McDonnell Center for the Space Sciences

Colliders, CLFV, and New Physics

Bhupal Dev

(bdev@wustl.edu)

Washington University in St. Louis

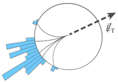
The 4th International Conference on Charged Lepton Flavor Violation

Physikalisches Institut, Universität Heidelberg

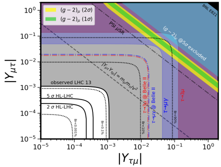
June 22, 2023

Outline

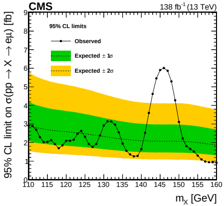
- Why LFV at colliders?



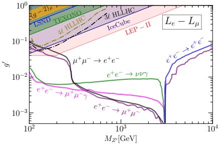
- LFV decays of heavy SM particles



- Hint of LFV Higgs?



- LFV Z' at future colliders



How do we know LFV exists?

- LFV is forbidden in the SM due to an accidental global symmetry: $U(1)_B \times U(1)_{L_e} \times U(1)_{L_\mu} \times U(1)_{L_\tau}$.
- Observed neutrino oscillations already imply LFV.
- But we don't see LFV in the *charged* lepton sector.

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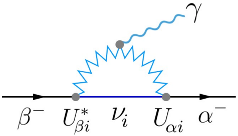
- Negligible in the SM(+neutrino mass):

$$\ell_\alpha \to \ell_\beta : \frac{3\alpha}{32\pi} \left| \sum_i U^*_{\beta i} U_{\alpha i} \frac{m^2_{\nu_i}}{m^2_W} \right|^2 \lesssim \mathcal{O}(10^{-54})$$



- Opportunity for new physics: $m^2_\nu / m^2_W \to m^2_F / \Lambda^2$.
- Could be enhanced by orders of magnitude over the SM.

[see talk by S. Davidson]

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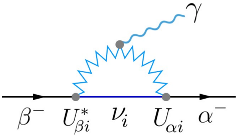

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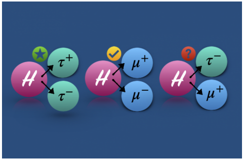
- Low-energy experiments are doing a great job.
- High-energy colliders provide a powerful complementary probe of LFV (e.g. in the Higgs sector).



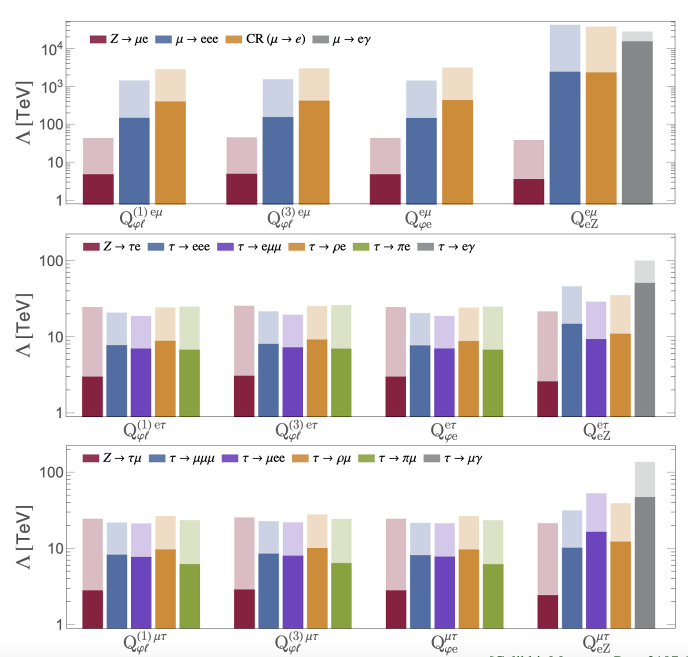
- Connection to $g-2$, EDM, neutrino mass, dark matter, baryogenesis, ... [*Universe* special issue on CLFV, eds. Bernstein and Echenard]

LFV decays of heavy SM particles

Process	Current bound on BR	Future sensitivity (Snowmass review 2205.10576)
$h \to e^\pm \mu^\mp$	4.4×10^{-5} (CMS 2305.18106) 6.1×10^{-5} (ATLAS 1909.10235)	2×10^{-5} (ILC)
$h \to e^\pm \tau^\mp$	2.0×10^{-3} (ATLAS 2302.05225) 2.2×10^{-3} (CMS 2105.03007)	2×10^{-4} (ILC) 5×10^{-4} (HL-LHC)
$h \to \mu^\pm \tau^\mp$	1.5×10^{-3} (CMS 2105.03007) 1.8×10^{-3} (ATLAS 2302.05225)	2×10^{-4} (ILC) 5×10^{-4} (HL-LHC)
$Z \to e^\pm \mu^\mp$	2.62×10^{-7} (ATLAS 2204.10783)	
$Z \to e^\pm \tau^\mp$	5.0×10^{-6} (ATLAS 2105.12491)	$\mathcal{O}(10^{-9})$ (FCC-ee)
$Z \to \mu^\pm \tau^\mp$	6.5×10^{-6} (ATLAS 2105.12491)	
$t \to e\mu u$	7.0×10^{-8} (CMS 2201.07859)	
$t \to e\mu c$	8.9×10^{-7} (CMS 2201.07859)	$\mathcal{O}(10^{-8})$ (HL-LHC)
$t \to \mu\tau q$	1.1×10^{-6} (ATLAS-CONF-2023-001)	

[see talks by G. Pezzullo and A. Lusiani for details]

Comparison with low-energy probes



[Calibbi, Marcano, Roy, 2107.10273 (EPJC '21)]

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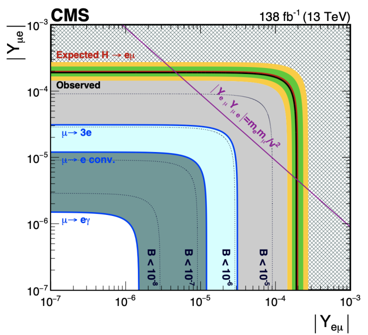
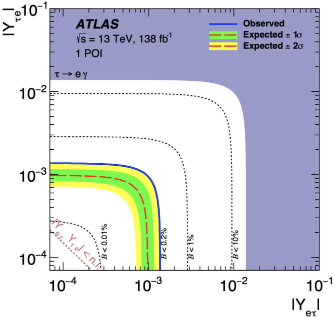
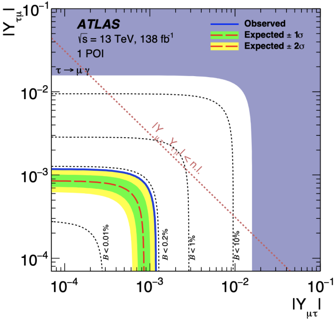
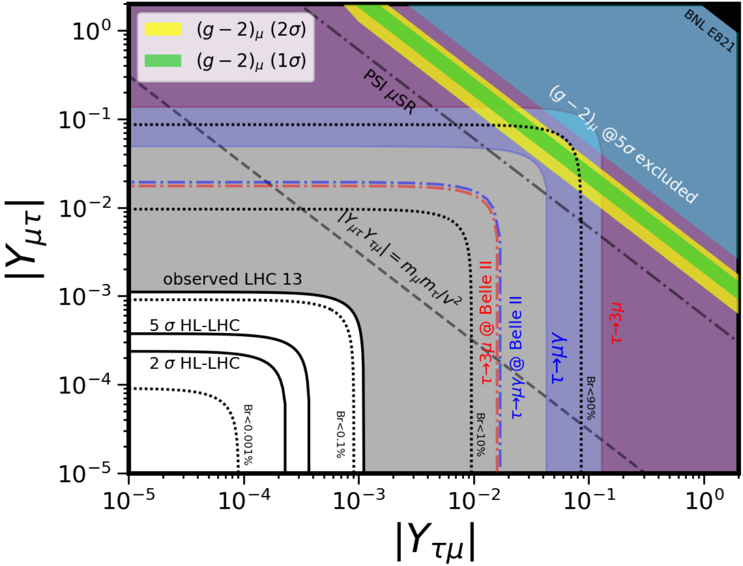




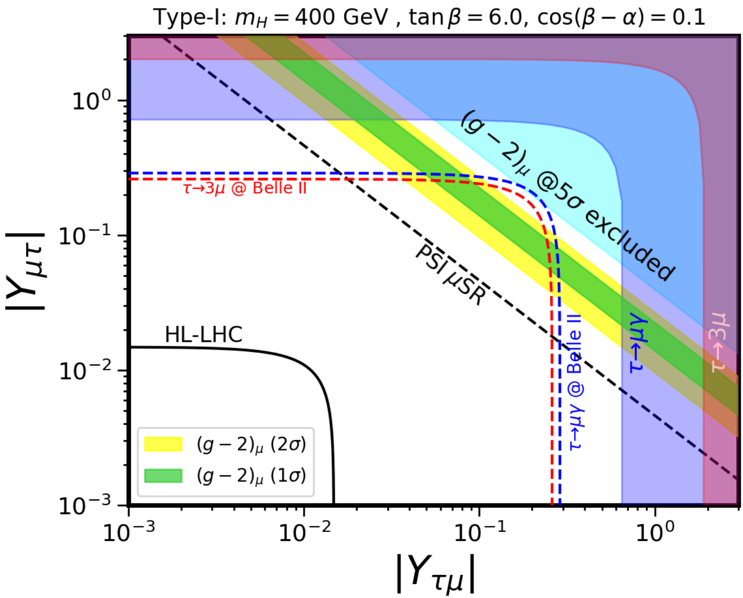


HL-LHC Prospects for $h(125) \to \mu^\pm\tau^\mp$



[Barman, BD, Thapa, 2210.16287 (PRD '23)]

HL-LHC Prospects for BSM Higgs $H \to \mu^\pm \tau^\mp$



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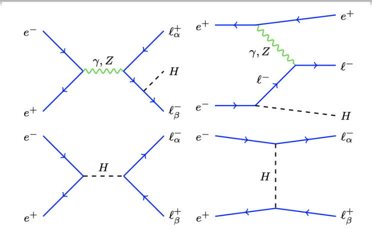
Leptophilic Higgs



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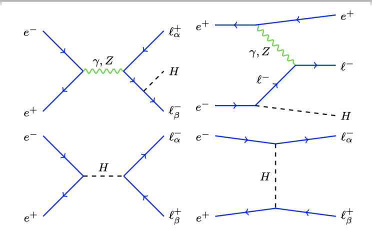
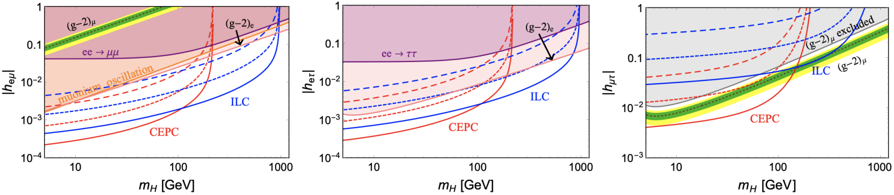


[BD, Mohapatra, Zhang, 1711.08430 (PRL '18)]



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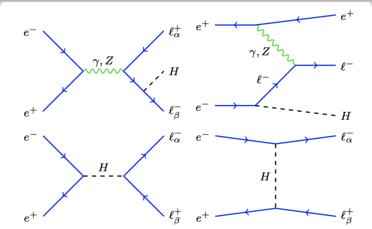

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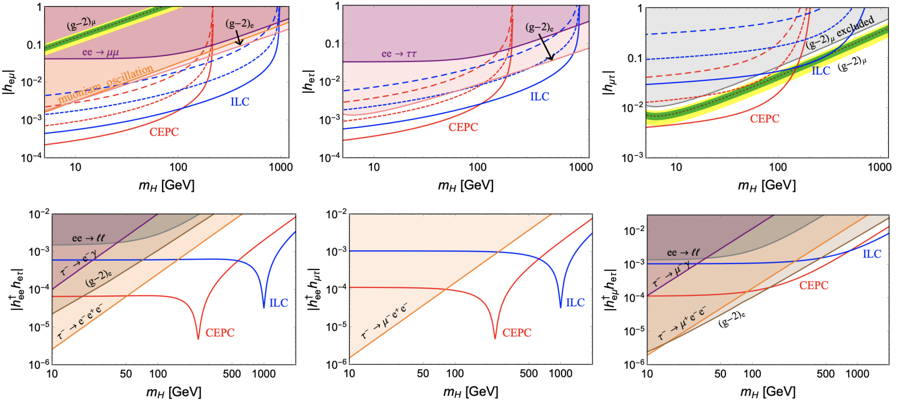
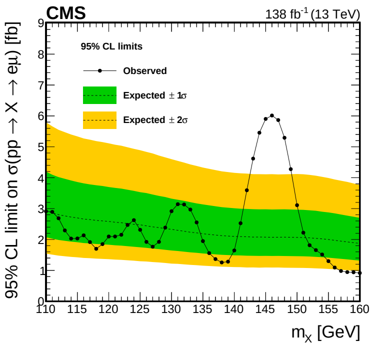


Leptophilic Higgs@LHC?



3.8σ (2.8σ) local (global) excess ☺

$$\sigma(pp \to H(146) \to e\mu)_{\text{CMS}} = 3.89^{+1.25}_{-1.13} \text{ fb}$$

Hint of LFV?

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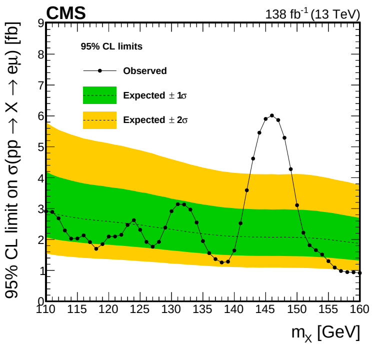

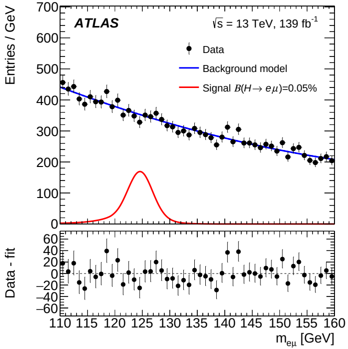

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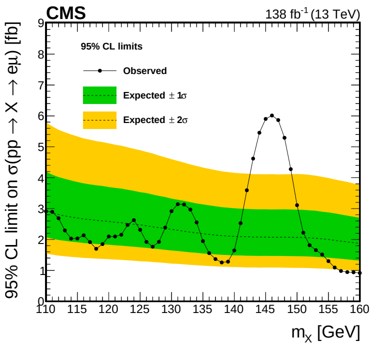

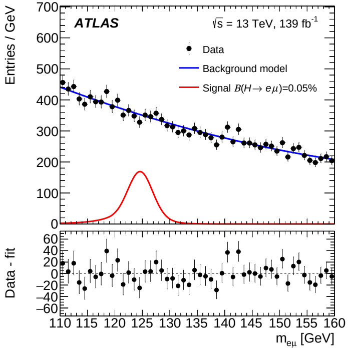

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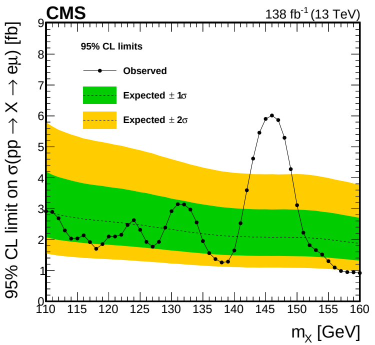
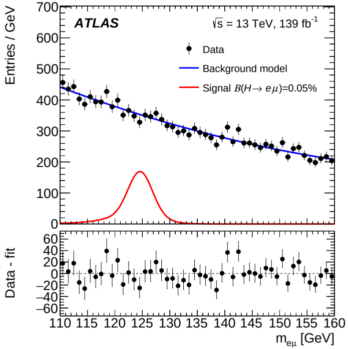
- Use *lepton* content of the proton. [Bertone, Carrazza, Pagani, Zaro (JHEP '15); Buonocore, Nason, Tramontano, Zanderighi (JHEP '20, '21)]
- Leptophilic 2HDM: $-\mathcal{L}_Y \supset Y_{\alpha\beta}\bar{L}_\alpha H_2 \ell_{\beta,R} + \text{H.c.}$





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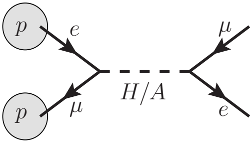
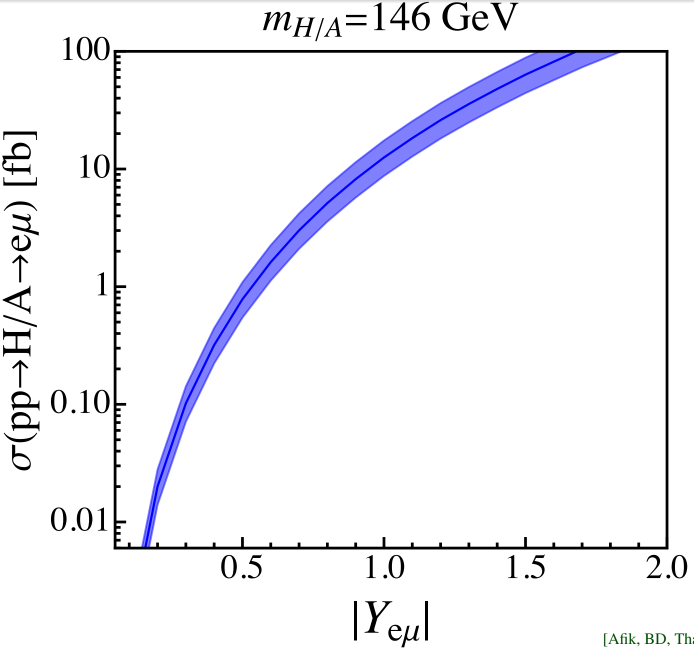
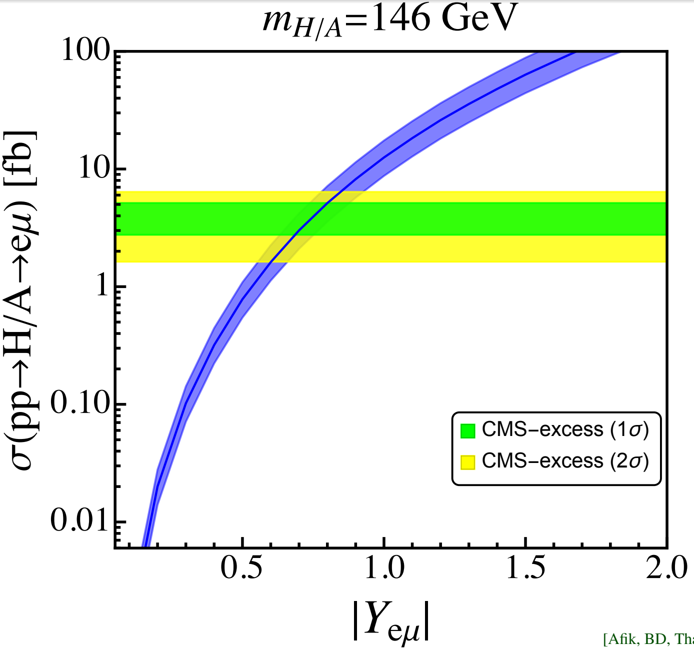




[Afik, BD, Thapa, 2305.19314]



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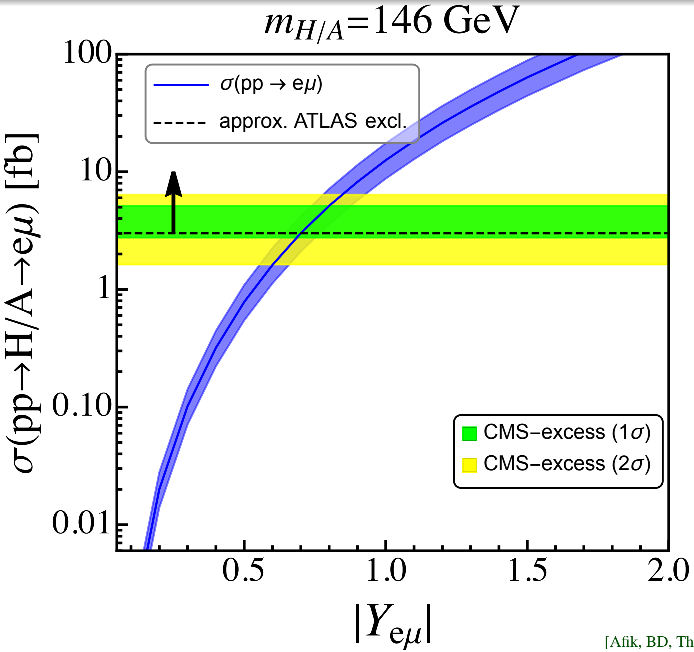
ATLAS exclusion



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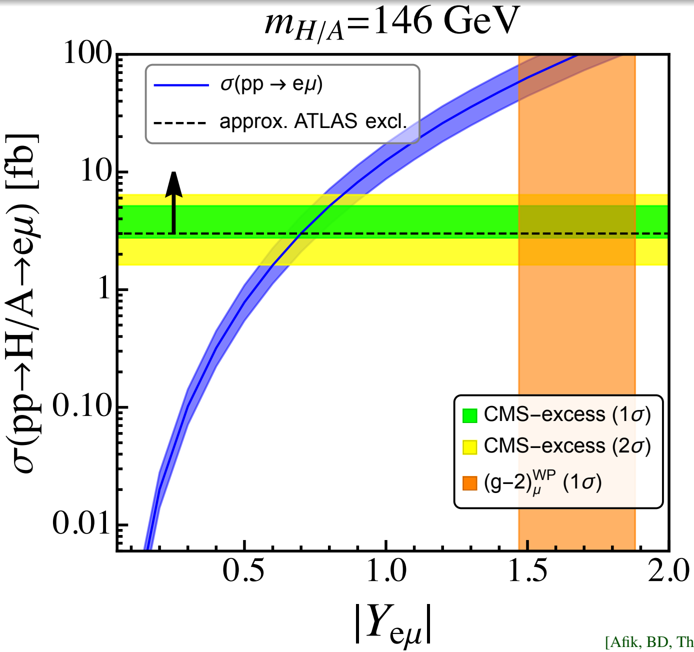
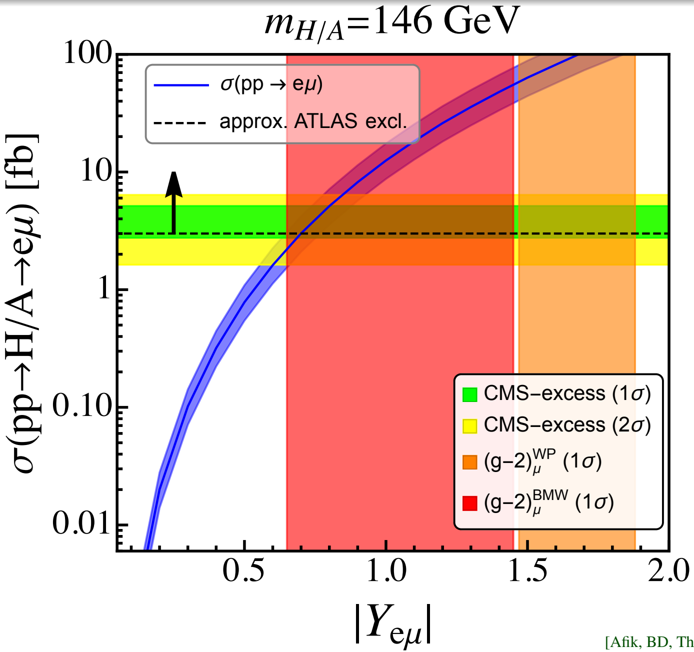


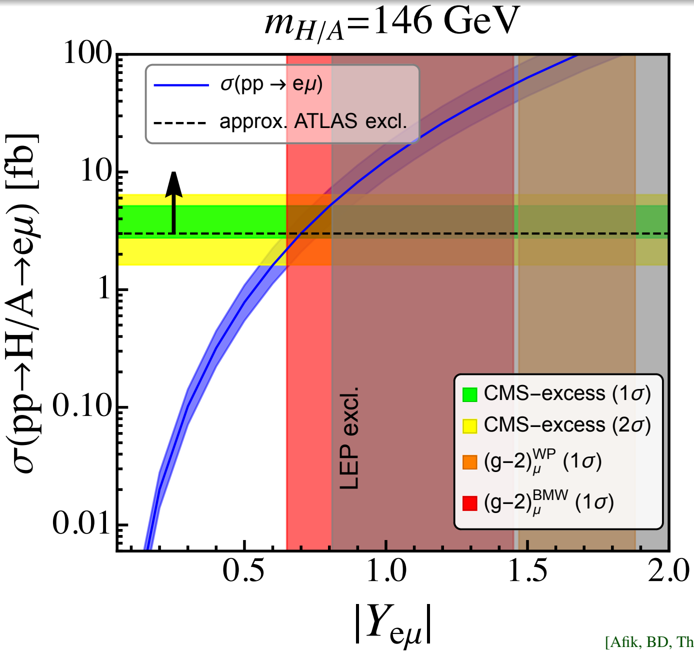
[Afik, BD, Thapa, 2305.19314]

BMW fits better than WP



[Afik, BD, Thapa, 2305.19314]

LEP dimuon constraint



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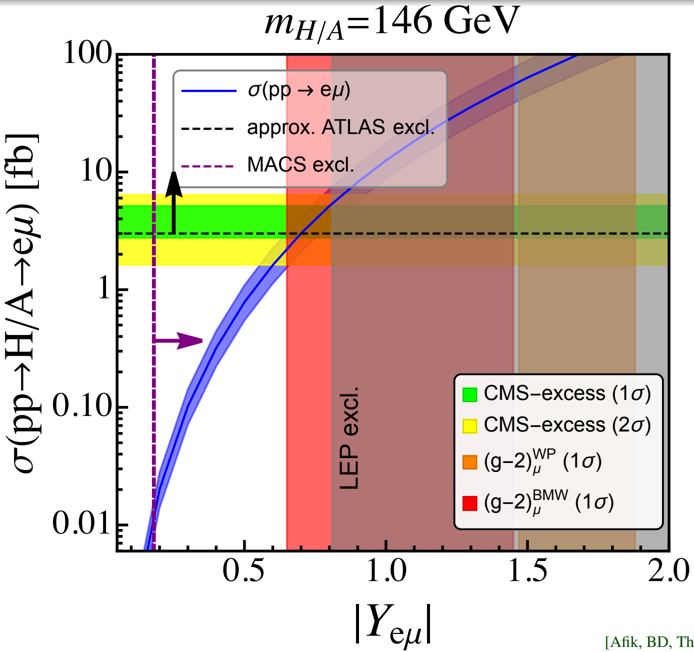
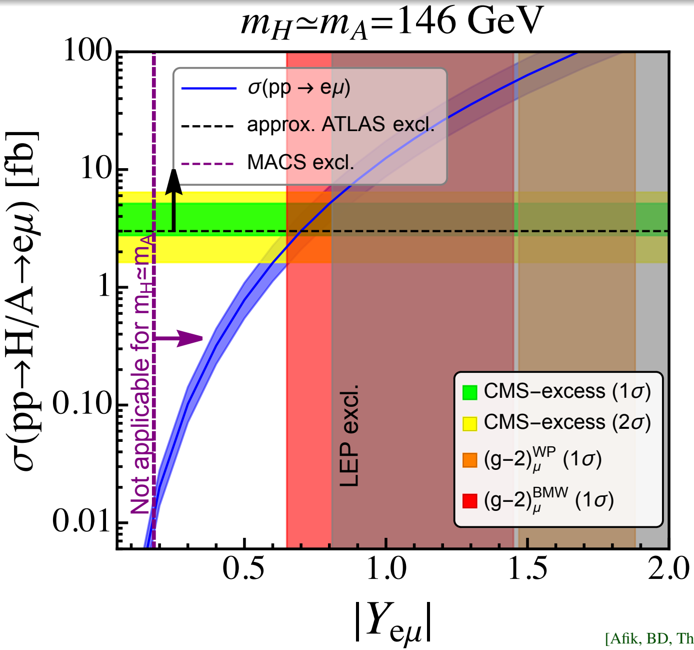
Muonium-antimuonium oscillation is the killer



[Afik, BD, Thapa, 2305.19314]

Can be evaded for a degenerate scalar spectrum



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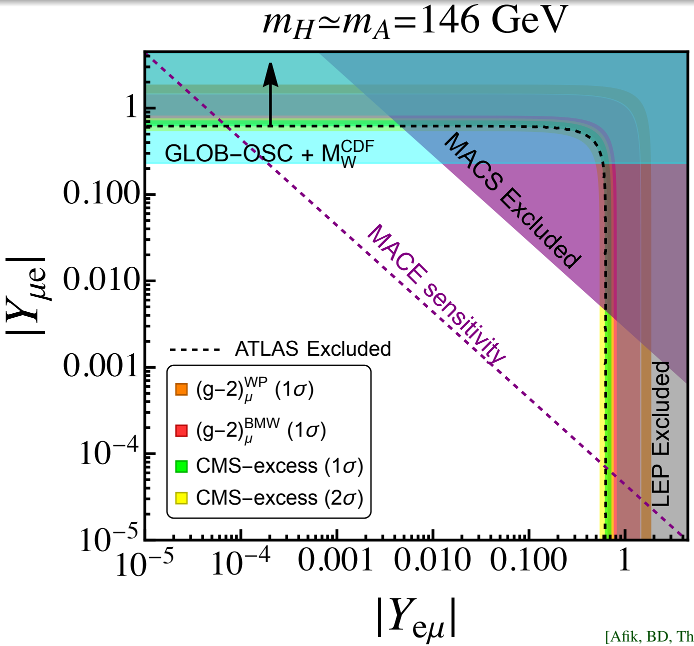
LFV in the Higgs sector, but no CLFV at tree level



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LFV vector boson

A simplified model: $-\mathcal{L} \supset g'_L(\bar{\mu}\gamma^\alpha P_L \tau + \bar{\nu}_\mu \gamma^\alpha P_L \nu_\tau) Z'_\alpha + g'_R(\bar{\mu}\gamma^\alpha P_R \tau) Z'_\alpha$+H.c.

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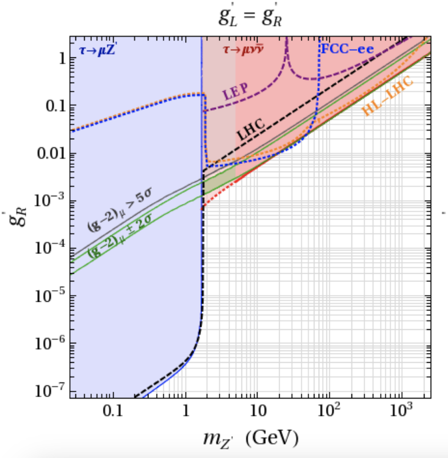
[Altmannshofer, BD, Chen, Soni, 1607.06832 (PLB '16)]



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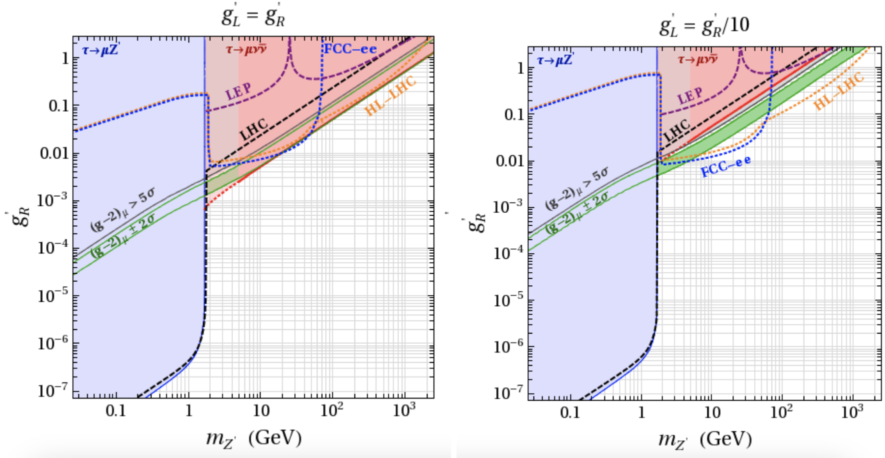

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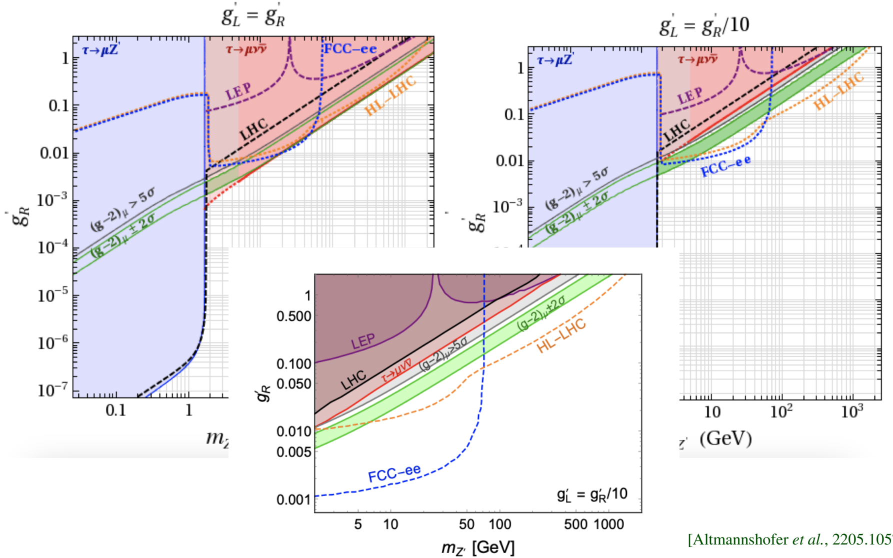
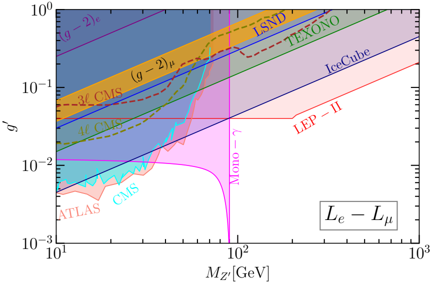
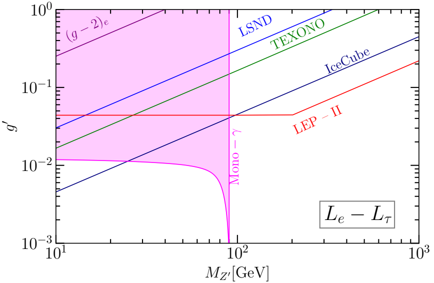


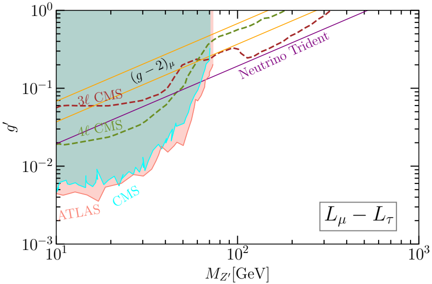
[Altmannshofer *et al.*, 2205.10576]

LFV Z' in $U(1)_{L_\alpha - L_\beta}$: Current constraints

$$\mathcal{L} \supset g' Z'_\mu (\bar{L}_\alpha \gamma^\mu L_\alpha + \bar{e}_{R,\alpha}\gamma^\mu e_{R,\alpha} - \bar{L}_\beta \gamma^\mu L_\beta - \bar{e}_{R,\beta}\gamma^\mu e_{R,\beta}).$$







[Dasgupta, BD, Han, Padhan, Wang, Xie (in preparation)]

LFV Z' in $U(1)_{L_\alpha - L_\beta}$: Future collider prospects

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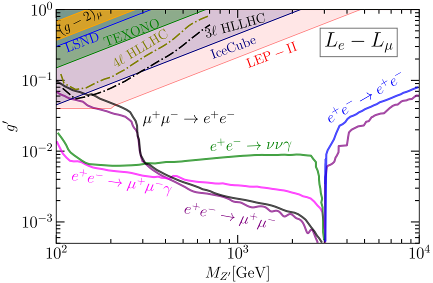

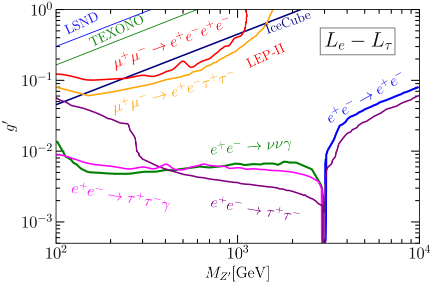

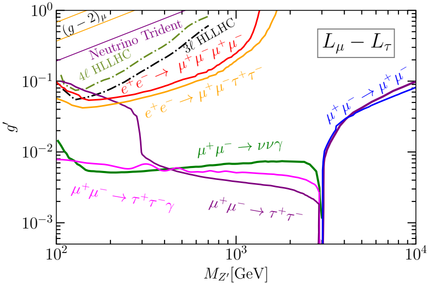

[Dasgupta, BD, Han, Padhan, Wang, Xie (in preparation)]

Conclusion

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- A flavorful way to BSM physics?