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Exclusive Photoproduction of $2\pi^+2\pi^-$ Final State at HERA

H1 Collaboration

Abstract

Exclusive production of four charged pions at the ep collider HERA is studied at small photon virtualities $Q^2 < 2\ \mathrm{GeV}^2$. The data were taken with the H1 detector in the years 2006 and 2007 at a centre-of-mass energies of $\sqrt{s} = 319$ GeV and $\sqrt{s} = 225$ GeV and correspond to an integrated luminosity of $7.6\ \mathrm{pb}^{-1}$ and $1.7\ \mathrm{pb}^{-1}$ respectively. The cross section of the reaction $\gamma p \to (2\pi^+2\pi^-)Y$ is determined in the phase space of $35 < W_{\gamma p} < 100$ GeV, $|t| < 1\ \mathrm{GeV}^2$ and $M_Y < 1.6$ GeV. The 4π mass spectra indicate that the reaction proceeds predominantly via production and decay of ρ' resonances. The fit however does not allow yet to distinguish unambiguously between the hypotheses of one or two broad and overlapping ρ' resonances.

1 Introduction

The aim of the analysis is to measure exclusive photoproduction of four charged pions at HERA and investigate which ρ' resonances contribute to this reaction. Although $\rho(1450)$ and $\rho(1700)$ resonances are by now well established [1], experimental information on their properties is sparse. In photoproduction, only early fixed target experiments [2–7] studied this reaction. HERA for the first time gives the possibility to investigate ρ' production in a new, much higher energy domain. Previously, ZEUS extracted ρ' cross sections in exclusive two-pion electroproduction [8] at HERA, where $\rho(1450), \rho(1700)$ are hidden by large ρ^0 signal. Contrary to that, in four-pion final state in absence of ρ^0 the dominant contribution is expected to be due to its higher mass excitations, generically called ρ'.

Here we start with photoproduction which allows for large statistics samples.

2 Analysis Outline and Main Results

The analysis presented here is based on two data sets, both recorded with the positron beam energy of $E_e = 27.6$ GeV. The first data set was taken in the years $2006 - 2007$ when HERA collider operated with the proton beam energy of $E_p = 920$ GeV, resulting in a centre of mass energy $\sqrt{s} = 319$ GeV. It corresponds to an integrated luminosity $\mathcal{L} = 7.6\ \mathrm{pb}^{-1}$ and is referred hereafter as high-energy (HE). The second data set was collected in the last month of HERA operation with the proton beam energy of $E_p = 460$ GeV, resulting in $\sqrt{s} = 225$ GeV. This sample is named low-energy (LE) and corresponds to $\mathcal{L} = 1.7\ \mathrm{pb}^{-1}$.

Medium multiplicity photoproduction events were collected with a special Fast Track Trigger (FTT) requiring at least 3 tracks with $p_t > 160$ MeV and in addition from 1 to 3 tracks with $p_t > 100$ MeV, all originating from the nominal event vertex. The efficiency of this trigger for signal events was found to be $\sim 70\%$.

For the analysis exclusive events are selected, containing four charged pion candidates with zero net charge in the central tracker and nothing else above noise level in the detector including its forward apparatus, which thus covers pseudorapidity range $-4 < \eta_{\mathrm{lab}} < 7.5$. The absence of the scattered beam positron signal ensures photoproduction regime with photon virtuality $Q^2 < 2\ \mathrm{GeV}^2$ and its average value of $0.02\ \mathrm{GeV}^2$, as deduced from Monte Carlo simulations. The veto on the forward activity suppresses proton dissociation down to very low masses, $M_Y < 1.6$ GeV and limits four-momentum transfer squared at the proton vertex, $|t| < 1\ \mathrm{GeV}^2$.

All 4 tracks are required to originate from the common vertex lying within ± 30 cm in z of the nominal e^+p interaction point and must have transverse momenta above 100 MeV and polar angles within the interval $20^\circ \leq \theta \leq 160^\circ$. Non-$ep$ background is controlled with the event vertex distribution shape and using unpaired e and p pilot bunches. The major part of this background is located at low $W_{\gamma p}$, which dictated the choice of the low W boundaries in HE and LE samples.

After all selections final samples contain $\sim 79,800$ and $\sim 14,400$ events in HE and LE data sets respectively. The remaining background, originating from non-exclusive events of the type

$2\pi^+2\pi^-X$, where X denotes any neutral or charged particle escaping undetected, is estimated to be 15% in HE sample and 20% in LE sample. Control plots illustrating the data description by the Monte Carlo model are shown in Fig. 2,3. Here both, signal processes (elastic $\rho(1450)$, $\rho(1700)$ production) and background events (proton-, photon and double-dissociation reactions) were generated using the program DIFFVM [9], which is based on Regge theory and the Vector Dominance Model. For $\rho(1450), \rho(1700)$ resonances decay modes to $\pi\pi, 4\pi$ and $\rho\pi\pi$ were included.

Main characteristics of two data sets are compared in table 1. The overall detector acceptance times efficiency for this event selection is $\approx 11\%$.

Item	HE set	LE set
$\mathcal{L}/\mathrm{pb}^{-1}$	7.6	1.7
$Q^2_{\max}/\mathrm{GeV}^2$	2.0	2.0
$\langle Q^2\rangle/\mathrm{GeV}^2$	0.02	0.02
W range, GeV	$45-100$	$35-75$
$\langle W\rangle$/GeV	66	48
WWA flux	0.07438	0.06940
Statistics	$79,776$	$14,411$
Non-ep bgr.	$(1.0\pm0.2)\%$	$(1.6\pm0.5)\%$

Table 1: Main characteristics of HE and LE data sets. WWA flux [10] is a flux factor, converting ep cross sections to γp ones.

The measurements are given in terms of photoproduction cross sections, $\sigma_{\gamma p}$, for the phase space of $M_Y < 1.6$ GeV, $|t| < 1$ GeV^2 and $45 < W < 100$ GeV (HE) and $35 < W < 75$ GeV (LE) respectively. The total cross section for exclusive $2\pi^+2\pi^-$ photoproduction, at the reference point $W = 75$ GeV is measured to be

$$\sigma_{\gamma p\to(2\pi^+2\pi^-)Y} = (1.07\pm0.01_{\mathrm{stat}}\pm0.14_{\mathrm{sys}})\ \mu\mathrm{b}.$$

The energy dependence of the elastic[1] photoproduction cross section $\sigma(\gamma p \to (2\pi^+2\pi^-)p)$ is shown in Fig. 4. Regge-motivated power low fit results in a value of W slope which is characteristic for reactions mediated by soft Pomeron, similar to those of light vector mesons in photoproduction. In Fig. 5 these results are compared to low energy cross sections obtained in fixed target experiments [2–6]. Here again, the Regge-inspired fit demonstrates the change in the energy dependence from the reggeon dominated to the pomeron dominated regime.

Fig. 6 shows the differential cross section $\mathrm{d}\sigma/\mathrm{d}p_t^2$ for 4π system. It exhibits exponential behaviour with the slope b_1 typical for elastic photoproduction processes involving light vector mesons.

Finally, the invariant mass distribution for the 4π system is shown in Fig. 7. It shows that the vast majority of events populate the mass range around 1.6 GeV with the width of ~ 600

[1]For this measurement an extra correction of $(10\pm4)\%$ has been applied to account for remaining low mass proton dissociation.

MeV. This supports the expectation of predominantly resonant production of the final state. For the moment however, a simple fit including interfering resonant and non-resonant production amplitudes does not allow to distinguish between the hypotheses of one or two broad and overlapping resonances and hence to make a quantitative conclusion about ρ' cross section.

3 Summary

Total and differential cross sections for exclusive photoproduction of four charged pions is measured for the first time at HERA. The analysis in terms of ρ' resonances continues.

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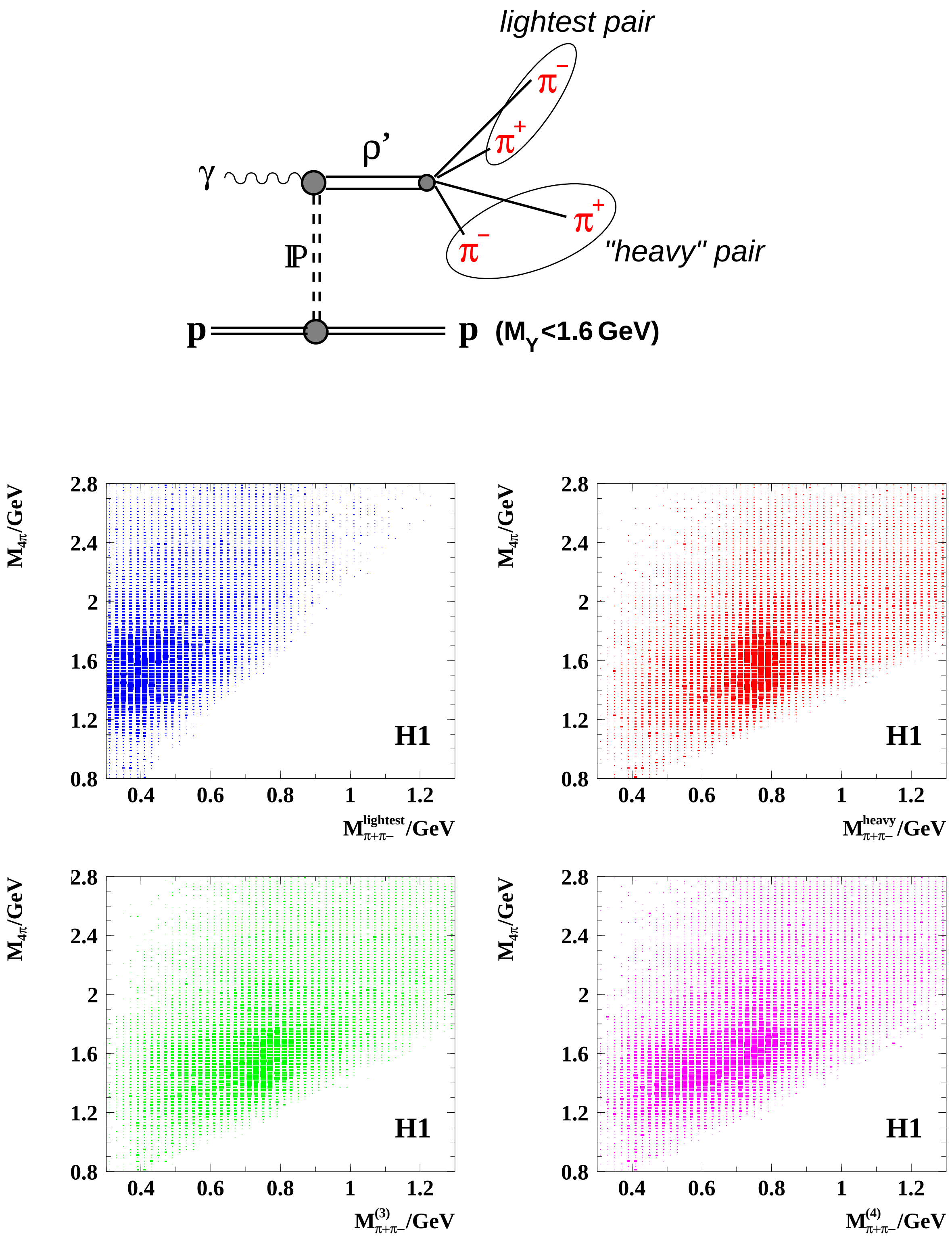


Figure 1: (a) Sketch illustrating 2π mass separation/correlation; (b) 2π-4π correlations of reconstructed invariant mass with the following naming convention: *lightest* - $\pi^+\pi^-$ pair with the minimal invariant mass among four possible combinations, *heavy* - the pair, opposite to the lightest, (3) and (4) - two remaining combinations.

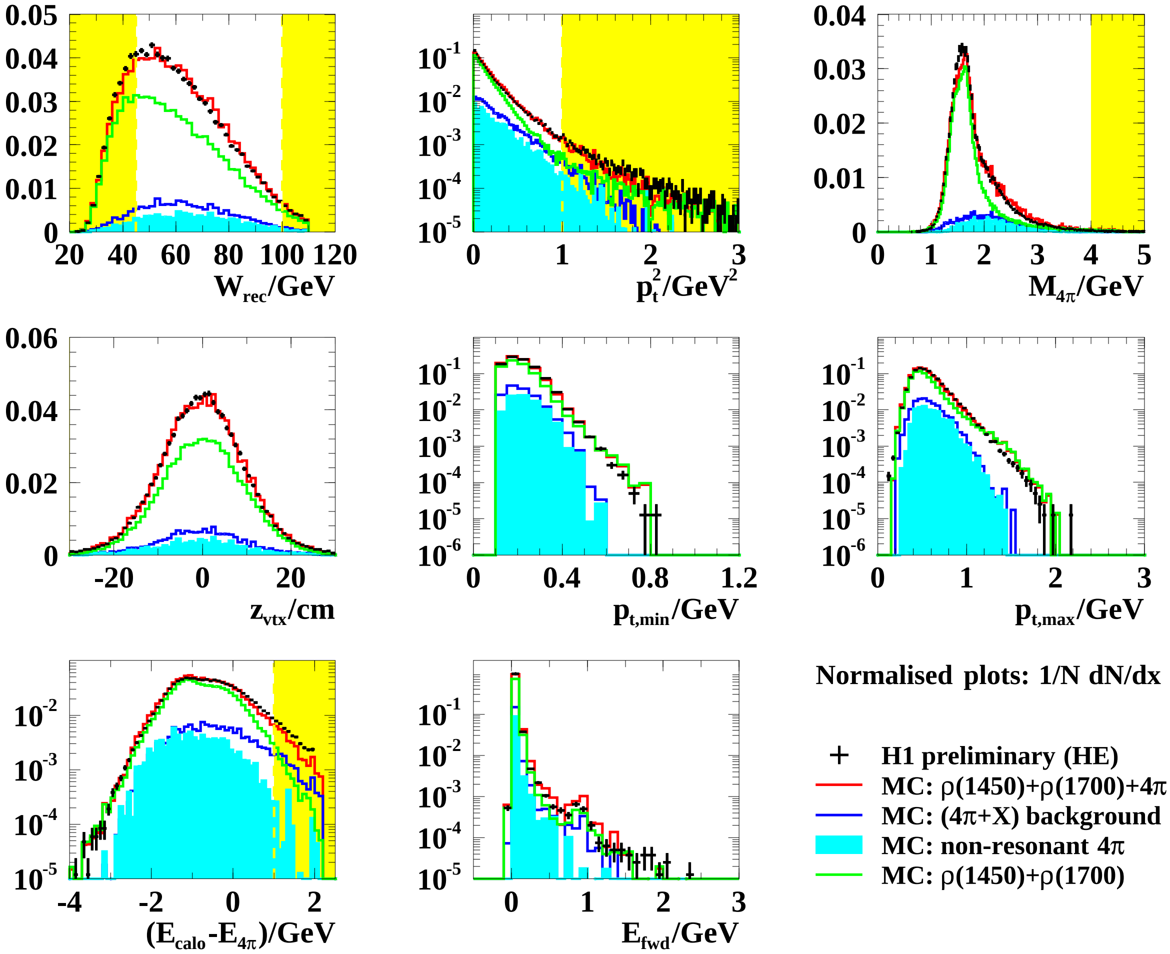


Figure 2: 8-panel control plot for $\sqrt{s} = 319$ GeV (HE) data sample before final selection cuts are applied. Top row: W, p_t^2 and mass of the 4π system. Middle row: event z-vertex, minimal and maximal transverse momenta among 4 charged pions ($p_{t,min}$ and $p_{t,max}$ respectively). Bottom row: The difference between total calorimeter energy and energy of the 4π system ($E_{calo} - E_{4\pi}$) and LAr energy in the forward direction, $\eta_{\rm lab} > 2$ (E_{fwd}). DIFFVM MC generator is used both for signal (elastic ρ', ρ'' and non-resonant 4π production) and background (proton- photon- and double-dissociation processes). Yellow bands indicate final selection cuts.

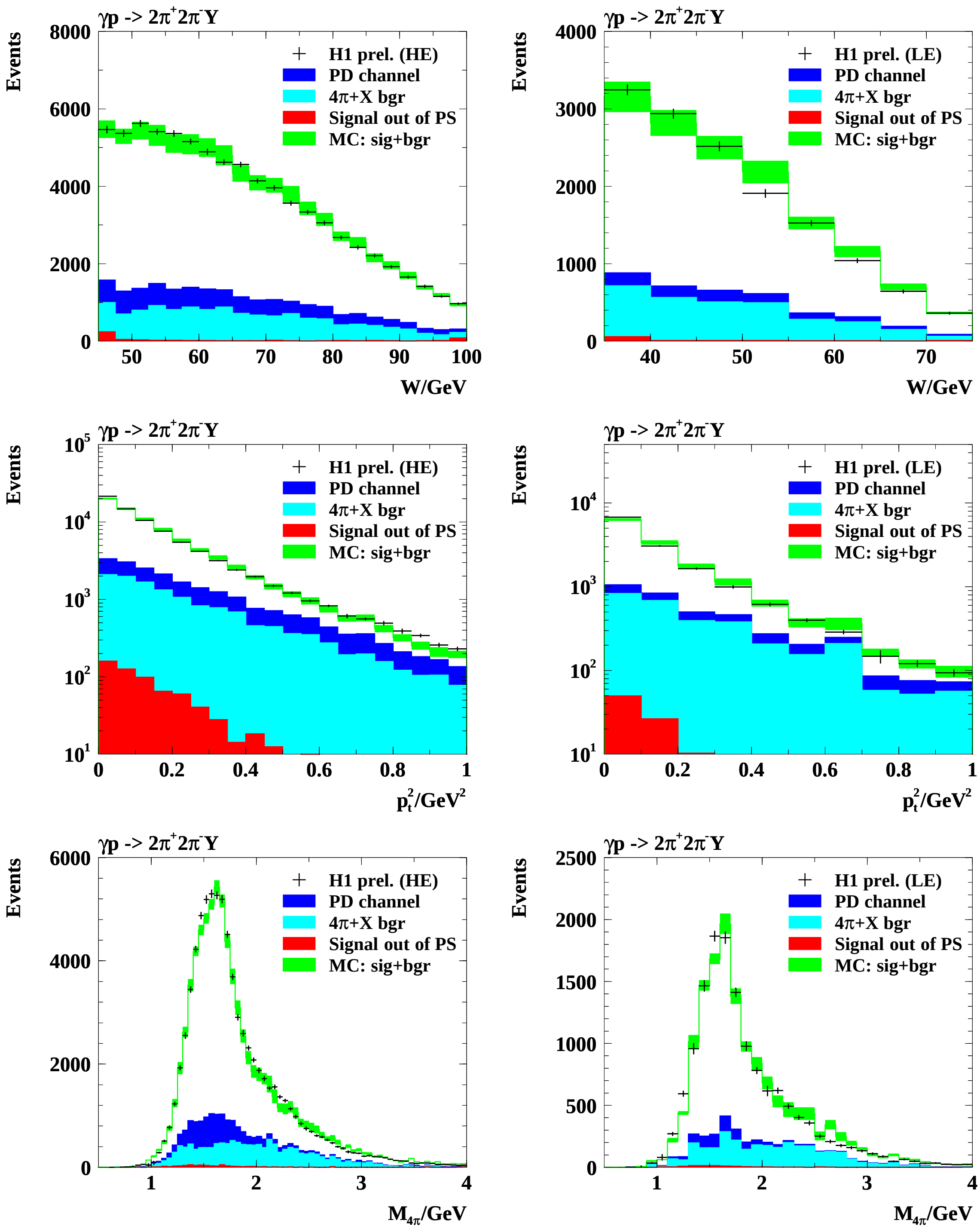


Figure 3: 6 **separate** control plots for W, p_t^2 and $M_{4\pi}$ after applying final selection cuts. Left column: in $\sqrt{s} = 319$ GeV (HE) data sample; right column: in $\sqrt{s} = 225$ GeV (LE) data sample. H1 data are compared to Monte Carlo simulation (normalised to the data) in which all signal and background channels are modelled by DIFFVM program [9]. Green band represents systematic uncertainty related to the $(4\pi + X)$ background subtraction only.

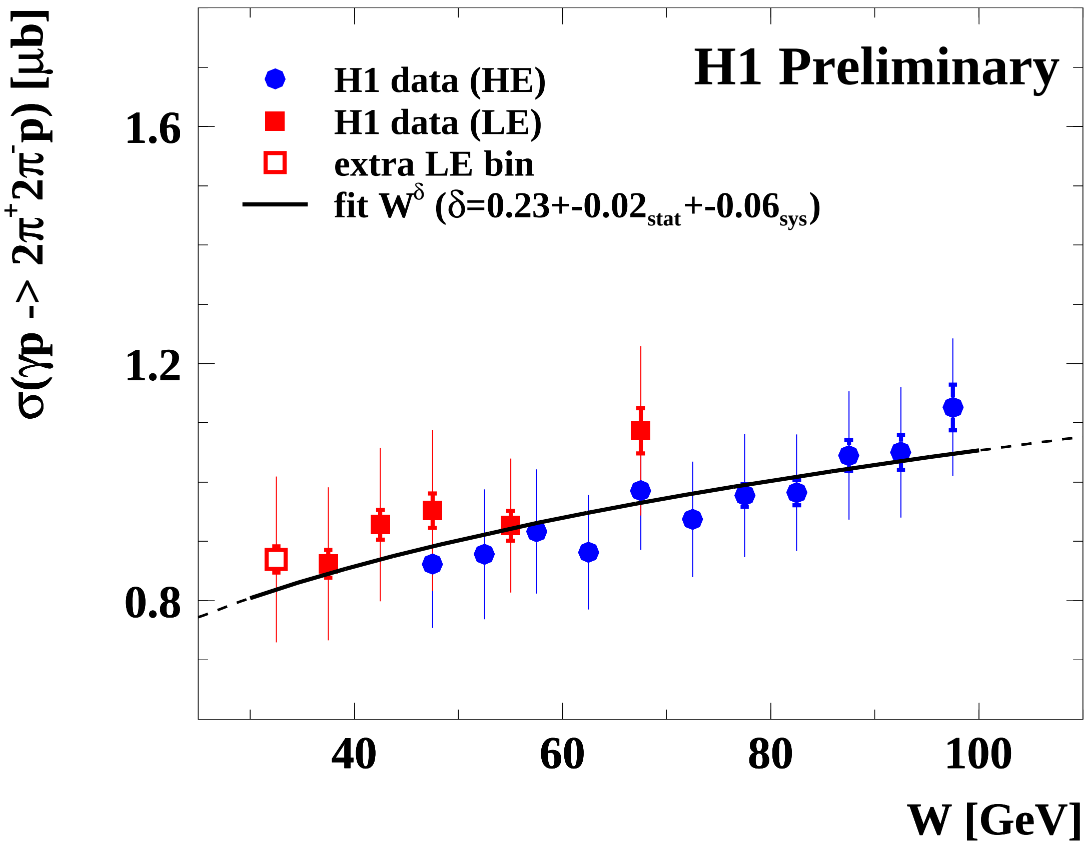


Figure 4: Energy dependence of the reaction $\gamma p \to (2\pi^+ 2\pi^-)p$ measured in e^+p collisions at two centre of mass energies: $\sqrt{s} = 319$ GeV (HE) and $\sqrt{s} = 225$ GeV (LE). Inner error bars are statistical uncertainty, while outer error bars represent total errors. An “extra LE bin” $30 < W < 35$ GeV, which is on 9.5% contaminated by non-ep background, is used only for this plot (the background is statistically subtracted). In addition, for this measurement an extra $(10 \pm 4)\%$ correction is appied for proton dissociation (PD) contamination. The curve represents Regge motivated power low fit to these data.

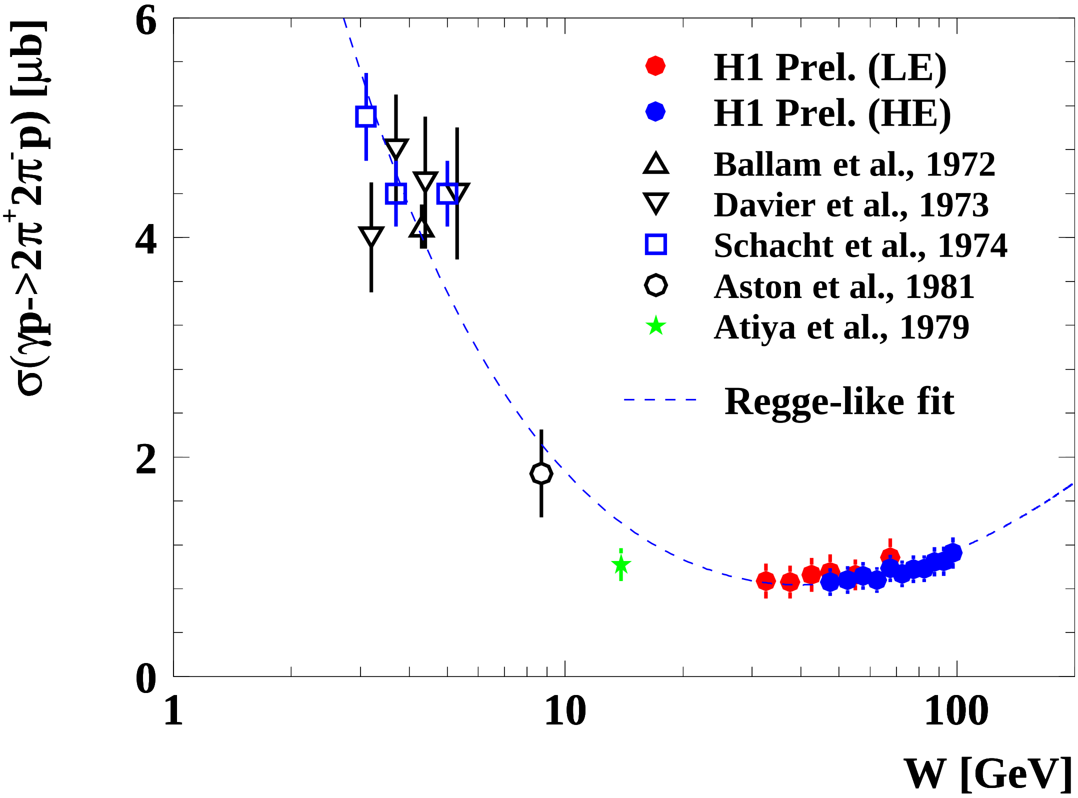


Figure 5: Energy dependence of the reaction $\gamma p \to (2\pi^+2\pi^-)p$ measured in e^+p collisions at two centre of mass energies: $\sqrt{s} = 319$ GeV (HE) and $\sqrt{s} = 225$ GeV (LE) compared to the world results obtained in fixed target photoproduction experiments [2–6]. Dashed curve represents Regge motivated fit to these data.

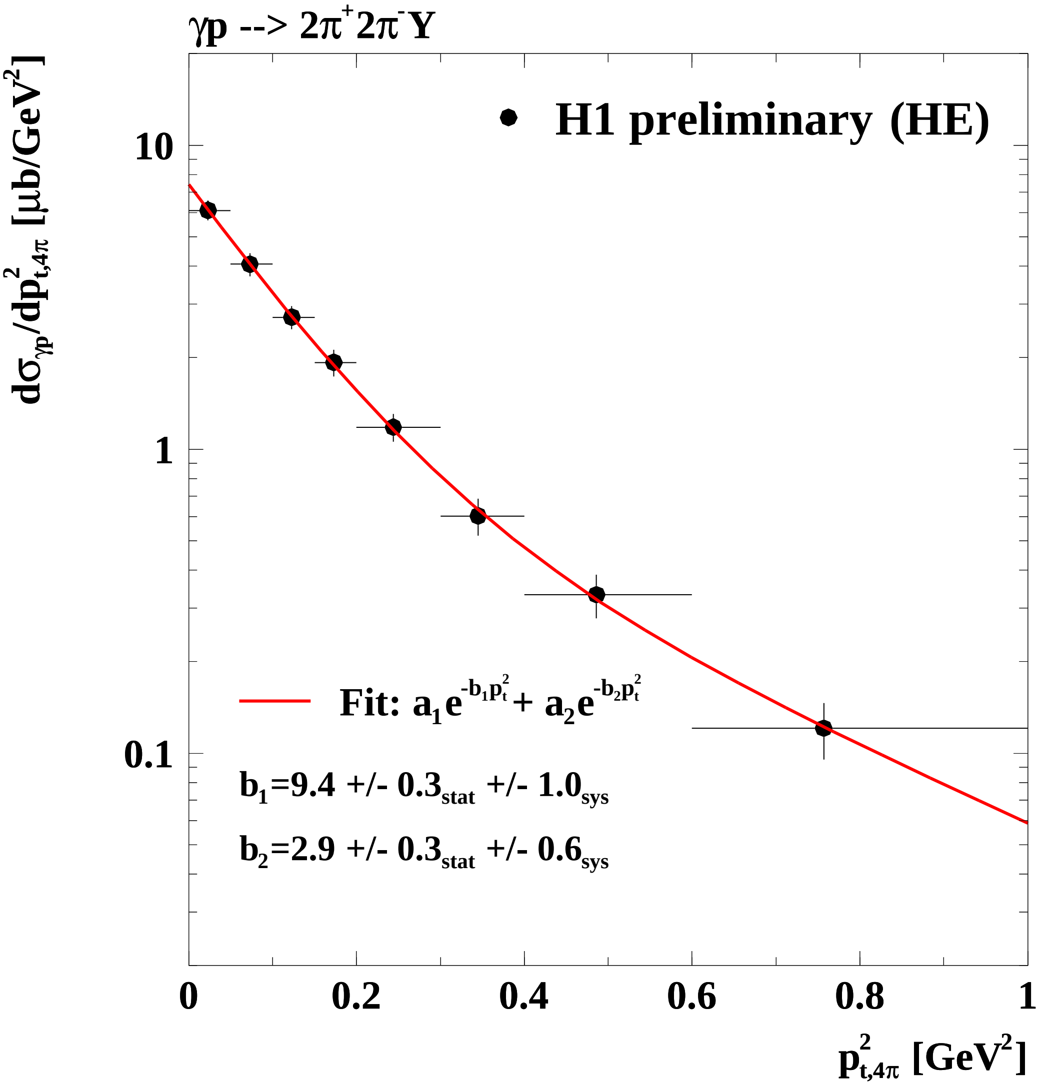
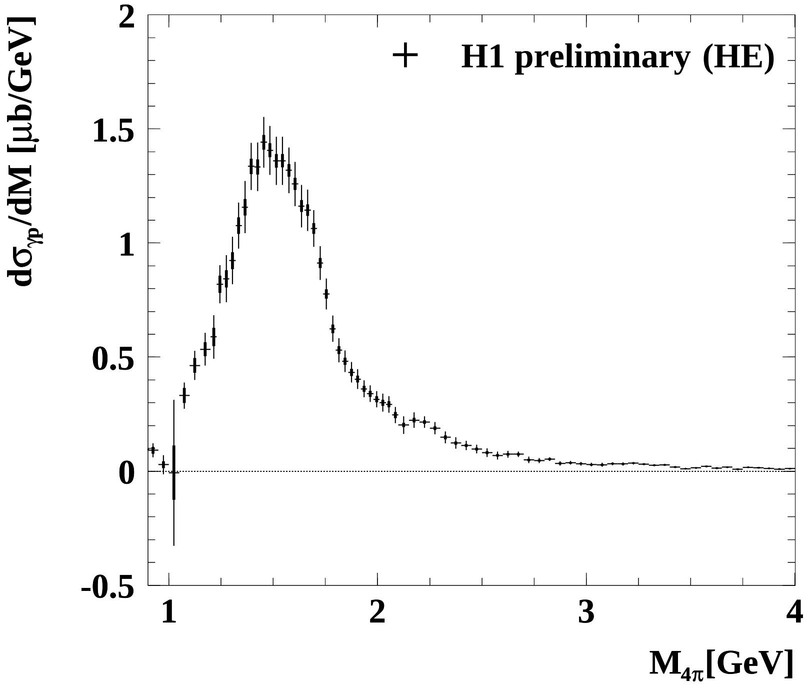


Figure 6: Differential cross section $\mathrm{d}\sigma/\mathrm{d}p_t^2$ for exclusive photoproduction of four charged pions at HERA. The measurement is performed in the phase space $45 < W_{\gamma p} < 100$ GeV, $M_Y < 1.6$ GeV and $M_{4\pi} < 4$ GeV at the centre of mass energy of $\sqrt{s_{ep}} = 319$ GeV.



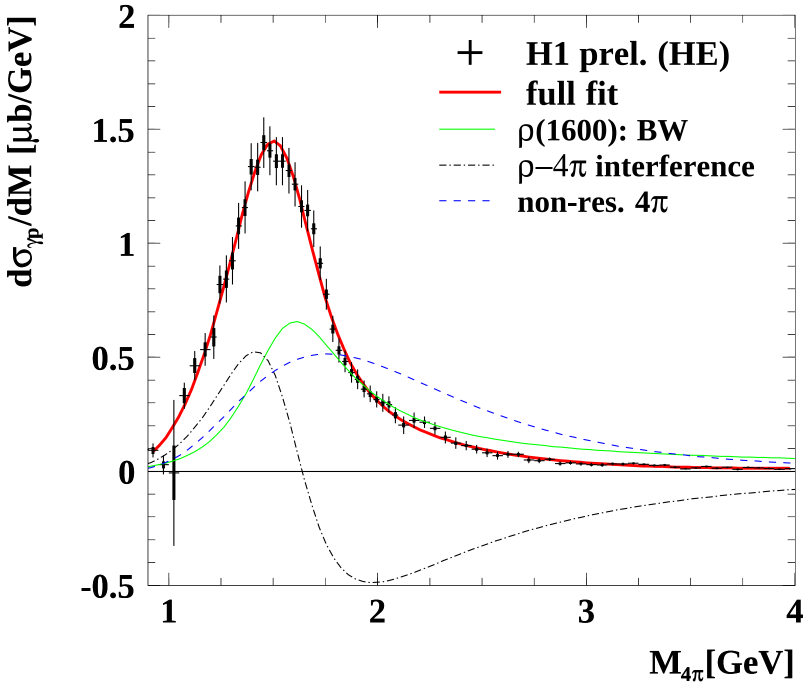


Figure 7: Differential cross section $\mathrm{d}\sigma/\mathrm{d}M$ for exclusive photoproduction of four charged pions at HERA. The measurement is performed in the phase space $45 < W_{\gamma p} < 100$ GeV, $M_Y < 1.6$ GeV and $|t| < 1\mathrm{GeV}^2$ at the centre of mass energy of $\sqrt{s_{ep}} = 319$ GeV. Inner error bars represent statistical uncertainty, while outer error bars are statistical and systematic uncertainty added in quadrature. Bottom figure also displays fit result, assuming that only one ρ' resonance contribute in addition to the non-resonant and interference terms.