INCLUSIVE JET MEASUREMENTS IN $\gamma\gamma$ COLLISIONS AT TRISTAN AND ESTIMATION OF MINIJETS FOR FUTURE LINEAR COLLIDERS

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Abstract

We have measured the inclusive jet production cross sections in $e^+e^- \to (ee)$ jets at $\sqrt{s}$ =58GeV using the TOPAZ detector at TRISTAN. We clearly observed the contribution of resolved photon processes. By taking account of this result, we estimated the minijet yields for future linear colliders at $\sqrt{s}$ =0.5TeV.

1. Introduction

The purpose of measuring the inclusive jets in a two-photon reaction, so-called minijets, is to probe the hadronic structure of the photon, which has been discussed in order to explain the excess of high-p_t hadronic events in $\gamma\gamma$ collisions from the expectation of the quark parton model or a direct process[1]. The resolved photon processes have been introduced for this excess[2]. Since the photon behaves like a vector meson in the low-p_t region, which is well described by the vector meson dominance model, it may have hadronic (quark and gluon) components during its hard scattering. The idea of a hadronic structure can be realized in terms of resolved processes. The first experimental evidence was reported by the AMY group at TRISTAN[3]. Subsequently, for additional evidence, the ZEUS[4] and the H1[5] groups published results concerning inclusive jet production and the total cross section in the γp interaction at HERA, respectively. There are still ambiguities concerning the value of $p_{t,min}$ as well as the quark/gluon density functions. Therefore, more quantitative understandings are highly necessary, especially for estimating minijet events in future linear colliders.

We present measurements of the differential cross section on inclusive jet production in $\gamma\gamma$ collisions as a function of the transverse momentum of an unfolded jet, that is a quark/gluon, in order to make a direct comparison with theoretical models. At this workshop we have reported the preliminary results. Recently, a paper concering the final results was accepted for publication[6]. Although the main conclusions have not changed, further evidence concerning the resolved processes are shown as the energy flow in the very forward/backward angular region, which results from remnant jets. Therefore, we briefly discuss here the event selection, analysis method and final results based on the new observation. Finally, we present an estimation of minijet yields for future linear colliders based on our improved knowledge concerning the resolved processes.

2. Event Selection

Data were collected at $\sqrt{s}$=58GeV for an integrated luminosity of 89.3pb^{-1}. Detailed descriptions of the TOPAZ detector can be found elsewhere[7]. A time-projection chamber measures the momenta of charged particles as well as their dE/dX's, which was used for the identification of protons in this analysis in order to effectively reject any beam-induced(gas) background. The energies of the electrons and photons were measured in electromagnetic calorimeters covering hermetically the polar angular region $|\cos\theta| < 0.9984$ (θ_{min}=3.2°).

The event selection was made for hadronic events in two-photon reactions with no tag condition, that is: (1)a minimum number of charged tracks must be 4 and the total net charge should be $\leq$3, (2) the maximum energy of electromagnetic energy cluster should be $\leq 0.25E_{beam}$, the criteria of which correspond to $Q^2 \leq$2.6 GeV^2, and (3) the invariant mass of an event (W_{vis}) should be $2 < W_{vis} <$15 GeV. As mentioned before, the beam-gas events are rejected by the requirement of (4) no proton contamination in an event, except for one with an anti-proton and (5) the event vertex position should be $r_{vtx} <$ 2 cm and $z_{vtx} <$ 4 cm. Based on these criteria, 36935 two-photon events were selected in total.

3. Analysis Method

3.1. Identification of a jet

We define a jet as a cluster comprising particles inside a unit circle, whose center is the particle having the highest transverse momentum among them on the pseudorapidity ($\eta \equiv -\ln\tan(\theta/2)$) $-$ azimuthal angle(ϕ) plane[8]. This jet clustering method has been used for experiments in hadron colliders, and is also suitable for this case, since a high-p_t jet can be well separated from any remnant jets originating from spectator quarks in the photon on the $\eta-\phi$ plane. For the jet clustering we used only particles in the angular region $|\cos\theta| <$0.83 or $|\eta| <$1.2 , where the transverse momentum of a charged particle and the energy of a neutral (electromagnetic) particle should be greater than 0.15 and 0.3 GeV, respectively. The angular region of the jet axis is further constrained within $|\eta_{jet}| <$ 0.7 in order to assure a jet fully contained inside of a well-defined fiducial region. We also required that the transverse energy of the jet be greater than 2.5GeV. We thus selected 2553 one-jet, 344 two-jet and 1 three jet events. To compare unambiguously two-jet events with the theoretical expectations we required that the opening angle between two jets in the $r\phi$ plane be greater than 150°. Finally, 273 two-jet events remained.

The background of the beam-gas events has been estimated to be 2.5%

(0.6%) for one-jet (two-jet) events based on the event vertex distributions. The other backgrounds from various processes were calculated to be 15.2%(7.5%) of $e^+e^- \to q\bar{q}(\gamma)$, 1.5%(4.1%) of $e^+e^- \to (ee)\tau^+\tau^-$ and negligibly small of $e^+e^- \to \tau^+\tau^-$ by Monte-Carlo simulations. These backgrounds were subtracted in the measured distributions on a bin-by-bin basis.

3.2. Monte Carlo Simulation

The direct and resolved processes were generated according to the formulae given by M. Drees and R.M. Godbole[2]. For the quark and gluon distribution functions inside a photon we used the parametrizations of Drees and Grassie(DG)[9] as well as those of Levy, Abramowicz and Charchula (LAC1,2,3)[10]. The energy scale in these parametrizations was set to be the square of the transverse momentum of the generated parton. Another parameter of $p_{t,min}$ was determined to be 2.0±0.2 GeV for the DG parametrization ($p_{t,min}$=2.4GeV for LAC1) by comparing various observed distributions with the simulated ones. The value of $p_{t,min}$ is rather sensitive to the contribution from the soft scattering process, which has been well described by the vector-meson dominance model(VMD); it also depends slightly on various hadronization parameters. For the total $\gamma\gamma$ cross section due to the VMD, we used $\sigma_{\gamma\gamma}(W) = 240 + 270/W$ (nb) with the transverse momentum distribution of the quark/gluon being $e^{-4p_t^2}$. The hadronization was made by the JETSET6.3 string-fragmentation scheme[8] with σ_q =0.4GeV, a=1.0 and b=0.7 GeV^{-2}.

4. Results

4.1. Inclusive Jet Cross Sections

In order to compare our experimental results directly with the theoretical expectations, we unfolded the data when deriving the cross sections at the parton level. Thus, the jet can be identified as being a quark/gluon. Therefore, the variables of jets are hereafter considered to be those of quarks or gluons. A detail description of the unfolding method can be found in our paper[6]. Integrating over the fiducial acceptance, the differential cross section of the inclusive jet production is expressed by

$$\frac{d\sigma^{(jets)}}{dp_t} \equiv \int_{-0.7}^{0.7} d\eta_1 \int_{|\eta_2|>0.7} d\eta_2 \frac{d\sigma}{d\eta_1 d\eta_2 dp_t} + 2 \cdot \int_{-0.7}^{0.7} d\eta_1 \int_{-0.7}^{0.7} \frac{d\sigma}{d\eta_1 d\eta_2 dp_t}, \qquad (1)$$

where η_1 and η_2 are the pseudorapidities of the measured and "unobserved" jets, respectively, and the jets in two-jet events are doubly counted. The cross section for the two-jet events is given by

$$\frac{d\sigma^{(two-jet)}}{dp_t} \equiv \int_{-0.7}^{0.7} d\eta_1 \int_{-0.7}^{0.7} \frac{d\sigma}{d\eta_1 d\eta_2 dp_t}. \qquad (2)$$

The results of the inclusive jets and two-jet measurements are shown in Fig.1 (a) and (b),respectively, as a function of the jet transverse momentum together with various theoretical expectations. The errors include both statistical and systematic uncertainties added in quadrature. The total systematic error was estimated to be

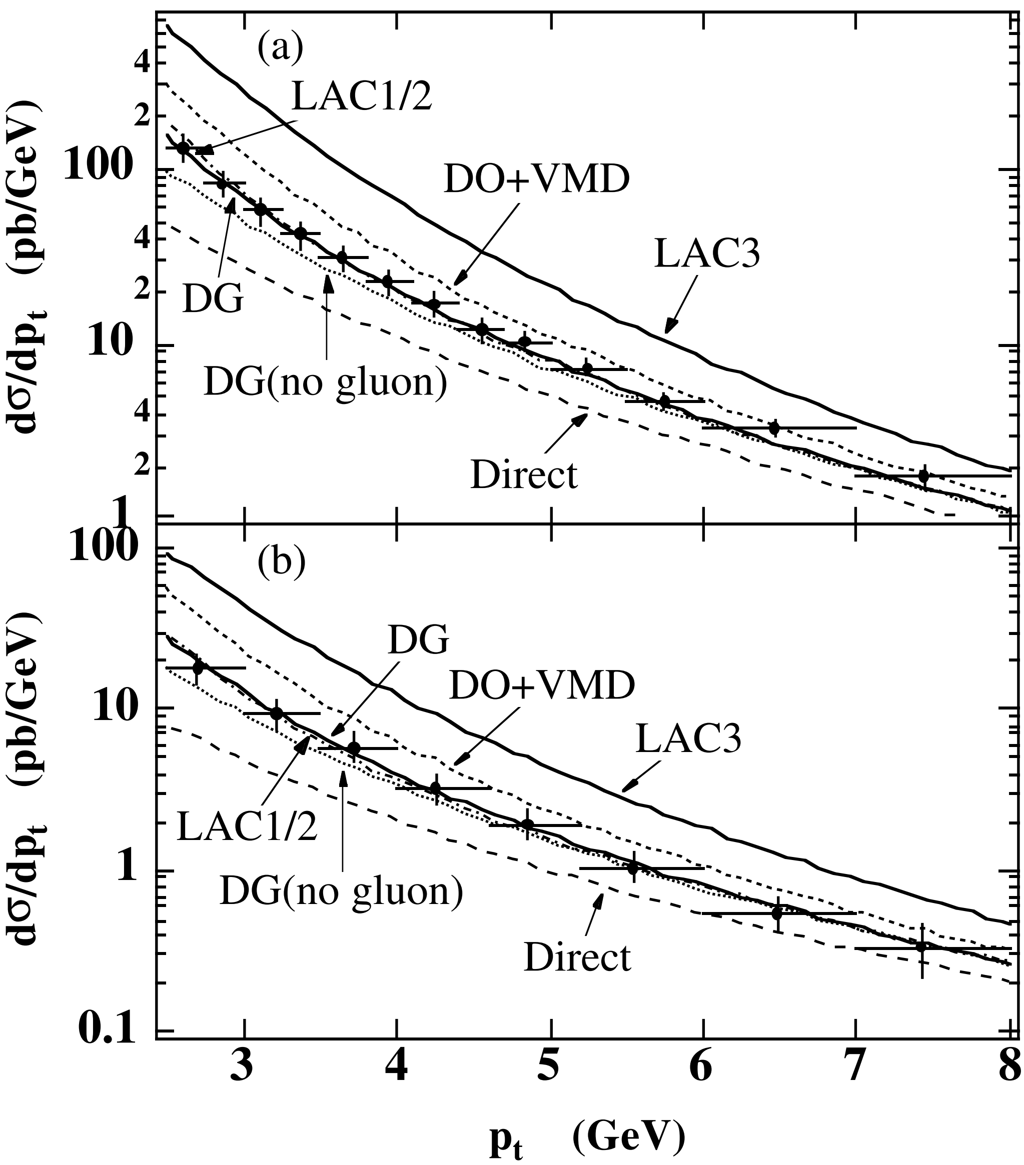

Figure 1: Inclusive (a) jet and (b) two-jet cross sections as a function of the jet transverse momentum for $|\eta_{jet}| < 0.7$. The error bars include both the statistical and systematical uncertainties. The dashed line is the expectation of the direct process only. The sum of the direct and the resolved processes based on DG, LAC1/2/3 and DO+VMD parametrizations are also plotted.

16 and 10% for inclusive jets and two-jet cross sections, respectively, where the uncertainties of $p_{t,min}$, the VMD contribution, hadronization effect, momentum/energy scale of particles, integrated luminosity and acceptance corrections were considered. As can be clearly seen in Figs.1 (a) and (b) resolved processes are definitely necessary to reproduce the observed cross section, where the direct process only contributes about $1/3 \sim 1/2$ and the VMD is only a few %. The QCD correction to the direct process cannot explain this deficit, since the magnitude of the QCD correction must be $O(\alpha_s)$, where there should be no such large k-factor as that of hadron interactions(k$\sim$2), since only a quark-antiquark pair exists in the final state. The data are consistent with the calculations of DG and LAC1/2 while the data disagree with those of LAC3 and DO+VMD of Duke and Owens[11], which have a larger gluon distribution in the large x(>0.1) region. In order to see the gluon contribution in the inclusive jet production, we also plotted the DG calculation with no gluon content by a dotted line in the same figures. Clearly, the gluon effect is only $1 \sim 1.5\ \sigma$ in our measurements, while it becomes extremely important in estimating minijets for future linear colliders as mentioned in the subsequent section.

4.2. Further Evidence for Resolved Processes

One of the distinct features of resolved processes is the existence of remnant jets(spectator quarks/gluons) along the beam axis. We can thus expect the observation of significant energy flows in very forward/backward angular regions from the resolved processes. Figure 2 shows the neutral energy flow per event as a function of the polar(θ) angle for the 2898 inclusive jets events. We can see large energy flows at $\theta = 3\sim 11^\circ$ and $\theta = 169 \sim 177^\circ$, where the background at the 10% level was estimated by random-triggered events during the same experimental period, as well as the flat energy distribution in the barrel region. The observed energy flows in the forward/backward region were reproduced only by a Monte-Carlo simulation with the resolved processes, as indicated by the solid line in Fig.2. We can conclude that the resolved process was directly verified by this experiment.

5. Estimation of minijets for Future Linear Colliders

5.1. General Properties of Minijets

For future e^+e^- linear colliders at the TeV energy region, real photons produced by a beamstrahlung effect[12] become major sources in $\gamma\gamma \rightarrow$ minijets. There has been much work regarding the minijets background for these colliders[13][14], where the resolved process dominates the direct one. We present some features of minijet production by using the DG parametrizations in the resolved process, since they are consistent with the experiment at TRISTAN. We used the calculation scheme described in ref.[14], which includes an analytic expression of the beamstrahlung photon spectrum.

The angular distributions of the minijets shown in Fig.3 were calculated for JLC-I($\sqrt{s}$=300 and 500GeV)[15] and TRISTAN(58GeV). In a detector region of $|\eta| < 2.3$ ($|\cos\theta| < 0.98$), the distribution is approximately flat; it drops rapidly outside

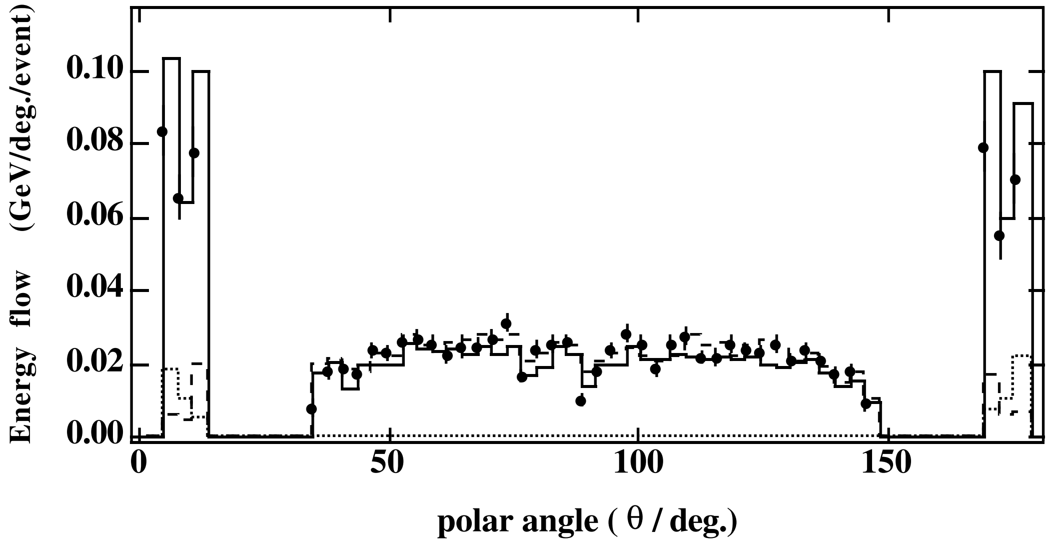

Figure 2: Measured neutral energy flow per event as a function of the polar angle (θ) together with the Monte-Carlo simulations, where the solid histogram shows the sum of the resolved and direct processes (DG with $p_{t,min}$ = 2.0GeV) and the dash one is for only the direct process. The background is also shown by the dotted line, which was estimated by random triggered events, and were already subtracted in the measured distribution.

of this region. The cross section integrated over the full angular region should be sufficiently good for the estimation. However, the calculated cross sections depend on $p_{t,min}$, which has been set to 2.0 GeV for DG. We can estimate the cross section of p_t(minijets) $> p_t^\circ$ for any value of p_t° based on the known p_t distribution of $p_t^{-4.7}$. To give greater detail in the calculations, we show the minijet cross sections for $3 < p_t < 4$ GeV as a function of x of the quark and the gluon distribution functions in Fig.4(a) and (b), respectively. As pointed out in the previous section, the gluon contributions at TRISTAN can only be seen as 1$\sim$1.5 σ effect, while they far exceed the quark contributions at JLC-I. However, since the calculation strongly depends on the gluon distribution in a very small x region (x<< 0.1) where almost no gluon participates at TRISTAN (see in Fig.4(a)), the experimental verification is poor. We should keep in mind that our calculation may have a large uncertainty.

5.2. The Cross Sections for Future Colliders

The cross sections and yields of minijets per bunch crossing were calculated for various 0.5 TeV linear colliders whose parameters were presented at LC92 and they are listed in Tab.1. The magnitude of the cross sections ranges from 0.03μb to 0.13μb among the colliders because of their different beamstrahlung photon intensities indicated by n_γ in Tab.1. The calculations of the LAC1 parametrizations are also listed in Tab.1, since the LAC1 ($p_{t,min}$=2.4GeV) was also consistent with the experiment. Although the LAC1 has a slightly larger $p_{t,min}$ than the DG, it has cross sections that are a few times larger. This difference results from an un-

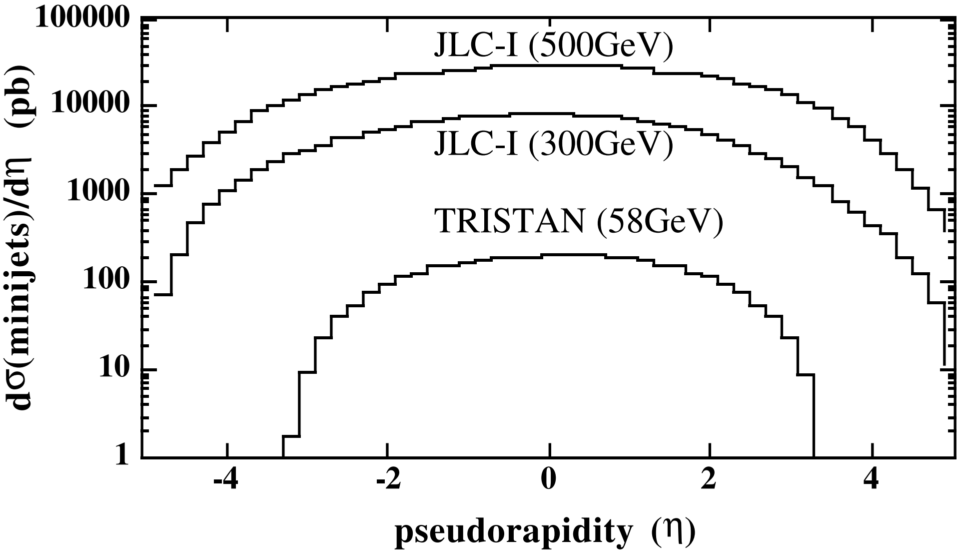

Figure 3: Angular distributions of minijets for JLC-I(300 and 500GeV) and TRISTAN(58GeV) calculated with the DG parametrizations($p_{t,min}$=2.0GeV) as a function of the pseudorapidity(η_J) of a quark/gluon.

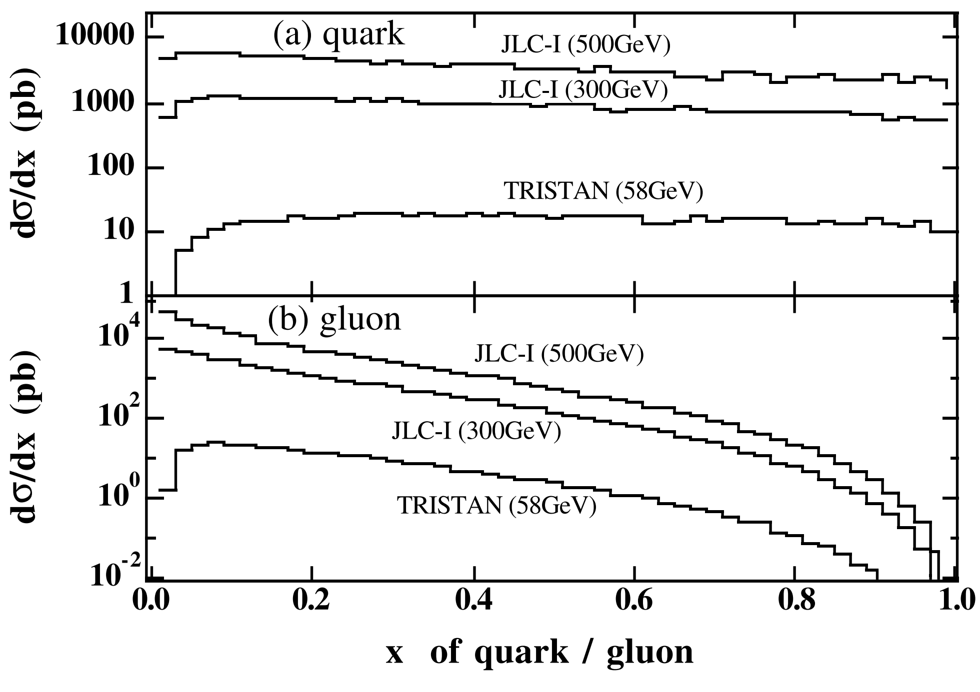

Figure 4: Cross sections of the minijets production ($3 < p_t < 4$GeV) for JLC-I(300 and 500GeV) and TRISTAN(58GeV) calculated with the DG parametrizations($p_{t,min}$=2.0GeV) as a function of x of the quark/gluon distribution functions.

Table 1: Estimation of minijets for 0.5 TeV Linear Colliders at LC92 together with the collider's parameters, where the luminosities are given along with the enhancement factors.

Linear Colliders	CLIC	DLC	JLC	NLC	TESLA	VLEPP
L (10^{33}cm^{-2}sec^{-1})	8.85	6.55	10.0	8.2	11.1	15.1
L (μb^{-1}bunch^{-1})	1.3	0.76	0.93	0.51	1.4	50.3
$f_{\rm rep}$ Hz	1700	50	150	180	10	300
n_b	4	172	72	90	800	1
bunch separation	58.8μs	10.7ns	2.8ns	1.4ns	1μs	6.67ms
n_γ	4.6	3.1	1.0	0.84	5.8	5.1
minijets						
DG($p_{t,min}$=2.0GeV): σ_{jet} μb	0.11	0.038	0.066	0.028	0.044	0.10
N_{jet}/bunch	0.14	0.029	0.061	0.014	0.062	5.03
LAC1($p_{t,min}$=2.4GeV): σ_{jet} μb	0.28	0.092	0.21	0.086	0.094	0.20
N_{jet}/bunch	0.36	0.070	0.20	0.044	0.13	10.1

certainty in the gluon distribution function at the small-x region. Even if we take the values of the LAC1, the minijet yields per bunch crossing are less than one except for VLEPP, which may have a problem. Also minijet yields drop rapidly with increasing p_t; for example, the yield for p_t >3GeV is about 1/5 of the listed values. Therefore, no serious problem is expected for these colliders.

6. Conclusions

We have measured the inclusive jet cross sections in the two-photon reaction as a function of the unfolded jet transverse momentum at $\sqrt{s}$=58GeV. The existence of a resolved process was clearly verified to explain the 2 or 3 times larger cross sections than those of the direct process only, and also the observation of a large energy flow in the very forward/backward angular region by this experiment. Further, we obtained consistent quark/gluon distribution functions inside a photon, that is the DG parametrizations with $p_{t,min}$=2.0GeV and the LAC1/2 ones with $p_{t,min}$=2.4GeV. However, there is still a large uncertainty of the gluon distribution in the small x (<0.1) region.

With this new knowledge we calculated the minijet cross sections for future e^+e^- linear colliders. Although the estimations suffer from the above-mensioned uncertainty, we can conclude that there is no serious background problem due to the minijets, at least for 0.5 TeV linear colliders.

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