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**TPHIC,
EVENT GENERATOR OF TWO PHOTON INTERACTIONS
IN HEAVY ION COLLISIONS**

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Abstract

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An event generator of two photon interactions induced by coherent heavy ion collisions is described. The basis of the generator is an effective $\gamma\gamma$ luminosity function derived in the equivalent photon approximation. A short survey of the two photon processes implemented in the generator is presented. In particular, the generator allows one to simulate processes of two photon interactions such as minimum bias events, resonance production and pair production of fermions, charged weak bosons and supersymmetric charginos.

Аннотация

Садовский С.А. и др. TPHIC, генератор событий двухфотонных взаимодействий в столкновениях тяжелых ионов: Препринт ИФВЭ 96-38. – Протвино, 1996. – 9 с., библиогр.: 12.

Описан генератор событий двухфотонных взаимодействий, вызванных когерентными столкновениями тяжелых ионов. Основой генератора является эффективная $\gamma\gamma$ функция светимости в приближении эквивалентных фотонов. Представлен краткий обзор двухфотонных процессов, заложенных в генератор. В частности, программа позволяет разыгрывать такие процессы двухфотонных взаимодействий, как события с наибольшим сечением, рождение резонансов и парное рождение фермионов, заряженных слабых бозонов и суперсимметричных чарджино.

Introduction

Up to now photon-photon collisions have been studied mainly at e^+e^- colliders. Only recently relativistic heavy ion collisions have been considered as a new realistic tool to study high-energy $\gamma\gamma$ collisions. In coherent interactions of ions with a charge Z the cross section of the two photon processes is enhanced by a factor Z^4 , which compensates a low luminosity of ion collisions as compared with that in e^+e^- collisions. Contrary to e^+e^- collisions the photons emitted by ions in coherent collisions are always quasi-real. These features allow one to use future heavy ion colliders, RHIC and LHC, to study two photon processes.

Following the needs to study two photon physics in heavy ion collisions we have constructed an event generator simulating several important processes. In section 1 we reproduce the basic formulae of the effective two photon luminosity function calculation discussed completely elsewhere [1,2]. A brief summary of two photon processes is also given in this section. General features of the generator TPHIC are described in the second section. It is followed by the usage guide of the generator with the explanation of main subroutines and variables. The description of the generator installation is given in the third section.

1. Two photon physics

1.1. Effective $\gamma\gamma$ luminosity function

In the equivalent photon approximation [1,2] the cross section of two photon processes in heavy ion collisions can be expressed in a factorized form [1,3,4]:

$$\frac{d\sigma}{d\Omega}(AA \rightarrow AAX) = \int dW \frac{d\mathcal{L}_{\gamma\gamma}}{dW} \frac{d\sigma}{d\Omega}(\gamma\gamma \rightarrow X), \quad (1)$$

where the effective $\gamma\gamma$ -luminosity function $\mathcal{L}_{\gamma\gamma}$ is determined in terms of the equivalent photon number $N(\omega, b)$ with energy ω and impact parameter b :

$$\frac{d\mathcal{L}_{\gamma\gamma}}{dW} = \int_R^\infty b_1 db_1 \int_R^\infty b_2 db_2 \int_0^{2\pi} d\phi \quad (2)$$

$$N\left(\frac{W}{2}e^Y, b_1\right)N\left(\frac{W}{2}e^{-Y}, b_2\right)\theta(b_1^2 + b_2^2 - 2b_1b_2 \cos \phi - 4R^2).$$

Here R is a cutoff of the impact parameter in order to avoid nuclear overlapping and, therefore, to get a clean signal; R is a nuclear radius defined via atomic number A as $R = 1.2A^{1/3}$ fm. The photon spectrum $N(\omega, b)$ is given by the equation:

$$N(\omega, b) = \frac{Z^2\alpha\omega^2}{\pi^2\gamma^2}K_1^2\left(\frac{\omega b}{\gamma}\right), \quad (3)$$

where γ stands for the c.m.s. Lorentz factor of a heavy ion, $\gamma = \sqrt{s_{AA}}/2M_A$; $K_1(x)$ is the modified Bessel function of the second kind. Since the impact parameter is limited by the nucleus radius, the photon energy has an upper bound $\omega \leq \gamma/R$. This feature of a photon spectrum in heavy ion collisions makes a difference in comparison with that in e^+e^- -collisions.

1.2. Physical processes in $\gamma\gamma$ collisions

Two photon collisions provide a remarkable possibility to study various processes in the framework of the Standard Model as well as in the advanced models such as supersymmetry. Below we discuss briefly the main two photon processes implemented in the generator TPIC.

Minimum bias events. Events with the largest cross section are referred to as minimum bias events. The (quasi-)real photon has a complicated structure. In the first approximation, the photon is a point-like particle. However, it can fluctuate into a virtual fermion-antifermion pair. The fluctuation $\gamma \leftrightarrow q\bar{q}$ can interact strongly and therefore provides the major part of the $\gamma\gamma$ total cross section. According to ref. [5] the spectrum of these fluctuations can be split into a low-virtuality and high-virtuality part. The former part can be well approximated by the phenomenological Vector Meson Dominance (VMD) ansatz, where a photon turns into a vector meson before the interaction. The high-virtuality part should be described perturbatively. The total $\gamma\gamma$ cross section at collision energy $\sqrt{s_{\gamma\gamma}}$ measured in GeV can be parametrized by the form [5]

$$\sigma_{\text{tot}}^{\gamma\gamma} \approx 211s_{\gamma\gamma}^\epsilon + 297s_{\gamma\gamma}^{-\eta} \text{ [nb]} \quad (4)$$

with powers ϵ and η

$$\epsilon \approx 0.0808, \quad \eta \approx 0.4525.$$

The event generator of minimum bias events in $\gamma\gamma$ collisions based on the photon picture described above exists as a part of the program package PYTHIA, v.5.7 [6]. A

similar approach is also used for generation of minimum bias events in the TWOGEN generator [7] for the case of e^+e^- collisions.

Resonance production. Hadrons with even angular momenta and positive C -parity like $J^{PC} = 0^{-+}, 0^{++}, 2^{++}$ can be produced in two photon fusion. The cross section of the resonance R production in $\gamma\gamma$ collisions is given by

$$\sigma_{\gamma\gamma\rightarrow R} = 8\pi(2J+1)\frac{\Gamma_{\gamma\gamma}\Gamma_{\text{tot}}}{(s-M_R^2)^2+M_R^2\Gamma_{\text{tot}}^2}, \quad (5)$$

where s is the two photon mass, M_R is a resonance mass, $\Gamma_{\gamma\gamma}$ and Γ_{tot} are two photon and total widths of the resonance, respectively. We consider charmonia $\eta_c(1S), \eta_c(2S), \chi_{c0}, \chi_{c2}$ and bottomonia $\eta_b, \chi_{b0}, \chi_{b2}$ production but no serious obstacles exist to extend this set to any other resonance of interest.

Fermion pair production. When the energy of the $\gamma\gamma$ collision is higher than a threshold $\sqrt{s} > 2m_f$, a charged fermion-antifermion pair with mass m_f can be produced. The fermion f can be either a lepton or a quark. The differential cross section of the process $\gamma\gamma \rightarrow f^+f^-$ in the c.m.s. of the $\gamma\gamma$ is given by [8]

$$\frac{d\sigma}{d\cos\theta}(\gamma\gamma \rightarrow f^+f^-) = \frac{e^4\beta Q_f^4 N_c}{8\pi s} \frac{1+2\beta^2(1-\beta^2)(1-\cos^2\theta) - \beta^4\cos^4\theta}{(1-\beta^2\cos^2\theta)^2}, \quad (6)$$

where Q_f is a fermion charge in units of electron charge, N_c is the number of colors and $\beta = \sqrt{1-4m_f^2/s}$. The integrated cross section of this process is [8]

$$\sigma(\gamma\gamma \rightarrow f^+f^-) = \frac{4\pi\alpha^2 Q_f^4 N_c}{s} \beta \left[\frac{3-\beta^4}{2\beta} \ln \frac{1+\beta}{1-\beta} - 2 + \beta^2 \right]. \quad (7)$$

If the fermion f is unstable or colored like μ, τ or a quark, it can be passed to the program JETSET to let it perform a fermion decay or fragmentation.

bf W^+W^- pair production. The process of W^+W^- production in $\gamma\gamma$ interactions can be considered as a main background process to the chargino pair production, however, this process can present a separate interest. The differential cross section in the c.m.s. is defined by the expression

$$\frac{d\sigma}{d\cos\theta}(\gamma\gamma \rightarrow W^+W^-) = \frac{\pi\alpha^2\beta}{s} \frac{19-6\beta^2(1-\beta^2) + 2(8-3\beta^2)\beta^2\cos^2\theta + 3\beta^4\cos^4\theta}{(1-\beta^2\cos^2\theta)^2}. \quad (8)$$

This formula was obtained using the computer system COMPHEP [9] of analytical matrix elements evaluation. The integrated cross section is given by [10]

$$\sigma(\gamma\gamma \rightarrow W^+W^-) = \frac{\pi\alpha^2}{s} \beta \left[-3\frac{1-\beta^4}{\beta} \ln \frac{1+\beta}{1-\beta} + 2\frac{22-9\beta^2+3\beta^4}{1-\beta^2} \right]. \quad (9)$$

Chargino pair production. Of special interest is the production of new particles, particularly in the framework of the Minimal Supersymmetric extension of the Standard

model (MSSM). Two photon collisions could be used to explore the pair production of charged supersymmetric particles. Following assumptions of ref. [11] we consider chargino $\tilde{\chi}_1^\pm$ as the lightest visible supersymmetric particle (LVSP) decaying into neutralino $\tilde{\chi}_1^0$ and a pair fermion-antifermion, where $\tilde{\chi}_1^0$ is the lightest supersymmetric particle (LSP) and, therefore, invisible. The differential and integrated cross sections of the process $\gamma\gamma \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^-$ are given by formulae (6) and (7) with $Q_f = 1$ and $N_c = 1$. A mass spectrum of supersymmetric particles, chargino and neutralino mixing matrix elements and decay branchings and widths are calculated by using the program package ISAJET/ISASUSY, v.7.13 [12] after setting supersymmetry breaking parameters. The decay $\tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 f_i \bar{f}_j$ is performed via its real matrix element calculated by COMPHEP. We do not give here this matrix element because of its rather complicated form.

2. A description of the event generator TPHIC

2.1. General features of TPHIC

The event generator TPHIC simulates two photon interactions in high energy heavy ion collisions. The generator calculates the effective two photon luminosity in heavy ion collisions, produces an event configuration and calculates the cross sections for the following five processes:

- | No. | Process type |
|-----|---|
| 1 | - minimum bias events; |
| 2 | - $\gamma\gamma \rightarrow$ quarkonium, where quarkonium can be any charmonium or bottomonium $J^{PC} = 0^{-+}, 0^{++}, 2^{++}$; |
| 3 | - $\gamma\gamma \rightarrow f^+ f^-$; |
| 4 | - $\gamma\gamma \rightarrow W^+ W^-$; |
| 5 | - $\gamma\gamma \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^-$ with subsequent chargino decay $\tilde{\chi}_1^+ \rightarrow \tilde{\chi}_1^0 l^+ \nu_l$, where l^\pm is either electron or muon. |

The generator allows one to calculate the effective $\gamma\gamma$ luminosity function $d^2\mathcal{L}_{\gamma\gamma}/dWdY$ on a grid according to formulae (3) and (2) and save it into a file for the next usage. The cross section of a chosen process is calculated by means of numerical integration with expressions (1), (4), (5), (7) and (9). The phase space point for process 4 and 5 is picked up randomly according to their differential cross sections (6) and (8).

The event generator uses well known event generators PYTHIA, v.5.706 [6] (for process 1 to produce minimum bias events in $\gamma\gamma$ collisions), ISAJET, v.7.13 [12] (for process 5 to calculate masses and decay parameters in MSSM) and JETSET, v.7.4 [6] for all processes to perform fragmentation, decays etc. Therefore the generator should be linked with these packages. A user should be aware of linking the program with PYTHIA and JETSET with release date not earlier than August 25, 1994, otherwise TPHIC will not work with process 1 properly.

2.2. Structure of a user's program

A user program has to contain some user assignments to fix initial variables and change their defaults values (if needed), to call subroutine **GGINIT** to initialize the generator, a loop over a desired number of events by calling **GGRUN** in each event to obtain the event configuration and to call **GGEXIT** at the end of the run to output a process cross section:

```
PROGRAM SAMPLE
...
User codes
...
CALL GGINIT
DO 100 IEVENT=1,NEVENT
  CALL GGRUN
  ...
  User codes
  ...
100  CONTINUE
CALL GGEXIT
...
User codes
...
END
```

2.3. Initialization of the generator

At the initialization phase a user needs to define some variables from the following common blocks:

```
+KEEP,ggini.
COMMON /ggini/ iproc,nevent,ilumf,lumfil,ebmn,eb,iz,ia,amas,
&              amin,amax,ymin,ymax,nmas,ny,kferm,
&              kf_onium,xmres,xgtres,xggres,xlumint,moddcy
CHARACTER lumfil*80,
```

where variables and their default values (denoted as $D = \dots$) are as follows:

IPROC	(D = 1) process number, see above
NEVENT	(D = 10000) number of events to be generated
ILUMF	(D = -1) flag to calculate Luminosity Function: 1 – read from a file, -1 – new calculation
LUMFIL	(D = 'gglum.dat') character variable with a file name with calculated luminosity function
EBMN	beam energy per nucleon
IZ	beam ion atomic number
IA	beam ion atomic mass
AMAS	beam ion mass in GeV
AMIN, AMAX	range of 2-gamma mass
YMIN, YMAX	range of 2-gamma rapidity
KFERM	LUND code for a fermion to be produced at IPROC=3
KF_ONIUM	LUND code for quarkonium to be produced at IPROC=2, all decay parameters but $\gamma\gamma$ -width are calculated via KF_ONIUM in GGINIT
XGGRES	two photon width of the quarkonium in GeV
NMAS, NY	(D = 50,50) number of steps in luminosity function calculation in two photon mass and rapidity, $NMAS \times NY \leq 10\,000$
MODDCY	a key to select chargino decay modes (for IPROC =5); =1 for decay into leptons (electrons and muons), =0 for all decay modes (not implemented yet).

A common block to the event output in the CWN format (see below):

```
+KEEP,ggcwn.
COMMON /ggcwn/ icwn, cwnfil
CHARACTER cwnfil*80
```

where

ICWN	(D = 0) a flag to produce the event output in the CWN format (if ICWN=1)
CWNFIL	(D = 'ggout.cwn') a file name with the CWN output

```
+KEEP,ggmssm.
COMMON /ggmssm/ xm1, xm2, xmg, xms, xmt1, xmtr,
& xml1, xmlr, xmnl, xtamb, xmha, xmu,
& xmt, xat, xmbr, xab, u11, v11
```

This common block is used for IPROC=5 only and contains the parameters of MSSM breaking. Masses and decay branchings of chargino and neutralino are defined through XM1, XM2, XMU, XTANB. All parameters have some default values and may be changed by the user. Default (D) and recommended (R) values are the following:

	(D)	(R)	
XM2	50.	$40 < XM2 < 1000 \text{ GeV}$	M_2
XM1	30.	$XM1 = XM2/2$	M_1
XMU	-300.	$-1 < XMU < 1 \text{ TeV}$	μ
XTANB	4.	$1 < XTANB < 50$	$\tan \beta$
XMS	700.		squark mass
XMTL	600.		left soft breaking stop mass
XMTR	600.		right soft breaking stop mass
XMLL	400.		left slepton mass
XMLR	400.		right slepton mass
XMNL	400.		sneutrino mass
XMHA	300.		pseudo-scalar Higgs mass
XMT	174.		top quark mass
XAT	300.		stop squark trilinear term
XMBR	300.		right soft breaking sbottom mass
XAB	300.		sbottom squark trilinear term

+KEEP,ggxs.

```
COMMON /ggxs/ xsmx, xscur, xsbra, xssum, ntry, xstot, xstote,
& ssbr(10)
```

Only the variable XSBRA of this common block may be defined during the initialization; during the run the cross section calculation will be multiplied by a factor XSBRA. Normally it is a product of branching ratios of studied decay modes. Other variables of this common block are calculated by the generator and may be used by a user to inquire cross section information of a process:

XSTOT the total cross section of the current process in nbarn, can be used after any full event, the more events, the more precise it is.
XSTOTE statistical error of XSTOT

2.4. Event output

Some items of the event configuration are available for the user through the common block GGEVNT.

+KEEP,ggevnt.

```
COMMON /ggevnt/ nrun,ievent,wsq,ygg,xmg1,xmg2, p2g(5),
& ptag1(4),ptag2(4), ngg, kgg(10),pgg(20,5)
```

NRUN run number
IEVENT current event number
WSQ squared 2-photon mass
YGG 2-photon rapidity
XMG1, XMG2 virtual photons masses
P2G(5) 4-momentum + mass of a 2-photon system

The full information about event configuration (code of each particle, its status, where it originates from, its momentum) is stored in the JETSET common block LUJETS

```
+KEEP, LUJETS
COMMON/LUJETS/N,K(4000,5),P(4000,5),V(4000,5)
SAVE /LUJETS/
```

The description of this common block can be found in the PYTHIA/JETSET manual. Since JETSET does not know about supersymmetric particles, we have implemented two new entries in a particle codes (KF) table:

KF	name	printed
41	$\tilde{\chi}_1^-$	chi_1-
42	$\tilde{\chi}_1^0$	chi_10.

The generator has also the interface to transform event records into the Column Wise Ntuple format (CWN) which is considered to be the standard ALICE output format for various event generators. This option can be switched on by putting the variable ICWN from the common block GGCWN to 1 (see above). This interface is represented by 3 subroutines:

```
CALL CWNINI (OUTFILE)  opens output file OUTFILE (of CHARACTER type) for
                        event data in CWN format;
CALL CWNFNT            event output routine in CWN format, called in each
                        event after GGRUN;
CALL CWNEND           closes the output CWN properly.
```

2.5. Cross section calculation

The cross section of a process is calculated in each event and can be retrieved through the common block GGXS as described above. Besides after the run calling of the subroutine GGEXIT prints out the process cross section and its statistical error.

3. Installation of TPHIC

The TPHIC package contains files TPHIC.CAR, TPHIC.CRA and TPHIC_MAKE.COM. The latter is a command file to create an object library at VAX and Alpha/OpenVMS. This library contains two BLOCK DATA modules GGDATA and GAUSSDATA, some linkers do not take these modules during linking stage and therefore these modules should be included explicitly. Five examples of the TPHIC usage can be produced by the command file TPHIC_EXA.COM with cradle files TPEXA1.CRA – TPEXA5.CRA.

Warning! In some versions of CERN library (at least, in version 94b for VAX/VMS and AXP/OpenVMS) JETSET74 object library is compiled improperly and does not correspond to the actual version of PYTHIA. If it is the case with your local computer it is necessary to recompile this library.

Conclusion

Two photon collisions allow one to explore new physics which cannot be reached in hadron and lepton interactions and therefore the former are complimentary to the latter. Future high energy heavy ion colliders provide a new tool to study two photon physics. The new physical task requires a proper event generator to model various two photon processes. Here we have presented a generator TPHIC based of the effective two-photon luminosity function in the equivalent photon approximation. This generator is closely connected with the event the generators PYTHIA/JETSET and ISAJET/ISASUSY. The generator allows one to study the main processes of $\gamma\gamma$ interactions in heavy ion collisions and can be useful to plan future experiments.

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References

- [1] G.Baur, L.G.Ferreira Filho. Nucl.Phys. A518 (1990) 786.
- [2] R.Cahn, J.D.Jackson. Phys.Rev. D42 (1990) 3690.
- [3] N.Baron, G.Baur. Phys.Rev. C49 (1994) 1127.
- [4] K.Hencken, D.Trautmann, G.Baur. Z. Phys. C 68 (1995) 479.
- [5] G.Schuler, T.Sjöstrand. Preprint CERN-TH.7193/94, e-print hep-ph/9403393.
- [6] T.Sjöstrand. PYTHIA 5.7 and JETSET 7.4 physics and manual. Preprint CERN-TH.7112/93.
- [7] A.Buijs et al. Preprint CERN-PPE/93-199, 22 November 1993; Comp. Phys. Comm. 79 (1994) 523. Source code can be found at <http://www.fys.ruu.nl/~buijs/twogen/twogen.for>.
- [8] T.Barklow. Preprint SLAC-PUB-5364 (1990).
- [9] E.E. Boos et al., in the Proceedings of the Second International Workshop on Software Engineering, ed. by D. Perret-Gallix, World Scientific, p.665 (1992); V.A. Ilyin, D.N. Kovalenko and A.E. Pukhov, INP MSU Preprint-95-2/366, Moscow State University, (1995).
- [10] M.Katuya. Phys.Lett. B124 (1993) 421.
- [11] J.Feng, M.Strassler. Phys.Rev. D51 (1995) 4661; preprint SLAC-PUB-6497, e-print hep-ph/9408359.
- [12] F.Paige, S.Protopopescu. ISAJET –ISASUSY 7.13.

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