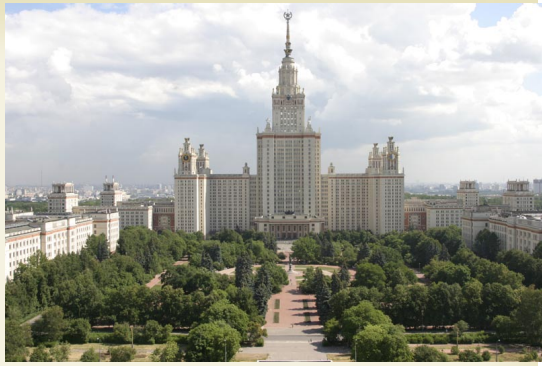
New physics searches with electroweak top quark production



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

Main directions to search for New Physics @LHC

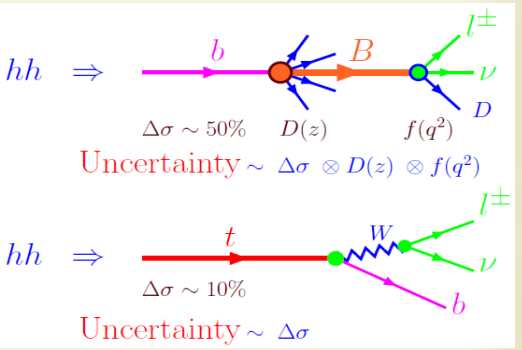
- Search for manifestation of the specific models

- Model independent search in
  - Higgs physics
  - **Top quark physics**
  - B-physics
  - Dark matter
  - Heavy Ion physics
  - ...

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

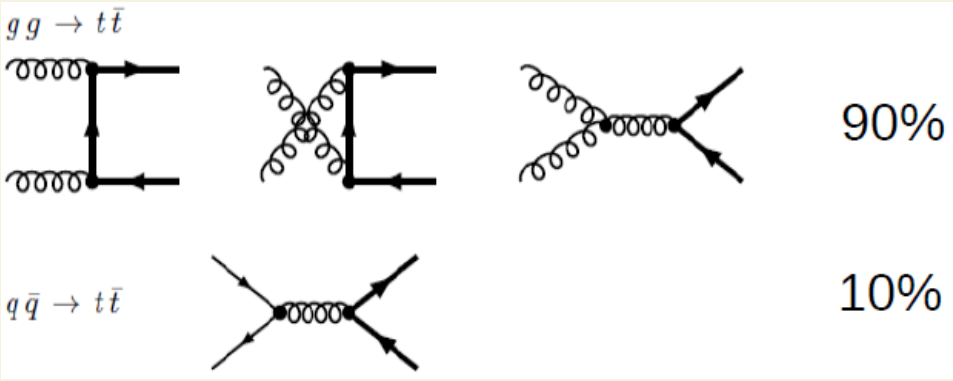
$$t \to Wb; \qquad Br(t \to other) < 10^{-3}$$

- 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

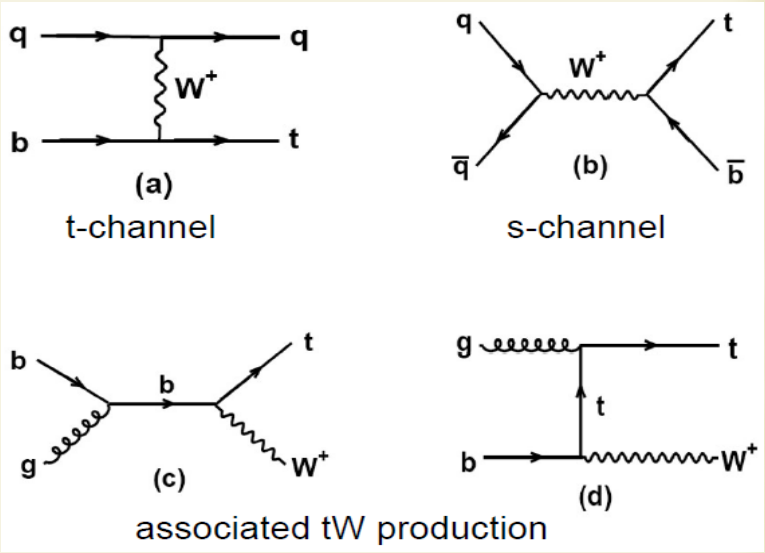
$t\bar{t}$ pair production (QCD)

	σ_{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)

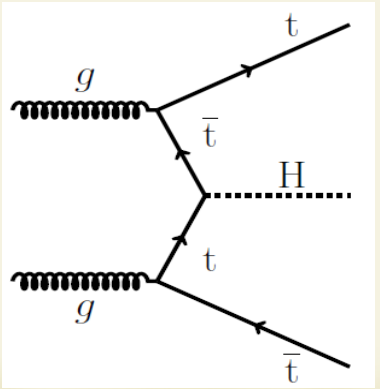
	s-channel	t-channel	Wt
Tevatron[50] ($\sqrt{s} = 1.96$ TeV $p\bar{p}$)	$1.04 \pm 4\%$	$2.26 \pm 5\%$	$0.14 \pm 20\%$
LHC[63,72] ($\sqrt{s} = 7$ TeV pp)	$4.6 \pm 5\%$	$64 \pm 4\%$	$15.6 \pm 8\%$
LHC[73] ($\sqrt{s} = 8$ TeV pp)	$5.55 \pm 4\%$	$87.2^{+4}_{-3}\%$	$11.1 \pm 7\%$
LHC[52] ($\sqrt{s} = 14$ TeV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



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

~ 0.1 - 1 pb

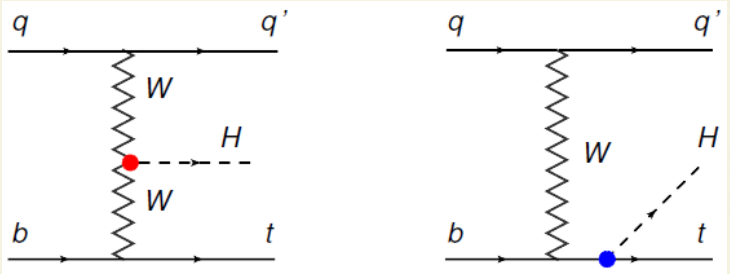
>5σ



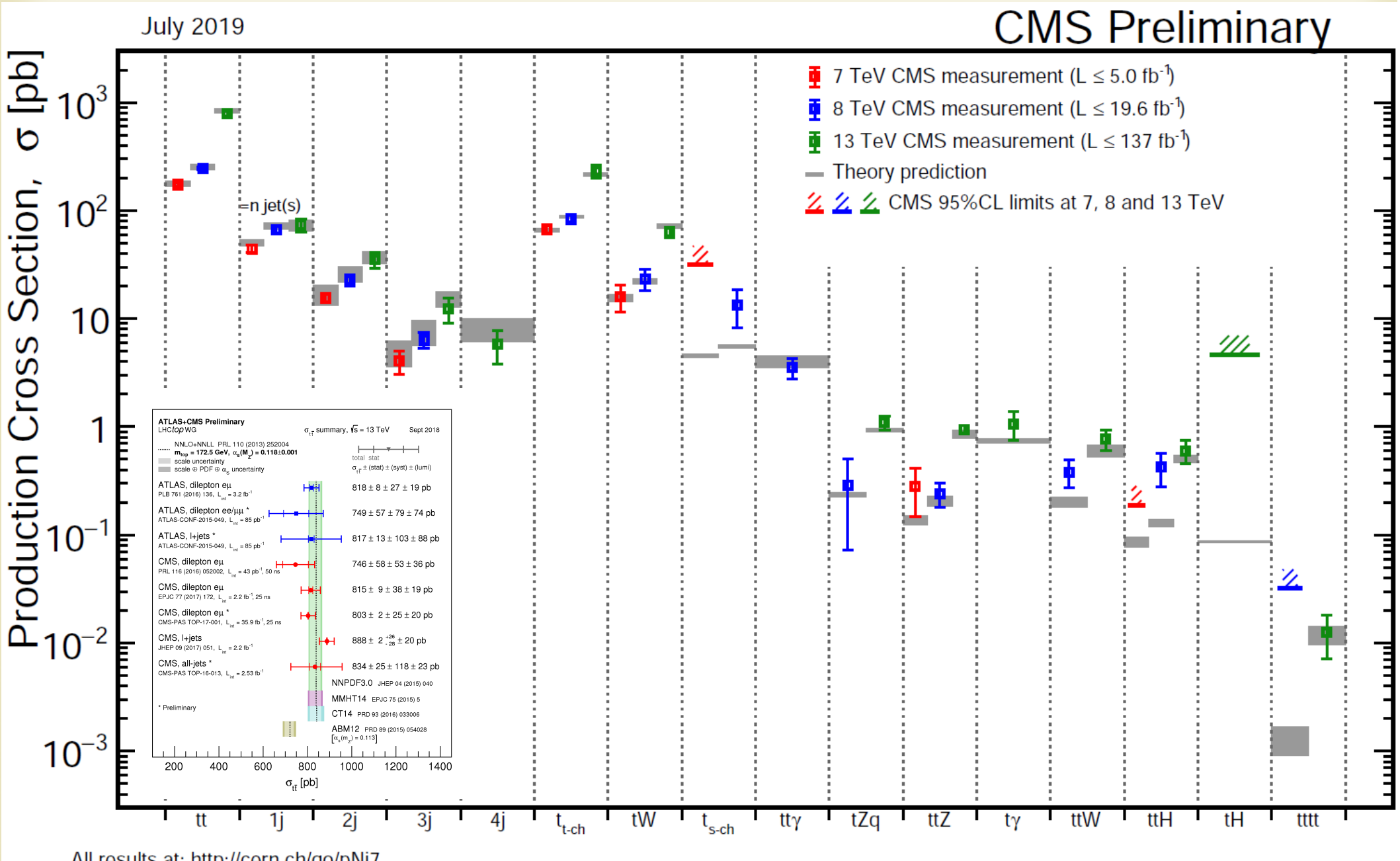
tHq (tZq,tAq) production

~ 0.01 - 0.1 pb

$\mu < 3$ @95CL



Measured top quark production cross sections



SM and BSM measurements

- Total and fiducial cross sections of the production processes
- Differential cross sections, asymmetries
- Top quark mass and other properties ($\Delta m, R_t, \ldots$)
- 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

New Physics in Wtb interactions

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

Operators that contribute to the Wtb vertex:

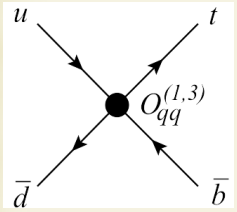
J. A. Aguilar-Saavedra, arXiv:1008.3225

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

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

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:

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

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

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

Anomalous Wtb couplings are not factorize with kinematic terms in matrix element

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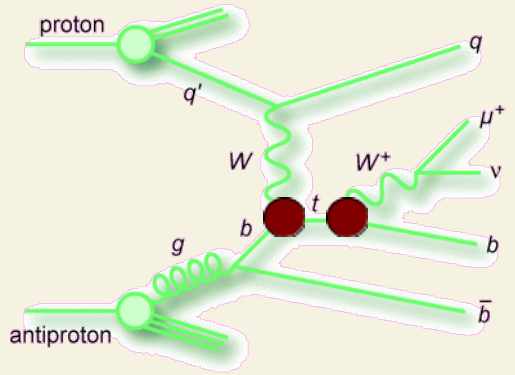
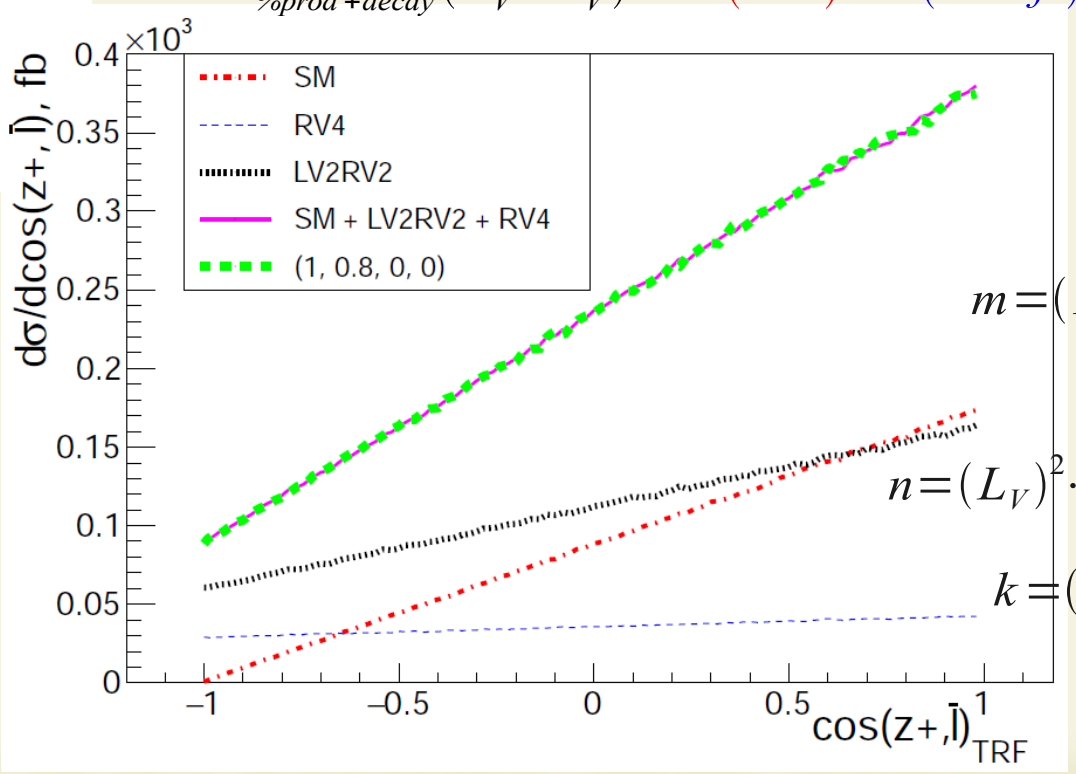
$$\sigma(\hat{s})_{ub\to td} = \frac{\pi \cdot V_{ud}^2 \cdot \alpha^2}{4 \cdot \hat{s} \cdot \sin^4 \Theta_W} \times$$
$$\Big[\ c_0 c_p \beta^4 \cdot f_{LV}^2$$
$$+ \left(-(1+c_1)\cdot ln(a_1) + (2+c_0)\cdot\beta^2\right)\cdot f_{RV}^2$$
$$+ \left((2+c_0)\cdot ln(a_1) - (1+c_1)\cdot c_0 c_p \beta^2\right)\cdot f_{RT}^2$$
$$+ \left(c_1 \cdot ln(a_1) - 2\beta^2\right)\cdot c_0 \beta^2 \cdot f_{LT}^2$$
$$+ \frac{2m_t}{m_W}\cdot\left((-ln(a_1) + c_p\beta^2)\cdot f_{LV}\cdot f_{RT}\right)$$
$$+ \frac{2m_t}{m_W}\cdot\left((c_1\cdot ln(a_1) - 2\beta^2)\cdot f_{RV}\cdot f_{LT}\right)\ \Big]$$

$$\beta^2 = 1 - \frac{m_t^2}{\hat{s}},\quad a_1 = 1 + \frac{\beta^2 \hat{s}}{m_W^2},\quad c_p = \frac{\hat{s}}{(\hat{s} - m_t^2 + m_W^2)},$$
$$c_0 = \frac{\hat{s}}{m_W^2},\quad c_1 = \frac{2m_W^2}{\hat{s}} + \beta^2;$$



Kinematic distributions are dependent on the coupling values

$$\sigma_{\%prod+decay}(L_V \quad R_V) = m\cdot(SM) + n\cdot(interf) + k\cdot(RV\,4)$$

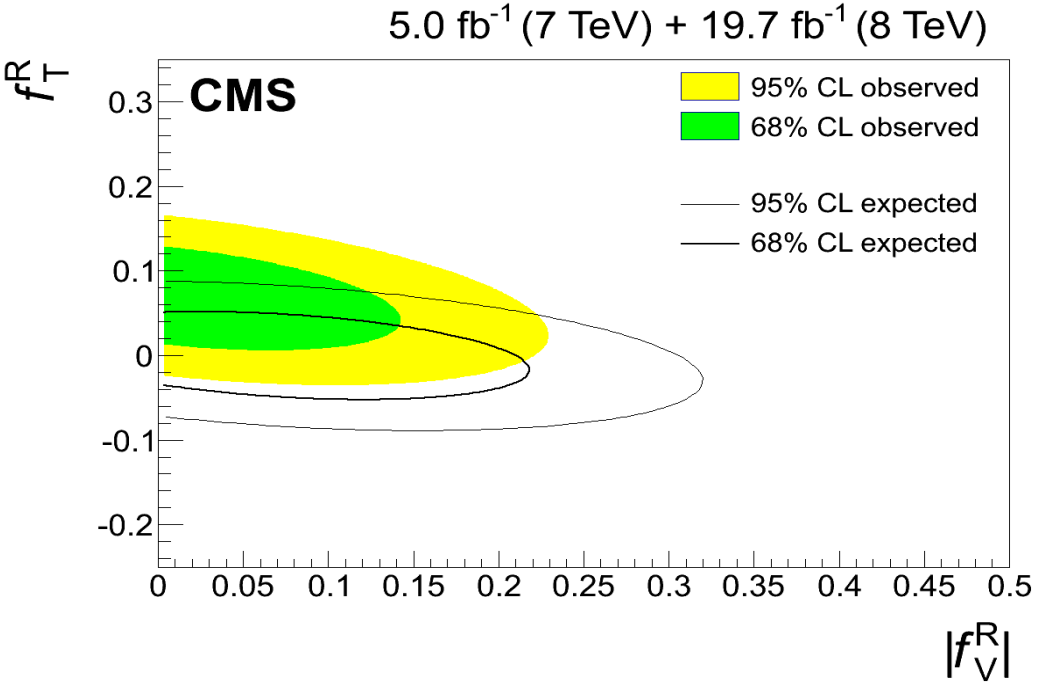


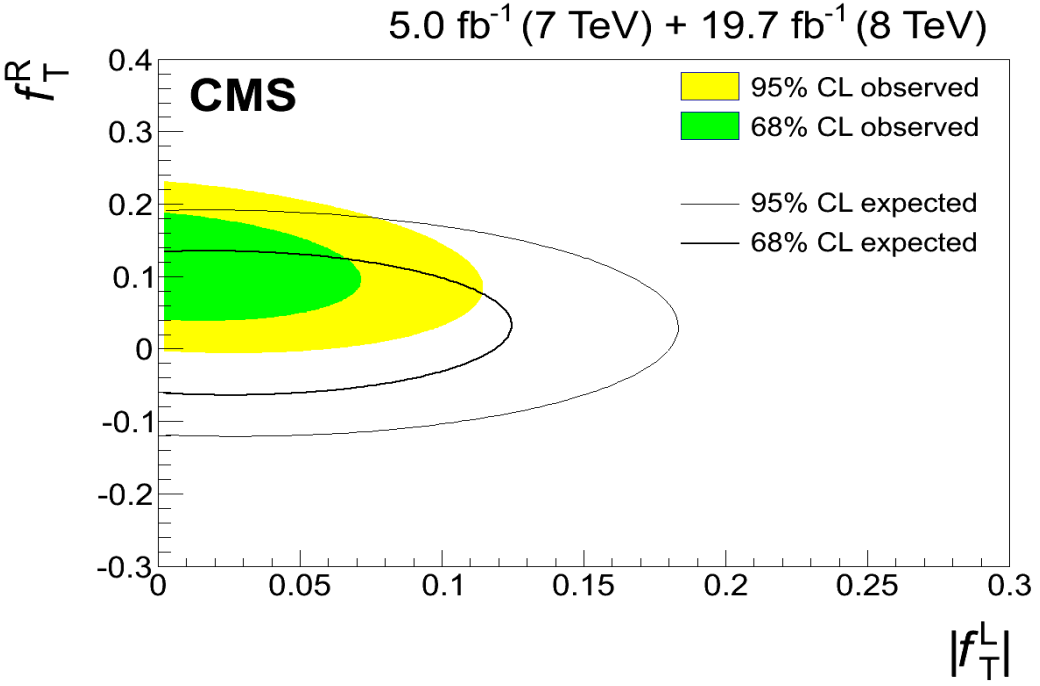
$$m = (L_V)^4 \frac{w_{SM}}{w_{(L_V,R_V)}}$$

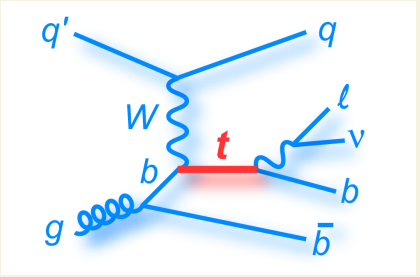
$$n = (L_V)^2\cdot(R_V)^2 \frac{w_{art}}{w_{(L_V,R_V)}}$$

$$k = (R_V)^4 \frac{w_{0100}}{w_{(L_V,R_V)}}$$

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







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

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

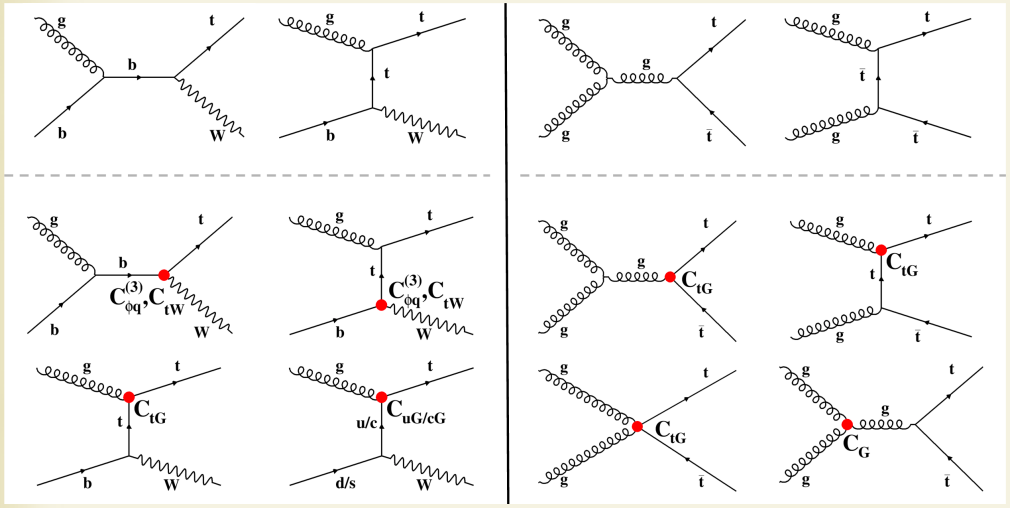
Observed (expected) 1D limits at 95% C.L.:

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

JHEP02(2017)028

tW+tt anomalous contribution, EFT interpretation

arXiv:1903.11144



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

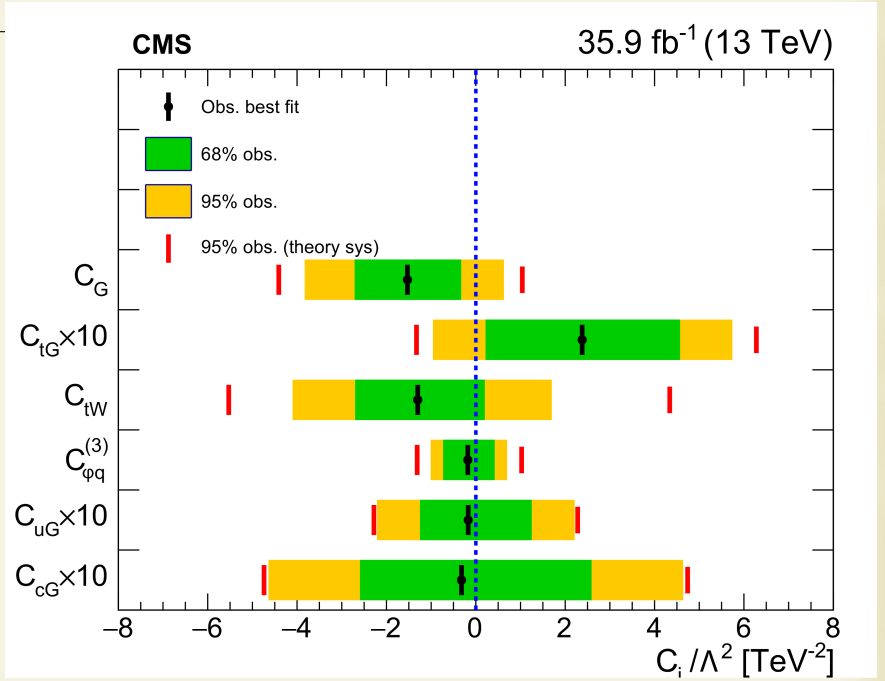
$$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^i t)\tilde{\phi} W^i_{\mu\nu}, \qquad L_{\text{eff}} = -2\frac{C_{tW}}{\Lambda^2} v \bar{b}\sigma^{\mu\nu} P_R t \partial_\nu W^-_\mu + \text{h.c.},$$

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

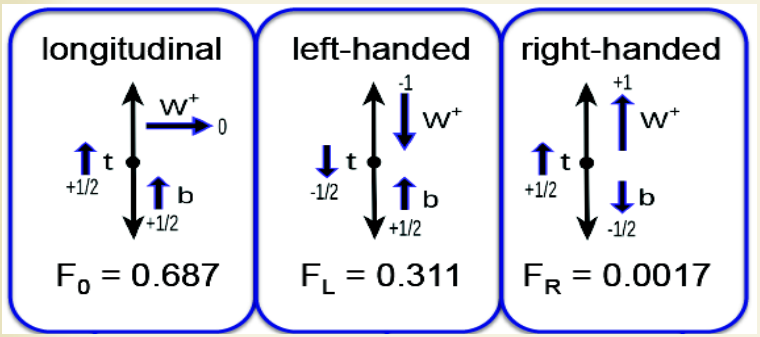
$$O_G = f_{abc} G^{a\nu}_\mu G^{b\rho}_\nu G^{c\mu}_\rho, \qquad L_{\text{eff}} = \frac{C_G}{\Lambda^2} f_{abc} G^{a\nu}_\mu G^{b\rho}_\nu G^{c\mu}_\rho,$$

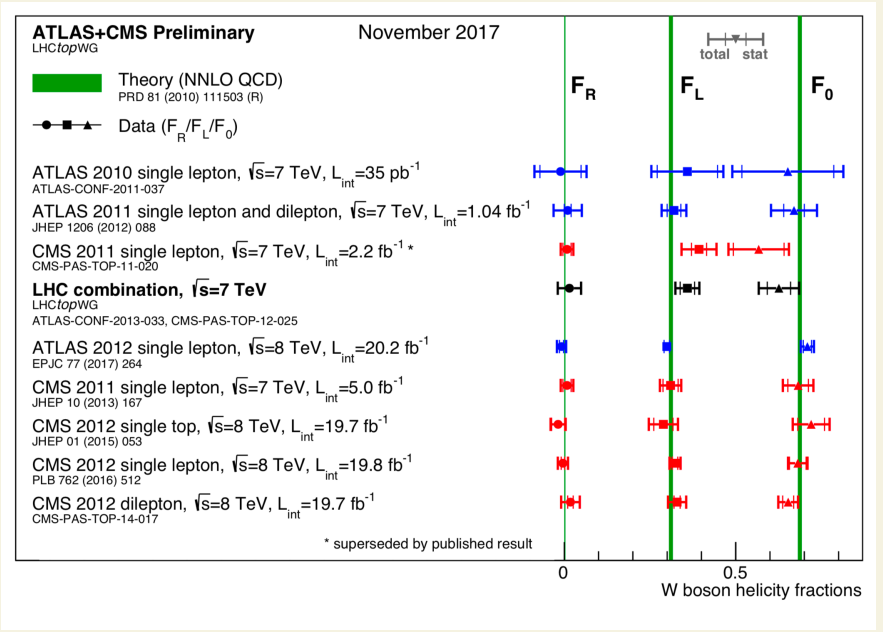
$$O_{u(c)G} = (\bar{q}\sigma^{\mu\nu}\lambda^a t)\tilde{\phi} G^a_{\mu\nu}, \qquad L_{\text{eff}} = \frac{C_{u(c)G}}{\sqrt{2}\Lambda^2} v\,(\bar{u}\,(\bar{c})\,\sigma^{\mu\nu}\lambda^a t)\, G^a_{\mu\nu} + \text{h.c.},$$

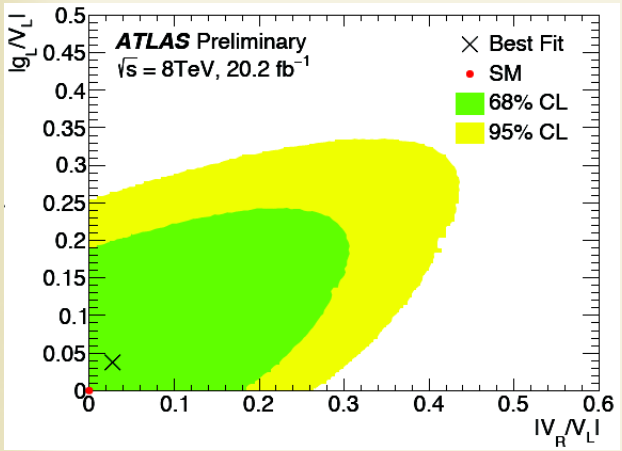
Effective coupling	Channel	Observed [TeV^{-2}] Best fit	[68% CI]	[95% CI]	Expected [TeV^{-2}] Best fit	[68% CI]	[95% CI]
C_G/Λ^2	ee	−0.14	[−0.82, 0.51]	[−1.14, 0.83]	0.00	[−0.90, 0.59]	[−1.20, 0.88]
	eμ	−0.18	[−0.73, 0.42]	[−1.01, 0.70]	0.00	[−0.82, 0.51]	[−1.08, 0.77]
	μμ	−0.14	[−0.75, 0.44]	[−1.06, 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}/Λ^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}/Λ^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}/Λ^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}/Λ^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]



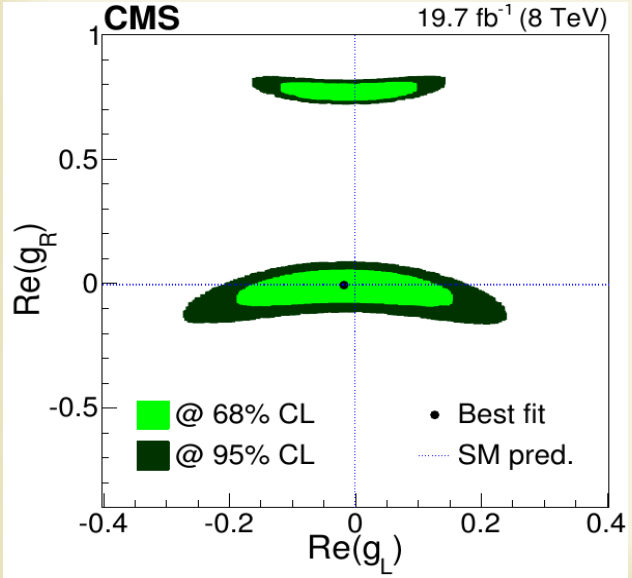
W helicity, top polarisation and Wtb anomalous couplings

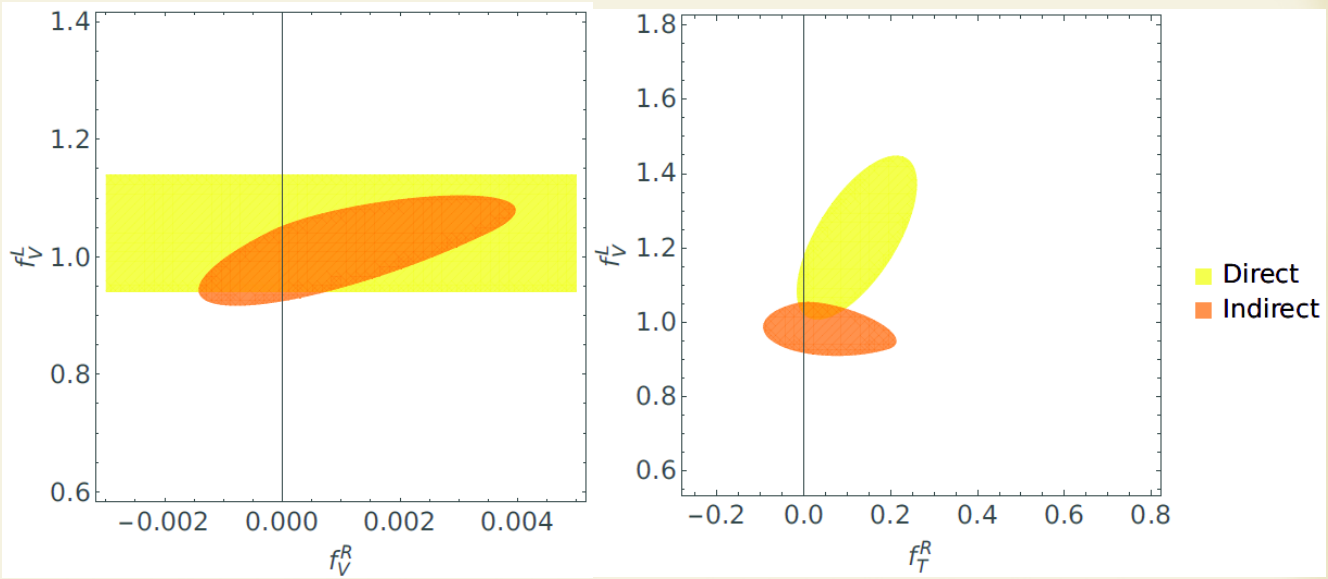






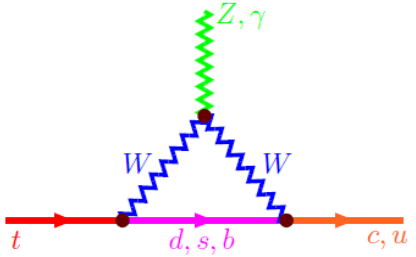
Indirect constrains from rare B decays
[e.g. EPJ Web of Conferences 222, 04008 (2019)]





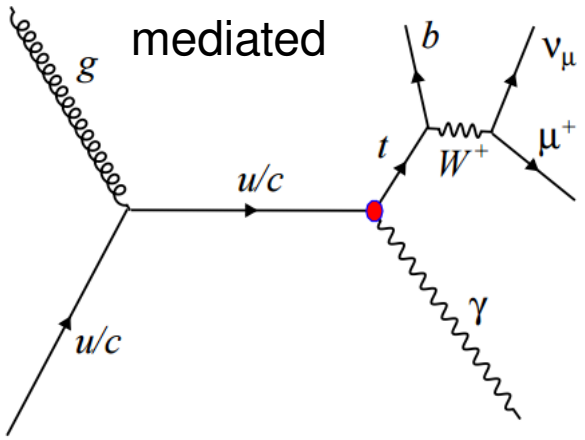
Flavor changing neutral currents (FCNC) in the production of top quark

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

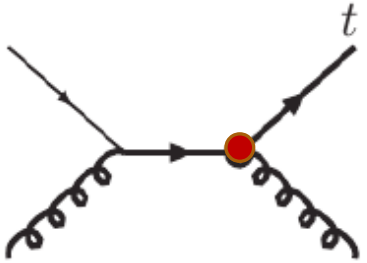


	SM	two-Higgs	SUSY
$B(t \to cg)$	$5 \cdot 10^{-11}$	10^{-6}	10^{-3}
$B(t \to c\gamma)$	$5 \cdot 10^{-13}$	10^{-6}	10^{-5}
$B(t \to cZ)$	$\sim 10^{-13}$	10^{-9}	10^{-4}

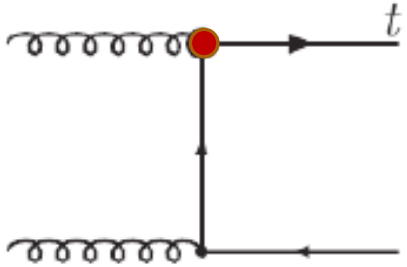
Photon mediated



Gluon mediated

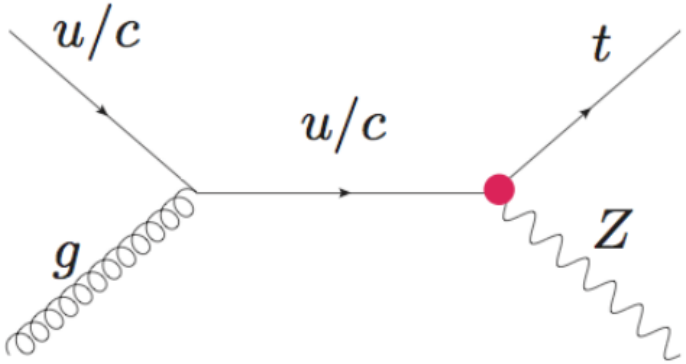


$cg \to tg$



$gg \to tc$

Z mediated

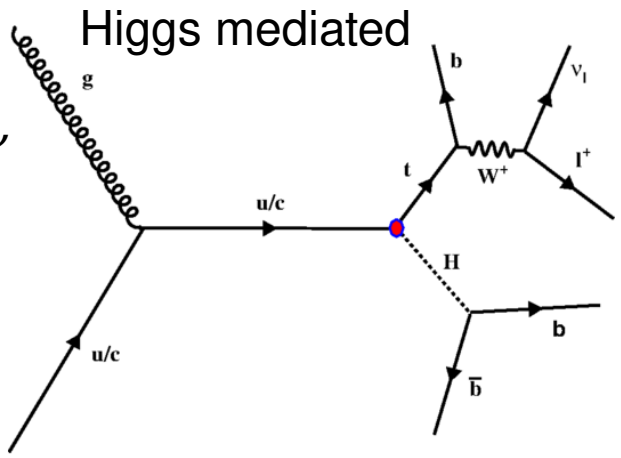


SM predictions:

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

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

Higgs mediated



Gluon mediated FCNC top quark production

There is almost direct correspondence of the couplings at Lorentz-invariant structures and Willson coefficients at EFT opearators for LO tqg FCNC
[Phys. Rev. D 91, 074017 (2015), arXiv:1802.07237, arXiv:1903.11144]

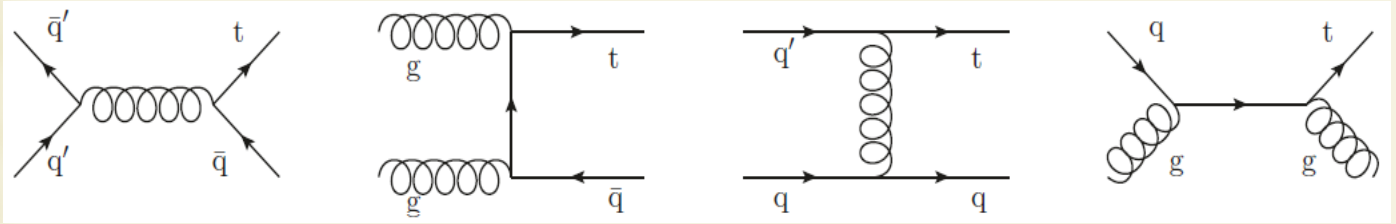
$$O_{u(c)G} = (\bar{q}\sigma^{\mu\nu}\lambda^a t)\tilde{\phi}G^a_{\mu\nu},$$

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

Effective Lagrangian in our FCNC signal calculations (CompHEP):

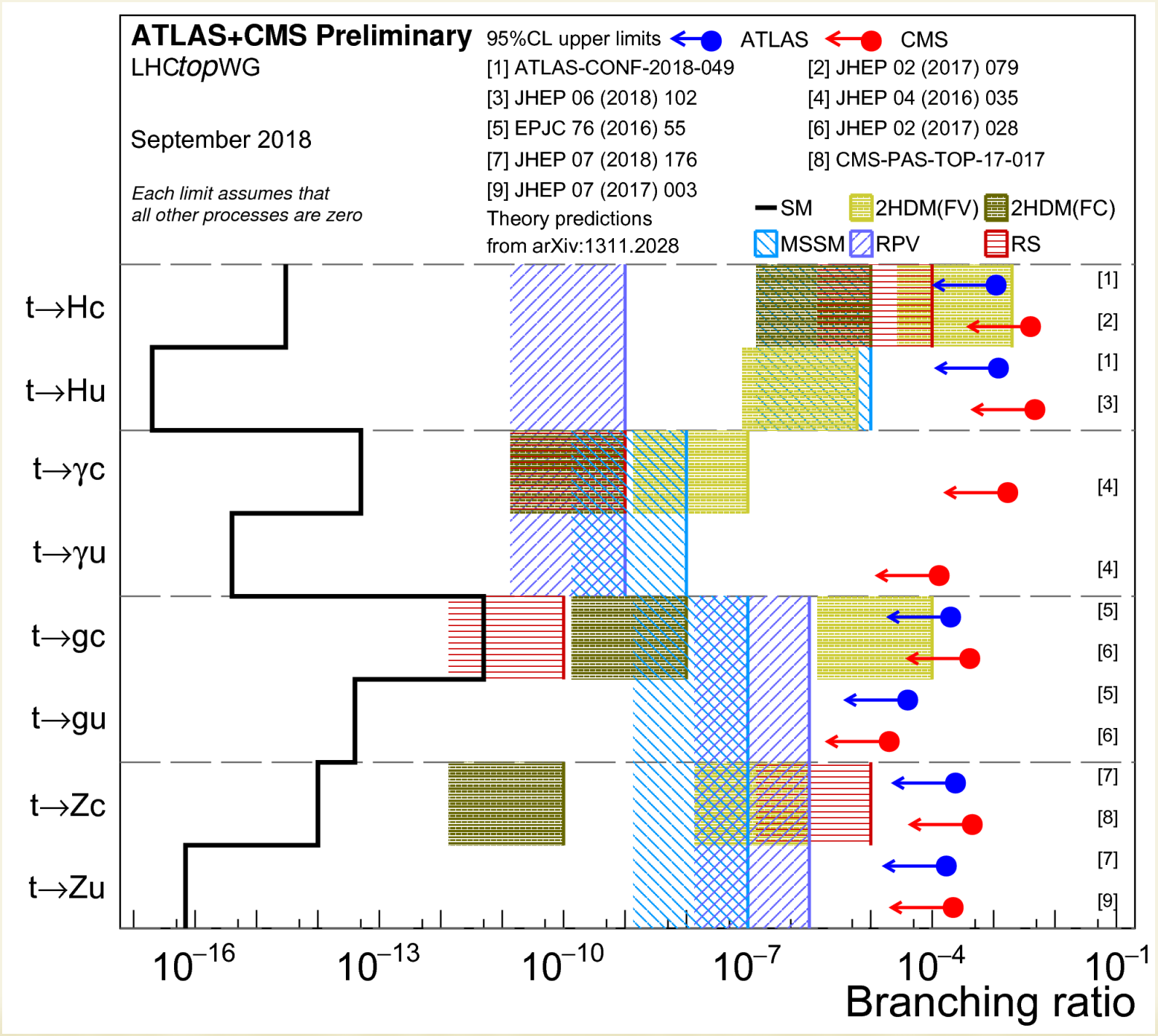
$$g_s\frac{\kappa_{tug}}{\Lambda}\,\bar{u}\,\sigma^{\mu\nu}\frac{\lambda^a}{2}t\,G^a_{\mu\nu} + g_s\frac{\kappa_{tcg}}{\Lambda}\,\bar{c}\,\sigma^{\mu\nu}\frac{\lambda^a}{2}t\,G^a_{\mu\nu} + h.c.$$

Representative diagrams of the most sensitive pp->tq->Wbj channel:



κ/Λ=0.03 TeV^{-1}
NLO K-factor (tgu) = 1.52
NLO K-factor (tgc) = 1.4
(Phys.Rev. D72 (2005) 074018)

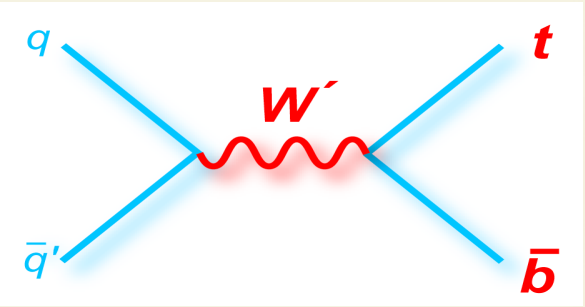
95% CL upper limits on FCNC top quark decays



W' searhes

$$L = \frac{V_{q_i q_j}}{2\sqrt{2}} g_W \bar{q}_i \gamma_\mu [a^R_{q_i q_j}(1+\gamma_5) + a^L_{q_i q_j}(1-\gamma_5)] W' q_j + H.C.$$

Heavy gauge boson



W'

models of
Universal Extra Dimensions
*Datta et al, Phys. Lett B **483**, 203 (2000)*

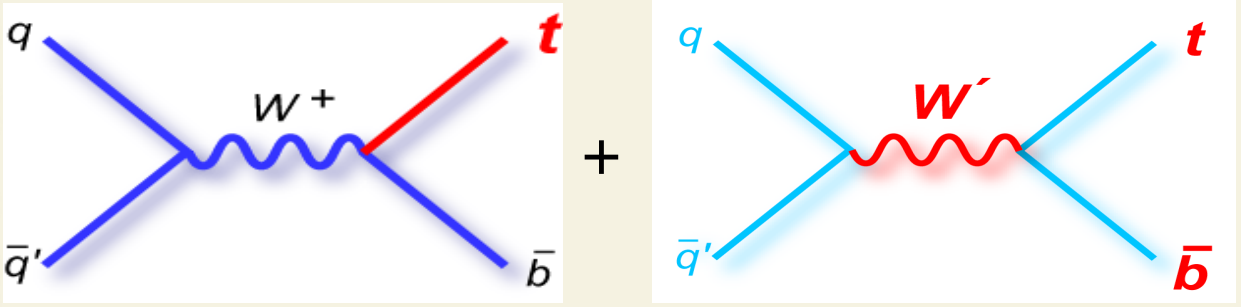
Technicolor models
*Chivukula et al, Phys Rev D **53**, 5258 (1996)*

composite models , Little Higgs models
Grand Unification Theory

top-flavor models
*Malkawi et al, Phys Lett. B **385**, 304 (1996)*

Left-Right symmetric models
Pati, Salam, Phys Rev D 10, 275 (1974)
*Mohapatra, Pati, Phys Rev. D **11**, 566 (1975)*

W' search: W — W' interference



~considered three scenarios of W' interaction to fermions:

1) SM + purely left-handed W' , 2)purely right-handed W'

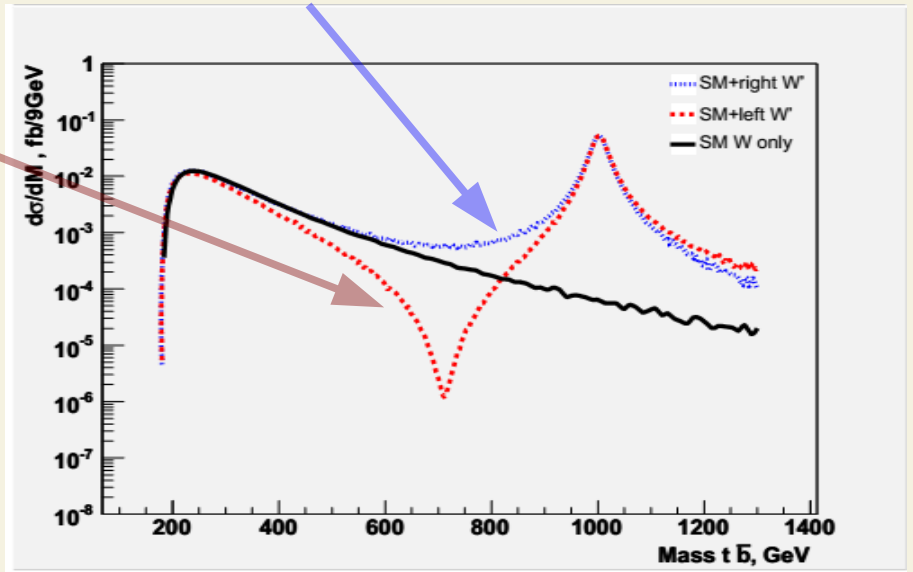
~Interference of W and W'

in the s-channel usually takes

into account

- destructive influence on the CS

~squared matrix element of the process:



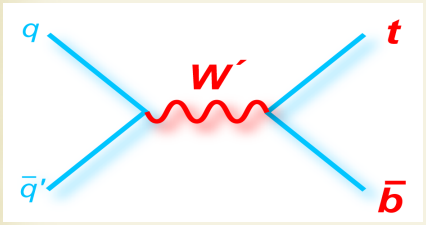
$$|M|^2 = \text{SM} + 2 \cdot a_{ud}^L \cdot a_{tb}^L$$

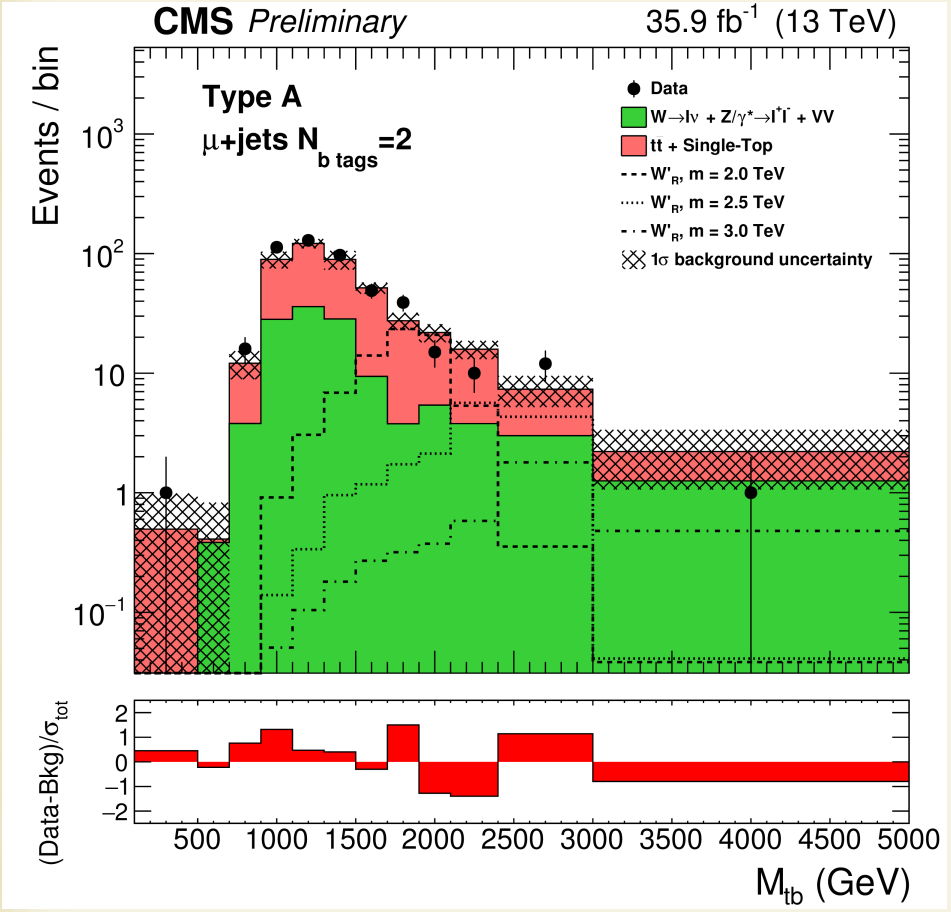
Interference of W and W'

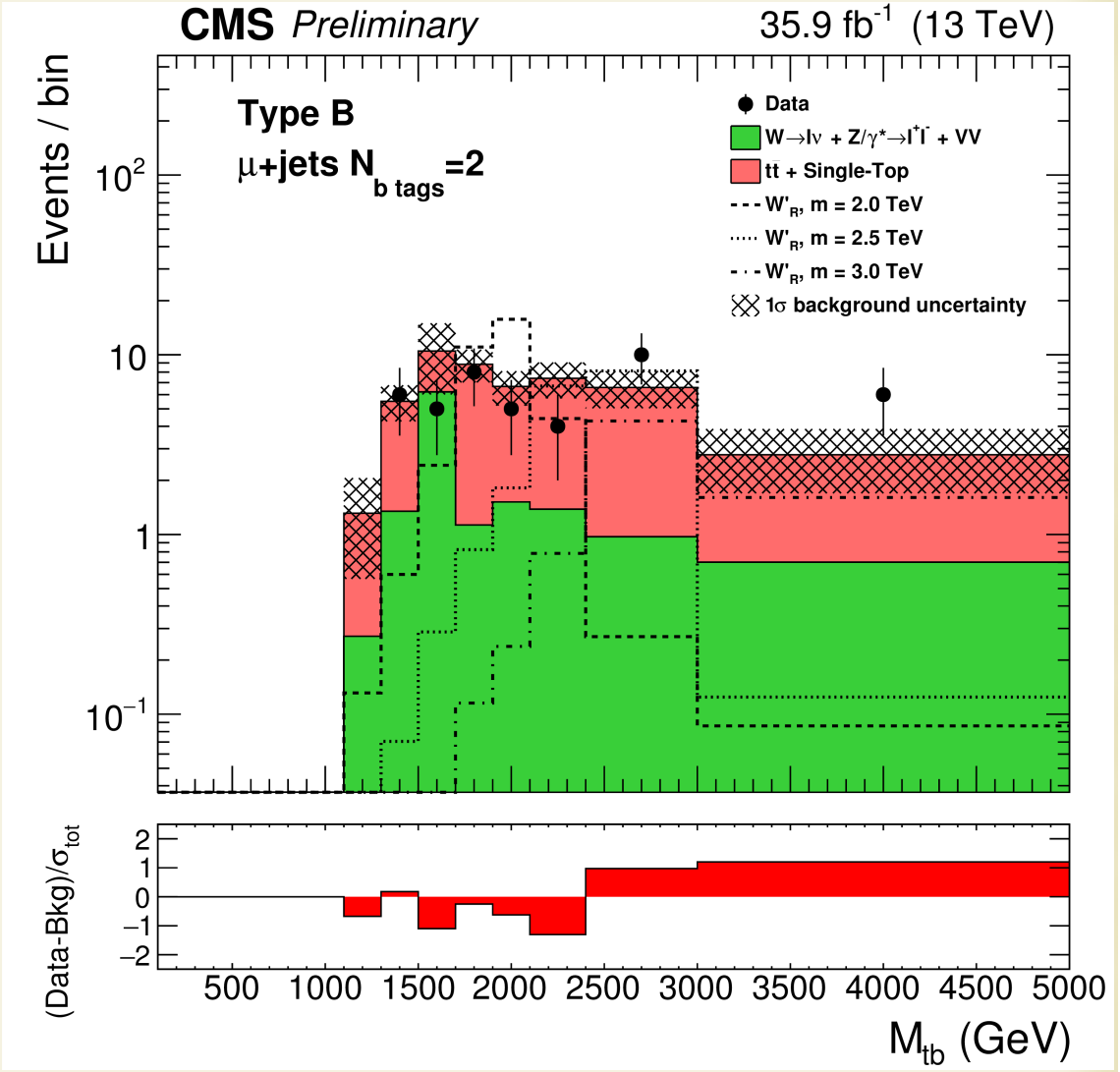
\+ W' part

E.Boos, V.Bunichev, L.Dudko, M.Perfilov
Phys.Lett.B655:245-250,2007

Search for W'->tb

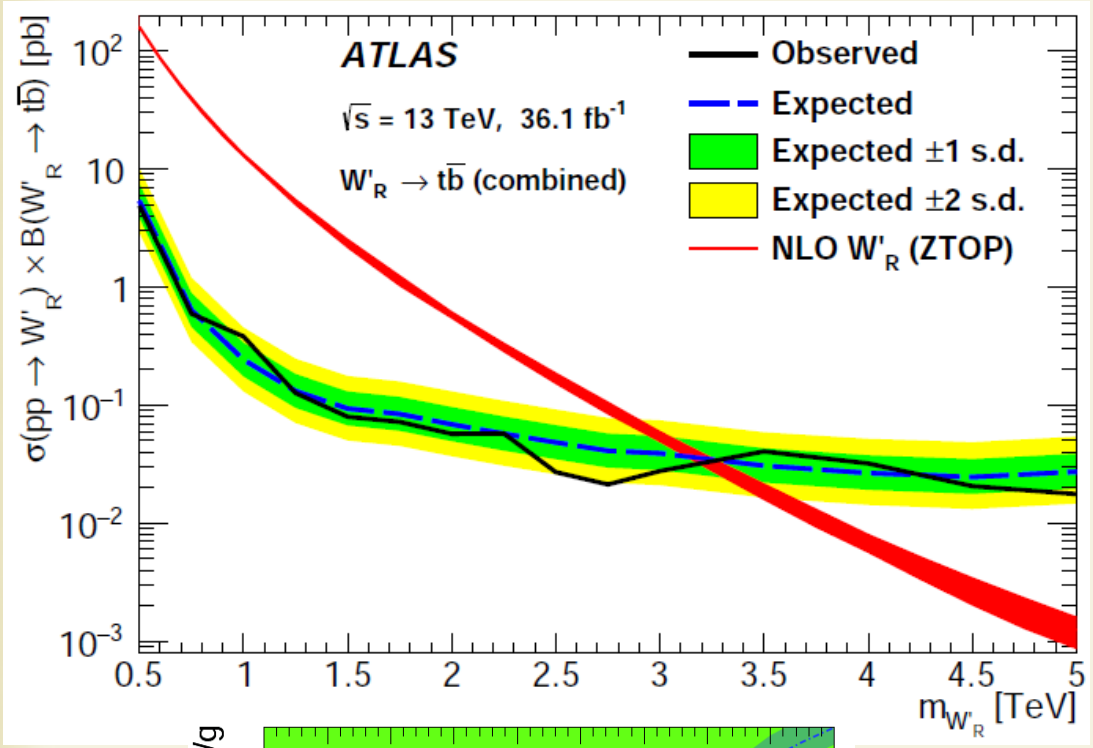


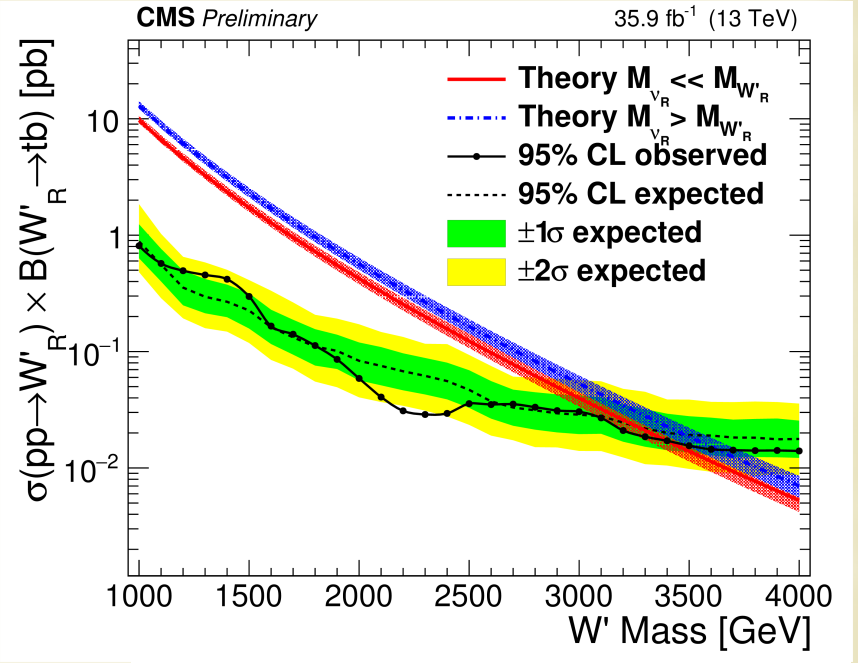


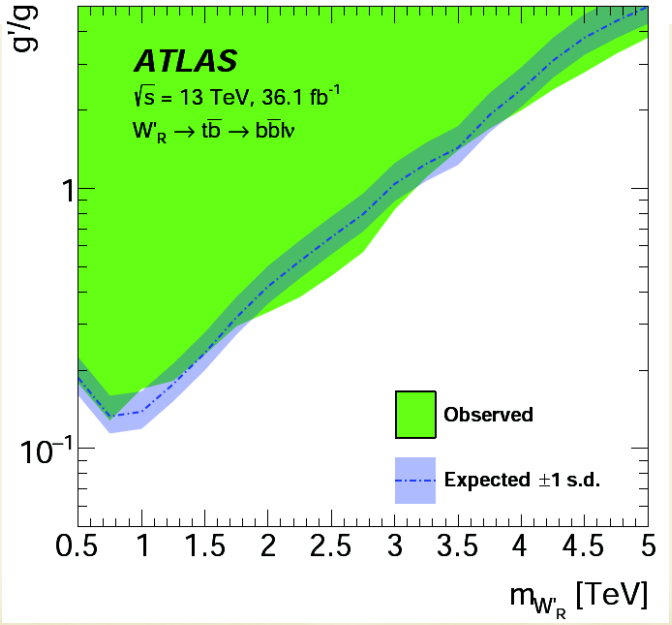


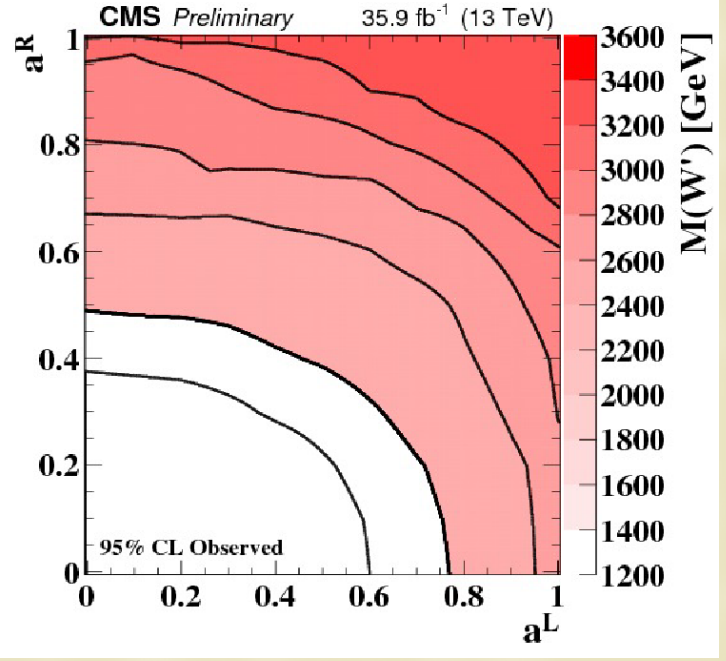
p_T^{top} >650 GeV and $p_T^{j_1+j_2}$ >700 GeV

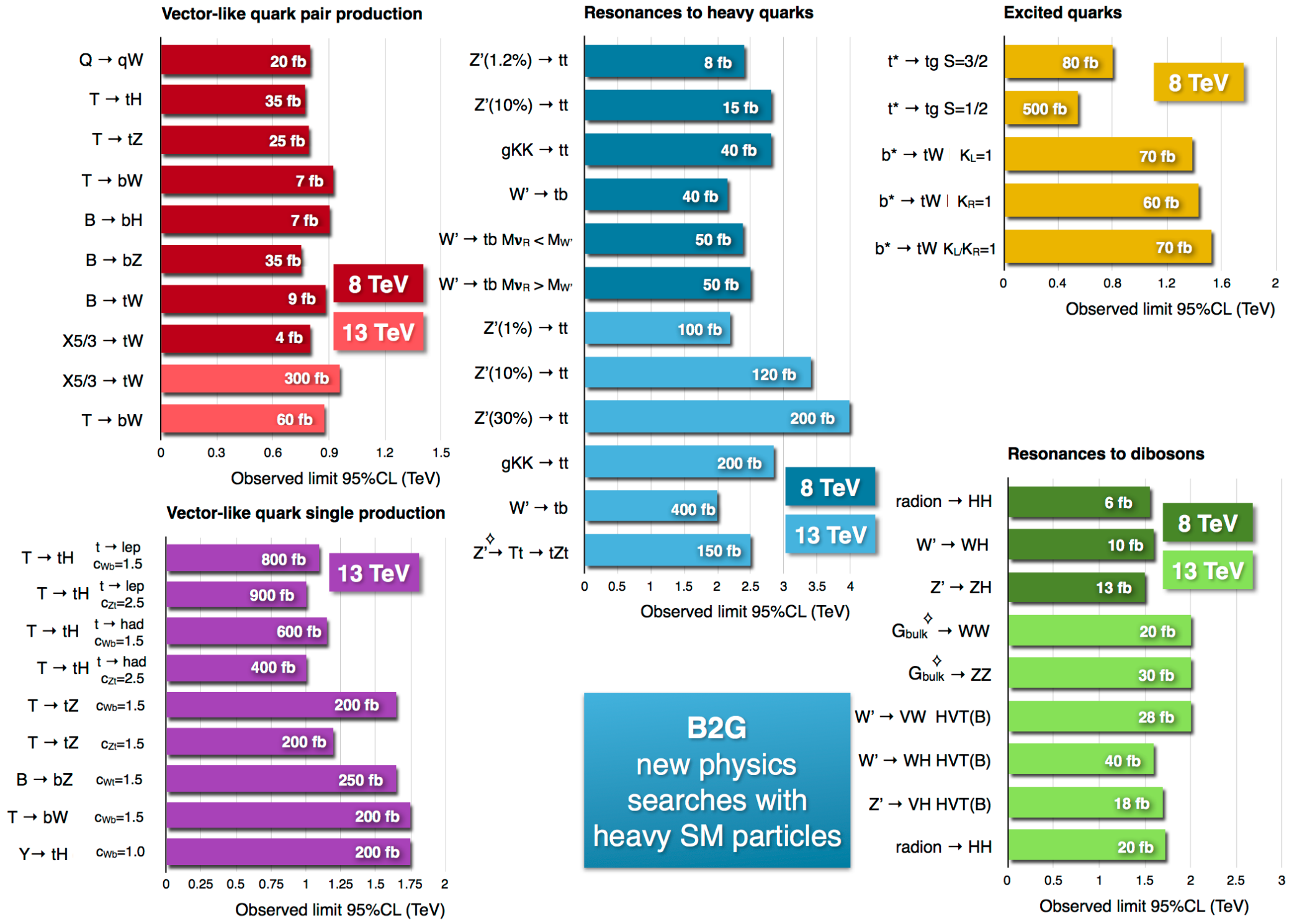
Search for W' in single top



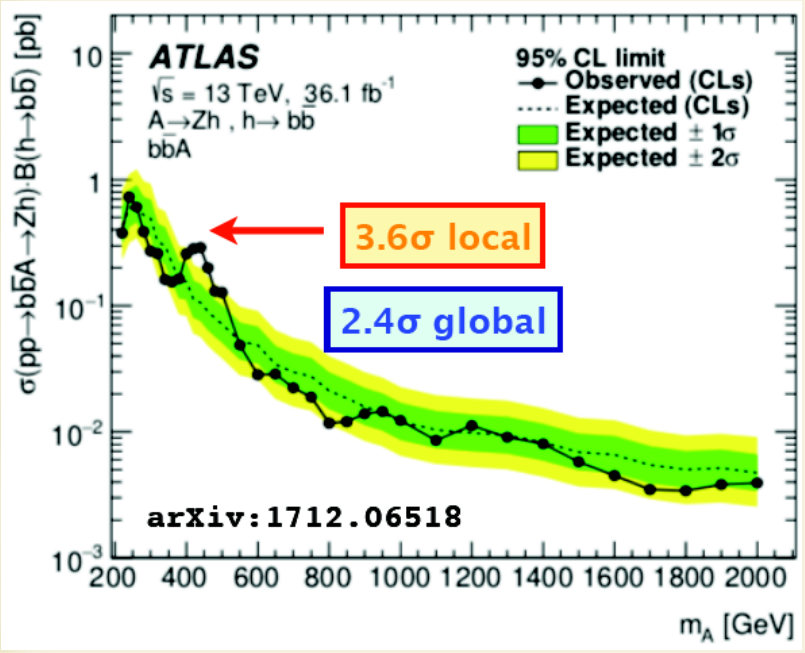


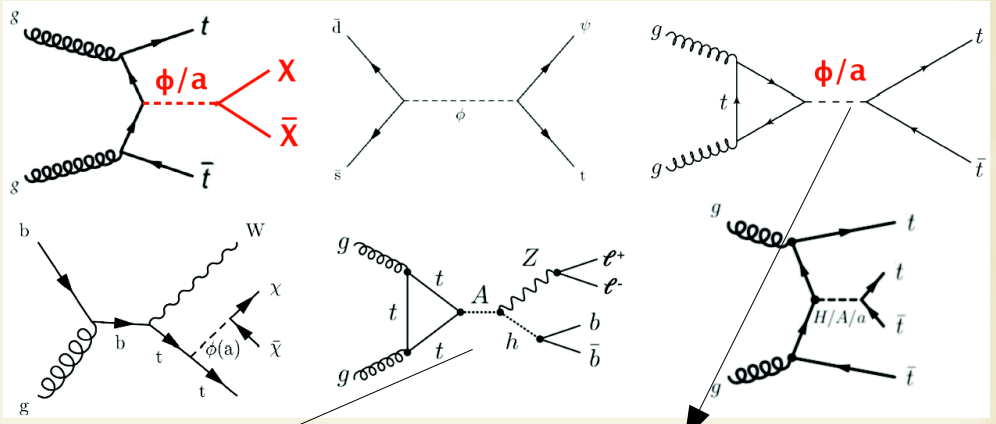


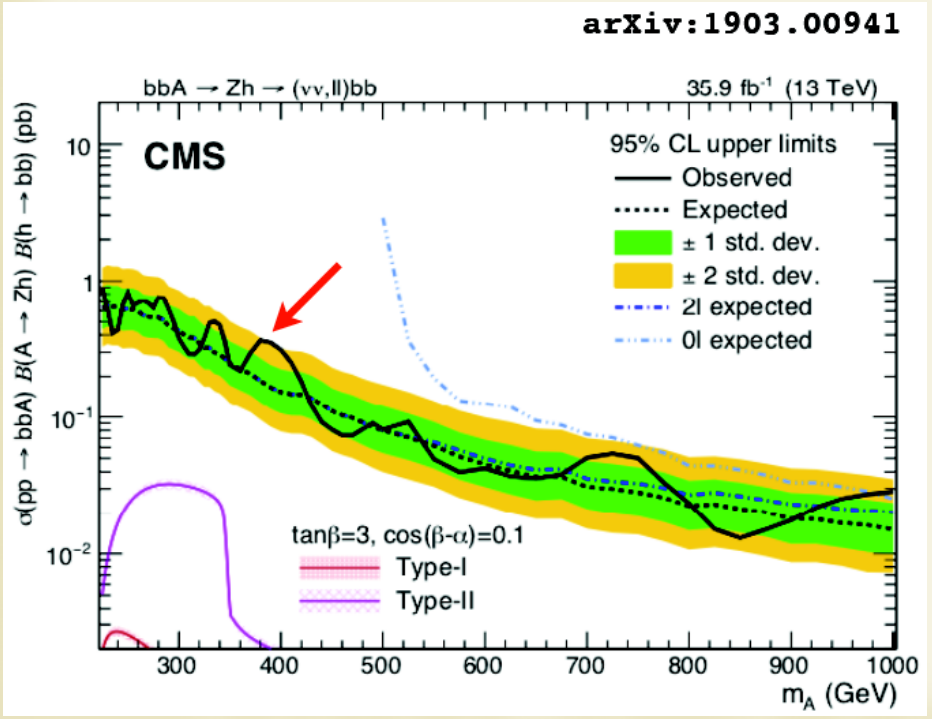


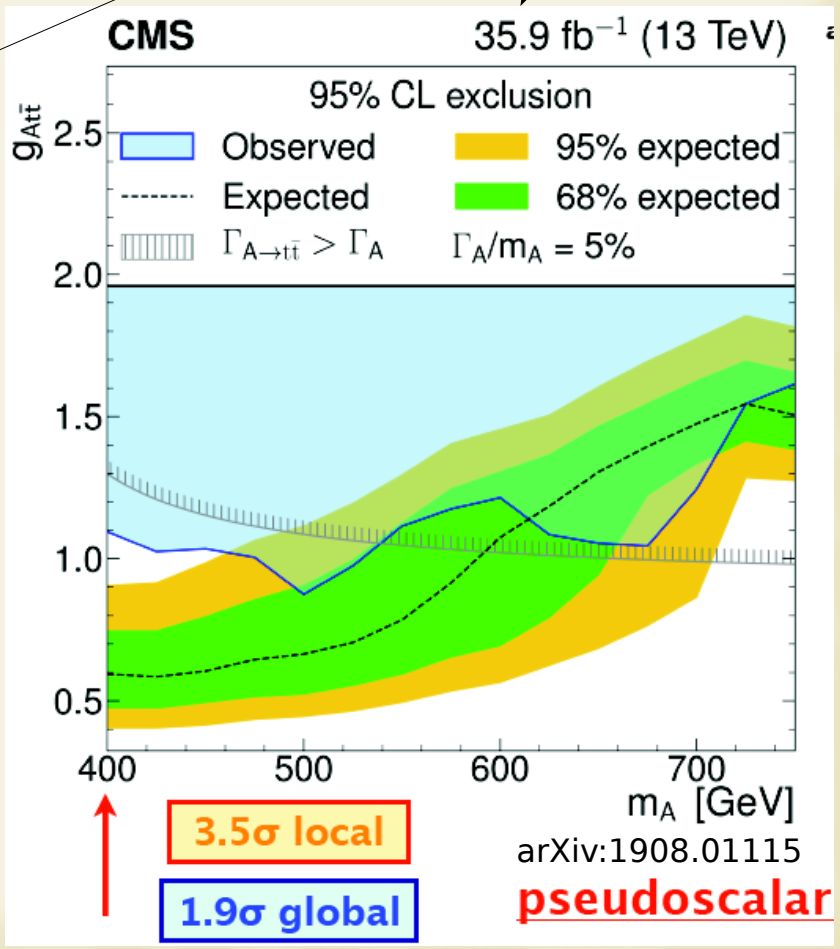

Vector-like quark pair production
Q → qW 20 fb
T → tH 35 fb
T → tZ 25 fb
T → bW 7 fb
B → bH 7 fb
B → bZ 35 fb
B → tW 9 fb
X5/3 → tW 4 fb
X5/3 → tW 300 fb
T → bW 60 fb
8 TeV
13 TeV
0 0.3 0.6 0.9 1.2 1.5
Observed limit 95%CL (TeV)
Resonances to heavy quarks
Z'(1.2%) → tt 8 fb
Z'(10%) → tt 15 fb
gKK → tt 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





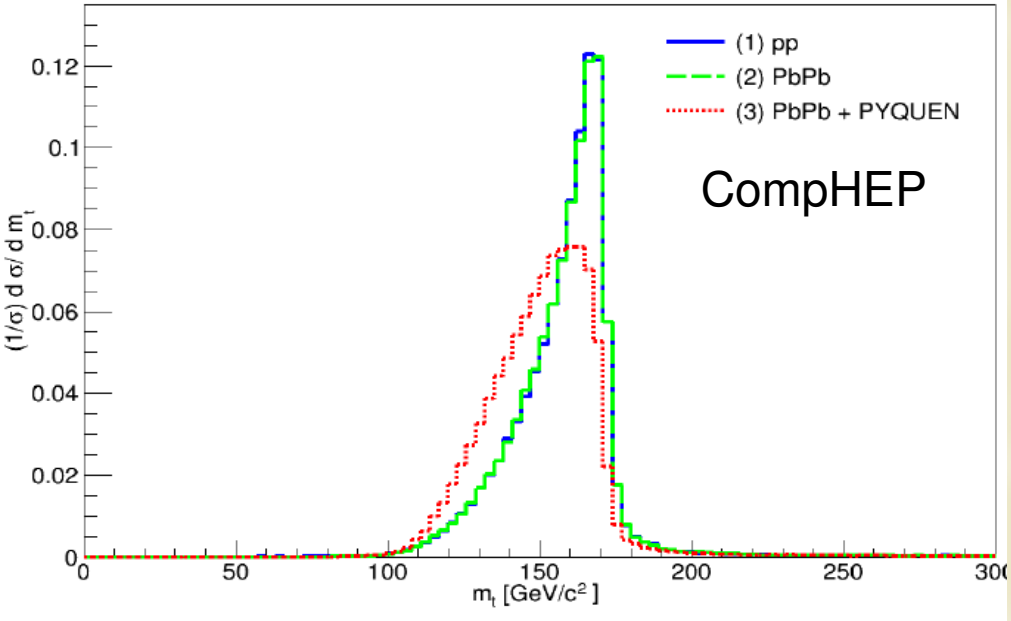




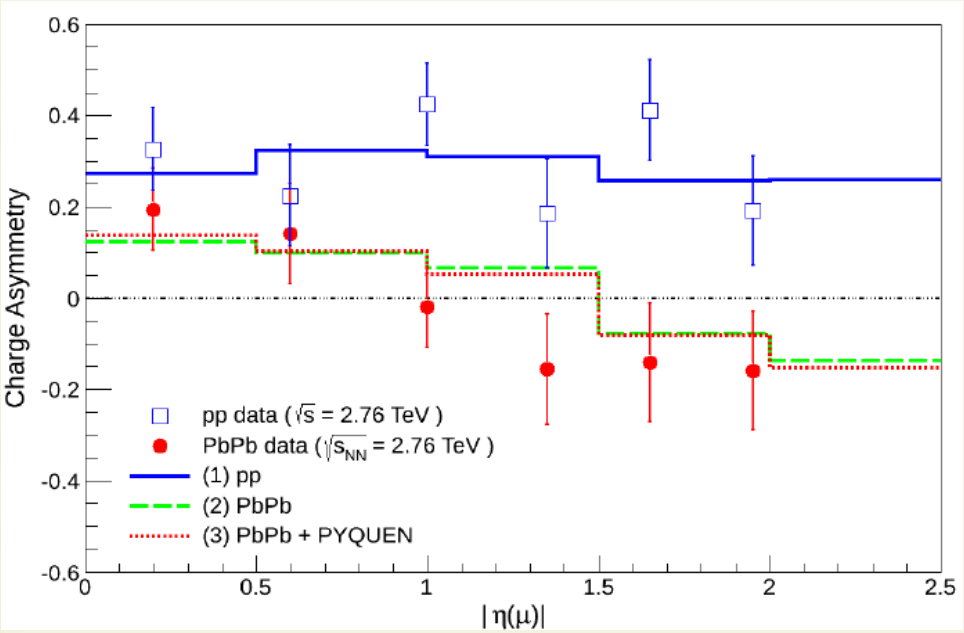
Single Top in Heavy Ion Collisions

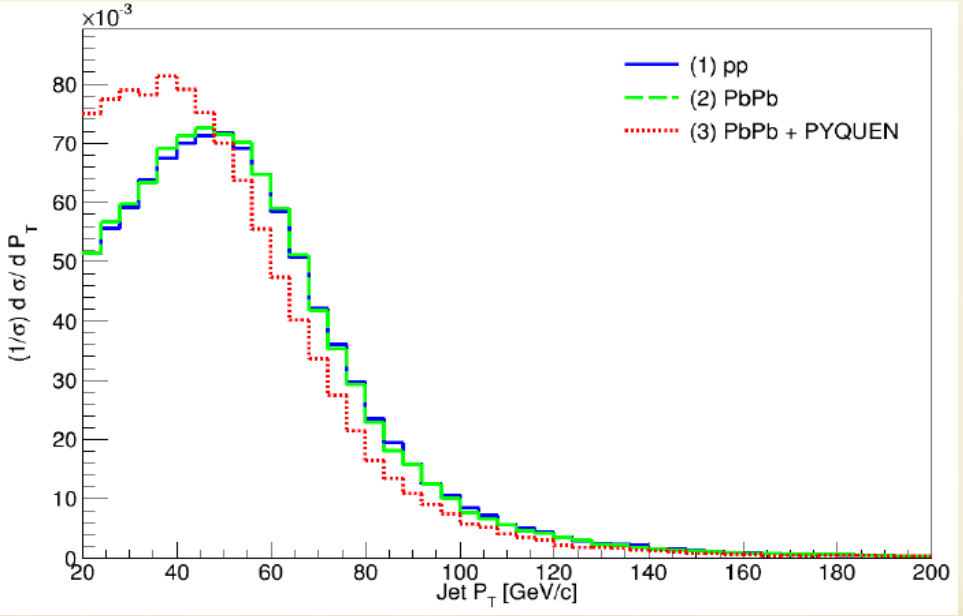
	EPS09	PYQUEN
(1) pp	-	-
(2) PbPb	+	-
(3) PbPb + PYQUEN	+	+

Single top simulation:



Test of MC simulation (W+/W- production)





A. Baskakov, E. Boos, L. Dudko,
I. Lokhtin, A. Snigirev
Phys.Rev. C92 (2015) no.4, 044901

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

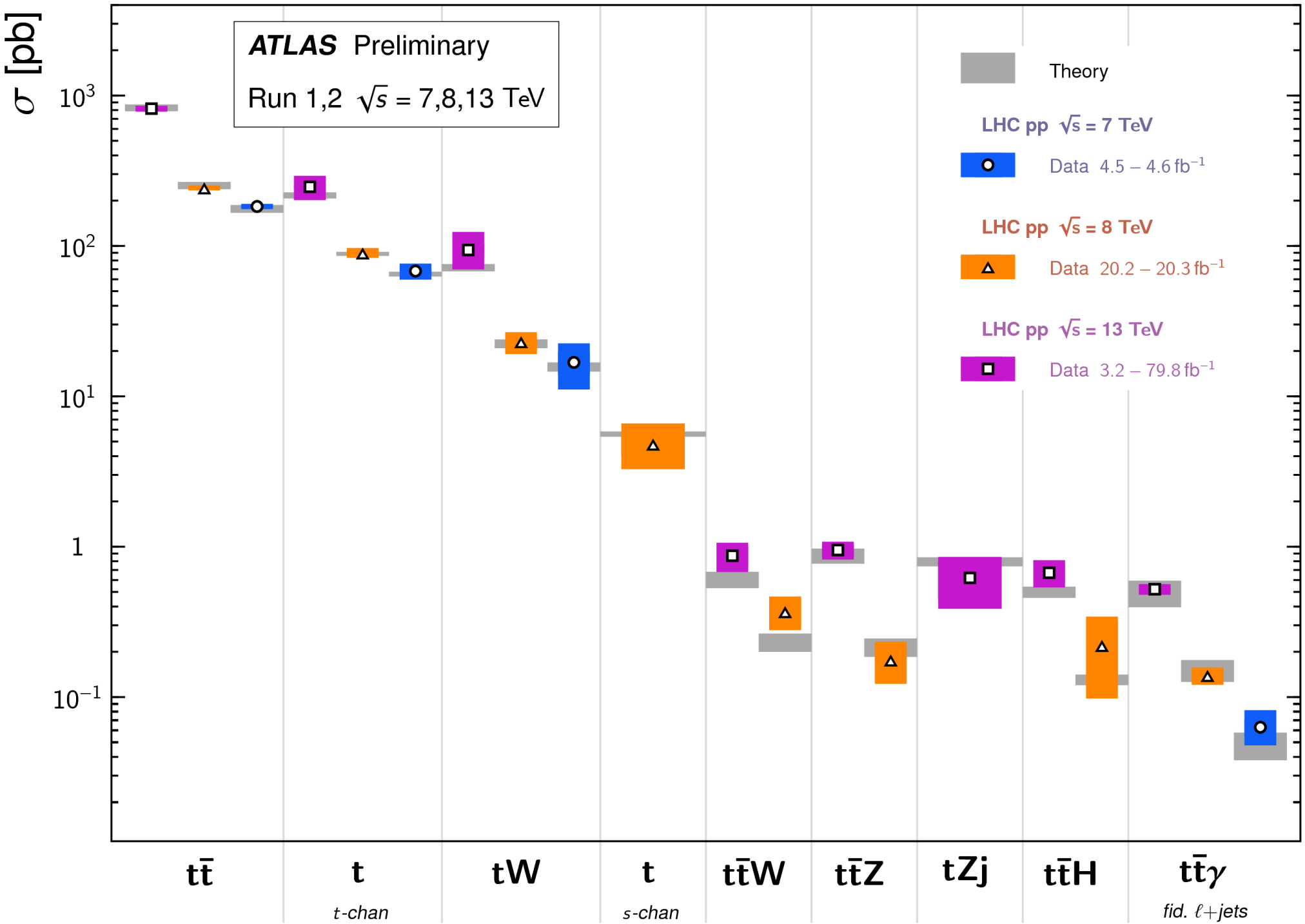
  - additional charged vector or scalar bosons

  - 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

Back Up Slides

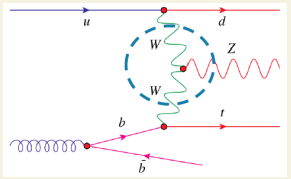
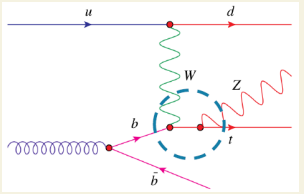
Top Quark Production Cross Section Measurements

Status: November 2018



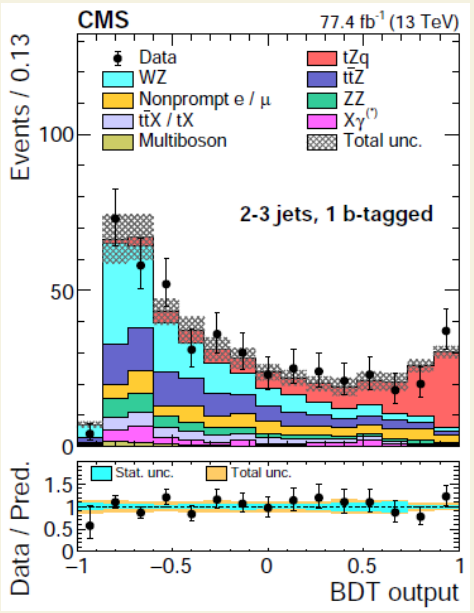
Recent measurements of rare top quark processes

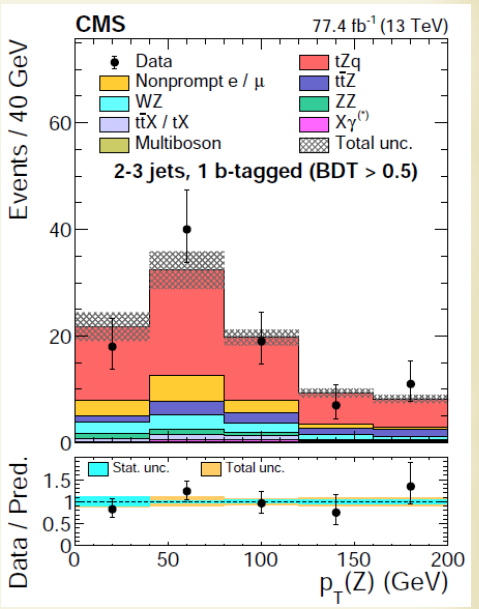
- First observation of tZq (8.2σ) [PRL 122 (2019) 132003]

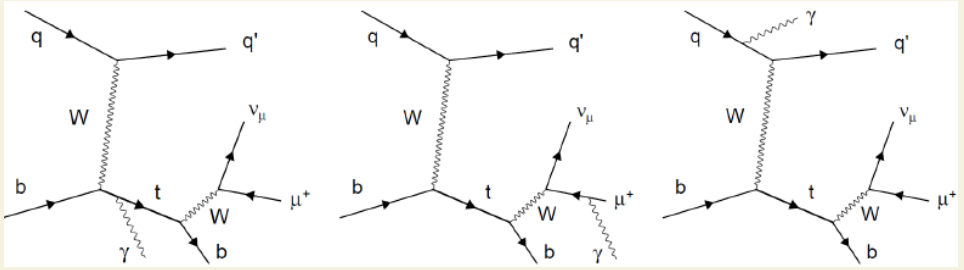
$\sigma(pp \to tZq \to t\ell^+\ell^- q) = 111 \pm 13\ (stat)\ ^{+11}_{-9}\ (syst)$ fb

SM expectation 94.2±3.1 fb



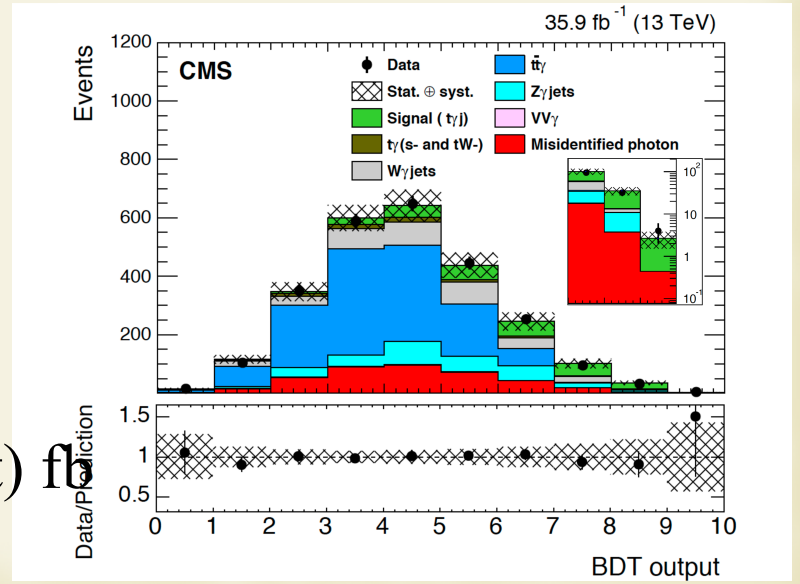


- First evidence of tγq (4.4σ)

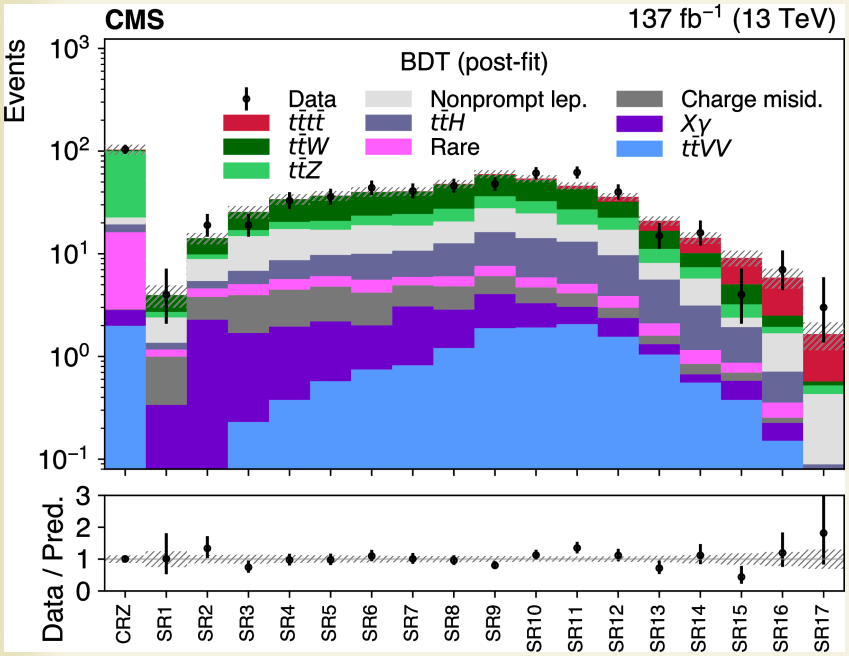


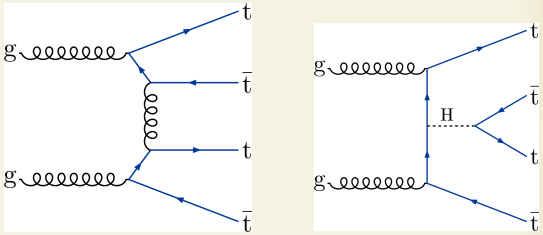
$\sigma(pp \to t\gamma j)B(t \to \mu\nu b) = 115 \pm 17\ (stat) \pm 30\ (syst)$ fb

SM expectation 81±4 fb

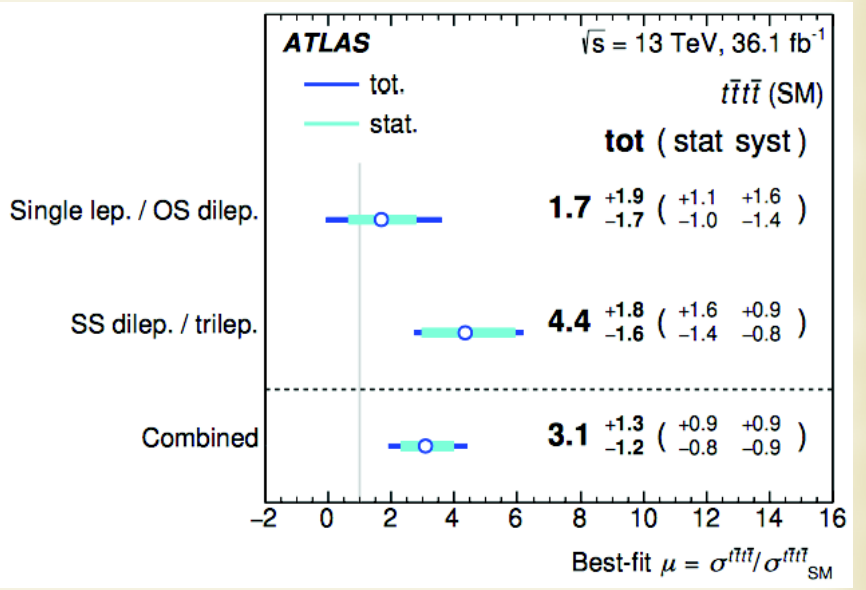


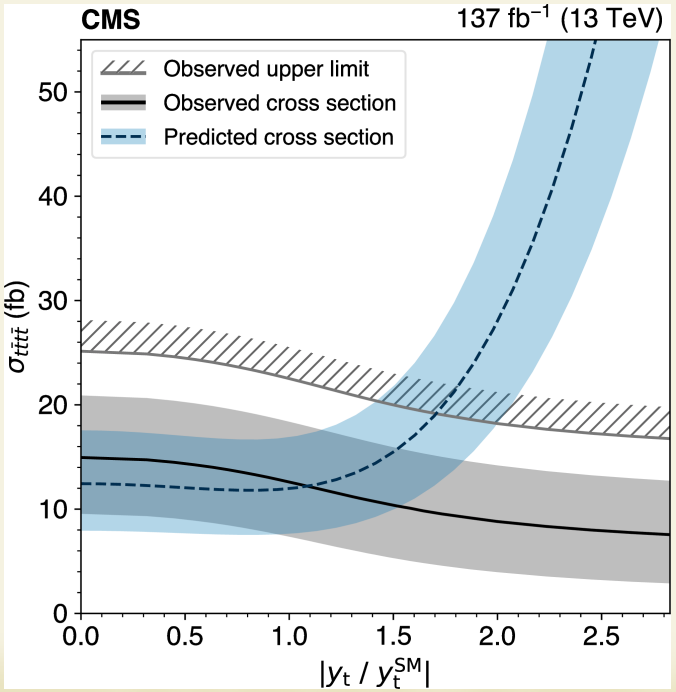
Four tops cs measurement and top-Yukawa coupling (y_t)





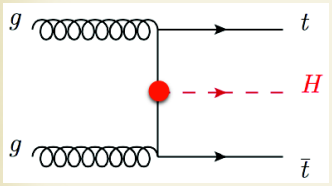
Final states:
single lepton and opposit-sign dilepton (1L/OS)
same-sign dilepton and multilepton (SS/ML)

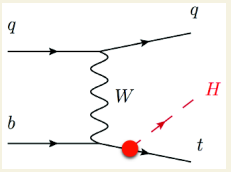


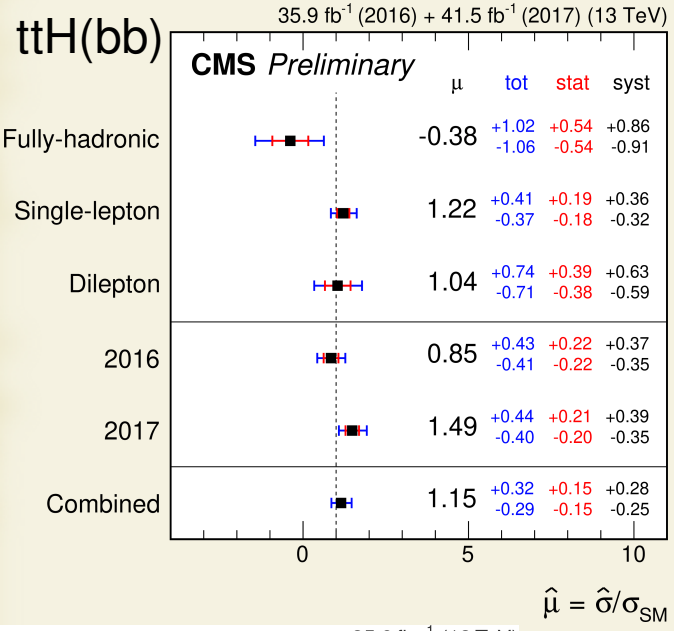


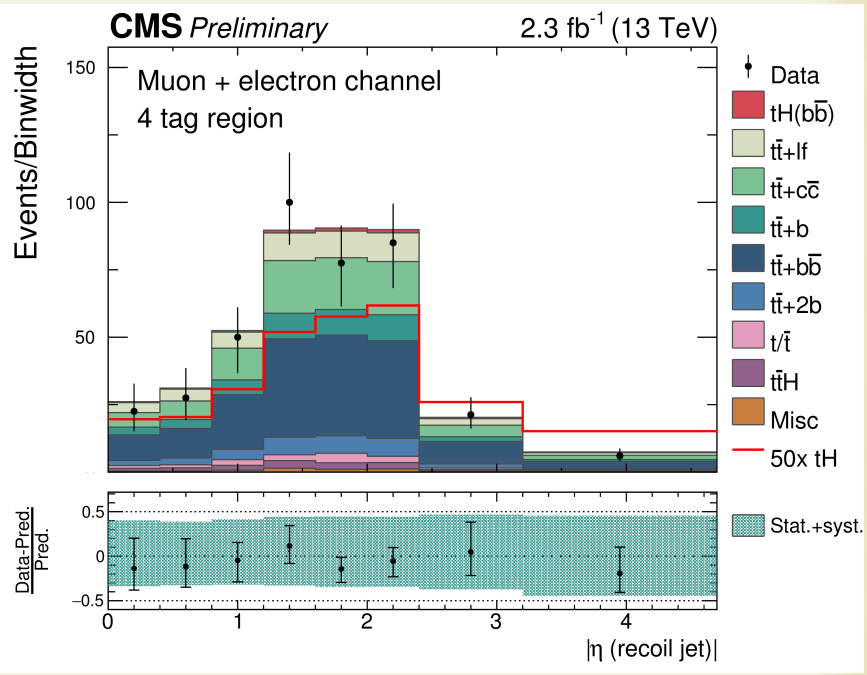
Significance obs. (exp.) [σ]	ATLAS 36 fb^{-1}	CMS 36 fb^{-1}	CMS 140 fb^{-1}
SS/ML	3.0 (0.8) [1]	1.6 (1.0) [3]	2.6 (2.7) [5]
1L/OS	1.0 (0.6) [2]	0.0 (0.4) [4]	-
Combintion	2.8 (1.0) [2]	1.4 (1.1) [4]	-

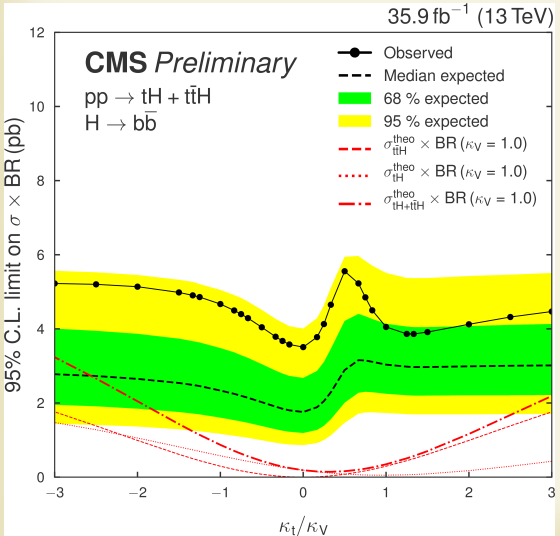
$t\bar{t}H$ and tHq measurements

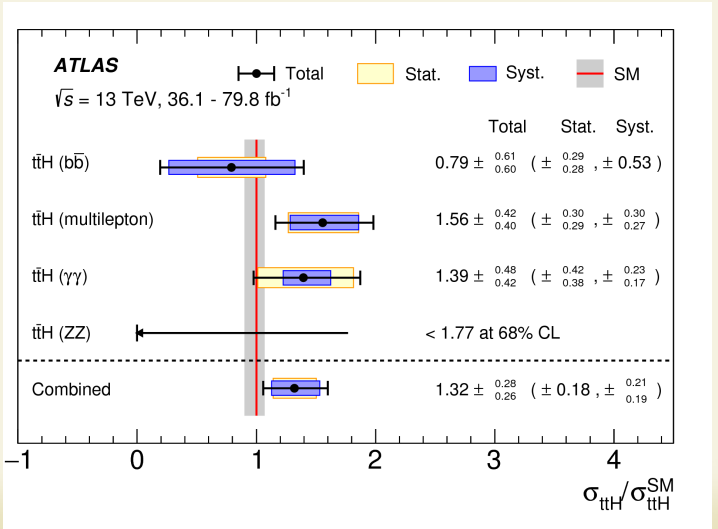


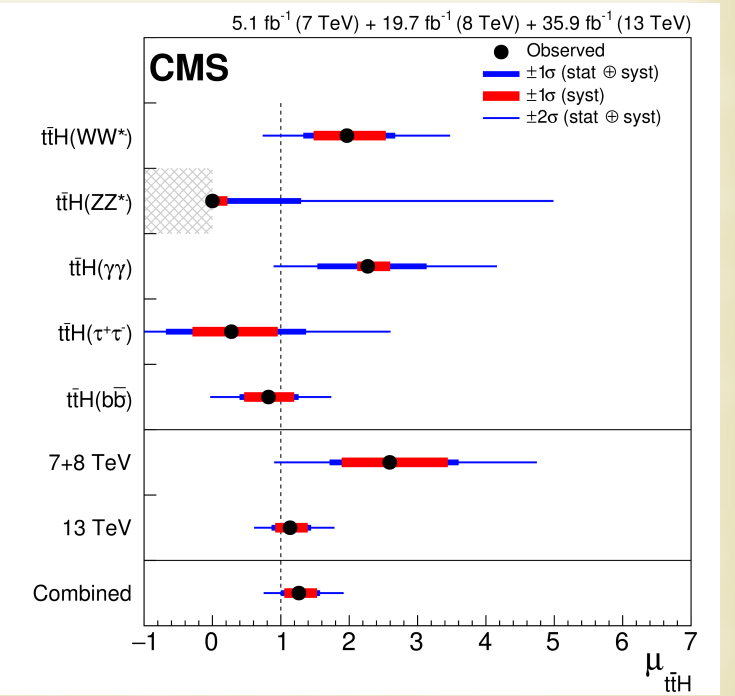






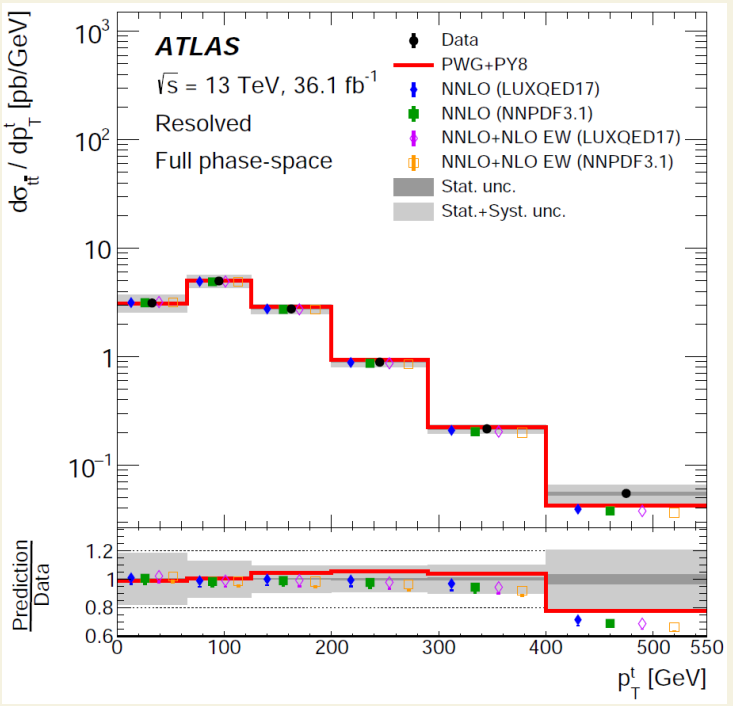


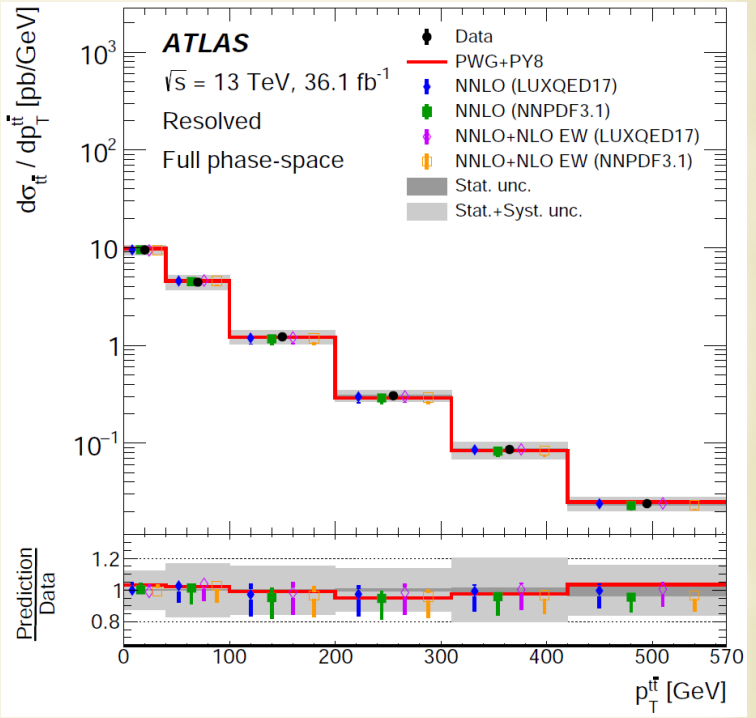


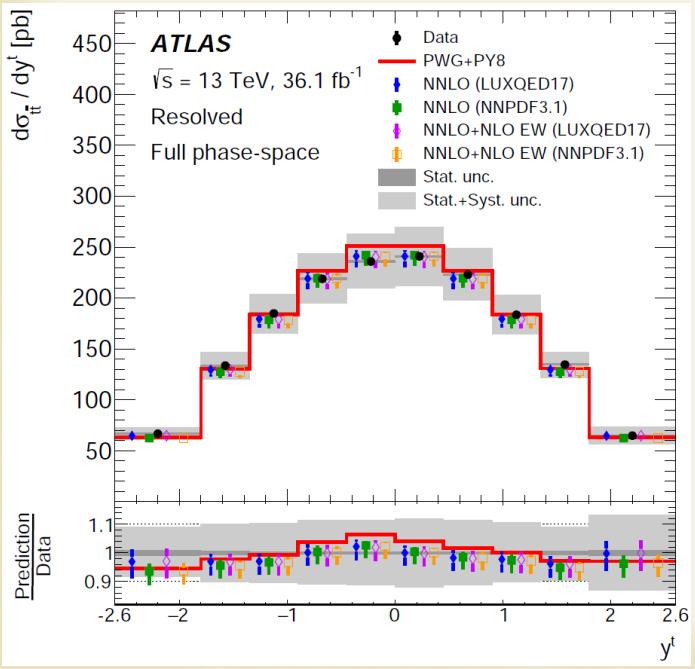


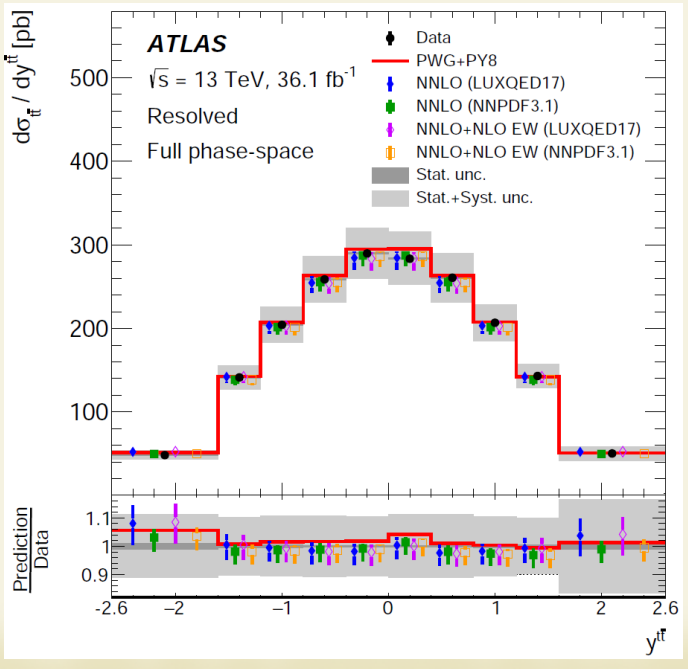
Differential $t\bar{t}$ cross sections

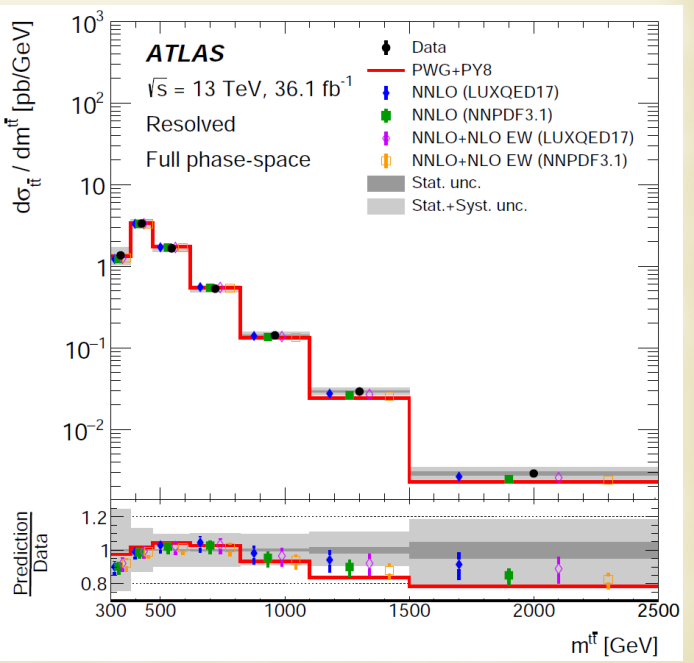
arXiv:1908.07305





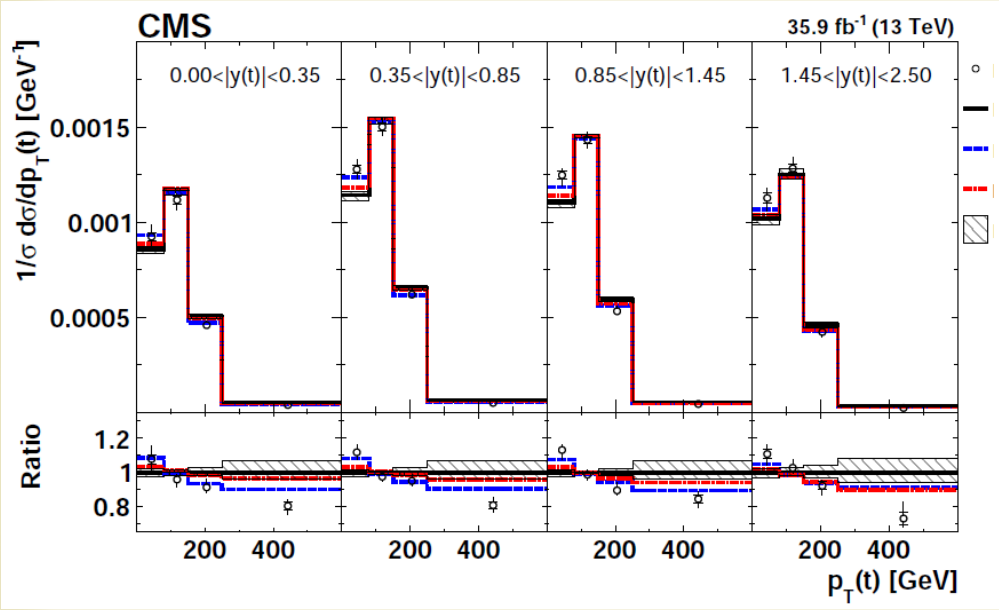


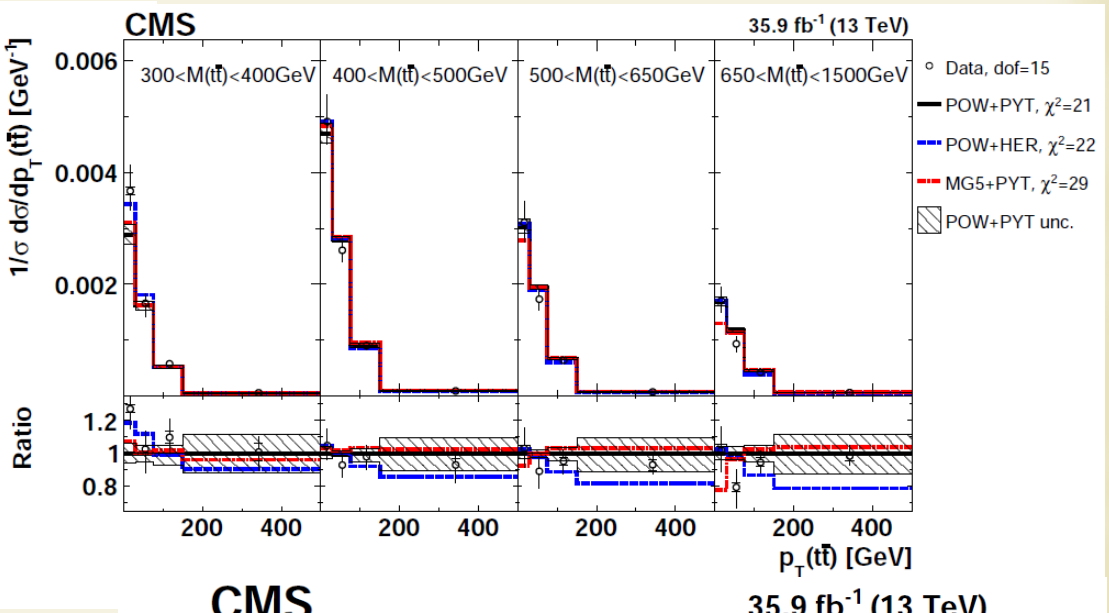


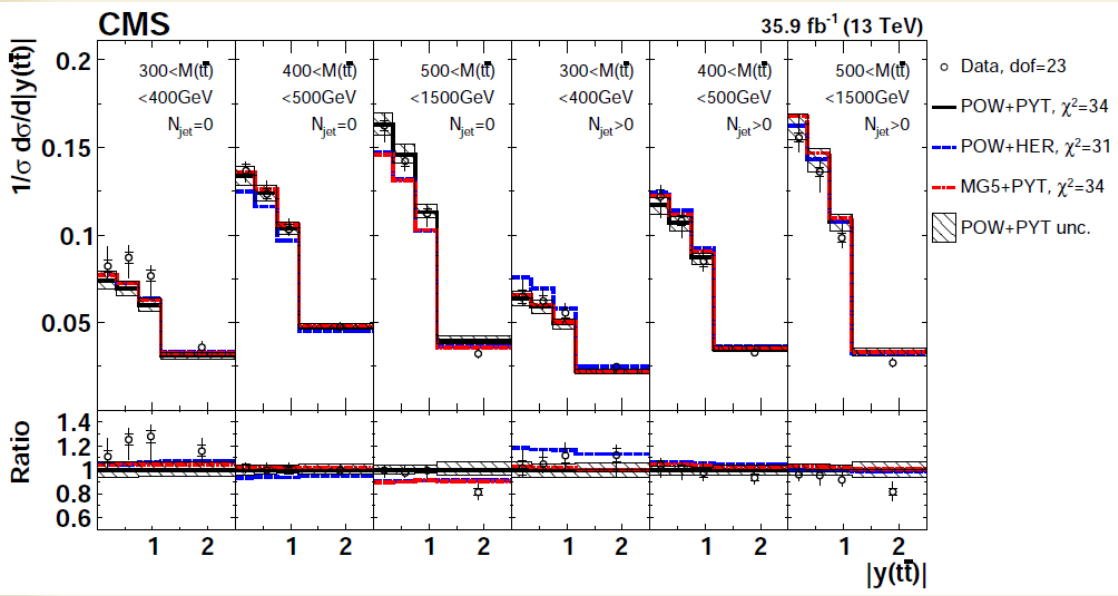


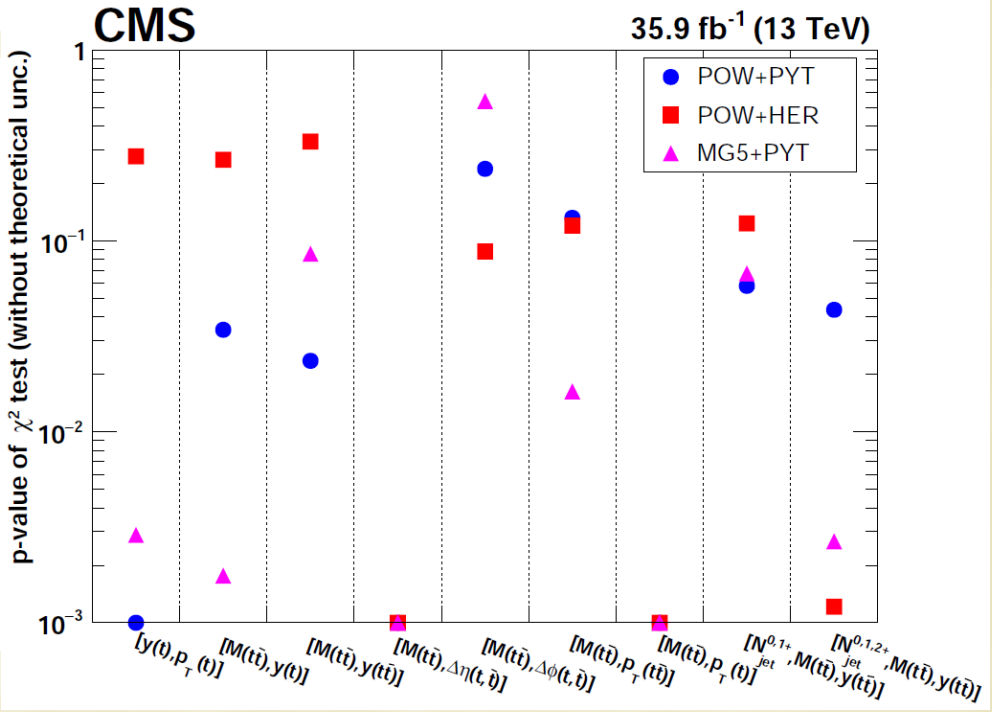
Double differential $t\bar{t}$ cross section

arXiv:1904.05237



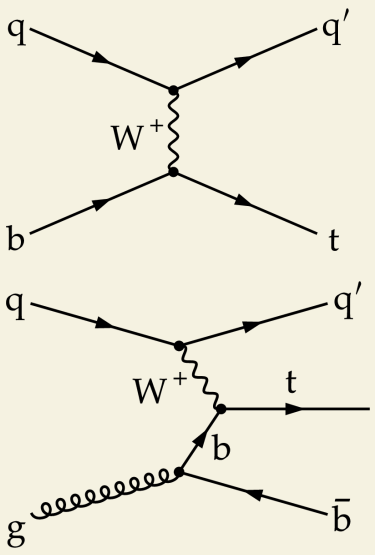


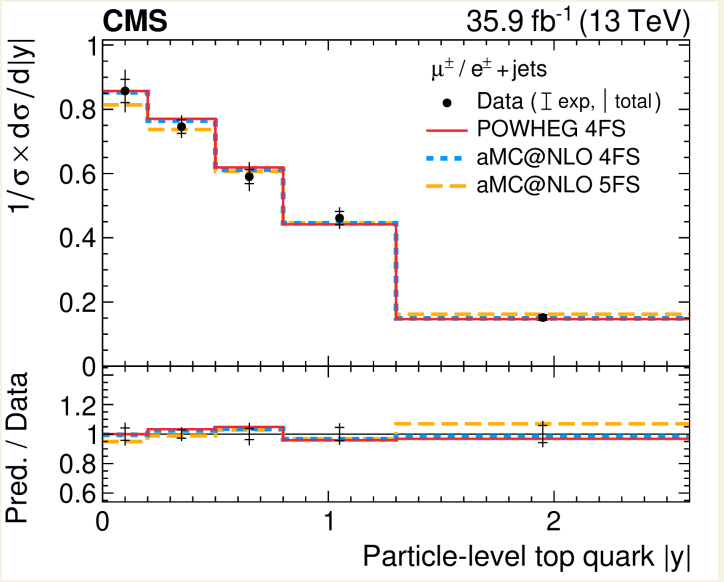


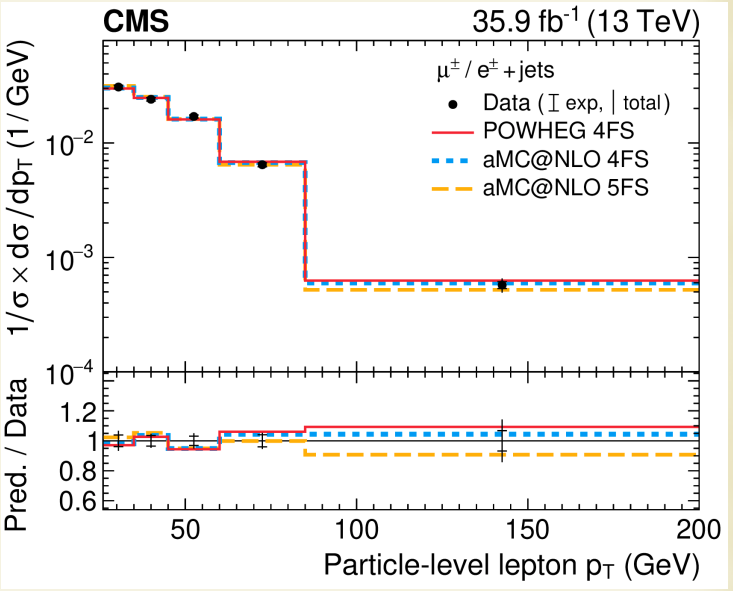


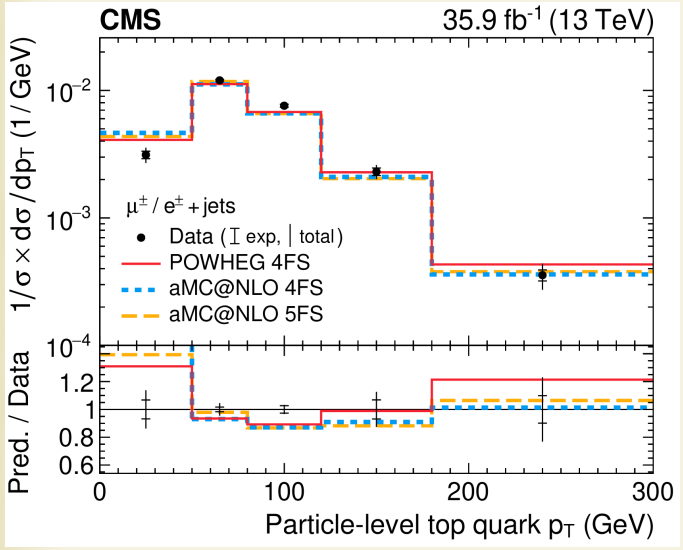
Differential single top t-channel cross section

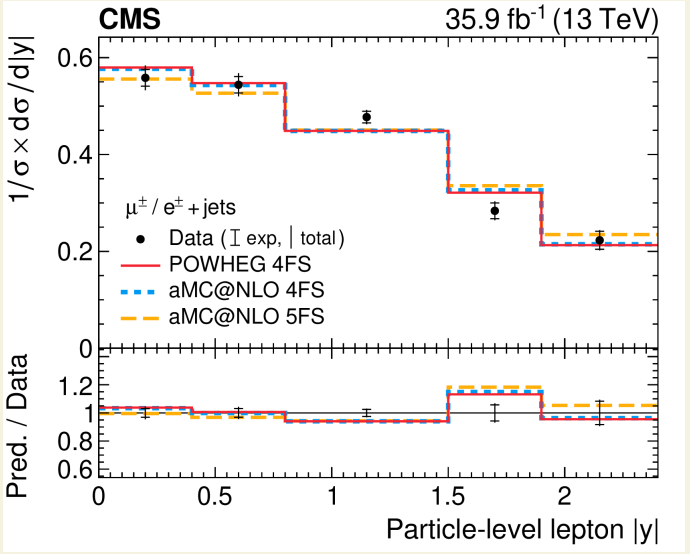
arXiv:1907.08330

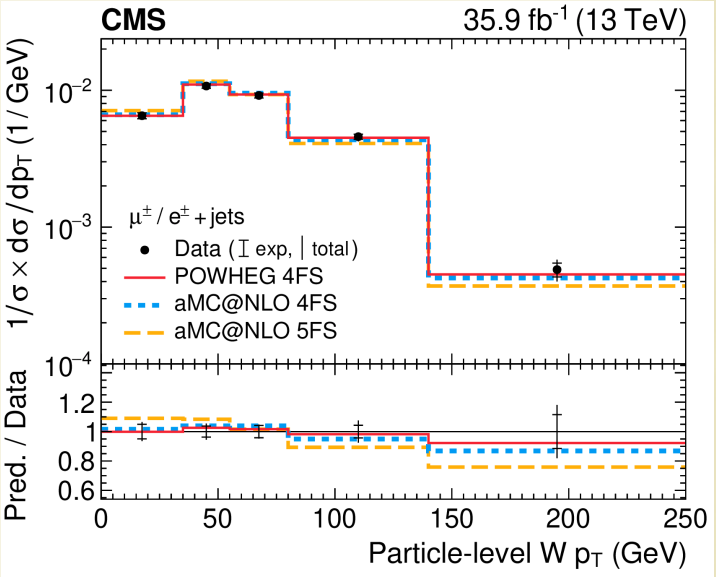






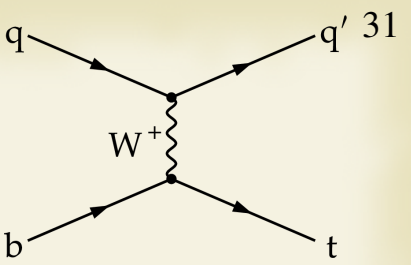






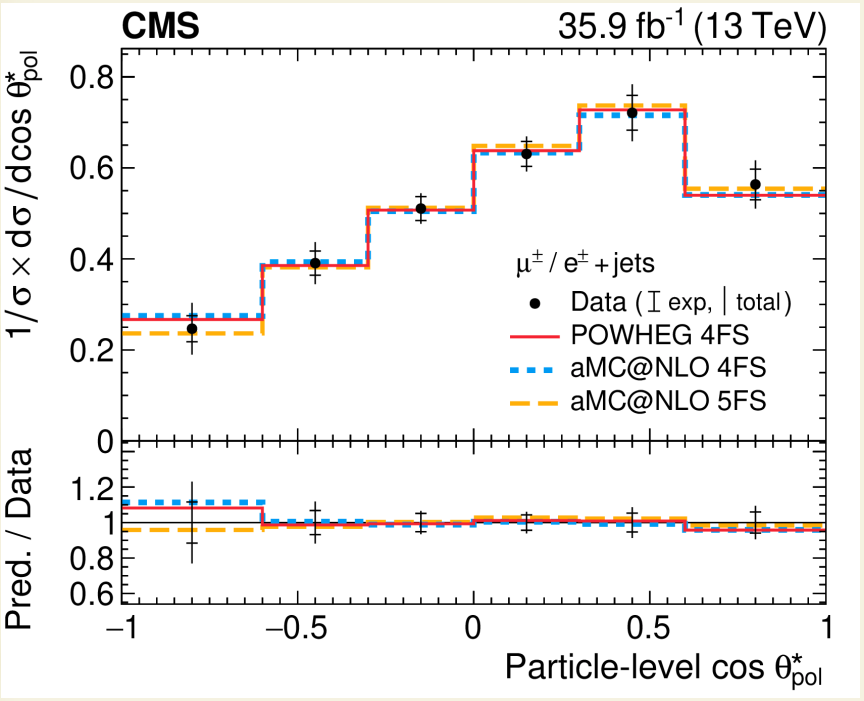
Differential single top t-channel cross section, polarisation, charge ratio

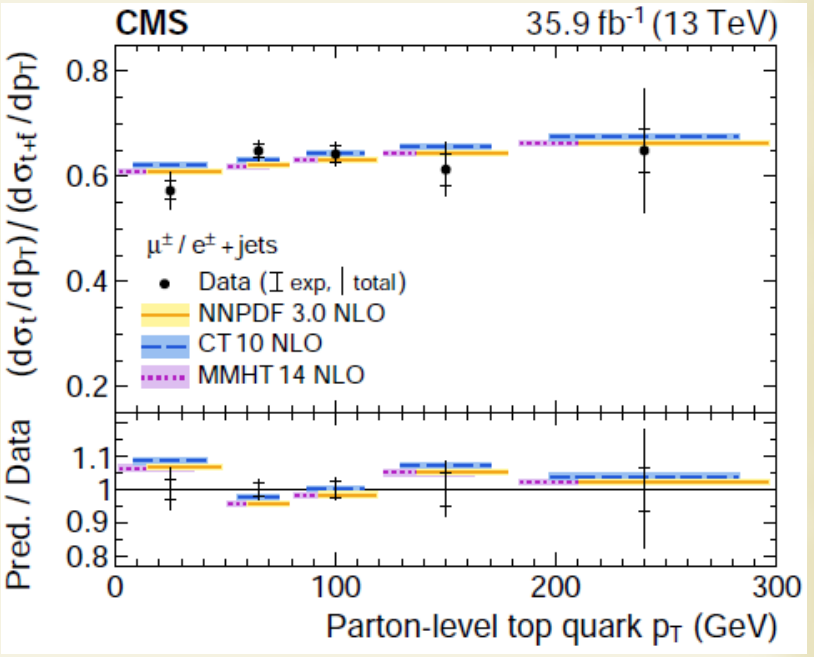
arXiv:1907.08330

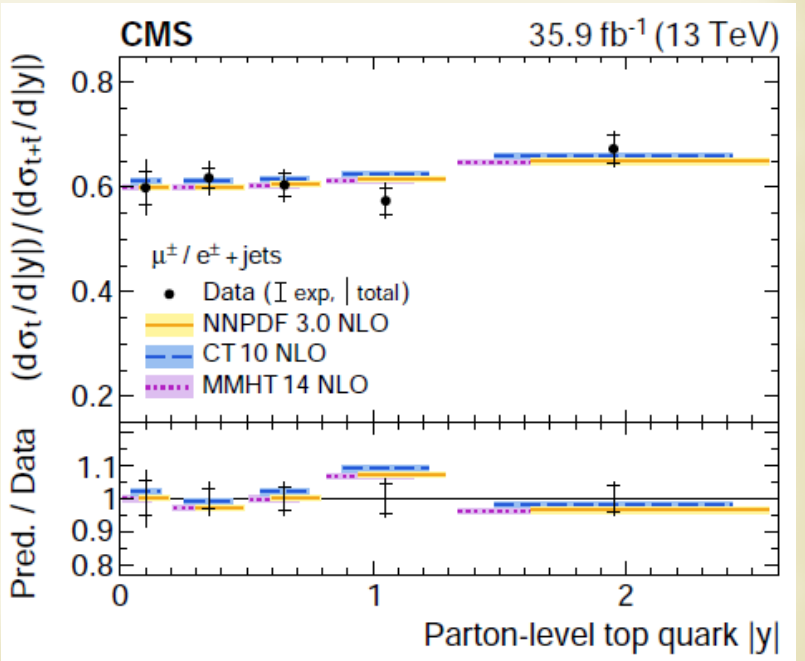


$$\cos\theta^*_{pol} = \frac{\vec{p}^{\,*}_{q'} \cdot \vec{p}^{\,*}_{\ell}}{|\vec{p}^{\,*}_{q'}||\vec{p}^{\,*}_{\ell}|}$$

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





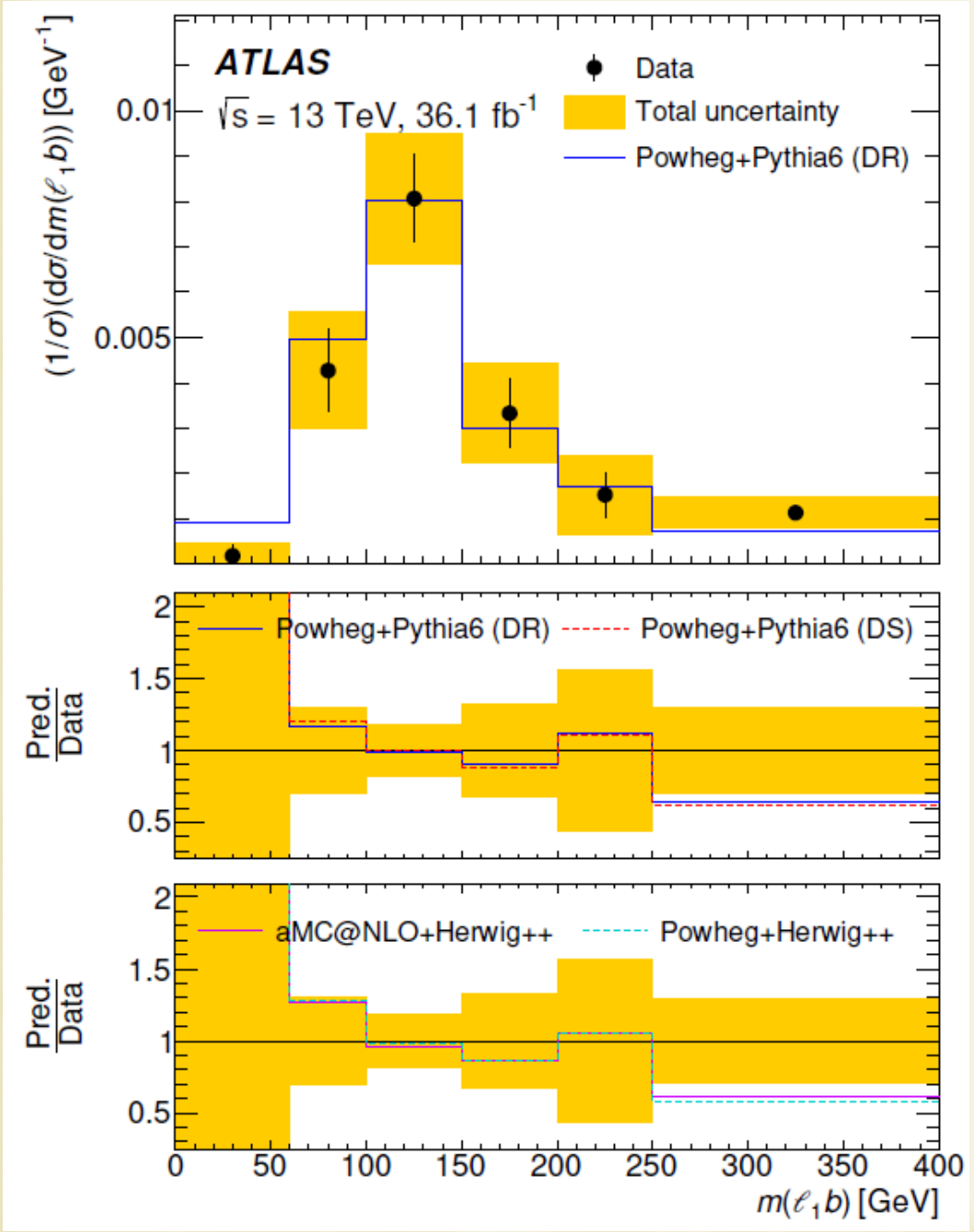


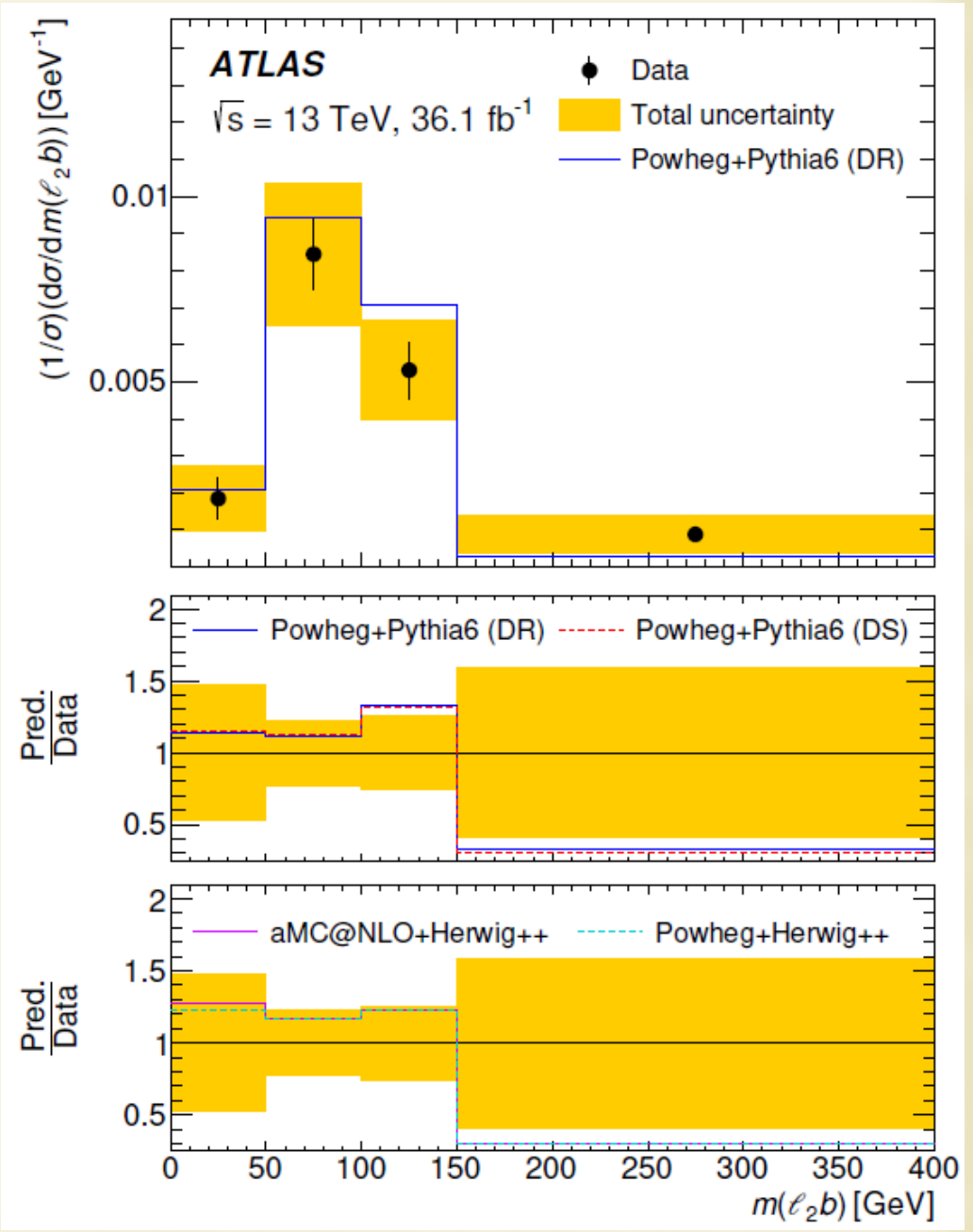
$A_{\mu+e} = 0.439 \pm 0.062$

(Powheg NLO 0.436)

Differential single top tW-channel cross section

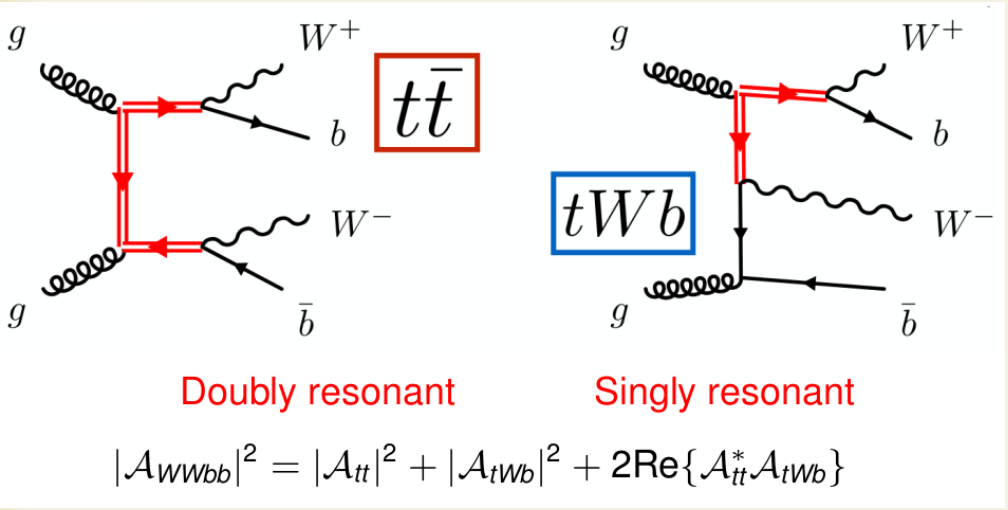
EPJC 78 (2018) 186





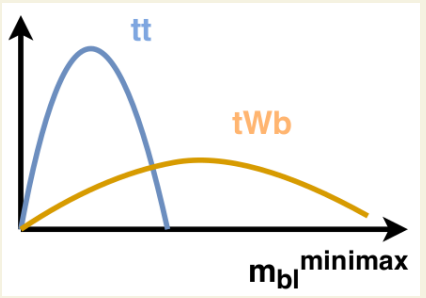
First measurement of differential tW-$t\bar{t}$ cross section

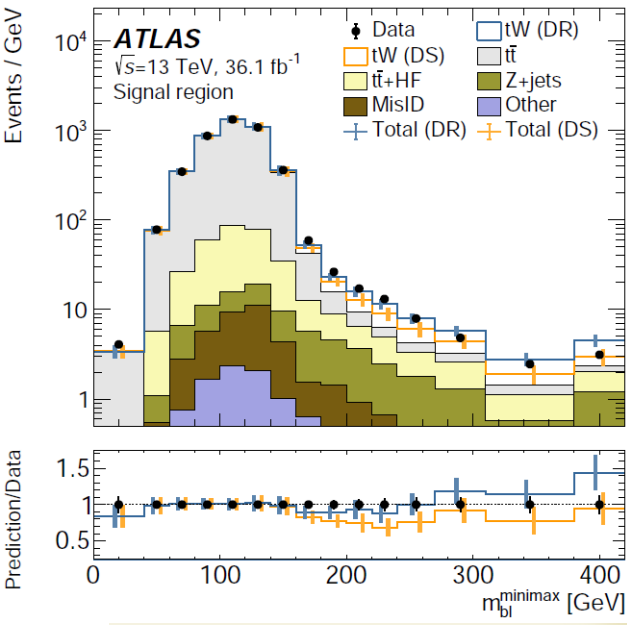
PRL 121 (2018) 152002

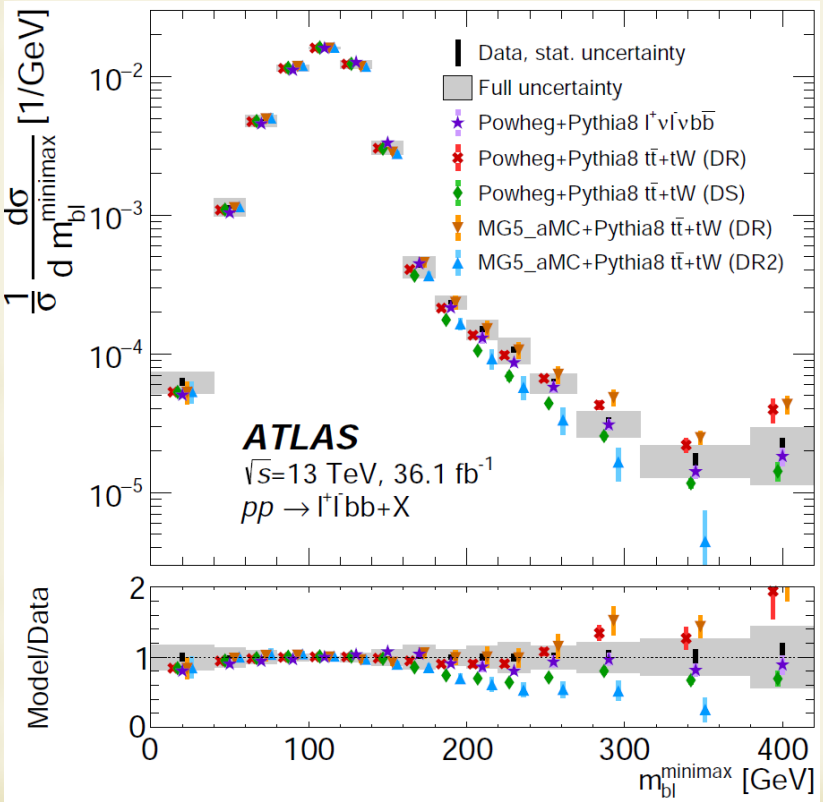


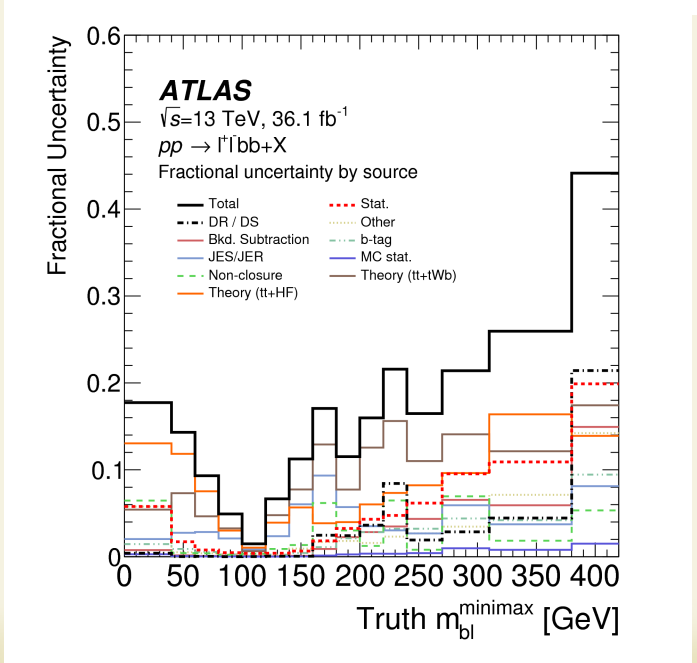
$$|\mathcal{A}_{WWbb}|^2 = |\mathcal{A}_{tt}|^2 + |\mathcal{A}_{tWb}|^2 + 2\mathrm{Re}\{\mathcal{A}_{tt}^{*}\mathcal{A}_{tWb}\}$$

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



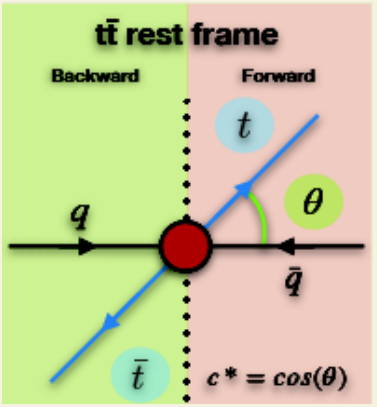






$t\bar{t}$ forward-backward asymmetry

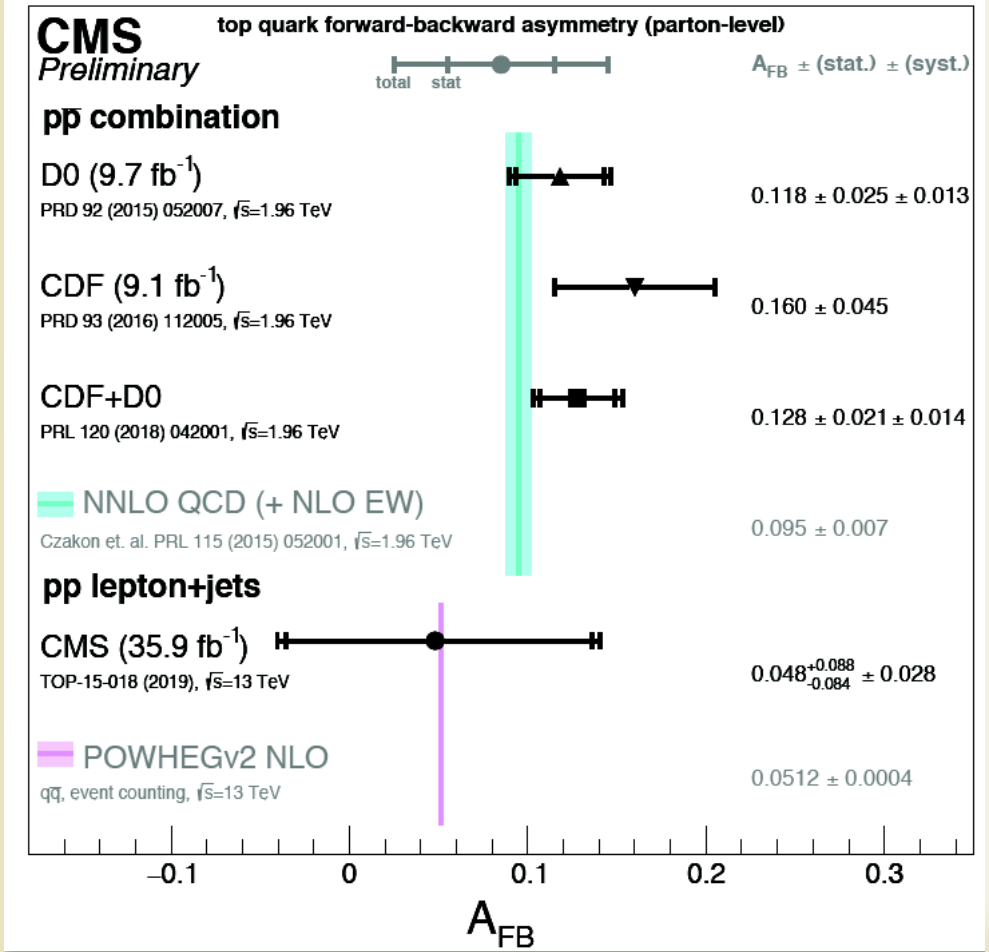
$$A_{FB} = \frac{\sigma(c^* > 0) - \sigma(c^* < 0)}{\sigma(c^* > 0) + \sigma(c^* < 0)}$$

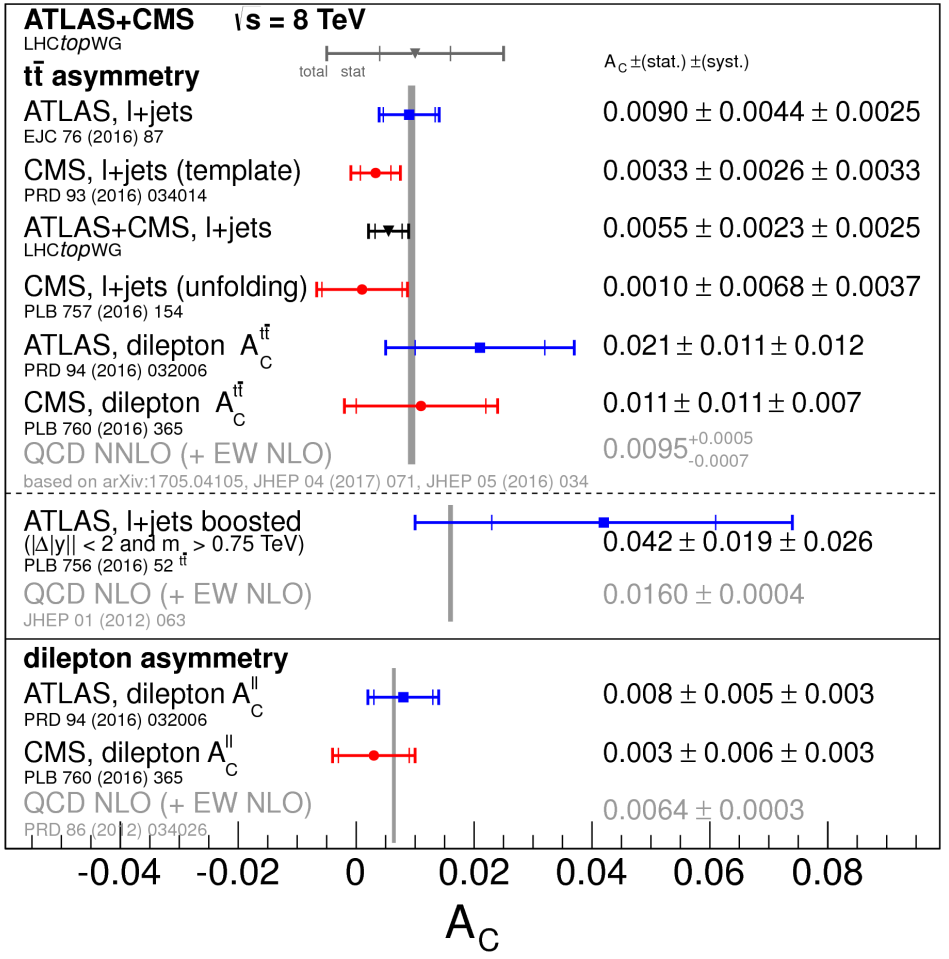


$$A_C = \frac{N^{\Delta|y|>0} - N^{\Delta|y|<0}}{N^{\Delta|y|>0} + N^{\Delta|y|<0}}$$

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

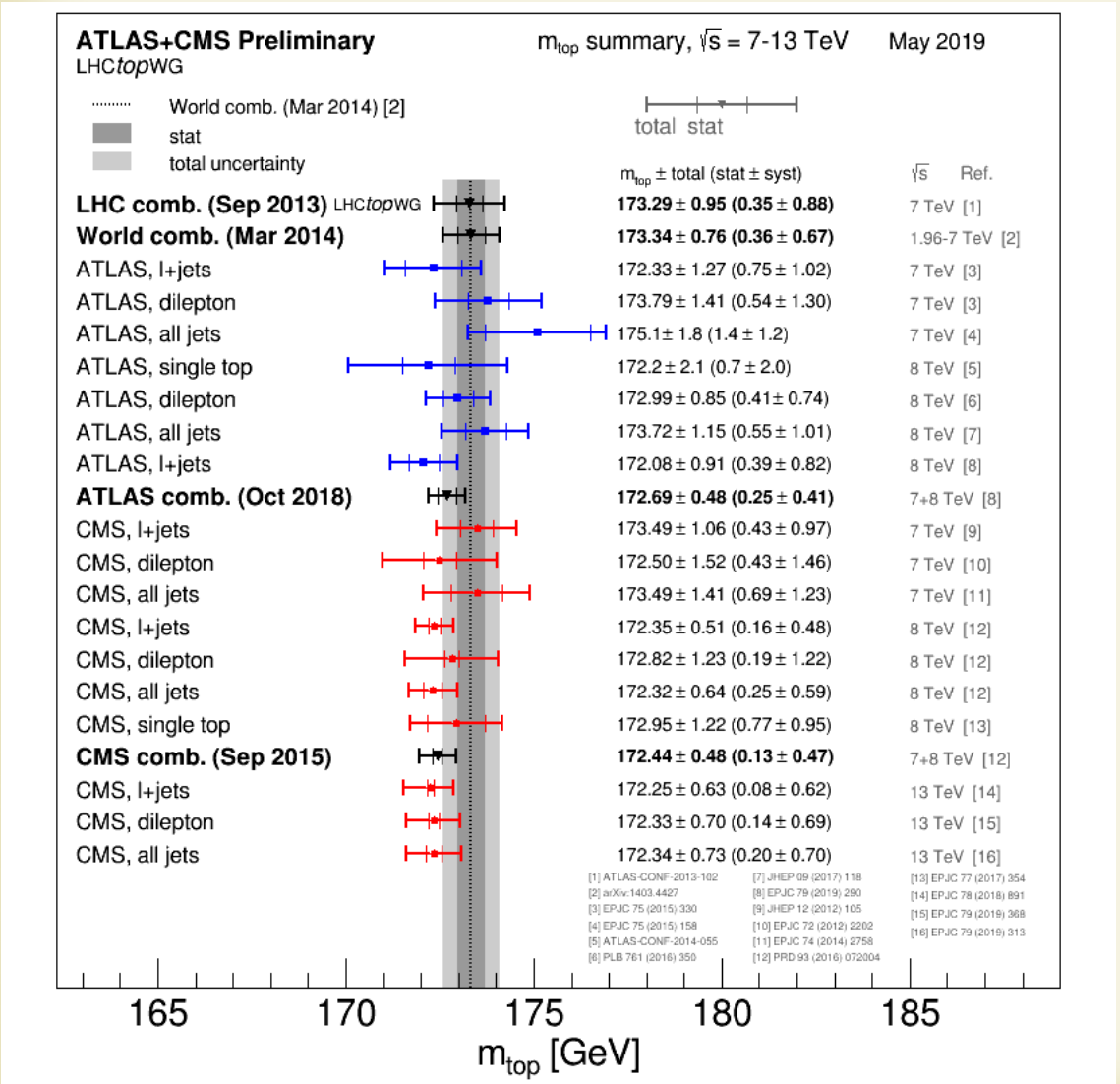
TOP2019





Direct and indirect measurements of the top quark mass

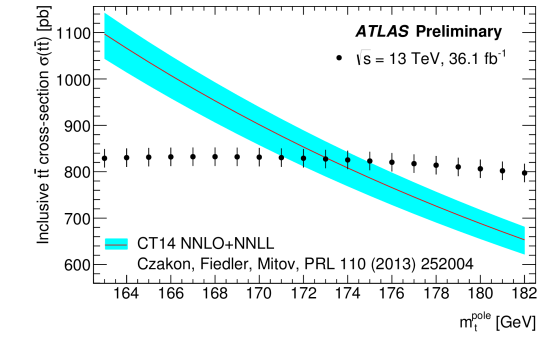
Precision <0.5 GeV (<0.3%)

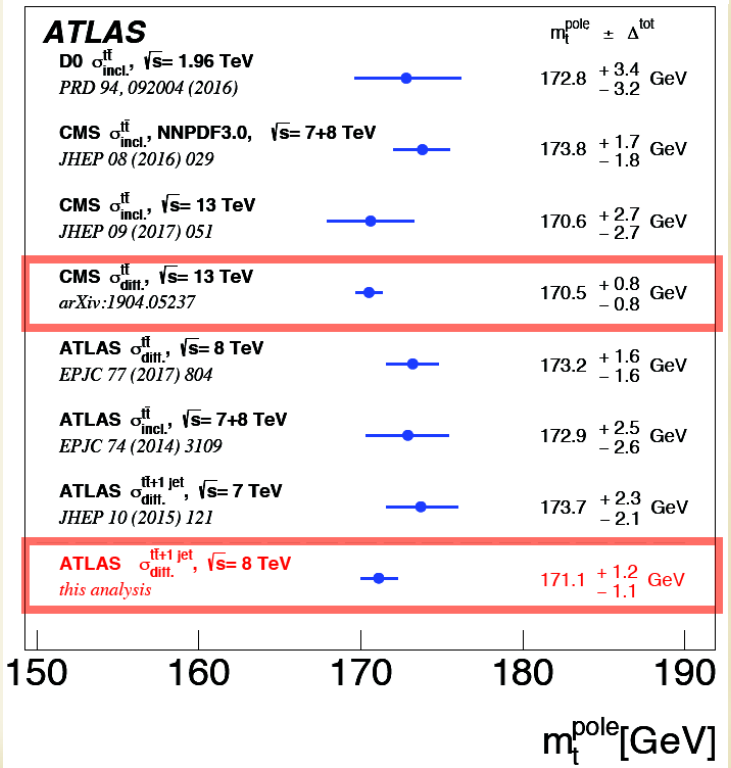


ATLAS-CONF-2019-041

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

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

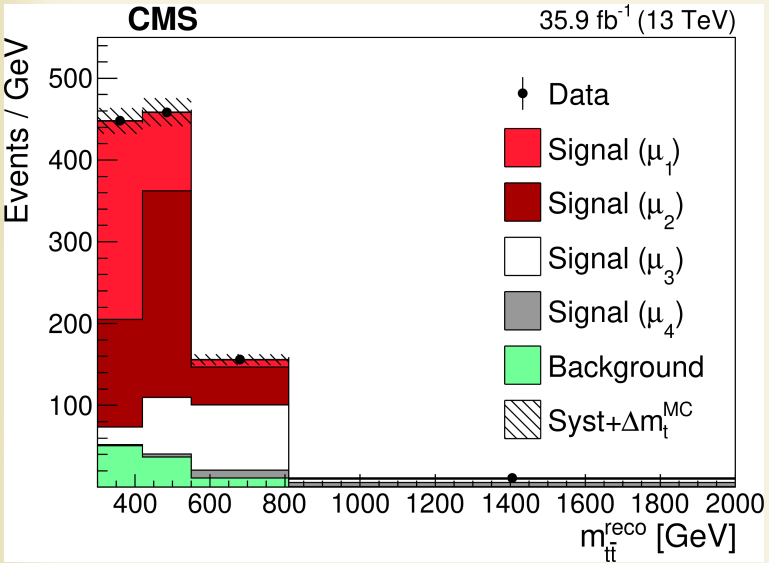




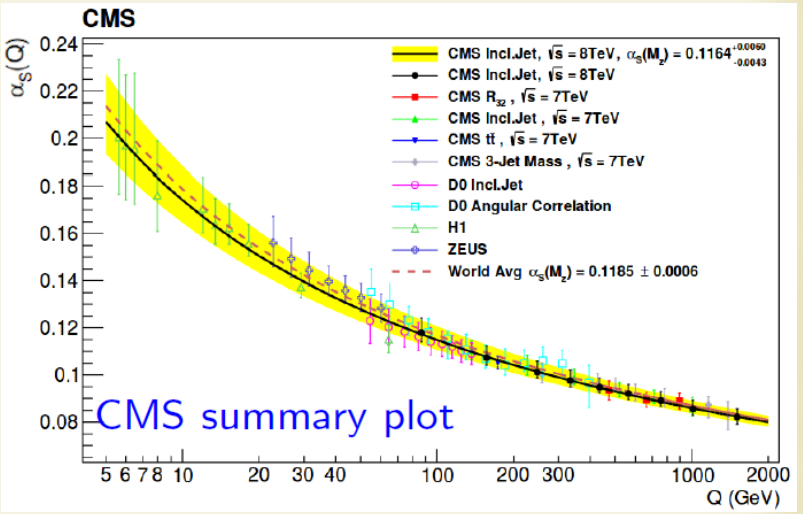
First measurement of the running top quark mass

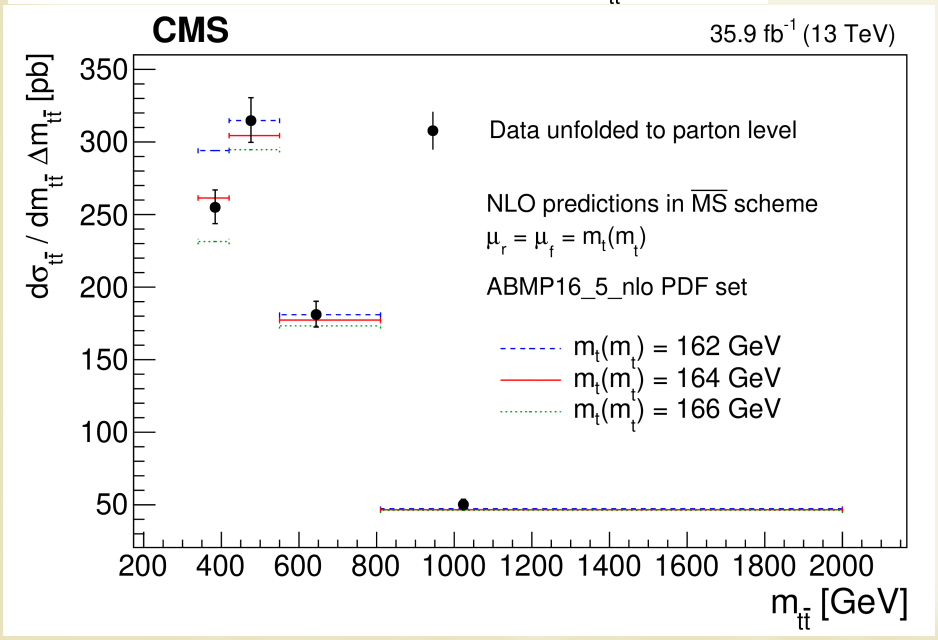
CMS-TOP-19-007

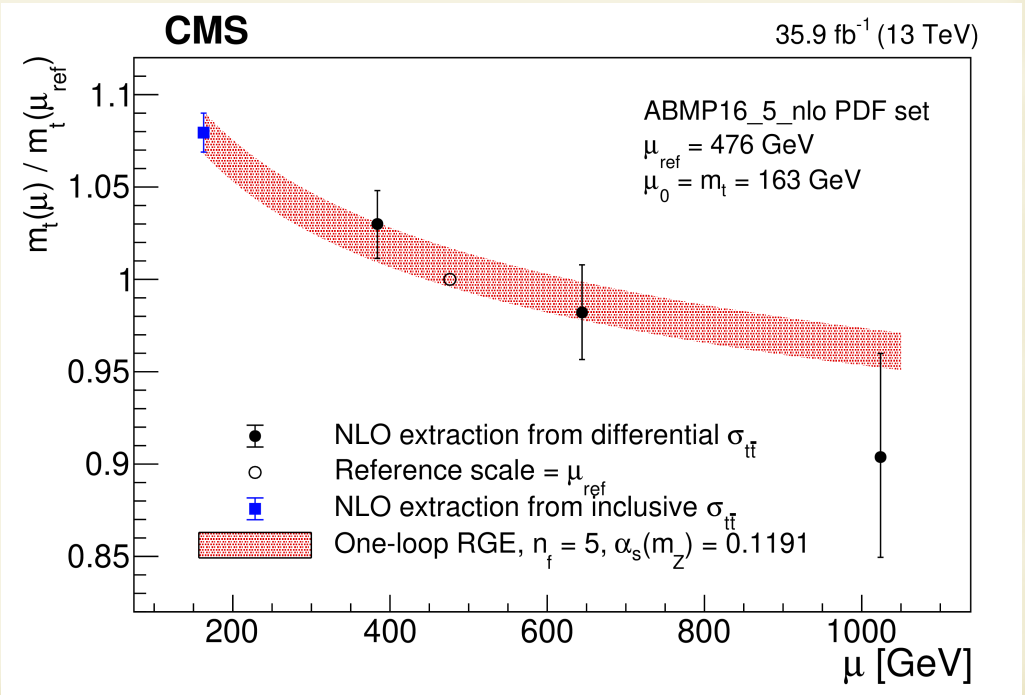
$$\mu^2 \frac{\mathrm{d}m(\mu)}{\mathrm{d}\mu^2} = -\gamma(\alpha_S(\mu))\, m(\mu)$$



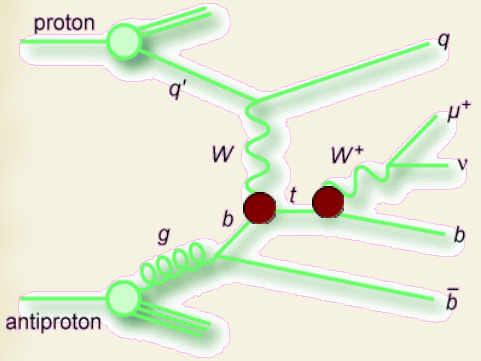
bin	range [GeV]	μ_k [GeV]
1	< 420	384
2	420-550	476
3	550-810	644
4	> 810	1024







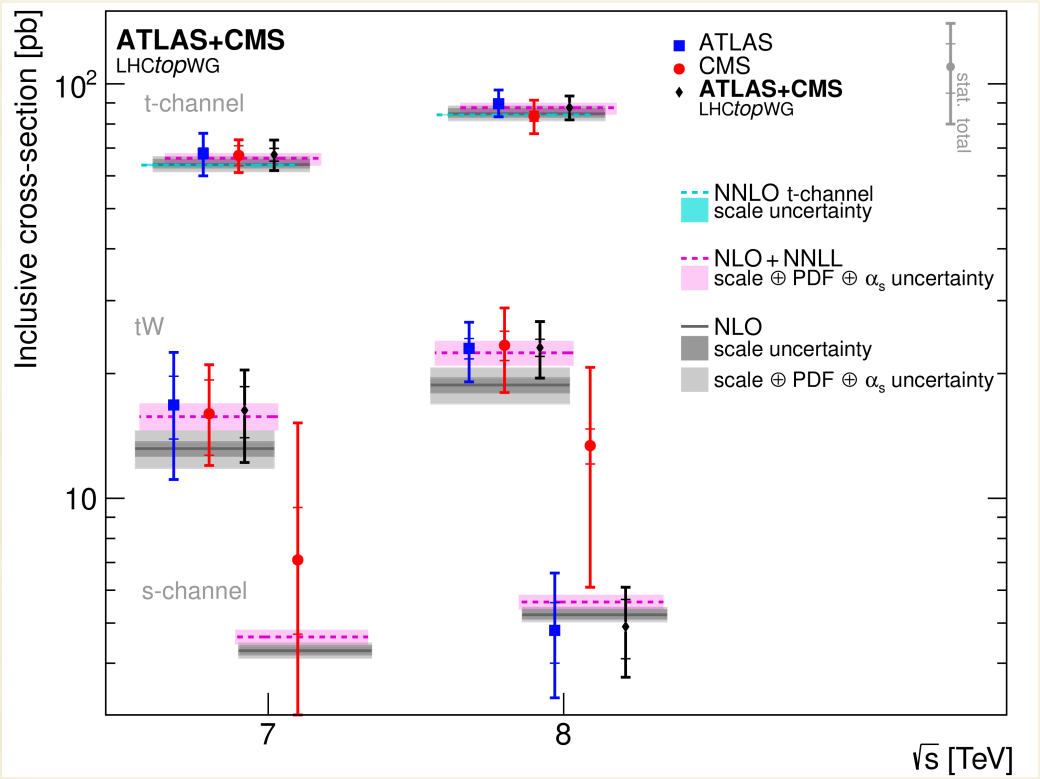
Direct measurement of CKM V_{tb}

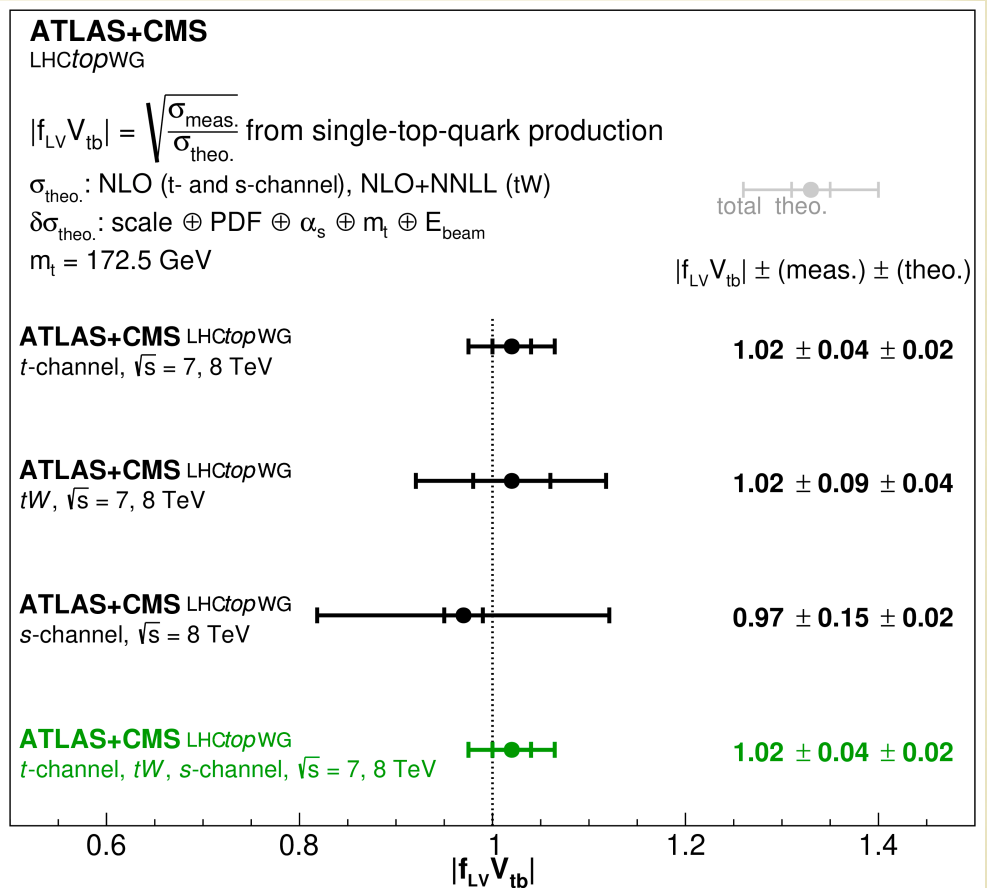


$$|f_{LV}V_{tb}| = \sqrt{\frac{\sigma_{t\text{-ch.},t+\bar{t}}}{\sigma^{th}_{t\text{-ch.},t+\bar{t}}}},$$

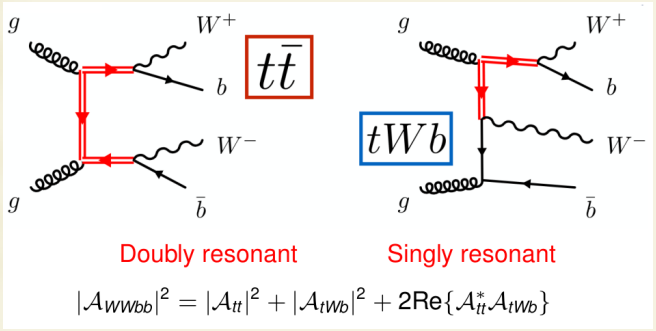
$$|V_{td}|^2 + |V_{ts}|^2 \ll |V_{tb}|^2$$

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





Simultaneous search for anomalous Wtb contribution in t-channel and tW+ttbar



- Significant uncertainty of the approximate simulation schemes suppress the sensitivity for aWtb.

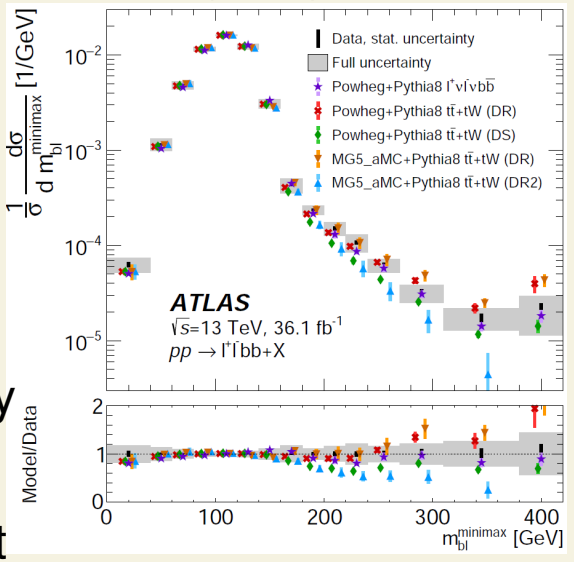
- Need to simulate all of the diagrams tW+tt (full scheme)

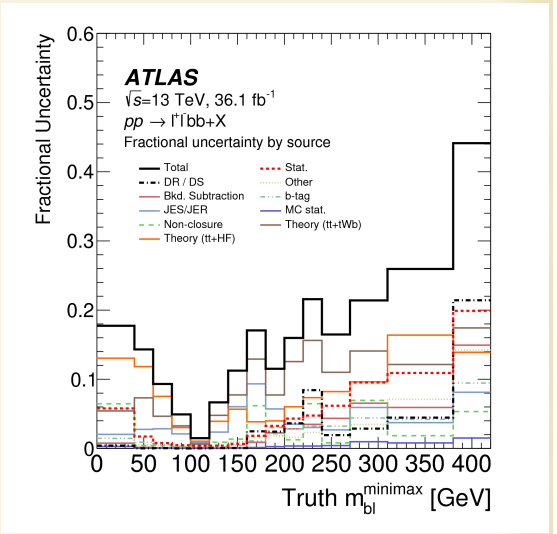
- tW and tt both are sensitive to aWtb but in different way (different observables)

- Contribution of tt is in about 30 times higher than tW and requires special approach in multivariate analysis [EPJ Web Conf. 191 (2018) 02008]

- necessary MC samples are in preparation by CompHEP, some of them are already available

PRL 121 (2018) 152002 tW+tt differential XS





Recent CMS search for EFT In tW+tt (di-lepton) arXiv:1903.11144