# SANC Status Report

D. Bardin[a] *, P. Christova[b]*, L. Kalinovskaya[c]*

[a]Laboratory of Nuclear Problems, Joint Institute for Nuclear Research, Dubna, Russia

In this talk, we present the current status of the SANC project aimed at a theoretical Support of Analytic and Numeric calculations for experiments at Colliders. We describe the version 0.10 which is capable of automatically computing the decay rates and the distributions for the simplest SM decays $Z(H,W) \to f\bar{f}$ in the one-loop approximation as well as the one-loop scalar form factors of arbitrary NC and CC $2f \to 2f$ processes.

## 1. INTRODUCTION

The main goal of SANC project is the creation of a software product, accessible via Internet, for the automatic computation of pseudo- and realistic observables with a one-loop precision for various processes of elementary particle interactions, such as: $1 \to 2$, $1 \to 3$, $2 \to 2$, etc. The version 0.03 of the project, intended to demonstrate its workability, was described in a series of contributions to previous conferences [1–5] and [6].

The SANC environment was already used for a reanalysis of the EW radiative corrections for the Atomic Parity Violation [7] and of the QED+EW one-loop corrections for the process $e^+e^- \to t\bar{t}$ [8–10]; for the latter an agreement up to 11 digits with FeynArts [11] and topfit [12] was found.

The SANC project has two roots: 1) Codes aimed at a theoretical support of HEP experiments, such as TOPAZ0 [13] and ZFITTER [14]; 2) Numerous FORM2-codes, written by the authors of Ref. [15] while they were working on it.

It is supposed that the one of main program products of the project should be the Monte-Carlo event generators that are being created in collaboration with S. Jadach and Z. Was from INF (Krakow, Poland) and B.F.L. Ward from University of Tennessee (Knoxville, USA).

The SANC version v.0.03 realizes, in an Internet-based environment, the full chain of calculations 'from the SM Lagrangian in the $R_\xi$ gauge to realistic distribution' for the case of simplest $1 \to 2$ decays. It returns numbers and distributions for these decays at the one-loop level of precision.

SANC computes analytically the one-loop covariant amplitude of a process parameterized in a certain basis by a certain number of scalar form factors (SFF). Next, it computes helicity amplitudes (HA) in terms of these SFF. At present, we use in here the method of Vega and Wudka [16]. All these calculations (**level 1**) are realized in FORM3 language [17]. An example of calculations of the SFF and HA for the processes $e^+e^- \to f\bar{f}$ is given in [4]. The main chain of calculations is shown in the flow chart in Fig. 1.

The chain of calculations at level 1 continues with another bunch of FORM3 codes which compute analytically the contributions to the decay rates from the bremsstrahlung processes: $H(Z,W) \to f_1\bar{f}_2\gamma$, see [5] for more details.

At **level 2** an s2n.f software generates automatically the fortran codes for decay rates at one loop.

At **level 3** an infrared rearrangement (or exponentiation) procedure should work out (it is still at the stage of development).

Finally, at **level 4** one has a Monte Carlo event generator. It uses the HA for the accompanying bremsstrahlung processes (HA-Br), and for the time being we use the Kleiss–Stirling techniques [18]–[19] to derive them. Ref. [6] contains a description how this is realized for the case of decays $B \to f\bar{f}$ as well as the results of numerical comparisons with the well-known codes PHOTOS [20] and KORALZ [21]. A more comprehensive description of this work is given in paper [22].

*Supported by INTAS grant N° 00-00313

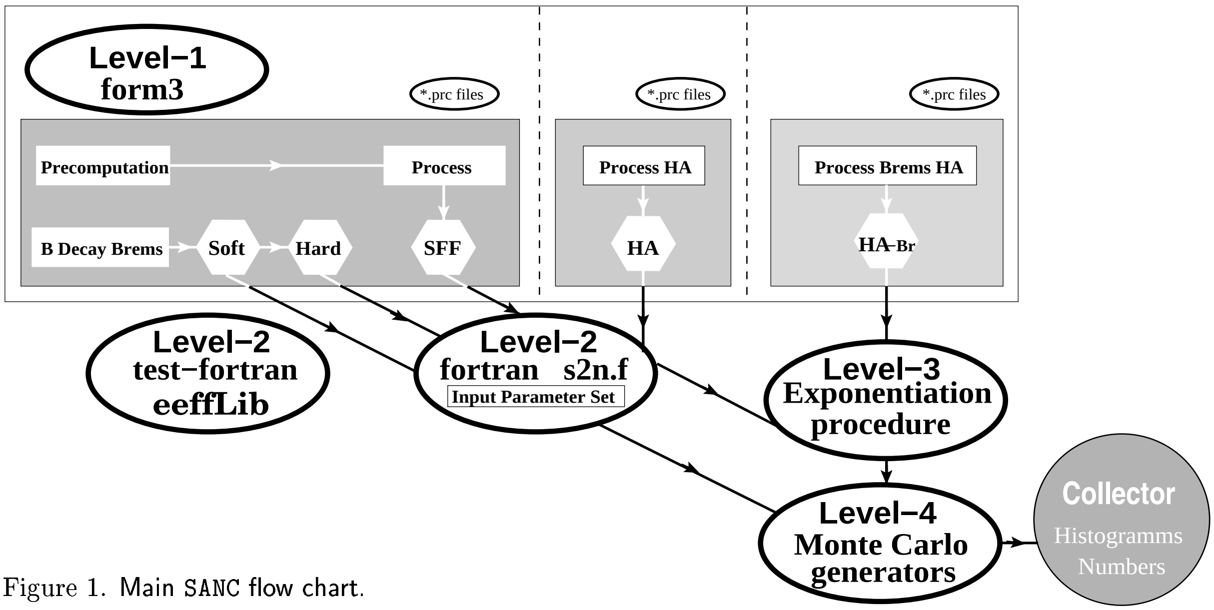


Figure 1. Main SANC flow chart.

## 2. AMPLITUDE BASIS, SCALAR FORM FACTORS, HELICITY AMPLITUDES

SANC computes the one-loop covariant amplitude ($\mathcal{A}$) of a process parameterized in a certain basis by a certain number of SFF. Next, it computes HA in terms of SFF.

### 2.1. Amplitudes for $B \to ff$ decays

We present the amplitudes of the decays $B(Q) \to f(p_1)\bar{f}(p_2)$, where $B = H, Z, W$:

$$H \to f\bar{f} : \mathcal{A} \propto I\mathcal{F}_S, \qquad (1)$$

1 structure (S-basis), 1 SFF, 1 HA;

$$Z \to f\bar{f} : \mathcal{A} \propto i\gamma_\mu\gamma_6\mathcal{F}_L + i\gamma_\mu\mathcal{F}_Q + m_f D_\mu \mathcal{F}_D,$$

3 structures (LQD-basis), 3 SFF, 3 HA;

$$W \to u\bar{d} : \mathcal{A} \propto i\gamma_\mu\gamma_6\mathcal{F}_L + i\gamma_\mu\gamma_7\mathcal{F}_R + m_u D_\mu\gamma_6\mathcal{F}_{LD} + m_d D_\mu\gamma_7\mathcal{F}_{RD},$$

4 structures (LRD-basis), 4 SFF, 4 HA, where $D_\mu = (p_1 - p_2)_\mu$.

• For $Z$ decay the three independent (four non-zero) HA are:

$$\mathcal{A}_{0\pm\pm} = \frac{gm_f}{c_W}\left[a_f\mathcal{F}_L + \delta_f\mathcal{F}_Q + \frac{1}{2}a_f\beta_f^2 M_Z^2\mathcal{F}_D\right],$$

$$\mathcal{A}_{\pm\pm\mp} = \frac{gM_Z}{\sqrt{2}c_W}\left[a_f(1\mp\beta_f)\mathcal{F}_L + \delta_f\mathcal{F}_Q\right], \qquad (2)$$

where $\beta_f^2 = 1 - 4\frac{m_f^2}{M_Z^2}$, $\delta_f = v_f - a_f = -2Q_f s_W^2$. As seen, only three HA are independent.

• For $W$ decay the four non-zero, independent HA read:

$$\begin{aligned}\mathcal{A}_{0\pm\pm} &= \frac{g}{\sqrt{2}}N_{1,2}\Big[ + \left(Pm_d + Pm_u \pm m_d E_d \mp m_u E_u\right)\mathcal{F}_L \\ &\quad + \left(Pm_d + Pm_u \mp m_d E_d \pm m_u E_u\right)\mathcal{F}_R \\ &\quad +2Pm_d\left(P^2 \pm PM_W + E_{ud}\right)\mathcal{F}_{RD} \\ &\quad +2Pm_u\left(P^2 \mp PM_W + E_{ud}\right)\mathcal{F}_{LD}\Big], \\ \mathcal{A}_{\pm\pm\mp} &= gN_{1,2}\Big[ -\left(P^2 \mp PM_W + E_{ud}\right)\mathcal{F}_L \\ &\quad + \left(P^2 \pm PM_W + E_{ud}\right)\mathcal{F}_R\Big], \end{aligned} \qquad (3)$$

where

$$\begin{aligned} E_d &= \frac{M_W^2 + m_u^2 - m_d^2}{2M_W}, \\ E_u &= \frac{M_W^2 - m_u^2 + m_d^2}{2M_W}, \\ E_{ud} &= E_u E_d - m_d m_u, \\ P &= \frac{\lambda(M_W^2, m_u^2, m_d^2)}{2M_W}, \\ N_{1,2} &= \left[M_W^2 - (m_u + m_d)^2\right]^{-1/2}. \end{aligned} \qquad (4)$$

### 2.2. Amplitudes for $2f \to 2f$ processes

• In case of $e^+e^- \to t\bar{t}$ process, one has six SFF and six HA if the electron mass is ignored [8–10]:

$$
\begin{aligned}
\mathcal{A}_{++\pm\pm} &= 0, \qquad \mathcal{A}_{++\pm\mp} = 0, \\
\mathcal{A}_{+-\pm\mp} &= s\,(1 \mp \cos\vartheta)\,\Big(Q_e Q_f \mathcal{F}_{GG} \\
&\quad + \chi_Z \delta_e \Big[\,(1 \pm \beta_f)\, I_f^{(3)} \mathcal{F}_{QL} + \delta_f \mathcal{F}_{QQ}\Big]\Big), \\
\mathcal{A}_{+-\mp\mp} &= 2\sqrt{s} m_f \sin\vartheta \Big(Q_e Q_f \mathcal{F}_{GG} \\
&\quad + \chi_Z \delta_e \Big[I_f^{(3)} \mathcal{F}_{QL} + \delta_f \mathcal{F}_{QQ} \\
&\quad + \frac{1}{2} s {\beta_f}^2 I_f^{(3)} \mathcal{F}_{QD}\Big]\Big), \\
\mathcal{A}_{-+\pm\pm} &= -2\sqrt{s} m_f \sin\vartheta \Big(Q_e Q_f \mathcal{F}_{GG} \\
&\quad + \chi_Z \Big[2 I_e^{(3)} I_f^{(3)} \mathcal{F}_{LL} + 2 I_e^{(3)} \delta_f \mathcal{F}_{LQ} \\
&\quad + \delta_e I_f^{(3)} \mathcal{F}_{QL} + \delta_e \delta_f \mathcal{F}_{QQ} \\
&\quad + \frac{1}{2} s {\beta_f}^2 I_f^{(3)} \Big(2 I_e^{(3)} \mathcal{F}_{LD} + \delta_e \mathcal{F}_{QD}\Big)\Big]\Big), \\
\mathcal{A}_{-+\pm\mp} &= s\,(1 \pm \cos\vartheta)\,\Big(Q_e Q_f \mathcal{F}_{GG} \\
&\quad + \chi_Z \Big[\,(1 \pm \beta_f)\,\Big(2 I_e^{(3)} I_f^{(3)} \mathcal{F}_{LL} \\
&\quad + \delta_e I_f^{(3)} \mathcal{F}_{QL}\Big) \\
&\quad + \delta_f \Big(2 I_e^{(3)} \mathcal{F}_{LQ} + \delta_e \mathcal{F}_{QQ}\Big)\,\Big]\Big), \\
\mathcal{A}_{--\pm\pm} &= 0, \qquad \mathcal{A}_{--\pm\mp} = 0,
\end{aligned}
\tag{5}
$$

where

$$
\cos\vartheta = \left(t - m_f^2 + \frac{s}{2}\right)\frac{2}{s\beta_f}\,, \quad \beta_f^2 = 1 - 4\frac{m_f^2}{s}\,. \tag{6}
$$

• In case of a CC annihilation process $\bar{u}d \to l\bar{\nu}$ with only $u$ being massive, there are two SFF and two independent HA, which read:

$$
\begin{aligned}
\mathcal{A}_{-++-} &= 8\sqrt{1 - m_u^2/s}\; s\,\chi\,\mathcal{F}_{LL}\,, \\
\mathcal{A}_{--\pm\pm} &= 2\sqrt{1 - m_u^2/s}\; s\, m_u^2\, \mathcal{F}_{LD}\,.
\end{aligned}
\tag{7}
$$

To conclude, the number of SFF and the number of independent HA always coincide. A general $2f \to 2f$ process with four different external fermions is described by 16 SFF and 16 HA.

## 3. VERSION 0.10 OF THE PROJECT

`SANC` is a **database-based** system. This means that there is a storage of source codes written in several languages, which talk to one another, being placed into a homogeneous environment written in `JAVA` (linker).

Starting from version `0.10`, `SANC` is developed as an exportable *software product*. `SANC` system consists of `SANC` servers living in the Internet (at present one has only one server, address *http://brg.jinr.ru*) which communicate among themselves.

`SANC` server provides access to various applications, performs compilation from several computer languages (`FORM3`, `FORTRAN`, `C++`, `PERL`, `JAVA`). It provides the so-called *intermediate access* which means that: 1) All the relevant one-loop diagrams are precomputed and stored; 2) There are several intermediate 'entries' to bypass CPU consuming computations. On the other hand, the full chain of calculation can be worked out in real time upon the user request. This option is intended to demonstrate the self-reproducibility of the full chain of calculation at any time.

Finally, at each computer one may install the `SANC` client, a multi-purpose environment for developing of the `SANC` system.

In the next two figures we show two main menus accessible by `SANC` client. Three field theories are accessible: QED, EW and QCD. Each theory has two main modes: `Precomputation` and `Processes`.

In Fig.2 we show all items of `Precomputation` menu for the EW theory. As seen, we have the full collection of one-loop `self-energies`, `vertices` and `boxes` which are met in $2f \to 2f$ processes.

## 4. CONCLUDING REMARKS

`SANC` clearly is a long-term project. Its first phase is realized in *demonstration version 0.10.*

Its second phase assumes the realization of the full chain of calculations at the one-loop level including *processes 2 → 3* and *decays 1 → 4.*

**Acknowledgment.** The authors are deeply indebted to W. von Schlippe for a critical reading of the manuscript and useful remarks.

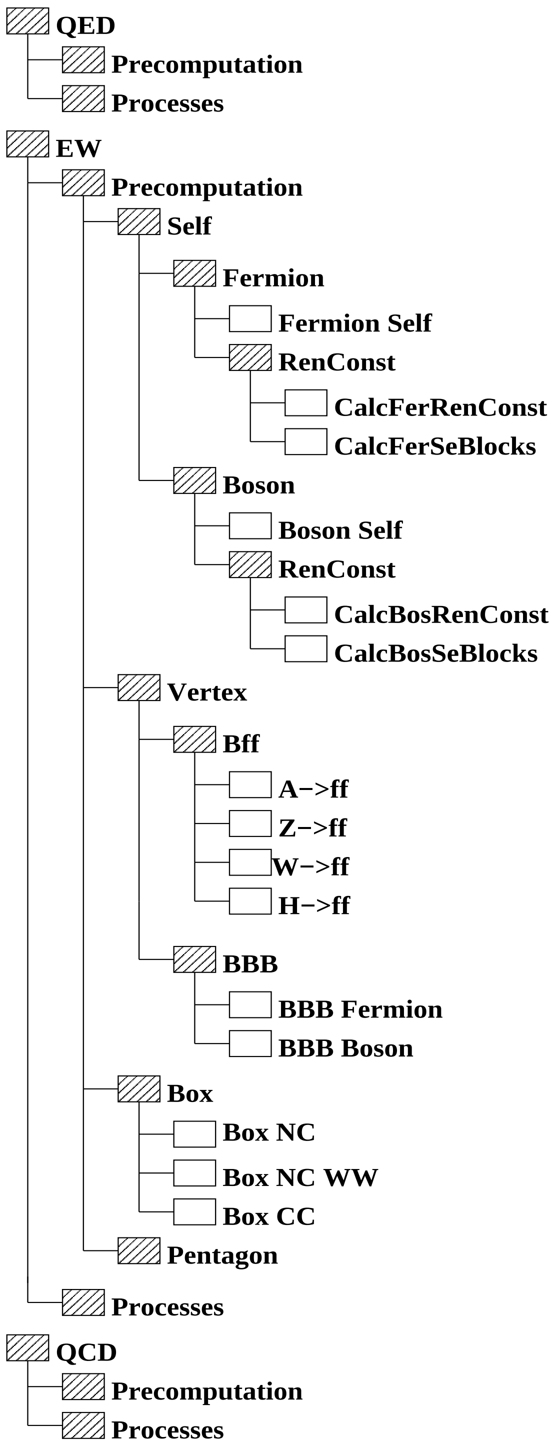


Figure 2. Precomputation for the EW theory.

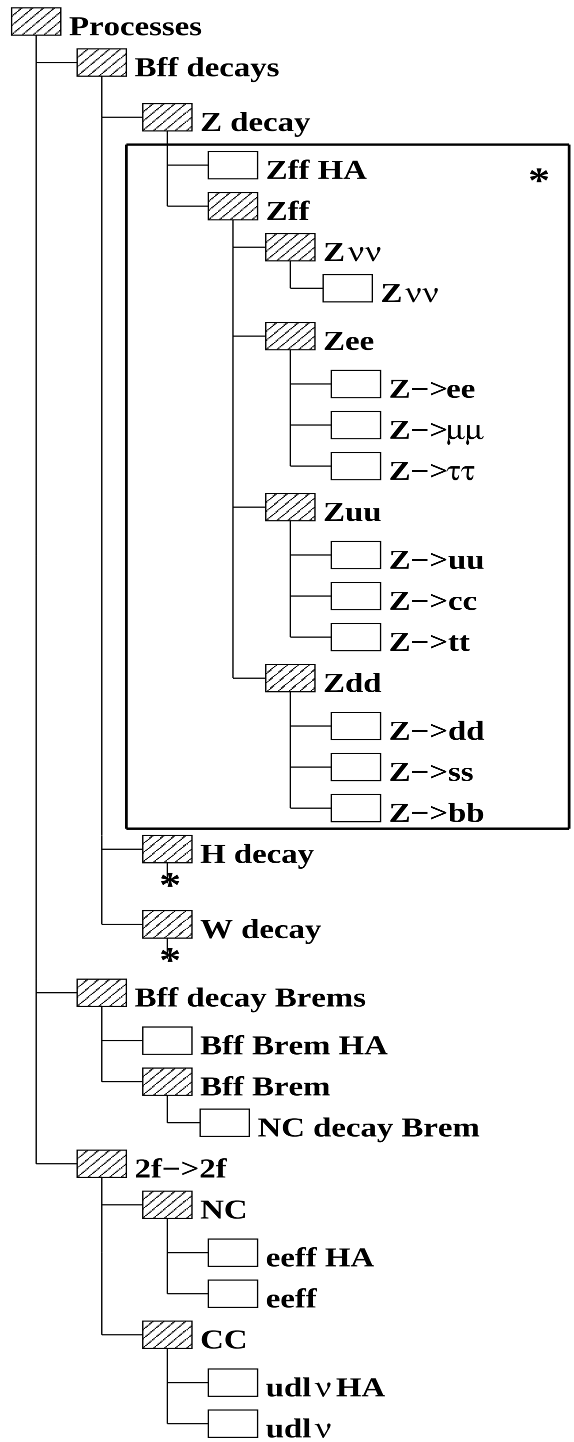


Figure 3. Presently available EW processes.

## REFERENCES


1. D. Bardin, G. Passarino, L. Kalinovskaya, P. Christova, A. Andonov, S. Bondarenko and G. Nanava, 'Project CalcPHEP: Calculus for precision high energy physics', hep-ph/0202004, CAAP-2001 Proceedings, Dubna 2001.
2. A. Andonov, D. Bardin, S. Bondarenko, P. Christova, L. Kalinovskaya, G. Nanava and G. Passarino, 'Project SANC (former CalcPHEP): Support of Analytic and Numeric calculations for experiments at Colliders', CERN-TH/2002-245, hep-ph/0209297, to be published in ICHEP2002 Proceedings.
3. A. Andonov, D. Bardin, S. Bondarenko, P. Christova, L. Kalinovskaya, G. Nanava and G. Passarino, 'SANC press release', to be published in ACAT2002 Proceedings.
4. L. Kalinovskaya, 'About implementation of $e^+e^- \to f\bar{f}$ processes into the framework of SANC system', to be published in ACAT2002 Proceedings.
5. P. Christova, 'QED Radiative Corrections within the SANC project', to be published in ACAT2002 Proceedings.
6. G. Nanava, 'A Monte Carlo simulation of decays within the SANC project', to be published in ACAT2002 Proceedings.
7. D. Bardin, P. Christova, L. Kalinovskaya and G. Passarino, *Eur.Phys.J.* **C22** (2001) 99–104.
8. D. Bardin, L. Kalinovskaya and G. Nanava, 'An electroweak library for the calculation of EWRC to $e^+e^- \to f\bar{f}$ within the CalcPHEP project', CERN-TH/2001-308, hep-ph/0012080.
9. A. Andonov, D. Bardin, S. Bondarenko, P. Christova, L. Kalinovskaya and G. Nanava, 'Further study of the $e^+e^- \to f\bar{f}$ process with the aid of CalcPHEP system', CERN-TH/2002-068, hep-ph/0202112.
10. A. Andonov, D. Bardin, S. Bondarenko, P. Christova, L. Kalinovskaya and G. Nanava, 'Update of one-loop corrections for $e^+e^- \to f\bar{f}$, first run of CalcPHEP system', hep-ph/0207156, to appear in *Particles and Nuclei.*
11. J. Küblbeck, M. Böhm, A. Denner, *Comput. Phys. Commun.* **60** (1990) 165;
    T. Hahn, M. Perez-Victoria, *Comput. Phys. Commun.* **118** (1999) 153;
    T. Hahn, *Nucl. Phys. Proc. Suppl.* **89** (2000) 231; T. Hahn, *Comput. Phys. Commun.* **140** (2001) 418;
    T. Hahn, C. Schappacher, 'The implementation of the minimal supersymmetric standard model in FeynArts and FormCalc', hep-ph/0105349.
12. J. Fleischer, T. Hahn, W. Hollik, T. Riemann, C. Schappacher and A. Wertenbach, 'Complete electroweak one-loop radiative corrections to top-pair production at TESLA: – a comparison', hep-ph/0202109;
    J. Fleischer, J. Fujimoto, T. Ishikawa, A. Leike, T. Riemann, Y. Shimizu and A. Wertenbach, 'One-loop corrections to the process $e^+e^- \to t\bar{t}$ including hard bremsstrahlung', hep-ph/0203220.
13. G. Montagna, O. Nicrosini, F. Piccinini and G. Passarino, *Comput. Phys. Commun.* **117** (1999) 278.
14. D. Bardin, M. Bilenky, P. Christova, M. Jack, L. Kalinovskaya, A. Olshevsky, S. Riemann and T. Riemann, *Comput. Phys. Commun.* **133** (2001) 229-395.
15. D. Bardin and G. Passarino, *The standard model in the making: Precision study of the electroweak interactions.* Oxford, UK: Clarendon (1999) 685 p.
16. R. Vega and J. Wudka, *Phys. Rev.* **D53** (1996) 5286.
17. J. A. M. Vermaseren, 'New features of FORM', math-ph/0010025.
18. R. Kleiss and W. Stirling, *Nucl. Phys.* **B262** (1985) 235.
19. S.Jadach, B. F. L. Ward, and Z. Was, *Phys. Lett.* **B449** (1999) 97.
20. E. Barberio, B. van Eijik and Z. Was, *Comput. Phys. Commun.* **66** (1991) 115.
21. S.Jadach, B. F. L. Ward, and Z. Was, *Comput. Phys. Commun.* **79** (1994) 503.
22. A. Andonov, S. Jadach, G. Nanava and Z. Was, 'Comparison of SANC with KORALZ and PHOTOS', CERN-TH/2002-315, November 2002.