CHAPTER 5

DATA ANALYSIS AND RESULTS

5.1 ORANGE (Overlying Routine Analysis of Ntuple Generation)

ORANGE [42] is a standard analysis tool in a standard analysis environment which had been created and implemented to enhance the analysis structure at DESY since 1999. In order to overcome some issues of data disarrangement, linking and updating, ORANGE was created as a solution introducing a systematic data handling with specific system flows and structures. In ORANGE, there are routines and subroutines available for different kind of analysis which referred to specific events or components of the detector. One can pre-select the information that is needed using control cards and generate the data accordingly. Back then, one needed to edit their own control cards to produce data, however after the new initiative of grand reprocessed data, the data have already been prepared accordingly and are ready to be used by the end user. More on grand reprocessed data will be discussed in the coming section 5.3. Figure 5.1 shows the example of control cards for an analysis done in 2005. Data entries for the routines selected then will be processed and gathered in specific data files in the form of ntuples.

```
C
C          Orange Control Cards
C       version 2005a from 05.06.2005
C
C Enable ORANGE
OREAZE-ENABLE ON
C ==========================================================
C Switches and paramters for each of the major code sections
C These cards determine which ORANGE common blocks are filled
C and also how they are filled. To determine which common blocks
C are written to the ntuple, see the ORANGE-NTBLOCKS cards below
C ==========================================================
C
C Fill trigger information
ORANGE-TRIGFILL ON
C
C Collect information for diffractive analyses
ORANGE-DIFFFILL OFF
C
C ======= JET FINDING ========
C Jet finding master switch
ORANGE-JETSFILL ON
C
C Cone jet finding algorithm
ORANGE-CONEJET ON
C mode 0=CAL cells, 1=zufos, 2=hadron level, 3=cone islands, 4=CAL+FPC cells
ORANGE-CONEMODE 0
ORANGE-CNETAMIN -2.0
ORANGE-CNETAMAX 3.2
ORANGE-CNPTMIN  2.5
ORANGE-CNSEED   0.5
ORANGE-CNRCONE  1.0
C 0=no ele rejection, 1=rej EM ele, 2=rej Sira ele
ORANGE-CNEREJ   1
C
C KT jet finding algorithm
C Four finders A,B,C,D, each fully variable, but with a
C different set of defaults (see manual).
ORANGE-KTJETSA ON
```

Figure 5.1 : Example of initial page of control cards which show selection of several routines applicable in ORANGE.

5.2 Data Analysis Software

5.2.1 Physics Analysis Worstation (PAW)

PAW is an interactive utility for visualizing experimental data on a computer graphics display. It may be run in batch mode if desired for very large and time consuming data analyses; typically, however, the user will decide on an analysis procedure interactively before running a batch job. PAW combines a handful of CERN High Energy Physics Library systems that may also used individually in software that processes and displays data. The purpose of PAW is to provide many common analysis and display procedures that would be duplicated needlessly by individual programmers, to supply a flexible way to invoke these common procedures, and yet also to allow user customization where necessary. Thus, PAW's strong point is that it provides quick access to many facilities in the CERN library. One of its limitations is that these libraries were not designed from scratch to work together, so that a PAW user must eventually become somewhat familiar with many dissimilar subsystems in order to make effective use of PAW's more complex capabilities. As PAW evolves in the direction of more sophisticated interactive graphics interfaces and object-oriented interaction styles, the hope is that such limitations will gradually become less visible to the user.

In ORANGE analysis, PAW will be used as an interpreter for the processed data. The data which has been processed by ORANGE can be plotted and execute by PAW using its programming language, FORTRAN. As interactive software, PAW will recognize the routine in ORANGE and display the data in a table called the ntuple blocks. If the network traffic can be tolerated, PAW can be run remotely over the network from a large, multi user client machine to more economical servers such as an X-terminal. In case such facilities are unavailable, substantial effort has been made to ensure that PAW can be used also in non interactive or batch mode from mainframes or minicomputers using ASCII terminals. Figure 5.2 shows the components of PAW with its functions.

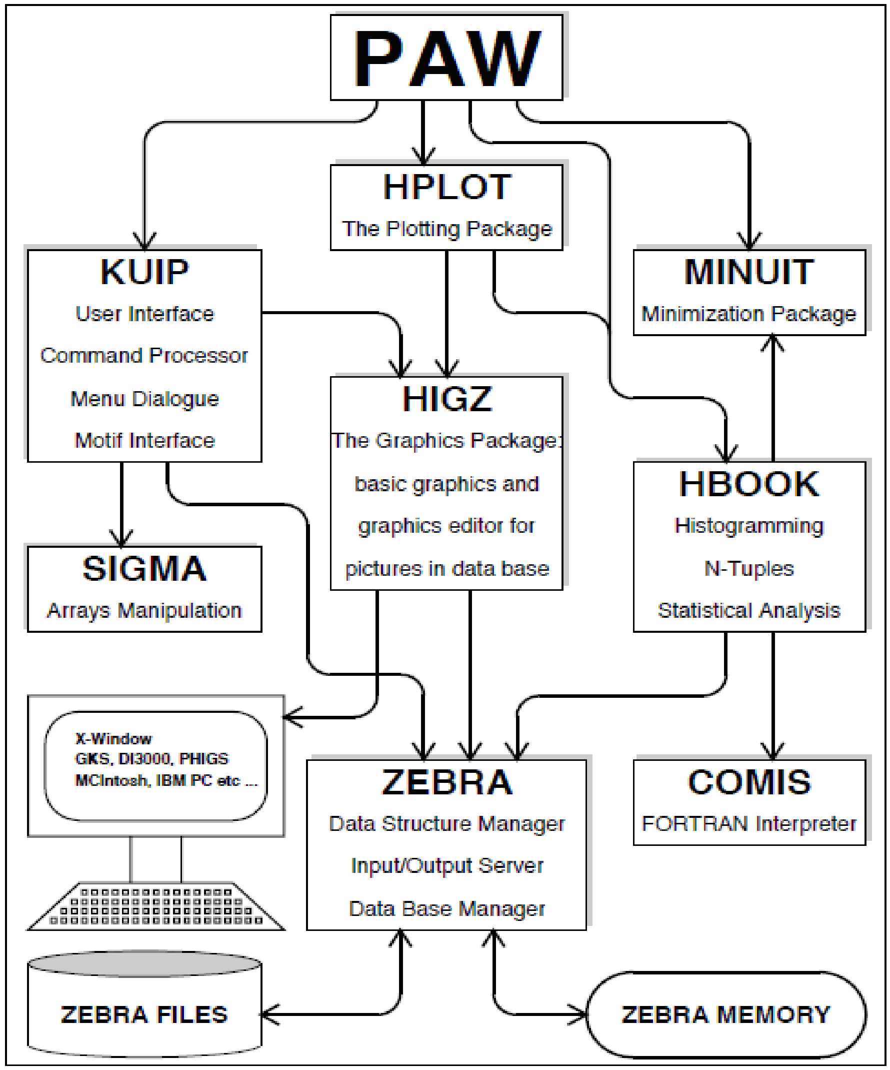

Figure 5.2: PAW and its components

5.2.2 ROOT

ROOT is another software analysis used at ZEUS which is familiar with ORANGE routines. Compared to PAW, ROOT is a newer data processing technology which was introduced by CERN through its experiment called the NA49. The objective of ROOT development is to build software that can generate and process bigger amount of data up to 10 Tb per run. Rough comparison between PAW and ROOT is listed in Table 1.0. As new enhanced and modern software of data analysis, ROOT provides platform independent access to a computer's graphics subsystem and operating system using abstract layers. Parts of the abstract platform are such as a graphical user interface and a GUI builder, container classes, reflection, a C++ script and command line interpreter (CINT), object serialization and persistence. In ZEUS analysis, ROOT plays the same function as PAW. Using specific command, ORANGE data can be linked and displayed in ROOT interface. The format of the data is also supported by ROOT and can be executed using CINT. Figure 5.3 shows the main systems in ROOT with its specific routines and executing files.

Table 1.0 : Rough comparison between PAW and ROOT.

	PAW	**ROOT**
Developers	CERN	CERN
Stable Release	16-Sep-02	22-Sep-11
File Format	.ntp	.root
Type	Particle Physics	Data Analysis
Programming Language	Fortran	C++

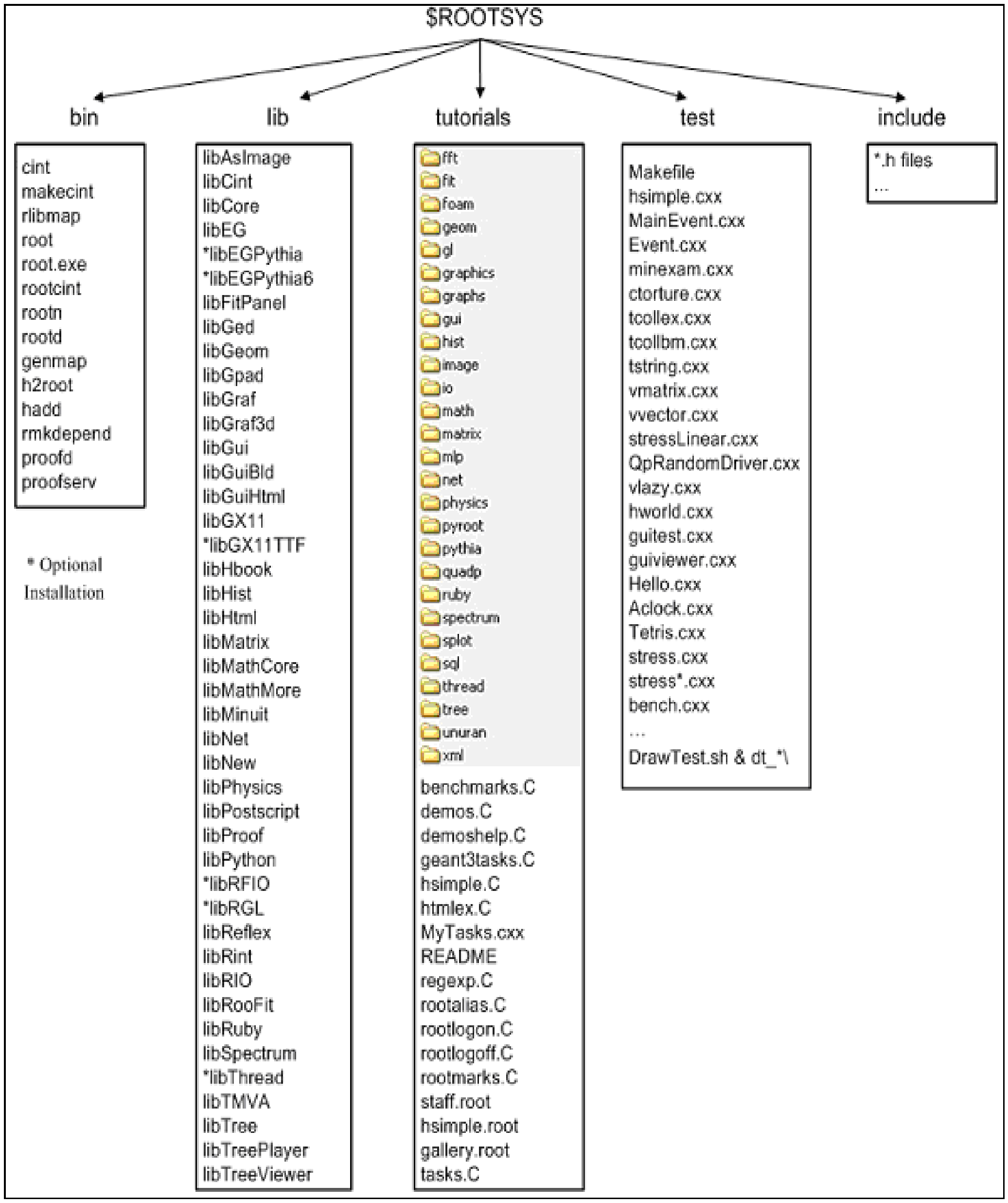

Figure 5.3: ROOT framework directories

5.2.3 Zeus Event Visualization (ZEVIS)

After installation of new components (MVD and STT) for HERA II, there was a challenge in event display as the available software at that time was not maintainable and portable to the new platforms. Therefore, ZEVIS was developed and introduced with better resolution and specifications as listed below,

- New facilities with integrated display of 2-Dimentional and 3-Dimentional view
- Portability, able to support available and relevant ZEUS software platforms
- Modality, able to use display without direct data access.

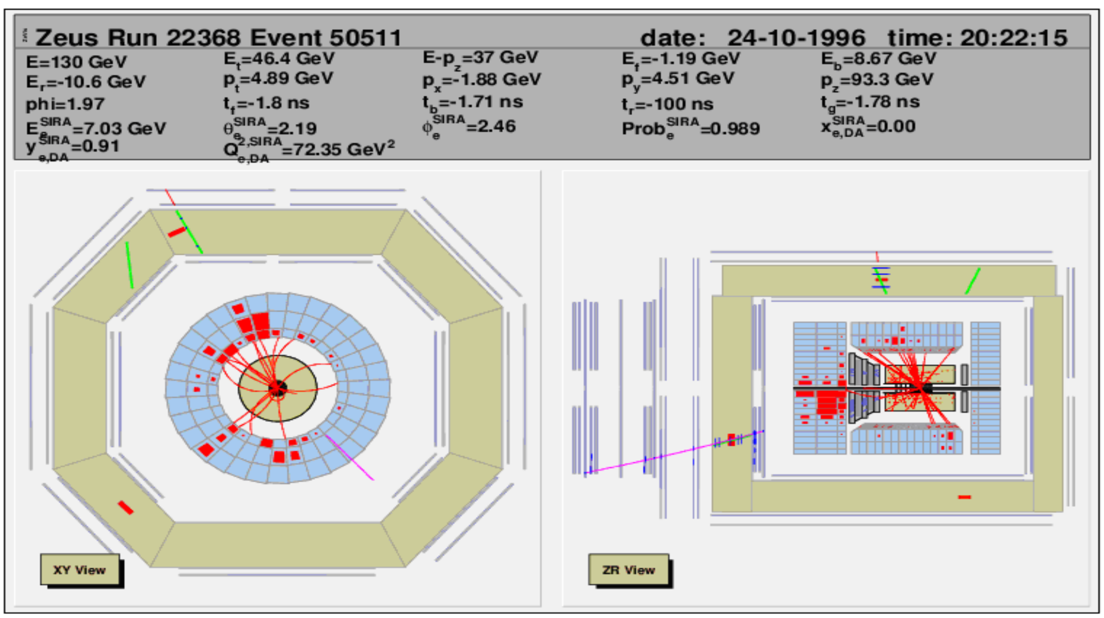

Figure 5.4: ZEVIS display of trimuon event. One of the muons is identified in the outer barrel muon chambers and in BAC (both hits and pads), embedded into a jet. The second is seen in BAC only (pads only).The third is seen in the forward muon chambers (clean long track starting in the inner chambers) and in the forward BAC, embedded into a forward jet.

5.3 Grand Reprocessed (GR) Data

In the middle of 2007, HERA operation had been stopped. Since its launch, a huge amount of data has been collected. Until 2011, the ZEUS collaboration is confident that the infrastructure of data processing in ZEUS system can be well maintained. However, beyond that year, they are uncertain whether this infrastructure can be preserved. To overcome such impact, the collaboration has come up with the idea of general data set or ntuple production called the GR data. Thus, these GR ntuples are useful for all kind of analysis and can be easily preserved for future reference and research. The first step of GR data production had been done in 2006. Now, after nearly 5 years of development, the collaboration has succeeded to produce GR ntuples of millions events in real data and Monte Carlo (MC) starting from running year 2003 to 2007 in various versions. The latest versions are v05 and v06 which still under development and construction. There are two file formats for GR data to support two common offline analysis softwares at ZEUS which are PAW and ROOT.

5.4 Monte Carlo (MC) Data

To evaluate the reconstruction of particle in real data, Monte Carlo (MC) simulation is used as comparison. At ZEUS, there are several MC generators available for different interactions. For exclusive vector meson production, the DIFFVM generator is used. The mechanism of DIFFVM simulation is based on

Regge Phenomenology and Vector Dominance Model (See Section 3.9). When electron collides with proton at high energy, the electron will emit a photon which subsequently fluctuates into a vector meson.

The steps of the MC simulation process are listed below:-

- Physics generator. This is a program that generates events coming from the reaction $ep \to X$. Each event consists of a table of the four momenta of all the particles involved in the reaction: incoming, intermediate and final state.

- MOZART (MOnteCarlo for ZEUS Analysis, Reconstruction and Trigger) is a software that contains the full simulation of the ZEUS detector. The interaction of particles with the various components of the ZEUS detector is simulated by GEANT package. The geometrical and material structure of components of the ZEUS detector as well as the mapping of the magnetic field in the volume of the CTD is known to MOZART. The program produces two types of tables, the table that contains the full information of all particles created in the event and the tables that contain the output of the various components of the ZEUS detector.

- ZGANA (ZG313 ANAlysis). This is a program that simulates the three-level trigger of the ZEUS detector as available at the various trigger levels.

- Once the generated MC file has been processed through the steps enumerated it is ready to go through the event reconstruction by the program ZEPHYR. After this the MC file undergoes the same off-line treatment as data.

These steps can be viewed in simpler diagram as shown in Figure 5.5.

Comparison of GR data and MC data in term of ntuple volume is shown in Table 2.0. From this figure, we can see that the volume of MC data generated is bigger than the GR data as more simulation has been done to ensure all events scenarios are captured for reference.

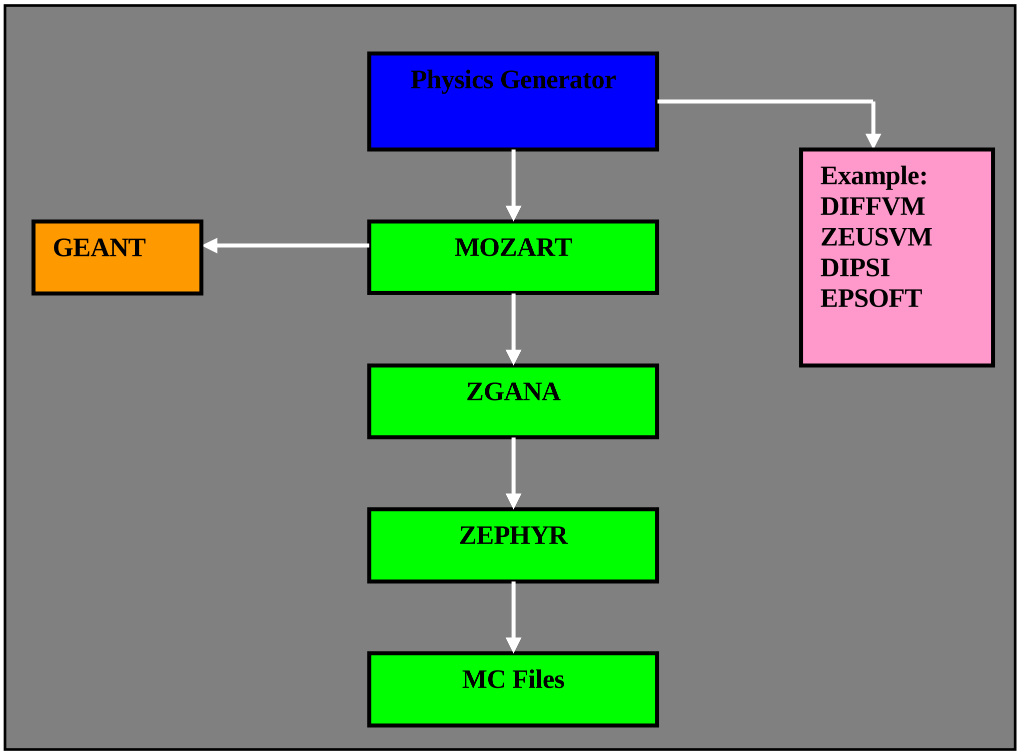

Figure 5.5: Steps of Monte Carlo Simulation

Table 2.0 : Size of GR ntuple for v02 and v04.

VERSION	TYPE	EVENTS	PAW	ROOT
v02d	DATA	410M	1.9TB	3.0TB
v02e	MC	660M	14.0TB	6.6TB
v02f	MC	477M	2.4TB	5.6TB
v04b	DATA	410M	4.4TB	5.0TB
v04b	MC	208M	4.7TB	3.0TB
v04b	MC	1137M	25.7TB	16.3TB

5.5 ψ' Photoproduction (PHP)

The production of particle that originates from photon is called the photoproduction (PHP). Photon can be seen either exclusively or inclusively in the interaction. ‘Exclusive’ means the photon is produced exclusively from the first interaction of the proton and electron. Meanwhile, ‘inclusive’ means the photon is produced within the interaction which may or may not come from the incident electron or proton itself.

In this analysis of ψ' PHP, some significant aspects of the analysis should be noted. The exclusivity of the events has to be the most important aspect, whereby, in each event, the number of tracks for charged particles must be exclusively similar with the search particle decay products. In the interaction of $\psi' \rightarrow J/\psi\pi^+\pi^-$ there will be exactly 4 tracks which represent 2 muons (from J/ψ decay) and 2 pions. The offline selection will involve specific parameters from a data arrangement table in GR data, called the ntuple blocks which can be viewed using the software analysis PAW or ROOT. All of ORANGE routine are listed in this table with its specific parameters. These parameters are used or called in PAW or ROOT using the software recognized command language and can be executed in a program.

The offline selections for $\psi' \to J/\psi\pi^{+}\pi^{-}$ PHP are listed as following;

- Exclusively 4 tracks which consist of 2 tracks of muons and 2 tracks of pions. These particles must be distinguished correctly base on the ID to prevent overlapping between particles and must have a correct charges. Entries of muons are taken from the GMUON routine in the ntuple block which is measured by the muon detector. Meanwhile for pions, the TRACKING routine used where particles entries are measured by tracking detector i.e CTD, MVD.

- The newest routine track type ZTTRACK is chosen. This routine can be viewed in the ntuple block. For GR data, the track type has already been set to this routine.

- The interaction area must cover in the primary vertex region. This is done by setting the zvtx within the 50cm. zvtx parameter is listed under the TRACKING routine in ntuple blocks.

- The polar angle for muon pairs are set to be within $17^{\circ} < \theta < 163^{\circ}$, in the region of CTD acceptance. The θ parameter is listed under GMUON routine in ntuple blocks.

- Collinearity cut for J/ψ , $\Omega < 174^{\circ}$, where Ω is the angle between the two muon tracks to reject cosmic rays events. The formula used for this cut is $\cos\Omega = \frac{-P_i \bullet P_j}{|P_i||P_j|}$ where P_i is the momentum x,y and z for muon i and P_j is the momentum x,y and z for muon j. The parameters for these momentum also can be obtained from the ntuple blocks under the GMUON table.

- The J/ψ mass reconstruction, $M_{J/\psi}$ are cut within a small region around the mass peak to decrease the background.

- Trigger selection for FMUON/BRMUON are applied.

ψ' Mass reconstruction is calculated using equation below,

$$M_{\psi(2S)} = M_{\mu^+\mu^-\pi^+\pi^-} - M_{\mu^+\mu^-} + M_{J/\psi}(PDG) \tag{53}$$

where $M_{\mu^+\mu^-\pi^+\pi^-}$ is the reconstructed mass for $\psi(2S)$ using 2 muons and 2 pions, $M_{\mu^+\mu^-}$ is reconstructed mass for J/ψ and $M_{J/\psi}(PDG)$ is the mass value for J/ψ in particle data group (PDG) reference. This formula is used to confirm the accuracy of the ψ' reconstructed mass which must be balanced with the value in the PDG. After ψ’ reconstructed signal is observed in the plotted graph, to obtain the number of ψ' entries in the mass region $N_{\psi(2S)}$, some fitting algorithm are used i.e Gaussian. This fitting routine option is also available in PAW and ROOT.

5.6 Results

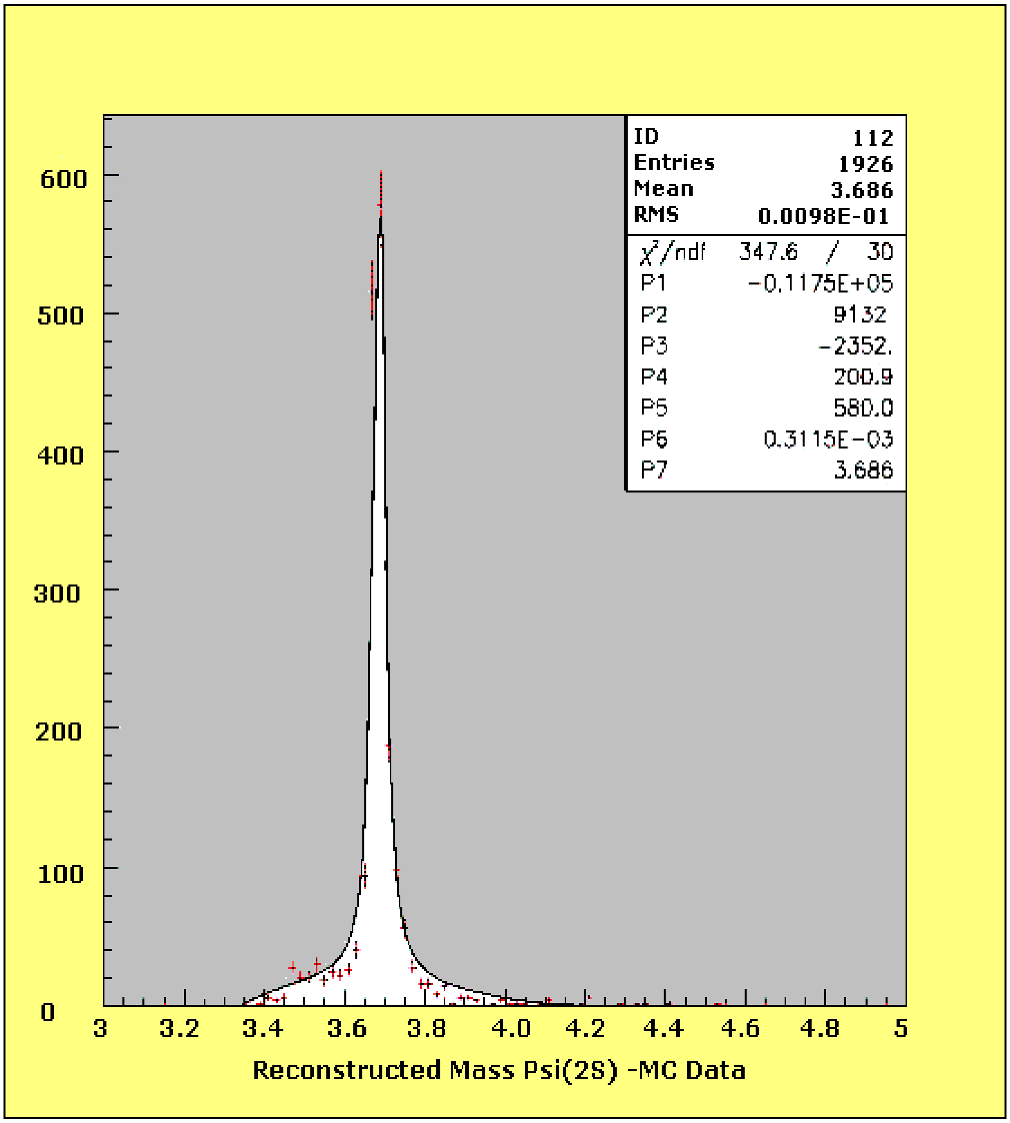

Figure 5.6: Figure shows the reconstructed mass of ψ' generated by PAW using the simulated ZEUS MC data for $\psi' \to J/\psi\pi^+\pi^-$ decay channel.

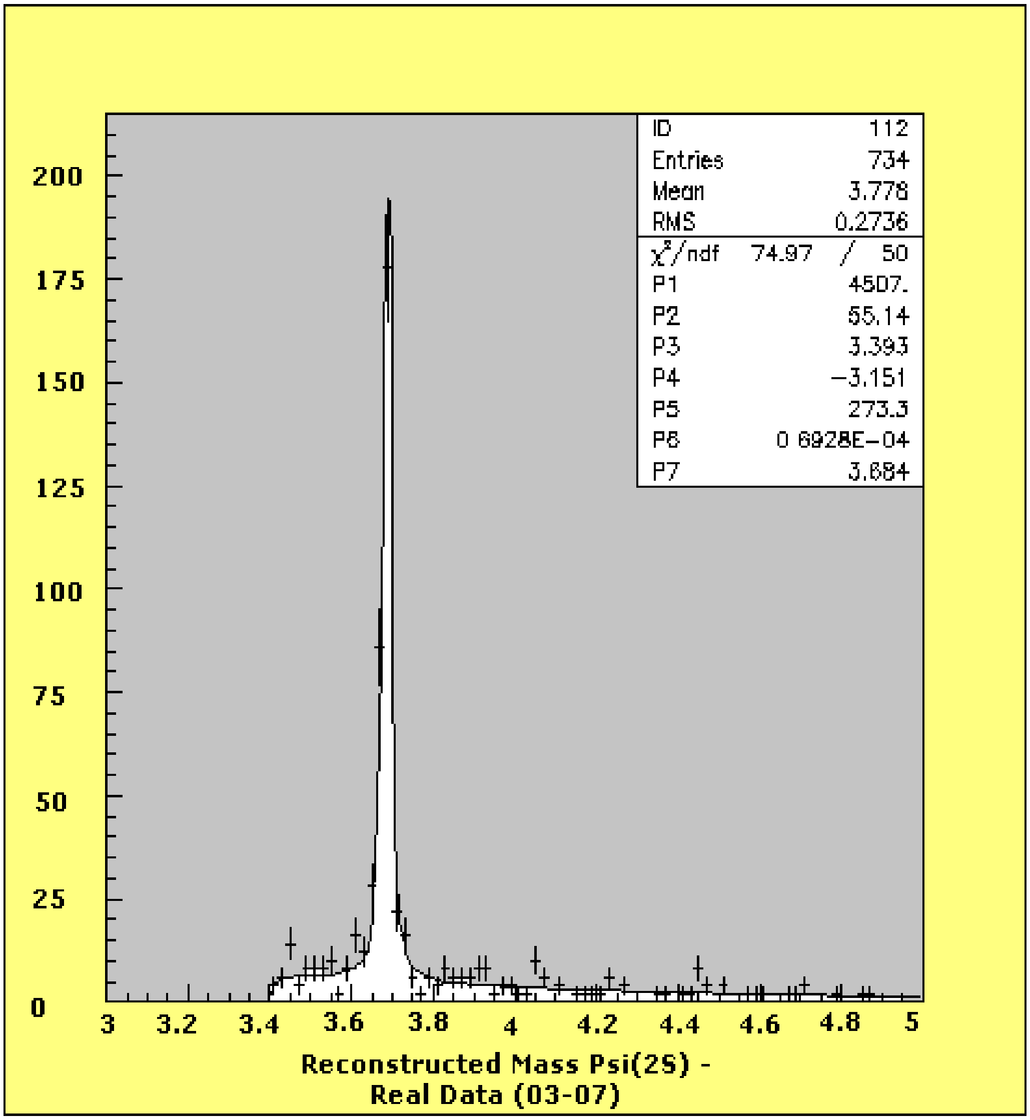

Figure 5.7: Figure shows the reconstructed mass of ψ' generated by PAW using the ZEUS GR data for $\psi' \to \mu^+\mu^-\pi^+\pi^-$ decay channel in 2003-2007 events.

Table 3.0: Properties of ψ' photoproduction with number of ψ' particles, Nψ(2S), acceptance, A, photon flux, Φ and the cross section, σ, in different W range.

W (GeV)	<W>	$N_{\psi'}$	A	Φ	σ(Pb)	σ(μb)	Logσ (μb)	Error Logσ(μb)
30-50	40	47	0.107	0.056	1166.6	0.0012	-2.933	± 0.0381
50-70	60	63	0.161	0.034	1745.1	0.0017	-2.758	± 0.0317
70-90	80	71	0.105	0.023	4398.2	0.0044	-2.357	± 0.0202
90-110	100	45	0.130	0.017	3062.4	0.0031	-2.514	± 0.0241
110-130	120	55	0.150	0.013	4277.7	0.0043	-2.369	± 0.0204
130-150	140	70	0.149	0.010	6960.0	0.0070	-2.157	± 0.0162
150-170	160	26	0.117	0.008	4147.9	0.0041	-2.382	± 0.0208

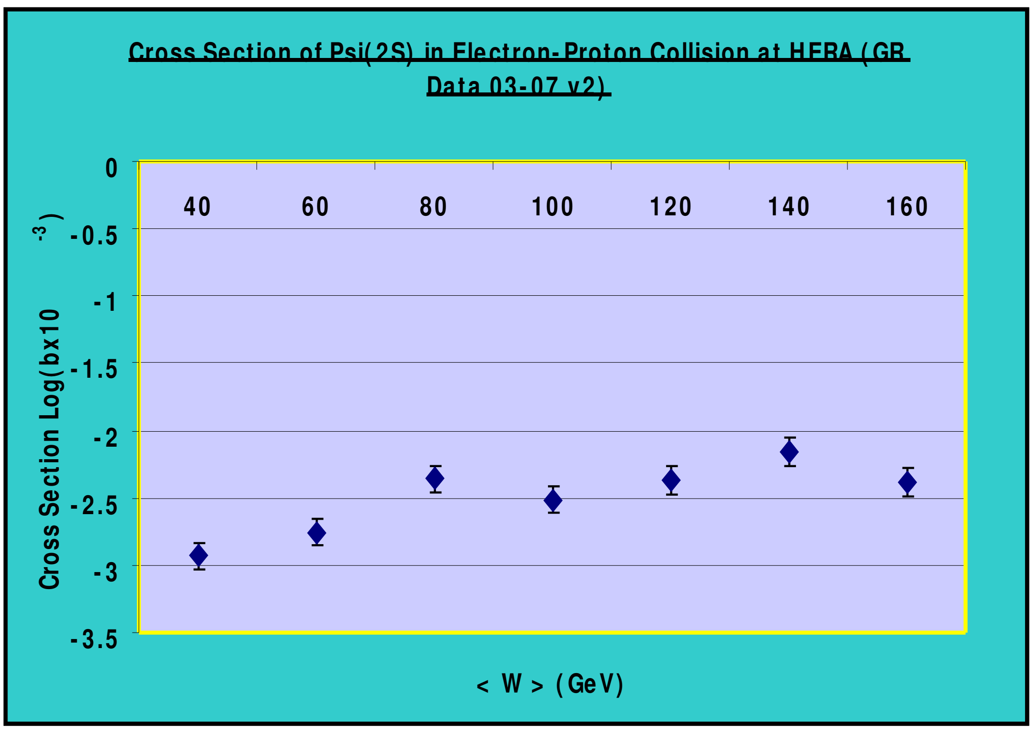

Figure 5.8 : Cross section of ψ' in e-p collision at HERA for ZEUS GR data in 2003-2007 events.

CHAPTER 6

DISCUSSION AND CONCLUSION

In conclusion, ZEUS experiment can be divided into five main aspects. Firstly, we need to understand the physics background which is the main key of the whole experiment. As mentioned in Chapter 1, Standard Model has motivated many physicists to do a lot of researches in particle searching. ZEUS experiment is focusing on the electrons and protons collisions at high energy which is significantly suitable to observe physics events such as photoproduction and deep inelastic scattering. In order to implement that, here comes the second aspect of ZEUS experiment which is the experiment tools; the ZEUS detector and HERA collider. The ZEUS detector consists of two main components; the calorimeter and the tracking detectors. The calorimeter is specially designed to measure the energy of traversing particles, meanwhile the tracking detectors detect the particles tracks as well as measuring the momentum. In measuring the energies and momentum of particles trajectories, ZEUS detector is equipped with many internal computing systems. This is our third aspect. Briefly, there are a lot of routines, files, links, directories, software and programs that had been used in ZEUS experiment. These systems are implemented in detector components, data processing, data simulation, initial selection and many more. In producing raw data from the electrons and protons collisions and extracting it to a better data arrangement, ORANGE is used. The data will then be collected in the form of ntuples. The fourth aspect of ZEUS experiment is the particle offline reconstruction. At this stage, offline selection will be done on the real and simulation data using the analysis software. Lastly, after successfully reconstructing a signal, results are ready for physics analysis and discussions in order to understand the particle behaviours.

As discussion to our results, exclusive photoproduction events are actually compromising specific and narrower region for particle searching in the detector. This is because at initial selection, we have cut off all other events which contribute much bigger percentage in the GR data, such as the DIS and inclusive events. Moreover, in searching for $\psi(2S)$ particle at ZEUS, the specialty of muons as MIPs and specific detector component and system provided in the experiment, leads more convenient searching and facilities for this particle. Muons are easily recognized in the event display by its isolated trajectories which traverse the inner parts of the detector, and reached to the outer layer of where the muon detector is located. After several cut off and event selection, we have seen that the refined distribution of the reconstructed mass before fitting procedure has already shown a remarkable peak.

Our results of $\psi(2S)$ are compared to the production of other VMs in figure 6.1. As a conclusion, we can see that the cross section obtained for $\psi(2S)$ in this research is slightly lower than the H1 results, but is still withim acceptable limits. It is also consistent with the theoretical and parameterization fit given in the graph.

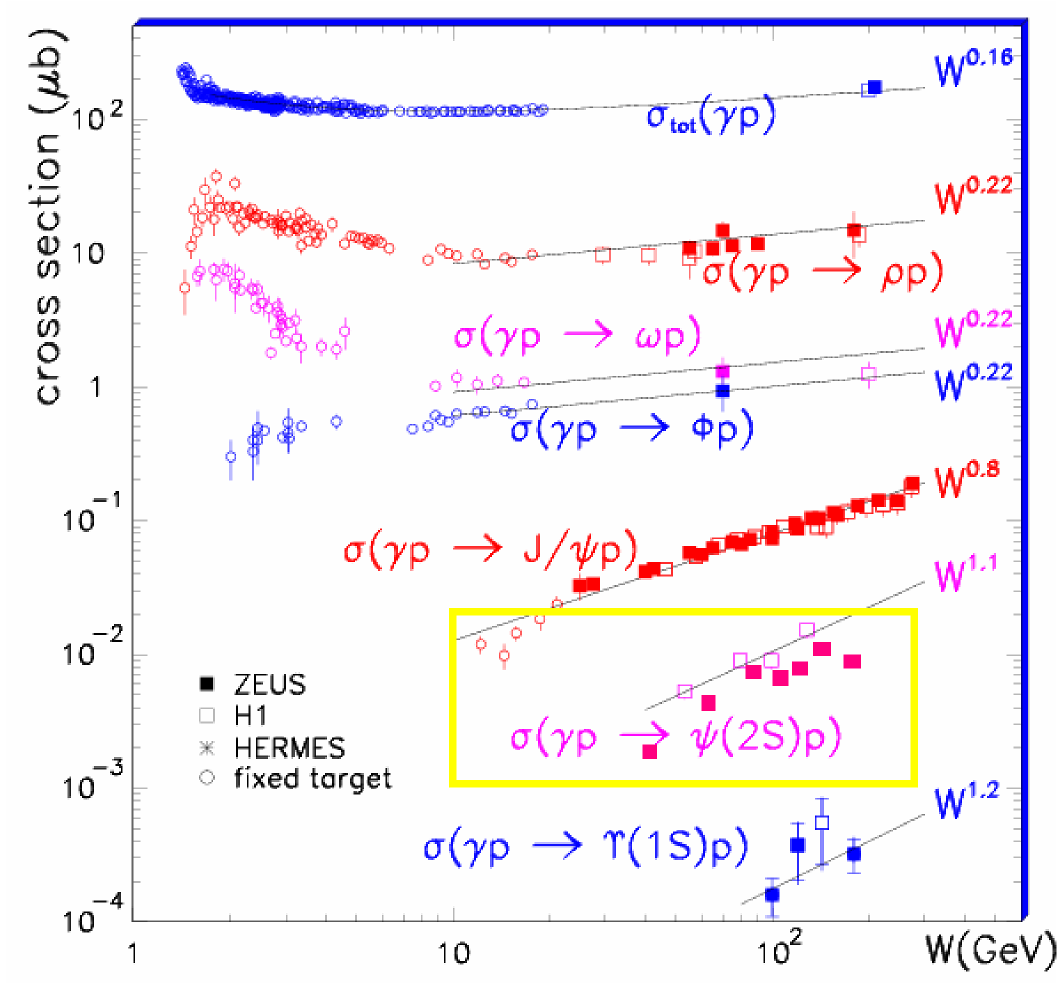

Figure 6.1: The cross section for ψ' at ZEUS highlighted in yellow block, in comparison with H1 experiment and other vector mesons.