

# Particle spectrograph

## Wave operator and propagator

Quadratic (free) action

S==  
$$\begin{aligned} & \iiint (\frac{1}{6} (6 f^{\alpha\beta} \tau_{\alpha\beta} + 6 \omega^{\alpha\beta\chi} \sigma_{\alpha\beta\chi} - 3 r_3 \partial_\beta \omega_{\phantom{\beta}\theta}^{\phantom{\beta}\theta} \partial'_\theta \omega^{\alpha\beta}_{\phantom{\alpha\beta}\alpha} - 3 r_3 \partial_\theta \omega_{\phantom{\theta}\beta}^{\phantom{\theta}\theta} \partial'_\beta \omega^{\alpha\beta}_{\phantom{\alpha\beta}\alpha} - 3 \\ & r_3 \partial_\alpha \omega^{\alpha\beta\gamma} \partial_\theta \omega_{\phantom{\theta}\beta}^{\phantom{\theta}\theta} + 6 r_3 \partial'_\theta \omega^{\alpha\beta}_{\phantom{\alpha\beta}\alpha} \partial_\theta \omega_{\phantom{\theta}\beta}^{\phantom{\theta}\theta} - 3 r_3 \partial_\alpha \omega^{\alpha\beta\gamma} \partial_\theta \omega_{\phantom{\theta}\beta}^{\phantom{\theta}\theta} + \\ & 6 r_3 \partial'_\theta \omega^{\alpha\beta}_{\phantom{\alpha\beta}\alpha} \partial_\theta \omega_{\phantom{\theta}\beta}^{\phantom{\theta}\theta} + 4 t_2 \omega_{\phantom{\theta}\beta}^{\phantom{\theta}\theta} \partial_\theta \omega^{\alpha\beta}_{\phantom{\alpha\beta}\alpha} + 2 t_2 \partial_\alpha f_{\phantom{\alpha}\theta}^{\phantom{\alpha}\theta} \partial^\theta f^{\alpha\beta}_{\phantom{\alpha\beta}\alpha} - t_2 \partial_\alpha f_{\phantom{\alpha}\theta}^{\phantom{\alpha}\theta} \partial^\theta f^{\alpha\beta}_{\phantom{\alpha\beta}\alpha} - \\ & t_2 \partial_\theta f_{\phantom{\theta}\alpha}^{\phantom{\theta}\alpha} \partial^\alpha f^{\alpha\beta}_{\phantom{\alpha\beta}\alpha} + t_2 \partial_\theta f_{\phantom{\theta}\alpha}^{\phantom{\theta}\alpha} \partial^\alpha f^{\alpha\beta}_{\phantom{\alpha\beta}\alpha} - t_2 \partial_\theta f_{\phantom{\theta}\alpha}^{\phantom{\theta}\alpha} \partial^\alpha f^{\alpha\beta}_{\phantom{\alpha\beta}\alpha} - 4 t_2 \omega_{\phantom{\theta}\alpha}^{\phantom{\theta}\alpha} (\omega^{\alpha\theta} + 2 \partial^\theta f^{\alpha\beta}_{\phantom{\alpha\beta}\alpha}) + 8 r_2 \partial_\beta \omega_{\phantom{\beta}\alpha}^{\phantom{\beta}\alpha} \partial^\theta \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} - 4 r_2 \partial_\beta \omega_{\phantom{\beta}\alpha}^{\phantom{\beta}\alpha} \partial^\theta \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} + \\ & 2 t_2 \omega_{\phantom{\theta}\alpha}^{\phantom{\theta}\alpha} (\omega^{\alpha\theta} + 2 \partial^\theta f^{\alpha\beta}_{\phantom{\alpha\beta}\alpha}) + 8 r_2 \partial_\beta \omega_{\phantom{\beta}\alpha}^{\phantom{\beta}\alpha} \partial^\theta \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} - 4 r_2 \partial_\beta \omega_{\phantom{\beta}\alpha}^{\phantom{\beta}\alpha} \partial^\theta \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} + \\ & 4 r_2 \partial_\beta \omega_{\phantom{\beta}\alpha}^{\phantom{\beta}\alpha} \partial^\theta \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} - 24 r_3 \partial_\beta \omega_{\phantom{\beta}\alpha}^{\phantom{\beta}\alpha} \partial^\theta \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} - 2 r_2 \partial_\theta \omega_{\phantom{\theta}\alpha}^{\phantom{\theta}\alpha} \partial^\alpha \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} + 6 r_5 \partial_\theta \omega_{\phantom{\theta}\alpha}^{\phantom{\theta}\alpha} \partial^\alpha \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} - \\ & 2 r_2 \partial_\theta \omega_{\phantom{\theta}\alpha}^{\phantom{\theta}\alpha} \partial^\alpha \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} - 4 r_2 \partial_\theta \omega_{\phantom{\theta}\alpha}^{\phantom{\theta}\alpha} \partial^\alpha \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} + 6 r_5 \partial_\theta \omega_{\phantom{\theta}\alpha}^{\phantom{\theta}\alpha} \partial^\alpha \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} - \\ & 6 r_5 \partial_\theta \omega_{\phantom{\theta}\alpha}^{\phantom{\theta}\alpha} \partial^\alpha \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} - 6 r_5 \partial_\alpha \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} \partial_\theta \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} + 12 r_5 \partial^\theta \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} \partial_\theta \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} + \\ & 6 r_5 \partial_\alpha \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} \partial_\theta \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} - 12 r_5 \partial^\theta \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} \partial_\theta \omega^{\alpha\beta\gamma}_{\phantom{\alpha\beta\gamma}\alpha} ) [t, x, y, z] dz dy dx dt \end{aligned}$$

$\sigma_{1+}^{\#1} \dagger^{\alpha\beta}$	$\sigma_{1+}^{\#2} \dagger^{\alpha\beta}$	$\tau_{1+}^{\#1} \dagger^{\alpha\beta}$	$\sigma_{1-}^{\#1} \dagger^{\alpha}$	$\sigma_{1-}^{\#2} \dagger^{\alpha}$	$\tau_{1-}^{\#1} \dagger^{\alpha}$	$\tau_{1-}^{\#2} \dagger^{\alpha}$
$\frac{1}{k^2 (2r_3+r_5)}$	$-\frac{\sqrt{2}}{k^2 (1+k^2) (2r_3+r_5)}$	$-\frac{i \sqrt{2}}{k (1+k^2) (2r_3+r_5)}$	0	0	0	0
$-\frac{\sqrt{2}}{k^2 (1+k^2) (2r_3+r_5)}$	$\frac{3k^2 (2r_3+r_5)+2t_2}{(k+k^3)^2 (2r_3+r_5)t_2}$	$\frac{i (3k^2 (2r_3+r_5)+2t_2)}{k (1+k^2)^2 (2r_3+r_5)t_2}$	0	0	0	0
$\frac{i \sqrt{2}}{k (1+k^2) (2r_3+r_5)}$	$-\frac{i (3k^2 (2r_3+r_5)+2t_2)}{k (1+k^2)^2 (2r_3+r_5)t_2}$	$\frac{3k^2 (2r_3+r_5)+2t_2}{(1+k^2)^2 (2r_3+r_5)t_2}$	0	0	0	0
0	0	0	$\frac{2}{k^2 (r_3+2r_5)}$	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

$\omega_{1+}^{\#1} \dagger^{\alpha\beta}$	$\omega_{1+}^{\#2} \dagger^{\alpha\beta}$	$f_{1+}^{\#1} \dagger^{\alpha\beta}$	$\omega_{1-}^{\#1} \dagger^{\alpha}$	$\omega_{1-}^{\#2} \dagger^{\alpha}$	$f_{1-}^{\#1} \dagger^{\alpha}$	$f_{1-}^{\#2} \dagger^{\alpha}$
$k^2 (2r_3+r_5) + \frac{2t_2}{3}$	$\frac{\sqrt{2} t_2}{3}$	$\frac{1}{3} i \sqrt{2} k t_2$	0	0	0	0
$\frac{\sqrt{2} t_2}{3}$	$\frac{t_2}{3}$	$\frac{i k t_2}{3}$	0	0	0	0
$-\frac{1}{3} i \sqrt{2} k t_2$	$-\frac{1}{3} i k t_2$	$\frac{k^2 t_2}{3}$	0	0	0	0
0	0	0	$\frac{1}{2} k^2 (r_3+2r_5)$	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

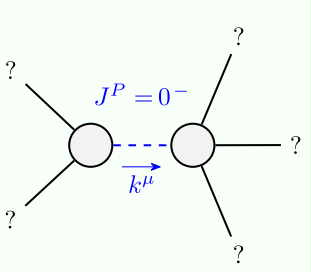
Source constraints/gauge generators	Multiplicities
$\tau_{0+}^{\#2} == 0$	1
$\tau_{0+}^{\#1} == 0$	1
$\sigma_{0+}^{\#1} == 0$	1
$\tau_{1-}^{\#2\alpha} == 0$	3
$\tau_{1-}^{\#1\alpha} == 0$	3
$\sigma_{1-}^{\#2\alpha} == 0$	3
$\tau_{1+}^{\#1\alpha\beta} + i k \sigma_{1+}^{\#2\alpha\beta} == 0$	3
$\sigma_{2-}^{\#1\alpha\beta\chi} == 0$	5
$\tau_{2+}^{\#1\alpha\beta} == 0$	5
Total constraints:	25

$\sigma_{0+}^{\#1} \dagger$	$\tau_{0+}^{\#1} \dagger$	$\tau_{0+}^{\#2} \dagger$	$\sigma_{0-}^{\#1} \dagger$
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	$\frac{1}{k^2 r_2+t_2}$

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

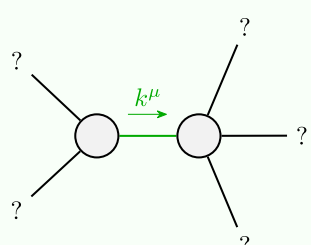
$\omega_{2+}^{\#1} \dagger^{\alpha\beta}$	$\omega_{2+}^{\#1} \dagger^{\alpha\beta}$	$\omega_{2-}^{\#1} \dagger^{\alpha\beta\chi}$	$\omega_{0+}^{\#1} \dagger^{\alpha}$	$\omega_{0+}^{\#1} \dagger^{\alpha}$	$\omega_{0-}^{\#1} \dagger^{\alpha}$
$-\frac{3k^2 r_3}{2}$	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	$k^2 r_2+t_2$

## Massive and massless spectra



Massive particle

Pole residue:	$-\frac{1}{r_2} > 0$
Polarisations:	1
Square mass:	$-\frac{t_2}{r_2} > 0$
Spin:	0
Parity:	Odd



Quadratic pole

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

## Unitarity conditions

$$r_2 < 0 \& \& r_3 < 0 \& \& r_5 < -\frac{r_3}{2} \& \& t_2 > 0 \parallel r_2 < 0 \& \& r_3 < 0 \& \& r_5 > -2r_3 \& \& t_2 > 0 \parallel r_2 < 0 \& \& r_3 > 0 \& \& -2r_3 < r_5 < -\frac{r_3}{2} \& \& t_2 > 0$$