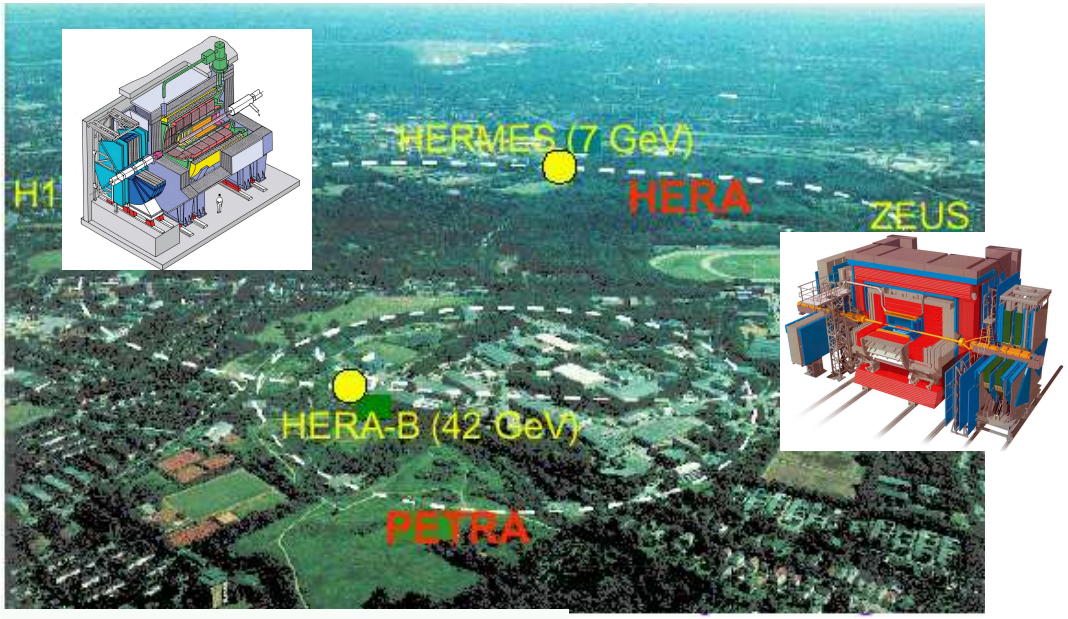
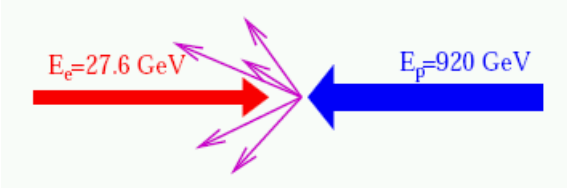
Exclusive ρ^0 and ρ' Photoproduction at HERA

Sergey Levonian, DESY

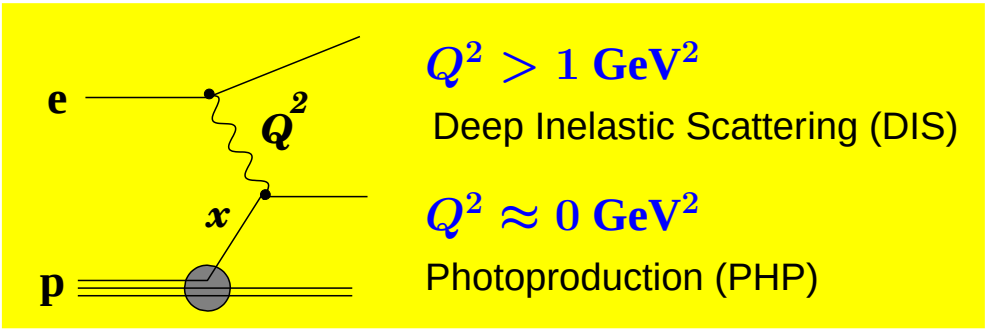
for the H1 Collaboration

HERA: The World's Only ep Collider





$(\sqrt{s} = 319$ GeV)



$Q^2 > 1$ GeV^2

Deep Inelastic Scattering (DIS)

$Q^2 \approx 0$ GeV^2

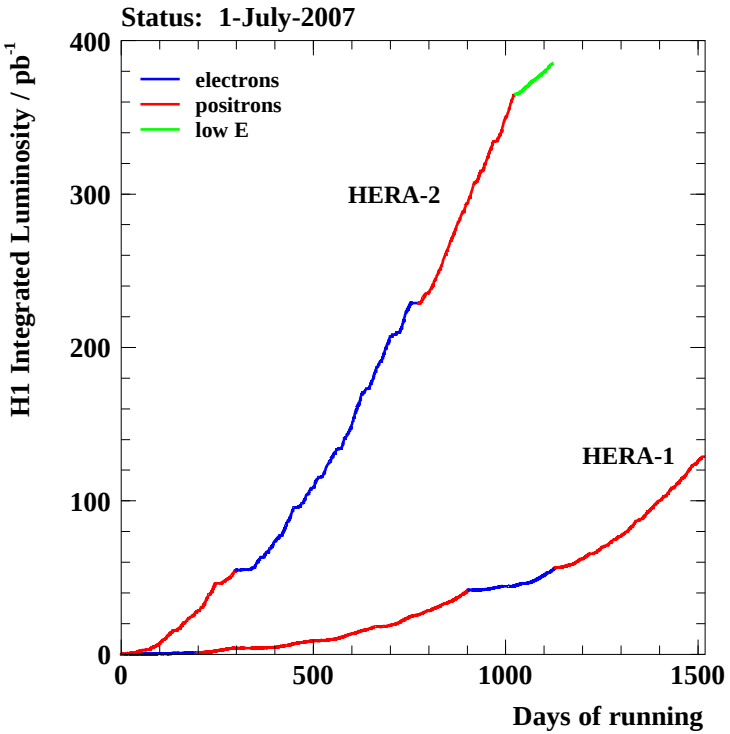
Photoproduction (PHP)

HERA-1 (1993-2000) $\simeq 120$ pb^{-1}

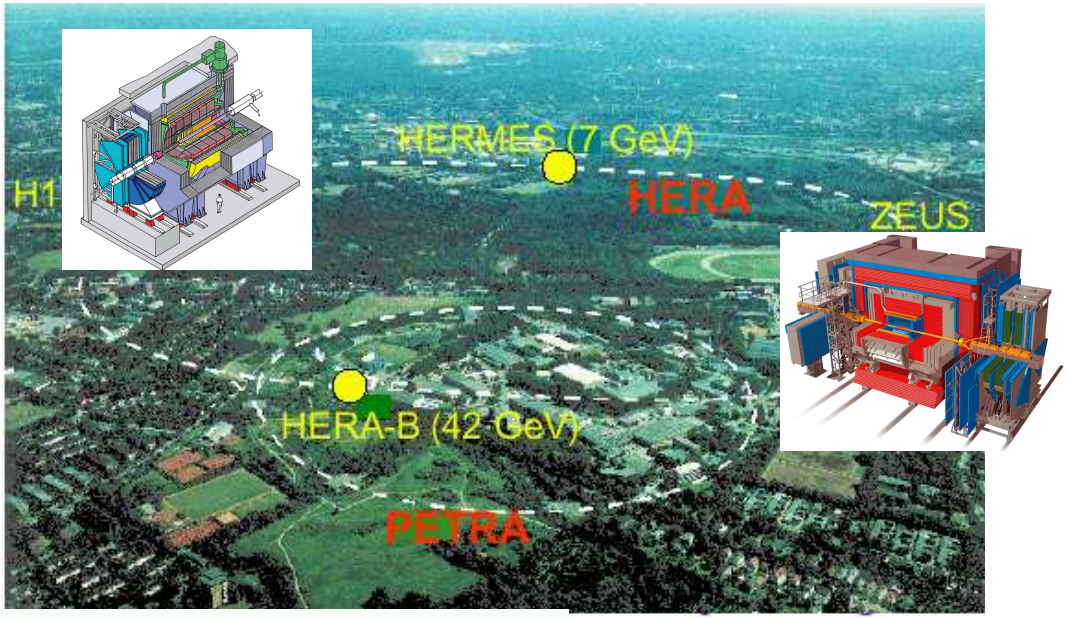
HERA-2 (2003-2007) $\simeq 380$ pb^{-1}

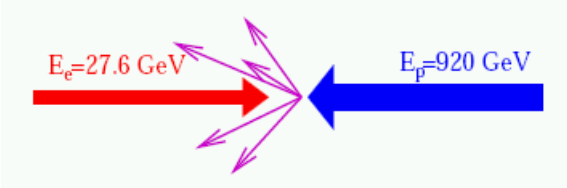
Final Data samples

H1+ZEUS: 2×0.5 fb^{-1}

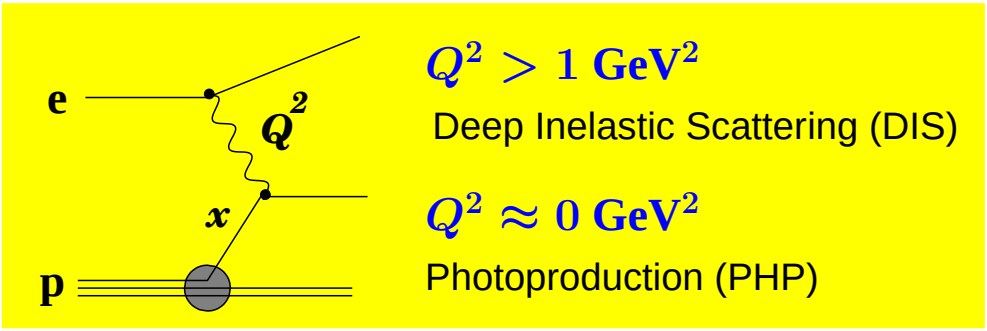


HERA: The World's Only ep Collider





$(\sqrt{s} = 319$ GeV)



$Q^2 > 1$ GeV^2

Deep Inelastic Scattering (DIS)

$Q^2 \approx 0$ GeV^2

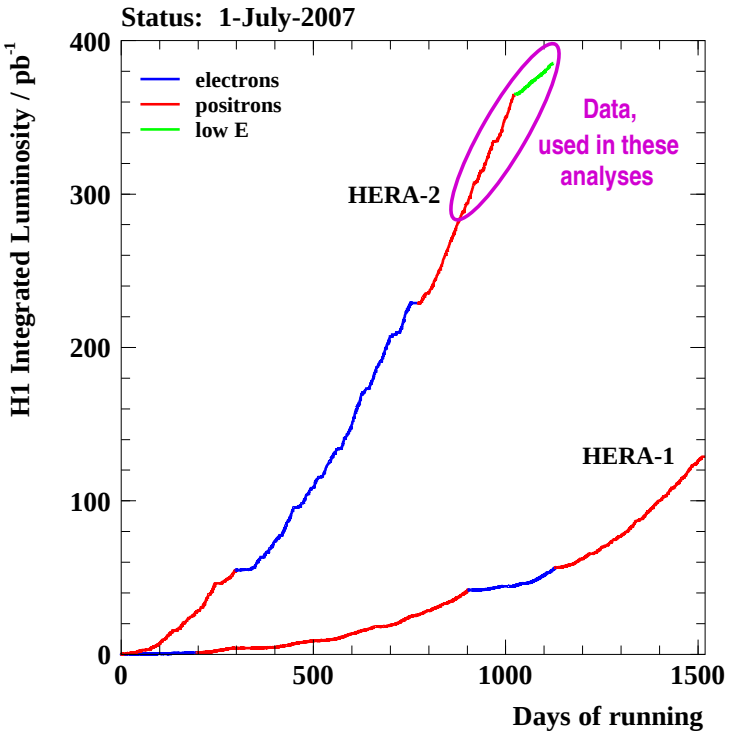
Photoproduction (PHP)

HERA-1 (1993-2000) $\simeq 120$ pb^{-1}

HERA-2 (2003-2007) $\simeq 380$ pb^{-1}

Final Data samples

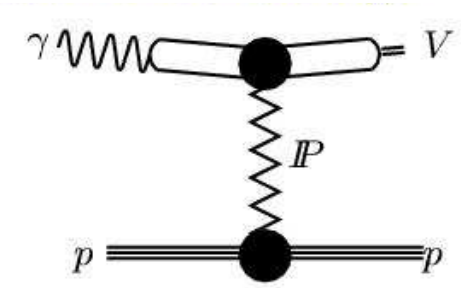
H1+ZEUS: 2×0.5 fb^{-1}



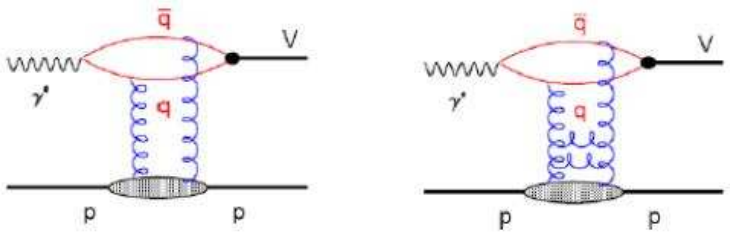
Vector Mesons at HERA

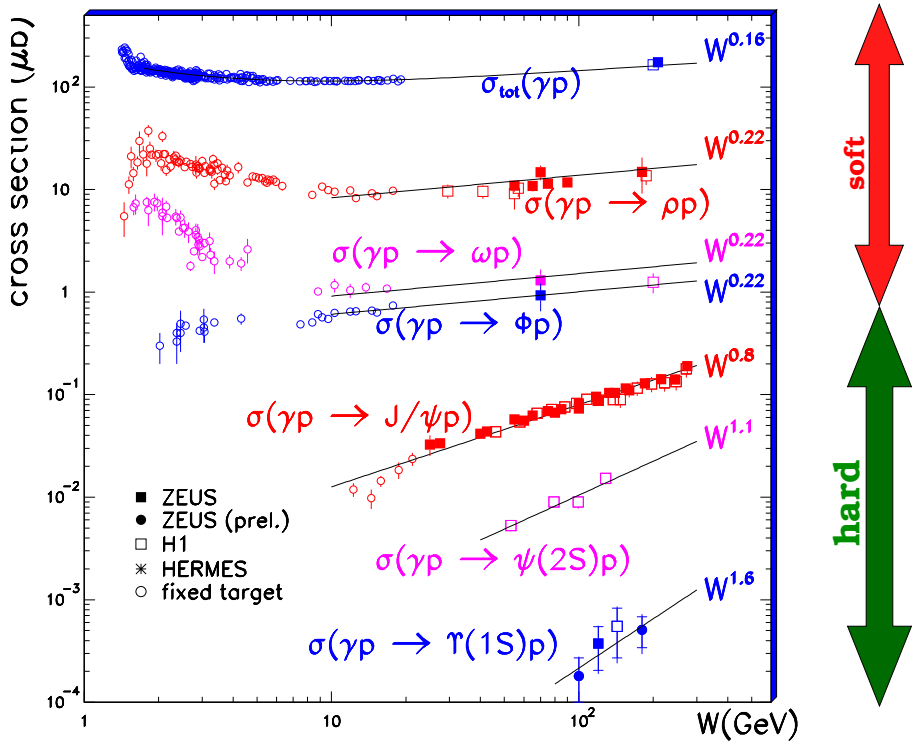
- Data at $W > 20$ GeV are all from HERA
- HERA VM Photoproduction data are well described by Regge-type power law $\sigma \propto W^{\delta}$
- Transition from soft to hard regime at universal scale $\mu^2 = (Q^2 + M_V^2)/4 \approx 4 \div 5$ GeV^2
- Low-mass VM: only few points are measured and only for ground states ρ, ω, ϕ

VM: soft vs hard $I\!P$



$\alpha_{I\!P}(t) = \alpha(0) + \alpha' t; \qquad \delta = 4(\alpha_{I\!P} - 1)$





H1 Detector

- Central Tracker: drift chambers and two-layer silicon strip detector

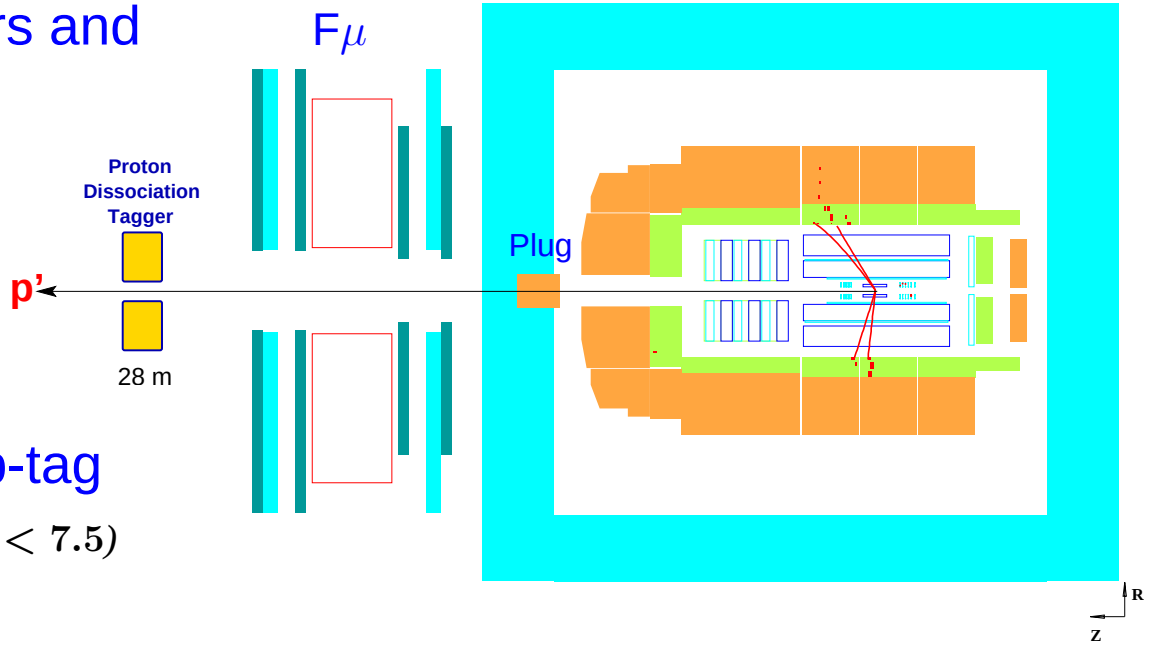
  ($20^\circ < \theta < 160^\circ$ used in VM analyses)

- EM+Had Calorimeters

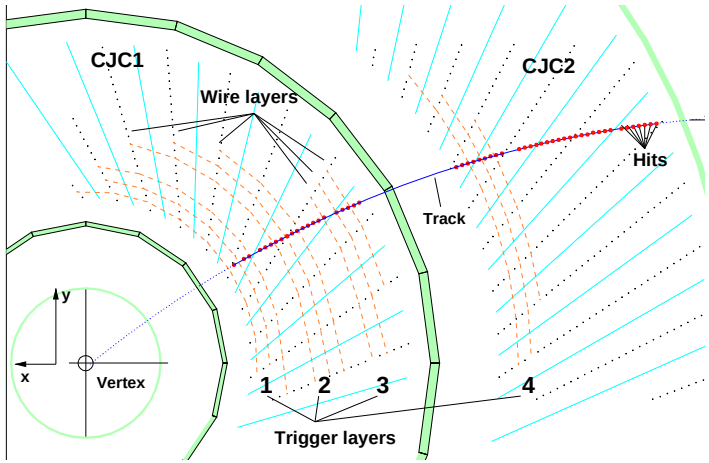
  ($4^\circ < \theta < 178^\circ$)

- Forward Detectors: Fμ,Plug,p-tag

  (effective pseudorapidity coverage $\mathbf{3.5 < \eta_{lab} < 7.5}$)



Powerful fast track trigger (allows untagged soft γp to be collected)



$$\gamma p \to \pi^+\pi^- Y$$

HE $\mathcal{L} = 1.3\ \mathbf{pb}^{-1}$ $\sim 700,000$ **events**

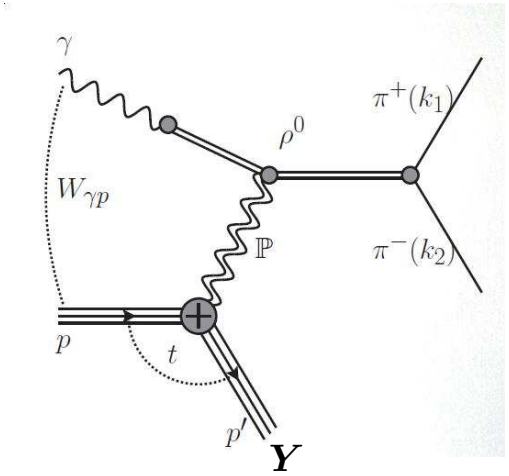
$$\gamma p \to 2\pi^+ 2\pi^- Y$$

HE $\mathcal{L} = 7.6\ \mathbf{pb}^{-1}$ $\sim 80,000$ **events**

LE $\mathcal{L} = 1.7\ \mathbf{pb}^{-1}$ $\sim 14,400$ **events**

ρ^0 Analysis

$$\gamma p \to \pi^+ \pi^- Y$$



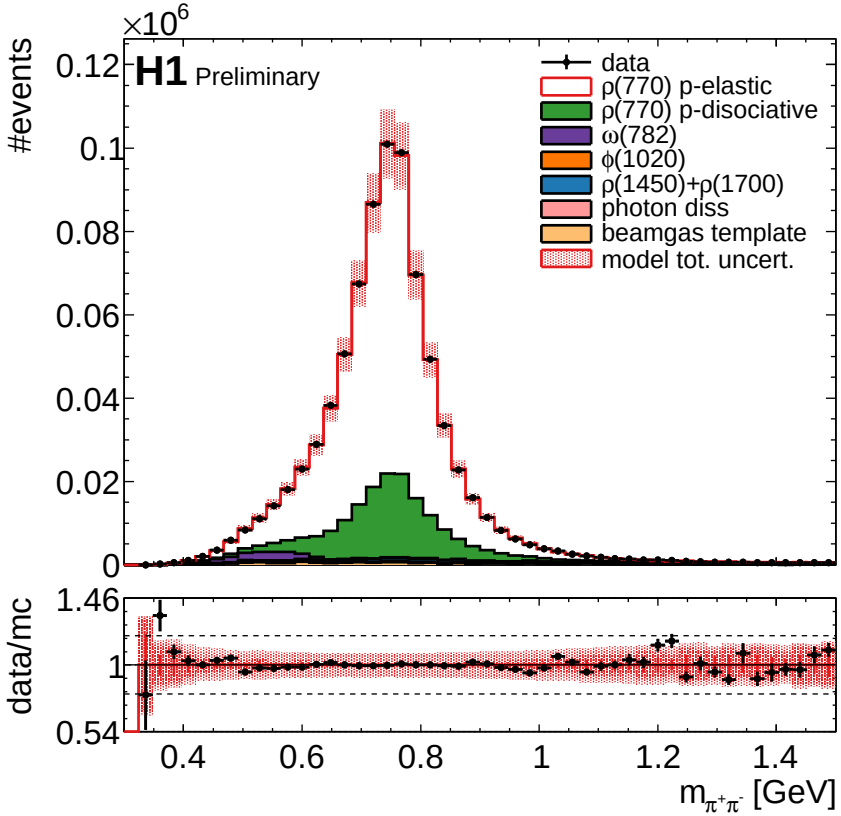
Data Sample and MC modelling

$15\ \text{GeV} < W_{\gamma p} < 100\ \text{GeV}$

$0.3\ \text{GeV} < m_{\pi\pi} < 1.5\ \text{GeV}$

$p^2_{t,\pi\pi} \simeq |t| < 2\ \text{GeV}^2$

$Q^2 < 2\ \text{GeV}^2; \quad M_Y < 10\ \text{GeV}$



DiffVM MC (Regge + VDM)

- **$\pi^+\pi^-$ signal:** elastic and p-dissociative

  tuned to data in $W_{\gamma p}$, $m_{\pi\pi}$, t

  includes also $\omega \to \pi^+\pi^-$ and non-resonant $\pi^+\pi^-$ contributions

- **backgrounds:**

  $\omega \to \pi^+\pi^-\pi^0$

  $\phi \to K^+K^-,\ K_SK_L,\ \pi^+\pi^-\pi^0,\ \rho\pi,\ \eta\gamma$

  $\rho' \to \rho\pi\pi,\ 4\pi$

  γ-dissociation: $M_X \to$hadrons via Jetset

- **proton dissociation:**

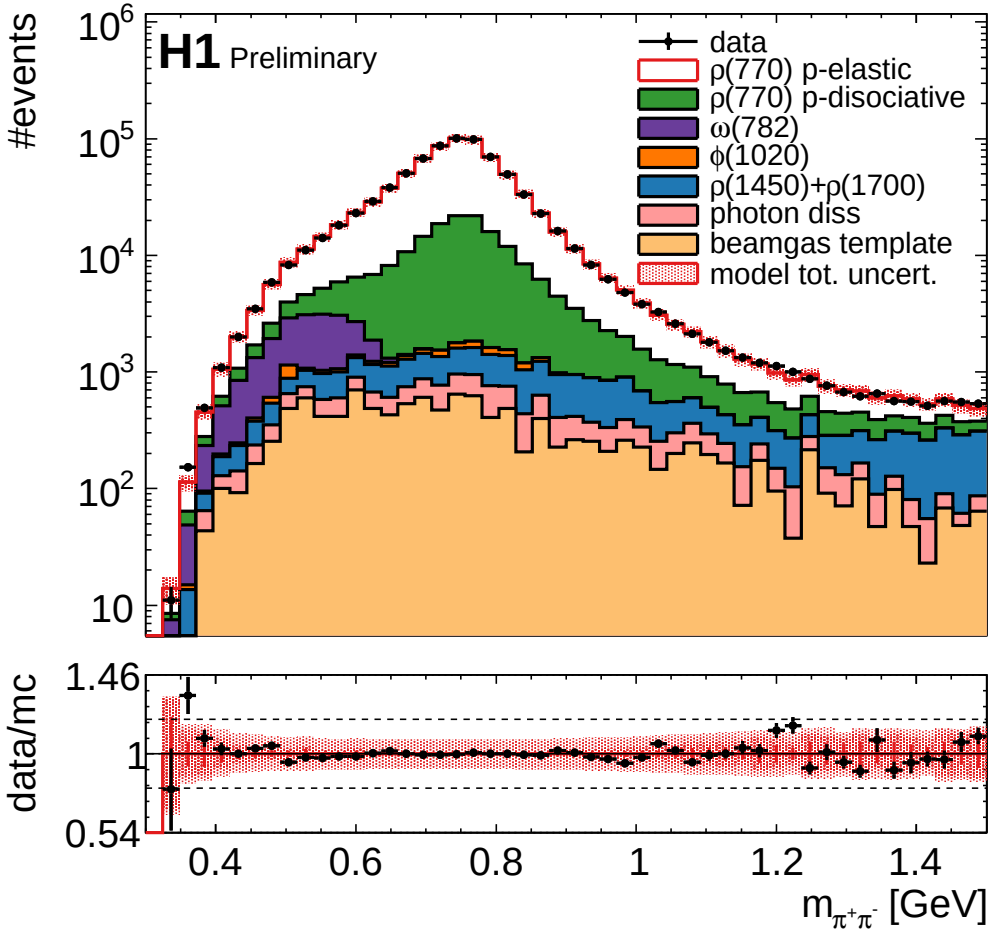
  continuum & resonances; $\mathrm{d}\sigma_{\gamma p}/\mathrm{d}M_Y^2 \propto (1/M_Y^2)^\delta$

  $M_Y < 1.9$ GeV: $N^\star$ with measured decay channels

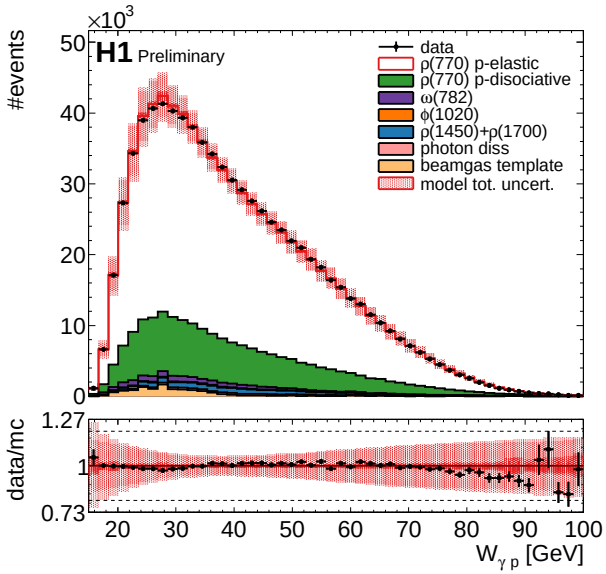
  $M_Y > 1.9$ GeV: $p' \to$hadrons via Jetset

Control Plots

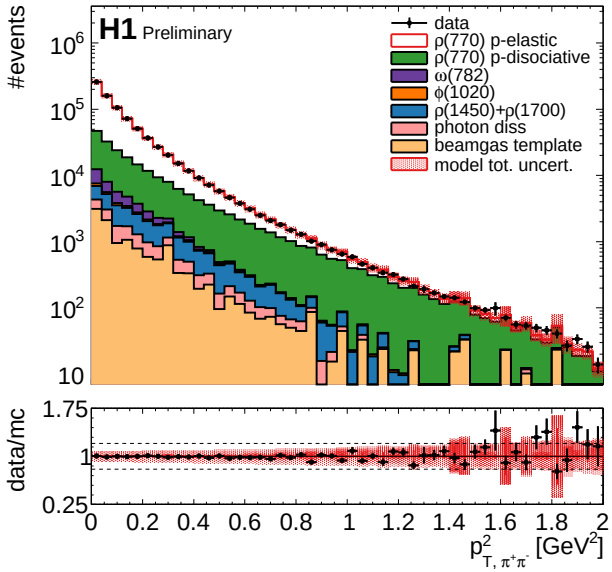
$m_{\pi\pi}$



$W_{\gamma p}$



$p^2_{t,\pi\pi}$



Good description in all variables

$\pi^+\pi^-$ Cross Section Determination

Differential cross section definition

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

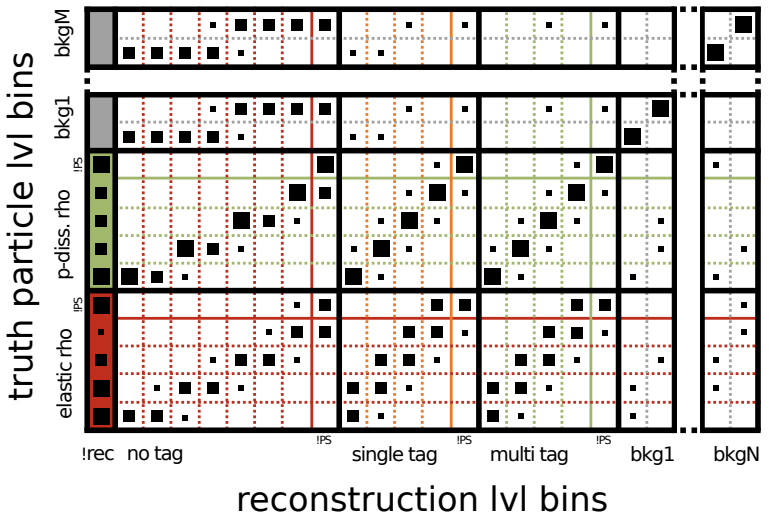
Reduced measurement Phase Space

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

Unfolding particle level cross sections:

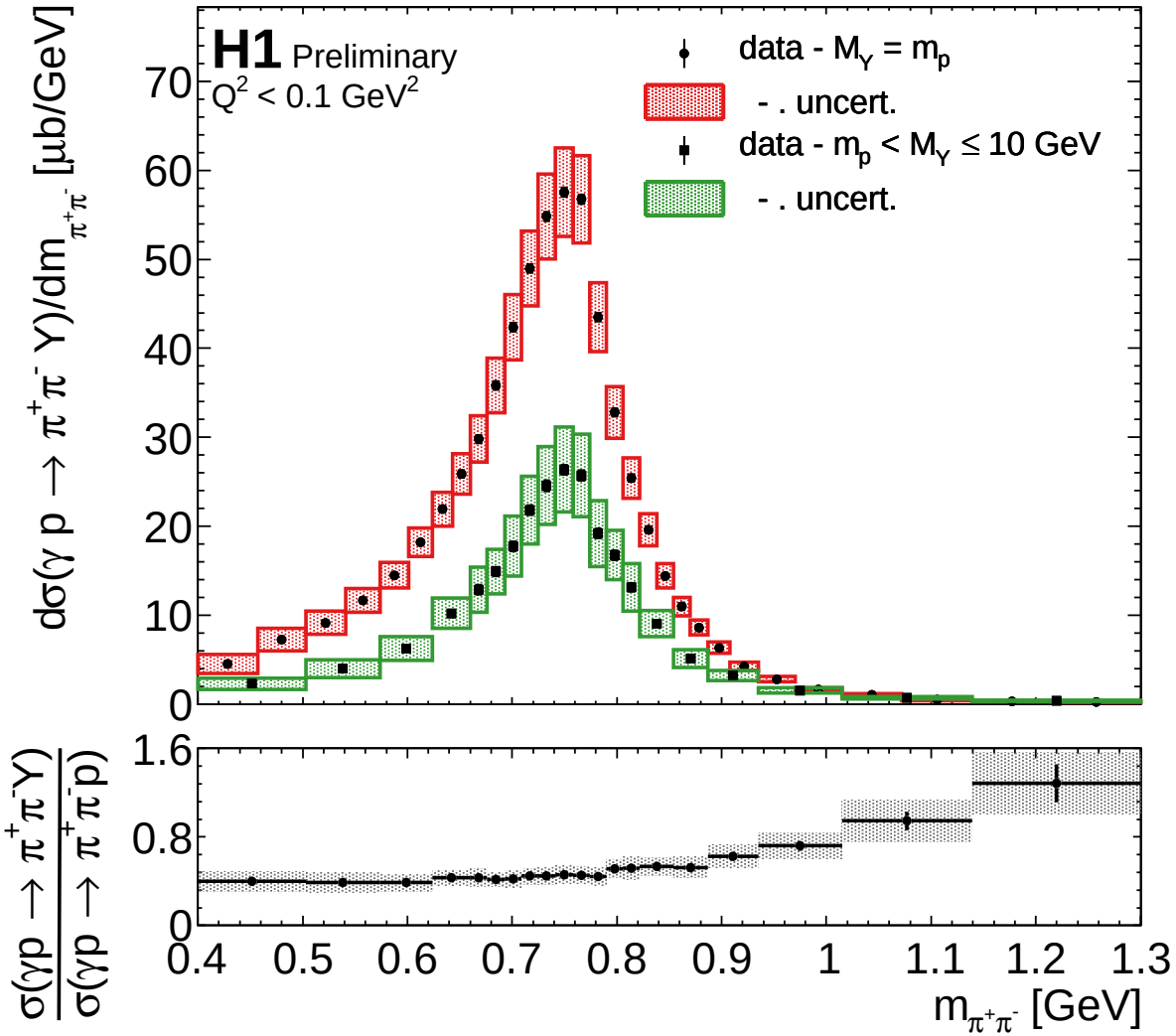
- subtract backgrounds
- correct signal for detector efficiency and resolution
- separate elastic from p-dissociative contributions

Regularised template fit using *TUnfold* package



- p-dissociation separated using 3 tagging control regions
- backgrounds normalised in 4 control regions

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



Unfolded 1D $m_{\pi\pi}$ distribution

Fiducial Cross sections

	$\sigma[\mu b]$	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 syst. uncertainty:

- trigger
- forward tagging
- calorimeter

Extracting ρ^0 Cross Section

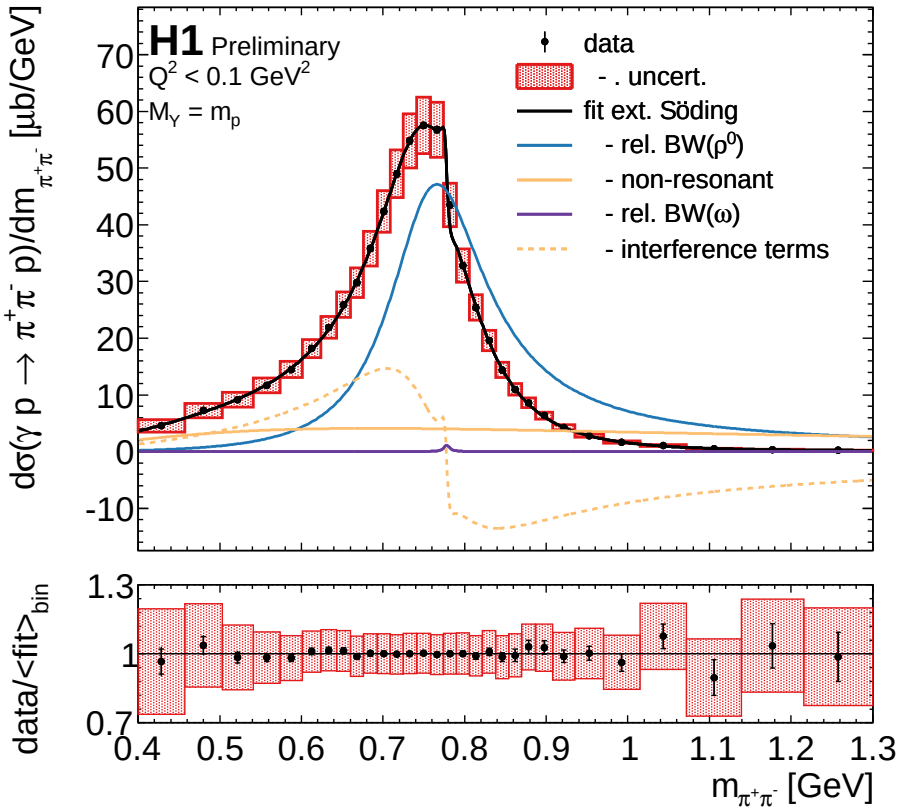
$$\frac{d\sigma_{\pi^+\pi^-}}{dm_{\pi\pi}}(m_{\pi\pi}) = \frac{N}{(1+f_\omega+f_{nr})^2} \cdot \left| \mathcal{RBW}_\rho(m_{\pi\pi}) + f_\omega e^{i\phi_\omega} \mathcal{RBW}_\omega(m_{\pi\pi}) + f_{nr} e^{i\phi_{nr}} \frac{B_{nr}(m_{\pi\pi})}{B_{nr}(m_\rho)} \right|^2$$

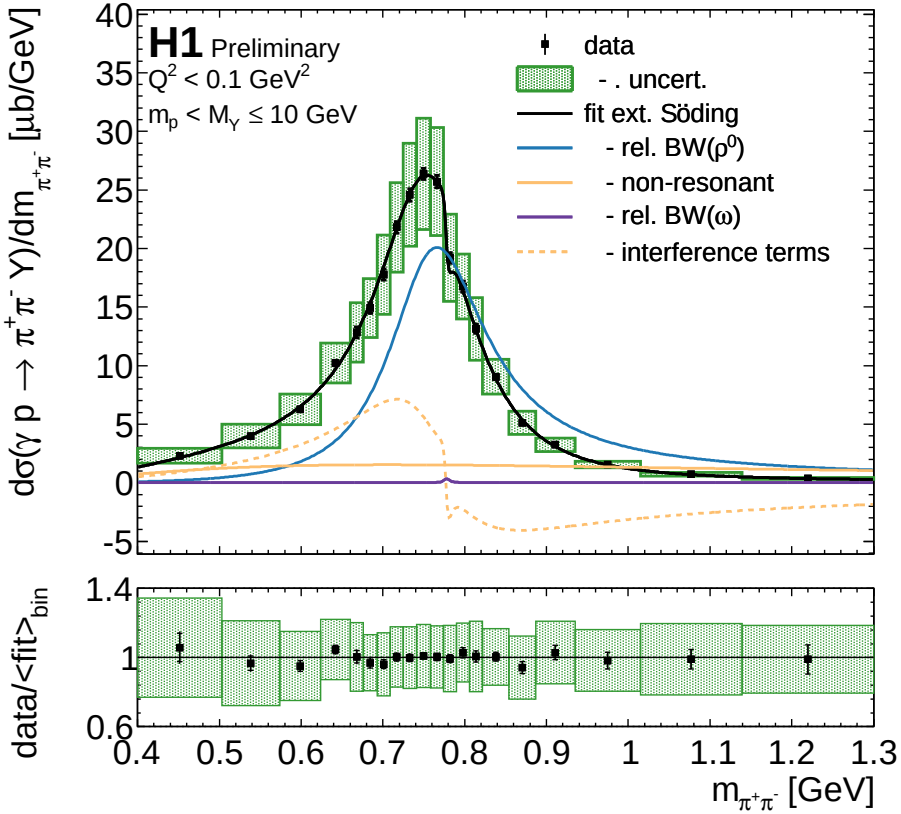
non-res term: $B_{nr} = \left(\frac{m_{\pi\pi}-2m_\pi}{(m_{\pi\pi}-2m_\pi)^2+\Lambda_{nr}^2} \right)^{\delta_{nr}}$

Fitted parameters:

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

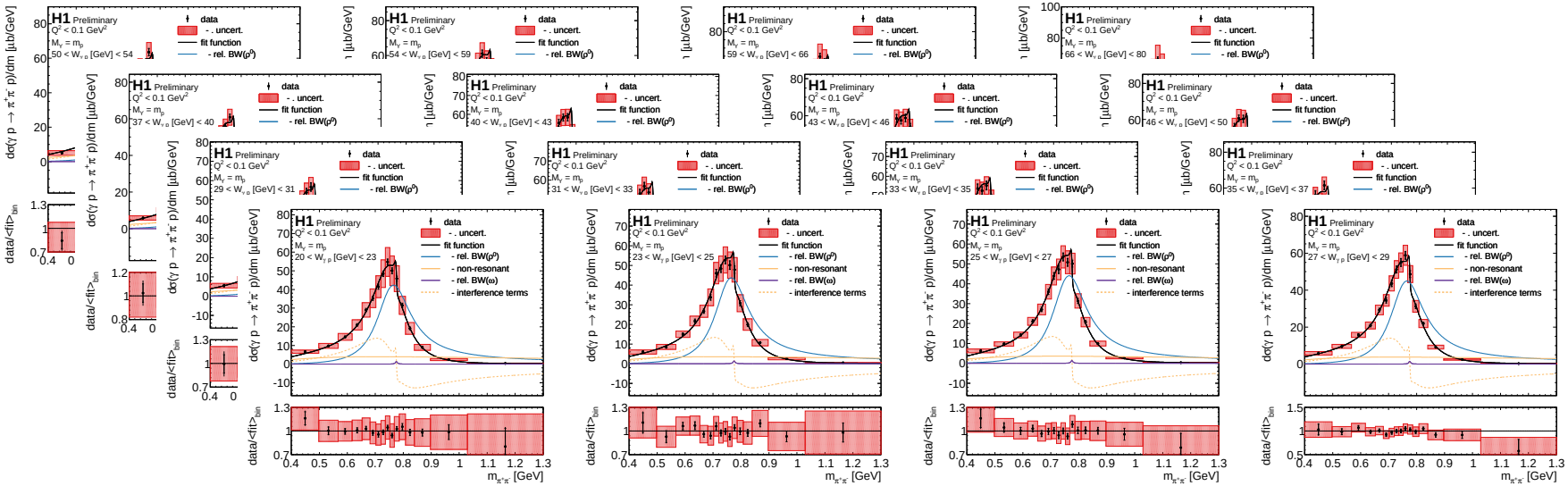
$\Gamma_{\rho^0} = 150 \pm 1(\text{stat.})$ MeV



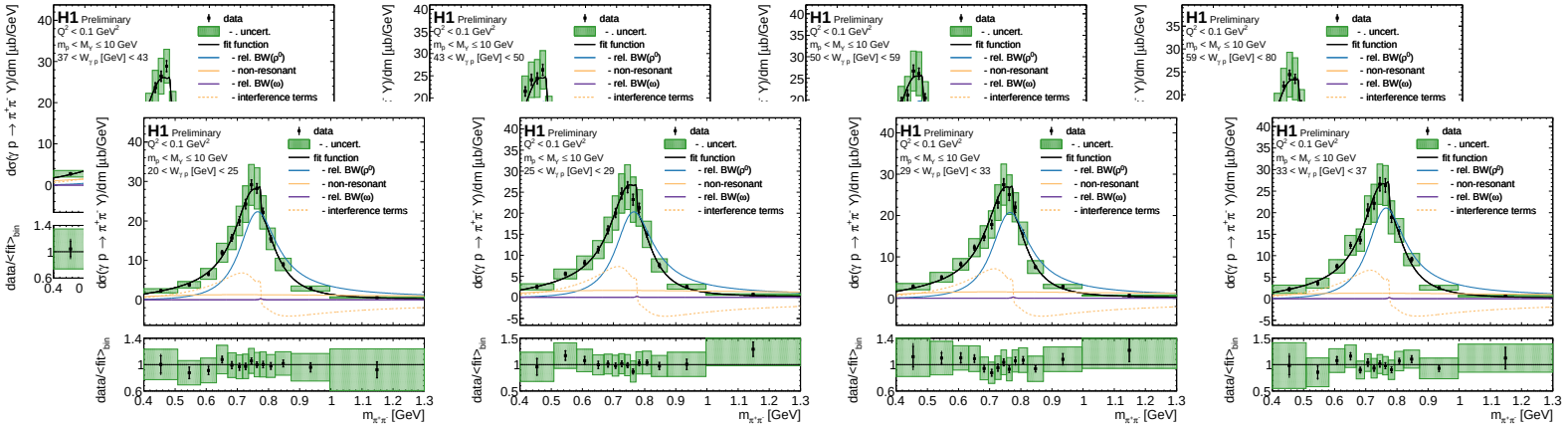


Extracting ρ^0 Cross Section in bins of $W_{\gamma p}$

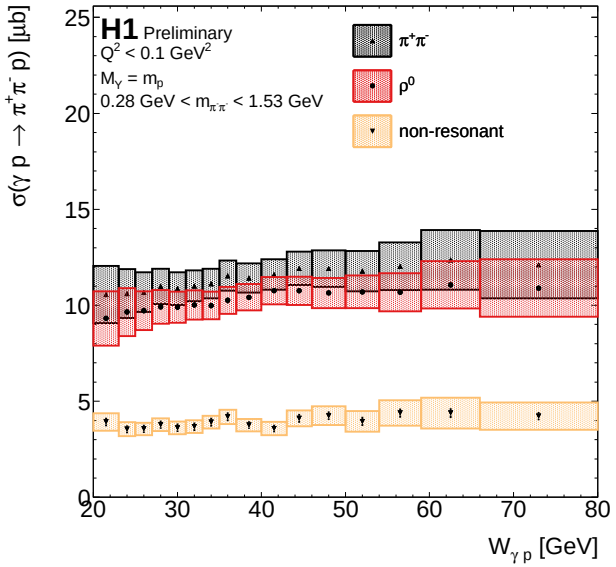
2D unfolding $(m_{\pi\pi} \otimes W_{\gamma p}) \Rightarrow \mathrm{d}\sigma(\gamma p \to \pi^+\pi^- Y)/\mathrm{d}m_{\pi\pi}$ in 16 elastic $W_{\gamma p}$ bins



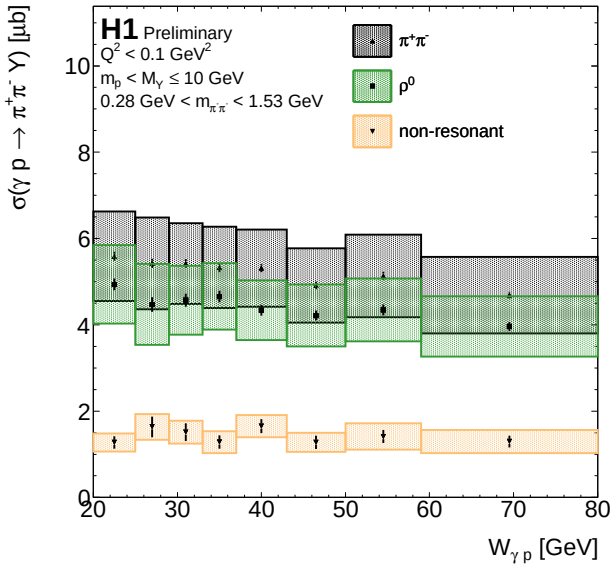
2D unfolding $(m_{\pi\pi} \otimes W_{\gamma p}) \Rightarrow \mathrm{d}\sigma(\gamma p \to \pi^+\pi^- Y)/\mathrm{d}m_{\pi\pi}$ in 8 proton-dissociative $W_{\gamma p}$ bins



Energy Dependence of ρ^0 Cross Sections

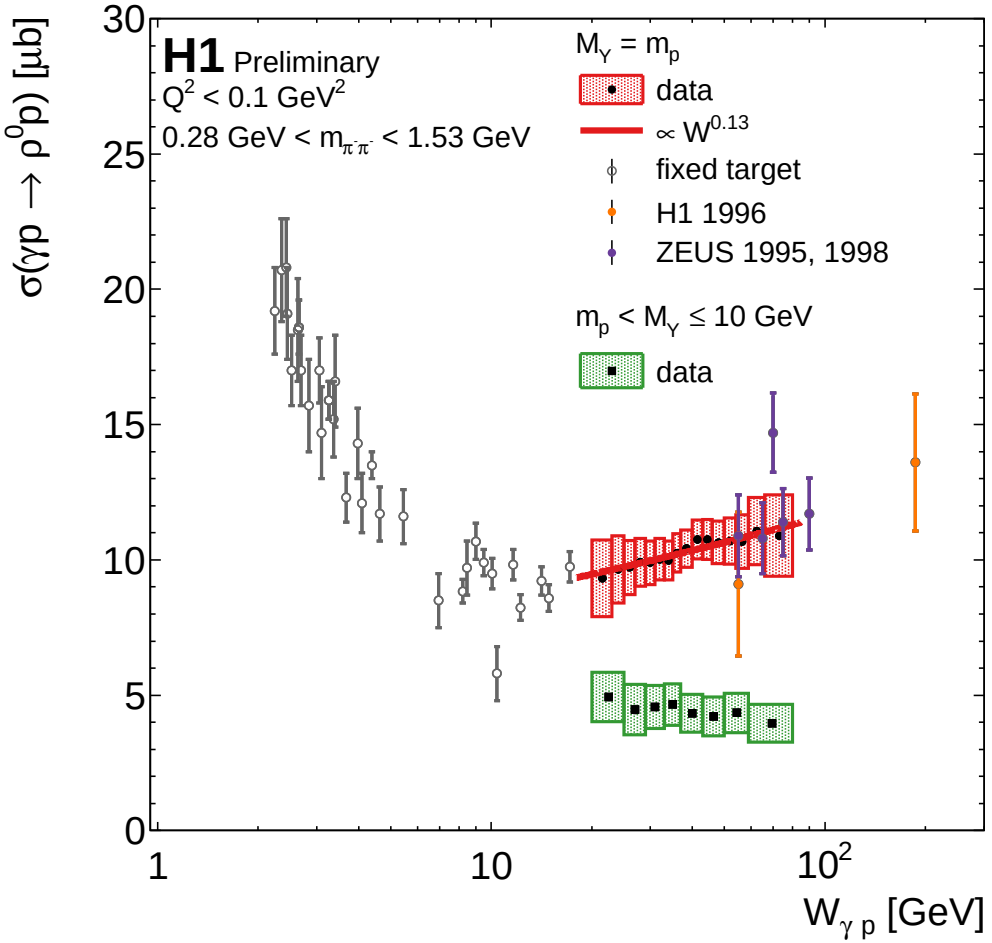


elastic



p–dissociative

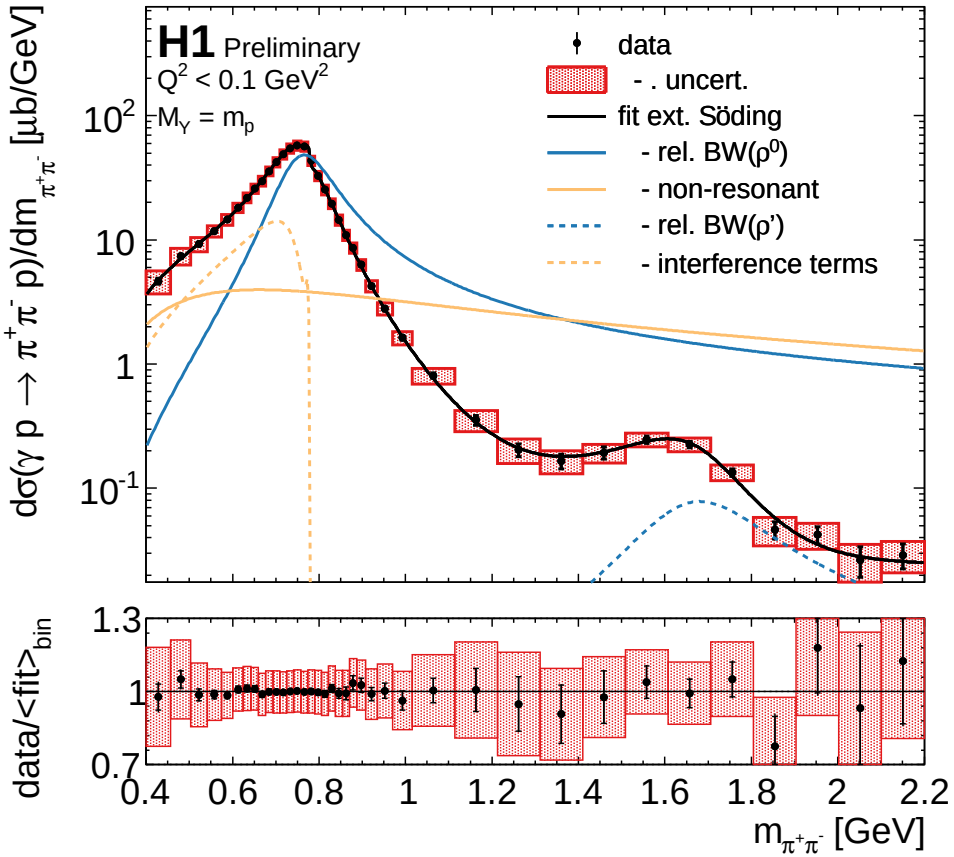
- Cross sections - from fit function integral
- P-diss. cross section affected by PS restrictions



$\pi^+\pi^-$ Mass Spectra in Extended Mass Range

- look at extended range $m_{\pi\pi} < 2.2$ GeV
- good fit with one extra $BW_{\rho'}$

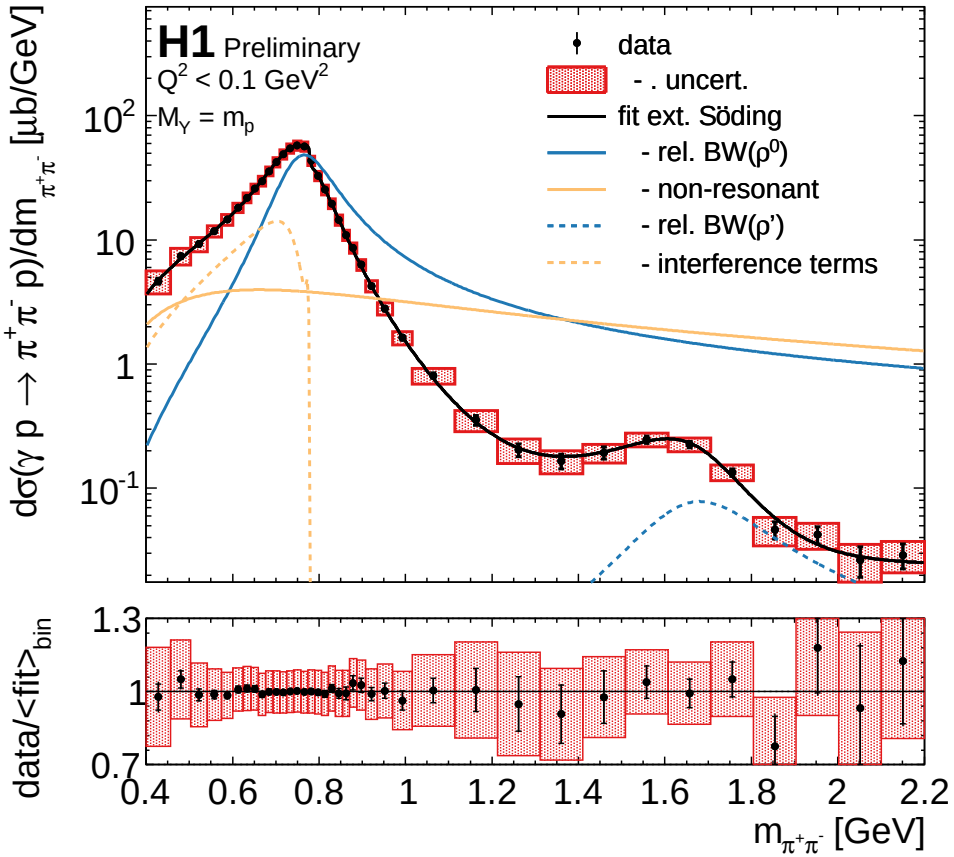
$m_{\rho'} \simeq 1700$ MeV $\Gamma_{\rho'} \simeq 300$ MeV



$\pi^+\pi^-$ Mass Spectra in Extended Mass Range

- look at extended range $m_{\pi\pi} < 2.2$ GeV
- good fit with one extra $BW_{\rho'}$

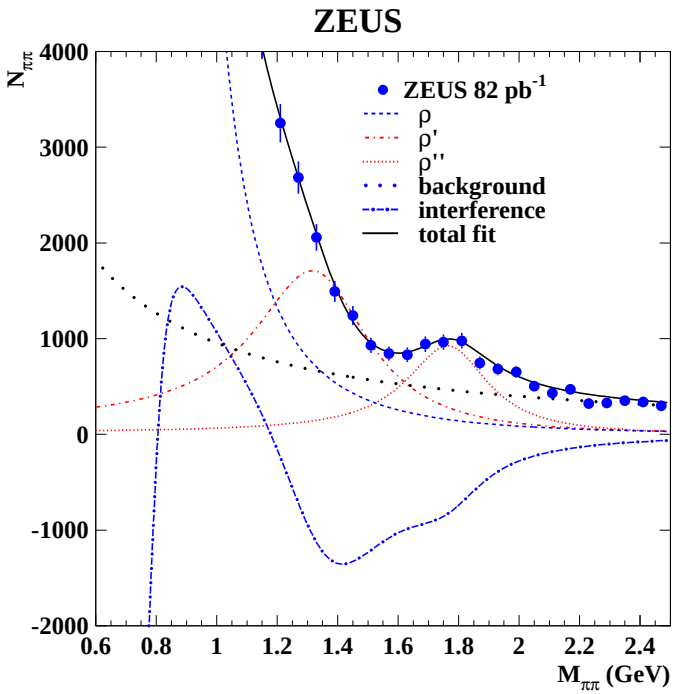
$m_{\rho'} \simeq 1700$ MeV $\Gamma_{\rho'} \simeq 300$ MeV



Similar measurement by ZEUS [2012] but in DIS regime ($Q^2 > 2$ GeV^2)

Complicated fit, large $\rho(770)$ 'bgr'

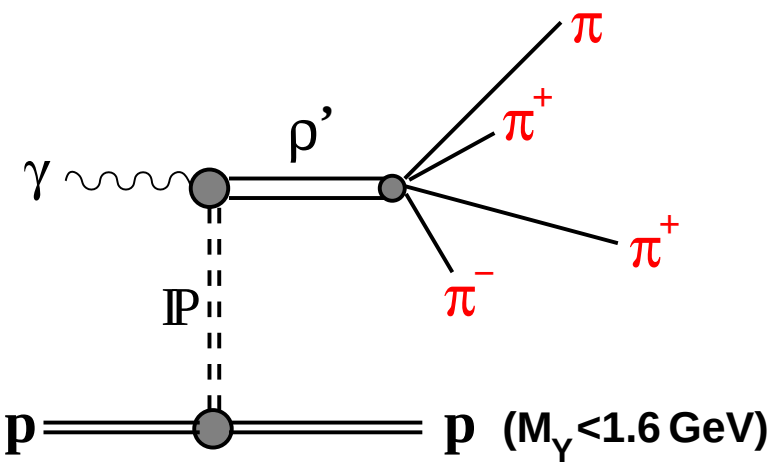
both $\rho(1450)$ and $\rho(1700)$ observed



Try 4π final state

ρ' Analysis

$\gamma p \rightarrow 2\pi^+ 2\pi^- Y$



Analysis sketch

Experimental information is sparse

Dominant decay channel: $\rho\pi\pi$

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

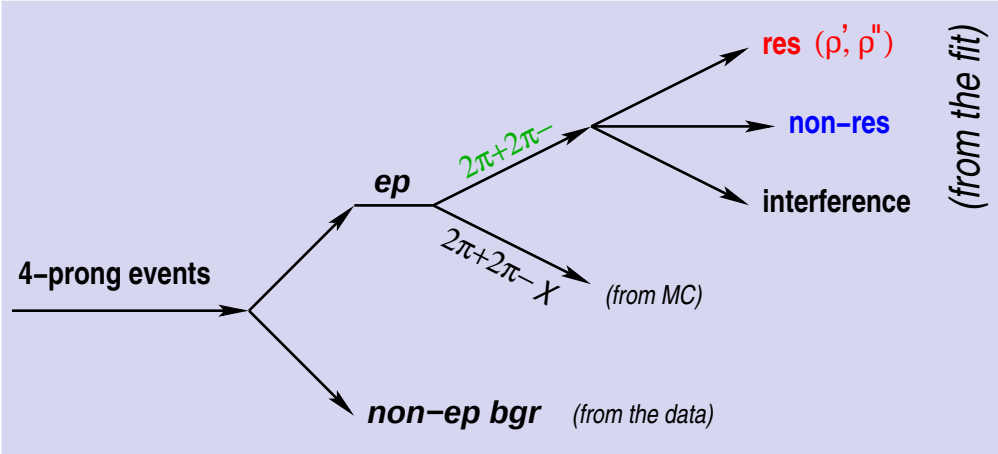
Mass $m = 1465 \pm 25$ MeV [l]
Full width $\Gamma = 400 \pm 60$ MeV [l]

$\rho(1450)$ 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

$\rho(1700)$ [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
$\rho\rho$	seen	372
$\pi^+\pi^-$	seen	849



- 4 tracks with zero net charge, from nominal vertex
  veto e' and other energies not associated with tracks
  veto on forward activity (LRG)
- non-ep background at low $W_{\gamma p} \Rightarrow$ defines $W_{\gamma p}^{\min}$ cut
- $2\pi^+2\pi^- X$ background: take from MC (DiffVM/PYTHIA)
  cross-check MC vs data using wrong charge background
- fit 4π mass spectra to extract ρ' cross sections

Control Plots

Two data samples: **HE** ($\sqrt{s} = 319$ GeV, $\mathcal{L} = 7.6$ pb^{-1}), **LE** ($\sqrt{s} = 225$ GeV, $\mathcal{L} = 1.7$ pb^{-1})

Phase Space:

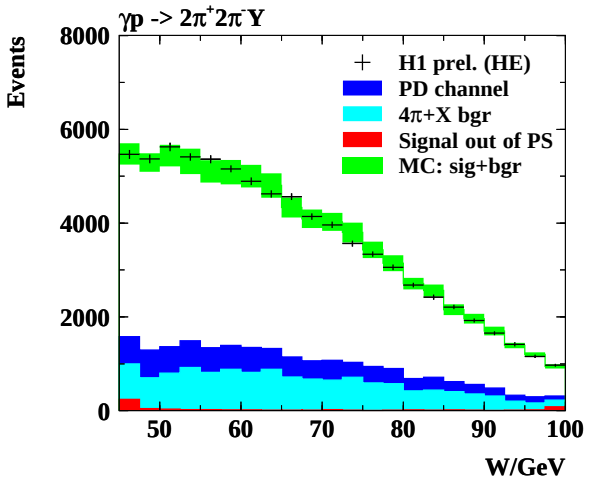
$Q^2 < 2$ GeV^2 (PHP)

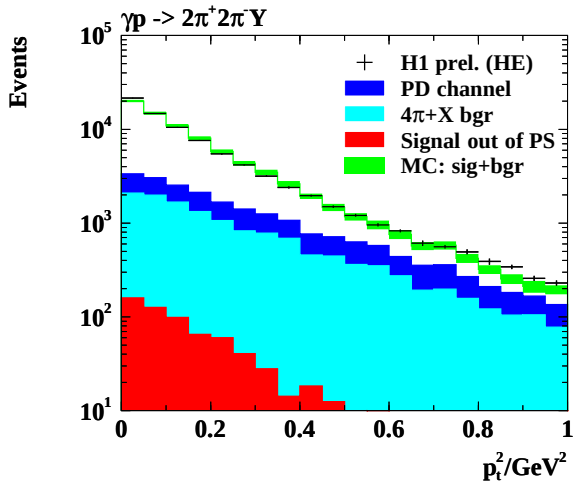
$45 < W/GeV < 100$ (at $\sqrt{s} = 319$ GeV)
$35 < W/GeV < 75$ (at $\sqrt{s} = 225$ GeV)

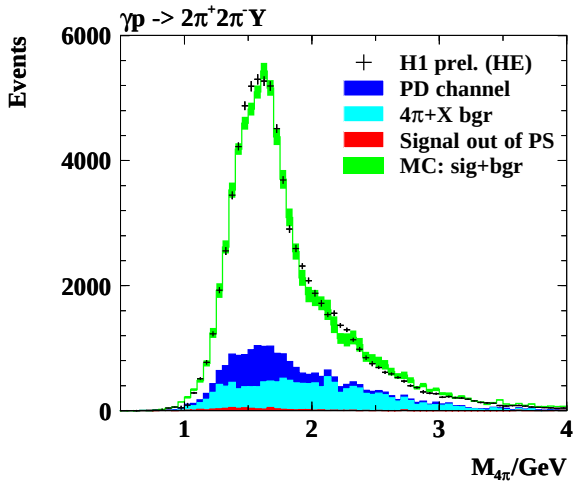
$M_Y < 1.6$ GeV, $|t| < 1$ GeV^2

- Remaining background $\sim 15\%$
- Contamination from p-diss. events with $M_Y < 1.6$ GeV: $\sim 10\%$

Control plots for **HE** sample *(more in backup)*







Green band represents $(4\pi + X)$ background subtraction systematics only

Cross Section vs $W_{\gamma p}$

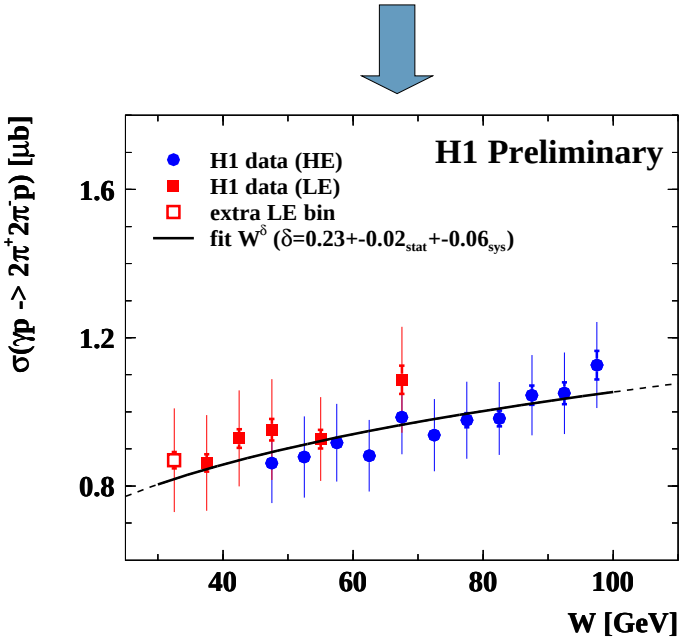
Total cross section at the reference point $W = 75$ GeV:

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

$$R = \frac{\sigma(\gamma p \to 2\pi^+ 2\pi^- p)}{\sigma(\gamma p \to \pi^+ \pi^- p)} \approx 9\%$$

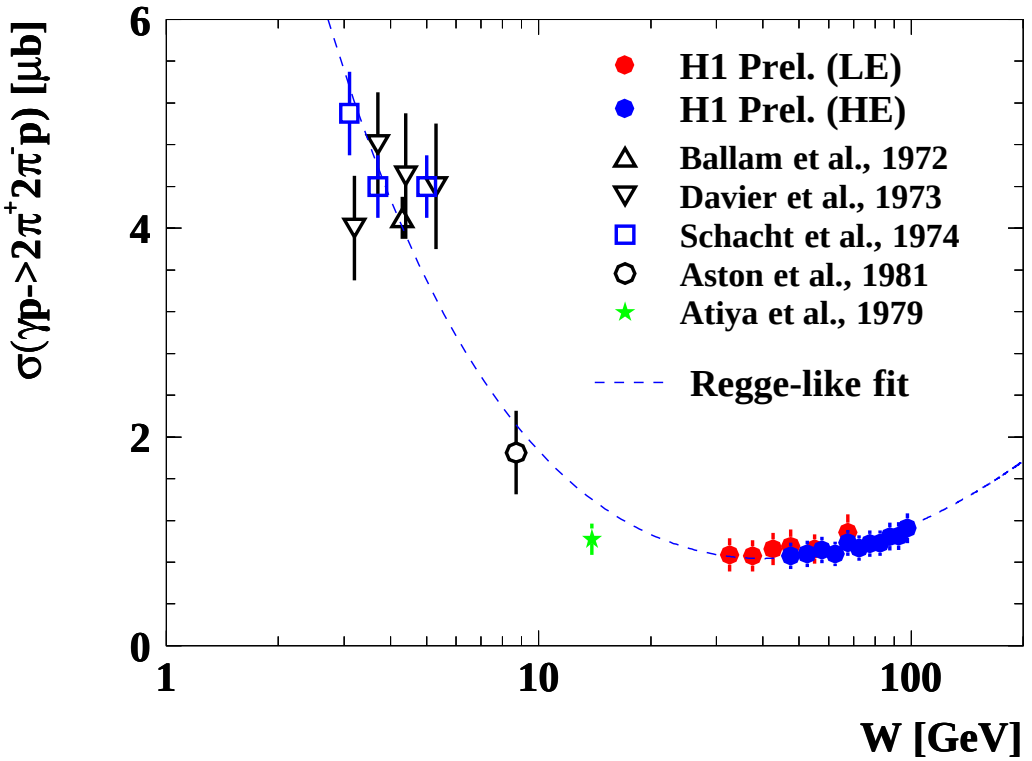
Subtract remaining p-dissociative contribution

to compare to fixed target photoproduction data

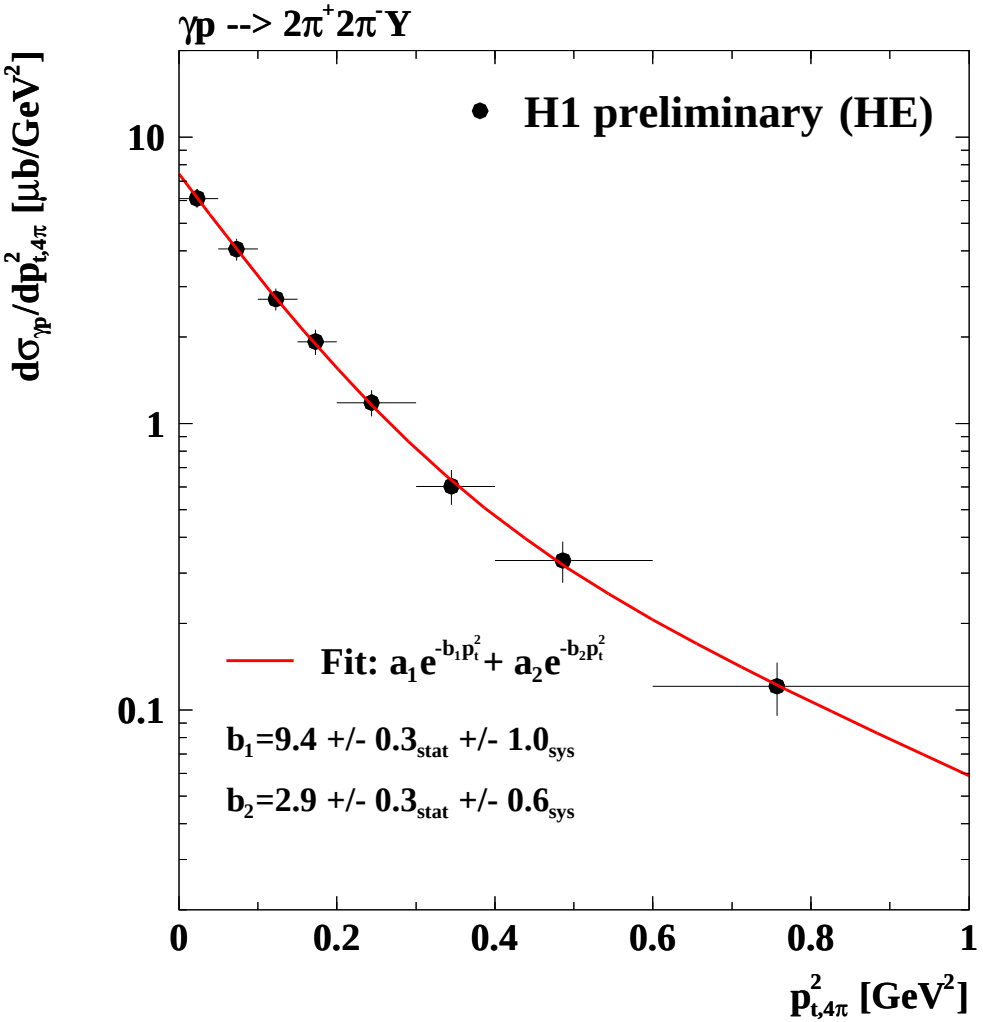


World data are well described by Regge-like fit

(Reggeon and soft Pomeron contributions)

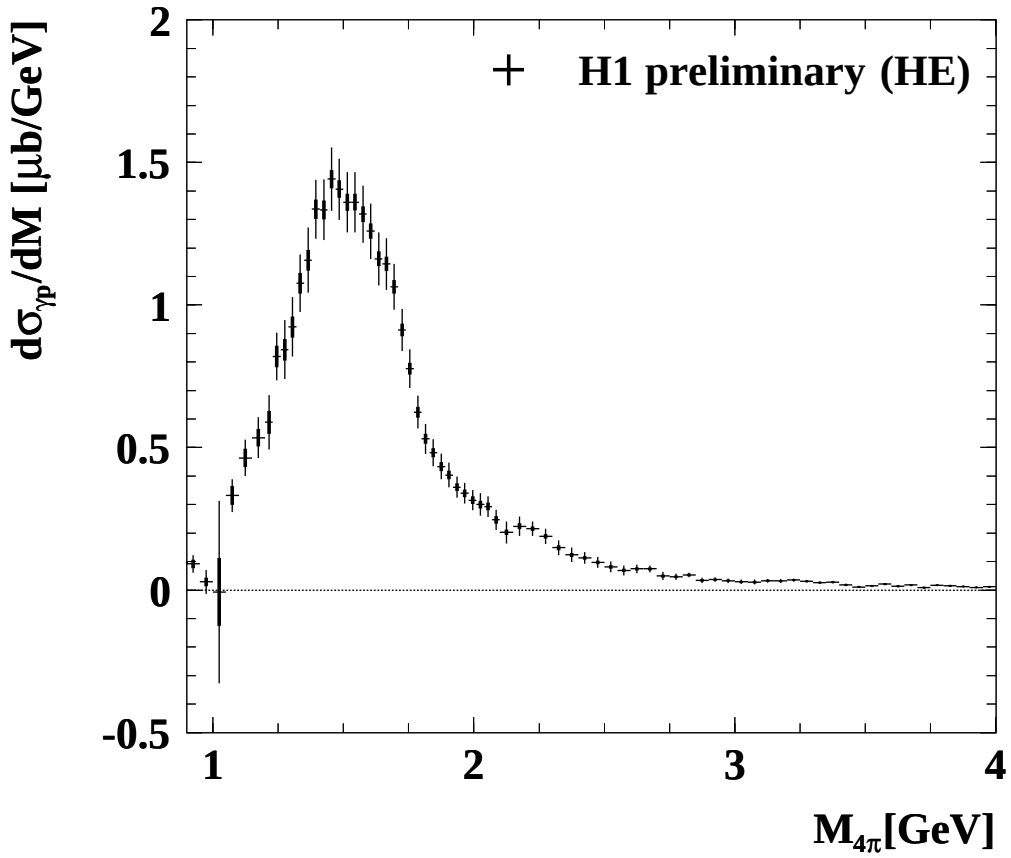


Cross Section as a function of t



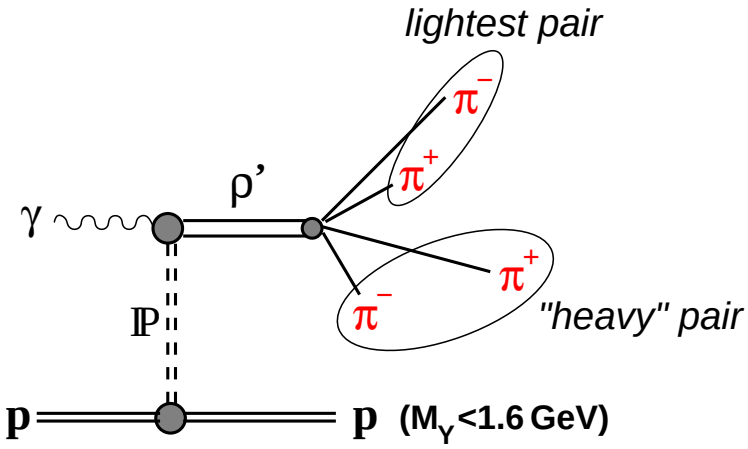
- Exponential fall-off in t, typical for diffractive VM production
- Slope b_1 is similar to that of $\rho(770)$ in photoproduction
- Second exponent possibly due to: proton-dissociative processes, non-resonant production amplitude

Cross Section as a function of Mass



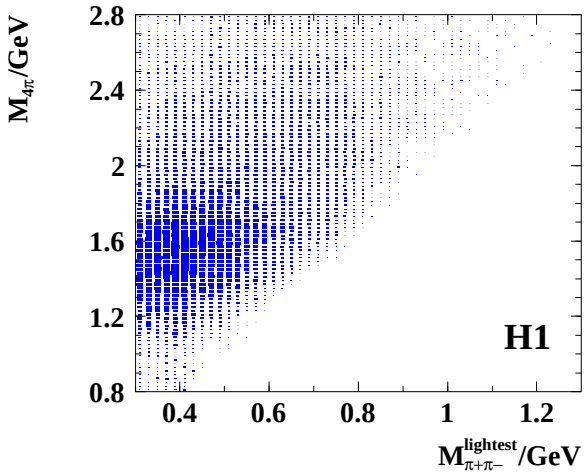
- Vast majority of events populate mass range around 1.6 GeV with the width of ~ 600 MeV
- This supports the expectation of predominantly resonant production of the final state
- No clear indication of 2 resonances; distribution shape similar to that in earlier fixed target γp experiments

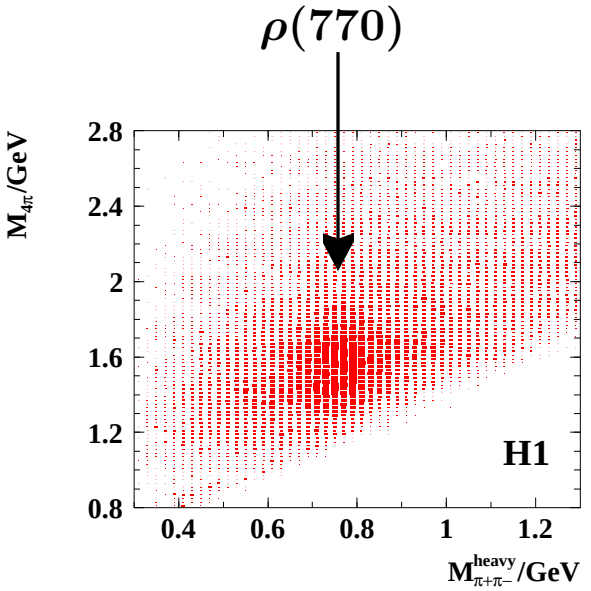
Decay modes



- Study correlations of $M_{4\pi}$ with invariant mass of oppositely charged pion pairs
- Caveat: these distributions are not corrected for acceptance effects

- Prominent structure at m_{ρ^0} is observed
- One broad resonance at $M_{4\pi} = 1600$ or two at $M_{4\pi} = 1450$ and 1700 ?



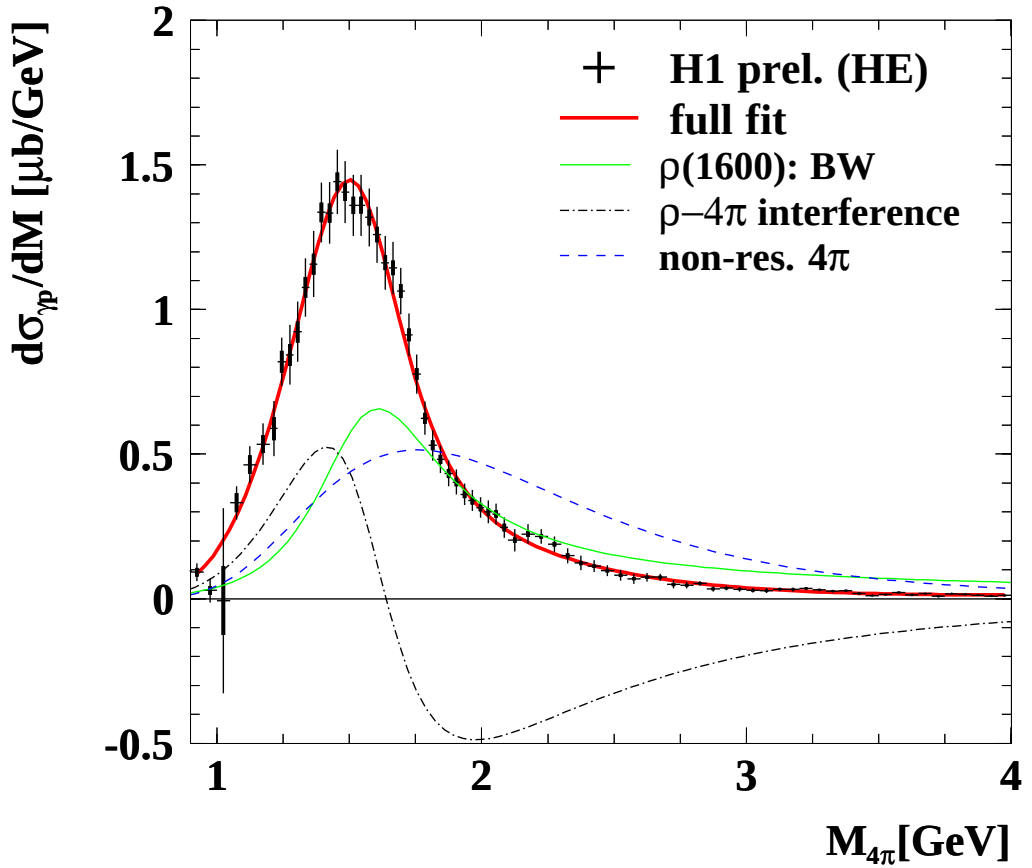


A simple resonance fit

- Simple fit including one Breit-Wigner, non-resonant term and complex phase describes data fairly well

- Fit with two resonances gives similar quality

- More sophisticated fits in progress taking into account intermediate ρ^0 in cascade decay $\rho' \rightarrow \rho\pi\pi \rightarrow 4\pi$

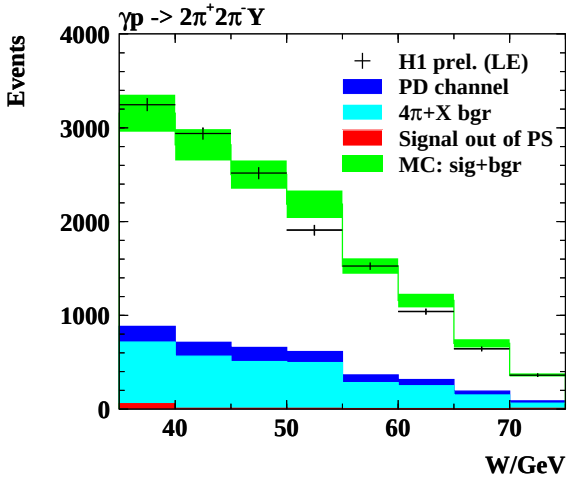


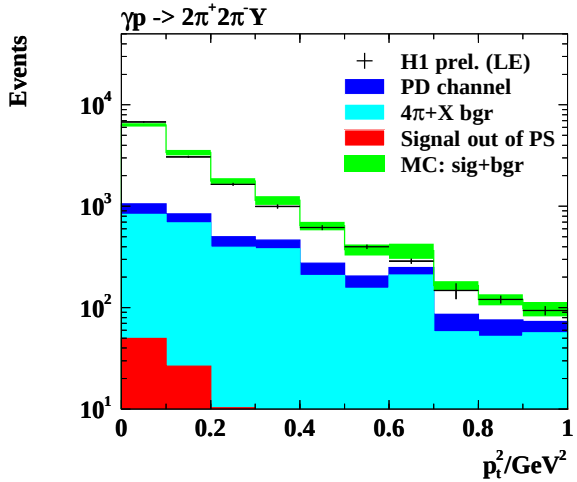
Summary and Outlook

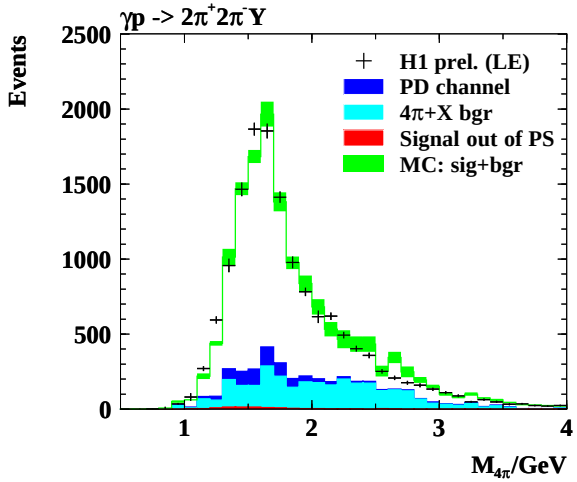
- Large statistics $\pi^+\pi^-$ sample collected and analysed thanks to the upgraded H1 detector capabilities.
- Sophisticated unfolding procedure allowed to measure differential $\pi^+\pi^-$ photoproduction cross sections and separate elastic from proton-dissociative components.
- ρ^0 cross sections are extracted using extended Söding model and taking into account interfering ρ^0, ω and non-resonant $\pi^+\pi^-$ terms.
- $3D$ unfolding in progress, with the aim to measure double-differential cross section in W and t and to extract Pomeron trajectory.
- Photoproduction of exclusive $2\pi^+2\pi^-$ final states is measured for the first time at HERA.
- The W and t dependencies are similar to previous $\rho(770)$ measurement.
- Mass distribution indicates, that the reaction proceeds predominantly via ρ' production and decay. More sophisticated mass fits are being worked on to distinguish one- from two-resonance hypotheses.
- An extension to DIS regime is in progress, with the aim to investigate Q^2 dependence for the ratio $R(\rho'/\rho)$.

Backup Slides

Basic Control Plots (LE)

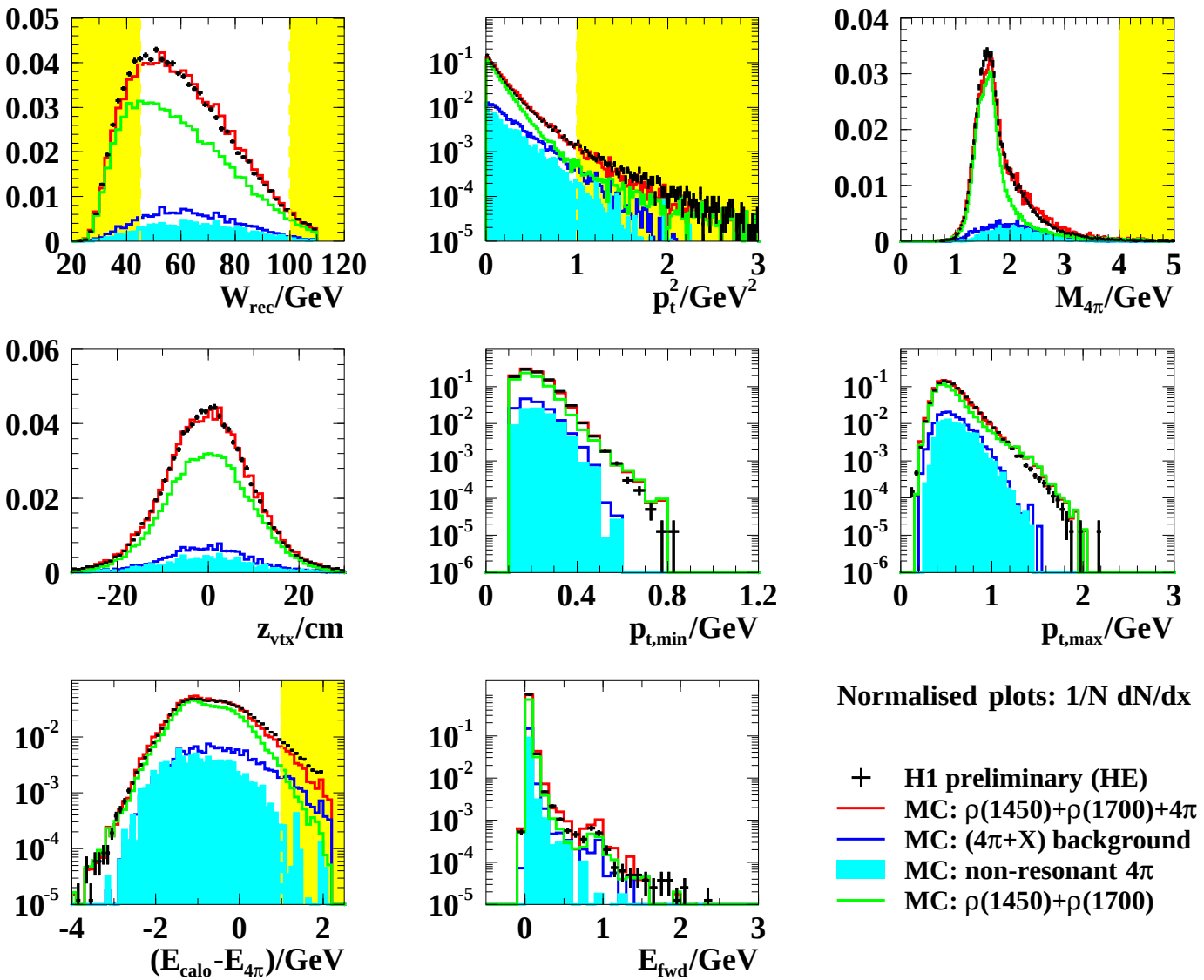






Green band represents $(4\pi + X)$ background subtraction systematics only

Control Plots (HE)



Acceptances in HE PHP regime