Particle spectrograph

Wave operator and propagator

Source constraints/gauge generators

SO(3) irreps	Multiplicities
$\sigma_{0^-}^{\#1} == 0$	1
$\tau_{0^+}^{\#2} == 0$	1
$\tau_{0^+}^{\#1} - 2ik\,\sigma_{0^+}^{\#1} == 0$	1
$\tau_{1^-}^{\#2\,\alpha} + 2ik\,\sigma_{1^-}^{\#2\,\alpha} == 0$	3
$\tau_{1^-}^{\#1\,\alpha} == 0$	3
$\tau_{1^+}^{\#1\,\alpha\beta} + ik\,\sigma_{1^+}^{\#2\,\alpha\beta} == 0$	3
$\tau_{2^+}^{\#1\,\alpha\beta} - 2ik\,\sigma_{2^+}^{\#1\,\alpha\beta} == 0$	5
Total constraints:	17

Propagator ($0^+/0^-$ source sector):

	$\sigma_{0^+}^{\#1}$	$\tau_{0^+}^{\#1}$	$\tau_{0^+}^{\#2}$	$\sigma_{0^-}^{\#1}$
$\sigma_{0^+}^{\#1}\dagger$	$-\frac{1}{(1+2k^2)^2 t_1}$	$\frac{i\sqrt{2}\,k}{(1+2k^2)^2 t_1}$	0	0
$\tau_{0^+}^{\#1}\dagger$	$\frac{i\sqrt{2}\,k}{(1+2k^2)^2 t_1}$	$-\frac{2k^2}{(1+2k^2)^2 t_1}$	0	0
$\tau_{0^+}^{\#2}\dagger$	0	0	0	0
$\sigma_{0^-}^{\#1}\dagger$	0	0	0	0

Propagator ($2^+/2^-$ source sector):

	$\sigma_{2^+}^{\#1}{}_{\alpha\beta}$	$\tau_{2^+}^{\#1}{}_{\alpha\beta}$	$\sigma_{2^-}^{\#1}{}_{\alpha\beta\chi}$
$\sigma_{2^+}^{\#1}\dagger^{\alpha\beta}$	$\frac{2}{(1+2k^2)^2 t_1}$	$-\frac{2i\sqrt{2}\,k}{(1+2k^2)^2 t_1}$	0
$\tau_{2^+}^{\#1}\dagger^{\alpha\beta}$	$\frac{2i\sqrt{2}\,k}{(1+2k^2)^2 t_1}$	$\frac{4k^2}{(1+2k^2)^2 t_1}$	0
$\sigma_{2^-}^{\#1}\dagger^{\alpha\beta\chi}$	0	0	$\frac{2}{2k^2 r_1 + t_1}$

Wave operator ($2^+/2^-$ field sector):

|	$\omega_{2^+}^{\#1}{}_{\alpha\beta}$	$f_{2^+}^{\#1}{}_{\alpha\beta}$	$\omega_{2^-}^{\#1}{}_{\alpha\beta\chi}$
$\omega_{2^+}^{\#1}\dagger^{\alpha\beta}$	$\frac{t_1}{2}$	$-\frac{ikt_1}{\sqrt{2}}$	0
$f_{2^+}^{\#1}\dagger^{\alpha\beta}$	$\frac{ikt_1}{\sqrt{2}}$	$k^2 t_1$	0
$\omega_{2^-}^{\#1}\dagger^{\alpha\beta\chi}$	0	0	$k^2 r_1 + \frac{t_1}{2}$

Wave operator ($0^+/0^-$ field sector):

	$\omega_{0^+}^{\#1}\dagger$	$f_{0^+}^{\#1}\dagger$	$f_{0^+}^{\#2}\dagger$	$\omega_{0^-}^{\#1}\dagger$
$f_{0^+}^{\#2}$	0	0	0	0
$f_{0^+}^{\#1}$	$i\sqrt{2}\,kt_1$	$-2k^2 t_1$	0	0
$\omega_{0^+}^{\#1}$	$-t_1$	$-i\sqrt{2}\,kt_1$	0	0

Wave operator ($1^\pm$ source sector):

	$\sigma_{1^+}^{\#1}\dagger^{\alpha\beta}$	$\sigma_{1^+}^{\#2}\dagger^{\alpha\beta}$	$\tau_{1^+}^{\#1}\dagger^{\alpha\beta}$	$\sigma_{1^-}^{\#1}\dagger^{\alpha}$	$\sigma_{1^-}^{\#2}\dagger^{\alpha}$	$\tau_{1^-}^{\#1}\dagger^{\alpha}$	$\tau_{1^-}^{\#2}\dagger^{\alpha}$
$\tau_{1^-}^{\#2}{}_\alpha$	0	0	0	$\frac{2ik}{t_1+2k^2 t_1}$	$-\frac{i\sqrt{2}\,k(2k^2(r_1+r_5)-t_1)}{(t_1+2k^2 t_1)^2}$	0	$-\frac{4k^4(r_1+r_5)+2k^2 t_1}{(t_1+2k^2 t_1)^2}$
$\tau_{1^-}^{\#1}{}_\alpha$	0	0	0	0	0	0	0
$\sigma_{1^-}^{\#2}{}_\alpha$	0	0	0	$\frac{\sqrt{2}}{t_1+2k^2 t_1}$	$-\frac{2k^2(r_1+r_5)+t_1}{(t_1+2k^2 t_1)^2}$	0	$\frac{i\sqrt{2}\,k(2k^2(r_1+r_5)-t_1)}{(t_1+2k^2 t_1)^2}$
$\sigma_{1^-}^{\#1}{}_\alpha$	0	0	0	0	$\frac{\sqrt{2}}{t_1+2k^2 t_1}$	0	$-\frac{2ik}{t_1+2k^2 t_1}$
$\tau_{1^+}^{\#1}{}_{\alpha\beta}$	$\frac{i}{\sqrt{2}(k+k^3)(2r_1+r_5)}$	$\frac{i(6k^2(2r_1+r_5)+t_1)}{2k(1+k^2)^2(2r_1+r_5)t_1}$	$\frac{6k^2(2r_1+r_5)+t_1}{2(1+k^2)^2(2r_1+r_5)t_1}$	0	0	0	0
$\sigma_{1^+}^{\#2}{}_{\alpha\beta}$	$\frac{1}{\sqrt{2}(k^2+k^4)(2r_1+r_5)}$	$\frac{6k^2(2r_1+r_5)+t_1}{2(k+k^3)^2(2r_1+r_5)t_1}$	$-\frac{i(6k^2(2r_1+r_5)+t_1)}{2k(1+k^2)^2(2r_1+r_5)t_1}$	0	0	0	0
$\sigma_{1^+}^{\#1}{}_{\alpha\beta}$	$\frac{1}{k^2(2r_1+r_5)}$	$\frac{1}{\sqrt{2}(k^2+k^4)(2r_1+r_5)}$	$-\frac{i}{\sqrt{2}(k+k^3)(2r_1+r_5)}$	0	0	0	0

Wave operator ($1^\pm$ field sector):

	$\omega_{1^+}^{\#1}\dagger^{\alpha\beta}$	$\omega_{1^+}^{\#2}\dagger^{\alpha\beta}$	$f_{1^+}^{\#1}\dagger^{\alpha\beta}$	$\omega_{1^-}^{\#1}\dagger^{\alpha}$	$\omega_{1^-}^{\#2}\dagger^{\alpha}$	$f_{1^-}^{\#1}\dagger^{\alpha}$	$f_{1^-}^{\#2}\dagger^{\alpha}$
$f_{1^-}^{\#2}{}_\alpha$	0	0	0	ikt_1	0	0	0
$f_{1^-}^{\#1}{}_\alpha$	0	0	0	0	$\frac{t_1}{\sqrt{2}}$	0	0
$\omega_{1^-}^{\#2}{}_\alpha$	0	0	0	0	$\frac{t_1}{\sqrt{2}}$	$\frac{t_1}{\sqrt{2}}$	0
$\omega_{1^-}^{\#1}{}_\alpha$	0	0	0	$k^2(r_1+r_5)$	$\frac{t_1}{\sqrt{2}}$	0	$-ikt_1$
$f_{1^+}^{\#1}{}_{\alpha\beta}$	$-\frac{ikt_1}{3\sqrt{2}}$	$\frac{ikt_1}{3}$	$\frac{k^2 t_1}{3}$	0	0	0	0
$\omega_{1^+}^{\#2}{}_{\alpha\beta}$	$-\frac{t_1}{3\sqrt{2}}$	$\frac{t_1}{3}$	$-\frac{1}{3}ikt_1$	0	0	0	0
$\omega_{1^+}^{\#1}{}_{\alpha\beta}$	$k^2(2r_1+r_5)+\frac{t_1}{6}$	$-\frac{t_1}{3\sqrt{2}}$	$\frac{ikt_1}{3\sqrt{2}}$	0	0	0	0

Quadratic (free) action

$$S = \iiiint \Big(\tfrac{1}{3}\big(3t_1\,\omega^{\alpha\iota}{}_\alpha\,\omega_{\iota\,\theta}{}^\theta + 3f^\alpha{}_\alpha\,\tau_{\alpha\beta} + 3f^{\alpha\beta\chi}\,\sigma_{\alpha\beta\chi} - 6t_1\,\omega_\alpha{}^\theta{}_\theta\,\partial_\iota f^{\alpha\iota} + 6t_1\,\omega_{\iota\,\theta}{}^\theta$$
$$\partial_\iota f^\alpha{}_\alpha - 3t_1\,\partial_\iota f^\theta{}_\theta\,\partial^\iota f^\alpha{}_\alpha - 3t_1\,\partial_\iota f^{\alpha\iota}\,\partial_\theta f_\alpha{}^\theta + 6t_1\,\partial_\iota f_{\alpha\theta}\,\partial^\theta f^{\alpha\iota} -$$
$$2t_1\,\partial_\iota f_{\iota\theta}\,\partial^\theta f^{\alpha\iota} - 2t_1\,\partial_\iota f_{\theta\iota}\,\partial^\theta f^{\alpha\iota} + t_1\,\partial_\iota f_{\alpha\theta}\,\partial^\theta f^{\alpha\iota} + 2t_1\,\partial_\iota f_{\alpha}{}^\theta\,\partial^\theta f^{\alpha\iota} +$$
$$t_1\,\partial_\iota f_{\iota\alpha}\,\partial^\theta f^{\alpha\iota} + t_1\,\omega_{\alpha\iota\theta}(\omega^{\alpha\iota\theta} + 2\partial^\theta f^{\alpha\iota}) + t_1\,\omega_{\alpha\theta\iota}(\omega^{\alpha\iota\theta} + 4\partial^\theta f^{\alpha\iota}) -$$
$$4r_1\,\partial_\beta\omega_{\alpha\iota\theta}\,\partial^\theta\omega^{\alpha\beta\iota} + 2r_1\,\partial_\beta\omega_{\alpha\theta\iota}\,\partial^\theta\omega^{\alpha\beta\iota} - 8t_1\,\partial_\beta\omega_{\iota\theta\alpha}\,\partial^\theta\omega^{\alpha\beta\iota} -$$
$$2r_1\,\partial_\iota\omega_{\alpha\beta\theta}\,\partial^\theta\omega^{\alpha\beta\iota} + 2r_1\,\partial_\theta\omega_{\alpha\beta\iota}\,\partial^\theta\omega^{\alpha\beta\iota} +$$
$$3r_5\,\partial_\theta\omega_{\iota\,\kappa}{}^\kappa\,\partial^\theta\omega^{\alpha\iota}{}_\alpha - 3r_5\,\partial_\alpha\omega^{\alpha\iota\theta}\,\partial_\kappa\omega^\kappa{}_{\iota\,\theta} + 6r_5\,\partial^\theta\omega^{\alpha\iota}{}_\alpha$$
$$\partial_\kappa\omega^\kappa{}_{\iota\,\theta} + 3r_5\,\partial_\alpha\omega^{\alpha\iota\theta}\,\partial_\kappa\omega^\kappa{}_{\iota\,\theta} - 6r_5\,\partial^\theta\omega^{\alpha\iota}{}_\alpha\,\partial_\kappa\omega^\kappa{}_{\theta\,\iota}\big)\big)[t,x,y,z]\,dz\,dy\,dx\,dt$$

Massive and massless spectra

Massive particle ($J^P = 2^-$, momentum k^μ)
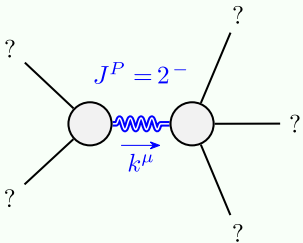
Massive particle	
Pole residue:	$-\frac{1}{r_1} > 0$
Polarisations:	5
Square mass:	$-\frac{t_1}{2r_1} > 0$
Spin:	2
Parity:	Odd

Quadratic pole (momentum k^μ)
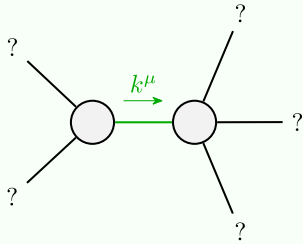
Quadratic pole	
Pole residue:	$\frac{1}{(2r_1+r_5)\,t_1^2\,p^2} > 0$
Polarisations:	2

Unitarity conditions

$r_1 < 0$ && $r_5 > -2r_1$ && $t_1 > 0$