Quark mass dependence of the $D_{s0}^*(2317)$

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Excited QCD 2024 Workshop
18th January

D meson functions

✦ Heavy meson masses from χPT with HQSS at one loop order

$$\frac{1}{4}(D+3D^*) = m_H + \alpha_a - \sum_{X=\pi,K,\eta} \beta_a^{(X)} \frac{M_X^3}{16\pi f^2} + \sum_{X=\pi,K,\eta} \left(\gamma_a^{(X)} - \lambda_a^{(X)}\alpha_a\right) \frac{M_X^2}{16\pi^2 f^2} \log\left(M_X^2/\mu^2\right) + c_a$$

$$(D^* - D) = \Delta + \sum_{X=\pi,K,\eta} \left(\gamma_a^{(X)} - \lambda_a^{(X)}\Delta\right) \frac{M_X^2}{16\pi^2 f^2} \log\left(M_X^2/\mu^2\right) + \delta c_a$$

❋ E. E. Jenkins, Nucl. Phys. B 412, 181 (1994), hep-ph/9212295

$$\frac{1}{4}(D+3D^*) = m_H + f(\sigma, a, b, c, d)$$

$$(D^* - D) = \Delta + g(\Delta^{(\sigma)}, \Delta^{(a)})$$

} $2 \cdot 12$ tree level parameters + 7 parameters → 31 parameters

160 points

LASSO Regression Method

$$\chi^2_P(p,d) = \chi^2(p,d) + \lambda^4 \sum_i^n |p_i| \longrightarrow$$

70% of data $\chi^2_P(p, d_{train})$

30% of data $\chi^2_P(p, d_{test})$

❋J. Landay, M. Döring, C. Fernández-Ramírez, B. Hu, and R. Molina, Phys. Rev. C 95, 015203 (2017), 1610.07547.

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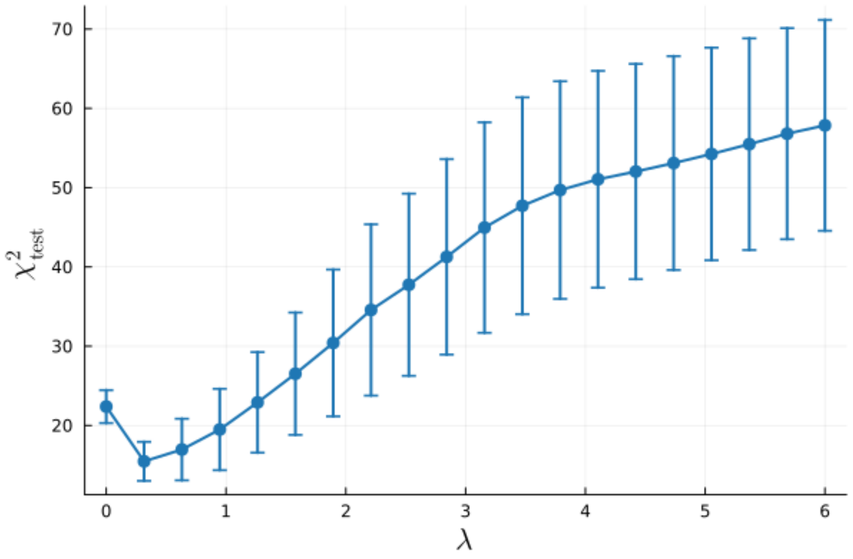
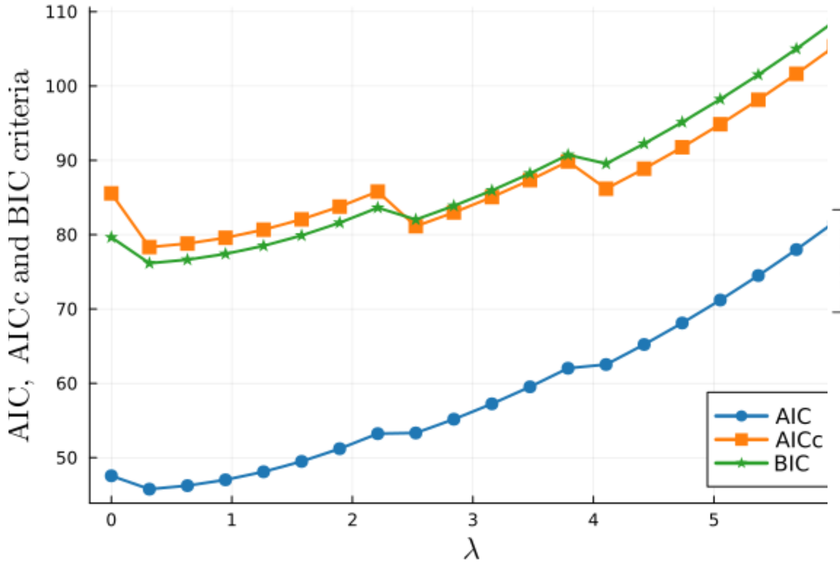
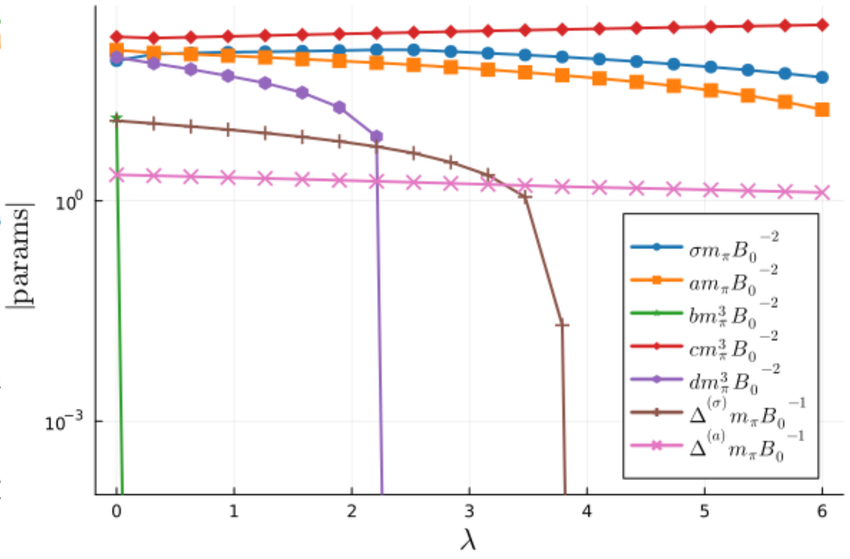
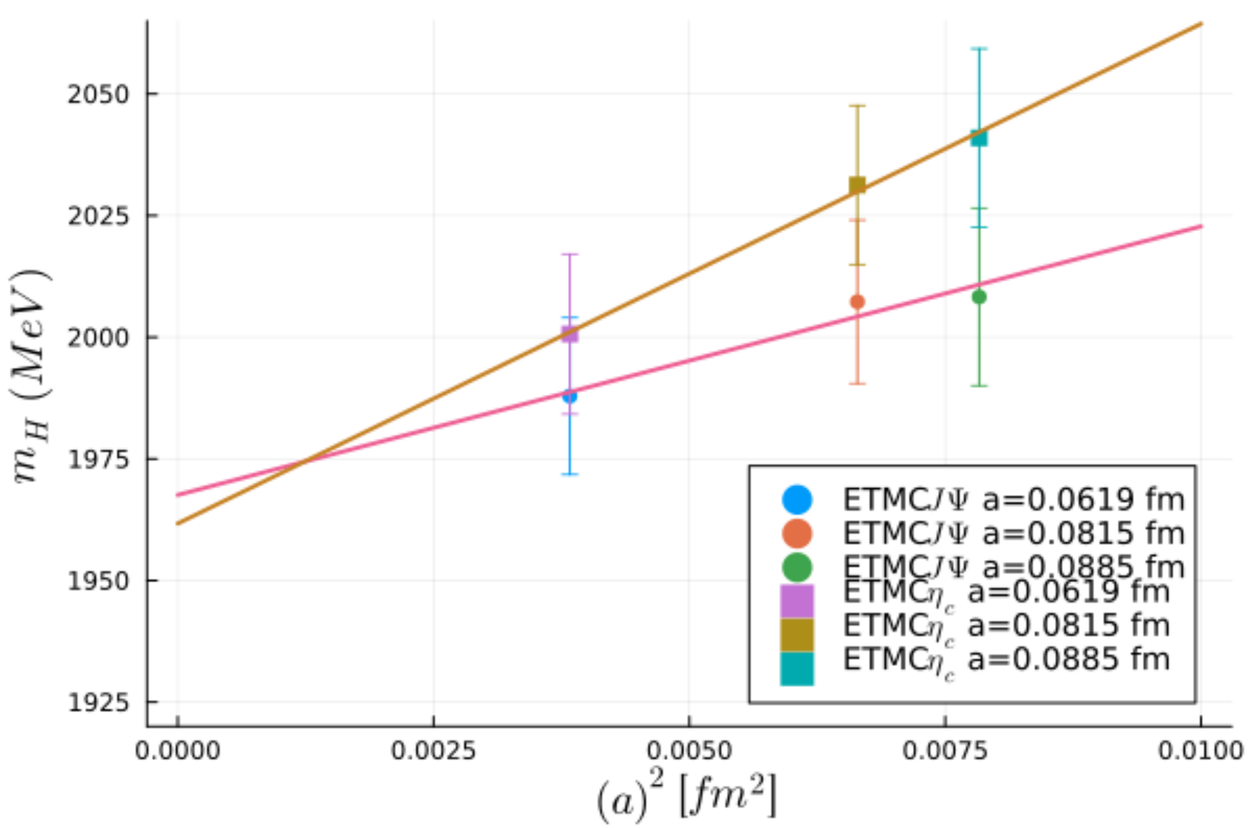
For ETMC data:

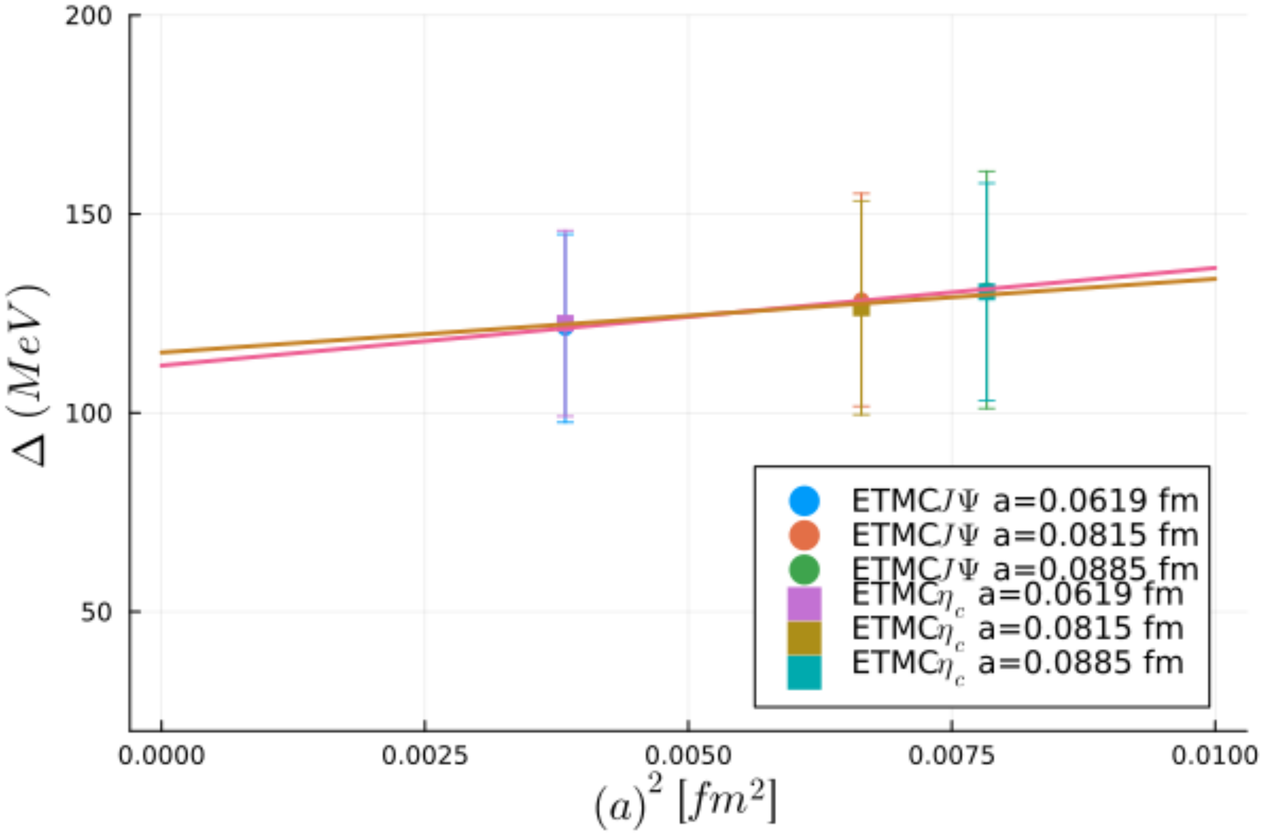






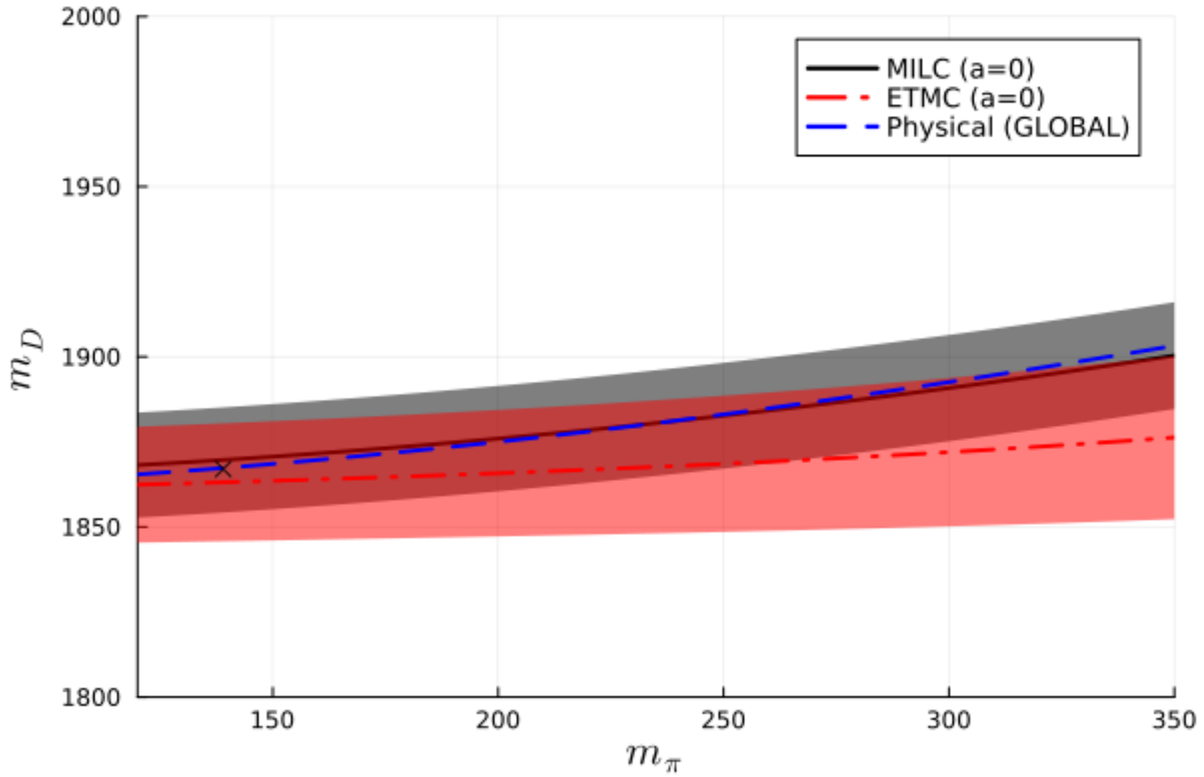
ETMC continuum extrapolation

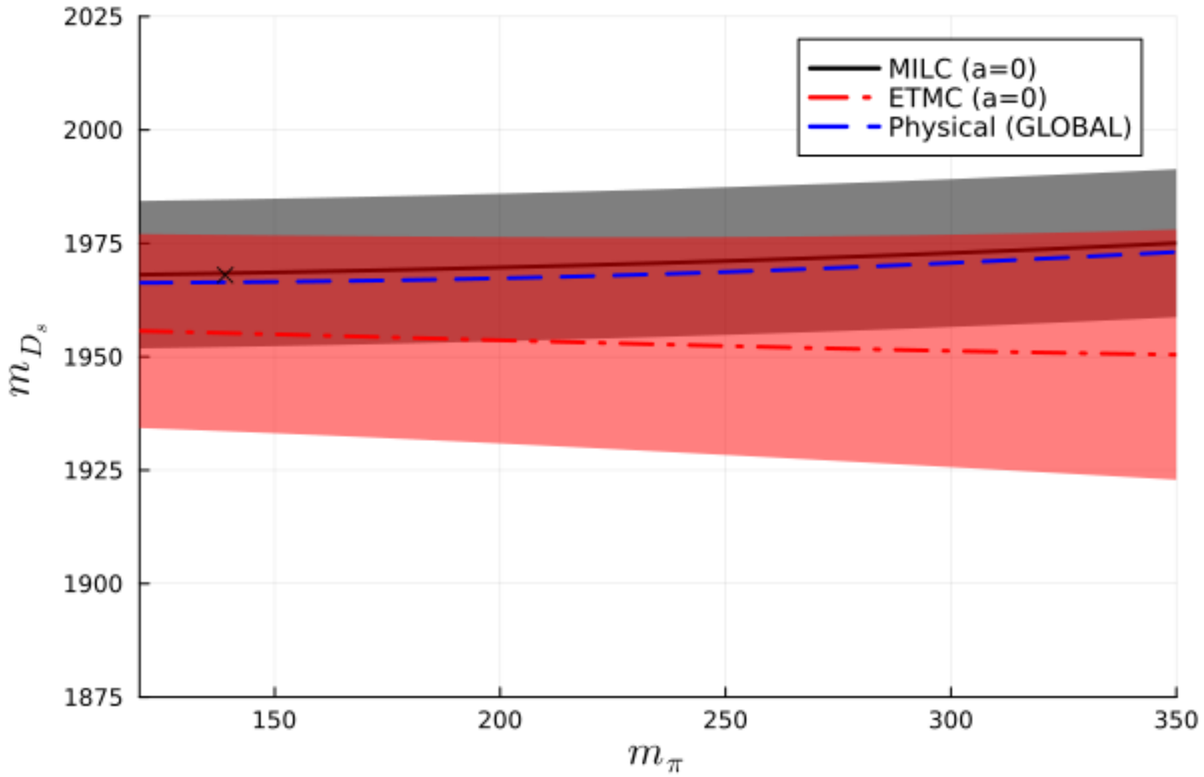




✺F. Gil-Domínguez and R. Molina, Phys. Lett. B 843 (2023), 2302.12861

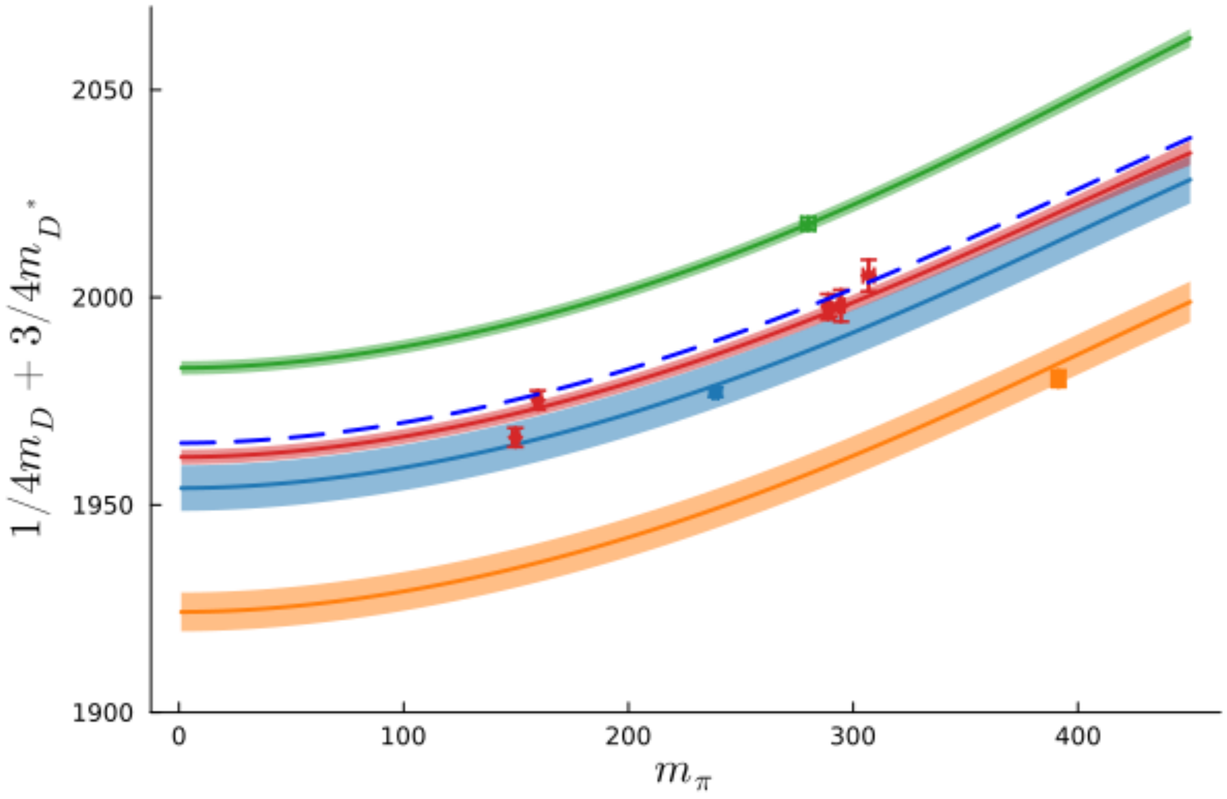
ETMC continuum extrapolation

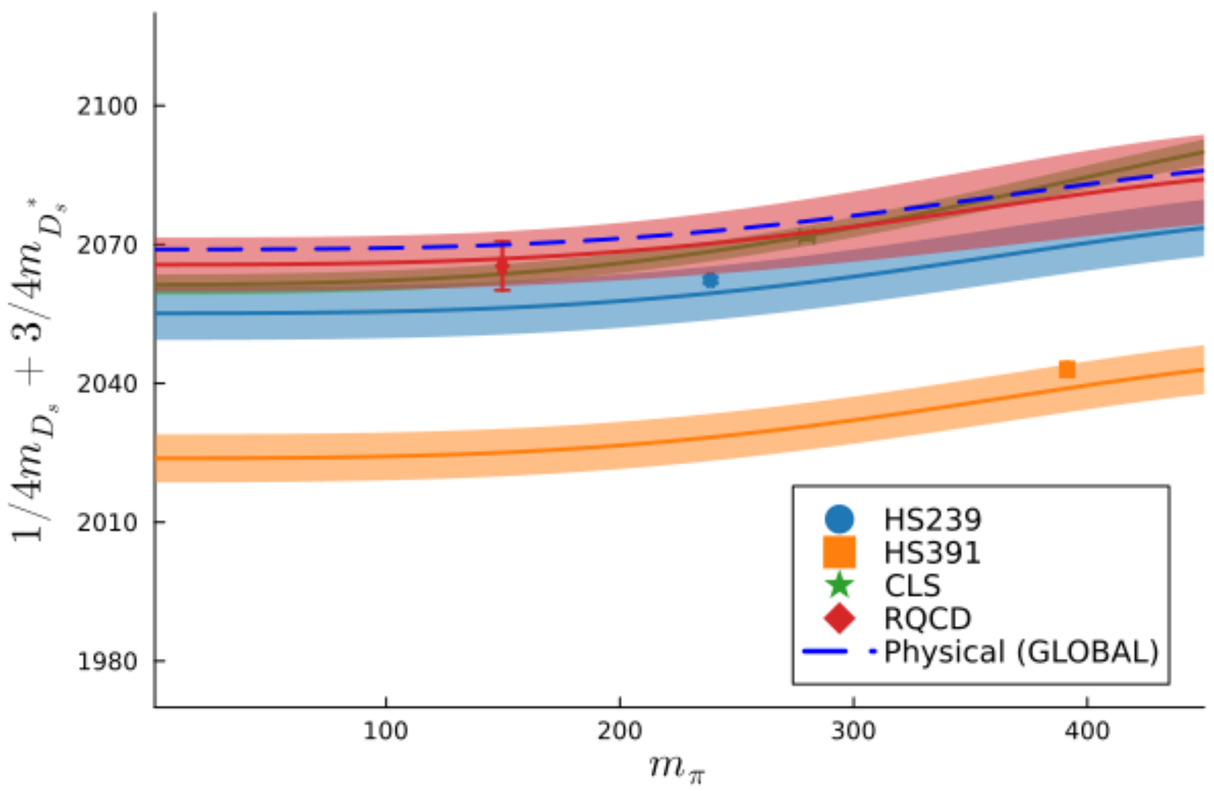




✵F. Gil-Domínguez and R. Molina, Phys. Lett. B 843 (2023), 2302.12861

D and D_s meson mass functions



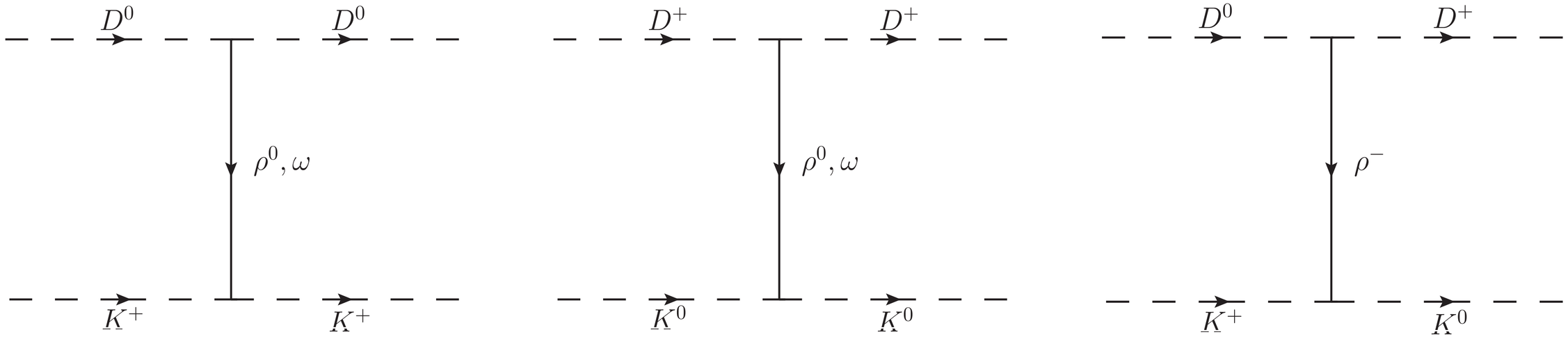


❋F. Gil-Domínguez and R. Molina, Phys. Lett. B 843 (2023), 2302.12861

Scattering amplitude for DK I=0

- Lagrangian from Hidden gauge symmetry formalism

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



$$V = -\frac{s-u}{2{f_\pi}^2}$$

Coupling with a bare $c\bar{s}$ state

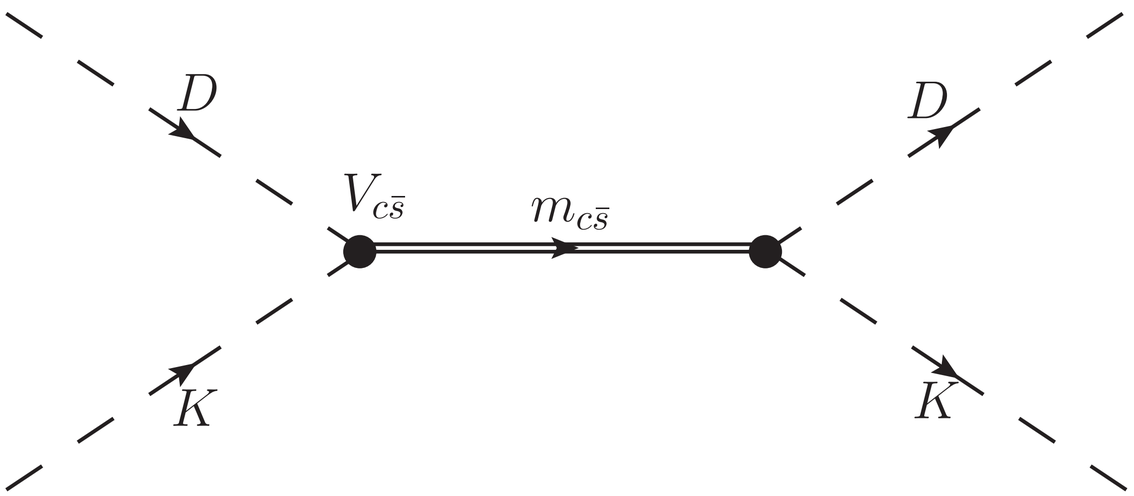
$$V \to V + V_{ex}$$

$$V_{ex} = \frac{V_{c\bar{s}}^2}{s - m_{c\bar{s}}^2}$$

$$V_{c\bar{s}}(s) = -\frac{c}{f}\sqrt{M_D m_{c\bar{s}}}\frac{s + m_K^2 - M_D^2}{\sqrt{s}},$$

+2 parameters

$c, m_{c\bar{s}}$



Parameters for the energy levels fit

✦ Total amplitude from Bethe-Salpeter equation

$$T = \frac{V}{1 - \tilde{G}V}$$

$$\tilde{G}(s,\alpha) = G^{DM}(s,\alpha) + \lim_{q_{\max}\to\infty} \Delta G(s, q_{\max})$$

$$\Delta G = \frac{1}{L^3}\sum_{q_i}^{q_{\max}} I(\vec{q}_i) - \int_0^{q_{\max}} \frac{d^3q}{(2\pi)^3} I(\vec{q})$$

The subtraction constant is defined as

$$\alpha = \alpha_1 + \alpha_2 m_\pi^2$$

+2 parameters
α_1, α_2

Fit I 2 parameters: α_1, α_2

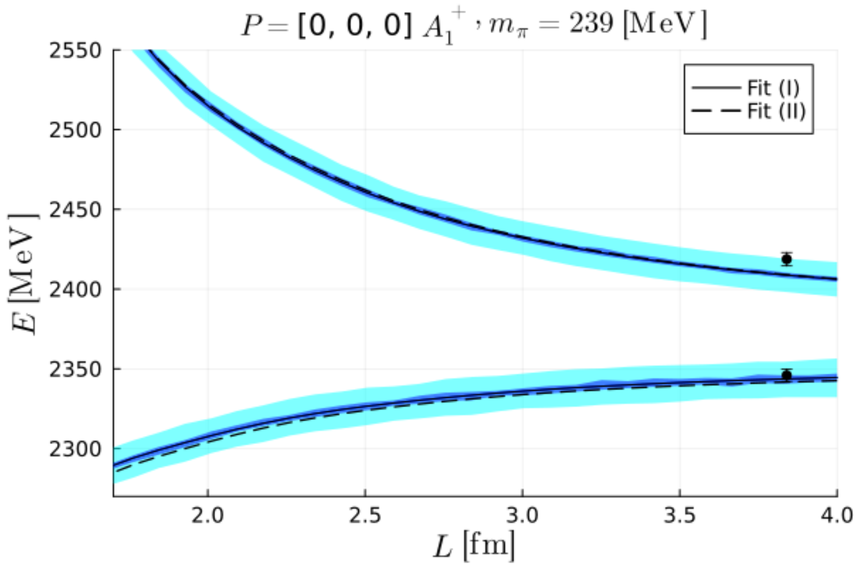
Fit II 4 parameters: $\alpha_1, \alpha_2, c, m_{c\bar{s}}$

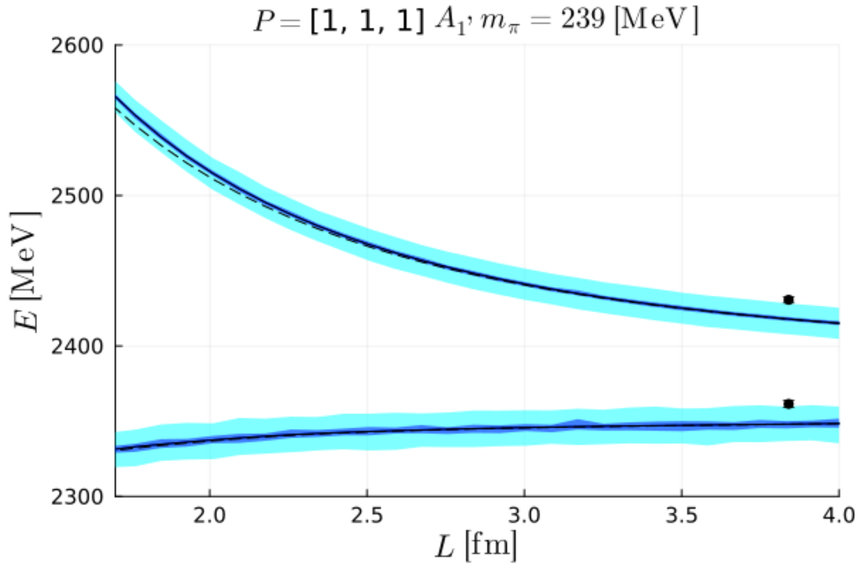
Finite volume energy levels

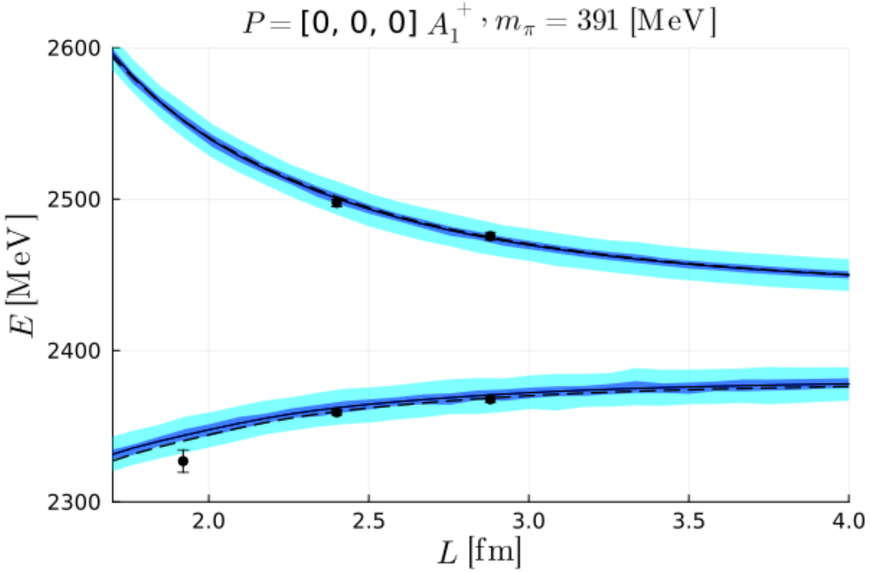
- HSC energy levels
  - $m_\pi = 239$ MeV

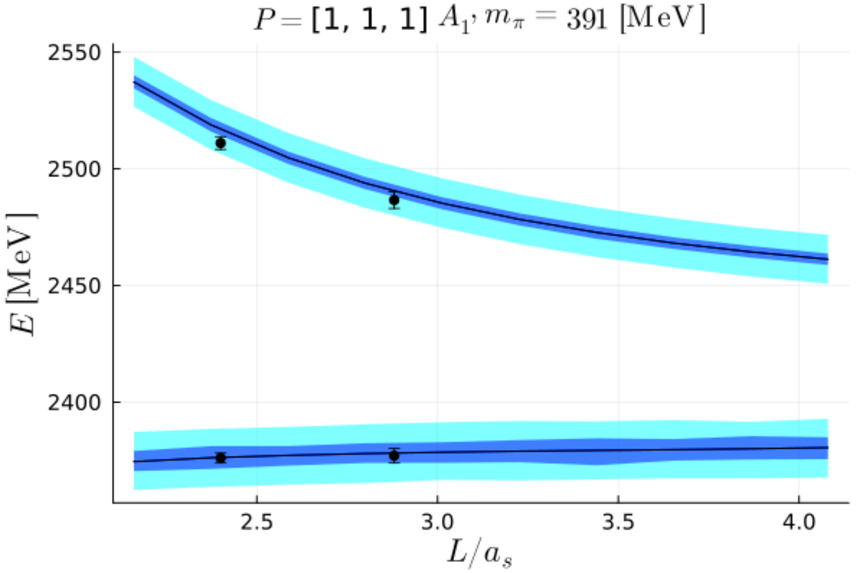
    (13 points)
  - $m_\pi = 391$ MeV

    (17 points)



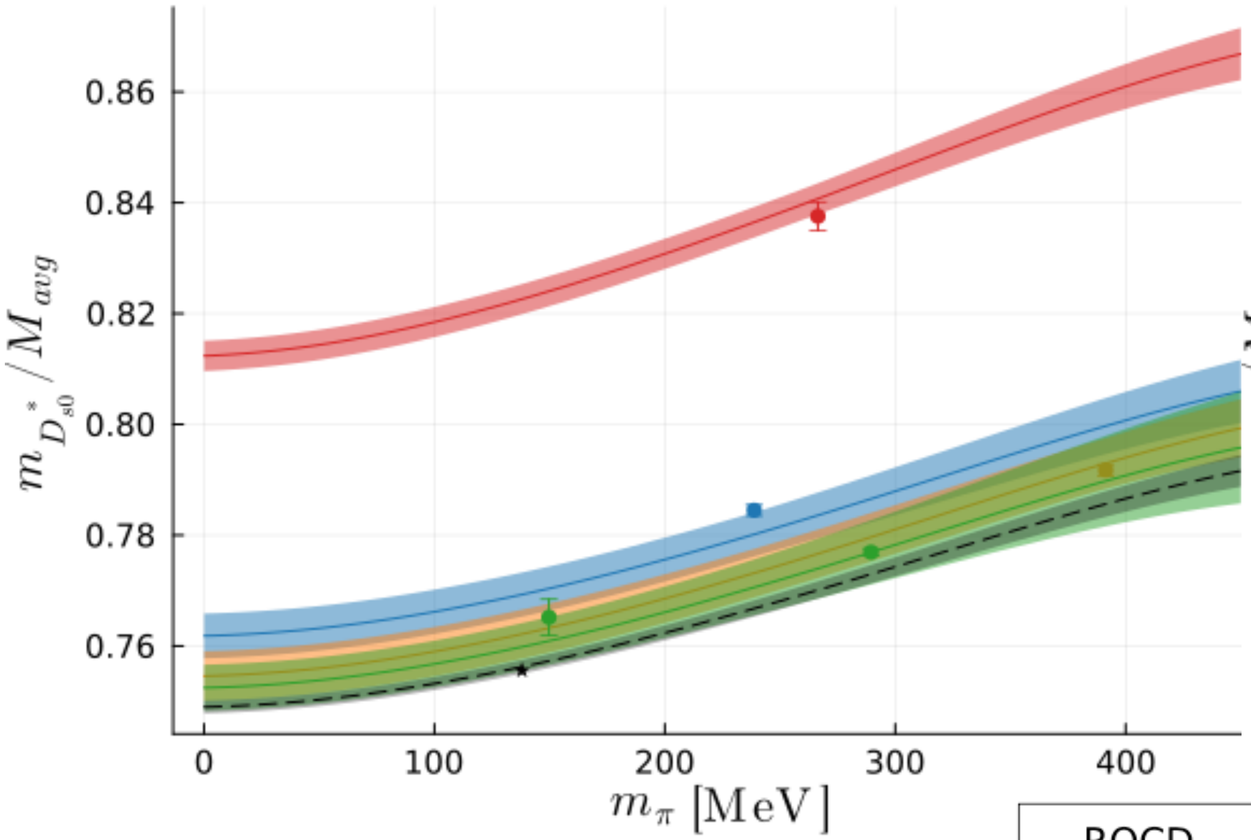


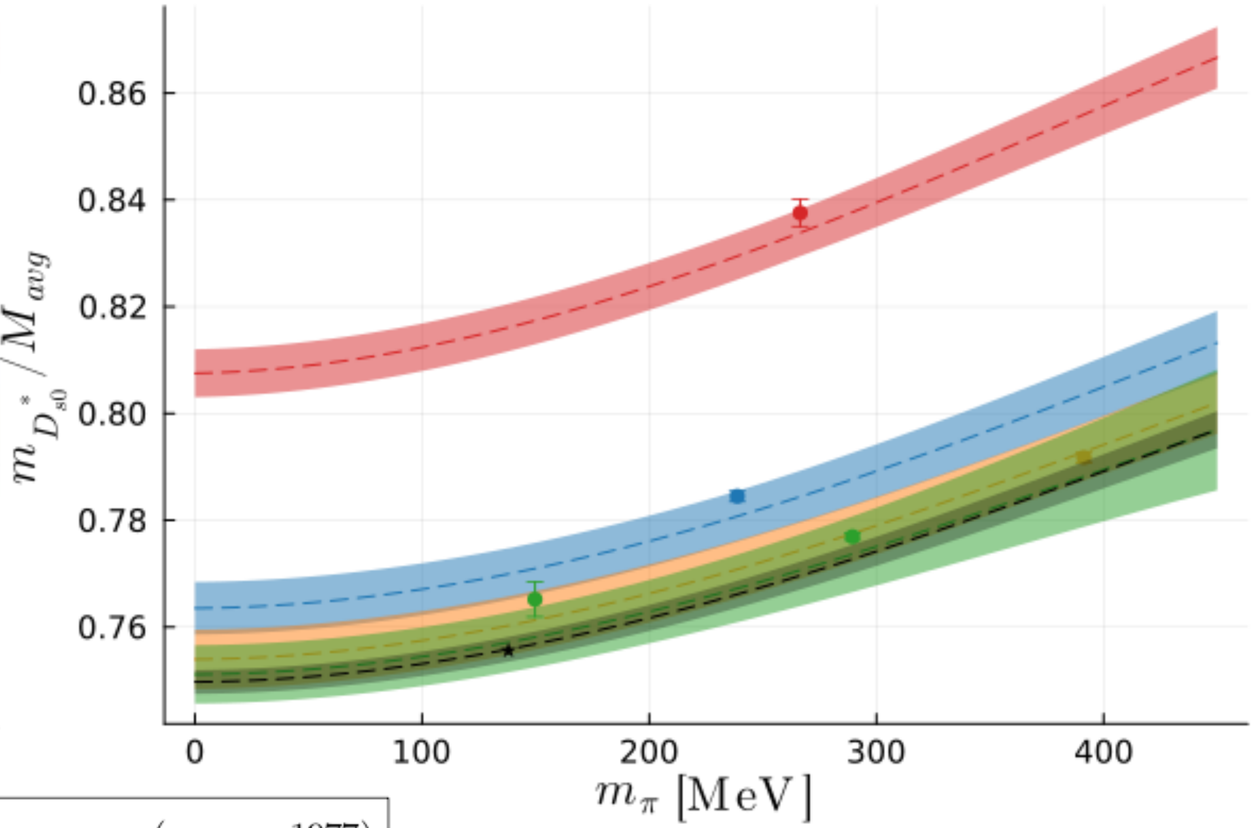


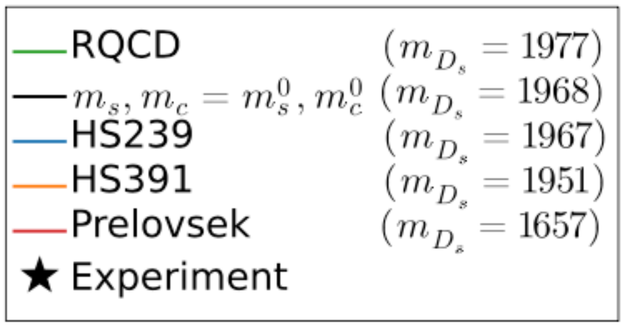


✺G. K. C. Cheung, C. E. Thomas, D. J. Wilson, G. Moir, M. Peardon and S. M. Ryan (Hadron Spectrum), JHEP02, 100 (2021), 2008.06432.

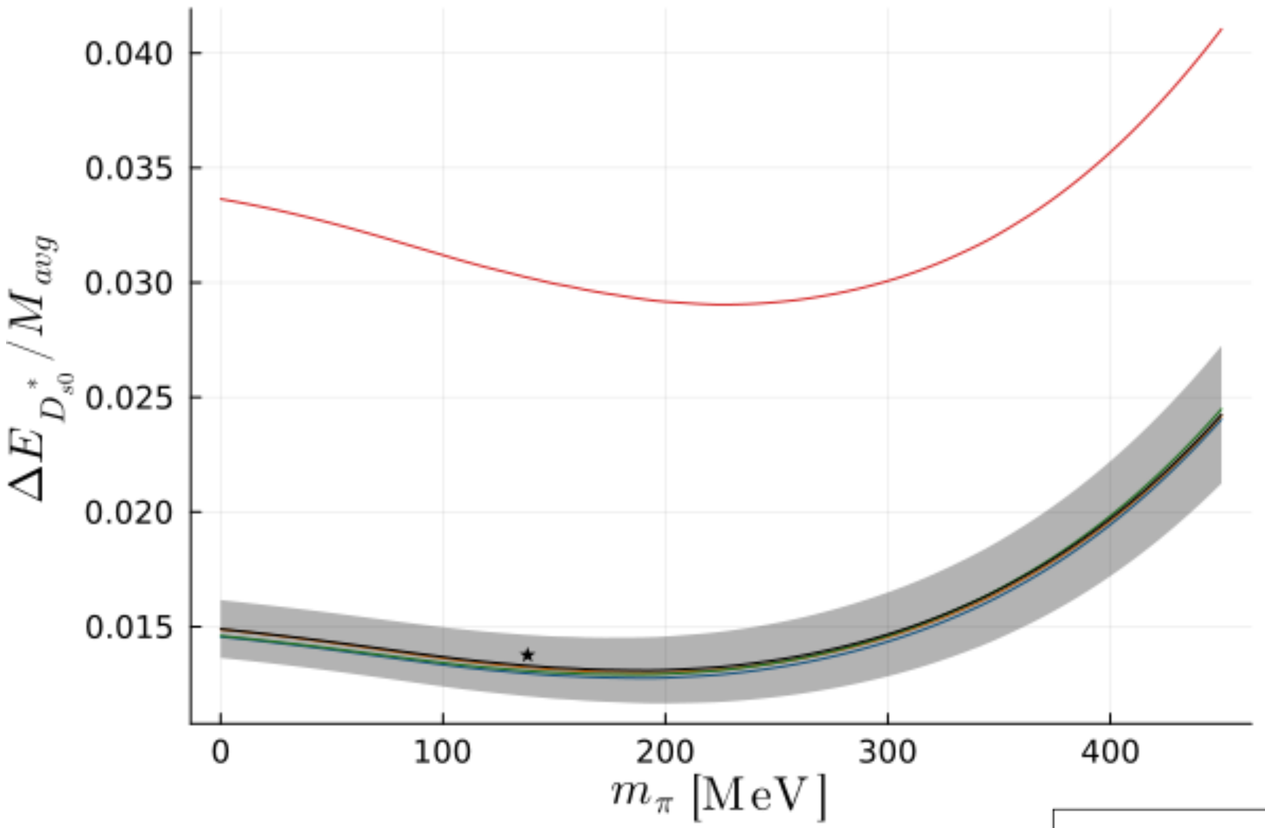
$D^*_{s0}(2317)$ pole

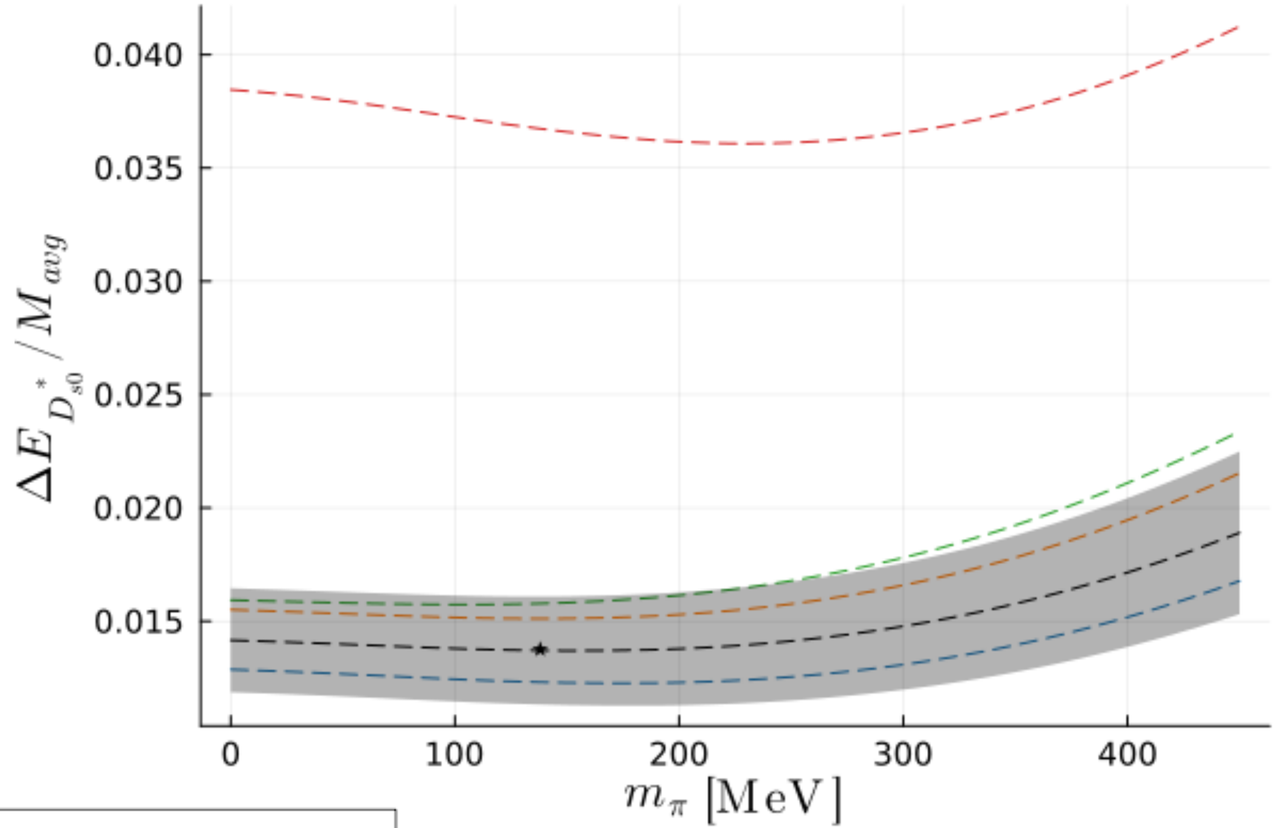


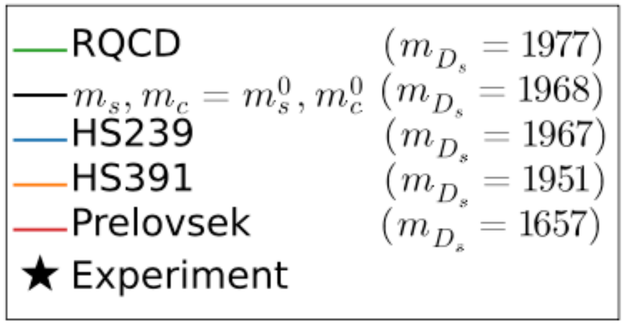




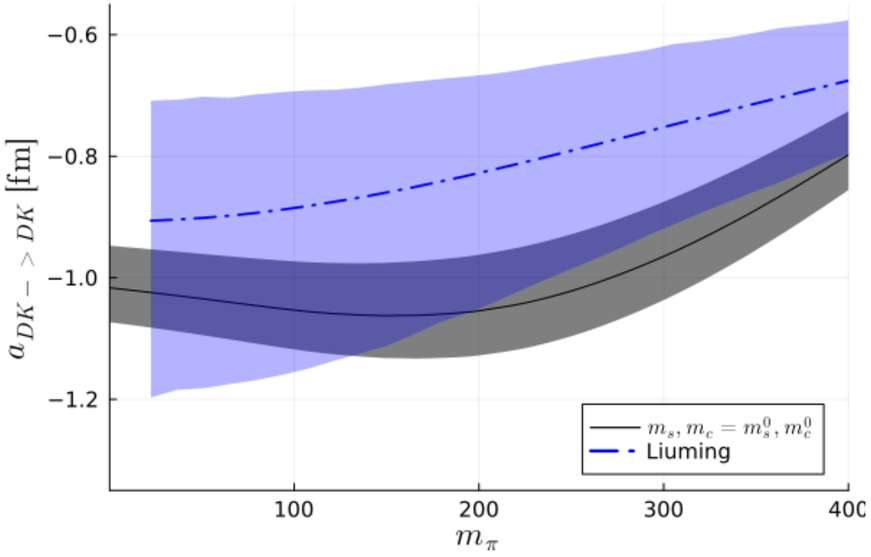
Binding energy

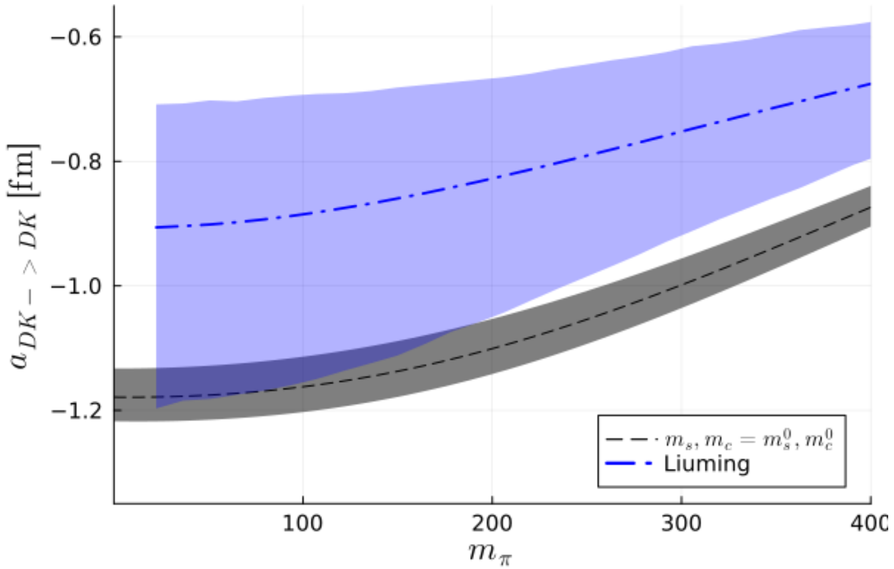




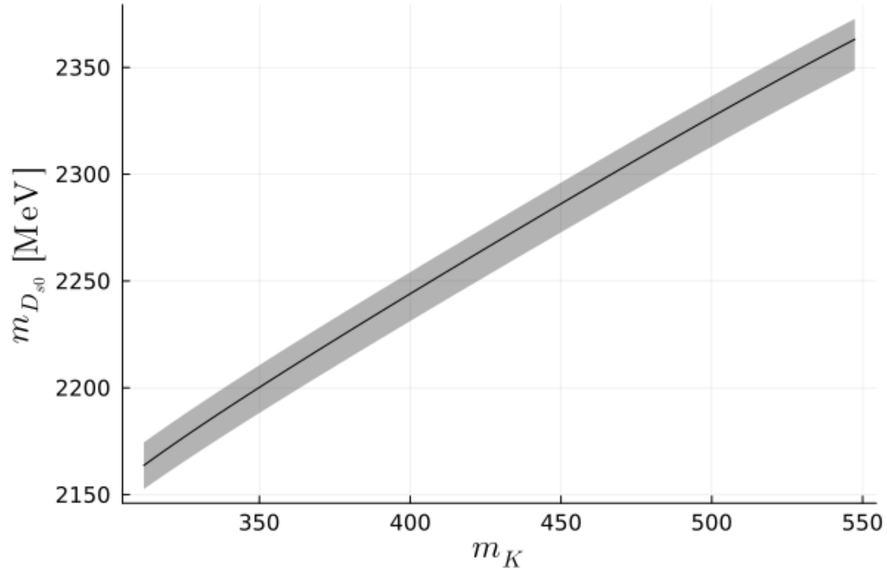


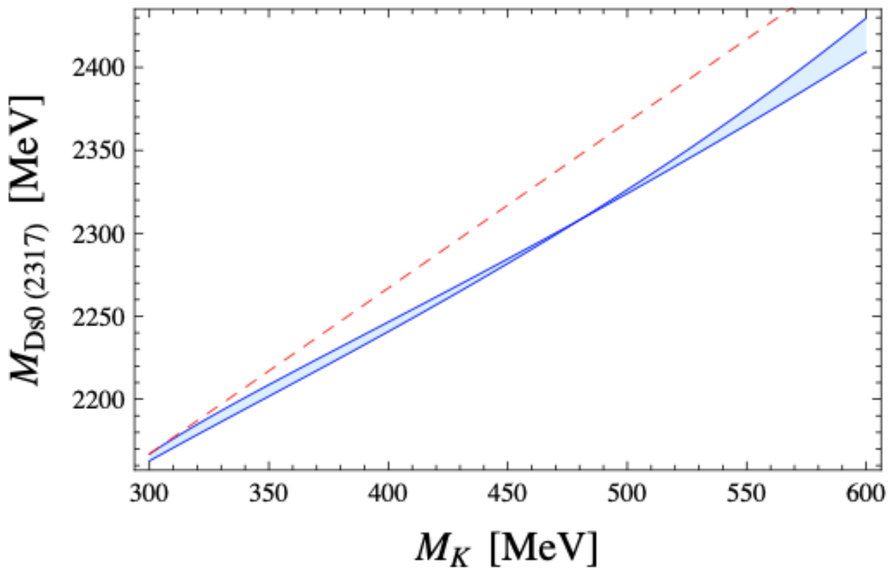
Comparison with previous results





❋L. Liu, K. Orginos, F.-K. Guo, C. Hanhart, and U.-G. Meissner, Phys. Rev. D 87, 014508 (2013), 1208.4535.

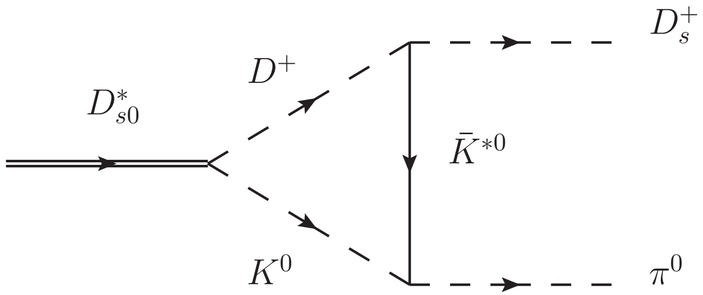


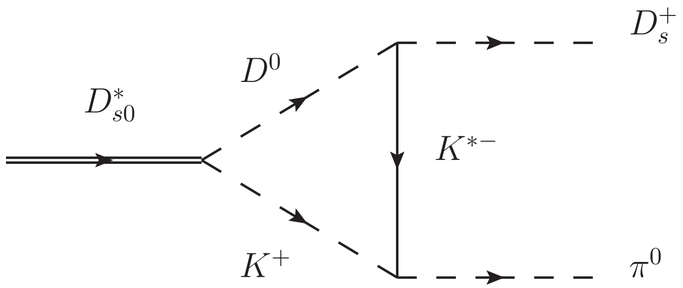


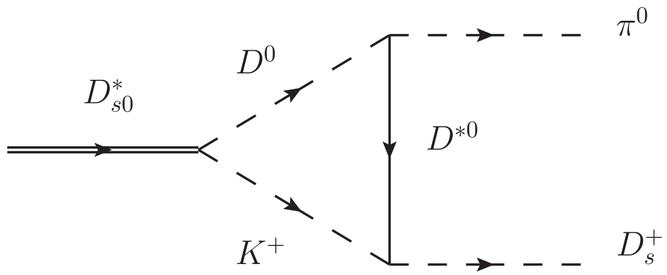
❋M. Cleven, F.-K. Guo, C. Hanhart, and U.-G. Meissner, Eur. Phys. J. A 47, 19 (2011), 1009.3804.

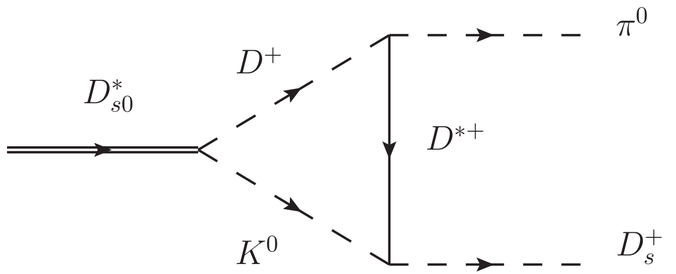
Decay width of the $D_{s0}^*(2317) \to D_s^+\pi^0$

$$t = \int \frac{d^4q}{(2\pi)^4} \frac{g_X g^2 c_1 (p - p_f + q)(p + p_f - q)}{\left[(p-q)^2 - m_2 + i\epsilon\right]\left[(q - p + p_f)^2 - M + i\epsilon\right](q^2 - m_1 + i\epsilon)}$$









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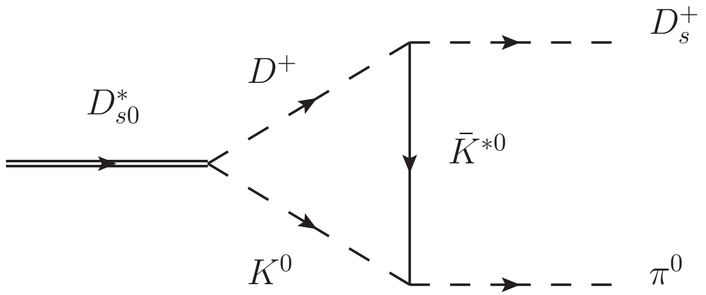
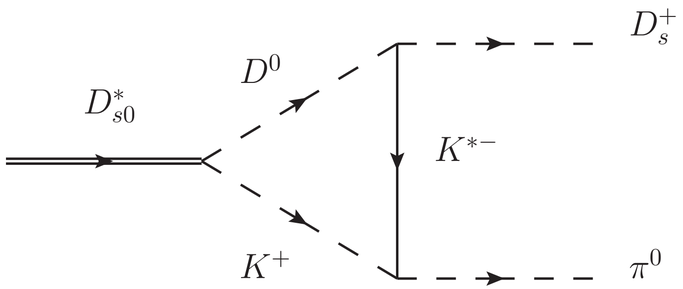
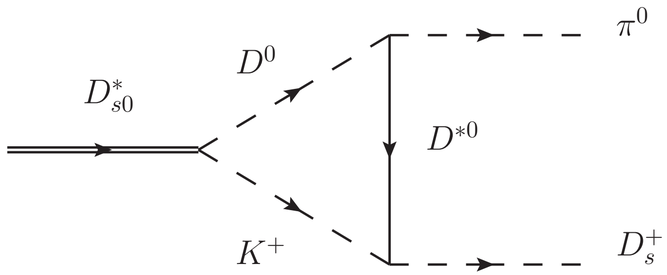
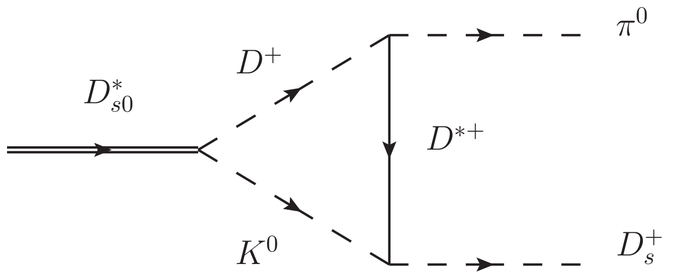




$$\Gamma_X = |\vec{p}_f| \frac{|t|^2}{8\pi m_X^2}$$





$$\Gamma_{D_{s0}^*} = 128 \pm 40 \text{ KeV}$$

Conclusions

- The results of the HSC data analysis agree reasonably well with experiment, and with other previous LQCD studies on DK, suggesting the possibility of a global fit.
- Our results suggest that the attractive DK interaction reduces with the charm quark mass, and becomes large for high pion masses. We obtain that this state is predominantly molecular.
- Future LQCD data analyses for different pion masses than the ones included in our fit, could be a good test for this study.