USQCD All Hands Meeting

April 22, 2022

Nuclear Physics from the Standard Model

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NPLQCD

Recent work

Spectroscopy

Baryon-baryon interactions

PRD 103 (2021), 054508

$m_\pi \sim 450 \text{ MeV}$

Variational nucleon-nucleon

arXiv:2108.10835 [hep-lat]

$m_\pi \sim 806 \text{ MeV}$

Matrix elements

Triton axial charge

PRD 103 (2021), 074511

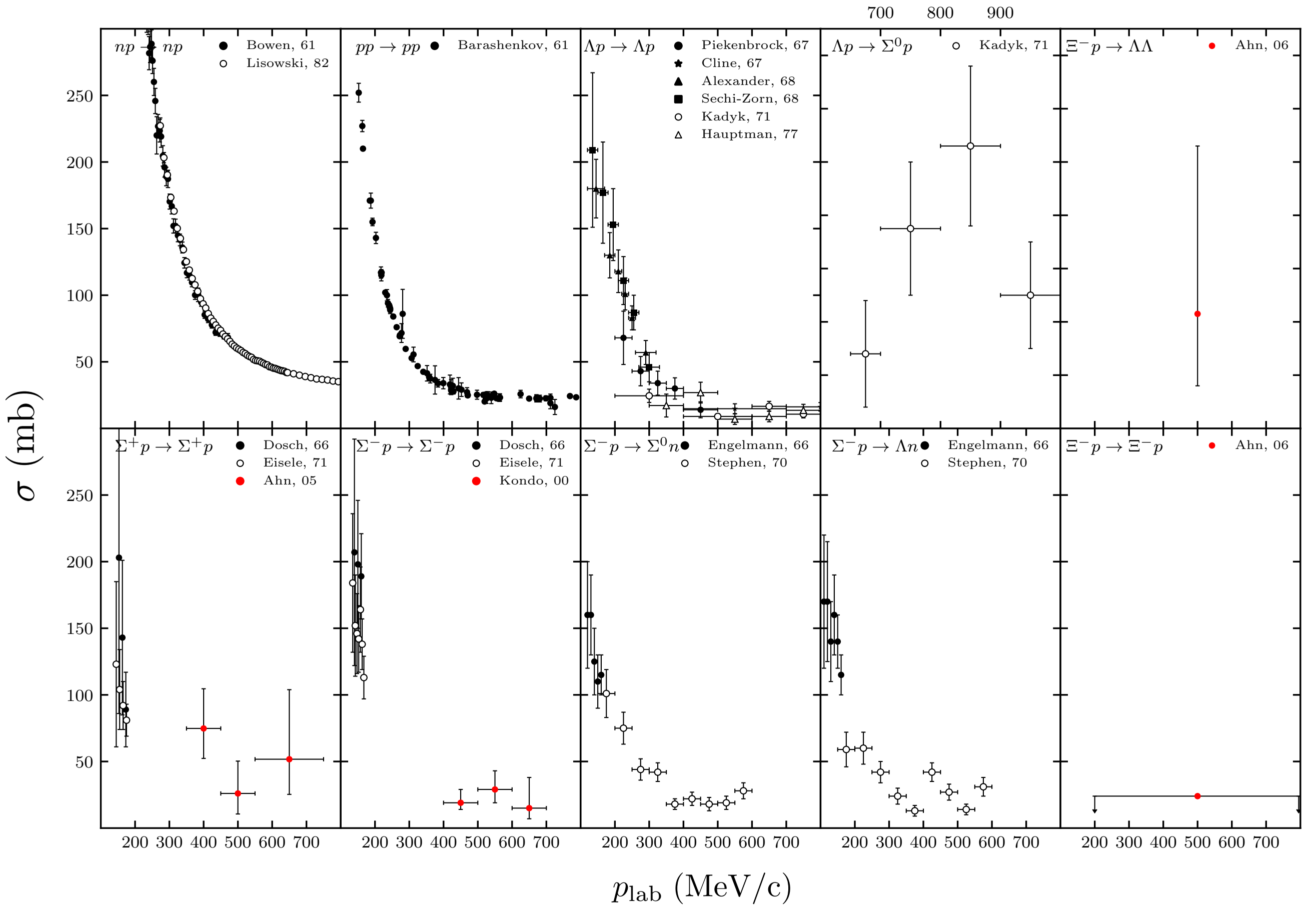
$m_\pi \sim 450 \text{ MeV}$

Momentum fraction of ^{3}He

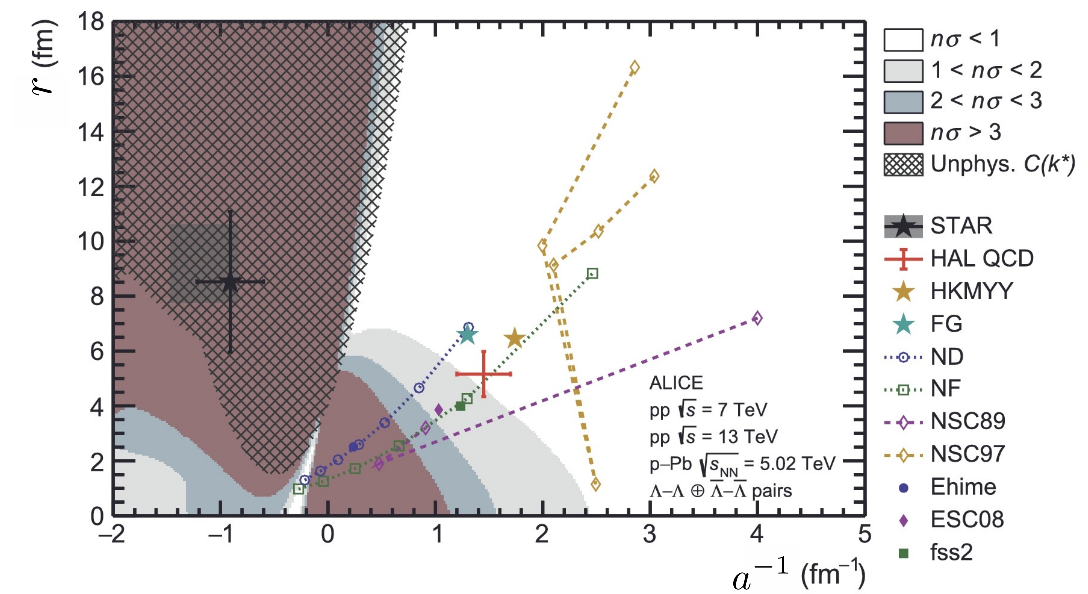
PRL 126 (2021), 202001

$m_\pi \sim 806 \text{ MeV}$

Baryon-baryon interactions



updated from Dover and Feshbach, Ann. Phys. 198 (1990)



ALICE Collaboration, PLB 797 (2019)

$$\mathbf{8} \otimes \mathbf{8} = \mathbf{27} \oplus \mathbf{8}_s \oplus \mathbf{1} \oplus \overline{\mathbf{10}} \oplus \mathbf{10} \oplus \mathbf{8}_a$$

Wagman et al. [NPLQCD], PRD 96 (2017)

$$m_u = m_d = m_s$$

$$m_\pi = m_K \sim 806 \text{ MeV}$$

Illa et al. [NPLQCD], PRD 103 (2021)

$$m_u = m_d \neq m_s$$

$$m_\pi \sim 450 \text{ MeV}, \; m_K \sim 600 \text{ MeV}$$

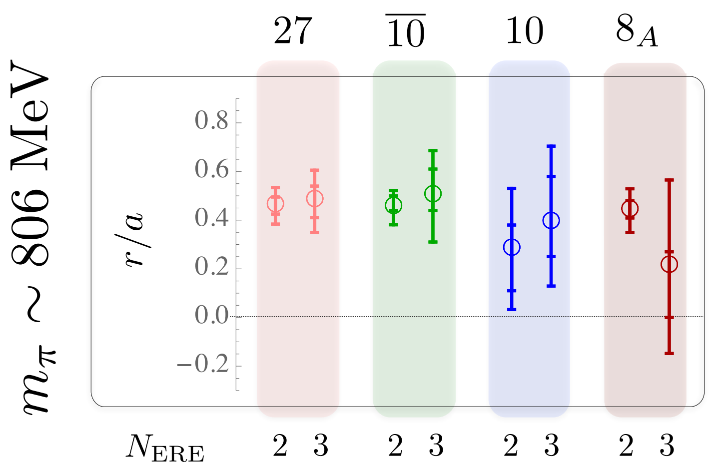
$\mathbf{27}$ | $\overline{\mathbf{10}}$ | $\mathbf{10}$ | $\mathbf{8}_a$

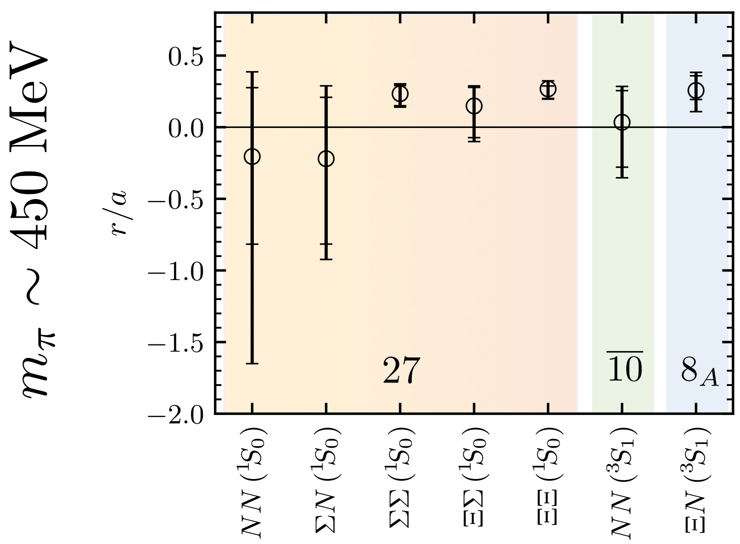
$NN, \Sigma N, \Sigma\Sigma, \Xi\Sigma, \Xi\Xi$

NN | $\Sigma N, \Xi\Xi$ | ΞN

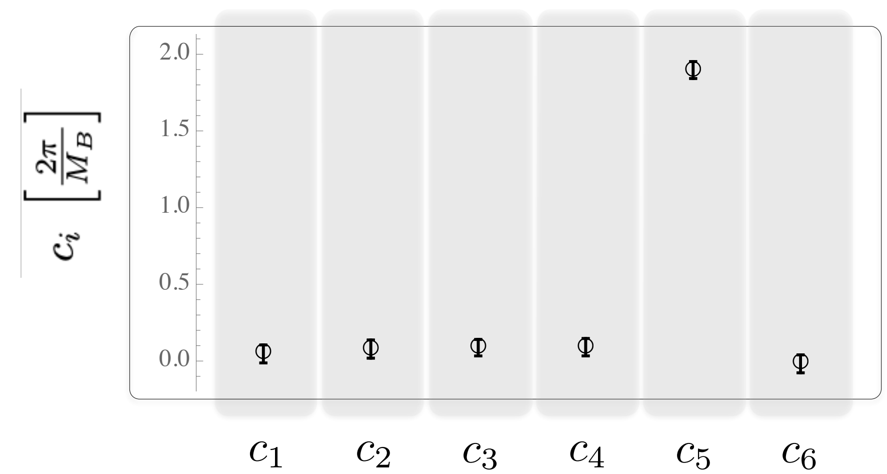
Baryon-baryon interactions

Scattering parameters

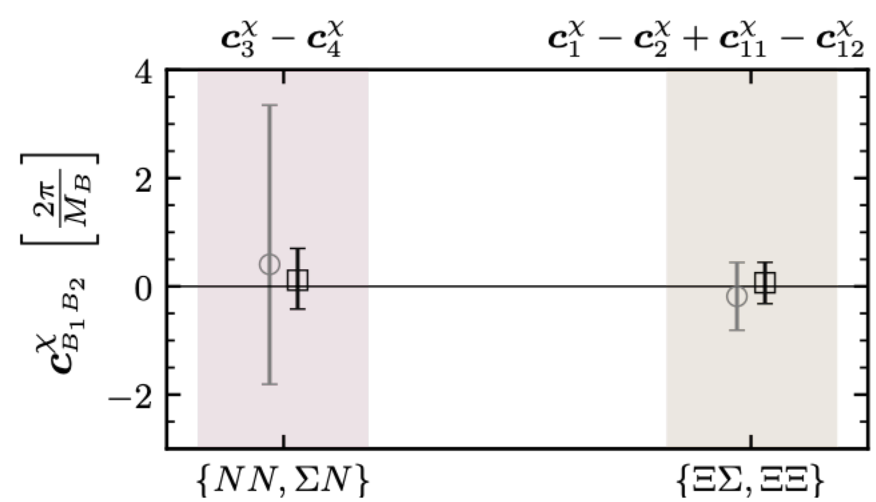




EFT matching



Wagman et al. [NPLQCD], PRD 96 (2017)



Illa et al. [NPLQCD], PRD 103 (2021)

Heavier-than-physical quark masses

Only one lattice spacing ⟶ possible discretization effects? Green et al., PRL 127 (2021)

Asymmetrical correlation funtions ⟶ excited state contamination?

Baryon-baryon interactions

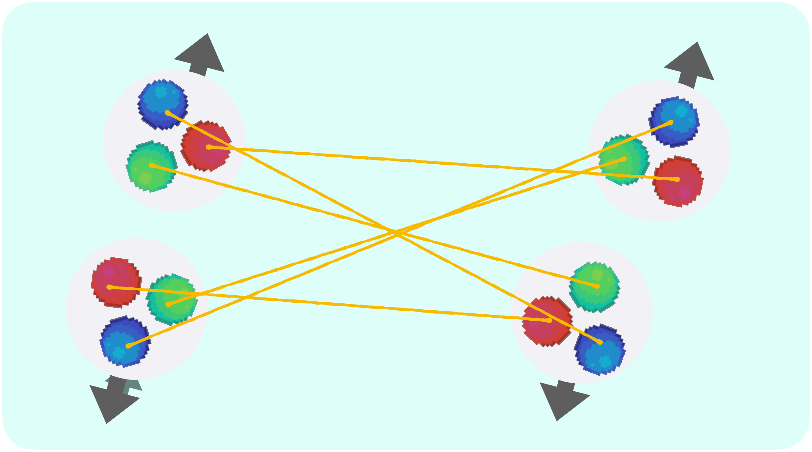
Firsts steps towards a variational study of the baryon-baryon interaction

Francis et al., PRD 99 (2019)
Green et al., PRL 127 (2021)

H dibaryon

Hörz et al., PRC 103 (2021)

NN systems



Matrix of dibaryon-like operators with different boost and back-to-back momenta

↓

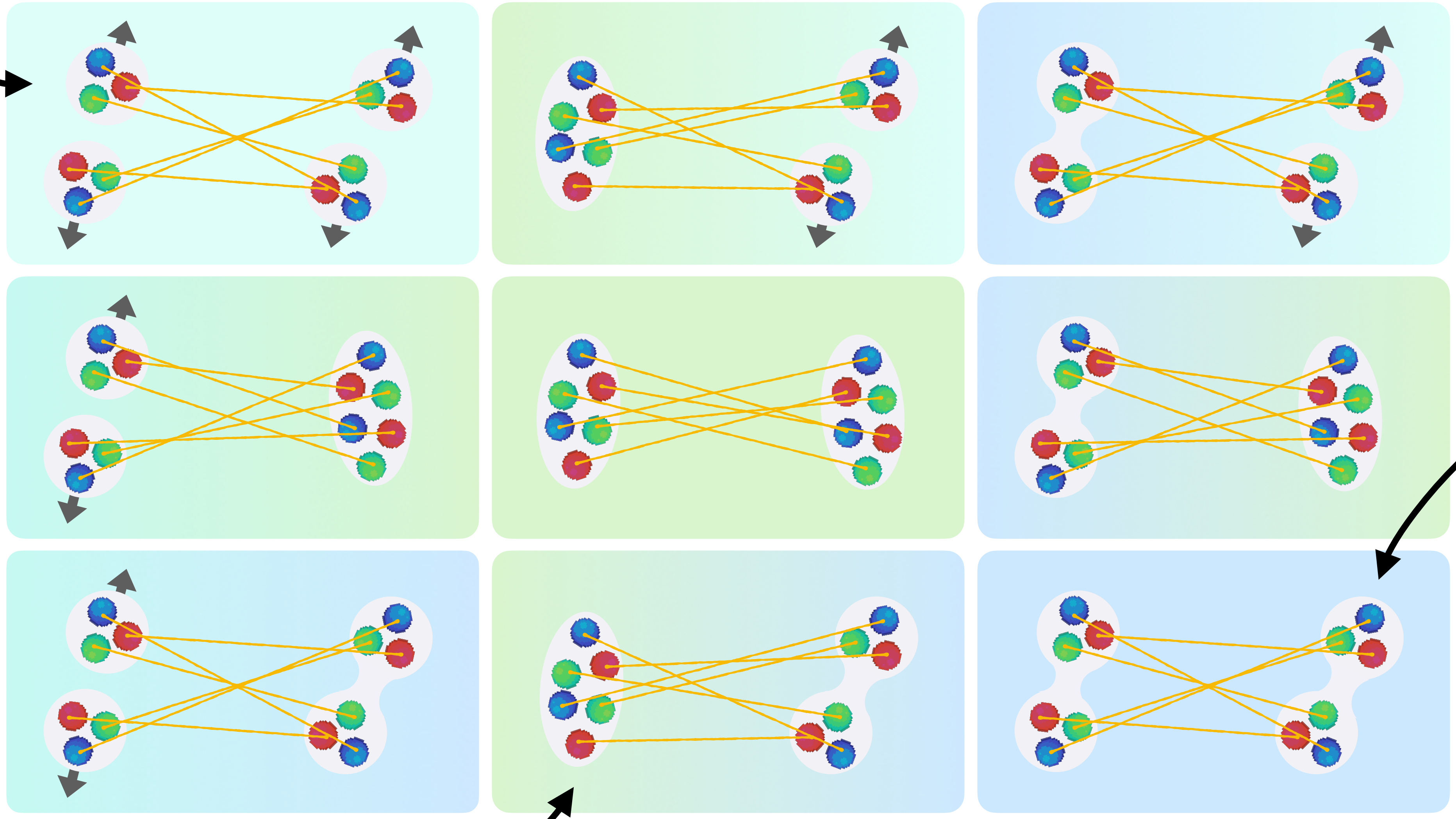
Discrepancies with previous results

Maybe dibaryon operators have small overlap with deeply-bound states?

Baryon-baryon interactions

Extend previous variational studies by including hexaquark and quasi-local operators Amarasinghe et al. [NPLQCD], arXiv:2108.10835 [hep-lat]

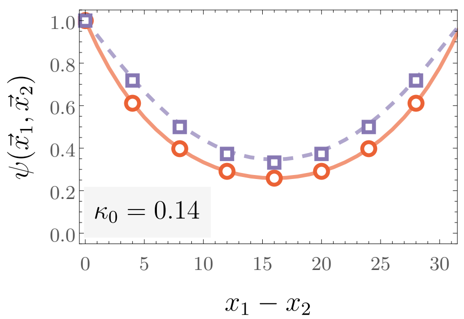
Dibaryon $\psi(\vec{x}_1, \vec{x}_2) = e^{i\vec{k}\cdot(\vec{x}_1 - \vec{x}_2)}$



Hexaquark

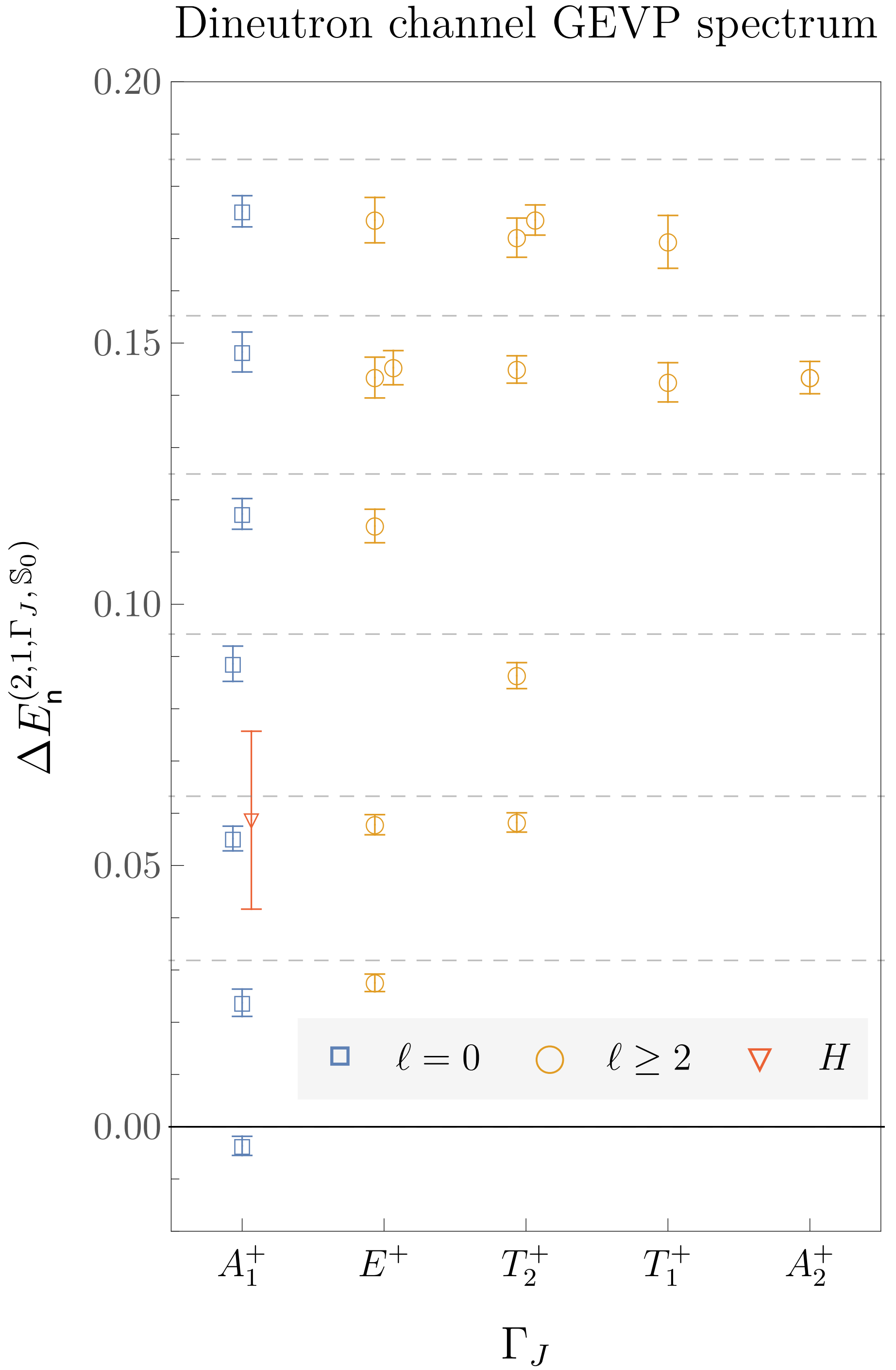
Quasi-local

$$\psi(\vec{x}_1, \vec{x}_2) = \sum_n e^{-\kappa_d|\vec{x}_1 - \vec{x}_2 + nL|}$$



Baryon-baryon interactions

Extend previous variational studies by including hexaquark and quasi-local operators Amarasinghe et al. [NPLQCD], arXiv:2108.10835 [hep-lat]

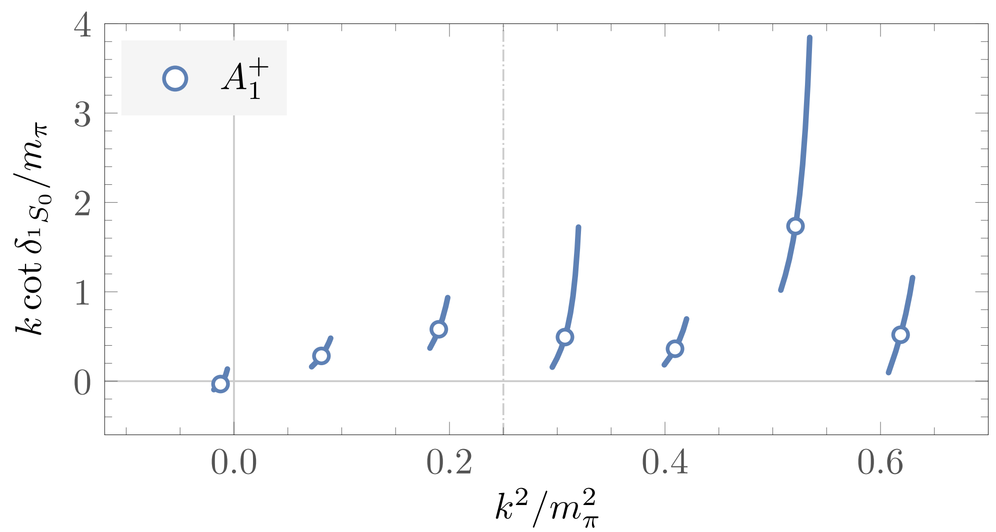


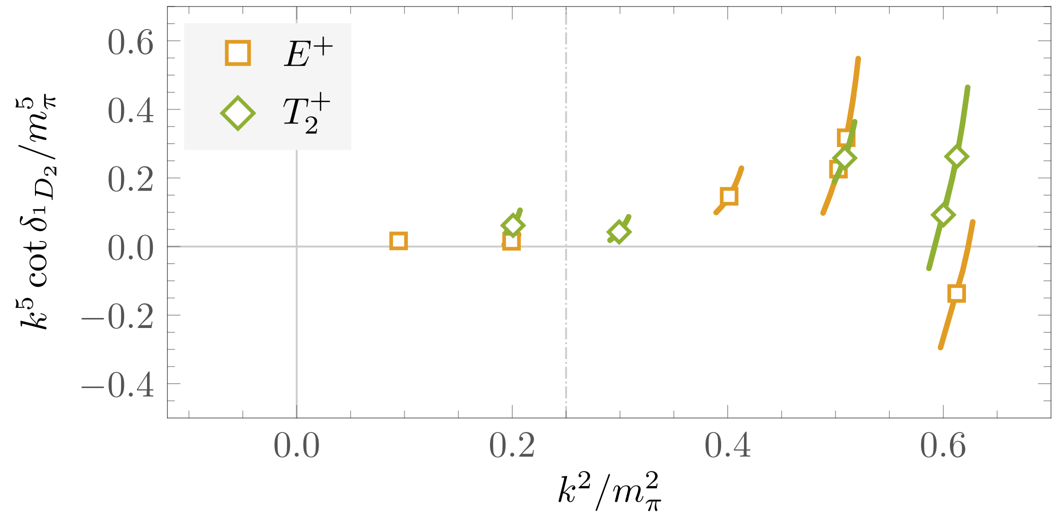
Lüscher's QC

Higher partial waves

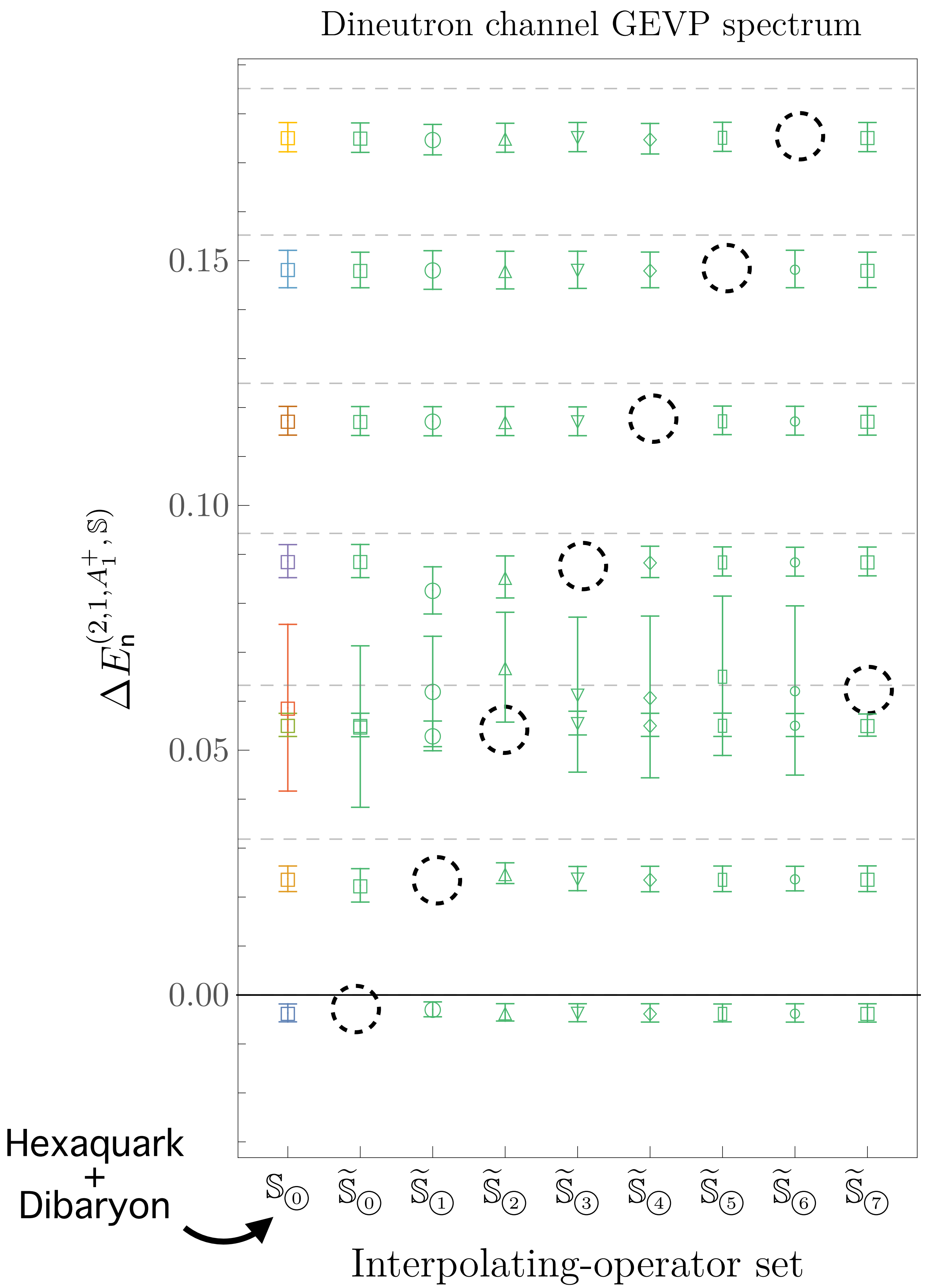
Luu, Savage, PRD 83 (2011)

Briceño, Davoudi, Luu, PRD 88 (2013)





Baryon-baryon interactions



Large interpolating-operator depence is observed

Amarasinghe et al. [NPLQCD], arXiv:2108.10835 [hep-lat]

Energy levels disappear when the operator with the corresponding larger overlap is removed

$\pi\pi$ Dudek et al. [HadSpec], PRD 87 (2013)
Wislon et al. [HadSpec], PRD 92 (2015)

$N\pi$ Lang, Verduci, PRD 87 (2013)
Kiratidis et al., PRD 91 (2015)

Are we still missing operators?

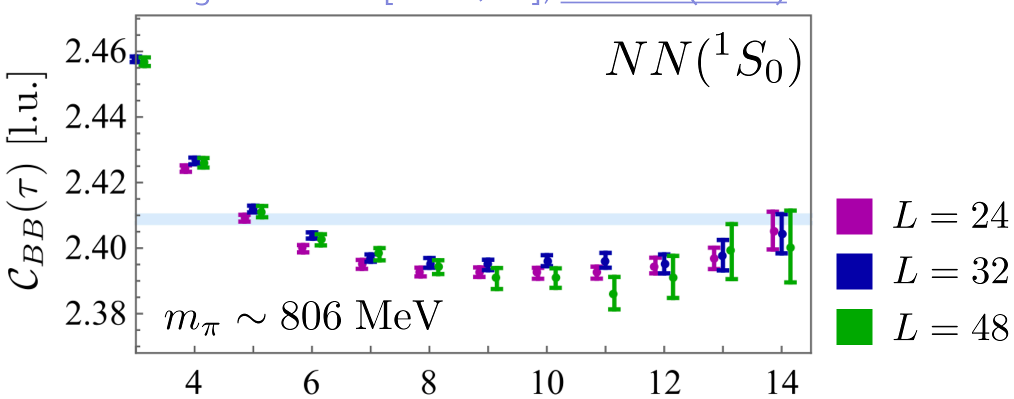
Baryon-baryon interactions

Are we still missing operators?

Coincidence?

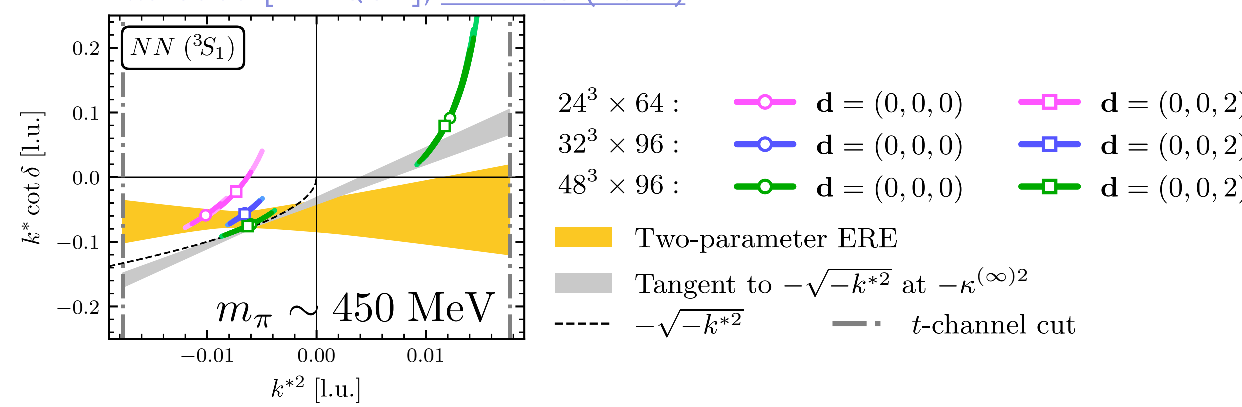
Option a) There is no deep-bound state, however...

Wagman et al. [NPLQCD], PRD 96 (2017)



Volume independence of the ground state

Illa et al. [NPLQCD], PRD 103 (2021)

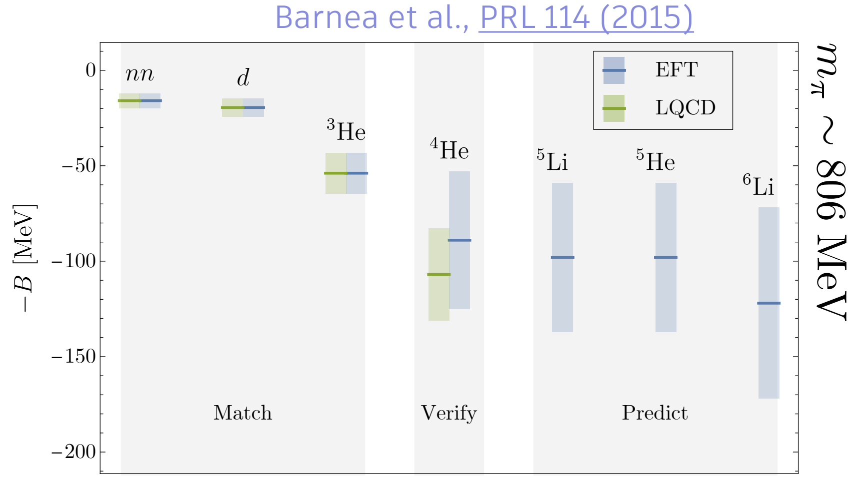


Analysis of the phase-shifts and checks on scattering parameters

Figure from Davoudi et al., Phys. Rep. 900 (2020)

Data from Beane et al. [NPLQCD], PRD 87 (2013)

Barnea et al., PRL 114 (2015)



Agreement between LQCD and EFT calculations (fitted with B=2 and 3 systems)

$$\sigma_{B;\pi A} = \sigma_{\pi A} - A\sigma_{\pi p}$$

Chang et al. [NPLQCD], PRL 120 (2018)

Beane et al., PRD 89 (2014)

	Direct calculation	Feynman-Hellmann approach
d	$-7(14)$	$-9.1(6.0)$
^{3}He	$-40(22)$	$-50.8(11.8)$

$m_\pi \sim 806$ MeV

Consistency in scalar ME extraction

Baryon-baryon interactions

Are we still missing operators?

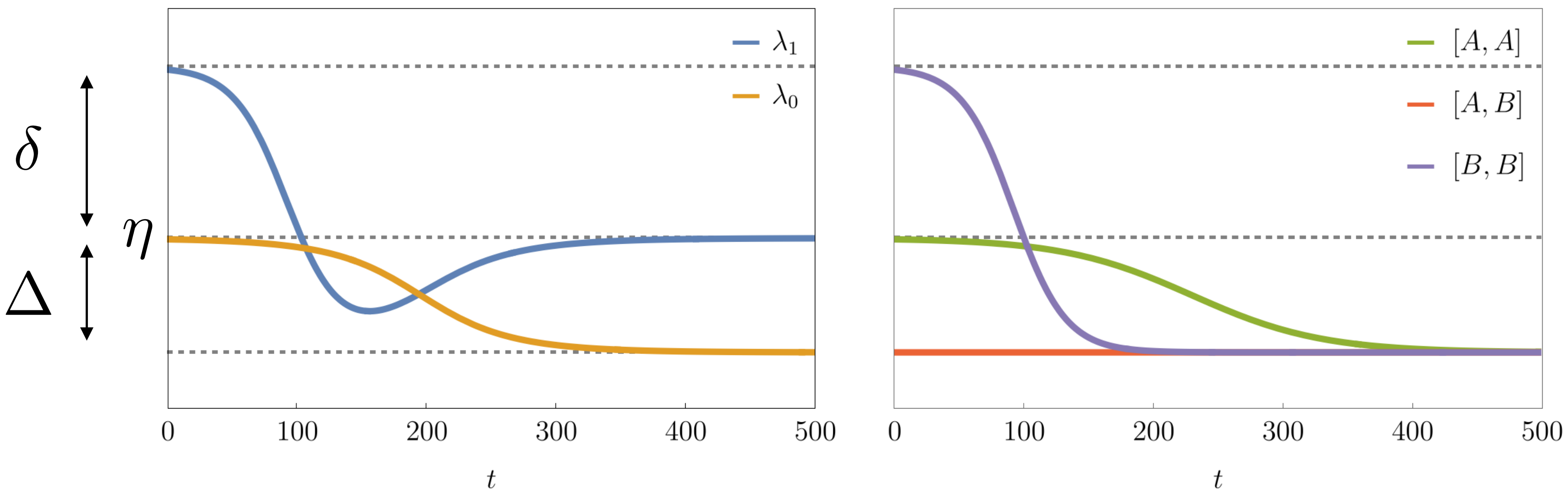
Option b) There is a deep-bound state, but the current operators have a small overlap

Toy model: $Z_n^{(A)} = (\epsilon, \sqrt{1-\epsilon^2}, 0)$ $\quad Z_n^{(B)} = (\epsilon, 0, \sqrt{1-\epsilon^2})$

$$E_0^{(AB)} = \eta - \Delta \qquad E_1^{(AB)} = \eta \qquad E_2^{(AB)} = \eta + \delta$$

$$\lambda_0^{(AB)} = e^{-(t-t_0)\eta}[1 + \epsilon^2(e^{t\Delta} - e^{t_0\Delta}) + \mathcal{O}(\epsilon^4)]$$

$$\lambda_1^{(AB)} = e^{-(t-t_0)(\eta+\delta)}[1 + \epsilon^2(e^{t(\Delta+\delta)} - e^{t_0(\Delta+\delta)}) + \mathcal{O}(\epsilon^4)]$$



Summary

We can use LQCD to reach systems that are difficult for experimentalists (like strange systems)

It is still not clear what the best operators are to include in a variational analysis for two-baryon systems

Ongoing study with 15 additional hexaquark operators and a different volume at $m_\pi \sim 806$ MeV

→ Compute contractions for different baryon-baryon systems closer to the physical point ($m_\pi \sim 170$ MeV) at two different volumes (4.4 and 5.8 fm)

(optimized tiramisu contraction code on GPUs)

Thank you