On Theoretical Uncertainties of the W Mass Measurement

WIESŁAW PŁACZEK
Jagiellonian University, Kraków, Poland

In collaboration with:

S. JADACH, M. SKRZYPEK, B.F.L. WARD, Z. WĄS

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Outline:

- **Introduction.**
- **Fitting.**
- **Semi-quntitative estimates.**
- **Conclusions.**

Introduction

- $\mathbf{M_W}$ **at LEP2 measured by direct fit to** $\mathbf{W}$ **invariant mass distribution**:

  Level-1: Constrained kinematic fit $\Rightarrow$ two $\mathbf{W}$ invariant masses $+$ auxiliary parameters (controlling the detector energy resolution, etc.)

  Level-2: Actual $\mathbf{M_W}$ fit using MC Event Generator (ALEPH, L3, OPAL) or analytical function (DELPHI)

- **Final LEP2 Experimental Precision:** $\mathbf{\Delta M_W \simeq 30}$ **MeV**

- **Theoretical Untertainty (TU) should be:** $\mathbf{\leq 15\,(10)}$ **MeV**

- **Missing detailed study on TU of** $\mathbf{M_W}$ **(before this work)**

  $\Rightarrow$ **TU of** $\mathbf{M_W}$ **is almost completely independent of TU on** $\sigma_{\mathbf{WW}}$ (studied in detail during 2000 LEP2 MC Workshop, cf. Report CERN 2000-009)

Fitting

Assumptions:

- **Semileptonic process:** $\mathbf{e^+e^- \to W^+W^- \to u\bar{d}\mu^-\bar{\nu}_\mu}$
- **Parton level with simplified cuts/acceptances**
- **One-dimensional fit of a single $\mathbf{W}$ invariant mass**
- **Mass of $\mathbf{W^-} \to \mu^-\bar{\nu}_\mu$ considered**
- **Invariant mass distributions from MCs:** **YFSWW3-KoralW** **(Jadach et al.)** **and** **RacoonWW** **(Denner et al.)**
- **Fitting function (FF) from semi-analytical program** **KorWan** **(Jadach et al.)**

Notation:

Born – Born level

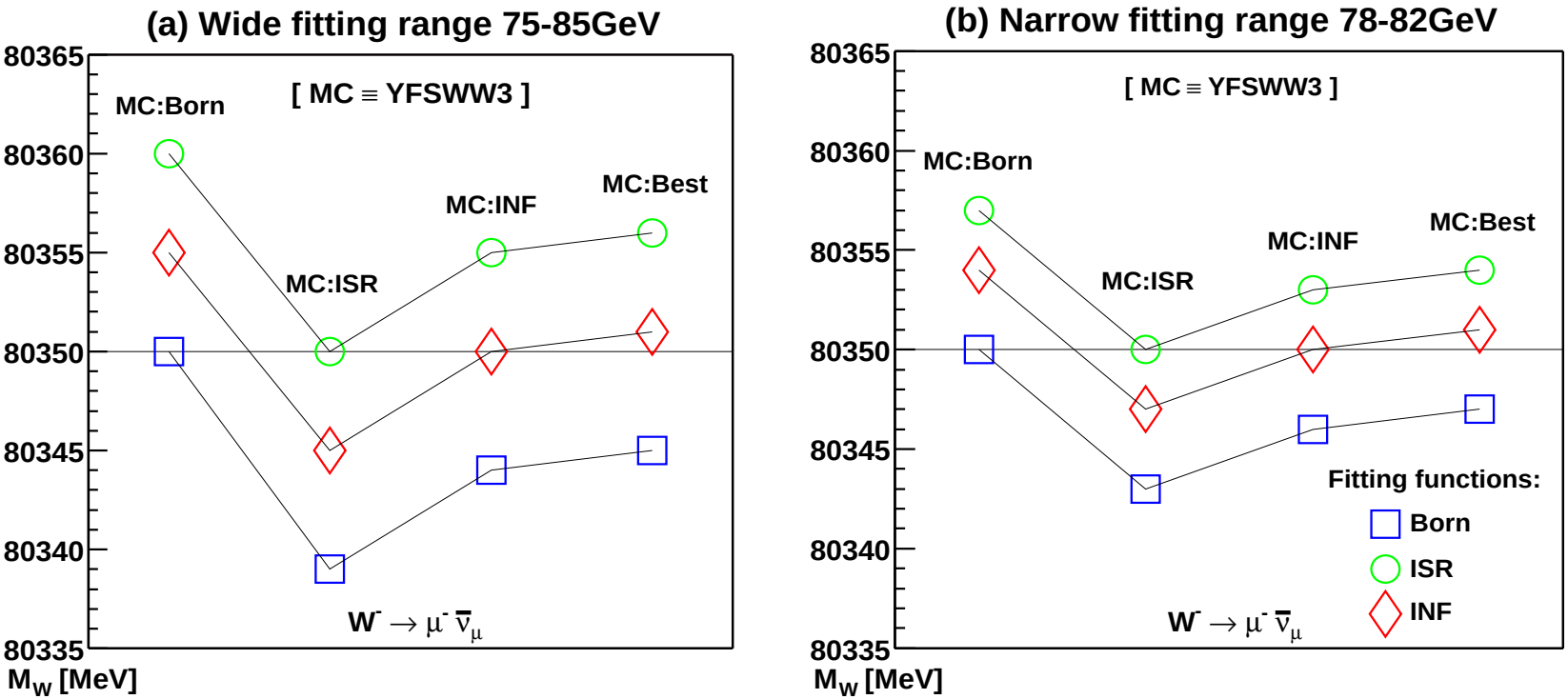
ISR – $\mathcal{O}(\alpha^3)$ LL YFS exponentiation for ISR and Coulomb correction

INF – the above plus non-factorizable corrections (NF) in the inclusive approx. of Chapovsky & Khoze (“screened” Coulomb ansatz)

Best – best predictions from YFSWW3, i.e. all the above plus the $\mathcal{O}(\alpha^1)$ EW non-leading (NL) corrections (Fleischer et al.)

Fitting

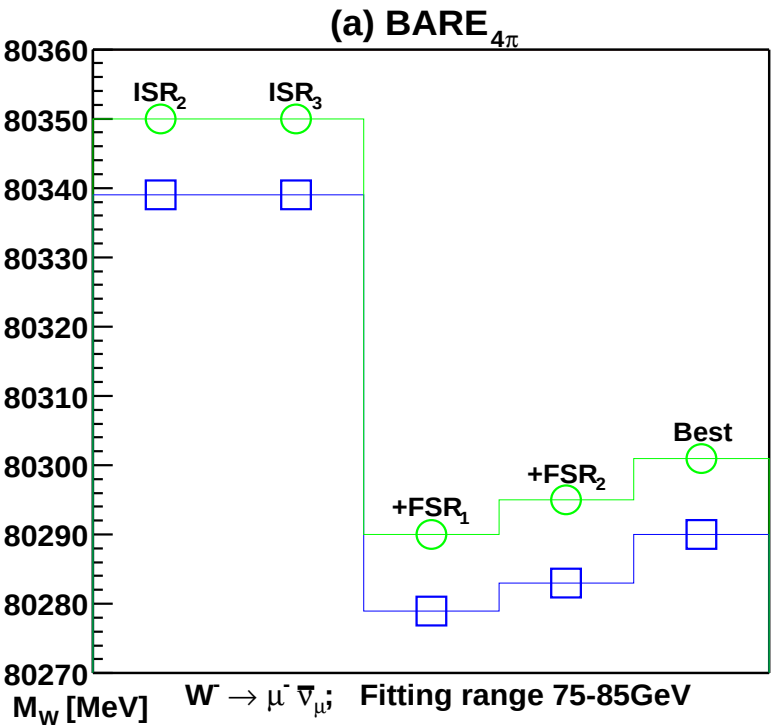
"Calibration" fits (No Cuts):

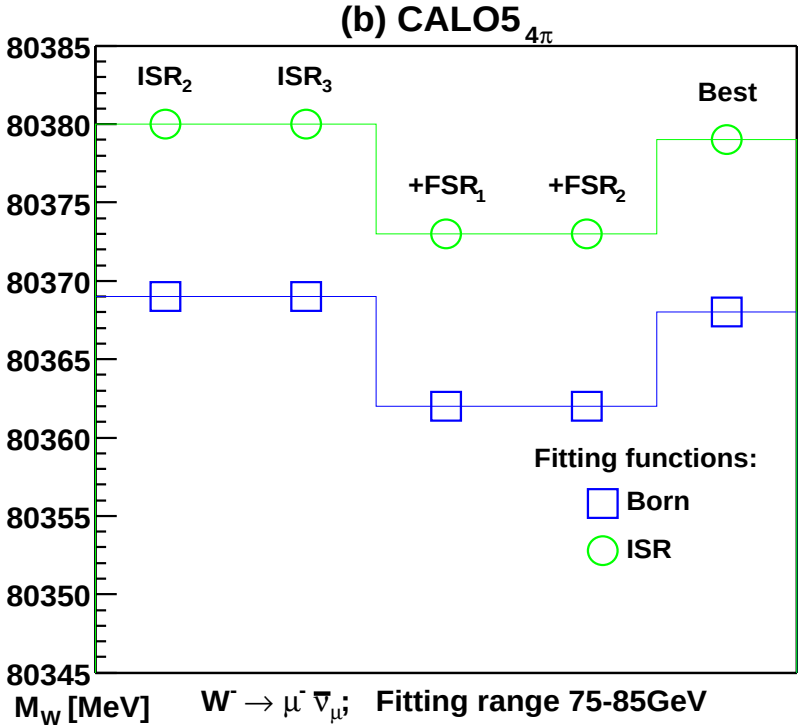


- The fitted $\mathrm{M_W}$ exactly agrees with the input $\mathrm{M_W}$ in the case when the same effects are included both in FF and the MC.
- If one is interested only in the shift of $\mathrm{M_W}$, then any FF can be used.
- The size of the ISR effect is about -10 MeV, that of the INF about $+5$ MeV, and the size of the NL corrections ~ 1 MeV (negligible!).

Fitting

Effects of ISR and FSR on M_W:





Acceptances:

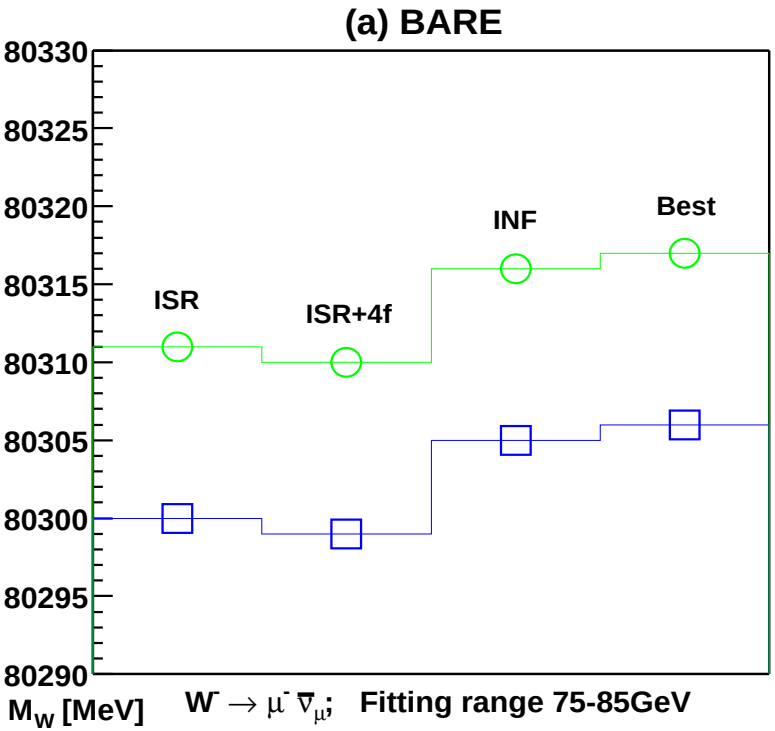
BARE$_{4\pi}$ – "bare" parton level with full solid-angle coverage

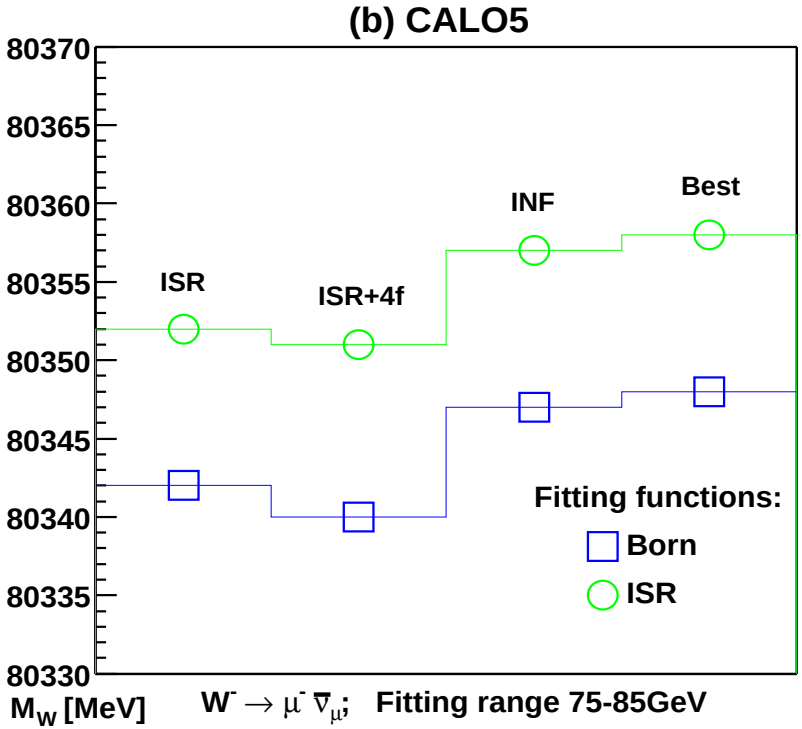
CALO5$_{4\pi}$ – photons for which the invariant mass with a final-state charged fermion was < 5 GeV were recombined with that fermion

→ **FSR** from **PHOTOS** (Wąs et al.)

Fitting

Effects of $4f$ background on M_W:





Acceptances: (2000 LEP2 MC Workshop)

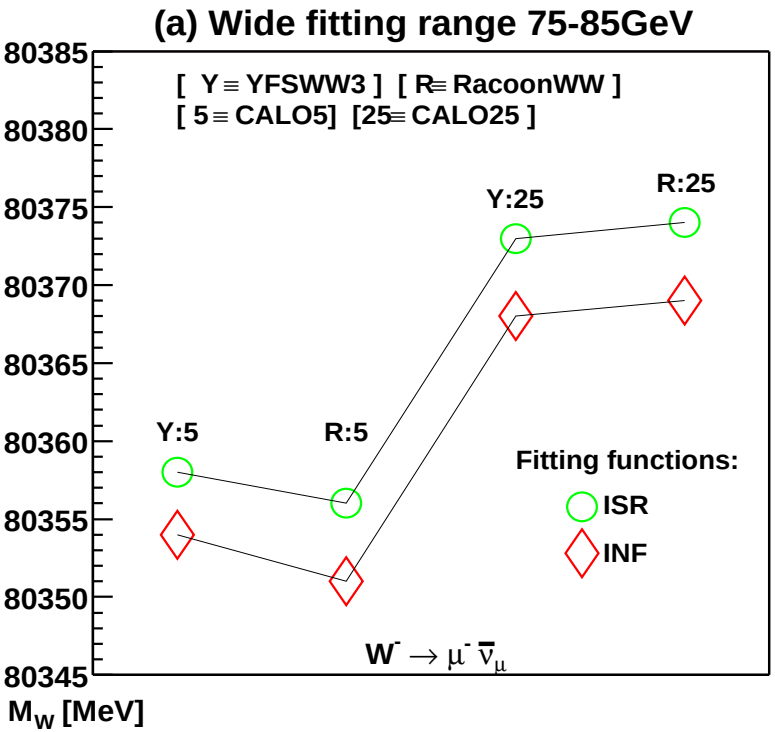
1. $\theta_{f_{ch}} > 10°$; 2. $\theta_\gamma > 5°$;

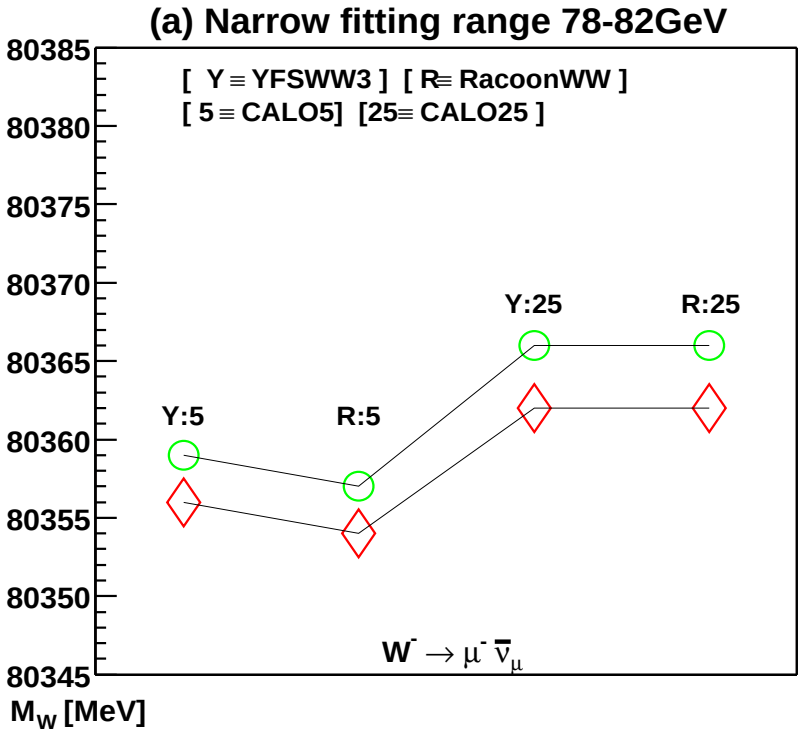
3. $M_{rec}^{\gamma f} \leq$

0 GeV:	**BARE**
5 GeV:	**CALO5**
25 GeV:	**CALO25**

Fitting

Comparison of YFSWW3 and RacoonWW:





- The comparison of **YFSWW3** with **RacoonWW** is very interesting because the two calculations differ in almost every aspect of the implementation of the ISR, FSR, NL and NF corrections.
- The results of **YFSWW3** and **RacoonWW** differ, in terms of the fitted mass, by only ≤ 3 **MeV**, slightly more for **CALO5** than for **CALO25**.

Semi-quntitative estimates

Estimation of the missing effects in the K-Y MC tandem:

ΔM_W			
Error Type	Scale Param. $\Delta M_W = \Gamma \times \epsilon$	Numerical cross-check	ΔM_W
WW production			
ISR $\mathcal{O}(\alpha^4 L_e^4)$	$\epsilon \simeq \frac{\Gamma_W M_W}{s\beta_W^2}\left(\frac{\alpha}{\pi}\right)^4 L_e^4 \sim 5\cdot 10^{-6}$	$[\mathcal{O}(\alpha^3 L_e^3) - \mathcal{O}(\alpha^2 L_e^2)]_{\mathrm{KoralW}}$	$\ll 1$ MeV
ISR $\mathcal{O}(\alpha^2 L_e)$	$\epsilon \simeq \frac{\Gamma_W M_W}{s\beta_W^2}\left(\frac{\alpha}{\pi}\right)^2 L_e \sim 5\cdot 10^{-6}$	KorWan	$\ll 1$ MeV
ISR $\mathcal{O}(\alpha^2)_{pairs}$	$\epsilon \simeq \frac{\Gamma_W M_W}{s\beta_W^2}\left(\frac{\alpha}{\pi}\right)^2 L_e^2 \sim 4\cdot 10^{-4}$	KorWan	< 1 MeV
W decay			
FSR $\mathcal{O}(\alpha)_{miss.}$	$\epsilon \simeq 0.2\left(\frac{\pi}{8}\frac{\alpha}{\pi} 2\ln\frac{M_W}{p_T}\right) \sim 10^{-3}$	Basic tests of PHOTOS	~ 2 MeV
FSR $\mathcal{O}(\alpha^2)_{miss.}$	$\epsilon \simeq \frac{1}{2}\left(\frac{\pi}{8}\frac{\alpha}{\pi} 2\ln\frac{M_W}{p_T}\right)^2 \sim 10^{-5}$	On/off 2γ in PHOTOS	$\ll 1$ MeV
Non-factorizable QED interferences (between production and 2 decays)			
$\mathcal{O}(\alpha^1)^{inclusive}_{miss.}$	$\epsilon \simeq 0.1\left(\frac{\alpha}{4}\frac{(1-\beta)^2}{\beta}\right) \sim 10^{-4}$	Chapovsky & Khoze	< 1 MeV
$\mathcal{O}(\alpha^2)^{inclusive}$	$\epsilon \simeq \frac{1}{2}\left(\frac{\alpha^2}{4}\frac{(1-\beta)^2}{\beta}\right)^2 \sim 10^{-7}$	None	$\ll 1$ MeV

- **TU due to LPA: $\Delta \mathrm{M_W} = 1$ MeV (LPA options in YFSWW3)**

Conclusions

- **The Electroweak Theoretical Uncertainty in $\mathbf{M_W}$ of the KoralW-YFSWW3 MC tandem at LEP2 energies is $\boxed{\sim 5}$ MeV**

  (< 10 MeV – targeted TU for LEP2)

- **The above conclusion is strengthened by the smallness of the differences between YFSWW3 and RacoonWW (≤ 3 MeV).**

  We attribute it to the standard *factorizable* corrections (ISR, FSR, etc.) and purely technical/numerical effects.

- **In the above estimate we included a "safety factor" of 2, corresponding to the fact that our fits of $\mathbf{M_W}$ were done for 1-dimensional effective $\mathbf{W}$ mass distributions.**

  In order to eliminate it, our analysis should be repeated for the realistic measurements of the LEP2 experiments.