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Predictions for the $\gamma\gamma$ total cross-section in the TeV region: an update ¹

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ABSTRACT

In this talk we present an update of model predictions for the $\gamma\gamma$ total cross-section in the TeV region. The update includes preliminary results for $\gamma\gamma$ cross-sections using the Bloch-Nordsieck model for the overlap function of the partons in the transverse space, use of the CJLK parametrisation of the photonic parton densities that has recently become available and extension to the higher $\gamma\gamma$ energies relevant to the planned CLIC collider.

¹Talk presented by A. De Roeck at the International Linear Collider Workshop, Jeju Island, Aug. 26-30,2002.

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Abstract

In this talk we present an update of model predictions for the $\gamma\gamma$ total cross-section in the TeV region. The update includes preliminary results for $\gamma\gamma$ cross-sections using the Bloch-Nordsieck model for the overlap function of the partons in the transverse space, use of the CJLK parametrisation of the photonic parton densities that has recently become available and extension to the higher $\gamma\gamma$ energies relevant to the planned CLIC collider.

1 Introduction

It is well known that a knowledge of $\sigma(\gamma\gamma \rightarrow \text{hadrons})$ is quite important to be able to estimate the hadronic backgrounds [1] at the future $\gamma\gamma$ colliders[2] and also at the next generation e^+e^- colliders like TESLA [3] and still higher energy options like CLIC[4]. Theoretical computation of total/inelastic cross-sections for hadronic collisions, from ‘first’ principles in QCD, is a challenging problem. All the QCD based descriptions involve modelling of the non perturbative part. The data for

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total hadronic cross-sections at higher energies $\sim 100\text{--}200$ GeV, now available, from HERA[5] for the γp processes and from LEP for $\gamma\gamma$ processes[6], have provided an additional testing ground for these models and help in model development[7, 8]. Recently a new five flavour parametrisation[9] of the parton densities in the photon for heavy quark densities, has become available. Physics possibilities at the TeV energy e^+e^- collider, are being seriously studied[4]. The range of theoretical expectations for the hadronic $\gamma\gamma$ cross-sections for the TESLA energies and possibilities of distinguishing between various models in the $\gamma\gamma$ collider option were studied in detail[10] and a summary was presented in the TESLA-TDR[3]. Fig. 1 shows that

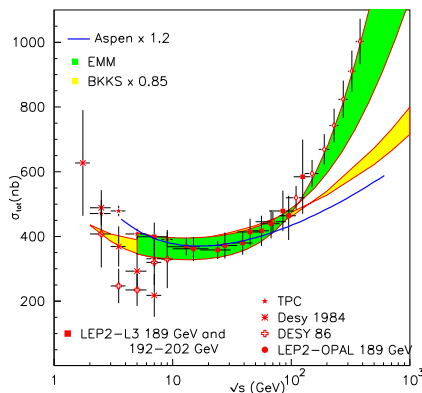


Figure 1: The energy dependence of the $\gamma\gamma$ cross-sections for different models rescaled so as to agree with the observed normalisation at LEP, along with the data. The wider band is obtained from the Eikonal Mini-jet Model(EMM)[11], the thinner one from the predictions of a QCD based model BKKS[12] multiplied by 0.85 and the solid line shows representative predictions of a model which treats proton like a photon, multiplied by 1.2[13]. Pseudo-data points (empty diamonds) following the EMM predictions at higher energies along with estimated measurement errors, are also shown.

the model predictions of $\gamma\gamma$ hadronic cross-sections can differ by a factor 2 already at the TESLA energies. In this contribution we update the predictions to extend to higher $\gamma\gamma$ energies, including the newer CJKL[9] densities for the photonic partons and also present predictions of a new model[14] for the overlap functions of the partons in the transverse plane, including effect of resummation of the soft gluon emission by the partons. The latter results in a taming of the fast energy rise of total

hadronic cross-sections at higher energies in the EMM model[7], thus increasing the reliability of these predictions.

2 Normalisation and energy dependence of σ^{tot}

All theoretical models which try to calculate the total cross-section have to provide a prediction for two quantities: the normalisation and the energy dependence. The issue of obtaining a theoretical description of the rise with energy of total cross-sections in hadronic collisions has occupied theoretical physicists from the early days of strong interaction physics. As said in the introduction, data are now available in the same energy range for $pp/p\bar{p}$, γp and $\gamma\gamma$ processes. Using simple quark counting rules and the Vector Meson Dominance (VMD) all the observed cross-sections can be put on the same scale. For example, $\sigma_{p\bar{p}}^{\text{tot}}$ and $\frac{3}{2P_{\text{had}}}\sigma_{\gamma p}^{\text{tot}}$ have similar normalisation. Here P_{had} is a factor which essentially measures the probability that a γ will behave like a hadron, and is given in VMD by $\sum_{\rho,\omega,\phi} \frac{4\pi\alpha_{QED}(\sqrt{s})}{f_V^2} = \frac{1}{240}$ at $\sqrt{s} = 200 \text{ GeV}$. For $\sigma_{\gamma\gamma}^{\text{tot}}$, factorisation implies that the multiplying factor be $\frac{9}{4(P_{\text{had}})^2}$. We see in Fig. 2 that the different cross-sections so multiplied by these factors implied by factorisation indeed have similar normalisation at the point where the rise with energy starts. Having fixed the overall normalisation of different cross-sections by using VDM and factorisation, we notice that the rate of the rise of the cross-sections with energy seems to be higher when one or more of the colliding hadrons is a photon. This statement can be made more quantitative by using the ‘classic’ Regge-Pomeron parametrisation of the total cross-sections given by

$$\sigma^{\text{tot}} = Xs^\epsilon + Ys^{-\eta}. \quad (1)$$

As a matter of fact, a fit of this form to σ^{tot} , keeping the normalisation free, shows that ϵ describing the high energy behaviour is different for the pp and the $\gamma\gamma$ data and the best fit values are $\epsilon_{pp} = 0.08$ and $\epsilon_{\gamma\gamma} \sim 0.1\text{--}0.2$ respectively [15].

The theoretical models which have been put forward to explain the energy rise of σ^{tot} fall in three broad classes: 1) the Regge-Pomeron models where to accommodate the faster rise of σ^{tot} more power terms are suggested, 2) a factorization approach which predicts the photon cross-section in terms of those measured for proton, but the problem of calculating the proton cross-sections from first principles still remains and 3) in a QCD based approach in terms of quarks and gluons where the rise of

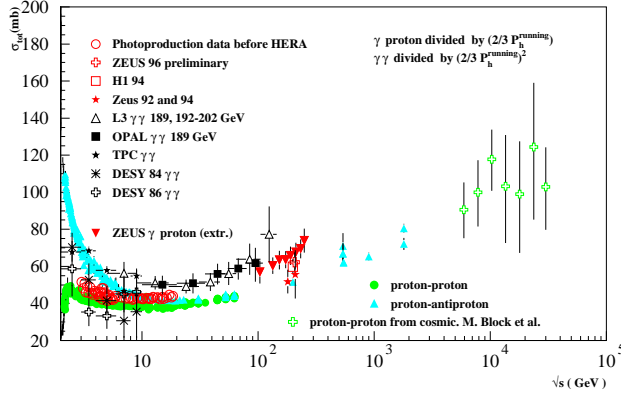


Figure 2: $pp/p\bar{p}, \gamma p$ and $\gamma\gamma$ cross-sections on the same scale.

the total hadronic cross-sections with energy is attributed to the increased number of parton collisions. We had included in Fig. 1 a representative prediction of each class of models. Various model predictions for $\sigma_{\gamma\gamma}^{\text{tot}}$ can be fitted in the form of Eq. (1) yielding values of ϵ between 0.1 – 0.3[16].

3 Minijet model and Bloch Nordsieck Resummation

In this section we briefly mention some features of the Eikonalised Minijet Model(EMM) and the Bloch Nordsieck(BN) resummation. In the EMM the rise of σ^{tot} with energy is ascribed to the rise with energy of the ‘minijet’ cross-section :

$$\begin{aligned} \sigma_{jet} &= \int_{p_{tmin}} \frac{d^2\sigma_{jet}}{d^2\vec{p}_t} d^2\vec{p}_t \\ &= \sum_{partons} \int_{p_{tmin}} d^2\vec{p}_t \int f(x_1) dx_1 \int f(x_2) dx_2 \frac{d^2\sigma^{partons}}{d^2\vec{p}_t}. \end{aligned} \quad (2)$$

The rise of σ_{jet} with energy is controlled by the small x dependence of the parton densities, and hence mostly by the gluon densities at high energies, in the concerned hadron and by the value of p_t^{min} , the minimum transverse momentum cut-off. In

the unitarised formulation, only part of the energy rise of the σ_{jet} is reflected in the rise of $\sigma^{inel}, \sigma^{tot}$ with energy. The $\sigma^{inel}, \sigma^{tot}$ in unitarised form are then given by

$$\begin{aligned}\sigma_{pp(\bar{p})}^{inel} &= 2 \int d^2\vec{b} [1 - e^{-n(b,s)}] \\ \sigma_{pp(\bar{p})}^{tot} &= 2 \int d^2\vec{b} [1 - e^{-n(b,s)/2} \cos(\chi_R)]\end{aligned}\quad (3)$$

where $n(b, s)$ is the number of collisions of the partons in the hadrons in the transverse space and $\chi_R = 0$. In the simplest model $n(b, s)$ is assumed to have a factorised form as a sum of the perturbative and non-perturbative contributions:

$$n(b, s) = n_{NP}(b, s) + n_P(b, s) = A(b)[\sigma_{soft} + \sigma_{jet}], \quad (4)$$

Here $A(b)$ is the overlap of the partons in the transverse space. This can be calculated as the inverse Fourier Transform of the Form Factor of the hadrons or from the inverse Fourier Transform of the intrinsic transverse momentum distribution of the partons in the hadron [7], σ_{jet} is given by Eq. 2 and σ_{soft} is parametrised. When the colliding partons are photons, the model has to include the fact that a photon has to ‘hadronise’ before this formalism can be applied. If P_{had} measures this ‘hadronisation’ probability for the γ , the EMM expression for $\sigma_{\gamma\gamma}^{tot}$ is given by

$$\sigma_{\gamma\gamma}^{tot} = 2P_{had}^{\gamma\gamma} \int d^2\vec{b} [1 - e^{-n^{\gamma\gamma}(b,s)/2}], \quad (5)$$

with $n^{\gamma\gamma}(b, s) = 2/3n_{soft}^{\gamma p} + A^{\gamma\gamma}(b)\sigma_{jet}(s)/P_{had}^{\gamma\gamma}$ with $P_{had}^{\gamma\gamma} = [P_{had}]^2$. One gets a very good description of the $\gamma\gamma$ data with the EMM predictions obtained with the same set of parameters which fit the γp data, by adjusting the overall normalization upwards by 10%. The EMM predictions shown in the Fig. 1 are obtained in the above framework and the predictions are in line with the generally observed trend of faster energy rise with energy.

However, even though the EMM model is qualitatively correct, it is unable to provide a correct description of the early energy rise for the $p\bar{p}$ data. The rather steep rise of $\sigma_{\gamma\gamma}^{inel}$ also raises the question whether such a rise is realistic at high energies. Clearly this simple picture requires further refinements.

It is clear that the factorisation assumed in Eq. 4 is too severe an approximation and must be relaxed. The transverse momentum distribution of the partons in a hadron and hence the transverse overlap function are sure to have an energy dependence. Thus one writes the number of collisions as

$$n(b, s) = n_{soft}(b, s) + A_{PQCD}(b, s)\sigma_{jet}^{LO}. \quad (6)$$

where n_{soft} is to be fitted just like the σ_{soft} earlier. A_{PQCD} is calculated in terms of the intrinsic transverse momentum distribution of partons in a hadron calculated in a semi-classical approach as being built, to leading order, from the resummation of the soft gluon emissions from a valence quark [17]. The expression for $A_{PQCD}(b, s)$ in this model is given by

$$A_{PQCD}(b, s) \equiv \frac{e^{-h(b,s)}}{\int d^2\vec{b} e^{-h(b,s)}} \quad (7)$$

where,

$$h(b, s) = \int_{k_{min}}^{k_{max}} d^3\vec{n}_{gluons}(k) [1 - e^{ik_t \cdot b}].$$

In the above k_{max} is the kinematic upper limit for the momentum for the soft gluon emission, whose resummation builds the intrinsic transverse momentum distribution of the partons in the hadron. k_{min} in principle is zero; but then one needs to have a model for $\alpha_s(k_t)$ as $k_t \rightarrow 0$. Since the intrinsic transverse momentum distribution is built here in terms of the resummation of soft gluons, this is termed as the Bloch Nordsieck model of $A(b, s)$. The $A_{PQCD}(b, s)$ depends on p_{tmin} and the parton densities. As \sqrt{s} increases the phase space available for soft gluon emission also increases causing a rise in k_{max} . Further, the transverse momentum of the initial colliding pair due to soft gluon emission increases with increasing energy and causes more straggling of initial partons reducing the probability for the collision and hence $n(b, s)$. A good fit to the pp and $p\bar{p}$ data is obtained[18], using A_{PQCD} as given by Eq. 7, with a σ_{soft} which is a constant or very slowly falling with \sqrt{s} and A_{soft}^{BN} also very slowly falling at low energy and then remaining constant. Figure 3 shows that this model reproduces both the initial fall and the final rise, correctly.

4 Results and Outlook.

In this section we present the results of the updates of the EMM model, namely two types of densities and soft gluon resummation for both of them. In this we use for the photons the soft part of the eikonal $n(b, s)$ directly from the $pp/p\bar{p}$ processes and we use $n_{\text{soft}}^{\gamma\gamma}(b, s)$ given by $\frac{4}{9} \frac{n_{\text{soft}}^{pp} + n_{\text{soft}}^{p\bar{p}}}{2}$ using the values obtained in the fit shown in Fig. 3. In Fig. 4, we show results for two different partonic densities in the photon, the GRS[19] and the newer CJLK[9] densities. We further extend our predictions to energies relevant for CLIC. We have used here soft resummation

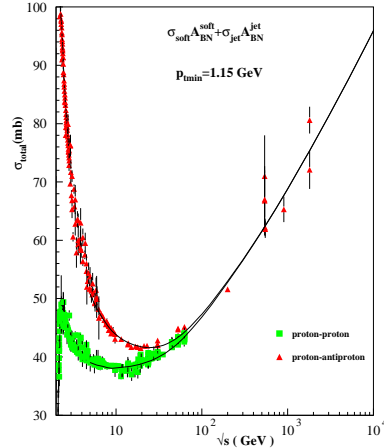


Figure 3: Energy dependence of the σ^{tot} for $pp/p\bar{p}$ in the BN model.

for hard scattering as described in the earlier section. The dashed line in Fig. 4 shows the expected cross-sections upto CLIC energies in the EMM model[11], for parameters which give the nice agreement with the LEP data shown in Fig. 1. The dash-dotted line shows the predictions for the ASPEN model[13]. The solid and the dotted curves show predictions of the EMM model with soft resummation for the CJLK and GRS densities with the various parameters as indicated in the figure. As we see, the soft resummation of the hard scattering does indeed tame the rise at high energies. We notice, that the soft gluon emission also provides the initial decrease of the cross-sections. The CJLK densities have steeper x dependence and that is reflected in steeper energy rise for those densities. We have chosen the value of p_t^{min} in each case such that the model predictions agree with the LEP data. The difference between predictions for the different parton densities is about 20% at higher energies. The expected errors on the ‘pseudo data points’ show clearly that the measurements at a high energy $\gamma\gamma$ collider have the potential of distinguishing between different formulation of the EMM model as well as between the QCD based models and those which treat γ as a ‘proton’ for the purposes of these calculations.

Of course, one needs to also study the γp cross-sections in the EMM model with soft resummation and see whether a unified description, with soft parameters related by VMD, Quark Model and factorisation, is possible for all four cross-sections, pp , $p\bar{p}$, γp and $\gamma\gamma$ in this modified EMM picture. Further, one also needs to fold these

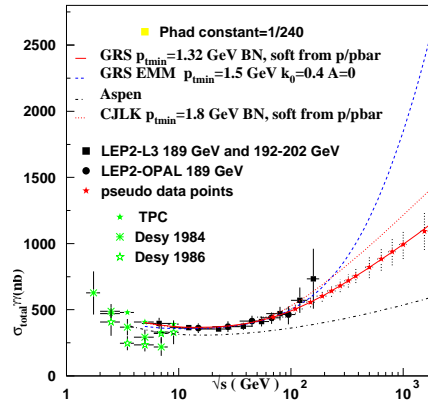


Figure 4: Updated $\sigma_{\gamma\gamma}^{\text{tot}}$ predictions for CJLK,GRS densities upto CLIC energies, with expected accuracy of measurement. Parameters as given in the figure.

hadronic cross-sections for the $\gamma\gamma$ collisions with the γ spectra expected in the e^+e^- collisions at CLIC energies, including the beamstrahlung photons, to estimate the hadronic backgrounds at these multi-TeV e^+e^- colliders[20]. Work to do this is in progress.

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References

- [1] M. Drees and R.M. Godbole, *Zeit. Phys.* **C59** (1993) 591.
- [2] B. Badelek *et al.* [ECFA/DESY Photon Collider Working Group Collaboration], “TESLA Technical Design Report, Part VI,” arXiv:hep-ex/0108012.
- [3] J. A. Aguilar-Saavedra *et al.* [ECFA/DESY LC Physics Working Group Collaboration], “TESLA Technical Design Report Part III,” arXiv:hep-ph/0106315.

- [4] <http://cliphysics.web.cern.ch/CLICphysics/>
- [5] H1 Collaboration, Aid, S., et al., *Zeit. Phys. C* **69**, 27 (1995), **hep-ex/9405006**; ZEUS Collaboration, Derrick, M., et al., *Phys. Lett. B* **293**, 465 (1992); Derrick, M., et al., *Zeit. Phys. C* **63**, 391 (1994); Breitweg, J., et al., **DESY-00-071**, **hep-ex/0005018**; C. Ginsburg et al., Proc. 8th International Workshop on Deep Inelastic Scattering, April 2000, Liverpool.
- [6] Acciarri, M., et al, *Phys.Lett.* **B 519** 33,2001, G. Abbiendi et al., *Eur. Phys. J.* **C14** (2000) 199.
- [7] A. Corsetti, R.M. Godbole and G. Pancheri, *Phys.Lett.* **B435** (1998) 441.
- [8] A. Grau, G. Pancheri and Y.N. Srivastava, *Phys.Rev.* **D60** (1999) 114020.
- [9] F. Cornet, P. Jankowski, M. Krawczyk and A. Lorca, arXiv:hep-ph/0212160.
- [10] G. Pancheri, R. M. Godbole and A. De Roeck, LC-TH-2001-030.
- [11] R. M. Godbole, G. Pancheri, *Eur.Phys.J.* **C19** 129, 2001.
- [12] B. Badelek, M. Krawczyk, J. Kwiecinski and A.M. Stasto, *Phys.Rev.* **D62** (2000) 074021.
- [13] M.M. Block, E.M. Gregores, F. Halzen and G. Pancheri, *Phys.Rev.* **D58** (1998) 17503; M.M. Block, E.M. Gregores, F. Halzen and G. Pancheri, *Phys.Rev.* **D60** (1999) 54024.
- [14] A. Grau, G. Pancheri and Y. N. Srivastava, *Phys. Rev.* **D 60**, 114020 (1999).
- [15] A.De Roeck, hep-ph/0101076.
- [16] R.M. Godbole, A.Grau, G. Pancheri and A. De Roeck, in hep-ph/0109166: K. Abe *et al.*, ACFA Linear Collider Working Group Collaboration.
- [17] A. Corsetti, A. Grau, G. Pancheri and Y. N. Srivastava, *Phys. Lett.* **B 382**, 282 (1996).
- [18] A. Grau, G. Pancheri and Y. Srivastava, preliminary result.
- [19] M. Glueck, E. Reya and I. Scheinbein, *Phys. Rev.* **D 60** (1999) 054019.
- [20] R.M. Godbole, Talk at the Meeting on CLIC physics, CERN, Feb. 10, 2003.