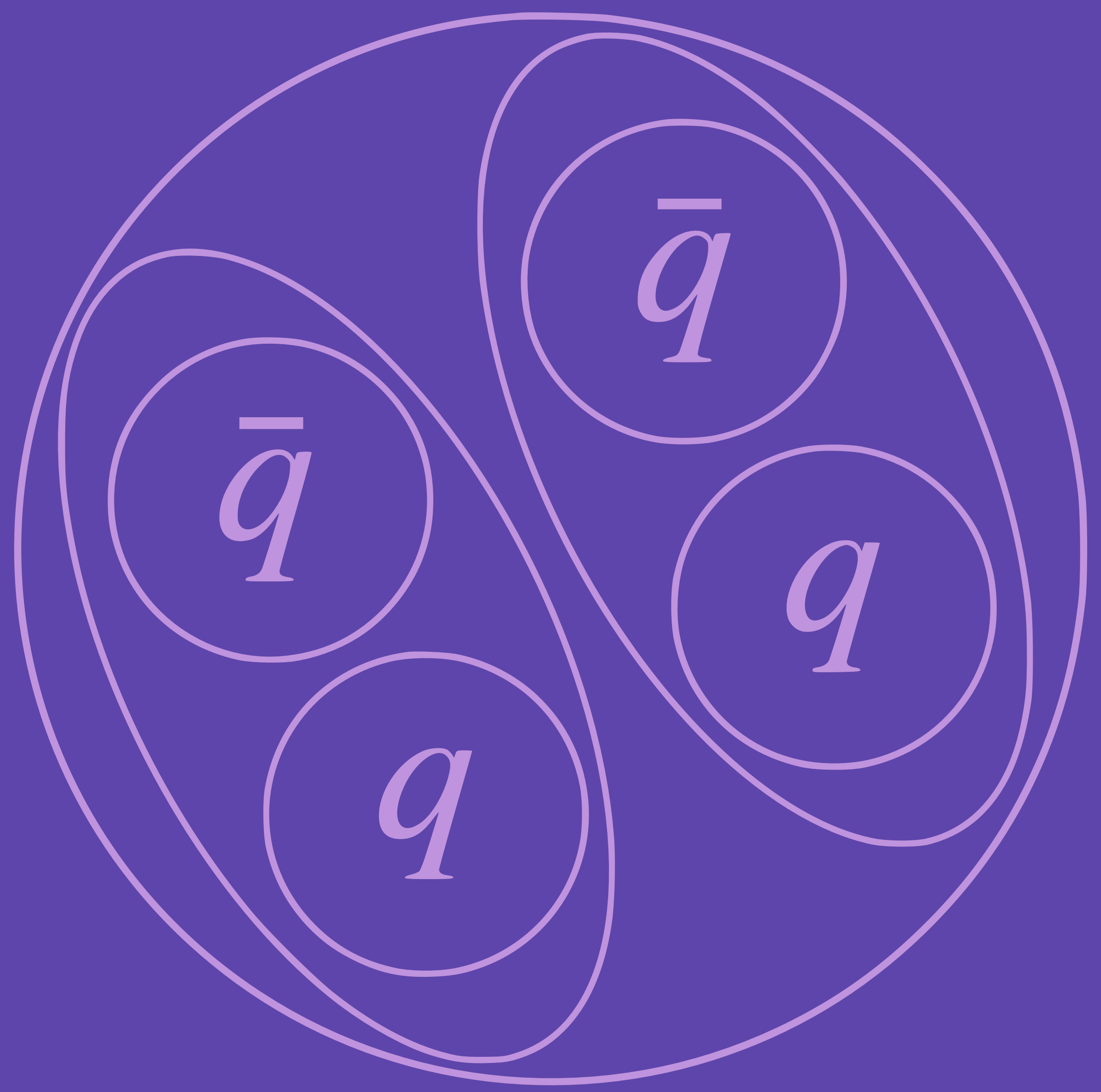
Pion mas dependence of the $T_{cc}(3875)^+$ and $\chi_{c1}(3872)$ from Lattice QCD

Fernando Gil Domínguez

Du MengLin



第十一届手征有效场论研讨会

2026.08.15

Motivation

- **Exotic States of interest**: The $\chi_{c1}(3872)$ and the recently observed $T_{cc}(3875)^+$ highlight the need to explore their unique properties and structure. Both lie remarkably close to heavy-meson thresholds, suggesting a non-ordinary nature.

- **Testing Molecular State Hypothesis**: Their small binding energies and proximity to their thresholds make them prime candidates for molecular state studies. A joint analysis allows testing the universality of the molecular mechanism in the charm sector.

- **Connecting Theory and Observation**: Accurate theoretical predictions can clarify experimental and LQCD findings and guide new investigations into charm physics.

$T_{cc}(3875)^+$ and $\chi_{c1}(3872)$ quark mass dependence

Scattering amplitude for DD^*

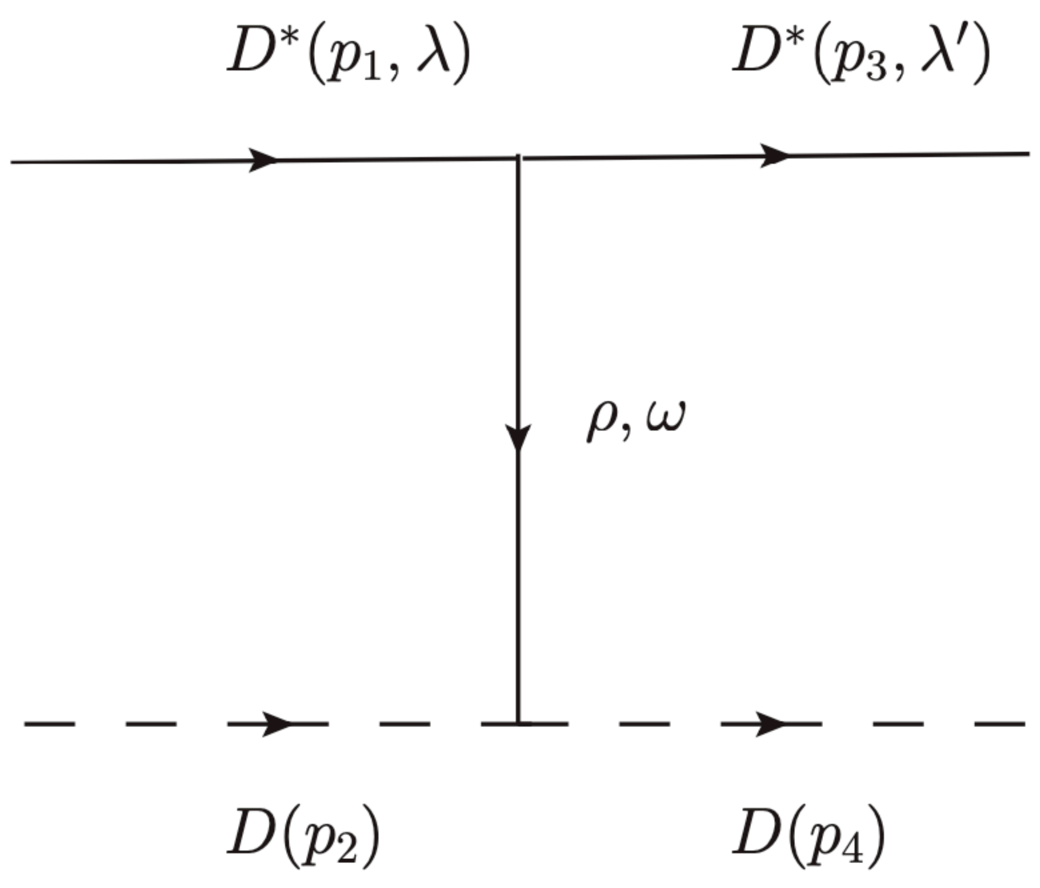
The Lagrangian

Hidden Gauge Lagrangian

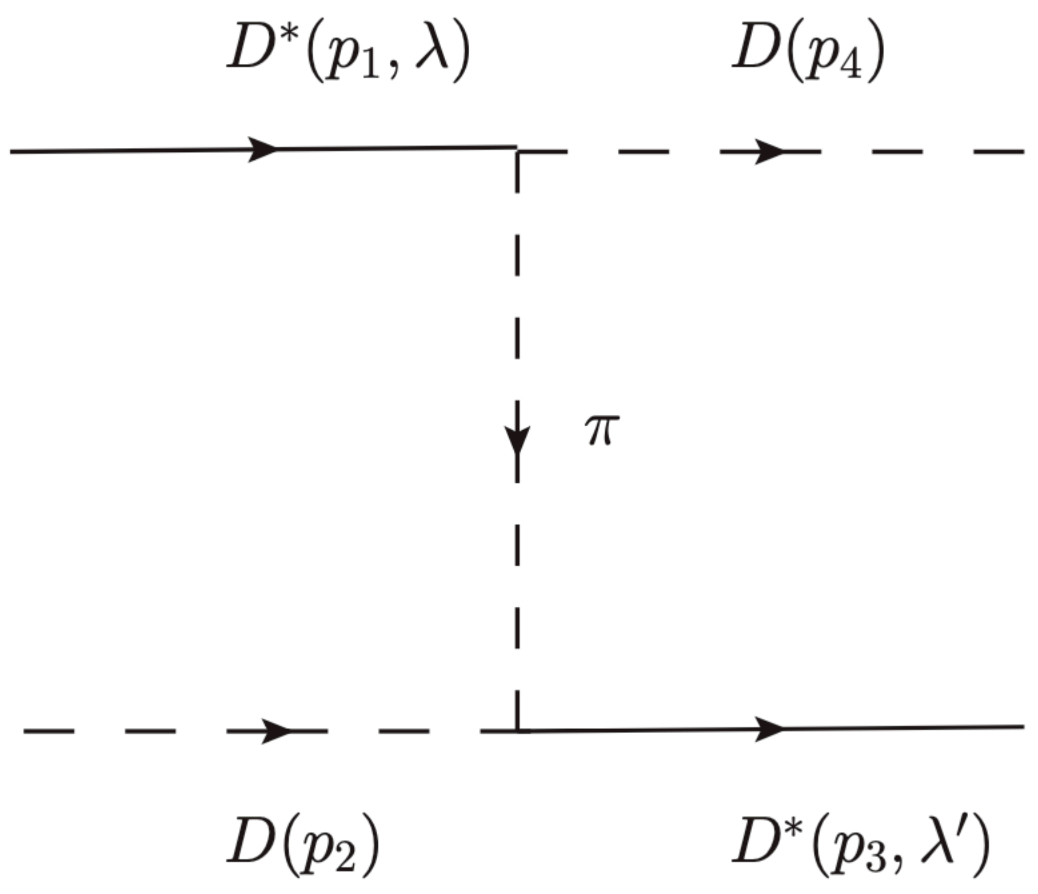
- $\mathscr{L}_{VPP} = ig < [\partial_\mu \Phi, \Phi] V^\mu >$
- $\mathscr{L}_{VVV} = ig < [V^\mu, V^\nu] \partial_\mu V_\nu >$

The diagrams

ρ exchange



π exchange



$T_{cc}(3875)^+$ and $\chi_{c1}(3872)$ in the finite volume

$$V_\rho = g_\rho^2 \frac{(E_1 + E_3)(E_2 + E_4) - (\overrightarrow{p_1} + \overrightarrow{p_3}) \cdot (\overrightarrow{p_2} + \overrightarrow{p_4})}{-(\overrightarrow{p_1} - \overrightarrow{p_3})^2 - m_\rho^2} \overrightarrow{\epsilon_\lambda} \cdot \overrightarrow{\epsilon_{\lambda'}}^*$$

$$V_\pi = \frac{3}{2} g_\pi^2 D_\pi (2\overrightarrow{p_4} - \overrightarrow{p_1}) \cdot \overrightarrow{\epsilon_\lambda}\, (2\overrightarrow{p_2} - \overrightarrow{p_3}) \cdot \overrightarrow{\epsilon_{\lambda'}}^*$$

$$V_{c\bar{c}} = \frac{c^2}{s - m_{c\bar{c}}{}^2} \overrightarrow{\epsilon_\lambda} \cdot \overrightarrow{\epsilon_{\lambda'}}^*$$

For the $T_{cc}(3875)^+$

$$V_{\lambda\lambda'}^{T_{cc}}(p, p') = V_\rho + V_\pi$$

For the $\chi_{c1}(3872)$

$$V_{\lambda\lambda'}^{\chi_{c1}}(p, p') = 2V_\rho + V_\pi + V_{c\bar{c}}$$

Momentum dependent LSE

$$T(s,p,p') = V(p,p') + \frac{4\pi}{(2\pi)^3}\int_0^{q_{max}} q^2 dq\, V(p,q)I(s,q)T(s,q,p'),$$

Plane wave basis method

We solve the following determinant to fit the energy levels.

$$\det\left[1 - \frac{1}{L^3}\frac{\sqrt{s}}{P^0}\sum_{\vec{n}}^{q_{\max}} U^\Gamma V(p,q)I(q)\left(U^\Gamma\right)^\dagger\right] = 0$$

- Here, U^Γ is the projection matrix from the momentum and vector polarization basis to the finite volume irrep basis.
- And $I(q)$ is defined as

$$I(q) = \frac{\omega_{D^*}(q) + \omega_D(q)}{2\omega_{D^*}(q)\omega_D(q)\left[s - (\omega_{D^*}(q) + \omega_D(q))^2 + i\epsilon\right]}$$

Lattice data sets

For the $T_{cc}(3875)^+$

Col.	a	L	m_π	$M^{c\bar{c}}_{avg}$
Padmanath24 [179][182]	0.086	2.07 – 2.76	280	3103
CLQCD22 [180]	0.152	2.4	349	3069
HSC24 [183]	0.120	1.9 – 2.9	391	3024
HALQCD23 [181]	0.0846	8	146	3097
HALQCD14 [206]	0.0907	2.9	411	3070

Col.	m_π	Set	$\bar{m}_D$
Padmanath24 [179][182]	280	1	1864
		2	2019
		3	2148
		4	2269
		5	2484

- F. Gil-Dominguez, A. Giachino and R. Molina, Phys. Rev. D 111, 1 (2025)

Lattice data sets

For the $\chi_{c1}(3872)$

Col.	a	L	m_π	$M_{avg}^{c\bar{c}}$
Prelovsek13 *	0.1239	1.98	266	2428
Lee14 **	0.1527	2.4	305	2387
Li24 ***	0.136	2.18	250	3069
			307	
			362	
			417	

* S. Prelovsek and L. Leskovec, Phys. Rev. Lett. 111, 192001 (2013)

** S.-h. Lee, C. DeTar, D. Mohler, and H. Na (Fermilab Lattice, MILC) (2014)

*** H. Li, C. Shi, Y. Chen, M. Gong, J. Liang, Z. Liu, and W. Sun (2024)

Parameters and data for the global fit

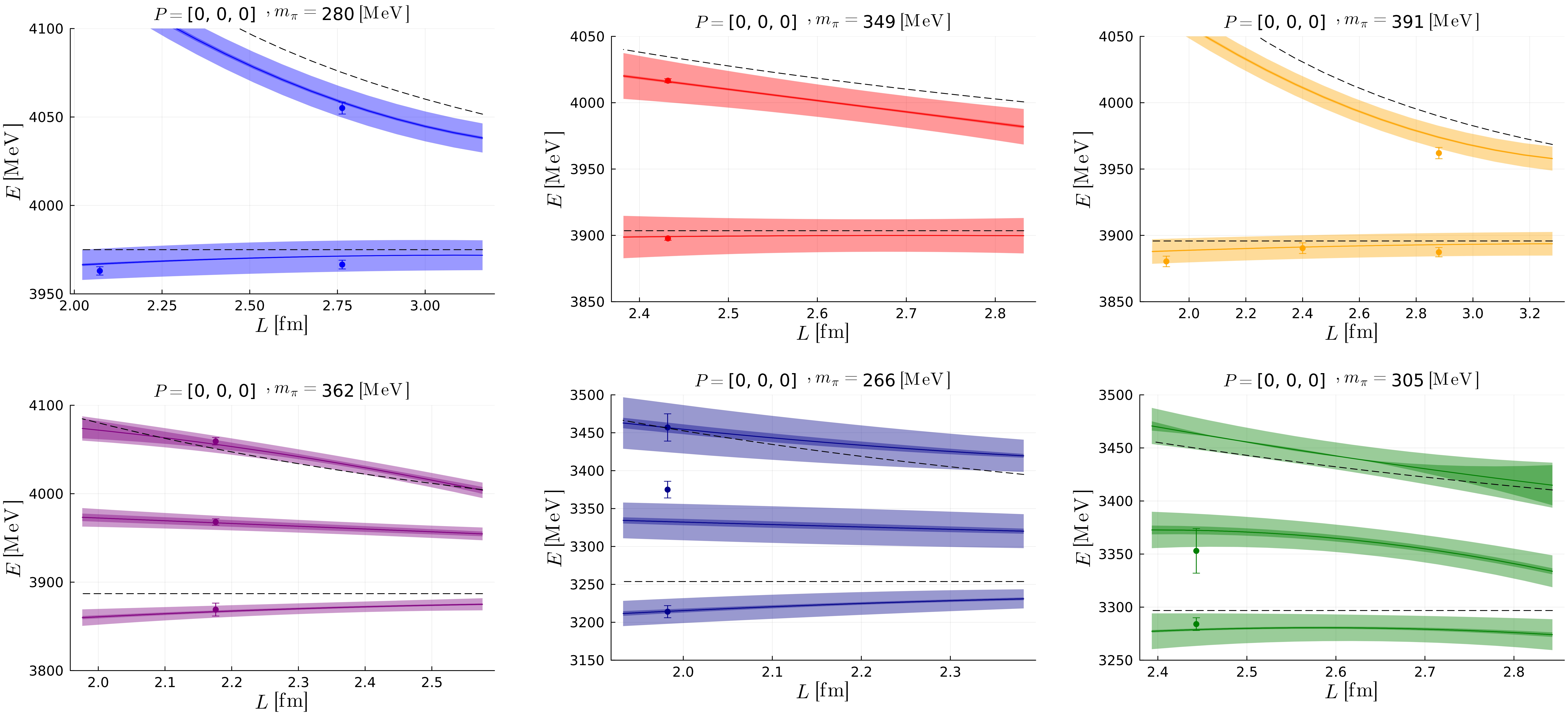
Free parameters:

- g_ρ and g_π from the ρ- and π-exchange potentials.
- c and $m_{c\bar{c}}$ from the coupling to the bare state.
- Total of 4 free parameters

Number of data:

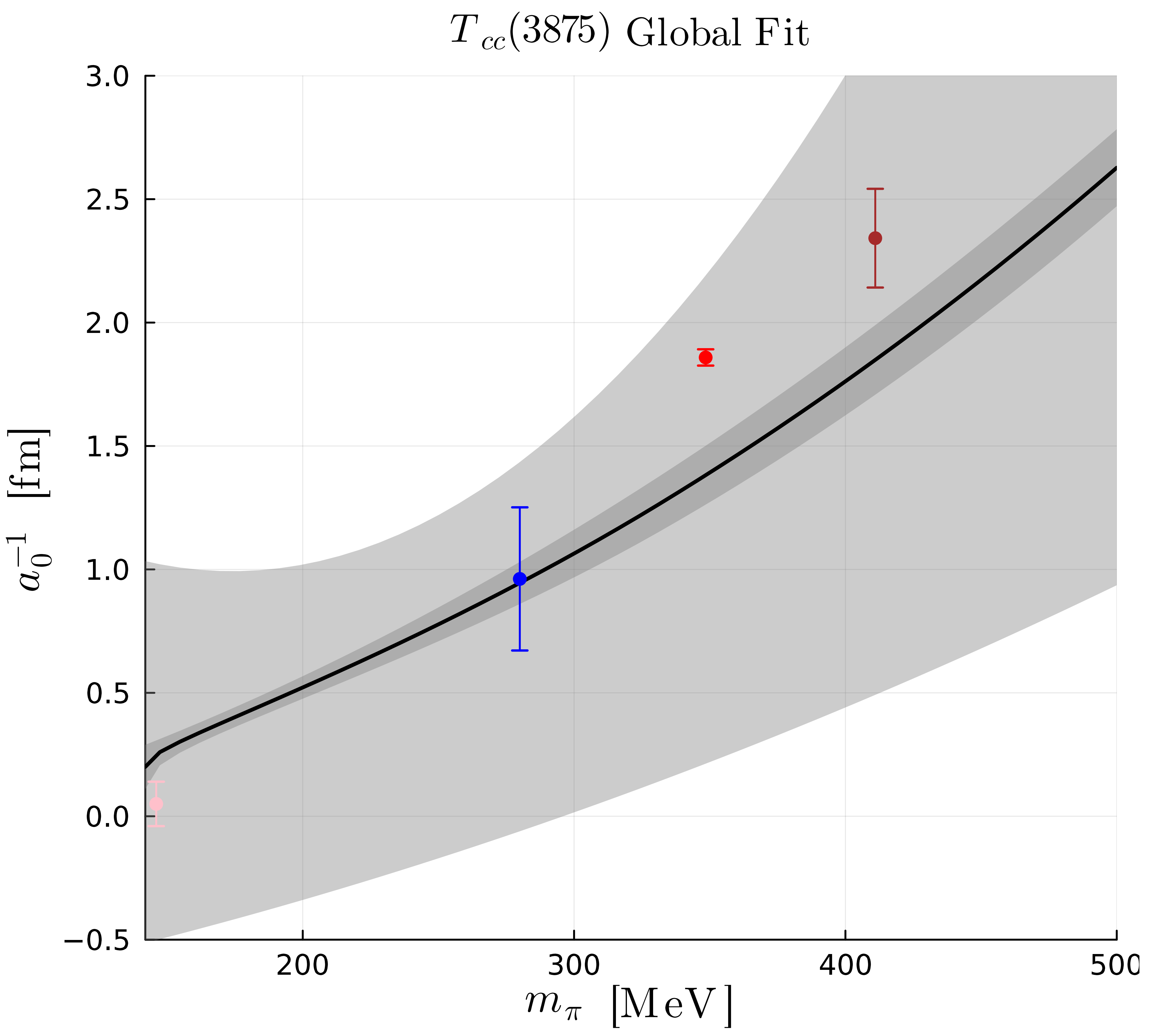
- 49 data points for the $T_{cc}(3875)^+$.
- 17 data points for the $\chi_{c1}(3872)$.
- Total of 66 data points.

Energy levels from the global fit

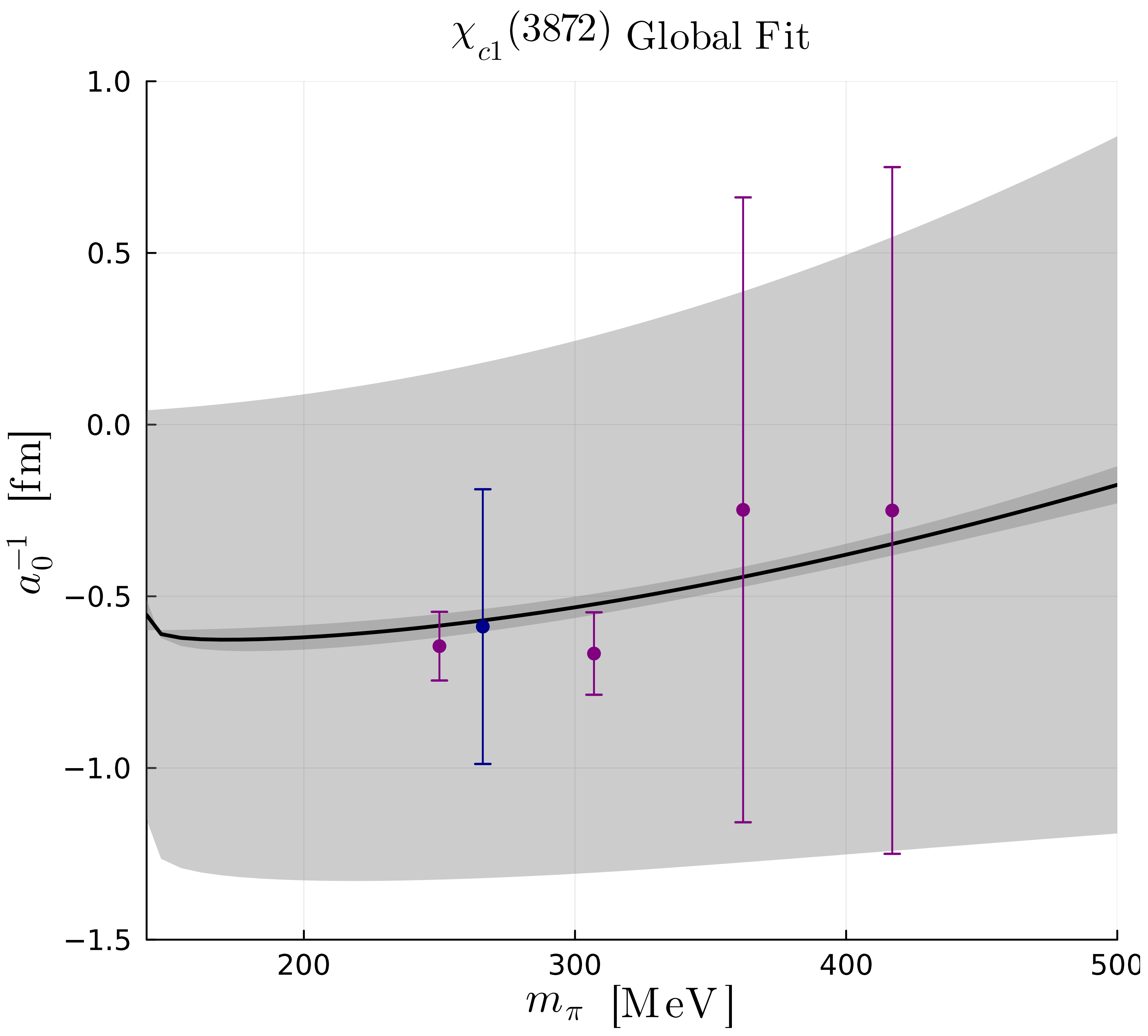


Scattering length

For the $T_{cc}(3875)^+$

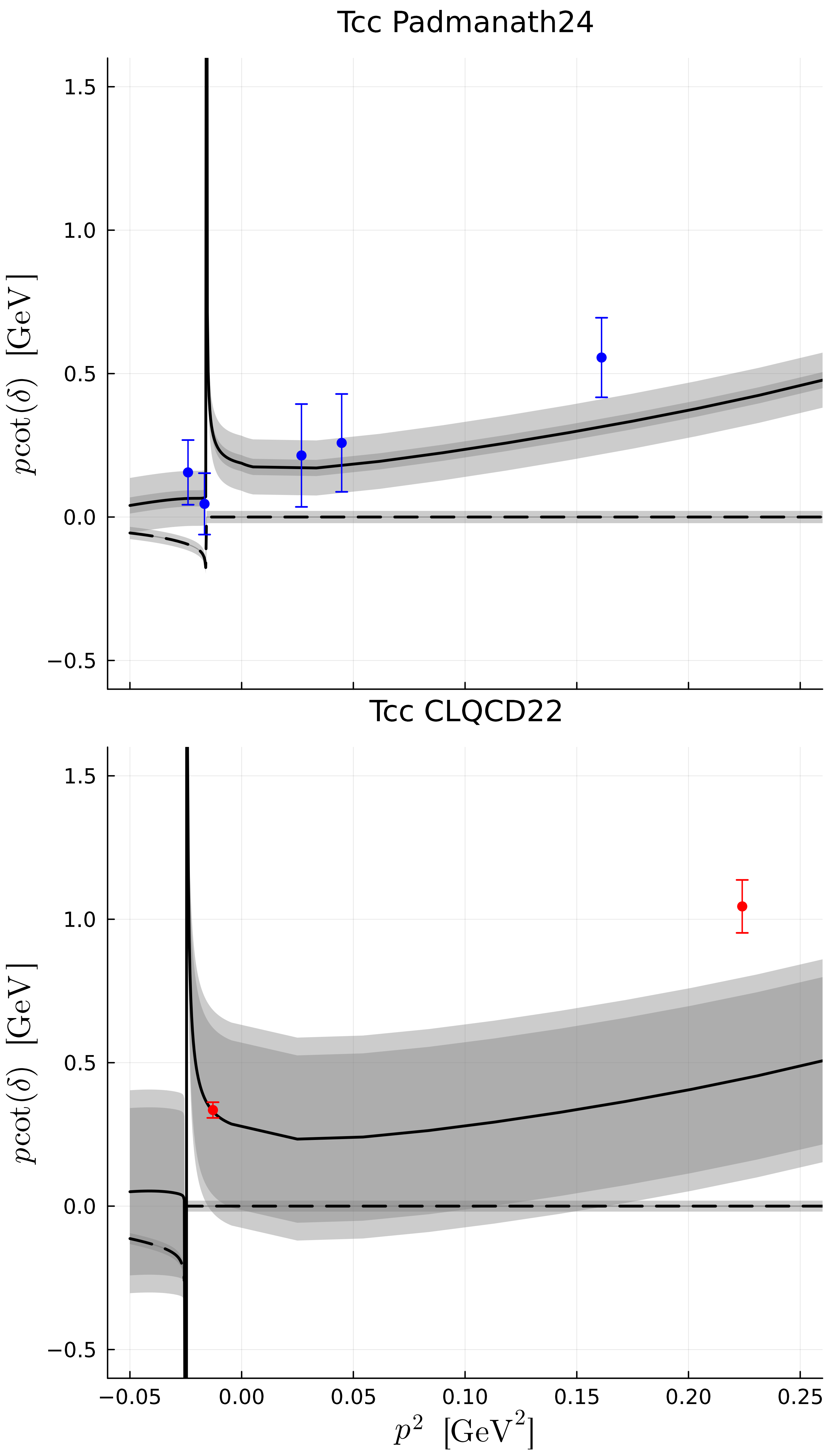


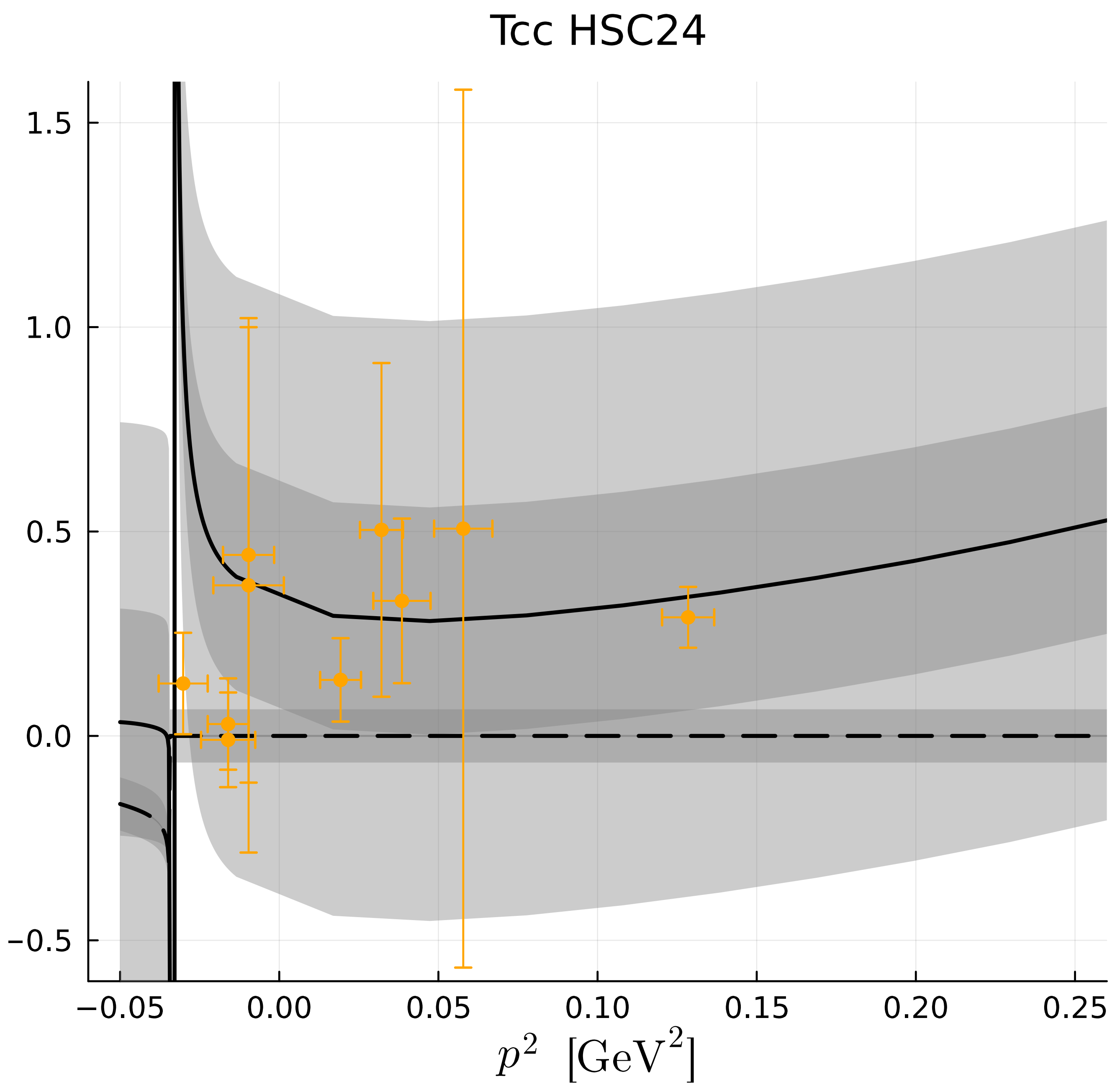
For the $\chi_{c1}(3872)$



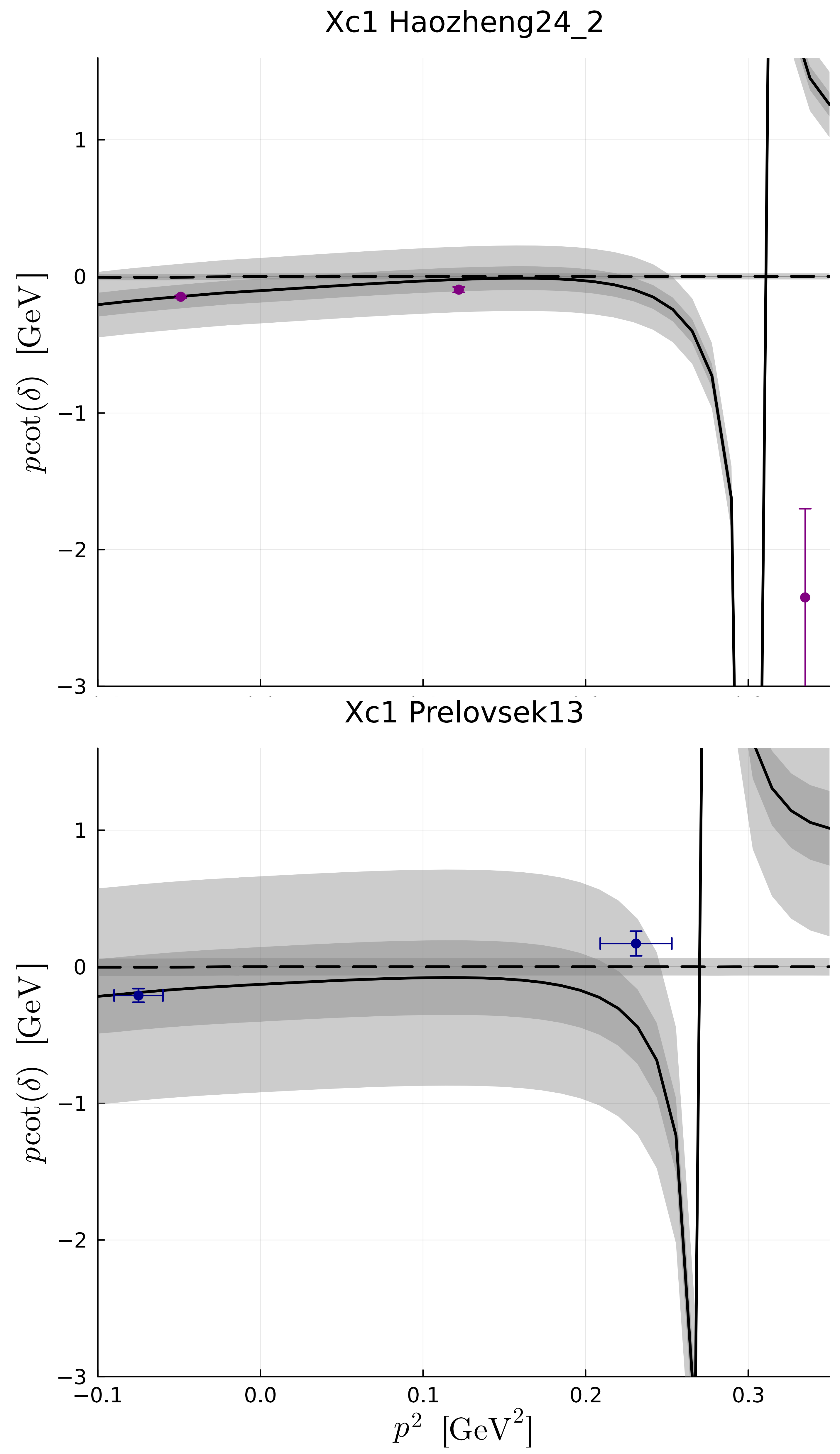
Phase shifts

For the $T_{cc}(3875)^+$



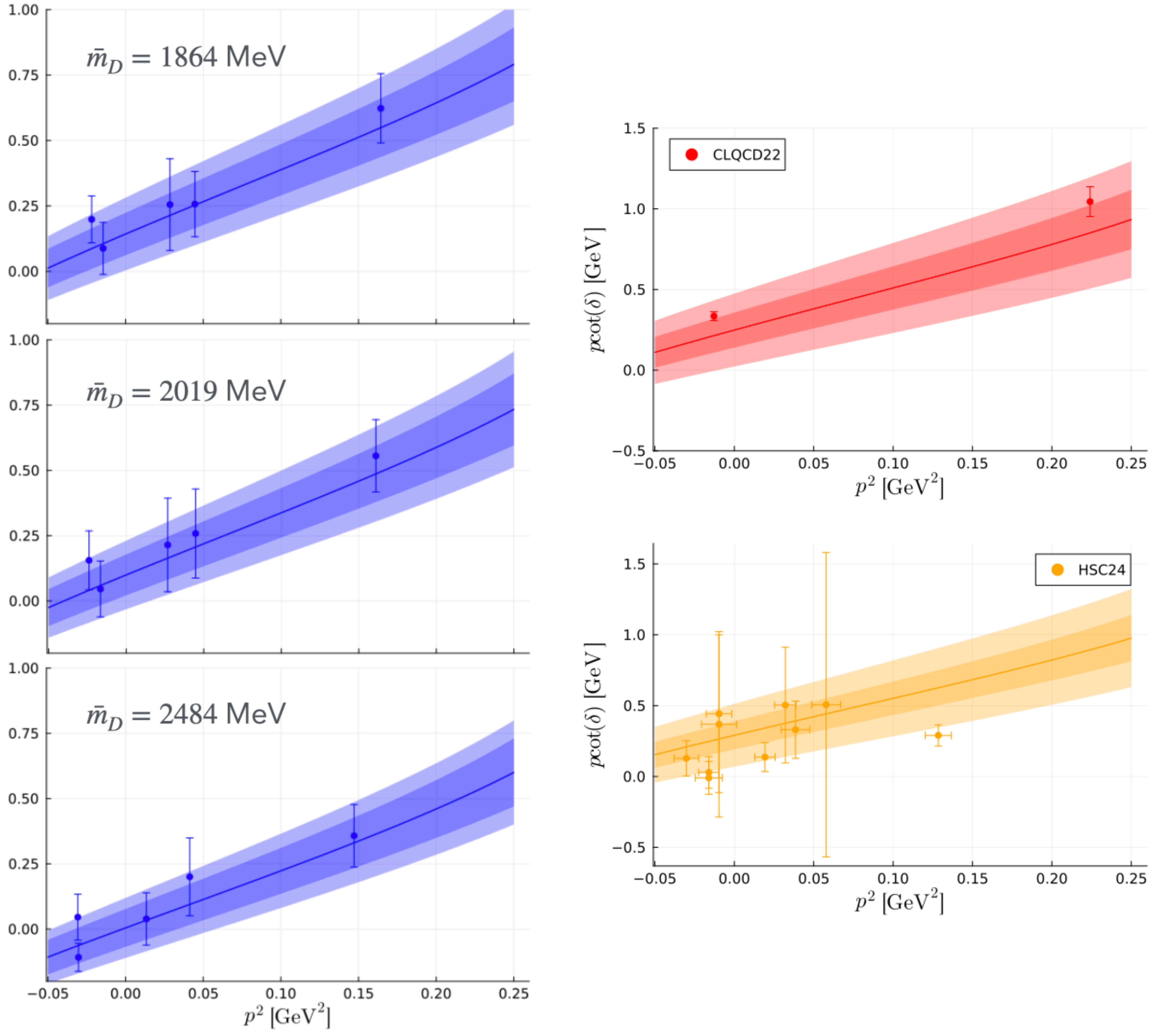


For the $\chi_{c1}(3872)$

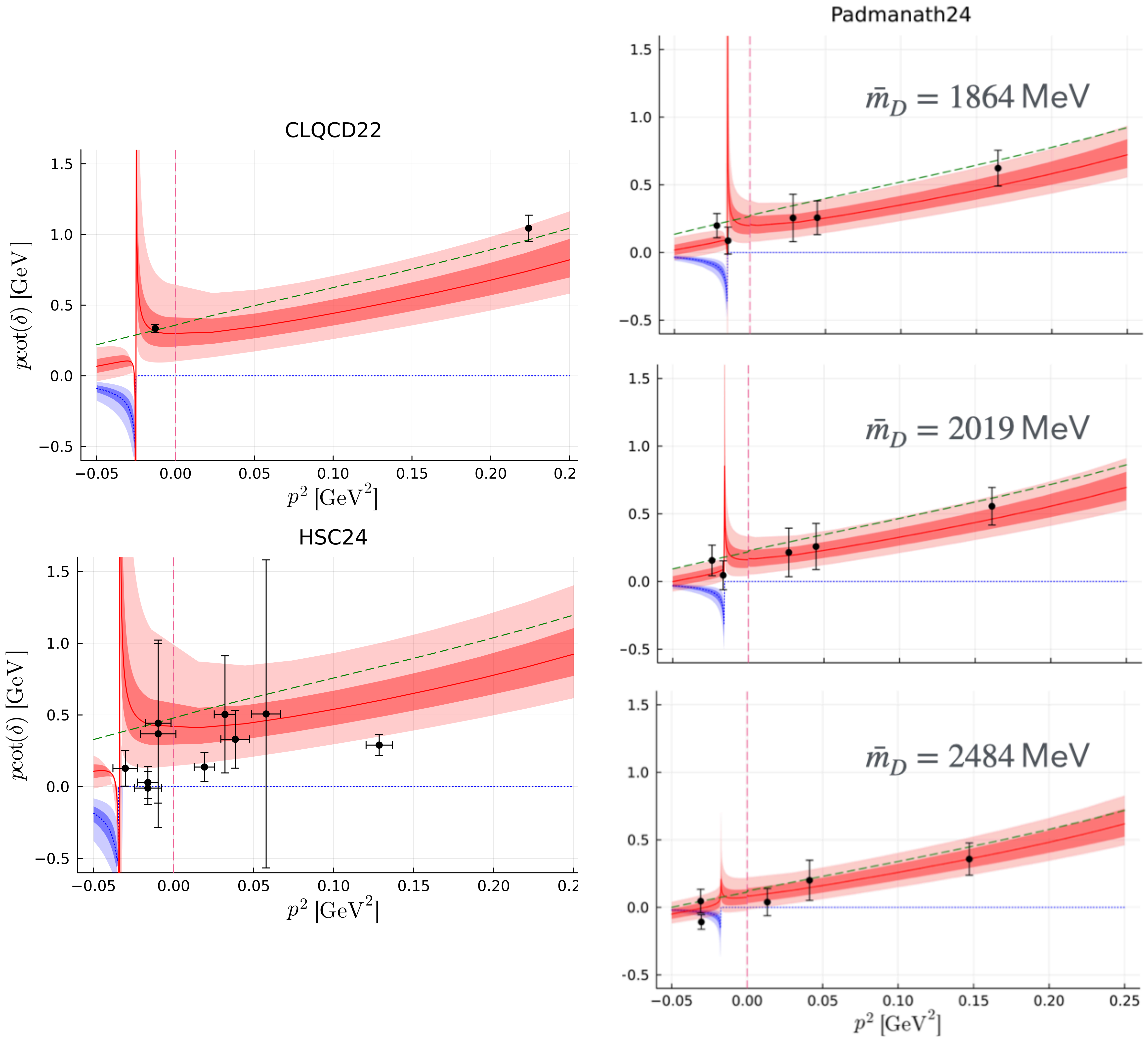


Phase shifts only for the $T_{cc}(3875)^+$

ρ exchange only

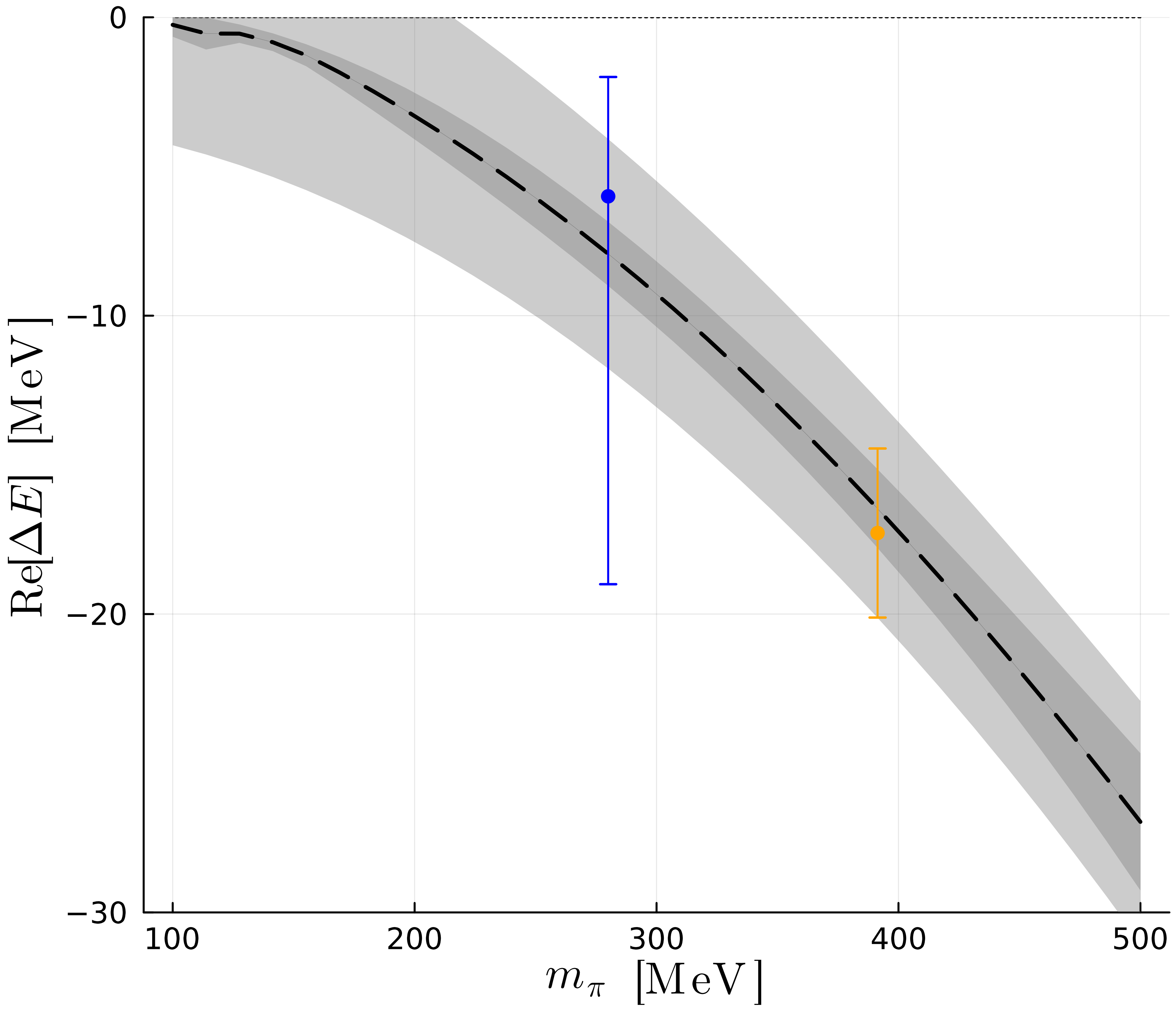


$\rho + \pi$ exchanges

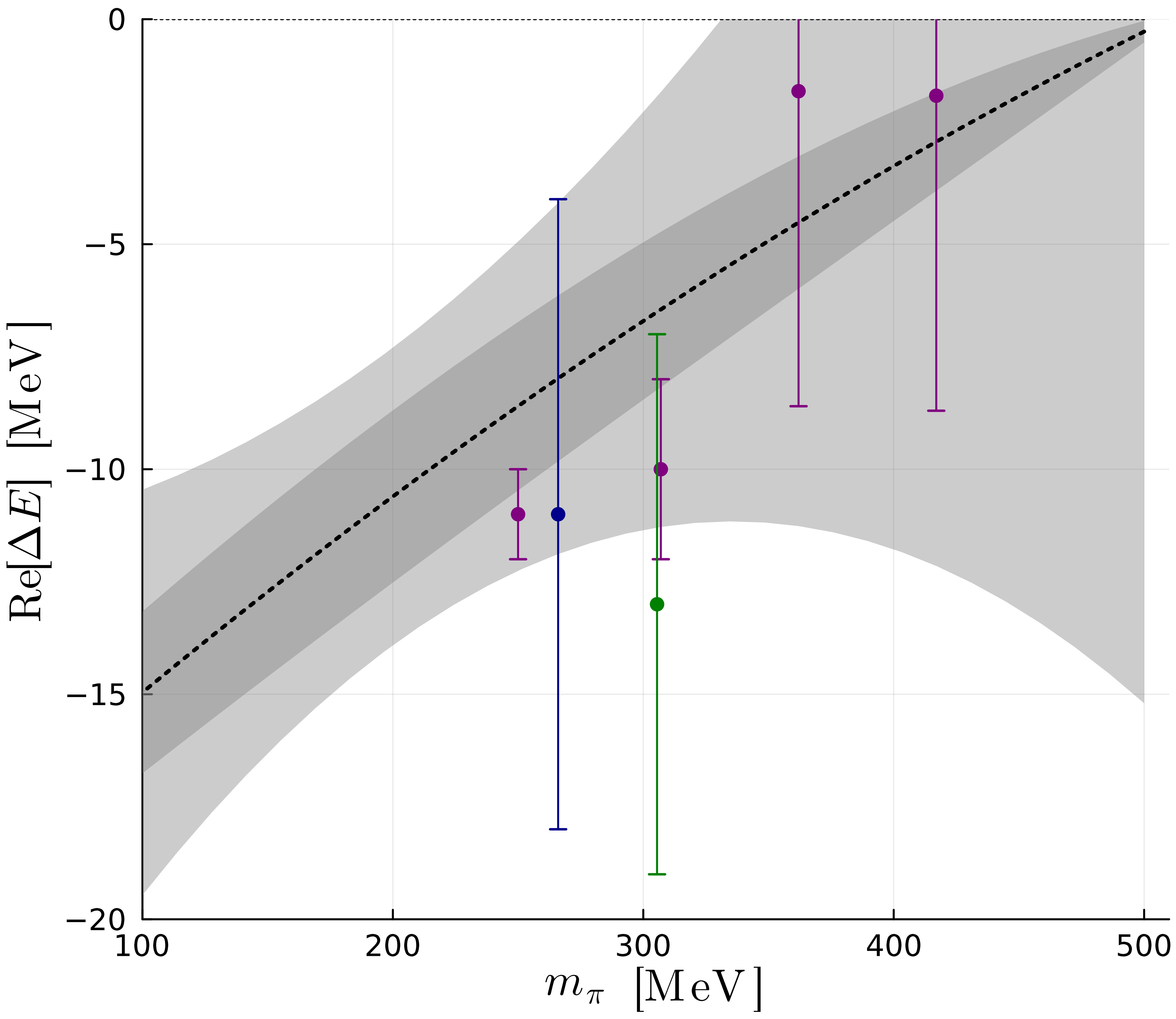


Pion mass dependence

For the $T_{cc}(3875)^+$



For the $\chi_{c1}(3872)$



Conclusions

- $T_{cc}(3875)^+$ and $\chi_{c1}(3872)$ lattice energy levels from different collaborations are compatible among them and can be analyzed together.

- We successfully extracted the pion mass dependence of their pole positions, extracting information from Lattice QCD to the physical region.

- In those channels, ρ meson exchange is dominant but the π exchange is not negligible.

- While the effect of the π is relevant near the lhc, it can be reabsorbed in the ρ coupling outside that region.

Thank you!