Studies on Photon Proton Cross Section at HERA

Rina Schwartz
Tel Aviv University, Tel Aviv, Israel

Abstract
This paper introduces the first steps towards adjustment of weights for different processes in the PYTHIA simulation. Namely, an analysis of the elastic rho found in data taken from the ZEUS detector.

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1. <u>Introduction</u>

1.1. The total cross section

The measurement of the total cross section of the photon-proton interaction is useful for QCD studies, and for better understanding of future colliders physics. This is due to the hadron-like nature of the virtual photon emitted from the positron: it can fluctuate into a pair of quarks, which can emit gluons, so that the interaction is similar to hadron-proton (or proton-proton) interaction. Therefore, one can extract information about proton-proton interactions via analysis of γ^*p interactions. In HERA, one can measure the e^+p cross section, and then extracted the γ^*p cross section via the Weizsäcker-Williams approximation. [3]

1.2. The HERA collider and the ZEUS detector

HERA (Hadron-Elektron-Ring-Anlage) operated between October 19, 1991, and June 30, 2007, as a lepton-proton collider at DESY (Deutche Elektronen Synchrotron), Hamburg. The nominal energy of the colliding protons was 920 GeV, and of the colliding electron (positron) – 27.5 GeV. This leads to a center of mass energy of ~ 318 GeV. In the last months of its physics program, HERA was operated with different center of mass energies[1]:
October 1991 to June 2007 – High Energy Run (HER), proton energy: 920 GeV.
March to May 2007 – Low Energy Run (LER), proton energy: 460 GeV.
June 2007 – Medium Energy Run (MER), proton energy: 575 GeV.

ZEUS is one out of four experiments that were installed in the HERA collider.

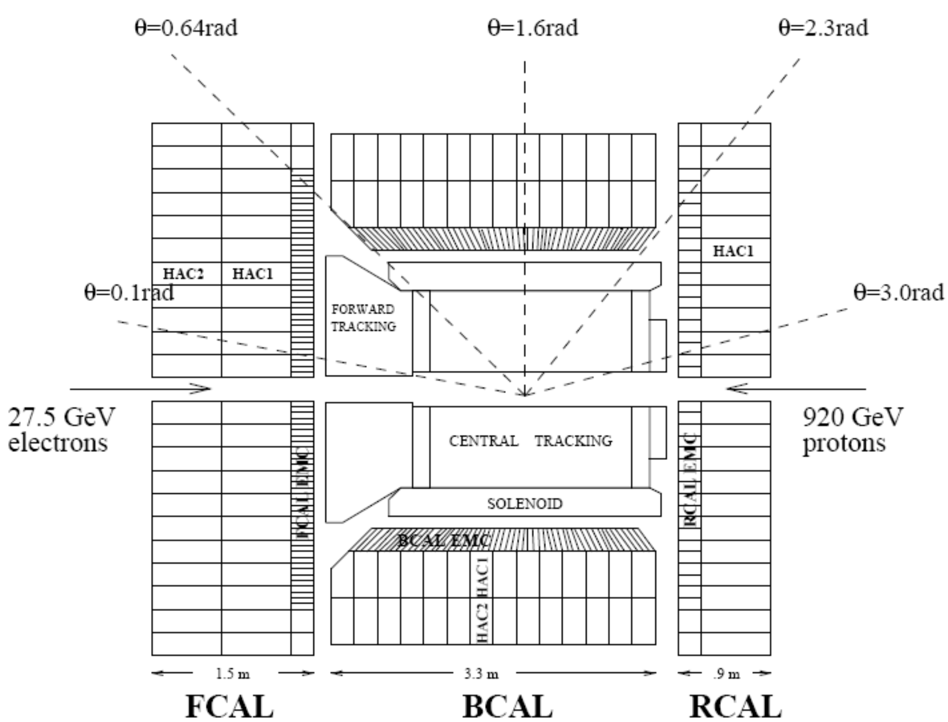

Figure 1. The ZEUS detector scheme [2]

The ZEUS structure includes tracking chambers surrounding the interaction point, around them magnets, and around them the calorimeters: RCAL (R stands for rear), BCAL (B for barrel), and FCAL (F for forward). The structure can be seen in fig. 1.[1]

In addition to the structure above, there is a calorimeter located 5.7 meters from the interaction point in the positron direction, called the 6 meter tagger (6mT). Due to the HERA dipole magnet, the low-angle scattered positrons with energies between 4-7 GeV are deflected out of the nominal beam orbit so that they hit the 6mT. [1]

1.3. The data Sample

My analysis runs on samples of data and MC, from HER. The trigger for recording events into these samples requires a hit in the RCAL with energy above 1.25 GeV[2] (inner and outer ring), and a positron hit in the 6mT. These events are in fact photoproduction events, as seen in the following diagram (figure 2):

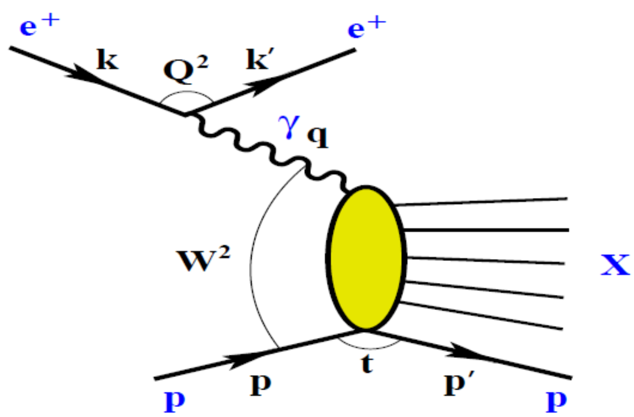

Figure 2: photoproduction – DIS in which $Q^2 \rightarrow 0$ so that the virtual photon is almost real. [3]

The scattered positron hits the 6mT, and the hadronic final state X hits the RCAL, satisfying the trigger requirement

2. <u>Contributions to the total cross section and PYTHIA</u>

There are several processes that contribute to the total cross section. They can be categorized in the following way[2]:

<u>Diffractive</u>: meaning that photon and the proton interacted via a pomeron.
Within the diffractive processes there are 4 categories:
- elastic process, where the proton remains intact, and the photon fluctuated into a vector meson (VM) with the same quantum numbers as the photon.
- photon dissociative, where the photon breaks into many particles and the proton remains intact.

- proton dissociative, where the proton breaks into many particles and the photon emerges as a VM.
- double dissociative, where both the photon and proton break into many particles.

Resolved: meaning that the photon resolved into partons, and they interacted with the partons of the proton via a parton-parton vertex.

Direct: meaning that the photon interacted with the partons of the proton via a photon-parton vertex.

In the PYTHIA simulation, these processes are taken into account with certain weights. The final goal of my work is to find better weights for the different processes, by examining separately the energy distributions of different processes and matching the data and the MC. As a first step towards this goal, I will look at the diffractive elastic process in which a rho meson is created.

3. The Rho meson

3.1. Kinematics of the rho decay

The rho decays as following: $\rho^0 \rightarrow \pi^+ \pi^-$. In this decay, helicity must be conserved. Since the rho is boosted, we expect the following angular distribution:

$$\tan\theta' = \frac{\sin\theta}{\gamma\cos\theta + \gamma\beta\frac{1}{\sqrt{1-\frac{4m_\pi^2}{m_\rho^2}}}}$$

θ' - is the angle of the boosted pion, θ - is the angle of the pions in the rho rest frame.

If we assume that the rho is produced in a photoproduction event, we can assume (from energy conservation) that its energy is between 20.5-23.5 GeV. For the same reason, this will also be the energy of the pions that the rho decays to. But, due to the geometry of the detector, most of the pions with this energy will escape through the beam-pipe and will not be detected in the detector. So the acceptance of the detector for these events is very low.

3.2. Cuts

In order to understand weather the rho can be seen in my sample, I applied the following cuts:

- $\eta_{max} < 2.2$
  η_{max} is a variable that indicates the maximal angle relative to the beam line, in which there was a significant signal in the ZEUS calorimeters. η_{max} is large when there are energy deposits near the proton beam in the FCAL; the cut eliminates proton dissociative events.
- Vertex - tracks cut
  First, make sure that there was a vertex in the event. Second, make sure that

there were exactly two tracks in the event, with opposite charge, and both of them came from the vertex.

- Trigger cut
  since the data taking was not consistent, this cut simulates the selection that the trigger was suppose to impose.
- fmax cut
  technical issue, subtract events that passed the trigger and should not have.

Then, I plotted twice the total energy distribution of the two tracks: once calculated from the tracking variables, and second calculated from ZUFO's (ZUFO - optimized combination of tracking and calorimetry). In addition, I plotted the difference between these energies, and imposed a cut so that this difference is smaller than 3 GeV. This cut required that all of the energy is in the tracks, eliminating photon dissociative events and keeping VMs. Along with the eta-max cut, these cuts select a sample enriched in elastic diffractive events.

After this last cut, I plotted the invariant mass of the two tracks (calculated from tracking variables).

4. Results and summary

The results can be seen in the following plots:

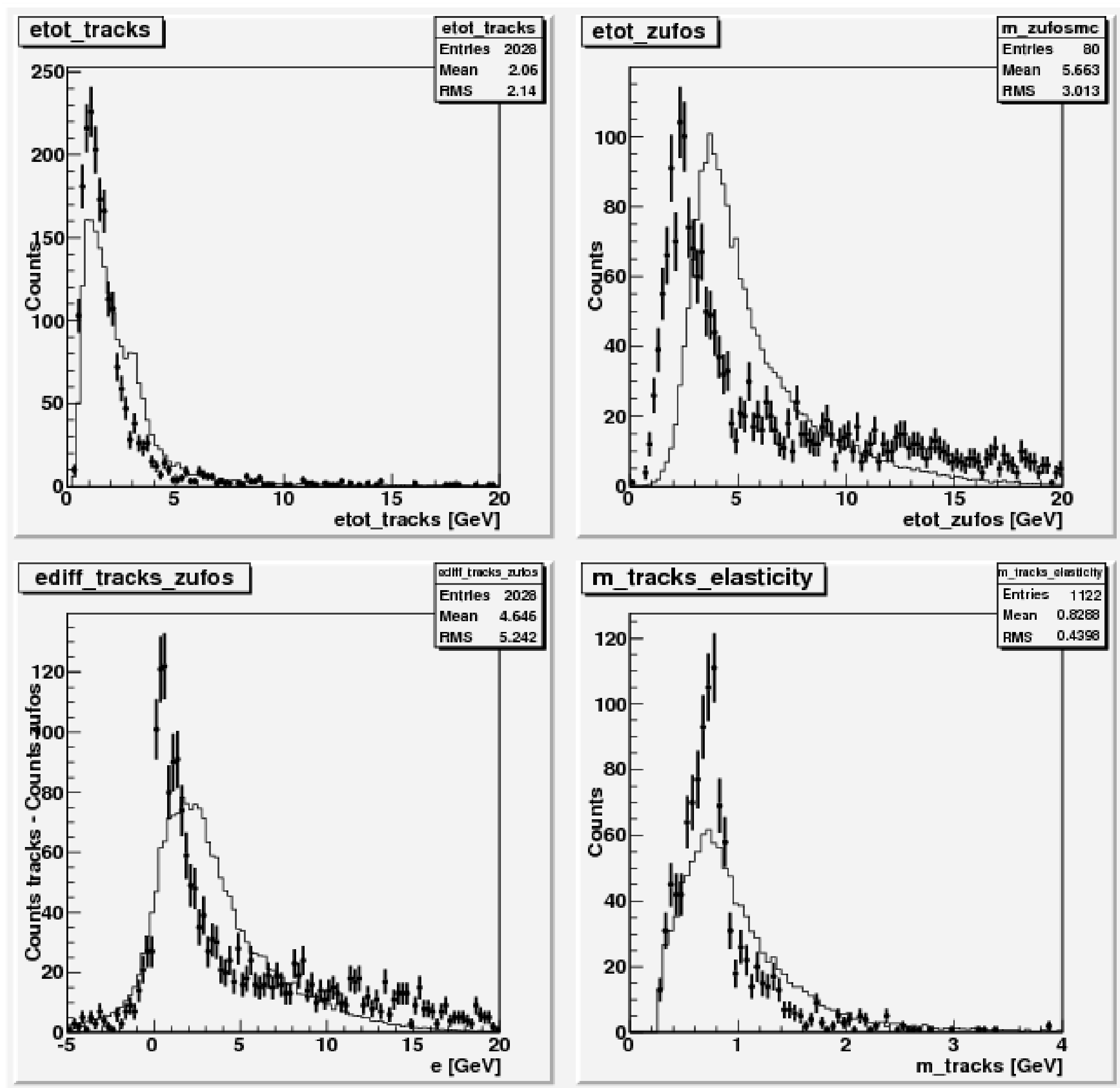

Figure 3: the four histograms described above.

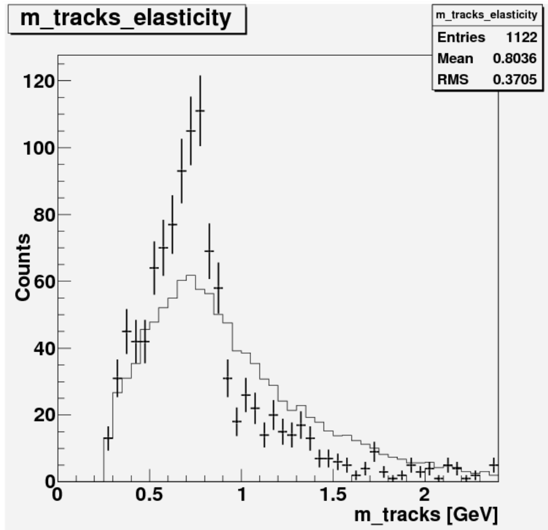

Figure 4: closer look on the invariant mass distribution.

In the plots above, the crosses stand for data, and the continuous line stands for MC. The plot shows a clear peak in the data corresponding to the rho mass (~0.77 GeV). On the other hand, the MC shows small peak if any at all.

In order to understand why the rho peak appears, overlaps should be considered. Overlaps are events in which the trigger was operated by two different physical interactions. For example in our case: one positron emitted a virtual photon with energy smaller than 20 GeV fluctuated into a rho, which decayed into two pions which were detected by the calorimeters. At the same time, another positron emitted a photon and was deflected so that it reached the 6mT.

One can check if indeed this is the reason for the rho peak, using the variable W (shown in figure 2). W is the center of mass energy of the photon and the proton. The higher this energy is, the higher the energy of the rho.

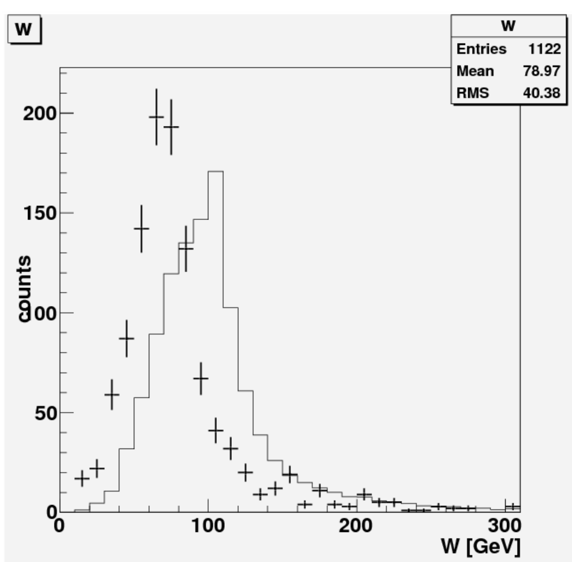

Figure 5: W histogram.

The W peaks around 70 GeV in the data, and around 100 GeV in the MC.
This means that the rho was with relatively low energy, and indeed the rho's that are detected come from overlaps.

Two remarks:
- In the context of paragraph 3, one can conclude from figure 4 that the weight of the elastic rho process needs to be larger.
- One can see that in the energy distribution histograms, the data and the MC are shifted. This can be corrected by re-weighting the processes in PYTHIA.

5. References

1. O. Gueta – PCAL + AEROGEL Calibration in the ZEUS Detector (2009)
2. O. Gueta – Energy dependence of $\sigma^{\gamma p}_{tot}$ measured with the ZEUS detector at HERA (2010)
3. A. Stern – Measurement of the W dependence of $\sigma^{\gamma p}_{tot}$ with the ZEUS detector at HERA (2008)

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