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Diffractive Vector Meson Production at HERA



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On behalf of the H1 and ZEUS Collaborations

- Introduction
- Diffractive J/ψ photoporoduction
- It dependence of exclusive Y(1S) photoproduction
- Pion form factor from exclusive di-pion electroproduction

[H1 Coll., arXiv:1304.5162]
[ZEUS Coll., PLB 708 (2012) 14]
[ZEUS Coll., EPJC 72 (2012) 1869]

HERA

The world's only electron/positron-proton collider at DESY, Hamburg $E_e = 27.6 \text{ GeV} \quad E_p = 920 \text{ GeV}$ (also 820, 460 and 575 GeV) (total centre-of-mass energy of collision up to $\sqrt{s} \approx 320 \text{ GeV}$)



Two collider experiments: <u>H1 and ZEUS</u>

HERA-1: 1992 - 2000 HERA-2: 2003 - 2007 total lumi: 0.5 fb⁻¹ per experiment

Introduction



no quantum numbers exchanged in the interaction

- the proton stays intact or dissociates
- Q²=-(k-k')² photon virtuality: Q²~0 → 'photoproduction' Q²>0 → Deep Inelastic Scattering (DIS)
- W $\gamma^* p$ center of mass energy
- +=(P-P')² -momentum transfer squared at the proton vertex

Introduction

Exclusive Vector Meson production – clean experimental signatures









 scattered e[±] reconstructed in e/m calorimeters (DIS) or undetected (photoproduction)

- scattered p undetected
- decay products of VM
- nothing else in the central detector

H1: ep \rightarrow e'+J/ Ψ +p, J/ Ψ \rightarrow $\mu^+\mu^-$



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Vector Mesons mass distributions



1.8 2 $M_{\pi\pi}$ (GeV)

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2.2 2.4

Description of diffractive Vector Meson production



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e



W dependence $\sigma(W) \propto W^{\delta}$

Low mass (ρ, ω, ϕ) - no perturbative scale \rightarrow <u>weak energy dependence</u>

High mass $(J/\psi, \psi', \Upsilon)$ - perturbative scale \rightarrow strong energy dependence

VM mass sets the hard scale of interaction

Process becomes hard (steeper W dependence) as M_{VM} becomes larger (J/ ψ , ψ' , Υ)

Elastic J/ ψ photoproduciton cross Sections vs $W_{\gamma p}$

New H1 measurement: extension to lower $W_{\gamma p}$: two energy ranges HE ($W_{\gamma p}$ =40-110 GeV, \sqrt{s} =318 GeV) and LE ($W_{\gamma p}$ =25-80 GeV, \sqrt{s} =225 GeV)



Fit function

 $\sigma \sim W_{\gamma p}^{\delta_{el}}$

arXiv:1304.5162

$$\delta_{el} = 0.67 \pm 0.03$$

HERA data in comparison with fixed target and LHCb data

arXiv:1304.5162



Elastic J/ ψ photoproduction

- New measurements in the transition region from fixed target to previous HERA data
- Good agreement with previous HERA measurements
- Fixed target data: steeper slope, lower normalisation
- Fit to H1 data extrapolated to higher W_{yp} describes the LHCb data

Elastic J/ψ Cross Sections vs t; b-slope

arXiv:1304.5162

t-momentum transfer squared at the proton vertex



 Q^2

 $\gamma^*(q)$

e(k')

 J/ψ

p(P')

e(k)

Elastic $\Upsilon(1s)$ in photoproduction: b-slope



First determination of b slope for Υ (15)

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VM production and DVCS: t-slope $b(Q^2+M^2)$



Asymptotic behaviour of the slope parameter b with effective scale $Q^2+M_V^2$

-**b** characterizes the size of interaction $(b=b_{VM}+b_p)$, expect **b** to decrease from 'soft' to 'hard'

-b decreases with Q²+M² from ~10 GeV⁻² (soft process) to ~4.5 GeV⁻² (hard process)

 \rightarrow size of scattered VM getting smaller with Q²+M²

Elastic vs proton dissociative J/ψ photoproduction

What happens at the proton vertex ?

Elastic process $ep \rightarrow e J/\psi p$



Proton dissociation process $ep \rightarrow e J/\psi Y$





e

p

Elastic and p-dissociation Cross Sections vs W_{vp}

arXiv:1304.5162





Simultaneous fit, taking into account correlations between elastic and p-diss. cross sections

 $N_{pd}/N_{el} = 0.81 \pm 0.10$ $\delta_{pd} - \delta_{el} = -0.25 \pm 0.06$

• Ratio σ_{pd}/σ_{el} slowly decreasing with $W_{\gamma p}$

Proton dissociative J/ψ Cross Sections vs t; b-slope



Pion Form Factor from Exclusive Dipion Production $\gamma^* p \rightarrow \pi^+ \pi^- p$

The two-pion invariant-mass distribution

- is related to the pion electromagnetic form factor
- includes the contributions of ρ,ρ' (radially excited 25 state) and ρ'' (orbitally excited 2D state) vector mesons

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

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

Kuhn-Santamaria parameterisation For $M_{\pi\pi}$ <2.5 GeV includes contributions from $\rho(770)$, $\rho'(1450)$ and $\rho''(1700)$

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 β , γ - relative amplitudes

$$BW_{V}(M_{\pi\pi}) = \frac{M_{V}^{2}}{M_{V}^{2} - M_{\pi\pi}^{2} - iM_{V}\Gamma_{V}(M_{\pi\pi})}$$

Breit-Wigner amplitide

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Exclusive dipion production $\gamma^* p \rightarrow \pi^+ \pi^- p$; fit to F_{π}







Masses and widths consistent with expectations
Relative amplitudes found to be real

Diffractive VM production at HERA

Exclusive dipion production $\gamma^* p \rightarrow \pi^+ \pi^- p$; Q² dependence of F_{π}



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

- β increases with Q^2
- γ is independent of Q^2

Features of pion form factor in ep are similar to e⁺e⁻ (some differences in the interference region)

In the ρ peak, the pion form factor is highest at highest Q^2

$Q^2 (\text{GeV}^2)$	2-5	5 - 10	10-80
β	$-0.249 \pm 0.008^{+0.005}_{-0.003}$	$-0.282\pm0.008^{+0.005}_{-0.008}$	$-0.35 \pm 0.02 \pm 0.01$
γ	$0.100 \pm 0.009 \pm 0.003$	$0.098 \pm 0.012^{+0.005}_{-0.003}$	$0.118 \pm 0.022^{+0.008}_{-0.006}$

Diffractive VM production at HERA

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Exclusive dipion production $\gamma^* \mathbf{p} \rightarrow \pi^+ \pi^- \mathbf{p}$



$$R_{V} = \frac{\sigma_{V} \cdot Br_{V \to \pi\pi}}{\sigma_{\rho}} \quad V = \rho', \rho''$$

ρ'/ρ ratio increases with Q^2

- predicted by pQCD

- suppression at low Q^2 due to a node in the ρ^\prime wave function

 ρ'' behaviour differs from that of ρ'

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Conclusions

- HERA provides large amount of vector meson data in a wide kinematic range
- Interplay of soft and hard region can extensively be tested

New results:

- Differential cross sections have been measured for elastic and proton dissociative diffractive J/ ψ production as function of t and $W_{\gamma p}$ in the kinematical range |t| < 8 GeV² and 25< $W_{\gamma p}$ < 110 GeV.
- Differential cross section of elastic $\Upsilon(1S)$ production as a function of t is measured; for the first time the b-slope for Υ is determined
- Asymptotic behaviour of b-slope vs (Q²+M²) is observed
- Pion formfactor $F_{\pi}(M_{\pi\pi})$ has been extracted, Q² dependence is observed
- Ratios of ρ'/ρ and ρ''/ρ vs Q² are measured. Strong rise of ρ'/ρ with Q² is observed