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A MONTE-CARLO PROGRAM TO GENERATE MINI-JET EVENTS IN THE TWO-PHOTON PROCESS

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ABSTRACT

An event generator for resolved photon processes in photon-photon collisions in e^+e^- reactions has been developed. The program can generate direct, once-resolved and twice-resolved processes either separately or simultaneously according to user switches.

PROGRAM SUMMARY

Title of program : MINIJET

Program obtainable from: CPC Program Library, Queen's University of Belfast, N. Ireland, and the authors upon the request by e-mail.

Computer for which the program is designed and others on which it is operable: FACOM and others with FORTRAN 77 compiler.

Computer: FACOM-M1800; *Installation*: National Laboratory for High Energy Physics (KEK), Tsukuba, Ibaraki, Japan.

Operating system: OSIV MSP-E20, OSIV EX.

Program language used: FORTRAN77

High speed storage required: 1300 k words.

No. of bits in a word: 32

Peripherals used: terminal or card reader for input, disk and printer for output.

No. of lines in combined program and test deck: 2570

Keywords: Monte-Carlo simulation, event generation, mini-jet, two-photon process, resolved photon process.

Nature of physical problem:

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In high energy two-photon processes in e^+e^- reactions, the hadronic components of the photon contribute significantly to the process. In particular, jet production in (almost real) photon-photon collisions offers an opportunity to test pertuabative QCD. In addition, on understanding of the process is indispensable for designing future high energy e^+e^- linear colliders

Method of solution:
The cross sections of the resolved photon processes are calculated at the parton level by a convolution of the photon luminosity function, the photon structure functions and the sub-process cross sections. Based on the calculation, high-p_t partons and remnant partons accompanied by the resolved photon processes are generated. They are subsequently hadronized, while neglecting scattered $e^{\pm}$.

Typical running time:
The running times depend upon the physical parameters. In the case of a default parameter set, it takes 487 sec to calculate the cross section on a FACOM-M1800 computer, while it takes 2.85 sec to generate 1k events.

LONG WRITE-UP

1 Introduction

The program package presented here is used to calculate the cross section of jet productions by a collision of almost real $\gamma\gamma$ in e^+e^- collisions and to generate such events for Monte-Calro studies. There are three different classes of diagrams which contribute to mini-jet production in $\gamma\gamma$ collisions, as shown in Fig. 1. We call each diagram direct(Fig. 1a), once-resolved(Fig. 1b) and twice-resolved(Fig. 1c), respectively. Those three processes contribute to jet production in a $\gamma\gamma$ collision in the same order, as pointed out theoretically by M. Drees and R. M. Godbole[1]. It was first experimentally confirmed by AMY[2] at TRISTAN. In recent studies performed at TOPAZ[3, 4] and ALEPH[5] for the two-photon process in e^+e^- collisions and those by H1[6] and ZEUS[7] for ep collisions, the resolved photon processes are shown to constitute an indispensable part of the jet production. However, the comparison of the data and theoretical predictions is rather qualitative. A more precise understanding of the resolved process is necessary, since it would allow us to test perturbative QCD[10] and would provide valuable information for designing future e^+e^- and $\gamma\gamma$ colliders[11, 12].

The program uses the program package BASES/SPRING[8, 9] to calculate the cross section, and, subsequently, to generate the four momenta of hard jets and remnant jets. Produced partons are then hadronized using the LUND 6.3[13] program package in the SPRING step. The origin of the γ can be either bremsstrahlung or beamstrahlung, according to the parameters of the program.

As Monte-Calro event generators for jet production by photon-photon collisions in e^+e^- reactions, PYTHIA[14] and HERWIG[15] are also available. They can include the $\gamma\gamma$ initial state to the existing general purpose generator. The program presented here and the default parameter sets correspond to those used by the TOPAZ group[3, 4]. The ALEPH[5] group reported that our program provides better descriptions of jet production in the two-photon process than those of PYTHIA and HERWIG.

In the following sections we will discuss the methods used to calculate the cross section and to generate Monte Calro events.

2 A method for Monte Calro simulation

We use the program package BASES/SPRING[8, 9] to calculate the cross section and to generate the four-momenta of the final particles. What we have to prepare when we use the package is a function to give a differential cross section.

The general expression for the differential cross section of jet production by photon-photon collisions in e^+e^- reactions is given as follows, according to M. Drees and R. M. Godbole[16]:

$$\frac{d\sigma}{dx_1 dx_2 dx_3 dx_4 dcos\hat{\theta}} = f_{\gamma/e^-}(Q^2, x_1) f_{\gamma/e^+}(Q^2, x_2) D_{p/\gamma}(Q^2, x_3) D_{p/\gamma}(Q^2, x_4) \frac{d\hat{\sigma}(\hat{s},\hat{t})}{dcos\hat{\theta}}, \quad (1)$$

where $f_{\gamma/e^\pm}$ are the photon flux factors, $D_{p/\gamma}$ are the parton (gluon or quark) density functions inside γ, and $\frac{d\hat{\sigma}(\hat{s},\hat{t})}{dcos\hat{\theta}}$ is a differential cross section of the sub-process. $\hat{\theta}$ is the scattering angle of the sub-process in its rest. x_1 and x_2 are the photon energies scaled by the beam energy(E_{beam}) and x_3 and x_4 are the parton energies scaled by the original photon energy. $\hat{s} \equiv x_1 x_2 x_3 x_4 s$ is the squared invariant energy of the sub-processes with $s = 4E_{beam}^2$. Both $D_{p/\gamma}$ are replaced by $\delta(1 - x_i)$ ($i = 3$ and 4) in the case of the direct process and either $D_{p/\gamma}(Q^2, x_3)$ or $D_{p/\gamma}(Q^2, x_4)$ is replaced with $\delta(1 - x_i)$ in the case of the once-resolved process.

In this program, $f_{\gamma/e^\pm}$ is calculated by the subroutine `MNJGAM`, $D_{p/\gamma}$ by `MNJPRB`, and $\frac{d\hat{\sigma}(\hat{s},\hat{t})}{dcos\hat{\theta}}$ by `MNJCRS`. Using these routines, the function `FNCMNJ` gives $\frac{d\sigma}{dx_1 dx_2 dx_3 dx_4 dcos\hat{\theta}}$ in a unit of pb for a BASES calculation. The number of dimensions in the BASES integration is six, five of which are used for x_1, x_2, x_3, x_4, and $\cos\hat{\theta}$, while the sixth dimension is used to select the relevant sub-processes.

2.1 Photon spectrum function

Three types of bremsstrahlung photon spectrum functions and one type of beamstrahlung photon spectrum functions are implemented in the program, which can be selected by variables `NGMINS` and `NGPLUS` stored in the common `/MNJPRM/`, separately for e^- and e^+ beams.

The default bremsstrahlung photon spectrum function is given by an equivalent photon approximation including a non-leading term[18],

$$\begin{aligned} f_{\gamma/e}(x) &= \frac{\alpha_{em}}{\pi x}\left[(1+(1-x)^2)\left\{\ln(\frac{E_{beam}}{m_e}) - \frac{1}{2}\right\} + \frac{x^2}{2}\left\{\ln(\frac{2(1-x)}{x}) + 1\right\}\right. \\ &+ \left.\frac{(2-x)^2}{2}\ln(\frac{2(1-x)}{2-x})\right], \end{aligned} \quad (2)$$

where E_{beam} is the electron(positron) beam energy and m_e is the electron mass. We use $\alpha_{em} = 1/137.0359895$ throughout the program.

The second form of the photon flux factor[17] includes the anti-tag condition as follows:

$$f_{\gamma/e}(x) \;=\; \frac{\alpha_{em}}{2\pi x}(1+(1-x)^2)\ln\frac{P^2_{max}}{P^2_{min}} - \frac{\alpha_{em}}{\pi}\frac{1-x}{x}, \tag{3}$$

where $P^2_{min} = m_e^2\frac{x^2}{1-x}$ and $P^2_{max} = min(P^2_{exp.max}, Q^2)$. P_{min} and P_{max} are the kinematical minimum and maximum of the photon virtuality. $P_{exp.max}$ is the maximum photon virtuality determined by the experimental anti-tag condition and given by $P^2_{exp.max} = 2E^2_{beam}(1-x)(1-\cos\theta_{max})$. Q^2 is equal to p_t^2 or $\hat{s}$, depending on `NQSSRC` in the common `/MNJPRM/`.

For the bremsstrahlung photon spectrum for high energy $e^{\pm}$, M. Drees *et al.*[16] suggested that the formula depend on the photon virtuallity with an additional suppression factor, which is given by

$$f_{\gamma/e}(Q^2, x) = 0.85\frac{\alpha_{em}}{2\pi}\frac{1+(1-x)^2}{x}\ln(\frac{Q^2}{m_e^2}). \tag{4}$$

The value of Q is set to be equal to the transverse momentum (p_t) of a hard jet or half of center-of-mass energy of a sub-process ($\frac{1}{2}\sqrt{\hat{s}}$) depending on the flag `NQSSRC` in the common `/MNJPRM/`.

The beamstrahlung photon spectrum is a function of the beam size at the interaction point (σ_x, σ_y, and σ_z), the initial beam energy (E_{beam}) and the number of particle per bunch(N). Using these parameters, the photon spectrum is given by[19]

$$\begin{aligned} f_{\gamma/e}(x) \;&=\; \frac{\kappa^{1/3}}{\Gamma(1/3)}x^{-2/3}(1-x)^{-1/3}e^{-\frac{\kappa x}{1-x}} \\ &\times \left[\frac{1-\frac{1}{6\sqrt{\kappa}}}{g}(1-\frac{1-e^{-gN_\gamma}}{gN_\gamma}) + \frac{1}{6\sqrt{\kappa}}(1-\frac{1-e^{-N_\gamma}}{N_\gamma})\right], \end{aligned} \tag{5}$$

where

$$x \;=\; E_\gamma/E_{beam}, \tag{6}$$

$$g \;=\; 1-\left[\frac{N_{CL}}{2N_\gamma}(1+x)+\frac{1}{2}(1-x)\right](1-x)^{2/3}, \tag{7}$$

$$\kappa \;=\; \left(\frac{3}{2}\bar{\Gamma}\right)^{-1}, \tag{8}$$

and

$$\bar{\Upsilon} \;=\; \frac{5\gamma_e^2\gamma_0 N}{6\alpha\sigma_z(\sigma_x+\sigma_y)}, \tag{9}$$

$$N_{CL} \;=\; 1.06\alpha\gamma_e N\frac{2}{\sigma_x+\sigma_y}, \tag{10}$$

$$N_\gamma \;=\; N_{CL}\frac{1}{\sqrt{1+\bar{\Upsilon}^{2/3}}}. \tag{11}$$

γ_0 is a gamma factor of the beam particle ($\gamma_0 = E_{beam}/m_e c^2$) and γ_e is the classical electron radius.

This function reproduces the exact spectrum obtained by the ABEL simulation[20], except for a slight difference in low photon energy region[11]. As default parameters, we prepared parameter sets for the proposed e^+e^- linear collider, JLC-I[21].

2.2 Parton density function inside the photon

Due to lack of experimental knowledge, the exact form of the parton density inside a photon is not well known. It is a subject of extensive physical investigation. Several parametrizations are available in the program.

DO parameterization[22] is an asymptotic solution to the photon's APE equation in leading order QCD. The analytical forms are given by

$$xD_{q/\gamma}(Q^2,x) = F\left[e_q^2\frac{(1.81-1.67x+2.16x^2)x^{0.70}}{1-0.4\ln(1-x)} + 0.0038(1-x)^{1.82}x^{-1.18}\right] \tag{12}$$

and

$$xD_{g/\gamma}(Q^2,x) = 0.194F(1-x)^{1.03}x^{-0.97} \tag{13}$$

where

$$F = \frac{\alpha_{em}}{2\pi}\ln(\frac{Q^2}{\Lambda^2}). \tag{14}$$

DO parameterization needs to be supplemented by a VDM term in order to reproduce data of the photon structure function. The form chosen by Drees and Godbole[1] is

$$D_{q/\gamma}^{VDM}(Q^2,x) = \alpha_{em}\left[5/16\frac{1-x}{\sqrt{x}} + 1/10\frac{(1-x)^5}{x}\right] \tag{15}$$

and

$$D_{g/\gamma}^{VDM}(Q^2,x) = \alpha\frac{2(1-x)^3}{x}. \tag{16}$$

We call this as a "DO+VDM" parameterization.

The DG parametrization[23] uses the APE equation to determine the Q^2 evolution of the density function. TASSO's data of the photon structure function at $Q^2 = 5.9$ GeV^2 is used to provide the input distribution at $Q^2 = 1$ GeV^2. H. Abramowicz, et al.[24] made the new DG-like analysis using a much larger data sample. They obtained three solutions which depend on the Q_0^2 values and the treatment of the gluon function. Their results for the gluon density function are quite different from DG parametrization, especially in the low x region.

More recently, M. Glück, *et al.* determined the photonic parton distribution including higher order by imposing a VDM valencelike structure at a low resolution scale[25].

In this program package we include the DO, DO+VMD and DG parameterization. The program of DG parameterization was obtained from PYTHIA 7.3, and was slightly modified so as to adopt our program package. The parton density function is calculated by the subroutine `MNJPRB` and the function can be selected by its argument, `NTYP`, which is also accessible by the variable `NDISTR` stored in the common `/MNJPRM/`. Other structure functions, such as LAC, are not supplied. They are provided by PDFLIB[26], and are easily implemented with a slight modification of the subroutine `MNJPRB`.

2.3 Sub-process cross sections

The cross section formula for the sub-processes are categorized into 12 different processes: (1) $\gamma\gamma \to q_i\bar{q}_i$, (2) $\gamma q_i \to g q_i$, (3) $\gamma g \to q_i\bar{q}_i$, (4) $q_i + q_i \to q_i + q_i$, (5) $q_i + q_j \to q_i + q_j$, (6) $q_i + \bar{q}_i \to q_i + \bar{q}_i$, (7) $q_i + \bar{q}_i \to q_j + \bar{q}_j$, (8) $q_i + \bar{q}_j \to q_i + \bar{q}_j$, (9) $q_i + \bar{q}_i \to g + g$, (10) $q_i + g \to q_i + g$, (11) $g + g \to q_i + \bar{q}_i$ and (12) $g + g \to g + g$, where the suffixes indicate the quark flavors. Sub-process (1) is a direct process, (2) and (3) are once-resolved processes and the rest are twice resolved processes. We use the sixth BASES varaible ($X(6)$) as an index for the sub-processes. The function `FNCMNJ` returns just the differential cross section of a given process in a unit of pb, and the total cross section is obtained by BASES as a part of the integration. As an option, it is also possible to calculate the cross section of each sub-process separetly by setting the parameters `NGNTYP` and `NGNPRC` in the common `/MNJPRM/` properly.

As initial state quarks, we consider only the u, d and s quarks, since no heavy quark components are seen in the photon structure functions. As final state quarks we include the charm and bottom quarks in addition to the light quarks. The cross section formula used in the program are summarized in the Appendix A. As a default (`NMASQ=1`), quark mass effects are included only for the charm and bottom quarks, and massless quark formula are applied for the light quarks. The thresholds for heavy quark production are set by `QHMASS(1:6)` in the common `/MNJQMS/`, and is also controlled by `NUMFLV` in the common `/MNJPRM/`. When we calculate the sub-process cross section, the strong coupling constant (α_S) is calculated as

$$\alpha_S(Q^2) = \frac{12\pi}{(33 - 2N_f)\log(Q^2/\Lambda^{(4)2})}, \tag{17}$$

where N_f is the number of flavors above the threshold. To allow for a continuous change in α_S at the flavor thresholds, $\Lambda^{(4)}$ is adjusted when N_f changes to 3 or 5, if `NLAM` is set to 1 (not a default).

3 Event Generation

Once the cross sections are evaluated by BASES, the generation of hard scattered partons is straight forward with the help of SPRING. The four momenta of scattered hard partons are calculated from the integral variables (x). We do not generate scattered electrons nor positrons, while we do generate remnant particles in the case of once-resolved and twice resolved processes. When a photon is resolved into a quark, anti-quark, or gluon, we generate an anti-quark, quark or gluon, respectively, along the direction of beam particle. Their energy is determined so that energy sum of the resolved parton and the remnant is equal to that of the photon. Finally, the produced partons are hadronized by using JETSET 6.3[13] string fragmentation routines. To use this hadronization program we needed a trick to treat the remnant jets in the subprocess $gg \to gg$, in which case we generate u quarks as remnant particles instead of gluons. No parton shower option in JETSET program is used.

The properties of generated events were studied using TOPAZ[3]. According to this study, particles flow along the jets and the particle activities due to the remnant jets are reasonably well described by this event generator.

4 Program description

4.1 Flow of the job

As mentioned in the previous section, we use the program packages BASES/SPRING[8, 9], which require two job steps, namely an integration step and a generation step.

The JCL example for a job is attached in Appendix B. The integration step requires four input cards for BASES. All of the physical parameters for the MINIJET calculations are prepared in the common `/MNJPRM/`, `/MNJQMS/`, and `/MNJBEM/`, which are initialized by the block data `MNJBLK`. To modify these parameters, the user can directly modify `MNJBLK` or implement an initialization procedure in the subroutine `MNJUIN`, which is called from `USERIN` of BASES. The user may initialize the histogram in `MNJUIN`.

At the end of BASES, histograms, scatter plots and the total cross section for given input parameters are printed. The information for the grids and weights of the integrations is written into logical unit 23 for latter use by SPRING.

There are two input cards for the generation step, SPRING: the number of events to be generated and the CPU time limits. It also reads the integration information from logical unit 23, which is used to generate events. Subroutines `MNJMPL` and `MNJHAD`, called from the subroutine `SPEVNT`, are used to convert the integration variables ($x(1:6)$) into the parton four momentum and hadronize, respectively. The generated particle information are stored in the common `/LUJETS/` with a standard JETSET 6.3 format. The user can access the common by the subroutine `MNJUSP`, which is called at the end of every event.

4.2 Switches for event type selection

In this section we describe the commons which are used to store the physical parameters which controll jet events. Those variables whose name starts by `N` are `INTEGER*4` type; the others `REAL*8`. The values indicated by D in parentheses are default values which are initialized in the block data `MNJBLK`. The user can use the subroutine `MNJUIN` to set their prefered values. (R) indicates READ ONLY variables; users should not alter them.

```
 COMMON /MNJPRM/ NGNTYP, NGNPRC, NQSSRC, NUMFLV, XXLAM, XLAM,
>                XXLAM2, XLAM2, YMAX3, YMAX4, PTMIN, PTMAX, COSMAX,
>                NDISTR, NMASQ, NLAM, NGMINS, NGPLUS, NONEJT
```

Purpose : switches and parameters to control the generated event type.

`NGNTYP` : (D=0) select the process type.

= 0 : generate all type of processes.

= 1 : generate only once resolved process.

= 2 : generate only twice resolved process.

= 3 : generate a sub-process specified by `NGNPRC`.

`NGNPRC` : (D=1) select the generated sub-process ID (1 to 12), valid only when `NGNTYP`=3. See section 2.3 for the meanings of sub-process ID.

`NQSSRC` : (D=1) a method to calculate Q^2

= 0 : use center-of-mass energy of hard process ($\hat{s}$) as Q^2.

= 1 : use p_t^2 of hard process as Q^2.

`NUMFLV` : (D=4) number of flavors to be generated.

= 0 : number of generated flavors depends on Q^2; u, d, s, c, and b quarks when $Q^2 > 500$ GeV/c^2, u, d, s, and c quarks when $50 < Q^2 < 500$ GeV/c^2, otherwise u, d, and s quarks are generated.

= 3 : generate u, d, and s quarks.

= 4 : generate u, d, s and c quarks.

= 5 : generate u, d, s, c, and b quarks.

`XXLAM` : (D=0.4 (GeV)) $\Lambda^{(4)}$ used to calculate α_S.

`XLAM` : (D=0.4 (GeV)) $\Lambda^{(4)}$ used to calculate photon structure function.

`XXLAM2,XLAM2` : (R) internal use only (`XXLAM2=XXLAM`^{2}, `XLAM2=XLAM`^{2}).

`NLAM` : (D=0) treatment of $\Lambda^{(4)}$ in hard scattering (`XXLAM`).

= 0 : use fixed value as given by `XXLAM` independent of number of generated flavors (N_f).

= 1 : `XXLAM` is used when N_f=4, but changed when N_f=3 or 5 so that α_s changes continuously at the threshold of new flavors.

`NDISTR` : (D=2) Type of photon structure function.

= 0 : use DG structure function[23]. Number of flavor is changed automatically as the case of `NUMFLV=0`.

= 1 : same as `NDISTR`=0 case but `NUMFLV` is fixed to 3.

= 2 : same as `NDISTR`=0 case but `NUMFLV` is fixed to 4.

= 3 : same as `NDISTR`=0 case but `NUMFLV` is fixed to 5.

= 4 : reserved for LAC[24] parameterization.

= 5 : reserved for LAC[24] parameterization.

= 6 : reserved for LAC[24] parameterization.

= 7 : use DO[22] structure function.

= 8 : use a sum of VMD and DO structure function.

= 9 : use a sum of modified VMD and DO structure function.

`NMASQ` : (D=1) select the method of quark treatment in hard processes.

= 0 : all quark are assumed to be massless.

= 1 : take into account c and b quark mass effect.

= 2 : take into account the mass effect for all quarks, but the formula used is correct only for direct process.

`NGMINS` : (D=1) photon spectrum function from e^- beam.

= 0 : bremsstrahlung photon spectrum by EPA as given in Eq.2.

= 1 : bremsstrahlung photon spectrum by modified EPA forumula as given in Eq.4.

= 21 - 26 : beamstrahlung photon spectrum of linear collider with a flat beam optics, whose parameter is given by an array `(BEMAMP(i,NGMINS-20),i=1,7)` in a common `/MNJBEM/`.

`NGPLUS` : (D=1) same as `NGMINS`, but for e^+ beam.

`YMAX3` : (D=0.7) maximum absolute value of rapidity for one of two jets produced in hard processes.

`YMAX4` : (D=0.7) maximum absolute value of rapidity for the other jet. If `YMAX4` is negative, no cut on rapidity is applied to this jet and the cross section is counted twice if `NONEJT` = 2 and the absolute values of the rapidities of both hard jets are less than `YMAX3`.

`PTMIN` : (D=3.0 (GeV)) minimum p_t of hard jet.

`PTMAX` : (D=8.0 (GeV)) maximum p_t of hard jet.

COSMAX : (D=0.998440764) anti-tag condition for the calculation of the photon flux. Electron (positron) is not detected when the cosine of the production angle is greater than COSMAX. Valid when NGMINS(NGPLUS)= 0.

NONEJT : (D=1) A way to count cross section, when calculate one-jet inclusive cross section, and valid when YMAX4 is negative.
- $= 1$: always count one-jet as one jet.
- $= 2$: count one-jet twice if the absolute values of the rapidity of both jets are less than YMAX3.

```
COMMON /MNJQMS/ QMAS(6), QHMAS(6)
```

Purpose : quark masses (QMAS(I)) and thresholds (QHMAS(I)) for corresponding flavor productions. These are REAL*8 variables. This common is used in the subroutine MNJCRS and MNJMPL.

QMAS(1) = : (D=0.325 GeV) d quark mass.
QMAS(2) = : (D=0.325 GeV) u quark mass.
QMAS(3) = : (D=0.5 GeV) s quark mass.
QMAS(4) = : (D=1.5 GeV) c quark mass.
QMAS(5) = : (D=4.5 GeV) b quark mass.
QHMAS(1) = : (D=0.325 GeV) threshold for d quark generation.
QHMAS(2) = : (D=0.325 GeV) threshold for u quark generation.
QHMAS(3) = : (D=0.5 GeV) threshold for s quark generation.
QHMAS(4) = : (D=1.87 GeV) threshold for c quark generation.
QHMAS(5) = : (D=5.3 GeV) threshold for b quark generation.

```
COMMON /MNJBEM/ BEAMPR(7,6)
```

Purpose : Beam parameters of linear colliders for beamstrahlung photon generation, which is used in the subroutine MNJGAM. BEAMPR is a REAL*8 array. The first index corresponds to the parameters as described below, while the second index corresponds to the different machine optics. As a default, JLC-I[21] parameters are stored; BEAMPR(1:7,1)=S-band at $\sqrt{s}$ = 300 GeV, BEAMPR(1:7,2)=S-band at $\sqrt{s}$ = 500 GeV, BEAMPR(1:7,3)=L-band at $\sqrt{s}$ = 300 GeV, BEAMPR(1:7,4)=L-band at $\sqrt{s}$ = 500 GeV, BEAMPR(1:7,5)=X-band at $\sqrt{s}$ = 300 GeV, BEAMPR(1:7,6)=X-band at $\sqrt{s}$ = 500 GeV.

BEAMPR(1,1:6) = : beam energy, E_0 (GeV).
BEAMPR(2,1:6) = : beam spot size in x direction at interaction point (IP), σ_x (cm).
BEAMPR(3,1:6) = : beam spot size in y at IP, σ_y (cm).
BEAMPR(4,1:6) = : beam spot size in y at IP, σ_z (cm).
BEAMPR(5,1:6) = : Number of particles in a bunch.
BEAMPR(6,1:6) = : Luminosity without pinch effect.
BEAMPR(7,1:6) = : Number of beamstrahlung photons.

4.3 Event information

Since we use JETSET 6.3 to hadronize partons, the four momenta of the final state particles are stored in the common /LUJETS/, whose format is described in Ref. [13]. The user can use the subroutine MNJUSP to access /LUJETS/, which is called at the end of the event generation in SPRING. The kinematical information used by BASES/SPRING is stored in the common /MNJEVT/, which is described below. Variables whose name starts by N are INTEGER*4 type; the others are REAL*8. All the variables other than EBEAM are READ ONLY. EBEAM is the electron/positron beam energy, whose default value is 29 GeV.

```
 COMMON /MNJEVT/ RS, EBEAM, XG(25), EGAM1, EGAM2, CS, PCM,
>                EGAM10, EGAM20, FONE, NPRC, INDX
```

Purpose : contains the generated event information.

RS : (R (GeV)) center of mass energy.

EBEAM : (D=29.0 GeV) beam energy, which should be set by user in the block data MNJBLK or the subroutine MNJUIN.

XG(1:6) : (R) a copy of random variables used for the event generation (see section 2 for description.).

XG(21) : (R) the scaled energy of photon emitted from e^- beam ($x_1 \equiv E_\gamma/E_{beam}$).

XG(22) : (R) the scaled energy of photon emitted from e^+ beam ($x_2 \equiv E_\gamma/E_{beam}$).

XG(23) : (R) the scaled energy of partons resolved from photon emitted by e^- ($x_3 \equiv E_{parton}/E_\gamma$).

XG(24) : (R) the scaled energy of partons resolved from photon emitted by e^+ ($x_4 \equiv E_{parton}/E_\gamma$).

CS : (R) $\cos\theta$ of hard jets in its center-of-mass system.

PCM : (R) momentum of hard jets.

EGAM10 : (R (GeV)) photon energy (GeV) emitted from e^-

EGAM20 : (R (GeV)) photon energy (GeV) emitted from e^+

EGAM1 : (R (GeV)) energy of a parton in the initial state of hard processes.

EGAM2 : (R (GeV)) energy of the other parton in the initial state of hard processes.

FONE : (R) weight factor of events, valid when calculating one jet inclusive cross section.

NPRC : (R) process ID of generated event.

INDX : (R) pointer to the array KCDATA, which gives the process type and parton IDs involved in hard process.

4.4 Breif description of the subroutines

The purpose and arguments of the subroutines are described. The first parameter (I or O) in the parenthises of the arguments discriptions are the flag used to indicate whether it is input or output arguments. The second parameter is a varaible type.

```
SUBROUTINE MNJGAM(NTYPE, X, EBEAM, QSQ, FX)
```

Purpose : Calculate the photon flux factor

NTYPE : (I, I*4) Type of photon spectrum. Its meaning is same as that used for NGMINS in the common /MNJPRM/.

X : (I, R*8) Integral variable used to generate the photon energy.

EBEAM : (I, R*8) Beam energy of the process.

QSQ : (I, R*8) Q^2 of the process.

FX : (O, R*8) The flux factor of photon.

```
SUBROUTINE MNJPRB(NTYP, NFLV, QSQ, X, XLAM2, PROB)
```

Purpose : calculate the parton density inside the photon.

`NTYP` : (I, `I*4`) select the type of photon structure function. See the description of the common `/MNJPRM/` for the meanings.

`NFLV` : (I, `I*4`) particle ID resolved from photon, 1=d quark, 2=u, 3=s, c=c, 5=b, and 21=gluon.

`QSQ` : (I, `R*8`) energy scale.

`X` : (I, (`R*8`) scaled energy.

`XLAM2` : (I, `R*8`) Λ^2.

`PROB` : (O, `R*8`) the value of the parton density in the photon.

```
 SUBROUTINE MNJCRS( NPROC, SHAT, IAD1, IAD2, IAD3, IAD4,
>           COSTH, PTMIN, NMASQ,    DSDCS , PCM, QSQ)
```

Purpose : calculate a cross section of sub-processes.

`NPROC` : (I,`I*4`) sub-process ID as described in the subsection 2.3. Negative `NPROC` means the process where the initial particles are interchanged.

`SHAT` : (I, `R*8`) squared center-of-mass energy of the sub-process.

`IAD1, IAD2, IAD3, IAD4` : (I, I*4) particles IDs involved in the sub-processes; `IAD1, IAD2` for initial particles, and `IAD3, IAD4` for final particles. Particle assignments to the IDs are same as those used by PDG group[27].

`COSTH` : (I, `R*8`) production angle in center-of-mass system of the sub-process.

`PTMIN` : (I, `R*8`) minimum p_t requirement for final particles.

`NMASQ` : (I, `I*4`) treatment of quark mass effect. Same meanings as those stored in the common `/MNJPRM/`.

`DSDCS` : (O, `R*8`) differential cross section ($d\sigma/d\cos\hat{\theta}$) for the sub-process in the unit of pb.

`PCM` : (O, `R*8`) momentum of a final state particle.

`QSQ` : (O, `R*8`) energy scale, Q^2, after take into account the quark mass effect.

```
SUBROUTINE MNJTYP( NTYPE, X, EBEAM, FX )
```

Purpose : get the weight of a photon.

`NTYPE` : (I, `I*4`) type of photon spectrum. See the description of the common `/MNJPRM/`.

`X` : (I, `R*8`) scaled photon energy, $X = E_\gamma/E_{beam}$.

`EBEAM` : (I, `R*8`) beam energy.

`FX` : (O, `R*8`) weight of the photon.

```
REAL FUNCTION FNCMNJ*8(X)
```

Purpose : called by BASES program and calculate the cross section in a unit of pb for the phase space given by `X`.

```
SUBROUTINE MNJHAD(NPART, RBUF)
```

Purpose : stores particle information generated by SPRING into the common `/LUJETS/` and hadronize them by using JETSET6.3 routines.

`NPART` : (I, `I*4`) number of particles.

`RBUF(20,NPART)` : (I, `I*4`) particle information generated by SPRING. The array elements not listed below are reserved for future use.

`RBUF( 1,I) =`: particle serial number.

RBUF(2,I) =: particle ID according to the PDG convension[27].
RBUF(3,I) =: particle mass (GeV).
RBUF(4,I) =: charge.
RBUF(5,I) =: P_x (GeV).
RBUF(6,I) =: P_y (GeV).
RBUF(7,I) =: P_z (GeV).
RBUF(8,I) =: Energy GeV).
RBUF(12,I) =: number of daughter particles.
RBUF(13,I) =: particle serial number of the first daughter.
RBUF(14,I) =: particle serial number of the last daughter.
RBUF(20,I) =: set to 0 when particle is at the end of the color string, otherwise set to 10000.

`SUBROUTINE MNJMPL(NFINAL, PARTON, GBUF, PVCT)`

Purpose : using the four-momentum information generated by SRING, prepares the array, PARTON, for the hadronization by the subroutine MNJHAD.

NFINAL : (O, I*4) number of final particles.

PARTON(20,4) : (O, R*4) final particle information. Contents are same as those stored in the argument array RBUF of the subroutine MNJHAD.

GBUF(20) : (O, R*4) general event information, prepared for documentation purpose.
GBUF(1) =: energy of resolved parton from e^- side (=EGAM1).
GBUF(2) =: energy of resolved parton from e^+ side (=EGAM2).
GBUF(3) =: energy of photon from e^- (=EGAM10).
GBUF(4) =: energy of photon from e^+ (=EGAM20).
GBUF(5) =: center-of-mass energy of hard process ($\hat{s}$).
GBUF(6) =: p_t of final particles of sub-process.
GBUF(7) =: $\cos\hat{\theta}$ of the sub-process.
GBUF(8) =: $\hat{\theta}$ of the sub-process.
GBUF(9) =: center-of-mass energy of the $\gamma\gamma$ system.
GBUF(10) =: rapidity of first parton in laboratory system.
GBUF(11) =: rapidity of the other parton in the laboratory system.
GBUF(12) =: momentum of final particle produced in hard process.
GBUF(20) =: weight factor of a event.

PVCT(4,3) : (O, R*4)four-momentum array, PVCT(1,I)=p_x, PVCT(2,I)=p_y, PVCT(3,I)=p_z, and PVCT(4,I)=energy.
PVCT(J,1) =: four-momentum of center-of-mass system of sub-process in laboratory system.
PVCT(J,2) =: four-momentum of first final state particle in the center-of-mass system of the sub-process.
PVCT(J,3) =: four-momentum of the other final state particle in the center-of-mass system of the sub-process.

`SUBROUTINE MNJSPE`

Purpose : called at the end of SPRING step and print out seed of a random variable.

`SUBROUTINE MNJUIN`

Purpose : called from `USERIN` and initialize parameters and histograms required for each calculations.

`SUBROUTINE MNJUFL`

Purpose : called from `FNCMNJ` to accumulate the histogram data.

`BLOCK DATA MNJBLK`

Purpose : block data, where the commons `/MNJPRM/, /MNJBEM/, /MNJQMS/` are initialized.

5 Conclusion

We have developed an event generation code for jet production in two-photon processes in e^+e^- reactions. The program can generate direct, once-resolved and twice-resolved processes either separately or simultaneously. The program was tested by TOPAZ and ALEPH experiments, and successful in reproducing the event properties of inclusive jet production and hadronic event topologies

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A The cross section formula for the sub-processes

For completeness, we summarize below the cross section formula for the sub-processes used in the program[28]. In the formula below, $\hat{\theta}$ is the scattering angle in the center-of-mass system and $\hat{s}$, $\hat{t}$ and $\hat{u}$ are mandelstarm variables. The suffixes for q indicate the quark flavour, e_q is a quark charge, and $\hat{\beta}$ is a quark velocity: $\hat{\beta} = \sqrt{1 - 4m_q^2/\hat{s}}$. Formula Eq. 21 and 29 do not include the factors of 2 in the original paper, since we integrate over the entire polar angle range.

A.1 $\gamma\gamma \to q_i \bar{q}_i$

$$
\begin{aligned}
\frac{d\sigma}{d\cos\hat{\theta}} &= \frac{3\pi\alpha^2 e_q^4 \hat{\beta}}{\hat{s}} \left[\frac{m_q^2 - \hat{t}}{m_q^2 - \hat{u}} + \frac{m_q^2 - \hat{u}}{m_q^2 - \hat{t}} + 4\left(\frac{m_q^2}{m_q^2 - \hat{t}} + \frac{m_q^2}{m_q^2 - \hat{u}} \right) \right. \\
&- \left. 4\left(\frac{m_q^2}{m_q^2 - \hat{t}} + \frac{m_q^2}{m_q^2 - \hat{u}} \right)^2 \right]. \qquad (18)
\end{aligned}
$$

A.2 $\gamma q_i \to q_i g$

$$
\frac{d\sigma}{d\cos\hat{\theta}} = -\frac{4\pi\alpha e_q^2 \alpha_S}{3\hat{s}} \left(\frac{\hat{t}}{\hat{s}} + \frac{\hat{s}}{\hat{t}} \right) \qquad (19)
$$

A.3 $\gamma g \to q_i \bar{q}_i$

$$
\begin{aligned}
\frac{d\sigma}{d\cos\hat{\theta}} &= \frac{\pi\alpha e_q^2 \alpha_S \hat{\beta}}{2\hat{s}} \left[\frac{m_q^2 - \hat{t}}{m_q^2 - \hat{u}} + \frac{m_q^2 - \hat{u}}{m_q^2 - \hat{t}} + 4\left(\frac{m_q^2}{m_q^2 - \hat{t}} + \frac{m_q^2}{m_q^2 - \hat{u}} \right) \right. \\
&- \left. 4\left(\frac{m_q^2}{m_q^2 - \hat{t}} + \frac{m_q^2}{m_q^2 - \hat{u}} \right)^2 \right]. \qquad (20)
\end{aligned}
$$

A.4 $q_i + q_i \to q_i + q_i$

$$
\frac{d\sigma}{d\cos\hat{\theta}} = \frac{\pi\alpha_S^2}{4\hat{s}} \left[\frac{4}{9} \left(\frac{\hat{s}^2 + \hat{u}^2}{\hat{t}^2} + \frac{\hat{s}^2 + \hat{t}^2}{\hat{u}^2} \right) - \frac{8}{27} \frac{\hat{s}^2}{\hat{u}\hat{t}} \right] \qquad (21)
$$

A.5 $q_i + q_j \to q_i + q_j$

$$
\frac{d\sigma}{d\cos\hat{\theta}} = \frac{\pi\alpha_S^2}{2\hat{s}} \left[\frac{4}{9} \frac{\hat{s}^2 + \hat{u}^2}{\hat{t}^2} \right] \qquad (22)
$$

A.6 $q_i + \bar{q}_i \to q_i + \bar{q}_i$

$$
\frac{d\sigma}{d\cos\hat{\theta}} = \frac{\pi\alpha_S^2}{2\hat{s}} \left[\frac{4}{9} \left(\frac{\hat{s}^2 + \hat{u}^2}{\hat{t}^2} + \frac{\hat{t}^2 + \hat{u}^2}{\hat{s}^2} \right) - \frac{8}{27} \frac{\hat{u}^2}{\hat{s}\hat{t}} \right] \qquad (23)
$$

A.7 $q_i + \bar{q}_i \to q_j + \bar{q}_j$

$$
\frac{d\sigma}{d\cos\hat{\theta}} = \frac{\pi\alpha_S^2 \hat{\beta}}{2\hat{s}} \frac{4}{9} \left[\frac{(m_q^2 - \hat{t})^2 + (m_q^2 - \hat{u})^2 + 2m_q^2 \hat{s}}{\hat{s}^2} \right] \qquad (24)
$$

A.8 $q_i + \bar{q}_j \to q_i + \bar{q}_j$

$$\frac{d\sigma}{d\cos\hat{\theta}} = \frac{\pi\alpha_S^2}{2\hat{s}}\frac{4}{9}\left[\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}\right] \tag{25}$$

A.9 $q_i + \bar{q}_i \to g + g$

$$\frac{d\sigma}{d\cos\hat{\theta}} = \frac{\pi\alpha_S^2}{2\hat{s}}\left[\frac{32}{27}\frac{\hat{u}^2+\hat{t}^2}{\hat{u}\hat{t}} - \frac{8}{3}\frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2}\right] \tag{26}$$

A.10 $q_i + g \to q_i + g$

$$\frac{d\sigma}{d\cos\hat{\theta}} = \frac{\pi\alpha_S^2}{2\hat{s}}\left[-\frac{4}{9}\frac{\hat{u}^2+\hat{s}^2}{\hat{u}\hat{s}} + \frac{\hat{u}^2+\hat{s}^2}{\hat{t}^2}\right] \tag{27}$$

A.11 $g + g \to q_i + \bar{q}_i$

$$\begin{aligned}\frac{d\sigma}{d\cos\hat{\theta}} &= \frac{\pi\alpha_S^2\hat{\beta}}{32\hat{s}}\left[12\frac{(m_q^2-\hat{t})(m_q^2-\hat{u})}{\hat{s}^2} + \frac{8}{3}\frac{(m_q^2-\hat{t})(m_q^2-\hat{u})-2m_q^2(m_q^2+\hat{t})}{(m_q^2-\hat{t})^2}\right.\\ &+ \frac{8}{3}\frac{(m_q^2-\hat{t})(m_q^2-\hat{u})-2m_q^2(m_q^2+\hat{u})}{(m_q^2-\hat{u})^2} - \frac{2}{3}\frac{m_q^2(\hat{s}-4m_q^2)}{(m_q^2-\hat{t})(m_q^2-\hat{u})}\\ &- 6\frac{(m_q^2-\hat{t})(m_q^2-\hat{u})+m_q^2(\hat{u}-\hat{t})}{\hat{s}(m_q^2-\hat{t})}\\ &- \left. 6\frac{(m_q^2-\hat{t})(m_q^2-\hat{u})+m_q^2(\hat{t}-\hat{u})}{\hat{s}(m_q^2-\hat{u})}\right]\end{aligned} \tag{28}$$

A.12 $g + g \to g + g$

$$\frac{d\sigma}{d\cos\hat{\theta}} = \frac{\pi\alpha_S^2}{4\hat{s}}\frac{9}{2}\left[3 - \frac{\hat{u}\hat{t}}{\hat{s}^2} - \frac{\hat{u}\hat{s}}{\hat{t}^2} - \frac{\hat{s}\hat{t}}{\hat{u}^2}\right] \tag{29}$$

B Example of JCL on the FACOM machine at KEK

```
//job-ID JOB CLASS=S
//*
//*  BASES step
//*
// EXEC FORT7CLG,
//      PARM.FORT='OPT(3),NOS,NOSTATIS',
//      PARM.LKED='NOMAP,LET'
//FORT.SYSINC DD DSN=user-ID.MINIJET.FORT,DISP=SHR
//FORT.SYSIN  DD DSN=user-ID.MINIJET.FORT(BSMAIN),DISP=SHR
//LKED.SYSLIB DD
//            DD DSN=user-ID.BASES50.LOAD,DISP=SHR
//*
//GO.SYSIN DD *
     1,  1  Current loop count,   Max. Loop count
    -4      Print Flag
     0      Input Flag
     5.     CPU time limit in minutes
//******   BASES results.
//GO.FT23F001 DD DISP=(NEW,PASS),
// DSN=&&BASES,SPACE=(TRK,(10,10),RLSE)
//*
//*  Spring step.
//*
//  EXEC  FORT7CLG,
//  PARM.FORT='OPT(3),NOS,AE,NOSTATIS',
//  PARM.LKED='NOMAP'
//FORT.SYSINC DD DSN=user-ID.MINIJET.FORT,DISP=SHR
//FORT.SYSIN  DD DSN=user-ID.MINIJET.FORT(MNJSPR),DISP=SHR
//LKED.SYSLIB DD
//            DD DSN=user-ID.BASES50.LOAD,DISP=SHR
//            DD DSN=user-ID.G#LUND63.LOAD,DISP=SHR
//*
//GO.FT05F001 DD *
    10000000
   20.0
//*
//******   BASES results to read
//GO.FT23F001 DD DISP=(OLD,PASS),DSN=&&BASES
//*
```

C Test run results

Test run outputs for p_t distribution of direct (ID=13), once-resolved(ID=14) and twice-resolved(ID=15) processes at $\sqrt{s} = 58$ GeV.

```
Histogram (ID = 13 ) for Pt(for Direct)
                             Linear Scale indicated by "*"
    x      d(Sigma)/dx     0.0E+00      1.4E+00      2.8E+00     4.1E+00
+-------+------------------+------------+------------+-----------+-----------+
I  E  0 I 0.000        E  0I                                                 I
I 3.000 I 4.273+-0.026 E  0I***************************************0000000   I
I 3.200 I 3.631+-0.020 E  0I***********************************000000000     I
I 3.400 I 2.981+-0.015 E  0I****************************0000000000000        I
I 3.600 I 2.527+-0.013 E  0I***********************0000000000000000          I
I 3.800 I 2.175+-0.011 E  0I********************000000000000000000           I
I 4.000 I 1.826+-0.009 E  0I*****************0000000000000000000             I
I 4.200 I 1.573+-0.008 E  0I***************0000000000000000000               I
I 4.400 I 1.387+-0.007 E  0I*************0000000000000000000                 I
I 4.600 I 1.176+-0.006 E  0I***********0000000000000000000                   I
I 4.800 I 1.041+-0.006 E  0I**********0000000000000000000                    I
I 5.000 I 9.198+-0.052 E -1I*********000000000000000000                      I
I 5.200 I 7.994+-0.048 E -1I********000000000000000000                       I
I 5.400 I 7.149+-0.044 E -1I*******00000000000000000                         I
I 5.600 I 6.342+-0.040 E -1I******00000000000000000                          I
I 5.800 I 5.563+-0.037 E -1I******000000000000000                            I
I 6.000 I 5.049+-0.035 E -1I*****000000000000000                             I
I 6.200 I 4.498+-0.036 E -1I*****00000000000000                              I
I 6.400 I 3.989+-0.031 E -1I****0000000000000                                I
I 6.600 I 3.666+-0.029 E -1I****000000000000                                 I
I 6.800 I 3.311+-0.027 E -1I****00000000000                                  I
I 7.000 I 2.980+-0.026 E -1I***00000000000                                   I
I 7.200 I 2.697+-0.023 E -1I***000000000                                     I
I 7.400 I 2.469+-0.023 E -1I***00000000                                      I
I 7.600 I 2.210+-0.020 E -1I***0000000                                       I
I 7.800 I 2.058+-0.020 E -1I**0000000                                        I
I  E  0 I 0.000        E  0I                                                 I
+-------+------------------+---------------------------+---------------------+
    x      d(Sigma)/dx     1.0E-01                     1.0E+00
                             Logarithmic Scale indicated by "0"
```

```
Histogram (ID = 14 ) for Pt(for 1 resolved)
                             Linear Scale indicated by "*"
    x      d(Sigma)/dx     0.0E+00      1.0E+00      2.0E+00     3.0E+00
+-------+------------------+-------------+------------+------------+-----------+
I  E  0 I 0.000        E  0I                                                   I
I 3.000 I 3.300+-0.036 E  0I*******************************************00000   I
I 3.200 I 2.444+-0.026 E  0I********************************00000000000000     I
I 3.400 I 1.935+-0.021 E  0I*************************0000000000000000000       I
I 3.600 I 1.568+-0.016 E  0I********************0000000000000000000000         I
I 3.800 I 1.216+-0.013 E  0I****************000000000000000000000000           I
I 4.000 I 1.014+-0.011 E  0I*************00000000000000000000000000            I
I 4.200 I 8.342+-0.091 E -1I***********00000000000000000000000000              I
I 4.400 I 6.795+-0.078 E -1I*********00000000000000000000000000                I
I 4.600 I 5.609+-0.069 E -1I********00000000000000000000000000                 I
I 4.800 I 4.621+-0.057 E -1I******00000000000000000000000000                   I
I 5.000 I 4.068+-0.051 E -1I******0000000000000000000000000                    I
I 5.200 I 3.358+-0.045 E -1I*****0000000000000000000000000                     I
I 5.400 I 2.776+-0.039 E -1I****000000000000000000000000                       I
I 5.600 I 2.447+-0.036 E -1I****00000000000000000000000                        I
I 5.800 I 2.077+-0.030 E -1I***00000000000000000000000                         I
I 6.000 I 1.846+-0.030 E -1I***0000000000000000000000                          I
I 6.200 I 1.540+-0.025 E -1I**000000000000000000000                            I
I 6.400 I 1.368+-0.023 E -1I**000000000000000000000                            I
I 6.600 I 1.149+-0.020 E -1I**0000000000000000000                              I
I 6.800 I 1.042+-0.019 E -1I**000000000000000000                               I
I 7.000 I 9.116+-0.184 E -2I**00000000000000000                                I
I 7.200 I 8.049+-0.158 E -2I**0000000000000000                                 I
I 7.400 I 7.143+-0.144 E -2I*0000000000000000                                  I
I 7.600 I 6.556+-0.129 E -2I*0000000000000000                                  I
I 7.800 I 5.782+-0.120 E -2I*000000000000000                                   I
I  E  0 I 0.000        E  0I                                                   I
+-------+------------------+-------------------+------------------+------------+
    x      d(Sigma)/dx     1.0E-02             1.0E-01             1.0E+00
                             Logarithmic Scale indicated by "0"
```

```
Histogram (ID = 15 ) for Pt(for two resolved)
                             Linear Scale indicated by "*"
    x      d(Sigma)/dx     0.0E+00      1.1E+00      2.3E+00     3.4E+00
+-------+------------------+------------+------------+-----------+-----------+
I  E  0 I 0.000        E  0I                                                 I
I 3.000 I 3.458+-0.053 E  0I***************************************000000000 I
I 3.200 I 2.380+-0.037 E  0I***************************000000000000000000    I
I 3.400 I 1.728+-0.028 E  0I********************0000000000000000000000       I
I 3.600 I 1.250+-0.020 E  0I**************0000000000000000000000000          I
I 3.800 I 9.584+-0.170 E -1I***********00000000000000000000000000            I
I 4.000 I 6.898+-0.122 E -1I********000000000000000000000000000              I
I 4.200 I 5.279+-0.095 E -1I******00000000000000000000000000                 I
I 4.400 I 4.144+-0.078 E -1I*****0000000000000000000000000                   I
I 4.600 I 3.297+-0.066 E -1I****0000000000000000000000000                    I
I 4.800 I 2.529+-0.052 E -1I***00000000000000000000000                       I
I 5.000 I 1.990+-0.040 E -1I***0000000000000000000000                        I
I 5.200 I 1.595+-0.034 E -1I**000000000000000000000                          I
I 5.400 I 1.245+-0.027 E -1I**0000000000000000000                            I
I 5.600 I 1.083+-0.031 E -1I**000000000000000000                             I
I 5.800 I 8.496+-0.213 E -2I*00000000000000000                               I
I 6.000 I 7.033+-0.236 E -2I*000000000000000                                 I
I 6.200 I 5.995+-0.196 E -2I*00000000000000                                  I
I 6.400 I 4.599+-0.144 E -2I*000000000000                                    I
I 6.600 I 4.343+-0.137 E -2I*00000000000                                     I
I 6.800 I 3.593+-0.170 E -2I*0000000000                                      I
I 7.000 I 2.881+-0.091 E -2I*00000000                                        I
I 7.200 I 2.612+-0.091 E -2I*0000000                                         I
I 7.400 I 2.037+-0.076 E -2I*00000                                           I
I 7.600 I 1.806+-0.068 E -2I*0000                                            I
I 7.800 I 1.621+-0.067 E -2I*000                                             I
I  E  0 I 0.000        E  0I                                                 I
+-------+------------------+------------------+------------------+-----------+
    x      d(Sigma)/dx     1.0E-02            1.0E-01            1.0E+00
                             Logarithmic Scale indicated by "0"
```

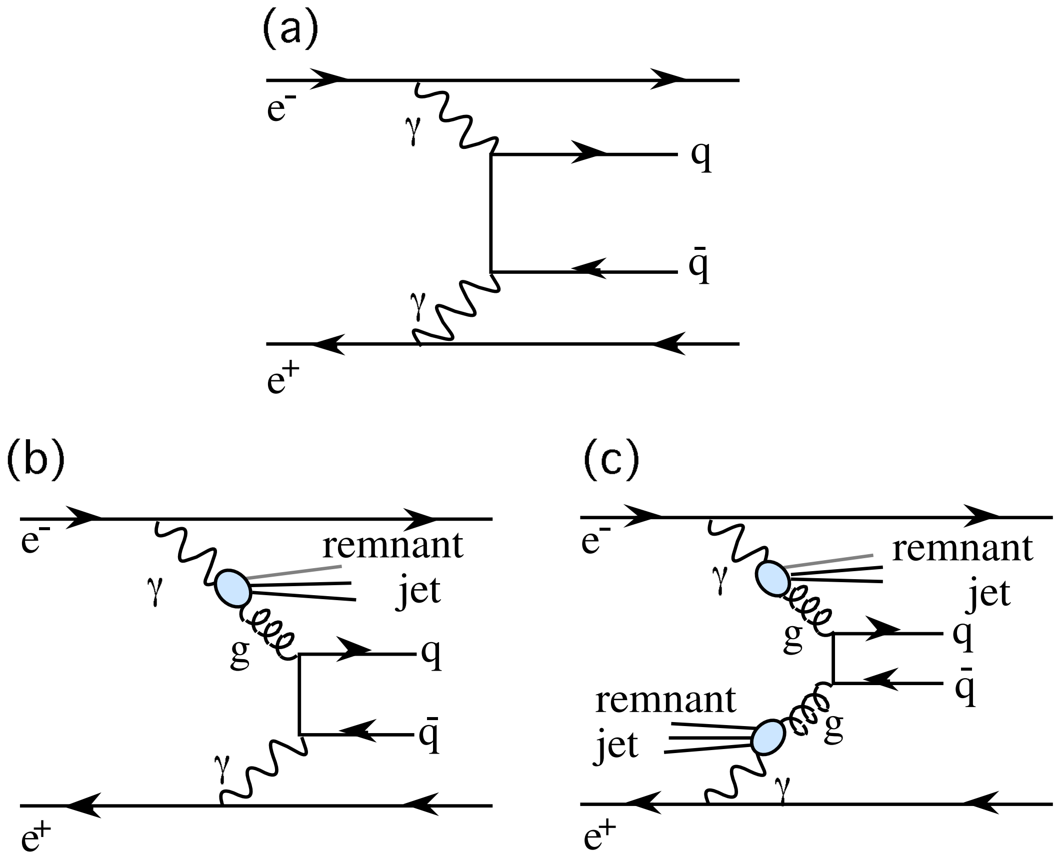

Figure 1: Diagrams contributing to the jet productions in two-photon processes in e^+e^- reactions; (a) direct process, (b) once-resolved process, (c) twice-resolved process.