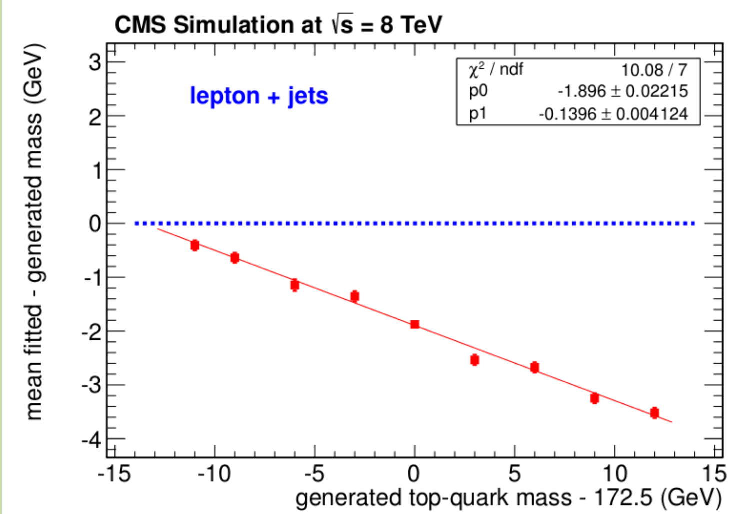


Two or three orders of magnitude in Top Quark sample size, but it will require lots of work to reduce the uncertainty by a factor 3-5.

ATLAS Phys. Lett. B 728C (2014); pp.363-379, CMS JHEP 06(2012)109; CMS TOP-12-031

Top Quark Mass – top versus anti-top





Unique testing of CPT invariance on bare quarks

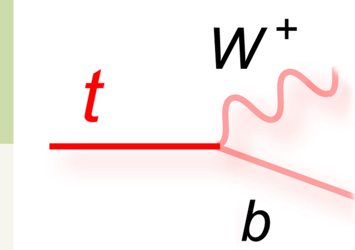
Source CMS TOP-12-031	Estimated effect (MeV)
Jet energy scale	**17** ± 15
Jet energy resolution	8 ± **11**
b vs. $\bar{b}$ jet response	**64** ± 7
Signal fraction	**45** ± 2
Background charge asymmetry	**12.43** ± 0.03
Background composition	**50** ± 1
Pileup	**17.4** ± 0.4
b-tagging efficiency	**20** ± 8
b vs. $\bar{b}$ tagging efficiency	**43** ± 6
Method calibration	15 ± **54**
Parton distribution functions	**12** ± 3
Total	122

Results (in GeV), still statistics dominated

CMS	7 TeV	-0.44 +- 0.46 (stat) +- 0.27 (syst)
CMS	8 TeV	-0.27 +- 0.20 (stat) +- 0.12 (syst)
ATLAS	7 TeV	0.67 +- 0.61 (stat) +- 0.41 (syst)

CMS arXiv:1404.2292

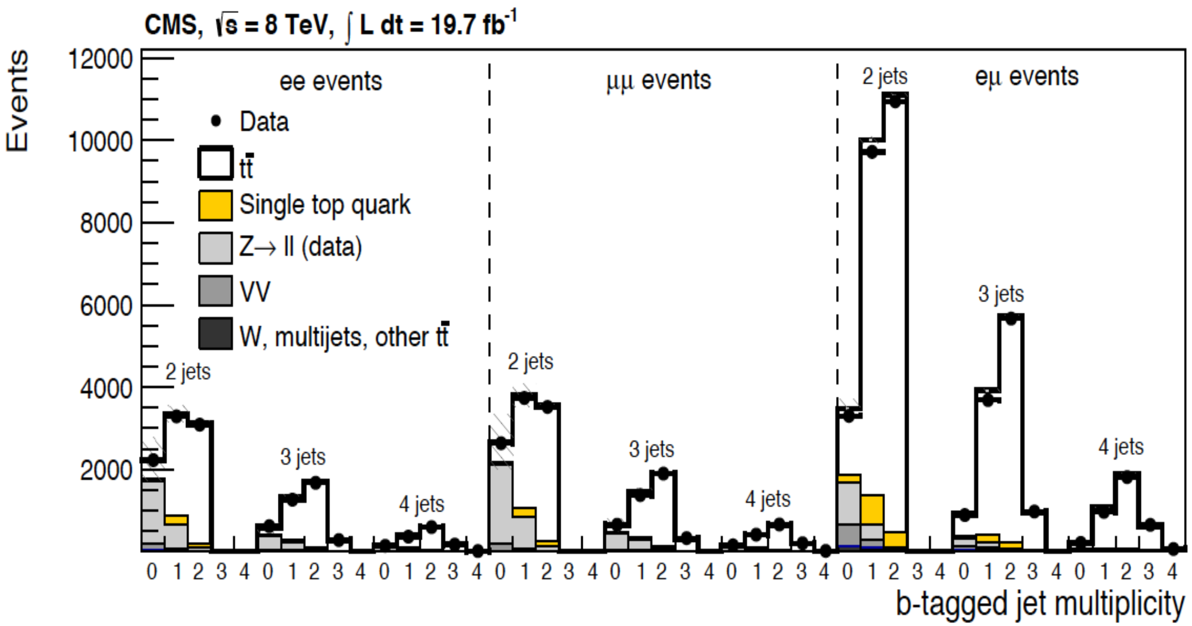
Top Quark Decay

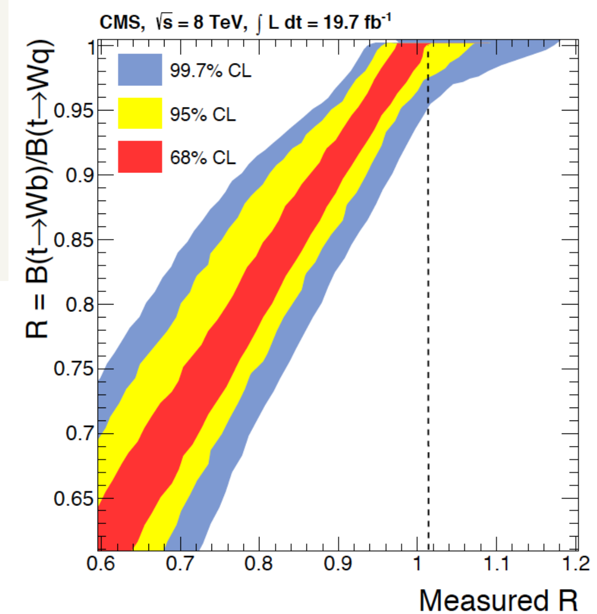


Branching to other quarks t→Wq is measured

R = BR(t→Wb) / BR(t→Wq)

Mis-reconstructions taken into account in a large likelihood fit (eg. jet assignment & flavor tagging matching). B-tagging efficiency from other measurements, and no $|V_{tb}|$ assumption made.





$$\mathcal{R} = 1.014 \pm 0.003\,(\text{stat.}) \pm 0.032\,(\text{syst.})$$

$$\mathcal{R} > 0.955 \text{ at } 95\% \text{ CL}$$

Also indirect Top Quark width:

$$\Gamma_t = \frac{\sigma_{t\text{-ch.}}}{\mathcal{B}(t \to Wb)} \cdot \frac{\Gamma(t \to Wb)}{\sigma^{\text{theor.}}_{t\text{-ch.}}}$$

$$\sum_q \mathcal{B}(t \to Wq) = 1$$

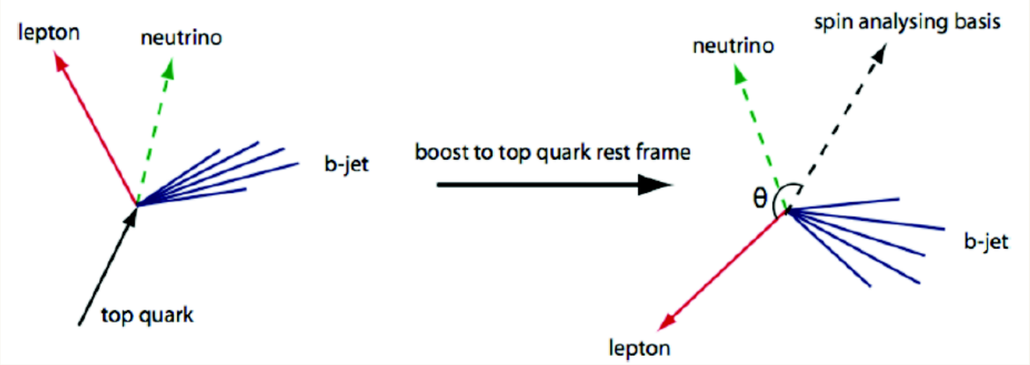
$$\Gamma_t = 1.36 \pm 0.02\,(\text{stat.})^{+0.14}_{-0.11}\,(\text{syst.})\,\text{GeV}$$

CMS TOP-13-008

W helicity in Top Quark Decay

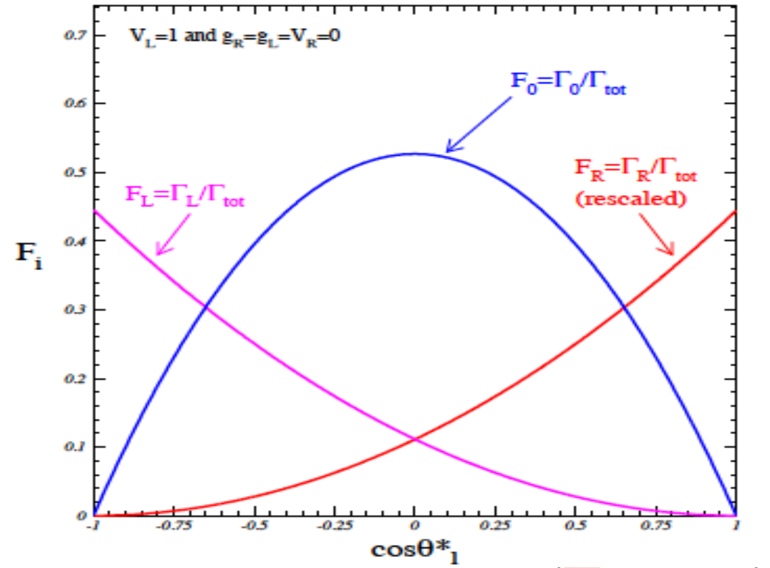
Reweighting method to fit the cosθ distribution with 2 free parameters

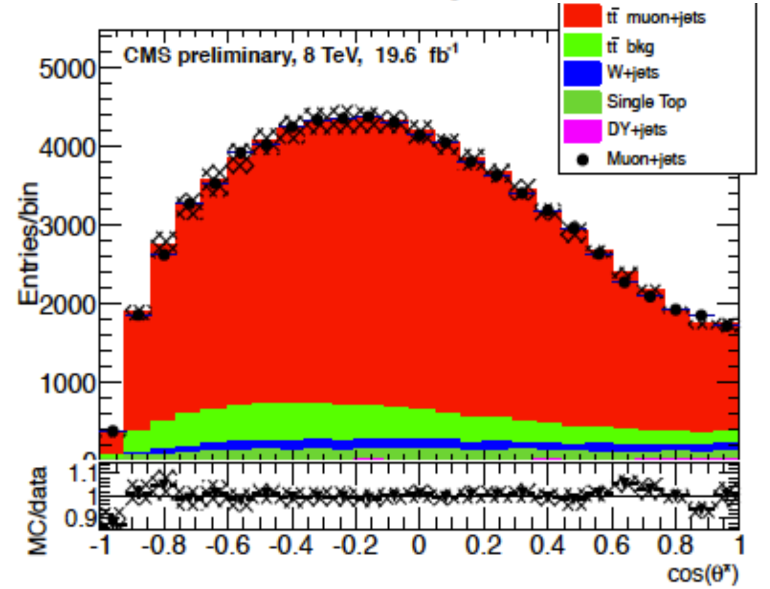
Theoretical uncertainties dominate and the MET shape



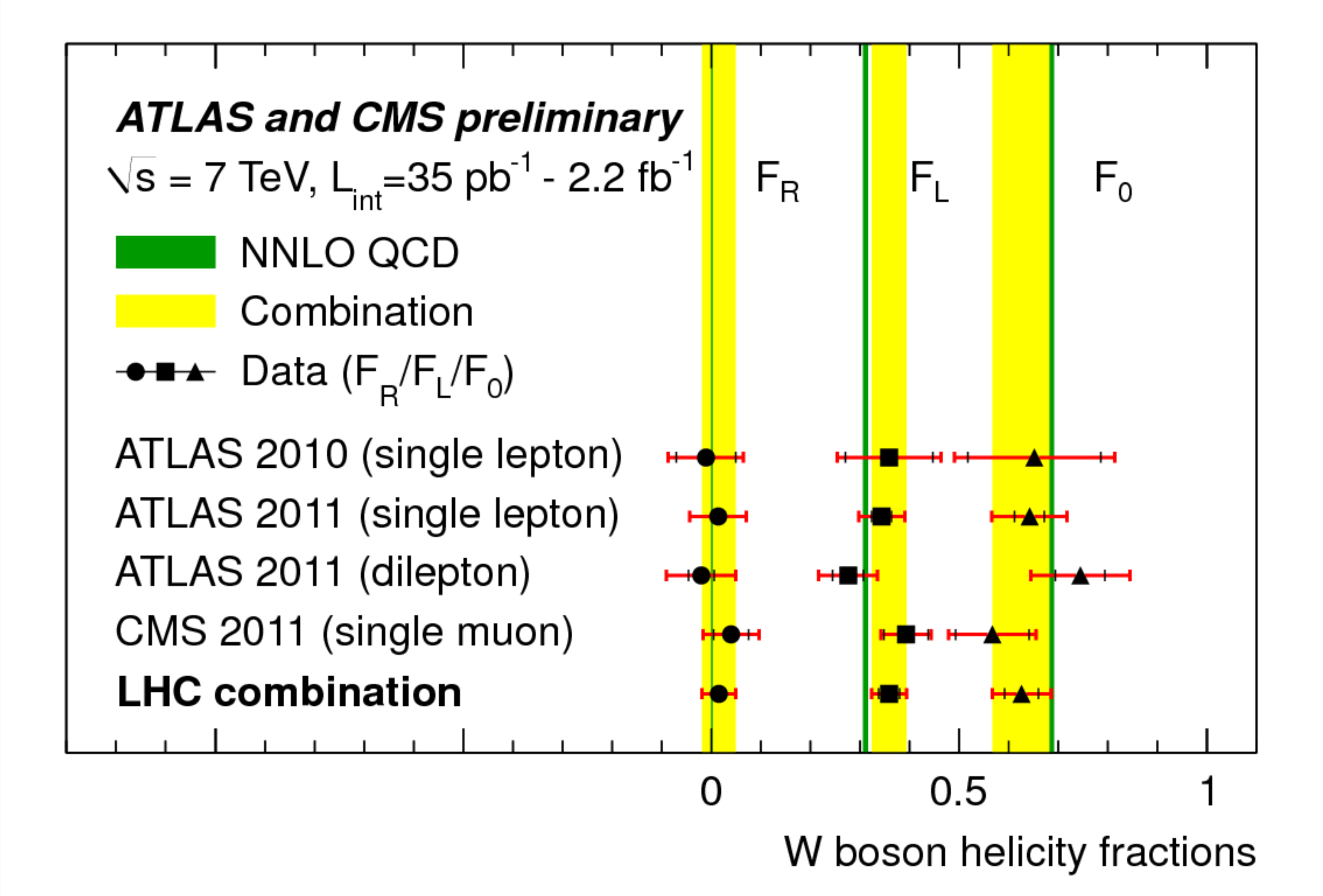
$$\rho(\cos\theta_l^*) \equiv \frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_l^*} = \frac{3}{8}(1-\cos\theta_l^*)^2 F_L + \frac{3}{8}(1+\cos\theta_l^*)^2 F_R + \frac{3}{4}\sin^2\theta_l^* F_0,$$

$$F_0 = 0.659 \pm 0.015(\text{stat.}) \pm 0.023(\text{syst.}),$$
$$F_L = 0.350 \pm 0.010(\text{stat.}) \pm 0.024(\text{syst.}),$$





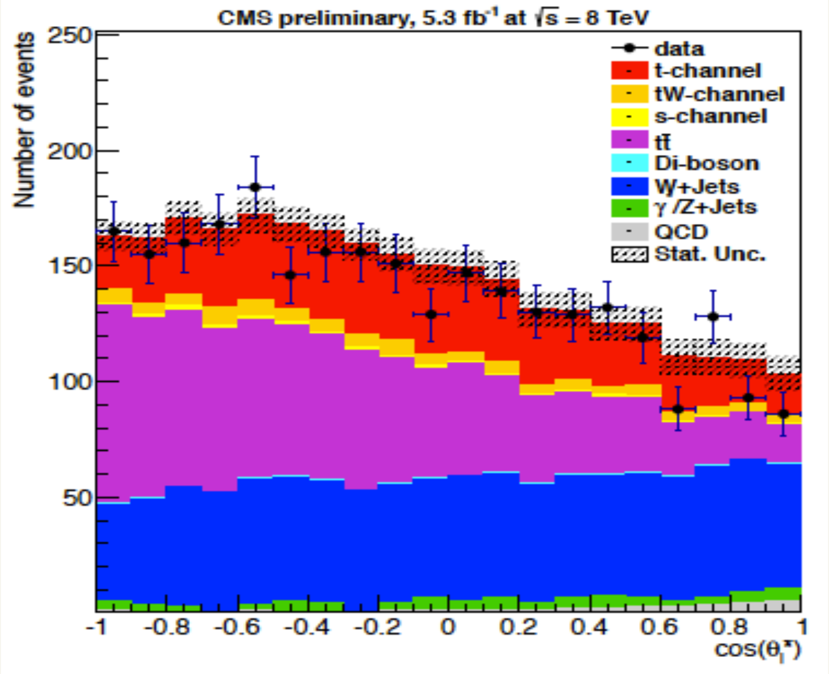
W helicity in Top Quark Decay

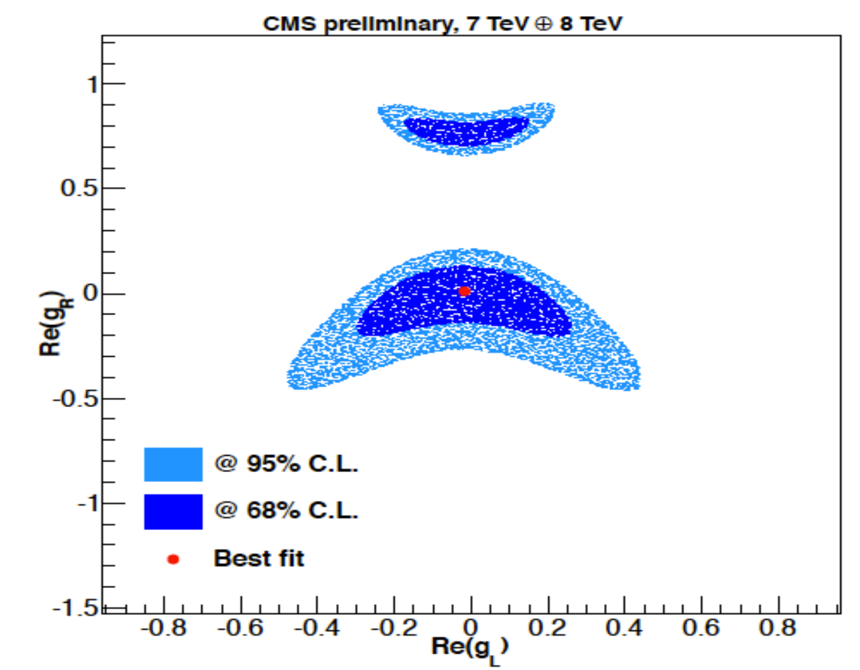


W helicity in Top Quark Decay

Also measured this distribution in single-top events

$$F_L^{\text{Comb.}} = 0.293 \pm 0.069(\text{stat.}) \pm 0.030(\text{syst.}),$$
$$F_0^{\text{Comb.}} = 0.713 \pm 0.114(\text{stat.}) \pm 0.023(\text{syst.}),$$
$$F_R^{\text{Comb.}} = -0.006 \pm 0.057(\text{stat.}) \pm 0.027(\text{syst.}),$$





$$\mathcal{L}_{tWb}^{anom.} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{m_W}(g_L P_L + g_R P_R)tW_{\mu}^{-} + H.C,$$

ATLAS Phys. Rev. Lett. 111, 232002 (2013)

Top Quark polarization

Parity conservation in the strong production of top quark pair events implies zero longitudinal polarization of the to quarks.

	b	ℓ	d	u
α (NLO)	-0.39	0.998	0.93	-0.31

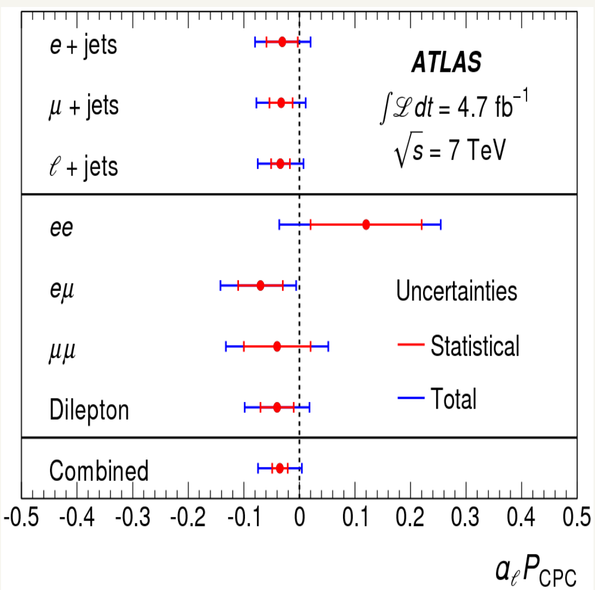
$P_{\rm SM} = 0.003 \pm 0.001$ [PLB 725 (2013) 115]

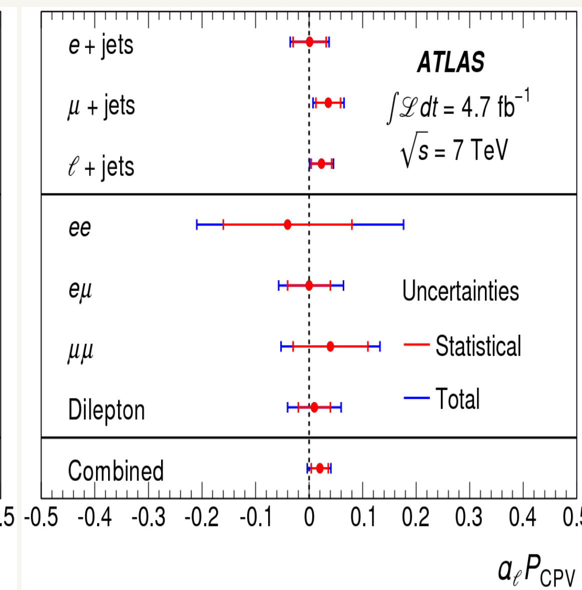
$$\frac{1}{\sigma}\frac{d^2\sigma}{d[\cos(\theta_i)]d[\cos(\theta_j)]} = \frac{1}{4}[P\alpha_i \cos(\theta_i) + P\alpha_j \cos(\theta_j) + A\alpha_i\alpha_j \cos(\theta_i)\cos(\theta_j)]$$

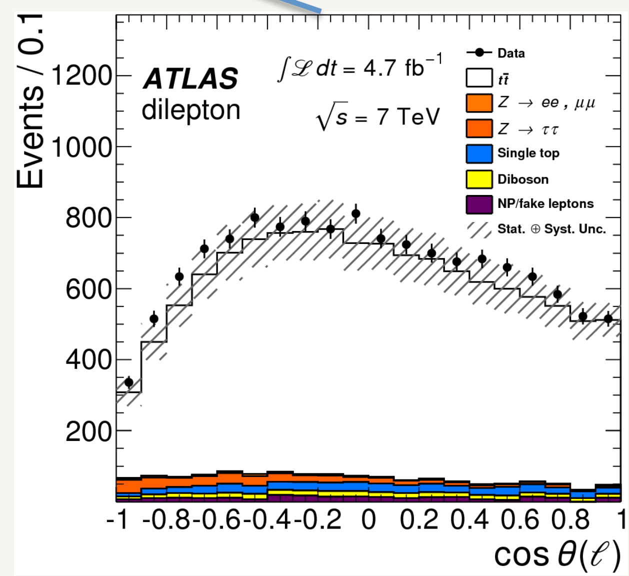
$$P = 2A_P$$

$$A_P = \frac{N(\cos\theta_\ell)>0 - N(\cos\theta_\ell)<0}{N(\cos\theta_\ell)>0 + N(\cos\theta_\ell)<0}$$

$$A_P = 0.005 \pm 0.013\,(\text{stat.}) \pm 0.020\,(\text{syst.}) \pm 0.008(p_{\rm T}^t\ \text{reweig.})$$







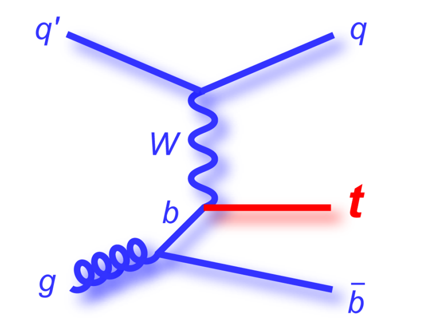
CP conservation/violation in top decays if top and anti-top have same/opposite Parity

Top Quark Decay – polarization

Also polarization measurement using Single-Top

$$\frac{d\Gamma}{d\cos\theta_X} = \frac{\Gamma}{2}(1 + P_t \alpha_X \cos\theta_X) \equiv \Gamma(\frac{1}{2} + A_X \cos\theta_X)$$

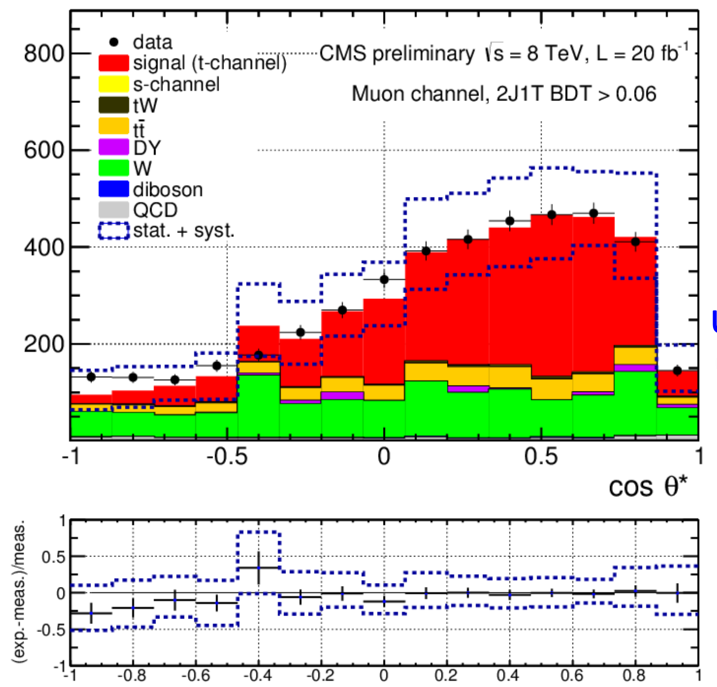
(angle between the charged lepton and the untagged jet)



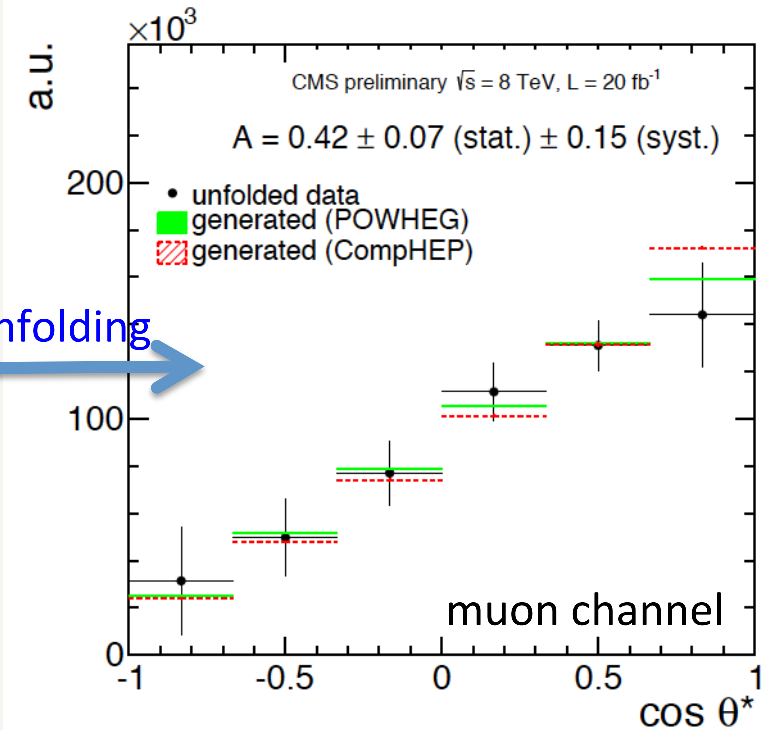
$$A_l \equiv \frac{1}{2} \cdot P_t \cdot \alpha_l = \frac{N(\uparrow) - N(\downarrow)}{N(\uparrow) + N(\downarrow)}$$

$$P_t = 0.82 \pm 0.12(stat.) \pm 0.32(syst.) = 0.82 \pm 0.34(tot.)$$

(with α_l = 1) *Should be 100% polarized due to V-A coupling*



unfolding



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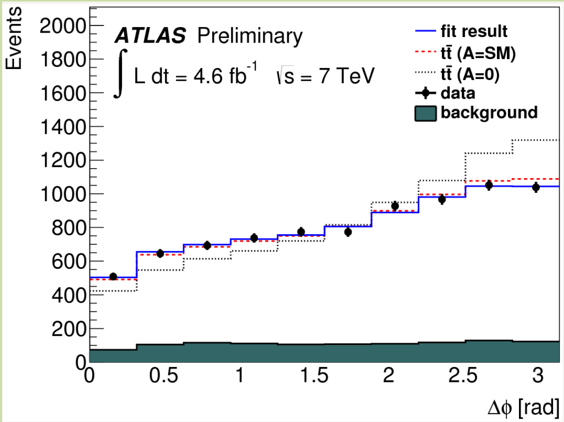
ATLAS Phys. Rev. Lett. 108, 212001 (2012); ATLAS CONF-2013-101; CMS Phys Rev Lett 112 (2014) 182001

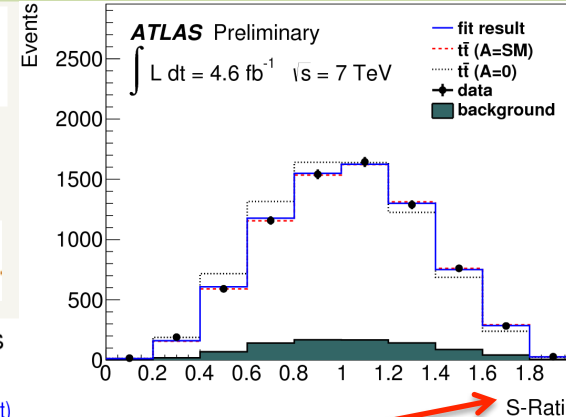
Top Quark spin correlations

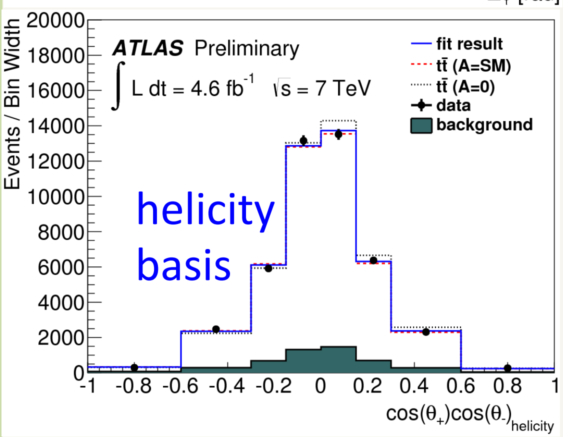


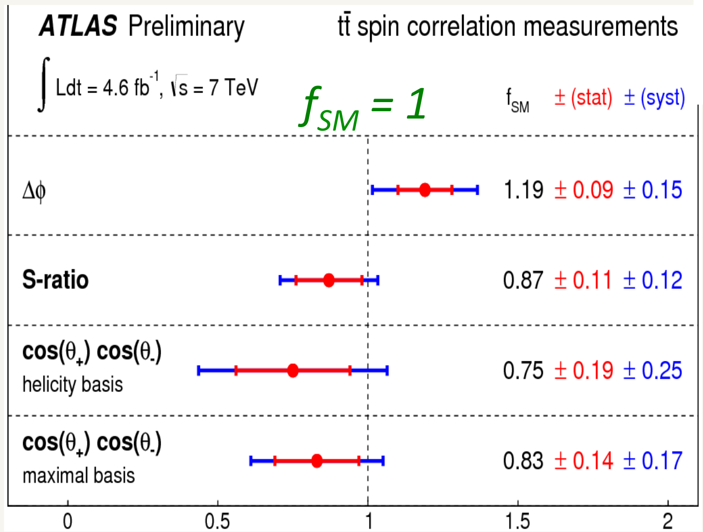
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_+\, d\cos\theta_-} = \frac{1}{4}(1 + A\,\alpha_+\alpha_-\cos\theta_+\cos\theta_-)$$

Fit fraction of top quark pair events with spin correlations

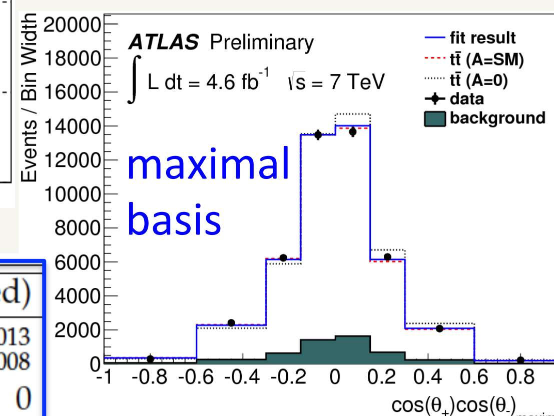
$$f_{SM} = N_{A=SM}/(N_{A=SM} + N_{A=0})$$







$$S = \frac{(|M|^2_{RR} + |M|^2_{LL})_{corr}}{(|M|^2_{RR} + |M|^2_{LL})_{uncorr}} = \frac{m_t^2\{(t\cdot l^+)(t\cdot l^-) + (\bar{t}\cdot l^+)(\bar{t}\cdot l^-) - m_t^2(l^+\cdot l^-)\}}{(t\cdot l^+)(\bar{t}\cdot l^-)(t\cdot \bar{t})}$$



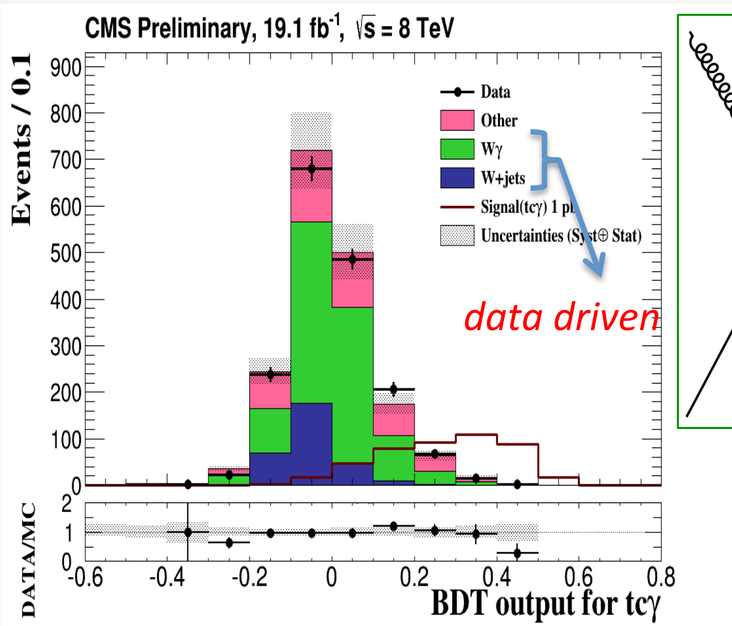
Asymmetry	Data (unfolded)	NLO (SM, correlated)	NLO (uncorrelated)
$A_{\Delta\phi}$	$0.113 \pm 0.010 \pm 0.006 \pm 0.012$	$0.115^{+0.014}_{-0.016}$	$0.210^{+0.013}_{-0.008}$
$A_{c_1c_2}$	$-0.021 \pm 0.023 \pm 0.025 \pm 0.010$	-0.078 ± 0.006	0

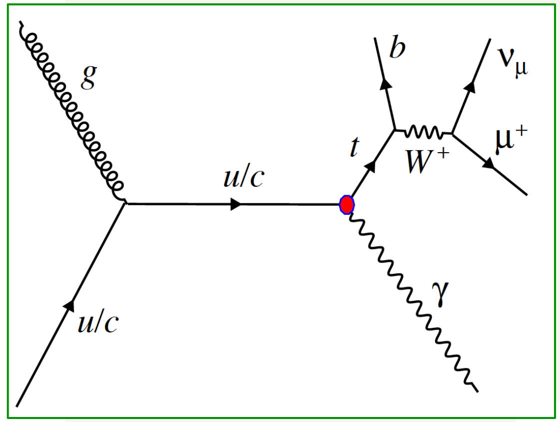
CMS 7 TeV

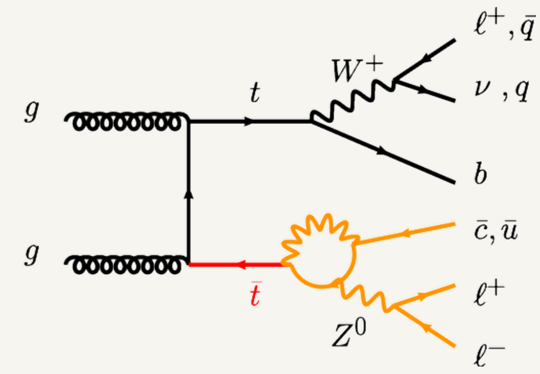
Dominated by systematic modeling uncertianties

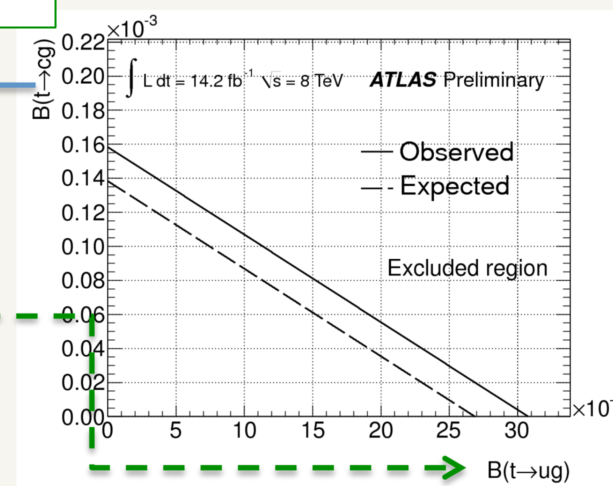
Top Quark Rare Decays – FCNC

BDT analysis combining for example kinematic variables of the photon, lepton and jets in the single-top event









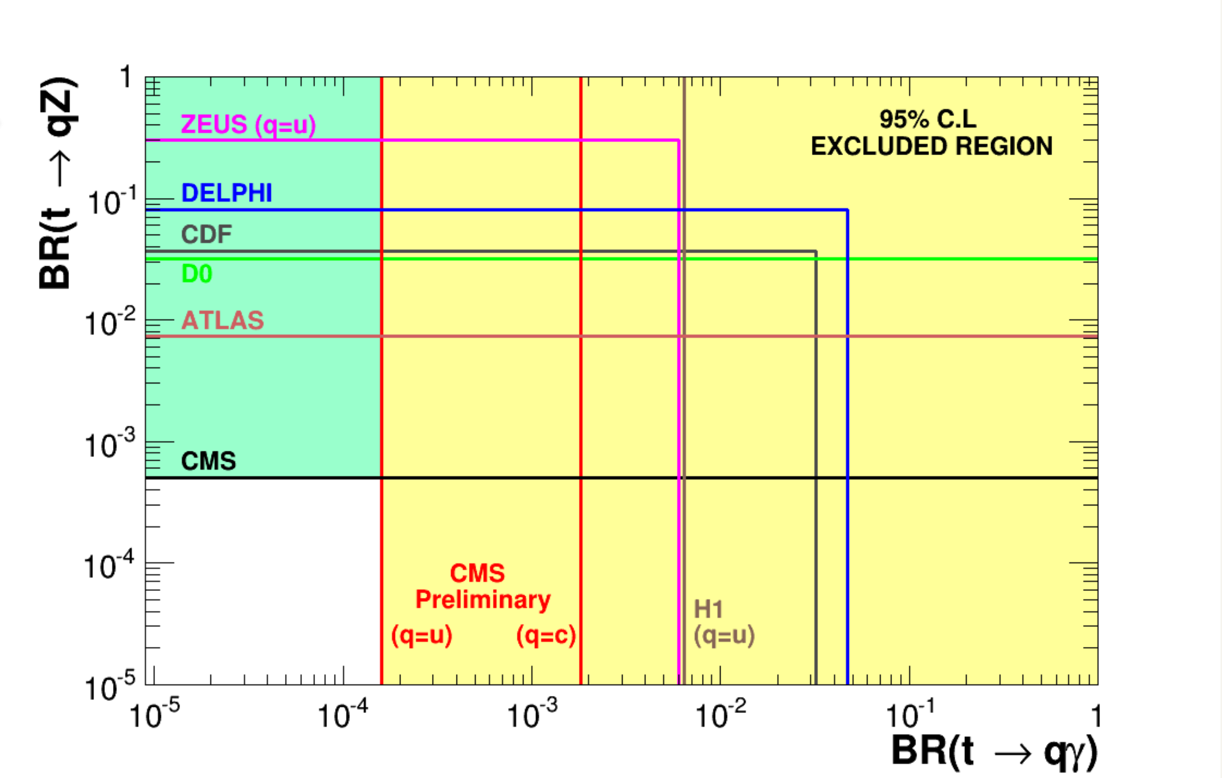
ATLAS and CMS best limits:

ATLAS	BR(t->ug)	< 0.0031%
ATLAS	BR(t->cg)	< 0.016%
CMS	BR(t->Zq)	< 0.05%
CMS	BR(t->uγ)	< 0.016%
CMS	BR(t->cγ)	< 0.18%

Towards inclusive EFT analyses collecting info from pair & single top production

Top Quark Rare Decays – FCNC

The limit for FCNC is reduced by orders of magnitude, and this will continue



CMS, projection using the selection efficiencies for signal and background

$\mathcal{B}(t \to Zq)$	$19.5\,fb^{-1}$ @ 8 TeV	$300\,fb^{-1}$ @ 14 TeV	$3000\,fb^{-1}$ @ 14 TeV
Exp. bkg. yield	3.2	184	1841
Expected limit	$< 0.10\%$	$< 0.011\%$	$< 0.007\%$

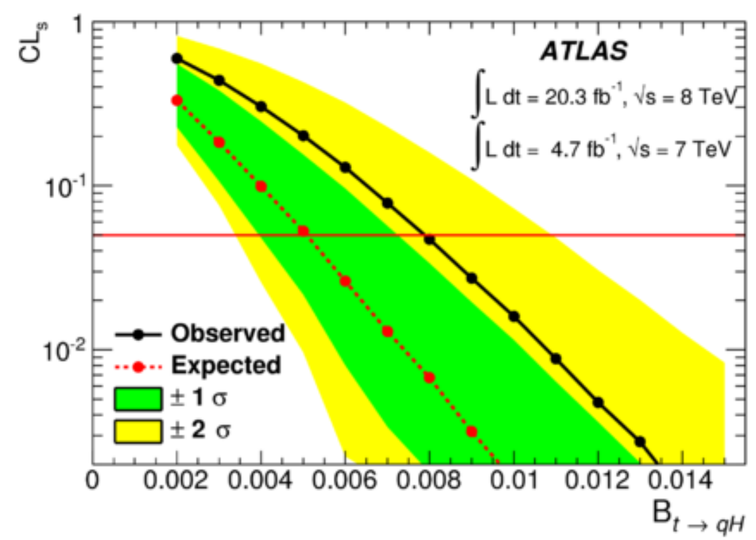
Top Quark Rare Decays – FCNC

CMS (8 TeV) re-interpretation of SUSY multi-lepton analyses
Limits at 95% CL
BR(t→cH) < 1.28%

Higgs Decay Mode	obs	exp	1σ range
$h \to WW^*$ (BR = 23.1 %)	1.58 %	1.57 %	(1.02–2.22) %
$h \to \tau\tau$ (BR = 6.15 %)	7.01 %	4.99 %	(3.53–7.74) %
$h \to ZZ^*$ (BR = 2.89 %)	5.31 %	4.11 %	(2.85–6.45) %
combined	1.28 %	1.17 %	(0.85–1.73) %

top-charm flavor violating Higgs Yukawa couplings of $\sqrt{|\lambda^h_{tc}|^2 + |\lambda^h_{ct}|^2} < 0.21$

ATLAS (7-8 TeV) using H→γγ
Limits at 95% CL
BR(t→qH) < 0.79%
$\sqrt{|\lambda^h_{tc}|^2 + |\lambda^h_{ct}|^2} < 0.17$



Expectation in SM: BR(t→cH) ≈ 3 . 10^{-15}
arXiv:hep-ph/0409342

Top Quark Charge

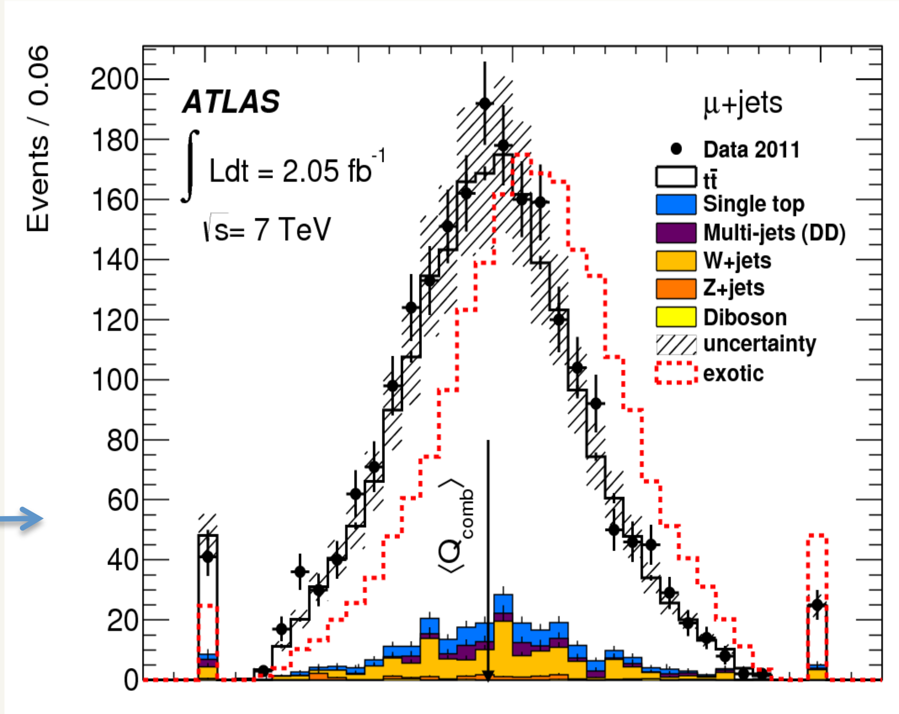
Event-by-event reconstruction of the b-quark charge and combine with the measured lepton charge: $\kappa=0.5$

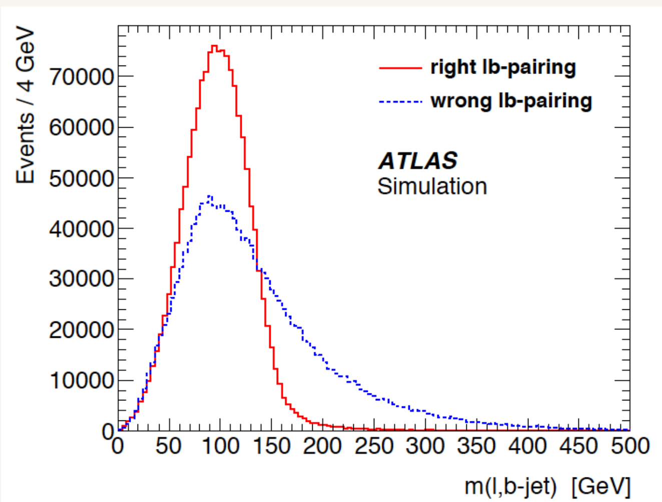
$$Q_{b-\text{jet}} = \frac{\sum_i Q_i |\vec{j}\cdot\vec{p}_i|^\kappa}{\sum_i |\vec{j}\cdot\vec{p}_i|^\kappa}$$

Weighted sum of track charges

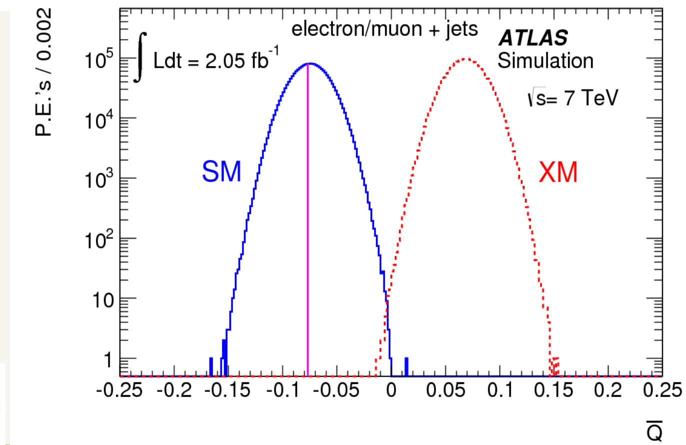
Lepton and b-quark pairing using the mass of the "b+l" system.

$$Q_{\text{comb}} = Q^{\ell}_{b-\text{jet}} \cdot Q_\ell$$





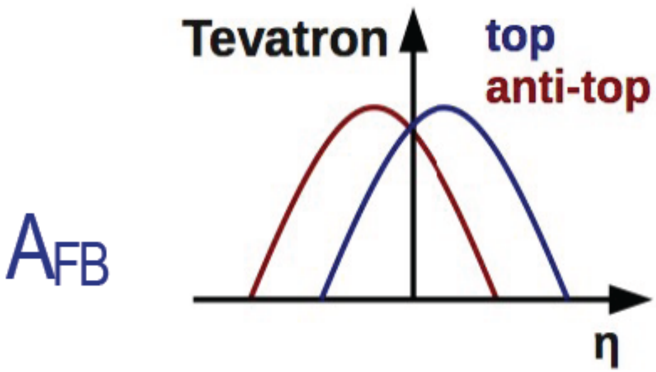
Charge -4/3 excluded by >8σ



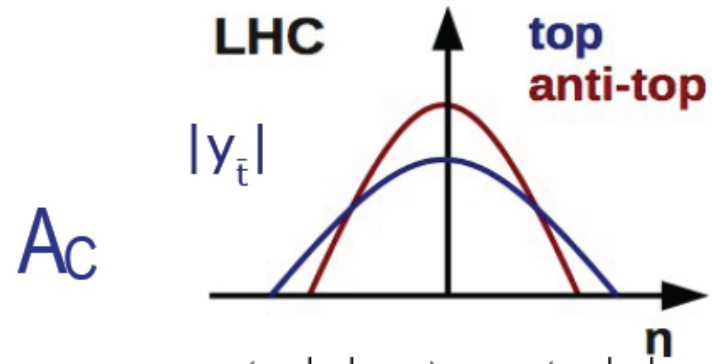
$$0.64 \pm 0.02\ (\text{stat.}) \pm 0.08\ (\text{syst.})$$

D0 arXiv:1405.0421; CDF Note 11035

Top Quark Event Variables – Asymmetries

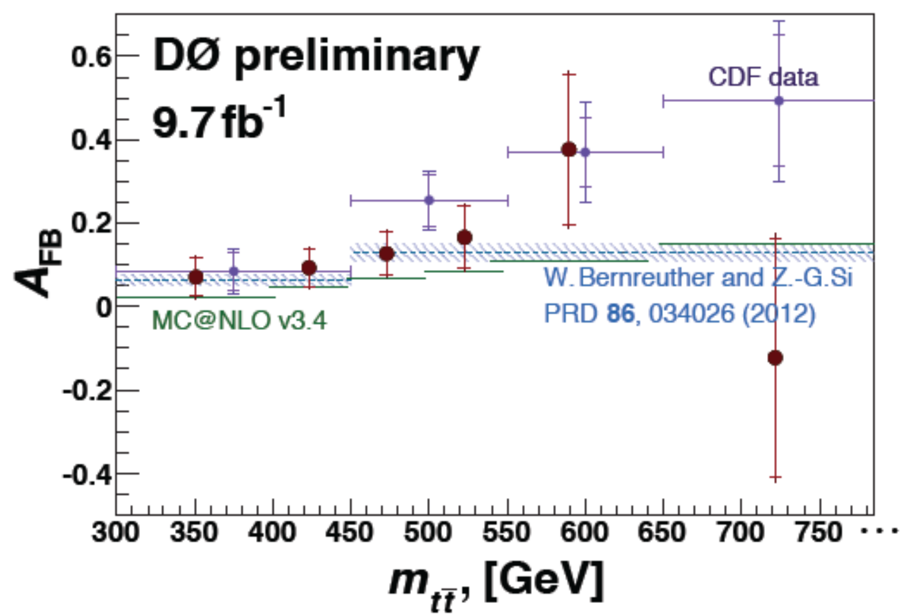


$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

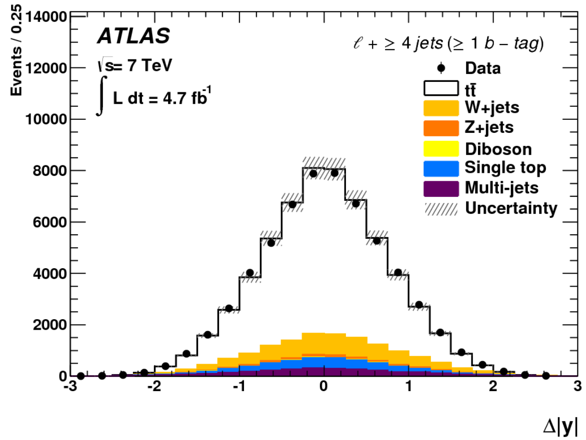


$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

- New A_{FB} measurement from D0
- Agrees with SM expectations
- CDF result with ~2σ deviation is shown



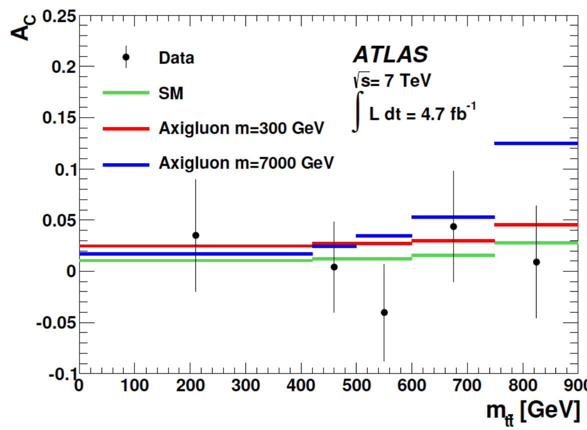
Top Quark Event Variables – Charge Asymmetry



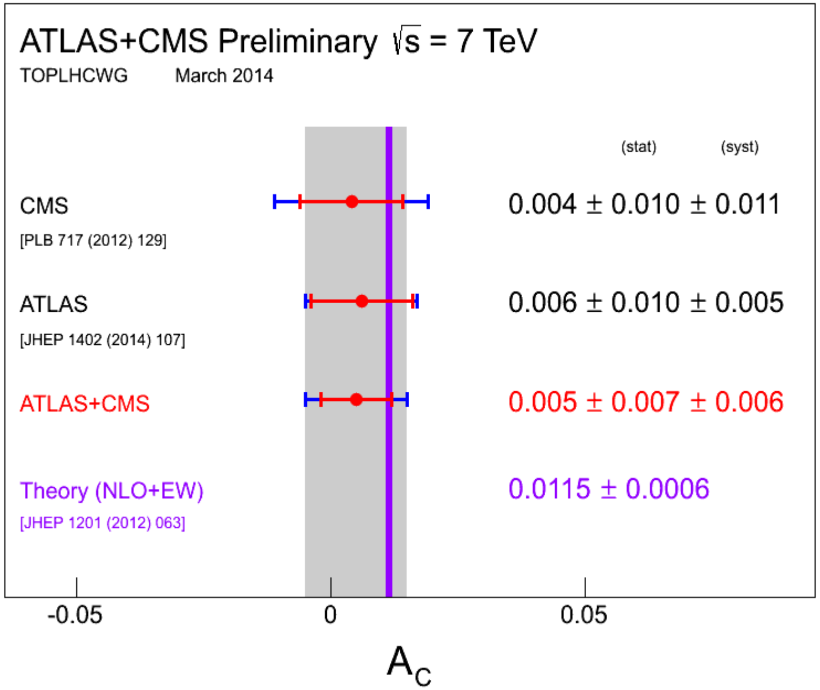
$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

$$\Delta|y| \equiv |y_t| - |y_{\bar{t}}|$$

After unfolding of acceptance and detector effects, hence a parton-level A_C measurement

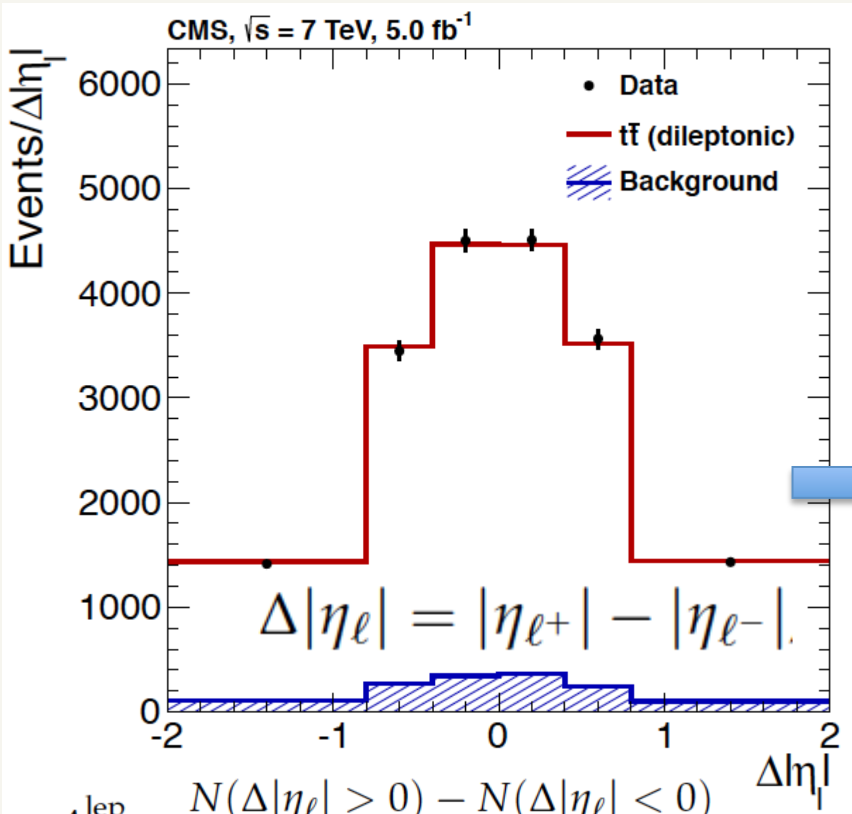


		ATLAS	CMS	Comb.	Corr.
	A_C	0.006	0.004	0.005	0.058
Uncertainties	Statistical	0.010	0.010	0.007	0
	Detector response model	0.004	0.007	0.004	0
	Signal model	< 0.001	0.002	0.001	1
	W+jets model	0.002	0.004	0.003	0.5
	QCD model	< 0.001	0.001	0.000	0
	Pileup+MET	0.002	< 0.001	0.001	0
	PDF	0.001	0.002	0.001	1
	MC statistics	0.002	0.002	0.001	0
	Model dependence				
	Specific physics models	< 0.001	*	0.000	0
	General simplified models	*	0.007	0.002	0
	Systematic uncertainty	0.005	0.011	0.006	
	Total uncertainty	0.011	0.015	0.009	



Top Quark Event Variables – Charge Asymmetry

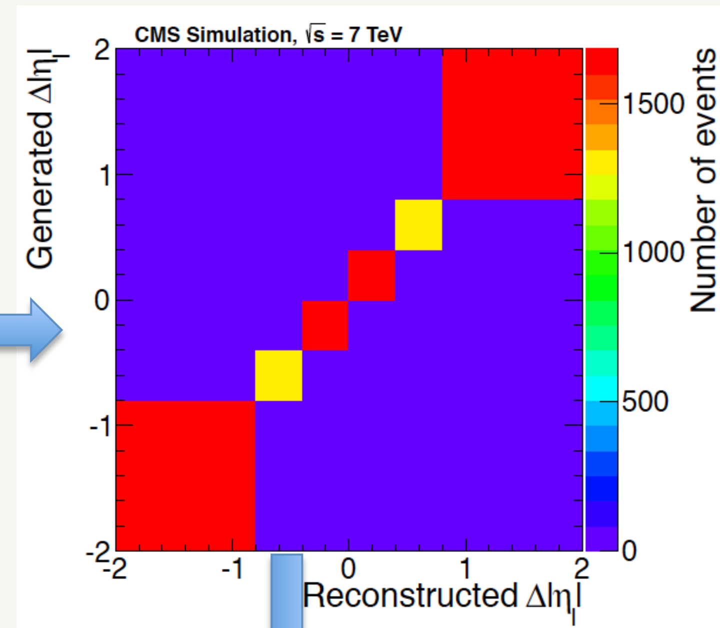
First measurement in the di-lepton channel of the lepton charge asymmetry



$$\Delta|\eta_\ell| = |\eta_{\ell^+}| - |\eta_{\ell^-}|.$$

$$A_C^{\text{lep}} = \frac{N(\Delta|\eta_\ell| > 0) - N(\Delta|\eta_\ell| < 0)}{N(\Delta|\eta_\ell| > 0) + N(\Delta|\eta_\ell| < 0)}$$

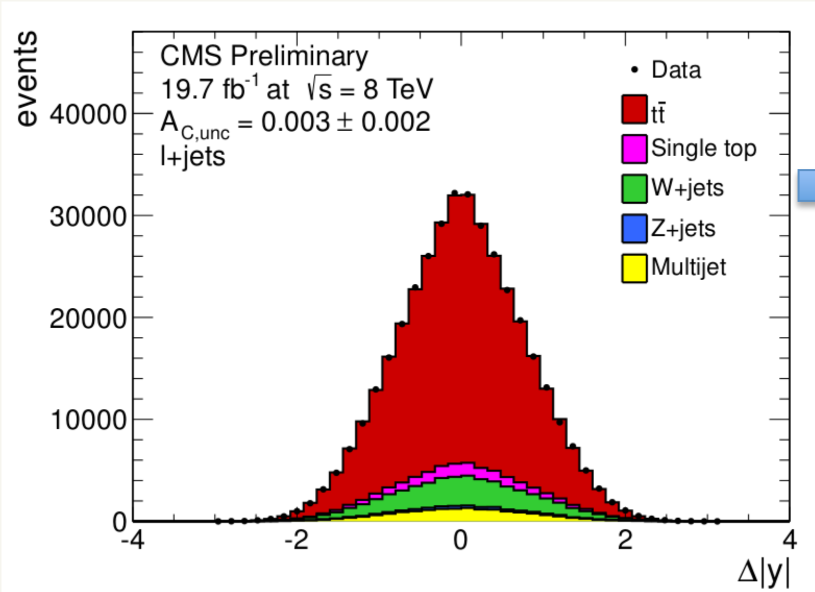
Unfolding to correct the data for acceptance, selection and resolution.

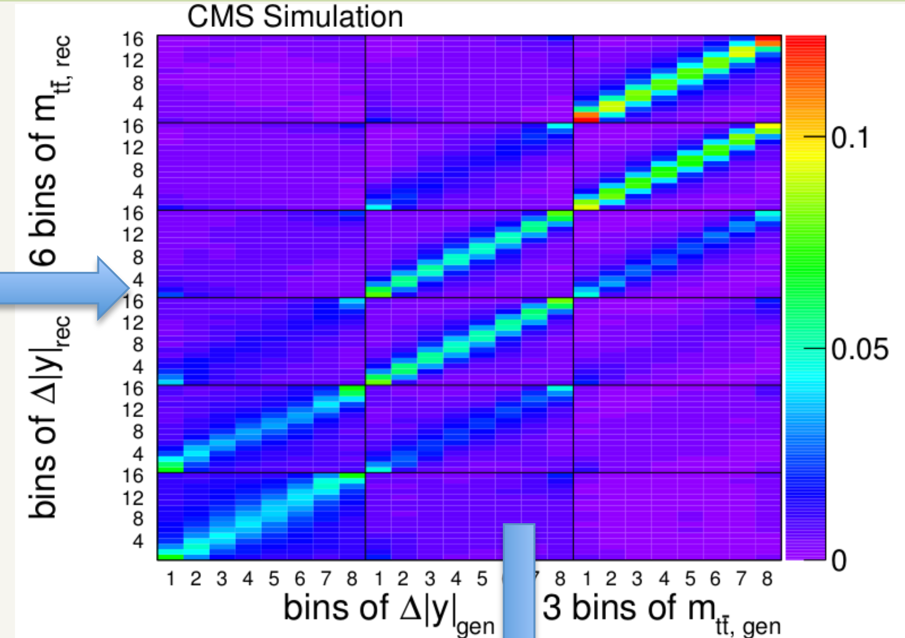


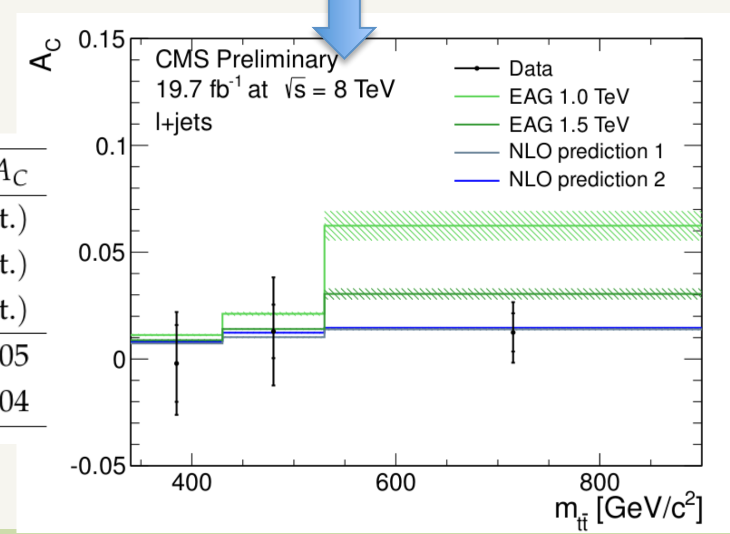
Variable	Data (unfolded)	MC@NLO prediction	NLO theory
A_C	$-0.010 \pm 0.017 \pm 0.008$	0.004 ± 0.001	0.0123 ± 0.0005
A_C^{lep}	$0.009 \pm 0.010 \pm 0.006$	0.004 ± 0.001	0.0070 ± 0.0003

Top Quark Event Variables – Charge Asymmetry

Measurement in the lepton+jet channel







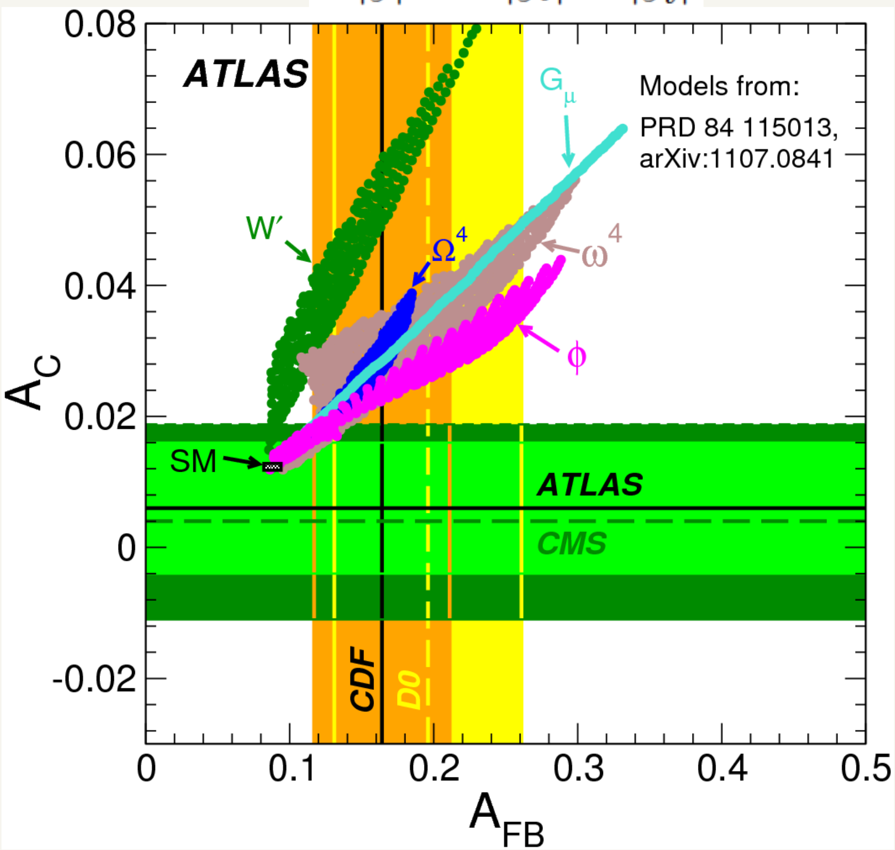
Asymmetry	A_C
Reconstructed	0.003 ± 0.002 (stat.)
BG-subtracted	0.002 ± 0.002 (stat.)
Unfolded	0.005 ± 0.007 (stat.) ± 0.006 (syst.)
Theory prediction [Kühn, Rodrigo] [9, 33]	0.0102 ± 0.0005
Theory prediction [Bernreuther, Si] [34, 35]	0.0111 ± 0.0004

Top Quark Event Variables – Asymmetries

LHC (proton-proton)

$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

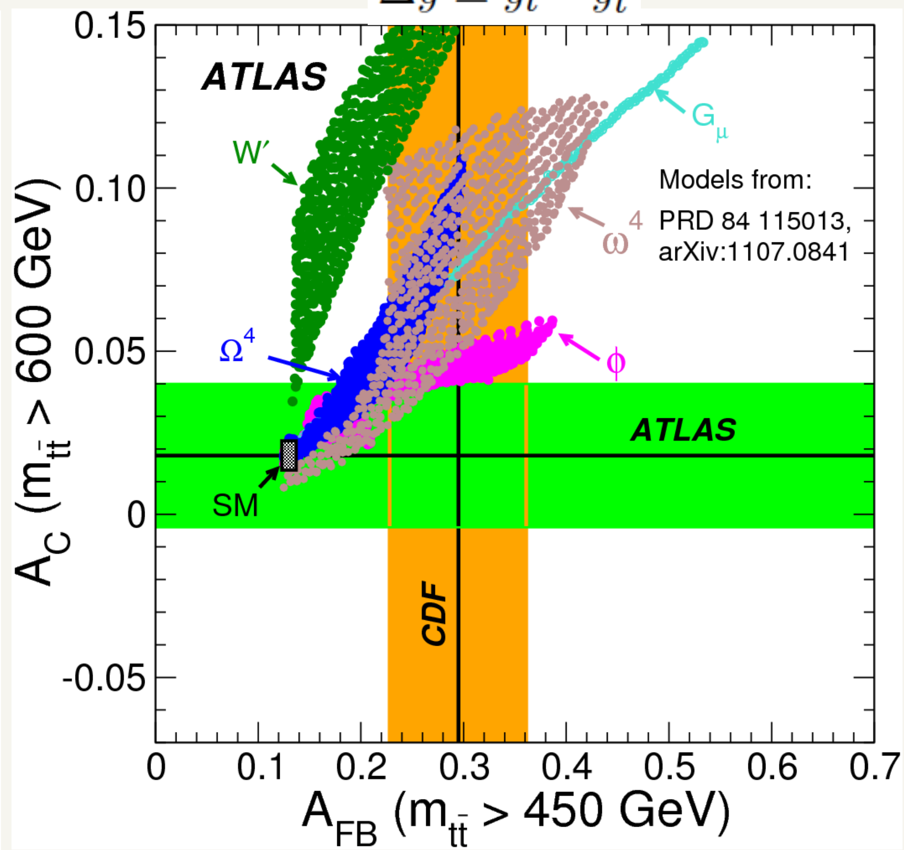
$$\Delta|y| \equiv |y_t| - |y_{\bar{t}}|$$



Tevatron (antiproton-proton)

$$A_{FB} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

$$\Delta y \equiv y_t - y_{\bar{t}}$$



Top Quark Physics – the future

- TOPLHCWG success