Recent results in lattice QCD spectroscopy

Ben Hörz (Johannes Gutenberg-Universität Mainz)

Light Cone 2018

May 14, 2018

Modern-day lattice spectroscopy

Scattering processes and resonances from lattice QCD

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[2] *Department of Physics, College of William and Mary, Williamsburg, Virginia 23187, USA*

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(Dated: June 21, 2017)

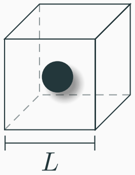
The vast majority of hadrons observed in nature are not stable under the strong interaction, rather they are *resonances* whose existence is deduced from enhancements in the energy dependence of scattering amplitudes. The study of hadron resonances of-

- state-of-the-art spectroscopy tries to treat resonances properly
- detailed review of status and prospects from last summer

[Briceño, Dudek, Young 1706.06223]

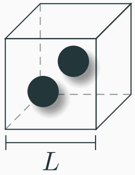
- here: brief introduction and recent highlights

Euclidean time, finite volume $\rightsquigarrow$ no direct access to scattering



single particle in a periodic box
$\rightsquigarrow \Delta E \propto \mathrm{e}^{-mL}$

two spinless particles in a periodic box
$\rightsquigarrow \Delta E \propto a_0/L^3 + O(L^{-4})$ [Lüscher '86, '91]



$\Rightarrow$ 'The Lüscher method'

Two-particle Quantization Condition

Formalism for two particles complete! [Briceño 1401.3312]

$$\boxed{\det\left[F(E_L,L)+\mathcal{M}^{-1}(E_L)\right]=0}$$

E_L – FV spectrum
$\mathcal{M}$ – scattering amplitude
F – known functions

- ☑ nonzero total momentum [e.g. Rummukainen, Gottlieb hep-lat/9503028]
- ☑ scattering of unequal particles [e.g. Fu 1110.0319]
- ☑ multiple strongly coupled channels [e.g. Liu, Feng, He hep-lat/0508022]
- ☑ particles with intrinsic spin [e.g. Göckeler et al. 1206.4141]

What took practitioners so long?

- FV spectroscopy is technically challenging
- algorithmic advances paved the way

[related results: see talk by Colin Egerer Thu 3pm]

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- F encodes the symmetries of the box
  i.e. it is not diagonal in partial wave
- relevant group theory worked out
  [Morningstar et al. 1707.05817]
- publicly available
  [github.com/cjmorningstar10/TwoHadronsInBox]

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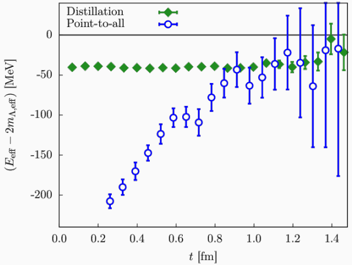
[Francis et al. 1805.03966]

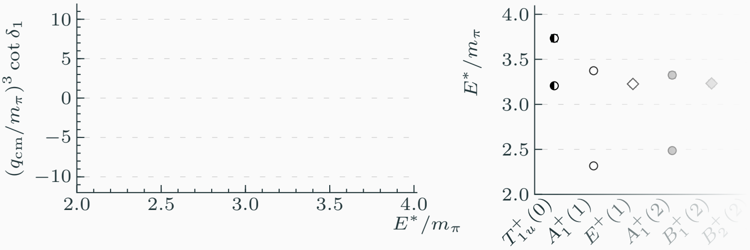


- good spectroscopy requires good operators
- necessitates efficient treatment of quark propagation
- *a* path to reliable spectroscopy:
  distillation & stoch. variants

  [Peardon et al. 0905.2160, Morningstar et al. 1104.3870]

A simple (yet relevant) resonance: $\rho(770)$

[plot adapted from Bulava et al. 1604.05593]



- elastic $\pi\pi$ scattering neglecting $\ell \geq 3$ partial wave
  spectrum $\Leftrightarrow$ scattering amplitude
- benchmark system for the lattice
  e.g. Lang et al. 1105.5636, Aoki et al. 1106.5365, ..., Dudek, Edwards, Thomas 1212.0830, ...
- survey of remaining systematics underway
  lattice spacing, quark mass, residual FV, partial-wave mixing

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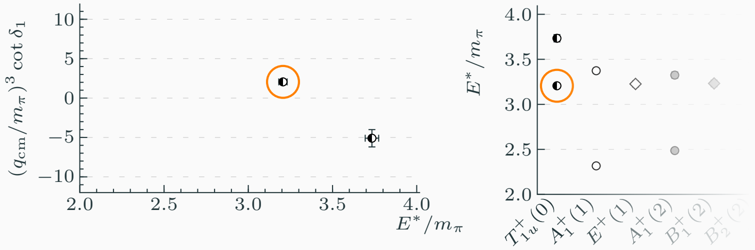

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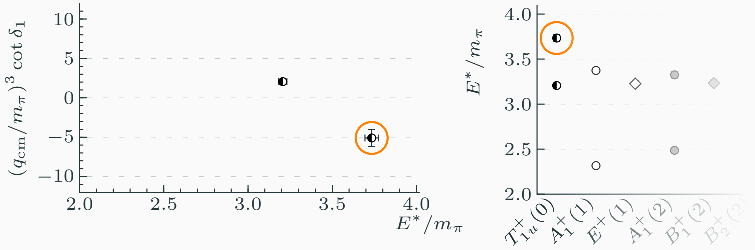

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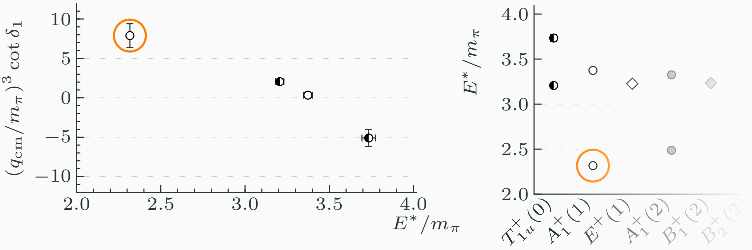

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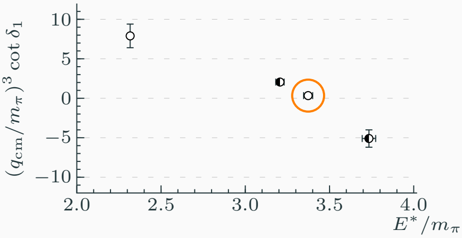

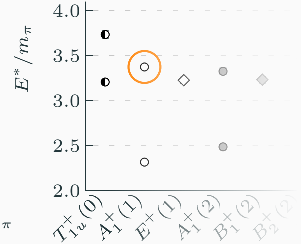

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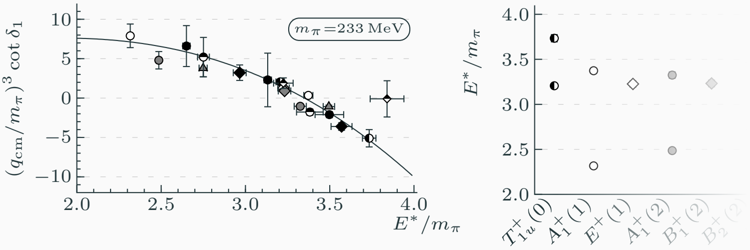

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Where do we go from here?

- determination of the QCD spectrum
  - low-lying resonances

    esp. scalar sector (σ, κ)
  - baryon resonances ($N(1440)$, $\Lambda(1405)$)
  - charm sector & exotics
  - ...
- electroweak processes above multi-particle thresholds
  - B decays
  - transition form factors for nuclear physics
  - ...

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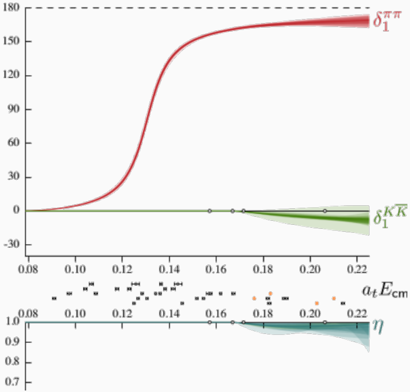
- mature two-particle formalism for matrix elements

  [for a survey see Briceño EPJ Web Conf. 175 (2018) 01016]
- spectroscopy a stepping stone towards this goal

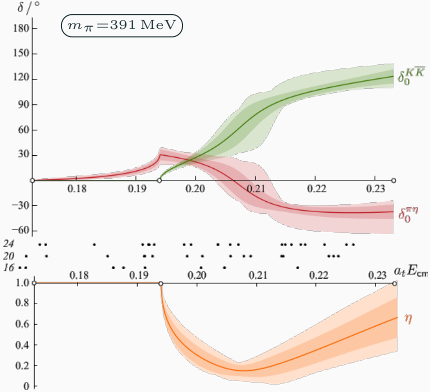
  Alessandro Baroni Thu 3.20pm

  Daniel Robaina Fri 4.10pm (for a different take on inclusive decay rates)



[Wilson et al. 1507.02599]

- amplitudes from global fits to FV spectrum
- parametrization uncertainty (shaded bands)
- limited by multi-particle thresholds
  - $\rightsquigarrow$ physical pion mass not necessarily desirable

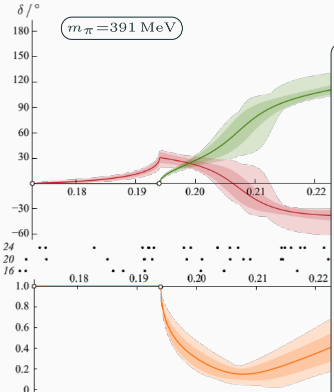


[Dudek, Edwards, Wilson 1602.05122]

- experiment-like analysis workflow (partial wave analysis)
- a prominent cusp-like structure in s-wave $\pi\eta \to \pi\eta$

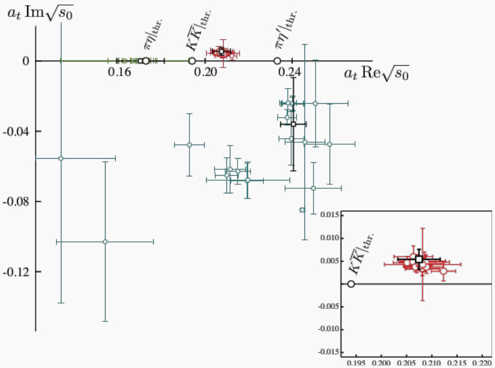
  $\rightsquigarrow$ $a_0(980)$-like resonance strongly coupled to $\pi\eta$, $K\bar{K}$
- resonances manifest in manifold ways

- experiment-like analysis

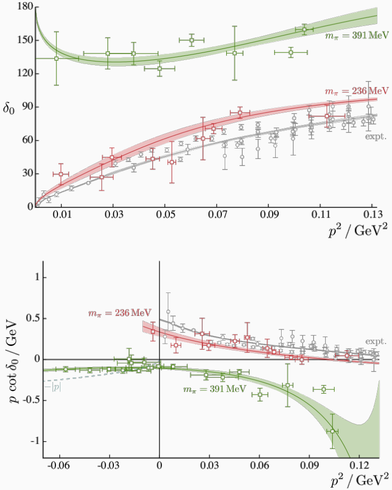


[Dudek, Edwards, Wilson 1602.05122]

amplitude singularity content

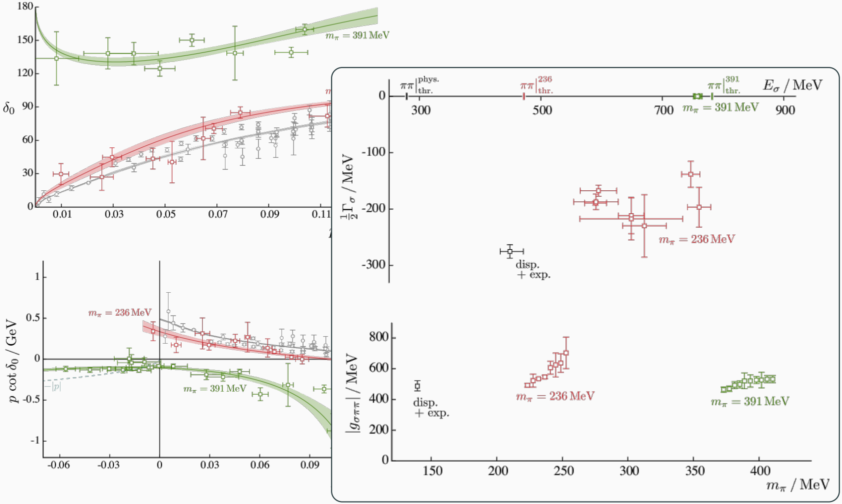


$I = 0$ $\pi\pi$ SCATTERING AND THE σ RESONANCE



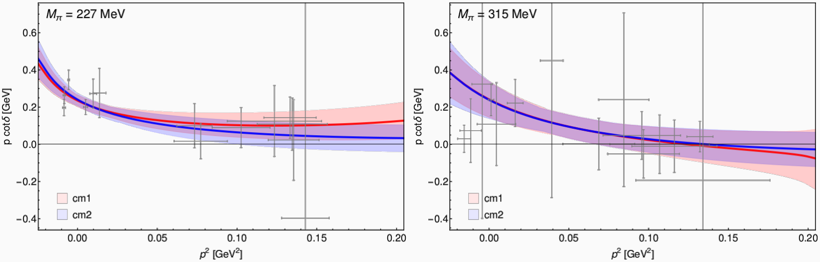
[Briceño et al. 1607.05900]

- σ / $f_0(500)$ controversial history
- adjustable pion mass as a tool
- sophisticated scattering amplitude analyses required



[Briceño et al. 1607.05900]

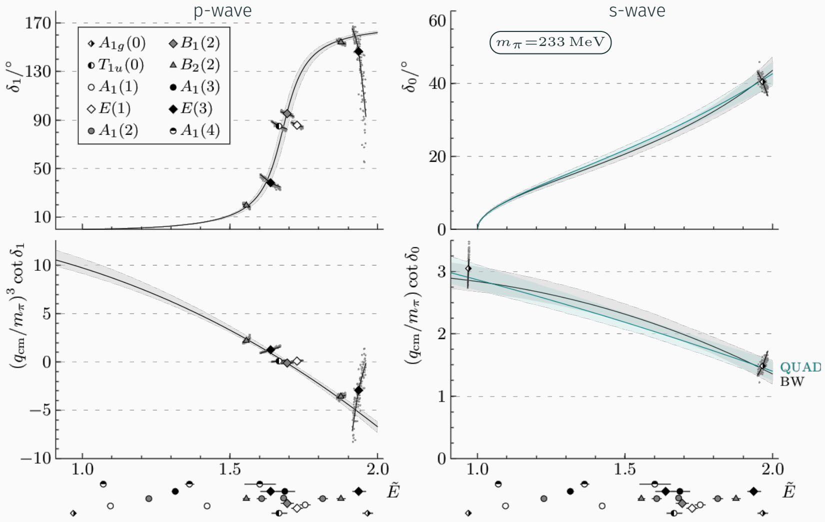
$I = 0$ $\pi\pi$ SCATTERING AND THE σ RESONANCE (II)



[Guo et al. 1803.02897]

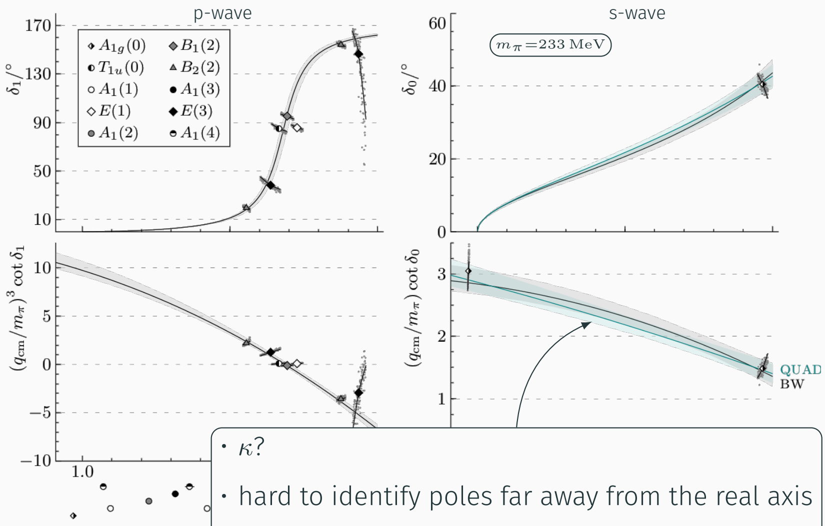
- independent measurements by various groups
- global analysis of different pion masses
  (overlap with EFT methods)

$K\pi$ SCATTERING: $K^*(892)$ AND κ



[Brett et al. 1802.03100]

$K\pi$ SCATTERING: $K^*(892)$ AND κ



[Brett et al. 1802.03100]

- κ?
- hard to identify poles far away from the real axis
- ideally track pole position for various m_π & m_K

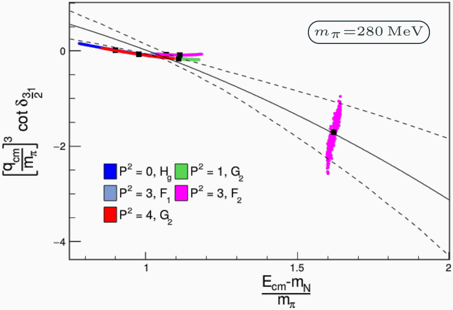
$I = 3/2$ $N\pi$ SCATTERING: $\Delta(1232)$

a baryonic resonance

$\rightsquigarrow$ combinatorically harder

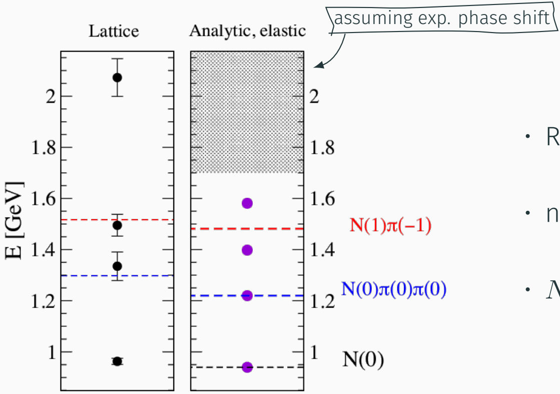
$\rightsquigarrow$ typically worse signal-to-noise

$\rightsquigarrow$ scattering of particles with spin: rotational-symmetry breaking more restricting



[Andersen et al. 1710.01557]

- Breit-Wigner shape
- $\Delta(1232)$ found on threshold



[Lang et al. 1610.01422]

- Roper elusive on the Lattice
- no $N\pi\pi$ interpolator, but $N\sigma$
- $N\pi\pi$ channel likely relevant

$\rightsquigarrow$ a lot of progress on three-particle formalism in recent years

various 'competing' approaches, seeming to converge

Summary

- treat unstable particles properly
- two-particle formalism fully understood, three-body formalism nearing completion
- practical numerical implementation ongoing by many groups
- prerequisite to unlocking matrix elements

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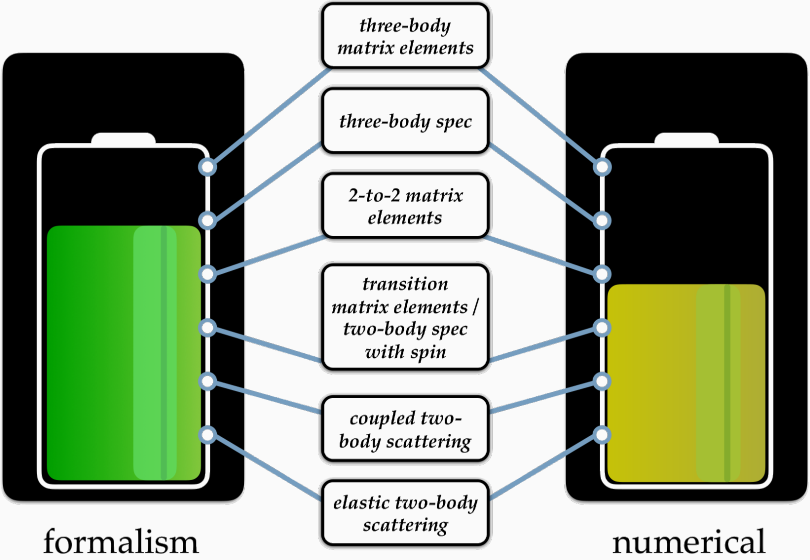
$\boxed{\rightsquigarrow \text{ interesting times ahead for those efforts}}$



[slide from Raul's Lattice 2017 talk]