P'_5 Anomaly for Top: tZ' Associated Production at LHC

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tZ' Associated Production at LHC

Outline

I. Intro

P'_5 Anomaly in B; gauged $L_\mu - L_\tau$

tZ' ← Direct Search for Top Analog at LHC!

II. Discovering RH tcZ', & ccZ' Corollary

- $cg \to tZ'$: generic $\mathcal{L}$ & $L_\mu - L_\tau$
- $cc \to Z'$: generic $\mathcal{L}$ & $L_\mu - L_\tau$

III. Probing gauged $L_\mu - L_\tau$

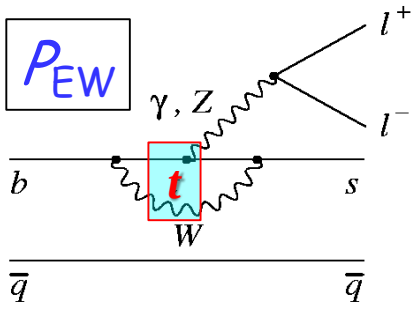
Yuk. couplings, mixing angles, VLQ U: interpretations

IV. Discussion & Conclusion

Discovery Potential: Run 2 .... 'til end of HL-LHC

WSH, Kohda, Modak, 1702.07275 [PRD'17]

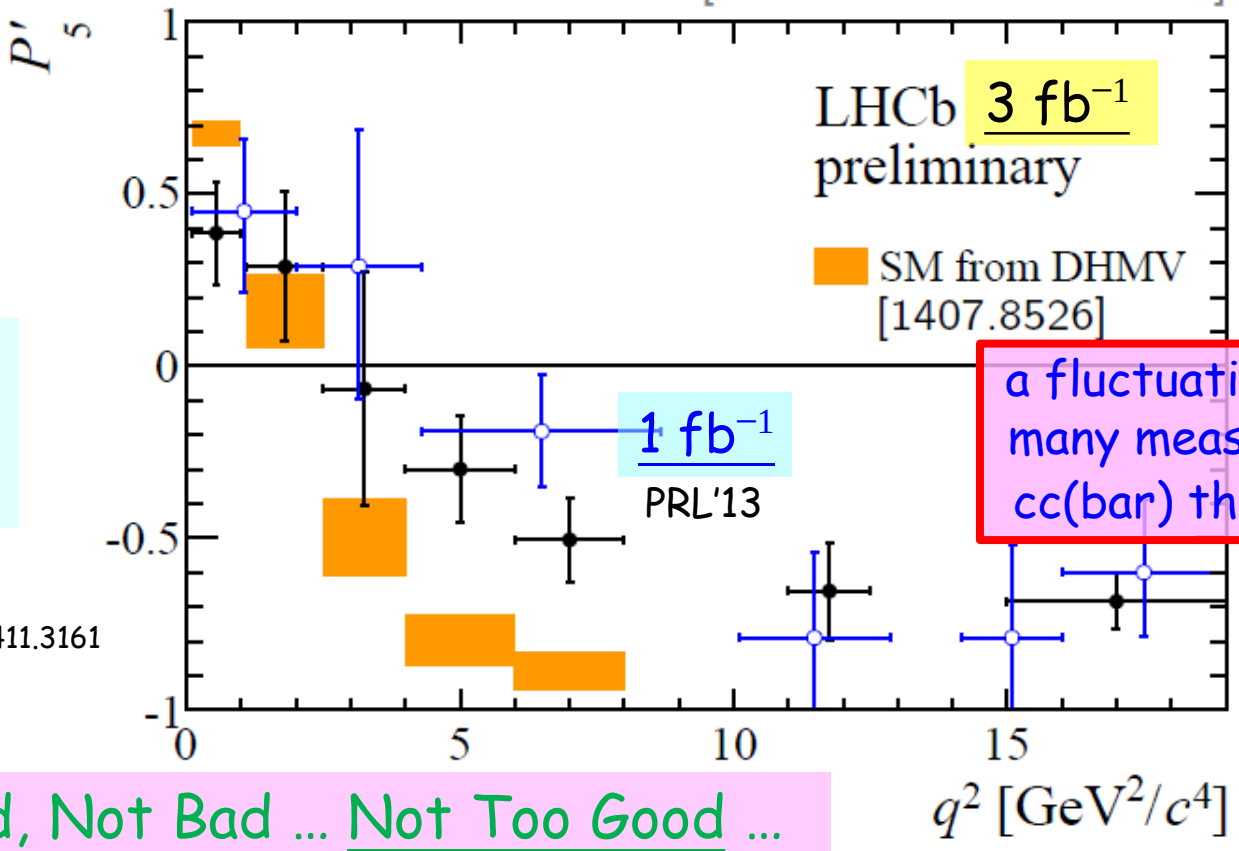
I. Intro



P'_5

B → K*μμ angular anal.

[LHCb-CONF-2015-002]



NP? $\Delta C_9 \sim -1$: heavy Z′ (tree)
[gives R_K, too]

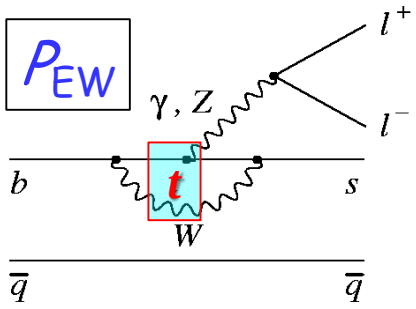
e.g. 1307.5683; 1308.1501;
1310.2478; 1310.3877;
1310.1082; 1311.6729 … 1411.3161

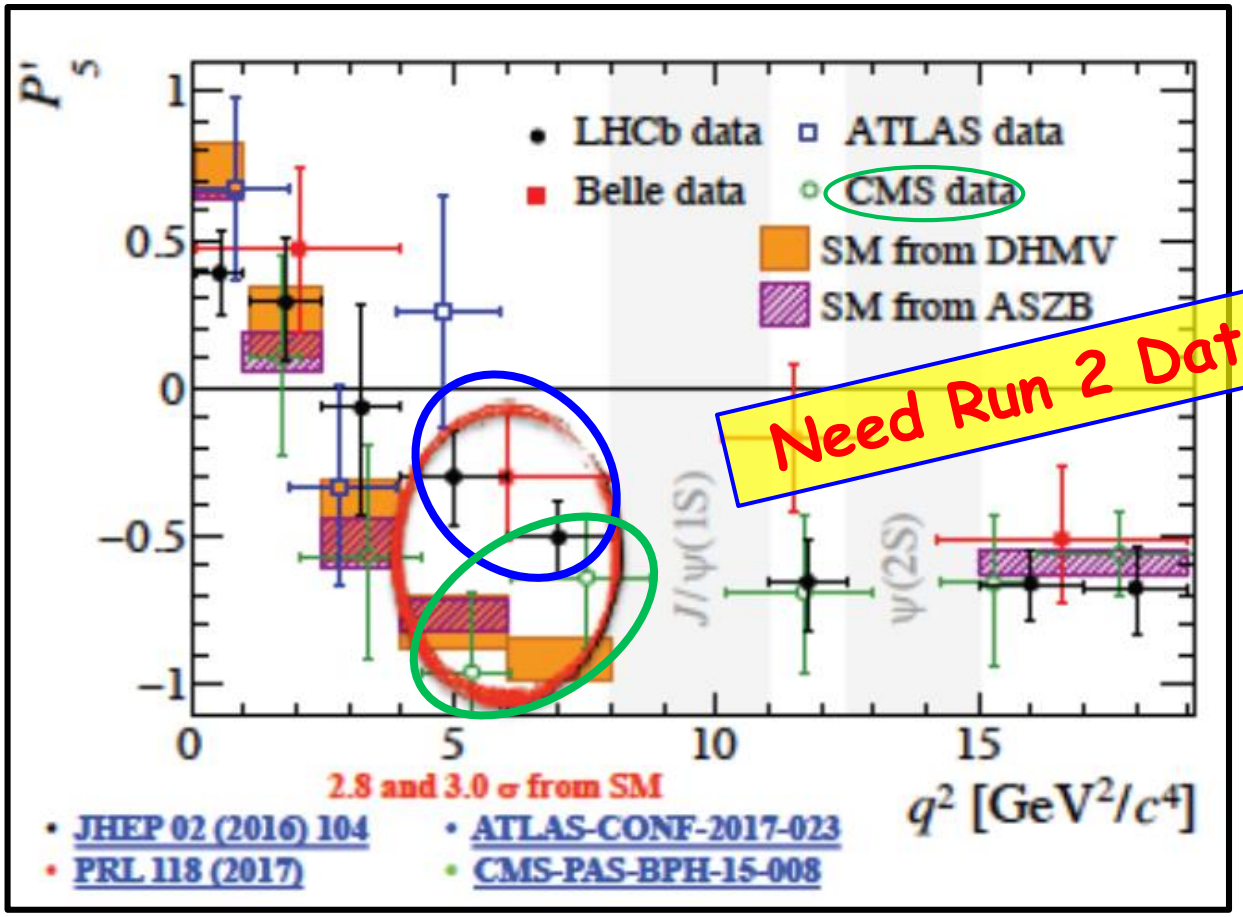
a fluctuation among many measurables? cc(bar) threshold?

Not Good, Not Bad … Not Too Good …

Significance did not improve.

Is P'_5 Real?





Need Run 2 Data !

NP? $\Delta C_9 \sim -1$: heavy Z' (tree) [gives R_K, too]

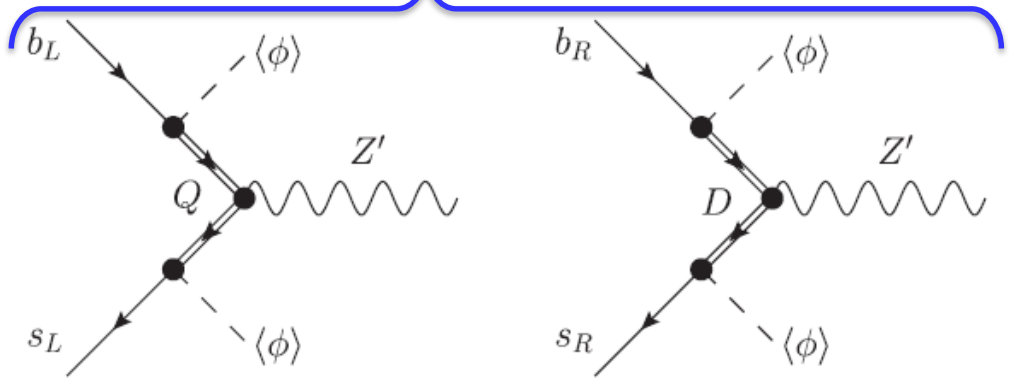
gauged $L_\mu - L_\tau$?

original concept 1993

Motivate Top "P'_5"

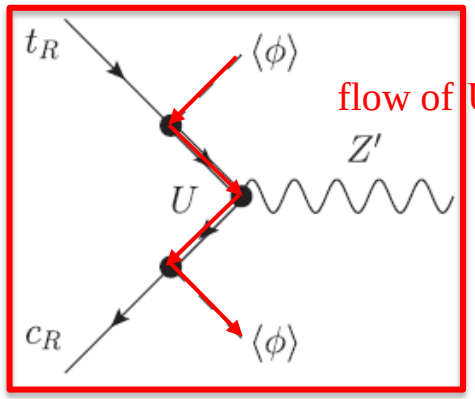
P'_5-motivated Z' induces $t \to cZ'$

ALTMANNSHOFER *et al.*



Add Q, D, U: vector-like quarks with Z' charge

PHYSICAL REVIEW D **89,** 095033 (2014)



~ unconstrained & RH

⇒ Should Search for $t \to cZ' \to c\mu^+\mu^-$

Fuyuto, WSH, Kohda, PRL'15, PRD'16

$Z' \to \mu^+\mu^-$ BR ~ 1/3!

gauged $L_\mu - L_\tau$

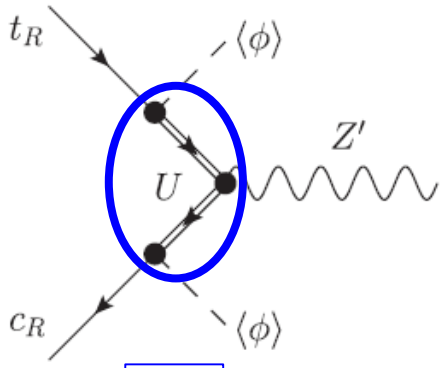
Alternatively: Search for $cg \to tZ'$

Whether P'_5 in B Real or Not

Top's Own "P'_5"

N.B. P'_5-related LH tZ' too weak; on other hand, U(1) allows having U alone.

II. RH tcZ' & ccZ'



g^R_{ct}

$$\Gamma_{Z'} \simeq 0.75\ \text{GeV} \left(\frac{m_{Z'}}{150\ \text{GeV}}\right)^3 \left(\frac{600\ \text{GeV}}{v_\Phi}\right)^2$$

$$g^R_{ct} = \left(g^R_{tc}\right)^* = -g' \frac{Y^*_{Uc} Y_{Ut} v^2_\Phi}{2m^2_U}$$

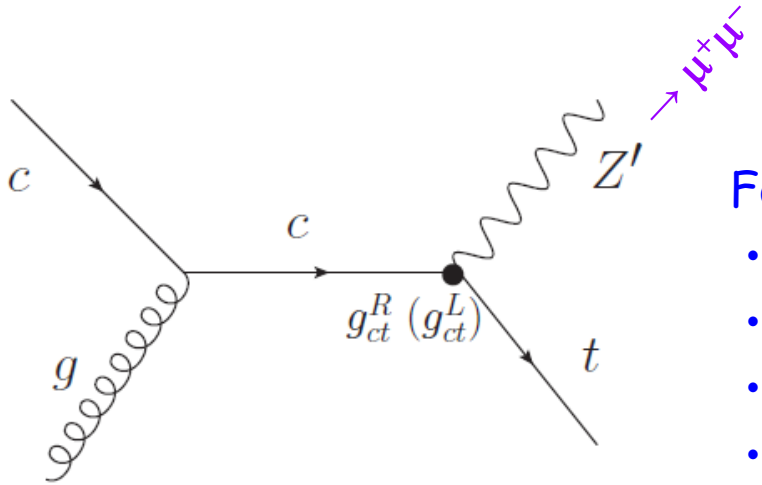
$L_\mu - L_\tau$ interpretation

generic $\mathcal{L}$: $g^R_{ct} \bar{c}_R \gamma^\alpha t_R Z'_\alpha + \text{h.c.}$

Benchmark, then Explore

Case A: $|g^R_{ct}| = 0.01$, $m_{Z'} = 150$ GeV below top

Case B: $|g^R_{ct}| = 0.01$, $m_{Z'} = 200$ GeV above top



MadGraph, PYTHIA, Delphes …

Follow CMS tZ via ctZ, 1702.01404 [JHEP'17] :

- Signal: $\ell\mu^+\mu^-$ + b + miss-E_T
- BG: tZj, ttZ, ttW, WZ + j …
- Pre-selection: lepton p_T, η, separation, jet p_T
- Selection: refine def. of $\ell\mu^+\mu^-$, b-jet, lepton p_T, top-related (softest ℓ, W-mass), veto 2nd p_T jet …

tZ' Benchmark

N.B. CMS study probes mZ′ ~ mZ
1702.01404

Case A: $|g_{ct}^R| = 0.01$, $m_{Z'} = 150$ GeV

(fb)

Cuts	Signal (Case A)	$\bar{t}Zj$	$t\bar{t}Z$	$t\bar{t}W^-$	W^-Z+light jets	W^-Z+h.f. jets	Total BG
Pre-selection cuts	0.410	0.872 (1.552)	1.672	0.514 (1.384)	0.641 (0.868)	4.55	8.25 (10.03)
Selection cuts (No jet veto)	0.090	0.012 (0.022)	0.026	0.023 (0.071)	0.012 (0.015)	0.017	0.090 (0.151)
Selection cuts	0.085	0.011 (0.020)	0.014	0.014 (0.039)	0.005 (0.007)	0.014	0.058 (0.094)

Case B: $|g_{ct}^R| = 0.01$, $m_{Z'} = 200$ GeV

Cuts	Signal (Case B)	$\bar{t}Zj$	$t\bar{t}Z$	$t\bar{t}W^-$	W^-Z+light jets	W^-Z+h.f. jets	Total BG
Pre-selection cuts	0.186	0.872 (1.552)	1.672	0.514 (1.384)	0.641 (0.868)	4.55	8.25 (10.03)
Selection cuts (No jet veto)	0.040	0.006 (0.010)	0.014	0.012 (0.035)	0.005 (0.007)	0.008	0.045 (0.074)
Selection cuts	0.037	0.005 (0.009)	0.007	0.008 (0.021)	0.002 (0.003)	0.007	0.029 (0.047)

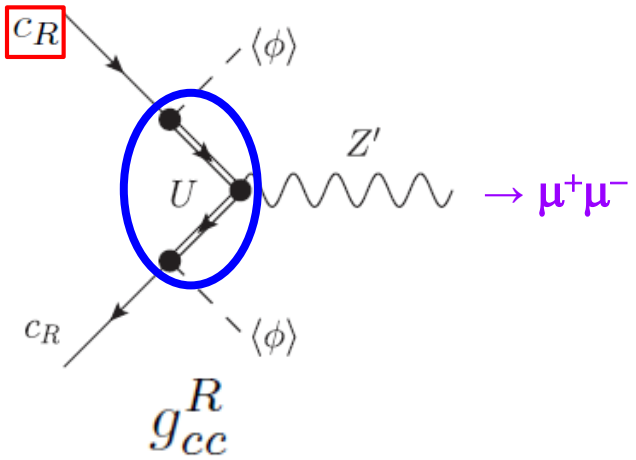
Significance $\mathcal{Z} = \sqrt{2\left[(S+B)\ln(1+S/B) - S\right]}$

14 TeV

Combining the tZ' and $\bar{t}Z'$ ⇒ $\mathcal{L} = 180\ (450)\ \text{fb}^{-1}$ in Case A (B)

discoverable

$cc \to Z' \to \mu^+\mu^-$ Benchmark



$$\Gamma_{Z'} \simeq 0.75 \text{ GeV} \left(\frac{m_{Z'}}{150 \text{ GeV}}\right)^3 \left(\frac{600 \text{ GeV}}{v_\Phi}\right)^2$$

not too broad

$$g^R_{cc} = -g' \frac{|Y_{Uc}|^2 v_\Phi^2}{2m_U^2}$$

$L_\mu - L_\tau$ interpretation

generic $\mathcal{L}$: $g^R_{cc} \bar{c}_R \gamma^\alpha c_R Z'_\alpha$

Benchmark, then Explore

Case I: $|g^R_{cc}| = 0.005$, $m_{Z'} = 150$ GeV below top

Case II: $|g^R_{cc}| = 0.005$, $m_{Z'} = 200$ GeV above top

Milli-weak Drell-Yan from cc(bar)!

$\mathcal{Z} \simeq S/\sqrt{B}$

5σ at 14 TeV

$\mathcal{L} = 110\ (170)\ \text{fb}^{-1}$

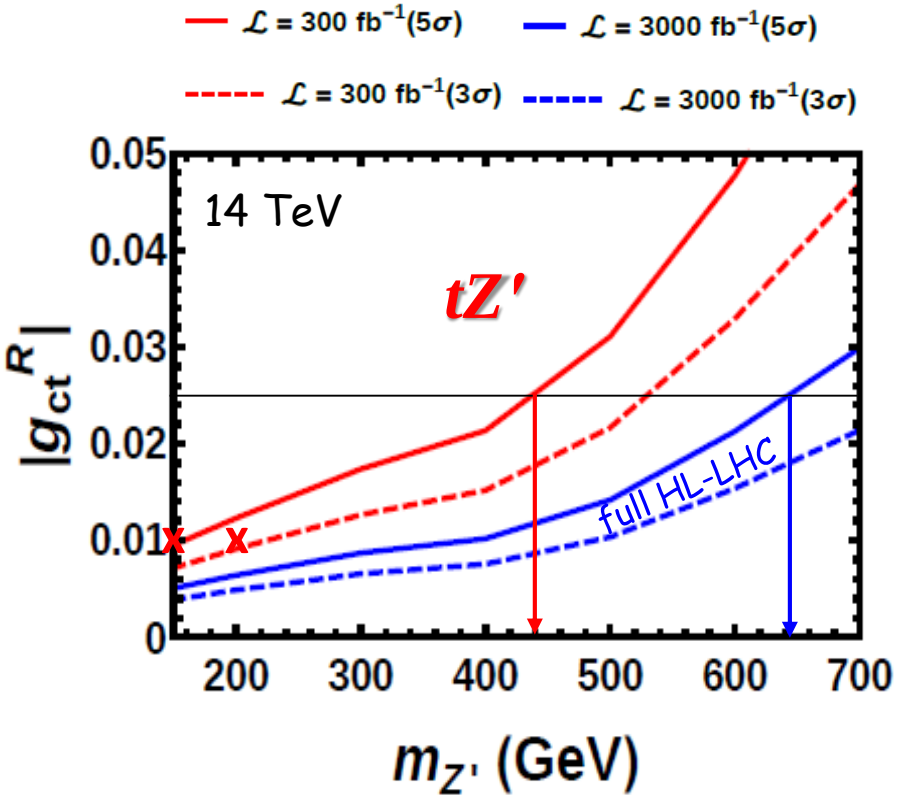
(fb)

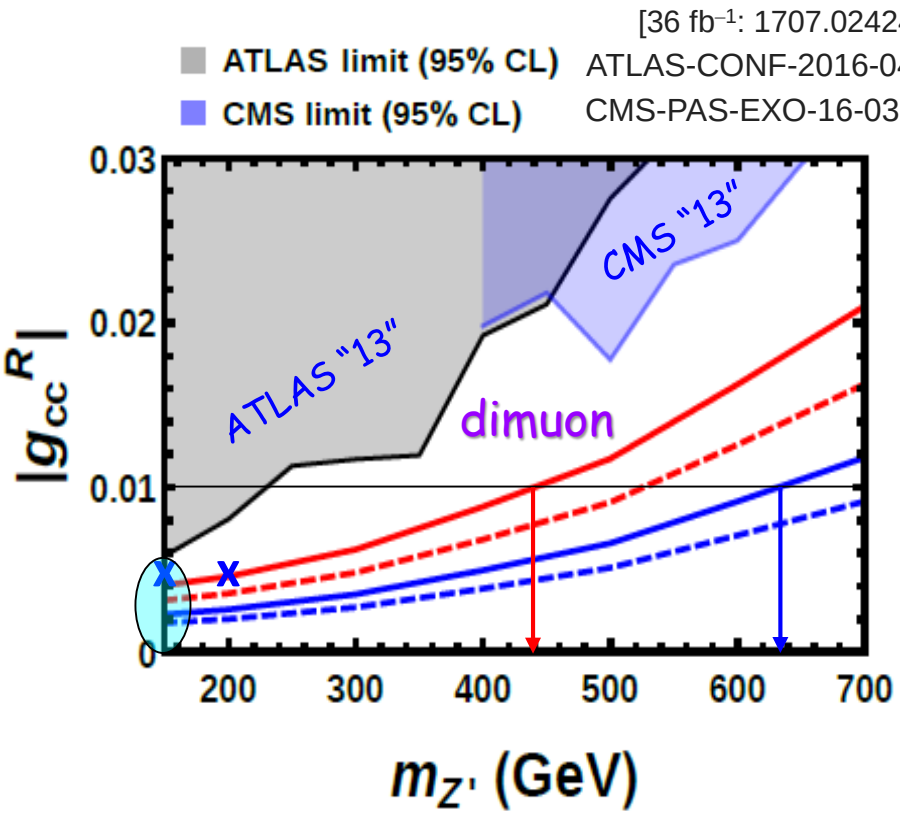
Cuts	Signal (Case I)	Z/γ^*	$t\bar{t}$	Wt	WW	WZ	ZZ	Total BG
Pre-selection cuts	38.65	19980	1785	166	212	128.44	74.82	22346
Selection cuts	20.96	1677	163	16	24	0.22	0.02	1880

Cuts	Signal (Case II)	Z/γ^*	$t\bar{t}$	Wt	WW	WZ	ZZ	Total BG
Pre-selection cuts	17.77	19980	1785	166	212	128.44	74.82	22346
Selection cuts	10.22	532	117	12	14	0.12	0.01	675

Model-indep. Discovery Potential

Extend Study for $m_{Z'}$ from 150 to 700 GeV, and coupling range

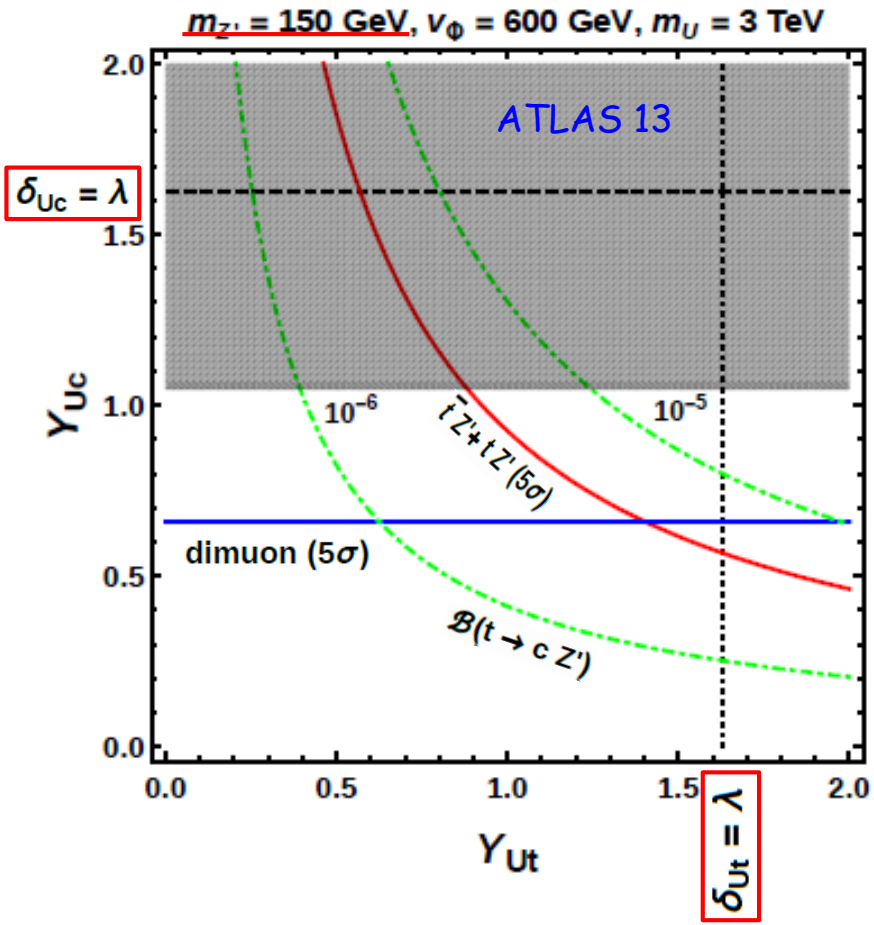


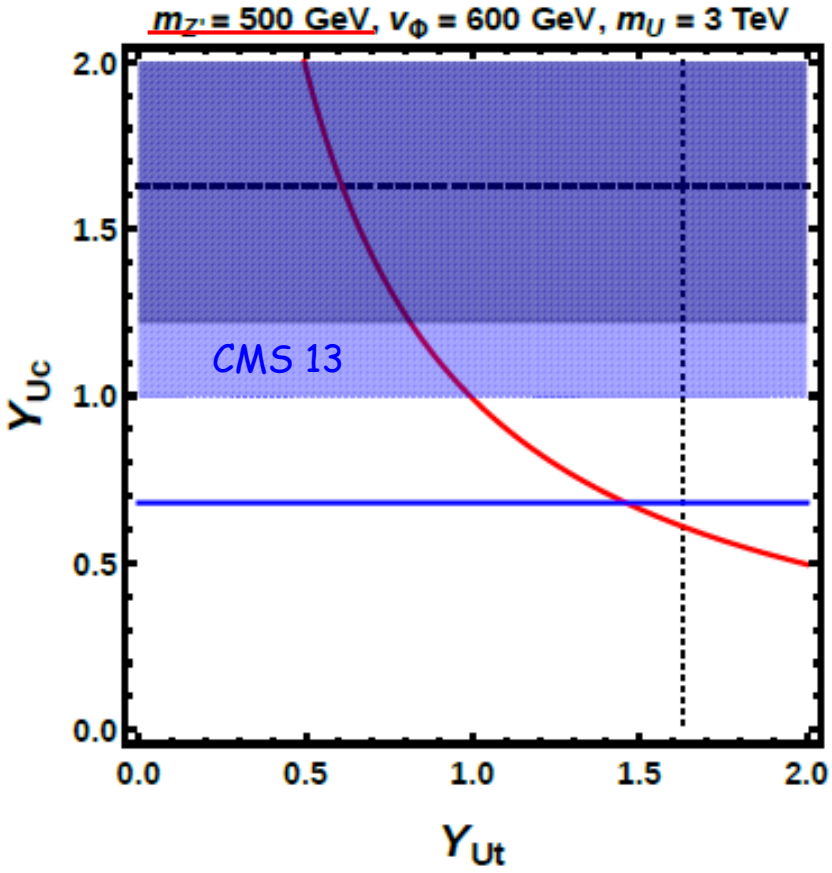


Both tZ' & dimuon have Discovery Potential

Moral: Weaker-coupled Resonances Probed by HL-LHC

III. Probing gauged $L_\mu - L_\tau$ interpretation





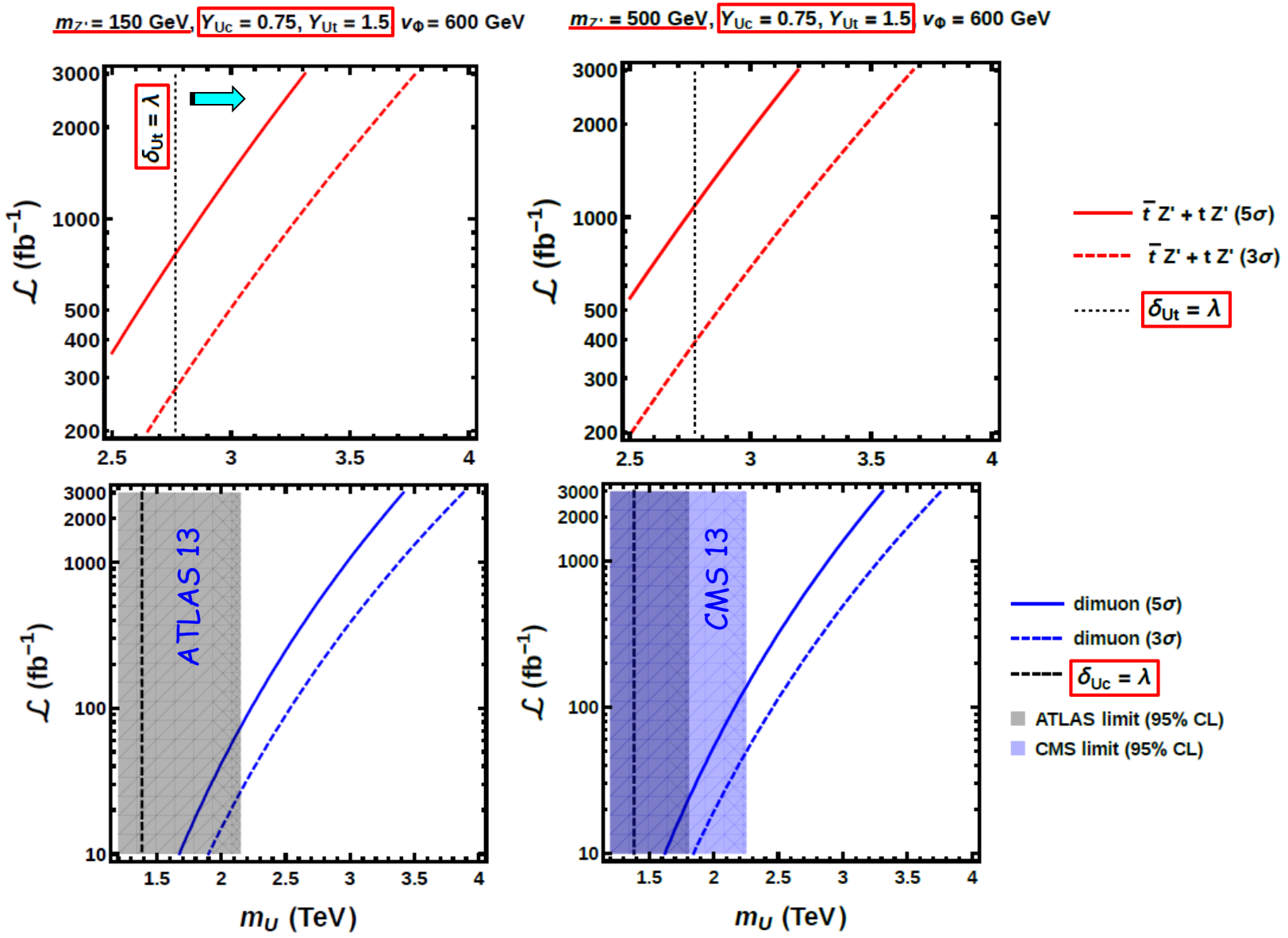
Mixing Angle

< Cabibbo ~ 0.22

$$\delta_{Uq} \equiv \frac{Y_{Uq} v_\Phi}{\sqrt{2} m_U}$$

Yukawa Coupling $Y_{Ut} - Y_{Uc}$

Probing Exotic Vector-like Quark *U*



IV. Discussion & Conclusion

- $|\delta_{Ut}| \sim |\delta_{Uc}|$: dimuon Z' more promising

  If discovered: study $cg \to cZ'$ if c-tagging possible [under study

- hierarchical $|\delta_{Uc}/\delta_{Ut}| \lesssim 0.4$: tZ' more promising

  If discovered: study handedness by angular analysis [under study

  ➔ Simultaneous discovery would give flavor structure!

  [but, if $|\delta_{Ut}| \leq \lambda$, $|\delta_{Uc}/\delta_{Ut}| \lesssim \lambda$, then scenario out of reach for HL-LHC

- g^L_{ct} directly linked to $B \to K^{(*)}$ anomalies: tZ' out of reach at HL-LHC

  Too Weak! Strength at SM loop level.

  However, still might have $bb \to Z'$ generically.

Conclusion: Top Flavor Physics tZ'; and DY dimuon

Discoverability of Top "P'_5": Run 2 .... 'til end of HL-LHC

Moral: Weaker-coupled Resonances Probed at Run 2 & by HL-LHC