A quasi-real photon tagger for CLAS12

D I Glazier[a,*], on behalf of the CLAS collaboration

[a]*School of Physics and Astronomy, University of Edinburgh, JCMB, Kings Buildings, Edinburgh, UK*

Abstract

The planned energy upgrade of the Jefferson Lab electron beam to 12 GeV will enable a host of different physics topics to be explored. The CLAS detector will undergo a corresponding upgrade to focus the detector systems in the forward angle region. As part of this CLAS12 project, a forward "quasi-real" photon tagger is being developed. This device will measure the scattered electrons with kinematics consistent with low Q^2 virtual photons. Such a system will enable a full reconstruction of the photoproduction of many poorly understood hadronic states, for example hybrid meson, cascade and Ω^- states. Investigation of these states will provide a much needed examination of our understanding of QCD in the nonpeturbative regime.

Keywords:

1. Introduction

The spectroscopy of hadrons is a crucial tool for studying the theory of the strong interaction, QCD, in the non-perturbative regime. The 12 GeV upgrade of the CEBAF electron beam at Jefferson Lab will provide an excellent opportunity for spectroscopy of hadronic states. The complementary upgrade of the CLAS (CEBAF Large Acceptance Spectrometer) detector systems, maintaining the characteristic large acceptance coupled with excellent particle identification and momentum reconstruction, are an important requirement of hadron spectroscopy experiments where several particles must be measured in the final state and intermediate particles reconstructed. To take full advantage of the high production rates at small electron scattering angles an additional piece of equipment is being developed, to detect scattered electrons between 2 and 5°. Such small scattering angles will tag almost real virtual photons with $Q^2 < 0.1$ (GeV/c)^2, i.e. a quasi-real photon tagger. The expected CLAS12 luminosity of 10^{-35} cm^{-2}s^{-1}, will give a tagged photon rate equivalent to 10^7 s^{-1}, competitive with fluxes attainable using tagged bremsstrahlung beams, such as that being developed for the GlueX experiment at JLAB.

The design of the forward tagger is constrained by a combination of both hardware and physics. The device must be able to operate in high magnetic fields with high electromagnetic backgrounds. It must also reconstruct the electron with sufficient accuracy to discriminate between similar final states and determine the plane of linear polarisation of the photon.

2. The JLAB upgrade and CLAS12

The new CLAS12 design will expand on many of the features of the current CLAS spectrometer. In the forward angle regions ($\theta < 40°$) the CLAS12 detector systems, shown in Fig. 1, will measure charged particles bent in a toroidal field. This leads to a 6 segment structure, to accommodate the superconducting magnet coils, with identical detectors in each segment. The new design will provide improved particle identification and resolutions, necessary for determining exclusive final states in the high hadron multiplicity reactions that will be produced by the intense 12 GeV beam. To determine charged particle momentum 3 layers of drift chamber will be used to measure the track through the magnetic optics. Time of flight scintillators will be used to measure the particle β. The existing CLAS electromagnetic calorimeter, comprising of 3 stereo readout planes of lead scintillator sandwich, orientated at 120°, will be used to measure electron and photon energies up to the highest particle momenta. This will be augmented with a pre-shower calorimeter, with greater spatial resolution, to improve separation of the 2 photons from a π^0 decay up to 9 GeV/c. Additional particle

*Speaker
Email address: `dglazier@ph.ed.ac.uk` (on behalf of the CLAS collaboration)

identification will be supplied by high and low threshold Cerenkov counters and RICH detectors. The region between $40-135°$ will be covered by the components of the central detector, featuring a solenoid magnet which is also critical for focusing Moeller electrons along the beamline, away from the forward detector. The detector will be responsible for measuring recoil baryons in electron scattering and hadron production reactions. A combination of Silicon and Micromegas tracking detectors will be used for momentum and vertex reconstruction, while the time of flight will be measured with a scintillator barrel.

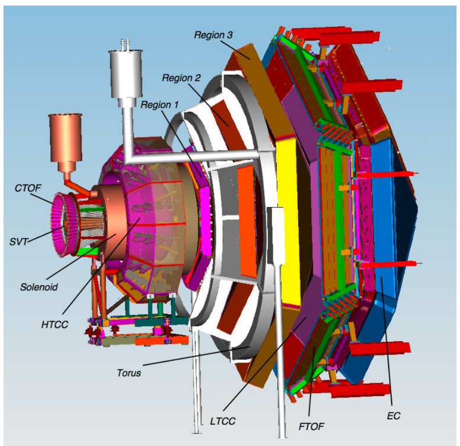

Figure 1: The CLAS12 detector system

3. The Forward Tagger

The proposed technique for producing a beam of linearly polarised photons is to use virtual photons with low Q^2, ($<$ 0.1 (GeV/c)^2), which can be considered "quasi-real" with the electron scattering plane defining the linear polarisation plane of the photon. To measure virtual photons with such low Q^2 requires detection of the scattered electron at very forward angles, less than $5°$. The proposed scheme for performing this involves 3 components: a tracker to accurately determine the scattering angle and plane, the latter being particularly important when utilising the linear polarisation; veto detectors to separate electrons from photons; and an electromagnetic calorimeter to determine the electron energy. Accurate determination of the scatter angle and energy are important to allow missing mass techniques to be used in determining unambiguous final states, as well as the degree of linear polarisation for the event.

All components are currently at the design stage. It is foreseen that the tracking will be accomplished by Micromegas detectors similar to those proposed for the central detector tracking. The most likely solution for the veto detectors is scintillator tiles with light read out through fibre optic cables. The most substantial component will be the calorimeter. It must be able to operate in a high radiation and magnetic field environment and provide sufficient energy resolution to resolve the different final states and fast enough timing to correlate timing coincidences with the main CLAS12 detectors. Current investigations show a segmented wall of $PbWO_4$ crystals would meet our requirements.

The calorimeter will consist of 408 crystals with dimensions $15 \times 15 \times 200$ mm, arranged in a hexagon and placed 1.8 m from the centre of CLAS12. This will cover the angular range $1.8-5.2°$ and tag approximately 70% of hadron production events. Fig. 2 shows a visualisation of the calorimeter as part of the full CLAS12 GEANT4 simulation. The position and dimensions are constrained by the planned CLAS12 detectors and supports. A tungsten pipe through the centre will shield the crystals from the beam halo, while a tungsten/Carbon fibre Moeller shield, will protect the detector from background produced in the hydrogen target by the electron beam. The main source of background is from Moeller scattering and results of simulations show this rate to be around 10 MHz over the whole detector, for the expected CLAS12 luminosity of 10^{-35} cm^{-2}s^{-1}. This provides a maximum dose of around 1 rad/h for crystals near the beamline, which would result in tolerable radiation damage, additionally $PbWO_4$ can be treated for radiation damage with infra-red light and it is proposed to illuminate the crystals online using optical fibres. Almost all of this rate is from electrons with energies below 0.7 GeV and in general they should not interfere with our signal electrons in the range 0.5 – 4 GeV and they will be rejected offline with a coincidence time cut of a few ns with the rest of CLAS12 as there are no hadrons from such events to reach the detectors.

The main coincident background in the forward tagger, also producing hadrons in CLAS12, will be from radiative elastic electron scattering, $p(e, e'\gamma)p$. Rate estimates for this process are around 80 kHz over the signal range 0.5 – 4 GeV and 230 kHz over the full energy range. The total inelastic rate on the forward tagger is expected to be around 8.5 kHz. With these rates it will be possible to separate the elastic and inelastic events with a timing cut of a few ns. In addition, a cut on particle multiplicity in CLAS12 should eliminate these events.

The characteristics of $PbWO_4$ that make it suitable to operate at high rates are its radiation hardness and small Moliere radius (2.1 cm), which limits the number of crystals hit per electron. Its small radiation length of 0.9 cm allow a small enough volume to fit the available space in the forward region of CLAS12. Its fast timing (τ = 6.5 ns) reduces pile-up effects and gives a timing resolution for an event of around 2 ns. The energy resolution achievable, particularly when cooled, is expected to be better than 5% which will allow good separation of final states using missing mass techniques.

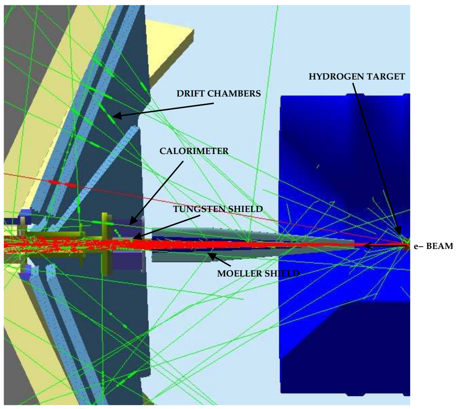

Figure 2: The forward tagger calorimeter included in the full CLAS12 GEANT4 simulation. Red lines show electrons, green photons

4. Some Hadron Spectroscopy

The nonperturbative regime of QCD remains somewhat obscure from both theoretical and experimental perspectives, and our understanding of the strong interaction incomplete. Nonperturbative QCD is the realm of hadrons; baryons and mesons. Currently the spectrum of both is uncertain, indeed even the types of both hadrons and mesons allowed is not established. For example the existence of pentaquark baryon states is still hotly debated and measurements of hybrid mesons are not yet conclusive. The priority for measurements with the forward tagger will be to ascertain a more complete picture.

4.1. Meson Spectroscopy

A complete mapping of meson states between 1 – 3 GeV will be particularly important for understanding the QCD quark confinement mechanism. QCD predicts a number of states outwith the quark model; for example glueballs, hybrids, tetraquarks [1, 2]. Hybrids include excited gluonic constituents, an excited flux tube joining two quarks would additionally contribute its quantum numbers to the mesonic state. Some of these hybrid states can have quantum numbers which are not allowed in the quark model and are therefore regarded as exotic. Measurements of meson states with exotic quantum numbers will therefore help establish the spectrum of hybrid mesons, providing a sensitive test for gluon dynamics and the QCD confinement mechanism. Evidence for an exotic $\pi_1(1600)$ exists from pion production experiments at Brookhaven for both the 3π [6, 7] and $\eta'\pi$ [8] final states, although subsequent analysis found no evidence for the 3π signal [10]. The VES collaboration also found evidence of a signal in the $\eta'\pi$ final state.

In photoproduction hybrid mesons are thought to be produced in a t-channel meson exchange mechanism, moreover their production rate should be comparable to that of regular mesons [3, 4, 5]. However, results from a recent paper from the CLAS collaboration [11], are indicative of a smaller production rate. With the forward tagger at CLAS12 we will be able to expand on this measurement and be able to perform meson spectroscopy for a large variety of states in the 1 – 3 GeV range and for different decay channels. We will also benefit from the linear polarisation of the beam. The linear polarisation filters the naturality of the exchanged meson. In this way normal mesons, produced by natural parity exchange and exotic mesons, by un-natural exchange, can be separated giving a cleaner exotic signal. Fig. 3 shows test results of a partial wave analysis on a model of a 3π final state, using Monte-Carlo events tracked through the CLAS12 detector. The generator model contained 5 isobar channels, including an exotic $\pi_1(1600)$. The plots show the fit results for the $\pi_1(1600)$ wave in black and an additional wave in the fit with opposite parity in green. The top plot with zero linear polarisation shows some leakage into the opposite parity wave, whereas the bottom plot with a linear polarisation of 1, results in only the true exotic wave.

4.2. Cascade Physics

The cascade baryons, Ξ, are members of the SU(3) octet and decuplet with 2 strange quarks. Most models predict a similar number of Ξ resonances as nucleon resonances, however only 11 are known of which only 2 are established with the PDG 4 star rating and 4 with 3 stars. Experimental determination of the quantum numbers of these states are also poorly established. Phenomenological model predictions of Ξ^* states and their properties are not in good agreement [12].

There are several advantages to measuring the Ξ^* spectrum; (i) the 2 strange quarks have heavier masses than the light quarks which reduces the uncertainty in lattice calculations of their mass and also gives faster calculations, (ii) the widths (around 20 MeV) are much

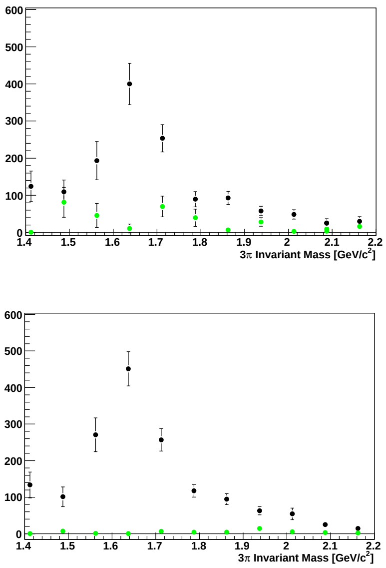

Figure 3: Results of Monte Carlo partial wave analysis, for $\pi_1(1600)$ wave in black. Green is for a similar wave but with opposite parity. Top for zero linear polarisation, bottom linear polarisation of 1.

narrower than for N^* resonances, (iii) the detached decay vertices and presence of two kaons in the final state give a clear signature for the Ξ allowing a straightforward separation from background. As the states are narrow and therefore separated, spin and parity can be determined from Byers-Fenster or Button-Schafer analysis, rather than a more complicated partial wave analysis. Particular aspects of interest, in cascade spectroscopy include; the possible existence of parity doublets (states degenerate in mass but with opposite parity) indicating the restoration of chiral symmetry in highly excited hadronic states, determination of the u-d quark mass difference and possible exotic cascades, e.g Ξ^{--} and Ξ^{+} pentaquark states.

Recent results from the CLAS collaboration show the feasibility for photoproducing and measuring cascades [13]. A Ξ^* programme within the CLAS12-forward tagger should allow determination of the excited states up to 3.4 GeV, benefiting from the higher cross section for $7 < E_\gamma < 10.5$ GeV and an increase in luminosity.

4.3. Ω^- : The Strangest Baryon

The Ω^- baryons, with 3 strange quarks, can be produced in association with three kaons in photoproduction reactions. The advantages given for cascade spectroscopy also apply to the Ω^-, but even less is known about the excitation spectrum and indeed even the quantum numbers of the ground state have not been determined in a model independent analysis. Another interesting aspect of the photoproductions reaction would be a study of the reaction mechanism itself as none of the constituents of the produced Ω^- could have existed in the initial proton. The mechanism is therefore likely to be quite specific. Production rates for the Ω^- with CLAS12 and the forward tagger are estimated to be around several hundred and hour, while the detection efficiency when determining the full final state should be around 5%. Such levels should allow measurement of the cross section and quantum numbers, through analysis of its decay to ΛK^-, within a few months of beamtime. It may also be possible to investigate some excited states.

5. Conclusions

The upgrade of the electron beam at Jefferson Lab. to 12 GeV, together with the complementary CLAS12 detector systems, will allow measurements to be made on many aspects of hadron spectroscopy, such as hybrid mesons, cascades and Ω^-. To take full advantage of these prospects an additional detector system must be realised; a forward quasi-real phototon tagger. Measuring scattered electrons at less than 5° will essentially provide a high intensity beam of linearly polarised tagged photons in the energy range $7 < E_\gamma < 10.5$ GeV, an ideal tool for investigating hadron physics.

Acknowledgements

D.G. would like to thank the LPTA-Montpellier for hospitality.

References

[1] N. Isgur and J. Paton, Phys. Rev. D **31** (1985) 2910 .
[2] N. Isgur, R. Kokoski and J. Paton, Phys. Rev. Lett. **54** (1985) 869 .
[3] A. Afanasev and P. R. Page, Phys. Rev. D **57** (1998) 6771 .
[4] A. Afanasev and A. Szczepaniak, Phys. Rev. D **61** (2000) 114008 .
[5] A. Szczepaniak and M. Swat, Phys. Lett. B **72** (2001) 516 .
[6] G. Adams *et al.*, Phys. Rev. Lett. **81** (1998) 5760 .
[7] S. U. Chung *et al.*, Phys. Rev. D. **65** (2002) 072001 .
[8] E. Ivannov *et al.*, Phys. Rev. Lett. **86** (2001) 3977 .
[9] Y. Khokhlov *et al.*, Nucl. Phys. **A663** (2000) 596 .
[10] A. Dzierba *et al.*, Phys. Rev. D **73** (2006) 072001 .
[11] M. Nozar *et al.*, Phys. Rev. Lett. **102** (2009) 102002 .
[12] Y. Oh, Phys. Rev. D **75** (2007) 074002 .
[13] L. Guo *et al.*, Phys. Rev. C **76** (2008) 025208 .