The Low-Energy Frontier of Particle Physics, LNF, 10-12 Feb., 2025

Some material for the discussion session

Antonio Masiero Univ. Padova and INFN, Padova Unit

Open questions

- Ultimate EDM experiments (electron and/or proton) to reach SM-CKM sensitivity?
- Complementarity of EDMs to disentangle origin of CP violation ?
- What insights into baryogenesis can be gained from the observation of an EDM ?
- EDM connections with other leptonic dipoles (MDM, LFV, ...)?
- EDM interplay with direct searches at LHC ?

L. Di Luzio, talk at this workshop

[Courtesy of A. Keshavarzi]





Blum, Winter Snowmass 2021 arXiv 2209.08041

The impressive potentialities to explore the "UNKNOWN" BSM physics through the study of the EDMs

many recent *advances in experimental techniques and technologies* + (experimental as well as **theoretical**) *synergies* with adjacent areas of particle physics (atomic, molecular, optical, nuclear, particle physics)

- New science opportunities in the (experimental and theoretical) current and near-future exploration of EDMs for various physical systems : electron, muon, tau neutron, proton, atom, molecule
- Coordinated program (with different scientific communities) of complementary EDM searches in AMO (Atomic Molecular Optical), NUCLEAR and PARTICLE physics
- An exceptionally sensitive way to explore the NEW source(s) of CP VIOLATION necessary to develop a cosmic asymmetry between matter and anti-matter starting with a symmetric early universe
- Feasible to achieve in a few years relevant improvements (from one to even 3-4 orders of magnitude) on EDM sensitivities in particular AMO physics considers it realistic to achieve 1, 2-3, 4-6 orders of magnitude improvements in the few, 5-10 and 15-20 year time-scales, respectively

Blum, Winter Snowmass 2021 arXiv 2209.08041

Report of the 2023 P5 (Particle Physics Project Prioritization Panel)

Charged Lepton Flavor Violation (CLFV)

CLFV not observed yet → any CLFV observation would be a clear sign of New Physics → a portal to High-Energy (GUT-scale?) NP or Low-Energy (feebly coupled) NP



Muon CLFV searches \rightarrow a global experimental (and theoretical) program underway in EU, US and Asia \rightarrow impressive sensitivity gains expected in this decade, with up to 4 orders of magnitude improvements in the rate of μ N \rightarrow e N conversion and μ $^+ \rightarrow$ e e e decay serasches



Observable

Snowmass Report of the Frontier for Rare Processes and Precision Measurements arXiv 2210.04765

The (vanishing) OLD and the (still existing) NEW muon g-2 puzzle



Model independent tests of the HVP contribution to the muon g-2



Di Luzio, Keshavarzi, A.M., Paradisi Phys.Rev.Lett. 134 (2025) 1, 011902

LFV, (g – 2)_{lept} and (EDM)_{lept} correlations in Effective Theories

Giudice, Paradisi and Passera JHEP 2012

• BR $(\ell_i
ightarrow \ell_j \gamma)$ vs. $(g-2)_{\mu}$

$$BR(\mu \to \boldsymbol{e}\gamma) \approx 3 \times 10^{-13} \left(\frac{\Delta a_{\mu}}{3 \times 10^{-9}}\right)^2 \left(\frac{\theta_{e\mu}}{10^{-5}}\right)^2$$
$$BR(\tau \to \mu\gamma) \approx 4 \times 10^{-8} \left(\frac{\Delta a_{\mu}}{3 \times 10^{-9}}\right)^2 \left(\frac{\theta_{\mu\tau}}{10^{-2}}\right)^2$$

EDMs vs. (g − 2)_µ

$$d_e \simeq \left(\frac{\Delta a_{\mu}}{3 \times 10^{-9}}\right) 10^{-29} \left(\frac{\phi_e^{CPV}}{10^{-5}}\right) e \,\mathrm{cm}\,,$$

$$d_{\mu} \simeq \left(\frac{\Delta a_{\mu}}{3 \times 10^{-9}}\right) 2 \times 10^{-22} \phi_{\mu}^{CPV} e \,\mathrm{cm}\,,$$

Main messages:

- ► $\Delta a_{\mu} \approx (3 \pm 1) \times 10^{-9}$ requires a nearly flavor and CP conserving NP
- ▶ Large effects in the muon EDM $d_{\mu} \sim 10^{-22} \ e \ {
 m cm}$ are still allowed!

Paradisi, muEDM Workshop Pisa, 2022

$$\frac{\Delta a_e}{\Delta a_{\mu}} = \frac{m_e^2}{m_{\mu}^2} \qquad \Longleftrightarrow \qquad \Delta a_e = \left(\frac{\Delta a_{\mu}}{3 \times 10^{-9}}\right) 0.7 \times 10^{-13}$$

A Scientific Mission for the 21st Century Rende Steerenberg ICHEP 2024

LHC Run 2 2014-2018 13 TeV 100% to 2x Nom. Lumi, PU 40 Int. Lumi. 190 fb-1 Higgs couplings to Fermions of the third generation (top, bottom		HL-LHC (Runs 4-6) 2029-2041 13.6 - 14 TeV and 2x Nominal Luminosity, PU 140 - 200 Int. Lumi. 3000 fb-1 di-Higgs boson production and Higgs self coupling and precision Higgs physics!		time sc	ale !	
LS2		CLIC 38	380 GeV- 3 TeV			
2018-2022 Experiments Phase-I		ILC 250	C 250 GeV - 1 TeV			
and accelerator upgrades		Cool Co	Cool Copper Collider 250 - 550 GeV			
2010 202	0	2030	2040	2050	2060	2070
$\rangle \rangle$	\rightarrow	\rangle	\rangle	\rightarrow	\rightarrow	
LS1 2012-204 Consolidation of LHC interconnections	LS3 2026-20 installatio upgrades	29 HL-LHC n and major exp. S CepC 90	FCC-ee - 240 GeV	90 - 265 GeV SppC		FCC-hh 100 TeV
LHC Run 1 2009-2012 7-8 TeV 75% Nom. Lumi, PU 30-40 Int. Lumi. 30 fb-1	LHC Run 3 2022-2026 13.6 TeV 2x Nom. Lumi., PU 60 Int. Lumi. 450 fb-1			Muon Collider		
Discovery of the Higgs H Boson, measurements of F Higgs Boson couplings to g bosons (gluons, photons, n W and Z)	liggs couplings to Fermions of the second generation (muons) and nore rare decays					
		LHC	Ultimate F	Precision e^+e^-	Ultimate	Energy (pp, $\mu^+\mu^-$)

some final thoughts ...

The experimental and theoretical precision physics community has entered an era of **unprecedented precision experiments**

SYNERGY between small/mid-scale & large-scale experiments → casting a wider and tighter net for possible effects of BSM physics Synergy among the various communities operating in precision physics in (very) different experimental, technological and theoretical environments

While relatively small in size and cost compared to their energy frontiers cousins, they are large in reach and discovery potential

These experiments are key to paradigm-shifting discoveries, both in their own right and as incubators for new technologies and physics directions

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