

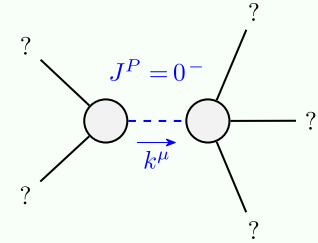
# Particle spectrograph

## Wave operator and propagator

### Quadratic (free) action

$$S_F = \iiint (\frac{1}{6} (-2t_1 \omega_{\kappa\alpha}^{\alpha\prime} \omega_{\kappa\alpha}^{\kappa} - 2(t_1 - 2t_2) \omega_{\kappa\lambda}^{\kappa\prime} \omega_{\kappa\lambda}^{\lambda\prime} + 2t_1 \omega_{\kappa\lambda}^{\lambda\prime} \omega_{\kappa\lambda}^{\kappa\prime} + 6 f^{\alpha\beta} \tau_{\alpha\beta} + 6 \omega^{\alpha\beta\chi} \sigma_{\alpha\beta\chi} + 4 r_2 \partial^\beta \omega_{\kappa}^{\theta\alpha} \partial_\theta \omega_{\alpha\beta}^{\kappa} - 2 r_2 \partial_\theta \omega_{\alpha\beta}^{\kappa} \partial_\kappa \omega^{\alpha\beta\theta} - 4 r_2 \partial_\theta \omega_{\alpha\beta}^{\kappa} \partial_\kappa \omega^{\theta\alpha\beta} - 2 t_1 \partial^\alpha f_{\theta\kappa} \partial^\kappa f_{\alpha}^{\theta} + t_2 \partial^\alpha f_{\theta\kappa} \partial^\kappa f_{\alpha}^{\theta} - 4 t_1 \partial^\alpha f_{\kappa\theta} \partial^\kappa f_{\alpha}^{\theta} - t_2 \partial^\alpha f_{\kappa\theta} \partial^\kappa f_{\alpha}^{\theta} - 2 t_1 \partial^\alpha f_{\kappa}^{\lambda} \partial^\kappa f_{\alpha}^{\lambda} + t_2 \partial^\alpha f_{\kappa}^{\lambda} \partial^\kappa f_{\alpha}^{\lambda} + 2 t_1 \omega_{\kappa\alpha}^{\alpha} \partial^\kappa f_{\kappa}^{\lambda} + 2 t_1 \omega_{\kappa\lambda}^{\lambda} \partial^\kappa f_{\kappa}^{\alpha} + 4 t_1 \partial^\alpha f_{\kappa\alpha} \partial^\kappa f_{\lambda}^{\alpha} - 2 t_1 \partial_\kappa f_{\lambda}^{\alpha} \partial^\kappa f_{\alpha}^{\lambda} + 2 t_1 \omega_{\kappa\theta} \partial^\kappa f_{\theta}^{\lambda} + 2 t_2 \omega_{\theta\kappa} \partial^\kappa f_{\theta}^{\lambda} + 8 t_1 \omega_{\kappa\theta} \partial^\kappa f_{\theta}^{\lambda} - 4 t_2 \omega_{\kappa\theta} \partial^\kappa f_{\theta}^{\lambda} - 2 t_1 \omega_{\theta\kappa} \partial^\kappa f_{\theta}^{\lambda} - 2 t_2 \omega_{\theta\kappa} \partial^\kappa f_{\theta}^{\lambda} + 4 t_1 \omega_{\theta\kappa\prime} \partial^\kappa f_{\theta}^{\lambda} + 4 t_2 \omega_{\theta\kappa\prime} \partial^\kappa f_{\theta}^{\lambda} - 2 t_1 \omega_{\iota\alpha}^{\alpha} \partial^\kappa f_{\kappa}^{\lambda} - 2 t_1 \omega_{\lambda\alpha}^{\lambda} \partial^\kappa f_{\kappa}^{\alpha} + 2 t_1 \partial^\alpha f_{\kappa}^{\lambda} \partial^\kappa f_{\lambda}^{\alpha} - t_2 \partial^\alpha f_{\kappa}^{\lambda} \partial^\kappa f_{\lambda}^{\alpha} + 2 t_1 \partial_\kappa f_{\theta}^{\lambda} \partial^\kappa f_{\lambda}^{\theta} - t_2 \partial_\kappa f_{\theta}^{\lambda} \partial^\kappa f_{\lambda}^{\theta} + 4 t_1 \partial_\kappa f_{\theta}^{\lambda} \partial^\kappa f_{\lambda}^{\theta} + t_2 \partial_\kappa f_{\theta}^{\lambda} \partial^\kappa f_{\lambda}^{\theta} - 2 t_1 \partial^\alpha f_{\alpha}^{\lambda} \partial_\lambda \omega_{\alpha\beta}^{\kappa} + 2 r_2 \partial_\kappa \omega_{\alpha\beta\theta}^{\kappa} \partial^\kappa \omega_{\alpha\beta\theta} + 4 r_2 \partial_\kappa \omega^{\theta\alpha\beta} \partial^\kappa \omega_{\alpha\beta\theta} - 4 r_2 \partial^\beta \omega_{\alpha\beta}^{\alpha\lambda} \partial_\lambda \omega_{\alpha\beta}^{\kappa\prime} + 4 r_2 \partial^\beta \omega_{\alpha\beta}^{\lambda\alpha} \partial_\lambda \omega_{\alpha\beta}^{\kappa\prime}) [t, x, y, z] dz dy dx dt$$

## 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

(no massless particles)

## Unitarity conditions

$r_2 < 0 \ \&\& \ t_2 > 0$

$\sigma_{1^+}^{\#1} \dagger^{\alpha\beta}$	$\sigma_{1^+}^{\#2} \dagger^{\alpha\beta}$	$\tau_{1^+}^{\#1} \dagger^{\alpha\beta}$	$\sigma_{1^+}^{\#1} \dagger^{\alpha}$	$\sigma_{1^+}^{\#2} \dagger^{\alpha}$	$\tau_{1^+}^{\#1} \dagger^{\alpha}$	$\tau_{1^+}^{\#2} \dagger^{\alpha}$
$\frac{2(t_1+t_2)}{3t_1t_2}$	$\frac{\sqrt{2}(t_1-2t_2)}{3(1+k^2)t_1t_2}$	$\frac{i\sqrt{2}k(t_1-2t_2)}{3(1+k^2)t_1t_2}$	0	0	0	0
$\frac{\sqrt{2}(t_1-2t_2)}{3(1+k^2)t_1t_2}$	$\frac{t_1+4t_2}{3(1+k^2)^2t_1t_2}$	$\frac{ik(t_1+4t_2)}{3(1+k^2)^2t_1t_2}$	0	0	0	0
$-\frac{i\sqrt{2}k(t_1-2t_2)}{3(1+k^2)t_1t_2}$	$-\frac{ik(t_1+4t_2)}{3(1+k^2)^2t_1t_2}$	$\frac{k^2(t_1+4t_2)}{3(1+k^2)^2t_1t_2}$	0	0	0	0
0	0	0	$\frac{6}{(3+4k^2)^2t_1}$	$\frac{6\sqrt{2}}{(3+4k^2)^2t_1}$	0	$\frac{12ik}{(3+4k^2)^2t_1}$
0	0	0	0	$\frac{12}{(3+4k^2)^2t_1}$	0	$\frac{12i\sqrt{2}k}{(3+4k^2)^2t_1}$
0	0	0	0	0	0	0
0	0	0	$-\frac{12ik}{(3+4k^2)^2t_1}$	$-\frac{12i\sqrt{2}k}{(3+4k^2)^2t_1}$	0	$\frac{24k^2}{(3+4k^2)^2t_1}$

$\omega_{1^+}^{\#1} \dagger^{\alpha\beta}$	$\omega_{1^+}^{\#2} \dagger^{\alpha\beta}$	$f_{1^+}^{\#1} \dagger^{\alpha\beta}$	$\omega_{1^+}^{\#1} \dagger^{\alpha}$	$\omega_{1^+}^{\#2} \dagger^{\alpha}$	$f_{1^+}^{\#1} \dagger^{\alpha}$	$f_{1^+}^{\#2} \dagger^{\alpha}$
$\frac{1}{6}(t_1+4t_2)$	$-\frac{t_1-2t_2}{3\sqrt{2}}$	$-\frac{ik(t_1-2t_2)}{3\sqrt{2}}$	0	0	0	0
$-\frac{t_1-2t_2}{3\sqrt{2}}$	$\frac{t_1+t_2}{3}$	$\frac{1}{3}ik(t_1+t_2)$	0	0	0	0
$\frac{ik(t_1-2t_2)}{3\sqrt{2}}$	$-\frac{1}{3}ik(t_1+t_2)$	$\frac{1}{3}k^2(t_1+t_2)$	0	0	0	0
0	0	0	$\frac{t_1}{6}$	$\frac{t_1}{3\sqrt{2}}$	0	$\frac{ikt_1}{3}$
0	0	0	$\frac{t_1}{3\sqrt{2}}$	$\frac{t_1}{3}$	0	$\frac{1}{3}i\sqrt{2}kt_1$
0	0	0	0	0	0	0
0	0	0	$-\frac{1}{3}ik t_1$	$-\frac{1}{3}i\sqrt{2}kt_1$	0	$\frac{2k^2t_1}{3}$

### Source constraints/gauge generators

SO(3) irreps	Multiplicities
$\tau_{0^+}^{\#2} == 0$	1
$\tau_{0^+}^{\#1} == 0$	1
$\sigma_{0^+}^{\#1} == 0$	1
$\tau_{1^+}^{\#2\alpha} + 2ik\sigma_{1^+}^{\#1\alpha} == 0$	3
$\tau_{1^+}^{\#1\alpha} == 0$	3
$\sigma_{1^+}^{\#1\alpha} == \sigma_{1^+}^{\#2\alpha}$	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:	20

$\omega_{0^+}^{\#1} \dagger$	$f_{0^+}^{\#1} \dagger$	$f_{0^+}^{\#2} \dagger$	$\omega_{0^+}^{\#1} \dagger$
0	0	0	0
$f_{0^+}^{\#1} \dagger$	0	0	0
$f_{0^+}^{\#2} \dagger$	0	0	0
$\omega_{0^+}^{\#1} \dagger$	0	0	$k^2r_2+t_2$

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

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

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