Analysis of systematic error in hadronic vacuum polarization contribution to muon g-2

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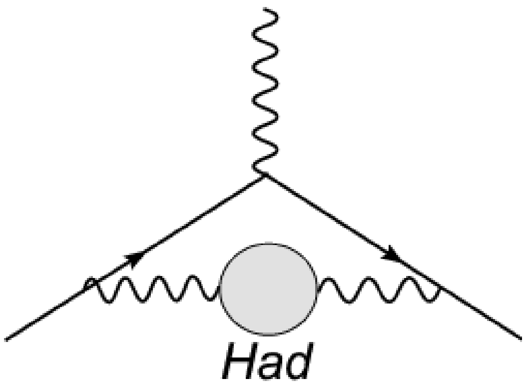
Contents

Motivation

- HVP contribution to muon g-2

Target precision is < 1% in LQCD



Dispersion approach(N_f=5) using R-ratio (e+e-) :

$a_\mu^{HLO} = 688.6(4.3) \times 10^{-10} \Rightarrow 0.6$ % precision

Jegerlehner, 1511.04473

Independent check in LQCD is important.

QCD uncertainty is comparable with BNL experimental uncertainty.

$\mathrm{Err}[a_\mu^{BNL}] = 6.3 \times 10^{-10}$

Will be factor 5 improvement in the new experiment in FNAL, JPARC

Need to improve the precision to ~0.5% of HVP muon g-2 in the SM.
⇒ search the new physics in muon g-2 anomaly (~3 σ deviation)

g-2 with time-slice integral

- Time-momentum rep. (TMR) method Bernecker, Meyer, EPL A47(2011)

$$a_\mu^{\rm HLO} = \int_0^\infty W_t(t)G(t), \quad G(t) = \int d^3x \langle V_i(x)V_i(0)\rangle$$

$$W_t(t) = 4\alpha^2 m_\mu t^3 \hat{K}(t)$$

$$\hat{K}(t) = \frac{2}{m_\mu t^3}\int_0^\infty \frac{d\omega}{\omega} K_E(\omega^2)\left[\omega^2 t^2 - 4\sin^2(\omega t/2)\right]$$

  - Vector current correlator <VV>(t) without momentum.

Possible uncertainties in both long and short distances

- FV effect and t_{cut} truncation error.
- Large statistical noise in long distance.
- Lattice artifact in short time-slice.

Our strategy

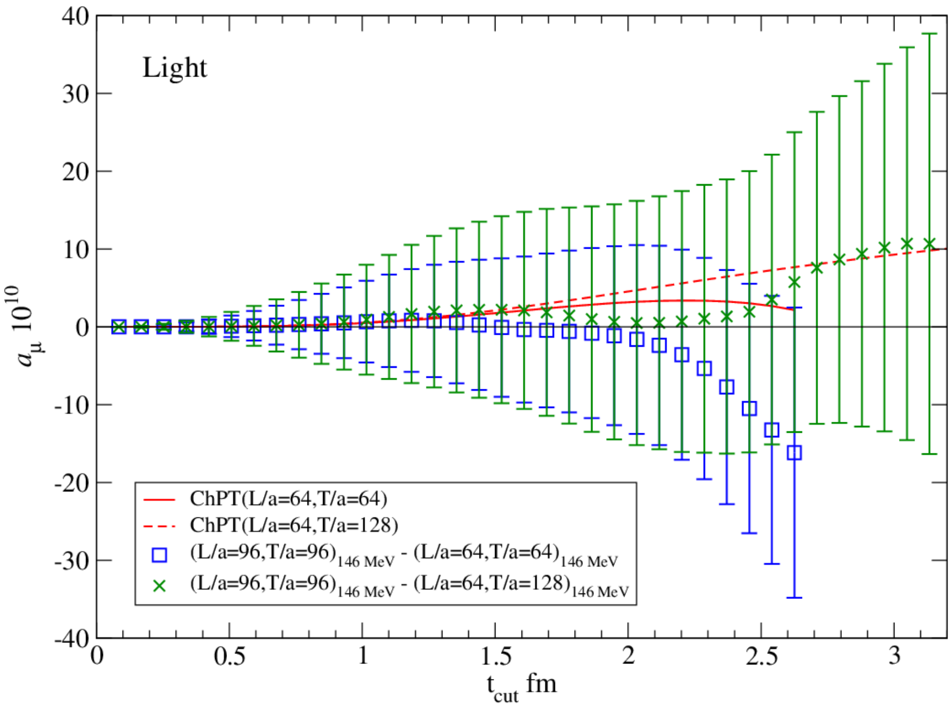
- FV effect
  - Using the new PACS configs., which are large box size L >10 fm, in the physical pion.
  - Two volumes at same cut-off ⇒ direct estimate of FV effect
- Statistical noise
  - Optimized AMA technique in Wilson-clover Mainz, NPB914 (2017)
  - Volume scaling of S/N ⇒ large volume can reduce noise
- Lattice artifact
  - Comparison with different cut-off.
  - Test of operator dependence

Here we calculate connected HVP contribution only.

Update

- Previous study on 96^4 and 64^4 lattice

PACS 1805.04250



- Attempt LQCD estimate of FV.
- 96^4 lattice: 145 MeV pion
  64^4 lattice: 135 MeV pion
  ⇒ chiral extrapolation
- a_μ[L=8.1fm] - a_μ[L=5.4fm] = (10±26) in 145 MeV
- LQCD does not disagree with ChPT, but statistical error is still large.

New PACS ensemble, which is L>10 fm in 135 MeV pion.
⇒ direct estimate of FV

2. Setup

PACS10 configuration

- Iwasaki gauge + stout smeared clover fermion
- Physical pion mass in N_f = 2+1
- Old configuration
  - 64^4, a^{-1}=2.33 GeV, m_π=139 MeV and 135 MeV(reweighted)
- New configuration generation (PACS10) PACS, 1807.06237
  - 128^4, a^{-1}=2.33 GeV, m_π=135 MeV
  - 160^4, a^{-1}=3.06 GeV, m_π=135 MeV

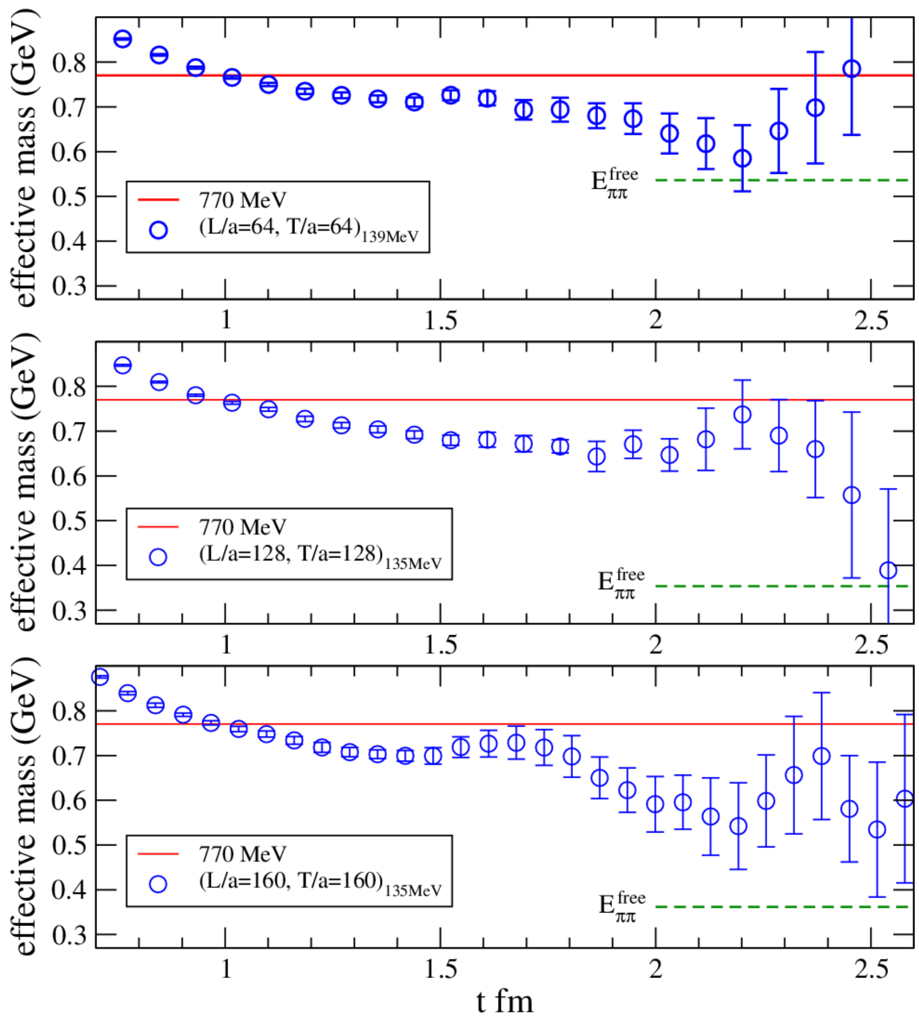
Using PACS10 configs., we can study

- Direct estimate of FV effect on L=5.4 fm in m_π =135 MeV
- Cut-off effect on L>10 fm box in m_π =135 MeV

All data is still preliminary !

2. Setup

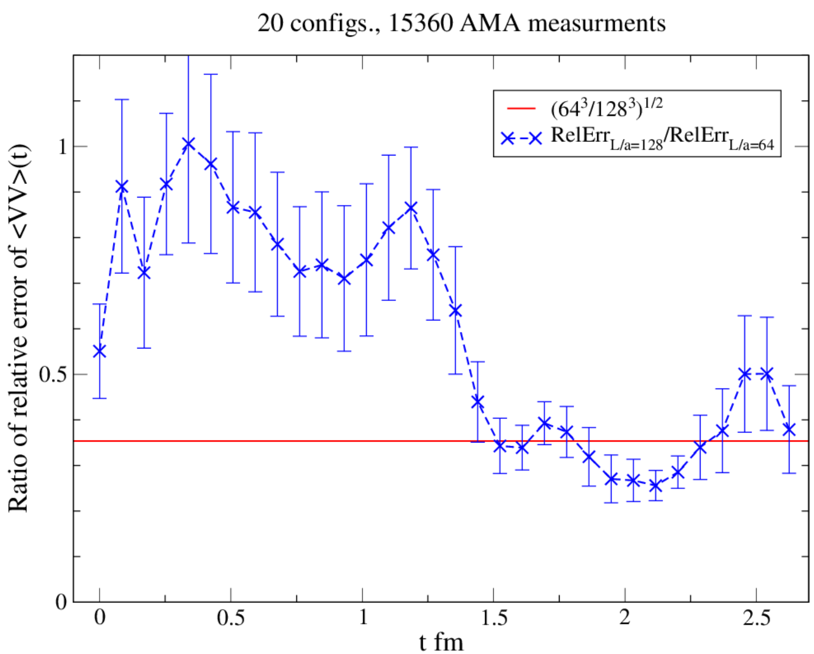
Effective mass

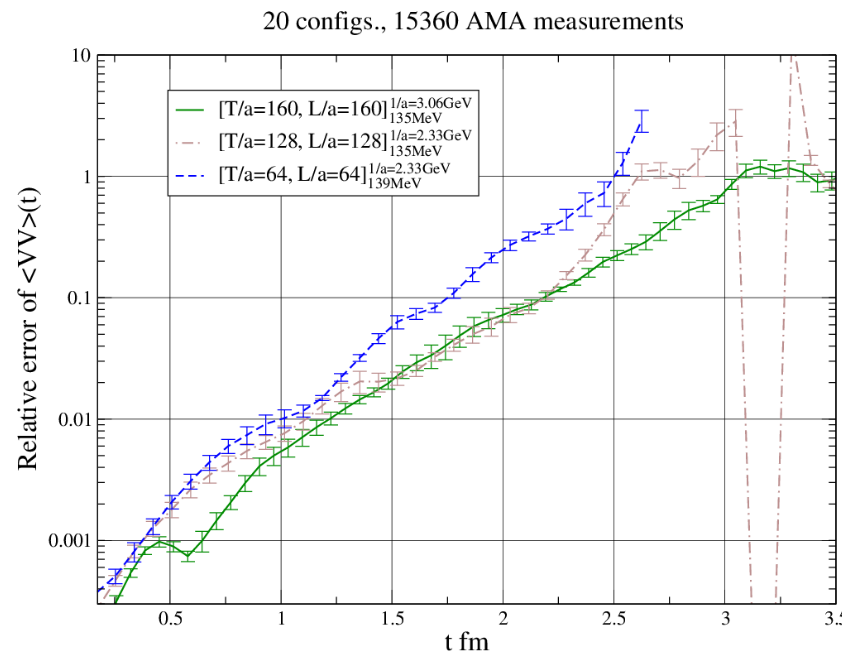


- In t > 1 fm, effective mass of vector channel is below rho meson mass.
- $E_{\pi\pi}^{free} < m_v < m_\rho$

$$E_{\pi\pi}^{\rm free} = 2\sqrt{m_\pi^2 + (2\pi/L)^2}$$

Volume scaling of stat. error





- Volume scaling of statistical error in long-distance, t > 1.5 fm
- Volume scaling is universal in different cut-off.
  ⇒ depending on physical volume

3. Finite volume study

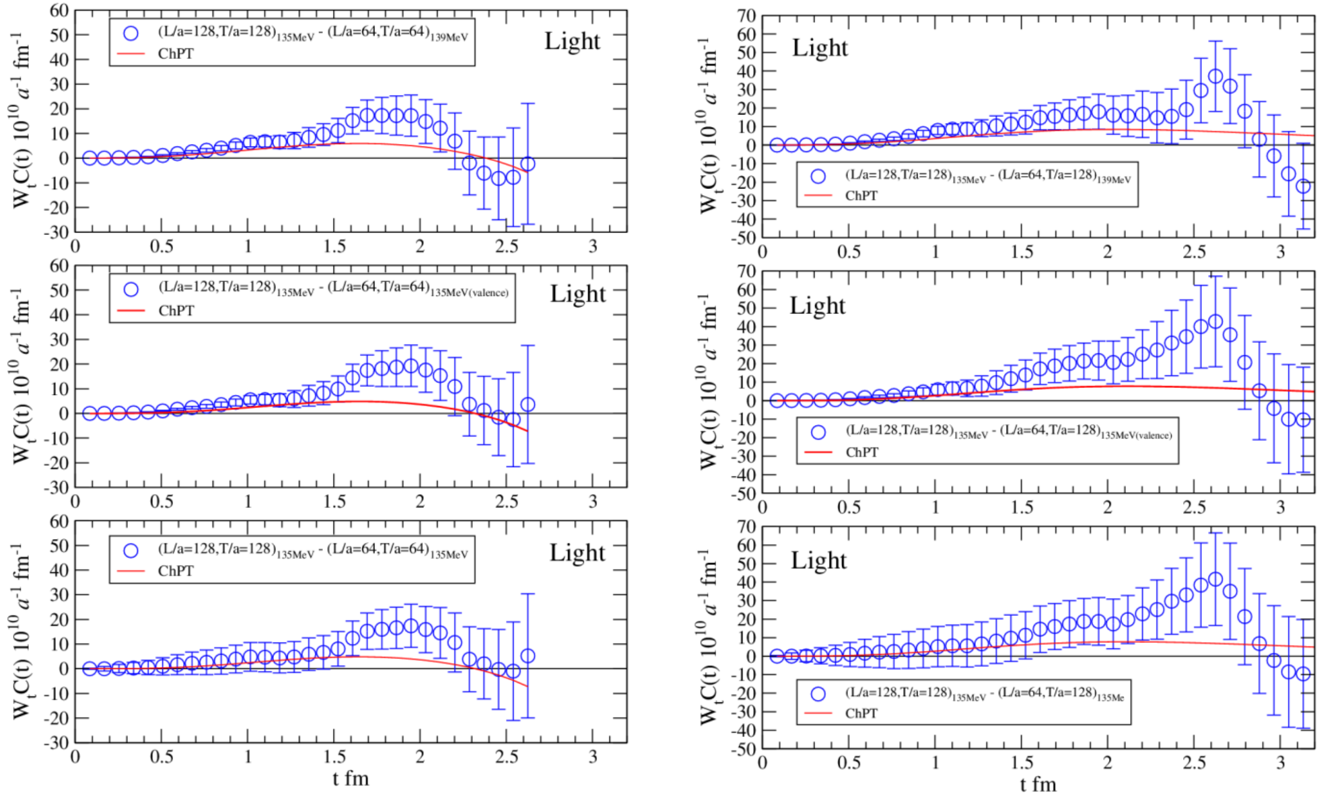
Comparison with 128^4 and 64^4

Integrand, T/a=64 | Integrand, T/a=128, extended t

m_π=139 MeV

m_π=135 MeV (valence)

m_π=135 MeV (reweighted)



- Backward propagation state significantly affects in T/a=64 from t~2 fm(~T/2)
  ⇒ check with extended temporal boundary   PACS 1805.04250
- LQCD estimate of FV correction is larger than ChPT at t>1.5 fm

3. Finite volume study

FV effect in L=5.4 fm

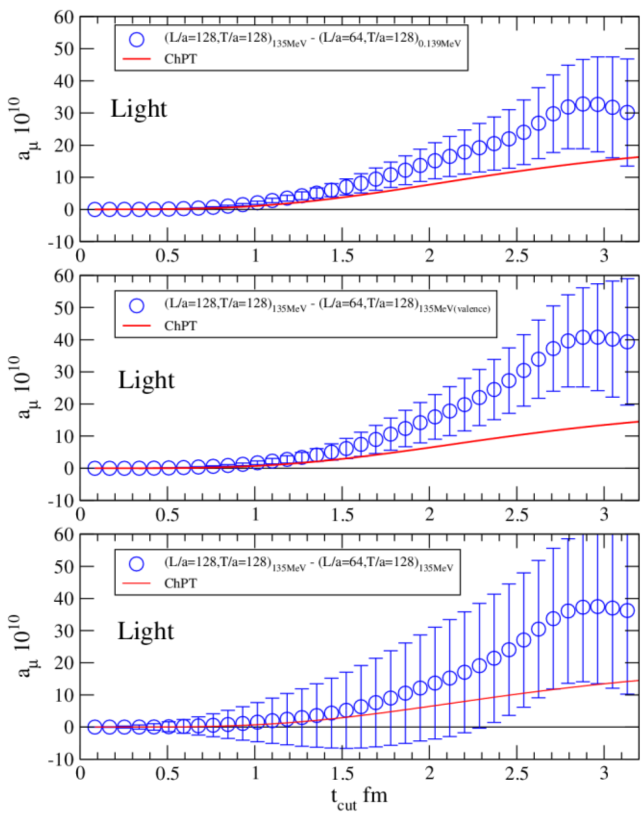
T-sum, T/a=128, extended t

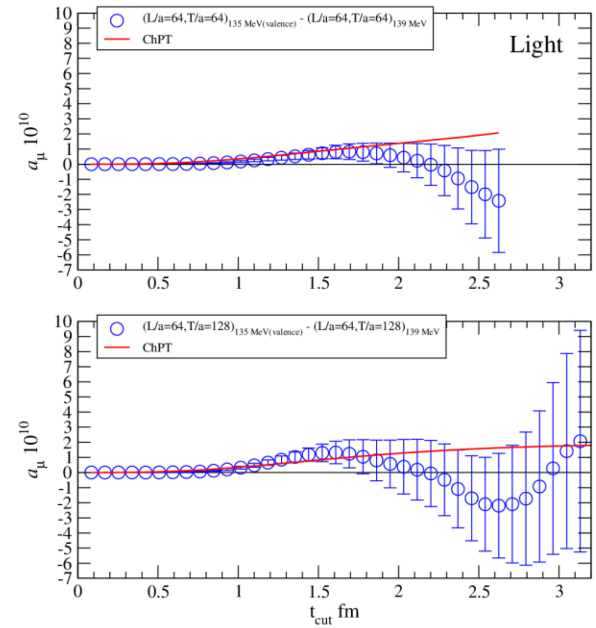
PACS 1805.04250

m_π=139 MeV

m_π=135 MeV (valence)

m_π=135 MeV (reweighted)



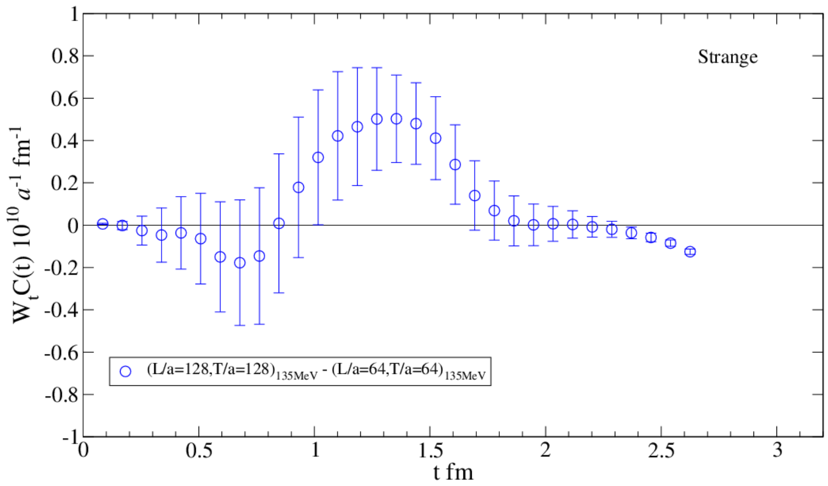


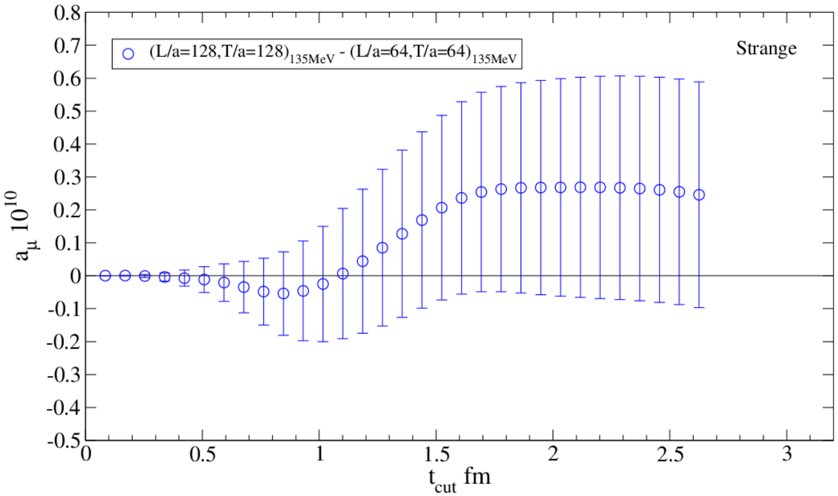
Mass correction (4 MeV) agrees with ChPT.

LQCD (t_{cut} = 3fm):

a_μ[L=10.8fm] - a_μ[L=5.4fm] = 40(18), ChPT: 14 ⇒ ~2.5x underestimate

3. Finite volume study
FV in Strange

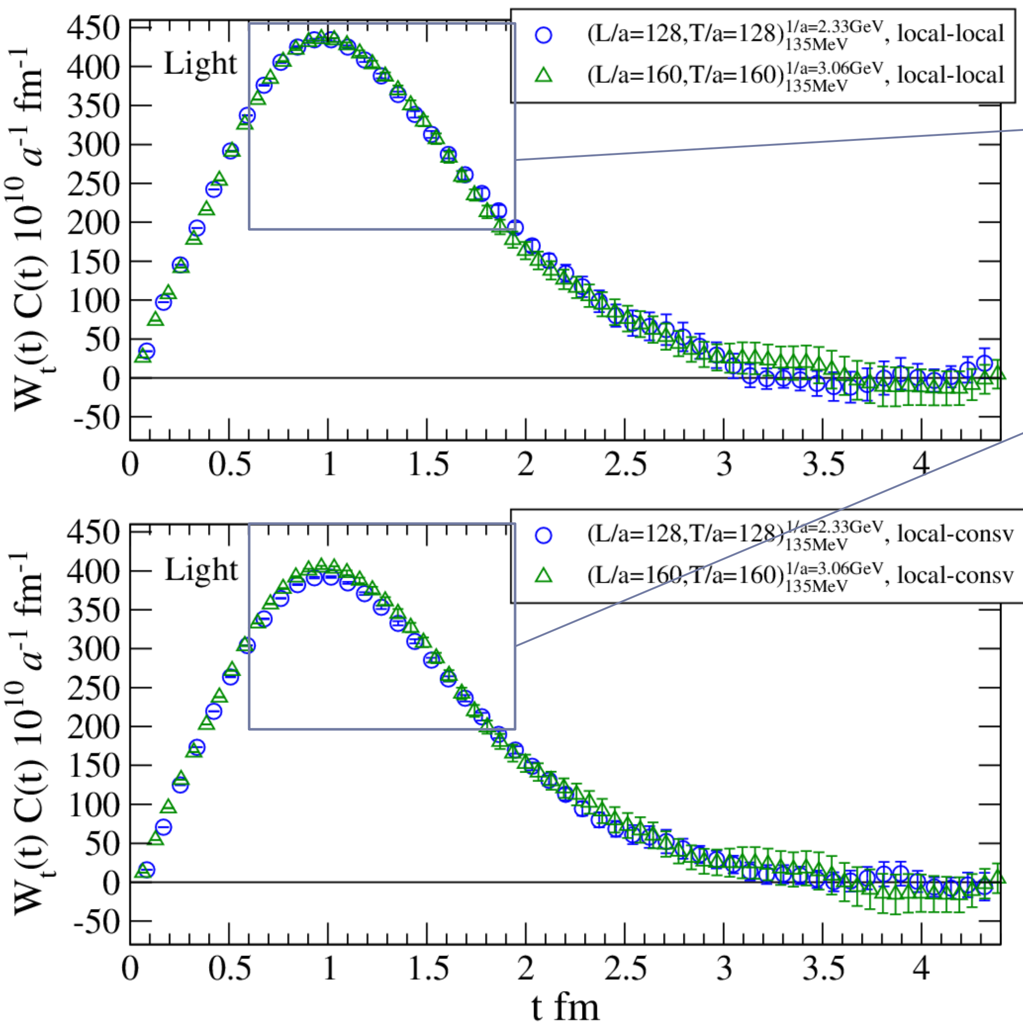


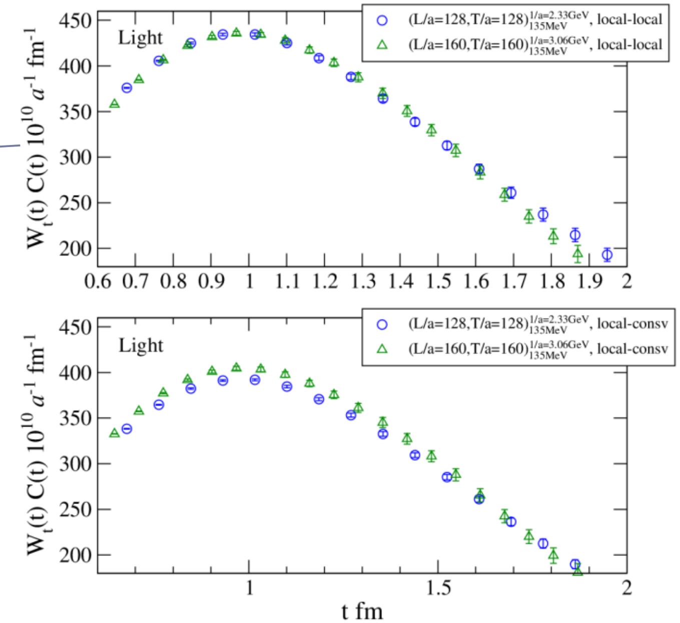


FV in strange is negligibly small.
⇒ light quark contribution is dominant

4. Lattice artifact study

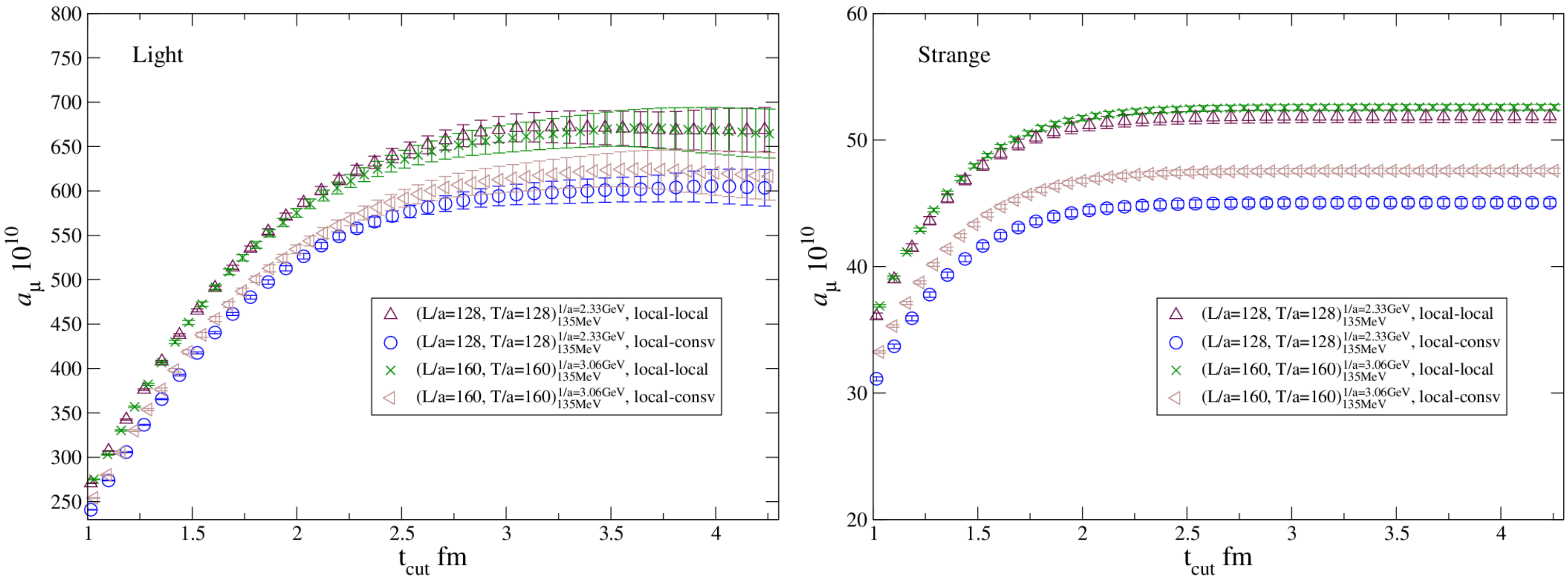
Comparison with a^{-1}=2.33 and 3.06 GeV





- Comparison between local-local and local-conserved(point-splitting) current.
- Local-local has good scaling rather than local-conserved one at t ~ 1 fm.

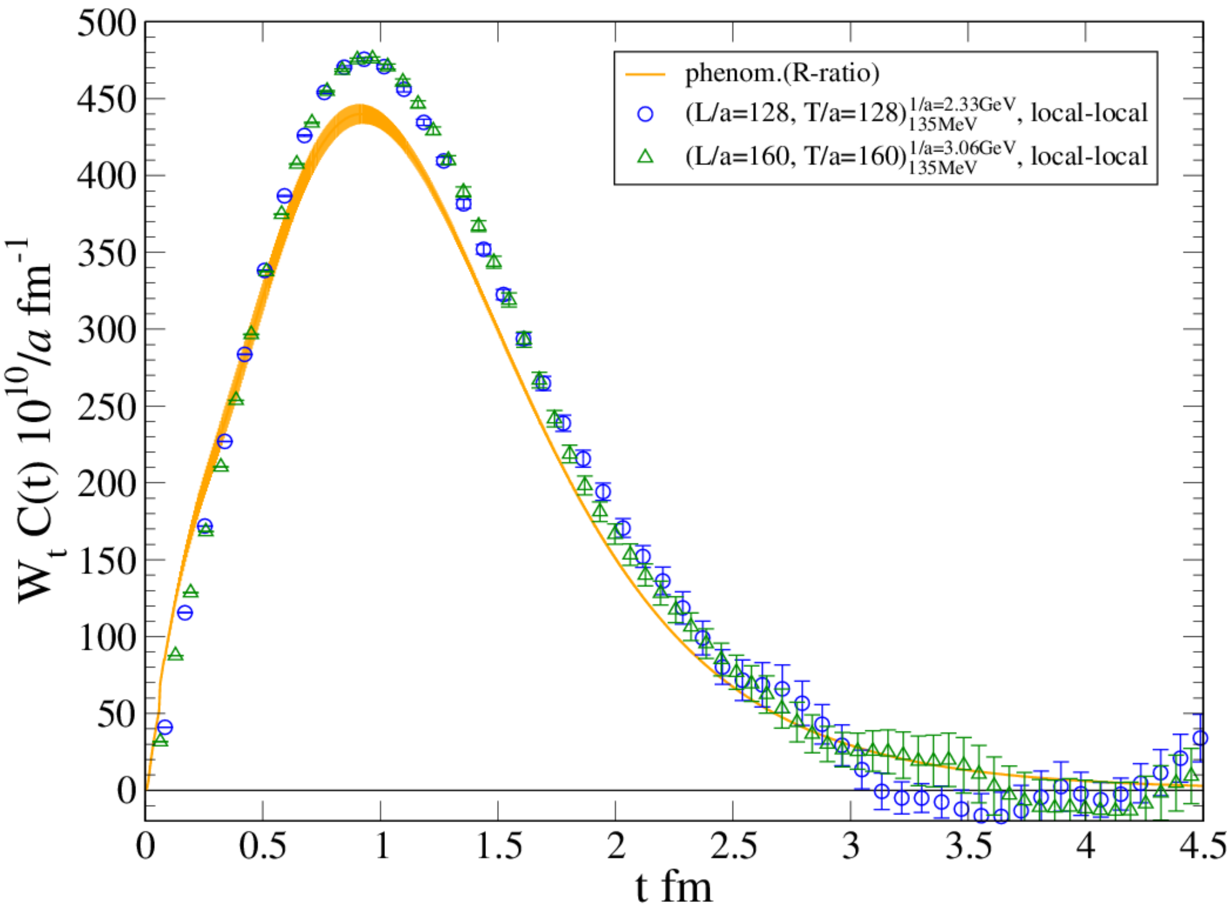
4. Lattice artifact study
Comparison with a^{-1}=2.33 and 3.06 GeV



- Small scaling violation in local-local current even without improvement.
- In local-conserved current, one can see 4—5 % cut-off effect in ud and s.

4. Lattice artifact study

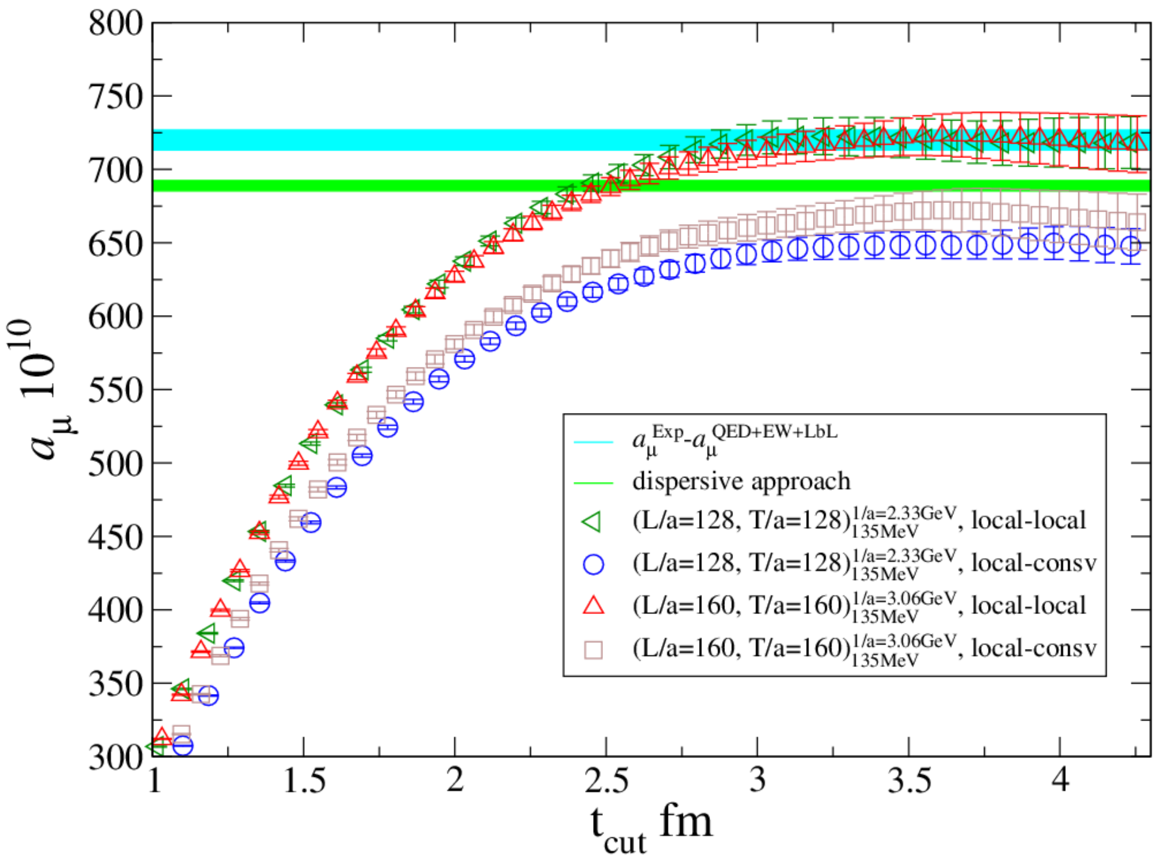
LQCD and phenomenology



- Compared to R-ratio, LQCD has large value at t < 3fm.
- From t ~ 3fm, R-ratio is relatively large, whose integral from t=3--∞ gives ~3% contribution in total a_μ.

4. Lattice artifact study

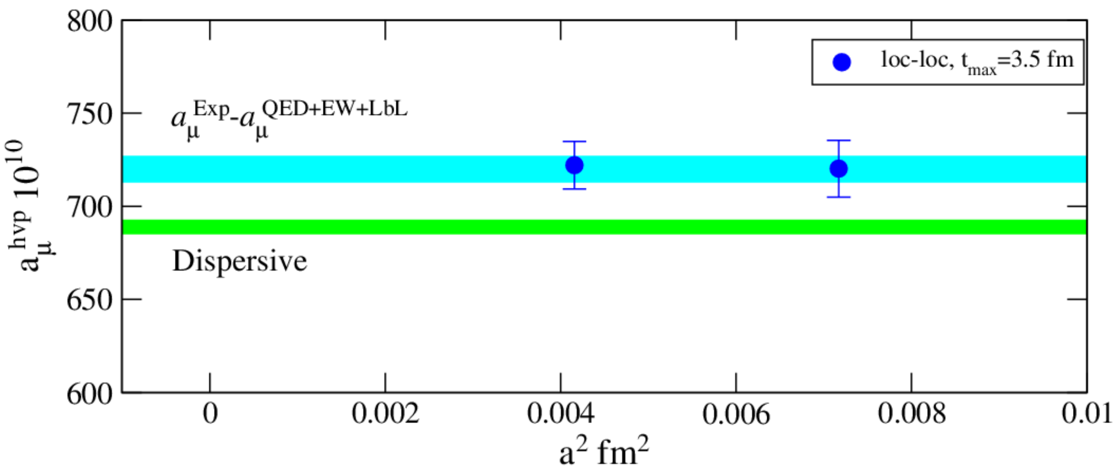
a_μ in LQCD and phenomenology

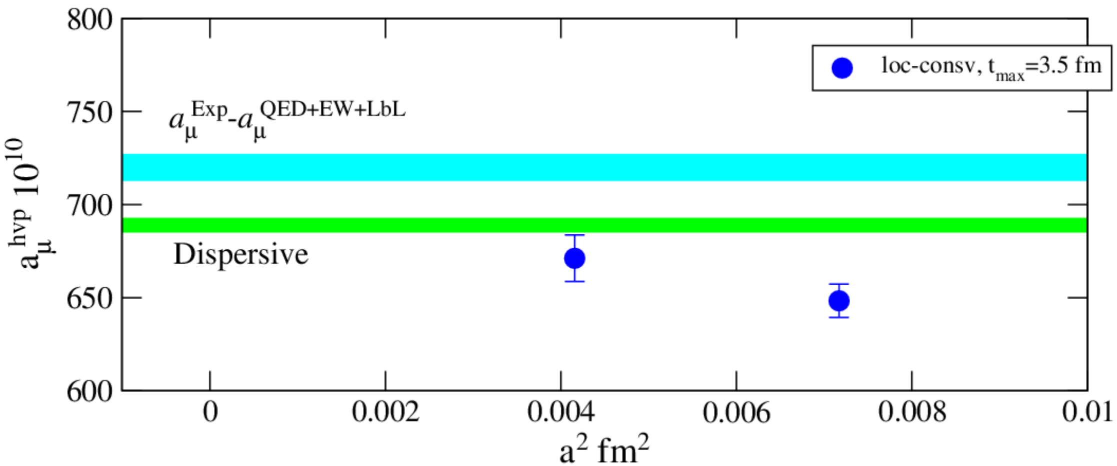


- t_{cut}>2.5 fm, we can see LQCD overshoot phenomenological estimate.
- t_{cut} > 3 fm, LQCD is saturated around $a_\mu^{Exp} - a_\mu^{QED+EW+LbL}$ ("no new physics")

4. Lattice artifact study

Cut-off effect in a_μ





- Estimate at t_{cut} = 3.5 fm, which may be ~1% truncation error.
- Scaling violation is not observed in local-local current beyond statistical error.
- LQCD will not favor phenomenological value.
- Continuum limit is mandatory, but not yet.

4. Summary

Outlook

- Updated result of FV study in LQCD. PACS 1805.04250
- FV study at physical pion
  - At t_{cut} = 3fm, LQCD estimate is ~2.5x larger than ChPT.
  - Possible impact to other LQCD estimate of FV based on ChPT.
- Lattice artifact study
  - Compared to two different cut-off
  - Scaling violation is small even in local-local current on PACS10, while local-conserved has large effect (4—5 %).
- Next work
  - $a_\mu^{ud} + a_\mu^{s}$ in LQCD is close to $a_\mu^{Exp} - a_\mu^{QED+EW+LbL}$ ("no new physics")
  - Missing $a_\mu^{c} + a_\mu^{disc}$, but may be <1%, since $|a_\mu^{c}| \sim -|a_\mu^{disc}| \sim 1\%$
  - Continuum limit is necessary for final result, need one more cut-off.

Backup

Backup
Operator dependence