Preliminary notes on two-fermion group activities

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Abstract

This note contains a preliminary discussion of the issues which are to be addressed by the 2-fermion group. New input or criticism would be most welcome. It contains a list of experimental and theoretical observables for difermion events, and provides estimates of their theoretical uncertainties, together with the one requested by experiments. Comparisons are made of predictions from different packages.

Technical Point: This file has the usepackage showkeys activated. For the normal printout form the appropriate line should be commented out. Then all information about the labels will disappear. At present it is printed for the sake of editing comfort.

To evolve into a chapter in future yellow book

Feb. 07 2000,

Contents

1 Introduction

It is probably fair to assume that the theoretical effort to describe difermion physics at LEP2 is now almost finished. The main goal of the difermion workshop should thus be to review our present knowledge of these theoretical predictions, collecting references from relevant papers and programs. It should estimate theoretical systematic errors for experimentally interesting quantities, etc. However, if important predictions are still missing, the present workshop should bring this to the attention of the theoretical community.

Our group will work closely with the LEP2 $f\bar{f}$ working group (coordinated by Pete Renton), which aims to develop the procedure for combining the results from the four LEP experiments. We should also interact with searches groups, for which Standard Model (SM) difermion processes are a source of background. It is natural that members of these working groups are best placed to formulate a list of practical observables for which theoretical predictions and their systematic errors are needed. They can also highlight cases where the theoretical issues need clarifying and estimate the relative urgency with which the different issues need to be addressed. Of course we should coordinate our efforts with other working groups of the workshop, in particular the 4-fermion as well as $\nu\bar{\nu}\gamma's$ working groups.

Two kinds of observables should be studied.

- Realistic observables which correspond more closely to the event selection cuts actually applied by experiments.

- Idealized theoretical quantities, such as the total cross sections or asymmetry with no cuts or very simple cuts. Such quantities are best suited for theoretically clear extraction of basic quantities such as particle masses or couplings. They also make it easier to average results from different experiments and allow a comparison with SM predictions from semi-analytical programs.

A list of such observables is given in **Section 2**. The list of realistic observables may be long and semi-repetitive . (e.g., Observables with cuts differing slightly by numerical value of some parameters – angles, energies etc.) However, this is necessary, as the discussion of theoretical systematic errors often depends on particular kinematical cuts applied. It may also contain observables which are known to have good theoretical predictions and reliably estimated theoretical errors. Later, we can decide on how to group and simplify the list according to e.g., convenience for discussion of theoretical errors. However, it is important that from the very beginning the list should be complete and describe exhaustively the event selections of the various experiments. Section 2 will also describe why some observables are better than others from an experimental point of view. It will also identify for which variables it is most urgent to have theoretical input, e.g., because experimental errors are small compared with theoretical ones, or where experimental cuts have to be modified to exclude phase space regions poorly known from theory. The list of idealized variables must use simple cuts, which make sense experimentally and can also be implemented in semi-analytical programs.

One of the most important tools to achieve the aim of this workshop is comparisons between different available theoretical calculations. Before making such comparisons, one need a clear understanding of definitions of quantities and tuning of input parameters. **Section** **3** will therefore address the question of conventions and definitions in order to avoid such inconsistencies when using different programs. This chapter on definitions should also address the question of compatibility of LEP1 and LEP2 conventions and motivation of why they are chosen like that (gauge invariance, conventions of LEP1 published results, etc.). Eventually such section(s) could be part of general section of the whole report and could be taken over by the main editor.

In **Section 4**, we plan to describe the various theoretical programs and give the basic ideas behind them, together with the list of main publications and indication of where the present versions of these programs can be taken from.

Section 5 will contain numerical results and present theoretical studies of systematic errors for the individual (or for groups of) observables presented in Section 2. It should also assess theoretical errors on the difference between idealized and experimental observables, to determine how reliably experiments can correct their results to the idealized case. The aim will be, of course, not to list all the predictions for each case but to provide numerical benchmark and concentrate on the discussion of possible systematic errors. In this discussion the breakdown of errors and understanding of applicability of different components is important.

The contributions to this section will be the responsibility of the individual authors of the various packages used in making predictions of difermion production. We should ensure that all such packages are considered, not only those already used by experimentalists, but also all other which are officially released.

The ideal item in this section would be just extended citation to published papers (preprints or completed entries in this book) of the form which may look like the following one: "Observables (*list of labels from Section 2*) have theoretical systematic uncertainties of xx% as shown in [32]. These uncertainties are estimated with the help of the program [31], by varying the following assumptions/parameters .... Simmilarily on the basis of that calculations we expect that in the following cases: (*another list of labels from Section 2*) systematic errors for predictions should not exceed the tag of xx %. Finally in the following cases: (*again another list of labels from Section 2*) the predictions and their systematic errors can be calculated accordingly to scenario explained above, but we can not guess the numerical size of the outcome with enough certaintity.

We can not expect the ideal situation in case of all observables. We will need to adopt our approach, stimulate effort etc., accordingly to experimental importance of the particular observable, available theoretical results and manpower. In the cases where the theory error is unknown or possibly big, we will try to find other alternative observables with reliable/small errors.

Section 6 will provide numerical comparisons of predictions from different theory packages, comparisons for the observables listed in Section 2 .These comparisons will check the robustness of the error estimates provided in Section 5. Eventual traps or potential misunderstandings due to different conventions will be presented here.

conclusion

Finally, **Section 8** will summarize the effort. In some cases we may find predictions to be insufficiently precise. In such cases stimulation for the future efforts can be generated.

2 Observables

list

From the preliminary discussion we find that at least the two classes of observables are to be discussed: those corresponding to realistic experimental cuts and those of an idealized nature. Furthermore, each of these may apply to either

1. 2 fermion final states
2. 2 fermion + visible photons (esp radiative return).

The perpendicular classification was of course on the basis of the level of the idealization of observable. It is thus rather reasonable to start with the creation first of individual entries in the list, and only later continue with ordering it.

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As it was pointed out, the first item should be discussed in close contact with the LEP2 ffbar subgroup of the LEP electroweak working group. It should help to facilitate the averaging procedure of the results of the four LEP experiments, and assess the theoretical and MC modelling errors for each experiment as well as their correlation in the average. It might even help to clearly define a benchmark 2-fermion "signal" for the averaging procedure in terms of s' definition, $\cos\theta$ definition, QED I/F interference, and pair radiation correction.

The 2f+photon final state (i.e. high pt photons) , mainly consisting of radiative return events, is essential to be understood for searches for excited leptons , decaying to gamma-ℓ and anomalous ZZ-γ and γZ-γ couplings. Here the theory predictions , semi-analytical programs and MC generators agree worst with the data, especially for electrons. An improvement of these predictions and an assessment of remaining errors is crucial for obtaining valid limits (or discoveries) of new physics.

Precise realistic observables together with the required precision for each of the above categories are currently set up by the experimentalists.

In the definition of cuts we need to address the question of possible contamination of one process by another one. Often experimental cuts are specifically designed to eliminate such contaminations, but in practice some remnant contaminations may still stay. As simple example we can imagine the τ-predictions (case of the $\tau \to \mu$ decay) which can provide non-negligible contribution for the observable designed eg. for the measurement of μ-pair with ISR photons. As prediction for such τ-channel can be easily calculated we may expect the question on its size and related uncertainty.

More complicated is the case of 2-f versus 4-f definition, i.e. how to set the limit defining which pair radiation is a radiative correction to the 2f signal, and should be included in the measurement and the efficiency determination, and which is background, to be subtracted. To understand this interplay between 2-f and 4-f processes three groups have to work closely together: Our group, the LEP2 ffbar subgroup of the LEP electroweak working group and the 4-fermion subgroup of this MC workshop. Theoretically little effort has yet gone in this problem at LEP2, and there is urgent need for theorists to talk to experimentalists and vice versa, in order to define the work that has to be done (e.g. common exponentiation of pairs and photons, options to apply a cut on the pair mass) The outcome might even have some impact on LEP1 results, although there the effect is very much suppressed.

We may expect other similar situations, due e.g. of particle misidentiffications which we may need to include in our scheme of predictions and their systematic errors. There is no doubt that the higher precision required the more cut off details need to be included into observable definition. Also discussion of theoretical uncertainties will depend rather strongly on required precision.

2.1 Precision requirements

As we can see the observables can be divided into different classes of abstraction depending where they are placed on the spectrum from full experimental condition toward final idealized observables with QED corrections subtracted, 4π-detector etc. One of the most important ingredient of the observable definition is its precision tag. Obviously the higher precision the more complicated study of its theoretical uncertainties will be. Also more of the details of experimental cuts will be needed to get the answer on theoretical systematic errors. In cases when description will become extremely long a reference to experimental paper can be the only solution. For the convenience of editing we suggest that the references are directly taken from SLAC database including the bib-tex-reference-name!. This should be helpful in matching all into one long (or more of shorter) list(s). Every observable will enter as individual item in the tex-enumerate list.

The following rule of thumb with respect to the errors obtained for the data taken at $\sqrt{s} = 189$ GeV was suggested for estimating required precision in cases when there is no better scenario.

1. Experimental statistical error is decreased by factor of $\sqrt{12} \simeq 3.5$ with respect to present (summer 1999) one for the single collaboration. We still expect statistics to grow by factor of 3 and combination of all 4 experiments brings total statistics factor of 12 bigger.

2. Experimental systematic error can be expected to go down by a factor of 2 (may be 3) due to improvements and partial non-correlations among experiments.

3. The above estimates of experimental statistical and systematic error should be added in quadrature.

4. The required precision should be 1/3 of that to assure that theoretical effects will not deteriorate experimental results (will not increase an error) by more than 10% .

The demand of maximum 10 % increase of final experimental overall error due to theoretical uncertainties is not an over-demand. It is equivalent to decrease in running time of experiments by 20 % in cases when statistical error dominates. Similar 10% deterioration of an overall detection performance would occur only after 30 % decrease in data taking for measurements where statistical and systematic errors are similar in size. Having this in mind and also an enormous effort of so many peoples over so many years, not mentioning the costs may even lead to conclusion that our rule for precision requirements from theory is not enough strict.

In general as inclusive we understand cross section for $\sqrt{s'/s} > 0.1$ and exclusive for $\sqrt{s'/s} > 0.85$. For Bhabha Excl$_1$ denotes $|\cos\theta| < 0.9$ and Excl$_2$ denotes $|\cos\theta| < 0.7$ For asymmetries the (absolute) error tag can be obtained from the one of cross section multiplying it by $0.01{\cdot}\sqrt{2}$ and dropping the % symbol.

The following precision tags can be assumed if explicit numbers do not overrule them in the text:

1. cross sections for $q\bar{q}$ final states: incl. 0.11 %, excl. 0.23 %
2. cross sections for e^-e^+ final states: excl$_1$ 0.13 %, excl$_2$ 0.21 %
3. cross sections and asymmetries for $\mu^-\mu^+$ final states: incl. 0.41 %, excl. 0.53 %
4. cross sections and asymmetries for $\tau^-\tau^+$ final states: incl. 0.44 %, excl. 0.61 %
5. searches background cross sections from quarks and tagged hard photons 0.3 %
6. searches background cross sections from leptons and tagged hard photons:
   single photons 1.5 %, multiple photons 5%
7. searches background cross sections from neutrinos and tagged hard photons
   single photons 0.2 %, multiple photons 1%

   These numbers can serve as a starting point for definition of precision tags required from complete theoretical calculations. For separate ingredients such as interferences pair corrections etc, physical precision tag must be even more strict, to assure that their combination will not overcome the required tag. Finally the tag for technical tests must be set another factor of few smaller. This point will be extended later, at the moment let us assume that in general case of physical effect which is not-dominating overall theoretical uncertainty its individual uncertainty must be smaller at least by factor of 3 from required precision tag. Of course technical precision of its calculation must be even more strict. To enable any meaningful comparisons between different theoretical calculations it must be at least another factor of 5 or so smaller, that is to be at the level of 0.05 of listed above precisions tags required by experiments.

2.2 General comments of observable definition

In the following chapters the observables will be defined. For more details see respectively: ALEPH [23], DELPHI [24], L3 [7] OPAL [4, 5, 10] ($f\bar{f}(\gamma)$), [9] ($\ell\ell+\gamma$) [3, 8] ($\nu\bar{\nu}+\gamma$)

Maing groups of observables are formed by physics processes, they are later divided into realistic and non-realistic ones corresponding to different stages of experimental analysic.

Finally specific solutions adopted by experiments are placed in subsection. Some points which could be extracted from observables definition like glossary or approach to the extra pair are discussed at the beginning of the chapter to avoid unecessary repetition.

The purpose of the list of observables is to review all necessary conditions for calculation of theoretical predictions. More explanatory example are given later in the section.

2.3 Notation

In definition of observables we will use some short-hand notations to make it easier. Let me illustrate just a few of them.

- E_{cm}: centre of mass energy.
- θ_γ: The polar angle of particle γ with respect to the electron beam.
- $|\cos\theta_{f/\bar{f}}| < 0.9$: The polar angle of both particles f and $\bar{f}$ must satisfy the cut.
- E_γ: The energy of particle γ.
- $x_\gamma = 2E_\gamma/E_{cm}$: The energy fraction of particle γ.
- N_{trk}: Number of charged tracks in the event.
- a$col(e^+e^-)$: The acollinearity angle between particles e^+ and e^-.
- A_{FB}: forward-backward asymmetry constructed on the basis of final state charged particles.
- $M_{prop-}(\mu^+\mu^-)$: invariant mass of the s-channel propagator, with ISR/FSR interference subtracted.
- $M_{prop+}(\mu^+\mu^-)$: invariant mass of the s-channel propagator, with ISR/FSR interference not subtracted. In this case, the propagator mass is ambiguous for the interference contribution, so this part is actually evaluated using the $\mu^+\mu^-$ invariant mass excluding radiative photons.
- $M_{inv}(\mu^+\mu^-)$: invariant mass of μ^+ and μ^- - all other particles such as collinear photons are excluded. For realistic observables, this is determined from the reconstructed 4-momenta of the two particles.
- $M_{ang}(\mu^+\mu^-)$: invariant mass determined from the measured polar angles of particles μ^+ and μ^- with respect to the electron beam. This calculation is based on four-momentum conservation assuming that only one radiative photon is present. If no photon is seen in the detector, this radiative photon is assumed to go along the beam axis. If an energetic, isolated photon is seen in the detector, then its reconstructed polar angle is used.

- $M_{kine}(\mu^+\mu^-)$: invariant mass determined from a kinematic fit. This uses 4-momentum conservation to improve the mass estimate based on the reconstructed 4-momenta of the μ^+ and μ^-.

- s'$_{L3}$ for $\mu^+\mu^-$ or $\tau^+\tau^-$ from observed ISR photon (E more than 10 GeV, $|\cos\theta_\gamma| <$ 0.985, separation to nearest fermion more than 10 degrees), *or* from fermion angles assuming photon escapes along the beam pipe

- s'$_{L3}$ for $q\bar{q}$ from observed ISR photon (E more than 10 GeV, $|\cos\theta_\gamma| < 0.985$, separation to nearest energy cluster more than 10 degrees), *or* from jet angles after kinematic fit

- s'$_{\mathrm{OPAL}}$ for $\mathrm{q\bar{q}}$: from a series of kinematic fits using observed ISR photons ($|\cos\theta_\gamma| <$ 0.985, isolated with less than 1 GeV energy flow in a cone of half angle 0.2 rad around them) plus hadronic jets. The fits allow zero, one or two additional photons emitted close to the beam direction. s' is taken from the fit with the lowest number of extra photons giving an acceptable χ^2.

2.4 questions and answers are temporarily here

2.4.1 ALEPH

= question to ALEPH:

Not, at all! I'm still waiting for any response concerning ALEPH's "Idealized Observable". Let me repeat my question below:

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Hello,

I have a question concerning ALEPH's cuts for Bhabha. For realistic observables the agular cuts are defined for θ^* ((**Obs.** Aleph3 19) and (**Obs.** Aleph4 20)), while for idealized observables these cut are for the electron θ only ((**Obs.** IAleph3 30) and (**Obs.** IAleph4 31)), without a cut on the positron angle. Is this a misprint or something really intended?

Best regards, Wiesiek Placzek

Answer: You should read θ^* in both , the text is now corrected. (M.N Minard)

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Another questios is about treatment of extra fermion pairs in Bhabha. So far, there is only an anwer from L3. Do the other experiments use the same criteria?

Answer: Updates are present now in appropriate sections.

Without exact specifications of observables/cuts we cannot start our tests/cross-checks of theoretical programs as proposed by LEP2MC Workshop.

Best regads, Wiesiek

2.4.2 DELPHI

= question to DELPHI:

we are producing NUNUGPV numbers for nu nu gamma(s) observables and have a couple of questions concerning the signature single photon plus missing energy in the case of the DELPHI set of cuts:
1) In case a), b) and c) it is always specified a forward angular coverage. Is it intended that the cuts have to be extended simmetrically to the backward emisphere or not?

Answer is yes

2) After case c), it is stated "No additional photons with $E_\gamma > 0.8 GeV$ and $\theta < 38$ mrad..."; we suspect that it should be $\theta > 38$ mrad, right?

Answer is yes

We will wait for your answer before going further. Thanks in advance for your reply, best regards

Fulvio, Guido and Oreste

2.4.3 *L3*

`supplement for some of the L3 observables: The threshold for registration ((`**Obs.** `LT5 23)-(`**Obs.** `LT7 25)) is 15-20 GeV. The signal definition ((`**Obs.** `ILT5 34)-(`**Obs.** `ILT7 36)) now is at least 1 GeV for both e+e- /can be changed to say 20 GeV if dictated by theory arguments/`

2.4.4 OPAL

2.5 Additional pair treatment

2.5.1 ALEPH

Apart from the cuts listed for realistic observables, no additional requirement is added to reject events with real or virtual pair emission, their contribution is taken in account for efficiency calculation. The main rejection to 4-fermions processed is due to invariant mass cuts associated the the topological cut on the event shape.
For a two-fermion final state are considered as backgrounds and their residual contribution estimated from Monte-Carlo four-fermion events for which both fermion pair invariant mass $\mathrm{f}\bar{\mathrm{f}}$ or $\mathrm{f}'\bar{\mathrm{f}}'$ are above 65 GeV. This exclude from the signal definition the 4-fermion arising from virtual Z or W contribution, but not the the contribution from virtual photon. The above requirement are valid for hadronic, muon pairs and taus pairs.

Note that for ALEPH the pair contribution is kept both in realistic and idealized observables.

2.5.2 DELPHI

In case of idealized observables it is assumed that theoretical predictions should not include neither real nor virtual pair corrections. These being subtracted from the data with the help of the Monte Carlo.

The appropriate systematic error is to be discussed with the help of Monte Carlo program or programs. We need matching Monte Carlo predictions for idealized observables with pair corrections excluded as well as for realistic observables with pair corrections included.

We expect that in case of realistic observables implicit cuts on additional fermion pairs are given with the sufficient detail for DELPHI observables. Exception are $\nu\bar{\nu}\gamma$ observables, where we request no jets/leptons (ch) within our acceptance that is of energy $E_{ch} > 0.5$ GeV and $|\cos\theta_{ch}| < 0.97$.

2.5.3 *L3*

Let us define first the cut on the secondary pairs for idealized observables:

1. We assume that all the phase space for the secondary pairs is included and integrated over, however contribution form resonant diagrams from 4-fermion processes etc. must be subtracted from the data first by means of Monte Carlo.

For the secondary pair cut to be used for realistic L3 observables our aim was to describe it in a form as brief as possible. In particular we accept ambiguities which may lead to differences much smaller than precision tag. The cut off on the secondary pair is performed in the following way:

1. The invariant mass of the primary pair must be at least 60 GeV for qq, 75 GeV for mm/tt. The invariant mass is determined from acollinearity of primary pair and other trackcs under assumption that missing is only single photon (collinear to the beam). The primary pair means lepton same-flavour anti-lepton or two jets, of highest energies.

2. cut on invariant mass of the secondary pair to be smaller than invariant mass of the primary pair is not explicitly required, but it is in practice through the selection targets on the 2 highest energy jets to form the primary pair, seen in the detector.

3. The W and Z-pair production background is reduced by applying the following cuts. Semi-leptonic W-pair decays are rejected by requiring the transverse energy imbalance to be smaller than 0.3 E_{vis}. The background from hadronic W(Z)-pair decays is reduced by rejecting events with at least four jets each with energy larger than 15 GeV. The jets are obtained using the JADE algorithm with a fixed jet resolution parameter $y_{\text{cut}} = 0.01$. The remaining part of the 4-fermion processes due to W and Z contributions remain and must be subtracted later with the help of Monte Carlo of well established theoretical uncertainty.

4. for bhabhas there is no explicit cut on primary mass, but implicit cut on secondary pair is present through the acollinearity cut. The primary electrons are selected as the two highest in energy clusters which are matched to charged tracks. Note that in this way we allow the presence of photon(s) which is harder than one or both of the final state e+e-.

5. $M_{inv}(e^+e^-)$ ($L3$) and electron clusters definitions: In L3 electrons are considered dressed, absorbing photons (or extra pairs) in a half-cone 2.5 deg, all these can be seen as detector coverage is larger than used phase space.
6. our definition is not practical for primary pair being neutrinos. Then, instead we request veto cut, no visible charged energy deposits above 1 GeV and $\cos_{\theta_X} < 0.97$.

2.5.4 OPAL

To define our strategy for additional pair treatment let us recall main points from the ref. [10]$_{OPAL}$. OPAL2F172

No additional cuts, apart those listed for the respective observables, are applied to reject events with pair emission. In general, we compare our measurements with analytical predictions including pair emission. This means that pair emission via virtual photons from both the initial and final state must be included in efficiency calculations, and be excluded from background estimates. In order to perform the separation, we ignore interference between s- and t-channel diagrams contributing to the same four-fermion final state, and generate separate Monte Carlo samples for the different diagrams for each final state. For a two-fermion final state $\mathrm{f\bar{f}}$ we then include as signal those four-fermion events arising from s-channel processes for which $m_{\mathrm{f\bar{f}}} > m_{\mathrm{f'\overline{f'}}}$, $m_{\mathrm{f'\overline{f'}}} < 70$ GeV and $m_{inv}(\mathrm{f\bar{f}})/\sqrt{s} > 0.1$ ($m_{inv}(\mathrm{f\bar{f}})/\sqrt{s} > 0.85$ in the non-radiative case). This kinematic classification closely models the desired classification of $\mathrm{f\bar{f}f'\overline{f'}}$ in terms of intermediate bosons, in that pairs arising from virtual photons are generally included as signal whereas those arising from virtual Z bosons are not. All events arising from s-channel processes failing the above cuts, together with those arising from the t-channel process (Zee) and two-photon processes are regarded as background. Four-fermion processes involving WW or single W production are also background in all cases. The overall efficiency, ϵ, is calculated as

$$\epsilon = (1 - \frac{\sigma_{\mathrm{f\bar{f}f'\overline{f'}}}}{\sigma_{\mathrm{tot}}})\epsilon_{\mathrm{f\bar{f}}} + \frac{\sigma_{\mathrm{f\bar{f}f'\overline{f'}}}}{\sigma_{\mathrm{tot}}}\epsilon_{\mathrm{f\bar{f}f'\overline{f'}}} \tag{1}$$

where $\epsilon_{\mathrm{f\bar{f}}}$, $\epsilon_{\mathrm{f\bar{f}f'\overline{f'}}}$ are the efficiencies derived from the two-fermion and four-fermion signal Monte Carlo events respectively, $\sigma_{\mathrm{f\bar{f}f'\overline{f'}}}$ is the generated four-fermion cross-section, and σ_{tot} is the total cross-section from the analytical prediction (e.g. ZFITTER) including pair emission. Using this definition of efficiency, effects of cuts on soft pair emission in the four-fermion generator are correctly summed with vertex corrections involving virtual pairs. The inclusion of the four-fermion part of the signal produces negligible changes to the efficiencies for hadronic events and for lepton pairs with $\sqrt{s'_{OPAL}/s} > 0.85$. The efficiencies for lepton pairs with $\sqrt{s'_{OPAL}/s} > 0.10$ are decreased by about 0.5%.

The discussion in the above paragraph applies to hadronic, muon pair and tau pair final states. In the case of electron pairs, the situation is slightly different. In principle the t-channel process with a second fermion pair arising from the conversion of a virtual photon emitted from an initial- or final-state electron should be included as signal. As this process is not included in any program we use for comparison we simply ignore such events: they are not included as background as this would underestimate the cross-section.

2.6 Realistic $e^+e^- \to q\bar{q}(\gamma)$ Observables

2.6.1 ALEPH

1. **Inclusive Selection:** $\boxed{\texttt{Aleph1}}$ Event clustered into jets with JADE algorithm until $(M_{jet-jet}/E_{cm})^2 > 0.008$. Low mass jets with high electro-magnetic energy fraction are assumed to be radiative photons. Non-photon jets then cluster together until only two left, corresponding to the $q\bar{q}$ system. Then

$\boxed{\texttt{Aleph1a}}$

   (a) $M_{inv}(q\bar{q}) > 50$ GeV (excluding photon jets),

$\boxed{\texttt{Aleph1b}}$

   (b) $M_{ang}(q\bar{q}) > 0.1E_{cm}$.

2. **Exclusive Selection:** $\boxed{\texttt{Aleph2}}$ Same as inclusive selection, then following extra cuts,

$\boxed{\texttt{Aleph2a}}$

   (a) $M_{inv}(q\bar{q}) > 0.7E_{cm}$ (excluding photon jets),

$\boxed{\texttt{Aleph2b}}$

   (b) $M_{ang}(q\bar{q}) > 0.9E_{cm}$,

$\boxed{\texttt{Aleph2c}}$

   (c) $|\cos\theta_{q/\bar{q}}| < 0.95$,

$\boxed{\texttt{Aleph2d}}$

   (d) Event thrust > 0.85.

2.6.2 DELPHI

Events were retained if they contained at least 7 charged tracks and if the charged energy was greater than 15 % of the collision energy. In addition, the quantity $E_{rad} = \sqrt{E_F^2 + E_B^2}$, where E_F and E_B stand for the total energy seen in the Forward and Backward electro-magnetic calorimeters, was required to be less than 90 % of the beam energy. Each event was first reconstructed assuming it was made of two jets and the $M_{prop+}(q\bar{q})$ was computed from jet directions. When an isolated energetic photon was reconstructed in the electro-magnetic calorimeters the value of $M_{prop+}(q\bar{q})$ was computed from the measured photon energy.

3. **Inclusive Selection:** $\boxed{\texttt{Delphi1}}$ $M_{prop+}(q\bar{q}) > 75\ GeV$

4. **Exclusive Selection:** $\boxed{\texttt{Delphi2}}$ $M_{prop+}(q\bar{q})/E_{cm} > 0.85$

2.6.3 L3

Events are selected by restricting the visible energy, E_{vis}, to $0.4 < E_{\text{vis}}/\sqrt{s} < 2.0$. The longitudinal energy imbalance must satisfy $|E_{\text{long}}|/E_{\text{vis}} < 0.7$. These cuts account for a large reduction of the two-photon background. In order to reject background originating from lepton pair events, more than 18 calorimetric clusters with an energy larger than 300 MeV are requested. To reconstruct the effective centre-of-mass energy two different methods are used. For the first one, all events are reclustered into two jets using the JADE algorithm. A single ISR photon is assumed to be emitted along the beam axis and to result in a missing momentum vector. From the polar angles of the jets, θ_1 and θ_2, the photon energy can be estimated. The second method uses the clustered jets ($y_{\rm cut} = 0.01$) obtained using the JADE algorithm. A kinematic fit is performed on the jets and the missing four-momentum vector using different hypotheses for the emitted ISR photons. The missing energy is attributed to zero, one or two ISR photons. From the differences given by the two methods, systematic errors on the effective centre-of-mass energy reconstruction are calculated. When an isolated energetic photon (energy larger than 10 GeV) is detected, the energy and momentum of this photon are added to the undetected ISR photons.

5. **Inclusive Selection 1:** `LT1` $M_{prop-}(q\bar{q})/E_{cm} > 0.10$

6. **Inclusive Selection 2:** `LT2` $M_{prop-}(q\bar{q}) > 60\ GeV$

7. **Exclusive Selection:** `LT3` $M_{prop-}(q\bar{q})/E_{cm} > 0.85$

2.6.4 OPAL

Events are required to have at least 7 electromagnetic clusters and at least 5 tracks. The total energy deposited in the electromagnetic calorimeter has to be at least 14% of the centre-of-mass energy. The energy balance R_{bal} along the beam direction has to satisfy $R_{bal} \equiv \mid \Sigma(E_{clus} \cdot \cos\theta) \mid / \Sigma E_{clus} < 0.75$, where the sum runs over all clusters in the electromagnetic calorimeter, θ is the polar angle, and E_{clus} is the energy of each cluster. Events selected as W-pair candidates according to the criteria of [6] are rejected.

8. **Inclusive Selection:** `OPAL1` $\sqrt{s'_{OPAL}/s} > 0.10$

9. **Exclusive Selection:** `OPAL2` $\sqrt{s'_{OPAL}/s} > 0.85$

2.7 Idealized $e^+e^- \to q\bar{q}(\gamma)$ Observables

2.7.1 ALEPH

10. **Inclusive Selection:** `IAleph1` $M_{prop+}(q\bar{q})/E_{cm} > 0.1$. No additional pair cut$_{ALEPH}$.

11. **Exclusive Selection:** `IAleph2` $M_{prop+}(q\bar{q})/E_{cm} > 0.9$ and $|\cos\theta_q| < 0.95$. No additional pair cut$_{ALEPH}$.

2.7.2 DELPHI

12. **Inclusive Selection:** $\boxed{\texttt{IDelphi1}}$ $M_{prop+}(q\bar{q})/E_{cm} > 0.1$ and $|\cos\theta_q| < 1.0$.

13. **Exclusive Selection:** $\boxed{\texttt{IDelphi2}}$ $M_{prop+}(q\bar{q})/E_{cm} > 0.85$ and $|\cos\theta_q| < 1.0$.

2.7.3 L3

14. **Inclusive Selection 1:** $\boxed{\texttt{ILT1}}$ $M_{prop-}(q\bar{q})/E_{cm} > 0.10$ and $|\cos\theta_q| < 1.0$.

15. **Inclusive Selection 2:** $\boxed{\texttt{ILT2}}$ $M_{prop-}(q\bar{q}) > 60\ GeV$ and $|\cos\theta_q| < 1.0$.

16. **Exclusive Selection:** $\boxed{\texttt{ILT3}}$ $M_{prop-}(q\bar{q})/E_{cm} > 0.85$ and $|\cos\theta_q| < 1.0$.

2.7.4 OPAL

17. **Inclusive Selection:** $\boxed{\texttt{IOpal1}}$ $M_{prop-}(q\bar{q})/E_{cm} > 0.10$ and $|\cos\theta_q| < 1.0$.

18. **Exclusive Selection:** $\boxed{\texttt{IOpal2}}$ $M_{prop-}(q\bar{q})/E_{cm} > 0.85$ and $|\cos\theta_q| < 1.0$.

2.8 Realistic $e^+e^- \to e^+e^-(\gamma)$ Observables

2.8.1 ALEPH

19. **Exclusive Selection 1:** $\boxed{\texttt{Aleph3}}$ $2 \le N_{trk} \le 8$. Two of tracks must be identified as electrons, have $|\cos\theta| < 0.95$ and opposite charge. The scalar sum of their momenta should exceed $0.3E_{cm}$. The sum of their energies including photons within $20°$ of each tracks should exceed $0.4E_{cm}$. Then $M_{inv}(e^+e^-) > 80$ GeV (reconstructed from track momenta), $M_{ang}(e^+e^-) > 0.9E_{cm}$ (where radiative photons reconstructed as for $q\bar{q}$ selection), and $-0.9 < \cos\theta^*_{e^-} < 0.9$.

20. **Exclusive Selection 2:** $\boxed{\texttt{Aleph4}}$ Same as exclusive selection 1, but $-0.9 < \cos\theta^*_{e^-} < 0.7$.

2.8.2 DELPHI

21. **Exclusive Selection:** $\boxed{\texttt{Delphi3}}$ The electron and positron were required to be in the polar angle range $44° < \theta < 136°$ and the non-radiative events were selected by asking the acollinearity to be smaller than $20°$.

2.8.3 L3

The electron and positron are required to be in the polar angle range $44° < \theta < 136°$ or $20° < \theta < 160°$ and non-radiative events are selected by asking the acollinearity to be smaller than $20°$ OR $M_{inv}(e^+e^-)/E_{cm} > 0.85$.

22. **Exclusive Selection 1:** $\boxed{\texttt{LT4}}$ $M_{inv}(e^+e^-)/E_{cm} > 0.85$ and $|\cos\theta_{e^+/e^-}| < 0.71934$.

23. **Exclusive Selection 2:** $\boxed{\texttt{LT5}}$ $acol(e^+e^-) < 25deg.$ and $|\cos\theta_{e^+/e^-}| < 0.71934$.

24. **Exclusive Selection 3:** $\boxed{\texttt{LT6}}$ $acol(e^+e^-) < 25deg.$ and $|\cos\theta_{e^+/e^-}| < 0.94$.

25. **Inclusive Selection 1:** $\boxed{\texttt{LT7}}$ $acol(e^+e^-) < 120deg.$ and $|\cos\theta_{e^+/e^-}| < 0.71934$.

26. **Inclusive Selection 2:** $\boxed{\texttt{LT8}}$ $M_{inv}(e^+e^-)/E_{cm} > 0.10$ and $|\cos\theta_{e^+/e^-}| < 0.94$.

2.8.4 OPAL

Events selected as electron pairs are required to have at least two and not more than eight clusters in the electromagnetic calorimeter, and not more than eight tracks in the central tracking chambers. At least two clusters must have an energy exceeding 20% of the beam energy, and the total energy deposited in the electromagnetic calorimeter must be at least 50% of the centre-of-mass energy. For the inclusive selection and the exclusive selection 1, at least two of the three highest energy clusters must each have an associated central detector track. If all three clusters have an associated track, the two highest energy clusters are chosen to be the electron and positron. For the large acceptance exclusiv selection 2, no requirement is placed on the associationof tracks to clusters, but the requirement on the total electromagnetic energy is increased to 70% of the centre-of-mass energy.

27. **Inclusive Selection :** $\boxed{\texttt{Opal3}}$ acol$(e^+e^-) < 170°$ and $|\cos\theta_{e^+/e^-}| < 0.9$.

28. **Exclusive Selection 1:** $\boxed{\texttt{Opal4}}$ acol$(e^+e^-) < 10°$ and $|\cos\theta_{e^-}| < 0.7$.

29. **Exclusive Selection 2:** $\boxed{\texttt{Opal5}}$ acol$(e^+e^-) < 10°$ and $|\cos\theta_{e^+/e^-}| < 0.96$.

2.9 Idealized $e^+e^- \to e^+e^-(\gamma)$ Observables

2.9.1 ALEPH

30. **Exclusive Selection 1:** $\boxed{\texttt{IAleph3}}$ $M_{inv}(e^+e^-)/E_{cm} > 0.9$ and $-0.9 < \cos\theta^*_{e^-} < 0.9$. No additional pair cut$_{ALEPH}$.

31. **Exclusive Selection 2:** $\boxed{\texttt{IAleph4}}$ $M_{inv}(e^+e^-)/E_{cm} > 0.9$ and $-0.9 < \cos\theta^*_{e^-} < 0.7$. No additional pair cut$_{ALEPH}$.

2.9.2 DELPHI

32. **Exclusive Selection:** $\boxed{\texttt{IDelphi4}}$ $M_{inv}(e^+e^-)/E_{cm} > 0.85$ and $|\cos\theta_{e^+/e^-}| < 0.7$.

2.9.3 L3

33. **Exclusive Selection 1:** `ILT4` $M_{inv}(e^+e^-)/E_{cm} > 0.85$ and $|\cos\theta_{e^+/e^-}| < 0.71934$.

34. **Exclusive Selection 2:** `ILT5` $acol(e^+e^-) < 25deg.$ and $|\cos\theta_{e^+/e^-}| < 0.71934$.

35. **Exclusive Selection 3:** `ILT6` $acol(e^+e^-) < 25deg.$ and $|\cos\theta_{e^+/e^-}| < 0.94$.

36. **Inclusive Selection 1:** `ILT7` $acol(e^+e^-) < 120deg.$ and $|\cos\theta_{e^+/e^-}| < 0.71934$.

37. **Inclusive Selection 2:** `ILT8` $M_{inv}(e^+e^-)/E_{cm} > 0.10$ and $|\cos\theta_{e^+/e^-}| < 0.94$.

2.9.4 OPAL

38. **Inclusive Selection :** `IOpal3` $\mathrm{acol}(e^+e^-) < 170^\circ$ and $|\cos\theta_{e^+/e^-}| < 0.9$.

39. **Exclusive Selection 1:** `IOpal4` $\mathrm{acol}(e^+e^-) < 10^\circ$ and $|\cos\theta_{e^-}| < 0.7$.

40. **Exclusive Selection 2:** `IOpal5` $\mathrm{acol}(e^+e^-) < 10^\circ$ and $|\cos\theta_{e^+/e^-}| < 0.96$.

2.10 Realistic $e^+e^- \to \mu^+\mu^-(\gamma)$ Observables

2.10.1 ALEPH

41. **Inclusive Selection:** `Aleph5` $2 \leq N_{trk} \leq 8$. Two tracks must be identified as muons, have $p > 6$ GeV, $|\cos\theta| < 0.95$ and opposite charge. The scalar sum of their momenta should exceed 60 GeV. Photons are identified from jets clustered with JADE algorithm until $(M_{jet-jet}/E_{cm})^2 > 0.008$. Then $M_{ang}(\mu^+\mu^)/E_{cm} > 0.10$ (where radiative photons reconstructed as for $q\bar{q}$ selection).

42. **Exclusive Selection:** `Aleph6` Same as inclusive selection, then following extra cuts, $M_{ang}(\mu^+\mu^)/E_{cm} > 0.9E_{cm}$ (where radiative photons reconstructed as for $q\bar{q}$ selection) and $M_{inv}(\mu^+\mu^) > 0.74$ (excluding photons).

2.10.2 DELPHI

An event was required to have two identified muons in the polar angle range $20^\circ \leq \theta_\mu \leq 160^\circ$ and the highest muon momentum of at least 30 GeV/c. $M_{inv}(\mu^+\mu^)$ was calculated from a kinematical fit, where four different topologies were investigated for each event: i) no photon radiated, ii) one photon radiated along the beam line, iii) one seen and one unseen photon in any direction, iv) a single unseen photon in any direction. The seen photon fit was performed if a neutral energy deposit greater than 5 GeV was measured in the electro-magnetic calorimeters.

43. **Inclusive Selection:** `Delphi4` $M_{inv}(\mu^+\mu^) > 75\ GeV$

44. **Exclusive Selection:** `Delphi5` $M_{inv}(\mu^+\mu^)/E_{cm} > 0.85$

2.10.3 L3

An event must have two identified muons in the polar angle range $20° \leq \theta_\mu \leq 160°$ and the highest muon momentum should exceed 35 GeV. The effective centre-of-mass energy for each event is determined assuming the emission of a single ISR photon. In case the photon is found in the detector it is required to have an energy, E_γ, larger than 15 GeV in the electro-magnetic calorimeter and an angular separation to the nearest muon of more than 10 degrees. Otherwise the photon is assumed to be emitted along the beam axis and its energy is calculated from the polar angles of the outgoing muons.

45. **Inclusive Selection:** $\boxed{\texttt{LT9}}$ $M_{ang}(\mu^+\mu^) > 75\ GeV$

46. **Exclusive Selection:** $\boxed{\texttt{LT10}}$ $M_{ang}(\mu^+\mu^)/E_{cm} > 0.85$

2.10.4 OPAL

$N_{trk} \geq 2$. A pair of tracks is taken as muon pair candidate, if both tracks are identified as muons, have $p > 6$ GeV, $|\cos\theta| < 0.95$ and are separated by 320 mrad in azimuthal angle ϕ. If more than one pair of tracks satisfies the above conditions, the pair with the largest scalar momentum sum is chosen. The event is rejected if more than one other track has a transverse momentum greater than 0.7 GeV. Finally, E_{vis}, defined as the scalar sum of the two muon momenta plus the energy of the highest energy cluster in the electromagnetic calorimeter, has to be larger than $0.35\sqrt{s} + 0.5M_z^2/\sqrt{s}$.

47. **Inclusive Selection:** $\boxed{\texttt{Opal6}}$ $M_{ang}(\mu^+\mu^)/E_{cm} > 0.10$ and $M_{inv}(\mu^+\mu^-) > 70$ GeV, if $0.35\sqrt{s} < E_{vis} - 0.5M_z^2/\sqrt{s} < 0.75\sqrt{s}$.

48. **Exclusive Selection:** $\boxed{\texttt{Opal7}}$ $M_{ang}(\mu^+\mu^)/E_{cm} > 0.85$ and $M_{inv}(\mu^+\mu^-) > \sqrt{M_Z^2 + 0.1s}$.

2.11 Idealized $e^+e^- \to \mu^+\mu^-(\gamma)$Observables

2.11.1 ALEPH

49. **Inclusive Selection:** $\boxed{\texttt{IAleph5}}$ $M_{inv}(\mu^+\mu^-)/E_{cm} > 0.1$ and $|\cos\theta_{\mu^-}| < 0.95$. No additional pair cut_{ALEPH}.

50. **Exclusive Selection:** $\boxed{\texttt{IAleph6}}$ $M_{inv}(\mu^+\mu^-)/E_{cm} > 0.9$ and $|\cos\theta_{\mu^-}| < 0.95$. No additional pair cut_{ALEPH}.

2.11.2 DELPHI

51. **Inclusive Selection:** $\boxed{\texttt{IDelphi5}}$$M_{inv}(\mu^+\mu^-) > 75\ GeV$ and $|\cos\theta_{\mu^-}| < 0.95$.

52. **Exclusive Selection:** $\boxed{\texttt{IDelphi6}}$$M_{inv}(\mu^+\mu^-)/E_{cm} > 0.85$ and $|\cos\theta_{\mu^-}| < 0.95$.

2.11.3 L3

53. **Inclusive Selection:** ILT9 $M_{inv}(\mu^+\mu^-) > 75\ GeV$ and $|\cos\theta_{\mu^-}| < 0.90$.

54. **Exclusive Selection 1:** ILT10 $M_{inv}(\mu^+\mu^-)/E_{cm} > 0.85$ and $|\cos\theta_{\mu^-}| < 0.90$.

55. **Exclusive Selection 2:** ILT11 $M_{inv}(\mu^+\mu^-)/E_{cm} > 0.85$ and $|\cos\theta_{\mu^-}| < 1.0$.

2.11.4 OPAL

56. **Inclusive Selection:** IOpal6 $M_{prop-}(\mu^+\mu^-)/\sqrt{s} > 0.10$ and $|\cos\theta_{\mu^-}| < 0.95$.

57. **Inclusive Selection:** IOpal7 $M_{prop-}(\mu^+\mu^-)/\sqrt{s} > 0.10$ and $|\cos\theta_{\mu^-}| < 1.00$.

58. **Exclusive Selection:** IOpal8 $M_{prop-}(\mu^+\mu^-)/\sqrt{s} > 0.85$ and $|\cos\theta_{\mu^-}| < 0.95$.

59. **Exclusive Selection:** IOpal9 $M_{prop-}(\mu^+\mu^-)/\sqrt{s} > 0.85$ and $|\cos\theta_{\mu^-}| < 1.00$.

2.12 Realistic $e^+e^- \to \tau^+\tau^-(\gamma)$Observables

2.12.1 ALEPH

60. **Inclusive Selection:** Aleph7 Two identified τ candidates with $M_{inv}(\tau^+\tau^-) > 25$ GeV and a$col(\tau^+\tau^-) < 250$ mrad in plane perpendicular to beam axis. Then $M_{ang}(\tau^+\tau^-) > 0.1E_{cm}$ (where radiative photons are reconstructed as for $q\bar{q}$ selection).

61. **Exclusive Selection:** Aleph8 Same as inclusive selection, then following extra cut $M_{ang}(\tau^+\tau^-) > 0.9E_{cm}$ (where radiative photons reconstructed as for $q\bar{q}$ selection) and $|\cos\theta_{\tau^-}| < 0.95$.

2.12.2 DELPHI

The leading track in each hemisphere was required to lie in the polar angle range $|\cos\theta| < 0.94$, and the observed charged particle multiplicity was requested to be unity in one hemisphere and no more than five in the other. At least one of the leading tracks was required to have momentum greater than $0.025 \times \sqrt{s}$. Full description of the cuts can be found in DELPUB172 [24]. The $M_{ang}(\tau^+\tau-)$ was calculated from fermion directions estimated by leading tracks.

62. **Inclusive Selection:** Delphi6 $M_{ang}(\tau^+\tau-) > 75\ GeV$

63. **Exclusive Selection:** Delphi7 $M_{ang}(\tau^+\tau-)/E_{cm} > 0.85$

2.12.3 L3

Taus are identified as narrow, low multiplicity jets, containing from one to five charged particles. Tau jets are formed by matching the energy depositions in the electro-magnetic and hadron calorimeters with tracks in the central tracker and the muon spectrometer. Two tau jets of at least 3.5 GeV are required to lie within the polar angular range $|\cos\theta| < 0.92$. To reject background from two photon processes the most energetic jet must have an energy larger than 20 GeV. The reconstruction of the effective centre-of-mass energy follows the procedure described in the muon subsection, using the polar angles of the two tau jets. Full description of the cuts can be found in [7]. L3PUB172

64. **Inclusive Selection:** LT11 $M_{ang}(\tau^{+}\tau-) > 75\ GeV$

65. **Exclusive Selection:** LT12 $M_{ang}(\tau^{+}\tau-)/E_{cm} > 0.85$

2.12.4 OPAL

Tau-pair candidates are events with exactly two charged, low multiplicity cones with 35° half-angle.

- The Event is rejected if it was selected as a μ pair.
- $\mathrm{N_{trk}} < 7$, where $\mathrm{N_{trk}}$ is the number of tracks in the central detector.
- $\mathrm{N_{trk}} + \mathrm{N_{clus}} < 16$, where $\mathrm{N_{clus}}$ is the number of ECAL clusters.
- $|\cos\theta_{\tau^+\tau^-}| < 0.90$, where $|\cos\theta_{\tau}|$ is the cosine of the respective cone axis.
- $0.02 < \mathrm{R_{shw}} < 0.7$, where $\mathrm{R_{shw}}$ is the summed ECAL energy scaled by the centre of mass energy.
- $\mathrm{R_{trk}} < 0.8$, where $\mathrm{R_{trk}}$ is the scalar sum of track momenta scaled by the centre of mass energy.
- $\mathrm{R_{shw}} > 0.2$ or $\mathrm{R_{trk}} > 0.2$.
- $\mathrm{R_{shw}} + \mathrm{R_{trk}} < 1.05(1.10)$, for $|\cos\theta| > 0.7$ (< 0.7),where $|\cos\theta|$ is the average of the two tau cones.
- $|\cos\theta_{\mathrm{p}^{\mathrm{ECAL}}_{\mathrm{missing}}}| < 0.99$, where $\cos\theta_{\mathrm{p}^{\mathrm{ECAL}}_{\mathrm{missing}}}$ is the cosine of the direction of missing momentum calculated using the ECAL.
- $\mathrm{p_t^{ECAL}} > 0.015\sqrt{\mathrm{s}}$ where p_t^{ECAL} is the sum of the transverse ECAL energy.
- Events are rejected if $0.9 < \mathrm{E/p} < 1.1$ in both cones.

- Using the values of θ_τ, the expected energy of each lepton is calculated assuming that the final state consists only of two leptons plus a single unobserved photon along the beam direction. We then require that $0.02 < \sqrt{(X_{E1}^2 + X_{E2}^2)} < 0.8$, and $\sqrt{(X_{P1}^2 + X_{P2}^2)} < 0.8$, where $X_{E1,E2}$ are the total electromagnetic calorimeter energies in each tau cone normalized to the expected value calculated above, and $X_{P1,P2}$ are the scalar sums of track momenta in the two tau cones, also normalized to the expected values.
- $\theta_{\mathrm{acolinearity}} < 180° - 2\tan^{-1}\left(\frac{2\mathrm{M_Z}\sqrt{\mathrm{s}}}{\mathrm{s}-\mathrm{M_Z^2}}\right) + 10°$. This cut is placed 10° degrees above the expected radiative return peak.
- $\theta_{\mathrm{acoplanarity}} < 30°$.

66. **Inclusive Selection:** $\boxed{\texttt{Opal8}}$ $M_{ang}(\tau^+\tau^-)/\sqrt{s} > 0.10$.
67. **Exclusive Selection:** $\boxed{\texttt{Opal9}}$ $M_{ang}(\tau^+\tau^-)/\sqrt{s} > 0.85$.

2.13 Idealized $e^+e^- \to \tau^+\tau^-(\gamma)$Observables

2.13.1 ALEPH

68. **Inclusive Selection:** $\boxed{\texttt{IAleph7}}$ $M_{inv}(\tau^+\tau^-)/E_{cm} > 0.1$ and $|\cos\theta_{\tau^-}| < 0.95$. No additional pair cut$_{ALEPH}$.
69. **Exclusive Selection:** $\boxed{\texttt{IAleph8}}$ $M_{inv}(\tau^+\tau^-)/E_{cm} > 0.9$ and $|\cos\theta_{\tau^-}| < 0.95$. No additional pair cut$_{ALEPH}$.

2.13.2 DELPHI

70. **Inclusive Selection:** $\boxed{\texttt{IDelphi7}}$ $M_{inv}(\tau^+\tau^-) > 75\ GeV$ and $|\cos\theta_{\tau^-}| < 0.95$.
71. **Exclusive Selection:** $\boxed{\texttt{IDelphi8}}$ $M_{inv}(\tau^+\tau^-)/E_{cm} > 0.85$ and $|\cos\theta_{\tau^-}| < 0.95$.

2.13.3 L3

72. **Inclusive Selection:** $\boxed{\texttt{ILT12}}$ $M_{inv}(\tau^+\tau^-) > 75\ GeV$ and $|\cos\theta_{\tau^-}| < 0.92$.
73. **Exclusive Selection 1:** $\boxed{\texttt{ILT13}}$ $M_{inv}(\tau^+\tau^-)/E_{cm} > 0.85$ and $|\cos\theta_{\tau^-}| < 0.92$.
74. **Exclusive Selection 2:** $\boxed{\texttt{ILT14}}$ $M_{inv}(\tau^+\tau^-)/E_{cm} > 0.85$ and $|\cos\theta_{\tau^-}| < 1.0$.

2.13.4 OPAL

75. **Inclusive Selection 1:** `IOpal10` $M_{prop-}(\tau^+\tau^-)/\sqrt{s} > 0.10$ and $|\cos\theta_{\tau^-}| < 0.90$.

76. **Inclusive Selection 2:** `IOpal11` $M_{prop-}(\tau^+\tau^-)/\sqrt{s} > 0.10$ and $|\cos\theta_{\tau^-}| < 1.00$.

77. **Exclusive Selection:** `IOpal12` $M_{prop-}(\tau^+\tau^-)/\sqrt{s} > 0.85$ and $|\cos\theta_{\tau^-}| < 0.90$.

78. **Exclusive Selection:** `IOpal13` $M_{prop-}(\tau^+\tau^-)/\sqrt{s} > 0.85$ and $|\cos\theta_{\tau^-}| < 1.00$.

2.14 $q\bar{q}\gamma$'s observables

This section contains precision requirements for regions of phase space selected in searches for anomalous neutral gauge couplings ($ZZ\gamma$,$Z\gamma\gamma$), especially for the visible $\gamma + Z \rightarrow \gamma + q\bar{q}$ final state. The prominent Standard Model process populating this region is the radiative return to the Z.

2.14.1 ALEPH

2.14.2 DELPHI

2.14.3 L3

79. **Total Cross-Section** `LT13`

    Hadronic events are selected by asking for more than 6 charged tracks and more than 11 calorimetric clusters. The transverse and longitudinal energy imbalances should be below 15 and 20 % respectively. A photon with $14° < \theta_\gamma < 166°$ and energy $80\ GeV < \sqrt{s - 2E_\gamma\sqrt{s}} < 110\ GeV$ is required.

    The precision tag is 0.3-0.4 %.

2.14.4 OPAL

80. **Total Cross-Section** `Opal10`

    Events are selected with two jets and one visible photon, fulfilling a 3C kinematic fit, allowing an additional photon of at most 5% of the beam energy to be radiated along the beam pipe. The relevant phase space is defined by

    (a) $E_\gamma > 50$ GeV
    (b) $15° < \theta_\gamma < 165°$
    (c) angle between photon and closest jet, $\alpha_{\gamma-jet} > 30°$.

    The required precision tag for the radiative return cross-section in this phase space for a LEP-combined analysis is 0.3%. It assumes uncorrelated experimental systematics and is dominated by the experimental statistics. For fully correlated experimental systematics the precision tag is 0.4%. Currently, the predictions of the KK2f and PYTHIA generators in this phase space differ by 15%.

81. **Differential Cross-Section** `Opal11` Selected Events in the above phase space are subjected to a maximum likelihood fit in the differential distributions of $E_\gamma, \cos\theta_\gamma$, and $\cos\theta^\star_q$, which is the angle of the final state quark-jets in the Z restframe.

    Precision tag: The ratio between the rate of events within $|\cos\theta_\gamma| < 0.7$ and the boundary of the acceptance has to be known within about 1%. The discrepancy between KK2f and Pythia in the region $|\cos\theta_\gamma| < 0.7$ is currently at level of 30% (stat. significance 2σ).

2.15 $\ell\bar{\ell}\gamma$'s observables

This final state is primarily used to search for single (one photon) or pair (two photons) production of excited leptons. In principle, the radiative return peak in $M_{\ell\ell}$ can be rejected in these searches, which is not possible in the anomalous neutral coupling analyses (see above). In practice, however, experimental resolution and further (final state) radiation reduce the power of such an anticut. Thererfore both topologies (inlcuding and omitting the anticut) need to be studied.

2.15.1 ALEPH

Photons are required to have at least 15 GeV and $|\cos\theta_\gamma|$ <0.95. Leptons are also required to have $|\cos\theta_l|$ <0.95, they are identified from oppositely charged jet clustered from charged tracks (at most 3) with at least one jet above 5 GeV. The angle between the 2 jets being at least 30 degree and the photon candidate at least 10 degree from the charged jet.

- **$\ell\bar{\ell}$ plus one photon**
  Two leptons of same type are required accompagnied of at least one photon. The two most energetic leptons and the most energetic photon are considered.

  82. **ee**γ `ALEPH-11` Two tracks are identified as electron and the sum of charged energy greater than 0.6*E_{cm}. Expected precision tag 1.4%
  83. $\mu\mu\gamma$ `ALEPH-12` Two muon have to be identied and charged energy greater than $0.6 * E_{cm}$. Precision tag 1.5%
  84. $\tau\tau\gamma$ `ALEPH-13` At least a 3 prong tau jet cancdidate in the event is required. Precision tag 1.7%

- **$\ell\bar{\ell}$ plus two photons**
  Two electron (or muon or tau) have to be identified and 2 photon jet identified Isolation cut on the 4 angles between photon and lepton required to be at least 20 degree . The 2 reconstructed lepton-gamma masses have to agree within 5 GeV/c**2

  85. **ee**$\gamma\gamma$ `ALEPH-14` Precision tag 3 %.
  86. $\mu\mu\gamma\gamma$ `ALEPH-15` Precision tag 5 %.
  87. $\tau\tau\gamma\gamma$ `ALEPH-16` Precision tag 8 %.

2.15.2 DELPHI

Events with a visible energy above $0.2\sqrt{s}$ in the region $|cos\theta| < 0.9397$ and not more than 6 charged tracks are selected.

Photons are required to have an energy above 5 GeV and $|cos\theta| < 0.9848$. The total charged (neutral) energy in a 15° cone around the photon is required to be below 1 GeV (2 GeV).

Charged particles are clustered into jets. Jets are required to have $|cos\theta| < 0.9063$ and the most energetic to have an energy above 5 GeV.

In three- or four-body topologies the energies are rescaled by imposing energy momentum conservation and using the measured angles. An improved energy resolution is obtained. Compatibility between the measured and rescaled energies is required.

- **$\ell\bar{\ell}$ plus one photon**

  The energy of the photon is required to be above 10 GeV. Events with one photon and one or two jets in the final state are considered. This accounts for situations in which one of the leptons was lost in the beam pipe or has very low momentum (close to the kinematic limit).

  The expected backgrounds and thus the further selections and the efficiencies are very dependent on the lepton flavour.

  88. **ee**γ `DELPHI8` At least one jet identified as an electron and the other not indentified as a muon, the most energetic jet with E¿10 GeV. One photon with $|cos\theta| < 0.7660$. If only one jet is found the angle between the jet and the photon must be in the between 100° and 179°.

      Precision tag: 1.4

  89. $\mu\mu\gamma$ `DELPHI9` At least one jet identified as a muon and no jets indentified as electrons, the most energetic jet with E¿10 GeV.

      Precision tag: 1.6

  90. $\tau\tau\gamma$ `DELPHI10` The most energetic jet with E¿10 GeV. One photon with $|cos\theta| < 0.94$. Tau events are selected by requiring a difference between the measured and the rescaled energy of the jets, expected due to the presence of neutrinos. If only one jet is found the angle between the jet and the photon must be between 100° and 179°.

      Precision tag: 1.8

- **$\ell\bar{\ell}$ plus two photons** Two jets and two photons in the event. Compatibility between two reconstructed $\ell\gamma$ masses is required. The relevant quantity is the minimum of the electron-photon invariant mass differences ($\Delta m_{\ell\gamma}$).

  The statistical error of the selection clearly dominates.

91. $\mathbf{ee}\gamma\gamma$ $\boxed{\texttt{DELPHI11}}$ $\Delta m_{e\gamma} < 15$ GeV/c^2.
Precision tag: 5

92. $\mu\mu\gamma\gamma$ $\boxed{\texttt{DELPHI12}}$ $\Delta m_{\mu\gamma} < 10$ GeV/c^2
Precision tag: 6

93. $\tau\tau\gamma\gamma$ $\boxed{\texttt{DELPHI13}}$ $\Delta m_{\tau\gamma} < 10$ GeV/c^2
Precision tag: 6

2.15.3 L3

Hadronic events are rejected by requiring less than 8 charged tracks. Photons are required to have at least 15 GeV and $|\cos\theta_\gamma|$ <0.97. Leptons are required to have the same flavor and $|\cos\theta_l|$ <0.94. They are identified from oppositely charged tracks/low multiplicity jets(for tau).

- **$\ell\bar{\ell}$ plus one photon**
  At least one lepton accompagnied by at most one hard photon. The second lepton may be in the beam pipe. The photon is required to have at least 20 GeV and $|\cos\theta_\gamma|$ <0.75. One mass (lγ) should be greater than 70 GeV.

94. $\mathbf{ee}\gamma$ $\boxed{\texttt{LT14}}$ Expected precision tag 1.2%

95. $\mu\mu\gamma$ $\boxed{\texttt{LT15}}$ Precision tag 1.5%

96. $\tau\tau\gamma$ $\boxed{\texttt{LT16}}$ Precision tag 1.8%

- **$\ell\bar{\ell}$ plus two photons**
  Two electron (or muon or tau) and 2 photons seen. The photons are required to have at least 15 GeV and one should be in $|\cos\theta_\gamma|$ <0.75, the second in $|\cos\theta_\gamma|$ <0.94. The difference of the 2 reconstructed lepton-gamma masses should be below 10 GeV and their sum above 100 GeV.

97. $\mathbf{ee}\gamma\gamma$ $\boxed{\texttt{LT17}}$ Precision tag 4 %.

98. $\mu\mu\gamma\gamma$ $\boxed{\texttt{LT18}}$ Precision tag 6 %.

99. $\tau\tau\gamma\gamma$ $\boxed{\texttt{LT19}}$ Precision tag 6 %.

2.15.4 OPAL

Photon candidates are required to have an energy exceeding 5% of the beam energy, and have to lie within $|\cos\theta_\gamma| < 0.95$. Leptons are also identified within $|\cos\theta_\ell| < 0.95$ and are required to have $p_t > 1$ GeV. Photons, electrons, and muons are required to be isolated by at least 20 degree from the nearest charged track of momentum larger than 1 GeV.

- **$\ell\bar{\ell}$ plus one photon**
  There must be at least two identified leptons of the same type and at least one

photon. The two most energetic leptons and the most energetic photon are used in the analysis. Their energy sum is called E_{vis} in the following. The precision tag assumes uncorrelated experimental systematics. Both, uncorrelated systematics, and expected statistical precision of the LEP combined result contribute to about equal parts to the precision tag. For correlated experimental systematics the required theoretical precision is loosened by about 0.9%.

100. **eeγ w/o rad return rejection** `Opal12`
    - $E_{vis} > 1.6 E_{\rm beam}$
    - $|\cos\theta_\gamma| < 0.70$
    - $|\cos\theta_e| < 0.70$ for at least one electron.

    Precision tag: 1.3%
101. **eeγ with rad return rejection** `Opal13`
    - $E_{vis} > 1.6 E_{\rm beam}$
    - $|\cos\theta_\gamma| < 0.70$
    - $|\cos\theta_e| < 0.70$ for at least one electron.
    - reject events with 85 GeV $< M_{ee} <$ 95 GeV

    Precision tag: 1.4%
102. **$\mu\mu\gamma$ w/o rad return rejection** `Opal14`
    - $E_{vis} > 1.6 E_{\rm beam}$

    Precision tag: 1.5%
103. **$\mu\mu\gamma$ with rad return rejection** `Opal15`
    - $E_{vis} > 1.6 E_{\rm beam}$
    - reject events with 85 GeV $< M_{\mu\mu} <$ 95 GeV

    Precision tag: 1.7%
104. **$\tau\tau\gamma$ w/o rad return rejection** `Opal16`
    - $0.8 E_{\rm beam} < E_{vis} > 1.9 E_{\rm beam}$

    Precision tag: 1.4%
105. **$\tau\tau\gamma$ with rad return rejection** `Opal17`
    - $0.8 E_{\rm beam} < E_{vis} < 1.9 E_{\rm beam}$
    - reject events with 85 GeV $< M_{\tau\tau} <$ 95 GeV

    Precision tag: 1.5%

- **$\ell\bar{\ell}$plus two photons**
  There must be at least two identified leptons of the same type and at least two photons. The two most energetic leptons and the two most energetic photons are used in the analysis. Their energy sum is called E_{vis} in the following. The precision tag is dominated by the statistical error of the selection.

106. **ee$\gamma\gamma$ w/o rad return rejection** $\boxed{\texttt{Opal18}}$

- $E_{vis} > 1.6 E_{\rm beam}$
- minimum opening angle among all electron-photon combinations $|\cos\alpha^{e\gamma}_{\rm min}| < 0.90$.

Precision tag: 3%

107. **ee$\gamma\gamma$ with rad return rejection** $\boxed{\texttt{Opal19}}$

- $E_{vis} > 1.6 E_{\rm beam}$
- minimum opening angle among all electron-photon combinations $|\cos\alpha^{e\gamma}_{\rm min}| < 0.90$.
- reject events with 85 GeV $< M_{ee} <$ 95 GeV

Precision tag: 3%

108. **$\mu\mu\gamma\gamma$ w/o rad return rejection** $\boxed{\texttt{Opal20}}$

- $E_{vis} > 1.6 E_{\rm beam}$

Precision tag: 5%

109. **$\mu\mu\gamma\gamma$ with rad return rejection** $\boxed{\texttt{Opal21}}$

- $E_{vis} > 1.6 E_{\rm beam}$
- reject events with 85 GeV $< M_{\mu\mu} <$ 95 GeV

Precision tag: 6%

110. **$\tau\tau\gamma\gamma$ w/o rad return rejection** $\boxed{\texttt{Opal22}}$

- $0.8 E_{\rm beam} < E_{vis} > 1.9 E_{\rm beam}$

Precision tag: 5%

111. **$\tau\tau\gamma\gamma$ with rad return rejection** $\boxed{\texttt{Opal23}}$

- $0.8 E_{\rm beam} < E_{vis} < 1.9 E_{\rm beam}$
- reject events with 85 GeV $< M_{\tau\tau} <$ 95 GeV

Precision tag: 6%

2.16 $\nu\bar{\nu}\gamma$'s observables

The observables listed above do not include the cut to eliminate regions of phase space dominated by the radiative return to Z. Such events are usually selected by the cut-off on the mass of the invisible system, or, cut on photon energy in simpler, single photon case. For such extended observables the required precision tag should be simply scaled with the somewhat decreased statistics. In general we need however complete predictions on full multi-dimensional distributions of photon(s) energies and directions, with the precision up to the level of the one for indicated for the total cross section.

2.16.1 ALEPH

Nu1

112. Single photon and missing energy:

Exactly one photon with $|\cos\theta_\gamma| < 0.95$ and $P_t > 0.0375 * E_{cm}$. No other photon with $|\cos\theta_\gamma| < 0.9997$ and $E_\gamma > 1$ GeV. No additional pair cut$_{ALEPH}$. The required precision tag is 0.2%.

Nu2

113. Two or more photons and missing energy:

Two or more photons with $E_\gamma > 1$ GeV and $|\cos\theta_\gamma| < 0.95$. The transverse momentum of the multi-photon system must be such that $\Sigma P_t > 0.0375 * (E_{cm} - \Sigma E)$. No additional pair cut$_{ALEPH}$. No other photon with $|\cos\theta_\gamma|$ between 0.95 and 0.9997, and $E_\gamma > 1$ GeV. The required precision tag is 1%.

2.16.2 DELPHI

114. Single photon and missing energy:

Require exactly one observed photon with energy requirement varying with polar angle

Nu11

(a) Very forward (or backward): $3.8^o < \theta < 6.5^o$, $x_\gamma > 0.3$ or $x_\gamma > (9.2 - \theta)/9$

Nu12

(b) Forward (or backward): $12^o < \theta < 32^o$, $x_\gamma > 0.2$

Nu13

(c) Barrel: $45^o < \theta < 90^o$, $x_\gamma > 0.06$

No additional photons with $E_\gamma > 0.8$ GeV and $\theta > 38$ mrad unless they are within 3^o, 15^o and 20^o from the primary photon for the very forward, forward and barrel regions, respectively. The required precision tag is 0.2%.

115. Two or more photons and missing energy Nu14 :

Two or more photons with $E_\gamma > 0.05 * E_{beam}$ and $|\cos\theta_\gamma| < 0.985$, at least one of which has $|\cos\theta_\gamma| < 0.906$. No additional photon with $E_\gamma > 0.02 * E_{cm}$ and $|\cos\theta_\gamma|$ between 0.985 and 0.9994. The required precision tag is 1%.

2.16.3 L3

116. Single photon and missing energy:

Exactly one photon with $|\cos\theta_\gamma| < 0.97$ and:

Nu3

(a) energy and $P_t > 5GeV$ if $14^o < \theta$ /endcaps/

Nu4

(b) energy and $P_t > 1GeV$ if $43^o < \theta$ /barrel/

No other photon with $|\cos\theta_\gamma| < 0.9997$ and $E_\gamma > 10$ GeV.

The required precision tag is 0.2%.

117. Two or more photons and missing energy:

Two or more photons selected as above:

Nu5

(a) energy and $P_t > 5GeV$ if $14^o < \theta$ /endcaps/

Nu6

(b) energy and $P_t > 1GeV$ if $43^o < \theta$ /barrel/

The transverse momentum of the multi-photon system must be greater than 5 GeV and the acollinearity greater than 2.5 deg.

No other photon with $|\cos\theta_\gamma| < 0.9997$ and $E_\gamma > 10$ GeV.

The required precision tag is 1%.

2.16.4 OPAL

118. Single photon and missing energy Nu7 :

The maximum energy photon must have $|\cos\theta_\gamma| < 0.9660$ and $P_t > 0.05 * E_{beam}$. There may be at most ONE additional photon with $E_\gamma > 0.3$ GeV and $|\cos\theta_\gamma| < 0.9848$. The required precision tag is 0.2%.

119. Two or more photons and missing energy:

Two or more photons with

Nu8

(a) $E_\gamma > 0.05 * E_{beam}$ and $|\cos\theta_\gamma| < 0.9660$,

Nu9

(b) $E_\gamma > 1.75$ GeV, $|\cos\theta_\gamma| < 0.8$ and the sum of their $P_t > 0.05 * E_{beam}$

Nu10

(c) $E_\gamma > 1.75$ GeV, $|\cos\theta_\gamma| < 0.966$ and the sum of their $P_t > 0.05 * E_{beam}$

The required precision tag is 1%.

3 Conventions and translation guidelines

conventions

This section should be written later, during the time of fixing discrepancies, adjusting progam inputs to LEP 1 conventions etc.

4 Semi-analytical and Monte Carlo tools used

program

4.1 presentation of the program MCdummy

This part of the description must be included:

1. Author(s)
2. Program name and version, date of release
3. Can be obtained from ...
4. Reference to main description (an appendix in our book?)
5. Reference to example discussion of prediction and its systematic uncertainty (an appendix in our book?).
6. Status: adverticement, preliminary, complete-draft, final.

It should be followed by 1-2 pages description of the program content, applicability region its systematic error there etc. References to the observables which can be handled should be given here. Also references to observables the program should not be used for.

Please create individual files for this section. Please refer to observables using labels. Look for the draft with labels on the workshop web-page. Use bibtex file for references so we can combine them all together.

LABSMC

4.2 presentation of the program LABSMC

1) Author: **A.B. Arbuzov**

2) Program: **LABSMC v.2.01, 15 Oct. 1999**

3) Can be obtained from the author (`arbuzov@to.infn.it`) upon request

4) Reference to main description

5) Reference to example

6) advertisement

Initially the `LABSMC` event generator was created [12] to simulate large–angle Bhabha scattering at energies of about a few GeV's at electron positron colliders like VEPP–2M and DAΦNE. The code included the Born level matrix element, the complete set of $\mathcal{O}(\alpha)$ QED RC, and the higher order leading logarithmic RC by means of the electron structure functions. The relevant set of formulae can be found in Ref. [14]. The generation of events is performed using an original algorithm, which combines advantages of semi–analytical programs and Monte Carlo generators.

The structure of our event generator was described in detail in paper [12]. The extension for LEP2 energies is done by introducing electroweak (EW) contributions, such as Z-exchange, into the matrix elements. The third [30] and fourth [13] order leading logarithmic photonic corrections were also included in the new version. The version of the program under consideration is suited for large–angle scattering. The small–angle version, which incorporates some additional second–order corrections [15], will be described elsewhere.

The code contains now

- the tree level electroweak Born cross section;
- the complete set of $\mathcal{O}(\alpha)$ QED radiative corrections (RC);
- vacuum polarization corrections by leptons, hadrons [26], and W-bosons;
- one–loop electroweak RC, either (default) according to Ref. [18] by means of `DIZET` [19] package, or called directly from the semi-analytical code `ALIBABA` [20];
- higher order leading log photonic corrections by means of electron structure functions [13, 29, 30];
- matrix element for radiative Bhabha scattering with both γ- and Z-exchange [21,22], vacuum polarization RC, and optionally ISR leading log RC (with exponentiation according to Ref. [29]);
- light pair corrections in the $\mathcal{O}(\alpha^2 L^2)$ leading log approximation [16].

A number of flags, to be set by user, allows to switch between different options and perform specific comparisons and investigations. In particular one can switch to generation of only radiative events with visible photons. That allows to avoid technical problems due to low statistics in this case.

The inclusion of the third and fourth order LLA photonic corrections allows not to use exponentiation. A simple estimate [13] shows that the difference between the two treatments at LEP2 is negligible, while the exponentiation requires a specific event generation procedure.

`LABSMC` is a `FORTRAN` program. It works as follows. First, the code makes initialisation and reads flags and parameters from a list provided by user. Then it performs integration (in semi-analytical branch) and generates events. The 4-momenta of generated particles are to be analysed in a user subroutine to perform a concrete event selection. A certain control of technical precision is provided by comparison of the results from semi-analytical and Monte Carlo branches. Note, that for a case of complicated cuts, which can not be done in the semi-analytical branch, one has to increase the number of generated events to reach the ordered precision.

The accuracy of the code is defined by two main points: technical precision (numerical precision in integrations, errors due to limited statistics, possible bugs *etc.*; and the theoretical uncertainty. Of course, one has than choose the proper (corresponding to his concrete problem) set of flags and parameters.

The technical precision has to be checked and impoved, if required, by detailed tests and comparisons with results of other codes. The theoretical uncertainty is defined by two main facts: absence of complete set of $\mathcal{O}(\alpha^2 L)$ corrections and by uncertainty in definiton of vacuum polarization. The theoretical uncertainty of the code in description of large–angle Bhabha scattering at LEP2 was estimated [11] to be of about 0.2%. The corresponding uncertainty for radiative Bhabha scattering with a visible photons is about 1.5%. But for the latter, we have an additional theoretical systematic uncertainty (about 1%), coming from non–standard radiative corrections [17].

5 Theoretical uncertainties of observables

5.1 MCdummy

The program can be used for many purposes it was shown in ref. [32] that in some cases precision is as high as 0.1 % . This analysis is in particular valis for the observables such as (**Obs.** 112) (**Obs.** 113) ..., the analysis can be easily extended to cases such as (**Obs.** 116a) ... and precision of the same order that is not worse than 0.2 % is expected. Numerical values have to be obtained by the users. However in case of observables (**Obs.** 116b) (**Obs.** 117a), for which the program can be still used but it is mandatory for the user to repeat the study of systematic error accordingly to procedure described in [32]. Finally for observables such as (**Obs.** 117b) our program should not be used unless .... is completed.

In the following table we collect some example results of our program for some of the observables from the list. For further numbers we refer the reader to following papers and web-pages ...

5.2 LABSMC

5.3 Manual for authors

Here is now the place for main activity. All observables are latex-labelled and should be referred in such a way in the presentations of individual programs and their capabilities In this way any change of observable content will not be a problem at all as indexing will get readjusted

And let us give here an example on how to refer to observables (**Obs.** Nu9 119b) (**Obs.** Nu12 114b)

```
I suggest the following format for program predictions:
Separator                             position    1
observable label  -  character string position    2-14
Separator                             position   15
program name      -  character string position   16-29
Separator                             position   30
Observable type   -   char*1 S or A   position   31
Separator                             position   32
CMS energy                            position   33-39
Separator                             position   40
prediction        -                   position   41-54
Separator                             position   55
Statistical error -                   position   56-69
Separator                             position   70
Systematic error  -                   position   71-84
Separator                             position   85
Prediction units  -  character string position   86-94
Separator                             position   95
Error      units  -  character string position   96-104
Separator                             position  105
Comment                               position  106-131
Separator                             position  132
```

```
        10        20        30        40        50        60        70        80        90       100       110       120       130
12345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
=             =              = =       =              =              =              =         =         =                          =

=OPAL1        =DummyMC       =S=198.5  =12.3          =0.4           =5.6           =pb       =pb       =                          =
=Aleph1       =DummyMC       =A=198.5  =0.123         =0.4           =0.56          =         =         =                          =
=ILT1         =DummyMC       =S=198.5  =12.3          =0.4           =5.6           =pb       =pb       =                          =
=Delphi3      =DummyMC       =A=198.5  =0.123         =0.4           =0.56          =         =         =                          =
```

From this I am able to generate all kind of tables automatically, simply combining all input files from you. As separator we can use = symbol.

Here are tables which are authomatically generated from the input file:

Table 1: this table use complete input. No ordering selection etc. is performed

obs.	program	lb.	ene	value	stat	syst	unit	err	comm.
OPAL1	DummyMC	S	198.50	.12E+02	.40E+00	.56E+01	pb	pb	
Aleph1	DummyMC	A	198.50	.12E+00	.40E+00	.56E+00			
ILT1	DummyMC	S	198.50	.12E+02	.40E+00	.56E+01	pb	pb	
Delphi3	DummyMC	A	198.50	.12E+00	.40E+00	.56E+00			

Table 2: this table use complete input. No ordering selection etc. is performed. However format is more elaborated. Labels are prepared for use.

obs.	program	ene	value; err. stat, err. syst
OPAL1 (**Obs.** 8) - S	DummyMC	198.50	.12E+02 $\pm$ .40E+00 $\pm$ .56E+01
Aleph1 (**Obs.** 1) - A	DummyMC	198.50	.12E+00 $\pm$ .40E+00 $\pm$ .56E+00
ILT1 (**Obs.** 14) - S	DummyMC	198.50	.12E+02 $\pm$ .40E+00 $\pm$ .56E+01
Delphi3 (**Obs.** 21) - A	DummyMC	198.50	.12E+00 $\pm$ .40E+00 $\pm$ .56E+00

In general for numerical input of any calculation we suggest physical parameters from the latest publication of workd averages in PDG. For QCD coupling average $\alpha_S(M_Z)$ should be used as an input. $\Delta\alpha^5_{had}(M_Z) = 0.027782 \pm 0.000254$ is not present in PDG, the suggested value is taken from Jegerlehner:1999hg [27] which contains updates of analysis Eidelman:1995ny [26].

For the Higggs mass $M_H = 120 GeV$, for CMS energies 189, 200 and 206 GeV, and in special cases such as discussion of contribution from $W-W$ boxes also 161 GeV.

Of course authors of programs using different input are welcomed to readjust the numbers to these values, also info about these readjustments/translations should find its place in **Section** conventions **3**.

6 Parts of the programms

compare

Having collected the necessary input from experiments and from authors of the progams used in data analysis, let us review now the situation. Let us stress that the programs are actually used in the interpretation of the experimental data. It is thus essential to discuss them, not only from the point of view whether they can serve all of our observables, but also from the point of view of the systematic error they contribute to actual *measurements* of the more idealized than direct measurement quantities such as masses couplings etc.

There are several classes of systematic errors which need to be adressed. First of all, every calculation has its technical precision originating e.g. from integration techniques used in calculation, numerically small programing bugs etc. The second class of systematic precision is originating from the physical assumptions actually used. There is no doubt that the program authors are best suited to give valid numbers for that errors.

This is however not the end. Comparisons of programs constructed by different authors using different calculative schemes are essential[1].

Quite complicated network of relations between different codes was built at this point. Sophisticated cut-off intensive observables[2] are calculated usually with the help of Monte Carlo programs, semi-analytical calculations are missing. Sometimes only single Monte Carlo program or even procedure of combining results from different runs of different programs is available. This is not such a big problem as required precision is usually not very high. The programs are cross checked for other observables. This helps to establish confidence in some but not all ingredients of the programs.

For less cut-off intensive observables such as asymmetries or total cross sections effects of the cuts can be approximated by the simpler idealized ones, and Monte Carlo programs may be used just to estimate size of the small effects beyond these. For idealized observables comparisons between Monte Carlo results and semianalytical calculations can be performed and provide powerful "final check" of the two. Unfortunatelly this is not a final answer at all even for idealized observables, as often both semianalytical calculations and MC programs use the same buiding blocks – so called electro-weak libraries. The comparisons at this level are essential for establishing correctness of complete semianalytical calculations and MC. On even lower level electroweak libraries use libraries of QCD/(low energy data) calculations for hadronic vacuum polarizations. These need to have some check presented also. The final states of quarks need to be hadronised. Related questions are covered elsewhere, outside 2f group, in QCD chapter of our repport.

Such multi-layer approach is advantageous in cases of problems and provides invaluable help for theoretical code authors in developpment and/or improvement phase of their work. Some of the discussion can be universal, whereas other will strongly depend on particular observable under consideration.

Let us go now into details:

6.1 hadronic low energy vacuum polarisation

6.2 QCD corrections for vacuum polarisation at higher energies

6.3 electroweak libraries

question of dyson summation and gauge invariance should be discussed here, question of renormalization scheme (effective subtraction at the point of smooth continuation from perturbative to data driven vacuum polarization) approximations in treatment of hadronic stuff.

[1]The comparisons can help also to fix seemingly trivial problems, related to misuse of input parameters.

[2]Here we have in mind mainly observables of the 1 or 2 hard photons tagged. These are often signatures of searches e.g. ....

6.4 pairs

Tthis is by far only the first approach to this section based on the approaches developped in OPAL.

In discussing question of pair effect the essential issue is how the related effect compares to expected total experimental error of combined all four experiments at the end of LEP. Let us use as the starting point in our discussion the study performed in OPAL [25]. Simmilar works were performed in other collaborations also ...

Let us evaluate now how important pair effects are for the final studies of 2-fermion final states and whether in practical cases pair effects once estimated can be still dropped out from final predictions or limited to approximations of the leading-log extended type such as in TOPAZ0 [2] or ZFITTER [1] and can be dropped out from the Monte Carlo predictions completely. We have here in mind corrections of the class ISNS_γ + FS_γ as defined in [2].

Having in mind our definitions of 2-fermion 4-fermion separation as defined in observable section of our repport we believe (see eg. [28] and ...) that the improvement of pair correction modelling in programs such as ZFITTER and TOPAZ0 (especially common exponentialtion of photons and pairs) should be sufficient. common exponentiation of photons and Pairs. This effort has been started but not yet fully completed, **we hope for the updated references here**.

Let us be more specific numerically. On pages 28 , 29 of [28] it is argued that the pair correction problem problem is not an issue at all for large s' All effects one observe there, are below 0.1%. Note, that up to now we averaged these large s' data.

For inclusive studies (e.g. s'/s > 0.01) (see page 28) real pairs add about 1.0% to the cross-section (as verified by independent 4f MC generators) with the signal definition of page 26 (feynman diagrams). The interference of virtual pairs subtracts 0.4% deduced from the (old!) Zfitter5.0 prediction of 0.6% total effect minus the 1.0% real pairs from above. This 0.4% number is uncertain due to the non-optimal ZFITTER5.0 pair treatment for LEP2, but should lie between 0 and -1.0%. (it has to be negative, and is very probably not absolutely bigger than the effect of real pairs.) In any case the *total* real+virtual pair correction from any SA program *must* not exceed the effect of real pairs: (Thus some numbers in 5.2x ZFITTER seem to be wrong) This issue is in my point of view the most important point for clarification, but it interfers in no way with the problem of vhow to define the 2f+4f signal (see below).

In addition to predictions of semianalytical programs, the experimentalists need a full 2f+4f Monte carlo dataset to determine: (i) signal efficiency, (ii) background. Again, with the OPAl definition (or any other definition close to it) the effect is 0.1% or less for high s'.

For inclusive selections one will have about:

1. 1% of the signal x-section from pairs (i.e. 4f MCs), which must be excluded from background subtraction

2. a (very experiment and channel dependent) correction to the selection efficiency due

to these 4f events of up to 0.5% (in OPAL).

The interference with virtual pairs can be inlcuded in these efficiency correction as explained on page 29 of [28]. For that, we again use the interference prediction from semianalytical programs, (e.g. the -0.4% from ZFITTER5.0.) but in effect it plays no role at all, since it represents a correction to the (small) efficiency correction. Quantitatively: completly ignoring the 0.4% interference would alter the efficiency by only 0.4%*0.5% = 0.002% !

So, the remaining point is the definition of the two-fermion signal and its realisation in 4f Monte carlo event generators. Here, we see four possible ways to go (all close to OPAL). We assume in all these 4 ways that we do not want to include any

1. CC diagrams (WW,Wev)

2. Multiperipheral 2-photon diagrams

The experimentalists have tried hard to optimize their selection to get rid of them. They were rather successful because these corrections are very forward peaked. Including them, would mean to get all this complications, which are either cut or even not observable at all back into the signal via efficiency corrections. We would have to accept then also additional theoretical errors in their prediction. These are the arguments against including 2-photon diagrams in any 2f signal.

Now let us go to four ways of signal definition (we use notation s'/s = z_p):

1. ISNS$_\gamma$ and FS$_\gamma$ diagrams as explained above (and page 26 of [28]) using mass cuts only to avoid overlap in ISNS$_\gamma$ with both primary and secondary pairs from γ^*. The mass cut will be just q^2(SIM)$<$ Q^2(HIM)

2. same as (1), but allowing in addition for all other diagrams except MP and ZZ, using the mass cut now for all diagrams, so that the primary pair (*defined* to be the one from e+e- annihilation) is the HIM pair. Practically this makes little difference to (1) for experimentalists, since all "new" diagrams (apart from ISS$_Z$) will be rejected by the definition primary pair= HIM. This option might trigger considerable additional work for theorists, though.

3. Defining signal by a HIM and SIM mass cut, only, thereby again including ISNS$_Z$, FS$_Z$ and both ISS$_\gamma$ and ISS$_Z$ as in (2), but even ZZ, if they pass this mass cuts. The primary pair is here *defined* as the HIM, so that also e.g. the FSR pair in FS$_Z$ can be called "primary". Still, MP two-photon and CC diagrams are excluded! To again exlude the bulk of ZZ, an additional mass cut (z_s) for the SIM pair (e.g. $q^2 < 70$ GeV^2) is necessary. This pattern of mass cut is shown in [28] page 27.

4. same as (3), but exclude not only MP and CC , but also ISS diagrams, for reasons similar to those explained for MP:

pairTOPAZ0

Options (1,2) and (3,4) coresspond respectively to [2] choice between diagram based and mass cut based definition

Numerically (1,4) and (2,3) will be very similar, and even the difference between the selected sets of events will be relatively small, and dominated by ISS_Z. Actually, what OPAL did, is a (1',4) mixture: Experimentally they use (4) to measure the cross-section (with generating MP, ISS and all other diagrams in three separate MC datasets, ignoring their interference.) The measurement is then compared to (1) w/o the mass cut. (Since ZFITTER/TOPAZ0 does not allow mass cuts) We convinced ourselves that any systematic bias from this procedure is really tiny (I dont have the number at hand, but way below 0.1%)

Taking Giampieros arguments, the pros and cons fro 1-4 are:

1. (pro): least additional theory work to do. (pro): pairing ambigities might be solved by event weights (con): (i) not easy to model exactly this in full 4-vectors suggestion: event weights (also resolving the paring ambiguity) (already existing in OPAL, but not yet used in 2f publications): (ii) each Mc event gets a weight according to its ME for a given diagram - some effective procedure similar to OPALs (4)

2. Same arguments as for (1) except: (pro): always fulfills primary pair =HIM, incontrast to (1) (con): much more difficult for SA programmers

3. (pro): closer to measurement (philospophically) (con): how to solve pairing ambiguity? (con): more complicated definition than (1)

4. (con): same as 3, even more complicated (pro): tiny numerical differnce to the predictable x-section of (1), can be used as an alternative to event weights.

One could consider solution (1) as the preferable one. But the other three (2)-(4), seem to be good as well. Actually, it should be possible to quantitatively calculate differences(or Upper limits on differences) between all these options, which should be very small if it would turn necessary. This would mean that each experiment could pick just one experimental definition in 1-4, and later corrected to a common definition (e.g. 1), which can be predicted by SA programs.

One could have difficulties, on the other hand with including any MP or CC diagram in the signal definition. Excluding thereby (e)νW, it seems somewhat natural to exclude (e)eZ, i.e. ISS. `ZW: I am lost at this moment what is the purpose of this sentence`.

6.5 special problems of hadronic final states

Question of correction to final state γ^5 terms for b-quarks should be discussed here and not only corrections to loops. Gluons from loops and whatever else.

Reference to other chapters of the book should be enough here?

7 Tests and comparisons

It is essential that comparisons of different programs were performed:

7.1 hadronic low energy vacuum polarisation

7.2 QCD corrections for vacuum polarisation at higher energies

7.3 electroweak libraries

7.4 pairs

7.5 semi-analytical programs and Monte Carlos for idealized observables

approximation in formfactor approach, separation impossible at genuine order α^2

7.6 Monte Carlos for strong cut-offs

7.7 report on final state hadronization

7.8 workshop status

```
At this moment it is difficult to continue work to make this section more specific.
Our activity is far behind the schedule.  Theoretical colleagues still wait
for definite form of observables and I must wait for the results and program
definitions.
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Finally let us note that comparisons with the data can serve only to indicate big problems of the calculations. It can never help in establishing precision at our requested level of $\frac{1}{3}$ of experimental statistical error. Problems at $2-3\sigma$ level can be found in this way at best.

Let me give here suggested time-table for our "future" work which was adopted to delays accumulated until Oct 15:

1. **Oct 20,** Final corrections from experiments on list of observables.

2. **Oct 30,** Feed back from theorists whether these definitions are complete enough in context of required precision tags.

3. **Nov 15,** Preliminary input from MC programs and SAN for the tables.

4. **Dec 3,** Informal (electronic ?) meeting

5. **Dec 15,** Preliminary layout of common sections.

6. **Jan 14,** Informal (electronic ?) meeting

   At this moment we are still finishing work for points 1 and 2, some material for section 3 (thanks to A. Arbuzov) is already included.

8 Summary – what will remain to be done by th community later ...

conclusion

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