RCs of Meson Decays with Lattice Method

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Background

Meson decays could provide the calculation of some basic parameters of the Standard Model, like the CKM matrix elements. The $|V_{ud}|$ could be derived from the π_{e3} decays, while the $|V_{us}|$ from the $K_{\ell 3}$ decays.
With the uncertainty reaching $\sim 1\%$, the electroweak(EW) Radiative Corrections (RCs) becomes non-negligible.

Introduction

Among various EWRCs, the electroweak radiative corrections involving the axial-vector current become important and ultimately dominate the theoretical uncertainties.
The relevant Feynman diagram to the axial γW-boson box contribution $\Box^{VA}_{\gamma W}$ is shown below.

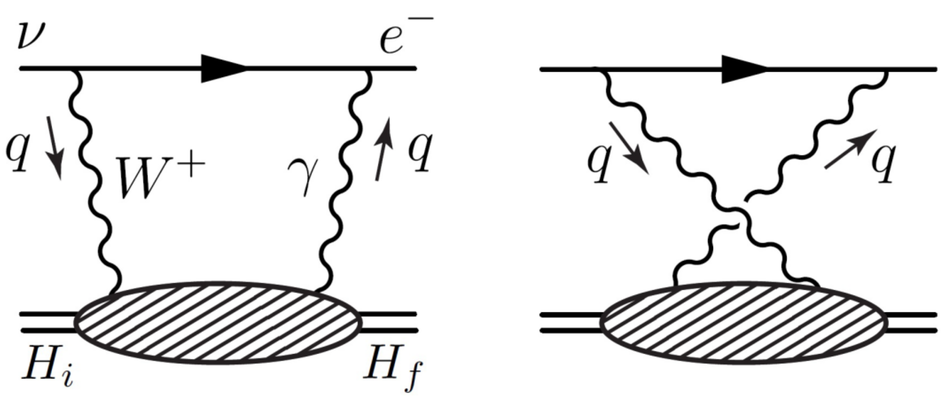

Figure 1: γW-box diagrams.

Methodology

We perform the first realistic lattice QCD calculation of the γW-box correction to the pion semileptonic decay.

- For small Q^2, lattice QCD can determine $M_H(Q^2)$.
- For large Q^2, we utilize the operator product expansion.

Computations for this work were carried out on the Blue Gene/Q (BG/Q) Mira computer at the Argonne Leadership Class Facility and Tianhe 3 prototype at Chinese National Supercomputer Center in Tianjin.
We use five lattice QCD gauge ensembles with multiple lattice spacings and volumes at the physical pion mass to control the continuum and infinite-volume limits.

lattice-setup

Ensemble	m_π[MeV]	L	T	a^{-1}[GeV]	$N_{\rm conf}$	N_r	$\Delta t/a$
24D	141.2(4)	24	64	1.015	46	1024	8
32D	141.4(3)	32	64	1.015	32	2048	8
32D-fine	143.0(3)	32	64	1.378	71	1024	10
48I	135.5(4)	48	96	1.730	28	1024	12
64I	135.3(2)	64	128	2.359	62	1024	18

Table 1: Ensembles used in this work.

Numerical results

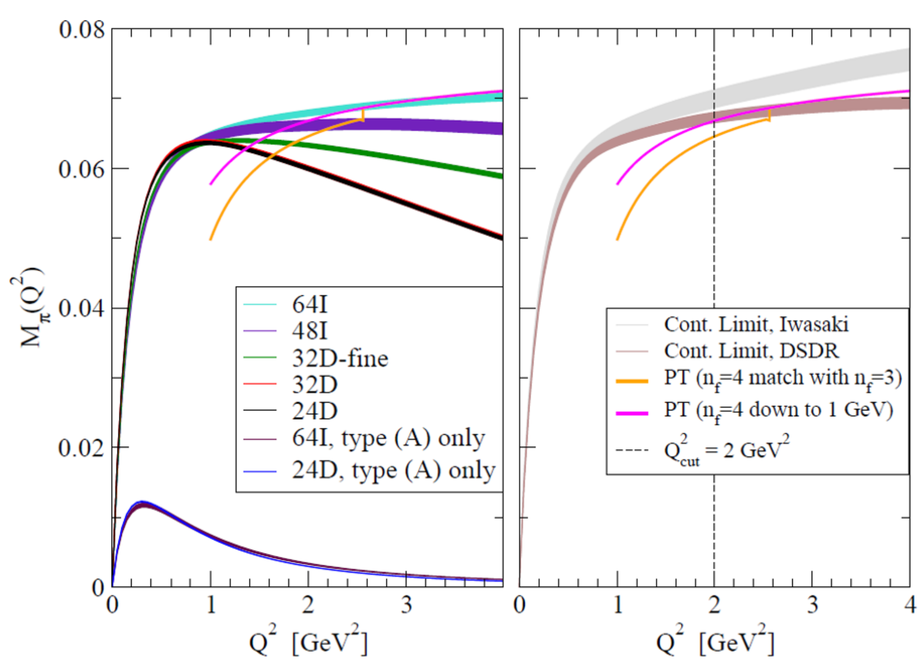

Figure 2: $M_\pi(Q^2)$ as a function of Q^2.

$$\delta = 0.0334(10)_{\rm LECs}(3)_{\rm HO} \to 0.0332(1)_{\gamma W}(3)_{\rm HO}$$

$$|V_{ud}| = 0.9739(28)_{\rm exp}(5)_{\rm th} \to 0.9740(28)_{\rm exp}(1)_{\rm th}$$

Conclusion

- The uncertainty of the theoretical prediction for the pion semileptonic decay rates is reduced by a factor of 3.
- For Kaon decays, the application could give the LECs of ChPT with reasonable uncertainty estimate.
- The technique presented in this work can be straightforwardly generalized to a lattice calculation of the nucleon γW-box corrections.
- This work has been published on Phys. Rev. Lett. **124**, 192002 (2020) and Phys. Rev. D **103**, 114503 (2021).

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