Sub-group 2 (4f) Status Report *

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*presented by G. Passarino

1 Experimental request

A detailed (too much?) proposal, compiled by

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- Hywel Phillips (DELPHI),
- Martin Grünewald (L3),
- Marco Verzocchi (OPAL)

with the final coordination by Giampiero Passarino has been circulated and posted in

- `http://www.to.infn.it/~giampier/lep2.html`

Here we want to emphasize some *conflict* between `ADLO` and `TH` when setting up the list:

ex ideas: event selections with many complicated cuts on particle level;

th ideas: simple phase-space cuts on 4f+ γ level. In particular theorists are not *necessarily* inclined to attach JETSET/HERWIG for hadronisation.

SO THE LIST IS A COMPROMISE

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2 Answer from the theoretical community

Here a list of items that will be studied in the framework of the 4f sub-group of the *LEP2/MC* workshop:

1. **Inclusion, for all(some) 4f processes, of the leading FERMION-LOOP corrections**. This is especially, relevant for the choice of the scale in $Z-\gamma^*$ and single W like processes, where the virtuality of the photon in the s and t channel respectively approaches zero. ▷ `EXCALIBUR, WPHACT, WTO`

2. **Inclusion of the CP violating anomalous couplings** ▷ `EXCALIBUR`

3. **t-channel dominated processes at small scattering angle.**

Fudge: ▷ `EXCALIBUR` Possibly to improve *fudge* or switch to an exact calculation.

QED: ▷ `EXCALIBUR, GRACE, WTO` Study the problem of the correct treatment of the QED radiation in t-channel dominated processes.

Exact: ▷ `EXCALIBUR` inclusion of fermion masses.

▷ WPHACT Beyond $e^+e^- \to e\nu_e\overline{q}q'$: has at present all massive amplitudes (in addition to the massless + massive b's ones) and they are confident to be able to deal, in the near future, with

$$\overline{q}qe\nu, e\nu e\nu, e\nu\mu\nu,$$

plus eventually study some $\gamma - \gamma$ contributions.

▷ GRACE Item 1,2,3 in single-W type signal. If requested GRACE can give some of answers for $W - W, Z - Z$ type signal, to be compared with the programs by Denner et al (hep-ph/9904472) and the ALPHA-group.

▷ PV+ALPHA 4f final states with the following features: massive matrix element and kinematics, trilinear anomalous gauge couplings, kinematical regions not affected by *resolved photon* uncertainties, LL photonic radiative corrections taken into account.

▷ KORALW/YFSWW Integration of ME over all kind of 4f phase space with some charged untagged particles, which therefore includes the full list in section 2.1 in the proposal, with the final precisions as yet to be specified.

▷ ERATO (*Miscellanea*) A project that aims to produce all EWK tree-order amplitudes (any number of particles ¡ 10) plus a massive (adaptive) phase space generator. As far as the amplitudes are concerbed the project has been successfully completed and they are still working on the phase space part.

4. **Issues of gauge invariance in CC03 and in 4f ($+\gamma$) processes**:

`EXCALIBUR` work in progress

`KORALW`: They will do everything connected with $\mathcal{O}(\alpha)$ corrections to CC03.

They approximate, up to but not including terms of $\mathcal{O}((\alpha/\pi)(\Gamma/M)), \mathcal{O}(\alpha))$ CC03 by using the DPA for it and, FURTHER, by approximating the attendant residues by projecting them on to their on-shell values.

- these on-shell fermion-loop $\mathcal{O}(\alpha)$ residues are then improved to the complete on-shell $\mathcal{O}(\alpha)$ residues
- At the same time, one takes advantage of the fact that, since we drop terms of $\mathcal{O}((\alpha/\pi)(\Gamma/M))$, we are also dropping terms of $\mathcal{O}\left((\alpha/\pi)^2\right)$, so that the pole positions in the DPA $\mathcal{O}(\alpha)$ CC03 may be identified with the fully corrected complex pole and this is still accurate up to but not including $\mathcal{O}((\alpha/\pi)(\Gamma/M))$.
- They also drop the non-factorizable part of the residue, an approximation valid up to but not including $\mathcal{O}((\alpha/\pi)(\Gamma/M))$;
- incorporate the FSR correction by using branching fraction ratios for YFSWW3-1.11 which is

then augmented by $\mathcal{O}\left((\alpha)^2\right)$ LL FSR via the module PHOTOS in version YFSWW3-1.12.

5. **Inclusion of photons.**

`CompHEP`: Calculation of the processes:

$$\begin{aligned} e^+e^- &\rightarrow l\nu l\nu(\gamma), \\ e^+e^- &\rightarrow q\overline{q}e\nu(\gamma), \\ e^+e^- &\rightarrow q\overline{q}\mu\nu(\gamma), \end{aligned}$$

The comparison of inclusive ISR case with the case when direct γ is separated, at the first stage for a simplified examples like

$$e^+e^- \rightarrow Wl\nu, \quad e^+e^- Wl\nu + \gamma,$$

W on shell. At the second stage, a full four and five particle final states simulation like

$$\begin{aligned} e^+e^- &\rightarrow \mu^+\mu^-\nu_\tau\nu_\tau(\gamma), \\ e^+e^- &\rightarrow \mu^+\mu^-\nu_\mu\nu_\mu(\gamma), \end{aligned}$$

with the γ radiated from the final muon line. (probably separate calculations for the contributions of the subsets $Z^*Z^*, Z^*\gamma^*, \gamma^*\gamma^*$ should be done). A rather clear qualitative and quantitative understanding of the p_t ISR and the situation with a separated gamma in the final state should be reached.

`GRACE`: has calculations of some of 4f + γ processes, $e\nu - eud\gamma$ and $udcs\gamma$) and experience to apply ISR by QEDPS for radiative matrix elements with avoiding double-counting. This should be compared with another method like the structure function with finite p_t.

`PV+ALPHA`: $e^+e^- \to$ 4f + γ (charged currents) with the following features:

- exclusive photon isolated from charged particles and energy greater than 1 GeV (exact matrix element);
- LL photonic radiative corrections taken into account;
- massive fermions;
- trilinear (quartic) anomalous gauge couplings;

`DDRW`: Complete calculation for $e^+e^- \to$4f + (visible)γ. Virtual corrections not yet available, work is in progress.

6. TGC in the process of single W production.

- The sensitivity of various distribution to the TGC. Recalculation of the single W signal with the red 1 cuts and the more detailed red 2, red 3 level simulations: $\triangleright$ `CompHEP`.

7. Background calculations for the Higgs search

- Higgs signal under the threshold $M_H + M_Z$. Can the fusion process in the 2 neutrino 2 b channel enhance the discovery limit for the Higgs even by a few GeV? $\triangleright$ `CompHEP`

8. **Resolved photon**

   - Some potentially interesting questions like the backscattered jets and leptons from the ladder diagrams and the contribution of *resolved* γ (possible also in the multi-peripheral mechanisms). Is the latter always small in comparison with ep (HERA) case? $\triangleright$ `CompHEP, WTO`

9. p_t **ISR in WW and ZZ-dominated channels** $\triangleright$ `GRACE`

10. **High mass hadronic final state** $\triangleright$ `GRACE`

11. **Leptonic final state** $\triangleright$ `GRACE`

12. **FSR in WW and ZZ-dominated channels** $\triangleright$ `GRACE`

13. $e^+e^- \to e^+e^-\nu_e\overline{\nu}_e$ $\triangleright$ `GRACE, WPHACT`

   - Recent version of the `GRC4F` can give them. Though sometimes it becomes unstable, it can calculate them properly after some tuning at energy-by-energy. OPAL group has been using those events generated by the `GRC4F`.

14. **Anomalous quartic gauge coupling**† $\triangleright$ `GRACE`

†) Any connections with $e^+e^- \to \nu\overline{\nu}\gamma\gamma$?

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3 Hot topics available now

- Hot topics for this meeting are:

  A Including the photon,

  B tackling the problems of unstable particles and RC.

- We are all aware of certain potential problems in any approach to [A,B].
- We want the problems to materialize, it does not help the community to have conflicting statements without an attempt to clarify the issues involved.

That's why we will have four talks:

1. F. Berends, $\mathcal{O}(\alpha)$ *corrections to W-pair mediated 4f production.*
2. `KORALW team`, *the solution of* `KORALW` *to the problems of unstable particles and RC.*
3. M. Roth, *a novel calculation of* $e^+e^- \to$ *4f + (visible)*γ.
4. M. Osmo, *the* `PV` *approach to 4f +* γ.

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4 Where we go?

- the set $\mathtt{EXP}_{\rm wishes} \cap \mathtt{TH}_{\rm answers}$, although not $\emptyset$, looks minimal: what do we do?

  1. What seems to be covered is not at all sufficient. Go fishing? $\frown$
  2. What seems to be covered is barely sufficient. Renormalize†? ?
  3. It suffices. Be happy? $\smile$

  †) `EXP` will only get a fraction of what they wanted and will learn that they have been asking questions that only get **No go** answers. But

  No go answer .BETTER. No answer

- **Which photon do we need?**

  1. Visible (only **radiative events**)?
  2. **radiative** $\oplus$ **non-radiative events**?

  Are there reasons to defend one choice with respect to the other?

- **Do we have consensus on** $\mathcal{O}(\alpha)$ CC03?