LATTICE QCD COMPUTATION OF THE MUON MAGNETIC MOMENT

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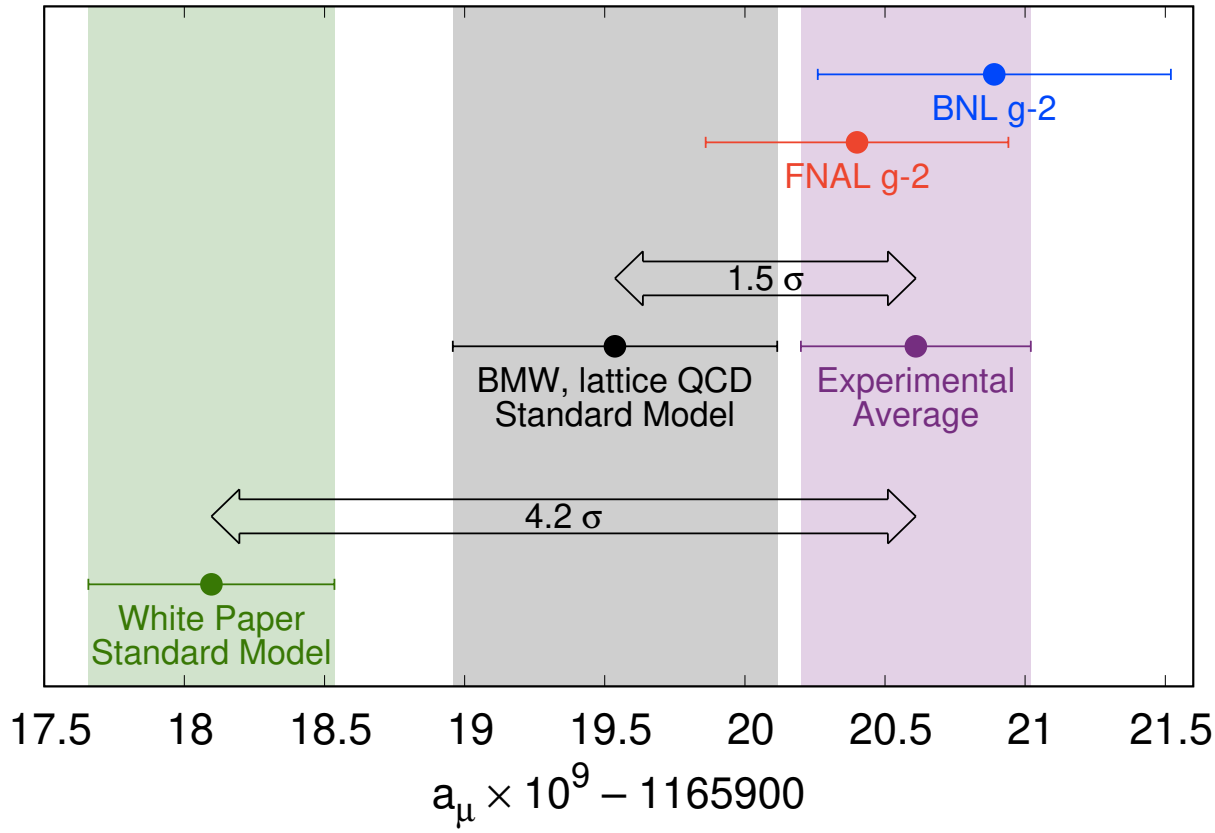
Borsanyi,Fodor,Guenther,Hoelbling,Katz,Lellouch,Lippert Miura, Parato, Stokes, Toth, Torok, Varnhorst

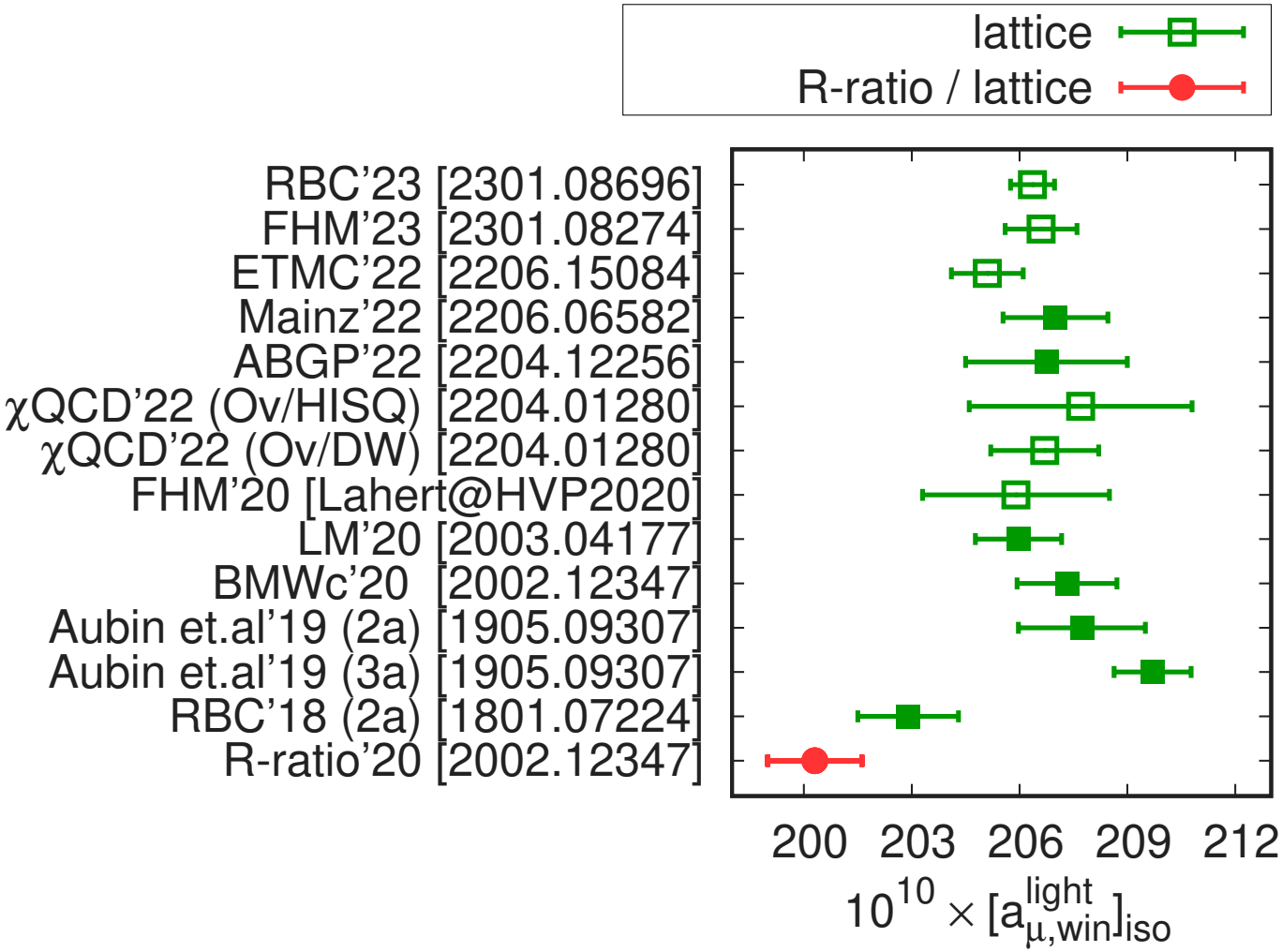
[2002.12347,Nature (2021)] Leading-order hadronic vacuum polariz ...

Status in 2021



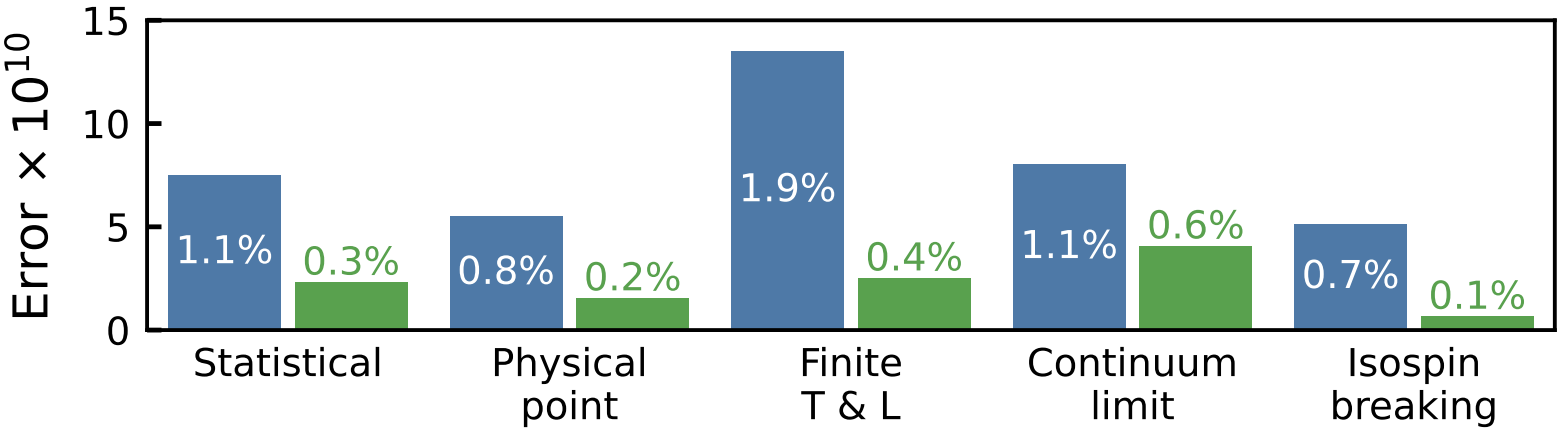
1. See if other lattice groups confirm or refute.
2. Understand the tension with R-ratio.
3. Improve precision.

New window results



- several groups, different discretizations and techniques
- high value seems to be confirmed
- combination gives 4.5σ deviation from R-ratio

Error budget



BMWc'17 → BMWc'21

711.0(18.9) → 707.5(5.5)

statistical (7.5) → (2.3)

finite-size (13.5) → (2.5)

cont.extrap (8.0) → (4.1)

isospin-breaking (5.1) → (1.4)

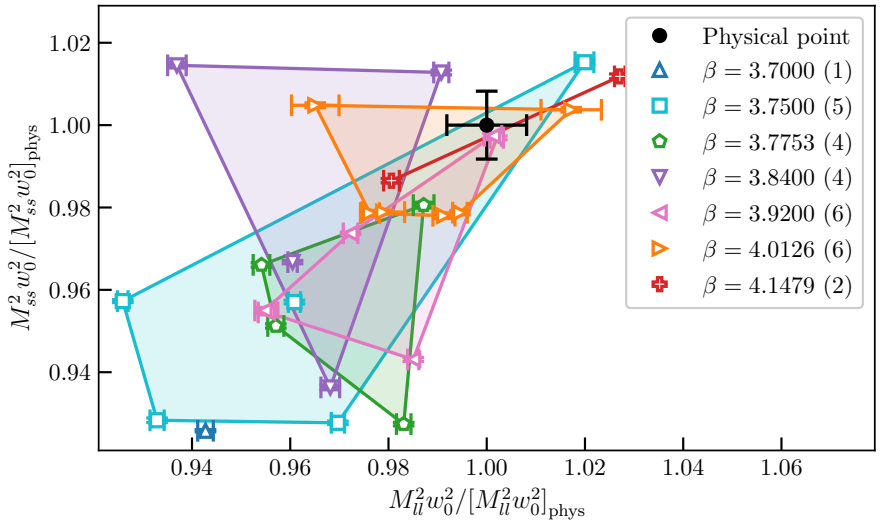
We have to reach (1.6) in total to keep up with experiment!

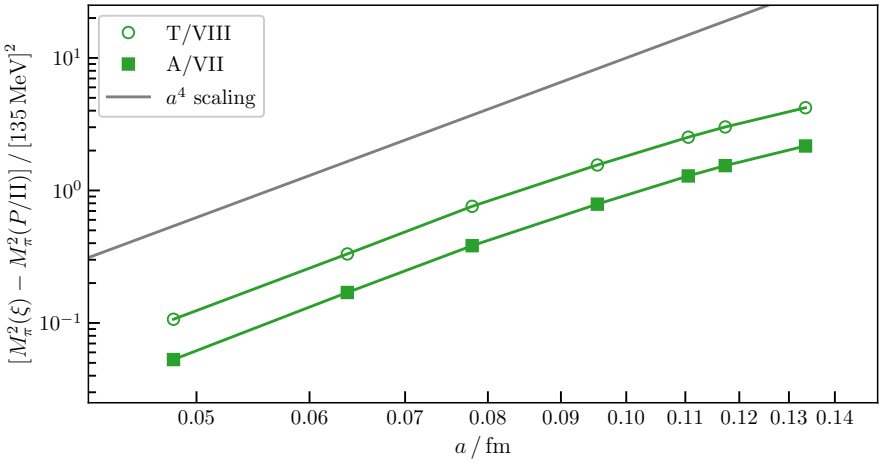
Needs the same error reduction as from 2017→2021.

Finer lattice

- spacing 0.064 → 0.048 fm

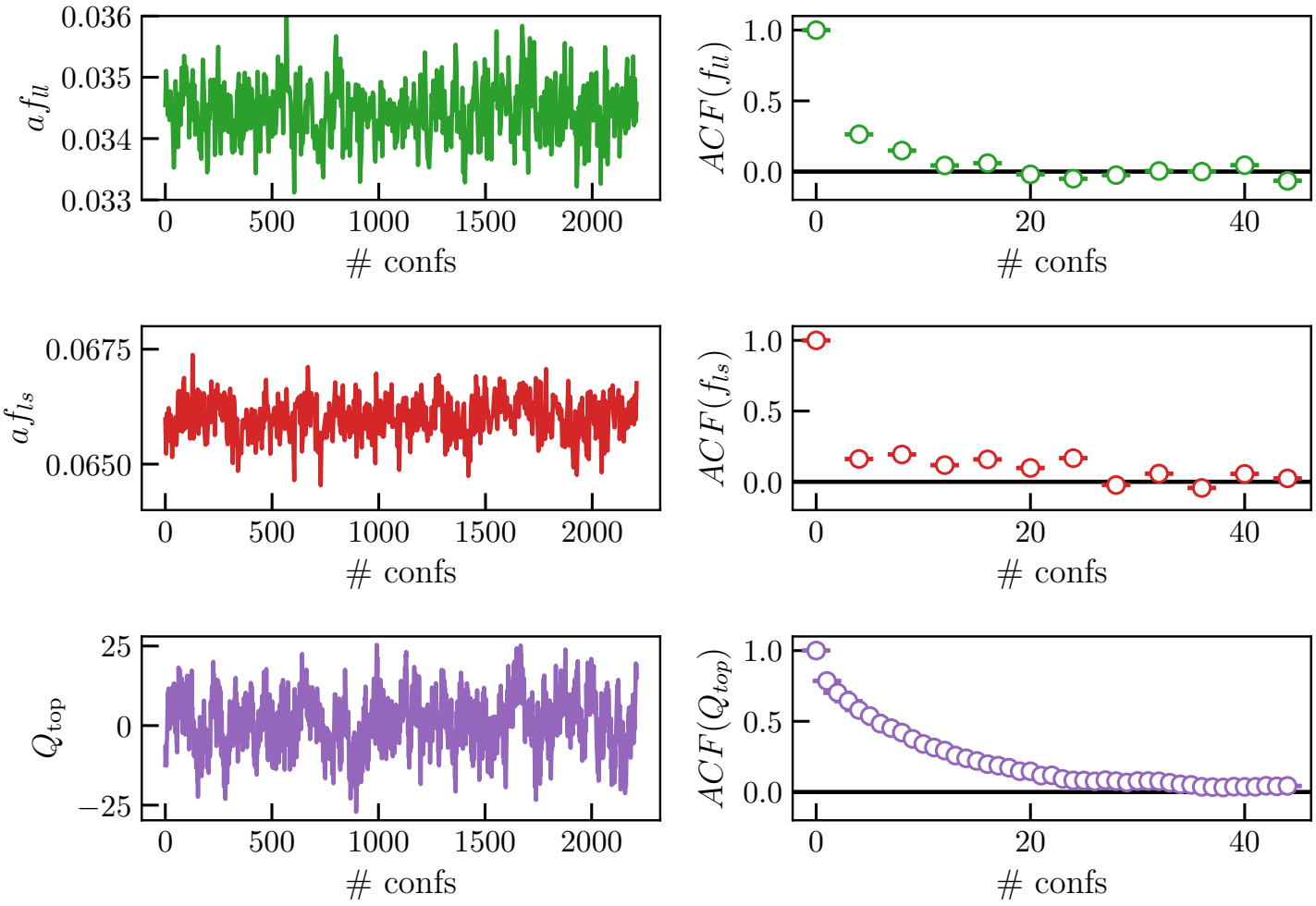
  $96^3 \times 144 \rightarrow 128^3 \times 192$





- staggered taste violation
- root mean squared M_π 142 MeV from 155 MeV (135 MeV in continuum)

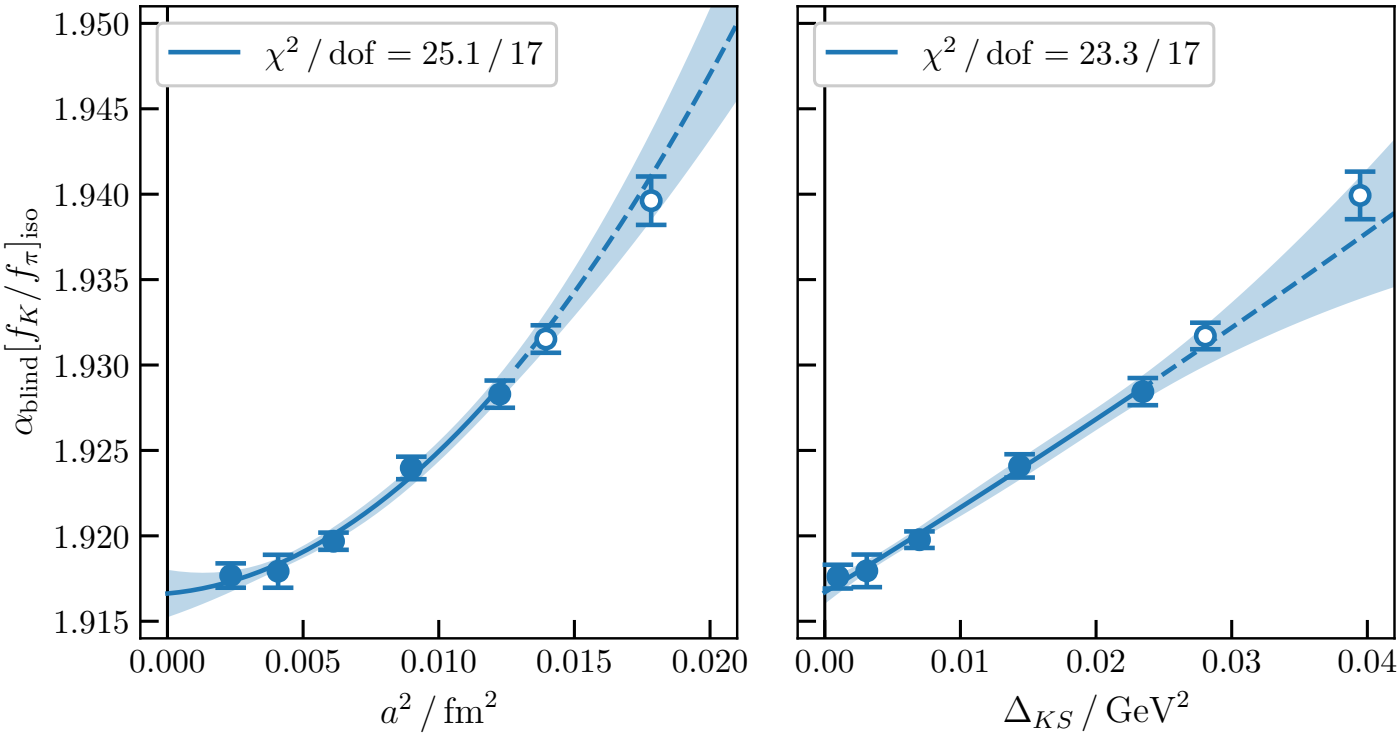
Autocorrelation



- topological charge $\tau_{\mathrm{int}} = 90(20)$, decay constants 50(10), omega baryon, vacuum polarization even smaller

Decay constants (in prep.)

- compute f_π, f_K, including strong-isospin-breaking effects



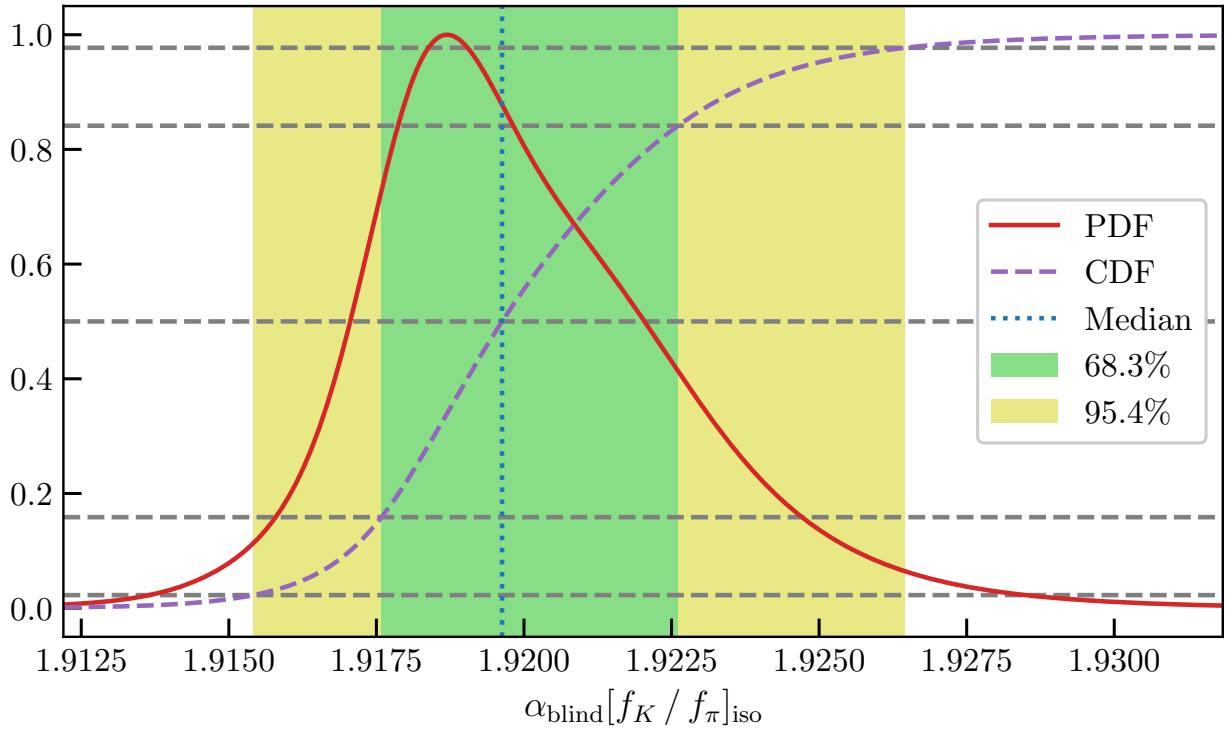
- continuum extrapolation with fits like:

$$A_0 + A_1 a^2 + A_2 a^4 + A'_1 \Delta_{KS}$$

- results are blinded

Histogram analysis

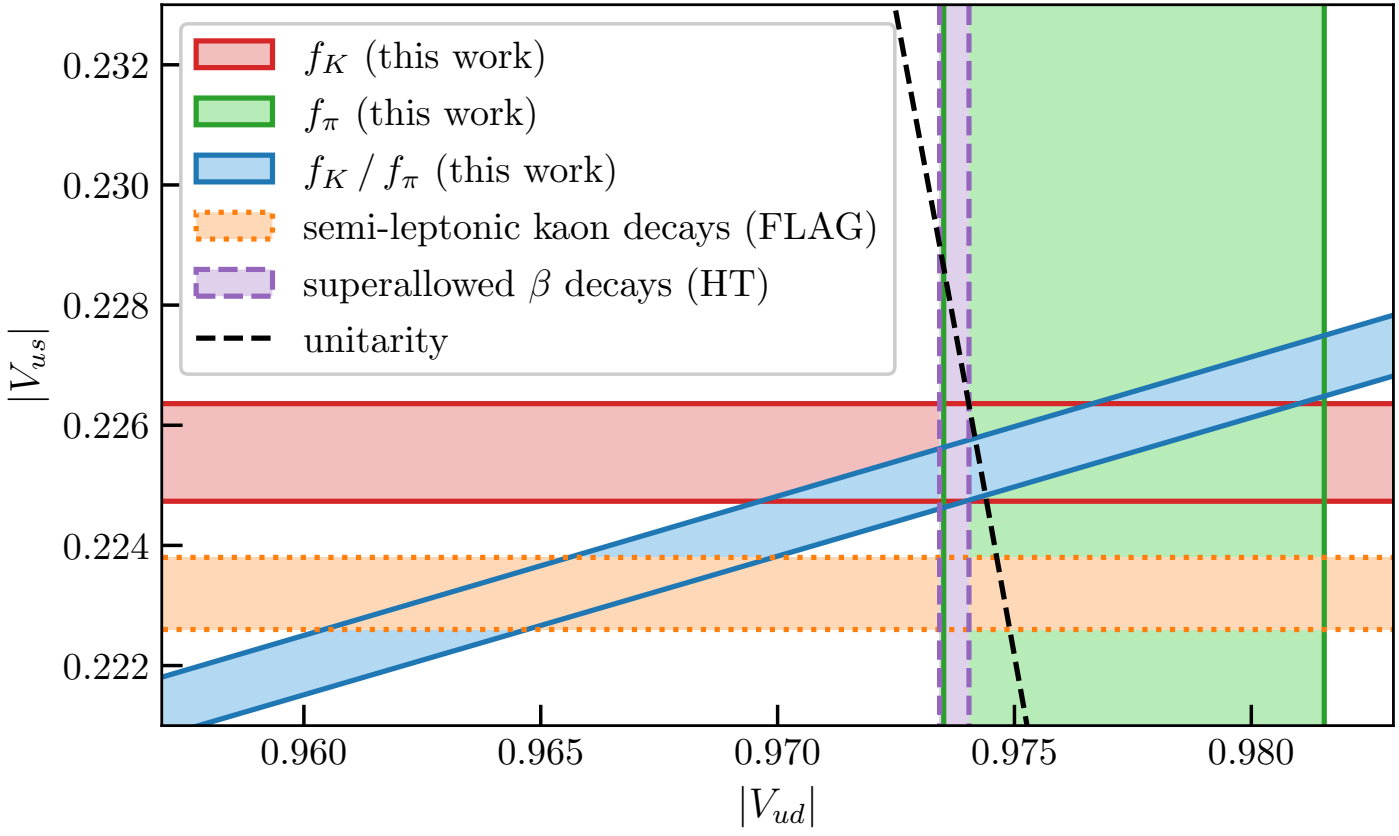
- estimate stat/syst errors and make error budgets
- 192×130 systematic ingredients (like plateau fit, cont. fit form, finite size corrections, ...)



- we apply weighting for each systematic ingredient
  - uniform
  - exp $\left(-\chi^2/2 + n_{\mathrm{par}} - n_{\mathrm{data}}/2\right)$ [Akaike]

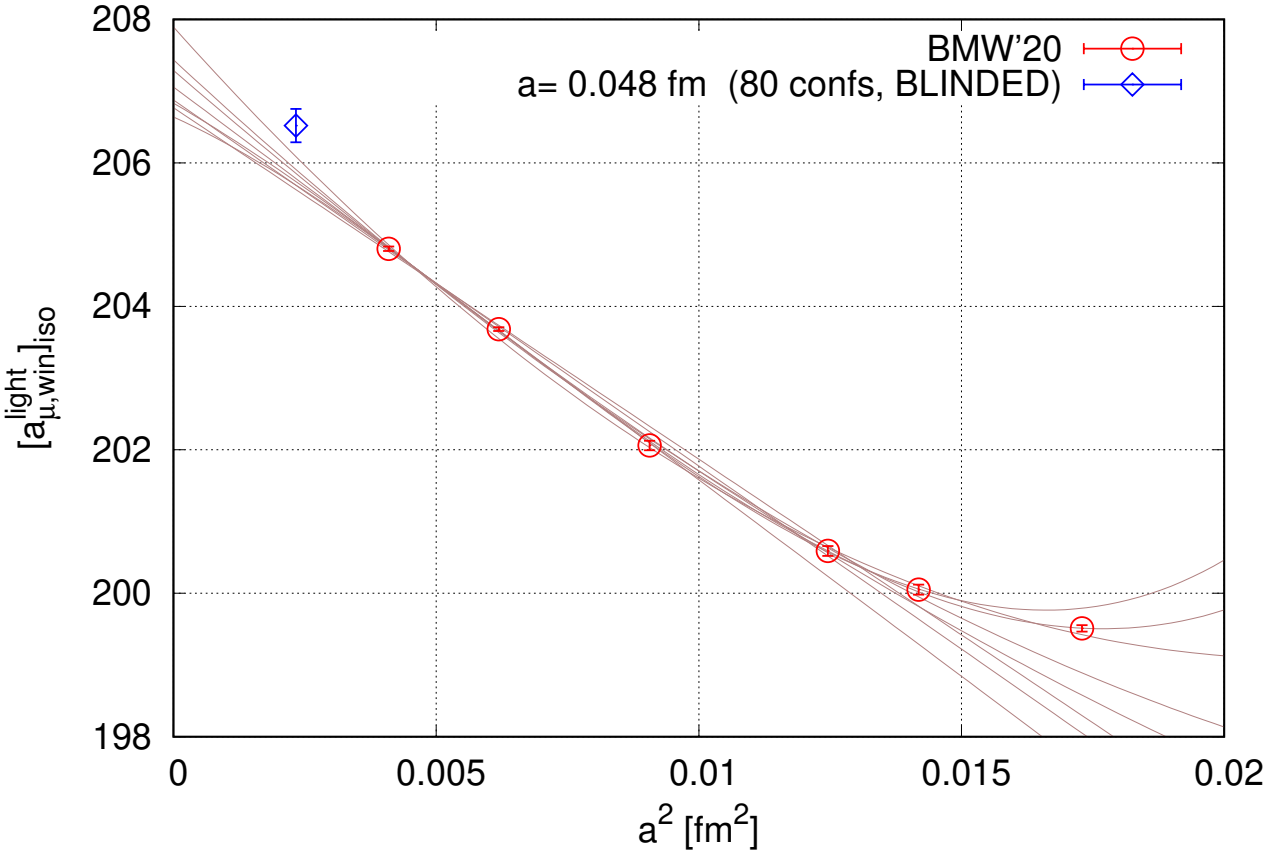
Impact on pheno

- will improve on current FLAG21 (preliminary)



- Cabibbo-anomaly= 2-3σ tensions in V_{ud} and V_{us}

HVP with finer lattice



- if consistent, halve error on cont. extrapolation

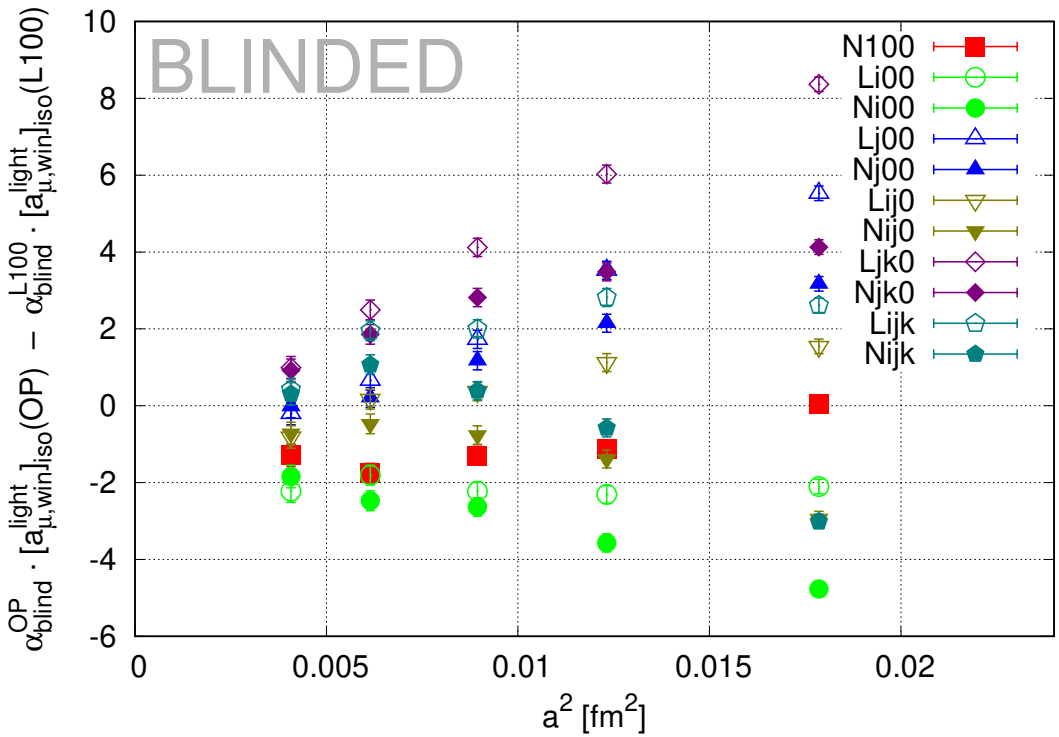
$$[a_\mu^{\mathrm{light}}]_{\mathrm{iso}} = 633.7(2.1)_{\mathrm{stat}}(4.2)_{\mathrm{syst}} \rightarrow xxx.x(1.5)_{\mathrm{stat}}(1.9)_{\mathrm{syst}}$$

- if not, ...

HVP with more operators

current operator can be discretized in many ways (here 48)

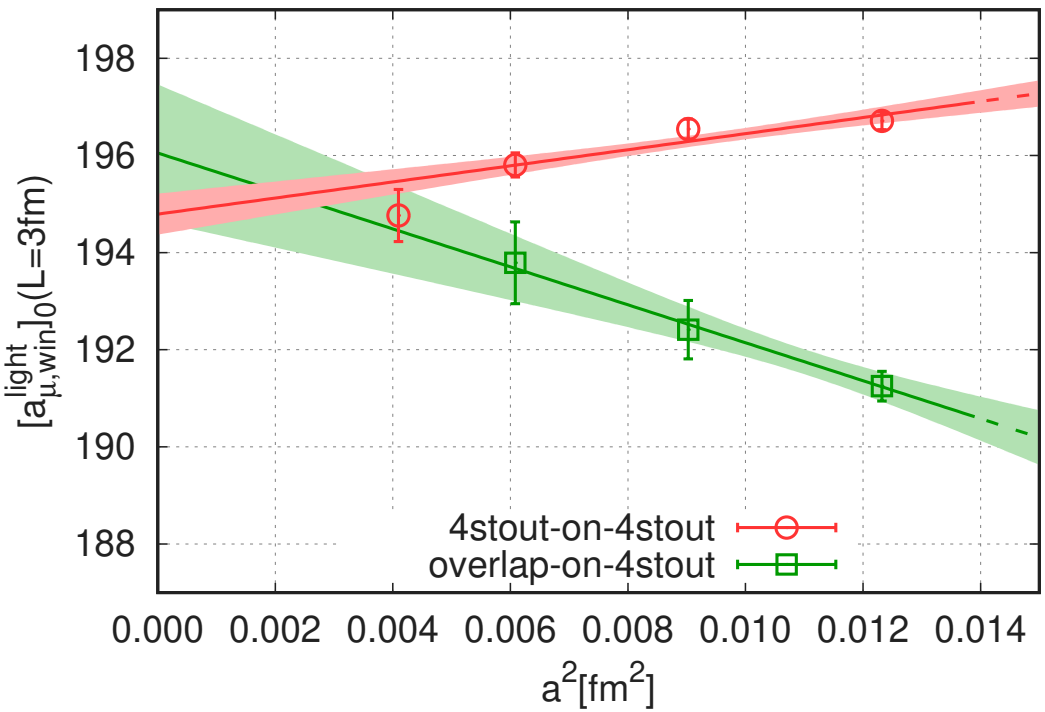
must all give the same continuum limit, but approach it differently



- do they extrapolate to the same point?
- howto use the information to constrain the cont. limit?

HVP with more fermion discretizations

Check staggered continuum limit with overlap-on-staggered in $L = 3$ fm boxes. (Universality: all discretizations of QCD should give the same result.)

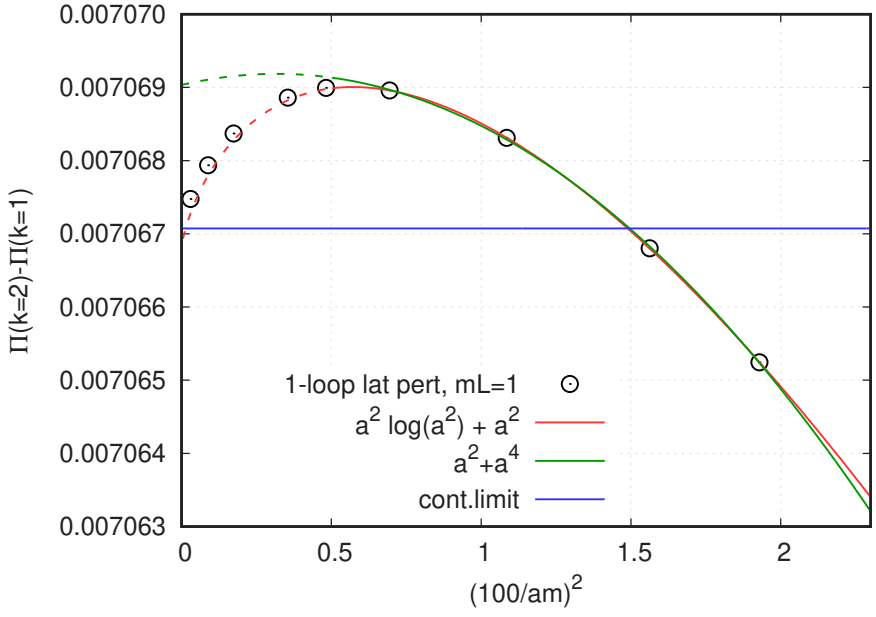


- Plot shows status in 2020.
- Updates: increasing statistics, improved noise reduction technique, different matching procedure.

More studies on lattice artefacts

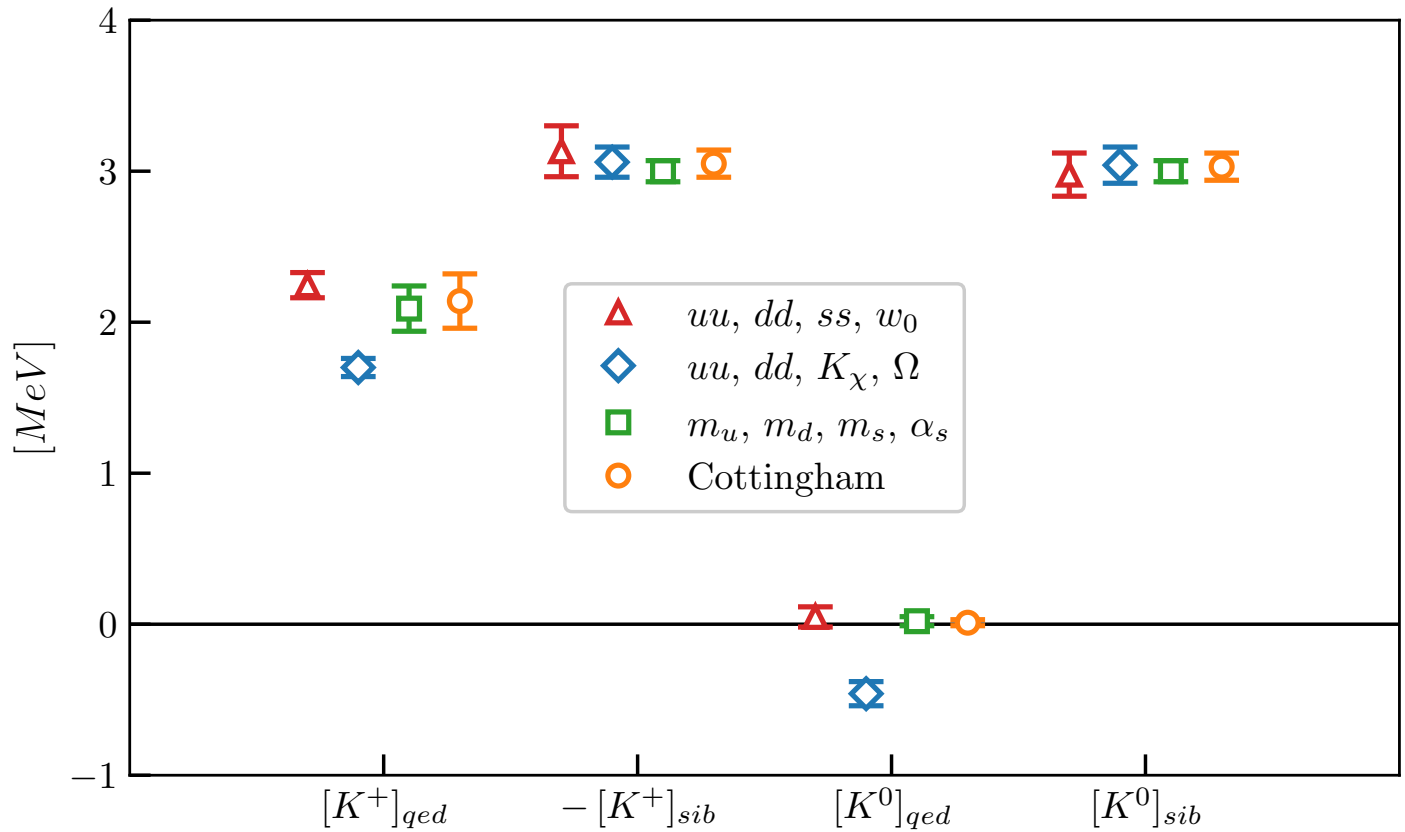
naively a^2 $\rightarrow$ modified by logarithms $a^2 / \log(a)^\Gamma$

- For 2d $O(3)$ model $\Gamma = -3$. For pure QCD or QCD with Wilson fermions $\Gamma \approx 0$ [Husung et al '19]
- major lattice artefact (staggered taste violation) scales approximately $a^2\alpha_s^3(\frac{1}{a})$, ie. $\Gamma \approx 3$
- a_μ integrates over all distances, there can be $\Gamma = -1$ exponent coming from short-distance part [Ce et al '21]



Isospin decomposition

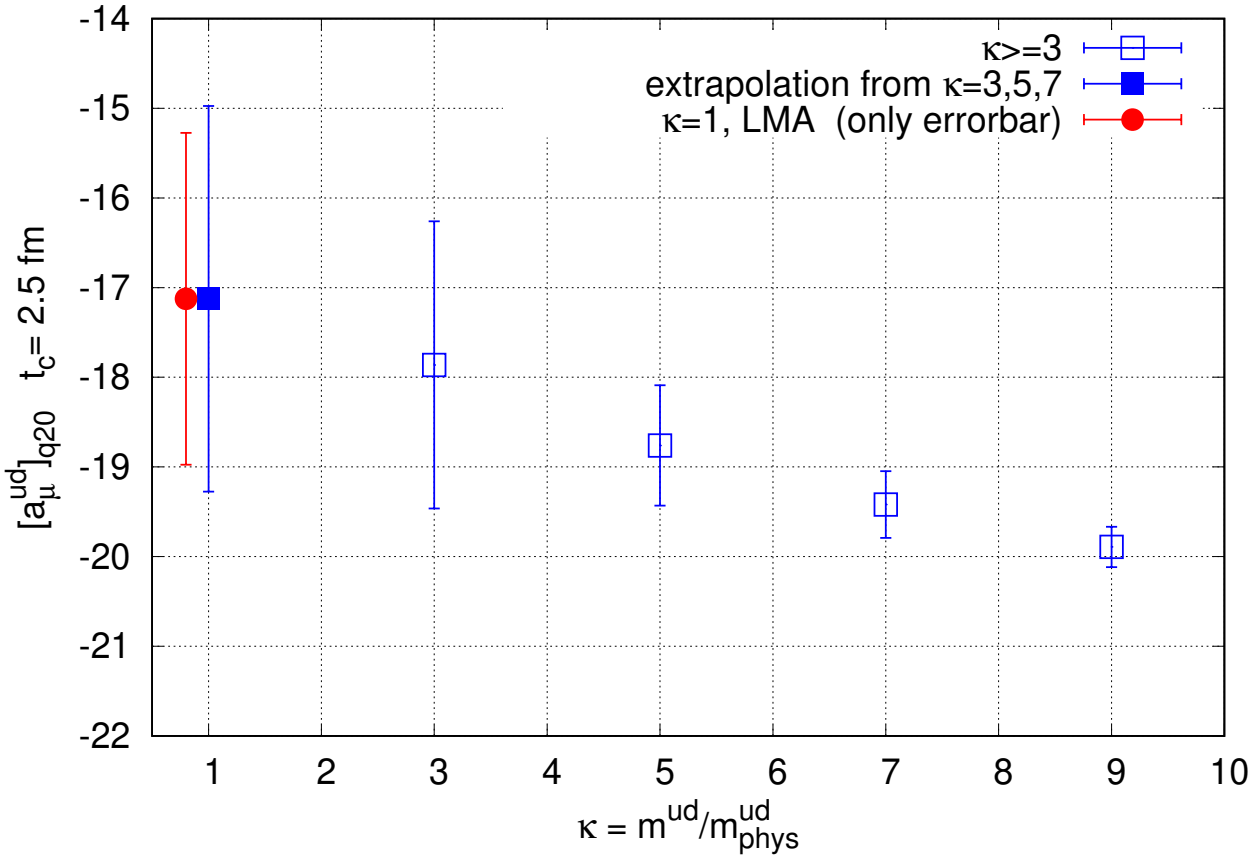
- different schemes can give different results, only total QCD+QED should be invariant
- decompose kaon mass $M_K = [M_K]_{\rm iso} + [M_K]_{\rm sib} + [M_K]_{\rm qed}$



[Borsanyi:2020mff] [Boyle:2022lsi] [DiCarlo:2019thl] [Stamen:2022uqh]

Isospin breaking with LMA

eliminating a chiral extrapolation by direct computation at the physical mass



Outlook

Improve continuum extrapolation

- finer lattice
- more operators
- other fermion actions
- tree level improvement at short distance

Improve isospin breaking

- eliminate chiral extrapolation

Also have to work on finite size and noise.