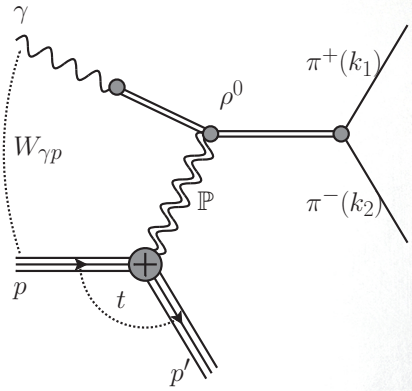
Measurement of Exclusive ρ^0 Meson Photoproduction at HERA

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

- H1prelim-18-012 4 ICHEP 2018



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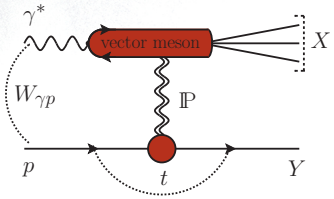
Vector Meson Photoproduction

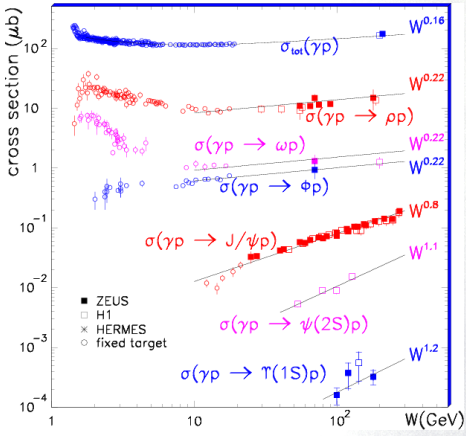


- $\gamma \rightarrow q\bar{q}$ fluctuations $\rightarrow$ bound states
- $J^{PC}(\gamma) = 1^{--} \rightarrow$ vector mesons $(\rho, \omega, \phi, \dots)$
- long lifetime $\rightarrow$ strong interaction: $\sigma(\gamma \text{ had}) \sim \sigma(\text{had had})$

Diffraction

- color singlet exchange:
  $\rightarrow$ Regge picture: low-erg. $\mathbb{R}$egeons, high-erg. $\mathbb{P}$omeron
- cross-section cms energy dependence: $\boldsymbol{\sigma(W_{\gamma p}) \sim W_{\gamma p}^{\delta}}$
  $\rightarrow$ related to Regge-trajectories: $\delta(t) = 4(\alpha_{\mathbb{P}}(t) - 1)$
- momentum transfer at p-vertex t: $\boldsymbol{d\sigma/dt(t) \sim e^{-b|t|}}$

Vector Meson Photoproduction



- $W_{\gamma p} > 20$ all HERA data
- newer/LHC results not included

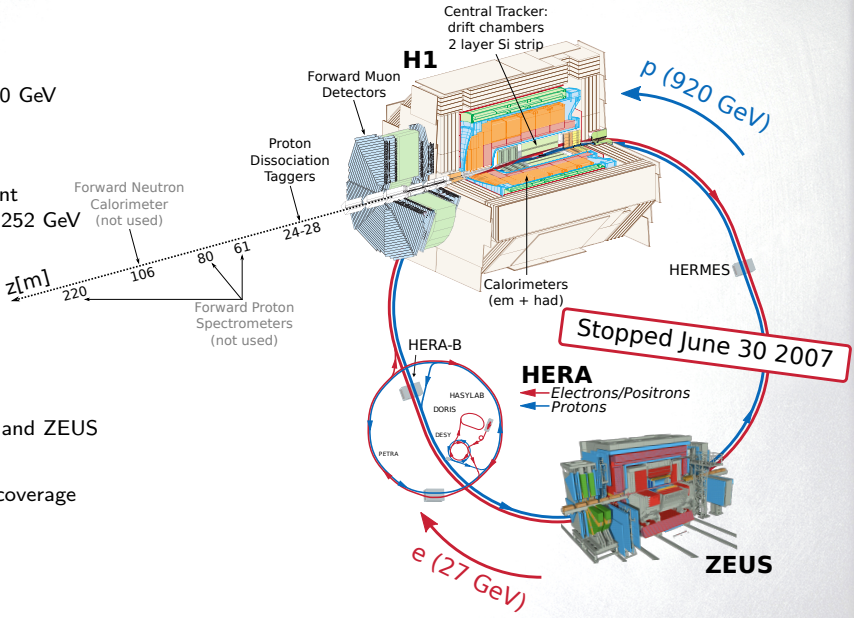
HERA $e^{\pm}p$ Collider at DESY

HERA:

- world's only ep collider
- $E_e = 27.6$ GeV, max $E_p = 920$ GeV
- max $\sqrt{s} = 319$ GeV
- e^+p and e^-p data
- $\mathcal{L}_{int} \sim 0.5$ fb^{-1} per experiment
  + datasets at $\sqrt{s} = 225$ and 252 GeV

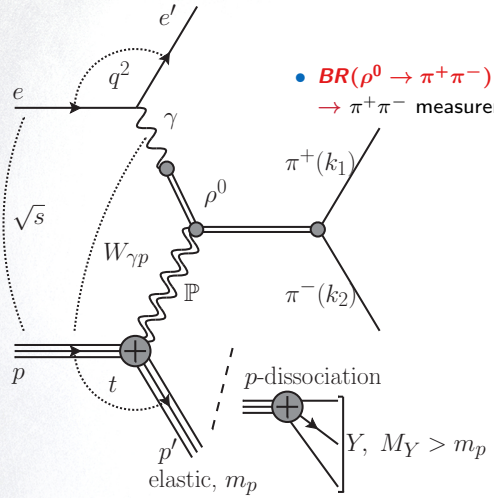
detectors

- two collider experiments: H1 and ZEUS
- multi-purpose detectors
- $\sim 4\pi$ calorimeter (em&had) coverage
- tracking in central region
- forward detectors



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

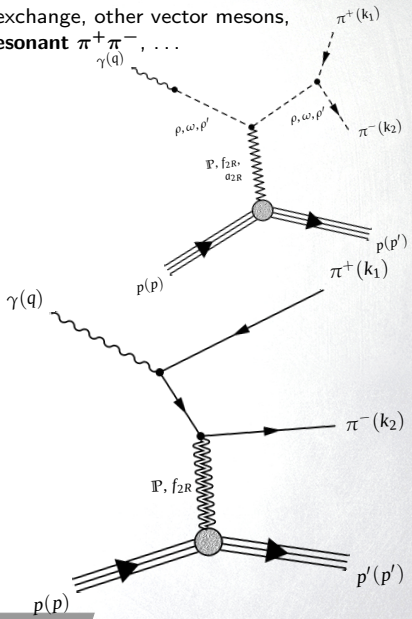
- **electro- → photoproduction**
  $Q^2 = -q^2 \to 0$ GeV^2 with quasi-real γ



- ***BR*($\rho^0 \to \pi^+\pi^-$) ∼ 100%**
  → $\pi^+\pi^-$ measurement

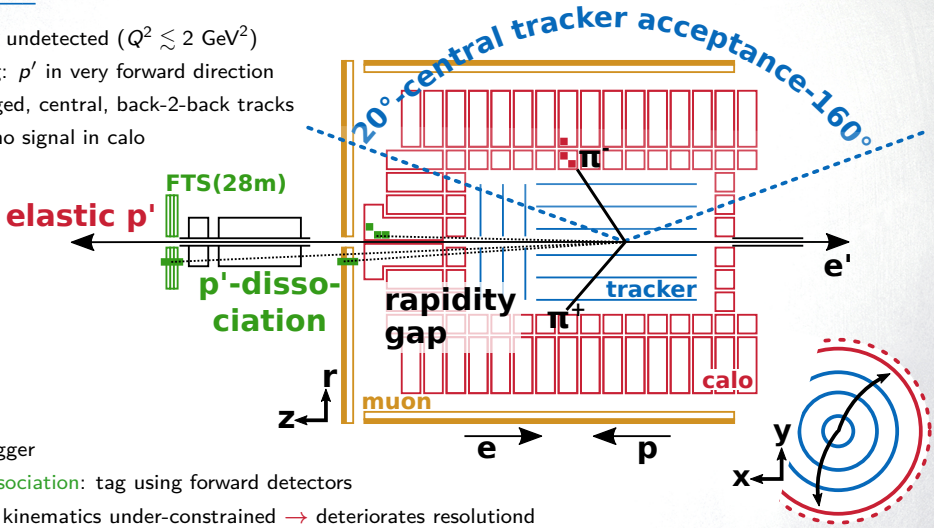
- **elastic scattering** vs **proton dissociating**
  dissociation: $p'^2 = M_Y^2 > m_p^2$ → dominates at large $|t|$

- **other contributions to $\pi^+\pi^-$**
  $\gamma, \mathbb{R}$ exchange, other vector mesons, **non-resonant $\pi^+\pi^-$**, . . .



Event Topology

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



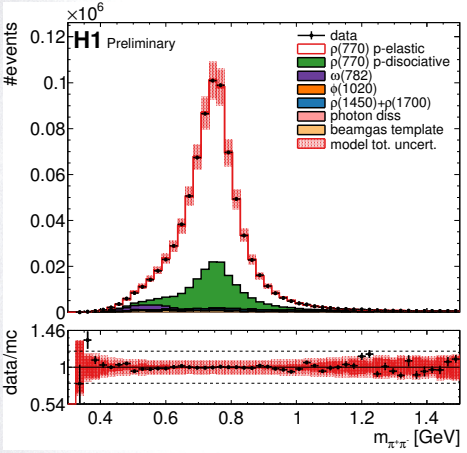
Challenges

- trigger: L1 track trigger
- elastic vs proton-dissociation: tag using forward detectors
- $Q^2 > 0$, $M_Y \neq m_p$: kinematics under-constrained $\rightarrow$ deteriorates resolutiond
- 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 trigger)
- $\sim 7 \cdot 10^5$ selected $\pi^+\pi^-$ events

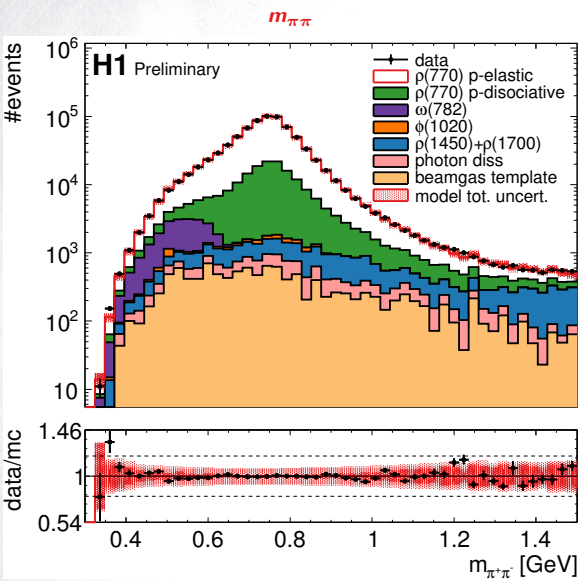
$m_{\pi\pi}$

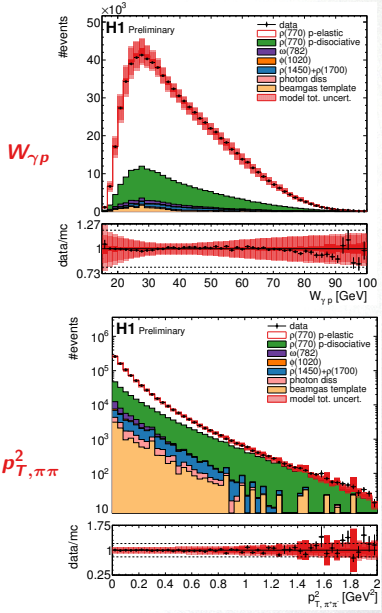


Modelling by DiffVM MC

- $\pi^+\pi^-$ **signal:** elastic & proton-dissociative
  - → tuned to data in $W_{\gamma p}$, $m_{\pi\pi}$, t
  - → models also ω, ρ', 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

Data-Set - Control Plots





Unfolding Particle Level Cross-Sections:

- subtract backgrounds
- correct signal for detector efficiency and resolution
- **separate elastic from dissociative contributions**
- regularized template fit using TUnfold

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

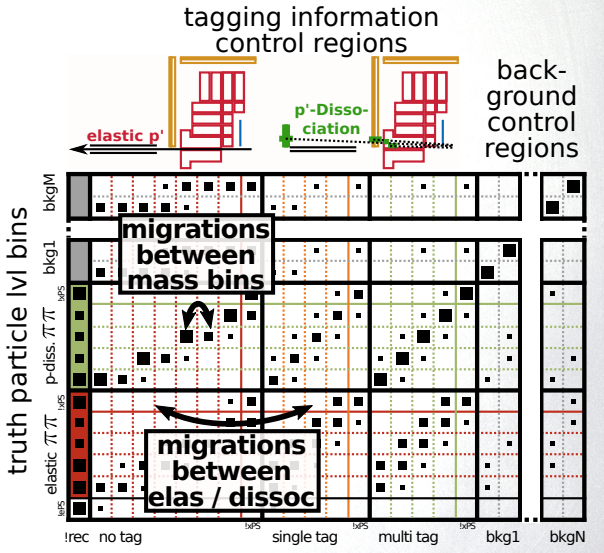
Reduced Fiducial Phasespace

20 GeV	$\leq$	$W_{\gamma p}$	≤ 80	GeV
0.4 GeV	$\leq$	$m_{\pi\pi}$	$\leq 1.3\ (2.2)$	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

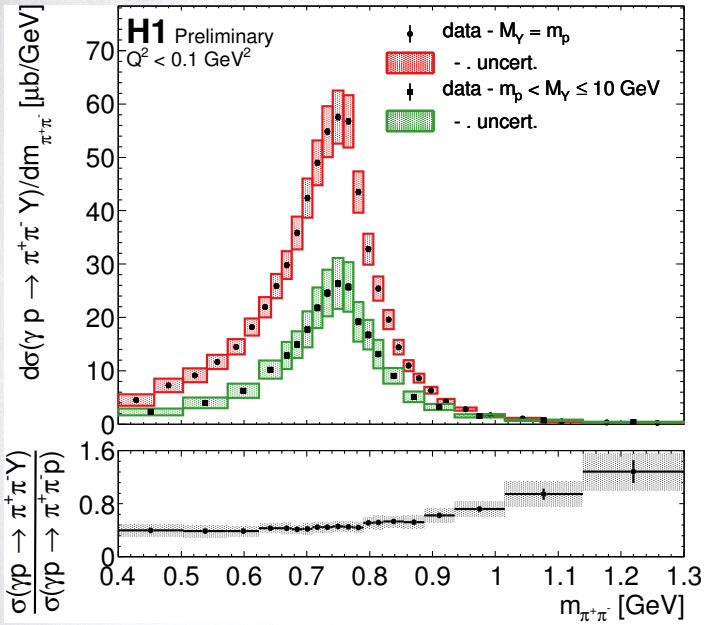
* bin-wise, no bin-center correction!

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

Response Matrix Schematic:



$d\sigma(\gamma p \to \pi^+\pi^- Y)/dm_{\pi\pi}$ 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

Uncertainty:

- very high statistical precision
- dominating systematic uncertainties:
  - → trigger
  - → forward tagging: elas/dissoc separation
  - → calorimeter: background normalization

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

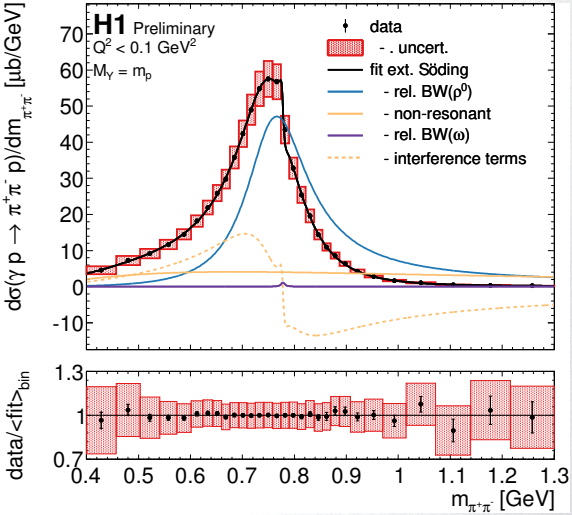
- ρ^0, $\omega(782)$ and non-resonant contributions
- added on amplitude level including global phase differences ϕ_ω, ϕ_{nr}
- ρ^0 and ω modelled by relativistic Breit-Wigner with mass-dependent width:

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

- non-resonant background model:

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

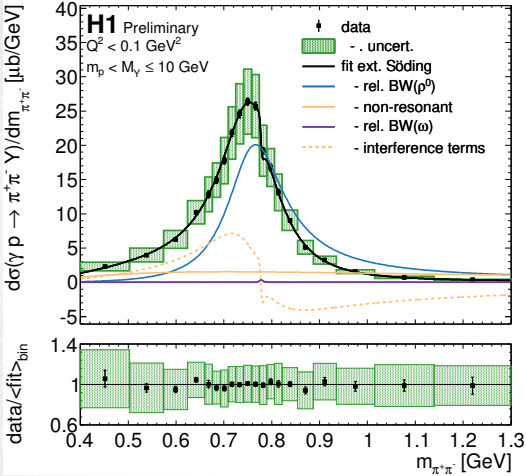
- ρ^0 dominant, but significant interference contributions

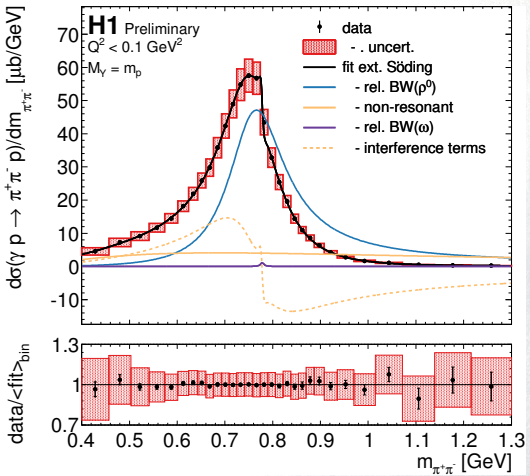


Extracting $\sigma(\gamma p \to \rho^0 Y)$ by Fitting $m_{\pi\pi}$ Distribution

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

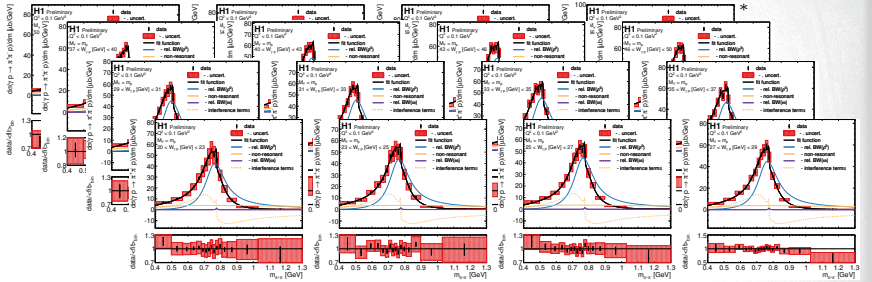
fitted parameters:
$m_{\rho^0} = 771 \pm 1$ (stat.) MeV
$\Gamma_{\rho^0} = 150 \pm 1$ (stat.) MeV
systematic uncertainties not fully evaluated





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

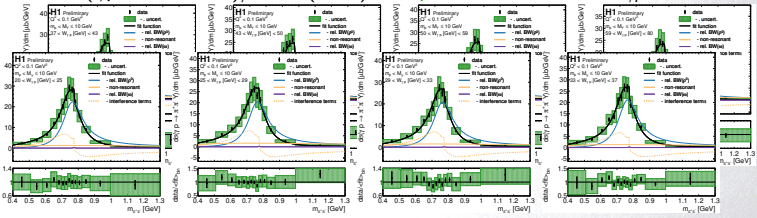


$\sigma(\gamma p \to \rho^0 Y)$

- 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:

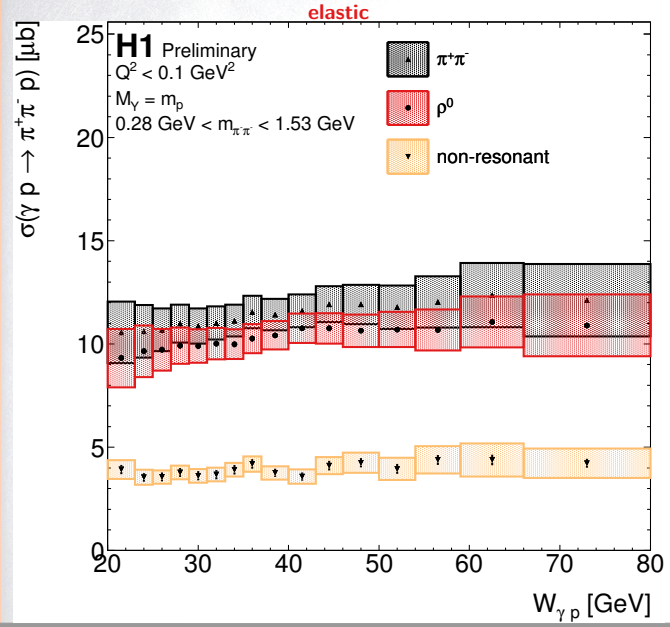
$$\sigma_{\rho^0} := \int_{2m_\pi}^{m_\rho + 5\Gamma_\rho} \left| \mathcal{RBW}_\rho(m_{\pi\pi}) \right|^2 \mathrm{d}m_{\pi\pi}$$

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

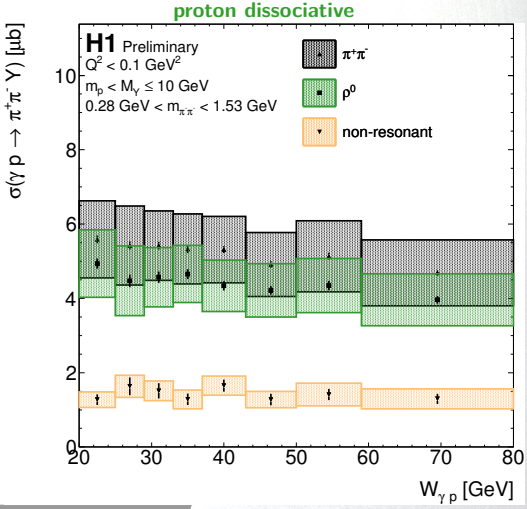


*all distribution shown in backup

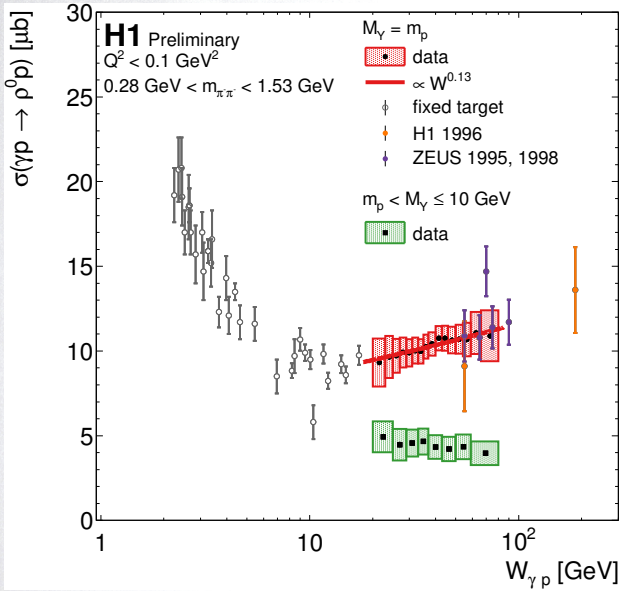
$\sigma(\gamma p \to \rho^0 Y)(W_{\gamma p})$



- all cross-sections from fit function integral
- proton dissociative cross-section shaped by phase-space restrictions $M_Y < 10$ GeV
  $\to$ $M_Y < 10$ GeV more restrictive at high $W_{\gamma p}$



Comparison to World Data



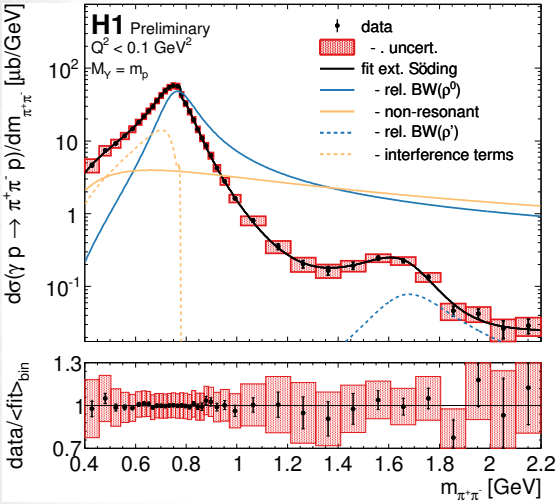
- measure ρ^0 $W_{\gamma p}$ dependence in range $20 < W_{\gamma p} < 80$ GeV
- fills "gap" between fixed target and HERA measurements

- elastic cross-section rises w/ $\sim W_{\gamma p}^{0.13}$
- p-dissociative consistent with constant in fiducial PS

- high statistical precision
- but very large systematic uncertainties
- $W_{\gamma p}$ shape uncertainty dominated by trigger

High $\pi^+\pi^-$ Mass Region

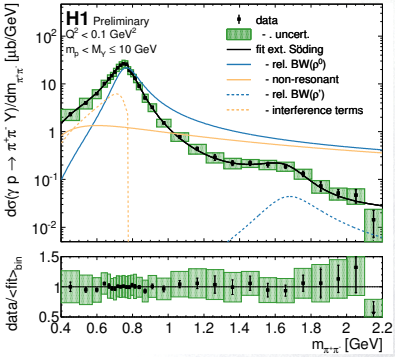
- further ρ resonances have been observed at higher $m_{\pi\pi}$
- also present in H1 data in extended range $m_{\pi\pi} \leq 2.2$ GeV



$m_{\rho'} \sim 1700$ 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



Summary

- presented fully unfolded $\pi^+\pi^-$ photoproduction cross-section vs. $m_{\pi\pi}$
  $\rightarrow$ elastic and p-dissociative contribution statistically separated
  $\rightarrow$ strongly reduces model dependence of distributions
  $\rightarrow$ detector resolution corrections e.g. allow to observe ω contribution

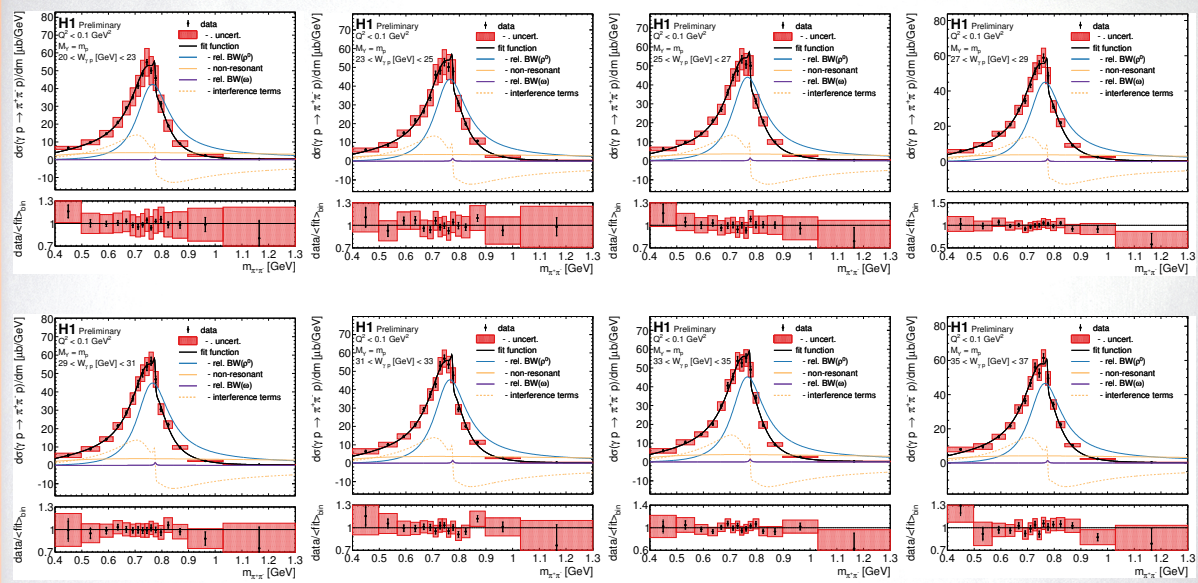
- $m_{\pi\pi}$ distribution well described by Söding model $\sim |\rho + \omega + \text{non-resonant}|^2$
  $\rightarrow$ high mass region described by single additional ρ' contribution

- very large $\pi^+\pi^-$ photoproduction dataset available at H1
  $\rightarrow$ blessing and curse b.c. very good understanding of small detector effects required

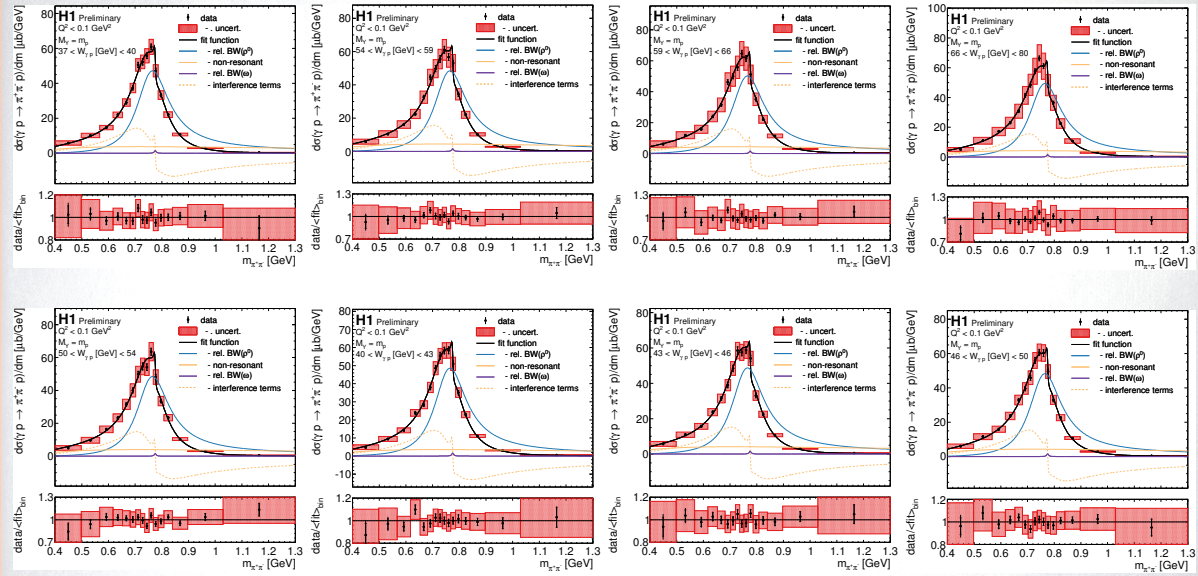
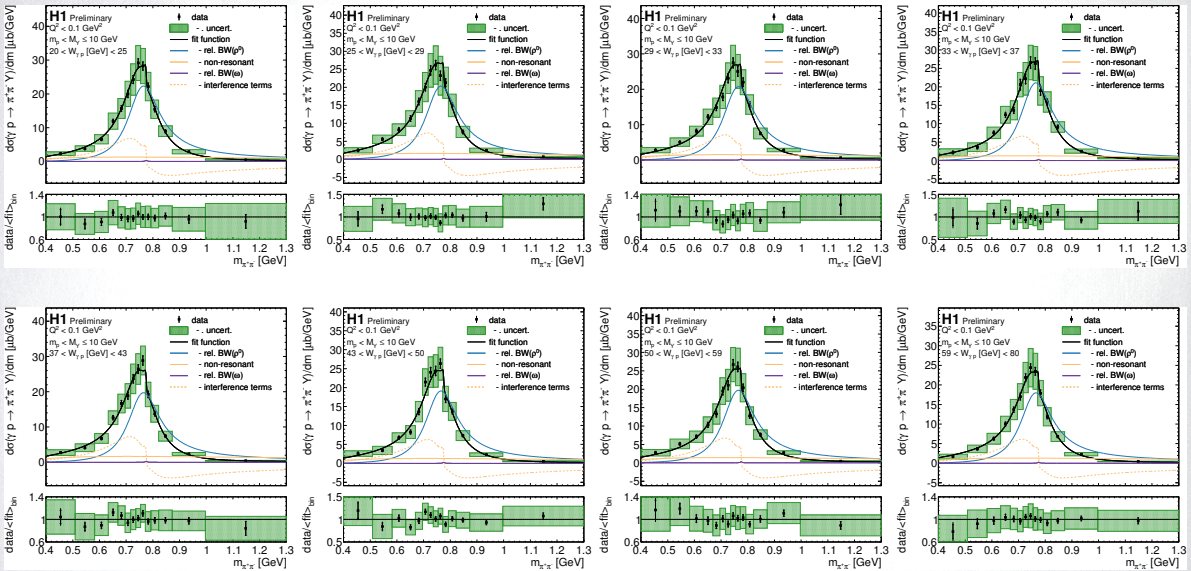
- systematics not fully evaluated
  $\rightarrow$ in particular w.r.t background contributions at high $m_{\pi\pi}$ and t, tagging and trigger
  $\rightarrow$ $\mathrm{d}\sigma(\pi^+\pi^-)/\mathrm{d}t(t)$ dependence more problematic and thus not shown today

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