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Light-Pair Corrections to Small-Angle Bhabha Scattering in a Realistic Set-up at LEP

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Light-pair corrections to small-angle Bhabha scattering have been computed in a realistic set-up for luminosity measurements at LEP. The effect of acollinearity and acoplanarity rejection criteria has been carefully analysed for typical calorimetric event selections. The magnitude of the correction, depending on the details of the considered set-up, is comparable with the present experimental error.

Key words: electron−positron collision, small-angle Bhabha scattering, theoretical error, light pairs, Monte Carlo
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Table 1
Current status of the theoretical error for the SABH scattering, as reported in refs. [5–7].

Type of correction/error	Uncertainty [5–7] LEP1 (%)	LEP2 (%)
Missing photonic $O(\alpha^2 L)$	0.027	0.040
Missing photonic $O(\alpha^3 L^3)$	0.015	0.030
Vacuum polarization	0.040	0.100
Light pairs	0.010	0.015
Z-exchange	0.015	0.000
Total error	0.054	0.113

In the last years, many efforts were made to reduce the sources of theoretical error in the prediction of the small-angle Bhabha (hereafter SABH) scattering cross section, in order to match the increased experimental accuracy. The main results were achieved in the sector of the $O(\alpha^2 L)$ photonic corrections, by lowering the associated uncertainty to the 0.03% level [1,2]. Moreover, the uncertainty associated to the light-pair contribution was reduced [3–5] to the 0.01% level. The ultimate result of these works was to lower the total theoretical error to the 0.05% level for LEP1 energies, as it can be read from table 1 (see also refs. [6,7]). On the other hand, at present, the experimental error associated to luminosity measurements is below the 0.05% level. Since the size of light-pair contributions is of the order of some 0.01% [3–5] and will depend, in general, on the event selection (hereafter ES), it is important to include the best available estimate for light-pair corrections. In particular, the presence of tight cuts, which select events with soft-pair emission, such as acollinearity and acoplanarity cuts, can significantly alter the light-pair correction.

At present, the theoretical error to SABH scattering, due to pair production, can be evaluated by approximate means, such as the Monte Carlo (hereafter MC) results based on t-channel approximation [4] or the analytical calculations in the quasi-collinear approximation [3], or by the MC calculation of ref. [5], which includes the exact QED four-fermion matrix element, two-loop virtual corrections according to ref. [8], initial-state radiation (hereafter ISR) in the collinear approximation, and realistic ES's. In this note the light-pair contribution is studied in the presence of ES's as realistic as possible by using the approach of ref. [5], to which the reader is addressed for any technical detail. Particular attention is payed to the OPAL ES [9], as a significant case study.

Before entering the details of the OPAL ES, it is worthwhile to consider a typical

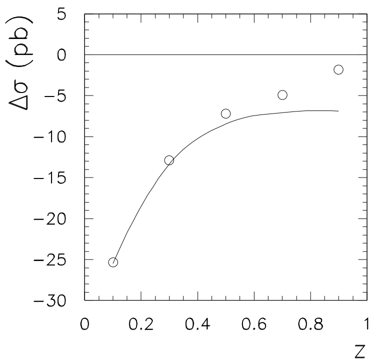

Fig. 1. The MC integration of the exact matrix element (markers) [5] and the t-channel approximation recalculated according to [4] (solid line) as a function of the energy cut $z \equiv 1 - E_1 E_2 / E^2_{\rm beam}$. Entry values are in pb and sum up real and virtual corrections; they are computed for the `CALO2` set-up with asymmetric acceptance $3.49^\circ \leq \theta_{\rm N} \leq 6.11^\circ$, $2.97^\circ \leq \theta_{\rm W} \leq 6.73^\circ$ at $\sqrt{s} = 92.0$ GeV. They include only the electron contribution without ISR. In this set-up, the tree-level Bhabha cross section is $\sigma_0 = 21939(1)$ pb.

calorimetric ES, such as one of the `CALO2` ES's adopted in ref. [5]. Apart from other technical features, it is characterized by an energy cut defined in terms of the kinematical variable z:

$$z \equiv 1 - \frac{E_1 E_2}{E^2_{\rm beam}} \leq z_{\rm max}, \tag{1}$$

where $E_{1,2}$ are the energies of the two clusters of particles hitting the forward and backward calorimeters. The definition of the ES, involving angular and energy cuts only, is reported in the caption of fig. 1. Notice that small values of z inhibit hard-pair emission, while large values do not. In fig. 1 the light-pair contribution to `SABH` scattering is shown as a function of z. As expected, the magnitude of the correction undergoes a significant variation by changing the z value. In particular the correction grows in absolute value if the available phase-space region favours soft-pair radiation. This is the same behaviour as observed if one studies photon emission, instead of pair emission. It is worth noticing that the enhancement of the pair correction is valid within the t-channel approximation too. It is also important to stress that superimposing an acollinearity and acoplanarity cut means inhibiting hard radiation, so that such a cut can effectively mimic a cut on z, constraining it in the soft region. As an example, these cuts were superimposed on `CALO2`, by considering only the electron-pair contribution at the tree level. The results are shown in table 2 for asymmetric angular acceptances ($3.49^\circ \leq \theta_{\rm N} \leq 6.11^\circ$ and $2.97^\circ \leq \theta_{\rm W} \leq 6.73^\circ$) at $\sqrt{s} = 92.0$ GeV with acollinearity and acoplanarity cuts ($\theta_{\rm ac} = 0.58^\circ$ and $\phi_{\rm ap} = 11.46^\circ$). This exercise shows that the presence of acollinearity and acoplanarity cuts increases, in absolute value, the light-pair correction

Table 2
Comparison between CALO2 asymmetric ES with and without a further cut in acollinearity and acoplanarity ($\theta_{\rm ac} = 0.58^\circ$, $\phi_{\rm ap} = 11.46^\circ$) at $\sqrt{s} = 92.0$ GeV. CALO2 set-up acceptances are $3.49^\circ \leq \theta_{\rm N} \leq 6.11^\circ$ and $2.97^\circ \leq \theta_{\rm W} \leq 6.73^\circ$. First-column entries are in pb and refer to the MC integration of the exact matrix element without ISR at $z = 0.3,\ 0.5,\ 0.7$, where $z \equiv 1 - E_1 E_2/E^2_{\rm beam}$, and sum up real and virtual part. Second-column entries refer to the relative correction with respect to the Bhabha tree-level cross section $\sigma_0 = 21939(1)$ pb.

Set-up modality	z	Abs. corr. (pb)	Rel. corr. (10^{-4})
CALO2	0.3	-12.85 ± 0.05	-5.86 ± 0.02
CALO2 with ac./ap.		-18.68 ± 0.06	-8.51 ± 0.03
CALO2	0.5	-7.14 ± 0.05	-3.25 ± 0.02
CALO2 with ac./ap.		-16.36 ± 0.19	-7.46 ± 0.08
CALO2	0.7	-4.98 ± 0.12	-2.27 ± 0.06
CALO2 with ac./ap.		-15.31 ± 0.10	-6.98 ± 0.05

significantly, i.e. it has the same effect of lowering the z cut.[2] This link can be easily understood since acollinearity and acoplanarity cuts select events with soft-pair radiation. It is worth noticing that the higher the value of z, the higher the relative enhancement of the correction with respect to the correction itself, as expected.

Let us now consider the more realistic OPAL case. The OPAL luminosity is measured with an experimental precision of 0.034% [9], and similar performances are attained by the other collaborations. On the other hand, the light-pair correction is of the order of some 0.01% and, moreover, it could be critically enhanced by tight acollinearity and acoplanarity cuts, as just shown in the CALO2 case (see table 2). It is thus crucial, for the luminosity measurements, to include a careful estimate of the pair corrections. The OPAL collaboration defines a reference theoretical cross section in terms of simple cuts at four-vector level on the generated particles [9]. This rejection set-up, reviewed in table 3, is named M4SEL; it comes in three flavours SWITL, SWITR and SWITA, corresponding to whether the narrow cut in polar angle is applied to the left or the right hand calorimeter, or, in the case of SWITA, to the average of the polar angles measured on the right and left [9].

A complete calculation, performed with the MC code of ref. [5], including ISR via collinear structure functions and the muons contribution, gives the results shown in table 4, leading to a correction of -0.044%. Two comments are in order here. The first is that the pair correction is of the same order as the

[2] With the given values of the acollinearity and acoplanarity cuts, the largely dominant effect is due to the acollinearity cut.

Table 3
OPAL rejection set-up defining the reference theoretical cross section for the luminosity acceptance calculation

Wide	1.56° − 3.19°
Narrow	1.79° − 2.96°
Max acollinearity	0.58°
Max acoplanarity	11.46°
Min energy per calo	$\sqrt{s}/4$
Min energy total	$3\sqrt{s}/4$

Table 4
Light-pair correction to SABH scattering. Entry values sum up real and virtual corrections, and are computed for the M4SEL set-up at 91.0 GeV. The first column shows the absolute correction in pb, while the second column shows the correction relative to the Born cross section $\sigma_0 = 81344(7)$ pb. The errors quoted sum up the physical and the technical error as estimated according to ref. [5].

Set-up modality	Abs. corr. (pb)	Rel. corr. (10^{-4})
SwitL	-35.99 ± 11.55	-4.42 ± 1.43
SwitR	-35.83 ± 11.33	-4.40 ± 1.40
SwitA	-35.64 ± 11.36	-4.38 ± 1.40

experimental error. The second is that the pair correction computed for an ES with similar angular and energy cuts, but without an acollinearity and acoplanarity cut, is at the level of −0.025 – 0.030% [5], i.e. smaller than the present prediction.

In this short discussion the relevance of taking into account the light-pair correction to SABH scattering for luminosity measurements at e^+e^- colliders is pointed out. This need is due to the high experimental accuracy now achieved by the LEP collaborations, better than the 0.05% level. In particular the effects of acollinearity and acoplanarity cuts are analysed, and general arguments are given to understand why the presence of such rejection criteria increases the size of light-pair corrections. Moreover a realistic ES, the M4SEL adopted by the OPAL collaboration, has been implemented in a MC code to size the light-pair contribution to SABH scattering, leading to a correction for light pairs at the 0.04% level.

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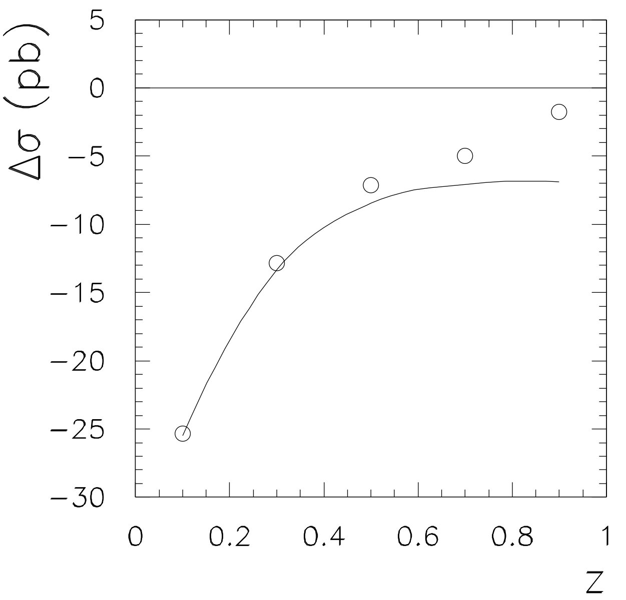

5
0
−5
−10
−15
−20
−25
−30
Δσ (pb)
0
0.2
0.4
0.6
0.8
1
Z