RBC+UKQCD Status Update

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Muon g-2 Theory Initiative Workshop – KEK

The RBC & UKQCD collaborations

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2018 PRL $\rightarrow$ today

$a_\mu^{\text{ud, conn, isospin}}$	$202.9(1.4)_\text{S}(0.2)_\text{C}(0.1)_\text{V}(0.2)_\text{A}(0.2)_\text{Z}$	$649.7(14.2)_\text{S}(2.8)_\text{C}(3.7)_\text{V}(1.5)_\text{A}(0.4)_\text{Z}(0.1)_\text{E48}(0.1)_\text{E64}$
$a_\mu^{\text{s, conn, isospin}}$	$27.0(0.2)_\text{S}(0.0)_\text{C}(0.1)_\text{A}(0.0)_\text{Z}$	$53.2(0.4)_\text{S}(0.0)_\text{C}(0.3)_\text{A}(0.0)_\text{Z}$
$a_\mu^{\text{c, conn, isospin}}$	$3.0(0.0)_\text{S}(0.1)_\text{C}(0.0)_\text{Z}(0.0)_\text{M}$	$14.3(0.0)_\text{S}(0.7)_\text{C}(0.1)_\text{Z}(0.0)_\text{M}$
$a_\mu^{\text{uds, disc, isospin}}$	$-1.0(0.1)_\text{S}(0.0)_\text{C}(0.0)_\text{V}(0.0)_\text{A}(0.0)_\text{Z}$	$-11.2(3.3)_\text{S}(0.4)_\text{V}(2.3)_\text{L}$
$a_\mu^{\text{QED, conn}}$	$0.2(0.2)_\text{S}(0.0)_\text{C}(0.0)_\text{V}(0.0)_\text{A}(0.0)_\text{Z}(0.0)_\text{E}$	$5.9(5.7)_\text{S}(0.3)_\text{C}(1.2)_\text{V}(0.0)_\text{A}(0.0)_\text{Z}(1.1)_\text{E}$
$a_\mu^{\text{QED, disc}}$	$-0.2(0.1)_\text{S}(0.0)_\text{C}(0.0)_\text{V}(0.0)_\text{A}(0.0)_\text{Z}(0.0)_\text{E}$	$-6.9(2.1)_\text{S}(0.4)_\text{C}(1.4)_\text{V}(0.0)_\text{A}(0.0)_\text{Z}(1.3)_\text{E}$
a_μ^{SIB}	$0.1(0.2)_\text{S}(0.0)_\text{C}(0.2)_\text{V}(0.0)_\text{A}(0.0)_\text{Z}(0.0)_\text{E48}$	$10.6(4.3)_\text{S}(0.6)_\text{C}(6.6)_\text{V}(0.1)_\text{A}(0.0)_\text{Z}(1.3)_\text{E48}$
$a_\mu^{\text{udsc, isospin}}$	$231.9(1.4)_\text{S}(0.2)_\text{C}(0.1)_\text{V}(0.3)_\text{A}(0.2)_\text{Z}(0.0)_\text{M}$	$705.9(14.6)_\text{S}(2.9)_\text{C}(3.7)_\text{V}(1.8)_\text{A}(0.4)_\text{Z}(2.3)_\text{L}(0.1)_\text{E48}$ $(0.1)_\text{E64}(0.0)_\text{M}$
$a_\mu^{\text{QED, SIB}}$	$0.1(0.3)_\text{S}(0.0)_\text{C}(0.2)_\text{V}(0.0)_\text{A}(0.0)_\text{Z}(0.0)_\text{E}(0.0)_\text{E48}$	$9.5(7.4)_\text{S}(0.7)_\text{C}(6.9)_\text{V}(0.1)_\text{A}(0.0)_\text{Z}(1.7)_\text{E}(1.3)_\text{E48}$
$a_\mu^{\text{R-ratio}}$	$460.4(0.7)_\text{RST}(2.1)_\text{RSY}$	
a_μ	$692.5(1.4)_\text{S}(0.2)_\text{C}(0.2)_\text{V}(0.3)_\text{A}(0.2)_\text{Z}(0.0)_\text{E}(0.0)_\text{E48}$ $(0.0)_\text{b}(0.1)_\text{c}(0.0)_{\overline{\text{S}}}(0.0)_{\overline{\text{Q}}}(0.0)_\text{M}(0.7)_\text{RST}(2.1)_\text{RSY}$	$715.4(16.3)_\text{S}(3.0)_\text{C}(7.8)_\text{V}(1.9)_\text{A}(0.4)_\text{Z}(1.7)_\text{E}(2.3)_\text{L}$ $(1.5)_\text{E48}(0.1)_\text{E64}(0.3)_\text{b}(0.2)_\text{c}(1.1)_{\overline{\text{S}}}(0.3)_{\overline{\text{Q}}}(0.0)_\text{M}$

$\Longrightarrow$ 2.6% uncertainty

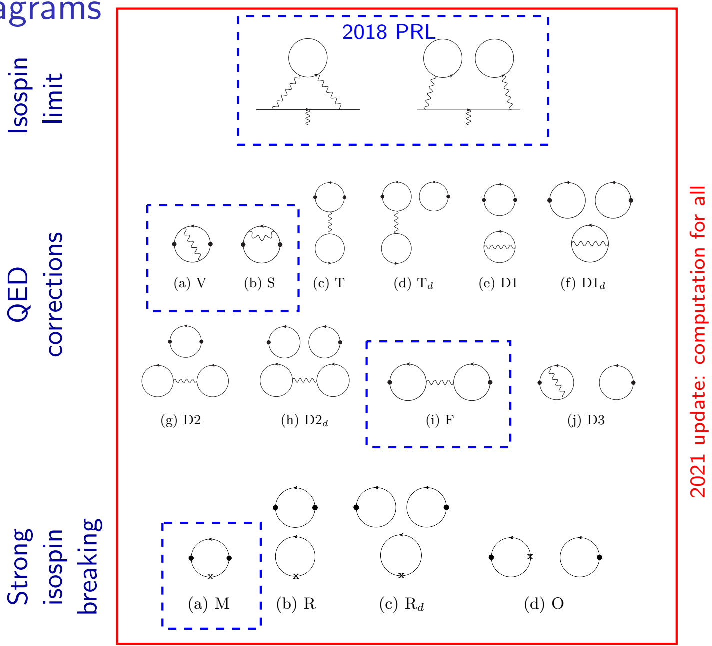
TABLE I. Individual and summed contributions to a_μ multiplied by 10^{10}. The left column lists results for the window method with $t_0 = 0.4$ fm and $t_1 = 1$ fm. The right column shows results for the pure first-principles lattice calculation. The respective uncertainties are defined in the main text.

[PRL 121, 022003 (2018)]

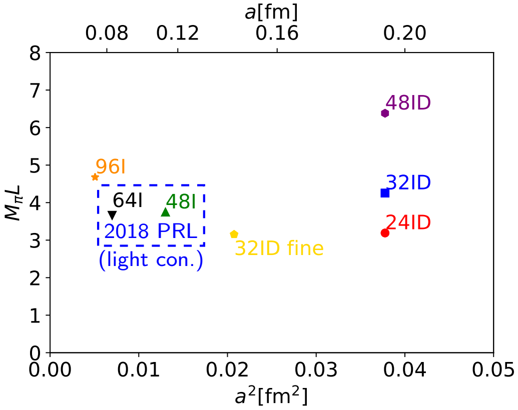
Full program of computations to improve total uncertainties:

- Approx 4$\times$ stats on 48I and 64I ensembles for VV correlator
- Additional lattice spacing around $a^{-1} = 2.7$ GeV
  w/ per-mille stats for short/middle windows
- Distillation exclusive study, improved bounding method, FV study
- QED corrections to M_Ω scale setting
- Isospin-symmetric disconnected diagram improvements
- Improve QED+SIB contributions w/ HLbL data

Diagrams

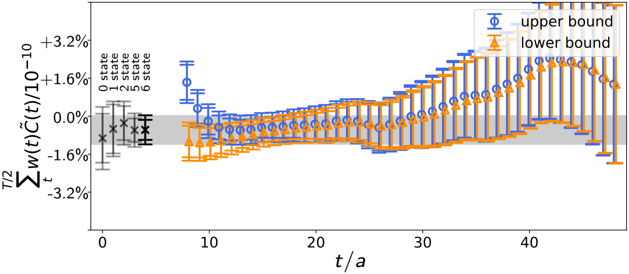

Isospin limit
2018 PRL
QED corrections
(a) V
(b) S
(c) T
(d) T_d
(e) D1
(f) $D1_d$
(g) D2
(h) $D2_d$
(i) F
(j) D3
Strong isospin breaking
(a) M
(b) R
(c) R_d
(d) O
2021 update: computation for all

Ensembles



- Additional ensembles compared to 2018 — all physical M_π
- Third lattice spacing 96I
- Two actions:
  - Iwasaki(I) ensembles for continuum study
  - Iwasaki+DSDR(ID) ensembles for studying FV corrections

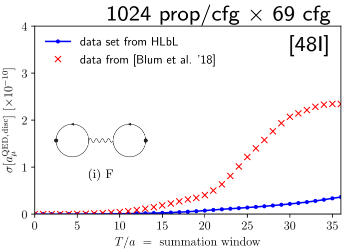
Improved Bounding Method - 48I

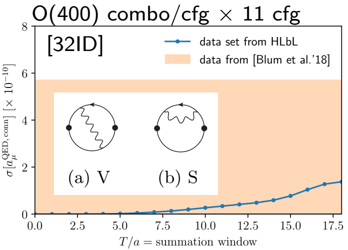


No bounding:	3.3% rel. unc. (total)
Bounding @ 3.0 fm:	1.3% rel. unc. (total)
Imp. bounding @ 1.7 fm:	0.6% rel. unc. (total)
	0.4% (stat), 0.4% (scale setting)

- Improved bounding method on 48I, 64I
  $\Longrightarrow$ stats improvement to light quark long distance
- Distillation FV study on 24ID, 32ID
  $\Longrightarrow$ explicit calculation of FV spectrum
  $\Longrightarrow$ MLLGS FV correction

QED from HLbL Data





- 2018: $M = 50$ prop/cfg $\times$ 30 cfg total, 48I
- today: $M =$ 1024 prop/cfg (2048 for 32ID)
  $\times$ $O(30)$ cfg from [PRL 124 (2020)]
- many ensembles available (48I, 64I, 24ID, 32ID, 32IDfine, 48ID)
- left: diagram F, full statistics
- right: partial statistics for (diag V,S)
  plan for all $\approx M^2$ combos $\times$ $O(30)$ cfg
- plot credit: M. Bruno

Plan going forward

- New method for studying charm sea quark effects
- Results to appear in update paper
- *We aim for a 2+1+1 calculation*

Next release:

- Keep analysis blind and have different independent analysis groups
- Updated window quantities as soon as our sea-quark effects study completes, should appear still this summer
- By end of year, publish a complete analysis of total a_μ, which we expect to yield a target uncertainty of $O(5 \times 10^{-10})$ [$\sim$ 0.7% rel. unc.]

Long-term plan:

- Computing proposals submitted that, if approved, should allow for a reduction of stat+syst uncertainties to $O(2 \times 10^{-10})$ [$\sim$ 0.3%] by 2023/24.
- This will include the generation + measurement on a 4 GeV 2+1+1 lattice.

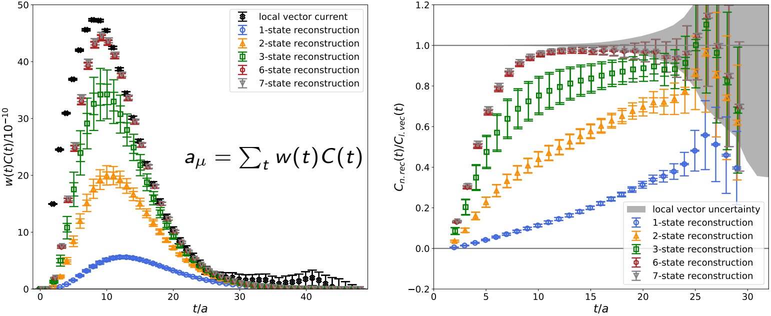
Backup

Summarized updates since 2018

- Distillation exclusive study/Improved Bounding for control of long distance tail
- Re-analysis of HLbL pt src data for conn+disc QED diagrams, should reduce total unc to $< 2 \times 10^{-10}$ for QED contrib
- New data for isospin-symmetric disc diagrams w/ much higher stats & multiple lattice spacings
- Results for diagram M and O through calculations at various different valence masses for the isospin symmetric connected and disconnected diagrams.
- Approx 4x stats on 48I and 64I ensembles for VV correlator
- Additional lattice spacing around $a^{-1} = 2.7$ GeV w/ per-mille stats for short/middle windows
- QED corrections to M_Ω scale setting included
- Just completing:
  Sea quark effects study for sea mass mistuning, SIB+QED subleading diagrams, AND inclusion of effects from sea charm quarks!

  We aim for a 2+1+1 calculation

Distillation Exclusive Study - 48I



Left: a_μ integrand, Right: ratio reconstruction/local vector

- Exclusive study incl. V_μ, 2π, 4π
- Operator improvement on 2π
- Good control of long distance tail
- 6 state $\implies$ 1σ consistent for $t \geq 16a \sim 1.7$ fm