Measurement of the Beam-Spin Azimuthal Asymmetry Associated with Deeply-Virtual Compton Scattering

The classical way of investigating the microscopic world is by using the microscope: light is being directed towards the object (a cell or microbe, for instance) we want to inspect, and by watching how the light is either reflected or transmitted by the object under study we are able to form a picture of its structure.

Unfortunately it is impossible to apply this simple technique when investigating the inner structure of the proton, since the diameter of the proton (of about 1.5 fm) is much smaller than the wavelength of visible light. The simple solution to this problem is the use of electromagnetic radiation of very small wavelength, i.e. gamma rays of 10 GeV in energy, which have a wavelength of about 0.1 fm. If such a high-energy photon is scattered off a quark – and subsequently observed in our experiment – information can be obtained on, for instance, the total angular momentum carried by the quarks. This photon scattering process is known under the name of Deeply-Virtual Compton Scattering (DVCS), and is schematically depicted in fig. 1a.

Gamma rays of 10 GeV or more can be generated by scattering high-energy electrons (such as the 27 GeV electrons available at the HERA electron-proton collider of DESY) off a proton target. However, when doing so the detectors will mainly observe the hard gamma rays emitted by an electron when approaching a charged object such as a proton. The emission of these hard gamma rays is usually referred to as the Bethe-Heitler process, which is depicted in fig. 1b. Amidst the dominant Bethe-Heitler photons we need to observe the DVCS photons that truely scattered off the inner structures in the proton, i.e. the quarks and gluons.

If an estimate is made of the relative importance of BH and DVCS photons, the result is that the BH photons dominate under essentially all realistic experimental circumstances. Until recently, it was therefore believed, that it would be close to impossible to apply the classical concept of photon scattering to the study of quarks and gluons in the proton.

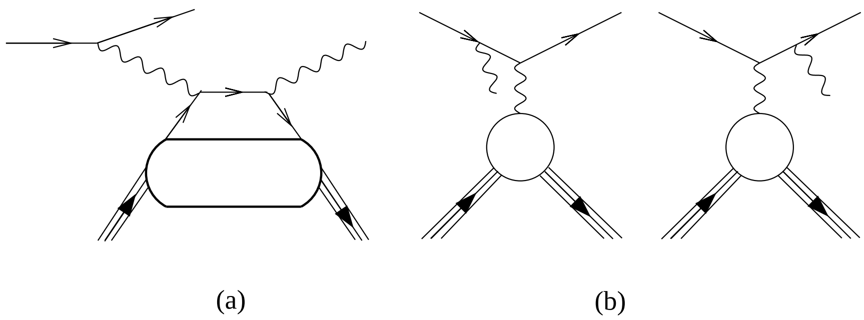

Figure 1: *Schematic picture of electron scattering off a proton. On the left-hand side (fig. 1a) the deeply-virtual Compton scattering process is depicted: an electron (single line in the upper-left part of the figure) interacts with a quark (one of three lines close together) through the exchange of a (virtual) photon resulting in the subsequent emission of real photon, where the photons are represented by wiggle lines. On the right-hand side (fig. 1b) the Bethe-Heitler process is shown: real photons are emitted by the incident or scattered electron in the electromagnetic field of the proton. These photons do not carry information on the quark structure of the proton. The ellipse in fig. 1a and the circles in fig. 1b represent complex quark rearrangements that occur in the scattering process.*

However, a few years ago it was noted that the two process shown in figure 1 would be subject to interference effects, as all physical processes do which have the same (undistinguishable) final state. Usually, interference effects are a nuisance, but in this case they are a blessing. Due to the interference between the dominant BH process and the DVCS process the DVCS contribution is amplified, provided that an experimental observable can be identified which is exclusively sensitive to the BH-DVCS interference. Such an observable is the 'beam- spin azimuthal asymmetry' quoted in the title of this paper. It means that we extract the azimuthal angular dependence of photons scattered from a proton target, when a spin-polarized positron beam is used. The azimuthal angle is the angle between the lepton plane (defined by the incident and scattered positron) and the photon plane (defined by the virtual photon - the left most curly line in fig 1a - and the detected photon). We plot the asymmetry, which is the ratio of the difference and the sum of the photon yields for the two orientations of the beam spin direction (or helicity), as a function of this azimuthal angle (see figure 2). A clear dependence of the asymmetry on the azimuthal angle is observed. This is a remarkable observation, as the BH process alone cannot give rise to any significant asymmetry in this plot. Hence, the azimuthal dependence observed in figure 2 can only be attributed to the interference between the BH and DVCS process.

The data shown in figure 2 represent the first unambiguous observation of evidence of photon (or Compton) scattering at the quark level. The scientific significance of this observation is that in due time (when more statistics comes available) such measurements can be used to extract information on the total angular momentum carried by the quarks.

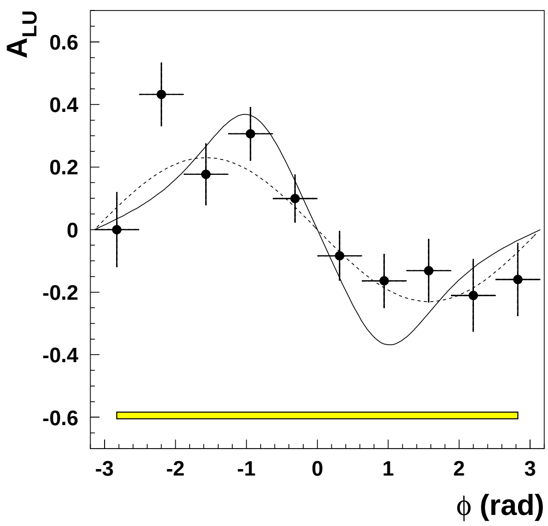

Figure 2: *Azimuthal dependence of the asymmetry of the photons produced in the experiment with respect to the orientation of the spin of the positron beam. If the photons had only originated from the Bethe-Heitler process, the azimuthal dependence would have been basically flat. However, the data show a clear* $\sin\phi$*-type dependence, as is illustrated by the dashed curve. Such a dependence is expected if the photons originate from deeply-virtual Compton scattering, i.e. photon scattering at the quark level. The solid curve represents one of the first complete calculations of this observable by N. Kivel et al., hep-ph/0012136.*