A Monte Carlo simulation of decays within the SANC project

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The library of Monte Carlo programs for simulation of two particle leptonic and quark decays of the W,Z and H(Higgs) bosons with single bremsstrahlung photon emission as a part of SANC system is described. The QED and EW $O(\alpha)$ radiative corrections are implemented.The decay amplitudes are evaluated numerically using Kleiss-Stirling spinor method. The comparison with KORALZ and PHOTOS are also presented [2,3].

1. INTRODUCTION

The calculation of cross sections and decay widths using the spin-projection operator method for the production of many particles has traditionally been restricted by the technical difficulties associated with the evaluation of the corresponding multiparticle Feynman diagrams. This difficulty is overcome by employing the spinor methods. For evaluation decay amplitudes we use Kleiss-Stirling spinor technique [1].

2. KLEISS–STIRLING SPINOR METHOD

The basic idea is to reduce the amplitudes to an expression involving only spinor products (objects like $\bar{u}_{\lambda_1}(p_1)u_{\lambda_2}(p_2)$), which itself can be expressed in terms of the four vectors involving in the precesses. The arbitrary spinor $u_\lambda(p)$ can be constructed out of the two basic spinors $\mathbf{u}_\pm(\zeta)$, which represent the helicity states of a massless fermion of momentum ζ:

$$\begin{aligned} \widehat{\zeta}\,\mathbf{u}_\lambda(\zeta) &= 0, \quad \widehat{\zeta} = \zeta^\mu\gamma_\mu, \quad \lambda = \pm(\pm 1), \\ \omega_\lambda \mathbf{u}_\lambda(\zeta) &= \mathbf{u}_\lambda(\zeta), \quad \omega_\lambda = \frac{1}{2}(1+\lambda\gamma_5), \\ \mathbf{u}_\lambda(\zeta) &= \lambda\,\widehat{\eta}\,\mathbf{u}_{-\lambda}(\zeta), \quad \eta.\zeta = 0, \quad \eta^2 = -1. \end{aligned} \tag{1}$$

Any other spinor with mass m and momentum p may be defined as:

$$u_\lambda(p) = \frac{\widehat{p}+m}{\sqrt{2p.\zeta}}\mathbf{u}_{-\lambda}(\zeta). \tag{2}$$

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In actual computations we can specify ζ and η so that the $\bar{u}_\pm(p_1)\,u_\mp(p_2) \equiv s_\pm(p_1,p_2)$ becomes quite compact. In our calculations we use $\zeta = (1,1,0,0)$ and $\eta = (0,0,1,0)$, which leads to the following massless inner product:

$$\begin{aligned} s_+(p_1,p_2) &= -(p_2^y + i\,p_2^z)\sqrt{\frac{p_1^0 - p_1^x}{p_2^0 - p_2^x}} \\ &\quad +(p_1^y + i\,p_1^z)\sqrt{\frac{p_2^0 - p_2^x}{p_1^0 - p_1^x}}\,. \end{aligned} \tag{3}$$

Similarly, inner product for massive fermion comes from (2):

$$\bar{u}_{\lambda_1}(p_1)\,u_{\lambda_2}(p_2) \equiv S(p_1,m_1,\lambda_1,p_2,m_2,\lambda_2), \tag{4}$$

where

$$S(p_1,m_1,\lambda_1,p_2,m_2,\lambda_2) = \delta_{\lambda_1,-\lambda_2}\,s_{\lambda_1}(p_{1\zeta},p_{2\zeta}) + \delta_{\lambda_1,\lambda_2}\left(m_1\sqrt{\frac{\zeta.p_2}{\zeta.p_1}} + m_2\sqrt{\frac{\zeta.p_1}{\zeta.p_2}}\right).$$

We use the following expression for polarization vectors of massless spin-1 particle (axial gauge):

$$\epsilon^\mu_\sigma(k,\beta) = \frac{\bar{u}_\sigma(k)\gamma^\mu u_\sigma(\beta)}{\sqrt{2}\,s_{-\sigma}(k,\beta)}, \quad \sigma = \pm\,. \tag{5}$$

Similarly, for massive vector boson:

$$\begin{aligned} \epsilon^\mu_\pm(k) &= \frac{\bar{u}_\pm(k_1)\gamma^\mu u_\pm(k_2)}{\sqrt{2}\,m}, \\ \epsilon^\mu_0(k) &= \frac{\bar{u}_+(k_1)\gamma^\mu u_+(k_1) - \bar{u}_+(k_2)\gamma^\mu u_+(k_2)}{2m}. \end{aligned} \tag{6}$$

This spinor technique we use for computation of H, Z and W decay amplitudes with one real photon emission.
For example, the amplitude for decay $H \to f\bar{f}(\gamma)$ has the form:

$$
\begin{aligned}
&M^{\sigma}_{\lambda_1,\lambda_2}(k,p_1,p_2) = \\
&\quad\left(\frac{b_\sigma(k,p_2)}{2\,k.\,p_2} - \frac{b_\sigma(k,p_1)}{2\,k.\,p_1}\right) eQ_f\, B\begin{bmatrix} p_2 & p_1 \\ \lambda_2 & \lambda_1 \end{bmatrix} \\
&\quad+\frac{eQ_f}{2\,k.\,p_2}\sum_\rho U\begin{bmatrix} p_2 & k & k \\ \lambda_2 & \sigma & \rho \end{bmatrix}\; B\begin{bmatrix} k & p_1 \\ \rho, & -\lambda_1 \end{bmatrix} \qquad (7)\\
&\quad\frac{eQ_f}{2\,k.\,p_1}\sum_\rho B\begin{bmatrix} p_2 & k \\ \lambda_2 & -\rho \end{bmatrix}\; U\begin{bmatrix} k & k & p_1 \\ -\rho & \sigma & -\lambda_1 \end{bmatrix}, \\
&B\begin{bmatrix} p & q \\ \lambda_p & \lambda_q \end{bmatrix} = -\frac{g\, m_f}{2m_w} S(q, m_f, \lambda_q, p, -m_f, -\lambda_p)\,.
\end{aligned}
$$

Similarly, for $Z \to f\bar{f}(\gamma)$ we have:

$$
\begin{aligned}
&M^{\sigma}_{\lambda_z,\lambda_1,\lambda_2}(k,p_z,p_1,p_2) = \\
&\quad\left(\frac{b_\sigma(k,p_2)}{2\,k.\,p_2} - \frac{b_\sigma(k,p_1)}{2\,k.\,p_1}\right) eQ_f B\begin{bmatrix} p_2 & p_z & p_1 \\ \lambda_2 & \lambda_z & \lambda_1 \end{bmatrix} \\
&\quad+\frac{eQ_f}{2\,k.\,p_2}\sum_\rho U\begin{bmatrix} p_2 & k & k \\ \lambda_2 & \sigma & \rho \end{bmatrix}\; B\begin{bmatrix} k & p_z & p_1 \\ \rho & \lambda_z & -\lambda_1 \end{bmatrix} \qquad (8)\\
&\quad-\frac{eQ_f}{2\,k.\,p_1}\sum_\rho B\begin{bmatrix} p_2 & p_z & k \\ \lambda_2 & \lambda_z & -\rho \end{bmatrix} U\begin{bmatrix} k & k & p_1 \\ -\rho & \sigma & -\lambda_1 \end{bmatrix},
\end{aligned}
$$

where

$$
\begin{aligned}
&B\begin{bmatrix} p_2 & p & p_1 \\ \lambda_2 & \lambda & \lambda_1 \end{bmatrix} = \frac{g}{2\cos\theta_w} U\begin{bmatrix} p_1 & p & p_2 \\ \lambda_1 & \lambda & \lambda_2 \end{bmatrix}, \\
&U\begin{bmatrix} p_1 & k & p_2 \\ \lambda_1 & \sigma & \lambda_2 \end{bmatrix} \equiv \bar{u}_{\lambda_1}(p_1)\,\hat{\epsilon}_\sigma(k)\,(v_f + a_f\gamma_5)\, u_{\lambda_2}(p_2)\,.
\end{aligned}
$$

3. MONTE CARLO EVENT GENERATION PROCEDURE

The event generation procedure goes as follow:

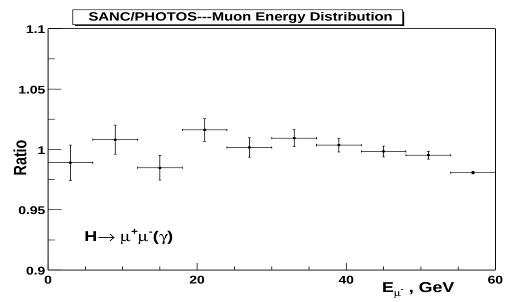
1) Generation of the photon with energy k^0 and direction $\cos\theta_\gamma,\phi_\gamma$ in the rest frame of the decaying particle. Because of *infrared* singularity k^0 is generated with a distribution $1/k^0$,

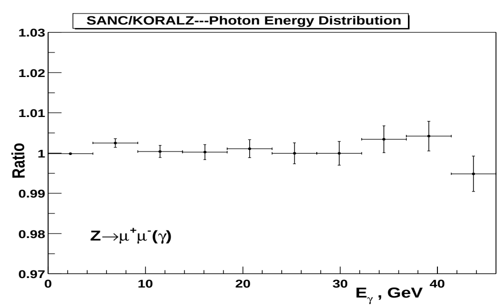
2) fermion — anti-fermion pair with energies $p^0_{1,2} = (s + m^2_{1,2} - m^2_{2,1})/\sqrt{4s}$ and direction $\cos\theta_2,\phi_2$ are generated in the rest frame of the (p_1,p_2) system, where due to a *collinearity* the variable $cos\theta_2$ is generated with a distribution $1/(1-\beta_1\cos\theta_2) + 1/(1+\beta_2\cos\theta_2)$,

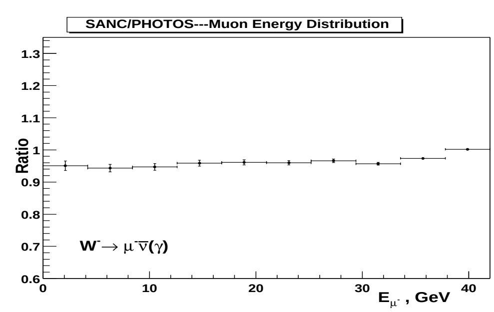
3) further the p_1 and p_2 momenta are boosted from their rest frame to the rest frame of the decaying particle along the $\vec{k}$ direction,

4) finally, we rotate $\vec{p}_1$ and $\vec{p}_2$ vectors respecting momentum conservation $\vec{k} + \vec{p}_1 + \vec{p}_2 = 0$.

4. COMPARISON







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