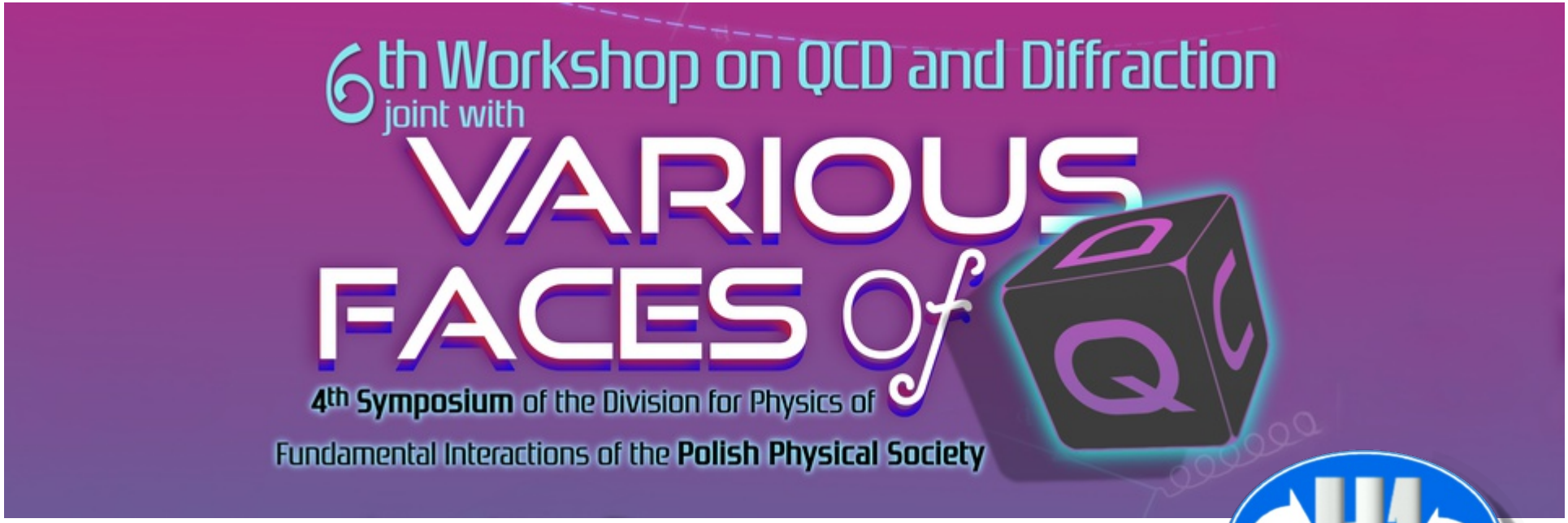
Exclusive Photoproduction of ρ,ρ' at HERA



Stefan Schmitt, DESY, for the H1 collaboration

Outline

- HERA and the H1 experiment
- Photoproduction of exclusive final states at HERA
- Analysis of $\rho(770) \rightarrow \pi^+\pi^-$
- High mass region and $2\pi^+2\pi^-$ final states

Preliminary result H1prelim-18-011 and H1prelim-18-012
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

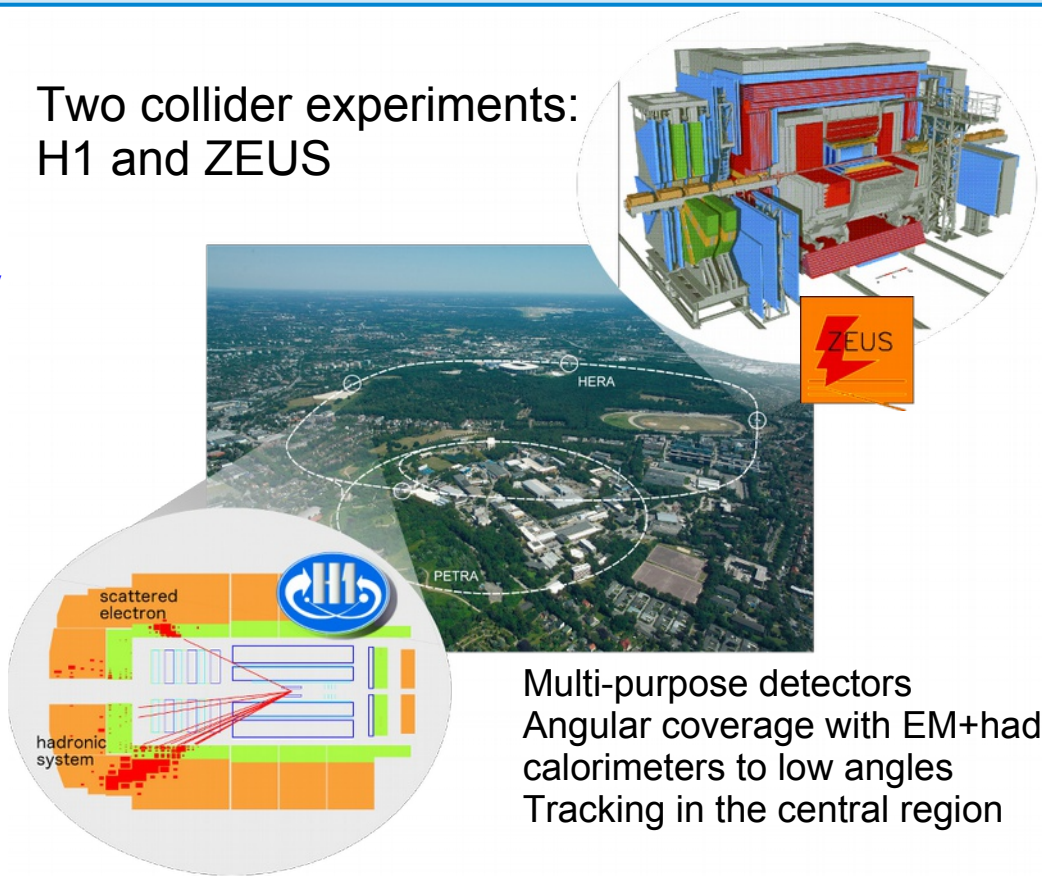
  460 x 27.6 : $\sqrt{s}$=225 GeV

  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

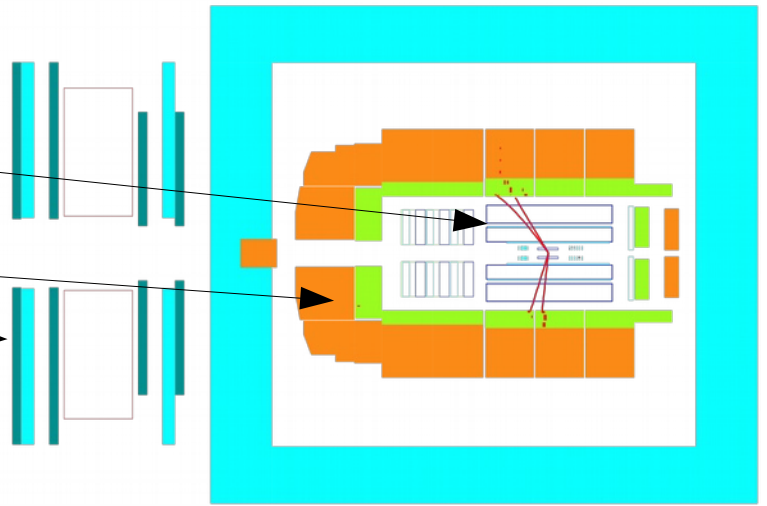
Two collider experiments:
H1 and ZEUS



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

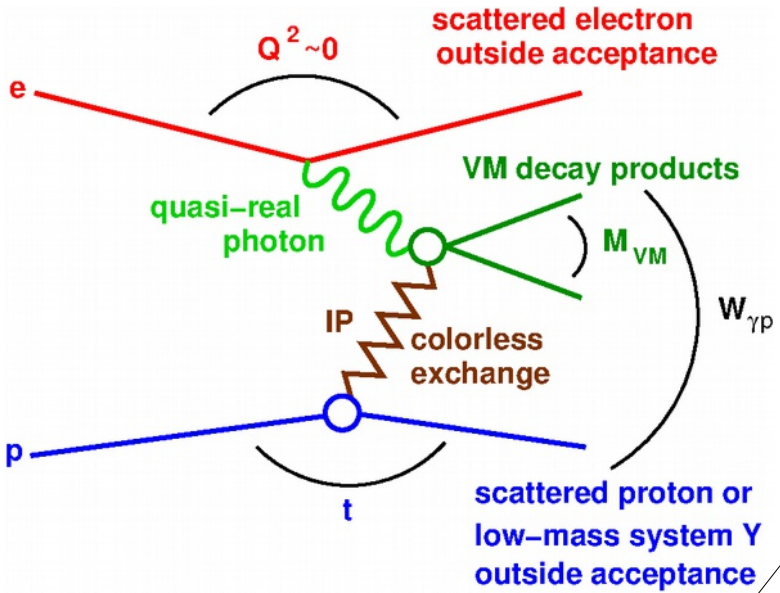
The H1 experiment

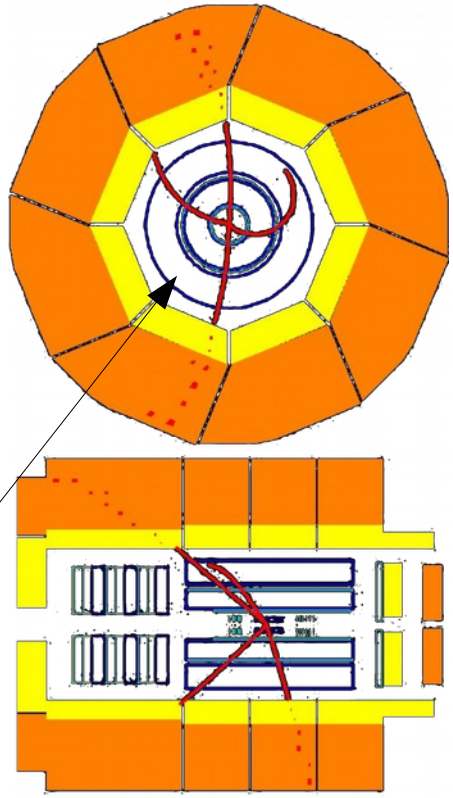
- Central tracker: drift-chambers and two-layer silicon strip detector
- Calorimeters (EM+hadr)
- Forward muon detector
- Proton dissociation taggers
- Dedicated detectors for leading protons or neutrons (not used for this analysis)



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

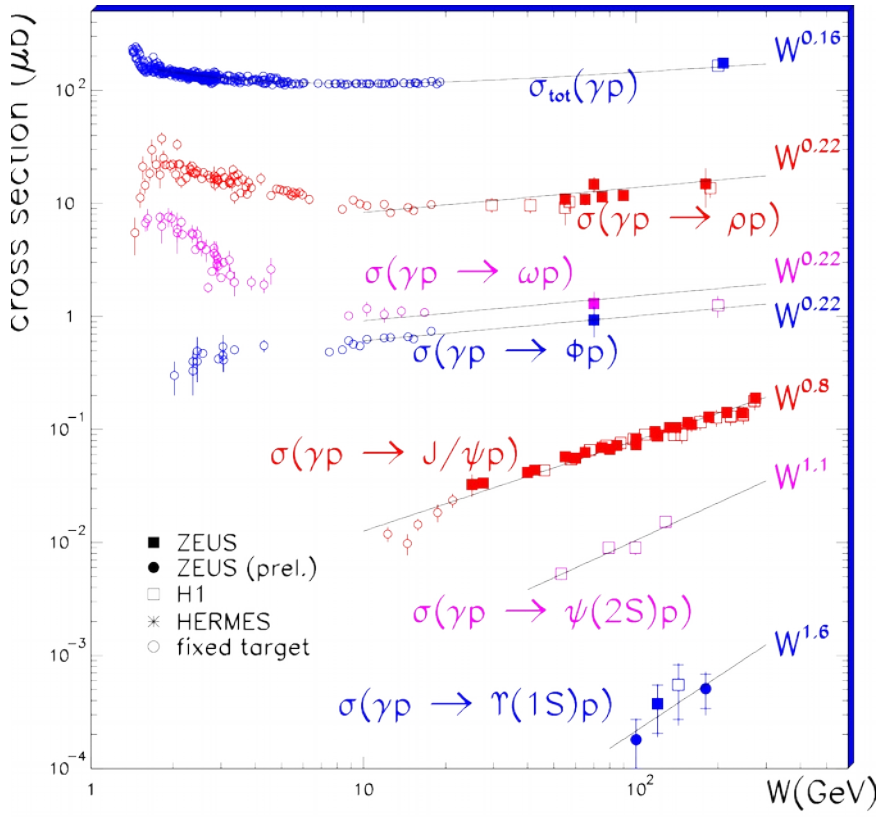
- Data at W>20 on this figure all are from HERA (LHC data not yet in)
- HERA VM production data are well described by Regge-type power law $\sigma \sim W^{2\epsilon}$
- For soft elastic reactions, exponent is expected to be related to soft pomeron intercept

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

- Low-mass vector mesons are not measured that well → new high-statistics HERA analyses

H1 elastic ρ(770) photoproduction paper: 1996 (~2000 events)
ZEUS elastic ρ(770) photoproduction paper: 1997 (~80000 events)

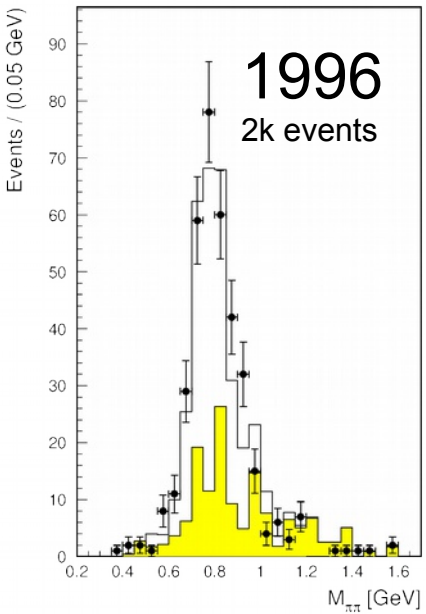
Summary of VM photoproduction

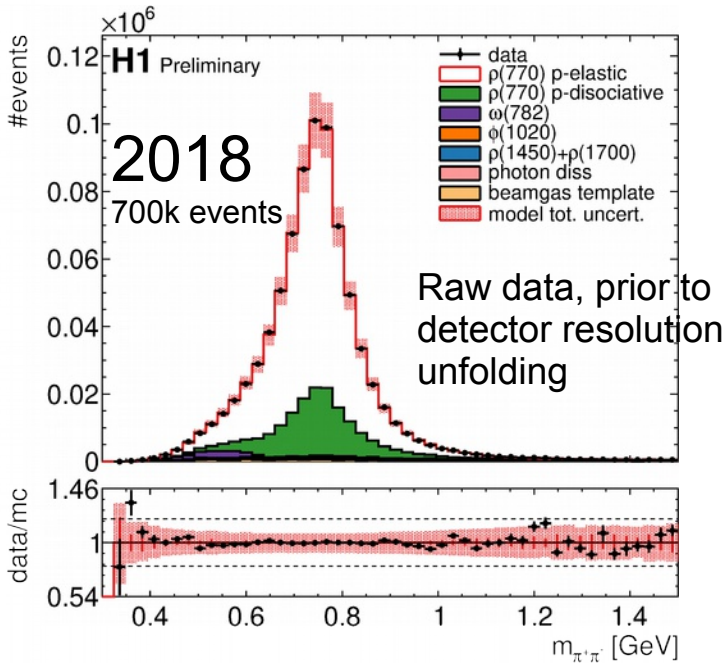


New analysis of the ρ(770)

- New analysis: use high-statistics sample collected in 2006/2007: ~700000 events
- Opens possibility to correct data for detector resolution prior to mass fit

  → accurate sampling of the m(ππ) line shape





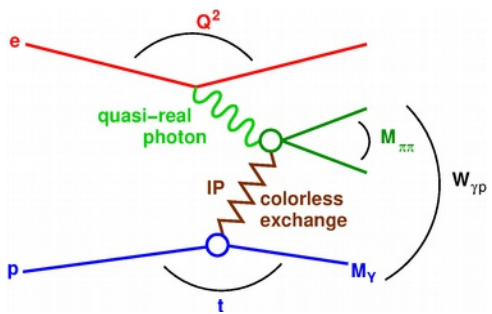
Analysis details: H1prelim-18-012
https://www-h1.desy.de/publications/H1preliminary.short_list.html

Selection criteria

- Integrated luminosity: 1.3 pb^{-1}
- Trigger condition: two tracks in central drift chamber + diffractive vetoes
- No electron in main detector
- Use forward detectors to separate elastic and proton-dissociatiove production

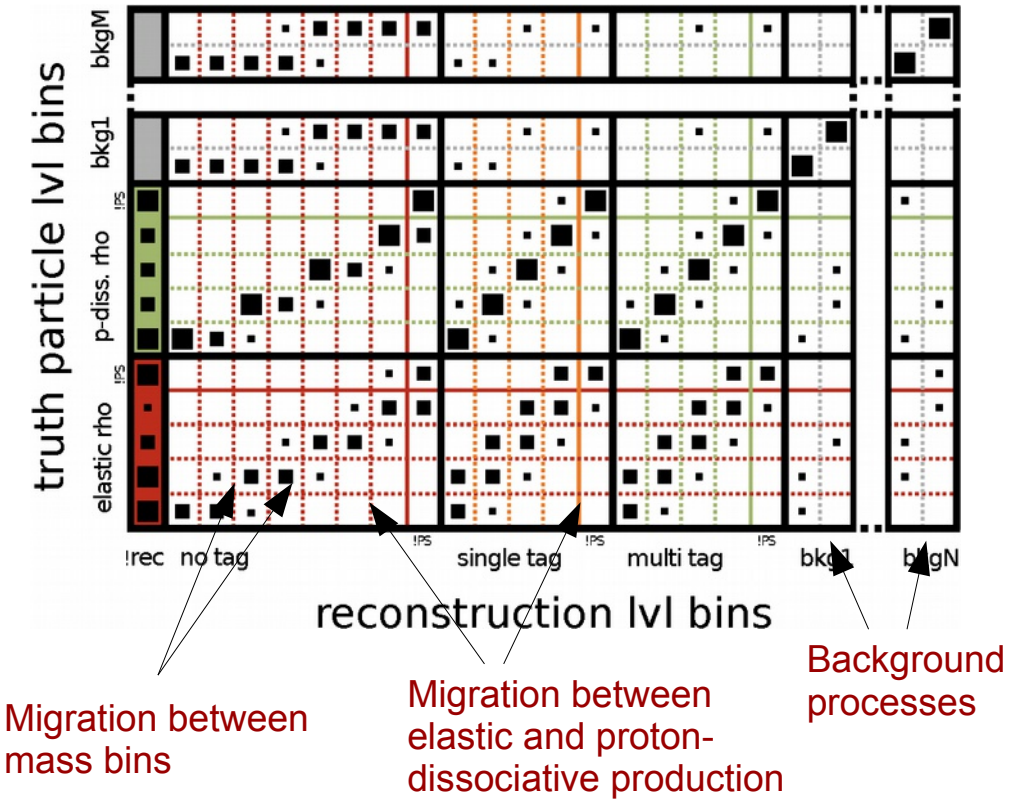
Fiducial cross section definition

γp energy	$20<W_{\gamma p}<80$ GeV
proton momentum transfer	$\lvert t\rvert<1.5$ GeV²
electron momentum transfer	$Q^2<0.1$ GeV²
Pion-pion mass	$0.4<m_{\pi\pi}<1.2$ GeV
Proton elastic	$M_Y=m_p$
Proton dissociative	$m_p<M_Y<10$ GeV



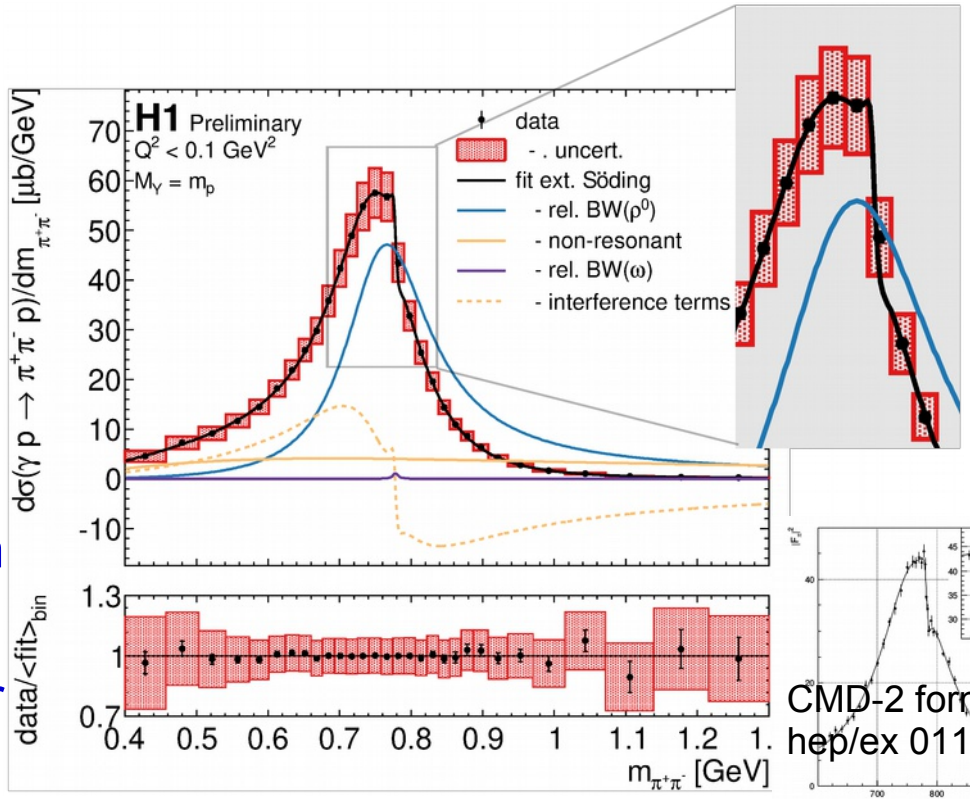
Unfolding of detector effects

- Detector effects: mass resolution causes migration between $m_{\pi\pi\pi\pi}$ bins
- Proton-dissociative and elastic production is separated on a statistical basis, using signals in forward detectors
- Illustration of migration effects considered in the unfolding is given to the right



Unfolded elastic $m_{\pi\pi}$ lineshape

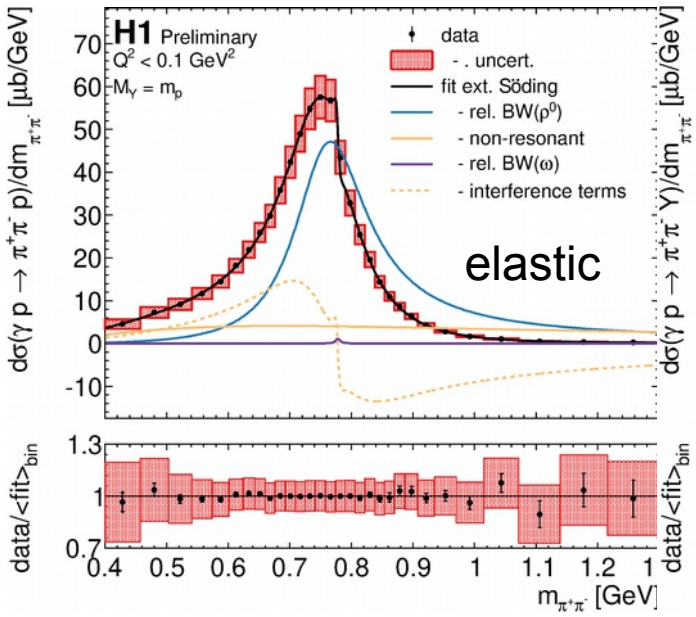
- Fine binning in resonance region
- Very good statistical precision
- Systematics dominated by normalisation (p-dissociation)
- Fit $|\rho(770)+\omega+\text{continuum}|^2$
- Masses, widths agree with PDG
- Clear evidence for ωρ interference in photoproduction off protons
- Similar in shape to 2-pion form factor in $e^+e^- \rightarrow \pi^+\pi^-$

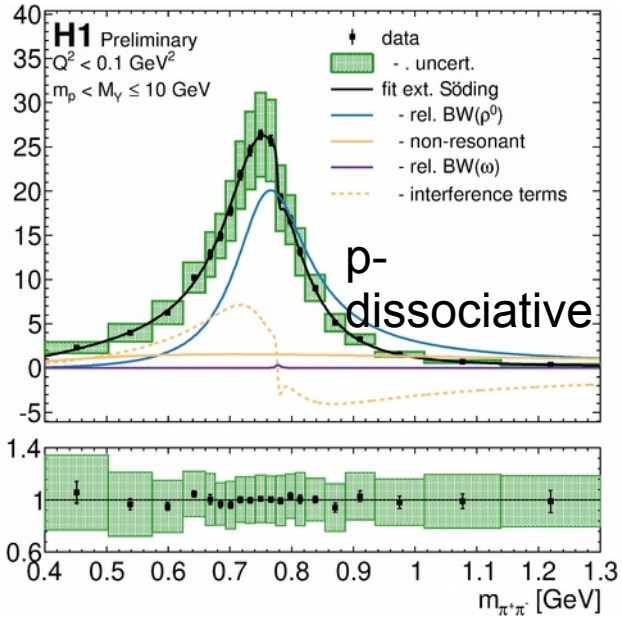


Lineshape in p-dissociative production

- Both elastic and proton-dissociative production (M_Y<10 GeV) are extracted

$$\sigma_{\pi^+\pi^-}(\text{elastic}) = (11.36 \pm 0.05 \pm 1.03)\,\mu\text{b}$$
$$\sigma_{\pi^+\pi^-}(\text{p-dissociative}) = (6.22 \pm 0.06 \pm 1.16)\,\mu\text{b}$$

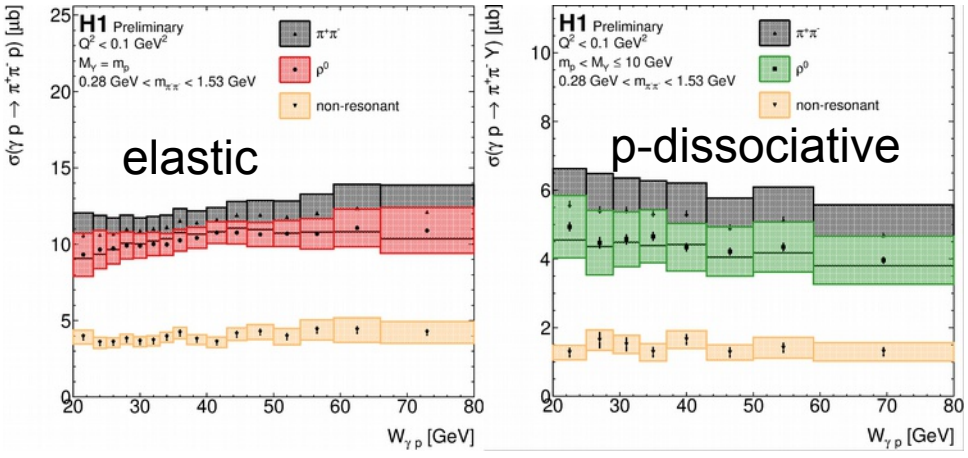


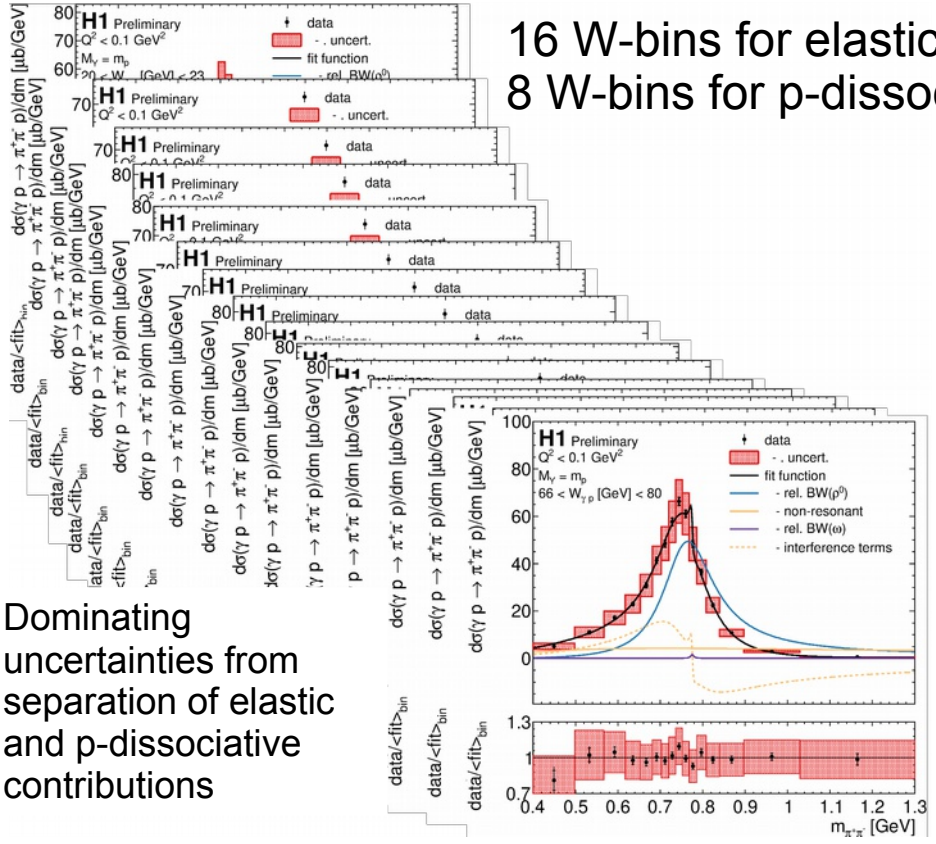


- Simultaneous fit of both $m_{\pi\pi}$ spectra with ρ+ω+continuum
- When looking in the full W-range, the relative sizes of the three contributions (ρ,ω,continuum) are similar for elastic and p-dissociative production
- Overall, p-dissociation is about ½ of the elastic production

Energy dependence determination

- Measure and unfold double-differentially in W and $m_{\pi\pi}$
- Lineshape analysis is repeated in each unfolded W bin to determine ρ(770) contribution as a function of W



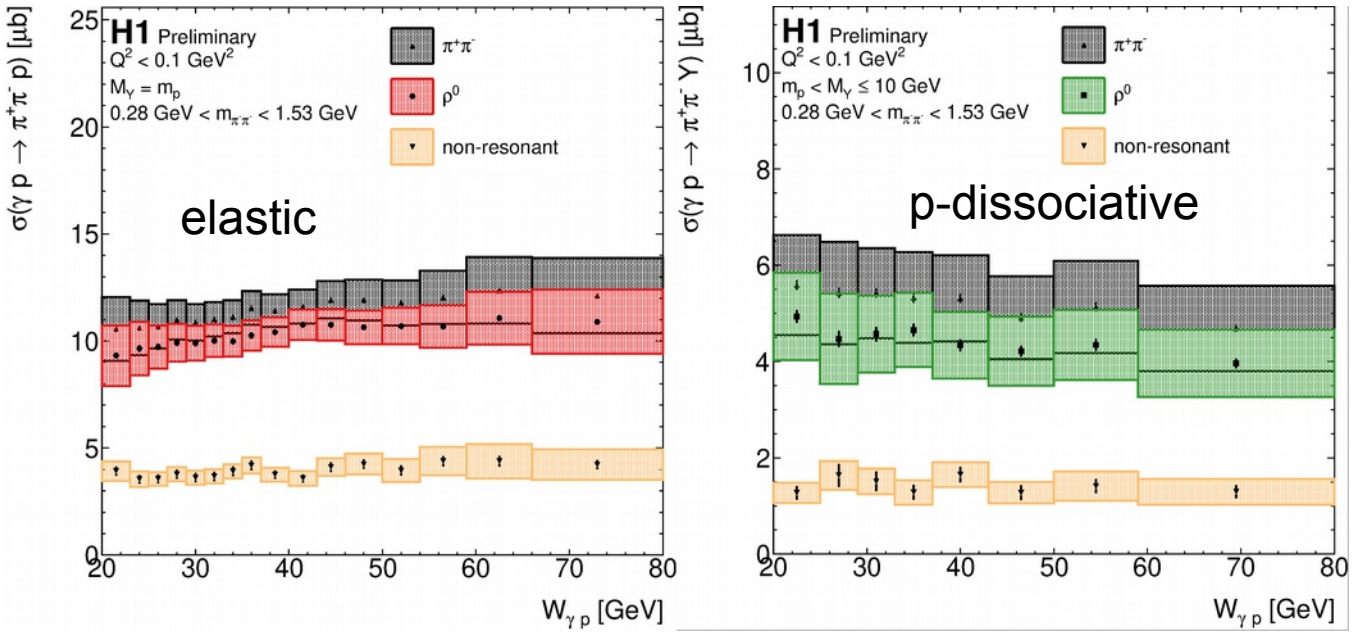


16 W-bins for elastic
8 W-bins for p-dissoc.

Dominating uncertainties from separation of elastic and p-dissociative contributions

Energy dependence

- Measure and unfold double-differentially in W and $m_{\pi\pi}$
- Lineshape analysis is repeated in each unfolded W bin to determine ρ(770) contribution as a function of W



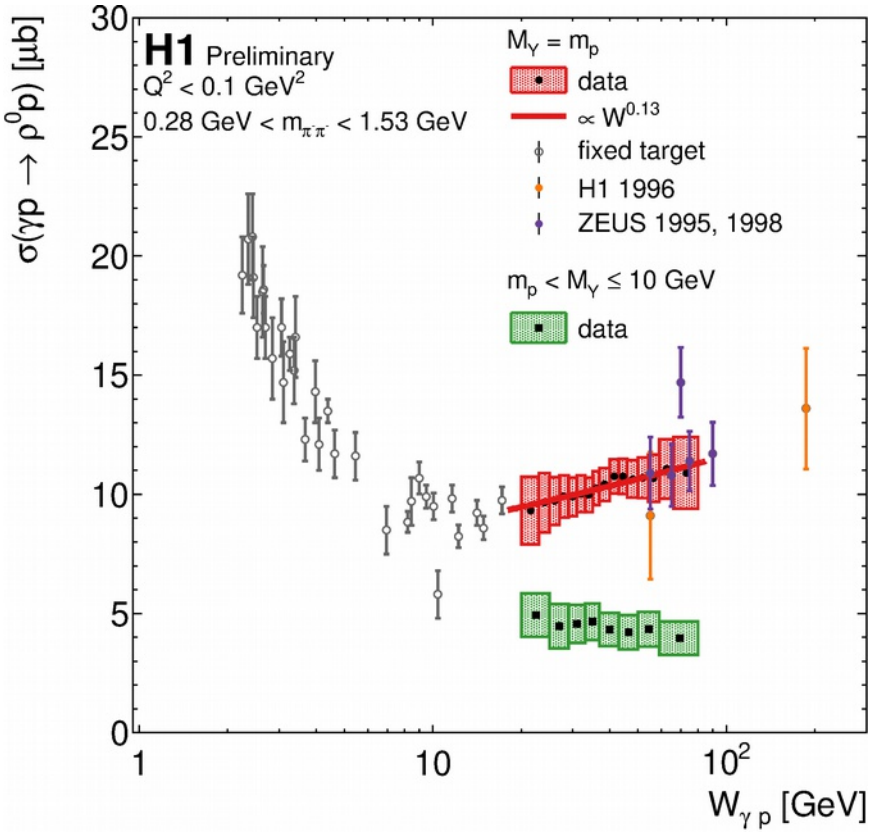
- Elastic cross section rises with W
- Proton-dissociation is about constant

  →possibly caused by M_Y<10 GeV condition

  As W grows, M_Y<10 GeV is a more restrictive condition

Comparison to world data

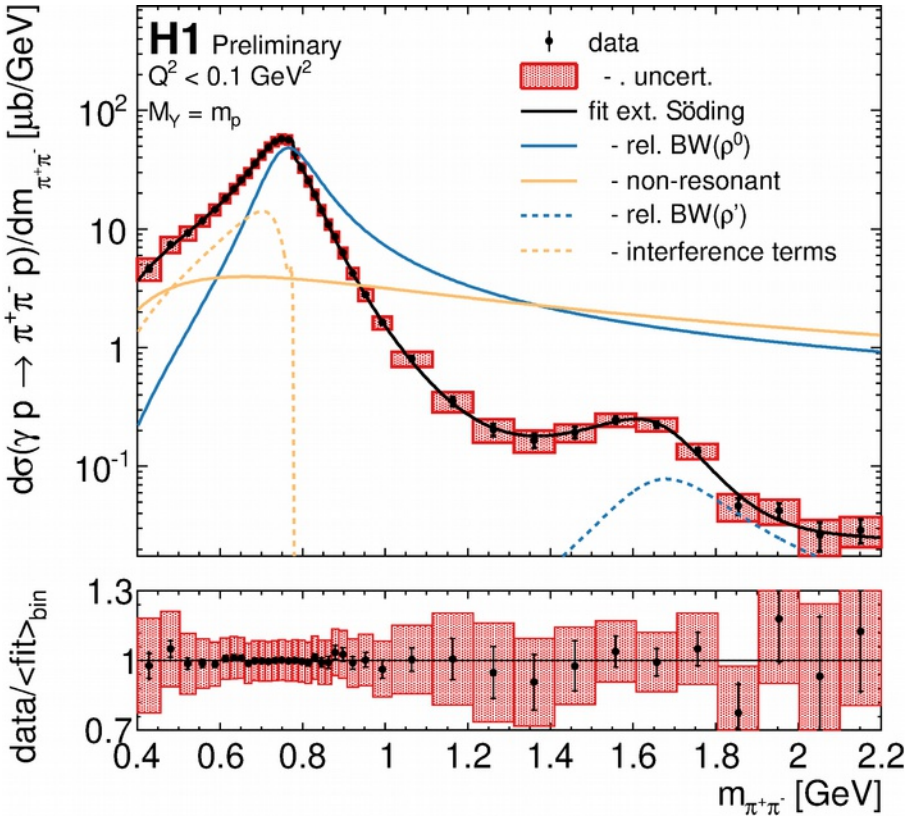
- W dependence of ρ(770) photoproduction off protons is measured in the range 20<W<80 GeV
- Very high statistical precision
- Dominating systematic uncertaintes: normalisation due to elastic/p-dissoc separation
- Described by power-law $W^{0.13}$
- Data fill the gap between low-energy experiments and older HERA experiments at high W



The high-mass region

- Investigate high $m_{\pi\pi}$ region
- PDG lists ρ(1450) and ρ(1700)
- Decay to two pions: no evidence for ρ(1400). ρ(1700) is required for a good fit

  → Look into 4π final states



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

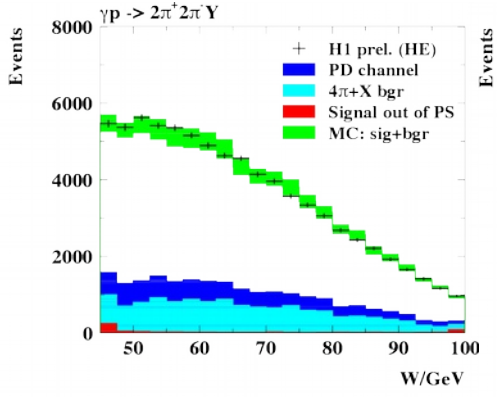
Phase-space definition:

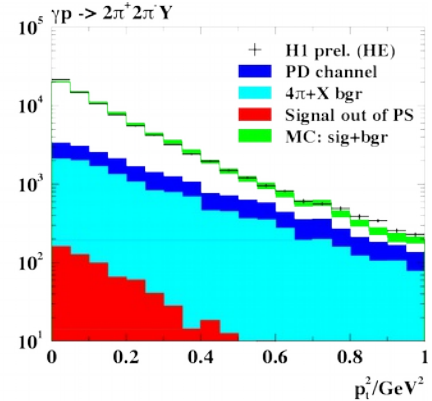
$Q^2 < 2\ \text{GeV}^2$

$|t| < 1\ \text{GeV}^2,\ M_Y < 1.6\ \text{GeV}$

High energy: $45 < W/\text{GeV} < 100$

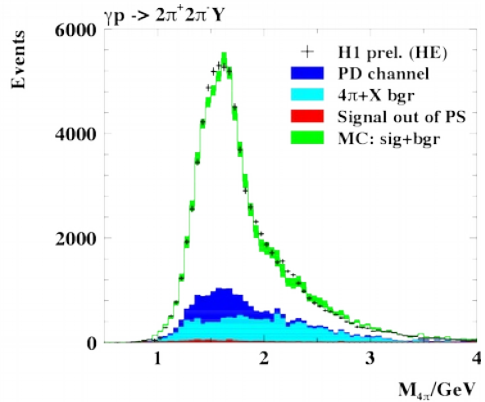
Low energy: $35 < W/\text{GeV} < 75$





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

Background of order 15%.
Contribution from p-dissociative 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:

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

Phase-space definition:
$Q^2<2$ GeV^2 (corrected to $Q^2=0$)
$|t|<1$ GeV^2, $M_Y<1.6$ GeV
High energy: $45<W/\text{GeV}<100$
Low energy: $35<W/\text{GeV}<75$

Compare to photoproduction of $\pi^+\pi^-$ (previous slides) and ρ(770) [1996,1997]

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

H1 prel. 2018: $\sigma_{\gamma p\to\pi^+\pi^- p}=\left(11.36\pm0.05\pm1.03\right)\mu\,\text{b}$ for $20<W<80$ GeV

H1 1996: $\sigma_{\gamma p\to\rho^0(770)p}=\left(9.1\pm0.9_{\text{stat}}\pm2.5_{\text{sys}}\right)\mu\,\text{b}$ at W=55 GeV

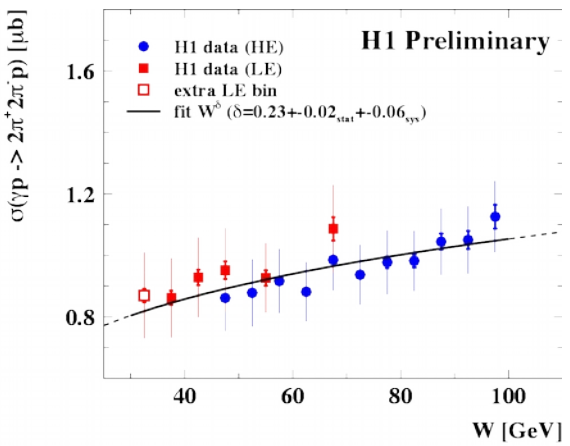
ZEUS 1997: $\sigma_{\gamma p\to\rho^0(770)p}=\left(11.2\pm0.1_{\text{stat}}\,{}^{+1.1}_{-1.2\,\text{sys}}\right)\mu\,\text{b}$ at W=71.7 GeV

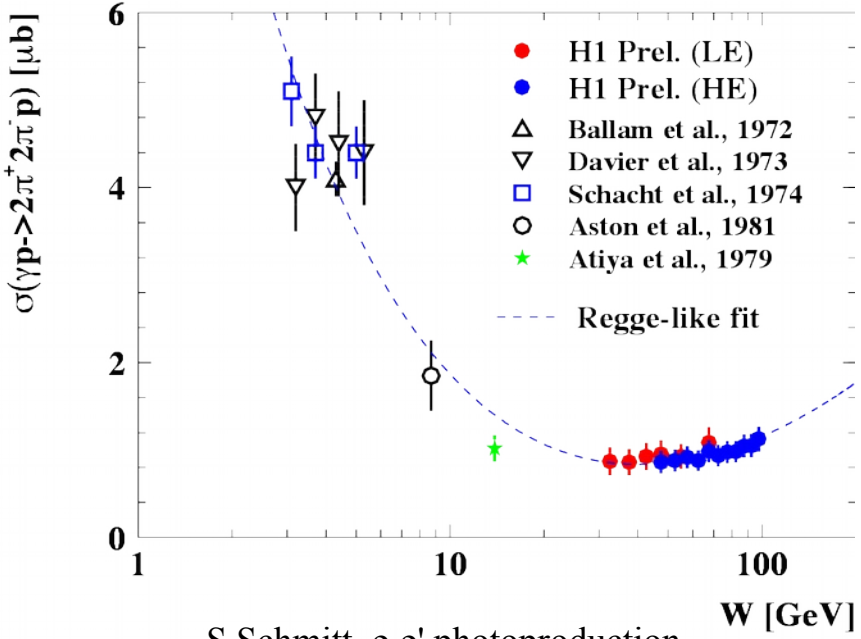
Production rate of $2\pi^+2\pi^-$ is about 1/10 of $\rho(770)\to\pi^+\pi^-$

Cross sections as a function of W

- Cross section for [γp→ $2\pi^+2\pi^-$p] as a function of energy
- Proton-dissociative contributions are subtracted (to compare to data at low W)

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



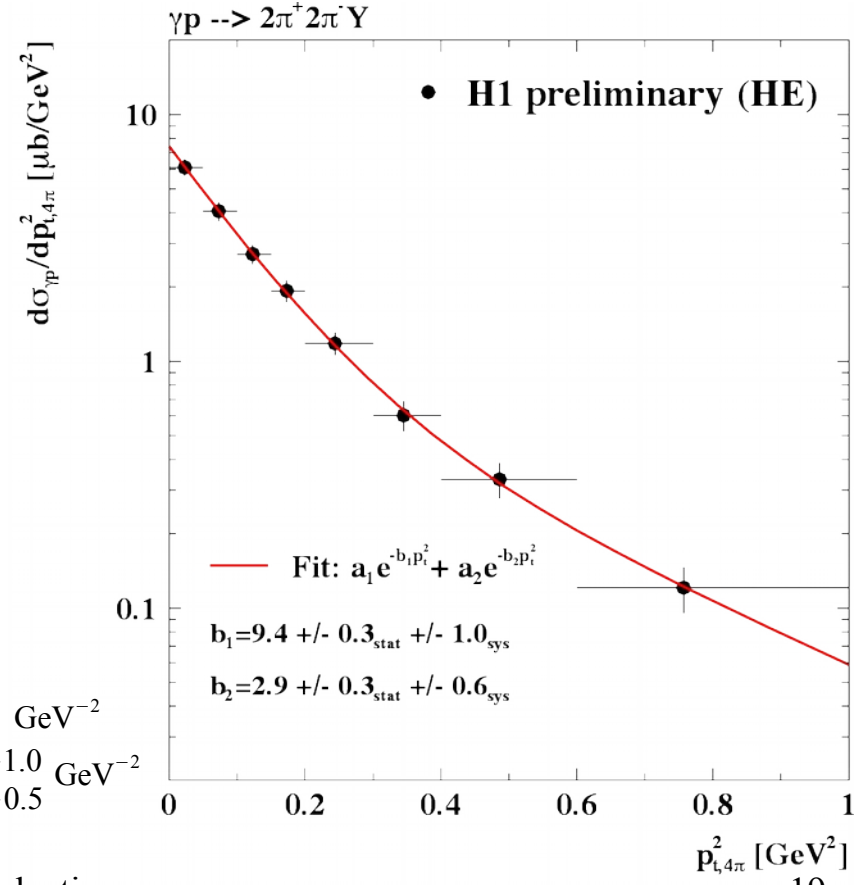


The H1 data are more precise than older measurements and explore the high energy regime

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)



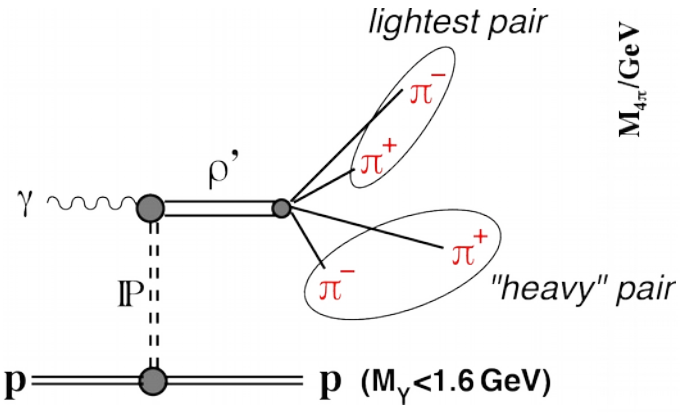
Compare to photoproduction of ρ(770)
H1: Nucl.Phys.B463 (1996) 3 [hep-ex/9601004] and
ZEUS: Eur.Phys.J. C2 (1998) 247 [hep-ex/9712020]

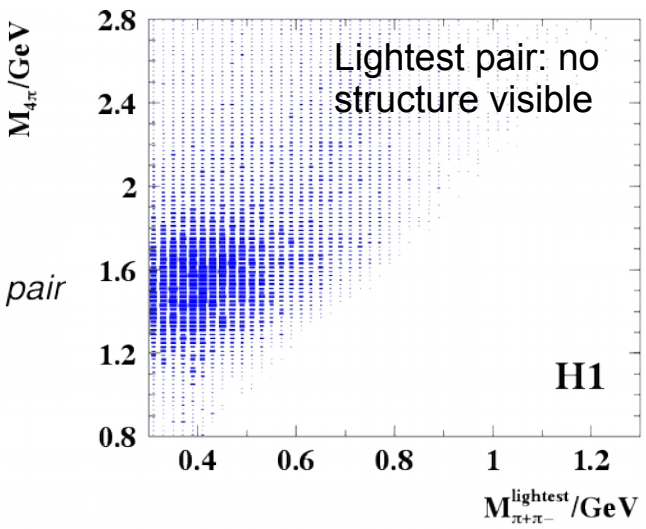
H1: $b_{\rho(770)} = 10.9 \pm 2.4 \pm 1.1$ GeV^{-2}

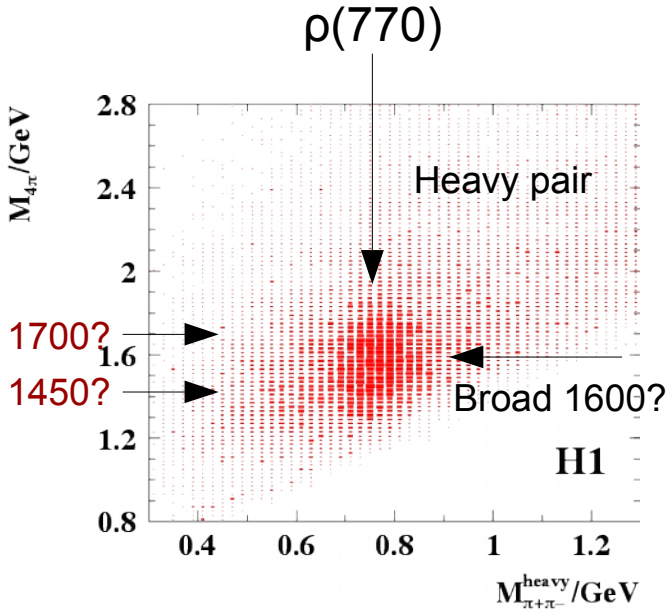
ZEUS: $b_{\rho(770)} = 10.9 \pm 0.3 \,^{+1.0}_{-0.5}$ GeV^{-2}

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



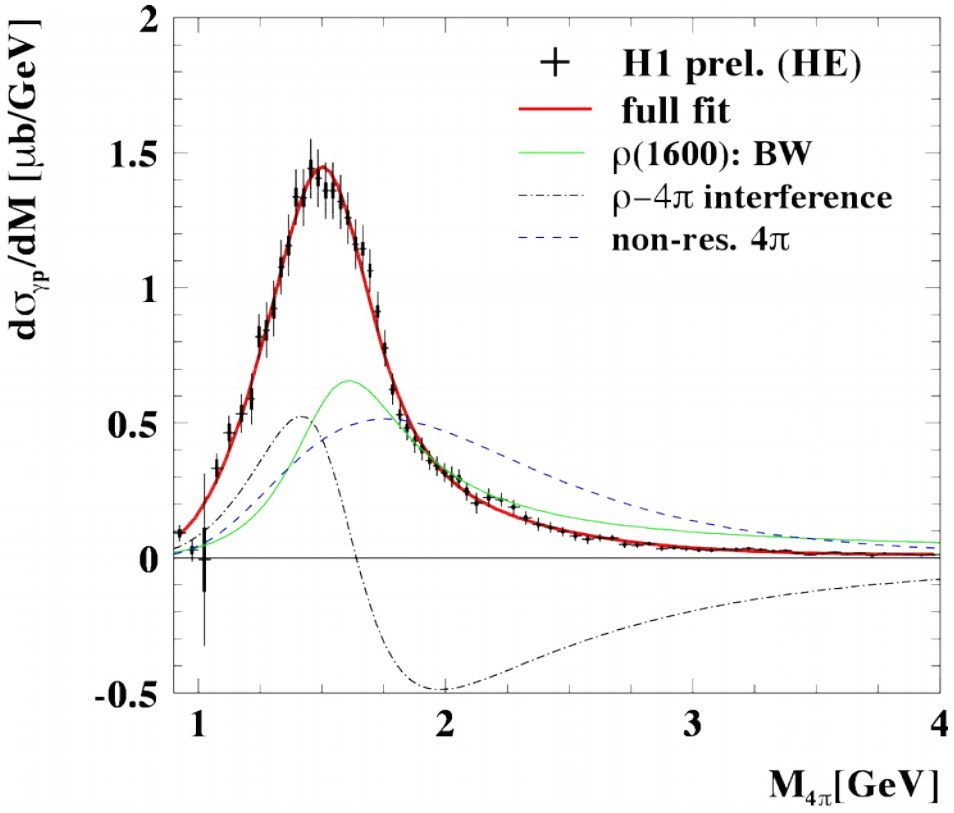




A simple resonance fit

- 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 ρ(1450) and ρ(1700): ongoing work



Summary

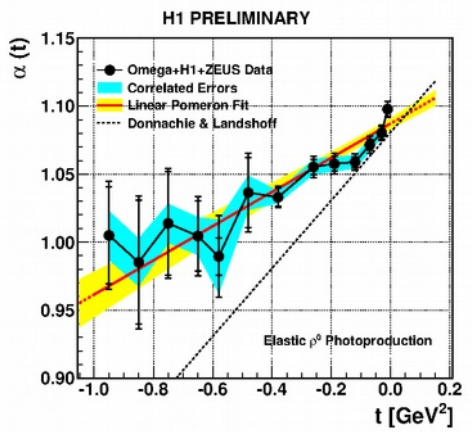
- New analyses by H1 to measure exclusive photoproduction of two or four charged pions

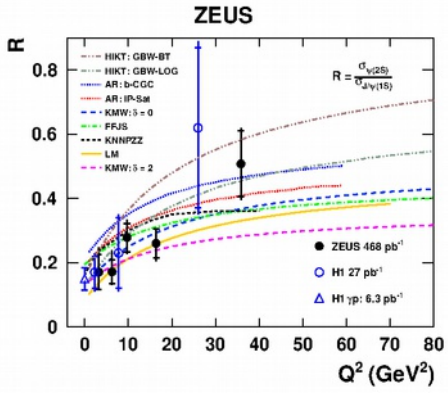
  using high statistics samples recorded in 2006/2007 with the H1 FastTrackTrigger
- Precision data on ρ(770) lineshape from ~700000 $\pi^+\pi^-$ events
- Evidence for ρω interference in photoproduction off protons
- W-dependence measured for 20<W<80 GeV → nicely complements existing world data
- High-mass region: region of ρ(1450) and ρ(1700) investigated in 2π and 4π final states. Extends previous measurements to high energy.

Outlook

- Plan to use ρ(770) event sample to also measure the t-dependence
- Plan to unfold cross-sections in 3D: $m_{\pi\pi}$,W,t

  → extract Pomeron trajectory [similar to H1prelim-09-016]
- For 4π final states: plan to extend measurement to DIS, measure production of excited states wrt Q^2 → probe wave-function [similar to J/psi, Nucl. Phys. B 909 (2016) 934]





Backup

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)

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	–

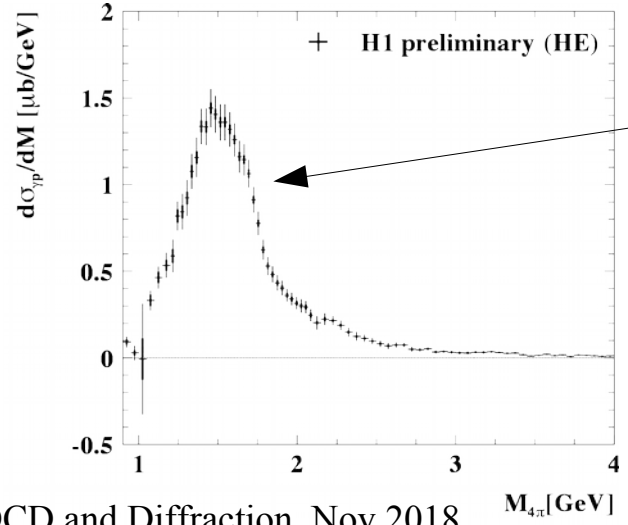
ρ(1700) [r] $I^G(J^{PC}) = 1^+(1^{--})$

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

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	–

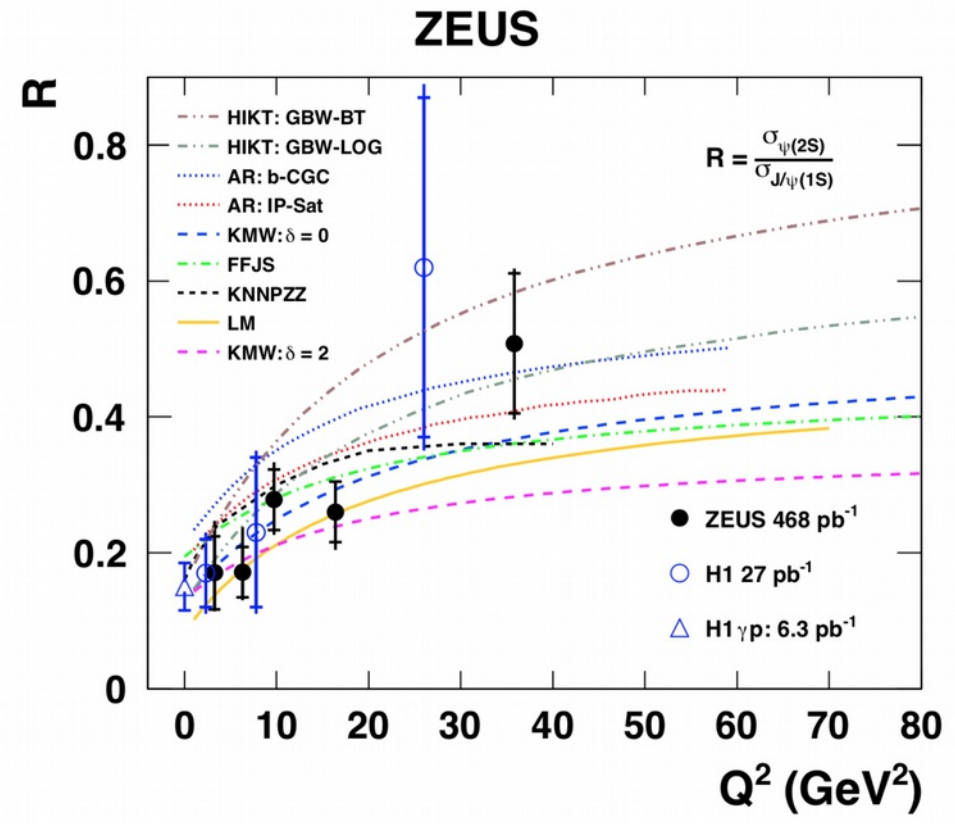
ρ(1700) [r] $I^G(J^{PC}) = 1^+(1^{--})$

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

Q^2 dependence

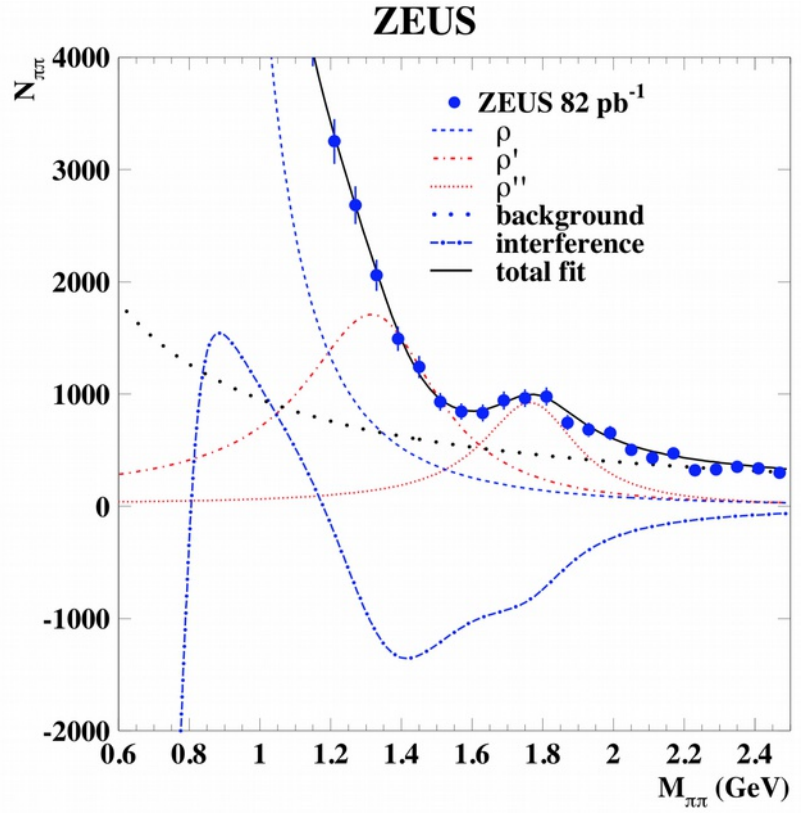
- Q^2 dependence is probing the VM wave function
- Example: measurement of ratio ψ'/ J/ψ wrt Q^2
- Cross section rises with Q^2 similar effect could be present for ρ'



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]