A2: Hadronic Dynamics on the Lattice

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CRC110 General Assembly, 8/2017

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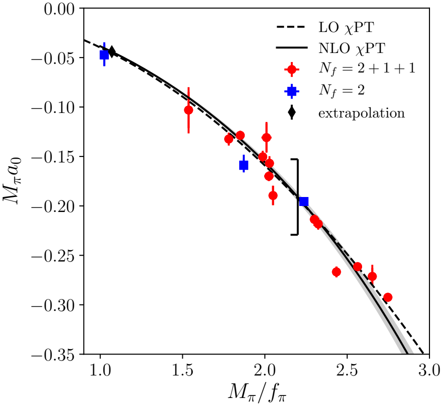
Pion-Pion Scattering ($I = 2$) at the Physical Point

- $N_f = 2$, one lattice spacing
- two volumes @$M_\pi = 135\ \mathrm{MeV}$: $L \approx 4\ \mathrm{fm}$ and $L \approx 6\ \mathrm{fm}$
- additional ensembles at larger pion masses



- no extrapolation in M_π needed!
- have to balance statistical versus extrapolation error
- $N_f = 2+1+1$ at physical point currently in production

K^+K^+ Scattering with $I = 1$: Motivation

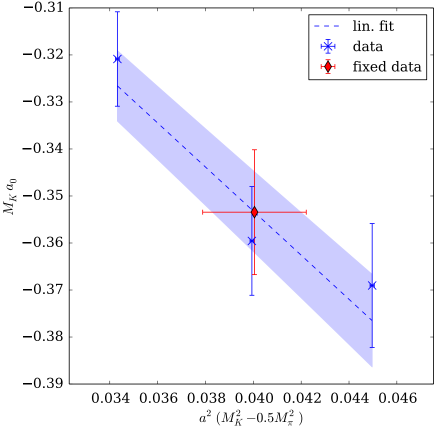
- at STAR or ALICE experiments: numerous light hadrons created
- kaons carry on average much lower momentum than pions
- kaons much more likely to interact elastically
- lattice computation of KK scattering valuable input
- theoretically interesting: does chiral perturbation theory still work for KK?

K^+K^+ Scattering with $I = 1$: Strange Quark Mass

- value of sea strange quark mass up to 10% off
- corrected for by varying the valence strange quark mass

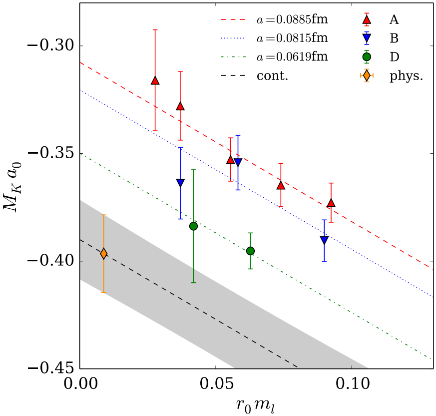
$\Rightarrow$ small unknown systematic uncertainty

- interpolate linearly in $M_K^2 - 0.5M_\pi^2$
- input: M_K, M_π and lattice spacing
- now work at fixed strange quark mass value



at fixed strange quark mass:

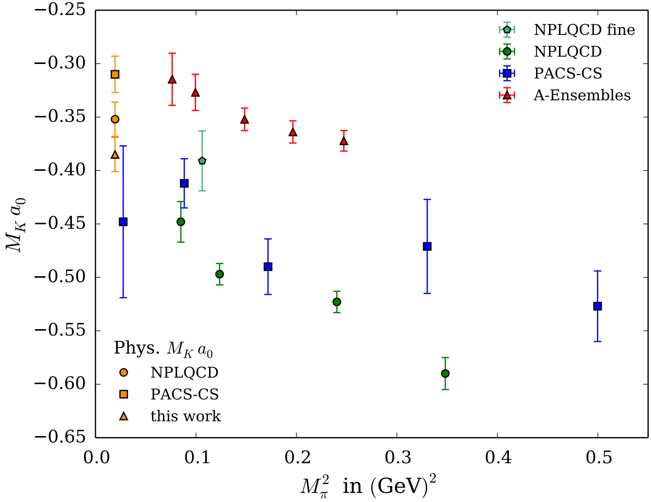
- extrapolate in light quark mass
- and lattice spacing a^2
- combined fit of all data simultaneously
- first continuum extrapolation of this quantity



- result

$$M_K a_0 = -0.385(16)_{\text{stat}}\binom{+0}{-12}_{m_s}\binom{+0}{-5}_{Z_P}(4)_{r_f}$$

K^+K^+ Scattering with $I = 1$: Comparison



[NPLQCD (2008), PACS-CS (2014), ETMC (PRD, 2017)]

Pion-Kaon Scattering (preliminary)

- similar to pion-pion or kaon-kaon, but two particles with different mass

$\Rightarrow$ time dependent pollution

- same strategy as for kaon-kaon

$\Rightarrow$ mixed action for the strange quark

- three lattice spacings

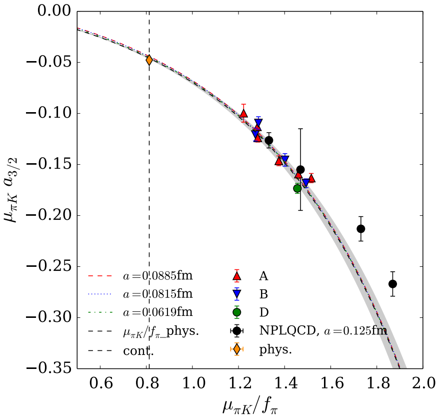
- $I = 3/2$ channel first

$\Rightarrow$ $I = 1/2$ channel via crossing symmetry and ChPT

- $I = 1/2$ direct calculation in progress

- fit with NLO ChPT $+ \mathcal{O}(a^2)$
- three lattice spacings
- compare to results of NPLQCD
  [NPLQCD, (2006)]
- preliminary result:

$$(\mu_{\pi K} a_{3/2})_{\text{phys}} = -0.0477(9)$$



$\Rightarrow$ almost ready to be published

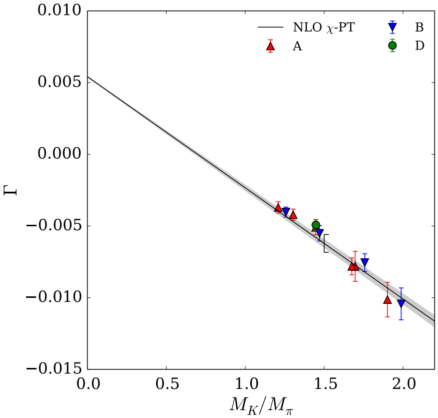
Pion-Kaon Scattering (preliminary)

- in NLO ChPT

$$\Gamma = L_5 - \frac{2M_K}{M_\pi} L_{\pi K}$$

- result (preliminary)

$$\begin{aligned} (\mu_{\pi K} a_{3/2})_{\text{phys}} &= -0.0469(6) \\ (M_\pi a_{3/2})_{\text{phys}} &= -0.0598(8) \\ (M_\pi a_{1/2})_{\text{phys}} &= +0.163(1) \end{aligned}$$



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Two and Three Particle Quantization Condition

- investigate formulae for “three particle quantization condition in a finite volume”

  [Hammer, Pang, Rusetsky, (2017)]

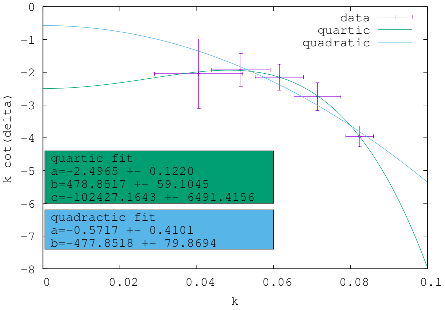
- first study in a toy model

$\Rightarrow$ complex ϕ^4 theory

- determine two and three particle energy levels

- in collaboration with project B4

- $k\cot(\delta)$ for the two particle system:



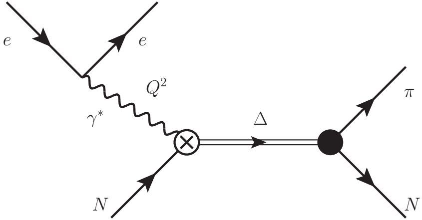
Pion-Nucleon Scattering

- ultimate goal: study of transition amplitude

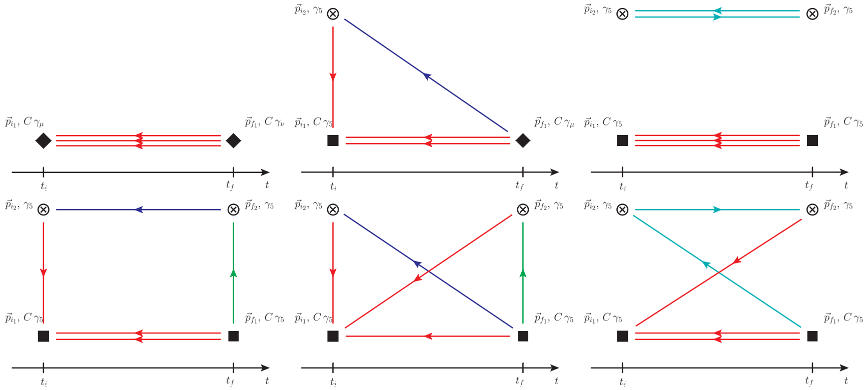
$$N\,\gamma^* \to \Delta \to N\,\pi$$

- energy dependent phase shift as required input for matrix elements of unstable Δ state $\langle \pi N \,|\, J_\mu \,|\, N \rangle$

- modified strategy
  - ETMC $N_f = 2$ @ physical pion mass (Δ as proper resonance, 2 lattice volumes)
  - non - stochastic distillation approach [Alexandrou et al. 2017] from $\pi\,\gamma \to \pi\,\pi$



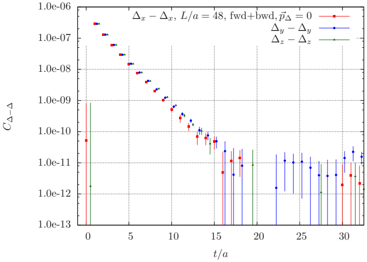
Pion-Nucleon Scattering

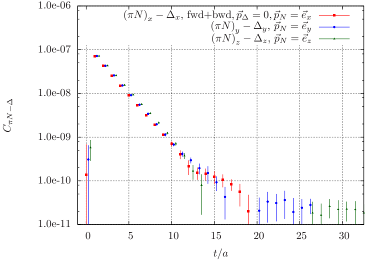


- work package implemented for $\pi - N$, any $I = 1/2,\ 3/2;\ I_3$
- data acquisition started for $N_f = 2$ physical point $L/a = 48$ and $L/a = 64$
- implementation of phase shift analysis on-going

Pion-Nucleon Scattering

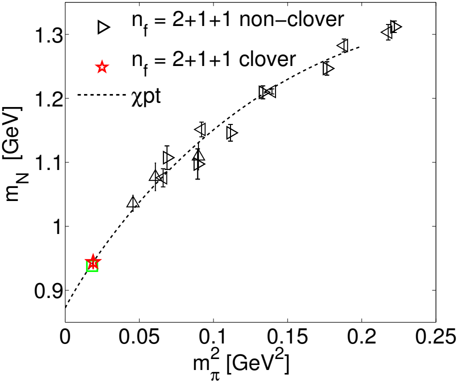
- daunting question about signal/noise, statistics for 3×3 or 4×4 GEVP
- computer time granted for 2017: 60 + 35 million core hours (Hazelhen @ HRLS and JuQueen @ FZJ)
- ETMC $N_f = 2 + 1 + 1$ physical point ensemble on the horizon for analysis





Simulations with $N_f = 2+1+1$ at the Physical Point

- physical point with Wilson like fermions and $a \approx 0.1$fm difficult
- twisted-clover:
  physical point at $a \approx 0.09$fm possible
- $L = 64$ production almost finished
- additional ensembles at non-physical M_π available



$\Rightarrow$ measurements currently in progress

- here: nucleon mass compared to previous simulations

Milestones

- 2016:
  - $N_f = 2+1+1$ ensemble with $L/a = 48$ at physical point with $a \approx 0.1$ fm, changed to $L/a = 64$ at $a \approx 0.09$ fm, ✓, finishing
  - $\pi\pi$ scattering with $I = 2$ at $N_f = 2$ physical point ✓
  - identify the most relevant channels in charmed meson scattering ✓

- 2017:
  - analysis of basic quantities on $N_f = 2+1+1$ physical point ✓, ongoing
  - $\pi\pi$ scattering with $I = 0$ on $N_f = 2$ physical point ✓
  - Pion-Nucleon: change of strategy, ✓, ongoing
  - charmed meson scattering, extract scattering parameters for one ensemble

  $\Rightarrow$ see talk of Ting Chen