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.

To evolve into a chapter in future yellow book

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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 inx [3]. These uncertainties are estimated with the help of the program [2], 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.

Finally, **Section 7** 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

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 modeling 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 , semianalytical 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 adress the question of possible contamiation of one process by another one. Often experimental cuts are specifically designed to elliminate 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 simmilar 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 abstaction 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 wil 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 bibtex-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 was suggested for estimating required precision in cases when there is no better scenario:

1. Experimental statistical error is decreased by factor of 3.5 with respect to present 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 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-demant. It is eqivalent to decrease in running time of experiments by 20 % in cases when statistical error dominates. Simmilar 10% deterioration of an overall detection performance would occur only after 30 % decrease in data taking for measurements where statistical and systematic errors are simmilar 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 $0.01{\cdot}\sqrt{2}$ anddropping 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 leptons and tagged hard photons 1 % (?)
6. searches background cross sections from neutrinos and tagged hard photons 0.5 % (?)

2.2 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.
- $|\theta_{f/\bar{f}}| < 0.9$: The polar angle of both particles f and $\bar{f}$ must satisfy the cut.
- E_γ: The energy of particle γ.
- 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 propogator, with ISR/FSR interference subtracted.

- $M_{prop+}(\mu^+\mu^-)$: invariant mass of the s-channel propogator, with ISR/FSR interference not subtracted. In this case, the propogator 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 bsaed 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

2.3 Preliminary Realistic Observables

A) $e^+e^- \to \nu\bar{\nu}(\gamma)$: 1-4 photons with $E_\gamma > 1GeV$

1. $|\cos\theta_\gamma| < 0.7$ (barrel); $|\cos\theta_\gamma| < 0.985$(barrel+endcap) inclusive 1% (barrel) 0.5% (barrel+endcap) photon energy and polar angle ($E_\gamma > 2GeV$, $|\cos\theta_\gamma| > 0.985$) spectrum

2. $|\cos\theta_\gamma| =< 0.71$ (barrel); $|\cos\theta_\gamma| =< 0.98$ (forward); $|\cos\theta_\gamma| =< 0.998$ (very forward); 0.5%, photon energy and polar angle ($E_\gamma > 1GeV$) spectrum

B) $e^+e^- \to e^+e^-(\gamma)$:

1. $|\cos\theta_{e_1/e_2}| < 0.7$, $E_{e_1/e_2} > 1GeV$, a$col(e_1e_2) < 20^o$ and 90^o inclusive, cross section 0.4% and A_{FB} 0.004 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

2. $|\cos\theta_{e_1/e_2}| < 0.72$, $E_{e_1/e_2} > 1GeV$, a$col(e_1e_2) < 20^o$ and 90^o inclusive, cross section 0.4% and A_{FB} 0.002 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

3. $|\cos\theta_{e_1/e_2}| < 0.72$, $E_{e_1/e_2} > 1GeV$, a$col(e_1e_2) < 20^o$ and 90^o inclusive, cross section 0.5% and A_{FB} 0.005, photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.998$) spectrum

4. $|\cos\theta_{e_1/e_2}| < 0.9$ and 0.985, $E_{e_1/e_2} > 1GeV$, $acol(e_1e_2) < 20^o$ and 90^o inclusive, cross section 0.1% and A_{FB} 0.001 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

5. $|\cos\theta_{e_1}| < 0.7$, $E_{e_1} > 1GeV$, no cut on 2nd inclusive, cross section 0.4% and A_{FB} 0.004 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

6. $|\cos\theta_{e_1}| < 0.72$, $E_{e_1} > 1GeV$, no cut on 2nd inclusive, cross section 0.4% and A_{FB} 0.002 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

7. $|\cos\theta_{e_1}| < 0.9$ and 0.985, $E_{e_1} > 1GeV$, no cut on 2nd inclusive, cross section 0.1% photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

C) $e^+e^- \to \mu^+\mu^-(\gamma)$:

1. $|\cos\theta_{\mu_1/\mu_2}| < 0.9$, $M_{inv}(\mu^+\mu^-) > 10GeV$, a$col(\mu_1\mu_2) < 90^o$ inclusive, cross section 1% and A_{FB} 0.01 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

2. $|\cos\theta_{\mu_1/\mu_2}| < 0.9$, $M_{inv}(\mu^+\mu^-) > 0.85Ecm$ inclusive, cross section 1% and A_{FB} 0.01 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

3. $|\cos\theta_{\mu_1/\mu_2}| < 0.94$, $M_{inv}(\mu^+\mu^-) > 0.85Ecm$ and $M_{inv}(\mu^+\mu^-) > 75GeV$, cross section 1% and A_{FB} 0.01, photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.998$) spectrum

4. $|\cos\theta_{\mu_1/\mu_2}| < 0.9$, a$col(\mu_1\mu_2) < 20^o$ inclusive, cross section 1% and A_{FB} 0.01 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

5. $|\cos\theta_{\mu_1}|$, $E_{\mu_1} > 4GeV$, no cut on 2nd inclusive, cross section 1% photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

D) $e^+e^- \to \tau^+\tau^-(\gamma)$:

1. $|\cos\theta_{\tau_1/\tau_2}| < 0.9$, $M_{inv}(\tau^+\tau^-) > 10GeV$, a$col(t1t2) < 90^o$ inclusive, cross section 1% and A_{FB} 0.01 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

2. $|\cos\theta_{\tau_1/\tau_2}| < 0.9$, $M_{inv}(\tau^+\tau^-) > 0.85Ecm$ inclusive, cross section 1% and A_{FB} 0.01 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

3. $|\cos\theta_{\tau_1/\tau_2}| < 0.92$, $M_{inv}(\tau^+\tau^-) > 10GeV$, $acol(t1,t2) < 90^o$ inclusive, cross section 1% and fb asymmetry 0.01 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

4. $|\cos\theta_{\tau_1/\tau_2}| < 0.92$, $M_{inv}(\tau^+\tau^-) > 0.85Ecm$ inclusive, cross section 1% and fb asymmetry 0.01 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

5. $|\cos\theta_{\tau_1/\tau_2}| < 0.94$, $M_{inv}(\tau^+\tau^-) > 0.85Ecm$ and $M_{inv}(\tau^+\tau^-) > 75GeV$, cross section 1% and A_{FB} 0.01, photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.998$) spectrum

6. $|\cos\theta_{\tau_1/\tau_2}| < 0.9$, a$col(t1t2) < 20^o$ inclusive, cross section 1% and A_{FB} 0.01 photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

7. $|\cos\theta_{\tau_1}|$, $E_{\tau_1} > 4GeV$, no cut on 2nd inclusive, cross section 1% photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.985$) spectrum

E) $e^+e^- \rightarrow q\bar{q}(\gamma)$: q-flavour blind, summed, heavy q-flavours

1. $M_{inv}(q\bar{q}) > 10GeV$ and $> 45GeV$ inclusive, cross section 0.1% photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.997$) spectrum

2. $M_{inv}(q\bar{q}) > 0.85Ecm$ inclusive, cross section 0.4% photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.997$) spectrum

3. $M_{inv}(q\bar{q}) > 0.85Ecm$ inclusive, cross section 0.3% photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.998$) spectrum

4. $M_{inv}(q\bar{q}) > 0.10Ecm$ inclusive, cross section 0.1% photon energy and polar angle ($E_\gamma > 1GeV$, $|\cos\theta_\gamma| < 0.998$) spectrum

2.4 Preliminary Idealized Observables

With the exception of the Bhabha channel, the following observables are frequently used:

- $M_{inv}(f\bar{f}) > 0.9E_{cm}$ or $> 0.1E_{cm}$, where M_{inv} is the invariant mass of the s-channel propagator after subtracting ISR/FSR photon interference.

- $M_{inv}(f\bar{f}) > 0.9E_{cm}$ or $> 0.1E_{cm}$, where M_{inv} is the invariant mass of the s-channel propagator with no subtraction of ISR/FSR photon interference. M_{inv} is ambiguous for the component of the cross section arising from interference, so should be clarified. For this component, ZFITTER defines M_{inv} as the mass of the difermion pair excluding all photon radiation.

- $M_{inv}(f\bar{f}) > 0.9E_{cm}$ or $> 0.1E_{cm}$, where M_{inv} is the invariant mass of outgoing difermion pair excluding photonic radiation. This is clearly defined for leptons, but less clear for quarks because of gluon radiation.

- $M_{inv}(f\bar{f}) > 0.9E_{cm}$ or $> 0.1E_{cm}$, where M_{inv} is the invariant mass of outgoing difermion pair excluding photonic radiation. This is clearly defined for leptons, but less clear for quarks because of gluon radiation.

- In all of the above, additional polar angle cuts, e.g. $|\cos\theta| < 0.95$ may also be applied to reduce sensitivity to ISR/FSR interference and avoid extrapolating outside the experimental acceptance.

- $M_{inv}(f\bar{f}) > 0.85E_{cm}$ or $> 0.1E_{cm}$, where M_{inv} is the invariant mass of the s-channel propagator after subtracting ISR/FSR photon interference.

For the Bhabha channel, one uses:

- $M_{inv}(e\bar{e}) > 0.9E_{cm}$ or $> 0.1E_{cm}$, where M_{inv} is the invariant mass of outgoing difermion pair excluding photonic radiation.

- a$col(ee) < 10°$ or $10°$.

- These cuts are combined with cuts on the polar angles of the e^+e^- system: $-0.7 < \cos\theta < 0.7$, $-0.9 < \cos\theta < 0.7$ or $-0.9 < \cos\theta < 0.9$.

- $M_{inv}(e\bar{e}) > 0.85E_{cm}$ or $> 0.1E_{cm}$, where M_{inv} is the invariant mass of outgoing dielectron pair excluding photonic radiation.

- $M_{inv}(e\bar{e}) > 0.85E_{cm}$ or $> 0.1E_{cm}$, where M_{inv} is the invariant mass of outgoing dielectron pair including photons in a 5 degree cone around the electrons

2.5 Realistic ALEPH Observables

[1]

2.5.1 $e^+e^- \to q\bar{q}(g)$

- **Inclusive Selection:** Event clustered into jets with JADE algorithm until $(M_{jet-jet}/E_{cm})^2 > 0.008$. Low mass jets with high electromagnetic energy fraction assumed to be radiative photons. Non-photon jets then cluster together until only two left, corresponding to the $q\bar{q}$ system. Then (i) $M_{inv}(q\bar{q}) > 50$ GeV (excluding photon jets), (ii) $M_{ang}(q\bar{q}) > 0.1E_{cm}$, (iii) $|\cos\theta_{q/\bar{q}}| < 0.95$.

- **Exclusive Selection:** Same as inclusive selection, then following extra cuts, (i) $M_{inv}(q\bar{q}) > 0.7E_{cm}$ (excluding photon jets), (ii) $M_{ang}(q\bar{q}) > 0.9E_{cm}$, (iii) Event thrust > 0.85.

2.5.2 $e^+e^- \to e^+e^-(g)$

- **Exclusive Selection 1:** $2 \leq N_{trk} \leq 8$. Two of tracks must be identified as electrons, have $|\cos\theta| < 0.9$ 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 $-0.9 < \cos\theta_{e^-} < 0.9$.

- **Exclusive Selection 2:** Same as exclusive selection 1, but $-0.9 < \cos\theta_{e^-} < 0.7$.

2.5.3 $e^+e^- \to \mu^+\mu^-(g)$

- **Inclusive Selection:** $2 \leq N_{trk} \leq 8$. Two of 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. Event clustered into jets with JADE algorithm until $(M_{jet-jet}/E_{cm})^2 > 0.008$. Then $M_{ang}(q\bar{q}) > 0.1E_{cm}$ (where radiative photons reconstructed as for $q\bar{q}$ selection).

- **Exclusive Selection:** Same as inclusive selection, then following extra cuts, $M_{ang}(q\bar{q}) > 0.9E_{cm}$ (where radiative photons reconstructed as for $q\bar{q}$ selection) and $M_{inv}(q\bar{q}) > 110$ GeV (excluding these photons).

2.5.4 $e^+e^- \to \tau^+\tau^-(g)$

- **Inclusive Selection:** 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 reconstructed as for $q\bar{q}$ selection).

- **Exclusive Selection:** Same as inclusive selection, then following extra cut $M_{ang}(q\bar{q}) > 0.9E_{cm}$ (where radiative photons reconstructed as for $q\bar{q}$ selection).

2.6 Idealized ALEPH Observables

2.6.1 $e^+e^- \to q\bar{q}(g)$

- **Inclusive Selection:** $M_{prop+}(q\bar{q})/E_{cm} > 0.1$ and $|\cos\theta_q| < 0.95$.

- **Exclusive Selection:** $M_{prop+}(q\bar{q})/E_{cm} > 0.9$ and $|\cos\theta_q| < 0.95$.

2.6.2 $e^+e^- \to e^+e^-(g)$

- **Exclusive Selection 1:** $M_{inv}(e^+e^-)/E_{cm} > 0.1$ and $-0.9 < \cos\theta_{e^-} < 0.9$.

- **Exclusive Selection 2:** $M_{inv}(e^+e^-)/E_{cm} > 0.9$ and $-0.9 < \cos\theta_{e^-} < 0.7$.

2.6.3 $e^+e^- \to \mu^+\mu^-(g)$

- **Inclusive Selection:** $M_{inv}(\mu^+\mu^-)/E_{cm} > 0.1$ and $|\cos\theta_{\mu^-}| < 0.95$.
- **Exclusive Selection:** $M_{inv}(\mu^+\mu^-)/E_{cm} > 0.9$ and $|\cos\theta_{\mu^-}| < 0.95$.

2.6.4 $e^+e^- \to \tau^+\tau^-(g)$

- **Inclusive Selection:** $M_{inv}(\tau^+\tau^-)/E_{cm} > 0.1$ and $|\cos\theta_{\tau^-}| < 0.95$.
- **Exclusive Selection:** $M_{inv}(\tau^+\tau^-)/E_{cm} > 0.9$ and $|\cos\theta_{\tau^-}| < 0.95$.

3 Conventions and translation guidelines

4 Semianalytical and Monte Carlo tools used

5 Theoretical uncertainties of observables

6 Tests and comparisons

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

References

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