Diffraction in Two-Photon Collisions at TESLA

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Abstract

Diffractive reactions have been studied in hadron-hadron and photon-hadron interactions. Up to now, such investigations have not been made in two-photon collisions. In this letter we discuss the possibility to measure diffraction dissociation in collisions of real and weakly virtual photons at a 500 GeV $e^+e^-$ linear collider.

1 Introduction

At a high energy $e^+e^-$ collider the interaction of photons with low virtualities represents the bulk of the events. Similar to hadron interactions, a rise of the total two-photon cross section with the collision energy and a large diffractive contribution are expected.

Diffractive reactions have been investigated for many years in hadron-hadron scattering, photoproduction and, recently, also in deep-inelastic scattering. They have typically

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large partial cross sections and manifest themselves in spectacular topologies with rapidity gaps. Furthermore, new HERA data on $ep$ scattering show that these phenomena also persist for highly virtual photon-proton interactions, where the photon probes the short distance structure of the interaction and perturbative QCD calculations can be applied. At a high energy linear collider, the photons available for the collision can be selected within a broad range of the energy and virtuality. This makes two-photon collisions an unique testing ground for investigations of strong interaction phenomena [1, 2].

In the present work we discuss a possible method of measuring photon diffraction dissociation in two-photon collisions at TESLA. In the following, only photons with low virtualities are considered. However, tagging one or both scattered beam leptons, the same method of measurement can be applied to deep-inelastic $\gamma\gamma$ or $\gamma^*\gamma^*$ interactions.

2 Cross section estimate

Since soft processes cannot be calculated within perturbative QCD, it is difficult to obtain a reliable estimate for the expected cross section for photon diffraction dissociation. Simple Regge factorization arguments imply the following relations for diffraction in $\gamma\gamma$, $\gamma p$, and $pp$ interactions

$$
\sigma_{SD,\gamma}^{\gamma\gamma} \approx \left( \frac{b_{SD,\gamma}^{\gamma\gamma}}{b_{SD,\gamma}^{pp}} \right) \left( \frac{\sigma_{SD,\gamma}^{\gamma p}}{\sigma_{SD,\gamma}^{pp}} \right) \sigma_{SD,\gamma}^{\gamma p} \left( \frac{b_{SD,\gamma}^{\gamma p}}{b_{SD,\gamma}^{pp}} \right) \left( \frac{\sigma_{\gamma p}^{\gamma p}}{\sigma_{\gamma p}^{\gamma p}} \right),
$$

(1)

where $\sigma_{SD,a}^{ab}$ is the cross sections for diffraction dissociation of particle $a$ and $\sigma_{\gamma p}^{ab}$ is the total cross section in $ab$ collisions. The average slope characterizing the diffractive momentum transfer is denoted by $b_{SD,\gamma}^{ab}$, respectively.

Both relations (1) are equivalent since Regge factorization also predicts

$$
\frac{\sigma_{SD,\gamma}^{\gamma p}}{\sigma_{SD,\gamma}^{pp}} \approx \left( \frac{b_{SD,\gamma}^{pp}}{b_{SD,\gamma}^{\gamma p}} \right) \left( \frac{\sigma_{\gamma p}^{\gamma p}}{\sigma_{\gamma p}^{\gamma p}} \right).
$$

(2)

Assuming a ratio $b_{SD,\gamma}^{pp}/b_{SD,\gamma}^{\gamma p} \approx 7/5$ as indicated by low energy measurements [3, 4], Eq. (2) predicts $\sigma_{SD,\gamma}^{\gamma p} \approx 21$ nb being in good agreement with recent H1 and ZEUS measurements [5, 6]. Taking, for example, $b_{SD,\gamma}^{pp}/b_{SD,\gamma}^{\gamma p} = 1$ and an interpolated cross section for $p\bar{p}$ of $\sigma_{SD,\gamma}^{\gamma p} \approx 4.5 - 5$ mb, one gets $\sigma_{SD,\gamma}^{\gamma p} \approx 20 - 35$ nb for $\sqrt{s_{\gamma\gamma}} = 200$ GeV photon-photon collisions. This cross section refers to one side only, to get the total cross section for diffraction dissociation it has to be doubled.

Applying vector dominance arguments, the influence of the photon virtualities on the diffractive cross section of weakly virtual photons can be estimated. Supposing that photon 1 diffractively dissociates into a system with the mass $M_{D,1}$ the differential diffractive cross section reads

$$
\frac{d\sigma_{SD,1}^{\gamma\gamma}(Q_1^2, Q_2^2)}{dM_{D,1}} \approx \frac{M_{D,1}^2}{Q_1^2 + M_{D,1}^2} \left( \frac{m_p^2}{Q_2^2 + m_p^2} \right) \left( \frac{\sigma_{total}^{\gamma\gamma}(Q_1^2, Q_2^2)}{\sigma_{total}^{\gamma\gamma}(0, 0)} \right) \frac{d\sigma_{SD,1}^{\gamma\gamma}(0, 0)}{dM_{D,1}}
$$

(3)

2
where $m_\rho$, $Q_1^2$ and $Q_2^2$ denote the rho meson mass and the virtualities of the photons, respectively.

These estimates are subject to large uncertainties. However, models involving unitarity corrections and non-factorizable contributions (see for example [1]) predict a diffractive cross section compatible with the above mentioned range.

Finally it should be mentioned that a cross section of similar size is also expected for quasi-elastic vector meson production [7, 8]. Assuming $\sigma_{\gamma\gamma}^{\text{tot}} \approx (\sigma_{\gamma p}^{\text{tot}})^2/\sigma_{p\bar{p}}^{\text{tot}}$, about 20 - 30% of all $\gamma\gamma$ events are expected to belong to diffraction – either quasi-elastic vector meson production or diffraction dissociation.

## 3 Method of measurement

Experimentally, events with diffraction dissociation can be identified using the rapidity gap technique. In non-diffractive reactions, rapidity gaps between the final state hadrons are exponentially suppressed. In contrast, the differential cross section $d\sigma_{SD,\gamma}/d\eta_{\text{gap}}$ of diffraction dissociation at fixed $\sqrt{s_{\gamma\gamma}}$ is almost independent of the width $\eta_{\text{gap}}$ of such rapidity gaps. Hence diffractive particle production can be measured triggering on large rapidity gaps. However, the limited angular detector acceptance of the main detector makes the measurement of both edges of the gap hardly possible. As shown by the HERA Collaborations [9, 10], the measurement of the so-called $\eta_{\text{max}}$ distribution can be used instead to obtain experimental evidence for diffraction. The variable $\eta_{\text{max}}$ is defined as the pseudorapidity of the most forward going hadron entering the central detector part, see Fig. 1. In case of diffraction dissociation, one gets with

\[
\frac{d\sigma_{SD,\gamma}}{dM_{SD}^2} \sim \frac{1}{M_{SD}^2} \quad \text{and} \quad \eta_{\text{max}} \sim \ln \left( \frac{M_{SD}^2}{s_{\gamma\gamma}} \right)
\]

a differential cross section $d\sigma_{SD,\gamma}/d\eta_{\text{max}}$ which is almost independent of $\eta_{\text{max}}$. Events with a small $\eta_{\text{max}}$ value correspond to diffractive final states characterized by a large rapidity gap.

![Figure 1: Photon single diffraction dissociation and the expected pseudorapidity distribution of final state hadrons.](image-url)
For this analysis, only events with forward activity (i.e. at least 1 GeV energy deposit in the forward tagging detector) are considered. Particles with large pseudorapidities could be measured with the planned small angle tagging calorimeter. It should be emphasized that it is not needed to measure the hadrons in the entire pseudorapidity range allowed by phase space. The combination of a forward detector with the central main detector parts is well suited to find evidence for diffraction (it is also unimportant whether there is a gap in the pseudorapidity coverage between these detector parts). In other words, the variable $\eta_{\text{max}}$ used here measures the pseudorapidity edge of the multi-hadronic system produced in central main detector.

![Figure 2](image)

Figure 2: The $\eta_{\text{max}}$ cross section as calculated using the PHOJET MC event generator in two photon collisions with $W_{\text{vis}} \geq 20$ GeV (full curve). The dotted curve shows the results of calculations for non-diffractive $\gamma\gamma$ interactions.

As an example, a prediction of the $\eta_{\text{max}}$ cross section is shown in Fig. 2 for bremsstrahlung photon-photon interactions in $ee$ collisions at TESLA ($\sqrt{s_{\text{ee}}} = 500$ GeV). The calculations were made using the PHOJET Monte Carlo event generator [11, 12]. The $\eta_{\text{max}}$ distribution is obtained using the hadrons produced at pseudorapidities in the central range $-3.3 \leq \eta \leq 3.3$. Only events having also particles produced in very forward direction ($3.5 \leq \eta \leq 4.0$) are accepted. This trigger on forward going particles is important to suppress the major background to the diffractive signal due to highly asymmetric $\gamma\gamma$ collisions where the $\eta_{\text{max}}$ variable would refer to the edge of the non-diffractively produced hadronic final state. Furthermore, a cut on the visible invariant mass $W_{\text{vis}} > 20$ GeV was applied. The visible invariant mass $W_{\text{vis}}$ is calculated from all particles entering the central and the forward detector.

The exponential suppression of the rapidity gap in non-diffractive events is clearly seen (dotted curve). Almost all events with $\eta_{\text{max}} < 0$ belong to diffraction (diffraction dissociation and quasi-elastic vector meson production). In diffractive events with a large rapidity gap passing the cuts, the particles produced in the very forward region are mainly
decay products of diffractively produced vector mesons. However, it is not necessary to reconstruct these vector mesons. In Fig. 3 the different diffractive contributions are shown separately for the same kinematics and cuts as used in Fig. 2. For $W_{\text{vis}} > 20$ GeV, the 

$$\eta_{\text{max}}$$ region from $-2$ to $-1$ is clearly dominated by single diffraction dissociation of the photon along the $-z$ axis whereas for $\eta_{\text{max}} < -2$ quasi-elastic vector meson production becomes important. The average mass of the diffractively produced system is shown in Fig. 4 for two different $W_{\text{vis}}$ cuts.

Figs. 2, 3 have been obtained without using information on the kinematics of the scattered beam leptons and, therefore, are dominated by the quasi-real photon interactions. All final state particles are treated in this analysis in the same way regardless whether they are scattered beam leptons or hadrons. For $W_{\text{vis}} \lesssim 20$ GeV, almost all of the particles entering the forward detector are hadrons. Lowering the cut on the visible invariant mass increases the contribution of quasi-elastic vector meson production entering the $\eta_{\text{max}}$ distribution. Furthermore, quasi-elastic vector meson production events could be identified on an event-by-event basis by reconstructing the decay products of the backward scattered vector meson.

On the other hand, in order to consider large diffractive masses (diffractive jet production etc.), one has to increase significantly the $W_{\text{vis}}$ cut. For large values of $W_{\text{vis}}$, the cross section for having an electron scattered into the forward detector becomes comparable

![Figure 3: Breakdown of the $\eta_{\text{max}}$ cross section for $W_{\text{vis}} \geq 20$ GeV into non-diffractive (non-diff) and diffractive contributions: quasi-elastic vector meson production (q-el), single diffraction dissociation of the photon parallel to the $z$ axis (sd-1), single diffraction dissociation of the photon anti-parallel to the $z$ axis, and double diffraction dissociation (dd).](image)
with the cross section for finding hadrons there. Consequently, the scattered beam leptons have to be removed from the particles used for the trigger in the forward detector system in order to suppress the non-diffractive background.

In general, the kinematics of the diffractive process (momentum transfer and invariant diffractive mass) cannot directly be measured. Tagging the scattered beam leptons will allow one to reconstruct the kinematics of the diffractive process, however, the cross section will be suppressed by the photon virtualities. With 250 GeV beam energy a tagging angle of 40 mrad corresponds to a photon virtuality of about 50 – 100 GeV$^2$. This virtuality is too large to apply simple vector dominance arguments (see Eq. (3)) to estimate the two-photon cross section for diffraction in single- or double-tag events.

4 Conclusions

The current study has shown that photon single diffraction dissociation as well as quasi-elastic vector meson production can be measured in two-photon collisions at a $\sqrt{s} = 500$ GeV $e^+e^-$ linear collider. Such measurements will allow us to check frequently applied Regge factorization arguments and will help us to understand soft multiparticle production. Furthermore, the determination of the diffractive contribution to the total $\gamma\gamma$ cross section can be employed to reduce the systematic uncertainties of many model-based theoretical predictions.

Whereas diffractive and non-diffractive events can be clearly separated on the basis of the $\eta_{\text{max}}$ distribution, only in a restricted phase space region is it possible to distinguish on a event-by-event basis between different diffractive processes such as vector meson
production or single diffraction dissociation. For $W_{\gamma\gamma} \lesssim 20$ GeV the measurement of quasi-elastic vector meson production might be possible by reconstructing the meson from the decay products.

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