The Infrared Structure of Nambu-Goldstone Bosons

Based on 1709.08639, 1804.08629 by Ian Low and Zhewei Yin

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Subleading single soft theorem for NLSM

Interesting results discovered using the CHY formalism:

$$M_{n+1}^{\text{NLSM}}(\mathbb{I}_{n+1}) = \tau \sum_{i=2}^{n-1} s_{n+1,i}\ M_n^{\text{NLSM}\oplus\phi^3}(\mathbb{I}_n|1,n,i) + \mathcal{O}(\tau^2),$$

Cachazo, Cha, Mizera, 1604.03893.

Adler's zero from Ward identity:

$$\pi(x) \to \pi(x) + \varepsilon + \cdots, \qquad \langle\Omega|\mathcal{J}^\mu(x)|\pi(p)\rangle = ifp^\mu e^{-ip\cdot x}$$

$$\partial_\mu\langle f|\mathcal{J}^\mu|i\rangle = 0, \qquad \langle f+\pi(p)|i\rangle = p_\mu R^\mu(p).$$

To go beyond Adler's zero, simply need to calculated R.

Identification of Feynman vertices of the extended theory

$$M(\mathbb{I}_n) = -i \sum_{k=1}^{[n/2]} \sum_{\{l_m\}} V_{\mathbb{I}_{2k+1}}(q_{l_1}, \cdots, q_{l_{2k+1}}) \prod_{m=1}^{2k+1} J(l_{m-1}+1, \cdots, l_m) \ ,$$

$$V(\mathbb{I}_{2k+1}) = \frac{-i(-4)^k}{(2k+1)! f^{2k}} \sum_{j=1}^{2k-1} \left[\begin{pmatrix} 2k \\ j \end{pmatrix} (-1)^j - 1 \right] q \cdot p_{j+1} \ .$$

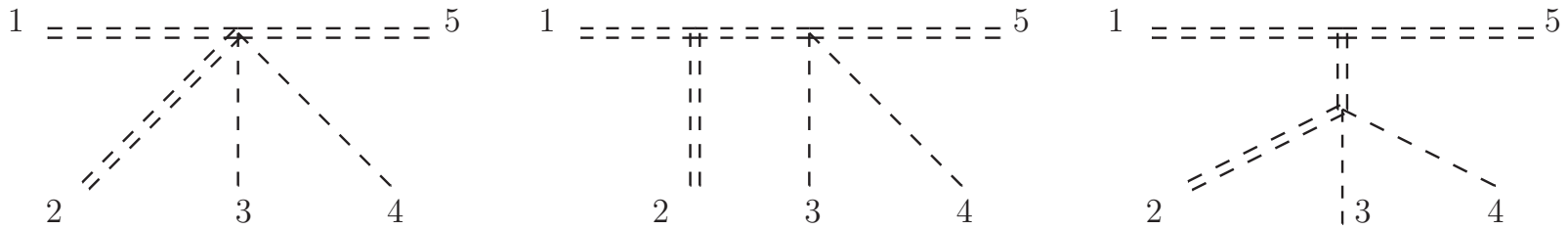
- No vertex with one ϕ
- ϕ^2 vertices exactly the same as NLSM
- ϕ^3 vertices:

$$\begin{aligned} & V^{\text{NLSM}\oplus\phi^3}(\mathbb{I}_{2k+1}|1, 2k+1, j) \\ = \ & \frac{i}{2} \frac{-(-4)^k}{(2k+1)! f^{2k}} \left[\begin{pmatrix} 2k \\ j-1 \end{pmatrix} (-1)^{j-1} - 1 \right] \ . \end{aligned}$$

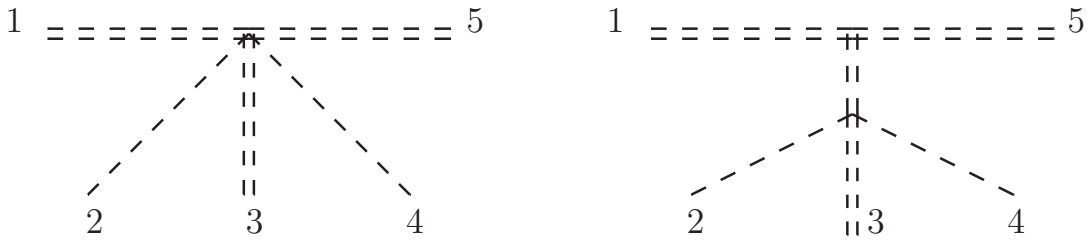
Recovers self-interaction of ϕ

Examples of extended theory amplitude

$$M_5^{\text{NLSM}\oplus\phi^3}(\mathbb{I}_5|1,5,2)$$



$$M_5^{\text{NLSM}\oplus\phi^3}(\mathbb{I}_5|1,5,3)$$



More results

- Leading double soft from the Ward identity
- Triple soft from Cayley parameterization, where the extended theory also emerges
- Applicable to other scalar EFTs, including DBI, galileon and special Galileon
- Identification of Feynman rules in $M^{\text{sGal}\oplus\text{NLSM}^2\oplus\phi^3}$