Meson Spectroscopy using Electron Scattering at Very Small Q^2 in CLAS

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A LETTER OF INTENT

Abstract

Jefferson Lab offers an excellent opportunity to undertake the study of meson spectroscopy at intermediate energies. We intend to perform meson spectroscopy using a very forward electron tagger (FET) in addition to CLAS, in Hall B. Electron scattering at very small angles (i.e., scattering angles of about 1° using unpolarized electrons) is equivalent to photoproduction using partially linearly polarized photons. Linearly polarized beams are very helpful in the partial wave analysis (PWA) of the meson final states. We will study mesons with masses ranging from 1 to 2 GeV produced using electrons (effectively photoproduction) incident on a liquid hydrogen target. Our PWA will concentrate on the study of exotic and strangeonia mesons. We will study reactions having up to three charged particles in the final state, of the form: $\gamma^* p \to p\phi^* \to pKK^*$ or $p\phi\eta$, where ϕ^* represents radial excited states of the ϕ meson. Similarly exotic mesons will be studied in multi-particle final states, for example, $\gamma^* p \to nX \to n\eta'\pi$ or $\to n\pi\pi\pi$, where X represents exotic mesons. The proponents will

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have main responsibilities in the design and construction of the FET detector.

1 Introduction

The study of hadrons lying in the mass region between 1 to about 2 GeV is particularly important for the understanding of the strong interactions, Quantum Chromodynamics (QCD). QCD based theoretical models predict hadrons lying outside the scope of the constituent quark model, in particular the existence of multi-quark and hybrid hadrons as well as purely gluonic states [1]. Gluons play a central role in strongly interacting matter – quark confinement is a consequence of self-interacting gluons.

A fundamental experimental signature for the presence and dynamics of gluons is the spectrum of gluonic excitations of quarkonia (hybrid mesons), i.e. $q\bar{q}g$ systems. The identification of hybrid states from the normal quarkonia spectrum is of fundamental importance in QCD phenomenology. Irrefutable evidence for mesons beyond the constituent quark model would be the discovery of states with exotic quantum numbers ("exotic hybrid mesons") $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}$, etc. since a $q\bar{q}$ pair cannot form a spin-parity state with such quantum numbers [2, 3]. Determination of the properties of such states sheds light on the underlying dynamics of quark confinement [4].

It has also been suggested, within the context of the flux-tube model, that such states should be produced copiously with a photon beam [5]. CLAS photoproduction experiments E99-005 [6] and E01-017 [7], using the CLAS detector in Hall B, have already begun meson spectroscopic studies at Jefferson Lab. Preliminary results of these experiments, as discussed below, show the viability of these studies using the CLAS detector.

To fully understand the meson spectrum, we must catalog all meson states in a given mass range. This is the long term plan of the meson community. Taking into account acceptance and luminosity restrictions of CLAS, we will concentrate in the following reactions of particular importance:

$$\gamma p \to n\pi_1[\to \rho\pi^+] \to n\pi^+\pi^+\pi^-$$
$$\gamma p \to n\pi_1[\to \pi^+\eta'[\to \rho\gamma]] \to n\pi^+\pi^+\pi^-\gamma$$
$$\gamma p \to p\phi*[\to \phi\eta] \to pK^+K^-\eta$$

We will study these channels in CLAS using electron scattering at very small angles, detecting the scattered electron with a forward electron tagger (FET) detector. The advantages provided by such a facility (possibility of relatively higher photon linear polarization at high energies) will improve our ability to determine the quantum numbers through partial wave analysis (PWA), as well as provide information on production mechanisms. The existing real photon tagger system of CLAS will not be available for the $CLAS^{++}$ upgrade. The proposed FET detector will extend CLAS photoproduction studies to higher energies. The construction of this facility before the upgrade will advance its understanding well before its full potential can be exploited with $CLAS^{++}$.

Meson spectroscopy has been identified by the JLab management as the most important physics justification for the accelerator upgrade and the creation of a new experimental Hall (Hall D). An important part of this program can be executed with current energies and facilities. While current conditions are not optimized for meson spectroscopy, the lowest lying hybrids should be produced at the current energies. The energy upgrade is expected until 2011. The present study of meson spectroscopy, as presented in this LOI, will provide a training ground for the crucial expertise needed for future experiments, and provide learning experience to improve the hardware and software necessary for future dedicated experiments.

1.1 Exotic Channels

Low energy QCD suggests that a rich spectrum of hybrid mesons, that is mesons containing gluonic excitations[8, 2]. The clearest evidence for these states would be the identification of states with manifestly exotic quantum numbers, i.e. J^{PC} combinations not accessible by $q\bar{q}$ states, for example $J^{PC} = 1^{-+}$.

Theoretical predictions for the mass of the lightest $J^{PC} = 1^{-+}$ hybrid meson are based on various models. The flux tube model [2] predicts

1^{-+} states at 1.8–2.0 GeV/c^2. Similar results are obtained in the calculations based upon lattice QCD in the quenched approximation [8]. Earlier bag model estimates suggest somewhat lower masses in the 1.3–1.8 GeV/c^2 range [9]. QCD sum-rule predictions vary widely between 1.5 GeV/c^2 and 2.5 GeV/c^2 [10]. The diquark cluster model [11] predicts the 1^{-+} state to be at 1.4 GeV/c^2. Finally, the constituent gluon model [12] concludes that light exotics should lie in the region 1.8–2.2 GeV/c^2. Most of these models predict the dominance of such decay modes of the 1^{-+} isovector hybrid meson as $b_1(1235)\pi$ or $f_1(1285)\pi$, with small (but non-negligible) $\rho\pi$ and $\eta\pi$ decay probability [13, 14].

Currently, only two candidates for such states exist [16, 17, 21, 22, 18, 19]. In particular, in 1998 the E852 collaboration at Brookhaven National Laboratory announced the observation of a $J^{PC} = 1^{-+}$ isovector exotic meson decaying to $\pi^+\pi^-\pi^-$ with a mass of about 1600 MeV [17]. The VES collaboration at Serpukov , however, report a strong $J^{PC} = 1^{-+}$, but no evidence for a state [15]. In 2001, the E852 collaboration [19] presented evidence for the same state, the $\pi_1(1600)$, decaying to $\eta'\pi^-$. The state can be easily seen in the mass plot of figure 1. The same state is seen by the VES collaboration [20], but they fail to clearly identify the wave as a resonance.

It has been suggested within the context of the flux-tube model, that such states should be produced copiously in a photon beam [5, 23, 24]. CLAS photoproduction experiments E99-005 [6] and E01-017 [7], using the CLAS detector in Hall B, have already started meson spectroscopy at Jefferson Lab. Early preliminary results of these experiments, as discussed below, show the viability of these studies using the CLAS detector.

1.2 Strangeonia Channels

Strangeonia are mesons made primarily of $s\bar{s}$ unflavored quarkonia. They are associated with the radial and orbital excited states of the $\phi(1020)$ meson, which is known to be composed of $s\bar{s}$ valence quarks. We will study strangeonium states with masses ranging from 1 up to about 2.0 GeV. These states will be studied via the reactions:

$$\gamma^* \; p \rightarrow \phi^* p \rightarrow K\bar{K}p$$

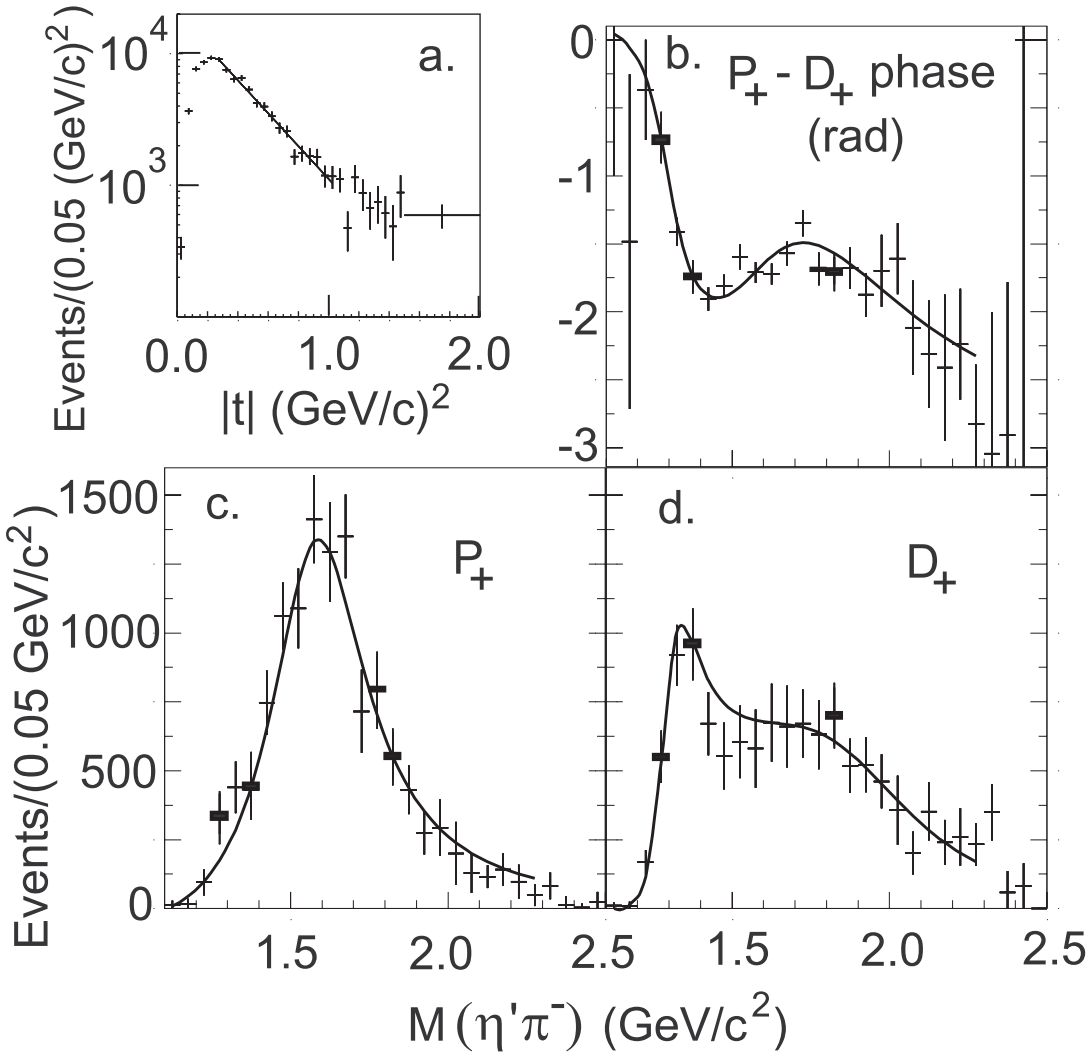

Figure 1: $\pi_1(1600)$ decaying to $\eta'\pi^-$ in E852 at BNL

$$\gamma^* \ p \rightarrow \phi^* p \rightarrow [K\bar{K}^* + \bar{K}K^*]p$$
$$\gamma^* \ p \rightarrow \phi^* p \rightarrow \eta\phi p$$

where ϕ^* represents the excited strangeonium states . Those final topologies are predicted, by strong decay models, to dominate the excited $s\bar{s}$ decays. Given that strangeonium states have intermediate masses between the light (up, down) and heavy (charm, bottom) quarkonia, they are very useful in the study of the QCD confinement potential in the transition region between short and large distance. Particularly, $s\bar{s}$ excitations provide a range of quark separations where the confinement potential can be explored from the perturbative to the non-perturbative regimes. This character has been pointed out by Gell-Mann and recently by Barnes, Page and Black [25]: "the similarity between the $s\bar{s}$ spectrum, the light meson $n\bar{n}$ and the heavy $Q\bar{Q}$ systems needs to be understood to bridge the gap between Heavy Quark Effective Theory (HQET) and the light quark world in which we live".

Hybrid exotic mesons will provide a clear signal for the gluonic degree of freedom ($q\bar{q}g$) in the meson spectrum, however, most of the hybrids are expected to be mesons with "normal" quantum numbers. To understand the behavior of the gluon (i.e, confinement) it will be necessary to measure not only the exotics (perhaps necessary only for discovery) but, more importantly, we need to study the full quark-antiquark-gluon spectrum. It is then necessary to understand the full hybrid and glueball (gg) spectra to understand the properties of the gluon field (QCD).

One of the main reasons why hybrid states have not yet been clearly identified is that their masses lie in the range populated by many normal mesons, and mixing of states may be significant. The strangeonium spectra populates precisely the same region as the low mass hybrids. Strangeonia are poorly understood – of the 22 strangeonium states expected below a mass of 2.2 GeV, only 5 are well identified. The clarification of the strangeonium spectra in this mass range is an important and necessary step for the advance of light quark meson spectroscopy.

Predictions for masses and widths of all the $s\bar{s}$ excitations are available within the flux tube model [25], where decays have been calculated in the $^3P_0$ model. However, production mechanisms are not fully understood.

Due to the significant $s\bar{s}$ content of the photon, and the high luminosity beams available, quasi-photoproduction of mesons with significant $s\bar{s}$

production	mass(MeV)	width(MeV)	*experiment*	decay	ref
e^+e^-	1650		DM1	$K_L K_S$	[29]
	1650			K^+K^-	[30]
	1650		VEPP-2M	K^+K^-	[31]
	1680		DM2	K^+K^-	[32]
	1677	102		$K_S K^+\pi^-$.	[33]
	1680	185	DM1	KK, $KK\pi$	[34]
	1657	146	DM2	K^+K^-	[35]
photo-	1748	80	CERN Omega	KK	[26]
	1760	80	CERN WA57	KK	[36]
	1726	121	Fermi E401	KK	[37]
	1753	122	Fermi FOCUS	KK	[38]

Table 1: Experimental data on the $\phi(1680)$

content are expected to take place with unprecedented statistics at Jefferson Lab. The present study, using 5 GeV quasi-real photons, will focus on $\phi(1680)$ and $\phi(1850)$ production. The $\phi(1680)$, a $2S(J^{PC} = 1^{--})$ radial excitation, has been seen in electro-production [27] and photoproduction [28]. A summary of the current data on the $\phi(1680)$ is shown in table 1.

The interpretation of the current data is not conclusive. Photoproduction and electroproduction experiments have observed different properties of the $\phi(1680)$ decay modes. The mass of the resonance is consistently higher in photoproduction than in e^+e^-. Furthermore, there is no evidence of KK^* decay in photoproduction, however, in e^+e^- this channel is dominant. Figure 2 shows recent high statistics photoproduction data in the K^+K^- channel from the Fermilab FOCUS collaboration.

2 Previous CLAS results (g6)

Experiment E99-005 [6], g6b, ran in August 1999 for 4 days, with real photon beam in the 4.8 to 5.4 GeV energy range. Since the conditions of the experiment were not optimal for meson spectroscopy, the experiment produced very little acceptance in the low $-t$ region. Its extension, E01-017 [7], ran in August-September of 2001 during the g6c running period with the

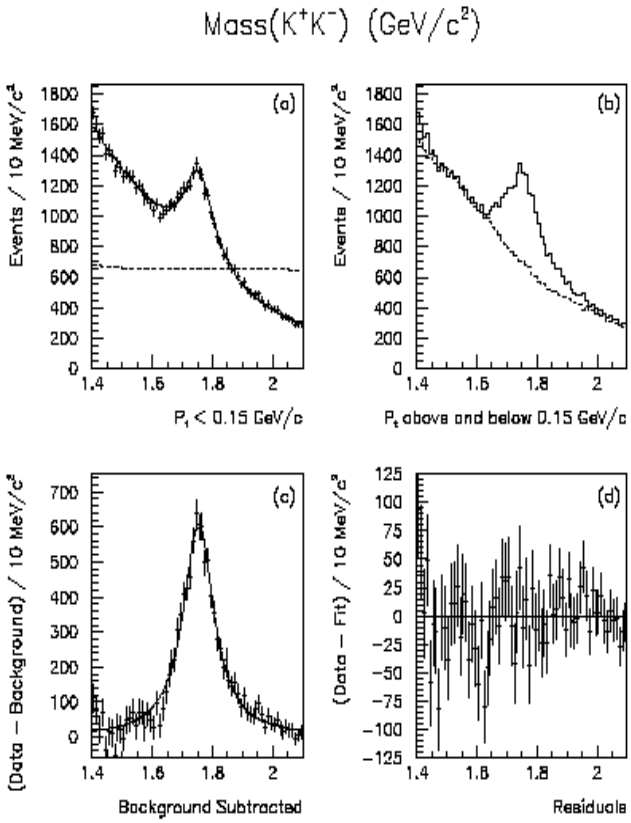

Figure 2: $\phi(1680)$ to K^+K^- mass in photoproduction [38]

photon beam in the same energy range, but with the torus magnet set at half maximum field and the target pulled upstream by 100 cm of its nominal position. These conditions maximized acceptance for meson production at low $-t$.

We have some preliminary results from the analysis of the $g6c$ data. The final states under investigation are written below.

$$\begin{aligned}
\gamma p &\rightarrow \pi^+\pi^- p \\
\gamma p &\rightarrow \pi^+\pi^-\pi^0 p \\
\gamma p &\rightarrow K^+K^- p \\
\gamma p &\rightarrow \pi^+\pi^+\pi^- n \\
\gamma p &\rightarrow K^+K^-\pi^+ n
\end{aligned}$$

As an example of CLAS ability to study multi-particle final states we present some results. While exotic meson studies are concentrated in $\pi\pi\pi$ final states, we also study the reaction $\gamma p \rightarrow p\pi^+\pi^-$ as a test of our PWA program. For the purpose of this study, we have chosen exclusive final states where a π^+, a π^-, and a proton are detected in CLAS. The $\pi^+\pi^-$ invariant mass distribution shows a clear signal at the mass of the ρ and the f_2. The result of a preliminary PWA is shown in Figure 3. The ρ meson is identified as a $J^{PC} = 1^{--}$ state, with s-channel helicity conservation clearly observed, as the ρ signal is dominated by the $|J_z| = 1$ partial wave. There is also some leakage from the $J^{PC} = 2^{++}$ $f_2(1270)$ partial wave into the 1^{--} wave as observed in Figure 3, in the 1^{--} partial wave intensity in the 1.1 to 1.2 mass range. Since the final state is composed of a two pseudoscalars, there are also purely mathematical ambiguous solutions that have not accounted for, but will be incorporated into the analysis as it matures.

Another channel under study is the three charged pion final state in the $\gamma p \rightarrow n\pi^+\pi^+\pi^-$ reaction, where we have detected the three pions in the CLAS and reconstruct the neutron through the missing mass technique. Figure 4 shows the general characteristics for the $\pi^+\pi^+\pi^- n$ exclusive channel. The left plot, shows the $-t'$ distribution. The spectrum is fitted to an exponential function, with the resulting slope of -2.7 GeV^{-2}. The middle plot of the figure shows the $\pi^+\pi^+\pi^-$ mass vs $-t'$. From this figure, the peripheral production of the mesonic system is evident. The right plot of the figure shows the $\pi^+\pi^+\pi^-$ mass spectrum for all $-t'$ and for $-t' < 0.2$ GeV^2. There are two peaks in the spectrum, one around the mass of the $a_2(1320)$,

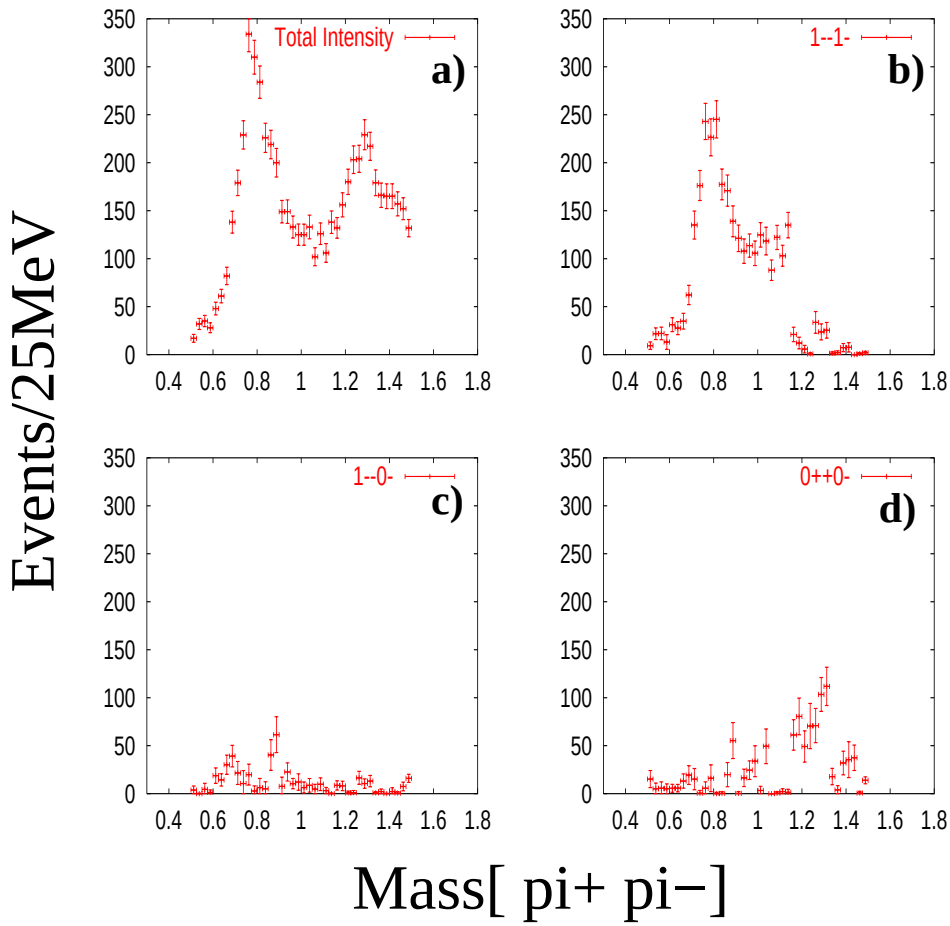

Figure 3: Preliminary partial wave analysis results of the reaction $\gamma p \rightarrow p\pi^+\pi^-$. (a) Total intensity distribution. (b) Intensity for the $J^{PC} = 1^{--}, |J_z| = 1$ wave. (c) Intensity for the $J^{PC} = 1^{--}, |J_z| = 0$ wave. (d) Intensity for the $J^{PC} = 0^{++}$ wave.

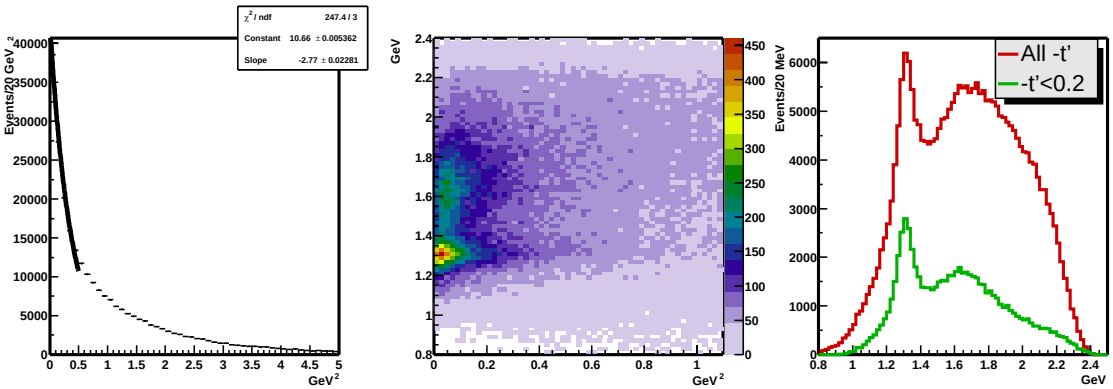

Figure 4: General distributions for the $\pi^+\pi^+\pi^-n$ exclusive channel. Left: $-t'$ distribution. Middle: Correlation between the $-t'$ and the $\pi^+\pi^+\pi^-$ invariant mass distribution. Right: $\pi^+\pi^+\pi^-$ effective mass distribution for all $-t'$ and for the low $-t'$ region.

and a broad one around the $\pi_2(1700)/\pi_1(1600)$ mass.

We expect to have well advanced PWA results in several of these channels at the time of the proposal submission.

$E_{scattered}$	0.8 - 1.2 GeV
θ	0.5^o - 1.2^o
ϕ	$0^o - 360^o$
ν	4.8 - 5.2 GeV
Q^2	0.006 - 0.013 GeV^2
W	3.2 - 3.4 GeV
x_{Bj}	0.0006 - 0.001

Table 2: Kinematics of the proposed FET facility.

3 Electron Scattering at Very Low Q^2

Electron scattering at very small angles, in conjunction with detection of hadronic final states, is a very attractive alternative to real photon experiments. We plan to build a small angle forward electron tagger (FET) to be used in coincidence with detection of multi-particle final states at the CLAS detector to study meson electroproduction at Q^2 of about 10^{-3} GeV^2 (almost real photons). The kinematic range covered by such facility, for 6 GeV incoming electrons, is shown in table 2.

Our flux limitations will come from the CLAS detector's ability, in particular the drift chambers, to handle Moller electron backgrounds. Previous experience with electron beams at similar energies indicates that CLAS can be efficiently operated up to fluxes of 10^{34} cm^{-2} sec^{-1}. The total electroproduction rate expected in our kinematic range and in the entire detector, considering these electron luminosities, is approximately 30 kHz.

Backgrounds to the FET include bremsstrahlung and Moller processes. We used GEANT 3 [39] simulations to evaluate these contributions. The integrated rate in the FET is about 4 MHz. The hadronic backgrounds (from target and beam components) are two order of magnitude lower than the electron contribution. The most important contribution comes from Moller electrons. Calculations using only Moller cross sections, for a luminosity of 10^{34} cm^{-2} sec^{-1}, produce background rates of about 4 MHz in the FET, in agreement with Geant 3 estimates. In the kinematic range covered by the detector, both Moller electrons will hit the FET, producing two clusters with a total energy deposited in the calorimeter of about 6 GeV, i.e. the beam energy. We believe that these backgrounds can be well separated from the

signal *at the trigger level* by requiring clustering and high-energy thresholds in the detector (signal events will deposit 1 GeV in a single cluster).

Electroproduction at very small values of Q^2 (i.e., scattering angles of about 1° using unpolarized electrons) is equivalent to photoproduction using partially linearly polarized photons. Defining [40]:

$$\epsilon = [1 + 2\frac{(Q^2 + \nu^2)}{Q^2}\tan^2(\theta/2)]^{-1}$$

and $\epsilon_L = \frac{Q^2}{\nu}\epsilon$, the polarization density matrix can be written as [40]:

$$\begin{pmatrix} \frac{1}{2}(1+\epsilon) & 0 & -[\frac{1}{2}\epsilon_L(1+\epsilon)]^{1/2} \\ 0 & \frac{1}{2}(1-\epsilon) & 0 \\ -[\frac{1}{2}\epsilon_L(1+\epsilon)]^{1/2} & 0 & \epsilon_L \end{pmatrix}$$

At very low values of Q^2 the virtual photon beam becomes, for all practical purposes, almost a real photon beam, since:

$$\epsilon_L = \frac{Q^2}{\nu^2}\epsilon = 10^{-3}\epsilon \approx 0$$

and there is no longitudinal contribution. Therefore, the above matrix becomes two-dimensional, representing the spin density matrix of real photons. The photon polarization is obtained by measuring the energy and direction of the scattered electron.

Figure 5 shows the values for the linear photon polarization, ϵ, in our kinematic range. The linear polarization of a 5 GeV photon is about 30%.

In summary, virtual ('quasi-real') photoproduction presents an alternative and complementary solution to photon bremsstrahlung beams. The forward tagger registers only photons that produced hadronic interactions, not limiting in principle the beam flux due to accidental triggers. The rate limitation comes from the ability of CLAS to handle the background. Linear polarization of the photon is known in an event-by-event basis, and higher polarizations are obtained near endpoint energies.

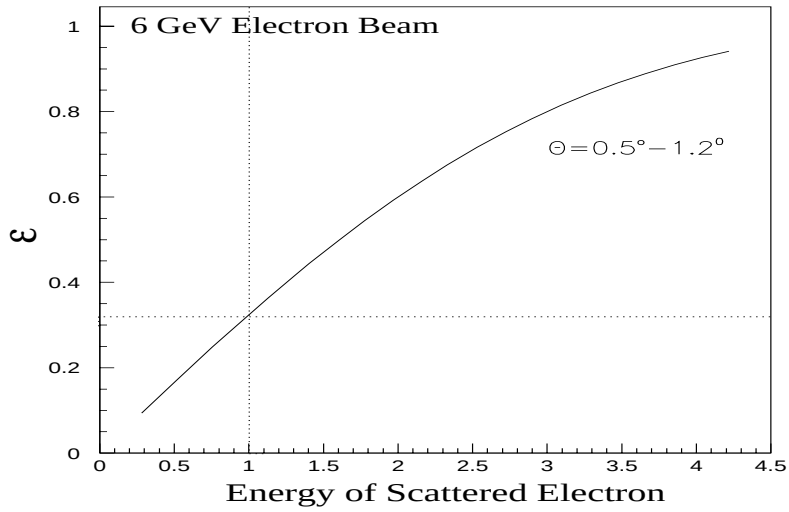

Figure 5: Virtual Photon Polarization

4 Forward Electron Tagger

The forward electron tagger (FET) will be located at about 7 meters downstream of the CLAS target. Its position relative to CLAS is shown in figure 6. The main task of the FET is to measure position (θ, ϕ) and energy of scattered electrons. It should be sensitive in the angular range of $0.5^o \leq \theta \leq 1.2^o$, $0^o \leq \phi \leq 360^o$ and electron energies of 0.5 GeV to 6 GeV. The proposed detector will be a compact device of about 35-cm external diameter and about a meter long, the final dimensions will depend of the final position respect to the CLAS target.

These goals can be obtained by a small magnetic spectrometer or by a calorimeter-based detector. The magnetic options will be more expensive and difficult to implement. We plan to achieve these goals using a cheaper and more efficient crystal-calorimeter and MWPC detector.

The FET detector will consist of high rate MWPC and a calorimeter. The MWPC will be used to measure θ and ϕ of the electrons and to discriminate neutral and charged particles. Triggering and energy deposition will be determined by a high-resolution highly segmented calorimeter. Fig-

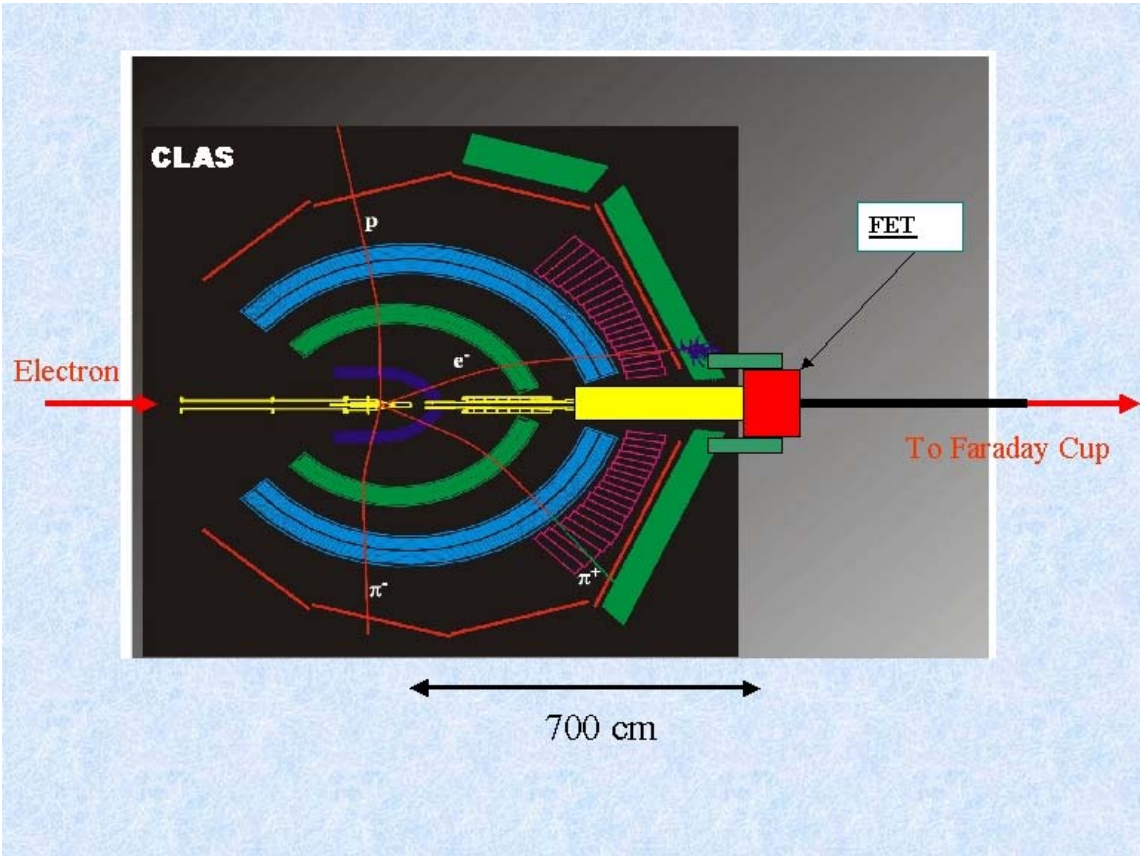

Figure 6: CLAS and the Forward Electron Tagger

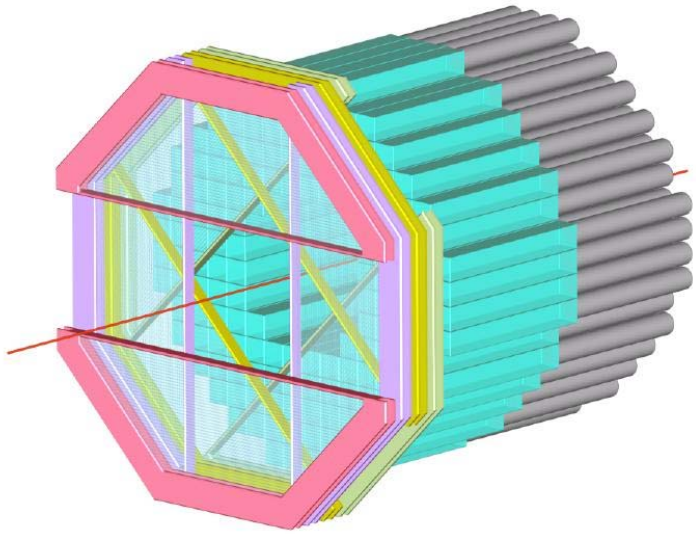

Figure 7: Forward Electron Tagger

year	activity
2003	Feasibility and trigger test (June)
	Full Proposal to PAC24 (July)
	Final design of FET (Summer and Fall)
2004	Construction (Winter, Spring and Summer)
	Beam Tests (Fall)
2005	Data taken and Calibrations
	Calibrations (Fall)
2006	Reconstruction and Analysis
2007	Analysis and Publication

Table 3: Schedule.

ure 7 shows a schematic view of the full FET detector. Our group will assume main responsibility for the design, construction and functioning of the FET detector. The NSU group plans to submit a MRI proposal to NSF to fund the calorimeter construction and triggering electronics, and will be responsible, together with ITEP (Russia) and Jefferson Lab, for fabrication. The FSU and UVA groups will be responsible for the MWPC design and construction. The MWPC construction will follow a design already in use by the Fermilab CKM collaboration [41]. For meson spectroscopy measurements (using missing mass technique), we require a 50 MeV virtual photon energy (ν) resolution (or about 1%). The energy resolution is also important for the measurement of the photon polarization. Given the large lever arm up to the detector and the high resolution of the MWPC, the angular measurements will a small contribution to errors.

We expect to perform a test of a detector prototype by May 2003 (we already have the main components for the test) and then start the final design and construction of the detector by the summer of 2003. We could begin taking data not later than the Fall of 2004. A possible schedule for full project is shown in table 3. This experiment needs to run before the planned Hall B shutdown for the CLAS upgrade, expected for 2006.

5 Running Conditions

The CLAS running conditions for this experiment will be similar to those on the previous g6c run. The running conditions are summarized in table 4. We will run with a $10^{34} cm^{-2} sec^{-1}$ electron luminosity and energy as close to 6 GeV as possible. A 5 cm LH2 target will be used.

The "virtual photon" luminosity ($\mathcal{L}^*$) corresponding to an electron beam luminosity ($\mathcal{L}$) can be obtained by:

$\mathcal{L}^* = \Gamma_S(E, \nu, \theta)\mathcal{L}$

where

$$\Gamma_S = \int\int \Gamma(E, \nu, \theta) d\nu d\Omega$$

$$\Gamma = \frac{\alpha}{4\pi^2} \cdot \frac{E'}{E} \cdot \frac{\nu}{Q^2} \cdot \frac{2}{(1-\epsilon)}$$

and

$$\epsilon = [1 + 2\frac{(Q^2 + \nu^2)}{Q^2} \tan^2(\theta/2)]^{-1}$$

Figure 8 shows the virtual photon rates, with a luminosity of $\mathcal{L} = 10^{34} cm^{-2} sec^{-1}$, versus photon energy ($\nu$). In our kinematical range $\Gamma = 0.000167$, therefore, we obtain $\mathcal{L}^* = 1.67 \cdot 10^{30} cm^{-2} sec^{-1}$ or total photons rates of about 2 x 10^6 Hz.

Our goal is to obtain data samples sufficient for an accurate partial-wave analysis in a number of reaction channels. Running time is determined in order to get enough events in the $\eta\phi$ channel, where observation of a resonance will have very important physics consequences.

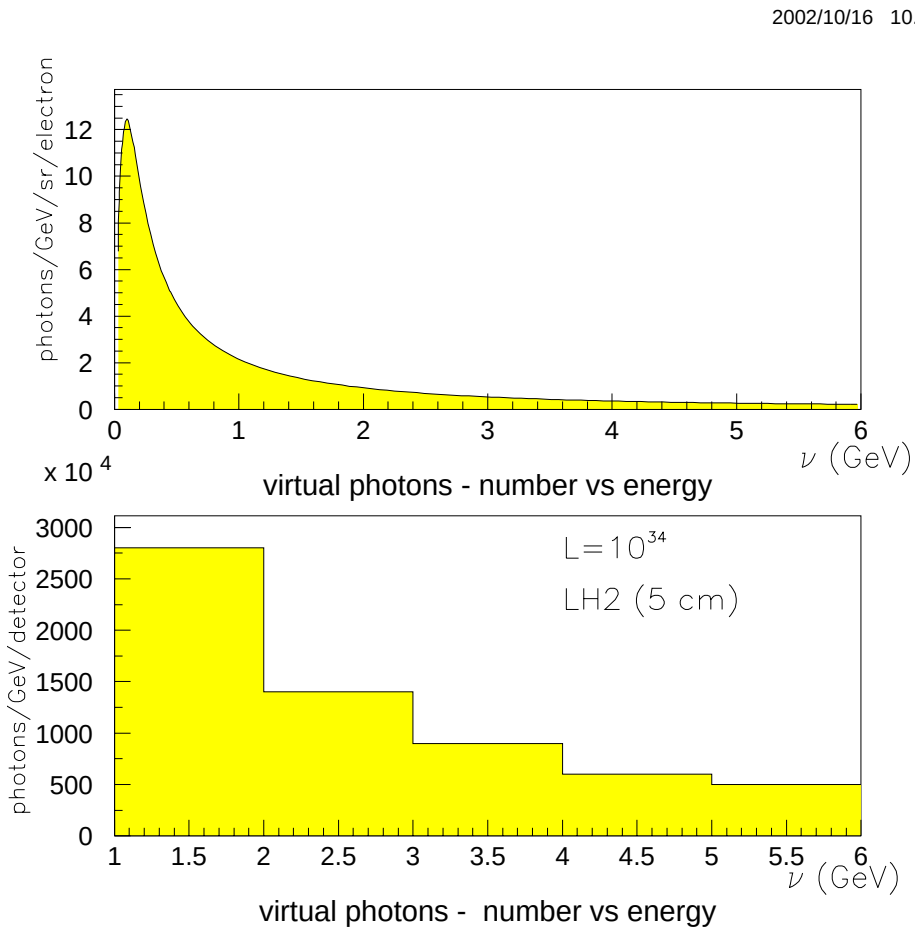

Figure 8: Virtual Photon Flux versus photon energy

E_{beam}	6 GeV - unpolarized electrons
Target	5 cm LH2
B Field	1/2 B_{max}
trigger (CLAS)	2 charged particles, L2
trigger (FET)	0.8-1.2 GeV in FET-CAL, one hit
Daq rate	$\sim$ 3 kHz
Run Time	1000 Hours

Table 4: Running Conditions.

6 Summary

One of Jefferson Lab's most important missions is the study of QCD at intermediate energies. The light-quark meson spectrum provides insight to QCD at the confinement scale. Exotics and strangeonia are as yet not well understood, and they represent the next frontier in meson spectroscopy.

We intend to perform meson spectroscopy in the $1-2$ GeV mass range using linearly polarized virtual photons. The use of linearly polarized photons is critical for identifying the production mechanisms, and simplifies partial wave analysis.

The experiment will be performed using quasi-real photons by constructing a forward electron tagger (FET) detector as an addition to the CLAS. The FET will tag scattered electrons at about 1 GeV and a forward angle of 1°, therefore, with very low values of Q^2 - about 10^{-3} GeV^2. Using this technique, we will obtain linearly polarized photons ($\approx 35\%$) very near the endpoint energy (up to 5.2 GeV). Fluxes are limited by the CLAS ability to handle electron backgrounds, and it is expected to be of about 2 x 10^6 photons per second. The FET will provide a new facility for very low Q^2 physics with CLAS and will take data well before (and during) the planned accelerator ($CLAS^{++}$) upgrade.

References

[1] F. E.Close and P. R. Page, Nucl.Phys.**B443**, 233, (1995).

[2] N. Isgur and J. Paton, Phys. Rev. D **31**, 2910 (1985).

[3] N. Isgur, R. Kokoski, and J. Paton, Phys. Rev. Lett. **54**, 869 (1985).

[4] N. Isgur, Hadron Spectroscopy:An overview with strings attached, proceedings of the BNL Workshop on Glueballs, Hybrids, and Exotic Hadrons, ed. S.-U. Chung, Upton, New York, 1988 (AIP, New York, 1989).

[5] N. Isgur, Phys.Rev. **D60**, 114016, (1999).

[6] G. S. Adams, C.W.Salgado and D.P.Weygand, PAC15 proposal 99-005(1999).

[7] G. S. Adams, C.W.Salgado and D.P.Weygand, PAC19 proposal 01-017(2001).

[8] C. Bernard *et al.*, Phys. Rev. D **56**, 7039 (1997); P. Lacock *et al.*, Phys. Lett. B **401**, 308 (1997).

[9] T. Barnes and F. E. Close, Phys. Lett. B **116**, 365 (1982).

[10] I. I. Balitsky, D. I. Dyakonov, and A. V. Yung, Z.Phys. C **33**, 265 (1986); J. I. Latorre, P. Pascual, and S. Narison, Z.Phys. C **34**, 347 (1987); J. Govaerts *et al.*, Nucl. Phys. B **284**, 674 (1987).

[11] Y.Uehara *et al.*, Nucl. Phys. A **606**, 357 (1996).

[12] S. Ishida, H. Sawazaki, M. Oda, and K. Yamada, Phys. Rev. D **47**, 179 (1992).

[13] N. Isgur, R. Kokoski, and J. Paton, Phys. Rev. Lett. **54**, 869 (1985).

[14] Frank E. Close and Philip R. Page, Nucl. Phys. B **443**,233-254 (1995).

[15] Igor A. Kachaev *et al.*, AIP Conf.Proc.619:577-581,2002 (Hadron 2001).

[16] D. R. Thompson *et al.*, Phys.Rev.Lett. **79**:1630-1633 (1997).

[17] G. S. Adams *et al.*,Phys.Rev.Lett. **81**, 5760-5763 (1998).

[18] S. U. Chung *et al.*, Phys.Rev.D**60**:092001 (1999).

[19] E.I. Ivanov, *et al.*, Phys. Rev. Lett. 86, 3977 (2001).

[20] V. Dorofeev *et al.*, *Proceedings of Hadron2001*, Serpokov, Russia (2001).

[21] A. Abele,*et al.*, Phys.Lett.**B423**:175-184 (1998).

[22] A. Abele,*et al.*, Phys.Lett.**B446**:349-355 (1999).

[23] A. Afanasev and P. R. Page Phys.Rev.D**57**:6771-6777 (1997).

[24] A. P. Szczepaniak and M. Swat, Phys.Lett.**B115**:72-76, (2001).

[25] T. Barnes, N. Black and P.R. Page,"Strong Decays of Strange Quarkonia", Nucl-th/0208072 (2002).

[26] D. Aston, et al., Phys. Lett. 104B, 231 (1981)

[27] D. Bisello, *et al.*, Z. Phys. C52, 227 (1991); J. Buon, et al., Phys. Lett.118B, 221 (1982).

[28] M. Atkinson, *et al.*, Nucl. Phys. B231, 1 (1984).

[29] F. Mane et al., (DM1), Phys. Lett. 99B, 261 (1981)

[30] B. Delcourt, et al., (DM1) Phys. Lett. 99B, 257 (1981)

[31] P.M.Ivanov, et al., Phys. Lett. 107B, 297 (1981)

[32] D. Bisello, et al., (DM2) Z. Phys. C39, 13 (1988)

[33] F. Mane et al., (DM1), Phys. Lett. 112B, 178 (1982)

[34] J. Buon, et al., (DM1) Phys. Lett. 118B, 221 (1982)

[35] A. Antonelli, et al., (DM2) Z. Phys. C56, 15 (1992)

[36] M. Atkinson, et al., Z. Phys. C27, 233 (1985)

[37] J. Busenitz, et al., Phys. rev. D40, 1 (1989)

[38] J.M. Link, et al., (FOCUS) hep-ex/0208027 (2002)

[39] Geant 3, R. Brun *et al.*, CERN (1987). Thanks to P. Degtiarenko for providing his code with the hadronic interactions DINREG code.

[40] N.Dombey, Rev.of Mod. Phys., **41**, 236, (1969).

[41] Fermilab CKM Collaboratioin, High Rate MWPC (private communication) (2002).