Very Forward/Backward Detectors at the LHeC

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This contribution briefly describes the possibilities for the measurements in the very forward and backward directions at the proposed future LHeC $e^{\pm}p$ collider. The ideas for the detector design for luminosity, polarisation and forward baryon measurements are presented.

1 Introduction

The Large Hadron Electron Collider (LHeC) is a proposed future deep-inelastic scattering facility at CERN, where protons or heavy ions from an existing LHC storage ring collide with electrons or positrons beam of energy 60 to 140 GeV from a newly built machine. The LHeC is presently being evaluated in the form of two options, 'ring-ring' (RR) and 'linac-ring' (LR), either of which operate simultaneously with proton-proton or heavy ion collisions at the existing LHC experiments. The conceptual design of the LHeC detector was presented in this workshop by A. Polini [1]. In this report I discuss the detector components which are located outside of the main apparatus, in the very forward and backward directions, and aimed for the measurement of luminosity, electron beam polarisation and the baryons scattered at very low angles. In order to finalise the study of the geometry of detectors, a detailed simulation of the LHeC interaction region and the beamline must be performed.

2 Luminosity measurements and Electron tagging

Luminosity measurement is a crucial issue for the LHeC, where precision measurements constitute a significant part of the physics programme. In addition to an accurate determination of integrated luminosity with the 1% precision for the normalisation of physics cross sections, the luminosity system should allow for fast beam monitoring for tuning and optimisation of ep-collisions and has to provide control of the mid-term variations of instantaneous luminosity.

An important lesson from HERA is that one has to prepare alternative methods for luminosity determination. The physics processes which are best suitable for luminosity determination are the electromagnetic Bethe-Heitler (BH) and QED Compton (QEDC) scattering processes $ep \to e + \gamma + p$, which have a large and well known cross sections. In addition, Neutral Current DIS events in a well understood (x, Q^2) range can be used for the relative normalisation and mid-term yield control. The methods are complementary, having very different systematics and providing useful redundancy and cross check for the luminosity determination.

The QEDC events, for which the scattered electron and photon are measured in the backward part of the LHeC main detector with stable and well known acceptance, are well suited

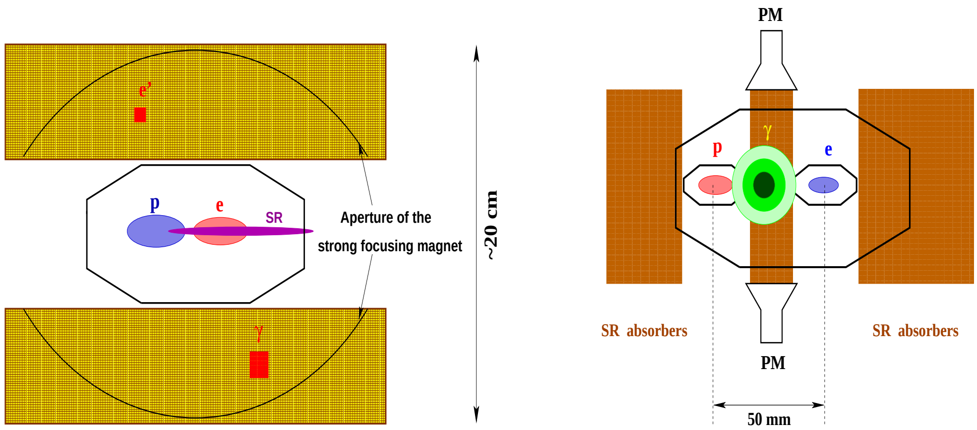

Figure 1: Options for the luminosity monitoring. (a) QEDC tagger at $z = -6$m; (b) active SR absorber and liminosity detector at $z = -22$m.

for global normalisation of the physics samples. The visible cross section of QEDC events can be increased by installing a dedicated small 'QEDC tagger' at $z = -6$m, consisting of two movable calorimeter sections approaching the beampipe from the top and the bottom (Figure 1a), supplemented by small silicon tracking detector for e/γ separation and background rejection.

The BH process has a very high cross section and can be measured in the dedicated 'tunnel detectors'. This method is, however, very sensitive to the details of the beam optics at the interaction point, requires a large and precisely known geometrical acceptance, and may suffer from synchrotron radiation (SR). In case of the RR-option the dominant part of the BH photons will end up at $z \simeq -22$m, between electron and proton beam-pipes. At this position measurement of photons is very difficult due to large SR flux. There is however an interesting possibility to use cooling water of SR absorber as an active media for Čerenkov radiation from electromagnetic showers initiated by the energetic photons. The Čerenkov light can be read out by two photomultipliers as sketched on Figure 1b. For the actual RR design the 90% acceptance to the BH photons can be reached, thus allowing fast and reliable luminosity monitoring with $3 - 5\%$ uncertainty. In case of LR-option the luminosity detector will be placed in the median plane next to the interacting proton beam. The major uncertainty will come from the knowledge of the limited geometric acceptance. This limitation is defined by the proton beam-line aperture. The geometric acceptance of the Photon Detector up to 95% is possible at the nominal beam conditions. The total 1% luminosity error can be achieved.

The BH reaction can be tagged also by detecting the outgoing electron. In order to determine the best positions for the electron taggers the LHeC beamline simulation has been performed. The best position for the electron tagger is at $z{=}{-}62$ m, which less suffers from SR flux and provide reasonable acceptance, reaching approximately $(20-25)\%$ at the maximum. The actual acceptance strongly depends both on the distance of the sensitive detector volume from the e-beam axis and on the details of the electron optics at the IP. Therefore a precise independent monitoring of beam optics and accurate position measurement of the e-tagger are required in order to control geometrical acceptance to a sufficient precision.

3 Polarimeters

The polarisation measurement of the electrons and positrons at the LHeC will be based on Compton polarimetry. This technique has been successfully used in the past at SLC [2] and at HERA [3], and is foreseen for the polarisation measurement at the future linear colliders [4]. The experimental setup consists of a laser beam, which scatteres off the lepton beam, and calorimeters, which measure the scattered photon and lepton. The longitudinal polarisation of lepton is obtained from a fit to the scattered photon and/or to the lepton energy spectra.

For the extraction of the longitudinal polarisation one may then distinguish between the single (or few) scattered photon regime, where the polarisation can be determined from a fit to the scattered photon energy spectrum, and the multi-photon regime, where the photons can not be distinguished in the calorimeter and the polarisation is calculated from an asymmetry between the average scattered energies corresponding to a circularly left and right laser beam polarisations [5]. Considering a very stable pulsed laser beam with adjustable pulse energy and operating in different regimes, one can calibrate the calorimeter in situ, optimise the dynamical regime and minimise the final uncertainty on the polarisation measurement.

The Compton interaction region will include a dedicated electron spectrometer followed by a segmented electron detector [4], which will measure the scattered electron angular spectrum. The measurements of both the scattered photon and leptons are complementary and allow for a precise control of the systematic uncertainties of the polarisation measurement [2].

4 Zero Degree Calorimeter (ZDC)

The position of the ZDC in the tunnel and the overall dimensions depend mainly on the space available for the installation. The geometry, technical specifications and proposed design of ZDC detectors are to large extent similar to the ZDCs of the LHC experiments [6, 7, 8]. The ZDC can be placed in a 90 mm narrow space available at about 100 m next to the interacting proton beam pipe. The detector has to be capable of detecting neutrons and photons produced with scattering angles up to 0.3 mrad and energies between some hundreds GeV to the proton beam energy (7 TeV) with a resolution of few percents. It must be able to separate neutrons from photons and to distinguish showers from two or more particles.

The ZDC can be built as a longitudinally segmented tungsten-quartz calorimeter with the electromagnetic and hadronic sections. The electromagnetic section with fine granularity is needed for precise determination of the position of the impact point, discrimination of the electromagnetic and hadronic showers and separation of the showers from two or more particles. The hadronic section of the ZDC can be built with coarser sampling. The longitudinal segmentation will allow the control of the change of energy response due to radiation damage.

Another possibility for the ZDC design is provided by the the Dual Readout calorimetry [9]. The detector will have tungsten absorber and equipped with scintillating and quartz fibres readout by the SiPM. Two kind of fibres are sensitive to the different components of the hadron shower, which leads to the improved hadronic energy resolution. The discrimination between neutrons and photons will be possible using the time structure of the signals.

In addition to the ZDC calorimeter for measurement of neural particles at 0°, a proton calorimeter positioned externally to the outgoing proton beam can be installed for the measurement of spectator protons from eD and eA scattering produced at zero degree. This calorimeter will be made using the same technique as the neutron ZDC.

Due to the hard radiation and temperature environment it is essential to control of the stability of the ZDC response. The stability of the gain of the PMTs and the radiation damage in fibres can be monitored using the laser or LED light pulses. The stability of absolute calibration can be monitored using the interactions of the proton beam and residual gas molecules in the beam-pipe, as used at HERA [10, 11]. A useful tool for absolute energy calibration will be the reconstruction of invariant masses, e.g. $\pi^0 \to 2\gamma$ or $\Lambda, \Delta \to n\pi^0$, with decay particles produced at very small opening angles and reconstructed in ZDC. It is therefore essential that several particles in the ZDC within the same event are reconstructed.

5 Forward Proton Spectrometer (FPS)

In diffractive ep interactions the proton may survive a hard collision and scatter at a low angle along the beamline while loosing a small fraction $\xi \approx \mathcal{O}(1\%)$ of its energy. The ATLAS and CMS collaborations have investigated the feasibility to install proton detectors along the LHC beamline [12]. The conclusions reached in these R&D studies are relevant for the LHeC detector.

The acceptance window in ξ is determined by the closest possible approach of the proton detectors to the beam for low ξ and by the distance of the beam pipe walls from the nominal proton trajectory for high ξ. The maximaum allowed four-momentum transfer squared t is defined by the radius of the LHC beam pipe, which is approximately 2 cm at the large distances from the interaction point. The acceptance for diffractively scattered protons as a function of ξ and t at 420 m from the interaction point, determined using the LHC proton beam optics, is shown in Figure 2. A quite good acceptnace is reached in the range $0.002 < \xi < 0.013$. The kinematics of diffractive interaction can be reconstructed from the accurate measurements of the proton's position and angle with respect to the nominal beam. However the resolution of the reconstructed variables will be determined by the intrinsic width and divergence of the proton beam.

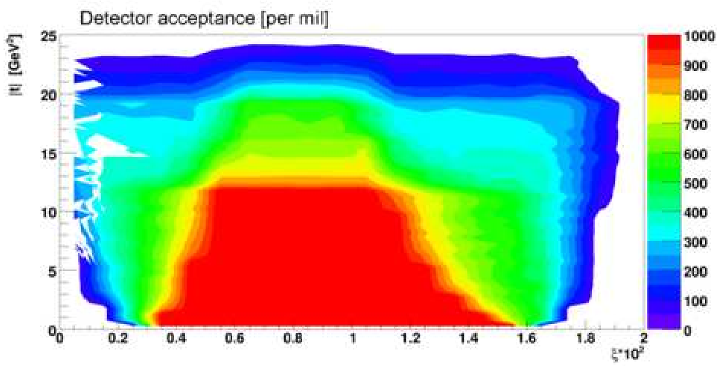

Figure 2: The acceptance for a proton detector placed at 420 m from the interaction point as a function of the momentum loss ξ and 4-momemtum transfer squared t.

A crucial issue in the operation of proton detectors is the alignment of the detectors with respect to the nonimal beam. The detectors have to be aligned for each accelerator run and the drifts have to be monitored. As at HERA, alignment constants will be determined by requirement that the observed cross section is maximal for forward scattering. This procedure can be cross-checked using a physics process with a exclusive system produced in the central detector such that the proton kinematics is fixed by applying energy-momentum conservation to the full set of final state particles. The feasibility of various alignment methods at the LHeC has to be studied.

6 Summary

Forward and backward 'tunnel' detectors are the important parts of the future *ep* experiment at the proposed LHeC collider. The ideas for the detector design for luminosity, polarisation and forward neutron and proton measurements are presented.

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