

D meson – pion scattering on CLS 2+1 flavor ensembles

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Bonn,
August 9, 2022

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- 1 Motivation and Introduction
- 2 Project descriptions and technicalities
- 3 Relativistic charm-quark tuning
- 4 Some preliminary results
- 5 Outlook

Charmed meson spectroscopy and scattering - Project goals

Physics goals:

- Determine Charmed-meson – Goldstone boson scattering lengths
- Map out the scattering phase-shifts in the elastic region to determine the poles related to well-established states like the $D_{s0}^*(2317)$ or $D_0^*(2300)$
- (Further) Map out their light-, strange-quark dependence
- Explore the coupled-channel region and look for predicted states (like the exotic sextet pole predicted by unitarized χ PT calculations)
- EFT or dispersive analysis to implement proper constraints (from analyticity, unitarity, crossing symmetry) for the amplitudes.

Required Lattice QCD infrastructure:

- Need to utilize moving frames; discretization effects in the dispersion relation are a particular challenge
→ Use of a suitable heavy-quark action
- Calculation on a larger library of gauge-field ensembles with various quark-masses and lattice spacings → CLS

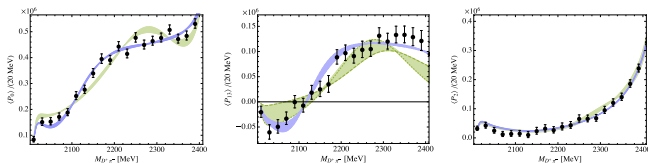
The lightest $J^P = 0^+$ mesons

$D_0^*(2300)$

$$I(J^P) = \frac{1}{2}(0^+)$$

M.-L. Du *et al.*, PRL 126 192001 (2021)

- Unitarized ChiPT leads to a much lower mass than indicated by the PDG
- Authors compare data from LHCb to PDG (Breit Wigner) and Unitarized ChiPT scenarios



- Recent Lattice QCD results from HSC also obtain a much lighter state
HSC L. Gayer *et al.*, JHEP 07 (2021) 123
- Not in contradiction to older results when a pole search is performed

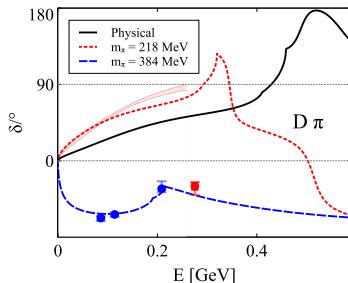
DM, Prelovsek, Woloshyn, PRD 87 034501 (2013)

Physical predictions from EFT fits to lattice data

$D_0^*(2300)$

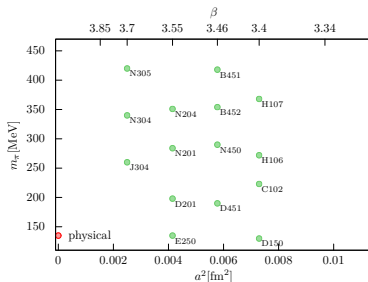
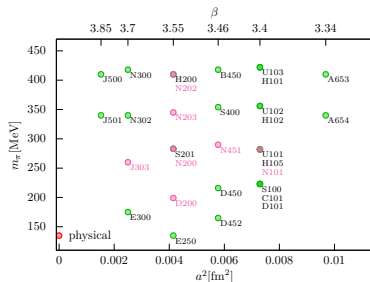
$$I(J^P) = \frac{1}{2}(0^+)$$

Guo, Heo, Lutz, PRD 98 014510 (2018)



- Low energy constants from fits to heavy-light ground-state masses and elastic phase-shift from Lattice QCD
- Chiral EFT bridges the gap between lattice data at unphysical pion masses and physical (coupled-channel) system
- Approach for future studies at GSI: Use EFT setup to arrive at predictions for physical coupled-channel scattering

2+1 flavor CLS gauge field ensembles



- Large discretization effects in H-Dibaryon binding on CLS lattices

Green, Hanlon, Junnarkar, Wittig, PRL 127 242003 (2021)

- Gauge-field library with 6 lattice spacings and three quark-mass trajectories
- Ensembles with magenta highlighting will be used for D-meson – pion scattering
- See **talk by W. Söldner Tuesday at 15:40**

Quark sources and propagators

- We use the (stochastic) distillation approach (fancy quark smearing)

Peardon et al. PRD 80, 054506 (2009)

Morningstar et al. PRD 83, 114505 (2011)

quark-line type	dilution scheme	# source times	N_η	# inversions
charm NXXX	(TF,SF,LI12)	2	4	384 each
light fixed NXXX	(TF,SF,LI12)	2	6	576 each
light relative NXXX	(TI8,SF,LI12)	interlaced	2	768 each
strange fixed NXXX	(TF,SF,LI12)	2	3	288 each
charm D200	(TF,SF,LI16)	3	4	768
charm J303	(TF,SF,LI12)	4	4	768
strange fixed J303	(TF,SF,LI12)	4	3	576

- Scheme has been used extensively, see for example

Andersen et al. Nucl. Phys. B 939, 145 (2019)

- We construct a mixed basis of quark-antiquark and meson-meson interpolating fields

Tuning an RHQ action with a neural network

R.J.Hudspith, DM, arXiv:2112.01997, accepted by PRD

We opted for a specific heavy-quark action with 5 parameters

S. Aoki, Y. Kuramashi, S. Tominaga, Prog.Theor.Phys. 109 383 (2003)

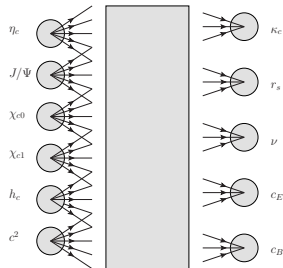
Type of action is extensively discussed in the literature, see for example

El-Khadra, Kronfeld, Mackenzie, PRD 55 3933 (1977)

Oktay, Kronfeld, PRD 78 014504 (2008)

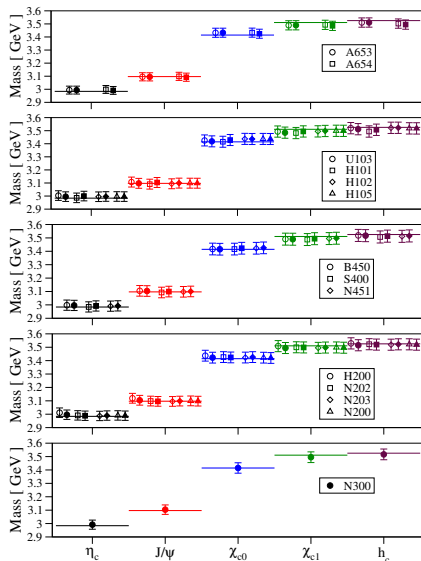
Christ, Li, Lin, PRD 76 074505 (2007)

- For details see **talk by Jamie Hudspith on Thursday at 12:10.**
- Calculate runs with a random distribution for the action parameters
- Train a neural network with about 20-50 runs per gauge ensemble
- Let the neural network make parameter predictions which reproduce some stable states and result in a relativistic dispersion relation.

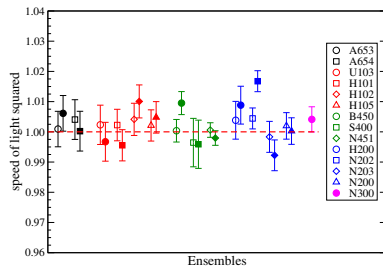


Tuning results

R.J.Hudspith, DM, arXiv:2112.01997, accepted by PRD

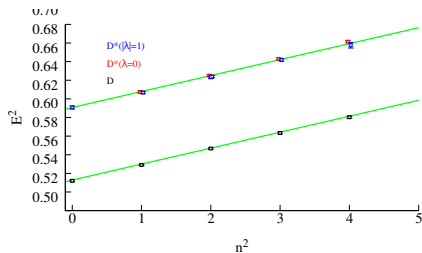
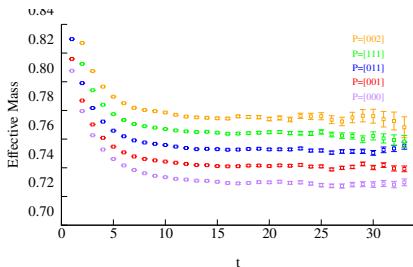


- A $c^2 \approx 1$ has been achieved on all ensembles



- We are currently testing the dispersion relation for heavy-light states

$D^{(*)}$ -meson dispersion relation



- Measured speed of light compatible with relativistic dispersion relation
- Quantitative analysis across all ensembles still in progress

Subduction of continuum J^P into lattice irreps

$\vec{P}/\frac{2\pi}{L}$	Irrep	$J^P(\vec{P}=0), \lambda (\eta)(\vec{P} \neq 0)$	$D\pi J^P$	$D^*\pi J^P$
(0,0,0)	$A1^+$	$0^+, 4^+$	0^+	
	$T1^-$	$1^-, 3^-$	1^-	
	E^+	$2^+, 4^+$	2^+	
(0,0,n)	$A1$	$0^{(+)}, 4$	$0^+, 1^-, 2^+$	
	$E2$	$1, 3$	$1^-, 2^+$	1^+
(0,n,n)	$A1$	$0^{(+)}, 2, 4$	$0^+, 1^-, 2^+$	
	$B1$	$1, 3$	$1^-, 2^+$	1^+
	$B2$	$1, 3$	$1^-, 2^+$	1^+
(n,n,n)	$A1$	$0^{(+)}, 3$	$0^+, 1^-, 2^+$	

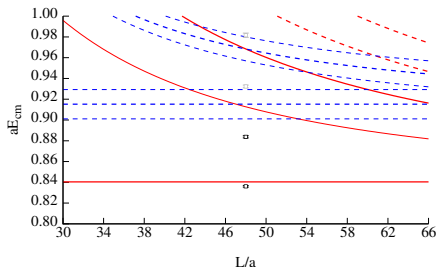
- Complicated mixing pattern in case of unequal masses
- S-, P-, and D-wave contributions listed
- Pattern from

HSC Wilson, Dudek, Edwards, Thomas, PRD 91 054008 (2015)

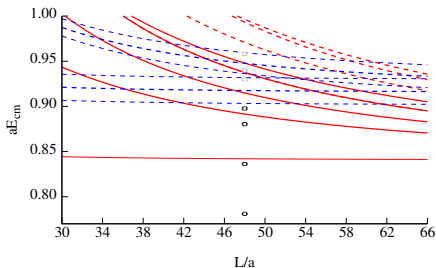
L. Gayer et al., JHEP 07 (2021) 123

Finite volume energies: Example results

Results from $A1^+$ with momentum $(0, 0, 0)$

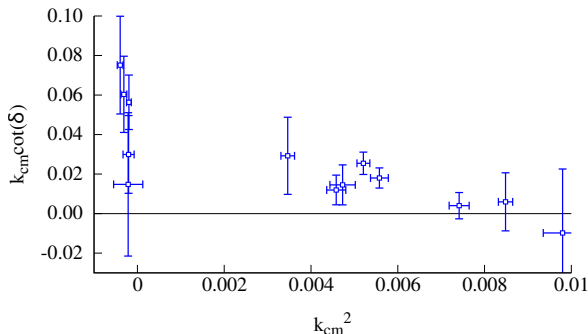


Results from $A1$ with momentum $(0, 0, 1)$



- Currently considering energy levels well below the $D\eta$ -threshold (blue line with dashed uncertainty)
- Moving frame irreps also show additional low lying level due to the D^*
- Pattern of states as expected (and similar to HSC)

Preliminary phase-shift results

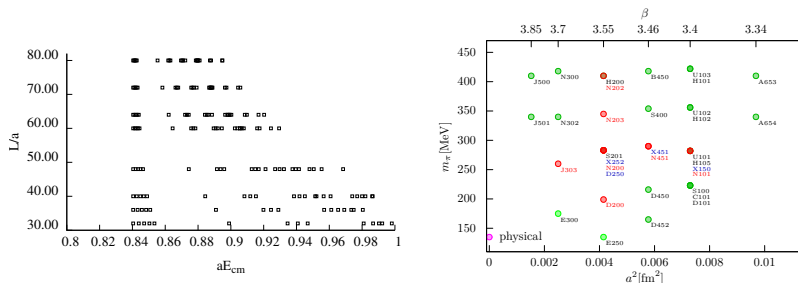


- Results for N451 with $m_\pi \approx 280$ MeV and $a \approx 0.074$ fm
- Not yet from a fully correlated analysis
- Full number of configurations but not all time sources
→ Statistics will be increased
- We are starting to also investigate the P-wave

Summary

- We are studying elastic D-meson – pion scattering with various light- and strange-quark masses and for multiple lattice-spacings
- Perambulators encoding the quark-propagation are fully done for light and charm
- No strange-quark relative lines (needed for η/η') yet
- We plan to study multiple partial waves and different flavor quantum numbers
- We are particularly interested in the quark-mass dependence

Outlook: New volumes for coupled-channel studies

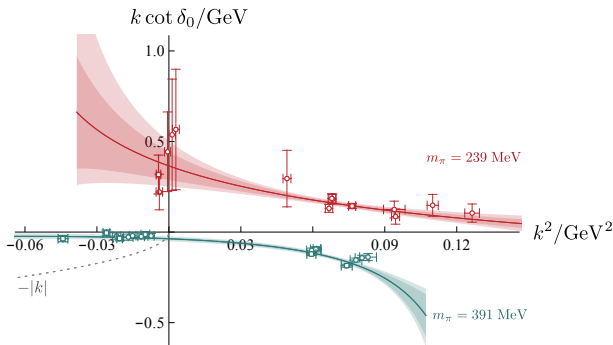


- Coupled channel studies (including $D\eta$ and $D_s\bar{K}$) will profit from multiple volumes with the same lattice spacing
- Moderate changes in the volume help in that regard
- We plan to produce new volumes at existing CLS simulation points

Backup slides

Isospin $\frac{1}{2} D\pi$ scattering amplitude at $m_\pi = 239$ MeV

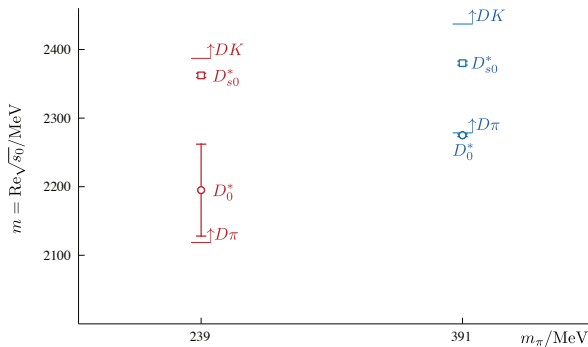
Hadron Spectrum collaboration, Gayer et al. arXiv:2102.04973



- Uses multiple moving frames and extracts pole position from various simple parameterizations

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