New Results On Precision Studies of Heavy Vector Boson Physics

B.F.L. Ward

Department of Physics, Baylor University

Waco, TX, USA

Outline:

- **Introduction**
- **Virtual Corrections to Hard Bremsstrahlung**
- **Electric Charge Screening Effects in 1W Production**

Papers by C. Glosser *et al.*, S. Jadach *et al.*, hep-ph/0406298; EPJ**C27**:19-32,2003; and references therein - CG,SJ,WP,MS,BFLW,ZW,SY

Motivation

- SM $\mathcal{O}(\alpha)$ EW LOOP CORR.('T HOOFT&VELTMAN) ESTABLISHED:
  PRECISION LEP PHYSICS, $m_t, \cdots$
- STAGE SET: 1GeV - 1TeV, HIGH PRECISION
  TESTS(SIGNAL)/PREDICTIONS(BACKGRD)
  $\Rightarrow$ EXACT $\mathcal{O}(\alpha^2)$, $\mathcal{O}(\alpha^3 L^3)$
  ON AN EVENT-BY-EVENT BASIS:
  RAD. RETURN FROM 1-2GEV to $\pi\pi$ RESONANCE REGIME IN DAPHNE,
  RAD. RETURN FROM 200GeV to Z IN FINAL LEP2 DATA ANALYSIS,
  Z FACTORY AT LC, ...
- TODAY, WE PRESENT NEW RESULTS ON TWO ASPECTS:
  1. VIR. CORR. TO 1γ BREMSSTRAHLUNG
  2. ELECTRIC CHARGE SCREENING IN $1W$ PRODUCTION,
  SEE ALSO PASSARINO,NP**B578**(2000)3;**B619**(2001)313, & REFS. THEREIN

PRELIMINARIES

- WE USE THE GPS CONVENTIONS OF JWW FOR SPINORS.
- PHOTON(-GLUON) POLARIZATION VECTORS FOLLOW THEREFROM:

$$(\epsilon^{\mu}_{\sigma}(\beta))^* = \frac{\bar{u}_\sigma(k)\gamma^\mu u_\sigma(\beta)}{\sqrt{2}\ \bar{u}_{-\sigma}(k)u_\sigma(\beta)}, \quad (\epsilon^{\mu}_{\sigma}(\zeta))^* = \frac{\bar{u}_\sigma(k)\gamma^\mu \mathfrak{u}_\sigma(\zeta)}{\sqrt{2}\ \bar{u}_{-\sigma}(k)\mathfrak{u}_\sigma(\zeta)}, \tag{1}$$

Virtual Corrections to Hard Bremsstrahlung

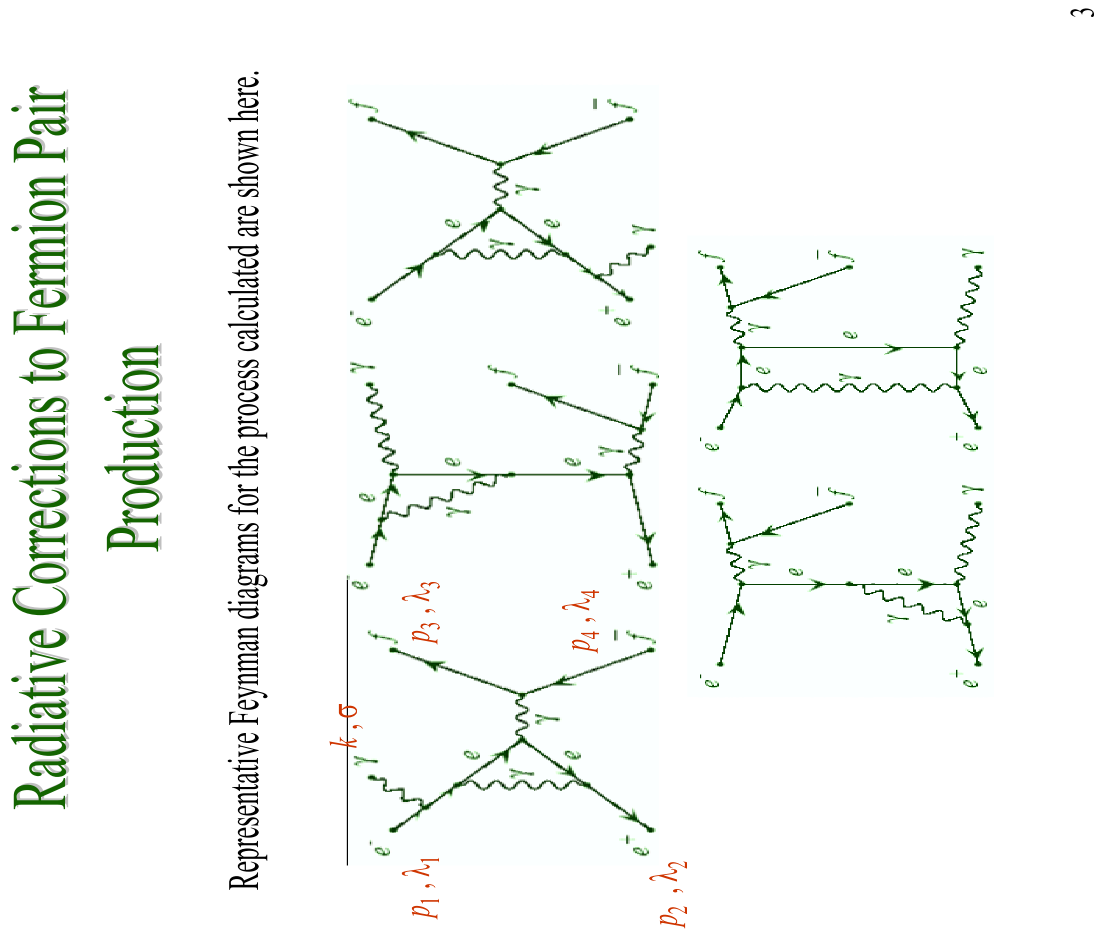


FIG. 1.

Computational Method

The graphs shown were calculated by S. Jadach, M. Melles, B.F.L. Ward and S. Yost in *Phys. Rev.* **D65**, 073030 (2002), based on earlier results for the corresponding *t*-channel graphs by the same authors, *Phys. Lett.* **B377**, 168 (1996).

The results were obtained using

- Helicity spinor methods
- Vermaseren's algebraic manipulation program FORM
- Oldenborgh's FF package of scalar one-loop Feynman integrals (later replaced by analytic expressions)
- Mass corrections added via methods of Berends *et al* (CALCUL Collaboration), which were checked to show that all significant collinear mass corrections were included

Mass Corrections

Mass corrections were added following Berends, *et al* (CALCUL collaboration). We checked that all significant mass corrections are obtained in this manner.

The most important corrections for a photon with momentum k radiated collinearly with each incoming fermion line p_1 and p_2 are added via the prescription

$$\left|\mathcal{M}_{1_\gamma}^{(m)}\right|^2 = -\sum_i \frac{e^2 m_e^2}{p\cdot k}\left|\mathcal{M}_{\rm Born}(p_i - k)\right|^2$$

At the cross-section level, the net effect is that the spin-averaged form factor f_0 receives an additional mass term

$$\begin{aligned}\langle f_0\rangle^m &= \frac{2m_e^2}{s}\left(\frac{r_1}{r_2}+\frac{r_2}{r_1}\right)\frac{z}{(1-r_1)^2+(1-r_2)^2} \\ &\times \left\{\langle f_0\rangle + \ln\left(\frac{s}{m_e^2}\right)(\ln z - 1) - \frac{3}{2}\ln z + \frac{1}{2}\ln^2 z + 1\right\}\end{aligned}$$

Comparisons

IN Igarashi and Nakazawa, *Nucl. Phys.* **B288** (1987) 301

- spin-averaged cross section, fully differential in r_1 and r_2, no mass corrections

BVNB Berends, Van Neerven and Burgers, *Nucl. Phys.* **B297** (1988) 429

- spin-averaged cross section, differential only in $v = r_1 + r_2$, includes mass corrections

KR Kuhn and Rodrigo, *Eur. Phys. J.* **C25** (2002) 215

- spin-averaged Leptonic tensor, fully differential in r_1 and r_2, includes mass corrections

The **KR** comparison is new, and closest to our calculation in its assumptions.

The New Comparison

The new comparison is to the leptonic tensor of Kuhn and Rodrigo, which was constructed for radiative return in hadron production, but can be adapted to fermion pairs by changing the final state tensor. The form of the cross section in this case is

$$\left|\overline{\mathcal{M}_i^{\mathrm{ISR}(1)}}\right|^2 = \frac{1}{4ss'r_1r_2} L_i^{\mu\nu} H_{\mu\nu}$$

with Leptonic tensor

$$L_i^{\mu\nu} = a_{00}^{(i)} \eta^{\mu\nu} s + a_{11}^{(i)} p_1^\mu p_1^\nu + a_{22}^{(i)} p_2^\mu p_2^\nu + a_{22}^{(i)} (p_1^\mu p_2^\nu + p_2^\mu p_1^\nu) + i\pi a_{-1}^{(i)} (p_1^\mu p_2^\nu - p_2^\mu p_1^\nu)$$

and final state tensor (for our problem)

$$H^{\mu\nu} = 4e^2 (p_3^\mu p_4^\nu + p_4^\mu p_3^\nu - p_3 \cdot p_4 \eta^{\mu\nu})$$

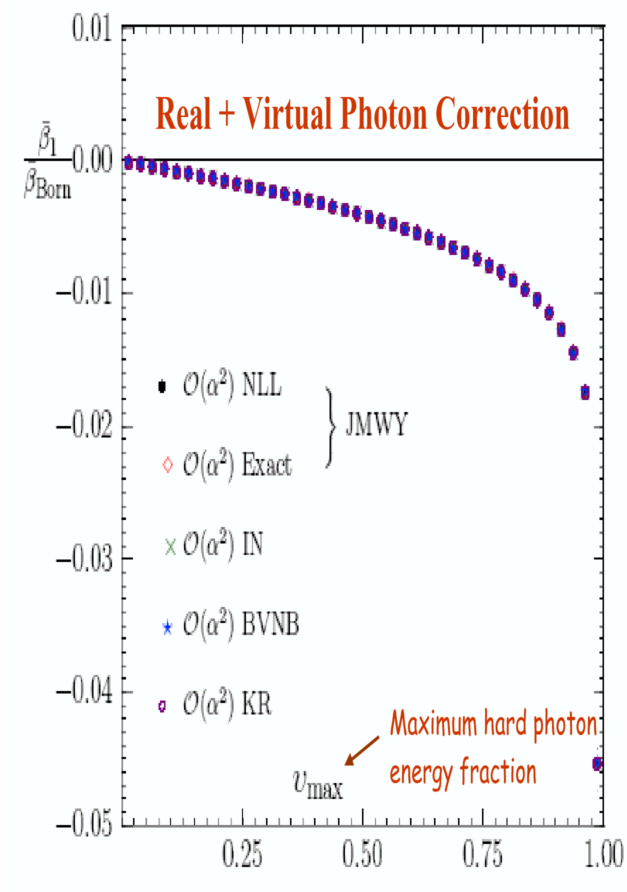
For comparisons, the YFS infrared term is subtracted. The coefficient functions a_{ij} must be calculated very carefully to obtain stable collinear limits.

Monte Carlo Results

Results of a KK Monte Carlo run with 10^8 events at $E_{CMS} = 200$ GeV.

This figure shows the complete real + virtual photon radiative correctionto muon pair production.

The standard YFS infrared term $4\pi B_{YFS}$ has been subtracted to create a finite result.



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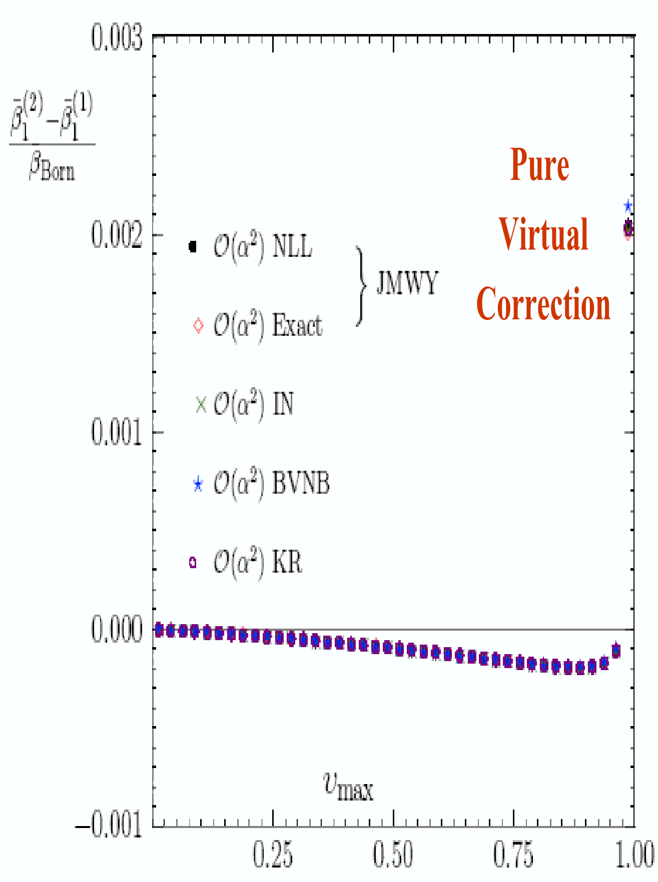
Monte Carlo Results

Results of a KK Monte Carlo run with 10^8 events at $E_{CMS} = 200$ GeV.

This figure shows only the pure virtual photon correction to single hard bremmstrahlung.

The standard YFS infrared term $4\pi B_{YFS}$ has been subtracted to create a finite result.



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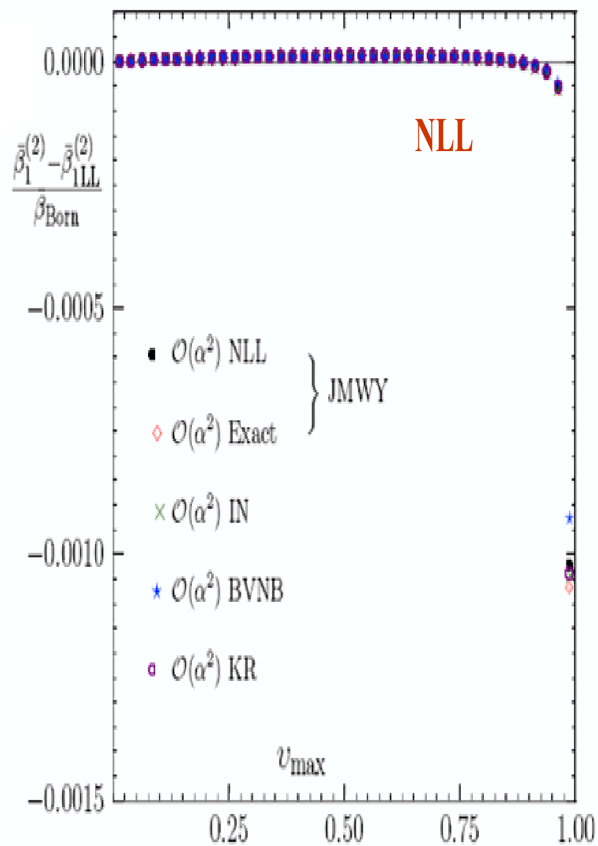
Monte Carlo Results

Results of a KK Monte Carlo run with 10^8 events at $E_{CMS} = 200$ GeV.

This figure shows the next to leading log (NLL) contribution to the real + virtual photon cross section.

The leading log (LL) contribution has been subtracted from each expression.



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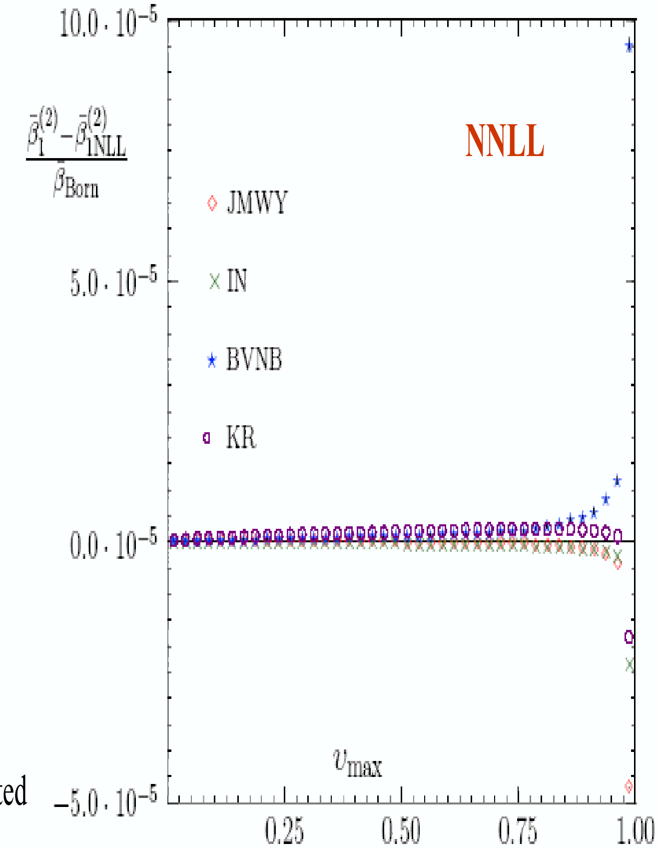
Monte Carlo Results

Results of a KK Monte Carlo run with 10^8 events at $E_{CMS} = 200$ GeV.

This figure shows the sub-NLL contribution to the real + virtual photon correction to muon pair production

The NLL expression of JMWY has been subtracted in each case to reveal the NNLL contributions.



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Summary

- The size of the NNLL corrections for all of the compared "exact" expressions is less than 2x10^{-6} in units of the Born cross section for photon energy cut $v_{max} < 0.75$.
- For $v_{max} < 0.95$ (5 Gev photon), all the results except BVNB agree to within 2.5x10^{-6} of the Born cross ection.
- For the final data point, $v_{max} = 0.975$ (2.5 Gev photon), the KR and JMWY results differ by 3x10^{-5} of the Born cross ection.
- These comparisons show that we have a firm understanding of the precision tag for an important part of the order α^2 corrections to fermion pair production in precision studies of the final LEP2 data analysis, radiative return at Φ and B-factories, and future NLC physics.

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Electric Charge Screening Effects in 1W Production

- **Electric Charge Screening(ECS)/Leading Log Scale Transmutation(LLST): Known From Low Angle Bhabha Scattering –** $L(s) \equiv ln\frac{s}{m_e^2} \Rightarrow L(|t|)$.
- **In the toy model**

$$\mu^-(p_a) + \mu^+(p_b) \rightarrow \mu^-(p_c) + \mu^+(p_d) + \gamma(k), \quad (2)$$

we illustrate the effect already in the following plot:

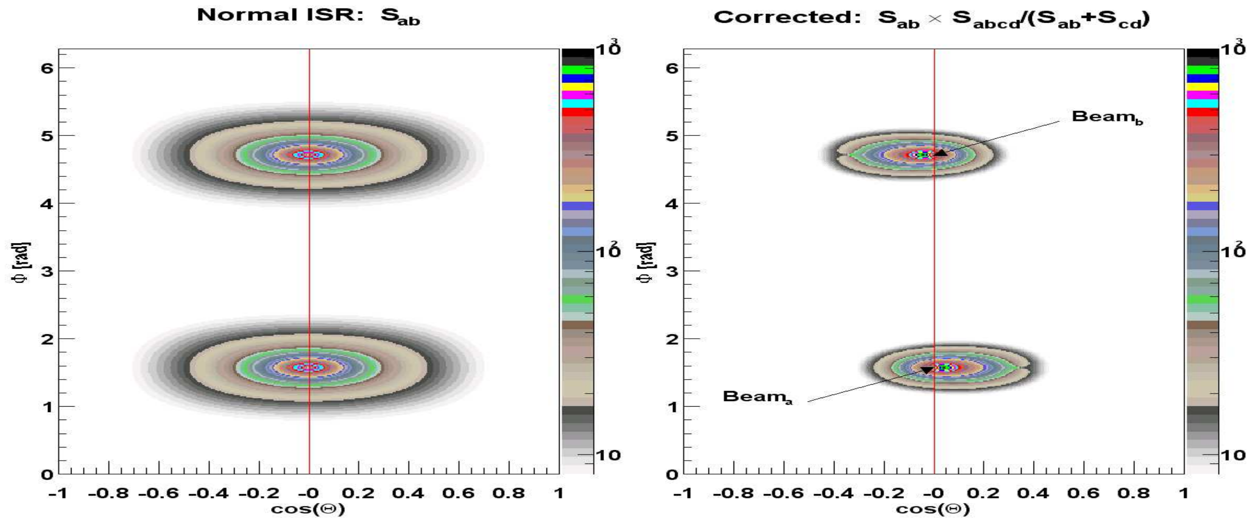

Figure 4: Photon angular distribution in "Mhamha scattering" $\mu^-\mu^+ \to \mu^-\mu^+\gamma$ at $\sqrt{s} = 5$ GeV and muon scattering angle of 20° for the case of ISR only. The difference between left- and right-hand side plots shows the effect of the ECS correction weight.

Here, we plot the ECS Corrected Weight

$$\tilde{S}_{ab}(k) W_{\rm ECS}(k) \tag{3}$$

and the ISR IR Emission Factor $\tilde{S}_{ab}(k)$

where

$$W_{\rm ECS}(k) = \frac{\tilde{S}_{abcd}(k)}{\tilde{S}_{ab}(k) + \tilde{S}_{cd}(k)}, \tag{4}$$

- For the Single W Production $e^- e^+ \to f_c(p_c) + \bar{f}_d(p_d) + f_e(p_e) + \bar{f}_f(p_f)$ we find that we can do the same:

$$W^{real}_{\rm ECS} = \prod_i w^R(k_i), \quad w^R(k) = \frac{\tilde{S}_{ab}(k) + \tilde{S}_{CD}(k) + \tilde{S}_{aC}(k) + \tilde{S}_{bD}(k) + \tilde{S}_{aD}(k) + \tilde{S}_{bC}(k)}{\tilde{S}_{ab}(k) + \tilde{S}_{CD}(k)}. \tag{5}$$

for the effective final particles 'C' and 'D' close to the incoming beams, as we illustrate in the following figure. The factor $\exp(\Delta U)$ cancels *exactly* the ϵ-dependence and compensates *approximately* for the normalization change due to the $\langle W^{real}_{\rm ECS} \rangle$ weight. The effective coupling is also that at $|t|$, by standard RG arguments.

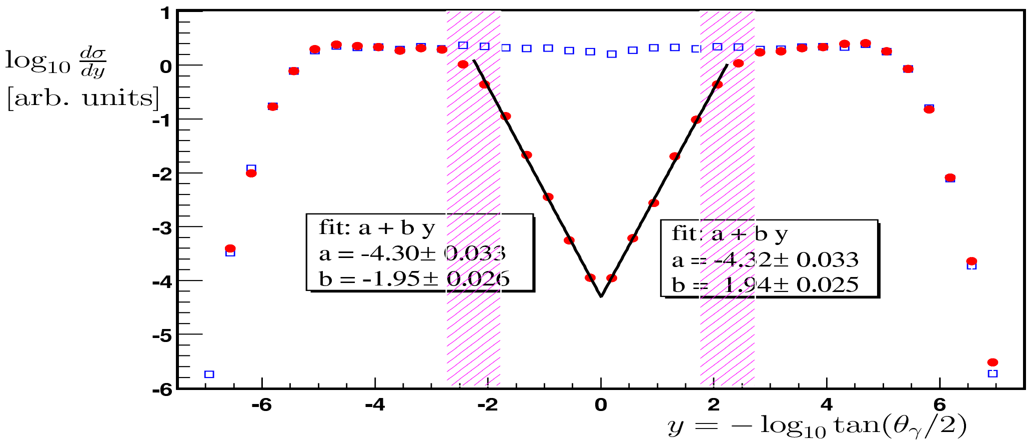

Figure 5: $\log_{10}$ of $d\sigma/d\log_{10}\tan(\theta_\gamma/2)$ with (red dots) and without (blue open squares) the ECS correction, arbitrary units. In boxes the values of fits are shown.

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This requires the NORMALIZATION CORRECTION

$$W_{ECS}^{norm} = \exp\left(\frac{3}{4}(\bar{\gamma}_t - \gamma_s)\right)\exp\left(\Delta U(\epsilon)\right)$$

$$\Delta U(\epsilon) = U(\epsilon) - U_R(\epsilon), \quad U(\epsilon) = \int_{\epsilon\sqrt{s}/2}^{\sqrt{s}} \frac{d^3k}{k^0}\tilde{S}_{ab}(k), \quad U_R(\epsilon) = \int_{\epsilon\sqrt{s}/2}^{\sqrt{s}} \frac{d^3k}{k^0}\tilde{S}_{ab}(k)w^R(k). \tag{6}$$

to maintain the exact IR CANCELLATION in the MC (KoralW, for example).

SUMMARY

- The only purpose of the weight $W_{\rm ECS}^{real}$ is to restore the ECS effect due to ISR$\otimes$FSR interference.
- We do not aim at re-creating the FSR. This would be formally possible with a similar weight; however, it would lead to an awful weight distribution and a non-convergent MC calculation.
- We get $W_{\rm ECS}^{real} \to 1$ for photons collinear with the FS effective fermions C and D. This ensures a very good weight distribution.
- The FSR can be treated separately, either inclusively (calorimetric acceptance) or exclusively, generated with the help of PHOTOS[a].
- Precision Tag of $\leq 2\%$ IS Realized – Good Enough For Final LEP2 Data Analysis.

[a] Care has to be taken to implement ECS for FSR, if necessary.