

Towards Scattering Amplitudes and Cross Sections from Quantum Chromodynamics

Heisenberg project: Hadronstreuung und
hadronische Resonanzen aus der
Gitterquantenchromodynamik



■ Three research areas

- Baryons with strangeness – PANDA is a strangeness factory!
 - Heavy-light mesons
 - **Charmonium** – energy scans at PANDA elucidate close-to-threshold states
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- Close ties with EFT calculations by Matthias F.M. Lutz at GSI
 - Close ties with HIM, researchers at DESY-Zeuthen

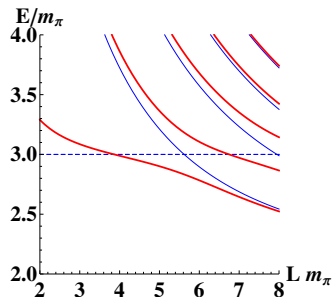
Progress from an old idea: Lüscher's finite-volume method

M. Lüscher Commun. Math. Phys. 105 (1986) 153;
Nucl. Phys. B 354 (1991) 531; Nucl. Phys. B 364 (1991) 237.

Basic observation: Finite-volume, multi-particle energies are shifted with regard to the free energy levels due to the interaction

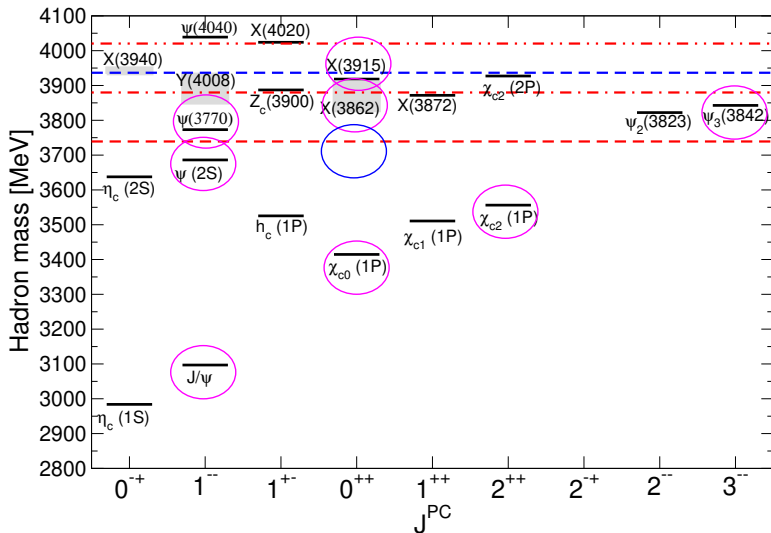
$$E = E(p_1) + E(p_2) + \Delta_E$$

- Energy shifts encode scattering amplitude(s)
- Original method: Elastic scattering in the rest-frame in multiple spatial volumes L^3
- Coupled 2-hadron channels well understood
- 3-particle scattering largely understood



For review see Briceno, Dudek, Young, Rev.Mod.Phys. 90, 025001 (2018)

Charmonium-like states in the vicinity of double open-charm thresholds



with S. Collins, M. Padmanath, S. Piemonte, S. Prelovsek

S. Piemonte, DM *et al.* PRD 100 074505 (2019)

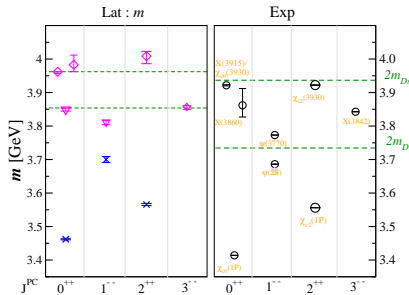
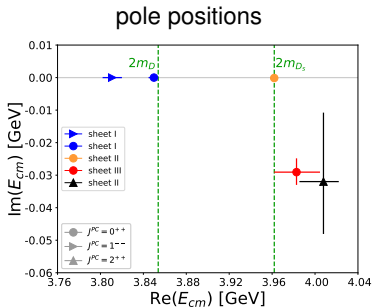
S. Prelovsek, DM *et al.* JHEP 06 035 (2021)

Features of this calculation:

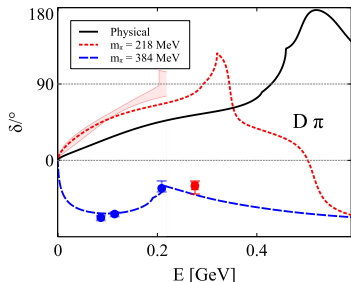
- Calculation in multiple volumes; rest frame and moving frames
- For $J^{PC} = 0^{++}$: Consider coupled channel $D\bar{D}$, $D_s\bar{D}_s$
- Disclaimer: Current study neglects further channels, charm-annihilation, and uses crude models for scattering K -matrix
- Currently unphysical pion masses

Charmonium(-like) resonances from Lattice QCD

S. Piemonte, DM *et al.* PRD 100 074505 (2019)
S. Prelovsek, DM *et al.* JHEP 06 035 (2021)



- Results suggest 3 charmonium(-like) states with $J^{PC} = 0^{++}$ below ≈ 4.13 GeV (in addition to $\chi_{c0}(1P)$)
- We obtain various other states, some which previously uncertain quantum numbers
- Future studies need more physical masses / relax the assumptions that went into these results!



- 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