# EtabFDC: an $\eta_b$ event generator in hadroproduction at LHC

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#### Abstract

The EtabFDC is a matrix-element event generator package for  $\eta_b$  hadroproduction at LHC. It generates  $pp \rightarrow \eta_b X$  events for all possible parton-level  $2 \rightarrow 2$ leading-order processes with three commonly used  $\eta_b$  decay channels being implemented. The PYTHIA interface is used for parton-shower and hadronization to obtain the hadronic events. The FORTRAN codes of this package are generated by FDC (Feynman Diagram Calculation) system automatically.

Key words: Event generator, FDC, Etab PACS: 02.70-c, 11.55.Hx

#### Program summary

Program Title: EtabFDC (Version 1.01)

Keywords: Event generator, FDC, Etab

*PACS:* 02.70-c; 11.55.Hx

*Operating system:* Linux (with GNU FORTRAN 77 compiler)

Programming language: FORTRAN 77

*External libraries:* CERNLIB 2001 (or CERNLIB 2003)

Distribution format: tar gzip file

Size of the compressed distribution file: 17.1M Bytes.

Classification: 11.1

Nature of physical problem: This package generates  $pp \to \eta_b X$  events for partonic  $2 \to 2$  tree-level processes with implementing three  $\eta_b$  decay channels. It then interfaces with PYTHIA for parton-shower and hadronization to obtain the hadronic events.

*Method of solution:* The FORTRAN codes of this package are generated by FDC system[10] automatically.

Typical running time: To generate 1,000 events on a 3.2G Intel-P4 CPU platform (with hyper-technology), it will take approximate 20, 30 and 300 seconds for decay channel  $\eta_b \to J/\psi\gamma$ ,  $\eta_b \to J/\psi J/\psi$  and  $\eta_b \to J/\psi c\bar{c}$  respectively.

### 1 Introduction

As the  $b\bar{b}$  ground state,  $\eta_b$  has been a focus in high energy physics since it had not been found experimentally for more than thirty years. Many theoretical models [1,2,3,4,5,6,7,8,9] estimated the properties of  $\eta_b$ . The commissioning LHC experiments will provide a excellent opportunity to search for the signal of  $\eta_b$ . Thus, an event generator software, that simulates the  $\eta_b$  production and decays, is necessary to understand the reconstructed signal and backgrounds in the pp collision environment. In this work, we just present such a package, named EtabFDC, that can generate  $pp \to \eta_b X$  events from leading-order (LO) processes (Fig. 4 and Fig. 5) at parton-level. Here, the total cross-section of the  $\eta_b$  production is calculated to be  $9.3 \times 10^7$  Pb. Three  $\eta_b$  decay modes, that may be reconstructed by the LHC experiments, are included in this package. They are:  $\eta_b \to J/\psi\gamma$  [12],  $\eta_b \to J/\psi J/\psi$  and  $\eta_b \to J/\psi c\bar{c}$  [13]. If the branching-ratio is provided, we can estimate the number of produced  $\eta_b$  events of a specific decay channel in LHC for a given luminosity. For example, the theoretical prediction of the branching-ratio of channel  $\eta_b \to J/\psi J/\psi$  is  $5 \times 10^{-8}$ . And considering the  $1fb^{-1}$  data collected by the LHC detector in the first year, the number of  $\eta_b \to J/\psi J/\psi$  events produced is about 4650. Under current software framework, more decay channels can be added as the independent modules by the future demand.

Feynman Diagram Calculation package (FDC) [10,11] is one of the projects which aimed at calculationg Feynman diagram automatically. It can conveniently implement physical models from the first principle, then construct their *Lagrangians*, deduce the Feynman rules and generate FORTRAN codes for calculations of physical quantities such as decay width, cross-section and matrix-element. EtabFDC is a FDC application and its FORTRAN codes for the calculation of the  $\eta_b$  production processes are generated by FDC automatically. And the three decay modes of  $\eta_b$  are added by manual wrok. In this way, many careless errors can be systematically checked and debugged. EtabFDC has interface with PYTHIA to generating the hadronic events.

As a test, we plot the 2-initial-partons' centre of mass (c.m.) energy (Fig. 1) and the transverse-momentum  $p_t$  (Fig. 2) distributions with generating 20million  $\eta_b$  events. Here, we put the pp collisions energy at  $\sqrt{s} = 14$  TeV. And the  $\eta_b$  mass value is set to be 9.3 GeV. In Fig. 1, the peak at 9.3 GeV corresponds to the  $g + g \rightarrow \eta_b$  process, where the c.m. energy of the two initial gluons has to be equal to the mass of  $\eta_b$ . Please also note that, in Fig. 2, a bump around 3 GeV is produced for the fragmentation processes. The crosssection shortfall below 3 GeV is caused by a transverse-momentum cut,  $p_t > 3$ GeV, on the fragmented parton b or g, which then form the  $\eta_b$ . We obtained the expected results from the simulation output.

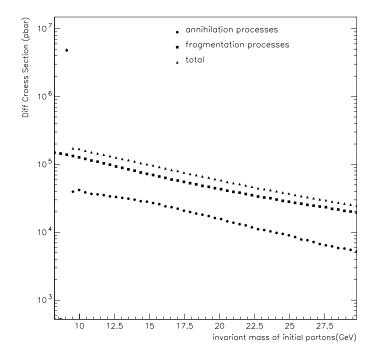


Fig. 1. Differential cross-section of  $\eta_b$  production vs c.m. energy of the 2 initial partons for the  $2 \rightarrow 2$  tree-level processes

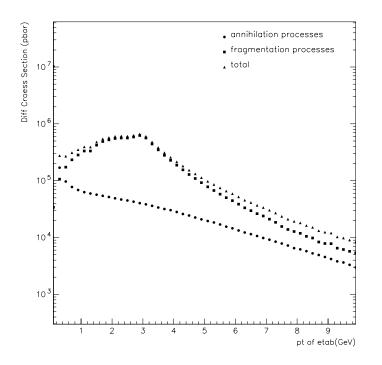


Fig. 2.  $\eta_b$  production cross-section vs transverse momentum  $p_t$ 

This paper is organized as follows: The installation procedures and the directory structures are described in Section 2. In Section 3, we describe the details of the implementation of EtabFDC package. Section 4 presents the usage manual. Sections 5 describes the interface and format of the output files. The summary is presented in Section 6.

### 2 Installation and the directory structures

### 2.1 Installation

The EtabFDC runs under Linux system and GNU FORTRAN 77 compiler is required (other FORTRAN compilers are not tested). The necessary PYTHIA library files are included in the package for convenience. The CERN program Library 2001 or 2003 is also required, but not included with this package to avoid possible platform and compiler incompatibility. The package is distributed in a compressed file named etabfdc.taz and can be downloaded from FDC homepage:

http://www.ihep.ac.cn/lunwen/wjx/public\_html/genpack/genpack.html

The installation steps are given below and for convenience we assume that  $^{1}$ :

- 1. the current user account is **user**;
- 2. the current directory is /home/user;
- 3. it is assumed that the user use "csh"; if not, the user should execute "chsh useraccount" or "ypchsh useraccount" to change the shell class to cshell;
- 4. CERN library should be CERN2001.

For the installation, user first need to decompress the downloaded gzip file by typing the following command.

"tar -xzvf etabfdc.taz"

then home directory "etabfdc" is generated. Secondly, get into it by "cd etabfdc" and set the correct path of CERN library in env.csh,then execute:

"source env.csh" and "installlib".

It will do the installation.

### 2.2 Directory structures

After the successful decompression and setting up the environment, user can find six sub-directories (see Fig. 3) in the installation directory. They are basesv5.1, etab-generator, f77, ggetab1, ggetab2 and ggetab3. The directory basev5.1 stores BASES libraries used for Monte-Carlo calculation of the cross-section integral. The directory f77 are the common-shared computational tools for  $\eta_b$  decay processes and the directory etab-generator contains the  $\eta_b$  production information.

ggetab1,ggetab2 and ggetab3 are three important directories that contain the parton-level annihilation and fragmentation channels, and correspond to three different  $\eta_b$  decay channels:  $\eta_b \to J/\psi\gamma$ ,  $\eta_b \to J/\psi J/\psi$  and  $\eta_b \to J/\psi c\bar{c}$ , respectively. All the compiled executable programs and the input files for each decay channel are stored here. Fully installed package substructure are shown in Fig. 3, based on which the EtabFDC package is constructed into three running levels.

Many generators (such as PYTHIA ) are programmed in such a way that all implemented processes are packed into a single FORTRAN file and some variables are used to enable or disable these processes. Nevertheless, EtabFDC works in a different way. There are three running levels for generating  $pp \rightarrow \eta_b X$  events. And each running level consists of a series of stand-alone executable programs and input-files which are stored in different sub-directories.

 $<sup>^1\,</sup>$  Users can substitute the paths with their own working directory while installing the EtabFDC package.

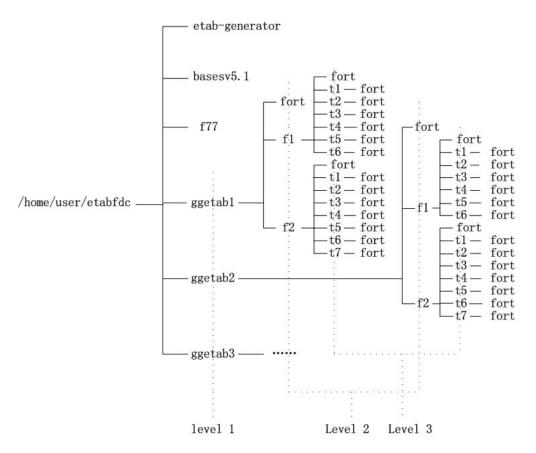


Fig. 3. Directory structure of EtabFDC

The introduction to the running levels and the details of substructure of the directories will be given in the following section.

### 3 Implementation

In EtabFDC, the cross section of each LO process is calculated by using BASES[15] package) at first and these cross sections are used as the weight for each processes. The spring in BASES is used to generate parton-level  $\eta_b$  events for each processes. and then the parton-level  $\eta_b$  events are passed to PYTHIA [17] by Les Houches Interface Standard[18] for partonic showering and hadronization. The interface with PYTHIA is shown in Fig. 6, and will be described in section 3.5.

We implement the EtabFDC in such a flexible way that users have options to select on generating events from three running levels.

#### 3.1 Generality about running levels

As shown in Fig. 3, There is a set of stand-alone programs to generate events at each running level as, for all processes at running level 1, for a certain class, annihilation or fragmentation, of processes at running level 2, or for a specific process at running level 3.

For the three  $\eta_b$  decay channels, the programs for "level 1" are stored in ggetab1/fort, ggetab2/fort and ggetab3/fort respectively. The directories f1 and f2 under ggetab1(or ggetab2,ggetab3) are called f-directories, which contain the stand-alone programs for "level 2". These programs are stored in fn/fort. f1 or f1 contains the annihilation or the fragmentation processes. The directories t1, t2 and etc under f-directories are called t-directories for "level 3". These programs are stored in tn/fort and can generate unweighted events for each specific process.

In the following, the symbol "q" is used to represent "u, d, s" quarks. The **t-directories** under **f1** for annihilation processes is :

 $\begin{array}{l} \mathrm{t1}: q + \bar{q} \rightarrow \eta_b + \gamma \\ \mathrm{t2}: g + s \rightarrow \eta_b + s \\ \mathrm{t3}: g + d \rightarrow \eta_b + d \\ \mathrm{t4}: g + u \rightarrow \eta_b + u \\ \mathrm{t5}: g + g \rightarrow \eta_b + g \\ \mathrm{t6}: g + g \rightarrow \eta_b. \end{array}$ The Feynman diagrams are shown in Fig. 4 (u quark is used as example for q here).

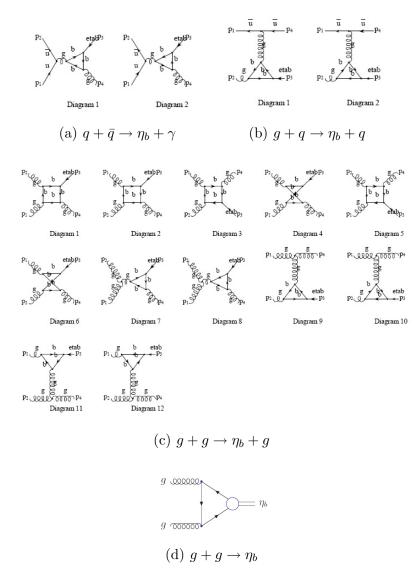


Fig. 4. Feynman diagrams for the leading-order annihilation processes in the  $\eta_b$  generation.

Similarly, the t-directories under f2 for the fragmentation processes is:

 $\begin{array}{l} \mathrm{t1}:q+\bar{q}\rightarrow g+g\\ \mathrm{t2}:g+s\rightarrow g+s\\ \mathrm{t3}:g+d\rightarrow g+d\\ \mathrm{t4}:g+u\rightarrow g+u\\ \mathrm{t5}:g+g\rightarrow g+g\\ \mathrm{t6}:q+\bar{q}\rightarrow b+\bar{b}\\ \mathrm{t7}:g+g\rightarrow b+\bar{b}, \end{array}$ 

Where the gluon and b or  $\bar{b}$  can fragment into  $\eta_b$ . The Feynman diagrams are shown in Fig. 5 (u quark is used as example for q here).

For each process, the value of cross-section is saved in the file **fresult.dat** in **fort** directory under the directory of the process.

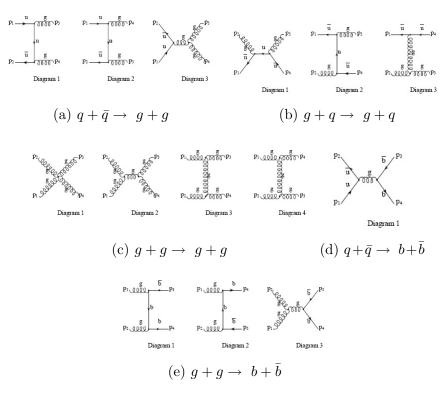


Fig. 5. Feynman diagrams for the leading-order fragmentation processes in the  $\eta_b$  generation.

Among the three running levels, only level 3 interfaces with PYTHIA directly, while level 1 and 2 interface with PYTHIA through level 3. Interfacing details will be discribed in section 3.5.

#### 3.2 Running level 3

When EtabFDC runs at level 3, it first generates unweighted matrix-element events and then interfaces with PYTHIA for parton-showering and hadronization to obtain hadronic events. In this running level, each **t-directory** contains a specific parton-level process. There are three executable programs and one input-file stored in ggetabn/tn/fort. They are listed in table 1.

The programs int and gevent can be called by fdcpythia automatically. The program fdcpythia reads parameter.input for the initial parameters. The format of parameter.input is described as: each parameter occupies one line; in each line, the parameter name and value are separated by a equal sign (i.e. "=") like:

| Executable programs in level 3 |  |
|--------------------------------|--|
| int                            | calculates and stores the cross-section                              |
|                                | in file fort/fresult.dat   |
| gevent                         | generates and stores parton-level events with $\eta_b$ being decayed |
|                                | in file fort/pdata1.dat  |
| fdcpythia                      | interfaces with PYTHIA and stores the final hadronic events          |
|                                | in file fort/pyresult.dat  |
| parameter.input                | input-file in which users can specify initial parameters             |
|                                | such as running level and number of events                           |

Table 1 Executable programs in level 3

parameter = value;

the line which begins with a number sign (i.e. "#") is recognized as the comment. All parameters used by EtabFDC in parameter.input of running level 3 are listed with brief explanation as:

RUNNINGLEVEL(=1,2,3) : To specify the running level. When EtabFDC runs at level 3, it should be set to 3 by users. Otherwise it will be set automatically.

**EVNTNUM** : To specify the number of the generated hadronic events.

- PARTONEVNTNUM : The number of the generated parton-level events. Since PYTHIA can reject some parton-level events, we need to set this number greater than the final event number. Typically, it should be set at least 20 percent more than EVNTNUM.
- PRESENTEVNTNUM : The number of generated hadronic events in the last run. It is set automatically and should not be modified by users.
- RESET : To control the program fdcpythia to run in two different modes Re-generation mode and Appending mode. In EtabFDC package, we only use the Re-generation mode (=1), since all the generated events are erased, and new parton-level events and hadronic events are generated.

## 3.3 Running level 2

When EtabFDC runs at level 2, it generates either annihilation or fragmentation class of parton-level events. For each class, the cross-section of each parton-level process are used as weight of the total generated number of events. In this level, each class of the processes corresponds to an f-directory. There are six programs for each class of processes which are stored in ggetabn/fn/fort and listed in table 2

Table 2Executable programs for level 2

| Executable programs for level 2 |  |
|---------------------------------|--|
| int                             | call int of every t-directory of the current class and stores      |
|                                 | the total cross-section in file fort/fresult.dat                   |
| gevent                          | generates and stores parton-level $\eta_b$ events of current class |
|                                 | in file fort/pdata1.dat  |
| fdcpythia                       | generates hadronic events of the current class using               |
|                                 | cross-section of each process as weight and stores                 |
|                                 | in file fort/pyresult.dat  |
| parameter.input                 | input-file in which users can specify intimal parameters           |
|                                 | for the current run level  |
| pararefresh1                    | pass parameter RESET in level 2 to level 3                         |
|                                 | and overwrite its value in level 3                                 |
| pararefresh2                    | pass parameter RUNNINGLEVEL in level 2 to level 3 $$               |
|                                 | and overwrite its value in level 3                                 |
| pararefresh3                    | pass parameter PARTONEVNTNUM in level 2 to level 3 $$              |
|                                 | and overwrite its value in level 3                                 |

The program fdcpythia uses cross-section as weight to determine the number of events for each process in the current class. And then each process calls its own fdcpythia for the event generation. After executed fdcpythia, user should go back to ggetabn/fn to execute mvdir to generate the hbook document for the annihilation or fragmentation process

The content of the configuration-file parameter.input is the same as the one at level 3 except the parameter RUNNINGLEVEL should be set to 2.

# 3.4 Running level 1

When EtabFDC runs at level 1, both annihilation and fragmentation processes are enabled in the event generation. There are six programs int, gevent, fdcpythia, pararefresh1, pararefresh2 and pararefresh3 stored in directory ggetabn/fort and function similarly as their counterparts at level 2. After executed fdcpythia, user should also go back to ggetabn to execute mvdir to generate the hbook document. The input-file parameter.input is also kept in ggetabn/fort, and its content is the same as the one at level 2 except that the parameter RUNNINGLEVEL should be set to 1.

### 3.5 Interface with PYTHIA

The EtabFDC generates parton-level events which consists of four-momenta and color flow information of all particles involved in a process. The event data are then stored in file pdata1.dat in corresponding directory tn/fort(see section 5 for the format of pdata1.dat). In turn, like many other matrix element generators such as AMEGIC++ [14] and AcerMC [16], EtabFDC interfaces with PYTHIA for parton showering and hadronization. This interface complies with PYTHIA standard and users can refer to PYTHIA manual[17]. Figure 6 shows the general procedures of the interface, and the source codes below is the event loop part in program fdcpythia

```
C... Event loop
DO IEV=1,NEVNT
CALL PYEVNT()
CALL PYEDIT(1)
IRECS=PYLIST_FDC(IFU2,IRECNO)
IRECNO=IRECNO+IRECS
ENDDO
```

A hadronic event is generated in a single run of the event loop. First, the PYTHIA subroutine PYEVNT calls another subroutine UPEVNT (which is provided by EtabFDC) to input a parton-level event. Then PYEVNT showers and hadronizes the parton-level event and stores the consequent hadronic event in common block COMMON/PYJETS/. Next, another PYTHIA subroutine PYEDIT is called to remove from the event record the jets or particles that have fragmented or decayed. Finally, a function PYLIST\_FDC, which is a modified version of PYTHIA subroutine PYLIST, writes the COMMON/PYJETS/ into file pyresult.hbk in ntuple mode.

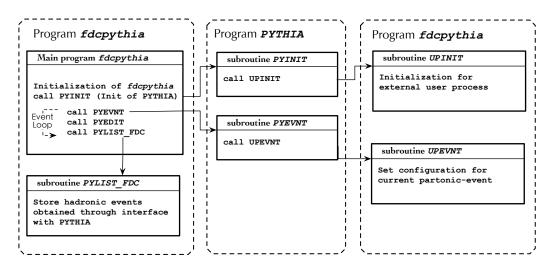


Fig. 6. Interface with PYTHIA

# 4 Usage

Users can choose the running level accordingly to their own needs. Instructions for running EtabFDC at the three running levels are given below.

# 4.1 For running level 3

It will be relatively convenient to add new physical processes in the future as well.

In this running level, EtabFDC can generate events for a specific process. To do this, follow the steps below:

- (1) Decide the physical process for which EtabFDC will generate events;
- (2) change current directory to the sub-directory fort under it (eg. ggetab1/f2/t1/fort);
- (3) Execute program make clean to remove old links;
- (4) Execute program ./make to link and ./int to calculate the cross-section;
- (5) Edit parameter.input and set parameters:
  - RUNNINGLEVEL=3;
  - PARTONEVNTNUM and EVNTNUM according to users' needs;
- (6) Execute program ./fdcpythia.

With the steps above, EVNTNUM hadronic events are then stored in file pyresult.hbk.

## 4.2 For running level 2

In this running level, EtabFDC can generate events for either annihilation or fragmentation class of processes. To do this, follow the steps below:

- (1) Decide which class of process EtabFDC will generate events for and change current directory to the f-directory (eg. ggetab2/f2);
- (2) Execute program ./mkclean to remove old links;
- (3) Execute program ./domake to link and ./doint to calculate the cross-section;
- (4) Change current directory to ggetab2/f2/fort
- $(5)~{\rm Edit}~{\tt parameter.input}$  in current directory:
  - RUNNINGLEVEL=2;
  - PARTONEVNTNUM and EVNTNUM according to users' needs; and then execute ./pararefresh1, ./pararefresh2 and ./pararefresh3
  - in directory ggetab2/f2/fort.
- (6) Execute ./fdcpythia for hadronic events.

(7) Go back to ggetab2/f2 and execute ./mvdir to get hbook document for the fragmentation processes.

With the above steps, the exact number of generated hadronic events in this run is given on screen and the data for these hadronic events are then stored in f2.hbk under ggetab2/f2 directory.

### 4.3 For running level 1

In this running level, EtabFDC can generate events for all the implemented LO  $2 \rightarrow 2$  processes for  $pp \rightarrow \eta_b X$ . To do this, follow the steps below:

- Change the current directory to the sub-directory fort under it (eg. ggetab2);
- (2) Execute program ./mkclean to cancel old links;
- Execute program ./domake to link and ./doint to calculate the crosssection;
- (4) Change current directory to ggetab2/fort
- (5) Edit parameter.input in current directory:
  - RUNNINGLEVEL=1;
  - PARTONEVNTNUM and EVNTNUM according to users' needs; and then execute ./pararefresh1, ./pararefresh2 and ./pararefresh3 in directory ggetab2/fort.
- (6) Execute ./fdcpythia for hadronic events.
- (7) Go back to /ggetab2 and execute ./mvdir to get hbook document for all LO  $2 \rightarrow 2$  processes for  $pp \rightarrow \eta_b + X$ .

With steps above, the exact number of generated hadronic events in this run is given on screen and the data for these hadronic events are then stored in ggetab2.hbk under ggetab2 directory.

## 5 Output files

As described above, the EtabFDC interfaces with PYTHIA directly at level 3. The partonic events information are kept in files named pdata1.dat of the corresponding directories tn/fort in ASCII format, and the hadronic events information are in file pyresult.dat in BINARY format in the same directory.

### 5.1 Format of pdata1.dat

File pdata1.dat is generated by program gevent. In this file, parton-level events are recorded in ASCII format sequentially. For a  $2 \rightarrow n$  process, each partonic event in the file pdata1.dat occupies 2 + n lines (if not colored) or 2 + n + 1 lines (if colored). The first 2 + n lines are four-momenta  $(\vec{p}, E)$  of initial and final particles. The (2+n+1)th line is the coefficients of color bases, which are used as weight when there is a color-flow multiplicity. The colorflow assignment complies with the PYTHIA standard and users can refer to PYTHIA manual[17]. In this version of EtabFDC, no subroutines are provided for accessing to the parton-level events. The FORMAT statements which are used in gevent to output the four-momenta and the coefficients of color-flow bases is given below

> FORMAT(2X,4(F14.8,1X)) FORMAT(2X,N(F14.8,1X))

where  $\mathcal{N}$  is the number of color bases.

### 5.2 Format of pyresult.hbk

File pyresult.hbk is created by fdcpythia. As described in section 3.5, Pythia stores the hadronized events in a common block as below:

INTEGER N,NPAD,K
DOUBLE PRECISION P,V
COMMON/PYJETS/N,NPAD,K(4000,5),P(4000,5),V(4000,5)

Program fdcpythia then writes them into pyresult.hbk in ntuple format. If running level 1 or level 2,after executed ./fdcpythia,the user should go back to ggetabn(for level 1) or ggetabn/fn(for level 2) and execute ./mvdir to get the hbook document for level 1 or level 2 seperately.The hbook document could be read by paw directly.

### 6 Summary

We have presented a FORTRAN program package EtabFDC which is a matrix element event generator for simulating the production and the decays of  $\eta_b$ . It has implemented all possible leading-order  $2 \rightarrow 2$  processes and can generate parton-level events through three running levels, and then interfaces with PYTHIA to obtain hadronic events, which are stored in the binary files and can be accessed by the provided FORTRAN subroutines. This package has been tested with setting the pp collisions energy at  $\sqrt{s} = 14$  TeV and the mass of  $\eta_b$  to be 9.3 GeV. One of the attractive features of this package is that all its FORTRAN codes are generated by FDC with full automation. With this feature, the errors caused by carelessness can be systematically avoided.

### Acknowledgments

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# Appendix : Usage Illustrations

Users can choose the running level for their own purposes.

Following examples will be used to explain the usage of EtabFDC for 3 running levels.

.1 Level 3

In this level, user can generate events for a specific process.

It is supposed to generated 1,000 hadronic events for process  $q + \bar{q} \rightarrow g + \eta_b (q = uds)$ ,  $\eta_b \rightarrow J/\psi J/\psi$ .

For this purpose, following steps are needed.

- 1) This process corresponds to directory ggetab2/f1/t1.
- 2) Change current directory to ggetab2/f1/t1/fort.
- 3) Edit parameter.input and set EVNTNUM = 1000, RUNNINGLEVEL = 3, RESET = 1.
- 4) Execute ./int for cross-section. (optional)
- 5) Execute ./fdcpythia for hadronic events.

Remarks:

- The step 4 is optional since the events are generated unweighted in level
   Therefore, if users do not want to know the cross-section, they can omit this step.
- 2) When ./int runs successfully, it will give no message on screen. However, if the mass of final-particles are greater than that of initial particles, which means the process is prohibited by current energy configuration, ./int prints a message, "The center mass energy < the sum of all final mass". When this message appears, users should not execute ./fdcpythia or ./gevent.
- 3) As mentioned in section 3, the parton-level events are generated by ./gevent. However, as shown in steps above, ./gevent is not used explicitly. That is because ./fdcpythia can execute ./gevent automatically according to parameters set in parameter.input. Of course, if users are only interested in the parton-level events, they can execute ./gevent manually instead of ./fdcpythia.
- 4) Parton-level and hadronic events are stored in pdata1.dat and pyresult.hbk

respectively in the directory ggetabn/f1/t1/fort. The access to them is formulated in section 5.

# .2 Level 2

In this level, users can generates events for the annihilation or fragmentation processes followed by which  $\eta_b$  decays in certain channel.

As an example, we take annihilation-etab-generating processes decay as  $\eta_b \rightarrow J/\psi + J/\psi$ . It is assumed to generate 5,000 hadronic events. For this purpose, users need to go through steps below.

- 1) The annihilation-etab-generating processes correspond to ggetab2/f1, then go into this directory.
- 2) Execute shell script ./doint.
- 3) Change current directory to ggetab2/f1/fort
- 4) Edit parameter.input in current directory and set

```
EVNTNUM = 5000,
RUNNINGLEVEL = 2,
RESET = 1.
```

and then execute ./pararefresh1, ./pararefresh2 and ./pararefresh3 in directory ggetab2/f1/fort.

- 5) Execute ./fdcpythia for hadronic events.
- 6) Go back to ggetab2/f1 and execute ./mvdir to get the hbook document

Remarks:

- 1) Users should notice that in level 2 (also in level 1), shell scripts should be used instead of executable programs ./int.
- 2) In level 2 (also in level 1), the execution of ./doint is a necessary step since the generator needs the cross-section as weight to determine the number of events for each specific process.
- 3) As in level 3, parton-level events are stored in sub-directory fort of corresponding t-directories under ggetab2/f1. The access to them has been described in section 5.

# .3 Level 1

In this level, users can generate events for all processes. We take the  $\eta_b \rightarrow J/\psi\gamma$  decay channel as an example. It is assumed that 10,000 hadronic events are generated. For this purpose, following steps are necessary.

- 1) Change current directory to ggetab1.
- 2) Execute shell script ./doint.
- 3) Change current directory to ggetab1/fort
- 4) Edit parameter.input in current directory. Set EVNTNUM = 10000, RUNNINGLEVEL = 1, RESET = 1.

and then execute ./pararefresh1, ./pararefresh2 and ./pararefresh3 in directory ggetab1/fort.

- 5) Execute ./fdcpythia for hadronic events.
- 6) Go back to ggetab1 and execute ./mvdir to get the hbook document.

Remark:

Except the directory, everything is the same as in level 2. The parton-level event files are also kept in **fort** of corresponding t-directories.