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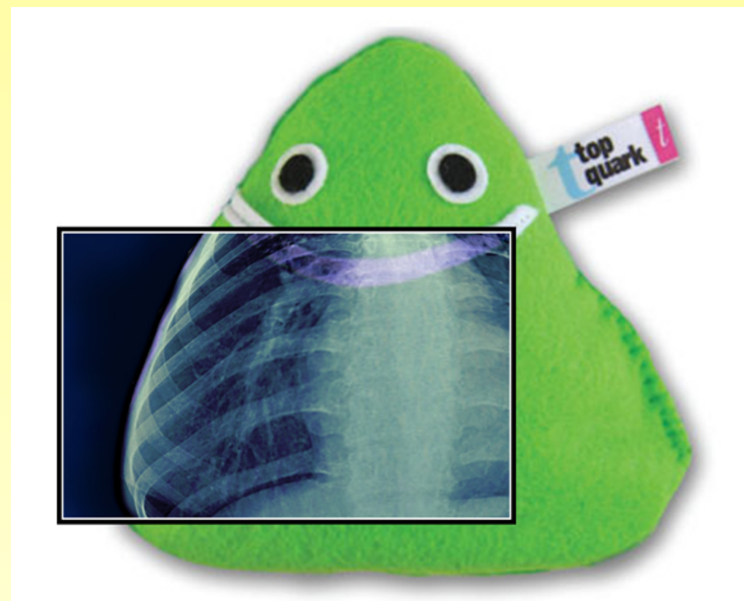
Top Quark Properties at the LHC

Most recent results



Frédéric Déliot
CEA/Irfu-Saclay

On behalf of the ATLAS and CMS collaborations

LHCP 2015, Saint Petersburg, 2 September 2015

Why do we study the top quark ?

- The top quark is the heaviest elementary particle:

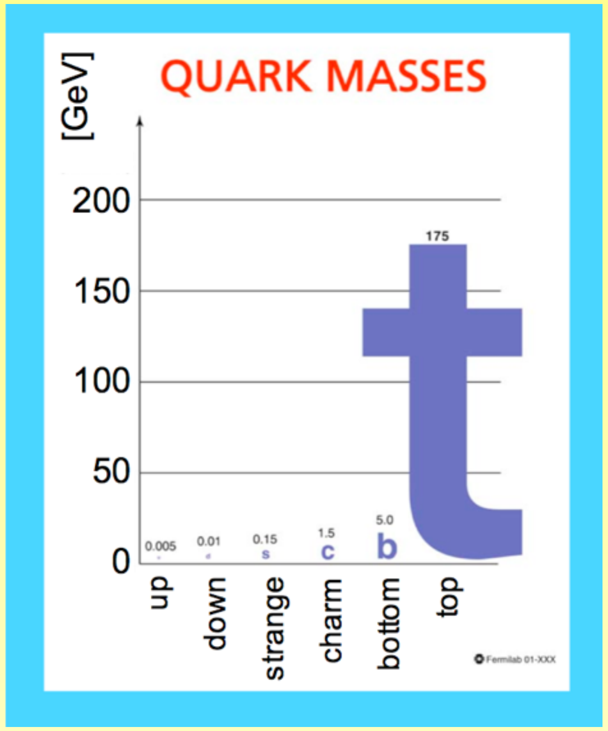
$$\mathcal{L}_{\text{Yukawa}} = -\lambda_t \overline{\psi_{Lt}} \Phi \psi_{Rt}$$

$$\lambda_t \approx 1 \text{ !!}$$

$$m_t >> m_b$$

$$\tau \approx 3.10^{-25} s << \tau_{\text{decorrel}} \approx 10^{-21} s$$

$$\tau \approx 3.10^{-25} s << \Lambda_{\text{QCD}}^{-1}$$



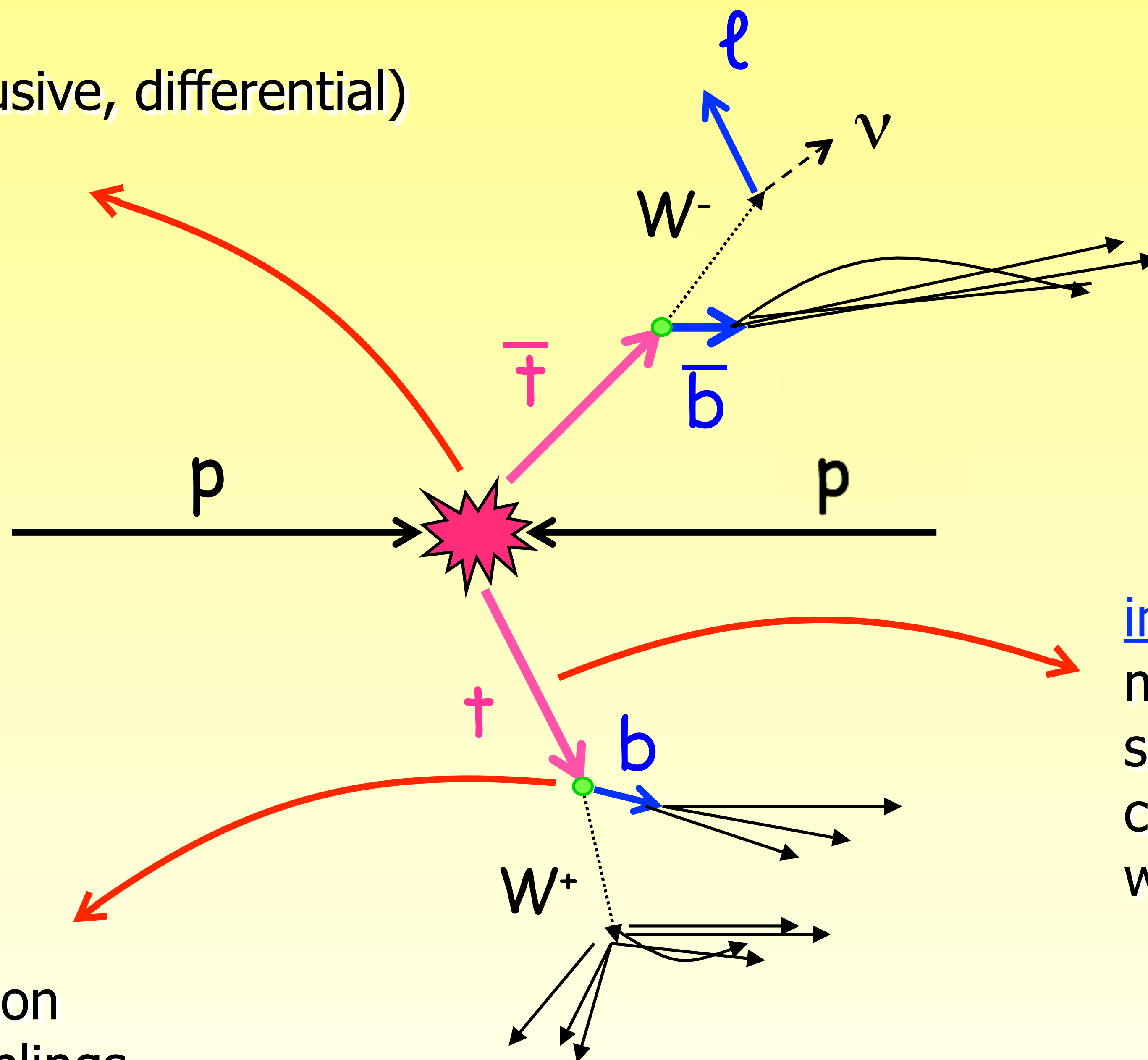
- The top quark is unique:
  - coupling to the Higgs boson close to 1: special role in the electroweak symmetry breaking ?
  - decay before hadronizing: unique way to observe a bare quark

- Special sector to search for new physics:
  - top quark properties can be "altered" by new physics (Z′, charged Higgs, SUSY, …)

Top quark properties

example from $t\bar{t}$ events

production:
cross sections (inclusive, differential)
charge asymmetry
top polarization
color flow



intrinsic:
mass
spin correlation
charge
width

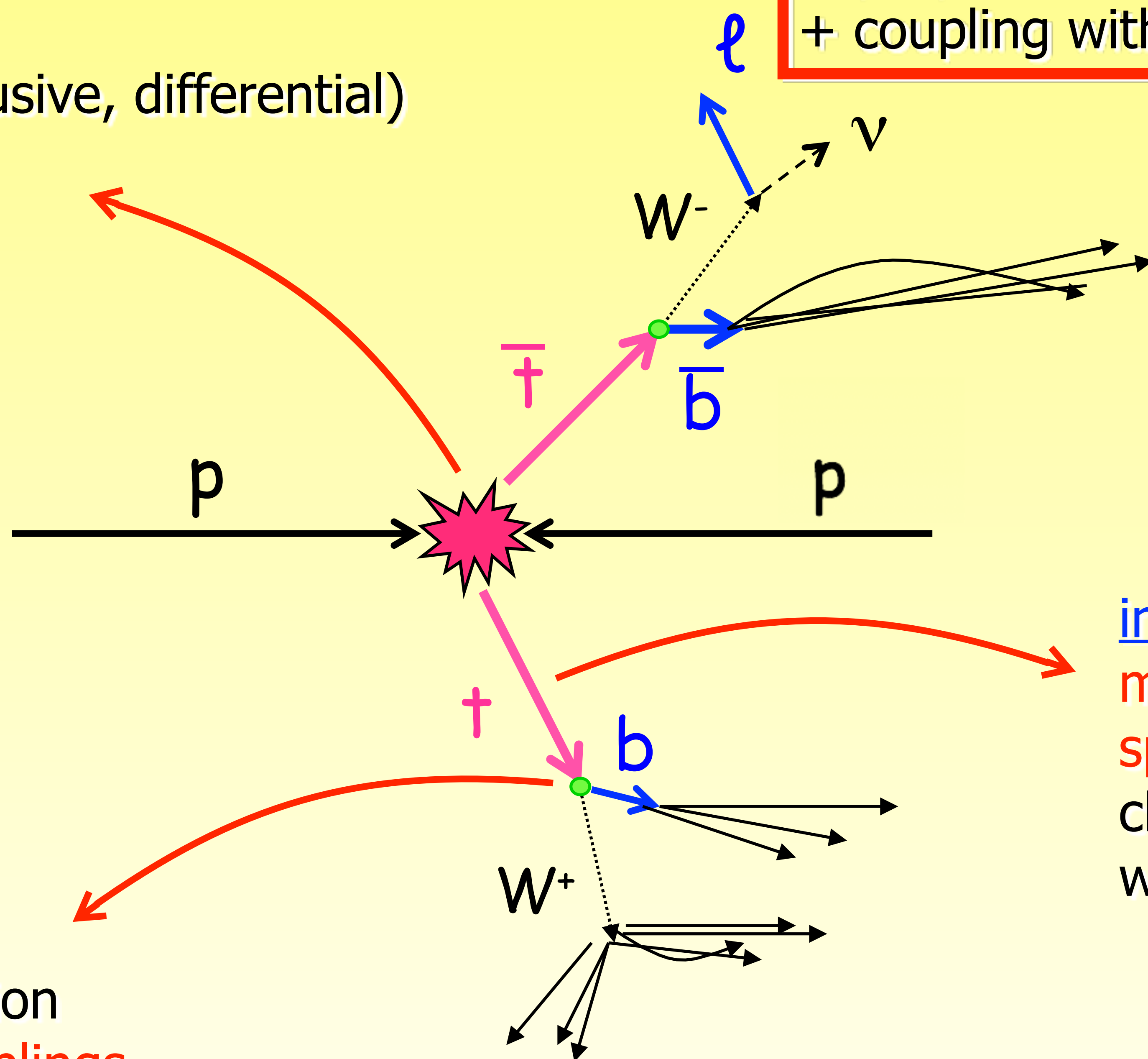
decay:
W helicity
branching fraction
anomalous couplings

Does the heaviest elementary particle behave as predicted by the Standard Model ?

Top quark properties

+ properties with single top events
+ coupling with electroweak bosons

[production:]
cross sections (inclusive, differential)
charge asymmetry
top polarization
color flow



[intrinsic:]
mass
spin correlation
charge
width

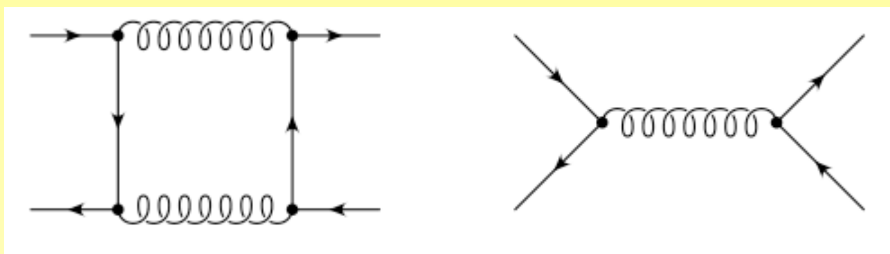
[decay:]
W helicity
branching fraction
anomalous couplings

Does the heaviest elementary particle behave as predicted by the Standard Model ?

Production and intrinsic properties

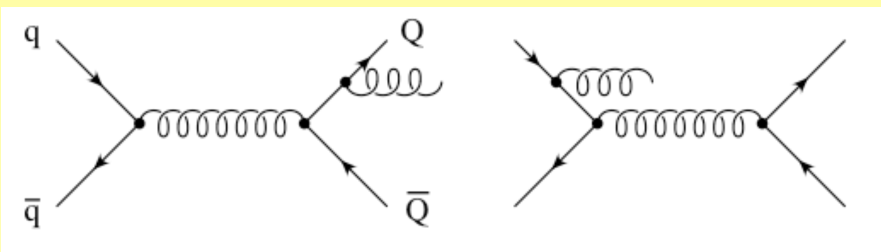
Top-antitop charge asymmetry at the LHC

- At NLO, QCD predicts an asymmetry for $t\bar{t}$ produced via $q\tilde{q}$ initial state
  - the top quark is predicted to be emitted preferably in the direction of the incoming quark
  - gg remains symmetric
  - this asymmetry can be modified by new physics (Z′, axigluons, …)

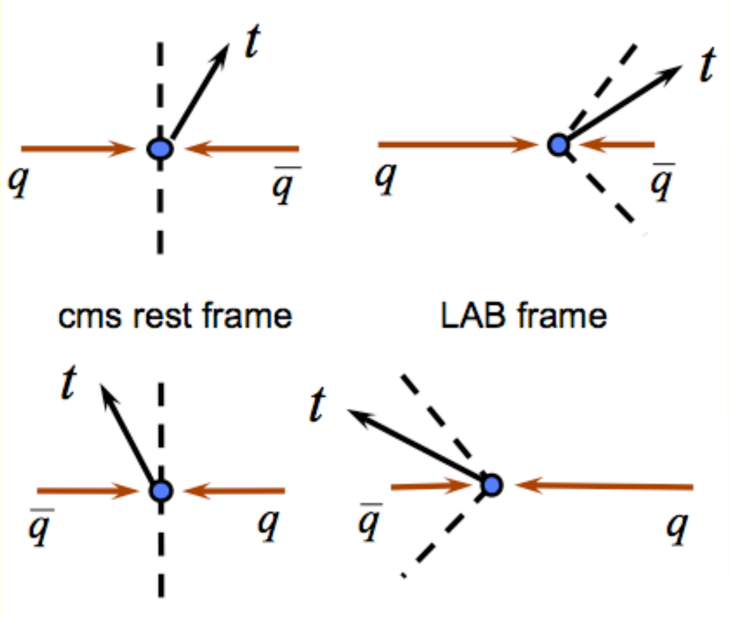


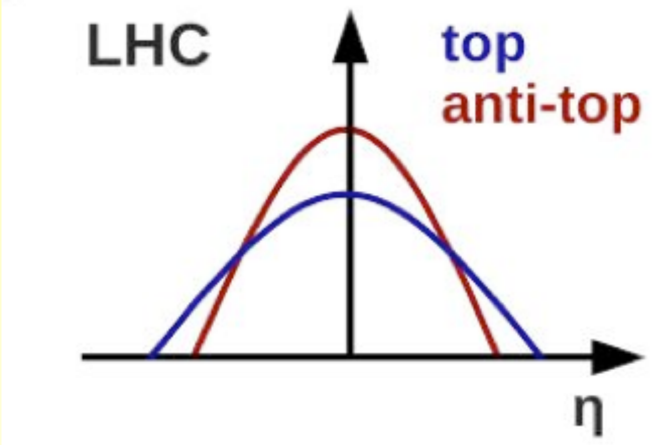
positive asymmetry

+



negative asymmetry





central-forward/backward asymmetry

small since low $q\bar{q}$ fraction

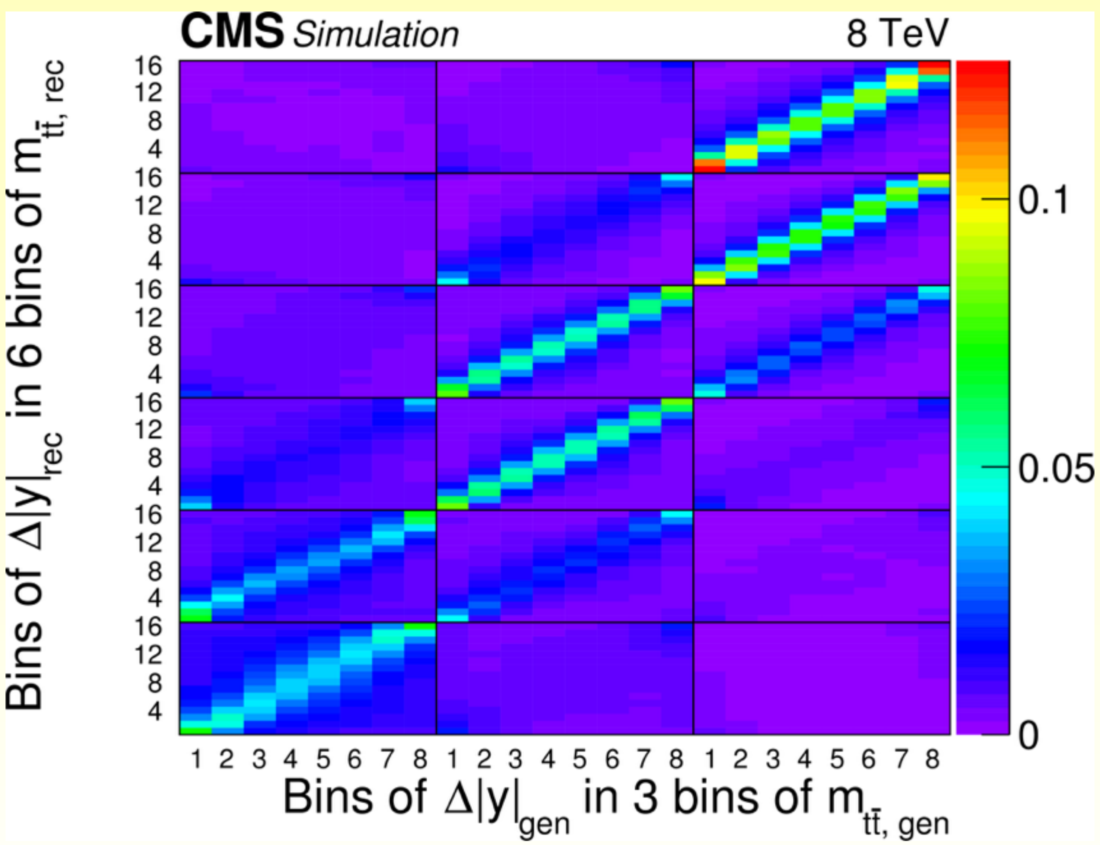
$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)}$$

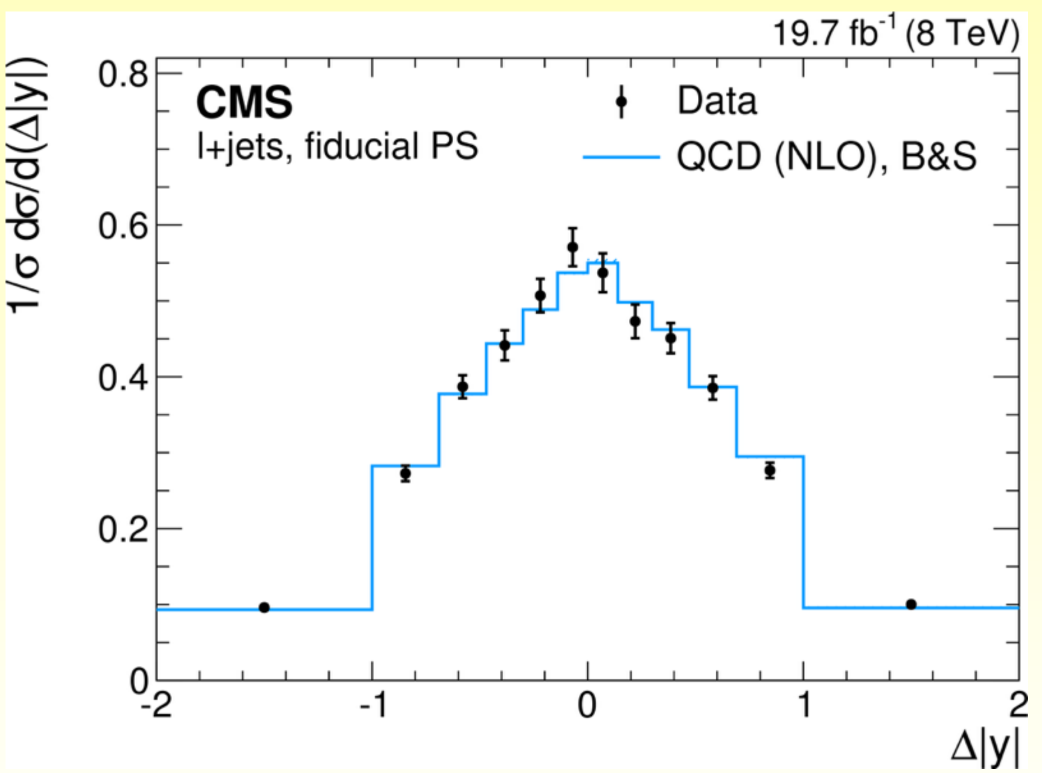
$$\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$$

CMS $t\bar{t}$ charge asymmetry measurement

arXiv:1507.03119

- Several measurements
  - inclusive and differential (vs $|y_{t\bar{t}}|$, $m_{t\bar{t}}$, $pT_{t\bar{t}}$: enhance new physics sensitivity)
  - fiducial (minimize extrapolation) and full phase space
- Procedure (lepton+jets channel)
  - reconstruction of the t and $\bar{t}$ four-momenta (likelihood criteria)
  - background subtraction (fit M_3 and MT_W)
  - correction for resolution/selection effects (unfolding through generalized matrix inversion with regularization)
  - acceptance correction to the fiducial or full phase space (diagonal matrix)



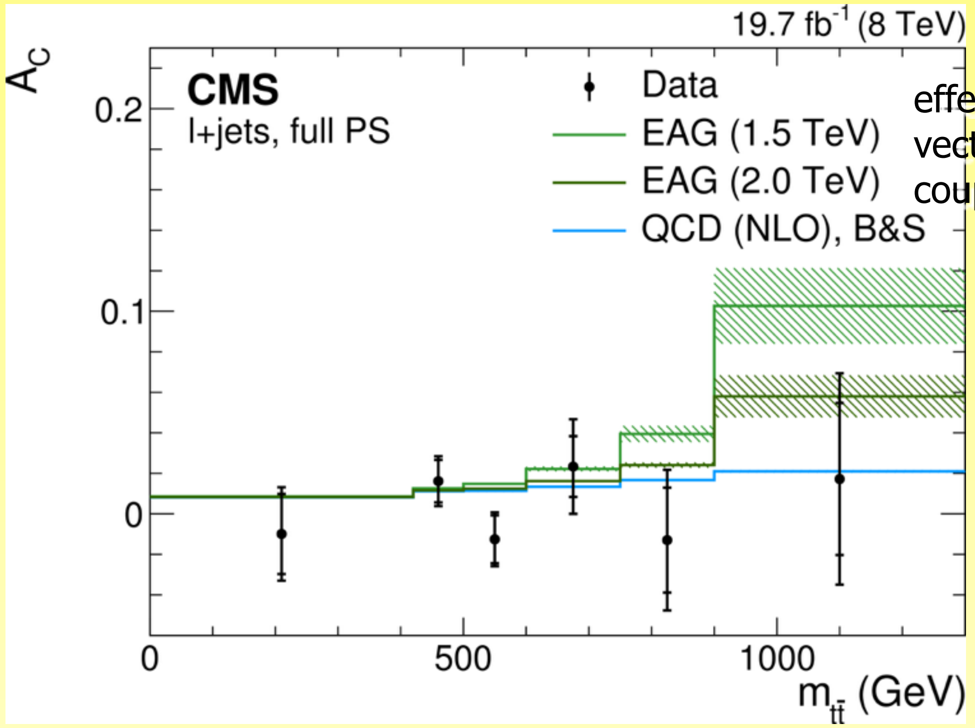


CMS $t\bar{t}$ charge asymmetry results

arXiv:1507.03119

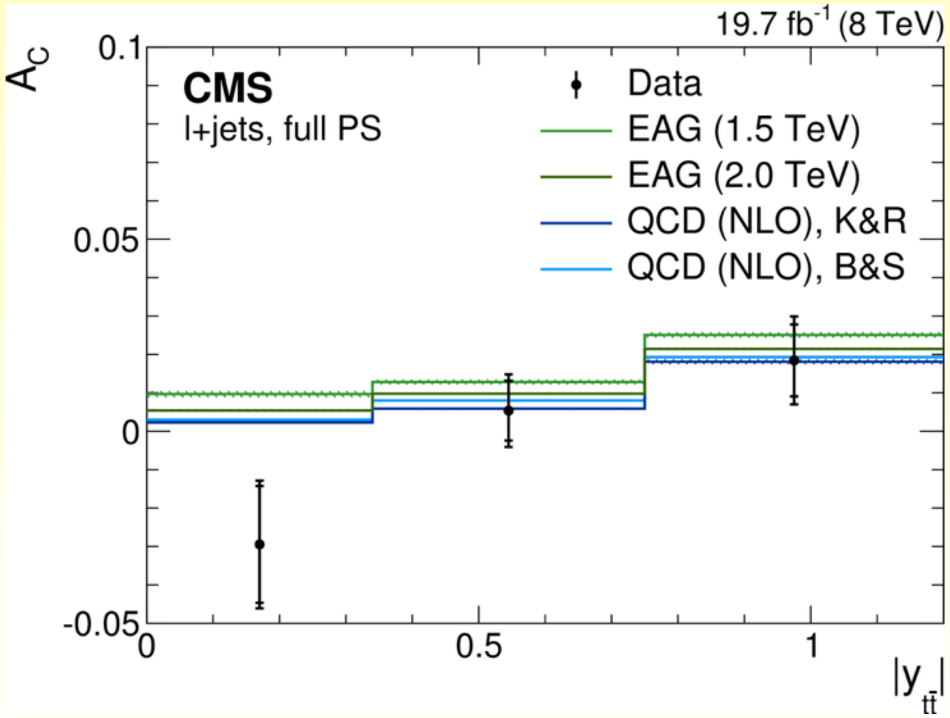
	Asymmetry (A_C)
Reconstructed	0.0036 ± 0.0017 (stat)
Background-subtracted	0.0008 ± 0.0023 (stat)
Corrected for migration effects	-0.0042 ± 0.0072 (stat)
Fiducial phase space	-0.0035 ± 0.0072 (stat) ± 0.0031 (syst)
Theoretical prediction [Bernreuther, Si] [42]	0.0101 ± 0.0010
Full phase space	0.0010 ± 0.0068 (stat) ± 0.0037 (syst)
Theoretical prediction [Kühn, Rodrigo] [9]	0.0102 ± 0.0005
Theoretical prediction [Bernreuther, Si] [42]	0.0111 ± 0.0004

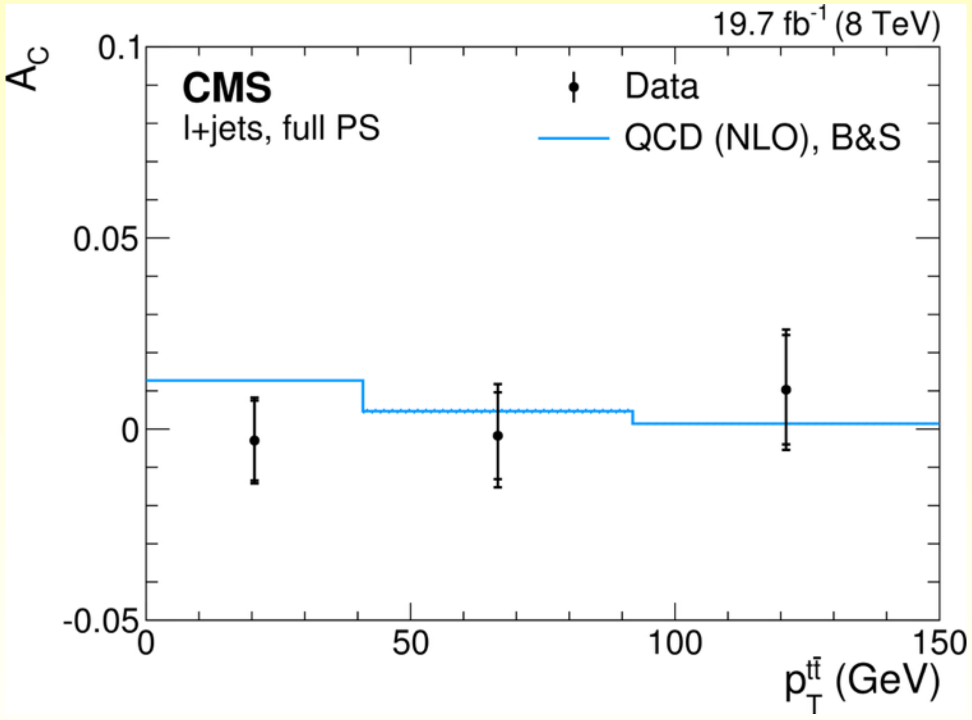
Statistical uncertainty dominates
Largest systematic uncertainties: JES, unfolding



effective axial-vector gluon coupling

The measurement at high $m_{t\bar{t}}$ excludes new physics below 1.5 TeV at 95% CL





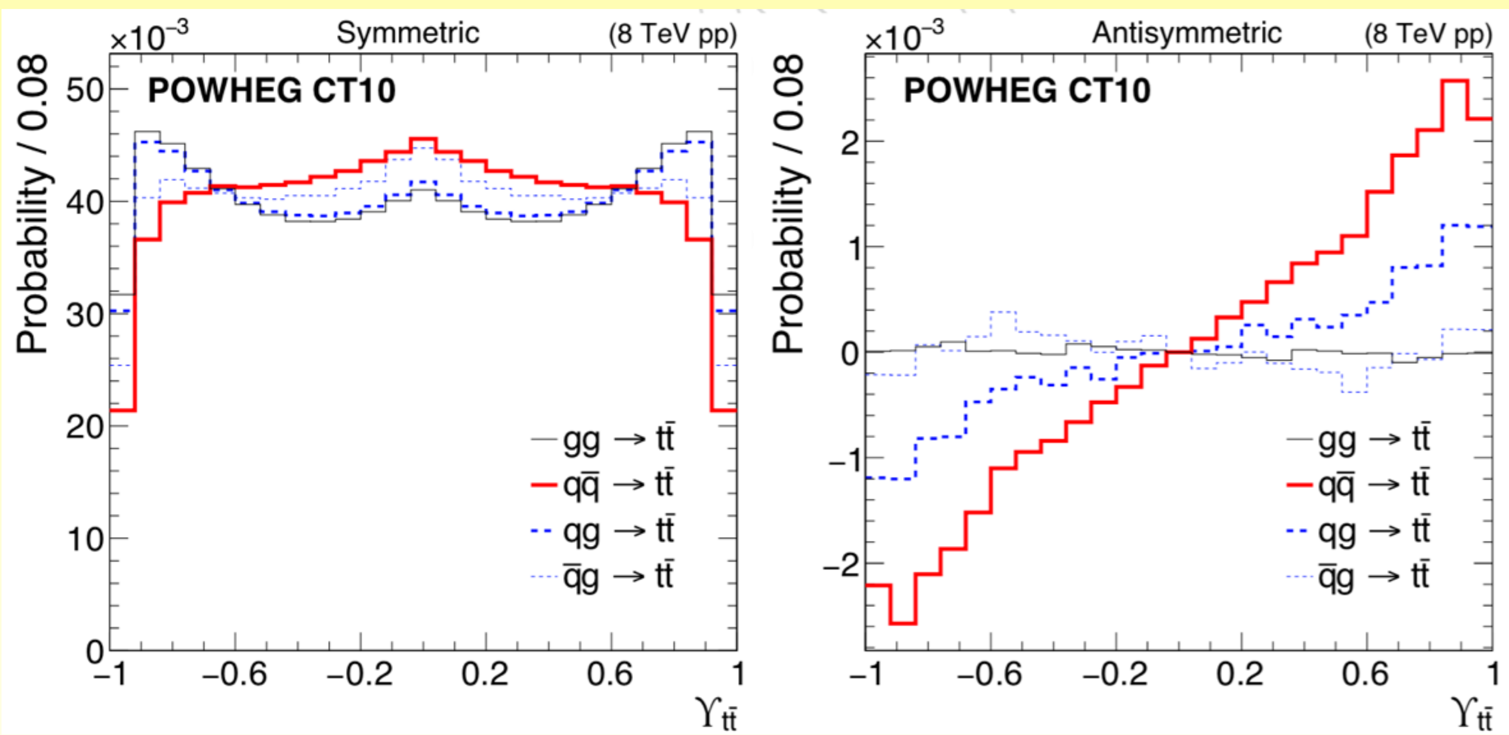
Latest CMS $t\bar{t}$ charge asymmetry result

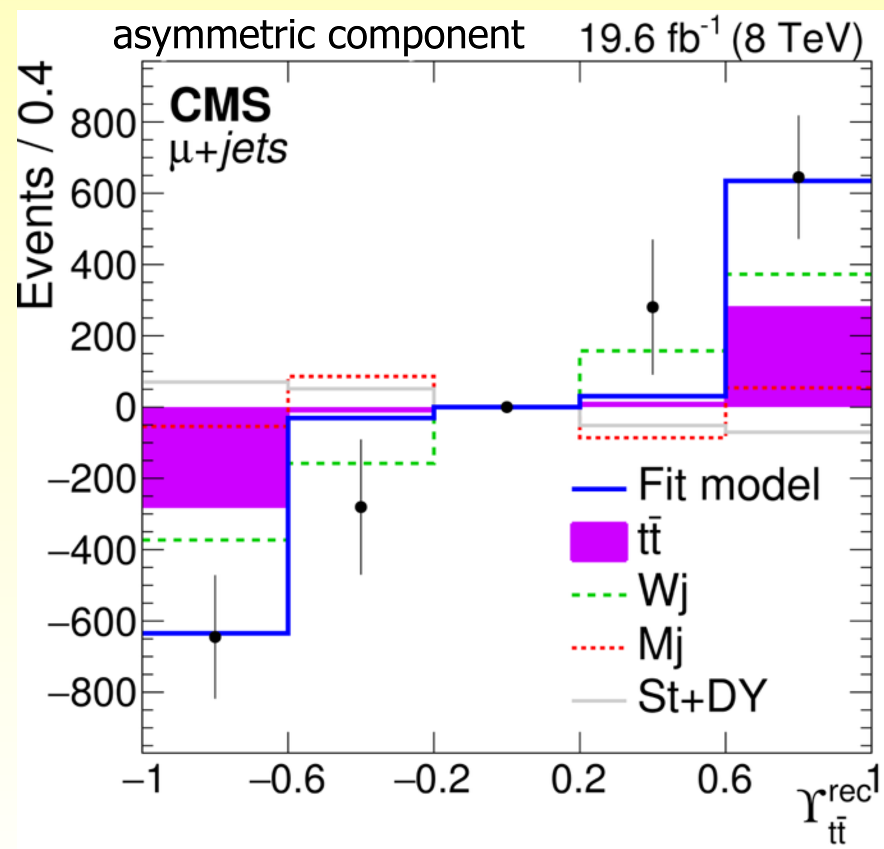
arXiv:1508.03862

- Other analysis method
  - same data set (lower jet pt cut: pt>20 GeV)
  - template fit of the symmetric and asymmetric part of the reconstructed $Y_{t\bar{t}}$ distribution (no unfolding)
    $\mathcal{Y}_{t\bar{t}} = \tanh \Delta|y|_{t\bar{t}}$
  - sample composition estimated using a likelihood-ratio-based discriminant
  - biais checked with several MC models

$$A_c^y = (0.33 \pm 0.26\ (\text{stat}) \pm 0.33\ (\text{syst}))\%$$

better inclusive measurement than the unfolded result





ATLAS $t\bar{t}$ charge asymmetry measurement

TOPQ-2014-16

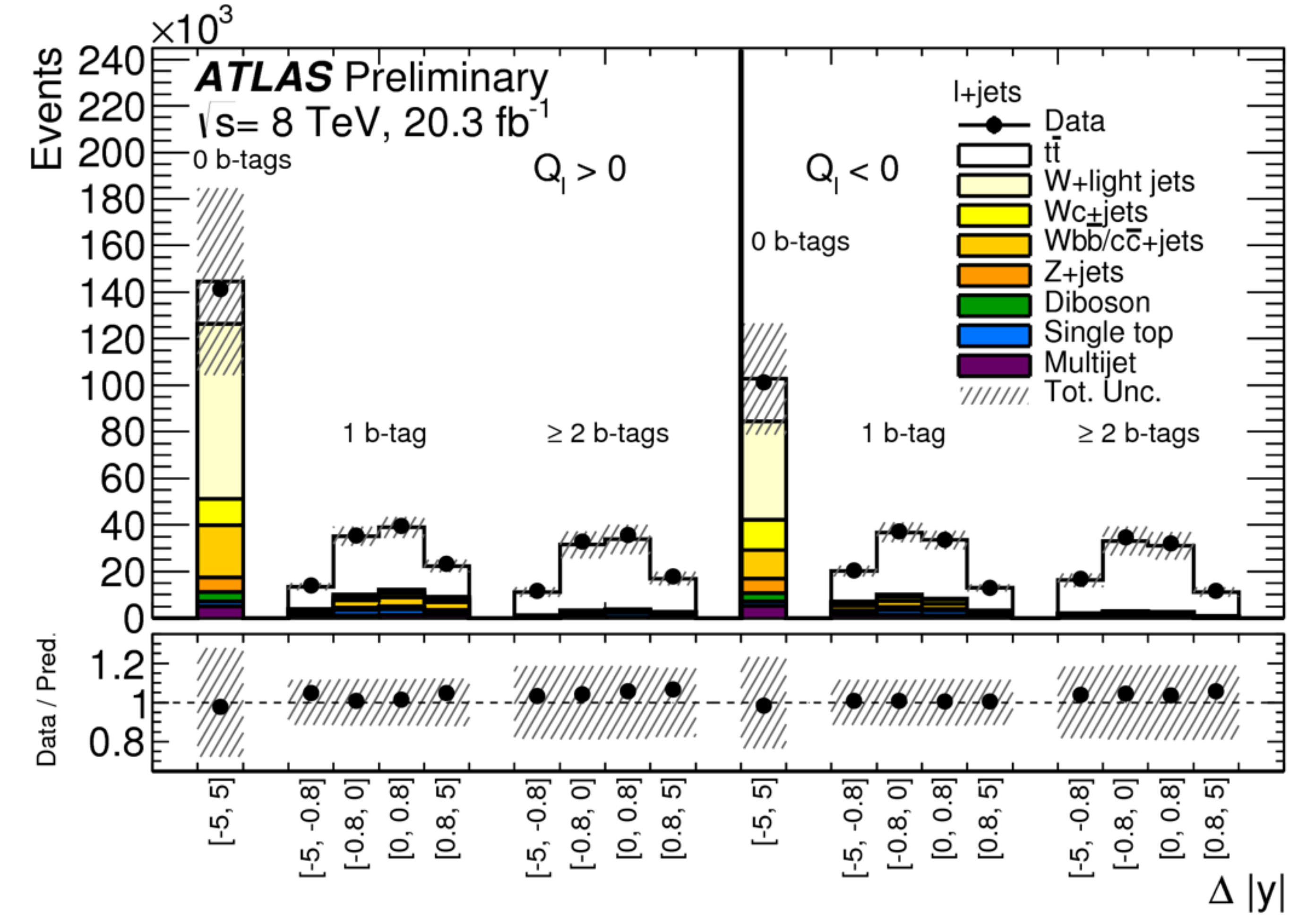
- **Measurements**
  - inclusive and differential (vs $m_{t\bar{t}}$, $pT_{t\bar{t}}$, and $|\beta_{t\bar{t}}|$: enhance new physics sensitivity)
  - measurements corrected to parton level

- **Procedure (lepton+jets channel)**
  - reconstruction of the t and $\bar{t}$ four-momenta (likelihood fit)
  - W+heavy flavor scale factors: in-situ calibration in the unfolding
  - correction for resolution/acceptance effects using full Bayesian unfolding

$$p(T|D) \propto \mathcal{L}(D|T) \cdot \pi(T)$$

D: observed spectrum
T: true spectrum
π: prior

  - systematics: marginalized through nuisance parameters in the likelihood
  - fit in 6 channels (vs b-jet multiplicity and lepton charge)



ATLAS $t\bar{t}$ charge asymmetry measurement

TOPQ-2014-16

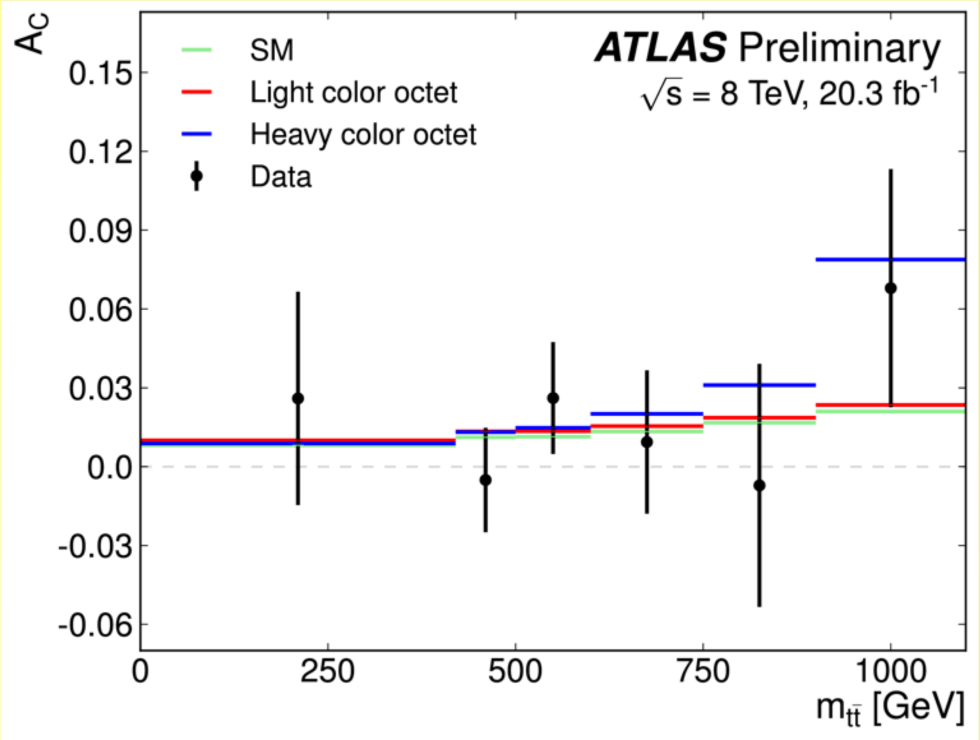
	Source of systematic uncertainty	δA_C
(a)	Jet energy scale and resolution	0.0016
	Multijet background normalisation	0.0005
(b)	Initial-/final-state radiation	0.0009
	Monte Carlo statistics	0.0010
	PDF	0.0007
	Statistical uncertainty	0.0044
	Total uncertainty	0.0049

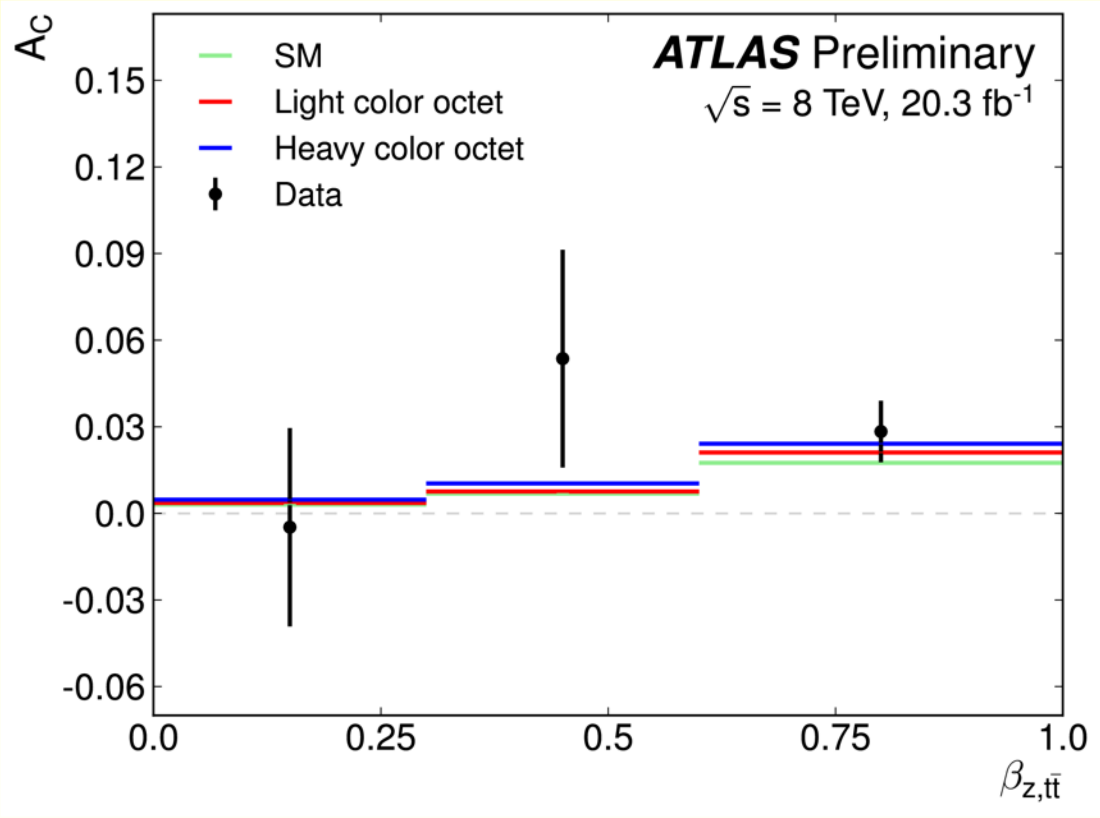
list of syst if larger than 10% of the stat error

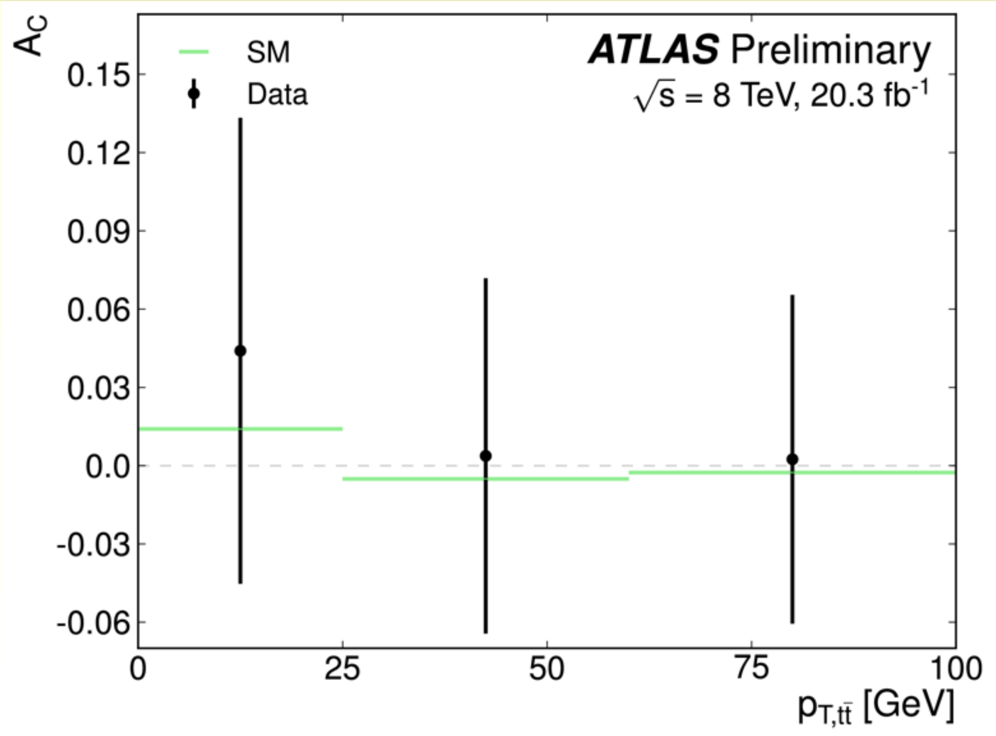
inclusive measurement:

$$A_C = 0.009 \pm 0.005 \text{ (stat.+syst.)}$$

in agreement with the SM (~ 1.1%)



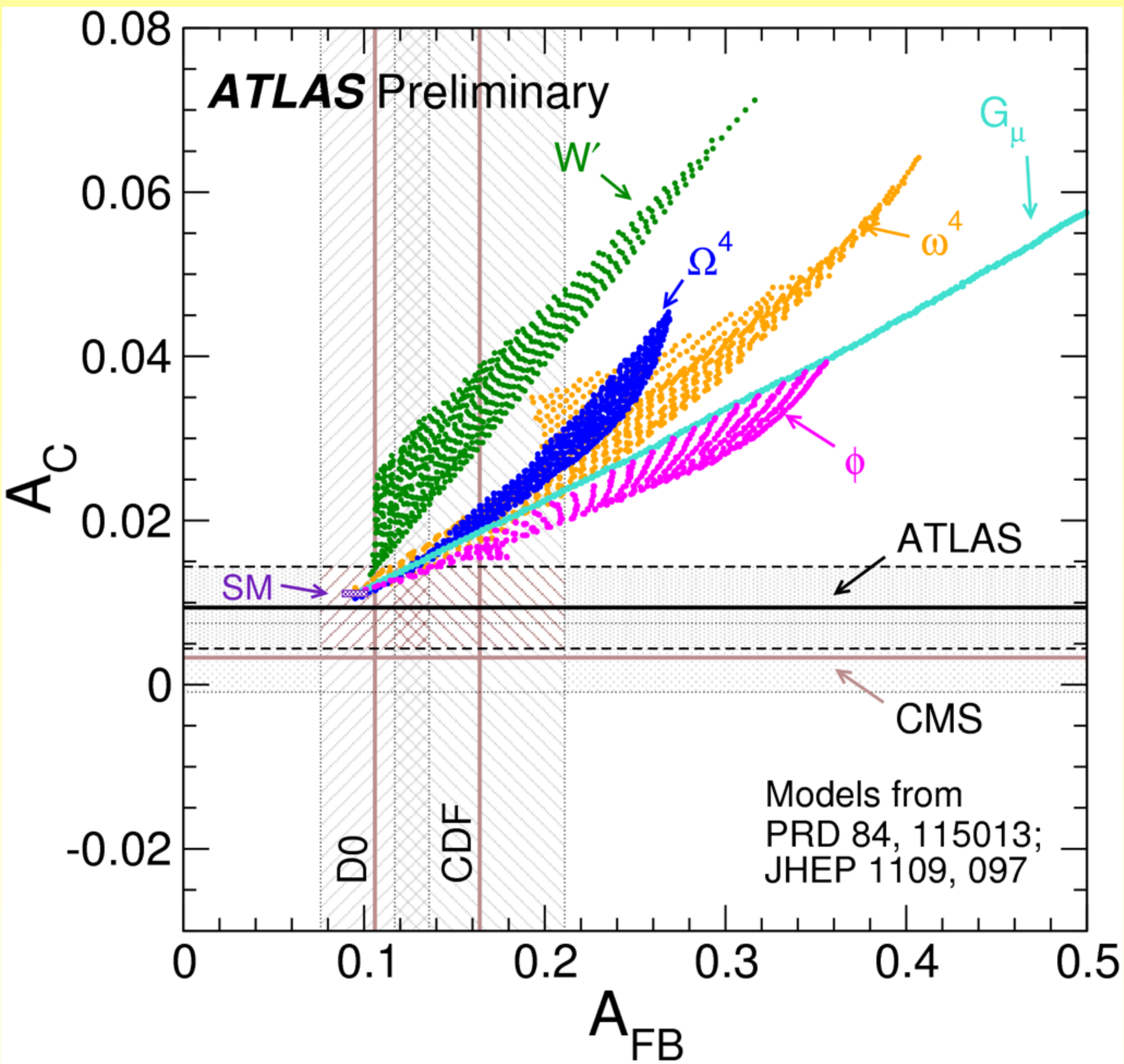


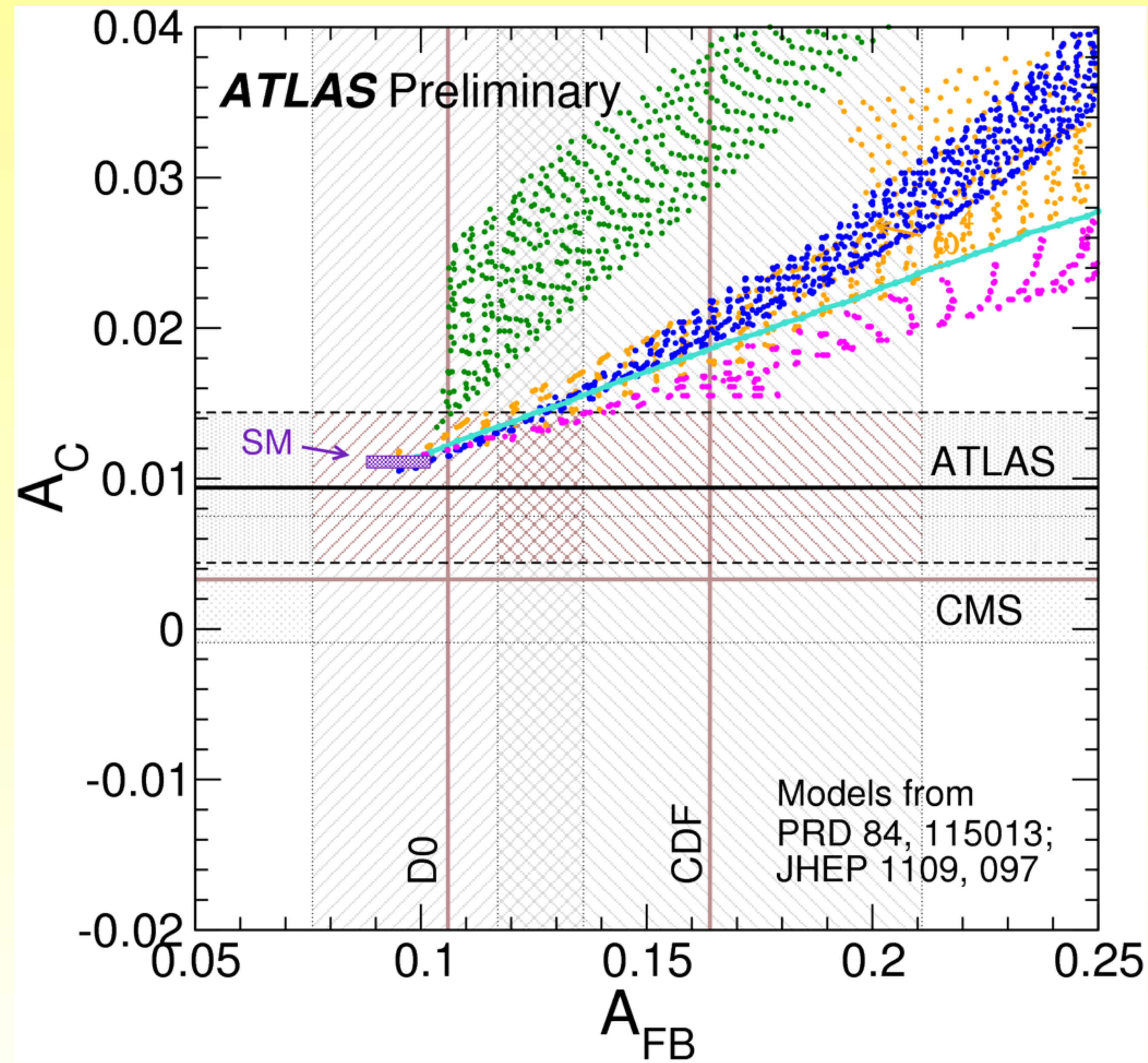


Interpretation of the measurements

TOPQ-2014-16

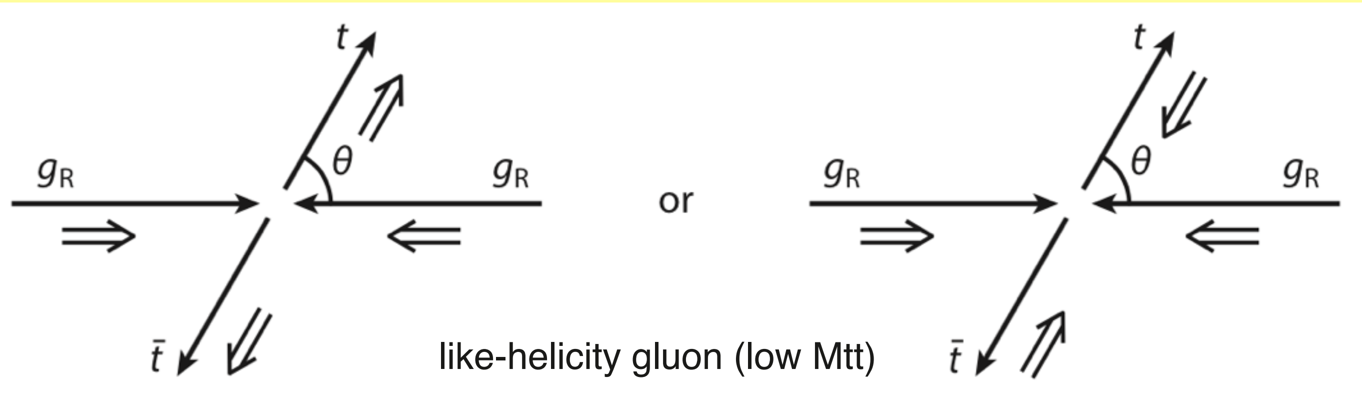
A wide range of parameters for the BSM models can be excluded

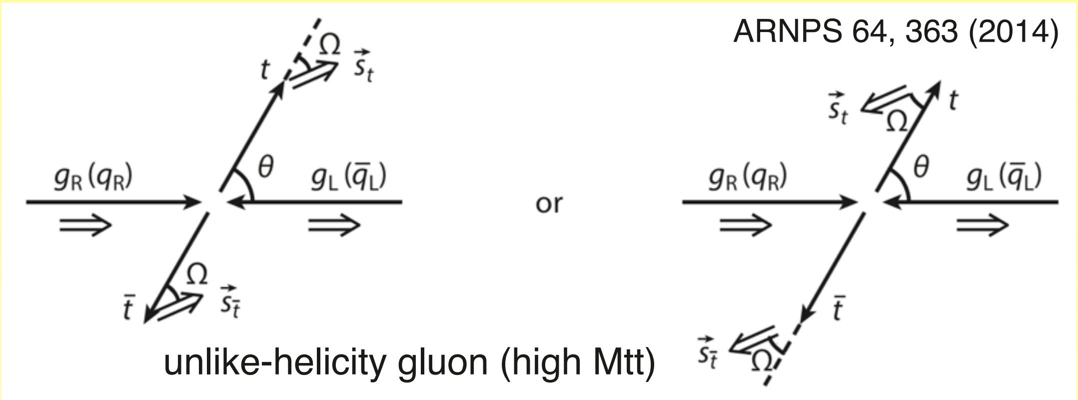




$t\bar{t}$ spin correlation

- Top quark lifetime is small:
  - decay before $t\bar{t}$ spin decorrelates
  - spin correlation propagates to top quark decay products





Fraction of $t\bar{t}$ events with spin correlation:

$$f = \frac{N_{SM}^{t\bar{t}}}{N_{SM}^{t\bar{t}} + N_{Uncor}^{t\bar{t}}}$$

- CMS measurement using a matrix element method
  - pioneered at the Tevatron
  - mu+jets channel
  - per-event probability with either H_{cor} or H_{uncor}:

$$P(x_i|H) = \frac{1}{\sigma} \int f_{PDF}(q_1) f_{PDF}(q_2) dq_1 dq_2 \frac{(2\pi)^4 |M(y,H)|^2}{q_1 q_2 s} W(x,y) d\Phi_6$$

  - fit of the event likelihood ratio: $-2 \ln \lambda_{event}$ to extract f

$$\lambda_{event} = \frac{P(H_{uncor})}{P(H_{cor})}$$

CMS $t\bar{t}$ spin correlation results

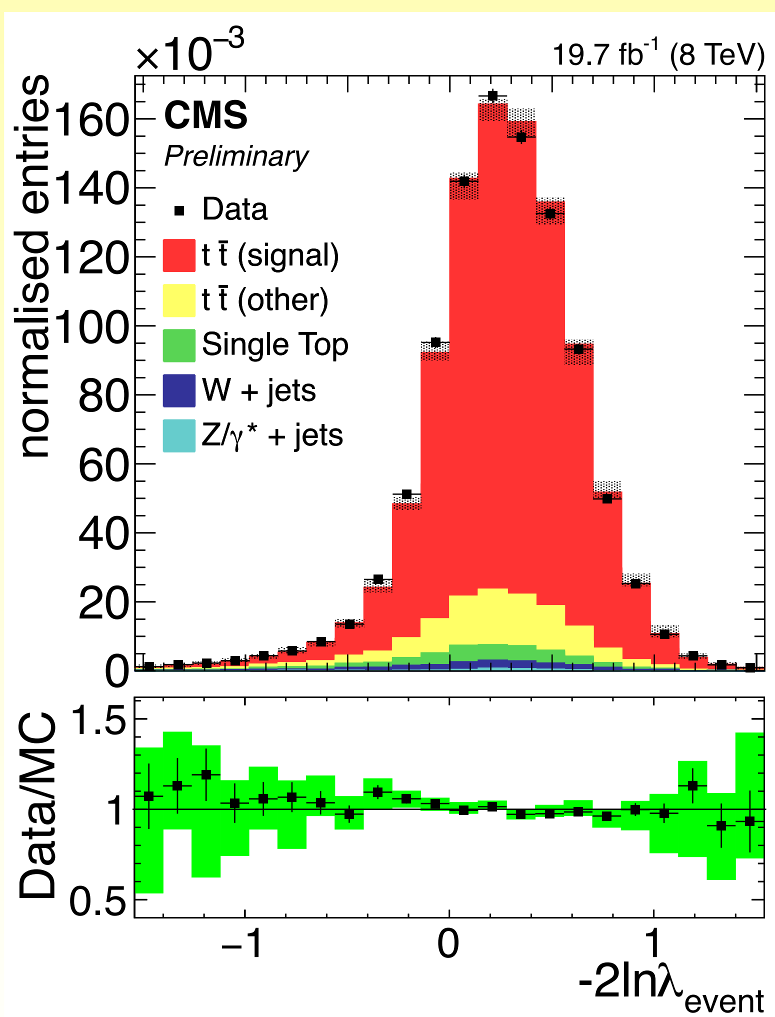
CMS-PAS-TOP-13-015

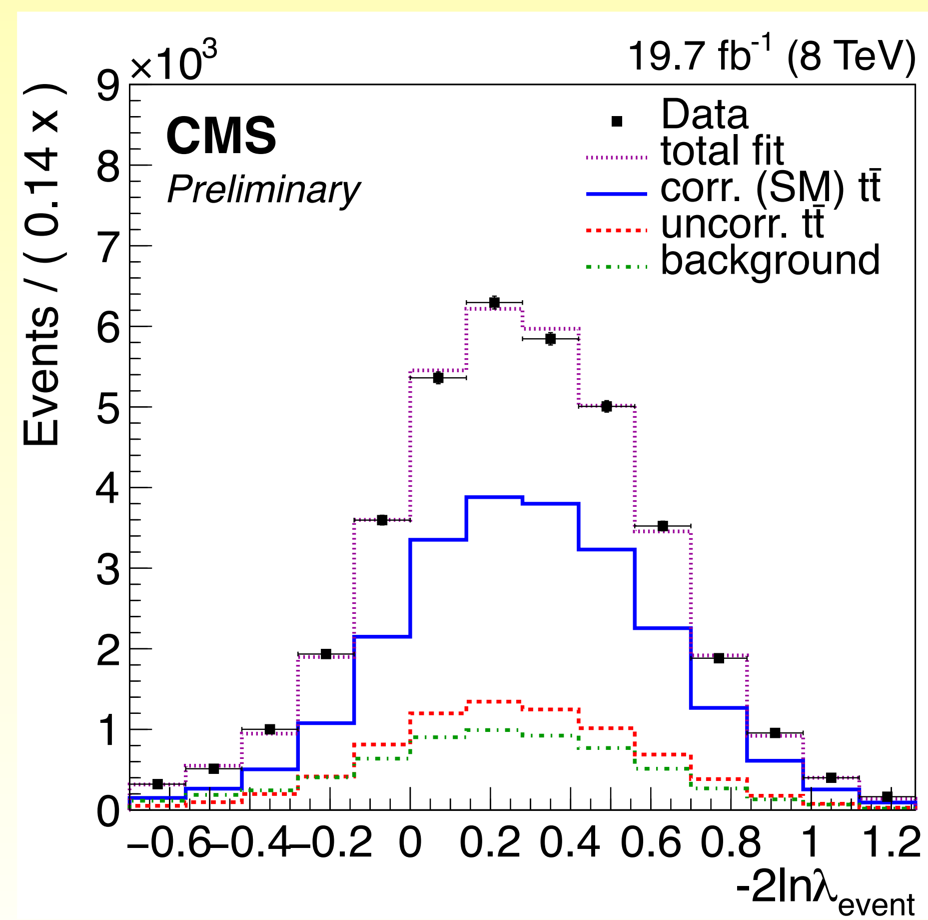
- Extraction of the event fraction with spin correlation
  - up to five jet events into the ME (kinematic fitter used to choose the 4 jets from $t\bar{t}$)
  - f and bkg fraction is fit with bkg, correlated and uncorrelated templates
  - calibration of the results

$$f_{calibrated} = 0.72 \pm 0.09\,(\mathrm{stat})\,^{+0.15}_{-0.13}\,(\mathrm{syst})$$

dominant systematic uncertainties: JES, scale variation, top mass

agree at 2.2σ with the SM and 2.9σ with uncorrelated hypothesis

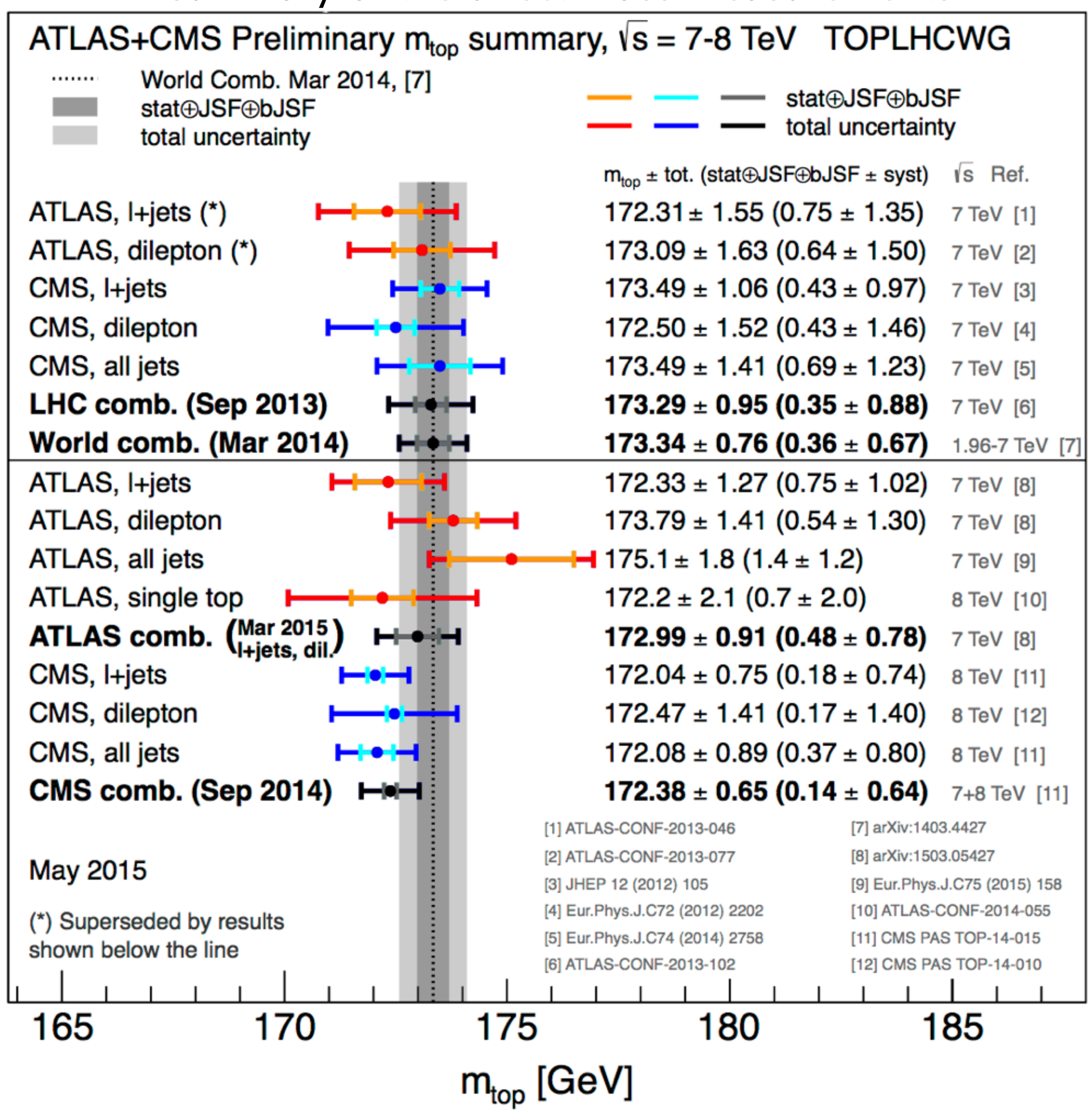




Top quark mass

- Why measuring the top quark mass ?
  - free parameter of the SM
  - important parameter for vacuum stability
  - consistency of the SM (m_t, m_W, m_H)

summary of the direct mass measurements



- uncertainty on direct measurements now below 1 GeV
- uncertainty in interpreting the direct measurements into the top quark pole mass up to O(1 GeV)

ATLAS top quark pole mass using $t\bar{t}$+1 jets events

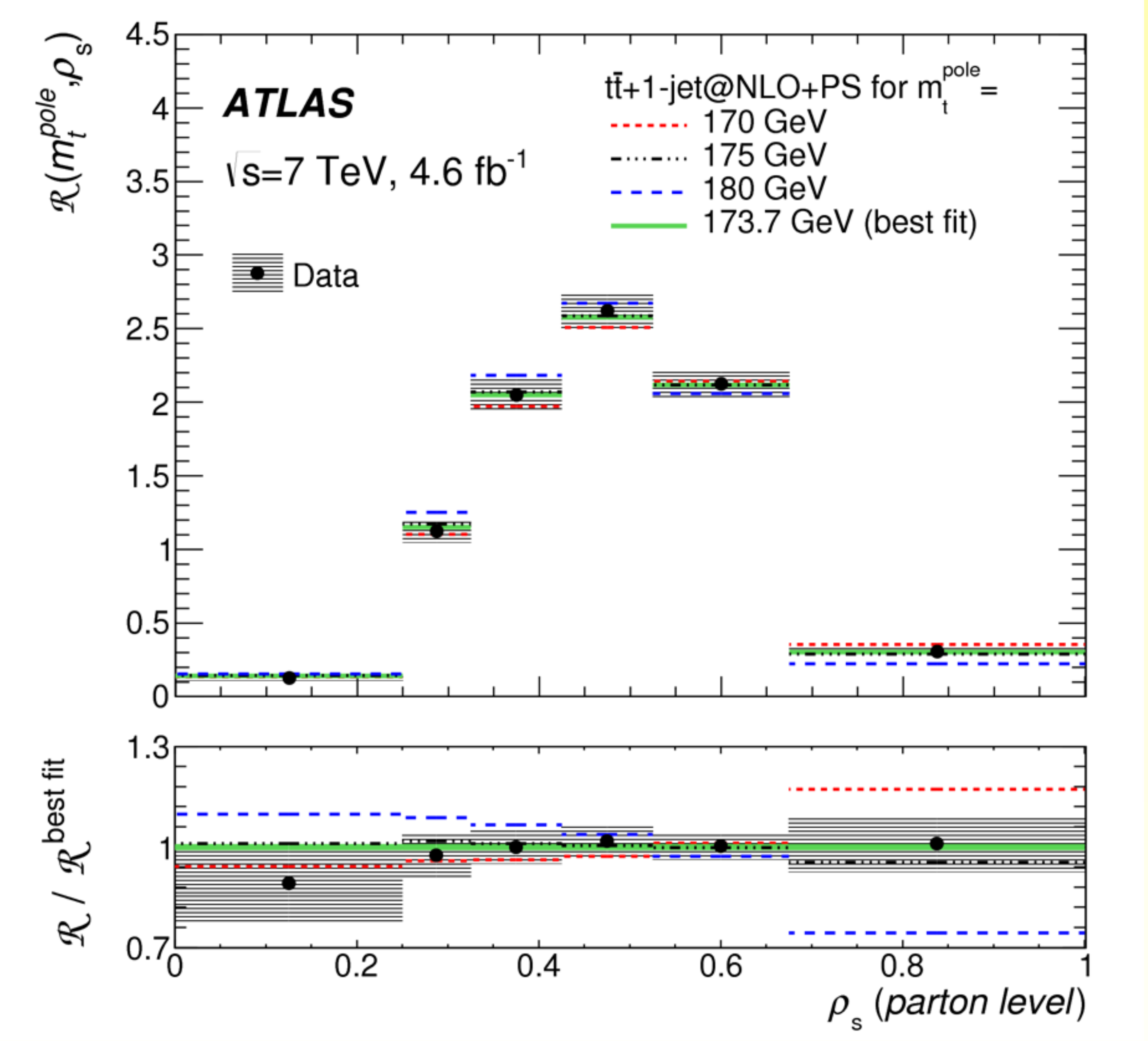
arXiv:1507.01769

- New method to extract the top quark pole mass:
  - from the normalized differential $t\bar{t}$+1 jets cross section as a function of the inverse of the invariant mass of the $t\bar{t}$+1jet system: ρ_s
  - lepton+jets channel (five jets events with 2 b-tagged jets)
  - differential cross section unfolded to the parton level (SVD) compared to NLO +parton shower predictions

$$\rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}+1\text{-jet}}}}$$

$$m_t^{\text{pole}} = 173.7 \pm 1.5\,(\text{stat.}) \pm 1.4\,(\text{syst.})^{+1.0}_{-0.5}\,(\text{theory})\ \text{GeV}$$

Description	Value [GeV]	%
m_t^{pole}	**173.71**	
Statistical uncertainty	**1.50**	**0.9**
Scale variations	(+0.93, −0.44)	(+0.5, −0.3)
Proton PDF (theory) and α_s	0.21	0.1
Total theory systematic uncertainty	**(+0.95, −0.49)**	**(+0.5, −0.3)**
Jet energy scale (including *b*-jet energy scale)	0.94	0.5
Jet energy resolution	0.02	< 0.1
Jet reconstruction efficiency	0.05	< 0.1
b-tagging efficiency and mistag rate	0.17	0.1
Lepton uncertainties	0.07	< 0.1
Missing transverse momentum	0.02	0.1
MC statistics	0.13	< 0.1
Signal MC generator	0.28	0.2
Hadronization	0.33	0.2
ISR/FSR	0.72	0.4
Colour reconnection	0.14	< 0.1
Underlying event	0.25	0.1
Proton PDF (experimental)	0.54	0.3
Background	0.20	0.1
Total experimental systematic uncertainty	**1.44**	**0.8**
Total uncertainty	**(+2.29, −2.14)**	**(+1.3, −1.2)**



CMS top mass from the $t\bar{t}$ cross section

CMS-PAS-TOP-13-004

- **Method:**
  - extract the top quark mass in a well defined renormalization scheme by comparing the measured $t\bar{t}$ cross section with the NNLO(+NNLL) theory computation
  - precise measurement of the $t\bar{t}$ cross section (7+8 TeV) in the eμ channel using a template fit to the b jet multiplicity, the multiplicity and pt of other jets

$$\sigma_{t\bar{t}} = 174.5 \pm 2.1\,(\text{stat}) \pm^{4.5}_{4.0}\,(\text{syst}) \pm 3.8\,(\text{lumi})\,\text{pb} \quad \text{at } \sqrt{s} = 7\,\text{TeV and}$$
$$\sigma_{t\bar{t}} = 245.6 \pm 1.3\,(\text{stat}) \pm^{6.6}_{5.5}\,(\text{syst}) \pm 6.5\,(\text{lumi})\,\text{pb} \quad \text{at } \sqrt{s} = 8\,\text{TeV}.$$

  - maximize the product of the experimental and prediction likelihoods

exp: gaussian likelihood

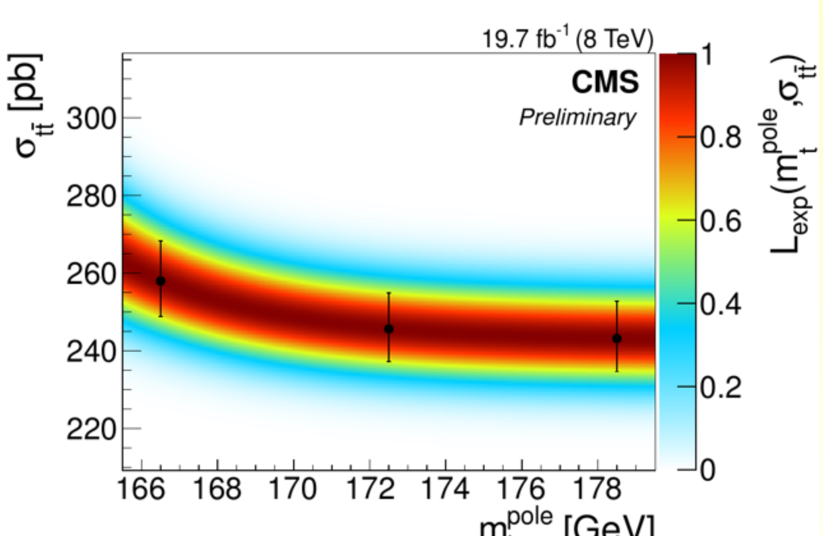
$$L(m_t, \sigma_{t\bar{t}}) = exp\left[\frac{(\sigma_{t\bar{t}}(m_t) - \sigma_{t\bar{t}})^2}{-2(\Delta^2 + \Delta^2_{m_t \pm})}\right]$$

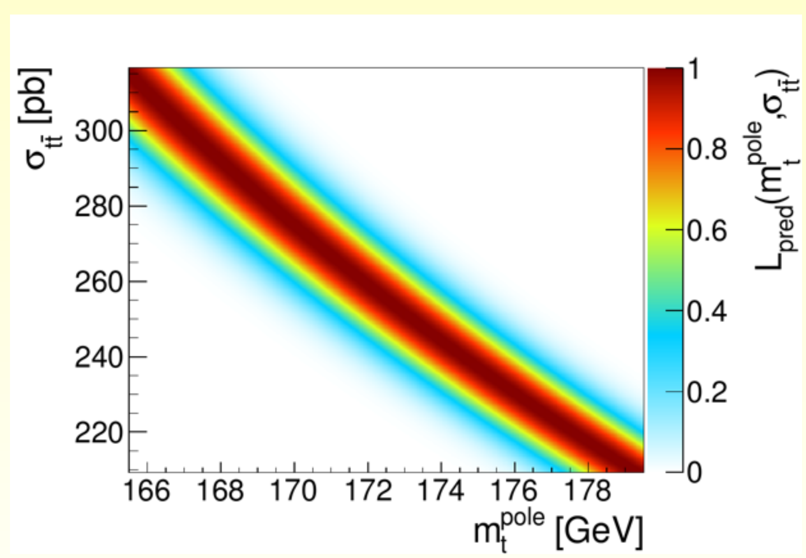
th: asymmetric Gaussian (PDF, α_S, beam) convoluted with a box prior for the scales

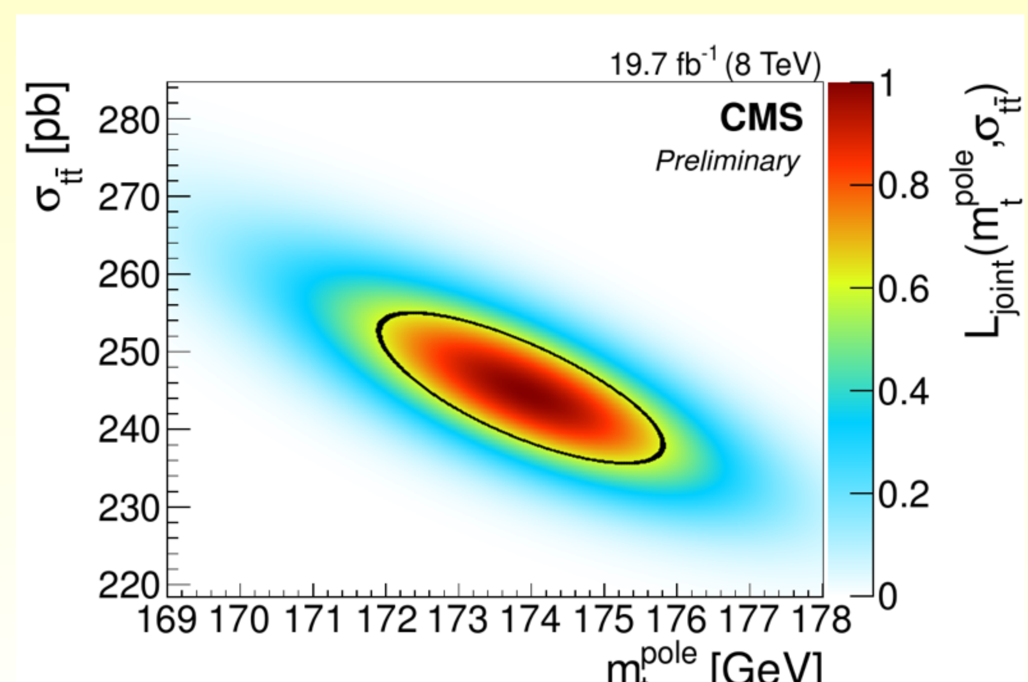
$$L_{\text{pred}}(m_t, \sigma_{t\bar{t}}) = \frac{1}{C(m_t)}\left(\text{erf}\left[\frac{\sigma^{(h)}_{t\bar{t}}(m_t) - \sigma_{t\bar{t}}}{\sqrt{2}\Delta_{p,+}}\right] - \text{erf}\left[\frac{\sigma^{(l)}_{t\bar{t}}(m_t) - \sigma_{t\bar{t}}}{\sqrt{2}\Delta_{p,-}}\right]\right)$$

	m_t
NNPDF30	$173.6 \pm^{1.7}_{1.8}$ GeV
MMHT2014	$173.9 \pm^{1.8}_{1.9}$ GeV
CT14	$174.1 \pm^{2.1}_{2.2}$ GeV

dependency fit by an exponential

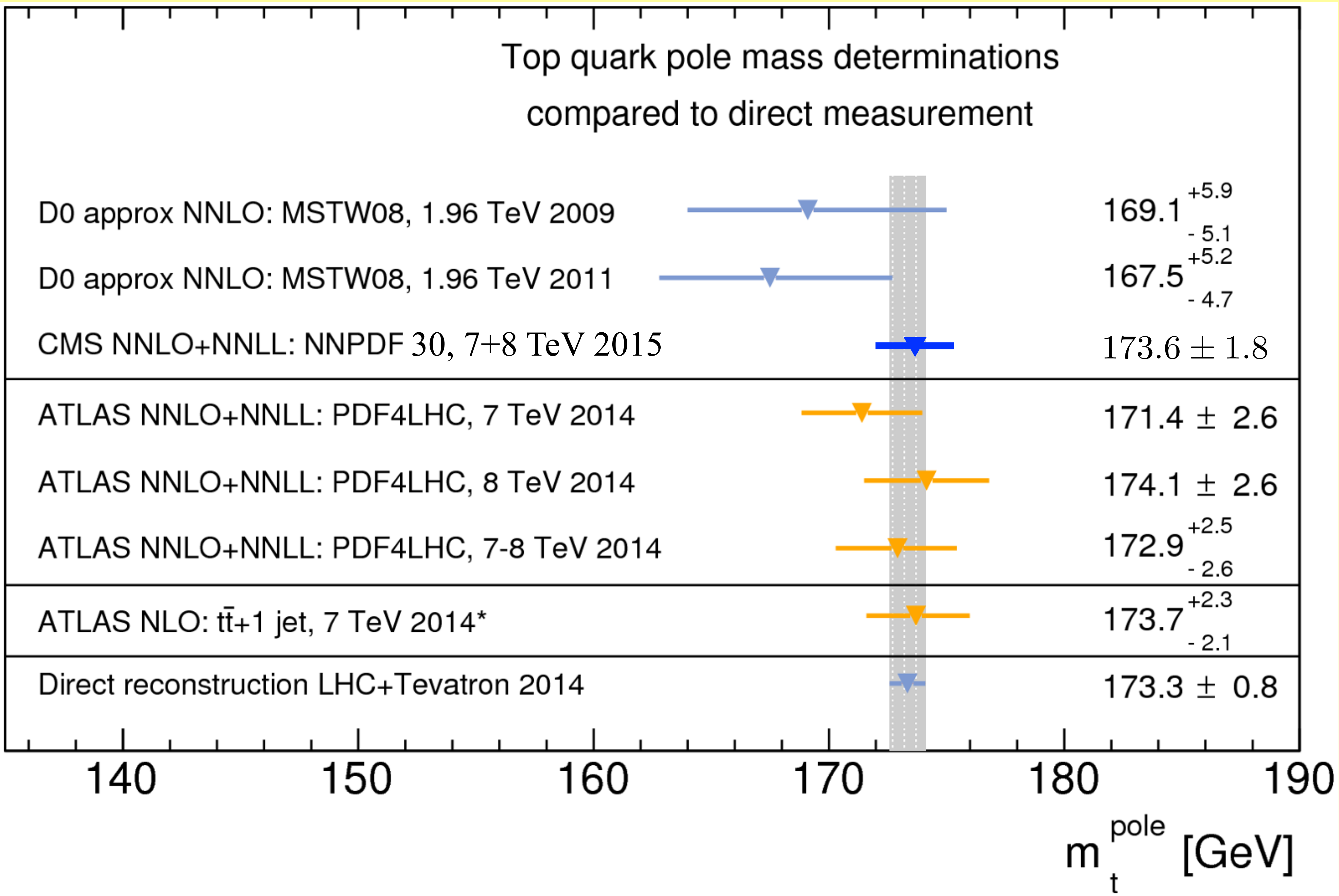






Alternative top quark mass measurements

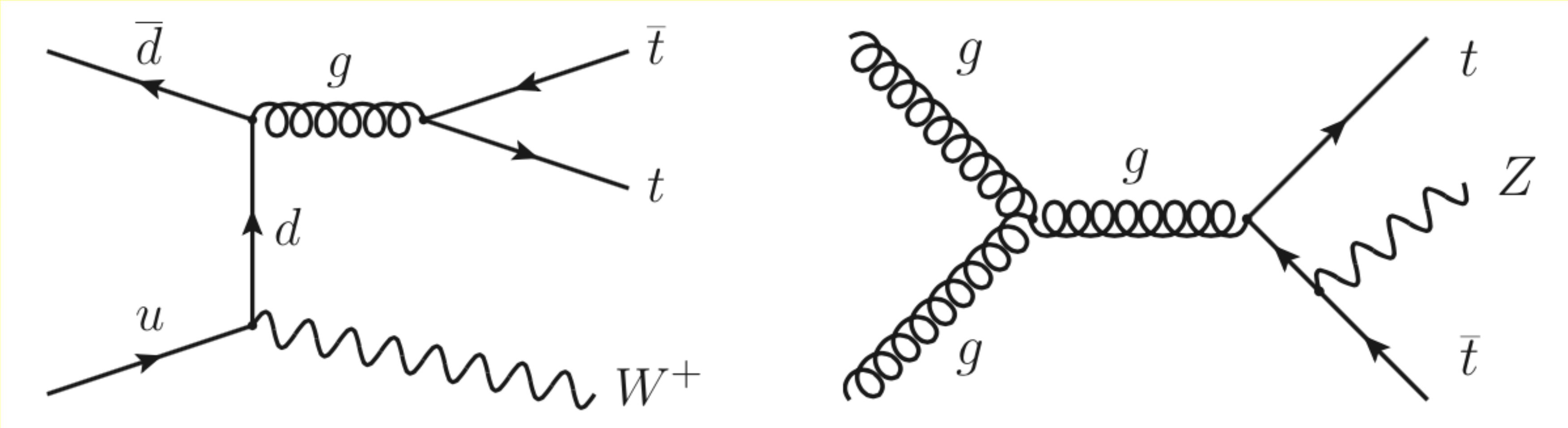
in agreement with the direct determinations, getting below the 2 GeV precision



Couplings with electroweak bosons

Top couplings with electroweak bosons

- The top quark might be connected to electroweak symmetry breaking
  - couplings to Z and photon were never measured so far
  - $t\bar{t}W$ and $t\bar{t}Z$ are the heaviest SM process that could be observed with Run 1 data (expected cross section around 200 fb)
  - extension of the Standard Model can modify them



- $t\bar{t}W$ and $t\bar{t}Z$
  - bins of lepton: 2, 3 or 4 leptons (2ℓ OS, 2ℓ SS, 3ℓ, 4ℓ)
  - constrain on Z mass depending on the channels
  - increase sensitivity by splitting in jet multiplicity/b-tagged jets
  - backgrounds from data: "fake" leptons, charge misidentification
  - background dominated regions to constrain it

ATLAS $t\bar{t}W$ et $t\bar{t}Z$ results

ATLAS-CONF-2015-032

- Analysis strategy
  - cut and count except for the 2ℓ OS channel that uses a neural network
  - simultaneous likelihood fit of $t\bar{t}W$ and $t\bar{t}Z$ cross sections

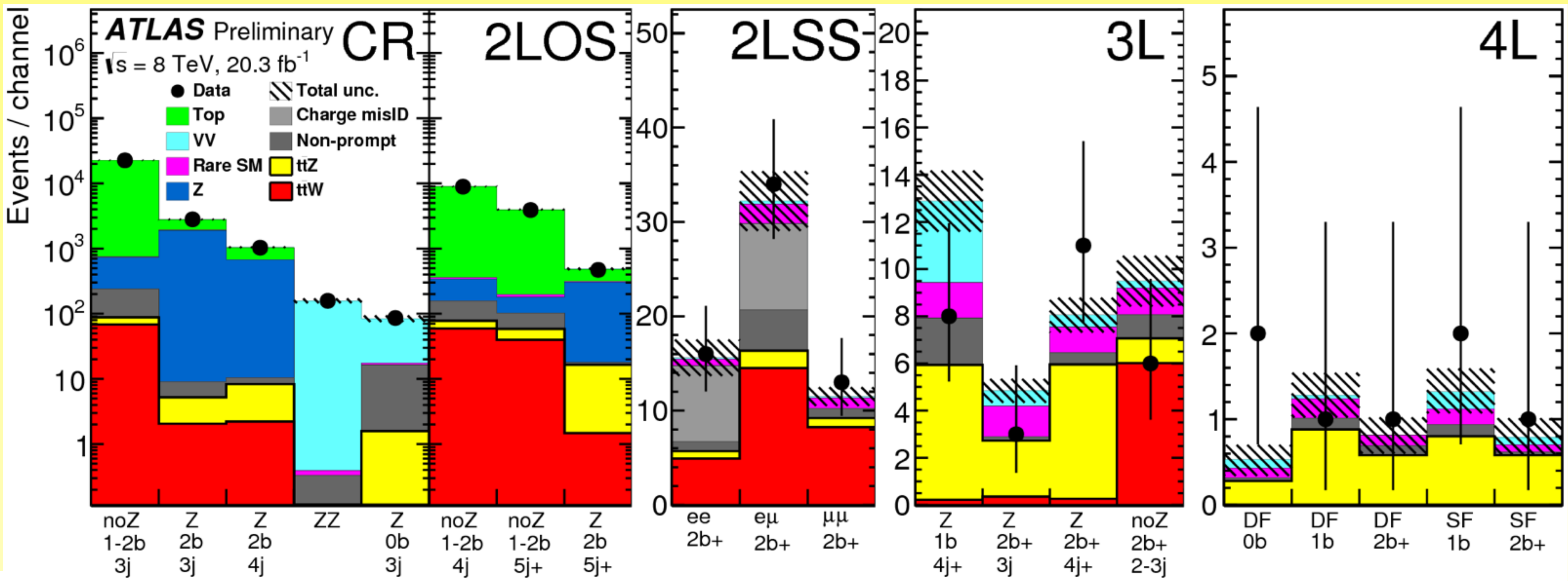
Process	$t\bar{t}$ decay	Boson decay	Signature	has $Z \to \ell^+\ell^-$
$t\bar{t}W^\pm$	$(\ell^\mp\nu b)(q\bar{q}b)$	$\ell^\pm\nu$	OS dilepton	no
	$(\ell^\pm\nu b)(q\bar{q}b)$	$\ell^\pm\nu$	SS dilepton	n/a
	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$\ell^\pm\nu$	Trilepton	no
$t\bar{t}Z$	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$q\bar{q}$	OS dilepton	no
	$(q\bar{q}b)(q\bar{q}b)$	$\ell^+\ell^-$	OS dilepton	yes
	$(\ell^\pm\nu b)(q\bar{q}b)$	$\ell^+\ell^-$	Trilepton	yes
	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$\ell^+\ell^-$	Tetralepton	yes

- Uncertainties
  - statistical dominates
  - systematic treated as nuisance parameters

Uncertainty	$\sigma_{t\bar{t}W}$	$\sigma_{t\bar{t}Z}$
Luminosity	3.2%	4.6%
Reconstructed objects	3.7%	7.4%
Background from simulation	5.8%	8.0%
Fake leptons and charge misID	7.5%	3.0%
Signal modelling	1.8%	4.5%
Total systematics	12%	13%
Statistical	+24% / −21%	+30% / −27%
Total	+27% / −24%	+33% / −29%

ATLAS $t\bar{t}W$ and $t\bar{t}Z$ results

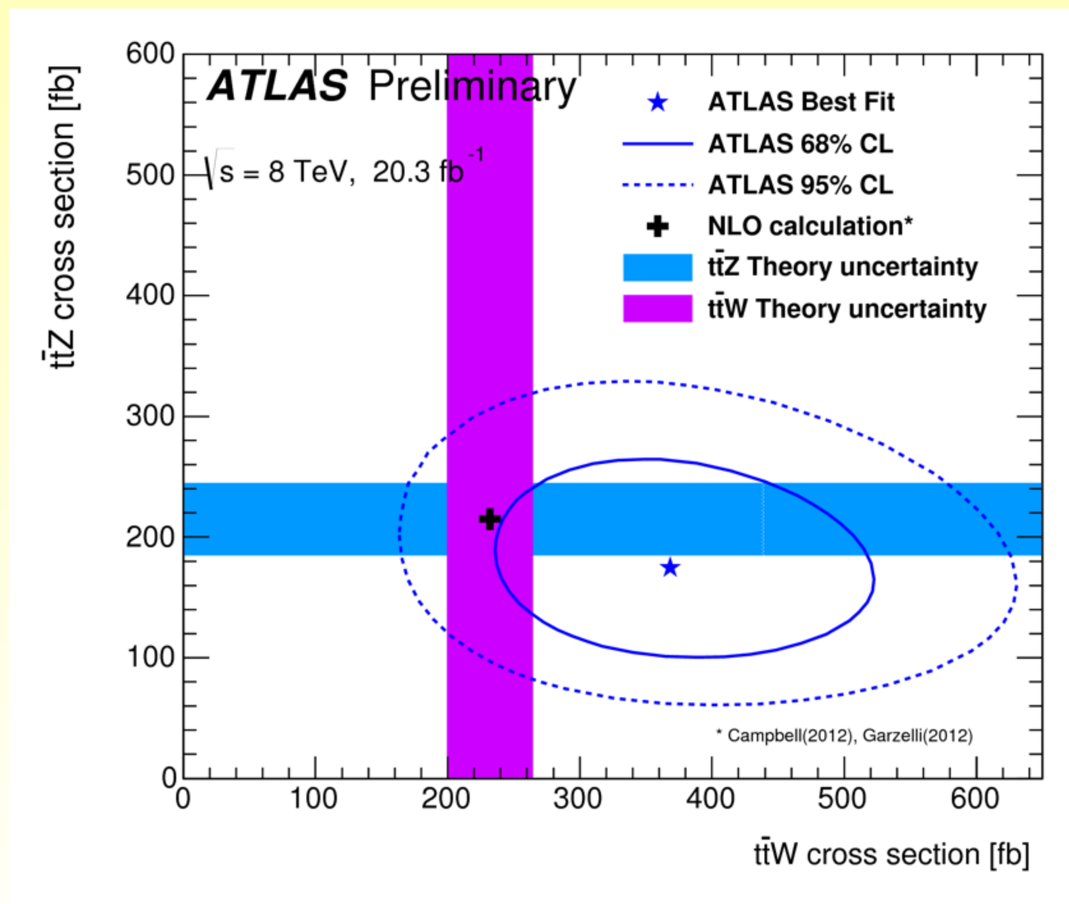
ATLAS-CONF-2015-032



Channel	$t\bar{t}W$ significance Expected	$t\bar{t}W$ significance Observed	$t\bar{t}Z$ significance Expected	$t\bar{t}Z$ significance Observed
2ℓOS	0.4	0.1	1.4	1.1
2ℓSS	2.8	5.0	-	-
3ℓ	1.4	1.0	3.7	3.3
4ℓ	-	-	2.0	2.4
Combined	3.2	5.0	4.5	4.2

$$\sigma_{t\bar{t}W} = 369^{+86}_{-79}\,(\text{stat.}) \pm 44\,(\text{syst.})\ \text{fb}$$

$$\sigma_{t\bar{t}Z} = 176^{+52}_{-48}\,(\text{stat.}) \pm 24\,(\text{syst.})\ \text{fb}$$



first observation of $t\bar{t}W$

cross section consistent with the SM

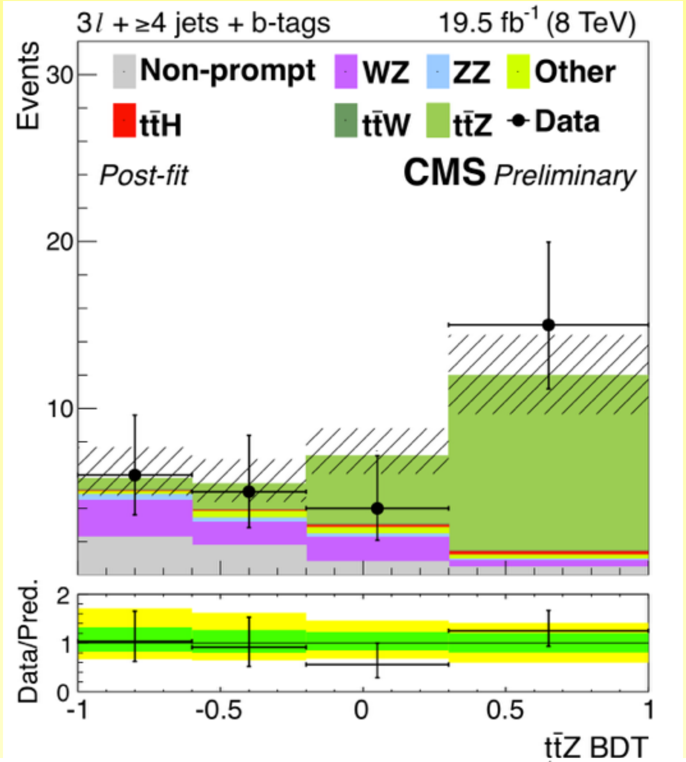
CMS $t\bar{t}W$ and $t\bar{t}Z$ results

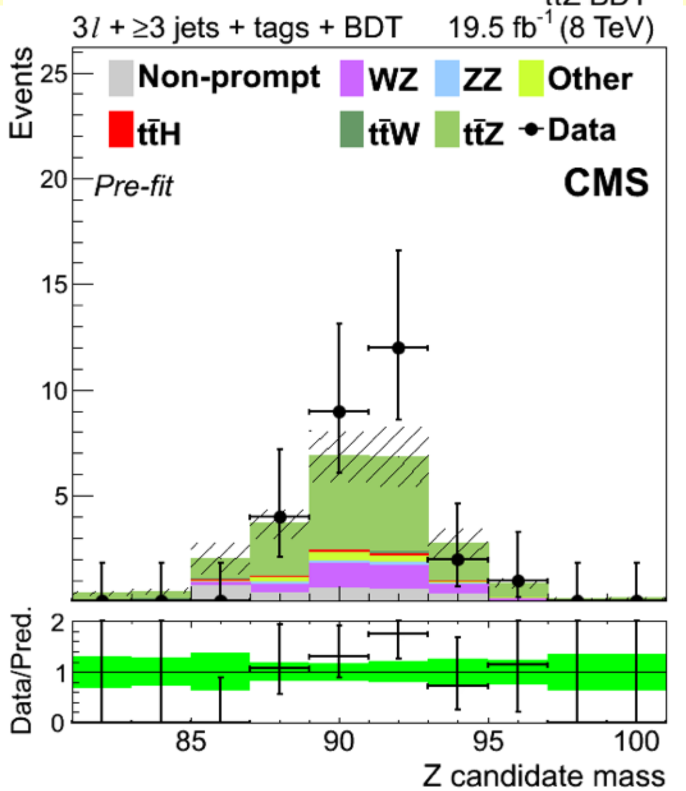
CMS-PAS-TOP-13-015

- **Analysis strategy**
  - full event reconstruction (likelihood ratio to match jets with lepton from the top)
  - matching reconstruction quality and kinematic quantities input to BDT to distinguish signal from background

- **Uncertainties**
  - statistical dominates
  - systematic treated as nuisance parameters

Reduction in signal strength uncertainty		
Systematic uncertainties removed	$t\bar{t}W$	$t\bar{t}Z$
Signal modeling	5.2%	7.1%
Nonprompt backgrounds	12.5%	0.5%
Inclusive prompt backgrounds	0.7%	2.6%
Prompt backgrounds with extra jets	0.2%	3.4%
Prompt backgrounds with extra heavy flavor jets	0.0%	1.1%
b tagging efficiency	6.1%	7.3%
Jet energy scale	1.4%	$< 0.1\%$
Lepton ID and trigger efficiency	0.3%	0.5%
Luminosity and pileup	0.7%	0.5%
Bin-by-bin statistical uncertainty	4.4%	1.2%
All systematic uncertainties	31%	29%





CMS $t\bar{t}W$ and $t\bar{t}Z$ results

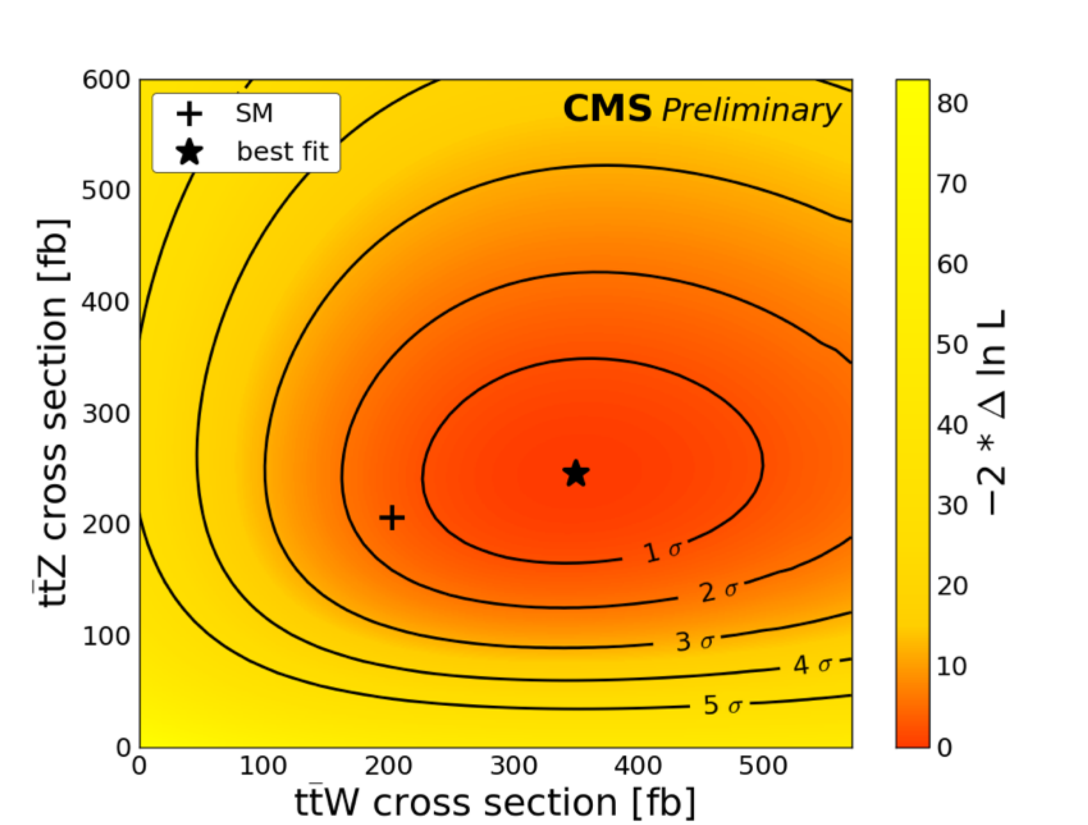
CMS-PAS-TOP-13-015

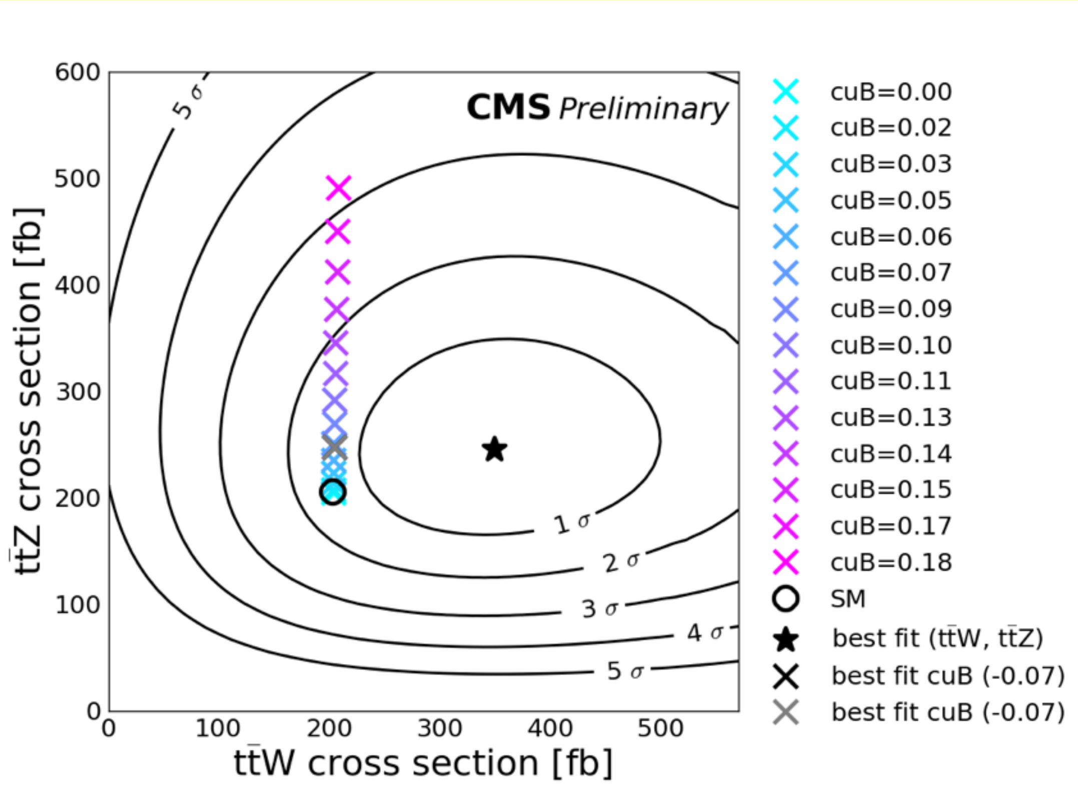
$t\bar{t}W$	Cross section (fb)		Signal strength (μ)		Significance	
Channels	Expected	Observed	Expected	Observed	Expected	Observed
SS	203^{+88}_{-73}	414^{+135}_{-112}	$1.0^{+0.45}_{-0.36}$	$2.04^{+0.74}_{-0.61}$	3.4	4.9
3ℓ	203^{+215}_{-194}	210^{+225}_{-203}	$1.0^{+1.09}_{-0.96}$	$1.03^{+1.07}_{-0.99}$	1.0	1.0
SS + 3ℓ	203^{+84}_{-71}	382^{+117}_{-102}	$1.0^{+0.43}_{-0.35}$	$1.88^{+0.66}_{-0.56}$	3.5	4.8

$t\bar{t}Z$	Cross section (fb)		Signal strength (μ)		Significance	
Channels	Expected	Observed	Expected	Observed	Expected	Observed
OS	206^{+142}_{-118}	257^{+158}_{-129}	$1.0^{+0.72}_{-0.57}$	$1.25^{+0.76}_{-0.62}$	1.8	2.1
3ℓ	206^{+79}_{-63}	257^{+85}_{-67}	$1.0^{+0.42}_{-0.32}$	$1.25^{+0.45}_{-0.36}$	4.6	5.1
4ℓ	206^{+153}_{-109}	228^{+150}_{-107}	$1.0^{+0.77}_{-0.53}$	$1.11^{+0.76}_{-0.52}$	2.7	3.4
OS + 3ℓ + 4ℓ	206^{+62}_{-52}	242^{+65}_{-55}	$1.0^{+0.34}_{-0.27}$	$1.18^{+0.35}_{-0.29}$	5.7	6.4

first observation of $t\bar{t}Z$

cross section consistent with the SM



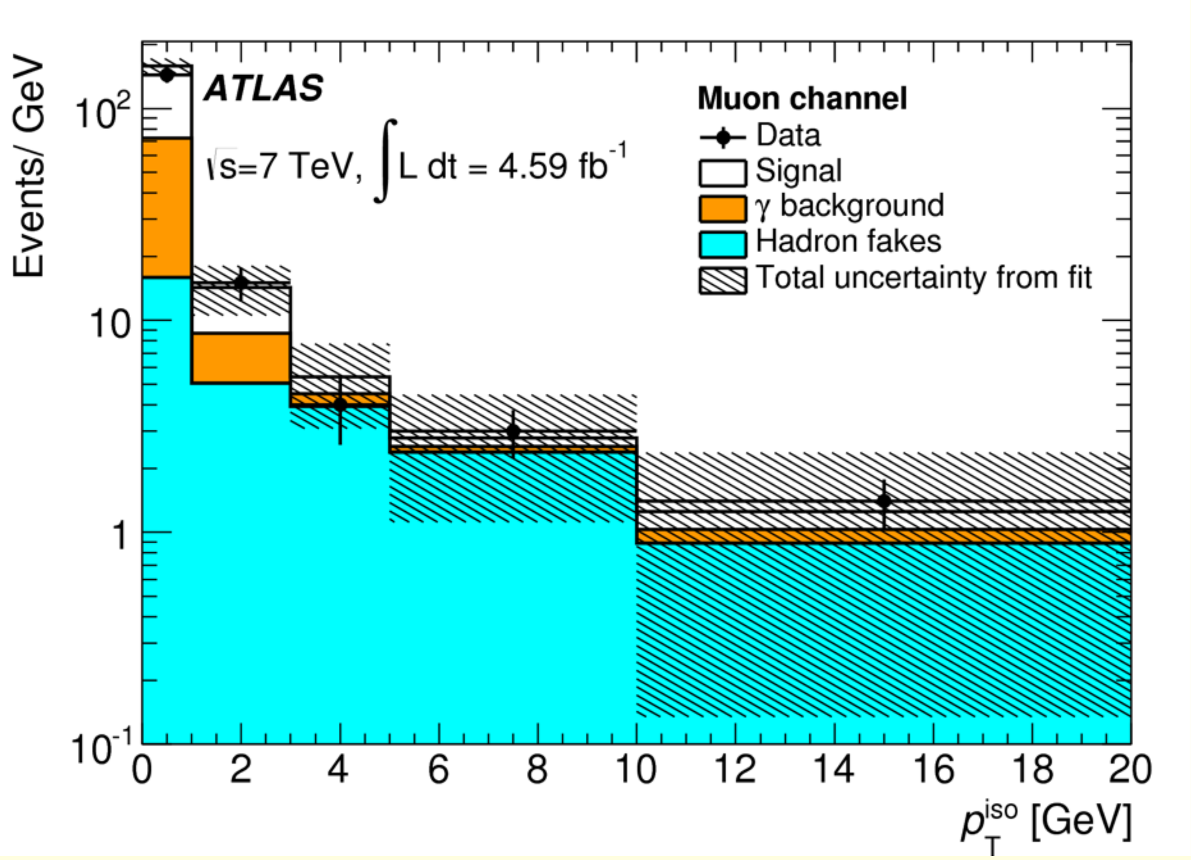


- New physics interpretation
  - effective field theory approach
  - 5 selected dim-6 operators

ATLAS $t\bar{t}\gamma$ result

PRD91, 072007 (2015)

- Analysis strategy
  - lepton+jets channel with at least 1 b-tagged jet, $E_T(\gamma)$ > 20 GeV
  - profile likelihood fit to the photon track-isolation distribution
  - background template from multijet events with inverted photon shower shape
  - measurement within the fiducial phase space



Uncertainty source	Uncertainty [%]
Background template shapes	3.7
Signal template shapes	6.6
Signal modeling	8.4
Photon modeling	8.8
Lepton modeling	2.5
Jet modeling	16.6
b-tagging	8.2
E_T^{miss} modeling	0.9
Luminosity	1.8
Background contributions	7.7

140 (e) and 222 (μ) events observed
52±14 and 100±28 determined to be $t\bar{t}\gamma$

$$\sigma^{\text{fid}}_{t\bar{t}\gamma} \times \text{BR} = 63 \pm 8(\text{stat.})\,^{+17}_{-13}\,(\text{syst.}) \pm 1\,(\text{lumi.})\text{ fb}$$

first observation of $t\bar{t}\gamma$ (5.3σ)

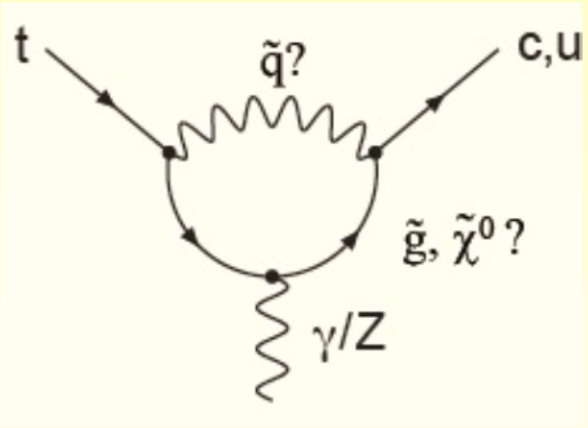
SM: 48±10 fb

Flavor changing neutral currents

Flavor changing neutral current in top decays

- FCNC
  - in the Standard Model, FCNC forbidden at tree level due to the GIM mechanism
  - allowed at one-loop level but orders of magnitude suppressed: $< 10^{-12}$
  - numerous Standard Model extensions predict higher branching ratio (quark singlet, 2HDM, MSSM, …): enhancement up to 10^{-4} - 10^{-5}

- any measurable branching ratio for top FCNC decays would be an indication of new physics



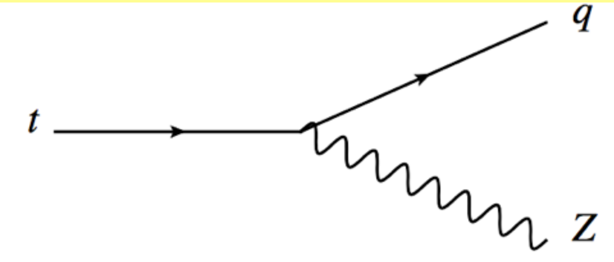
Snowmass, arXiv:1311.2028

Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

ATLAS search for t→qZ

arXiv:1508.05796

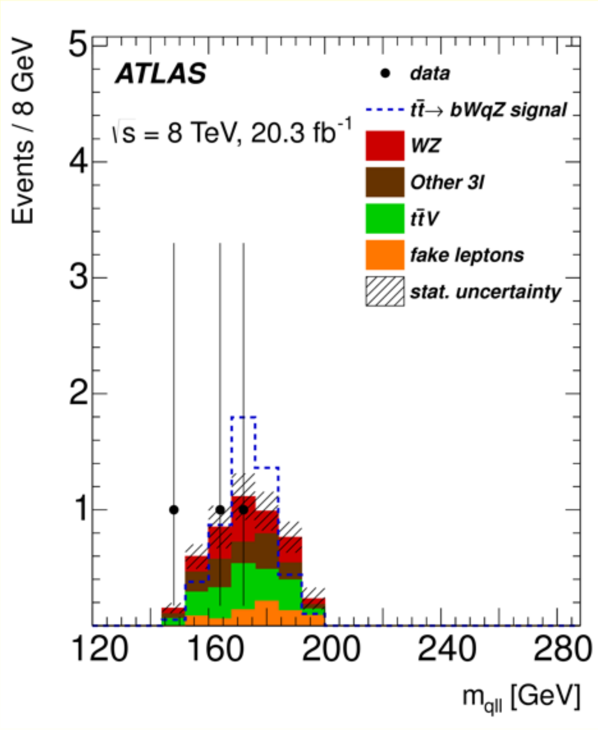
- Analysis strategy
  - final state with 3 leptons: $t\bar{t} \to u/cZ(\to \ell\ell)\, W(\to \ell\nu)b$
  - dim-6 effective couplings implemented in simulation
  - best combination to reconstruct the top kinematics determined with a χ^2
  - WZ, $t\bar{t}Z$ and fake control region

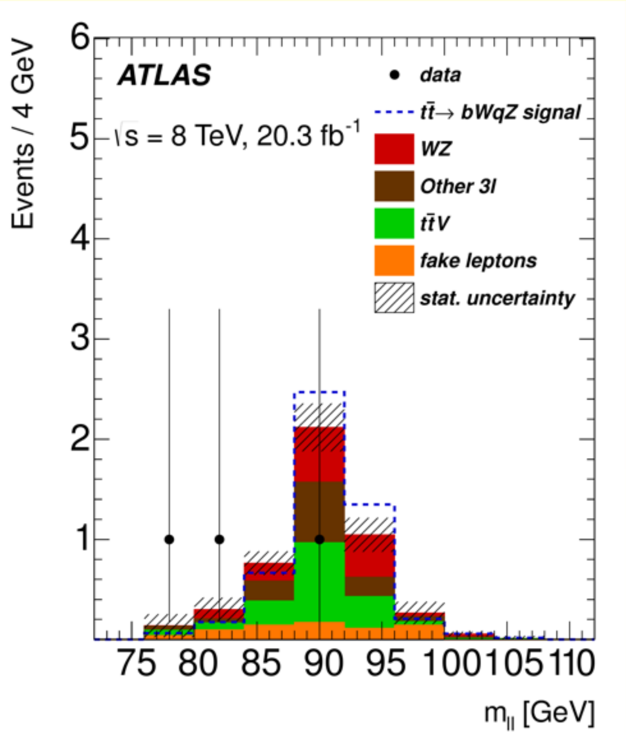


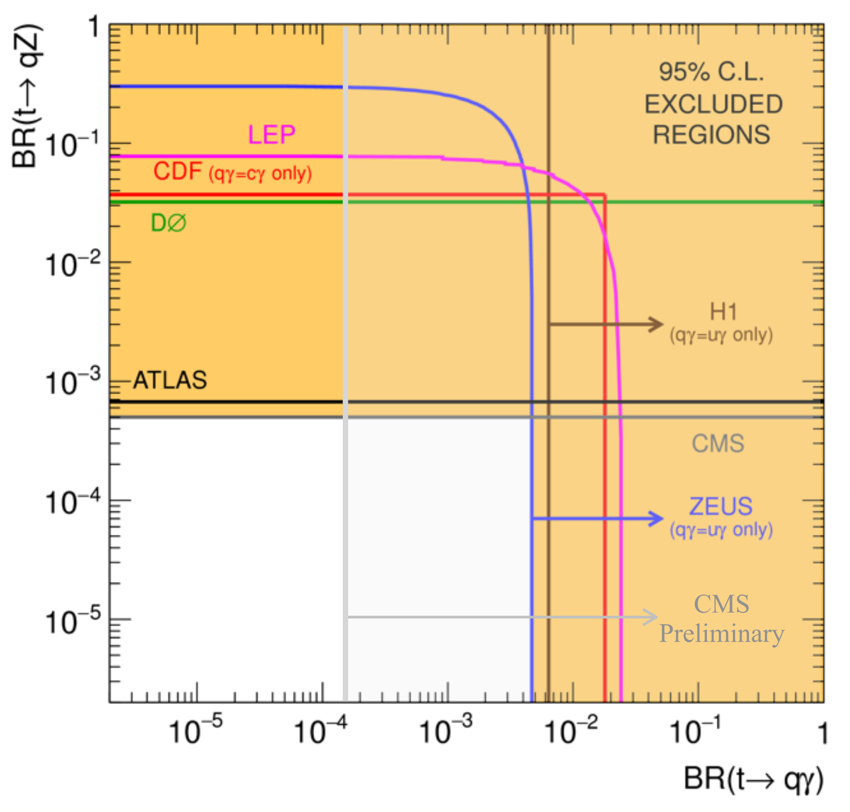
Sample	Yields
WZ	1.3 ± 0.2 ± 0.6
$t\bar{t}V$	1.5 ± 0.1 ± 0.5
tZ	1.0 ± 0.1 ± 0.5
Fake leptons	0.7 ± 0.3 ± 0.4
Other backgrounds	0.2 ± 0.1 ± 0.1
Total background	4.7 ± 0.4 ± 1.0
Data	3
Signal efficiency [$\times 10^{-4}$]	7.8 ± 0.1 ± 0.8

Source	Background [%]	Signal [%]
Background modelling	17	—
Signal modelling	—	5.5
Leptons	4.7	2.9
Jets	7.7	4.9
b-tagging	3.9	7.2
$E_{\mathrm{T}}^{\mathrm{miss}}$	3.2	1.5
Luminosity	2.4	2.8
Statistical	8.1	1.5

BR(t→qZ) < 7.10^{-4} (exp: 8.10^{-4}) at 95% CL

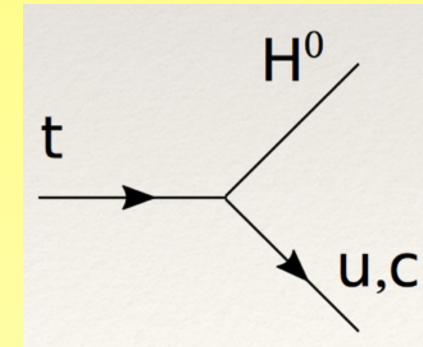






CMS search for t→c/uH

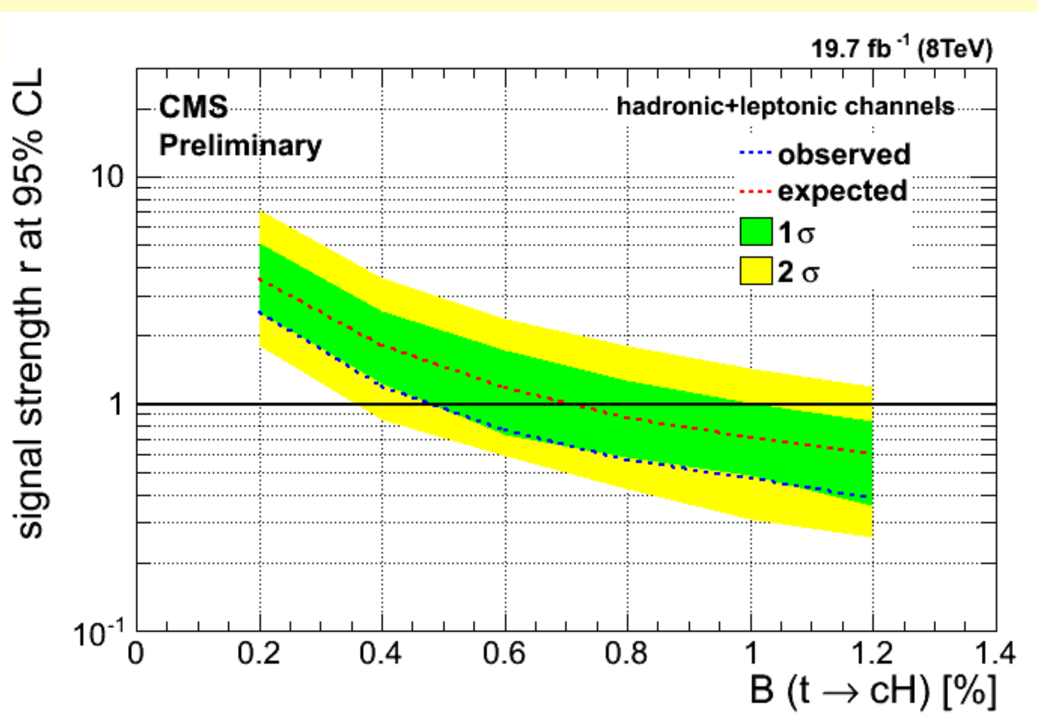
CMS-PAS-TOP-14-019

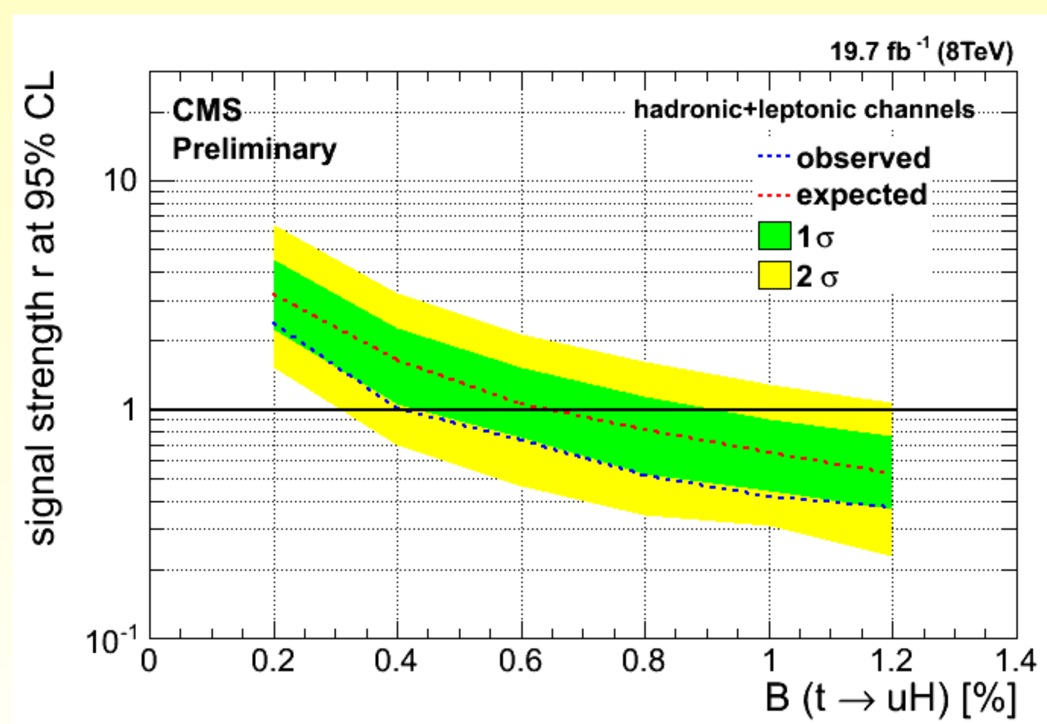


- Analysis strategy
  - hadronic and leptonic final states: $t\bar{t} \rightarrow u/cH(\rightarrow \gamma\gamma)\ W(\rightarrow \ell/h)b$
  - jet/photon/lepton pairing to get close top and antitop masses
  - background:
    - * shape of resonant γγ background from MC
    - * shape/normalization of non resonant γγ background fitted from data

$100 < M_{\gamma\gamma} < 180$ GeV	Hadronic channel	Leptonic channel
Data	29	8
Resonant diphoton background	0.152 ± 0.021 (stat.)	0.038 ± 0.008 (stat.)
Non-resonant diphoton background	28.9 ± 5.4 (stat.)	8.0 ± 2.8 (stat.)
expected signal yields for $\mathcal{B}$ (t → cH) = 1%	6.26 ± 0.07 (stat.)	1.91 ± 0.04 (stat.)
expected signal yields for $\mathcal{B}$ (t → uH) = 1%	7.09 ± 0.08 (stat.)	2.02 ± 0.04 (stat.)

BR(t→cH)< 0.47 (exp: 0.71)
BR(t→uH)< 0.42 (exp: 0.65)
at 95% CL

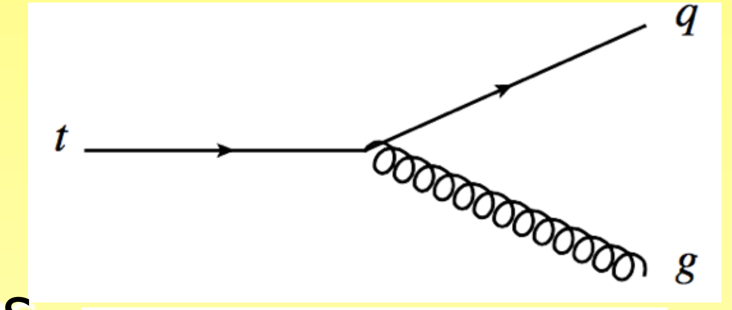


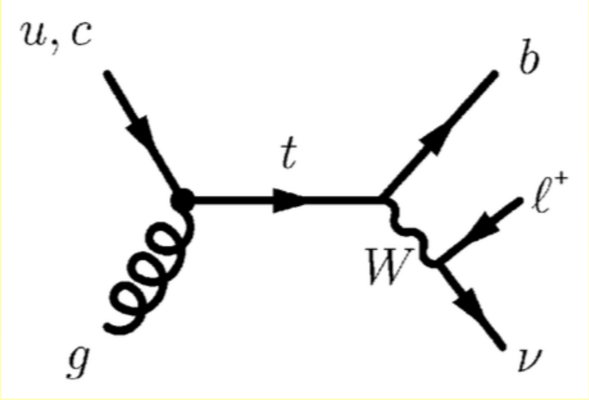


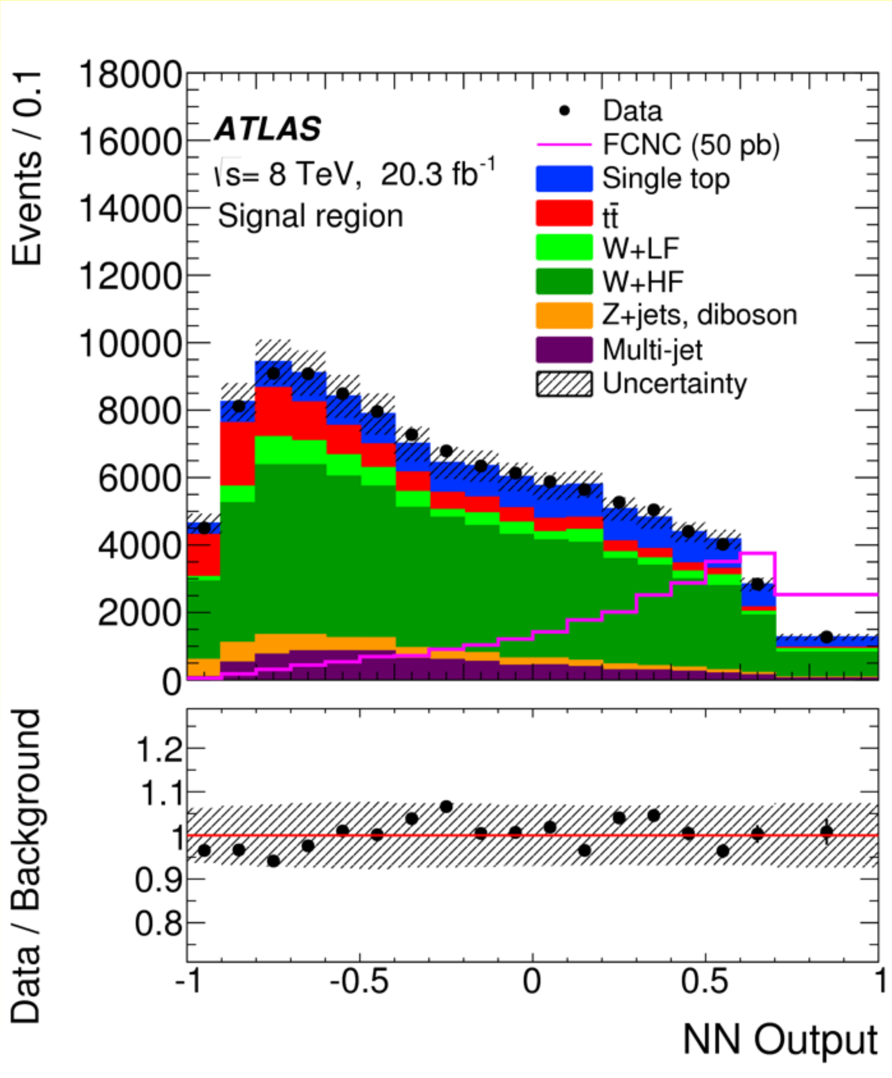
ATLAS search for t→u/cg

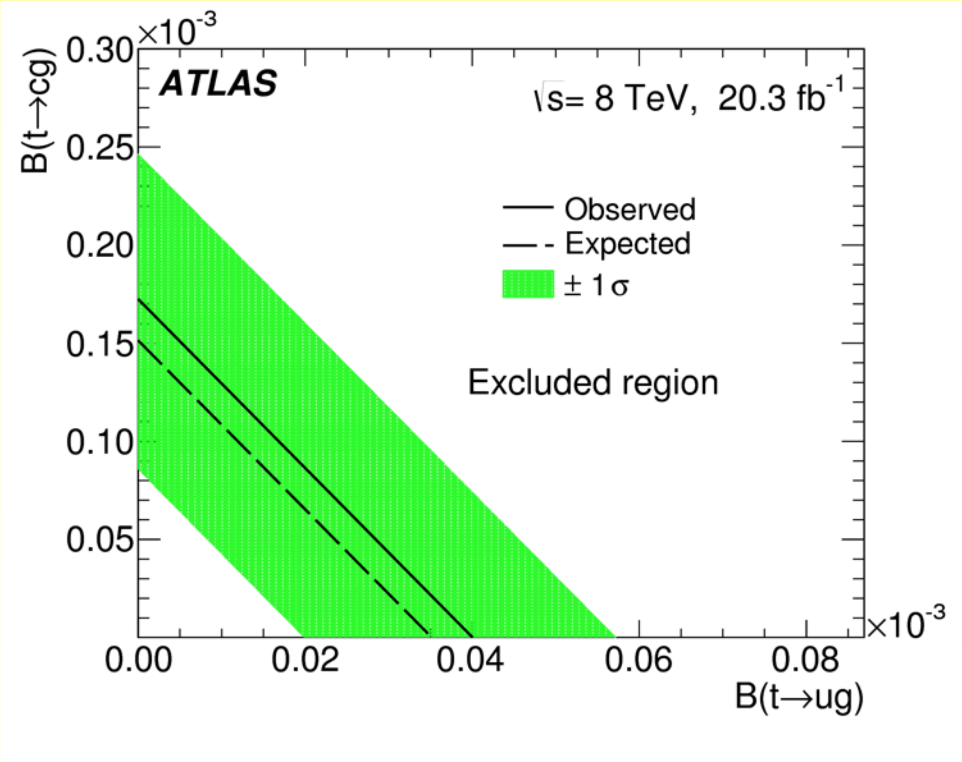
arxiv:1509.00294

- t→qg in $t\bar{t}$ is overwhelmed with multijet background
  - sensitivity via single top production
- Analysis strategy
  - lepton+jets channel
  - strong top FCNC implemented through dim-6 effective couplings
  - a Neural Network is used to separate signal from background with 13 input variables









$$\mathcal{B}(t \to ug) < 4.0 \times 10^{-5}$$

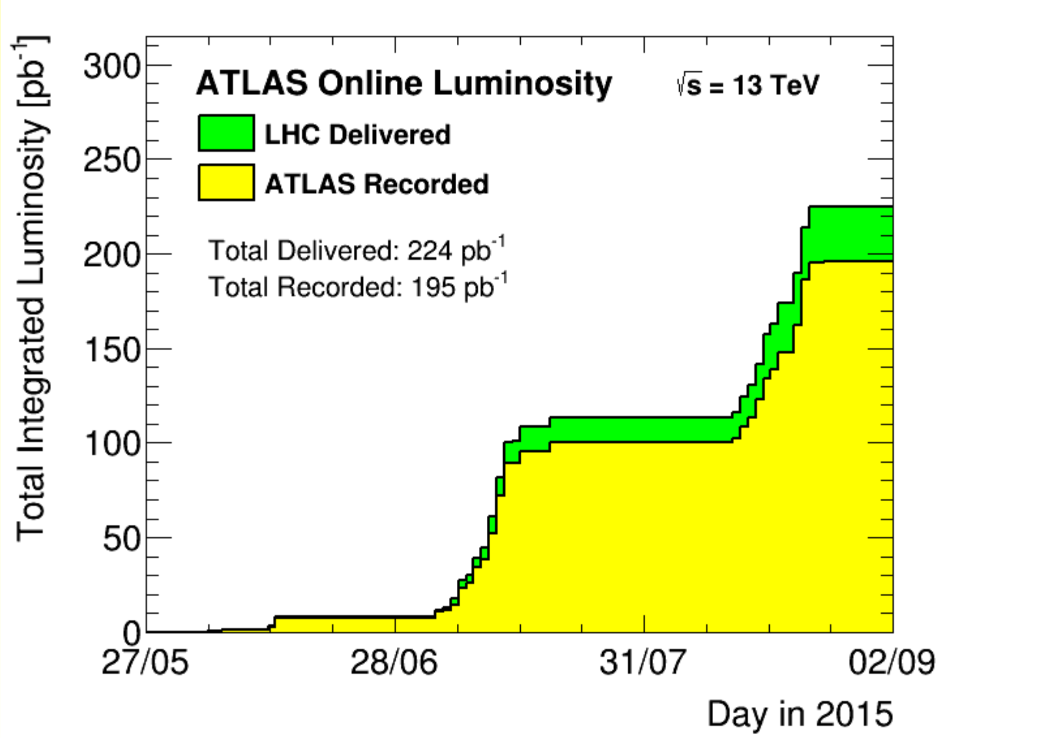
$$\mathcal{B}(t \to cg) < 17 \times 10^{-5}$$

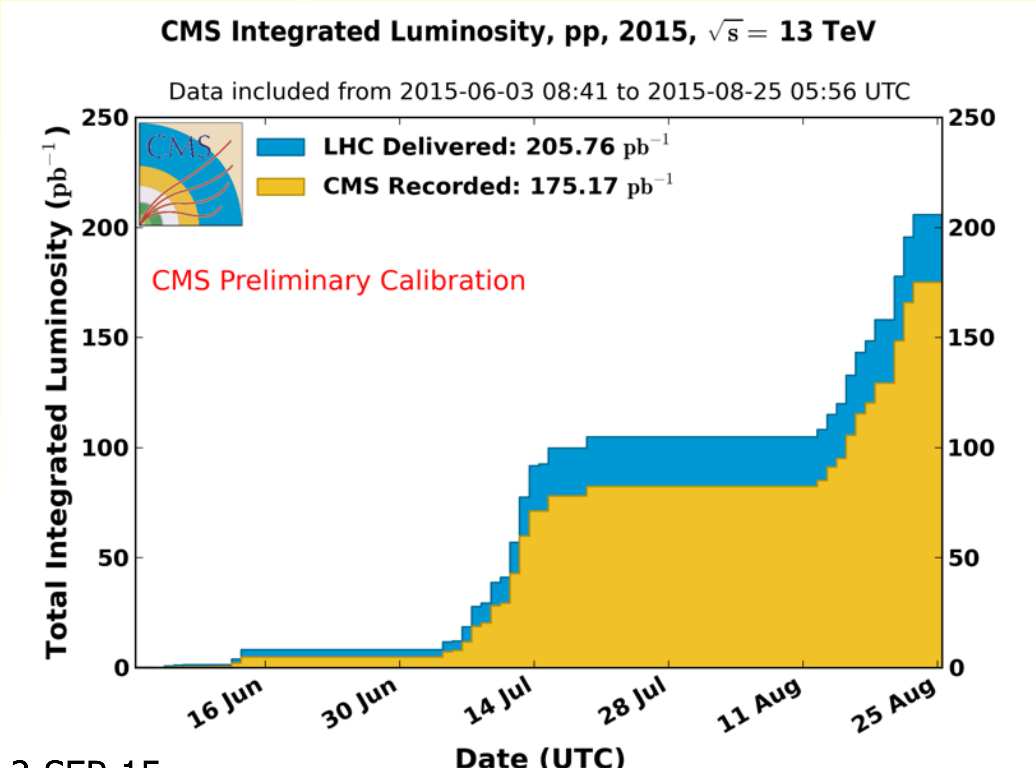
at 95% CL

Systematic uncertainties dominated by jet energy resolution, MET modeling and multijet background modeling

Conclusion

- The top quark is an unique tool to search for new physics
  - the top quark properties have been precisely scrutinized with Run 1 LHC data
  - several processes were observed for the first time ($t\bar{t}$+Z/W/γ)
  - single top production starts to be utilized for top quark property measurements
    so far it seems to behave as expected by the Standard Model
- See all details in the parallel session talks
  - mass: Nathan Mirnan, Teresa Barillari
  - single top: Benedikt Maier, Reinhard Schwienhorst
  - $t\bar{t}$: Cecilia Gerber, Boris Lemmer
- With LHC Run 2 at 13 TeV, we will enter another new area for top physics
  - higher energy (e.g. $t\bar{t}$+Z/W/γ/H)
  - higher precision (i.e higher mass scales for new physics)
  - higher statistics (differential property measurements)

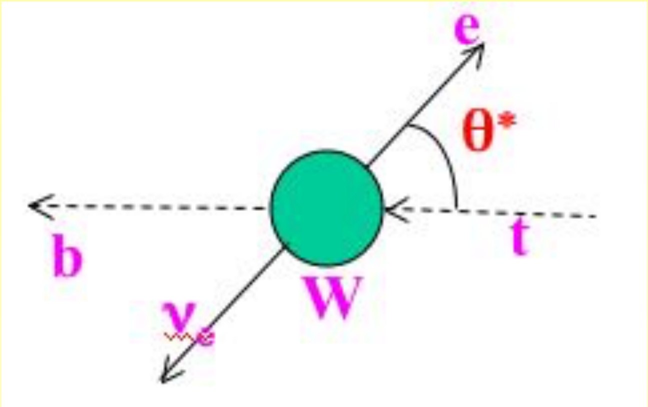




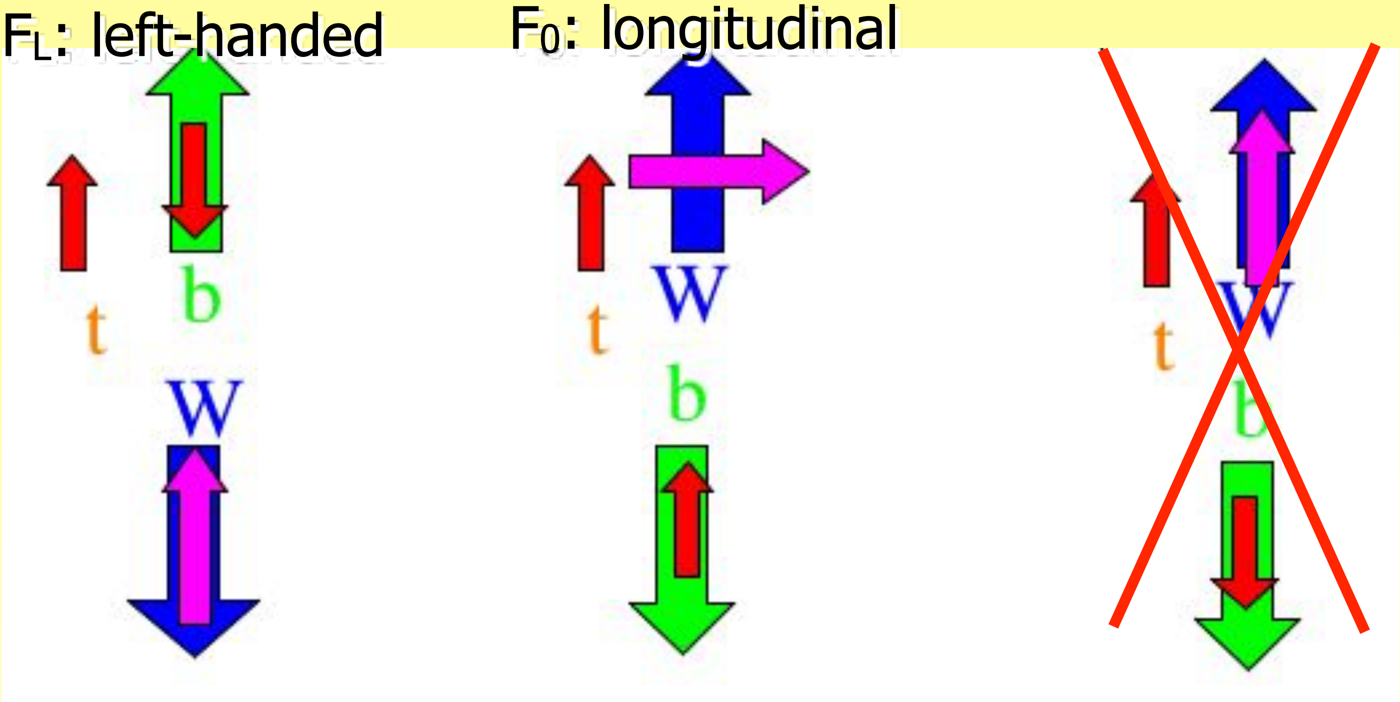
backup

W-boson helicity

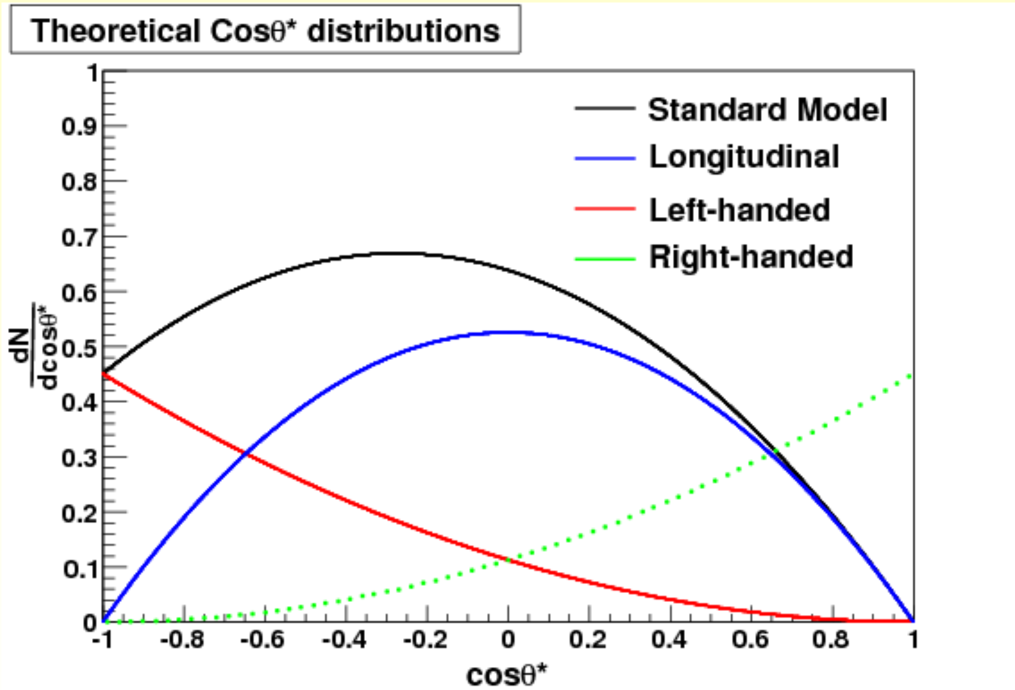
- Study of the Wtb vertex
  - through W boson polarization in top decays
  - right-handed W not predicted in the b-quark massless limit
  - W helicity fraction measured using angular distributions of the charged lepton from the top decays



angle between the charged lepton in the W rest frame and the momentum of the W in the top rest frame



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



CMS W-boson helicity results

CMS-PAS-TOP-14-017

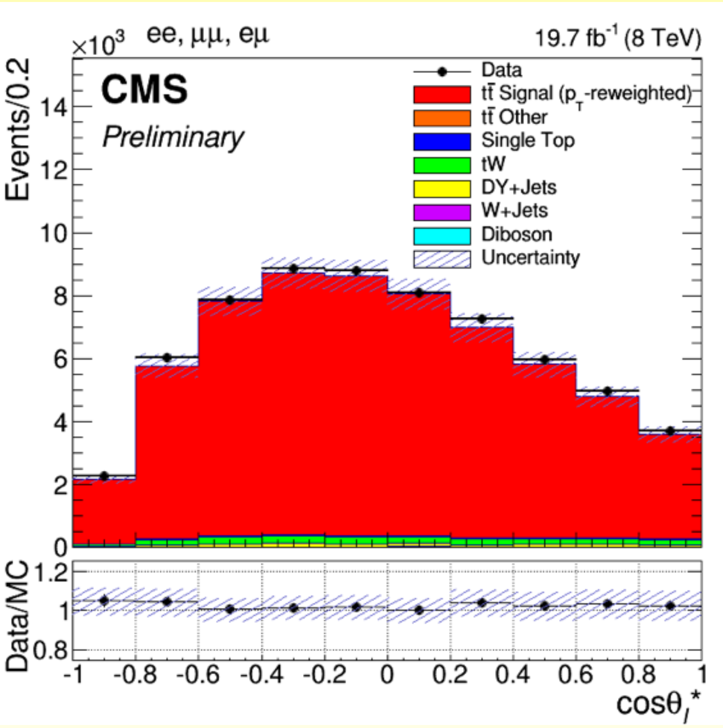
- CMS measurement using dilepton events with 2 b-tagged jets
  - need to reconstruct the $t\bar{t}$ kinematics (analytical matrix weighting technique)
  - fit the reweighted simulated distributions to the observed $\cos\theta^*$ data distribution
  - F_0, F_L and detector inefficiencies/acceptance extracted from the fit

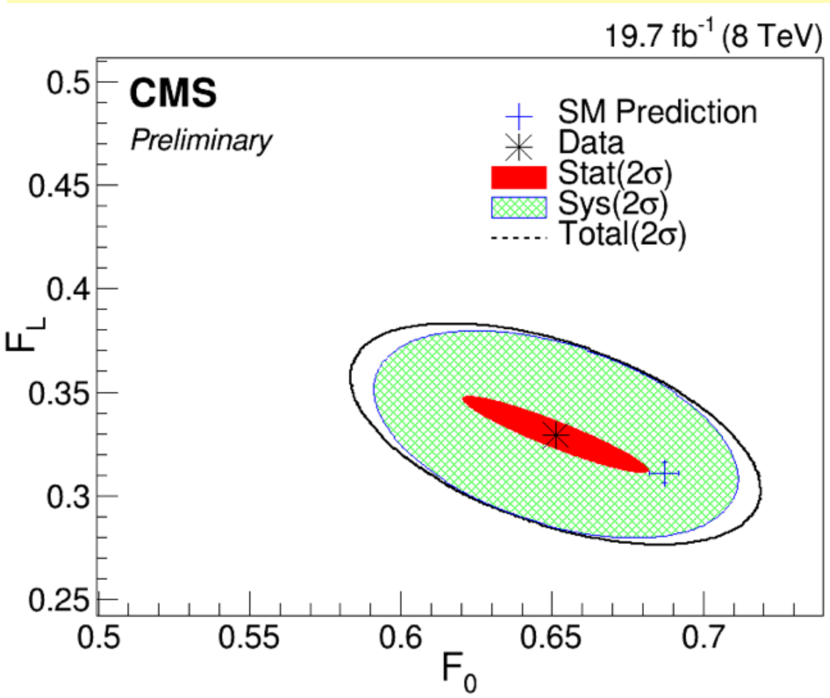
$$F_0 = 0.653 \pm 0.016(\text{stat}) \pm 0.024(\text{syst})$$

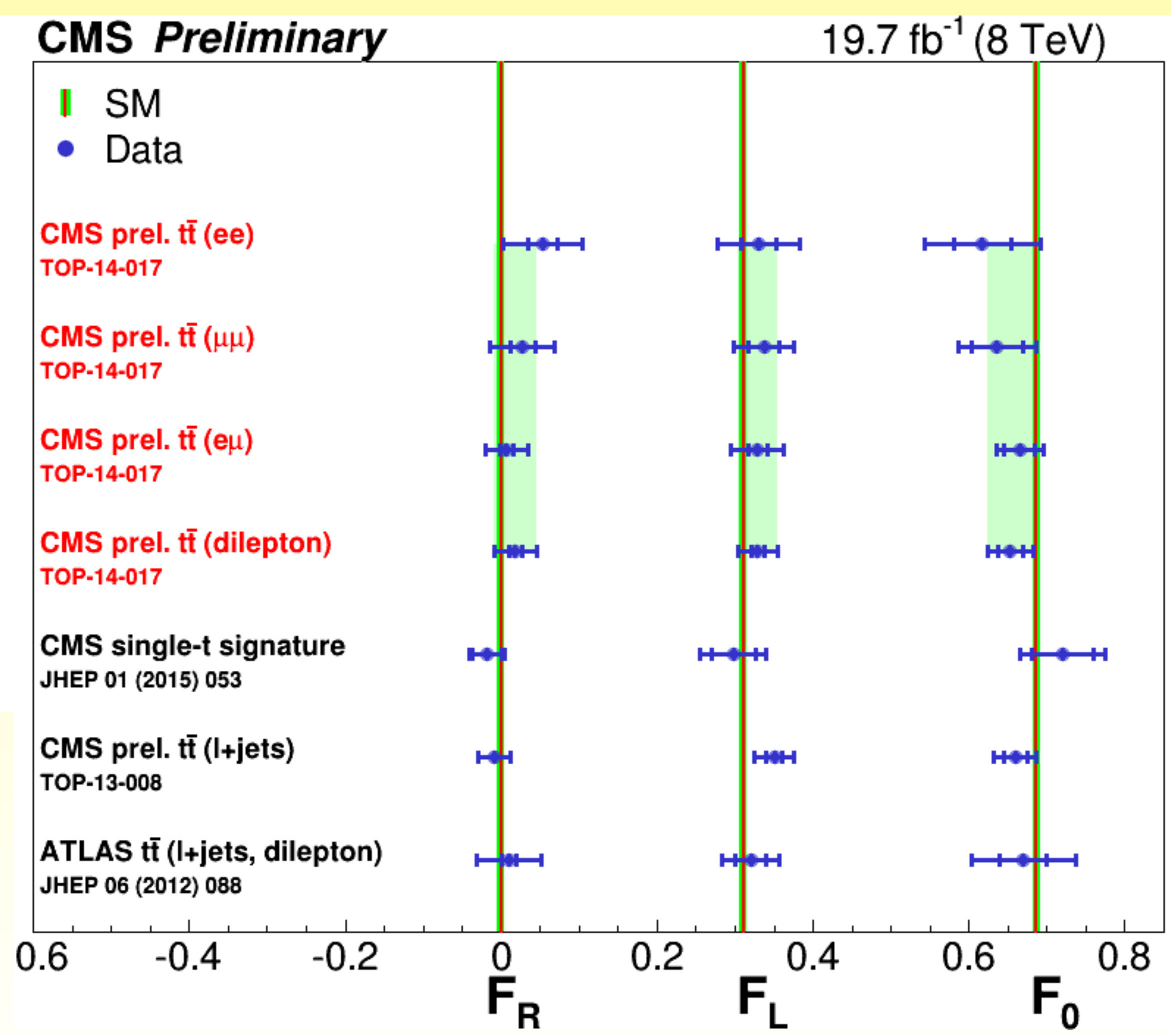
$$F_L = 0.329 \pm 0.009(\text{stat}) \pm 0.025(\text{syst})$$

in agreement with the SM predictions

dominant systematic uncertainty: scale variations



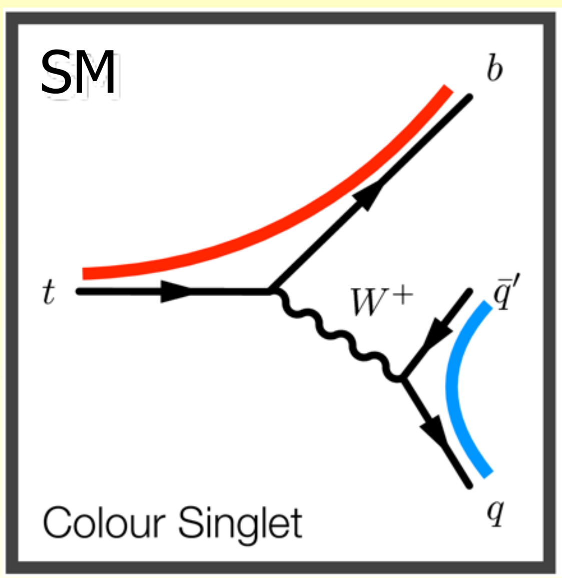


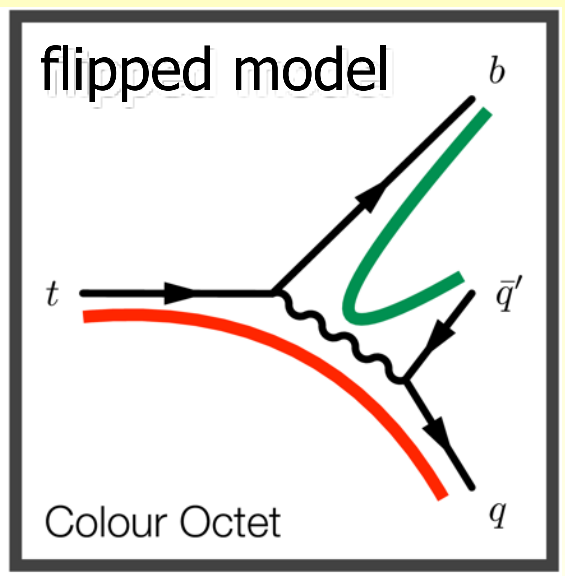


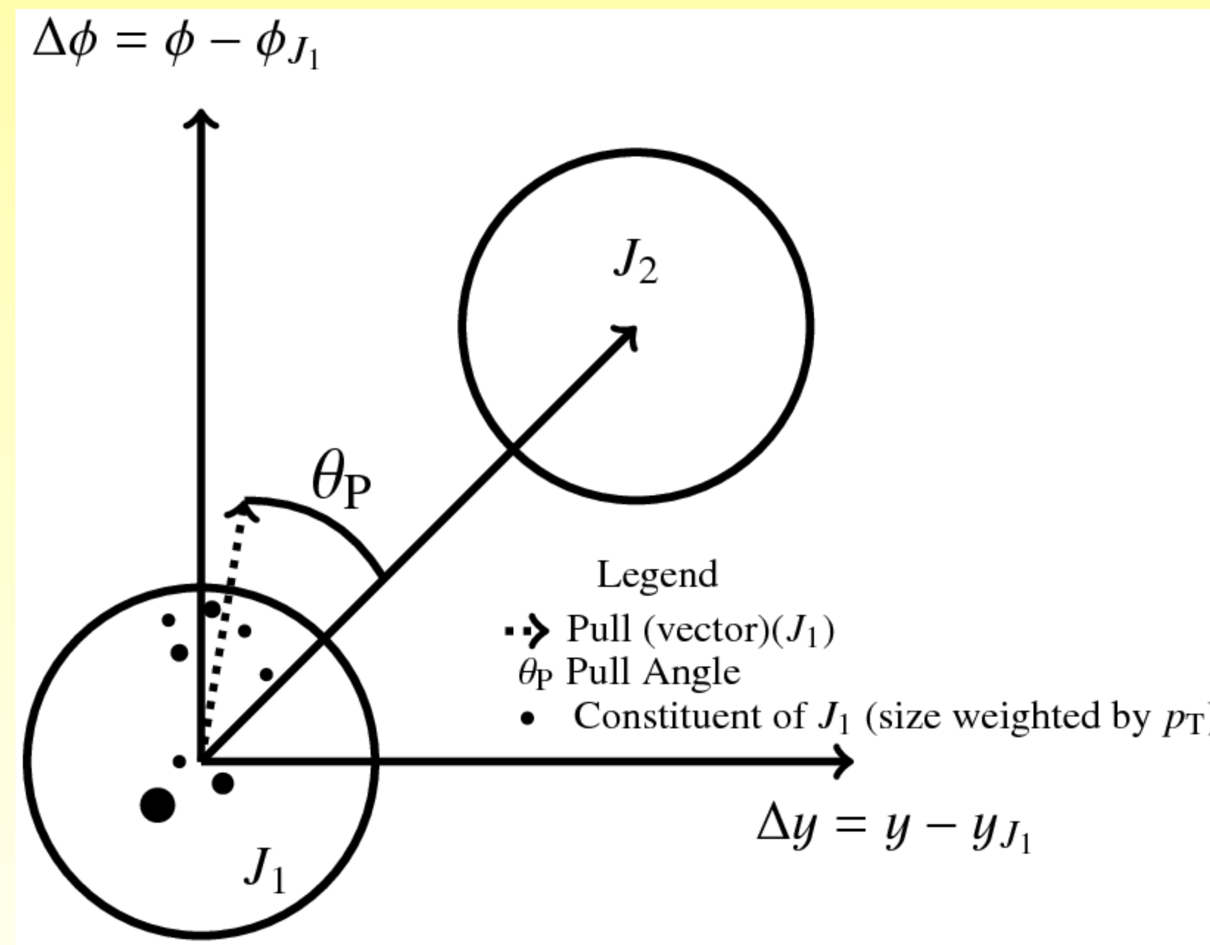
Color flow in $t\bar{t}$ events

- $t\bar{t}$ final state: unique tool to study color connections in QCD
  - data compared to simulation with a W that is color-charged or color-neutral
  - observable: jet pull angle, i.e. angle between pull vector and vector connecting two jets
  - jet pull angle: expected to be ~ 0 if the 2 jets are color-connected

$$\vec{v}_p^{\,J} = \sum_{i \in J} \frac{p_T^i |r_i|}{p_T^J} \vec{r}_i$$





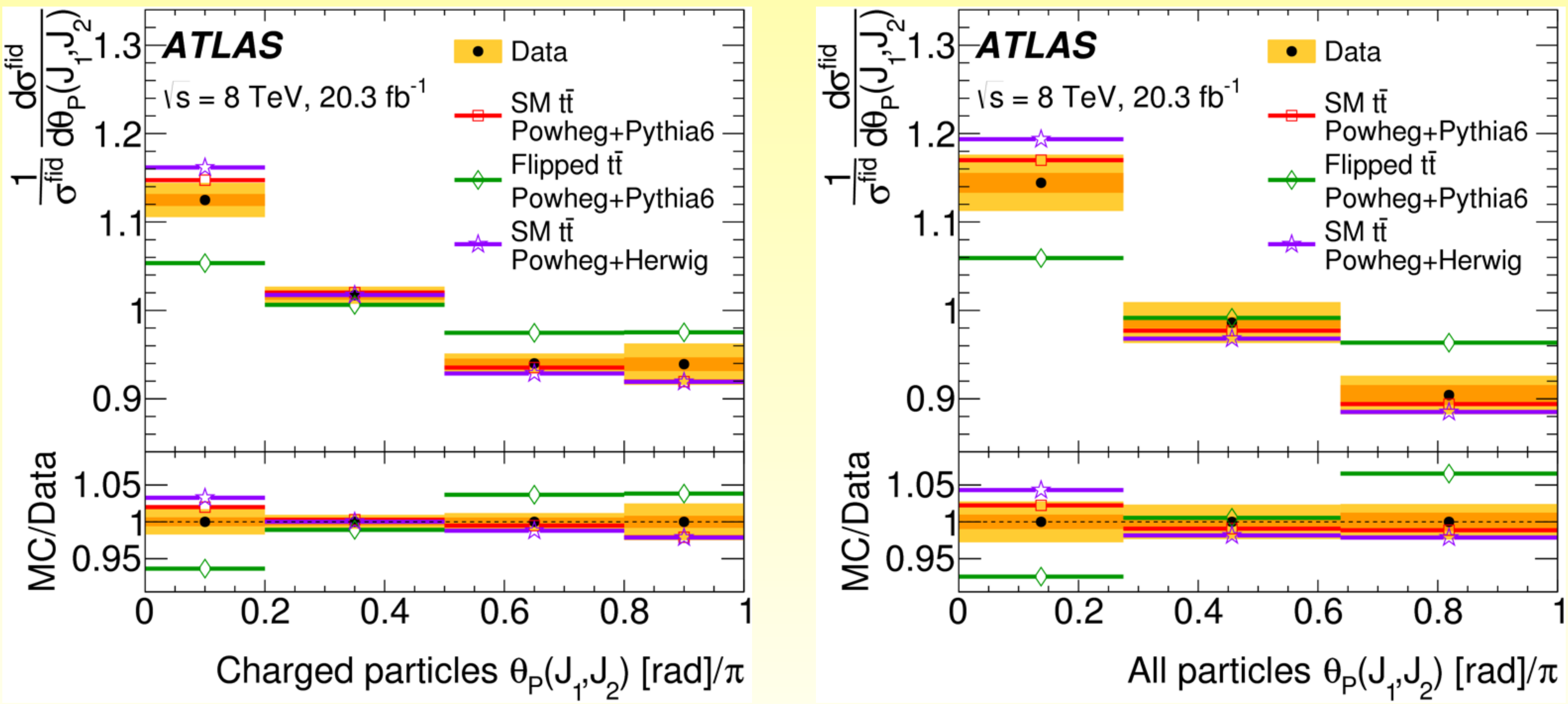


ATLAS color flow measurements

arXiv:1506.05629

- Measurement procedure (lepton+jets channel)
  - background subtraction
  - corrections for detector resolution and acceptance effects: unfolding to particle level (iterative bayesian technique)
  - jet pull angle using charged particles (tracking based) or all particles (calorimeter based)

agree with the SM color flow at 1.1σ, differ from flipped model at 3.3σ



dominant systematic uncertainties: $t\bar{t}$ modeling

see also CMS note: CMS-PAS-JME-14-002