KLOE NOTE n^{o}156
February 23, 1996

BHABHA generator for GEANFI code

V.Glagolev[1], *M.Incagli, G.Venanzoni — INFN Pisa*

Abstract

This *memo* describes the BHABHA generator recently included in GEANFI code.

The program is based on calculations by *Berends et al* [1]. It includes elastic scattering, at the tree level, and Hard Bremmstrahlung diffraction (real photon emission).

This generator can be useful to study calorimeter energy and time calibration. It can be used also for trigger studies, although a more refined version including soft photon emission is under development.

1 Physical basis for generator

This BHABHA generator accounts for two kinds of processes: elastic scattering (1) at the Born level and inelastic scattering (2) with the emission of a real photon (*Hard Bremsstrahlung*).

$$e^+(p_+)e^-(p_-) \rightarrow e^+(q_+)e^-(q_-) \tag{1}$$
$$e^+(p_+)e^-(p_-) \rightarrow e^+(q_+)e^-(q_-)\gamma(k) \tag{2}$$

The differential cross section in the Centre of Mass System (C.M.S.) at lowest order in QED is:

$$\frac{d\sigma_0}{d\Omega} = \frac{\alpha^2}{16E_b^2} \times (\frac{3+cos^2\theta}{1-cos\theta})^2 \tag{3}$$

where $\alpha \sim \frac{1}{137}$ is the QED fine-structure constant, E_b is the beam energy, $d\Omega$ is the solid angle element and θ is the positron polar scattering angle.

For this version of generator we neglect the virtual corrections to vertices and fermion lines, as well as vacuum polarization contributions, electroweak and ϕ interference effect.

[1]On leave from the Joint Institute for Nuclear Research, Dubna, Russia

For the generation of the inelastic processes we have used the cross section in the ultrarelativistic limit according to [1]:

$$d^5\sigma = \frac{\alpha^3}{\pi^2 s} A W_{IR} W_m d^5\Gamma, \tag{4}$$

$$A = (ss'(s^2+s'^2) + tt'(t^2+t'^2) + uu'(u^2+u'^2))/(ss'tt'), \tag{5}$$

$$W_{IR} = \frac{s}{x_1 x_2} + \frac{s'}{y_1 y_2} - \frac{t}{x_1 y_1} - \frac{t'}{x_2 y_2} + \frac{u}{x_1 y_2} + \frac{u'}{x_2 y_1}, \tag{6}$$

$$W_m = 1 - \frac{m_e^2(s-s')}{s^2+s'^2}(\frac{s'}{x_1} + \frac{s'}{x_2} + \frac{s}{y_1} + \frac{s}{y_2}), \tag{7}$$

$$d^5\Gamma = \delta^4(p_+ + p_- - q_+ - q_- - k)(d^3q_+/2q_+^0)(d^3q_-/2q_-^0)(d^3k/2k^0), \tag{8}$$

$$s = (p_+ + p_-)^2, \quad t = (p_+ - q_+)^2, \quad u = (p_+ - q_-)^2, \tag{9}$$

$$s' = (q_+ + q_-)^2, \quad t' = (p_- - q_-)^2, \quad u' = (p_- - q_+)^2, \tag{10}$$

$$x_1 = p_+k, \quad x_2 = p_-k, \quad y_1 = q_+k, \quad y_2 = q_-k. \tag{11}$$

In the above expression W_{IR} describes the infrared contribution of photon emission, diverging for photons collinear with the incoming or the outgoing beams, while W_m takes into account the electron mass terms.

The generation of inelastic events is accomplished by first generating *trial* events according to some approximate cross section $d^5\sigma_a/d^5\Gamma$, and then assigning to each trial event a weight

$$w = (\frac{d^5\sigma}{d^5\Gamma})(\frac{d^5\sigma_a}{d^5\Gamma})^{-1}. \tag{12}$$

For $d^5\sigma_a$ we have used:

$$d^5\sigma_a = \frac{\alpha^3}{\pi^2 E_b^2} \frac{1}{k(1-c)(e+z)(e+c_\gamma)} dk d\Omega_\gamma dc d\phi, \tag{13}$$

where ϕ is the azimuthal angle of q_+ around the beam,

$$k = k^0/E_b, \quad e = (1 + m_e^2/E_b^2)^{0.5} \tag{14}$$

$$c = cos\angle(\mathbf{p}_+, \mathbf{q}_+), \quad c_\gamma = cos\angle(\mathbf{p}_+, \mathbf{k}), \quad z = cos\angle(\mathbf{q}_+, \mathbf{k}). \tag{15}$$

The correct event distribution is then obtained by accepting the trial events with a probability propotional to w.

$e^+(e^-)$ polar angle	$\sigma_{elastic}$ (mb)	σ_{hard} (mb)	σ_{tot} (mb)
$9^0 < \theta < 171^0$	3.85×10^{-2}	1.92×10^{-2}	5.77×10^{-2}
$1^0 < \theta < 179^0$	3.28	0.95	4.23

Table 1: Elastic (Born) cross section and Inelastic approximate cross section from integration of equations (3) and (13), respectively. σ_{tot} is the sum of the two.

2 Structure of the program

The block scheme of the BHABHA generator program is shown in Figure 1.

At the GEANFI initialization stage the elastic and inelastic total cross sections are calculated, given the input parameters (Minimum and Maximum polar angles), by integrating the differential expressions.

Then the generator evaluates, for each event, the outgoing particles 4-momenta, according to the algorithm described in [1].

Finally the outgoing particle 4-momenta are transformed from the C.M.S. to the LAB system, taking into account the beam crossing angle of 25 mrad, and stored in the GEANT KINE bank.

The BHABHA generator is initialized, in the GEANFI environement, via the *BHAB* data card. This card has two input parameters: minimum and maximum positron (electron) polar scattering angles in the C.M.S. Their default values are 1^0 and 179^0. We have chosen to use the C.M.S. polar angles because the Lorents Boost mixes the polar and azimuthal angles in the LAB system. Thus a cut in θ_{LAB} would result in an anisotropic distribution of events in the transvers plane.

The photon cut-off energy has been fixed, inside the generator, at one hundreth of the beam energy (5.1 MeV). This value has been chosen for backward compatibility (see section 4) and can be (sligthly) tuned in the following releases.

3 Analisys of the elastic and inelastic processes

The analysis of BHABHA events is particularly important in KLOE experiment in what they have a very high cross sections, as compared to ϕ events. In table 1 the BHABHA cross section, calculated in the intervals $9^0 < \theta < 171^0$ (relevant for the em calorimeter) and $1^0 < \theta < 179^0$, is shown. They have to be compared with the ϕ cross section of $\simeq 5\mu b$ (!).

Choosing the polar angle in the interval $[1^0, 179^0]$ a sample of 100.000 events has been generated. With these values of the phase space parameters 77.470 elastic events and 22.530 inelastic ones were obtained.

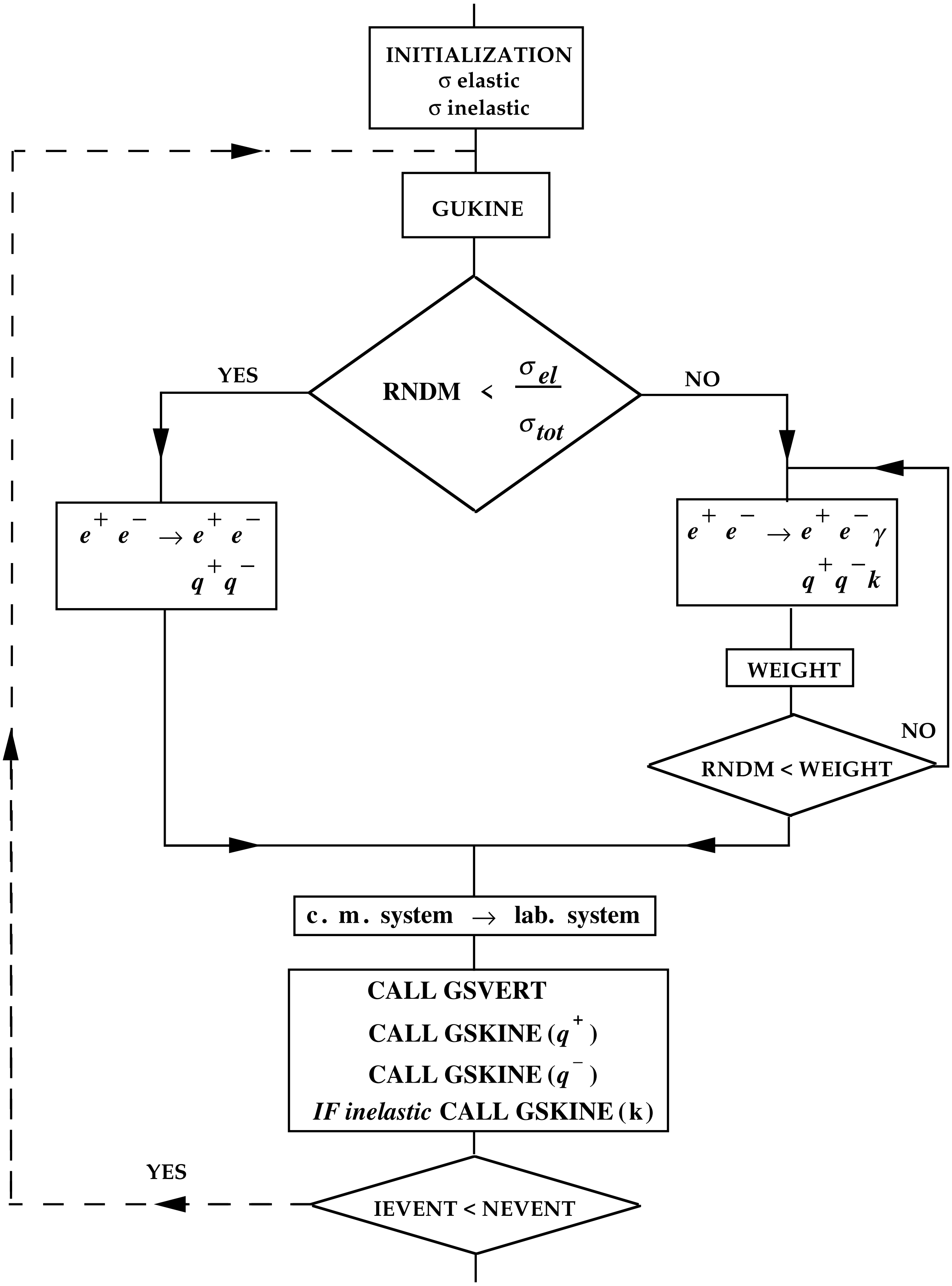

Figure 1: Block scheme of BHABHA generator.

In Figure 2 the photon and positron energy spectra, for inelastic scattering, are plotted. The peak at 510 MeV in the e^+ spectrum is characteristic of the events in which the photon is emitted by the electron. The gap between this peak and the inelastic tail is due to the photon cut-off energy of $5.1\, MeV$.

In order to check the effect of the photon cut-off energy, the Montecarlo has been run varying the threshold between 1MeV and 10MeV. Of course the elastic cross section remains unchanged while the hard component varies as follows:

$$E = 1MeV \quad \rightarrow \quad \sigma_{hard}(mb) = 2.59 \times 10^{-2} \tag{16}$$

$$E = 5.11MeV \quad \rightarrow \quad \sigma_{hard}(mb) = 1.92 \times 10^{-2} \tag{17}$$

$$E = 10MeV \quad \rightarrow \quad \sigma_{hard}(mb) = 1.64 \times 10^{-2} \tag{18}$$

The above values refer to the angular region $9^0 < \theta < 171^0$ and show that there is no strong dependence upon the energy cut-off (30% effect on hard Bremmsthralung).

In the following plots we have studied the effect of the Lorenz boost.

Figure 3 shows the positron and photon polar angle distribution in the C.M.S. (solid hisogram) and in the LAB system (shaded region). It is evident the effect of the $\simeq 1^o$ crossing angle between the two beams.

Figure 4 is the scatter plot of the photon and positron polar angles. The points cluster in two bands corresponding to photon emitted along the incoming and outgoing positron, respectively. Similar bands in the 180^o region are due to photons collinear to the electron. They are not shown in the plot to make evident the clustering of events at $\theta_\gamma = 0^o$ and $\theta_\gamma = \theta_{e^+}$.

The effect of the Lorentz boost seems to be much more dramatic on the acoplanarity distributions, both for inelastic and inelastic processes (see Fig.5). The acoplanarity is defined as the angle between the projections on the transverse $(r - \phi)$ plane of the positron and electron momenta.

However this effect is only apparent. Infact, looking at the profile histogram of Figure 6, it is evident that the events with a large acoplanarity value are the forward ones, for which a small boost in the x direction has a big effect on the transverse plane.

4 Comparison with the previous KLOE data

Our BHABHA generator has been compared with the results obtained with the generator described in KLOE notes 70, 118, 125 (by E.Drago and A.Smilzo).

Both generators have been run using the same selection criteria on the phase space variables.

On Figures 7-10 the solid line is obtained using our generator, while the shadowed histogram represents previous Montecarlo data.

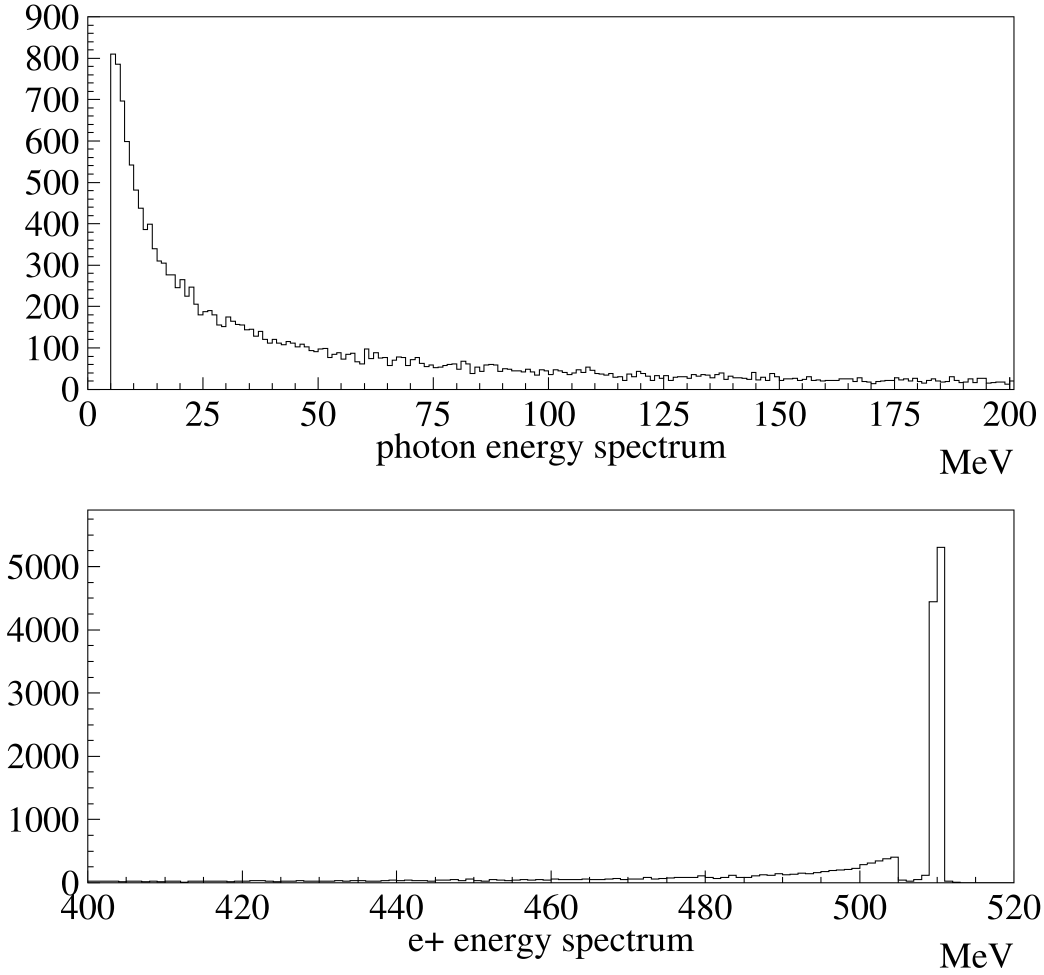

Figure 2: Photon and Positron energy spectra for inelastic events. Only part of the two spectra (that extend from 0 to 510 MeV) is shown.

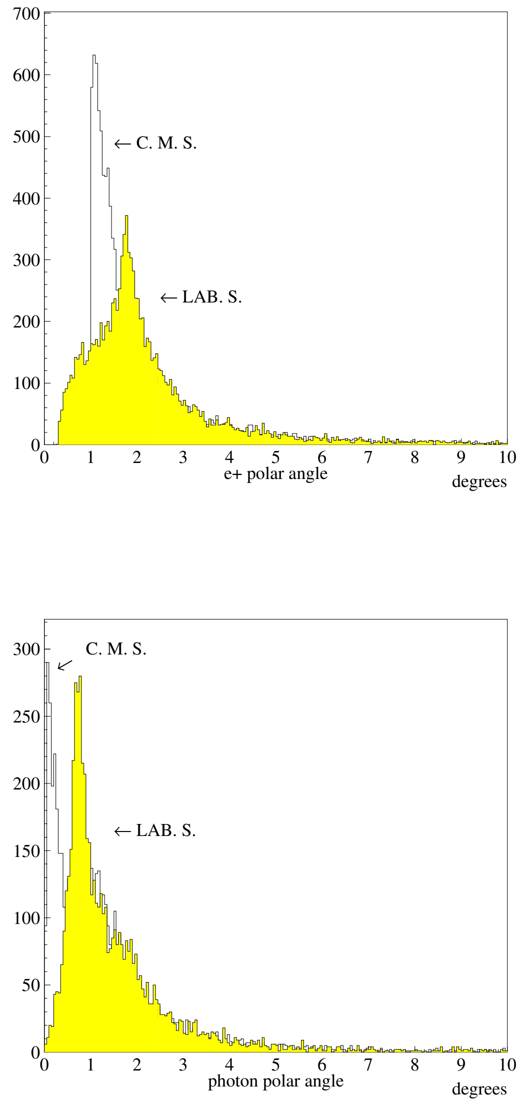

Figure 3: Polar angle distribution for Positron and Photon. Effect of the beam crossing angle (Lorentz boost).

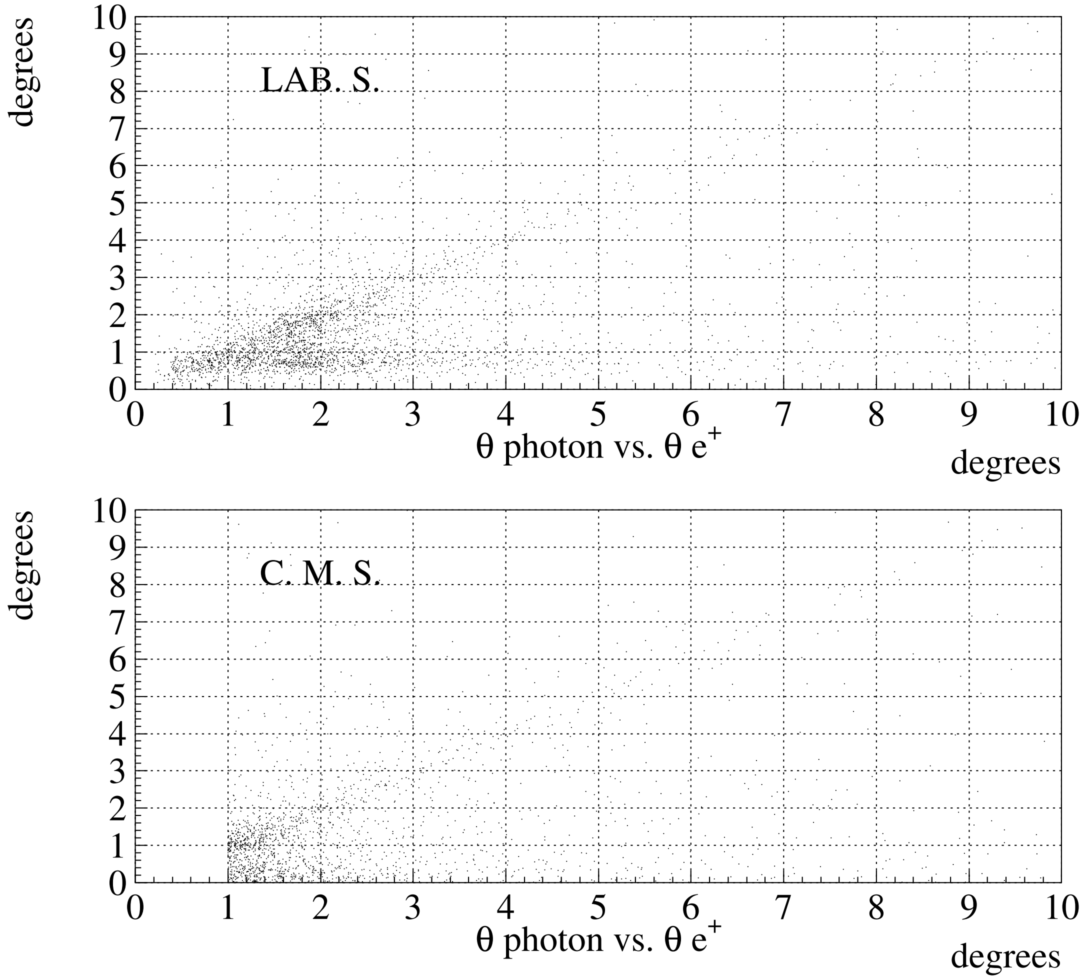

Figure 4: Scatter plot of Photon versus Positron polar angle. The two bands are characteristic of photons emitted by the incoming (at $\theta_\gamma = 0^o$) and by the outgoing (at $\theta_\gamma = \theta_{e^+}$) positron. Mirror bands are present in the $\theta_\gamma = 180^o$ region for the case of photons emitted by the incoming or by the outgoing electron.

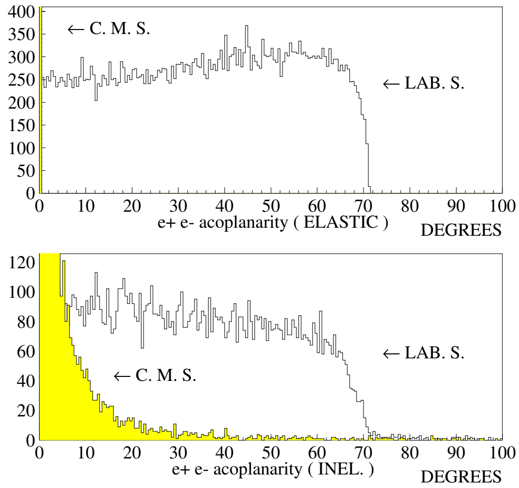

Figure 5: Comparison of acoplanarity distributions between C.M.S and Laboratory System. It's evident the effect of the beam crossing angle.

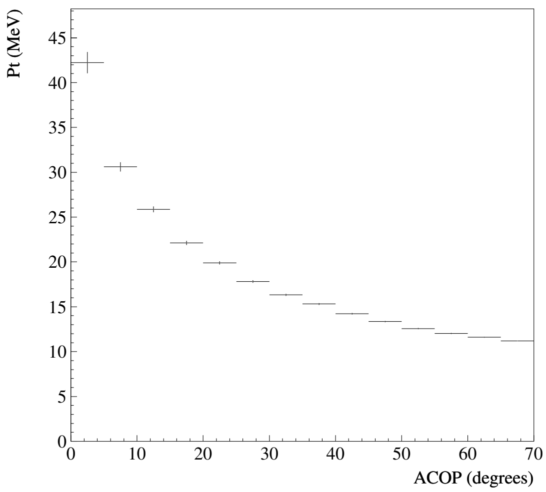

Figure 6: Profile histogram of positron transverse momentum versus the acoplanarity angle (see text for the definition of this angle).

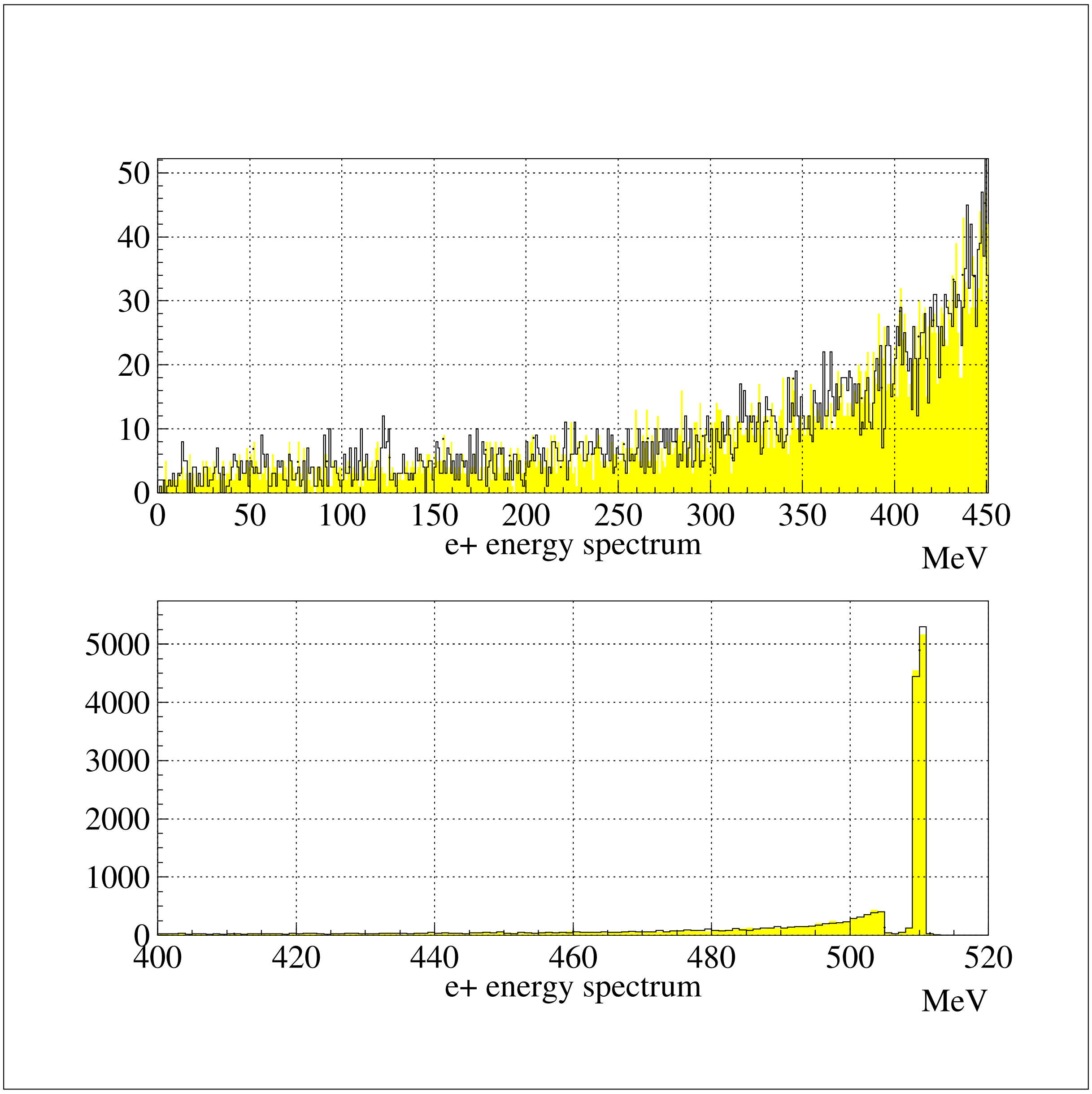

Figure 7: Positron energy distribution. In the second plot the peak corresponds to inelastic events with the photon emitted by the electron. In the first plot the peak is cut out to make the tail visible.

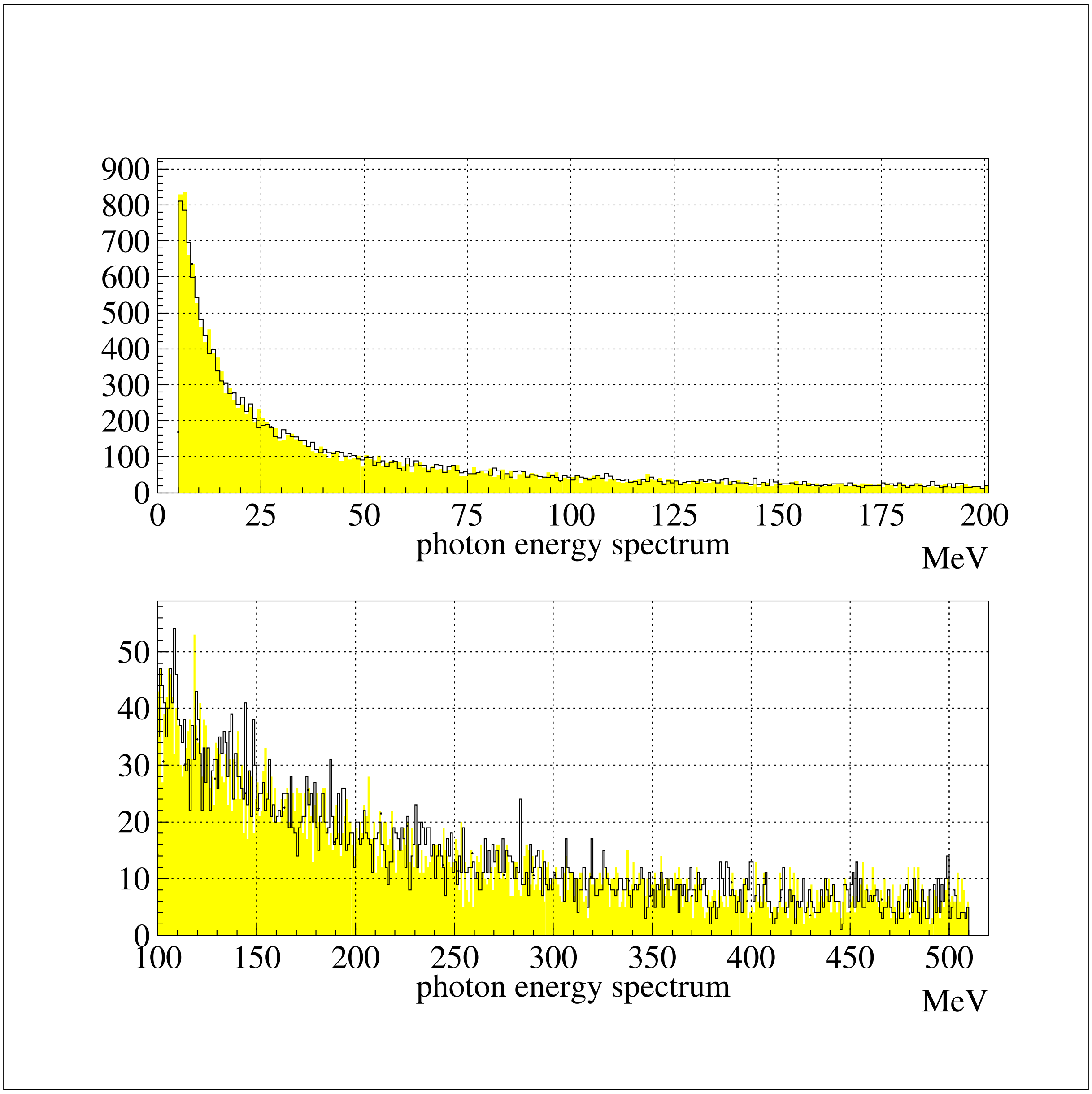

Figure 8: Photon energy spectrum. In the second plot *hard* photons are put in evidence.

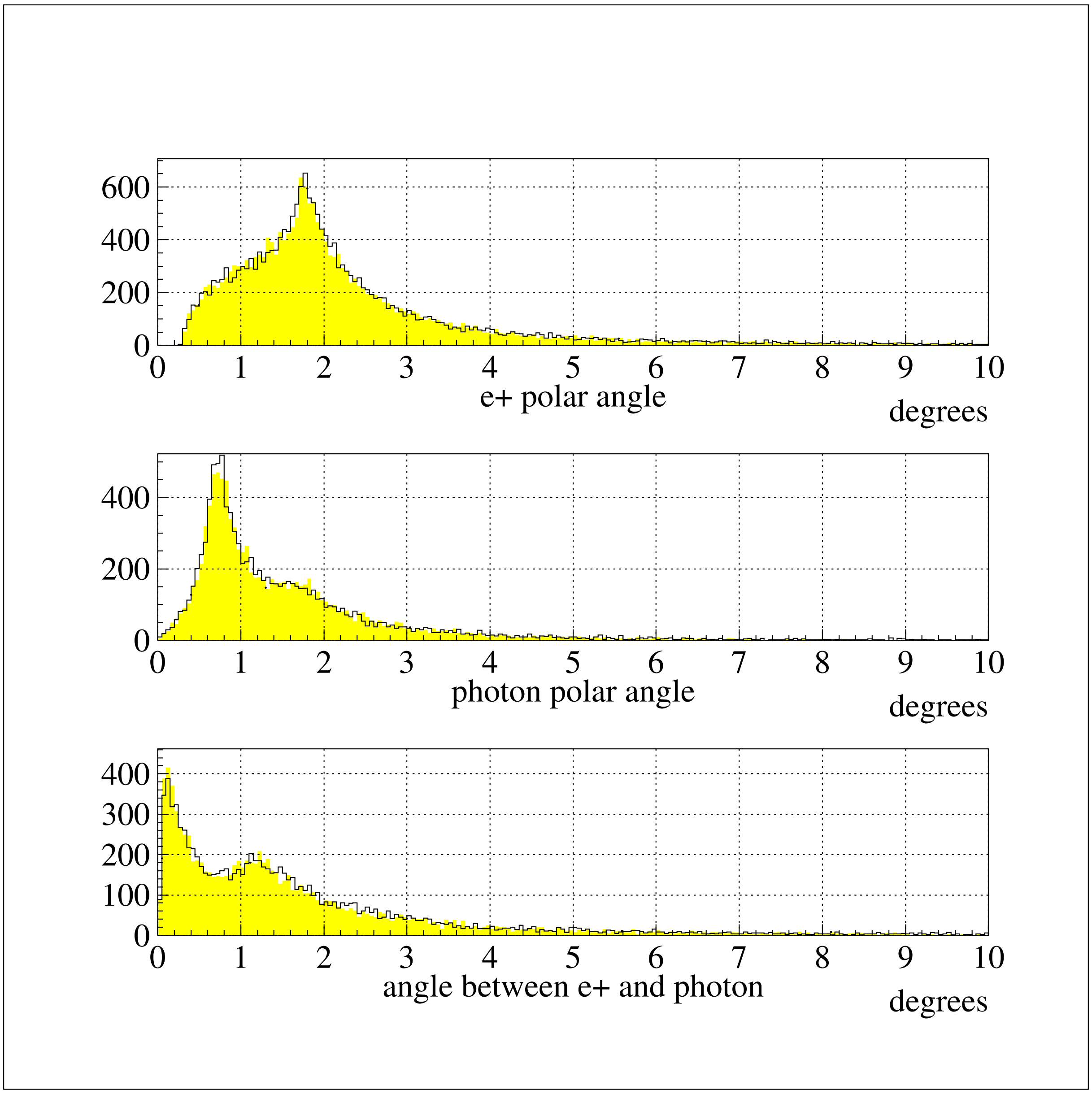

Figure 9: Absolute angles of positron and photon and relative angle between the two. The Lorentz Boost shift from 0^0 the photon peak.

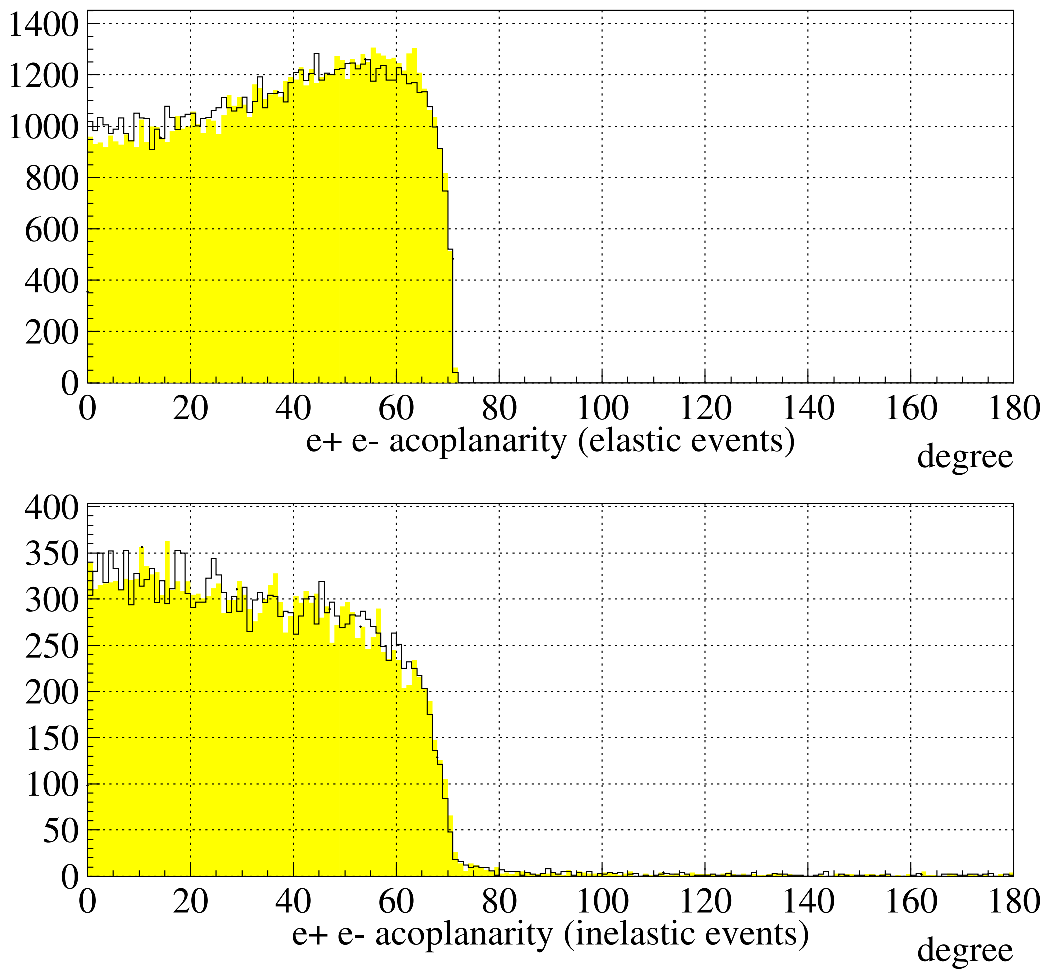

Figure 10: Acoplanarity distribution (see text for its definition).

Results from the two generators agree very well, showing that the BHABHA generator included in GEANFI can be used for the EmC calibration with good confidence in the results.

For a more refined analysis, where small angle effects become important (quadrupole instrumentation, study of trigger performances, ...) a more complete BHABHA generator may be needed.

In this sense another version of the generator is under developement. In particular the soft corrections to the elastic cross section and interference terms with the ϕ resonance will be implemented. This further work will be done in collaboration with Elena Drago (INFN Napoli).

References

[1] F.A.Berends and R.Kleiss *Nuclear Phys. B228 (1983) 537*

[2] F.A.Berends, P.de Causmaecker et al. *Phys. Lett. 103B (1981) 124*