

# Probing New Physics at the Hadronic Scale

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## Precision EFT

Our work is based on the Standard Model (SM) of particle physics, the best theory so far that describes fundamental particle interactions

- The SM has achieved impressive predictive power, but must be incomplete since it fails to explain certain phenomena (e.g. neutrino masses, matter-antimatter asymmetry)
- Deviations from the SM may originate from an exchange of an undiscovered heavy particle
- To account for the unknown ultraviolet (UV) physics at higher energies, we treat the SM as an Effective Field Theory (EFT). The SM EFT is

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{d \geq 5} \frac{1}{\Lambda_{\text{NP}}^{d-4}} \sum_i C_i^{(d)} Q_i^{(d)}$$

and is valid below the scale  $\Lambda_{\text{NP}}$  of new physics

- Our goal is to identify effects of New Physics (NP) indirectly in low-energy observables like  $g - 2$ ,  $\mu \rightarrow 3e$ ,  $\mu \rightarrow e\gamma$ , etc.
- This indirect search requires high precision, but not larger energies to produce new particles
- We work with various EFTs such as Low-Energy EFT (LEFT) and Chiral Perturbation Theory (ChPT)<sup>1</sup>

[1] arXiv: 2310.13051, 2412.13251, 2505.03871, 2507.08926, 2510.08682

## CP and lepton-flavor violation

The violation of charge and parity (CP) is necessary to produce the observed matter-antimatter asymmetry

- In the SM, the sources of CP violation enter through the CKM phase and the  $\theta$ -term

$$\mathcal{L}_{\theta_s} = \theta_s \frac{g_s^2}{16\pi^2} \tilde{G}_{\mu\nu}^A G^{A\mu\nu}$$

- CP violation directly affects the electric dipole moment of the neutron (nEDM)
- The nEDM collaboration at the Paul Scherrer Institute (PSI) provides a strong upper bound causing a theory (strong CP) problem

In addition, the SM predicts lepton-flavor conservation, which forbids  $\mu \rightarrow e\gamma$  and  $\mu \rightarrow 3e$

- These processes are searched for by the MEG and Mu3e collaborations at PSI and we analyze the contributing hadronic effects<sup>2</sup>

[2] arXiv: 1810.05675

## Muon $g - 2$

The **anomalous magnetic moment** of the muon is an extremely high-precision quantity

- $g$ -factor of muon predicted to be 2 by Dirac's equation:
 
$$\vec{\mu}_s = g \frac{e\vec{S}}{2m}$$
- Radiative corrections induce deviations  $a_\mu := \frac{g_\mu - 2}{2} \neq 0$

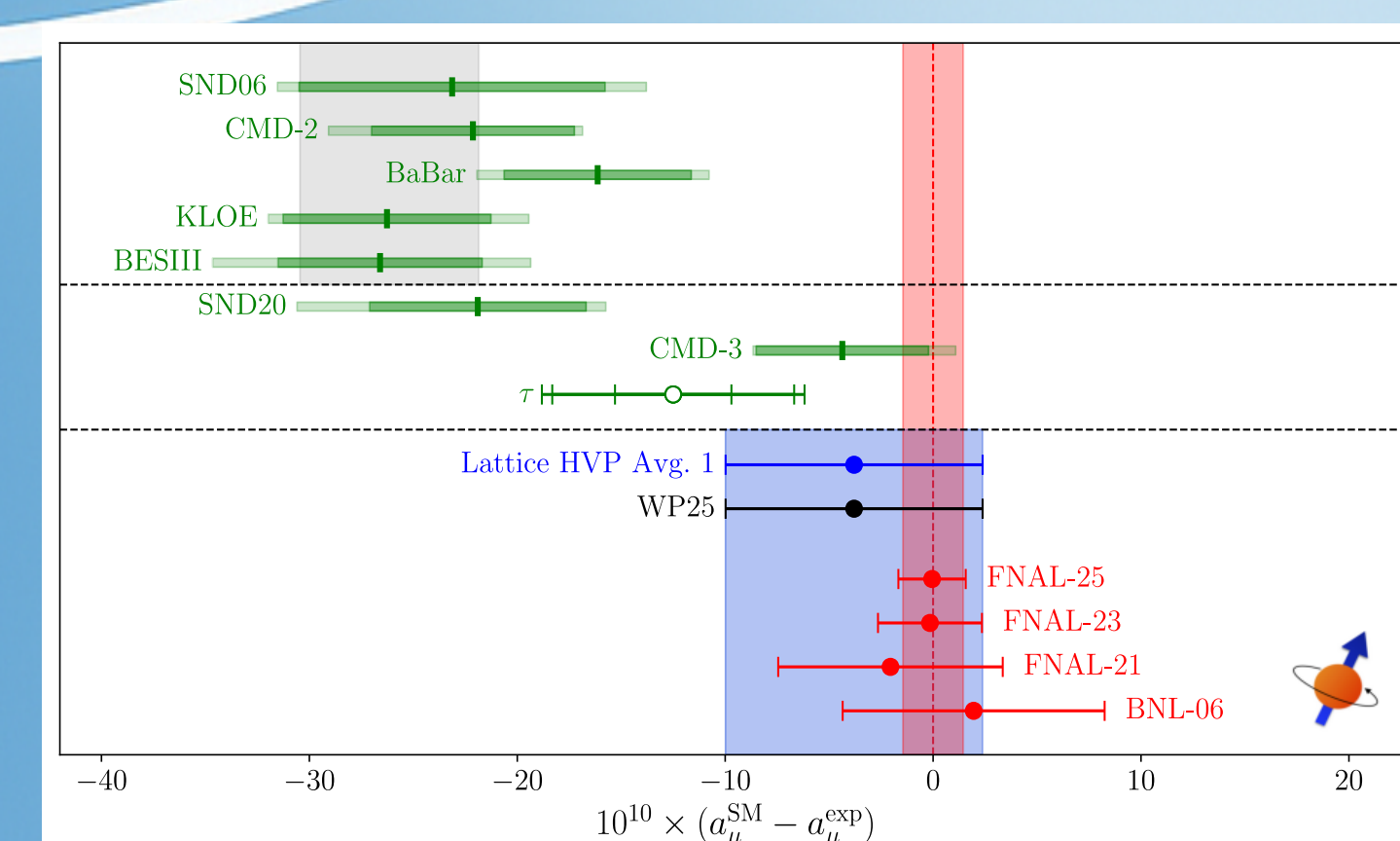
and can be measured by observing muon spin precession in a magnetic storage ring

- Most recent theoretical prediction and experimental measurement (WP 2025)<sup>3</sup>:

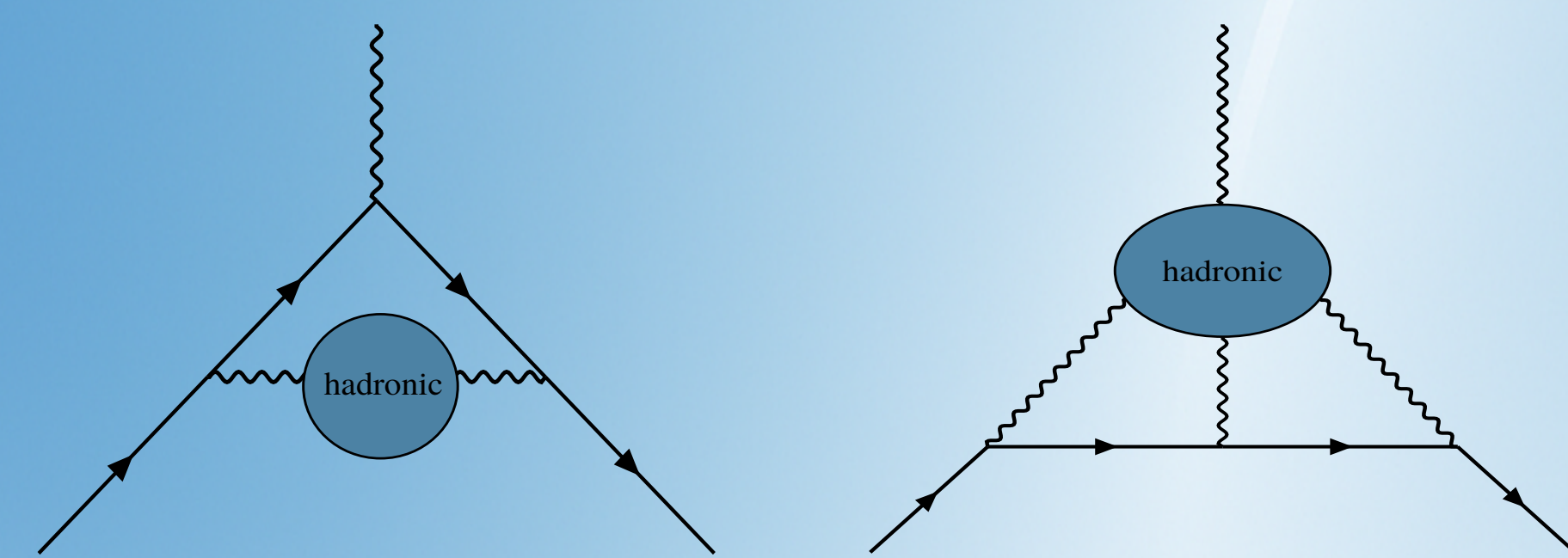
$$a_\mu^{\text{SM}} = 116592033(62) \times 10^{-11},$$

$$a_\mu^{\text{exp}} = 116592071.5(14.5) \times 10^{-11},$$

but significant discrepancies are still present for theoretical data-driven dispersive approach<sup>4</sup>



driven by hadronic contributions (mainly HVP)



- We aim to lower uncertainties in the hadronic light-by-light and hadronic vacuum polarization contributions<sup>2</sup>

[3] arXiv: 2505.21476

[4] arXiv: 2208.08993, 2302.12264, 2308.04217, 2402.14060, 2410.11946

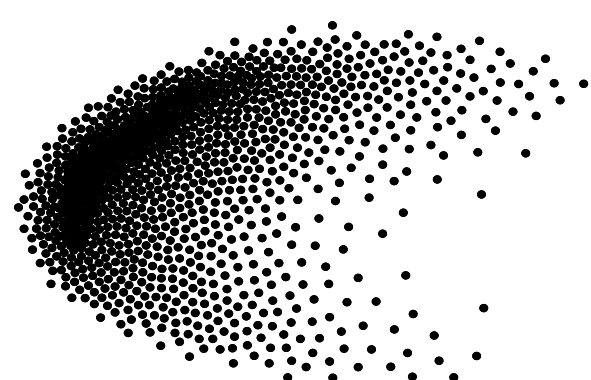
## Gradient-flow formalism for CP violating observables

- Hadronic EDMs are non-perturbative quantities  $\Rightarrow$  we require matrix elements from lattice QCD
- The EFT tower requires results given in  $D = 4 - 2\epsilon$  space-time dimensions. But lattice QCD is tied to integer dimensions
- We are involved in the translation between lattice scheme (gradient flow) and EFT-tower scheme (minimal subtraction)<sup>5</sup>
- We are also interested in using the gradient flow to extract the renormalization group equations

[5] arXiv: 2111.11449, 2304.00985, 2308.16221



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