GENXICC2.0: An Upgraded Version of the Generator for Hadronic Production of Double Heavy Baryons Ξ_{cc} , Ξ_{bc} and Ξ_{bb}

Chao-Hsi Chang^{1,2,3*} Jian-Xiong Wang^{4†} and Xing-Gang Wu^{1‡}

¹Department of Physics, Chongqing University, Chongqing 400044, China

²CCAST (World Laboratory), P.O.Box 8730, Beijing 100080, China

³Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, China

⁴Institute of High Energy Physics, P.O.Box 918(4), Beijing 100049, P.R. China

(Dated: October 3, 2018)

Abstract

An upgraded (second) version of the package GENXICC (A Generator for Hadronic Production of the Double Heavy Baryons Ξ_{cc} , Ξ_{bc} and Ξ_{bb} by C.H. Chang, J.X. Wang and X.G. Wu, [its first version: in Comput. Phys. Commun. 177 (2007) 467-478]) is presented. Users, with this version being implemented in PYTHIA and a GNU C compiler, may simulate full events of the production in various experimental environments conveniently. In comparison with the previous version, in order to implement it in PYTHIA properly, a subprogram for the fragmentation of the produced double heavy diquark to the relevant baryon is complemented and the interphase of the generator to PYTHIA is changed accordingly. In the subprogram, with explanation, certain necessary assumptions (approximations) are made so as to conserve the momenta and the QCD 'color' flow for the fragmentation.

^{*} zhangzx@itp.ac.cn

[†] jxwang@ihep.ac.cn

[‡] wuxg@cqu.edu.cn

NEW VERSION PROGRAM SUMMARY

 $Title\ of\ program: GENXICC2.0$

Program obtained from: CPC Program Library or the Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing, P.R. China: www.itp.ac.cn/~zhangzx/genxicc2.0.

Reference to original program: GENXICC

Reference in CPC: Comput. Phys. Commun. 177, 467(2007)

Does the new version supersede the old program: No

Computer: Any LINUX based on PC with FORTRAN 77 or FORTRAN 90 and GNU C compiler as well.

Operating systems: LINUX.

Programming language used: FORTRAN 77/90.

Memory required to execute with typical data: About 2.0 MB.

No. of bytes in distributed program, (including PYTHIA6.4): About 1.5 MB.

Distribution format: .tar.gz.

Nature of physical problem: Hadronic production of double heavy baryons Ξ_{cc} , Ξ_{bc} and Ξ_{bb} .

Method of solution: The code is based on NRQCD framework. With proper option, it can generate weighted and un-weighted events of hadronic double heavy baryon production. When the hadronizations of the produced jets and double heavy diquark are taken into account in the production, the upgraded version with proper interface to PYTHIA can well

generate the events in full.

Restrictions on the complexity of the problem: The color flow, particularly, in the piece of programming the fragmentation from the produced colorful double heavy diquark into a relevant double heavy baryon, is treated carefully so as to implement it in PYTHIA properly.

Reasons for new version: Responding to the feedback from users[1], we improve the generator mainly by careful completing the 'final nonperturbative process' i.e. the formulation of the double heavy baryon from relevant intermediate diquark. In the present version, the information for fragmentation about momentum-flow and the-color flow, that is necessary for PYTHIA to generate full events, is retained although reasonable approximations are made. In comparison with the original version, the upgraded one can implement it in PYTHIA properly to do the full event simulation of the double heavy baryon production.

Typical running time: It depends on which option is chosen to match PYTHIA when generating the events in full and also on which mechanism is chosen to generate the events. Typically, for the most complicated case with gluon-gluon fusion mechanism to generate the mixed events via the intermediate diquark in $(cc)[^3S_1]_{\bar{3}}$ and $(cc)[^1S_0]_6$ states, and to generate 1000 events, it takes about 20 hours on a 1.8 GHz Intel P4-processor machine if IDWTUP=1, whereas to generate 10^6 events it takes about 40 minutes only if IDWTUP=3.

Keywords: Event generator; Hadronic production; double heavy baryons.

Summary of the changes (improvements): 1) We try to explain the treatment of the momentum distribution of the process more clearly than the original version, and show how the final baryon is generated through the typical intermediate diquark precisely. 2) We present color flow of the involved processes precisely and the corresponding changes for the program are made. 3). The corresponding changes of the program are explained in the paper.

TABLE I: All considered mechanisms for step A, which are defined by the two parameters **mgenxi** and **ixiccstate**. Here the symbol gg-mechanism stands for the gluon-gluon fusion mechanism and etc..

	mgenxi=1	mgenxi=2	mgenxi=3
ixiccstate=1	gg-mechanism, $(cc)_{\bar{3}}(^3S_1)$	gg-mechanism, $(bc)_{\bar{3}}(^3S_1)$	gg-mechanism, $(bb)_{\bar{3}}(^3S_1)$
ixiccstate=2	gg-mechanism, $(cc)_{6}(^{1}S_{0})$	gg-mechanism, $(bc)_{6}(^{1}S_{0})$	gg-mechanism, $(bb)_{6}(^{1}S_{0})$
ixiccstate=3	gc-mechanism, $(cc)_{\bar{3}}(^3S_1)$	gg-mechanism, $(bc)_{6}(^3S_1)$	_
ixiccstate=4	gc-mechanism, $(cc)_{6}(^{1}S_{0})$	gg-mechanism, $(bc)_{\bar{3}}(^1S_0)$	_
ixiccstate=5	cc-mechanism, $(cc)_{\bar{3}}(^3S_1)$	_	_
ixiccstate=6	cc-mechanism, $(cc)_{6}(^{1}S_{0})$	_	_

I. MOMENTUM DISTRIBUTION OF THE PRODUCTION

In fact, in the program we divide the production of a double heavy baryon Ξ_{cc} or Ξ_{bc} or Ξ_{bb} into two steps: Step-A is up-to the production of a relevant double heavy diquark and Step-B is followed for the fragmentation of the double heavy diquark into the desired baryon. Therefore, in Step-A, there are three possible mechanisms: the gluon-gluon fusion mechanism (g+g), gluon-charm collision mechanism (g+c) and charm-charm collision mechanism (c+c), so in the program we need to fix one of them to produce the diquarks (cc), (bc) and (bb) accordingly in term. All the three mechanisms and the calculation techniques for them are described in Refs. 2, 3, 4. In Step-B, it is for the fragmentation of the double heavy diquark into the desired baryon. In the step we assume the intermediate diquark is to 'decay' into the baryon plus soft parton(s) exclusively, e.g., either $(QQ')[^3S_1]_{\bar{3}} \to \Xi_{QQ'} + \bar{q}$ or $(QQ')[^1S_0]_{\bar{6}} \to \Xi_{QQ'} + \bar{q} + g$ (here Q, Q' denote c, b-quark, \bar{q} an light anti-quark, g a gluon). For convenience, in the program we name the mechanisms and intermediate diquarks in terms of the parameters as those in TAB.I, where **mgenxi** stands for the double-heavy diquarks, (cc) or (bc) or (bb), and ixiccstate stands for the mechanisms. Note that in the previous version of GENXICC (we call it GENXICC1.0), we did not program how the diquark forms the relevant baryon, but alternatively we simply assumed that the relevant baryon is formed with 100% efficiency.

According to QCD confinement, the produced diquarks (QQ'), i.e. (cc), (bc), (bb), must be fragmented into relevant baryons by grabbing a light quark q (even suitable number of gluons q) with definite probability. Since the fragmentation for the heavy diquarks is absent from the available version of PYTHIA, thus in the upgraded version of GENXICC we program the fragmentation precisely and make its interphase still to suit PYTHIA properly. For consistency, in the upgraded version for the fragmentation we adopt the assumptions and method similar to those taken by PYTHIA [5] in the case for the fragmentation of a color-octet component $(c\bar{c})_8$ into a colorless charmonium. Namely here the double heavy quark to grab a light quark (with gluons if necessary) from the 'environment' to form a colorless double heavy baryon with a relative possibility for various flavors of the light quark as $u:d:s:c\simeq 1:1:0.3:10^{-11}$. Hence in the program we introduce three new parameters ratiou (default=1), ratiod(default=1), ratios(default=0.3) so as to dictate the probability for a double heavy diquark to grab a light quark (antiquark) in forming the relevant baryon finally. These parameters may be changed by setting the values of the parameters in the parameter.F, when the relative possibilities for various flavors are assumed precisely. One more parameter **nbound** is naturally introduced to dictate which type of baryon: $\Xi_{cc}^{+,++}$ or Ω_{cc}^+ (**nbound**=1), $\Xi_{bc}^{+,0}$ or Ω_{bc}^0 (**nbound**=2), $\Xi_{bb}^{0,-}$ or Ω_{bb}^- (**nbound**=3) is to be generated from the relevant produced diquark. (**nbound**=4) is to derive the diquark results that can be generated by previous version (GENXICC1.0). The relative possibilities for the baryons Ξ_{cc}^+ , Ξ_{cc}^{++} and Ω_{cc}^+ are decided by the value of **ratiou**, **ratiod** and **ratios**. More precisely, if the diquark $(cc)[^3S_1]_{\bar{3}}$ is produced, then it will fragment into Ξ_{cc}^{++} with 43% probability, Ξ_{cc}^+ with 43% probability and Ω_{cc}^+ with 14% probability accordingly, when default values of ratiou, ratiod and ratios are taken.

Below we shall only take the hadronic production of Ξ_{cc} as an example to show how the generator GENXICC works, because the production for the baryon Ξ_{bc} or Ξ_{bb} is similar.

At the end of the Step-A, the final particles' momenta are set by using the **phase_gen** routine, that is based on RAMBO (Random Momentum Booster) program [6], and the irrelevant phase space is integrated by VEGAS [7]. For the Step-B, we adopt the 'decay' method (as that to deal with the intermediate color octet $(c\bar{c})$ states to produce J/ψ in PYTHIA [5]). According to the method, we start with assuming the diquark mass to be slightly bigger than that of the baryon (> $2m_c$), so the diquark may 'decay' into a relevant baryon by emitting very soft partons (anti-quark and/or gluons), and the soft partons take

away very tiny momentum from the diquark. To keep gauge invariance of the hard process in Step-A, we must set (cc)-diquark mass to be $2m_c$ exactly [3, 4], thus in the present case, we set the diquark mass to be $2m'_c$ i.e. slightly bigger value, e.g. $m'_c \geq m_c + m_q/2$ (m_q is mass of the light quark), and let the mass of the produced baryon be less than but very close to $2m_c + m_q$ approximately. In the program, we introduce the parameters slqmass to stand for the soft-light-quark mass $m_q(q=u,d,s)$: qmassu for u-quark, qmassd for dquark and **qmasss** for s-quark respectively. Since the Step-B in the case for the diquark $(cc)[^3S_1]_{\bar{3}}$ being produced is of a $(1 \to 2)$ -body process $((cc)[^3S_1]_{\bar{3}} \to \Xi_{cc} + \bar{q})$ and we have averaged the polarization of the produced diquark $(cc)[^3S_1]_{\bar{3}}$ in Step-A, so we reasonably treat the fragmentation as that, for the double heavy baryon and the light anti-quark, the absolute values of the momenta is fixed by momentum conservation and the masses of the three relevant particles, whereas the direction of the momenta is isotropic in the diquark rest frame. It can be found that such a light anti-quark indeed affects very slightly in the momentum distribution of the generated double heavy baryon. We should note here that even though such a soft light quark gives slightly correction to the distribution in momentum, it must be involved so as to make the color flow of the process right for each event in full. If the color flow of the process were not correct, then the program would not be able to implement in PYTHIA to generate full events. As for the Step-B in the case for the diquark $(cc)[^1S_0]_6$ being produced, that is of a $(1 \to 3)$ -body process $((cc)[^1S_0]_6 \to \Xi_{cc} + \bar{q} + g$, one more gluon is needed) indeed due to the color-flow request as pointed out in the next section, we still treat it as a $(1 \rightarrow 2)$ -body process for momentum distribution of the fragmentation by letting \bar{q} and g always move together. "letting \bar{q} and g always move together" is a very strong constraint but here \bar{q} and g are very 'light' and carry the momenta very tiny, so it does not affect the distribution of the baryon, what we are interested in, substantially.

To record all the useful data, we improve the data manipulation method. All the recorded data are still put in the directory data, while in this directory, we introduce 12 subdirectories; xiccu, xiccd, xiccs, xibcu, xibcd, xibcs, xibbu, xibbd, xibbs, ccdiq, bcdiq and bbdiq. These subdirectories record the needed data respective to the settings determined by the user in **parameter.F**, e.g. xiccu, xiccd and xiccs record data for Ξ_{ccu}^{++} , Ξ_{ccd}^{+} , Ω_{ccs}^{+} respectively; ccdiq, bcdiq and bbdiq record data for (cc)-diquark, (bc)-diquark, (bb)-diquark respectively. We should note that the subdirectories ccdiq, bcdiq and bbdiq record the data just as those generated by GENXICC1.0.

II. THE COLOR FLOW OF THE PRODUCTION

Ignoring the color flow of the fragmentation at all, still one can obtain incomplete information of the event for the baryon production, such as the observables: total cross section, transverse momentum p_t and rapidity y differential distributions of the baryon etc. Thus, even GENXICC1.0, the previous version, can do all these jobs well. The present (upgraded) version deals with the color flow not only for the double heavy diquark production but also for the fragmentation carefully, so by complementing the upgraded version of the generator into PYTHIA properly, it can generate full events and record all information of the outgoing partons, besides that of the baryon itself.

The color flow for Ξ_{cc} and Ξ_{bb} production is much more involved than that of Ξ_{bc} production, so at the present, firstly we focus the color flow for Ξ_{cc} production precisely. Moreover to meet the needs in most cases, we only include the most important gluon-gluon fusion mechanism for the Ξ_{bc} and Ξ_{bb} production. The interesting readers can obtain the color flow for the Ξ_{bc} and Ξ_{bb} production by following the same method, but we note that for Ξ_{bc} production since the heavy quarks inside it are different flavored so its production via the diquark (bc) with the quantum number as $(bc)[^1S_0]_{\bar{3}}$ or $(bc)[^3S_1]_{\bar{3}}$ or $(bc)[^1S_0]_6$ or $(bc)[^3S_1]_6$ (four possibilities) instead of $(QQ)[^3S_1]_{\bar{3}}$ or $(QQ)[^1S_0]_6$ (Q=c,b), two possibilities) for Ξ_{QQ} production.

A. The color flow for $(cc)[^3S_1]_{\bar{3}}$ being produced

To show the color flow of Ξ_{cc} production, the mechanisms for $(cc)[^3S_1]_{\bar{3}}$ production and the followed fragmentation can be more precisely written as

$$gg \to (cc)[^3S_1]_{\bar{3}} + \bar{c}\bar{c} \to (\Xi_{cc}^+ + \bar{d}) + \bar{c}\bar{c} \quad or \quad (\Xi_{cc}^{++} + \bar{u}) + \bar{c}\bar{c} \quad or \quad (\Omega_{cc}^+ + \bar{s}) + \bar{c}\bar{c} \quad (1)$$

$$gc \to (cc)[^{3}S_{1}]_{\bar{3}} + \bar{c} \to (\Xi_{cc}^{+} + \bar{d}) + \bar{c} \quad or \quad (\Xi_{cc}^{++} + \bar{u}) + \bar{c} \quad or \quad (\Omega_{cc}^{+} + \bar{s}) + \bar{c}$$
 (2)

$$cc \to (cc)[^{3}S_{1}]_{\bar{3}} + g \to (\Xi_{cc}^{+} + \bar{d}) + g \text{ or } (\Xi_{cc}^{++} + \bar{u}) + g \text{ or } (\Omega_{cc}^{+} + \bar{s}) + g$$
 (3)

According to the discussion in Ref.[8], for the (cc)-diquark in 3S_1 state with the color $\bar{\bf 3}$, one of the two heavy c quarks emits a soft gluon and then this gluon splits into a light $q\bar{q}$ pair, and the (cc)-pair can combine the light quark q to form the baryon Ξ_{cc} (in $|ccq\rangle$ Fock state). To fit the needs of PYTHIA running, here we program the second step properly, i.e. to deal

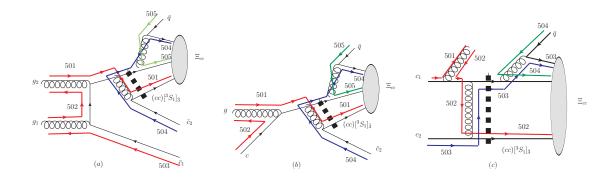


FIG. 1: (Color on line) Typical color flow for gluon-gluon fusion mechanism (Left), gluon-charm collision mechanism (Middle) and charm-charm collision mechanism (Right), where the thick dashed line shows the corresponding intermediate diquark state $(cc)[^3S_1]_{\bar{3}}$. Three colorful lines are for color flow lines according to PYTHIA naming rules. Three colorful lines are for color flow lines according to PYTHIA naming rules. The black lines are for Feynman diagrams.

with the color flow of the fragmentation process carefully.

As for the gluon-gluon fusion mechanism, there are six independent color factors for Step-A [3]: $C_{1ij} = \frac{1}{2\sqrt{2}} \left(T^a T^b\right)_{mi} G_{mjk}$, $C_{2ij} = \frac{1}{2\sqrt{2}} \left(T^b T^a\right)_{mi} G_{mjk}$, $C_{3ij} = \frac{1}{2\sqrt{2}} (T^a)_{mj} (T^b)_{ni} G_{mnk}$, $C_{4ij} = \frac{1}{2\sqrt{2}} (T^b)_{mj} (T^a)_{ni} G_{mnk}$, $C_{5ij} = \frac{1}{2\sqrt{2}} \left(T^a T^b\right)_{mj} G_{mik}$ and $C_{6ij} = \frac{1}{2\sqrt{2}} \left(T^b T^a\right)_{mj} G_{mik}$, where i, j = 1, 2, 3 are color indices of the two outgoing anti-quarks \bar{c} and \bar{c} respectively, and the indices a and b are color indices for gluon-1 and gluon-2 respectively. Here, the function G_{mjk} either equals to the anti-symmetric ε_{mjk} when the (cc)-diquark is in $\bar{\mathbf{3}}$ configuration or equals to the symmetric f_{mjk} when the (cc)-diquark is in $\bar{\mathbf{6}}$ configuration. While implementing Step-B, one may find that there are only two independent color flows for the case of $(cc)[^3S_1]_{\bar{\mathbf{3}}}$ with 50% probability each¹. We draw the typical color flows for the gluon-gluon fusion mechanism, gluon-charm collision mechanism and charm-charm collision mechanism in FIG.(1) respectively, the other color flow can be obtained by gluon exchange.

Now let us consider the three mechanisms in turn.

For the gluon-gluon fusion mechanism as shown by FIG.(1a), according to the naming rule of PYTHIA, there are three color flow lines:

$$[0,503] \to [502,503] \to [501,502] \to [501,0] \to \textbf{colorless bound state $\Xi_{\mathbf{cc}}^{+,++}/\Omega_{cc}^{+}$, (4)}$$

¹ This is slightly different from BCVEGPY, the generator for B_c meson production, where there are five independent color factors in Step-A which lead to independent color flows accordingly [9].

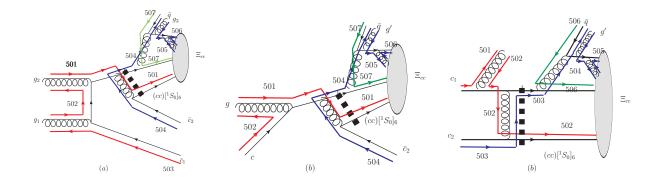


FIG. 2: (Color on line) Typical color flow for gluon-gluon fusion mechanism (Left), gluon-charm collision mechanism (Middle) and charm-charm collision mechanism (Right), where the thick dashed line shows the corresponding intermediate diquark state $(cc)[^1S_0]_6$. Three colorful lines are for color flow lines according to PYTHIA naming rules. The black lines are for Feynman diagrams.

$$[0, 504] \rightarrow [504, 0] \rightarrow \text{colorless bound state } \Xi_{cc}^{+,++}/\Omega_{cc}^{+},$$
 (5)

$$[0, 505] \rightarrow [505, 0] \rightarrow \text{colorless bound state } \Xi_{cc}^{+,++}/\Omega_{cc}^{+},$$
 (6)

where the final sub-step in Step-B shows that the three partons c[501, 0], c[505, 0] and q[504, 0] form the Fock state |ccq>.

For the gluon-charm collision mechanism, the typical color flow as shown in FIG.(1b) is

$$[502, 0] \to [501, 502] \to [501, 0] \to \text{colorless bound state } \Xi_{cc}^{+,++}/\Omega_{cc}^{+},$$
 (7)

$$[0, 504] \rightarrow [504, 0] \rightarrow \text{colorless bound state } \Xi_{cc}^{+,++}/\Omega_{cc}^{+},$$
 (8)

$$[0, 505] \rightarrow [505, 0] \rightarrow \text{colorless bound state } \Xi_{cc}^{+,++}/\Omega_{cc}^{+}.$$
 (9)

For the charm-charm collision mechanism, the typical color flow as shown by FIG.(1c) is

$$[501, 0] \to [502, 501] \to [502, 0] \to$$
colorless bound state $\Xi_{cc}^{+,++}/\Omega_{cc}^{+},$ (10)

$$[503, 0] \rightarrow [503, 0] \rightarrow$$
colorless bound state $\Xi_{cc}^{+,++}/\Omega_{cc}^{+},$ (11)

$$[0, 504] \rightarrow [504, 0] \rightarrow \text{colorless bound state } \Xi_{cc}^{+,++}/\Omega_{cc}^{+}.$$
 (12)

B. The color flow for $(cc)[^1S_0]_6$ being produced

In the case for $(cc)[^1S_0]_6$ diquark being produced, except the color and the spin of the diquark, programming the Step-A is the same as that of $(cc)[^3S_1]_{\bar{3}}$, but programming the Step-B is changed quite a lot:

- As pointed out in Ref.[8], the fragmentation of the color-sixtet diquark into the baryon is most likely via the Fock state $|ccqg\rangle$ instead via the Fock state $|ccq\rangle$ (the later need to change the heavy diquark spin, that it must be suppressed some). Note that as pointed out above, for the production of Ξ_{bc} without 'identity particle rule', the role of the two Fock states $|bcq\rangle$ and $|bcqg\rangle$ played in the fragmentation is similar. So the difference in color flow for the $|bcq\rangle$ and $|bcqg\rangle$ does not cause different result in Ξ_{bc} production.
- Since the diquark $(cc)[^1S_0]_6$ is in a color sixtet, in order to keep color flow of the production correctly, at least one more extra soft gluon, besides a light anti-quark, must be remained in the final state when the fragmentation is completed. It is because that, as the most simple case, a gluon and an anti-quark can construct a color-sixtet:

$$8 \bigotimes \bar{3} = 15 \bigoplus 6 \bigoplus \bar{3}, \tag{13}$$

and the sixtet may fully 'absorb' the color of the diquark $(cc)[^1S_0]_6$. Namely it is only due to the request to make color flow correctly that here an extra gluon is needed.

• The most simple 'mechanism', which may be the biggest one, to generate the extra soft gluon is by emitting from another soft light quark or a soft gluon, which is necessary in the fragmentation sub-process (one typical example can be found in FIG.(2)), so the extra so soft gluon causes negligible consequence in momentum distribution, even though all the subprocess are of non-perturbative nature. Hence in dealing with the momentum distribution among the baryon and jets etc, we can treat the soft antiquark and soft gluon in the final state as a whole object ². Once more one may see that to introduce the soft anti-quarks and so soft gluons is only for keeping the color conserves (flows correctly) in the production.

Some of typical color flows in the production via $(cc)[^1S_0]_6$ are shown in FIG.(2), where FIG.(2a), FIG.(2b) and FIG.(2c) are for gluon-gluon fusion, gluon-charm collision and charm-charm collision mechanisms respectively. All possible colors for the production may be obtained by interchanging the connect points among the soft partons properly.

² It is reasonable, since numerically, one find that the soft quark itself gives negligible contributions to the momentum distributions for the rest particles in final state.

For the gluon-gluon fusion mechanism, i.e. the case as shown by FIG.(2a), the three color flow lines are:

a).
$$[0, 503] \rightarrow [502, 503] \rightarrow [501, 502] \rightarrow [501, 0]$$

 \rightarrow colorless bound state $\Xi_{cc}^{+,++}/\Omega_{cc}^{+}$, (14)

b).
$$[0,504] \rightarrow [504,505] \rightarrow [505,506] \xrightarrow{} [506,0] \xrightarrow{}$$

colorless bound state
$$\Xi_{cc}^{+,++}/\Omega_{cc}^{+}$$
, (15)

c).
$$[0,507] \rightarrow [507,0] \rightarrow \text{colorless bound state } \Xi_{cc}^{+,++}/\Omega_{cc}^{+},$$
 (16)

where an extra soft gluon with color [505, 506] is introduced, in comparison with the case of $(cc)[^3S_1]_{\bar{3}}$, and connected to the second color flow line respectively. For the second color-flow line Eq.(15), both the gluon color g[505, 506] and the quark color q[506, 0] flow into the baryon. Thus here the equations Eqs.(14-16) correspond to that the four partons c[501, 0], c[507, 0], q[506, 0] and g[505, 506] form the Fock state |ccqg| finally. It can be found that the color octet gluon $g_3[504, 505]$ and the color anti-triplet anti-quark $\bar{q}[0, 507]$ can form a color 6 state so as to keep the color conservation of the process.

For the gluon-charm collision mechanism, as shown by FIG.(2b), we have

a).
$$[502,0] \to [501,502] \to [501,0] \to \text{colorless bound state } \Xi_{cc}^{+,++}/\Omega_{cc}^{+},$$
 (17)

b).
$$[0,504] \rightarrow [504,505] \rightarrow [505,506] \xrightarrow{} [506,0] \xrightarrow{}$$

colorless bound state
$$\Xi_{cc}^{+,++}/\Omega_{cc}^{+}$$
, (18)

c).
$$[0,507] \rightarrow [507,0] \rightarrow \text{colorless bound state } \Xi_{cc}^{+,++}/\Omega_{cc}^{+}.$$
 (19)

The equations Eqs.(17-19) correspond to the four partons c[501, 0], c[507, 0], q[506, 0] and g[505, 506] form the Fock state $|ccqg\rangle$ finally.

For the charm-charm collision mechanism, as shown by FIG.(2c), we have

$$a). \quad [501,0] \rightarrow [502,501] \rightarrow [502,0] \rightarrow \textbf{colorless bound state } \Xi_{\textbf{cc}}^{+,++}/\Omega_{cc}^{+}, \quad \ (20)$$

b).
$$[503, 0] \rightarrow [503, 504] \rightarrow [504, 505] \xrightarrow{} [505, 0] \xrightarrow{}$$

colorless bound state
$$\Xi_{cc}^{+,++}/\Omega_{cc}^{+}$$
, (21)

c).
$$[0,506] \rightarrow [506,0] \rightarrow \text{colorless bound state } \Xi_{cc}^{+,++}/\Omega_{cc}^{+}.$$
 (22)

The equations Eqs.(20-22) correspond to the four partons c[502,0], c[506,0], q[505,0] and g[504,505] form the Fock state |ccqg> finally. In Eqs.(15,18,21) the symbol " $\rightarrow [\cdots] \rightarrow$ " means a soft gluon is accompanied.

C. The color flow lines ended at a baryon and simplification with 'cheat'

In the above two subsection, based on the color-flow decomposition method of Ref.[10] we have designed a strict way to deal with the color flows for the baryon production.

In fact since a baryon contains three valance quarks in different colors so as to form a colorless object, thus under the color-flow decomposition method, there must be three color flow lines being ended at a baryon. Namely it is different from the case of meson, where the color flow lines of the quark and anti-quark inside a meson are continued. To simplify the present situation, reminding the fact that $3 \otimes 3 = 6 \oplus \bar{3}$ in general QCD SU(3) color space: 1) Firstly, we can combine any two of the flow lines ended with two quarks into one anti-flow line ended with one anti-quark with a color $\bar{3}$ (the direction of the line is turned back completely) that is different from the two quarks (the third kind of color in respect those kinds of the two quarks); 2) Secondly, such anti-flow line obtained by the combination may be continued (connected) to the third color-flow line in the baryon; 3) Finally, as a consequence, the color-flow lines ended at a baryon become 'joined without ends' at all, which is the requirement of the color-singlet bound state.

With the method for the color-flow lines ended at baryon, practically, the present version of PYTHIA (version 6.4) can generate full events with two or less independent color-flow lines in most cases well even a baryon being involved.

When there are three or more independent color-flow lines in process, PYTHIA will stop at the step of running the 'final parton showers' or parton cascade radiations etc, and will present an error message to show that the color flow rearrangement is wrong during the parton's evolution process. For the present problem to generate the full events for the baryon production, it is found that in GENXICC all the mentioned production mechanisms: gluon-gluon fusion, gluon-charm collision and charm-charm collision, have exactly three independent color flows as shown by the last subsections when the color flow lines ended at the produced baryon are not treated as the above (to combine two of the three lines into one anti-color flow line). So with GENXICC1.0 being directly complemented, PYTHIA can not work well with these mechanisms at the step of 'final parton showers' or parton cascade radiations etc. To overcome the difficulty and to achieve full useful information for each event of the baryon production, the best approach perhaps is that PYTHIA itself is improved to deal with three or more color-flow lines' processes etc, e.g. to add the useful

intermediate diquark states with color $\bar{\bf 3}$ or color ${\bf 6}$, such as $(cc)[^3S_1]_{\bar{\bf 3}}$, $(cc)[^1S_0]_{\bar{\bf 6}}$ etc, into the particle tabular of PYTHIA, and properly to treat the color-flow lines ended at the baryon in fragmenting them into baryons accordingly. We suspect that it can be realized as done in a similar way as that in PYTHIA [5] to treat color-octet mechanisms for the J/Ψ production without difficulty.

Since GENXICC1.0, the previous version of the generator, without precisely strict colorflow lines being defined, cannot run well for the available versions of PYTHIA, and furthermore, now there is no the improved PYTHIA as mentioned above, thus in GENXICC2.0 the upgraded version of the generator, we have to suggest another way so as to complete the fullevent generation under a controlled approximate level (not to deviate from true too much) with the color flow lines ended at a baryon. Namely, we properly vary the color flows of the process as depicted in the last subsections, so as to make PYTHIA running well for final parton shower process. Aiming at the purpose, we precisely restrict the state constructed by either (ccq) or (ccqq) is equal to the desired colorless baryon, then I) to keep color conservation, all the outgoing particles' colors are arranged properly such that they form a color state as that of the incoming particles; II) The details in color of the constitute partons are ignored. PYTHIA is cheated to believe that the state constructed by either (ccq) or (ccqq)is colorless baryon, so we force it 'steady' without any evolution, thus any programs, which are called from PYTHIA, may run smoothly. In this way and only to introduce necessary soft enough light quark(s) anti-quark(s) and gluon(s), the momentum distribution and the other factors for the production will not be affected much. Moreover, we further simplify the program for the production in color as follows: 1) Ignoring the details about the color flow when the diquark fragments into a colorless baryon, the initial color-flow lines are reduced to be less than or equal to two. More explicitly, for instance the three color-flow lines in Eqs.(4,5,6) for the gluon-gluon fusion mechanism $((cc)[^3S_1]_{\bar{3}})$ lead to two independent color-flow lines: $[0,503] \rightarrow [502,503] \rightarrow [501,502] \rightarrow [501,0] \rightarrow \textbf{colorless bound state}$ and $[0,504] \rightarrow [504,0] \rightarrow$ colorless bound state $\rightarrow [0,504]; 2)$ A working assumption in program is made by setting the outgoing light anti-quark's color to be the same as that of the outgoing \bar{c}_2 or (\bar{c}) (see FIG.1) in the case of gluon-gluon fusion or gluon-charm collision mechanism respectively; 3) In the production, to 'introduce' a soft anti-quarks and a soft gluon for the diquark $(cc)[{}^{1}S_{0}]_{6}$ is only to keep the color conservation, so we may formally combine these two soft objects as an effective soft 'parton'. Therefore, as for the color freedom-degree only, for the $(cc)[^1S_0]_6$ we force the outgoing soft gluon and soft anti-quark to be combined into an effective one color-sixtet object (parton) formally, so the color flow for both $(cc)[^3S_1]_{\bar{3}}$ and $(cc)[^1S_0]_6$ is treated in the same manner in the program. Namely in color, the effective soft 'parton' is \bar{q} for $(cc)[^3S_1]_{\bar{3}}$ and is $(\bar{q}g)$ for $(cc)[^1S_0]_6$ accordingly. Moreover, in GENXICC2.0, we provide an interface of these soft objects to PYTHIA and users, who are interested in this part, can conveniently use these code to do the event evolution. We should note here that this simplification in treating the color flows cannot be applied to the charm-charm collision mechanism, i.e., we can not simultaneously simplify the three independent color-flow lines into two and also keep the process in color conservation. However, the contribution from this mechanism is small in comparison with the other two mechanisms at higher energy colliders as TEVATRON and LHC[3] fortunately, so in the generator we safely ignore the charm-charm collision mechanism at all.

III. DISCUSSION

To generate full events for the production of the double heavy baryons with GENXICC complemented into PYTHIA, as pointed out above, obviously the best way is to improve PITHIA with proper treatment the color-flow lines ended at the baryon. Whereas due to the fact that the improved version of PYTHIA is not available now, thus we 'have to suggest' another way with certain approximation, i.e. when writing down the program, the upgraded version has additionally made certain simplification with 'cheat' so as to generate the full events by applying GENXICC2.0, the upgraded generator, being complemented in PYTHIA, quite efficiently. However we should point out here that due to approximation and simplification with 'cheat' explained in the above subsection, the obtained information about the 'tiny jets', corresponding to the soft anti-quark and soft gluon(s) produced in fragmentation of double heavy diquark, may not be very reliable, although the information about hard jets and the baryon as well in the full events is reliable.

Acknowledgments: The authors would like to thank Braden Keim Abbott and Richard J. Van Kooten for drawing their attention to the program defaulting the precise fragmentation from the heavy diquarks into the baryons in GENXICC1.0. This work was supported in part by Natural Science Foundation of China (NSFC) under Grant No.10805082

No.10875155, No. 10847001 and No. 10875155, and by Natural Science Foundation Project of CQ CSTC under Grant No.2008BB0298. This research was also supported in part by the Project of Knowledge Innovation Program (PKIP) of Chinese Academy of Sciences, Grant No. KJCX2.YW.W10.

- [1] Private communications with Braden Keim Abbott and Richard J. Van Kooten (D0 Collaboration).
- [2] Chao-Hsi Chang, Jian-Xiong Wang and Xing-Gang Wu, Comput. Phys. Commun. 177, 467(2007).
- [3] Chao-Hsi Chang, Cong-Feng Qiao, Jian-Xiong Wang and Xing-Gang Wu, Phys. Rev. D73, 094022(2006).
- [4] Chao-Hsi Chang, Jian-Ping Ma, Cong-Feng Qiao and Xing-Gang Wu, J.Phys. G34, 845(2007).
- [5] T. Sjostrand, S. Mrenna and P. Skands, JHEP **0605**, 026(2006).
- [6] R. Kleiss and W.J. Stirling, Comput. Phys. Commun. 40, 359(1986).
- [7] G.P. Lepage, J. Comp. Phys **27**, 192 (1978).
- [8] J.P. Ma and Z.G. Si, Phys. Lett. B**568**, 135(2003).
- [9] Chao-Hsi Chang, Chafik Driouich, Paula Eerola and Xing-Gang Wu, Comput.Phys. Commun. 159, 192 (2004); Chao-Hsi Chang, Jian-Xiong Wang and Xing-Gang Wu, Comput.Phys. Commun. 174, 241 (2006); Chao-Hsi Chang, Jian-Xiong Wang and Xing-Gang Wu, Comput.Phys. Commun. 175, 624 (2006).
- [10] F. Maltoni, K. Paul, T. Stelzer, S. Willenbrock, Phys.Rev. D67, 014026(2003).