Bhabha and ee-gamma observables with LABSMC

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Abstract

With help of LABSMC event generator we consider large angle Bhabha scattering at LEP2 energies. The Bhabha process with visible photon is analysed also. The theoretical precision is discussed.

1 Motivation

Within the complete list of LEP2 observables for 2-fermion processes the Bhabha scattering occupies an important position. The high experimental precision pushes us to make detailed comparisons and derive a solid estimate of the theoretical uncertainty.

At the previous LEP2 Monte Carlo workshop (see [1] I introduced the new event generator LABSMC [2], suited for large–angle Bhabha scattering. In the present report, concrete situations of event selection are considered, and the precision of the code is discussed. At first we present the general features of the code and indicate some new improvements. Then we present some results for LEP2, according the preliminary notes of the 2-fermion sub–group. Some problems, which are relevant to derive the theoretical precision are discussed. In Conclusions we discuss the theoretical precision.

2 LABSMC event generator

Initially the `LABSMC` event generator [2] was developed to simulate large–angle Bhabha scattering at energies of about a few GeV's at electron positron colliders like VEPP–2M, DAΦNE, *etc.* The code included the Born level matrix element, the complete set of $\mathcal{O}(\alpha)$ QED radiative corrections (RC), and higher order leading logarithmic RC by means of the electron

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structure functions. The relevant set of formulae can be found in Ref. [4]. The generation of events is performed using an original algorithm, which combines advantages of semi–analytical programs and Monte Carlo generators.

In order to consider higher energies a set of electroweak effects [5, 6, 7] was included [3]. The Born level cross section in the program contains now both the photon and Z-boson exchange contributions; it is used also as a kernel cross section for higher order leading log RC. The first order virtual and soft EW RC are called now directly from the semi–analytical code `ALIBABA` [6]. The EW matrix element for radiative Bhabha is taken from Ref. [7]. The third [8] and fourth [9] order leading logarithmic photonic corrections were also included in the new version.

3 Results

At first I performed a test of the generator at LEP2 energies as follows. A comparison of the integrated Bhabha cross section shows a reasonably good agreement (see Table 1) with the published numbers of other codes [10]. In Table 1 the error–bars are omitted: we are not going to discuss here the precision of all the codes.

Table 1: Comparison with Fig. 21 from Ref. [10], cross–sections in pb.

E_{CM}, GeV	`BHWIDE`	`TOPAZ0`	`BHAGENE3`	`UNIBAB`	`SABSPV`	`BHAGEN95`	`LABSMC`
	$\vartheta_{\text{acol}} = 10°$						
175	35.257	35.455	34.690	34.498	35.740	35.847	35.337
190	29.899	30.024	28.780	29.189	30.270	30.352	29.941
205	25.593	25.738	24.690	25.976	25.960	26.007	25.687
	$\vartheta_{\text{acol}} = 25°$						
175	39.741	40.487	39.170	39.521	40.240	40.505	40.029
190	33.698	34.336	32.400	33.512	34.100	34.331	33.954
205	28.929	29.460	27.840	28.710	29.280	29.437	29.178

There about 20 different sets of event selection (ES) for Bhabha scattering in the preliminary notes of the 2-fermion sub–group. Here we put only several numbers:

1	ALEPH realistic exclusive ES1:	108.24 pb
2	DELPHI realistic exclusive ES1:	23.297 pb
3	L3 realistic inclusive ES:	209.03 pb
4	OPAL realistic inclusive ES:	110.01 pb
5	ALEPH idealised exclusive ES1:	111.27 pb
6	DELPHI idealised exclusive ES:	18.456 pb
7	L3 idealised inclusive ES1:	25.187 pb
8	OPAL idealised inclusive ES:	111.94 pb

The ES differ from each other mainly by angular ranges, but there also many important details in their definitions. One of our purposes is to get a clear description of them, which can be implemented in Monte Carlo simulations.

The $e^+e^-\gamma$ observables are not so numerous. Here we consider the OPAL ES with and without the rejection of radiative return to the Z-peak:

1	OPAL $e^+e^-\gamma$ w/o rad. ret. rejection	1.0219 pb
2	OPAL $e^+e^-\gamma$ with rad. ret. rejection	0.8821 pb

The distribution in the invariant mass M_{ee} of the final electron and positron is considered. A clear peak is seen in the region of the invariant mass between 85 and 95 GeV, which corresponds to the radiative return to the Z-resonance. To reduce the dependence on detector efficiencies, I consider in Table 2 the ratio of the number of events in the Z-peak region ($85 < M_{ee} < 95$ GeV) to the total one. The experimental data are taken from OPAL preliminary results (see talk of D. Bourilkov at the workshop [1]). A more detailed comparison with `BHWIDE` [11] Monte Carlo should be done. The difference between the theoretical predictions

Table 2: Ratio of $N_Z/N_{\rm tot}$ for different energies.

$E_{\rm CM}$, GeV	data	`BHWIDE`	`LABSMC`
189	0.171	0.122	0.136
183	0.359	0.101	0.139

and data is large, especially for $E_{\rm CM} = 183$ GeV, but there the experimental statistics is small. To my mind, the difference has no chance to be due to some extra radiative corrections. I hardly can also imagine also that some new physics could contribute here so much, being invisible at LEP1. Presumably, the difference is due to a systematics effect in the data analysis.

The pure tree level matrix element [7] for radiative process was supplemented in `LABSMC` by radiative corrections due to initial state radiation by means of the structure function approach [12] with exponentiation. The ISR corrections increase the ratio: they push down peak with M_{ee} close to E_{cm} and do not affect so much on the Z-peak region. The effect of vacuum polarization to virtual photon propagators is also taken into account. It gives a negative shift to the ratio, because it increases the contribution of the t-channel photon exchange and does not affect on the contribution with s-channel Z-exchange, which is responsible for the returning to the peak.

4 Problems

Here we are going to discuss some problems, which are relevant for the theoretical precision in description of large–angle Bhabha scattering at LEP2 energies.

• First we note, that the second order next–to–leading radiative corrections $\mathcal{O}(\alpha^2 L)$ in our case are not yet calculated completely. The quantity

$$\left(\frac{\alpha}{\pi}\right)^2 \ln\frac{s}{m_e^2} \approx 1.4\cdot 10^{-4} \tag{1}$$

is small, but the coefficient is unknown. This fact imposes a serious restriction on the resulting precision. The main difficulty is to calculate the contribution of two–loop box

diagrams. The group of E.A. Kuraev is working on this problem, but certainly the result will not be ready before the end of the workshop.
• In the present version of the program the pair corrections are included in the $\mathcal{O}(\alpha^2 L^2)$ order by means of the electron structure functions. We take into account both the non–singlet and singlet channels for pair production. The RC are implemented according to the Drell–Yan picture, where in the kernel we have the Bhabha sub–process.

But there are two more mechanisms for e^+e^- pair production of the same order $\mathcal{O}(\alpha^2 L^2)$. One of those is the two–photon mechanism, the other one has the Compton sub–process. The situations were considered in Ref. [13]. My nearest plan is to implement these additional channels of pair production into the event generator.
• Recently there appeared preprint [14], where the authors considered virtual and soft corrections to collinear hard photon emission in large–angle Bhabha scattering. Their results contradict the structure function approach in the order $\mathcal{O}(\alpha^2 L^2)$. I have some objections to the derivation, we have a discussion, but the problem is still there.
• Another non–standard contribution was found in the set of virtual and soft corrections to the Bhabha process with emission of a hard photon at large angles [15]. There were found leading log corrections to $e^+e^-\gamma$ observables of the type $\alpha L \ln(-t/s)$. These terms disappear, if consider only s- or t-channel process, like $e^+e^- \to \mu^+\mu^-\gamma$ or $e^+\mu^- \to e^+\mu^-\gamma$. The origin of the unusual RC and the details of derivation are given in our paper [15]. They change the prediction for the $e^+e^-\gamma$ observables at LEP2 by about 1%. So, an independent verification is desirable.
• Presumably an update of the electroweak library in my code is required.

5 Conclusions

The requirements for theoretical precision are high. They are coming from the experimental accuracy, which can be achieved. So, 0.13% is requested for a typical *wide* angular range ($|\cos\theta_{e^+/e^-}| < 0.9$), and 0.21% for a *narrow* one ($|\cos\theta_{e^+/e^-}| < 0.7$). From the theoretical point of view, I do not see any critical difference in the estimates of the calculation precision in these two angular ranges.

Looking at the set of radiative corrections, taken into account in my code, and the ones, which were omitted, I estimate the theoretical precision at the level of 0.2%. The precision is limited mainly by the second order next–to–leading corrections. Those give about 0.1% contribution to small–angle Bhabha at LEP1, and we may expect the same size of the correction in our case. Another important source of uncertainty is coming from the parametrisation of the hadronic contribution into vacuum polarization. To reach the level of 0.2% we have to perform within the workshop deep comparisons with other available codes to eliminate possible bugs and increase the technical precision.

As about $e^+e^-\gamma$ observables, the required level of 1.5% seems to be quite reachable. The main source of uncertainty here is the unknown sub–leading $\mathcal{O}(\alpha)$ RC to the radiative process. To estimate their contribution I looked at the difference of the total $\mathcal{O}(\alpha)$ RC and the leading log part $\mathcal{O}(\alpha L)$ in the non–radiative Bhabha itself in a similar angular range. The difference $\delta_{\mathrm{tot}} - \delta_{\mathrm{LLA}}$ was found to be below 1%. If we apply the asymmetric cut "*at* *least one electron has* $|\cos\theta_e| < 0.7$", the difference becomes even much less.

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