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

Some material for the discussion session

Antonio Masiero

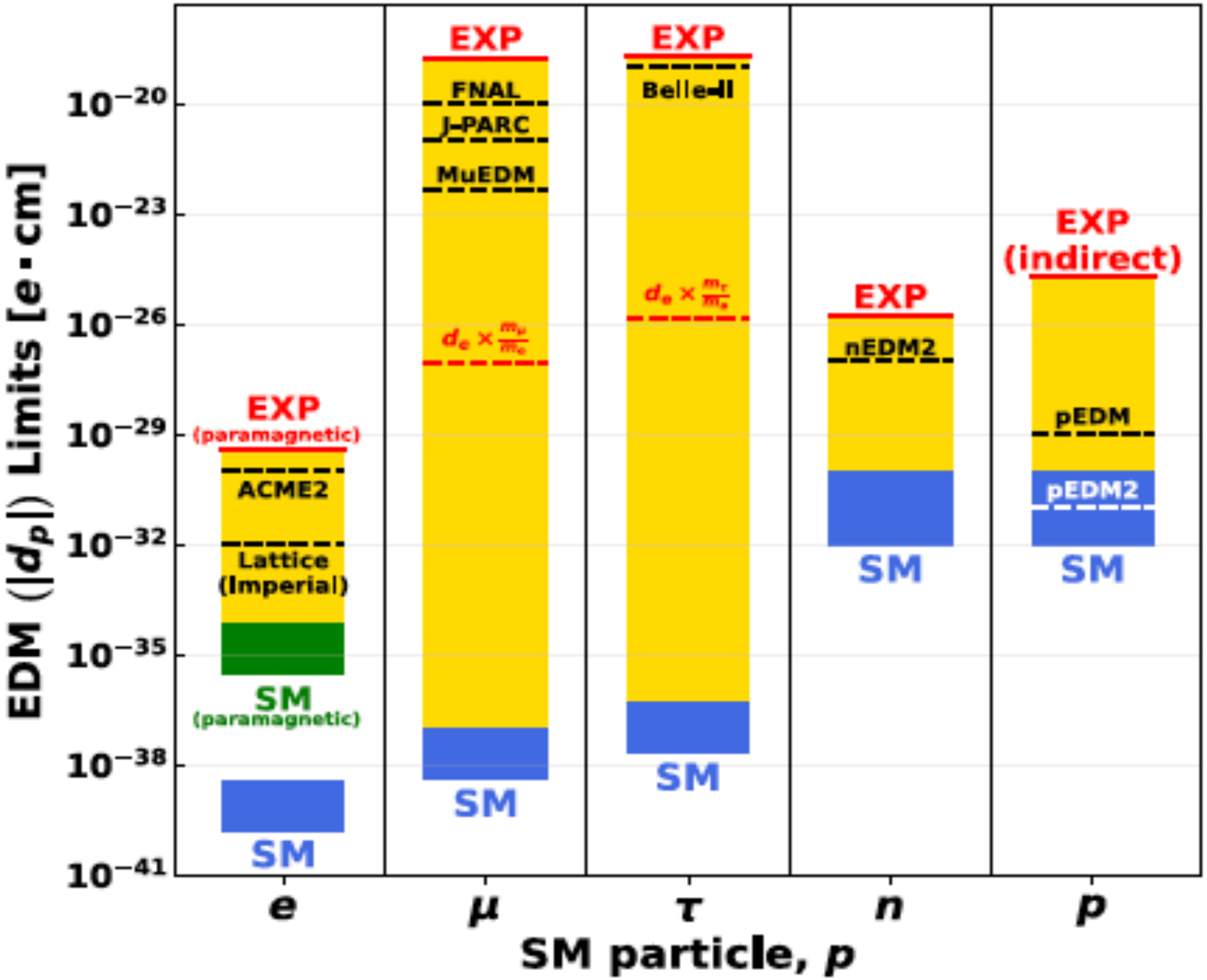
Univ. Padova and INFN, Padova Unit

Open questions

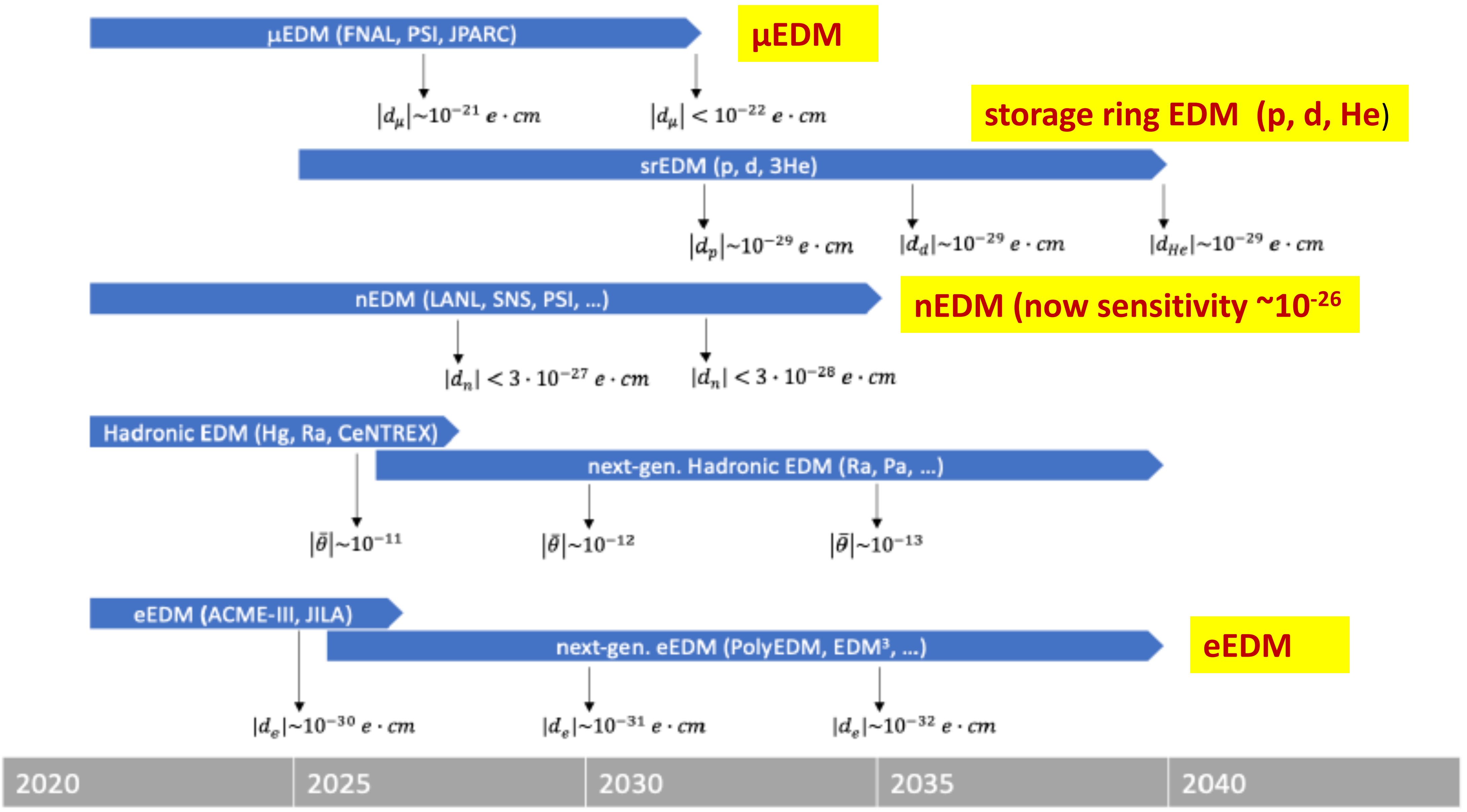
- Ultimate EDM experiments (electron and/or proton) to reach SM-CKM sensitivity ?
- Complementarity of EDMs to disentangle origin of CP violation ?
- What insights into baryogenesis can be gained from the observation of an EDM ?
- EDM connections with other leptonic dipoles (MDM, LFV, ...) ?
- EDM interplay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

L. Di Luzio, talk at this workshop

[Courtesy of A. Keshavarzi]



Electric Dipole Moments



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)

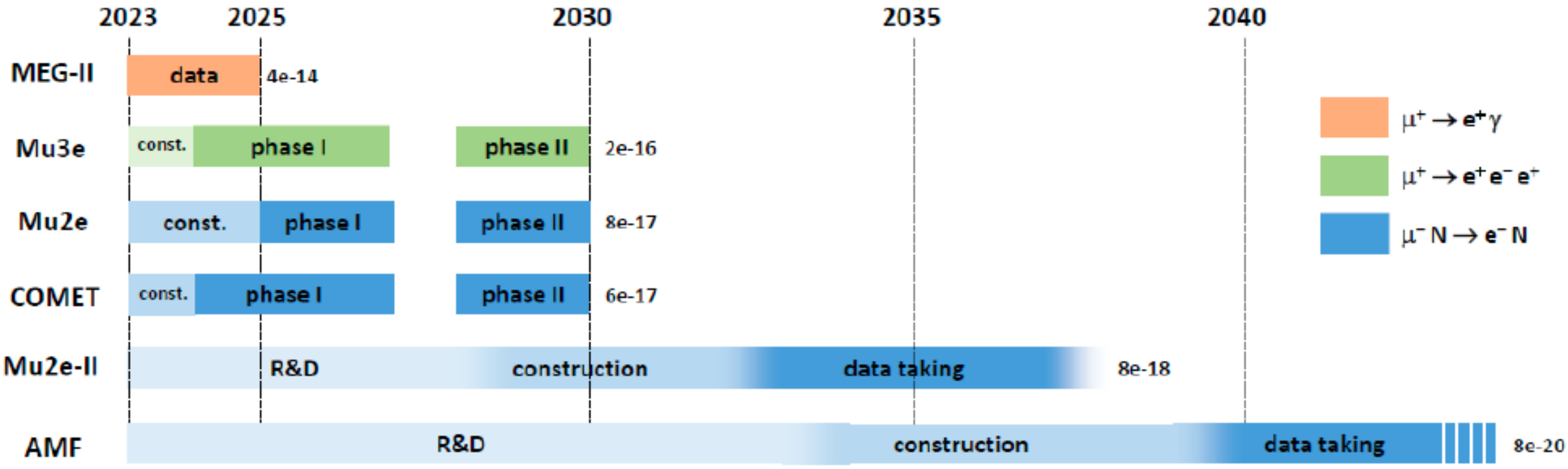
- **New science opportunities** in the (experimental and theoretical) current and near-future exploration of EDMs for various physical systems : **electron**, **muon**, **tau neutron**, **proton**, **atom**, **molecule**
- Coordinated program (with different scientific communities) of complementary EDM 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

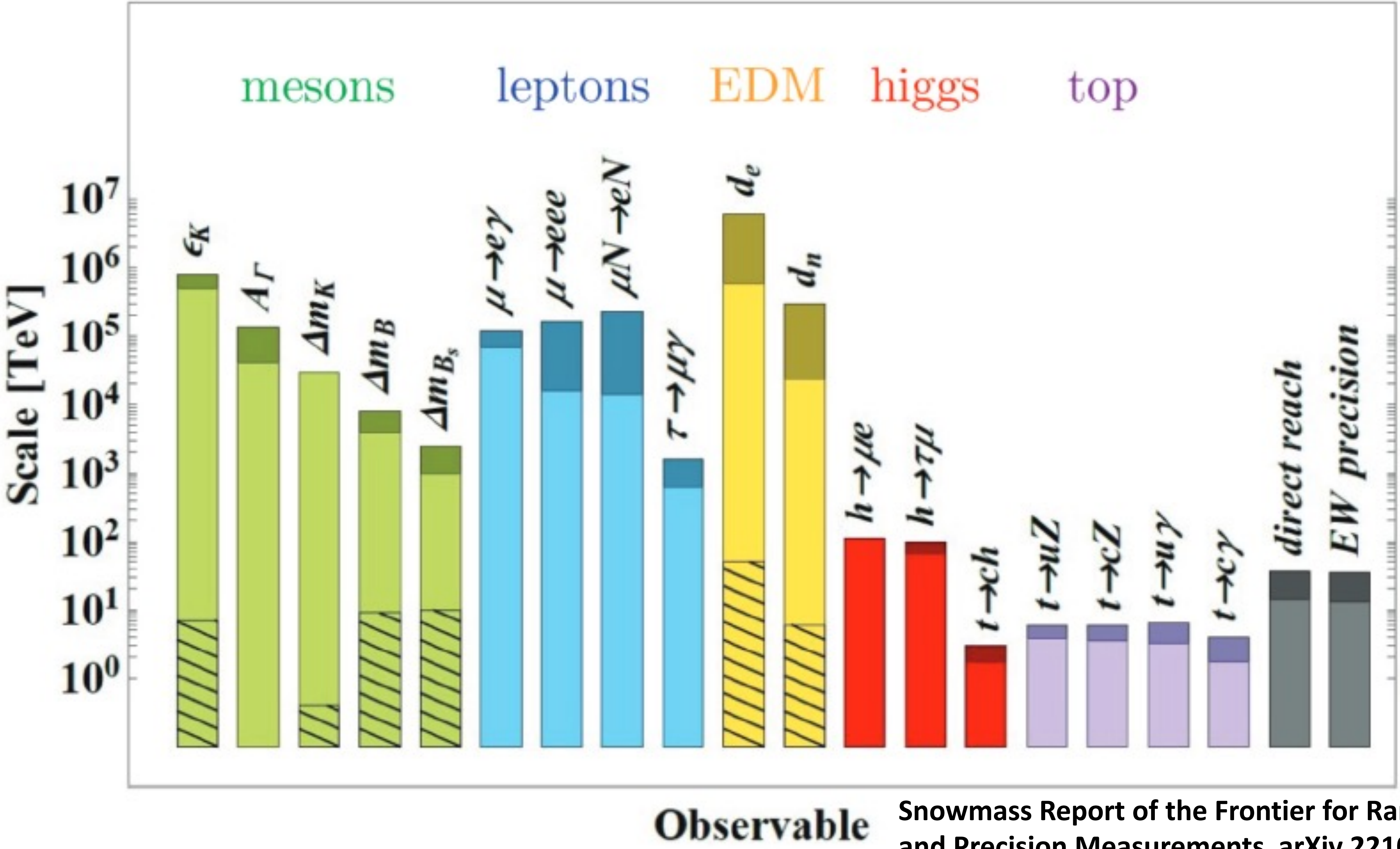
Report of the 2023 P5 (Particle Physics Project Prioritization Panel)

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

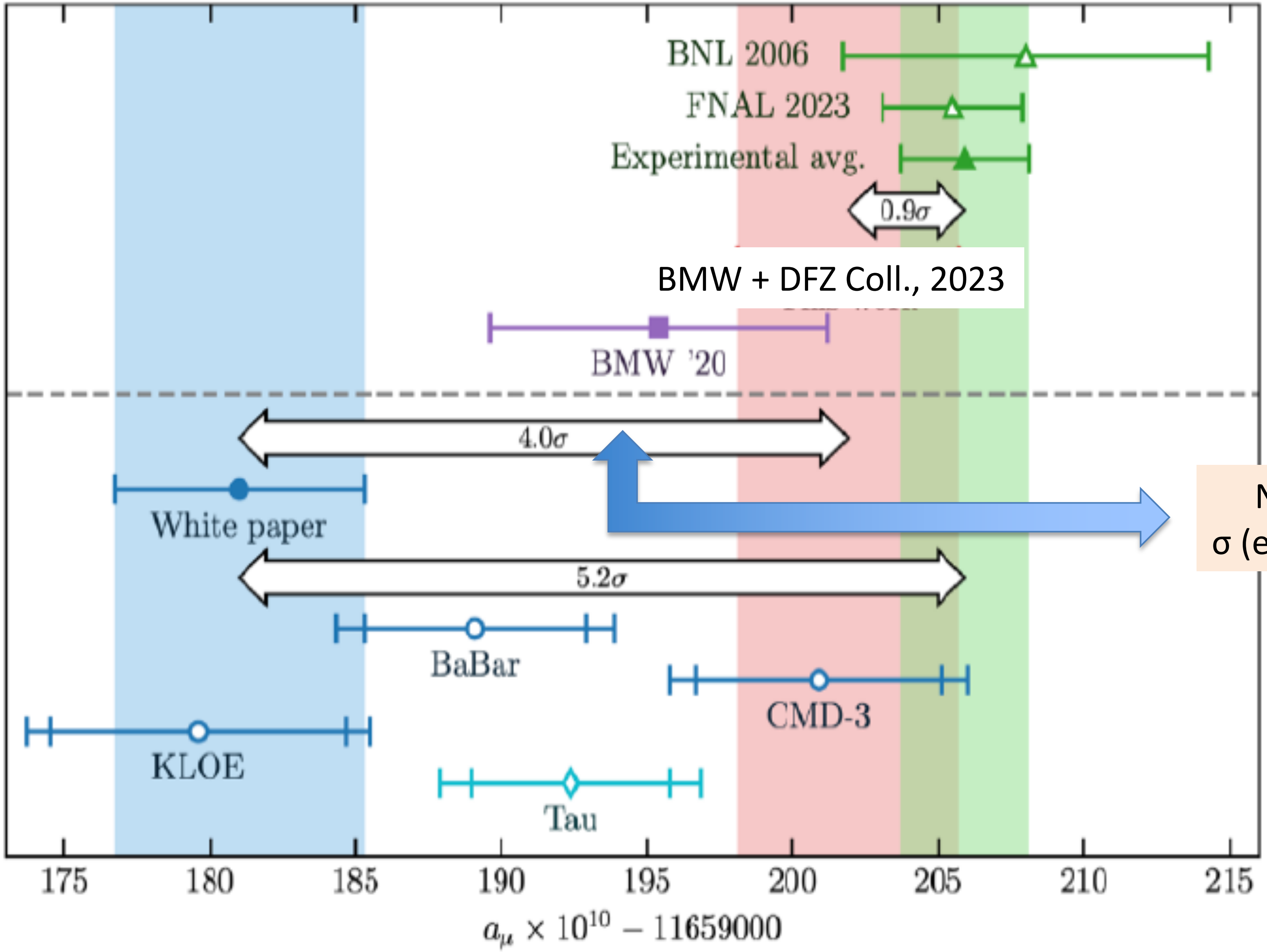


Muon CLFV searches → a **global experimental (and theoretical) program** underway in EU, US and Asia
→ **impressive sensitivity gains** expected in this decade, with up to **4 orders of magnitude** improvements in the rate of $\mu^- N \to e^- N$ conversion and $\mu^+ \to e^+ e^- e^+$ decay serasches



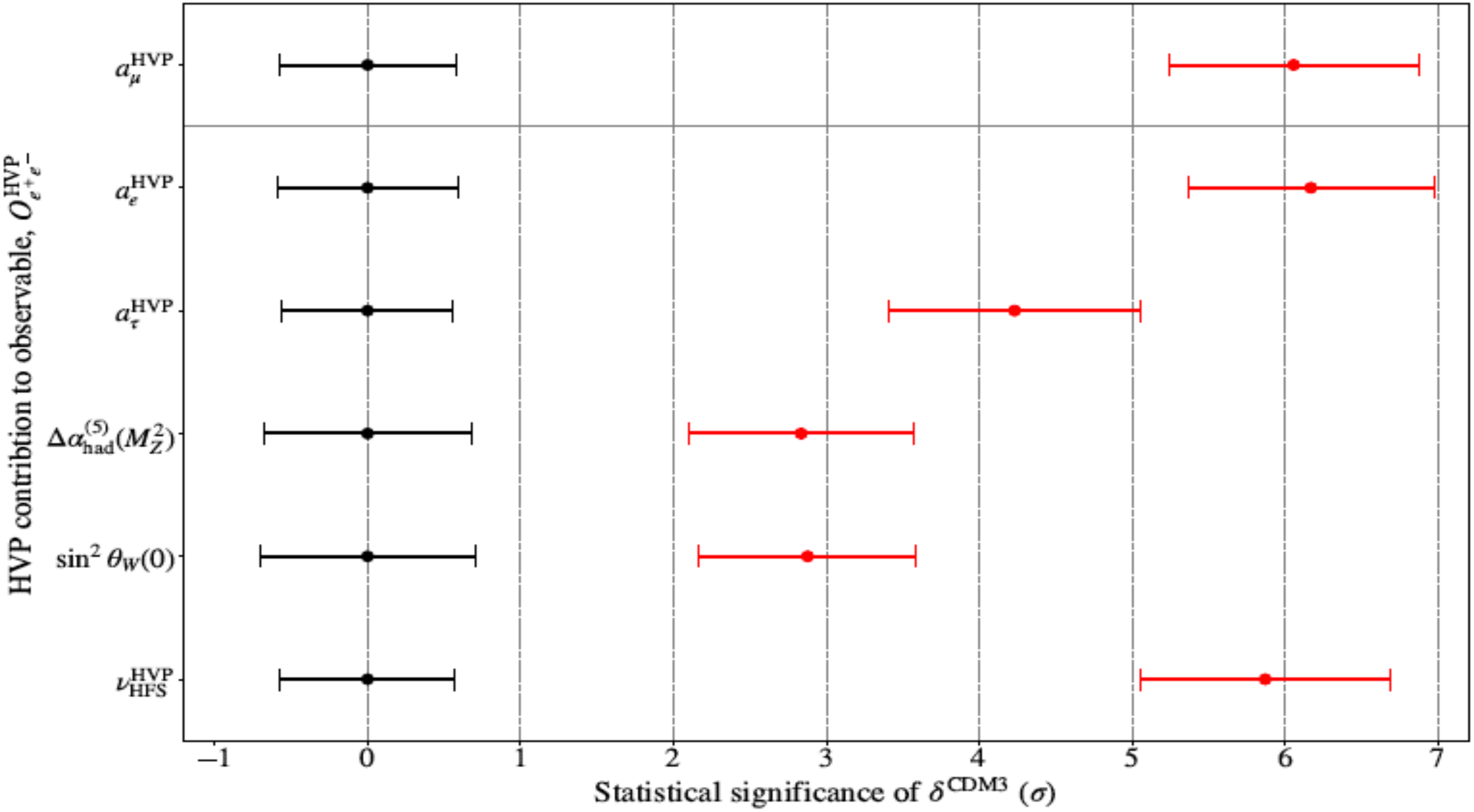
Snowmass Report of the Frontier for Rare Processes and Precision Measurements arXiv 2210.04765

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



New Physics in
$\sigma\,(e^+e^- \to \text{hadrons})$?

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

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

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

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

- EDMs vs. $(g-2)_\mu$

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

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

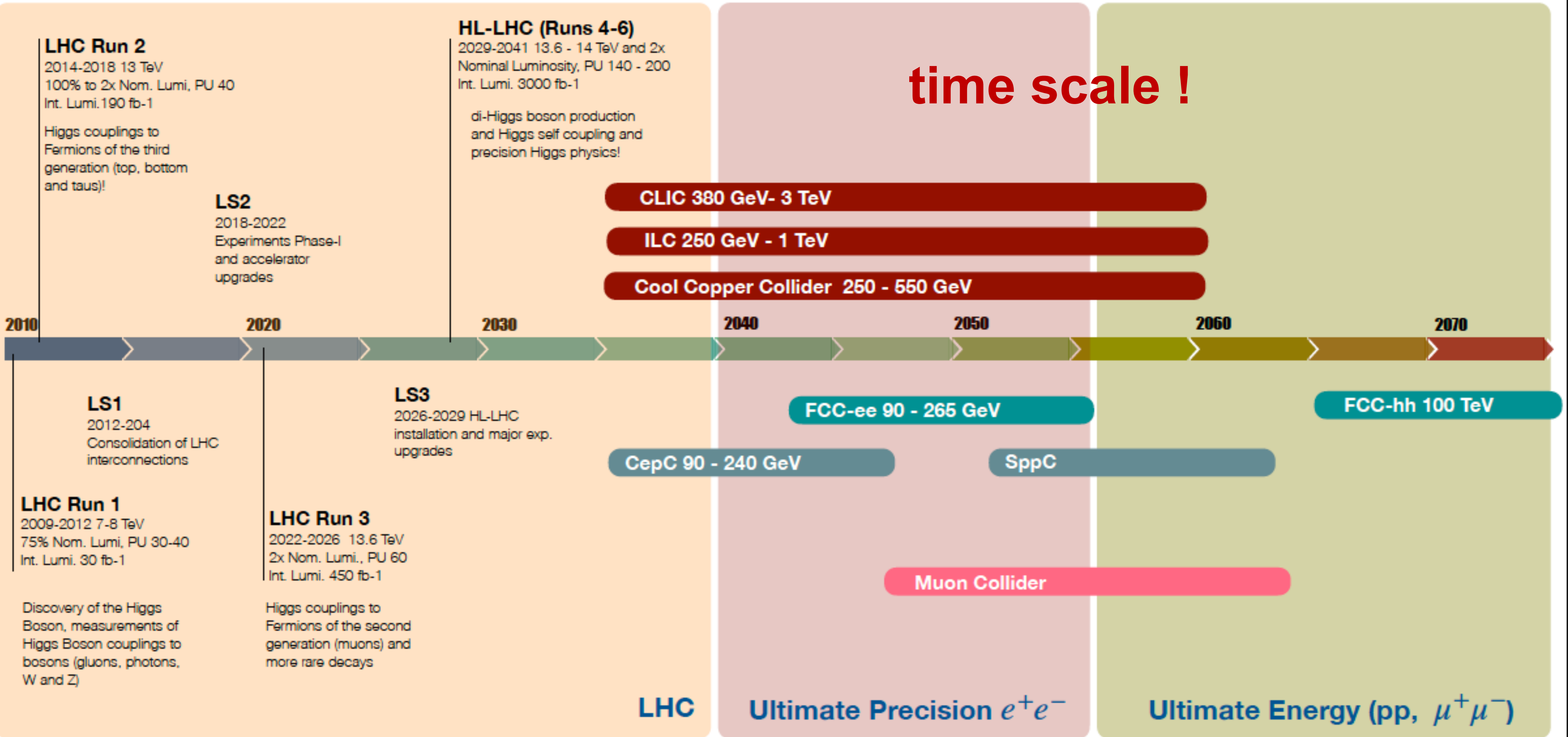
- Main messages:
  - $\Delta a_\mu \approx (3 \pm 1) \times 10^{-9}$ requires a nearly flavor and CP conserving NP
  - Large effects in the muon EDM $d_\mu \sim 10^{-22}\, e\,\mathrm{cm}$ are still allowed!

Paradisi, muEDM Workshop Pisa, 2022

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

A Scientific Mission for the 21st Century

Rende Steerenberg ICHEP 2024



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

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