1 User Guide

1.1 Getting started

1.1.1 SANC installation

To work with SANC, one must install a SANC client on ones computer. The SANC client can be downloaded from the SANC project homepage *http://sanc.jinr.ru* or *http://pcphsanc.cern.ch*. On the homepage select **Download**, then download the client, unzip it and follow the instruction in the README file.[1]

1.1.2 SANC windows

At the beginning of a client session the main SANC window opens, see Fig. 1,[2] with several **toolbars** and **windows** or **fields**:
• on top is the **Menu bar** with menus *File*, *Edit*, *Build*, *Applications* and *View*;
• underneath is a row of three **Toolbars**: File, Edit and Build
• underneath that on the left is the **SANC tree** field, and to the right of it the **Editors List** window;
• underneath is the **Output** window and underneath that is the **Console**;
• below, at the bottom, lies the **Status** bar.
Other fields do arise in the course of the work.

The five menus have the options shown in Table 1. Menus with → have further extensions. For example, *Toolbars* has four options; they duplicate the *File*, *Edit* and *Build* toolbars, which are activated by default, and a latent option *Memory*. When the latter option is activated, two numbers are displayed: the first one is the current usage of the Java Virtual Machine (JVM) memory, and the second one is the total size of the JVM memory. All options can be unchecked in menu *View* → *Toolbars* →.

Table 1: The SANC Menus and their options.

File	*Edit*	*Build*	*Applications*	*View*
Login ...	*Undo*	*Compile*	*Editor Form*	*Toolbars* →
Open Project ...	*Redo*	*Run S2N*	*Numeric Form*	*Projects*
Mount Filesystem →	*Cut*		*Graphics Form*	*Editors List*
Unmount Filesystem	*Copy*			*Processes Table*
Save	*Paste*			*Console*
Save All	*Find*			*Output*
Print ... →	*Replace*			*Status Bar*
Exit	*Settings*			*ProgressBar*
				Full Screen
				Look And Feel →
				Suggestions

1.1.3 Login procedure

• To log in, click the **Login** icon (the first icon of the File toolbar). The Login panel opens with a choice

[1] To install and run SANC client one should have the Java Runtime Environment (JRE) at least version 5.0 Update 5 installed, see section **Minimum System Requirements** of the **Download** page at the SANC project homepage.
[2] In the figure the windows are shown after several of the steps described below.

of SANC servers: *local*, *sanc.jinr.ru* and *pcphsanc.cern.ch*; choose one of the latter ones (the *local* server is for PCs which have the server itself installed), then enter the login name *guest* and password *guest*.
• Click the **Open Project** icon (the second icon of the File toolbar). This opens the **Open Project** panel. There are two projects: Lessons and SANC. Select project SANC and press **OK**; then the SANC tree appears in the SANC tree field.

1.1.4 The SANC tree

The SANC tree has three options: **QED, EW** and **QCD**. Selection of one of these opens the next level of options: **Precomputation** and **Processes**.

Here we describe the sequence of steps for option **EW** > **Processes**. The use of the **Precomputation** branch was described to an extent in Section 3 of Ref. [1].

The available processes are subdivided into **3legs** and **4legs**. The two branches of **3legs** are **3b** and **b2f** decays, and those of **4legs** are **4f** and **2f2b** processes; here **b** and **f** denote any *boson* and *fermion*, respectively. For each of the latter two there is a branch for **Neutral Current** and a branch for **Charged Current** processes. The next branching is into the available processes of that class.

1.1.5 Naming conventions

In SANC we use naming conventions for fields (or particles) shown in Table 2 where N is the field index, and in the columns headed "name" we show the names used internally in SANC. All associated parameter symbols are derived from these names. Thus the mass, charge and weak isospin of the electron are denoted mel, qel and i3el, respectively, also the vector and axial vector coupling constants (vel, ael) and their sum (vpael) and difference (vmael).

Table 2: List of fields.

bosons			fermions									QCD		
			1st generation			2nd generation			3rd generation					
N	field	name	N	field	name	N	field	name	N	field	name	N	field	name
1	A	gm	11	ν_e	en	15	ν_μ	mn	19	ν_τ	tn	23	g	gn
2	Z	z	12	e^-	el	16	μ^-	mo	20	τ^-	ta	24	Y_g	-
± 3	$W^\pm$	w	13	u	up	17	c	ch	21	t	tp			
4	H	h	14	d	dn	18	s	st	22	b	bt			
5	ϕ^0	-												
± 6	$\phi^\pm$	-												
7	X^+	-												
8	X^-	-												
9	Y_Z	-												
10	Y_A	-												

Figure 1: Main SANC window

1.2 Benchmark case 1: $b \to f f$ decays

1.2.1 Semianalytical calculation

Consider the $Z \to b\bar{b}$ decay. First we open the relevant branch of the `SANC` tree:

EW → Processes → b2f → Z → ff

There are three FORM programs: (**FF**) *Form Factor*, (**HA**) *Helicity Amplitudes*, and (**BR**) *Bremsstrahlung*.

Select (**FF**) by a click with the right mouse button, this also pulls down a menu. On the menu left-click on **Open**. A **Source Editor** window opens with three tags: **Form Editor**, **Fortran Editor**, and **Monte Carlo Editor**. The first of these is activated by default and the FORM source code is displayed in the field.

The particle indices can be seen in the **Console** field; by default they are: `typeB = 2` (Z boson), `typeU = 22` and `typeD = 22` (b quarks). To change the final state fermions, their particle numbers can be changed by editing them in the **Console** field and pressing `Enter`.[3]

After choosing the process, open the **Numeric Form** panel from the *Application* menu. In this panel the particle masses and other relevant information are displayed.

Next the FORM code is compiled by clicking on the **Compile** button — the first icon in the `Build` toolbar (or by pressing the **F7** function key). After compilation the FORM *log file* is shown in the **Output** field.

Clicking on the **Run S2N** button generates the FORTRAN code; the FORTRAN code can be seen in the **Output** field.

Repeat the sequence of steps for (**HA**) and (**BR**).

The progress of work can be monitored by activating the **Processes Table** (see Table 1).

The entire **Output** field is arranged in sheets with tags; for inspection any sheet can be brought to the forground by clicking on its tag.

Once the three FORM codes (**FF**), (**HA**) and (**BR**) have been compiled and transferred to the FORTRAN codes one can get the numeric results by the following sequence of operations:

(i) open the *FORTRAN editor* sheet of the `Editors List` (belonging to the (**FF**) FORM code),

(ii) open the **Numeric Form** panel from the `Applications` menu,

(iii) press the **Rehash** button at the bottom of the **Numeric Form** panel, then the **Compile** button.

The answer appears in the **Output** field. It consists of a list of **Input parameters** and a set of results: Γ(born), the total width [TotalWidth] in Born approximation, Γ(born+virt+soft) and the total width, Γ(born+virt+soft+hard). Also shown is the parameter ω, set to 10^{-10} GeV by default. This parameter defines the separation between soft and hard radiation. It can be modified in the corresponding box of the **Numeric Form** panel. Rerunning the program after changing the value of ω (using the sequence **Rehash** > **Compile**) gives a result that differs only in the value of Γ(born+virt+soft). The born+virt+soft width is sensitive to parameter ω and can become unphysical (negative) for very small values of ω. Increasing ω and rerunning gives positive values.

[3]This need be done only once for a particular choice; to repeat, put the cursor at the end of the **Console** field, press the down-arrow key, select the required line of particle numbers using the up- and down-arrow keys and confirm by pressing `Enter`.

1.2.2 Monte Carlo calculation

The user can also carry out a Monte Carlo calculation generating various histograms: **Photon Energy**, **Fermion Energy**, **Photon-Fermion Angular** and **Fermion-antiFermion Angular**. To do this one must bring the Monte Carlo sheet of the **Numeric Form** to the foreground, check the boxes of the required histograms, then bring the MC sheet of the **Editors List** to the forground and rerun the program by clicking the **Compile** button. After a while the **Histogram Form** is displayed. This form has a menu bar; menu *Option* allows display of the histogram statistics. On the Monte Carlo sheet one can also select the random number generator,[4] modify the number of MC events and the range of real photon energies $k_{0\,min}$ and $k_{0\,max}$, where $k_{0\,min} = \omega$ and $k_{0\,max}$ can be used as an experimental cut.
The **Rehash** button must be pressed after each change in the **Numeric Form** before clicking on the **Compile** button.

The results for the decay rates (in GeV) of the semianalytical calculation and of the Monte Carlo calculation for 100 000 events are summarised in Table 3. The numerical values are truncated to 6 significant figures.

Table 3: Benchmark Results for $\Gamma(Z \to b\bar{b})$ decay

	Γ_{Born}	$\Gamma_{Born+virt+soft}$	Γ_{Total}
SA	0.355428	0.335345	0.358738
MC 100 k			0.358742 ± 0.000718

1.3 Benchmark case 2: the process $2f \to 2f$

Consider the $4f$ **CC** process $f_1\bar{f}_1' \to f\bar{f}'$. Implemented are the processes $u\,\bar{d} \to \ell^+\,\nu_\ell$, its charge conjugate and the decay $t \to b\,\ell^+\,\nu_\ell$. For each process there are three FORM programs: (**FF**) *Form Factor*, (**HA**) *Helicity Amplitudes*, and (**BR**) *Bremsstrahlung*. Each of these in turn is opened, compiled and run as above in Section 1.2.

For process $u\,\bar{d} \to e^+\,\nu_e$ we have in the **Console** window the particle indices shown in Table 4. These

Table 4: Assignment of particle numbers for process $u\,\bar{d} \to e^+\,\nu_e$

typeIU = 14	initial Up-type antiparticle (d quark)
typeID = 13	initial Down-type particle (u quark)
typeFU = 12	final Up-type antiparticle (positron)
typeFD = 11	final Down-type particle (neutrino)

can be changed to typeIU = 13, typeID = 14, typeFU = 11 and typeFD = 12 for process $\bar{u}\,d \to e^-\,\bar{\nu}_e$ by editing the particle numbers as explained above[5].

Next bring the *Fortran Editor* sheet of the **Editors List** and the **Numeric Form** panel to the foreground. Shown on the **Numeric Parameter** sheet are the particle masses in GeV and the CMS energy in GeV, also the cosine of the CMS angle between the incident and outgoing particle momenta.

Click on the **Rehash** button at the bottom of the **Numeric Form** panel: the main module of FORTRAN code appears in the *Fortran Editor* sheet of the **Editors List**. Then click on **Compile**. The

[4] Three random number generators provided are: Ranlux, Ranmar and Mersenne Twister.
[5] See Table 2 for definitions of particle types typeXX.

final answer appears in the **Output** field. It consists of the parameters used (α, G_F, particle masses, the 't Hooft scale μ and the Mandelstam variables), and the resulting differential cross sections $d\,\sigma/d\,\cos\,\theta$ in picobarns in the Born approximation and Born+one-loop. The results for the default parameters and for several scattering angles are summarised in Table 5. The numerical values are truncated to 6 figures.

Table 5: CMS differential cross sections in pb for $u\bar{d} \to e^+\nu_e$

		$\sqrt{s}$ GeV		
$\cos\theta$		40	80	120
-0.9	Born	3.33973	9361.58	11.3047
	Born + one-loop	3.50144	9379.90	22.2332
-0.5	Born	2.08155	5834.78	7.04592
	Born + one-loop	2.17360	5845.82	10.8827
0.0	Born	0.92513	2593.23	3.13152
	Born + one-loop	0.96582	2600.17	4.43144
0.5	Born	0.23128	648.308	0.78288
	Born + one-loop	0.24296	652.669	1.22250
0.9	Born	0.00925	25.9323	0.03131
	Born + one-loop	0.01062	28.2548	0.07098

Here the one-loop corrections are purely weak and QED corrections comprise one-loop virtual QED corrections and soft and hard radiations.

The Born+one-loop cross section is insensitive to the 't Hooft scale parameter μ which cancels between one-loop electroweak and the QED part of virtual corrections.

Input parameters can be changed by editing the appropriate field of the **Numeric Form** panel and pressing the **Rehash** button. Again the **Rehash** button must be pressed before pressing **Compile**. [6]

In the NC sector there are many more processes. Here f_1 is a *massless* fermion of the *first generation*[7] or *any* neutrino, and f is *any* fermion. All procedures described above for the CC processes apply also in this case.

Monte Carlo calculations are not yet implemented for $2 \to 2$ processes.

1.4 Benchmark case 3: the process $H \to f_1\bar{f}_1 Z$

Here we consider the $2f2b$ **NC** process $H \to f_1\bar{f}_1 Z$.

One can open the relevant branch of the `SANC` tree as follows:

EW → Processes → 4 legs → 2f2b → Neutral Current → H→f1f1Z

For this process there are three FORM programs: (**FF**) *Form Factors*, (**HA**) *Helicity Amplitudes*, and (**BR**) *Bremsstrahlung*. Each of them in turn is opened, compiled and run as described in Section 1.2.

For the process $H \to e^+e^- Z$ we have in the **Console** window the particle indices shown in Table 6.

These can be changed to typeID (typeFU) = 13,14 for up- and down-quarks in the final state of the process $H \to (u\bar{u}, d\bar{d})Z$ by editing the particle numbers as explained in Section 1.2. [8].

[6] To produce the whole Table 5 one can set flag `tbprint = 1` in the *Fortran Editors* sheet. After editing the code just press **Compile**.; there is no need to press the **Rehash** button.

[7] The masses of first generation fermions are retained only in logs to regulate collinear singularities.

[8] See Table 2 for definitions of particle types typeXX.

Table 6: Assignment of particle indices for the process $H \to e^+e^-Z$

typeIU = 4	initial partile (H-boson)
typeID = 12	final particle (electron)
typeFU = 12	final antiparticle (positron)
typeFD = 2	final particle (Z-boson)

Next bring the *Fortran Editor* sheet of the **Editors List** and the **Numeric Form** panel to the foreground. Shown in the **Numeric Parameter** sheet are the particle masses in GeV and the invariant mass of $f\bar{f}Z$ compaund in GeV, also the cosine of the angle ϑ_l defined in Fig.4 of Ref. [2].

Click on the **Rehash** button at the bottom of the **Numeric Form** panel: the main module of FORTRAN code appears in the *Fortran Editor* sheet of the **Editors List**. Then click on **Compile**. The final answer appears in the **Output** field. It consists of the parameters used (α, G_F, particle masses, the 't Hooft scale μ and the invariant mass of compaund), and the resulting differential width $d^2\Gamma/ds\,d\cos\vartheta_l$ in the Born approximation and Born+one-loop. The results for the default parameters and for several scattering angles are summarised in Table 7.

Table 7: The double differential widths for $H \to e^+e^-Z$ channel in α-scheme: first row: the double differential decay width $d^2\Gamma/ds\,d\cos\vartheta_l \cdot 10^8\mathrm{GeV}^{-1}$ at the Born level; second row: the double differential decay width at the 1-loop level; third row: relative correction $\delta = d^2\Gamma^{1-\mathrm{loop}}/d^2\Gamma^{\mathrm{Born}}$. Numerical values are truncated to 6 figures.

$H \to e^+e^-Z$					
		Part 1, $d^2\Gamma/ds\,d\cos\vartheta_l \cdot 10^8$, GeV^{-1}			
	$\sqrt{s}$, GeV	1	3	10	28
Born	$\cos\vartheta_l = \pm 0.9$	0.02019	0.02144	0.03505	0.04261
1-loop		0.21060	0.04321	0.03874	0.04602
δ		9.43022	1.01508	0.10537	0.07984
Born	$\cos\vartheta_l = \pm 0.5$	0.07914	0.07964	0.08478	0.04353
1-loop		0.21495	0.09898	0.09150	0.04701
δ		1.71589	0.24281	0.07922	0.07976
Born	$\cos\vartheta_l = 0.0$	0.10546	0.10562	0.10698	0.04394
1-loop		0.21695	0.12394	0.11510	0.04745
δ		1.05716	0.17343	0.07586	0.07972

Input parameters can be changed by editing the appropriate field of the **Numeric Form** panel and pressing the **Rehash** button. Again the **Rehash** button must be pressed before pressing **Compile**.

To produce the whole Table 7 one can consult the footnote[6].

One can also produce the differential width $d\Gamma/ds$ and total width Γ in GeV by integrating the above differential width. To produce these numbers one can set flag `inflag = 1,2`, respectevely, in the *Fortran Editors* sheet. After editing the code just press **Compile**; there is no need to press the **Rehash** button.

References

[1] A. Andonov *et al.*, Comput. Phys. Commun. **174** (2006) 481–517.

[2] D. Bardin, S. Bondarenko, L. Kalinovskaya, G. Nanava, L. Rumyantsev and W. von Schlippe, "SANCnews: Sector $ffbb$," hep-ph/0506120.