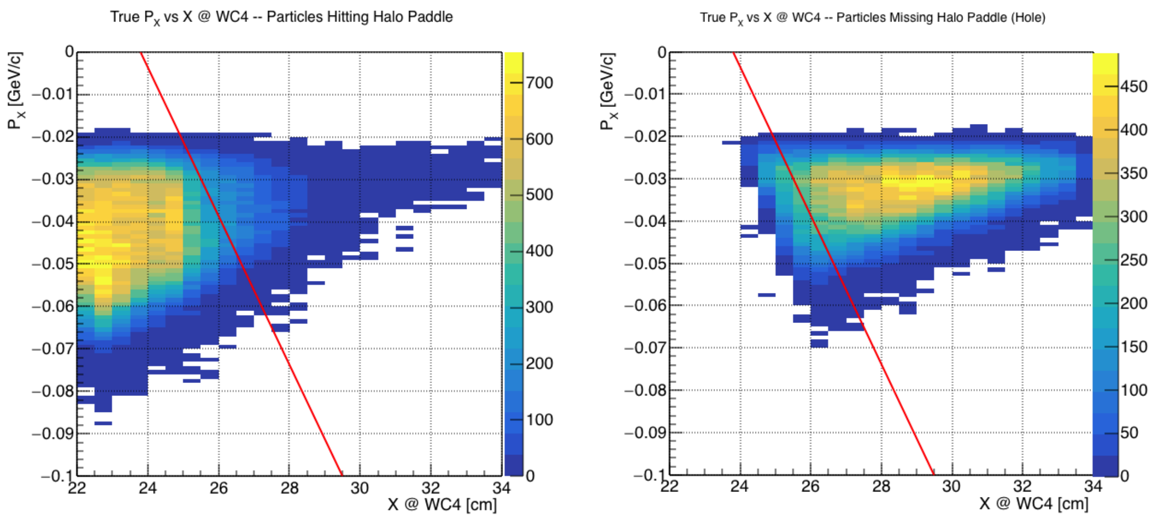


Figure 5.14: Horizontal component of the true momentum vs the horizontal position at WC4 for MC simulated pions of the 60A runs. The plot on the left shows the distribution for pion that miss the halo paddle and the plot on the right shows the distributions for pions that hit the halo. The form of the classifier is overlaid to both plots (red line).

and we optimized the clustering algorithm to maximize the efficiency of finding the interaction point on MC. Given the technical nature of these studies, we report them in Appendix B. We only report here the evaluation of the angular resolution of the tracking algorithm in data and MC, due to its important implications on the physics measurement.

5.5.1 Angular Resolution

Scope of this study is to understand and compare the tracking performances and the angular resolution of the TPC tracking on data and MC. We use the angular resolution of the tracking to determine the value of smallest angle that the tracking algorithms allow to reconstruct with a non-zero efficiency, effectively determining a selection on the distribution of the scattering angle of hadronic interaction entering the cross section measurement.

We start by selecting all the WC2TPC matched tracks used for the cross section analysis. These tracks can contain from a minimum of 3 3D-space points to a maximum of 240 3D-space points. We fit a straight line to all the 3D-space points associated with the track. For each track we calculate the average distance between each point in space and the fit line as follows

$$\bar{d} = \frac{\sum_i^N d_i}{N}, \tag{5.4}$$

where N is the number of 3D-space points of the track and d_i is the distance of the i-th space point to the line fit. Several tests to compare the goodness of fit between data and MC have been considered. We decided to use $\bar{d}$ for its straightforward interpretation. The $\bar{d}$ distribution for data and MC is shown in Figure 5.17 for pions and in Figure 5.19 for kaons and shows a relatively good agreement between data and MC.

A visual representation of the procedure used to evaluate the angular resolution is shown in Figure 5.15. For each track, we order the space points according to their Z position along the positive beam direction (panel a) and we split them in two sets: the first set contains all the points belonging to the first half of the track and the second set contains all the points belonging the second half of the track. We remove the last four points in the first set and the first four points in the second set, so to have a gap in the middle of the original track (panel b). We fit the first and the second set of points with two lines (panel c). We then calculate the angle between the fit of the first and second half α (panel d). The angle α determines the angular resolution of the tracking. The distributions for data and MC for α are given in Figure 5.18 for pions and in Figure 5.20 for kaons. The mean of the data and MC angular resolution are reported in Table 5.6 for pions and kaons in data and MC.

Interaction angles smaller than the angular resolution are indistinguishable for the reconstruction. Therefore, we assess our ability to measure the cross section to be limited to interaction angles greater than 5.0 deg. More accurate studies of the angular resolution as a function of the kinetic energy and track length, albeit interesting, are left for an improvement of the analysis.

As we discussed in Section 1.4.1, several different interaction topologies are included as signal in the total hadronic cross section. The ability to detect a minimum interaction angle and to stop the tracking accordingly mainly effects two interaction channels: the pion elastic interaction (see Table 1.4, second line) and the pion inelastic interaction in case of neutral particle emission (see Table 1.4, fourth line); the overall effect of this limitation is to reduced the cross section measurement to the measurement of the cross section relative to interaction angles greater than a ∼5.0 deg . It is beneficial to take a moment to describe the definition of interaction angle. In case of elastic scattering, the definition is straightforward: the interaction angle is the angle between the incoming and outgoing hadron, i.e.

$$\theta = \cos^{-1}\left(\frac{\vec{p}_{\text{incoming}} \cdot \vec{p}_{\text{outgoing}}}{|\vec{p}_{\text{incoming}}||\vec{p}_{\text{outgoing}}|}\right). \tag{5.5}$$

In case of the reaction channel, the presence of several topologies requires a more complex definition, as shown in figure 5.16. We define the scattering angle as the biggest of the angles between the incoming hadron and the visible daughters, where the visible daughters are charged particles that travel more than the average pitch length (δX = 47 mm) in the detector (see panel a); in case all the daughters are invisible, the angle is assigned to be 90 deg (see panel b). We chose this working definition of scattering angle for inelastic scattering keeping in mind how our tracking reconstruction works: the tracking will stop correctly if none of the daughters is visible

	Data	MC
Pions	$\bar{\alpha}_{Data} = (5.0 \pm 4.5)$ deg	$\bar{\alpha}_{MC} = (4.5 \pm 3.9)$ deg
Kaons	$\bar{\alpha}_{Data} = (4.3 \pm 3.7)$ deg	$\bar{\alpha}_{MC} = (4.4 \pm 3.6)$ deg

Table 5.6: Angular resolution for Pion and Kaon tracking in both data and MC.

in the detector and it is likely to stop correctly if multiple visible daughters form an interaction vertex. The only "dangerous" case is the production of one charged daughter plus neutrals, which we can study with this working definition of scattering angle (see panel c).

Once we fix the scattering angle definition, we can study the effects of the angular resolution on the cross section by plotting the true Geant4 total hadronic cross section for interaction angles greater than a minimum interaction angle. The left side of Figure 5.21 shows the true Geant4 cross section for interaction angles greater than 0 deg (green), 4.5 deg (red) corresponding to the MC angular resolution, 5.0 deg (blue) corresponding to the data angular resolution, and 9.0 deg (yellow). A small 0.5 deg systematic shift between the mean of the data and MC angular resolution is present, which has a negligible impact on the cross section. The right side of Figure 5.21 shows the ratio between the true cross section for interaction angles greater than 5 deg and the true interaction cross section for all angles; the cross section for angles greater than $5°$ accounts for more than 80% than the total cross section in every energy bin.

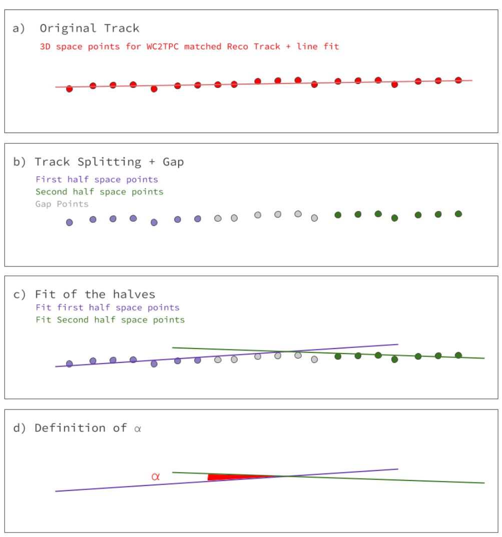


Figure 5.15: A visual representation of the procedure used to evaluate the angular resolution.

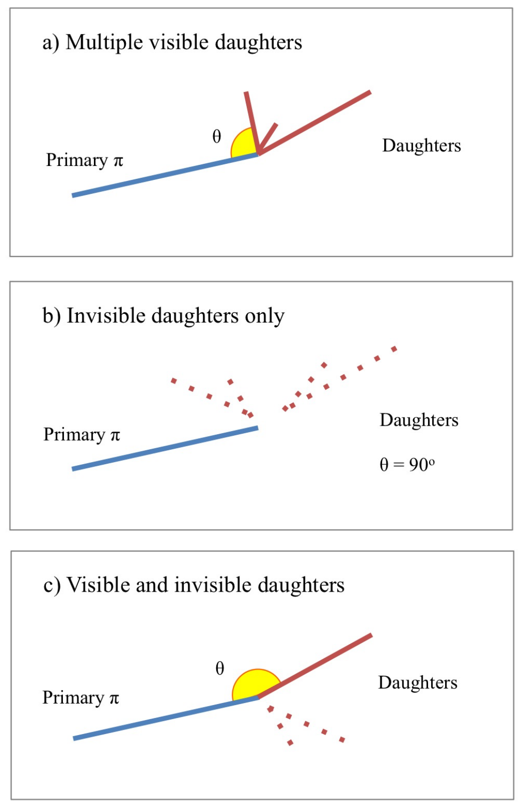
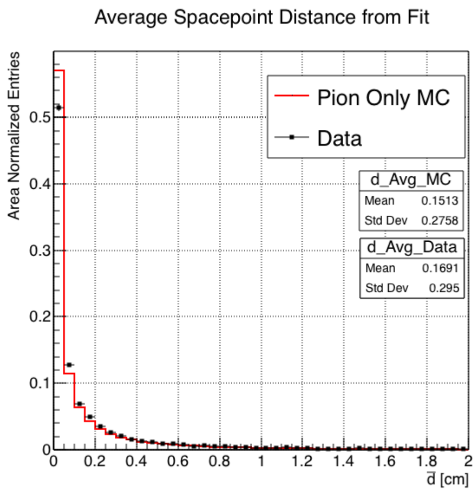


Figure 5.16: A visual representation of the scattering angle definition in case of inelastic scattering.



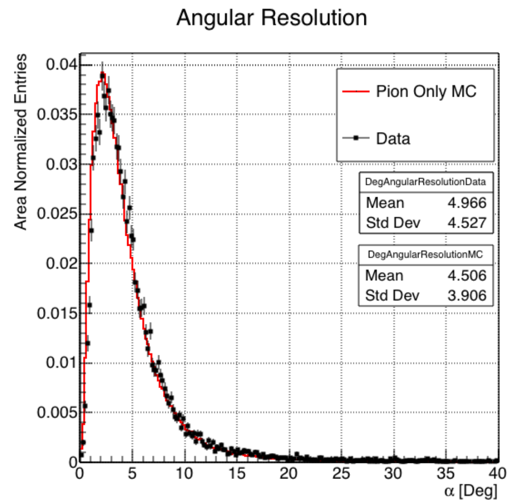
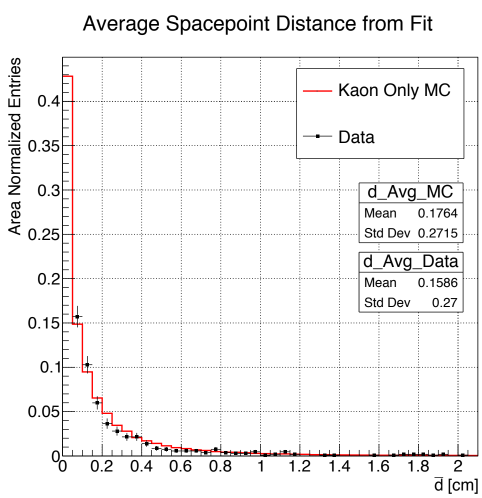


Figure 5.17: Distributions of the average distance between each 3D point in space and the fit line, $\bar{d}$ for the data used in the pion cross section analysis and the pion only DDMC. The distributions are area normalized.

Figure 5.18: Distributions of angular resolution α for data used in the pion cross section analysis and pion only DDMC. The distributions are area normalized.



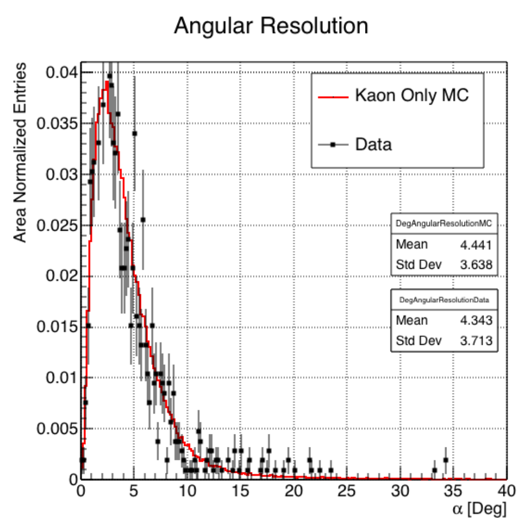


Figure 5.19: Distributions of the average distance between each 3D point in space and the fit line, $\bar{d}$ for the data used in the kaon cross section analysis and the kaon only DDMC. The distributions are area normalized.

Figure 5.20: Distributions of angular resolution α for data used in the kaon cross section analysis and kaon only DDMC. The distributions are area normalized.

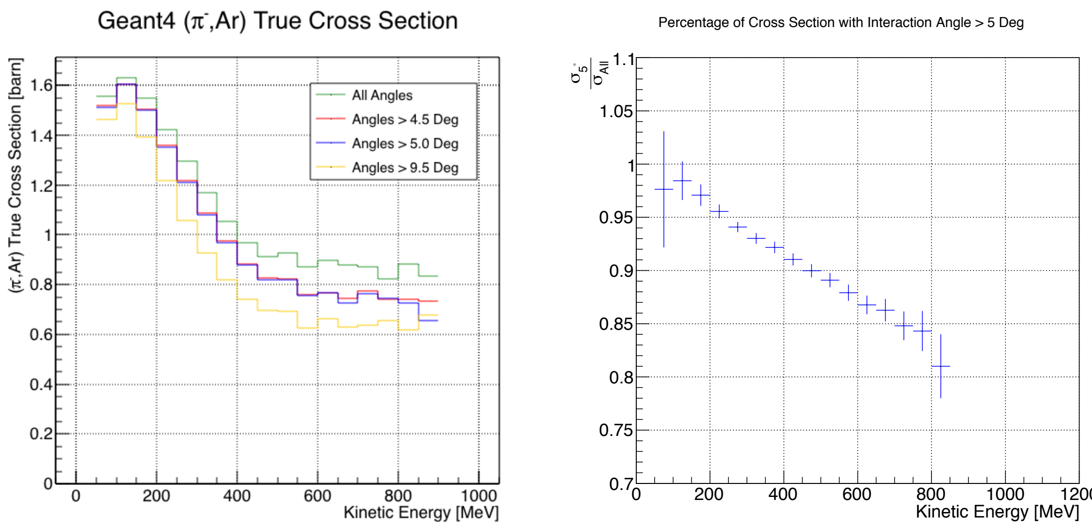


Figure 5.21: *Left:* True (π^-, Ar) cross section for interaction angles greater than 0 deg (green), 4.5 deg (red), 5.0 deg (blue) and 9.0 deg (yellow). *Right:* Ratio between the true cross section for interaction angles greater than 5 deg and the true interaction cross section for all angles.