

Figure 1: Born kinematics.

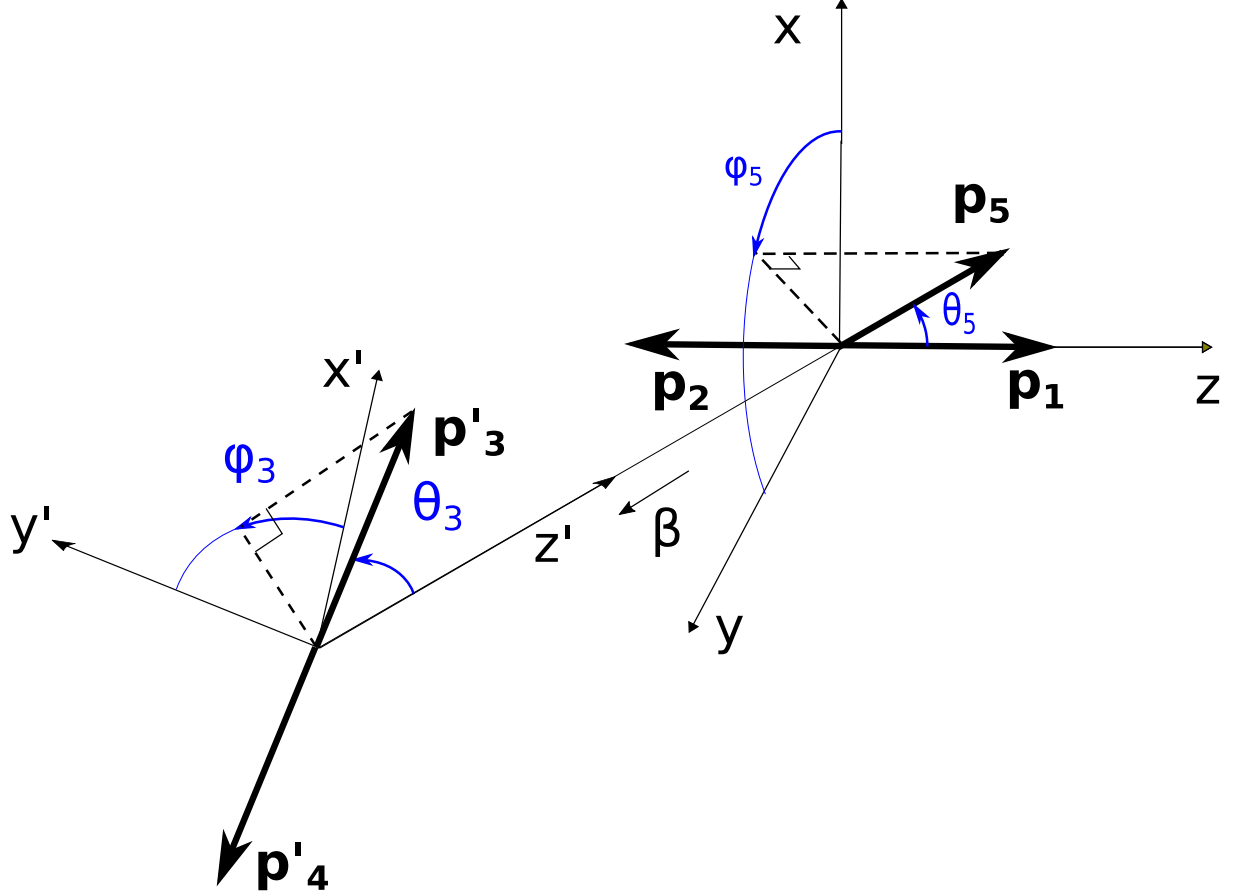


Figure 2: Hard kinematics. 3-momenta \vec{p}_1 , \vec{p}_2 and \vec{p}_5 lies in $y'z'$ -plane, $\beta = \frac{|\vec{p}_3 + \vec{p}_4|}{E_3 + E_4} = \frac{s - s'}{s + s'}$.

The four-momenta $p = \begin{bmatrix} p_x \\ p_y \\ p_z \\ E' \end{bmatrix}$ in the R' frame:

$$p_1 = \begin{bmatrix} 0 \\ -\kappa_1 \beta_1 \frac{\sqrt{s}}{2} \sin \theta_5 \\ -\frac{\kappa_1}{2} \left(-\sqrt{\frac{s}{s'}} (1 + \beta_1 \cos \theta_5) + \sqrt{\frac{s'}{s}} (1 - \beta_1 \cos \theta_5) \right) \frac{\sqrt{s}}{2} \\ \frac{\kappa_1}{2} \left(\sqrt{\frac{s}{s'}} (1 + \beta_1 \cos \theta_5) + \sqrt{\frac{s'}{s}} (1 - \beta_1 \cos \theta_5) \right) \frac{\sqrt{s}}{2} \end{bmatrix},$$

$$p_2 = \begin{bmatrix} 0 \\ \kappa_2 \beta_2 \frac{\sqrt{s}}{2} \sin \theta_5 \\ -\frac{\kappa_2}{2} \left(-\sqrt{\frac{s}{s'}} (1 - \beta_2 \cos \theta_5) + \sqrt{\frac{s'}{s}} (1 + \beta_2 \cos \theta_5) \right) \frac{\sqrt{s}}{2} \\ \frac{\kappa_2}{2} \left(\sqrt{\frac{s}{s'}} (1 - \beta_2 \cos \theta_5) + \sqrt{\frac{s'}{s}} (1 + \beta_2 \cos \theta_5) \right) \frac{\sqrt{s}}{2} \end{bmatrix},$$

$$p_3 = \begin{bmatrix} \kappa_3 \beta_3 \frac{\sqrt{s'}}{2} \sin \theta_3 \cos \phi_3 \\ \kappa_3 \beta_3 \frac{\sqrt{s'}}{2} \sin \theta_3 \sin \phi_3 \\ \kappa_3 \beta_3 \frac{\sqrt{s'}}{2} \cos \theta_3 \\ \kappa_3 \frac{\sqrt{s'}}{2} \end{bmatrix},$$

$$p_4 = \begin{bmatrix} -\kappa_4 \beta_4 \frac{\sqrt{s'}}{2} \sin \theta_3 \cos \phi_3 \\ -\kappa_4 \beta_4 \frac{\sqrt{s'}}{2} \sin \theta_3 \sin \phi_3 \\ -\kappa_4 \beta_4 \frac{\sqrt{s'}}{2} \cos \theta_3 \\ \kappa_4 \frac{\sqrt{s'}}{2} \end{bmatrix},$$

$$p_5 = \begin{bmatrix} 0 \\ 0 \\ \frac{s - s'}{2\sqrt{s'}} \\ \frac{s - s'}{2\sqrt{s'}} \end{bmatrix}.$$

$$\kappa_1 = 1 + \frac{m_1^2 - m_2^2}{s}, \quad \kappa_2 = 1 + \frac{m_2^2 - m_1^2}{s}, \quad \kappa_3 = 1 + \frac{m_3^2 - m_4^2}{s'}, \quad \kappa_4 = 1 + \frac{m_4^2 - m_3^2}{s'}.$$

$$\beta_1 = \frac{\sqrt{\lambda(s, m_1^2, m_2^2)}}{s + m_1^2 - m_2^2}, \quad \beta_2 = \frac{\sqrt{\lambda(s, m_1^2, m_2^2)}}{s + m_2^2 - m_1^2}, \quad \beta_3 = \frac{\sqrt{\lambda(s', m_3^2, m_4^2)}}{s' + m_3^2 - m_4^2}, \quad \beta_4 = \frac{\sqrt{\lambda(s', m_3^2, m_4^2)}}{s' + m_4^2 - m_3^2}.$$

Scalar products:

$$p_1 p_2 = \frac{s}{2} - \frac{m_1^2 + m_2^2}{2},$$

$$p_3 p_4 = \frac{s'}{2} - \frac{m_3^2 + m_4^2}{2},$$

$$p_1 p_5 = \frac{s - s'}{4} \kappa_1 (1 - \beta_1 \cos \theta_5),$$

$$p_2 p_5 = \frac{s - s'}{4} \kappa_2 (1 + \beta_2 \cos \theta_5),$$

$$p_3 p_5 = \frac{s - s'}{4} \kappa_3 (1 - \beta_3 \cos \theta_3),$$

$$p_4 p_5 = \frac{s - s'}{4} \kappa_4 (1 + \beta_4 \cos \theta_3),$$

$$p_1 p_3 = \kappa_1 \kappa_3 \left(\frac{s}{8} (1 + \beta_1 \cos \theta_5) (1 - \beta_3 \cos \theta_3) + \frac{s'}{8} (1 - \beta_1 \cos \theta_5) (1 + \beta_3 \cos \theta_3) + \frac{\sqrt{s} \sqrt{s'}}{4} \beta_1 \beta_3 \sin \theta_5 \sin \theta_3 \sin \phi_3 \right),$$

$$p_1 p_4 = \kappa_1 \kappa_4 \left(\frac{s}{8} (1 + \beta_1 \cos \theta_5) (1 + \beta_4 \cos \theta_3) + \frac{s'}{8} (1 - \beta_1 \cos \theta_5) (1 - \beta_4 \cos \theta_3) - \frac{\sqrt{s} \sqrt{s'}}{4} \beta_1 \beta_4 \sin \theta_5 \sin \theta_3 \sin \phi_3 \right),$$

$$p_2 p_3 = \kappa_2 \kappa_3 \left(\frac{s}{8} (1 - \beta_2 \cos \theta_5) (1 - \beta_3 \cos \theta_3) + \frac{s'}{8} (1 + \beta_2 \cos \theta_5) (1 + \beta_3 \cos \theta_3) - \frac{\sqrt{s} \sqrt{s'}}{4} \beta_2 \beta_3 \sin \theta_5 \sin \theta_3 \sin \phi_3 \right),$$

$$p_2 p_4 = \kappa_2 \kappa_4 \left(\frac{s}{8} (1 - \beta_2 \cos \theta_5) (1 + \beta_4 \cos \theta_3) + \frac{s'}{8} (1 + \beta_2 \cos \theta_5) (1 - \beta_4 \cos \theta_3) + \frac{\sqrt{s} \sqrt{s'}}{4} \beta_2 \beta_4 \sin \theta_5 \sin \theta_3 \sin \phi_3 \right).$$

Cross section for the $2 \rightarrow 2$ process:

$$d\sigma = \frac{1}{64\pi^2 s} \frac{\sqrt{\lambda(s, m_3^2, m_4^2)}}{\sqrt{\lambda(s, m_1^2, m_2^2)}} |\mathcal{M}|^2 d\cos\theta_3 d\phi_3.$$

Cross section for the $2 \rightarrow 3$ process:

$$d\sigma = \frac{s - s'}{4096\pi^5 s s'} \frac{\sqrt{\lambda(s, m_3^2, m_4^2)}}{\sqrt{\lambda(s, m_1^2, m_2^2)}} |\mathcal{M}|^2 ds' d\cos\theta_3 d\phi_3 d\cos\theta_5 d\phi_5.$$