Constraints on Spin-2 Interactions

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Can there exist a large-$N$ QCD theory with an isolated massive spin-2 glueball as the lightest state?

Is there a bound on the gap to the next lightest state?
Causality constraints

To address the first question, we calculate the Shapiro time delay/advance in this theory CEMZ, 2014.

This is captured by the Eikonal scattering amplitude:

\[ i\mathcal{M}_{\text{eik}}(s, t) = 2s \int d^2 \vec{b} e^{i\vec{q} \cdot \vec{b}} (e^{i\delta(s, \vec{b})} - 1). \]

The Eikonal phase \( \delta \) depends only on on-shell cubic vertices.

A time advance, \( \delta < 0 \), would imply that new physics is needed around the mass scale \( m \) to restore causality.
**Constraining cubics**

- Prohibiting time advances gives the following cubic vertices:

\[ \mathcal{V}_{EH} = \mathcal{V}_{EH}, \]

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\[ \mathcal{V}_{EH} = \frac{2i}{M_p} \left[ (\epsilon_1 \cdot \epsilon_2)(\epsilon_3 \cdot p_1) + (\epsilon_1 \cdot \epsilon_3)(\epsilon_2 \cdot p_3) + (\epsilon_2 \cdot \epsilon_3)(\epsilon_1 \cdot p_2) \right]^2. \]
Constraining the gap

- Tree amplitudes violate unitarity at $(m^4 M_p)^{1/5}$, so the EFT cutoff is below this scale.

\[ \frac{E_{10}}{M_p^2 m^8}. \]

- Contact terms can cancel the bad high-energy behaviour and raise the cutoff, increasing the gap.
- To find the maximum cutoff, calculate the general four-point amplitude consistent with locality, unitarity, Lorentz invariance, gauge invariance, and crossing symmetry.
- This gives $(m^2 M_p)^{1/3}$ as the highest cutoff.
Can there exist a large-$N$ theory with an isolated massive spin-2 glueball as the lightest state? Perhaps! Causality implies that on-shell cubic vertices must be of EH form.

Is there a bound on the gap to the next lightest state? Perturbative unitarity implies that new states must enter by $\Lambda = (m^2 M_p)^{1/3}$.

Can generalize beyond this simple example to other particle spectra, e.g. higher spins, Higgs-like particles.