Elastic form-factors of resonances from lattice QCD

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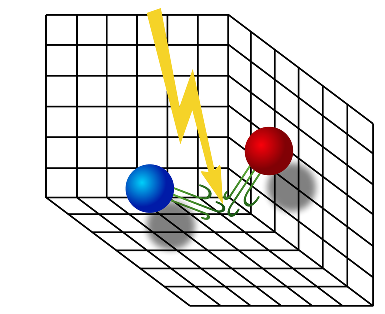
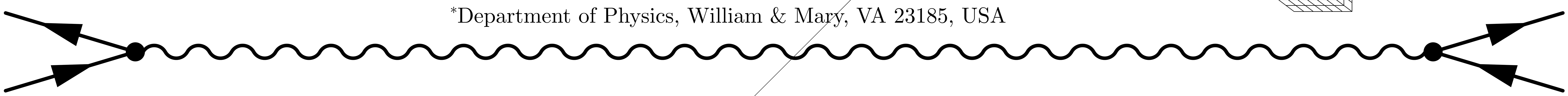
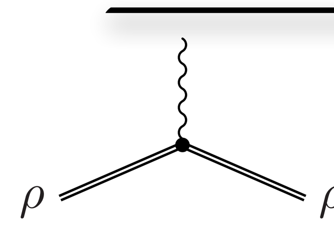




1. Introduction

- To better characterize the strong resonant spectrum we propose a method to extract their elastic form factors (FF).
- To tackle the strong coupling regime we rely on non-perturbative methods: lattice QCD (LQCD), and an all-orders analytic study of transition amplitudes.
- This allows for a rigorous quantitative description of resonances.

2. LQCD Now



$$= \sum_i C_i^\mu G_i(Q^2) \qquad \frac{\langle r_\rho^2\rangle^{1/2}}{\langle r_\pi^2\rangle^{1/2}} = 1.2(2)$$

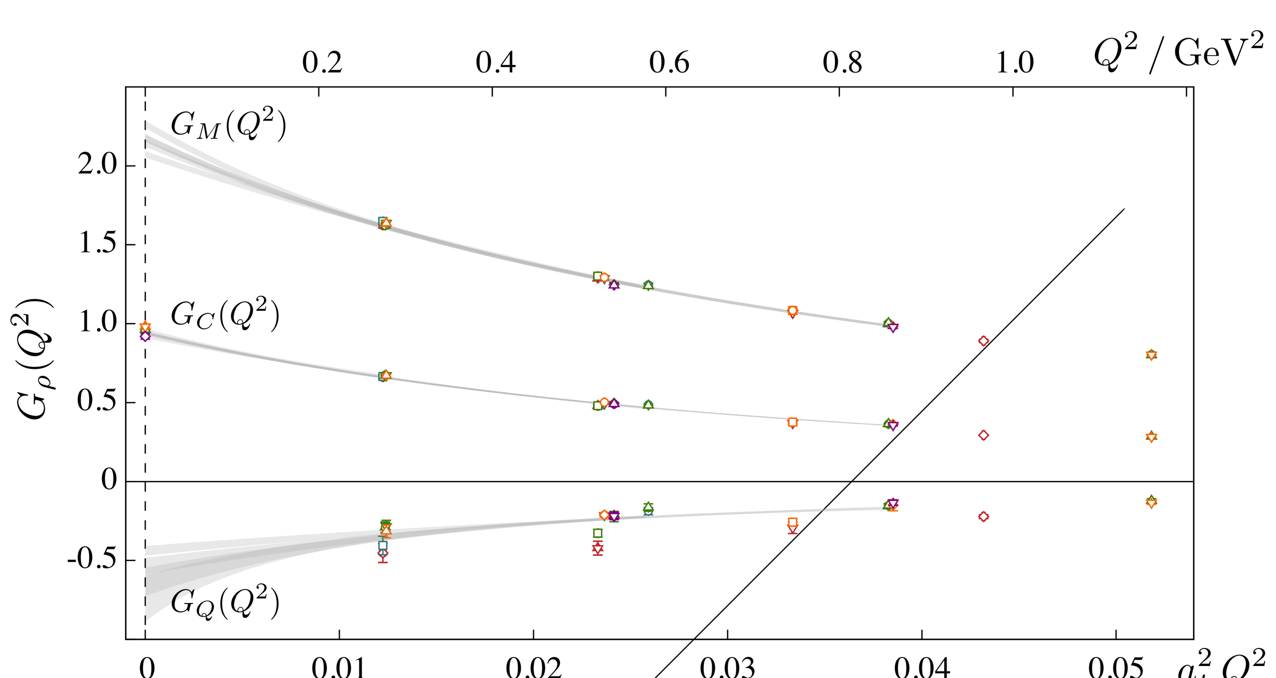


Figure 1: HadSpec FF calculation of a *stable* ρ [1].

3. The Complex Energy Plane

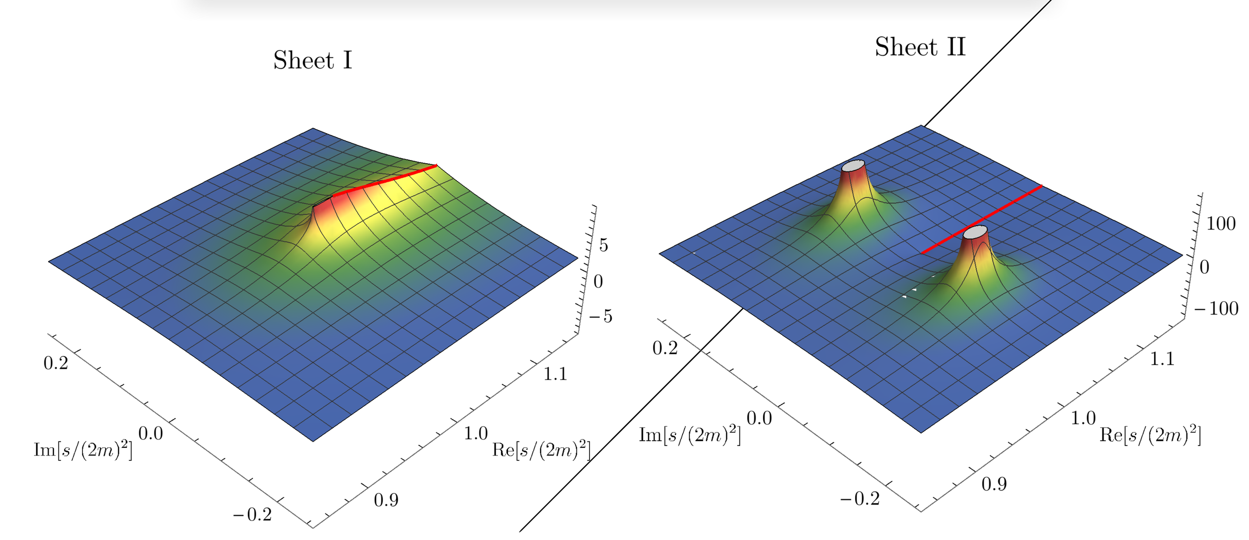
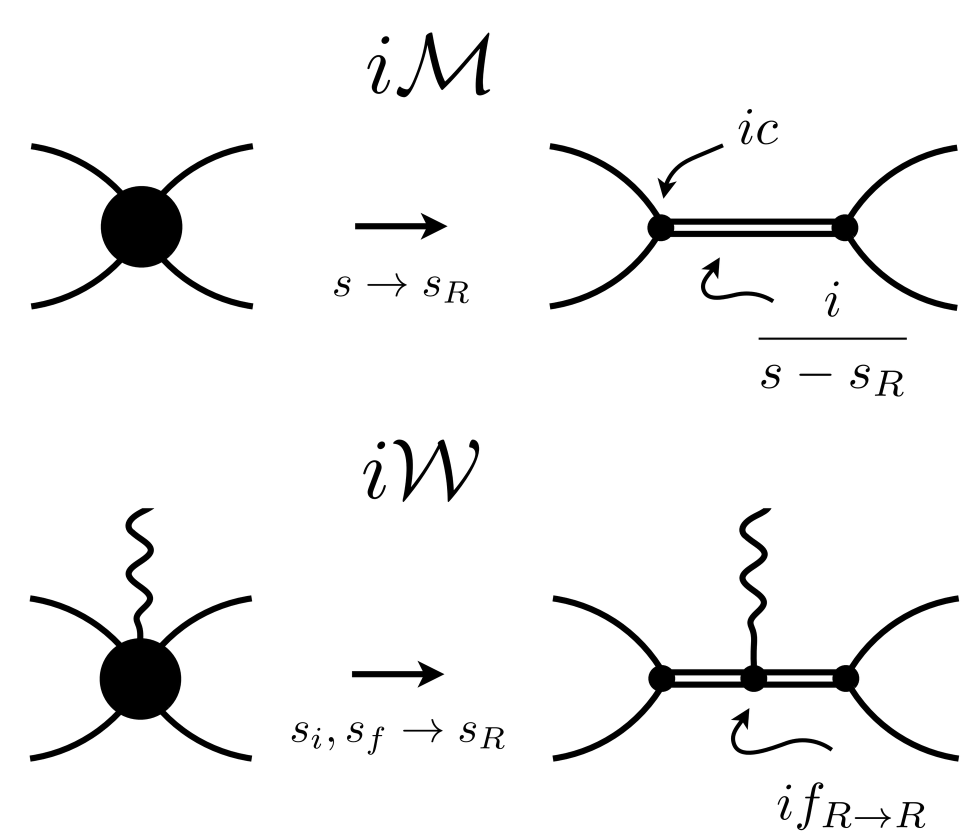
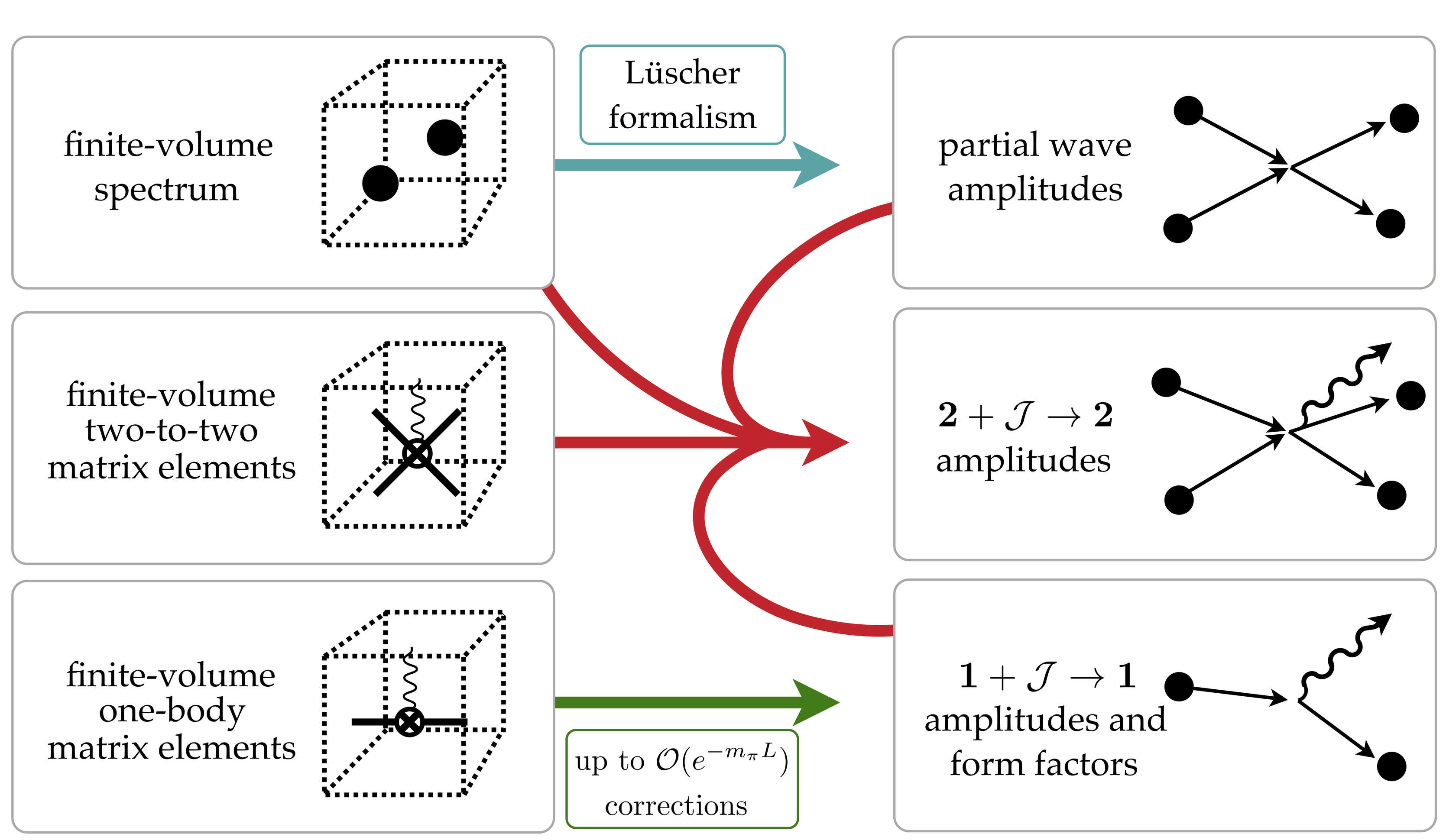


Figure 2: Riemann sheet structure of $i\mathcal{M}$.



The poles of $i\mathcal{M}$ in the complex energy plane provide the mass m, width Γ, and couplings c of the resonance, i.e. $\sqrt{s_R} = m - i\Gamma/2$. The $i\mathcal{W}$ amplitude features second-order poles at s_R with residue proportional to the FF.

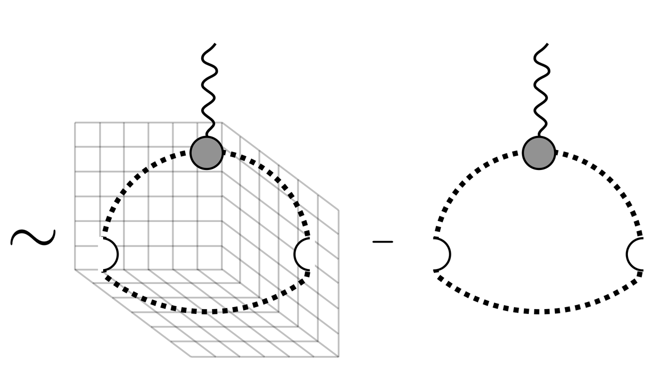
4. LQCD Finite Volume Formalism



$$\left|\langle \mathfrak{n}|\mathcal{J}(0)|\mathfrak{m}\rangle_L\right|^2 = \mathrm{tr}(\mathcal{R}_\mathfrak{n} \mathcal{W}_L \mathcal{R}_\mathfrak{m} \mathcal{W}_L)$$

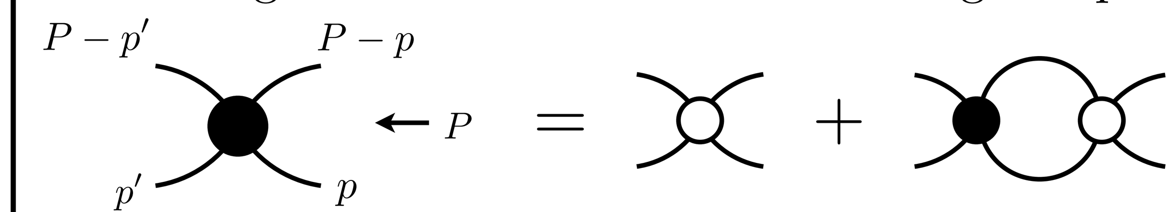
$$\mathcal{W}_{\mathrm{df}} = \mathcal{W}_L - \mathcal{M}[f \cdot G]\mathcal{M}$$

$$f \cdot G \sim$$

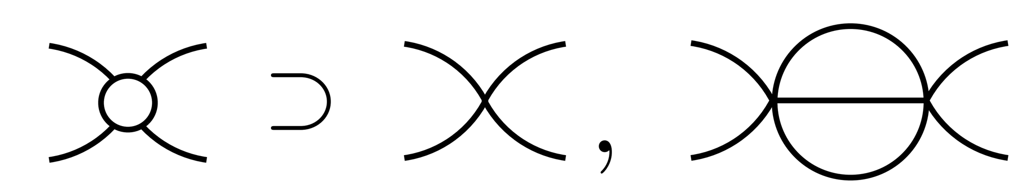


5. Analytic Decomposition

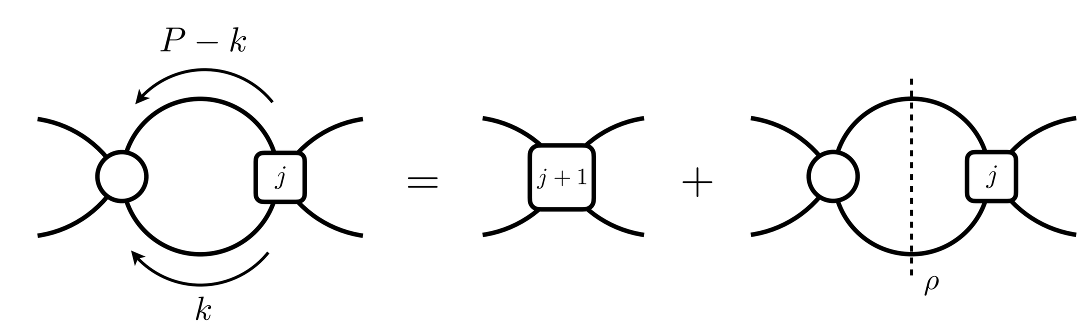
The extraction of the analytic properties of the amplitudes begins with the self-consistent integral equation



The white circle represents the kernel of all two-particle irreducible diagrams in the s-channel

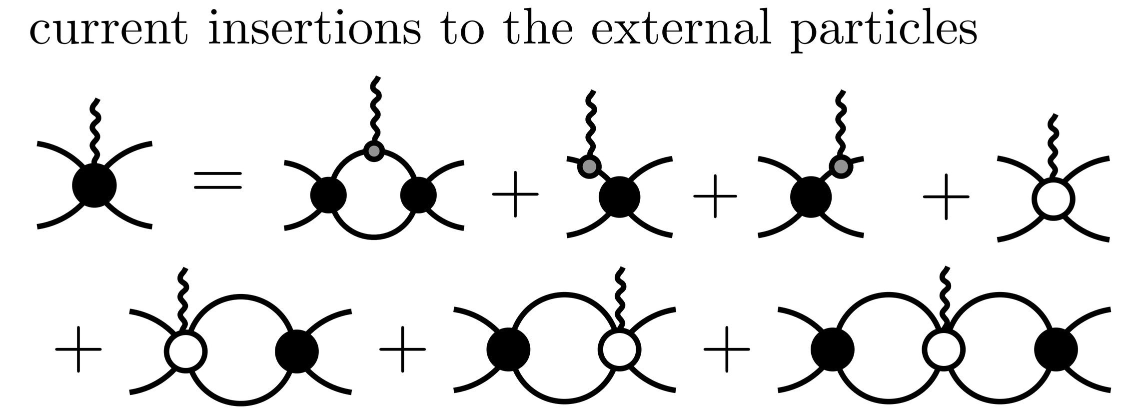


The bubble loop is split iteratively into its singular part, proportional to the phase space ρ, and a real non-singular piece



6. Current insertion

The equation for amplitude $i\mathcal{W}$ involves the rescattering of the initial and final states, plus the long-range current insertions to the external particles



In this case the triangle loop introduces a new kind of non-analytic behavior, i.e. the triangle singularities.

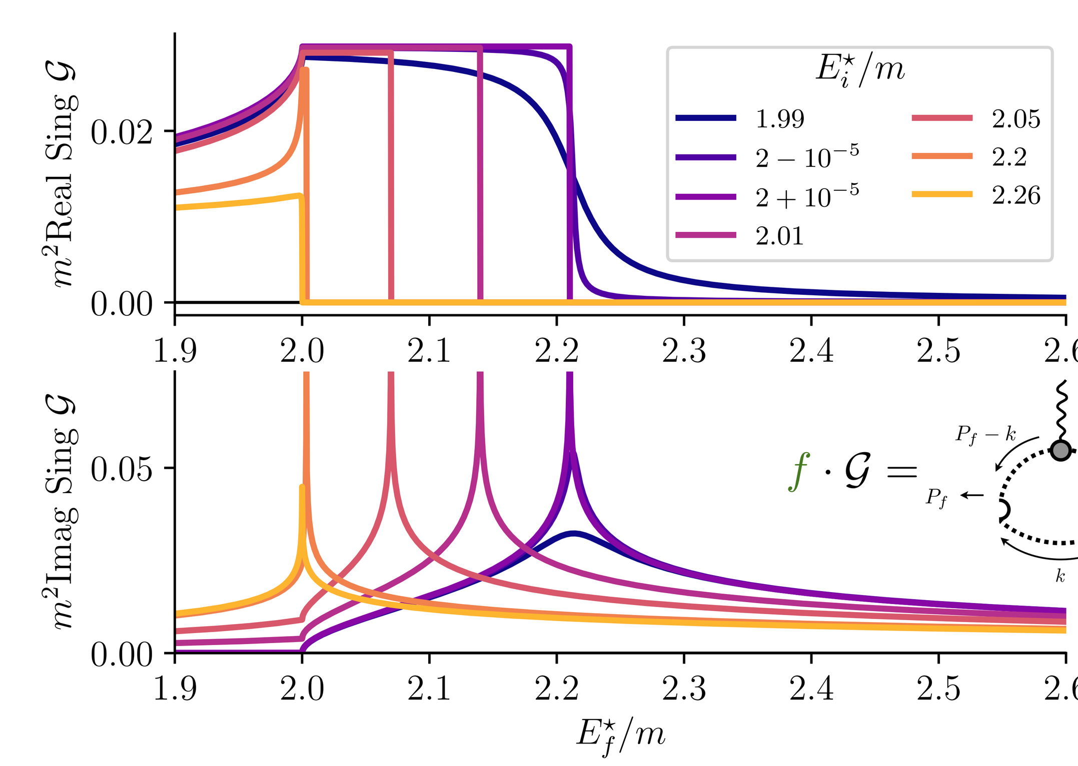
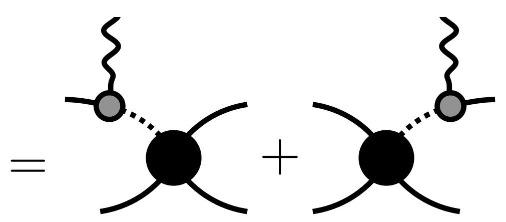


Figure 3: Triangle singularity of $\mathcal{G}$.

7. On-Shell Amplitudes

$$i\mathcal{M} = \frac{i}{\mathcal{K}^{-1} - i\rho} \tag{5}$$



$$i\mathcal{W} = \quad + \quad + i\mathcal{W}_{\mathrm{df}} \tag{6}$$

$$\mathcal{W}_{\mathrm{df}} = \mathcal{M}(\mathcal{A}_{22} + f \cdot \mathcal{G})\mathcal{M} \tag{7}$$

The kernels $\mathcal{K}$ and $\mathcal{A}_{22}$ are yet to be determined, e.g. via LQCD, but both have to be real and free of kinematic singularities.

8. Conclusions and OutLook

$$f_{R\to R} = c^2 \left[\mathcal{A}_{22}(s_R, s_R) + f \cdot \mathcal{G}^{\mathrm{II,II}}(s_R, s_R)\right] \tag{8}$$

- We present a rigorous non-perturbative method to extract structural information of resonant states, opening the door for more rigorous LQCD results.
- The Ward identity further constrains the $\mathcal{A}_{22}$ kernel, this implies charge conservation in two-to-two matrix elements in a finite volume [2].
- Knowing the analytic decomposition of this amplitude is needed to understand more complicated ones, from which PDFs or GPDs can be extracted, or BSM studies can be done.

Acknowledgments

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