# Top quark physics at ATLAS and CMS

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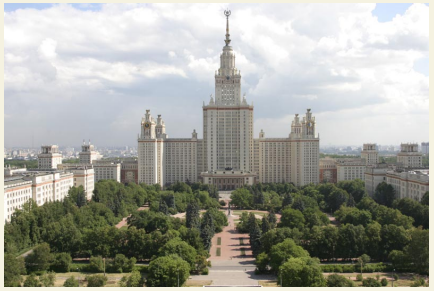
*On behalf of CMS and ATLAS Collaborations*
QFTHEP 2019

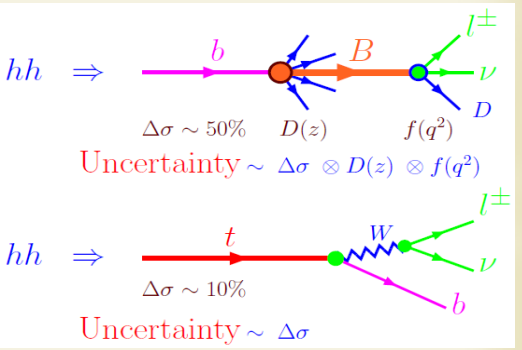


- Top quark production and SM measurements
- Anomalous structures in Wtb vertex
- Additional processes with FCNC tgq, tZq, tAq, tHq couplings
- New heavy resonanses (W', $H^+$, T, …) and DM

# Why the top quark is still very attractive topic?

- The top quark is the heaviest (173±0.5 GeV) known elementary particle and is point-like down to about $10^{-17}$ cm. Largest Yukawa coupling and may be dark matter couplings.
- Top quark decays before hadronization

$$\tau_t = \frac{1}{\Gamma_{tot}} \approx 10^{-25} < \tau_{had} \approx 10^{-24}$$




- Top quark decays through one decay channel

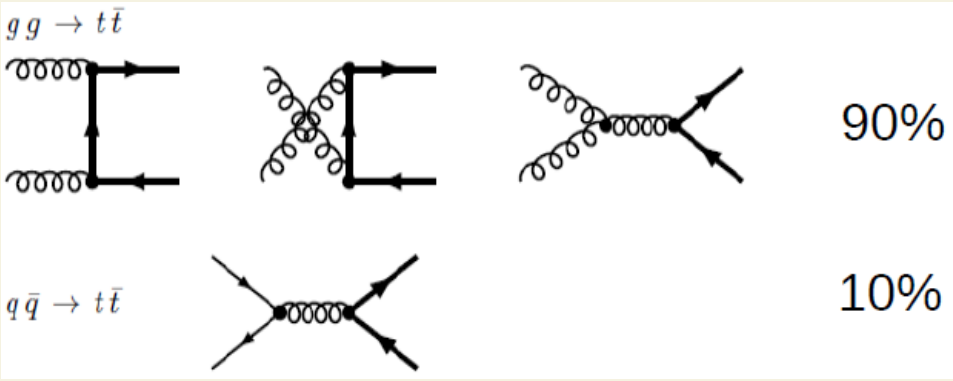
$$t \to Wb; \qquad Br(t \to other) < 10^{-3}$$

- The total and differential rates are calculated with $\mathbb{O}$(5-10%) accuracy
- Top quark is unique and powerful instrument to study SM physics and search for manifestation of New Physics beyond SM

# Top quark production processes

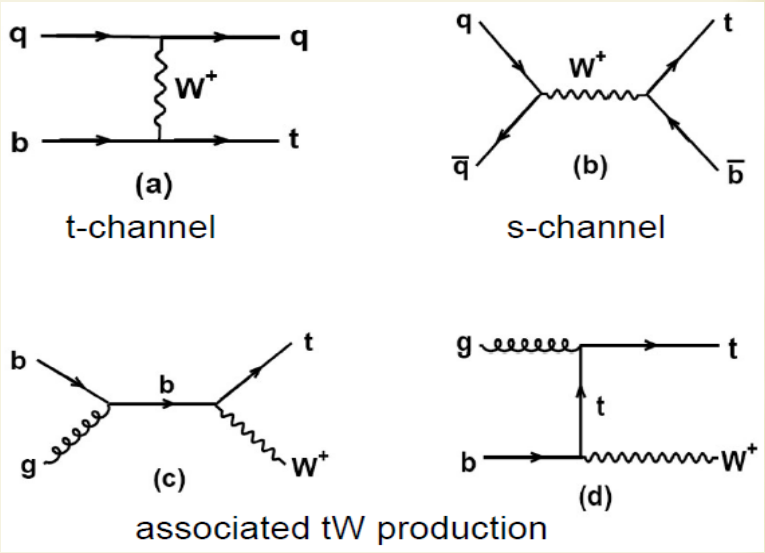
## $t\bar{t}$ pair production (QCD)

| | $\sigma_{\text{NLO}}$ (пб) |
|---|---|
| Tevatron ($\sqrt{s} = 1.96$ ТэВ $p\bar{p}$) | $7.08 \pm 5\%$ |
| LHC ($\sqrt{s} = 7$ ТэВ $pp$) | $165 \pm 6\%$ |
| LHC ($\sqrt{s} = 8$ ТэВ $pp$) | $234 \pm 4\%$ |
| LHC ($\sqrt{s} = 14$ ТэВ $pp$) | $920 \pm 5\%$ |




## $t(\bar{t})$ single production (electroweak)

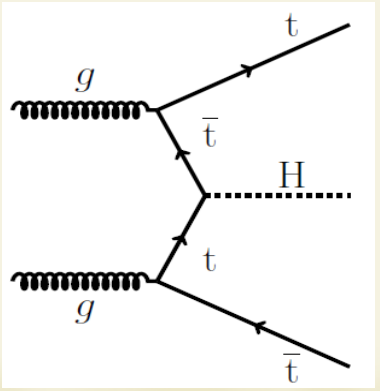
| | $s$-channel | $t$-channel | $Wt$ |
|---|---|---|---|
| Tevatron[50] ($\sqrt{s} = 1.96$ TeV $p\bar{p}$) | $1.04 \pm 4\%$ | $2.26 \pm 5\%$ | $0.14 \pm 20\%$ |
| LHC[63,72] ($\sqrt{s} = 7$ TeV $pp$) | $4.6 \pm 5\%$ | $64 \pm 4\%$ | $15.6 \pm 8\%$ |
| LHC[73] ($\sqrt{s} = 8$ TeV $pp$) | $5.55 \pm 4\%$ | $87.2^{+4}_{-3}\%$ | $11.1 \pm 7\%$ |
| LHC[52] ($\sqrt{s} = 14$ TeV $pp$) | $12 \pm 6\%$ | $243 \pm 4\%$ | $75 \pm 10\%$ |




## $t\bar{t}H(W,Z,A)$ production

~ 0.1 - 1 pb

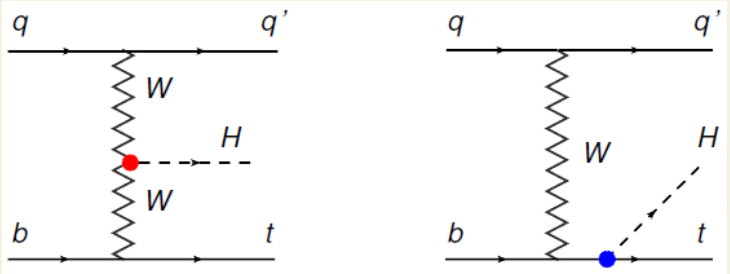
>5σ




## tHq (tZq,tAq) production

~ 0.01 - 0.1 pb

$\mu < 3$ @95CL

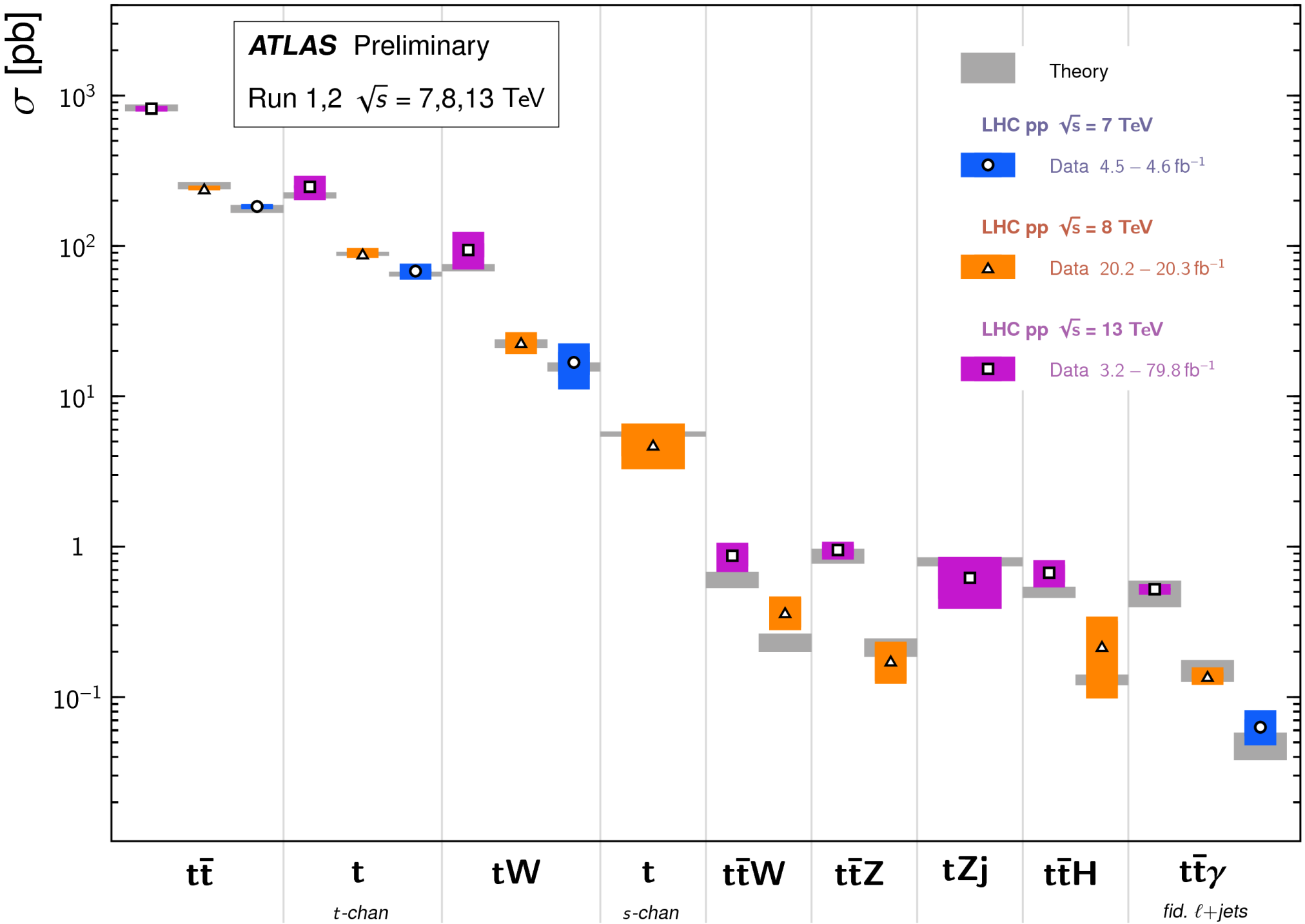


# SM and BSM measurements

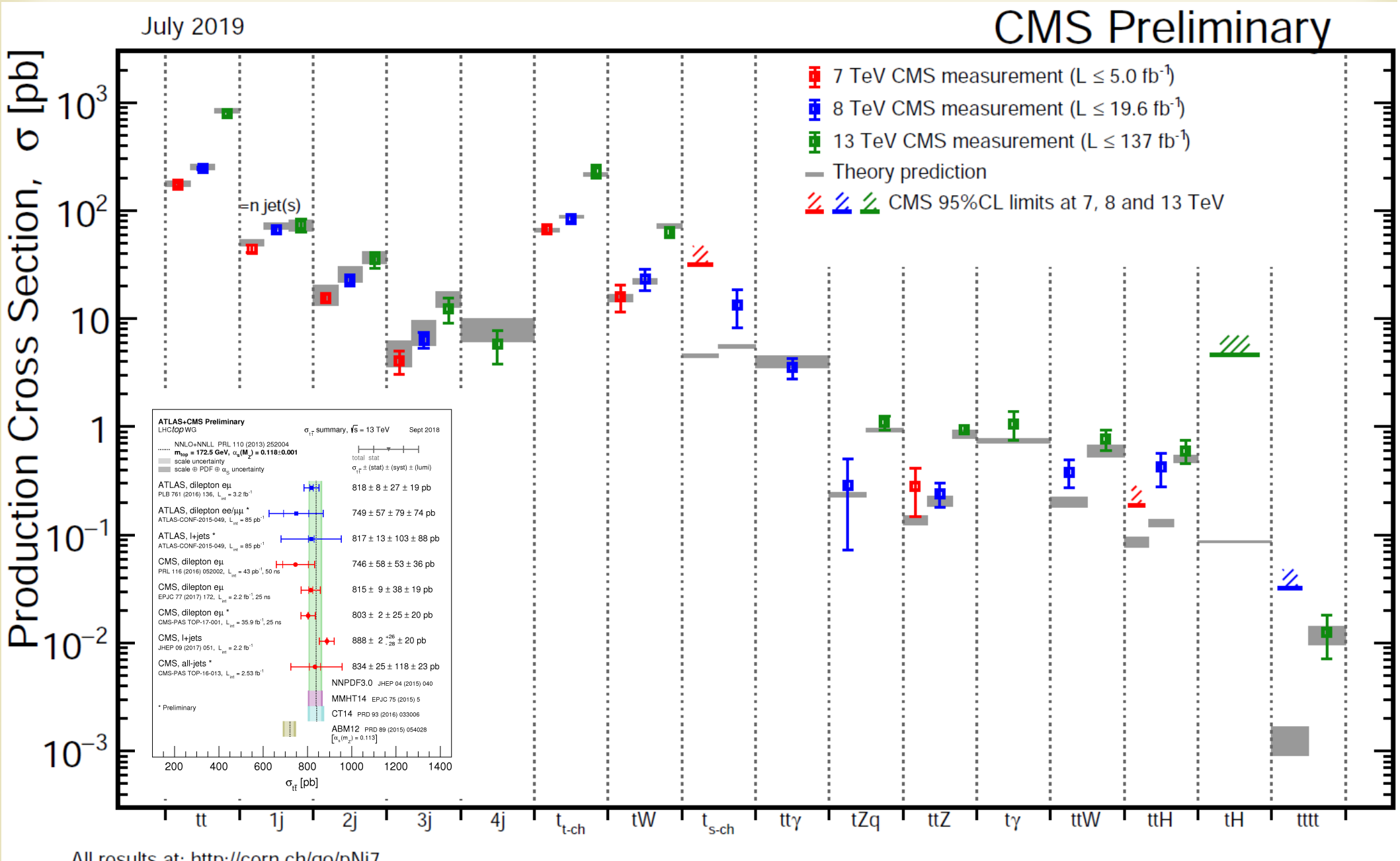
- Total and fiducial cross sections of the production processes
- Differential cross sections
- Top quark mass and other properties
- Top quark couplings (gtt, Wtb, FCNC, ...)
- Search for new resonances (W', $H^+$, T, DM, ...) decaying to top quark and new particles in the decay of top quark

# Top Quark Production Cross Section Measurements

*Status: November 2018*

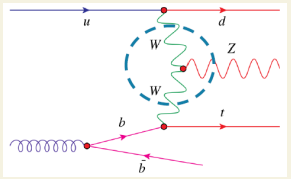
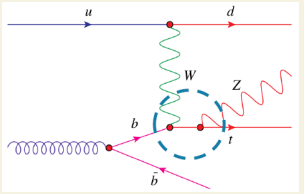


# Measured top quark production cross sections



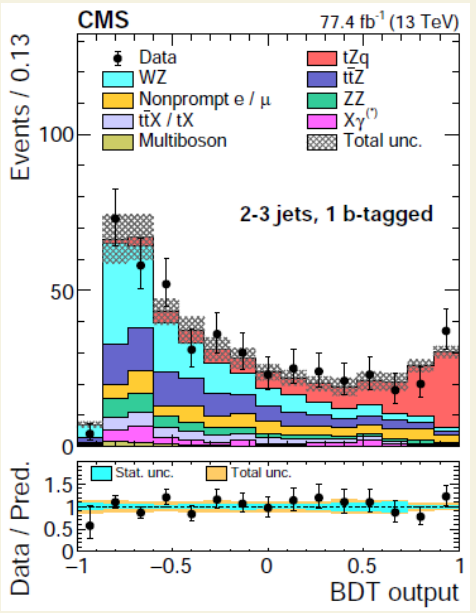
# Recent measurements of rare top quark processes

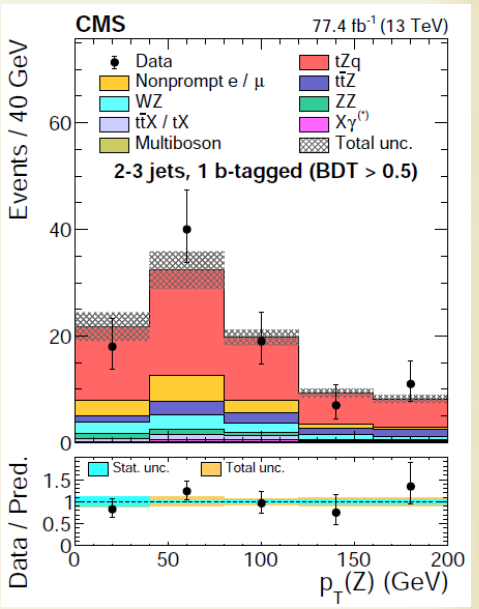
- First observation of tZq (8.2σ) [PRL 122 (2019) 132003]

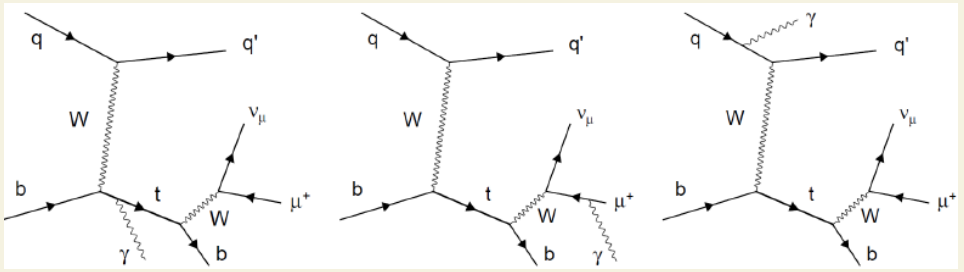
$\sigma(pp \to tZq \to t\ell^+\ell^- q) = 111 \pm 13\ (stat)\ ^{+11}_{-9}\ (syst)$ fb

SM expectation 94.2±3.1 fb



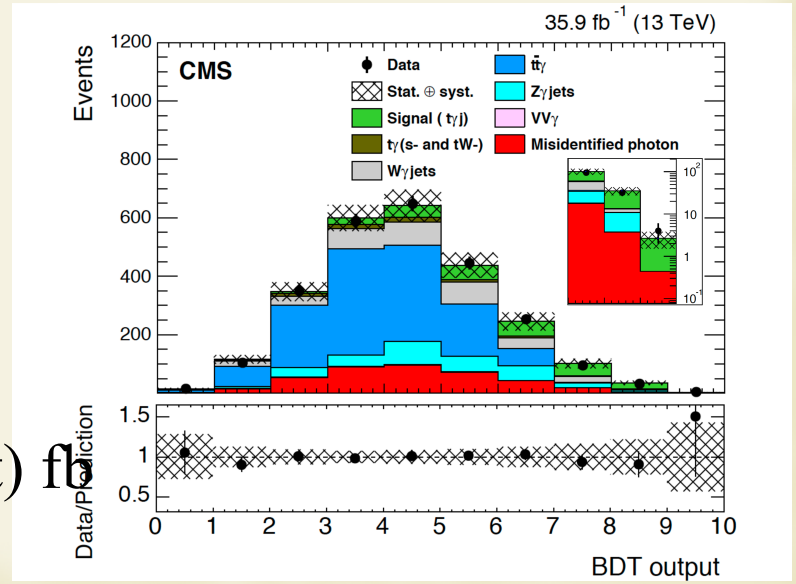




- First evidence of tγq (4.4σ)

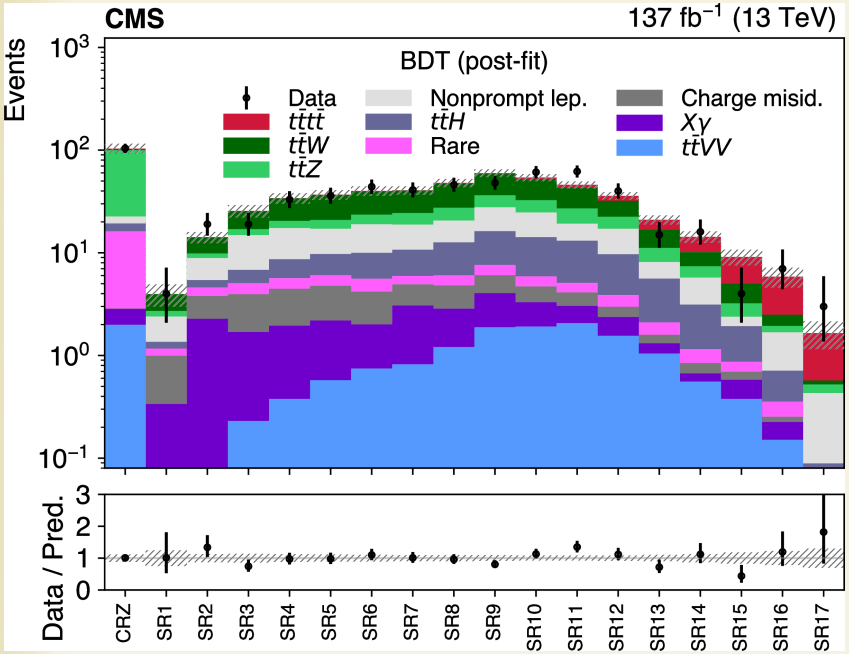


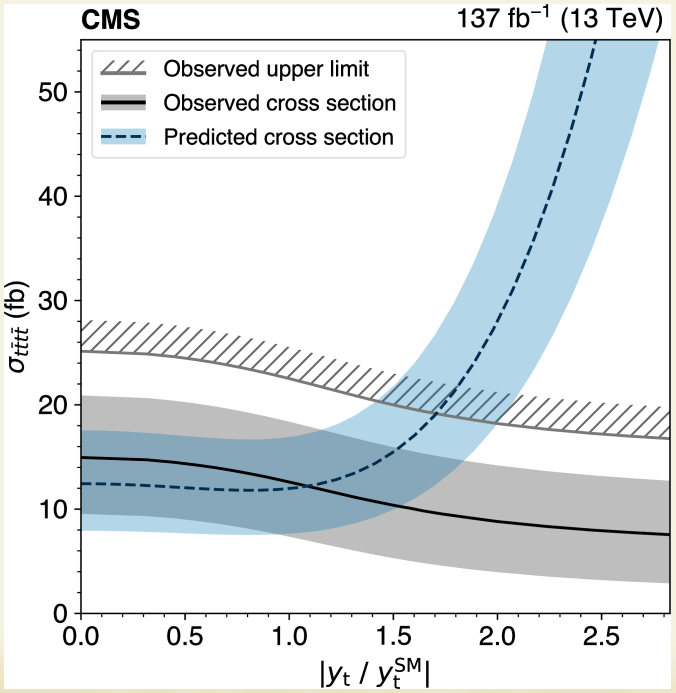
$\sigma(pp \to t\gamma j)B(t \to \mu\nu b) = 115 \pm 17\ (stat) \pm 30\ (syst)$ fb

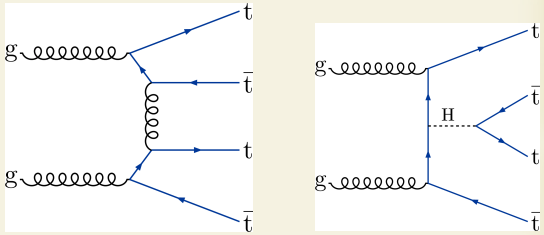
SM expectation 81±4 fb



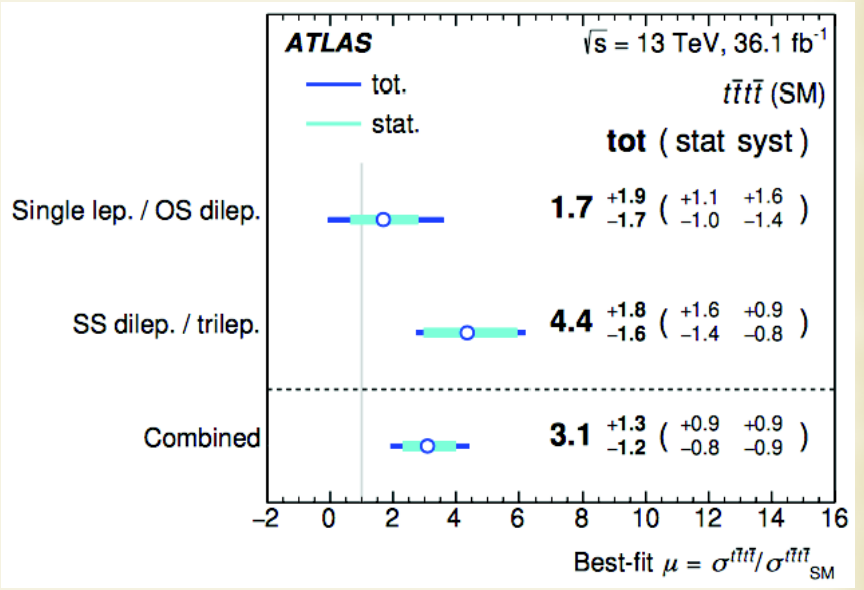
# Four tops cs measurement and top-Yukawa coupling ($y_t$)



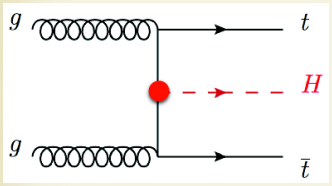



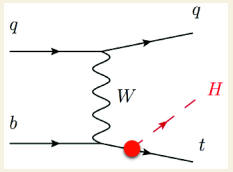

Final states:
single lepton and opposit-sign dilepton (1L/OS)
same-sign dilepton and multilepton (SS/ML)

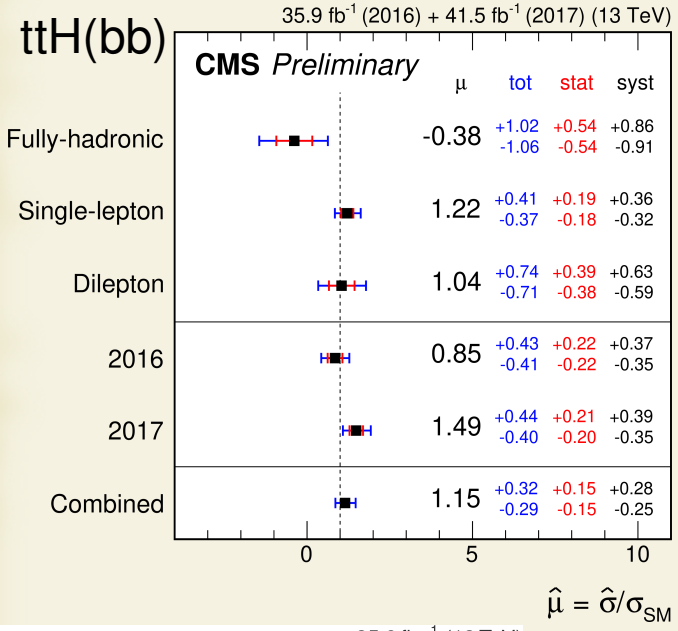


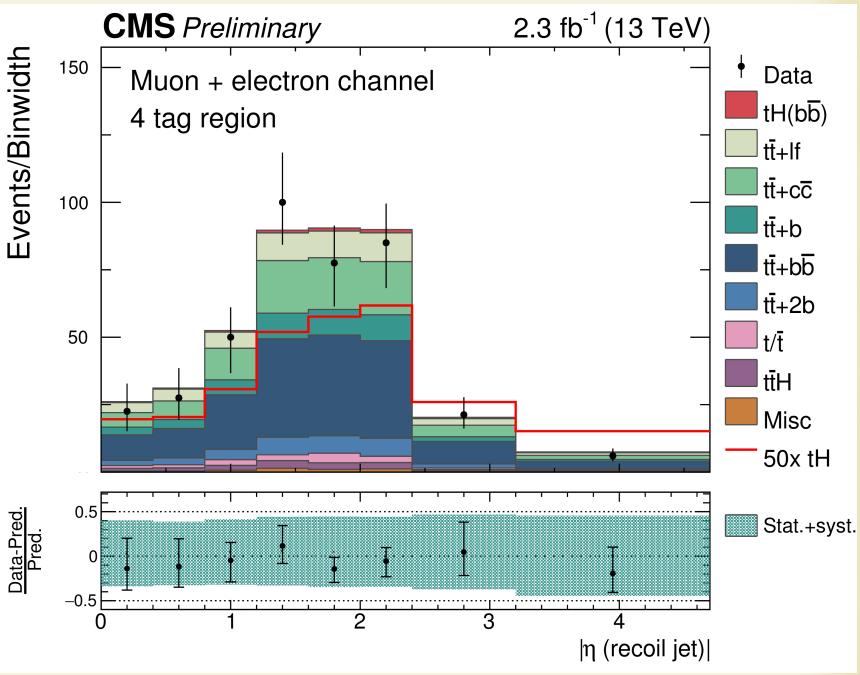

| Significance obs. (exp.) [σ] | ATLAS 36 fb$^{-1}$ | CMS 36 fb$^{-1}$ | CMS 140 fb$^{-1}$ |
|---|---|---|---|
| SS/ML | 3.0 (0.8) [1] | 1.6 (1.0) [3] | 2.6 (2.7) [5] |
| 1L/OS | 1.0 (0.6) [2] | 0.0 (0.4) [4] | - |
| Combintion | 2.8 (1.0) [2] | 1.4 (1.1) [4] | - |

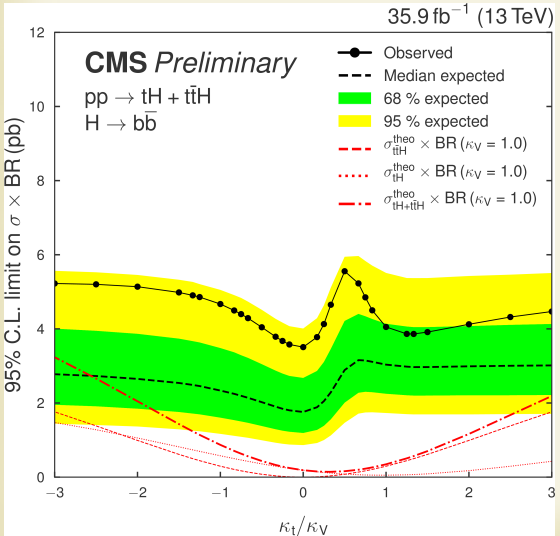
# $t\bar{t}H$ and tHq measurements

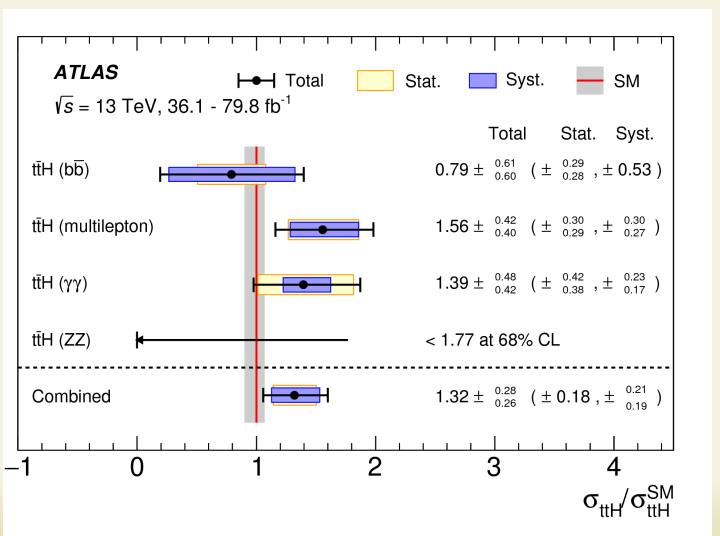


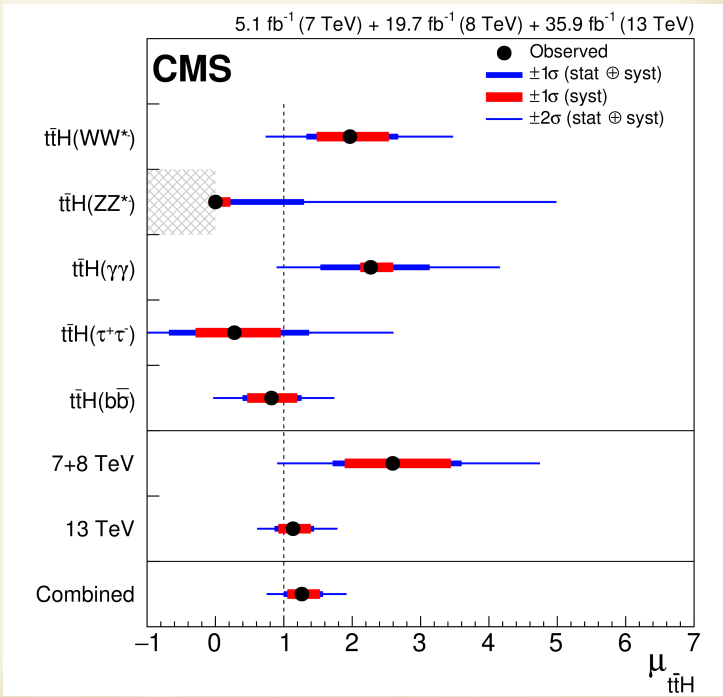



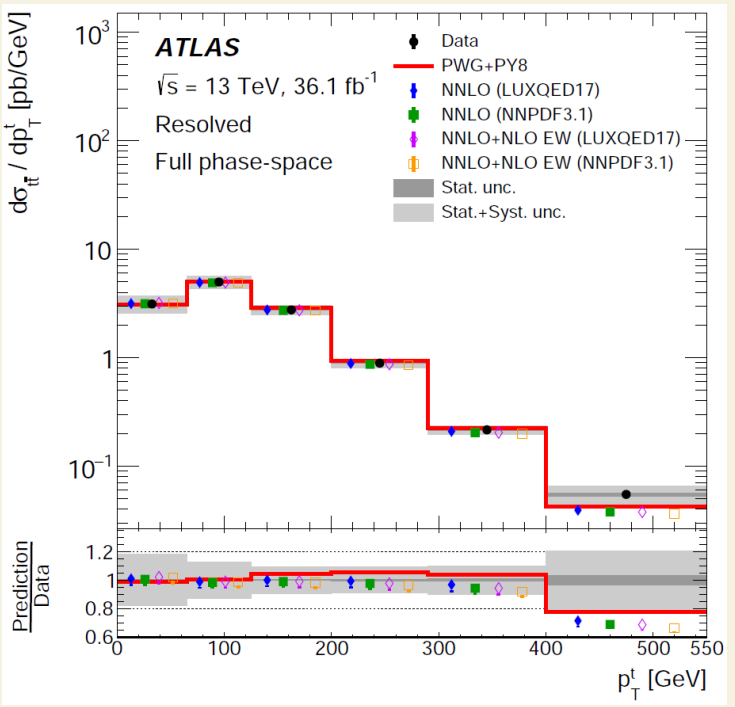



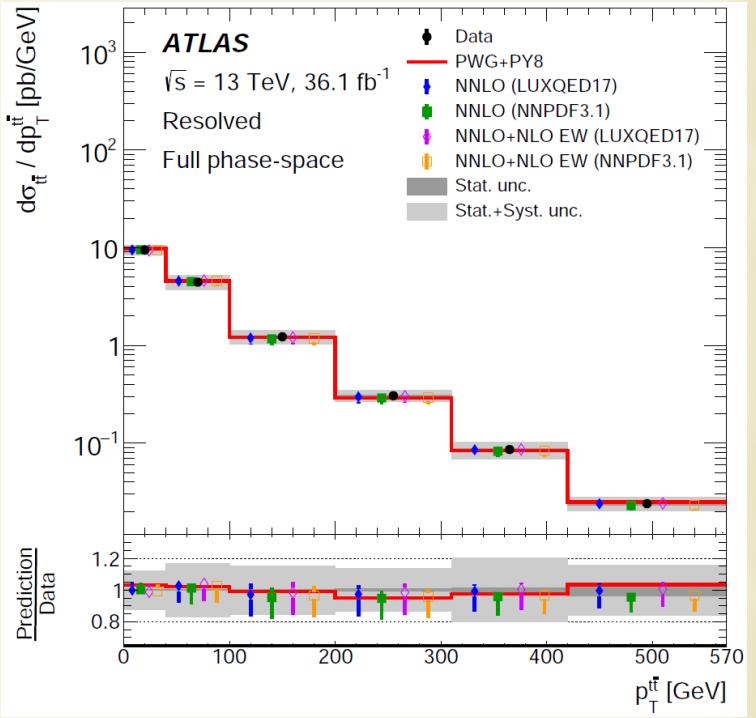



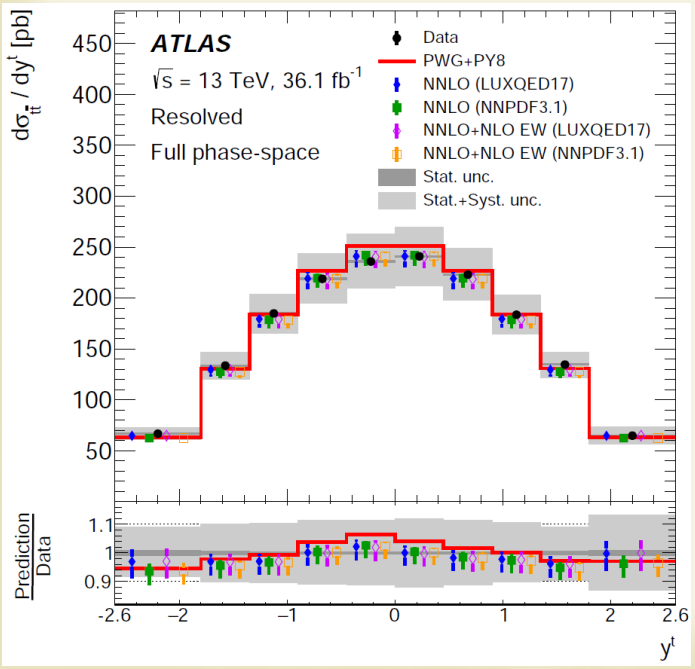



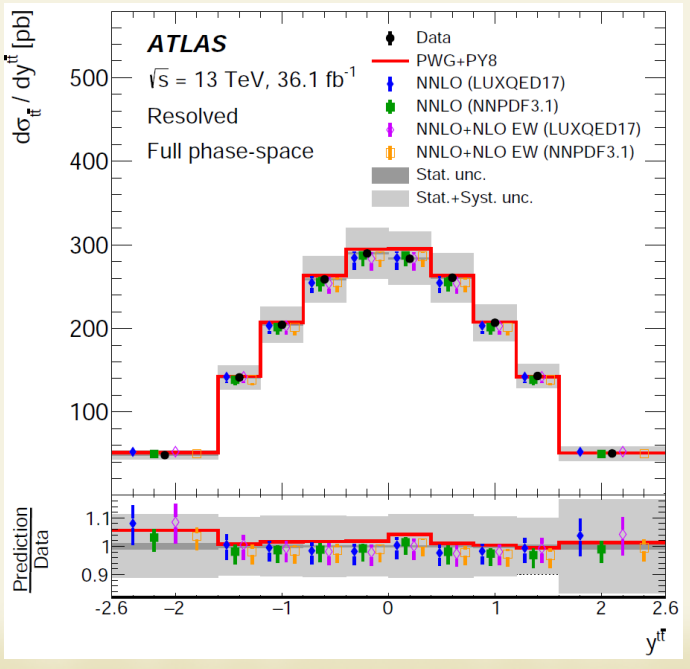
# Differential $t\bar{t}$ cross sections

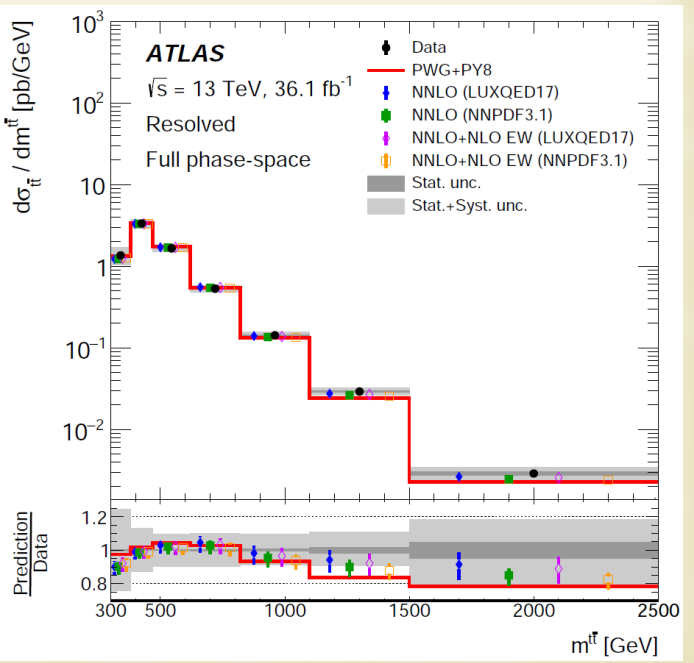
arXiv:1908.07305



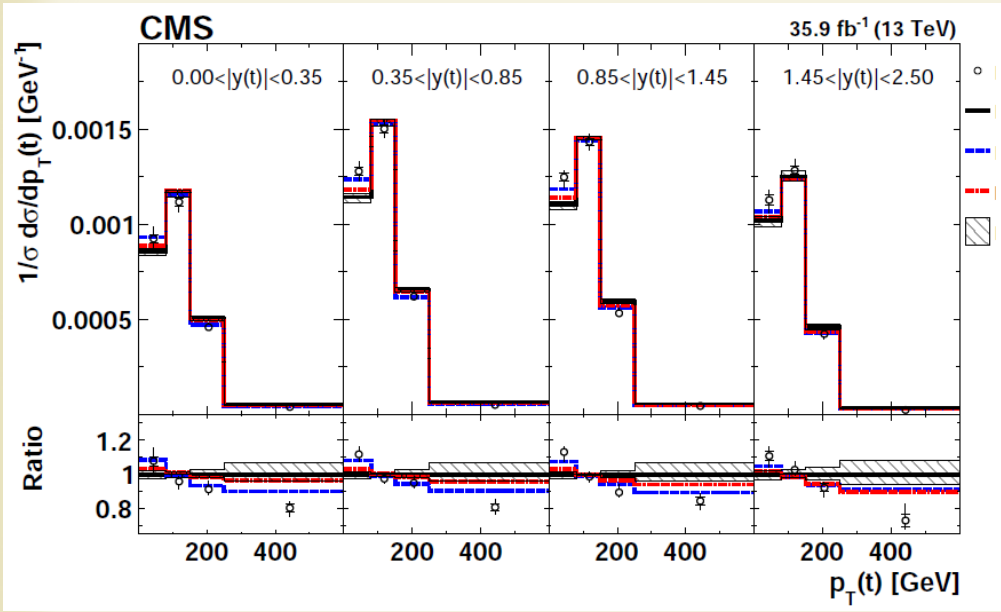



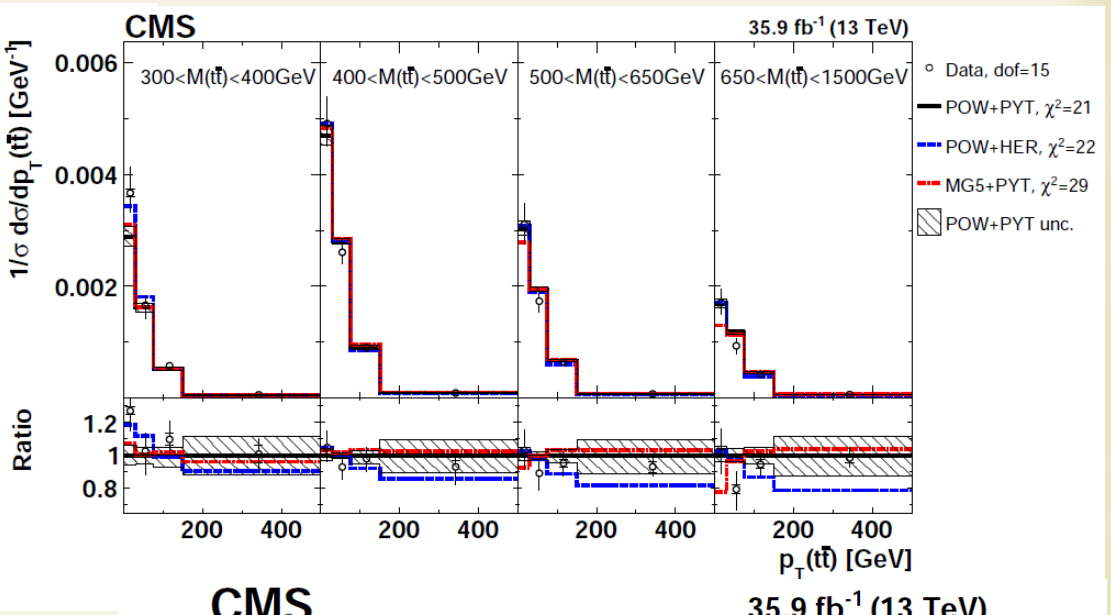



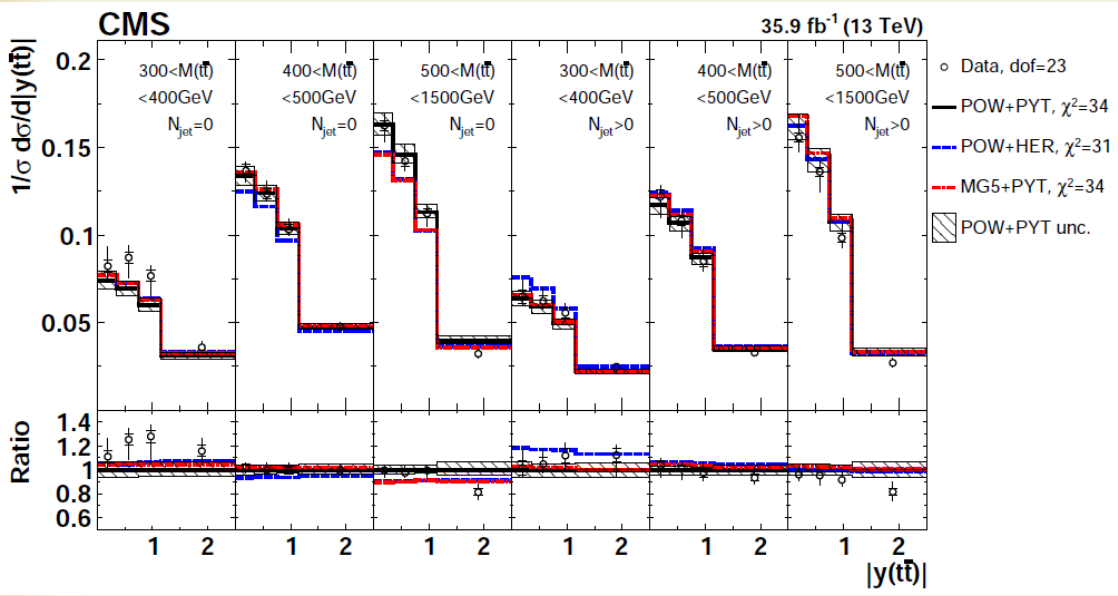



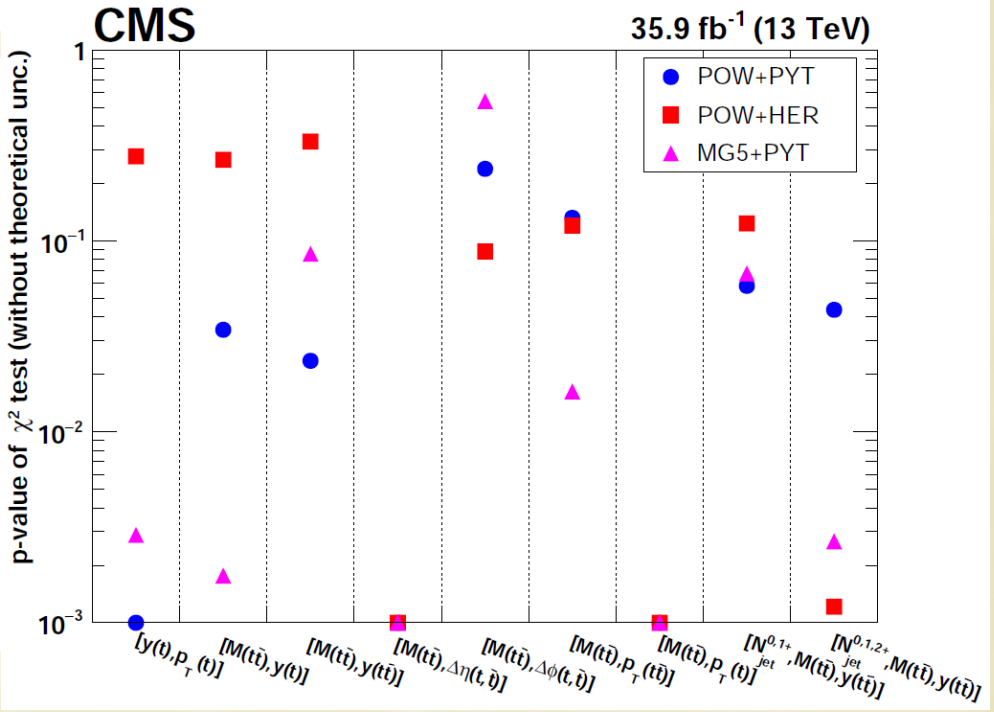
# Double differential $t\bar{t}$ cross section

arXiv:1904.05237



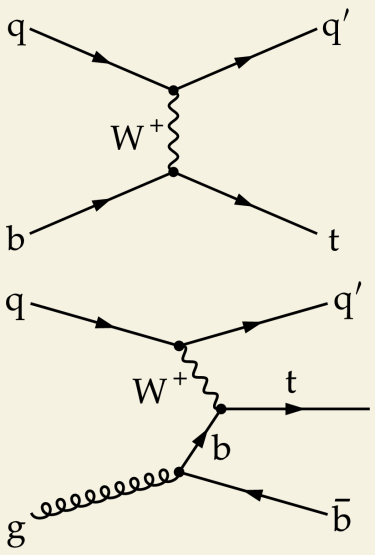



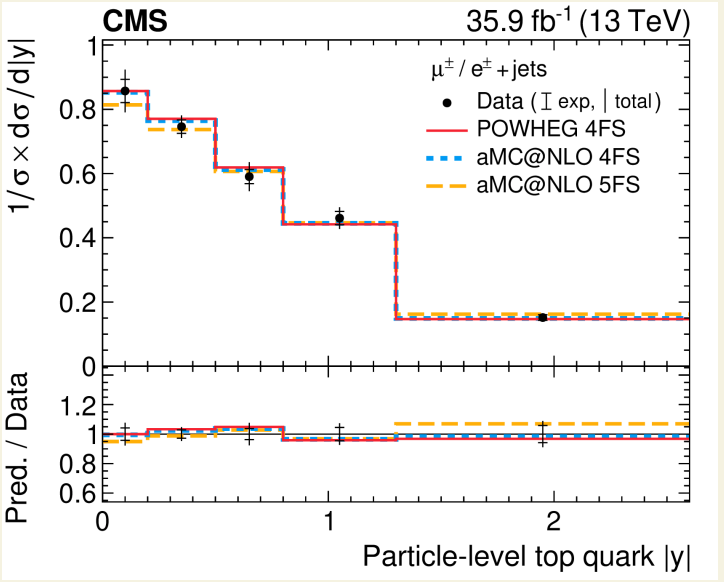



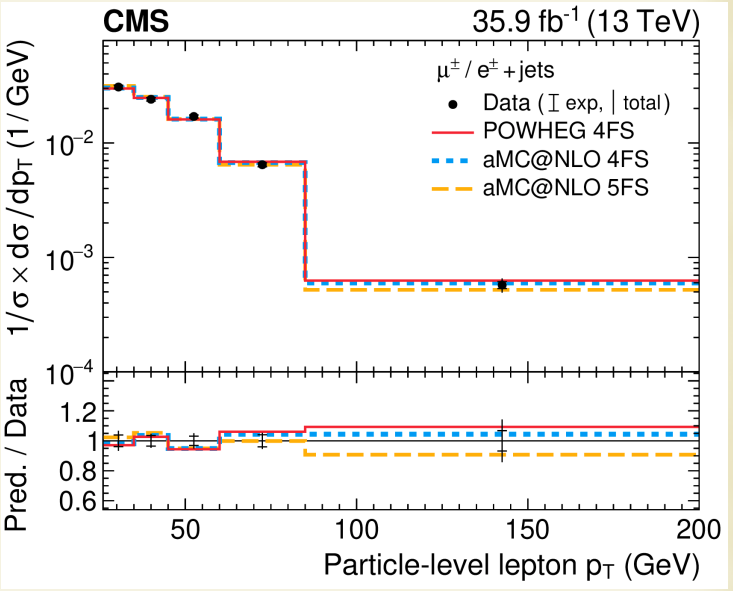



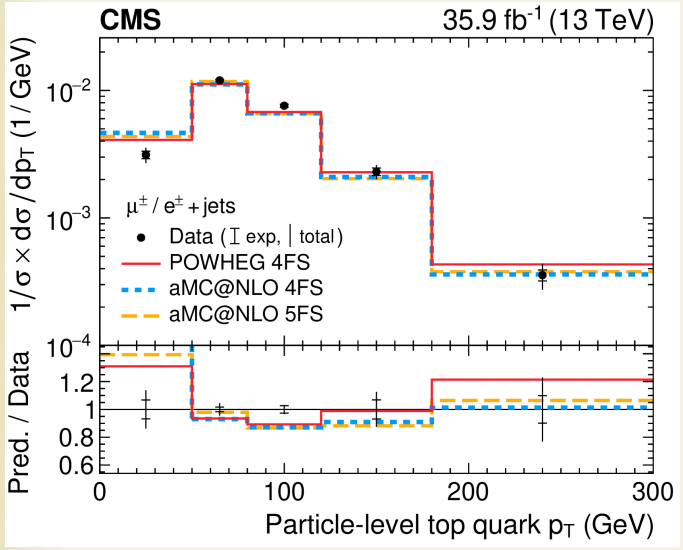
# Differential single top t-channel cross section

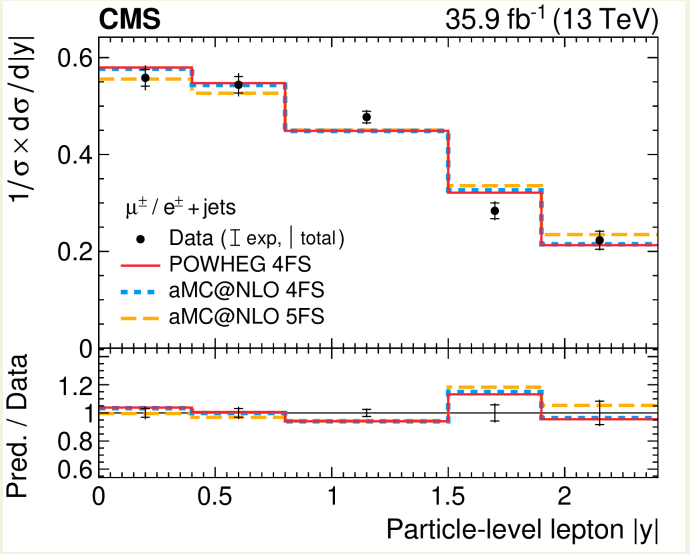
arXiv:1907.08330

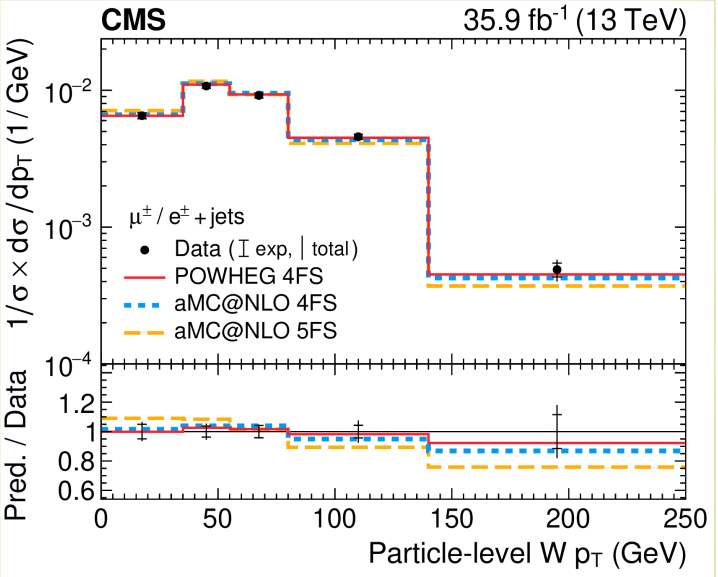


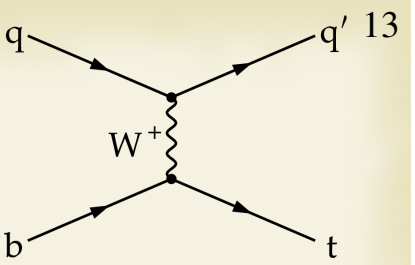



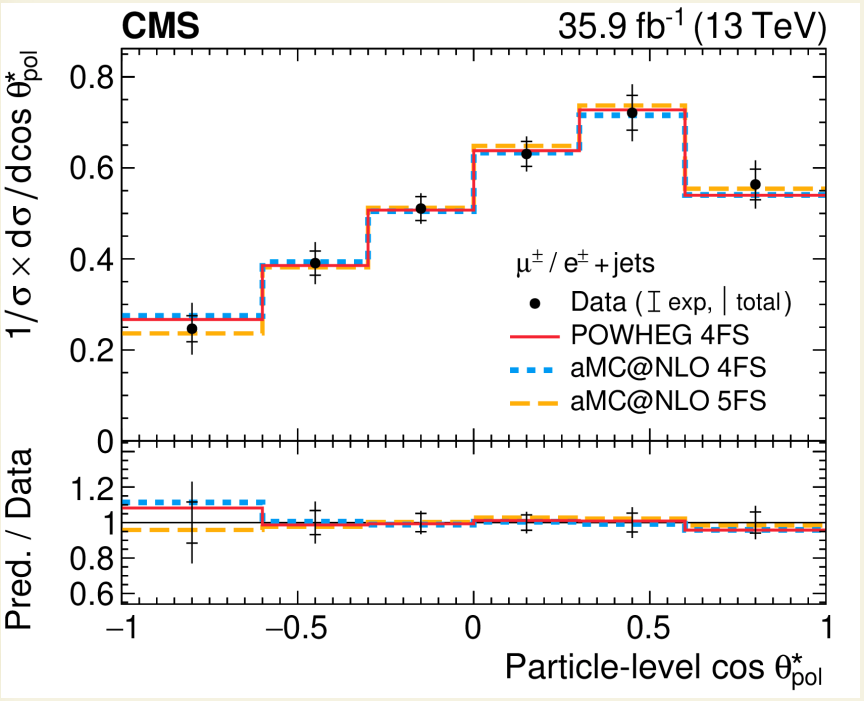
# Differential single top t-channel cross section, polarisation, charge ratio

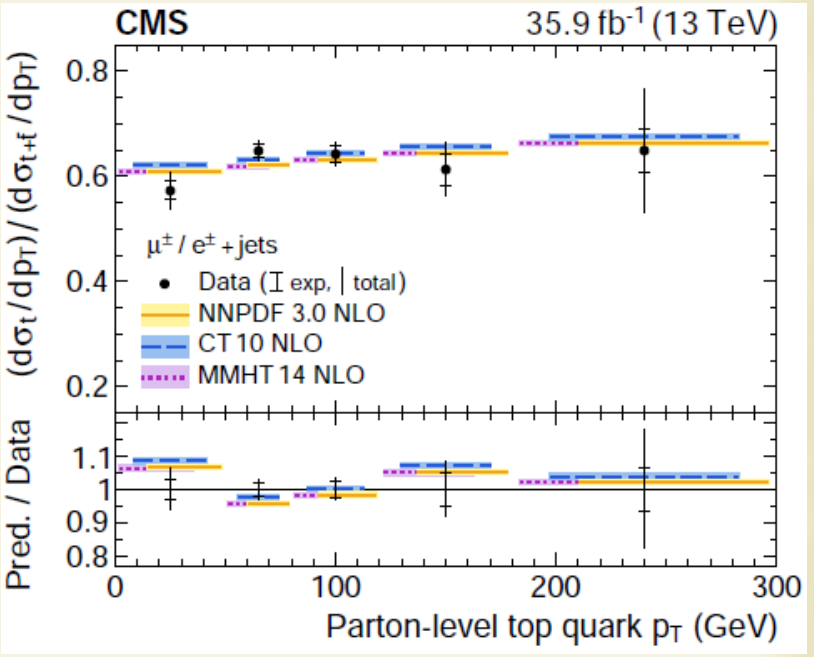
arXiv:1907.08330

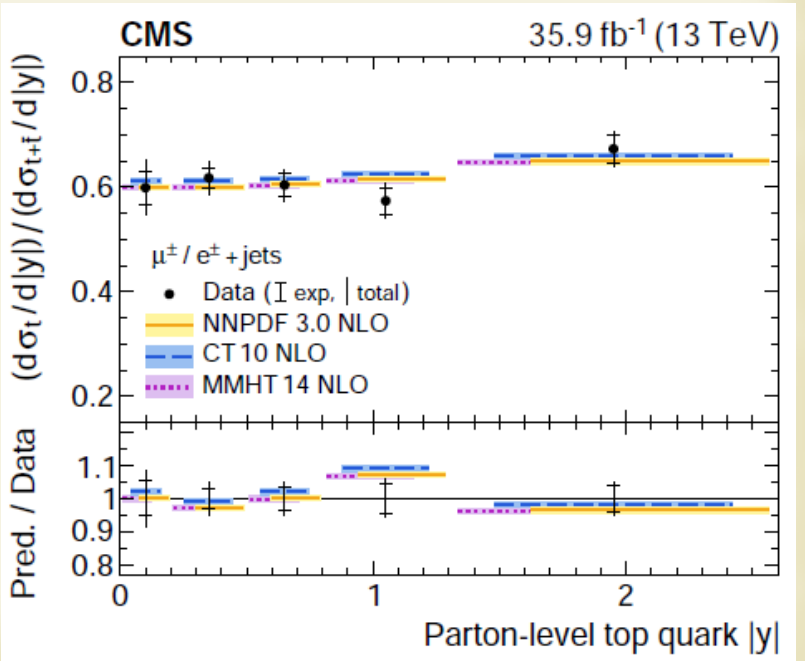



$$\cos\theta^*_{pol} = \frac{\vec{p}^{\,*}_{q'} \cdot \vec{p}^{\,*}_{\ell}}{|\vec{p}^{\,*}_{q'}||\vec{p}^{\,*}_{\ell}|}$$

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*_{pol}} = \frac{1}{2}\left(1 + 2A_\ell \cos\theta^*_{pol}\right)$$



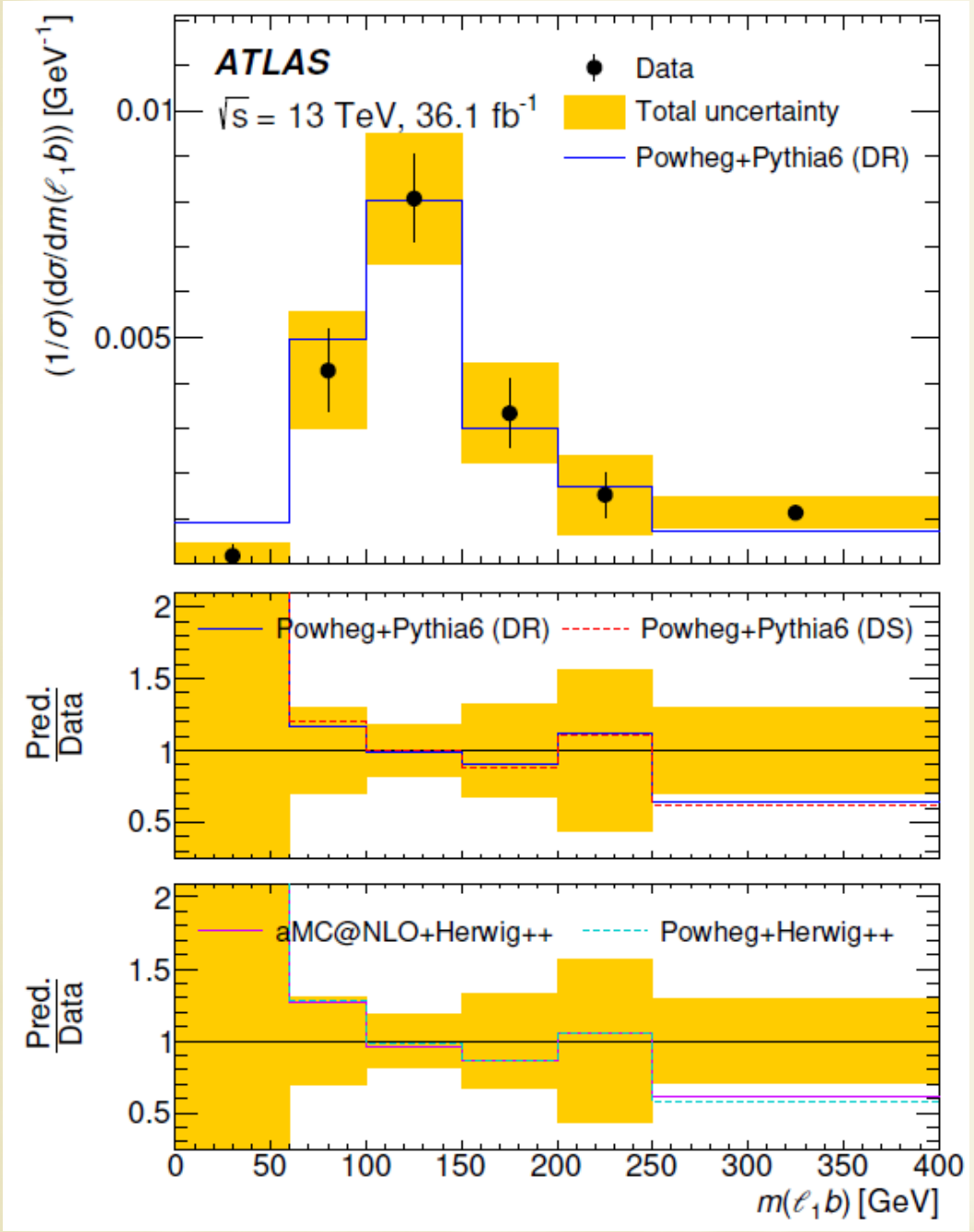



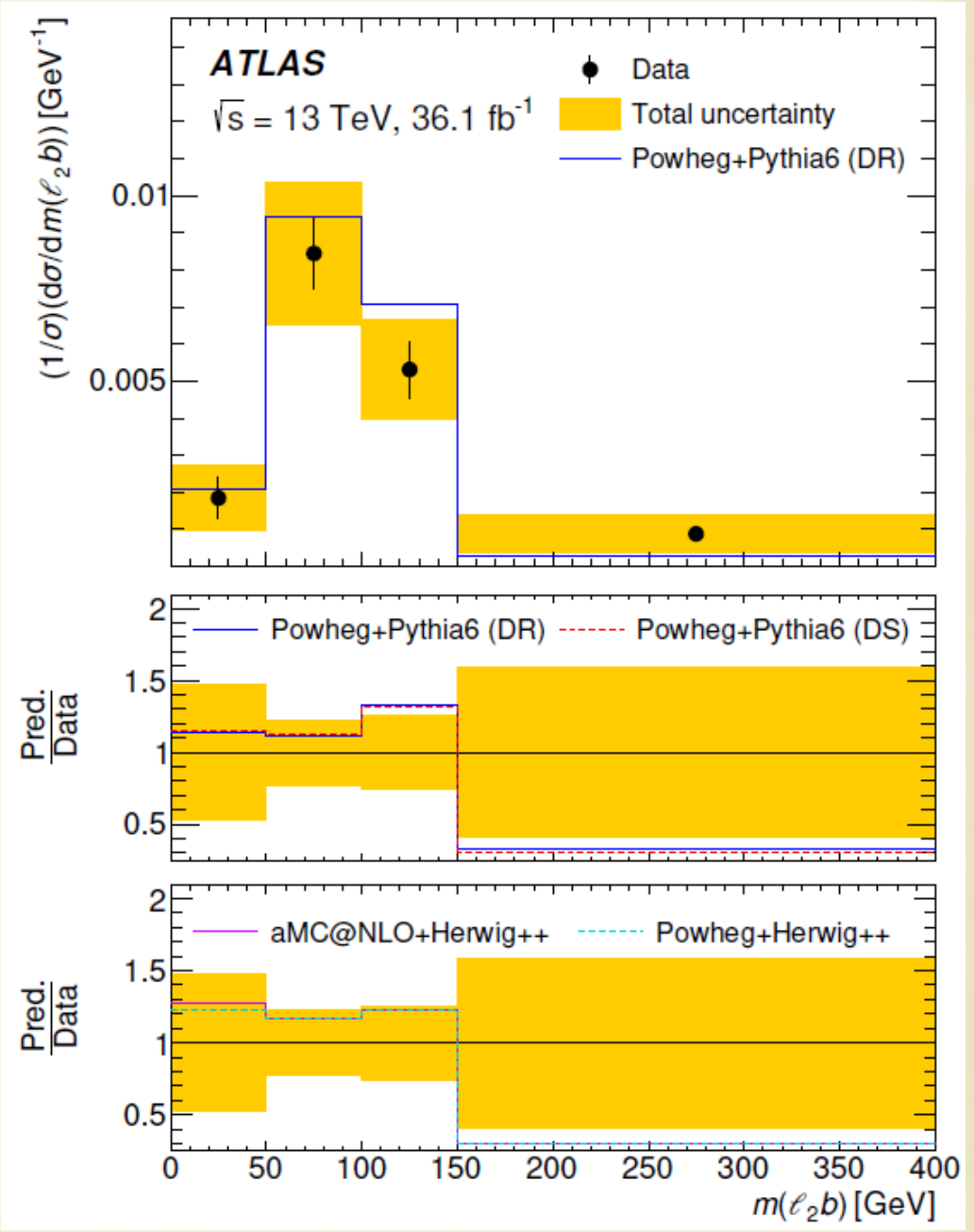

$A_{\mu+e} = 0.439 \pm 0.062$

(Powheg NLO 0.436)

# Differential single top tW-channel cross section

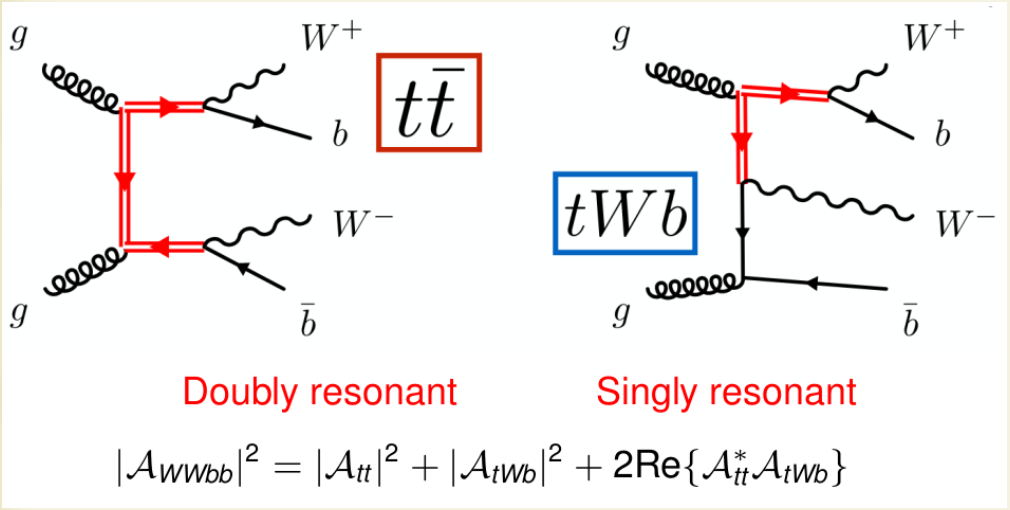
## EPJC 78 (2018) 186



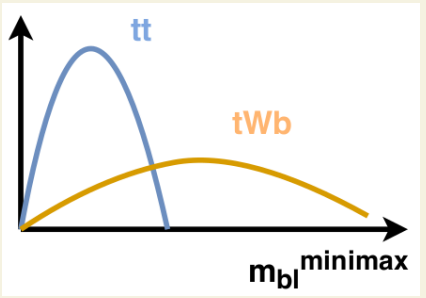
# First measurement of differential tW-$t\bar{t}$ cross section

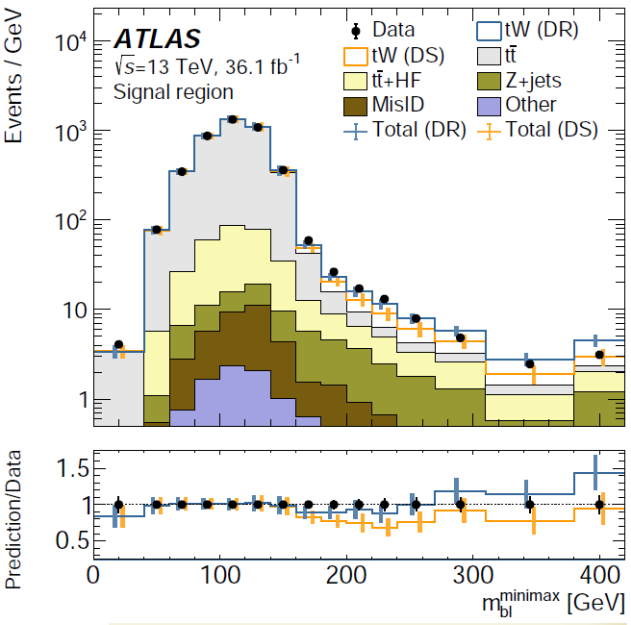
## PRL 121 (2018) 152002

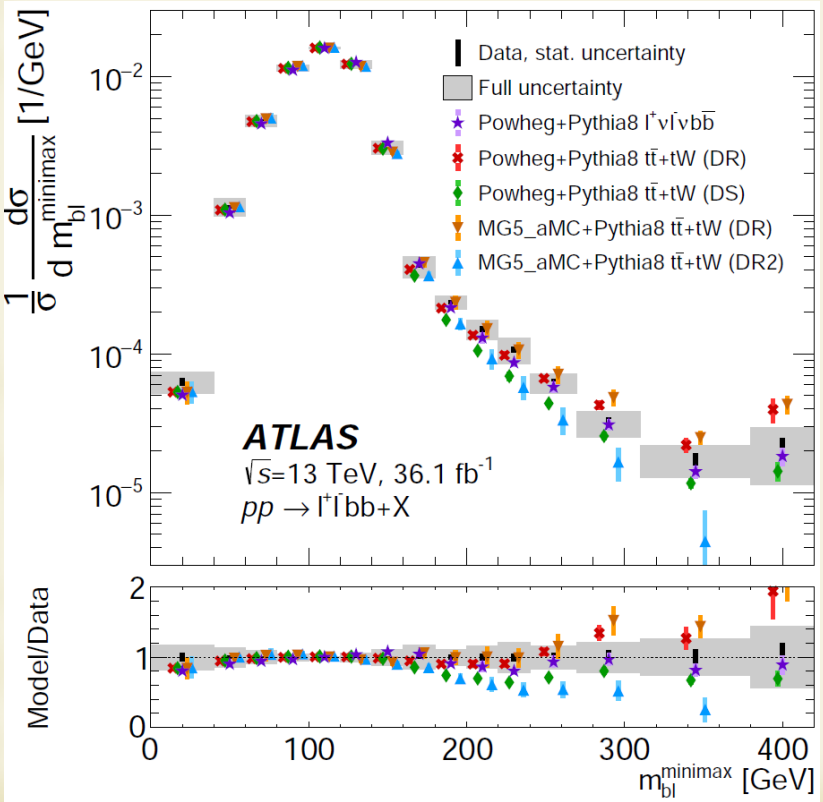


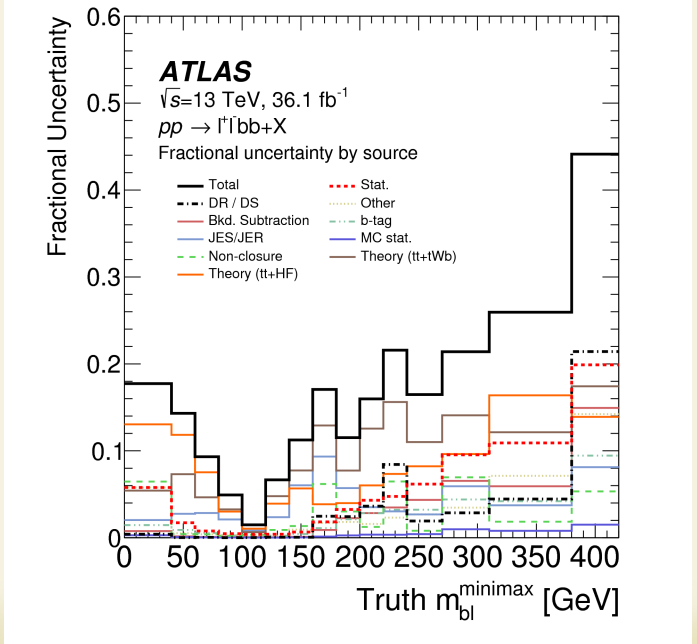

$$|\mathcal{A}_{WWbb}|^2 = |\mathcal{A}_{tt}|^2 + |\mathcal{A}_{tWb}|^2 + 2\mathrm{Re}\{\mathcal{A}_{tt}^{*}\mathcal{A}_{tWb}\}$$

$$m_{b\ell}^{minimax} = \min\left(\max\left(m(b_1\ell_1), m(b_2\ell_2)\right), \max\left(m(b_1\ell_2), m(b_2\ell_1)\right)\right)$$



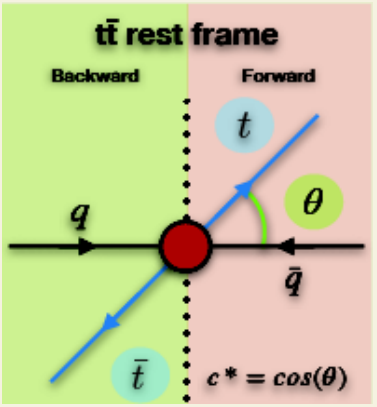



# $t\bar{t}$ forward-backward asymmetry

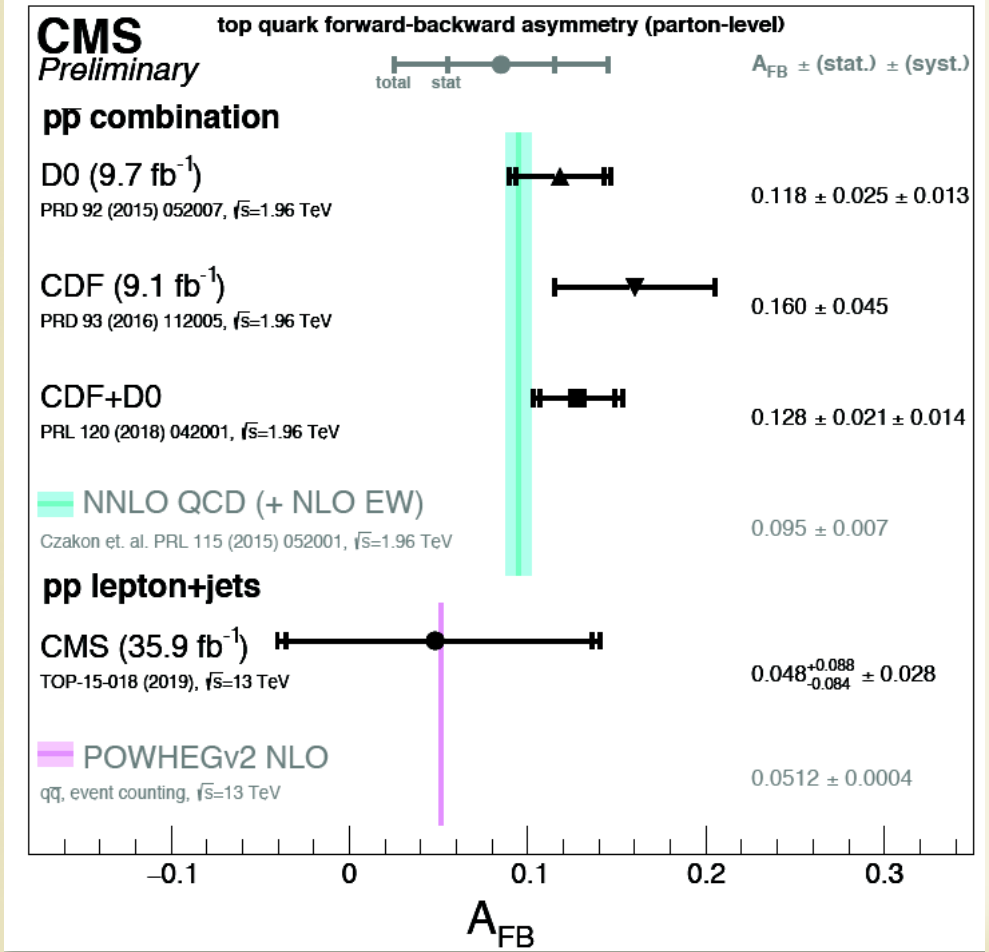
$$A_{FB} = \frac{\sigma(c^* > 0) - \sigma(c^* < 0)}{\sigma(c^* > 0) + \sigma(c^* < 0)}$$

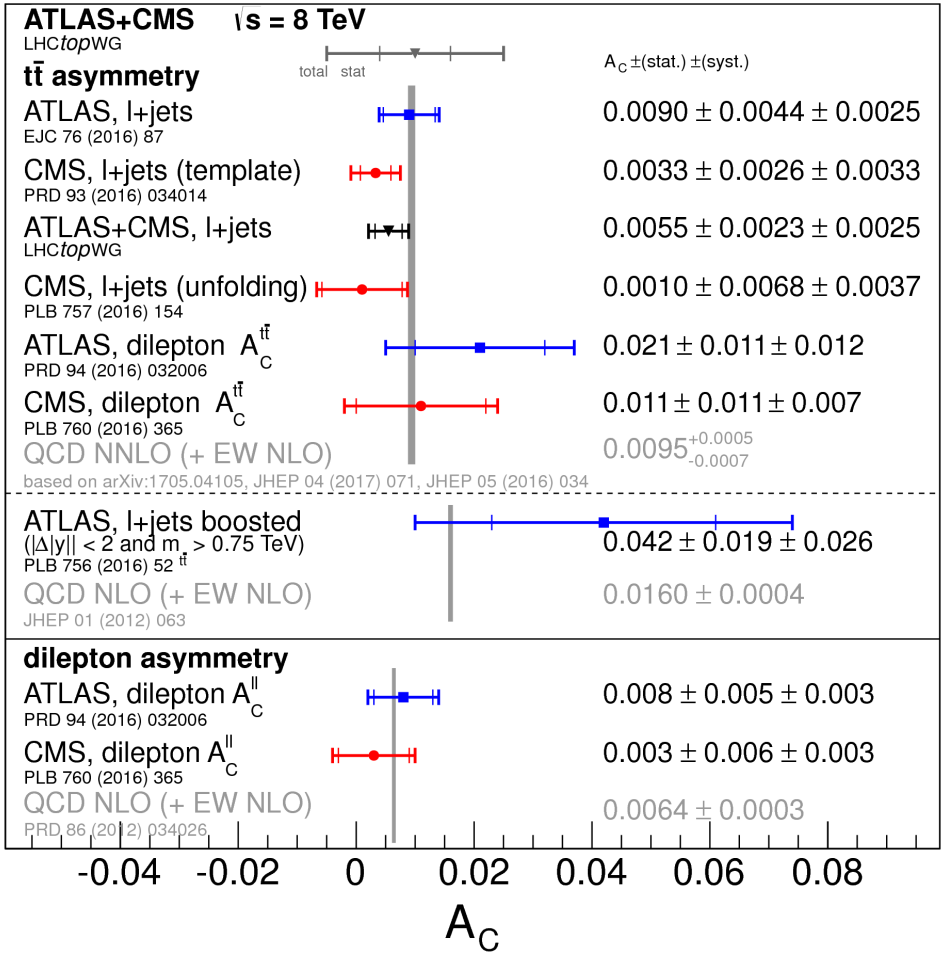



$$A_C = \frac{N^{\Delta|y|>0} - N^{\Delta|y|<0}}{N^{\Delta|y|>0} + N^{\Delta|y|<0}}$$

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

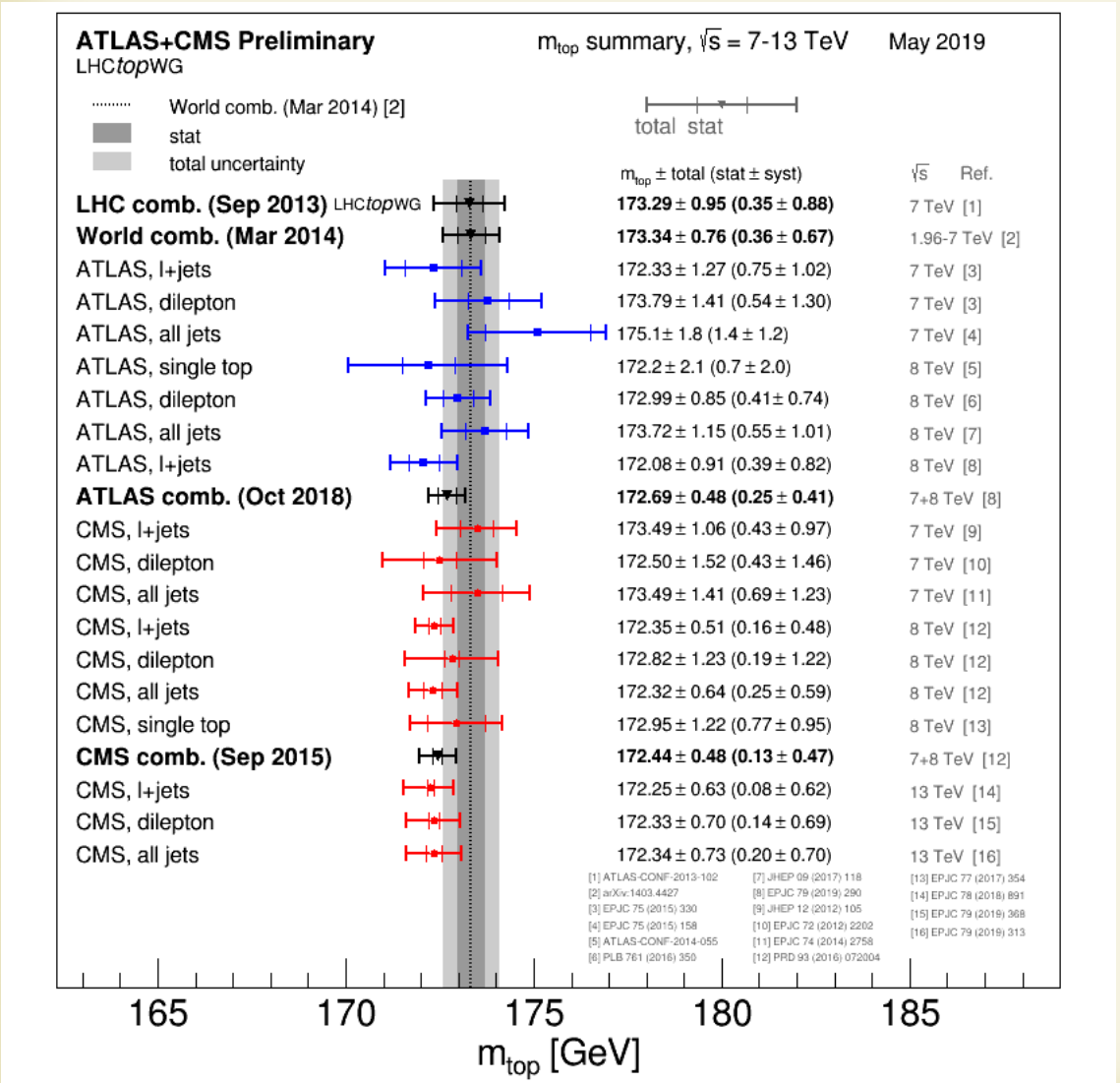
TOP2019



# Direct and indirect measurements of the top quark mass

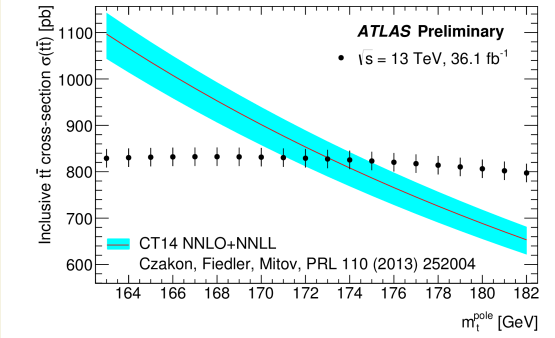
Precision <0.5 GeV (<0.3%)

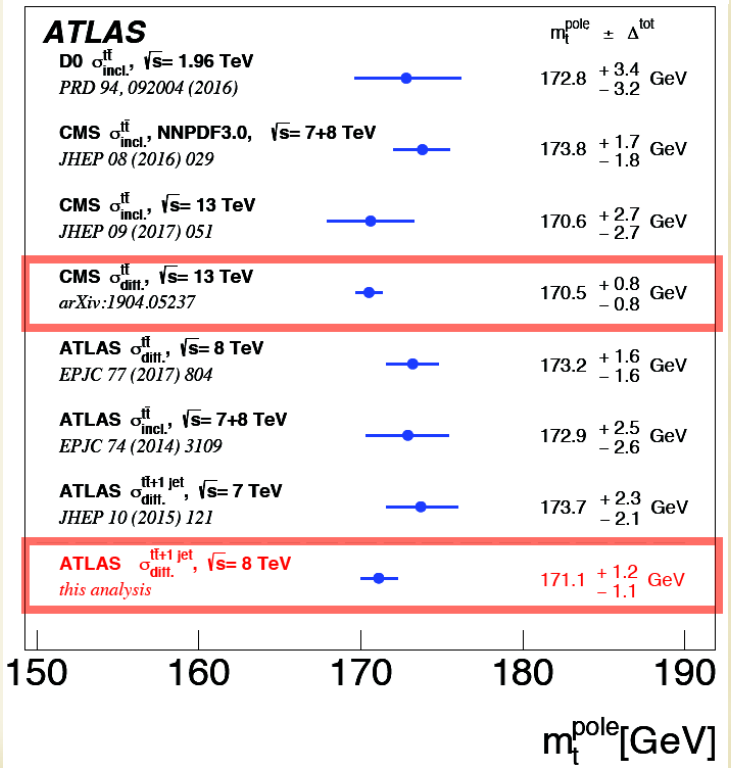



ATLAS-CONF-2019-041

$$\sigma_{tt}^{theo}(m_t^{pole}) = \sigma(172.5)\left(\frac{172.5}{m_t^{pole}}\right)^4 (1 + a_1 x + a_2 x^2)$$

$$x = (m_t^{pole} - 172.5)/172.5$$

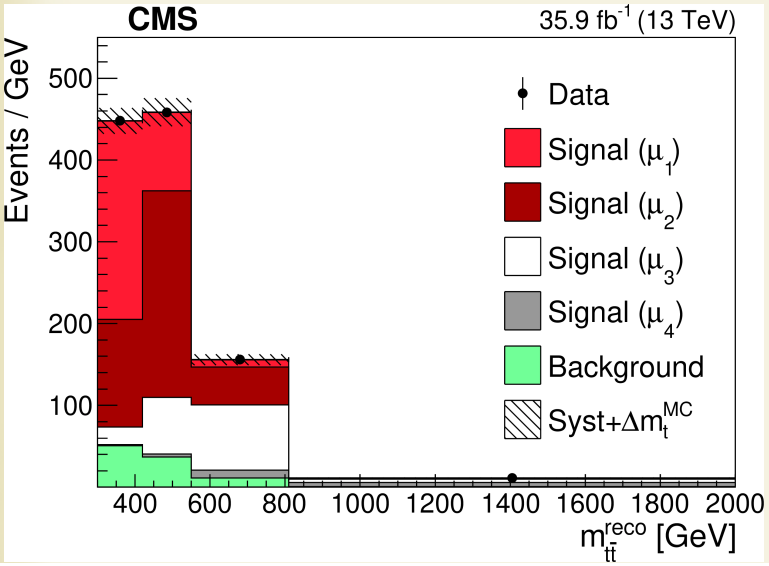


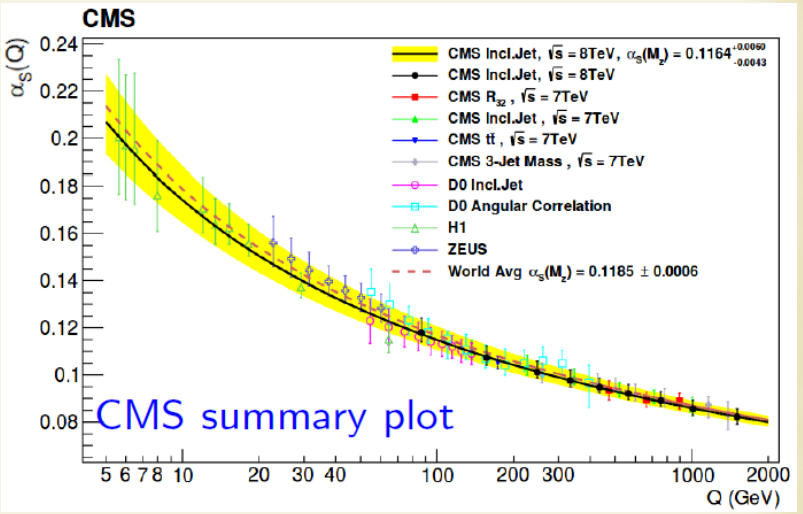
# First measurement of the running top quark mass

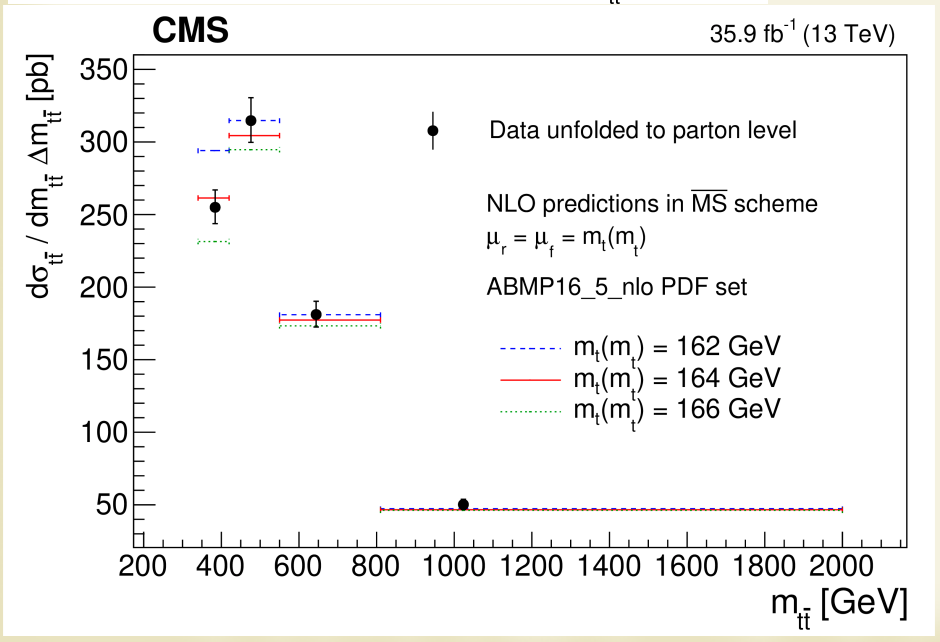
## CMS-TOP-19-007

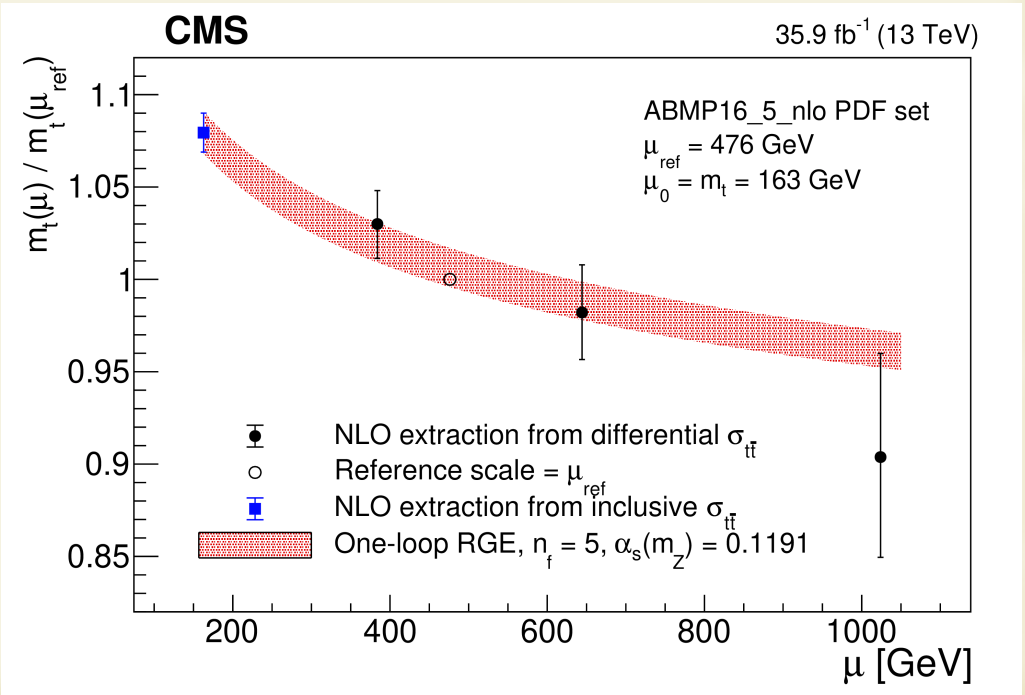
$$\mu^2 \frac{\mathrm{d}m(\mu)}{\mathrm{d}\mu^2} = -\gamma(\alpha_S(\mu))\, m(\mu)$$



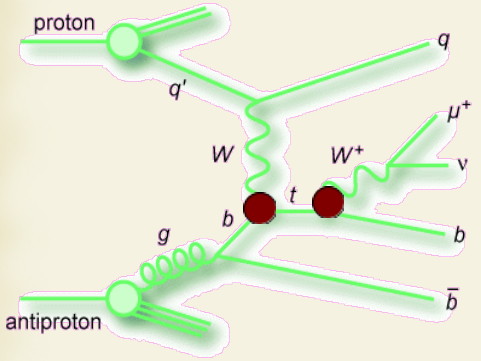

| bin | range [GeV] | $\mu_k$ [GeV] |
|---|---|---|
| 1 | $< 420$ | 384 |
| 2 | 420-550 | 476 |
| 3 | 550-810 | 644 |
| 4 | $> 810$ | 1024 |



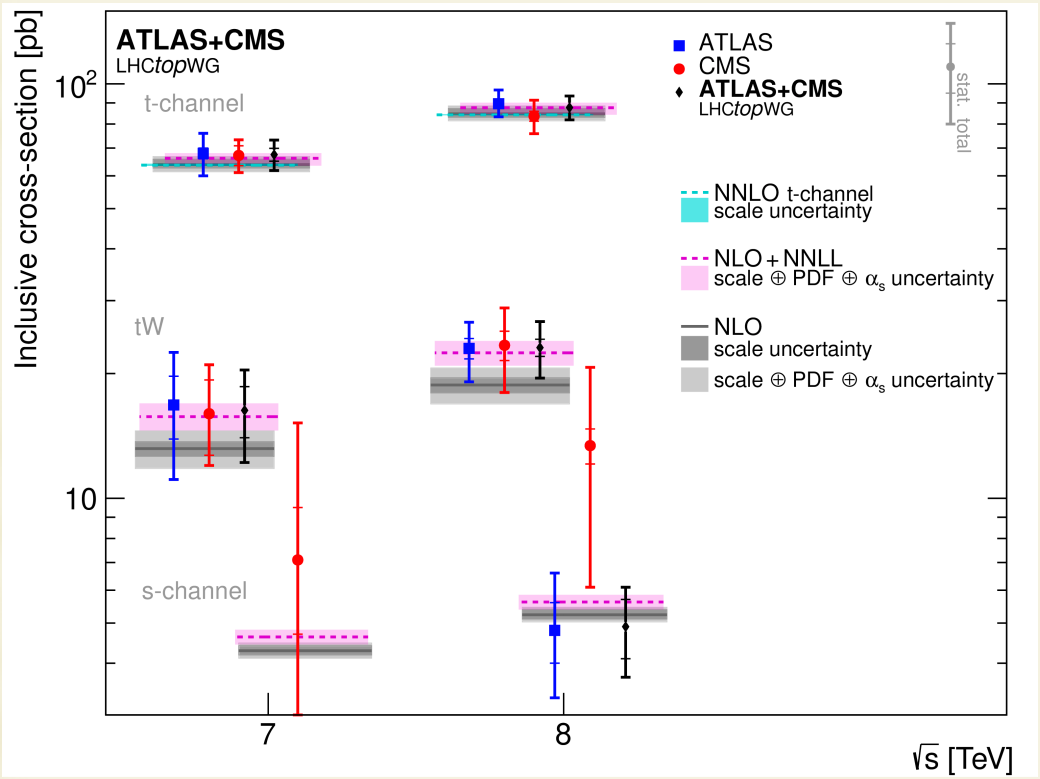
# Direct measurement of CKM $V_{tb}$

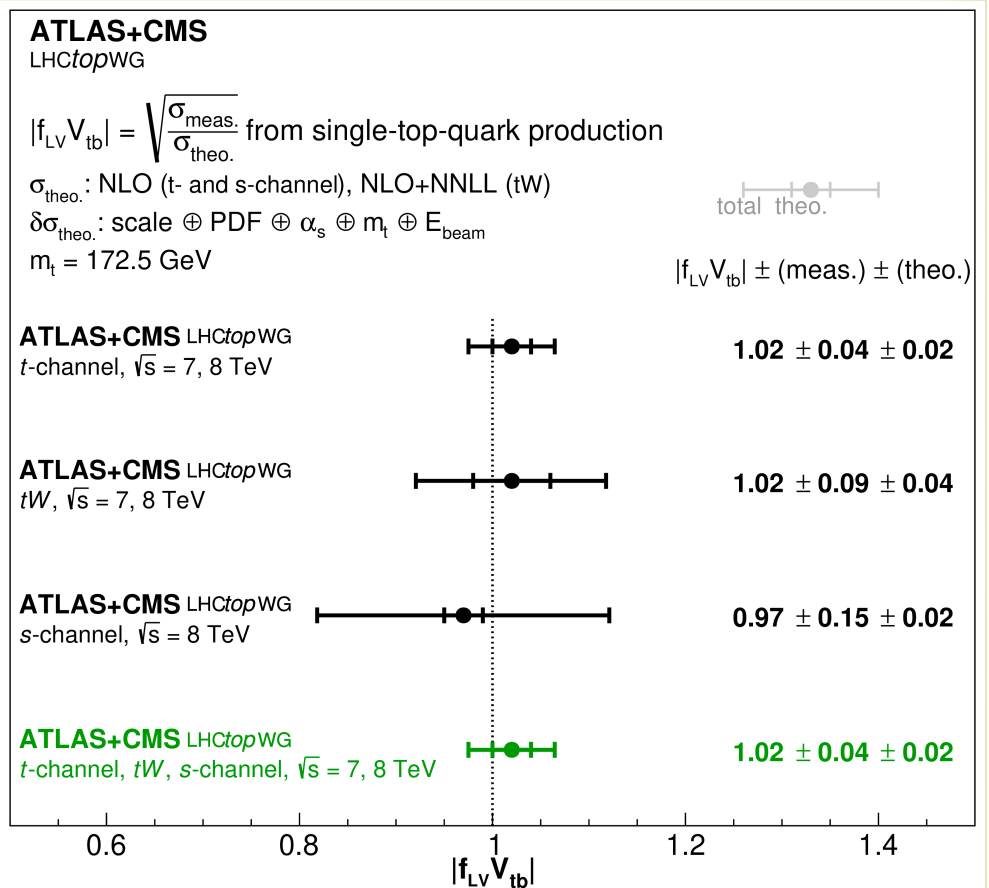



$$|f_{LV}V_{tb}| = \sqrt{\frac{\sigma_{t\text{-ch.},t+\bar{t}}}{\sigma^{th}_{t\text{-ch.},t+\bar{t}}}},$$

$$|V_{td}|^2 + |V_{ts}|^2 \ll |V_{tb}|^2$$

| **Combined $\|f_{LV}V_{tb}\|^2$** | 1.05 | |
|---|---|---|
| Uncertainty category | Uncertainty | |
| | [%] | $\Delta\|f_{LV}V_{tb}\|^2$ |
| Data statistical | 1.8 | 0.02 |
| Simulation statistical | 0.9 | 0.01 |
| Integrated luminosity | 1.3 | 0.01 |
| Theory modelling | 4.5 | 0.05 |
| Background normalisation | 1.3 | 0.01 |
| Jets | 2.6 | 0.03 |
| Detector modelling | 1.6 | 0.02 |
| Top-quark mass | 0.7 | 0.01 |
| Theoretical cross-section | 4.3 | 0.04 |
| Total syst. unc. (excl. lumi.) | 7.1 | 0.07 |
| Total syst. unc. (incl. lumi.) | 7.2 | 0.08 |
| **Total uncertainty** | 7.4 | 0.08 |



# What we call anomalous Wtb couplings?

$$\mathcal{L}_{eff} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i}{\Lambda^2} O_i$$

Operators that contribute to the Wtb vertex:

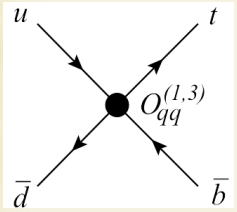
J. A. Aguilar-Saavedra, arXiv:1008.3225

$$O_{\phi q}^{(3,3+3)} = \frac{i}{2}\left[\phi^\dagger(\tau^I D_\mu - \overleftarrow{D}_\mu \tau^I)\phi\right](\bar{q}_{L3}\gamma^\mu \tau^I q_{L3}), \qquad O_{\phi\phi}^{33} = i(\tilde{\phi}^\dagger D_\mu \phi)(\bar{t}_R \gamma^\mu b_R),$$

$$O_{dW}^{33} = (\bar{q}_{L3}\sigma^{\mu\nu}\tau^I b_R)\phi\, W_{\mu\nu}^I, \qquad O_{uW}^{33} = (\bar{q}_{L3}\sigma^{\mu\nu}\tau^I t_R)\tilde{\phi}\, W_{\mu\nu}^I,$$

contact four-fermion interactions (not a part of Wtb vertex):

$$O_{qq}^{(1,3)} = (\bar{q}^i \gamma_\mu \tau^I q^j)(\bar{q}\gamma^\mu \tau^I q)$$




Cen Zhang, Scott Willenbrock, arXiv:1008.3869

one can derive vertices:

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^\mu (V_L P_L + V_R P_R)\, t\, W_\mu^- - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_\nu}{M_W}(g_L P_L + g_R P_R)\, t\, W_\mu^- + \text{h.c.}$$

$V_L \equiv F^{LV} \equiv F^L_1$,
$V_R \equiv F^{RV} \equiv F^R_1$
$g_L \equiv F^{LT} \equiv F^L_2$,
$g_R \equiv F^{RT} \equiv F^R_2$

| order: | $1/\Lambda^2$ | $1/\Lambda^4$ |
|---|---|---|
| | $V_L$ | $(V_L)^2$ |
| | - | $(V_R)^2$ |
| | - | $(g_L)^2$ |
| | $g_R$ | $(g_R)^2$ |

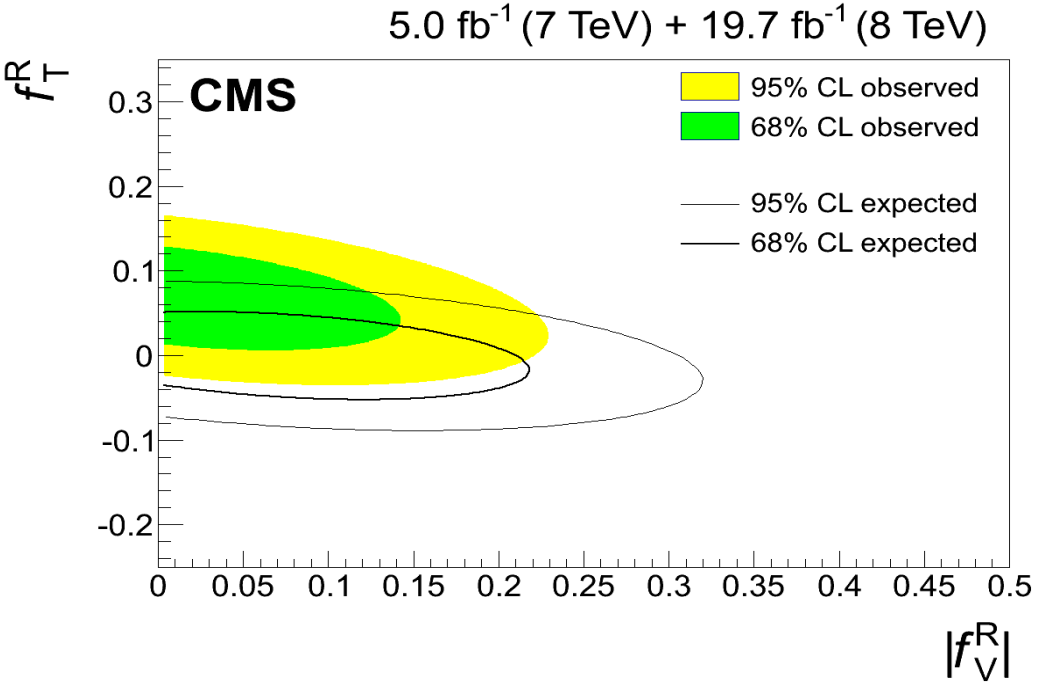
Where corrections to SM coupling:

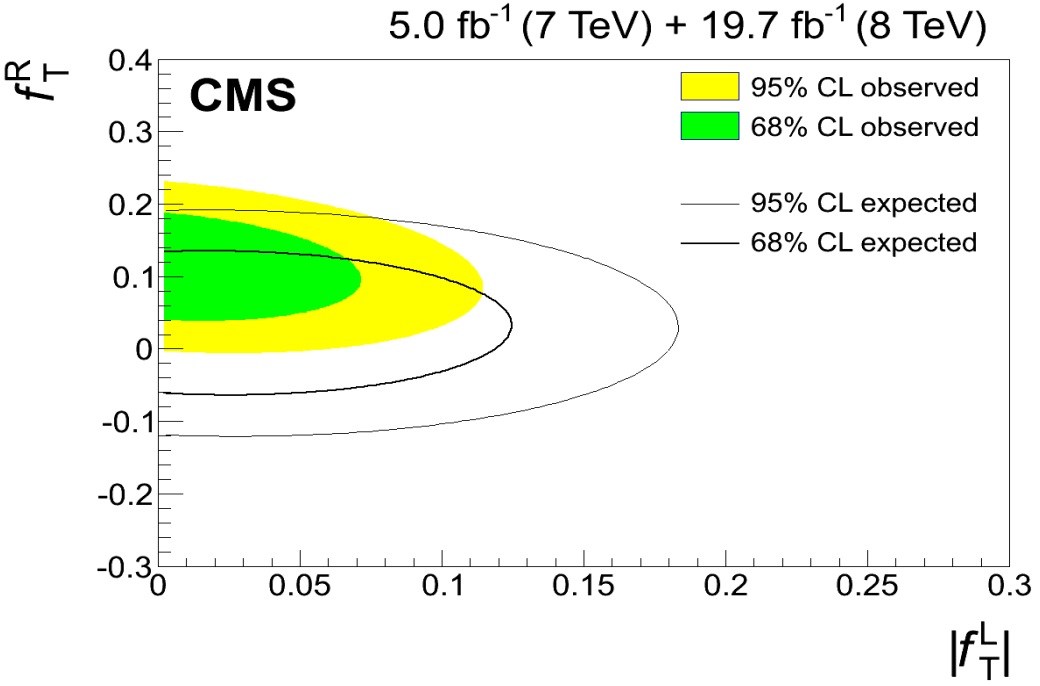
$$V_L = V_{tb} + C_{\phi q}^{(3,3+3)}\frac{v^2}{\Lambda^2}, \qquad g_L = \sqrt{2}C_{dW}^{33}\frac{v^2}{\Lambda^2},$$

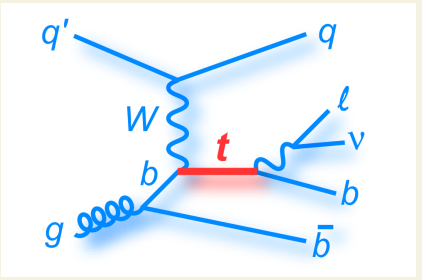
$$V_R = \tfrac{1}{2}C_{\phi\phi}^{33}\frac{v^2}{\Lambda^2}, \qquad g_R = \sqrt{2}C_{uW}^{33}\frac{v^2}{\Lambda^2},$$

$$\sigma \propto A\cdot(f_1^L)^2 + B\cdot(f_1^R)^2 + C\cdot(f_1^L\cdot f_2^R) + D\cdot(f_1^R\cdot f_2^L) + E\cdot(f_2^L)^2 + G\cdot(f_2^R)^2$$

# $(F^{LV},F^{RV},F^{RT})$ и $(F^{LV},F^{LT},F^{RT})$ scenarios



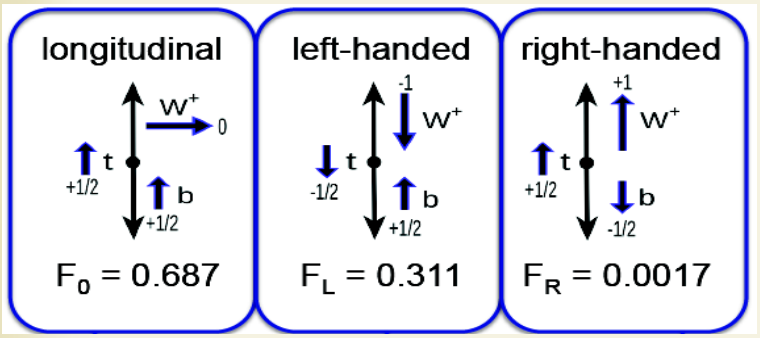

**Observed (expected) 1D limits at 95% C.L.:**

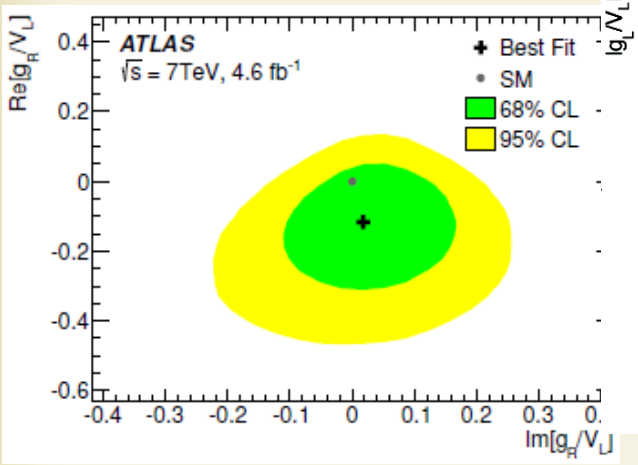
$$|f_V^L|<0.98\,(0.97),$$
$$|f_V^R|<0.16\,(0.22),$$
$$-0.049\,(-0.049)<f_T^R<0.039\,(0.037)$$

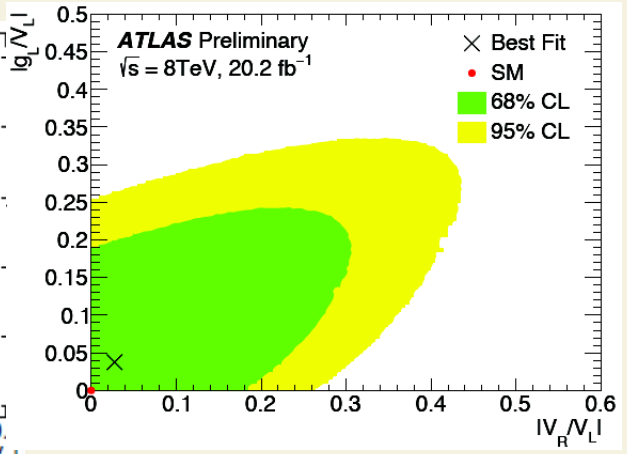
**Observed (expected) 1D limits at 95% C.L.:**

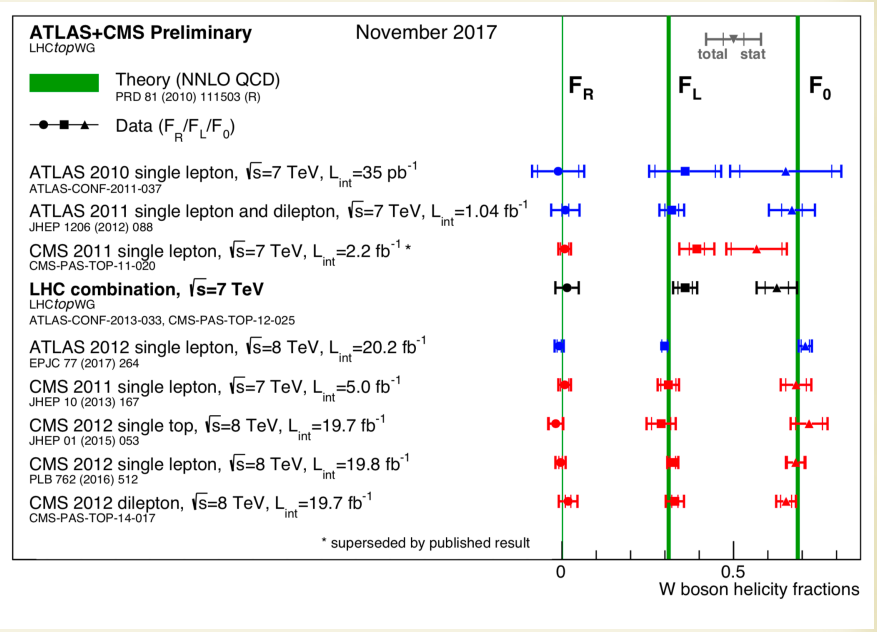
$$|f_V^L|<0.98\,(0.97),$$
$$|f_T^L|<0.057\,(0.10),$$
$$-0.049\,(-0.051)<f_T^R<0.048\,(0.046)$$

# W helicity, top polarisation and Wtb anomalous couplings

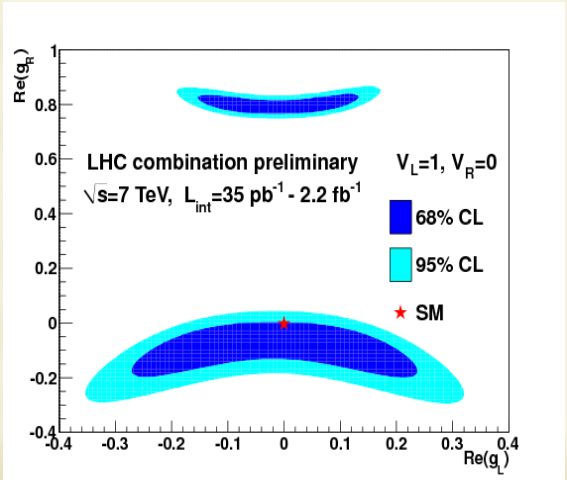


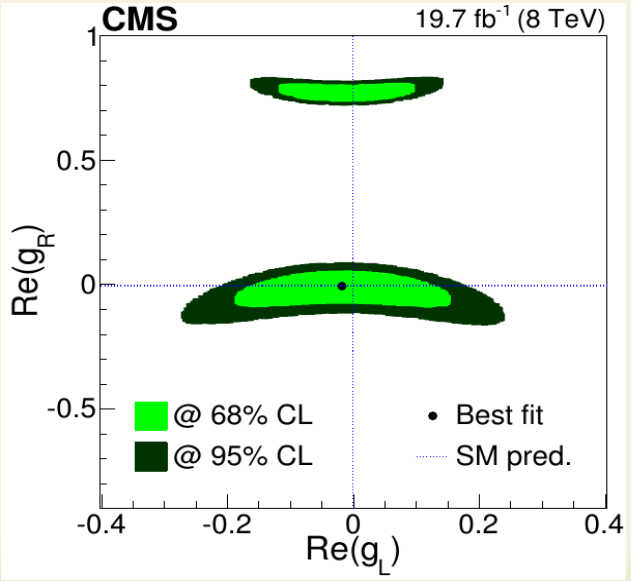



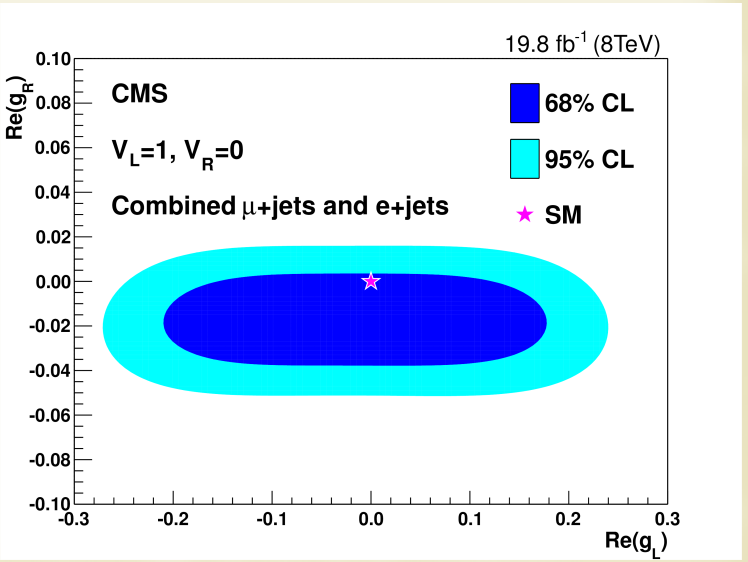




$$\mathrm{Im}\, g_R \in [-0.18,\ 0.06]$$

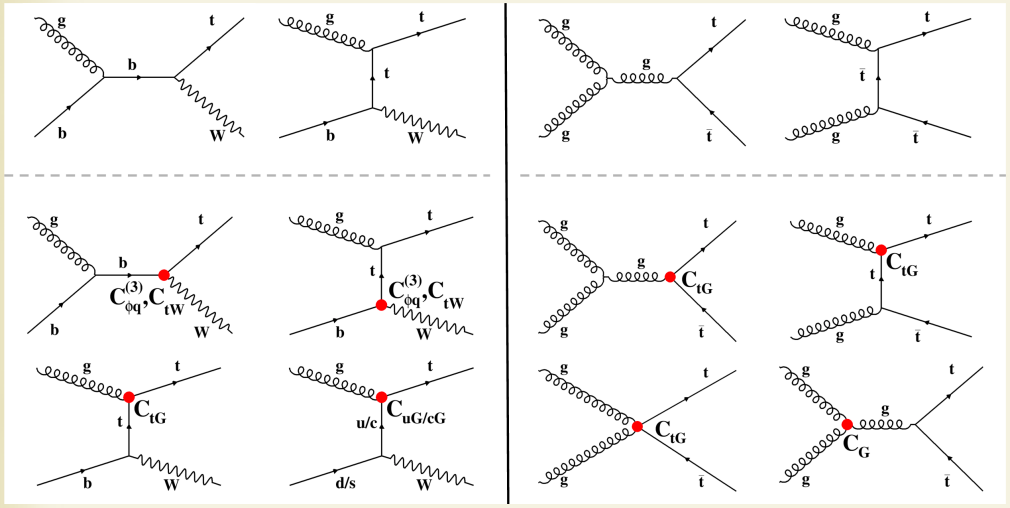


# tW+tt anomalous contribution, EFT interpretation

arXiv:1903.11144




$$O^{(3)}_{\phi q} = (\phi^+ \tau^i D_\mu \phi)(\bar{q}\gamma^\mu \tau^i q),$$

$$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^i t)\tilde{\phi} W^i_{\mu\nu},$$

$$O_{tG} = (\bar{q}\sigma^{\mu\nu}\lambda^a t)\tilde{\phi} G^a_{\mu\nu},$$

$$O_G = f_{abc} G^{a\nu}_\mu G^{b\rho}_\nu G^{c\mu}_\rho,$$

$$O_{u(c)G} = (\bar{q}\sigma^{\mu\nu}\lambda^a t)\tilde{\phi} G^a_{\mu\nu},$$

$$L_{eff} = \frac{C^{(3)}_{\phi q}}{\sqrt{2}\Lambda^2} g v^2 \bar{b}\gamma^\mu P_L t W^-_\mu + h.c.,$$

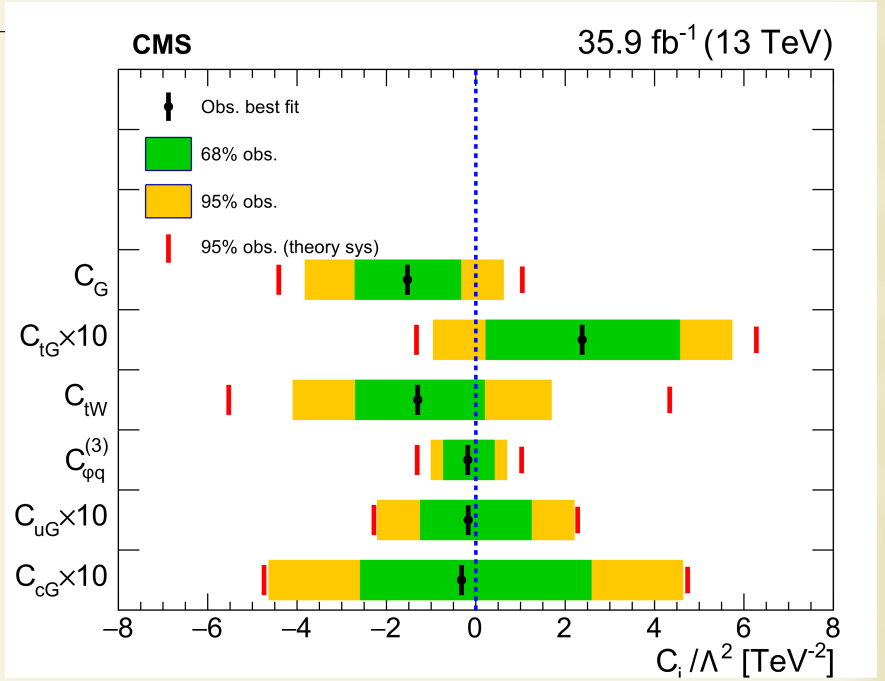
$$L_{eff} = -2\frac{C_{tW}}{\Lambda^2} v \bar{b}\sigma^{\mu\nu} P_R t \partial_\nu W^-_\mu + h.c.,$$

$$L_{eff} = \frac{C_{tG}}{\sqrt{2}\Lambda^2} v\,(\bar{t}\sigma^{\mu\nu}\lambda^a t)\, G^a_{\mu\nu} + h.c.,$$

$$L_{eff} = \frac{C_G}{\Lambda^2} f_{abc} G^{a\nu}_\mu G^{b\rho}_\nu G^{c\mu}_\rho,$$

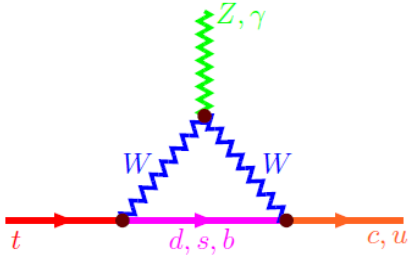
$$L_{eff} = \frac{C_{u(c)G}}{\sqrt{2}\Lambda^2} v\,(\bar{u}\,(\bar{c})\,\sigma^{\mu\nu}\lambda^a t)\, G^a_{\mu\nu} + h.c.,$$

| Effective coupling | Channel | Observed [TeV$^{-2}$] Best fit | [68% CI] | [95% CI] | Expected [TeV$^{-2}$] Best fit | [68% CI] | [95% CI] |
|---|---|---|---|---|---|---|---|
| $C_G/\Lambda^2$ | ee | −0.14 | [−0.82, 0.51] | [−1.14, 0.83] | 0.00 | [−0.90, 0.59] | [−1.20, 0.88] |
| | eμ | −0.18 | [−0.73, 0.42] | [−1.01, 0.70] | 0.00 | [−0.82, 0.51] | [−1.08, 0.77] |
| | μμ | −0.14 | [−0.75, 0.44] | [−1.06, 0.75] | 0.00 | [−0.88, 0.57] | [−1.16, 0.85] |
| | Combined | −0.18 | [−0.73, 0.42] | [−1.01, 0.70] | 0.00 | [−0.82, 0.51] | [−1.07, 0.76] |
| $C^{(3)}_{\phi q}/\Lambda^2$ | ee | 1.12 | [−1.18, 2.89] | [−4.03, 4.37] | 0.00 | [−2.53, 1.74] | [−6.40, 3.27] |
| | eμ | −0.70 | [−2.16, 0.59] | [−3.74, 1.61] | 0.00 | [−1.34, 1.12] | [−2.57, 2.15] |
| | μμ | 1.13 | [−0.87, 2.86] | [−3.58, 4.46] | 0.00 | [−2.20, 1.92] | [−4.68, 3.66] |
| | Combined | −1.52 | [−2.71, −0.33] | [−3.82, 0.63] | 0.00 | [−1.05, 0.88] | [−2.04, 1.63] |
| $C_{tW}/\Lambda^2$ | ee | 6.18 | [−3.02, 7.81] | [−4.16, 8.95] | 0.00 | [−2.02, 6.81] | [−3.33, 8.12] |
| | eμ | 1.64 | [−0.80, 5.59] | [−1.89, 6.68] | 0.00 | [−1.40, 6.19] | [−2.39, 7.18] |
| | μμ | −1.40 | [−3.00, 7.79] | [−4.23, 9.01] | 0.00 | [−2.18, 6.97] | [−3.63, 8.42] |
| | Combined | 2.38 | [0.22, 4.57] | [−0.96, 5.74] | 0.00 | [−1.14, 5.93] | [−1.91, 6.70] |
| $C_{tG}/\Lambda^2$ | ee | −0.19 | [−0.40, 0.02] | [−0.65, 0.22] | 0.00 | [−0.22, 0.21] | [−0.44, 0.41] |
| | eμ | −0.03 | [−0.19, 0.11] | [−0.34, 0.27] | 0.00 | [−0.17, 0.15] | [−0.34, 0.29] |
| | μμ | −0.15 | [−0.34, 0.02] | [−0.53, 0.19] | 0.00 | [−0.19, 0.18] | [−0.40, 0.35] |
| | Combined | −0.13 | [−0.27, 0.02] | [−0.41, 0.17] | 0.00 | [−0.15, 0.14] | [−0.30, 0.28] |
| $C_{uG}/\Lambda^2$ | ee | −0.017 | [−0.22, 0.22] | [−0.37, 0.37] | 0.00 | [−0.29, 0.29] | [−0.42, 0.42] |
| | eμ | −0.017 | [−0.17, 0.17] | [−0.29, 0.29] | 0.00 | [−0.26, 0.26] | [−0.38, 0.38] |
| | μμ | −0.017 | [−0.17, 0.17] | [−0.29, 0.29] | 0.00 | [−0.27, 0.27] | [−0.38, 0.38] |
| | Combined | −0.017 | [−0.13, 0.13] | [−0.22, 0.22] | 0.00 | [−0.21, 0.21] | [−0.30, 0.30] |
| $C_{cG}/\Lambda^2$ | ee | −0.032 | [−0.47, 0.47] | [−0.78, 0.78] | 0.00 | [−0.63, 0.63] | [−0.92, 0.92] |
| | eμ | −0.032 | [−0.34, 0.34] | [−0.60, 0.60] | 0.00 | [−0.56, 0.56] | [−0.81, 0.81] |
| | μμ | −0.032 | [−0.36, 0.36] | [−0.63, 0.63] | 0.00 | [−0.58, 0.58] | [−0.84, 0.84] |
| | Combined | −0.032 | [−0.26, 0.26] | [−0.46, 0.46] | 0.00 | [−0.46, 0.46] | [−0.65, 0.65] |



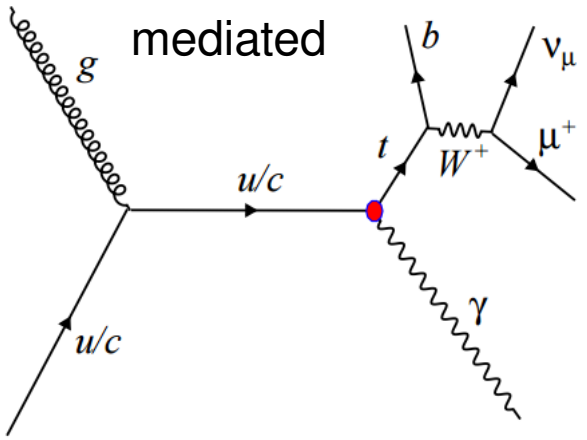
# Flavor changing neutral currents (FCNC) in the production of top quark

Flavor Changing Neutral Currents (FCNC) $t \to qg$, $t \to q\gamma$, $t \to qZ$

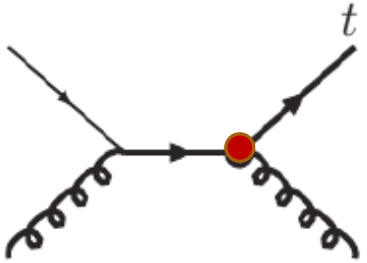



| | SM | two-Higgs | SUSY |
|---|---|---|---|
| $B(t \to cg)$ | $5 \cdot 10^{-11}$ | $10^{-6}$ | $10^{-3}$ |
| $B(t \to c\gamma)$ | $5 \cdot 10^{-13}$ | $10^{-6}$ | $10^{-5}$ |
| $B(t \to cZ)$ | $\sim 10^{-13}$ | $10^{-9}$ | $10^{-4}$ |

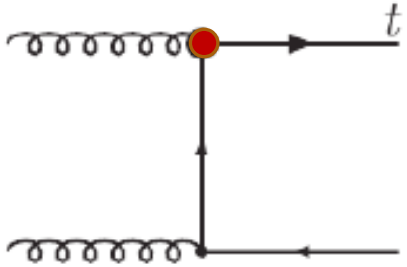
Photon mediated




Gluon mediated

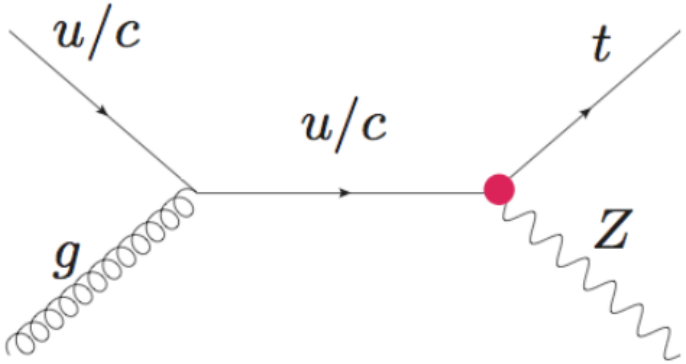



$cg \to tg$




$gg \to tc$

Z mediated

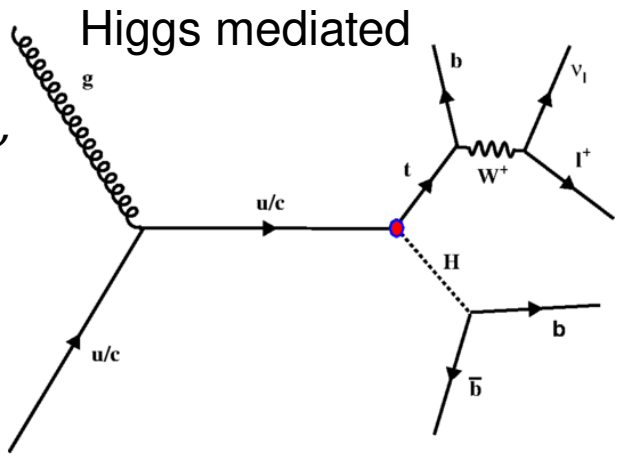



SM predictions:

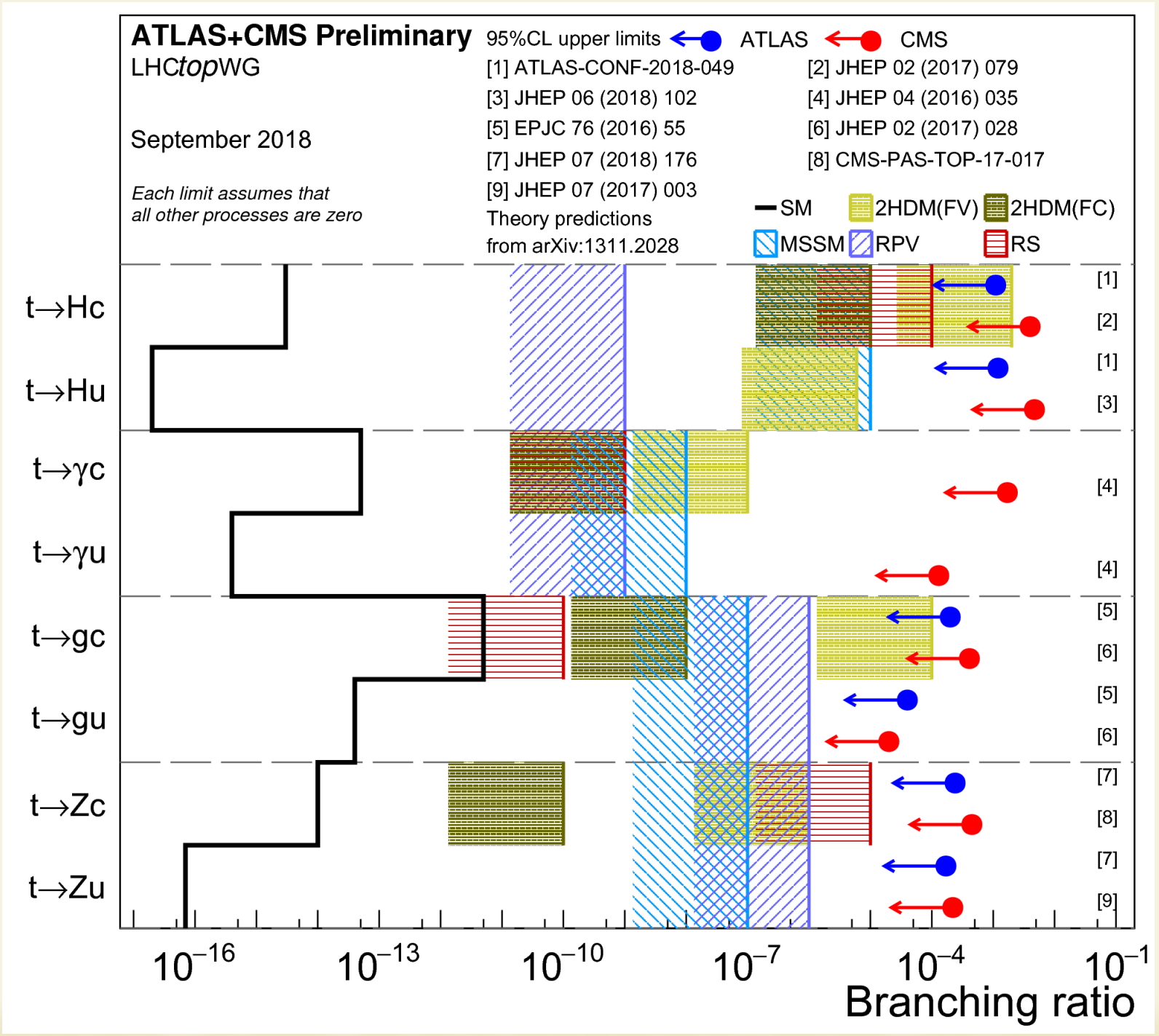
$Br(t \to Hu) \sim 10^{-17}$,

$Br(t \to Hc) \sim 10^{-15}$

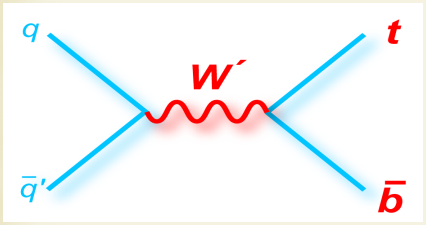
Higgs mediated

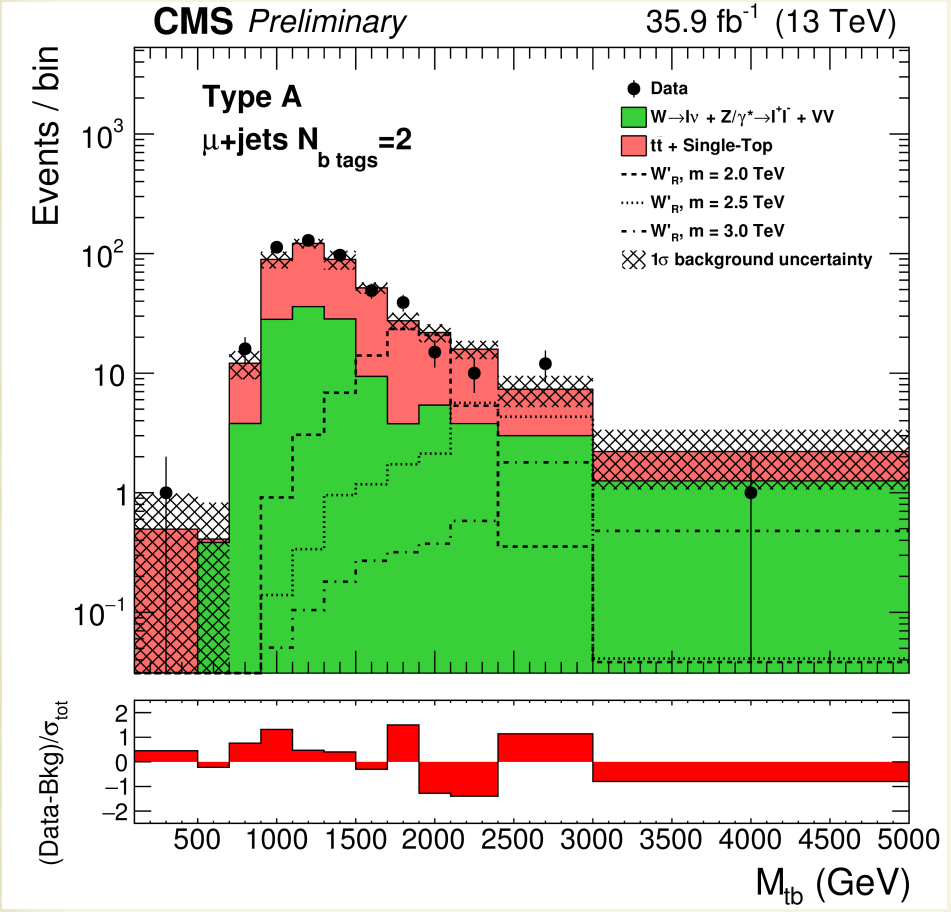


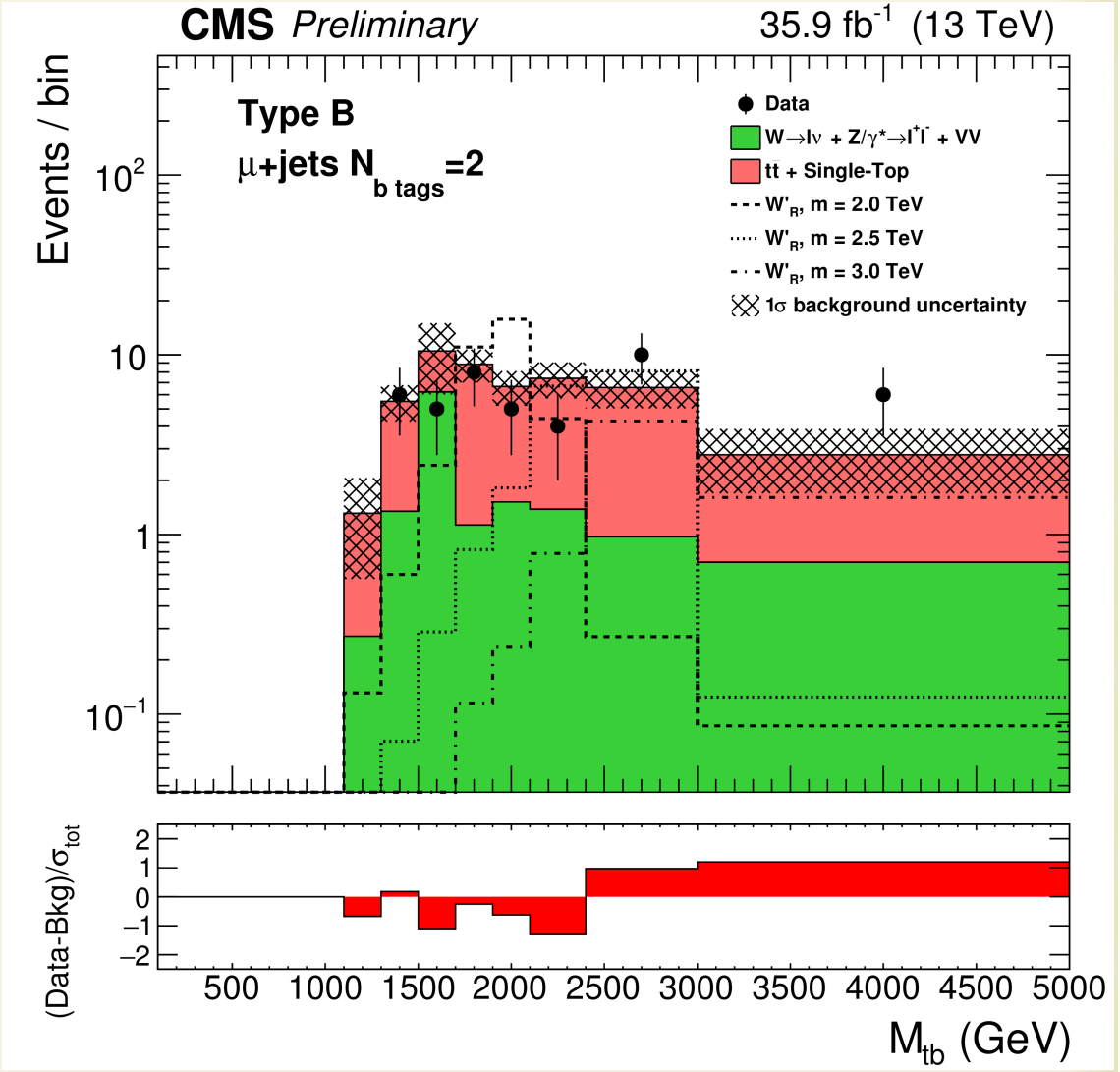
# 95% CL upper limits on FCNC top quark decays



# Search for W'->tb

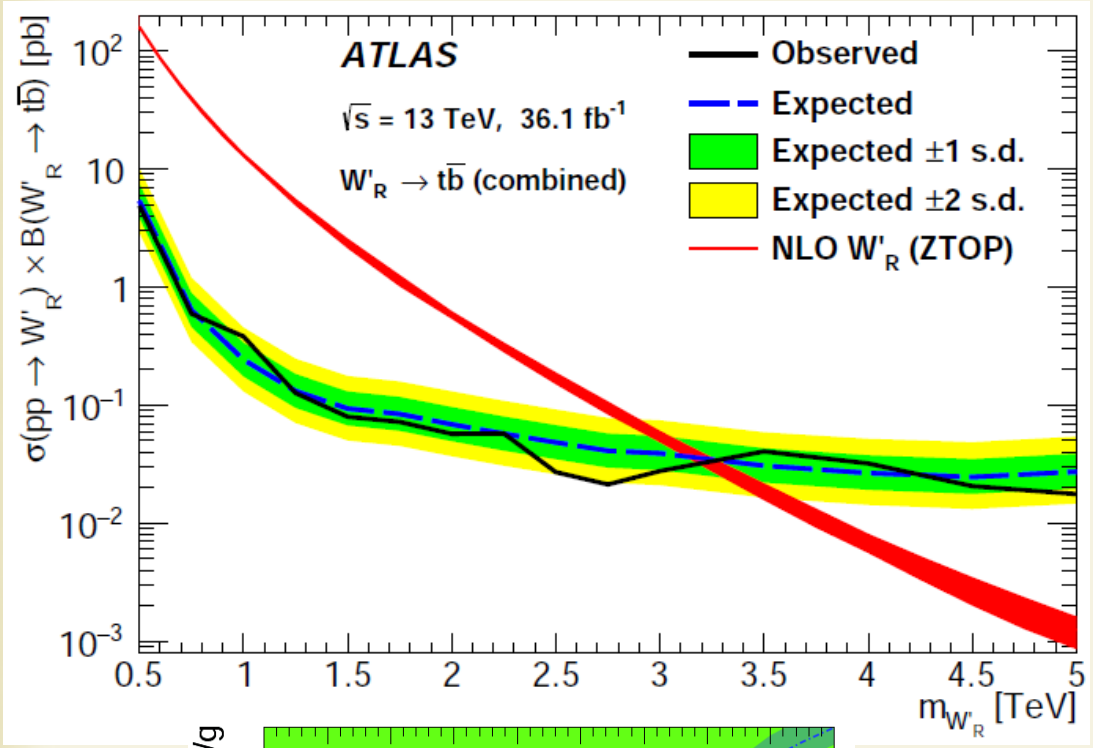


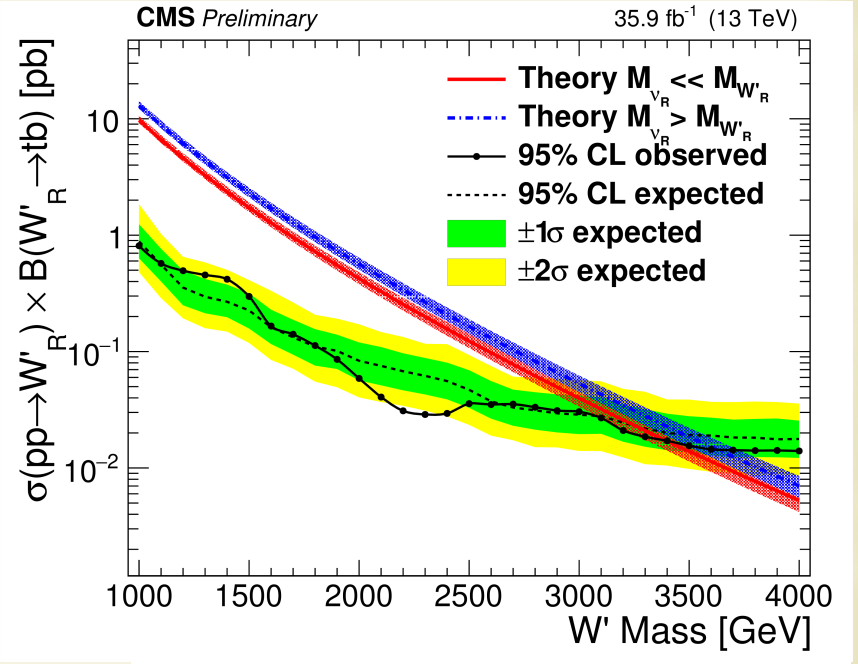



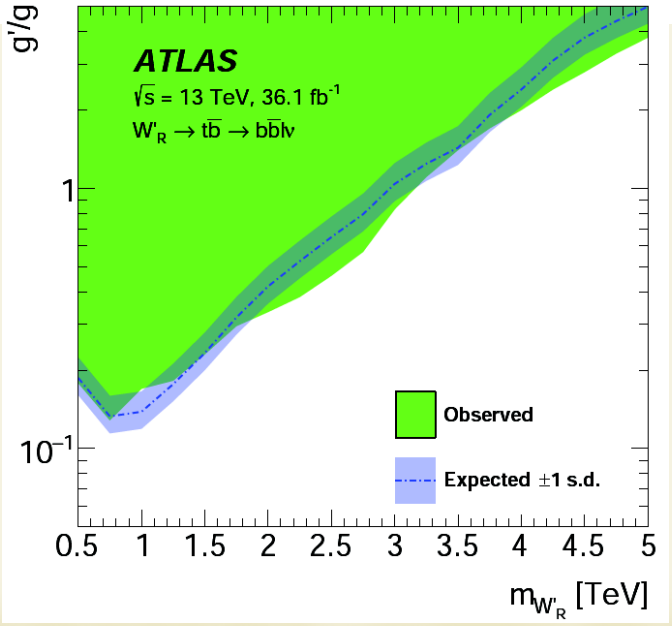



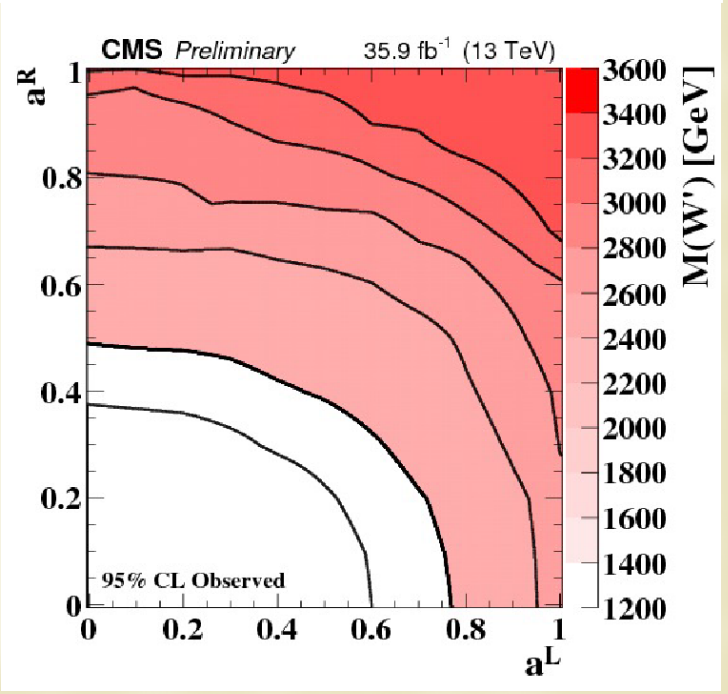

$p_T^{top}$ >650 GeV and $p_T^{j_1+j_2}$ >700 GeV

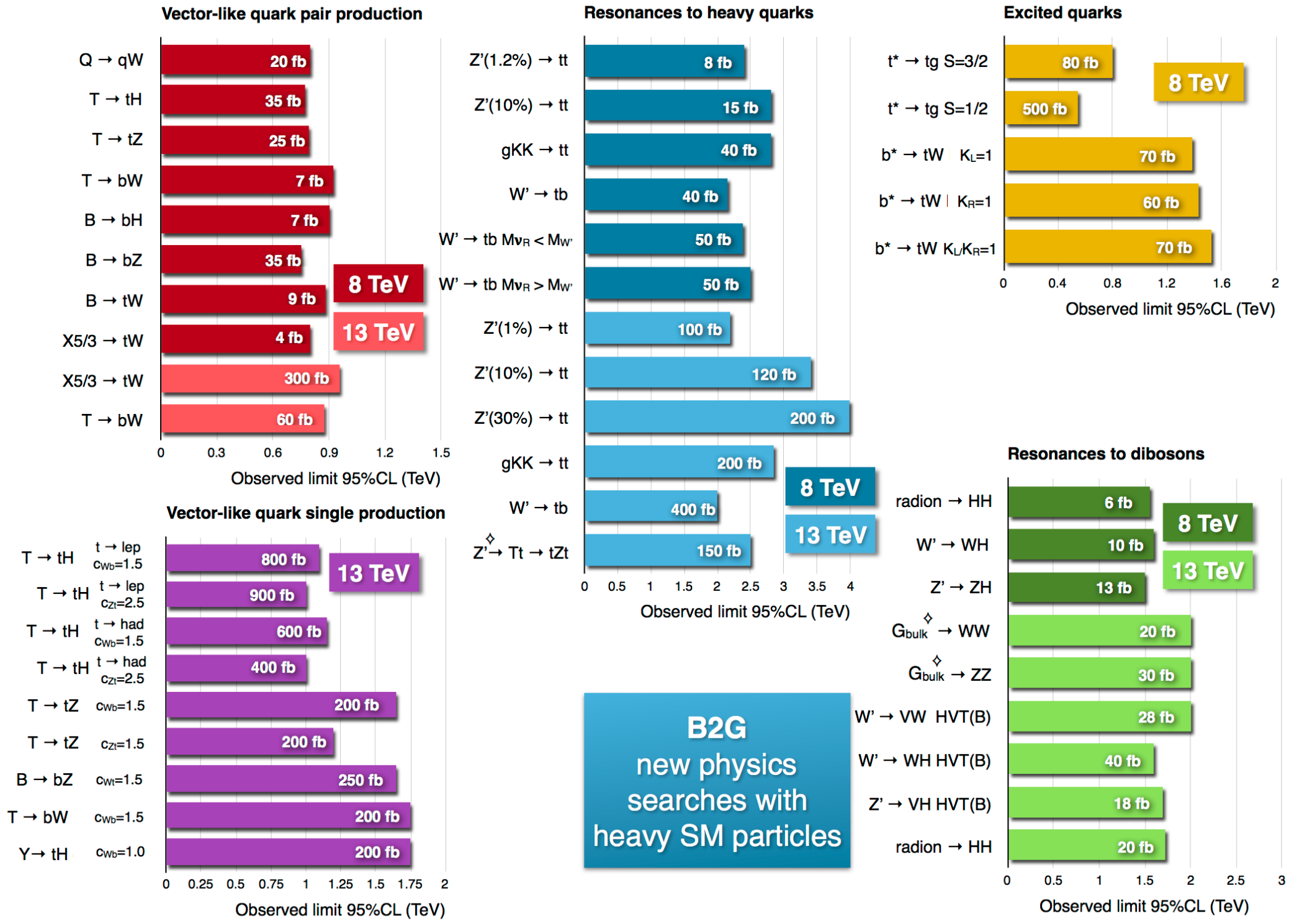
# Search for W' in single top



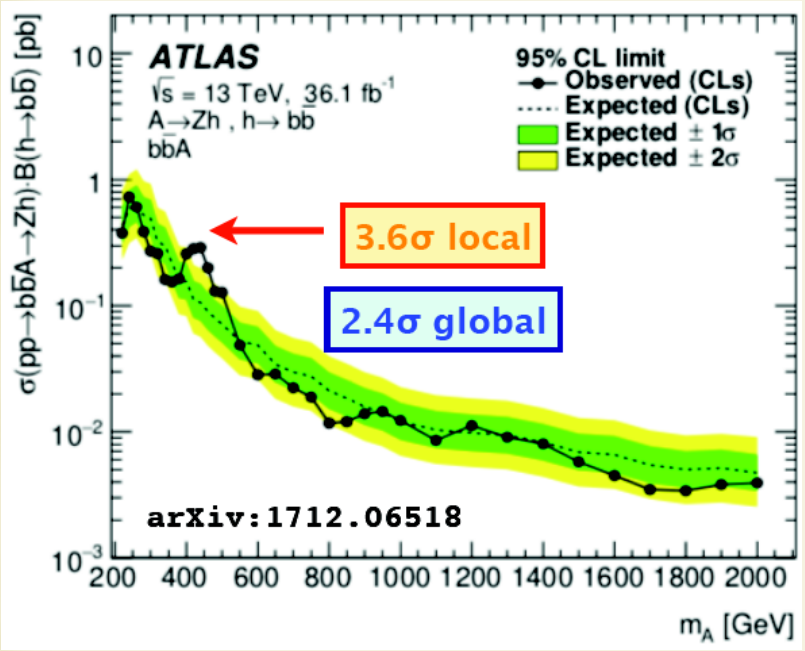



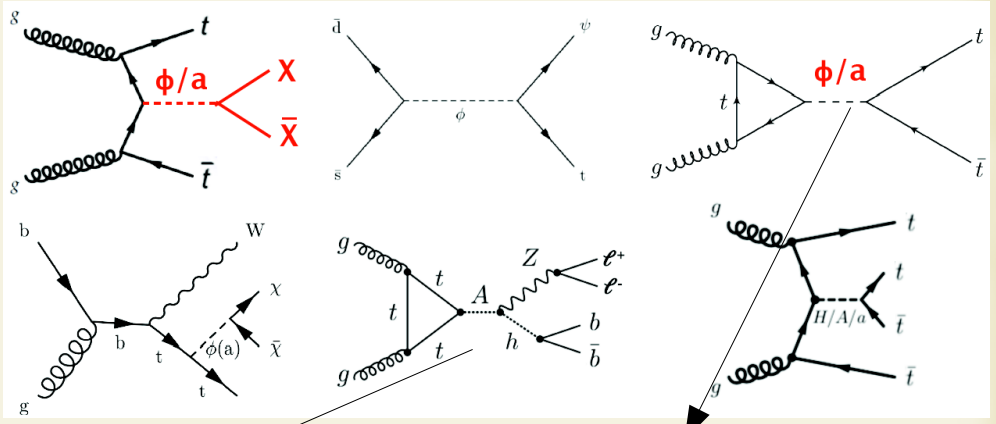



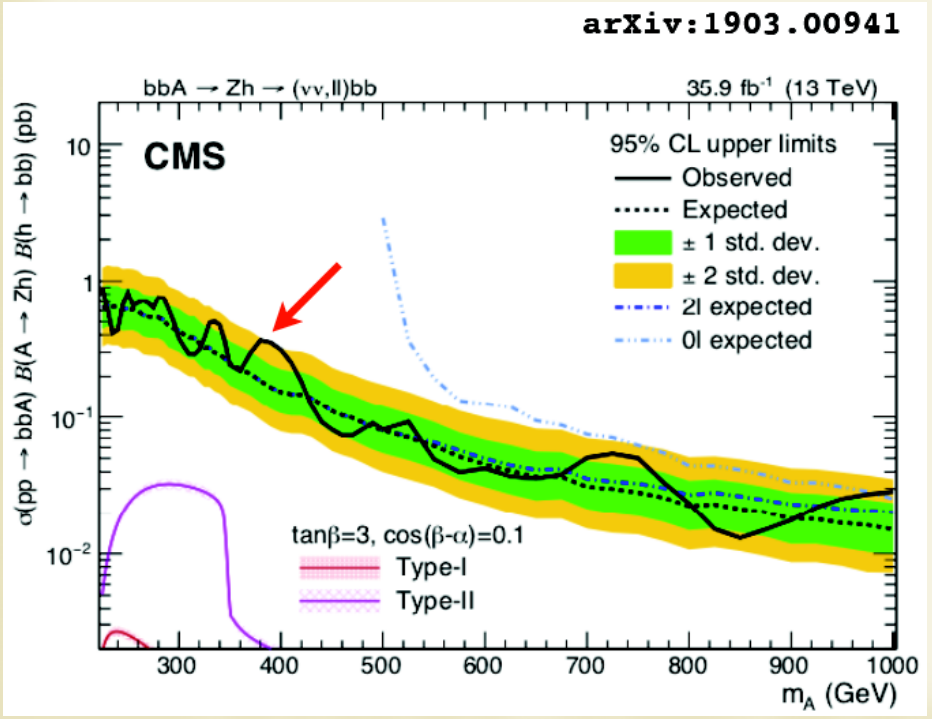



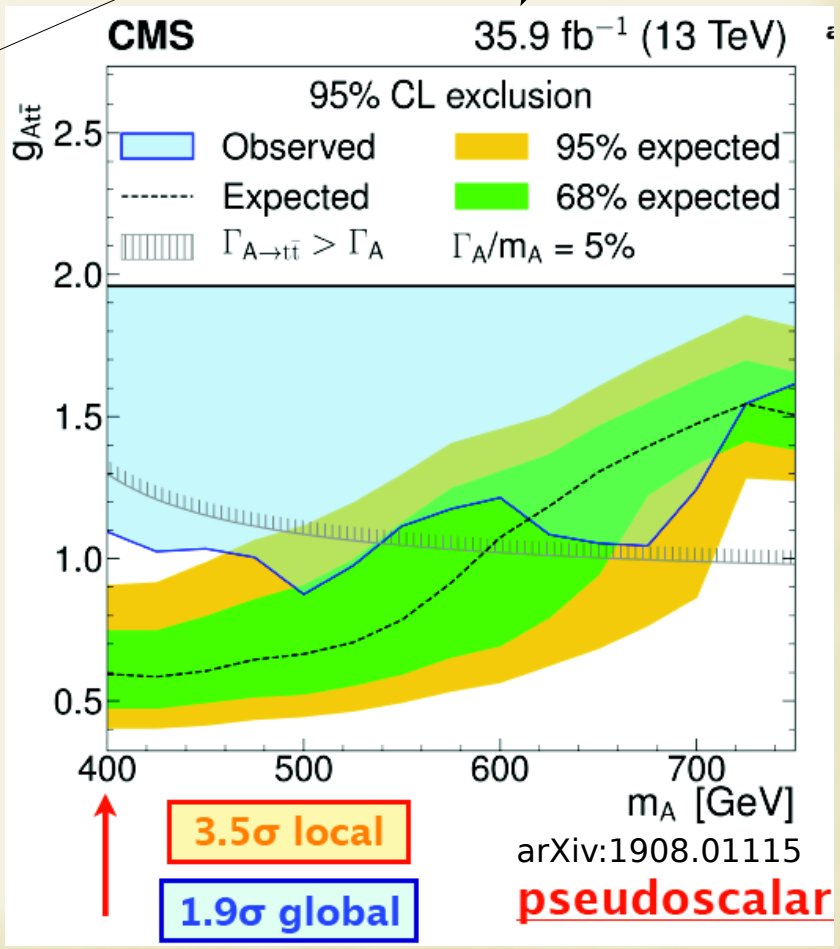

Vector-like quark pair production
Q → qW 20 fb
T → tH 35 fb
T → tZ 25 fb
T → bW 7 fb
B → bH 7 fb
B → bZ 35 fb
B → tW 9 fb
X5/3 → tW 4 fb
X5/3 → tW 300 fb
T → bW 60 fb
8 TeV
13 TeV
0 0.3 0.6 0.9 1.2 1.5
Observed limit 95%CL (TeV)
Resonances to heavy quarks
Z'(1.2%) → tt 8 fb
Z'(10%) → tt 15 fb
gKK → tt 40 fb
W' → tb 40 fb
W' → tb Mν_R < M_W' 50 fb
W' → tb Mν_R > M_W' 50 fb
Z'(1%) → tt 100 fb
Z'(10%) → tt 120 fb
Z'(30%) → tt 200 fb
gKK → tt 200 fb
W' → tb 400 fb
Z'◇ → Tt → tZt 150 fb
8 TeV
13 TeV
0 0.5 1 1.5 2 2.5 3 3.5 4
Observed limit 95%CL (TeV)
Excited quarks
t* → tg S=3/2 80 fb
t* → tg S=1/2 500 fb
b* → tW K_L=1 70 fb
b* → tW K_R=1 60 fb
b* → tW K_L/K_R=1 70 fb
8 TeV
0 0.4 0.8 1.2 1.6 2
Observed limit 95%CL (TeV)
Vector-like quark single production
T → tH t → lep c_Wb=1.5 800 fb
T → tH t → lep c_Zt=2.5 900 fb
T → tH t → had c_Wb=1.5 600 fb
T → tH t → had c_Zt=2.5 400 fb
T → tZ c_Wb=1.5 200 fb
T → tZ c_Zt=1.5 200 fb
B → bZ c_Wt=1.5 250 fb
T → bW c_Wb=1.5 200 fb
Y → tH c_Wb=1.0 200 fb
13 TeV
0 0.25 0.5 0.75 1 1.25 1.5 1.75 2
Observed limit 95%CL (TeV)
B2G
new physics
searches with
heavy SM particles
Resonances to dibosons
radion → HH 6 fb
W' → WH 10 fb
Z' → ZH 13 fb
G_bulk◇ → WW 20 fb
G_bulk◇ → ZZ 30 fb
W' → VW HVT(B) 28 fb
W' → WH HVT(B) 40 fb
Z' → VH HVT(B) 18 fb
radion → HH 20 fb
8 TeV
13 TeV
0 0.5 1 1.5 2 2.5 3
Observed limit 95%CL (TeV)
◇model-independent

# Dark Matter with top quarks in simplified models



# Summary

- LHC provides a lot of precise measurements within top sector of the SM
- There are no experimental observation of deviation from SM in top quark sector
- Main search directions:

  - all possible modifications of top quark interactions

  - additional charged vector or scalar bosons

  - additional top quark interactions, e.g. tgu(c), tZu(c), tγu(c)
- With a new LHC data it will be possible to test tHq interactions