DJpsiFDC: an event generator for the process gg → J/ψJ/ψ at the LHC*

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Abstract: DJpsiFDC is an event generator package for the process gg → J/ψJ/ψ. It generates events for primary leading-order $2 \to 2$ processes. The package could generate a Les Houches Event (LHE) document and this could easily be embedded into detector simulation software frameworks. The package is produced in Fortran code.

Key words: event generator, FDC, J/ψ pair, color-octet

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1 Introduction

NRQCD [1] has now become a basic theory to parameterize non-perturbative contributions represented by color-singlet (CS) and color-octet (CO) matrix elements in heavy quarkonium production and decays. The color-octet mechanism supplies a way to partly understand the prompt J/ψ and ψ′ surplus production at the Fermilab Tevatron [2–5]. However, there is still something unclear in this scheme [6–25]. To investigate the charmonium production mechanism has become an urgent and important task in the study of quarkonium physics.

The J/ψ pair production process could be a candidate for testing and verifying the color-octet scheme. This process has an exclusive multi-muon final state with extremely small backgrounds. According to the results of previous unpolarized calculations [26, 27] for the Tevatron experiment, however, the cross-section of this process at the Tevatron is small, and the Tevatron experiment also has not supplied any solid evidence for having detected it.

The running of the LHC provides a great opportunity to realize this aim. With high center-of-mass energy of 14 TeV and luminosity of about 10^{32}–10^{34} cm^{-2}·s^{-1}, results from the LHC experiment may be able to dtermine how much the color-octet mechanism contributes to J/ψ production under high col-

lision energy. With regard to the calculations of Qiao et al. [28] and Li et al. [29], the J/ψ pair production process at the LHC could be used to study charmonium production mechanisms. But first we must perform a Monte Carlo simulation on this process to study its experimental feasibility. Thus, we have developed a generator package on this process based on a Feynman Diagram Calculation (FDC) system [30]. The generator contains only primary leading order gg → J/ψJ/ψ channels, and we neglected the channels such as qq̄ → J/ψJ/ψ, and those in the J/ψ pair hybrid production scheme, i.e., one J/ψ in a pair is produced through the CS scheme but the other one is via the CO scheme, for those channels contribute much less than dominant gg → J/ψJ/ψ processes. The output of the generator is a standard Les Houches Event (LHE) file [31] and could be embedded into the detector simulation software framework.

This paper is organized as follows. In Section 2, the directory structures of the event generator package are described. In Section 3, we describe the details of the installation and implementation of the DJpsiFDC package. Section 4 describes the format of the output files. The summary is presented in Section 5.

2 Directory structures

There are five sub-directories in the package:

basesv5.1, DJpsi-generator, f77, gg2jpsi and octet_gg2jpsi. The directory basev5.1 stores BASES libraries [32] used for Monte-Carlo calculation of the cross-section integral. The directory f77 is the common-shared computational tool for physics quantities, such as α_s, and the directory DJpsi-generator contains the J/ψ pair production information.

gg2jpsi and octet_gg2jpsi are two directories containing color-singlet and color-octet schemes of the J/ψ pair production process, respectively. All of the compiled executable programs and the input files are stored in these two directories. In the following, the two parts are described sequentially.

2.1 Color-singlet scheme

The typical Feynman diagrams of J/ψ pair pro-

duction in pp collision at leading order in the color-singlet scheme used in the generator package are shown in Fig. 1.

2.2 Color-octet scheme

In the color-octet scheme, the final objects produced in the hard parton interaction are not J/ψs, but the color-octet bound states, as shown in Fig. 2. Here we comply with the convention in the PYTHIA system by considering this color-octet bound state as a new particle, and assuming that its invariant mass is 30 MeV larger than J/ψ, which is 3.126 GeV. The color-octet bound state would radiate a soft gluon and decay to a real J/ψ.
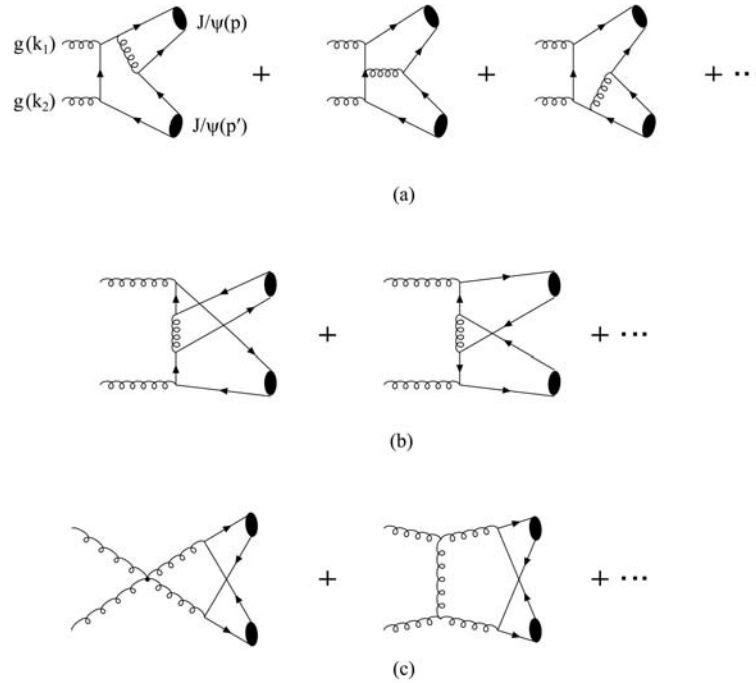

Fig. 1. Typical Feynman diagrams of J/ψ pair production in pp collision at leading order in the color-singlet scheme.

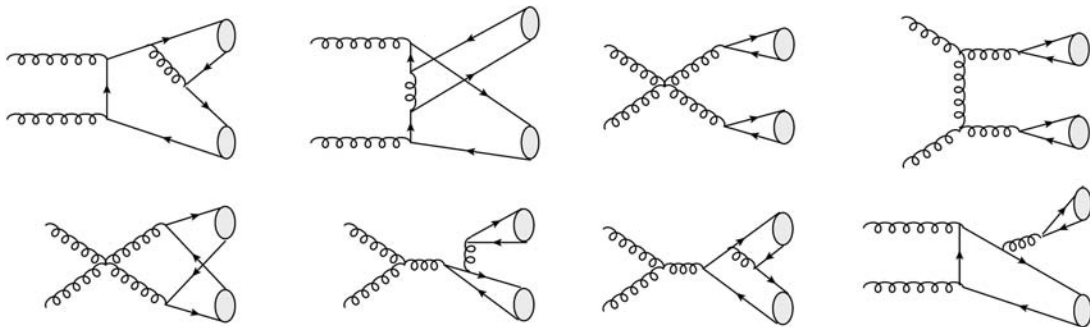Fig. 2. Typical Feynman diagrams at leading order in the color-octet scheme.

3 Installation and implementation

The generator is compressed in a file named DJpsiFDC.taz and users can download it from:

http://cid-4fc4170d6530982b.

office.live.com/browse.aspx/

.Public

Installation and implementation procedures are described below.

3.1 Installation

The installation steps are listed below, and for convenience we assume that:

1) the current user account is user;

2) the current directory is /home/user;

3) the user uses "csh"; if not, the user should execute "chsh useraccount" or "ypchsh useraccount" to change the shell class to cshell;

4) the user has installed the CERN library and this should be CERN2001.

For the installation, the user first needs to decompress the downloaded gzip file by typing

"tar -xzvf DJpsiFDC.taz"

then the home directory "DJpsiFDC" is created. Secondly, they get into it by typing "cd DJpsiFDC" and executing

"source env.csh" and "installlib".

It will then carry out the installation.

Note: users must first modify the path and the CERN library location in "env.csh" into their local paths to establish the environment.

3.2 Implementation

To implement the generator, the user first needs to establish links to the program library. Then they must enter the color-singlet part or the color-octet part by executing "cd gg2jpsi/fort" or "cd octet_gg2jpsi/fort". Take the color-singlet part as an example.

After changing the current directory to gg2jpsi/fort, execute program make, then three executable programs will appear:

int: calculates and stores the cross-section in file fresult.dat;

gevent: generates and stores parton-level events information in file pdata1.dat;

fdcpythia: generates and stores the final events information in file DJpsiFDC.lhe.

Users only need to execute the programs to generate events and get output files, but they must call int ahead to fdcpythia.

There are two input-files for users to change the input parameters: input.dat and parameter.input. input.dat stores center-of-mass energy, and the user can generate events under different collision energies by changing it. In parameter.input, the user can configure initial parameters such as event number to generate. The format of parameter.input is described as: each parameter occupies one line; in each line, the parameter name and value are separated by an equals sign (i.e. "=") like:

parameter = value;

The line thath begins with a number sign (i.e. "#") is recognized as the comment. All parameters used by DJpsiFDC in parameter.input are listed with brief a explanation as:

RUNNINGLEVEL(=1): To specify the running level. It needs not to be cared here.

EVNTNUM: To specify the number of the generated events.

PARTONEVNTNUM: The number of the generated parton-level events. It must be at least twice the 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 the DJpsiFDC package, we only use the Re-generation mode (=1), since all of the generated events are erased, and new parton-level events and hadronic events are generated.

It should be noted that after changing the collision energy in input.dat, the user must re-execute int to calculate the cross-section under new energy, or the generator would generate events under the original collision energy.

The generator could also change transverse momentum and rapidity restrictions on the generated J/ψ pair. Users can edit the file "func.f" at Line 166–176 to get the following codes:

a = dsqrt(p(3,3)**2+p(2,3)**2)

if(a.lt.4) out_of_physical_region = .true.

if(a.gt.40) out_of_physical_region = .true.

b = -dlog(tan(0.5*acos(dsqrt(p(3,3)**2

. +p(2,3)**2+p(4,3)**2)**(-1)*p(4,3))))

c = -dlog(tan(0.5*acos(dsqrt(p(3,4)**2

. +p(2,4)**2+p(4,4)**2)**(-1)*p(4,4))))

if(b.lt.-2.2) out_of_physical_region = .true.

if(b.gt.2.2) out_of_physical_region = .true.

if(c.lt.-2.2) out_of_physical_region = .true.

if(c.gt.2.2) out_of_physical_region = .true.

a is the transverse momentum, and b, c are the pseudorapidity of respective J/ψ. Users can change

the limitations by modifying the numbers after ".lt." or ".gt.". ".lt." means "less than", and ".gt." means "greater than". After changed limitations, users must re-execute make to re-compile, then operate according to the above procedures.

4   Output format

There are two output files for users: fresult.dat and DJpsiFDC.lhe. fresult.dat stores the calculated cross-section by the generator, and the user can use this value to estimate the number of events in certain integrated luminosity.

DJpsiFDC.lhe is the primary output file storing the main information of the original and final particles. "LHE" means Les Houches Event, its content is identical with what was already defined by the Les Houches Accord in 2003 [31]. This information is embedded in a minimal XML-style structure. The complete file format looks like

<LesHouchesEvents version="1.0">
<!–
optional information in completely free format,
except for the reserved endtag (see next line)
–>
<header>
<!– individually designed XML tags, in fancy XML style –>
</header>
<init>
compulsory initialization information
optional initialization information
</init>
<event>
compulsory event information
optional event information
</event>
(further <event> ... </event> blocks, one for each event)
</LesHouchesEvents>.

The LHE file includes all necessary information of the original and final parton-level particles, such as beam energy, color label, particle ID, mom particle ID, four-momentum and invariant mass.

The transverse momentum(p_t) distributions of the muons from J/ψ generated in the color-singlet and color-octet schemes are shown in Fig. 3. In the large p_t region(p_t >10 GeV), the muons from J/ψ gener-

ated in the color-octet scheme are more than those from J/ψ generated in the color-singlet scheme. That means that significantly more J/ψ in the color-octet scheme could be reconstructed in the large p_t region. If more J/ψ events were detected in the large p_t region, then it could be considered that the color-octet scheme contributes significantly to the cross-section of the process. If the cross-section was measured, the contribution of the color-octet scheme could also be determined.
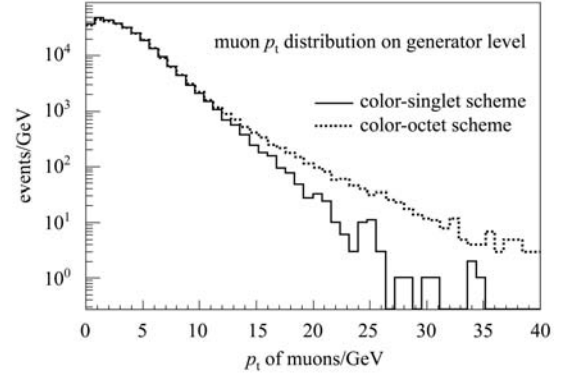

Fig. 3. Transverse momentum distribution of the muons from J/ψ in the color-singlet and color-octet schemes generated by the DJpsiFDC package.

5   Summary

We have presented a FORTRAN program package DJpsiFDC, which is a generator for simulating J/ψ pair production. It has implemented primary leading-order 2 → 2 processes and can generate events in color-singlet and color-octet mechanisms. The generator would create a LHE document containing initial and final particle information, and could be embedded into detector software systems. This package has been tested by setting the pp collisions energy at $\sqrt{s}$=10 TeV and 14 TeV, and the collision energy could be changed. Monte Carlo simulation is being processed, and according to the actual LHC operation status, the case under 7 TeV is being studied. With data accumulation on the LHC, the conclusions for this process could be obtained in the next two or three years.

References

1　Bodwin G T, Braaten E, Lepage G P. Phys. Rev. D, 1995, **51**: 1125–1171

2　Abe F et al. (CDF collaboration). Phys. Rev. Lett., 1992, **69**: 3704–3708

3　Abe F et al. (CDF collaboration). Phys. Rev. Lett., 1997, **79**: 572–577

4　Abe F et al. (CDF collaboration). Phys. Rev. Lett., 1997, **79**: 578–583

5　Braaten E, Fleming S, Leibovich A K. Phys. Rev. D, 2001, **63**: 094006

6　Braaten E, Lee J. Phys. Rev. D, 2003, **67**: 054007

7　Braaten E, Lee J. Phys. Rev. D, 2005, **72**: 099901

8　LIU Kui-Yong, HE Zhi-Guo, CHAO Kuang-Ta. Phys. Lett. B, 2003, **557**: 45–54

9　Hagiwara K, Kou E, QIAO Cong-Feng. Phys. Lett. B, 2003, **570**: 39–45

10　Abe K et al. (BELLE collaboration). Phys. Rev. Lett. 2002, **89**: 142001

11　Abe K et al. (BELLE collaboration). Phys. Rev. D, 2004, **70**: 071102

12　Aubert B et al. (BABAR collaboration). Phys. Rev. D, 2005, **72**: 031101

13　Cho P, Leibovich A K. Phys. Rev. D, 1996, **54**: 6690–6695

14　YUAN Feng, QIAO Cong-Feng, CHAO Kuang-Ta. Phys. Rev. D, 1997, **56**: 321–328

15　YUAN Feng, QIAO Cong-Feng, CHAO Kuang-Ta. Phys. Rev. D, 1997, **56**: 1663–1667

16　Kiselev V V et al. Phys. Lett. B, 1994, **332**: 411–414

17　Aubert B et al. (BABAR collaboration). Phys. Rev. Lett. 2001, **87**: 162002

18　Abe K et al. (BELLE collaboration). Phys. Rev. Lett. 2002, **88**: 052001

19　ZHANG Yu-Jie, GAO Ying-Jia, CHAO Kuang-Ta. Phys. Rev. Lett. 2006, **96**: 092001

20　GONG Bin，WANG Jian-Xiong. Phys. Rev. D, 2008, **77**: 054028

21　MA Yan-Qing, ZHANG Yu-Jie, CHAO Kuang-Ta. Phys. Rev. Lett. 2009, **102**: 162002

22　GONG Bin, WANG Jian-Xiong. Phys. Rev. Lett. 2009, **102**: 162003

23　ZHANG Yu-Jie, MA Yan-Qing, CHAO Kuang-Ta. Phys. Rev. D, 2008, **78**: 054006

24　Bodwin G T, Kang D, Lee J. Phys. Rev. D, 2006, **74**: 014014

25　Bodwin G T, Kang D, Lee J. Phys. Rev. D, 2006, **74**: 114028

26　Barger V, Fleming S, Phillips R J N. Phys. Lett. B, 1996, **371**: 111–116

27　QIAO Cong-Feng. Phys. Rev. D, 2002, **66**: 057504

28　QIAO Cong-Feng, SUN Peng, SUN Li-Ping. J. Phys. G, 2010, **37**: 075019

29　LI Rong, ZHANG Yu-Jie, CHAO Kuang-Ta. Phys. Rev. D, 2009, **80**: 014020

30　WANG Jian-Xiong. Nucl. Instrum. Meth. A, 2004, **534**: 241–245

31　Alwall J, Ballestrero A, Bartalini P et al. Comput. Phys. Commun., 2007, **176**: 300–304

32　Kawabata S. Computer Phys. Commun., 1995, **88**: 309–326