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The Forward Tagger facility for low Q^2 experiments at Jefferson Laboratory

Andrea Celentano[1,a], for the CLAS collaboration

[1] *INFN Genova and Università di Genova, Dipartimento di Fisica*

Abstract.
Low Q^2 electron scattering is an efficient and competitive experimental technique to provide intense, quasi-real photon beams, with a high degree of linear polarization. Such a technique will be employed in Hall B at Jefferson Laboratory by having the primary 11 GeV electron beam from the CEBAF accelerator impinging on a liquid hydrogen target. Low-angle scattered electrons will be detected with the new Forward Tagger facility, while the final state hadrons will be measured with the CLAS12 spectrometer. The unique combination of the two detectors will permit to carry out a broad physics program, and to explore new possibilities for high quality physics.

1 Introduction

Low Q^2 electron scattering provides an alternative to real photoproduction to produce intense photon beams, with high energy and high degree of linear polarization. In the process, a high energy electron beam impinges on a nucleon target and electrons scattered at very low angle are detected. The electron-target interaction proceeds trough the exchange of a virtual, i.e. off-shell, photon. The virtual photon effective mass, or *virtuality*, Q^2 is:

$$Q^2 = 4EE' \sin^2(\theta_e/2) \quad , \tag{1}$$

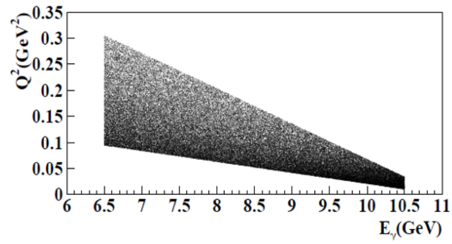
where E and E' are the beam and the scattered electron energy, and θ_e is the scattering angle. At low scattering angle, Q^2 is almost zero, and the virtual photon behaves as a real, on-shell, particle. Moreover, in the low Q^2 limit the virtual photon polarization corresponds to a real, linear photon polarization [1]. The transverse component ε_T is only related to the beam and the scattered electron energy, and the polarization plane is perpendicular to the electron scattering one. On the contrary, the longitudinal component ε_L scales linearly with Q^2, being

$$\varepsilon_L = \frac{Q^2}{(E-E')^2} \cdot \varepsilon_T \quad , \tag{2}$$

and becomes negligible at small scattering angle.

The technique was used in the past to produce high energy ($\simeq$ 100 GeV) photon beams at CERN (Ω and COMPASS experiments) and at DESY (ZEUS and H1 experiments). In the near future, low Q^2

[a] e-mail: andrea.celentano@ge.infn.it



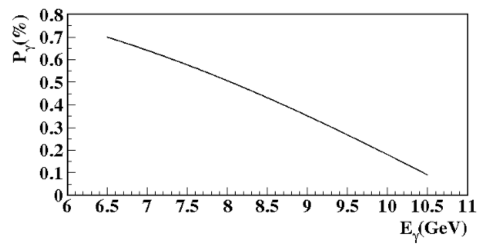


Figure 1. Left: Q^2 vs. virtual photon energy $E_\gamma \equiv E - E'$ for inelastic events for electrons within the Forward Tagger geometrical and momentum acceptance. Right: virtual photon linear polarization as a function of E_γ.

experiments will be performed at Jefferson Laboratory in Hall B, where a dedicated facility, extending the capabilities of the CLAS12 detector, will be installed: the Forward Tagger. The facility will be used to detect electrons scattered in the angular range between 2.5° and 4.5°, with energy between 0.5 and 4.5 GeV, corresponding to an average Q^2 of 0.1 GeV^2. The degree of linear polarization will vary between 10 and 65%. The expected rate of hadronic events, at the CLAS12 nominal luminosity ($10^{35} cm^{-2} s^{-1}$), is about 7 KHz: this corresponds to an equivalent photon flux of about $5 \cdot 10^7\ \gamma/s$, for a "traditional" photo-production experiment employing a 40 cm-long LH_2 target. This value is comparable to the photon fluxes of present real photo-production experiments, such as GlueX at Jefferson Laboratory.

2 Jefferson Laboratory

The Thomas Jefferson National Accelerator Facility (TJNAF or JLab) houses the Continuous Electron Beam Accelerator Facility (CEBAF), a high-current, high-duty cycle electron beam machine. CEBAF is composed by two linear accelerators, each adding to the electrons up to 0.4 GeV per pass, and two sets of recirculating arcs. The electron beam circulates up to five times in the accelerator to reach the maximum energy. Multiple and independent beams, with different energies and currents, can be sent to the experimental halls. JLab is currently undergoing an upgrade of the accelerator and of the existing experimental Halls (Hall A, B, and C), while a new experimental Hall (Hall D) is being constructed. The accelerator upgrade will preserve the present race-track configuration, with an increase of the maximum beam energy that will reach 11 GeV for Halls A, B and C and 12 GeV for Hall D.

As part of the JLab 12-GeV upgrade, the existing CLAS detector in Hall B will be upgraded to CLAS12 [2, 3]. The detector is designed to perform experiments using high energy electron beam impinging on polarized and unpolarized targets at luminosities up to $L = 10^{35}\ cm^{-2}\ s^{-1}$. CLAS12 consists of two parts, a Forward Detector (FD) and a Central Detector (CD): the Forward Detector will detect and identify charged and neutral particles scattered between 5° and 35°, in the full momentum range, while the Central Detector is meant to measure charged hadrons and neutrons in the angular range from 35° to 125° and momenta lower than 1.5 GeV/c.

3 The Forward Tagger Facility

The Forward Tagger Facility will extend the CLAS12 nominal acceptance for electrons in the angular range between 2.5° and 4.5°, thus permitting to perform low Q^2 experiments by detecting the scattered

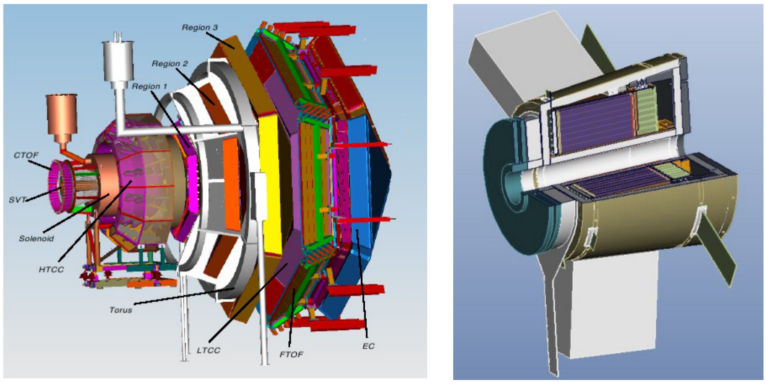


Figure 2. Left: the CLAS12 detector. Right: CAD view of the Forward Tagger Facility, showing the $PbWO_4$ crystals (purple), the FT-Hodo layers (gray), and the FT-Trck planes (cian).

electron in the aforementioned kinematic range. The facility will be made of a calorimeter (FT-Cal), to identify the electron, measure the energy, and provide a fast trigger signal, a tracker (FT-Trck), to measure the scattering angles, and a scintillation counter (FT-Hodo), to provide e/γ separation. The Forward Tagger will be placed within the CLAS12 setup, at about 190 cm downstream of the target nominal position.

3.1 FT-Cal

The FT-Cal is the "core" of the Forward Tagger Facility. The design is an homogeneous calorimeter based on $PbWO_4$ scintillating crystals. Due to the expected high rate from electromagnetic background, of the order of 200 KHz in the energy range of interest, the calorimeter will be highly segmented in the transverse direction to maintain each channel at a sustainable readout-rate. The size of each crystal will be 1.5x1.5 cm^2, comparable with the characteristic transverse size of the electromagnetic shower to contain the signal induced by incident electrons to few crystals. The light from each crystal will be collected by a Large Area Avalanche Photo Diode (LA-APD), with active area of 10x10 mm^2, whose signal will be readout trough a custom transmipedance preamplifier. The detector design was supported by dedicated characterization of all the sub-components. Small scales prototypes were also realized and the response to cosmic muons and high-energy electrons measured, to validate the technical choices and demonstrate the detector operation feasibility. A detailed Monte-Carlo simulation of the detector was developed, tuning the parameters to fit the experimental results obtained with the prototypes. The simulation was then used to estimate the detector energy resolution, which resulted to be $\frac{\sigma_E}{E} = 2.3\%/\sqrt{E} \oplus 0.5\%$.

3.2 FT-Hodo

The primary aim of the FT-Hodo is to discriminate between photons and electrons hitting the FT-Cal, both producing electromagnetic showers. Electrons are identified by observing the presence of a hit in the hodoscope which is correlated in position and time with a signal in the calorimeter. The design foresees two layers of plastic scintillator tiles covering the FT-Cal. The high segmentation and the limited space available precludes the use of standard light guides for the readout. Instead, the FT-hodo design foresees wavelength shifting fibers (WLS) embedded in each tile, twisted on it to increase the optical coupling with the scintillator. Silicon Photo-Multipliers (SiPM) will be employed for the readout. The front-end electronics was specifically designed, allowing each photo-detector gain to be independently tunable, while providing the same bias voltage to groups of 8 SiPMs to minimize the number of power channels. For effective operation, the FT-Hodo timing resolution has to be enough to make a coincidence between calorimeter and hodoscope hits with a sufficient low rate of accidentals. The FT-Hodo expected timing resolution is about 1 ns, comparable with the corresponding FT-Cal resolution of about 300 ps.

3.3 FT-Trck

The FT-Trck provides reconstruction of polar and azimuthal angles for the electrons hitting the FT-Cal. These particles, having non-zero transverse momentum, are rotated in the transverse plane by the CLAS12 solenoidal field while propagating from the target to the Forward Tagger. The 3-momentum direction is reconstructed from the measured hit position, accounting for the rotation between the production vertex and a tracking plane placed in front of the calorimeter. The FT-Trck is made of two double-layers of Micromegas detectors, located in front of the FT-Hodo. The use of two layers results from a compromise between efficient background rejection and track reconstruction with a low material budget. Each layer is composed of two single Micromegas detectors with strips oriented perpendicular one respect to the other, such that the (X,Y) coordinates of a track can be determined. The angular resolution of the detector is determined by the size of the readout strips: for 500 μm strips a spatial resolution of $\simeq$ 144 μm is expected, roughly corresponding to 1.7% and 2.8° resolution on θ and ϕ.

4 Conclusions

The Forward Tagger facility in Hall B at Jefferson Laboratory will permit to perform low Q^2 experiments, by tagging low angle scattered electrons. Hadrons in the final state will be measured in coincidence with the CLAS12 detector, with a large acceptance and high resolution. The unique combination of the two detectors will permit to carry out a broad physics program, mainly focused on meson and barion spectroscopy, and to explore new possibilities for high quality physics beyond the already approved program. The different components of the Forward Tagger facility are presently under construction and are expected to be installed in 2015, ready for the commissioning and beginning of data taking in Hall B.

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