CHAPTER 5

EVENT SELECTION AND RECONSTRUCTION

In **Section 3.3** of **Chapter 3**, the particles that emerged from the electron-proton collision in the ZEUS detector and traveled through the detector to deposit their energies in the hadronic and electromagnetic calorimeter of the ZEUS detector and labeled as the ZUFOs (Zeus Unidentified Flow Objects) i.e. objects identified with track type and island information in the CAL (Calorimeter) of the ZEUS detector, has been described.

The kinematic variables of the ZUFO objects reaching the EMC (electronic calorimeter) and hadronic calorimeter (HAC) were reconstructed using the data from energy deposits.

In the following sections, the selection criteria for long-live neutral hadrons in the final states that traveled from in interaction point in the ZEUS detector to deposit their energies in the calorimeter, will be described.

The selection criteria for the potential candidates for the mother of these long-live neutral hadrons were also given. In all cases, the background energy cuts were carried on the ZUFOs energy using curve fit $\exp(a+bx)$, where a and b were the constants determined from the curve fit, and x the energy of ZUFO object-i

5.1 Selection of K_L^0 and n candidates

In **Figure 3.2** of Chapter 3, the longitudinal cross section of the ZEUS detector showed the distance between the centre of the detector and the mid section of the barrel calorimeter (BHAC) was about 2 meters. The distance were the about the same between the centre of the ZEUS detector and the mid section of the forward and rear calorimeters (FHAC and RHAC respectively).

Table 5.1 gives the decay length and mean life of neutron and K_L^0. With the decay length of 2.655×10^8 km and mean life of 885.7 s neutrons originating from the interaction point would be able to reach the hadronic calorimeter of the ZEUS detector in without much decaying, while K_L^0 with decay length of 15.33 m and mean life 5.114×10^{-8} s could also reach the hadronic calorimeter in its final state.

Table 5.1 Properties of Neutral hadrons and their decay products

hadron	Invariant mass	Mean life τ	Decay length $c\tau$	Fraction Γ_j / Γ
μ	0.106GeV	20.19703 $\times 10^{-6} s$	658.654m	
$\pi \pm$	0.139GeV	$2.6033 \times 10^{-8} s$	7.8045m	
$\pi^0 \to \gamma\gamma$	0.135GeV	$8.4 \times 10^{-17} s$	25.1 *nm*	98.8%
K^0	0.497GeV			
$K_S^0 \to \pi^+\pi^-$		$0.8958 \times 10^{-10} s$	2.6842 *cm*	69.2%
K_L^0	$m_{K_l} - m_{K_S} = 3.483 \times 10^{-12}$ MeV	$5.114 \times 10^{-8} s$	15.33 *m*	50% K_S, 50% K_L
n	0.939GeV	885.7 *s*	2.655×10^8 *km*	
$\phi(1020) \to K_L^0 K_S^0$	1.019GeV			34.0%
$\Lambda^0 \to n\, \pi^0$	1.115GeV	$2.631 \times 10^{-10} s$	7.89*cm*	35.5%

In selecting potential candidates for K_L^0, the ZUFOs entries associated with potential neutral hadrons in the final states were chosen, with following cuts:

(i) Tufo(4,Nzufos)=31: 0 track, 1 island , use CAL

The objects not associated with any tracks i.e. non-charge particles, and form an island in the CAL cells should be selected as potential neutral hadrons in the final states. (If CTD were selected, then object will be tracked using CTD for charged particles).

(ii) $\theta > 17^{\,0}$ *or* $\theta < 163^0$ and pseudo rapidity $-2 < \eta$ *or* $\eta < 2$)

This removes signal near the beam pipes, especially in near the rear end of the calorimeter. Pseudorapidity $\eta_i = -\ln\left(\tan\frac{\theta_i}{2}\right)$ i.e. Lorentz transformation of θ_i that would give invariant values along the z-axis, particularly useful when photons were involved during the interaction.

(iii) More than 30% of the ZUFOs energy should be deposited in HACs

For potential neutral hadrons candidates in the final states (not associated with electromagnetic radiation) reaching the ZEUs calorimeter, at least 70% of its energy deposited should be deposited in the HACs regions, while the remaining 30% could be deposited in the EMC region as the neutral hadrons passed through it [3].

(iv) $38\,GeV < \delta < 65\,GeV$.

The above cut will ensure that the potential hadron candidates were not from events with large initial-state radioactive corrections and further reduce the background photon contamination. [7], [28], [64]. Here, $\delta = E_i - p_{z_i} = E_i(1-\cos\theta)$ is energy of object-i in z-direction.

(v) Background cuts on energy selection were applied, when less than 1% of the ZUFOs energy deposited in HACs region.

Background fits were carried out using $\exp(a+bx)$, where *a* and *b* were the constants determined from the curve fit and *x* as the energy of ZUFOs object-i. The above (i) to (iv) cuts were applied after background cut on energy entries were carried out.

For neutron event selection, the cuts (i) to (v) were used, but in cut (iv) **only** the first part of i.e. $\theta > 17^0$ *or* $\theta < 163^0$, was used to ensure that potential neutron candidates in the forward direction were not totally eliminated from event selection, as neutrons has low transverse momentum but high in the z-component.

5.2 Selection of K_S^0 candidates

The selection of K_S^0 candidates were carried out using the $K_S^0 \rightarrow \pi^+\pi^-$ channel using the entries in the V0 block. With mean life of $0.8953 \times 10^{-10}\,s$ and decay length of 2.6842cm, measurement of K_s^0 momentum directly is difficult, as it would decay before reaching the any superlayers of the CTD. But the decay products of K_s^0, i.e. $\pi^{\pm}$ with mean life of $\pi^{\pm}$ of $2.6033 \times 10^{-8}\,s$ and decay length of 7.8045m, would be more suitable as CTD hit candidates. **Table 5.1** gives the properties of production $\pi^+\pi^-$ production from the $K_S^0 \rightarrow \pi^+\pi^-$ channel.

Momentum of π^+ and π^- (with invariant mass =0.139GeV) candidates of pions selected should fulfill certain criteria [31], one of them being that the candidate should at least reach superlayer 3 outwards to fulfill the decay length of $\pi^{\pm}$. **Table 3.1** of Chapter 3 gave the centre radius of superlayers in the CTD of ZEUS detector, while **Figure 3.8** gave the radial layout of the CTD. Assuming that pions should reach at least superlayer 3 of the CTD, candidates are selected such it should reach superlayer 3, 5,7 and 9 [41].

The selected $\pi^+\pi^-$ pair should have the following criteria:

(i) The V0 candidates should be exclusive i.e. it should only be associated with only one lone hadron

(ii) The V0 candidate associated with $\pi^+\pi^-$ pair should be associated with only two tracks of ZTT type, to reduce multiplicity of tracks from other sources than $K_S^0 \rightarrow \pi^+\pi^-$ from the vertex

(iii) The $\pi^{\pm}$ pair should reach at least superlayer 3 of the central tracking detector (CTD)

(iv) The separation Δz of the two tracks at their xy intersection point, should be $|\Delta z| < 2.cm$ [16]. As an approximation $|(\sin\theta_{p\pi^+} - \sin\theta_{p\pi^-})| < 2.5$ were used, this cut would ensure that $\pi^+\pi^-$ pair lays within the decay length range of K_S^0.

(v) The angle α_{XY} between the transverse plane of the K_S^0 candidate and its reconstruction momentum direction, should in the same direction i.e. $Cos(\alpha_{XY}) > 0.9$ [16].

(vi) The decay length of K_S^0 candidate should be less than 10cm [16]. (Mean life of K_S^0 $\approx c\tau(M\ c)/p$, with p as the momentum of $K_S^0\cdot$ candidate, M its invariant mass and $c\tau$ as its mean life, and c as the speed of light.

(vii) The transverse momentum p_T of K_S^0 candidate should be greater than 0.15GeV for daughter –track [16].

(viii) $38\,GeV < \delta < 65\,GeV$ cut for K_S^0 was applied to reduce events from large initial-state radiative corrections and further reduces the background photon contamination [7], [28], [64], with $\delta = E_i - p_{z_i} = E_i(1-\cos\theta)$ as the energy of K_S^0 candidates in z-direction.

(ix) Cuts $abs(Mass(\pi^+\pi^-) - Mass(K_S^0)) < 0.02GeV$ was applied to narrow down mass selection of $\pi^+\pi^-$ candidates that contributed to actual K_S^0 mass.

(x) The acollinearity angle of the $\pi^+\pi^-$ candidates should be less than 3.0 [65]

5.3 Selection of scattered electrons and photons in $e(k)\ p(P) \rightarrow e'(k')\ p'(P')\ X\gamma$ interaction

During the electron-proton collision in the ZEUS detector, the incoming electron would transfer some of its initial momentum in deep inelastic scattering (DIS) and scattered off towards the rear calorimeter, as shown in **Figure 2.3** through VDM or **Figure 2.4** through pQCD model**.** The magnitude of electron's momentum loss from its initial state during DIS would give an indication of the DIS process through the variable Q^2 given by **Equation (2.19)** in **Section 2.7.1.**

In the following **Section 5.3.1,** the selection of electrons that scattered off from the DIS interaction using the ZUFOs entries is described, while **Section 5.3.2** describes the selection of photons in the direction of the scattered electron.

5.3.1 Selection of scattered electrons

The following cuts were applied to select electron candidates that scattered off from the DIS interaction using the ZUFOs entry:

(i) Tufo(4,Nzufos)=1: 1 track, 1 island , use CTD

The ZUFO objects associated with one track charge particles, and form an island in the CAL cells should be selected as potential electron candidates using CTD.

(ii) More than 95% of the ZUFOs energy should be deposited in EMC

For potential electron candidates (associated with electromagnetic radiation) reaching the EMC, majority 95% of its energy deposited should be deposited in the EMC regions, while the remaining 5% could be loss throughout its trajectory from the interaction point.

(iii) The scattered electron should be in 1.2 rad and 3.1 rad region for K_L^0 event selection i.e. in backward region of the detector.

Electron candidate should be in the rear region of the calorimeter, but not in near the beampipe region

(iv) $38\,GeV < \delta < 65\,GeV$ cut was applied to reduce events from large initial-state radiative corrections and further reduces the background photon contamination [7], [28],[64], with $\delta = E_i - p_{z_i} = E_i(1 - \cos\theta)$ as the energy of scattered electron candidates in z-direction

(v) The scattered electron candidates should be associated with only two tracks of ZTT type.

(vi) Electron candidates should be also in the same direction of electrons from SIRA finder, as SIRA finder has the necessary algorithm for finding electrons in the ZEUS detector

5.4 Selection of Double Photon candidates from $\pi^0 \to \gamma\gamma$ decay

To reconstruct Λ^0 mass from the $\Lambda^0 \to n\,\pi^0$ channel, double photon candidates in the direction of neutron production would have to be selected. The following cuts were applied on the neutral ZUFOs object to select potential $\gamma\gamma$ candidates for the $\pi^0 \to \gamma\gamma$ reconstruction:

(i) Tufo(4,Nzufos)=31: 0 track, 1 island , use CAL

The photon candidates should not be associated with any track i.e. non-charge particles, and form an island in the CAL

(ii) $38\,GeV < \delta < 65\,GeV$

The photons selected should be clear from contamination of photons from background events and large initial-state radiative corrections events [7], [28],[64], with $\delta = E_i - p_{z_i} = E_i(1-\cos\theta)$ as energy of selected photons in z-direction.

(iii) More than 90% of the ZUFOs energy should be deposited in EMC [50]

For potential photon candidates more than 90% of its energy should be deposited EMC regions .

(iv) Momentum component in the z-direction of selected candidates should be greater than 0.9GeV, to ensure that the selected photon candidates moved in the forward direction

(v) Pseudorapidity $-1.25 < \eta < 2.0$

The above cut ensure that the photon candidates would be in the 'forward' region in the laboratory mass, or in the central region in the hadron centre-of-mass frame [50]

(vi) The angle α_{XY} between the transverse plane of the neutron from $\Lambda \rightarrow n\pi^0$ and the photons candidates from $\pi^0 \rightarrow \gamma\gamma$ decay and the photon's reconstruction momentum direction, should in the same direction i.e. $Cos(\alpha_{XY}) > 0.9$

(vii) The distance between two photon candidates should be between 1.5cm and 4cm

The above cuts was to ensure that the double photon was sufficiently separated from the decay of 50GeV π^0 and, the minimal separation in the very low Q^2 of 4cm for the two photons from the decays of π^0 mesons with actual minimum energy of 20GeV [51]

(viii) The reconstructed π^0 mass should be between $0.133 < \sqrt{E_{\gamma\gamma}^2 - p_{\gamma\gamma}^2} < 0.137\ GeV/c^2$ to narrow down the photon candidates that actually contributed to π^0 mass.

5.5 Reconstruction of $\phi(1020)$ from $\phi(1020) \rightarrow K_L^0 K_S^0$ channel

In the **Section 5.1** to **Section 5.3**, the selection of long-lived neutral hadrons K_L^0 candidates reaching the hadronic calorimeter of the ZEUS detector were described. The kinematic variables of K_L^0 candidates as given in **equations (2.14) to (2.28) of Section 2.7 in Chapter 2**, were reconstructed.

The mass of $\phi(1020)$ i.e. $M(\phi(1020)) = M(K_L^0\ K_S^0)$, were reconstructed from the reconstructed masses of K_L^0 and K_S^0 respectively. Results from the reconstructed events were given in **Chapter 6** of this thesis.

5.6 Reconstruction of Λ^0 from $\Lambda \rightarrow n\pi^0$ channel

In **Sections 5.1** the selection of neutron candidates has been described, while in **Sections 5.4** the selection of double photon from $\pi^0 \rightarrow \gamma\gamma$ decay were given. With both masses, the mass of Λ^0 i.e. $M(\Lambda) = M(n\ \pi^0)$, were reconstructed. Results from the reconstructed events were given in **Chapter 6** of this thesis.

5.7 Comparison with Monte Carlo Simulation

To compensate deficiencies of the detector during measurements, factors efficiency and purity would be used to correct for actual measurements. The efficiency is defined as [9],

$$Efficiency(i) = \frac{n^{\det.and.had}(i)}{n^{had}(i)} \tag{5.1}$$

where $n^{had}(i)$ is the number of Monte Carlo events simulated in at the hadron level after passing selection criteria in bin-i, and $n^{\det}(i)$ is the number of events measured at the detector level after passing all cuts in bin-i.

Purity is defined as [9],

$$Purity(i) = \frac{n^{\det.and.had}(i)}{n^{\det}(i)} \tag{5.2}$$

Acceptance is the ratio of the number of events generated in a bin and passed event selection to the number of events generated in the selected bin [2]. It takes into account the geometric effect of the detector and is with is defined as [9],

$$Acceptance(i) = \frac{Efficiency(i)}{Purity(i)} \tag{5.3}$$

To correct for the deficiency of the detector, the correction factor is defined as,

$$Correction(i) = \frac{1}{Acceptance(i)} \tag{5.4}$$

The corrected variable is determined by [9],

$$P^{cor}(i) = Correction(i) \cdot P^{CAL} \tag{5.5}$$

with P^{CAL} as the measured parameter from the calorimeter of the ZEUS detector.

Equations (5.1) to (5.5) above would be used to correct the measurements of the ZUFOs objects in the calorimeter of the ZEUS detector.

In efficiency selection, the momentum of potential hadron candidates from the ZUFOs objects not associated with any tracks but form islands in the ZEUS calorimeter were matched against simulation data from generated Monte Carlo. These momentums were then matched in magnitude and direction of the measured hadrons that has passed selection criteria.

In purity selection, the momentum of potential hadron candidates after passing event selection was matched in magnitude and direction against the momentum simulated by Monte Carlo.

5.8 Differential Cross Section

The differential cross section σ of the variable momentum p of hadron candidates, calculated using a standard by bin correction is given by [28],[64],

$$\frac{d\sigma}{dp} = \frac{N}{A \cdot L \cdot B \cdot \Delta Y.} \tag{5.6}$$

where N is the number of events hadron candidates in a bin of size ΔY, A is the acceptance, L is the integrated luminosity (2006/2007) of 145.90pb^{-1} and B is the branching ratio taken to be 34.0% for $\phi(1020) \rightarrow K_L^0\ K_S^0$ decay channel and 35.5% for $\Lambda \rightarrow n\ \pi^0$ decay channel.

5.9 Summary

In this chapter, the event selections for the reconstruction of $\phi(1020)$ from decay channel $\phi(1020) \rightarrow K_L^0\ K_S^0$ and Λ from decay channel $\Lambda \rightarrow n\ \pi^0$ were described using the ZUFOs objects in the calorimeter of the ZEUS detector were described.

The selection of K_L^0 and neutron n candidates using ZUFOs objects not associated with any track is limited to only four variables (azimuthal and polar angle, CAL energy, EMC energy of the ZUFOs object) may reduce the resolution of the K_L^0 and neutron n mass peak and consequently the mass peak of $\phi(1020)$ and Λ .

The differential cross section of $K_L^0, \phi(1020)$, neutron and Λ with respect to its momentum would be compared with its respective momentum from Monte Carlo simulation in the next section.