

An Upgraded Version of the Generator BCVEGPY2.0 for Hadronic Production of B_c Meson and Its Excited States

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Summary of the changes (improvements) :

(1) The structure and organization of the program have been changed a lot. The new version package BCVEGPY2.1 has been divided into several modules with less cross communication among the modules (some old version source files are divided into several parts for the purpose). The main program is slimmed down and all the further actions are decoupled from the main program so that they can be easily called for various applications. All of the Fortran codes are organized in the main code directory named as *bcveppy2.1*, which contains the main program, all of its prerequisite files and subsidiary ‘folders’ (subdirectory to the main code directory). The method for setting the parameter is the same as that of the previous versions [1,2], i.e. the parameters are set in a file named *parameter.F*. Each subsidiary ‘folders’ contains the necessary files to complete specific tasks accordingly. And there are totally seven modules/‘folders’ in the program:

- The module **generate**: it is the key module, which contains the files for generating the B_c events. There are seven source files in this ‘folder’: *evntinit.F*, *colorflow.F*, *genevnt.F*, *py6208.F* (a nickname of PYTHIA6.208 [3]), *totfun.F*, *outerpdf.F* and *initmixgrade.F*. The function of the module **generate** is to set the initialize conditions for event simulation; to establish a connection with PYTHIA [3]; to establish a connection to the parton distribution functions (PDFs) that are not included in PYTHIA according to specific need; to record the color flow information of the generated B_c events and may provide it according to one’s need; to calculate the kernel for phase space integration with the help of **swave** module and **pwave** module; to do the phase space integration with the help of **phase** module. A useful trick for generating the mixed type of B_c events is suggested (three types of mixed events are provided in the generator [2], e.g. by setting the parameter *IMIXTYPE=2*, one can generate the mixed events for the two color-singlet $(c\bar{b})$ -quarkonium states $(c\bar{b})_1(^1S_0)$ and $(c\bar{b})_1(^3S_1)$). The file *initmixgrade.F* is used to initialize the importance sampling function for Monte Carlo simulation, i.e., either by using the importance sampling function given by the current VEGAS running [4] or by using the existed importance sampling function recorded in an existed grade file in *data* subdirectory that has already been generated by earlier VEGAS running. Once the importance sampling function has been obtained

by VEGAS, it is recorded in a grade file (with suffix `.grid`) automatically, and can be conveniently used (by `initmixgrade.F`) for later usage without running VEGAS again. Some more detail on this point will be shown in the following item (2).

- The module **phase**: it contains the files for generating the allowed phase-space point and for generating an importance sampling function with VEGAS program [4]. It contains three source files: `phase_gen.F`, `phase_point.F` and `vegas.F`.
- The module **swave**: it contains the files for calculating the square of the amplitudes for producing the four color-singlet and color-octet $(c\bar{b})$ -quarkonium in S -wave: $(c\bar{b})_{\mathbf{1}}(^1S_0)$, $(c\bar{b})_{\mathbf{1}}(^3S_1)$, $(c\bar{b})_{\mathbf{8}}(^1S_0)$ and $(c\bar{b})_{\mathbf{8}}(^3S_1)$, where the subscripts **1** and **8** stand for color-singlet and color-octet accordingly. Note that in fact the configurations $(c\bar{b})_{\mathbf{8}}(^1S_0)$ and $(c\bar{b})_{\mathbf{8}}(^3S_1)$ play comparatively important role only for the production of the P -wave excited B_c states as shown in Ref [5]. It contains five source files: `s_bound.F`, `s_common.F`, `s_foursets.F`, `s_free.F` and `s_samp.F`.
- The module **pwave**: it contains the files for calculating the square of the amplitudes for producing the four color-singlet $(c\bar{b})$ -quarkonium in P -wave: $(c\bar{b})_{\mathbf{1}}(^1P_1)$ and $(c\bar{b})_{\mathbf{1}}(^3P_J)$ ($J = 1, 2, 3$). It contains six source files: `p_lorentz.F`, `p1p1amp.F`, `pj0amp.F`, `pj1amp.F`, `pj2amp.F` and `p_samp.F`.
- The module **pybook**: it contains the files for initializing the subroutine PYBOOK of PYTHIA to record the events. The user may conveniently switch off this module in the main program to use his/her own way to record the data. It contains five source files: `pybookinit.F`, `uphistrange.F`, `uppydump.F`, `uppyfact.F` and `uppyfill.F`.
- The module **setparameter**: it contains the files for inner use of the parameters (mainly generates some short notations for the parameters) that have been set in `parameter.F`. It has only two source files: `simparameter.F` and `uperror.F`, where `uperror.F` lists some typical error messages for the cases when the input parameters are out of allowed (reasonable) range.
- The module **system**: it contains files to open or close the record files and to print out certain running messages at the intermediate steps according to need, which may tell

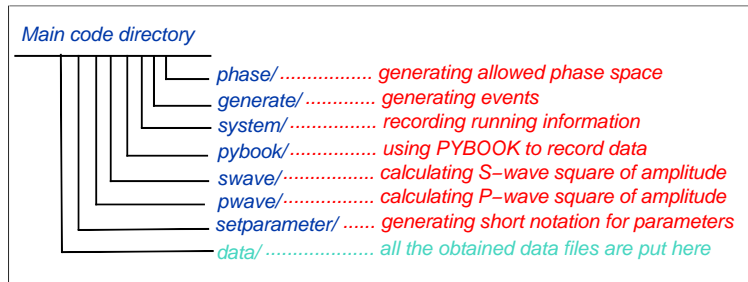


FIG. 1: The schematic structure for the new version of BCVEGPY.

the users at what step the program is running. It contains six source files: `upopenfile.F`, `uplogo.F`, `vegaslogo.F`, `updatefile.F`, `upclosegradfile.F` and `upclosepyfile.F`.

Each module is equipped with its own **makefile** that will be used to make a library of the same name, e.g. the **makefile** in the ‘folder’ `swave/` will be used by the GNU command **make** to generate a library `swave.a`. These sub-makefiles are orchestrated by a master **makefile** in the main code directory. Libraries required for the main program are listed in the `LIBS` variable of the master **makefile** and built automatically by invoking the sub-makefiles:

`LIBS = generate.a swave.a pwave.a phase.a setparameter.a system.a pybook.a`

In the way that based on **makefile** then the **make** command builds an executable file whose default name is **run**, the program acquires good modularity and code reusability, and the user can easily make the BCVEGPY generator to suit his/her experimental simulation environment as wish. Namely, to connect this generator with his/her own generator package such as ANTENNA (used by ATLAS group), LHCb (used by LHCb group) and SIMUB (used by CMS group)¹ only a few pieces of the program need to be changed. By doing this way, the time for compiling the Fortran source files can be saved, because once the source file has been compiled, it does not need to be recompiled again unless some changes have been made. The schematic structure of the program is shown in FIG. 1. Note that in order to let the **make** command work smoothly, especially, to deal with some preprocessor parameters in the source files, all the suffixes of the source files (with suffix **.for**) in the

¹ The first version BCVEGPY1.0 has already been introduced into ANTENNA [1,8] and SIMUB [9], and the import of BCVEGPY2.1 into LHCb package GAUSS is in progress [10].

original version of BCVEGPY2.0 [2] are renamed as **.F** and the suffixes of the original header files (with suffix **.f**) are renamed as **.h**.

(2) To simulate the events in mixture of the B_c and its excited states properly and in order to save CPU time, we offer an additional option in the package BCVEGPY2.1: by setting IVEGASOPEN=0 and IGRADE=1, one may generate the mixed B_c events just by reading the existent importance sampling function and total cross-section from ‘previous’ VEGAS runs for the production, when they have been saved in data files with `initmixgrade.F` accordingly. Thus, it means that when using the package under the option, one runs VEGAS once enough. Whereas, in BCVEGPY2.0 [2], there is only one option by setting IVEGASOPEN=1: it is to run VEGAS every time, although the importance sampling function obtained by each run is recorded in an existed grade file in the *data* subdirectory. For the new option offered here, the trick to save CPU time is not to run VEGAS, once the importance sampling function has been recorded in the **.grid** file already.

(3) In the package BCVEGPY2.1, for testing the importance sampling function obtained by VEGAS and simulating the true situation as well as possible, we have further offered another option: with setting IVEGASOPEN=0 and IGRADE=0, VEGAS or the importance sampling function (grade function) generated in previous runs will not be used at all. In this case, being different from the other options, all of the files with suffix **.grid** must be generated and saved via previous run(s) for the states which one would like to mix according to their weights. Namely one should have them in advance, because the program needs to read the total cross-sections of these states from the **.grid** files accordingly, so as to determine the relative weight of each state in making the mixing correctly.

(4) As stated in Ref. [2], the precision of the generated importance sampling function by running VEGAS can be improved by properly adjusting the maximum iteration number, the number of calls to the integrand in each time of the iteration, and the number of bins (the $[0, 1]$ region is divided into how many sub-regions) as well. In the present version, we define three overall parameters: NVEGITMX, NVEGCALL and NVEGBIN in the head file `invegas.h`, with these three parameters one can easily adjust them. Similarly, for convenience, the parameters which are not changed frequently are also defined in the source

file run.F, e.g. NUMOFEVENTS (number of events to be generated), ENERGYOFTEVA (TEVATRON energy) and ENERGYOFLHC (LHC energy).

(5) All the files for obtained data are put in the subdirectory **data**. For clarity, in recording the obtained data, all of the grade files are ended with the suffix **.grid**, all the intermediate files, that record the used parameter values and the VEGAS running information, are ended with suffix **.cs** and all the files that record the differential distributions, e.g. the transverse momentum and rapidity distributions of the $(c\bar{b})$ -quarkonium, are ended with suffix **.dat**. In a specific grade file, not only the information for the sampling importance function is recorded, but also the total cross-section and the maximum differential cross-section are recorded.

(6) A simple script, named as **do** which does all the necessary jobs for generating the events, is put in the main code directory. For convenience, a script, named as **pnuglot** that may produce a high-quality plot in Encapsulated PostScript (EPS) format from a data file, is supplied here (taken from the FormCalc package [7]).

(7) We have found several typos in BCVEGPY2.0 [2], so we list all of them and their corrections here:

- In the subprogram bcvegpu.for: in line 493-507, the values for MSTU(112) and PARU(112) should be exchanged; in line 212, IMIXTYPE=1 should be replaced by IMIXTYPE=3; in line 956, PETA=PYP(I,19) should be replaced with PSETA=PYP(I,19).
- In the subprogram genevnt.for: in line 505, ICOLUP(1,3)=503 should be replaced by ICOLUP(1,4)=503.
- In the subprogram parameter.for: we should add the statement ‘double complex colmat, bundamp’ for assigning the nature of the variables in all of the three subroutines there; in the subroutine setparameter when calling the subroutine setctq6, to match to the default setting of the parameters, the original setctq6(3) should be replaced by setctq6(4), which corresponds to the default setting of PDF as CTEQ6L1 [6].

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