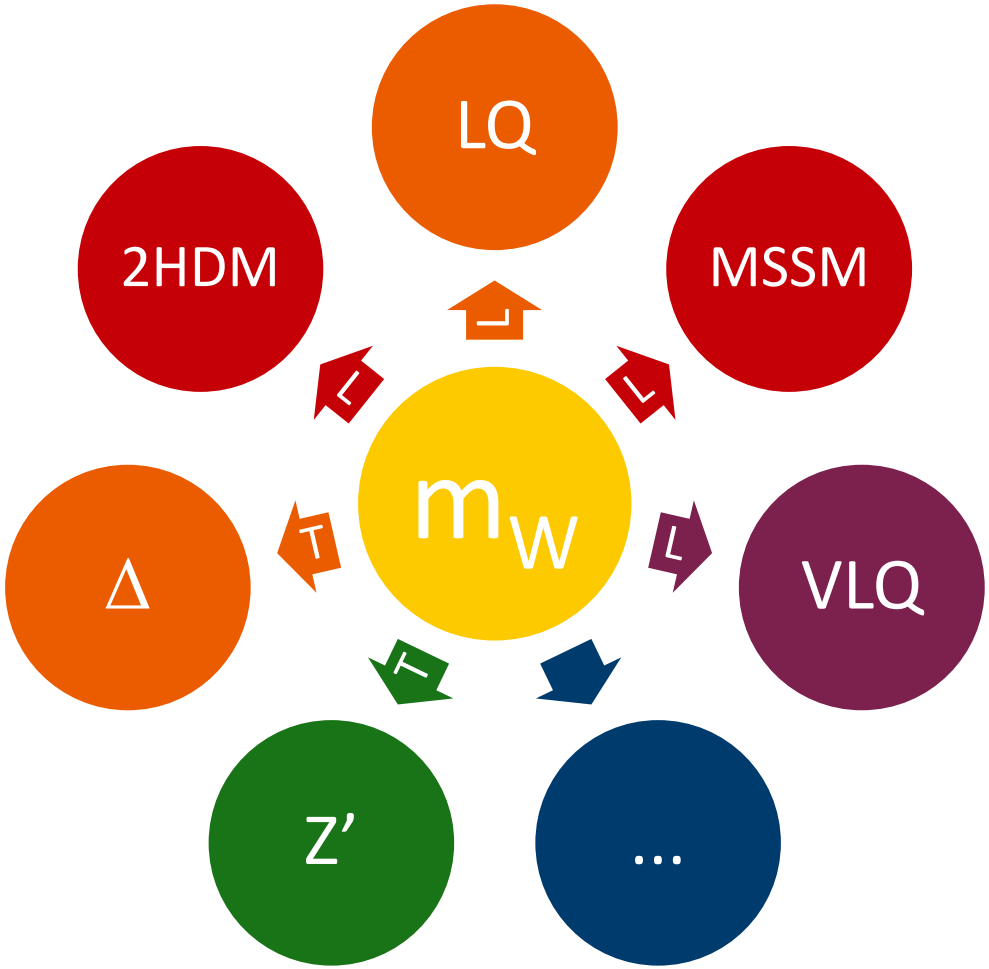
Andreas Crivellin

PSI & UZH

Anomalies: The W mass and beyond

CERN, MWDays23, 20.04.2023

NP affecting the W Mass prediction



See previous talks for details

T: Tree level

L: Loop level

- LQ: Leptoquark
- VLQ: Vector-like quark
- Z': Neutral heavy gauge boson
- Δ: Scalar triplet (Y=0)

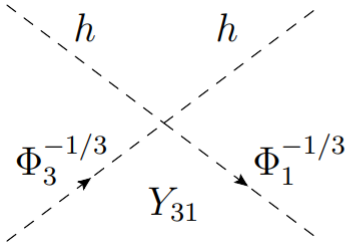
Many options, how do we discriminate them?

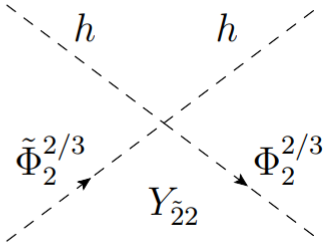
Leptoquarks

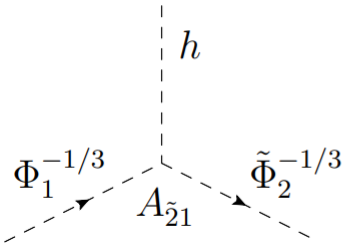
- Scalar LQs (renormalizable)

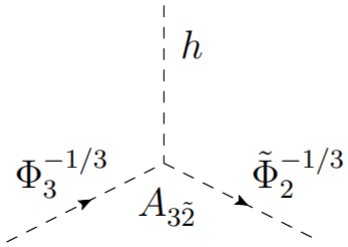
	$SU(3)$	$SU(2)_L$	$U(1)_Y$
Φ_1	3	1	$-1/3$
$\tilde{\Phi}_1$	3	1	$-4/3$
Φ_2	3	2	$7/6$
$\tilde{\Phi}_2$	3	2	$1/6$
Φ_3	3	3	$-1/3$

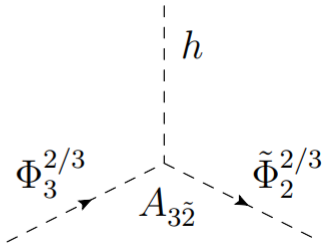
- Higgs interactions





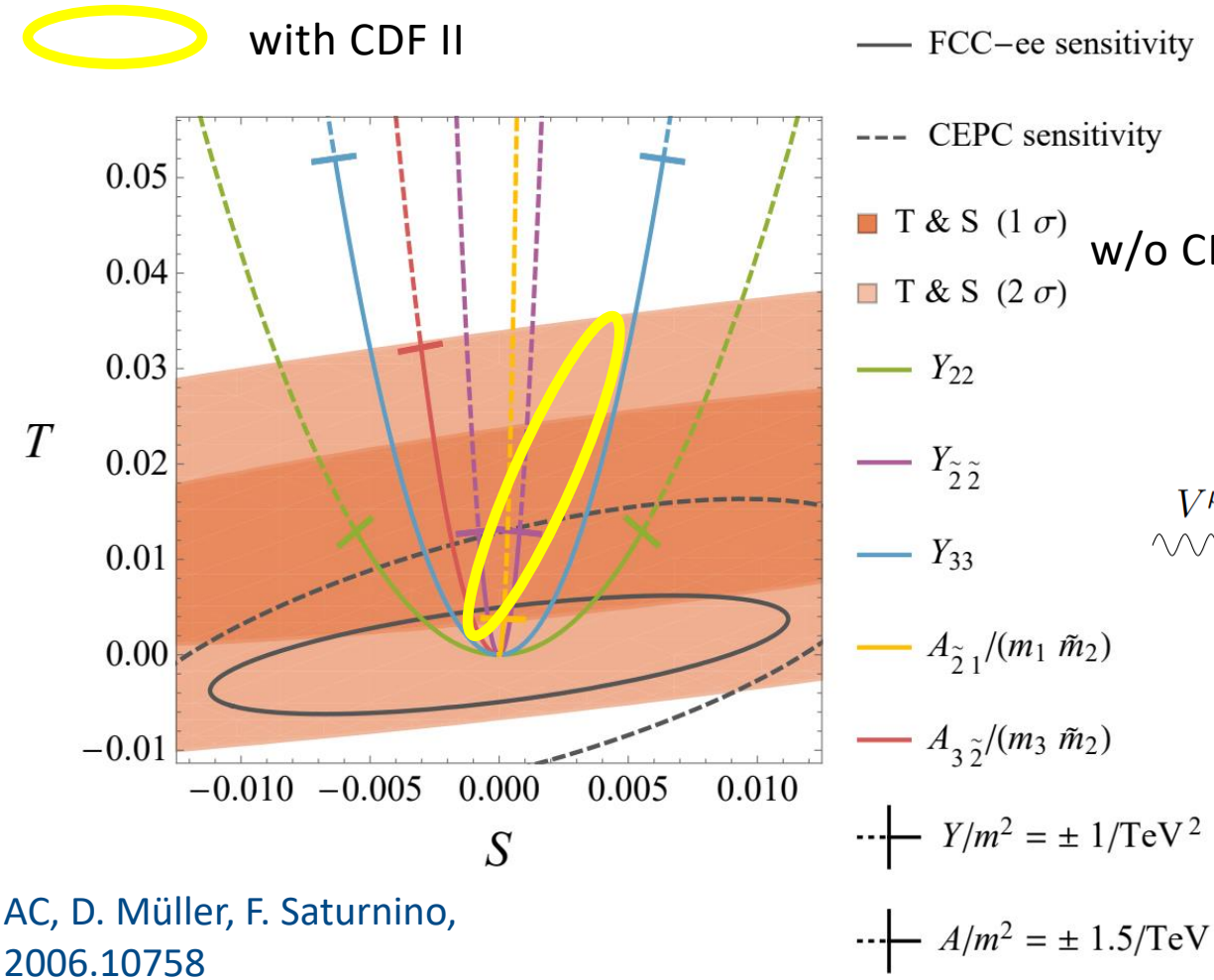






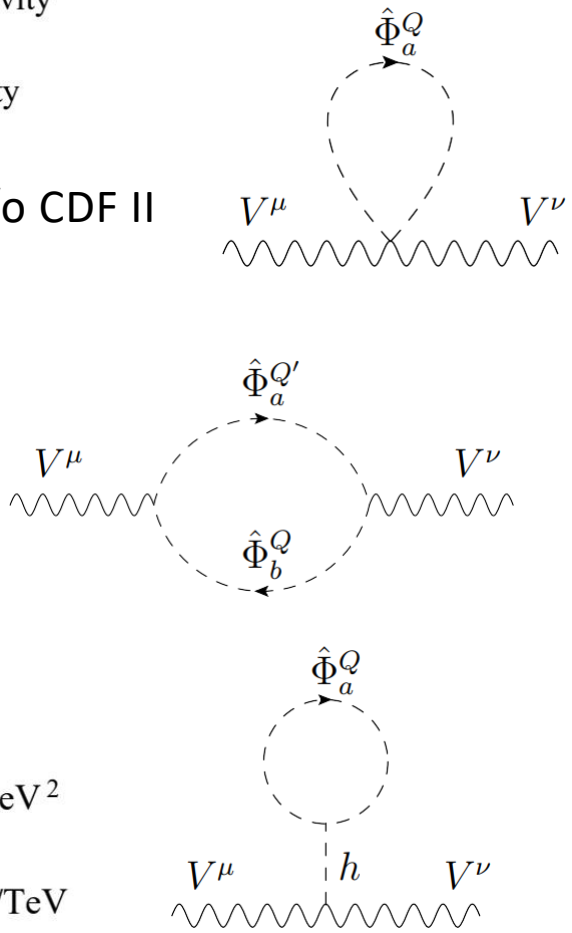
Higgs couplings give effect in the W mass

Leptoquarks



AC, D. Müller, F. Saturnino, 2006.10758

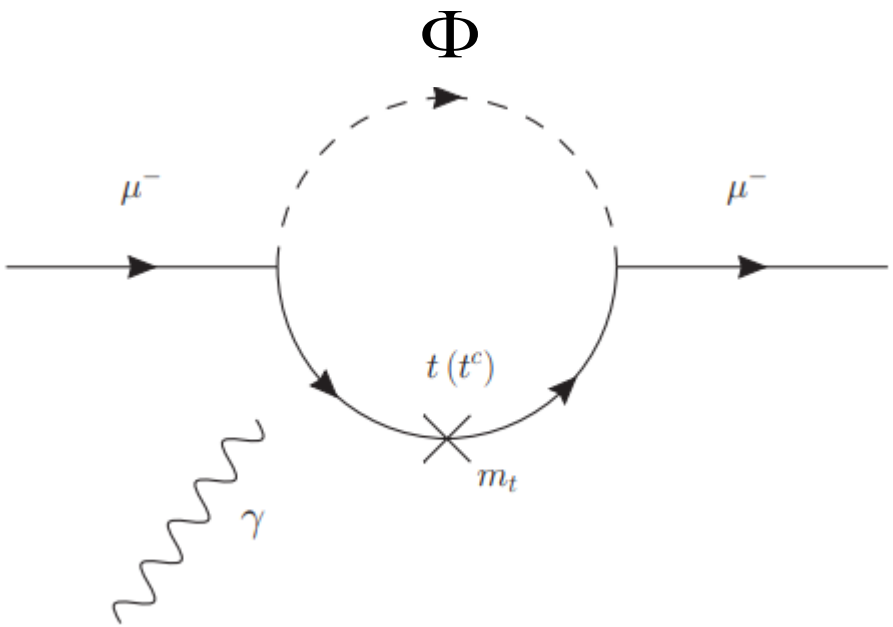
w/o CDF II

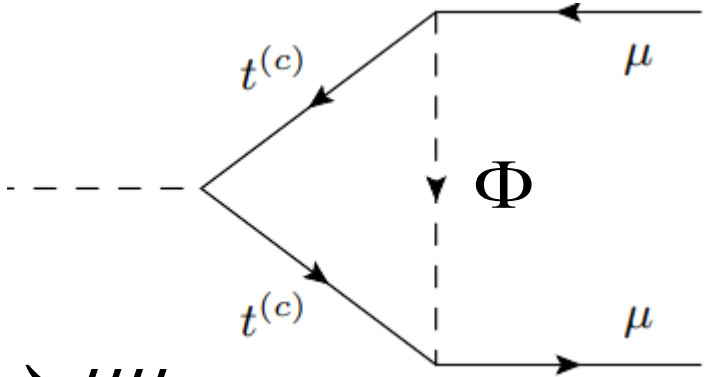


Effect necessarily positive, $\Phi_{\tilde{2}}$ works best

Leptoquarks in $a_\mu=(g-2)/2$

- Chirally enhanced effects via top-loops involving Φ_1 and Φ_2



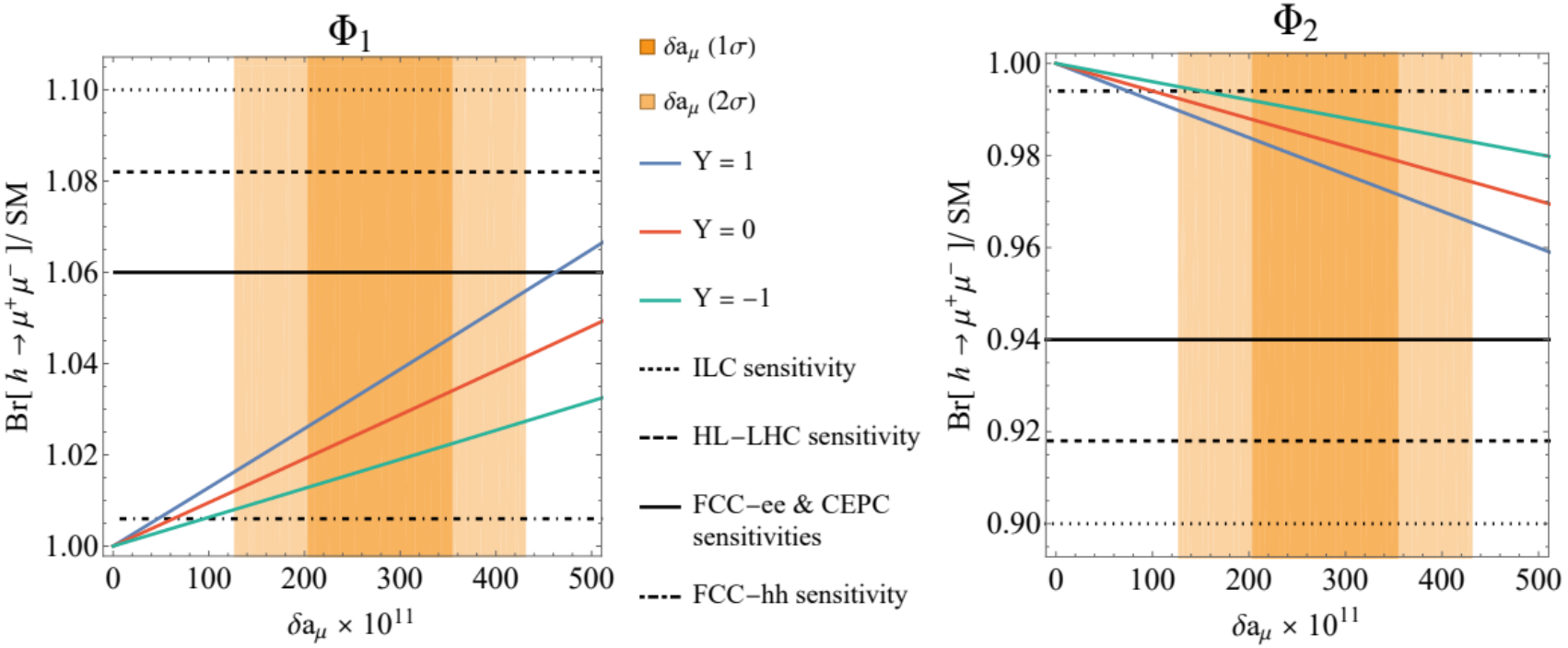


- m_t/m_μ enhanced effect in $h \to \mu\mu$
- m_t^2/m_Z^2 enhanced effect in $Z \to \mu\mu$

Correlations with h→μμ and Z→μμ

a_μ vs h→μμ with Leptoquarks

- Chirally enhanced effects via top-loops
- Same coupling structure → direct correlation

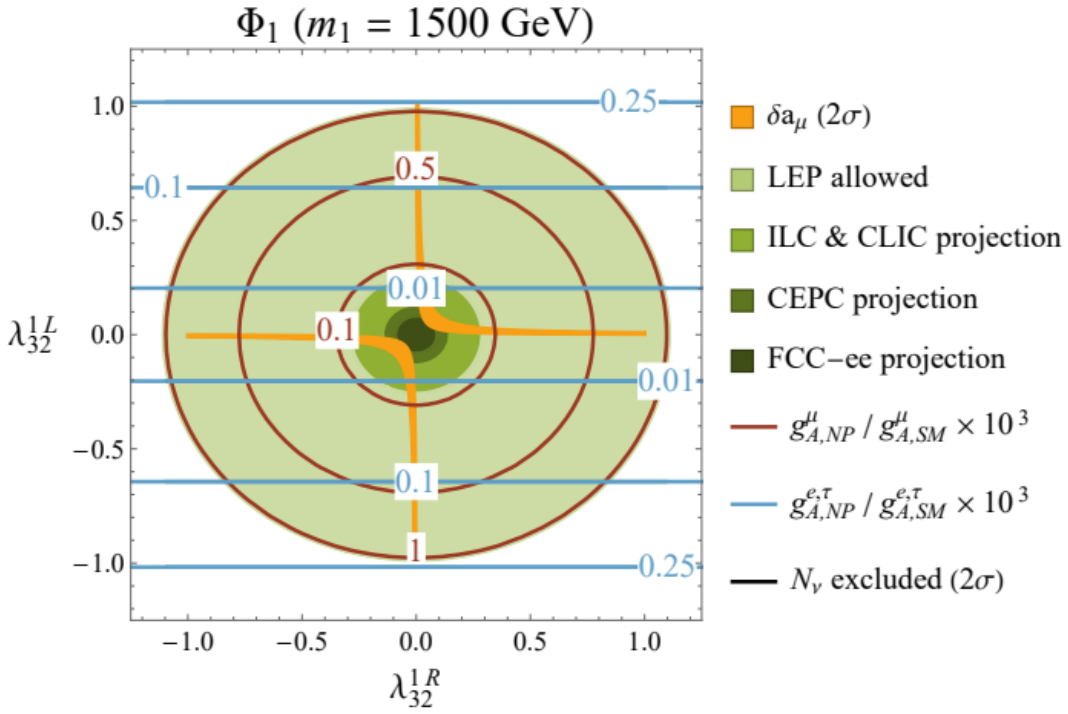


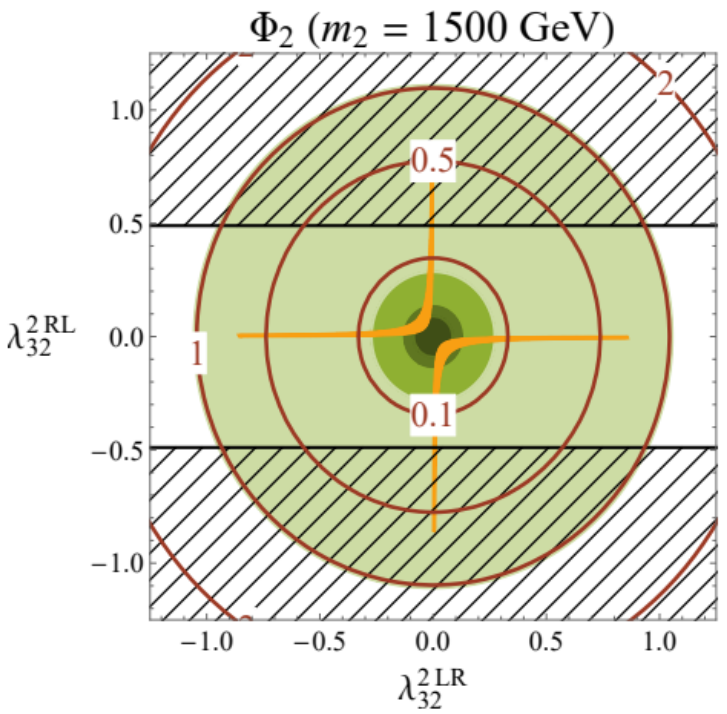
A.C., D. Mueller, F. Saturnino, PRL 2021

h→μμ at future colliders

a_μ vs Z→μμ with Leptoquarks

- Chirally enhanced effects via top-loops





λ_{32} muon-top coupling

E. Leskow, A.C., G. D'Ambrosio, D. Müller 1612.06858
A.C, C. Greub, D. Müller, F. Saturnino, 2010.06593

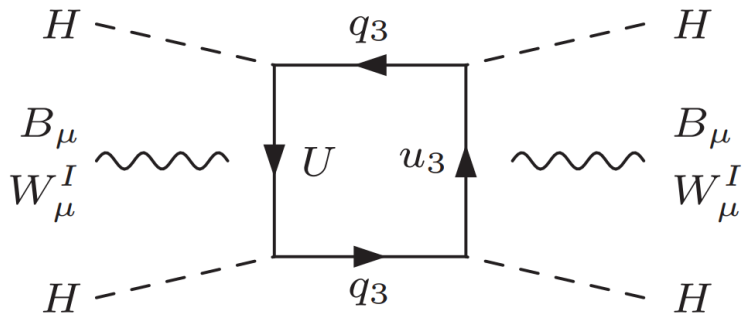
Z→μμ at FCC-ee

Vector-like Quarks

- Vector-like quark representations

	$SU(3)$	$SU(2)_L$	$U(1)_Y$
U	3	1	$2/3$
D	3	1	$-1/3$
Q_1	3	2	$1/6$
Q_5	3	2	$-5/6$
Q_7	3	2	$7/6$
T_1	3	3	$-1/3$
T_2	3	3	$2/3$

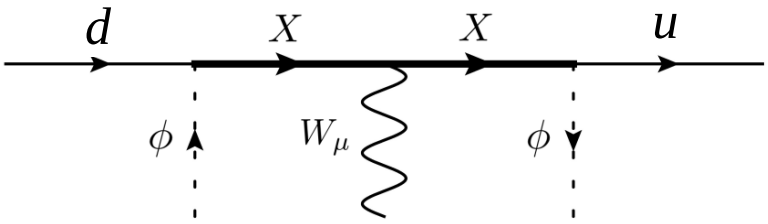
Dominant contribution to W mass



- Higgs interactions

$$-\mathrm{L}_{\mathrm{VLQ}} = \xi^{U}\bar{U}\tilde{H}^{\dagger}q + \xi^{D}\bar{D}H^{\dagger}q + \xi^{u_1}\bar{Q}_1\tilde{H}u + \xi^{d_1}\bar{Q}_1Hd + \xi^{Q_5}\bar{Q}_5\tilde{H}d + \xi^{Q_7}\bar{Q}_7Hu + \frac{1}{2}\xi^{T_1}H^{\dagger}\tau\cdot\bar{T}_1q + \frac{1}{2}\xi^{T_2}\tilde{H}^{\dagger}\tau\cdot\bar{T}_2q + \text{h.c.}$$

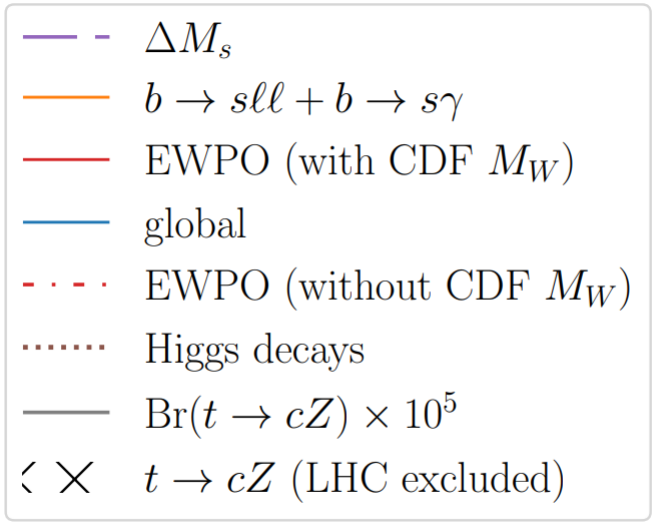
Modified W-quark coupling

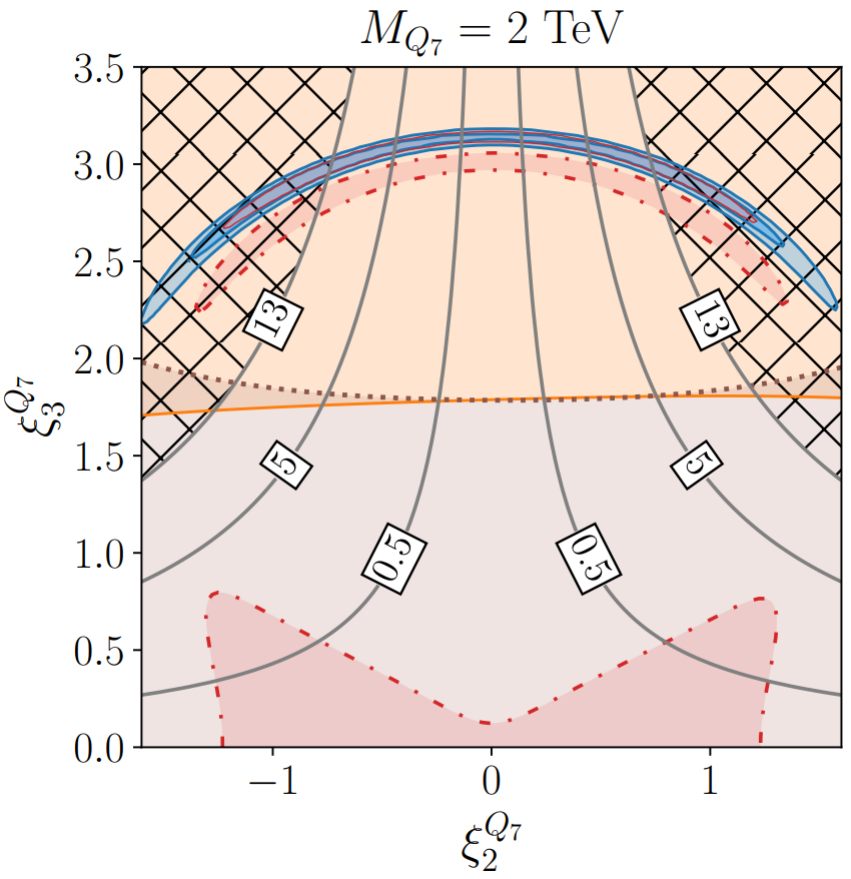


Modified W and Z coupling

W mass and t→Zc

- Couplings to right-handed quarks needed avoid flavour bounds





A. Crivellin, M. Kirk, T. Kitahara, F.~Mescia, 2204.05962

VLQ only option for sizable t→cZ

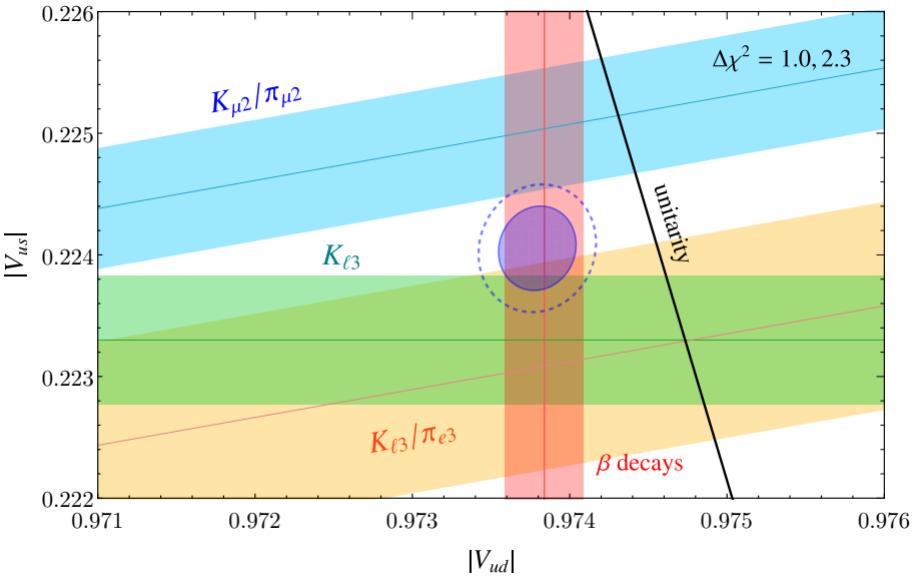
Cabibbo Angle Anomaly (CAA)

- Deficit in first row and first column CKM unitarity

$$\left|V_{ud}^2\right| + \left|V_{us}^2\right| + \left|V_{ub}^2\right| = 0.9985 \pm 0.0005 \quad (\text{PDG})$$

$$\left|V_{ud}^2\right| + \left|V_{cd}^2\right| + \left|V_{td}^2\right| = 0.9970 \pm 0.0018$$

➡ can be explained by left or right-handed modified W-u-d coupling



- Discrepancy between V_{us} from K_{l2} and K_{l3} decays

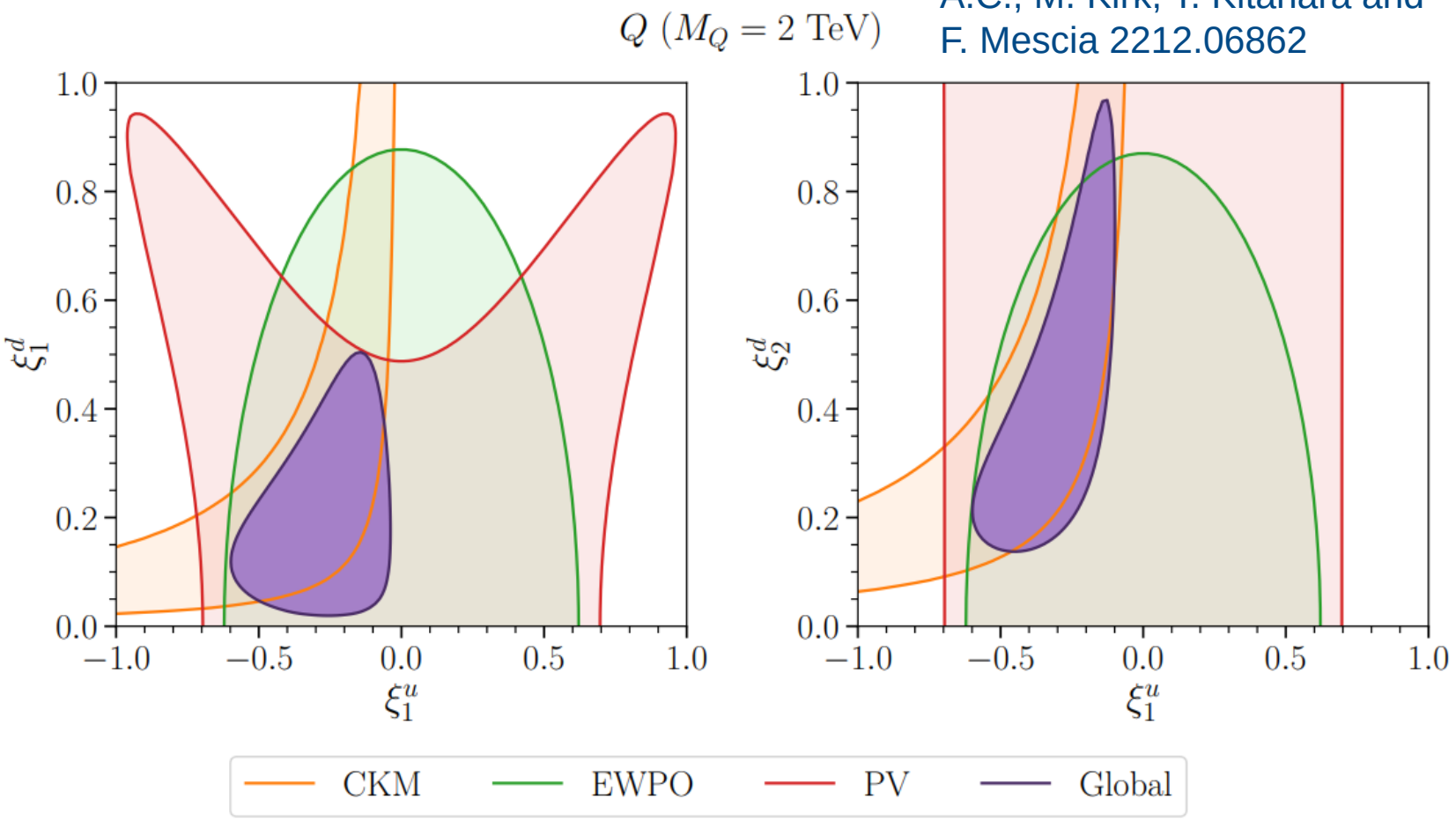
➡ only via a right-handed W coupling

Both O(3σ) tensions, can be explained by VLQs

VLQs and the CAA

- Modified W coupling

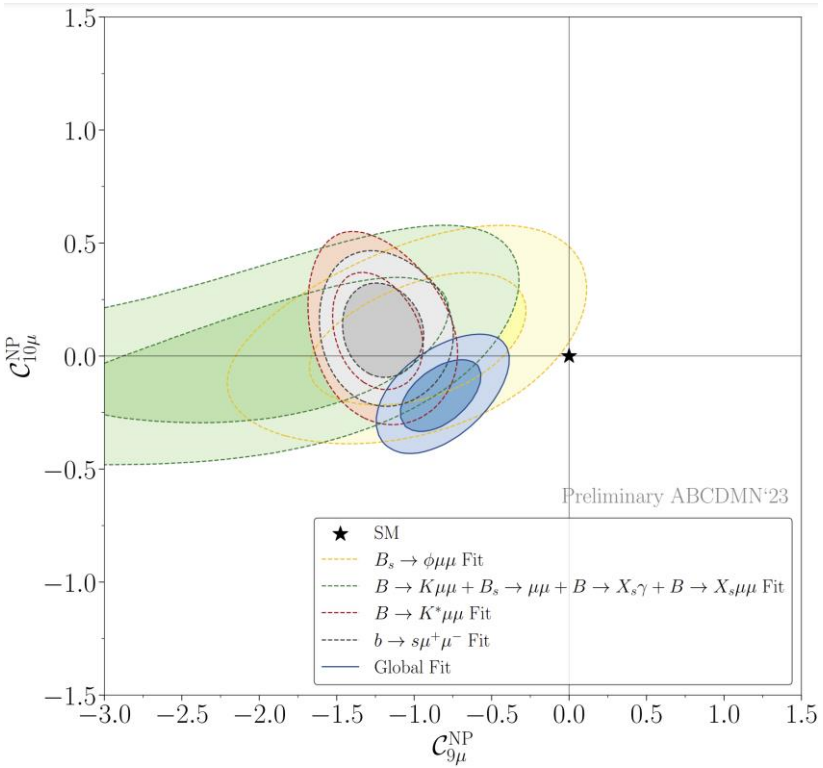
A.C., M. Kirk, T. Kitahara and F. Mescia 2212.06862

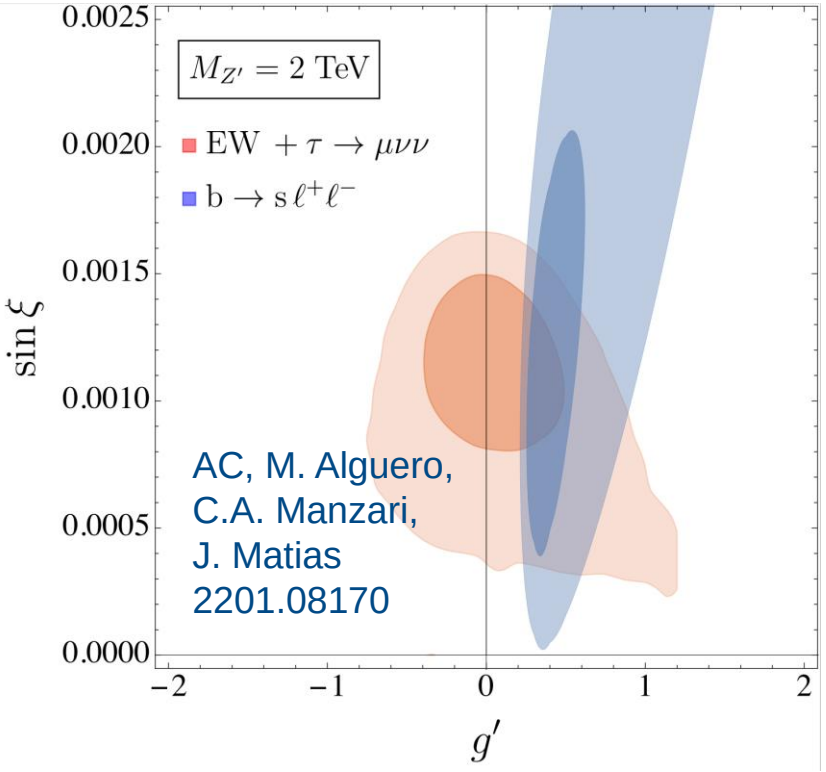


SU(2) doublet VLQ can explain both tensions

Z' boson

- Z-Z' mixing ➡ positive shift in W mass
- Still significant tensions in LFU b→sll observables





Z-Z' mixing improves b→sll fit

Model for m_W, $b\to s\ell\ell$, CAA, $Z\to bb$ & $\tau\to\mu\nu\nu$

- VLQs combined with Z' can explain $b\to s\ell\ell$

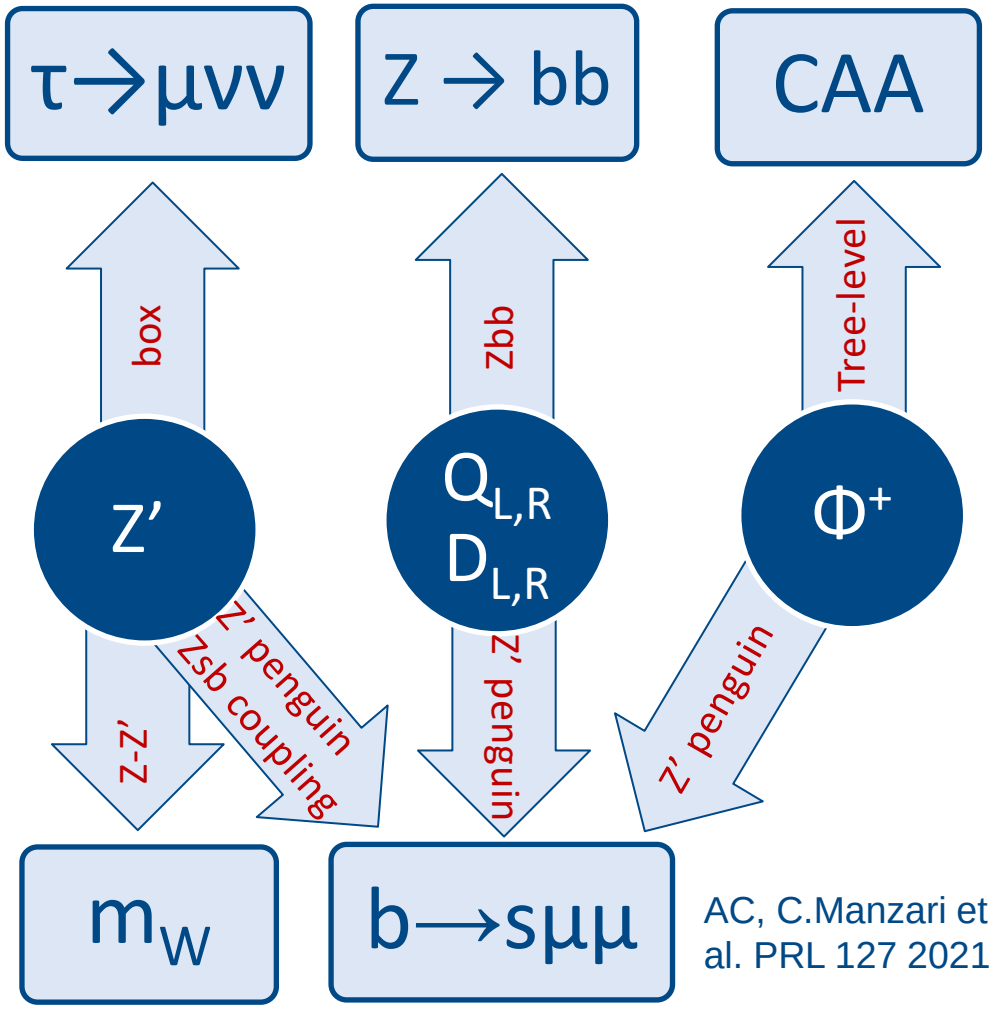
  Altmannshofer et. al1403.1269, C. Bobeth, A. Buras, A. Celis, M. Jung, 1609.04783

- $L_e+L_\mu-2L_\tau$ model with vector-like quarks

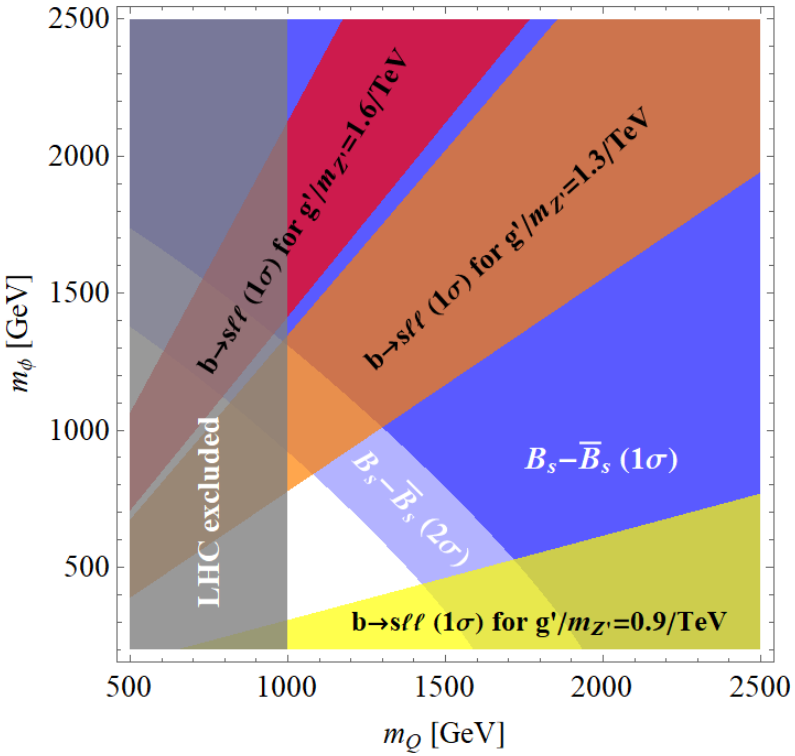
	q_L	d_R	u_R	H	ℓ_L	e_R	Q_L	Q_R	D_L	D_R	ϕ^+	S
$SU(3)_c$	3	3	3	1	1	1	3	3	3	3	1	1
$SU(2)_L$	2	1	1	2	2	1	2	2	1	1	1	1
$U(1)_Y$	$\frac{1}{6}$	$\frac{-1}{3}$	$\frac{2}{3}$	$\frac{1}{2}$	$\frac{-1}{2}$	-1	$\frac{-5}{6}$	$\frac{-5}{6}$	$\frac{-1}{3}$	$\frac{-1}{3}$	1	0
$U(1)'$	0	0	0	$(1,1,-2)$			0	1	1	0	-1	-1

Lepton flavour universal effect in C9

Model for b→sℓℓ, CAA, Z→bb and τ → μνν



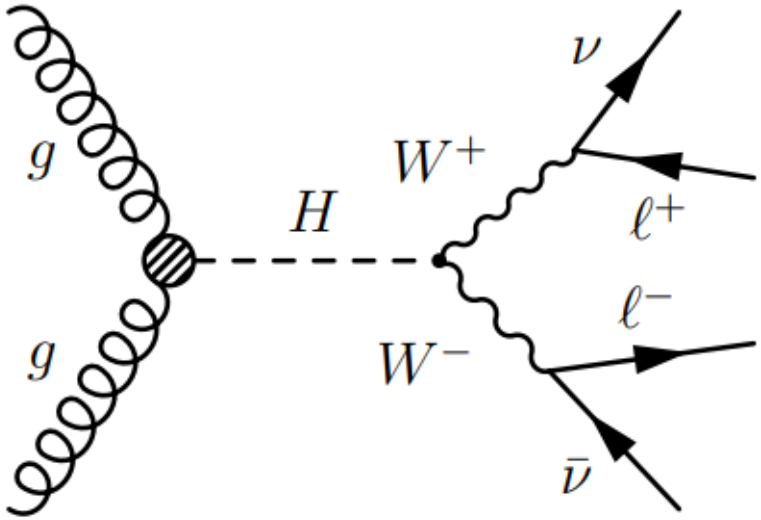
AC, C.Manzari et al. PRL 127 2021



Simple model provides combined explanation

Scalar Triplet with Y=0

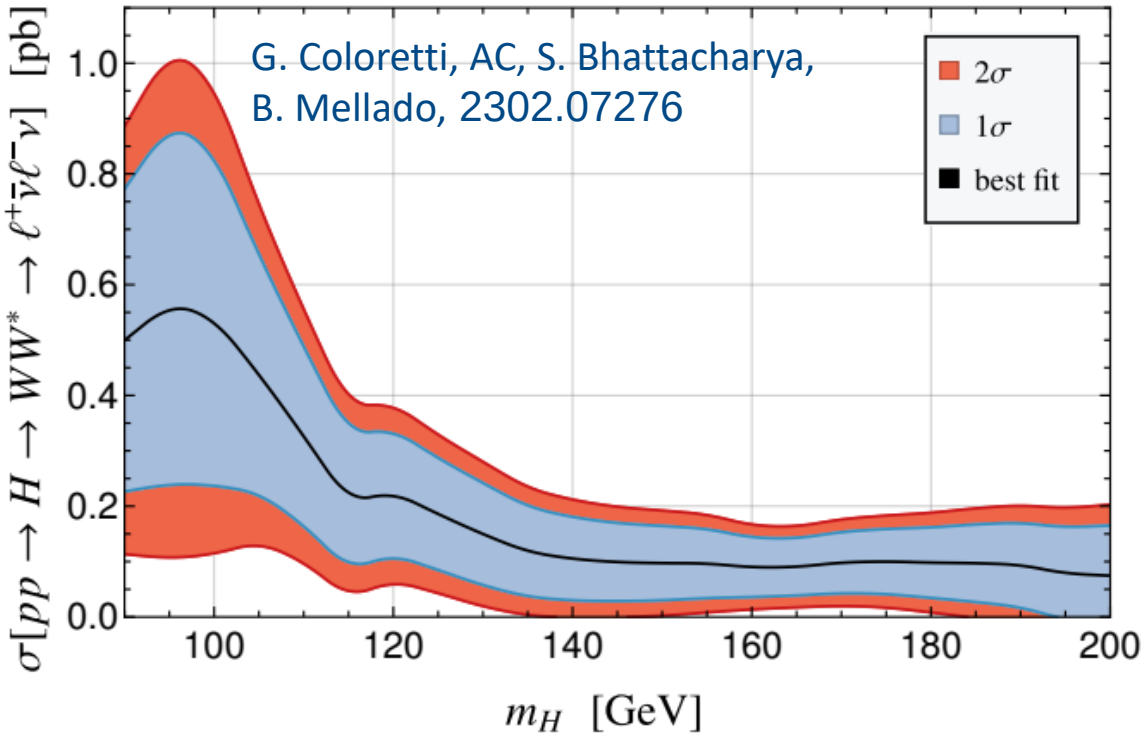
- Tree-level effect
- Necessary positive shift in the W mass
- Neutral component decays at tree-level (without mixing) only to W bosons
- Production via gluon fusion from mixing



Weak LHC bounds

Low mass WW resonances searches

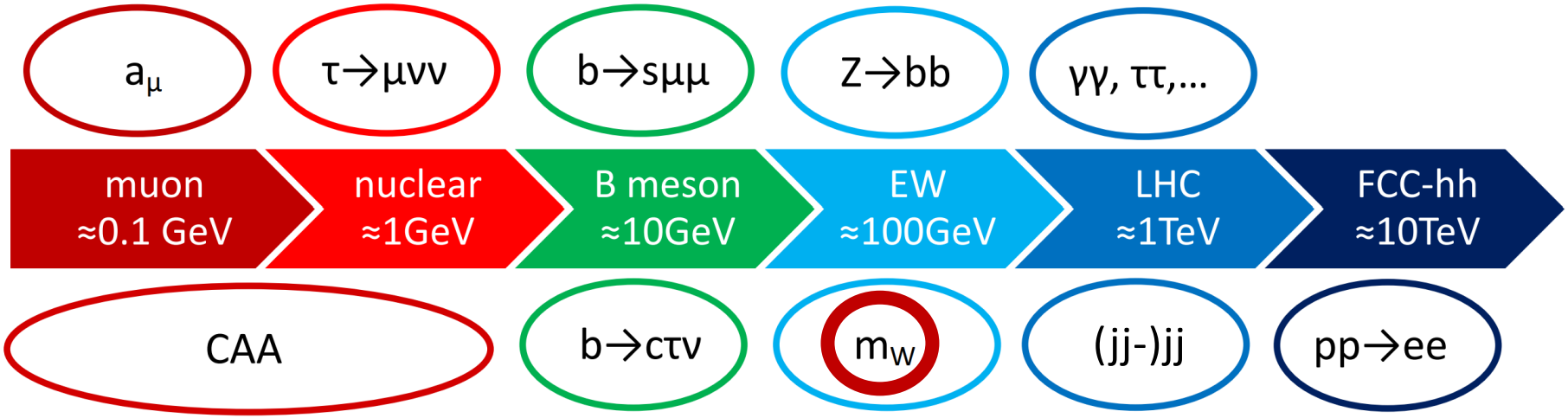
- No search available below 130 GeV
- Recasted and combined ATLAS and CMS searches for SM Higgs
- Related to 95 GeV H→γγ excess?



Room for new resonances decaying to WW

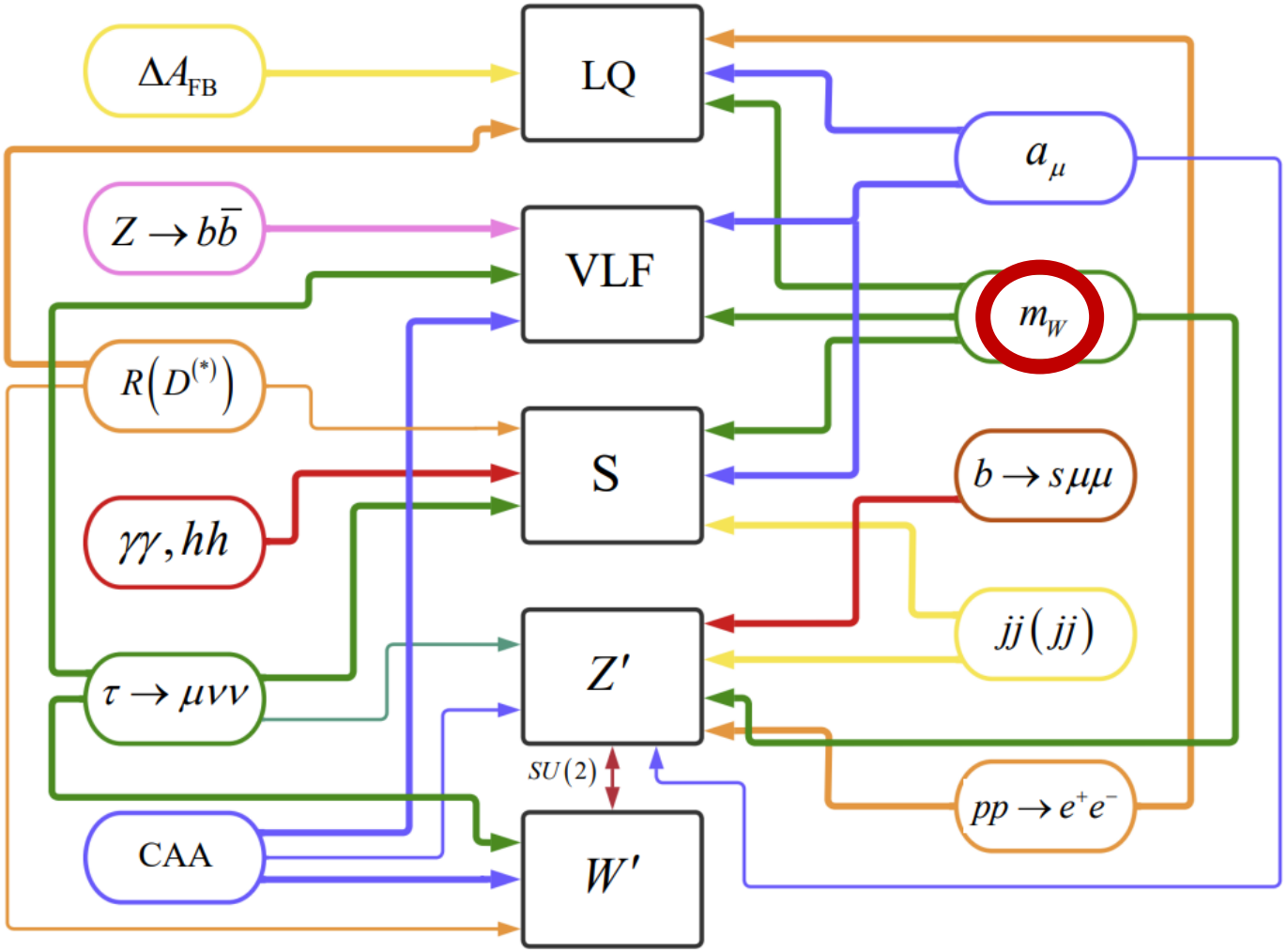
Conclusions I

- Many hints for physics beyond the SM in
  - Flavour
  - EW observables (including W mass)
  - Direct LHC searches



Large range of energies

Conclusions II



W mass a interesting part of the NP puzzle

τ→μνν

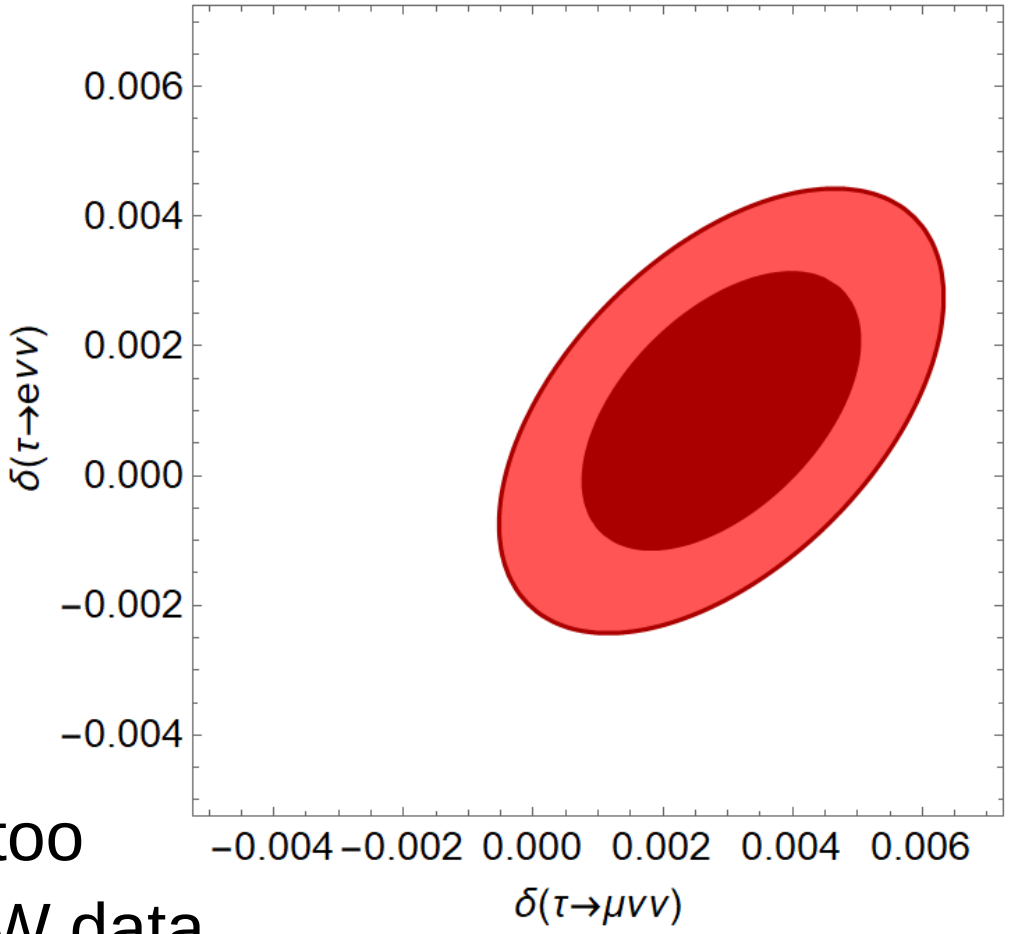
- Ratios of leptonic tau decays

$$\frac{A_{EXP}(\tau \to \mu\nu\bar{\nu})}{A_{SM}(\mu \to e\nu\bar{\nu})} = 1.0029 \pm 0.0014$$

$$\frac{A_{EXP}(\tau \to \mu\nu\bar{\nu})}{A_{SM}(\tau \to e\nu\bar{\nu})} = 1.0018 \pm 0.0014$$

$$\frac{A_{EXP}(\tau \to e\nu\bar{\nu})}{A_{SM}(\mu \to e\nu\bar{\nu})} = 1.0010 \pm 0.0014$$

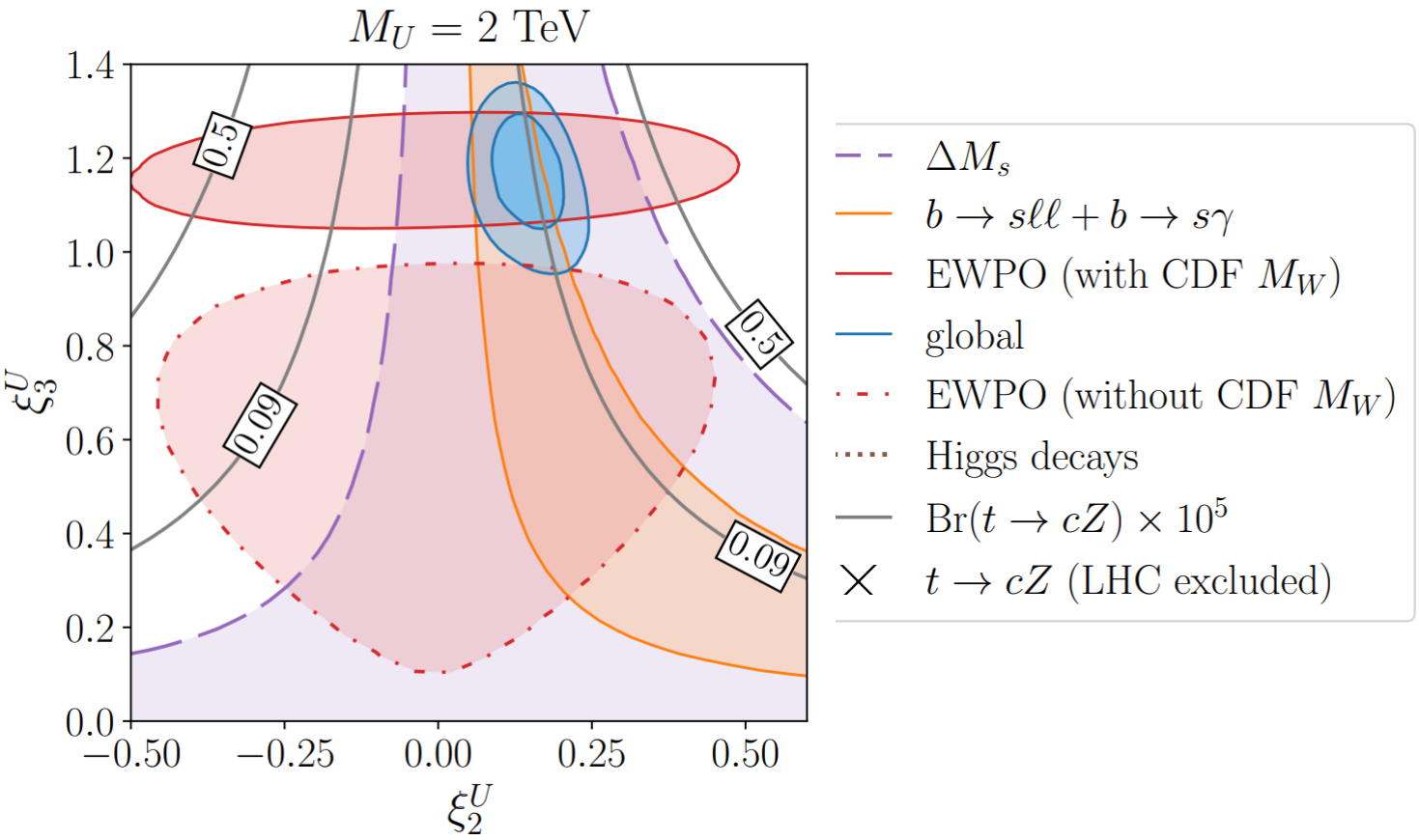
$$\rho = \begin{pmatrix} 1.00 & 0.49 & 0.51 \\ 0.49 & 1.00 & -0.49 \\ 0.51 & -0.49 & 1.00 \end{pmatrix}$$



- NP in muon decay too constrained from EW data

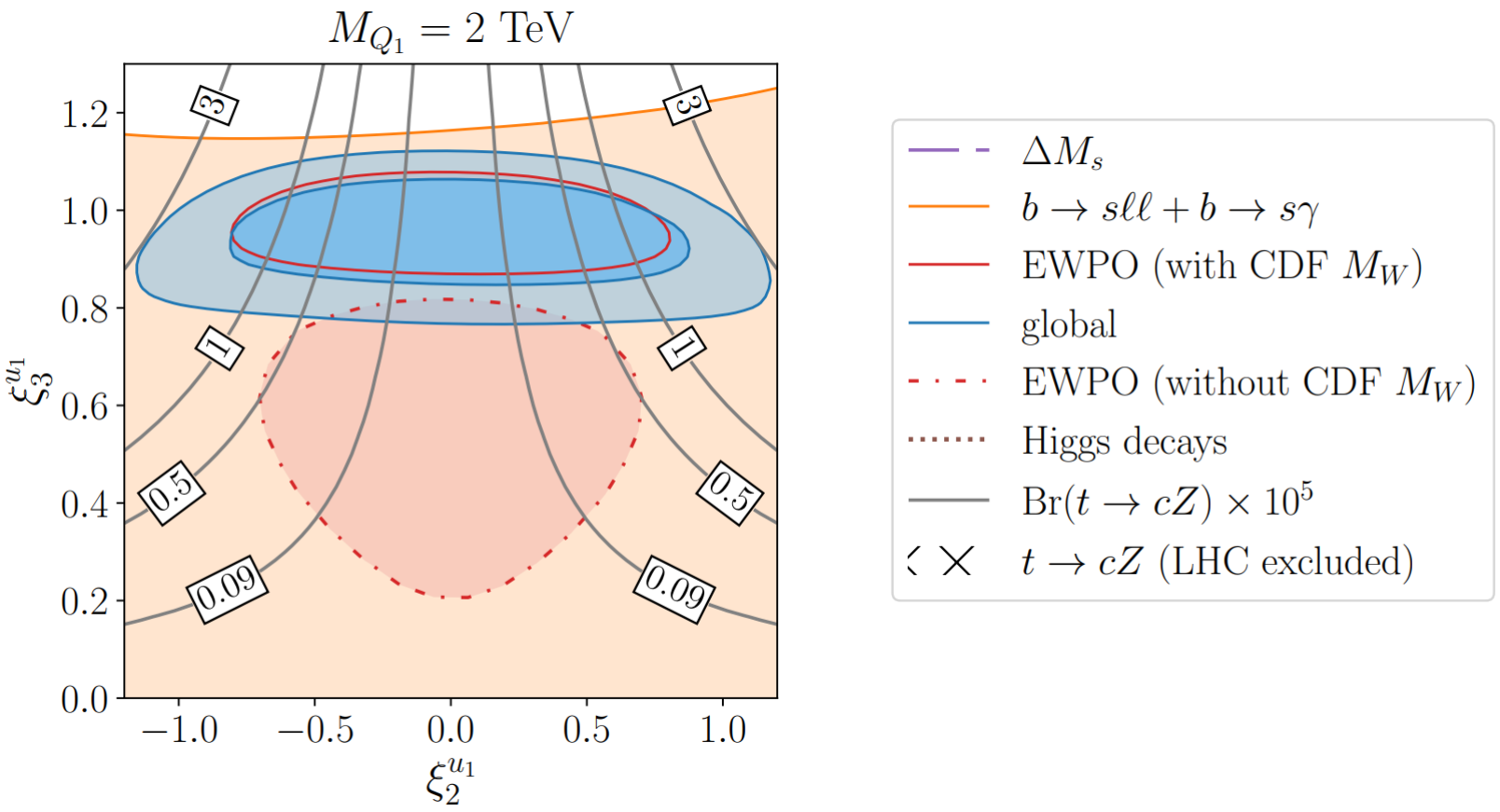
≈2σ hint for LFUV in tau decays

t→Zc and W mass



VLQ only option for large t→cZ

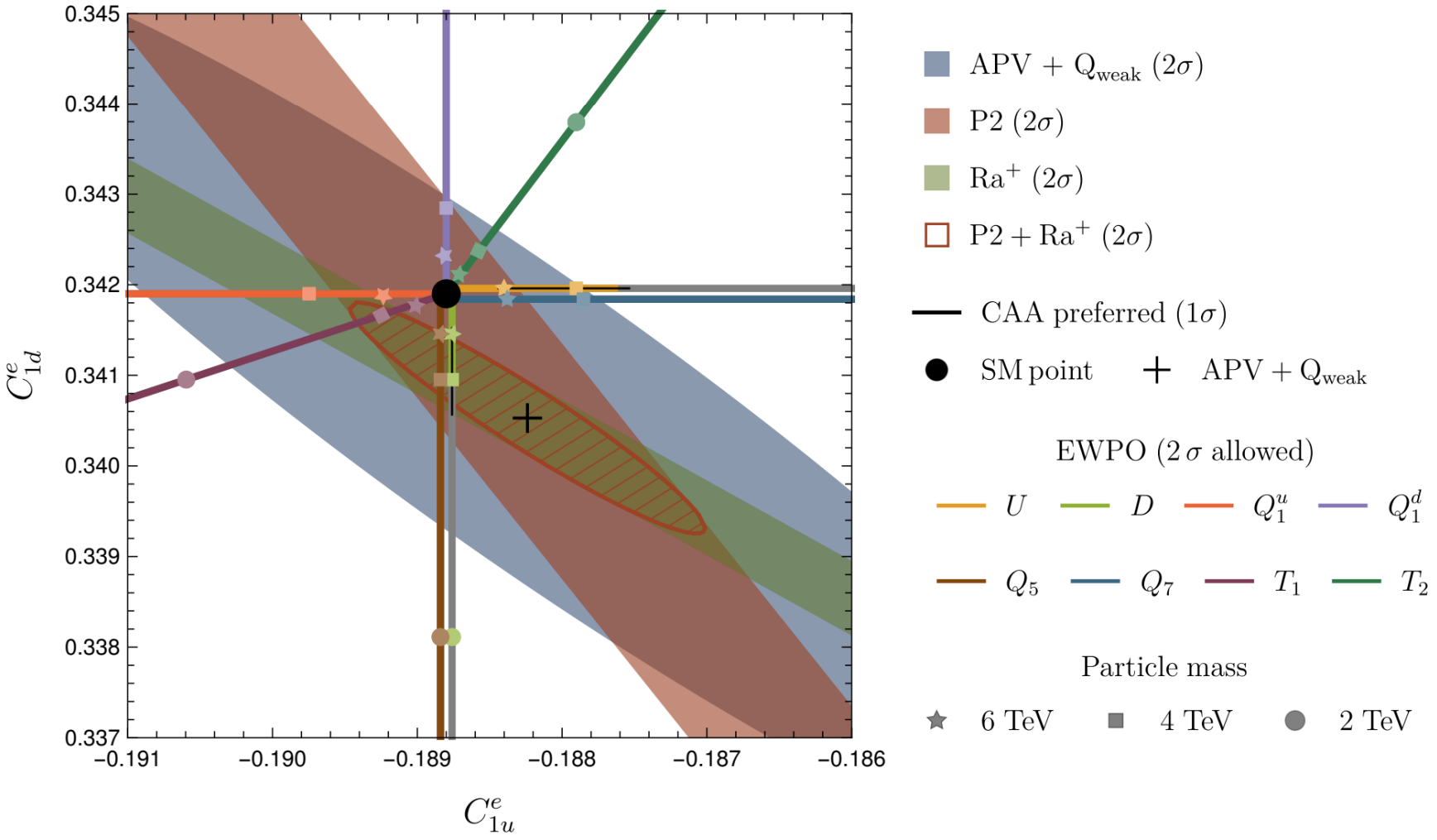
t→Zc and W mass



VLQ only option for large t→cZ

1th generation VLQs

A.C., M. Hoferichter, M. Kirk,
C. Manzari and L. Schnell, 2107.13569



Observable effect in low-energy PV possible