2024 Belle II Physics Week

LFV in tau decays and possibility for new mediators

τ & μ complementarity

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Introduction

In the SM, electroweak interactions are *lepton flavour universal* and (with massless neutrinos) *lepton flavour conserving*

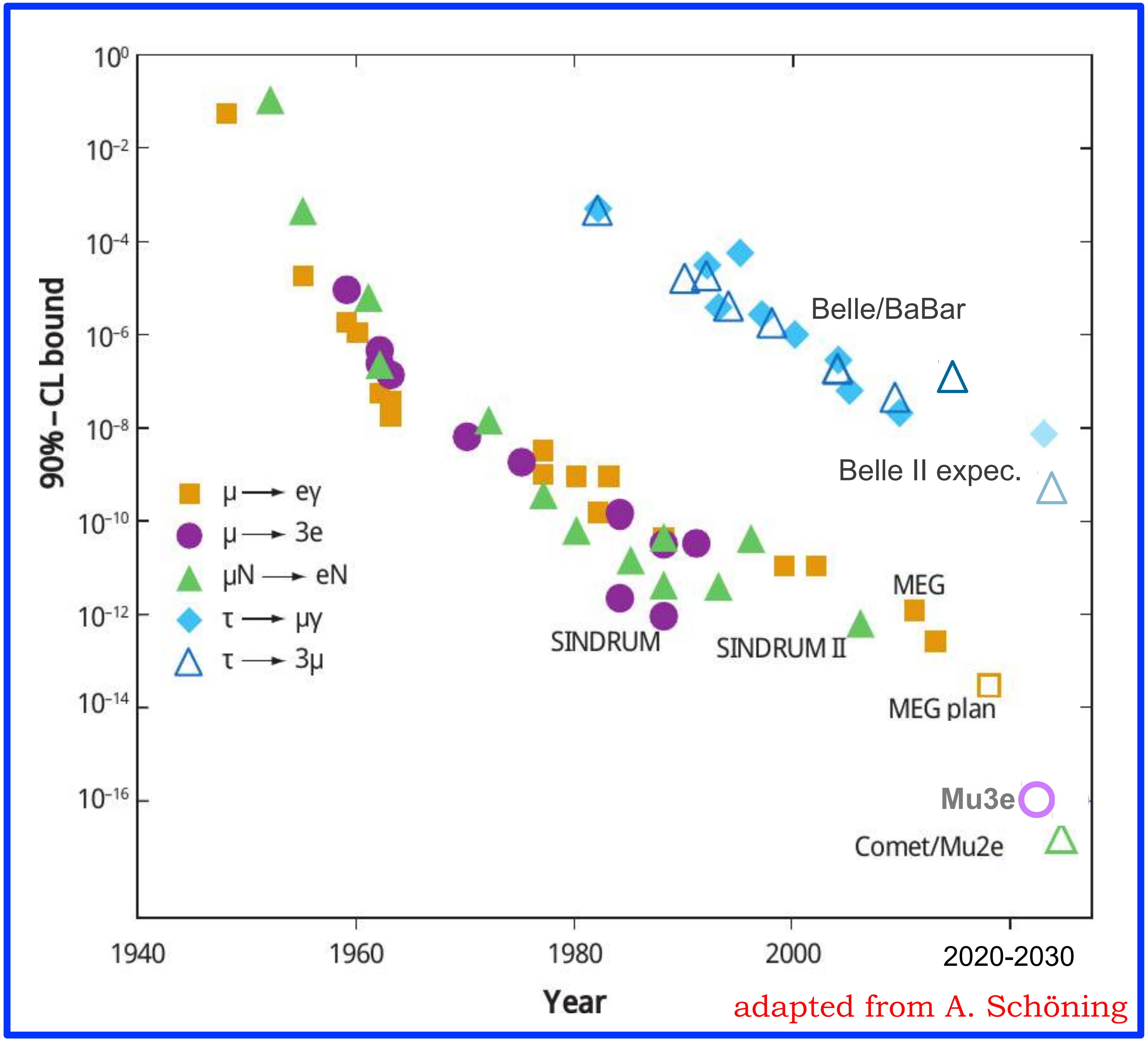
Neutrino masses/oscillations $\Longleftrightarrow \cancel{L}_e, \cancel{L}_\mu, \cancel{L}_\tau$

Lepton family numbers are not conserved: why not *charged* lepton flavour violation (CLFV): $\mu \to e\gamma, \quad \tau \to \mu\gamma, \quad \mu \to eee, \text{ etc.}\,?$

In the SM + neutrino masses, CLFV rates suppressed by a factor $\sim \left(\frac{\Delta m_\nu}{M_W}\right)^4 \approx 10^{-48}$

CLFV: clear signal of New Physics, stringent test of NP physics coupling to leptons, probe of scales way beyond the LHC reach

CLFV has been sought for more than 70 years…



adapted from A. Schöning

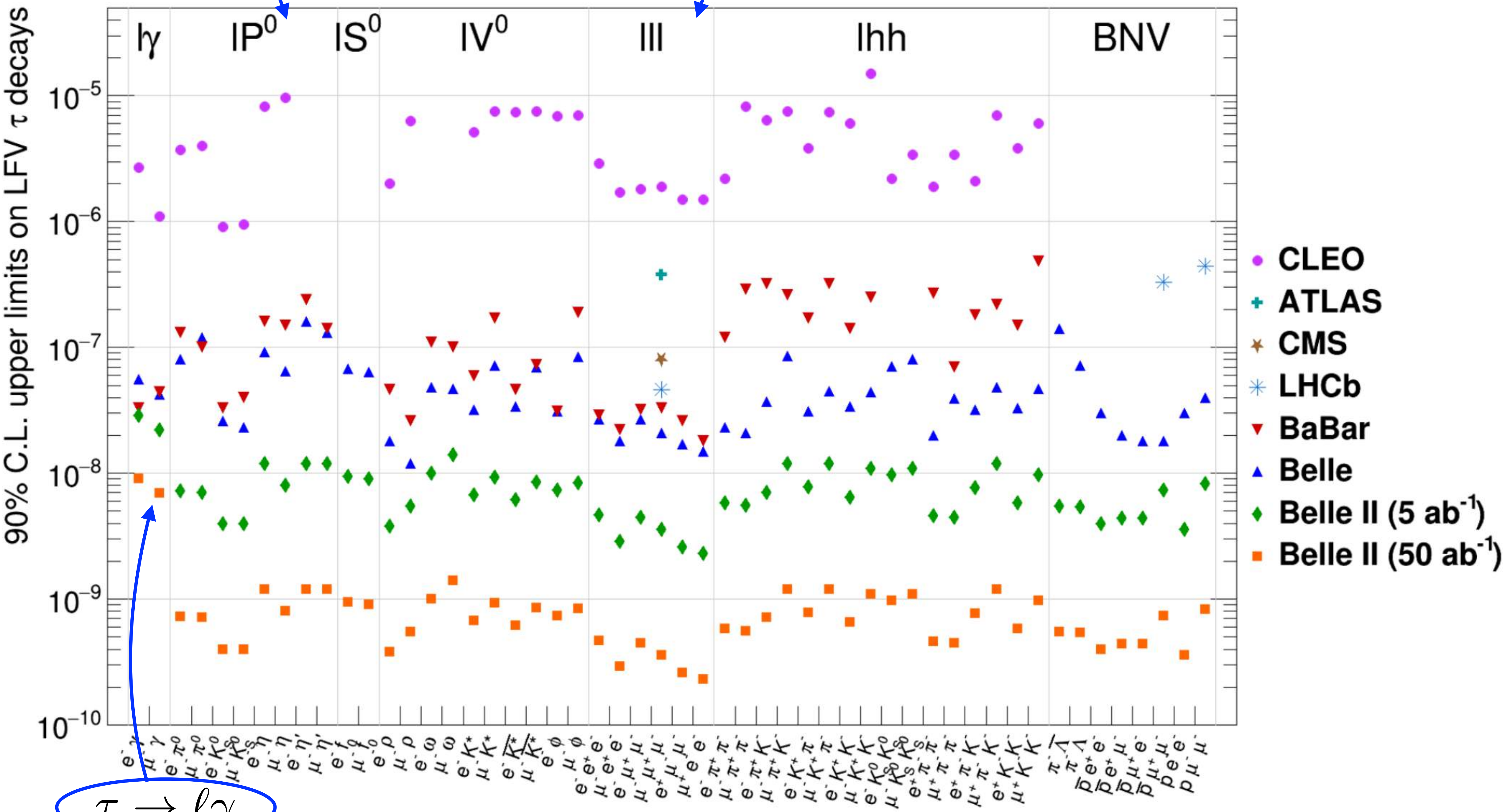
Belle II prospects for tau LFV

$\tau \to \ell P$

$\tau \to \ell V$

$\tau \to \ell \ell' \ell'$

Belle II Snowmass, arXiv:2207.06307



$\tau \to \ell \gamma$

(limited by ISR bg)

→ cf. Soeren's lecture

Introduction

Definitely worth to keep searching for these “standard” modes

→ cf. Jure’s lecture and Marco’s talk

but…

What if we haven’t searched (enough) in the right place?

New Physics (NP) may be light and/or “dark”

→ cf. Stefania’s lectures and Olcyr’s talk

Motivation

Dark Matter exists! (About 27% of the energy of the universe)

DM direct detection searches and LHC searches for heavy new physics are giving increasingly tight constraints on WIMP models

This is why people increasingly focus *also* on other paradigms, *e.g.* axions, dark photons, light DM/light dark sectors etc.

E.g. : axion-like-particles (ALPs) (*often flavour-violating*) arise in a broad class of models with spontaneously broken global U(1)

Flavour-violating axion-like-particles

- ALPs ~ (pseudo) Nambu-Goldstone bosons are naturally *light* and interact weakly with the SM (couplings suppressed by the U(1)-breaking scale f_a)

- Many scenarios motivated by outstanding problems of the SM (strong CP problem → PQ symmetry → axion, neutrino masses → lepton number → majoron, fermion hierarchies → family symmetry → familon, …)

- Model-independently, the couplings to the SM fermions are of the form:

$$\boxed{\mathcal{L}_{aff} = \frac{\partial_\mu a}{2 f_a}\, \bar{f}_i \gamma^\mu (C^V_{f_i f_j} + C^A_{f_i f_j} \gamma_5) f_j}$$

- *Flavour-violating* couplings can arise from loops or automatically if fermions have non-universal U(1) charges (e.g. flaxion/axiflavon)

- They can be DM candidates (accounting for the observed DM abundance through the misalignment or the freeze-in mechanism) or they can serve as portals to a light DM sector, e.g. :

$$\mathcal{L}_{a\chi\chi} = \frac{\partial_\mu a}{2 f_a} C^A_{\chi\chi}\, \bar{\chi} \gamma^\mu \gamma_5 \chi$$

dark fermion

Flavour-violating axion-like-particles

- ALPs ~ (pseudo) Nambu-Goldstone bosons are naturally *light* and interact weakly with the SM (couplings suppressed by the U(1)-breaking scale f_a)

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⇨ Signature at flavour experiments:

2-body flavour-violating decays into a long-lived/invisible ALP

$$K \to \pi a,\ D \to \pi a,\ B \to K a, \boxed{\mu \to e a,\ \tau \to \mu a,} \ldots$$

fermions have non-universal U(1) charges (e.g. flaxion/axiflavon)

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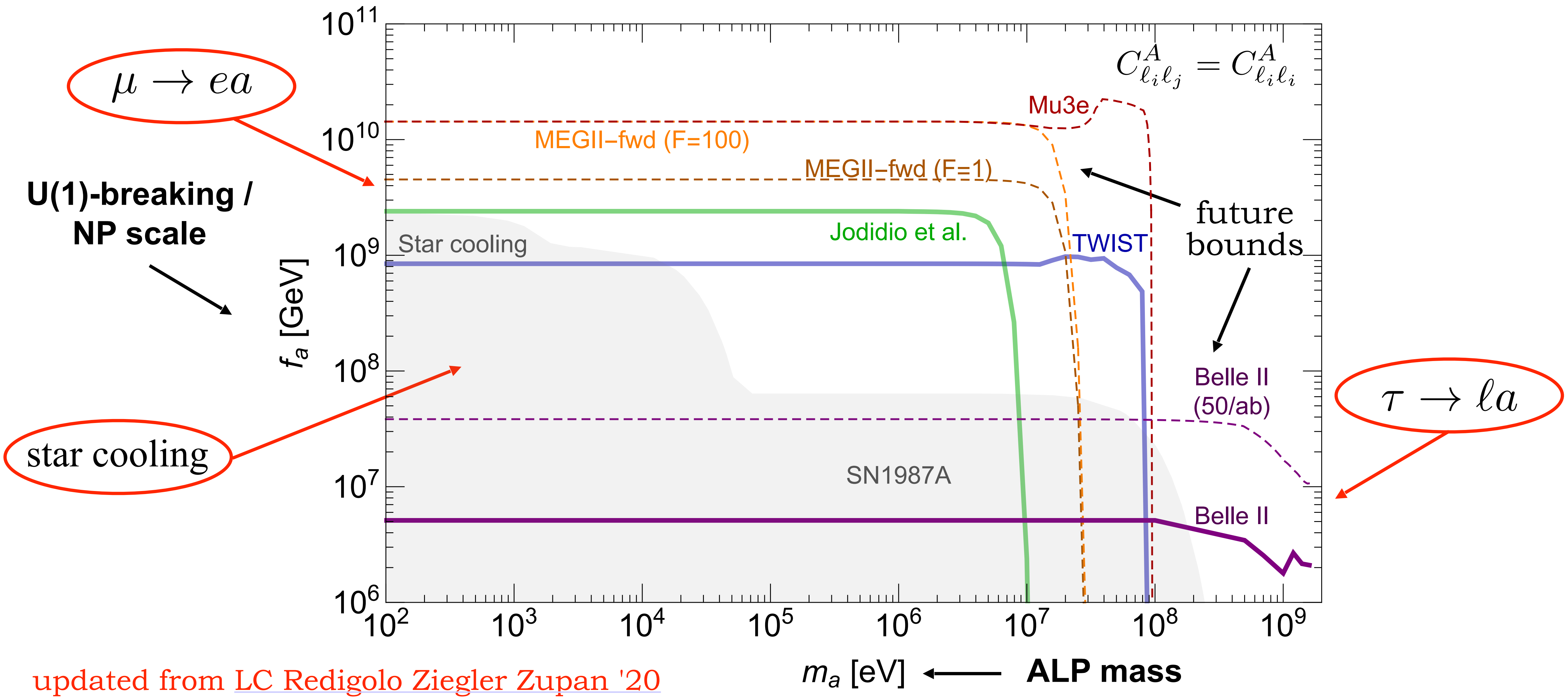
$$\mathcal{L}_{a\chi\chi} = \frac{\partial_\mu a}{2 f_a} C^A_{\chi\chi}\, \bar{\chi}\gamma^\mu\gamma_5\chi$$

dark fermion

Summary of searches for LFV invisible ALPs

$$\mathcal{L}_{a\ell\ell} = \frac{\partial^\mu a}{2f_a}\left(C^V_{ij}\,\bar{\ell}_i\gamma_\mu\ell_j + C^A_{ij}\,\bar{\ell}_i\gamma_\mu\gamma_5\ell_j\right) \Rightarrow \Gamma(\ell_i \to \ell_j\, a) = \frac{1}{64\pi}\frac{m^3_{\ell_i}}{f_a^2}\left(|C^V_{\ell_i\ell_j}|^2 + |C^A_{\ell_i\ell_j}|^2\right)\left(1-\frac{m_a^2}{m^2_{\ell_i}}\right)^2$$

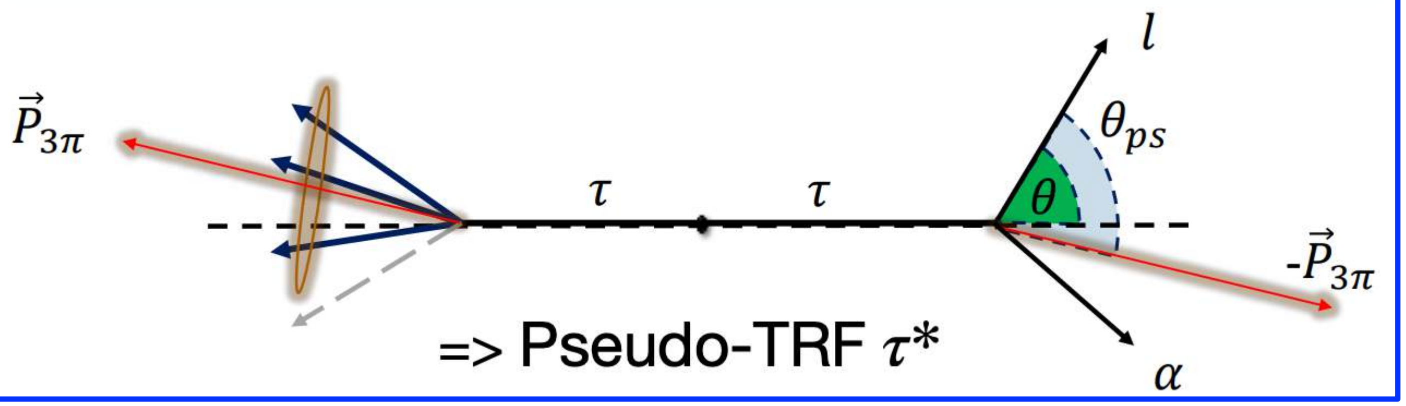


updated from LC Redigolo Ziegler Zupan '20

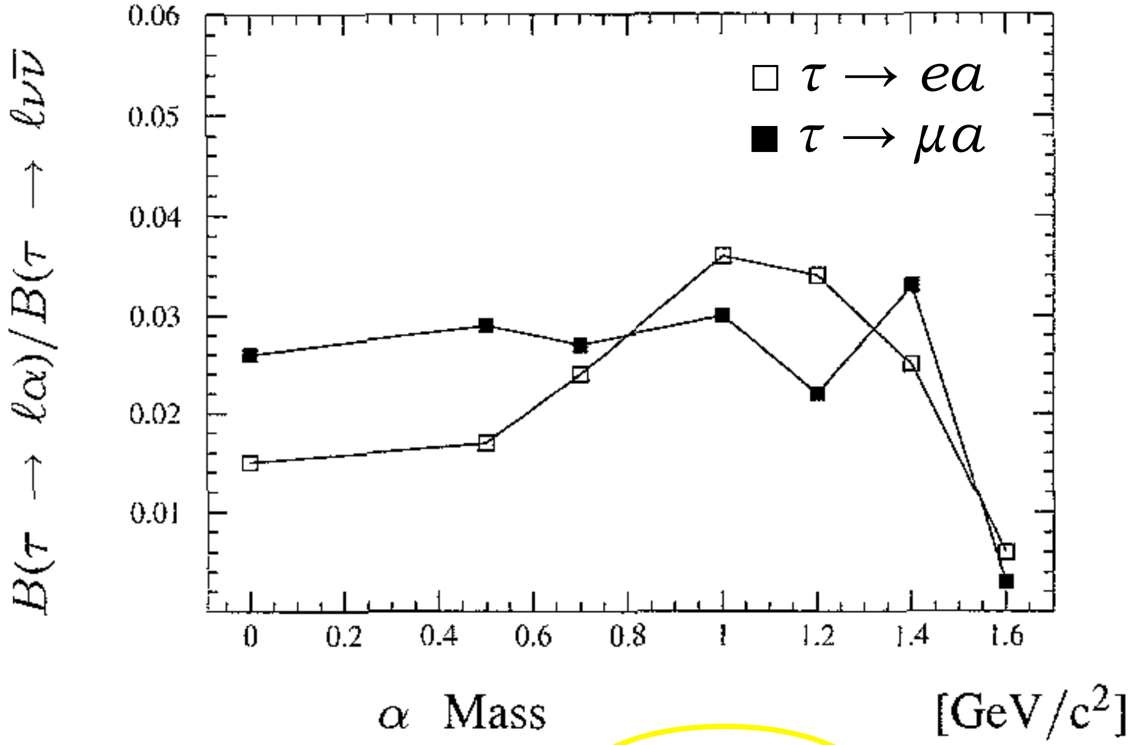
- Decays mediated by dimension-5 operators: much larger NP scales can be reached than with $\mu \to e\gamma$, $\mu \to eee$ etc. (from dim-6 operators)
- Mu/tau/astro interplay: if $m_a > m_\mu$ the only constraints come from τ decays…

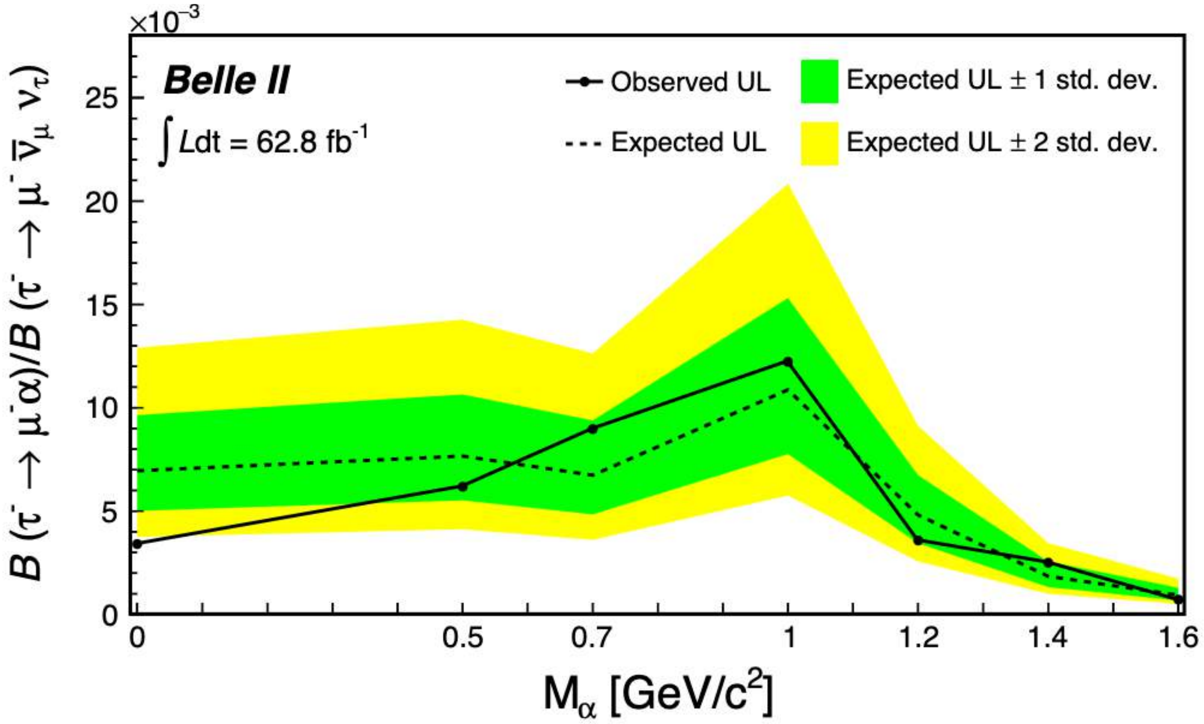
Present limits on $\tau \to e\,a$, $\tau \to \mu\,a$ (invisible a)

A challenging search:
tau momentum / rest frame
cannot be exactly reconstructed
BG: ordinary $\tau \to \ell\nu\bar{\nu}$



=> Pseudo-TRF τ^*





ARGUS 1995 (472 pb^{-1}) → Belle II 2023 (62.8 fb^{-1})

up to O(10) improvement!

$m_a \approx 0$:

$$\mathrm{BR}(\tau \to \mu\,a) < 4.7 \times 10^{-4}\ (90\%\ \mathrm{CL}) \quad \Rightarrow \quad f_a/C^{V,A}_{\mu\tau} > 5.1 \times 10^{6}\ \mathrm{GeV}$$

$$\mathrm{BR}(\tau \to e\,a) < 7.6 \times 10^{-4}\ (90\%\ \mathrm{CL}) \quad \Rightarrow \quad f_a/C^{V,A}_{e\tau} > 4.0 \times 10^{6}\ \mathrm{GeV}$$

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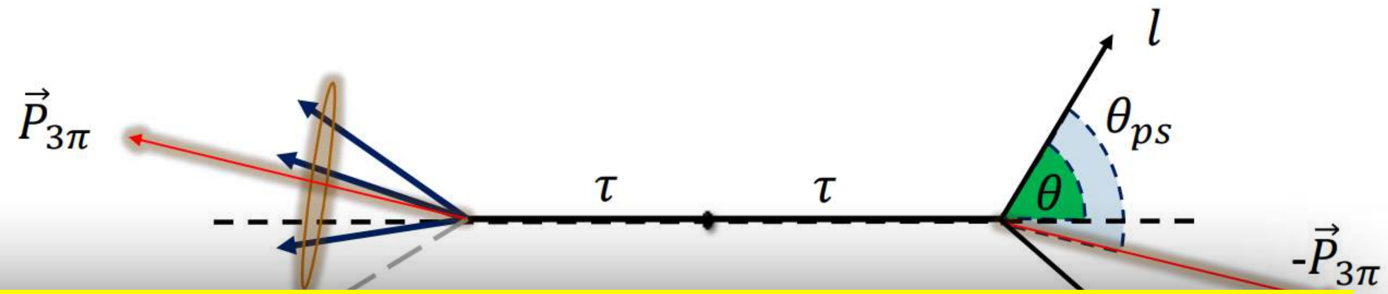

Taus vs. muons: Life is not easy at muon experiments either
However, they have certain advantages:

- Muons long-lived: they can work with high-intensity beams $> 10^8\ \mu/\mathrm{s}$, they can stop muons on targets and let them decay at rest
- Muons long-lived: smaller width implies higher sensitivity to NP scale
- Muon beams easily polarised: this can enhance the sensitivity

Open question: could Belle II use information on the tau polarisation to increase the sensitivity too?

Let's have a look at how it works in the muon case…

$m_a \approx 0$:

$$\mathrm{BR}(\tau \to \mu\, a) < 4.7 \times 10^{-4}\ (90\%\ \mathrm{CL}) \quad \Rightarrow \quad f_a / C^{V,A}_{\mu\tau} > 5.1 \times 10^{6}\ \mathrm{GeV}$$

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$\mu \to e\, a$: signal and background

Signal: monochromatic positron with $p_e = \sqrt{\left(\frac{m_\mu^2 - m_a^2 + m_e^2}{2m_\mu}\right)^2 - m_e^2}$

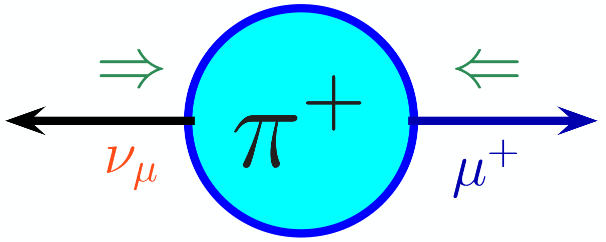
Differential decay rate: $\frac{\mathrm{d}\Gamma(\ell_i \to \ell_j\, a)}{\mathrm{d}\cos\theta} = \frac{m_{\ell_i}^3}{32\pi F_{\ell_i\ell_j}^2}\left(1 - \frac{m_a^2}{m_{\ell_i}^2}\right)^2\left[1 + 2P_{\ell_i}\cos\theta\,\frac{C^V_{\ell_i\ell_j} C^A_{\ell_i\ell_j}}{(C^V_{\ell_i\ell_j})^2 + (C^A_{\ell_i\ell_j})^2}\right]$

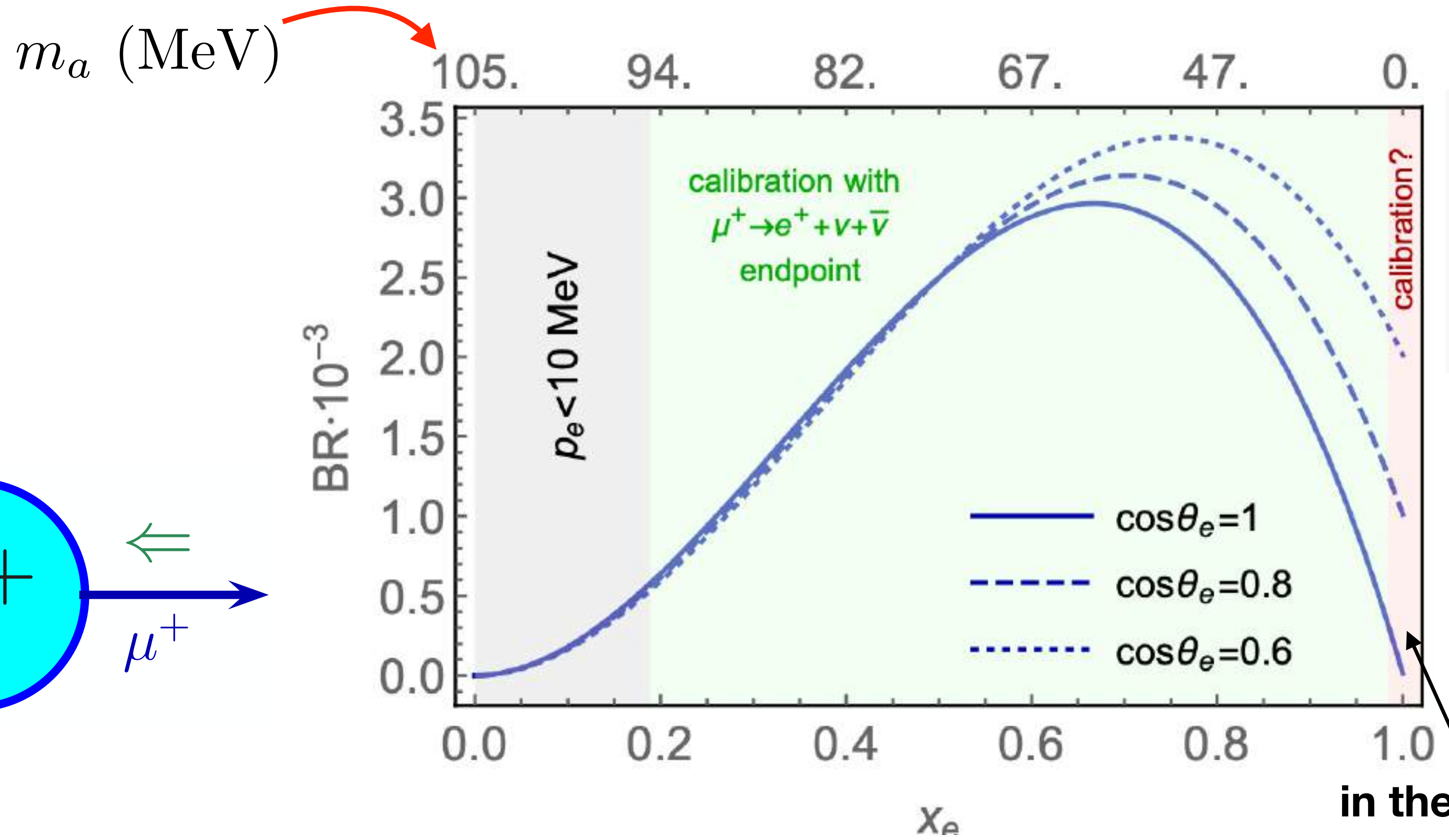
signal anisotropy depends on the chirality of the couplings

Michel spectrum: $\frac{\mathrm{d}^2\Gamma(\mu^+ \to e^+\,\nu_e\,\bar\nu_\mu)}{\mathrm{d}x_e\,\mathrm{d}\cos\theta} \simeq \Gamma_\mu\left((3 - 2x_e) - P_\mu(2x_e - 1)\cos\theta\right) x_e^2$ $\quad x_e = \frac{2p_e}{m_\mu}$

μ polarisation

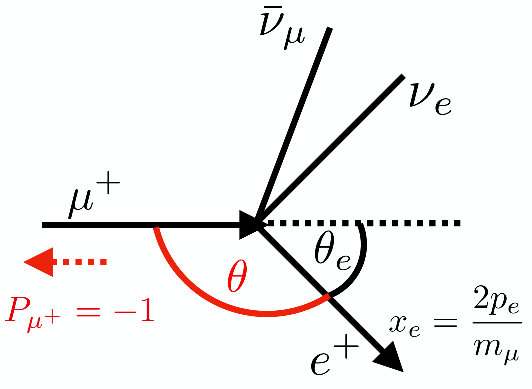
And "surface" muons are highly polarised (produced by pion decays at rest on the surface of the production target) → the SM background can be suppressed





in the massless case

the bkd goes to zero
in the "forward"direction
(the direction opposite
to the muon polarization)



Currently strongest limit on $\mu \to e\, a$

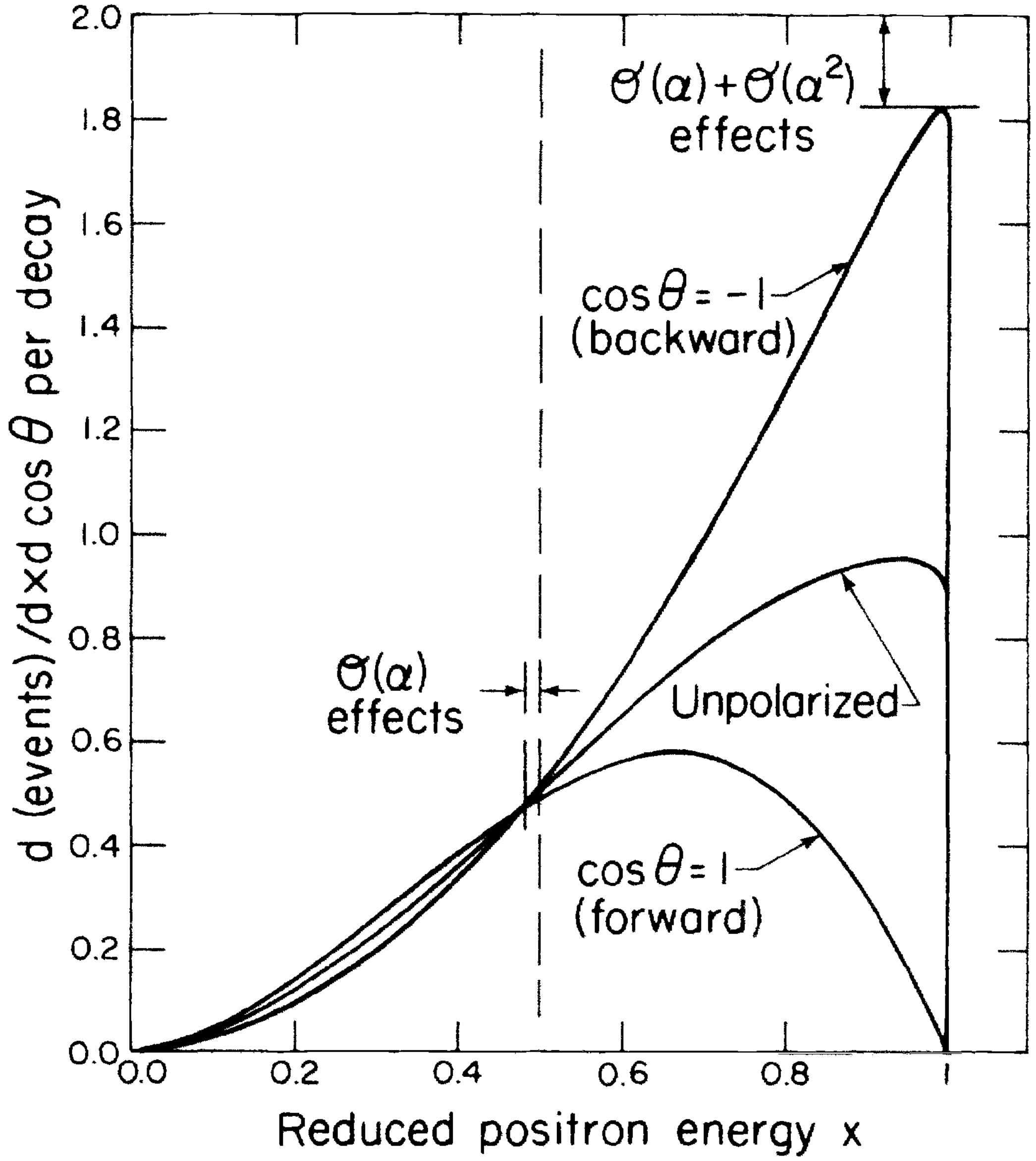
- Jodidio et al. (TRIUMF) 1986

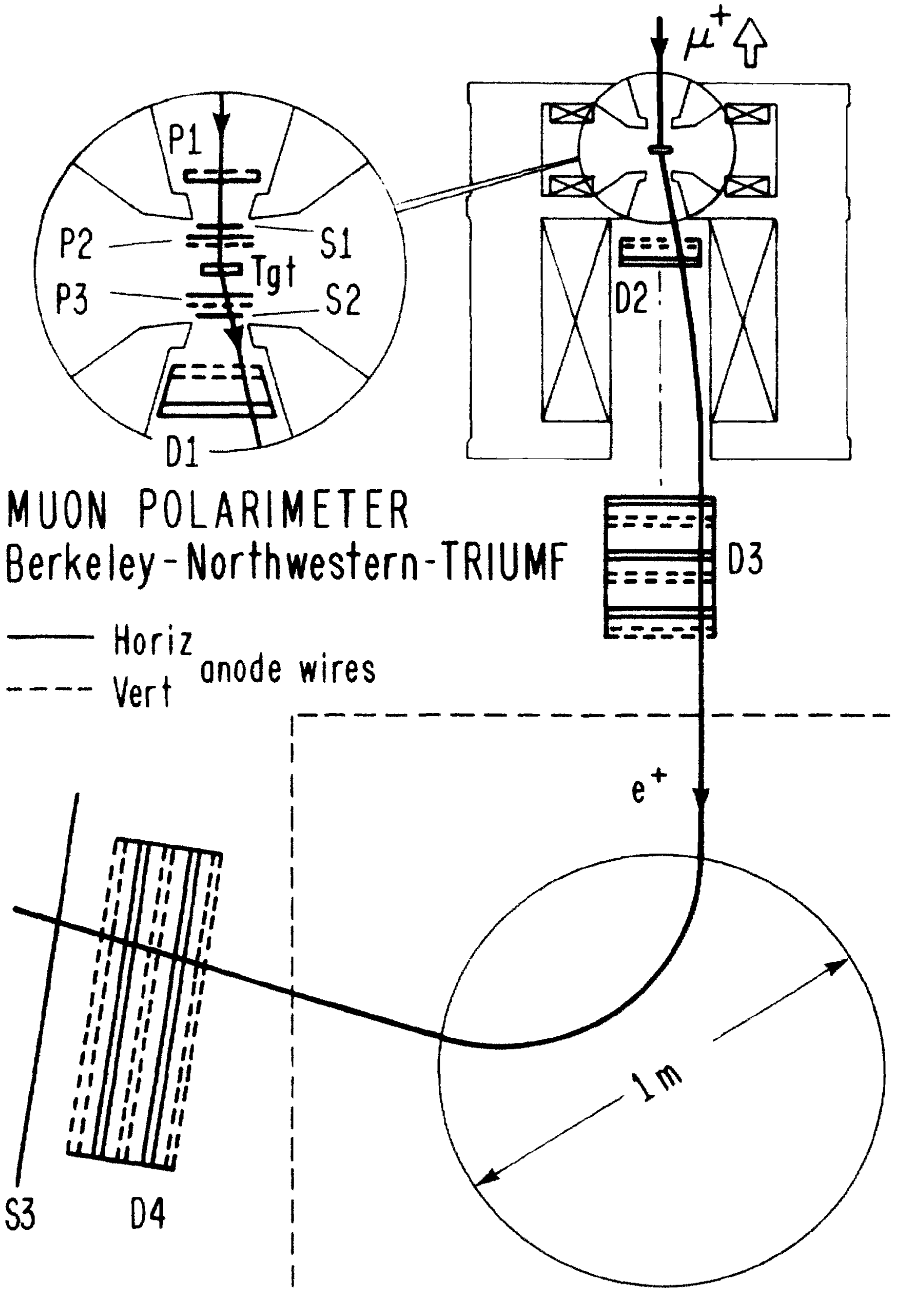
Search for RH currents with $1.8{\times}10^7$ polarised μ^+

Ordinary $\mu \to e\bar{\nu}\nu$

$$\frac{d^2\Gamma}{dx\, d\cos\theta} = \Gamma_\mu \left((3-2x) - P(2x-1)\cos\theta\right) x^2$$

$$x = 2E_e/m_\mu$$





Very good e+ momentum resolution
(~70 KeV at the e.p.)

Currently strongest limit on $\mu \to e\, a$

- Jodidio et al. (TRIUMF) 1986

Search for RH currents with $1.8{\times}10^7$ polarised μ^+ interpreted in terms of $\mu \to ea$ too

Ordinary $\mu \to e\bar{\nu}\nu$

$$\frac{d^2\Gamma}{dx\, d\cos\theta} = \Gamma_\mu \left((3-2x) - P(2x-1)\cos\theta\right) x^2$$

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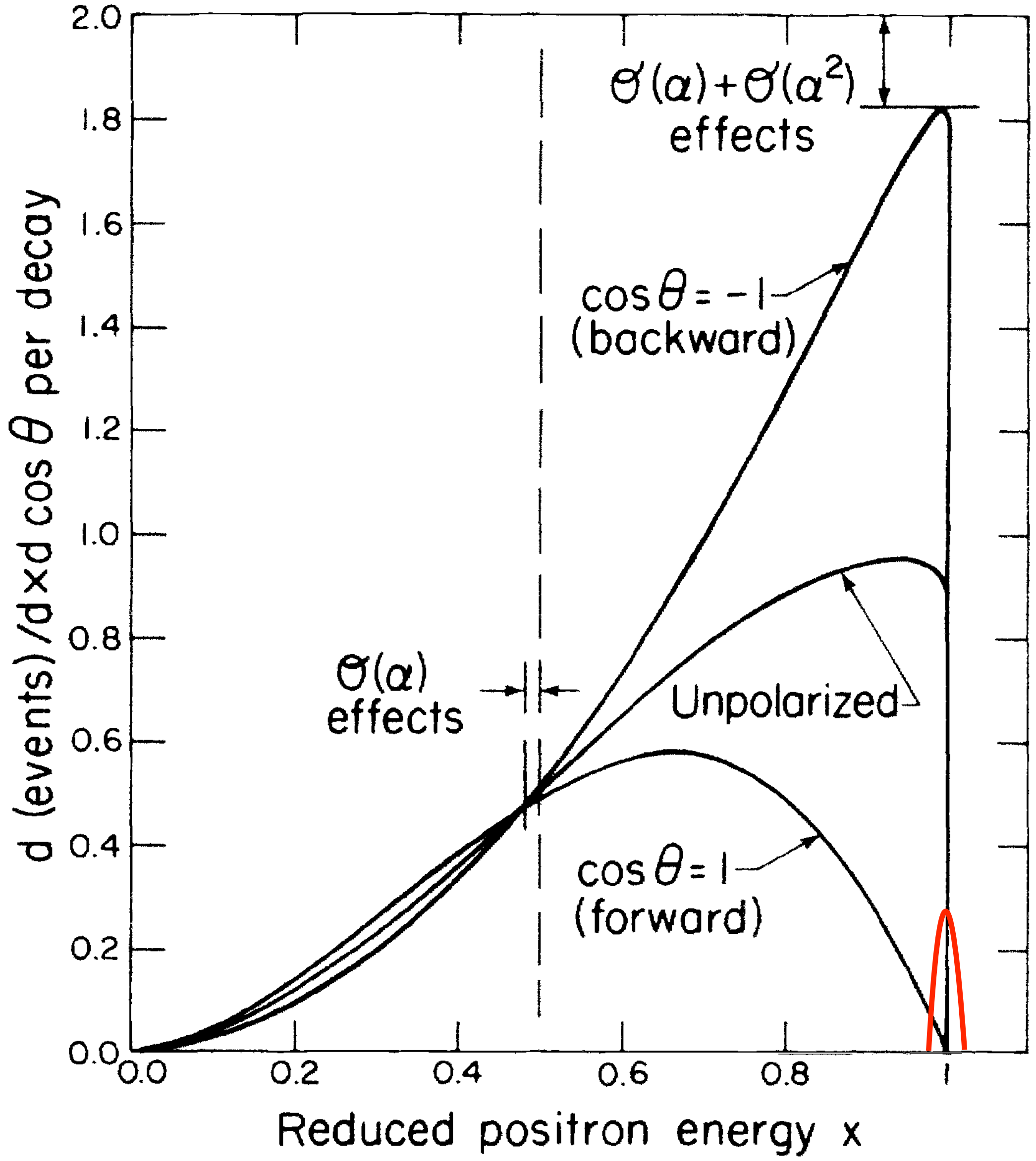


$\mu \to e\, a$ signal for $m_a \approx 0$:

monochromatic e^+ at $m_\mu/2$

Unless it couples (V-A) like in the SM:

$$\frac{d\Gamma(\mu^+ \to e^+ a)}{d\cos\theta} = \frac{\Gamma_{\mu\to e\, a}}{2}\left[1 + 2P\cos\theta \frac{C^V_{e\mu} C^A_{e\mu}}{(C^V_{e\mu})^2 + (C^A_{e\mu})^2}\right]$$

for the *isotropic* case, they set the limit

$$\Rightarrow \quad \mathrm{BR}(\mu^+ \to e^+ a) < 2.6 \times 10^{-6}$$

thus one gets

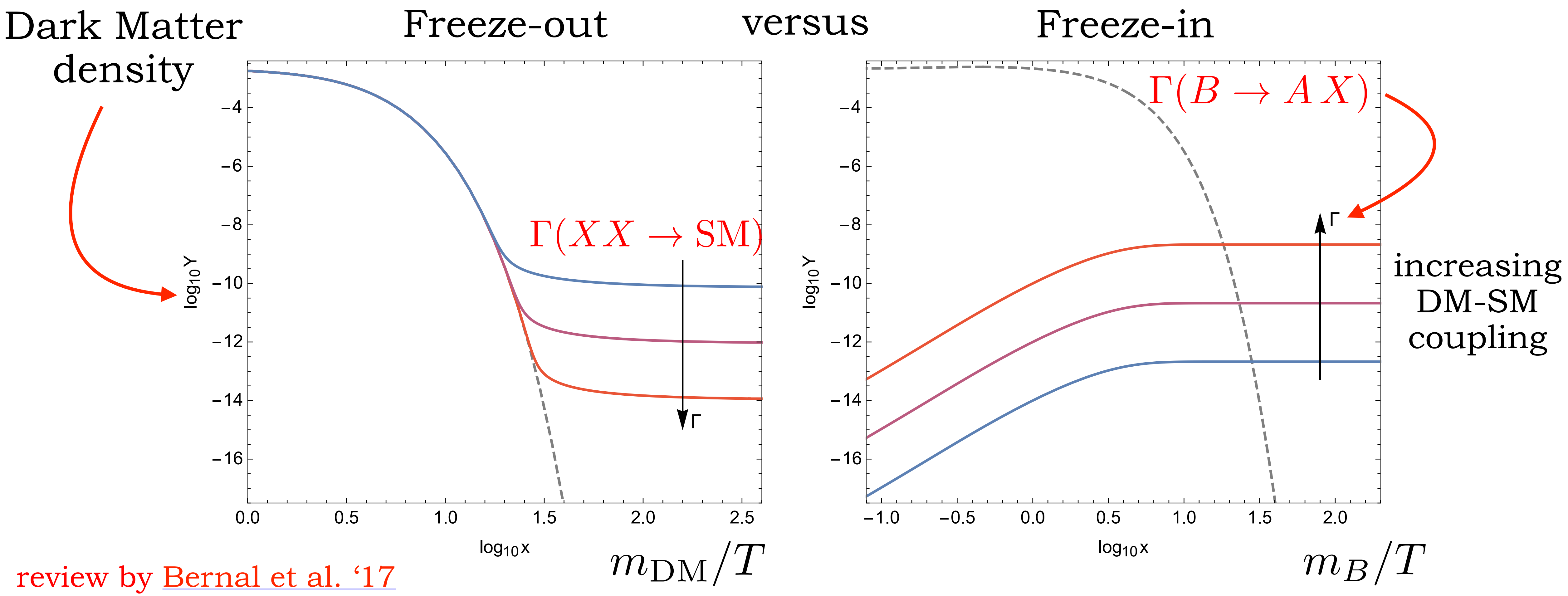
$$\Rightarrow \quad f_a / C^{V,A}_{e\mu} > 2.4 \times 10^9 \ \mathrm{GeV}$$

LFV dark matter production?

What if $\mu \to ea$, $\tau \to \mu a$ also produce DM ALPs in the early universe, via the *freeze-in* mechanism? Panci Redigolo Schwetz Ziegler '22

Freeze-in: a production mechanism for DM that was never in thermal equilibrium with the Standard Model bath (because too *feebly-coupled*), but can be produced via scattering or decays of bath particles

Hall Jedamzik March-Russell West '09



Dark Matter density

Freeze-out versus Freeze-in

$\Gamma(XX \to \mathrm{SM})$

$\Gamma(B \to A\,X)$

increasing DM-SM coupling

m_{DM}/T

m_B/T

review by Bernal et al. '17

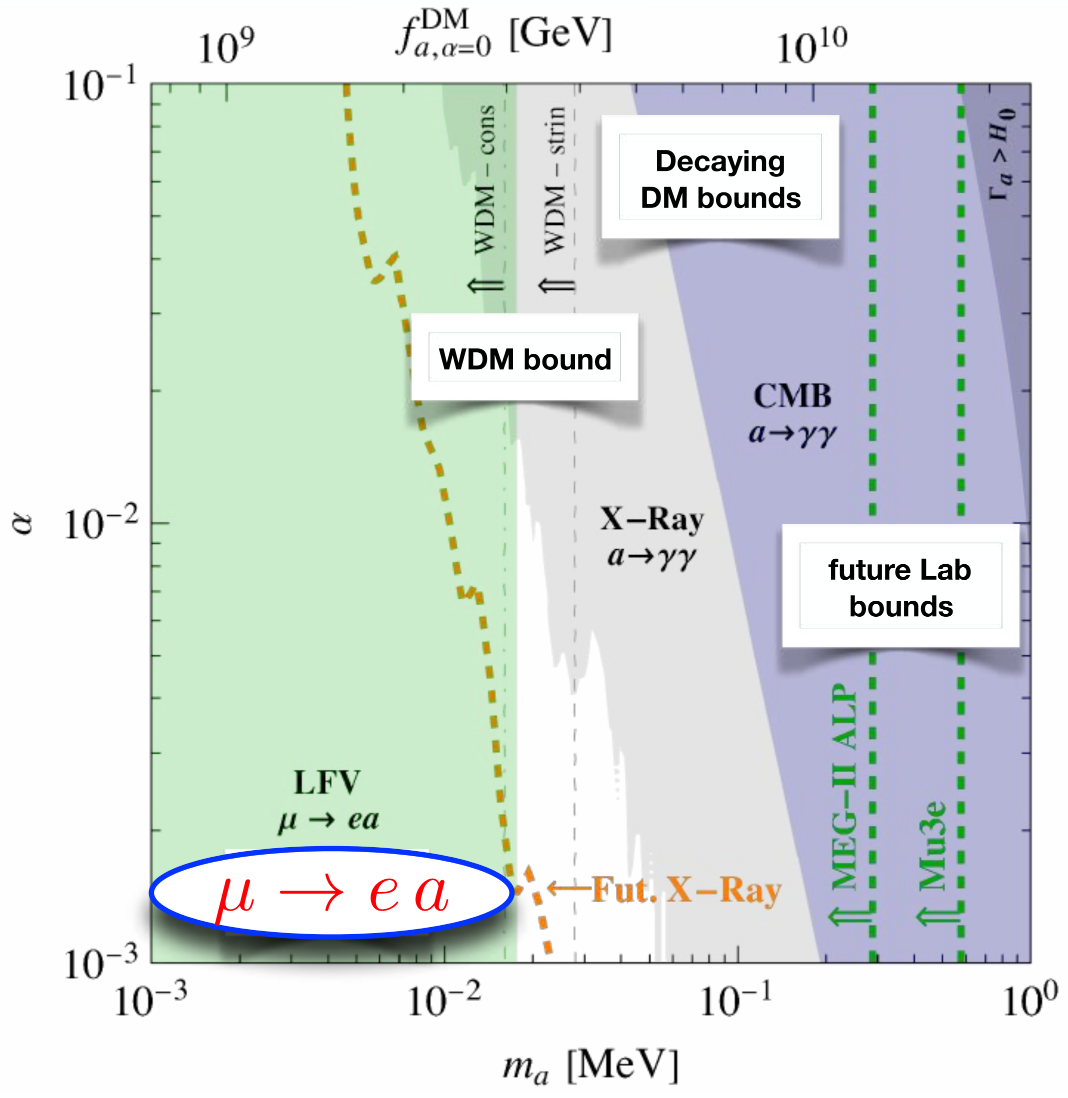
LFV dark matter production?

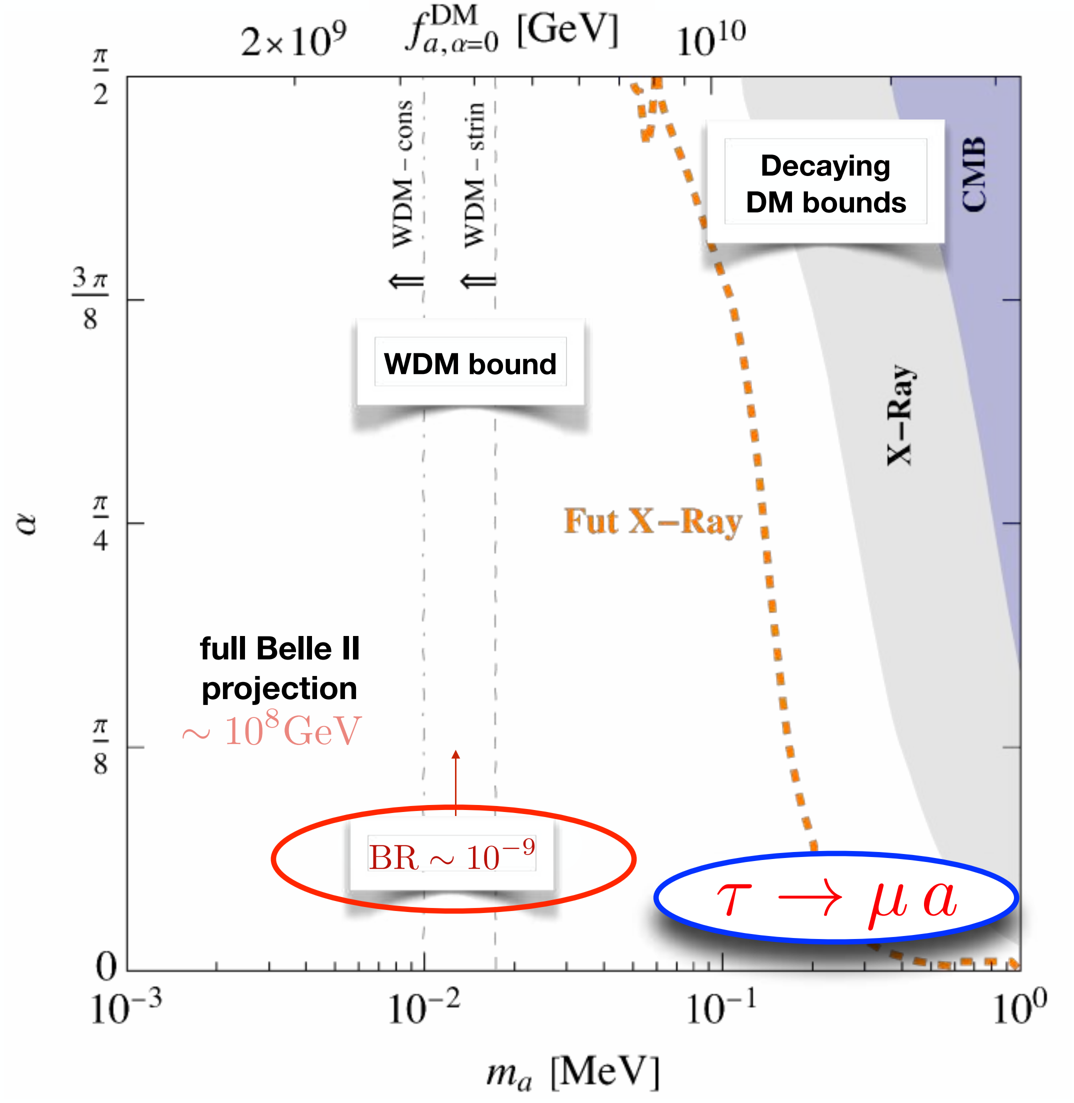
What if $\mu \to e a,\ \tau \to \mu a$ also produce DM ALPs in the early universe, via the *freeze-in* mechanism?

$$\mathcal{L}_a = \frac{\partial_\nu a}{2 f_a}\left[\cos\alpha \cdot \bar{\tau}\gamma^\nu\gamma_5\mu + \sin\alpha \cdot \bar{\tau}\gamma^\nu\gamma_5\tau - \sin\alpha \cdot \bar{\mu}\gamma^\nu\gamma_5\mu\right] - \frac{1}{2}m_a^2 a^2$$

overall coupling strength **relative coupling strength** **ALP mass**

ALP mass / couplings fixed by matching the observed DM abundance:



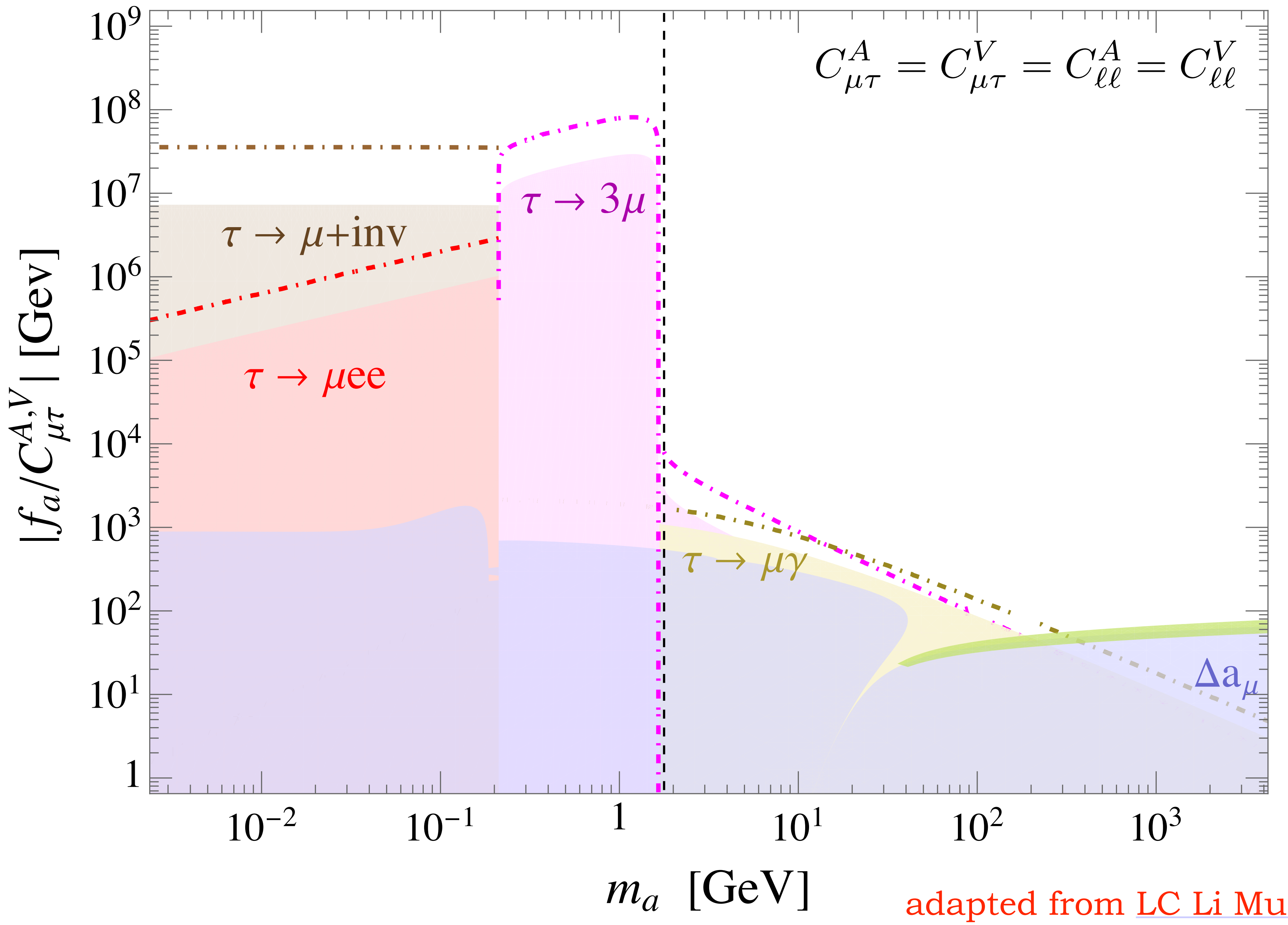


courtesy of R. Ziegler, based on Panci Redigolo Schwetz Ziegler '22

ALP-mediated CLFV

If the ALP is not that light nor long-lived, it can decay on-shell (or off-shell) back to leptons: $\tau \to \mu\, a^{(*)} \to \mu\ell\ell$

(or mediate radiative processes)



adapted from LC Li Mukherjee Yang '24
(see also Cornella Paradisi Sumensari '19)

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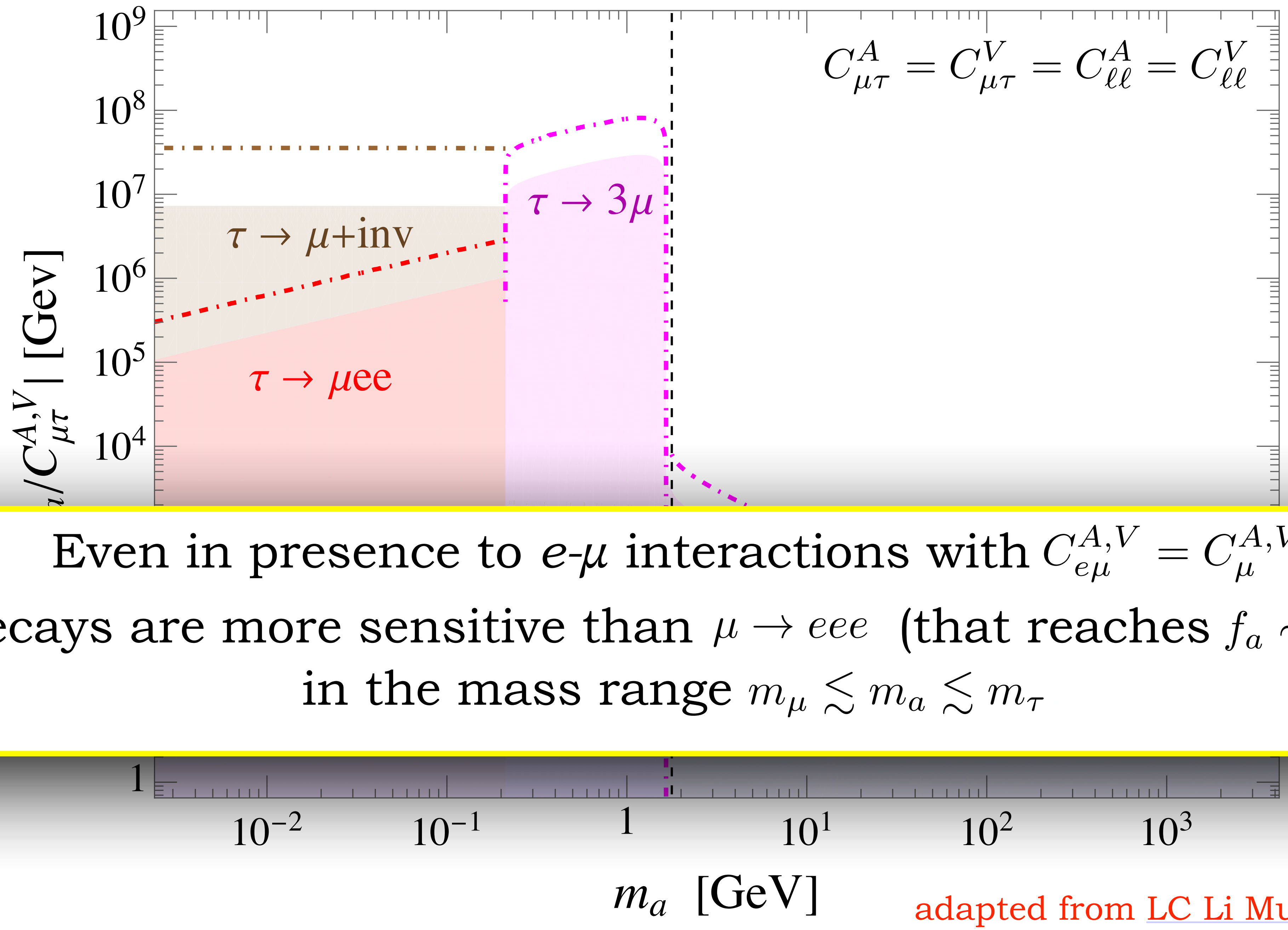


Even in presence to e-μ interactions with $C^{A,V}_{e\mu} = C^{A,V}_{\mu}$
tau decays are more sensitive than $\mu \to eee$ (that reaches $f_a \sim 10^5\,\text{GeV}$)
in the mass range $m_\mu \lesssim m_a \lesssim m_\tau$

adapted from LC Li Mukherjee Yang '24
(see also Cornella Paradisi Sumensari '19)

Another example: flavoured Z'

Flavour non-universal *local* U(1) symmetry generating the hierarchies of fermion masses and mixing through the Froggatt-Nielsen mechanism

Smolkovič Tammaro Zupan '19

Interactions of the new gauge boson Z' flavour-violating by construction:

$$\mathcal{L} \;=\; g_F\, Z'_\mu \,\Big[\bar u_\alpha \gamma^\mu (C^u_{L\,\alpha\beta}\, P_L + C^u_{R\,\alpha\beta}\, P_R) u_\beta \,+ \bar d_\alpha \gamma^\mu (C^d_{L\,\alpha\beta}\, P_L + C^d_{R\,\alpha\beta}\, P_R) d_\beta \,+ \bar\ell_\alpha \gamma^\mu (C^\ell_{L\,\alpha\beta}\, P_L + C^\ell_{R\,\alpha\beta}\, P_R) \ell_\beta \,+ \bar\nu_\alpha \gamma^\mu\, C^\nu_{L\,\alpha\beta}\, P_L \nu_\beta \Big]\,,$$

new U(1) gauge coupling

$$C^f_{L\,\alpha\beta} \equiv V^f_{\alpha i}\, \mathcal{Q}_{f_{L_i}}\, V^{f\,*}_{\beta i} \qquad C^f_{R\,\alpha\beta} \equiv W^f_{\alpha i}\, \mathcal{Q}_{f_{R_i}}\, W^{f\,*}_{\beta i}$$

unitary rotations to the fermion mass basis

matrices of U(1) charges

⇨ $$\mathrm{BR}(\ell_\alpha \to \ell_\beta Z') = \frac{g_F^2}{16\pi\, \Gamma_{\ell_\alpha}} \frac{m_{\ell_\alpha}^3}{m_{Z'}^2} \left(|C^\ell_{V\,\alpha\beta}|^2 + |C^\ell_{A\,\alpha\beta}|^2\right) \left(1 + 2\frac{m_{Z'}^2}{m_{\ell_\alpha}^2}\right) \left(1 - \frac{m_{Z'}^2}{m_{\ell_\alpha}^2}\right)^2, \quad C^f_{V,A} = \frac{C^f_R \pm C^f_L}{2}$$

Depending on g_F and $m_{Z'}$, Z' can be long-lived or decay inside the detector, *e.g.* :

$$\Gamma(Z' \to \ell_\alpha \bar\ell_\alpha) = \frac{N_c^f\, g_F^2\, m_{Z'}}{12\pi} \sqrt{1 - 4\frac{m_{\ell_\alpha}^2}{m_{Z'}^2}} \left[\left(1 + 2\frac{m_{\ell_\alpha}^2}{m_{Z'}^2}\right) |C^\ell_{V\,\alpha\alpha}|^2 + \left(1 - 4\frac{m_{\ell_\alpha}^2}{m_{Z'}^2}\right) |C^\ell_{A\,\alpha\alpha}|^2\right.$$

(while heavier off-shell Z' mediate 'standard' LFV decays)

Another example: flavoured Z’

Flavour non-universal *local* U(1) symmetry generating the hierarchies of fermion masses and mixing through the Froggatt-Nielsen mechanism

Smolkovič Tammaro Zupan '19

Intera uction:

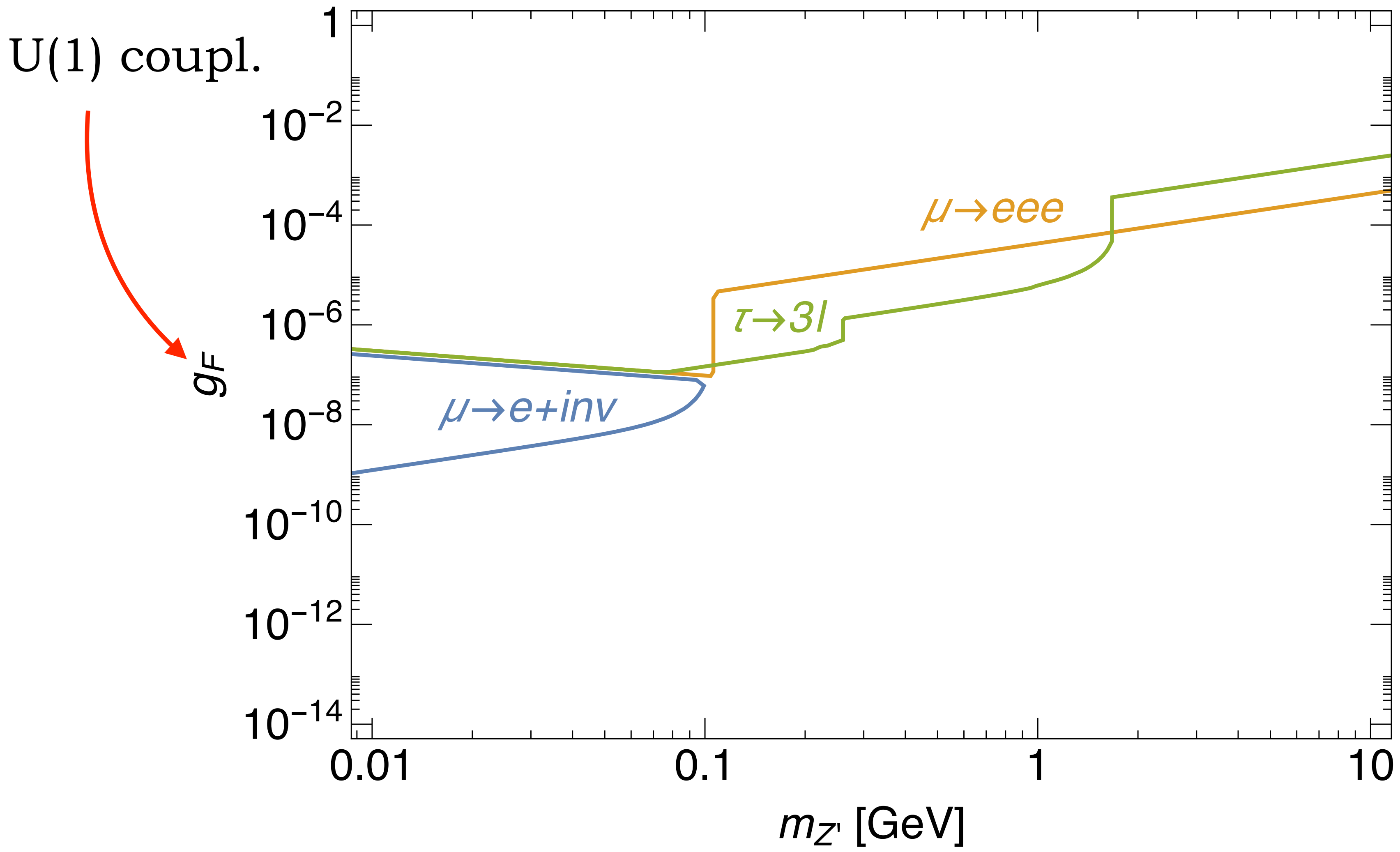
new U
cou

u
to the

BR($= \frac{C_R^f \pm C_L^f}{2}$

Dependi tor, *e.g.* :

$\Gamma(Z'$ $\alpha\alpha|^2$



Blasi LC Mariotti Turbang ‘24

(while heavier off-shell Z’ mediate ‘standard’ LFV decays)

Summary

Light bosons with flavour-violating couplings to leptons arise within a wide class of new physics models

We have large room for improvement over the old limits searching for LFV decays into light bosons

Essential interplay among μ, τ, and astrophysical bounds

Very large symmetry-breaking scales can be probed

ありがとうございました!

謝謝大家!

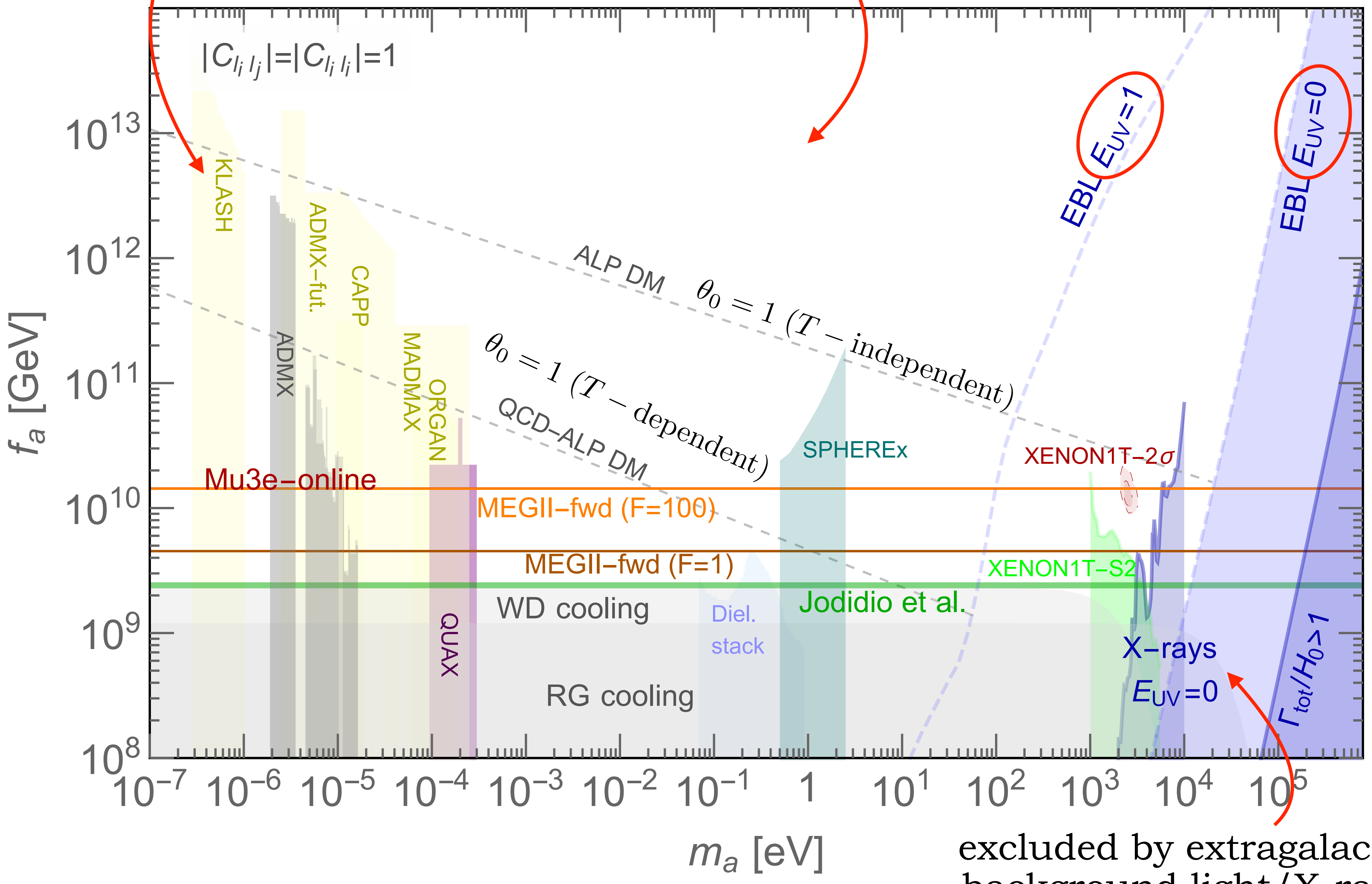
Thank you very much!

Additional slides

ALP dark matter

axion/ALP
DM searches
$(E_{\rm UV}=1)$

everywhere here ALP can be DM



excluded by extragalactic
background light/X-rays

LFV in the SM effective field theory

If NP scale **Λ**≫m_W : $\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\sum_a C_a^{(5)} Q_a^{(5)} + \frac{1}{\Lambda^2}\sum_a C_a^{(6)} Q_a^{(6)} + \ldots$

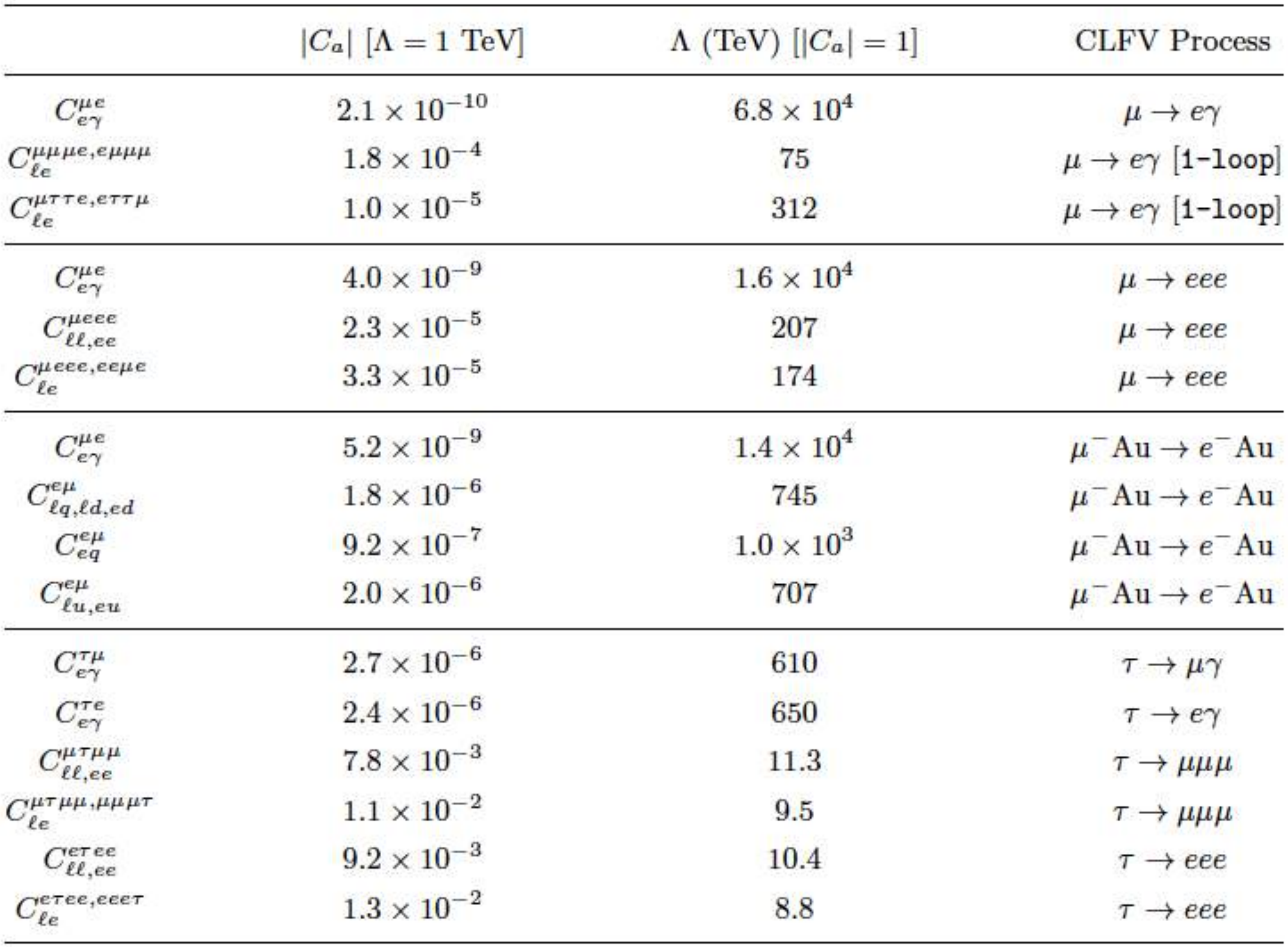
Dimension-6 effective operators that can induce CLFV

4-leptons operators		Dipole operators	
$Q_{\ell\ell}$	$(\bar L_L \gamma_\mu L_L)(\bar L_L \gamma^\mu L_L)$	Q_{eW}	$(\bar L_L \sigma^{\mu\nu} e_R)\tau_I \Phi W^I_{\mu\nu}$
Q_{ee}	$(\bar e_R \gamma_\mu e_R)(\bar e_R \gamma^\mu e_R)$	Q_{eB}	$(\bar L_L \sigma^{\mu\nu} e_R)\Phi B_{\mu\nu}$
$Q_{\ell e}$	$(\bar L_L \gamma_\mu L_L)(\bar e_R \gamma^\mu e_R)$		
2-lepton 2-quark operators			
$Q_{\ell q}^{(1)}$	$(\bar L_L \gamma_\mu L_L)(\bar Q_L \gamma^\mu Q_L)$	$Q_{\ell u}$	$(\bar L_L \gamma_\mu L_L)(\bar u_R \gamma^\mu u_R)$
$Q_{\ell q}^{(3)}$	$(\bar L_L \gamma_\mu \tau_I L_L)(\bar Q_L \gamma^\mu \tau_I Q_L)$	Q_{eu}	$(\bar e_R \gamma_\mu e_R)(\bar u_R \gamma^\mu u_R)$
Q_{eq}	$(\bar e_R \gamma^\mu e_R)(\bar Q_L \gamma_\mu Q_L)$	$Q_{\ell edq}$	$(\bar L_L^a e_R)(\bar d_R Q_L^a)$
$Q_{\ell d}$	$(\bar L_L \gamma_\mu L_L)(\bar d_R \gamma^\mu d_R)$	$Q_{\ell equ}^{(1)}$	$(\bar L_L^a e_R)\epsilon_{ab}(\bar Q_L^b u_R)$
Q_{ed}	$(\bar e_R \gamma_\mu e_R)(\bar d_R \gamma^\mu d_R)$	$Q_{\ell equ}^{(3)}$	$(\bar L_i^a \sigma_{\mu\nu} e_R)\epsilon_{ab}(\bar Q_L^b \sigma^{\mu\nu} u_R)$
Lepton-Higgs operators			
$Q_{\Phi\ell}^{(1)}$	$(\Phi^\dagger i \overleftrightarrow{D}_\mu \Phi)(\bar L_L \gamma^\mu L_L)$	$Q_{\Phi\ell}^{(3)}$	$(\Phi^\dagger i \overleftrightarrow{D}^I_\mu \Phi)(\bar L_L \tau_I \gamma^\mu L_L)$
$Q_{\Phi e}$	$(\Phi^\dagger i \overleftrightarrow{D}_\mu \Phi)(\bar e_R \gamma^\mu e_R)$	$Q_{e\Phi 3}$	$(\bar L_L e_R \Phi)(\Phi^\dagger \Phi)$

Grzadkowski et al. ’10; Crivellin Najjari Rosiek ‘13

Probing very high-energy scales

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\sum_a C_a^{(5)} Q_a^{(5)} + \frac{1}{\Lambda^2}\sum_a C_a^{(6)} Q_a^{(6)} + \dots$$



	$\lvert C_a\rvert$ $[\Lambda = 1$ TeV$]$	Λ (TeV) $[\lvert C_a\rvert = 1]$	CLFV Process
$C_{e\gamma}^{\mu e}$	2.1×10^{-10}	6.8×10^{4}	$\mu\to e\gamma$
$C_{\ell e}^{\mu\mu\mu e,e\mu\mu\mu}$	1.8×10^{-4}	75	$\mu\to e\gamma$ [`1-loop`]
$C_{\ell e}^{\mu\tau\tau e,e\tau\tau\mu}$	1.0×10^{-5}	312	$\mu\to e\gamma$ [`1-loop`]
$C_{e\gamma}^{\mu e}$	4.0×10^{-9}	1.6×10^{4}	$\mu\to eee$
$C_{\ell\ell,ee}^{\mu eee}$	2.3×10^{-5}	207	$\mu\to eee$
$C_{\ell e}^{\mu eee,ee\mu e}$	3.3×10^{-5}	174	$\mu\to eee$
$C_{e\gamma}^{\mu e}$	5.2×10^{-9}	1.4×10^{4}	$\mu^-{\rm Au}\to e^-{\rm Au}$
$C_{\ell q,\ell d,ed}^{e\mu}$	1.8×10^{-6}	745	$\mu^-{\rm Au}\to e^-{\rm Au}$
$C_{eq}^{e\mu}$	9.2×10^{-7}	1.0×10^{3}	$\mu^-{\rm Au}\to e^-{\rm Au}$
$C_{\ell u,eu}^{e\mu}$	2.0×10^{-6}	707	$\mu^-{\rm Au}\to e^-{\rm Au}$
$C_{e\gamma}^{\tau\mu}$	2.7×10^{-6}	610	$\tau\to\mu\gamma$
$C_{e\gamma}^{\tau e}$	2.4×10^{-6}	650	$\tau\to e\gamma$
$C_{\ell\ell,ee}^{\mu\tau\mu\mu}$	7.8×10^{-3}	11.3	$\tau\to\mu\mu\mu$
$C_{\ell e}^{\mu\tau\mu\mu,\mu\mu\mu\tau}$	1.1×10^{-2}	9.5	$\tau\to\mu\mu\mu$
$C_{\ell\ell,ee}^{e\tau ee}$	9.2×10^{-3}	10.4	$\tau\to eee$
$C_{\ell e}^{e\tau ee,eee\tau}$	1.3×10^{-2}	8.8	$\tau\to eee$

LFV quarkonium decays

LFVQD	Present bounds on BR (90% CL)		
$J/\psi \to e\mu$	4.5×10^{-9}	BESIII (2022)	[16]
$\Upsilon(1S) \to e\mu$	3.6×10^{-7}	Belle (2022)	[17]
$\Upsilon(1S) \to e\mu\gamma$	4.2×10^{-7}	Belle (2022)	[17]
$J/\psi \to e\tau$	7.5×10^{-8}	BESIII (2021)	[18]
$\Upsilon(1S) \to e\tau$	2.4×10^{-6}	Belle (2022)	[17]
$\Upsilon(1S) \to e\tau\gamma$	6.5×10^{-6}	Belle (2022)	[17]
$\Upsilon(2S) \to e\tau$	3.2×10^{-6}	BaBar (2010)	[19]
$\Upsilon(3S) \to e\tau$	4.2×10^{-6}	BaBar (2010)	[19]
$J/\psi \to \mu\tau$	2.0×10^{-6}	BES (2004)	[20]
$\Upsilon(1S) \to \mu\tau$	2.6×10^{-6}	Belle (2022)	[17]
$\Upsilon(1S) \to \mu\tau\gamma$	6.1×10^{-6}	Belle (2022)	[17]
$\Upsilon(2S) \to \mu\tau$	3.3×10^{-6}	BaBar (2010)	[19]
$\Upsilon(3S) \to \mu\tau$	3.1×10^{-6}	BaBar (2010)	[19]

Table 1: Present 90% CL upper limits on vector quarkonium LFV decays. No limit is currently available for LFV decays of (pseudo)scalar or other vector resonances.

BESIII continues taking data, a high-lumi Super Tau-Charm Factory (STCF) is being discussed with c.o.m. E ~2-7 GeV that could produce ~10^{13} J/ψ (x1000 current BESIII), Belle II will collect x50-100 the data of Belle/BaBar

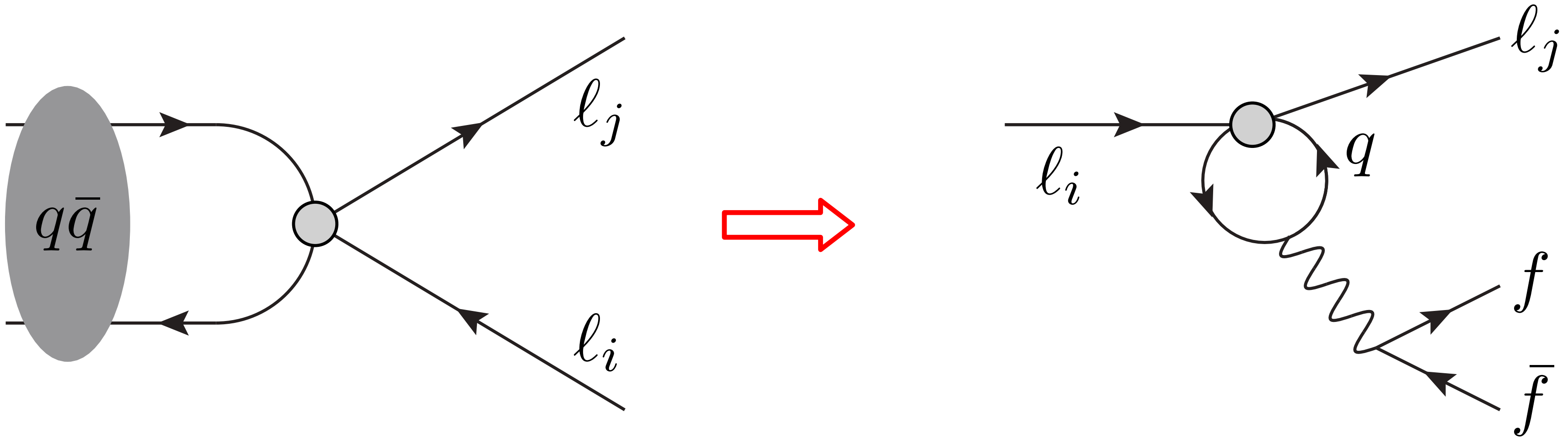
What can we learn from these processes?

- In principle, ideal modes to test $2q2\ell$ operators involving heavy quarks (that could stem *e.g.* from by *Z'*/LQs with MFV-like couplings)

- Searches for radiative modes and decays of (pseudo)scalar resonances would be sensitive to different LEFT operators than the vector ones

- The question is: can we find new physics searching for these modes?

- Tau/mu processes unavoidably induced: strong indirect constraints:

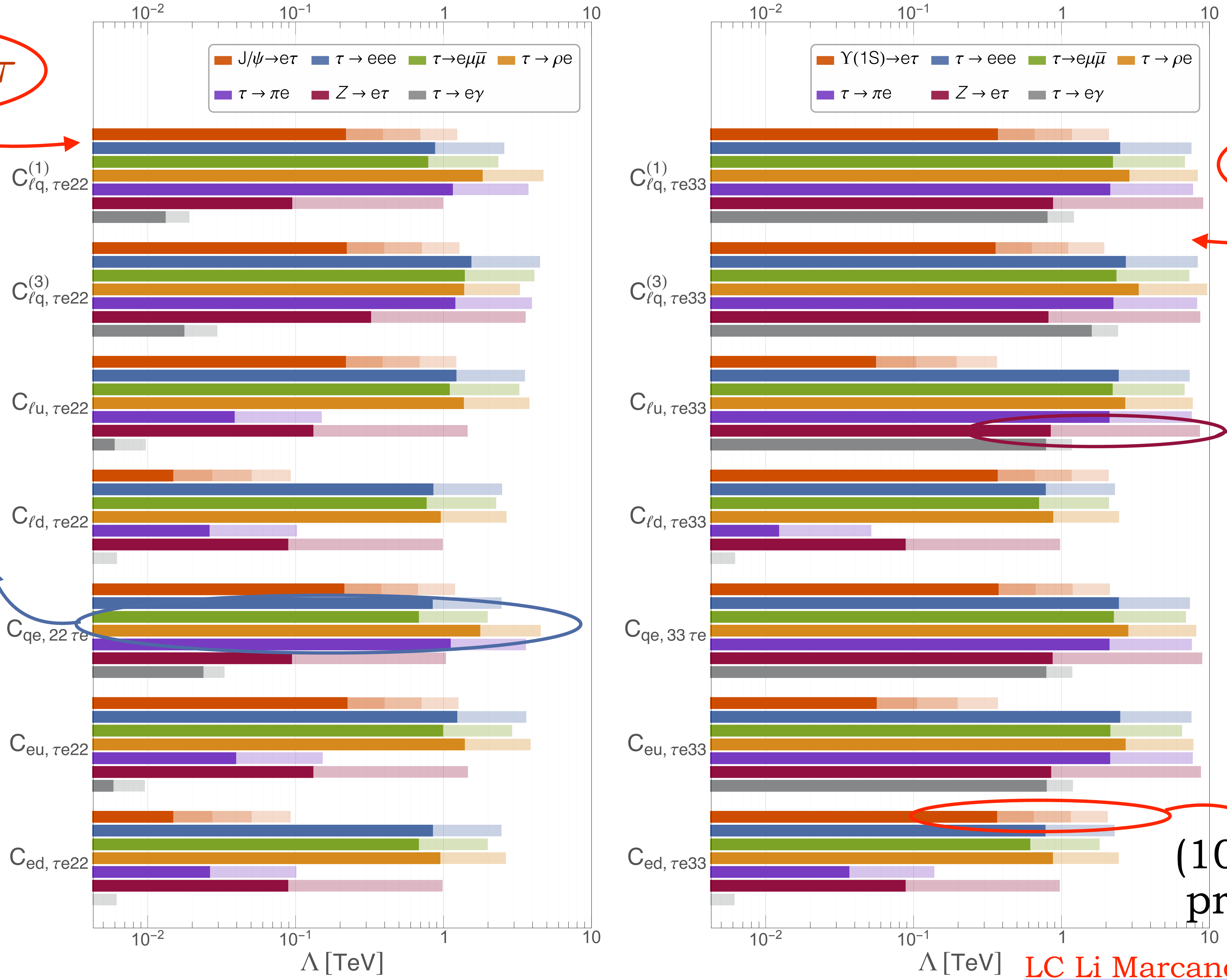


Effect summarised by the RGE running of the EFT operators

SMEFT analysis

SMEFT running and SMEFT/LEFT matching induce stronger bounds:

$J/\psi \to e\tau$



$\Upsilon(1S) \to e\tau$

Tau LFV
(almost)
always
wins

Z LFV

(10,100,100)x
present limit

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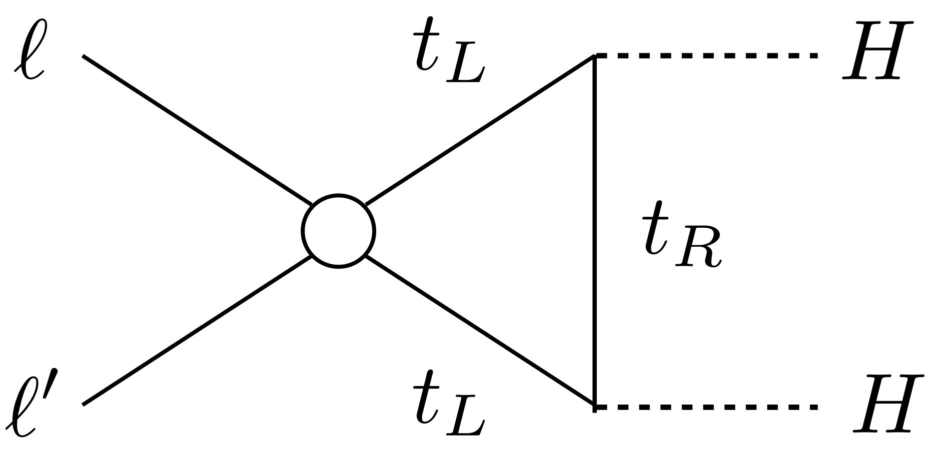
SMEFT analysis

SMEFT running and SMEFT/LEFT matching induce stronger bounds:

$J/\psi \rightarrow$

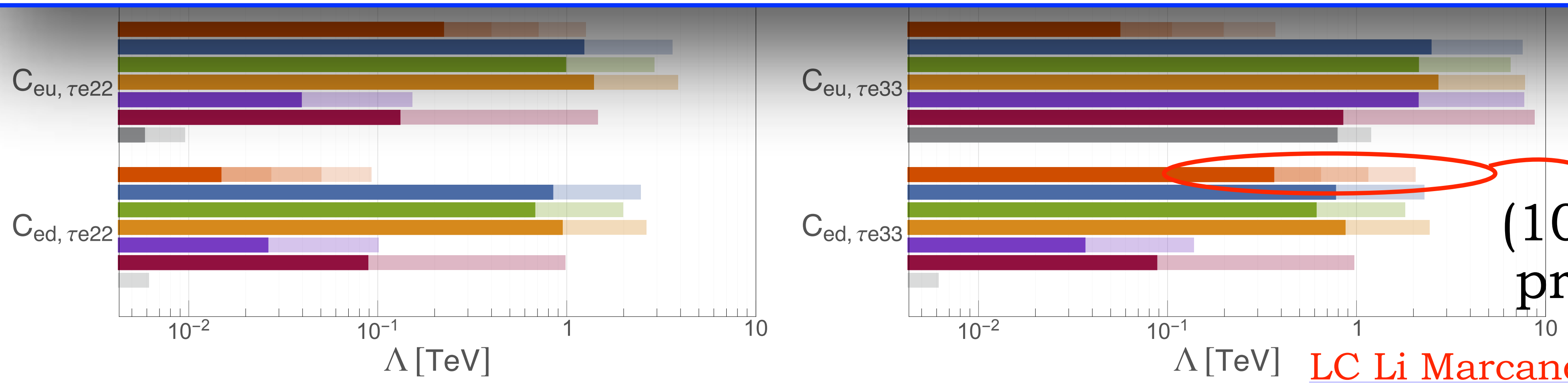
SMEFT running induce large coefficients of Higgs-lepton ops (for 2q2l ops involving top quarks):



⇒ large effects for tau decays and Z LFV

S) $\rightarrow e\tau$

LFV



(10,100,100)x present limit

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SMEFT analysis

Flat directions are possible along which tau/Z constraints vanish:

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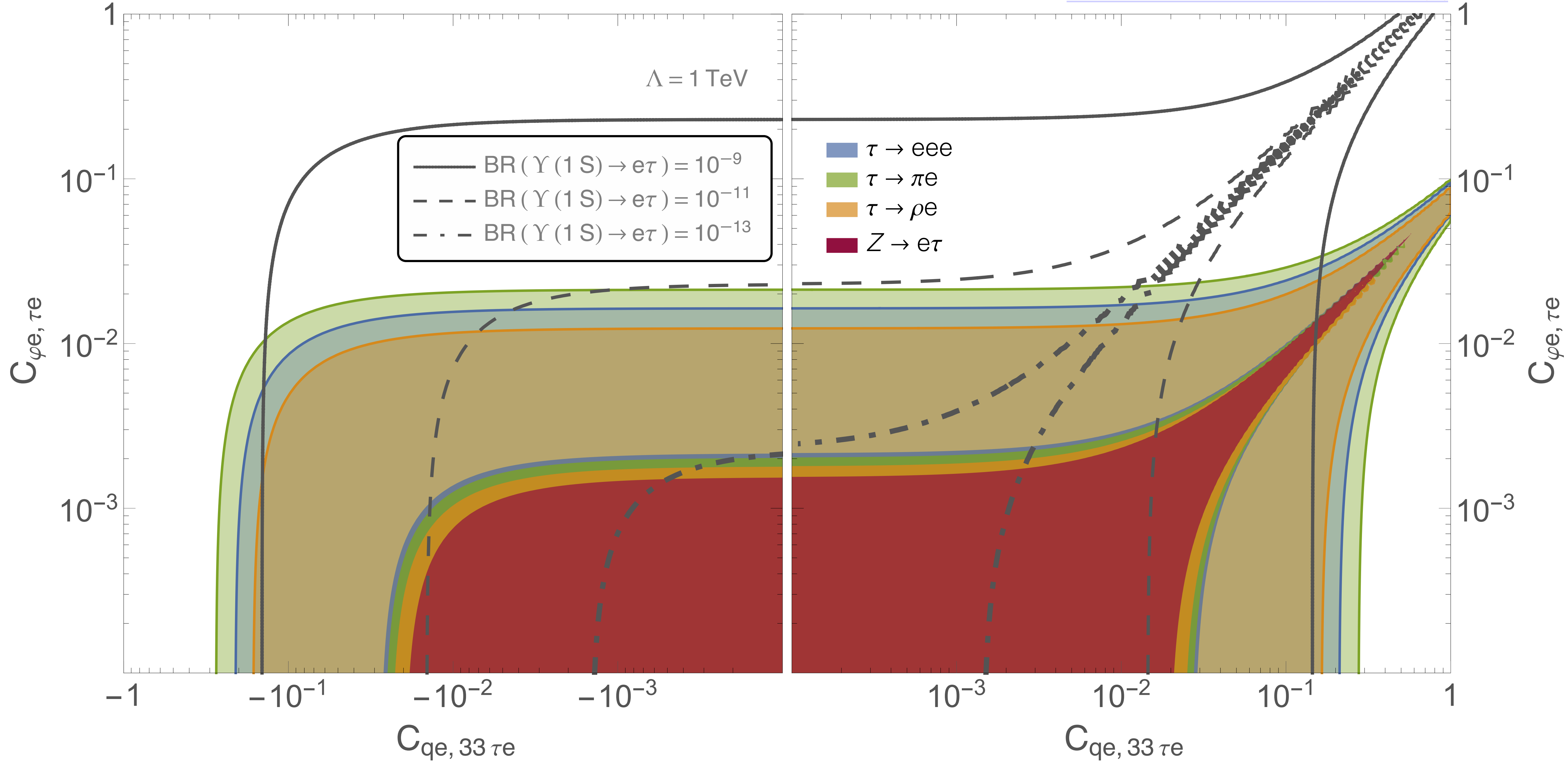

(similar situation for operators involving LH leptonic currents)

SMEFT analysis

That’s not the case for charmonium decays:

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