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1 Proposal for the LEP2 MC workshop, 4F sub-group

Dear Colleagues,

an informal workshop took place at CERN on March 12th and 13th, with the goal of reviewing the progress made in Monte Carlo generators since the LEP2 Yellow report. Organizers have been M. Mangano and R. Pittau. A report on that meeting was given on March 24th at the LEPC meeting, and an official decision has been taken by LEPC to continue the activity of the workshop. It has been already established that such a workshop should produce official documentation before the end of this year, and have close contacts with the other LEPC groups working on searches. The reason of that is the need of having official statements before deciding on LEP2 activities for year 2000.

Here we present a scientific proposal for the activity of the 4 f sub-group of the workshop.

We want to point out that this document serves to start the calculations and that it will hopefully evolve in the course of the workshop towards more detailed and complicated requests

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Goals to be achieved in the 4F sub-group:

a) Describe the new calculations, the improvements and the upgrading in the theoretical understanding and in the MC implementations.

b) Indicate where new contributions have changed previous predictions in the MCs adopted by the collaborations. Why, how, how much.

c) In those cases where a substantial discrepancy has been registered and the physical origin has been understood, we should be able to make recommendations on what to use.

d) In those cases where we have found incompleteness of the existing MCs, but no complete improvement is available we should be able to indicate a possible time scale for the solution and a sound estimate of the theoretical uncertainty.

e) Regarding the time-scale of the effort, one could identify two classes of problems with 2 different time-scales: a reliable estimate of the Standard Model background to searches, for which, in a finite set of cases, we crucially need some initial answers very soon (within 1999), even if the final treatments and/or estimates of theoretical precision are not ready by then, and then the measurements, which naturally have a longer time-scale (18 months). The problem of the SM background to searches should have high priority, so we should aim for a 9 months time-table with the understanding that some preliminary answers have to be produced on what matters most for the searches on that time-scale.

The strategy

We strongly recommend to take into proper account physical issues. Therefore, the experimental contact-persons have collected a list, process by process, with the level of the requested theoretical accuracy and with statements on the impact of new theoretical input.

Clearly, experiments look at and measure lots of different processes, so we'll have to manage with lots of different sets of cuts. Nevertheless an attempt has been made to come up, as much as possible, with some set of quasi-realistic cuts for each process.

From the following list you will see that we have collected processes and/or phase space regions where better theoretical predictions would be desirable. A weight has been given to the problems, according to their relevance/urgency.

We ask you

a) to improve, when possible, your predictions for these processes and/or phase space regions, and give at least a definite value for the theoretical uncertainty;

b) to remember that the final output of the whole operation should not be a collection of comparison tables (that are probably unavoidable, but will be produced for internal use only), but a solid value for the theoretical uncertainty to be associated to any specific process.

Of course we want to reach a general consensus on the theoretical accuracy and not only some vague statement on overall agreement among different generators. Naturally, if differences are found, we want to be sure that they are due to physics, and not some different input, so we must have first a technical benchmark. Once trivial bugs are found we have to assign physics uncertainties.

So, we do not skip technical benchmarks, but this should be a rather quick operation and then we move immediately to physics uncertainties.

2 Reference list

The four experiments have presented a list of recommendations that reflect different styles and different approaches, therefore it will not be as simple as producing a new, improved, version of the ADLO/TH cuts.

As indicated below, the lists of observables LEP experiments vary greatly, ranging from a list with observables defined by simple phase-space cuts on four-fermion (+photon) level to full event-selection procedures. Nevertheless, we may distinguish three levels of action, to be denoted **red 1,2,3** in the the following. You should remember that it is difficult to summarize all acceptance cuts of all the analyses (particularly for the searches).

You will see that in a vast majority of cases the main problem is represented by the inclusion of QED radiation. We ask you: could you improve upon your treatment of QED radiation or give some safe estimate of the theoretical uncertainty associated with it? Next we start discussing details.

2.1 The basic reference table

This is the **red 1**, *i.e.*, basic reference table of four-fermion processes.

For all processes, radiative corrections and radiative photons in the final state should be considered, discussing energy and polar-angle spectra. Typical minimal requirements on photons are: energy $E_\gamma > 1\,\mathrm{GeV}$; polar angle $|\cos\theta_\gamma| < 0.985, 0.997, 0.9995$ depending on channel (see below); and minimal angle between photon and any charged final-state fermion $\xi > 5°$.

The following list contains a precision tag in %. The accuracy of MC simulations should be better than the requested precision tag, i.e. the physics(!) uncertainty should be smaller and at worst the one indicated How much better is left to the contributors; clearly, for benchmarking (see below) it would be advisable to use the maximum available precision.

- $WW - ZZ$ **type signal**:

1. $e^+e^- \to WW \to$ all (CC03). The full phase space is needed and the inclusive cross-section accuracy is 0.2%. The spectrum for the photon energy and the polar angle is needed ($|\cos\theta_\gamma| < 0.985$ (0.997)).

2. $e^+e^- \to ZZ \to$ all (NC02). The full phase space is needed and the inclusive cross-section accuracy is 1%. The spectrum for the photon energy and the polar angle is needed ($|\cos\theta_\gamma| < 0.985$ (0.997)).

3. $e^+e^- \to l\nu l\nu(\gamma)$ where all $\{e/\mu/\tau\} \otimes \{e/\mu/\tau\}$ combinations are requested with the following conditions: ($|\cos\theta_{l_1/l_2}| < 0.985$, $E_{l_1/l_2} > 5\,\mathrm{GeV}$, $M(l^+l^-) >$ 10 (45) GeV (full and high-mass region). The inclusive cross-section accuracy is 4% for individual combination; the inclusive cross-section accuracy is 1% for the summed one; photon energy and polar angle spectrum ($|\cos\theta_\gamma| < 0.985$ (0.997)).

4. $e^+e^- \to \overline{q}qe\nu(\gamma)$ (CC20), q-flavour blind, $|\cos\theta_e| < 0.985$, $E_e > 5\,\mathrm{GeV}$, $M(q\overline{q}) > 10$ (45) GeV (full and high-mass region); inclusive cross-section accuracy is 1% (5% for low-mass region); photon energy and polar angle spectrum ($|\cos\theta_\gamma| < 0.985$ (0.997)).

5. $e^+e^- \to \overline{q}q\mu\nu(\gamma)$ and $e^+e^- \to \overline{q}q\tau\nu(\gamma)$ (incl. tau polarization in tau decay) (CC10), $|\cos\theta_{\mu/\tau}| < 0.985$, $E_{\mu/\tau} > 5\,\mathrm{GeV}$, $M(q\overline{q}) > 10$ (45) GeV (full and high-mass region), inclusive cross-section accuracy 1%. Photon energy and polar angle ($|\cos\theta_\gamma| < 0.985$ (0.997)) spectrum.

6. $e^+e^- \to q\overline{q}q\overline{q}(\gamma)$, flavour blind, $bbq\overline{q}$, $bbbb$. At least two pairs with $M(q_i, q_j) > 10$ (45) GeV (full and high-mass region), inclusive cross-section accuracy 1%. photon energy and polar angle ($|\cos\theta_\gamma| < 0.985$ (0.997)) spectrum.

7. $e^+e^- \to q\overline{q}l^+l^-(\gamma)$, q-flavour blind, heavy q-flavours, $l = e/\mu/\tau$, $|\cos\theta_{l_1}| < 0.985$, no cut on 2nd lepton (only one lepton tagged), $M(q\overline{q}) > 10$ (45) GeV (full and high-mass region), inclusive cross-section accuracy 2%. Photon energy and polar angle ($|\cos\theta_\gamma| < 0.985$ (0.997)) spectrum.

8. $e^+e^- \to q\overline{q}l^+l^-(\gamma)$, q-flavour blind, heavy q-flavours, $|\cos\theta_{l_1}|, |\cos\theta_{l_2}| < 0.985$ (both leptons tagged), full and high-mass regions: $M(l^+l^-) > 10$ (45) GeV, $M(q\overline{q}) > 10$ (45) GeV, inclusive cross-section accuracy 2%. Photon energy and polar angle ($|\cos\theta_\gamma| < 0.985$ (0.997)) spectrum.

9. $e^+e^- \to q\overline{q}e^+e^-(\gamma)$, q-flavour blind, heavy q-flavours, with one electron in the beam pipe, $|\cos\theta_e| > 0.997$, and one electron tagged, $|\cos\theta_e| < 0.985$, $M(q\overline{q}) > 10$ (45) GeV (full and high-mass region) . Photon energy and polar angle ($|\cos\theta_\gamma| < 0.985$ (0.997)) spectrum.

10. $e^+e^- \to q\overline{q}\nu\overline{\nu}(\gamma)$, q-flavour blind, heavy q-flavours, $M(q\overline{q}) > 10$ (45) GeV, inclusive cross-section accuracy 4% (10% for low-mass region). Photon energy and polar angle ($|\cos\theta_\gamma| < 0.985$ (0.997)) spectrum.

11. $e^+e^-l^+l^-L^+L^-(\gamma)$, $l^+l^-l^+l^-(\gamma)$ (all possible charged lepton flavour combinations): 3 or 4 leptons within acceptance $|\cos\theta| < 0.985$, $M(l^+l^-)$ and $M(L^+L^-) > 10$ (45) GeV (full and high-mass region). Photon energy and polar angle ($|\cos\theta_\gamma| < 0.985$ (0.997)) spectrum.

- **single-W type signal**:

1. $e^+e^- \to q\overline{q}e\nu(\gamma)$, $|\cos\theta_e| > 0.997$, either $M(q\overline{q}) > 45\,\mathrm{GeV}$ or $E_{q_1}, E_{q_2} > 15\,\mathrm{GeV}$, inclusive cross-section accuracy 2%, photon energy and polar angle ($|\cos\theta_\gamma| < 0.997$ (0.9995)) spectrum

2. $e^+e^- \to e\nu e\nu(\gamma)$, $|\cos\theta_e| > 0.997$, $E_e > 15\,\mathrm{GeV}$, $|\cos\theta_e| < 0.7$ (0.95), inclusive cross-section accuracy 5%, photon energy and polar angle ($|\cos\theta_\gamma| < 0.997$ (0.9995)) spectrum.

3. $e^+e^- \to e\nu\mu\nu(\gamma)$ and $e^+e^- \to e\nu\tau\nu(\gamma)$, $|\cos\theta_e| > 0.997$, $E_{\mu/\tau} > 15\,\mathrm{GeV}$, $|\cos\theta_{\mu/\tau}| < 0.95$, inclusive cross-section accuracy 5%, photon energy and polar angle ($|\cos\theta_\gamma| < 0.997$ (0.9995)) spectrum.

The list above deserves already few words of comment:

For hadronic systems (NC or CC), there is usually a requirement of 45 GeV invariant mass (W and Z signal) or 10 GeV (background for other processes). Even lower invariant masses, down to 1 GeV, should be handled by the dedicated $\gamma\gamma$ subgroup. For leptons, there should be no problem to go down to even lower invariant masses or energies than listed above.

We consider as radiative events those events with photons where at least one photon passes the photon requirements listed above, and as non-radiative events those with no photon or only photons below the minimal photon requirements. In case of non-radiative and radiative events, the cross section and its accuracy is needed. In case of non-radiative events, this amounts to adding up virtual and soft radiative corrections. In case of radiative events, some distributions are needed in addition, in particular photon energy and polar angle, and photon angle w.r.t. the nearest charged final-sate fermion.

As was correctly pointed out during the first meeting, taking any radiative on-shell calculation and moving it to off shell final state particles is a dangerous thing; cancellation of divergences heavily depends on the on-shellness of particles. So, there is no CC03 $\mathcal{O}(\alpha)$ full calculation, there is an $\mathcal{O}(\alpha)$ $e^+e^- \to (\mathrm{on-shell})W^+W^-$ followed by a — ??? — transition to off shell W's towards CC03. This we need to discuss, deeply. Otherwise, if nothing new can be calculated in time for the workshop, it is still needed to estimate (guess?) say how accurate are things now - although tough without the explicit calculation.

The energy cut on charged leptons depends generally from the multiplicity of the final state and the topology of the event. It can be as low as 1GeV, so you could extend your analyses to this value.

2.2 Detailed Questions

In this section we elaborate in more detail on specific questions associated to specific processes, and give examples. This section is clearly assumed to evolve during the course of the workshop.

- **p_t ISR in WW and ZZ-dominated channels.**

The principle effects will be on the selection efficiency and on the differential distributions used for mass and TGC studies. The interest in photons is twofold: photons explicitly identified as such - usually at higher polar angles - and photons who simply create noticeable activity in the detector. The latter is, for example, important in single-W type analysis, therefore the photon angular range is extended to very low polar angles.

TGC studies should be repeated with and without p_t to quantify the size of any possible bias. At generator level it would probably be enough to look at

$e\nu\overline{q}q$, $\mu\nu\overline{q}q$ and $q\overline{q}q\overline{q}$. The following simplified set of selections at generator level could be used.

- semileptonic WW;

1. $E_{\text{vis}} > 50\,\text{GeV}$;
2. no photon with $E > 40\,\text{GeV}$ detected (use canonical cuts);
3. $p_{t,\text{mis}} > 10\,\text{GeV}$;
4. mass of $q\overline{q}$ system $> 30\,\text{GeV}$;
5. identified e or μ with at least 25 GeV;
6. missing momentum makes an angle of more than $15°$ to both beam axes.

- hadronic WW:

1. mass of $q\overline{q}q\overline{q}$ system $> 120\,\text{GeV}$;
2. it is of interest to try both the mass of $q\overline{q}q\overline{q}$ and the mass of $q\overline{q}q\overline{q}$ + any photon above $10°$ to see how much difference it makes;
3. if done at hadron level, cluster with LUCLUS djoin=5.5 GeV and require at least four jets with at least four particles (charged or neutral) per jet;
4. $D = E_{\text{min}}/E_{\text{max}}\theta_{\text{min}}/(E_{\text{max}} - E_{\text{min}}) > 0.0055\,\text{GeV}^{-}1$, where $E_{\text{min}}, E_{\text{max}}$ are minimum and maximum jet energies and θ_{min} is the smallest interjet angle.

Additional interesting variables, sensitive for TGC analyses, are the W production angle, and the energy and polar angle of the lepton in the lab frame, or the polar and azimuthal decay angles of the fermions in the W restframes.

- ZZ;

Neutral-current four-fermion production involves the mixture of Z and photon. Thus, ZZ selection cuts are more involved for two reasons. There is generally more background and we can also select $Z\gamma^*$ events with one on-shell Z and one much softer γ^*. The easiest processes to look at are probably $e^+e^-q\overline{q}$ and $\mu^+\mu^-q\overline{q}$.

In order to isolate the high-mass Z component, additional cuts are usually applied

1. all analyses: tight cuts: $|M_{z_1} - M_{z_2}| < 20\,\text{GeV}$, $|M_{z_1} + M_{z_2}| > 170\,\text{GeV}$; loose cuts: $|M_{z_1} - M_{z_2}| < 35\,\text{GeV}$, $|M_{z_1} + M_{z_2}| > 140\,\text{GeV}$;
2. $q\overline{q}q\overline{q}$: same angular acceptance as $WW \to q\overline{q}q\overline{q}$.

3. $q\overline{q}\nu\overline{\nu}$: veto $q\overline{q}l\nu$ events, less than 3 GeV at $|\cos\theta| > 0.95$, $< \cos\theta >< 0.80$ (this could be replaced by $\cos\theta_{\rm thrust}$), $(M_{\rm vis} + M_{\rm rec})/E_{\rm cm} > 0.80$ (0.89).

4. $q\overline{q}ee/q\overline{q}\mu\mu$: 5° degrees isolation cuts for leptons, lowest energy lepton with at least 2 GeV, higher with at least 20 GeV, sum of lepton energies > 70 GeV.

5. $l^+l^-L^+L^-(l^+l^-l^+l^-)$: 3 or 4 leptons within acceptance $|\cos\theta| < 0.985$, at least one of them with $E > 5$ GeV, $E_{\rm vis} > 0.9E_{\rm cm}$ or $|\cos\theta_{\rm miss}| < 0.98$.

Simplified selections for $l^+l^-q\overline{q}$:

1. $E_{\rm vis} > 50$ GeV;

2. two leptons of opposite sign and same flavour observed with invariant mass of at least 2 GeV and momentum each at least 5 GeV.

3. For on-shell ZZ require masses of l^+l^- and $q\overline{q}$ be within $M_{_Z} \pm 10$ GeV;

4. for $Z\gamma^*$ require that one mass be within $M_{_Z} \pm 10$ GeV.

The p_t ISR question is probably more important for $\nu\nu\overline{q}q$ which is an important Higgs search channel as well.

More urgent questions are the total cross-section of single W and the p_t ISR in the two fermion final state $q\bar{q} + (n)\gamma$. Here the selections are extremely complicated. A very loose selection might be:

1. visible energy carried by charged particles > 20 GeV;

2. mass of visible system within $M_{_Z} \pm 10$ GeV;

3. recoil mass of hadronic system > 60 GeV;

4. missing momentum at $\theta > 10°$ with respect to both beam axes.

The single-W requires further specifications and it is better to. split this into several issues.

The above is a clear example of **red 2** list.

- **High mass hadronic final states (> 40 GeV).**

This is important for searches and TGC measurements. The following scenario could be used: $q\overline{q}e\nu$ final state without an observed electron in the detector starts to be sensitive in the region $|\cos\theta_e| > 0.985$. Jets are identified within $|\cos_\theta| < 0.96$, and the sum of the jet momenta is required to point inside the detector $|\cos\theta| < 0.96$. We then have loose acoplanarity and missing momentum cuts: $\phi > 7.5°$ degrees, and $p_t > 5$ GeV. This is a **red 3** level.

Assuming a cross section of 500 fb and an efficiency of 50% at the end of LEP 2 the statistical error on the cross section (per experiment) will be of the order of 10%. The goal for the bf theoretical uncertainty should be around 5%. One topic of investigation should be ISR: this process is dominated by t-channel diagrams, whereas the current MC program implement ISR assuming s-channel reactions.

1. Which approach is better for the simulation of this channel?
2. How should we assess uncertainties on the detection efficiency due to the presence of ISR?
3. A second issue is the treatment of the $\alpha_{\rm em}$ scale. Is it better to reweight on a event by event basis? Or on a diagram basis?

In connection with the following point one of the outcomes of the workshop should be a recommendation on the mass cut which distinguishes the high mass (more reliable) from the low mass region, i.e. the lower value to which the 5% (or better) precision tag applies. The 5% precision requirement is also fine for the background estimation for Higgs searches.

Cross-section variation as a function of TGC's is also needed to similar precision as this is one the main reasons for interest in this channel.

The importance of ISR in this channel is threefold:

1. Change in total cross-section due to normal radiative corrections.
2. Change in event distributions used to make cuts which changes the fraction of the total that fall inside our cuts.
3. Fraction of events with identified photons- this forms a background to some of the chargino searches where a detected gamma is required.

Since the *single W topology* is defined as the one where a high mass object is found in the detector and the electron is not observed, we would like to know how the presence of p_t ISR changes the fraction of events where the electron gets *kicked* out of the beampipe, how the differential distributions are distorted for TGC studies and what the explicit hard photon rate is.

A simplified version of cuts for TGC would be:

1. $W \to q\bar{q}$ at parton level;
2. $E_{\rm vis} < 110\,{\rm GeV}$;
3. $p_{t,{\rm miss}} > 15\,{\rm GeV}$;
4. $M_{\rm vis} > 45\,{\rm GeV}$;
5. $E_{\rm lumi} < 65\,{\rm GeV}$ (energy in luminosity monitor, $\approx 1.7^\circ \div 10.6^\circ$);
6. no identified lepton with $E > 10\,{\rm GeV}$;
7. acollinearity of two quarks $> 20^\circ$;
8. acoplanarity of two quarks $> 20^\circ$.

Visible here means inside the main tracking and calorimetry, LEP2 workshop canonical cuts are fine. This is a level **red 3** list, so probably it would be enough to ask for no lepton inside canonical cuts, $M(q\overline{q}) > 45\,{\rm GeV}$, $p_t(\nu) > 15\,{\rm GeV}$.

- **Low mass hadronic final states (<40 GeV).**

This is mostly important for searches and should be studied in connection with the $\gamma\gamma$ working group, in particular for very low masses. One would like to trust the MC predictions down to 5-10 GeV invariant mass for the hadronic system. The required precision should be around 10%.

1. Simplified cuts: no identified lepton within $|\cos\theta| < 0.98$; the energy corresponding to $0.9 < |\cos\theta| < 0.9995$ is smaller than 15% of total visible energy; energy in luminosity monitors ($0.98 < |\cos\theta| < 0.9995$) smaller than 15 GeV; $|\cos\theta_{\rm miss}| < 0.9$ (angle of missing momentum vector); missing transverse momentum $> 14\,$GeV; two jets in the detector acceptance ($|\cos\theta| < 0.95$) with acoplanarity $> 15°$; mass between 10 and 50 GeV. Also monojet events will satisfy these cuts provided the jet has at least 4 tracks.

Again a **red 3** level.

- **Leptonic final states.**

The study presented during the first meeting of the workshop should be extended also to leptonic final states (as already indicated). A **red2** level could be to require at least one lepton observed in the detector ($|\cos\theta| < 0.98$), with a transverse momentum of at least $10\,$GeV. Again the issue of ISR in t-channel dominated processes should be addressed. Given the limited statistics a precision around 10% should be sufficient.

For $W \to l\nu$ it is basically a single lepton with $p < 75\,$GeV, $p_t > 20\,$GeV, above 10° with the electron being below the acceptance. In the $e\nu l\nu$ case the only distributions which could be useful are the momentum and theta of the lepton, for l^+ and l^- separately.

At present there seems to be no reliable generator for $e\nu e\nu$.

- $e\gamma \to e\gamma^* \to eq\overline{q}$ and $e\gamma \to eZ \to eq\overline{q}(Zee)$.

You could use the following definition of signal: $\cos\theta_{e^-} > 0.9995$, $|\cos\theta_{e^+}| < 0.985$, $|\cos\theta_q| < 0.985$, $M(q\overline{q}) > 5\,$GeV, or, $M(q\overline{q}) > 5\,$GeV, $\min(|t_1|,|t_2|) < 10\,$GeV^2, $\max(|t_1|,|t_2|) > 400\,$GeV^2, where t_1, t_2 are defined as follows: $t_1 = p_1 - k_1, t_2 = p_2 - k_2$, where p_1, p_2 are the 4-momenta of the incoming electrons, k_1, k_2 the 4-momenta of the outgoing electrons.

In the low hadronic mass region (5-60 GeV) the cross section measurement might reach (at the end of LEP2) a precision around 5% (per experiment) (between 5 and 10% for the Z region, above 60 GeV). This implies that the theory prediction should be known better than 5%.

Topics which we would like to be discussed are:

1. t-channel ISR (same issue as in single W),
2. interference with $\gamma\gamma \to q\overline{q}$.

In the analysis cuts are applied to reduce contributions from the $\gamma\gamma \to q\overline{q}$ reactions. These cuts could be added to the signal definition if it is necessary for reducing the theory uncertainty. The main cuts of the analysis are:

1. $-Q_e \cos\theta_e < 0.6$ if $E_e > 0.35 E_{\rm beam}$;
2. $-Q_e \cos\theta_{\rm miss} > 0.95$,

where θ_e is the angle of the electron observed in the detector, and $\theta_{\rm miss}$ corresponds more or less to the angle of the second undetected electron. The electron observed in the detector should have at least 1 GeV of energy and be isolated.

- **FSR in WW- and ZZ-dominated channels**.

The accurate modelling of FSR from isolated leptons in channels like $l^+l^-q\overline{q}$ and $l\nu q\overline{q}$ is important because it may affect the selection efficiency and the kinematic event reconstruction. How accurate are the current codes for the lepton being electron, muon, or tau?

A question to be answered by the experimentalists is how accurate a description is needed, eg, by switching on/off FSR and look for shifts.

- **4F contributions to Monojets**.

We are also interested in looking at *monojet* events which have hadronic activity which looks like a single jet. For example, one concern we have is that the six-fermion process $e^+e^- \to e^+e^-q\overline{q}Z \to e^+e^-q\overline{q}\nu\overline{\nu}$ for example, which is like a *weak correction* to the gamma-gamma fusion multi-peripheral process where a Z is radiated off a quark line may have appreciable cross-section and may not have been considered in the current generators.

It is important to know the cross-section for all processes that could give a significant contribution to monojets. 10% precision is probably enough at least to assess how significant the processes are.

We currently have only a simple treatment for the fragmentation of low mass γ^* that treats the ρ; a better implementation of this region would be useful.

A simplified generator-level monojet selection:

1. No isolated electron or photon with $E > 45\,$GeV. Isolated means at least $5°$ from any other charged or neutral particle with $E > 1\,$GeV;
2. anti WW cut: when the event is forced into two jets (using the Durham algorithm) find the track with the largest p_t with respect to the jet axis and reject the event if this p_t is larger than 8 GeV;
3. anti $Z\gamma$: after the previous cut reject any event with a photon of more than 10 GeV of energy;
4. reject events with more than 70% of energy in the forward $30°$ cone;

5. require that the p_t missing is at least 10 GeV;
6. reject events where, when forcing to two jets, the reconstructed $\cos\theta$ of the one closest to the beam pipe is ¿ 0.95;
7. require at least 25 GeV of energy visible;
8. when forcing to two jets (Durham) require that the angular distance between the two jets is less than $50°$.

Again a level **red 3** list.

3 Final comments

Now that you have everything you asked for, it is time to summarize some of the most important questions to be answered.

LEP is now quoting $1-2\%$ theoretical uncertainty (not changed since Yellow Report). Although no complete 1-loop $\mathcal{O}(\alpha)$ EW calculation exist (and will not in near future) for off-shell $e^+e^- \to WW \to 4\,\mathrm{f}$ production, we wish the theoretical uncertainty to be below 1% (0.5% if possible) with justification. Also the uncertainties in CC03 $\to$ 4F corrections when measuring the WW cross section should be studied.

- **WW (CC03) Questions**:

1. Coulomb corrections: becoming less important, but which should be taken as default?
2. ISR, α/π (NLL) terms (+0.7% effect) can be taken into account as YFS form-factor. Should this be included? Which theoretical error should be assigned?
3. ISR non-universal correction for t-channel of +0.4%. With which error?
4. Comparison of differential distributions among different MC generators with ISR/FSR on/off.

- **General 4F Questions**:

1. p_t effect of ISR/FSR ($d\sigma/dp_t$).
2. ISR/FSR implementation for exxx final states.
3. Compare ISR; QEDPS v.s. YFS with p_t and establish uncertainty on them.
4. Compare FSR; QEDPS v.s. PHOTOS for $\mu\nu q\overline{q}, \mu\mu\nu_\mu\nu_\mu$.
5. Visible photon effect in the detector (efficiency change).

6. How to adopt FSR (prompt photon) for non-resonant 4F diagrams.

7. Renormalization scheme and gauge invariance problem, establish theoretical uncertainty.

- **CC20 Questions**:

1. ISR p_t effect for single W. New QEDPSt v.s. YFS v.s. SF v.s. etc, visible photon effect.

2. Which effective $\alpha_{\rm QED}$? (also for $ZZ, Z\gamma^*, eeZ$ etc.) For the $\gamma - \gamma$ dominated final states like $e^+e^-q\overline{q}$ a running scale is usually implemented *alpha* and one would very much like theoretical input as to the correctness of this prescription.

   This scale choice is a very significant problem as it has a 30% effect on the total cross-section for channels like $e^+e^-q\overline{q}$ when turning the running α on and off. This is also a particular concern for the measurement of the ZZ cross-section as here there is significant contribution from Zee even in the region where both $q\overline{q}$ and e^+e^- have mass within 10 GeV of the A mass.

3. Multi-peripheral diagram: one should note the low momentum transfer in photon propagator. For $e\nu_e\mu\nu_\mu$ case, for example, muon is forward scattered with low energy, thus experimentally barely visible. For $e\nu_e\overline{q}q$ case, one quark goes forward, thus simulates mono-jet ($\nu\nu q\overline{q}$ is also the source of mono-jet).

4. Resolved photon effect for low invariant mass case (multi-peripheral diagrams). The estimate on uncertainty should be established. Use PDF like HERA if necessary?

5. $e^+e^-\nu_e\nu_e$: it would be extremely interesting if one can generate this channel without cut and compare among different generators (total cross section is not so large), one also should be realistic. Some cut like at least one visible $e^\pm$ could be applied.

- **ZZ (NC02/NC08) Questions**:

1. Which effective $\alpha_{\rm QED}$ for ZZ? For $Z\gamma^*$, the situation is worse since the running QED α would be largely different between low invariant mass and high mass cases.

2. Low Q^2 γ^* (ZZ) fragmentation for invariant mass below 12 GeV. How to take into account resonances?

- **Zee/Z$\nu\nu$ Questions**:

1. ISR and its p_t effect for $e^+e^-l^+l^-$ and $e^+e^-\nu\bar{\nu}$ (similar to $e\nu W$).

- **Two-photon collision processes - Questions**:

1. Double counting problem $|4F - \gamma\gamma|^2$, how to avoid it? - proposal; 4F MC subtract diagrams of Multi-peripheral (and Bremsstrahlung), and use PHOT02 for these. The 4F MC naturally includes $e^+e^-l^+l^-$ final states. It is not practical to generate hard processes (CC03, NC02 etc.) and two photon process together since the cross sections are different by three order of magnitude. There is a possibility to separate Multi-peripheral and Bremsstrahlung type graphs from others. Kinematics and cuts to be applied to these t-channel processes are so different from s-channel.

- **Miscellaneous Questions and Wishes**:

1. $\mathcal{O}(\alpha)$ calculation
2. Inclusion of quadruple-gauge-boson vertex with anomalous quartic gauge couplings.
3. Anomalous NC couplings - anomalous $\gamma\gamma Z, \gamma ZZ$ and ZZZ vertices.
4. Non-factorisable (i.e. non-naive) QCD corrections to $\overline{q}q\overline{q}q$ and $\overline{q}ql\nu$ final state, do they affect angular distributions? This seems to be a problem between the pure ew phase and QCD parton-shower.

- **Technical wishes**:

1. Easy access to matrix elements for reweighting purposes including anomalous couplings everywhere (Subroutine for initialisation with masses and couplings, subroutine for event-by-event calculation based on four-vector kinematics of fermions and photons).
2. Faster event generation of weight=1 events for detector simulation.
3. Event mix in 4F (eg $\overline{q}qe\nu$ summing all quark flavours and charge modes).
4. Non-trivial CKM matrix.
5. More cuts in phase-space sampling to implement the ZZ signal definition: Upper cuts on $M(\overline{f}f)$, $M(\overline{f}f)$ cuts in.or.on the three combinations (12)(34) (13)(24) (14)(23).

All participants of the 4F sub-group are cordially invited to look at the list of open problems; they should select those problems where they think that progress can be obtained in a reasonable amount of time. It would be nice if you could send a short message signalling your active interest on some particular issue, so that we will be able to keep track of who is doing what for a better coordination of the subgroup.

The subgroup activity is far from being confined to MC developments and upgradings. Clearly MC's is what experimentalists use but one should not forget that important contributions are expected showing, whenever possible, where the actual MC fail or where their accuracy level is, by far, above the expected one. Therefore, we encourage, as much as possible, analytical results and constructive criticism on all sort of approximations used in the current analysis.

There are several sets of cuts reported in this proposal. We suggest that you use this message as a guideline for your work. The **red 1** level is the minimal generalization of the old set of canonical cuts. Use it as a starting point. All those who are willing to move ahead and have the necessary technology, could select one, or several, processes where **red 2,3** levels are indicated.

4 A starting point.

Some good starting point would be to collect results for cross-sections for all processes at the **red 1** level for

$$\sqrt{s} = 183, 189, 200\,\mathrm{GeV}. \tag{1}$$

The IPS is, therefore, fixed to be as follows:

- No QED ISR, this is the issue not the benchmark;
- No QCD naive corrections (irrelevant, we need some real input);
- No Final State Coulomb correction factor (see list of questions)
- No Final State QED radiation (irrelevant, we need some real input);
- trivial CKM matrix element;
- No anomalous couplings;
- lepton masses according to PDG; light quark masses 5 (up) and 10(down) MeV;
- $G_F = 1.16637\,10^{-5}$ (recent Fermi coupling);
- G_F-scheme, that is

$$\sin^2\theta = 1 - \frac{M_W^2}{M_Z^2}, \qquad \alpha = 4\sqrt{2}\,\frac{G_F M_W^2 \sin^2\theta}{4\,\pi}, \tag{2}$$

- $M_Z = 91.1867\,\mathrm{GeV}$, $M_W = 80.350\,\mathrm{GeV}$.
- the widths of the gauge bosons have to be taken fixed for CC20 and running for those processes without complications with gauge invariance.

- For those who can do one-loop,

$$m_t = 175\,\text{GeV}, \qquad M_H = 150\,\text{GeV}, \qquad \alpha_S(M_Z^2) = 0.119. \qquad (3)$$

When received these results will be collected into some database and will represent the benchmark.

Naturally, if differences are found, we want to be sure that they are due to physics, and not some different input, so we must have first a technical benchmark. Once trivial bugs are found we have to assign **physics uncertainties**. So, we do not skip technical benchmarks, but this should be a rather quick operation and then we move immediately to physics uncertainties.

5 Recommendations.

The following recommendations can be made:

- Each group/individual should compute, asap, cross-sections for as many processes as possible within the *basic reference table* and with the setup presented in the previous section. This is technical benchmarking. Only wide differences will deserve further action.

- A Single W-like comparison, this time extended to all single W-processes must be started with the setup of Sect. 4. let's start with $e^+e^- \to q\overline{q}e\nu(\gamma)$, $|\cos\theta_e| > 0.997$, $M(q\overline{q}) > 45\,\text{GeV}$ or $E_{q_1}, E_{q_2} > 15\,\text{GeV}$ and let's add the final-electron angular distribution (*true* $d\sigma/d\theta$) normalized to σ_{tot}, 20 bins in the range $0° < \theta < 2°$ at $\sqrt{s} = 183, 189, 200\,\text{GeV}$, with and without ISR. After that we will discuss. Single W comparisons and some other examples (like $\gamma\gamma$ to exclusive states) show the relevance of *fermion mass effects* for specific channels. We strongly recommend to have them under control.

- Each group/individual should communicate, asap, his/her status with respect to radiative and non-radiative events. In particular, indicate the following options:

  1. ISR collinear/soft only,
  2. ISR with p_t,
  3. full $\mathcal{O}(\alpha)$ radiative events,
  4. $\mathcal{O}(\alpha)$ non-radiative events.

  We would like to understand who can produce, and in which conditions, our *basic reference table* with photons. Your way to approach the problem should be explained in some detail, so that the full sub-group will know what to compare and among which generators. Most likely this is *work in progress* and we may even have different opinions about the correct strategy. The need for *exact* results in $4\text{F}+\gamma$ should be evaluated, process by process, from the point of view of achieving the required accuracy. If ISR structure functions, or equivalent formulations (with p_t) are used then we cannot do without an estimate of the uncertainty. How to do that, without a full calculation, is open for discussion.

- We have an urgent need to collect few relevant items for the next general meeting. If we come up with a short benchmark - table, a realistic and extended single W - table and a clear picture of radiative versus non-radiative generation then we are already in business.

- Most important, all results should be sent to your experimental coordinator (see below).

Have a nice and productive period between here and the end of the workshop. Remember:

- your exp-contact persons:

```
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```

- your *temporary* theo. coordinator:

```
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```

- your exp. coordinator:

```
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```

Compiled by Jorgen Beck Hansen and Reisaburo Tanaka (ALEPH), Hywel Phillips (DELPHI), Martin Grünewald (L3), Marco Verzocchi (OPAL) with the final coordination by Giampiero Passarino.