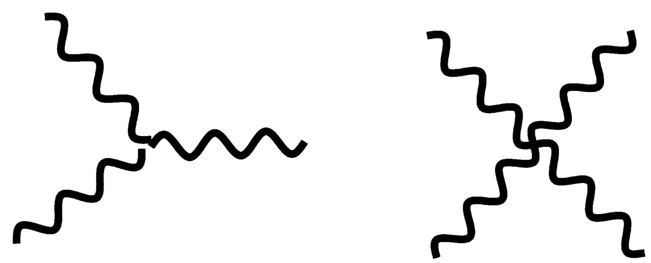
UV Structure from Double Copy in Effective Field Theory

ICHEP, 20 July 2024



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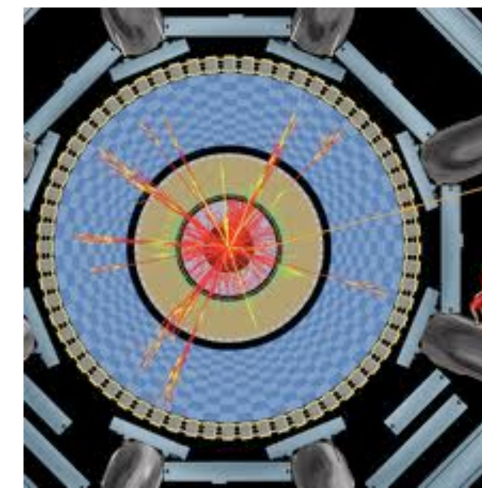

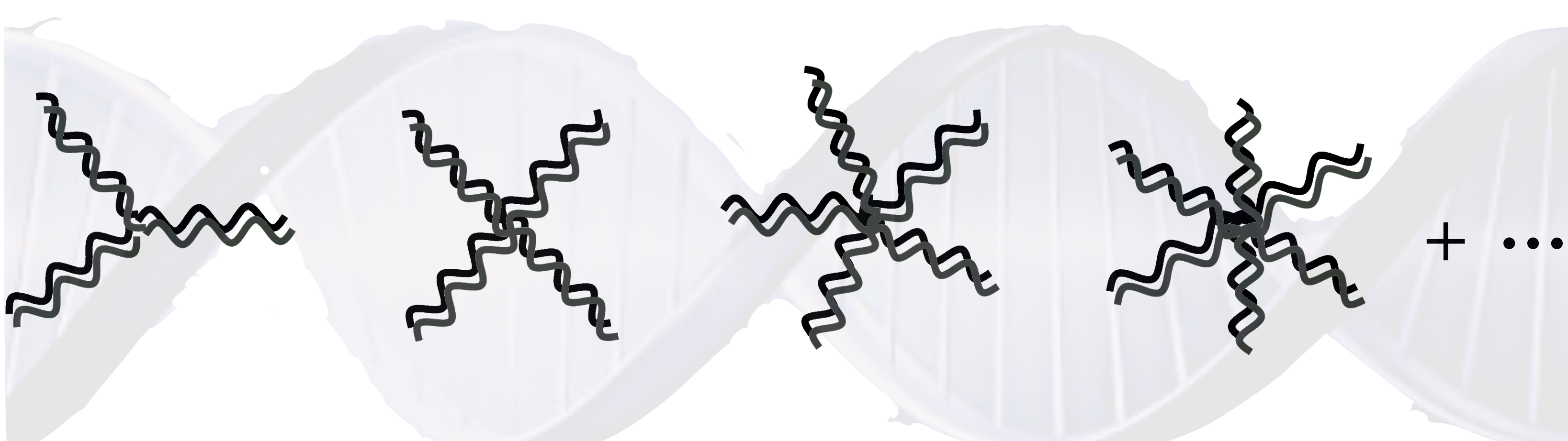

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Based on work with Matt Lewandowski and Nic Pavao

Northwestern University

Amplitudes & Insights

Where I'm going:

Mixed HD duality between color and kinematics + factorization consistency induces a TOWER of EFT operators to the UV

In case of F^3 + YM, double copy lands on so called "twisted" string theory amplitudes — with HD freedom that lands on e.g. open, closed, heterotic

This has implications for UV completions of N=4 SG

This has applications to inflationary cosmology

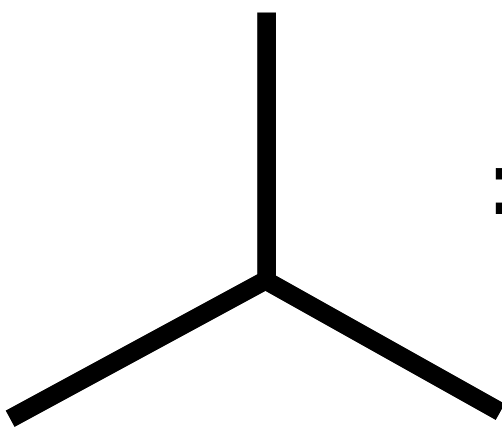
Can be easily exploited for bootstrapping encoding of massive resonances.

JJMC, Pavao, Lewandowski
2203.03592, 2211.04441, 2310.06316

Intuition around color-dual and operator constraints:

color-dual kinematics = linearized gauge-invariance

$$\mathcal{L} = (\partial A)^2 + g_1 A^2 (\partial A)$$



$\neq 0$

Given:

$k_i \cdot k_j = 0 \quad k_i \cdot \varepsilon_i = 0$

Kinematic building blocks:

$\varepsilon_i \cdot \varepsilon_j \quad k_i \cdot \varepsilon_j$

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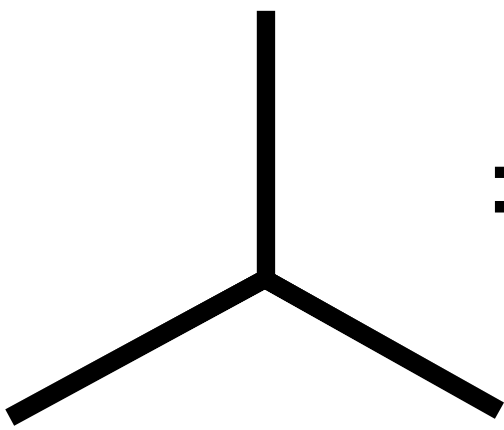
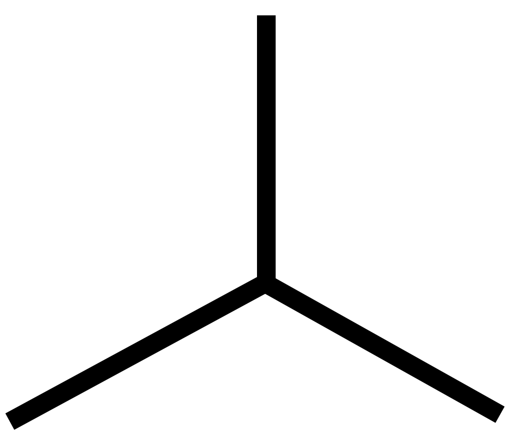
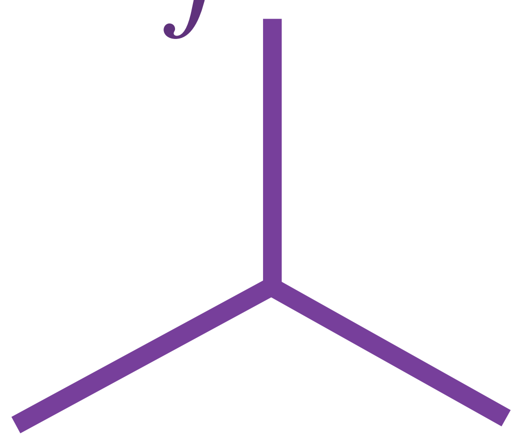


$\neq 0 \iff$ Fixed by Bose Symmetry

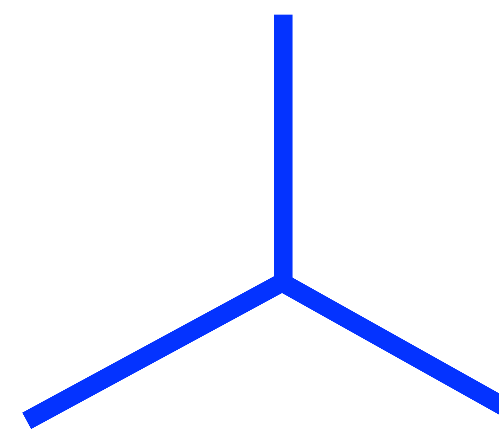


$=$

f^{abc}



$\times$



$$(\varepsilon_1 \cdot \varepsilon_2)(k_1 - k_2) \cdot \varepsilon_3 + \ldots$$

Intuition around color-dual and operator constraints:

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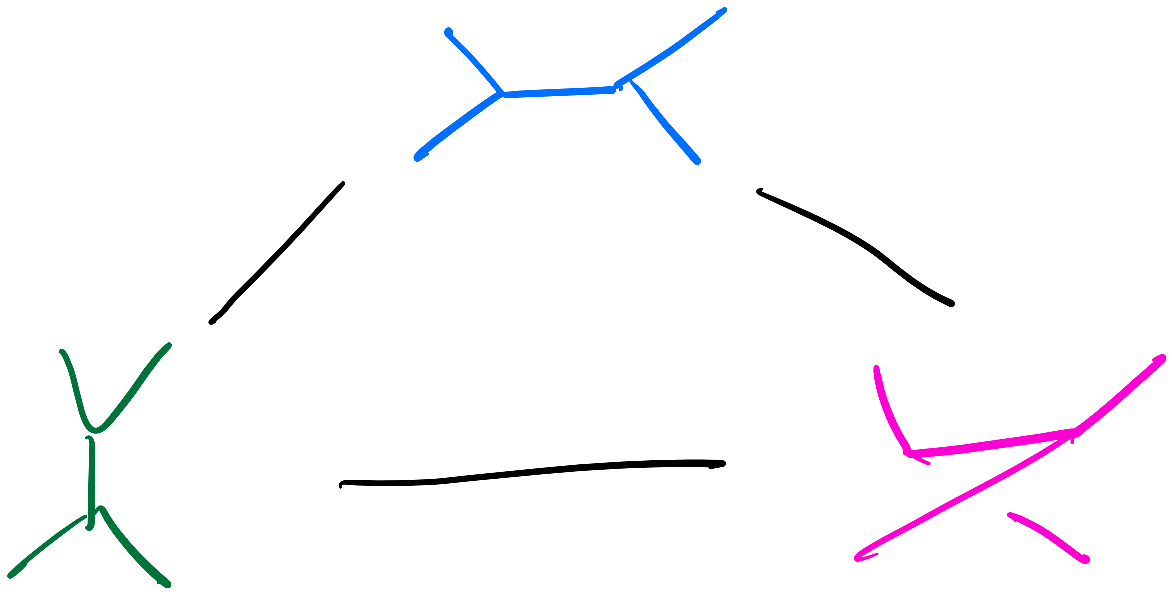

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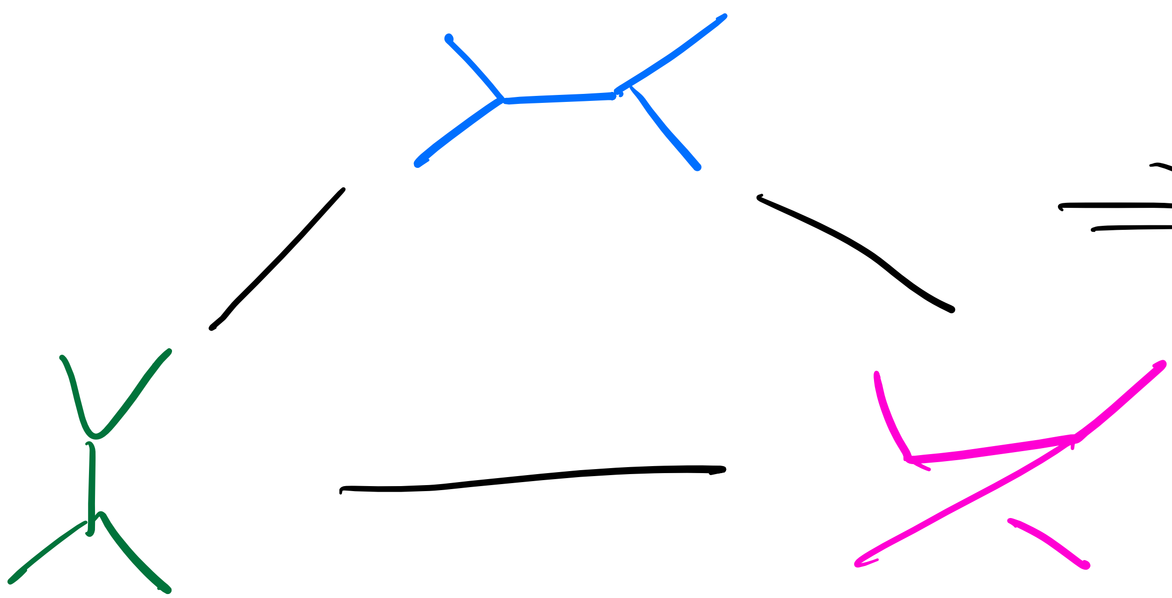

$\Longrightarrow g_2 \sim g_1^2 \Rightarrow \mathcal{L} = -\frac{1}{4} \mathrm{tr} F^2$

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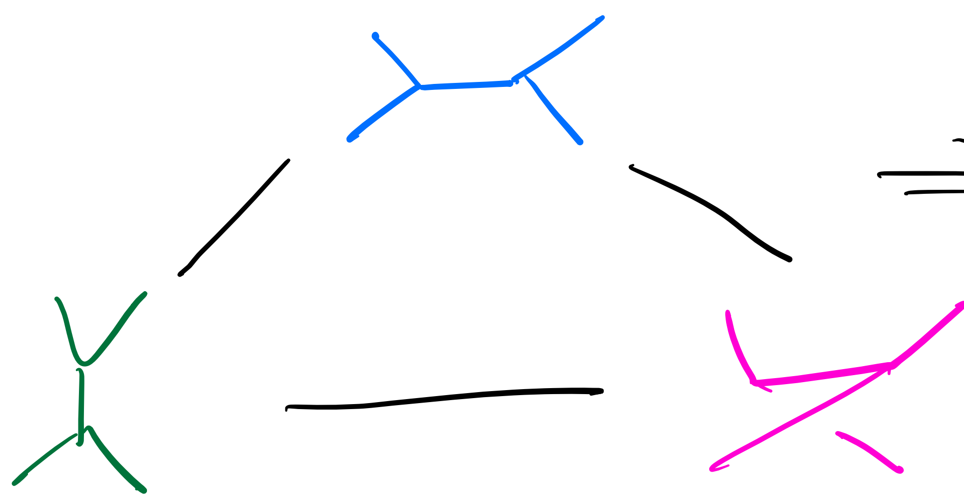

$$\Rightarrow g_2 \sim g_1^2 \Rightarrow \mathcal{L} = -\frac{1}{4} \mathrm{tr} F^2$$

color-dual kinematics + DC = linear diffeo inv.

$$M_5^{GR} = \sum \frac{n(|\!\!\perp\!\!|)\, n(|\!\!\perp\!\!|)}{d_g}$$

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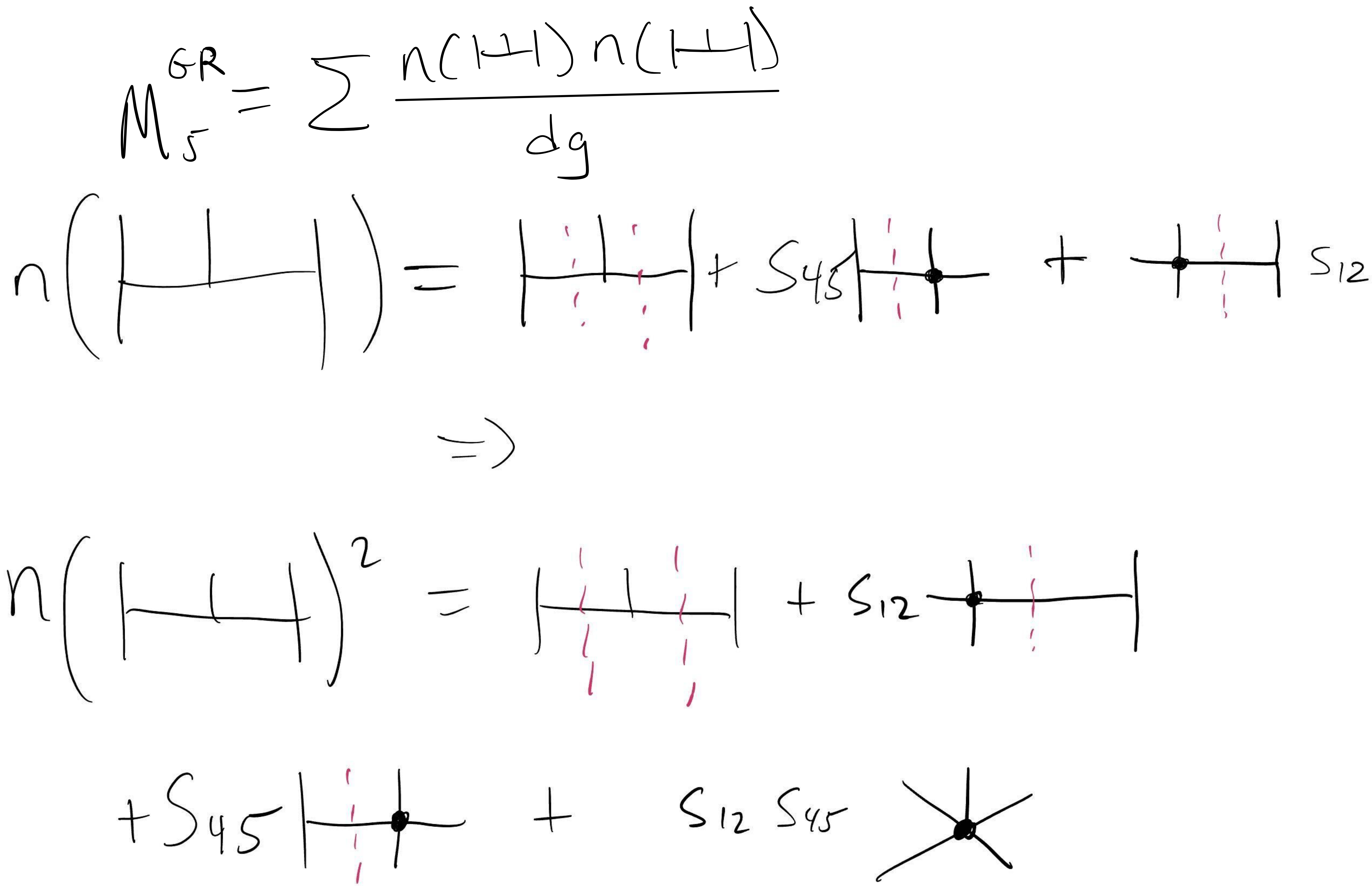

Intuition around color-dual and operator constraints:

color-dual kinematics = soft bootstrap

$$\mathcal{L} = (\partial\pi)^2 \sum_{k=0} c_k \pi^{2k}$$

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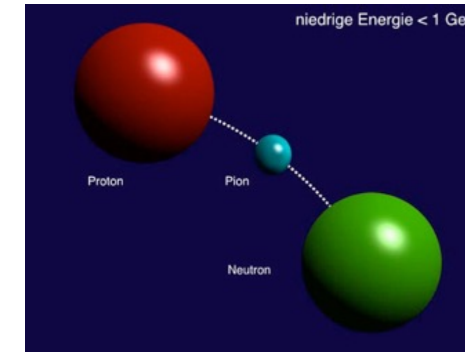

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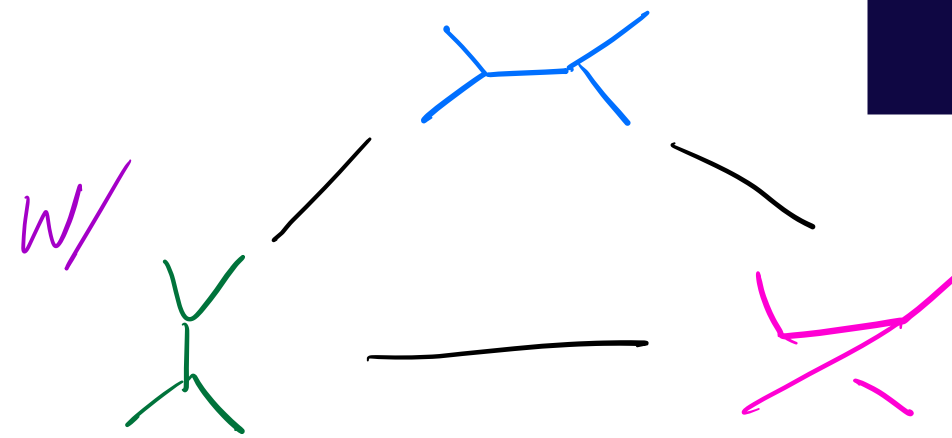
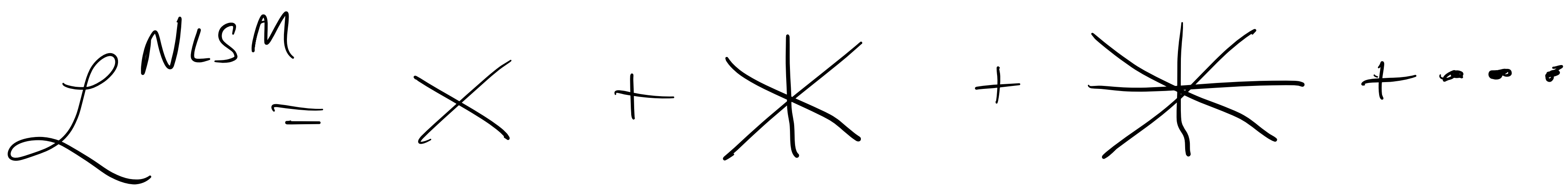


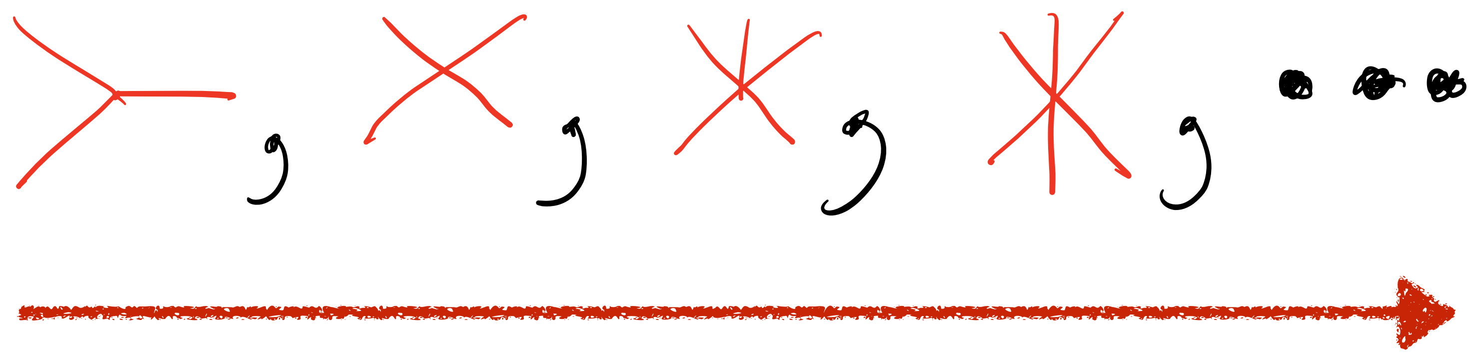
Resums to NLSM:



$$\mathcal{L}^{\mathrm{NLSM}} = (\partial U)^\dagger (\partial U) \qquad U = e^{i\pi}$$

Intuition around color-dual and operator constraints:

Color/kinematics fixes out…



New story in the UV!

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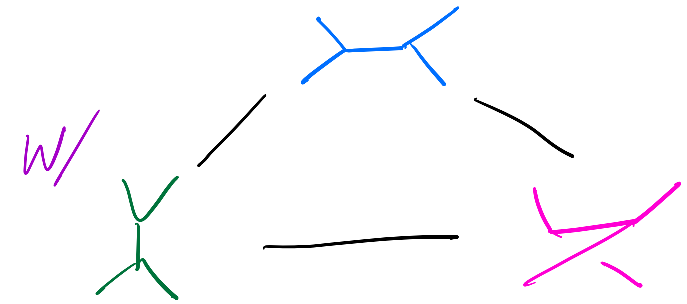
2203.03592, 2211.04441

New story in the UV!

Color/Kinematics + EFT (mixed HD contacts) constraints **UP**!

$$\mathcal{L}^{YM+F^3} = -\frac{1}{4}F^2 + \frac{\alpha'}{3}F^3 + \alpha'^2 F^4 + \alpha'^2 \sum_n c_{(n)} \alpha'^n D^{2n} F^4$$



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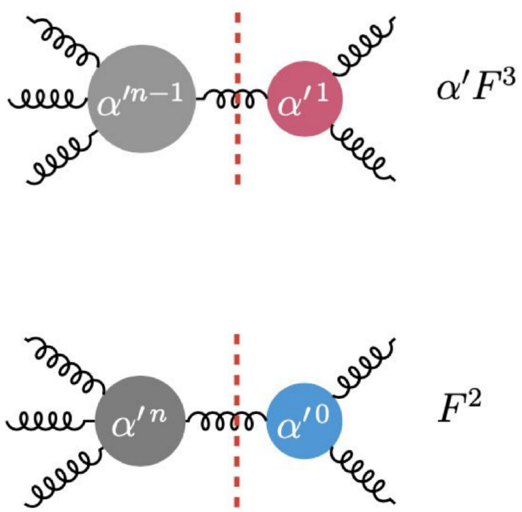

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$$\mathcal{L}^{DF^2+\text{YM}+\text{HD}}$$

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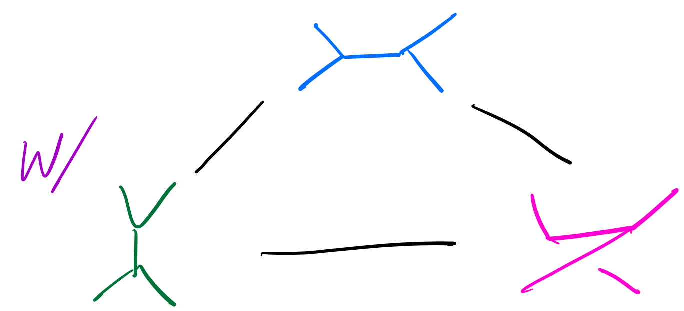

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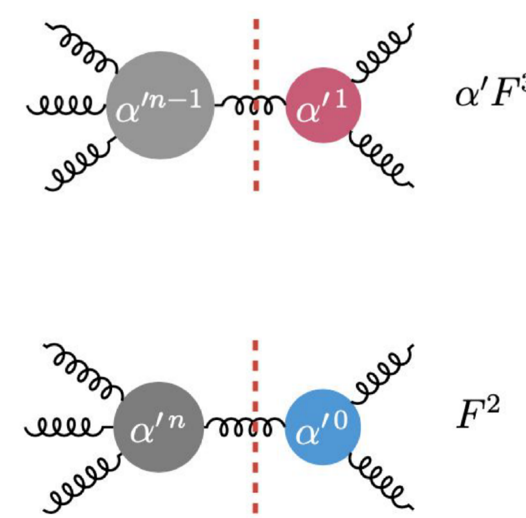

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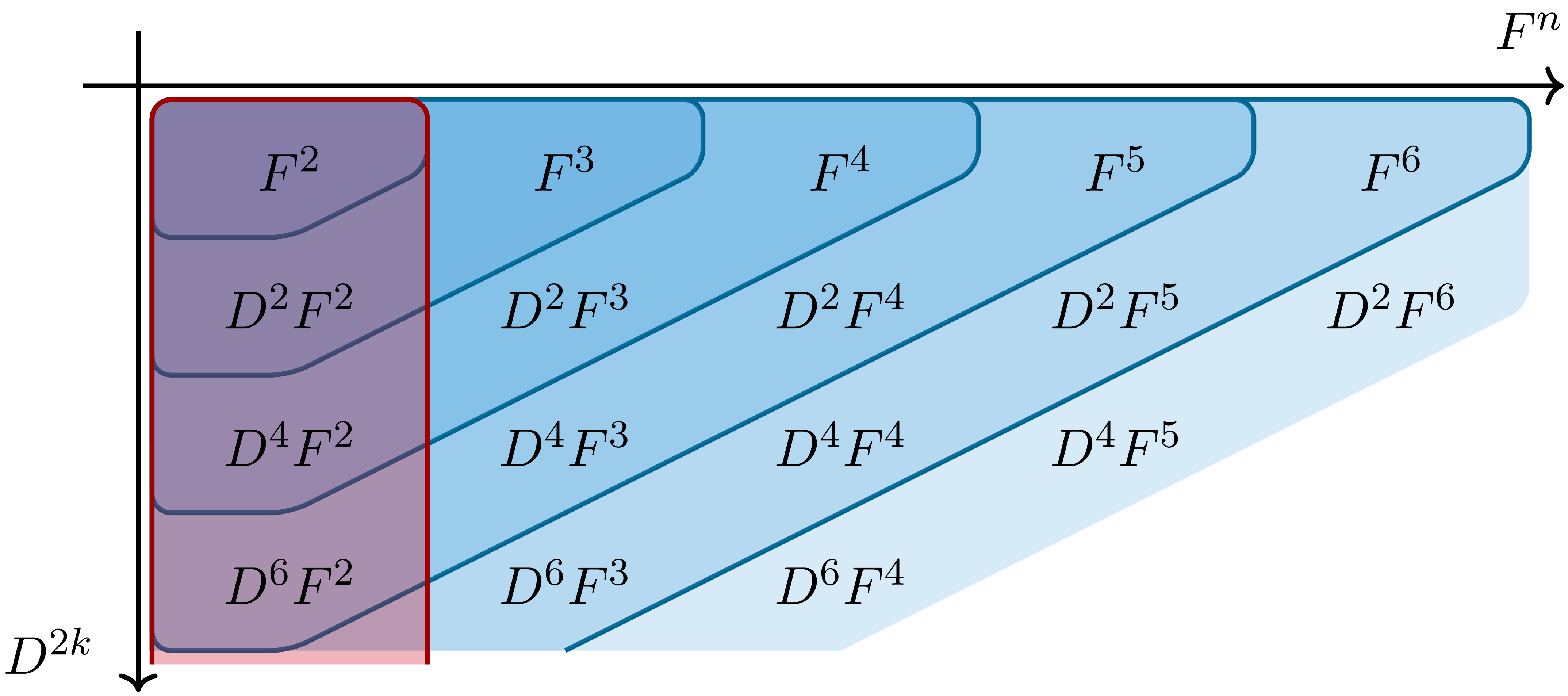
Color-dual consistency and EFT



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Natural encoding of massive resonances in a bootstrapped tower of color-dual HD operators

$$\mathcal{A} = \sum_g \frac{c_g n_g}{d_g - m_g^2} \quad \longrightarrow \quad \mathcal{M} = \sum_g \frac{\tilde{n}_g n_g}{d_g - m_g^2}$$

vs

$$\mathcal{A}^{\text{UV}} = \sum_g \frac{c_g N_g}{d_g} \quad \longrightarrow \quad \mathcal{M}^{\text{UV}} = \sum_g \frac{\tilde{n}_g N_g}{d_g}$$

$$N_g = n_g + \sum_k c_k (\alpha')^k n_g^{(k)}$$

From Masses to Wilson Coefficients:

$$\begin{aligned} A_4^{\text{UV}} &= A_4^{\text{IR}} \times \prod_{k=1} \frac{P_k(\sigma_2, \sigma_3)}{(s-\mu_k)(t-\mu_k)(u-\mu_k)} \\ &= A_4^{\text{IR}} \times \prod_{k=1}^{\infty} \exp\left[c_k\, \Omega_k(\sigma_2, \sigma_3)\right] \end{aligned}$$

From Wilson Coefficients to Masses?

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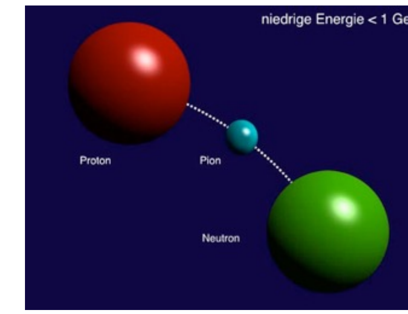
$$\mathcal{A}_{\mathrm{IR}} = f^{a_1 a_2 b} f^{b a_3 a_4}(s_{23} - s_{13}) + f^{a_4 a_1 b} f^{b a_2 a_3}(s_{12} - s_{13}) + f^{a_3 a_1 b} f^{b a_4 a_2}(s_{23} - s_{12})$$



$$M^{\text{2-mode}} = \frac{1 \times 10^3}{(s\alpha' - 1)(t\alpha' - 1)(u\alpha' - 1)(s\alpha' - 10)(t\alpha' - 10)(u\alpha' - 10)} \, .$$

Consider e.g. 10 Wilson Coefficients w/ fixed precision

$$\begin{aligned}\mathcal{A} = \mathcal{A}^{\mathrm{IR}} \times \big[& 1.000 + 1.010(\alpha')^2\sigma_2 + 1.001(\alpha')^3\sigma_3 + 1.010(\alpha')^4\sigma_2^2 + 2.01(\alpha')^5\sigma_2\sigma_3 \\ & + (\alpha')^6\left(1.010\sigma_2^3 + 1.001\sigma_3^2\right) + 3.02(\alpha')^7\sigma_2^2\sigma_3 + (\alpha')^8\left(1.010\sigma_2^4 + 3.01\sigma_2\sigma_3^2\right) \\ & + (\alpha')^9\left(4.03\sigma_2^3\sigma_3 + 1.001\sigma_3^3\right) + (\alpha')^{10}\left(1.01\sigma_2^5 + 6.03\sigma_2^2\sigma_3^2\right) + \mathcal{O}(\alpha')^{11} \big] \, .\end{aligned}$$

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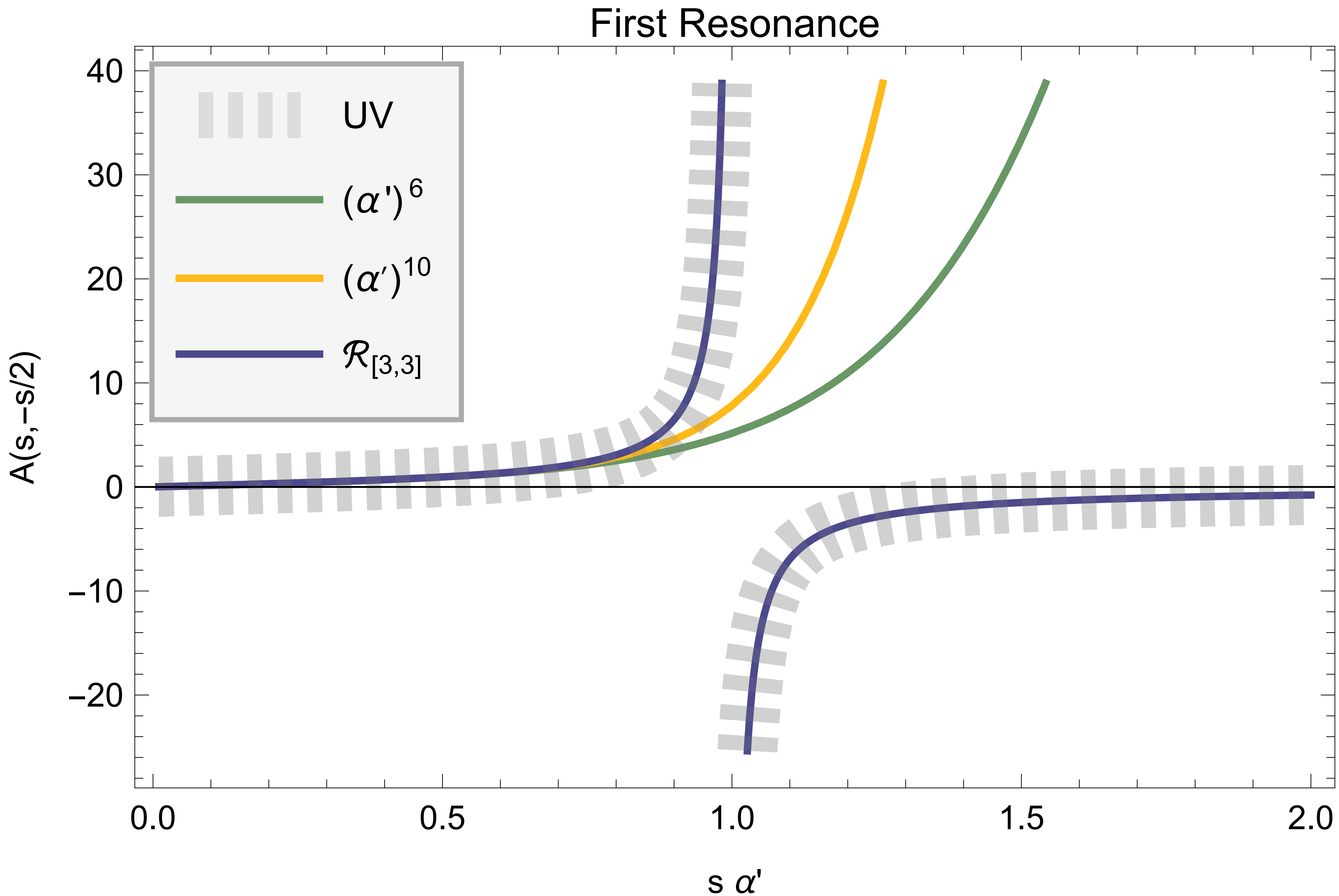

Padé approximants

$$\mathcal{R}_{[m,n]}(x) \equiv \frac{A_m(x)}{B_n(x)}\,,$$

$$A_m(x) = \sum_{j=0}^{m} a_j x^j\,, \quad B_n(x) = 1 + \sum_{j=0}^{n} b_j x^j\,.$$

Coefficients matched by taking derivatives

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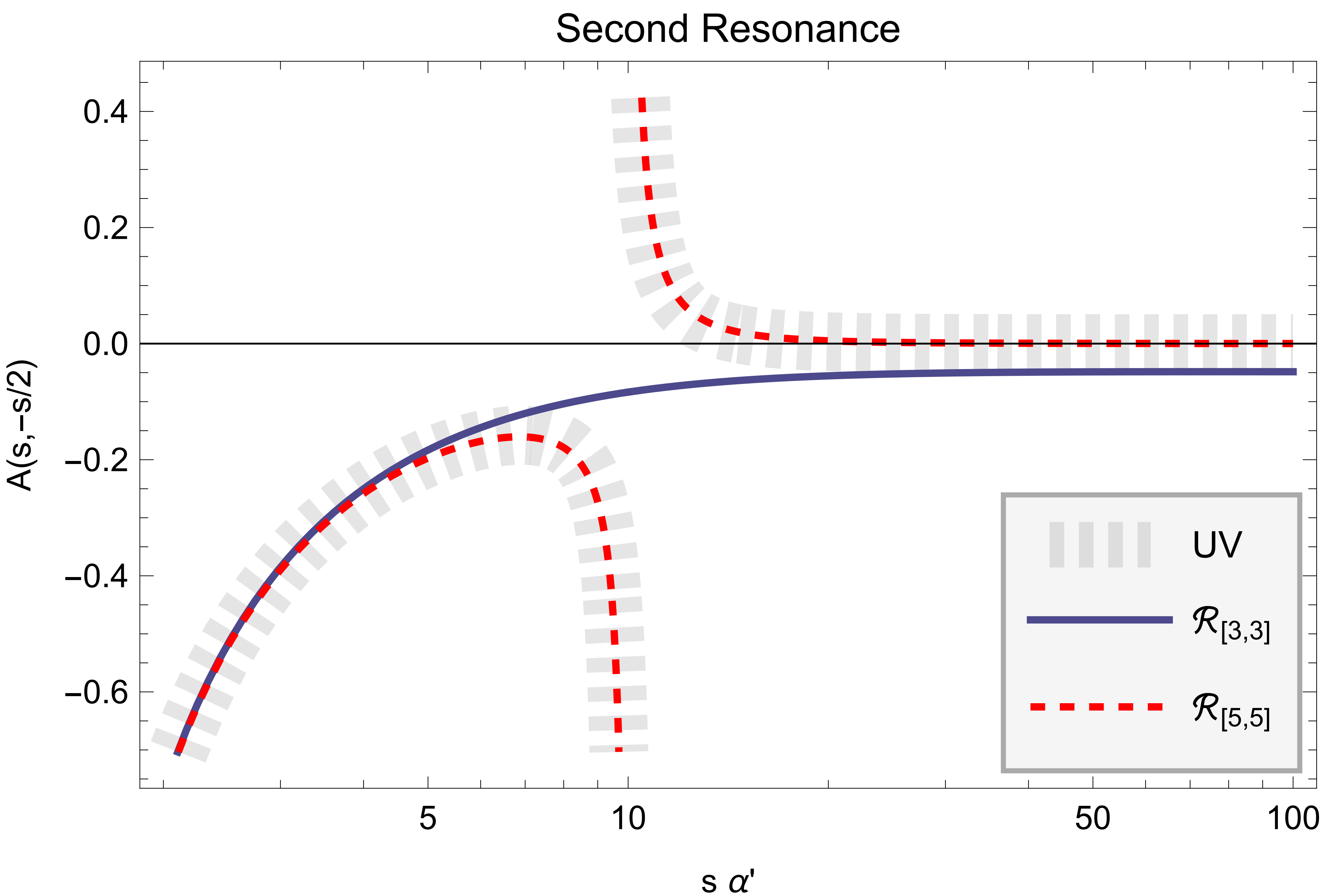

Takeaways:

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Consider this talk an invitation, there are many reviews:

Snowmass White Paper: the Double Copy and its Applications, 2204.06547

-gentle overview for broad audience, nice discussion including non-flat backgrounds, classical solns, GW astrophysics, cosmological challenges

Snowmass White Paper: Gravitational Waves and Scattering Amplitudes, 2204.05194

The SAGEX review on scattering amplitudes (chapter 2), 2203.13013

-gentle introduction targeting amplitudes expertise

The Duality Between Color and Kinematics and its Applications, 1909.01358

-technical, overview of literature ~ 2019

Supergravity amplitudes, the double copy and ultraviolet behavior, 2304.07392

-focus on UV behavior of SG