Recent Theoretical Developments in LEP 2 Physics

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Abstract

We briefly summarize the result of the recent LEP/MC Workshop held at CERN.

LEGENDA:

- `CompHEP` E. Boos, M. Dubinin and V. Ilyin
- `GENTLE` D. Bardin, A. Olchevski and T. Riemann
- `GRACE` Y. Kurihara, M. Kuroda and Y. Shimizu
- `YFSWW/YFSZZ/KorlaW` S. Jadach, W. Placzek, M. Skrzypek, B. Ward and Z. Was
- `NEXTCALIBUR` F.A.Berends, C. G. Papadopoulos and R.Pittau
- `PHEGAS/HELAC` C. G. Papadopoulos
- `RacoonWW` A.Denner, S.Dittmaier, M.Roth and D.Wackeroth
- `SWAP/WRAP` G. Montagna, M. Moretti, O. Nicrosini, A. Pallavicini and F. Piccinini
- `WPHACT` E. Accomando, A. Ballestrero and E. Maina
- `WTO/ZZTO` G. Passarino

The LEP/MC Workshop

- An extensive collection of **theoretical predictions** for observables in e^+e^- interactions at **LEP 2** energies had been presented in the 1996 CERN *Report of the Workshop on Physics at* **LEP 2**.

- However, an update with improved **theoretical prescriptions** is needed in order to match the precision achieved by now in the experimental analyses.

The aim of this talk is twofold

- ∇ We summarize the most recent theoretical developments concerning e^+e^- annihilation into four-fermions at **LEP 2** energies.

▷ Applications to the four most important classes of processes will be discussed. In decreasing order of importance they are

- ⊘ the WW-signal,
- ⊘ the inclusion of an extra γ in the final state,
- ⊘ the **single**-W production and
- ⊘ the ZZ-signal.

To gauge the priorities one should remember

that the experimental situation is rather different for WW when compared to the other processes.

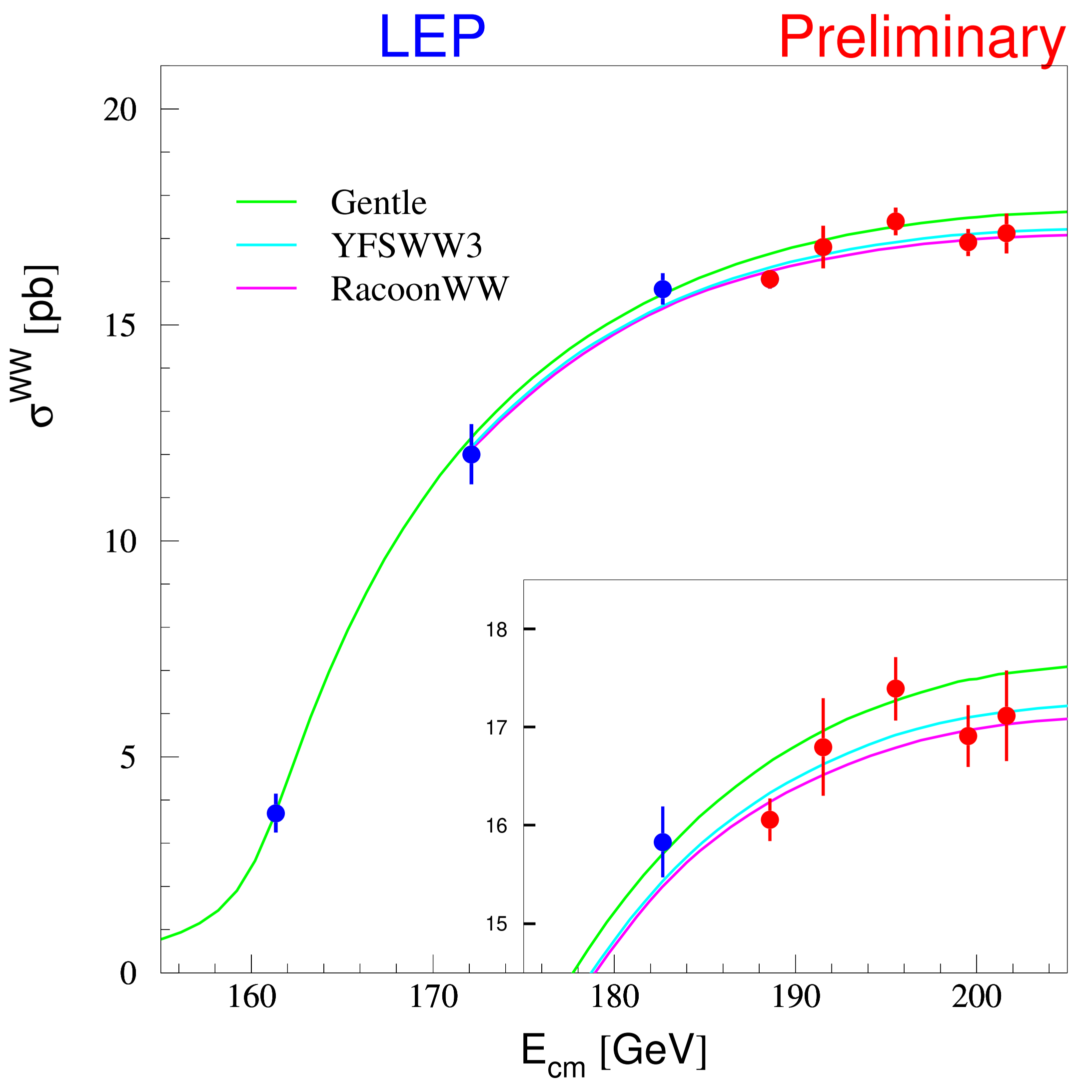
♣ For W-pairs, **LEP** (**ADLO**) is able to test the theory to below 1%, i.e. , below the old **uncertainty** of ±2% established in 1995.

♢ Thus the **CC03-DPA**, including non-leading electroweak corrections, constitutes a very important theoretical development.

♡ However, **ADLO** cannot test **single**-W or ZZ-signal to an equivalent level,

♠ since their total σ is of the order of $1\,pb$ or less, 20 times smaller than that of W-pair production: For ZZ with **1997+1998+1999** data, the present analyses and global **LEP** combination method give an average measurement with 7% accuracy.

△ At the end of **LEP**, we may reach better than 5%.



LEP
Preliminary
Gentle
YFSWW3
RacoonWW
σ^{WW} [pb]
E_{cm} [GeV]
0
5
10
15
20
160
170
180
190
200
15
16
17
18

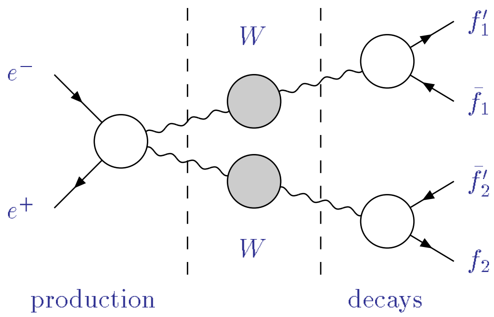


Figure 1: **The generic structure of the virtual factorizable W-pair contributions. The shaded circles indicate the Breit–Wigner resonances, whereas the open circles denote the Green functions for the production and decay sub-processes up to $\mathcal{O}(\alpha)$ precision.**

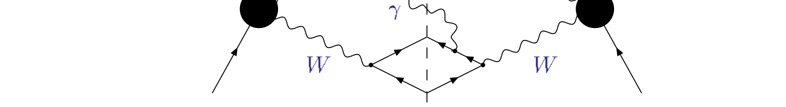


Figure 2: **Examples for virtual (top) and real (bottom) non-factorizable corrections to W-pair production. The black circles denote the lowest-order Green functions for the production of the virtual W-boson pair.**

CC20 Diagrams

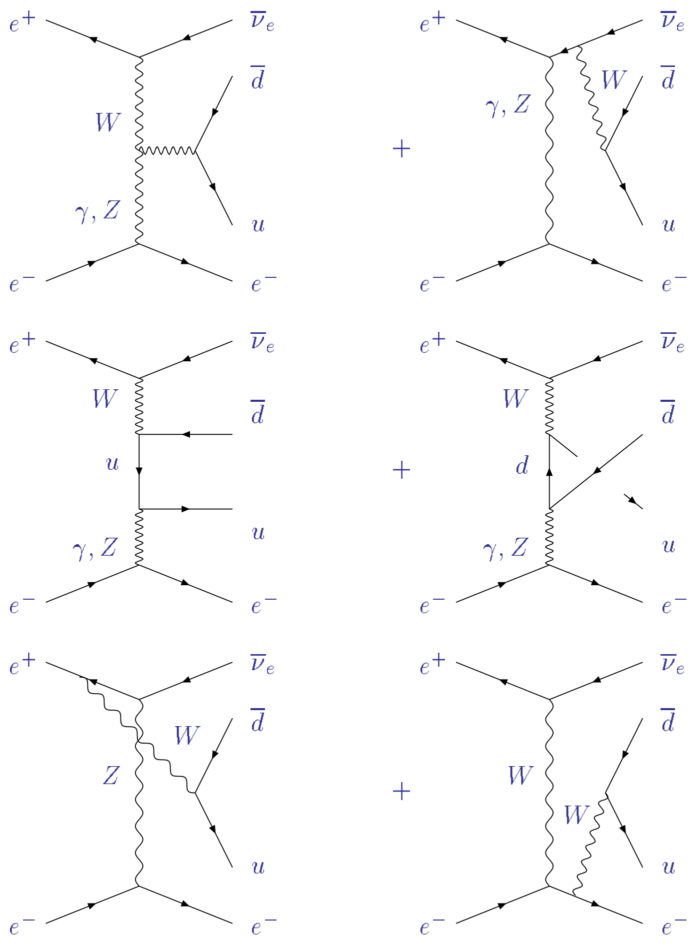


Figure 3: **The t-channel component of the CC20 family of diagrams: fusion, bremsstrahlung and multi-peripheral.**

NC Diagrams

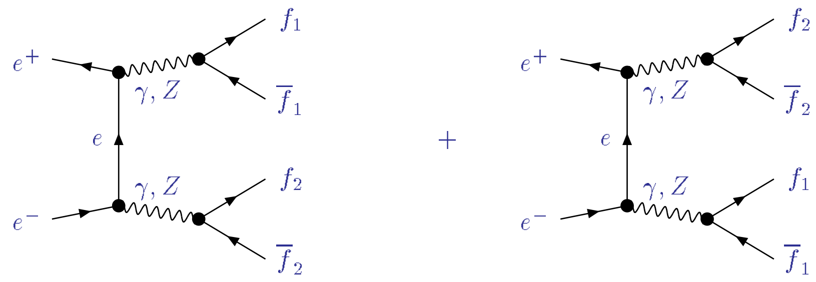


Figure 4: **The NC08 sub-family of diagrams.**

The authors of the four-fermion report agree on the following conclusions:

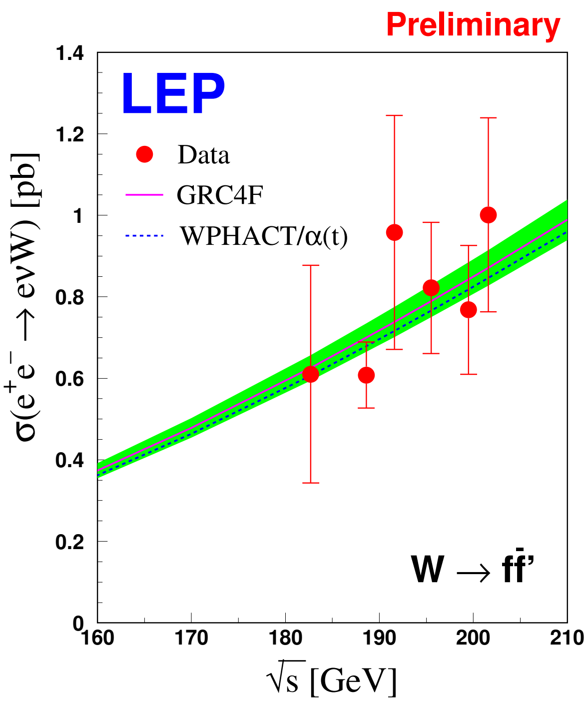
$\boxed{WW \text{ signal}}$

1 There is a nice global agreement between the new **DPA** predictions for **CC03**, which are $2\% \div 3\%$ lower than the old approach

2 The Monte Carlo programs `RacoonWW` and `YFSWW3` agree within 0.3% at $\sqrt{s} = 200\,\mathrm{GeV}$. The present estimated **TU** of these programs is 0.4%, 0.5%, and 0.7% for $\sqrt{s} = 200\,\mathrm{GeV}$, $180\,\mathrm{GeV}$, and $170\,\mathrm{GeV}$, respectively.

3 There is a general satisfaction with the progress induced by new **DPA** calculations. Nevertheless, the **TU** could probably be improved somewhat in the future.

4 More work will be needed to reduce the **uncertainty** for $4\mathrm{f} + \gamma$ and of **PS** with p_t.



$\boxed{\textbf{single-}W}$

1 In **single-W** production most of the theorists were interested in **gauge-invariance** issues due to unstable particle. The experimentalists were asking for **ISR** and p_t effects, comparisons including parton shower, **SF** and exponentiation. Unfortunately, only few groups have been working on these issues.

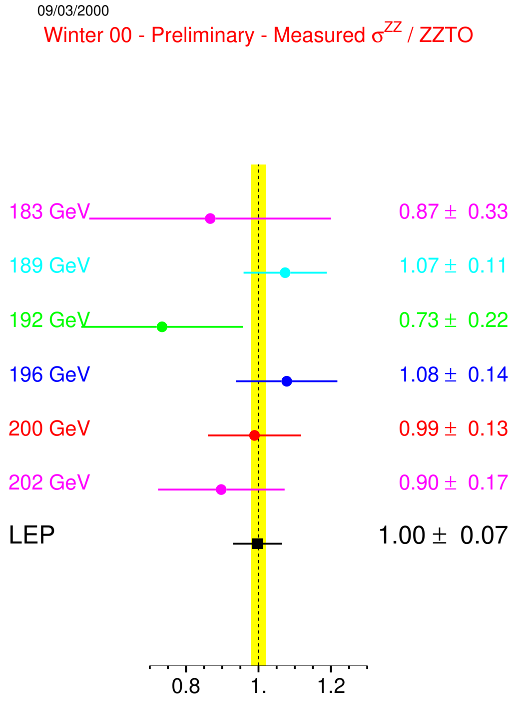
2 In **single**-W we have a (global) $2\% \div 3\%$ **TU** associated with the scale of the t-channel γ, with a projected 1% **uncertainty** when the implementation of the **FL** scheme will receive more cross-checks.

3 For simple processes like e^+e^- annihilation and $\gamma\gamma$ collision, the evolution of the energy scale in the **SF** or in the **PS** algorithms can be determined by the exact perturbative calculations. However, this is not available for more complicated processes.

- □ When no exact first order calculations are available then one resorts to the scale occurring in the first order soft corrections.

- □ At the moment, we may apply a very conservative (global) upper bound of 4% **TU** for **ISR** in **single**-W.

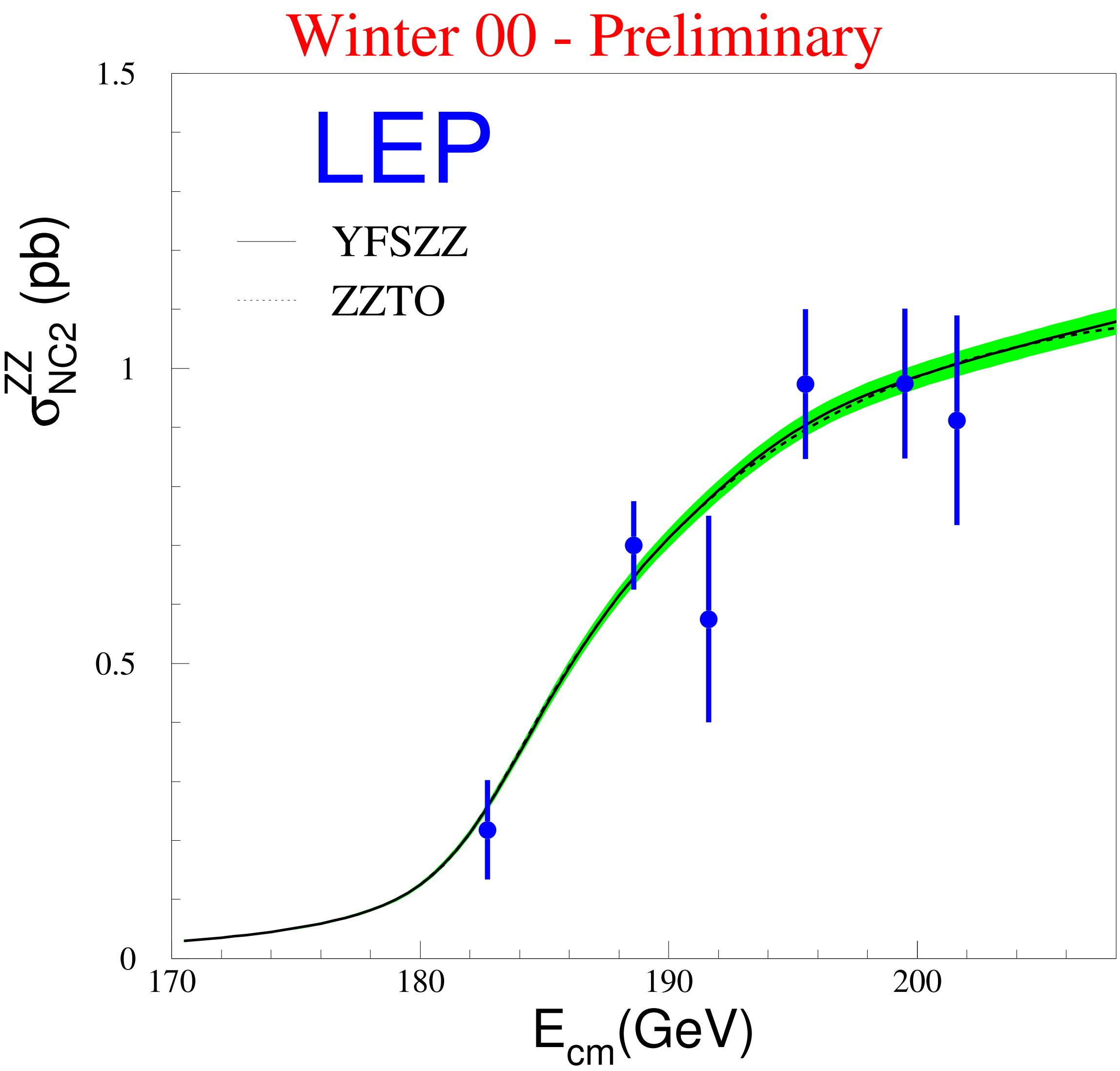
- □ The current upper bound on the global estimate of the **TU** is 5% for **single**-W.



$\boxed{ZZ \text{ signal}}$

1 Compared to the experimental **uncertainty** on the **NC02** ZZ σ a difference of about 1% between theoretical predictions is acceptable.

2 The global estimate of **TU** is 2%, again acceptable. However, it would be nice to improve upon the existing calculations.



Winter 00 - Preliminary
LEP
YFSZZ
ZZTO
σ^{ZZ}_{NC2} (pb)
E_{cm}(GeV)
0
0.5
1
1.5
170
180
190
200

These points are discussed in more detail in the following

$\boxed{\text{DETAILS OF } WW\text{-SIGNAL}}$

- $\triangle$ The new **DPA** predictions for **CC03** are $2\% \div 3\%$ lower than in the old approach. The new Monte Carlo programs `RacoonWW` and `YFSWW3` agree within 0.3% **at** $\sqrt{s} = 200\,\mathrm{GeV}$, i.e. at a level that is consistent with the accuracy of the **DPA**.

- $\triangle$ The **TU** of these programs for the **CC03** W-pair σ, which we estimate to be below $0.4 \div 0.5\%$ for $\sqrt{s} = 180$–$210\,\mathrm{GeV}$, should be compared with the current experimental precision of $\pm 0.9\%$ with all **ADLO** data at 183–202 GeV combined.

- $\triangle$ It should be mentioned as well that `RacoonWW` and the semi-analytical `BBC` calculations agree very well where they should, i.e. above 185 GeV.

- $\triangle$ To go below the level of a few **per-mille** of accuracy would require the complete calculation of **one-loop** RC in four-fermion production for all 4f final states, a program that does not seem feasible in a forseeable future.

$$\boxed{\text{DETAILS OF } e^+e^- \to 4\mathrm{f} + \gamma}$$

- $\triangle$ The technical precision for $e^+e^- \to 4\mathrm{f} + \gamma$ has reached high standards as shown by the comparisons among `PHEGAS/HELAC`, `RacoonWW` and `WRAP`, but at the moment we are unable to present any overall statement on the **TU** process by process.
- $\triangle$ In general more work will be needed to establish the **uncertainty** for $4\mathrm{f} + \gamma$. At the moment we can fix an upper bound of 2.5% based on missing non-logarithmic corrections.

DETAILS OF **SINGLE**-W

- △ In **single**-W production most of our activity was centered around **gauge-invariance** issues due to unstable particle.

- △ Few programs, noticeably `GRACE` and `SWAP`, have produced a preliminary internal estimate of the **uncertainty** associated with the treatment of **QED** radiation;

  - □ the net effect of **QED** is between 8% and 10% in the **LEP 2** energy range, with s-channel **SF** over-estimating the effect by $\approx 4\%$.

  - □ Furthermore, **SF** with a modified scale seems to agree with parton shower at the level of 1% when experimental cuts are included or even better for a fully extrapolated setup.

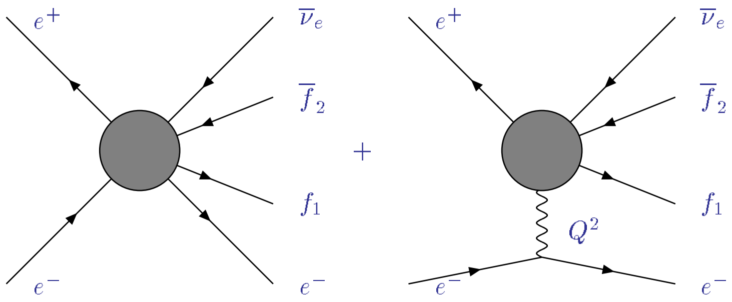


Figure 5: **The CC20 family of diagrams with the explicit component containing a t-channel photon.**

- △ As far as the scale of the electromagnetic coupling is concerned we find that the results with a rescaling of $\alpha_{\mathbf{QED}}$ for the t-channel photon that has been implemented in `NEXTCALIBUR`, `SWAP` and `WPHACT` show an agreement with `WTO` predictions that is roughly around 2%.

- △ For **single**-W, therefore, we register a conservative, overall, upper bound of $\pm 5\%$ for the **TU**.

  - □ **single** programs may claim better internal estimates but this does not transform, yet, into a global one

  - □ we recall that, at the moment an **uncertainty** associated to **QED ISR** is

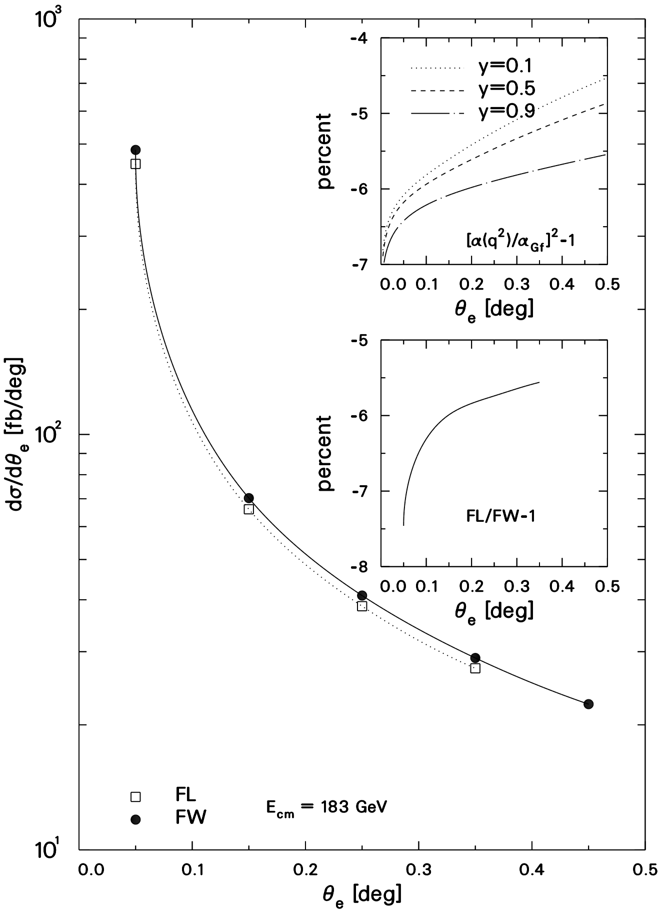


Figure 6: **WTO predictions for $d\sigma/d\cos\theta_e$ [fb/degrees] for $e^+e^- \to u\overline{d}e^-\overline{\nu}_e$ with $M(u\overline{d}) > 45\,\mathrm{GeV}$ and $\sqrt{s} = 183\,\mathrm{GeV}$.**

quoted, by the **LEP EWWG**, that follows from taking the average of the Born result with the one corrected via s-channel **SF**, where $\mathrm{SF}(t, p^2_{tW}) > \mathrm{SF}(s)$ by $+5\%$ **at** 200 GeV and Born $> \mathrm{SF}(s)$ **by** $+12\%$. Note, however, that this is not a real estimate of **uncertainty** but just a pragmatic way of determining the effects of **ISR**.

△ Implementation of the EFL-scheme in **single**-W (in addition to `WTO`) will give a more solid basis to the estimate of $1 \div 2\%$ for the **uncertainty** associated with the scale of the e.m. coupling.

△ The next, obvious, step is represented by the evaluation of missing $\mathcal{O}(\alpha)$ electroweak effects, e.g. in **Weizsäcker-Williams** approximation (for the sub-process $\mathrm{e}\gamma \to \mathrm{W}\nu_{\mathrm{e}}$), the analogous of **DPA** for **CC03**.

△ A better understanding of **QED ISR** and of all radiative corrections in **single**-W production is certainly needed in order to reduce the corresponding **uncertainty**, hopefully around 1%.

- This, however, requires to go beyond the present approximations, not an easy task and with a considerably large experimental error.

- Since **DPA** cannot be applied to **single**-W production one has to follow some alternative path, like including radiative corrections in (improved) **Weizsäcker-Williams** approximation, or **WWA**. It is expected that already the normal **WWA** (i.e. logarithmic terms only), with a typical Born accuracy of 5%, will yield results accurate at the level of 5% $\times\ \alpha/\pi$.

- For the moment this is not strictly needed but one should consider that **single**-W will be one of the major processes at LC.

DETAILS OF ZZ-SIGNAL

- △ For **NC02** we have a 1% variation, obtained by changing the **IPS** in `GENTLE` and in `ZZTO` and by varying from the standard `GENTLE` approach for **ISR** to the complete lowest order corrections. We estimate the real **uncertainty** to be 2%.

- △ Given the experimental **uncertainty** a **th. uncertainty** in this order is acceptable and does not seem to require the implementation of missing effects.

- △ **ZZTO** which is a **FL** calculation agrees rather well with **YFSZZ**, (leading pole approximation on $\mathcal{O}\left(\alpha^2\right)$ **LL YFS** exponentiation) roughly below the **DPA** accuracy of 0.5%