JLAB12

M. Aghasyan (Art. 23), A. Courtoy (Ass.), S. Anefalos Pereira (Ass.), E. De Sanctis (Ass.), D. Hasch, M. Hoek (Ass.), V. Lucherini, M. Mirazita (Resp.), R. Montgomery (Ass.), J. de Oliveira Echeimberg (Bors. PD), D. Orecchini (Tecn.), A. Orlandi (Tecn.), J. Phillips (Ass.), S. Pisano (Ass.), E. Polli (Ass.), P. Rossi, L. Trevisan (Bors.), M. Turisini (Ass.), A. Viticchié (Tecn.)

1 Introduction

The Frascati JLAB12 group participates into the physics program carried on by the CLAS collaboration in the Hall B of the Jefferson Laboratory (JLab). The Continuous Electron Beam Accelerator Facility (CEBAF) ran with maximum energy of 6 GeV till may 2012, when it has been shut down to start the upgrade of the facility that will bring the maximum electron energy to 12 GeV. The new CLAS12 spectrometer is also under costruction.

The physics program of the group is focused on the precision study of the three-dimensional structure of the nucleon and its internal dynamics. This is achieved through the determination of new parton distribution functions, the so-called TMDs, which include information not only on the longitudinal but also on the transverse distributions of partons in a fast moving hadron. TMDs can be studied through the measurement of azimuthal asymmetries in Semi-Inclusive Deep Inelastic Scattering (SIDIS) processes, in which one (or more) hadron is detected in coincidence with the scattered electron.

In the period covered by this report, the group has continued to work to the analysis of already available experimental data with 6 GeV and in the *R&D* for the construction of a RICH detector for CLAS12.

2 Transverse Momentum Dependent parton distribution functions (TMDs)

The exploration of the internal structure of the hadrons has undergone enormous progress in the last decades. The Transverse Momentum Dependent (TMD) parton distribution and fragmentation functions [1, 2] are one of the framework to obtain information towards a genuine multi-dimensional picture of the nucleon structure. They are the three-dimensional generalization of the collinear Parton Distribution Functions (PDFs) introduced in the 60s to explain the Deep Inelastic Scattering (DIS) experiments. A major role in the TMD study is played by by Semi-Inclusive Deep-Inelastic Scattering (SIDIS) processes, where in addition to the scattered lepton, also a hadron is detected in the final state. This hadron is generated in the fragmentation of the scattered quark, the so-called Current Fragmentation Region (CFR).

There are eight leading-twist quark TMD distributions. Three of them survive after integration over the transverse momenta: the unpolarized and helicity distributions already introduced in the DIS experiments and the transversity distribution, which is related to transverse polarization of quarks. The other five distributions describe the correlations between the transverse momentum of quarks, their spin and/or the spin of the nucleon and provide a way to access the orbital angular momentum of the partons. Similar spin-orbit correlations arise in the hadronization process of the struck quark into the final hadron, described by TMD fragmentation functions. Besides the unpolarized one, the other relevant TMD fragmentation function is the Collins function [3], representing a correlation between the transverse polarization of the fragmenting quark and the transverse momentum of the produced hadron.

The connection between TMDs and the physics observables was put on a firm theoretical basis with the appropriate factorization proof [4, 5]. The cross section for hadron production in SIDIS processes can be written [2] as a Fourier expansion in the azimuthal angle ϕ of the hadron

$$\sigma \propto \sigma_{UU} + \lambda\sigma_{LU}\sin(\phi) + S_{\parallel}\sigma_{UL}\sin(\phi) + \lambda S_{\parallel}\sigma_{LL} + ... \qquad (1)$$

where λ and $S_{\parallel}$ are the electron helicity and longitudinal nucleon target spin and the labels indicate unpolarized (U) or longitudinally polarized (L) beam or target, the first index referring to the beam and the second to the target. The dots represent other contributions, including transverse polarization (T) terms. The different Fourier components of the cross section, each containing a well defined convolution of distribution and fragmentation functions, can be isolated by measuring beam and/or target spin asymmetries.

TMDs studies are one of the primary goal of experiments at JLab with the 12 GeV electron beam, but their investigation has already started with the 6 GeV beam using unpolarized and polarized targets.

3 Data analysis activity

The data analysis activity has been devoted to the following two main items:

3.1 *Studies of new methodes to extract the TMDs from the experimental data*

The TMDs enter in the observables through convolution integrals that makes their extraction a complicated task. A common way to deal with this problem is to use phenomenological parametrizations of the TMDs (for example, gaussian distributions for their transverse momentum dependence) and to fit them to the experimental data. A different approach is to introduce the so-called weighted asymmetries, defined as

$$A^w = \frac{\int w(\sigma^+ - \sigma^-)}{\int(\sigma^+ + \sigma^-)} \qquad (2)$$

where the weight function w can be appropriately chosen to project out the relevant azimuthal modulation in eq. (1).

In a recent paper [6], Bessel-weighted asymmetries in the Fourier space, conjugated to the outgoing hadron transverse momentum, have been introduced. Besides some other theoretical advantages, the resulting compact expression of the asymmetries is a simple product of Fourier transformed TMDs, that can be now directly extracted from the experimental data.

The experimental study of Bessel-weighted asymmetries has been initiated using simulated data produced with a new Monte Carlo event generator for SIDIS reactions, based on the parton model [7] and on some of the latest parametrizations of the TMDs. It has been found that the correlations between the parton and hadron momenta can heavily distort the expected kinematical distributions, particularly in the transverse momentum. These correlations may also be important in the understanding of asymmetries (for example, the Cahn effect) that model calculations were in general not able to reproduce. The extraction of Bessel weighted TMDs from these simulated data is currently underway for a set of benchmark reaction channels, in order to understand uncertainties and limitations due to experimental effects. Preliminary results of this studies have been shown in International Conferences.

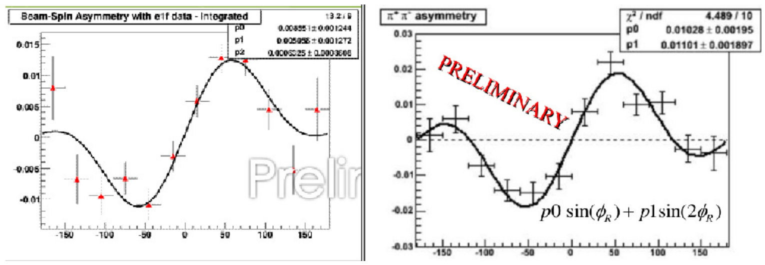

Figure 1: *Comparison between the preliminary CLAS results for Beam Single Spin Asymmetry in two pion SIDIS production extracted from the two data sets under analysis.*

3.2 *Two pion semi-inclusive electroproduction*

When two hadrons are semi-inclusively produced in the CFR, the cross section takes a simpler form than in the single pion case [8]. The Fourier components of eq. (1) are in fact given by a simple product of a TMD distribution function and a TMD DiHadron Fragmentation Function (DiFF). Thus, extraction of TMD information from this process is easier. In addition, the two hadron SIDIS processes, allow access to the sub-leading PDFs e, h_L and g_T that, together with the well known f_1 and g_1 and the transversity h_1, provide the complete description of the collinear (i.e. transverse momentum integrated) structure of the nucleon.

The study of two pion SIDIS electroproduction with CLAS data is underway with 6 GeV polarized electron beam and unpolarized as well as longitudinally polarized hydrogen target. Because of the polarized targets, the two data sets have different kinematic coverage and acceptance. The measured observables are single (beam or target) and double (beam and target) spin asymmetries, both of them having a $\sin(\phi_R)$ Fourier component (where ϕ_R is the azimuthal angle of the relative momentum of the detected hadron pair). Both asymmetries are small (few percent), but non-zero in the whole kinematical plane covered by the experiments. As an example, in Fig. 1, the comparison of the Beam Spin Asymmetry measured from the two data sets is shown. Good agreement between the two measurements has been found.

Preliminary results of these analyses have been presented in International Conferences. Currently, the acceptance effects and other systematic uncertainties are under evaluation.

4 The RICH detector for CLAS12

The CLAS12 large acceptance spectrometer in the Hall-B of JLab will have unique features (luminosity and resolution) to allow substantial progresses in the TMD studies. However, the approved physics program requires discrimination between kaons and other hadrons for momenta up to about 8 GeV/c that is not achievable in the present configuration of the detector. For this reason, the group proposed the construction of a RICH detector of large area to extend the measurements in the most interesting kinematical region.

The present solution [9] foresees a hybris proximity and mirror focusing configuration, that uses variable thickness aerogel radiator and multi-anode photomultipliers (MAPMTs) as photon detectors. A large elliptical mirror will be used to direct the Cerenkov light produced at large angles toward the MAPMTs, that will cover about 1 m^2. The project presents some critical points, that have been addressed in laboratory as well as in test beam measurements.

Laboratory tests performed in Frascati using a low intensity, high stability laser in the 400nm wave length region have shown that the Hamamatsu H8500 MAPMTs (8x8 pixels of 6mm pitch size)

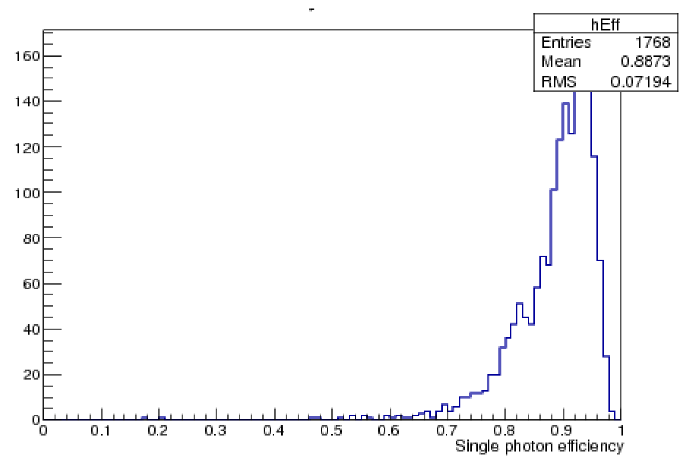

Figure 2: *Distribution of the pixel-by-pixel single photon detection efficiency measured for 28 H8500 MAPMTs in laser tests.*

provide high efficiency (about 80% or more) and uniformity of response as single photon detectors. The Fig. 2 shows the distribution of the pixel-by-pixel single photon efficiency measured in our tests of 28 H8500 MAPMTs. On average, an efficiency bigger than 80% has been measured, with a small tail of pixel with efficiency below 75%.

For the Data Aquisition, we have used an integrated electronics based on the MAROC3 chip, that provides analog information of up to 4096 channels in a very compact system. Test and setup of this electronics and of the Data Aquisition system have been performed in laboratory and also in a real experiment environment at the LNF Beam Test Facility in July 2012.

A large scale prototype has been designed and constructed at LNF in order to study the main feature of the final RICH detector. Test using a monochromatic hadron beam, composed by about 98% of pions and 2% of kaons, has been performed at the T9 beam line of the CERN in two runs in summer and winter 2012. The prototype was made by a large black box (about 2x2x2 m^3) containing an array of 28 H8500 MAPMTs, two supports for the aerogel radiator tiles and spherical and planar mirrors. The experimental setup was completed by two planar GEM chambers for particles tracking, two small plastic scintillators for triggering and a gas threshold Cerenkov detector for π/K separation. The data have been taken in two different configurations, as schematically shown in Fig. 3. In the direct light configuration, the Cerenkov photons produced by the beam particles were directly detected on the MAPMTs array. In the reflected light one, the Cerenkov photons were produced on a second radiator, then reflected by a system of a spherical plus planar mirrors toward the MAPMTs. In front of the planar mirrors, aerogel tiles were placed in order to mimic the geometry of the final detector and to study the light absorption. A picture of the prototype is shown in Fig. 4.

During the data taking, several elements of the prototype have been changed in order to fully test the features of the RICH. For the direct light measurements, we ran with:

- aerogel with different refractive index ($n = 1.04$, 1.05 and 1.06) and thickness ($t = 2$, 3 and 4 cm) to study the photon yield production;
- various optical filters placed in front of the radiator, in order to study the chromatic contribution to the single photon detection resolution;

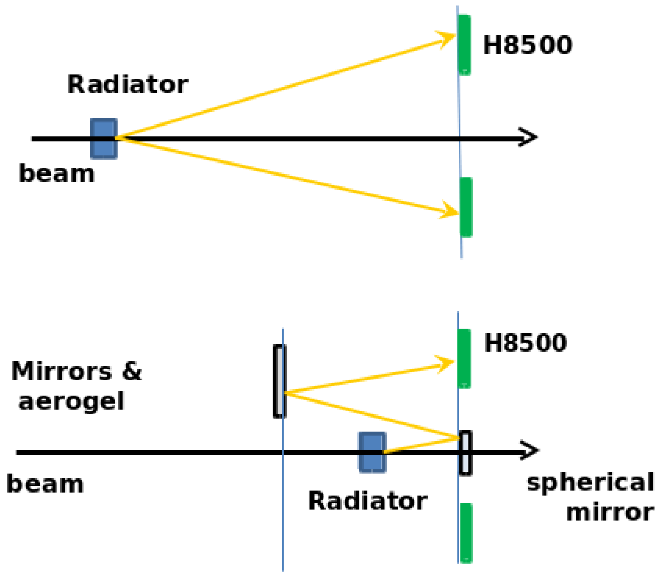

Figure 3: *Schematic of the two configurations of the RICH prototype for direct (upper plot) and reflected (lower plot) light measurements.*

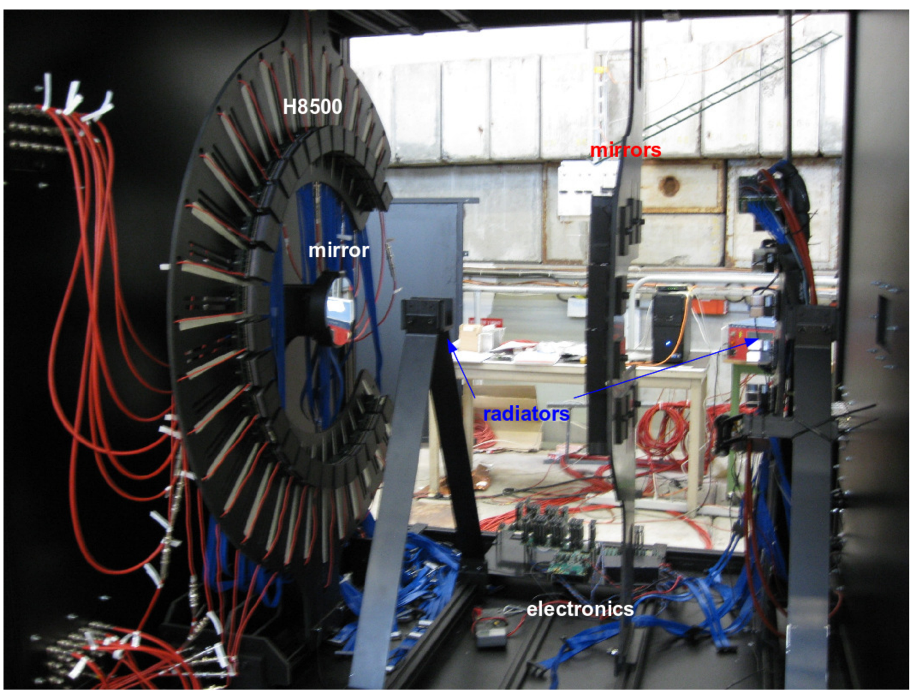

Figure 4: *Picture of the inner elements of the RICH prototype.*

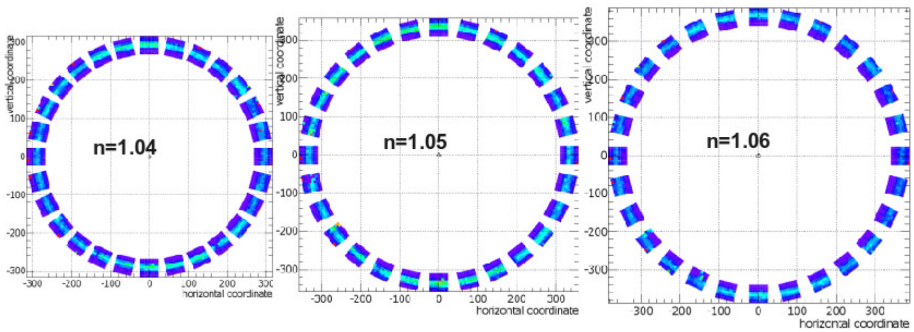

Figure 5: *Examples of Cerenkov rings measured in the direct light configuration for aerogel with n=1.04 (left), n=1.05 (center) and n=1.06 (right) refractive index.*

- MAPMTs moved away from the expected Cerenkov ring, to study background Rayleigh photon production;
- beam energy of 6, 7 and 8 GeV/c, to study momentum dependence in the π/K separation;

Main goal of these data is to fully exploit the kaon identification of the RICH, possibly estimating a detection efficiency using the gas Cerenkov detector as reference.

In the reflected light configuration, data were taken with a beam energy of 6 GeV/c (the maximum reachable in the real RICH detector for this configuration) and with:

- aerogel radiator with different refractive index ($n = 1.04$, 1.05 and 1.06) and thickness (from 2 to 8 cm);
- without the aerogel in front of the mirror and with aerogel of various thickness and quality;

Main goal here is to study the absorption of Cerenkov photons when passing multiple times through the aerogel.

An example of the measured Cerenkov rings in the direct light configuration is shown in the on-line monitoring plots reported in Fig. 5. The analysis of the data taken is currently underway. A document reporting the project of the final detector is also in preparation.

5 List of Conference Talks by JLAB12 members in 2011

1. D. Hasch, *Data analysis of hard exclusive and semi-inclusive DIS processes* - Lecture for the Doctoral Training Programme of the ECT* Trento on the 'THE 3-DIMENSIONAL NUCLEON STRUCTURE', 30. April - 15 June 2012, Trento (Italy).
2. S. Anefalos Pereira, *Probing the nucleon structure at Jefferson Lab* - QCD2012, July 2 - 7, 2012, Montpellier (France).
3. S. Pisano, *Analyzing nucleon spin structure through SIDIS at Jefferson Lab* - ENPC 2012, September 17 - 21, 2012, Bucharest (Romania).
4. M. Aghasyan, *Fully Differential Monte-Carlo Generator Dedicated to TMDs and Bessel-Weighted Asymmetries* - QCD-N12, October 22-26, 2012, Bilbao (Spain).
5. M. Mirazita, *From partons to hadrons: a challenge for the QCD* National workshop on Nuclear Physics- November 12-14, 2012, Catania (Italy)

6 Publications

1. Transverse Polarization of $\Sigma^+(1189)$ in Photoproduction on a Hydrogen Target CLAS Collaboration, C.S. Nepali *et al.*, submitted to Phys. Rev. C.

2. Measurement of the $\Sigma\pi$ Photoproduction Line Shapes Near the $\Lambda(1405)$ CLAS Collaboration, K. Moriya *et al.*, submitted to Phys. Rev. C.

3. Measurement of Transparency Ratios for Protons from Short-Range Correlated Pairs CLAS Collaboration, H. Hakobyan *et al.*, submitted to Phys. Rev. C.

4. Separated Structure Functions for Exclusive $K^+ \Lambda$ and $K^+ \Sigma^0$ Electroproduction at 5.5 GeV with CLAS CLAS Collaboration, D.S. Carman *et al.*, submitted to Phys. Rev. C.

5. Near Threshold Neutral Pion Electroproduction at High Momentum Transfers and Generalized Form Factors CLAS Collaboration, P. Khetarpal *et al.*, submitted to Phys. Rev. C.

6. Shrunken particles pass freely through nuclear matter CLAS Collaboration, L. El Fassi *et al.*, Phys. Lett. **B 712** (2012) 326.

7. Probing Strangeness in Hard Processes: The science case of a RICH detector for CLAS12 H. Avakian *et al.*, arXiv:1202.1910

8. Deep exclusive π^+ electroproduction off the proton at CLAS CLAS Collaboration, K. Park *et al.*, Eur. Phys. J. **A 49** (2013) 16.

9. Measurement of Exclusive π^0 Electroproduction Structure Functions and their Relationship to Transversity GPDs CLAS Collaboration, I. Bedlinskiy *et al.*, Phys. Rev. Lett. **109**, 112001 (2012).

10. A study of the P11(1440) and D13(1520) resonances from CLAS data on $ep \to e'\pi^+\pi^-p'$ CLAS Collaboration, V. Mokeev *et al.*, Phys. Rev. **C 86**, 035203 (2012).

11. A comparison of forward and backward pp pair knockout in 3He(e,e'pp)n CLAS Collaboration, H. Baghdasaryan *et al.*, Phys. Rev. **C 85**, 064318 (2012)

12. Measurement of the generalized form factors near threshold via $\gamma p \to n\pi^+$ at high Q^2 CLAS Collaboration, K. Park *et al.*, Phys. Rrv. **C 85**, 035208 (2012)

13. Branching Ratio of the Electromagnetic Decay of the $\Sigma^+(1385)$ CLAS Collaboration, D. Keller *et al.*, Phys. Rev. **D 85**, 052004 (2012)

14. Comment on the narrow baryon peak reported by Amaryan et al. CLAS Collaboration, V.D. Burkert *et al.*, Phys. Rev. **C 86**, 069801 (2012)

15. Amplitude analysis of $\gamma n \to \pi^- p$ data above 1 GeV W. Chen *et al.*, Phys. Rev. **C 86**, 015206 (2012)

16. Measurement of the neutron F_2 structure function via spectator tagging CLAS Collaboration, N. Baillie *et al.*, Phys. Rev. Lett. **108**, 142001 (2012)

17. Upper limits for the photoproduction cross section for the $\Phi^{--}(1860)$ pentaquark state off the deuteron CLAS Collaboration, H. Egiyan *et al.*, Phys. Rev. **C 85**, 015205 (2012)

References

1. P.J. Mulders and R.D. Tangerman, Nucl. Phys. **B461**, 197 (1996).
2. A. Bacchetta et al., JHEP **02**, 093 (2007).
3. J.C. Collins, Nucl. Phys. **B396**, 161 (1993).
4. J.C. Collins and D.E. Soper, Nucl. Phys. **B193**, 381 (1981).
5. X. Ji, J. Ma and F. Yuan, Phys. Rev. **D71**, 034005 (2005).
6. D. Boer, L. Gamber, B. Musch and A. Prokudin, JHEP **1110** 021 (2011).
7. M. Anselmino et al., Phys. Rev. **D71** 074006 (2005).
8. A. Bacchetta and M. Radici, Phys. Rev. **D69**, 074026 (2004).
9. M. Contalbrigo et al., NIM **A639** (2011) 302.