Hadron-hadron interaction in SU(3) chiral perturbation theory

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Introduction

- SU(2) ChPT has been widely used to study low-energy hadronic processes and achieved many successes. For processes involving kaons or hyperons, one has to use SU(3) chiral dynamics.

$$\text{SU(2):} \quad T = C_1\left(\frac{m_\pi/q}{\Lambda_\chi}\right) + C_2\left(\frac{m_\pi/q}{\Lambda_\chi}\right)^2 + \cdots$$

$$\text{SU(3):} \quad T = C_1'\left(\frac{m_\pi/q/m_K}{\Lambda_\chi}\right) + C_2'\left(\frac{m_\pi/q/m_K}{\Lambda_\chi}\right)^2 + \cdots$$

- In this talk: Hadron-hadron interaction in SU(3) case based on papers:
  - B.-L. Huang, *et. al.*, Phys. Rev. D, 2015, **92: 114033**; Phys. Rev. D, 2017, **96: 016021**; Phys. Rev. D, 2020, **101: 056021**; Phys. Rev. D, 2020, **102: 116001**; Phys. Rev. D, 2021, **104: 116030**; arXiv: **2409.09388**.
  - B.-L. Huang, *et. al.*, Phys. Rev. D, 2022, **105: 036016**; Eur. Phys. J. C, 2023, **83: 76**; Eur. Phys. J. C, 2023, **83: 1071**; Phys. Rev. D, 2023, **108: 114014**; arXiv: **2402.00460**

Fields

(u, d, s quarks)

Eight meson and baryon fields in terms of the traceless hermitian 3×3 matrices Φ and B:

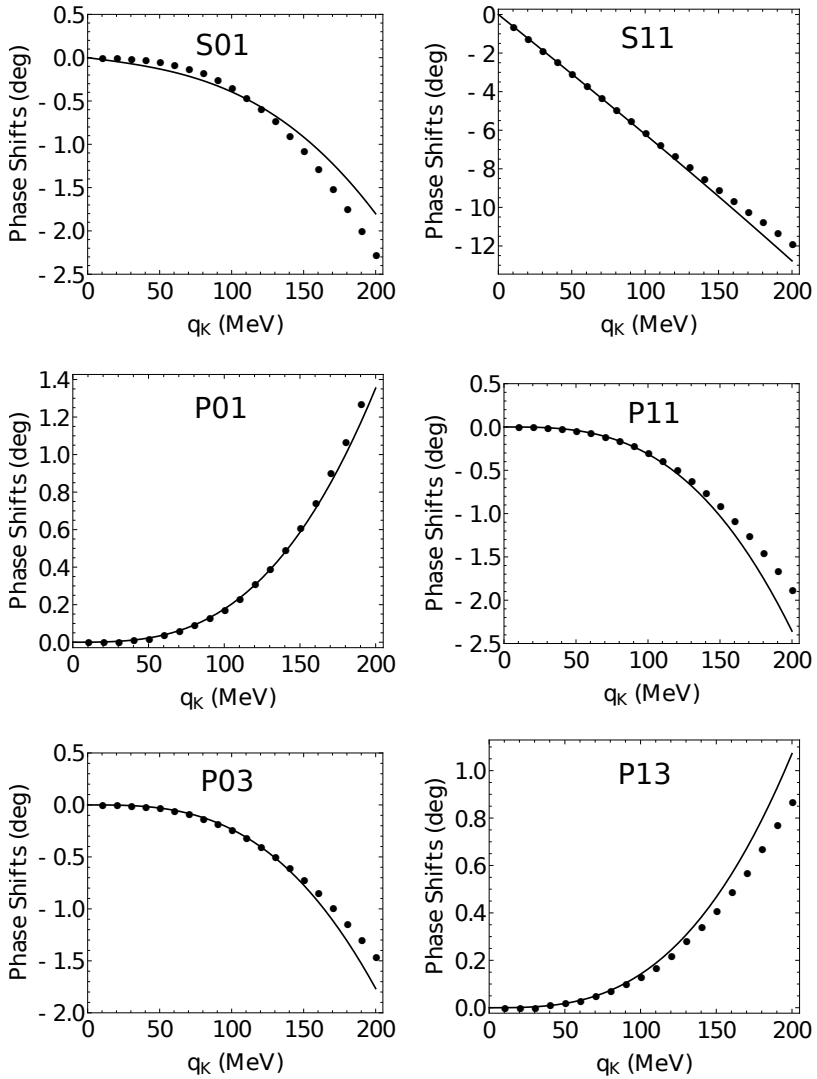
$$\Phi = \sqrt{2} \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \overline{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix},$$

$$B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix},$$

with the SU(3) matrix $U = \xi^2 = \exp(i\Phi/f)$.

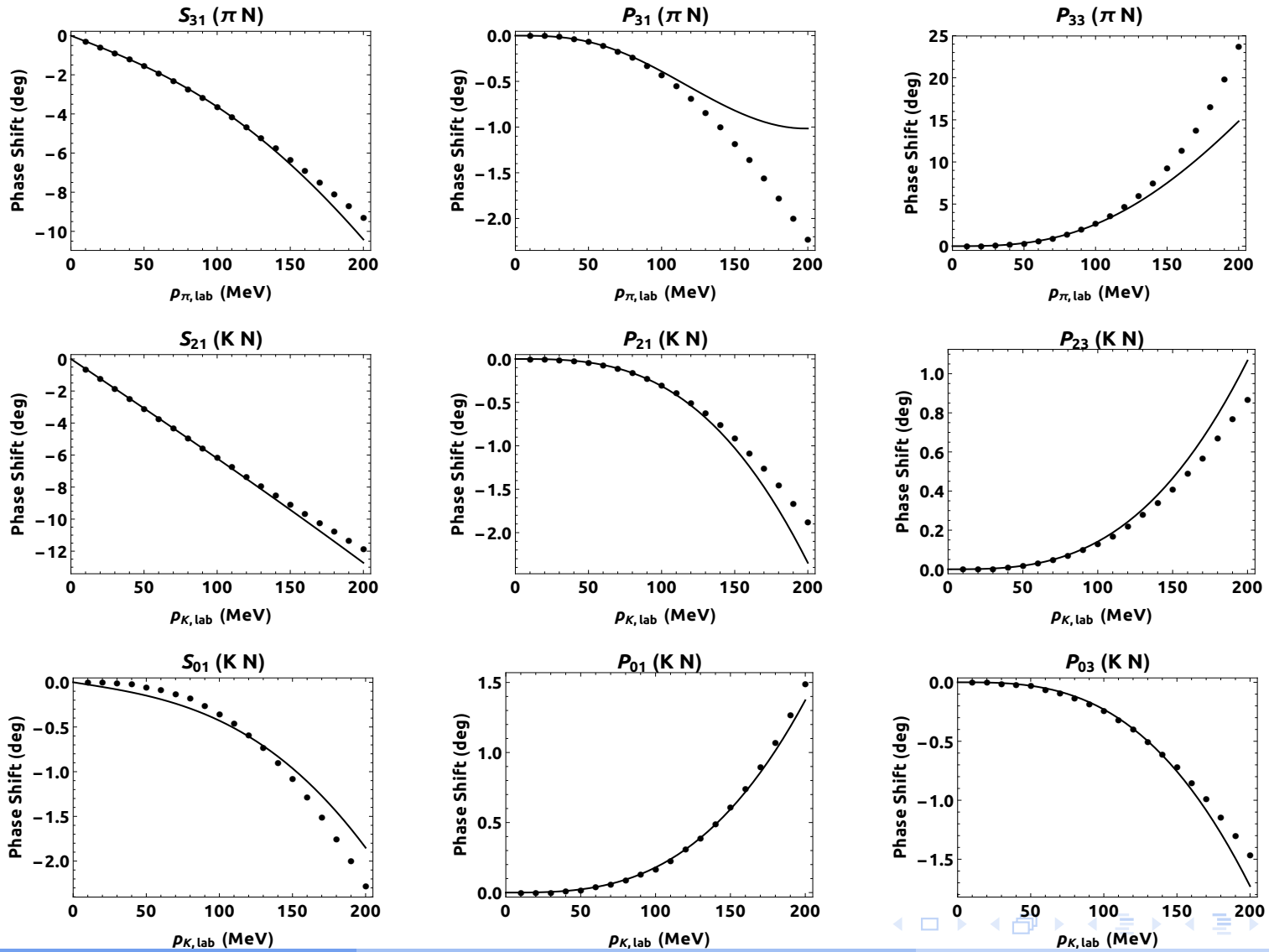
Kaon-nucleon scattering to one-loop order

Phase Shifts [B.-L. Huang, Y.-D. Li, **Phys. Rev. D, 2015, 92: 114033**]



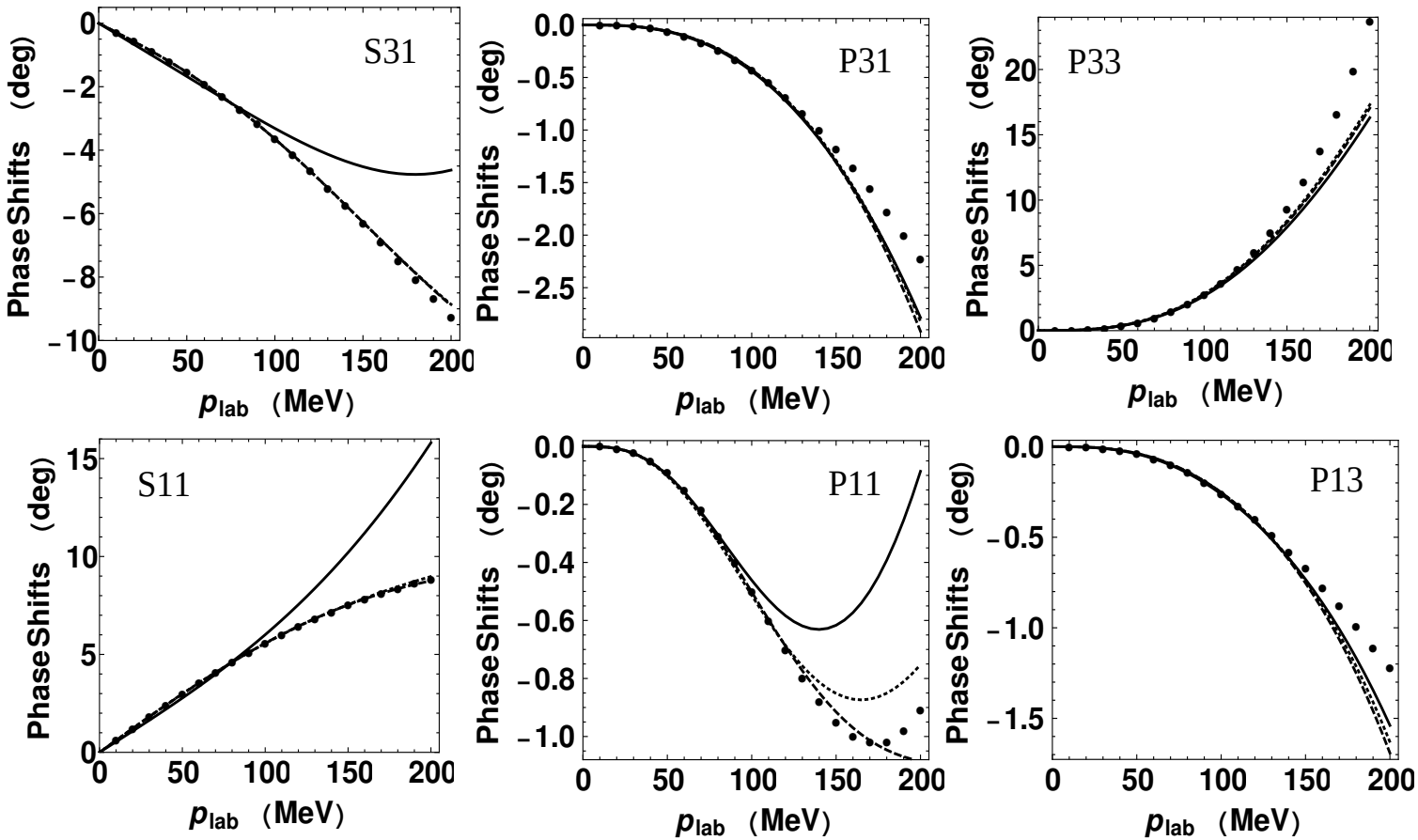
Meson-baryon scattering to one-loop order

Phase Shifts [B.-L. Huang, J.-S. Zhang, Y.-D. Li, N. Kaiser, **Phys. Rev. D, 2017, 96: 016021**]



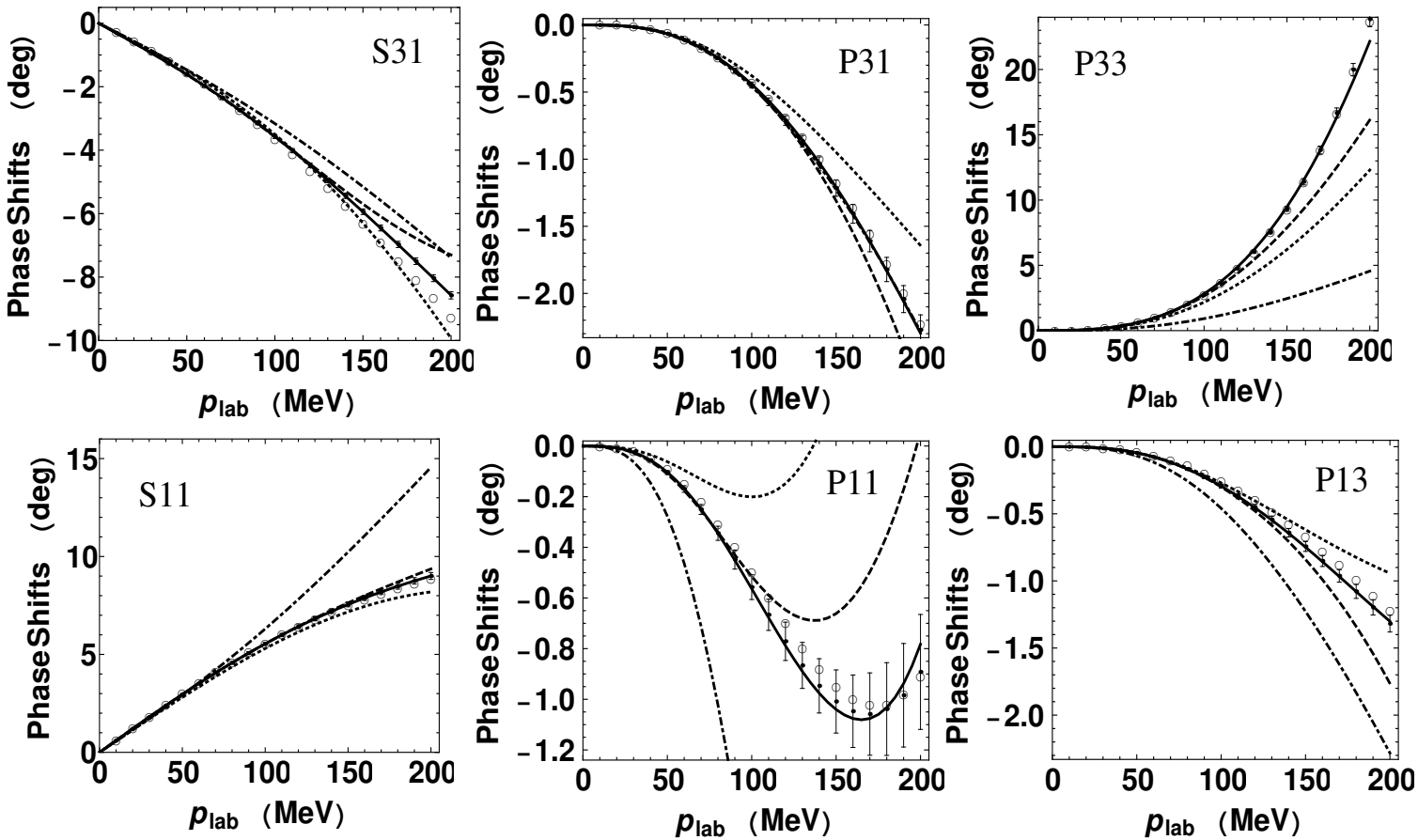
Pion-nucleon scattering to order $\mathcal{O}(p^3)$

Phase Shifts [B.-L. Huang, J. Ou-Yang, **Phys. Rev. D, 2020, 101: 056021**]



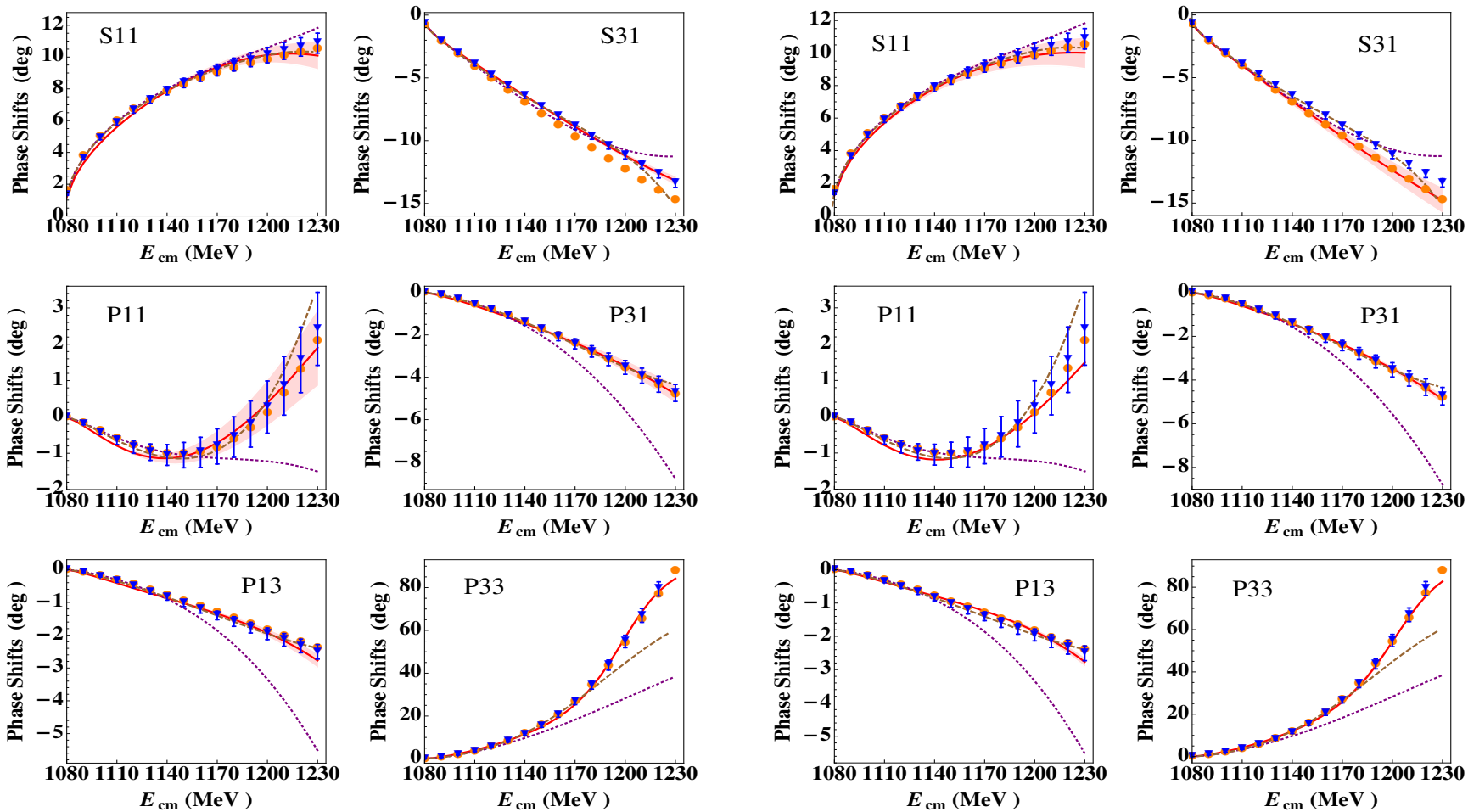
Pion-nucleon scattering to order $\mathcal{O}(p^4)$

Phase Shifts [B.-L. Huang, **Phys. Rev. D, 2020, 102: 116001**]



Pion-nucleon scattering with decuplet contribution

Phase Shifts [J. Ou-Yang, B.-L. Huang, **arXiv: 2409.09388**]



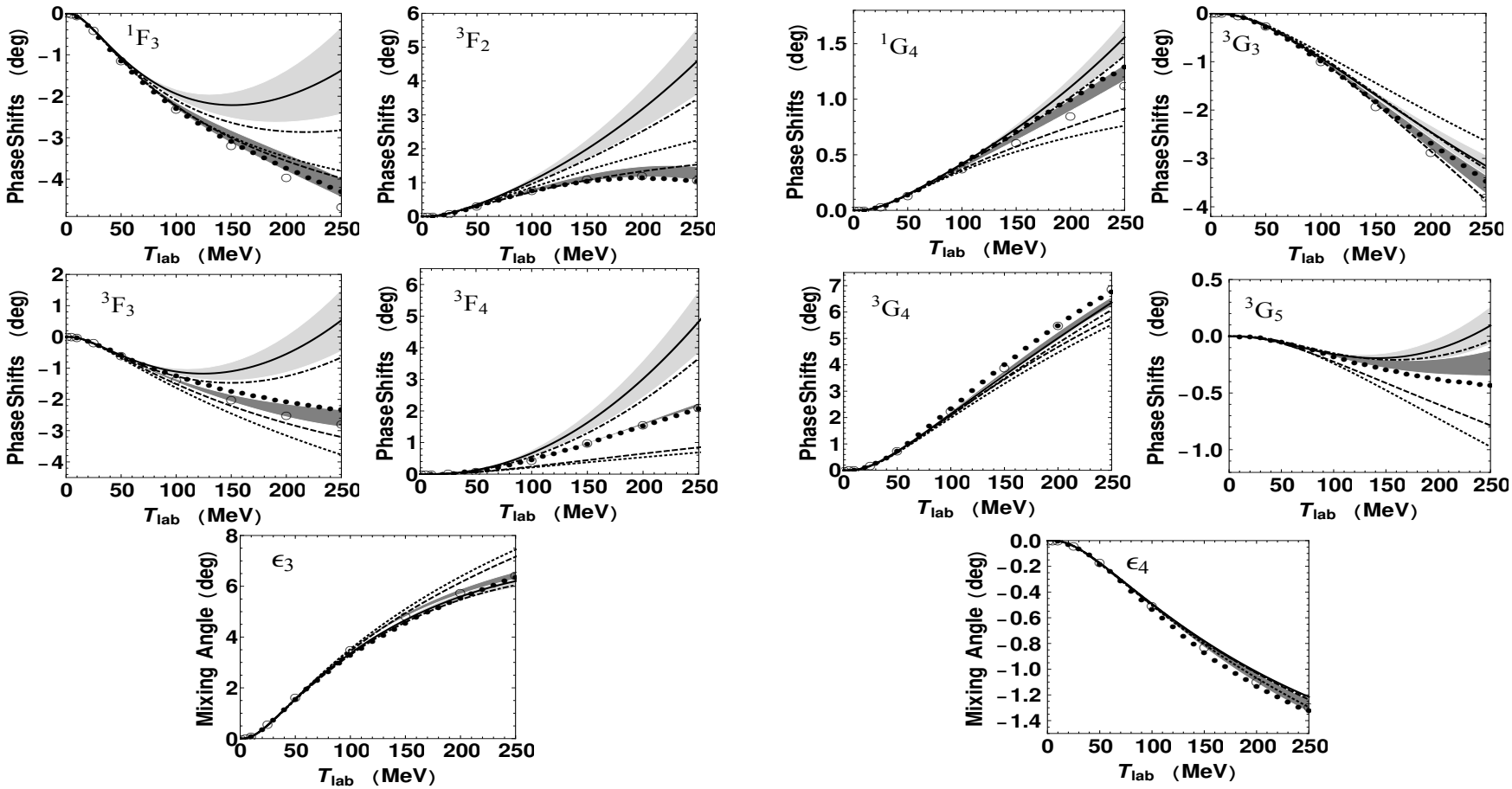
Pion-nucleon scattering with decuplet contribution

Baryon Masses and σ-terms [J. Ou-Yang, B.-L. Huang, **arXiv: 2409.09388**]

	Input	Fit RS	Fit WI08
M_N (MeV)	938.92 ± 1.29	939.08 ± 8.51	939.06 ± 5.86
M_Σ (MeV)	1191.01 ± 4.86	1190.37 ± 12.90	1191.28 ± 14.19
M_Ξ (MeV)	1318.26 ± 6.30	1322.83 ± 25.05	1323.88 ± 27.22
M_Λ (MeV)	1115.68 ± 5.58	1111.25 ± 13.32	1111.63 ± 13.06
$\sigma_{\pi N}$ (MeV)	59.1 ± 3.5	52.08 ± 2.61	40.30 ± 2.31
$\sigma_{KN}^{(1)}$ (MeV)	—/—	375.07 ± 33.02	226.48 ± 29.93
$\sigma_{KN}^{(2)}$ (MeV)	—/—	275.32 ± 32.24	126.59 ± 35.62

Nucleon-nucleon scattering in SU(3) case

Phase Shifts [B.-L. Huang, J.-B. Cheng, S.-L. Zhu, **Phys. Rev. D, 2021, 104: 116030**]



Fields

(c, b quarks)

$$P = (D^0, D^+, D_s^+), \quad P_\mu^* = (D^{0*}, D^{+*}, D_s^{+*})_\mu,$$

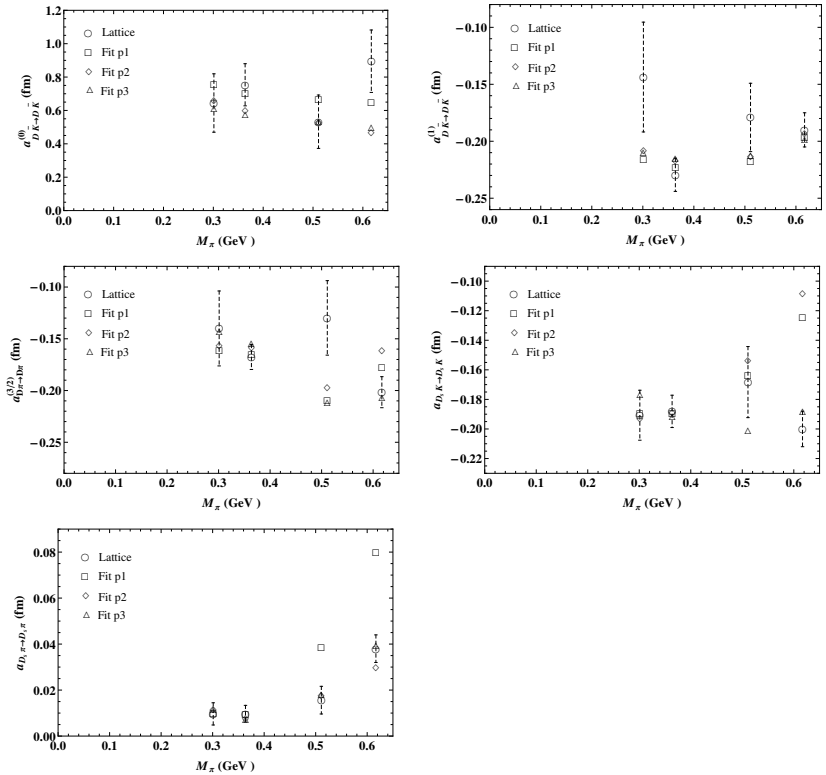
$$H = \frac{1+\not{v}}{2}(P_\mu^* \gamma^\mu + iP\gamma_5), \quad \bar{H} = (P_\mu^{*\dagger}\gamma^\mu + iP^\dagger\gamma_5)\frac{1+\not{v}}{2}.$$

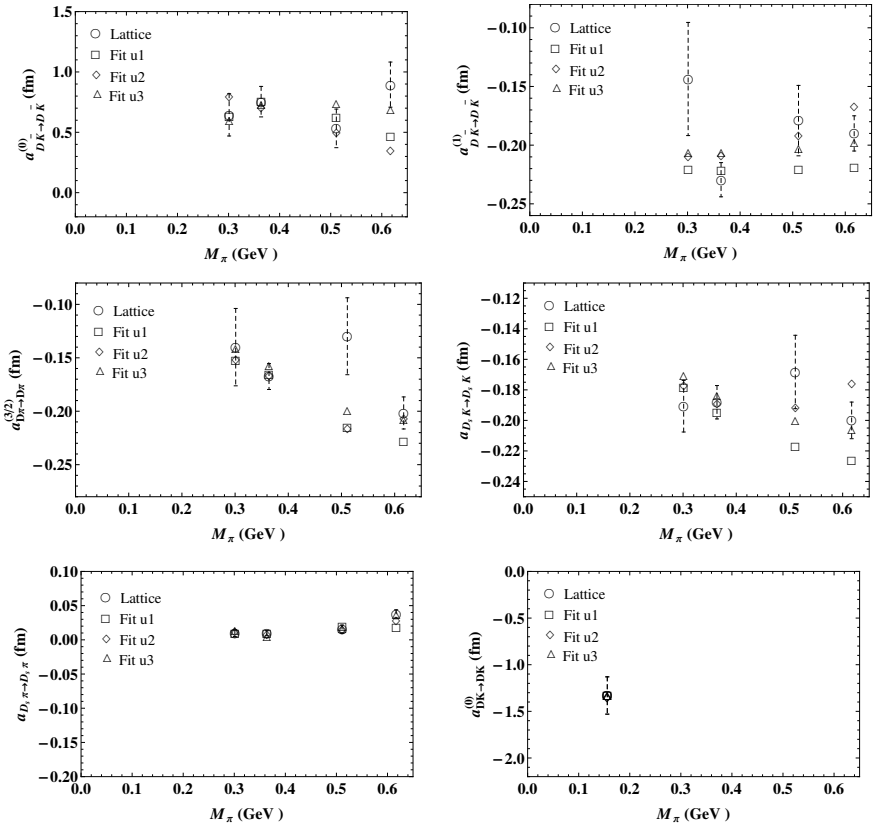
$$\Phi = \sqrt{2}\begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \overline{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix},$$

$$B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}.$$

Light pseudoscalar meson and D meson scattering

Scattering Lengths [B.-L. Huang, Z.-Y. Lin, S.-L. Zhu, **Phys. Rev. D, 2022, 105: 036016**]





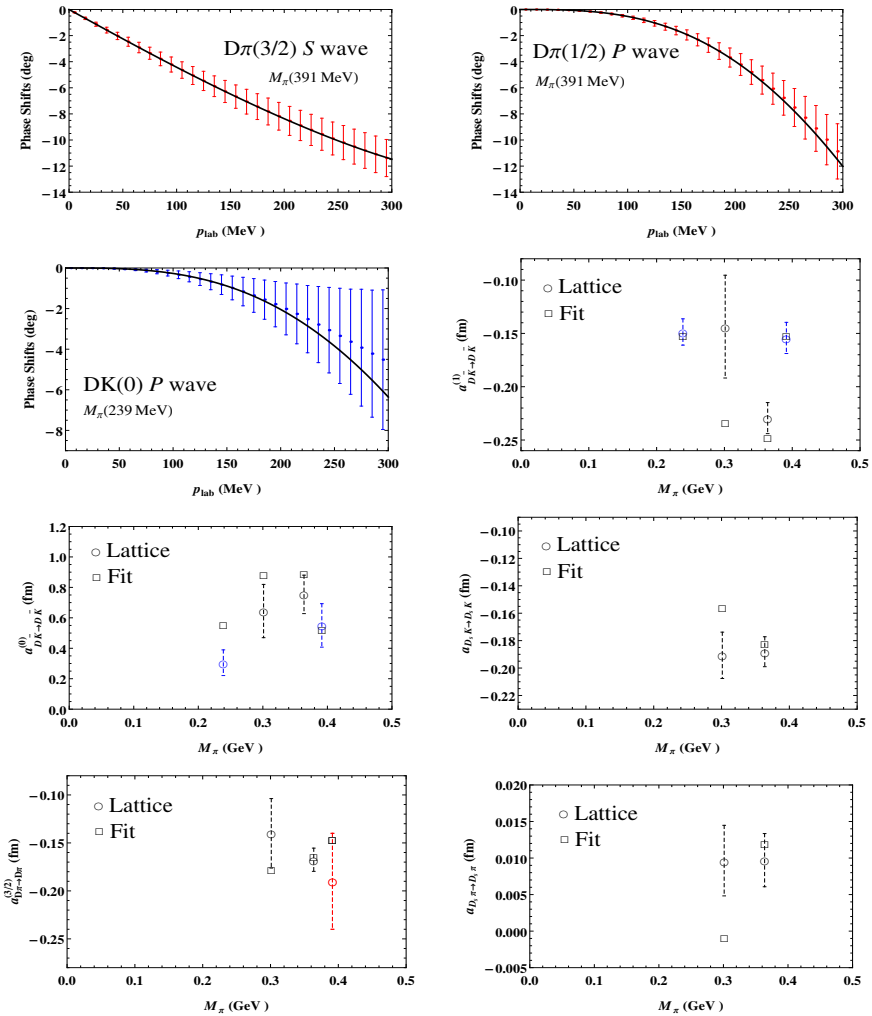
Light pseudoscalar meson and D meson scattering

Scattering Lengths [B.-L. Huang, Z.-Y. Lin, S.-L. Zhu, **Phys. Rev. D, 2022, 105: 036016**]

	Fit u1	Fit u2	Fit u3	Liu2013	Guo2019
$a_{DK}^{(1)}$	$-0.03(4)$	$-0.01(3)$	$-0.06(1)$	$0.07^{+0.03}_{-0.03}+i0.17^{+0.02}_{-0.01}$	$-0.01^{+0.05}_{-0.03}+i0.39^{+0.04}_{-0.04}$
$a_{DK}^{(0)}$	$-1.55(39)$	$-1.42(28)$	$-1.67(45)$	$-0.84^{+0.17}_{-0.22}$	$-1.51^{+0.72}_{-2.35}$
$a_{D\bar{K}}^{(1)}$	$-0.23(2)$	$-0.24(2)$	$-0.21(1)$	$-0.20(1)$	$-0.20^{+0.01}_{-0.01}$
$a_{D\bar{K}}^{(0)}$	8.76^{*}	$1.81(48)$	8.95^{*}	$0.84(15)$	21.9^{*}
a_{D_sK}	$-0.14(3)$	$-0.17(3)$	$-0.14(1)$	$-0.18(1)$	$-0.20^{+0.01}_{-0.01}$
$a_{D_s\bar{K}}$	$0.14(36)$	371.58^{*}	$0.05(18)$	$-0.09^{+0.06}_{-0.05}+i0.44^{+0.05}_{-0.05}$	$-0.57^{+0.06}_{-0.04}+i0.35^{+0.08}_{-0.07}$
$a_{D\pi}^{(3/2)}$	$-0.07(4)$	$-0.06(2)$	$-0.05(1)$	$-0.100(2)$	$-0.103^{+0.003}_{-0.003}$
$a_{D\pi}^{(1/2)}$	$1.45(169)$	$0.61(11)$	6.00^{*}	$0.37^{+0.03}_{-0.02}$	$0.40^{+0.03}_{-0.02}$
$a_{D_s\pi}$	$0.02(3)$	$0.03(2)$	$0.05(2)$	$-0.002(1)$	$0.012^{+0.003}_{-0.003}$
$a_{D\eta}$	$-0.04(14)$	$0.03(8)$	$-0.09(2)$		$0.29^{+0.15}_{-0.22}+i0.61^{+0.30}_{-0.26}$
$a_{D_s\eta}$	$-0.18(8)$	$0.03(16)$	$-0.19(2)$		$-0.39^{+0.05}_{-0.03}+i0.06^{+0.02}_{-0.02}$

Light pseudoscalar meson and D meson scattering

Phase Shifts and Scattering Lengths [B.-L. Huang, Z.-Y. Lin, K. Chen, S.-L. Zhu, **Eur. Phys. J. C, 2023, 83: 76**]



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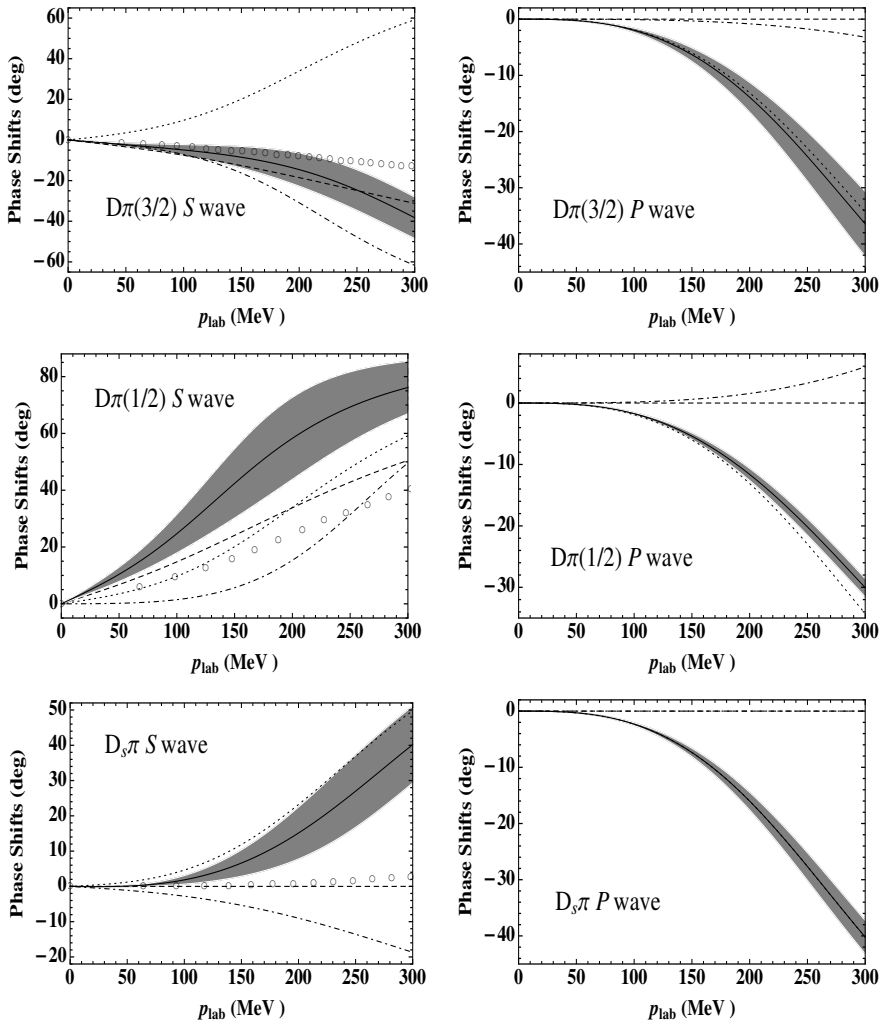

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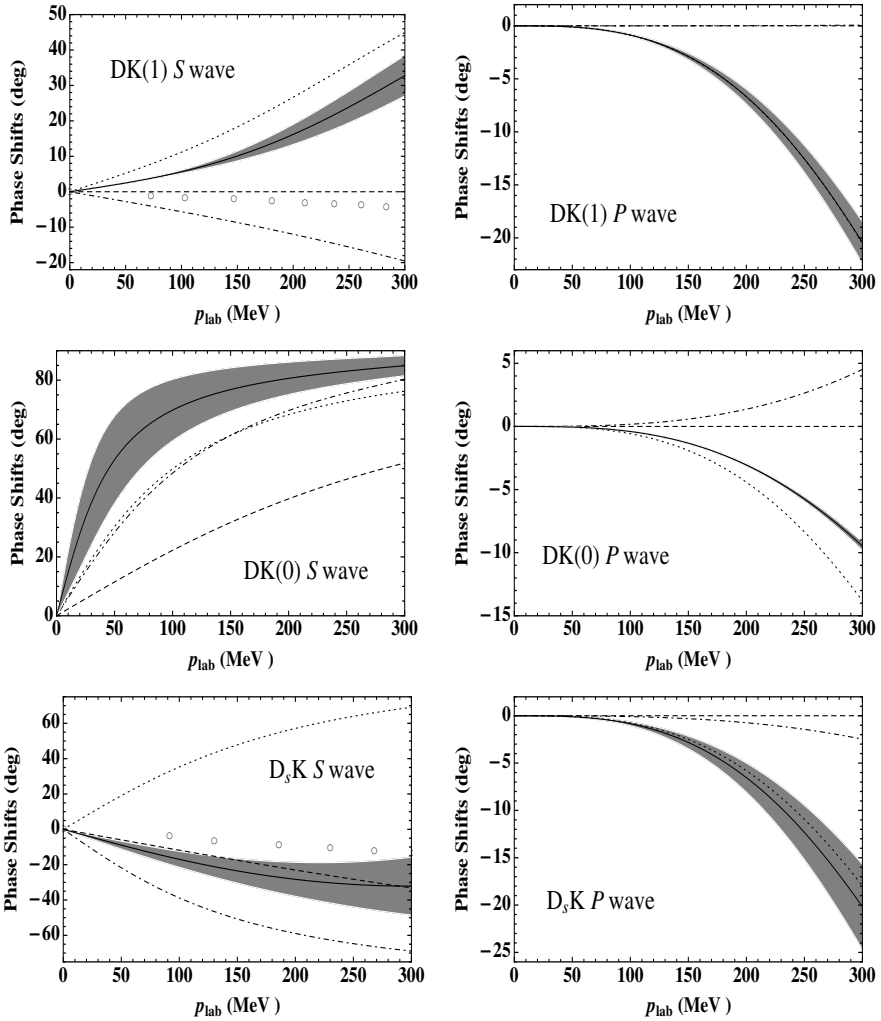
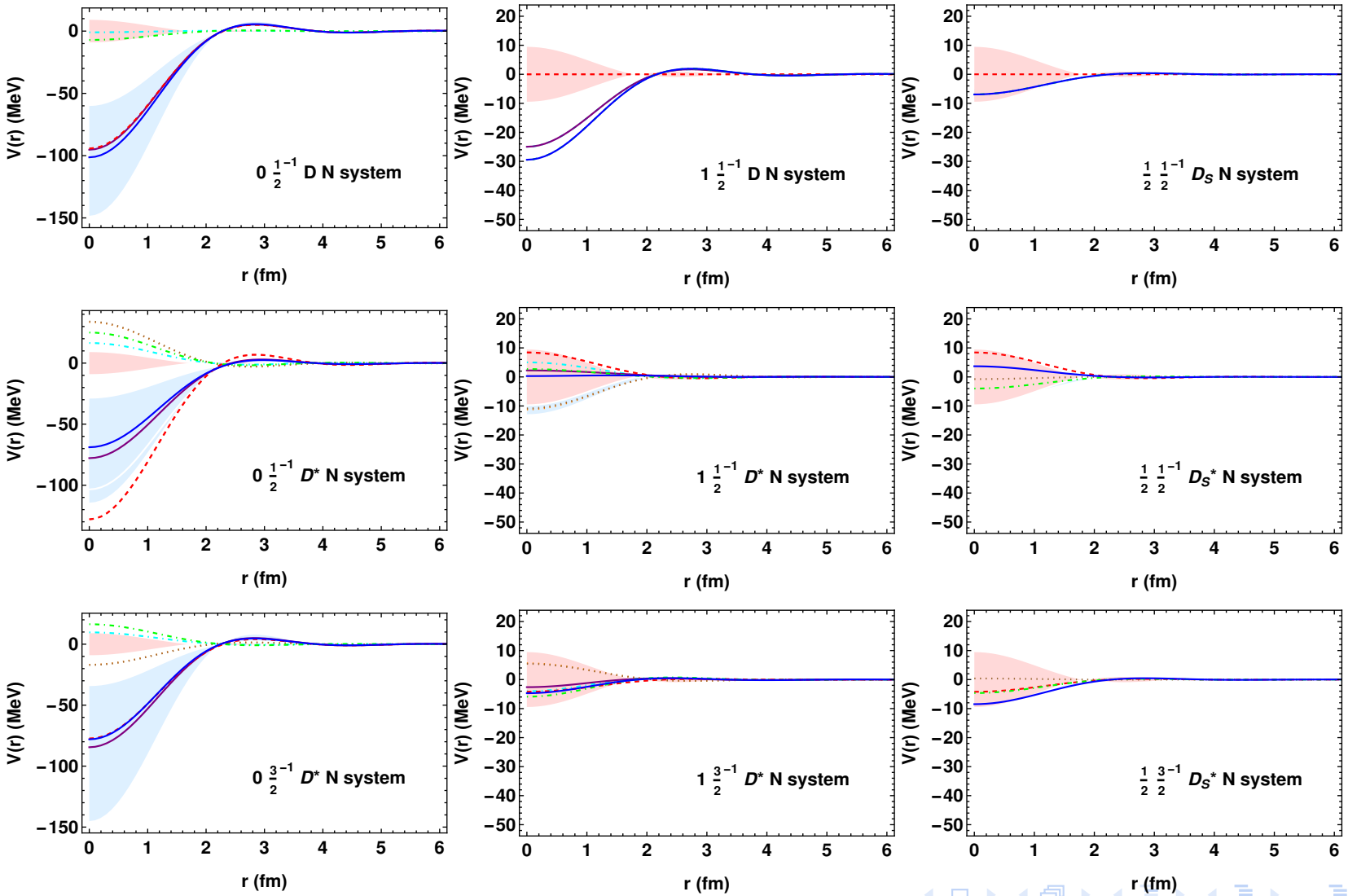


Octect-Baryon and Heavy Meson Interaction

Potential [B.-L. Huang, B. Wang, S.-L. Zhu, **arXiv: 2402.00460**]



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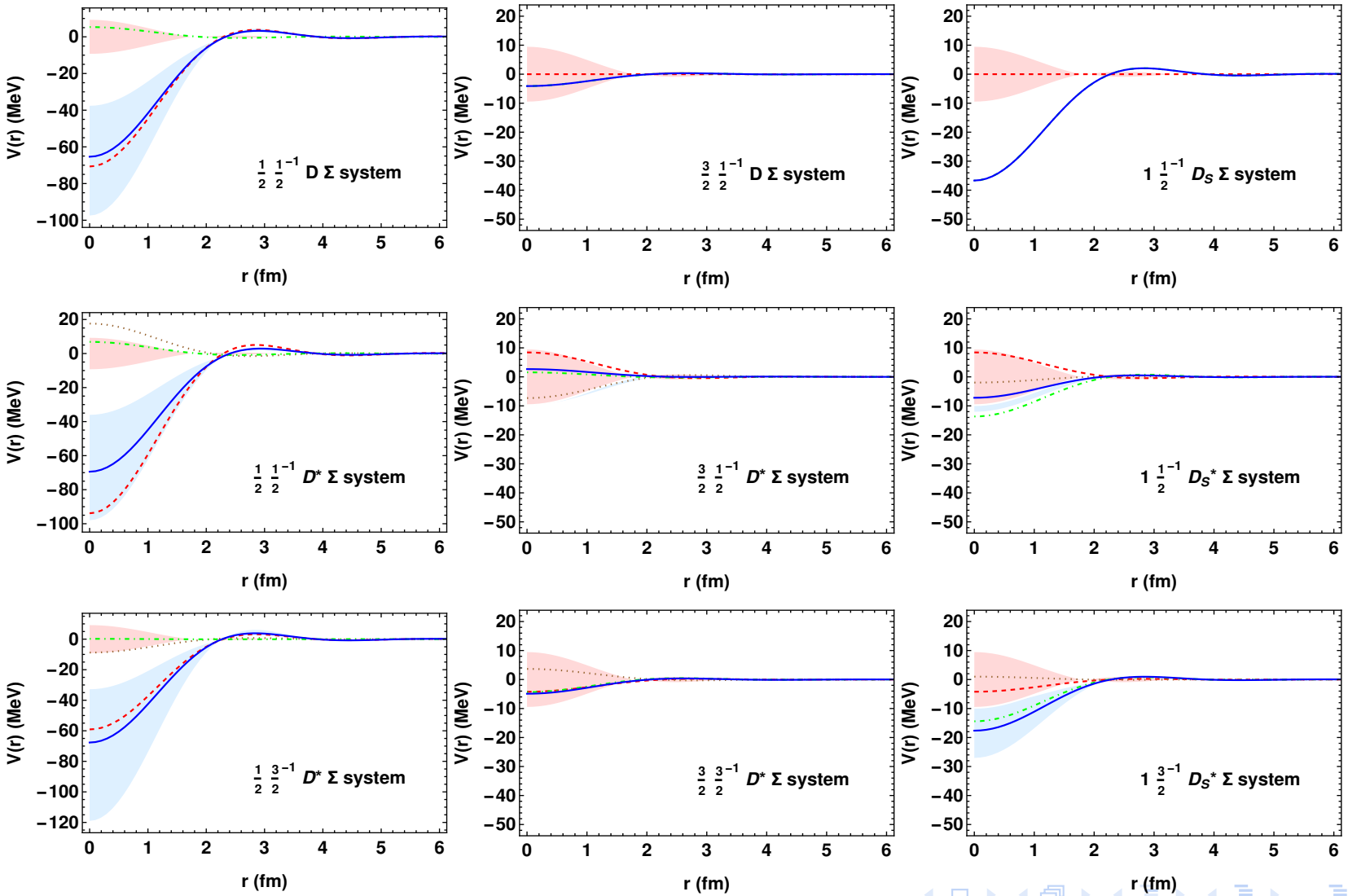

Octect-Baryon and Heavy Meson Interaction

Bound States [B.-L. Huang, B. Wang, S.-L. Zhu, **arXiv: 2402.00460**]

SU(3) / SU(2)	$[DN]^{I=0}_{J=1/2}$	$[D^*N]^{I=0}_{J=1/2}$	$[D^*N]^{I=0}_{J=3/2}$
ΔE (MeV)	$-13.4^{+8.8}_{-8.1} \pm 3.2$	$-4.5^{+4.5}_{-4.6} \pm 2.1$	$-5.0^{+5.0}_{-19.1} \pm 2.5$
	$-10.9^{+8.0}_{-7.8} \pm 3.1$	$-7.1^{+7.1}_{-5.2} \pm 2.4$	$-7.2^{+7.2}_{-20.2} \pm 2.8$
M (MeV)	$2792.8^{+8.8}_{-8.1} \pm 3.2$	$2942.9^{+4.5}_{-4.6} \pm 2.1$	$2942.4^{+5.0}_{-19.1} \pm 2.5$
	$2795.1^{+8.0}_{-7.8} \pm 3.1$	$2940.4^{+7.1}_{-5.2} \pm 2.4$	$2940.2^{+7.2}_{-20.2} \pm 2.8$
$\sqrt{\langle r^2 \rangle}$ (fm)	$1.7^{+0.6}_{-0.3} \pm 0.1$	$2.5^{+9.4}_{-0.6} \pm 0.3$	$2.3^{+12.7}_{-1.1} \pm 0.3$
	$1.8^{+0.7}_{-0.3} \pm 0.1$	$2.1^{+4.9}_{-0.3} \pm 0.2$	$2.0^{+8.5}_{-0.7} \pm 0.2$

Octect-Baryon and Heavy Meson Interaction

Bound States [B.-L. Huang, B. Wang, S.-L. Zhu, **arXiv: 2402.00460**]

SU(3)	$[D\Sigma]^{I=1/2}_{J=1/2}$	$[D^*\Sigma]^{I=1/2}_{J=1/2}$	$[D^*\Sigma]^{I=1/2}_{J=3/2}$
ΔE (MeV)	$-4.3^{+4.3}_{-4.9} \pm 2.3$	$-6.8^{+6.8}_{-3.5} \pm 2.7$	$-4.9^{+4.9}_{-14.1} \pm 2.5$
M (MeV)	$3056.1^{+4.3}_{-4.9} \pm 2.3$	$3194.9^{+6.8}_{-3.5} \pm 2.7$	$3196.8^{+4.9}_{-14.1} \pm 2.5$
$\sqrt{\langle r^2 \rangle}$ (fm)	$2.4^{+2.1}_{-0.8} \pm 0.4$	$2.0^{+2.1}_{-0.2} \pm 0.2$	$2.2^{+8.3}_{-0.9} \pm 0.3$

Summary

- Light Flavor Hadron-Hadron Interaction in SU(3) ChPT.
- Heavy Flavor Hadron-Hadron Interaction in SU(3) ChPT.

- Outlook
  - More Precise Calculations.
  - Calculating More Channels.

Thank you for your attention!