Physics with CLAS at Jefferson Lab

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The CLAS collaboration at Jefferson Lab is engaged in a wide range of experiments, covering mostly meson and baryon spectroscopy, nucleon structure through elastic and deep inelastic scattering, nuclear transparency and nucleon correlations in nuclei. These experiments use the CEBAF highly polarized electron beam, or the secondary tagged photon beam, together with the CLAS detector (CEBAF Large Acceptance Spectrometer), to which specific experiments bring additional equipment. In this talk, examples of recent results on subjects mentioned hereabove will be given, with special emphasis on nucleon structure. A short description of the planned upgrade from CLAS to CLAS12 is presented.

1. THE SPECIFICITIES OF CLAS

The CEBAF Large Acceptance Spectrometer [1] has been in operation at Jefferson Lab since 1998. Covering a wide range of experiments, from nucleon structure and spectroscopy to studies of reaction in the nuclear medium, it benefits from the highly polarized (now 85% routinely) electron beam and a tagged photon beam, including a recent capability for linear polarization in excess of 90%. Most experiments now add to the standard version of CLAS a specific equipment in a dedicated run. In the past year, this has been the case for Deeply Virtual Compton Scattering (DVCS) with the addition of an inner calorimeter for small angle photon coverage, of the measurement of neutron structure functions through low momenta spectator proton tagging with a radial time projection chamber, or of the determination of the extended Gerasimov-Drell-Hearn (GDH) sum at very low Q^2 with the addition of a specially designed Čerenkov counter.

CLAS gives access to a large range of x_B (up from 0.15 for $Q^2 > 1$ GeV^2), from the resonance region to the deep inelastic regime. Since 2001, with the advent of the 6 GeV beam, CLAS and other facilities at JLab have a "window" above the resonance region (see Fig. 1) and contribute significantly to the study of (polarized) parton distributions [2]. The combination of high luminosity and large acceptance allows us, for example in the case of hard exclusive measurements, to reach the same or higher Q^2 values as higher energy machines. And finally, the good resolution allows for truly exclusive measurements over a large phase space.

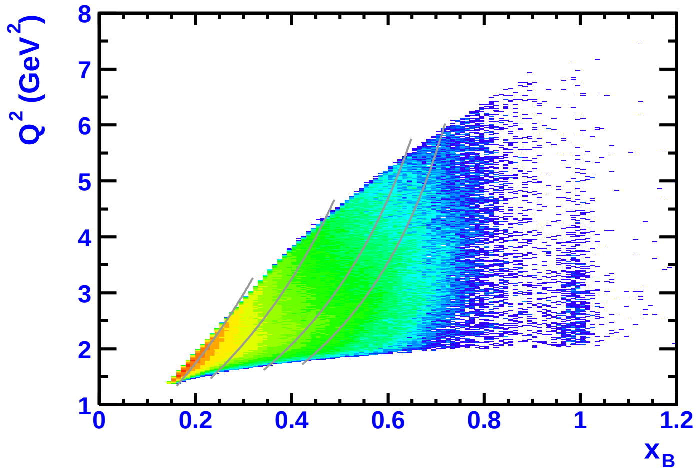

Figure 1. Typical kinematical coverage accessible with a 5.75 GeV beam at CLAS. The lines correspond to constant values of W (from left to right 2.8, 2.4, 2 and 1.8 GeV), illustrating the Jefferson Lab "window" in the deep inelastic regime.

2. NUCLEON TO DELTA TRANSITION

Fits of dynamical pion models to pion photoproduction data in the Δ excitation region suggest that 1/3 to 1/2 of the M1 photocoupling strength at low Q^2 electroproduction is due to meson rescattering at the electromagnetic vertex [3]. In other terms, this process is very sensitive to the presence of a pion cloud around the nucleon. This is also the case for the small E2 and C2 transitions which can now be measured with increasing precision. Lattice QCD has been applied with very good success to the description of these small quadrupole transitions [4] and CLAS is contributing with precise new data in the range $0.15 < Q^2 < 0.4$ GeV^2.

In a separate experiment, the determination of the three transition amplitudes has been extended to $Q^2 = 6$ GeV^2 [5]. The ratio E2/M1 remains small and negative, indicating that helicity is not conserved in this transition, even at these high values of Q^2.

3. THE SEARCH FOR PENTAQUARKS

Following the initial reports for the observation of a narrow resonance Θ^+ characteristic of an exotic pentaquark, including by the CLAS collaboration [6,7], CLAS took high statistics data in two dedicated runs in photoproduction on hydrogen and on deuterium targets. The first results from these runs are just being published. On the deuterium, the same channel used in one of the previous publications was measured with an increase in statistics of a factor 7. The backgound was then much better determined and no statistically significant signal remains. On both hydrogen and deuterium, new channels were investigated, resulting also in very stringent upper limits in the production of such pentaquarks. The CLAS contributions to this field are summarized in Table 1.

Table 1
Experimental searches (expts) for pentaquarks at CLAS. Particles underlined correspond to the decay channel explored. The non-dedicated experiments yielded low-statistics positive observations, while so far the high statistics experiments yield only tight upper limits. Other channels are being explored as well.

Reaction channel	Non-dedicated expts	Dedicated expts
$\gamma d \to \underline{nK^+}K^- p$	[6]	[8]
$\gamma d \to \Lambda \underline{nK^+}$	-	[9]
$\gamma p \to \pi^+ K^- \underline{nK^+}$	[7]	E-04-017 (2008)
$\gamma p \to \bar{K}^0 \underline{nK^+}$	-	[10]
$\gamma p \to \bar{K}^0 \underline{nK^+}$ / $\bar{K}^0 \underline{pK^0}$	-	[11]
$\gamma p \to \underline{pK^+}K^-(\Theta^{++})$	-	[12]
Exotic Ξ^{--}	-	E-04-010 (2005)

4. DEEP INELASTIC SCATTERING

As mentioned earlier, the kinematical coverage of CLAS extends significantly above 2 GeV for the $\gamma^* p$ center-of-mass energy (W up to 3 GeV at small x_B), thus allowing studies of the partonic structure of the nucleon, mostly in the valence quark region.

4.1. Inclusive scattering and parton distributions

Polarized structure functions were measured for x_B up to 0.6, both on proton and deuteron [2]. From these data [13], neglecting antiquark contributions and using evolution only at leading-order, I generated the resulting polarized valence quark distributions $x\Delta u_v$ and $x\Delta d_v$ (see Fig. 2). These results, though obtained with some simplifying assumptions, illustrate the constraints that the JLab experiments bring to these distributions.

The ratio of unpolarized quark distributions $d(x)/u(x)$ at high values of x is very badly determined by existing data. A dedicated effort in this direction was done in 2005 with the BoNuS experiment (E-03-012). Backward emitted spectators protons from the reaction $ed \to e' p_{back} X$, with momenta as low as 70 MeV/c, were detected in a small radial time projection chamber surrounding a presurized deuterium gas target. From this data, structure functions of a quasi-free neutron will be extracted.

4.2. Semi-inclusive scattering (SIDIS)

CLAS data on $p(e, e'\pi)X$ has been analyzed for single spin (either beam or target) asymmetries, with the first objective to test the so-called "naïve" leading-order x-z factorization between quark distributions and fragmentation functions. This factorization seems to be satisfied to a very good degree, which opens the way to a rich phenomenology and to the extraction of quark transverse momentum dependent distributions [16].

4.3. Exclusive reactions and generalized parton distributions

Generalized parton distributions (GPDs) offer a much more complete and unifying description of the nucleon structure than hereto available. GPDs are in principle accessible in the deeply virtual and exclusive production of mesons (DVMP) and of photons (DVCS), where different reactions and observables have a different sensitivity to different GPDs,

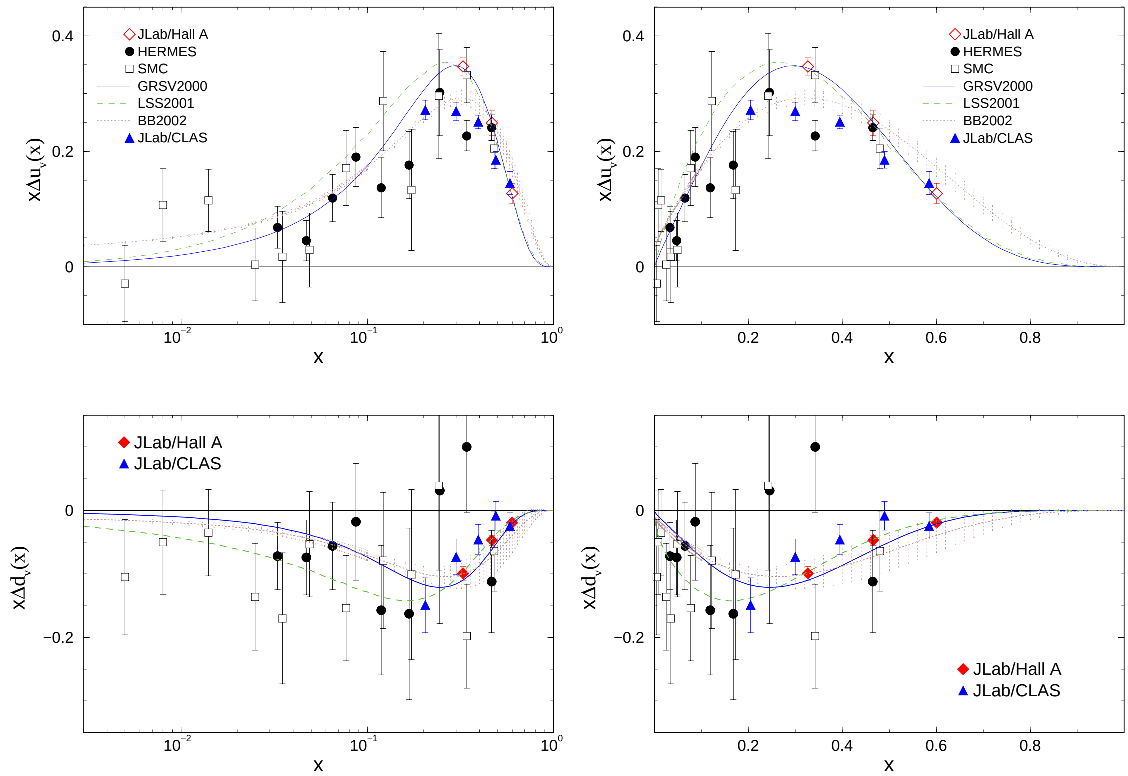

Figure 2. Polarized valence quark distributions (at $Q^2 = 2.5$ GeV^2) from inclusive lepton scattering. The points from CLAS (blue triangles) and from Hall A (red diamonds) were calculated by the author from the data of Refs [13,14]; they are not the official results of these collaborations. See Ref. [15] for references to other data and to parametrizations.

or combinations of GPDs. For a short summary, see e.g. Ref. [21].

The first experiment proposed at Jefferson Lab with GPDs in mind was the electroproduction of vector mesons. A dedicated experiment took place in 2001. The electroproduction of ω mesons was shown to proceed in good part through π^0 exchange in the t channel, for Q^2 as high as 5 GeV^2, and therefore not amenable to a description in terms of GPDs [19]. On the other hand it revealed new features at high values of the momentum transfer t [22]. Preliminary results for the ρ production at 5.75 GeV were shown at this conference. At these energies, ρ production is difficult to separate from baryonic resonance production. Nevertheless these and earlier results [17] are in qualitative agreement with GPD-based models.

Following the observation of a sizeable beam spin asymmetry in $\vec{e}p \to ep\gamma$ [18], of the shape and size anticipated from the interference of Bethe-Heitler and DVCS processes, a dedicated DVCS experiment was designed. In order to be fully exclusive, the photon detection coverage was extended to forward angles with the addition of an inner calorimeter, covering the polar angles 5 to 16 degrees. This calorimeter is built of 424 small tapered lead-tungstate crystals, read-out by avalanche photodiodes. In addition, a specially designed supraconducting solenoid provided a magnetic shield against the low-energy Møller electrons. The experiment ran successfully in the spring of 2005. Since all three final-state particles are detected, several kinematical constraints can be applied, which result in a very clean identication of the $ep \to ep\gamma$ reaction (see Fig. 3). Note however that a small contamination of the $\vec{e}p \to ep\pi^0$ with the neutral pions undergoing a very asymmetrical decay into two photons is always possible even after tight kinematical cuts. Preliminary results (not available for publication at this time) are extremely encouraging. DVCS will now be measured with unprecedented kinematical coverage and high statistics. In combination with the new Hall A results [23] of unprecedented precision, these Jefferson Lab results are likely to represent a landmark in this relatively new field.

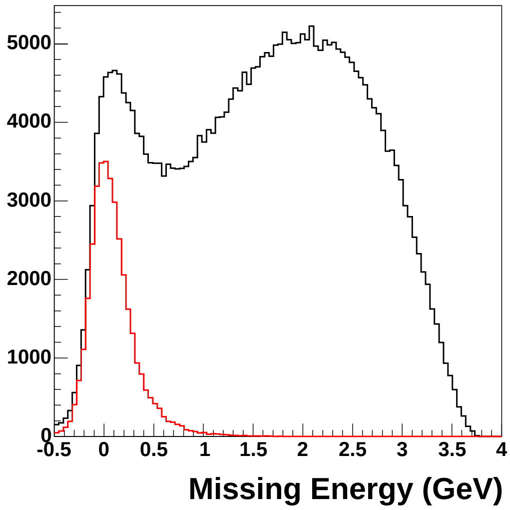

Figure 3. Histogram of missing energy ΔE in the reaction $ep \to ep\gamma X$, from the DVCS experiment with the new inner calorimeter. In black, for all measured $ep\gamma X$ configurations in CLAS. In red, after kinematical cuts on missing transverse momentum and on photon angles. The exclusive $ep \to ep\gamma$ reaction is thus well identified.

Table 2
DVMP and DVCS (beam and target spin asymmetries) experiments at CLAS

Experiments	DVMP	DVCS/BSA	DVCS/TSA
Non-dedicated expts	ρ [17]	[18] + ongoing analyses	[20]
Performed expts	ω [19] ρ/ϕ under analyses	E-01-113 (2005)	-
Planned expts (2008)		E-06-003	E-05-114
Proposed with CLAS12	PR-06-108	PR-06-119	PR-06-119

Two other large statistics runs at 6 GeV beam energy are being prepared for 2008, one on beam spin asymmetry, in the same configuration as the 2005 run and doubling the statistics, another one for longitudinally polarized target spin asymmetry. Whereas the beam spin asymmetry is sensitive essentially to the GPD H, especially at small values of t, the target spin asymmetry has an enhanced sensitivity to the GPD $\tilde{H}$. This is indeed the observation which is made in a recent study based on a non-dedicated experiment (see Fig. 5 in Ref. [20]).

GPD studies will then be one of the primary objective of the CEBAF 12 GeV upgrade, and of the new CLAS12 (see next section). All these experiments on hard exclusive reactions are summarized in Table 2.

5. CLAS12 UPGRADE

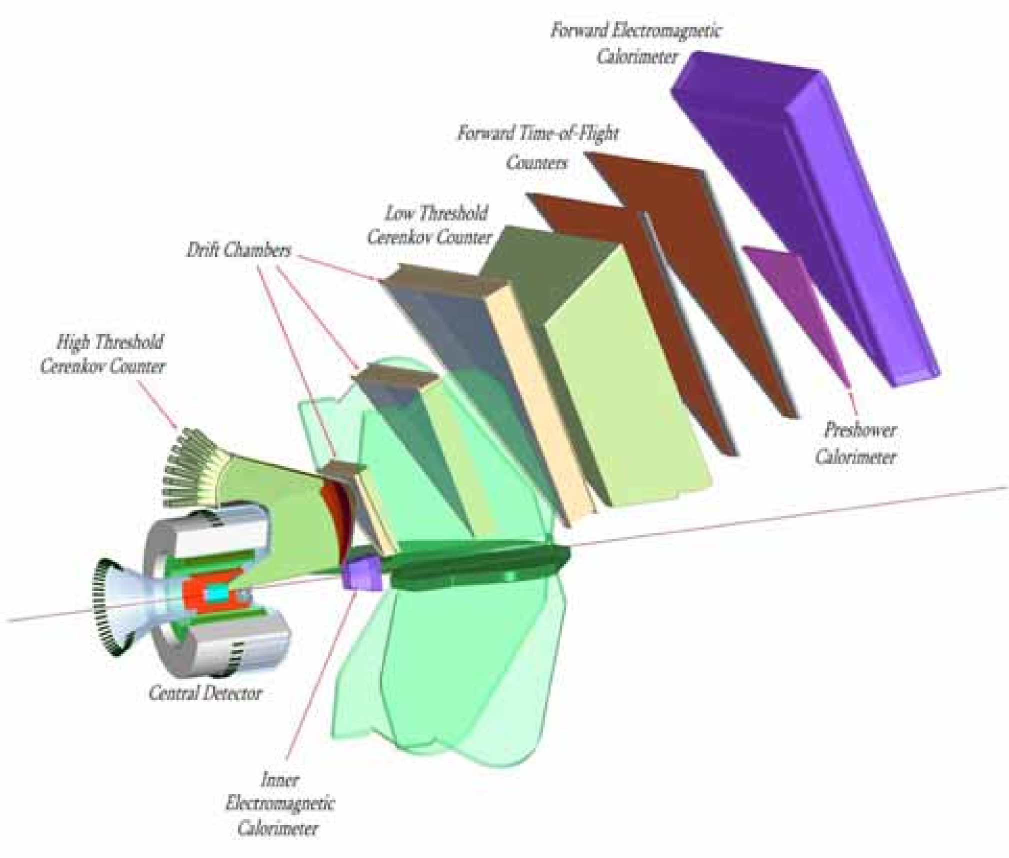

Figure 4. Exploded view of the CLAS12 detector system. For the forward part (to the right), the detection is shown for only one of the six sectors.

The 12 GeV upgrade at Jefferson Lab is on tracks. In addition to the CEBAF accelerator upgrade, a significant part of the project covers the upgrade of existing detectors, or the construction of new ones. CLAS will undergo several changes. The toroidal magnetic configuration will remain, with six sectors, but the coils and detectors will be transformed or rebuilt in order to cover a more forward angle region (5 to 40 degrees). In addition, a central detector will be added, covering the polar angle range from 40 to 135 degrees.

This central detector will include a supraconducting solenoid, for detection of high angle particles and for Møller shielding, and also for use in conjunction with a polarized target. In between the central and the forward detectors, a new high-threshold Čerenkov counter and/or the inner calorimeter for small angle photon coverage will be inserted. Figure 4 gives a schematic view of the new CLAS12 and Fig. 5 illustrates the kinematical range available with an 11 GeV beam.

The first round of proposals for experiments in this new configuration has just been submitted, including DVCS and DVMP (production of pseudoscalar mesons), SIDIS, DIS and parton distributions at high x, studies of high-lying baryonic resonances, short-range nucleon-nucleon correlations and deuteron structure, hadronization and quark propagation in the nuclear medium, color transparency. More proposals will be elaborated in the coming years.

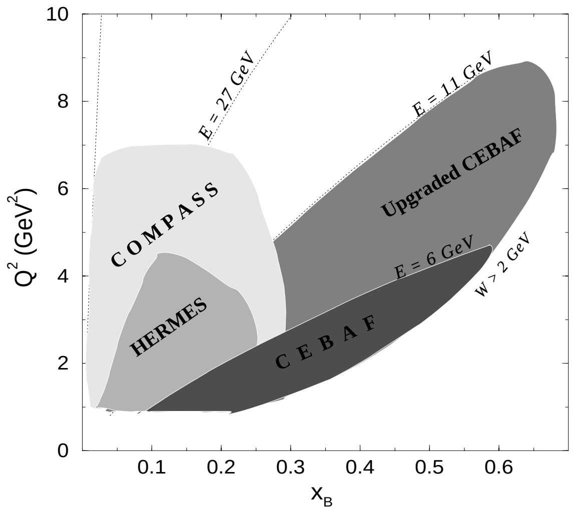

Figure 5. Kinematical coverage accessible with CLAS12 and an 11 GeV beam. In the case of the complementary coverage of COMPASS and HERMES, the extension to higher Q^2 and x_B (here for exclusive, and thus low cross section, reactions) is governed by the available luminosity.

6. CONCLUSION AND PERSPECTIVES

In this brief overview of physics with CLAS, many topics were not covered: meson spectroscopy, "non-exotic" baryon spectroscopy, properties of vector mesons inside the nucleus, short-range nucleon-nucleon correlations, QCD properties such as quark propagation and color transparency, studied in nuclei.

In the immediate future, a good part of the program will be devoted to baryon spectroscopy, through photoproduction experiments using a new frozen spin target. Then, as the CEBAF accelerator resumes its 6 GeV operation in 2008, we will check with much higher statistics our earlier observation of a pentaquark signal on a hydrogen target (see

Table 1) and perform two more dedicated DVCS experiments (see Table 2). After that, a new beam line will be configured to measure two-photon exchange contributions to *ep* elastic scattering using electrons and positrons from photon conversion impinging simultaneously on the same hydrogen target.

Finally, as part of the CEBAF 12 GeV upgrade, the detector CLAS will be upgraded to a new CLAS12. The physics proposals mentioned earlier show the rich program and perspectives which lie ahead of us, as well as the healthy dynamics at work within the CLAS collaboration.

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