Status of the RBC/UKQCD HVP program

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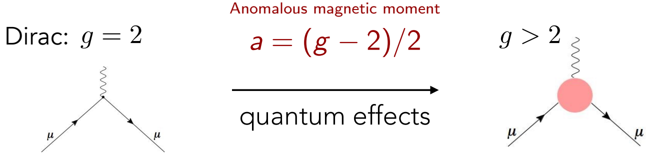
The magnetic moment and quantum corrections

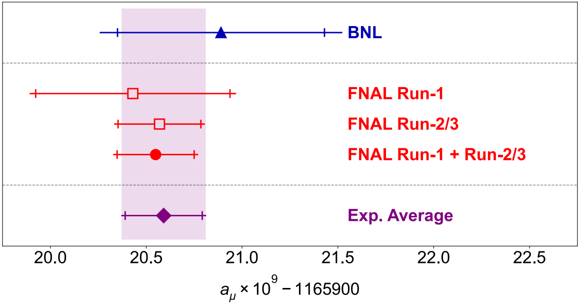
The g-factor in $\vec{\mu} = g\left(\frac{e}{2m}\right)\vec{S}$ describes the strength of coupling to a magnetic field, which can be measured and computed from theory **very** precisely.

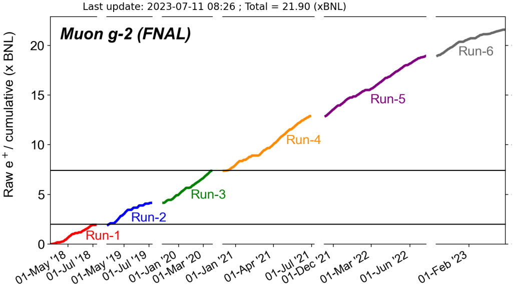


The quantum effects arise from virtual particle contributions from all known **and unknown** particles.

By comparing high-precision experiments and theory, we have the potential to learn about such contributions of new particles.

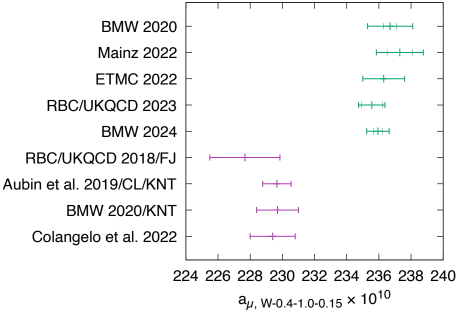
Experimental status (PRL 131 (2023) 16, 161802)

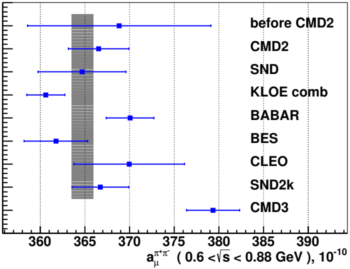




Standard model theory is work in progress

- Tensions for the intermediate window between lattice and e^+e^- data (minus CMD3) clearly established. Tensions within e^+e^- data so far unresolved.

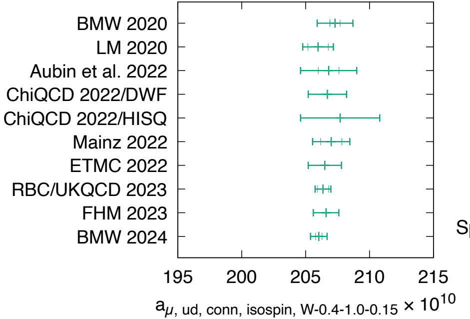


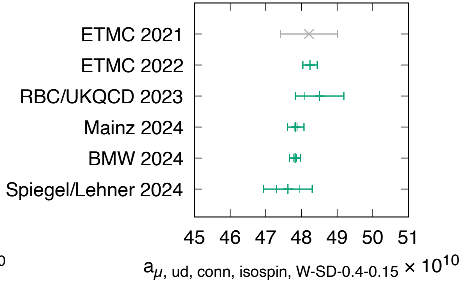


- There is a clear desire to have full first-principles lattice QCD result with competitive precision (final goal is below 2/1000 relative error).
- Alternative idea suggested in RBC/UKQCD18: if data and lattice agrees, can supplement lattice data at long distances by dispersive results. Picked up by BMW24 paper for tail beyond 2.8 fm (5/100 of total).

Establishing lattice QCD at per-mille level precision

- Follow RBC/UKQCD18 strategy to split into Euclidean windows and compute short-distance ($a_\mu^{\rm SD}$ up to 0.4 fm), intermediate distance ($a_\mu^{\rm W}$), and long-distance ($a_\mu^{\rm LD}$ beyond 1.0 fm) separately.
- For isospin-symmetric light-quark connected (lqc) contributions, agreement for $a_\mu^{\rm SD}$ and $a_\mu^{\rm W}$ has been established (see also talk by S. Spiegel on Wed 11:15):





- Aim for final precision of $O(1.5 \times 10^{-10})$, satisfied already for isospin symmetric $a_\mu^{\rm SD}$ and $a_\mu^{\rm W}$.

Next frontier: isospin symmetric lqc a_μ^{LD}

- This talk: new unblinded RBC/UKQCD24 results for this window and total iso lqc results at 7.5/1000 precision
- Long-distance reconstruction of vector-vector correlator for hadronic vacuum polarization

$$C(t) = \frac{1}{3} \sum_{i=0,1,2} \sum_{\vec{x}} \langle 0 | V_i(\vec{x}, t) V_i(0) | 0 \rangle$$

  by lowest N finite-volume state contributions

$$C_{\mathrm{exclusive,\ N}}(t) = \frac{1}{3} \sum_{i=0,1,2} \sum_{\vec{x}} \sum_{n=1}^{N} |\langle 0 | V_i | n \rangle|^2 e^{-E_n t}$$

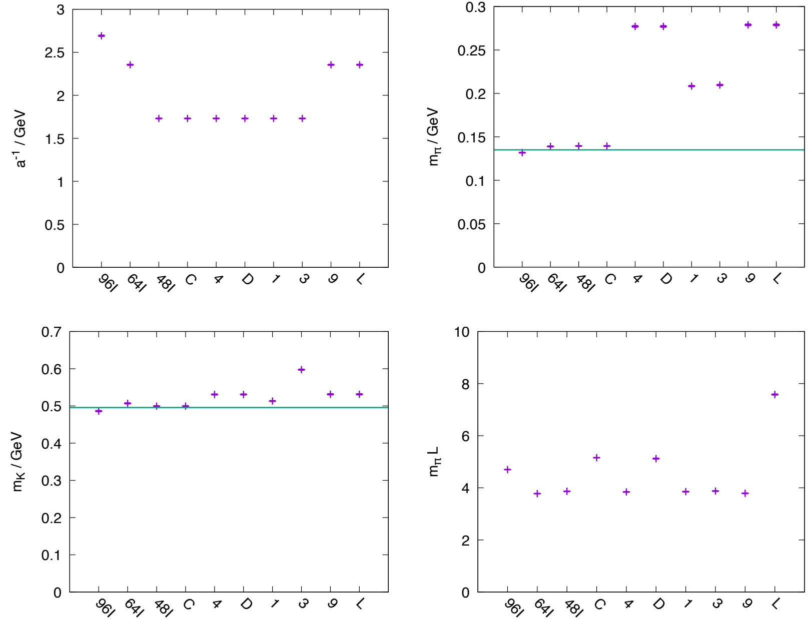
  see arXiv:1710.10072,1910.11745.

- Our dedicated distillation effort started in 2017, first talk at KEK-TI workshop in 2018
- Substantial computing investment: GCS Jülich and LRZ, EuroHPC LUMI-G and Leonardo, ALCC, INCITE at OakRidge and Argonne
- Supported by substantial coding effort: Grid/GPT

Analysis was conducted in a blinded manner

- Overall blinding factor applied to every insertion of a vector current
- Each group (A, B, C, D, E) has their own blinding factor
- No person in collaboration knows blinding factors
- CL knows non-invertible hash function that computes the blinding factors but not the numbers
- Blinded analysis cross checked between groups by studying non-blinded intermediate results (spectra, ratio of C_{excl}/C)
- Scripts executed in joint meetings to reveal the relative blinding factors for relative unblinding between groups and same for full unblinding
- Absolute unblinding happened in a joint Zoom call on July 19 2024

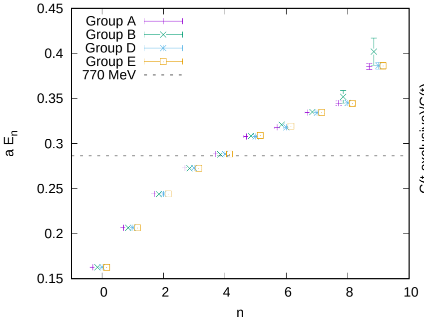
Data for new analysis (10 ensembles)

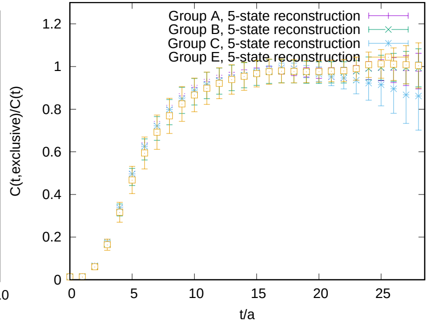


Distillation strategy

- Distillation with heavily stout-smeared Laplace eigenvectors
- 60 eigenmodes for $m_\pi L \approx 4$ at physical pion mass and 200 eigenmodes for $m_\pi L \approx 5$ at physical pion mass
- Operator basis: two-pion operators with relative momentum $\vec{p}$ plus (smeared) vector current; 10-operator basis up to $\vec{p} = (2\pi/L)(2,2,0)$ for larger volume and 5-operator basis for smaller volumes with $\vec{p}$ up to $(2\pi/L)(2,0,0)$
- Dedicated two-pion scattering study will be published separately
- Dedicated four-pion study conducted (arXiv:1910.11745), zero-consistent coupling of additional states
- Distillation and vector-vector code publicly available at `https://github.com/lehner/gpt`
- See CL Bern TI 2023 talk for more details of data generation and group A analysis, next talk by Joe Mckeon for details of group E analysis.

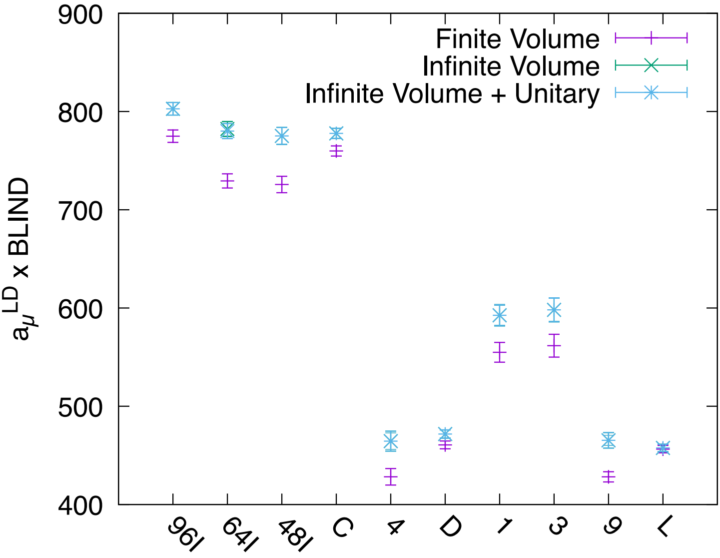
Cross checks and comparisons before relative unblinding





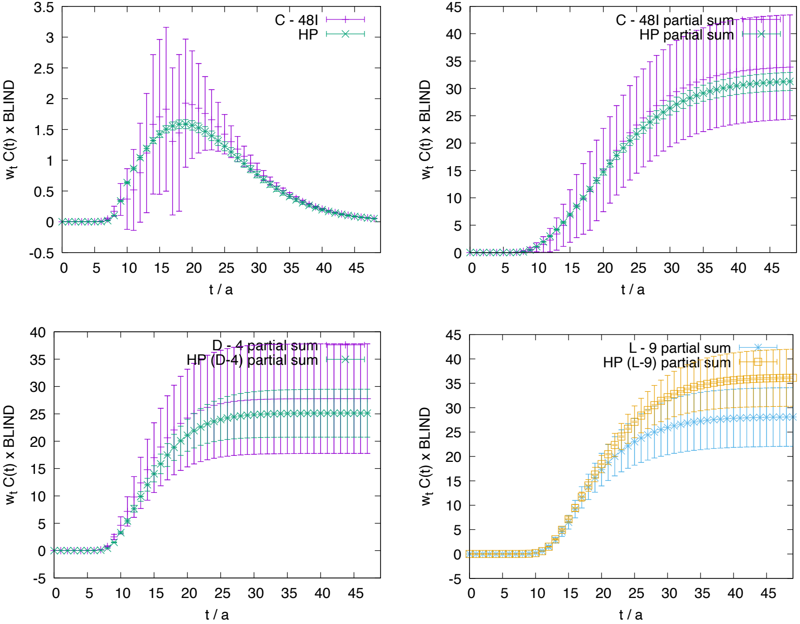
Example tests: 96I spectrum (left) and 64I long-distance reconstruction (right)

Results group A with and without finite-volume corrections



FV correction for largest ensemble is within statistical noise, FV corrections consistent with data.

Checks of finite-volume behavior against Hansen-Patella (HP)



Group A global fits and model average (1/2)

- Fit local-local and local-conserved with Z_V^{π} and $Z_V^{\star}$ (local-conserved to local-local ratio at 1 fm).
- Fit linear and linear plus quadratic pion-mass dependence
- Fit linear m_K (RBC/UKQCD20 world), $m_{ss^\star}$ (BMW20 world) term
- Fit additive

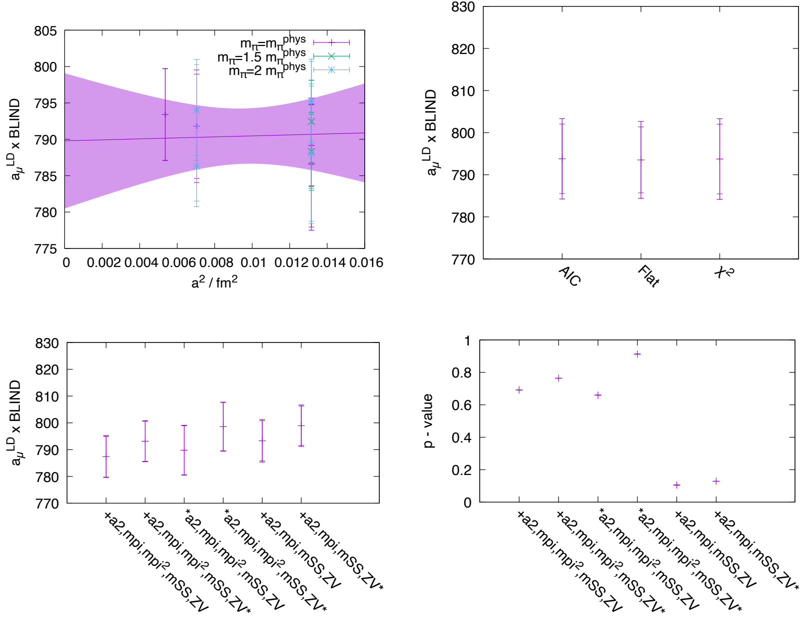
$$f(a^2) = f_0 + f_1 a^2 + f_2(w_0 m_\pi - (w_0 m_\pi)_{\mathrm{phys}}) + \ldots$$

and multiplicative

$$f(a^2) = f_0(1 + f_1 a^2)(1 + f_2(w_0 m_\pi - (w_0 m_\pi)_{\mathrm{phys}}) + \ldots$$

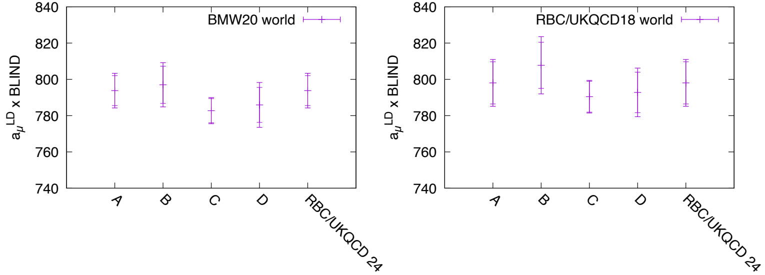
ansatz for discretization errors.

Group A global fits and model average (2/2)



$a \to 0$ correction is within statistical noise! Result statistics dominated.

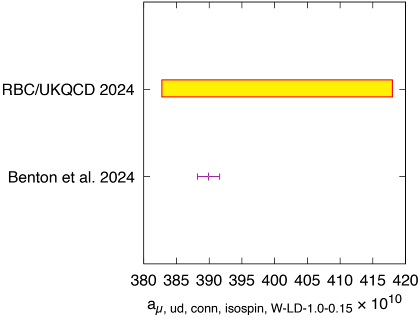
Result of relative unblinding

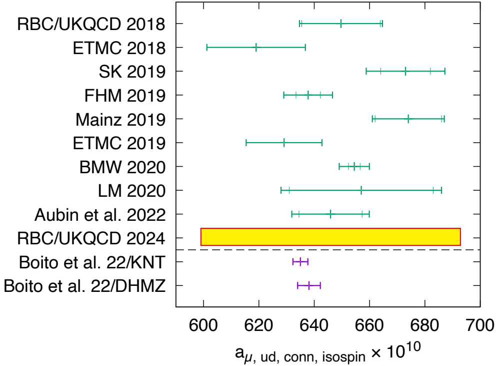


Good agreement, some observations:

- Group D only took continuum limit of physical pion mass ensembles
- Groups A and B also verified the consistency of the continuum limits with and without ensembles 9 and L
- Lattice spacing uncertainty due to Ω^- mass responsible for larger errors in RBC/UKQCD18 world. Work on more precise determination is in progress.
- RBC/UKQCD18 and BMW20 worlds are consistent at current precision

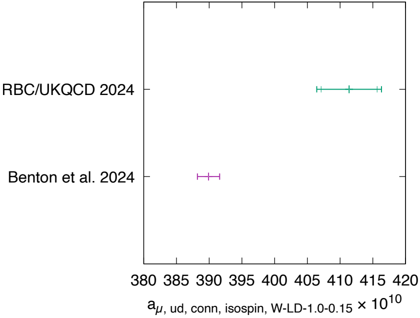
Unblinded results in BMW20 isospin-symmetric world

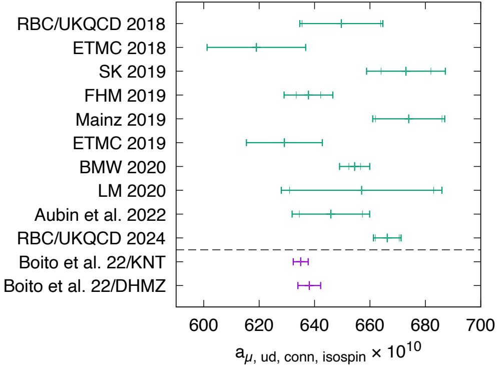




Result for $a_\mu^{\text{iso lqc}}$ with 7.5/1000 precision.

Unblinded results in BMW20 isospin-symmetric world





Result for $a_\mu^{\mathrm{iso\ lqc}}$ with 7.5/1000 precision.

$$a_\mu^{\mathrm{LD\ iso\ lqc}} = 411.4(4.3)_{\mathrm{stat.}}(2.3)_{\mathrm{syst.}} \times 10^{-10}\,,$$
$$a_\mu^{\mathrm{iso\ lqc}} = 666.2(4.3)_{\mathrm{stat.}}(2.5)_{\mathrm{syst.}} \times 10^{-10}\,.$$

More high-precision lattice results needed for consolidation of full $a_\mu^{\mathrm{iso\ lqc}}$!

Summary

- First lattice result for the isospin symmetric light-quark connected long-distance window a_μ^{LD} now unblinded.
- Combined with RBC/UKQCD23 short and intermediate-distance windows yields the currently most precise lattice QCD result for the total isospin symmetric light-quark connected result with an uncertainty of 7.5/1000
- Publication will appear soon
- Data for updates on disconnected contributions, strange, charm, QED and SIB at physical pion mass including diagrams beyond the electro-quenched approximation is mostly generated. Will focus on analysis in the remainder of 2024. Aim to complete update of RBC/UKQCD18 as soon as possible.
- See talk by M. Bruno at 12:55 later in this session for an update on a part of the QED data and our tau program.
- Further precision improvements for the long-distance window are also planned for the near future, more data is being generated (also at new finer physical pion mass lattice ensemble with $a^{-1} = 3.5$ GeV)