Using lattice QCD for the hadronic contributions to the muon g-2

A. Bazavov, C. DeTar, A.X. El-Khadra, E. Gamiz, Z. Gelzer, ***S. Gottlieb***, U.M. Heller, W.I. Jay, A.S. Kronfeld, S. Lahert, J. Laiho, P.B. Mackenzie, E.T. Neil, R. Sugar, J.N. Simone, D. Toussaint, R.S. Van de Water, A. Vaquero

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Physics/Basic Idea

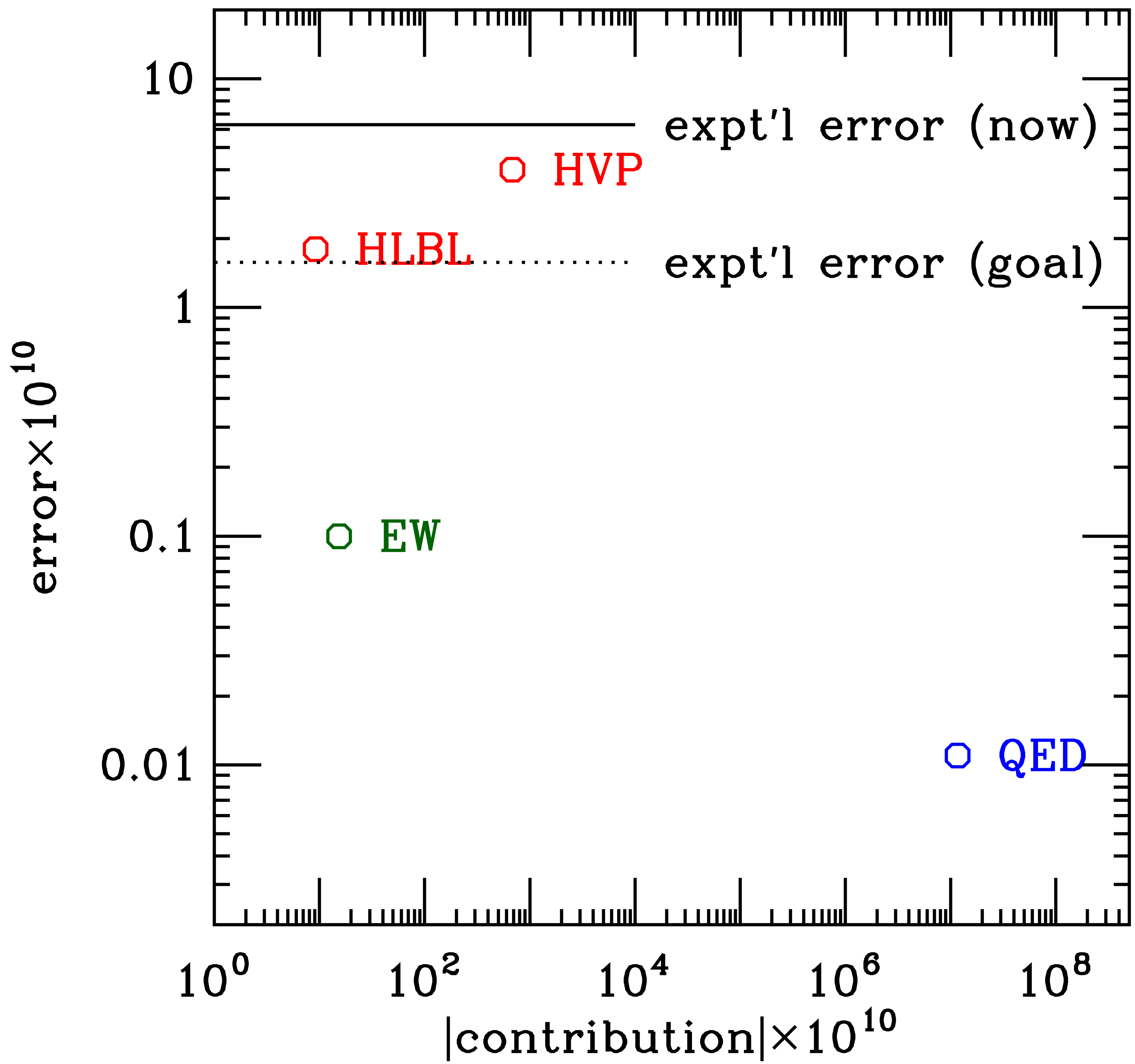
- ✦ Lattice QCD calculations of Standard Model contribution to anomalous magnetic moment are important for interpretation of the upcoming more precise measurements
- ✦ These techniques are also important in flavor physics
- ✦ Strong overlap with Computational Frontier

Summary Table (2006:04822)

Contribution	Value $\times 10^{11}$	References
Experiment (E821)	116 592 089(63)	Ref. [1]
HVP LO (e^+e^-)	6931(40)	Refs. [2–7]
HVP NLO (e^+e^-)	−98.3(7)	Ref. [7]
HVP NNLO (e^+e^-)	12.4(1)	Ref. [8]
HVP LO (lattice, *udsc*)	7116(184)	Refs. [9–17]
HLbL (phenomenology)	92(19)	Refs. [18–30]
HLbL NLO (phenomenology)	2(1)	Ref. [31]
HLbL (lattice, *uds*)	79(35)	Ref. [32]
HLbL (phenomenology + lattice)	90(17)	Refs. [18–30, 32]
QED	116 584 718.931(104)	Refs. [33, 34]
Electroweak	153.6(1.0)	Refs. [35, 36]
HVP (e^+e^-, LO + NLO + NNLO)	6845(40)	Refs. [2–8]
HLbL (phenomenology + lattice + NLO)	92(18)	Refs. [18–32]
Total SM Value	116 591 810(43)	Refs. [2–8, 18–24, 31–36]
Difference: $\Delta a_\mu := a_\mu^{\text{exp}} - a_\mu^{\text{SM}}$	279(76)	

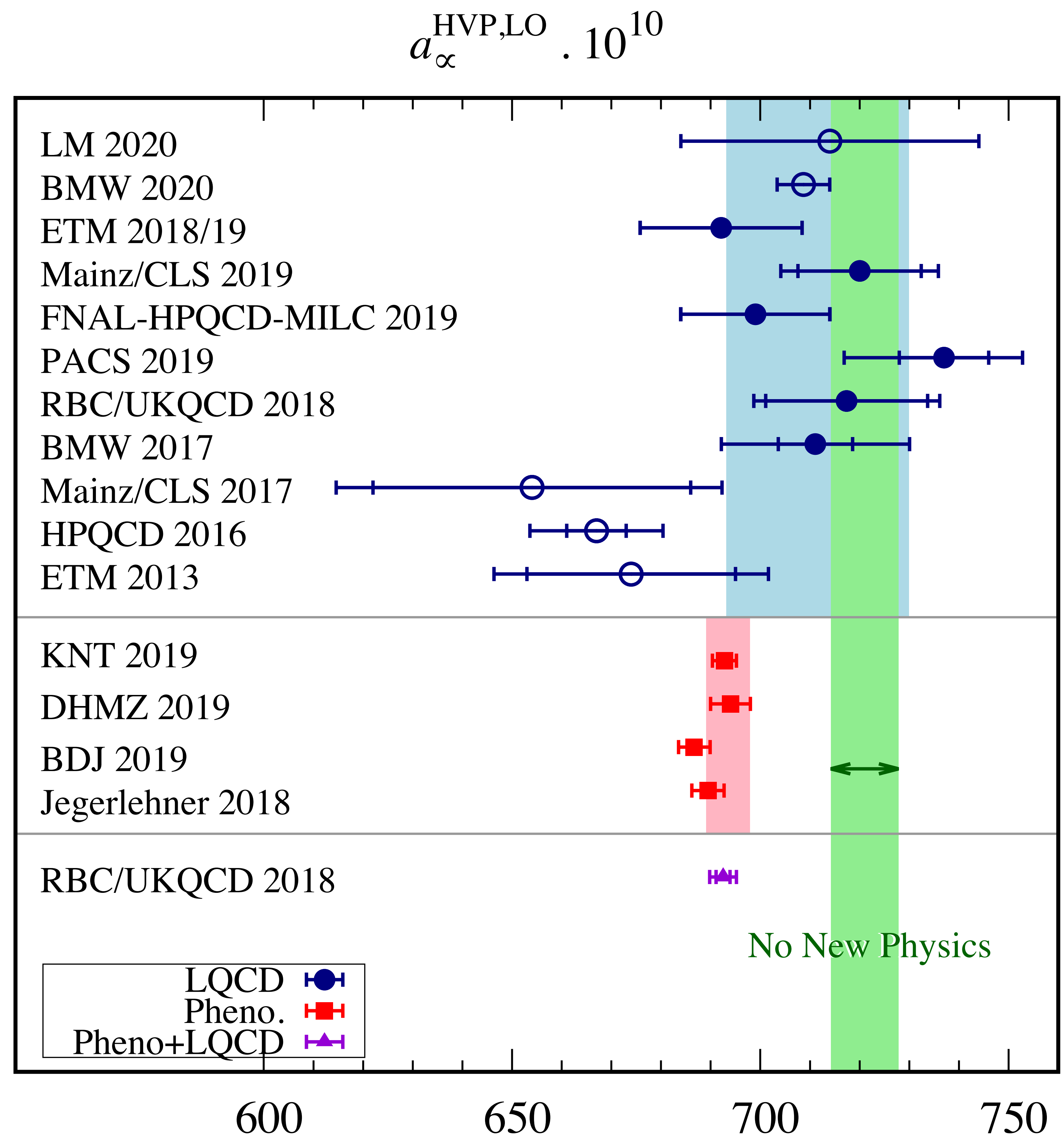
Error vs. Contribution

- QED in blue has very small error
- Electroweak in green has larger error, but small contribution
- Hadronic contributions are both in red
  - LO Hadronic vacuum polarization largest error and 2nd largest contribution
  - HLBL 2nd largest error



HVP Summary

- Fermilab Lattice/ HPQCD/MILC are calculating HVP contribution, the major source of error
- Dispersive error (pink) about 0.6%
- Would like to reduce lattice QCD error to <1% (currently about 2% except for BMW2020)



What is required to succeed?

- ✦ We will need additional computing time on next generation computers
  - Perlmutter (NERSC)
  - Aurora (ALCF)
  - Frontier (ORNL)
  - Frontera (TACC) is currently running
  - New NSF funded computers at NCSA, elsewhere
- ✦ Software development may also be needed to optimize code on new computers and improve algorithms
- ✦ Some details on next slides

Lattice HVP Error Sources

- ✦Main current sources of error in FNAL/HPQCD/MILC connected HVP calculation:
  - Lattice spacing uncertainty: 0.8%
  - Monte Carlo statistics: 0.7%
  - Continuum extrapolation: 0.7%
  - Finite-volume & discretization corrections: 0.6%
    - Will update at HVP workshop in November
- ✦Other sources of error:
  - Disconnected diagrams [Lattice 19 proceedings; arXiv:1912:04382]
  - Isospin breaking [PRL 120 (2018) 15; arXiv:1710,11212]
  - QED corrections [in progress]
- ✦We are working on calculations/projects to address all these issues. Goal is HVP error <1%.

Longer Term Opportunities

- ✦ Producing dynamical QED+QCD ensemble
  - Also useful for our flavor physics calculations where QED corrections are next step needed for increased precision.
- ✦ Working on determinant reweighting method for lowest order QED correction
  - Also potentially useful for flavor physics
- ✦ In addition to 2-point correlators looking at 2,3,4-point correlators with up to 2 pions in initial and final states to better reconstruct tail of vector-current correlator.
  - First calculation with staggered multi-hadron operator done at physical quark masses
  - Tests noise reduction strategy and finite volume corrections
  - This lays groundwork for new calculations such as weak decays with resonance in final state

What do we plan to do during Snowmass?

- Continue above calculations and update results by summer 2021 for next white paper
- Personally, help lead Computational Frontier

What do we hope to get from Snowmass?

- Strong statements of support for Computational Frontier and Theory Frontier resulting in adequate future funding

Muon g-2 Theory Initiative

- ✦ Started in 2017, several of us are involved
- ✦ Comprehensive, collaborative approach to providing timely theoretical input for interpretation of new experimental results
  - Both dispersive and lattice QCD approaches are considered
  - Covers hadronic vacuum polarization and hadronic light-by-light contributions
- ✦ Initial paper to be published in Physics Reports (very soon)
  - arXiv:2006:04822, T. Aoyama et al.
- ✦ Initiative will continue its work and plans to update theory results ahead of each major experimental update
  - Focused workshops provide opportunity for detailed cross checks among various approaches and groups
  - Also provides opportunity for interaction with experimentalists