ZFITTER and LHC physics

for the ZFITTER collaboration [∼1985 - 2012]
http://zfitter.com

Tord Riemann

DESY, Zeuthen, Germany

page 23 changed after presentation

https://indico.desy.de/conferenceDisplay.py?confId=4362

Talk held at 6th Annual Workshop of the Helmholtz Alliance "Physics at the Terascale"
3 –5 December 2012, DESY, Hamburg, Germany

20 years after

The first published version of ZFITTER was in 1992, in hep-ph 2 years later [1, CERN-TH-6443-92,hep-ph/9412201]

http://en.wikipedia.org/wiki/The_Three_Musketeers – D'Artagnan is not one of the musketeers of the title; those are his friends Athos, Porthos, and Aramis, inseparable friends who live by the motto "all for one, one for all"

20 years are a long term.

http://en.wikipedia.org/wiki/Twenty_Years_After

The Beatles cooperated about 7 years
http://en.wikipedia.org/wiki/The_Beatles

CERN-TH. 6443/92

ZFITTER

An Analytical Program for Fermion Pair Production in e^+e^- Annihilation

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[8] University of California, San Diego, USA

Abstract

We describe how to use ZFITTER, a program based on a semi-analytical approach to fermion pair production in e^+e^- annihilation and Bhabha scattering. A flexible treatment of complete $\mathcal{O}(\alpha)$ QED corrections, also including higher orders, allows for three calculational **chains** with different realistic sets of restrictions in the photon phase space. ZFITTER consists of several **branches** with varying assumptions on the underlying hard scattering process. One includes complete $\mathcal{O}(\alpha)$ weak loop corrections with a resummation of leading higher-order terms. Alternatively, an ansatz inspired from S-matrix theory, or several model-independent effective Born cross sections may be convoluted. The program calculates cross sections, forward-backward asymmetries, and for τ pair production also the final-state polarization. Various **interfaces** allow fits to be performed with different sets of free parameters.

† Alexander-von-Humboldt Fellow
‡ Partly supported by the German Bundesministerium für Forschung und Technologie

CERN-TH. 6443/92

Hunting the Standard Model Higgs Boson → LHC

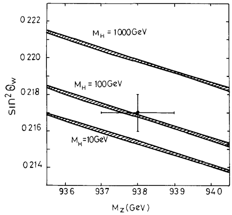
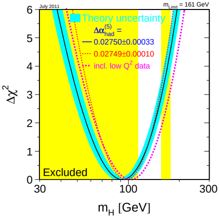


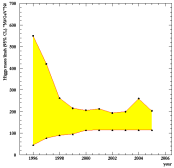
Fig 1 Graph of $\sin^2\theta_W$ versus M_Z, influenced by M_H through radiative corrections The thickness corresponds to the range 30 GeV $\leqslant m_t \leqslant$ 40 GeV, the error bars indicate the accuracy expected at Z boson factories.



1993 – 2011 by LEPEWWG

Quotations: 1 in 1986, 1 in 2012

⟵ Akhundov, Bardin, T.R. [2, Akhundov:1985cf]



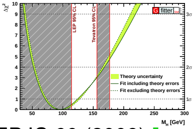
upper limits on M_H:

indirect searches

lower limits on M_H:

direct searches

[3, SRiemann:2012xx]



EPJC 60 (2009) **[competitors]**,
[4, Bardin:1999yd], [5, Arbuzov:2005ma]

Why this talk? (I)

There are folks around distributing rumors like
. . . those found in a diploma thesis in 2008 . . . **we quote from there:**

"**Several fit programs** exist to extract ... electroweak precision measurements and lots of results have been published in the past.

The most prominent fitting packages are **ZFitter** [1, 2] and **TOPAZ0** [3, 4].

However,

- **the present situation is unsatisfactory**.

Most programs are . . .

- **relatively old**,
- **coded in Fortran** and
- **no longer maintained**.

This makes it

- **dangerous to rely on them** in the LHC and later ILC times when they are still needed..."

Why this talk? (II)

There are two immediate applications where ZFITTER is useful

- **Global fits** in the Standard Model
- **New Physics searches** on top of the Standard Model

Precise predictions

- **Drell-Yan** processes at LHC:
  $q\bar{q} \to (\gamma, Z, \cdots) \to l^+ l^-$
- **Two-fermion** production:
  – at meson factories $[a_\mu]$
  – at ILC, w or w/o GigaZ:
  $e^+ e^- \to (\gamma, Z, \cdots) \to l^+ l^-$

“The ZFITTER approach” in a nutshell

- **Social aspects:**
  – Kind of open source status
  – Personal copyrights
  Aserbaidshan, Bulgaria, Czechia, (East) Germany, Russia, etc.
  – Licence (Comput. Phys. Commun. 1989, 2000, 2005)
  – Interactions with users
  – Interfaces
- – **QED corrections** were handled strictly semi-analytically
- – **Weak corrections** described by four process-dependent form factors
- – **Strict modular structure**

- **The ZFITTER project is probably the first ‘open-source project’ for the calculation of precision cross-sections in high energy physics**
- **ZFITTER software was not made for use by its authors, but by users**
- **Support over more than 25 years**

The ZFITTER approach in a nutshell

ZFITTER is a library of QED and Standard Model predictions for

$$e^+e^- \to \bar{f}f \quad (+\gamma, \quad +n\,\gamma)$$

at energies in the range $\sqrt{s} \approx$ **20 GeV to 150 GeV**
above quark bound states [meson factories] and below the top threshold

ZFITTER

→ is to be called by **Interfaces**

→ in the Standard Model, or in a model-independent approach, or with Z' bosons etc.

→ which may evaluate the **(pseudo-) observables of interest**:

$$M_Z, \quad \Gamma_Z, \quad \sigma^{tot}_{had}, \quad R_{had}, \quad A^{lept}_{FB}, \quad \lambda_\tau, \quad etc.$$

or

$$M_Z, \quad M_W, \quad m_{top}, \quad M_H, \quad etc.$$

or

$$\text{running weak mixing angle} \quad \sin^{2,eff}_{ew}, \quad etc.$$

ZFITTER Authors (1976–2012) and ZFITTER Support Group (2005)

ZFITTER authors, longest list:

(blue: the actual "main" authors)

A. Akhundov, **A. Arbuzov**, M. Awramik, **D. Bardin**, M. Bilenky, A. Chizhov, **P. Christova**, M. Czakon, O. Fedorenko (1951-1994), A. Freitas, M. Grünewald, M. Jack, **L. Kalinovskaya**, **A. Olshevsky**, **S. Riemann**, **T. Riemann**, M. Sachwitz, A. Sazonov, Yu. Sedykh, I. Sheer, L. Vertogradov, H. Vogt **et al.**

ZFITTER support group:

Founded in 2004/2005 after D. Bardin finished active support of ZFITTER [5, Arbuzov:2005ma]
Closed January 2012

Spokesperson 2004 – 2012: T.R.

ZFITTER group – meeting in July 2012 at JINR, Dubna, Russia:
Lida, Pena, Dima, Tord, Sabine, Andrej.

Also: Sacha, Arif

ZFITTER Approach to QED corrections

- Real emission: Subtraction method for IR handling [6, Bardin:1976qa]

  and also [7, Passarino:1982zp] for clever analytical cuts
- Analytical formulae with cuts for cross sections in $e^+e^- \to f^+f^-(+n\gamma)$:

$$\frac{1}{|s - M_Z^2 + iM_Z\gamma_Z|^2} \sim \frac{i}{2M_Z\Gamma_Z}\left(\frac{1}{s - M_Z^2 + iM_Z\Gamma_Z} - \frac{1}{s - M_Z^2 - iM_Z\Gamma_Z}\right)$$

- Many ZFITTER references $\to$ see backup transparencies

Sirlin's approach to N.C. matrix elements – two form factors ρ and κ

The notion of form factors ρ and κ in the weak neutral current were, to our knowledge, introduced by **A. Sirlin**:

- ρ – contains the electroweak corrections to the Fermi constant G_F
- κ – contains the electroweak corrections to the weak mixing angle $\sin^2\theta_W$

This approach allows to retain in the on-mass-shell renormalization scheme the Born definitions also in higher orders:

$$G_F^{eff} = \rho_Z \, G_F$$
$$\sin^2\theta_W^{eff} = \kappa_Z \, \sin^2\theta_W$$

where

$$\frac{G_F}{\sqrt{2}} = \frac{g^2}{8M_W^2}$$
$$\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2}$$

ZFITTER approach to effective Born cross sections – four form factors: one ρ and three κ's I

For general scattering amplitudes, describing e.g. two-fermion scattering, one needs a more general description.

This was first introduced, to our knowledge, by the Dubna/Zeuthen group.

1988/1989

"Electroweak Radiative Corrections To Deep Inelastic Scattering At Hera. Neutral Current Scattering"
D. Bardin, C. Burdik (Dubna), P. Khristova (Shoumen), T. Riemann (Zeuthen)
Z. Phys. C42 (1989) 679, Zeuthen preprint PHE-88-15
We use four form factors $\rho, \kappa_{ini}, \kappa_{fin}, \kappa_{inifin}$ for the parameterization of the weak amplitude, including *WW* and *ZZ* box diagrams.

"A Realistic Approach to the Standard Z Peak"
D. Bardin, M. Bilenky, G. Mitselmakher (Dubna), T. Riemann, M. Sachwitz (Zeuthen)
Z. Phys. C44 (1989) 493, Zeuthen preprint PHE 89-05 (May 1989)
Here we excluded the weak *WW* and *ZZ* box diagrams from the form factors, making them independent of the scattering angle.

The Born amplitude is factorized in two pieces:

$$A \otimes B \equiv [\bar{u}_i \gamma_\mu (v_i + a_i \gamma_5) u_i] \times [\bar{u}_f \gamma^\mu (v_f + a_f \gamma_5) u_f] \,,$$

and is generalized by loop corrections to

$$A_{vv} \gamma \otimes \gamma + A_{av} \gamma\gamma_5 \otimes \gamma + A_{va} \gamma \otimes \gamma\gamma_5 + A_{aa} \gamma\gamma_5 \otimes \gamma\gamma_5$$

or, equivalently,

$$B_{LL} \gamma(1+\gamma_5) \otimes \gamma(1+\gamma_5) + B_{\gamma L} \gamma \otimes \gamma(1+\gamma_5) + B_{L\gamma} \gamma(1+\gamma_5) \otimes \gamma + B_{\gamma\gamma} \gamma \otimes \gamma$$

With Z boson and photon exchanges:

$$\begin{aligned} \mathcal{M} &= \mathcal{M}_\gamma + \mathcal{M}_Z \\ \mathcal{M}_\gamma &\sim F_A \, [\gamma \otimes \gamma] \\ \mathcal{M}_Z &\sim \rho_Z \, [\gamma\gamma_5 \otimes \gamma\gamma_5 + v_q \gamma \otimes \gamma\gamma_5 + v_l \gamma\gamma_5 \otimes \gamma + v_{ql} \gamma \otimes \gamma] \end{aligned}$$

Born approximation: $v_{ql} \approx v_q \times v_l$

The form factors are F_A, ρ, κ_q, κ_l, κ_{ql}:

$$
\begin{aligned}
F_A(s) &= \frac{\alpha_{QED}(s)}{\alpha_{em}} = 1 + \delta\alpha_{QED}(s), \quad \alpha_{em} = \frac{1}{137\cdots} \\
\rho(s',\theta) & \quad \cdots \\
a_f &= 1, \qquad\qquad f = q, l \\
v_f(s',\theta) &= 1 - 4\sin^2\theta_w |Q_f| \kappa_f(s',\theta), \quad f = q, l \\
v_{ql}(s',\theta) &= v_q + v_l - 1 + 16\sin^4\theta_W |Q_q Q_l| \kappa_{ql}(s',\theta)
\end{aligned}
$$

From hep-ph-9908433v3, eq. (3.3.1), we take:

$$\mathcal{A}_Z^{OLA}(s,t) = i\, e^2\, 4\, I_e^{(3)} I_f^{(3)} \frac{\chi_Z(s)}{s}$$

$$\rho_{ef}(s,t) \Big\{ \gamma_\mu(1+\gamma_5) \otimes \gamma_\mu(1+\gamma_5)$$

$$-4|Q_e| s_W^2 \kappa_e(s,t) \gamma_\mu \otimes \gamma_\mu(1+\gamma_5)$$

$$-4|Q_f| s_W^2 \kappa_f(s,t) \gamma_\mu(1+\gamma_5) \otimes \gamma_\mu$$

$$+16|Q_e Q_f| s_W^4 \kappa_{e,f}(s,t) \gamma_\mu \otimes \gamma_\mu \Big\}.$$

The form factors of the so-called **ZFITTER approach in 1988, 1989** are simply related to the one-loop form factors introduced in the original renormalization articles by **Bardin, Fedorenko, JINR Dubna preprints (1978)** and **Bardin, Christova, Fedorenko, Nucl. Phys. (1980)**:

$$
\begin{aligned}
\rho_{ef} &= 1 + F_{LL}\,(s,t) - s_W^2 \Delta r, \\
\kappa_e &= 1 + F_{QL}\,(s,t) - F_{LL}\,(s,t)\,, \\
\kappa_f &= 1 + F_{LQ}\,(s,t) - F_{LL}\,(s,t)\,, \\
\kappa_{ef} &= 1 + F_{QQ}\,(s,t) - F_{LL}\,(s,t)\,.
\end{aligned}
$$

The notations before 1987 are:

$$
\begin{aligned}
\mathcal{A}_Z^{OLA} &= i\frac{g^2}{16\pi^2}\, e^2\, 4\, I_e^{(3)} I_f^{(3)} \frac{\chi_Z(s)}{s} \\
&\times\Big\{ \gamma_\mu(1+\gamma_5)\otimes\gamma_\mu(1+\gamma_5)F_{LL}(s,t) - 4|Q_e|s_W^2\gamma_\mu\otimes\gamma_\mu(1+\gamma_5)F_{QL}(s,t) \\
&-4|Q_f|s_W^2\gamma_\mu(1+\gamma_5)\otimes\gamma_\mu F_{LQ}(s,t) + 16|Q_eQ_f|s_W^4\gamma_\mu\otimes\gamma_\mu F_{QQ}(s,t)\Big\}.
\end{aligned}
$$

So far we discussed matrix elements.

The differential cross section is:

$$\frac{d\sigma}{d\cos\vartheta} = \frac{\pi\alpha_{em}^2}{2s}\Bigg\{\left(1+\cos\vartheta^2\right)\left[K_T(\gamma)+\Re e(\chi(s)\;\;K_T(l))+|\chi(s)|^2\;\;K_T(Z)\right]$$

$$+\,2\cos\vartheta\left[K_{FB}(\gamma)+\Re e(\chi(s)\;\;K_{FB}(l))+|\chi(s)|^2\;\;K_{FB}(Z)\right]\Bigg\}$$

with

$$\chi(s) = \frac{G_F}{\sqrt{2}}\;\frac{M_Z^2}{8\pi\alpha}\;\frac{s}{s-M_Z^2+i\Gamma_Z M_Z}$$

The effective couplings are:

$$
\begin{aligned}
K_T(\gamma) &= c_{color}\ Q_i^2 Q_f^2 |F_\gamma(s)|^2 \\
&=_{Born} c_{color}\ Q_i^2 Q_f^2, \\
K_T(I) &= 2c_{color}\ |Q_i Q_f|\ F_\gamma(s)^* \rho_{if}(s,t) v_i v_f \\
&=_{Born} 2c_{color}\ |Q_i Q_f| v_{B,i} v_{B,f}, \\
K_T(Z) &= c_{color}\ |\rho_{if}(s,t)|^2 (1 + |v_i|^2 + |v_f|^2 + |v_{if}|^2) \\
&=_{Born} c_{color}\ (v_{B,i}^2 + a_{B,i}^2)(v_{B,f}^2 + a_{B,f}^2), \\
K_{FB}(\gamma) &= 0, \\
K_{FB}(I) &= 2c_{color}\ |Q_i Q_f|\ F_\gamma(s)^* \rho_{if}(s,t) \\
&=_{Born} 2c_{color}\ |Q_i Q_f|\ a_{B,i} a_{B,f}, \\
K_{FB}(Z) &= 2c_{color}\ |\rho_{if}(s,t)|^2 2\Re(v_i v_f + v_{if}) \\
&=_{Born} 2c_{color}\ (2v_{B,i} a_{B,i})(2v_{B,f} a_{B,f}).
\end{aligned}
$$

Here, i denotes the intial state and f the final state. For the Drell-Yan process $\bar{q}q \to e^+e^-$, it is $q = u, d$ and $f = e$.

The c_{color} is the color factor, e.g. $c_{color} = 3$ for initial state quarks and final state leptons.

Monte Carlo Program for Drell-Yan processess at LHC and weak form factors I

One may study e.g. the **running of the weak mixing angle** $\sin^{2,eff}\theta_W(s')$ as a function of the scale s' from $\sigma_0(s')$:

$$\sigma_0(s') = \mathcal{L}_u \;\; \sigma_0(u\bar{u} \to l^+ l^-) \;\; + \;\; \mathcal{L}_d \;\; \sigma_0(d\bar{d} \to l^+ l^-)$$

where the hard scattering cross-sections $\sigma_0(u\bar{u} \to l^+ l^-)$ and $\sigma_0(d\bar{d} \to l^+ l^-)$ **each depend on four complex valued, process-dependent form factors** $\rho_{ql}, \kappa_q, \kappa_l, \kappa_{ql}$.

Further, the σ_0 depends on s', but also on the **scattering angle** θ.

Further, we have not only initial and final state photonic corrections, but also **initial-final state interferences**.

An elegant way to cover at least part of the complexity of all this in a modern QCD Montre Carlo program is as follows:
– Define a photon exchange amplitude
– Define a Z exchange amplitude
Assume a Born like structure with ρ, v_q, v_l and put the deviation from that structure – which is in the difference $(v_{ql} - v_q v_l)$ into the photon amplitude:

Split the v_{ql} into a Z-part and a photon part:

$$v_{ql} \to (v_{ql} - v_q \ v_l) \ + \ v_q \ v_l$$

But evidently, once there are accurate data, one has to carefully understand how to model the correct physics ansatz with a smaller number of parameters.

This is under study by experimentalists presently.

Instead of a Summary

I would like to thank the audience for the attention and the expressed interest in a future of the ZFITTER project.

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- P. Baikov, K. Chetyrkin, J. H. Kuhn, Order alpha**4(s) QCD Corrections to Z and tau Decays, Phys.Rev.Lett. 101 (2008) 012002.
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- P. Baikov, K. Chetyrkin, J. Kuhn, J. Rittinger, Complete QCD Corrections to Hadronic *Z*–Decays in Order α_s^4arXiv:1201.5804.
- K. Nakamura, et al., Review of particle physics, J.Phys.G G37 (2010) 075021.
  doi:10.1088/0954-3899/37/7A/075021.

Backup

ZFITTER Webpage: http://zfitter.com

ZFITTER Webpages at DESY during 1992 – July 2011:
http://www-zeuthen.desy.de/~riemann/
http://www-zeuthen.desy.de/theory/research/zfitter/
http://zfitter.desy.de/theory/research/zfitter/
Since July 2011:
http://zfitter.com
About 30 versions of ZFITTER may be found here [no linking since July 2011]

Important versions:

ZFITTER v.4.00 (dated June 1991), older versions seem to be lost.
ZFITTER v.4.5 (19 April 1992) – described in CERN-TH. 6443/92 (1992) [hep-ph/9412201]
ZFITTER v.4.9 (1995)
– used for D. Bardin et al., **Electroweak Working Group Report**, in "Reports of the working group on precision calculations at the Z resonance", CERN 95-03 (March 1995), hep-ph/9709229
– also used for F. Boudjema et al., Standard Model Processes, in **Physics at LEP2**, CERN 96-01 (Feb 1996), hep-ph/9601224)
. . .
ZFITTER v.6.42–44 (18 May 2005 onwards)
actual versions, ZFITTER v.6.42 in use for the **final LEP analyses**.

QED and one-loop corrections in the SM I

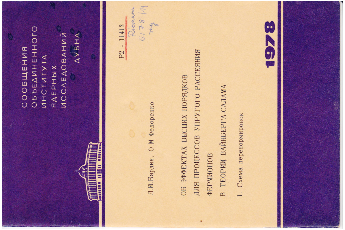
Pre-history ∼ 1975-1982 **1983-1987 T.R. in JINR, Dubna, Russia**

Bardin, Shumeiko, [6, NPB 1976]

InfraRed divergent part of QED corrections treated by subtraction method

D. Bardin and O. Fedorenko, [9, JINR-P2-11413], [9, JINR-P2-11413] unpubl. 1978

"On High Order Effects For Fermion Elastic Scattering Processes In Weinberg-salam Theory. **1. Renormalization Scheme**"
"On High Order Effects For Fermion Elastic Scattering Processes In Weinberg-salam Theory.**2. Calculation Of One Loop Diagrams**"



←
Title page of Dubna preprint JINR-P2-11413

QED and one-loop corrections in the SM II

JINR Dubna, The two parts of "Bible"
D. Bardin, P. Christova, O. Fedorenko, [10, NPB 1981], [11, NPB 1982]
"Bible I" – The electroweak one loop **diagrammar**
"Bible II" – The electroweak One Loop **Amplitudes**

G. Mann, T.R., IfH Zeuthen [Institute for High Energy Physics, now DESY]:
[12, PHE-83-09] "On mass shell renormalization of the Weinberg-Salam theory: an introductory lecture"
[13, Ann.Phys.1984] "Effective flavor changing weak neutral current in the standard theory and Z boson decay"

Papers by Wetzel, Lynn+Stuart and others: electroweak problems finally solved . . . ???

The first ZFITTER paper on QED corrections in e^+e^- annihilation:
A. Akhundov (Baku), D. Bardin (Dubna), O. Fedorenko (Petrozavodsk), T. Riemann (Dubna)
"Some Integrals For Exact Calculation Of QED Bremsstrahlung"
[14, JINR-E2-84-777 1984], unpubl.

A bit arbitrarily, one may choose as one of the first papers in the ZFITTER project:

A. Akhundov, D. Bardin, T. Riemann

"Hunting the hidden standard Higgs", [2, PLB166 1986], submitted in 1985.

The Δr with a top mass and Higgs mass dependence became later the kernel of the Standard Model library of ZFITTER.

QED with more and more realistic cuts:

[15, Bardin:1988ze] – Complete QED corrections with γ and Z, no cuts
rejected by NPB

[16, PLB,Bardin:1988xt] – Energy Dependent Width Effects

[17, JINR prepr.,Bilenky:1989zg] – QED with accolinearity cut
[rejected by PLB]

[18, PLB,Bardin:1989cw] – QED Convolutions, no cuts

[19, ZfPC,Bardin:1989di] – A Realistic Approach, ZfPC: combined ew f.f. + QED

[20, NPB,Bardin:1990fu] – complete set of QED corrections, NPB

[21, PLB,Bardin:1990de] – QED corrections with partial angular integration, PLB

[1, CERN prepr.,Bardin:1992jc] – ZFITTER CERN prepr. TH 92/6443

[22, PLB,Christova:1999cc] – Integrated QED with accolinearity cut

Higgs hunting, Z-width, W-width

The weak library of ZFITTER was created in 1985/1986

- **A. Akhundov, D. Bardin, T. Riemann** [2, Akhundov:1985cf] [1 citation for long]
  Δ_r with $m_{top} \neq 0 \to$ PLB
- **A. Akhundov, D. Bardin, T. Riemann** [23, Akhundov:1985fc] [360 citations]
  Z-**decay** width with $m_{top} \neq 0 \to$ NPB
- **D. Bardin, S. Riemann, T. Riemann** [24, Bardin:1986fi]
  W-**decay** width with $m_{top} \neq 0 \to$ ZfPC [EPJC]

First publication of the Standard Model library was in 1989
This was not yet ZFITTER, because it did not cover the QED corrections
[25, CPC59 1989] Dizet
There are 3 descriptions of ZFITTER with 350 pages [plus some contributions to Yellow Reports]
[1, prepr. CERN TH 1992]
[4, CPC133 2000]
[5, CPC174 2006]

The software library of Comput. Phys. Commun. gives a *licence to authors* and allows *anonymous downloads*.

The 1989 Workshop on Physics at LEP 1

Z Physics at LEP 1 - 1989, CERN 89–08, 3 volumes
Altarelli, Kleiss, Verzegnassi,
http://cdsweb.cern.ch/record/116932/files/CERN-89-08-V-1.pdf
http://cdsweb.cern.ch/record/367652/files/CERN-89-08-V-2.pdf
http://cdsweb.cern.ch/record/367653/files/CERN-89-08-V-3.pdf

1993 – Foundation of the LEP ElectroWeak WorkingGroup I

Information Courtesy Dorothee Schaile, Jan 2012:

Originally a group with members of the four LEP experiments, led by **Jack Steinberger**, investigated the combination of the Z line shape.
→ Phys. Lett. B 276 (1992) 247 [26], with about 350 citations

In 1993 **Dorothee Schaile** was asked to take over the coordination of the group and she had then already ideas about how to include other electroweak observables into a combined analysis.
She remembers that from then on **they called themselves the LEP EWWG**;
http://lepewwg.web.cern.ch/LEPEWWG/.
The first publicly accessible document with this name is also the initial summary of the LEP results for the electroweak Summer conferences, which appeared annually from then on:
→ CERN/PPE/93-157 (26 August 1993) [27], with about 3 citations

1993 – Foundation of the LEP ElectroWeak WorkingGroup II

The LEP EWWG was lead by **D. Schaile** from 1993-1996, then she became professor with chair in Munich.
Martin Gruenewald is coordinating the LEP EEWG till now.

The work of the LEPEWWG relies on ZFITTER and TOPAZ0 and many other resources.

1995 – The ElectroWeak Working Group Report

At a certain moment, the community has to set benchmarks

They have to be documented with great care, because they are valid longer than one expects at that moment

Setting the stage in 1995, till now relevant:

"Electroweak Working Group Report" [2 years later e-Print: hep-ph/9709229]

It is a part of:
D. Bardin, W. Hollik, G. Passarino (eds.)
"Reports of the working group on precision calculations for the Z resonance"
CERN 95-03 (31 March 1995) [no e-Print, but pdf available at CERN]

This work is one of the basics for the successful work of the LEP Electroweak Working Group

D. Schaile et al., M. Gruenewald et al.

Standard Model Higher-order Corrections in ZFITTER I

Reports of the working group on precision calculations for the Z resonance - 1995, CERN 95–03
Bardin, Hollik, Passarino,
http://cdsweb.cern.ch/record/280836/files/CERN-95-03.pdf
[28, CERN-95-03A, hep-ph/9709229]

From the EWWGR report:
" ... compare results of independent calculations. Such a comparison has been done once for Δr, and an agreement of up to 12 digits (computer precision) was found [14].

[14] Bardin, Kniehl, Stuart, 1992

The Report EWWGR is of relevance until today.
During that time period, ZFITTER absorbed higher-order calculations of other groups, notably:

J.J. van der Bij, Nucl. Phys. B248 (1984) 141

B.A. Kniehl, M. Krawczyk, J.H. Kuhn and R.G. Stuart, Phys. Lett. B209 (1988) 337

M. Consoli, W. Hollik and F. Jegerlehner, Phys. Lett. B227 (1989) 167

B.A. Kniehl, Nucl.Phys. B347 (1990) 86

R. Barbieri et al., Phys. Lett. B288 (1992) 95; Nucl. Phys. B409 (1993) 105

G. Degrassi, S. Fanchiotti and P. Gambino, CERN-TH.7180/94

Standard Model Higher-order Corrections in ZFITTER II

L. Avdeev, J. Fleischer, S. Mikhailov and O. Tarasov, Phys. Lett. B336 (1994) 560; hep-ph/9406363, last revision: 16.02.1995
K.G. Chetyrkin, J.H. Kuhn, M. Steinhauser, Karlsruhe University Report, No. TTP 9503; hep-ph/9502291, last revision: 15.02.95

K.G. Chetyrkin, A. Kwiatkowski and J.H. Kuhn, in EWWGR 1995

S. Eidelman and F. Jegerlehner, PSI-PR-95-1, Budker INP 95-5, January 1995

plus more contributions ...

Later, $>$ 2004 several "Add-ons" had to be inserted into ZFITTER, notably:

Y. Schröder, M. Steinhauser: "Four-Loop Singlet Contribution to the rho Parameter" Phys.Lett. B622 (2005)

- Hollik et al.: electroweak 2-loop corrections to the $M_Z - -M_W$ mass relation and to the effective weak mixing angle

- Czakon et al.: electroweak 2-loop corrections to the $M_Z - -M_W$ mass relation and to the effective weak mixing angle

- Baikov et al.: QCD 4-loop corrections to the Z-decay rate

Lacking in ZFITTER until today:
electroweak 2-loop corrections to the Z-decay rate normalization [$\delta\rho$]

annihilation Fedorenko Riemann, M.

ZFITTER v.6.42 (2005) $\rightarrow$ v.6.44 (2012)

ZFITTER v.6.42 (2005) – Inclusion of the
Hollik-Freitas-Weiglein & Awramik-Czakon **2-loop electroweak corrections**
...
M_W - the W-boson mass, eq. (5.2) in CPC174, from [29, Awramik:2003rn]
$\sin^{2,eff}_w$ – the weak mixing angle, eq. (5.7) in CPC174, from [30, Awramik:2004ge]

...we need yet the **2-loop electroweak corrections** to the Z-decay rate

Recent improvement, see Talk by K.Chetyrkin at LL2012:
QCD corrections to the Z decay width:
QCD 3-loop corrections - in ZFITTER v.6.42
QCD 4-loop corrections - **now: update in ZFITTER v.6.44, being released**
Baikov, Chetyrkin, Kühn – Phys.Rev.Lett. 101 (2008) [31, Baikov:2008j]
Baikov, Chetyrkin, Kühn, Rittinger – subm. to Phys.Rev.Lett. [32, Baikov:2012er], Eq. (6)