Report JSA Graduate Fellowship AY 2017-2018

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Abstract

In this document the work done during the period covered by JSA Graduate Fellowship is discussed. The work done is divided into two main categories: (i) the work on the Ring Imaging Cherenkov Detector is summarized, and (ii) the analysis of CLAS12 data is presented. Specifically, the the $\pi^0$ multiplicity in Semi-Inclusive Deep Inelastic scattering (SIDIS) is obtained as a function of the $z$ variable by using the updated CLAS spectrometer at JLab.

During the period covered by the JSA Graduate Fellowships, I have been working on both analysis of SIDIS events obtained from CLAS12 data and on the reconstruction algorithms used by the Ring Imaging Cherenkov Detector (RICH). In this report it is summarized my work on these two topics, specifically some preliminary results obtained by the RICH detector and the work done in order to obtain multiplicity of neutral pion in current fragmentation region. These results have been presented in a seminar at the LNFN (INFN, Italy) and the DNP meeting 2018 (Hawaii).

This report is divided in three parts. Part I contains a summary of the work done on the RICH detector. Part II contains a summary of the work done on the physics results using the CLAS12 detector. Part III collects the presentation done during the period cover by this fellowship.
1. Part I: CLAS12 RICH Reconstruction

A Ring Imaging Cherenkov Detector (RICH) has been installed in the Hall B with the purpose of enhancing the Particle Identification (PID) for particle produced with momenta between 3-8 GeV/c. In this region the pion/kaon separation of the Time of Flight is not good enough to allow high precision measurements of kaons yields. The RICH has been installed during the end of 2017 in the experimental hall in order to replace one of the LTTC sector. Geometrical and material budget requirements strongly constrained the design of the RICH not allowing a large photo-detection area. A complex mirror system has been developed in order to guide the Cherenkov Radiation to the multianodes Photo-Multipliers (PMTs). This complex system presents an obstacle for the reconstruction algorithm and part of my time has been spent working on this algorithm.

I will not enter into the details of the algorithm but I will just briefly explain the logic behind it. The algorithm divides into two parts: (i) a direct radiation algorithm, and (ii) a traced radiation algorithm. When a charged particle cross the PMTs region, a great number of photons are emitted from the Cherenkov effect by the PMT’s window. These photons are closely clustered and have an different time with respect the photons generated in the radiator by the same particle. This cluster (and its time) is used to search for a match with the direction of the track direction obtained after the drift chambers. If a match is successful, the signals in the photo multipliers are studied using the method explained in ref. In case the track, traced after the drift chambers, doesn’t intersect the plane of the PMTs a ray-tracing algorithm is used. In this case we assume a given PID and generated about one thousands photons in the radiator with random azimuthal angle but fixed polar angle (the Cherenkov angle), the algorithm trace each of them until they hit a PMTs. The PID is changed and new photons are generated. For each PID a likelihoods is built based on the distance between the traced photons and the hits measured in the events. An example of the results of this algorithm, obtained from simulation, is presented in Fig. 1. Here, 100 kaons have been generated in the RICH and the direct radiation algorithm has been used for the PID. The algorithm has recognized 92% of the time a kaon.

Results on data shown a similar performance both for direct light then for reconstructed light. However the traced radiation algorithm is overall slow and not implemented yet in the CLAS12 reconstruction engine since is being optimized by the CLAS12 collaboration. Results on real data have been
obtained after the end of the fellowship and not discussed in this report.

Figure 1: (a) 10 events displayed from the RICH simulations performed using GEMC (b) The results of the reconstruction algorithm applied on 100 kaons of 6 GeV/c. The histogram represent the reconstructed Cherenkov angle. The red and green line are placed were the Cherenkov angle for a kaon and for a pion should be. It is clear that in most of the case the reconstruction algorithm finds an angle compatible with a kaon.

2. Part II: Pi0 SIDIS Multiplicity

The multiplicity is defined as the ratio of the cross section of the Semi-Inclusive Deep Inelastic Scattering (SIDIS) for a given hadron, with respect the cross section of the Deep Inelastic Scattering (DIS), and can give important information on the hadronization process through the so-called Fragmentation Functions. Formally this ratio can be written as:

\[ M^h(x, z, P_{KT}^2, Q^2) = \frac{d\sigma^h_{SIDIS}/dx \ dz \ dP_{KT}^2 \ dQ^2}{d\sigma_{DIS}/dx \ dQ^2} \]

where the variables here are defined following the so-called Trento Convention for the DIS \(^1\).

\(^1\)Semi-inclusive deep inelastic scattering at small transverse momentum, JHEP 0702 (2007) 093
During the period covered by the JSA fellowship I have obtained this quantity for neutral pion as function of the only $z$ variable, i.e. the energy fraction carried from the measured hadron electroproduced during the scattering. Initially I developed the code on the simulations since data were not available and later I have applied the code on real data.

2.1. Data Selection

We are interested in obtaining the ratio of the cross section of the process $eP \rightarrow e\pi^0X$ with respect to $eP \rightarrow eX$, as a function of $z$.

MC simulations have been performed using the CLASDIS\(^2\) generation.

The data sample is composed by one single run from the Spring Run 2018: Run 4013, equivalent to few hours of data taking and to the 0.1 percent of the overall statistics. In this run the beam energy is of 10.6 GeV and the target used was an unpolarized liquid hydrogen target.

Even if one single run is considered, the high luminosity allows for obtaining statistical errors of the order of few percent. More statistics will be needed when the data will be binned in $Q^2$, $x_B$ and $P_T$.

2.2. electron selection

The scattered electron has been obtained by using the standard CLAS Event Builder (EB).

In order to reduce the $\pi^-$ contamination, only the reconstructed electron with a calorimeter sampling fraction between 0.2 and 0.3 have been considered for the analysis.

Basic fiducial cuts have been implemented in order to remove the borders of the calorimeters (PCAL and ECAL) and of the Drift Chambers. The results of the fiducial cuts on the PCAl and first DC layer are shown in Fig.2. Similar cuts has been applied to all the other layers.

In addition, a generous cut of $\pm8\,cm$ around the mean value of the vertex ($z$-component) distribution has been applied to MC e to Data, resulting in an accepted region of $(-10, +6)\,cm$ for the data and $(-8, +8)\,cm$ for the MC. The $Q^2$ vs $x_b$, $Q^2$ vs $W$ and $Q^2$ vs $y$ obtained from data and MC - after the fiducial cuts - are shown in Fig. 3. In order to compare data and MC, only events with $Q^2 > 1\,GeV^2$, $W > 2\,GeV$, and $y < 0.80$ have been considered. The cut on $y$ is a strict cut due to two main reasons: a) with this cut we get

\(^2\)based on LEPTO and tuned on CLAS 6 data.
Figure 2: Top left: Selected clusters in PCAL. Top Right: Excluded clusters in PCAL. Bottom left: Select positions in DC region 1. Bottom Right: Excluded positions in DC region 1. The position of the cluster is in the x-y plane.

rid of all scattered electron with momentum lower than 2GeV/c, for which a big discrepancy between MC and data has been observed; b) reducing y we reduce the probability to have radiative photons. The resulting comparison of scattered electron kinematics for MC and data can be seen in Fig. 4.
Figure 3: Lorentz invariant distributions. On the left: $Q^2$ vs $x_B$. On the center: $Q^2$ vs $y$. On the right: $Q^2$ vs $W$

Figure 4: Comparison Data and MC. Left: Momentum distribution for the reconstructed electrons in GeV/c (Red: MC, blue: Run 4013). Right: Theta angle distribution for the reconstructed electrons in degrees (Red: MC, blue: Run 4013).

On the selected sample, the agreement between data and MC for the invariants $Q^2$, $x$, $W$ and $y$ is shown in Fig. 5
2.3. $\pi^0$ selection

Photons are selected from EB with the request to have at least one cluster in the calorimeter. The first cluster is required to be in the PCAL otherwise the photon is removed from the sample under investigation. In fact, the probability that the first cluster is after the PCAL is is less than 1% \(^3\) but about 30% of the overall reconstructed photons do not have the first cluster in PCAL. In addition, I excluded all the photons within 2° from the direction of the scattered electron in order to avoid radiative photons. The same fiducial cuts used on the calorimeter for the electrons have been applied on the photons. The kinematic of the selected photon compared between MC and data for the reconstructed photons is shown in Fig.6.

\(^3\)The PCAL has material budget equivalent to 5.5$X_0$ for electrons
The $\pi^0$s have been selected by computing the invariant mass of the selected photons. I have used two different approaches for doing so: a) by considering all possible combinations of photons with a threshold energy above 400 MeV; and b) by selecting the two most energetic photons with a threshold of energy of 400 MeV. The comparison between MC and data is shown in Fig.7. The stability of the invariant mass distribution has been checked for all sectors and summarized in Fig.8.
Figure 7: Left: MC (red) vs Data (blue) invariant mass using all permutations of photons. Right: MC (red) vs Data (blue) invariant mass using the two most energetic photons.

Figure 8: DATA sector comparison. Each color is associated with a different sector of the calorimeter.
2.4. Multiplicity

In order to extract the multiplicity, the data set has been divided in \( z \) bins and the reconstruction efficiency (within the detector acceptances) for each bin has been computed from the MC simulations. I have fitted the invariant mass distribution with a Gaussian distribution and the background with a third order polynomial. The number of \( \pi^0 \)s has been obtained from the integral of the fitted Gaussian. As an example Fig.9 shows this fit for some different bin of \( z \) obtained from the data. The first bin \((z < 0.1)\) does not contain much statistic because of the minimum threshold energy applied to the photon, and it has been not considered for the extraction of the multiplicity. The last bin has been removed as well.

The acceptance has been computed for the two methods presented in the previous paragraph, within the cuts discussed before and it is summarized in Fig.10. The final result is summarized in Fig.10 where the multiplicity is extracted by considering all combination of photons. The extracted multiplicity is compared with the results obtained by Sassot et al \(^4\) with a fit

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Figure 10: The reconstruction acceptance (efficiency within the cuts), obtained for the all combination (red) and for the two most energetic photon (black). The statistical error shown in the plot is related to the relative small amount of simulation run for this analysis.

on global date at Leading and Next to Leading order. The agreement is remarkable. In order to check the result the same analysis has been performed on other runs in-bending run (run 4701), resulting in value of multiplicity compatible within few percent of deviation. The error shown in the plot is only statistics and of the order of few percent up to 20 percent on the last data point.

3. Part III: Presentation done

The work done on the RICH detector has been presented a part of a seminar given at the Laboratory of Frascati (LNFN) in Rome during the summer of 2018 while the multiplicity has been presented at the APS DNP meeting in 2018 (Hawaii). The results will be part of future publications.
Figure 11: The extracted multiplicity for $\pi^0$ electroproduction. Compared with global fits obtained at leading order (solid line) and next to leading order (dashed line).