PACS Collaboration for Muon g-2 Precision Physics (in Collaboration with J-PARC Muon g-2 Project)

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Talk at Muon g-2 Theory Initiative Workshop, August 5th, 2026

PACS - J-PARC Joint Collaboration

- PACS: Takeshi Yamazaki and K.M.
- J-PARC: Tsutomu Mibe, Tamaki Yoshioka

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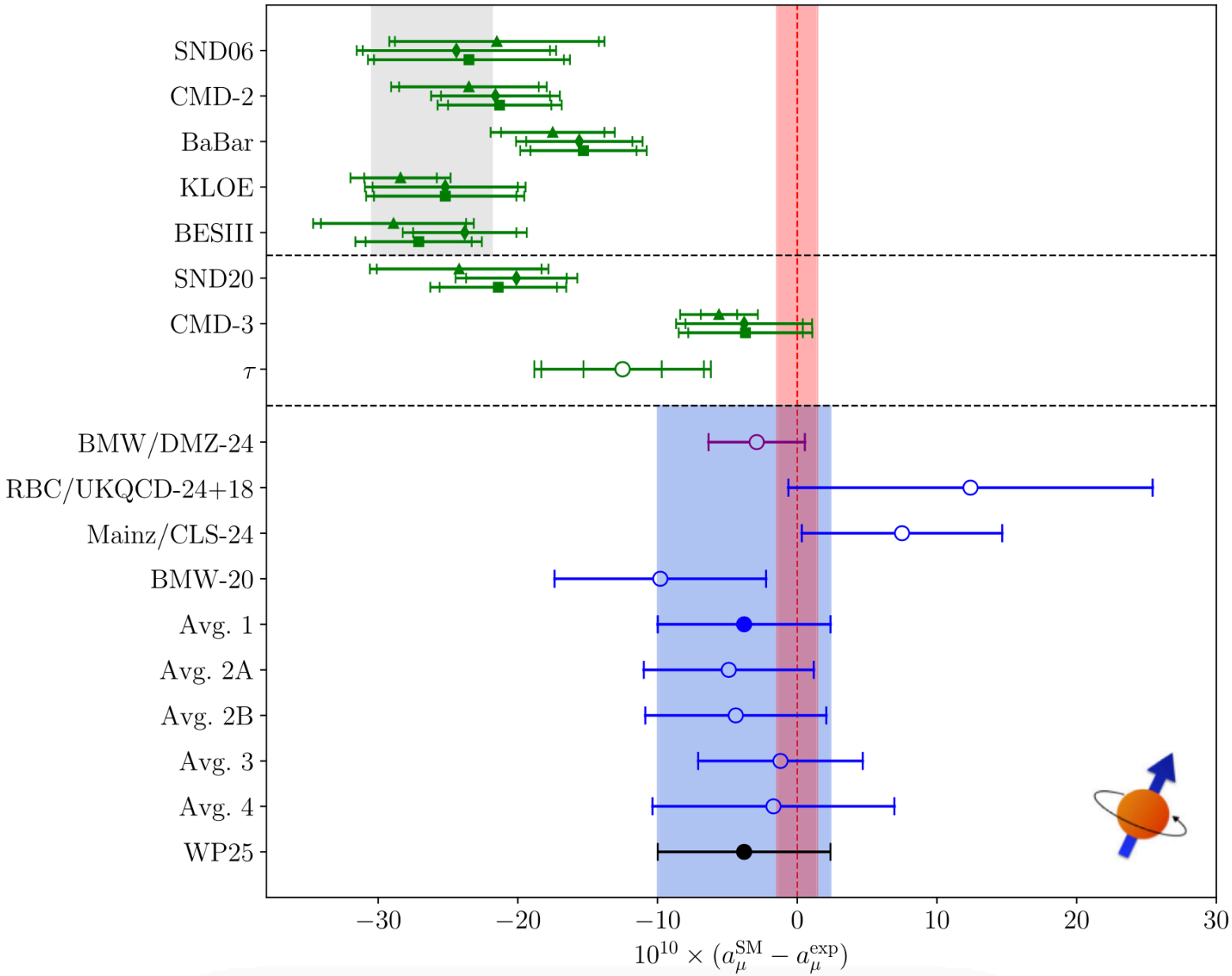
Muon g-2 Whitepaper-2025



Requirements Near Future

Request for Theory (Standard Model Prediction):

- Precision: 0.2% uncertainty for HVP contributions to muon g-2 (a_μ^{HVP}).
- Consistency: Understand the origin of tensions between Lattice QCD and Data-Driven Approach, and establish Theory Consensus.

J-PARC (Yamanaka-san's Talk Today):

- A novel idea (Ultra-Cold Muon Beam) without electric field tuning, aiming at a level of 0.1*ppm*.
- Completely independent systematics from the FNAL/BNL.
- Muon EDM and CP violation.

Guide

PACS Collaboration: Lattice QCD Group around University of Tsukuba

PACS = Parallel Array Computer System

PACS10

N_f	2+1 (PACS10)			2+1+1 (PACS10$_c$)		
$L^3 \cdot T$	128^4	160^4	256^4	128^4	168^4	256^4
L [fm]	10.9	10.2	10.5	10.7	10.5	$\sim$10.5
a [fm]	0.08	0.06	0.04	0.08	0.06	$\sim$0.04
m_π [GeV]	0.135	0.138	0.141	0.137	0.137	$\sim$0.137
m_K [GeV]	0.497	0.505	0.514	0.498	0.497	$\sim$0.497

PACS10 Ensemble

- $N_f = 2 + 1(+1)$ six-stout-smeared non-perturbarively $\mathcal{O}(a)$-inproved Wilson quark + Iwasaki gauge action.
- PACS10/L128,L160,L256 are generated in the Fugaku Supercomputer. PACS10$_c$/L256 is still under way (Publication: PACS10/L128 [PRD101,9,094504(2020)] PACS10/L160 [PRD106,9,094501(2022)]).
- Ensambles are mainly generated and managed by Ukita-san.

PACS10: Spacelike Pion Form Factor Preliminary

✓ π^+ charge radius

Combination
(BaBar, KLOE and so on)

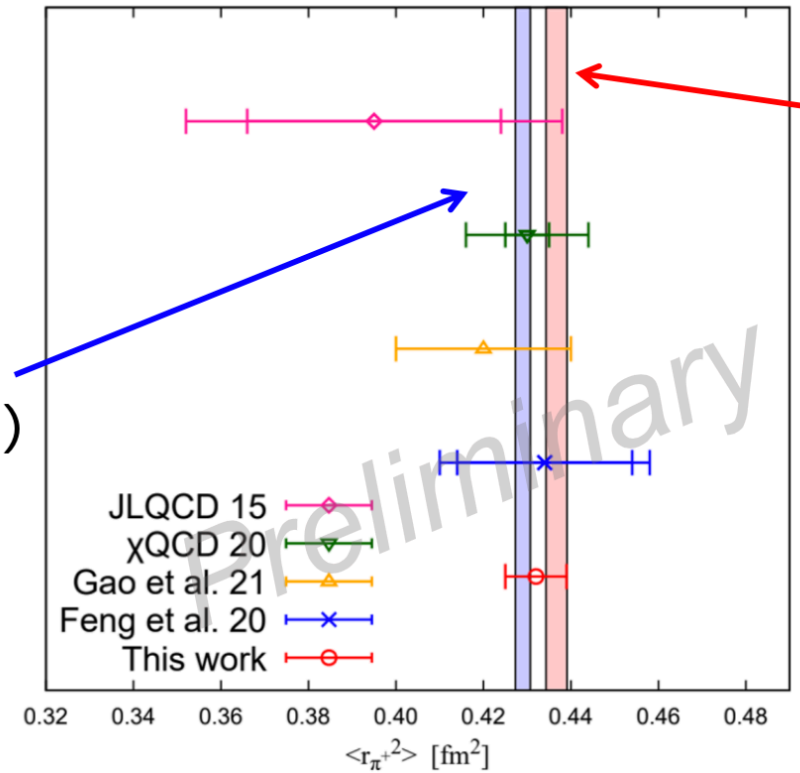


Figure: Borrowed from Sato-san's slide in Lattice 2026

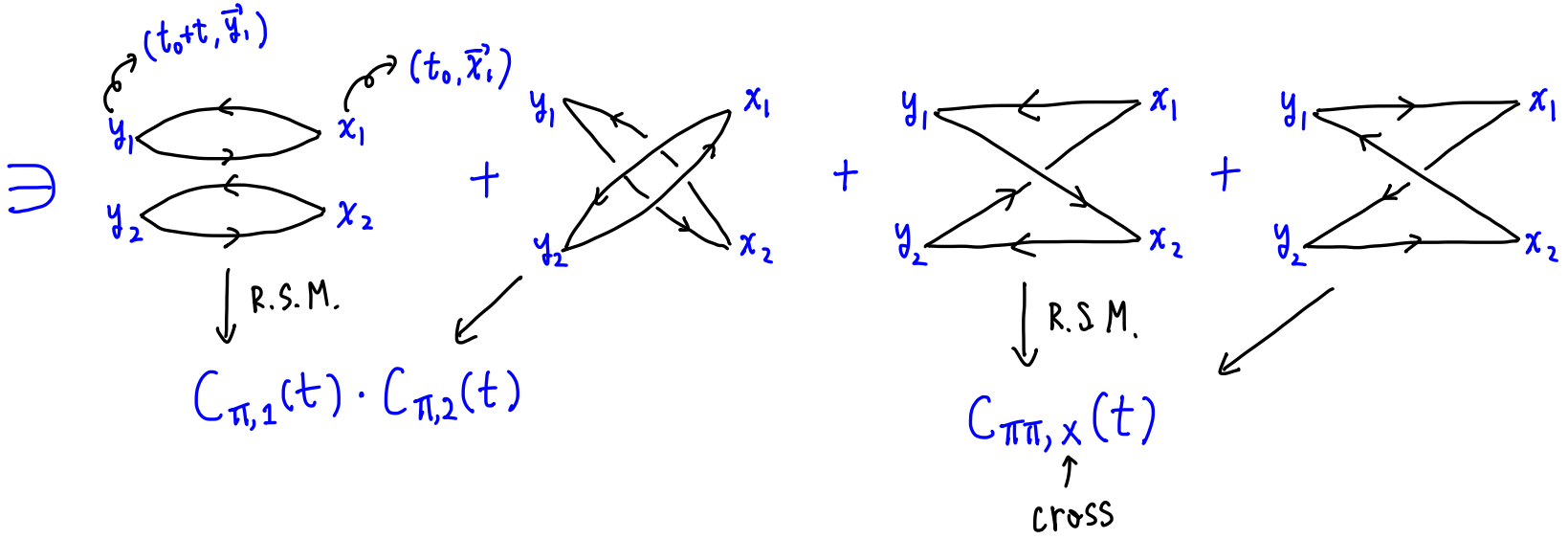
Guide

- Pilot Study: $I = 2$ Two-Pion Scattering using PACS5.
- PACS5: Same as PACS10/L128 except for $5fm$ Volume. Generated by Ukita-san.
- Toward Timelike Pion Form Factor.

$I = 2$ Two-Pion Scattering Length

$$C_{\pi\pi}(t) = \left\langle (\pi^+\pi^+)(\vec{P}, t+t_0)\ (\pi^+\pi^+)^\dagger(\vec{P}, t_0) \right\rangle$$

- $(\pi^+\pi^+)(\vec{P}, t) = \pi^+(\vec{P}_1, t)\,\pi^+(\vec{P}_2, t+1)$
- $\pi^+(\vec{P}, t) = \frac{1}{L^{3/2}} \sum_{\vec{x}} e^{-i\vec{P}\cdot\vec{x}} (\bar{d}\,\gamma_5\,u)^\dagger(\vec{x}, t)$



$I = 2$ Two-Pion Scattering Length

$$C_{\pi\pi}(t) = 2\left(C_{\pi,1}(t) \cdot C_{\pi,2}(t) + C_{\pi\pi,x}(t) \right)$$

large t

$$\sim e^{-m_\pi t} + A \qquad \sim e^{-E_{\pi\pi} t} + B$$

$$R(t) = \left\langle \frac{C_{\pi\pi,x}(t) - C_{\pi\pi,x}(t+1)}{C_{\pi,1}(t) \cdot C_{\pi,2}(t) - C_{\pi,1}(t+1)\, C_{\pi,2}(t+1)} \right\rangle \sim e^{-\Delta E_{\pi\pi}}$$

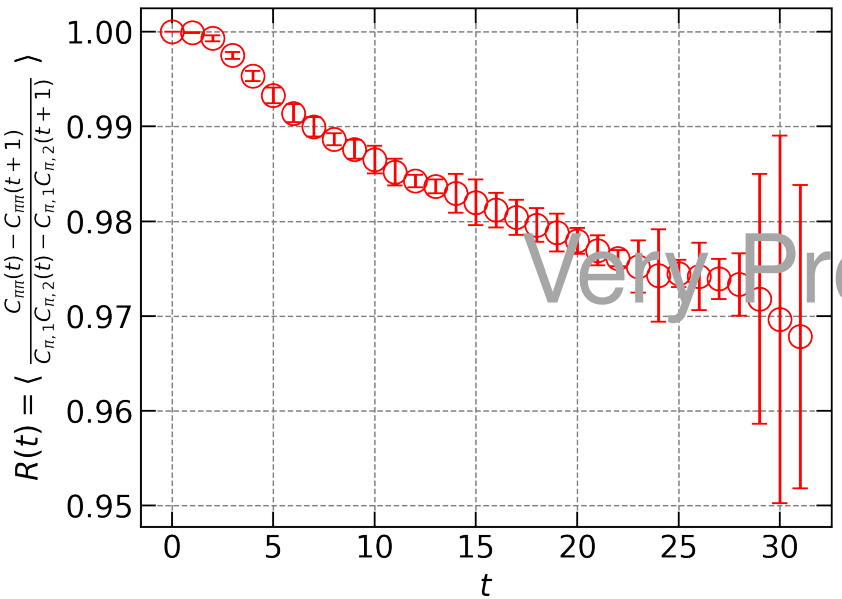
$\Delta E_{\pi\pi} = E_{\pi\pi} - 2m_\pi$: Binding Energy

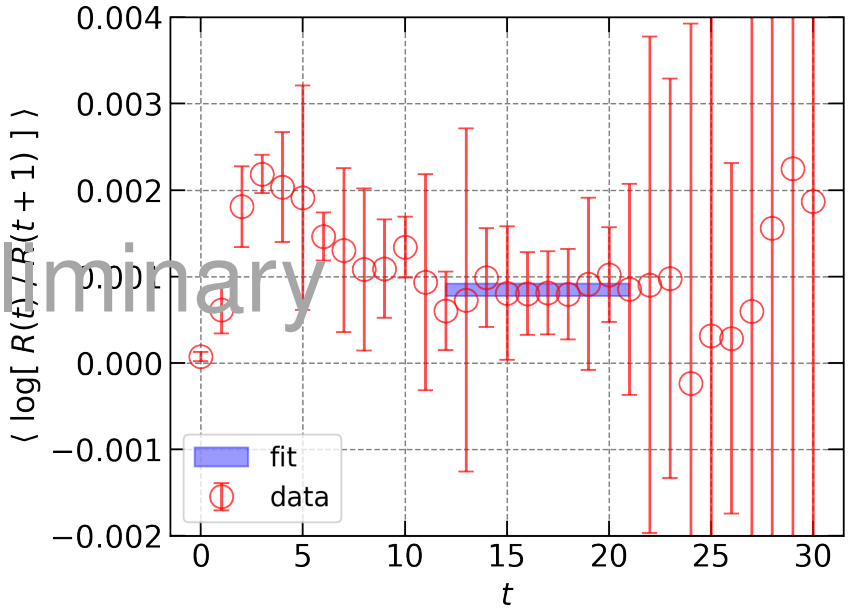
$I=2$, two Pion Scattering Length

$$\Delta E_{\pi\pi} L = \frac{4\pi}{m_\pi L} \frac{a_{\pi\pi}}{L} \left(1 - 2.837297 \frac{a_{\pi\pi}}{L} + 6.375183 \left(\frac{a_{\pi\pi}}{L} \right)^2 \right)$$

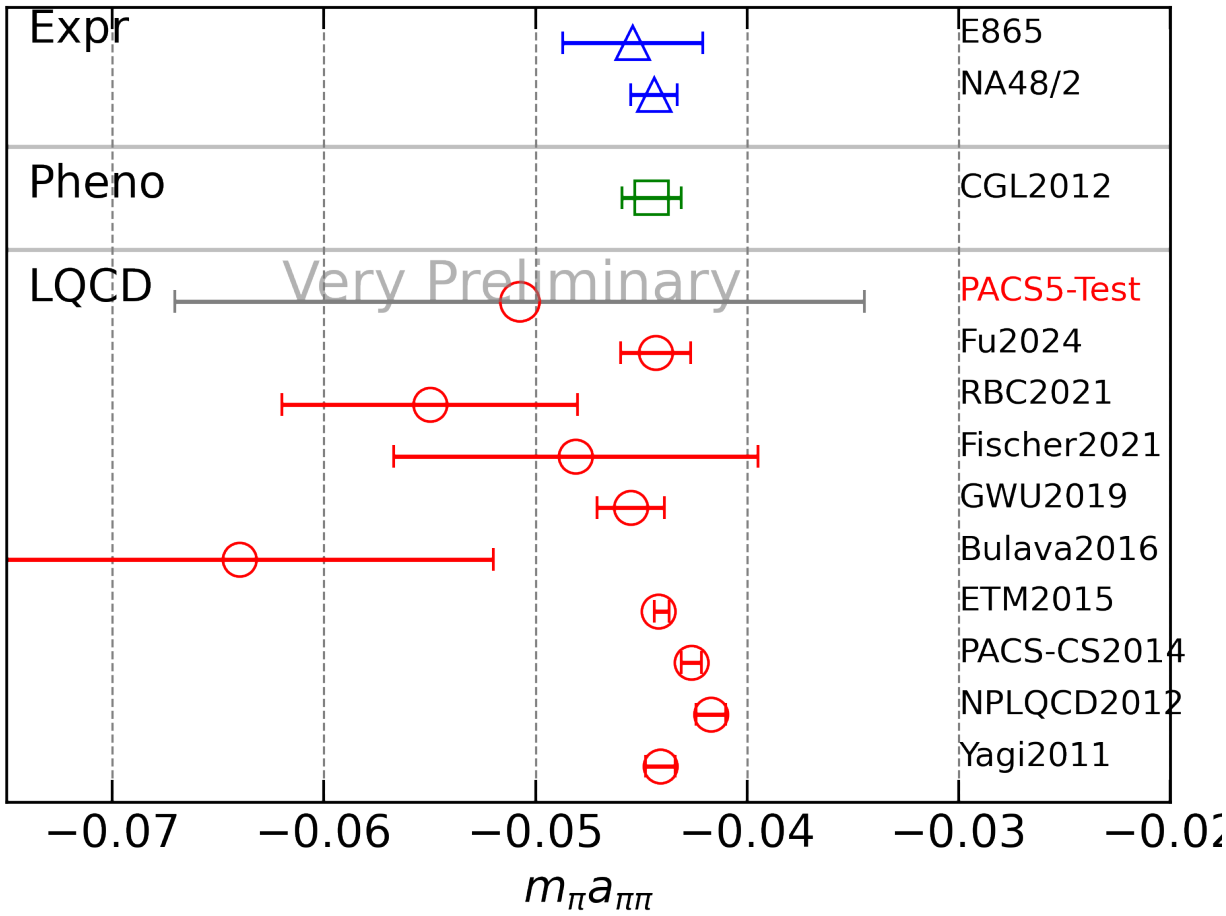
Lüscher [Commun. Math. Phys. **104 & 105**, (1986)]

$I = 2$ Two-Pion Scattering Length





$I = 2$ Two-Pion Scattering Length

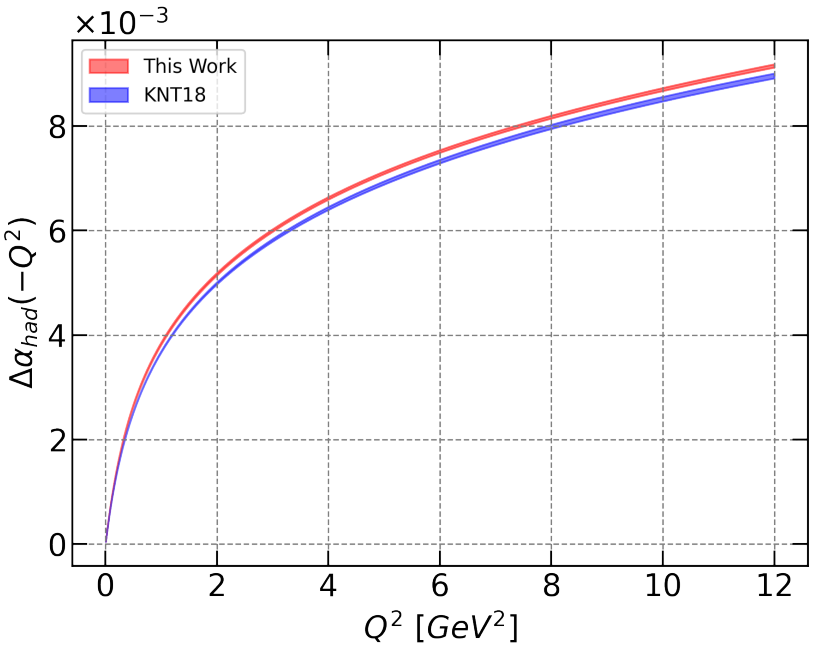


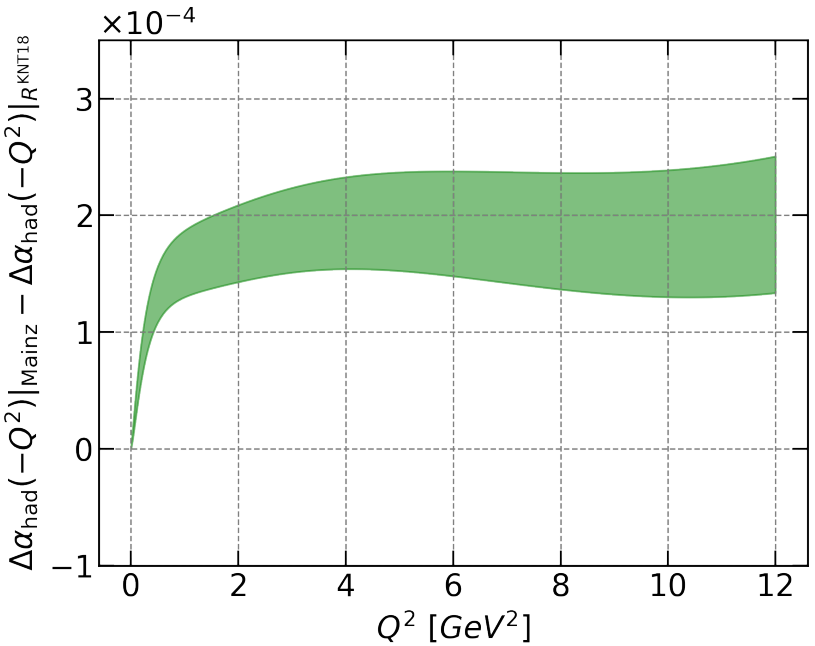
Summary

- Utilizing PACS10 ensembles, most of which are already generated, we aim at 0.2% precision physics on the muon g-2.
- This will be proceeded via various comparisons of observables which can be calculated by the data-driven approach.
- The first observable will be the spacelike and timelike pion form factors.
- A time scale for the latter is approximately one year: We plan to apply the GEVP including the extended operator sets and higher eigen energies.
- This will naturally bring us to the subject of the long-distance control on the muon g-2.
- Measurements will be carried out on the large GPU clusters alloated in the University of Tsukuba.

Backup

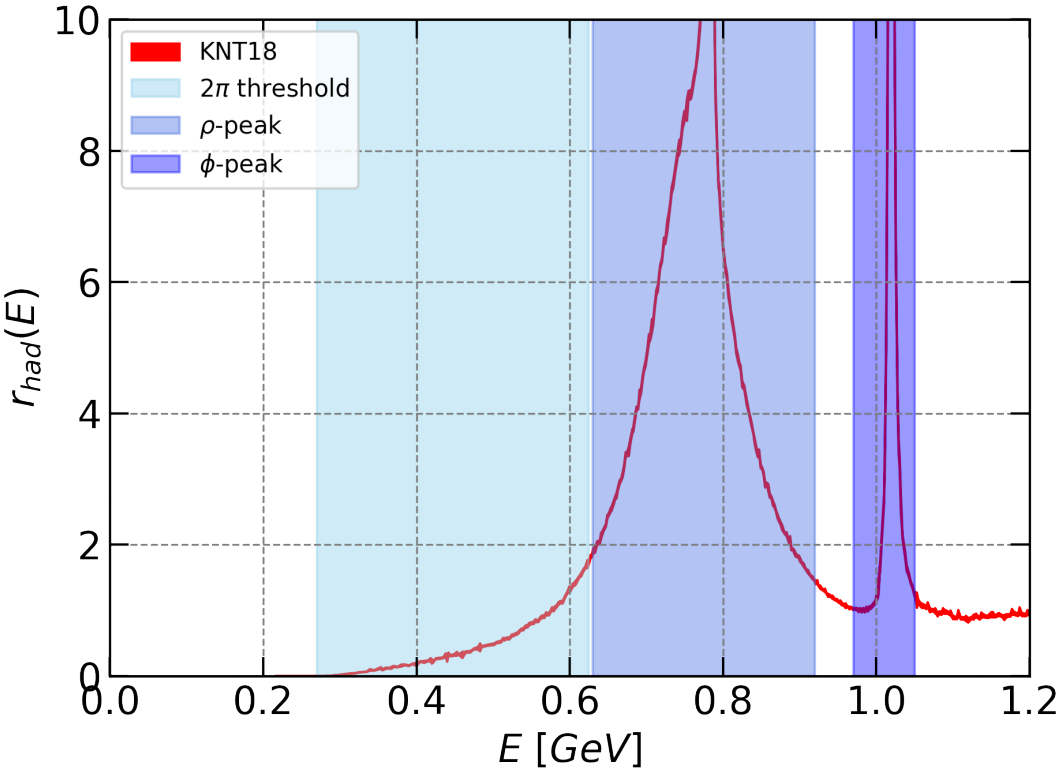
LQCD(Mainz2025) vs. Data Driven(R-ratio)





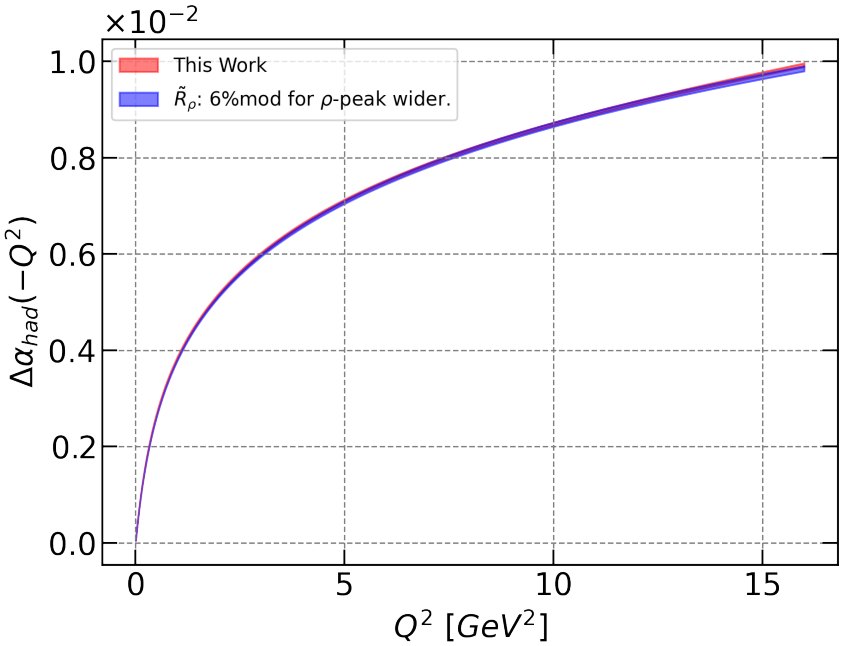
Large tension between Mainz-2025 and Data Driven (R-ratio, KNT-18) Approach.

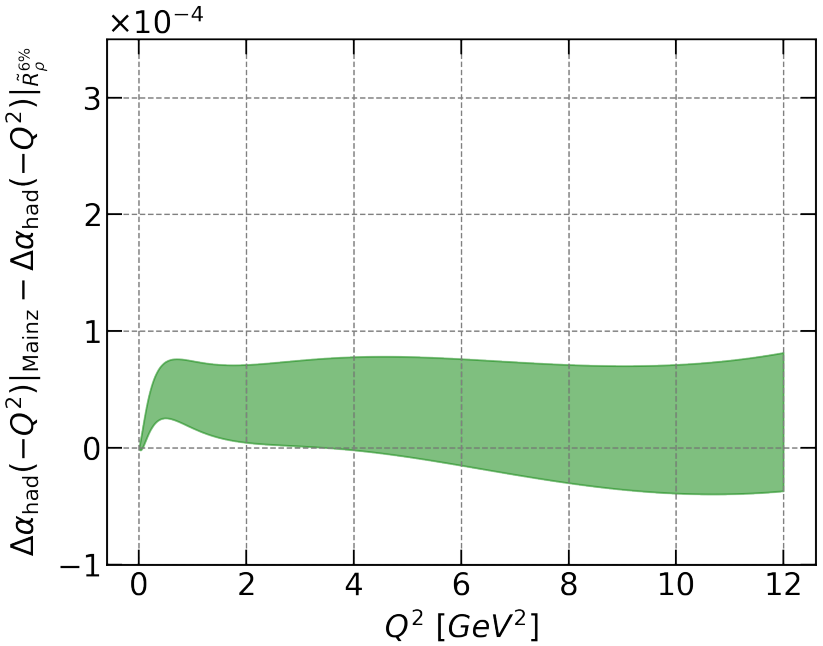
R-Ratio Modification



$$\Delta\alpha_{\text{had}}(-Q^2)|_{\tilde{R}^{6\%}} = \frac{\alpha Q^2}{3\pi}\int_0^\infty ds \frac{\tilde{R}^{6\%}(s)}{s(s+Q^2)} \,. \tag{1}$$

LQCD(Mainz2025) vs. Data-Driven($\tilde{R}_\rho^{6\%}$)





- 6% modification for ρ-peak region makes the data driven approach be consistent with Mainz-2025.
- This observation is also consistent with previous work (BMW-Pheno Collab. PRD'24).