Update the status of electron g-2

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1810.11028 [JHEP 1903 (2019) 008]
2001.06522 [JHEP 2004 (2020) 197]
2102.10118

缪子g-2非正式研讨会
04/13/2021 @ CHEP-PKU, Beijing

The muon Magnetic Dipole Moment

- The muon g-2 calculation

$$a_\mu^{\text{th}} = a_\mu^{\text{QED}} + a_\mu^{\text{Had}} + a_\mu^{\text{EW}}$$

  - Hadronic uncertainty dominated

$$a_\mu^{\text{Had}}(\text{vac pol}) = (688 \pm 4) \times 10^{-10}$$

$$a_\mu^{\text{Had}}(\gamma \times \gamma) \simeq 10 \times 10^{-10}$$

  - EW uncertainty

$$a_\mu^{\text{EW}} = (15.1 \pm 0.4) \times 10^{-10}$$

- Positive value and a 4.2 σ (Fermilab + BNL) PRL 126.141801 (2021)

$$\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{th}} = (25.1 \pm 5.9) \times 10^{-10}$$

- The difference is close to EW contribution suggesting New Physics at the Weak scale: SUSY etc

The electron Magnetic Dipole Moment

- The electron g-2 calculation

$$a_e^{\rm th} = a_e^{\rm QED} + a_e^{\rm Had} + a_e^{\rm EW}$$

  - QED up to 10th order

$$(\alpha/\pi)^5 \sim 7 \times 10^{-14}$$

  - EW and Had (light-light) are small due to small m_e

$$a_e^{\rm th} = (115965218164.3 \pm \mathbf{2.5} \pm \mathbf{2.3} \pm \mathbf{1.6} \pm \mathbf{76.3}) \times 10^{-14}$$

QED **Had (l-l)+EW** α

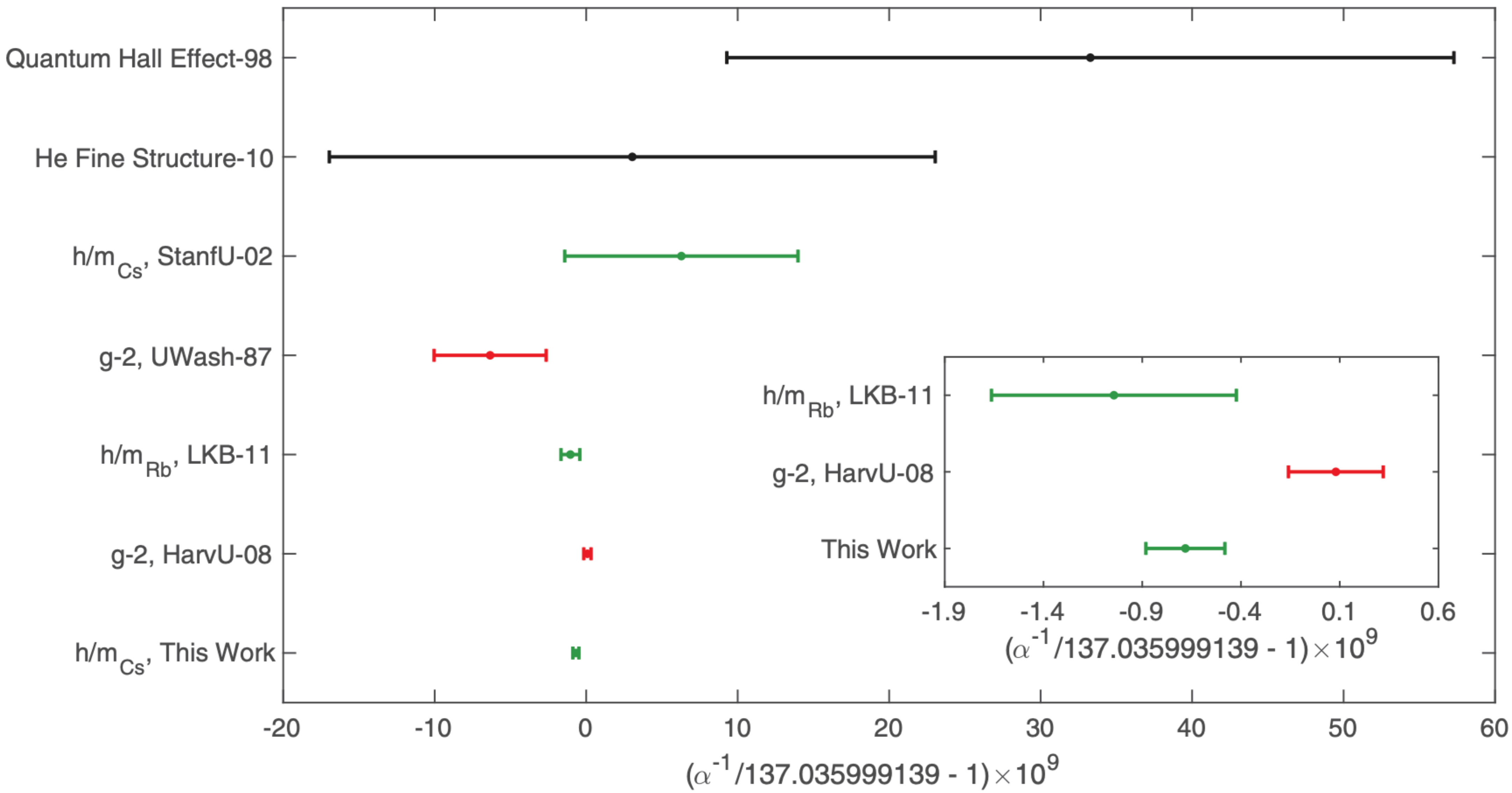
Aoyama et al 1412.8284, old fine structure constant from Rb measurement

- Fine structure constant induces the largest uncertainty for a_e
- Fine structure constant calculated via a_e has better uncertainty than direct measurement.

The electron MDM at 2018

- The most recent fine structure constant measurement

Parker et al., Science 360, 191–195 (2018)



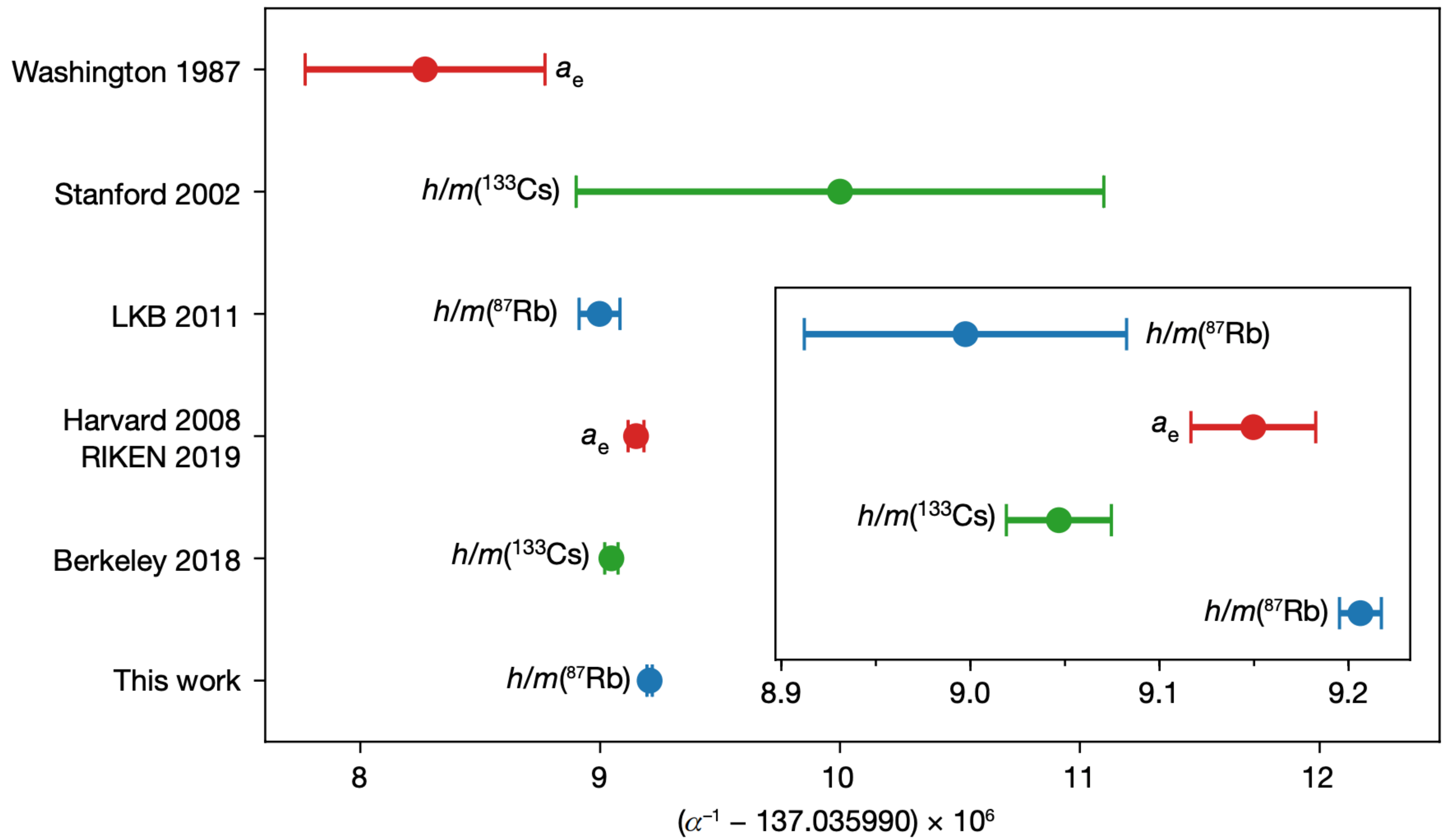
$$\Delta a_e = a_e^{\rm exp} - a_e^{\rm th} = (-88 \pm 36) \times 10^{-14}$$

- Negative value and a (- 2.4 σ) discrepancy

The electron MDM at 2020

- The most recent fine structure constant measurement

Morel et al., Nature 588, 61–65 (2020)



$$\Delta a_e = a_e^{\mathrm{exp}} - a_e^{\mathrm{th}} = (48 \pm 36) \times 10^{-14}$$

- Positive value and a (+ 1.6 σ) discrepancy
- **A 2.4 discrepancy with its own result in 2011!**

The status of electron MDM

Morel et al., Nature 588, 61–65 (2020)

- Morel et al 2020: 2.4 σ discrepancy with its own 2011 result
  - Nonlinearity in the delay of the optical phase-lock loop induces a residual phase shift that is measured and corrected for each spectrum. These systematic effects were not considered in our previous measurement (see Fig. 1), which could explain the 2.4σ discrepancy between that measurement and the present one

- Morel et al 2020: two experiments have discrepancy larger than 5 σ
  - Our result improves the accuracy on α by a factor of 2.5 over the previous caesium recoil measurement but, most notably, it reveals a 5.4σ difference from this latest measurement.

The status of electron MDM

Holger Muller., Nature, News and Views 02 Dec 2020

- Holger Muller 2020 article: Standard model of particle physics tested by the fine-structure constant
  - They suggest the difference between their research group's own measurements could be caused by speckle — small-scale spatial variations of the laser intensity — or by a phase shift arising in electronic-signal processing.
  - Morel and colleagues also leave open the reason for the disparity with the 2018 measurement. The two experiments differ in the use of rubidium versus caesium atoms, in the types of atom–light interaction used and in how the laser beams are prepared and aligned. These choices imply different influences of the environment on the atoms.
  - For example, the largest corrections applied to data taken in both experiments arise from the laser beams. Both the speckle mentioned earlier and the overall beam profiles affect the magnitude and direction of the atom recoil.
  - The discrepancy between the results could be explained if my team had over-corrected for these effects or Morel *et al.* had under-corrected.

A combined explanation for e/mu g-2?

$$\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm th} = (27.4 \pm 7.3) \times 10^{-10}$$
$$\Delta a_e = a_e^{\rm exp} - a_e^{\rm th} = (-88 \pm 36) \times 10^{-14}$$

- Possible solutions for negative and sizable a_e correction

Ya-dong Yang, Xin-qiang Li etc; Tianjun Li; Taifu Feng, Haibin Zhang etc; Tong Li; Xiaofang Han, Lei Wang etc; Xiao-gang He etc;

  - Higher order operator: 2-loop Barr-Zee
  - Heavy leptons
  - Charged Higgs/2HDM
  - Chargino-sneutrino/bino-slepton
  - Leptoquark with mixed chirality
  - A light complex scalar for e/mu g-2

JL, C. Wagner, X.P. Wang, JHEP 1903 (2019) 008

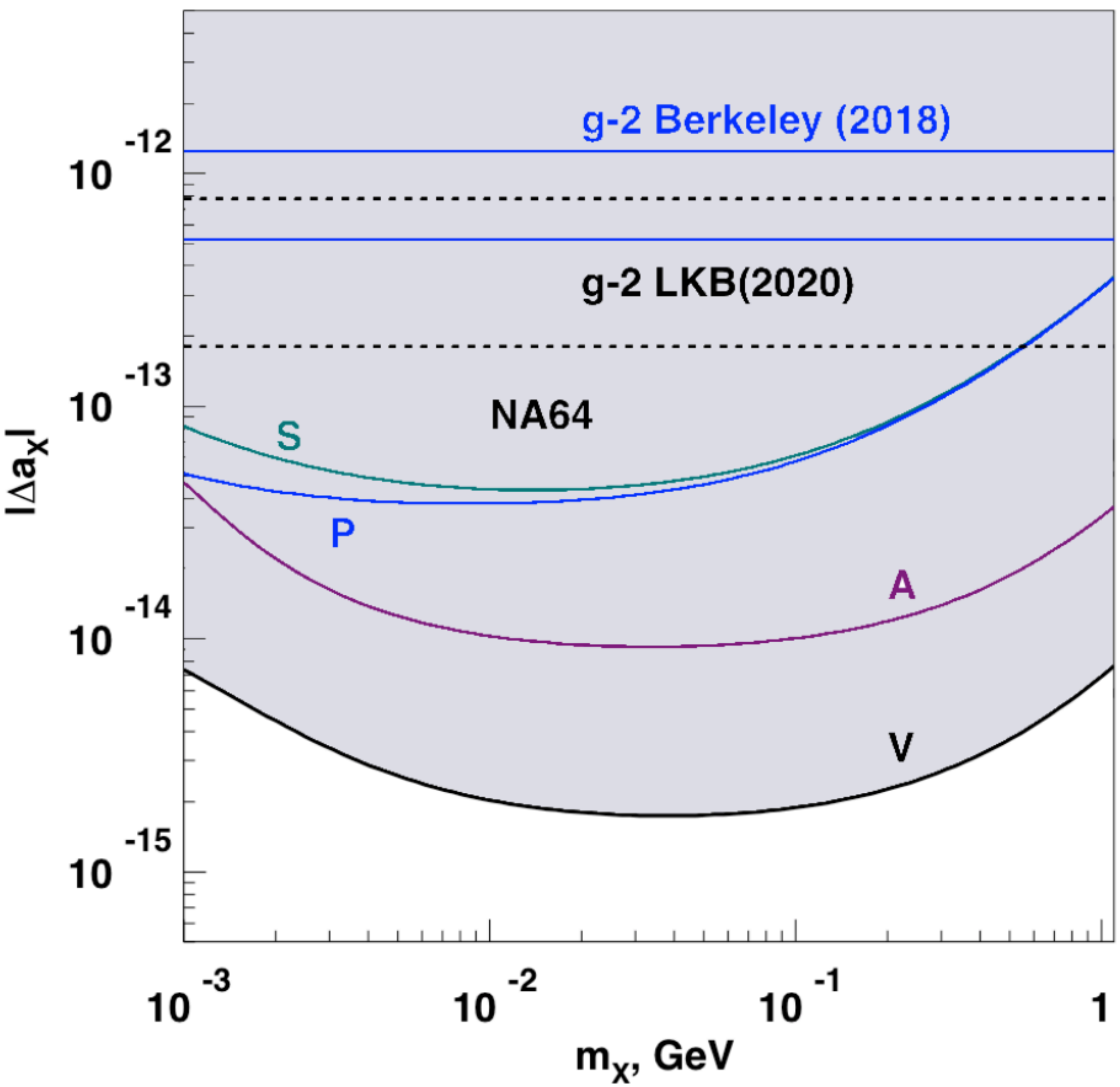
JL, N. McGinnis, C. Wagner, X.P. Wang, 2102.10118

JL, N. McGinnis, C. Wagner, X.P. Wang, JHEP 2004 (2020) 197

The electron MDM constraints

- Scalar, PS, Vector, Axial-V

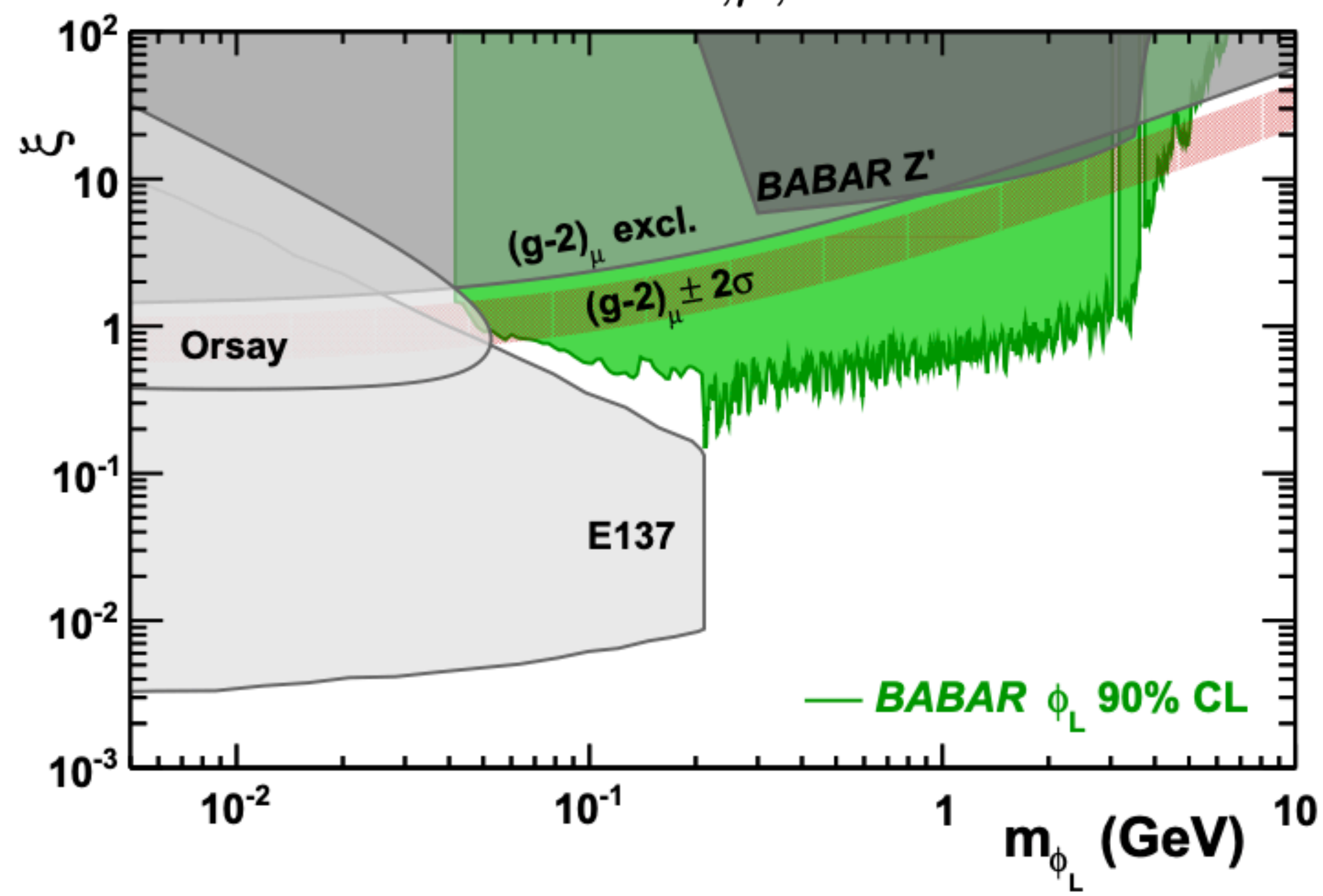
$$g_S\bar{e}eS, ig_P\bar{e}\gamma_5 eP, g_V\bar{e}\gamma_\mu eV^\mu, g_A\bar{e}\gamma_\mu\gamma_5 eA^\mu$$



NA64: 2102.01885

- For a SM-like scalar

$$\mathcal{L} = -\xi \sum_{\ell=e,\mu,\tau} \frac{m_\ell}{v} \bar{\ell}\,\phi_L \ell,$$



BaBar: PRL 125 (2020), 181801

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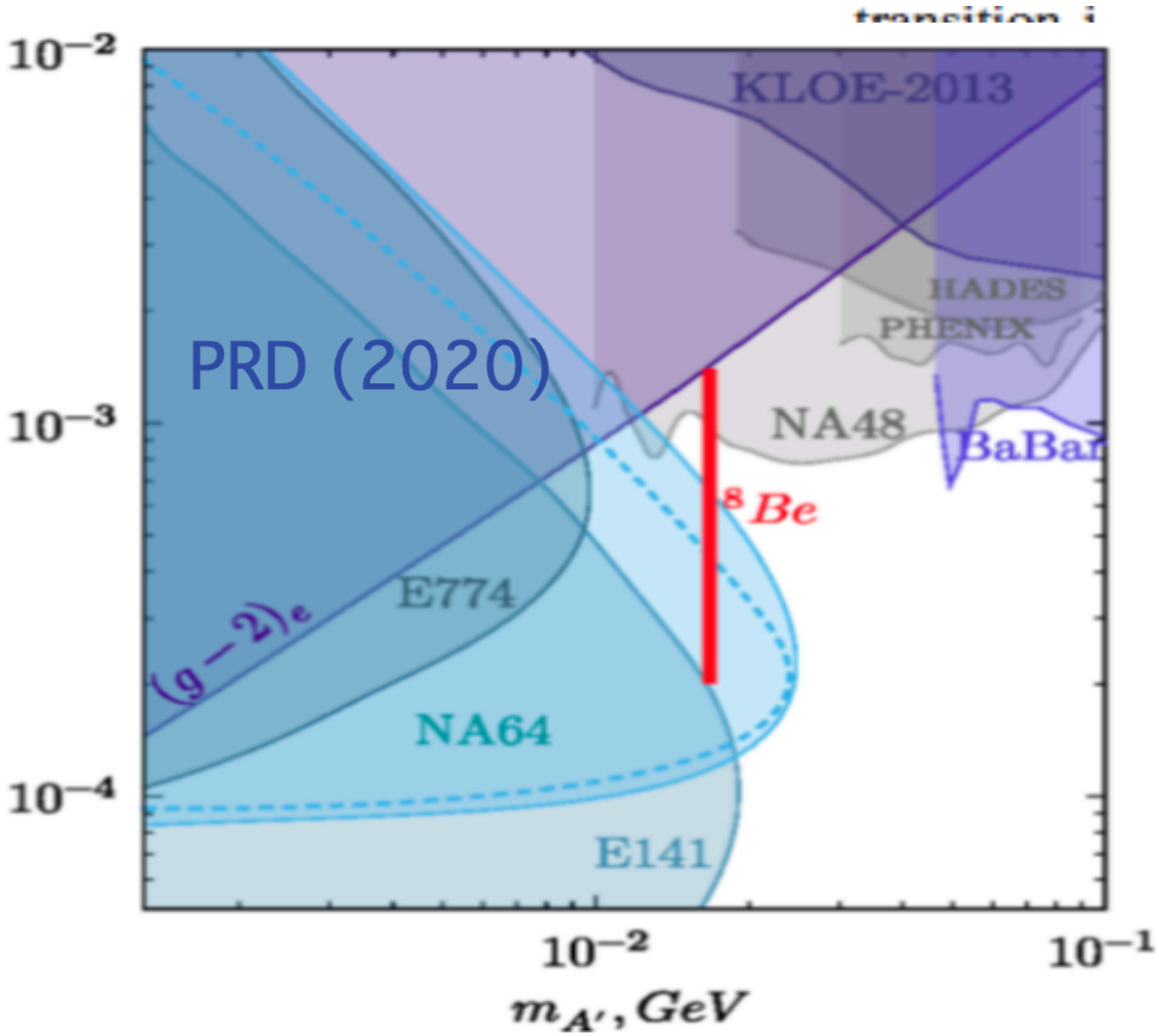
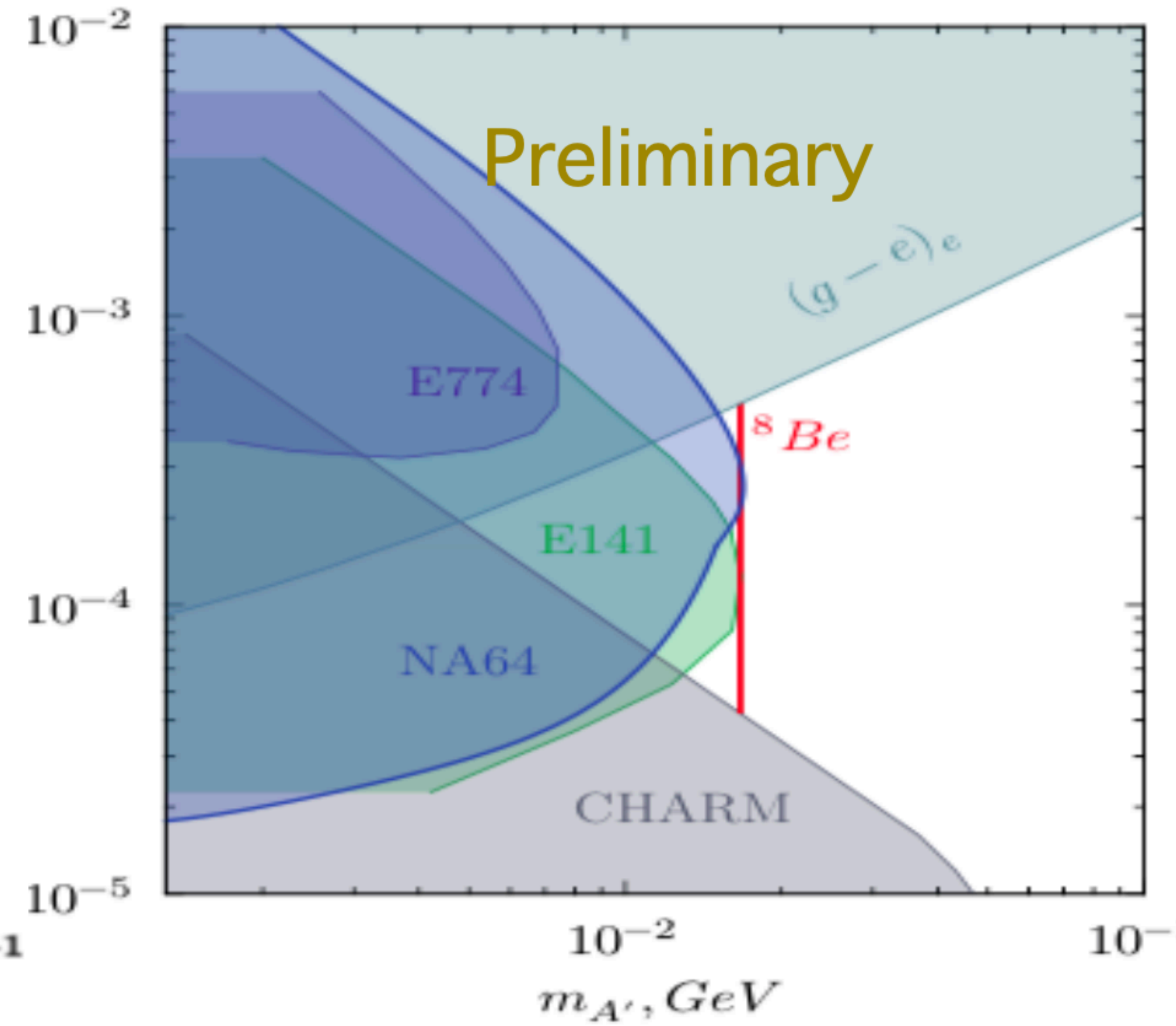


X17(V)



X17(P)

- Pseudo-scalar is still not excluded for mass > 10 MeV

NA64 S.N. Gninenko@ Physics Beyond Colliders workshop, March 1-4, 2021

Summary

- If there is an electron g-2 anomaly still needs future experiments to decide
- 2020 and 2018 experiment 5 σ discrepancy may come from corrections in the laser beams
- Scalar and pseudo-scalar coupling to electron g-2 is still viable for mass > 10 MeV, and is less constrained comparing with vector and axial-vector

Thank you!