On chiral extrapolations of charmed meson masses and coupled channel dynamics

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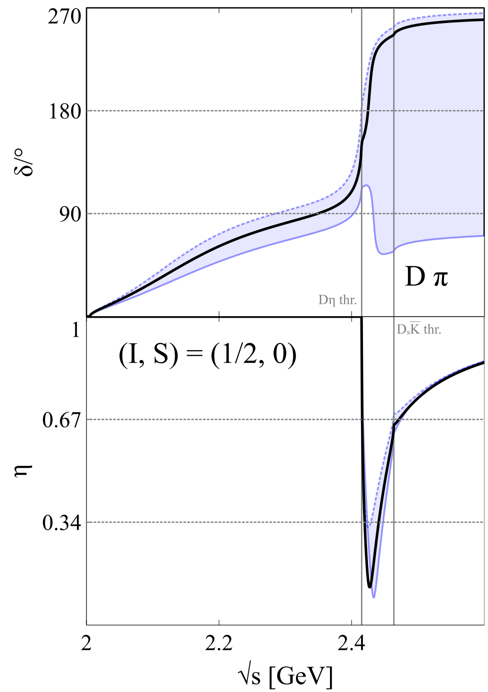
The chiral Lagrangian for charmed mesons

- Leading order SU(3) chiral Lagrangian

$$\mathcal{L} = \frac{1}{4}\,\mathrm{tr}(\partial_\mu \Phi)(\partial^\mu \Phi) - \frac{1}{4}\,\mathrm{tr}\,\chi_0 \Phi^2 + (\partial_\mu D)(\partial^\mu \bar{D}) - D M_{0^-}^2 \bar{D}$$
$$+ \frac{1}{8f^2}\{(\partial^\mu D)[\Phi, (\partial_\mu \Phi)]_- \bar{D} - D[\Phi, (\partial_\mu \Phi)]_- (\partial^\mu \bar{D})\},$$



- πD scattering isospin 1/2
  - A broad anti-triplet state and a narrow sextet state predicted [PLB582(2004)39]
  - The broad resonance confirmed by Belle and LHCb
  - Phase shift from LO chiral interaction
    - Clear signal for two states
    - Uncertainty indicated by the shaded area

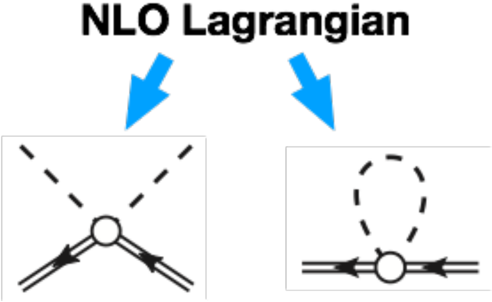
- Is there a flavor sextet in QCD?
  What is the role of higher order chiral corrections ?

The chiral Lagrangian for charmed mesons

- Chiral Lagrangian at next-to-leading order

$$\mathcal{L}^{(2)} = -\big(4\,c_0 - 2\,c_1\big)\,D\,\bar{D}\,\mathrm{tr}\,\chi_+ - 2\,c_1\,D\,\chi_+\,\bar{D}$$
$$+\,4\,\big(2\,c_2 + c_3\big)\,D\bar{D}\,\mathrm{tr}\,\big(U_\mu\,U^{\mu\dagger}\big) - 4\,c_3\,D\,U_\mu\,U^{\mu\dagger}\,\bar{D}$$
$$+\,\frac{1}{M^2}\,\big(4\,c_4 + 2\,c_5\big)\,(\partial_\mu D)(\partial_\nu \bar{D})\,\mathrm{tr}\,\big[U^\mu,\,U^{\nu\dagger}\big]_+ - \frac{1}{M^2}\,2\,c_5\,(\partial_\mu D)\big[U^\mu,\,U^{\nu\dagger}\big]_+(\partial_\nu \bar{D})$$

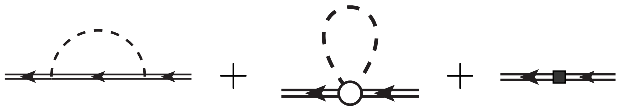
- Previous estimates for NLO low-energy constants:
  - from large N_c and πD invariant mass distribution from Belle [NPA813(2008)14]
  - based on elastic scattering lengths from lattice [PRD87(2013)014508]



- Fit to D-meson masses and scattering observables from lattice

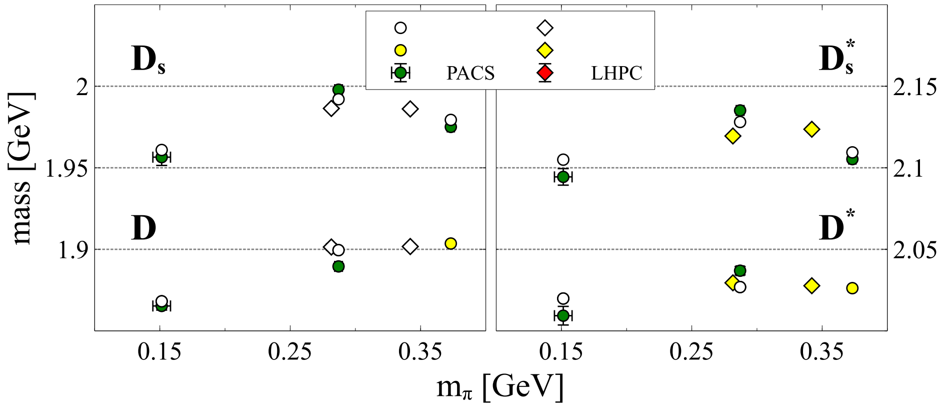
Chiral extrapolations of D-meson masses

- Quark mass dependence of $J^P = 0^-$, 1^- D-meson masses up to N^{3}LO
  - On-shell masses are used in the loops
  - Quark masses are determined by pion and kaon masses



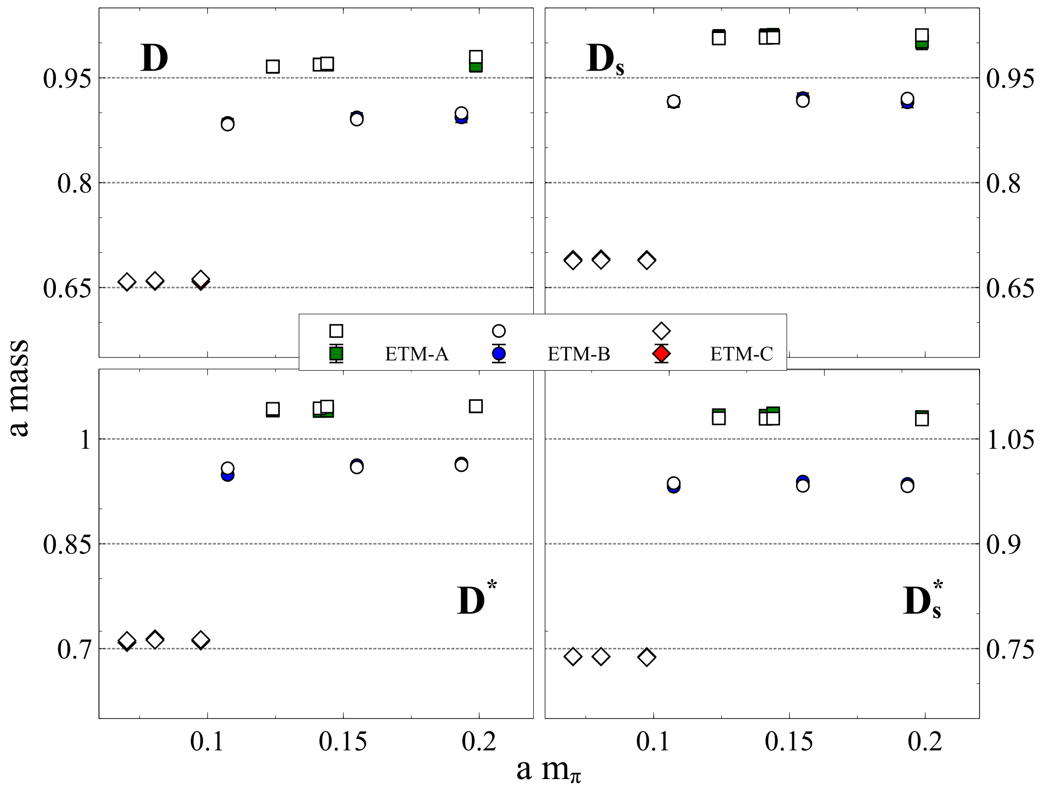
- 64 D/D_s and D^*/D_s^* masses from 5 lattice collaborations at different pion and kaon masses (ETMC, PACS, HPQCD, LHPC, HSC)
  - Finite-volume effects are taken into account

Mohler, Woloshyn: PRD84(2011)054505; Lang, et al: PRD90(2014)034510 (PACS-CS)
Liu, et al: PRD87(2013)014508 (NPLQCD/LHPC)



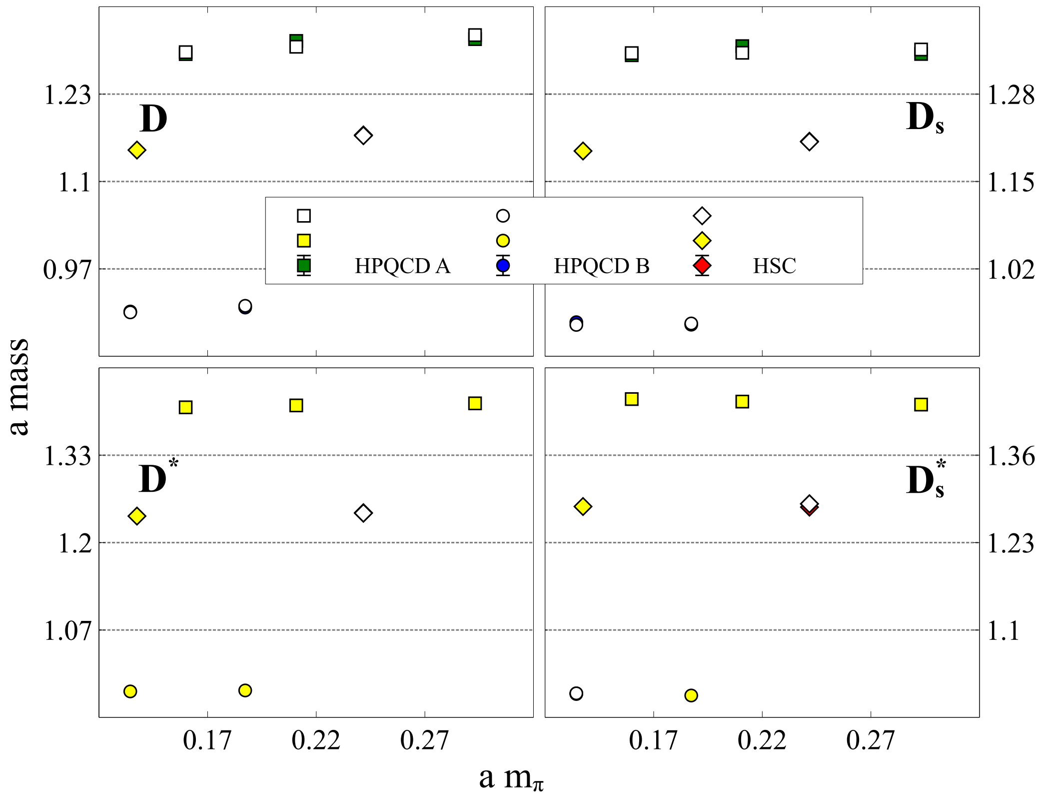
D-meson masses from ETM collaboration

ETMC: PRD92(2015)094508



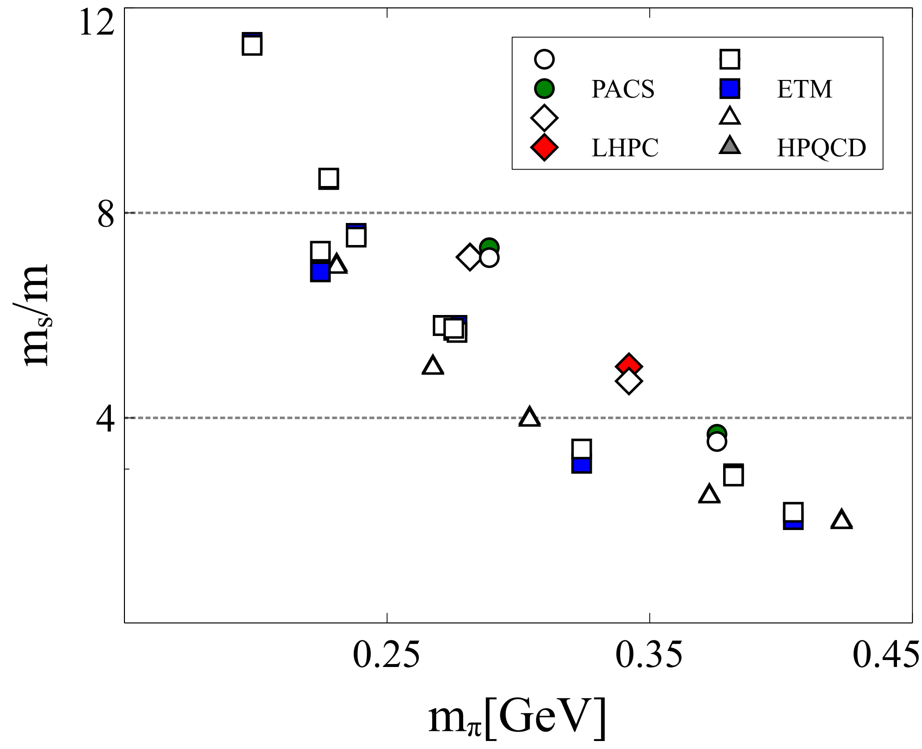
D-meson masses from HPQCD and HSC

HPQCD: PRD82(2010)114506; PRD86(2012)054510
HSC: JHEP10(2016)011



Prediction of quark mass ratios

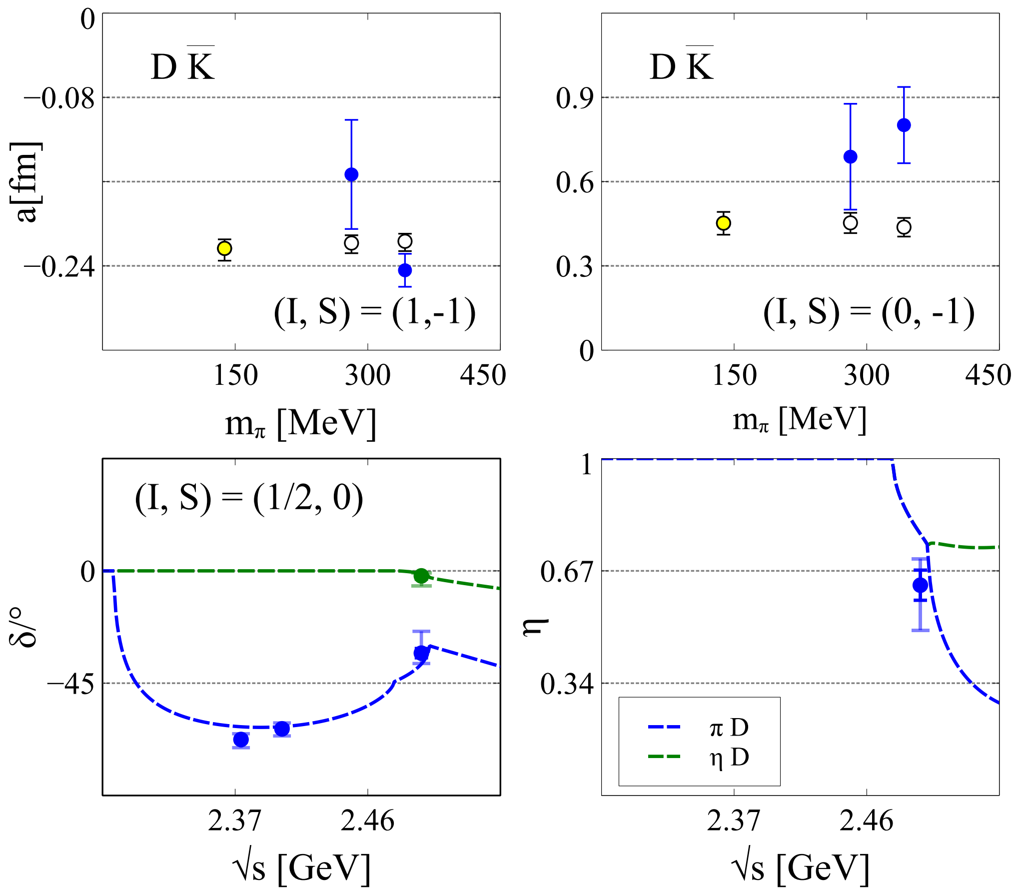
- m_s/m are comparable with the values given by lattice groups



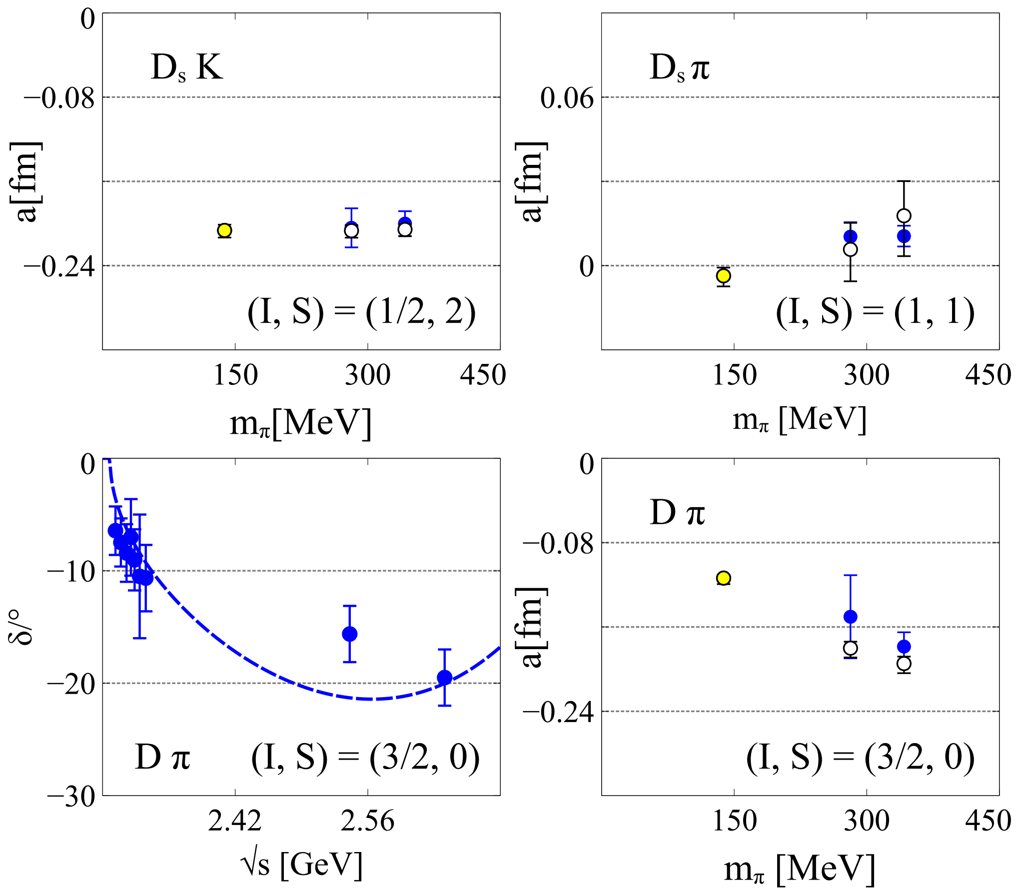
Constraints from scattering lengths and phase shifts

- Lattice results of D-meson masses do not lead to a unique set of LECs.
- Use additional information from lattice at unphysical quark masses.
  - Liu, et.al: PRD87(2013)014508:
    scattering lengths for $\bar{K}D$, KD_s, πD, πD_s channels
    - 10 data points
  - HSC: JHEP10(2016)011:
    phase shifts and inelasticities for πD and ηD channels
- Fit lattice data using coupled-channel dynamics from the chiral Lagrangian

Constraints from scattering lengths and phase shifts



Constraints from scattering lengths and phase shifts

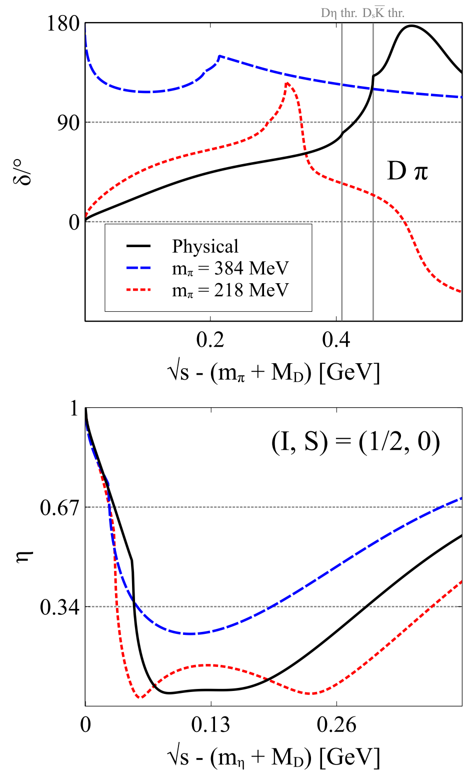


Isospin-violating decay width of $D_{s0}^*(2317)$

- Coupled-channel dynamics based on the leading order chiral Lagrangian predict $D_{s0}^*(2317)$
  - Hadronic decay width from $D_{s0}^*(2317) \to D_s(1968)\pi^0$
  - LO prediction: 75 keV [NPA813(2008)14]
- NLO corrections may significantly change the estimation of Γ:

  140 keV [NPA813(2008)14]; 133 keV [PRD87(2013)014508]
  - Measurement of the width will have significant impact on chiral dynamics in QCD
- In this work all relevant lattice data are used
  - Our prediction is $\Gamma = (104 \sim 116)$ keV
- The resolution of PANDA is capable of measuring this Γ.

Quark mass dependence of πD phase shift



- The $\pi\, D\, (I = 1/2)$ phase shift strongly depends on the quark masses
- Two resonance states are predicted
- Anti-triplet state is bound at $m_\pi = 384\text{MeV}$

  $\rightarrow$ very broad at physical quark masses
- Predict the sextet state at physical quark masses

  $\rightarrow$ above $\eta\, D$ threshold
- Our result is compatible with previous NLO calculations [NPA813(2008)14, PLB767(2017)465]
- Future measurement of $\eta\, D$ mass distribution is requested (PANDA)

Summary

- We considered the chiral Lagrangian for 0^- and 1^- D-mesons at NLO
- We simultaneously describe lattice data for:
  - D and D^* masses from 5 lattice collaborations
  - Scattering lengths, phase shifts and inelasticities from 2 lattice collaborations
  - The quark mass ratio from our fitting is compatible with the values given by lattice
- A complete set of LECs at NLO is established
  - The width of $D^*_{s0}(2317)$ is predicted as $(104 \sim 116)$ keV
  - A narrow sextet state is foreseen above the ηD threshold
- To be challenged by experiments (PANDA, LHCb, Belle II, etc.)

Thank You!

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