# Particle spectrograph

## Wave operator and propagator

| | $\sigma_{1^-}^{\#1}{}_{\alpha}$ | $\sigma_{1^-}^{\#2}{}_{\alpha}$ | $\tau_{1^-}^{\#1}{}_{\alpha}$ | $\tau_{1^-}^{\#2}{}_{\alpha}$ |
|---|---|---|---|---|
| $\sigma_{1^+}^{\#1}{}^{\alpha\beta}$ | 0 | 0 | 0 | 0 |
| $\sigma_{1^+}^{\#2}{}^{\alpha\beta}$ | 0 | 0 | 0 | 0 |
| $\tau_{1^+}^{\#1}{}^{\alpha\beta}$ | 0 | 0 | 0 | 0 |
| $\sigma_{1^-}^{\#1}{}^{\alpha}$ | $\frac{2}{k^2 (r_3+2 r_5)}$ | $\frac{2\sqrt{2}}{k^2 (1+2k^2)(r_3+2r_5)}$ | 0 | $\frac{4i}{k(1+2k^2)(r_3+2r_5)}$ |
| $\sigma_{1^-}^{\#2}{}^{\alpha}$ | $\frac{2\sqrt{2}}{k^2 (1+2k^2)(r_3+2r_5)}$ | $\frac{3k^2(r_3+2r_5)+4t_3}{(k+2k^3)^2(r_3+2r_5)t_3}$ | 0 | $\frac{i\sqrt{2}\,(3k^2(r_3+2r_5)+4t_3)}{k(1+2k^2)^2(r_3+2r_5)t_3}$ |
| $\tau_{1^-}^{\#1}{}^{\alpha}$ | 0 | 0 | 0 | 0 |
| $\tau_{1^-}^{\#2}{}^{\alpha}$ | $\frac{4i}{k(1+2k^2)(r_3+2r_5)}$ | $-\frac{i\sqrt{2}\,(3k^2(r_3+2r_5)+4t_3)}{k(1+2k^2)^2(r_3+2r_5)t_3}$ | 0 | $\frac{6k^2(r_3+2r_5)+8t_3}{(1+2k^2)^2(r_3+2r_5)t_3}$ |

| | $\omega_{1^-}^{\#1}{}_{\alpha}$ | $\omega_{1^-}^{\#2}{}_{\alpha}$ | $f_{1^-}^{\#1}{}_{\alpha}$ | $f_{1^-}^{\#2}{}_{\alpha}$ |
|---|---|---|---|---|
| $\omega_{1^+}^{\#1}{}^{\alpha\beta}$ | 0 | 0 | 0 | 0 |
| $\omega_{1^+}^{\#2}{}^{\alpha\beta}$ | 0 | 0 | 0 | 0 |
| $f_{1^+}^{\#1}{}^{\alpha\beta}$ | 0 | 0 | 0 | 0 |
| $\omega_{1^-}^{\#1}{}^{\alpha}$ | $k^2\left(\frac{r_3}{2}+r_5\right)+\frac{2t_3}{3}$ | $-\frac{\sqrt{2}\,t_3}{3}$ | 0 | $-\frac{2}{3}i\,k\,t_3$ |
| $\omega_{1^-}^{\#2}{}^{\alpha}$ | $-\frac{\sqrt{2}\,t_3}{3}$ | $\frac{t_3}{3}$ | 0 | $\frac{1}{3}i\sqrt{2}\,k\,t_3$ |
| $f_{1^-}^{\#1}{}^{\alpha}$ | 0 | 0 | 0 | 0 |
| $f_{1^-}^{\#2}{}^{\alpha}$ | $\frac{2ik\,t_3}{3}$ | $-\frac{1}{3}i\sqrt{2}\,k\,t_3$ | 0 | $\frac{2k^2 t_3}{3}$ |

Quadratic (free) action

$$S = \iiint (f^{\alpha\beta}\,\tau_{\alpha\beta} + \omega^{\alpha\beta\chi}\,\sigma_{\alpha\beta\chi} - \frac{1}{2} r_3 (\partial_\beta \omega_{\iota\ \theta}^{\ \theta}\,\partial^\prime \omega^{\alpha\beta}_{\ \ \alpha} + \partial_\iota \omega_\beta^{\ \theta}\,\partial^\prime \omega^{\alpha\beta}_{\ \ \alpha} + 8\,\partial_\beta \omega_{\iota\theta\alpha}\,\partial^\theta \omega^{\alpha\beta\iota}) - 2\,\partial^\prime \omega^{\alpha\beta}_{\ \ \alpha}\,\partial_\theta \omega_{\iota\ \beta}^{\ \theta} + 8\,\partial_\beta \omega_{\iota\theta\alpha}\,\partial^\theta \omega^{\alpha\beta\iota}) - 2\,\partial^\prime \omega^{\alpha\beta}_{\ \ \alpha}\,\partial_\theta \omega_{\iota\ \beta}^{\ \theta} + \partial_\alpha \omega^{\alpha\beta\iota}\,\partial_\theta \omega_{\iota\ \beta}^{\ \theta} - 2\,\partial^\prime \omega^{\alpha\beta}_{\ \ \alpha}\,\partial_\theta \omega_{\iota\ \beta}^{\ \theta} + \frac{2}{3} t_3 (\omega^{\alpha\iota}_{\ \ \alpha}\,\omega_{\iota\ \kappa}^{\ \kappa} - 2\,\omega_{\alpha\ \kappa}^{\ \kappa}\,\partial_\iota f^{\alpha\iota} + 2\,\omega_{\iota\ \kappa}^{\ \kappa}\,\partial_\iota f^{\alpha\iota} + \partial_\iota f^{\alpha\iota}\,\partial_\kappa f_\alpha^{\ \kappa}) + 2\,\partial^\prime f^{\alpha\iota}_{\ \ \alpha}\,\partial_\kappa f_\iota^{\ \kappa}) + r_5 (\partial_\iota \omega_\theta^{\ \kappa}\,\partial^\theta \omega^{\alpha\iota}_{\ \ \alpha} - \partial_\theta \omega_{\iota\ \kappa}^{\ \kappa}\,\partial^\theta \omega^{\alpha\iota}_{\ \ \alpha} - (\partial_\alpha \omega^{\alpha\iota\theta} - 2\,\partial^\theta \omega^{\alpha\iota}_{\ \ \alpha})\,(\partial_\kappa \omega_{\iota\ \theta}^{\ \kappa} - \partial_\kappa \omega_{\theta\ \iota}^{\ \kappa}))][t, x, y, z]\,dz\,dy\,dx\,dt$$

| | $\sigma_{0^+}^{\#1}$ | $\tau_{0^+}^{\#1}$ | $\tau_{0^+}^{\#2}$ | $\sigma_{0^-}^{\#1}$ |
|---|---|---|---|---|
| $\sigma_{0^+}^{\#1}\dagger$ | $\frac{1}{(1+2k^2)^2 t_3}$ | $-\frac{i\sqrt{2}\,k}{(1+2k^2)^2 t_3}$ | 0 | 0 |
| $\tau_{0^+}^{\#1}\dagger$ | $\frac{i\sqrt{2}\,k}{(1+2k^2)^2 t_3}$ | $\frac{2k^2}{(1+2k^2)^2 t_3}$ | 0 | 0 |
| $\tau_{0^+}^{\#2}\dagger$ | 0 | 0 | 0 | 0 |
| $\sigma_{0^-}^{\#1}\dagger$ | 0 | 0 | 0 | 0 |

| | $\omega_{2^+}^{\#1}{}^{\alpha\beta}$ | $f_{2^+}^{\#1}{}^{\alpha\beta}$ | $\omega_{2^-}^{\#1}{}^{\alpha\beta\chi}$ |
|---|---|---|---|
| $\omega_{2^+}^{\#1}{}^{\alpha\beta}\dagger$ | $-\frac{3k^2 r_3}{2}$ | 0 | 0 |
| $f_{2^+}^{\#1}{}^{\alpha\beta}\dagger$ | 0 | 0 | 0 |
| $\omega_{2^-}^{\#1}{}^{\alpha\beta\chi}\dagger$ | 0 | 0 | 0 |

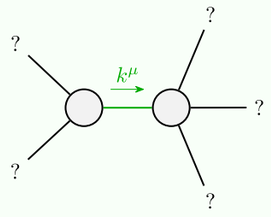
| | $\sigma_{2^+}^{\#1}{}^{\alpha\beta}$ | $\tau_{2^+}^{\#1}{}^{\alpha\beta}$ | $\sigma_{2^-}^{\#1}{}^{\alpha\beta\chi}$ |
|---|---|---|---|
| $\sigma_{2^+}^{\#1}{}^{\alpha\beta}\dagger$ | $-\frac{2}{3k^2 r_3}$ | 0 | 0 |
| $\tau_{2^+}^{\#1}{}^{\alpha\beta}\dagger$ | 0 | 0 | 0 |
| $\sigma_{2^-}^{\#1}{}^{\alpha\beta\chi}\dagger$ | 0 | 0 | 0 |

| | $\omega_{0^+}^{\#1}$ | $f_{0^+}^{\#1}$ | $f_{0^+}^{\#2}$ | $\omega_{0^-}^{\#1}$ |
|---|---|---|---|---|
| $\omega_{0^+}^{\#1}\dagger$ | $t_3$ | $-i\sqrt{2}\,k\,t_3$ | 0 | 0 |
| $f_{0^+}^{\#1}\dagger$ | $i\sqrt{2}\,k\,t_3$ | $2k^2 t_3$ | 0 | 0 |
| $f_{0^+}^{\#2}\dagger$ | 0 | 0 | 0 | 0 |
| $\omega_{0^-}^{\#1}\dagger$ | 0 | 0 | 0 | 0 |

Source constraints/gauge generators

| SO(3) irreps | Multiplicities |
|---|---|
| $\sigma_{0^-}^{\#1} == 0$ | 1 |
| $\tau_{0^+}^{\#2} == 0$ | 1 |
| $\tau_{0^+}^{\#1} - 2\,i\,k\,\sigma_{0^+}^{\#1} == 0$ | 1 |
| $\tau_{1^-}^{\#2\,\alpha} + 2\,i\,k\,\sigma_{1^-}^{\#2\,\alpha} == 0$ | 3 |
| $\tau_{1^-}^{\#1\,\alpha} == 0$ | 3 |
| $\tau_{1^+}^{\#1\,\alpha\beta} == 0$ | 3 |
| $\sigma_{1^+}^{\#2\,\alpha\beta} == 0$ | 3 |
| $\sigma_{2^-}^{\#1\,\alpha\beta\chi} == 0$ | 5 |
| $\tau_{2^+}^{\#1\,\alpha\beta} == 0$ | 5 |
| Total constraints: | 25 |

## Massive and massless spectra




Quadratic pole

| | |
|---|---|
| Pole residue: | $-\frac{1}{r_3 (2 r_3+r_5)(r_3+2 r_5) p^2} > 0$ |
| Polarisations: | 2 |

(No massive particles)

## Unitarity conditions

$$r_3 < 0 \,\&\&\, (r_5 < -\frac{r_3}{2} \,||\, r_5 > -2\,r_3) \,||\, r_3 > 0 \,\&\&\, -2\,r_3 < r_5 < -\frac{r_3}{2}$$