OPUCEM library: L'User's Manual (opucem-00-00-04)

December 16, 2010

1 Introduction

OPUCEM (pronounced ö-peu-gem, with o-umlaut as in French deux) is a C library which combines formulas from a multitude of references for calculating Peskin-Takeuchi parameters S-T-U. The aim is to provide a minimum-dependence code to facilitate the sharing of formulas, such that: article authors can provide typo-free versions of their formulas that match their published numerical results. Cross-checks are done to compare formulas in different papers directly. Reviews by any interested party is possible. Further studies can refer to a certain version of the code and future errata can easily be done. We aim to provide extra test functions in our library that does the cross-checking of different formulas - against approximations, against other calculations of the same quantities or against limiting cases of other quantities.

Currently implemented are:

- new lepton doublets with Dirac-or-Majorana-type neutral leptons
- new quark doublets
- SM and 2HDM Higgs boson
- recalculation of the SM origin in the S-T plane based on reference values of the masses of the top quark and the Higgs boson

References for the current code include:

- M.S. Chanowitz, Phys. Rev. D79 (2009) 113008
- H.-J. He, N. Polonsky, S. Su, Phys. Rev. D64 (2001) 053004
- J.R. Forshaw, D.A. Ross, B.E. White, JHEP0110:007 (2001)
- A.A. Natale, P.S. Rodriges Da Silva, Mod. Phys. Lett. A10 (1995) 1829
- B.A. Kniehl, H.-G. Kohrs, Phys. Rev. D48 (1993) 225
- E. Gates, J. Terning, Phys. Rev. Lett. 67 (1991) 1840

Further details and some example physics results can be found in [9].

2 Requirements, Download and Installation

OPUCEM-00-00-03 onwards compiles without any dependencies, but requires the C++ Technical Report 1 (TR1) extensions to the std::complex templates. Therefore it will only compile with compilers supporting those extensions, such as GNU g++ 4.2 or later. The graphical user interface, auxiliary tools and some code examples require the ROOT package to be present [8].

To download the latest development version of OPUCEM, you can checkout the trunk from SVN:

```
svn co http://svn.hepforge.org/opucem/trunk opucem
```

Alternatively, you can do the same by clicking the "Zip Archive" link located under the "Download in other formats:" phrase on our SVN web interface:

https://projects.hepforge.org/opucem/trac/browser/trunk

If you prefer to checkout the latest stable version, please have a look at our tags directory:

https://projects.hepforge.org/opucem/trac/browser/tags

The latest version that uses pure C (and thus is compilable with older compilers that support the C99 standard) is the 00-00-02 tag. To see how we switched to C++ (not in philosophy, but simply replacing C99 complex types with C++ std::complex templates), you can have a look at the 22nd svn changeset summary here:

https://projects.hepforge.org/opucem/trac/changeset/22/trunk

Finally, OPUCEM has mostly been developed and tested on Mac OSX and Linux so far. If you would like to use it on Windows, we recommend using cygwin or mingw. While we don't maintain it, we created a port of the 00-00-02 tag at some point and if you are a Windows user, you might want to see what we needed to change/fix for this port (a lot is explained in the makefile.cygwin) :

https://projects.hepforge.org/opucem/trac/changeset/20/branches/opucem-win

3 Running some examples

3.1 Kniehl and Khors

This is an simple example file that exactly reproduces Fig. 1 of Ref. [4], "Oblique radiative corrections from Majorana neutrinos". Executing the kniehl_khors_fig1.sh script found in examples/prd48_pg225 subdirectory first reproduces the numbers that are input to the plot and then uses ROOT to recreate the plot itself.

3.2 SM4 and the command line

This is the default example compiled automatically when the *make* command is invoked. The output binary is a small command-line program that does not require ROOT. It is used to compute S and T for the 4-family Standard Model (SM4). When it is run as *./st.exe* the program will print what is required as command line parameters (masses and mixings). The various input parameters (in the order they should be given) are u4 d4 s34 n4 l4 H [n4_heavier] - masses in GeV, s34=|sin theta_34| - absolute value of the mixing between 3rd and 4th generation quarks. A typical run could be

./st.exe 490 550 0.1 550 550 150 850

which results in an output as: S = 0.270106 T = 0.201198 R = 5.261443

3.3 SM4 and the graphical user interface

Fig. 1 shows the functional GUI components. Variables set up in the user inputs section are passed to the OPUCEM library and they form the function signatures. A sub-set of the entered values is used each time as necessary. Details of the computation are shown on the log view such as but not limited to the type of the calculation, input values and calculated outputs. The resulting coordinate is marked on the T-S plot (i.e. Op control button event). The last calculated coordinate is marked in red whereas all the others are in black. The content of the log file and the T-S plot can be saved in the *out* directory (i.e. Print control button event).

4 Summary of all function calls in the OPUCEM library

4.1 Higgs Boson related functions

double **THSM** (double Z, double $s2w$, double h);

THSM function returns the one loop exact contribution of a SM Higgs boson of mass h to the oblique parameter T. The mass of the Z boson and the value of the square of the sine of the Weak angle ($s2w$) are also input parameters.

double **SHSM** (double Z, double h);

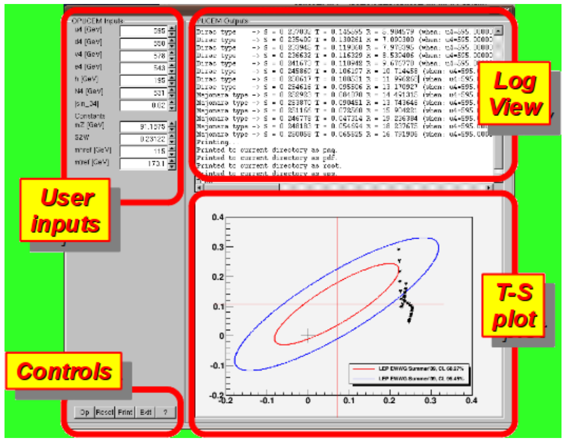

Figure 1: The GUI components

SHSM function returns the contribution of a SM Higgs boson of mass h to the oblique parameter S. The mass of the Z boson is the input parameter.

double **SH_2HDM** (double Z, double H, double A, double Hc, double h, double b, double a);

SH_2HDM function returns the one loop exact contribution of a 2 Higgs Doublet Model bosons to the oblique parameter S. The mass of the Z boson, the mass of the CP odd neutral Higgs A, CP even SM-like Higgs boson, h and its heavier parter H, and the mass of the charged Higgs, Hc are the mass related input parameters. Additionally the user is expected to supply two rotation angles, β (b) and α (a). β is defined via tanβ= $\langle H2\rangle/\langle H1\rangle$ with $H1$ ($H2$) being the Higgs doublet of negative (positive) hypercharge and α is the rotation angle for obtaining the CP-even mass-eigenstates (h, H).

double **SH** (double Z, double h);

SH function returns the one loop exact contribution of a SM Higgs boson of mass h to the oblique parameter S. The mass of the Z boson is the input parameter. This is the 2HDM S calculation, adapted to SM Higgs.

double **TH_2HDM** (double Z, double W, double $s2w$, double H, double A, double Hc, double h, double b, double a);

TH_2HDM function returns the one loop exact contribution of a 2 Higgs Doublet Model bosons to the oblique parameter S. The mass of the Z and W bosons, the mass of the CP odd neutral Higgs A, CP even SM-like Higgs boson, h and its heavier parter H, and the mass of the charged Higgs, Hc are the mass related input parameters. Additionally the user is expected to supply the value of the square of the sine of the Weak angle ($s2w$), and the two rotation angles, β (b) and α (a). β is defined via tanβ= $\langle H2\rangle/\langle H1\rangle$ with $H1$ ($H2$) being the Higgs doublet of negative (positive) hypercharge and α is the rotation angle for obtaining the CP-even mass-eigenstates (h, H).

double **TH** (double Z, double W, double $s2w$, double h);

TH function returns the one loop exact contribution of a SM Higgs boson of mass h to the oblique parameter T. The mass of the Z and W bosons together with the value of the square of the sine of the Weak angle ($s2w$) are also input parameters. This is the 2HDM T calculation, adapted to SM Higgs.

4.2 Fermion doublet related functions for Dirac type fermions

double **SF** (double Y, double Nc, double $m1$, double $m2$, double Z);

SF function returns the one loop exact contribution of a Dirac type fermion doublet of masses $m1$ and $m2$ to the oblique parameter S. The mass of the Z boson, the hypercharge of the fermions, Y and the number of QCD colors, Nc are the input parameters. For quarks Nc is 3 while for the leptons it is 1.

double **TF** (double Nc, double $m1$, double $m2$, double Z, double $s2w$);

TF function returns the one loop exact contribution of a Dirac type fermion doublet of masses $m1$ and $m2$ to the oblique parameter T. The mass of the Z boson, the value of the square of the sine of the Weak angle ($s2w$) and the number of QCD colors, Nc are the input parameters. For quarks Nc is 3 while for the leptons it is 1.

double **UF** (double Nc, double $m1$, double $m2$, double Z);

UF function returns the one loop exact contribution of a Dirac type fermion doublet of masses $m1$ and $m2$ to the oblique parameter U. The mass of the Z boson and the number of QCD colors, Nc are the input parameters. For quarks Nc is 3 while for the leptons it is 1.

4.3 Fermion doublet related functions for Majorana type leptons

double **SM** (double $m1$, double $m2$, double mE);

SM function returns the one loop approximate contribution of a lepton doublet with Majorana type neutrinos to the oblique parameter S. The input parameters are the mass of the charged lepton, mE and the masses of the neutral leptons, $m1$ and $m2$ where $m2$ is the heavier one. This function gives the same results as **SMapprox** defined below. It is simply the C implementation of the formula as it exists in Ref. [5] and was kept as a cross-check and for backwards compatibility. We recommend using **SMapprox** since that function was improved to also handle the equal-neutrino-mass case properly.

double **TM** (double $m1$, double $m2$, double mE, double $s2w$, double W);

TM function returns the one loop exact contribution of a lepton doublet with Majorana type neutrinos to the oblique parameter T. The input parameters are the mass of the charged lepton, mE, the masses of the neutral leptons, $m1$ and $m2$ where $m2$ is the heavier one, the value of the square of the sine of the Weak angle ($s2w$) and the mass of the W boson. This function gives exactly the same results as **TMexact** defined below. It is simply the C implementation of the formula as it exists in Ref. [5] and was kept as a cross-check and for backwards compatibility.

double **SMapprox**(double $m1$, double $m2$, double mE);

SMapprox function returns the one loop approximate contribution of a lepton doublet with Majorana type neutrinos to the oblique parameter S. The input parameters are the mass of the charged lepton, mE and the masses of the neutral leptons, $m1$ and $m2$ where $m2$ is the heavier one.

double **UMapprox**(double $m1$, double $m2$, double mE);

UMapprox function returns the one loop approximate contribution of a lepton doublet with Majorana type neutrinos to the oblique parameter U. The input parameters are the mass of the charged lepton, mE and the masses of the neutral leptons, $m1$ and $m2$ where $m2$ is the heavier one.

double **TMexact**(double $m1$, double $m2$, double mE, double $s2w$, double W);

TMexact function returns the one loop exact contribution of a lepton doublet with Majorana type neutrinos to the oblique parameter T. The input parameters are the mass of the charged lepton, mE and the masses of the neutral leptons, $m1$ and $m2$ where $m2$ is the heavier one, the value of the square of the sine of the Weak angle ($s2w$) and the mass of the W boson.

double **SMexact**(double $m1$, double $m2$, double mE, double Z);

SMexact function returns the one loop exact contribution of a lepton doublet with Majorana type neutrinos to the oblique parameter S. The input parameters are the mass of the charged lepton, mE and the masses of the neutral leptons, $m1$ and $m2$ where $m2$ is the heavier one, and the mass of the Z boson. See also **SMexactWithChecks** function below, which is the recommended version of this function for the endusers.

double **SpUMexact**(double $m1$, double $m2$, double mE, double W, double Z);

SpUMexact function returns the one loop exact contribution of a lepton doublet with Majorana type neutrinos to the sum of the oblique parameters S and U. The input parameters are the mass of the charged lepton, mE and the masses of the neutral leptons, $m1$ and $m2$ where $m2$ is the heavier one, and the mass of the Z boson. See also **UMexactWithChecks** function below, which is the recommended way of obtaining U itself.double **SMexactWithChecks**(double $m1$, double $m2$, double mE, double Z);

SMexactWithChecks function is the recommended version of the **SMexact** function described above. Underlying the Majorana S and U formulas from Ref.~[4] are complex integrals and subtractions of infinities. The implementation of these require computing the difference between two very large numbers to obtain very small results. Therefore the precision of the underlying computer variables becomes an issue. SMexactWithChecks does cross-checks of the results and warns the end-user if they appear suspicious. **SMexact** function should only be used when speed of computation is an important constraint and the enduser is willing to cross-check the results later.

double **UMexactWithChecks**(double $m1$, double $m2$, double mE, double $s2w$, double Z, double $smexact = 0$);

UMexactWithChecks function is the recommended way of obtaining the U contributions from the lepton doublet with Majorana neutrinos, as mentioned above under the description of **SpUMexact**. Please see the description of **SMexactWithChecks** function above for an explanation of why we recommend this function for the endusers. The last argument of this function, *smexact*, allows the enduser to supply an already computed S value to speed up the computation. If the default value of 0 is given, **UMexactWithChecks** calls **SMexactWithChecks** internally.

4.4 Auxiliary functions

double **SshiftFromRef**(double h, double $href$, double t, double $tref$, double Z);

SshiftFromRef function returns the origin shift in oblique parameter S, due to utilization of different reference values of Higgs and top quark masses. The function has as input parameters, the current value of Higgs mass, h, its reference (or original) value, $href$, the current value of top quark mass, t, its reference (or original) value , $tref$, and the mass of the Z boson.

double **TshiftFromRef**(double h, double $href$, double t, double $tref$, double Z, double $s2w$);

TshiftFromRef function returns the origin shift in oblique parameter T, due to utilization of different reference values of Higgs and top quark masses. The function has as input parameters, the current value of Higgs mass, h, its reference (or original) value, $href$, the current value of top quark mass, t, its reference (or original) value , $tref$, the mass of the Z boson and the value of the square of the sine of the Weak angle ($s2w$).

double **Tfor34mix**(double $mu4$, double $md4$, double mt, double mb, double $s2th34$, double Z, double $s2w$) ;

Tfor34mix function returns the origin shift in oblique parameter T, due to mixing between the quarks of the third and fourth generations. The function has as input parameters, the masses of the fourth generation quarks ($mu4$ and $md4$), the masses of the third generation quarks (mt and mb), the value of the square of the sine of mixing angle between 3rd and 4th generations, the mass of the Z boson and the value of the square of the sine of the Weak angle ($s2w$).

References

[1] H.-J. He, N. Polonsky and S. Su, Phys. Rev. D **64** (2001) 053004.

[2] J.R. Forshaw, D.A. Ross, B.E. White, JHEP0110:007 (2001).

[3] A.A. Natale, P.S. Rodriges Da Silva, Mod. Phys. Lett. A10 (1995) 1829.

[4] B.A. Kniehl, H.-G. Kohrs, Phys. Rev. D48 (1993) 225.

[5] E. Gates, J. Terning, Phys. Rev. Lett. 67 (1991) 1840.

[6] D.C. Kennedy. and B. W. Lynn, Nuclear Physics B322 (1989) 1 54.

[7] G. Bhattacharyya, S. Banerjee and P. Roy, PRD45, 3 (1992) R740.

[8] I. Antcheva et al., Comput. Phys. Commun. 180, 12 (2009) 2499. `http://root.cern.ch`

[9] OPUCEM paper, `http://arxiv.org/abs/1005.2784`