ZFITTER – 20 years after

ZFITTER collaboration [∼1985 - 2012] Tord Riemann DESY, Zeuthen, Germany

https://indico.desy.de/conferenceDisplay.py?confId=4362
Talk held at Loops and Legs in Quantum Field Theory, 15-20 April 2012, Wernigerode, Germany

20 years after

The first published version of ZFITTER was in 1992, in hep-ph 2 years later [4, 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, see http://en.wikipedia.org/wiki/The_Beatles

CERN-TH. 6443/92

$_{ZF}I^{T}T_{ER}$

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

D. Bardin[1], M. Bilenky[1,2,†], A. Chizhov[1], O. Fedorenko[3], S. Ganguli[4], A. Gurtu[4], M. Lokajicek[1], G. Mitselmakher[1], A. Olshevsky[1], J. Ridky[1], S. Riemann[5,‡], T. Riemann[5,6], M. Sachwitz[5], A. Sazonov[1], A.D. Schaile[7], Yu. Sedykh[1], I. Sheer[8], L. Vertogradov[1]

[1] Joint Institute for Nuclear Research, Dubna, Russia

[2] Universität Bielefeld, Germany

[3] Petrosavodsk State University, Petrosavodsk, Russia

[4] Tata Institute of Fundamental Research, Bombay, India

[5] DESY – Institut für Hochenergiephysik, Zeuthen, Germany

[6] Theory Division, CERN, Geneva, Switzerland

[7] Albert-Ludwigs-Universität, Freiburg, Germany

[8] University of California, San Diego, USA

Abstract

We describe how to use $_{ZF}I^{T}T_{ER}$, 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. $_{ZF}I^{T}T_{ER}$ 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

Hunting the Standard Model Higgs Boson → LHC

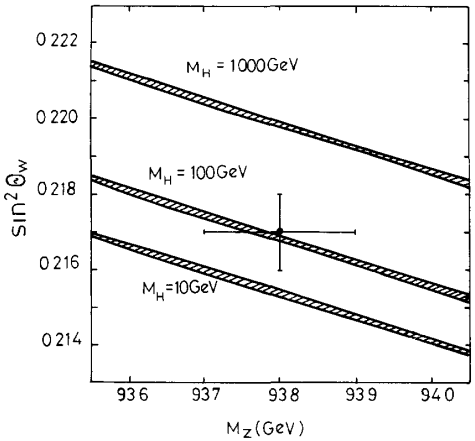
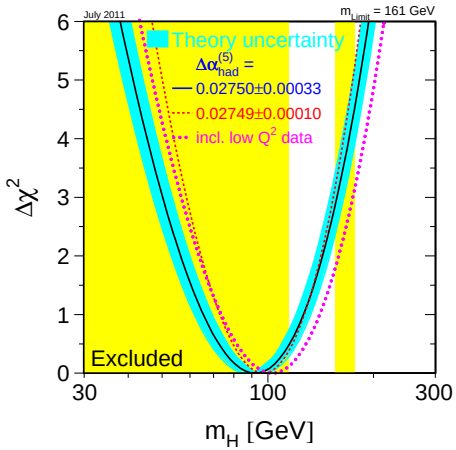


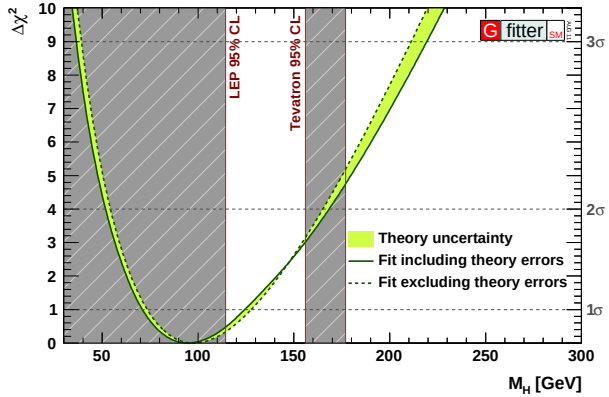
Fig 1 Graph of $\sin^2\theta_w$ versus M_Z, influenced by M_H through radiative corrections The thickness corresponds to the range 30 GeV $\leqslant m_t \leqslant$ 40 GeV, the error bars indicate the accuracy expected at Z boson factories.



1993 – 2011 by LEPEWWG

←

Akhundov, Bardin, T.R.
[1, Akhundov:1985cf]
Quotations: 1 in 1986, 1 in 2012



EPJC 60 (2009) **[competitors]**,
[2, Bardin:1999yd], [3, Arbuzov:2005ma]

Factsheet on EPJC60(2009)543 (and related productions)

- **The competitors used ZFITTER v.6.42** for their program and for their numerical results.

  They also used texts of ZFITTER authors.

- **They do not mention this**, over a period 2006 – 2011.
- **They quote** in EPJC60(2009)543 (Springer Publisher) **ZFITTER** papers **for something else**.
- The Editors-in-Chief of EPJC call this “proper citation”.

  They also say that the software license from Comput. Phys. Commun. is fulfilled.

  They see no case of “p.”, using their private “common sense approach to p.”.

- ZFITTER calls this a use of ZFITTER “without proper citation”.

  ZFITTER also says that the software license from Comput. Phys. Commun. is broken.

  The “Conditions of use” are also broken (→ No cannibalization, only linking of ZFITTER).

  ZFITTER sees a case of “p.” according to the definitions of “p.” of e.g. Springer Publisher or DESY.

More details may be found at **http://zfitter.com**.
e.g. http://zfitter.com/Letter_Riemann.pdf.

Precision Paradigm

Physics needs Precision Measurements and Precision Calculations at highest possible level

- **Galileo Galilei (1564-1642) et al.**
  Observations, Measurements, Reproducibility, Mathematics
- **Planets Movements + Kepler + Newton (1642-1724) et al.**
  True Precision and Interpretation
- **Black Body Radiation + Planck (1858-1947) et al.**
  Quantum Physics
- **LEP + Veltman (* 1931) et al.**
  Quantum Field Theory and Gauge Boson Self Interactions
- **LHC, Linear Collider, and some Theorists et al.**
  ? ? ?

(Theoretical) Particle Physics is extremely *competative*, but we also have to act *cooperatively*.

Precision calculations at work

Precision calculations

- $\rightarrow$ time-consuming
- $\rightarrow$ complicated
- their necessity depends on very details of the measuring machinery
- **often considered to be obtainable on demand and for free**

Long-term projects have a true history and meet specific problems

- who is an author and why?
- is a project just **the formulas** or **the software** or the **description** or **the webpage** or **the use** of the software or **the support**
- interaction with the community
- financing, manpower and all that
- long history before acceptance
- competitors
- legal problems - licenses - copyright - who gets the code why - who is the owner

ZFITTER in a nutshell

ZFITTER is a library of QED and Standard Model predictions for

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

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

$\to$ is to be called by **Interfaces**

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

$\to$ which may evaluate the **observables of interest**:

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

or

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

ZFITTER code - in a nutshell

Evaluates: Observables + Pseudo-Observables
Uses language of: QED + effective Born cross section

ZFITTER Approach:

- Real emission: Subtraction method for IR handling [6, Bardin:1976qa]
  and also [12, Passarino:1982zp] for clever analytical cuts
- Analytical formulae with cuts for cross sections in $e^+e^- \to f^+f^-(+n\gamma)$:

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

- Effective Born Cross sections with 4 form factors:
  $\rho_{ef}(s,t), \quad \kappa_e(s,t), \quad \kappa_f(s,t), \quad \kappa_{ef}(s,t)$

ZFITTER is open-source software, but has a licence of use and conditions of use:
please quote when use
and
please do not cannibalize

There is a **ZFITTER [Support] Group** with a spokesperson
1975 – 2005: Dima Bardin
since 2005: Tord Riemann

Main user: LEP Electroweak Working Group
`http://lepewwg.web.cern.ch/LEPEWWG/`, April 2012
7 September 2005
"Precision Electroweak Measurements on the Z Resonance"
The ALEPH, DELPHI, L3, OPAL, SLD Collaborations,
the LEP Electroweak Working Group,
the SLD Electroweak and Heavy Flavour Groups
CERN-PH-EP/2005-041 and hep-ex/0509008, Published in Physics Reports: Volume 427 Nos. 5-6 (May 2006) 257-454.
Final results and combinations of Z-pole measurements from ALEPH, DELPHI, L3, OPAL, and SLD!
(Still to do: final LEP-2 results!)

The most complete representation of the theory behind ZFITTER, and also behind TOPAZ0

[5, Monography]:

```
@article{Bardin:1999ak,
      author          = "Bardin, Dmitri Yu. and Passarino, G.",
      title           = "{The standard model in the making:
                         Precision study of the
                         electroweak interactions}",
      year            = "1999",
}
```

ZFITTER authors 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

ZFITTER support group:

Founded in 2004/2005 after D. Bardin finished active support of ZFITTER [3, Arbuzov:2005ma]

Spokesperson 2004 – 2012: T.R.

License and copyright and "Conditions of use" of ZFITTER

Does ZFITTER have rights with ZFITTER?

"Where there is ZFITTER should also stand upon ZFITTER"

The License of Comput. Phys. Commun. says:

- **When used, then quote** ZFITTER
- **ask for written permission from the authors** of ZFITTER before you give derivatives to a third party

ZFITTER furthers demand to **respect the integrity** of ZFITTER, i.e. we prefer you to write interfaces instead of cannibalizing ZFITTER.

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

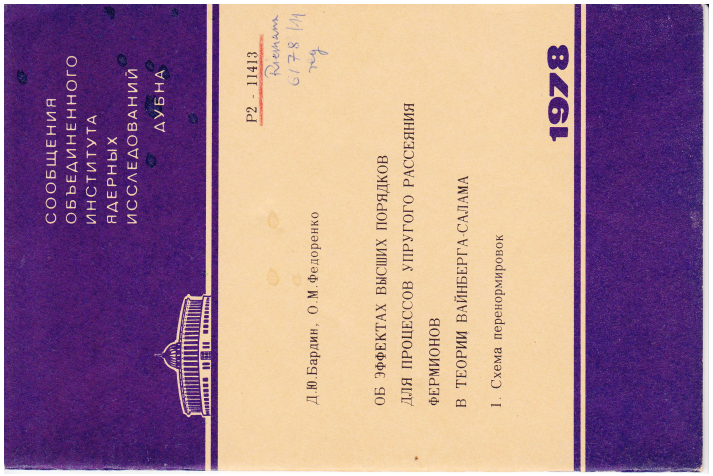
Pre-history ∼ 1975-1982 **1983-1987 T.R. in JINR, Dubna, Russia**

Bardin, Shumeiko, [6, NPB 1976]

InfraRed divergent part of QED corrections treated by subtraction method

D. Bardin and O. Fedorenko, [7, JINR-P2-11413], [7, 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, [8, NPB 1981], [9, 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]:
[10, PHE-83-09] "On mass shell renormalization of the Weinberg-Salam theory: an introductory lecture"
[11, 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"
[13, 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", [1, 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:

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

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

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

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

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

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

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

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

[21, 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** [1, Akhundov:1985cf] [1 citation for long]
  Δ_r with $m_{top} \neq 0 \rightarrow$ PLB
- **A. Akhundov, D. Bardin, T. Riemann** [22, Akhundov:1985fc] [360 citations]
  Z**-decay** width with $m_{top} \neq 0 \rightarrow$ NPB
- **D. Bardin, S. Riemann, T. Riemann** [23, Bardin:1986fi]
  W**-decay** width with $m_{top} \neq 0 \rightarrow$ 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
[24, CPC59 1989] Dizet
There are 3 descriptions of ZFITTER with 350 pages [plus some contributions to Yellow Reports]
[4, prepr. CERN TH 1992]
[2, CPC133 2000]
[3, 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 [25], 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) [26], 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
[27, 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 $[\delta\rho]$

ZFITTER v.6.42 (2005) → 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 [28, Awramik:2003rn]
$\sin^{2,eff}_w$ – the weak mixing angle, eq. (5.7) in CPC174, from [29, 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) [30, Baikov:2008j]
Baikov, Chetyrkin, Kühn, Rittinger – subm. to Phys.Rev.Lett. [31, Baikov:2012er], Eq. (6)

$$\Gamma_Z \rightarrow \Gamma_Z \times R_{nc}$$

$$R_{nc} = \left(1+\frac{\alpha_s}{\pi}\right) + A_2\left[\frac{\alpha_s}{\pi}\right]^2 + A_3\left[\frac{\alpha_s}{\pi}\right]^3 + A_4\left[\frac{\alpha_s}{\pi}\right]^4$$

$$\begin{aligned} R_{nc} = {} & 20.1945\left(1+\frac{\alpha_s}{\pi}\right) + (28.4587 - 13.0575 + 0)\left[\frac{\alpha_s}{\pi}\right]^2 \\ & +(-257.825 - 52.8736 - 2.12068)\left[\frac{\alpha_s}{\pi}\right]^3 \\ & +(\mathbf{-1615.17 + 263.388 - 25.5814})\left[\frac{\alpha_s}{\pi}\right]^4 \end{aligned}$$

Look at experimental numbers:
Experiment: The Z decay width is experimentally known to be (PDG 2010) [32]:

$$\Gamma_Z = (2.4952 \pm 0.0023)\ \text{GeV}$$

so that

$$\Delta\Gamma_Z/\Gamma_Z = 0.00092177 = 9 \times 10^{-4}$$

- The influence of the α_s^4 term from QCD is -2×10^{-4}:

$$\frac{\delta\Gamma_Z}{\Gamma_Z} = A_4 \times (0.12/\pi)^4 \approx -2 \times 10^{-4}$$

  i.e. about 1/4 of the experimental error

- If one wants to be truly sensitive to the NNNLO Baikov terms, -2×10^{-4}, one has to control the rest of the corrections equally good, and all truly known parts to about 5×10^{-5} or better.

ZFITTER v.6.42: a Lesson: 127 $\neq$ 1270

We have the α_s^4 terms of Baikov et al.

Do we control the α_s^3 terms and all that sufficiently?

Let us look into some actually promoted code from a competitor:

$$\begin{aligned} A_3 \sim m_{CA3} \quad = \quad & -4544045/864.0 + 1340\zeta(2) + 118915/36.0\zeta(3) - 1270\zeta(5) \\ & +(71621/162.0 - 209/2.0\zeta(2) - 216\zeta(3) + 5\zeta(4) + 55\zeta(5)m_{nf1} \\ & +(-13171/1944.0 + 16/9.0\zeta(2) + 26/9.0\zeta(3)m_{nf1}^2); \end{aligned}$$

In the **description of the competitor** [in fact a diploma thesis] we find:

$$\begin{aligned} A_3 \sim C_{23}^A \quad = \quad & -\frac{4544045}{864} + 1340\,\zeta(2) + \frac{118915}{36}\zeta(3) - 127\,\zeta(5) \\ & + \left[\frac{71621}{162} - \frac{209}{\zeta}(2) - 216\,\zeta(3) + 5\,\zeta(4) + 55\,\zeta(5)\right] m_{nf1} \\ & + \left[-\frac{13171}{1944} + \frac{16}{9}\zeta(2) + \frac{26}{9}\zeta(3)\right] m_{nf1}^2\,. \end{aligned}$$

These NNLO terms do not agree.

Look into the **original reference given**:

"QCD corrections to the e+e cross-section and the Z boson decay rate"
Chetyrkin, Kühn, Kwiatkowski, Dec 1994, 87 pp.
In: "Reports of the working group on precision calculations for the Z resonance", pp. 175-263, e-Print: hep-ph/9503396

There is no formula of this kind at all ...

Then we look into:
Bardin, Christova, Jack, Kalinovskaya, Olchevski, Riemann, Riemann
ZFITTER, CPC133 (2001): [2, Bardin:1999yd]

$$A_3 \sim C_{23}^A = \texttt{COEFA3} = -\frac{4544045}{864} + 1340\zeta(2) + \frac{118915}{36}\zeta(3) - 127\zeta(5) + \left[\frac{71621}{162} - \frac{209}{\zeta}(2) - 216\zeta(3) + 5\zeta(4) + 55\zeta(5)\right] m_{nf1} + \left[-\frac{13171}{1944} + \frac{16}{9}\zeta(2) + \frac{26}{9}\zeta(3)\right] m_{nf1}^2;$$

Here we see the $-127\zeta(5)$ of the description and not the $-1270\zeta(5)$ found in the C++ code.
The CPC133 is the only place where to find the expression ...
And finally ($D5 = \zeta(5)$):
In the Fortran program **ZFITTER/dizet6_42.f**:

$$COEFA3 = -4544045D0/864 + 1340 * D2 + 118915D0/36 * D3 - 1270D0 * D5 + (71621D0/162 - 209D0/2 * D2 - 216D0 * D3 + 5D0 * D4 + 55D0 * D5)ANF + (-13171D0/1944 + 16D0/9 * D2 + 26D0/9 * D3)ANF^2 *$$

This number agrees with the C++ code of the competitor of 2009 ..., but not with its description ...
Explanation: private communications, copy-paste, wrong and incomplete referencing and all that.

ZFITTER and a competitor: Another lesson – copy with care . . .

In ZFITTER file bkqcdl5_14.f we find the Fortran function XRMQCD, which is authored by ZFITTER:

```
      FUNCTION XRMQCD(AMZ2,AMW2,AMT2,S)
...
       XRMQCD=1D0/(12D0*SW2)
     &         *(3D0/4D0/CW2*(1D0+VB2)
     &         +AMT2/4D0/AMW2*(VT2*(XDVFTZ/ALTZ-XPVFTZ)
     &         +XDAFTZ/ALTZ-XPAFTZ)
     &         -AMT2/AMW2*(3D0*D2+105D0/8D0))
      ELSE
        XRMQCD=1D0/4D0/SW2/CW2
     &         *(AMT2/AMZ2*((1D0-4D0*QTM*SW2)**2*XV1r+XA1r)
     &         +AMT2/(AMZ2-S)*((1-4*QTM*SW2)**2*(XV1rs-XV1r)+XA1rs-XA1r)
     &         +2D0*AMT2/AMZ2*(-23D0/8D0+D2+3D0*D3)
     &     -1D0/4D0*(1D0+(1D0-4D0*QBM*SW2)**2)*S/(AMZ2-S)*LOG(S/AMZ2))
```

In a **C++ code of a competitor** we see similar but not identical coding:

```
rmqcd = 1.0/(4.0*SW2*CW2)*( mt2/MZ2*(VT2*XV1r + XA1r)
                                  + mt2/(MZ2-S)*(VT2*(XV1rs - XV1r) + XA1rs - XA1r)
                                  + 2.0*mt2/MZ2*(-23.0/8.0*D2+3.0*D3)
                                  - 1.0/4.0*(1.0 + QBM)*S/(MZ2-S)*TMath::Log(S/MZ2) );
```

One may **observe two mistakes**, resulting from copy-paste with a loss, in C++/rmqcd compared to ZFITTER, where we have:

$$\ldots = +2D0 * AMT2/AMZ2 * (-23D0/8D0 + D2 + 3D0 * D3) \qquad (1)$$
$$-1D0/4D0 * (1D0 + (1D0 - 4D0 * QBM * SW2) * *2) * S/(AMZ2 - S) * LOG(S/AMZ2))$$

In both cases: the $D3 = \zeta(3)$ comes from a QCD 2-loop Formula (Kniehl 1990).

Summary

- **Precision is a crucial item besides "Planned" Discovery**
- **Development of theoretical analysis tools is a long-term task**
  Example: ZFITTER project 1985 - 2012 $\rightarrow$ future
  Last update of ZFITTER $\rightarrow$ v.6.44 in February 2012
- **Other long-term projects of different "flavor" and in their own stages of development are e.g. FORM or Koral-Z or TOPAZ0 or LoopTools+Feynarts+Feyncalc or BlackHat or GoSam etc.**
- **The experimental data should be carefully retained.**
  How to proceed with the software like ZFITTER, TOPAZ0 etc.?
  Cannibalize for future?

ZFITTER assumes to have rights on ZFITTER

Zero tolerance to plagiarism in particle physics !

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