Particle spectrograph

Wave operator and propagator

| Source constraints | | |
|---|---|----------------|
| SO(3) irreps | Fundamental fields | Multiplicities |
| $\tau_0^{\#2} == 0$ | $\partial_{\beta}\partial_{\alpha}\tau^{\alpha\beta} == 0$ | 1 |
| $\tau_{0+}^{\#1} - 2 i k \sigma_{0+}^{\#1} == 0$ | $\partial_{\beta}\partial_{\alpha}\tau^{\alpha\beta} == \partial_{\beta}\partial^{\beta}\tau^{\alpha}_{\alpha} + 2 \partial_{\chi}\partial^{\chi}\partial_{\beta}\sigma^{\alpha\beta}_{\alpha}$ | 1 |
| $\tau_{1}^{\#2}{}^{\alpha} + 2ik \ \sigma_{1}^{\#2}{}^{\alpha} = 0$ | $\partial_{\chi}\partial_{\beta}\partial^{\alpha}\tau^{\beta\chi} == \partial_{\chi}\partial^{\chi}\partial_{\beta}\tau^{\alpha\beta} + 2\partial_{\delta}\partial^{\delta}\partial_{\chi}\partial_{\beta}\sigma^{\alpha\beta\chi}$ | 3 |
| $\tau_{1}^{\#1}{}^{\alpha} == 0$ | $\partial_{\chi}\partial_{\beta}\partial^{\alpha}\tau^{\beta\chi} == \partial_{\chi}\partial^{\chi}\partial_{\beta}\tau^{\beta\alpha}$ | 3 |
| $\tau_{1+}^{\#1}\alpha\beta + ik \ \sigma_{1+}^{\#2}\alpha\beta == 0$ | $\partial_{\chi}\partial^{\alpha}\tau^{\beta\chi} + \partial_{\chi}\partial^{\beta}\tau^{\chi\alpha} + \partial_{\chi}\partial^{\chi}\tau^{\alpha\beta} +$ | 3 |
| | $2 \partial_{\delta} \partial_{\chi} \partial^{\alpha} \sigma^{\beta \chi \delta} + 2 \partial_{\delta} \partial^{\delta} \partial_{\chi} \sigma^{\alpha \beta \chi} = =$ | |
| | $\partial_{\chi}\partial^{\alpha} \tau^{\chi\beta} + \partial_{\chi}\partial^{\beta} \tau^{\alpha\chi} +$ | |
| | $\partial_{\chi}\partial^{\chi} t^{\beta\alpha} + 2 \partial_{\delta}\partial_{\chi}\partial^{\beta}\sigma^{\alpha\chi\delta}$ | |
| $\tau_{2+}^{\#1}\alpha\beta - 2ik \sigma_{2+}^{\#1}\alpha\beta == 0$ | $t_{2+}^{\#1}\alpha\beta - 2ik \sigma_{2+}^{\#1}\alpha\beta == 0 -i(4\partial_{\delta}\partial_{\chi}\partial^{\beta}\partial^{\alpha}t^{\chi\delta} + 2\partial_{\delta}\partial^{\delta}\partial^{\alpha}t^{\chi})$ | 5 |
| | $3 \partial_{\delta} \partial_{\chi} \partial^{\alpha} \tau^{\beta \chi} - 3 \partial_{\delta} \partial^{\delta} \partial_{\chi} \partial^{\alpha} \tau^{\chi \beta} -$ | |
| | $3 \partial_{\delta} \partial_{\chi} \partial^{\beta} \tau^{\alpha \chi} - 3 \partial_{\delta} \partial^{\delta} \partial_{\chi} \partial^{\beta} \tau^{\chi \alpha} +$ | |
| | $3 \partial_{\delta} \partial^{\delta} \partial_{\chi} \partial^{\chi} \tau^{\alpha\beta} + 3 \partial_{\delta} \partial^{\delta} \partial_{\chi} \partial^{\chi} \tau^{\beta\alpha} +$ | |
| | $4\ i \ k^{\chi}\ \partial_{\epsilon}\partial_{\chi}\partial^{eta}\partial^{lpha}\sigma^{\delta arepsilon}_{\ \ \delta}$ - | |
| | $6 i k^{\chi} \partial_{\epsilon} \partial_{\delta} \partial_{\chi} \partial^{\alpha} \sigma^{\beta \delta \epsilon}$ - | |
| | $6 i k^{\chi} \partial_{\epsilon} \partial_{\delta} \partial_{\chi} \partial^{\beta} \sigma^{\alpha \delta \epsilon} +$ | |
| | $2 \eta^{\alpha\beta} \partial_{\epsilon} \partial^{\epsilon} \partial_{\delta} \partial_{\chi} \tau^{\chi\delta} +$ | |
| | $6 i k^{\chi} \partial_{\epsilon} \partial^{\epsilon} \partial_{\delta} \partial_{\chi} \sigma^{\alpha \delta \beta} +$ | |
| | $6 \ i \ k^{\chi} \ \partial_{\epsilon} \partial^{\epsilon} \partial_{\delta} \partial_{\chi} \sigma^{eta \delta lpha}$ - | |
| | $2 \eta^{\alpha\beta} \partial_{\epsilon} \partial^{\epsilon} \partial_{\delta} \partial^{\delta} t_{\chi}^{\chi}$ - | |
| | $4 i \eta^{\alpha\beta} k^{\chi} \partial_{\phi} \partial^{\phi} \partial_{\epsilon} \partial_{\chi} \sigma^{\delta\epsilon}_{\delta}) == 0$ | |
| Total constraints/gauge generators: | ge generators: | 16 |
| | | |

| $\iota eta \qquad \iota_{1}^{\#1} \qquad \sigma_{1}^{\#1} \qquad \sigma_{1}^{\#2} \qquad \iota_{1}^{\#2} \qquad \iota_{1}^{$ | | $\frac{+t_1}{t_1^2} - \frac{\frac{i(2k^3r_5 - kt_1)}{(1+k^2)^2 t_1^2}}{(1+k^2)^2 t_1^2} 0 0 0 0$ | $ \frac{kt_1}{t_1^2} = \frac{-2k^4 r_5 + k^2 t_1}{(1+k^2)^2 t_1^2} = 0 = 0 = 0 $ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $0 \qquad \frac{\sqrt{2}}{t_1 + 2k^2 t_1} \qquad \frac{-2k^2 r_5 + t_1}{(t_1 + 2k^2 t_1)^2} \qquad 0 \qquad -\frac{i\sqrt{2}k(2k^2 r_5 + t_1)}{(t_1 + 2k^2 t_1)^2}$ | 0 0 0 0 | $0 \qquad -\frac{2ik}{2} \frac{i\sqrt{2}k(2k^2r_5t_1)}{2} \qquad 0 \qquad \frac{-4k^4r_5+2k^2t_1}{2}$ |
|--|--------------------------------|--|--|---|---|---------|---|
| $\sigma_{1}^{\#2}$ | $-\frac{\sqrt{2}}{t_1+k^2t_1}$ | $\frac{-2k^2r_5+t_1}{(1+k^2)^2t_1^2} - \frac{i}{2}$ | $\frac{i(2k^3r_5-kt_1)}{(1+k^2)^2t_1^2} = \frac{-2}{(1+k^2)^2}$ | 0 | 0 | 0 | 0 |
| $\sigma_{1}^{\#1}\alpha\beta$ | $ + \alpha \beta = 0$ | $-\alpha\beta - \frac{\sqrt{2}}{t_1 + k^2 t_1}$ | $\dagger^{\alpha\beta} \frac{i\sqrt{2} k}{t_1 + k^2 t_1}$ | 0 | 0 | 0 | 0 |

| 7 | | | | | | | | | | | _ | | |
|---------------------------------------|-------------------------|---|--|--|--|--|--|---|--|--|-----------------------------|--|---------|
| $(t_1 + 2 k^2 t_1)^2$ | | | | $^{x}f_{1}\theta$ | + | | | | | | $\omega_{0}^{\#1}$ | 0 | (|
| | | | | - 2 <i>d</i> | $\theta^{f^{\alpha_{l}}}$ | | | | α) | ţ | $f_{0}^{\#1}$ $f_{0}^{\#2}$ | 0 | (|
| , | | | α, | $\theta^{f_{\theta}}$ | $\sigma_{\alpha \beta}$ | + | | | $^{0}\omega^{6}$ | [] X | +1 | kt_1 | ٠ , |
| t ₁) ² | | | , d'f | α^{α} | $+ \partial_{\theta} f$ | $f^{\alpha\prime}))$ | + θθλ | | θ -2 | dy c | f_0^* | $i\sqrt{2}kt_1$ | . 212 |
| $t_1 + 2k^2 t_1$ $(t_1 + 2k^2 t_1)^2$ | | | $+4 \omega_{, \epsilon}^{\theta}$ | $^{\theta} + 4 \partial' f$ | $^{\alpha\theta}\partial^{\theta}f^{\alpha\prime}$ | $^{1\theta} + 2 \theta^{\theta}$ | $^{\prime\prime}_{\prime}^{\prime}^{\prime}^{\prime}^{\prime}^{\prime}^{\prime}^{\prime}^{\prime}^{\prime}^$ | + | $_{r}$ - $(\partial_{\alpha}\omega^{\alpha\prime\prime})$ | y, z]ďz | $\omega_{0}^{\#1}$ | -t ₁ | f#1 + F |
| , t ₁ | | | $g'f_{\alpha i}$ | $\partial_{	heta} f_{c}$ | + 0,f | $(\omega^{lpha_{'}}$ | $\partial_{eta}\omega$ | $\omega^{\alpha\beta l}$ | $\omega^{\alpha\prime}$ | t, x, | | | |
| ^t 1+2 <i>k</i> | | | $\alpha \theta$ | $\partial_{\iota}f^{\alpha_{l}}$ | $f_{\alpha'}$ | $ u_{\alpha\theta_I} $ | , + 5 | 3) 9 ₉ (| к дв | k,)))[| | $\omega_{0}^{\#1}\dagger$ | 7#1 |
| | | | φ. | α-2 | ε ^{θ'} θ, | +2 (| $^g\!\omega_{lpha \ell}$ | $\omega_{\alpha_{I}}$ | $\partial_{	heta}\omega_{}^{\prime}$ | $^{\lambda}_{\kappa}\omega_{ ho}$ | | | |
| , | | αβχ + | $\frac{1}{2}t_1(2\omega^{\alpha\prime}_{\alpha}\omega^{\theta}_{\theta}\!-\!4\omega^{\theta}_{\theta}\partial_{}f^{\alpha\prime}\!+\!4\omega^{\theta}_{}\partial^{\prime}f^{\alpha}_{}\!-\!$ | $2\partial_i f^{\theta}_{\ \ \ }\partial^i f^{\alpha}_{\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ $ | $\partial^{\theta}f^{\alpha\prime} - \partial_{\alpha}f_{\theta\prime}\partial^{\theta}f^{\alpha\prime} + \partial_{\imath}f_{\alpha\theta}\partial^{\theta}f^{\alpha\prime} + \partial_{\theta}f_{\alpha\prime}\partial^{\theta}f^{\alpha\prime} +$ | $\partial_{\theta} f_{,\alpha} \partial^{\theta} f^{\alpha \prime} + 2 \ \omega_{\alpha \theta \prime} \ (\omega^{\alpha \prime \theta} + 2 \partial^{\theta} f^{\alpha \prime})) +$ | $\frac{1}{3} r_2 (4 \partial_\beta \omega_{\alpha l \theta} - 2 \partial_\beta \omega_{\alpha \theta l} + 2 \partial_\beta \omega_{l \theta \alpha} - \partial_l \omega_{\alpha \beta \theta} +$ | $\partial_\theta \omega_{\alpha\beta^I} \! - \! 2 \partial_\theta \omega_{\alpha I\beta}) \partial^\theta \omega^{\alpha\beta^I} +$ | $r_{5}\left(\partial_{i}\omega_{\theta}^{\kappa}\partial^{\theta}\omega^{\alpha\prime}_{\alpha}-\partial_{\theta}\omega_{\kappa}^{\kappa}\partial^{\theta}\omega^{\alpha\prime}_{\alpha}-(\partial_{\alpha}\omega^{\alpha\prime\theta}-2\partial^{\theta}\omega^{\alpha\prime}_{\alpha})\right.$ | $(\partial_{\kappa}\omega_{_{_{_{_{_{_{_{_{_{_{_{_{_{_{_{_{_{_{$ | $\omega_1^{\#}$ | ¹ / ₊ † ^{αμ} ² / ₊ † ^{αμ} ¹ / | 3 |
| | _ | × a | Ω ε | 2 | | ∂_{θ} | (4 0 ₆ | θ_{θ} | ω_{θ} | | $\omega_1^{\#}$ | $^{2}_{+}$ $\dagger^{\alpha\mu}$ | 3 |
| , | Quadratic (free) action | $S == \iiint (f^{\alpha\beta} \tau_{\alpha\beta} + \omega^{\alpha\beta\chi} \sigma_{\alpha\beta\chi} +$ | $\frac{1}{2}t_{1}$ (| | | | $\frac{1}{3}$ r_2 | | r ₅ (0, | | $f_{1}^{\#}$ | ¹ † ^{αμ} | 3 |
| | (ee) | $\tau_{\alpha\beta}$ | | | | | | | | | ω | #1 † | ľ |
| , | tic (fr | $\int \int (f^{\alpha eta})$ | | | | | | | | | ω | #2 †° | γ |
| - - , | adra | = [[] | | | | | | | | | f | - #1 †° #2 †° | ¥ |
| ⊣ | Ŏ | 2 | | | | | | | | | f | #2 †° | Υ |

| $f_0^{\#}$ | 0 | 0 | 0 | 0 | | | | | | | | $\alpha\beta$ | $\frac{2}{2}k$ | 2)2 12 | | | |
|--------------------|------------------------------|-----------------|--------------------------|---------------------------|------------------------|----------------------------------|---|----------------------------|-----------|---------------------------------|--------------------|------------------------------------|---|--|--|---------------------------|--|
| f_{0}^{*} | $\bar{i}\sqrt{2}kt_1$ | $-2 k^2 t_1$ | 0 | 0 | | | $\omega_{2^{+}lphaeta}^{\sharp 1}$ | f#1 | , | .,#1 | | $\tau_{2}^{\#1}_{\alpha\beta}$ | $-\frac{2 i \sqrt{2} k}{(1+2 k^2)^2 t}$ | $\frac{4k^2}{(1+2k^2)^2t_1}$ | 0 | | |
| $\omega_0^{* \pm}$ | $-t_1$ $ $ $ar{\it l}$. | $\sqrt{2} kt_1$ | 0 | 0 | ω | $_{2}^{\sharp1}$ † lphaeta | $\frac{\omega_2^+ \alpha \beta}{\frac{t_1}{2}}$ | $-\frac{i kt_1}{\sqrt{2}}$ | | 0 ₂ - _{αβ;} | X | $\sigma_{2}^{\#1}{}_{\alpha\beta}$ | $\frac{2}{1+2k^2)^2t_1}$ | $\frac{2i\sqrt{2}k}{(1+2k^2)^2t_1}$ | 0 | | |
| 3 | | <u> –</u> | | _ | f_{z}^{z} | $_{2}^{\#1}$ † $^{\alpha \beta}$ | $\frac{i k t_1}{\sqrt{2}}$ | $k^2 t_1$ | L | 0 | | | $-\alpha\beta$ | $+^{\alpha\beta}$ | $\chi g \chi$ | | |
| | $\omega_{0}^{\#1}\dagger$ | $f_0^{\#1}$ † | $f_{0}^{\#2} \uparrow$ | $\omega_{0}^{\#1}\dagger$ | $\omega_2^{\#}$ | 1 † $^{\alpha\beta\chi}$ | 0 | 0 | | <u>t</u> 1 2 | | | $\sigma_2^{\#1}$ † | $\tau_{2}^{\#1}$ 1 | $\sigma_{2}^{\#1} +^{\alpha\beta\chi}$ | | |
| | | ω | #1 1 ⁺ αβ | ω_1^{\sharp} | ‡2 .+ αβ | $f_{1}^{\#1}{}_{\alpha\beta}$ | $\omega_{1}^{\#1}$ a | ω_1^{\sharp} | ‡2 . α | $f_{1-\alpha}^{\#1}$ | $f_{1}^{#2}\alpha$ | $\sigma_{0^{	ext{-}1}}^{\#1}$ | 0 | 0 | 0 | $\frac{1}{k^2 r_2 - t_1}$ | |
| $\omega_1^{\#}$ | ¹ † ^{αμ} | k^2 | $r_5 - \frac{t_1}{2}$ | <u>.</u> | $\frac{t_1}{\sqrt{2}}$ | $-\frac{ikt_1}{\sqrt{2}}$ | 0 | (|) | 0 | 0 | | | | | | |
| $\omega_1^{\#_2}$ | ² † ^{αμ} | 3 | $\frac{t_1}{\sqrt{2}}$ | | 0 | 0 | 0 | (|) | 0 | 0 | $\tau_0^{\#2}$ | _ 0 _1 | $\begin{bmatrix} - \\ t_1 \end{bmatrix} 0$ | 0 | 0 | |
| $f_{1}^{\#}$ | ¹ † ^{αμ} | 3 | $\frac{ikt_1}{\sqrt{2}}$ | | 0 | 0 | 0 | (|) | 0 | 0 | $\tau_0^{\#1}$ | $i \sqrt{2} k $ (1+2 k ²) ² t ₁ | $\frac{2k^2}{(1+2k^2)^2t_1}$ | 0 | 0 | |
| ω | #1 † | γ | 0 | | 0 | 0 | $k^2 r_5 - \frac{t}{2}$ | $\frac{1}{2}$ $\frac{t}{}$ | <u>1</u> | 0 | Īkt1 | | · | 1 | | | |
| ω | #2 †° | χ | 0 | | 0 | 0 | $\frac{t_1}{\sqrt{2}}$ | (|) | 0 | 0 | $\sigma_{0}^{\#1}$ | $\frac{1}{(1+2k^2)^2t_1}$ | $\frac{i\sqrt{2}k}{(1+2k^2)^2t_1}$ | 0 | 0 | |
| f | #1 † | γ | 0 | | 0 | 0 | 0 | (|) | 0 | 0 | | - (1+ | i | | | |
| f | #2 †° | γ | 0 | | 0 | 0 | - ī k t 1 | . (|) | 0 | 0 | | $\sigma_{0}^{\#1}$ † | $\tau_0^{\#1}$ † | $\tau_{0}^{\#2}$ † | $\sigma_{0}^{\#1}$ † | |

Massive and massless spectra

Massive particle
Pole residue:
$$-\frac{1}{r_2} > 0$$
Polarisations: 1
Square mass: $\frac{t_1}{r_2} > 0$
Spin: 0
Parity: Odd

(No massless particles)

Unitarity conditions

 $r_2 < 0 \&\& t_1 < 0$