Measurement of Exclusive ρ^0 Meson Photoproduction at HERA

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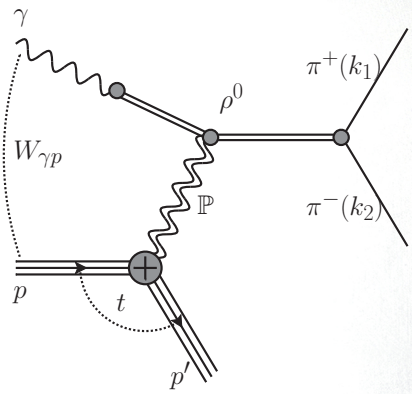

Contents

- $\pi^+\pi^-$ photoproduction at HERA
- modelling of the $m_{\pi\pi}$ spectrum
- extraction of the $\sigma(\gamma p \to \rho^0 Y)$ energy dependence

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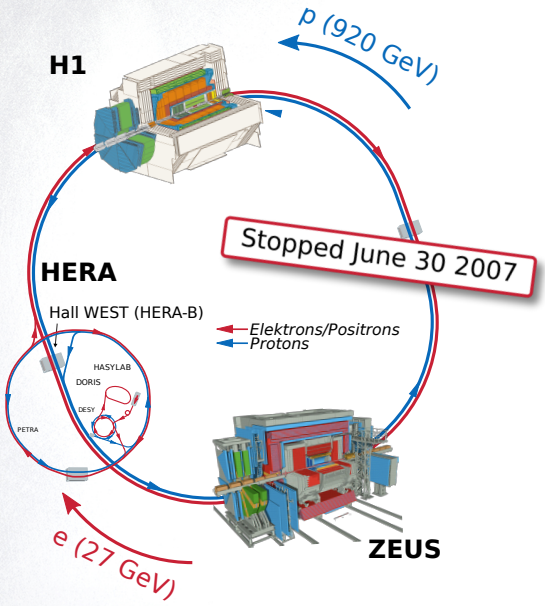
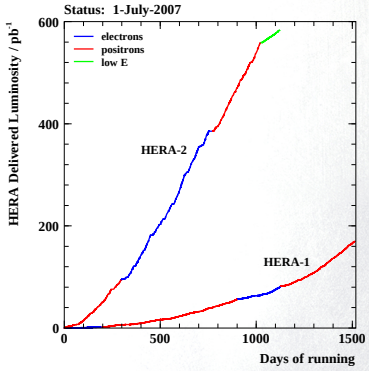
HERA $e^{\pm}p$ Collider at DESY

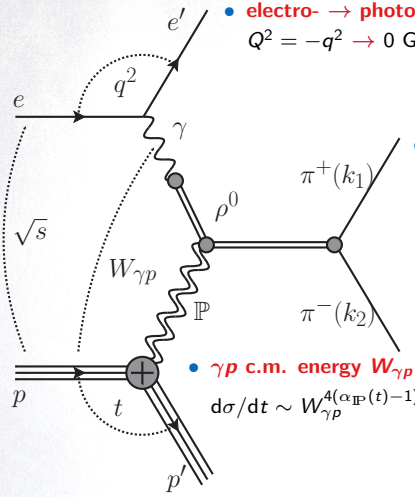


- $E_e = 27.6$ GeV
- $E_p = 920$ (460) GeV
- $\sqrt{s} = 319$ GeV
- $\mathcal{L}_{int} \sim 0.5$ fb^{-1} per experiment



[H1 Collaboration]

Diffractive $\rho^0 \to \pi^+\pi^-$ Photoproduction at HERA



- **electro- → photoproduction**
  $Q^2 = -q^2 \to 0$ GeV with quasi-real γ

- **measure $\pi^+\pi^-$**
  $BR(\rho^0 \to \pi^+\pi^-) \sim 100\%$

- **γp c.m. energy $W_{\gamma p} = \sqrt{(q+p)^2}$**
  $d\sigma/dt \sim W_{\gamma p}^{4(\alpha_{\mathbb{P}}(t)-1)}$ → slow rise due to soft $\mathbb{P}$omeron exchange

- **momentum transfer at p-vertex $t = (p-p')^2$**
  $d\sigma/dt \sim \exp(-b|t|)$ → steeply falling

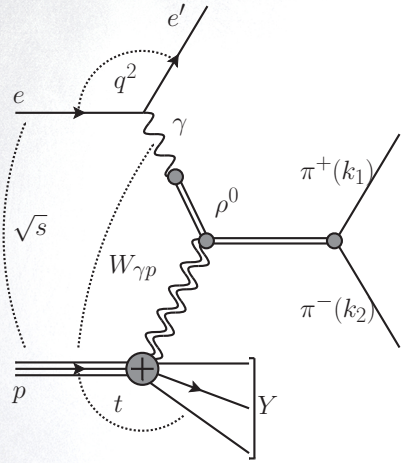
among highest HERA cross-sections

$\gamma p \to \pi^+\pi^- p'$ kinematics:

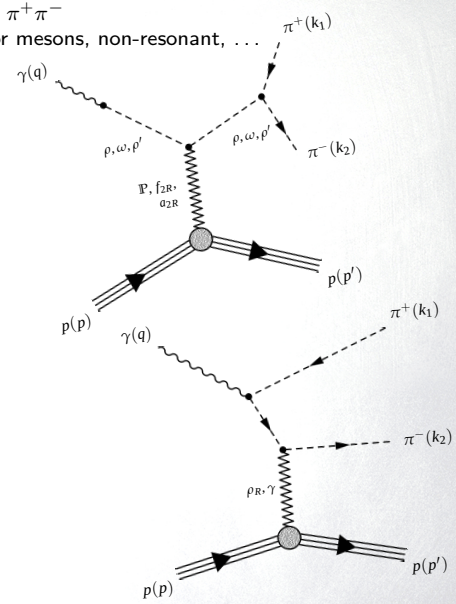
$W_{\gamma p} = \sqrt{2E_p(E_p - p_{z,\pi\pi})}$

$t = -p_{T,\pi\pi}^2$

Diffractive $\rho^0 \to \pi^+\pi^-$ Photoproduction at HERA



- **other contributions** to $\pi^+\pi^-$
  other exchanges, vector mesons, non-resonant, ...

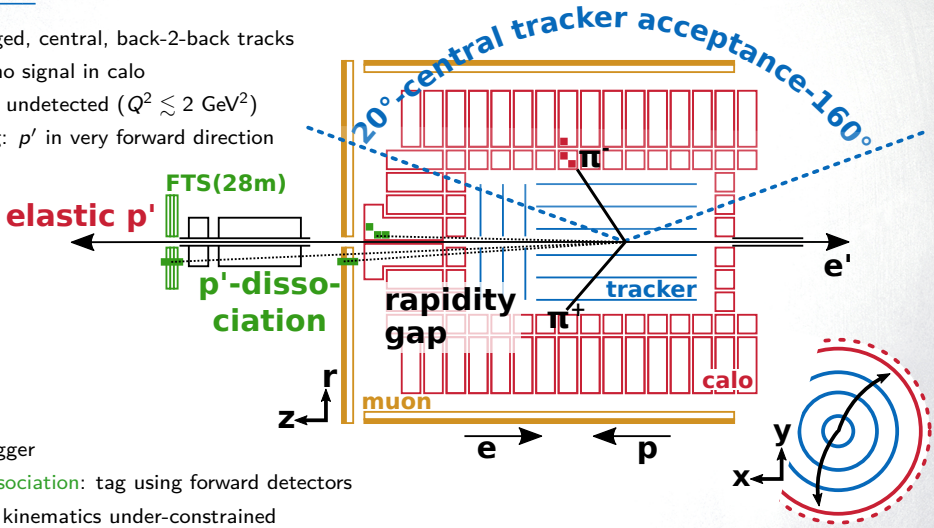


- **proton dissociation**
  $p'^2 = M_Y^2 > m_p^2 \to$ dominates at large $|t|$

Detecting $\pi^+\pi^-$ Photoproduction

Event Topology

- two oppositely charged, central, back-2-back tracks
- $p_T \lesssim 1$ GeV: often no signal in calo
- photoproduction: e' undetected ($Q^2 \lesssim 2$ GeV^2)
- diffractive scattering: p' in very forward direction



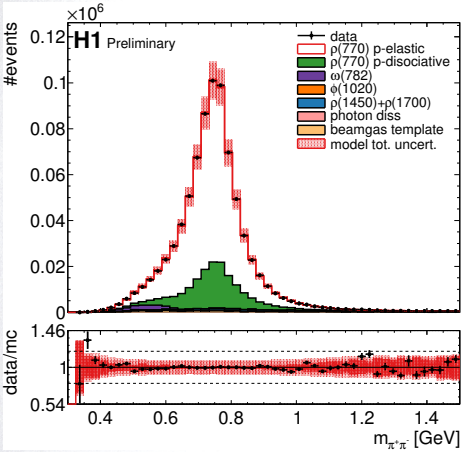
Challenges

- trigger: L1 track trigger
- elastic vs proton-dissociation: tag using forward detectors
- $Q^2 > 0$, $M_Y \neq m_p$: kinematics under-constrained
- tracker acceptance: many (small) backgrounds

Data-Set - MC Modelling

- $\sqrt{s} = 319$ GeV 2006/2007 positron data set
- $\mathcal{L} \simeq 1.3$ pb^{-1} (downscaled)
- $\sim 7 \cdot 10^5$ selected $\pi^+\pi^-$ events

$m_{\pi\pi}$

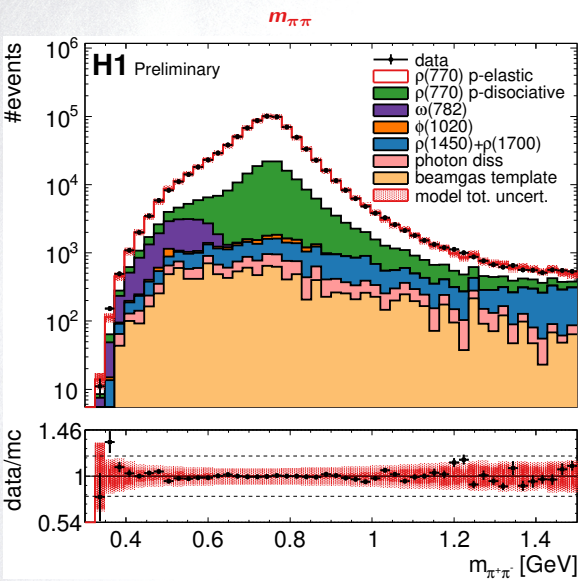


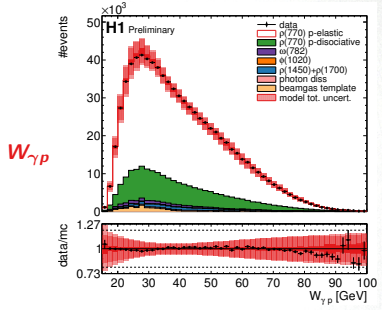
Modelling by DiffVM MC

- **$\pi^+\pi^-$ signal:** elastic & proton-dissociative
  → tuned to data in $W_{\gamma p}$, $m_{\pi\pi}$, t
  → models also ω, non-resonant → $\pi^+\pi^-$ contributions
- **backgrounds:**
  → $\omega \to \pi^+\pi^-\pi^0$
  → $\phi \to K^+K^-$, $K_S K_L$, $\pi^+\pi^-\pi^0$, $\rho\pi$, $\eta\gamma$
  → $\rho' \to \rho\pi\pi$, $\pi\pi\pi\pi$
  → γ-dissociation → hadrons via JETSET
- **proton-dissociation:**
  → $\mathrm{d}\sigma^{\gamma p}/\mathrm{d}M_Y^2 \propto (1/M_Y^2)^\delta \otimes$ measured resonance structure
  → $M_Y < 1.9$ GeV : N^* resonance with measured decay channels
  → $M_Y > 1.9$ GeV : $p' \to$ hadrons via JETSET

Phasespace:

15 GeV	$\leq$	$W_{\gamma p}$	≤ 100	GeV
0.3 GeV	$\leq$	$m_{\pi\pi}$	≤ 1.5	GeV
		$p^2_{T,\pi\pi} \sim \lvert t \rvert$	≤ 2	GeV^2
		$(Q^2$	$\gtrsim 2$	GeV^2)
		$(M_Y$	$\gtrsim 10$	GeV)


$m_{\pi\pi}$
H1 Preliminary
#events
data
ρ(770) p-elastic
ρ(770) p-disociative
ω(782)
φ(1020)
ρ(1450)+ρ(1700)
photon diss
beamgas template
model tot. uncert.
data/mc
$m_{\pi^+\pi^-}$ [GeV]


$W_{\gamma p}$
H1 Preliminary
#events
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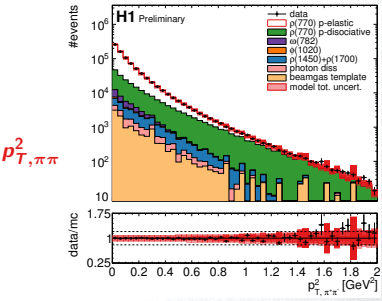
$W_{\gamma p}$ [GeV]


$p^2_{T,\pi\pi}$
H1 Preliminary
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ω(782)
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ρ(1450)+ρ(1700)
photon diss
beamgas template
model tot. uncert.
data/mc
$p^2_{T,\pi^+\pi^-}$ [GeV^2]

Differential Cross-Section Definition

$$\frac{\mathrm{d}\sigma(\gamma p \to \pi^+\pi^- Y)}{\mathrm{d}m_{\pi\pi}}(W_{\gamma p}, m_{\pi\pi}) = \frac{N^Y_{\text{unfolded}}(W_{\gamma p}, m_{\pi\pi})}{\mathcal{L}_{\text{int}}\,\Delta m_{\pi\pi}\,\Phi_{\gamma/e}(W_{\gamma p})^*}$$

Reduced Fiducial Phasespace

20 GeV	$\leq$	$W_{\gamma p}$	≤ 80	GeV
0.4 GeV	$\leq$	$m_{\pi\pi}$	≤ 1.2	GeV
		$-t$	≤ 1.5	GeV^2
		Q^2	≤ 0.1	GeV^2
elastic:				
		M_Y	$= m_p$	GeV
p-dissociative:				
m_p	$<$	M_Y	≤ 10	GeV

*bin-wise, no bin-center correction!

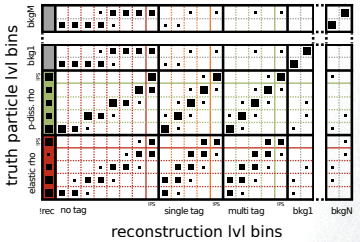
photon-flux $\Phi_{\gamma/e}(W_{\gamma p})$ using Weizsäcker-Williams

Unfolding Particle Level Cross-Sections:

- subtract backgrounds
- correct signal for detector efficiency and resolution
- separate elastic from p-dissociative contributions

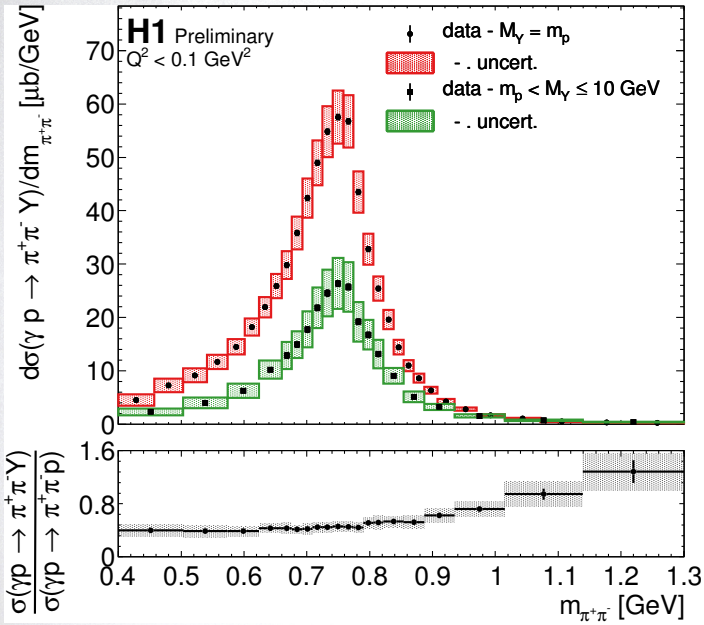
- **regularized template fit** using TUnfold

response matrix schematic:



- p-dissociation separated using 3 tagging control regions
- (MC) backgrounds normalized in 4 control regions
- regularize curvature to minimize global correlations

$d\sigma(\gamma p \to \pi^+\pi^- Y)/dm_{\pi\pi}$ vs $m_{\pi\pi}$ & Fiducial $\pi^+\pi^-$ Cross-Section



← unfold 1D $m_{\pi\pi}$ distribution

Fiducial Cross-Section:

	$\sigma[\mu b]$	stat.$[\mu b]$	syst. $[\mu b]$
$\gamma p \to \pi^+\pi^- p$	11.36	± 0.04	$\pm 1.17^*$
$\gamma p \to \pi^+\pi^- Y$	5.17	± 0.04	$\pm 0.94^*$

*not fully evaluated

Main Sources of Uncertainty:

- trigger
- forward tagging
- calorimeter

Extracting $\sigma(\gamma p \to \rho^0 Y)$ by Fitting $m_{\pi\pi}$ Distribution

$$\frac{d\sigma_{\pi^+\pi^-}}{dm_{\pi\pi}}(m_{\pi\pi}) = \frac{N}{(1+f_\omega+f_{nr})^2} \cdot \left| \mathcal{RBW}_\rho(m_{\pi\pi}) + f_\omega e^{i\phi_\omega} \mathcal{RBW}_\omega(m_{\pi\pi}) + f_{nr} e^{i\phi_{nr}} \frac{B_{nr}(m_{\pi\pi})}{B_{nr}(m_\rho)} \right|^2$$

Extended Söding Model

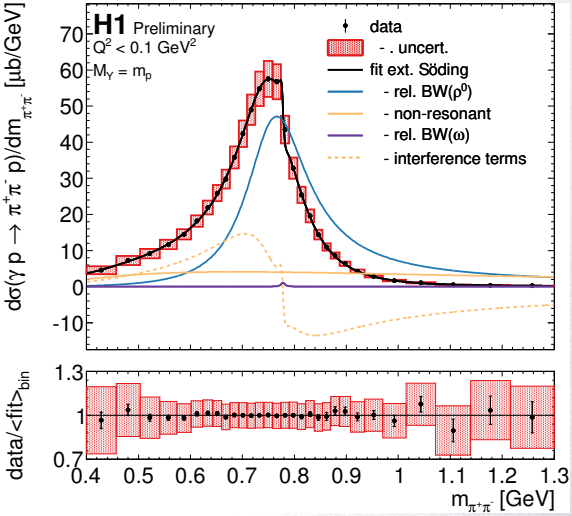
- ρ^0, $\omega(782)$ and non-resonant contributions
- added on amplitude level including global phase differences ϕ_ω, ϕ_{nr}
- ρ^0 and ω modelled by relativistic Breit-Wigner with mass-dependent width:

$$\mathcal{RBW}_{\mathrm{VM}}(m_{\pi\pi}) = \frac{\sqrt{m_{\pi\pi} m_{\mathrm{VM}} \Gamma(m_{\pi\pi})}}{m_{\pi\pi}^2 - m_{\mathrm{VM}}^2 + \mathrm{i}\, m_{\mathrm{VM}} \Gamma(m_{\pi\pi})}$$

- non-resonant background model:

$$B_{nr} = \left(\frac{m_{\pi\pi} - 2m_\pi}{(m_{\pi\pi} - 2m_\pi)^2 + \Lambda_{nr}^2} \right)^{\delta_{nr}}$$

- ρ^0 dominant, but significant interference contributions



Extracting $\sigma(\gamma p \to \rho^0 Y)$ by Fitting $m_{\pi\pi}$ Distribution

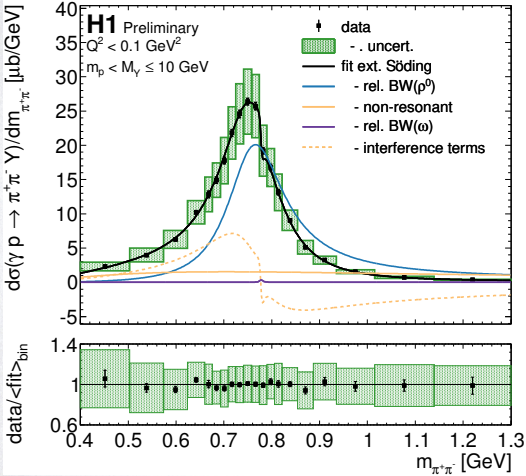
- elastic & p-dissociative fit together
- different non-resonant contributions $\to$ shape differences

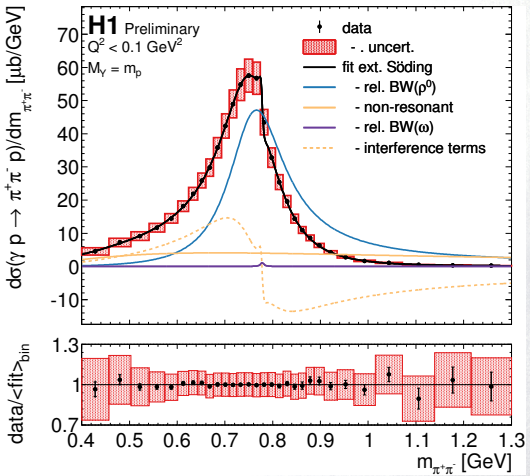
fitted parameters:

$m_{\rho^0} = 771 \pm 1$ (stat.) MeV

$\Gamma_{\rho^0} = 150 \pm 1$ (stat.) MeV

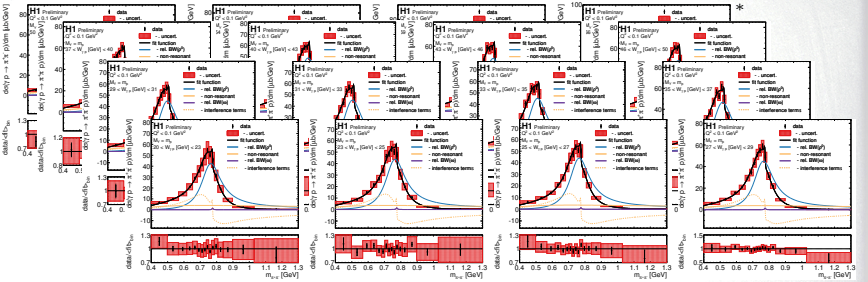
systematic uncertainties not fully evaluated





unfold 2D $m_{\pi\pi} \otimes W_{\gamma p}$ distribution →

$\mathrm{d}\sigma(\gamma p \to \pi^+\pi^- Y)/\mathrm{d}m_{\pi\pi}(m_{\pi\pi})$ in 16 elastic $W_{\gamma p}$ bins

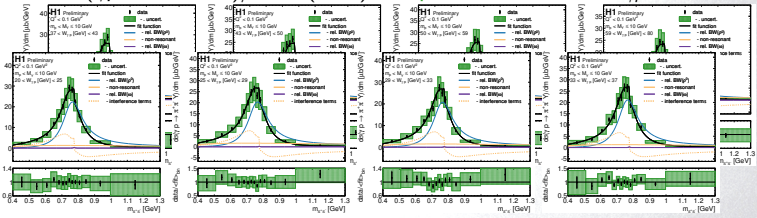


$\sigma(\gamma p \to \rho^0 Y)$

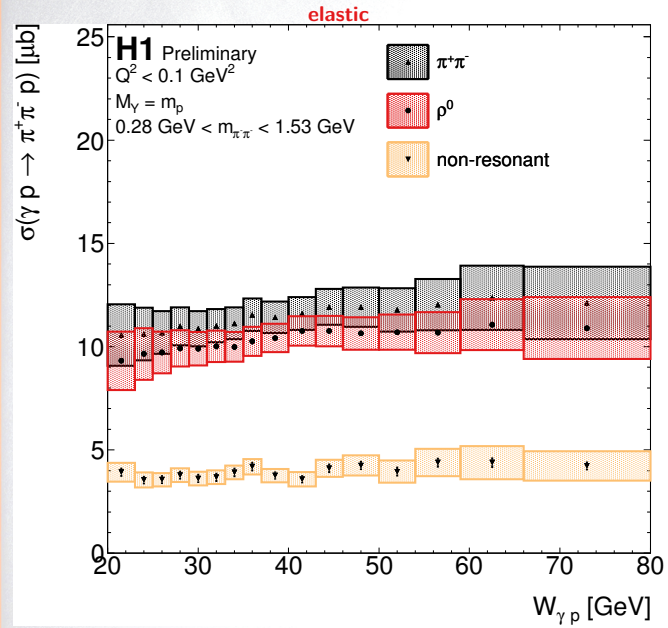
- parallel fit of 1D $\mathrm{d}\sigma(\gamma p \to \pi^+\pi^- Y)/\mathrm{d}m_{\pi\pi}(m_{\pi\pi})$ in $W_{\gamma p}$ bins
- many model parameters $W_{\gamma p}$-independent
  (no significant dependence observed)
- integrate out ρ^0 contribution:

$$\sigma_{\rho^0} := \int_{2m_\pi}^{m_\rho + 5\Gamma_\rho} \left| \mathcal{RBW}_\rho(m_{\pi\pi}) \right|^2 \mathrm{d}m_{\pi\pi}$$

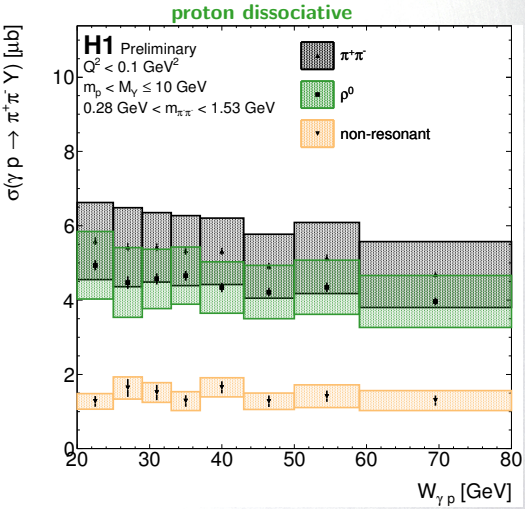
$\mathrm{d}\sigma(\gamma p \to \pi^+\pi^- Y)/\mathrm{d}m_{\pi\pi}(m_{\pi\pi})$ in 8 proton-dissociative $W_{\gamma p}$ bins



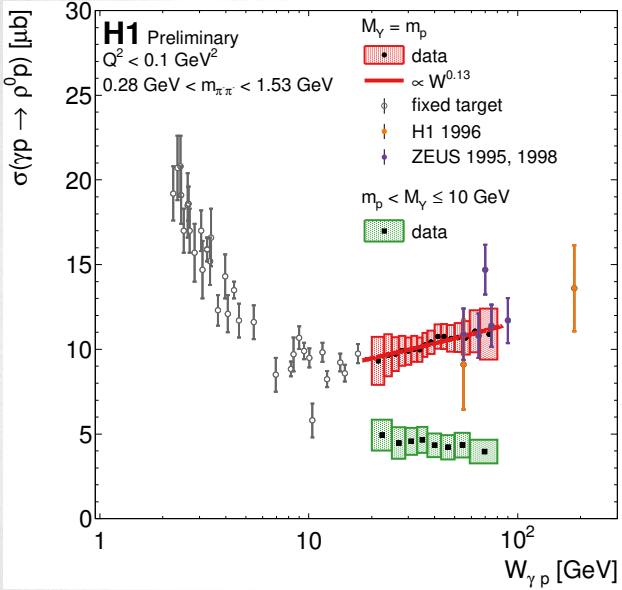
*all distribution shown in backup



- all cross-sections from fit function integral
- proton dissociative cross-section shaped by phase-space restrictions



Comparison w/ Previous Measurements



$\pi^+\pi^-$ Data-Set

analysed large H1 $\pi^+\pi^-$ photoproduction data-set

$\pi^+\pi^-$ Cross-Sections

extracted differential $\pi^+\pi^-$ cross-sections vs. $m_{\pi\pi}$, full unfolding allows to correct under-constrained kinematics, extrapolate to small Q^2, and separate the elastic from the proton-dissociative component

ρ^0 Cross-Sections

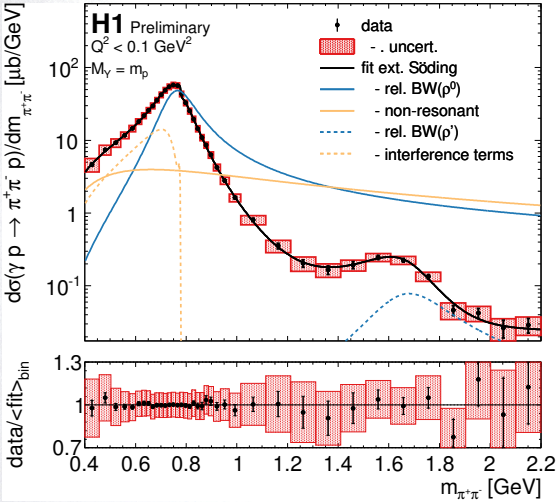
applied extended Söding model to $\pi^+\pi^-$ cross-sections ρ^0, ω, non-resonant $\pi^+\pi^-$ and interferences considered allows to extract ρ^0 cross-sections, $W_{\gamma p}$ dependence

Advertisment for Poster #92: Higher Mass ρ' Resonance(s)

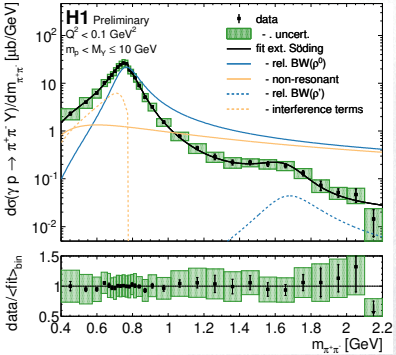
- further ρ resonances have been observed at higher $m_{\pi\pi}$
- also present in H1 data in extended range $m_{\pi\pi} \leq 2.2$ GeV
- **see also poster #92:**
  Exclusive Photoproduction of $2\pi^+2\pi^-$ Final State at HERA

$m_{\rho'} \sim 1700$ MeV
$\Gamma_{\rho'} \sim 300$ MeV

no evidence for $\rho(1450)$

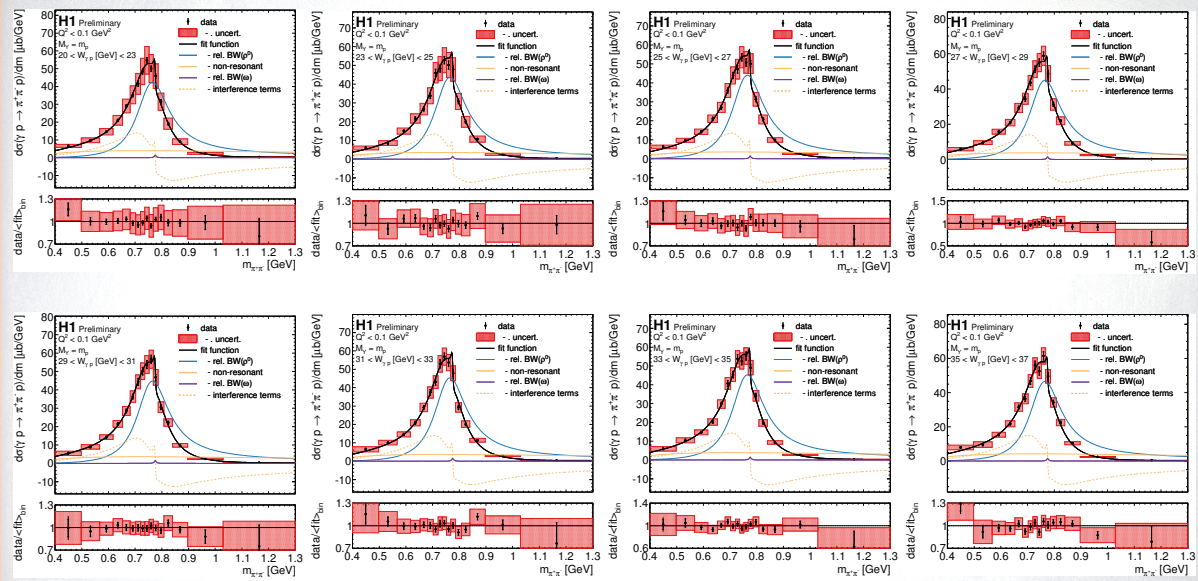


- fit extended Söding model with 3. Breit-Wigner to consider single ρ' contribution
- elastic & *p*-dissociative fit together

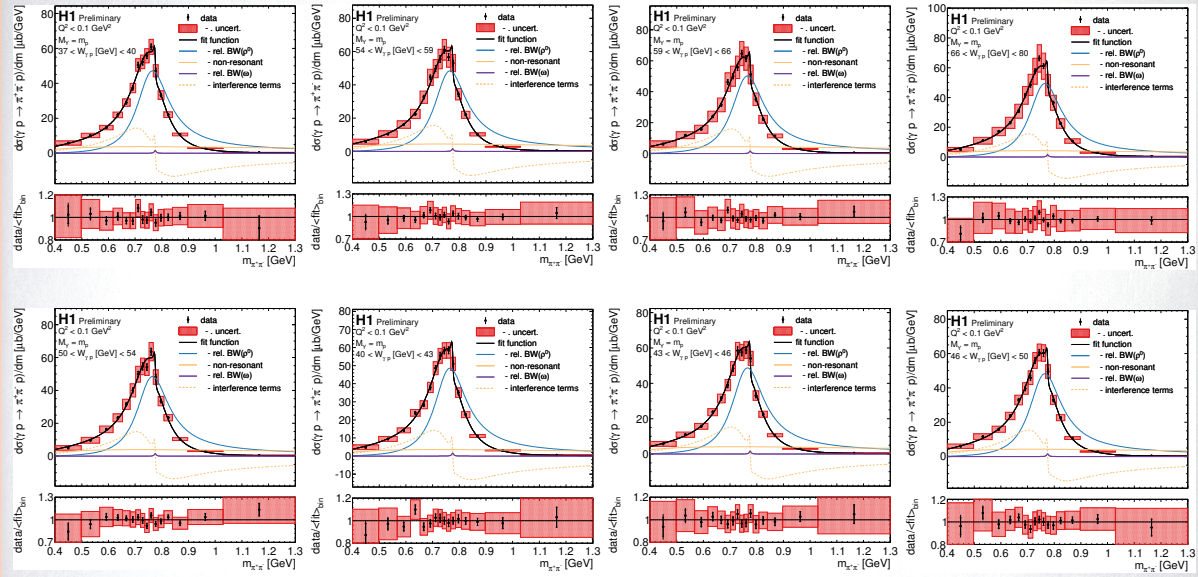


BACKUP

Fit Elastic $d\sigma(\gamma p \to \pi^+\pi^- p)/dm_{\pi\pi}$ ($m_{\pi\pi}$) in $W_{\gamma p}$ Bins



Fit Elastic $d\sigma(\gamma p \to \pi^+\pi^- p)/dm_{\pi\pi}$ ($m_{\pi\pi}$) in $W_{\gamma p}$ Bins



Fit p-Dissociative $\mathrm{d}\sigma(\gamma p \to \pi^+\pi^- Y)/\mathrm{d}m_{\pi\pi}$ ($m_{\pi\pi}$) in $W_{\gamma p}$ Bins