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

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What do we want to do?

as an important question to answer

- We want to:
  - Analyze the quark mass dependence on D_{s0}^{*} (2317)
- Why we want to do that?
  - Quark model predicts it above its threshold but it lie bellow it
  - There is debate about whether it is quark state or if it is molecular state

What do we need to do?

as an important question to answer

- We need to:
  - Compute the $DK \to DK$ scattering amplitude with I=0, S=1, C=1
  - Obtain D meson masses as functions of pion mass
  - Plot the curve of the bound state as function of light meson masses

D and D_s meson mass functions

fitting

- Meson mass equations from HQET 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

$$\left.\begin{aligned} \frac{1}{4}(D+3D^*) &= m_H + f(\sigma, a, b, c, d) \\ (D^* - D) &= \Delta + g(\Delta^{(\sigma)}, \Delta^{(a)}) \end{aligned}\right\}$$

10 parameters
+
7 parameters

→

17 parameters

72 points

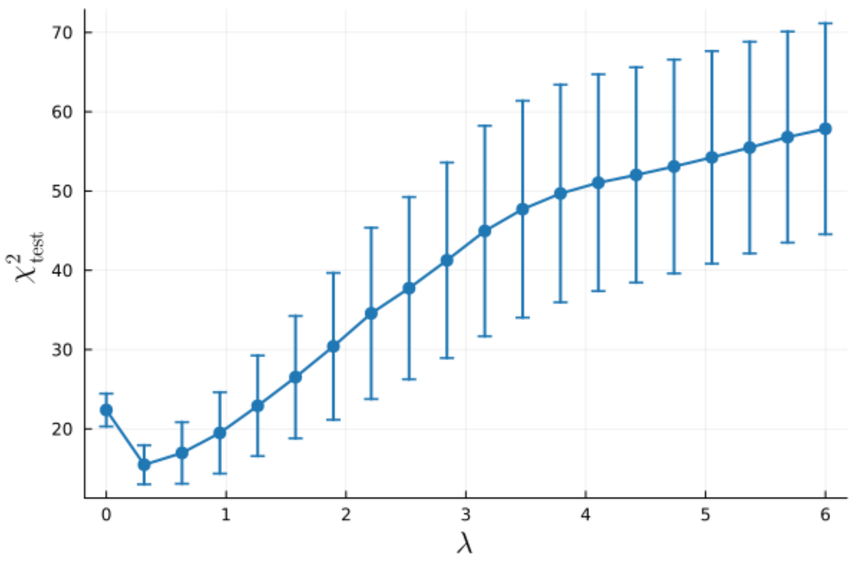
LASSO

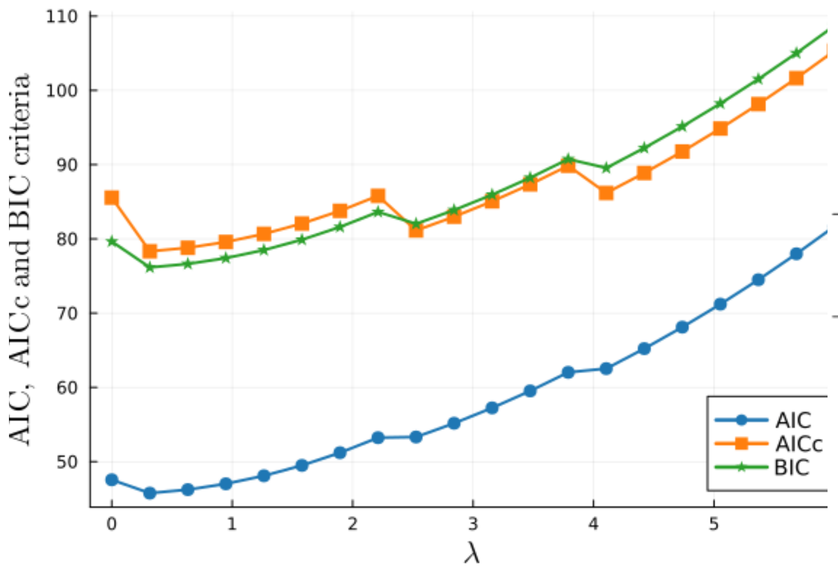
$$\chi^2_P(p,d) = \chi^2(p,d) + \lambda^4 \sum_i^n |p_i| \longrightarrow$$

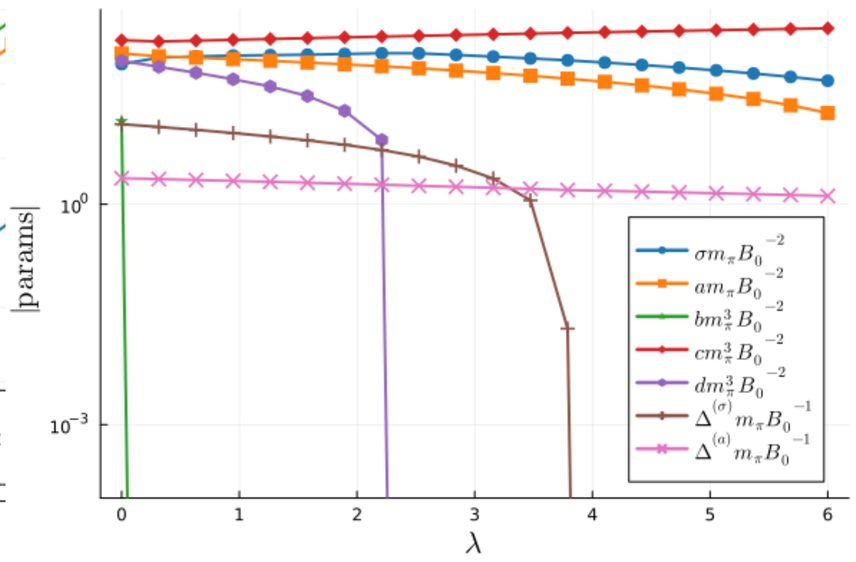
70% of data $\chi^2_P(p, d_{train})$

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

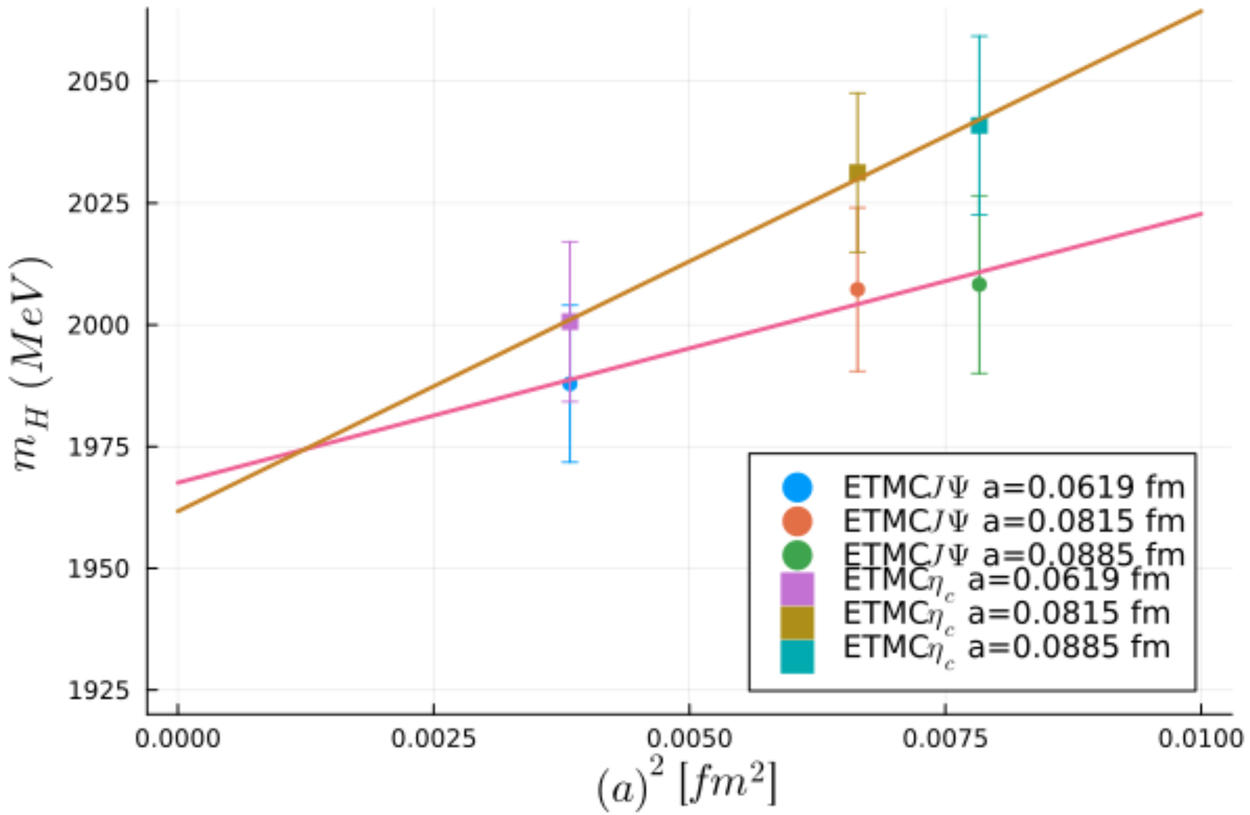
✺J. Landay, M. Döring, C. Fernández-Ramírez, B. Hu, and R. Molina, Phys. Rev. C 95, 015203 (2017), 1610.07547.

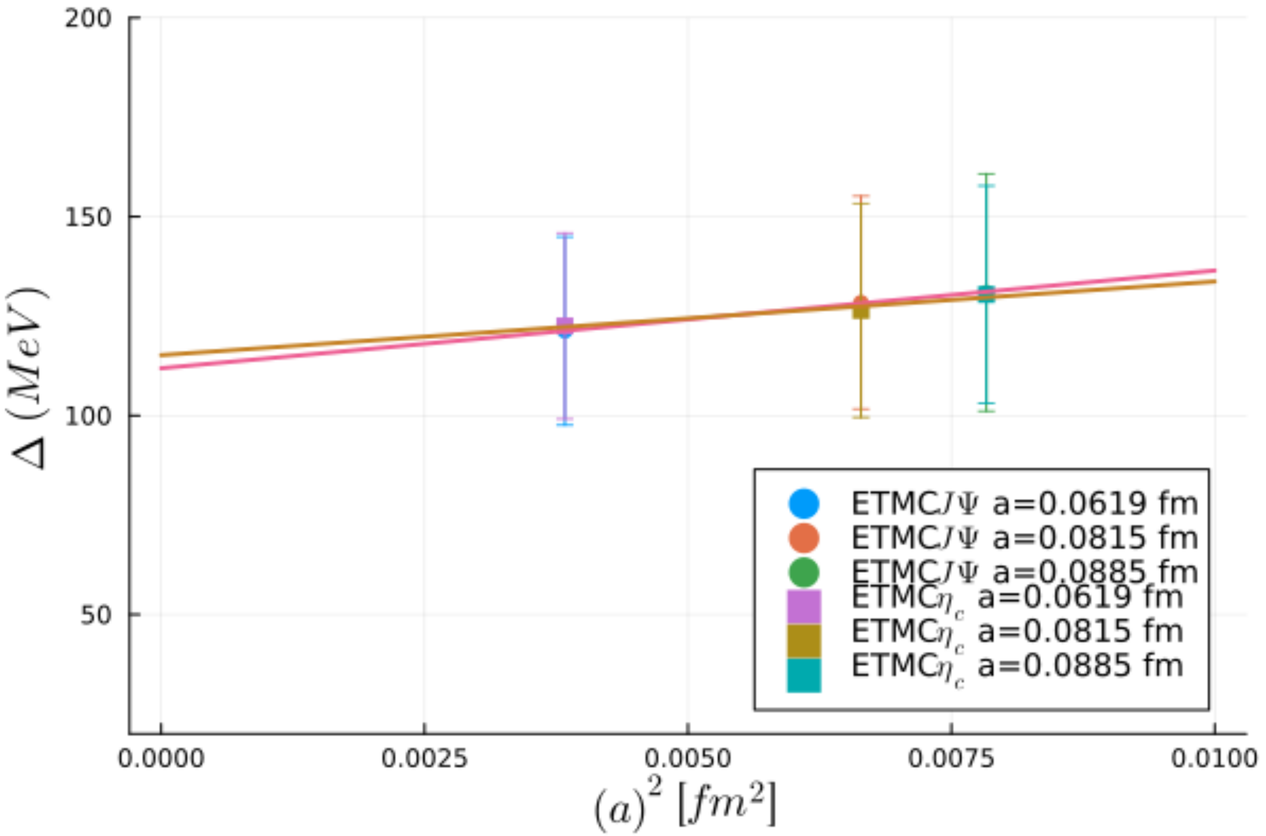






ETMC continuum extrapolation

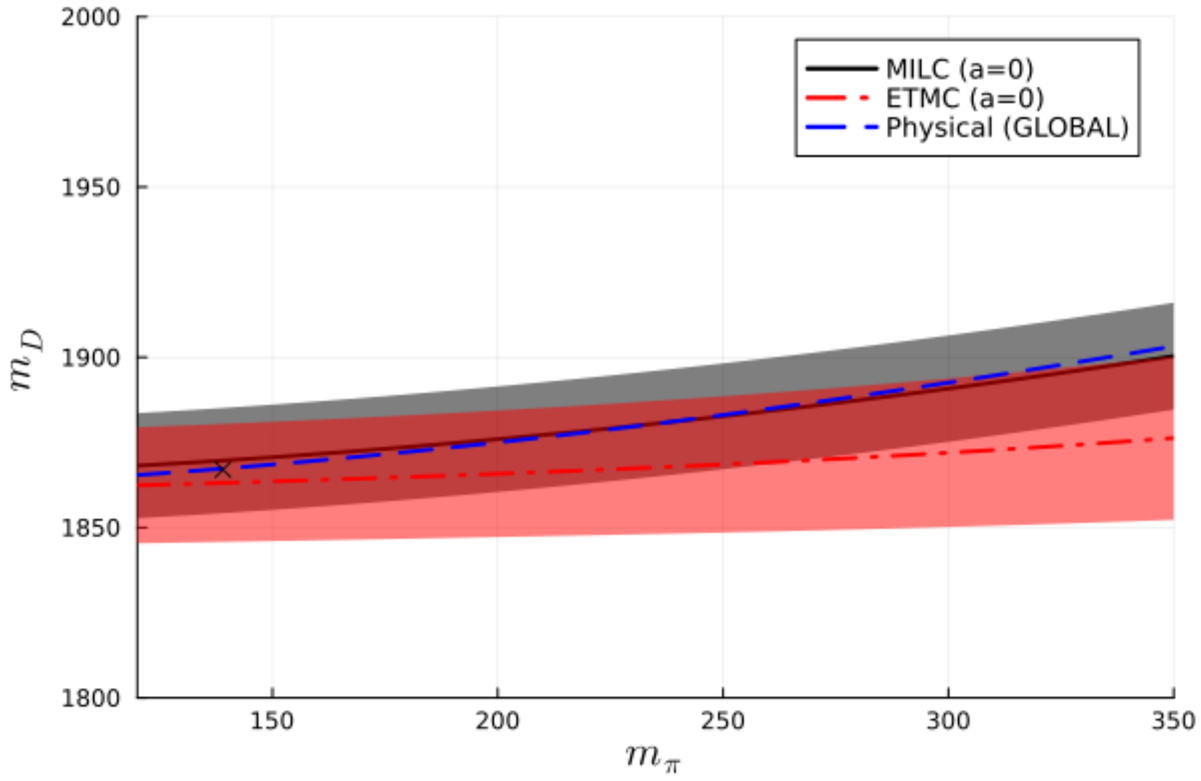


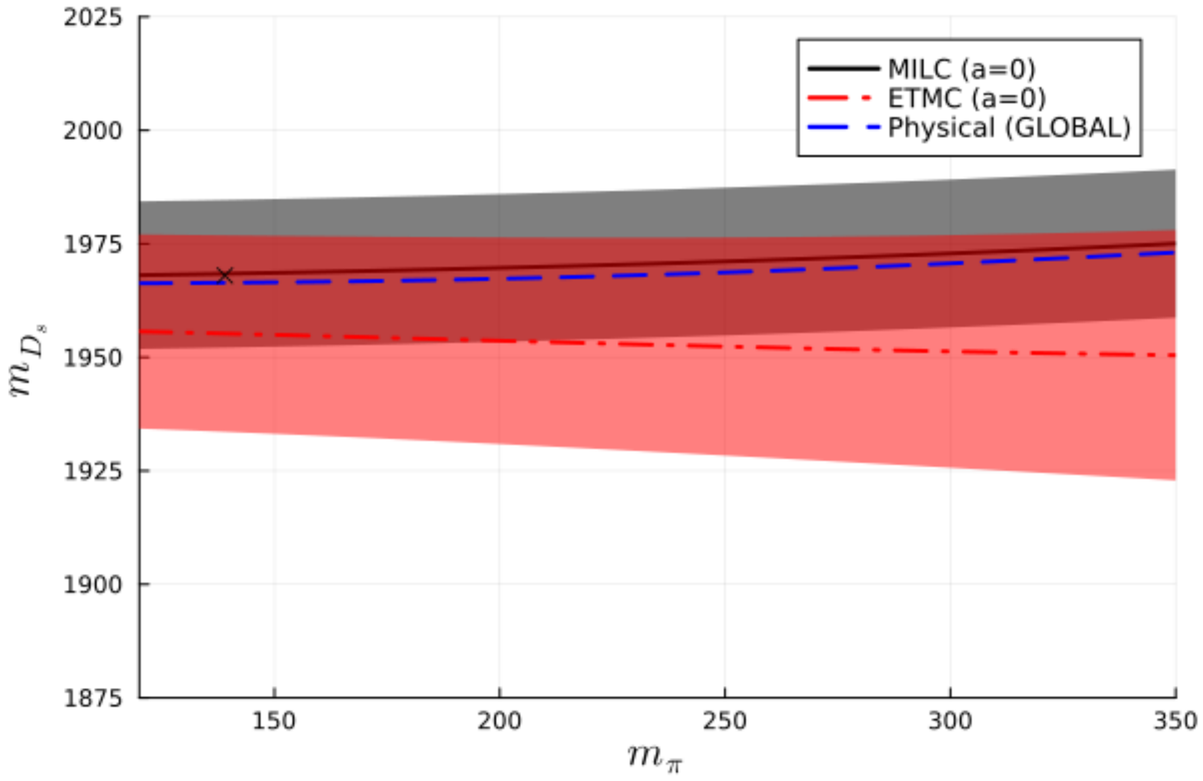


❋F. Gil-Domínguez and R. Molina, Phys. Lett. B 843 (2023), 2302.12861

D and D_s meson mass functions

continuum extrapolations

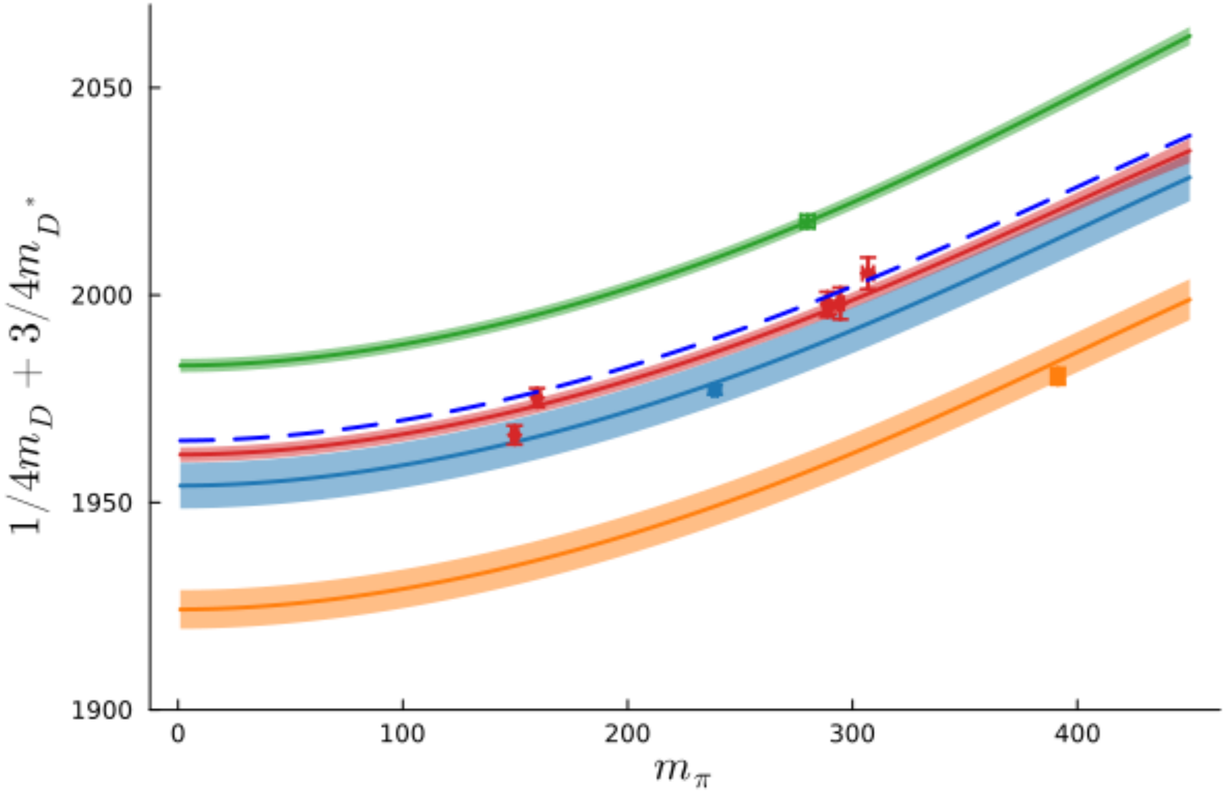


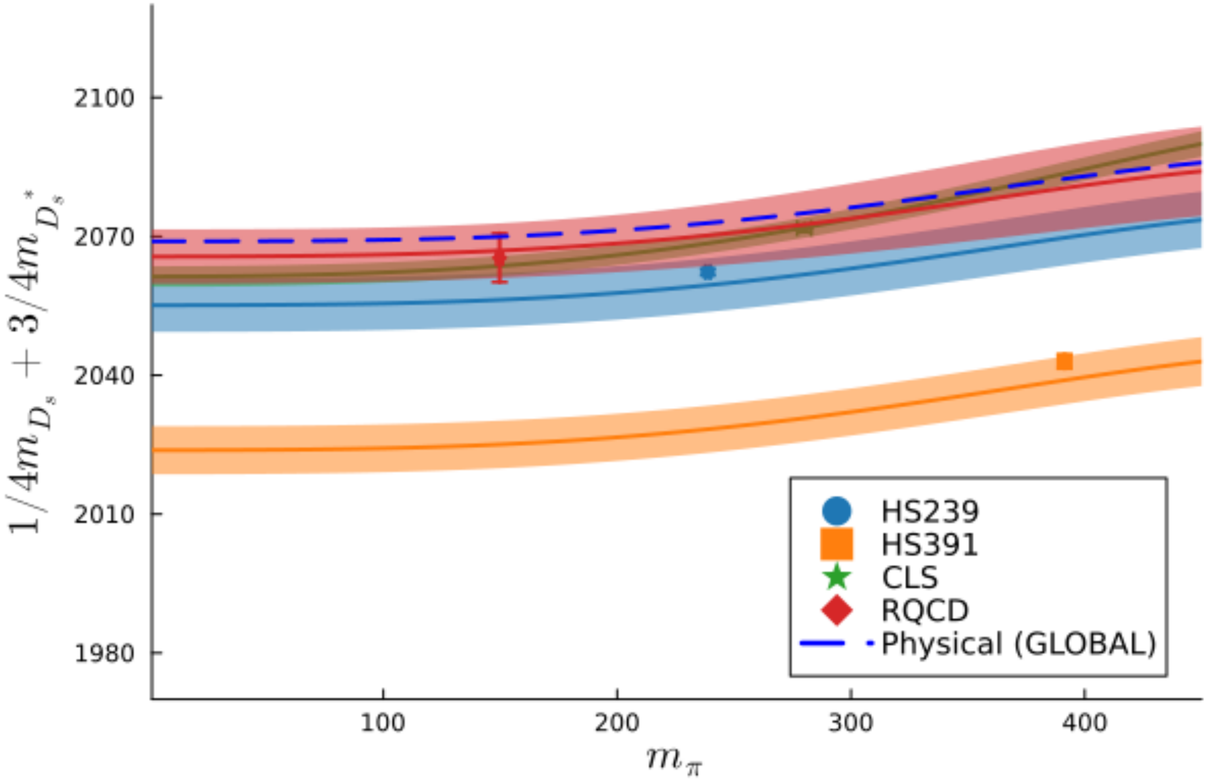


✺F. Gil-Domínguez and R. Molina, Phys. Lett. B 843 (2023), 2302.12861

D and D_s meson mass functions

for other collaborations

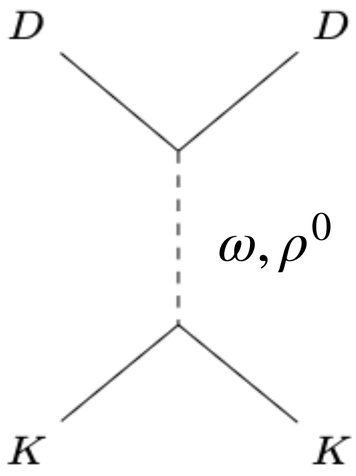


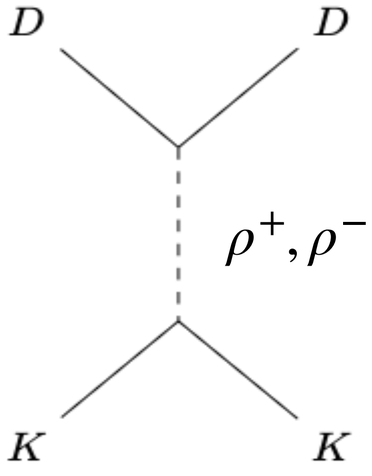


❋F. Gil-Domínguez and R. Molina, Phys. Lett. B 843 (2023), 2302.12861

Scattering amplitudes

- Lagrangian from Hidden gauge symmetry formalism
  - $\mathscr{L}_{VPP} = ig < [\partial_\mu \Phi, \Phi] V^\mu >$, $\mathscr{L}_{VVV} = ig < (\partial_\mu V_\nu - \partial_\nu V_\mu) V^\mu V^\nu >$
- The total amplitude from
  - Bethe-Salpeter equation $\rightarrow T = \dfrac{V}{1 - GV}$





Parameters for the energy levels fit

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

✺M. Albaladejo, P. Fernandez-Soler, J. Nieves, and P. G. Ortega, Eur. Phys. J. C 78, 722 (2018), 1805.07104.

$$V \to V + V_{ex} \quad \longrightarrow \quad c, m_{c\bar{s}}$$

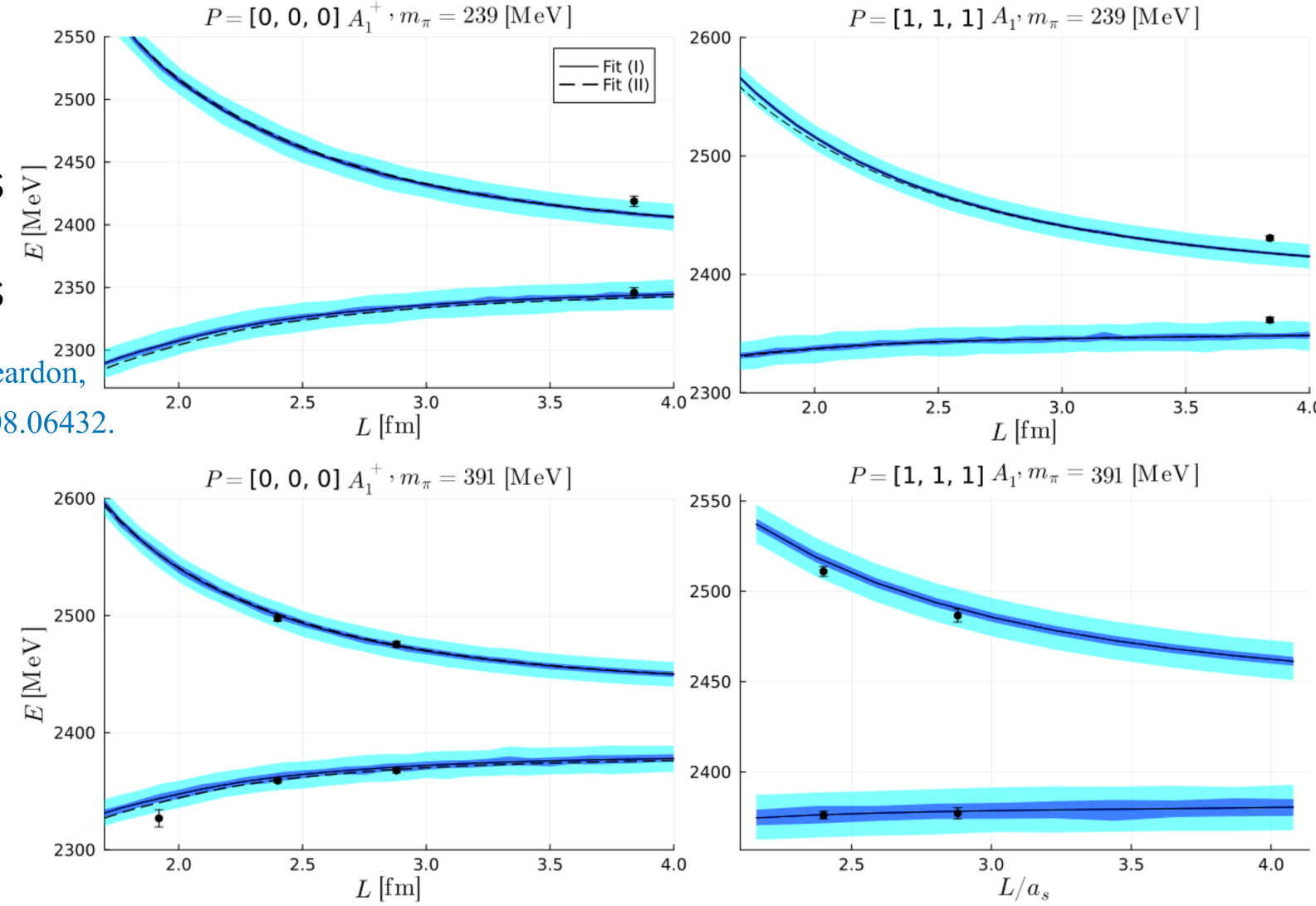
G $$a = a_1 + a_2 m_\pi^2 \quad \longrightarrow \quad a_1, a_2$$

Finite volume energy levels

(one more) fit

- HSC energy levels
  - $m_\pi = 239$ MeV $\rightarrow$ 13 points
  - $m_\pi = 391$ MeV $\rightarrow$ 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.



- Fit I

$$V_{ex} = 0 \rightarrow a_1, a_2$$

- Fit II

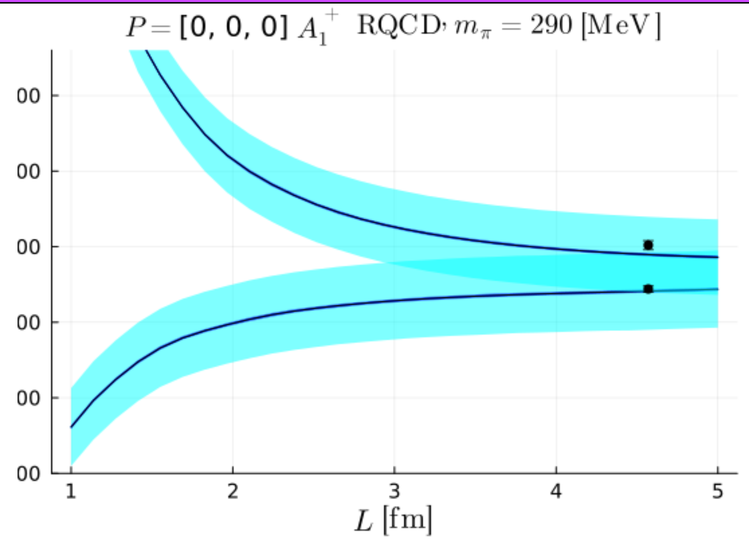
$$V_{ex} \neq 0 \rightarrow a_1, a_2, c, m_{c\bar{s}}$$

More energy levels

the global fit

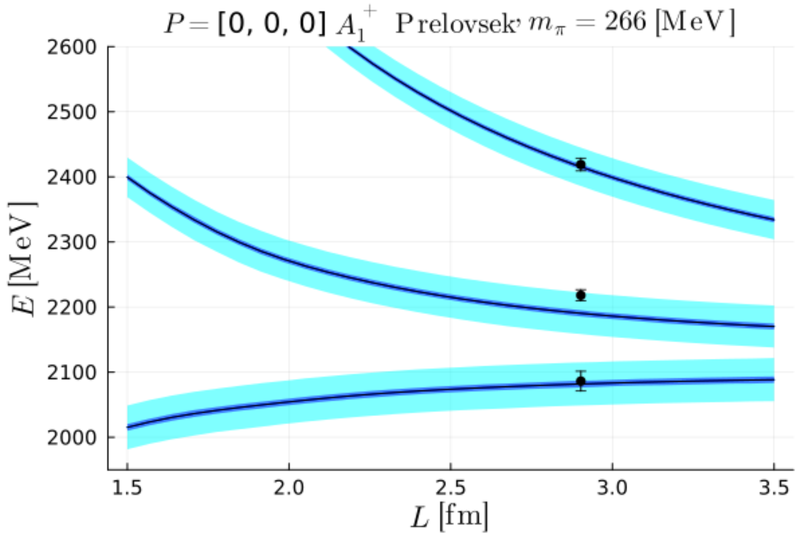
- RQCD energy levels
  - $m_\pi = 150$ MeV → 8 points
  - $m_\pi = 290$ MeV → 4 points

✺G. S. Bali, S. Collins, A. Cox, and A. Scha¨fer, Phys. Rev. D 96, 074501 (2017), 1706.01247.

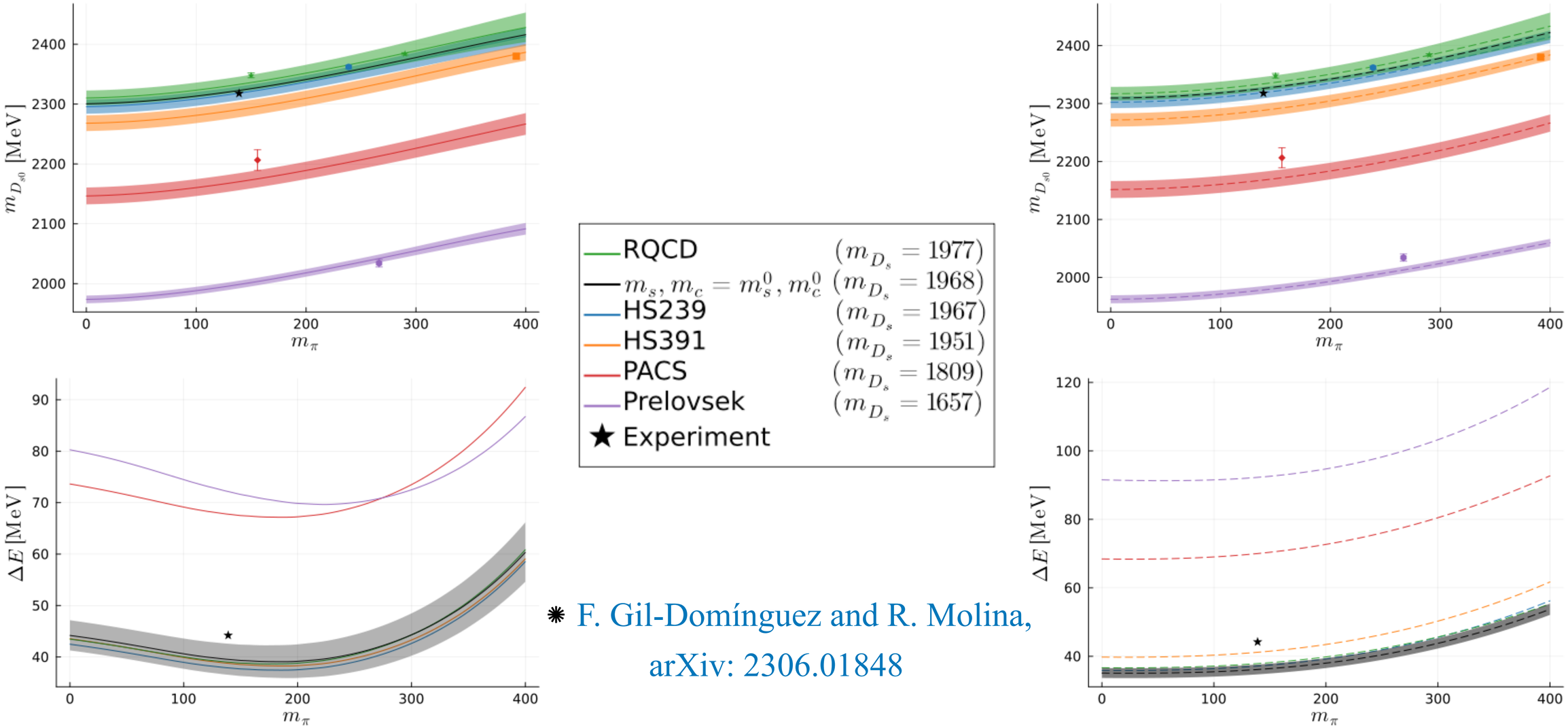


- PACS-CS, Prelovsek et al. energy levels
  - $m_\pi = 156$ MeV → 3 points
  - $m_\pi = 266$ MeV → 3 points

✺D. Mohler, C. B. Lang, L. Leskovec, S. Prelovsek, and R. M. Woloshyn, Phys. Rev. Lett. 111, 222001 (2013), 1308.3175.

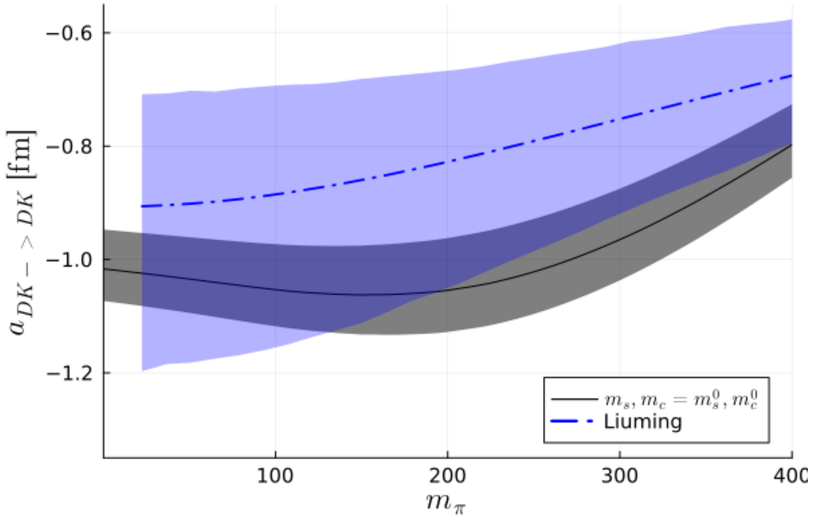


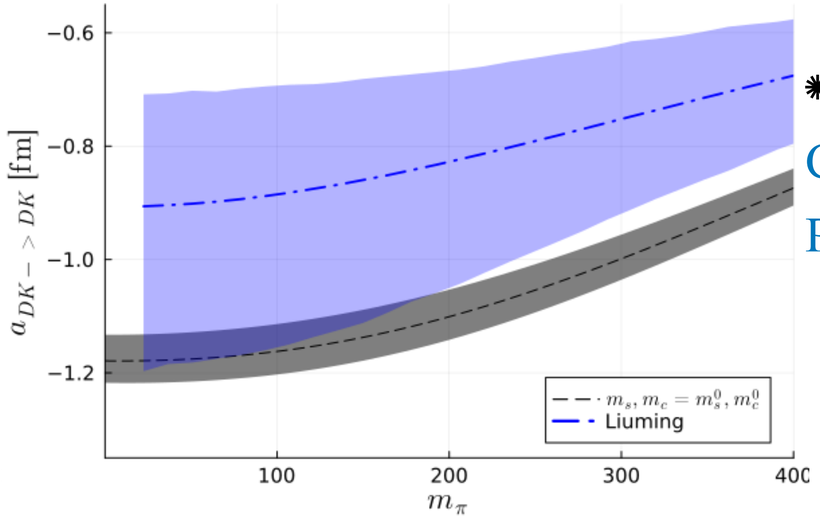
D^*_{s0} pole
finally



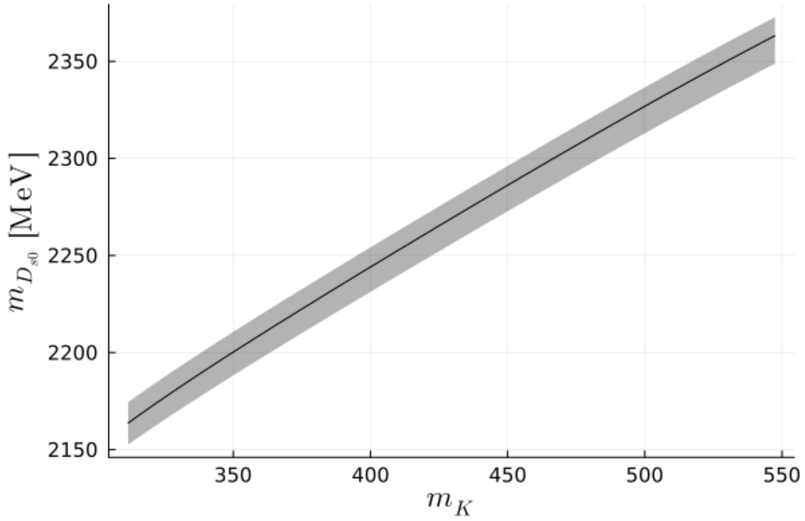
❋ F. Gil-Domínguez and R. Molina, arXiv: 2306.01848

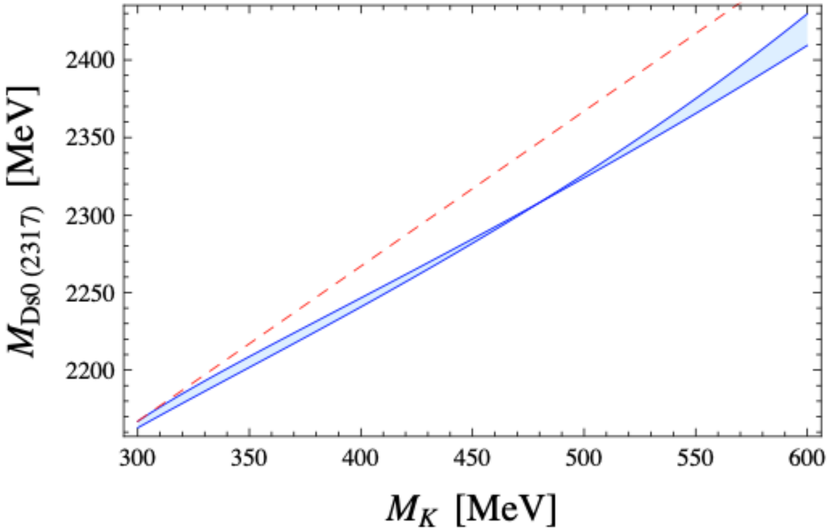
Comparison with previous results





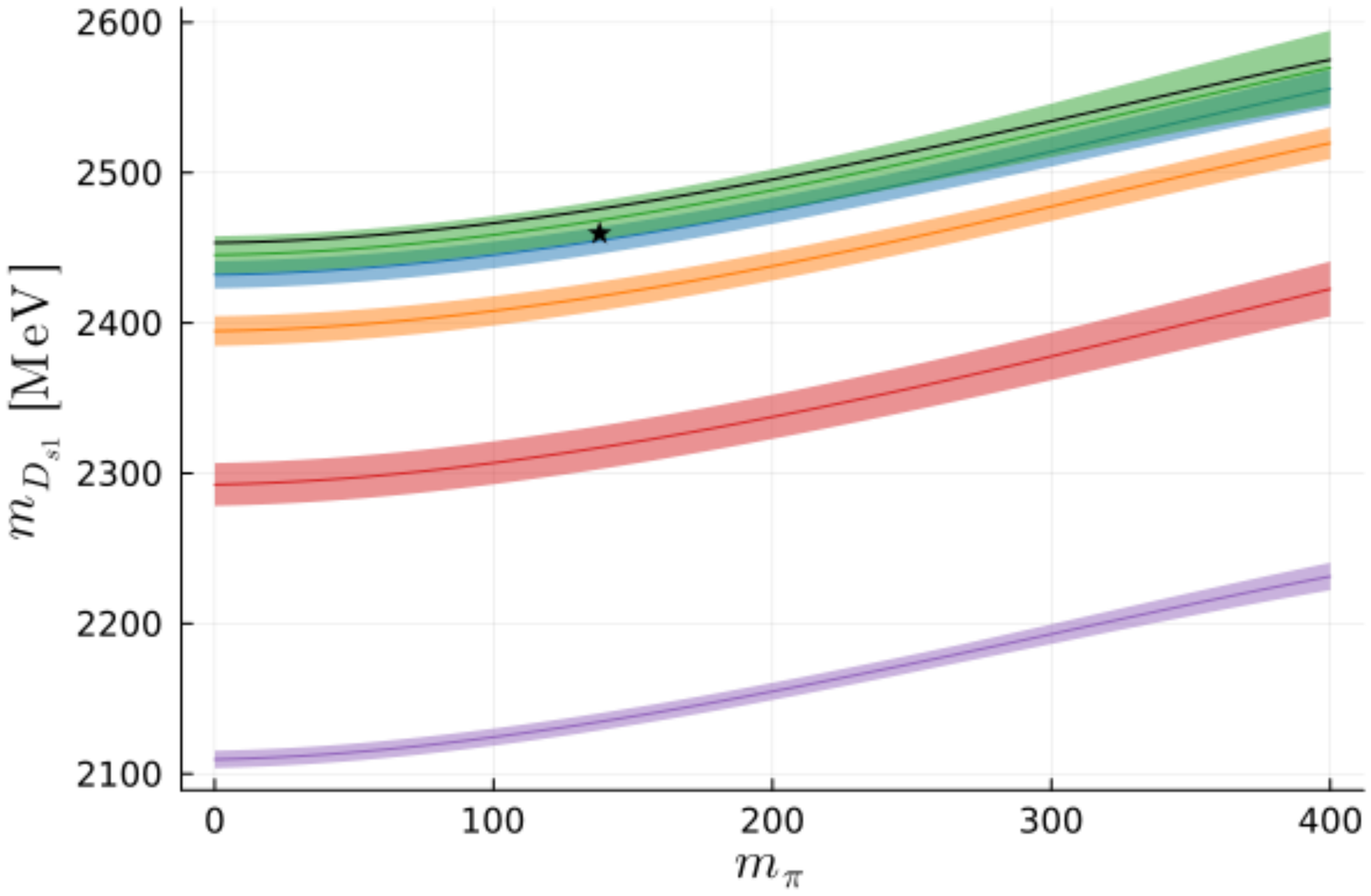
❋L. Liu, K. Orginos, F.-K. Guo,
C. Hanhart, and U.-G. Meissner,
Phys. Rev. D 87, 014508 (2013), 1208.4535.





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

D_{s1} pole
prediction



Conclusions

the end

- 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.

Thank you for your attention!