A study of scattering in open charm

Sinéad M Ryan

for the Hadron Spectrum Collaboration

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my Charming collaborators...

Graham Moir, Mike Peardon, **Christopher Thomas**

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Outline

- Background and calculation details
- Results
  - $D\pi$: $I = 3/2$ (preliminary); $I = 1/2$ (very preliminary)
  - DK: $I = 0$ (very preliminary); $I = 1$ (very preliminary)
- Outlook

Lattices for open charm scattering

described in detail in 1301.7670 and 1204.5425

- Symanzik-improved anisotropic gauge action with tree-level tadpole-improved coefficients and $N_f = 2 + 1$
- Anisotropic clover action with stout-smeared spatial links
- $\xi = a_s/a_t = 3.5$
- $a_s \approx 0.12$ fm, $a_t^{-1}(m_\Omega) = 5.67(4)$ GeV
- $20^3, 24^3 \times 128$
- $m_l \sim 400$ MeV
- distillation

HadSpec recipe for (single meson) spectroscopy

- a basis of local and non-local operators from distilled fields: $\mathcal{O}$ of the form $\bar{\Psi}(\vec{x},t)\Gamma D_i D_j \ldots \Psi(\vec{x},t)$
- build a correlation matrix of two-point functions

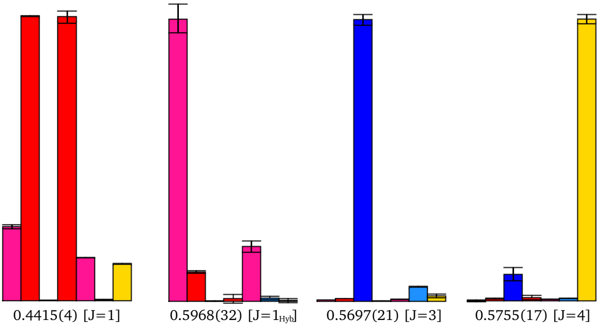
$$C_{ij} = \langle 0|\mathcal{O}_i \mathcal{O}_j^\dagger|0\rangle = \sum_n \frac{Z_i^n Z_j^{n\dagger}}{2E_n} e^{-E_n t}$$

- use a variational method - solve a generalised eigenvalue problem

$$C_{ij}(t) v_j^{(n)} = \lambda^{(n)}(t) C_{ij}(t_0) v_j^{(n)}$$

  this gives
  - eigenvalues: $\lambda^{(n)}(t) \sim e^{-E_n t}\left[1 + O(e^{-\Delta E t})\right]$ - principal correlator
  - eigenvectors: related to overlaps $Z_i^{(n)} = \sqrt{2E_n} e^{E_n t_0/2} v_j^{(n)\dagger} C_{ji}(t_0)$

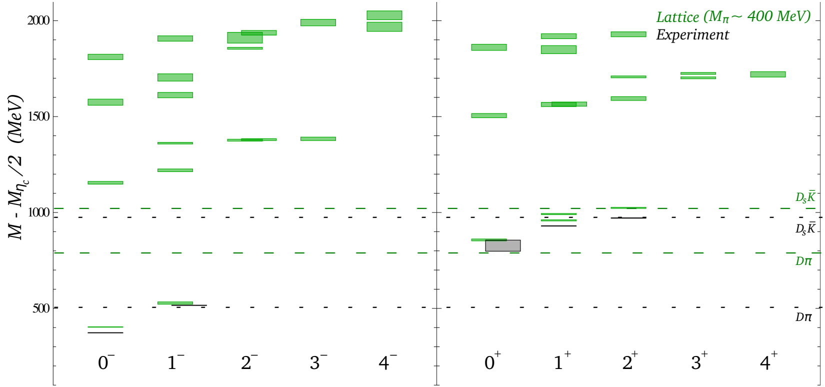
- use overlaps to assign each extracted level a continuum spin
  - operators of definite $\mathcal{J}^{PC}$ constructed in step 1 are subduced into the relevant irrep
  - a subduced operator carries a “memory” of continuum spin $\mathcal{J}$ from which it was subduced - it overlaps predominantly with states of this $\mathcal{J}$.



T_1^+, D_s

Open charm spectrum

Moir et al [JHEP 05 (2013) 021]



Clover anisotropic, relativistic charm;
$N_f = 2+1, 24^3 \times 128, a_s \sim 0.12\text{fm}, M_\pi L \sim 6, M_\pi \approx 400\text{MeV}$

Meson scattering

- Finite box $\Rightarrow$ discrete spectrum
- Lüscher: energy levels in finite volume give infinite volume scattering phase shift at E_{cm}
- Map out the phase shift to get resonance parameters:

$$\sigma_l(E) \propto \sin^2 \delta_l(E) = (\Gamma/2)^2/((E-E_R)^2 + (\Gamma/2)^2)$$

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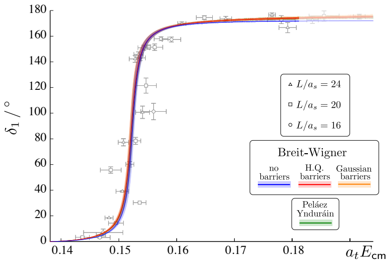
- many multi-hadron energy levels needed:
  - single and multi-hadron operaters; non-zero P_{cm}, different box sizes (shapes), twisted bcs etc
- reduced symmetry means mixing between partial waves

1212.0830



Coupled channels

- Lüscher approach and extensions successfully used to extract elastic hadron-hadron scattering phase shifts
- Extensions for outside center-of-mass and above the inelastic thresholds proposed: He et al '05; Döring et al '11; Aoki et al '11; Briceno & Davoudi '12; Hansen & Sharpe '12
- **1211.0929, Guo et al**: a practical strategy to extract scattering parameters of coupled-channel systems in moving center-of-mass frame
  Results for $K\pi$ presented by D. Wilson [talk] and in 1406.4158

The operator construction for multi-mesons

- use distillation: redefinition of quark smearing
  - operators of definite relative momentum at source and sink
  - variational analysis of a matrix of correlators
- construct two-point correlators: $\langle 0|\mathcal{O}_i(t)\mathcal{O}_j^\dagger(0)|0\rangle$ with two classes of interpolating field $\mathcal{O}_i^\dagger$
  - single-meson operators $\bar{\Psi}\Gamma\Psi$
  - two-meson operators with definite relative and total momentum ($\vec{P}$): $(\bar{\Psi}\Gamma_1\Psi)_{\vec{p}_1}(\bar{\Psi}\Gamma_2\Psi)_{\vec{p}_2}$ [Thomas et al 1107.1930]
  - $\vec{P} = \vec{p}_1 + \vec{p}_2$ and $\vec{P} = [0,0,0], [0,0,1], [0,1,1], [1,1,1]$
- operators are variationally optimised
- all relevant Wick contractions included
- two volumes used here: $20^3 (L \approx 2.4 fm)$, $24^3 (L \approx 2.9 fm)$

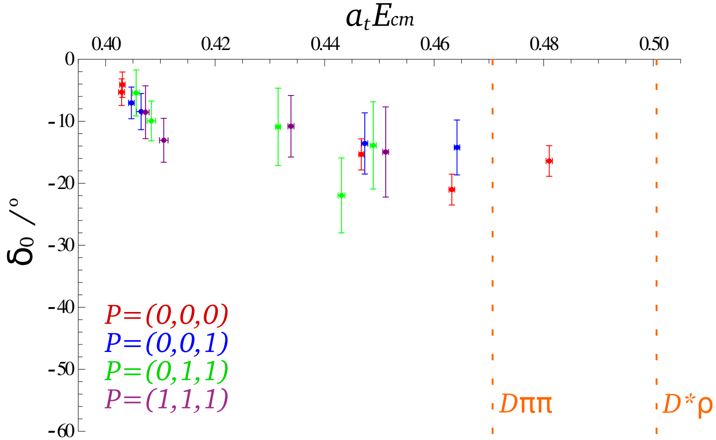
(Preliminary and Very Preliminary)

Results

$D\pi$ $(I = 3/2)$ PHASE SHIFT

PRELIMINARY

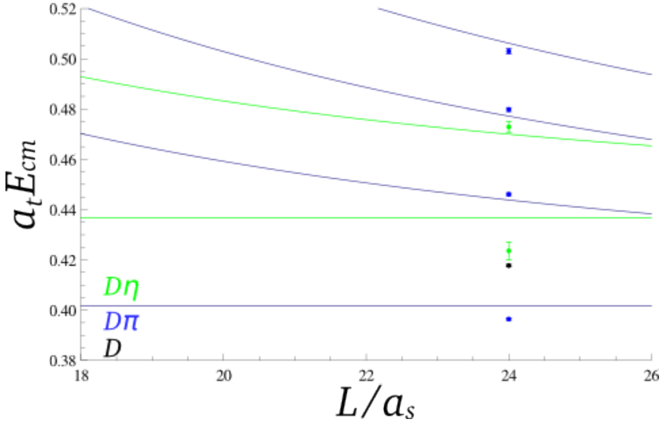
Update from Lattice 2013



- consider $l = 0$ since at modest momenta $\delta_0 \ll \delta_2 \ll \delta_4 \ldots$
- no resonance, weakly repulsive interaction

$D\pi$: $(I = 1/2)$, $\vec{P} = (0,0,0)$ VERY PRELIMINARY

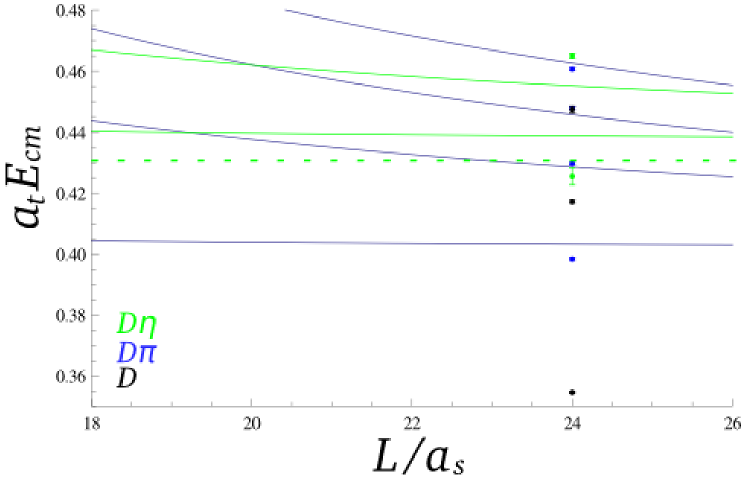
- 1 volume: 24^3; $D, D\pi, D\eta$ operators; A_1 irrep



- additional threshold: $D_s\bar{K} \sim 0.44$

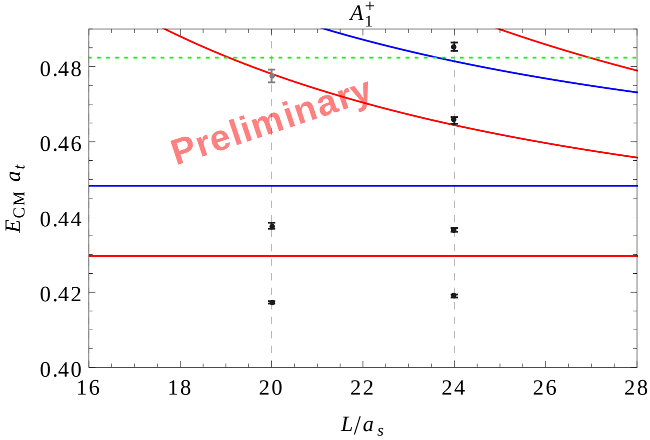
$D\pi$: $(I = 1/2)$, $\vec{P} = (0,0,1)$ VERY PRELIMINARY

- A_1 $P = (0,0,1)$



$DK\ (I=0)\ \vec{P}=(0,0,0)$ Very Preliminary

- single-meson D_s, two-meson DK operators; 2 volumes



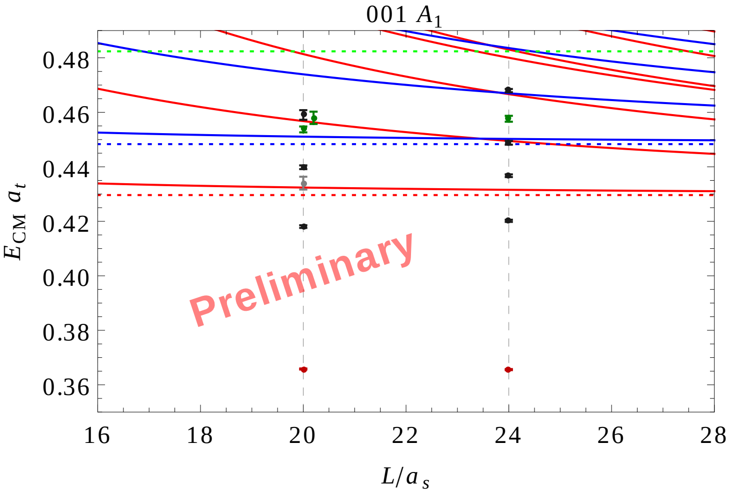
non-interacting levels : $-DK$ $-D_s\eta$

thresholds : $\cdots DK$ $\cdots D_s\eta$ $\cdots D_s\pi\pi$

Points:

0^+; 2^+; 1^-

DK $(I=0), \vec{P}=(0,0,1)$ Very Preliminary



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Points:

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Summary and Outlook

- $D\pi$ phase shift for $I = 3/2$ extracted: no resonance, weakly repulsive interaction
- Preliminary results for the spectrum extracted in $D\pi$ $I = 1/2$ and DK $I = 0, 1$.
- The extracted states are shifted away from the non-interacting levels and the shift can be determined with precision.
- $D\bar{K}$ also being studied.
- More irreps and statistics being accumulated.
- A coupled-channel analysis to extract scattering parameters is planned.