R. Pittau
WW99

4f Status Report

1) Introduction
2) Input parameter set
3) Single W production
4) 4f + 1 visible γ
5) σ_{WW} (and σ_{ZZ})
6) Conclusions

Flags

(O) "Official"

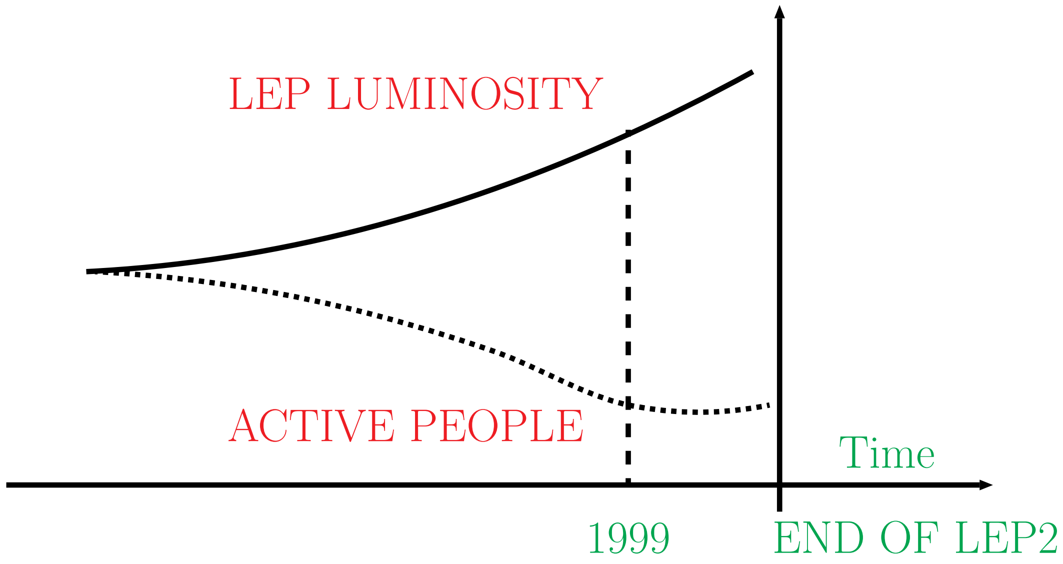
(C) During coffee break

(P) Personal point of view

INTRODUCTION

From the conclusions of my talk at LEPC (24-3-1999):

- A close collaboration between theorists and experimentalist is necessary to achieve the following



- Tasks:
  - Improve what can still be improved
  - Give a reliable estimate of the error for all the rest
- This is especially important for background studies

- (Some) slides of the workshop are available in

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

(P) The situation is not so bad.

Sub-group 2 (4f) Status Report *

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and

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Geneva October 12, 1999

Contributions from:

- `CompHEP`
- `GRACE`
- `KORALW + YFSWW3`
- `NEXTCALIBUR`
- `PVALPHA`
- `RACOONWW`
- `WPHACT`

*presented by G. Passarino

INPUT PARAMETERS

(P) The renomalization scheme commonly used and recommended is the following:

$$G_F = 1.16637 \times 10^{-5}$$

$$M_Z = 91.1867 \text{ GeV}$$

$$M_W = 80.350 \text{ GeV}$$

$$s_W^2 = 1 - \frac{M_W^2}{M_Z^2}$$

Therefore α_{QED} is a derived quantity

$$\alpha_{QED} = 4\sqrt{2}\,\frac{G_F\,M_W^2\,s_W^2}{4\,\pi} = 1/131.95798$$

This "high energy" renormalization scheme ($G_F - scheme$) allows the inclusion of part of higher order effects in the Born cross sections.

$\Rightarrow$ What to do with $q^2 \sim 0$ dominated processes like $Z - \gamma^*$ and single W?

See later...

SINGLE W

we want to check:

⊗ technical precision, BORN (no ISR) is enough,

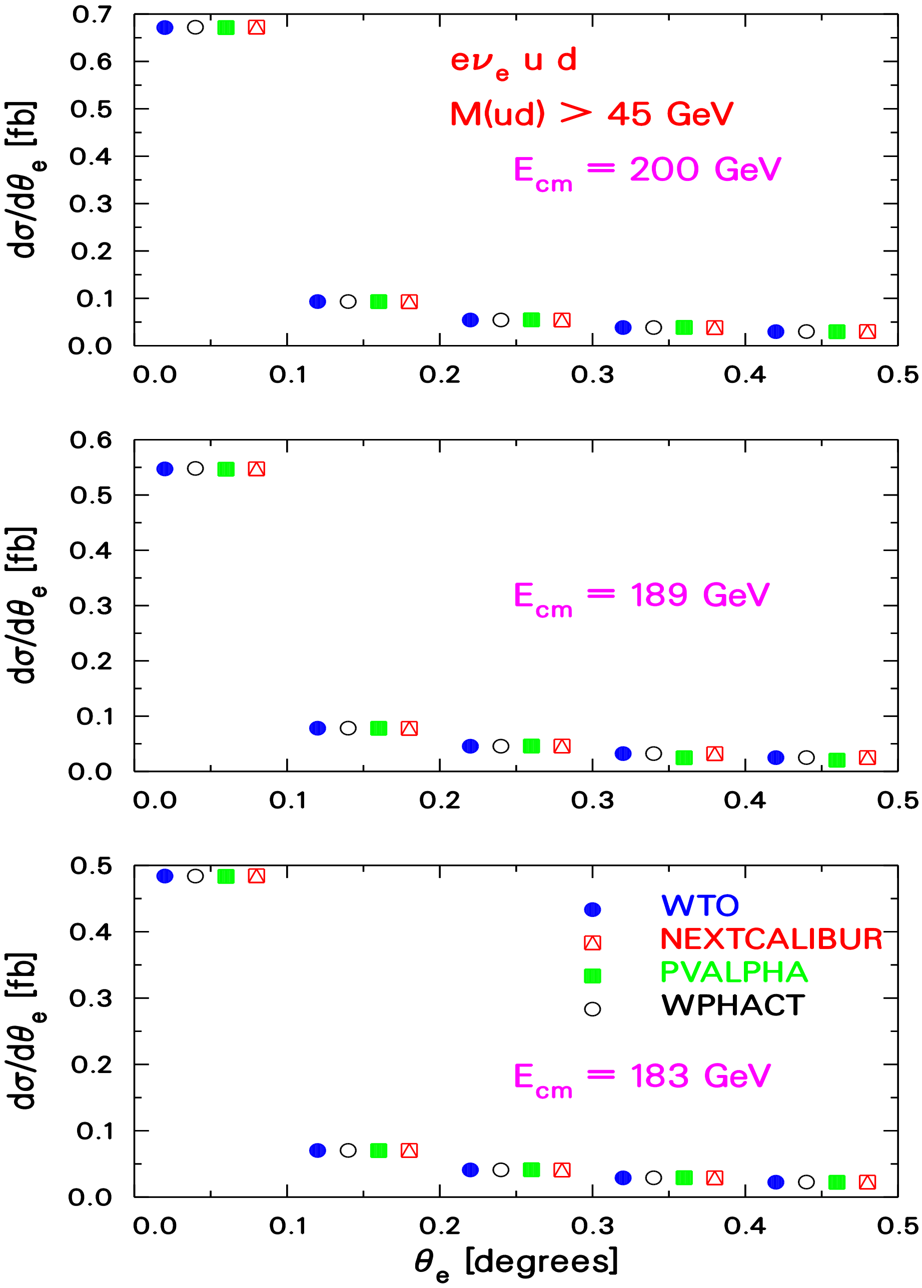
⊗ correct inclusion of QED radiation,

⊗ **QCD** correction, especially in the *low-mass* region.

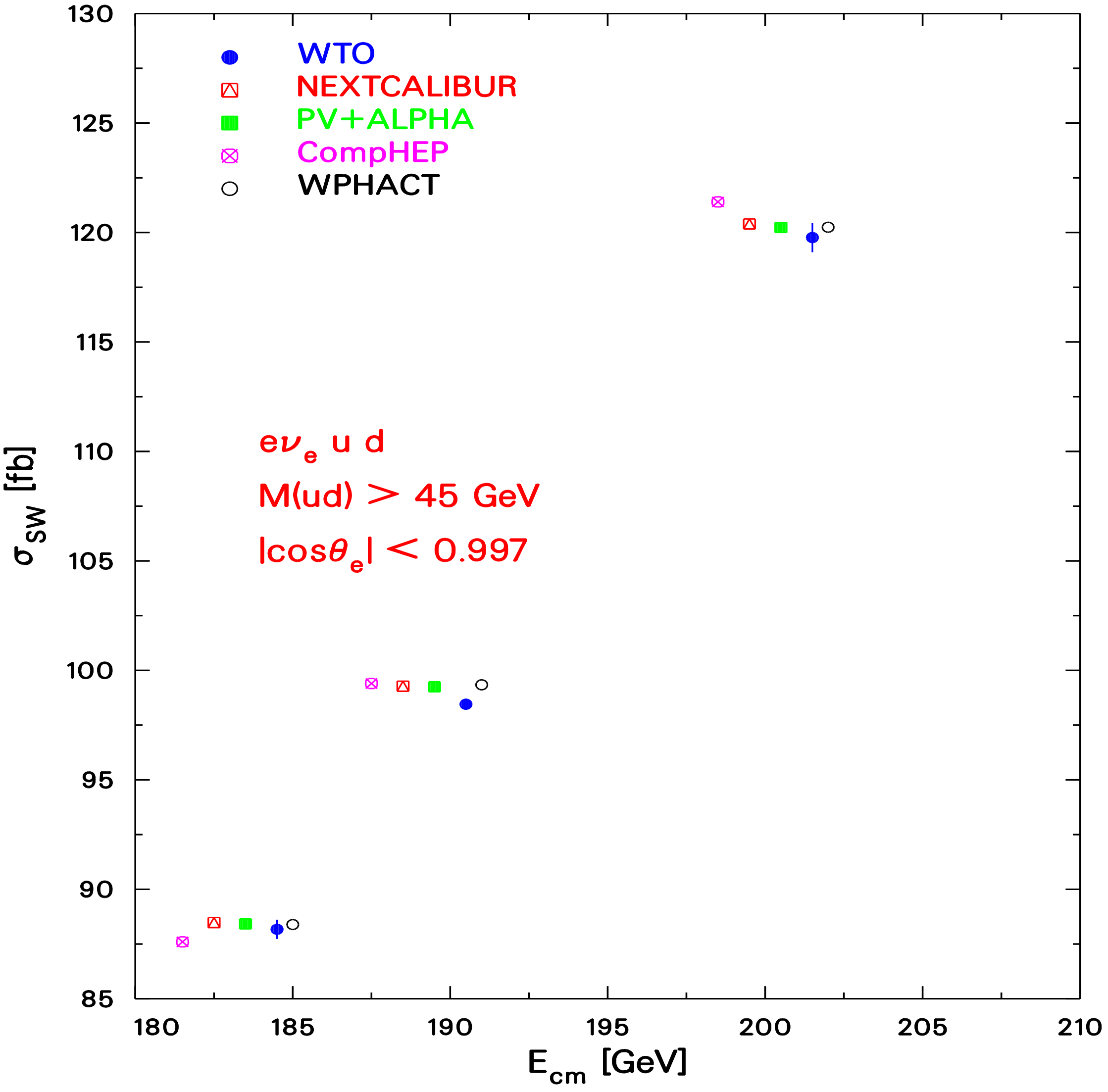
(O) Technical precision is not a problem anymore, we all agree on *single-W* cross-sections and distributions, even for $\theta_e < 0.1^\circ$ (`even for leptonic final states`).

- On $\sigma_{\rm Born}$ the technical accuracy is 0.1%, the same for $d\sigma/d\theta_e$ for $\theta_e \to 0$.
  - News are: `NEXTCALIBUR` with masses, uses a massive matrix element program called `HELAC`[1]
  - A completely independent check through `WTO`.
  - `WPHACT` has the implementation of the Imaginary Fermion Loop-scheme, besides the usual fixed-width-scheme)

[1] `HELAC` is a recursive algorithm for electroweak amplitude calculations based on Dyson-Schwinger equations developed by A. Kanaki and C .G. Papadopoulos.



$e\nu_e$ u d
M(ud) > 45 GeV
E_{cm} = 200 GeV
E_{cm} = 189 GeV
WTO
NEXTCALIBUR
PVALPHA
WPHACT
E_{cm} = 183 GeV
$d\sigma/d\theta_e$ [fb]
θ_e [degrees]



WTO
NEXTCALIBUR
PV+ALPHA
CompHEP
WPHACT
eν_e u d
M(ud) > 45 GeV
|cosθ_e| < 0.997
σ_SW [fb]
E_cm [GeV]
130
125
120
115
110
105
100
95
90
85
180
185
190
195
200
205
210

- Not only invariant-mass cuts, but also energy-cuts have been tested:

	$\sqrt{s} = 183\,\mathrm{GeV}$	$\sqrt{s} = 189\,\mathrm{GeV}$	$\sqrt{s} = 200\,\mathrm{GeV}$
NEXTCALIBUR	26.483 ± 0.041	29.679 ± 0.047	35.893 ± 0.048
PVALPHA	26.47 ± 0.04	29.70 ± 0.04	35.93 ± 0.05

Table 1: Cross-sections [fb] for $e^+e^- \to e^-\overline{\nu}_e\mu^+\overline{\nu}_\mu$.

	$\sqrt{s} = 183\,\mathrm{GeV}$	$\sqrt{s} = 189\,\mathrm{GeV}$	$\sqrt{s} = 200\,\mathrm{GeV}$
NEXTCALIBUR	26.422 ± 0.035	29.655 ± 0.046	35.954 ± 0.052
PVALPHA	26.3 ± 0.2	29.6 ± 0.2	35.92 ± 0.05

Table 2: Cross-sections [fb] for $e^+e^- \to e^-\overline{\nu}_e\tau^+\overline{\nu}_\tau$.

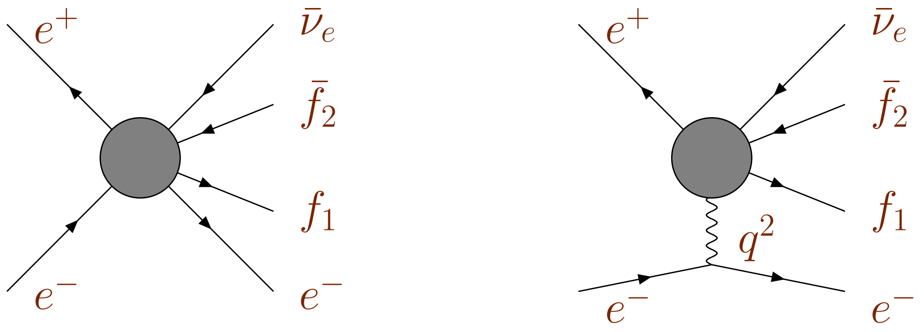
- There are results also for $e^+e^-\nu_e\overline{\nu}_e$, from WPHACT and from NEXTCALIBUR.
- There is an, apparently, stronger energy dependence of CompHEP in σ_{Born}. **Overall**-scheme?

QED Radiation in CC20

The Structure Function (**SF**) approach needs scales as input parameters:

$$d\sigma = \prod_i \int dx_i \; D(\Lambda_i{}^2, x_i)\; d\sigma_0 \qquad (1)$$

s-channel SF ($\Lambda_i^2 = s$) are not adequate enough to include QED radiation:



$\Rightarrow$ talks by `Kurihara` and `Pallavicini`.

`Kurihara` (`KEK+GRACE`) fixes Λ_i by comparing numerically eq. (1) with the complete calculation *in the soft limit*.

`Pallavicini` (`PV` group) by comparing with the complete analytic calculation *in the soft + collinear limit*.

(O) $\Lambda^2_{e^-} \sim |q|^2\,, \quad \Lambda^2_{e^+} \sim M^2_W.$

(O) By using $\Lambda^2_{e^\pm} = s\,,\ \sigma$ is underestimated (5%).

(C) Using YFS formalism Λ_i are automatically set.

(P) This allows to estimate the TH uncertainties.

• QEDPS vs SF vs exact ME calculations

(O) Agreement found by GRACE, *for 2 γ processes* ($e^+e^- \to e^+e^-\mu^+\mu^-$):

E_{CM} (GeV)	σ_0 (nb)	$\sigma_{\tt sf}$ (nb)	$\sigma_{\tt QEDPS}$ (nb)	$\sigma_{\tt BDK}$ (nb)
20	97.0(1)	96.3(1)	96.0(2)	96.0(1)
40	137.5(3)	136.3(1)	135.9(3)	135.9(1)
100	202.8(4)	201.0(2)	200.5(4)	200.5(2)
200	262.0(6)	259.8(3)	259.1(6)	258.8(2)

$\sigma_{\tt BDK}$ by *F.A. Berends et al. Nucl. Phys. B253 (1985) 421*

(O) Reasonable agreement (few %) in the e^- tagging case with visible muon-pair for

σ, $\frac{d\sigma}{dE_e}$, $\frac{d\sigma}{d\cos_{\theta_e}}$, $\frac{d\sigma}{d\hat{s}}$, $\frac{d\sigma}{dM_{\mu\mu}}$.

(P) The same agreement is expected for 1 γ processes.

(O) Agreement (1 %) in $\sigma_{\tt tot}$ between QEDPS and SF for $e^+e^- \to e^+\nu_e\, u\, \bar{d}$, distributions reasonable.

(O) QEDPS $\sim$ exact ME for $e^+e^- \to e^+\nu_e\, u\, \bar{d}\, \gamma$, E_γ distribution reproduced for soft γ ($\sim$ 20% differences in the hard region).

(P) Definite statements will be available by the end of the workshop.

- Running of $\alpha_{\texttt{QED}}$ in CC20 (and in $Z\,\gamma^*$)

Scale of $\alpha_{\texttt{QED}}$ in *single-W*, is somewhat connected to the gauge-invariant treatment. Everything has been used: *overall*, *fixed-width* and *Imaginary Fermion Loop* (by WPHACT). But scale is connected to the real part of the corrections, so we need *Complete FL* for *single-W*, that nobody has (WTO will), or techniques presented by **Chapovsky**. Some old FL results:

$\theta^{\rm min}_{e^-,\rm beam}$	$0.1°$	$0.5°$	$1°$	$5°$	$10°$
Running width	1.36(1)	0.654(3)	0.6249(4)	0.60167(6)	0.58907(5)
Fixed width	0.641(1)	0.6256(8)	0.6188(5)	0.6020(2)	0.58915(5)
Running width + γWW vertex factor	0.641(1)	0.6245(5)	0.6187(5)	0.60190(2)	0.589242(8)
Full FL scheme	0.642(3)	0.630(1)	0.6247(4)	0.6100(2)	0.59771(7)

Table 1: Total cross-sections in pb at $\sqrt{s} = 175$ GeV with canonical cuts except between the outgoing electron and either beam as predicted by WTO for the CC20 process.

(C) Is the naive rescaling $\sigma_0 \to \sigma_0 \left|\dfrac{\alpha(0)}{\alpha(\,M_W^2)}\right|^2 = \sigma_0 \cdot 0.93$ a good approximation?

(O) **Kurihara** and **Pallavicini** get 3 %.

(P) *Complete FL* includes other contributions that could compensate for it (see table).

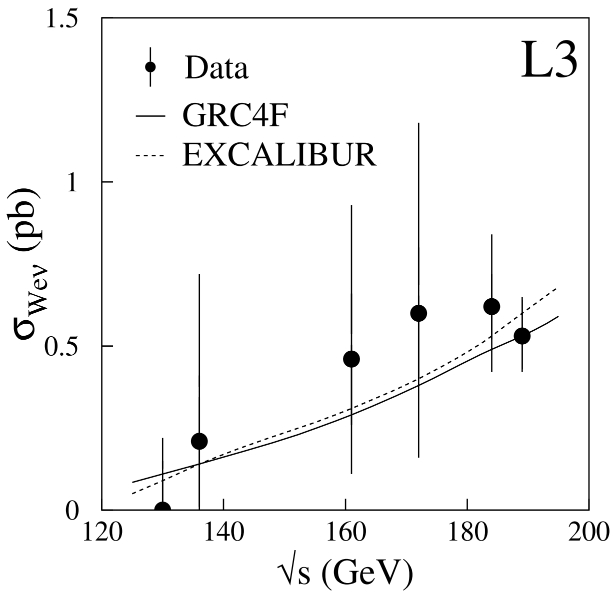
(P) Still to be discussed, it will be presumably fixed.

(P) Hadronic low-mass CC20 will not be studied.

Conclusions on single W processes

From the talk by A. Kounine (Cern 12/3/99):

Physics with Single Ws



What is the accuracy of the SM prediction?

4F final states — LEP-2 MC Workshop — Andrei Kounine

From the 4f proposal:

- 2% for $e^+e^- \longrightarrow e^- \; \bar{\nu}_e \; q \; \bar{q}' \; (\gamma)$
- 5% for $e^+e^- \longrightarrow e^- \; \bar{\nu}_e \; e^+ \; \nu_e \; (\gamma)$
- 5% for $e^+e^- \longrightarrow e^- \; \bar{\nu}_e \; \mu^+ \; \nu_\mu \; (\gamma)$

(P) These questions will be answered by the end of the workshop.

4f + 1 visible γ

It is a first step to get a safe estimate of the theoretical uncertainties associated with **QED** radiation in 4f processes.

A first comparison (according to the 4f proposal)

	$\sqrt{s} = 183\,\mathrm{GeV}$	$\sqrt{s} = 189\,\mathrm{GeV}$	$\sqrt{s} = 200\,\mathrm{GeV}$
PVALPHA	78.80 ± 0.26	75.18 ± 0.24	70.19 ± 0.19
CompHEP$^{1)}$			60.7 ± 0.8
CompHEP$^{2)}$			68.9 ± 0.9
GRACE			79.7 ± 0.2
RACOONWW			73.4 ± 0.1

Table 1: Cross-section for $e^+e^- \to \mu^-\bar{\nu}_\mu u\bar{d}\gamma$.

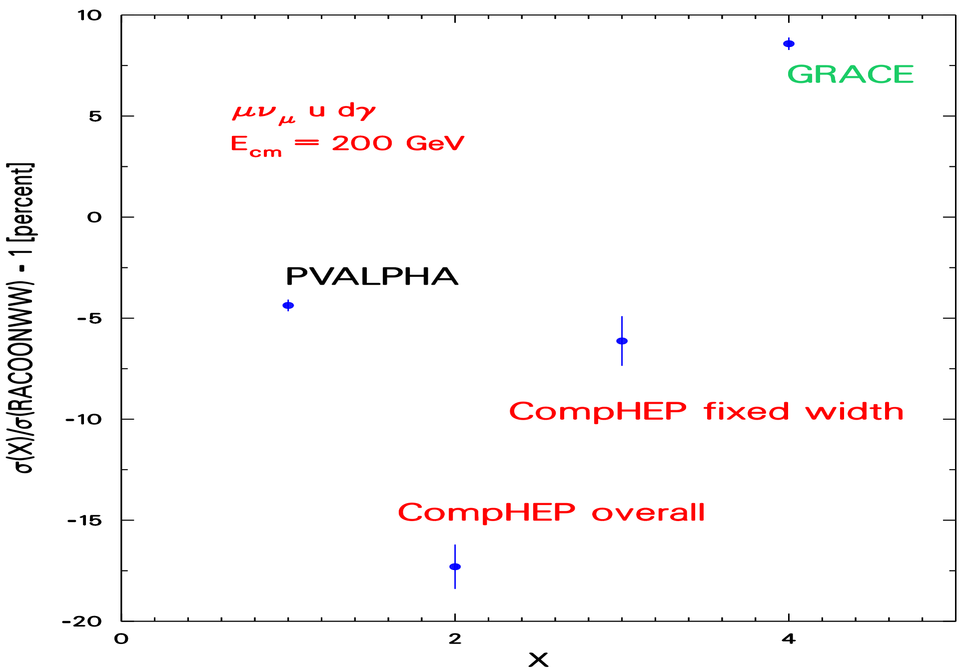
1) Overall

2) Fixed-width

When numbers are available we can compare and:

– **Differences seems to be** $> 15\%$

(O) More work needed.



There are several more results where, however, we cannot compare, the intersection being empty.

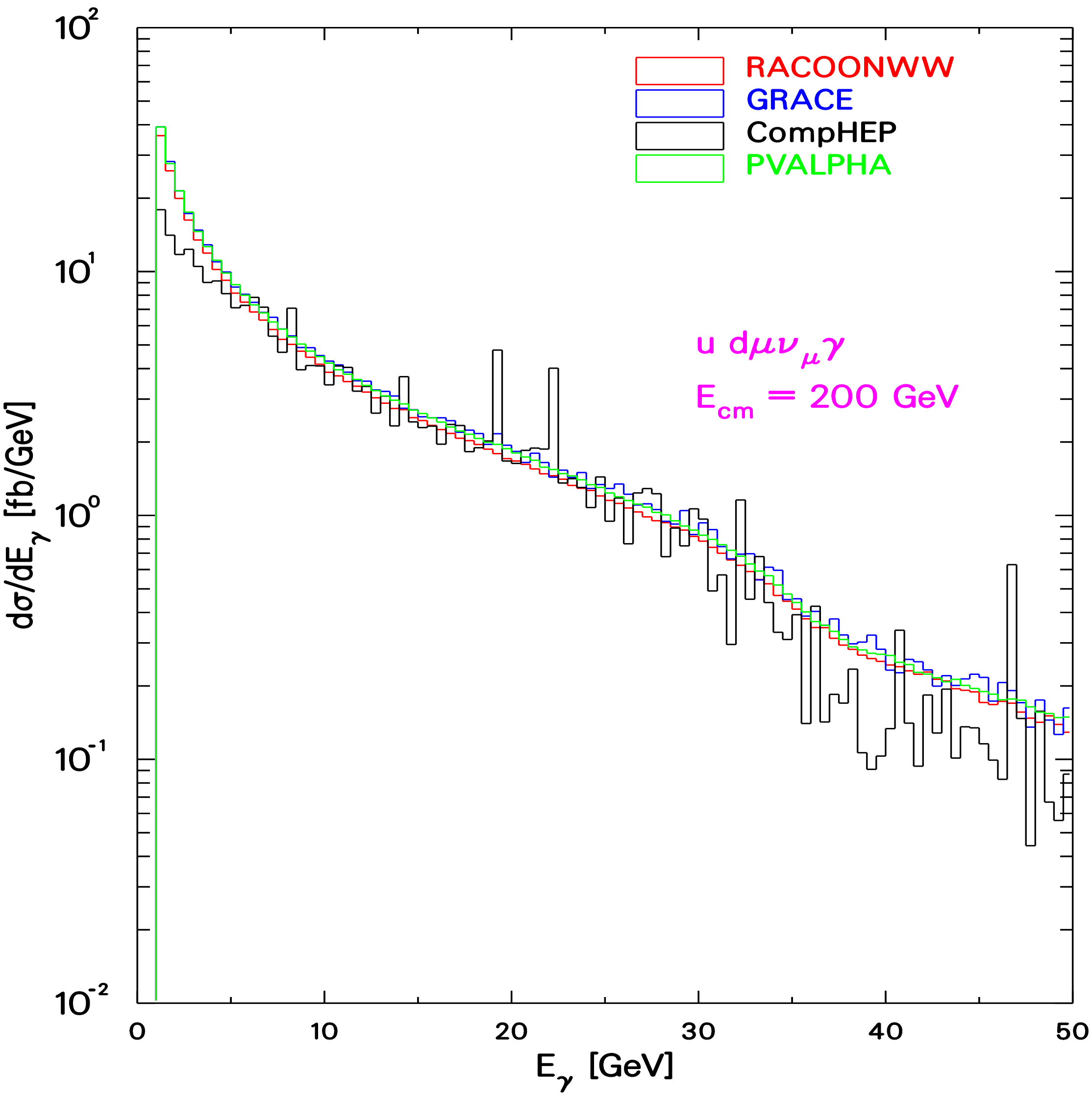
- Not only total cross-sections have been produced but also distributions.
- Again, they are shown only for the case of *maximal* comparison.

First the CC11 family

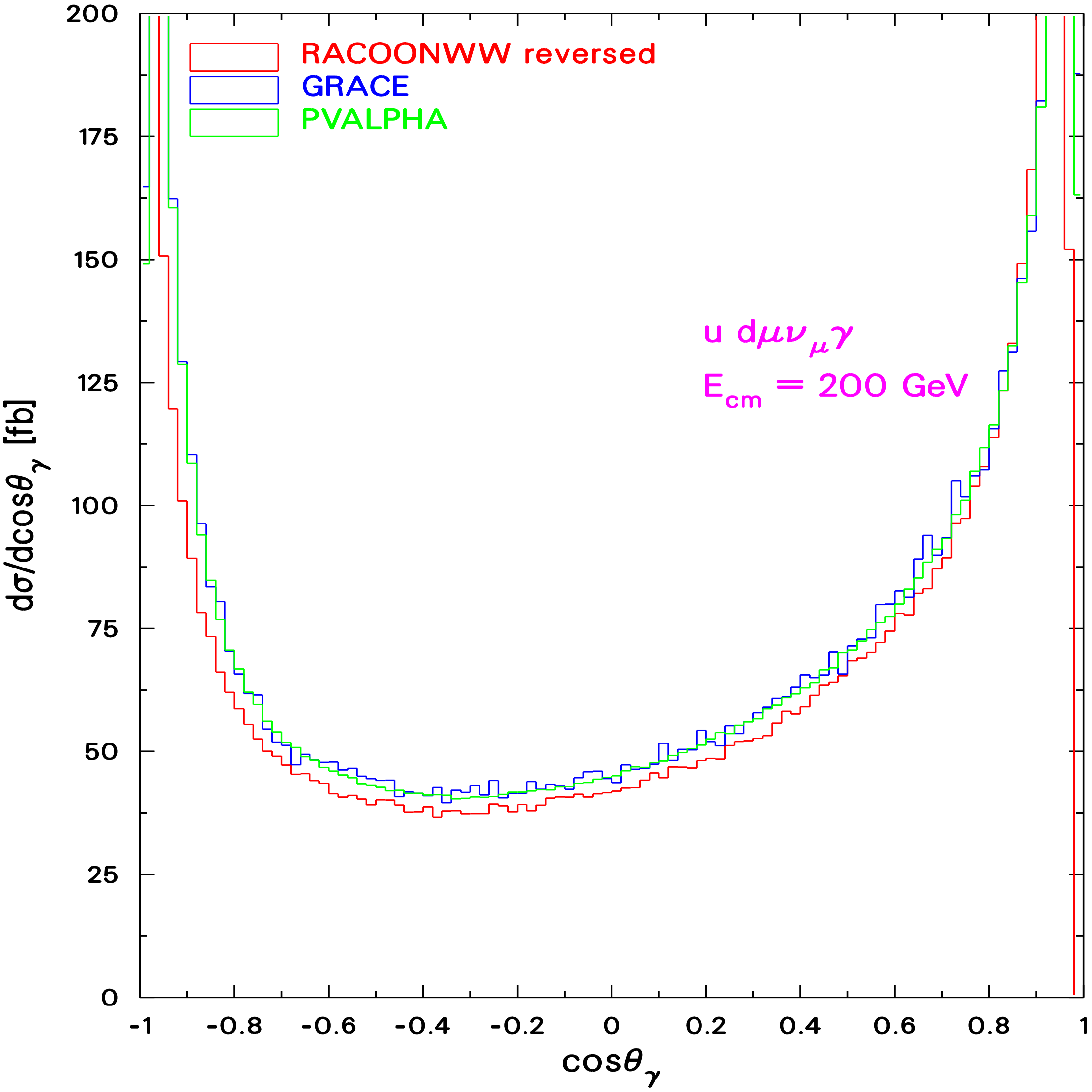
- KORALW has multiple-options in presence of multi-photonic events. It can define distributions for
  1. *visible* γ (*radiative*) or
  2. *all photons*, i.e. no cuts, in which case one can take only
     - **a** the most energetic photon to determine energy and angles (*hardest), or*
     - **b** *the sum (*sum*).*
- There is a substantial agreement between PVALPHA and RACOONWW (when available) and with GRACE (despite somehow large fluctuations in the GRACE histograms). A different convention $e^- \leftrightarrow e^+$ is suspected for RACOONWW in the $\cos\theta_\gamma$ distribution.

  Also a substantial agreement is registered between PVALPHA and GRACE for mass distributions.

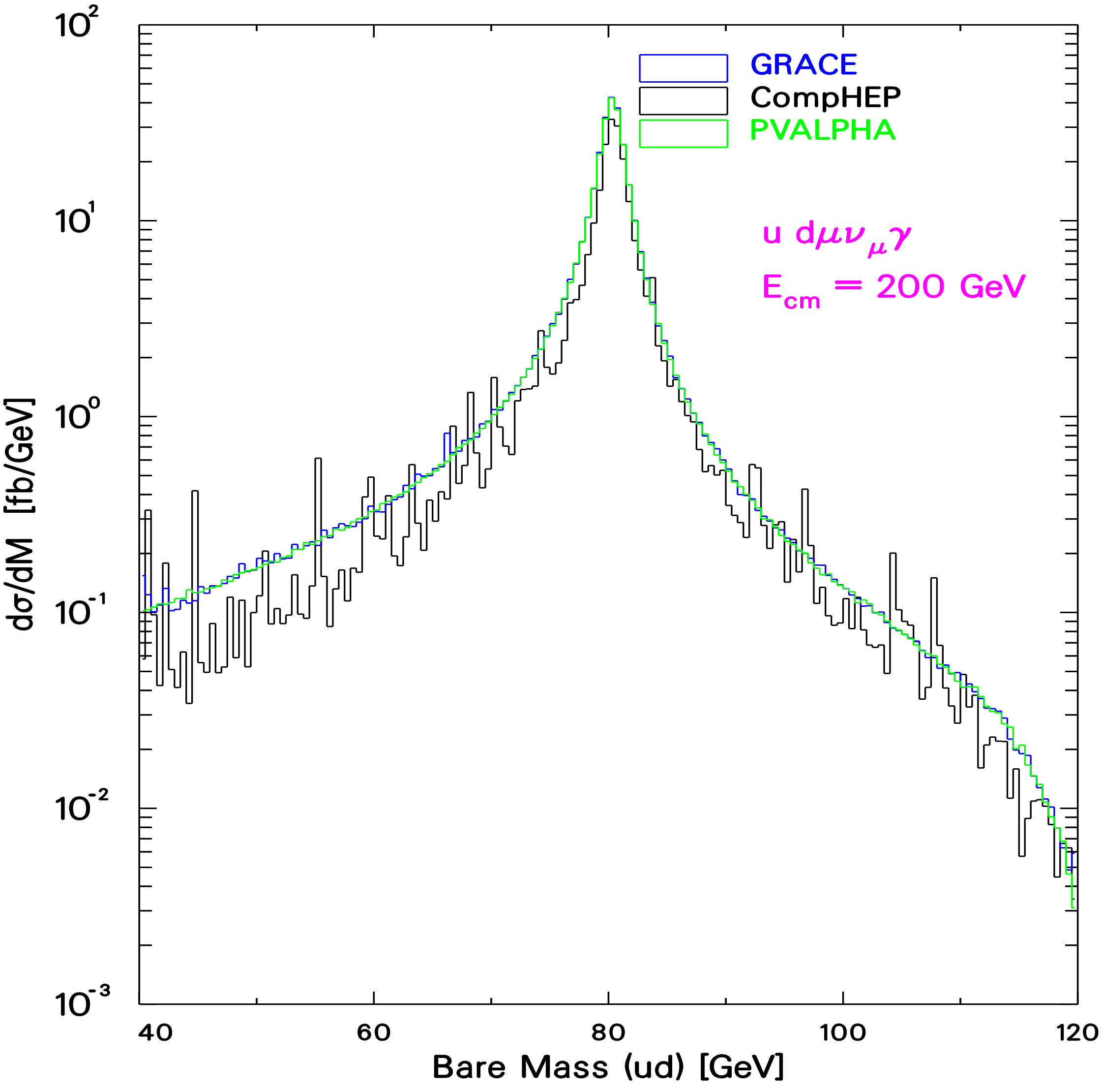
  CompHEP always shows large fluctuations in the histograms. A Blowup of the $\cos\theta_\gamma$-distributions shows with total cross-sections that are $60.7 \pm 0.8\,$fb for CompHEP and $73.4 \pm 0.1\,$fb for RACOONWW.



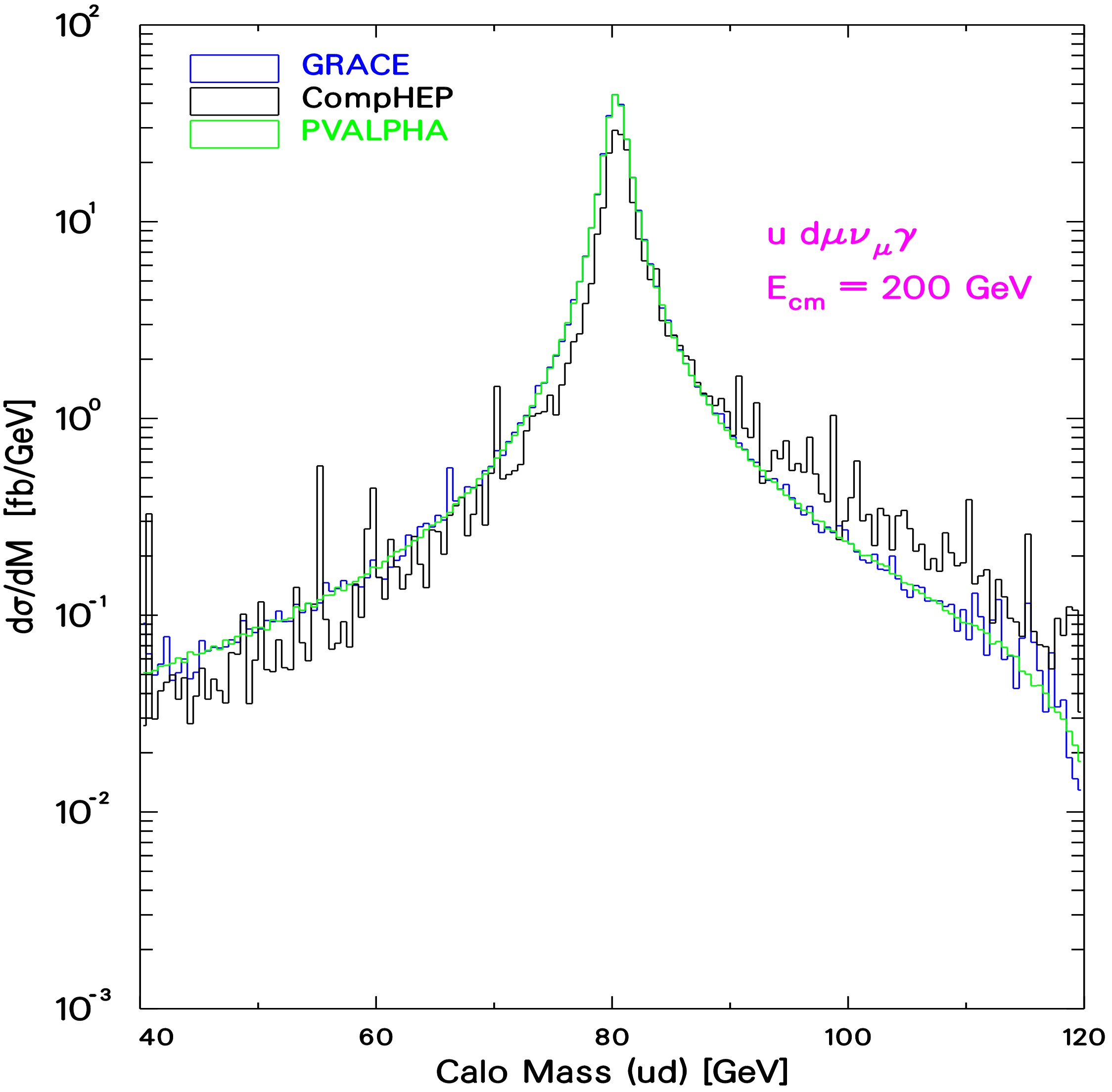
RACOONWW
GRACE
CompHEP
PVALPHA
$u\ d\mu\nu_\mu\gamma$
E_{cm} = 200 GeV
$d\sigma/dE_\gamma$ [fb/GeV]
E_γ [GeV]
10^2
10^1
10^0
10^{-1}
10^{-2}
0
10
20
30
40
50



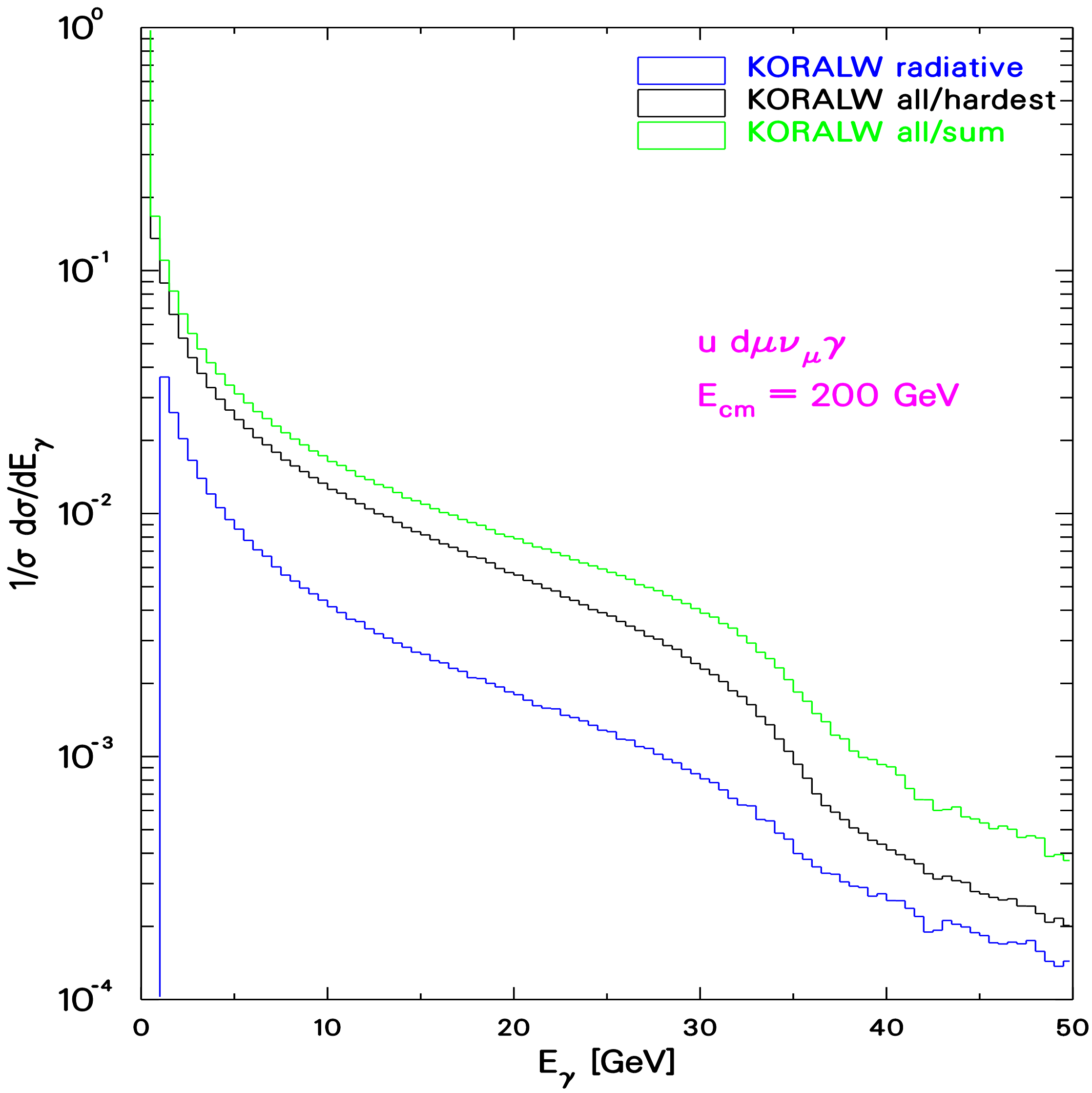
RACOONWW reversed
GRACE
PVALPHA
u dμν_μγ
E_cm = 200 GeV
dσ/dcosθ_γ [fb]
cosθ_γ
200
175
150
125
100
75
50
25
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1



GRACE
CompHEP
PVALPHA
u d$\mu\nu_\mu\gamma$
E_{cm} = 200 GeV
$d\sigma/dM$ [fb/GeV]
Bare Mass (ud) [GeV]
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
40
60
80
100
120



GRACE
CompHEP
PVALPHA
u dμν_μγ
E_cm = 200 GeV
dσ/dM [fb/GeV]
Calo Mass (ud) [GeV]
10^2
10^1
10^0
10^-1
10^-2
10^-3
40
60
80
100
120


KORALW radiative
KORALW all/hardest
KORALW all/sum
u d$\mu\nu_\mu\gamma$
E_{cm} = 200 GeV
$1/\sigma\ d\sigma/dE_\gamma$
E_γ [GeV]
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
10
20
30
40
50

Conclusions on 4f + 1 γ processes

(O) Tuning of codes is still necessary to have technical accuracy under control.

(O) KORALW has a different normalization for distributions, but the shape is comparable.

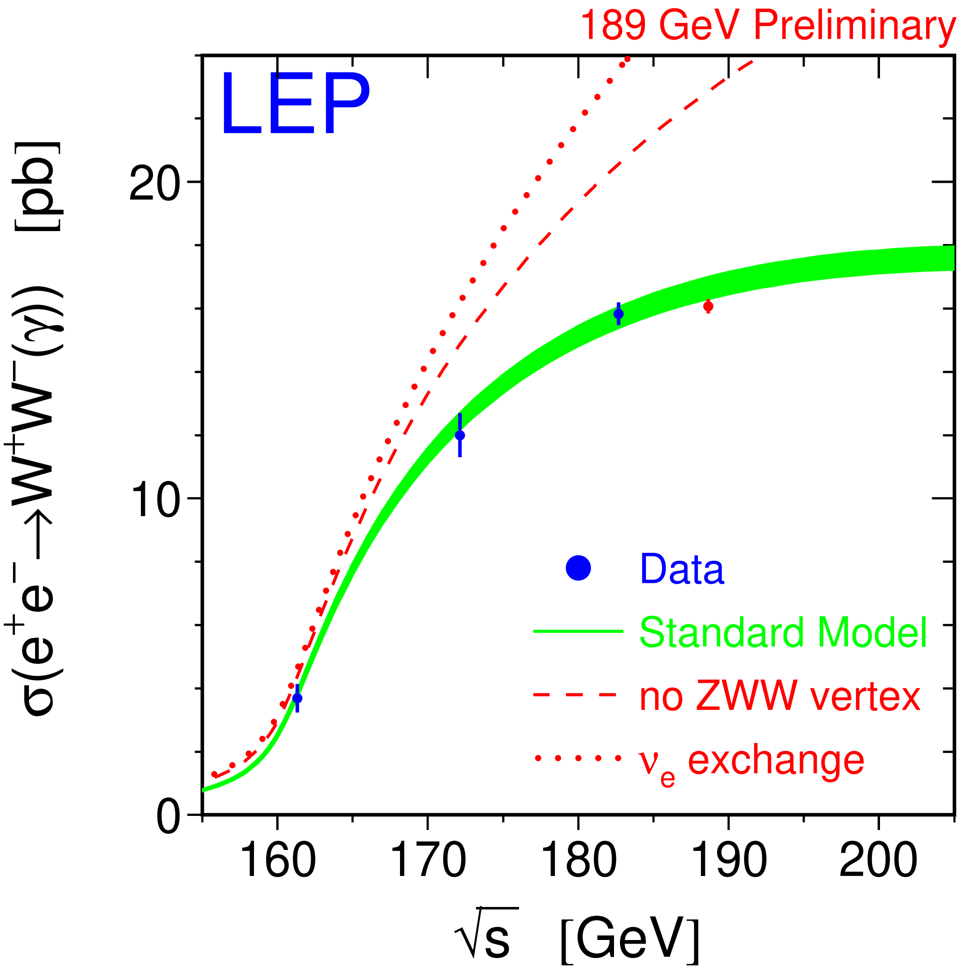
(C) Many differences are already understood.

(O) After that, one would really to understand better QEDPS vs SF vs ME, namely studies as presented by Kurihara for the radiation in CC20.

(P) This will be done by the end of the Workshop.

σ_{WW} (and σ_{ZZ})

The problem is the following [1]



Solutions:

1) Better understanding of $\mathcal{O}(\alpha)$ EW corrections

2) Better understanding of `Bose-Einstein` (BE) and `Color Reconnection` (CR) effects (see later)

[1] *From the* `LEPEWWG Web page.`

- Old strategy for the first item:

The present attribution of a theoretical error on **CC03** (WW) and **NC02** (ZZ) cross-section is still based on `GENTLE/4FAN` inclusion of ISR radiation (QED only) through the so-called *split-technique*, and it is probably `overestimated`.

(O) `GENTLE/4FAN` is invited to have a look at it.

- New strategy:

Inclusion of radiative electroweak correction in DPA-approximation has to replace the old estimate.

What is DPA?

DPA isolates the poles at the complex squared masses, with gauge invariant residues which are then projected onto the respective on-shell gauge invariant counterparts:

NB the projection is from the off-shell phase space to the on-shell phase space. The ambiguity in the projection is $\mathcal{O}(\frac{\alpha}{\pi}\frac{\Gamma_W}{M_W})$.

Contributions by `Dittmaier` (`RACOONWW`)

and `Placzek` (`YFSWW`).

- (O) At the moment DPA available for `CC03` only.
- (O) Expected uncertainty $\mathcal{O}\left(\frac{\alpha}{\pi}\frac{\Gamma_W}{M_W}\ln(\cdots)\right) < 0.5\%$.
- (O) DPA *is not reliable at threshold* (background diagrams important!).
- (O) Above threshold, namely $\sqrt{s} > 2\,M_W + n\Gamma_W$ with $n = \mathcal{O}(3-5)$, the background diagrams are of the order $\sim \frac{\alpha}{\pi}\frac{\Gamma_W}{\sqrt{s}-M_W}\ln(\cdots) \sim 0.1\%$.
- (P) The problem remain how to estimate the theoretical error above the resonant region (only `QED?`).

At present we have RACOONWW/YFSWW3 - 1

- $u\bar{d}s\bar{c}$,	1.81 ± 0.06 %
- $u\bar{d}\mu^-\bar{\nu}_\mu$,	0.44 ± 0.07 %
- $\nu_\mu\mu^+\tau^-\bar{\nu}_\tau$,	-0.75 ± 0.07 %

- (O) We are, now, better than before, when electroweak radiative corrections were not available. Now we have 2 **DPAs**. We need to understand their basics elements and their differences.
- (C) A lot of differences already understood.

Here the *BEST-level results* for CC03 cross sections by KORALW:

	Born	Best
$u\bar{d}s\bar{c}$ [fb]	2066.91 ± 0.40	1757.25 ± 0.96
$u\bar{d}d\bar{u}$ [fb]	2067.37 ± 0.41	1760.65 ± 0.82
$u\bar{d}\mu^-\bar{\nu}_\mu$ [fb]	688.99 ± 0.16	594.40 ± 0.26
$u\bar{d}e^-\bar{\nu}_e$ [fb]	689.13 ± 0.13	594.44 ± 0.27
$\mu^-\bar{\nu}_\mu\tau^+\nu_\tau$ [fb]	229.57 ± 0.05	200.65 ± 0.09
all WW channels [pb]	18.59649 ± 0.00383	17.09010 ± 0.00771

Table 1: YFSWW3 total cross-sections for the *Born*-level and the *Best*-level calculation (together with statistical errors) with NO CUTS APPLIED at $\sqrt{s} = 200\,\mathrm{GeV}$.

and by RACOONWW:

		Born: $\sigma_{\rm tot}$ [pb]	Born: $\sigma_{\rm tot}$ [pb]	Best: $\sigma_{\rm tot}$ [pb]
		CC03	full	full
$uds\bar{c}$	sub ps.sl	1.97733 ± 0.00079 1.97740 ± 0.00080	1.97884 ± 0.00085 1.98030 ± 0.00081	1.78938 ± 0.00085 1.79096 ± 0.00165
$ud\mu^-\bar{\nu}_\mu$	sub ps.sl	0.65911 ± 0.00026 0.65913 ± 0.00027	0.65957 ± 0.00028 0.66009 ± 0.00027	0.59700 ± 0.00031 0.59668 ± 0.00057
$\nu_\mu\mu^+\tau^-\bar{\nu}_\tau$	sub ps.sl	0.21970 ± 0.00009 0.21971 ± 0.00009	0.21984 ± 0.00009 0.22001 ± 0.00009	0.19914 ± 0.00010 0.19892 ± 0.00023

Table 2: RACOONWW total cross-sections for DPA at $\sqrt{s} = 200\,\mathrm{GeV}$.

(P) The 0.5% accuracy target on σ_{WW} is reachable.

There are also RACOONWW **DPA** distributions. They are on a restricted range since the **DPA** is not valid outside the resonance region, so we don't now how to interpret the results far away from the resonance:

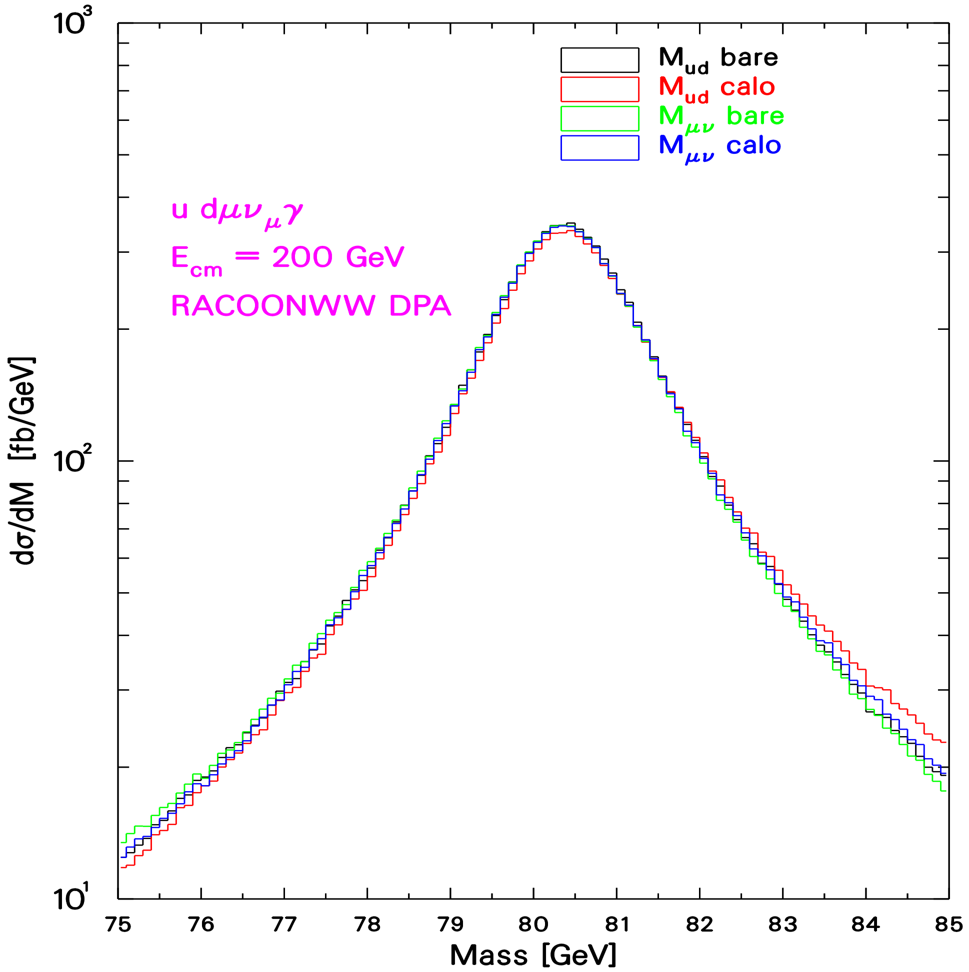


Figure 19: DPA (from RACOONWW) of *Bare* and *Calo* M spectra for $u\bar{d}\mu^-\bar{\nu}_\mu\gamma$.

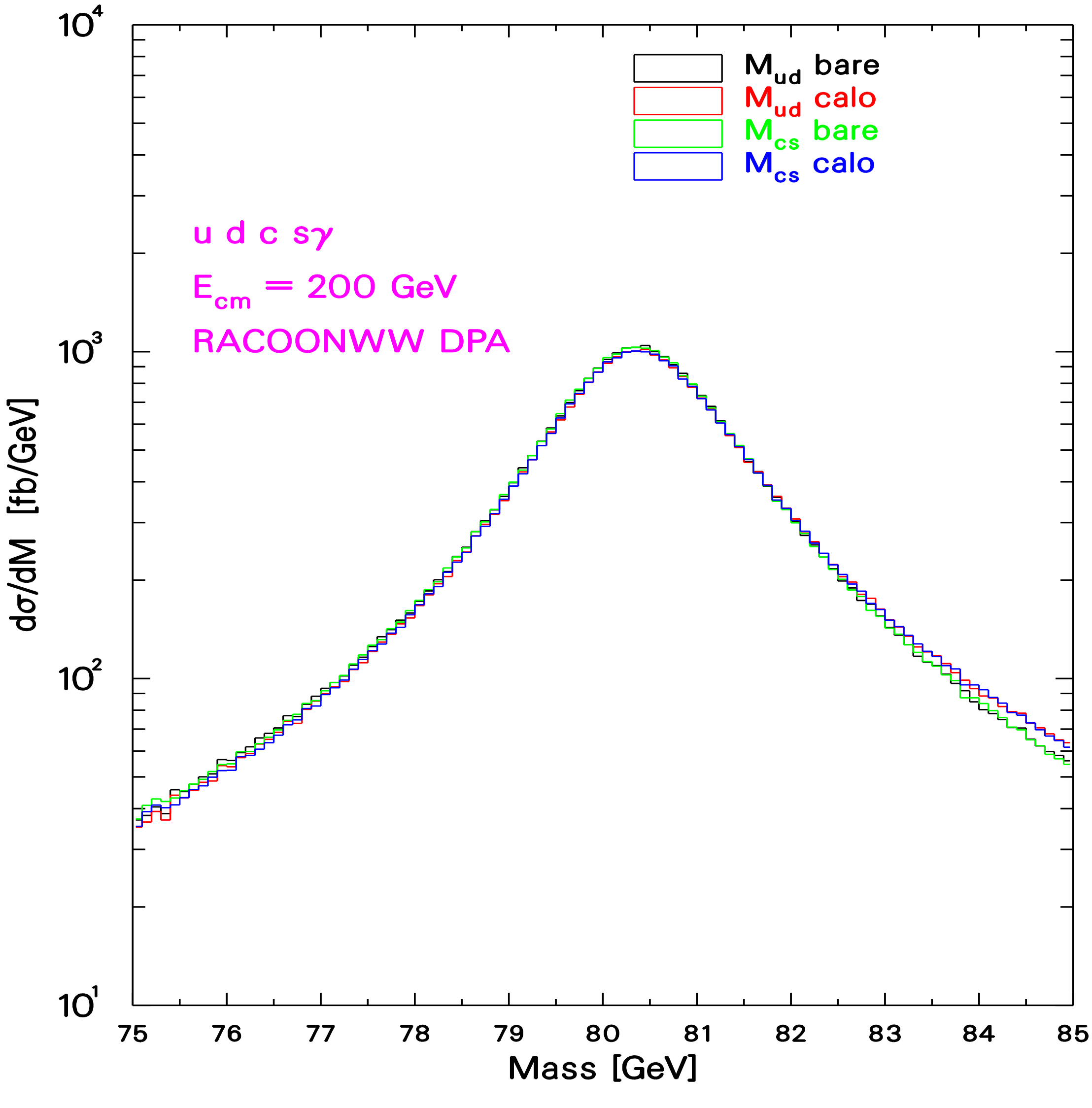


Figure 20: DPA (from RACOONWW) of *Bare* and *Calo* M spectra for $u\overline{d}s\overline{c}\gamma$.

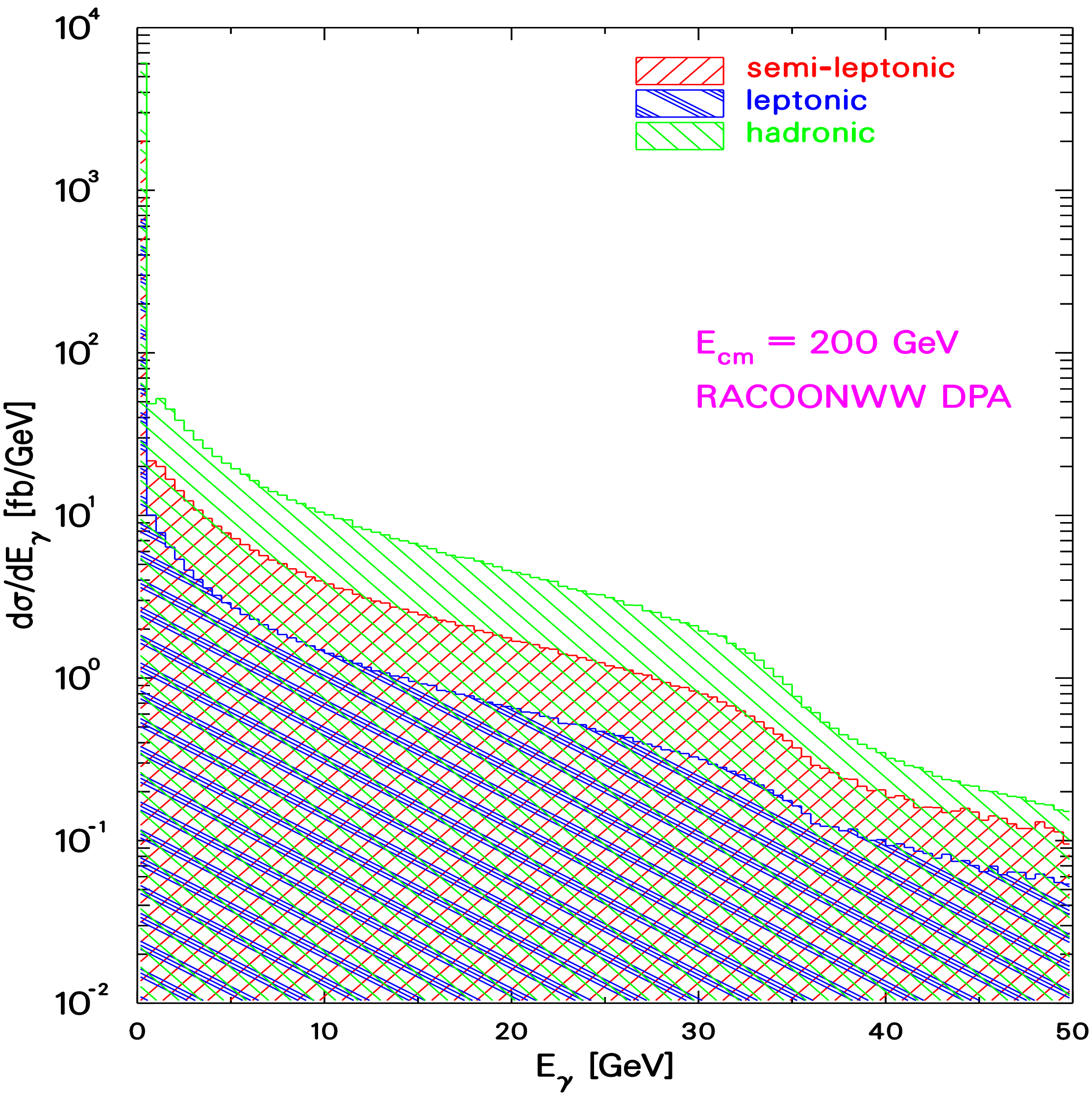


Figure 21: DPA (from `RACOONWW`) spectra for E_γ for semi-leptonic, leptonic and hadronic channels.

σ_{ZZ}

(O) No DPA for ZZ available yet.

(C) RACOONWW could in principle implement it in the code.

If not *how to proceed*?

(P) Estimate the TH uncertainties by using only QED corrections (is this the approach by KORALW, that presented *best predictions* for NC02?).

(C) Idea by P. Bambade: read the error from σ_{WW}.

(P) How reliable? If complete DPA will not available by the end of the workshop it could be a viable solution.

BE and CR effects

Not studied in the workshop (at the moment).

(P) They will not be in the future, unless

$$\boxed{\text{LEP2 MC WORKSHOP}} \longleftarrow \boxed{\text{WW99}}$$

(P) Try to find if there are M_W reconstruction methods less sensitive to BE and CR effects (WEXTER [1]?).

[1] Phys.Lett.B417:385-389,1998 and Comput.Phys.Commun.115:32-44,1998.

Conclusions for σ_{WW} and σ_{ZZ}

(O) TH uncertainties on `CC03` better than before.

(O, C, P) 0.5 % uncertainty on σ_{WW} can be reached.

The problem remains how to translate this into experimental procedures to extract σ_{WW} from the data.

What do the experimenters like?

(O) No cuts?

(O) All diagrams or 3 diagrams?

(P) Include also hard γ?

All this is needed to compare consistently theory and data.

(O) σ_{ZZ} needs more studies.

(P) Input needed for `BE` and `CR` effects.

Alternative reconstruction procedures could be tried out to minimise them.

(P) General conclusions

The situation in 4f is not so bad

provided we get a delay of the deadline
of the MC Workshop
(LEPC on 9–11–99)

Issues with high chance to get satisfactory answers by the end of the workshop:

- Single W (high-mass region)
- Pattern of the radiation in 4f processes
- σ_{WW} (and σ_{ZZ} ?)

Issues with low chance:

- QCD corrections to low-mass Single W
- `BE` and `CR` effects ?

As usual we are facing man-power problems. But provided we remember (at least from the theory side) that

... there is more glory in solving a specific problem, relevant to the final analysis, than in cloning your neighbour's MC... [1]

a satisfactory work can be done.

[1] G. Passarino, 4f report, Oct. 12th 1999.