

B-physics connection with High- p_T searches (@ LHC)

Based on work done with A. Dighe, D. Bhatia, and A. Sengupta

arXiv: 2109.07093, 2301.01754

Question of Interest

Can models that solve the B-physics anomalies have signatures in high- p_T searches at the LHC?

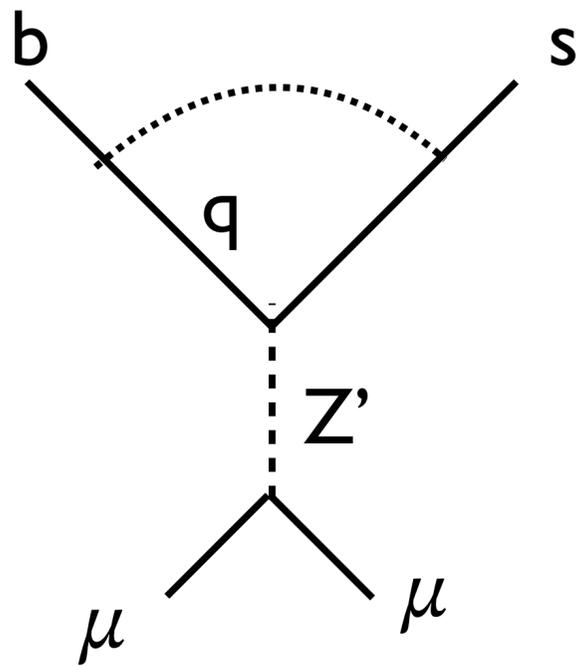
- Flavour observables tend to deal with (relatively) low-energy physics, EFT is a good description
- Multiple anomalies over the last few years in measurements of decays in rare $b \rightarrow s$ and $b \rightarrow c$ sectors.
- Multiple groups use sophisticated fits to higher dimensional operators to pinpoint underlying physics, in particular

$$\mathcal{O}_{9\ell}^{(l)} = \frac{\alpha_e}{4\pi} [\bar{s}\gamma_\mu P_{L(R)}b] [\bar{\ell}\gamma^\mu \ell] \quad \text{and} \quad \mathcal{O}_{10\ell}^{(l)} = \frac{\alpha_e}{4\pi} [\bar{s}\gamma_\mu P_{L(R)}b] [\bar{\ell}\gamma^\mu \gamma_5 \ell]$$

Favoured explanations

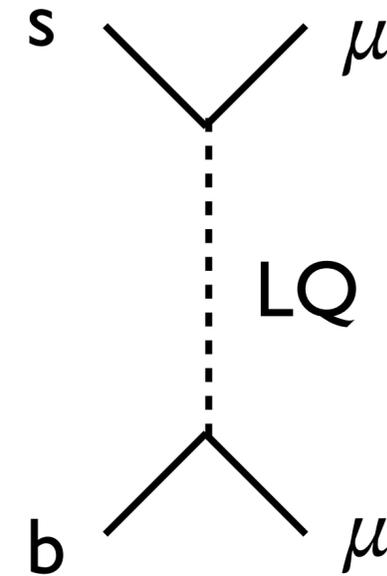
LHC is a high-energy machine \Rightarrow large momentum transfer \Rightarrow UV completion needed

Z' explanations



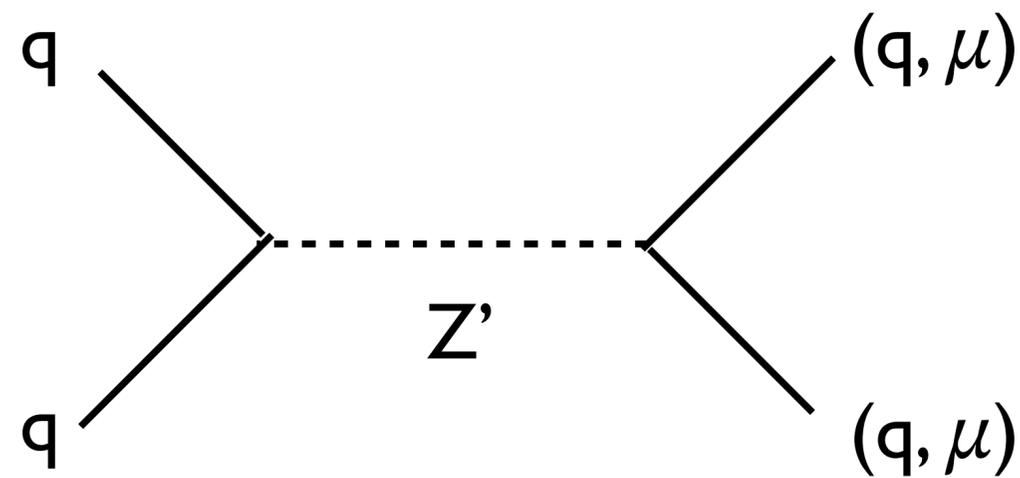
$$C_9 \sim \left(\frac{g_\mu g_q}{M} \right)^2$$

Leptoquark explanations

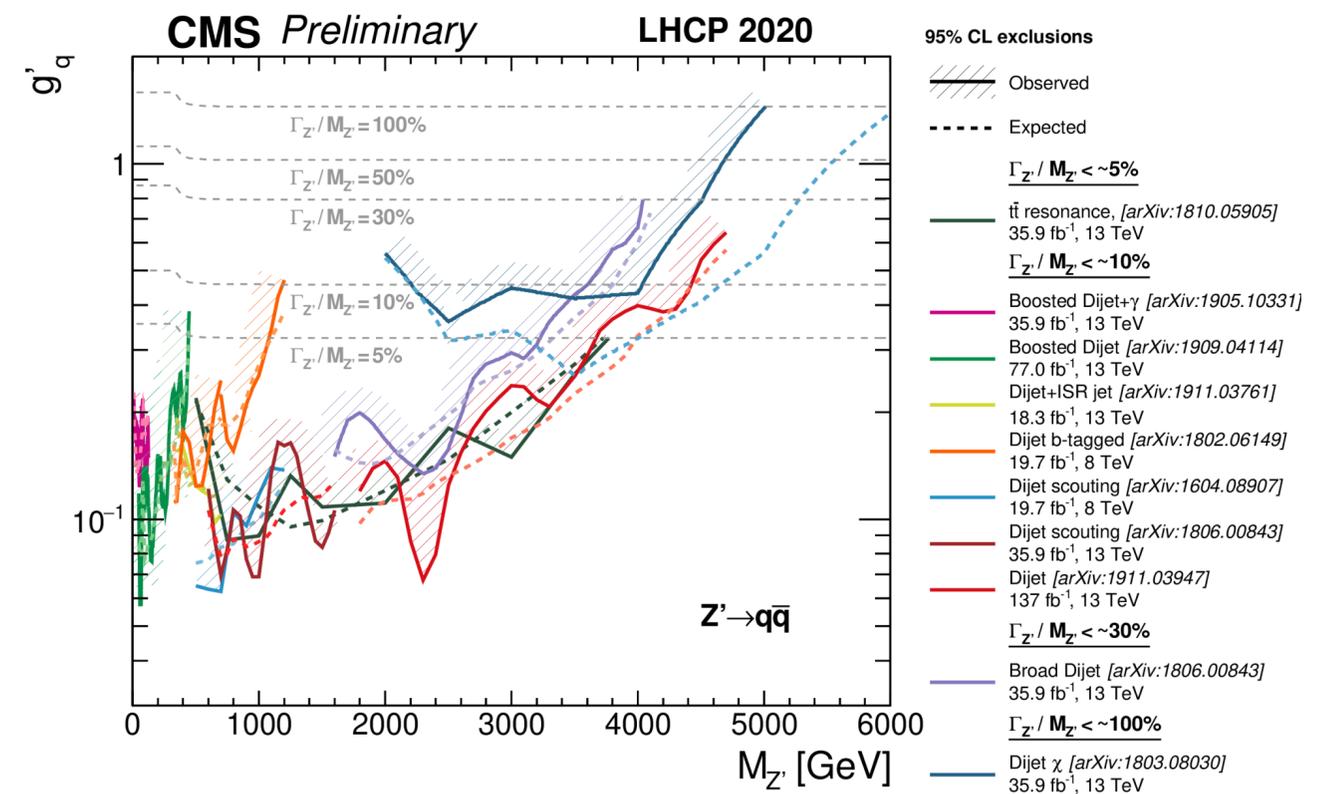


$$C_9 \sim \left(\frac{y_{22} y_{32}}{M} \right)^2$$

Production mechanisms at the LHC: Z'



- Can be seen in dilepton and dijet searches
- Typically have small decay width and searches use Narrow Width Approximation (NWA)



A Z' Model

$$U(1): \quad X \equiv \alpha_1 B_1 + \alpha_2 B_2 + \alpha_3 B_3 + \alpha_e L_e + \alpha_\mu L_\mu + \alpha_\tau L_\tau$$

Charge assignments

Fields	u, d	c, s	t, b	e, ν_e	μ, ν_μ	τ, ν_τ
X	$\alpha_1/3$	$\alpha_2/3$	$\alpha_3/3$	α_e	α_μ	α_τ

$$\mathcal{L}_{Z'} = g_{Z'} \bar{D}_L [V_{dL}^\dagger \cdot \mathbb{X}_q \cdot V_{dL}] \gamma^\mu D_L Z'_\mu$$

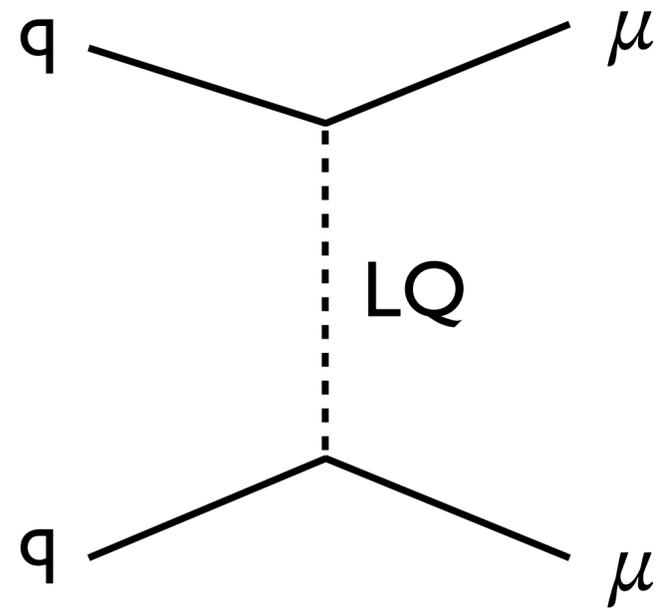
$$\mathbb{X} \equiv \text{diag}(X_u, X_c, X_t)$$

$$D_L \equiv (d_L, s_L, b_L)^T$$

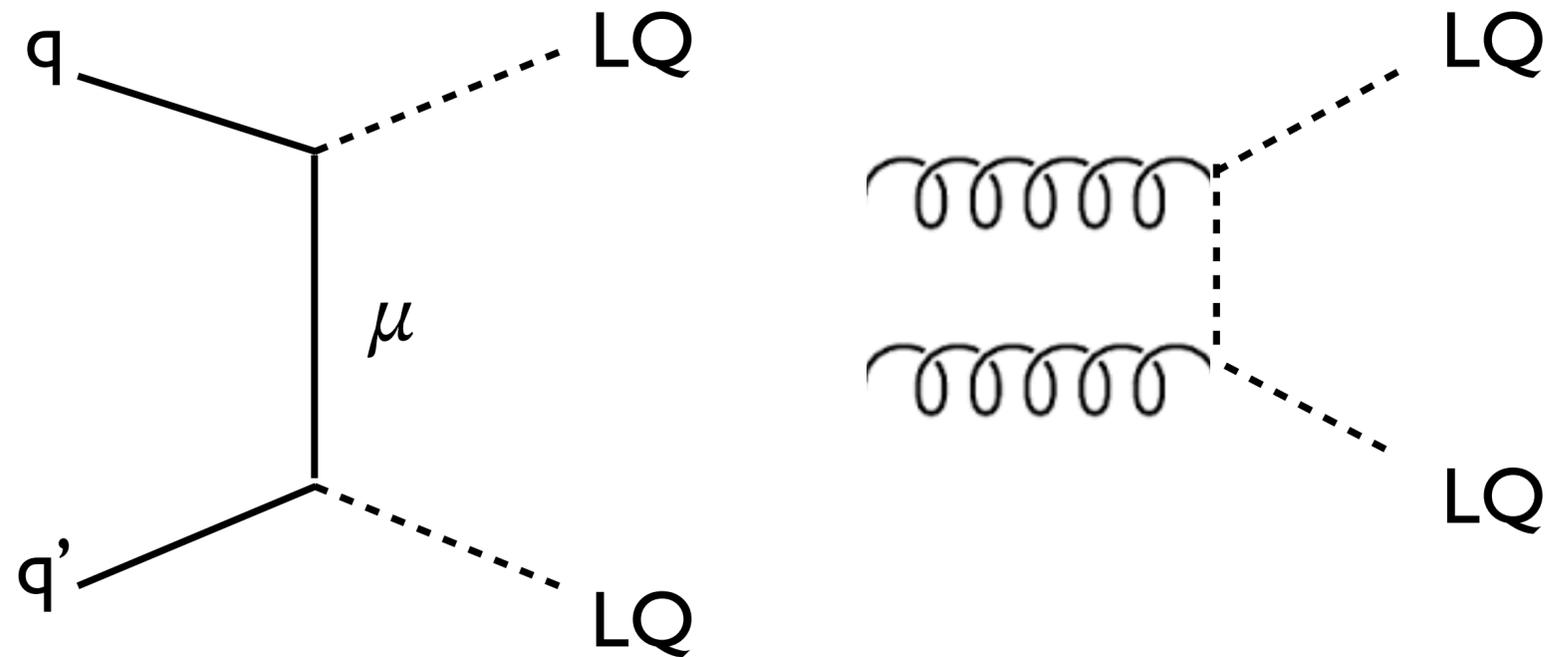
$$M_u^{\text{diag}} = V_{uL}^\dagger M_u V_{uR}, \quad M_d^{\text{diag}} = V_{dL}^\dagger M_d V_{dR}$$

$$C_{9\ell}^{\text{NP}} = \frac{4\sqrt{2} \pi^2 g_{Z'}^2}{G_F M_{Z'}^2 e^2} \cdot X_S \alpha_\ell \cdot \frac{[V_{dL}]_{tb} [V_{dL}]_{ts}^*}{[V_{\text{CKM}}]_{tb} [V_{\text{CKM}}]_{ts}^*}$$

Production mechanisms at the LHC: LQ



Can be seen in dilepton
(non-resonant)



Can be seen in: $2\mu+2$ jets
 $1\mu+2$ jets + MET or
2 jets + MET

Leptoquark models

$$S_3 (\bar{3}, 3, 1/3)$$

$$\mathcal{L}_{S_3} = y_L^{ij} \bar{Q}_i^C i\tau_2 (\tau_k S_3^k) L_j + h.c.$$

$$\begin{aligned} \mathcal{L}_{S_3} = & -y_L^{ij} \bar{d}_{Li}^C \nu_{Lj} S_3^{1/3} - \sqrt{2} y_L^{ij} \bar{d}_{Li}^C \ell_{Lj} S_3^{4/3} \\ & + \sqrt{2} (V^* y_L)^{ij} \bar{u}_{Li}^C \nu_{Lj} S_3^{-2/3} - (V^* y_L)^{ij} \bar{u}_{Li}^C \ell_{Lj} S_3^{1/3} + h.c. \end{aligned}$$

$$C_9^{l_1 l_2} = -C_{10}^{l_1 l_2} = \frac{\pi v^2}{V_{tb} V_{ts}^* \alpha_{em}} \frac{y_L^{bl_1} (y_L^{sl_2})^*}{m_{S_3}^2}$$

- Minimally: di-lepton production via ss, bb, bs. Also via cc (from CKM)
- For pair-production: Decays into jet+muon, jet + MET

Leptoquark models

$$\mathcal{L}_{R_2} = y_R^{ij} \bar{Q}_i l_{R_j} R_2 - y_L^{ij} \bar{u}_{R_i} R_2 i\tau_2 L_j + h.c.,$$

$$R_2 (3, 2, 7/6)$$

$$C_9^{l_1 l_2} = C_{10}^{l_1 l_2} = -\frac{\pi v^2}{2V_{tb}V_{ts}^* \alpha_{em}} \frac{y_R^{sl_1} (y_R^{bl_2})^*}{m_{R_2}^2},$$

$$U_1 (3, 1, 2/3)$$

$$\mathcal{L}_{U_1} = \beta_L^{ij} \bar{Q}_i \gamma_\mu L_j U_1^\mu + \beta_R^{ij} \bar{d}_{R_i} \gamma_\mu l_{R_j} U_1^\mu + h.c.,$$

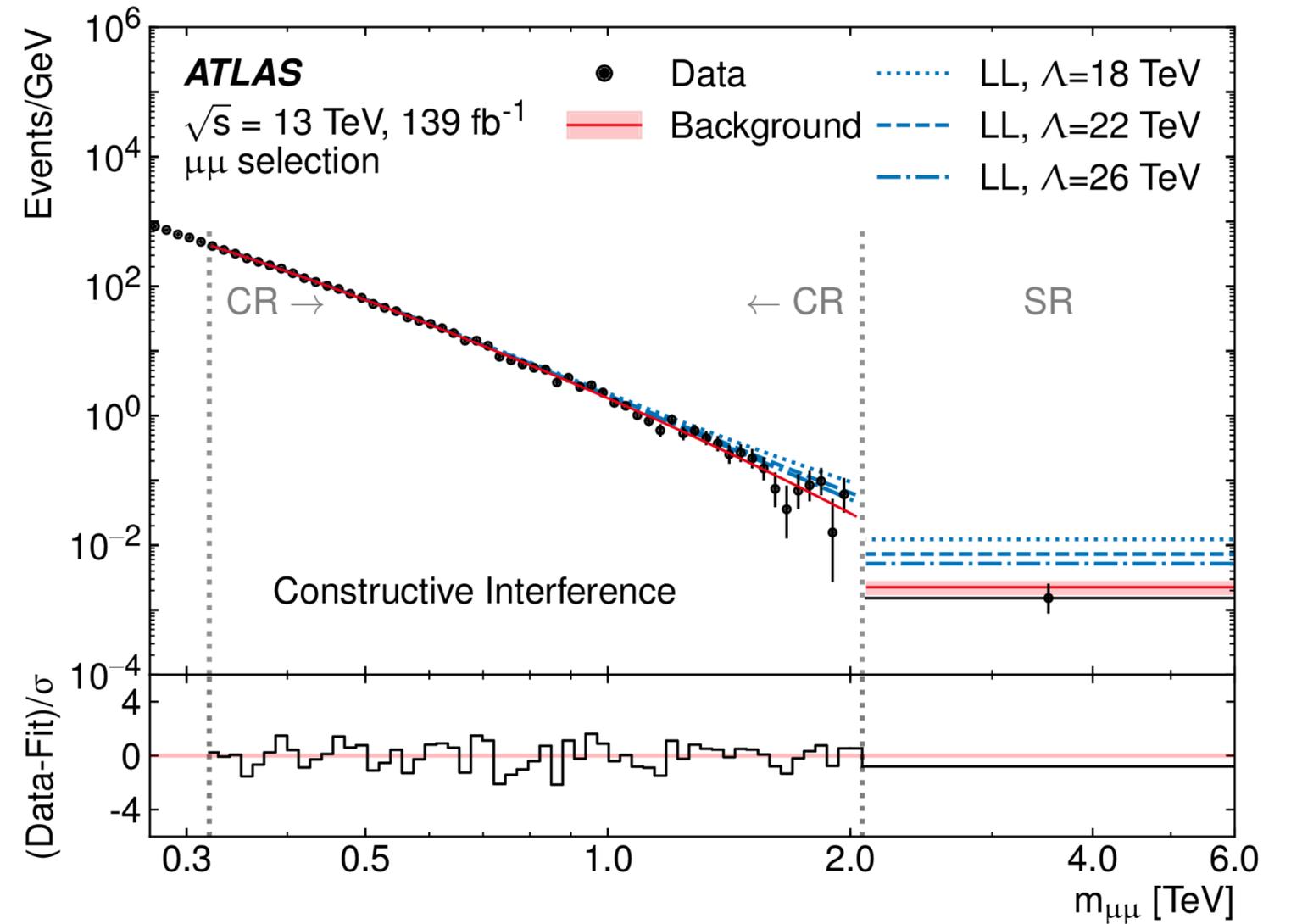
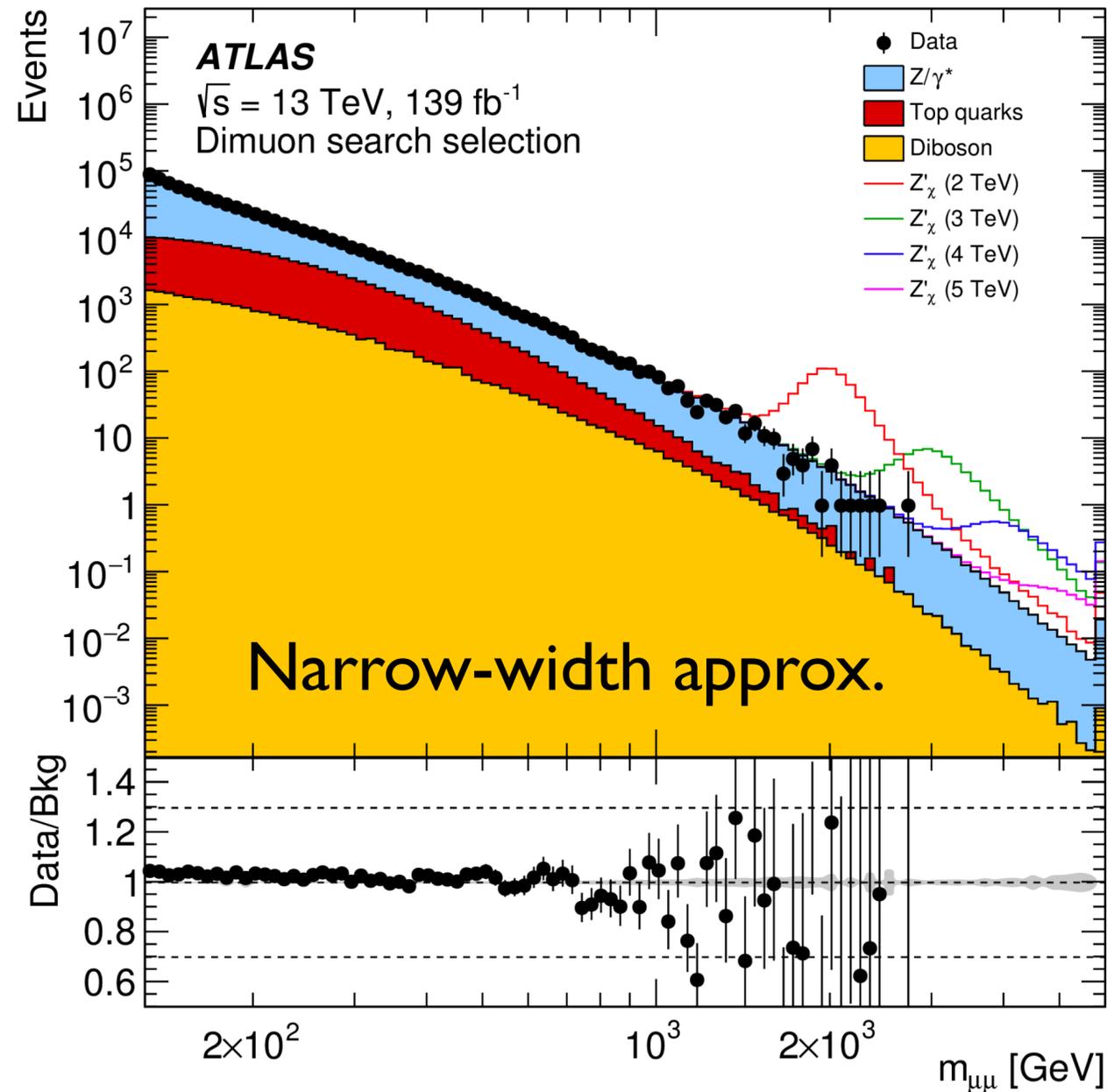
$$C_9^{l_1 l_2} = -C_{10}^{l_1 l_2} = -\frac{\pi v^2}{V_{tb}V_{ts}^* \alpha_{em}} \frac{\beta_L^{sl_1} (\beta_L^{bl_2})^*}{m_{U_1}^2},$$

Minimally, we only need the LH couplings

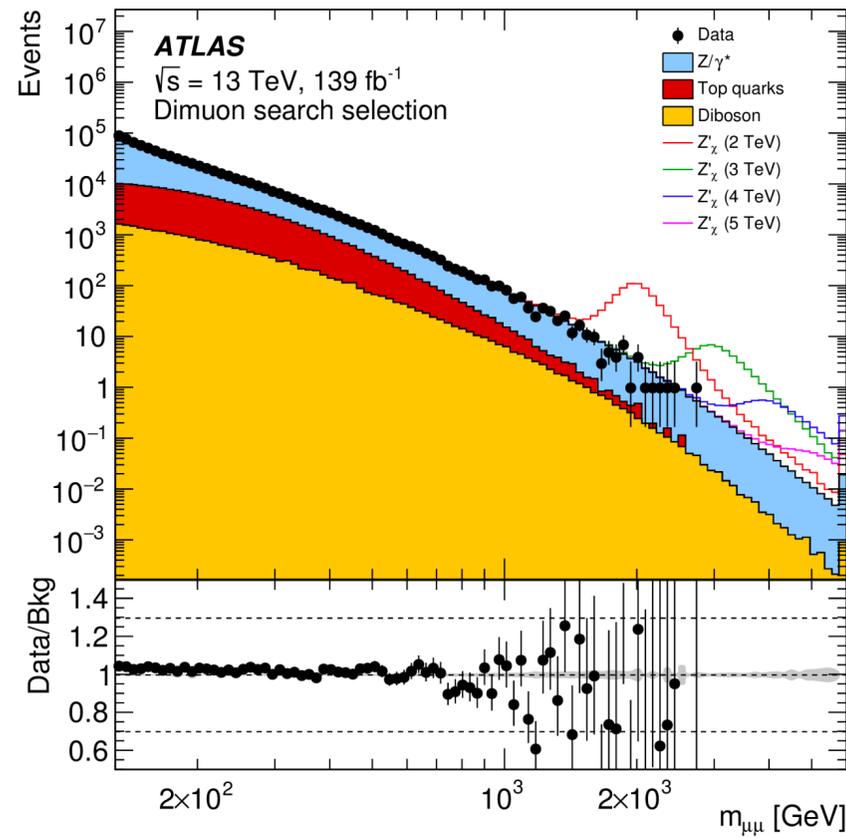
Main experimental channels: Dilepton channels

arXiv:1903.06248
EXOT-2018-08

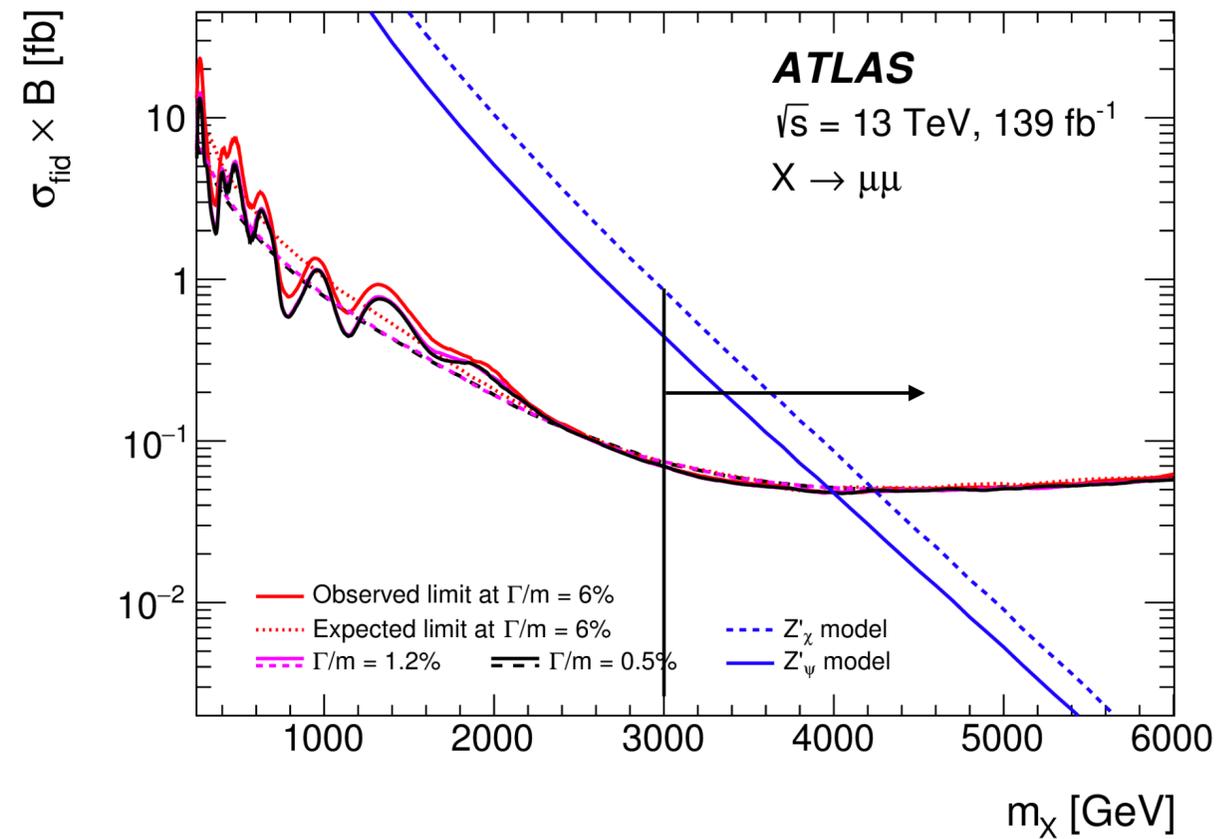
arXiv:2006.12946
EXOT-2019-16



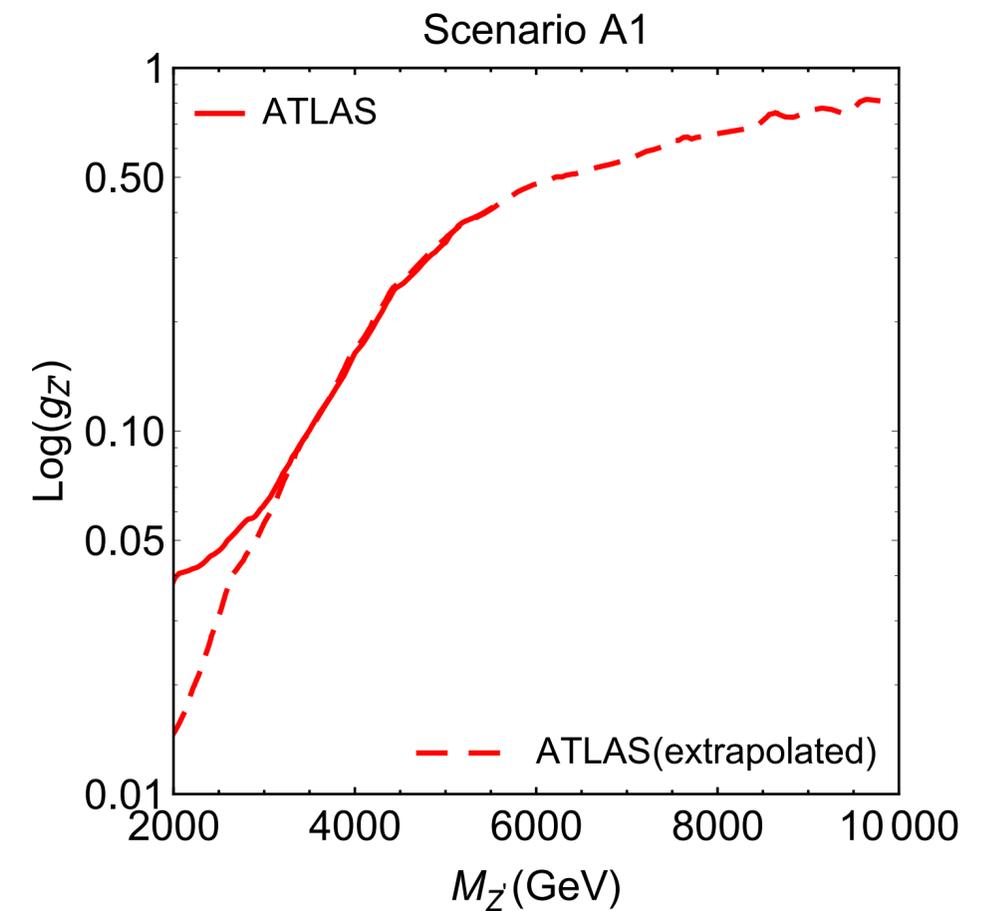
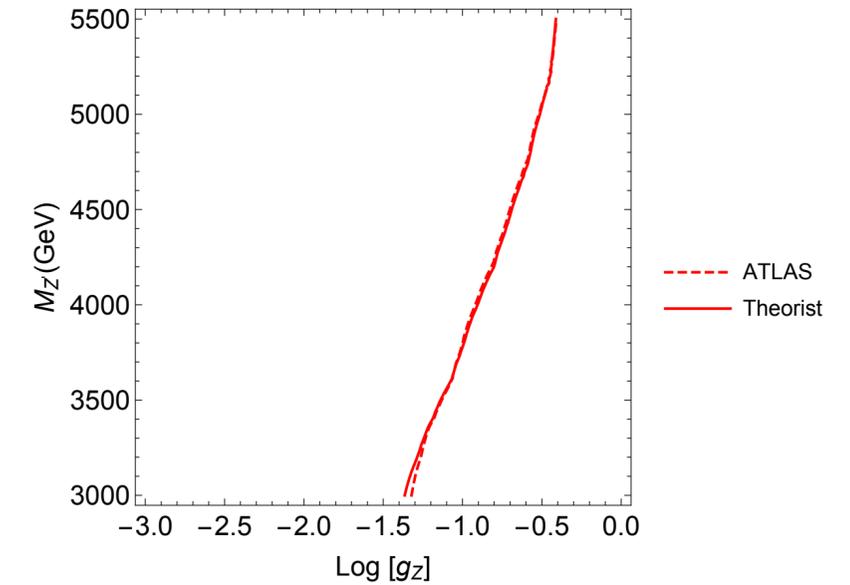
Extrapolation to other mass/coupling regimes



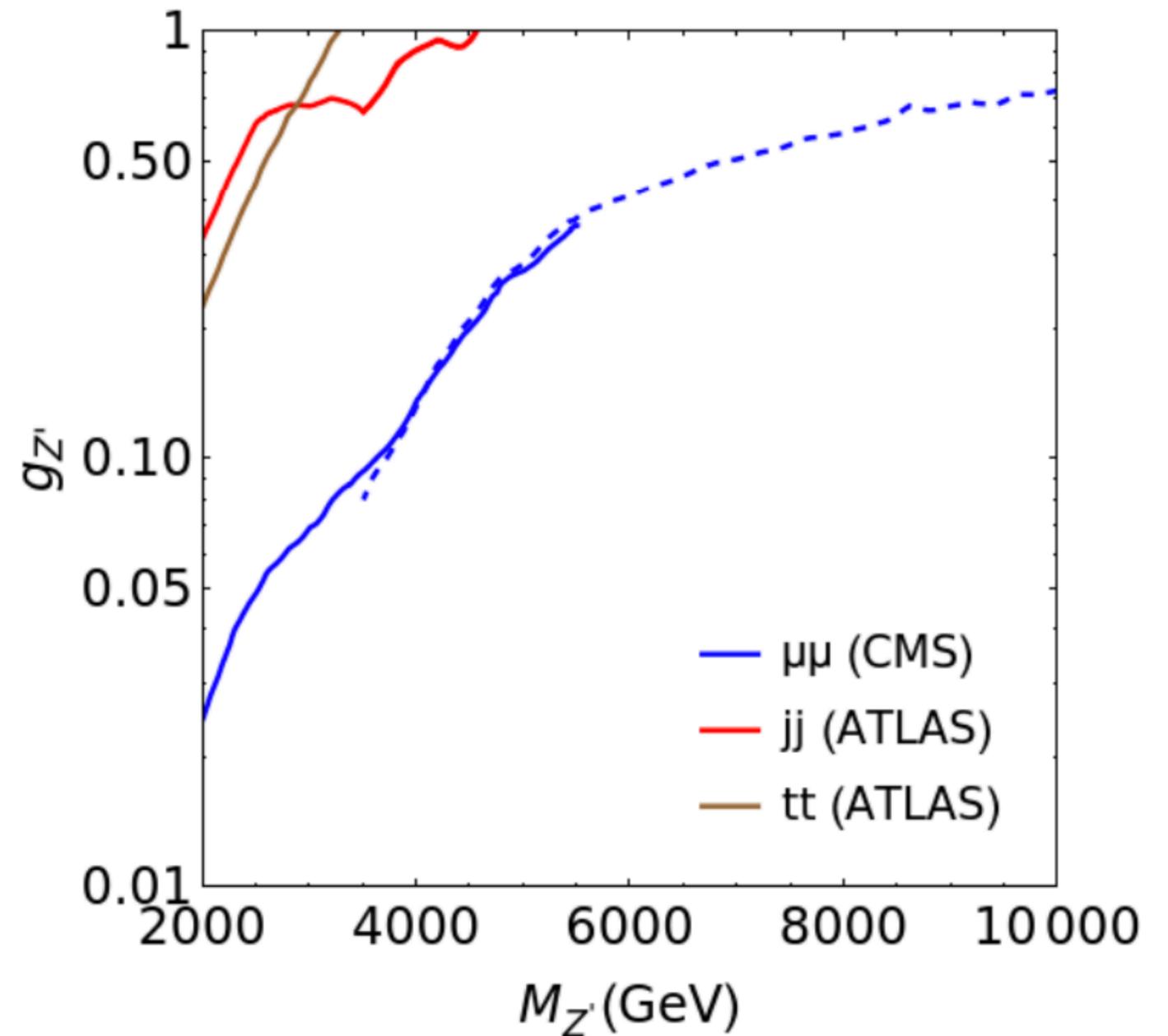
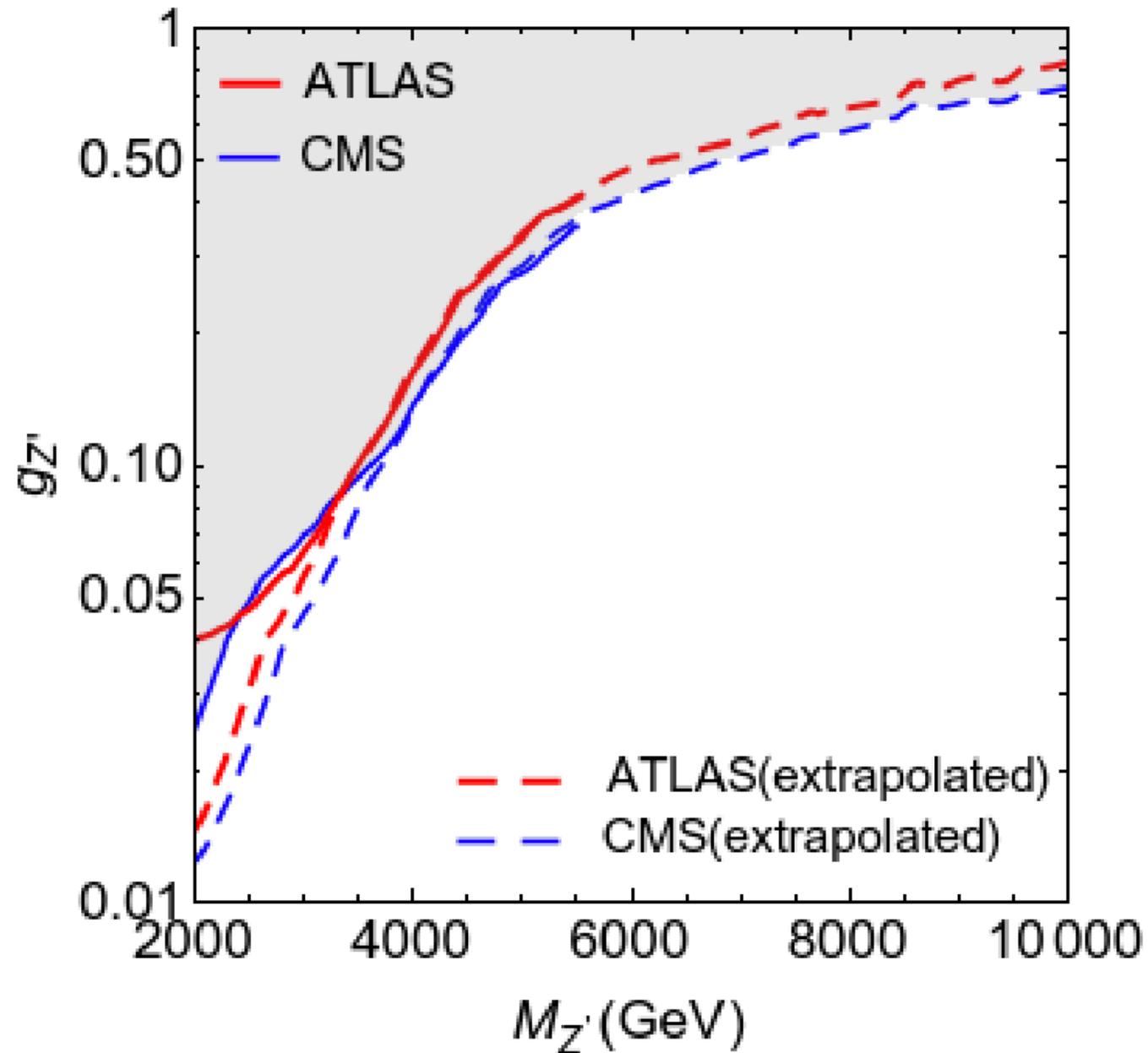
We use the last bin from this
 (applying all fiducial cuts)



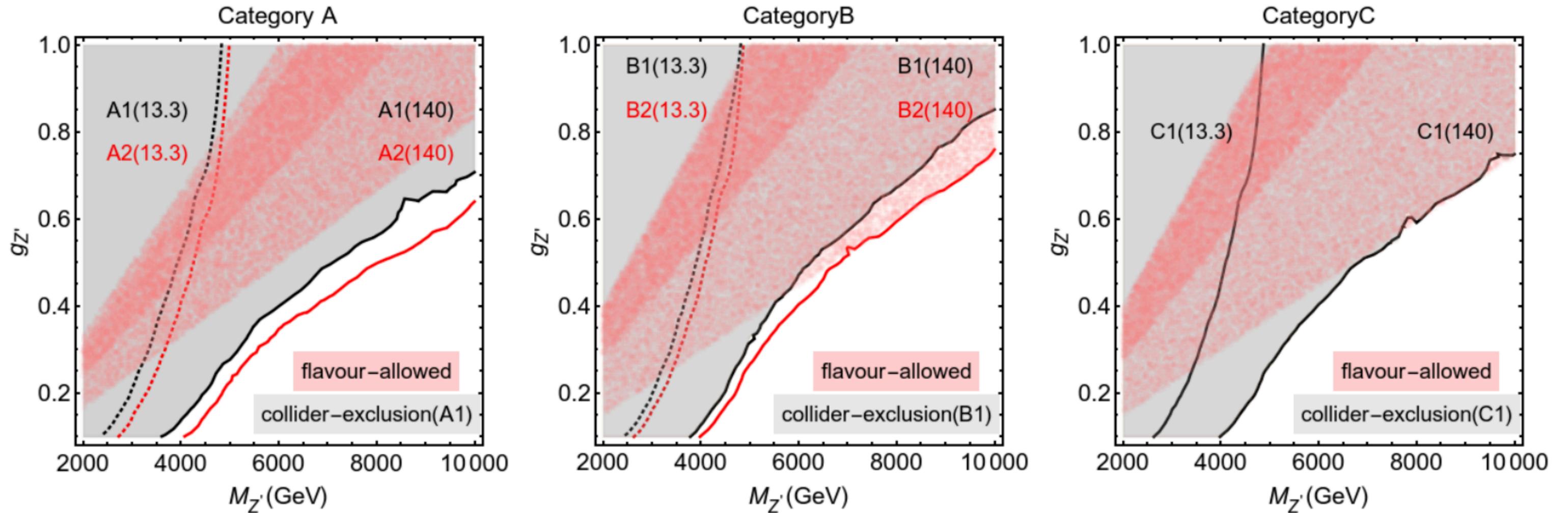
To compare with heavy mass exclusions



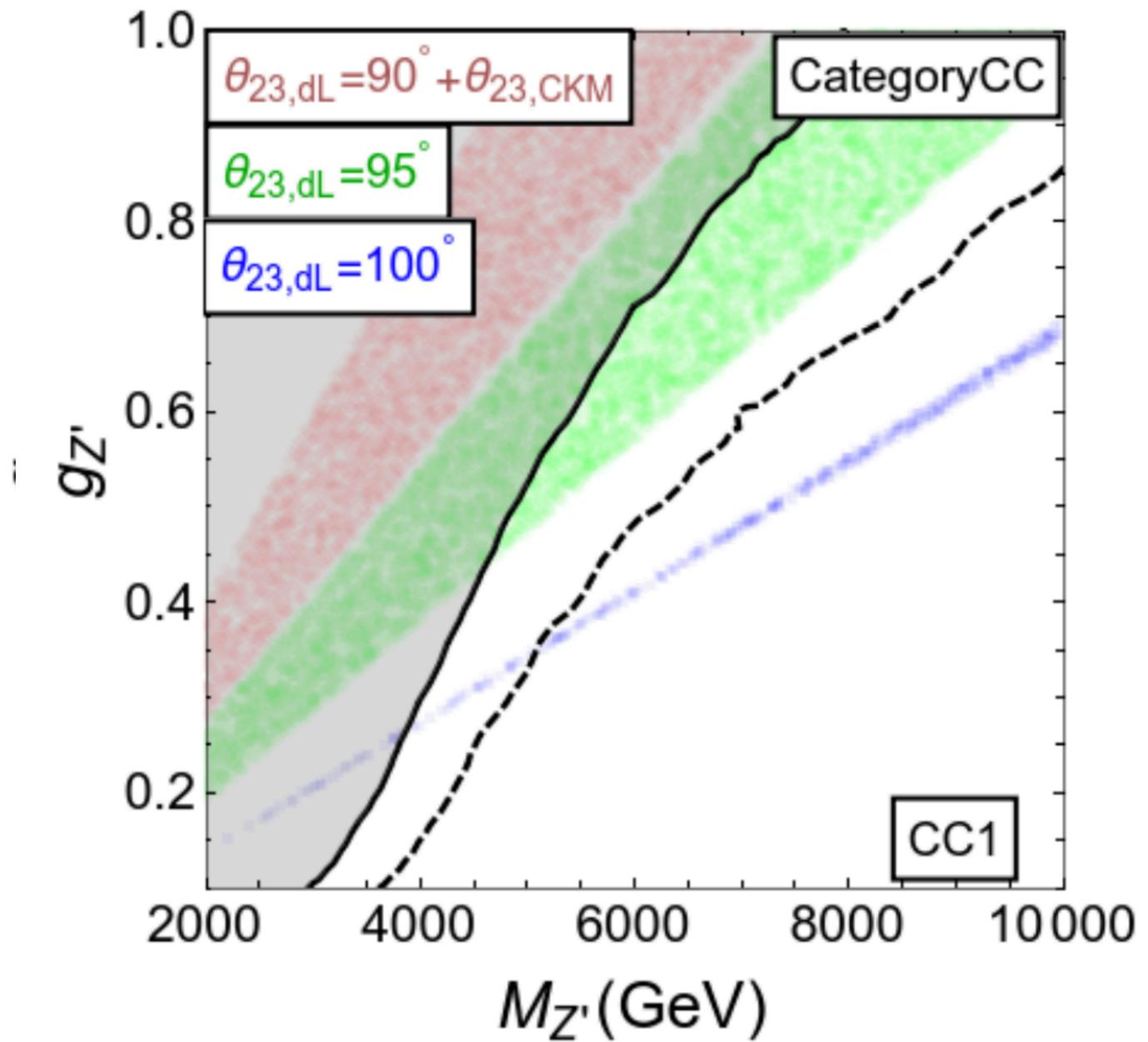
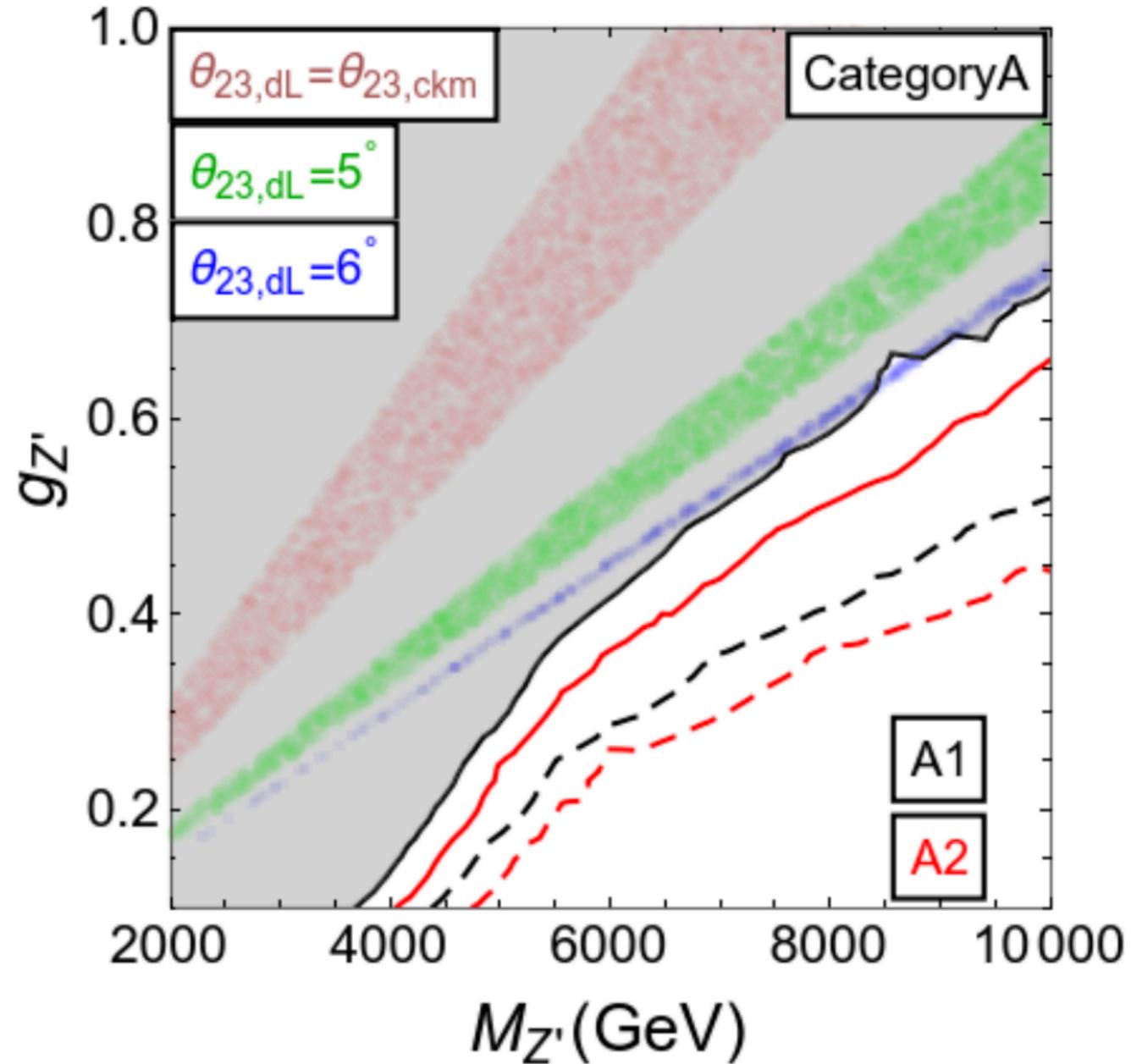
Reinterpretation of experimental searches: Z'



Situation of MFV scenarios

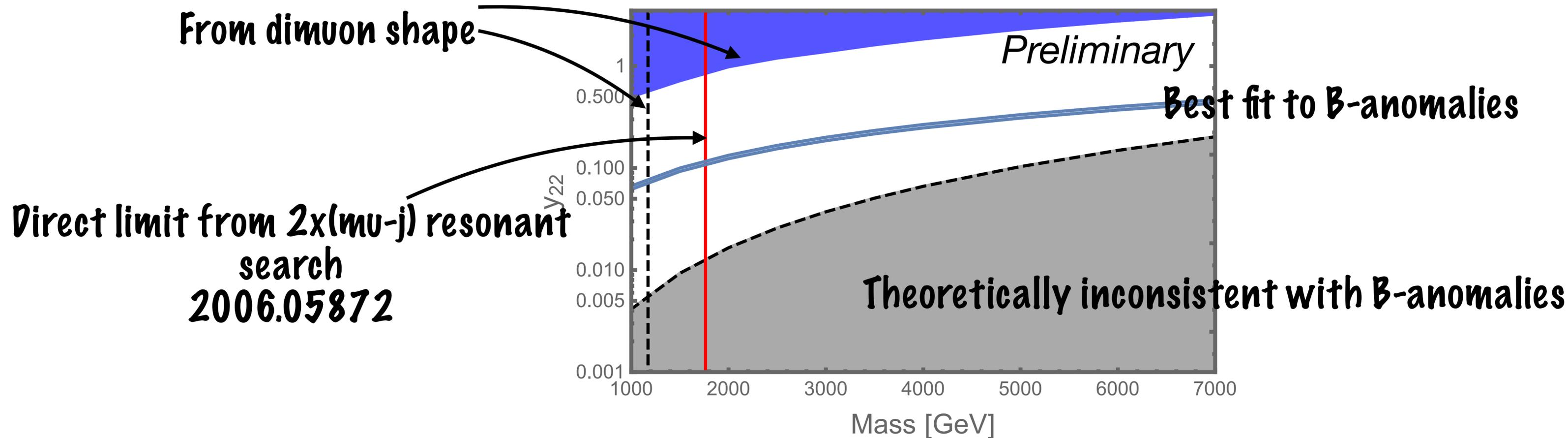
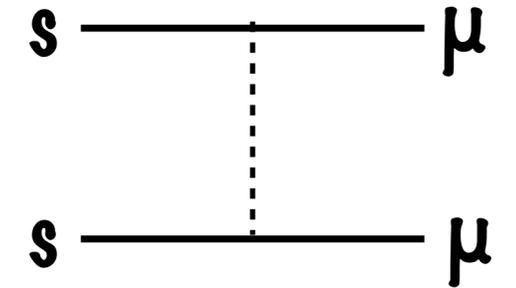


LHC Run-2 limits & HL-LHC prospects



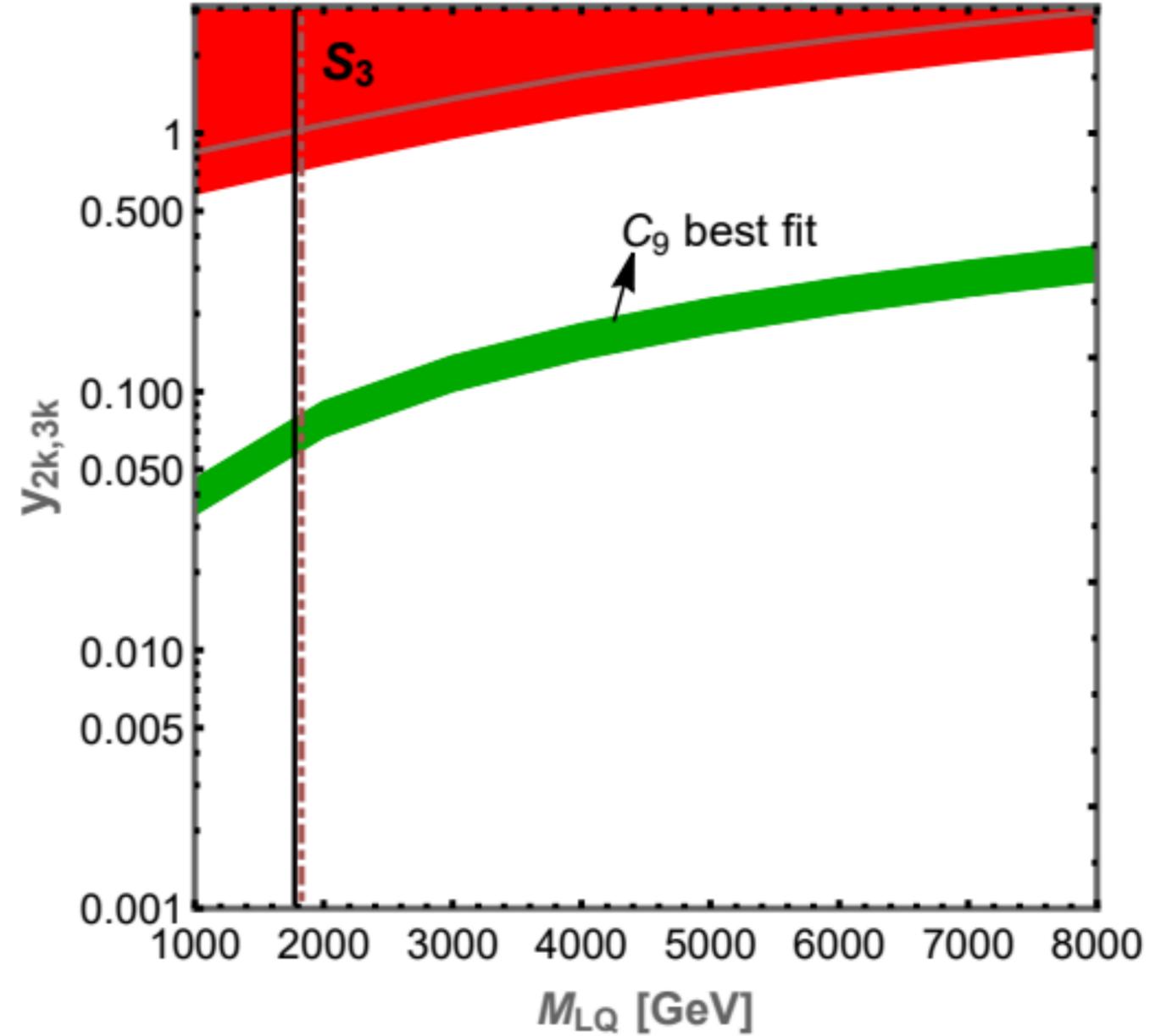
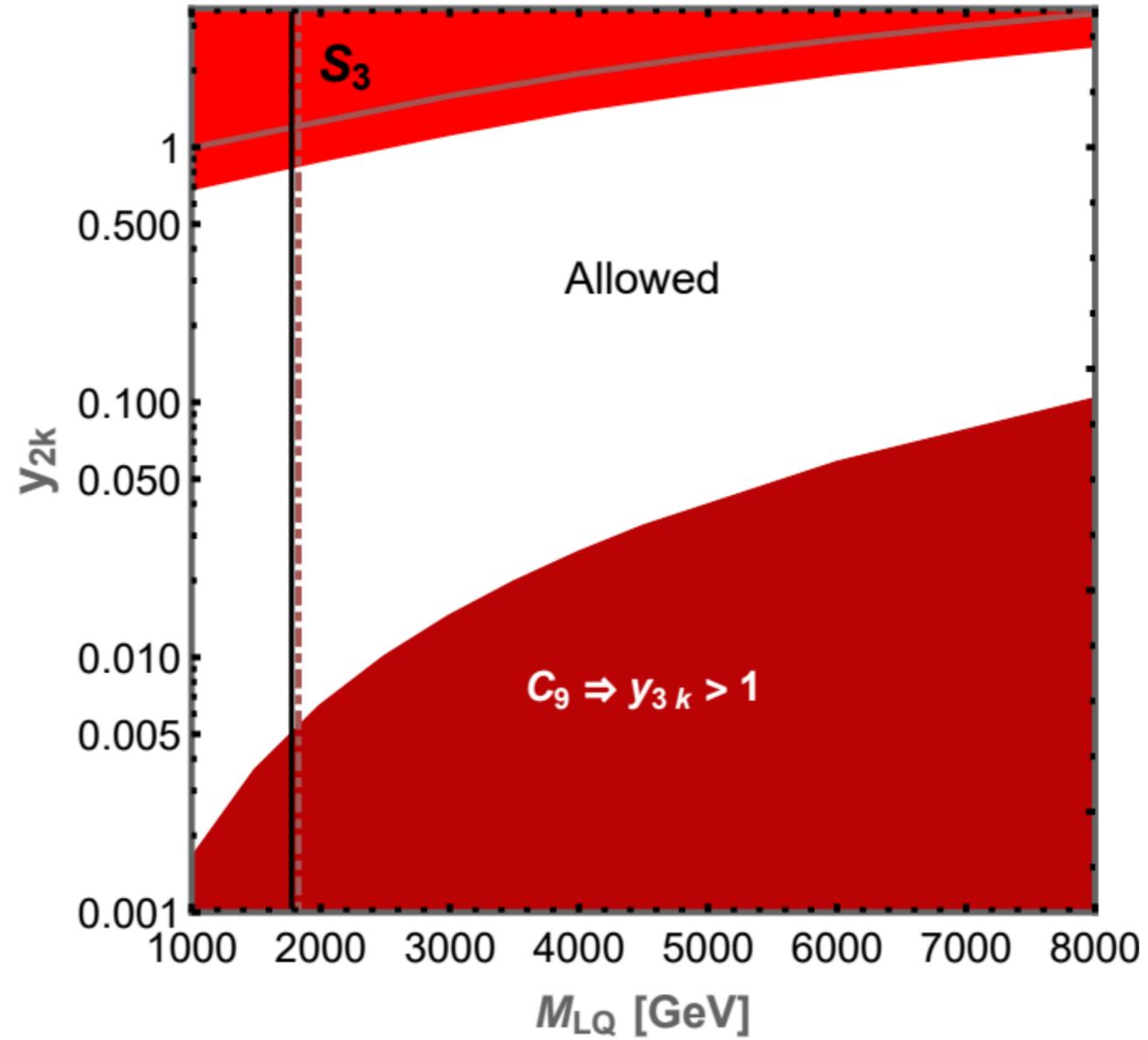
Apply to different model, same final state

E.g. Using dimuon spectrum to constrain leptoquark coupling (non-resonant)

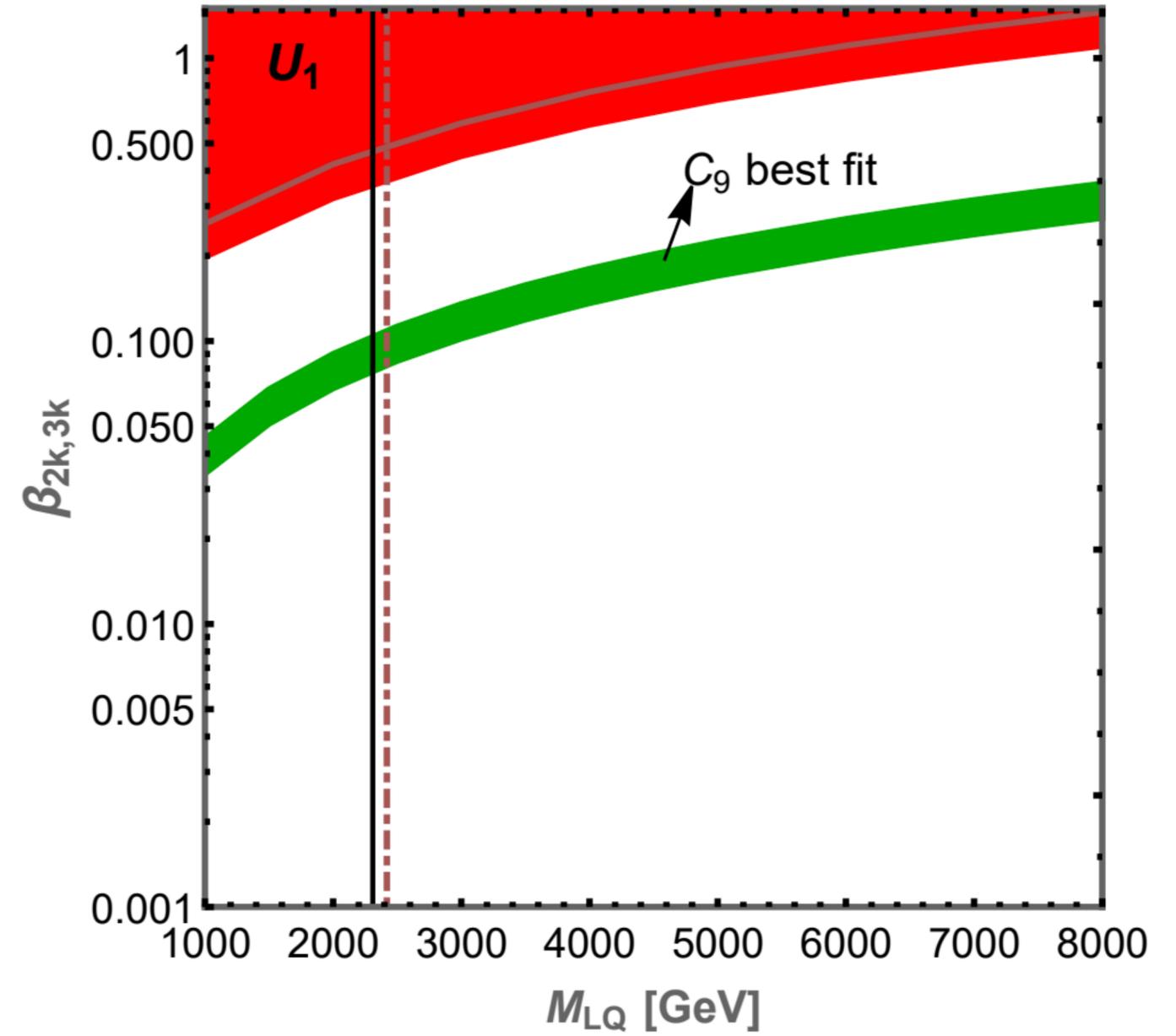
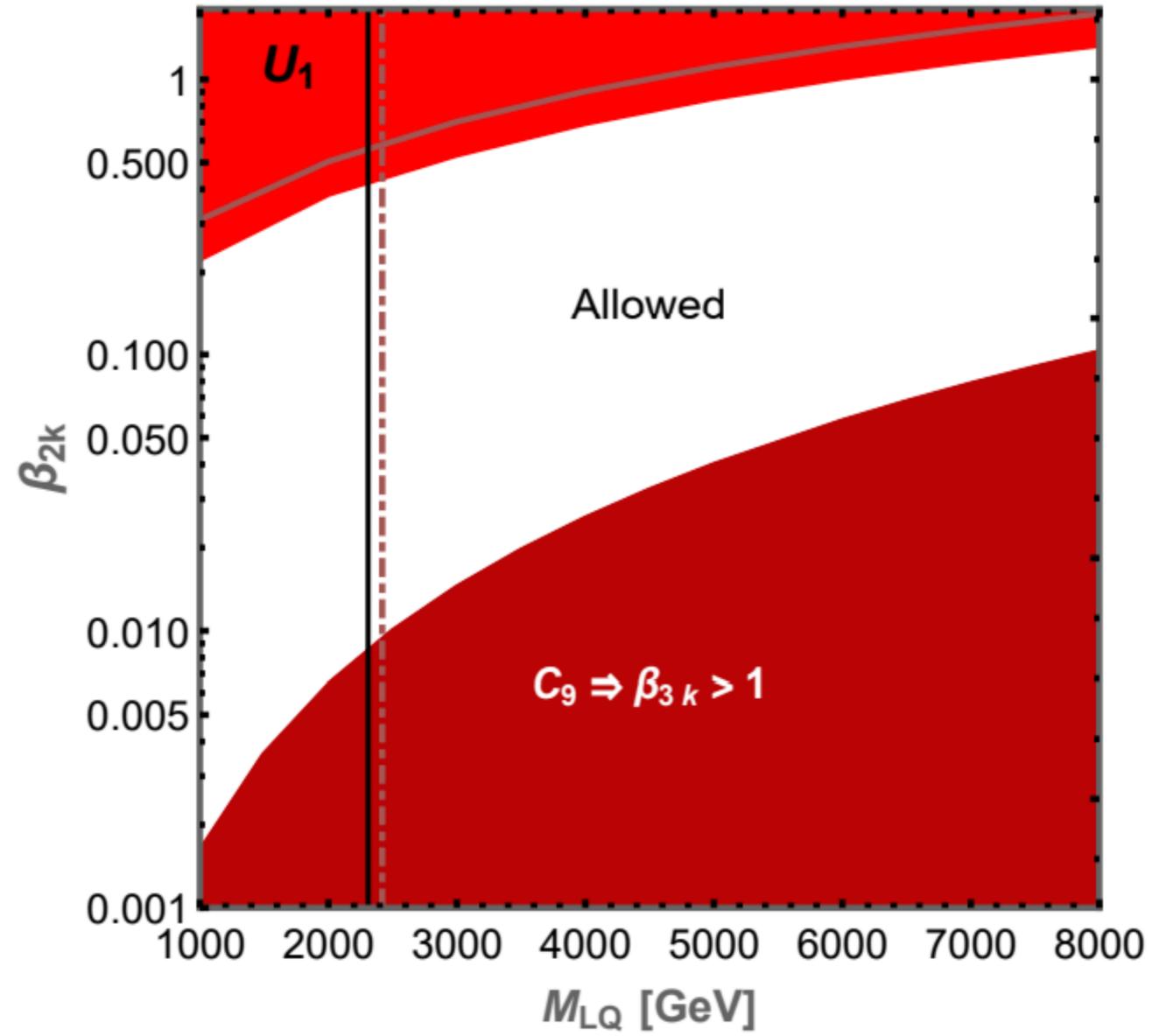


2006.12946 Also has background fits + simple (single bin) signal regions

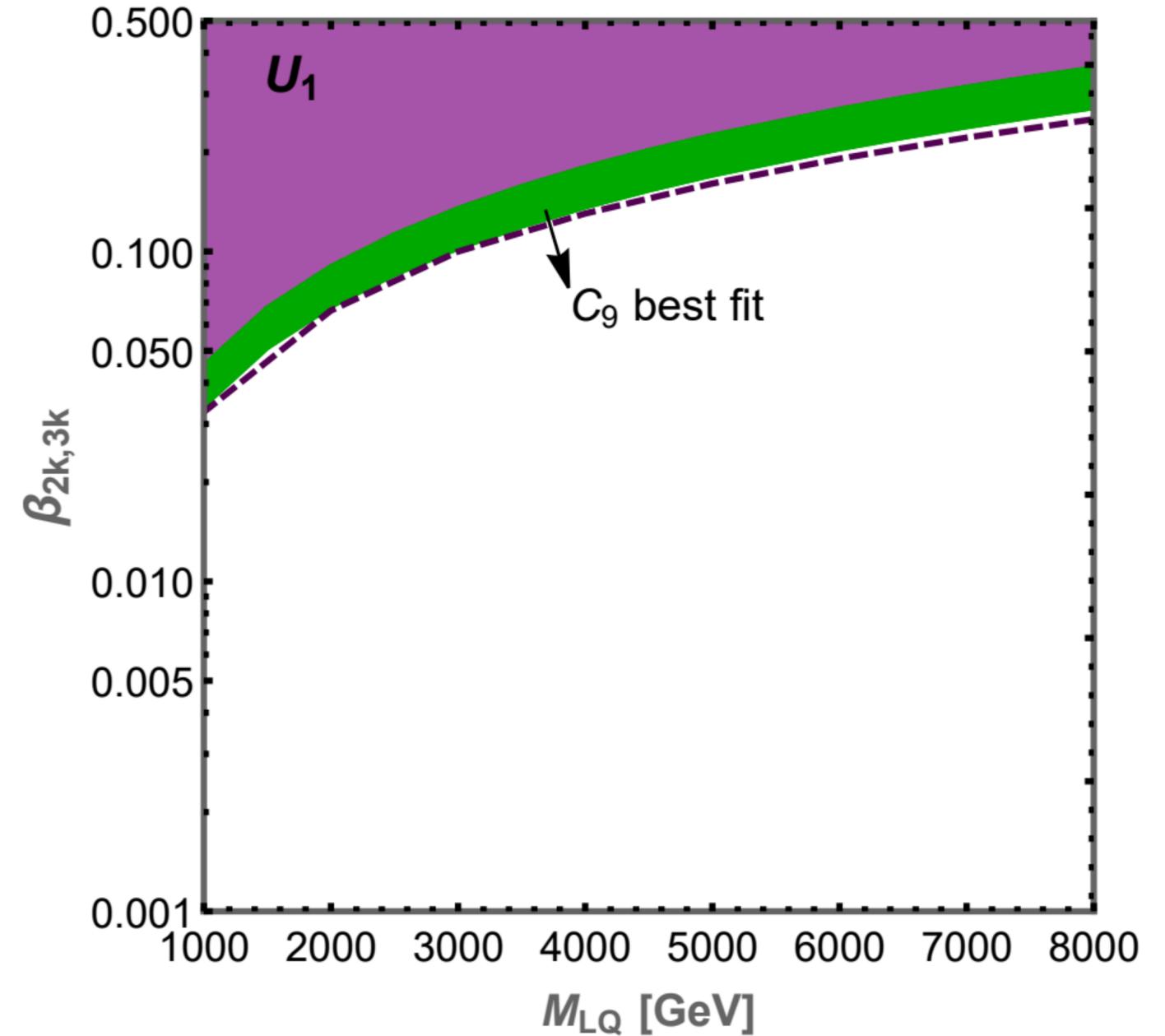
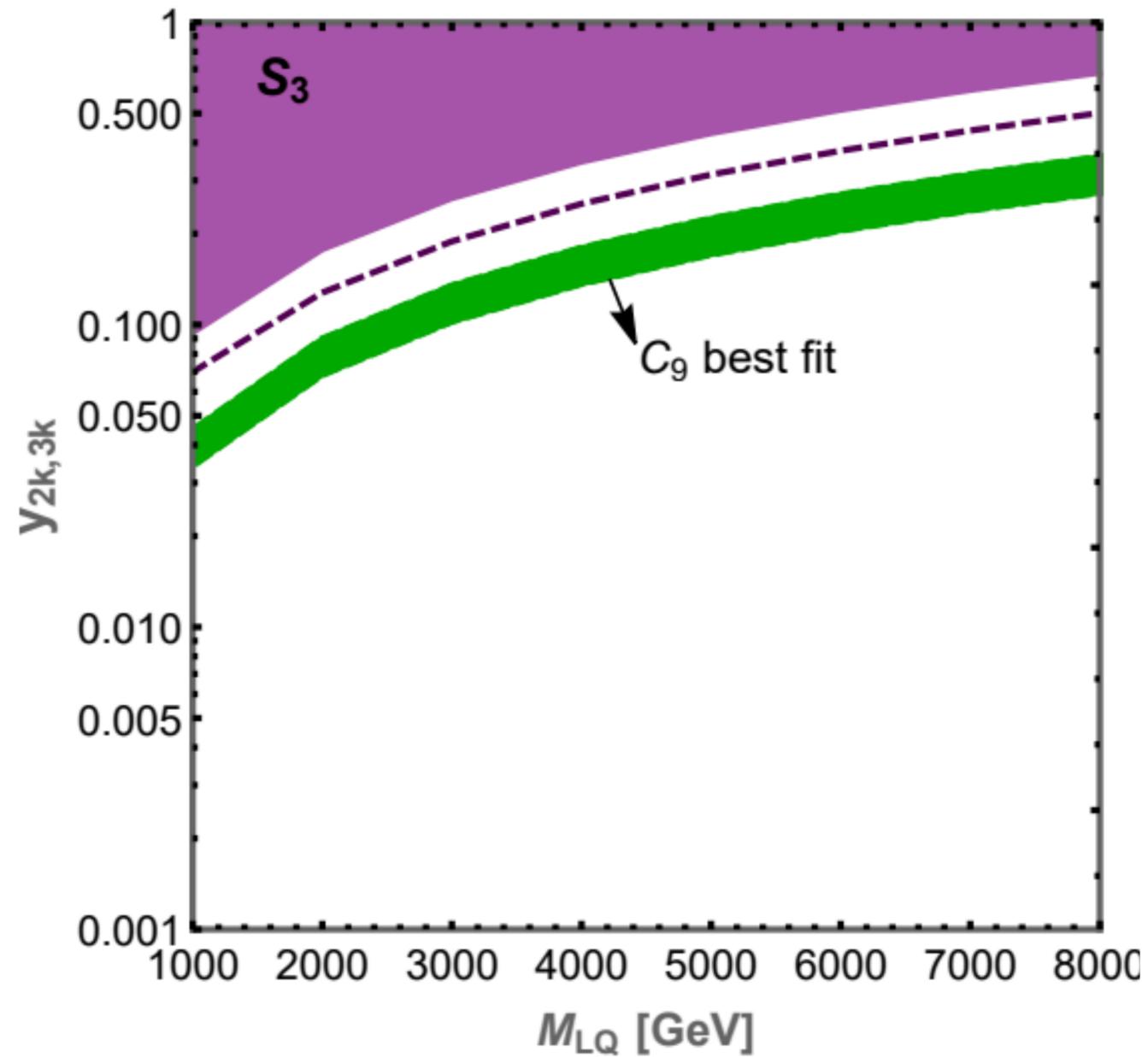
LHC Run-2 limits



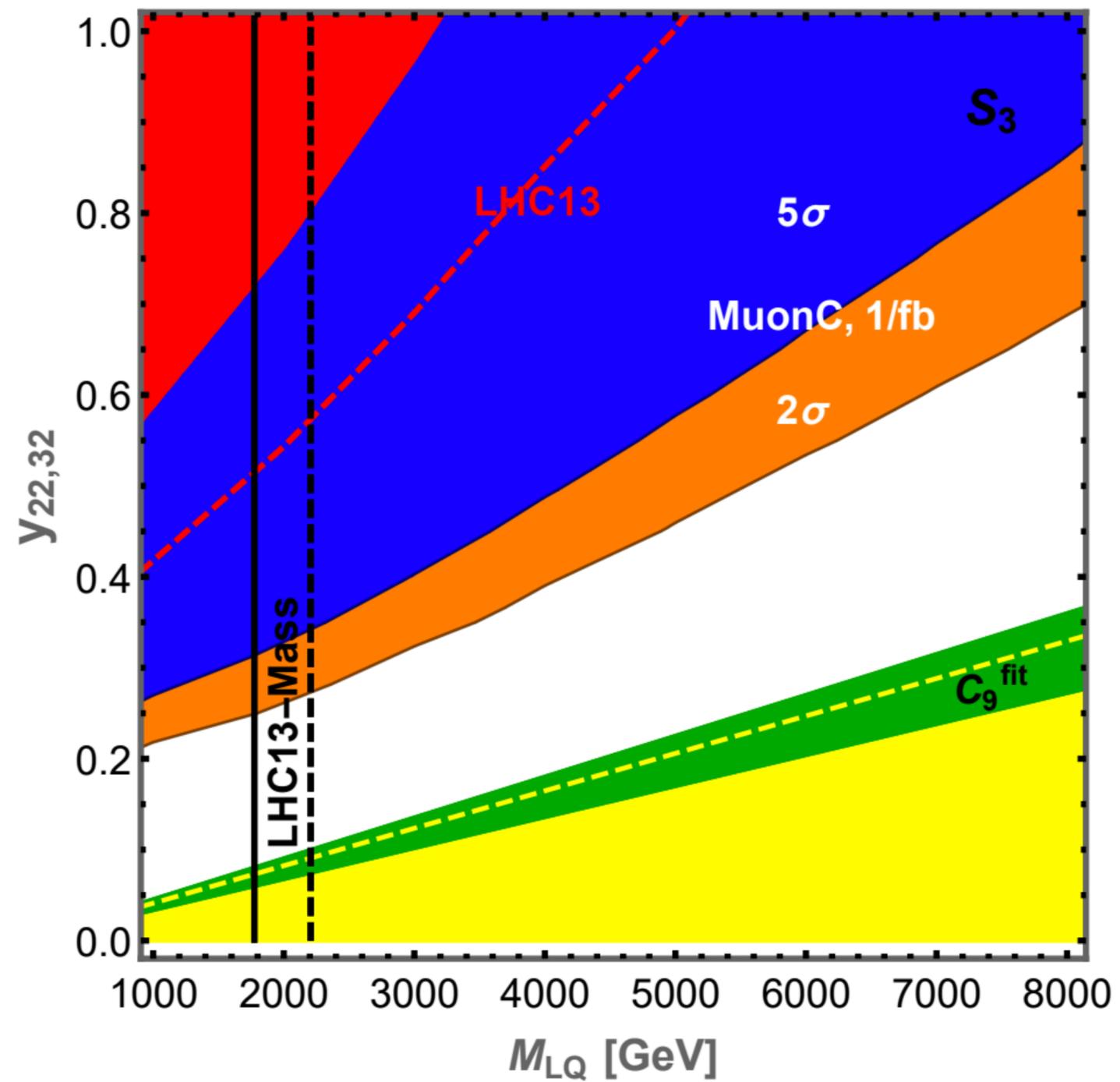
LHC Run-2 limits



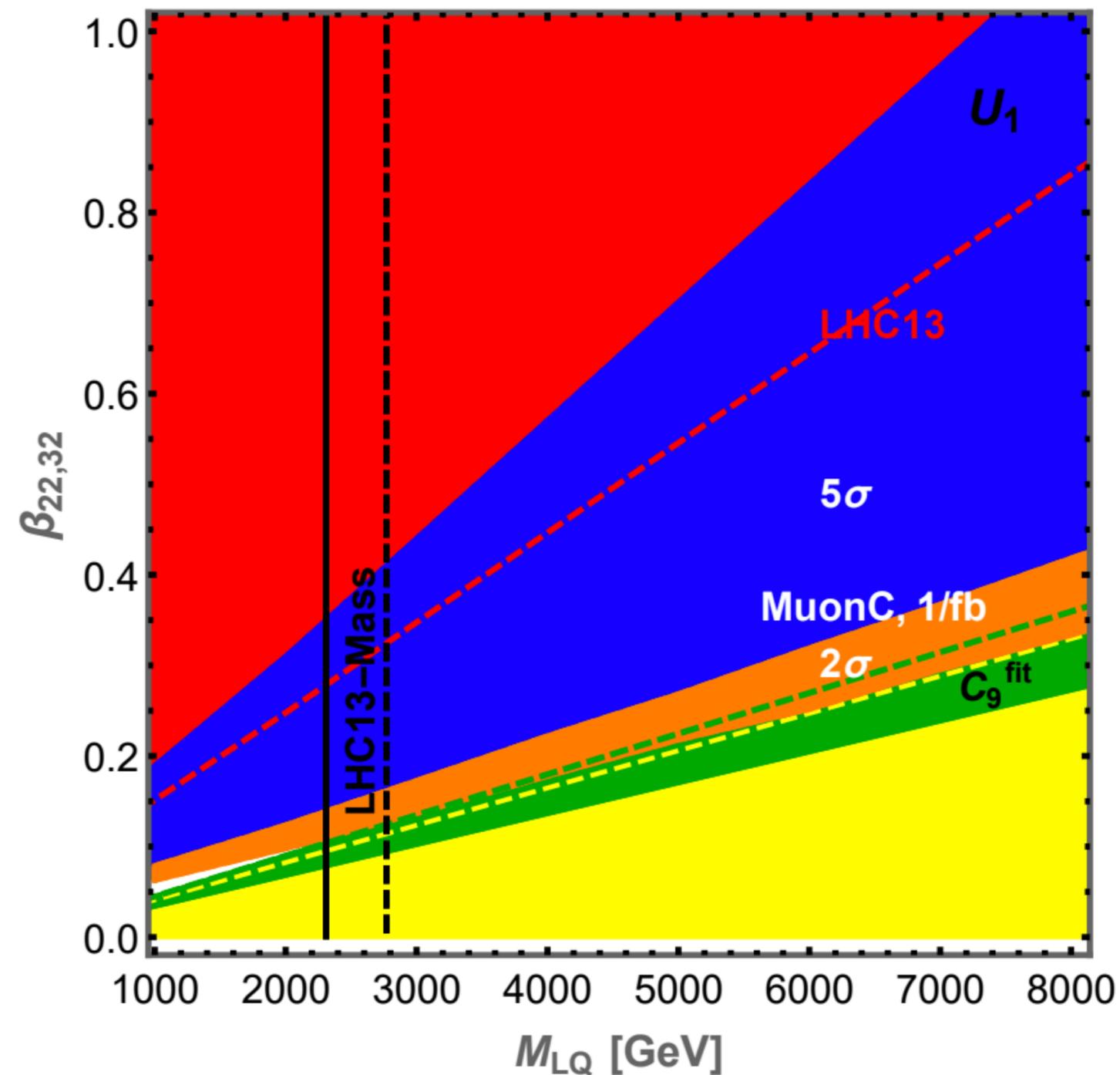
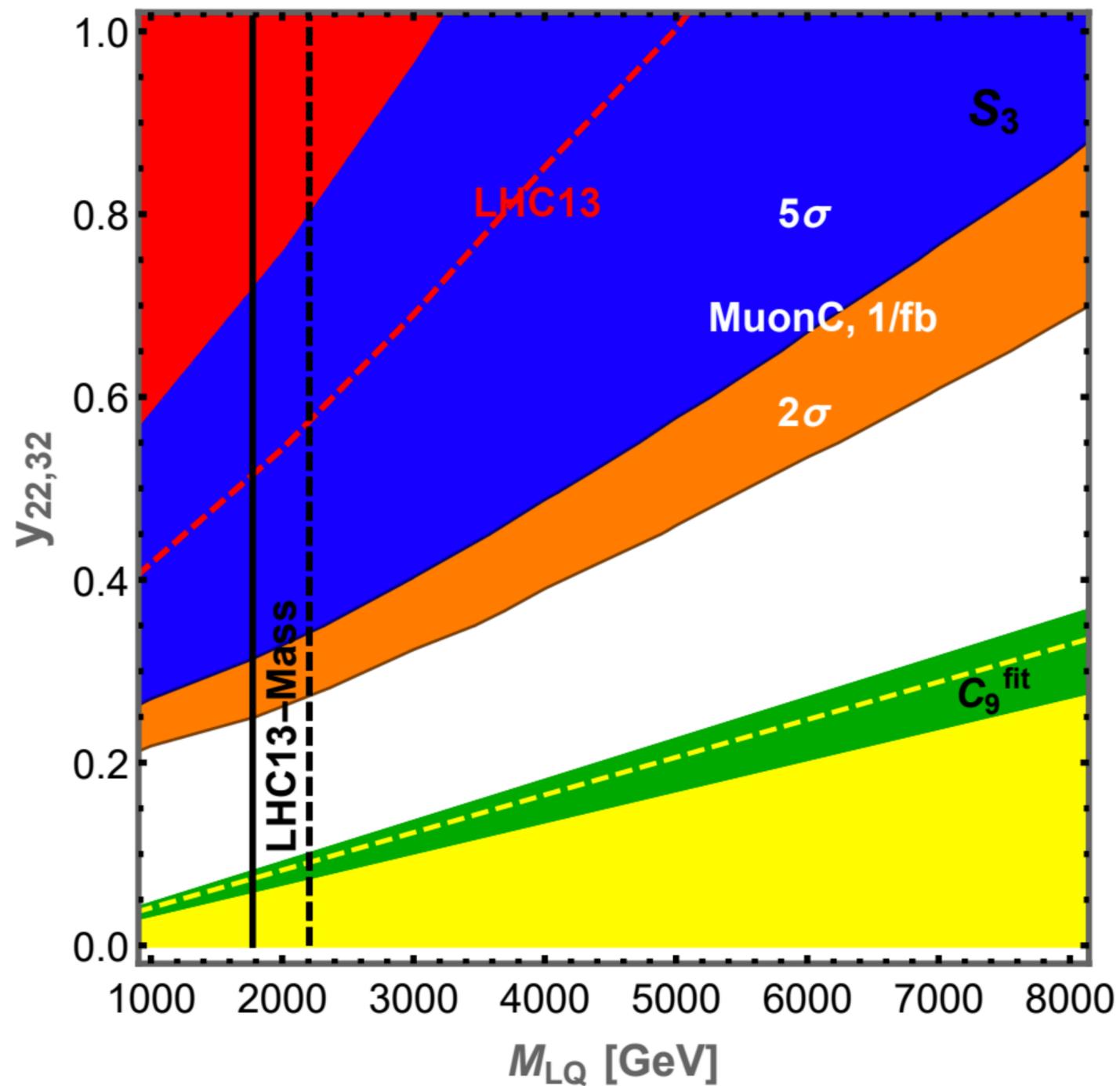
Run-2 limits with universal electron and muon couplings



Future prospects



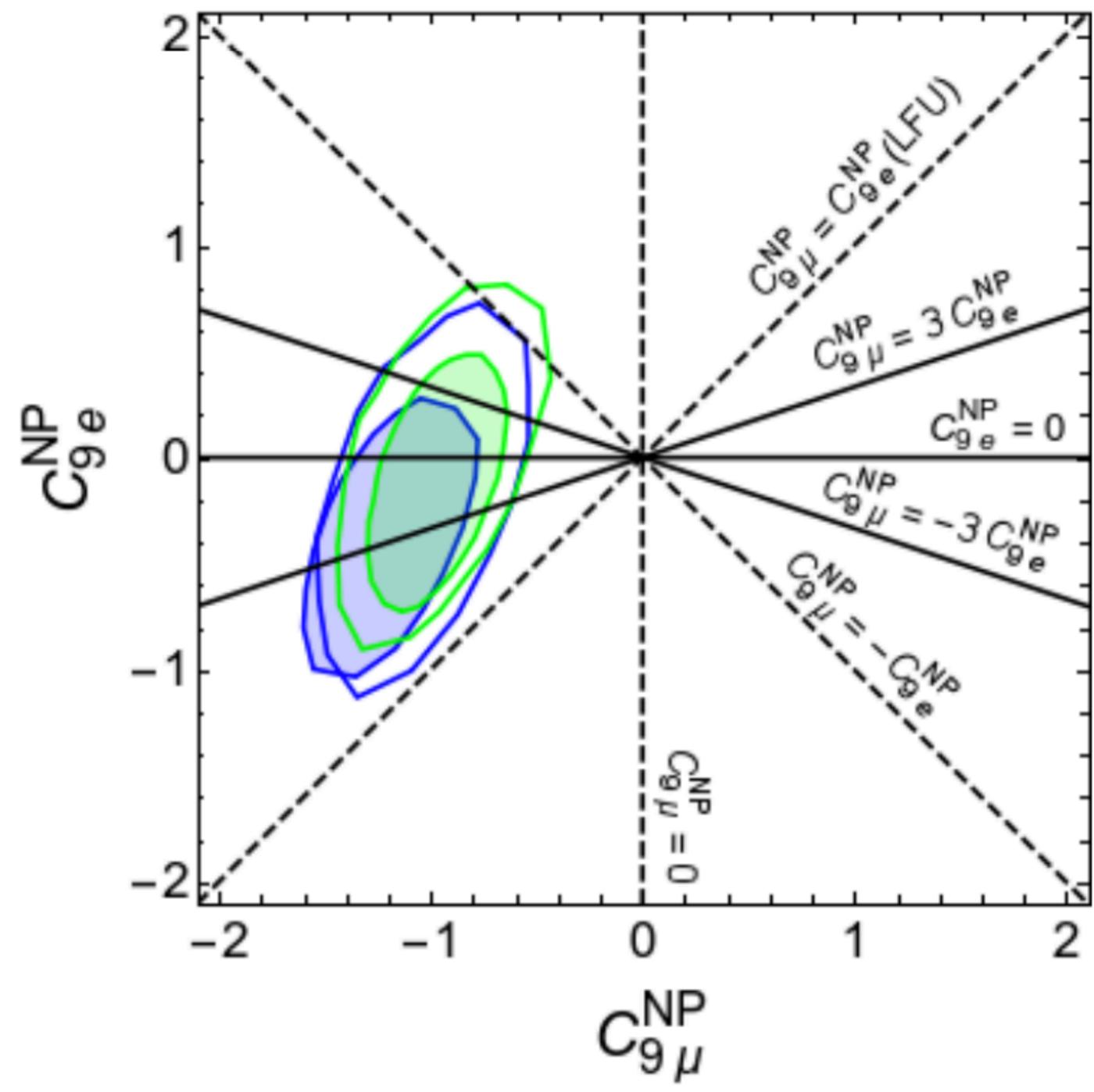
Future prospects



Summary

- Favoured explanations of B-anomalies invoke new vector bosons or leptoquarks. Since these are required to have couplings to quarks, they can be produced at the LHC.
- Z' models are typically more constrained because of anomaly cancellation etc.
 - For MFV case, most parameter space is excluded by LHC dimuon search
 - Without MFV case, taking into account constraints from meson mixing etc. leaves only small parameter space after LHC run-2, most are ruled out. Some models expected to remain viable after HL-LHC 3000/fb.
- Leptoquark models typically less constrained by LHC. Shape of dilepton spectrum can be used to constrain quark-lepton-leptoquark coupling. Pair production mainly constrains mass.
 - e - μ Flavour universal case expected to be ruled out by Run-2
 - Minimal Vector leptoquark model can be ruled out at a future muon collider

Backup



Category	Scenario	X_S	Leptonic symmetry	α_1	α_2	α_3	α_e	α_μ	α_τ
A	A1	-1	$L_\mu - L_\tau$	-1	-1	2	0	1	-1
	A2	-1	L_μ	$-\frac{4}{3}$	$-\frac{4}{3}$	$\frac{5}{3}$	0	1	0
B	B1	$-\frac{2}{3}$	$L_e - 3L_\mu + L_\tau$	$-\frac{7}{9}$	$-\frac{7}{9}$	$\frac{11}{9}$	$-\frac{1}{3}$	1	$-\frac{1}{3}$
	B2	$-\frac{2}{3}$	$L_e - 3L_\mu - L_\tau$	-1	-1	1	$-\frac{1}{3}$	1	$\frac{1}{3}$
C	C1	$-\frac{2}{3}$	$L_e + 3L_\mu - L_\tau$	-1	-1	1	$\frac{1}{3}$	1	$-\frac{1}{3}$
AA	AA1	1	$L_\mu - L_\tau$	1	1	-2	0	1	-1
	AA2	1	L_μ	$\frac{2}{3}$	$\frac{2}{3}$	$-\frac{7}{3}$	0	1	0
BB	BB1	$\frac{2}{3}$	$L_e - 3L_\mu + L_\tau$	$\frac{5}{9}$	$\frac{5}{9}$	$-\frac{13}{9}$	$-\frac{1}{3}$	1	$-\frac{1}{3}$
	BB2	$\frac{2}{3}$	$L_e - 3L_\mu - L_\tau$	$\frac{1}{3}$	$\frac{1}{3}$	$-\frac{5}{3}$	$-\frac{1}{3}$	1	$\frac{1}{3}$
CC	CC1	$\frac{2}{3}$	$L_e + 3L_\mu - L_\tau$	$\frac{1}{3}$	$\frac{1}{3}$	$-\frac{5}{3}$	$\frac{1}{3}$	1	$-\frac{1}{3}$