QFT vertex

Vector-pseudoscalar-pseudoscalar

Note

Following the notation on page 101 in Biplap Dey's thesis :
https://www.jlab.org/Hall-B/general/thesis/BDey_thesis.pdf

$V \equiv$ vector particle, $\phi \equiv$ pseudoscalar

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We will take $\mathcal{L}_{V\varphi_1\varphi_2} = -\frac{g}{\sqrt{2}} V^\mu (\varphi_1 \partial_\mu \varphi_2 - \varphi_2 \partial_\mu \varphi_1)$

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Similar to equations 4.14 or 4.15 in https://arxiv.org/pdf/hep-ph/9607431.pdf

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Note: $V^\mu = \epsilon^\mu e^{-ip_\nu x^\nu}$

polarization vector

Vector-pseudoscalar-pseudoscalar

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So $\mathcal{L}_{V\varphi_1\varphi_2} = \left(\frac{+ig}{\sqrt{2}}\right)\left[e^{-i(P_V^\alpha + P_{\varphi_1}^\alpha + P_{\varphi_2}^\alpha)x_\alpha}\right]\left[\epsilon^\mu (P_{\varphi_1\mu} - P_{\varphi_2\mu})\right]$

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Note: If polarization were along x-direction then $\epsilon^{\mu} = (0,1,0,0)$

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& $\mathcal{L} \propto P_1 \sin\theta_1 \cos\phi_1 - P_2 \sin\theta_2 \cos\phi_2$

$\mathcal{L} \propto P_1 \sin\theta_1 \cos\varphi_1 - P_2 \sin\theta_2 \cos\varphi_2$ In rest frame of V

$\vec{P}_1 = -\vec{P}_2$

$\mathcal{L} \propto P_1 \sin\theta_1 \cos\phi_1 - P_2 \sin\theta_2 \cos\phi_2$ In rest frame of V

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& since $Y_1^{-1} = \frac{1}{2}\sqrt{\frac{3}{2\pi}}\, e^{-i\phi} \sin\theta$

& $Y_1^{1} = -\frac{1}{2}\sqrt{\frac{3}{2\pi}}\, e^{i\phi} \sin\theta$

$\mathcal{L} \propto P_1 \sin\theta_1 \cos\phi_1 - P_2 \sin\theta_2 \cos\phi_2$ In rest frame of V

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$$\boxed{\begin{array}{l} \text{\& since } Y_1^{-1} = \frac{1}{2}\sqrt{\frac{3}{2\pi}}\, e^{-i\phi} \sin\theta \\ \qquad \text{\& } Y_1^{1} = -\frac{1}{2}\sqrt{\frac{3}{2\pi}}\, e^{i\phi} \sin\theta \end{array}}$$

Then $\mathcal{L} \propto P[Y_1^{-1} - Y_1^{1}]$

$\mathcal{L} \propto P_1 \sin\theta_1 \cos\phi_1 - P_2 \sin\theta_2 \cos\phi_2$ In rest frame of V

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1 unit of angular momentum

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Then $\mathcal{L} \propto P[Y_1^{-1} - Y_1^{1}]$

1 unit of angular momentum As it must ☺

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1 V_2 \phi} \propto \epsilon_{\mu\nu\alpha\beta}\, \partial^{\mu} V_1^{\nu}\, \partial^{\alpha} V_2^{\beta}$

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1 V_2 \phi} \propto \epsilon_{\mu\nu\alpha\beta}\, \partial^\mu V_1^\nu\, \partial^\alpha V_2^\beta$

For simplicity lets take V_1 polarized in x & at rest

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1 V_2 \phi} \propto \epsilon_{\mu\nu\alpha\beta}\, \partial^\mu V_1^\nu\, \partial^\alpha V_2^\beta$

For simplicity lets take V_1 polarized in x & at rest

$$\Rightarrow \mathcal{L} \propto \epsilon_{\mu\nu\alpha\beta}\left[\partial^\mu \epsilon^{\nu=1} e^{-\epsilon t}\right] p_2^\alpha\, \epsilon_2^\beta$$

Vector-vector-pseudoscalar

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$$\Rightarrow \mathcal{L} \propto \epsilon_{\mu\nu\alpha\beta} \left[\partial^\mu \epsilon^{\nu=1} e^{-\epsilon t}\right] P_2^\alpha \epsilon_2^\beta \Rightarrow \mathcal{L} \propto \epsilon_{01\alpha\beta}\, E_1\, P_2^\alpha \epsilon_2^\beta$$

Vector-vector-pseudoscalar

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For simplicity lets take V_1 polarized in x & at rest

$$\Rightarrow \mathcal{L} \propto \epsilon_{\mu\nu\alpha\beta} \left[\partial^\mu \epsilon^{\nu=1} e^{-Et}\right] P_2^\alpha \epsilon_2^\beta \Rightarrow \mathcal{L} \propto \epsilon_{01\alpha\beta} E_1 P_2^\alpha \epsilon_2^\beta$$

$$\Rightarrow \quad \mathcal{L} \propto \epsilon_{0123} E_1 P_2^2 \epsilon_2^3 + \epsilon_{0132} E_1 P_2^3 \epsilon_2^2$$

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1V_2\phi} \propto \epsilon_{\mu\nu\alpha\beta}\,\partial^\mu V_1^\nu\,\partial^\alpha V_2^\beta$

For simplicity lets take V_1 polarized in x & at rest

$\Rightarrow \mathcal{L} \propto \epsilon_{\mu\nu\alpha\beta}\left[\partial^\mu \epsilon^{\nu=1} e^{-Et}\right] P_2^\alpha \epsilon_2^\beta \Rightarrow \mathcal{L} \propto \epsilon_{01\alpha\beta} E_1 P_2^\alpha \epsilon_2^\beta$

$\Rightarrow \quad \mathcal{L} \propto \epsilon_{0123} E_1 P_2^2 \epsilon_2^3 + \epsilon_{0132} E_1 P_2^3 \epsilon_2^2 = E_1 \left(P_2^2\epsilon_2^3 - P_2^3\epsilon_2^2\right)$

Vector-vector-pseudoscalar

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$= E_1 (\vec{P}_2 \times \vec{\epsilon}_2) \cdot \hat{x}$

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1 V_2 \phi} \quad \alpha \quad \epsilon_{\mu\nu\alpha\beta}\, \partial^\mu V_1^\nu\, \partial^\alpha V_2^\beta$

For simplicity lets take V_1 polarized in x & at rest

$\Rightarrow \mathcal{L} \;\alpha\; \epsilon_{\mu\nu\alpha\beta} \left[\partial^\mu \epsilon^{\nu=1} e^{-Et}\right] P_2^\alpha \epsilon_2^\beta \Rightarrow \mathcal{L}\,\alpha\; \epsilon_{01\alpha\beta} E_1 P_2^\alpha \epsilon_2^\beta$

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$= E_1 (\vec{P}_2 \times \vec{\epsilon}_2) \cdot \hat{x}$ $\quad$ <u>Special cases</u>: (I) $\epsilon_2^3 = 0$

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1 V_2 \phi} \propto \epsilon_{\mu\nu\alpha\beta}\, \partial^\mu V_1^\nu\, \partial^\alpha V_2^\beta$

For simplicity lets take V_1 polarized in x & at rest

$$\Rightarrow \mathcal{L} \propto \epsilon_{\mu\nu\alpha\beta} \left[\partial^\mu \epsilon^{\nu=1} e^{-Et}\right] P_2^\alpha \epsilon_2^\beta \Rightarrow \mathcal{L} \propto \epsilon_{01\alpha\beta} E_1 P_2^\alpha \epsilon_2^\beta$$

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$$= E_1 (\vec{P}_2 \times \vec{\epsilon}_2) \cdot \hat{x}$$

Special cases: (I) $\epsilon_2^3 = 0$ Complete polarization transfer from vector particle to vector particle

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1 V_2 \phi} \propto \epsilon_{\mu\nu\alpha\beta}\, \partial^\mu V_1^\nu\, \partial^\alpha V_2^\beta$

For simplicity lets take V_1 polarized in x & at rest

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$$= E_1 (\vec{P}_2 \times \vec{\epsilon}_2) \cdot \hat{x}$$

<u>Special cases</u>: (I) $\epsilon_2^3 = 0$ Complete Linear polarization transfer from vector particle to vector particle

$$\Rightarrow \mathcal{L} \propto E_1 P_2 \cos\theta_2$$

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1 V_2 \phi} \propto \epsilon_{\mu\nu\alpha\beta}\, \partial^\mu V_1^\nu\, \partial^\alpha V_2^\beta$

For simplicity lets take V_1 polarized in x & at rest

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Special cases: (I) $\epsilon_2^3 = 0$ Complete Linear polarization transfer from vector particle to vector particle

$$\Rightarrow \mathcal{L} \propto E_1 P_2 \cos\theta_2 \qquad \text{But } Y_1^0 = \frac{1}{2}\sqrt{\frac{3}{\pi}} \cos\theta$$

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1V_2\phi} \propto \epsilon_{\mu\nu\alpha\beta}\,\partial^\mu V_1^\nu\,\partial^\alpha V_2^{*\beta}$

For simplicity lets take V_1 polarized in x & at rest

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$= E_1\left(\vec{P}_2 \times \vec{\epsilon}_2\right)\cdot\hat{x}$ $\quad$ Special cases: (I) $\epsilon_2^3 = 0$ Complete

Linear

polarization transfer from vector particle to vector particle

$\Rightarrow \mathcal{L} \propto E_1 P_2 \cos\theta_2$ $\quad$ But $Y_1^0 = \frac{1}{2}\sqrt{\frac{3}{\pi}}\cos\theta$ so $\mathcal{L} \propto E_1 P_2 Y_1^0$

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1 V_2 \phi} \propto \epsilon_{\mu\nu\alpha\beta}\, \partial^\mu V_1^\nu\, \partial^\alpha V_2^\beta$

For simplicity lets take V_1 polarized in x & at rest

$$\Rightarrow \mathcal{L} \propto \epsilon_{\mu\nu\alpha\beta}\left[\partial^\mu \epsilon^{\nu=1} e^{-Et}\right] P_2^\alpha \epsilon_2^\beta \Rightarrow \mathcal{L} \propto \epsilon_{01\alpha\beta} E_1 P_2^\alpha \epsilon_2^\beta$$

$$\Rightarrow \mathcal{L} \propto \epsilon_{0123} E_1 P_2^2 \epsilon_2^3 + \epsilon_{0132} E_1 P_2^3 \epsilon_2^2 = E_1 \left(P_2^2 \epsilon_2^3 - P_2^3 \epsilon_2^2\right)$$

$$= E_1 (\vec{P}_2 \times \vec{\epsilon}_2) \cdot \hat{x}$$

<u>Special cases</u>: (I) $\epsilon_2^3 = 0$ Complete linear polarization transfer from vector particle to vector particle

$\Rightarrow \mathcal{L} \propto E_1 P_2 \cos\theta_2$ But $Y_1^0 = \frac{1}{2}\sqrt{\frac{3}{\pi}} \cos\theta$ so $\mathcal{L} \propto E_1 P_2 Y_1^0$

(II) $\epsilon_2^2 = 0$

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1V_2\phi} \propto \epsilon_{\mu\nu\alpha\beta}\,\partial^\mu V_1^\nu\,\partial^\alpha V_2^\beta$

For simplicity lets take V_1 polarized in x & at rest

$\Rightarrow \mathcal{L} \propto \epsilon_{\mu\nu\alpha\beta}\left[\partial^\mu \epsilon^{\nu=1} e^{-Et}\right] P_2^\alpha \epsilon_2^\beta \Rightarrow \mathcal{L} \propto \epsilon_{01\alpha\beta} E_1 P_2^\alpha \epsilon_2^\beta$

$\Rightarrow \mathcal{L} \propto \epsilon_{0123} E_1 P_2^2 \epsilon_2^3 + \epsilon_{0132} E_1 P_2^3 \epsilon_2^2 = E_1\left(P_2^2\epsilon_2^3 - P_2^3\epsilon_2^2\right)$

$= E_1(\vec{P}_2 \times \vec{\epsilon}_2)\cdot\hat{x}$ Special cases: (I) $\epsilon_2^3 = 0$ Complete

Linear polarization transfer from vector particle to vector particle

$\Rightarrow \mathcal{L} \propto E_1 P_2 \cos\theta_2$ But $Y_1^0 = \frac{1}{2}\sqrt{\frac{3}{\pi}}\cos\theta$ so $\mathcal{L} \propto E_1 P_2 Y_1^0$

(II) $\epsilon_2^2 = 0$ Polarization of final vector particle is completely longitudinal

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1 V_2 \phi} \propto \epsilon_{\mu\nu\alpha\beta}\, \partial^\mu V_1^\nu\, \partial^\alpha V_2^{*\beta}$

For simplicity lets take V_1 polarized in x & at rest

$\Rightarrow \mathcal{L} \propto \epsilon_{\mu\nu\alpha\beta} \left[\partial^\mu \epsilon^{\nu=1} e^{-Et}\right] P_2^\alpha \epsilon_2^{*\beta} \Rightarrow \mathcal{L} \propto \epsilon_{01\alpha\beta} E_1 P_2^\alpha \epsilon_2^{*\beta}$

$\Rightarrow \quad \mathcal{L} \propto \epsilon_{0123} E_1 P_2^2 \epsilon_2^{*3} + \epsilon_{0132} E_1 P_2^3 \epsilon_2^{*2} = E_1 \left(P_2^2 \epsilon_2^{*3} - P_2^3 \epsilon_2^{*2}\right)$

$= E_1 (\vec{P}_2 \times \vec{\epsilon}_2) \cdot \hat{x}$ Special cases: (I) $\epsilon_2^3 = 0$ Complete Linear polarization transfer from vector particle to vector particle

$\Rightarrow \mathcal{L} \propto E_1 P_2 \cos\theta_2$ But $Y_1^0 = \frac{1}{2}\sqrt{\frac{3}{\pi}} \cos\theta$ so $\mathcal{L} \propto E_1 P_2 Y_1^0$

(II) $\epsilon_2^2 = 0$ Polarization of final vector particle is completely longitudinal $\Rightarrow \mathcal{L} \propto E_1 P_2 \sin\theta_2 \sin\phi$

Vector-vector-pseudoscalar

Here $\mathcal{L}_{V_1V_2\phi} \propto \epsilon_{\mu\nu\alpha\beta}\,\partial^\mu V_1^\nu\,\partial^\alpha V_2^\beta$

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Linear polarization transfer from vector particle to vector particle

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(II) $\epsilon_2^2 = 0$ Polarization of final vector particle is completely longitudinal $\Rightarrow \mathcal{L} \propto E_1 P_2 \sin\theta_2 \sin\phi \Rightarrow \mathcal{L} \propto E_1 P_2 \left[Y_1^{-1} + Y_1^1\right]$

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$\Rightarrow \mathcal{L} \propto \epsilon_{0123} E_1 P_2^2 \epsilon_2^3 + \epsilon_{0132} E_1 P_2^3 \epsilon_2^2 = E_1 (P_2^2 \epsilon_2^3 - P_2^3 \epsilon_2^2)$

$= E_1 (\vec{P}_2 \times \vec{\epsilon}_2) \cdot \hat{x}$ <u>Special cases</u>: (I) $\epsilon_2^3 = 0$ Complete linear polarization transfer from vector particle to vector particle

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(II) $\epsilon_2^2 = 0$ Polarization of final vector particle is completely longitudinal $\Rightarrow \mathcal{L} \propto E_1 P_2 \sin\theta_2 \sin\phi \Rightarrow \mathcal{L} \propto E_1 P_2 [Y_1^{-1} + Y_1^1]$

Interesting parts

The original polarization was set to X-direction

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For vector to 2 pseudoscalars the decay plane has a $\cos\varphi$ dependence in amplitude

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Note: $2\cos^2\varphi = 1+\cos(2\varphi)$

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Note: $2\cos^2\varphi = 1+\cos(2\varphi)$ & $2\sin^2\varphi = 1-\cos(2\varphi)$

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<u>note</u>: $2\cos^2\varphi = 1 + \cos(2\varphi)$ & $2\sin^2\varphi = 1 - \cos(2\varphi)$

Opposite sign for beam asymmetry

You should work out the sign of the beam asymmetry for pseudovector to vector $\oplus$ pseudoscalar with $\mathcal{L} \propto [\partial_\mu V_{1\nu}][\partial^\mu V_2^\nu]\varphi$

Title