PROBING THE HEAVY QUARK CONTENT OF THE PHOTON
USING b TAGGING AT ELECTRON PHOTON COLLIDERS

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ABSTRACT

We study the prospects for probing the quark content of the photon using b tagging at high energy electron-photon colliders. We find that heavy quark tagging provides a sensitive and effective probe of the quark content of the photon. Using a 500 GeV e^+e^- NLC in electron-photon mode, the cross section for ebγ → eb can be measured to 10% with b tagging. This is sufficient to differentiate between the various photon structure functions.

1. INTRODUCTION

There is a growing interest in the hadronic content of the photon as both a test of QCD and as a background to precision measurements of electroweak parameters. Although several theoretical predictions for the hadronic content of the photon exist in the literature, the experimental data is too sparse at this point to significantly constrain the theory. This paper will present a novel method of constraining the b content of the photon by using electron photon colliders to measure hard scattering of b-quarks from the photon with the electron beam. The advantage of investigating b-quarks will be that the b-quarks can be tagged, giving us a method to isolate the b-quark content of the photon from the light quark and gluon content.

Since the photon structure functions grow with increasing momentum transfer, Q^2, it is advantageous to work with the largest possible centre of mass energy in our collisions of electrons and photons. If we are using effective photon theory, where the photons are produced through the bremsstrahlung process, the photons are soft and the effective centre of mass energy will be small. Another possibility is to convert a high energy e^+e^- collider into an eγ collider by Compton backscattering a high intensity laser off one of the electron beams. Here the effective centre of mass energy for electron-photon collisions is very near the centre of mass energy of the original e^+e^- beam. The potential of eγ colliders to study the hadronic content of the photon

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has already been studied by other researchers, but this was in the context of dijet production where it is difficult to isolate the quark content from the gluonic content.

Using a 500 GeV $e^+e^-$ collider converted to an $e\gamma$ collider by backscattering laser photons, we find that the cross-section for the process $e + \gamma \rightarrow e + b + X$ can be measured to an accuracy of 9%, allowing one to discriminate between the various photon structure functions.

2. CALCULATIONS AND RESULTS

The process that we are interested in, $e + \gamma \rightarrow e + b + X$, is shown in figure 1. It is straightforward to calculate the cross section for the sub-process $e + b \rightarrow e + b$.

To obtain a physical cross section, we then fold in the sub-process cross section with the distribution functions for the hadronic content of the photon ($b^+(x, Q^2)$) and the backscattered laser ($f_\gamma(\tau)$):

$$\sigma(e + \gamma \rightarrow e + b + X) = \int d\tau f_\gamma(\tau) \int dx b^+(x, Q^2) \sigma(e + b \rightarrow e + b)(s),$$

where the effective centre of mass energies squared for $e\gamma$ and $eb$ collisions are

$$\tilde{s} = \tau s \quad \text{and} \quad \hat{s} = x\tilde{s} = x\tau s,$$

respectively. Unless explicitly stated otherwise, we will take $Q^2 = \hat{s}$ throughout this paper.

In the $eb$ centre of mass frame, our signal will be an electron back to back with a $b$ jet. Since the $eb$ centre of mass frame is boosted along the incoming electron direction, in the lab frame this will manifest itself as an electron and a $b$ jet with equal transverse momentum, balanced in azimuthal angle. To insure that both our $b$ jet and electron will be detected, we impose beam line cuts of $|\cos \theta_b| < 0.85$ on the angle of the $b$ jet and $|\cos \theta_e| < \cos 10^0$ on the angle of the electron.

The major backgrounds to this process will be:

$$e + \gamma \rightarrow e + b + \bar{b},$$
\[ e^+ + e^- \rightarrow \gamma + b + \overline{b}, \] (4)  
and  
\[ \gamma + g, \rightarrow b + \overline{b}, \] (5)  
where in each case, the \( b \) is successfully tagged and all the observable decay products of the \( \overline{b} \) go down the beam pipe with the exception of the \( e^+ \), which is mistakenly identified as the \( e^- \). If charge identification is possible, then all these backgrounds will immediately disappear. If not, then we shall demonstrate that they are still manageable once we impose that the transverse momentum of the electron (\( p_{Te} \)) must balance the transverse momentum of the \( b \) jet (\( p_{Tb} \)).

In figure 2a we show \( p_T \) distributions of the \( b \)-quark for the signal using various different photon structure functions. This can be compared with figure 2b, the \( p_T \) distributions of the major backgrounds where it has been imposed that the \( b \)-quark and electron transverse momentums balance,

\[ |p_{Tb} - p_{Te}| \leq 10 \text{GeV}. \] (6)

For the gluonic background we have used the Duke-Owen structure functions and \( Q^2 = \hat{s}(\gamma, g) \). As one can see, the backgrounds are all small compared to the signal, except possibly in the low \( p_T \) regions. These low \( p_T \) regions can be eliminated by a simple \( p_T \) cut of 25 GeV, since our signal has no cross section in that region.

The total cross sections for the various photon structure functions are given in table 1 together with the event rates assuming an integrated luminosity of 50(fb)\(^{-1}\) and a \( b \) reconstruction efficiency of 10%. Assuming a purely statistical error in the measurement of the cross section, we see that cross section for the Duke Owens structure functions can be evaluated to 9% at the 95% confidence level (2 sigma). Since that is the level of discrepancy between the various structure functions, it should be possible to discriminate between them.

| Structure Function | \( \sigma \) (fb) | Events | \( \delta \sigma \) (95% c.l.) | \( \left( \sigma_i - \sigma_{D.O.} \right)/\sigma_{D.O.} \) |
|-------------------|-----------------|--------|-----------------|---------------------------------|
| D.O.\(^\text{3}\)  | 102             | 510    | 9\%             | –                               |
| D.G.\(^\text{4}\)  | 108             | 540    | 9\%             | 6\%                             |
| G.R.V\(^\text{4}\) | 68              | 340    | 11\%            | 33\%                            |
| L.A.C.\(^\text{4}\) | 138             | 690    | 8\%             | 34\%                            |

Table 1. Cross sections for the various structure functions together with the corresponding number of events assuming \( \int \mathcal{L}dt = 50 fb^{-1} \) and a 10% \( b \) reconstruction efficiency. The third column is the accuracy to which the cross section could be measured at the 95% c.l. and the fourth column is the % difference between the various structure functions.

A more useful constraint on the structure functions could be obtained if one can measure the \( x \) distribution of the cross-section. This distribution is shown in figure 3a. Since \( x \) is not a directly measurable quantity, this distribution would have to
be obtained by deconvoluting the $x\tau$ distribution with the distribution function for backscattered lasers. This $x\tau$ distribution is given in figure 3b. Work on the analysis of these distributions is currently in progress.

2. CONCLUSIONS

We have seen that one can measure the cross section for $e + \gamma \rightarrow e + b + X$ to 9%. This should allow one to differentiate between the various structure functions parametrizing the hadronic content of the photon. We hope to be able to further constrain these structure functions through the use of the $x$ distributions of their cross sections.

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Fig. 2. Transverse momentum distributions for the signal and backgrounds. a) Transverse momentum distributions for different structure functions: Solid line is LAC set 1; Dashed line is GRV; Dotted line is DO set 2; Dot-dashed line is DG set.

b) Transverse momentum distributions for the major backgrounds: Solid line is $e^+ \gamma \rightarrow e + b + \bar{b}$; Dashed line is $e^+ e^- \rightarrow \gamma + b + \bar{b}$; Dot-dashed line is $\gamma + g \gamma \rightarrow b + \bar{b}$.
Fig. 3. a) $x$ distributions for the various structure functions. b) $x\tau$ distributions for the various structure functions. Solid line is LAC set 1; Dashed line is GRV; Dot - DO; Dotdash - DG.