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Distribution for products in asymmetric e^+e^- collider: an example in B and L violating τ decay

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General Considerations, part 1 of 2

It was written a stand-alone program in order to:

- given a differential cross section generates $\cos\theta$ and ϕ according to the proper distribution.
- computes the 4-momenta of the products (knowing the masses and the CM energy) in the most useful frame and takes them back in the LAB frame, provided that each decay is a 2-body one.
- computes the distribution for the flight length (knowing the mean lifetime,LAB frame) and the 3 momenta module (frame has to be chosen) of each particle

The electron has an energy $E_e >> m_e$ ans so it has the positron, in this condition:

$$E_p \sim \frac{s}{4E_e} \quad \beta_{cm} \sim \frac{E_e - E_p}{E_e + E_p} \qquad \gamma_{cm} = \frac{1}{\sqrt{1-\beta_{cm}^2}} \tag{1}$$

Where s is the Mandelstam variable, $\beta_c m$ is the center of mass speed. The differential cross section in the C.M. (center of mass) frame for the process can be factorized as:

$$d\sigma(e^+ + e^- \longrightarrow f + \bar{f}) = f(\cos(\theta))g(\phi)\ d\phi d\cos(\theta) \tag{2}$$

General Considerations, part 2 of 2

Expression for a generic Lorentz's Boost in the $\vec{v}$ direction.

$$B(\vec{v}) = \begin{bmatrix} \gamma & -\gamma v_x/c & -\gamma v_y/c & -\gamma v_z/c \\ -\gamma v_x/c & 1+(\gamma-1)\frac{v_x^2}{v^2} & (\gamma-1)\frac{v_x v_y}{v^2} & (\gamma-1)\frac{v_x v_z}{v^2} \\ -\gamma v_y/c & (\gamma-1)\frac{v_y v_x}{v^2} & 1+(\gamma-1)\frac{v_y^2}{v^2} & (\gamma-1)\frac{v_y v_z}{v^2} \\ -\gamma v_z/c & (\gamma-1)\frac{v_z v_x}{v^2} & (\gamma-1)\frac{v_z v_y}{v^2} & 1+(\gamma-1)\frac{v_z}{v^2} \end{bmatrix} \tag{3}$$

The mean flight length is:

$$< l >= \gamma\tau c\beta$$

Where $\gamma = \frac{1}{\sqrt{1-\beta^2}}$,$\beta$ is the speed of the particle in the LAB frame, τ is the particle mean lifetime, a particle decays in a length distributed as:

$$f(L) = \frac{1}{< l >} e^{-\frac{L}{< l >}} \tag{4}$$

It has been studied the decay $\tau \to \Lambda^0 + \pi$ in PEP-II asymmetric collider e^+e^- which e^-'s beam energy is 9.0 GeV and the center of mass energy is the $\Upsilon(4S)$ level: 10.56 GeV. Other useful datas are:

- the π's mass: 0.139 GeV;
- the τ's mass: 1.77 GeV;
- the Λ^0's mass: 1.11 GeV.

Here the
values in equation (1) for the case studied:

$$E_{pos} = 3.09\ GeV \quad \beta_{cm} = 0.487 \quad \gamma_{cm} = 1.14$$

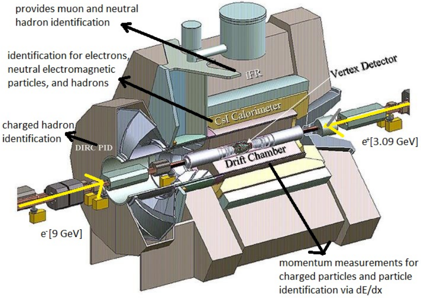


Figure: BaBar detector scheme.

The differential cross section for the process $e^+ + e^- \to \tau^+ + \tau^-$ in the C.M. frame is:

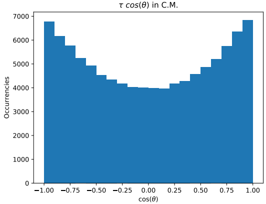
$$\frac{d\sigma}{d\Omega} = N_c \frac{\alpha^2}{4s} \beta [1 + \cos^2(\theta) + (1 - \beta^2) \sin^2(\theta)\ Q_f^2 \quad (5)$$

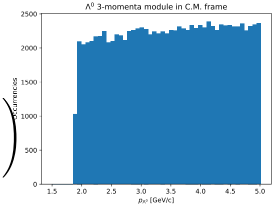
Where s is the Mandelstam variable, β is v/c for the produced fermions in the c.m., θ is the c.m scattering angle, Q_f is the charge of the lepton and N_c is 1 for

charged leptons and 3 for quarks.

Λ^0's 3-momenta kinematics lower limit is 1.8 GeV/c in the c.m., here is 4-momenta in frame at rest with respect the τ:

$$p^\mu_{\Lambda^0} = \left(\frac{m^2_{\Lambda^0} + m^2_\tau - m^2_{\pi/K}}{2m_\tau}, \sqrt{\left(\frac{m^2_{\Lambda^0} + m^2_\tau - m^2_{\pi/K}}{2m_\tau}\right)^2 - m^2_{\Lambda^0}} \right)$$





Example, part 3 of 3

The flight length of the Λ^0 is required to be $L_{\Lambda^0} > 1$ cm so the efficiency is about 97%. Within a sphere of radius 0.2 cm from the collisions center there are all the τ's decay.