Ideas for flavour studies with FCC-ee

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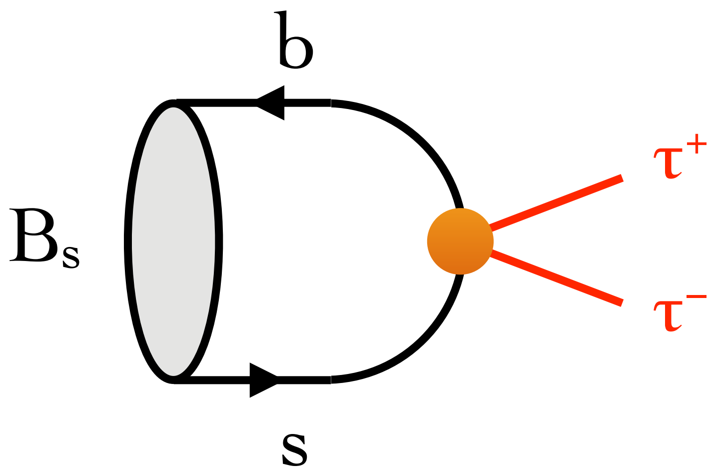
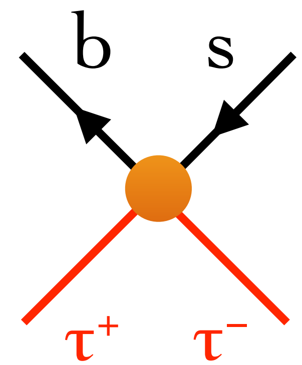
FCC-ee/TLEP physics workshop (TLEP7), 19-21 June 2014, CERN

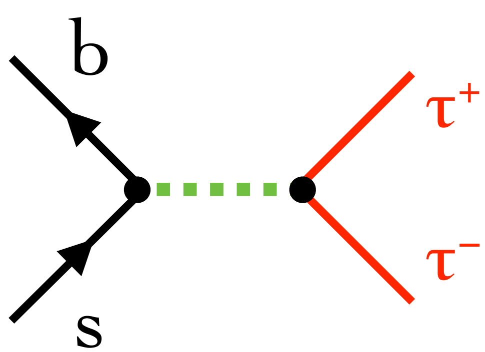
$B_s \to \tau^+\tau^-$: The unbounded



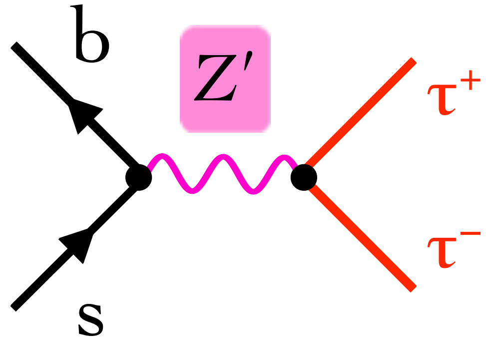


$$Q_{S,AB} = (\bar{s}P_A b)\,(\bar{\tau}P_B\tau)$$

$$Q_{V,AB} = (\bar{s}\gamma_\mu P_A b)\,(\bar{\tau}\gamma^\mu P_B\tau)$$

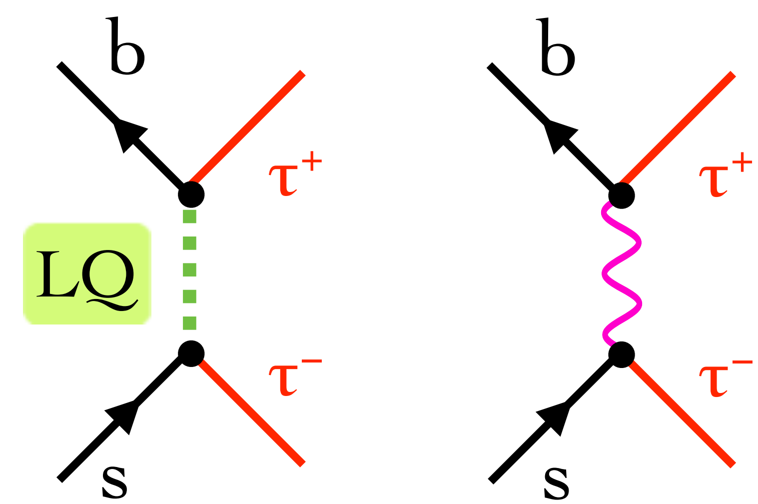


spin 0: S,P



spin 1: V,A

e.g. Z'

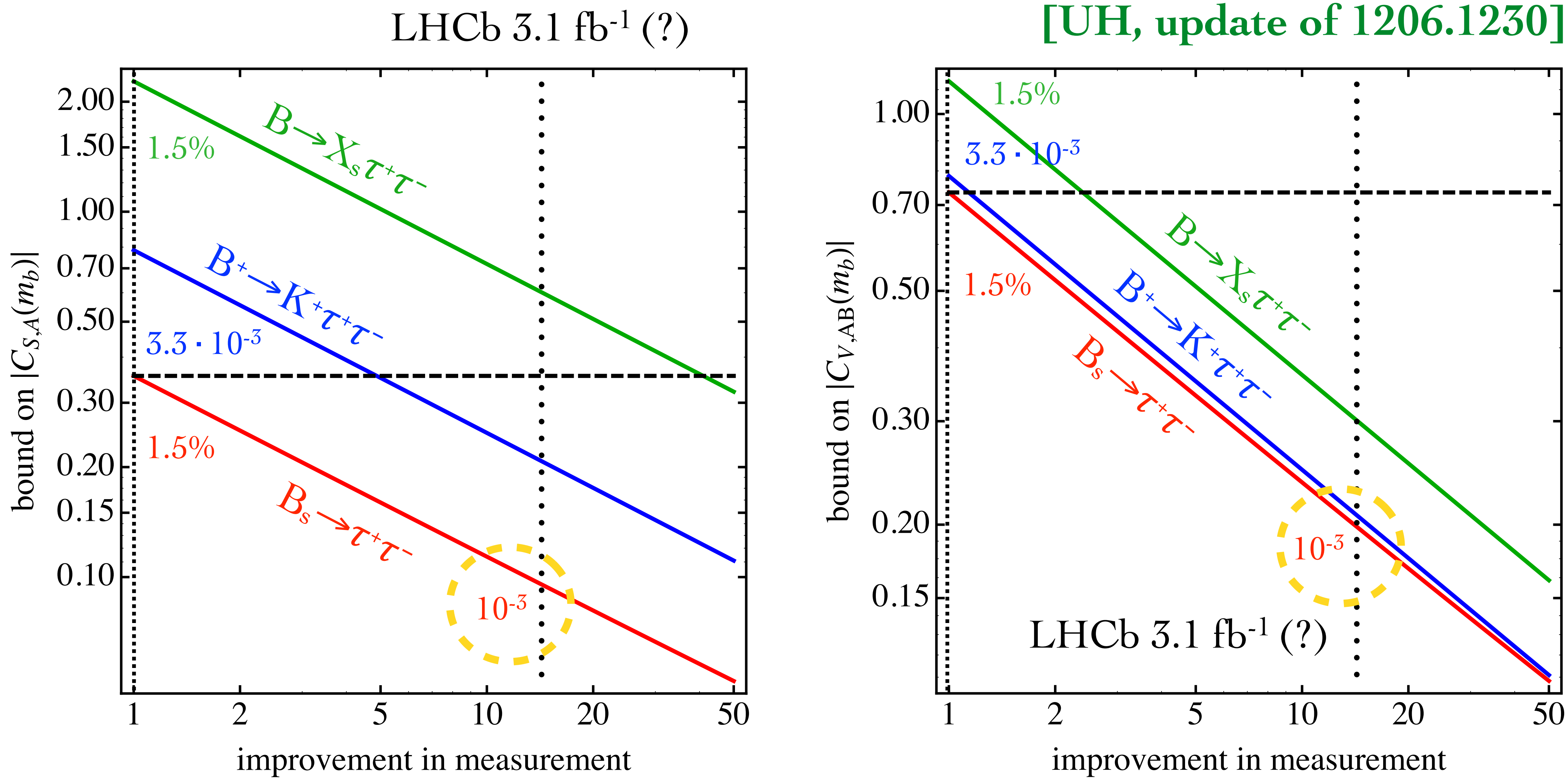


e.g. leptoquark (LQ)

Apart from tensor operators all Lorentz structures are tested

$B_s \to \tau^+\tau^-$: The unbounded

[UH, update of 1206.1230]



$B_s \to \tau^+\tau^-$ best probe of scalar & vector operators of form $\bar{s}b\bar{\tau}\tau$

$B_s \to \tau^+\tau^-$: The unbounded

- No direct limit & indirect bound $Br(B_s \to \tau^+\tau^-) < 1.5\%$ from $B_{d,s}$ lifetime ratio can be evaded through tuning
- SM predictions for all $B_{d,s} \to l^+l^-$ modes recently improved:

$$Br(B_s \to \tau^+\tau^-) = 7.73 \cdot (1 \pm 6\%) \cdot 10^{-7}$$

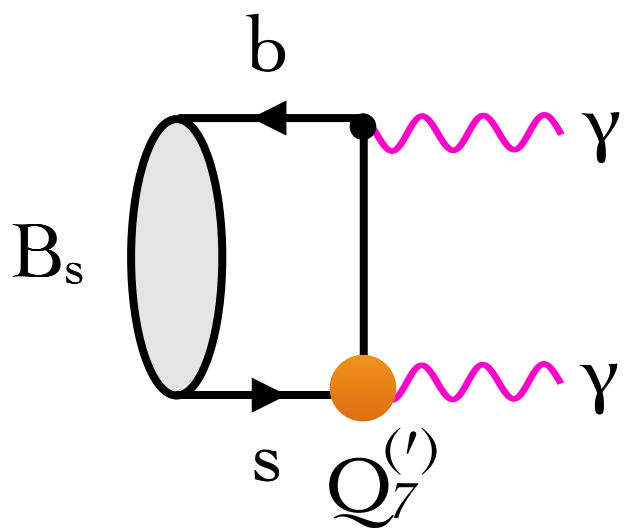
[Bobeth et al., 1311.0903]

- Challenging measurement at LHCb but a limit of $O(10^{-3})$ should be reachable with LHC Run I dataset. Bound of similar strength should also be attainable at Belle II

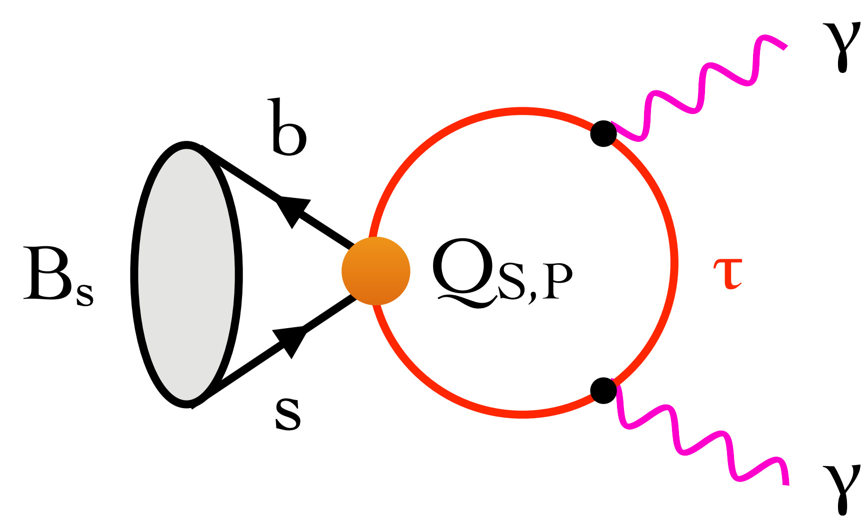
[Mordá, talk at "Flavor of New Physics in $b \to s$ transitions"]

How well performs FCC-ee compared to LHCb/Belle II?

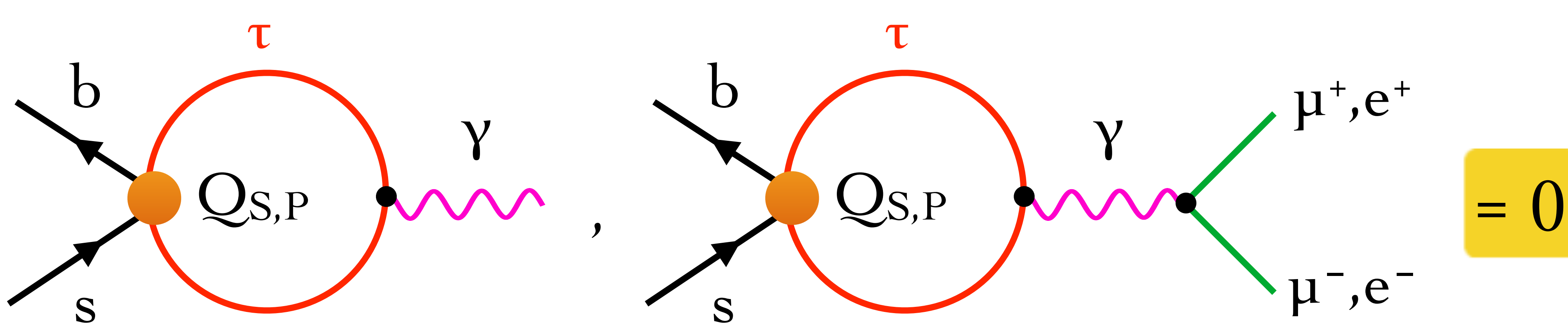
$B_s \to \gamma\gamma$: Heavy to light



1-particle reducible (1PR)

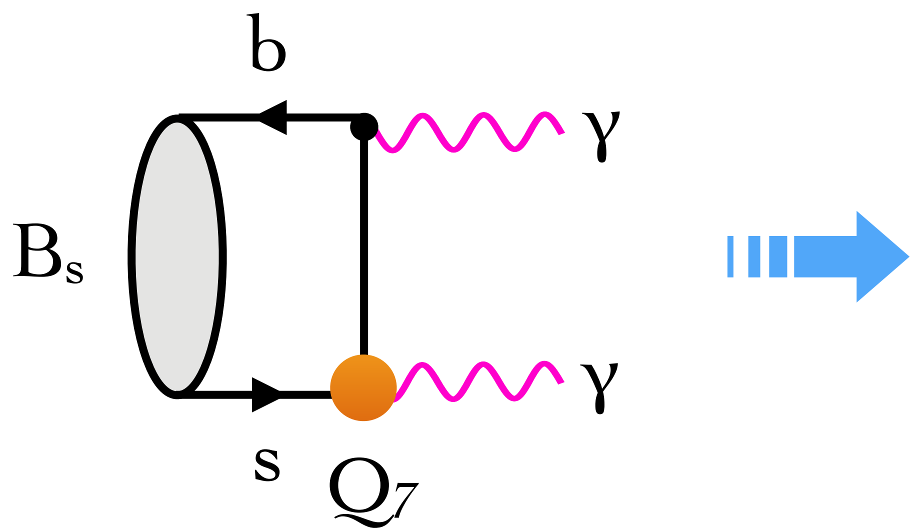


1-particle irreducible (1PI)



Ample room for exotic new physics entering via 1PI diagrams

$B_s \to \gamma\gamma$: Heavy to light



$$\mathrm{Br}\,(B_s \to \gamma\gamma)_{\mathrm{SM}} \propto \left| V_{ts}^* V_{tb}\, C_7\, \frac{m_{B_s}}{\lambda_{B_s}} \right|^2$$

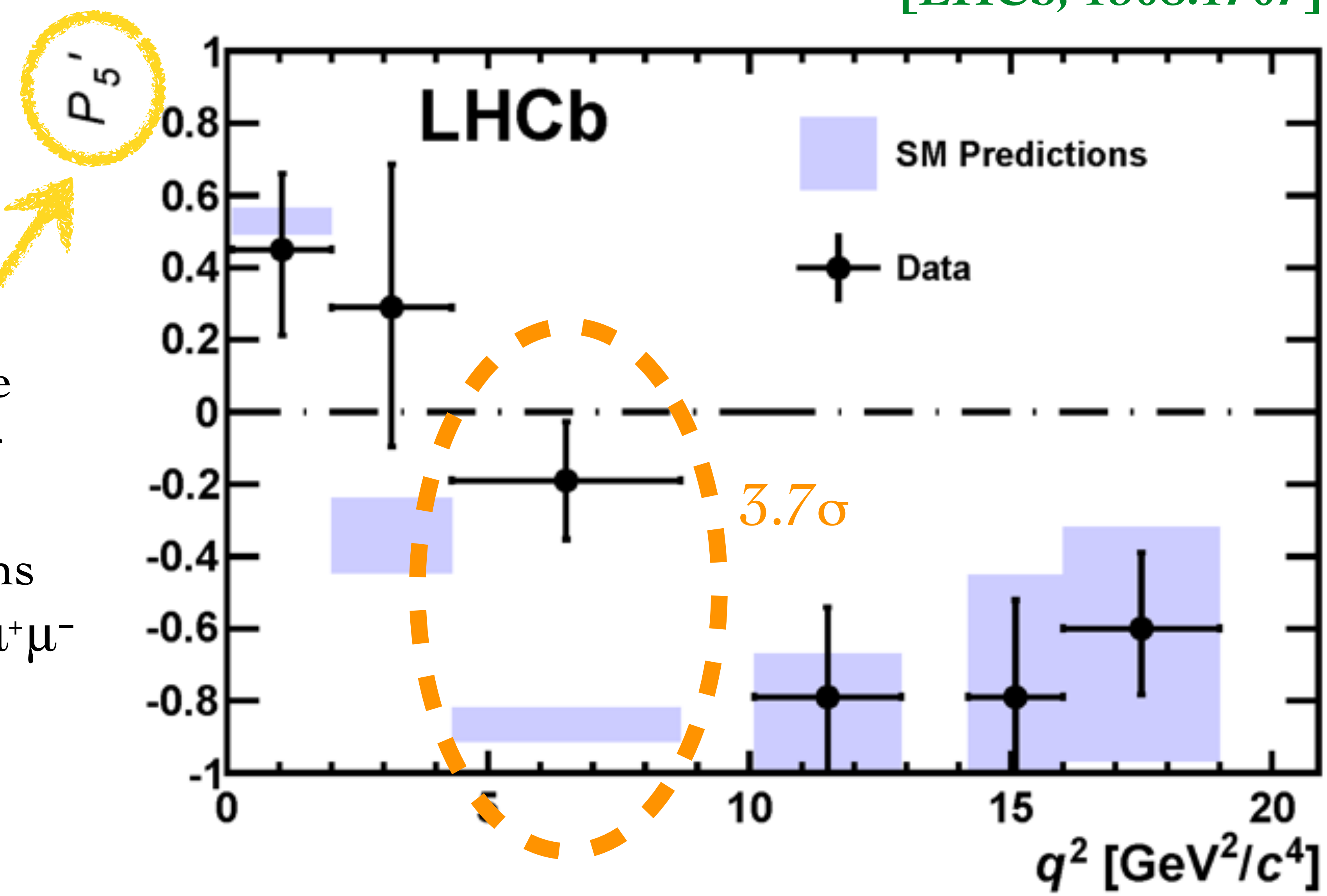
$+$ subleading power from 1PI graphs

- Double-radiative decay also offers possibility to determine properties of B_s-meson light-cone distribution amplitude, in particular of its inverse moment λ_{Bs}
- Combining $B_s \to \gamma\gamma$ with $B \to \gamma l \nu$, $B_s \to \varphi\gamma$, … into global fit might allow to cancel common hadronic uncertainties

Further theoretical studies needed to strengthen physics case

$B \to K l^+ l^-$ anomalies: Second opinion

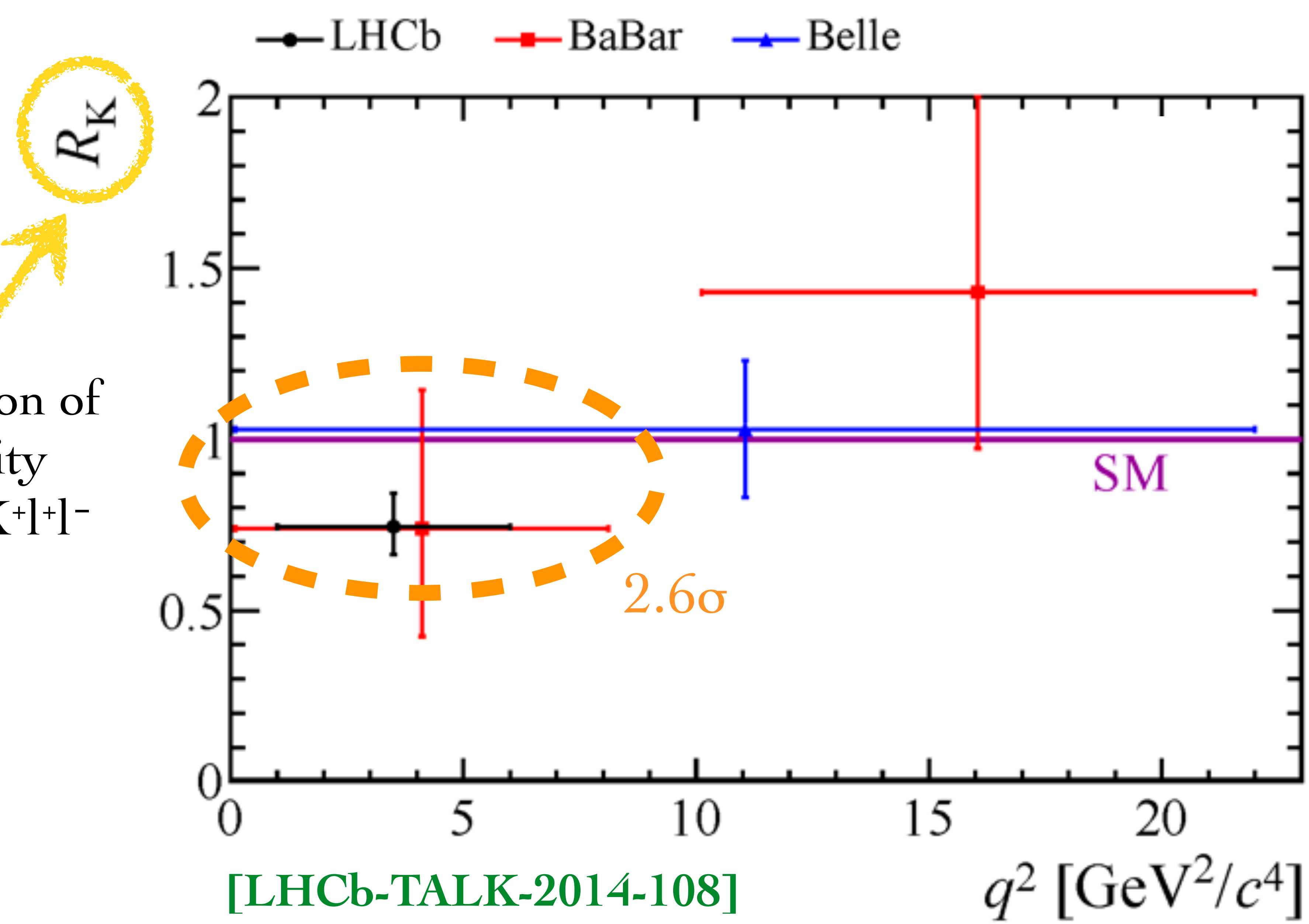
[LHCb, 1308.1707]



observable measuring angular correlations in $B \to K^* \mu^+ \mu^-$

One possible explanation provided by $\Delta C_9 \approx -1.5$ & $\Delta C_{7,10} \approx 0$

B→Kl⁺l⁻ anomalies: Second opinion



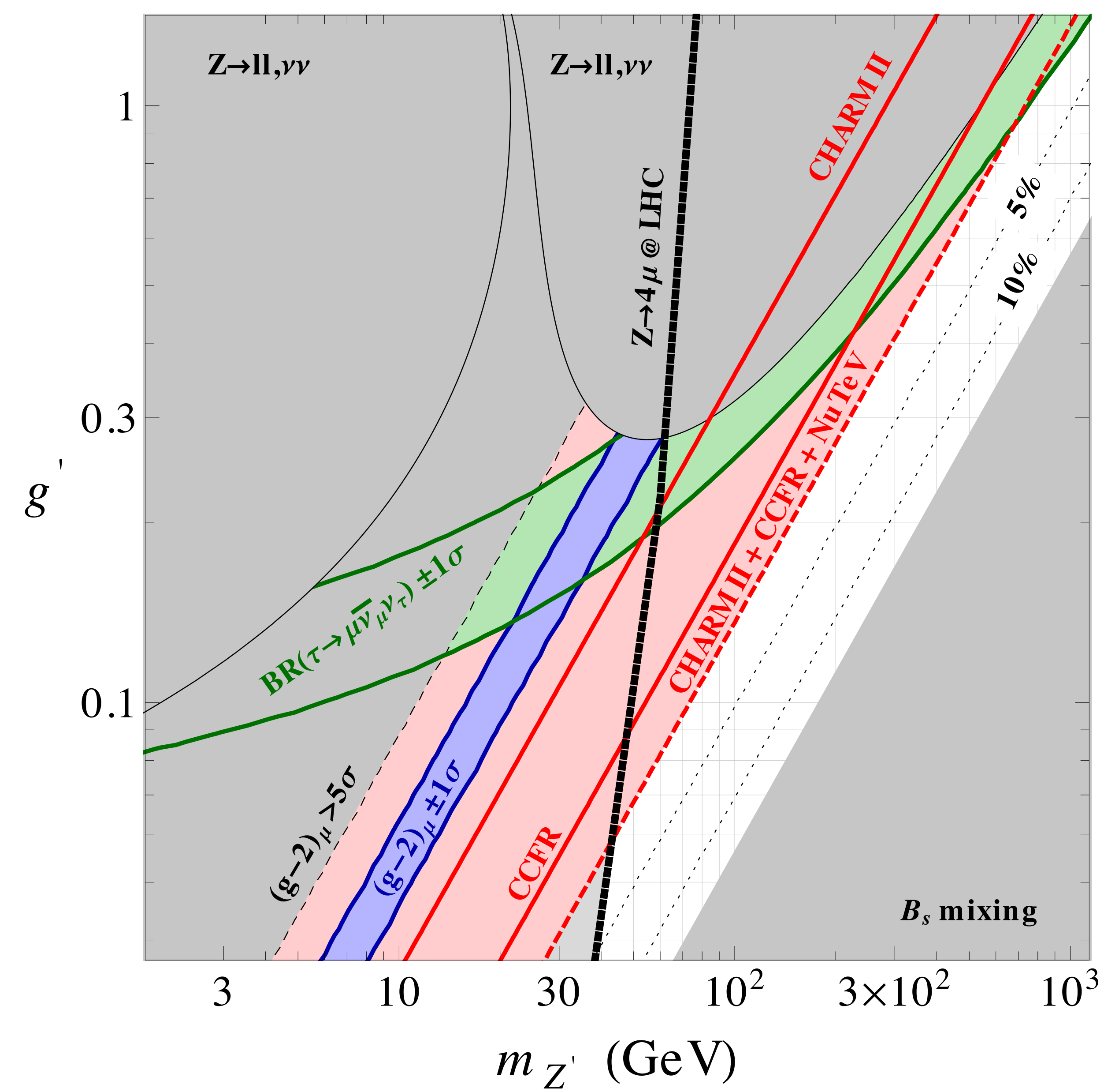
measures violation of lepton universality (LUV) in $B^+ \to K^+ l^+ l^-$

[LHCb-TALK-2014-108]

Right amount of LUV if only vector coupling to $\mu^+\mu^-$ altered

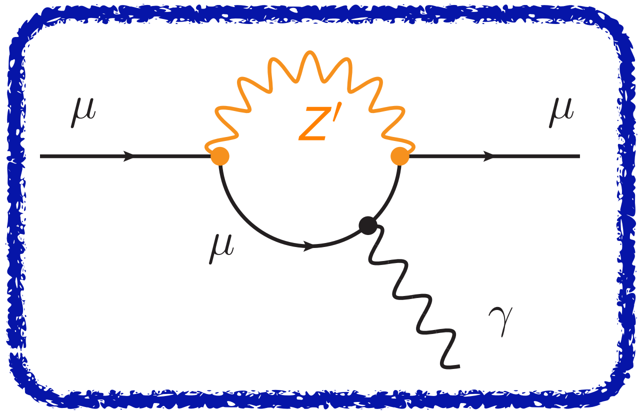
B→Kl⁺l⁻ anomalies: Second opinion

[Altmannshofer et al., 1403.1269]



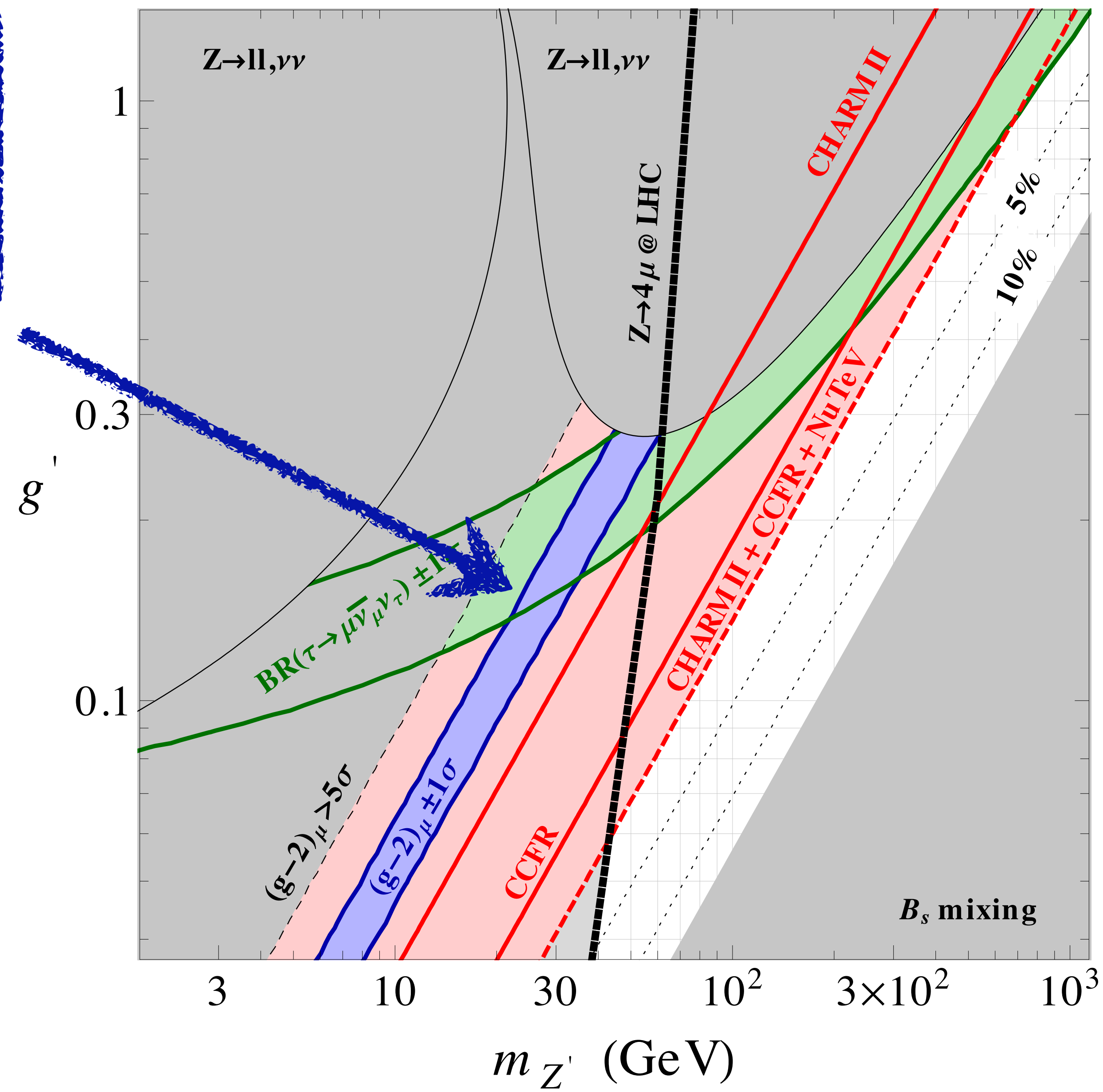
Z′ model based on gauged $L_\mu - L_\tau$ addresses both anomalies

B→Kl⁺l⁻ anomalies: Second opinion



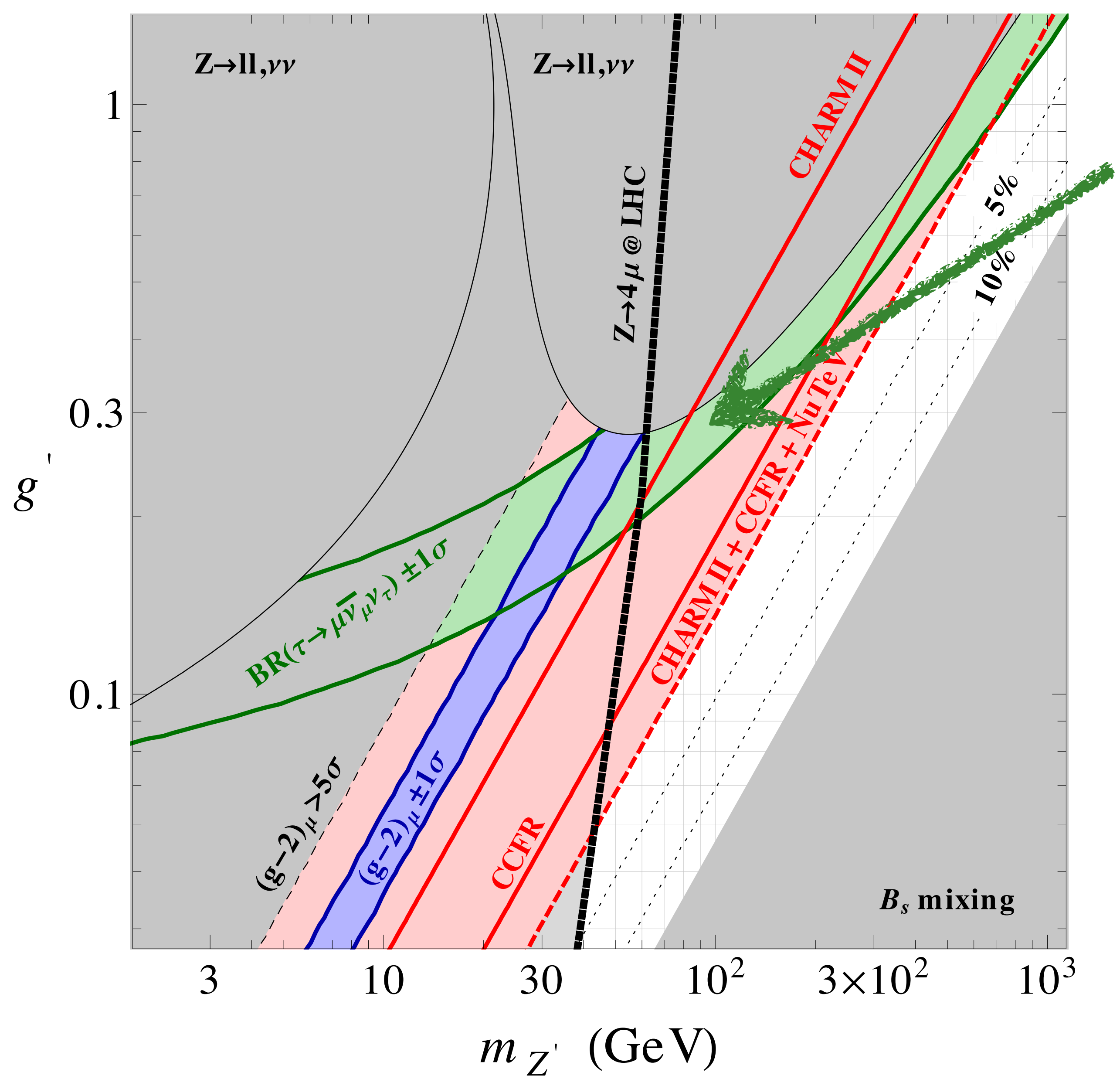
favoured by
$(g\text{-}2)_\mu$ anomaly

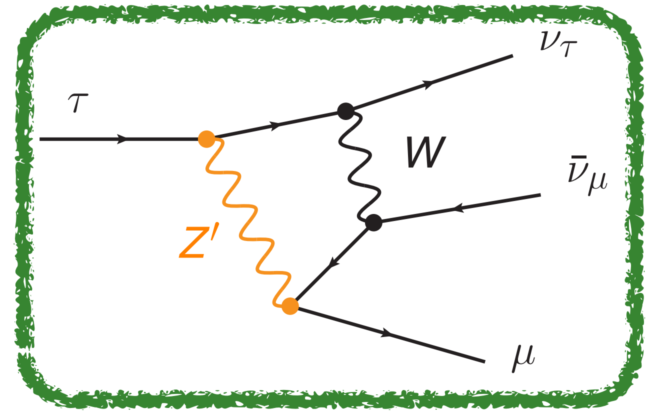
[Altmannshofer et al., 1403.1269]



B→Kl⁺l⁻ anomalies: Second opinion

[Altmannshofer et al., 1403.1269]

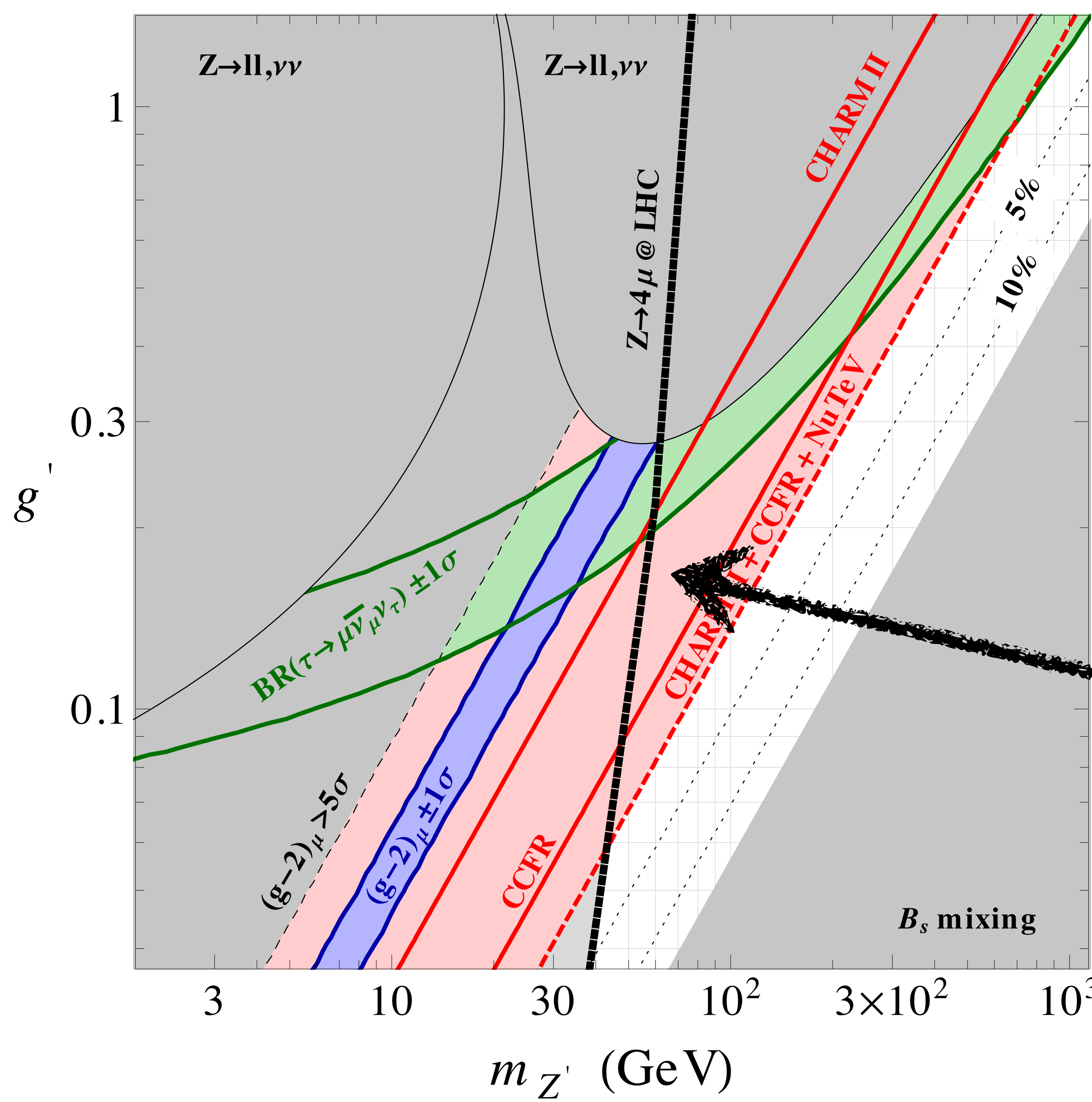


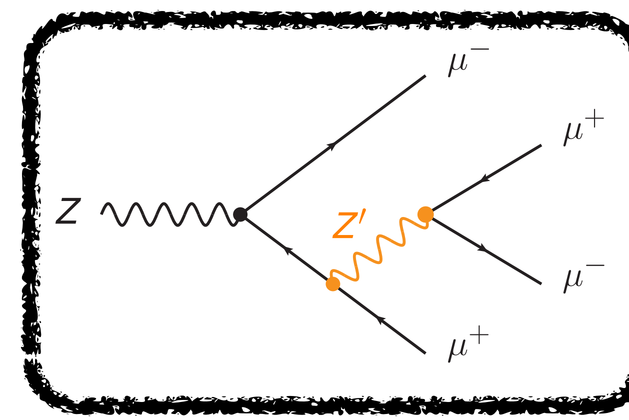


favoured by anomaly in τ decay

B→Kl⁺l⁻ anomalies: Second opinion

[Altmannshofer et al., 1403.1269]

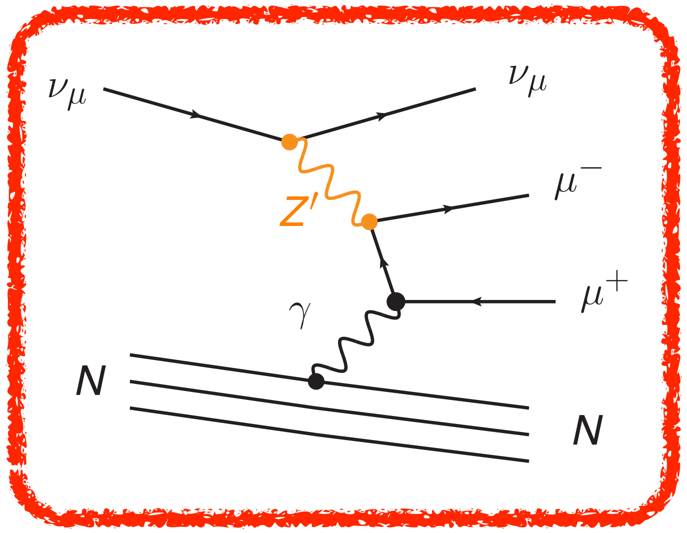




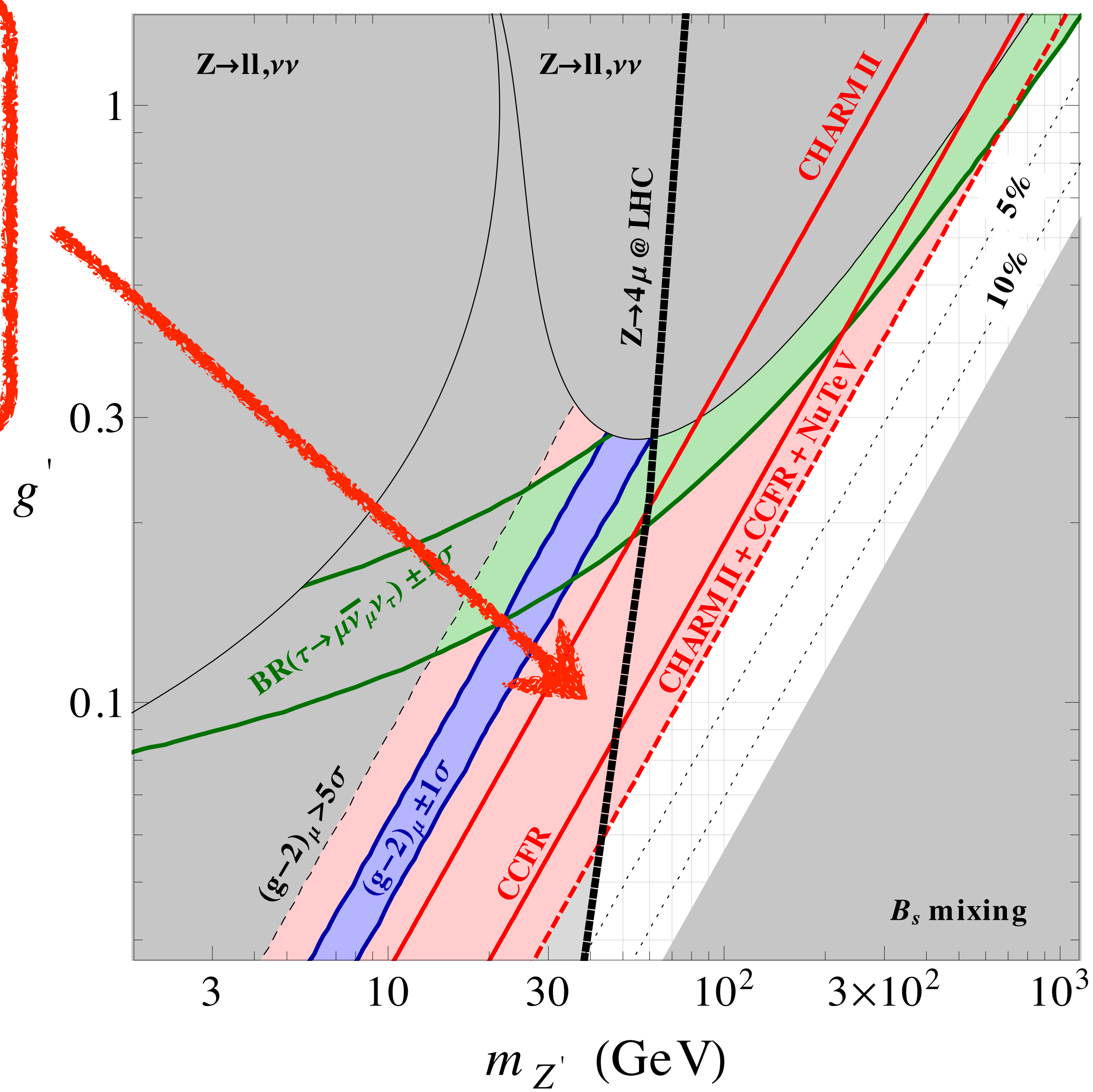
LHC bound from Z→4l

B→Kl⁺l⁻ anomalies: Second opinion

[Altmannshofer et al., 1403.1269]

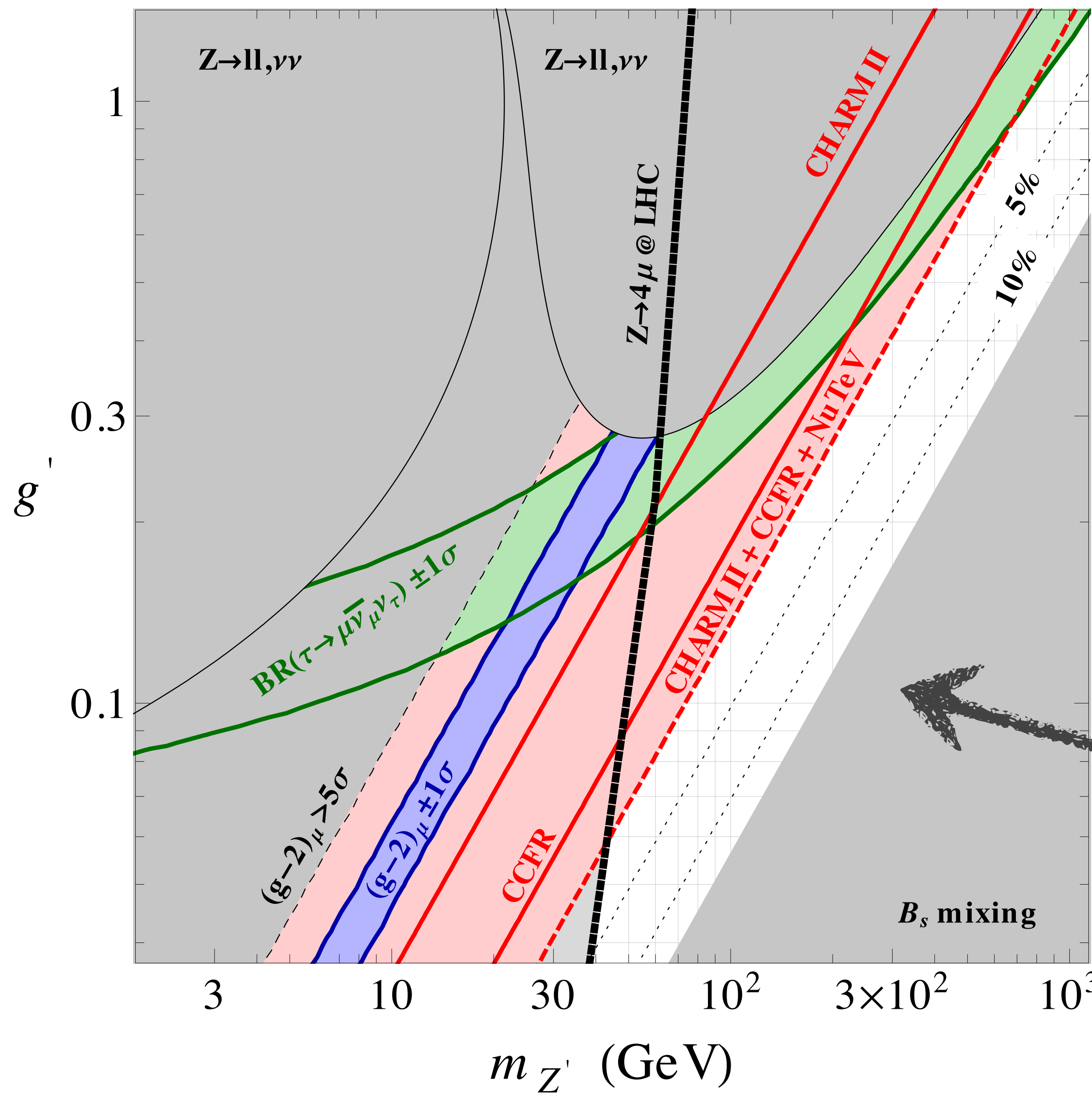


limits from neutrino trident production

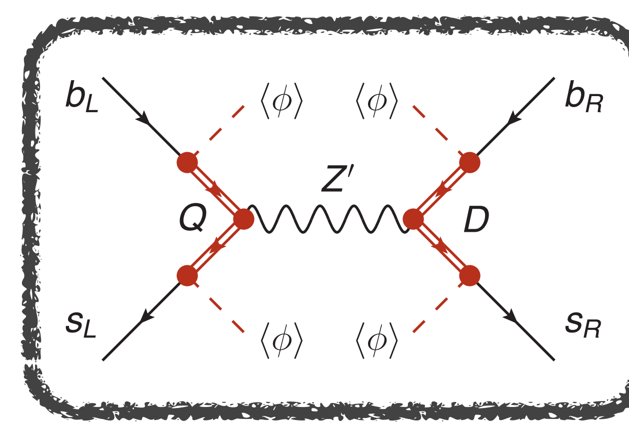


$B \to K l^+ l^-$ anomalies: Second opinion

[Altmannshofer et al., 1403.1269]



inconsistent with B_s-meson mixing



B→Kl⁺l⁻ anomalies: Second opinion

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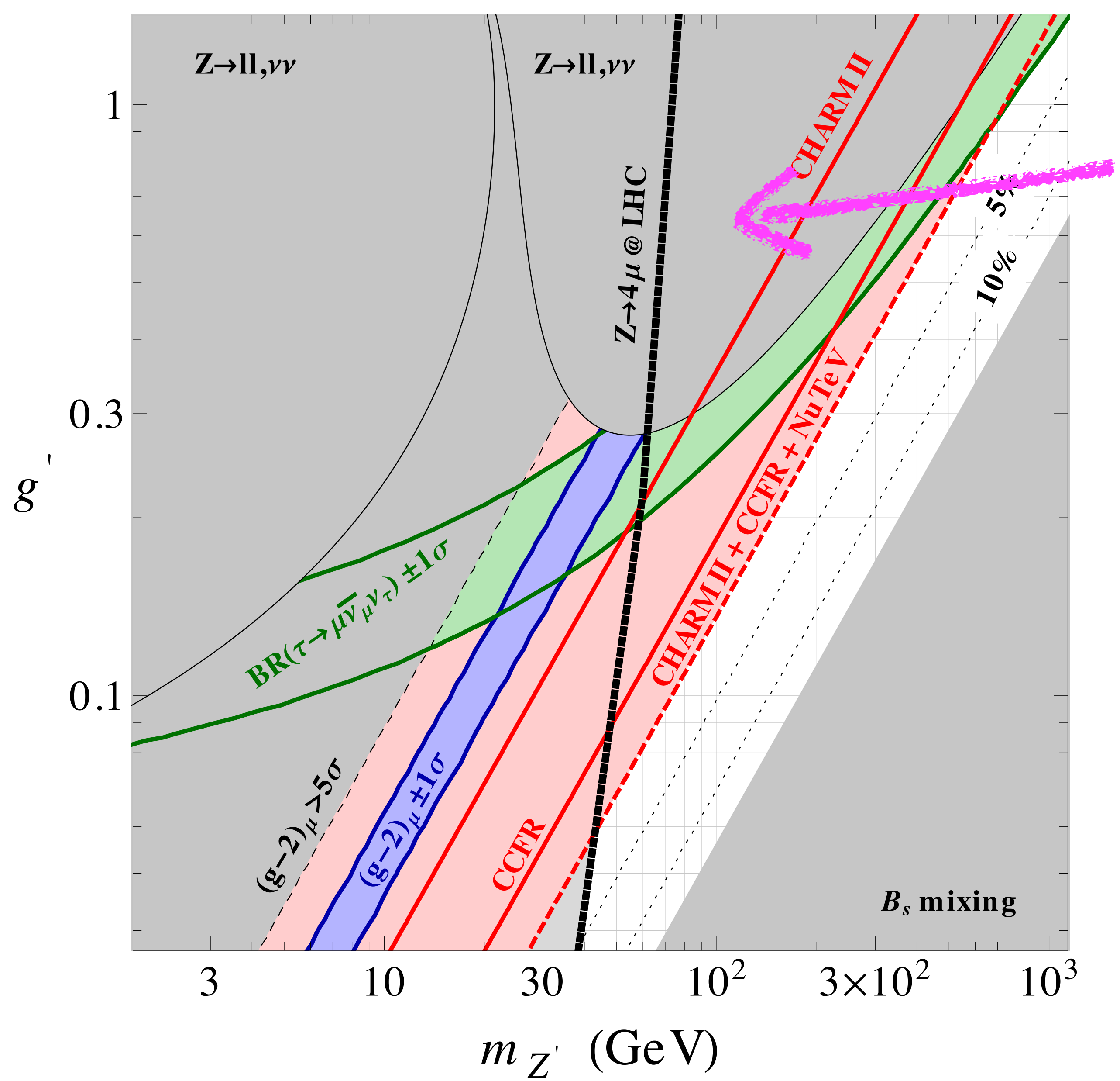
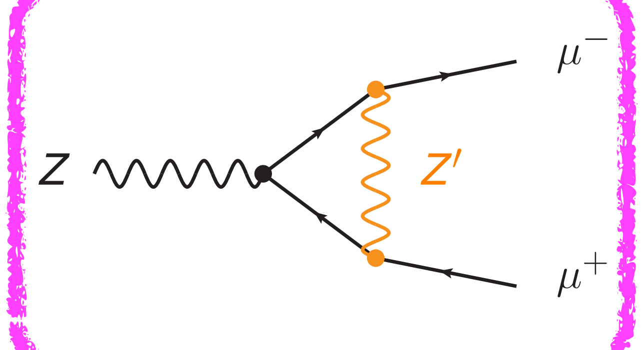
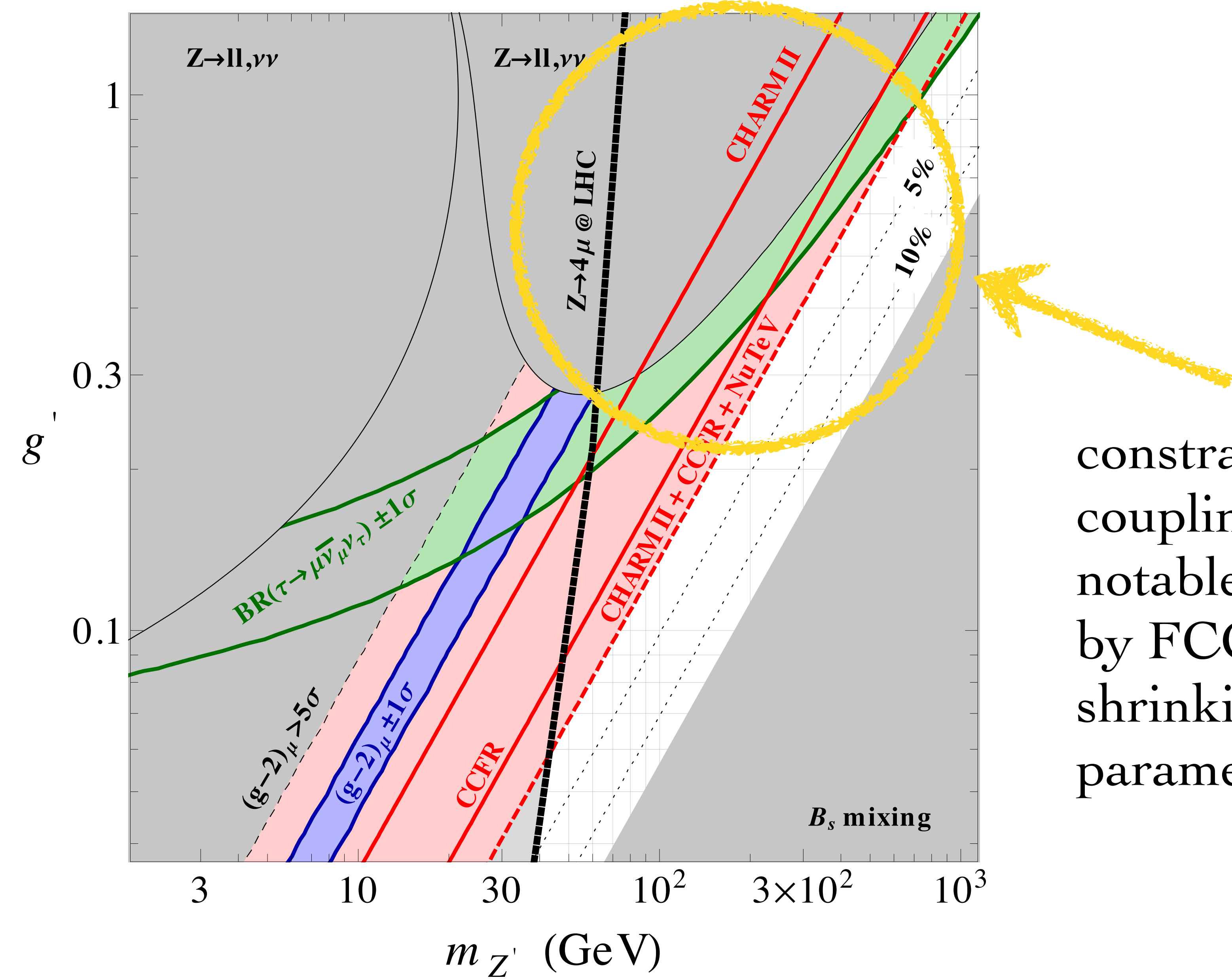




excluded by LEP measurements of Z couplings

B→Kl⁺l⁻ anomalies: Second opinion

[Altmannshofer et al., 1403.1269]



constraint from Z couplings would be notable improved by FCC-ee thereby shrinking allowed parameter space

FCC-ee can indirectly shed light on flavour anomalies

LFV: Using 10^{12} Z decays

[Pich, 1310.7922]

$\mathrm{Br}(\mu^- \to \mathrm{X}^-) \cdot 10^{12}$	(90% CL)								
$e^-\gamma$	0.57	$e^-2\gamma$	72	$e^-e^-e^+$	1.0				
$\mathrm{Br}(\tau^- \to \mathrm{X}^-) \cdot 10^{8}$	(90% CL)								
$e^-\gamma$	3.3	$e^-e^+e^-$	2.7	$e^-\mu^+\mu^-$	2.7	$e^-e^-\mu^+$	1.5	$e^-\pi^0$	8.0
$\mu^-\gamma$	4.4	$\mu^-e^+e^-$	1.8	$\mu^-\mu^+\mu^-$	2.1	$\mu^-\mu^-e^+$	1.7	$\mu^-\pi^0$	11
$e^-\eta$	9.2	$e^-\eta'$	16	$e^-\rho^0$	1.8	$e^-\omega$	4.8	$e^-\phi$	3.1
$\mu^-\eta$	6.5	$\mu^-\eta'$	13	$\mu^-\rho^0$	1.2	$\mu^-\omega$	4.7	$\mu^-\phi$	8.4
e^-K_S	2.6	e^-K^{*0}	3.2	$e^-\bar{K}^{*0}$	3.4	$e^-K^+\pi^-$	3.1	$e^-\pi^+K^-$	3.7
μ^-K_S	2.3	μ^-K^{*0}	5.9	$\mu^-\bar{K}^{*0}$	7.0	$\mu^-K^+\pi^-$	4.5	$\mu^-\pi^+K^-$	8.6
$e^-K_SK_S$	7.1	$e^-K^+K^-$	3.4	$e^-\pi^+\pi^-$	2.3				
$\mu^-K_SK_S$	8.0	$\mu^-K^+K^-$	4.4	$\mu^-\pi^+\pi^-$	2.1				
$e^-f_0(980) \to e^-\pi^+\pi^-$			3.2	$\mu^-f_0(980) \to \mu^-\pi^+\pi^-$			3.4		
$\mathrm{Br}(\mathrm{Z} \to \mathrm{X}^0) \cdot 10^{6}$	(95% CL)								
$e^\pm\mu^\mp$	1.7	$e^\pm\tau^\mp$	9.8	$\mu^\pm\tau^\mp$	12				
$\mathrm{Br}(\mathrm{B}^0_{(s)} \to \mathrm{X}^0) \cdot 10^{8}$	(95% CL)								
$B^0 \to e^\pm\mu^\mp$	0.37	$B^0_s \to e^\pm\mu^\mp$	1.4						
$\mathrm{Br}(\mu^- + \mathrm{N} \to \mathrm{e}^- + \mathrm{N}) \cdot 10^{12}$	(90% CL)								
Au	0.7	Ti	4.3	Pb	46				

bounds from DELPHI & OPAL obtained with $4 \cdot 10^6$ visible Z decays

Z→τl are most weakly limited lepton-flavour violation (LFV) modes

LFV: Using 10^{12} Z decays

$\mathrm{Br}\,(Z \to \tau e) < 9.8 \cdot 10^{-6}$

$\mathrm{Br}\,(Z \to \tau \mu) < 1.2 \cdot 10^{-5}$

LEP, $4 \cdot 10^6$ Z decays

[Wilson, talks at DESY-ECFA LC workshops '98 & '99]

$\mathrm{Br}\,(Z \to \tau e) < [1.3, 6.5] \cdot 10^{-8}$

$\mathrm{Br}\,(Z \to \tau \mu) < [0.4, 2.2] \cdot 10^{-8}$

GigaZ, $O(10^9)$ Z decays

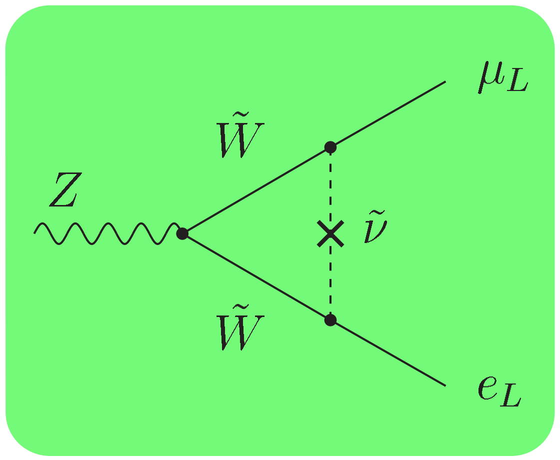
my naive extrapolation

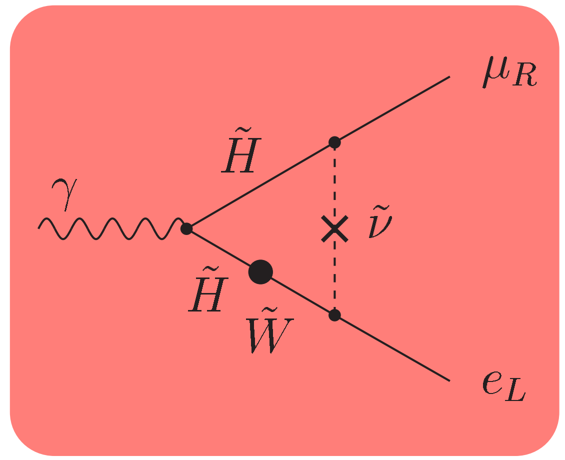
$\mathrm{Br}\,(Z \to \tau l) < \mathcal{O}(10^{-10} - 10^{-11})$

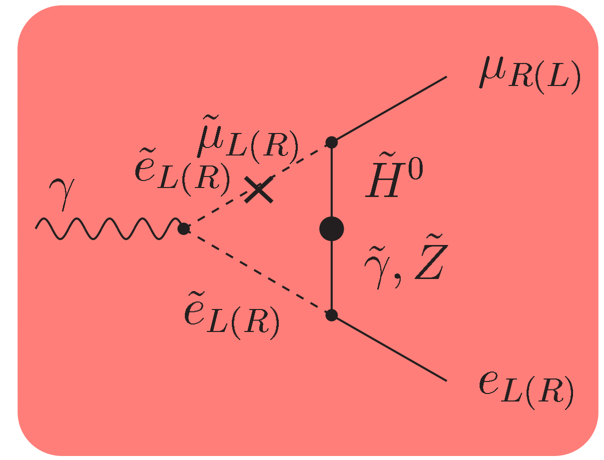
FCC-ee, $O(10^{12})$ Z decays

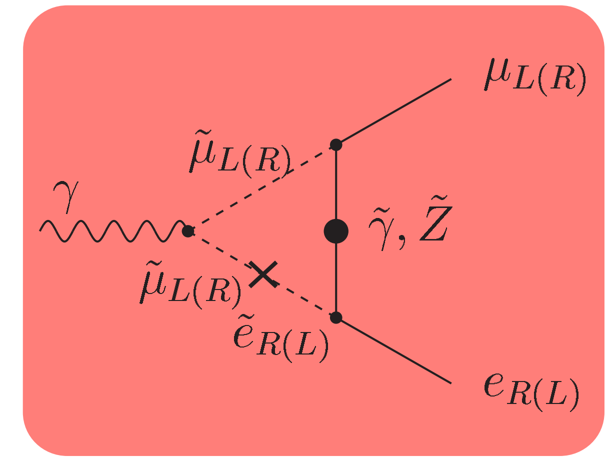
Improvement of bounds by 5 orders of magnitude seem possible

LFV: Using 10^{12} Z decays









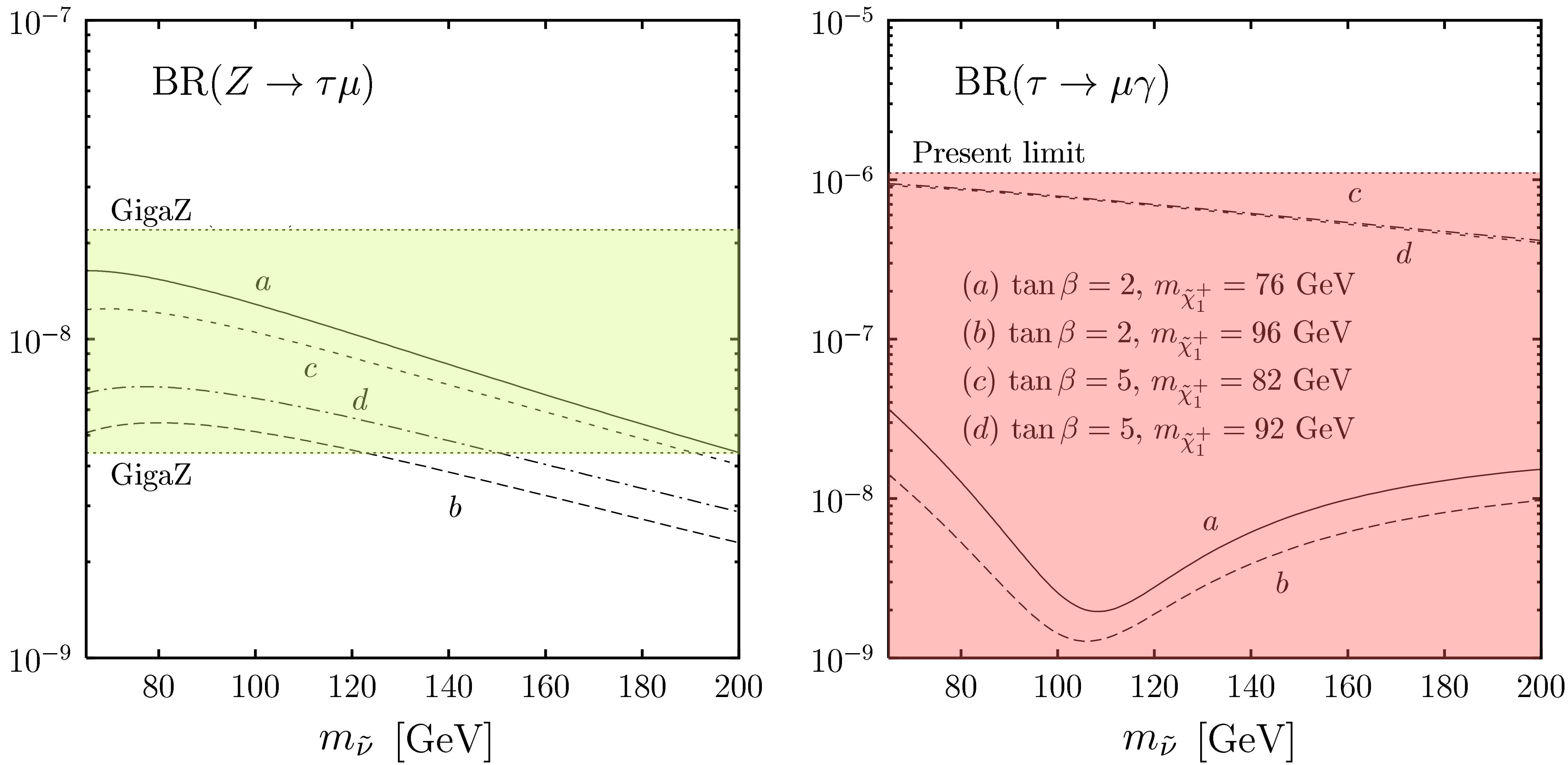
$\delta^{\tilde{\nu}\,12}_{LL}$ $\qquad$ $\delta^{\tilde{\nu}\,12}_{LL}\, m_\mu \tan\beta$ $\qquad$ $\delta^{\tilde{\nu}\,12}_{LL(RR)}\, m_\mu \tan\beta$ $\qquad$ $\delta^{\tilde{\nu}\,12}_{LR}\, m_{\tilde{\gamma},\tilde{Z}}$

for large mass insertions $\delta^{\tilde{\nu}\,13}_{LL}$ $(\delta^{\tilde{\nu}\,23}_{LL})$ & light sneutrinos of around 70 GeV one gets $Br(Z\to\tau l) \sim Br(\tau\to l\gamma) = O(10^{-8})$

τ→lγ bounds can by avoided allowing for largish Z→τl rates

LFV: Using 10^{12} Z decays

[Illiana & Masip,0207328]



Update studies of correlations between Z→τl & τ→lγ