Coupled-channel systems from and with QCD

:: CML Retreat ::

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Hadron Physics and QCD @ GSI

- ✔ **Two complementary approaches in QCD**
- ✔ **Chiral SU(3) dynamics for mesons and baryons**
- ✔ **Coupled-channel dynamics with realistic forces**
- ✔ **Challenges and future plans**

Two complentary approaches

✔ **Lattice QCD simulations (LQCD)** Daniel Mohler (TU Darmstadt)

- coupled-channel dynamics from Lüscher ansatz
- on-going projects with charmed mesons, light baryons, tetra-quarks etc

✔ **Effective field theory (EFT) approach to QCD** MFML (GSI)

- quark-mass dependence of hadron masses
- coupled-channel dynamics from the chiral Lagrangian with realistic forces

□ **LEC from Lattice QCD for EFT computations**

- controlled extrapolation of Lattice QCD to physical point

Chiral SU(3) dynamics from QCD

✔ The chiral Lagrangian with three light flavors

- the leading order term predicts a rich spectrum of $J^P = \frac{1}{2}^-$ and $\frac{3}{2}^-$ resonances
- on-going projects: how to make this quantitative with chiral corection terms

✔ Test bed for understanding chiral QCD

- quark-mass dependence of resonance masses and scattering amplitudes
- first results from LQCD on $\Lambda(1405)$ as a two pole system at unphysical quark-masses

□ LEC from Lattice QCD for EFT computations

- on-going projects towards infinite volume, continumm limit, physical quark-masses
- first global fit to the baryon octet and decuplet masses on CLS ensembles

Coupled-channel scattering with long range forces

$$T^J_{ab}(s) = U^J_{ab}(s) + \sum_{c,d} \int_{\mu^2_{thr}}^{\infty} \frac{d\bar{s}}{\pi} \frac{s-\mu_M^2}{\bar{s}-\mu_M^2} \frac{T^J_{ac}(\bar{s})\,\rho^J_{cd}(\bar{s})\,T^{J*}_{db}(\bar{s})}{\bar{s}-s-i\epsilon}$$

- ✔ **Derive $T^J_{ab}(s)$ from the Chiral Lagrangian (GPA)**
- ✔ **$T^J_{ab}(s)$ is computed in terms of non-linear integral equations**
  - use perturbation theory for $U^J_{ab}(s)$ followed by a conformal expansion

$$U(s) = U_{\rm close-by}(s) + U_{\rm far-distant}(s)$$

$$\text{with} \qquad U_{\rm far-distant}(s) = \sum_k c_k\,\xi^k(s)$$

- □ **Left-hand cuts are important in physical systems**

Anomalous thresholds and coupled-channel unitarity

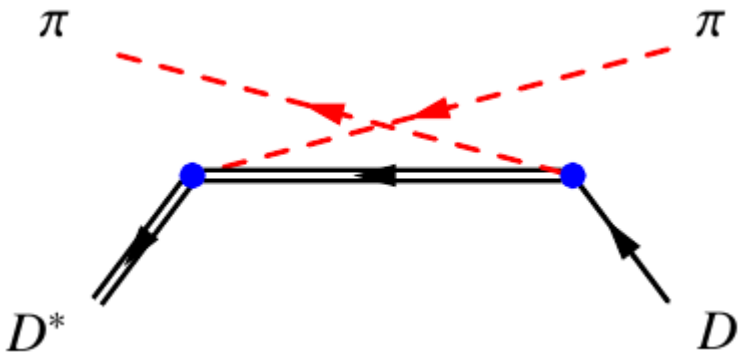
✔ A novel mechanism for p-wave resonances in QCD

- simple example of a p-wave πD^* channel already worked out

✔ Anomalous threshold occurs close to physical masses

- assume first $M_{D^*} < M_D + m_\pi$ (can be tuned on Lattice QCD ensembles)
- for $m_\pi = 150$ MeV we find a normal system
- for $m_\pi = 145$ MeV we find an anomalous reaction $\pi D \to \pi D^*$

✔ An anomalous threshold effect generates p-wave resonances



Challenges and future plans

✔ **LEC from Lattice QCD for EFT computations**

- bright future for LQCD-EFT approach to reaction amplitudes at the physical point

□ **HPC at GSI**

- support of local high-performance parallel computing indispensible
- support of use cases relevant for the theory research at GSI

□ **Current GSI IT stratgey poses significant challenges**

- do we have to plan for external computing resources?
- do we need IT support from external sources?

Future plans : 2028 and beyond

✔ Next generation lattice QCD computations

- further improved action for better control of discretization effects
- improved coverage of the quark-mass plane including multiple lattice spacings with approximately physical quark-masses
- large and consistent data sets for chiral SU(3) fits

✔ Coupled-channel framework for flavor SU(3) baryons at work

- application to specific systems accessible in experiments
- predict systems that are critical in the understanding of particle production in HIC

□ LEC from Lattice QCD for EFT computations

- bright future for LQCD-EFT approach to reaction amplitudes at the physical point
- sharpen the physics programme at CBM and PANDA