EPS-HEP, July 28 2021

EFT description of lepton magnetic and electric dipole moments

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Outline

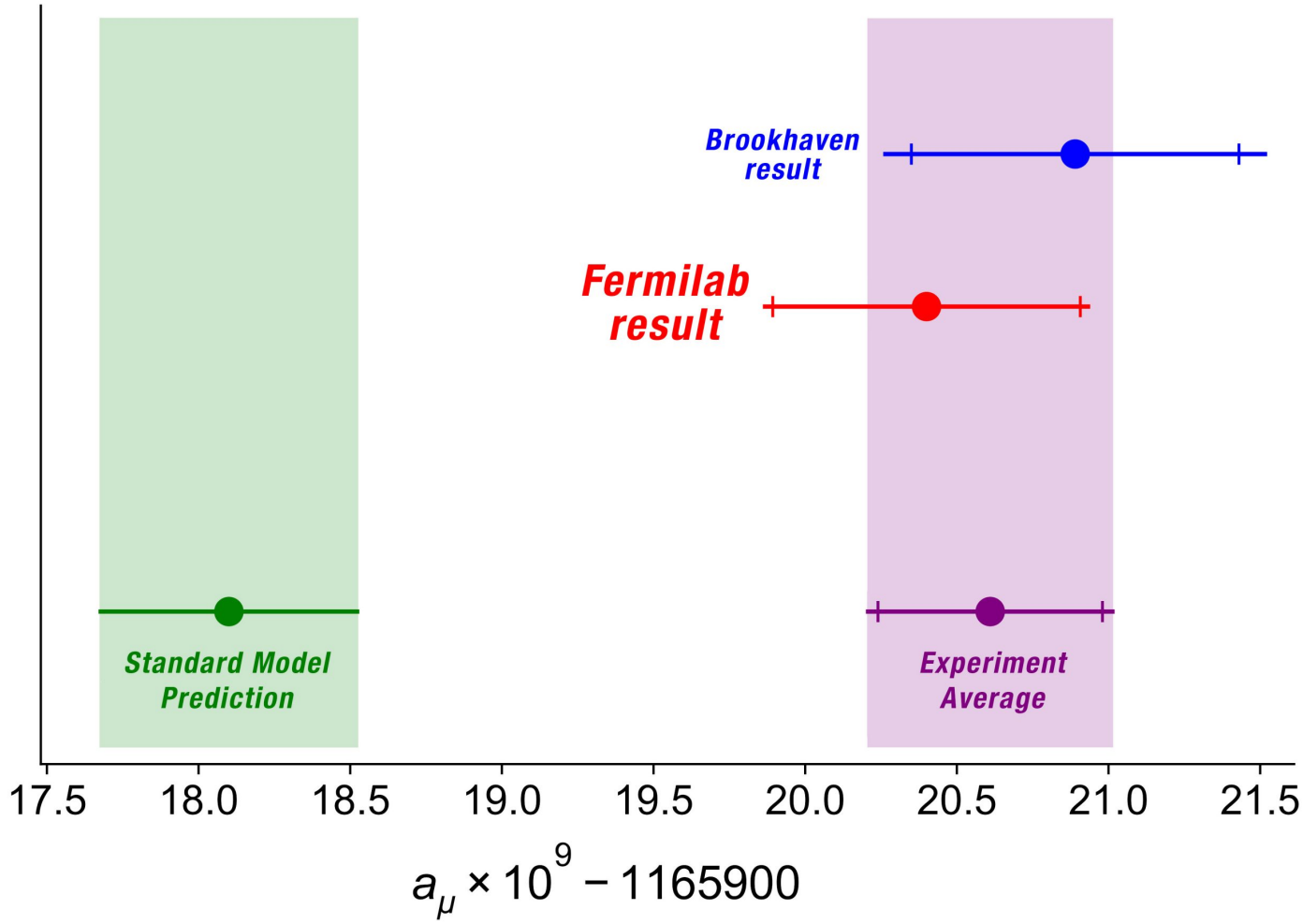
1. Motivation
2. EFT description
3. Numerics
4. Summary

based on: 2102.08954, in collaboration with Wouter Dekens, Elizabeth Jenkins, Aneesh Manohar, Dipan Sengupta and Peter Stoffer

Outline

$(g-2)_\mu$ discrepancy

Muon g-2 collaboration: 2104.03247



Overview

Experimental values

$a_\mu^{\text{exp}} = 116\,592\,040(54) \times 10^{-11}$ — Muon g-2 collaboration: 2104.03247

$a_e^{\text{exp}} = 1\,159\,652\,180.73(28) \times 10^{-12}$ — Hanneke/Fogwell/Gabrielse: 0801.1134

Theory predictions

$a_\mu^{\text{SM}} = 116\,591\,810(43) \times 10^{-11}$ — whitepaper: 2006.04822

$a_e^{\text{SM,Cs}} = 1\,159\,652\,181.61(23) \times 10^{-12}$ — Parker/Zhong/Estey/Müller: 1812.04130

Electric dipole moments

$|d_\mu| < 1.5 \times 10^{-19}\ e\text{–cm} \quad @\,90\%\,\text{CL}$ — Muon g 2 Collaboration: 0811.1207

$|d_e| < 1.1 \times 10^{-29}\ e\text{–cm} \quad @\,90\%\,\text{CL}$ — ACME Collaboration: Nature 562 (2018) 7727

Discrepancies

$\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}}$

4.2σ

Δa_e^{Cs}

2.4σ

Electric dipole moments

Upper bounds

Outline

EFT procedure

WET: Computation at low scale $\sim$ 2 GeV

a_ℓ, d_ℓ in terms of Wilson coefficients

WET: Above 2 GeV

Renormalization Group effects

SMEFT: Above EW scale

Matching and RG effects

Model

Match onto SMEFT or WET

Weak effective theory (WET)

Symmetry

$SU(3)_C \times U(1)_{em}$

Fields

$u, d, c, s, b, \ell, \nu_\ell, g, \gamma$

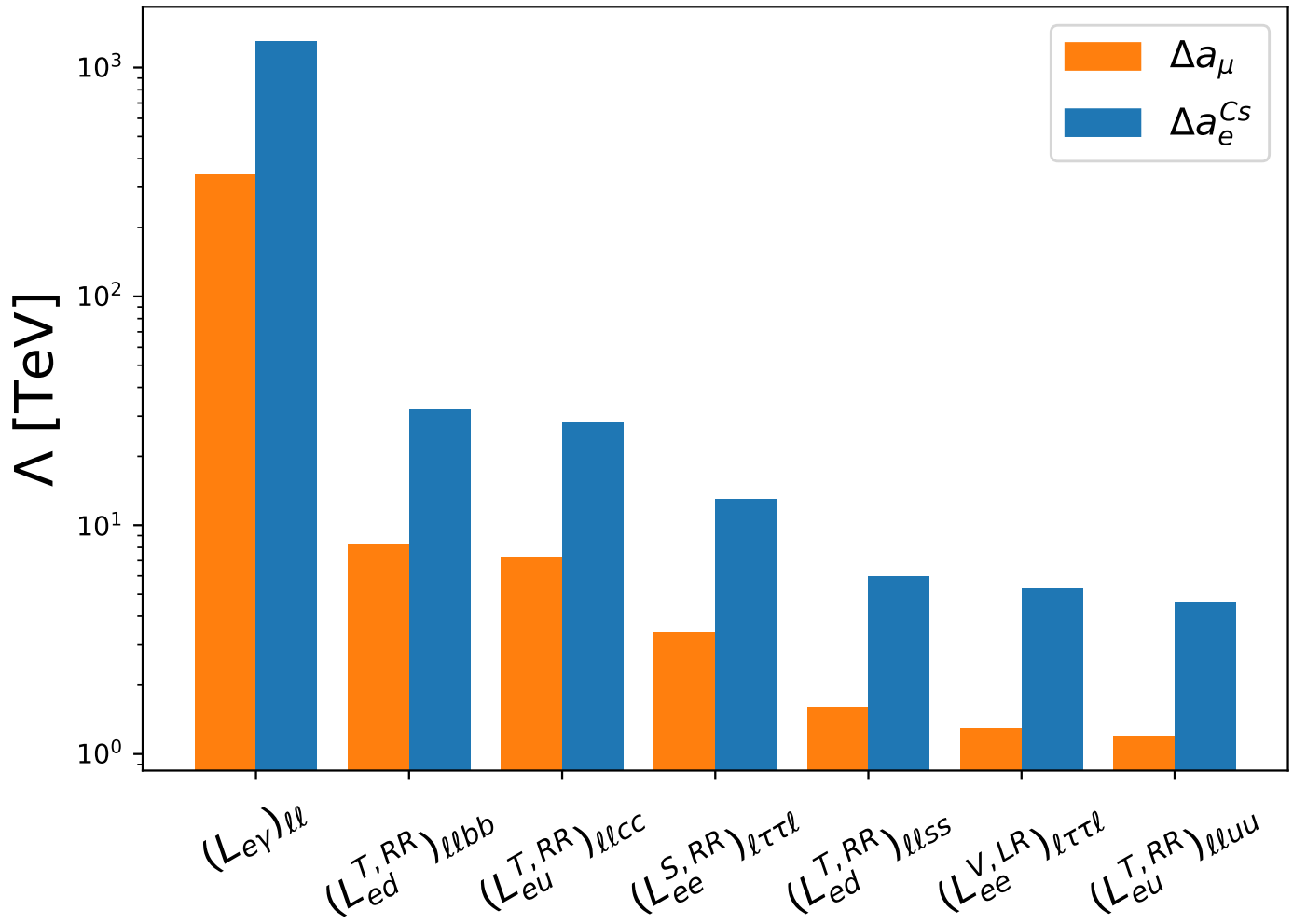
Poincaré invariance

Dim 6 operators

a_μ in WET

$$
\begin{aligned}
\Delta a_\mu^{60\ \mathrm{GeV}} = \mathrm{Re}\Bigg[& 2.2\times 10^{-2} L^{e\gamma}_{\mu\mu} - 5.3\times 10^{-5} L^{T,RR}_{ed\,\mu\mu bb} \\
& + \left(3.5 + 0.65 c_T^{(c)}\right)\times 10^{-5} L^{T,RR}_{eu\,\mu\mu cc} + 9.0\times 10^{-6} L^{S,RR}_{ee\,\mu\tau\tau\mu} - 1.4\times 10^{-6} L^{V,LR}_{ee\,\mu\tau\tau\mu} \\
& + 9.8\times 10^{-7} L^{S,RR}_{ee\,\mu\mu\mu\mu} - \left(10 c_T - 0.64\right)\times 10^{-7} L^{T,RR}_{eu\,\mu\mu uu} \\
& + \left(5.0 c_T - 14\right)\times 10^{-7} L^{T,RR}_{ed\,\mu\mu ss} + \left(5.0 c_T - 0.70\right)\times 10^{-7} L^{T,RR}_{ed\,\mu\mu dd} \\
& - 1.6\times 10^{-7} L^{S,RR}_{ee\,\mu\mu\tau\tau} - \left(5.9 + 2.3 c_T^{(c)} + 0.45 c_S^{(c)}\right)\times 10^{-8} L^{S,RR}_{eu\,\mu\mu cc} \\
& - 8.0\times 10^{-8} L^{V,LR}_{ee\,\mu\mu\mu\mu} - 3.3\times 10^{-8} L^{S,RR}_{ed\,\mu\mu bb} - 2.4\times 10^{-8} L^{S,RR}_{ee\,\mu\mu\mu\mu} + 8.8\times 10^{-9} L^{S,RR}_{ee\,\mu ee\mu} \\
& - 4.5\times 10^{-9} \widetilde{c}_S^{(c)} L^{S,RL}_{eu\,\mu\mu cc} + 3.5\times 10^{-9} c_T L^{S,RR}_{eu\,\mu\mu uu} - 1.2\times 10^{-9} L^{S,RR}_{ed\,\mu\mu ss} \Bigg]
\end{aligned}
$$

Scales


Δa_μ
Δa_e^{Cs}
Λ [TeV]
10^3
10^2
10^1
10^0
$(L_{eV})_{\ell\ell}$
$(L_{ed}^{T,RR})_{\ell\ell bb}$
$(L_{eu}^{T,RR})_{\ell\ell cc}$
$(L_{ee}^{S,RR})_{\ell\tau\tau\ell}$
$(L_{ed}^{T,RR})_{\ell\ell ss}$
$(L_{ee}^{V,LR})_{\ell\tau\tau\ell}$
$(L_{eu}^{T,RR})_{\ell\ell uu}$

SM Effective Theory (SMEFT)

Symmetry

$SU(3)_C \times SU(2)_L \times U(1)_Y$

Fields

$u, d, c, s, b, t, \ell, \nu_\ell, g, W, Z, H$

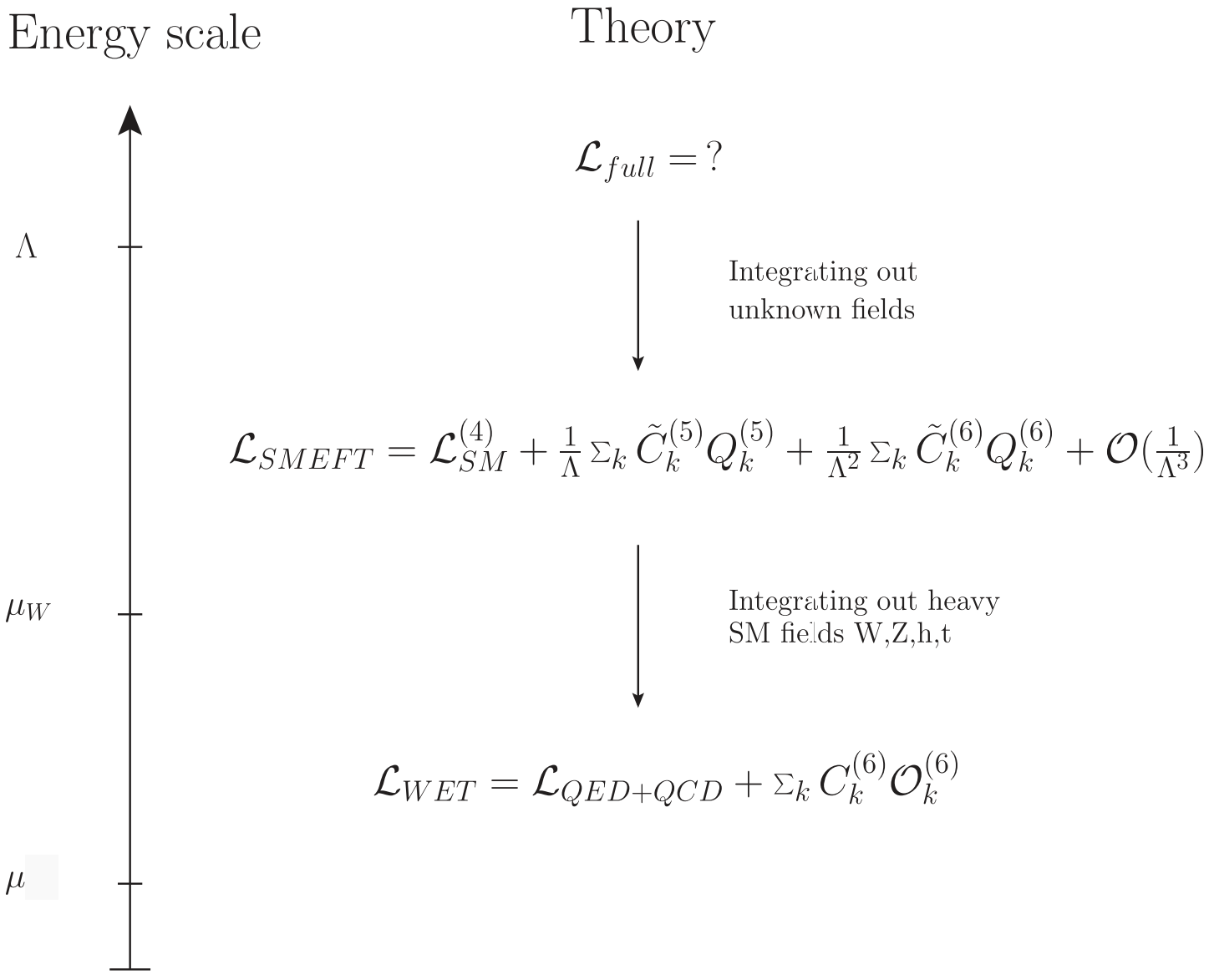
Poincaré invariance

Dim 6 operators

a_μ in SMEFT

$$\Delta a_\mu^{10\ \mathrm{TeV}} = \mathrm{Re}\Big[1.7\times 10^{-6}\mathcal{C}^{eB}_{\mu\mu} - 9.2\times 10^{-7}\mathcal{C}^{eW}_{\mu\mu} - 2.2\times 10^{-7}\mathcal{C}^{(3)}_{\ell equ\,\mu\mu 33} - \left(2.5+0.22c_T^{(c)}\right)\times 10^{-9}\mathcal{C}^{(3)}_{\ell equ\,\mu\mu 22}\Big]$$

Usage


Energy scale
Theory
$\mathcal{L}_{full} = ?$
Integrating out
unknown fields
$\mathcal{L}_{SMEFT} = \mathcal{L}^{(4)}_{SM} + \frac{1}{\Lambda}\Sigma_k \tilde{C}^{(5)}_k Q^{(5)}_k + \frac{1}{\Lambda^2}\Sigma_k \tilde{C}^{(6)}_k Q^{(6)}_k + \mathcal{O}(\frac{1}{\Lambda^3})$
Integrating out heavy
SM fields W,Z,h,t
$\mathcal{L}_{WET} = \mathcal{L}_{QED+QCD} + \Sigma_k C^{(6)}_k \mathcal{O}^{(6)}_k$
Λ
μ_W
μ

Outline

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JA/Kumar/Straub: 1804.05033

A Phyton package, which includes

SMEFT running

Complete 1-loop RGEs — Alonso/Jenkins/Manohar/Trott: 1312.2014, 1308.2627, 1310.4838

Matching

Complete tree-level matching — JA/Crivellin/Fael/Greub:1512.02830, Jenkins/Manohar/Stoffer:1709.04486

Complete one-loop matching — Dekens/Stoffer:1908.05295

WET running

Complete 1-loop running — JA/Fael/Greub/Virto:1704.06639, Jenkins/Manohar/Stoffer:1711.05270

GitHub: https://github.com/wilson-eft/wilson

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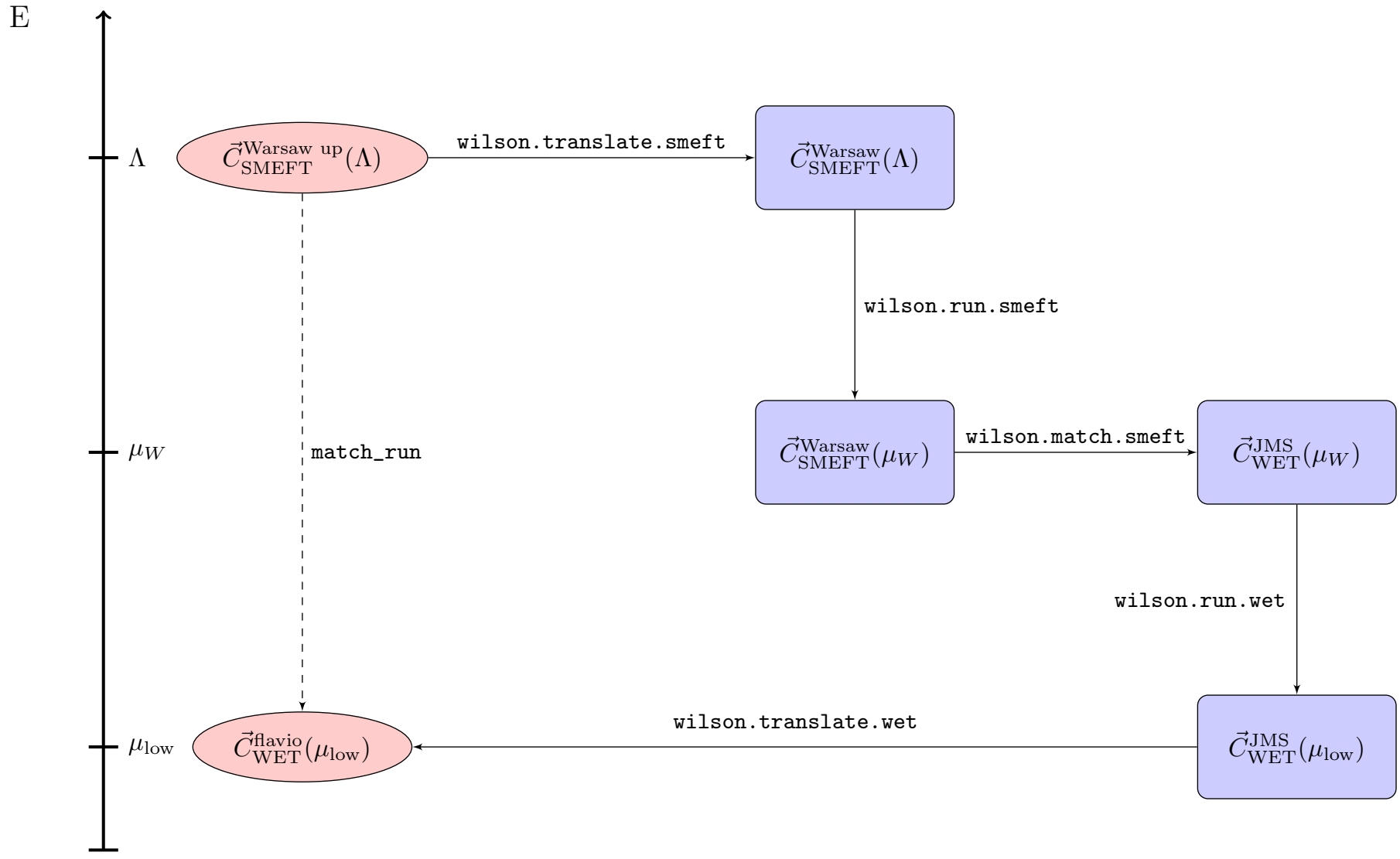
JA/Kumar/Straub: 1804.05033



Outline

Summary

Current discrepancy

$(g-2)_\mu$

EFT description

WET, SMEFT for $a_{\mu,e}$ and $d_{\mu,e}$

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Complete running and matching