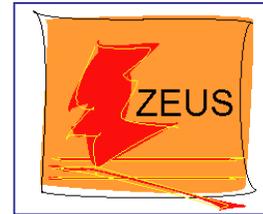


**XIX International Workshop on
Deep-Inelastic Scattering and
Related Subjects**



Exclusive electroproduction of two pions at HERA

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(on behalf of the ZEUS Collaboration)*

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Outline

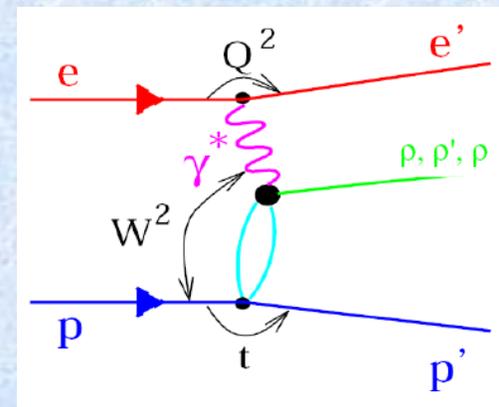
- Motivation;
- Dipion production;
- Pion form factor and $\pi\pi$ mass fit;
- Cross section ratios;
- Q^2 dependence;
- Summary;

Motivation

- The only radially excited $2S$ triplet $qq\bar{q}$ state studied at HERA so far is the photoproduction of the $\psi(2S)$ state. $\rho'(1450)$ is assumed to be predominantly a radially excited $2S$ state and the $\rho''(1700)$ - an orbitally excited $2D$ state, with some mixture of S and D waves .
- Calculations in a QCD framework predict interesting features in the Q^2 (photon virtuality) dependence of the ratio of excited to ground-state vector meson, in particular those consisting of light quarks, like $\rho'(1450)$ and $\rho''(1700)$.

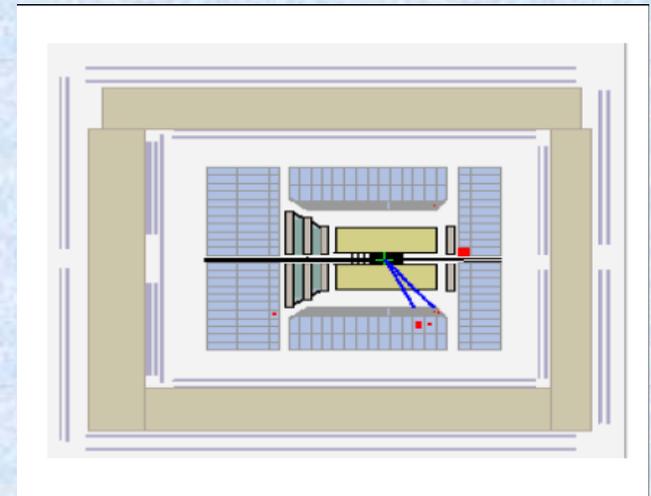
Measurement

- **ZEUS detector at HERA collider: protons 920 GeV, electrons or positrons 27.5 GeV. Sample 81.7 pb^{-1} ($16.7 \text{ pb}^{-1} e^-$ and $65.0 \text{ pb}^{-1} e^+$);**
- **study of exclusive electroproduction of two pions $\gamma^* p \rightarrow \pi^+ \pi^- p$ in the mass range $0.4 < M_{\pi\pi} < 2.5 \text{ GeV}$;**
- **contribution of the three vector mesons ρ^0 , ρ^+ and ρ^- and compare their Q^2 dependence to QCD predictions;**



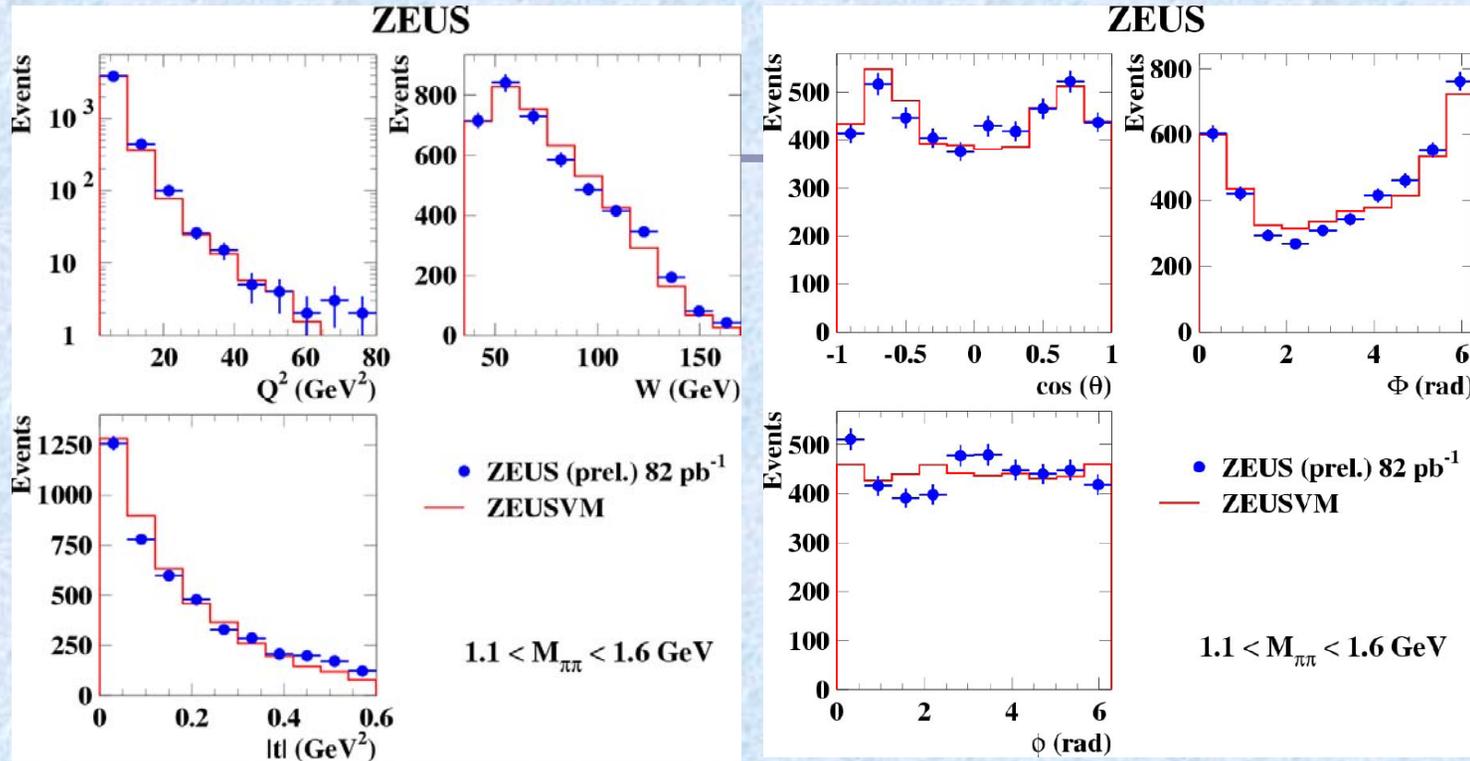
Offline selection

- scattered electron, with energy $> 10 \text{ GeV}$;
- $E - P_z > 45 \text{ GeV}$,
where $E - P_z = \sum_i (E_i - P_{zi})$ - summation over energies and longitudinal momenta of the final-state electron and pions;
- Z coordinate of the interaction vertex within $\pm 50 \text{ cm}$ of the nominal interaction point;
- in addition to the scattered electron, exactly two oppositely charged tracks, each associated with the reconstructed vertex, and each having pseudorapidity $|\eta| < 1.75$ and transverse momentum $p_t > 150 \text{ MeV}$.



62,511 events selected

Kinematic regions and MC



(MC program
Zeusvm
interfaced to
Heracles4.4)

- $2 < Q^2 < 80 \text{ GeV}^2$, four-momentum squared of the virtual photon;
- $32 < W < 180 \text{ GeV}$, centre-of-mass energy of the photon-proton system
- $|t| < 0.6 \text{ GeV}^2$ - squared four-momentum transfer at the proton vertex.
- θ and ϕ - the polar and azimuthal angles of the positively charged decay pion;
- Φ - angle between meson prod. plane and positron scattering plane in γ^*p c.m. frame.

Pion form factor

$M_{\pi\pi}$ two pion invariant mass distribution:

$$\frac{dN(M_{\pi\pi})}{dM_{\pi\pi}} \propto |F_{\pi}(M_{\pi\pi})|^2$$

Kuhn-Santamaria parameterization, includes $\rho(770)$, $\rho'(1450)$ and $\rho''(1700)$ resonances

$$F_{\pi}(M_{\pi\pi}) = \frac{BW(\rho) + \beta BW(\rho') + \gamma BW(\rho'')}{1 + \beta + \gamma}$$

where β and γ are relative amplitudes

BW - Breit-Wigner

$$BW(M_V) = \frac{M_V^2}{M_V^2 - M_{\pi\pi}^2 - iM_V\Gamma_V(M_{\pi\pi})}$$

where M_V – mass and

$\Gamma_V(M_{\pi\pi})$ -width

$$\Gamma_V(M_{\pi\pi}) = \Gamma_V \left[\frac{p_{\pi}(M_{\pi\pi})}{p_{\pi}(M_V)} \right]^3 \left[\frac{M_V^2}{M_{\pi\pi}^2} \right]$$

$\pi\pi$ mass fit

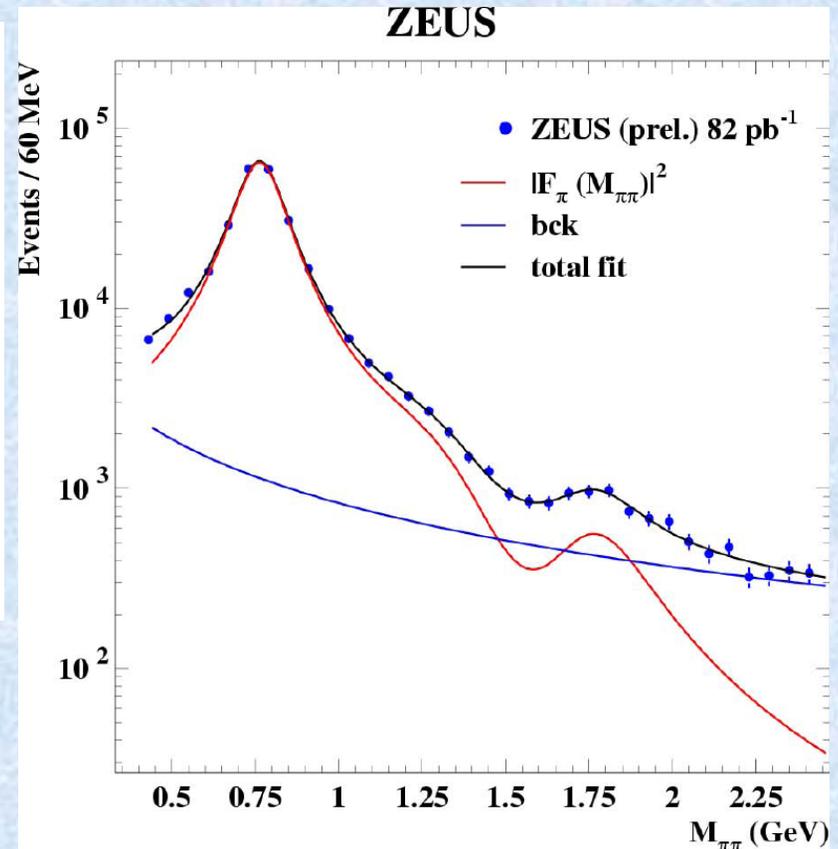
$$\frac{dN(M_{\pi\pi})}{dM_{\pi\pi}} = N \left[|F_{\pi}(M_{\pi\pi})|^2 + \frac{B}{M_{\pi\pi}^n} \right]$$

Fit parameters

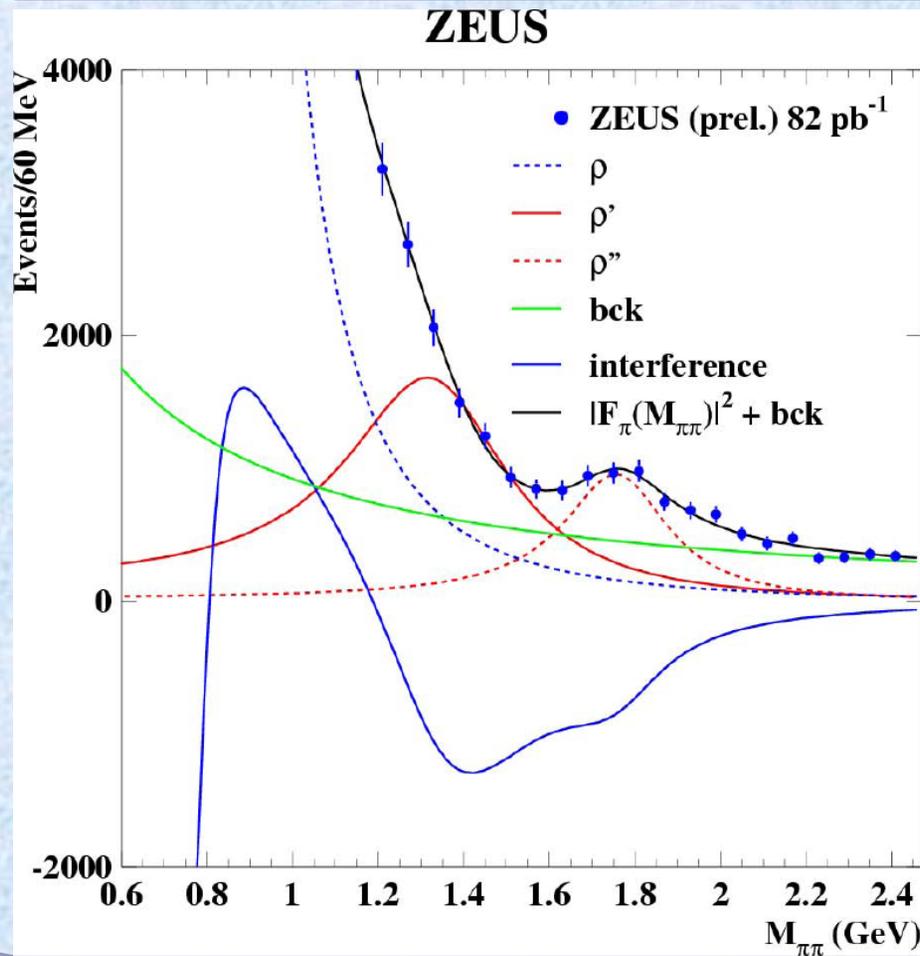
Parameter	ZEUS	PDG
M_{ρ} (MeV)	$772 \pm 2^{+2}_{-1}$	775.49 ± 0.34
Γ_{ρ} (MeV)	$155 \pm 5 \pm 2$	149.4 ± 1.0
β	$-0.27 \pm 0.02 \pm 0.02$	
$M_{\rho'}$ (MeV)	$1360 \pm 20^{+20}_{-30}$	1465 ± 25
$\Gamma_{\rho'}$ (MeV)	$460 \pm 30^{+40}_{-45}$	400 ± 60
γ	$0.10 \pm 0.02^{+0.02}_{-0.01}$	
$M_{\rho''}$ (MeV)	$1770 \pm 20^{+15}_{-20}$	1720 ± 20
$\Gamma_{\rho''}$ (MeV)	$310 \pm 30^{+25}_{-35}$	250 ± 100

Reasonable description ($\chi^2/\text{dof}=1.2$)

Two pion invariant mass distribution



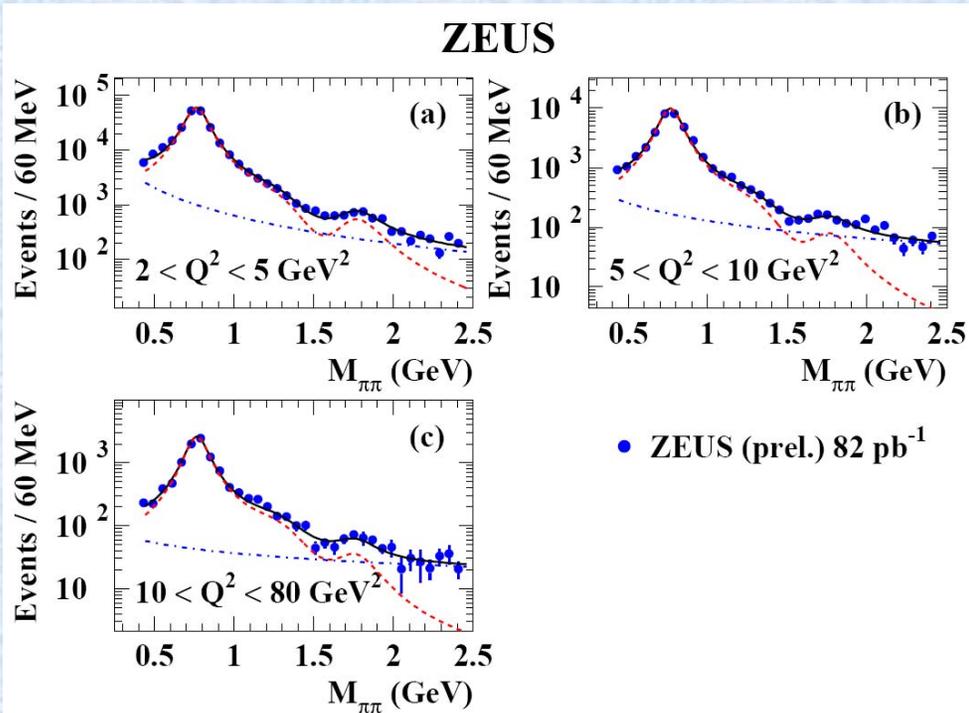
Mass fit



Separate contributions
of three resonances.

Total interference term (sum of
three interference terms)
and the background. The
total interference term is
negative in the ρ' region.

Q^2 dependence of the pion form factor



Q^2 dependence of the relative amplitudes was determined by repeating the fit to $M_{\pi\pi}$ in three Q^2 regions, 2-5, 5-10 and 10-80 GeV².

Reasonable description of the data is achieved in all Q^2 regions.

Q^2 dependence of β and γ parameters:

$Q^2(\text{GeV}^2)$	2-5	5-10	10-80
β	$-0.25 \pm 0.01^{+0.005}_{-0.003}$	$-0.28 \pm 0.01^{+0.005}_{-0.008}$	$-0.35 \pm 0.02 \pm 0.01$
γ	$0.10 \pm 0.01 \pm 0.003$	$0.10 \pm 0.01^{+0.005}_{-0.003}$	$0.12 \pm 0.02^{+0.008}_{-0.006}$

The Q^2 dependence of the ratio R_V

Cross section of V meson production:

$$\sigma(V) = \frac{N_V(1 - f_{pdiss})}{A \cdot Br(\pi\pi) \cdot L}$$

where

N_V - acceptance corrected number of V mesons;

A - acceptance;

$Br(\pi\pi)$ - branching ratio V meson into $\pi\pi$,

L - luminosity;

f_{pdiss} - fraction of proton dissociation events.

We studied:

$$R_V = \frac{\sigma(V) \cdot Br(V \rightarrow \pi\pi)}{\sigma(\rho^0)}$$

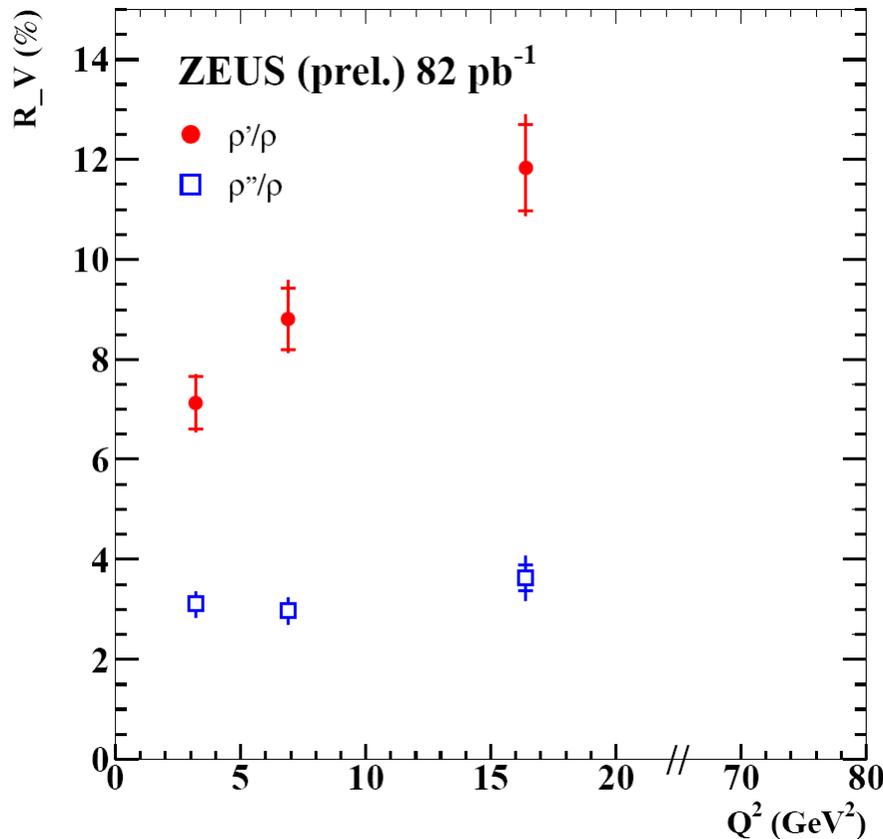
As A , L and f_{pdiss} is the same for all three resonances:

$$R_V = \frac{N_V}{N_\rho}$$

Cross section ratios vs. Q^2

R'_ρ increases with Q^2 , while R''_ρ is approximately constant or slightly increasing with Q^2

ZEUS



This behaviour has been predicted by several models

Acta Phys. Polon. B 33 (2002) 3517.

Phys. Lett. B 339 (1994) 194.

Surveys High Energy Phys. 11(1997)

ρ' and ρ'' states are suppressed, but Q^2 dependence of the suppression is very different.

suppression of the $2S$ state (ρ') is connected to a node effect (results in cancellations of contributions from different impact parameter regions at lower Q^2). At higher Q^2 the effect of cancellation vanishes. The D state (ρ'') suppression is connected to structure of the $qq\bar{q}$ state into which the photon fluctuates. Not a pure S wave but contains also a small admixture of D wave, which is Q^2 independent.

Summary

- Exclusive two pion electroproduction has been studied by ZEUS at HERA in the range $0.4 < M_{\pi\pi} < 2.5 \text{ GeV}$, $2 < Q^2 < 80 \text{ GeV}^2$, $32 < W < 180 \text{ GeV}$ and $|t| \leq 0.6 \text{ GeV}^2$.
- Mass distribution is well described by the pion electromagnetic form factor which includes three resonances, ρ^0 , $\rho^-(1450)$ and $\rho^-(1700)$. Masses and widths of resonances obtained.
- Q^2 dependence of cross section ratios show very different behaviour. Ratio ρ^-/ρ rises strongly with Q^2 while $\rho^-(1700)/\rho$ is approximately constant. This behaviour predicted by several models.