Measurement of the total photon-proton cross-section with the ZEUS detector at HERA

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Abstract

The dependence of the total photon-proton cross-section on the center-of-mass energy W can be described at high energies as W^{δ}, where $\delta \sim 0.16$. Using the recent runs of HERA with three different proton energies, an attempt is made to perform a precision measurement of δ using ratios of cross-sections at different W values. The acceptances of the ZEUS detector for photon-proton interactions were studied with the ZEUS detector Monte Carlo simulation for the three different proton energies and found to be the same.

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1 Introduction

Donnachie and Landshoff [1] showed that all hadron-hadron total cross sections can be described by a simple Regge motivated form as $\sigma_{\rm tot} = A \cdot (W^2)^{\alpha_P(0)-1} + B \cdot (W^2)^{\alpha_R(0)-1}$, where A and B are process dependent constants, W is the hadron-hadron center-of-mass energy, and $\alpha_P(0)$ ($\alpha_R(0)$) are the Pomeron (Reggeon) trajectory intercepts. The first measurement of the total γp cross section at HERA [2] showed that also the total photo-production cross section has a similar W dependence. Further measurements of $\sigma_{tot}(\gamma p)$ at HERA [3] reduced the statistical error but the systematic error remained too large for a precise determination of the W dependence of the cross section. Recently, just before the closing of the HERA collider , runs with different proton energies were taken, keeping the electron energy constant. This opened up the possibility to determine precisely the power of the W dependence by measuring the ratios of cross sections, where much of the systematic error cancels out.

The purpose of this project was to study the acceptances of the ZEUS detector for photoproduction events using the PYTHIA Monte-Carlo (MC) [4], in order to check if they are the same at the three different energy regions where data were taken. In addition, a first look at the data was attempted to estimate the number of the γp events remaining after the rejection of background.

2 Concept of measurement

The total photon-proton cross-section has a power dependence on W [5] $\sigma_{tot}(\gamma p) \propto W^\delta$. Knowing W (from the scattered positron energy, E'_e) and measuring $\sigma_{tot}(\gamma p)$, one can determine δ. Using the ratio of the cross-sections measured for different W values (i.e. proton beam energies), the determination of δ will be more precise, because the systematic uncertainty will cancel.

$$\frac{\sigma_1}{\sigma_2} = \left(\frac{W_1}{W_2}\right)^\delta .$$

$\sigma = \frac{N}{A\mathcal{L}}$ where A, $\mathcal{L}$ and N are the acceptance, luminosity and number of measured events, respectively. If the acceptances for the three different W values are the same, they will be canceled in the ratio.

3 Experimental details

During few months prior to its shut-down, the Hadron Electron Ring Accelerator (HERA) was running 27.5 GeV positrons and protons of three different energies. In the High

Energy Run (HER) the proton beam energy was 920 GeV, in the Medium Energy Run (MER) 575 GeV and in the Low Energy Run (LER) 460 GeV. Data were taken in some runs, with the ZEUS detector trigger system especially configured to collect events of the reaction $e^+p \to e^+\gamma p \to e^+X$. The energy of the scattered positron was measured in the 6 meter tagger. The ZEUS Calorimeter (CAL) and Central Tracking Detector (CTD) (see Fig. 1) are well described elsewhere [6] and therefor their description will be skipped in this report.

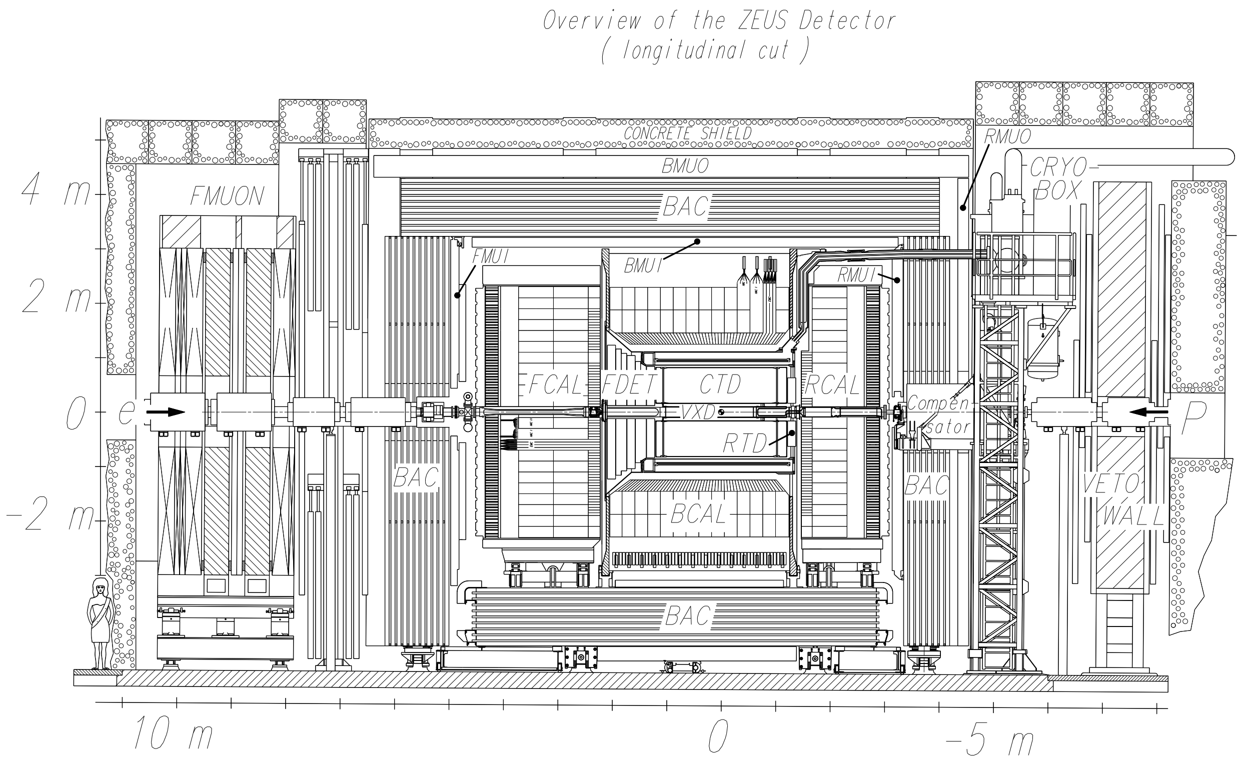

Figure 1: *The ZEUS main detector*

The 6 meter tagger [7] is a $84 \times 24 \times 100$ mm^3 spaghetti calorimeter that consists of 70 cells ordered in 5 rows and 14 columns and located 5.7 m from the interaction point in the backward direction, in one of the HERA magnets, as shown in Fig. 2. The magnetic field of the HERA magnet, in which the 6 meter tagger is located, drives the low-angle scattered positrons to the tagger. The tagger was used for tagging photoproduction events as well as to determine the acceptance of the luminosity system located 107 m down the beam-pipe in the backward direction. The luminosity system consists of a Photon Calorimeter (PCAL) and a Spectrometer (SPEC). It was used to absorb photons from the Bethe-Heitler process ($e^+p \to e^+\gamma p$) used to determine the ZEUS detector gated luminosity.

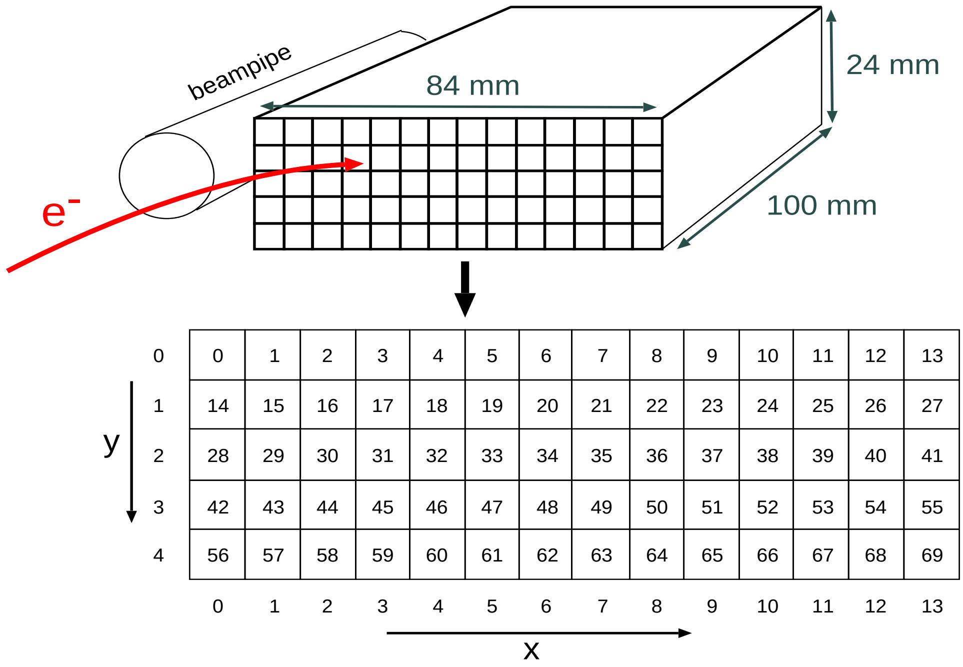

Figure 2: *The 6 meter tagger*

4 Kinematics

The event kinematics may be described in terms of Lorentz-invariant variables: the photon virtuality, Q^2, and the event inelasticity, y, defined by

$$Q^2 = -q^2 = -(k - k')^2$$

and

$$y = \frac{p \cdot q}{p \cdot k},$$

where k, k' and p are the four-momenta of the incoming positron, scattered positron and incident proton, respectively (see Fig. 3). The square of the photon-proton center-of-mass energy is given by

$$W_{\gamma p}^2 = (q + p)^2 .$$

These variables can be expressed in terms of the experimentally measured quantities E_e' and θ using

$$Q^2 = 2E_e E_e'(1 - \cos\theta) ,$$

$$y = 1 - \frac{E_e'}{2E_e}(1 + \cos\theta) \simeq 1 - \frac{E_e'}{E_e} ,$$

$$W_{\gamma p} = 2\sqrt{E_e E_p y} .$$

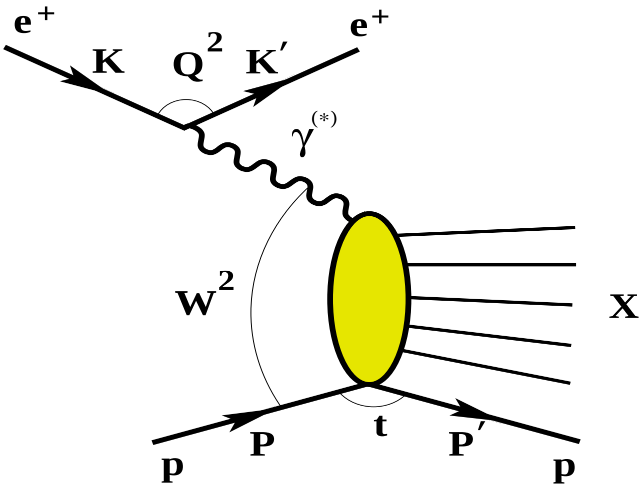

Figure 3: *Feynman diagram describing the process $e^+p \rightarrow e^+X$*

E_e, E'_e and E_p are the energies of the incoming positron, scattered positron and incident proton, respectively, and θ is the positron scattering angle with respect to the initial positron direction.

5 Analysis

The analysis is divided into two parts. First, the acceptances of the ZEUS detector for photoproduction events were studied for the three different proton energies. Later on the data are looked at in attempt to reject background.

5.1 MC acceptance studies

5.1.1 The MC sample

The ZEUS detector MC simulation for the processes $e^+p \rightarrow e^+X$ generated by PYTHIA 6.4 and HERACLES 4.6 (to include radiative corrections) was used where $y > 0.5$ and $Q^2 < 5\ GeV^2$.
It includes soft processes (elastic,diffractive,low Pt non-diffractive) and hard processes (high Pt,direct and resolved photon) in the proper weight (Minbiass MSTP(14)=30) to describe earlier data. For the hard processes, CTEQ5D parton densities were used for the proton and GRV-G-96 HO for the photon. The following number of events were generated:

HER	2,036,485	events
MER	3,975,986	events
LER	4,095,646	events

The acceptance is defined as $A = \frac{N_{rec}}{N_{gen}}$ where N_{rec}, N_{gen} are the number of reconstruced events with some properties and number of generated events, respectively. Since we aim measuring the W dependence of the total photon-proton cross section, the events should be generated in appropriate W range.

5.1.2 Cuts

On the generated level the following cuts were applied:

$Q^2 < 0.02\ GeV^2$ (it was originally generated with $Q^2 < 5\ GeV^2$)

A cut on the generated W values, corresponding to the defined 6 meter tagger's fiducial volume (see next section) was made as follows:

HER	269 GeV <W< 289 GeV
MER	213 GeV <W< 229 GeV
LER	190 GeV <W< 204 GeV

Events were counted in generated and reconstructed W (and y) bins. In order to determine the CAL and CTD acceptances the trigger logic was simulated in the MC.

The 6 meter tagger and main detector components' acceptance for elastic/diffractive [1] ρ^0 production in photoproduction were as well calculated in a similar way, where the following cuts were made (in addition to the W range cut) on the generated level:

$X_l > 0.9$

$0 < M_X < 1.2$ GeV

where $X_l = \frac{Pz_{p'}}{E_p}$ and M_X is the invariant mass of all final state particles excluding the proton ($M_X^2 = (q + p - p')^2$).

5.2 First look at the data

5.2.1 The data sample

2007 e^+ data taken with the SIGMATOT_070523 (HER) and STD_070523_SIGTOT_FL trigger configurations.

[1] The sample of ρ^0 with a proton-dissociation is denoted as diffractive ρ^0

HER	3,061,317	events
MER	9,942,301	events
LER	11,438,691	events

5.2.2 Cuts

The third level trigger bit TLT spp07 [8] was used.

2.5 GeV $<$6m tagger energy$<$ 9.5 GeV

6 mm $<$X position of hit in 6m tagger$<$ 78 mm

-20 mm $<$Y position of hit in 6m tagger$<$ 20 mm

At first, we have compared the total $E - Pz$ distribution in data and MC.

$$(E - P_z)_{tot} = (E - P_z)_{CAL} + 2E_{\text{6m tagger}}$$

Clear disagreement between data and MC have been seen. Since the CAL is well understood, we looked for the difference in the 6m tagger energy. The 6 meter tagger true energy of the scattered positron, the MC reconstructed energy, the data reconstructed energy in the 6 meter tagger, as well as MC corrected (using polynomial correction) reconstructed energy (meant to better describe the data) were compared. All 4 energies found to be different. A peak in the energy distributions around 2 GeV is seen. We checked the X position of the hits in the 6mT with energy smaller than 2 GeV. The hits positions that correspond to the low energies are mainly on the edges of the tagger as seen in fig. 5. These low energies are explained by leakage of energy - the showers of positrons hitting the edges of the 6mT are not fully contained in it and therefor only part of their energy is deposited in the tagger. The 6mT precise energy measurement is needed to determine W and therefor a 'safe' volume should have been defined. Assuming that the 6mT energy reconstruction method [7] (using 5×5 cells matrix) won't change, we choosed the volume in the 6mT for which showers will be fully contained -

15 mm $<$X position of hit in 6 meter tagger$<$ 69 mm

-12 mm $<$Y position of hit in 6 meter tagger$<$ 12 mm

In addition, we looked for correlation between energy and position in the 6mT. A clear correlation is seen in Fig. 8. We have looked at the energy distribution of hits in the 6mT located in a narrow stripe around the edges of the above defined fiducial volume (shown in fig. 6 and Fig. 7). From the mean energy in every stripe y and W values were calculated.

6 Results

The 6m tagger and the ZEUS main detector components' acceptances for photoproduction and ρ^0 elastic/diffractive production are shown in the following table for the three proton beam energies.

	Acceptance		
detector component	HER	MER	LER
6m tagger (in fiducial volume)	0.667	0.664	0.670
Calorimeter	0.601	0.603	0.605
Tracking (CTD)	0.681	0.682	0.686
Main Detector (CAL+CTD)	0.758	0.759	0.762
Full Detector (Main+ 6m tagger)	0.505	0.503	0.510

	ρ^0 Acceptance		
detector component	HER	MER	LER
6m tagger (in fiducial volume)	0.355	0.356	0.357
Calorimeter	0.168	0.170	0.171
Tracking (CTD)	0.125	0.126	0.126
Main Detector (CAL+CTD)	0.238	0.240	0.240
Full Detector (Main+ 6m tagger)	0.083	0.085	0.085

The 6m tagger acceptance for photoproduction was calculated in addition in y bins and W bins for the three energies and shown in the following tables and fig. 4.

W range	HER 6m tagger acceptance
269.0 < W < 274.0	0.401
274.0 < W < 279.0	0.661
279.0 < W < 284.0	0.815
284.0 < W < 289.0	0.658

W range	MER 6m tagger acceptance
213.0 < W < 217.0	0.408
217.0 < W < 221.0	0.676
221.0 < W < 225.0	0.823
225.0 < W < 229.0	0.636

W range	LER 6m tagger acceptance
190.0 < W < 193.5	0.402
193.5 < W < 197.0	0.648
197.0 < W < 200.5	0.805
200.5 < W < 204.0	0.670

	6 meter tagger acceptance		
y range	HER	MER	LER
0.715 < y < 0.725	0.338	0.344	0.346
0.725 < y < 0.735	0.408	0.414	0.411
0.735 < y < 0.745	0.521	0.514	0.512
0.745 < y < 0.755	0.622	0.614	0.618
0.755 < y < 0.765	0.692	0.702	0.695
0.765 < y < 0.775	0.758	0.765	0.755
0.775 < y < 0.785	0.811	0.808	0.818
0.785 < y < 0.795	0.821	0.825	0.827
0.795 < y < 0.805	0.780	0.780	0.784
0.805 < y < 0.815	0.663	0.657	0.658
0.815 < y < 0.825	0.643	0.643	0.642

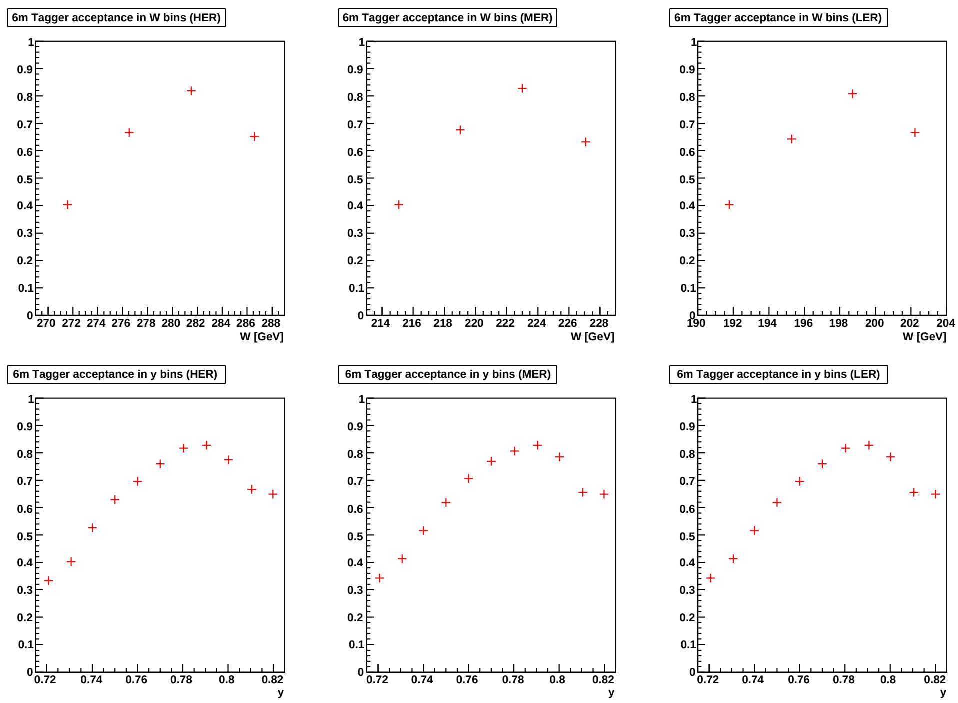

Figure 4: *6m tagger photoproduction acceptance in W bins (upper) and in y bins (lower).*

7 Conclusions

The acceptances of the ZEUS detector for photoproduction and elastic/diffractive ρ^0 production in photoproduction for the three different proton energies are the same. The precise determination of the W dependence of the γp cross-section is therfore possible.

7.1 Future work

As seen in fig. 9 and fig. 10 there is a lot of background that should be rejected. First trials were made to reject this background, but usually some of the good events were cut out too. The main effort will be to find clever cleaning cuts that will reject this backgroud without loosing good events.

8 Acknowledgments

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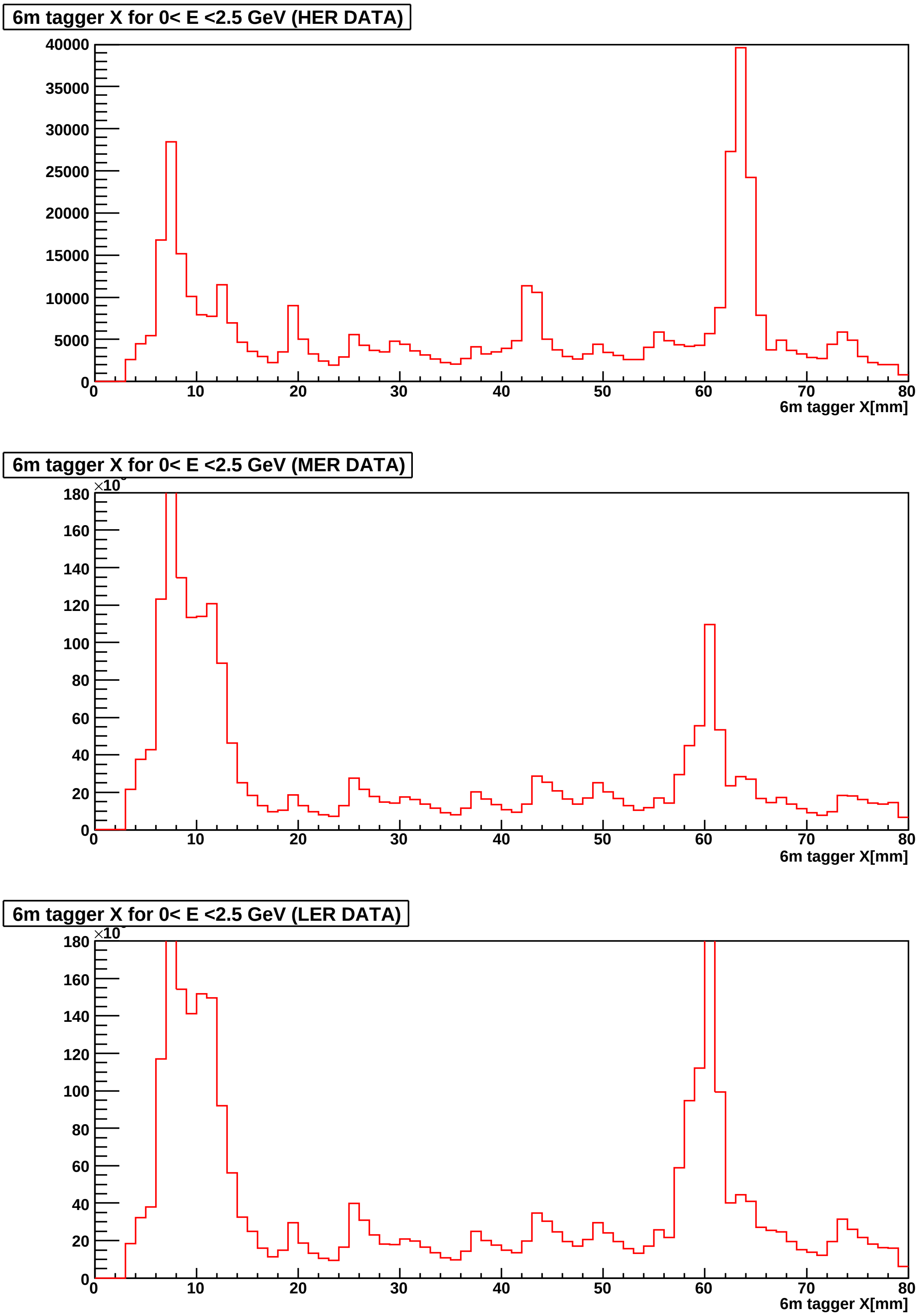

Figure 5: *6 meter tagger X position for hits with energy < 2 GeV*

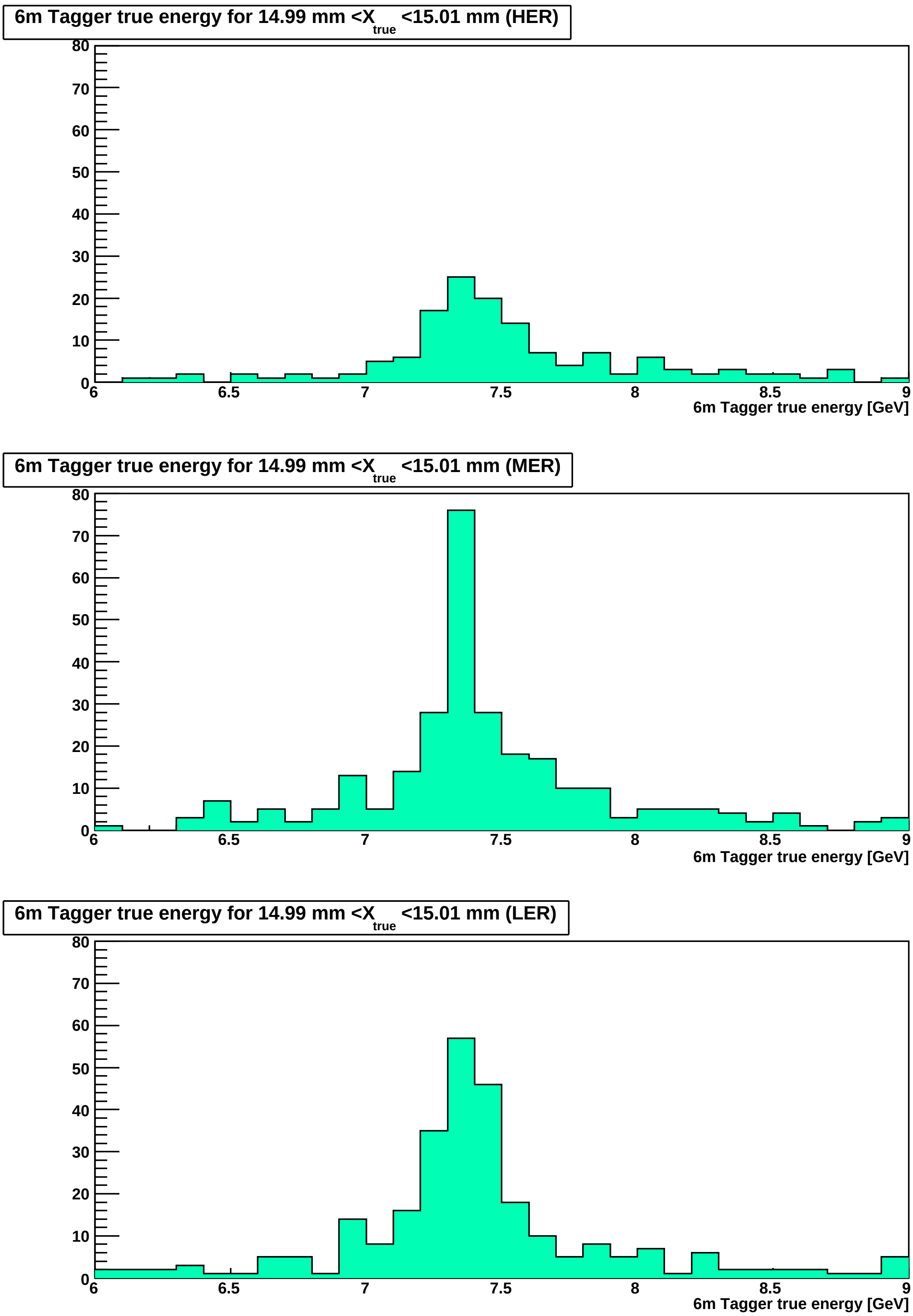

Figure 6: *6 meter tagger true energy for hits with 14.99 mm*$<X_{6mtagger}<$*15.01 mm*

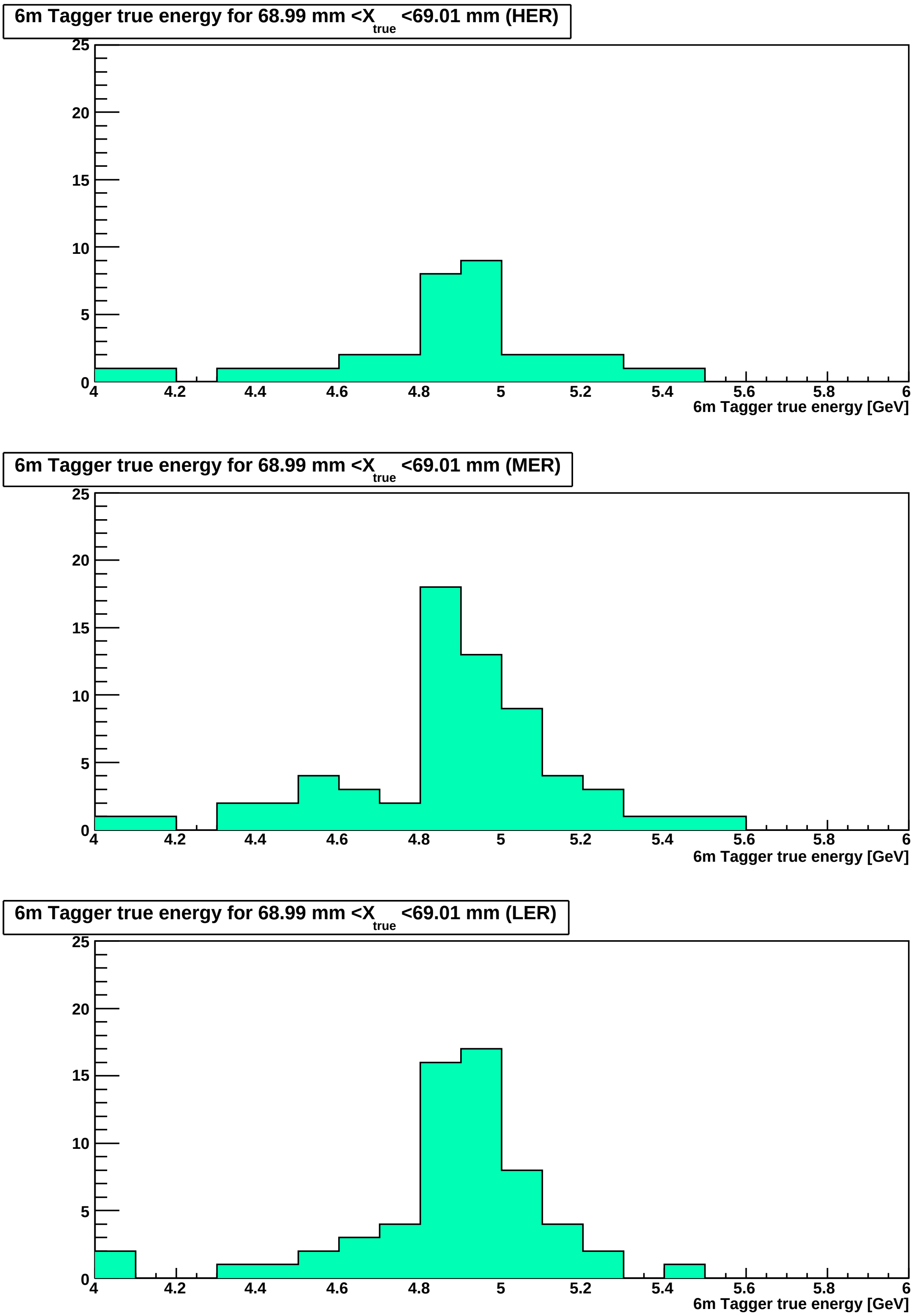

Figure 7: *6 meter tagger true energy for hits with 68.99 mm*$<X_{6mtagger}<$*69.01 mm*

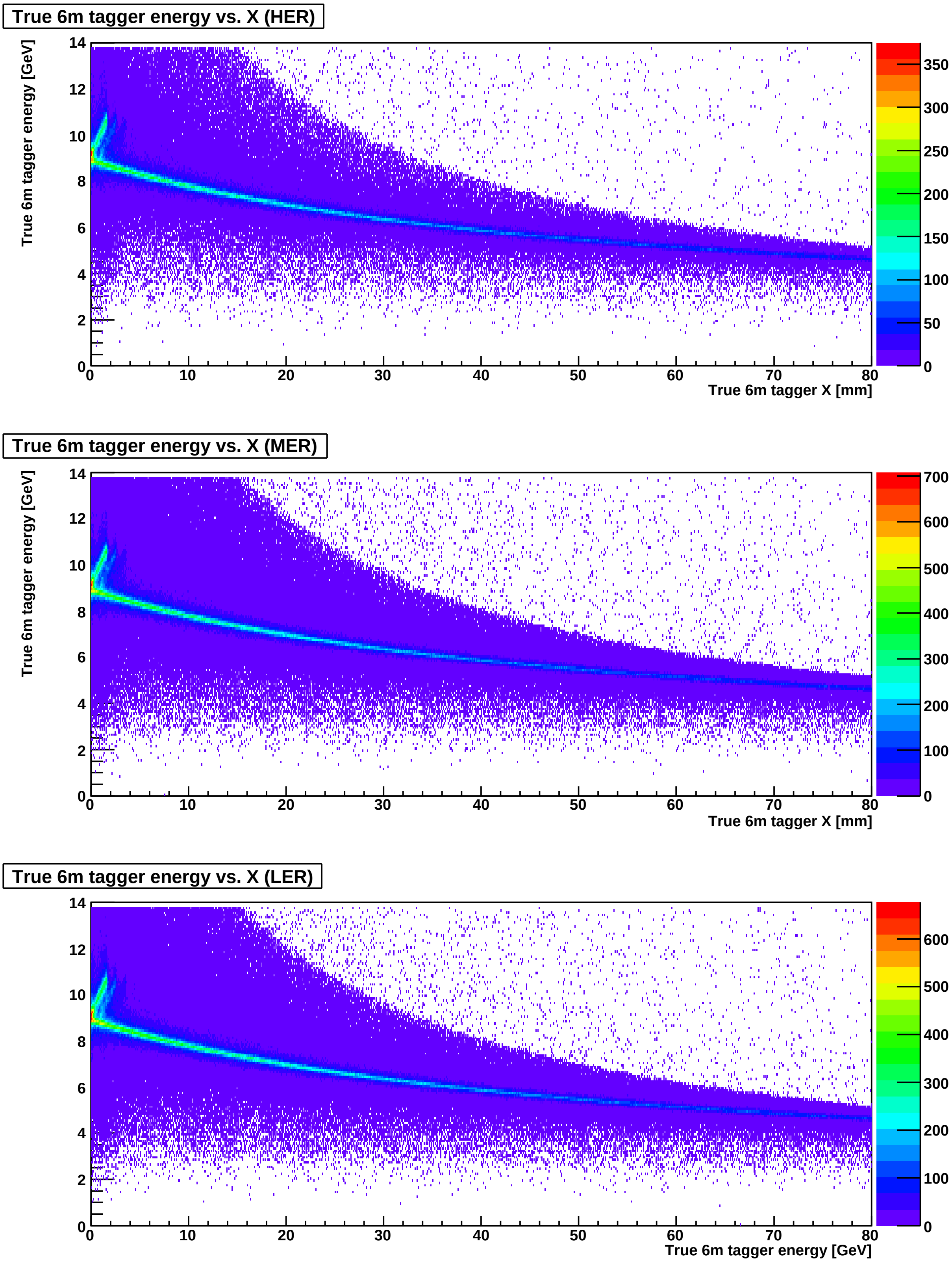

Figure 8: *6 meter tagger true energy vs. 6m tagger true X position*

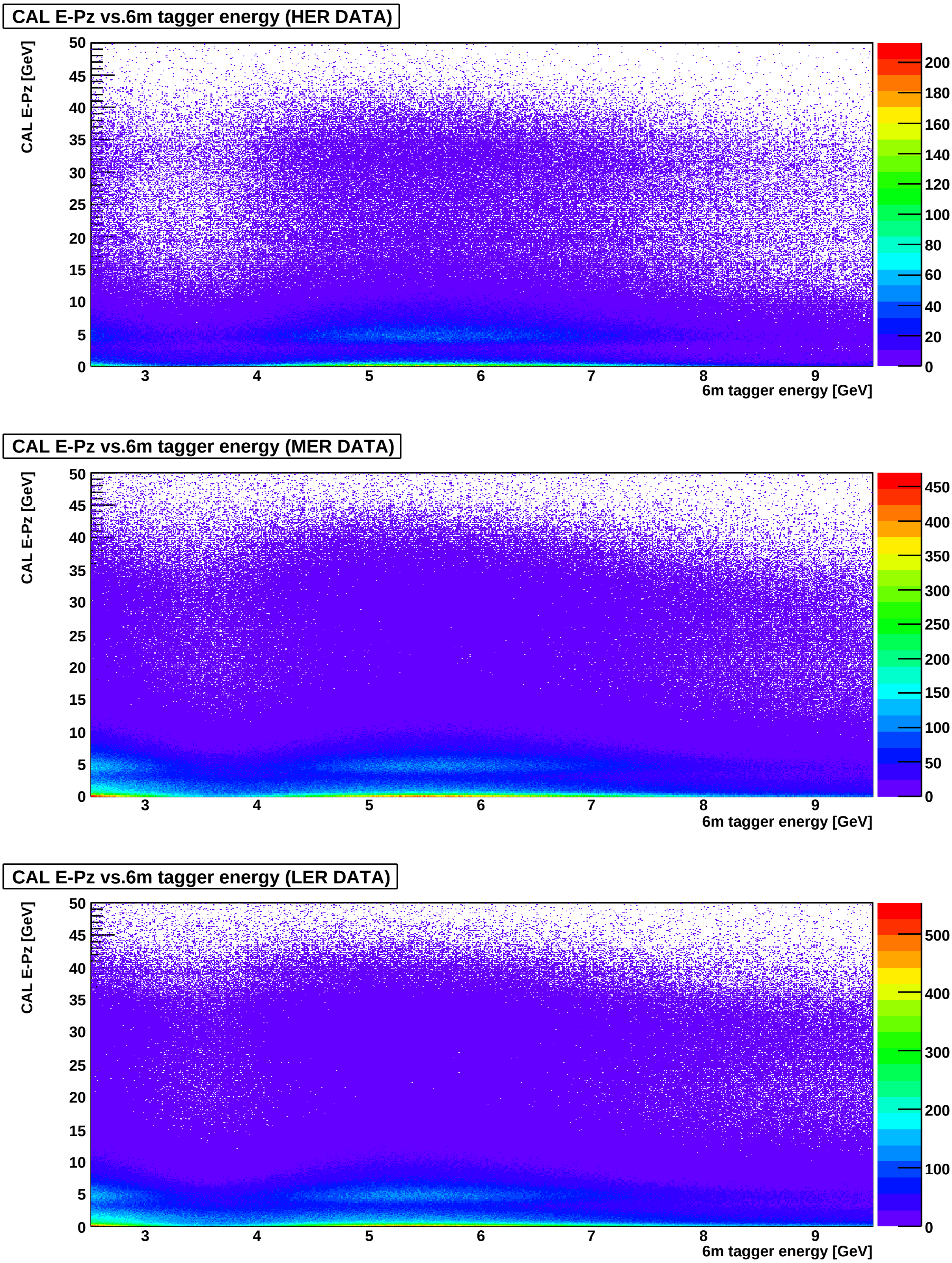

Figure 9: $(E - P_Z)_{CAL}$ *vs. 6 meter tagger reconstructed energy.*

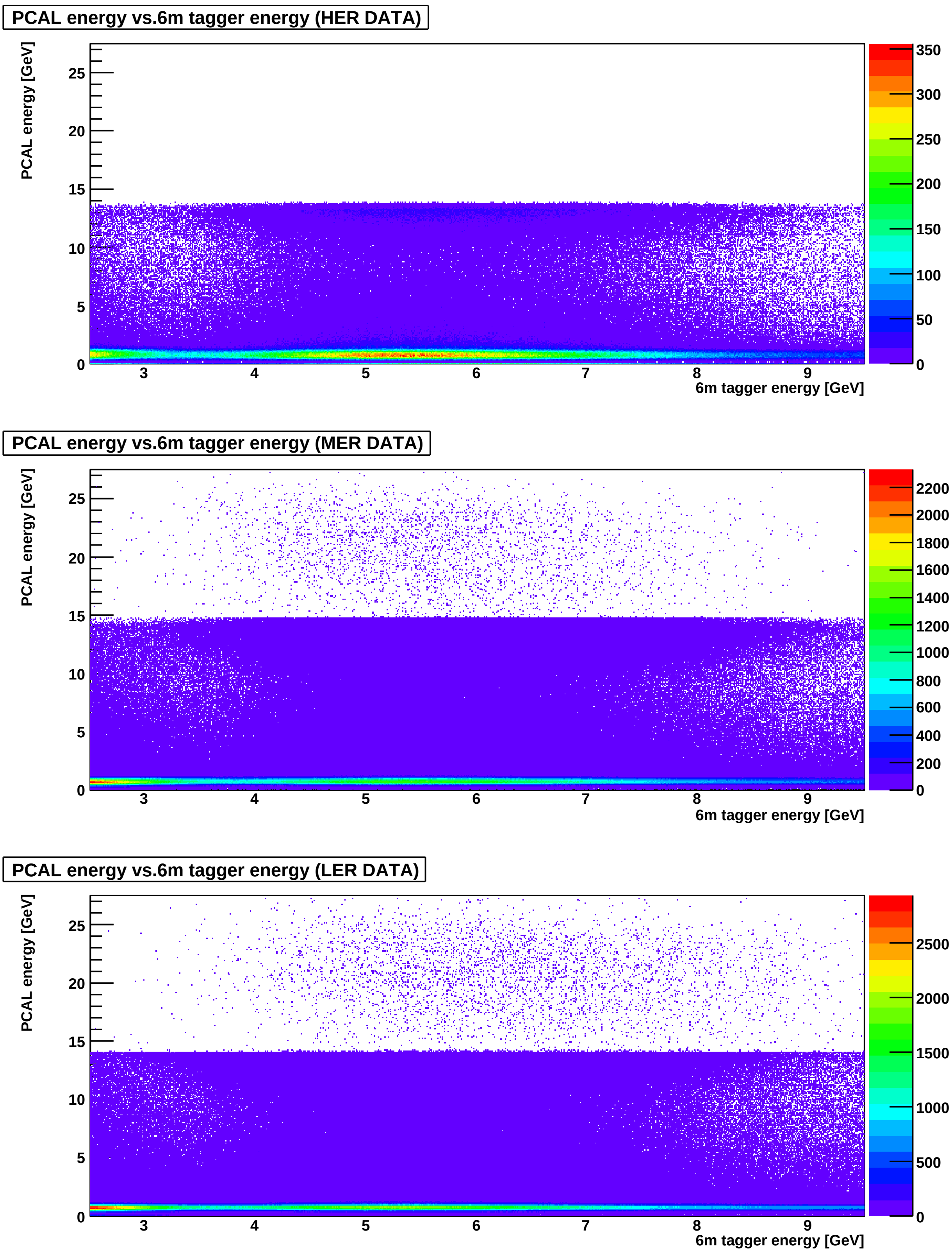

Figure 10: *PCAL energy vs. 6 meter tagger reconstructed energy.*