

Search for Exotic Hadrons

Overview of ExoHad

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William & Mary

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11th workshop of the APS Topical Group on Hadronic Physics (GHP2025)

March 14-16, 2025

Anaheim, CA

<https://www.exohad.org/>



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ajackura.github.io



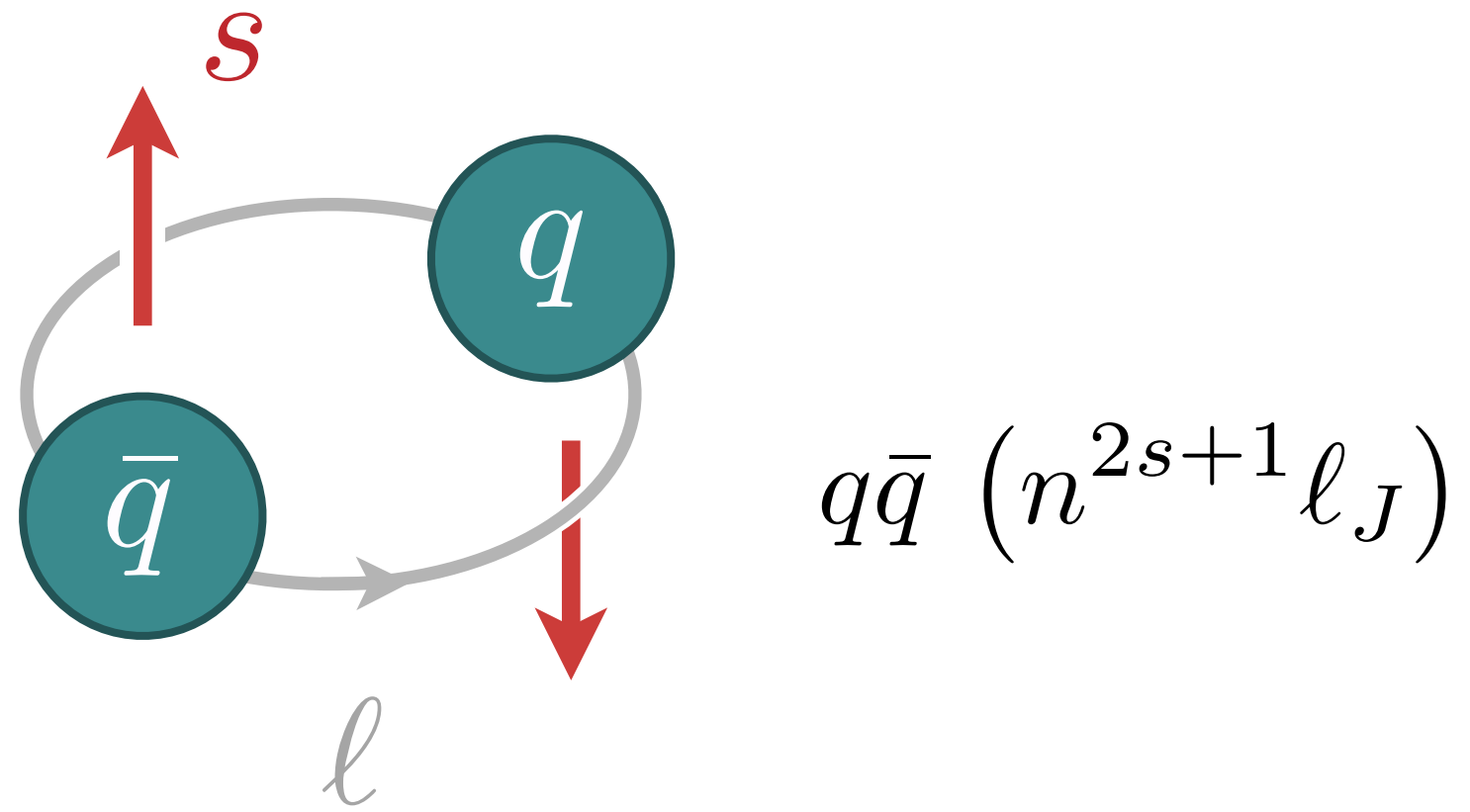
WILLIAM & MARY

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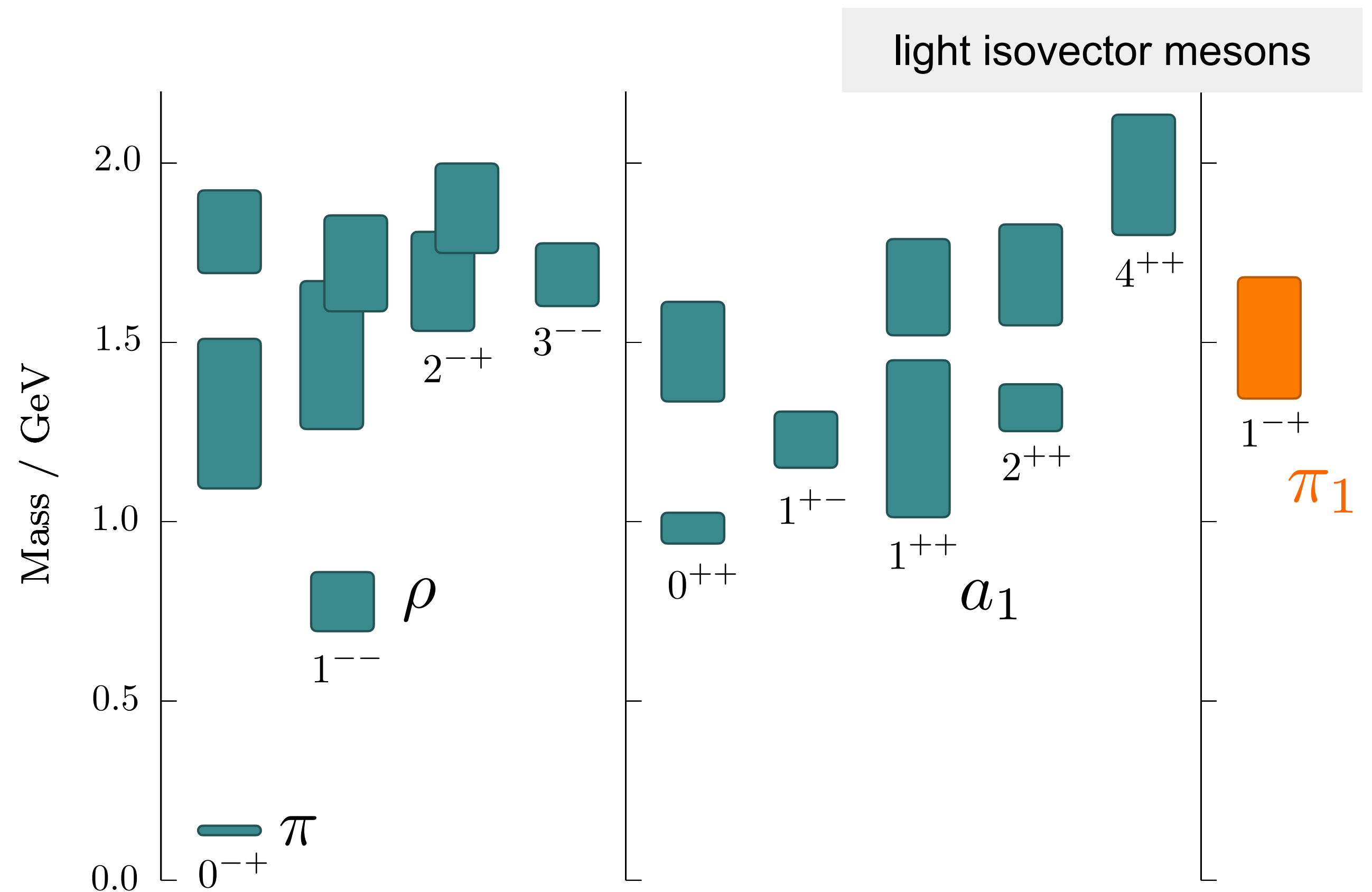
Exotic Hadrons

Many states in the hadron spectrum do not 'fit' the conventional quark model picture

- e.g., spin-exotic states



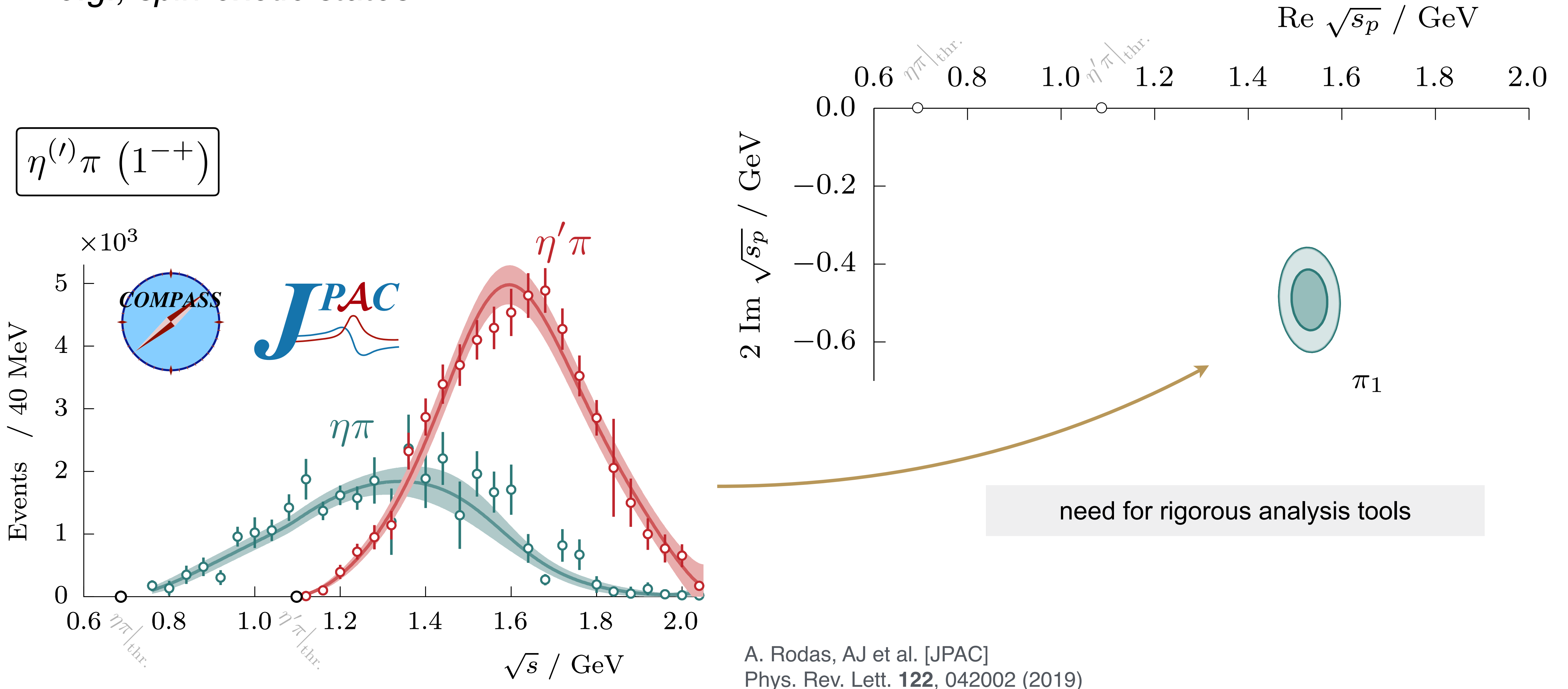
Forbidden Quantum Numbers: $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \dots$



Exotic Hadrons

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- *e.g., spin-exotic states*

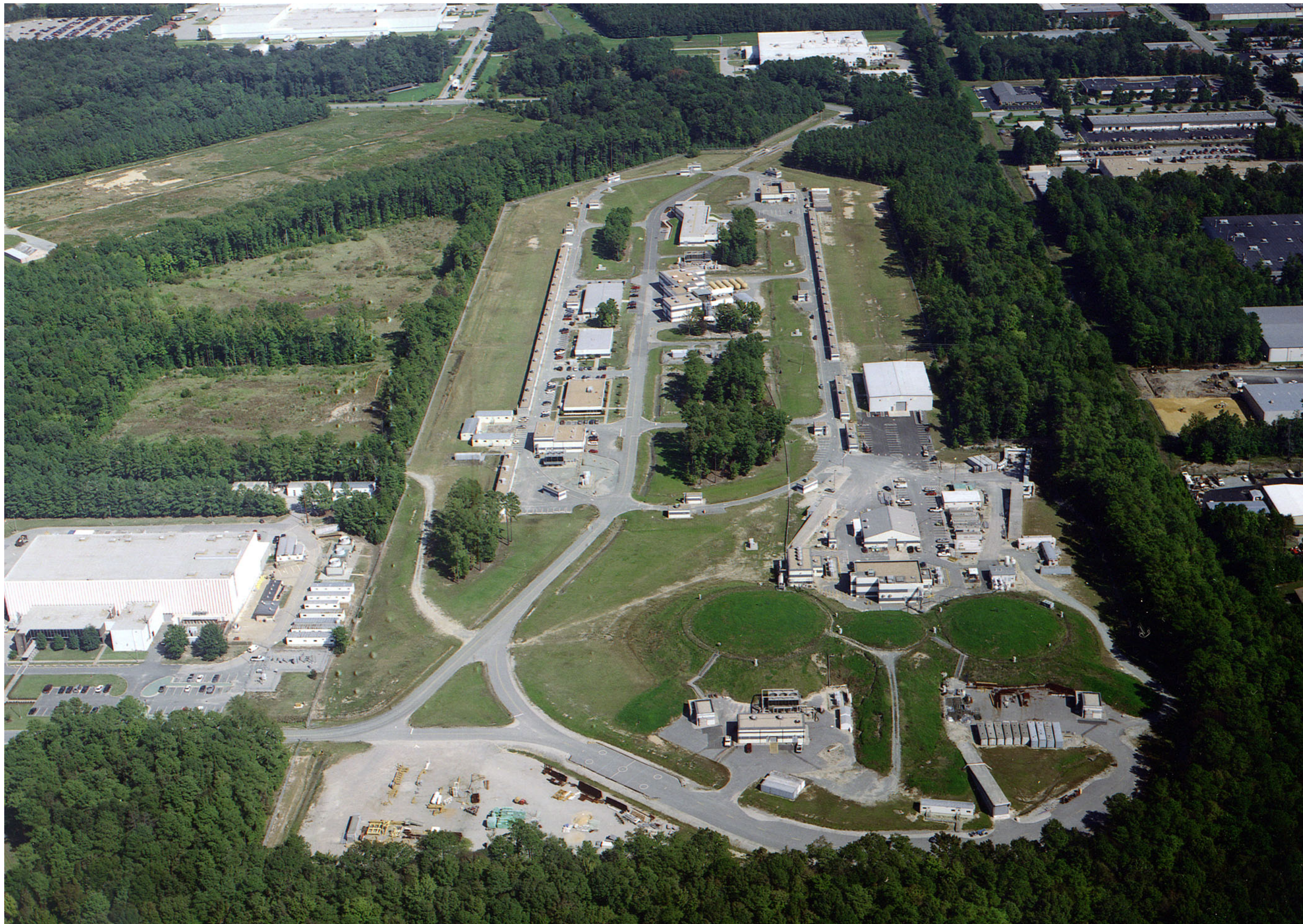


A. Rodas, AJ et al. [JPAC]
 Phys. Rev. Lett. **122**, 042002 (2019)

Exotic Hadrons

Many states in the hadron spectrum do not 'fit' the conventional quark model picture

- *e.g., spin-exotic states*



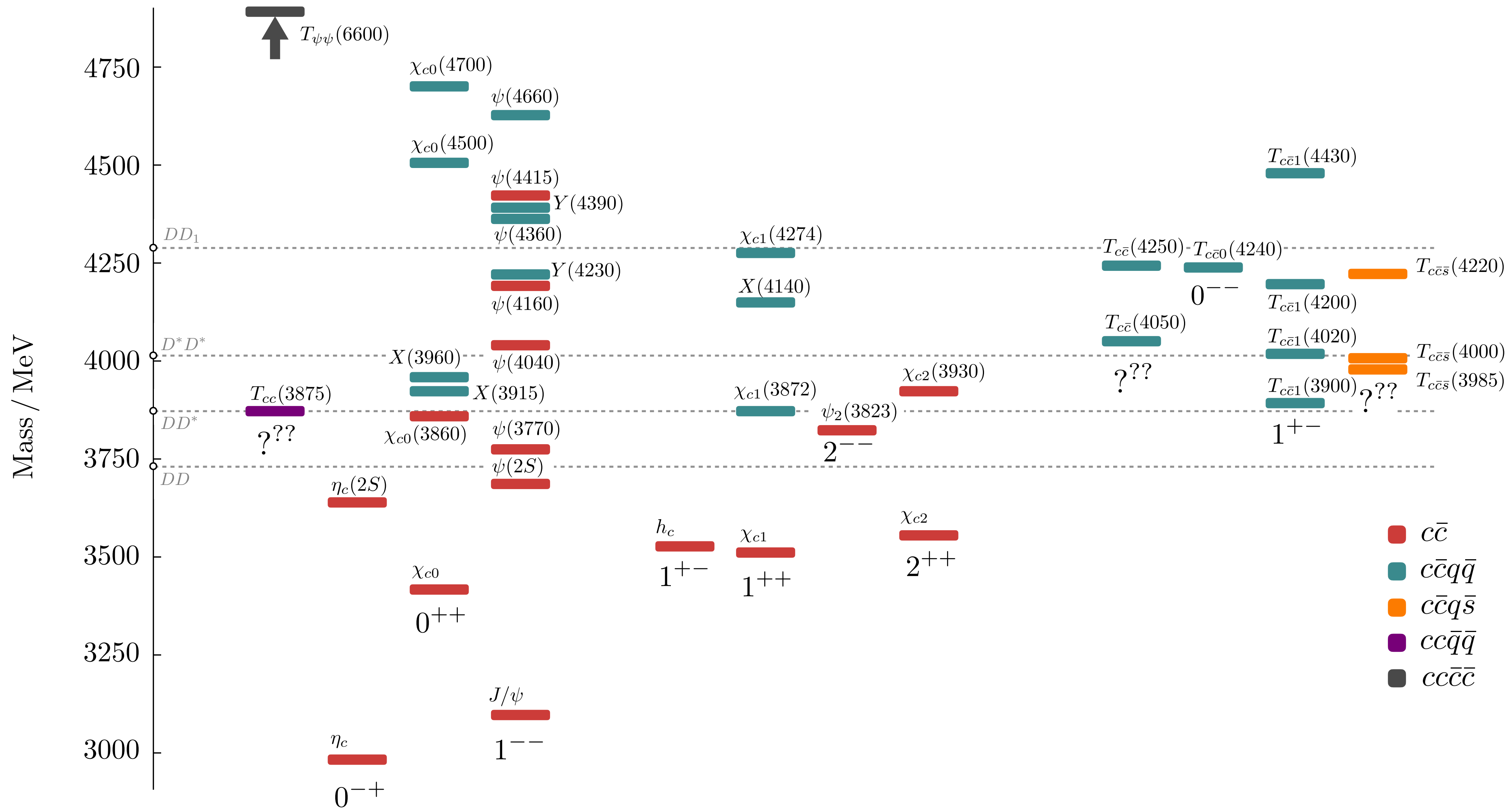
GLUEX

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Exotic Hadrons

Many states in the hadron spectrum do not 'fit' the conventional quark model picture

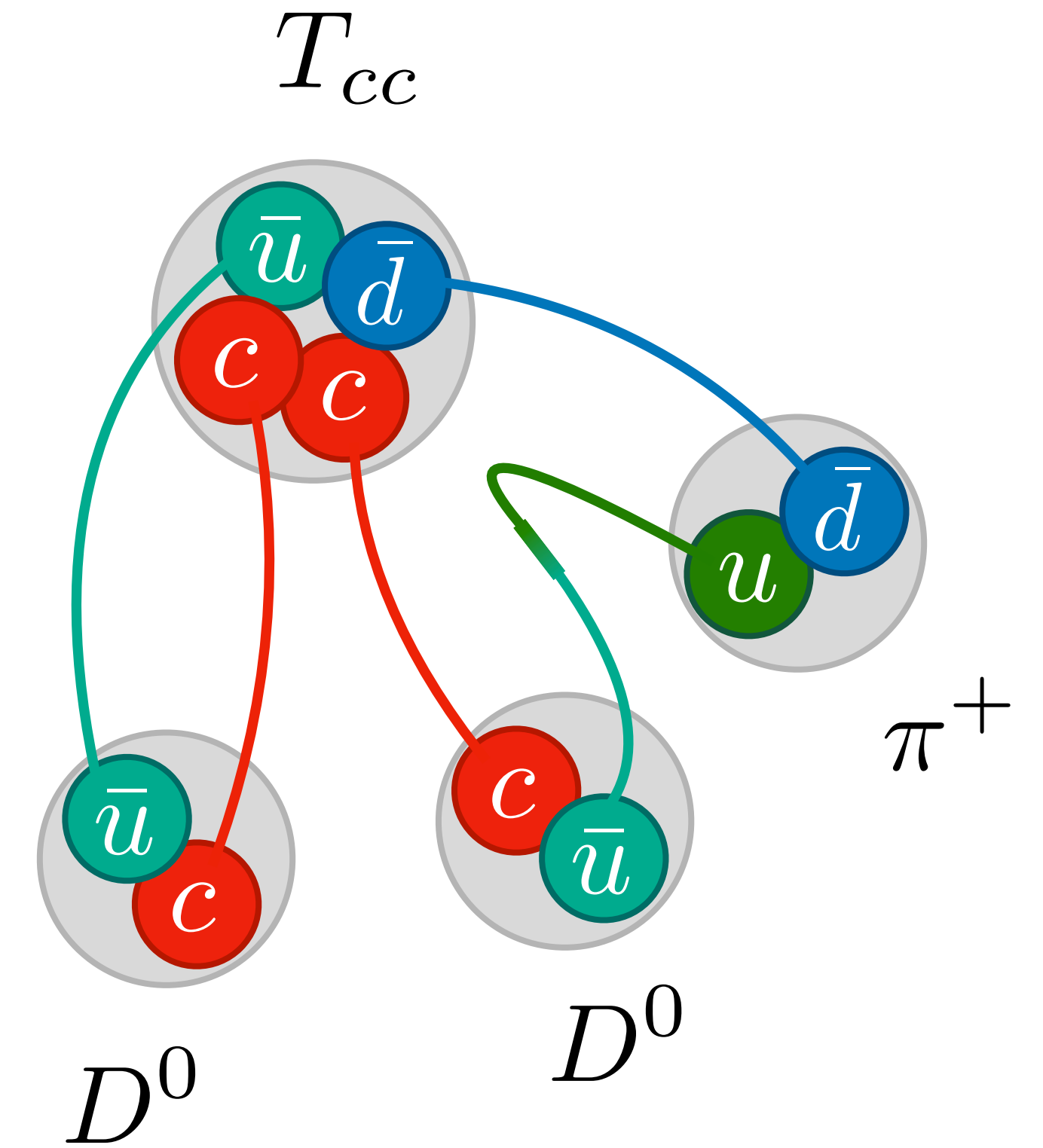
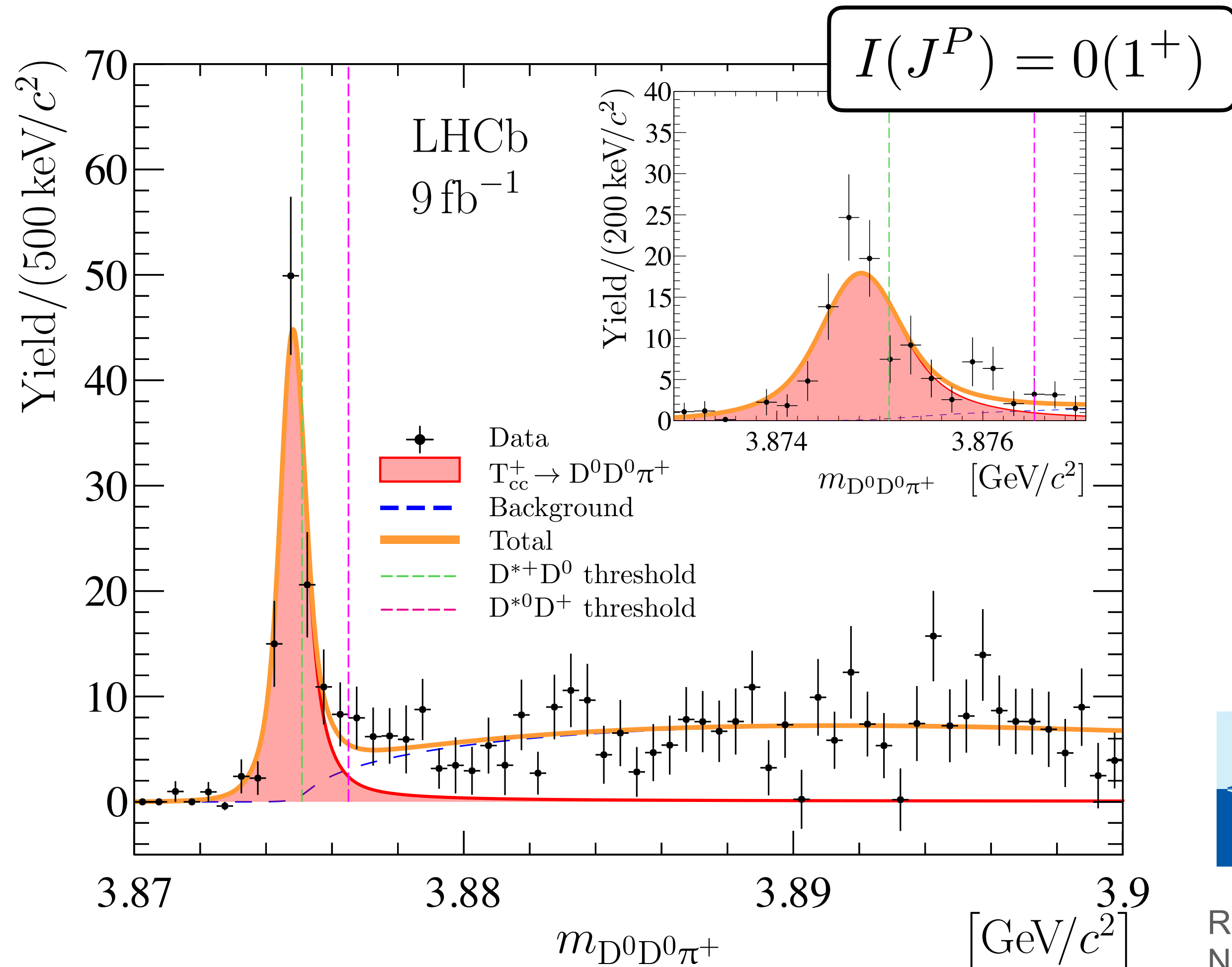
- e.g., *flavor/crypto-exotic states*



Exotic Hadrons

Many states in the hadron spectrum do not 'fit' the conventional quark model picture

- e.g., *flavor/crypto-exotic states*



need for three-body dynamics

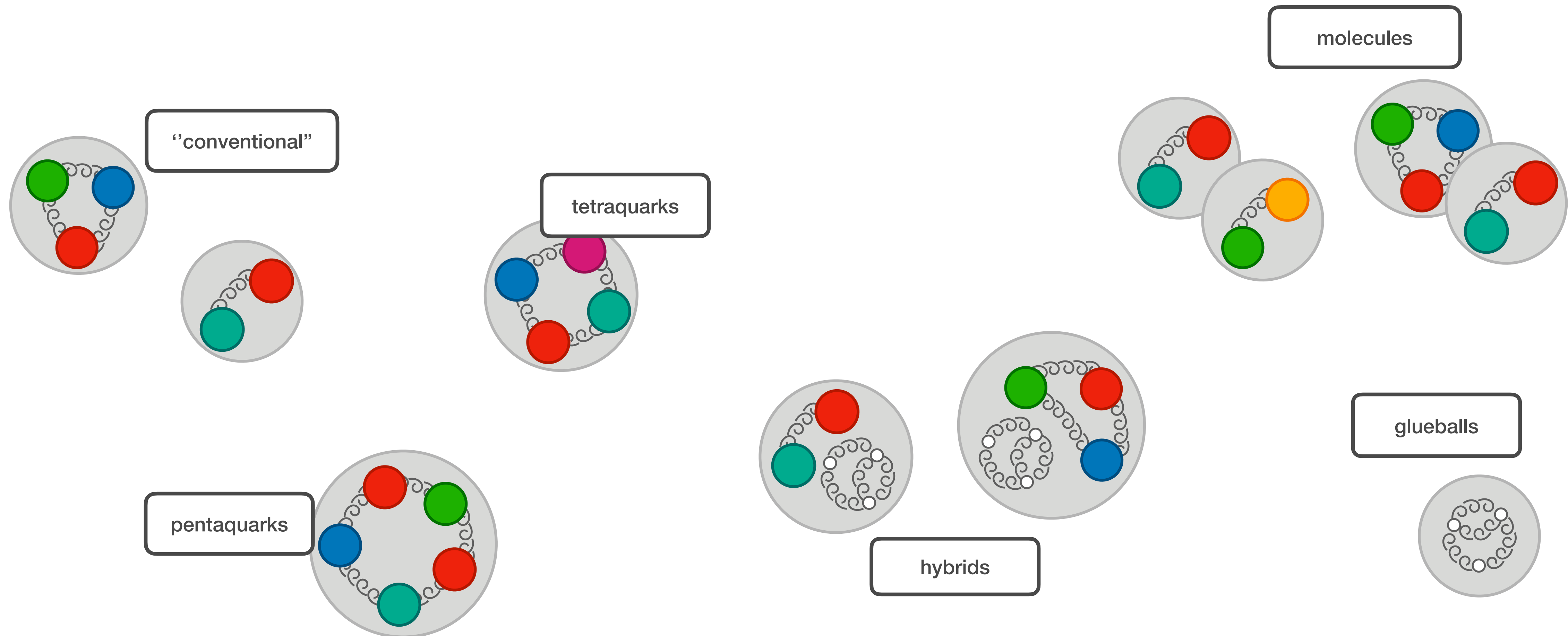


R. Aaij et al., [LHCb Collaboration]
Nature Physics **18**, 751–754 (2022)

Exotic Hadrons

Observation of O(100) of these states — **Modern Hadron Spectroscopy**

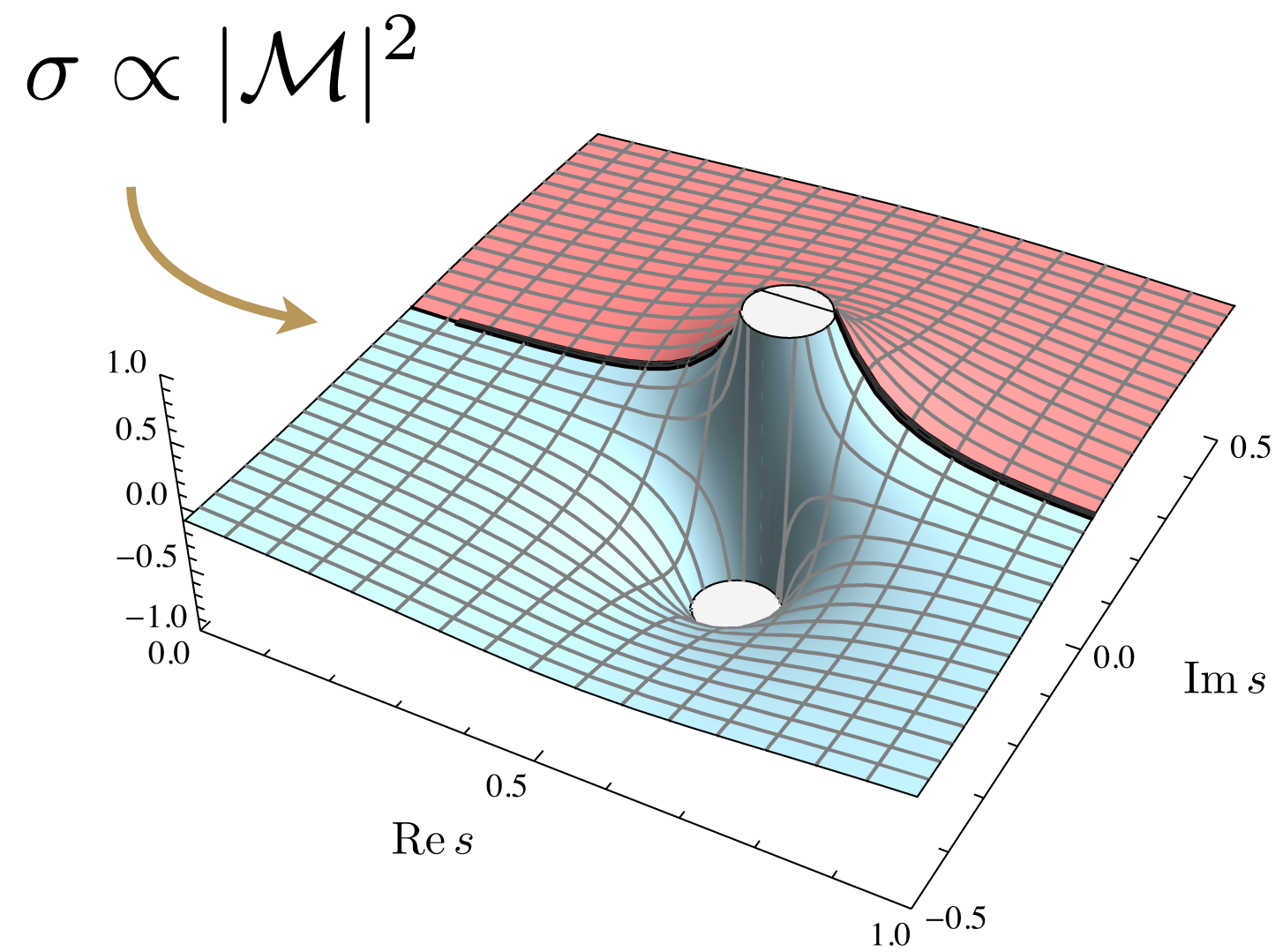
- *Use rigorously analysis frameworks to study reactions/spectrum*
- *Build reliable phenomenological models to gain insight into nature of hadrons*
- *Systematically connect observed hadrons to QCD*



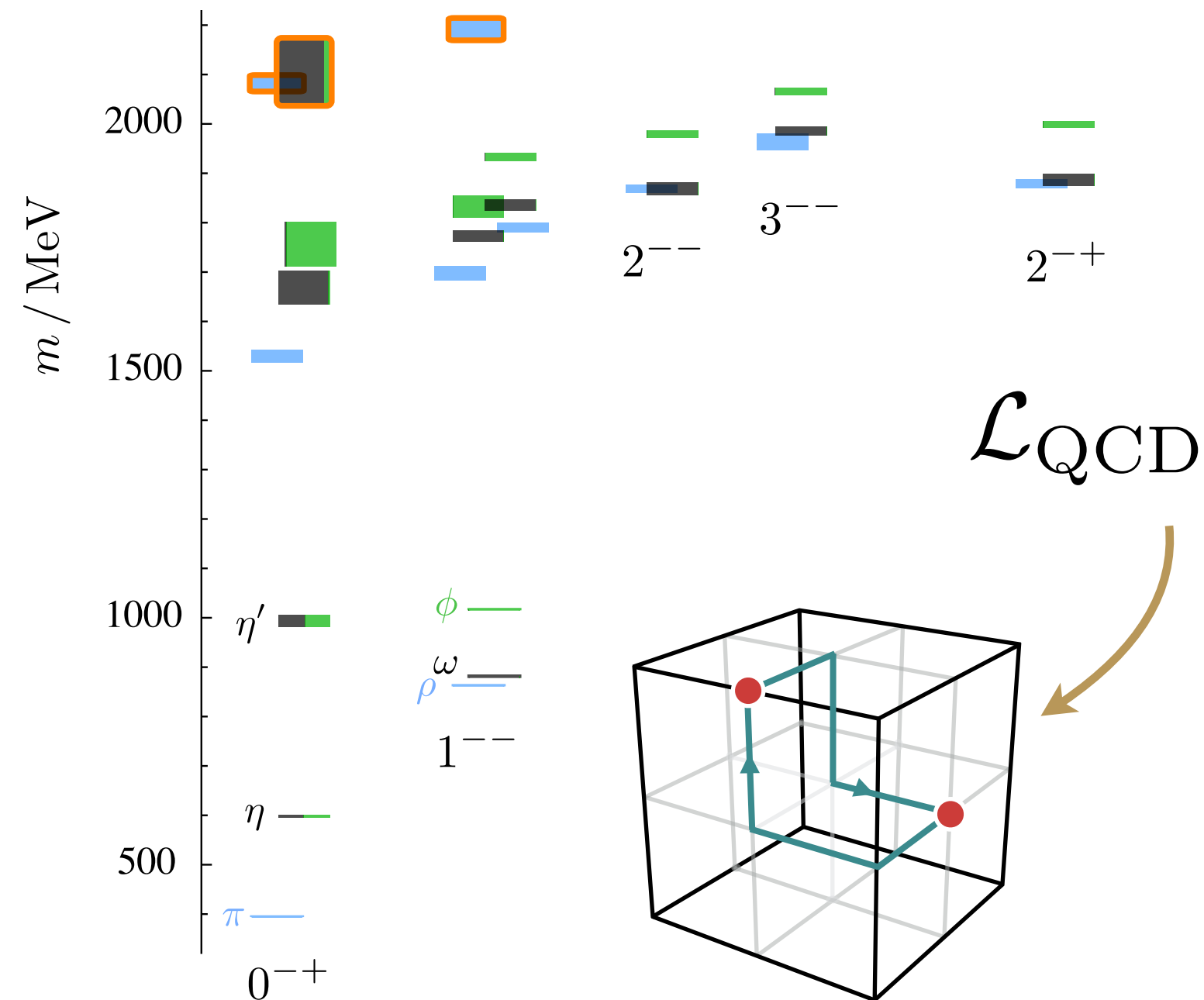
ExoHad

The Exotic Hadrons (ExoHad) Collaboration was formed in 2023 to explore exotic hadrons

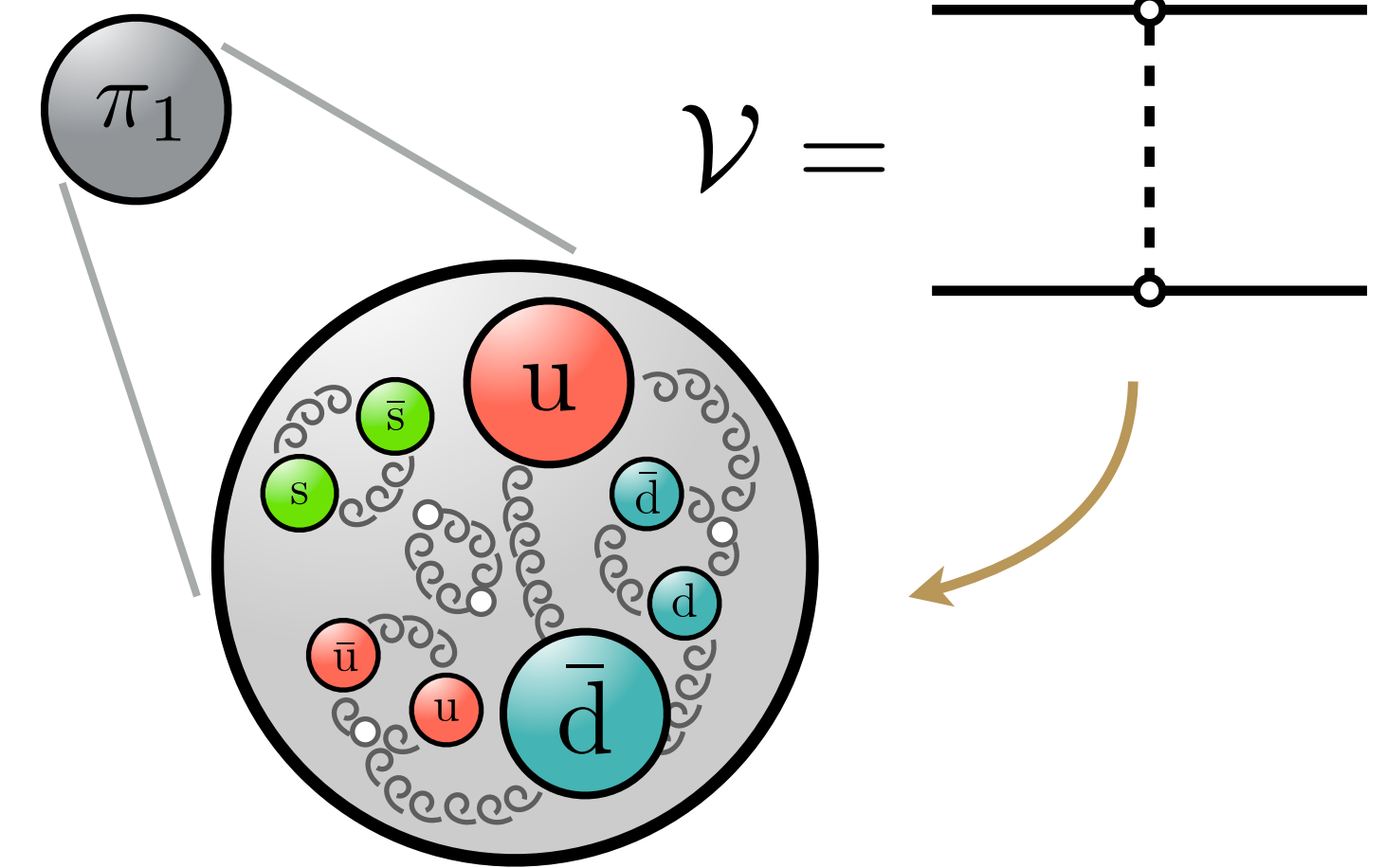
Amplitude Analysis



Lattice QCD



Phenomenology



ExoHad



Full Members



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[Raúl Briceño](#)

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[Michael Döring](#)

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[Alessandro Pilloni](#)

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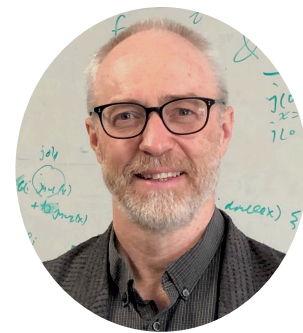
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[Stephen Sharpe](#)

University of Washington



[Eric Swanson](#)

University of Pittsburgh



[Adam Szczepaniak](#)

Indiana University

Students and Postdocs



[Mischa Batelaan](#)

William & Mary



[Roberto Bruschini](#)

Ohio State University



[Zack Draper](#)

University of Washington



[Yuchuan Feng](#)

George Washington University



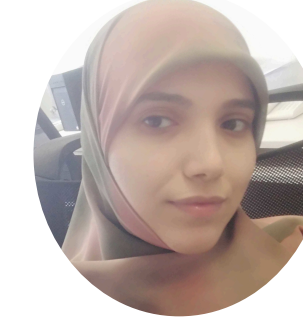
[Giorgio Foti](#)

Università di Messina



[Md Habib E Islam](#)

Old Dominion University



[Nadine Hammoud](#)

University of Barcelona



[Joshua Hoffer](#)

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Ohio State University



[Taylor Powell](#)

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[Wilder Schaaf](#)

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[Vanamali Shastry](#)

Indiana University



[Wyatt Smith](#)

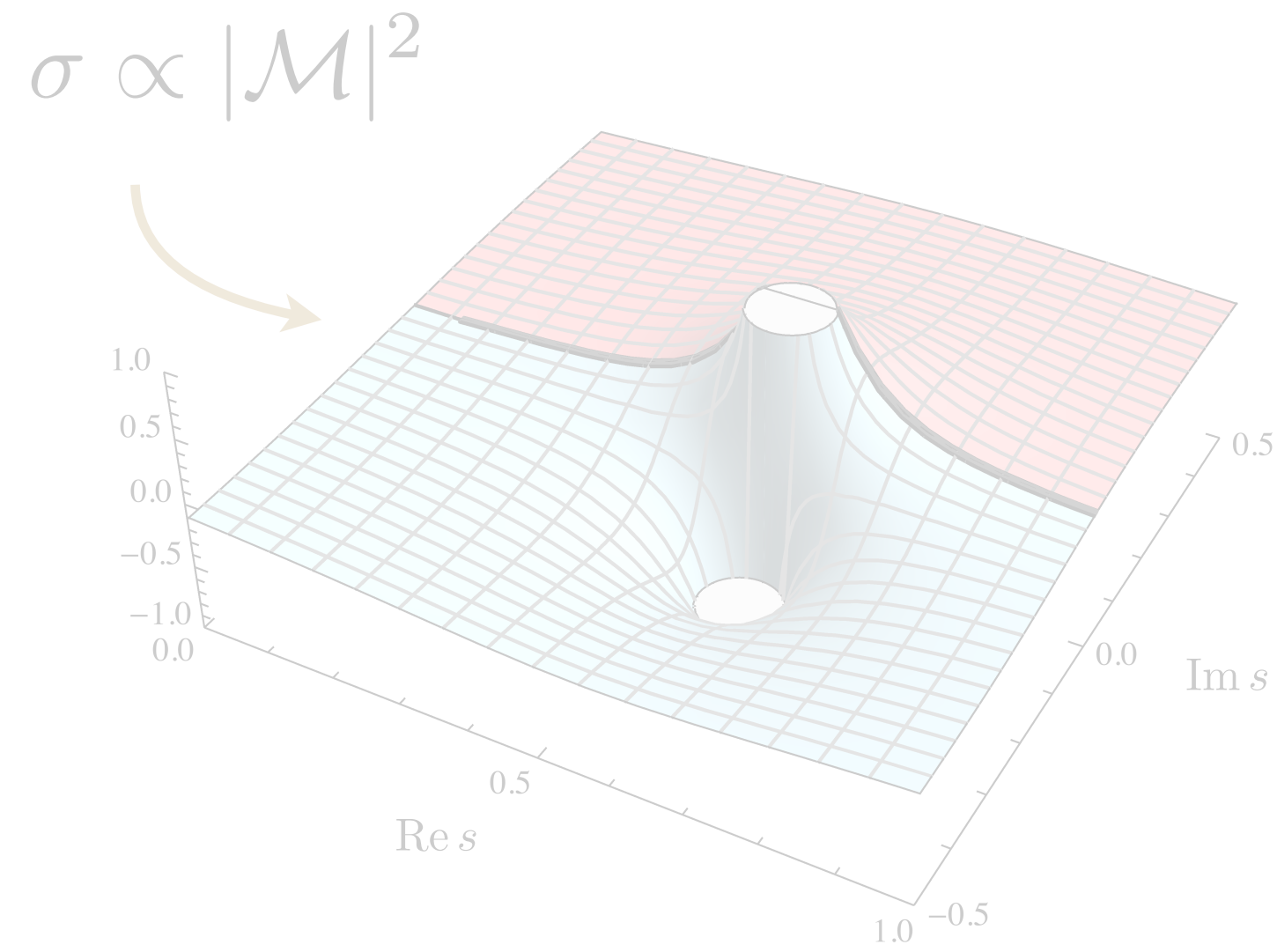
Università di Messina



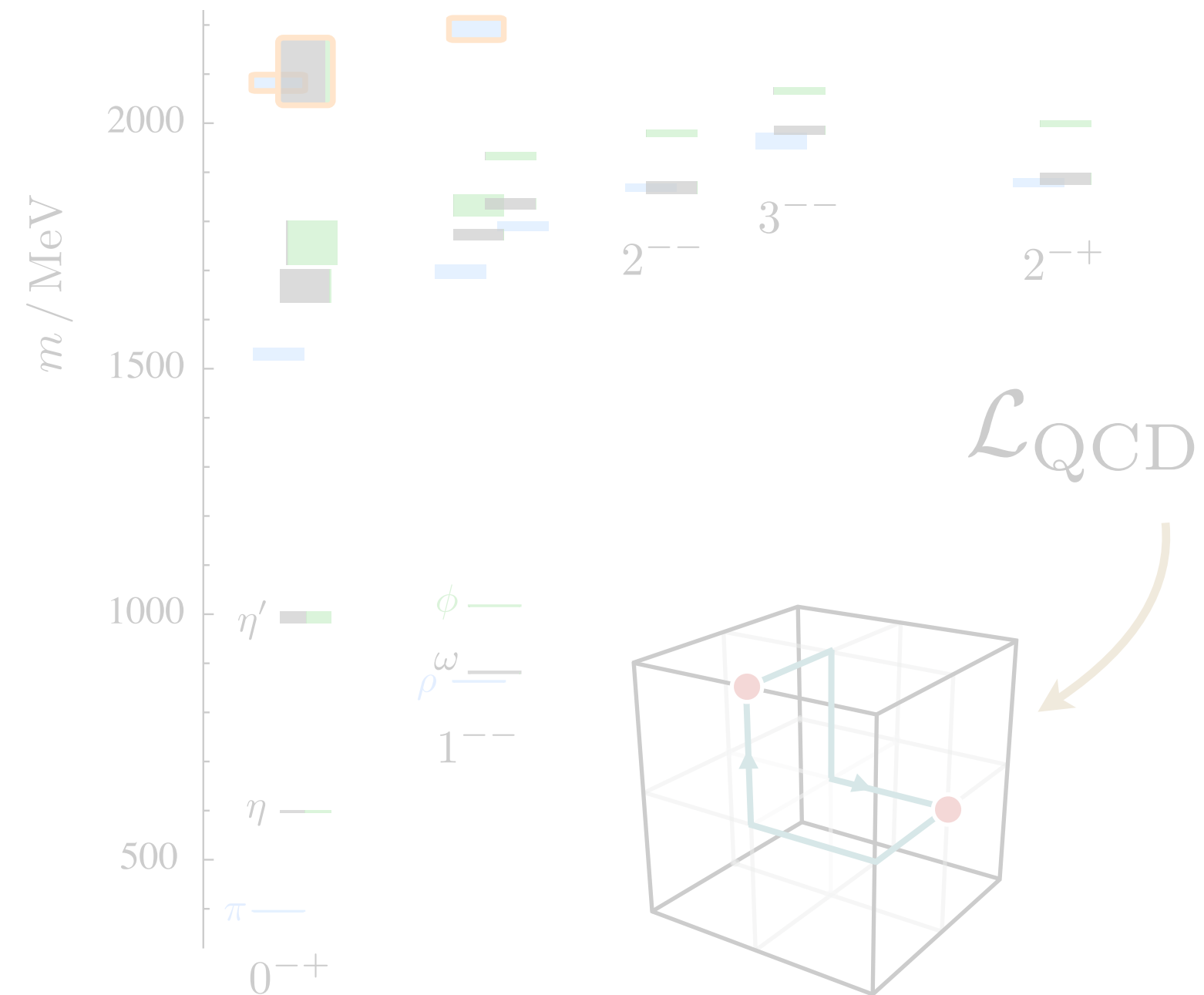
[Jinzi Wu](#)

George Washington University

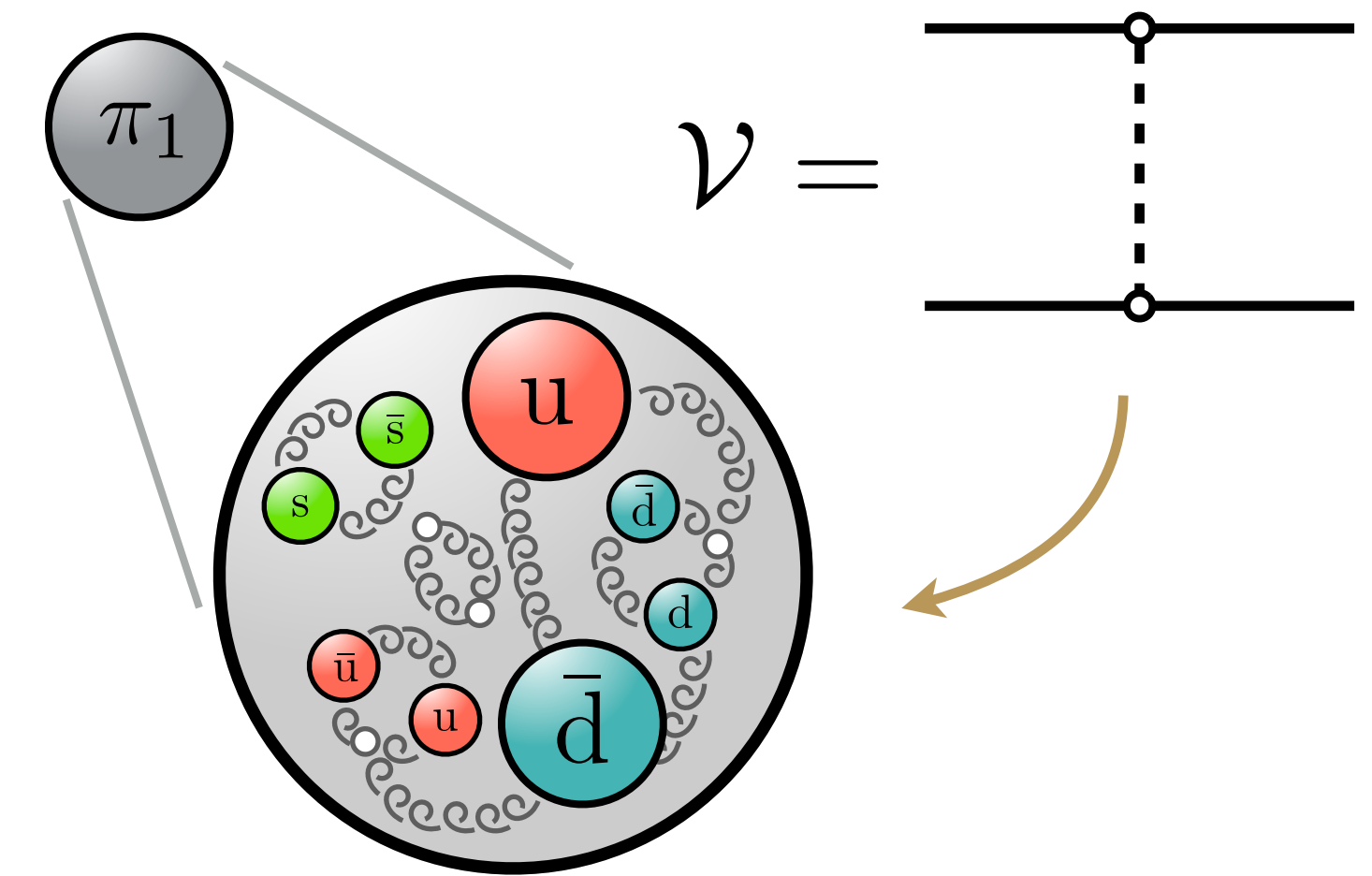
Amplitude Analysis



Lattice QCD

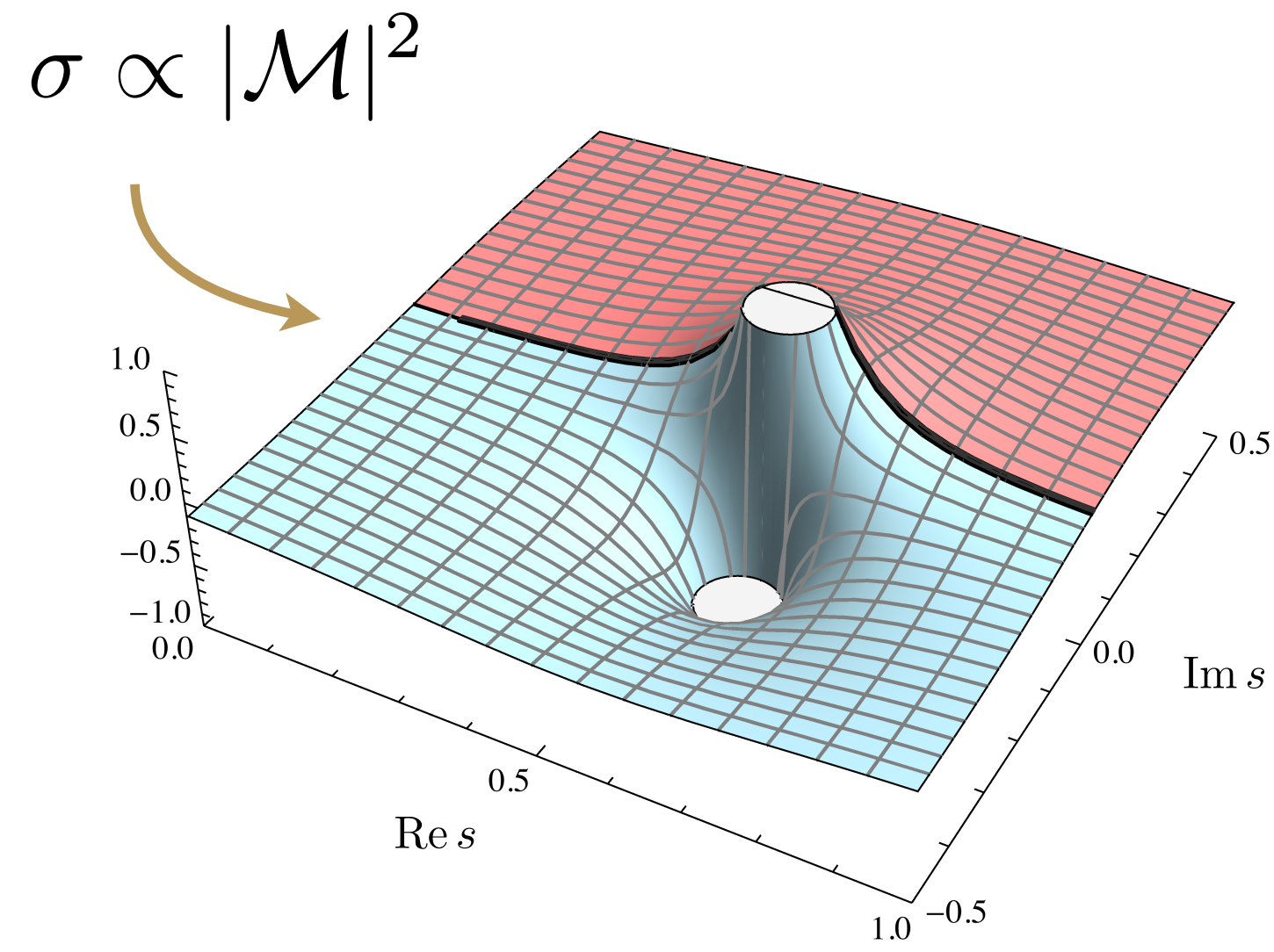


Phenomenology

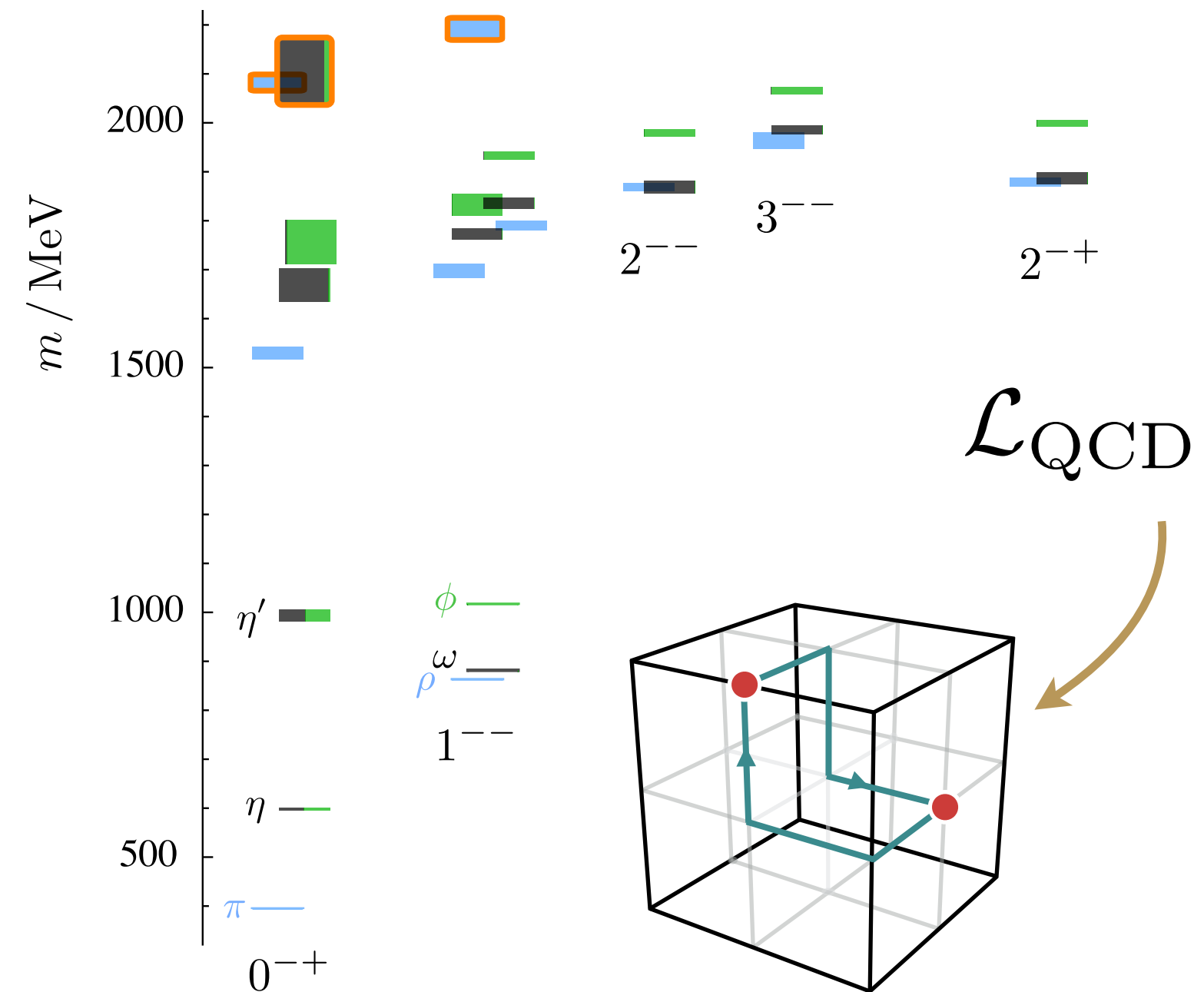


See J. Pickett, Fri. 2:20pm

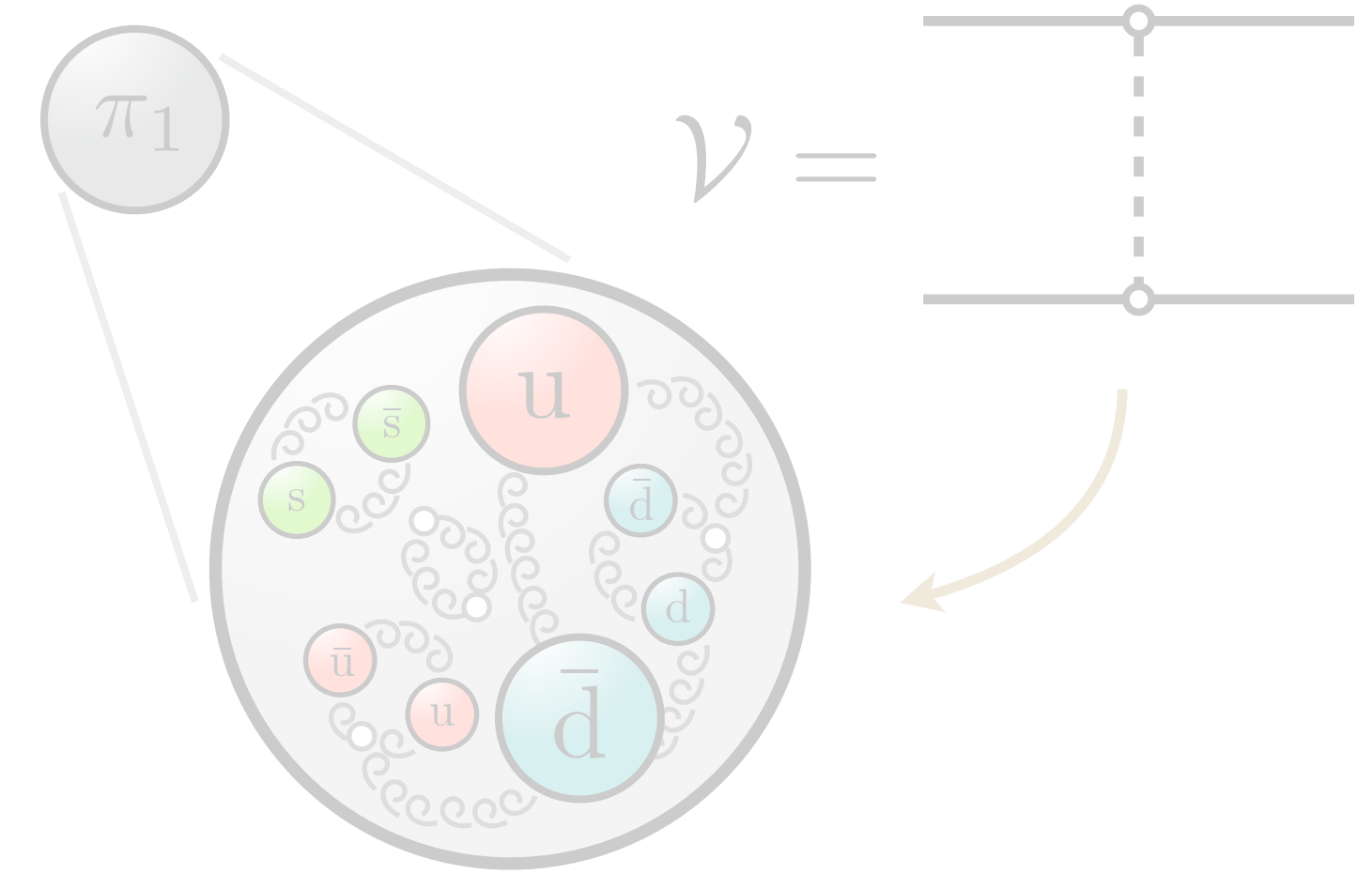
Amplitude Analysis



Lattice QCD



Phenomenology

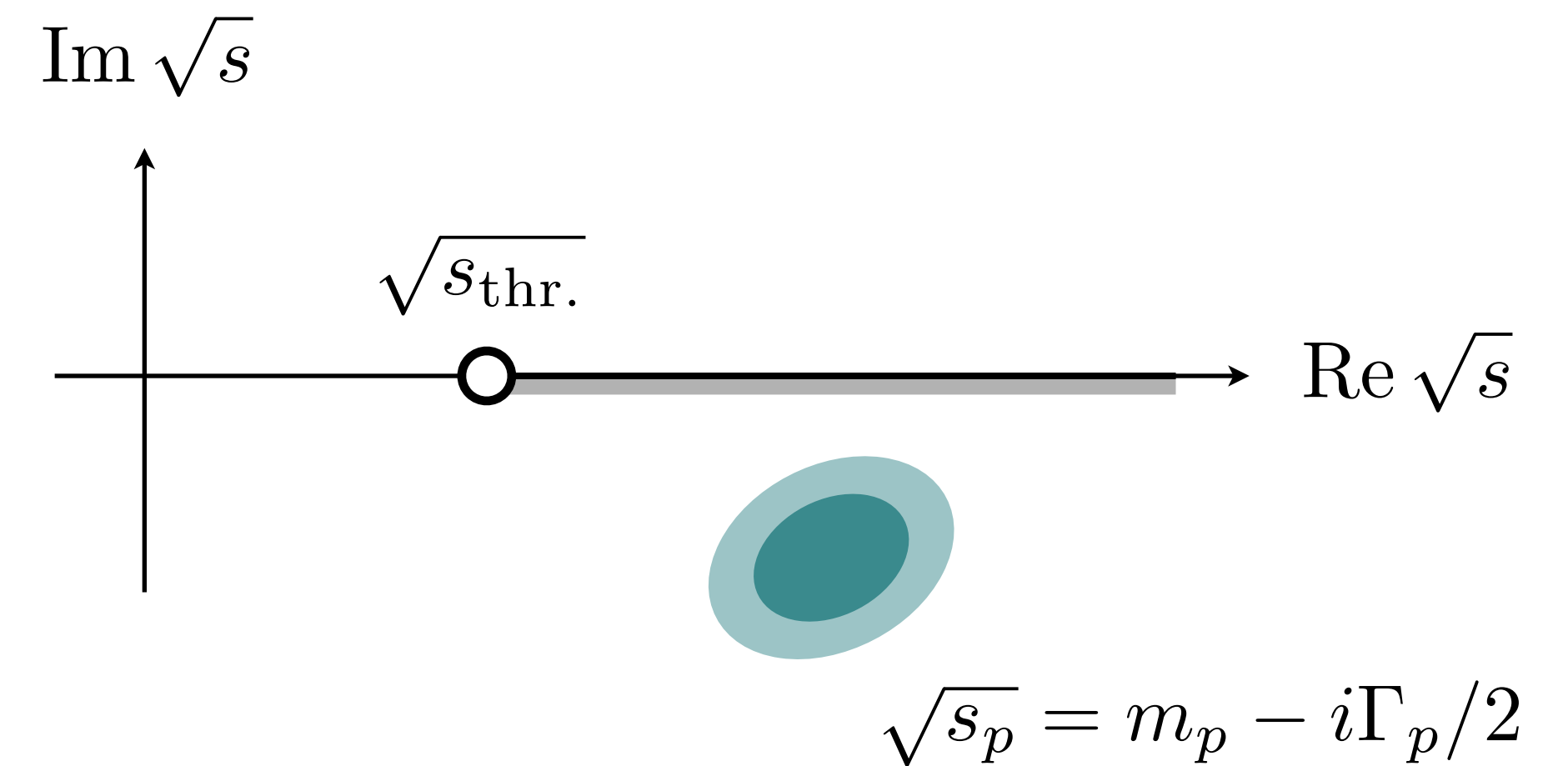
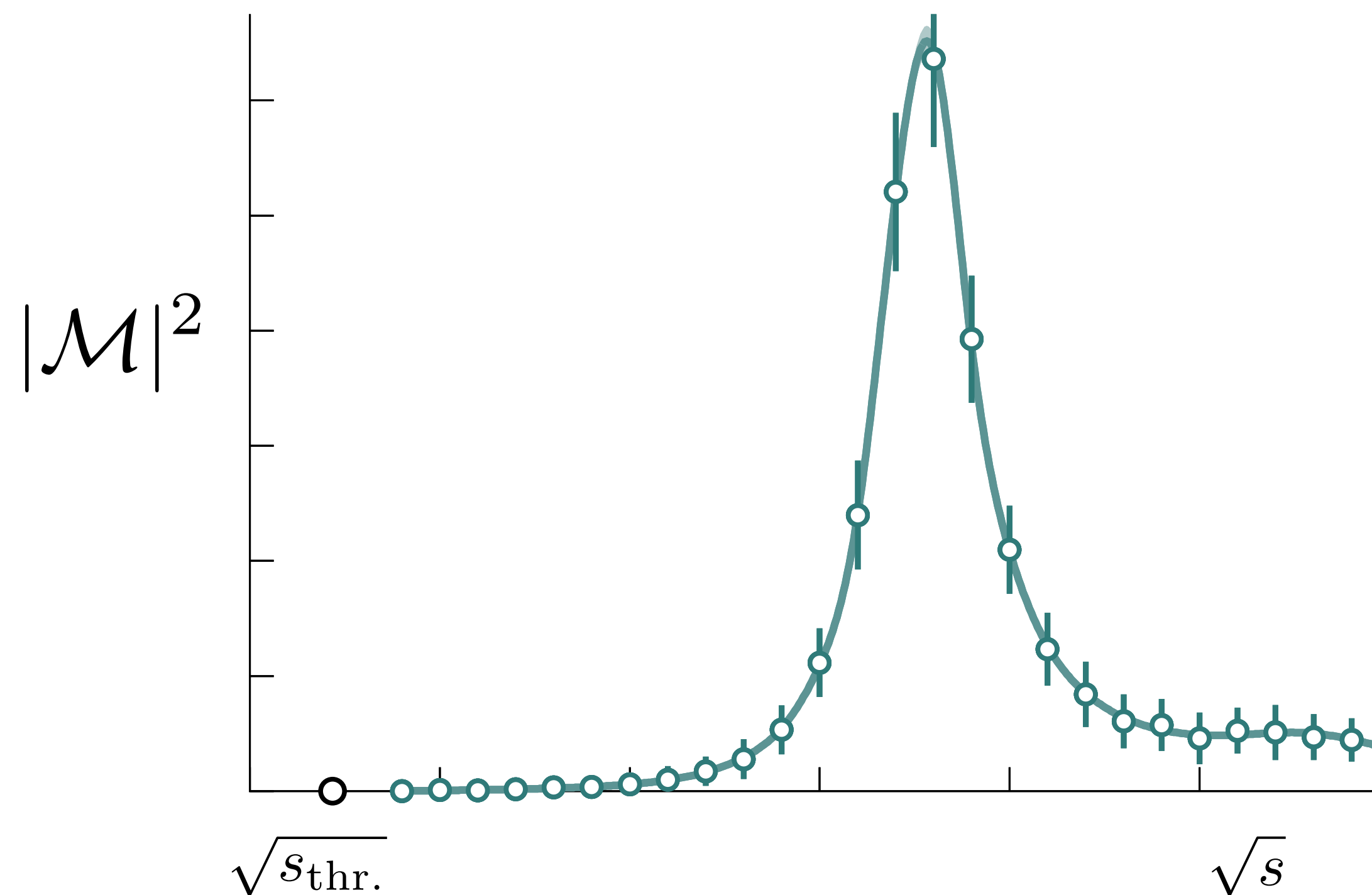


will showcase some works in this talk

Amplitude Analysis

Key concept — use fundamental S matrix principles to constrain amplitudes

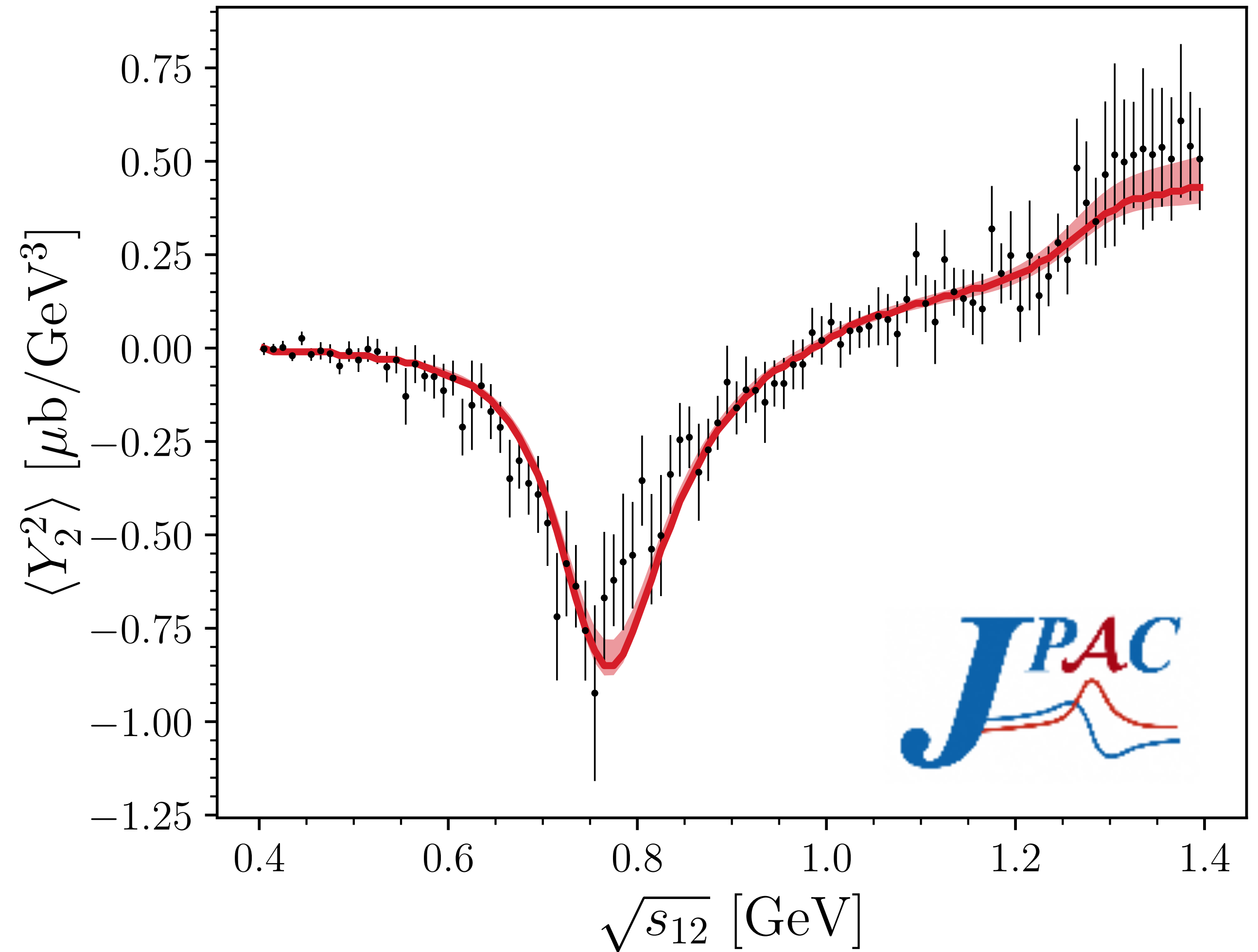
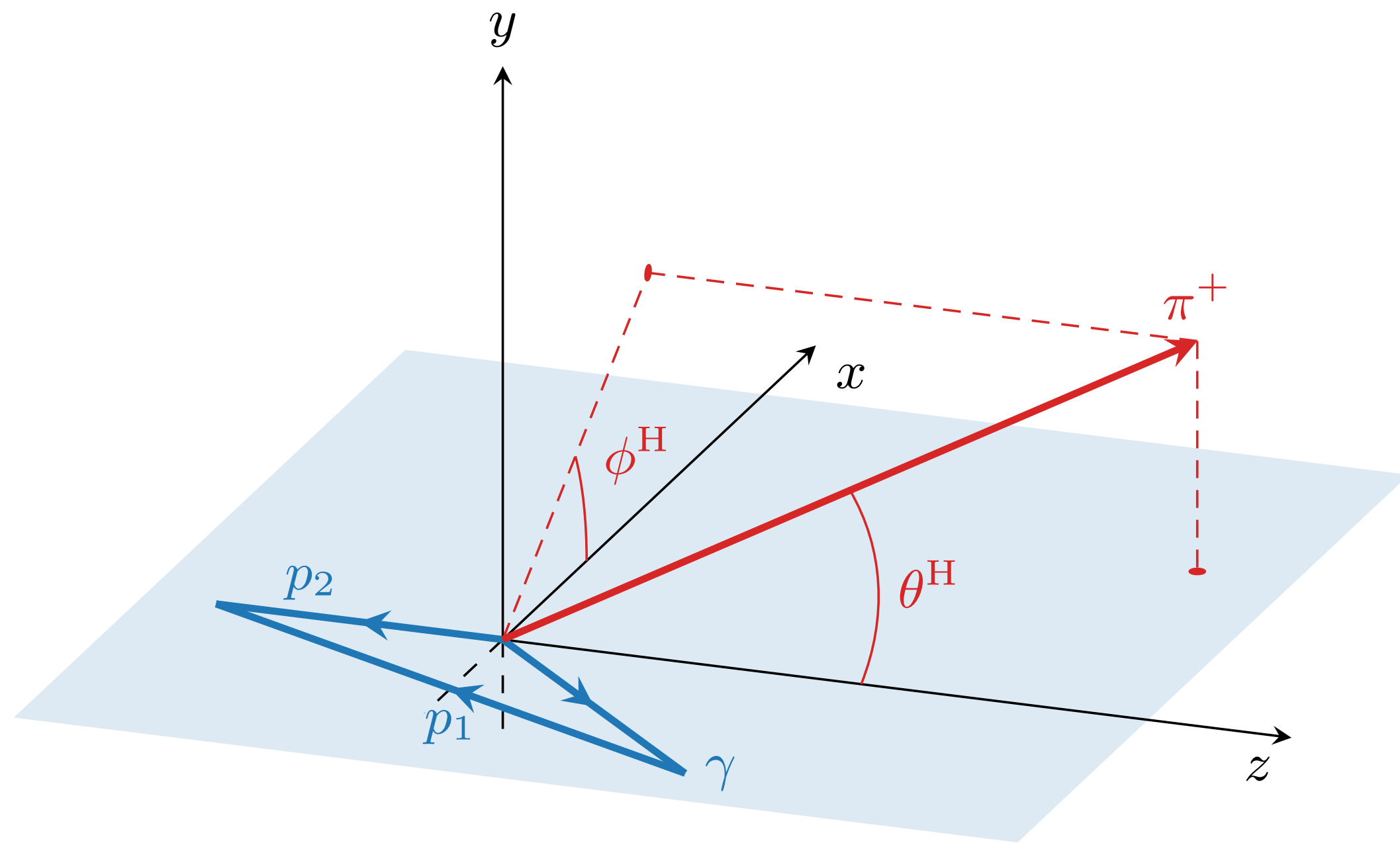
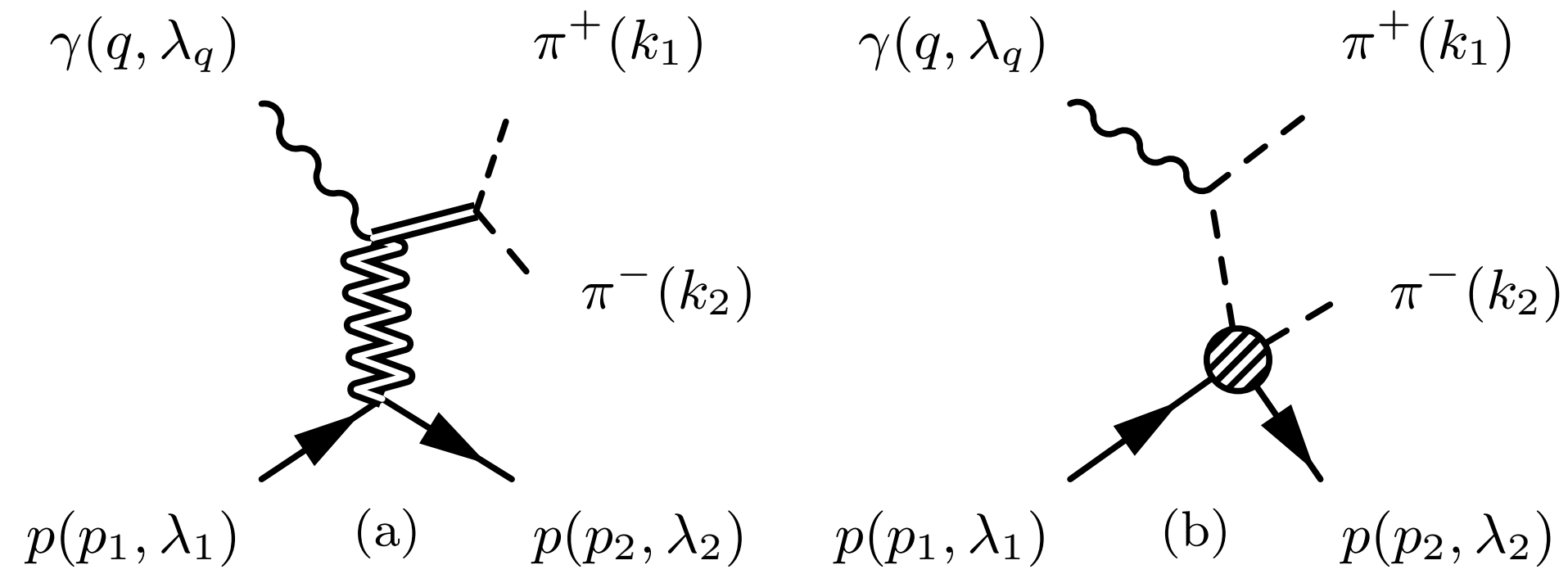
- Allows for unbiased amplitude construction
- Can determine spectrum via analytic continuation



$$\mathcal{M} = \mathcal{K} \frac{1}{1 - i\rho\mathcal{K}}$$

Amplitude Analysis

Photoproduction of $\pi^+\pi^-$ from CLAS data

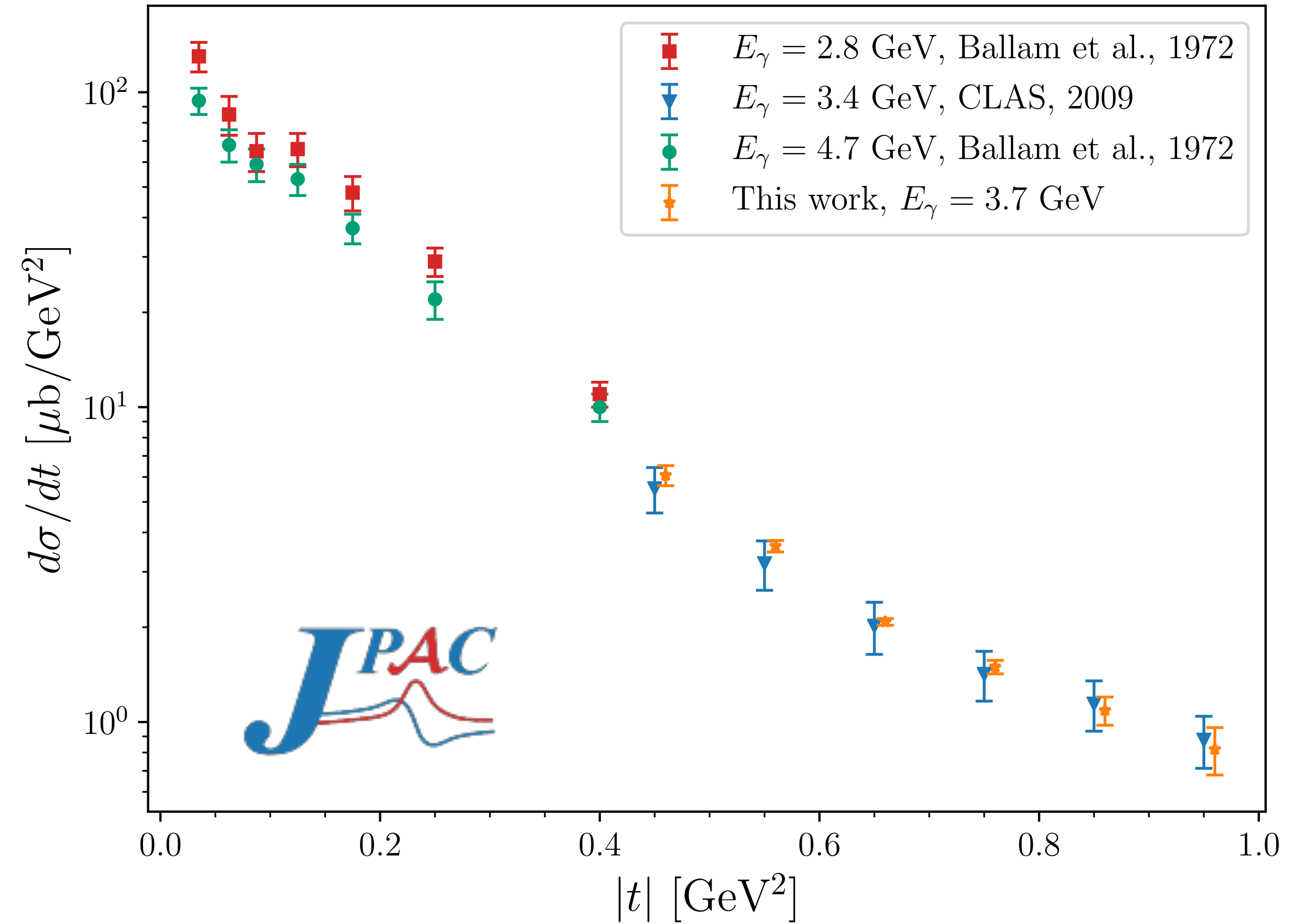
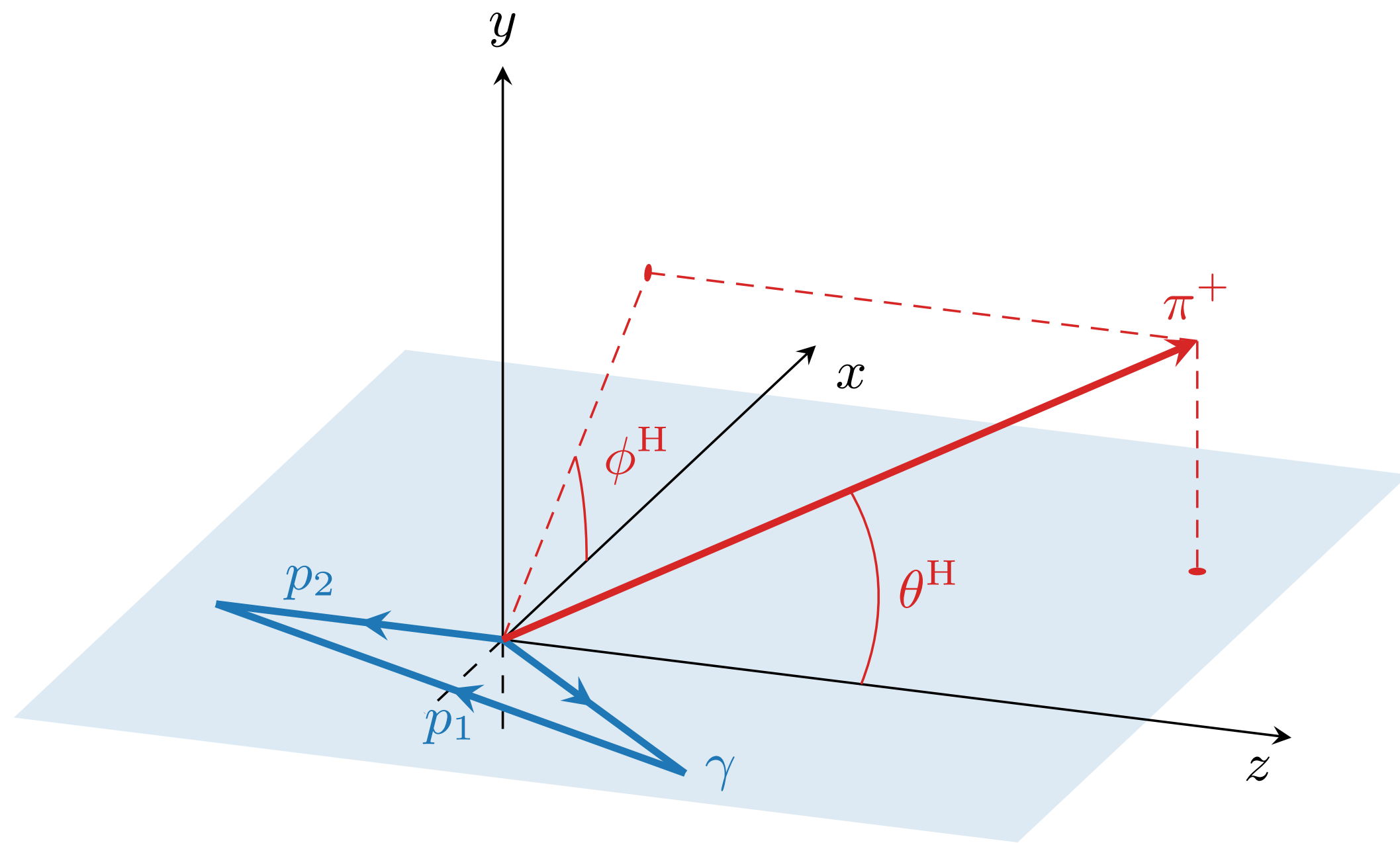
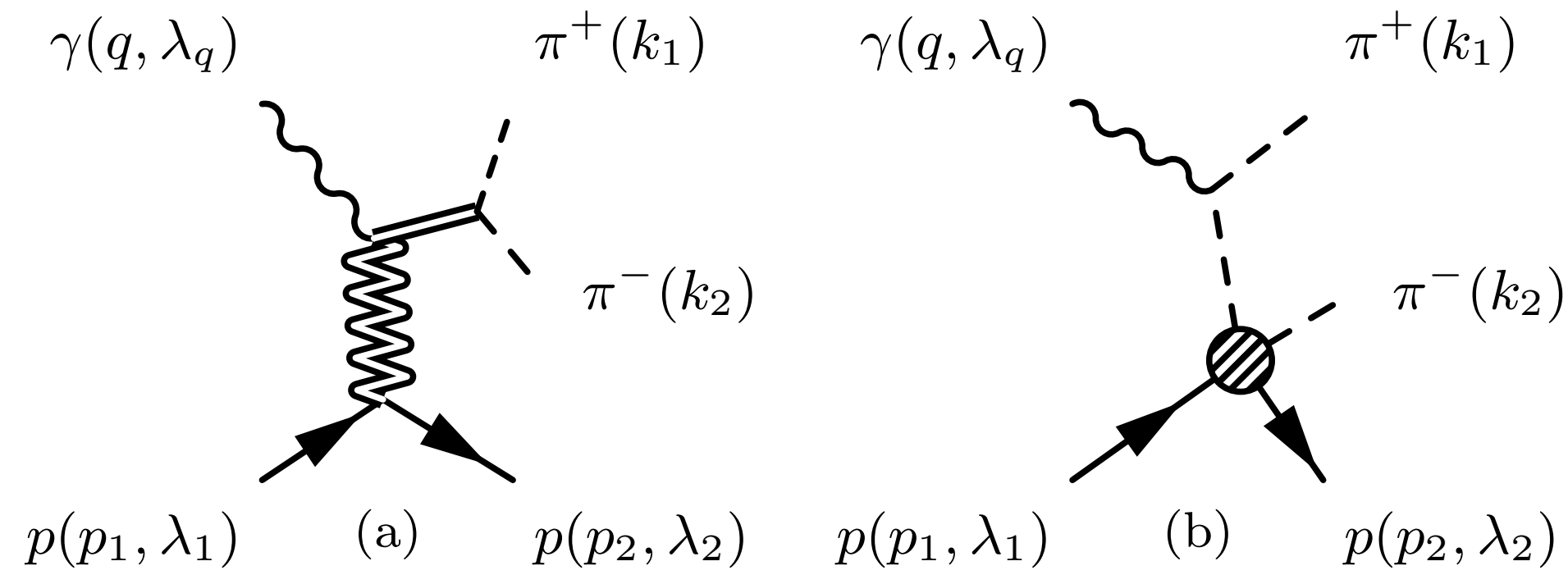


Ł. Bibrzycki et al.,
Phys. Rev. D **111** (2025) 014002

Amplitude Analysis

Photoproduction of $\pi^+\pi^-$ from CLAS data

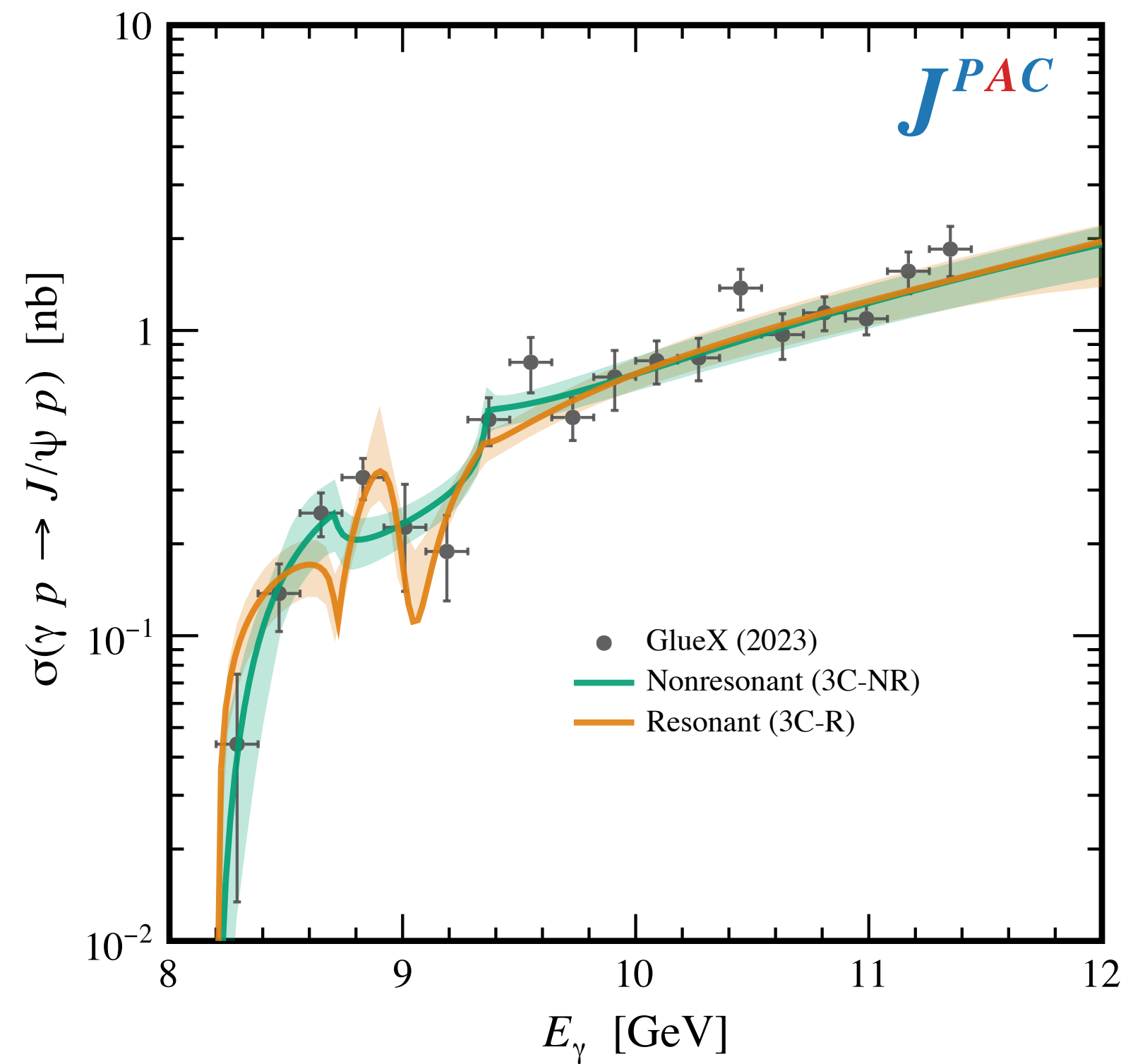
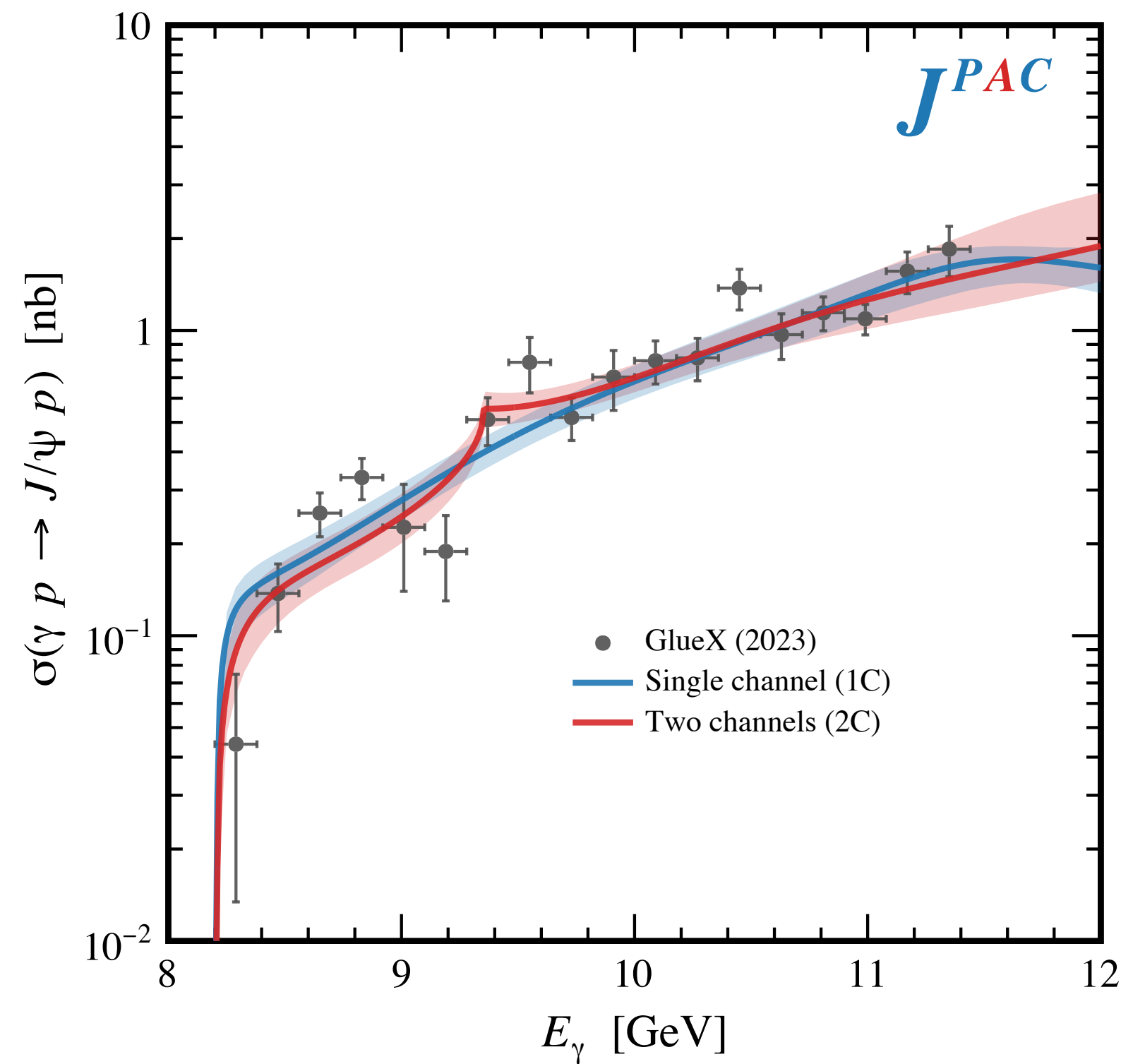
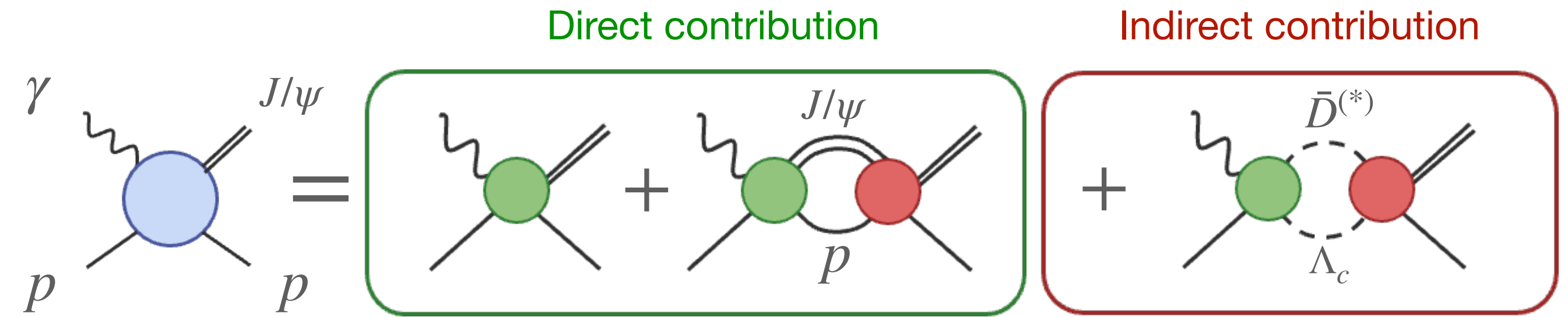
supports JLab experiments



Ł. Bibrzycki et al.,
Phys. Rev. D **111** (2025) 014002

Amplitude Analysis

Photoproduction of J/ψ at GlueX



D. Winney et al.,
Phys. Rev. D **108** (2023) 054018

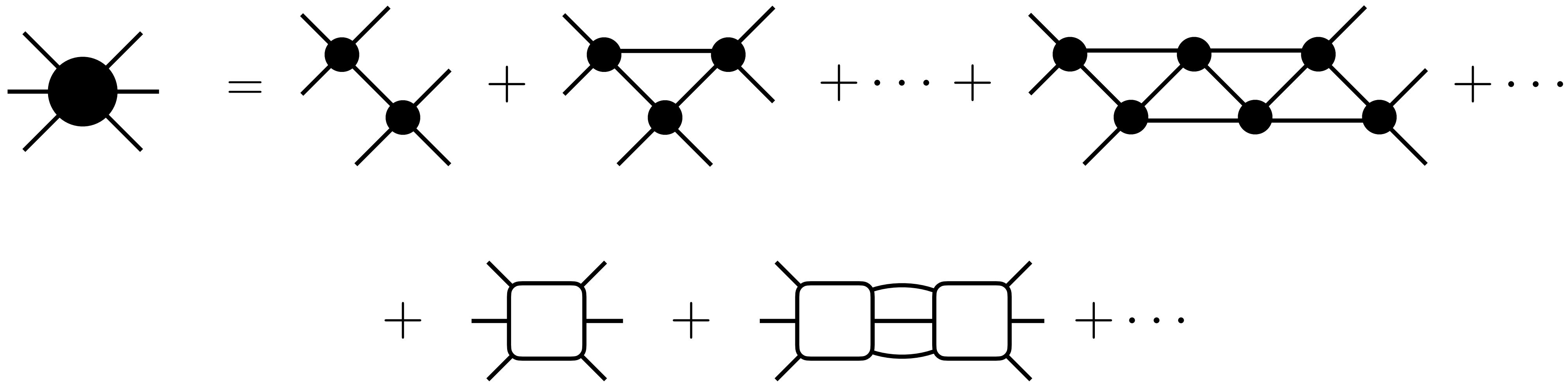
contribution of intermediate open-charm states is significant

Amplitude Analysis

Developing amplitude formalisms for three-body processes

$$\mathcal{M}_3 = \sum_{JP} \mathcal{M}_3^{JP} \mathcal{R}_{JP}$$

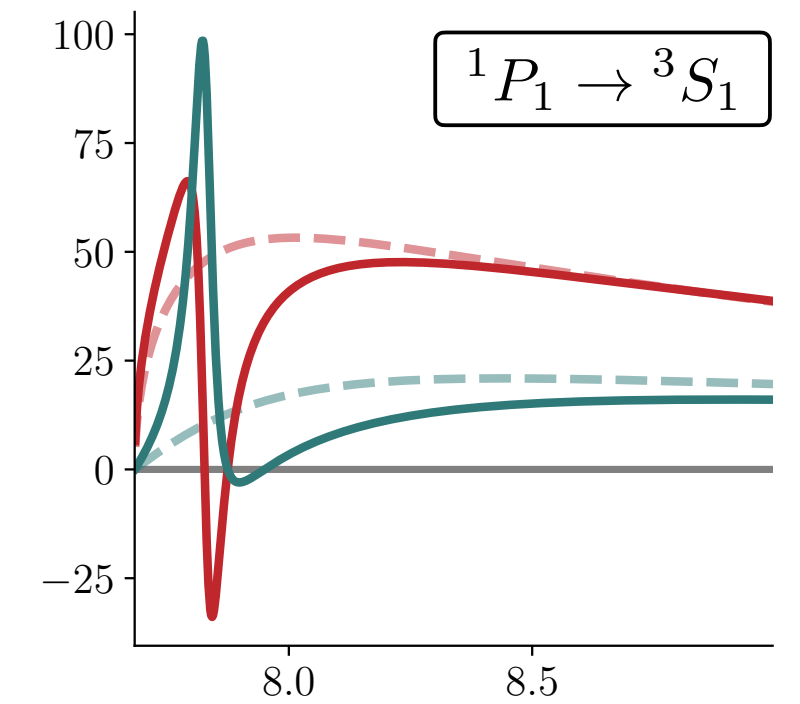
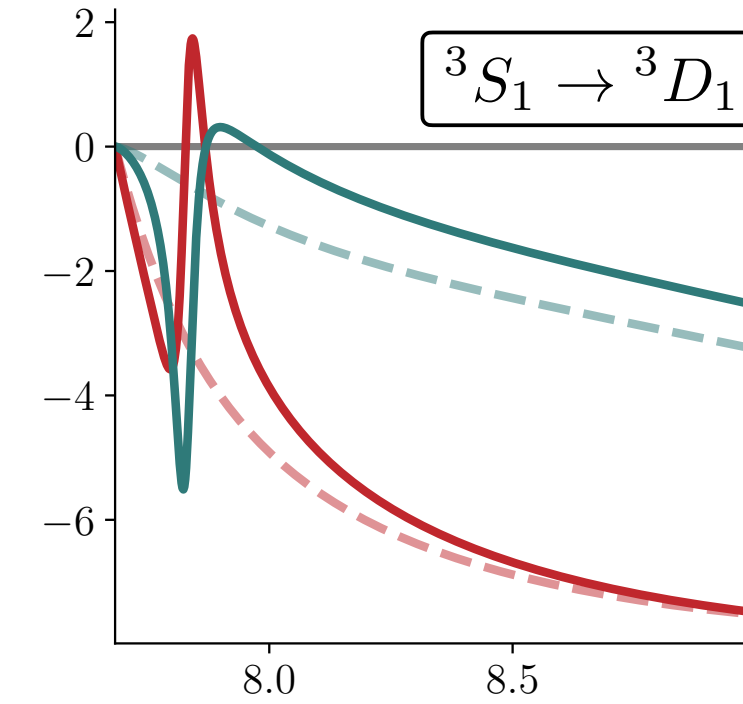
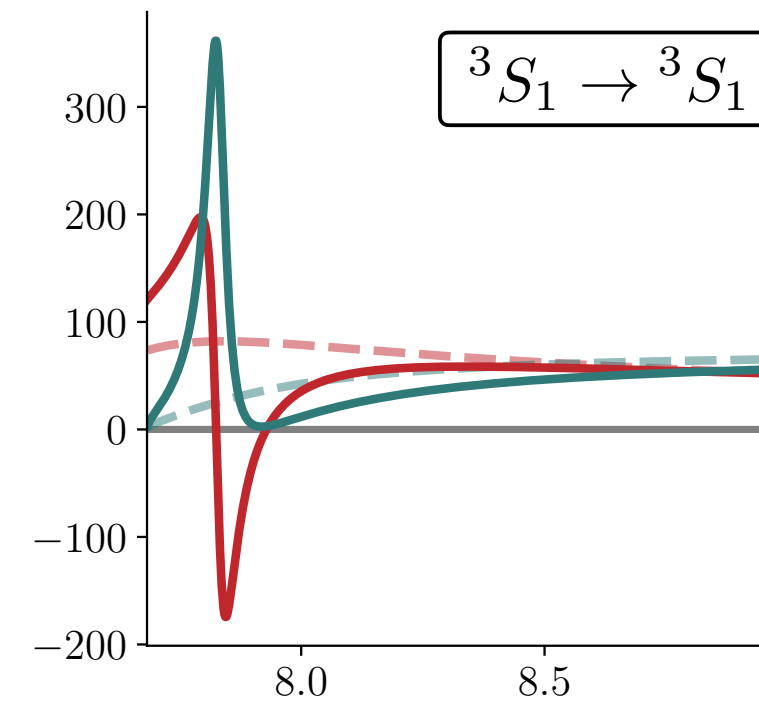
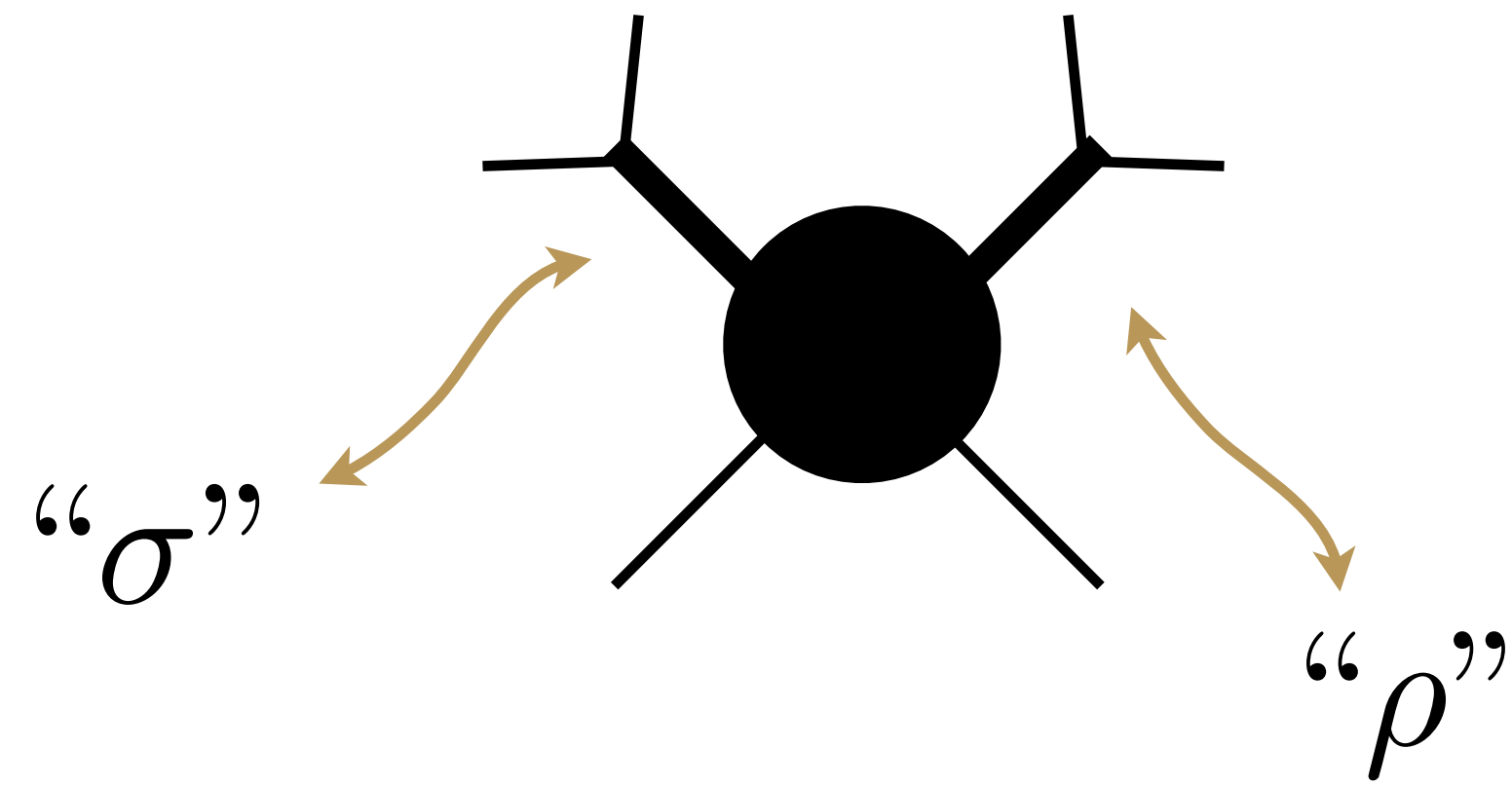
K matrix representation is set of integral equations



See M. Döring, Fri. 4:10pm

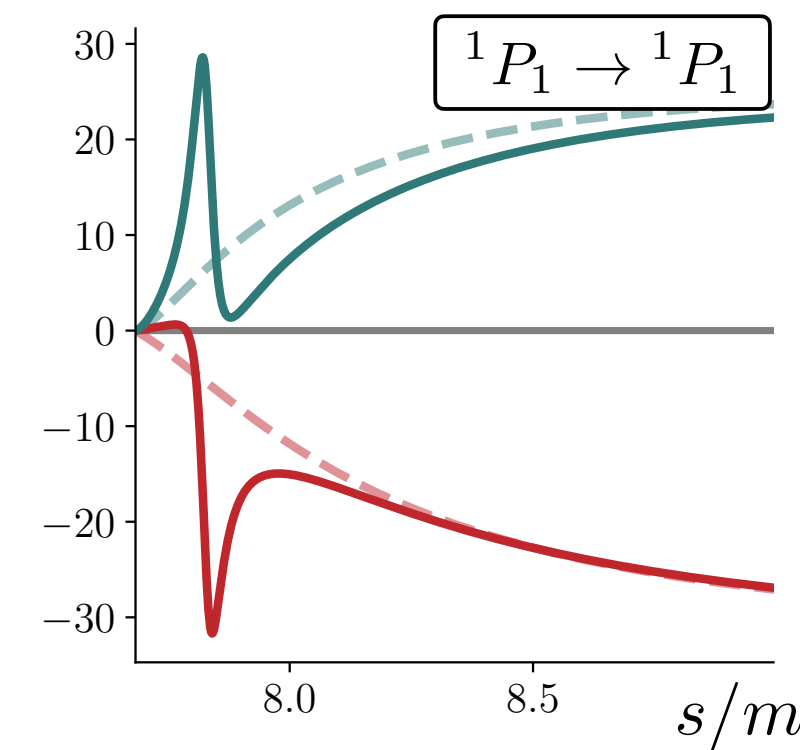
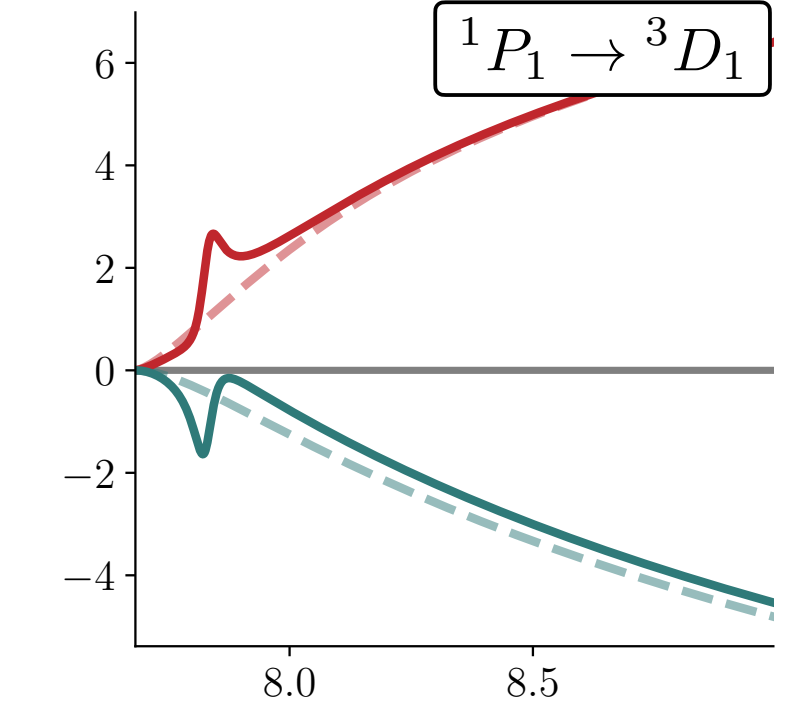
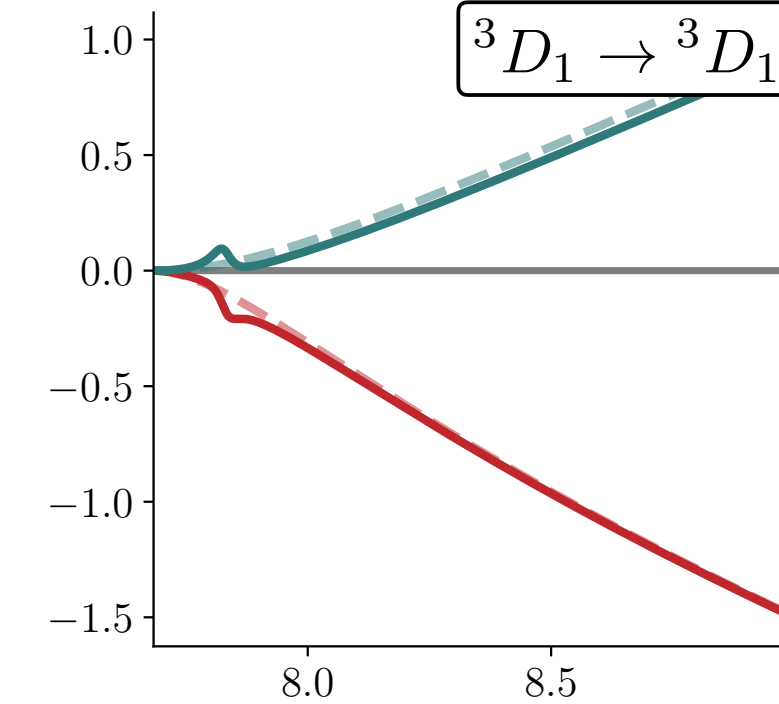
Amplitude Analysis

Developing amplitude formalisms for three-body processes



$$T(J^P) = 1(1^+)$$

— real
— imag



Testing frameworks for lattice QCD applications

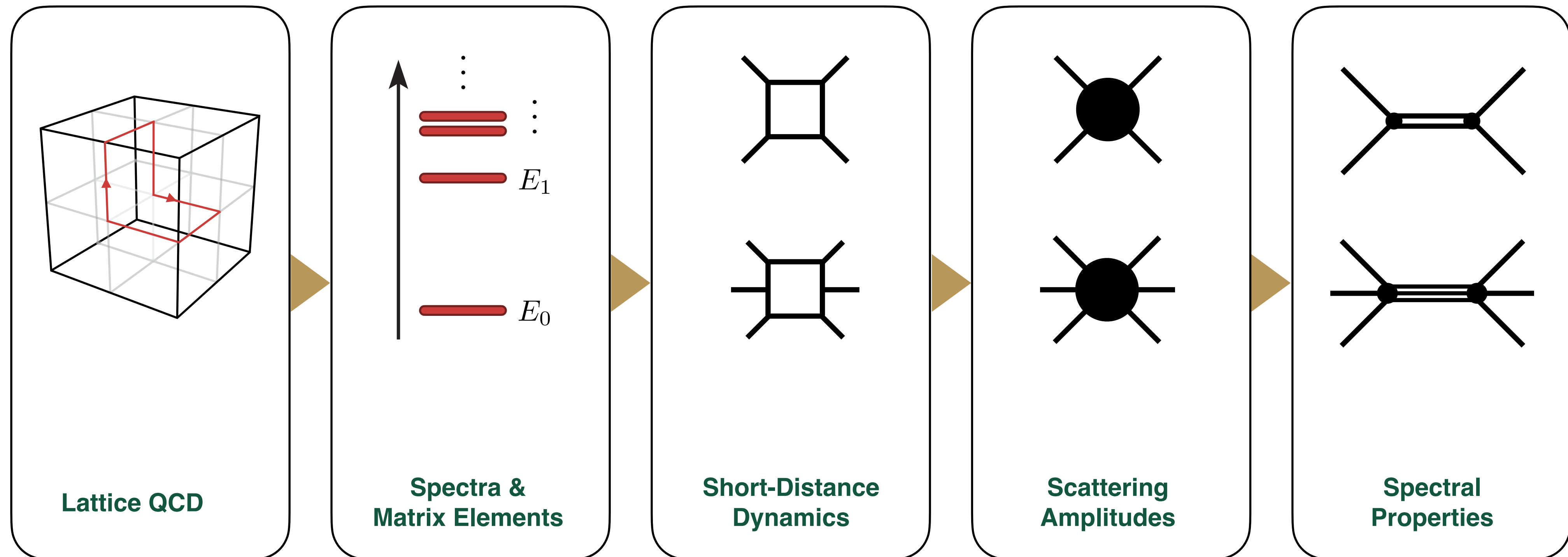
AJ and R. Briceño
Phys.Rev.D **109** (2024) 9, 096030

R. Briceño, C. Costa, AJ
Phys.Rev.D **111** (2025) 3, 036029

Lattice QCD

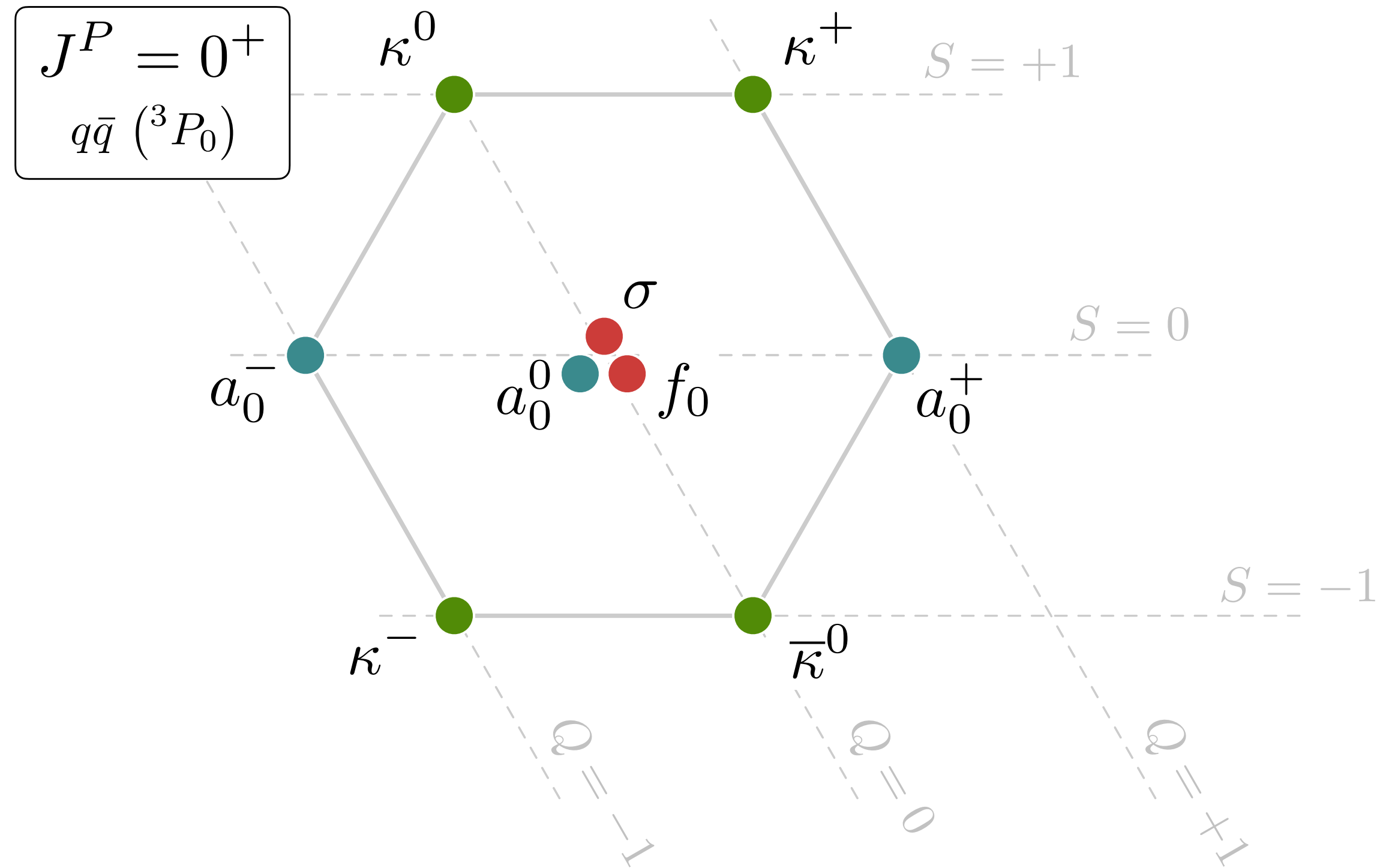
Numerical technique to systematically compute hadronic observables from QCD

$$\mathcal{L}_{\text{QCD}} = \sum_f \bar{\psi}_f (i\not{D} - m_f) \psi_f - \frac{1}{2} \text{tr} (\mathbf{G}_{\mu\nu} \mathbf{G}^{\mu\nu})$$

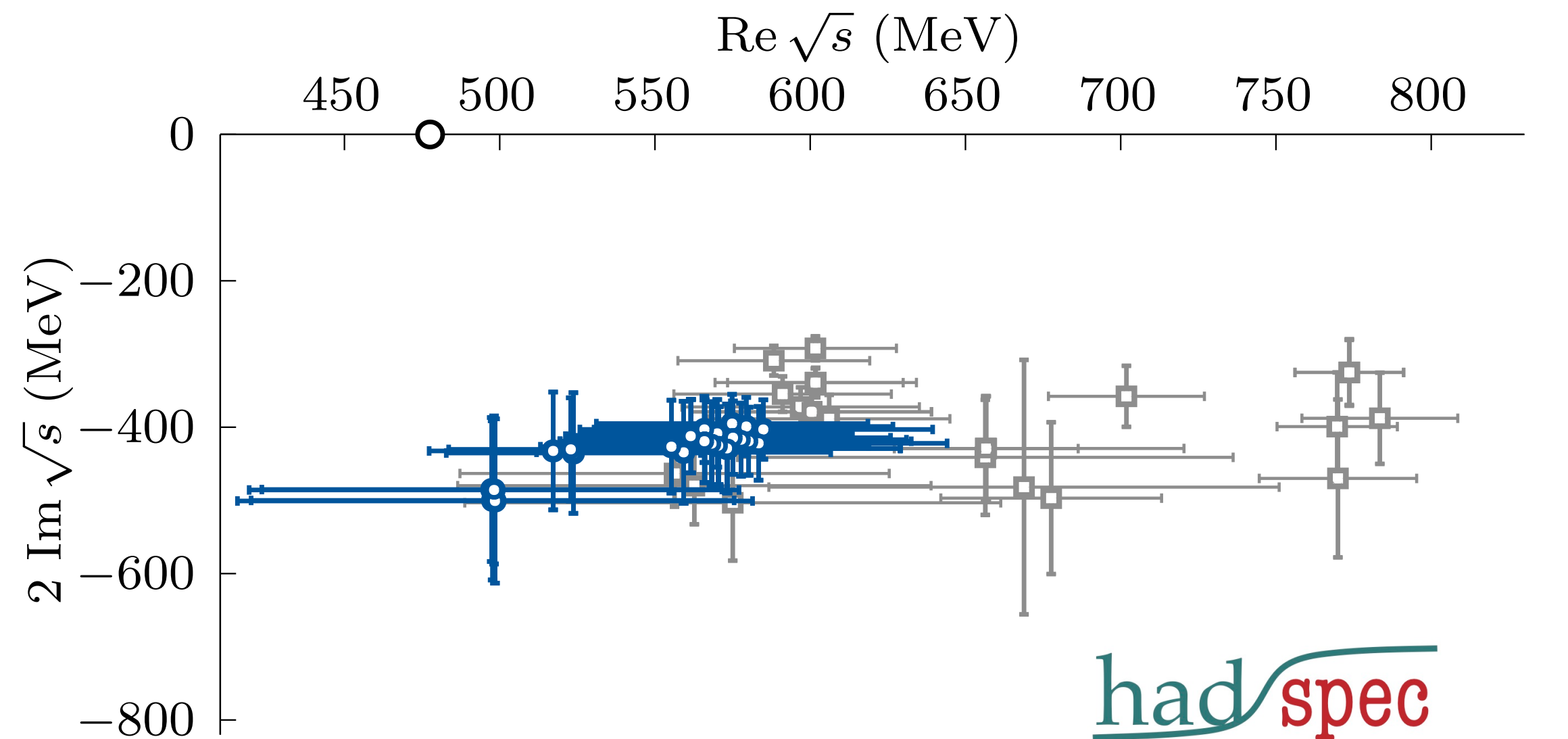
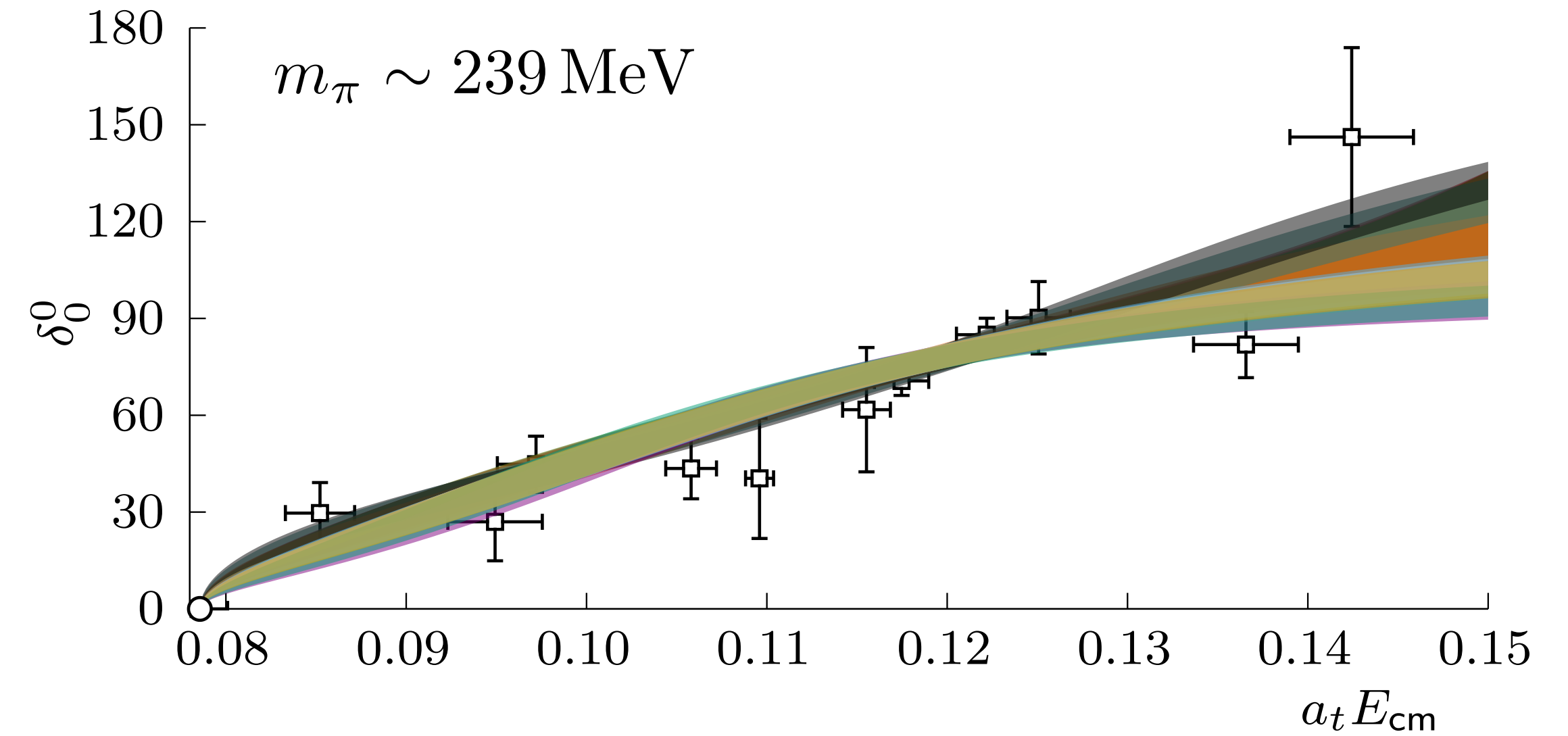


Lattice QCD

Scalar resonances and crossing constraints



$$\tilde{t}_\ell^I(s) = \tau_\ell^I(s) + \sum_{I', \ell'} \int_{4m_\pi^2}^{\infty} ds' K_{\ell\ell'}^{II'}(s', s) \text{Im} t_{\ell'}^{I'}(s')$$

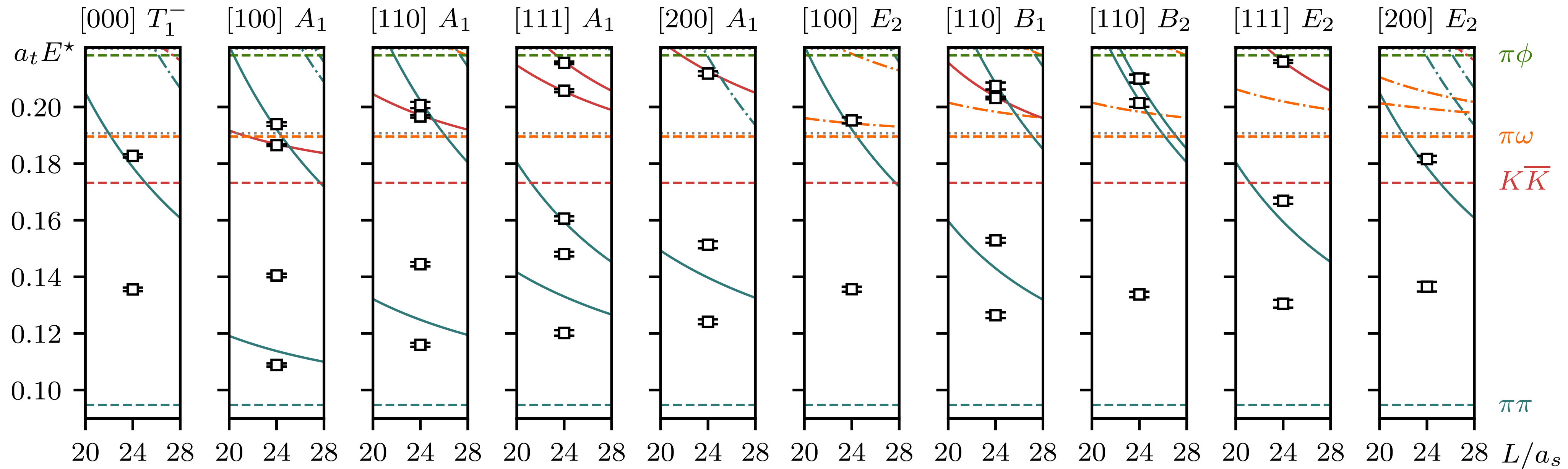
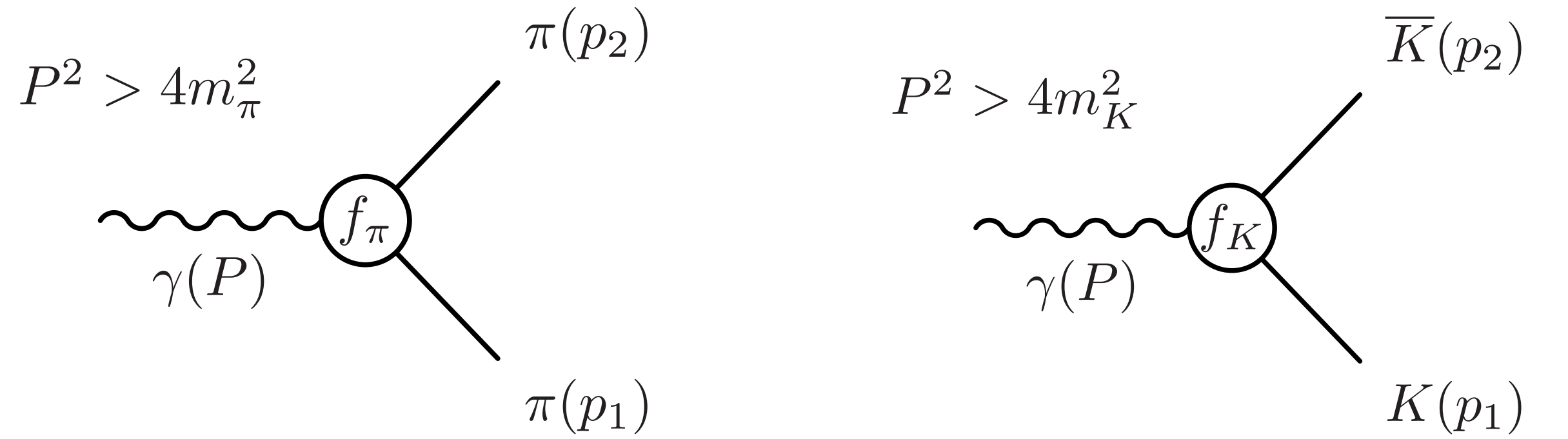


had spec

A. Rodas, J. Dudek, R. Edwards,
Phys. Rev. D **109** (2024) 3

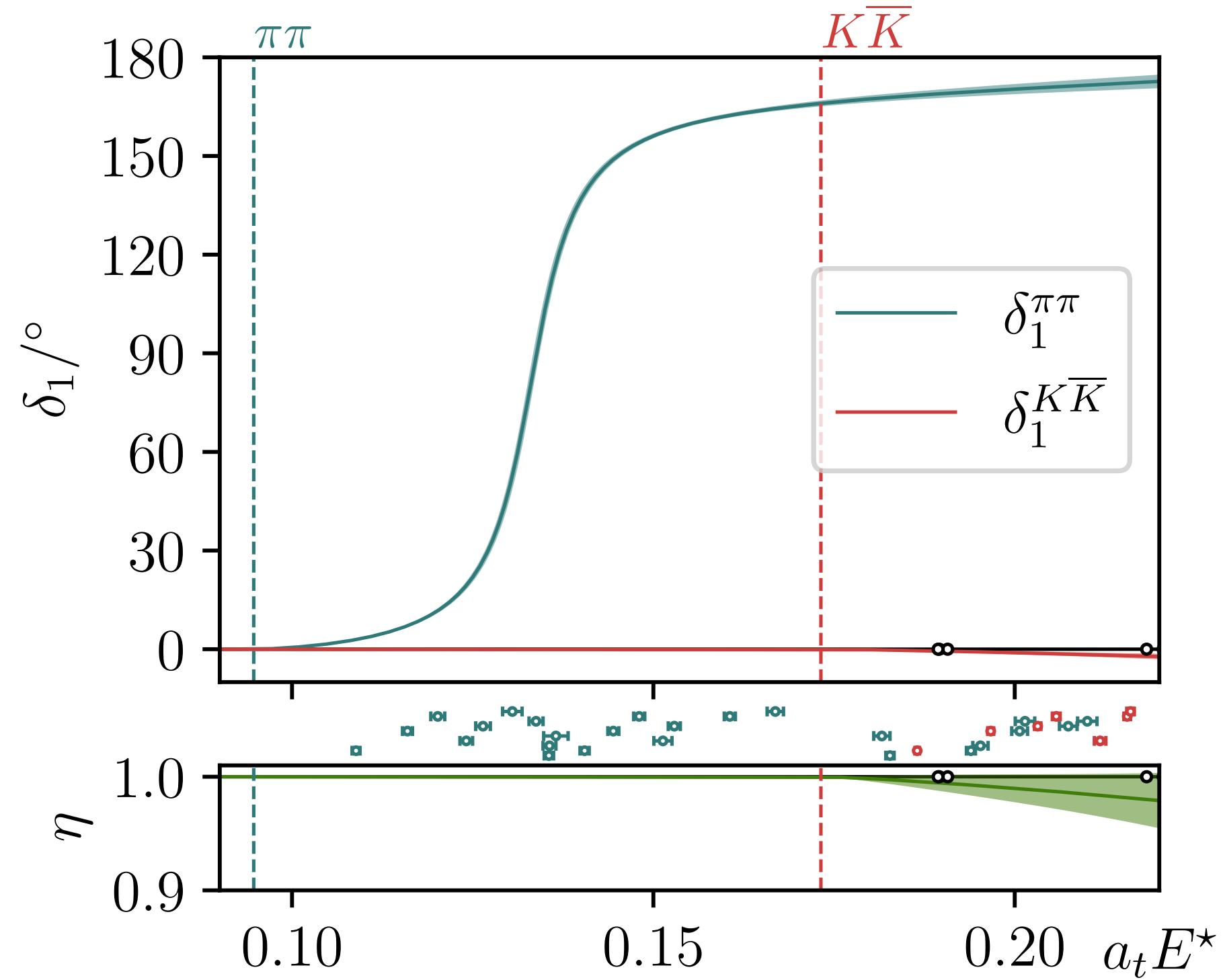
Lattice QCD

Pion/Kaon Vector Form-Factor

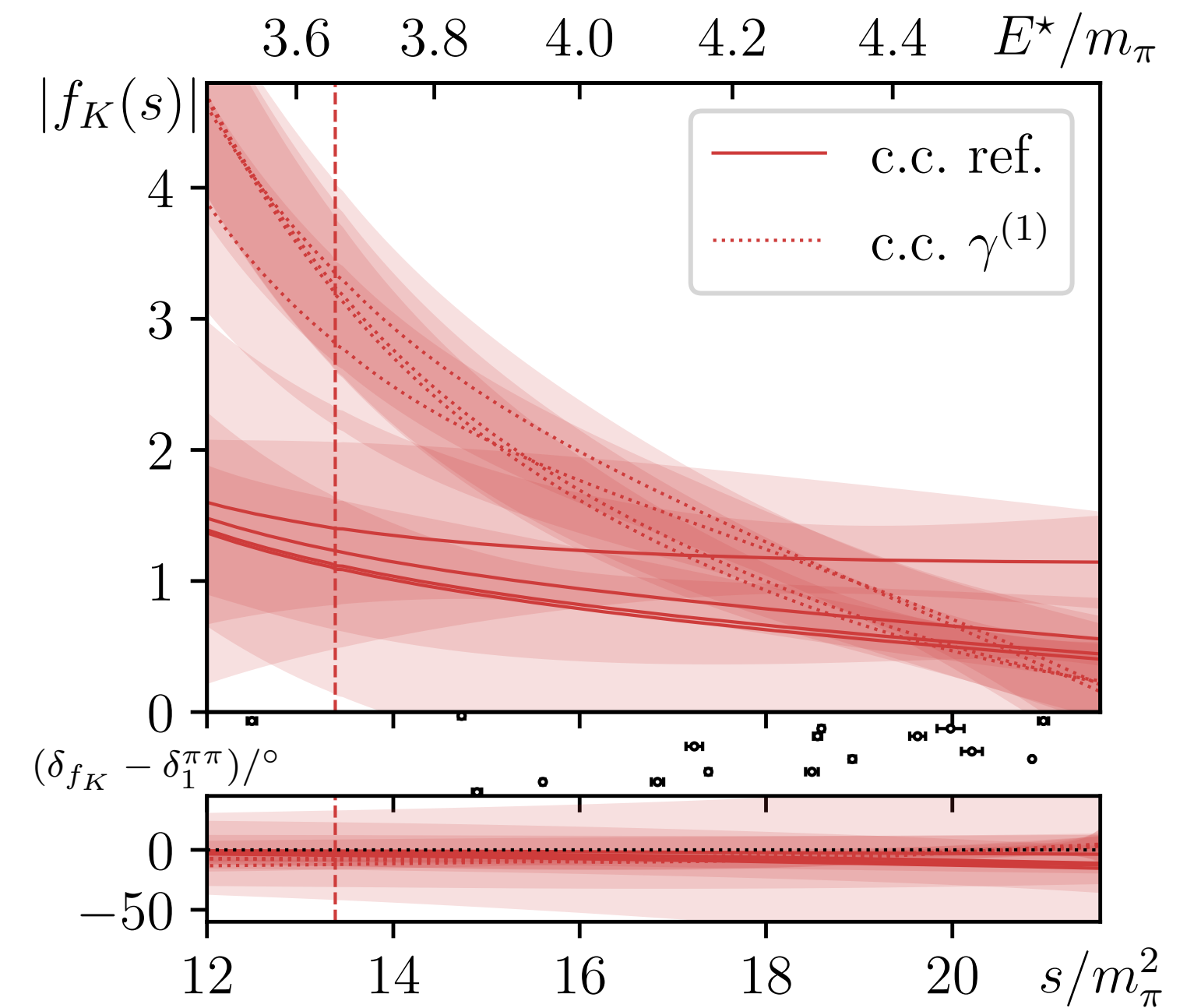
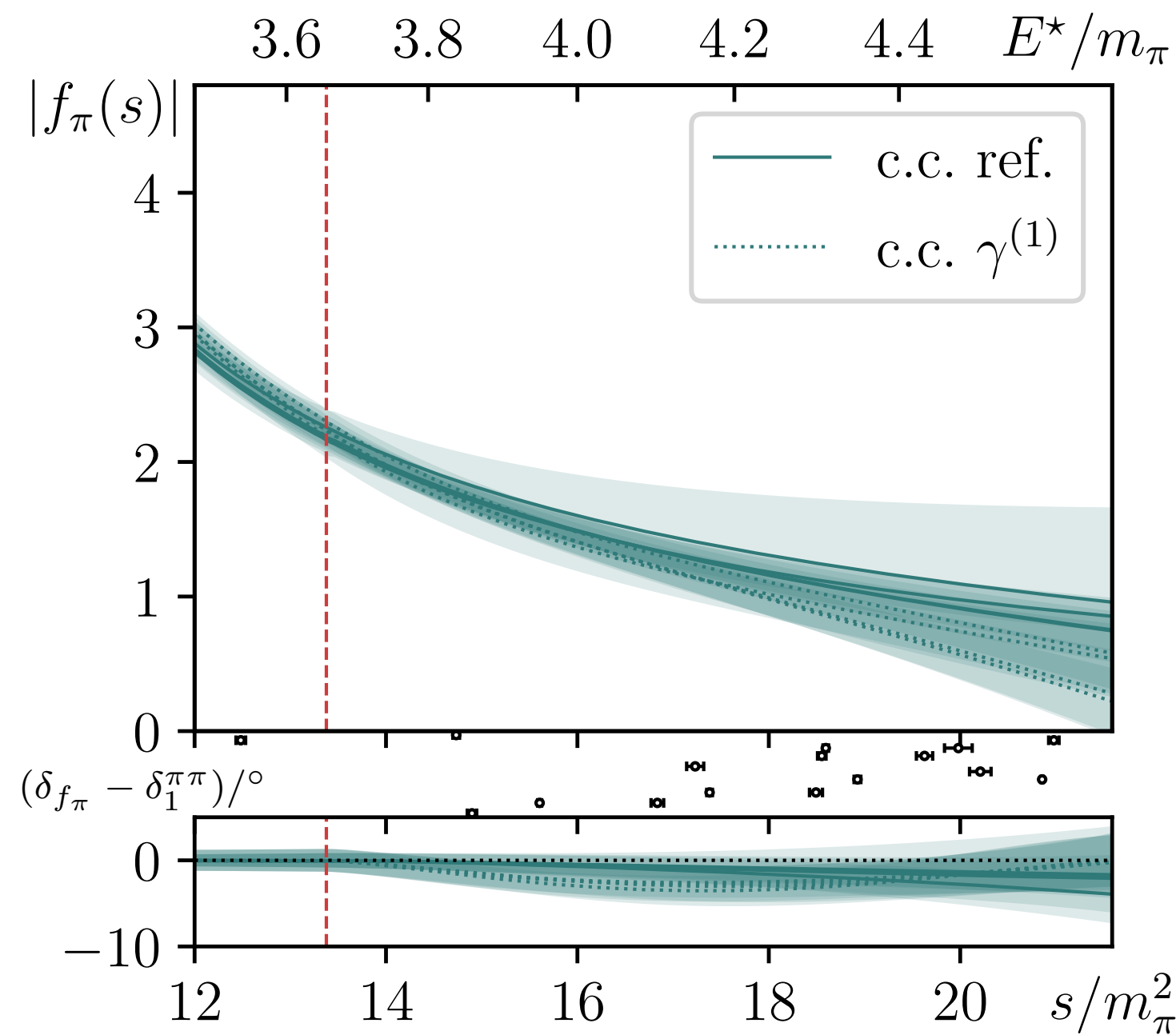
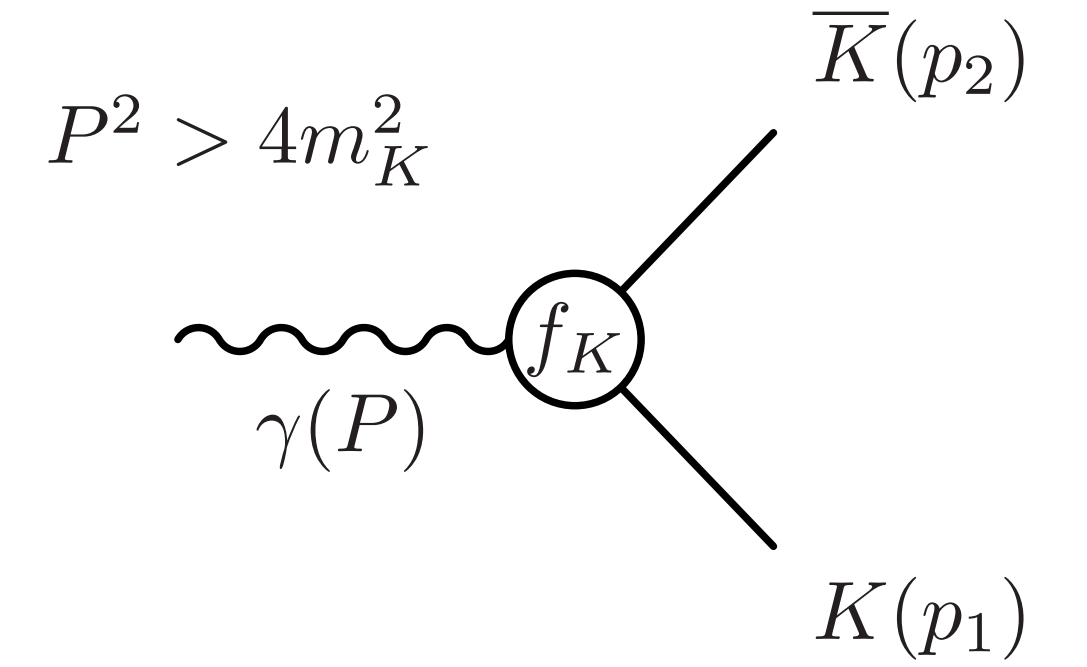
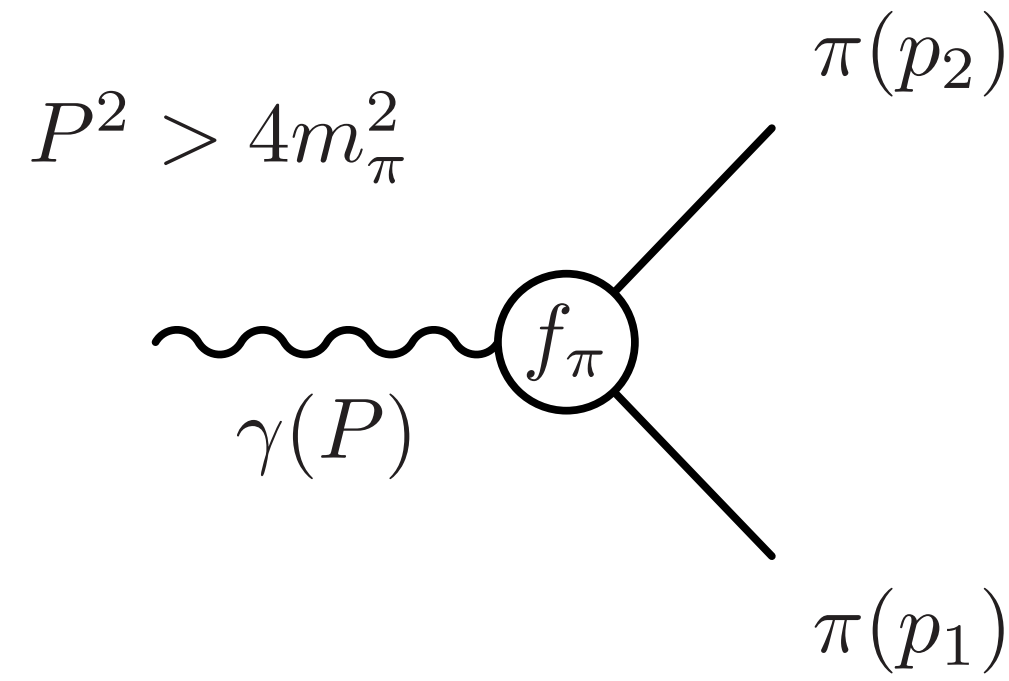


Lattice QCD

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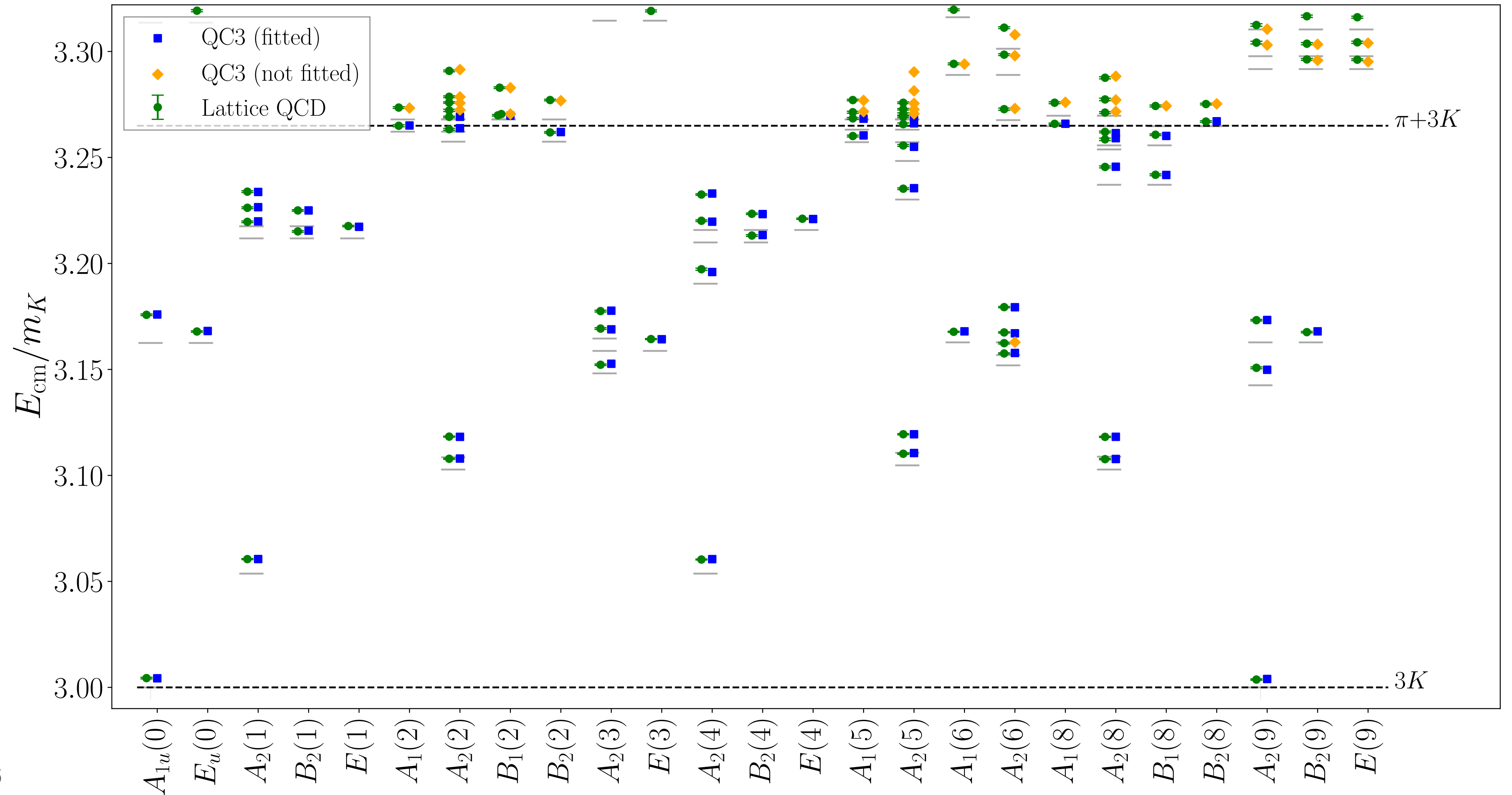


See F. Ortega-Gama, Sat. 5:00pm



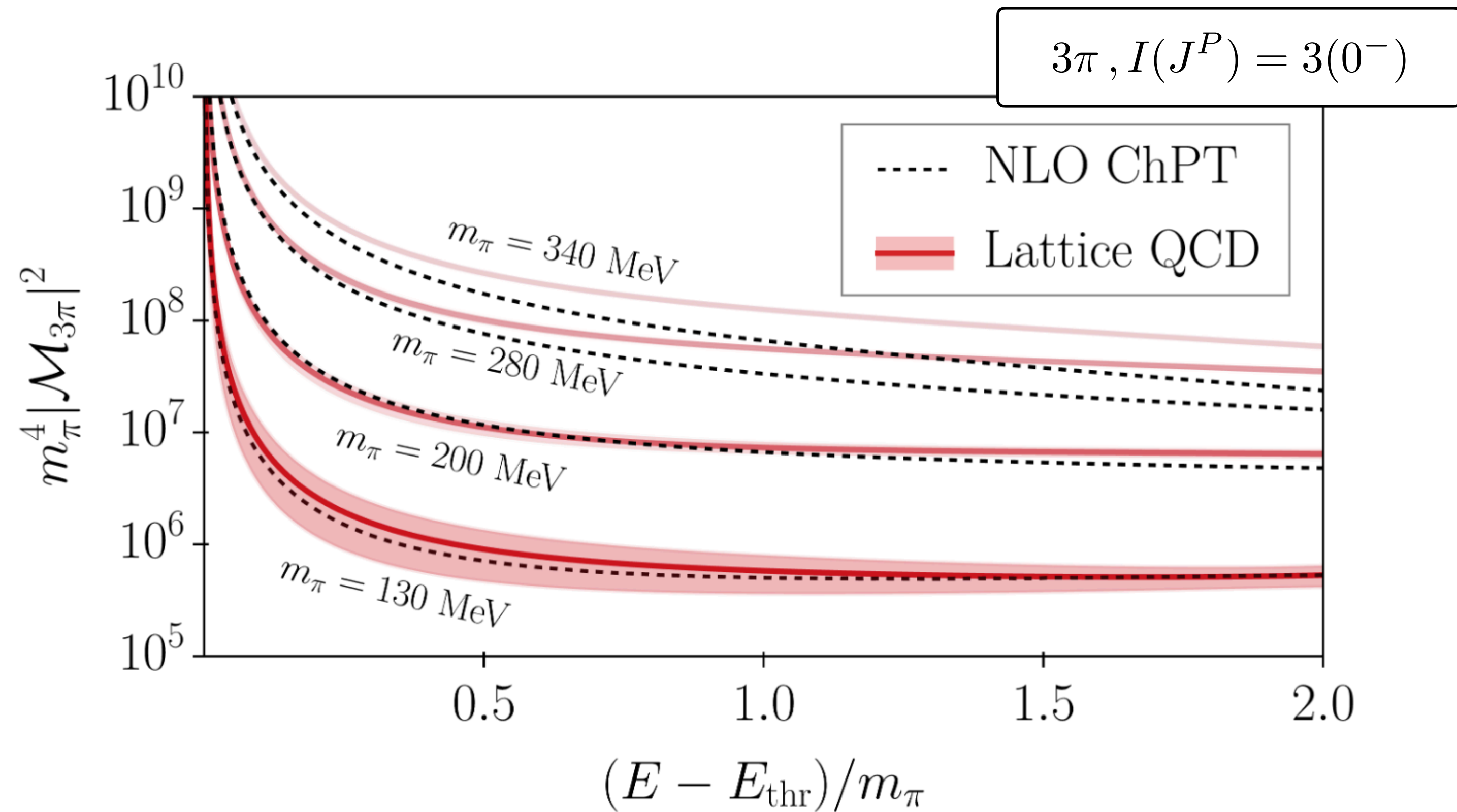
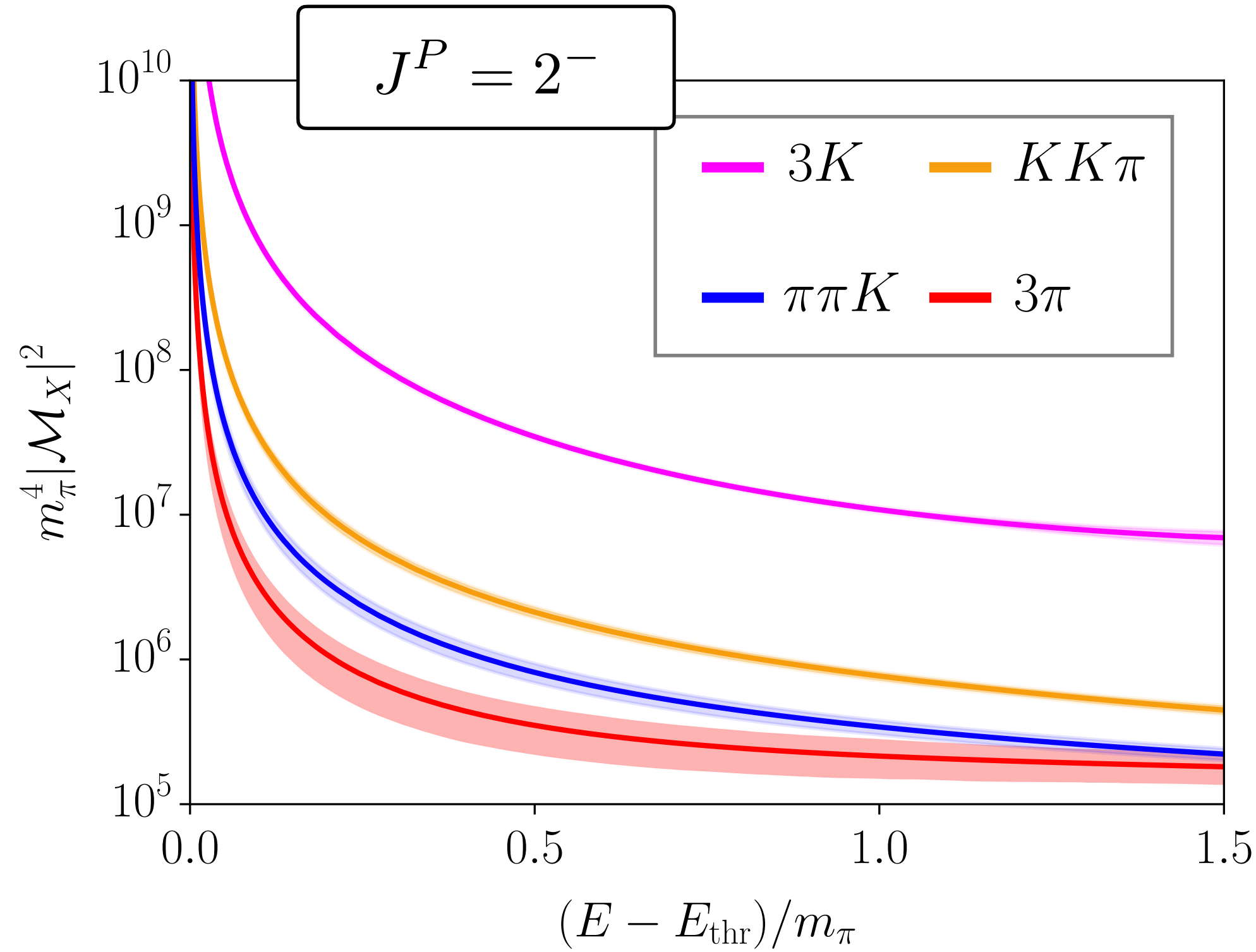
Lattice QCD

Three-body applications — $3\pi^+, 3K^+, \pi^+\pi^+K^+, K^+K^+\pi^+$



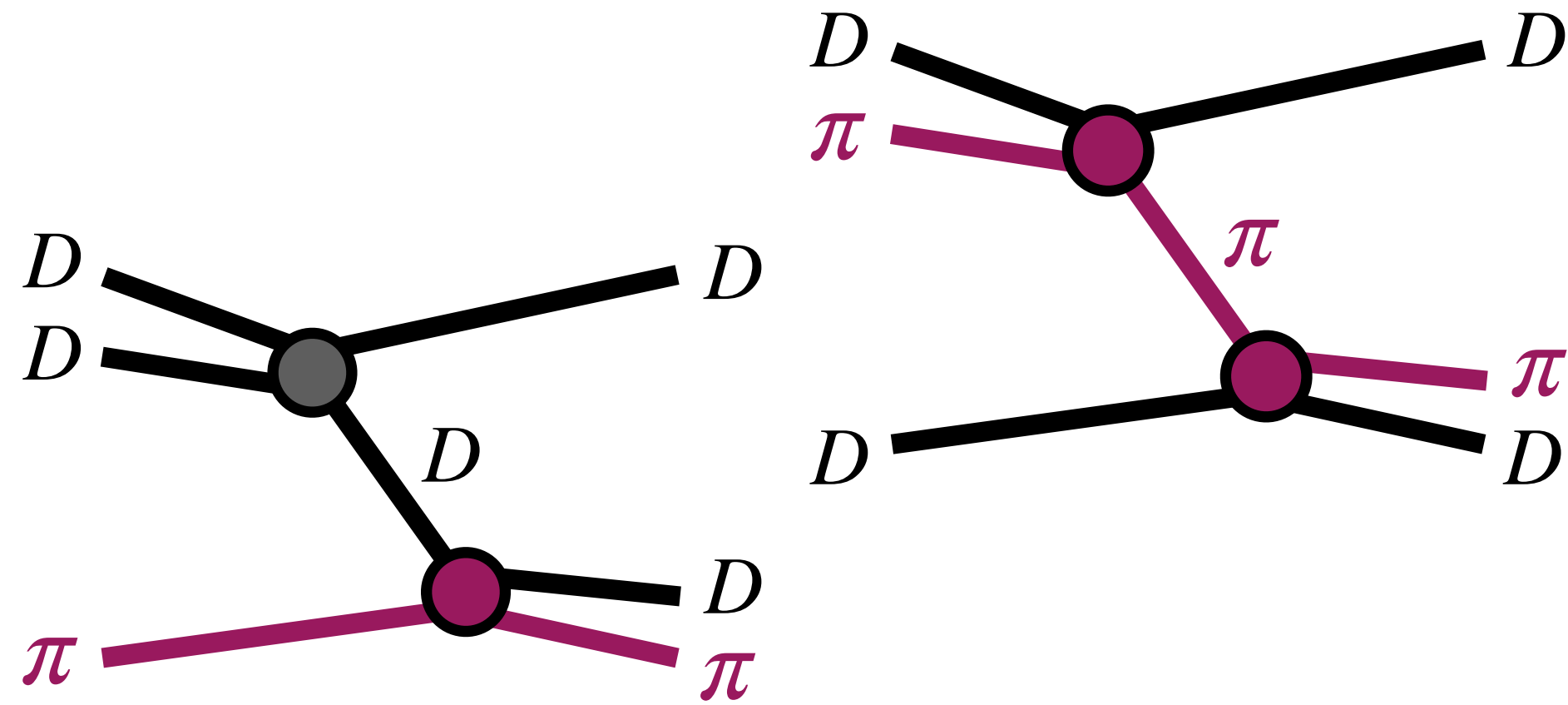
Lattice QCD

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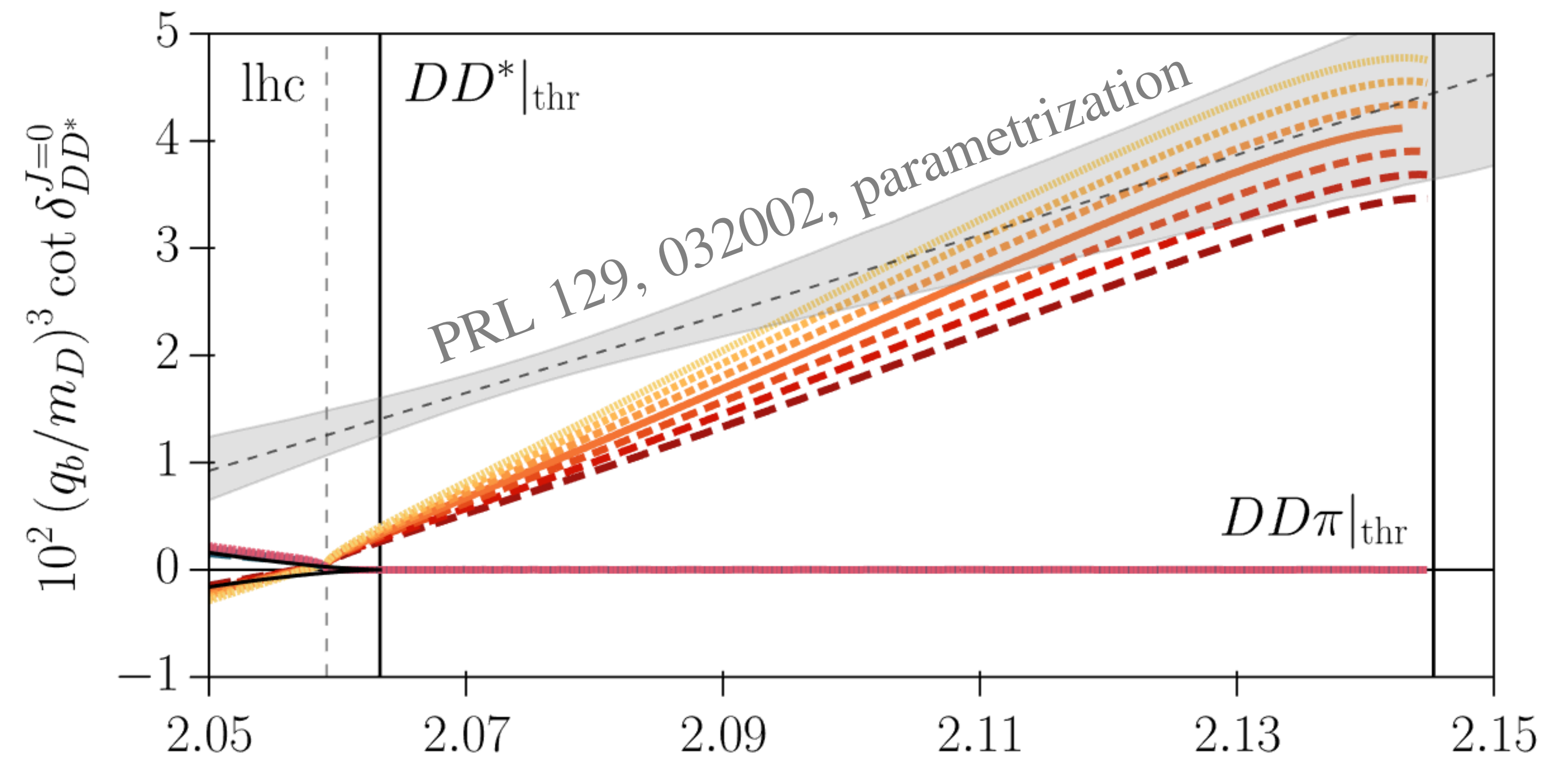


Lattice QCD

Three-body applications — T_{cc}



S. Dawid, F. Romero-López, S. Sharpe,
JHEP **01** (2025) 060



Summer School and Workshop on Multiparticle Reactions

Multi-Particle Reactions from the Standard Model: spectroscopy, precision tests and beyond

- School — https://conferences.lbl.gov/e/multi_school
- Workshop — https://conferences.lbl.gov/e/multi_work

Topics include:

Lattice QCD

Scattering theory

Effective field theories

Ab-initio methods for light and medium nuclei

Fundamental symmetries



Berkeley
UNIVERSITY OF CALIFORNIA



