Photoproduction of the b_1 resonance in $\pi\omega$ from lattice QCD

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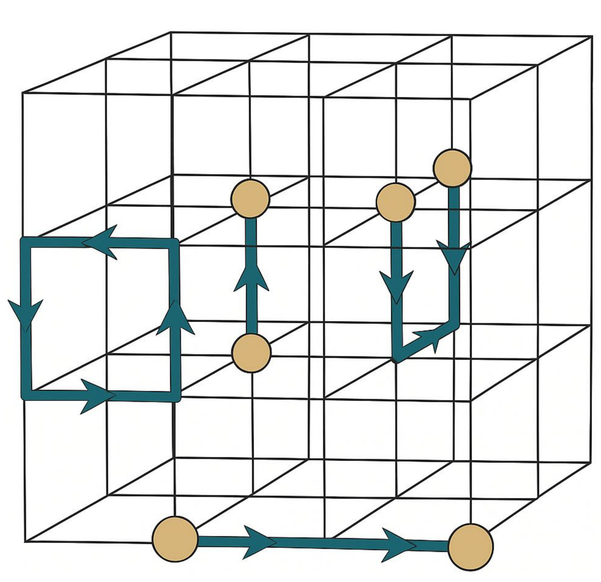
Abstract

This presentation outlines ongoing research using lattice QCD to compute the $\gamma\pi \to \pi\omega$ scattering amplitude with $J^P = 1^+$ quantum numbers, enabling the determination of the $b_1 \to \gamma\pi$ coupling as a function of photon virtuality. This process probes the internal structure of the $b_1(1235)$ meson, a hadronic resonance whose internal dynamics are of significant interest. The transition is experimentally accessible at Jefferson Lab through photoproduction reactions, and theoretical input from Lattice QCD is useful for constraining partial wave analyses and providing insight into the structure of the b_1 resonance. Building on prior work by the Hadron Spectrum Collaboration, the study employs advanced techniques, including distillation operators and optimized interpolating operators, to compute three-point correlation functions. These correlators will be analyzed by applying and extending the existing finite-volume formalism to extract the transition form factors for this process, specifically an electric dipole and a longitudinal component. The results aim to provide theoretical input for experimental analyses at Jefferson Lab's GlueX program.

Lattice QCD

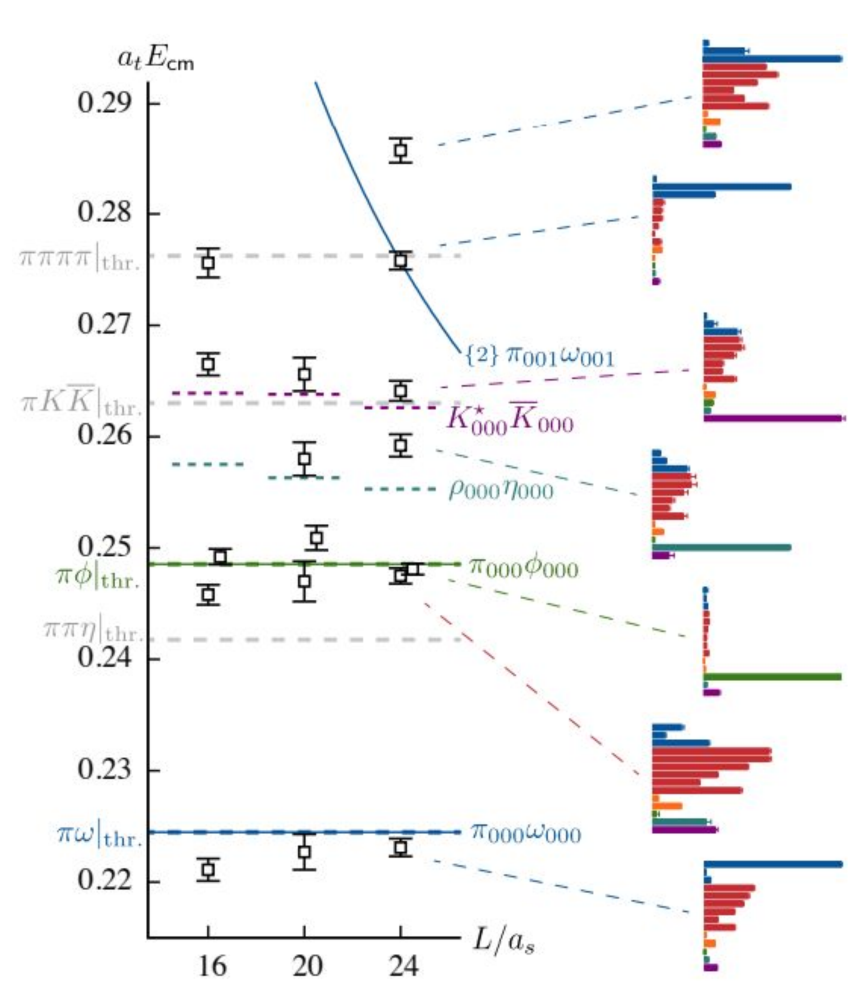
- In lattice QCD, the action of QCD is discretized onto a spacetime grid with a finite spacing and a finite volume
- Because scattering in a finite volume alters the behavior of particle scattering—preventing direct access to asymptotic states—we must account for these distortions by establishing a mapping between finite-volume observables and infinite-volume scattering amplitudes.
- Lattice calculations are done with unphysically heavy light-quark masses with exact isospin symmetry
- We compute matrices of correlation functions across a large set of importance sampled Monte-Carlo generated gauge field configurations and average the results across all configurations

$$
\begin{aligned}
C_{ij}(\tau) &\equiv \langle 0|\mathcal{O}_i(\tau)\mathcal{O}_j^\dagger(0)|0\rangle \\
&= \int \mathcal{D}\psi\mathcal{D}\overline{\psi}\mathcal{D}U\, e^{-S_E}\mathcal{O}_i(\tau)\mathcal{O}_j^\dagger(0) \\
&= \sum_n \langle 0|\mathcal{O}_i(\tau)|\mathbf{n}\rangle\langle\mathbf{n}|\mathcal{O}_j^\dagger(0)|0\rangle e^{-E_n\tau}
\end{aligned}
$$

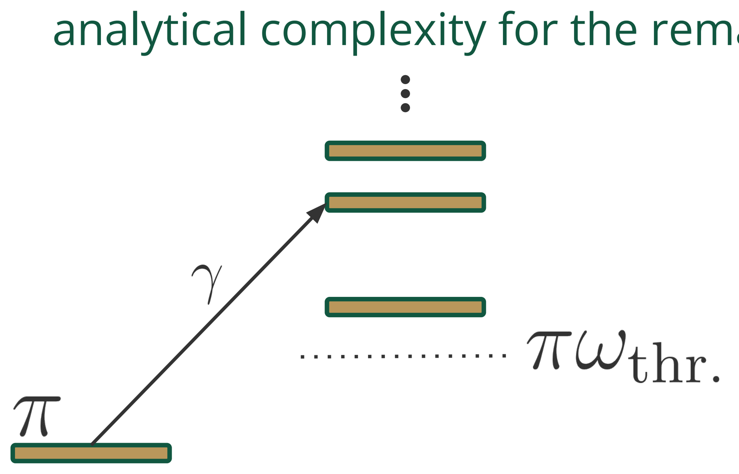


Photoproduction of the b_1 Resonance

- This work build upon a previous lattice calculation done by Woss et al. where the b_1 resonance was analyzed in a lattice calculation of coupled-channel $\pi\omega$, $\pi\phi$ scattering.
- The goal of this project is to compute three-point correlation functions which correspond to the process $\pi\omega\to\pi\gamma$ with $J^{PC}=1^{+-}$, where the b_1 appears as a resonance. From these correlation functions, we will be able to access the $b_1\to\pi\gamma$ decay coupling
- A novel aspect of this calculation involves the Lorentz-invariant decomposition of the matrix elements, which requires two form factors: an electric dipole and a longitudinal component



- In the previous analysis, they used a basis of operators which included $\pi\phi$-like as well as $\rho\eta$ and KK̅-like operators
  - The spectrum shows that the low-lying $\pi\omega$ levels of interest are sufficiently decoupled from the additional operators, allowing us to recompute the spectrum without them and still resolve the levels needed for our analysis.
  - Excluding these operators results in a large reduction of computational and analytical complexity for the remainder of the study



$$
\begin{aligned}
&\langle \pi(\mathbf{p}_\pi)|j^\mu(\mathbf{q})|\pi\omega(\mathbf{p}_{\pi\omega})\rangle \\
&\quad\propto K_E^\mu(\mathbf{p}_\pi,\mathbf{q},\mathbf{p}_{\pi\omega})F_E(Q^2,E_{\pi\omega}) \\
&\quad+K_C^\mu(\mathbf{p}_\pi,\mathbf{q},\mathbf{p}_{\pi\omega})F_C(Q^2,E_{\pi\omega})
\end{aligned}
$$

Finite Volume Formalism for 2→2 Reactions

- To extract physical parameters (e.g., resonance poles, form factors, decay couplings) for a given scattering reaction, we first determine the scattering amplitude from lattice QCD results. This involves computing correlation matrices and fitting their energy and time dependence to obtain the finite-volume spectrum.

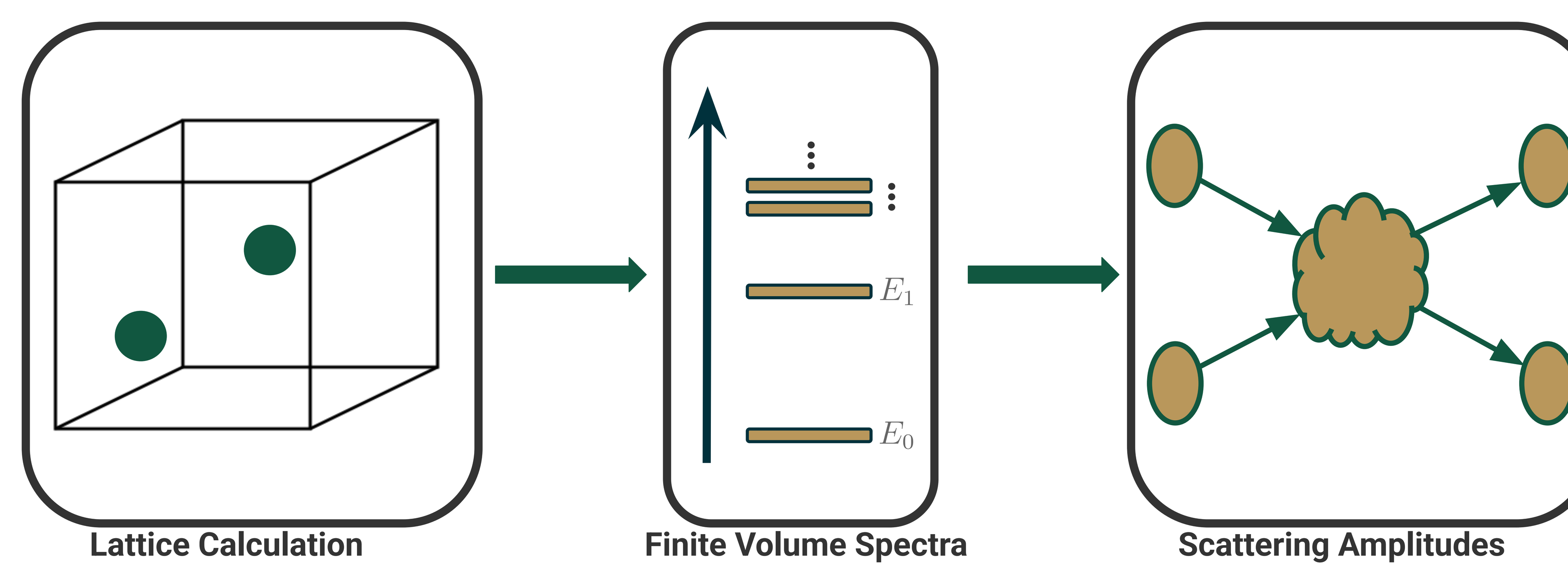
$$\mathbf{C}(t)v_n = \lambda_n(t,t_0)\mathbf{C}(t_0)v_n \qquad \lambda_n(t,t_0)\sim e^{-E_n(t-t_0)}$$

- Using a variety of parameterizations for the scattering amplitude, we then compute scattering amplitudes using the Luscher quantization condition,

$$\det\left[\mathbf{t}(E)+\mathbf{F}^{-1}(E,L)\right]=0$$

  where **t**(E) is the t-matrix of scattering amplitudes in channel-space and **F**(E,L) is a matrix of known geometric functions which encode the effect of the finite volume.
- In addition to the scattering amplitude, we also compute `optimized operators' for two-particle states by forming the linear superposition of basis operators which optimally excites a particular state of interest, which is needed for the three-point analysis.

$$\Omega_n \propto \sum_i (v_n)_i\,\mathcal{O}_i$$

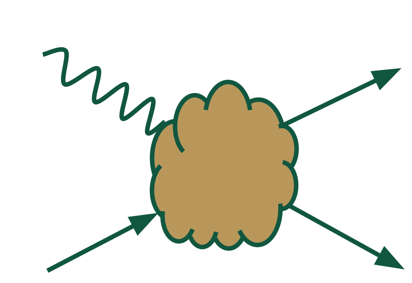


Finite Volume Formalism for 1+J→2 Reactions

- Using the variationally optimized operators generated from the two-point analysis, we compute three-point functions with a current insertion at times $0<t<\Delta t$. The use of optimized operators ensures residual contributions of other states is suppressed and the leading time dependence is that of the states $|\pi(\mathbf{p}_\pi)\rangle$ and $|\pi\omega(\mathbf{p}_{\pi\omega})\rangle$

$$
\begin{aligned}
&\langle 0|\Omega_\pi(\mathbf{p}_\pi,\Delta t)j^\mu(\mathbf{q},t)\Omega^\dagger_{\pi\omega}(\mathbf{p}_{\pi\omega},0)|0\rangle \\
&\qquad\propto e^{-E_\pi(\Delta t-t)}e^{-E_{\pi\omega}t}\langle\pi(\mathbf{p}_\pi)|j^\mu(\mathbf{q})|\pi\omega(\mathbf{p}_{\pi\omega})\rangle+\cdots
\end{aligned}
$$

- We then have a relation between the computed three-point functions and the decomposition, which is dependent on both the total energy of the system and the photon virtuality
- Given a set of at least two linearly-independent matrix elements at each kinematic point, we can then invert the relation to obtain values for the form factors
- These form factors may then be related to the decay coupling for $b_1\to\pi\gamma$, resulting in a first-principles lattice QCD prediction for this value



References

[1] A. Woss, C. Thomas, J. Dudek, R. Edwards, and D. Wilson, Phys. Rev. D 100 (2019), 1904.04136.
[2] A. Radhakrishnan, J. Dudek, R. Edwards, Phys. Rev. D 106 (2022), 2208.13755.
[3] C. Shultz, J. Dudek, and R. Edwards, Phys. Rev. D 91 (2015), 1501.07457.
[4] R. Briceño, J. Dudek, and L. Leskovec, Phys. Rev. D 104 (2021), 2105.02017.

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