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

XXVI International Workshop on Deep Inelastic Scattering and Related Subjects

16-20 April 2018 Kobe, Japan

Stefan Schmitt, DESY
for the H1 collaboration

Outline

- HERA and the H1 experiment
- Photoproduction of exclusive final states at HERA
- Selection of exclusive $2\pi^+2\pi^-$ events
- Measured cross sections
- Comparison to other experiments
- Interpretation of the invariant mass distribution

Preliminary result H1prelim-18-011
http://www-h1.desy.de/publications/H1preliminary.short_list.html

The HERA collider

- World's only ep collider 1992-2007
- E_p=920 GeV, E_e=27.6 GeV; $\sqrt{s}$=320 GeV
- Small datasets with reduced beam energy

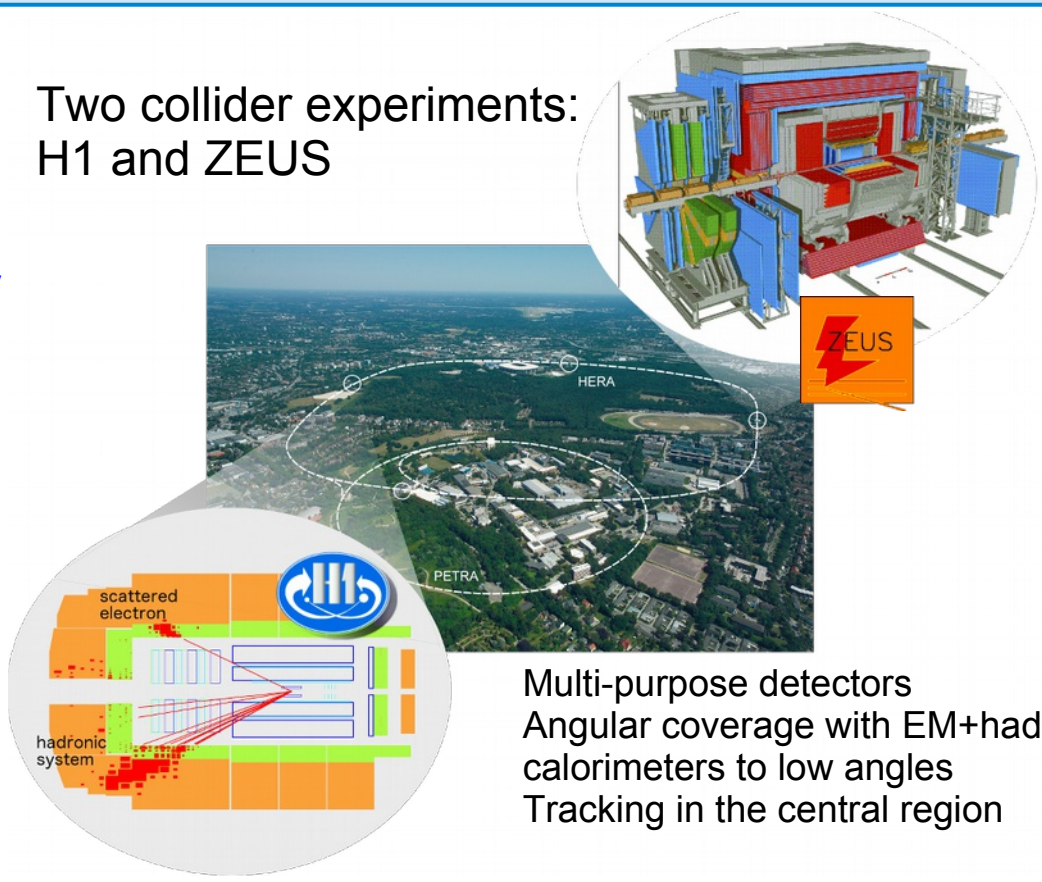
  460 x 27.6 : $\sqrt{s}$=225 GeV

  575 x 27.6 : $\sqrt{s}$=252 GeV
- Integrated Luminosity:

  ~0.5 fb^{-1} per experiment

  ~10 pb^{-1} per exp. at $\sqrt{s}$=225 GeV
- e^+p and e^-p data

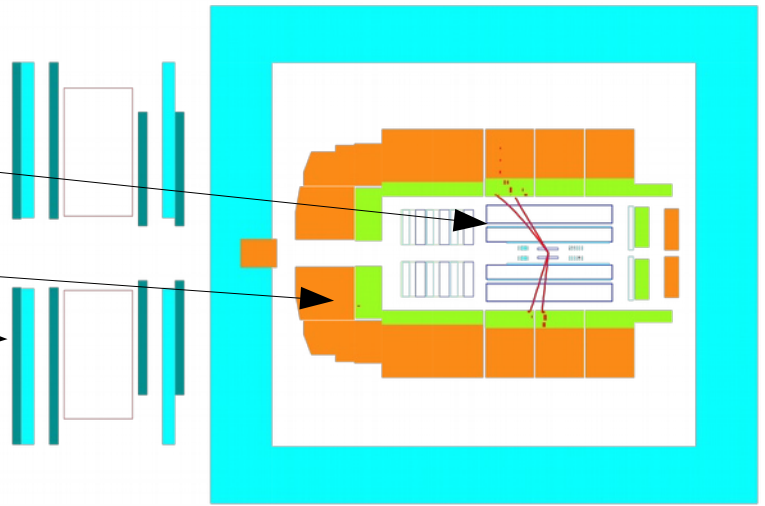
Two collider experiments:
H1 and ZEUS



Multi-purpose detectors
Angular coverage with EM+had calorimeters to low angles
Tracking in the central region

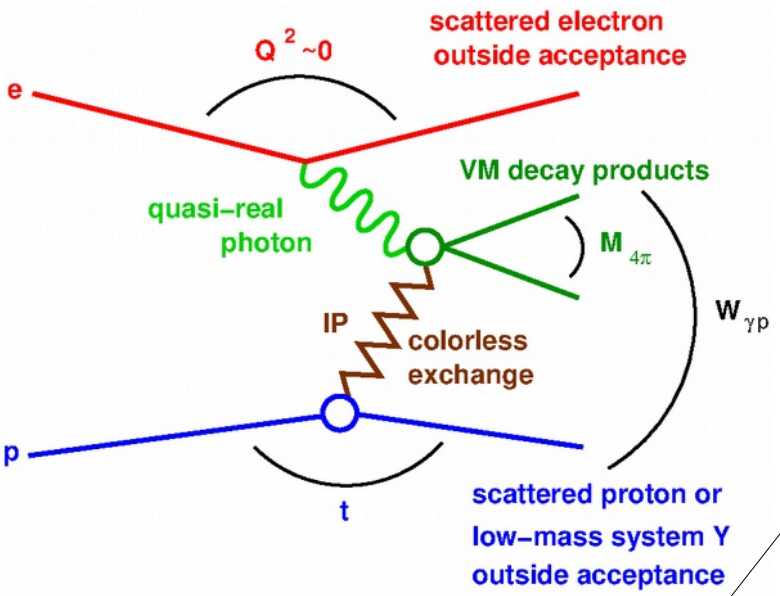
The H1 experiment

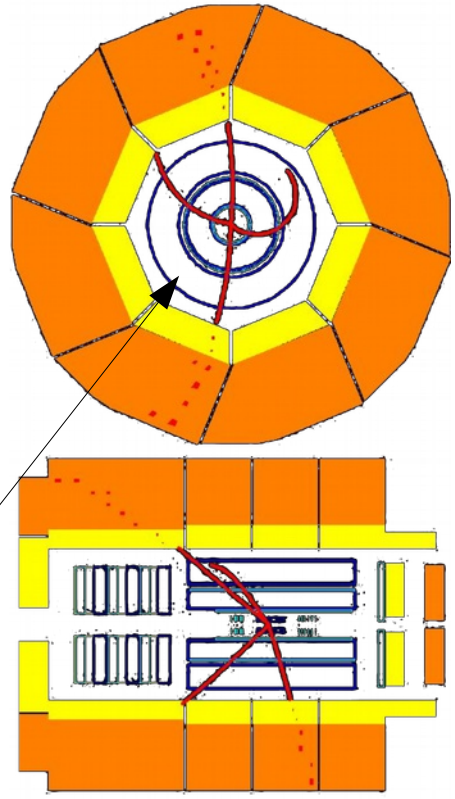
- Central tracker: drift-chambers and two-layer silicon strip detector
- Calorimeters (EM+hadr)
- Forward muon detector
- Proton dissociation taggers
- Dedicated detectors for leading protons or neutrons (not used for this analysis)



Diffractive vector meson production at HERA

- Photo-production: electron outside detector acceptance $Q^2<2$ GeV^2
- Diffractive scattering: proton stays intact or dissociates to low-mass system ($M_Y<1.6$ GeV)
- Vector-meson (VM=$\rho,\omega,\phi,J/\psi,\Upsilon,...$) quantum numbers identical to photon → VM dominance
- Variables: $W_{\gamma p}$, t, $M_{4\pi}$





Example: $\psi' \to \mu^+\mu^-\pi^+\pi^-$ in H1 detector

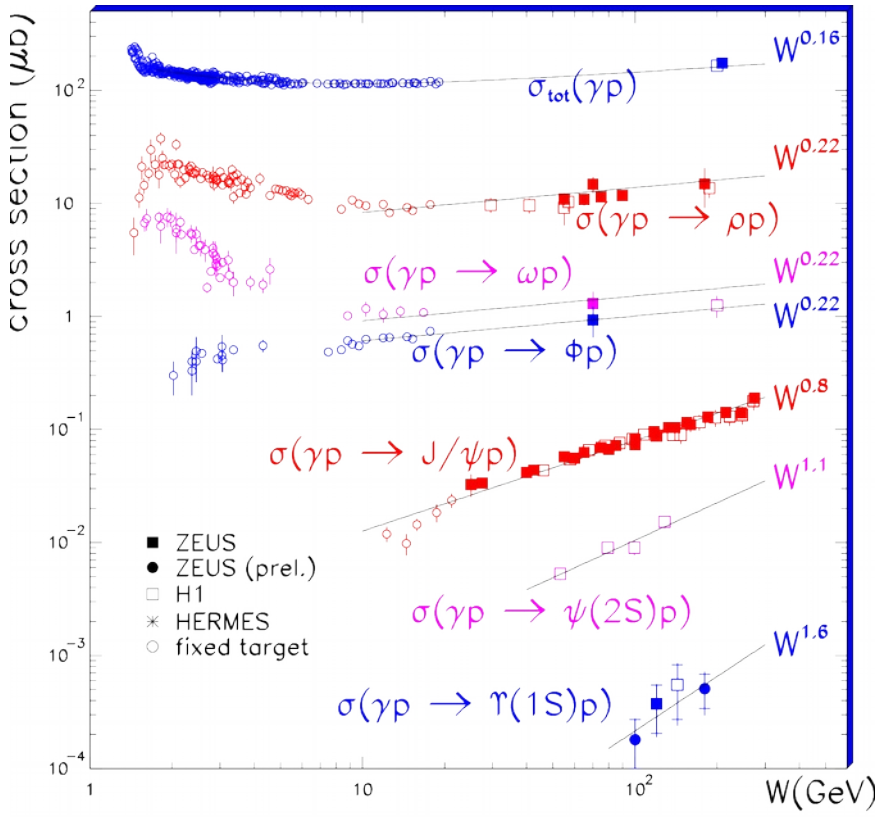
Vector meson photoproduction wrt W

- Data at W>20 all are from HERA
- HERA VM production data are well described by Regge-type power law $\sigma \sim W^{2\epsilon}$
- For soft elastic reactions, exponent is expected to be related to soft pomeron intercept

$$\epsilon \sim 2(\alpha_{IP}(t)-1) = 2\times(0.08+\alpha' \cdot t)$$

- Only the ground states of the low-mass vector mesons have been measured ρ(770),ω(782),ϕ(1020)

Summary of VM photoproduction



The ρ(1450) and ρ(1700)

Review article from PDG: one resonance ρ(1600) before 1988, now two resonances ρ(1450) and ρ(1700)

77. The $\rho(1450)$ and the $\rho(1700)$

Updated November 2015 by S. Eidelman (Novosibirsk), C. Hanhart (Juelich) and G. Venanzoni (Frascati).

In our 1988 edition, we replaced the $\rho(1600)$ entry with two new ones, the $\rho(1450)$ and the $\rho(1700)$, because there was emerging evidence that the 1600-MeV region actually contains two ρ-like resonances. Erkal [1] had pointed out this possibility with a theoretical analysis on the consistency of 2π and 4π electromagnetic form factors and the $\pi\pi$ scattering length. Donnachie [2], with a full analysis of data on the 2π and 4π final states in e^+e^- annihilation and photoproduction reactions, had also argued that in order

This analysis: measure exclusive diffractive photo-production of four charged pions (in the mass region corresponding to these resonances)

Mass, width, decay of ρ(1450) and ρ(1700)

$\rho(1450)$ [r] $I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 1465 \pm 25$ MeV [l]
Full width $\Gamma = 400 \pm 60$ MeV [l]

$\rho(1450)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	seen	720
4π	seen	669
e^+e^-	seen	732
$\eta\rho$	seen	311
$a_2(1320)\pi$	not seen	54
$K\overline{K}$	not seen	541
$K\overline{K}^*(892)+$ c.c.	possibly seen	229
$\eta\gamma$	seen	630
$f_0(500)\gamma$	not seen	–

$\rho(1700)$ [r] $I^G(J^{PC}) = 1^+(1^{--})$

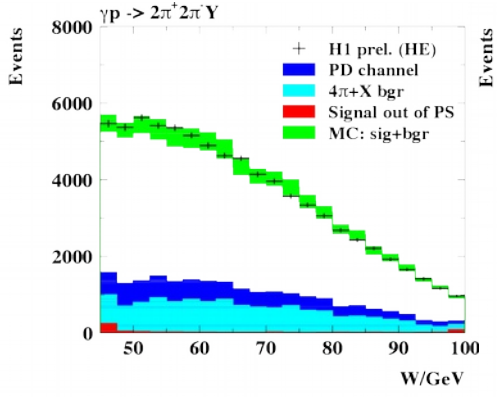
Mass $m = 1720 \pm 20$ MeV [l] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)
Full width $\Gamma = 250 \pm 100$ MeV [l] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)

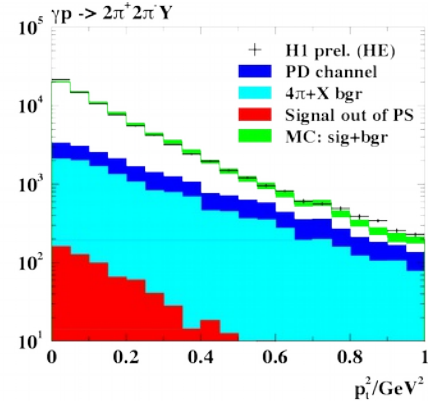
$\rho(1700)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$2(\pi^+\pi^-)$	large	803
$\rho\pi\pi$	dominant	653
$\rho^0\pi^+\pi^-$	large	651
$\rho^\pm\pi^\mp\pi^0$	large	652
$a_1(1260)\pi$	seen	404
$h_1(1170)\pi$	seen	447
$\pi(1300)\pi$	seen	349

Selection of exclusive $2\pi^+2\pi^-$ events

- Two data samples
  High energy $\sqrt{s}$=319 GeV, $\mathcal{L}$=7.6 pb^{-1}
  Low energy $\sqrt{s}$=225 GeV, $\mathcal{L}$=1.7 pb^{-1}
- Events with four tracks (net charge zero)
- Veto electrons and other energy deposits not associated with tracks
- Veto on signals in the forward muon and proton dissociation tagger

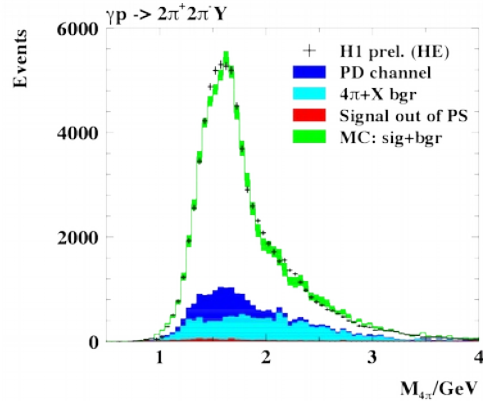
Phase-space definition:
$Q^2 < 2\ \text{GeV}^2$
$|t| < 1\ \text{GeV}^2,\ M_Y < 1.6\ \text{GeV}$
High energy: $45 < W/\text{GeV} < 100$
Low energy: $35 < W/\text{GeV} < 75$





Control plots for high-energy sample: W, p_T, $M_{4\pi}$

Background of order 15%.
Contribution from events with M_Y<1.6 GeV: ~10%



Cross section

- For calculating cross section, correct for acceptance
- Acceptance is approximately uniform in t and W but varies with $M_{4\pi}$
- Result for W=75 GeV:

Phase-space definition:
$Q^2 < 2\ \mathrm{GeV}^2$
$|t| < 1\ \mathrm{GeV}^2,\ M_Y < 1.6\ \mathrm{GeV}$
High energy: $45 < W/\mathrm{GeV} < 100$
Low energy: $35 < W/\mathrm{GeV} < 75$

$$\sigma_{\gamma p \to (2\pi^+ 2\pi^-) Y} = (1.07 \pm 0.01_{\mathrm{stat}} \pm 0.14_{\mathrm{sys}})\,\mu\mathrm{b}$$

Compare to photoproduction of ρ(770)
H1: Nucl.Phys.B463 (1996) 3 [hep-ex/9601004] and
ZEUS: Eur.Phys.J. C2 (1998) 247 [hep-ex/9712020]

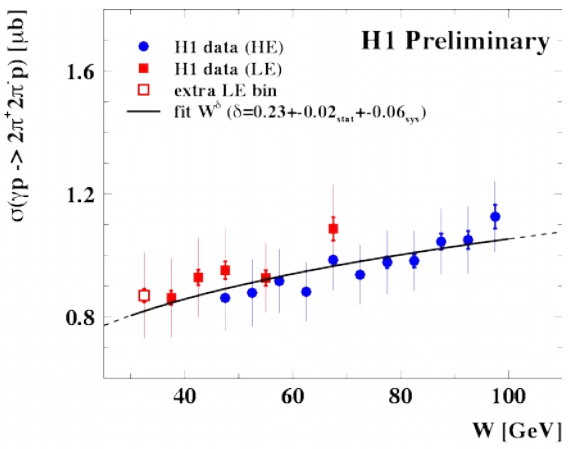
H1: $\sigma_{\gamma p \to \rho^0(770) p} = (9.1 \pm 0.9_{\mathrm{stat}} \pm 2.5_{\mathrm{sys}})\,\mu\mathrm{b}$ at $W = 55$ GeV

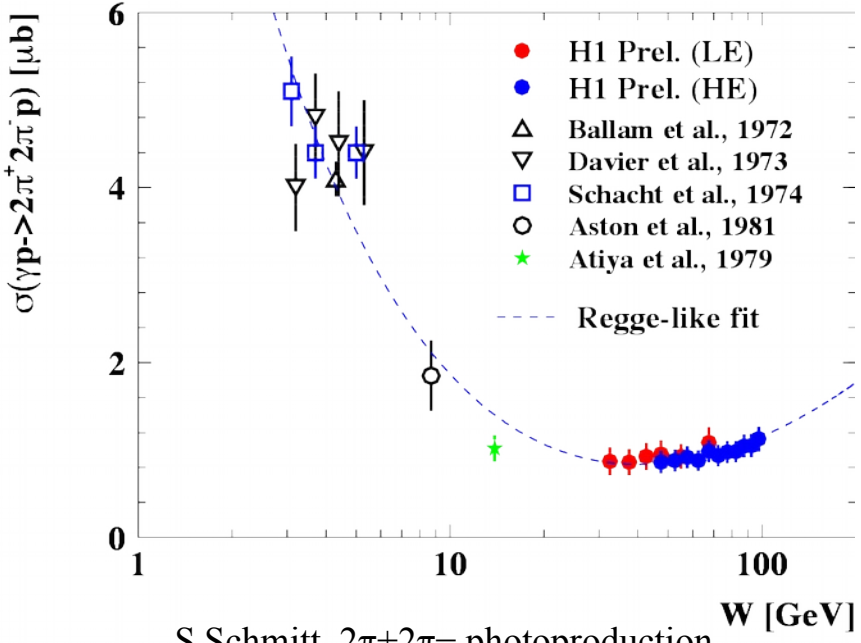
ZEUS: $\sigma_{\gamma p \to \rho^0(770) p} = (11.2 \pm 0.1_{\mathrm{stat}}\ ^{+1.1}_{-1.2\ \mathrm{sys}})\,\mu\mathrm{b}$ at $W = 71.7$ GeV

Cross sections as a function of W

- Cross section as a function of energy
- Here, the proton-dissociative contributions are subtracted (to compare to other data)

$Q^2 < 2\ \mathrm{GeV}^2$
$|t| < 1\ \mathrm{GeV}^2,\ M_Y = m_p$
High energy: $45 < W/\mathrm{GeV} < 100$
Low energy: $35 < W/\mathrm{GeV} < 75$



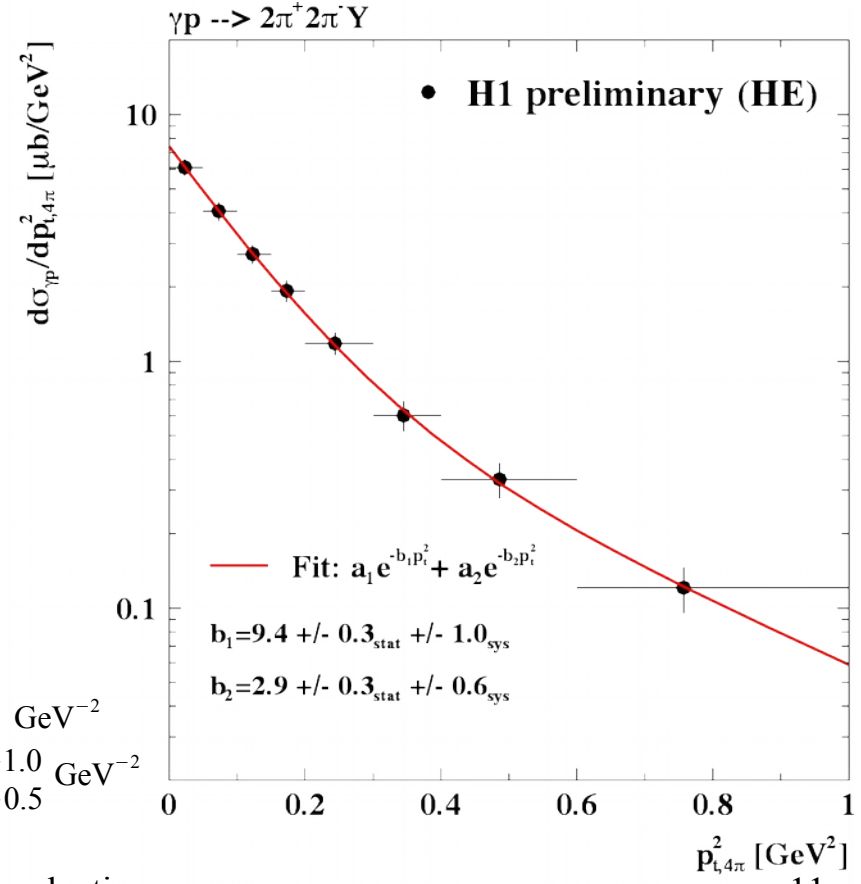


The H1 data are more precise than older measurements and explore the high energy regime

World data are well described by a Regge-like fit (Reggeon and soft Pomeron contributions)

Cross section in t

- Dependence on t: exponential drop-off, typical for VM production
- Described by sum of two exponentials
- Process has contributions from elastic and proton-dissociative processes (with different t-slope)
- Also: contributions from resonant and non-resonant reactions (with possibly different t-slope)



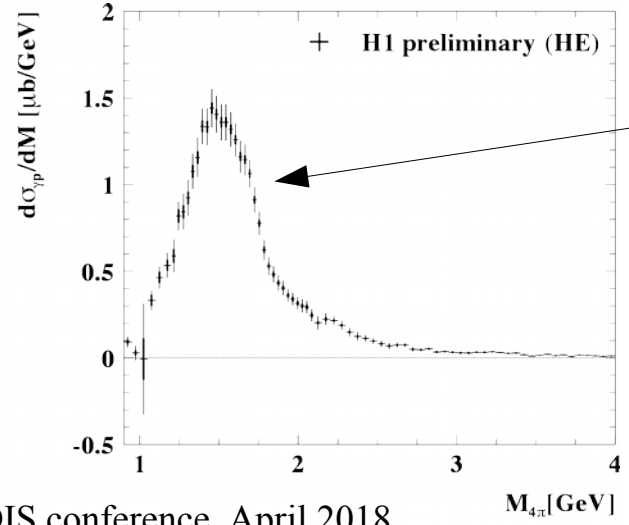
Compare to photoproduction of ρ(770)
H1: Nucl.Phys.B463 (1996) 3 [hep-ex/9601004] and
ZEUS: Eur.Phys.J. C2 (1998) 247 [hep-ex/9712020]

H1: $b_{\rho(770)} = 10.9 \pm 2.4 \pm 1.1$ GeV^{-2}

ZEUS: $b_{\rho(770)} = 10.9 \pm 0.3 \,^{+1.0}_{-0.5}$ GeV^{-2}

Mass distribution and known resonances

- Following the PDG, the mass distribution is expected to originate from two resonances ρ(1450) & ρ(1700)
- Before 1988, there was one broad ρ(1600) in PDG
- Decay to 4π, possibly by intermediate ρ(770) state



Line shape measured by H1 shows no clear indication of two distinct resonances.

Large width, interference, ...

ρ(1450) [r] $I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 1465 \pm 25$ MeV [l]
Full width $\Gamma = 400 \pm 60$ MeV [l]

ρ(1450) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	seen	720
4π	seen	669
e^+e^-	seen	732
$\eta\rho$	seen	311
$a_2(1320)\pi$	not seen	54
$K\overline{K}$	not seen	541
$K\overline{K}^*(892)$+ c.c.	possibly seen	229
$\eta\gamma$	seen	630
$f_0(500)\gamma$	not seen	–

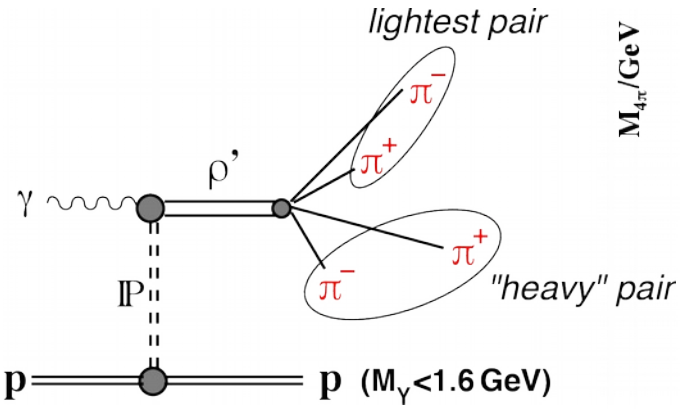
ρ(1700) [r] $I^G(J^{PC}) = 1^+(1^{--})$

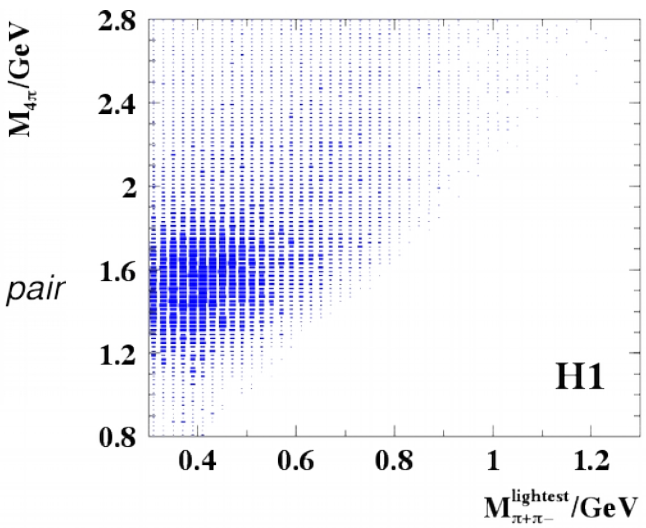
Mass $m = 1720 \pm 20$ MeV [l] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)
Full width $\Gamma = 250 \pm 100$ MeV [l] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)

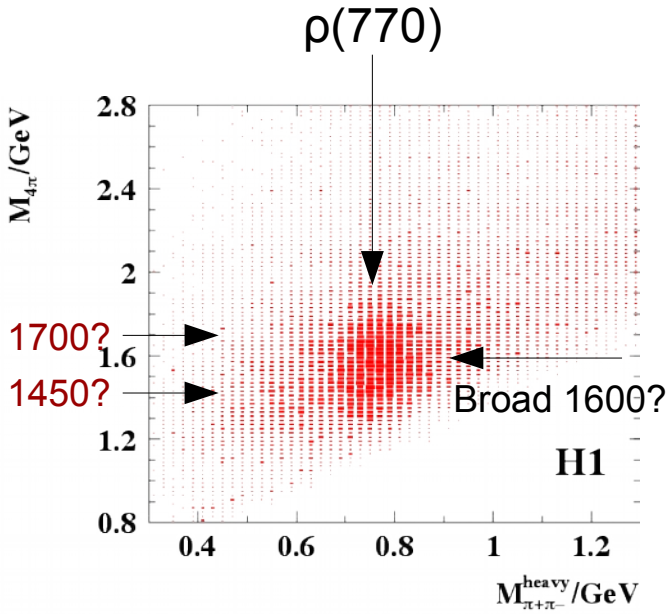
ρ(1700) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$2(\pi^+\pi^-)$	large	803
$\rho\pi\pi$	dominant	653
$\rho^0\pi^+\pi^-$	large	651
$\rho^\pm\pi^\mp\pi^0$	large	652
$a_1(1260)\pi$	seen	404
$h_1(1170)\pi$	seen	447
$\pi(1300)\pi$	seen	349

Decay by intermediate ρ(770)

- Investigate correlations of $M_{4\pi}$ with invariant mass of oppositely charged pion pairs
- Caveat: these figures are not corrected for acceptance effects
- A structure attributed to the ρ(770) is clearly visible



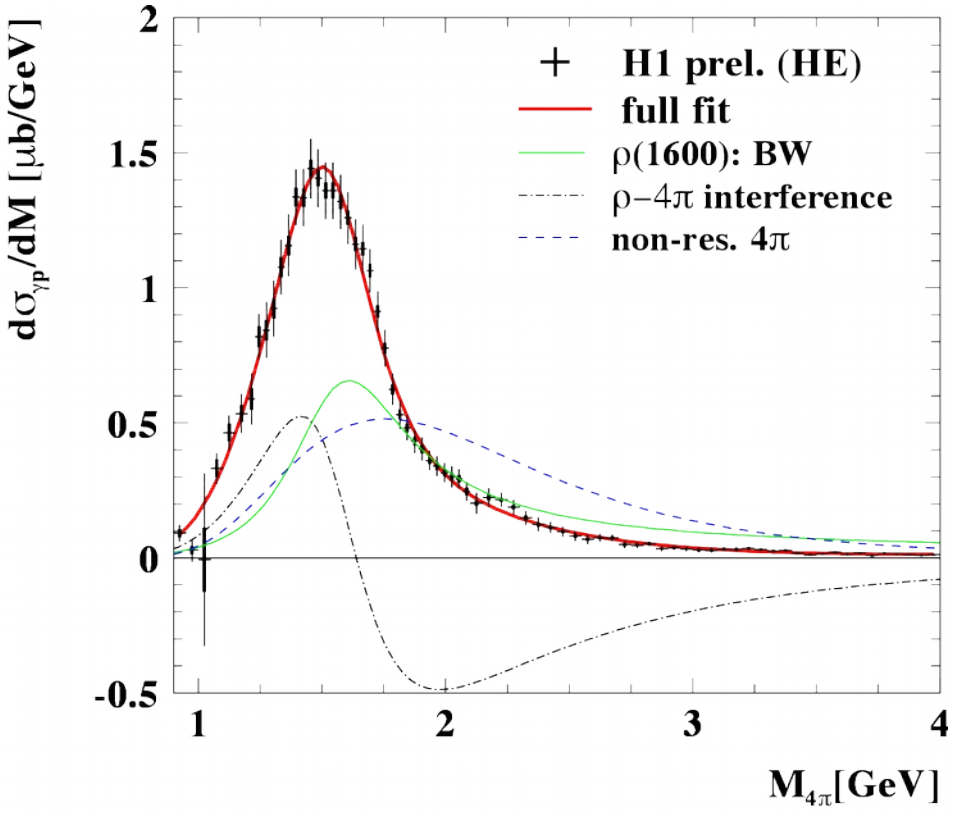




A simple resonance fit

- Simple fit including non-resonant background, Breit-Wigner and complex phase
- Describes data reasonably well

  → the ρ(1600) assumption from PDG before 1988 would work for the H1 data ...
- Fits with more than one resonance: ongoing work



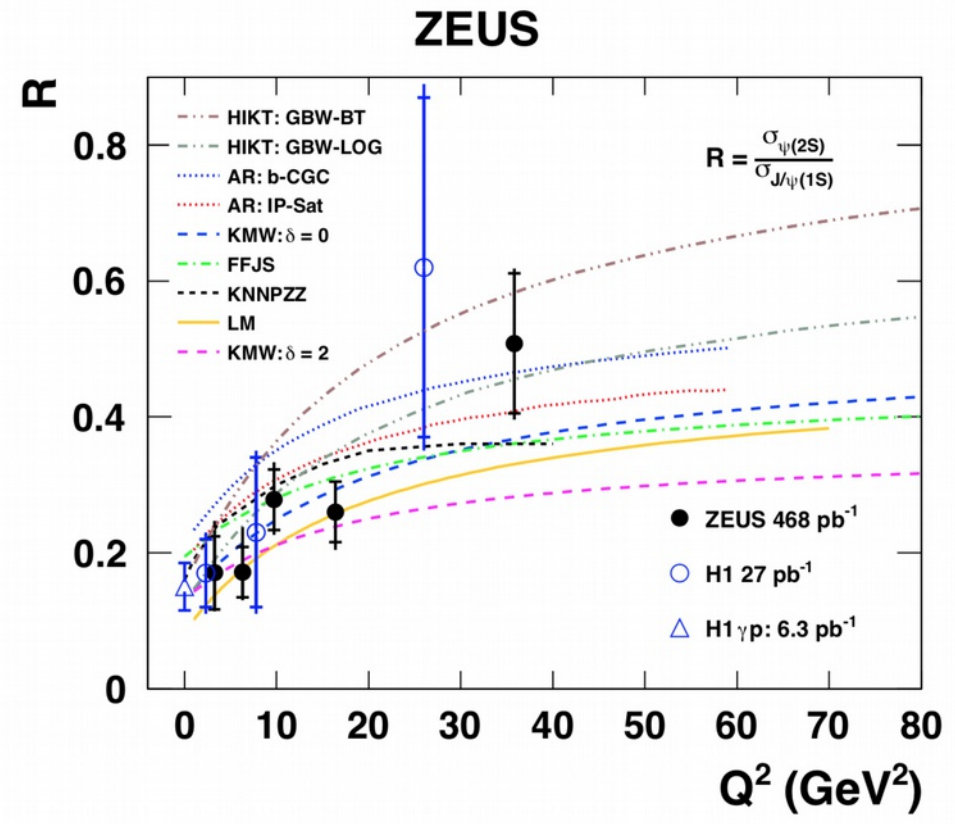
Summary / Outlook

- Photoproduction of exclusive $2\pi^+2\pi^-$ final states is measured in ep collisions by the H1 experiment
- Cross section for $2\pi^+2\pi^-$ is about 1/10 of ρ(770) [all ρ(770) decays counted]
- The W and t dependences are similar to previous ρ(770) measurements
- Invariant mass distributions of $\pi^+\pi^-$ pairs indicate the presence of an intermediate rho(770) state in the decay
- The mass distribution is compatible with a single broad ρ(1600) resonance structure
- More sophisticated mass fits are being worked on, to test compatibility with ρ(1450) and ρ(1700)
- An analysis of exclusive $2\pi^+2\pi^-$ final states in DIS has started, which possibly can add more insights

Backup

Q^2 dependence

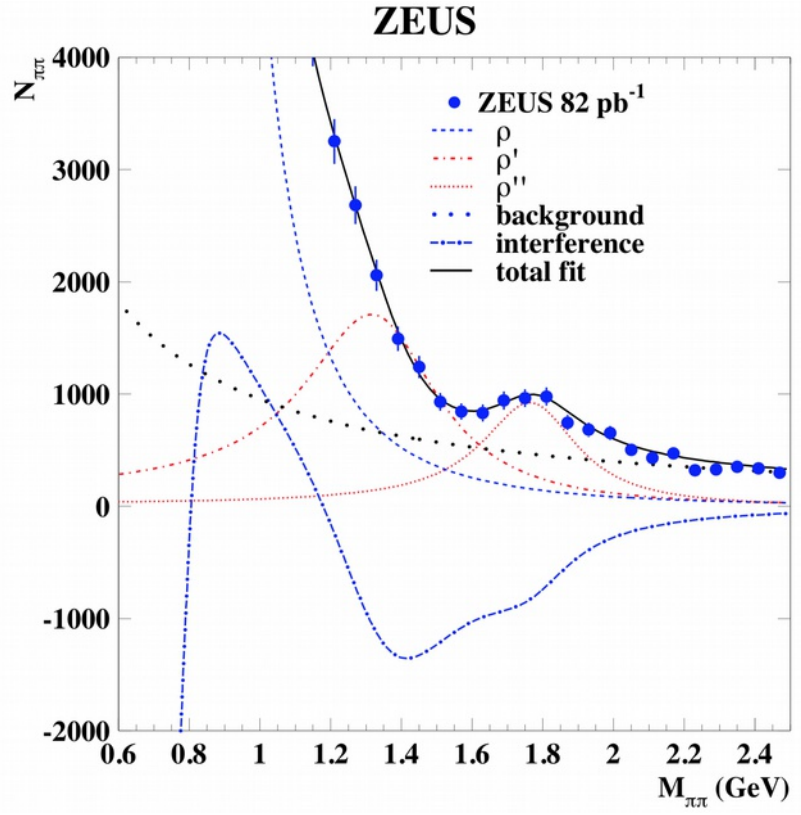
- Q^2 dependence is probing the VM wave function
- Example: measurement of ratio ψ'/ J/ψ wrt Q^2
- Cross section rises with Q^2 similar effect could be present for ρ'



ZEUS: Nucl.Phys. B909 (2016) 934-953 arXiv:1606.08652

ρ' in DIS to $\pi^+\pi^-$

- ZEUS measurement of the lineshape in DIS (Q^2>2 GeV^2)
- Here, ρ(1700) peak is clearly separate from ρ(1450)



EPJ C 72 (2012) 1869 [arXiv:1111.4905]