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What kind of New Physics for a muon $(g-2)$ anomaly?

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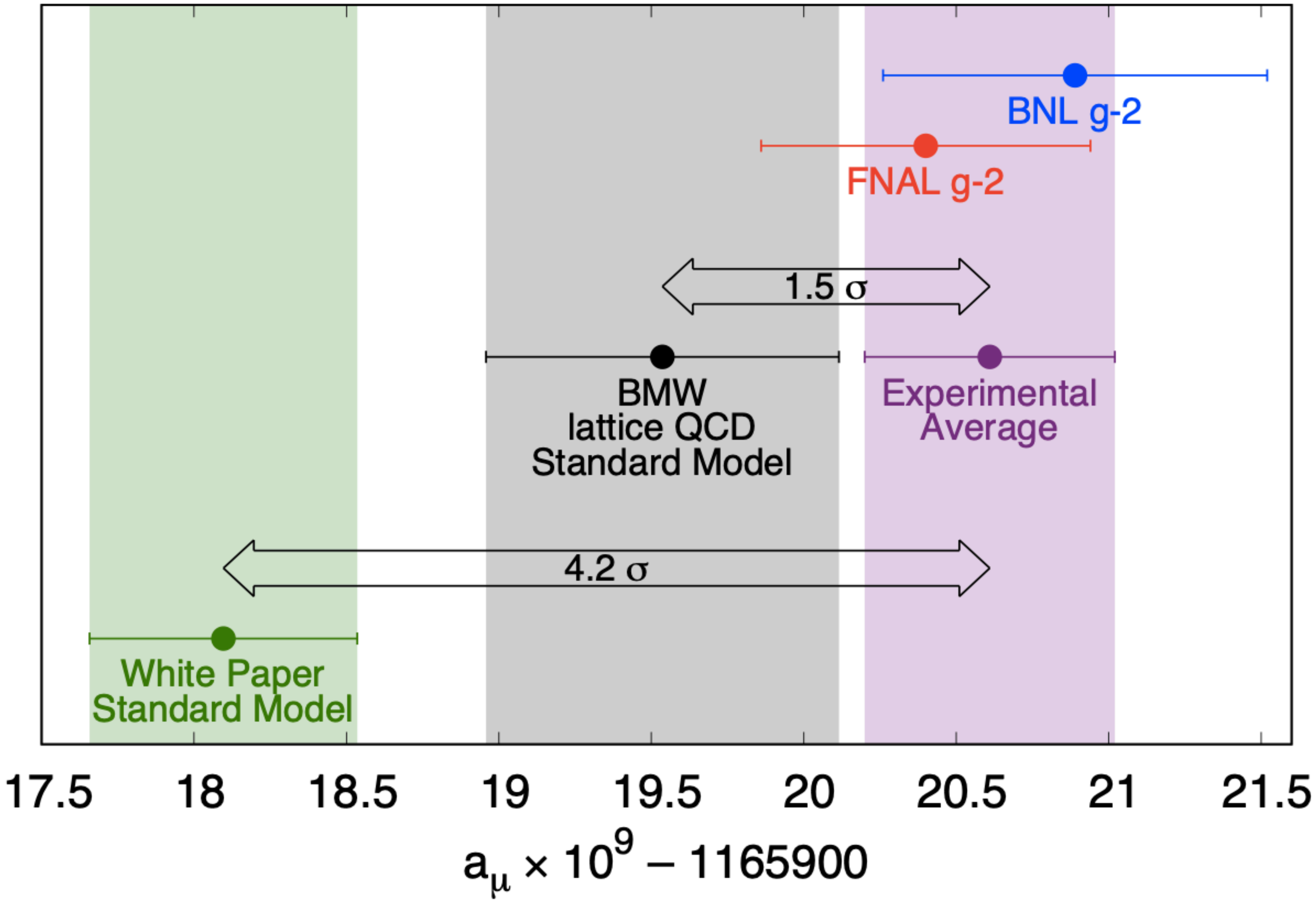
Aspen, March 27, 2023 - Prospecting for New Physics through Flavor, Dark Matter, and Machine Learning

Based on work in collaboration with *Gino Isidori* and *Felix Wilsch*, arXiv:2111.13724

Status of the $(g-2)_\mu$ anomaly



[Figure from BMWc collaboration]

- Agreement between experiments;
  [hep-ex/0602035, 2104.03281] see talk by Chris
- Disagreement between lattice see talk by Ethan
  and dispersive-based SM predictions:
  [WP, 2006.04822]
  - New disagreement in $e^+e^- \to \pi^+\pi^-$ experiments — main data input for the dispersive relations in HVP (R-ratio);
    [CMD-3 collaboration, 2303.08834]
  - Agreement between lattice collaborations in Euclidean time window.
    [Blum et. al., 2301.08696]

$\Rightarrow$ Still undecided but unclear if there is an anomaly or not.

Let us assume a 4.2σ deviation
and see what New Physics can explain it.

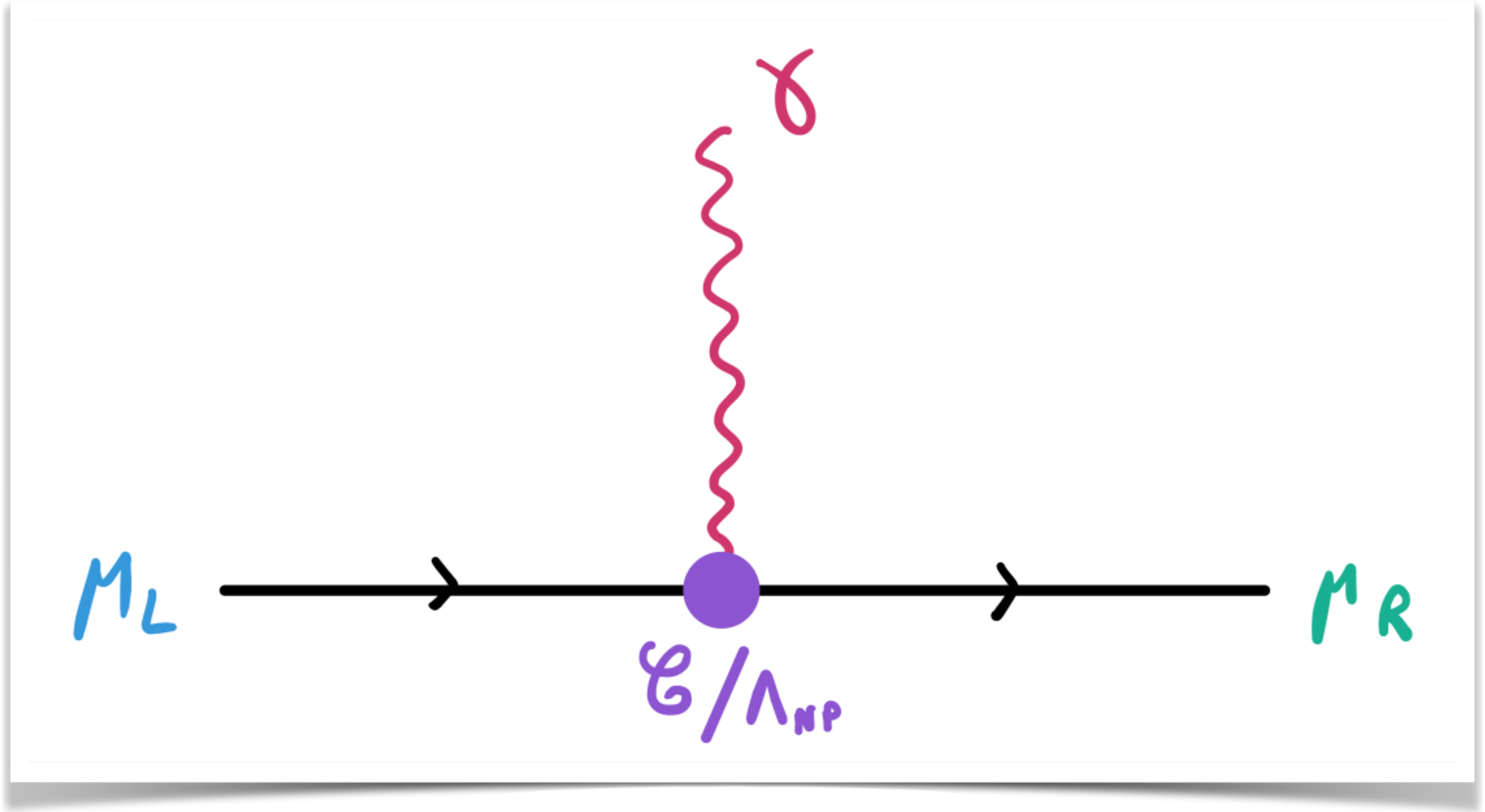
EFT approach

Assumed deviation is sizable

$$\Delta a_\mu \equiv a_\mu^{\rm exp} - a_\mu^{\rm SM} \;=\; 251(59)\times 10^{-11} \qquad \gtrsim [a_\mu^{\rm SM}]_{\rm EW} \approx \frac{1}{16\pi^2}\frac{m_\mu^2}{M_W^2}\frac{g^2}{2}$$

and can be parametrized with the effective operator [Aebischer et. al., 2102.0895]

$$\mathscr{L}_{\rm LEFT} \supset \frac{\mathscr{C}}{\Lambda_{\rm NP}}\, e\, \overline{\mu_L}\, \sigma^{\mu\nu} \mu_R\, F_{\mu\nu} + \text{h.c.} \qquad \Rightarrow \qquad \Delta a_\mu = 4\,\frac{m_\mu}{\Lambda_{\rm NP}}\,\mathrm{Re}\,\mathscr{C}$$



Sources of enhancement from New Physics

Any contribution to $\mathscr{C}$ includes:

[Athron et. al., 2104.03691]

$$\Delta a_\mu = 4\,\frac{m_\mu}{\Lambda_{\rm NP}}\,\mathrm{Re}\,\mathscr{C}$$

$$\mathcal{O} = e\,\overline{\mu_L}\,\sigma^{\mu\nu}\mu_R\,F_{\mu\nu} + \mathrm{h.c.}$$

- Chiral symmetry breaking
- Electroweak symmetry breaking
- Heavy scale
- Loop suppression

Example:

EW contribution in the SM

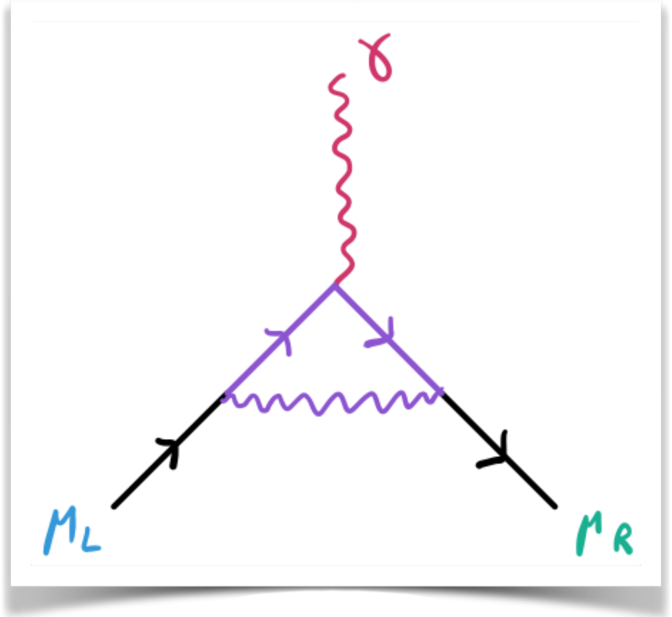
$$[a_\mu^{\rm SM}]_{\rm EW} \approx \frac{1}{16\pi^2}\,\frac{m_\mu^2}{M_W^2}\,\frac{g^2}{2}$$

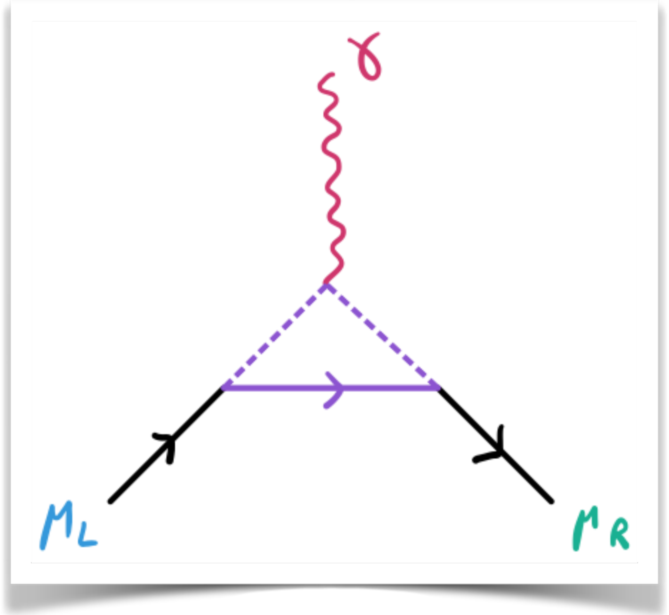
$$\left.\begin{array}{l}\to\ y_\mu \\ \to\ v\end{array}\right\}\ m_\mu$$

$$\to\ M_W$$

$$\to\ \frac{1}{16\pi^2}$$

Some new physics models:
providing enhancement
from new sources.

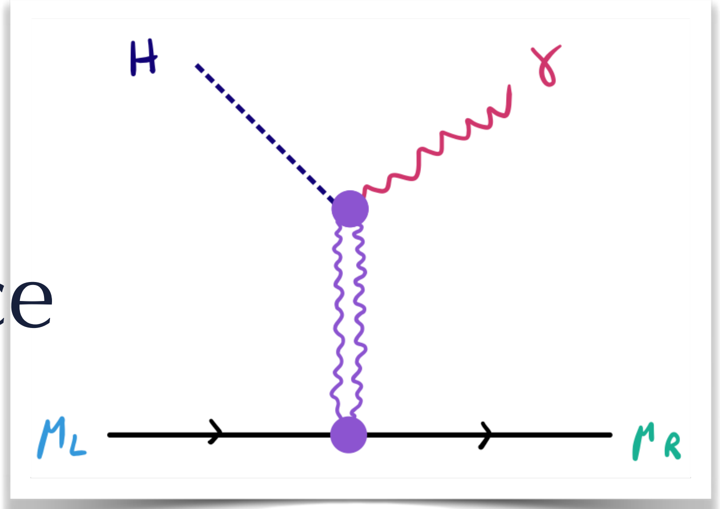




Leptoquarks, Vector-like fermions
[Chakraverty et. al., hep-ph/0102180]

MSSM, 2HDM
[Altmannshofer et. al., 2104.08293]

Dark photon, ALPs,
$U(1)_{L_\mu - L_\tau}$ gauge boson
[Greljo et. al., 2203.13731]
Spin-1 vector resonance



SMEFT approach

Light New Physics models ($\Lambda_{\text{NP}} < v$) are very constrained, but what about heavy New Physics models ($\Lambda_{\text{NP}} > v$)?

The effects on low energy observable from weakly coupled heavy NP can be included via the

Standard Model Effective Theory (SMEFT)

$$\boxed{\mathscr{L}_{\text{SMEFT}} = \mathscr{L}_{\text{SM}} + \sum_i \frac{C_i^{(5)}}{\Lambda} O_i^{(5)} + \sum_i \frac{C_i^{(6)}}{\Lambda^2} O_i^{(6)} + \mathcal{O}\left(\frac{1}{\Lambda^3}\right)}$$

where $O_i^{(n)}$ are all the operators:

- respecting Lorentz invariance and the gauge symmetry $SU(3)_c \times SU(2)_L \times U(1)_Y$;
- built from the SM field content (including the Higgs doublet);
- with mass dimension n.

Can we use the SMEFT to learn more about the New Physics required by a a_μ anomaly, without specifying a model?

Scale of New Physics

The sizable deviation

$$\Delta a_\mu \equiv a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} = 251(59) \times 10^{-11} \qquad \gtrsim [a_\mu^{\mathrm{SM}}]_{\mathrm{EW}} \approx \frac{1}{16\pi^2} \frac{m_\mu^2}{M_W^2} \frac{g^2}{2}$$

can be explained by the SMEFT operator (in the physical basis for gauge bosons)

$$\boxed{\mathscr{L}_{\mathrm{SMEFT}} \supset \frac{C}{\Lambda_{\mathrm{NP}}^2} \overline{\ell_{L,2}} H \sigma^{\mu\nu} \mu_R \, F_{\mu\nu} + \mathrm{h.c.}} \qquad \Rightarrow \qquad \Delta a_\mu = \frac{2\sqrt{2}}{e} \frac{m_\mu v}{\Lambda_{\mathrm{NP}}^2} \mathrm{Re}\, C$$

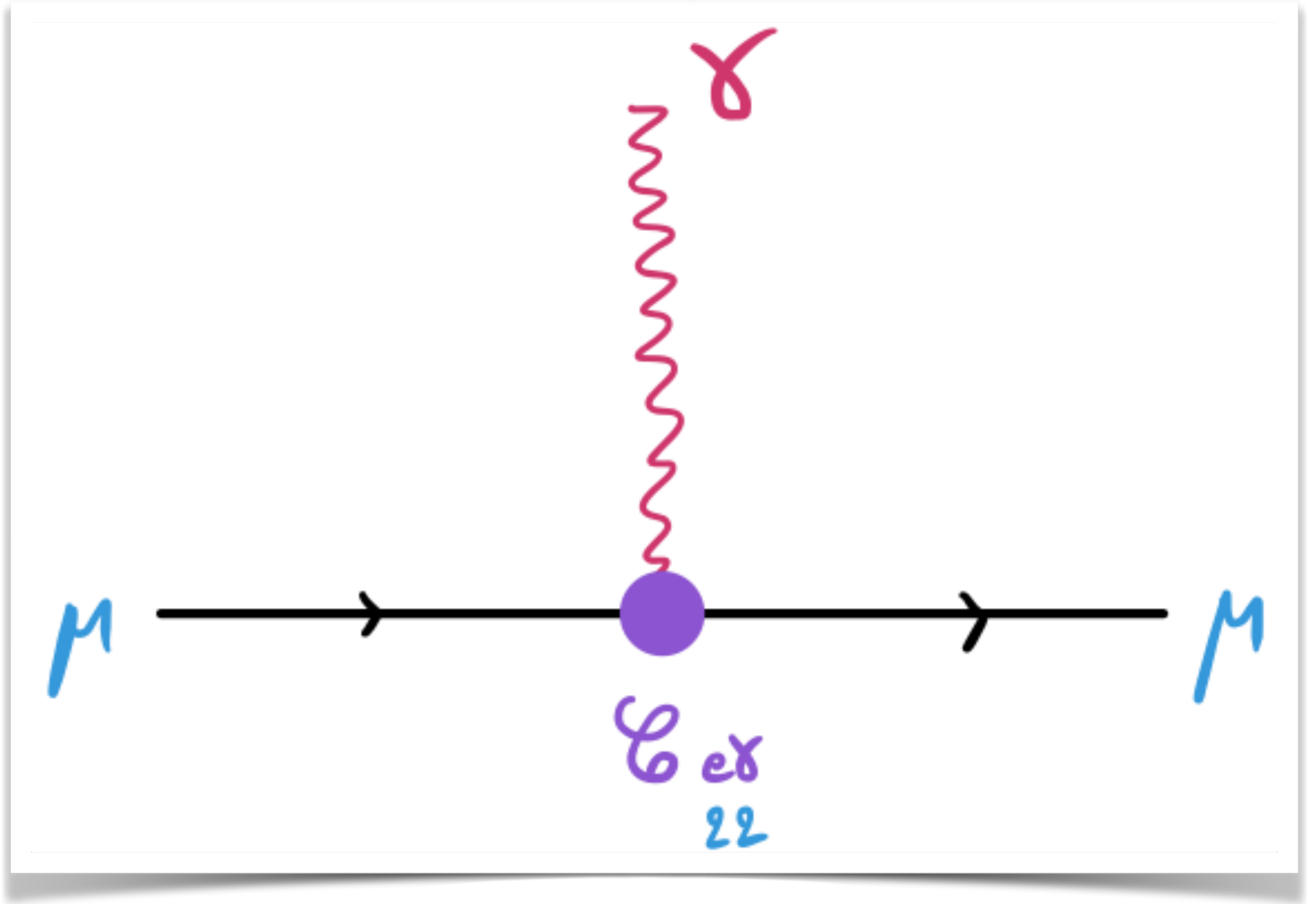
- Maximum scale from perturbative unitarity is $\Rightarrow$ $\Lambda_{\mathrm{NP}} \lesssim 1000$ TeV [Allwicher et. al., 2105.13981]
- Considering the loop suppression, $C \sim \dfrac{1}{16\pi^2}$ $\Rightarrow$ $\Lambda_{\mathrm{NP}} \lesssim 100$ TeV [Buttazzo, Paradisi, 2012.02769]

Moreover, heavy New Physics ($\Lambda_{\mathrm{NP}} > M_W$) has to be chirally enhanced, i.e. $16\pi^2\, C > y_\mu$.

$(g-2)_\mu$ and Lepton Flavor Violation

Opening the flavor structure of the dipole operator reveal interesting correlations with Lepton Flavor Violation obs.

$(g-2)_\mu$

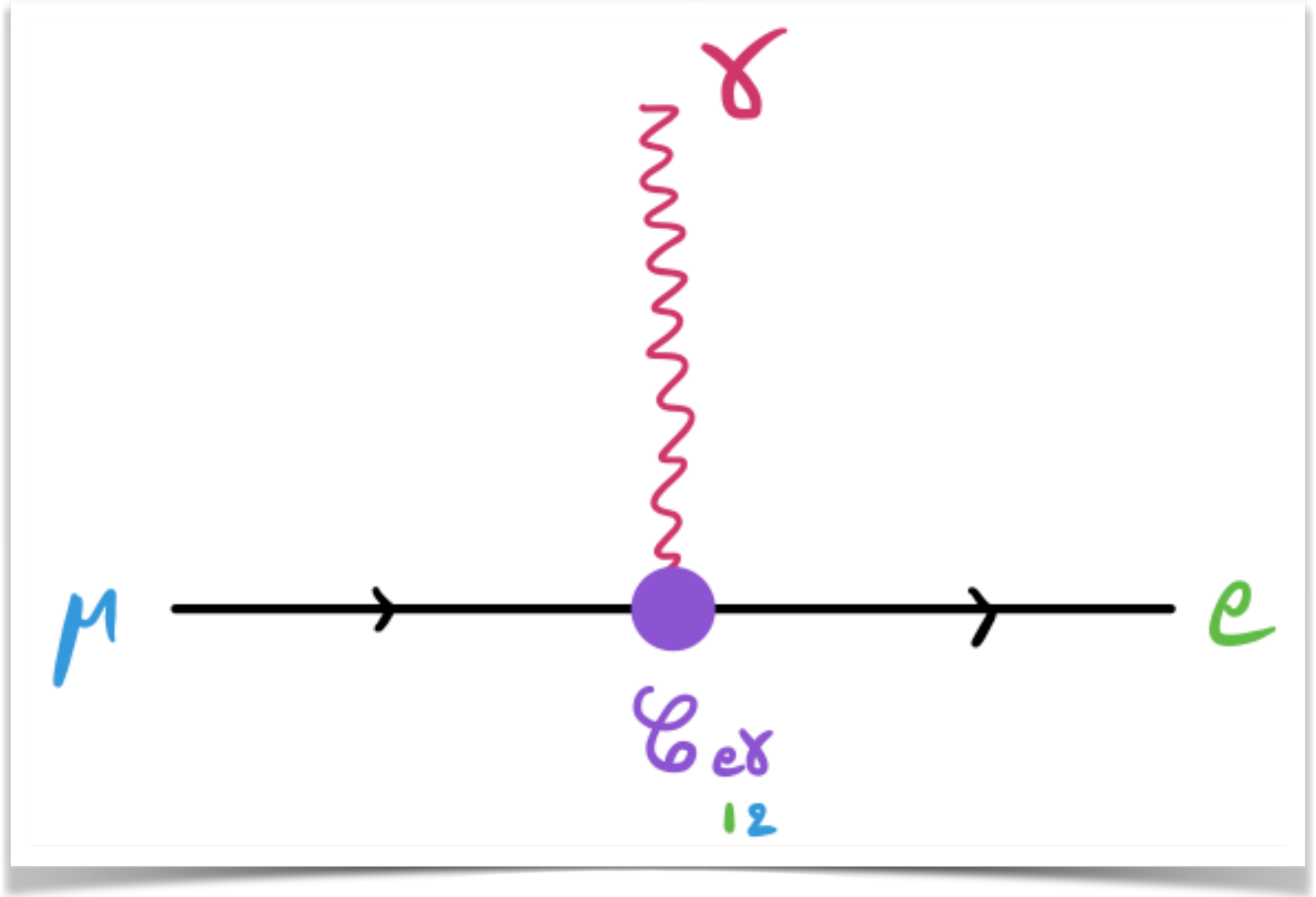


$$\mathcal{L} \supset \underset{rs}{\mathcal{C}_{e\gamma}}\ \underset{rs}{\mathcal{O}_{e\gamma}}$$

with

$$\underset{rs}{\mathcal{O}_{e\gamma}} = \frac{v}{\sqrt{2}}\, \bar{e}_{Lr}\, \sigma^{\mu\nu} e_{Rs} F_{\mu\nu}$$

$\mu \to e\gamma$



$$\Delta a_\mu = \frac{4 m_\mu v}{e\sqrt{2}} \,\mathrm{Re}\, \underset{22}{\mathcal{C}'_{e\gamma}}$$

← Tree-level contributions →

$$\mathcal{B}(\mu \to e\gamma) = \frac{m_\mu^3 v^2}{8\pi\Gamma_\mu}\left(|\underset{12}{\mathcal{C}'_{e\gamma}}|^2 + |\underset{21}{\mathcal{C}'_{e\gamma}}|^2 \right)$$

Flavor alignment at low scale

$(g-2)_\mu$

Sizable deviation

$$\Delta a_\mu \equiv a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (251 \pm 59) \times 10^{-11}$$

requires

$$\text{Re}\, \mathcal{C}'_{\substack{e\gamma \\ 22}} = 1 \times 10^{-5}\ \text{TeV}^{-2}$$

$\mu \to e\gamma$

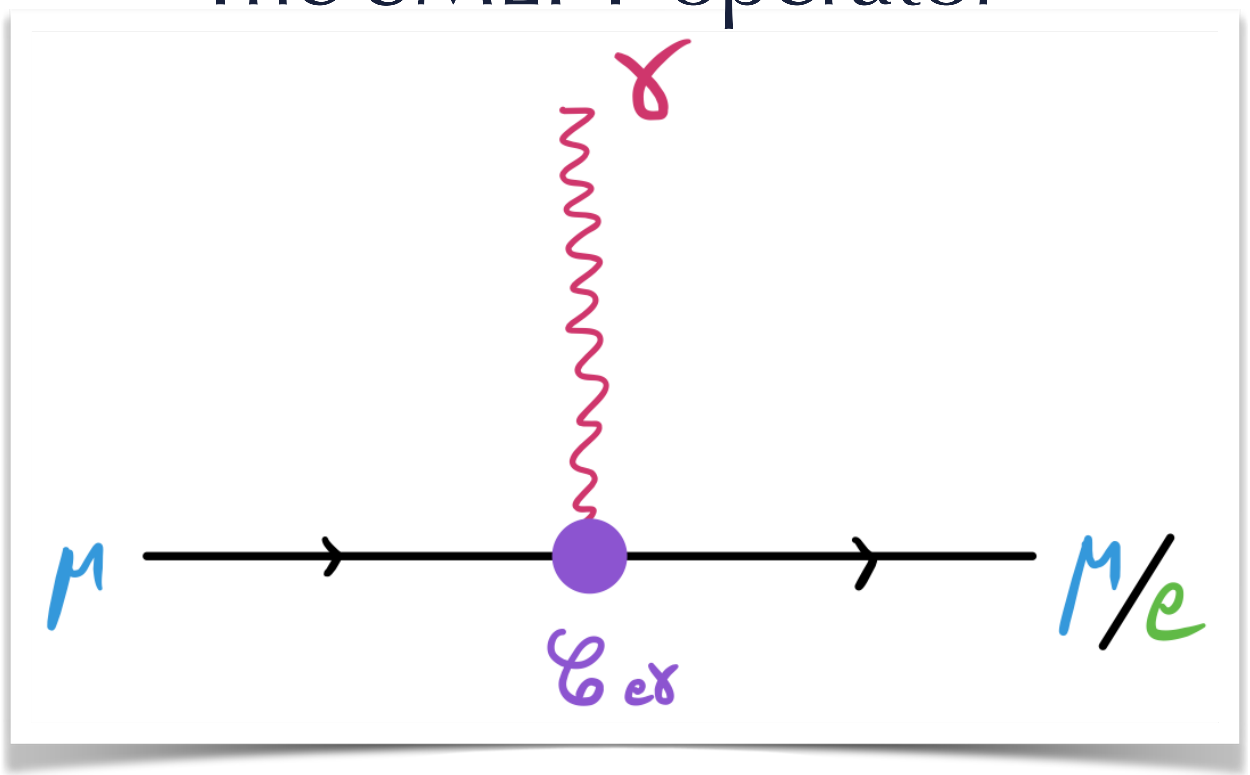
Branching ratio measured by MEG: [1605.05081]

$$\mathcal{B}(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13}\ [90\,\%\,\text{C.L.}]$$

puts upper bound on

$$|\mathcal{C}'_{\substack{e\gamma \\ 12}}| < 2 \times 10^{-10}\ \text{TeV}^{-2}$$

The SMEFT operator



has a specific flavor structure

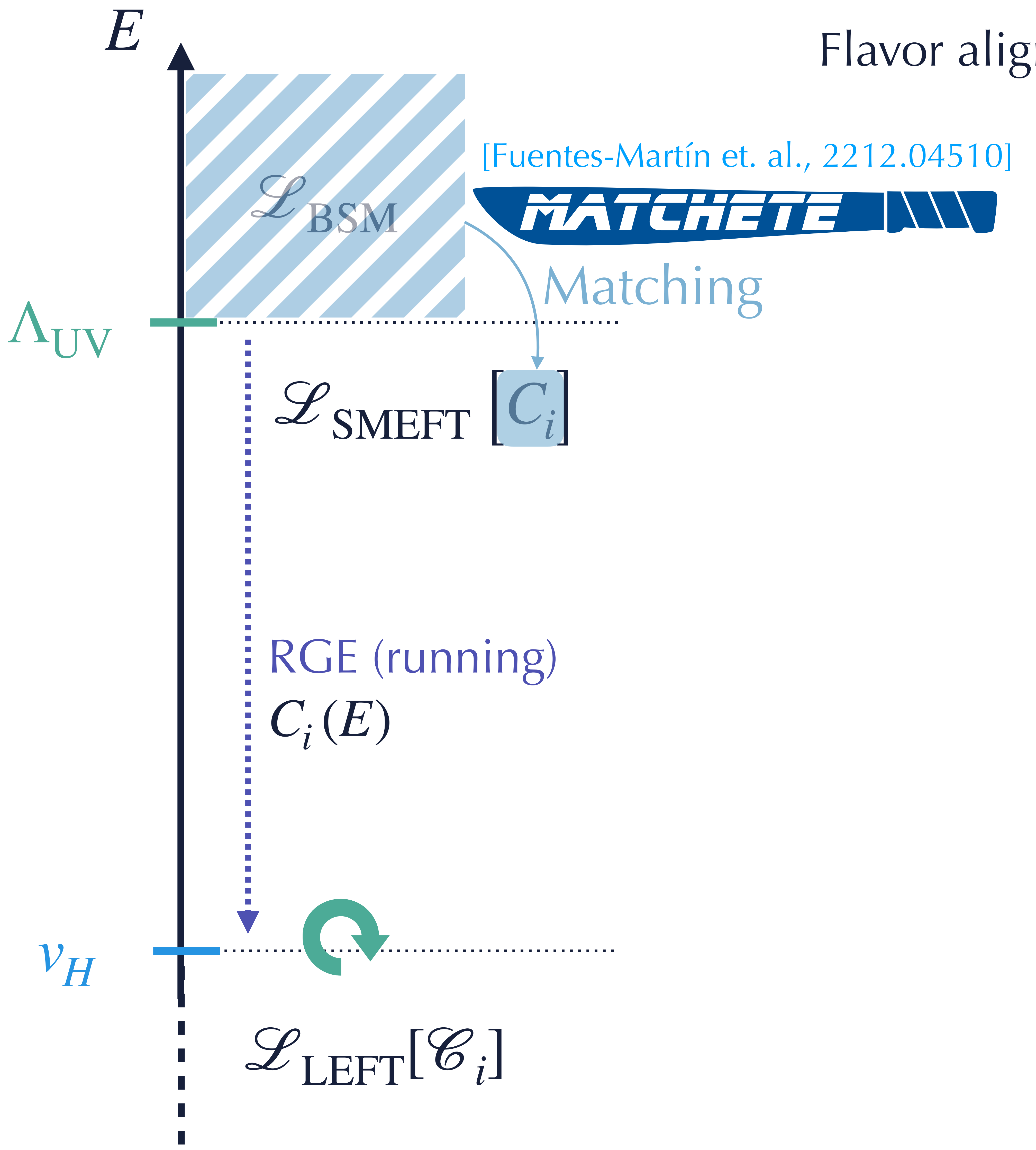
denote mass basis

$$\mathcal{C}'_{\substack{e\gamma \\ rs}} = \begin{pmatrix} \cdot & \cdot \\ \cdot & \blacksquare \end{pmatrix}$$

with strong flavor alignment

$$\epsilon^L_{12} \equiv \frac{\mathcal{C}'_{\substack{e\gamma \\ 12}}}{\mathcal{C}'_{\substack{e\gamma \\ 22}}} < 2 \times 10^{-5}$$

SMEFT Renormalization Group Evolution



Flavor alignment at high scale can be spoiled at low scale from 2 sources:

1. Operators mix through Renormalization Group Evolution
   Jenkins et al. [1308.2627, 1310.4838, 1312.2014]

$$\mu \frac{d}{d\mu} C_i = \frac{1}{16\pi^2}\beta_i \qquad \text{where} \quad \beta_i = \sum_j \gamma_{ij} C_j$$

with solution $$C_i(\mu_L) = C_i(\mu_H) + \underbrace{\frac{1}{16\pi^2}\log\left(\frac{\mu_L}{\mu_H}\right)}_{-\hat{L}}\beta_i$$

2. Rotation to the mass basis at low-scale

$$\Theta^{\mathcal{Y}}_{L(R)} = -\left.\frac{[\mathcal{Y}_e]_{12(21)}}{[\mathcal{Y}_e]_{22}}\right|_{\mu_L}$$

$\Rightarrow$ Dipole in the mass basis:

$$\mathscr{C}'_{\underset{12}{e\gamma}}(\mu_L) = \mathscr{C}_{\underset{12}{e\gamma}}(\mu_L) + \Theta^{\mathcal{Y}}_L \mathscr{C}_{\underset{22}{e\gamma}}(\mu_L)$$

$\neq 0$ for Δa_μ

$$\mathscr{C}'_{\underset{22}{e\gamma}}(\mu_L) \approx \mathscr{C}_{\underset{22}{e\gamma}}(\mu_L)$$

Definitions of Operators

Operators in the broken phase

$$\underset{rs}{\mathcal{O}_{e\gamma}} = \frac{v}{\sqrt{2}} \bar{e}_{Lr} \sigma^{\mu\nu} e_{Rs} F_{\mu\nu}$$

$$\underset{rs}{\mathcal{O}_{eZ}} = \frac{v}{\sqrt{2}} \bar{e}_{Lr} \sigma^{\mu\nu} e_{Rs} Z_{\mu\nu}$$

$$\underset{rs}{\mathcal{O}_{\mathcal{Y}_e}} = \frac{v}{\sqrt{2}} \bar{e}_{Lr} e_{Rs}$$

$$\underset{rs}{\mathcal{O}_{\mathcal{Y}_{he}}} = \frac{h}{\sqrt{2}} \bar{e}_{Lr} e_{Rs}$$

Operators in the unbroken phase

$$\underset{rs}{O_{eB}} = \bar{\ell}_{Lr} \sigma^{\mu\nu} e_{Rs} H B_{\mu\nu}$$

$$\underset{rs}{O_{eW}} = \bar{\ell}_{Lr} \sigma^{\mu\nu} e_{Rs} \tau^I H W^I_{\mu\nu}$$

$$\underset{rs}{O_{Y_e}} = \bar{\ell}_{Lr} e_{Rs} H$$

$$\underset{rs}{O_{eH}} = \bar{\ell}_{Lr} e_{Rs} H(H^\dagger H)$$

weak mixing angle

$$\begin{pmatrix} \mathcal{C}_{e\gamma} \\ \mathcal{C}_{eZ} \end{pmatrix} = \begin{pmatrix} c_\theta & -s_\theta \\ -s_\theta & -c_\theta \end{pmatrix} \begin{pmatrix} C_{eB} \\ C_{eW} \end{pmatrix}$$

$$\begin{pmatrix} \mathcal{Y}_e \\ \mathcal{Y}_{he} \end{pmatrix} = \begin{pmatrix} 1 & -\frac{1}{2} \\ 1 & -\frac{3}{2} \end{pmatrix} \begin{pmatrix} Y_e \\ v^2 C_{eH} \end{pmatrix}$$

Assumptions:

- $g_i^2, \lambda \to 0$
- $y_{i\neq t} \to 0$
- $\theta_{eH} = \theta_Y$

4-fermions operators for RGE mixing

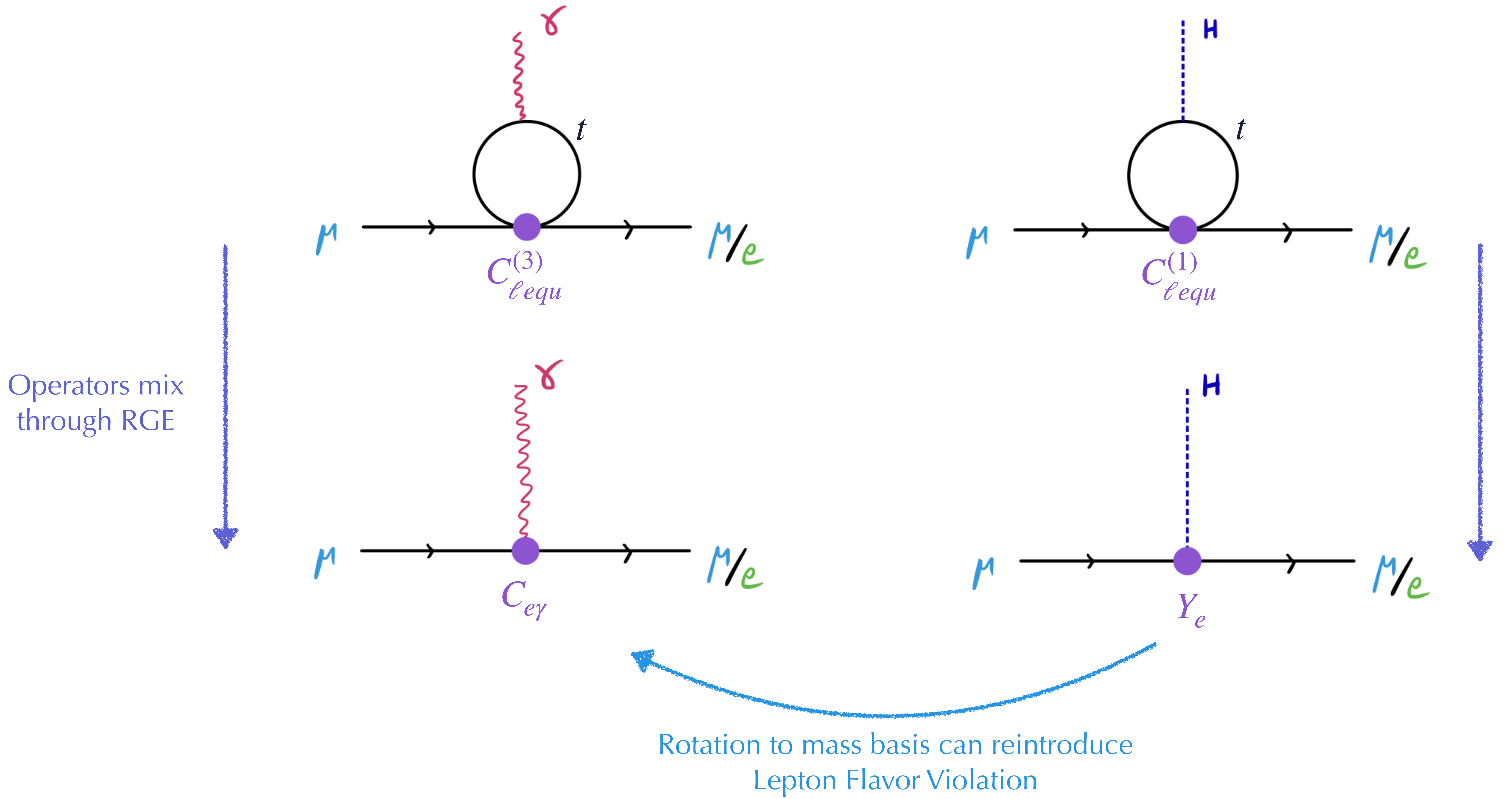
$$\underset{prst}{O^{(3)}_{lequ}} = (\bar{\ell}^j_{Lp} \sigma^{\mu\nu} e_{Rr}) \, \epsilon_{jk} \, (\bar{q}^k_{Ls} \sigma^{\mu\nu} u_{Rt})$$

$$\underset{prst}{O^{(1)}_{lequ}} = (\bar{\ell}^j_{Lp} e_{Rr}) \, \epsilon_{jk} \, (\bar{q}^k_{Ls} u_{Rt})$$

Flavor angles defined as

$$\theta_X = \left. \frac{\underset{12}{C_X}}{\underset{22}{C_X}} \right|_{\mu_H}$$

Contributions to dipole operator



Alignment of New Physics

Alignment master formula: [Isidori, Pagès, Wilsch, 2111.13724]

$$\epsilon^L_{12} \equiv \left.\frac{\mathcal{C}'_{\substack{e\gamma\\12}}}{\mathcal{C}'_{\substack{e\gamma\\22}}}\right|_{\mu_L} = (\theta_{e\gamma} - \theta_Y) + (\theta_{lequ^{(3)}} - \theta_{e\gamma})\,\Delta_3 + (\theta_{lequ^{(1)}} - \theta_Y)\,\Delta_1 \qquad < 2 \times 10^{-5}$$

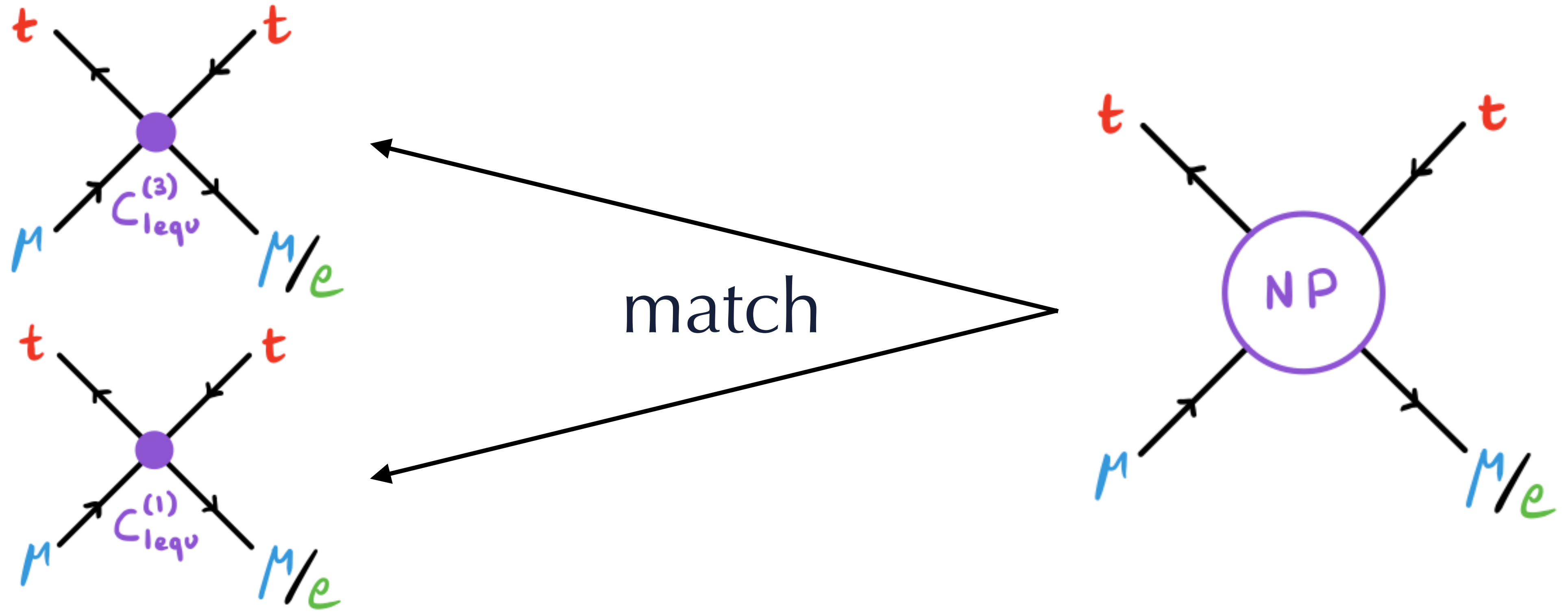
with $\Delta_3 = \dfrac{-16\hat{L}ey_t C^{(3)}_{\substack{lequ\\2233}}(\mu_H)}{\mathcal{C}_{\substack{e\gamma\\22}}(\mu_L)}$ and $\Delta_1 = \dfrac{-6\hat{L}y_t^3 v^2 C^{(1)}_{\substack{lequ\\2233}}(\mu_H)}{[\mathcal{Y}_e]_{22}(\mu_L)}$

How can we reach this alignment?

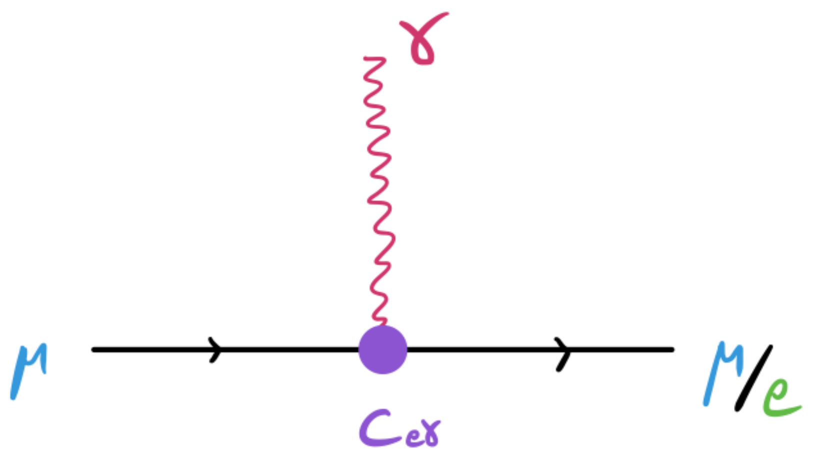
- Dynamical alignments
- Flavor symmetries

Dynamical Alignments

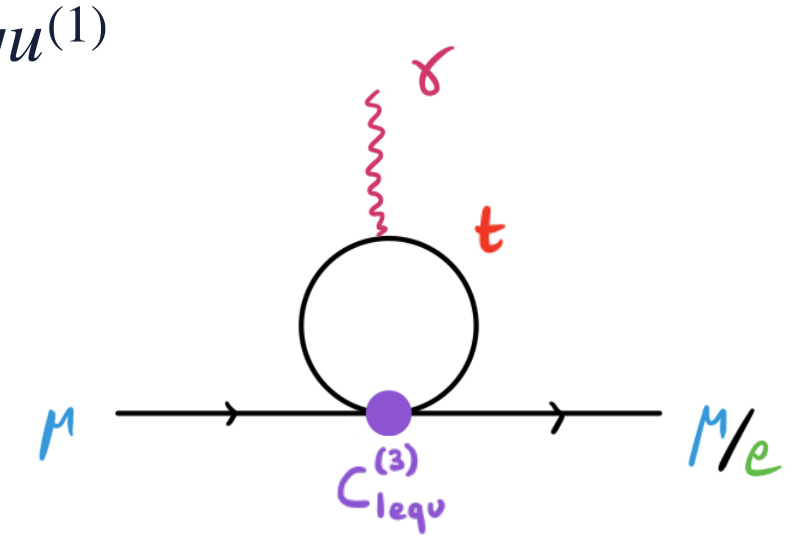
1) Same NP for $C_{lequ}^{(1),(3)}$ & radiative Dipole and Yukawa

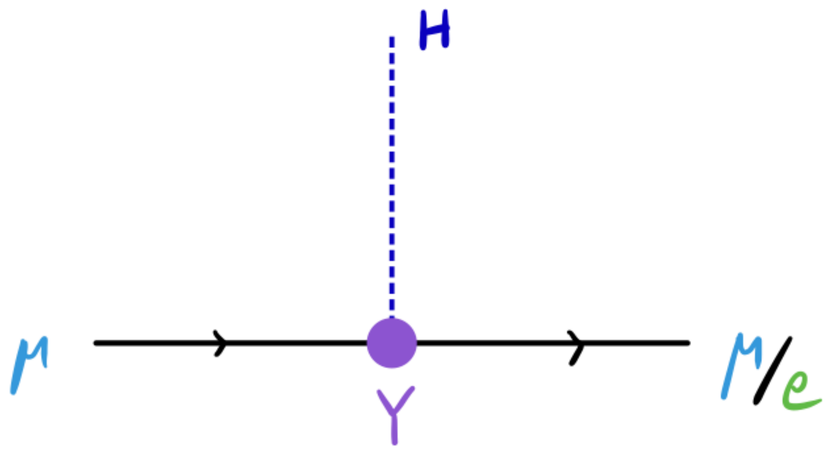


$$\Rightarrow \quad \theta_{lequ^{(3)}} = \theta_{lequ^{(1)}}$$

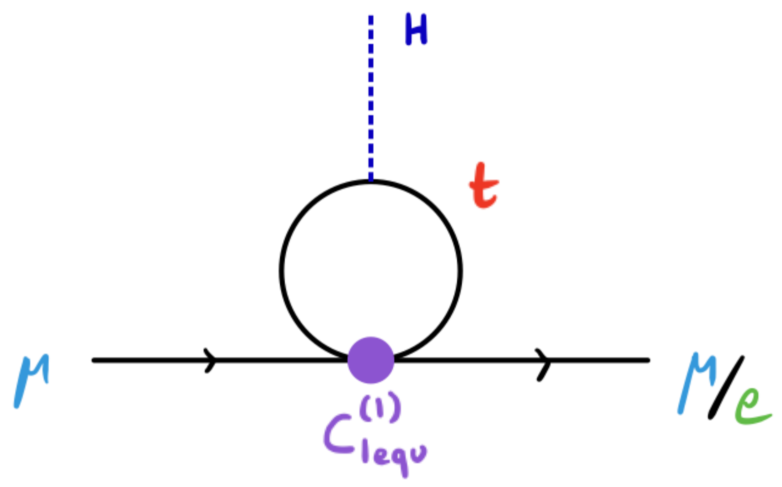


= RGE





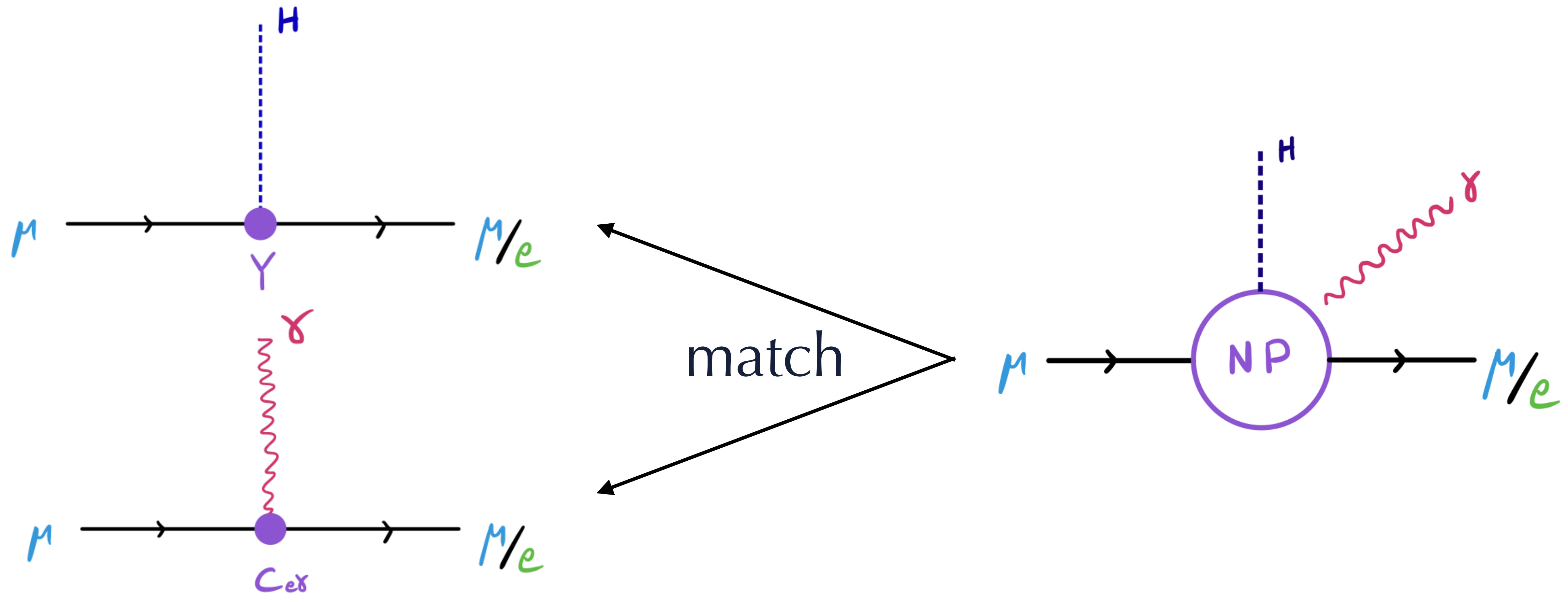
= RGE



$$\Rightarrow \quad \theta_{e\gamma} = \theta_Y = 0 \quad \text{and} \quad \Delta_3 = -\Delta_1 = 1$$

$$\epsilon_{12}^L = (\theta_{e\gamma} - \theta_Y) + (\theta_{lequ^{(3)}} - \theta_{e\gamma})\,\Delta_3 + (\theta_{lequ^{(1)}} - \theta_Y)\,\Delta_1$$

2) Dipole and Yukawa from same NP & no matching to 4-fermion operators



$$\Rightarrow \quad \Delta_3 = \Delta_1 = 0 \quad \text{and} \quad \theta_{e\gamma} = \theta_Y$$

3) Same NP for all operators

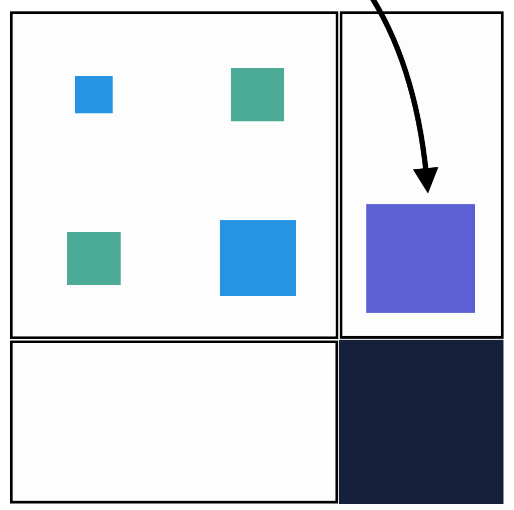
$$\Rightarrow \quad \theta_{e\gamma} = \theta_Y = \theta_{lequ^{(3)}} = \theta_{lequ^{(1)}}$$

Flavor Symmetries

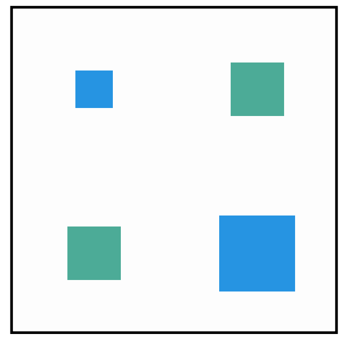
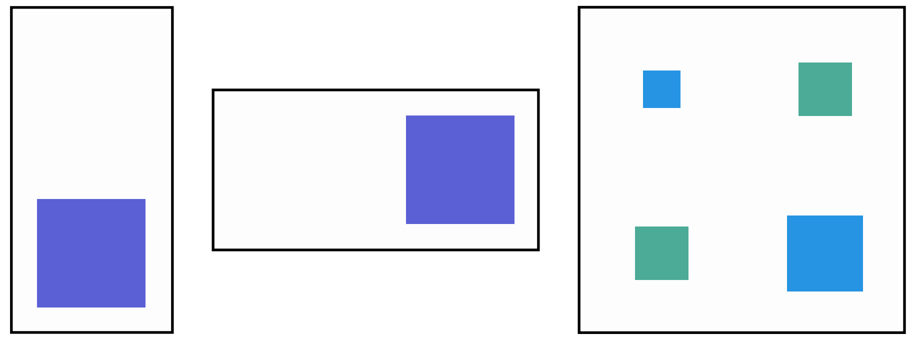
1) $U(2)_{\ell_L} \times U(2)_{e_R}$ symmetry

[Barbieri, Isidori, Jones-Pérez, Lodone, Straub, 1105.2296]

assumed $\mathcal{O}\left(10^{-1}\right)$

Spurions: $Y_e = y_\tau$ 

$\mathcal{O}(1)$ coefficients

$\Rightarrow$ operators flavor structure in 1-2 sector $= a_i$  $+\, b_i$ 

[Faroughy, Isidori, Wilsch, Yamamoto, 2005.05366]

naive expectation $\mathcal{O}\left(\sqrt{m_e/m_\mu}\right)$

Flavor angle: $\theta_i \approx \left(1 - \frac{b_i}{a_i}\ ^2\right)$ Alignment: $\theta_i - \theta_j = \ ^2 \left(\frac{b_j}{a_j} - \frac{b_i}{a_i}\right) < 2 \times 10^{-5}$ $\Rightarrow$ unnatural tuning

2) $U(1)_{L_e} \times U(1)_{L_\mu} \times U(1)_{L_\tau}$ symmetry

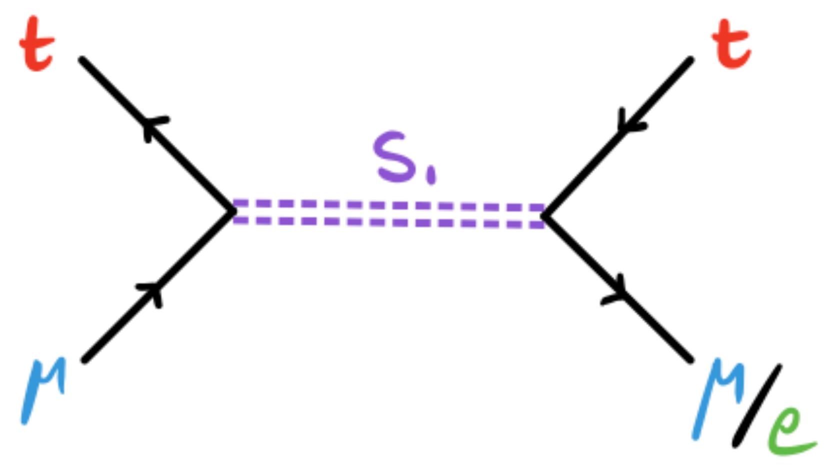
Same as 1) with $= \ = 0$ $\Rightarrow$ protect completely from LFV

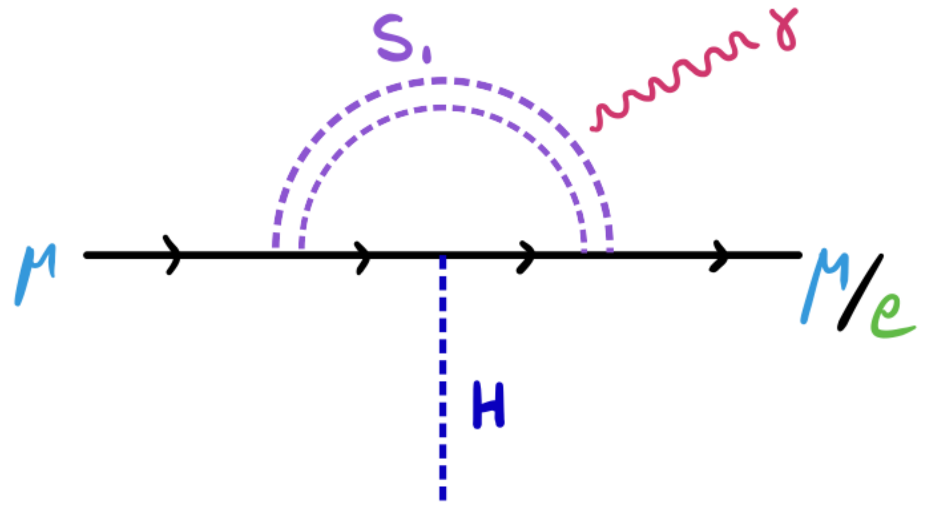
For the 1-2 sector any combination of $U(1)_{a\,L_\mu + b\,L_\tau}$ is enough

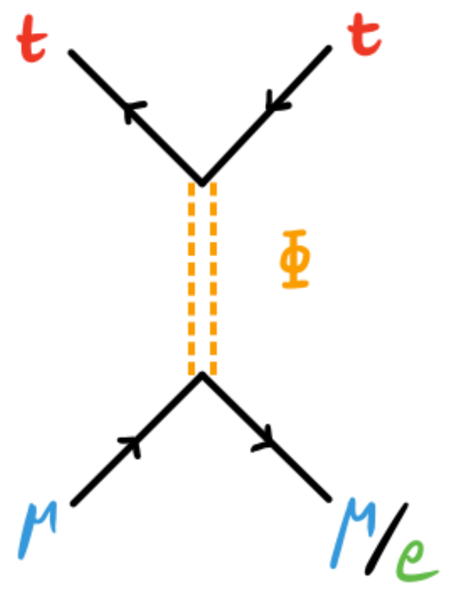
[Greljo, Stangl, Thomsen, Zupan, 2203.13731]

Example of alignment in explicit NP Model

UV theory: scalar leptoquark $S_1 \sim (\bar{3},1)_{1/3}$ additional Higgs $\Phi \sim (1,2)_{1/2}$







Match to: $C^{(1)}_{lequ}$, $C^{(3)}_{lequ}$ $C_{e\gamma}$ $C^{(1)}_{lequ}$

Assumptions to obtain alignment:

- $M^2_\Phi \gg M^2_{S_1}$ $\rightarrow$ $\theta_{lequ^{(1)}} = \theta_{lequ^{(3)}}$
- coupling to left-handed top dominant $\rightarrow$ $\theta_{e\gamma} = \theta_{lequ^{(3)}}$
- $U(2)^2$ for Yukawa coupling? $\rightarrow$ $\theta_Y - \theta_{e\gamma} \approx$ $< 2 \times 10^{-5}$

Tension in aligning: $\theta_Y \longleftrightarrow \theta_{e\gamma} \longleftrightarrow \theta_{lequ^{(3)}}$

Conclusion

The muon $(g-2)$ anomaly requires:

- relatively light New Physics and some kind of enhancement.
- together with the tight bounds on LFV:
  - Strong flavor alignment of the dipole operator,
  - Flavor alignment of some 4-fermion operators in the SMEFT at high-scale,
    ↪ RGE and mass diagonalization can spoil dipole alignment at low-scale,
  - Flavor symmetries and/or Dynamical mechanism to help explain the flavor alignment.

$\Rightarrow$ Also for heavy NP, solutions to the $(g-2)_\mu$ anomaly seem unnatural.

General remarks:

➡ SMEFT is a powerful framework to connect different phenomena in a model-independent way.

➡ Flavor in the SMEFT give interesting insights and should not be ignored.


Thank you for listening!
Any questions?

Back-up slides

Dipole 12 element in mass basis after RGE

$$\hat{L} = \frac{1}{16\pi^2}\log\left(\frac{\mu_H}{\mu_L}\right)$$

$$\underset{prst}{O_{ledq}} = (\bar{\ell}^j_{Lp}\, e_{Rr})\,(\bar{d}_{Rs}\, q_{Ltj})$$

RGE for dipole and mass Yukawa

$$\underset{ij}{\mathcal{C}_{e\gamma}}(\mu_L) = \left[1 - 3\hat{L}\left(y_t^2 + y_b^2\right)\right]\underset{ij}{\mathcal{C}_{e\gamma}}(\mu_H) - \left[16\hat{L}y_t e\right]\underset{ij33}{C^{(3)}_{lequ}}(\mu_H)\,,$$

$$[\mathcal{Y}_e]_{ij}(\mu_L) = [Y_e]_{ij}\,(\mu_H) - \frac{v^2}{2}\underset{ij}{C_{eH}}(\mu_H) + 6v^2\hat{L}\left[y_t^3\underset{ij33}{C^{(1)}_{lequ}} - y_b^3\underset{ij33}{C_{ledq}} + \frac{3}{4}(y_t^2 + y_b^2)\underset{ij}{C_{eH}}\right]_{\mu_H}$$

LFV Dipole in terms of high-scale quantities

$$\begin{aligned}
\underset{12}{\mathcal{C}'_{e\gamma}}(\mu_L) &= (\theta_L^{e\gamma} - \theta_L^{Y})\underset{22}{\mathcal{C}_{e\gamma}}(\mu_L) + (\theta_L^{e\gamma} - \theta_L^{u_3})(16\hat{L}ey_t)\underset{2233}{C^{(3)}_{lequ}}(\mu_H) \\
&+ \left[(\theta_L^{Y} - \theta_L^{u_1})(6y_t^3)\underset{2233}{C^{(1)}_{lequ}}(\mu_H) + (\theta_L^{d} - \theta_L^{Y})(6y_b^3)\underset{2233}{C_{ledq}}(\mu_H)\right]\frac{1}{[\mathcal{Y}_e]_{22}(\mu_L)}\hat{L}v^2\underset{22}{\mathcal{C}_{e\gamma}}(\mu_L) \\
&+ (\theta_L^{eH} - \theta_L^{Y})\frac{1 - 9(y_t^2 + y_b^2)\hat{L}}{2}\underset{22}{C_{eH}}(\mu_H)\frac{1}{[\mathcal{Y}_e]_{22}(\mu_L)}v^2\underset{22}{\mathcal{C}_{e\gamma}}(\mu_L)\,.
\end{aligned}$$

Explicit NP model Lagrangian and flavor phases

$S_1 \sim (\bar{3},1)_{1/3}$ scalar leptoquark + $\Phi \sim (1,2)_{1/2}$ scalar doublet

UV Lagrangian:

$$\begin{aligned}\mathcal{L}_{S_1} &= \mathcal{L}_{\rm SM} + (D_\mu S_1)^\dagger (D^\mu S_1) - M_{S_1}^2 S_1^\dagger S_1 - \left[\lambda^L_{i\alpha}(\bar{q}^c_i \epsilon \ell_\alpha) S_1 + \lambda^R_{i\alpha}(\bar{u}^c_i e_\alpha) S_1 + \text{h.c.}\right] \\ &\quad + (D_\mu \Phi)^\dagger (D^\mu \Phi) - M_\Phi^2 \Phi^\dagger \Phi - \left[\lambda^e_{\alpha\beta}(\bar{\ell}_\alpha e_\beta)\Phi + \lambda^u_{ij}(\bar{q}_i u_j)\tilde{\Phi} + \text{h.c.}\right]\end{aligned}$$

After matching:

$$\theta_L^{u_1} = \frac{\lambda^{L\,*}_{31}\lambda^R_{32} + 2\lambda^e_{12}\lambda^u_{33} M^2_{S_1}/M^2_\Phi}{\lambda^{L\,*}_{32}\lambda^R_{32} + 2\lambda^e_{22}\lambda^u_{33} M^2_{S_1}/M^2_\Phi}$$

$$\theta_L^{u_3} = \frac{\lambda^{L\,*}_{31}}{\lambda^{L\,*}_{32}}$$

$$\theta_L^{e\gamma} = \frac{(Y_e)_{1\alpha}\lambda^{R\,*}_{i\alpha}\lambda^R_{i2} + \lambda^{L\,*}_{i1}\lambda^L_{i\alpha}(Y_e)_{\alpha 2} - 14\, y_t \lambda^{L\,*}_{31}\lambda^R_{32}}{(Y_e)_{2\alpha}\lambda^{R\,*}_{i\alpha}\lambda^R_{i2} + \lambda^{L\,*}_{i2}\lambda^L_{i\alpha}(Y_e)_{\alpha 2} - 14\, y_t \lambda^{L\,*}_{32}\lambda^R_{32}}$$

Alignment in the 2-3 sector

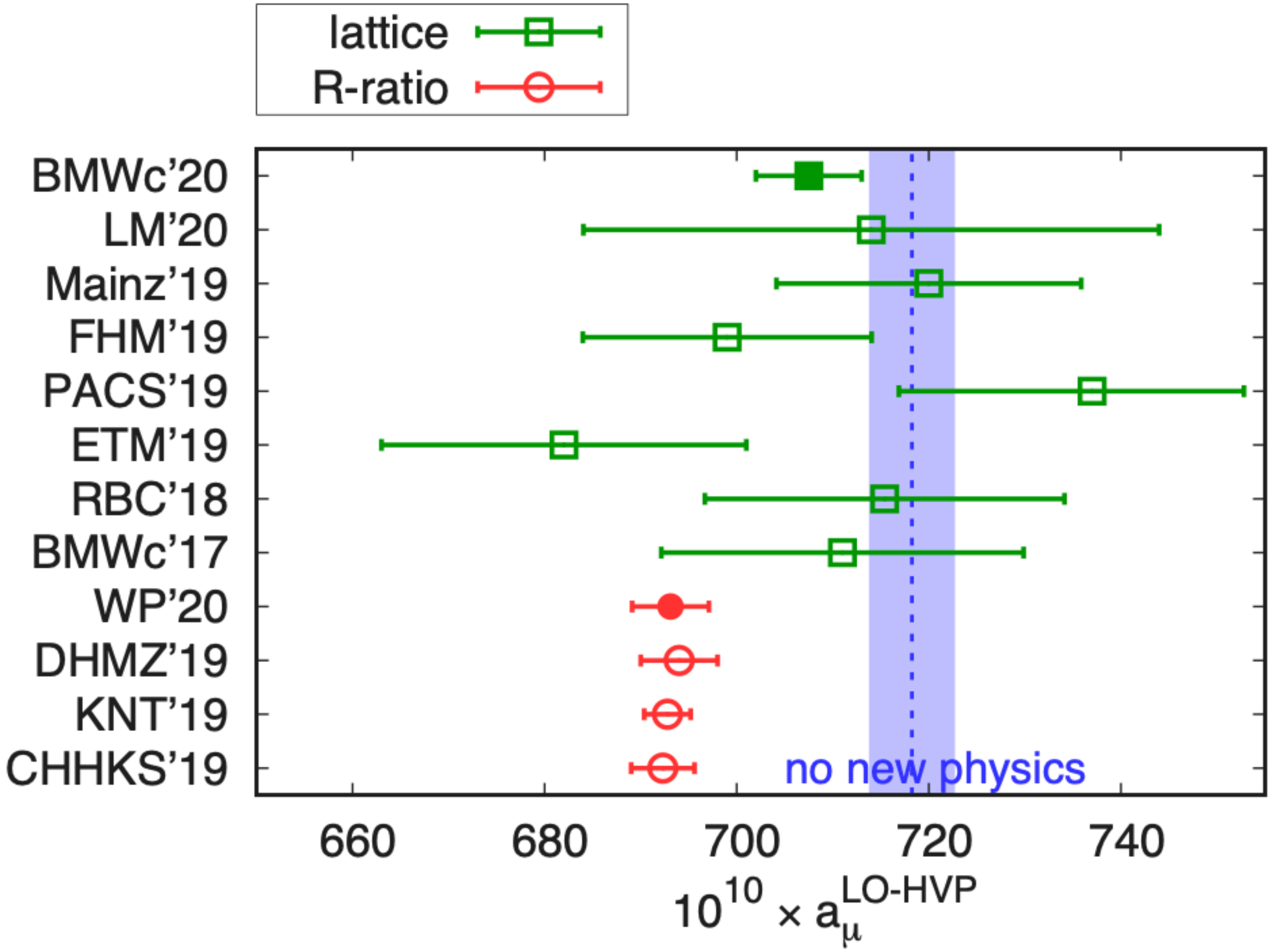
Flavor Alignment from $\tau \to \mu\gamma$

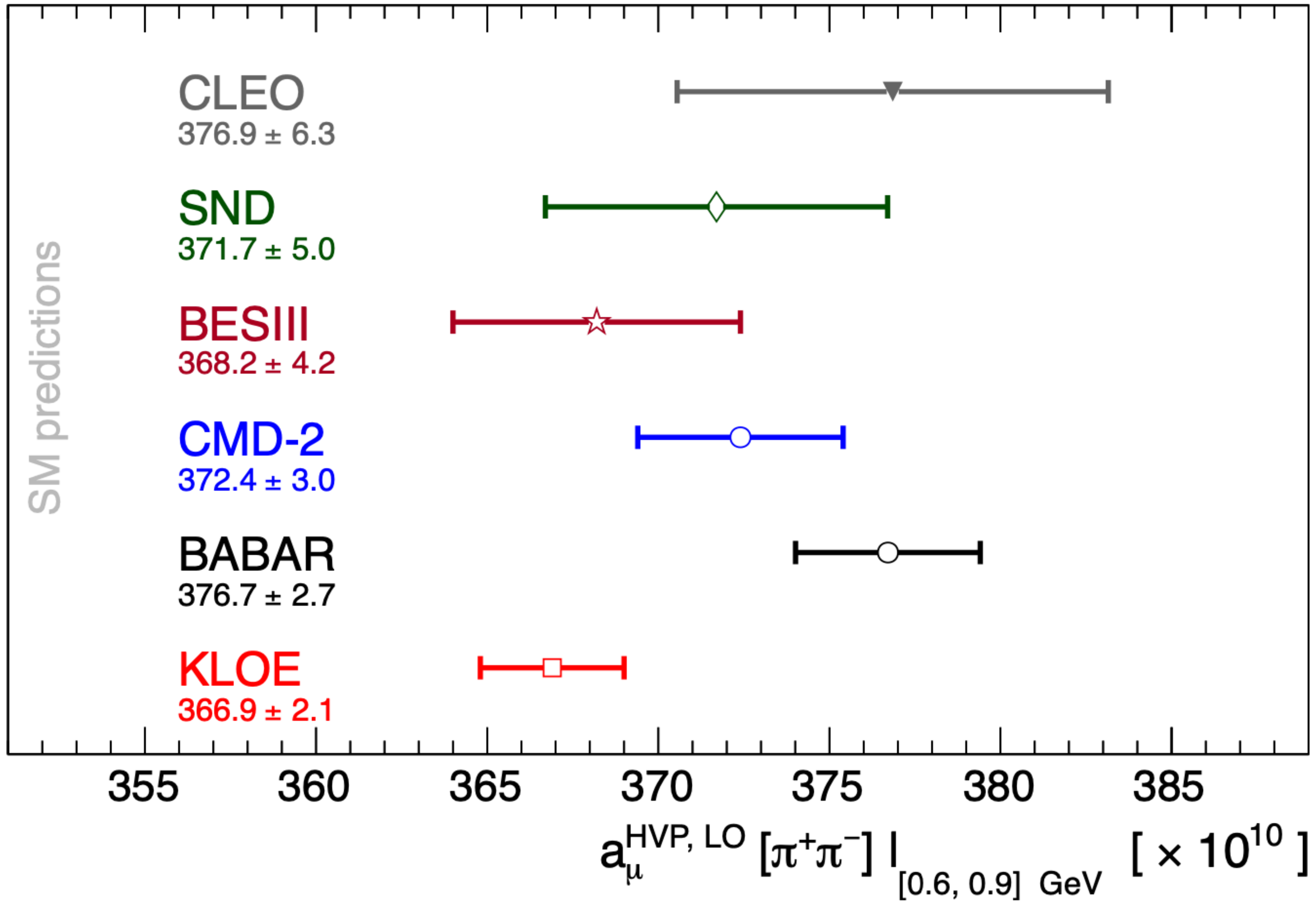
$$\mathcal{B}(\tau^\pm \to \mu^\pm\gamma) < 4.4 \times 10^{-8} \;(90\% \;\mathrm{CL}) \qquad \Rightarrow \qquad |\mathcal{C}'_{\underset{23(32)}{e\gamma}}| < 2.7 \times 10^{-6}\,\mathrm{TeV}^{-2}$$

Flavor alignment in 2-3: $$|\epsilon^L_{23}|\,,\; |\epsilon^R_{23}| < 1.6 \times 10^{-2} \times \left|\frac{y_\tau\, \mathcal{C}'_{\underset{22}{e\gamma}}}{y_\mu\, \mathcal{C}'_{\underset{33}{e\gamma}}}\right|$$

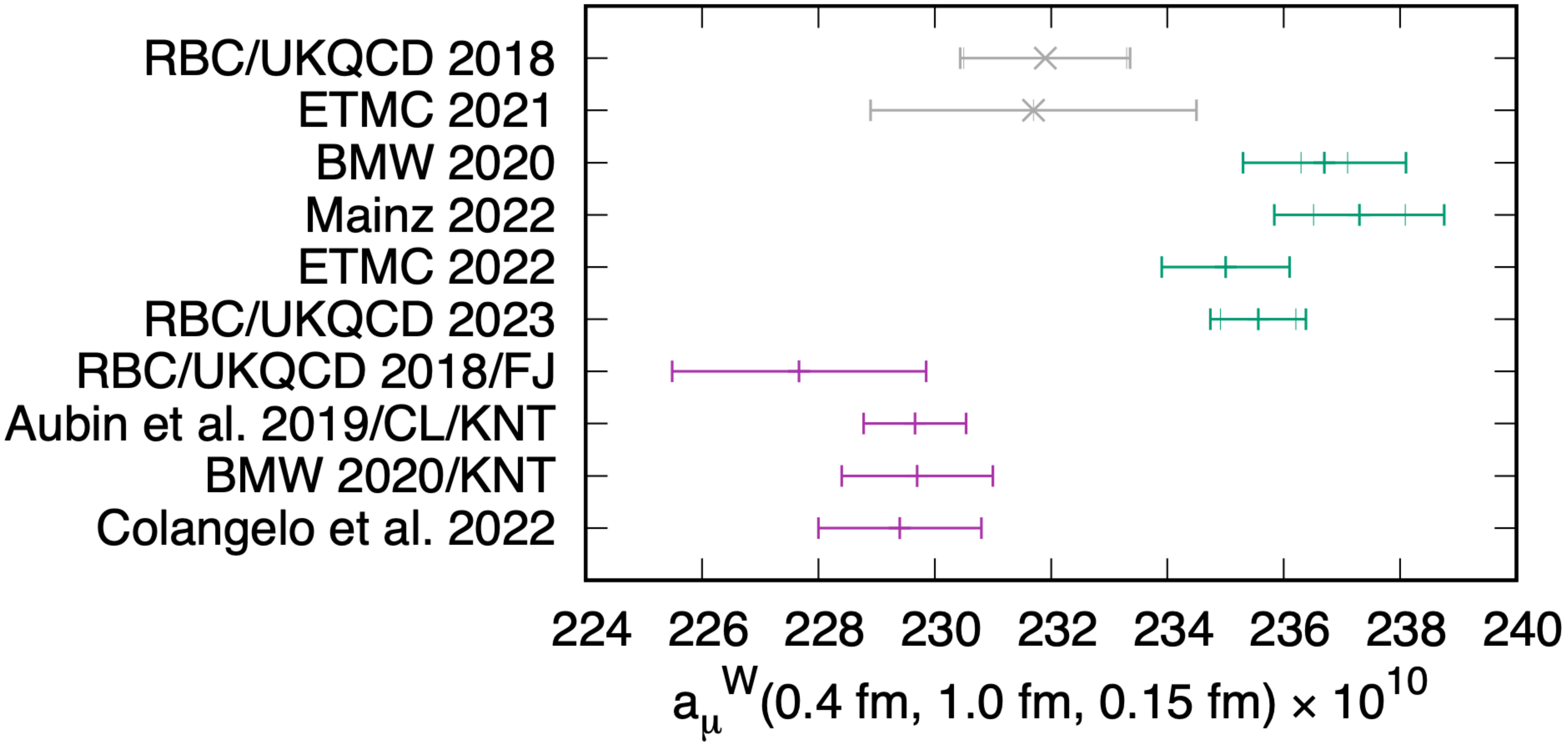
Anomaly status

Hadronic Vacuum Polarization contribution





Euclidean time window



Lattice

Dispersive

CMD-3 measurement of $e^+e^- \to \pi^+\pi^-$

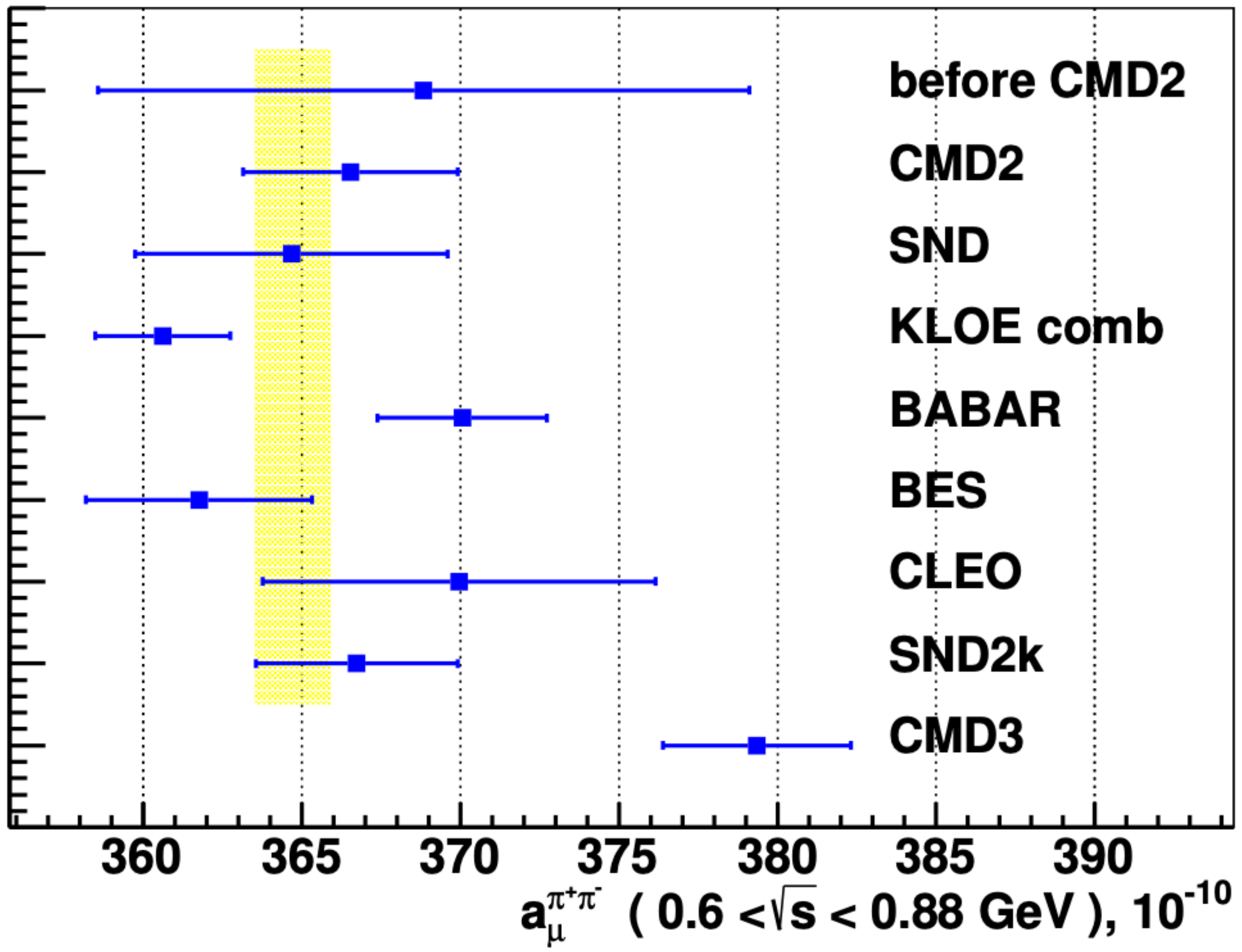
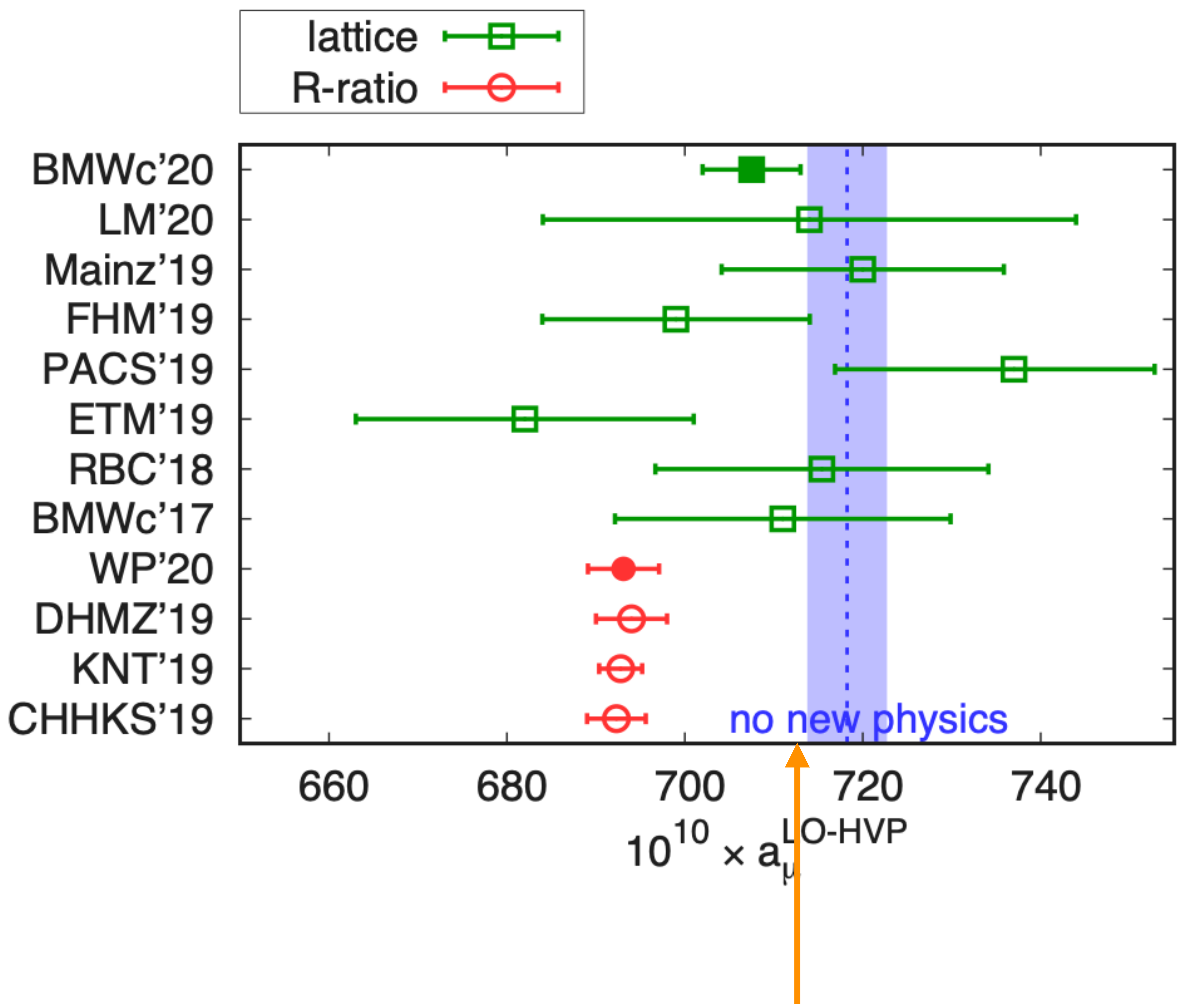


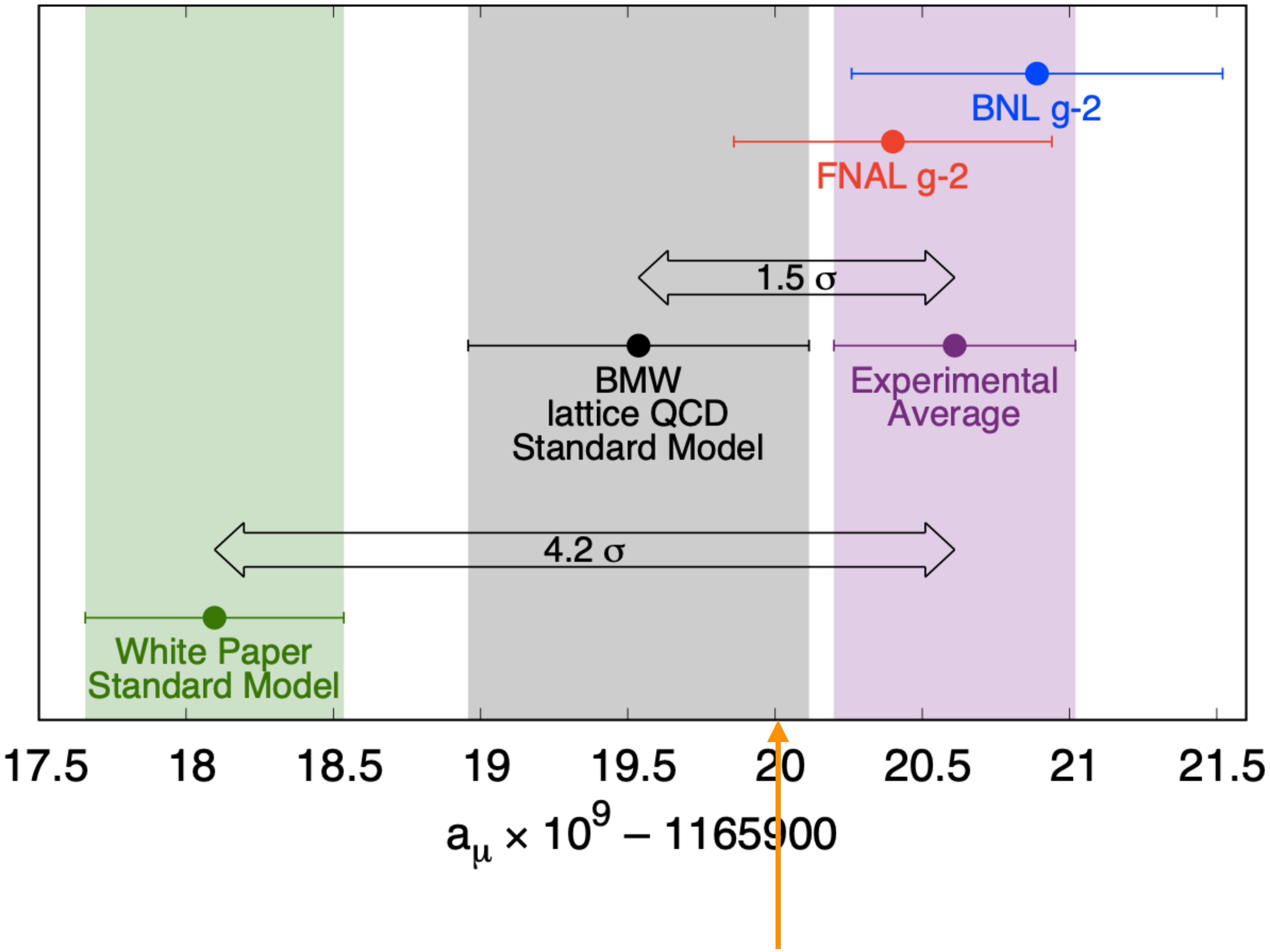
Figure 36: The $\pi^+\pi^-(\gamma)$ contribution to $a_\mu^{had,LO}$ from energy range $0.6 < \sqrt{s} < 0.88$ GeV obtained from this and other experiments.

Experiment	$a_\mu^{\pi^+\pi^-,LO}$, 10^{-10}
before CMD2	368.8 ± 10.3
CMD2	366.5 ± 3.4
SND	364.7 ± 4.9
KLOE	360.6 ± 2.1
BABAR	370.1 ± 2.7
BES	361.8 ± 3.6
CLEO	370.0 ± 6.2
SND2k	366.7 ± 3.2
CMD3	379.3 ± 3.0

Table 4: The $\pi^+\pi^-(\gamma)$ contribution to $a_\mu^{had,LO}$ from energy range $0.6 < \sqrt{s} < 0.88$ GeV obtained from this and other experiments.

Naive expectation on a_μ





new R-ratio prediction

new R-ratio prediction