Exclusive ρ^0 Meson Photoproduction with a Leading Neutron at HERA

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on behalf of the H1 collaboration

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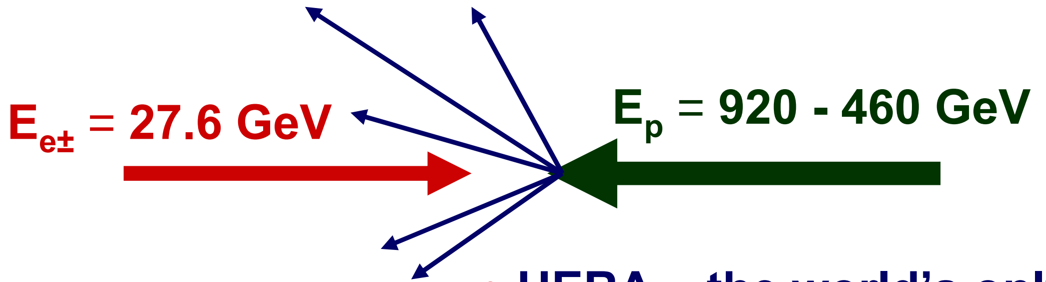
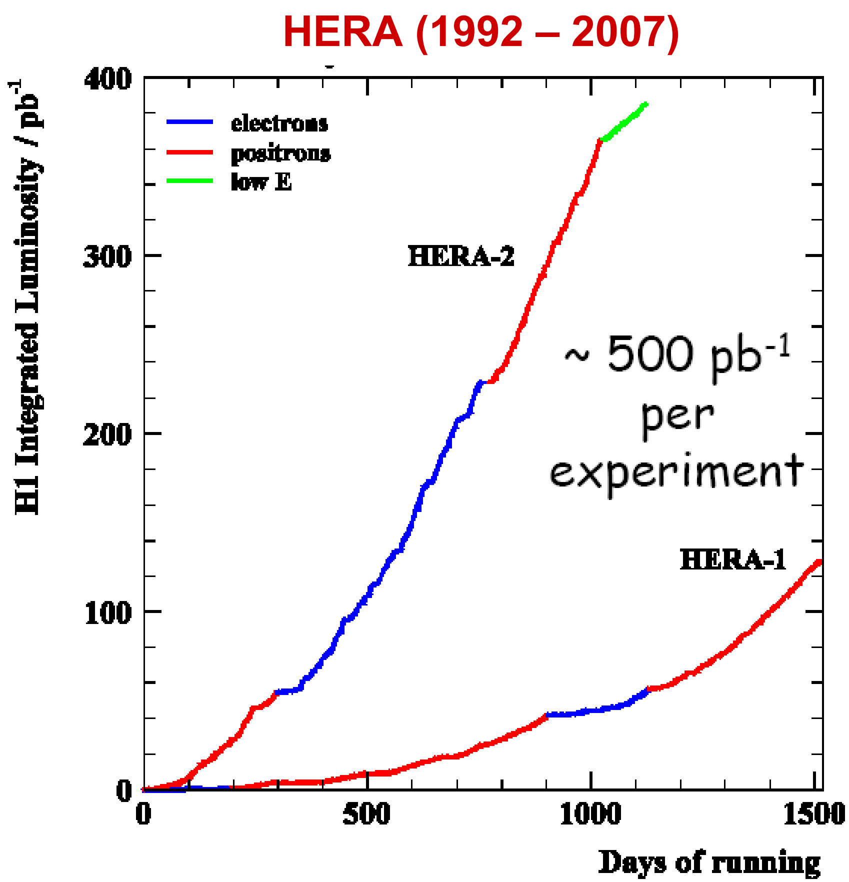
HERA



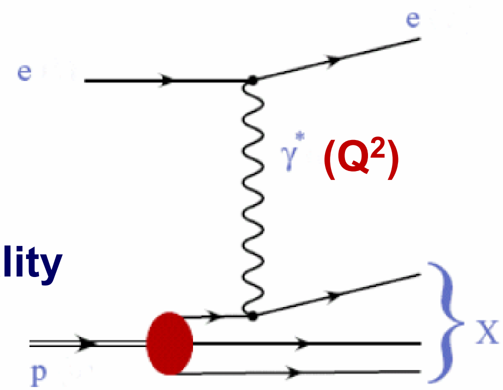
- HERA – the world's only ep collider



- two colliding beam experiments : H1 and ZEUS

γ^* p → hadrons

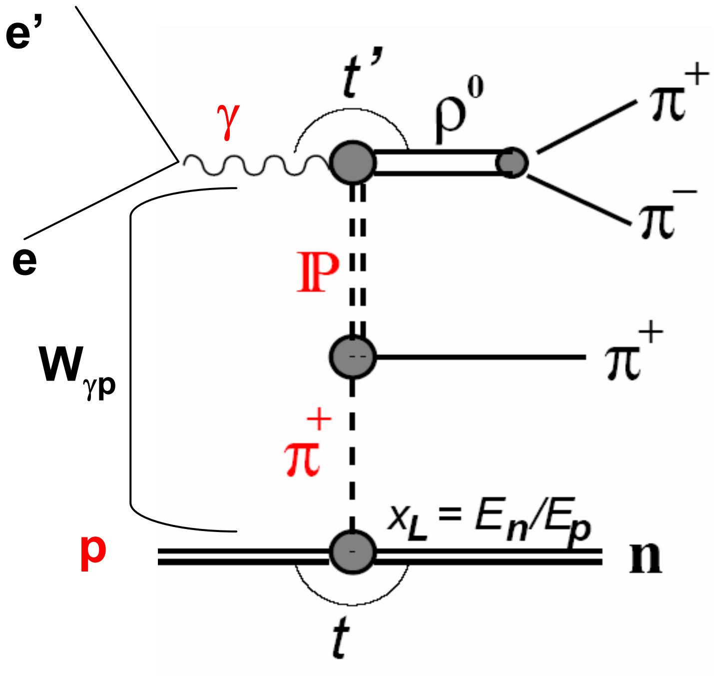
Q^2 – photon virtuality



Q^2 >> 1 GeV^2 deep inelastic scattering (DIS)

Q^2 ~ 0 GeV^2 photoproduction

Physics motivation



$e^+ + p \rightarrow e^+ + \rho^0 + n + \pi^+ ,\ \rho^0 \rightarrow \pi^+\pi^-$

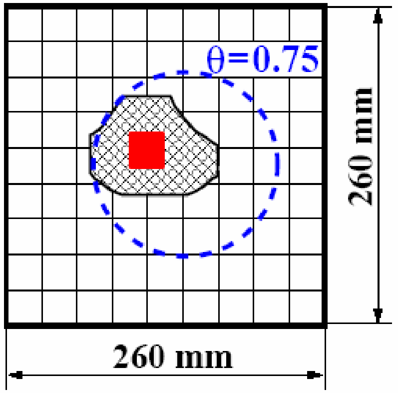
Kinematics:

- $\sqrt{s}$ ep centre-of-mass energy ($\sqrt{s}$ = 319 GeV)
- Q^2 photon virtuality (photoproduction)
- y inelasticity
- $W_{\gamma p}$ γp centre-of-mass energy
- x_L fraction of the proton energy carried by the leading neutron
- t $|$4-momentum transfer$|^2$ at the proton vertex
- t' $|$4-momentum transfer$|^2$ at the $\gamma\rho$ vertex

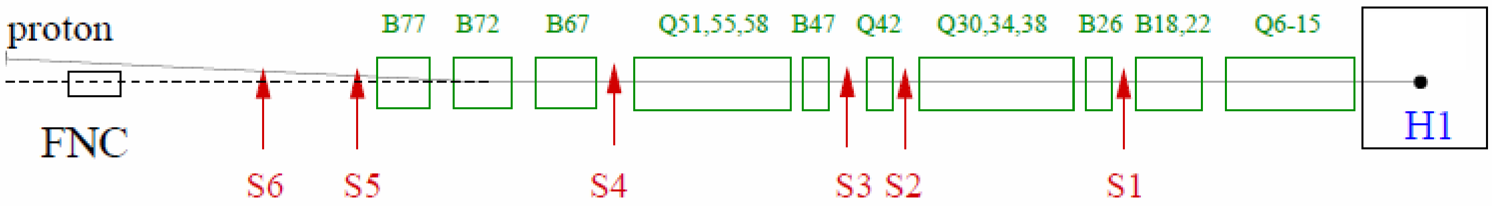
A virtual photon emitted from the electron interacts with a virtual pion from the proton cloud

- exclusive ρ^0 photoproduction on virtual pion : first extraction of elastic photon-pion cross section $\sigma(\gamma\pi^+ \rightarrow \rho^0\pi^+)$
- sensitivity to pion flux models
- importance of absorption effects in leading baryon production at HERA

$e^+ + p \rightarrow e^+ + \rho^0 + n + \pi^+, \rho^0 \rightarrow \pi^+\pi^-$

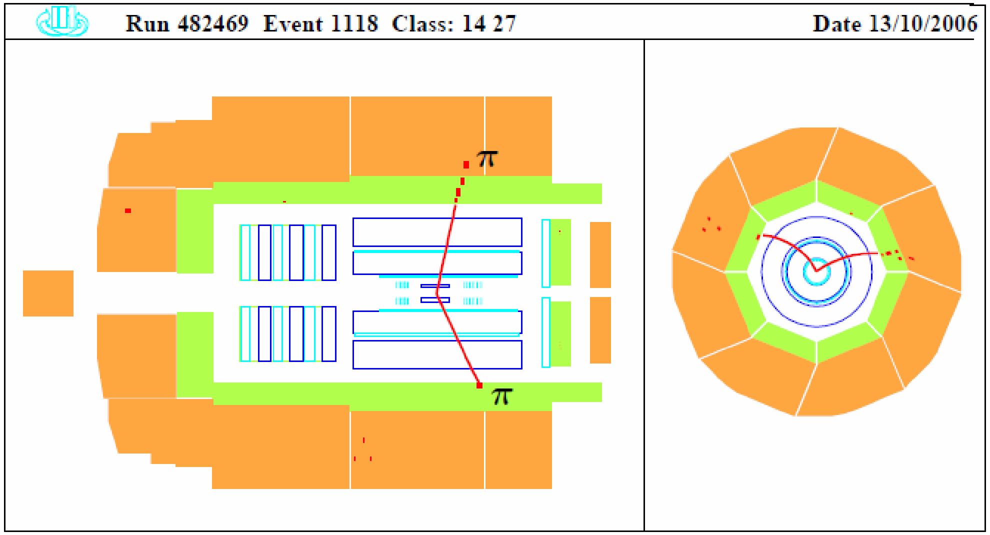


Forward Neutron Calorimeter (FNC)



FNC @ H1

- **Lead-scintillator sandwich calorimeter at 106 m from IP**
- **Detection of n and γ/π^0**
- **Preshower: 60 X_0**
  Main Calo : 8.9 λ
- **<A(θ < 0.8 mrad) > ≈ 30%**



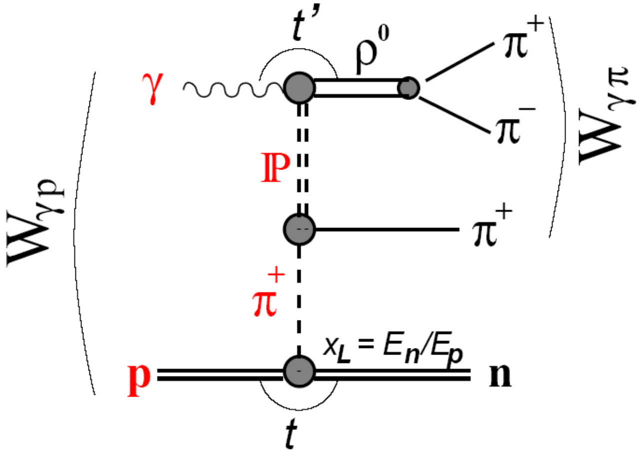
Selection of exclusive events in untagged (scatterd e^+ not detected) photoproduction:

- 2 oppositely charged tracks in Central Tracker (low multiplicity Fast Track Trigger)
- leading neutron in FNC (forward π^+ from the proton vertex not measured)
- no additional signals above noise in the main H1 calorimeters and forward detectors

Phase space of measurements

$\gamma^* + p \rightarrow \rho^0 n \pi^+, \rho^0 \rightarrow \pi^+\pi^-$

- Photoproduction : $Q^2 < 2$ GeV^2, $\langle Q^2 \rangle = 0.04$ GeV^2
- Low p_T of ρ^0 : $|t'| < 1$ GeV^2, $\langle |t'| \rangle = 0.20$ GeV^2
- Small ρ^0 mass : $0.3 < M_{\pi\pi} < 1.5$ GeV
- π^+, π^- in Central Tracker : $20 < W_{\gamma p} < 100$ GeV, $\langle W_{\gamma p} \rangle = 45$ GeV
- Leading neutron: $E_n > 120$ GeV, $\theta_n < 0.75$ mrad



Data sample : L = 1.16 pb^{-1} , ~ 7000 events

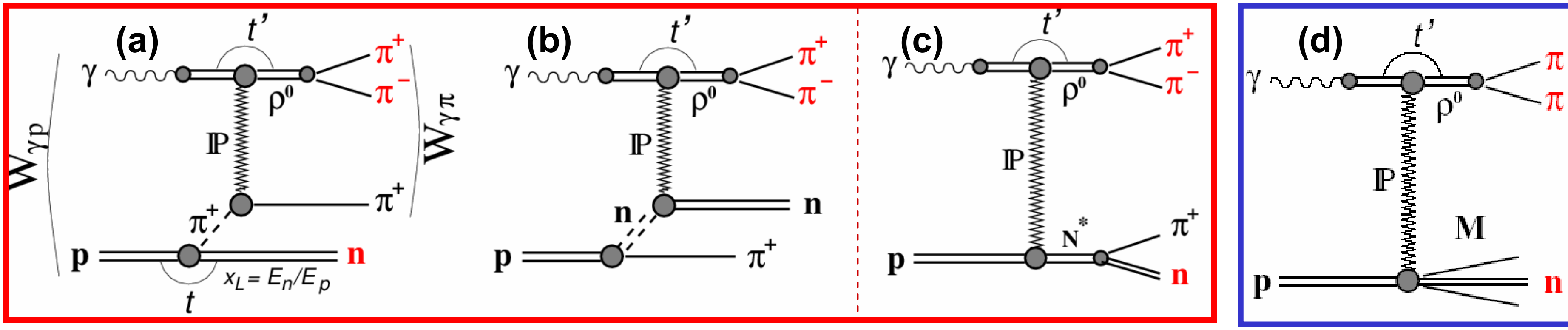
Soft process without hard scale present → application of Regge formalism

Unique measurement of Double Peripheral Process mediated by exchange of two, pion and Pomeron, Regge trajectories

Pomeron – phenomenological object with vacuum quantum numbers

Drell-Hiida-Deck diagrams and diffractive backgrounds

Pion exchange | **Neutron exchange** | **Direct pole** | **Proton dissociation**



Pompyt MC, signal (a) = pion flux + elastic scaterring of pion on photon

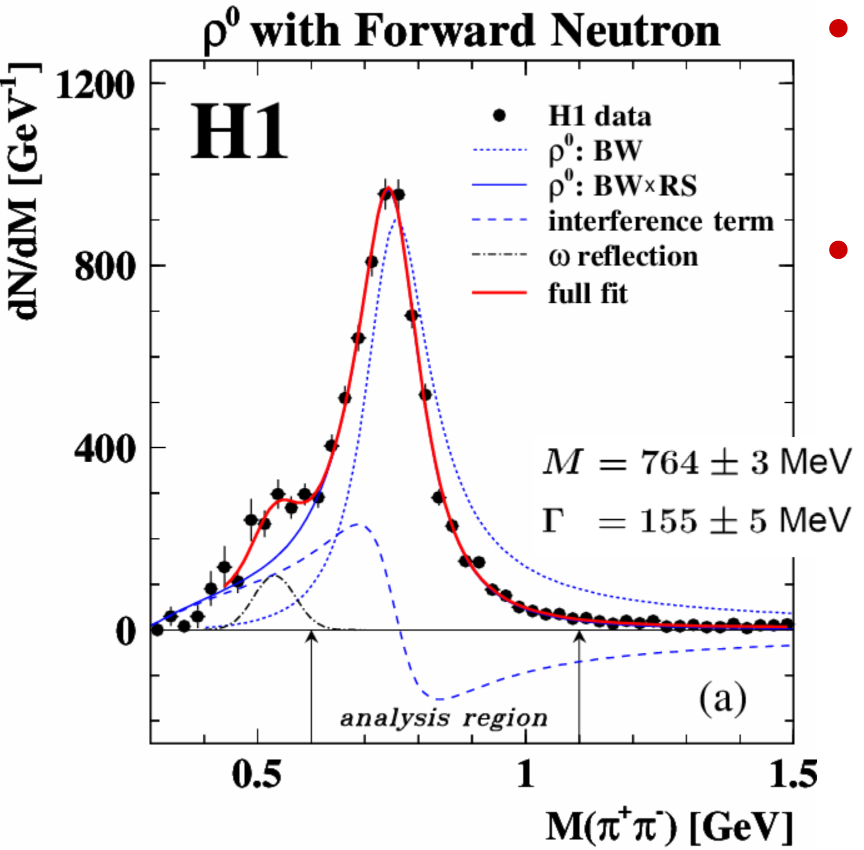
DiffVM MC, Regge theory + Vector Dominance Model, elastic, single & double-dissociation processes;

Estimation of background from $\omega(782)$, $\phi(1020)$ and $\rho'(1450\text{-}1700)$

The Drell-Hiida-Deck model (contributions of graphs a, b, c):

- At large s and $t \rightarrow 0$ $A_b \approx -A_c$ and π-exchange contribution dominates
- Interference effects are important to explain data $\sigma(\gamma p \rightarrow \rho^0 n\, \pi^+) = |A_a + A_b + A_c|^2$
- Slope of t' distribution dependent on $M_{n\pi+}$ $\rightarrow$ importance of interference effects

Extraction of the ρ-meson signal

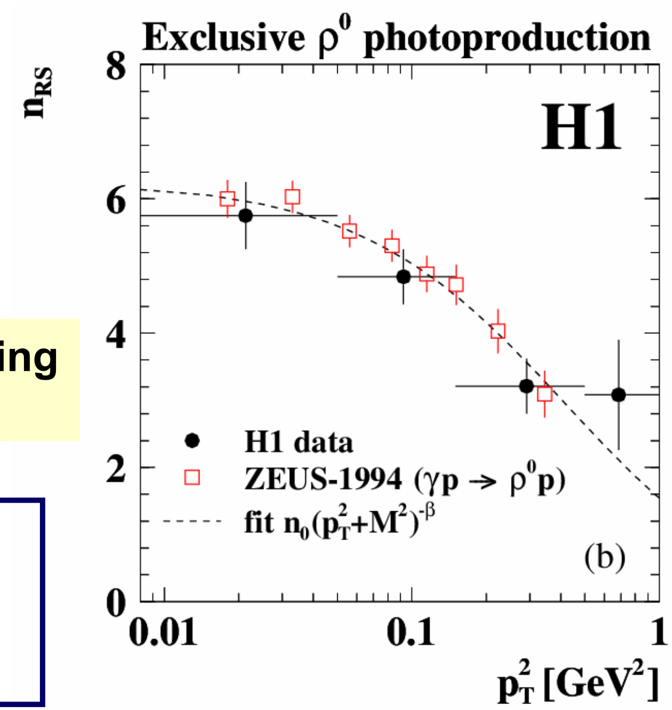


- **Distortion of the ρ^0 mass shape** due to the interference between the resonant and non-resonant $\pi^+\pi^-$ production is characterised by the Ross&Stodolsky skewing parameter n_{RS}
- contribution for the reflection from $\omega(782) \to \pi^+\pi^-\pi^0$ added

$$\frac{dN(M_{\pi\pi})}{dM_{\pi\pi}} \propto BW_\rho(M_{\pi\pi}) \left(\frac{M_\rho}{M_{\pi\pi}}\right)^{n_{RS}}$$

Analysis region ($0.6 < M_{\pi\pi} < 1.1$ GeV) extrapolated using BW to the full mass range: $2m_\pi < M_{\pi\pi} < M_\rho + 5\,\Gamma_\rho$

- skewing parameter n_{RS} vs. p_T^2 of the $\pi^+\pi^-$ system
- H1 and ZEUS values of n_{RS} (from $\gamma p \to \rho^0 p$) are in agreement



Extraction of the ρ-meson signal

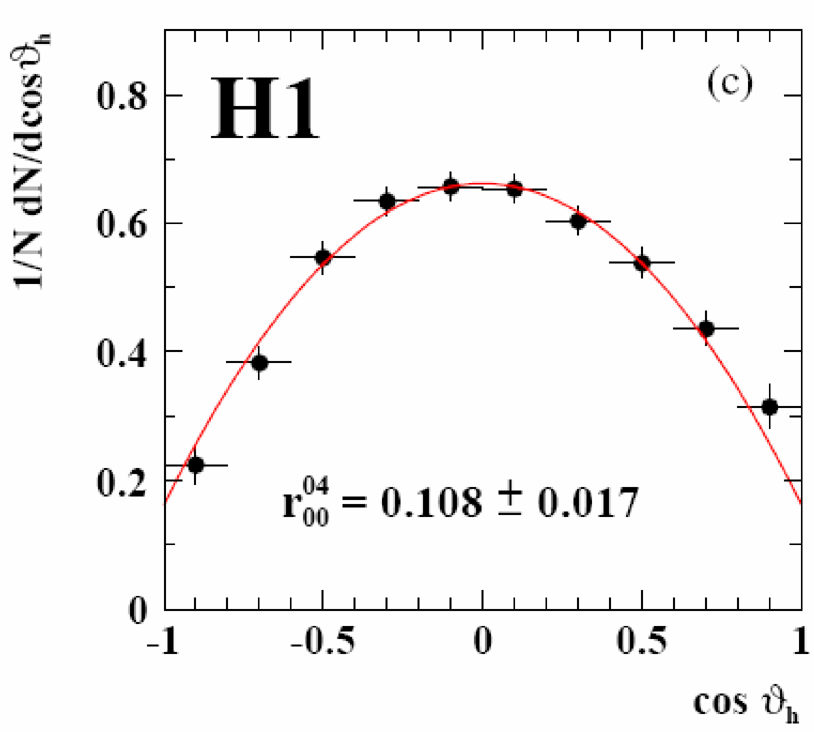
Polar angle distribution of the π^+ in the helicity frame :

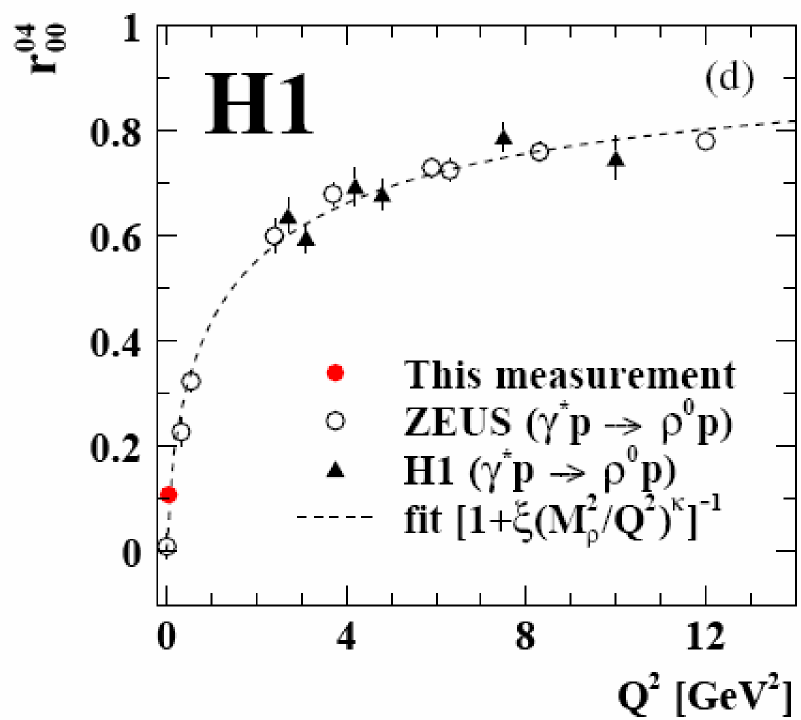
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_h} \propto 1 - r^{04}_{00} + (3r^{04}_{00} - 1)\cos^2\theta_h$$

Spin-density matrix element r^{04}_{00}

– probability that ρ^0 has helicity 0

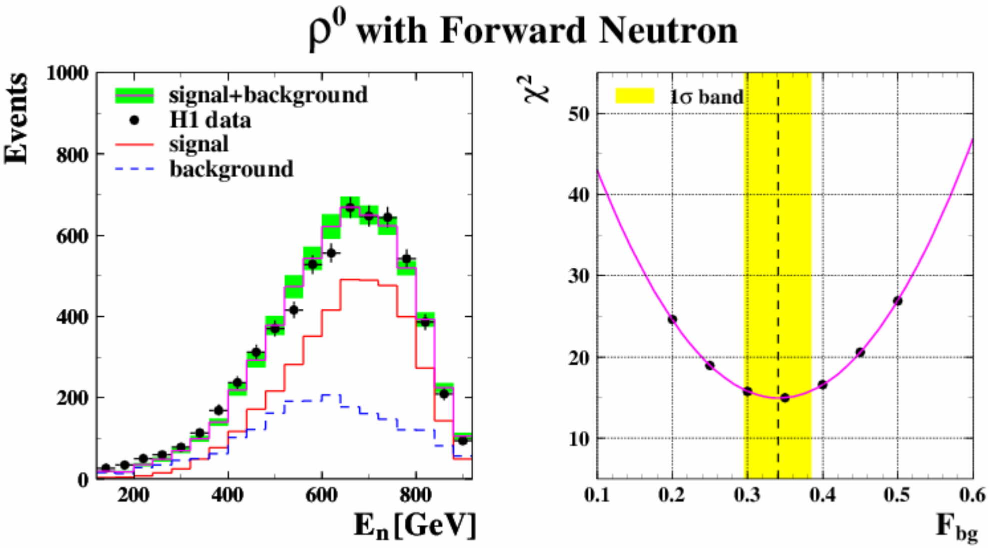
Empirical fit: $r^{04}_{00} = \frac{1}{1+\xi(M_\rho^2/Q^2)^\kappa}$





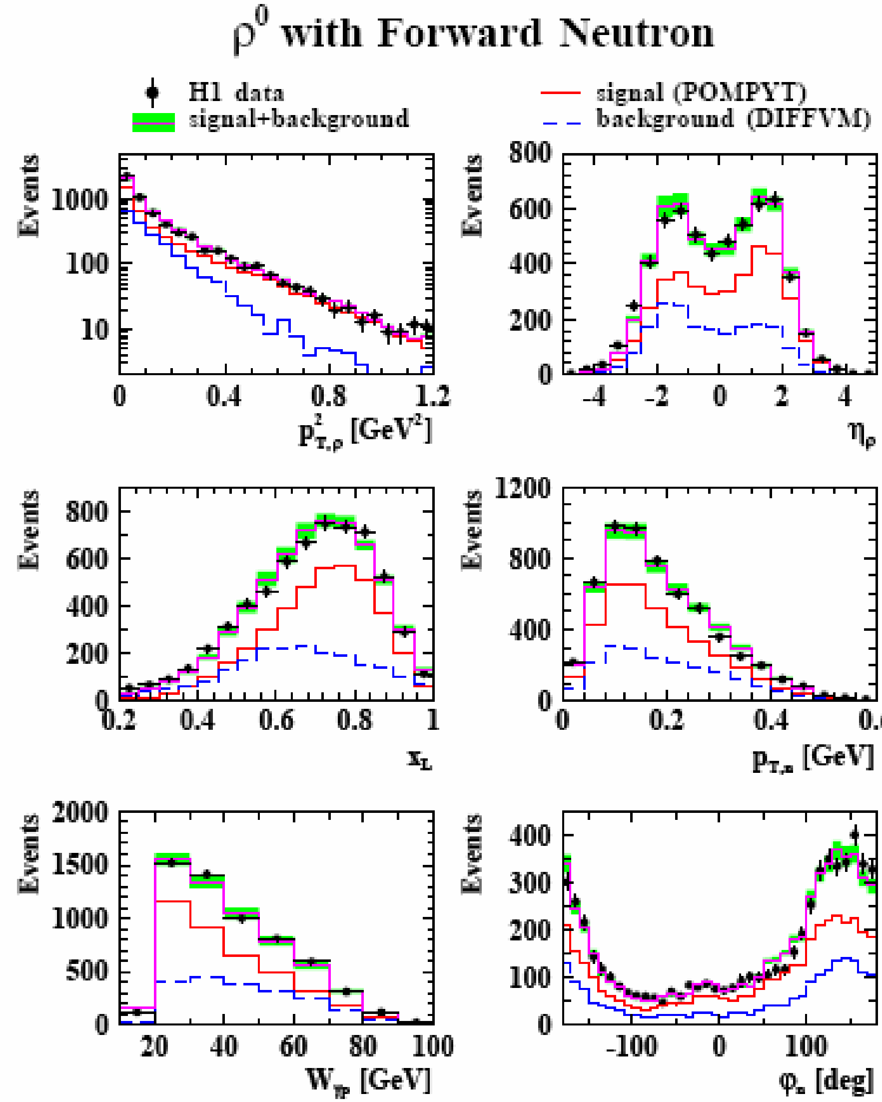
r^{04}_{00} **in diffractive ρ^0 photo- and electro-production at HERA**

Signal and background decomposition



- Different shapes of leading neutron energy for signal and background
- background mostly due to proton dissociation
- shape of signal and background modelled by POMPYT and DIFFVM MC

Background fraction fit to the data :
F_{bg} = B / (S+B) = 0.34 ± 0.05



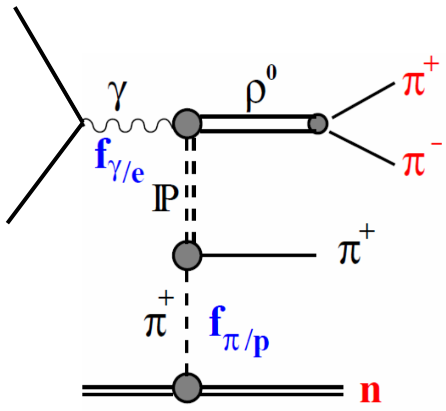
Shape comparison control plots

$\sigma_{\gamma p}$ and $\sigma_{\gamma\pi}$ cross sections

$\sigma_{\gamma p} = \sigma_{ep} / \Phi_\gamma$

photon flux :

$\Phi_\gamma = \int f_{\gamma/e}(y, Q^2)\,dy\,dQ^2$



One-pion-exchange approximation

$\sigma_{\gamma\pi} = \sigma_{\gamma p} / \Gamma_\pi$

pion flux :

$\Gamma_\pi = \int f_{\pi/p}(x_L, t)\,dx_L\,dt$

Effective photon flux from the Vector Dominance Model

converts the ep cross section into a real γp cross section at $Q^2 = 0$

$$f_{\gamma/e}(y,Q^2) = \frac{\alpha}{2\pi Q^2 y}\left\{\left[1+(1-y)^2 - 2(1-y)\left(\frac{Q^2_{\min}}{Q^2} - \frac{Q^2}{M^2_\rho}\right)\right]\frac{1}{\left(1+\frac{Q^2}{M^2_\rho}\right)^2}\right\}$$

Non-Reggeized pion flux in the light-cone representation (Holtmann *et al*.)

$$f_{\pi/p}(x_L,t) = \frac{1}{2\pi}\frac{g^2_{p\pi N}}{4\pi}(1-x_L)\frac{-t}{(m^2_\pi - t)^2}\exp\left[-R^2_{\pi n}\frac{m^2_\pi - t}{1-x_L}\right]$$

$R_{\pi n}$ – radius of the pion-neutron Fock state

$\sigma_{\gamma p}$ and $\sigma_{\gamma\pi}$ cross sections

γp cross section

$$\sigma_{\gamma \mathrm{p}} = \frac{\sigma_{ep}}{\int f_{\gamma/e}(y,Q^2)\mathrm{d}y\mathrm{d}Q^2} = \frac{N_{\mathrm{data}} - N_{\mathrm{bgr}}}{\mathcal{L}(A\cdot\epsilon)\mathcal{F}}\cdot C_\rho$$

N_{bgr} – diffractive dissociation background from MC
L – integrated luminosity
$A \cdot \varepsilon$ – correction for detector acceptance and efficiency
F – photon flux integrated over kinematic region $20 < W_{\gamma p} < 100$ GeV, $Q^2 < 2$ GeV
C_ρ – numerical factor extrapolating from the measured $\pi^+\pi^-$ mass range to full BW resonance

γp cross section in the range $0.35 < x_L < 0.95$ and averaged over $20 < W_{\gamma p} < 100$ GeV, precision: $\delta_{stat} = 2\%$, $\delta_{sys} = 14.6\%$

$\sigma(\gamma p \rightarrow \rho^0 n\pi^+) = (310 \pm 6_{stat} \pm 45_{sys})$ nb, for $\theta_n < 0.75$ mrad (full acceptance of FNC)
$\sigma(\gamma p \rightarrow \rho^0 n\pi^+) = (130 \pm 3_{stat} \pm 19_{sys})$ nb, for $p_{T,n} < 0.2$ GeV (OPE dominated range)

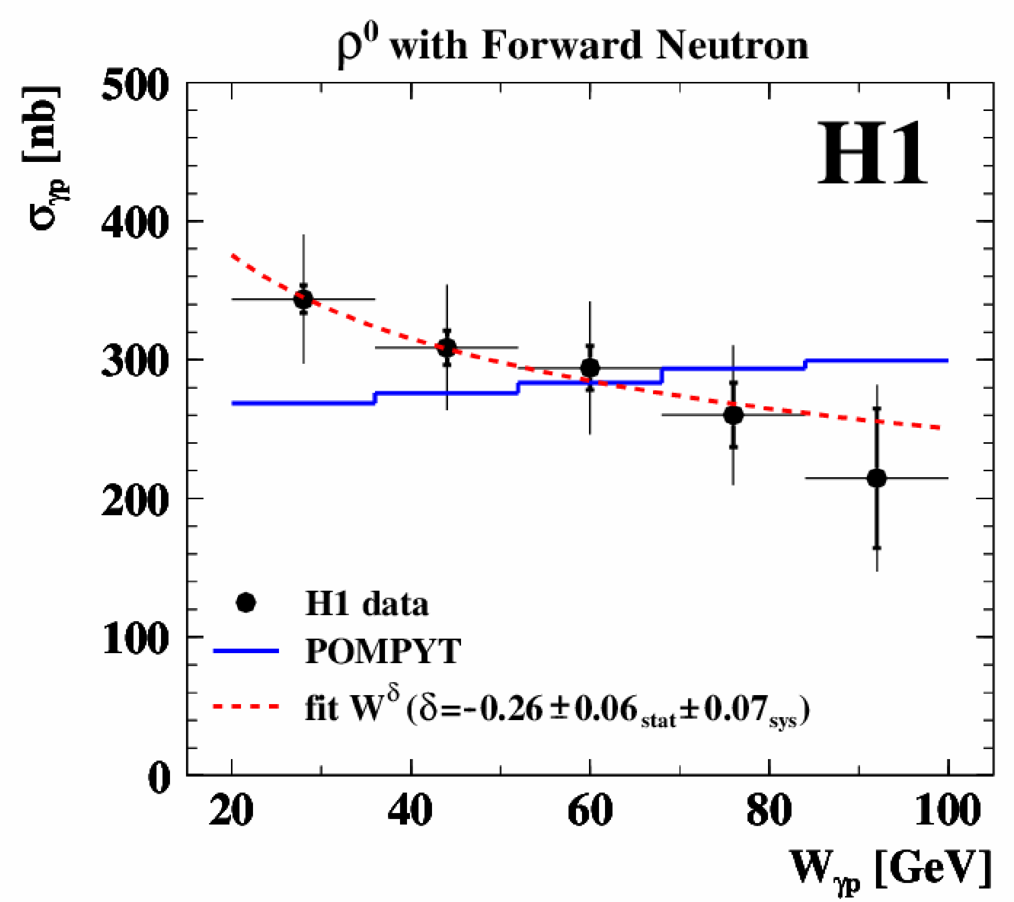
cross section of elastic photoproduction of ρ^0 on a pion target

OPE

$$\sigma_{\gamma\pi}(\langle W_{\gamma\pi}\rangle) = \frac{\sigma_{\gamma \mathrm{p}}}{\int f_{\pi^+/p}(x_L,t)dx_L dt}$$

$\sigma_{el}(\gamma\pi^+ \rightarrow \rho^0\pi^+) = (2.33 \pm 0.34(\mathrm{exp}) \pm^{0.47}_{0.40}(\mathrm{model}))$ μb, for $\langle W_{\gamma\pi}\rangle = 24$ GeV

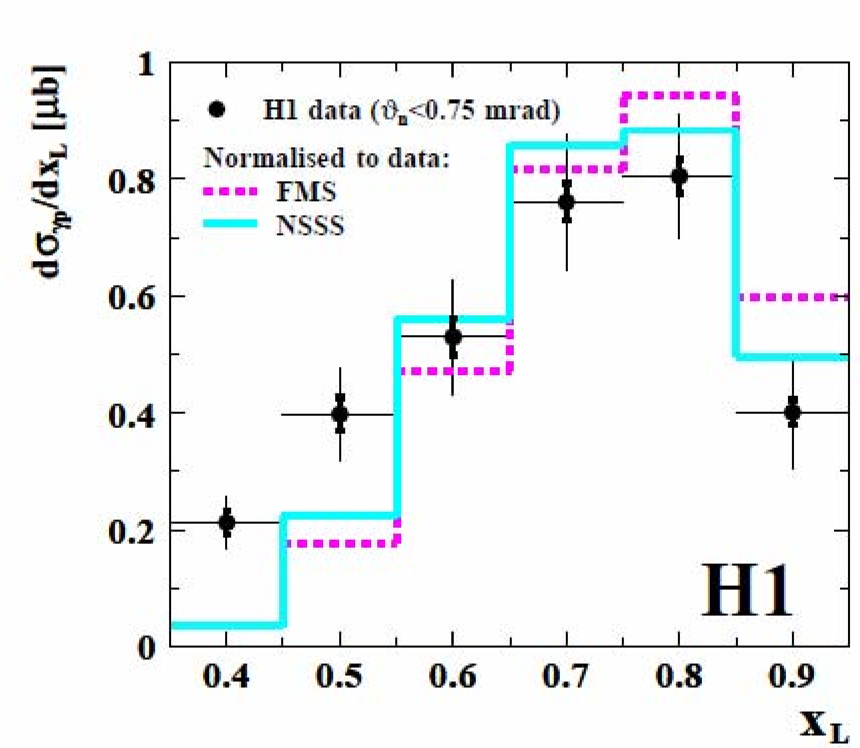
Energy dependence of $\sigma(\gamma p \rightarrow \rho^0 n \pi^+)$



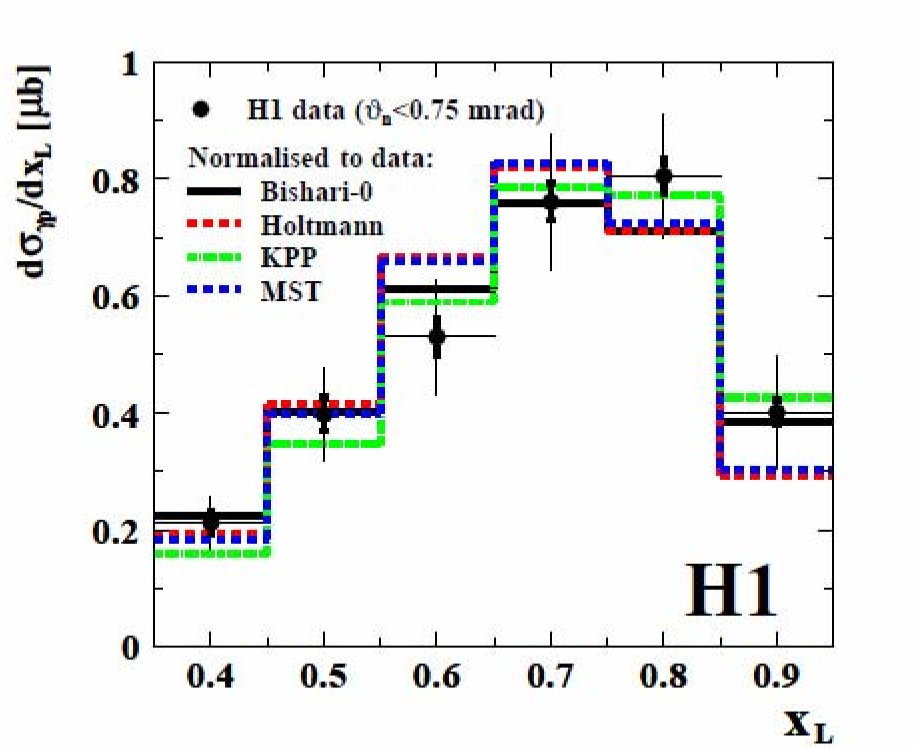
- Regge motivated power law fit $\sigma \approx W^\delta$: $\delta = -0.26 \pm 0.06_{stat} \pm 0.07_{sys}$
- POMPYT MC prediction : only Pomeron exchange

$d\sigma_{\gamma p} / dx_L$: constraining pion flux

$d\sigma_{\gamma p}$ / dx_L compared in shape to predictions based on different models for the pion flux

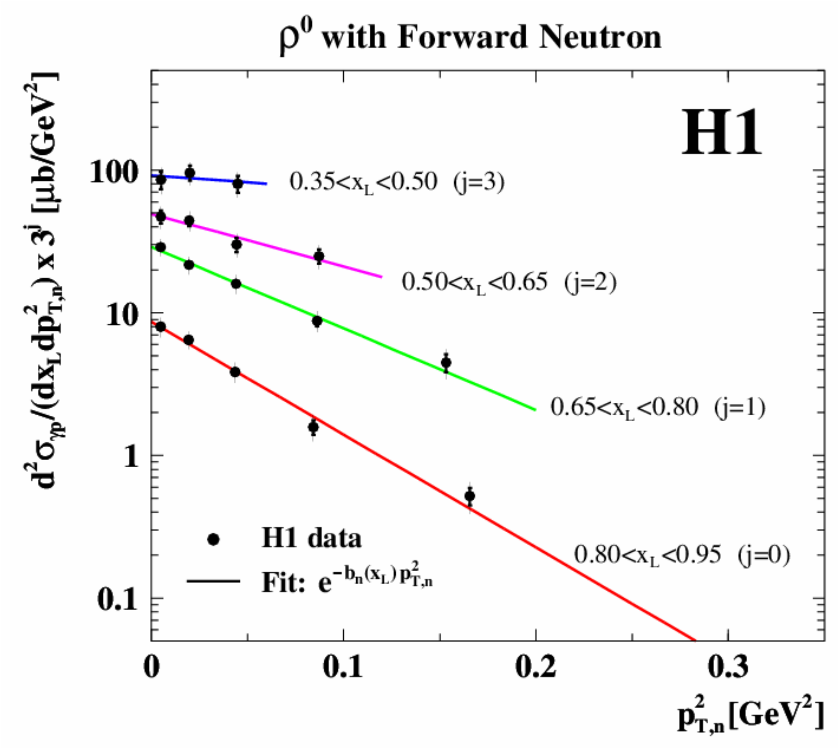


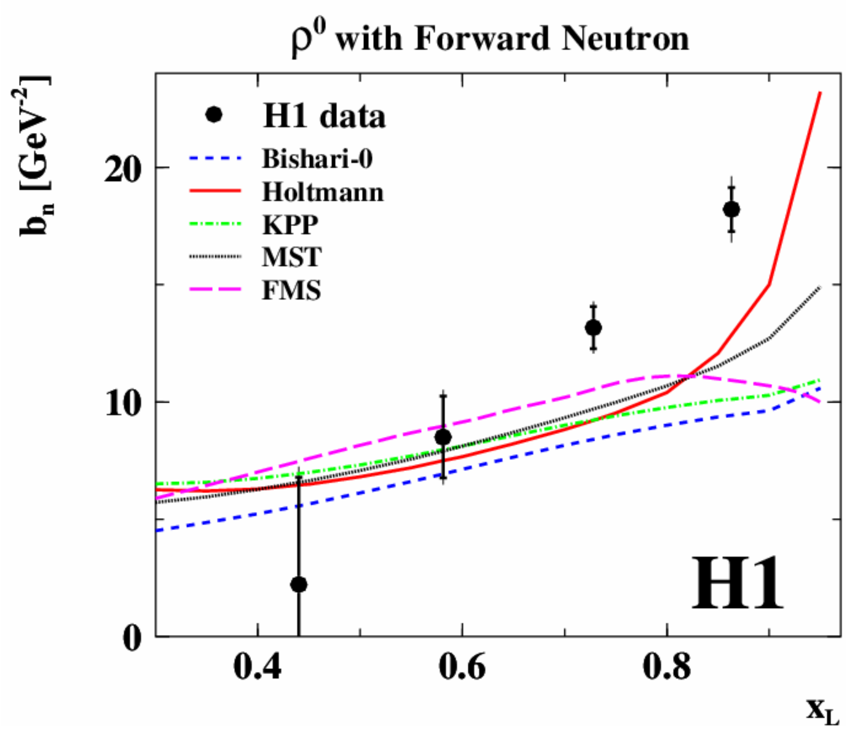
Pion flux models disfavoured by the data



Shape of the x_L distribution reproduced by most of the pion flux models

$d^2\sigma_{\gamma p}$ / $(dx_L dp_{T,n}^2)$: constraining pion flux



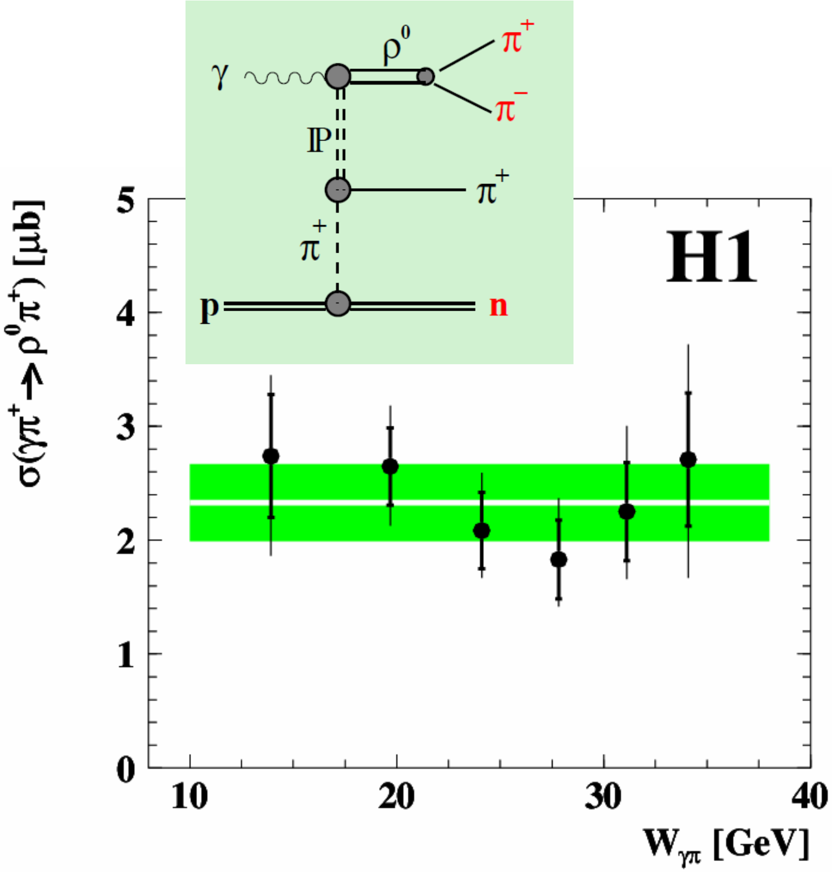


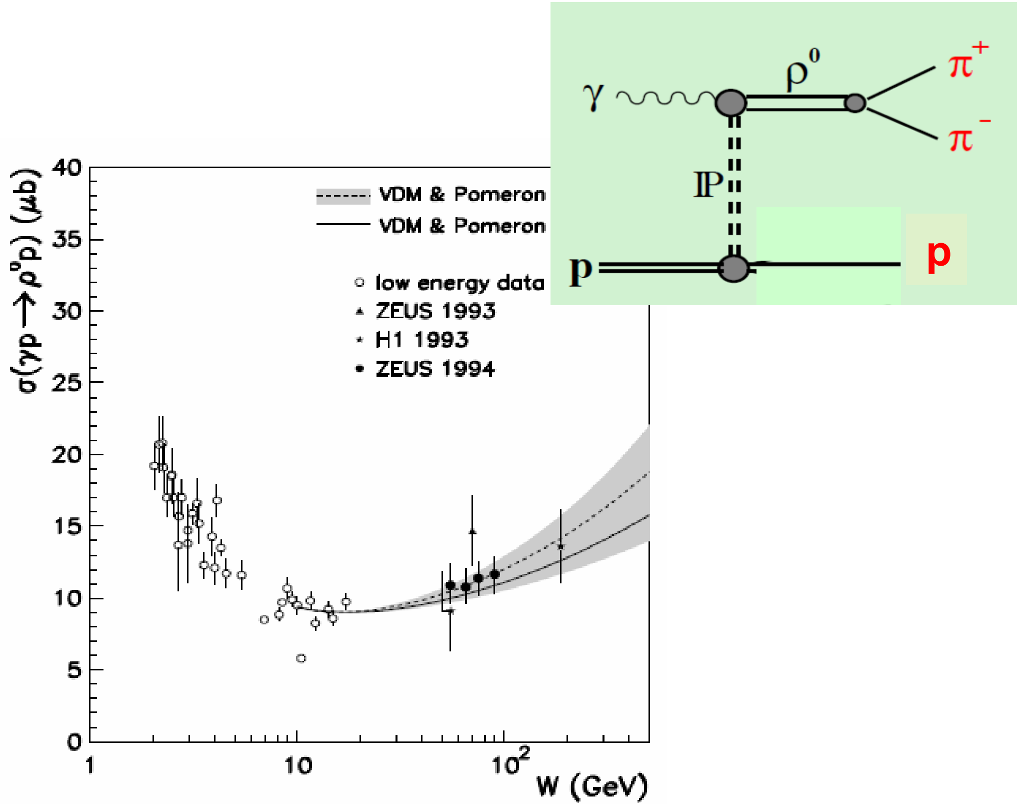
Fit by exponential function
$\exp[-b_n(x_L)p_{T,n}^2]$
in each x_L bin

x_L dependence of the p_T slope
of the leading neutron
is not described by models

→ importance of absorptive corrections ?

Estimation of absorption corrections



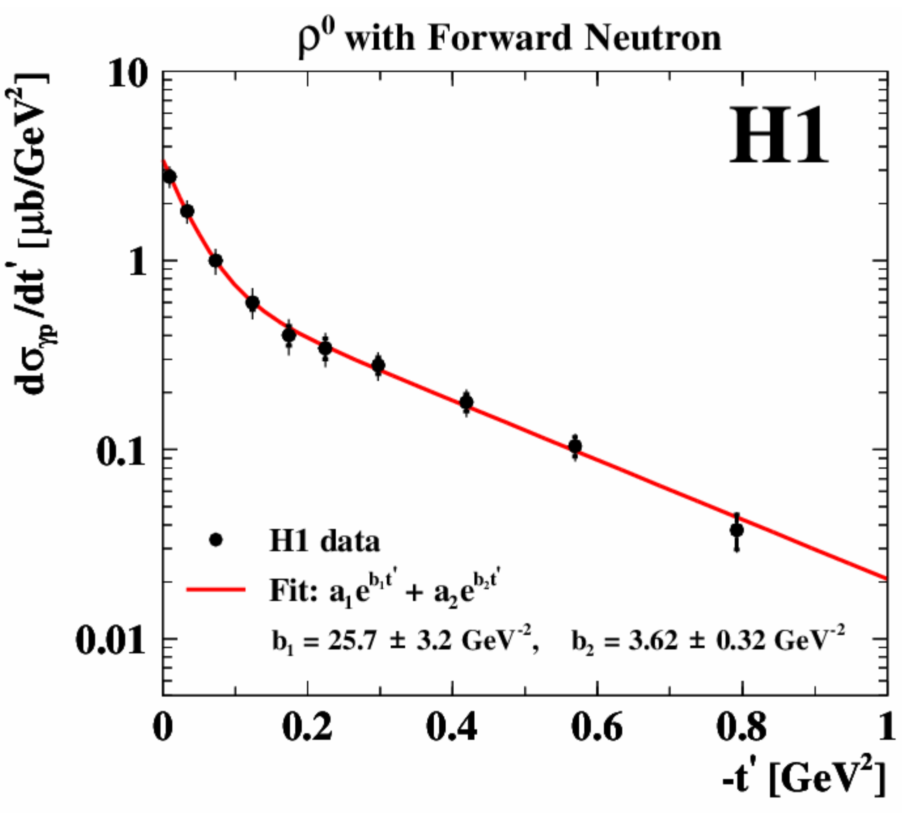


$r_{el} = \sigma_{el}(\gamma\pi \to \rho^0\pi) / \sigma_{el}(\gamma p \to \rho^0 p) = 0.25 \pm 0.06$ (experiment)

$r_{el} = 0.57 \pm 0.03$ (theory : Optical theorem + eikonal approach + data)

Absorption factor $K_{abs} = 0.44 \pm 0.11$

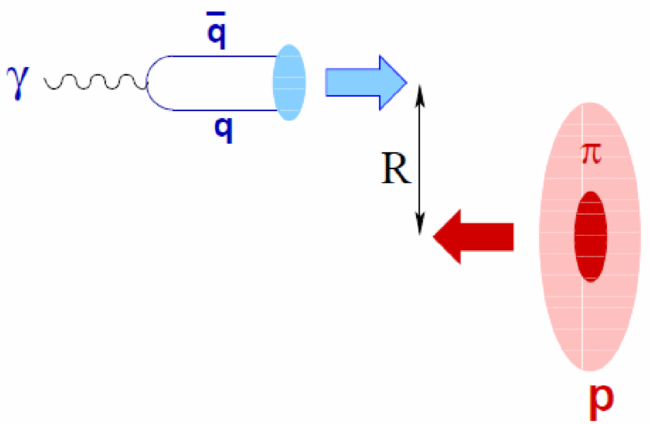
Differential cross section $d\sigma_{\gamma p}/dt'$ of ρ^0



Strongly changing slope between the low-t' and high-t'

$$\frac{d\sigma_{\gamma p}}{dt'} = a_1 e^{b_1 t'} + a_2 e^{b_2 t'}$$

$b_1 = 25.7 \pm 3.2$ GeV^{-2}, $b_2 = 3.62 \pm 0.32$ GeV^{-2}



- **Geometric picture: $\langle r^2 \rangle = 2b_1 \cdot (\hbar c)^2 \approx 2\text{fm}^2 \approx (1.6R_p)^2$**

  → ρ^0 **produced at large impact parameter** (ultraperipheral process)

- **Double Peripheral Process interpretation:**

  slope of t' distribution dependent on the invariant mass of the ($n\pi^+$) system,
  low $M(n\pi^+)$ → large slope, high $M(n\pi^+)$ → less steep slope

Summary

- The photoproduction cross section for exclusive ρ^0 production associated with a leading neutron is measured for the first time at HERA

- Differential cross sections for the reaction $\gamma p \rightarrow \rho^0 n \pi^+$ show behaviour typical for exclusive double peripheral process

- The elastic photon-pion cross section, $\sigma(\gamma\pi^+ \rightarrow \rho^0\pi^+)$, is extracted in the one-pion-approximation

- The differential cross sections for the leading neutron are sensitive to the pion flux models

- The estimated cross section ratio $r_{el} = \sigma_{el}(\gamma\pi \rightarrow \rho^0\pi) / \sigma_{el}(\gamma p \rightarrow \rho^0 p) = 0.25 \pm 0.06$ suggests large absorption corrections, of the order of 60%, suppressing the rate of the studied reaction $\gamma p \rightarrow \rho^0 n \pi^+$