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

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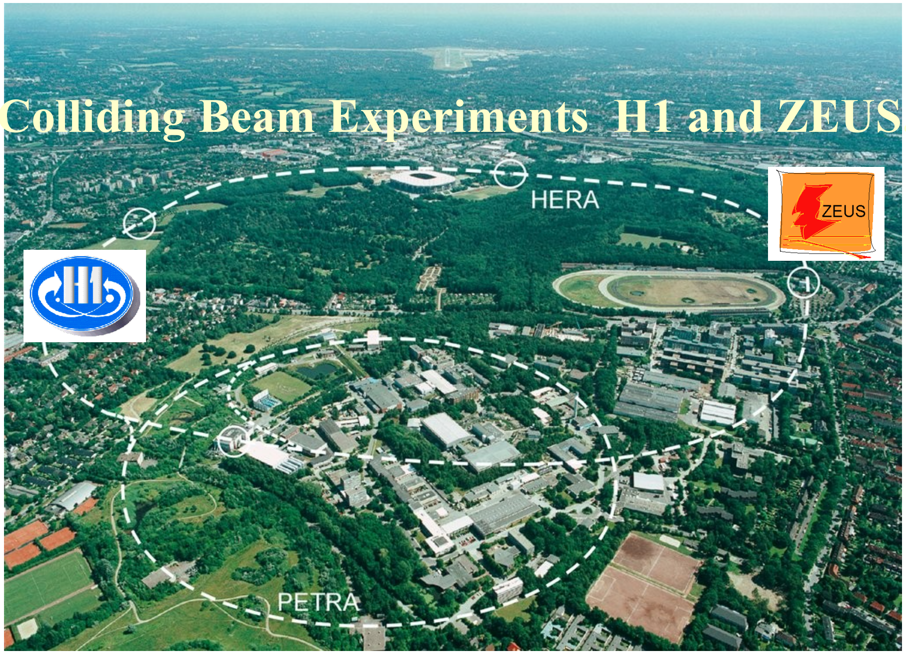
for the H1 Collaboration

HERA, the World's first and only High Energy ep Collider



DESY, Hamburg

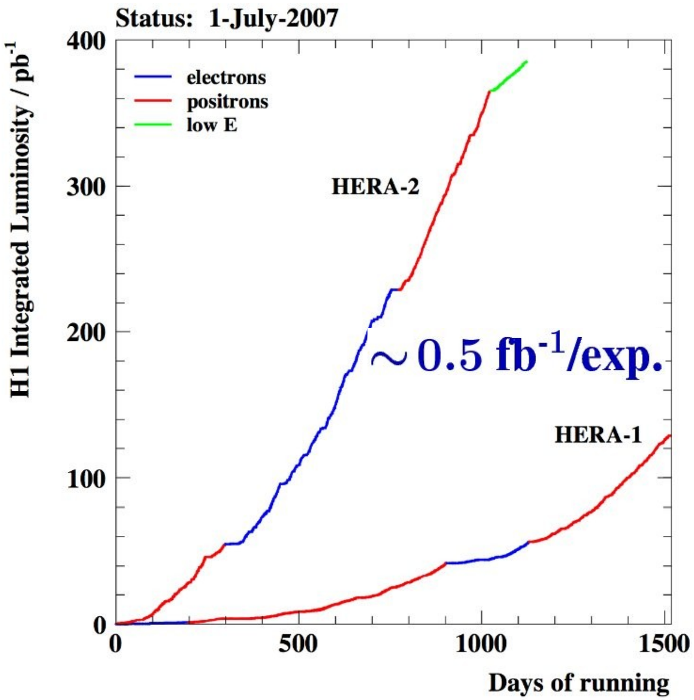
HERA Beams

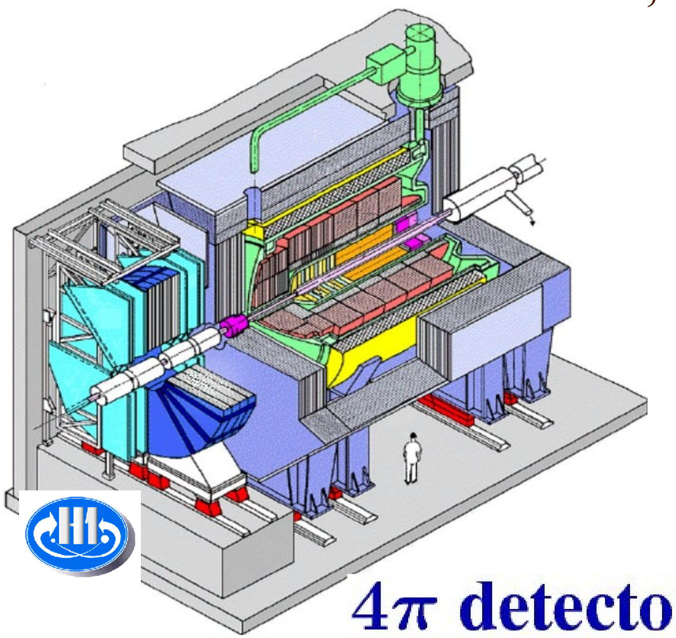
$E_e = 27$ GeV

$E_p = 920$ GeV

$\sqrt{s} = 319$ GeV

H1 Integrated Luminosity





4π detector

HERA Data Taking 1992-2007

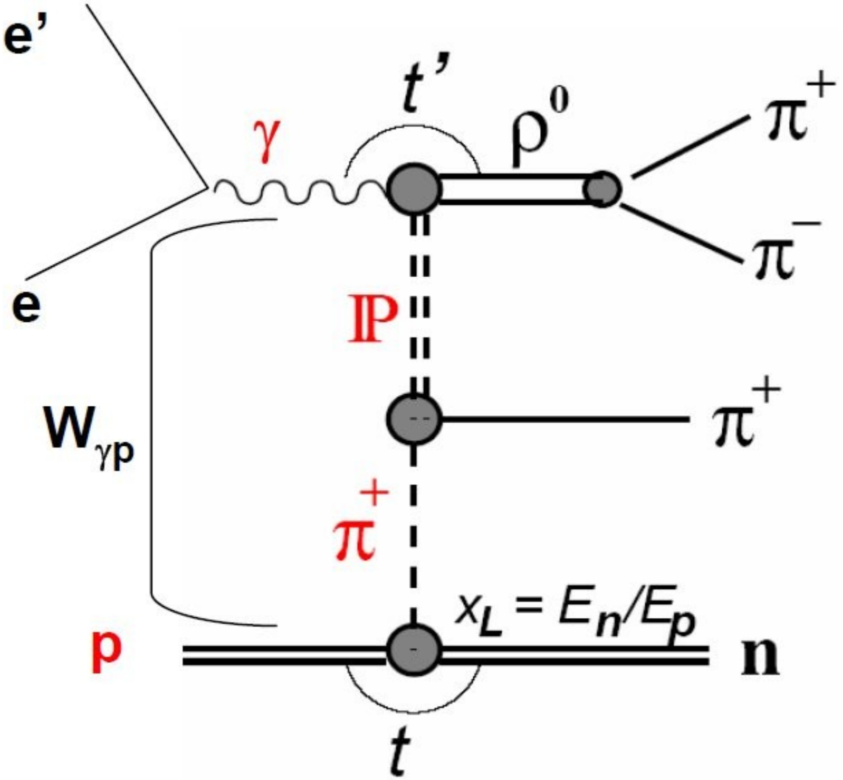
HERA Beams finally dumped
30 June 2007,
today exactly 10 years ago

Data Analysis still going strong

$\gamma\pi$ Scattering

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

$$\gamma\pi^+ \rightarrow \rho^0\pi^+$$



Kinematic Variables:

$\sqrt{s}$	ep CM Energy (319 GeV)
$W_{\gamma p}$	γp CM Energy (20-100 GeV)
$W_{\gamma\pi}$	$\gamma\pi$ CM Energy ($\langle W_{\gamma\pi}\rangle = 24$ GeV)
Q^2	Photon Virtuality (Photoproduction)
x_L	Fraction of Proton Energy, carried by Leading Neutron
$p_{T,n}$	Neutron Transverse Momentum
t	$\lvert$4-mom. transfer$\rvert^2$ at Proton Vertex
t'	$\lvert$4-mom. transfer$\rvert^2$ at $\gamma\rho^\circ$ Vertex

Double Peripheral Process (DPP):

Exchange of two Regge Trajectories

Virtual Photon from Electron interacts with Pion from Proton Cloud

First Measurement of Elastic $\gamma\pi^+ \rightarrow \rho^0\pi^+$ Scattering!

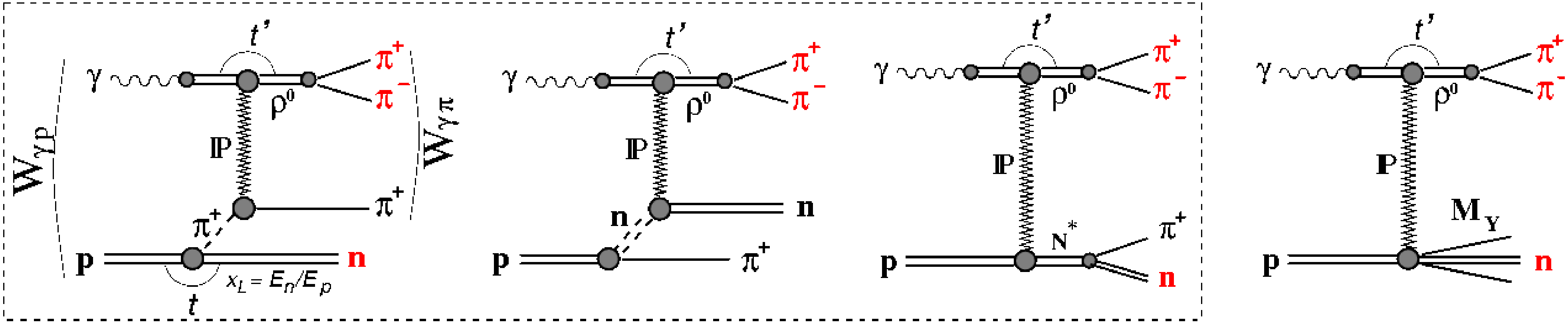
Scattering on an Unstable Particle:

Suggested 1959 by Chew & Low   Experimental Challenge!

Sensitivity to the Pion Flux: Valuable New Constraints for Models

Long Tradition at HERA: Exclusive Vector Meson & Leading Baryon Production

Drell-Hiida-Deck Diagrams and Background



(a) **pion exchange** (b) **neutron exchange** (c) **direct pole** (d) **p dissociation (Background)**

Drell - Hiida - Deck (DHD, 1961,1964):

Three Diagrams a), b), c) contribute to the Signal Process

$\sigma(\gamma p \to \rho^0 n \pi^+) \sim |A_a + A_b + Ac|^2$: Interference

Large s and small t' : $A_b \simeq -A_c$, π exchange dominates

For small masses $M_{n\pi^+}$, expect peak at small values in t' distribution

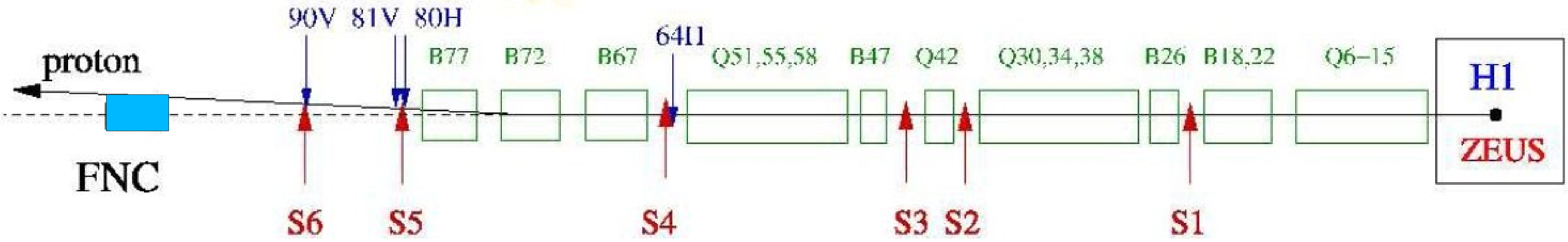
Monte Carlo Simulation:

POMPYT for the Signal Diagram a) Pion Flux , One Pion Exchange

DIFFVM for the Background Diagram d)

and also for Reflections from ω, ϕ and $\rho'(1450-1700)$ production

H1 Forward Neutron Detector, FNC



Main Calorimeter: 8.9λ

$\sigma(E)/E \approx 63\%/\sqrt{E\,[\mathrm{GeV}]} \oplus 3\%$

$\sigma(x,y) \approx 10\mathrm{cm}/\sqrt{\mathrm{E}\,[\mathrm{GeV}]} \oplus 0.6\,\mathrm{cm}$

Preshower: 1.6λ $(60X_0)$

$\sigma(E)/E \approx 20\%/\sqrt{E\,[\mathrm{GeV}]} \oplus 2\%$

$\sigma(x,y) \approx 2\mathrm{mm}$

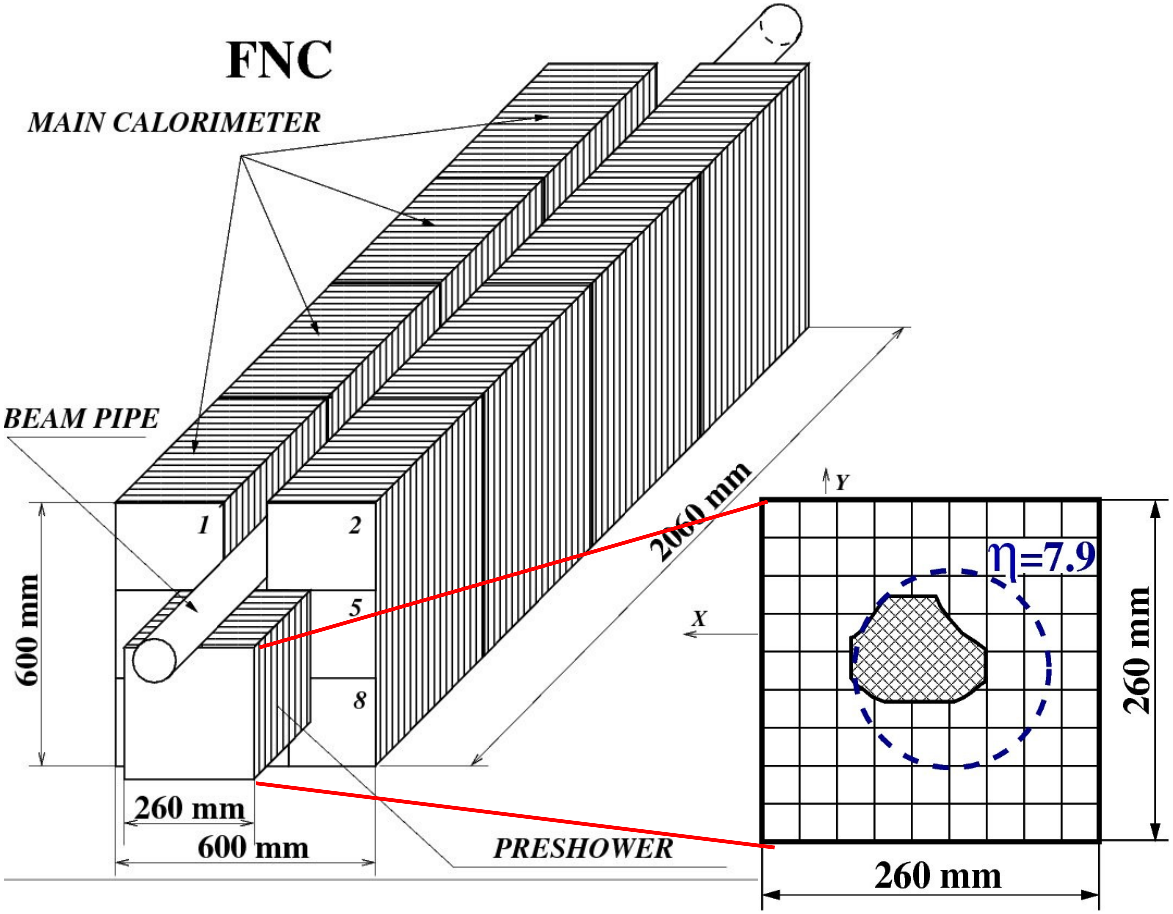
FNC located 106 m from I.P.

Lead-Scintillator Sandwich

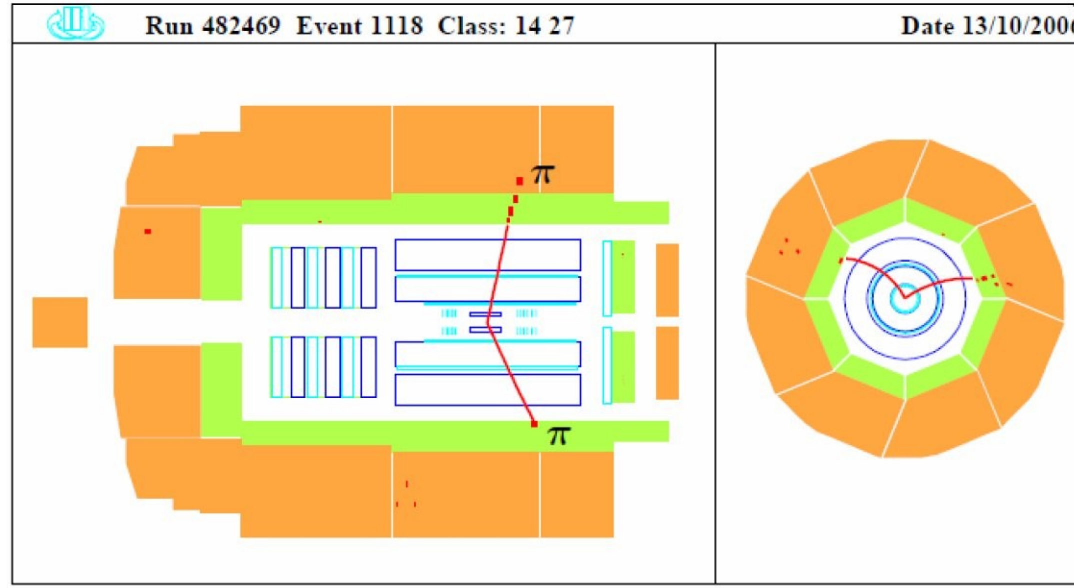
"Very Forward":

$\eta > 7.9 \quad (\theta < 0.75\mathrm{mrad})$

Azimuthal Coverage ~30%



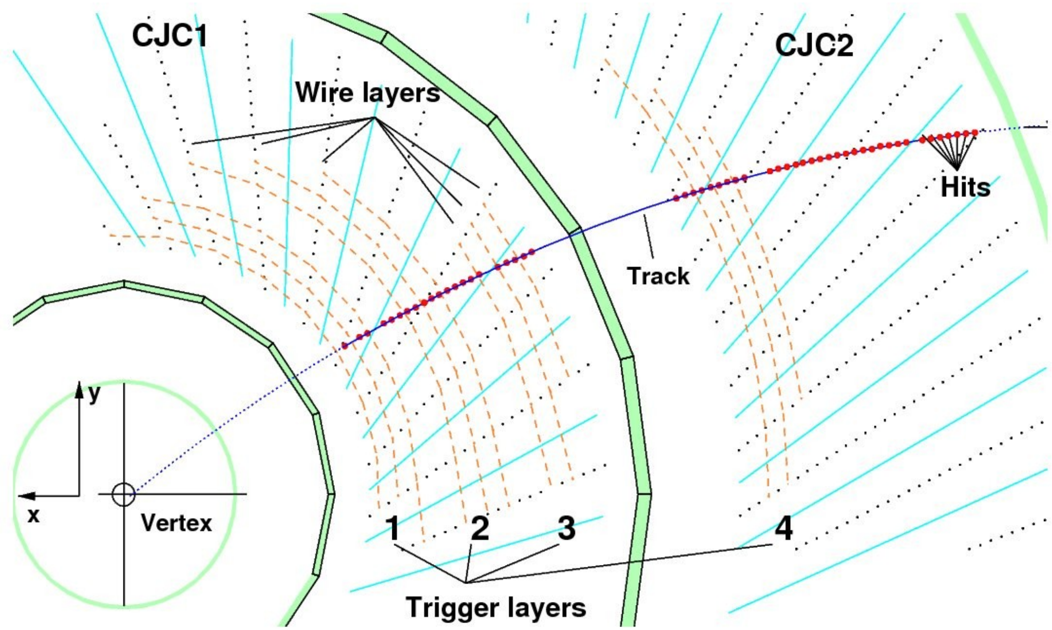
H1 Fast Track Trigger, FTT



Final visible State :

- Neutron in the FNC
- Two charged particles in the CJC
- 3rd pion is not seen !

Low Multiplicity Track Trigger.
uses the
Fast Track Trigger FTT
based on CJC hits
75% efficiency
in analysis phase space



High Trigger Rate ⇒ Downscaling

Effective Integrated Luminosity in this Analysis: 1.16 pb^{-1}

(Total Lumi of period: 131 pb^{-1})

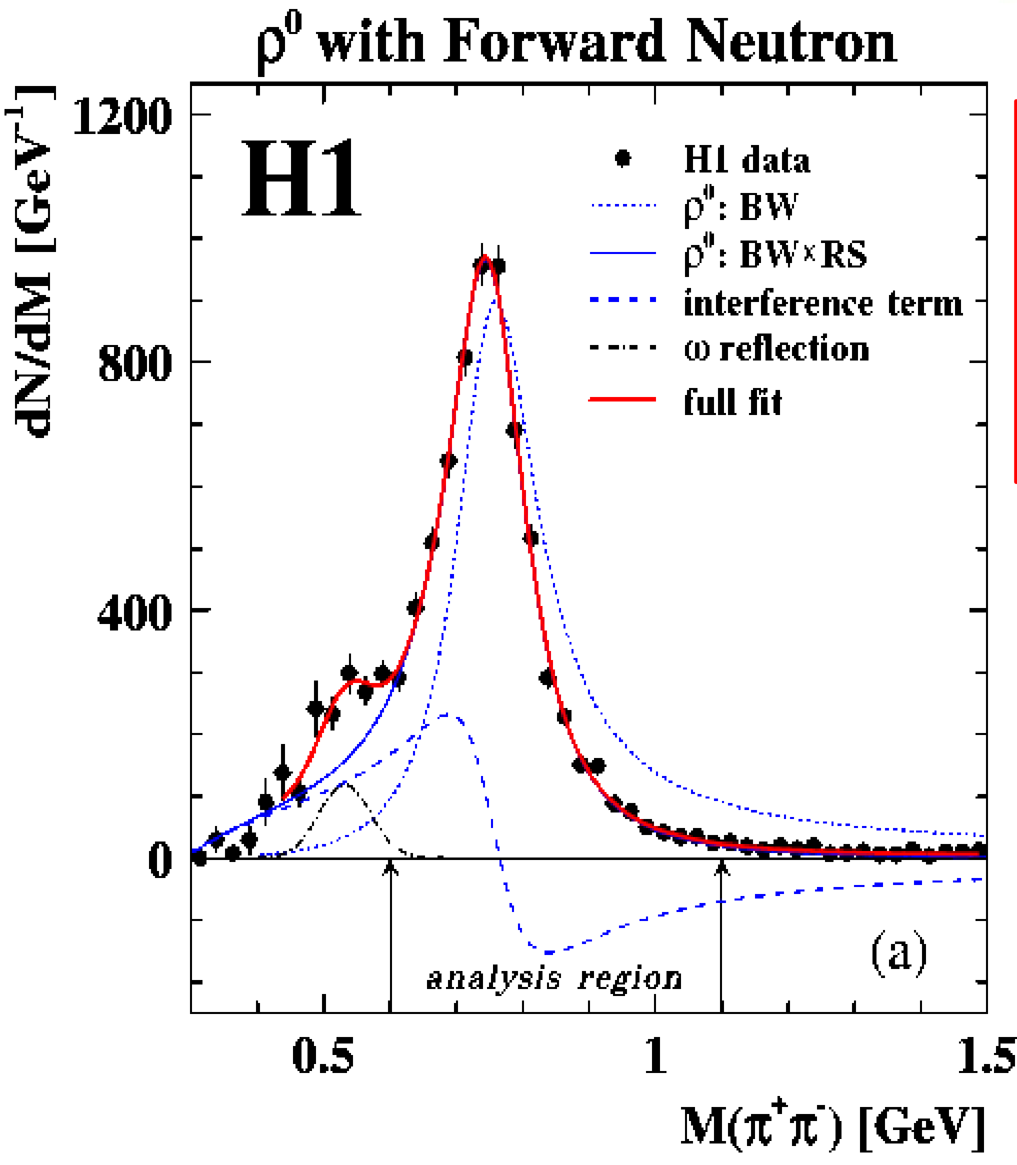
Event Selection and Phase Space of the H1 Measurement

Event selection	Analysis PS	Measurement PS
No e' in the detector	$Q^2 < 2$ GeV^2 $\langle Q^2 \rangle = 0.04$ GeV^2	$Q^2 = 0$ GeV^2 *
2 tracks, net charge = 0 $p_T > 0.2$ GeV, $20^o < \theta < 160^o$, from $\lvert z_{vx} \rvert < 30$ cm $0.3 < M_{\pi\pi} < 1.5$ GeV	$20 < W_{\gamma p} < 100$ GeV $\langle W_{\gamma p} \rangle = 45$ GeV $p_{T,\rho} < 1.0$ GeV $0.6 < M_{\pi\pi} < 1.1$ GeV	$20 < W_{\gamma p} < 100$ GeV $-t' < 1.0$ GeV^2 $2m_\pi < M_\rho < M_\rho + 5\Gamma_\rho$
LRG requirement	$\sim 637,000$ events	
Neutron requirements $E_n > 120$ GeV $\theta_n < 0.75$ mrad	$x_L > 0.2$ $\theta_n < 0.75$ mrad	$0.35 < x_L < 0.95$ $p_{T,n} < x_L \cdot 0.69$ GeV
$\sim$ 7000 events	$\sim$ 6100 events	$\sim$ 5770 events
OPE dominated range	$p_{T,n} < 0.2$ GeV	$\sim$ 3600 events

* The measured cross sections are determined at $Q^2 = 0$, using an effective photon flux based on VDM

The ρ^0 Signal

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

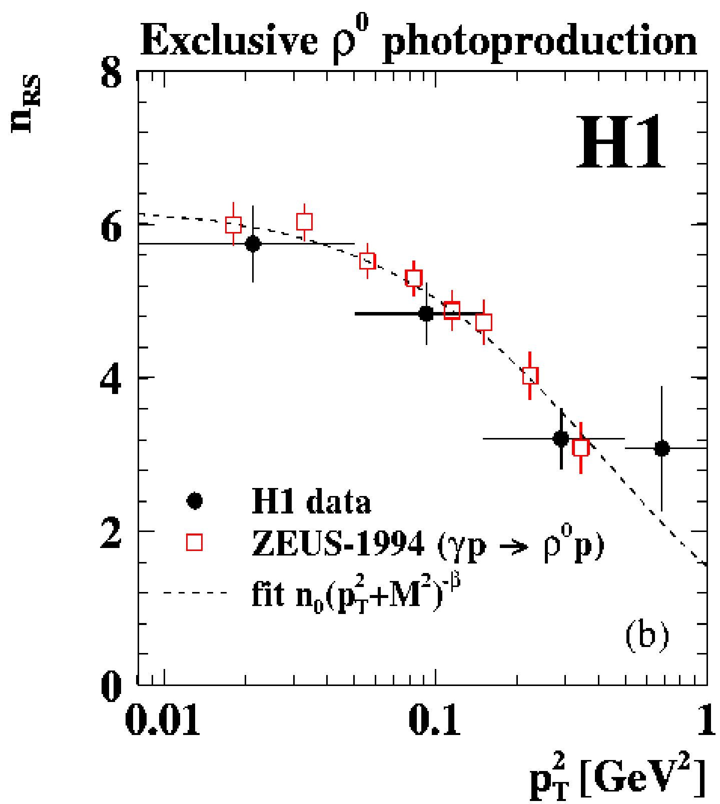


BW Shape distorted, due to interference with non-resonant $\pi^+\pi^-$ production

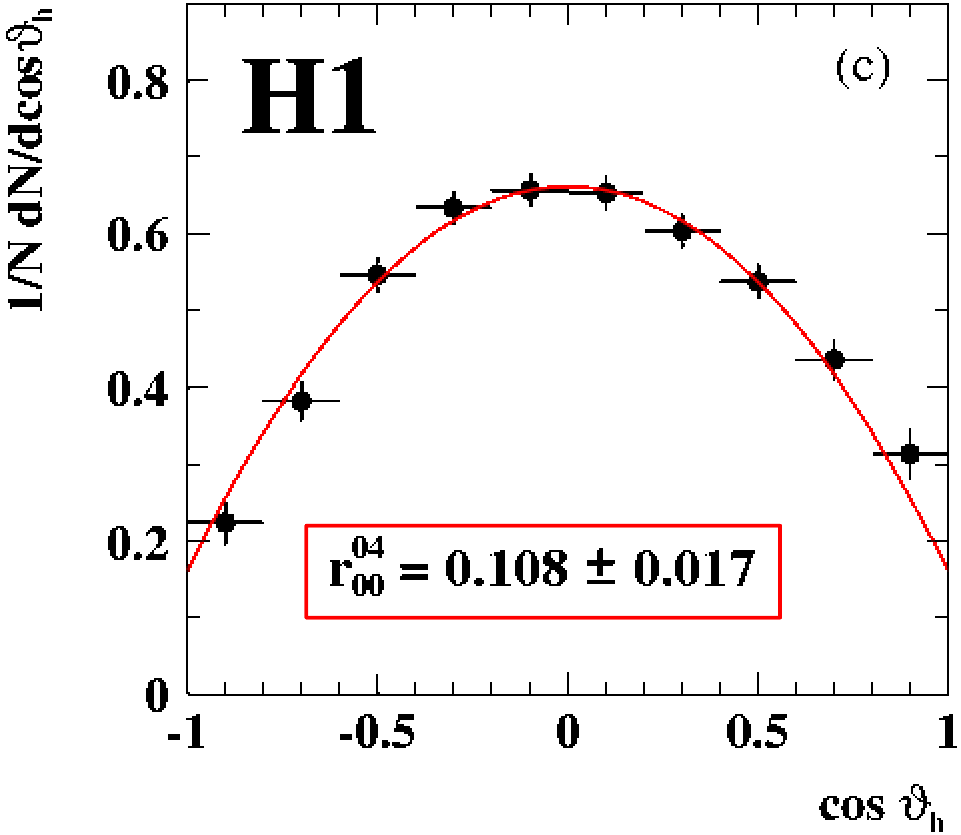
Distortion depends on $p_{T,\pi^+\pi^-}$

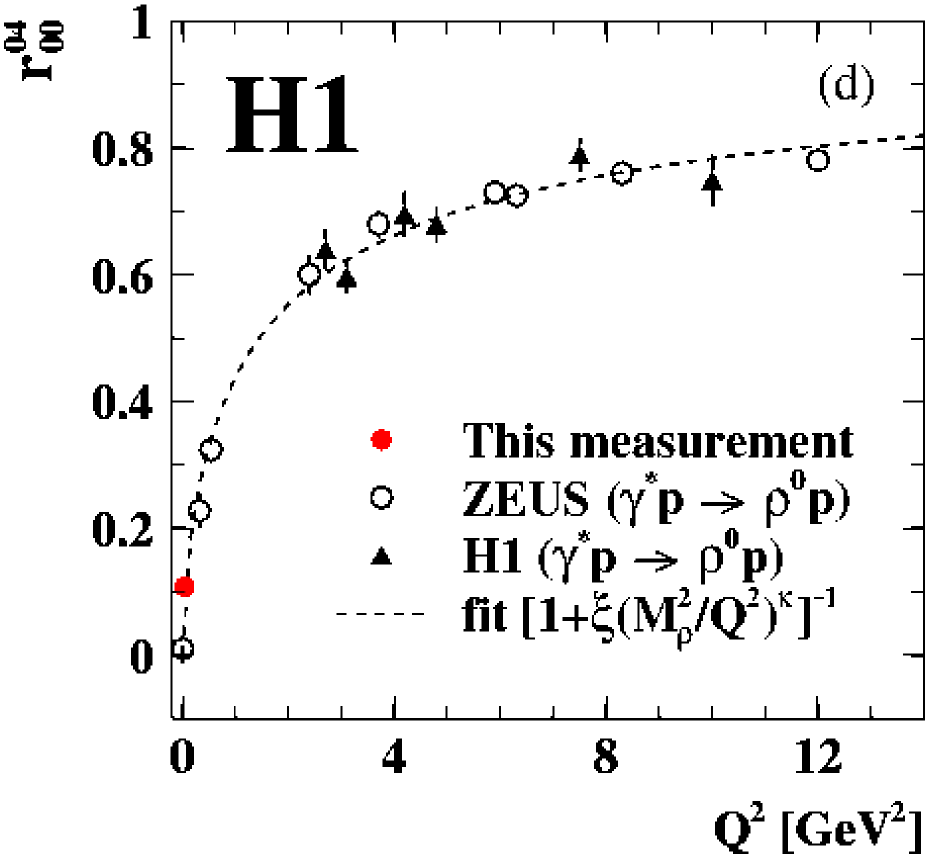
Skewing Parameter n_{RS}

Ross-Stodolsky, 1966



Helicity properties of ρ^0





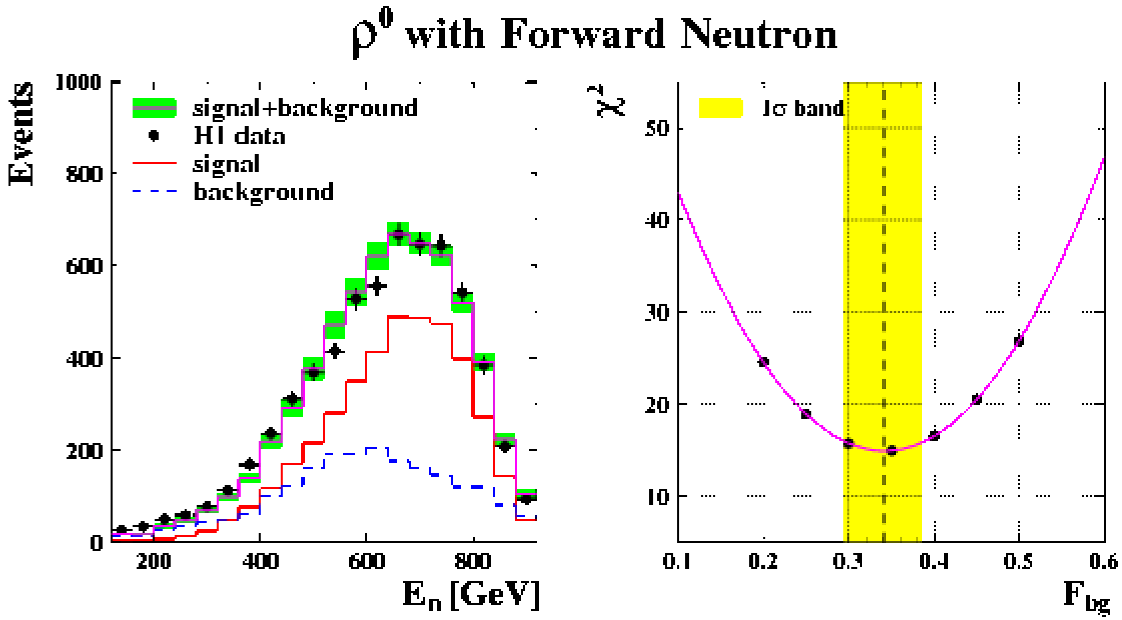
ϑ_h **is the polar angle in the ρ° helicity frame**

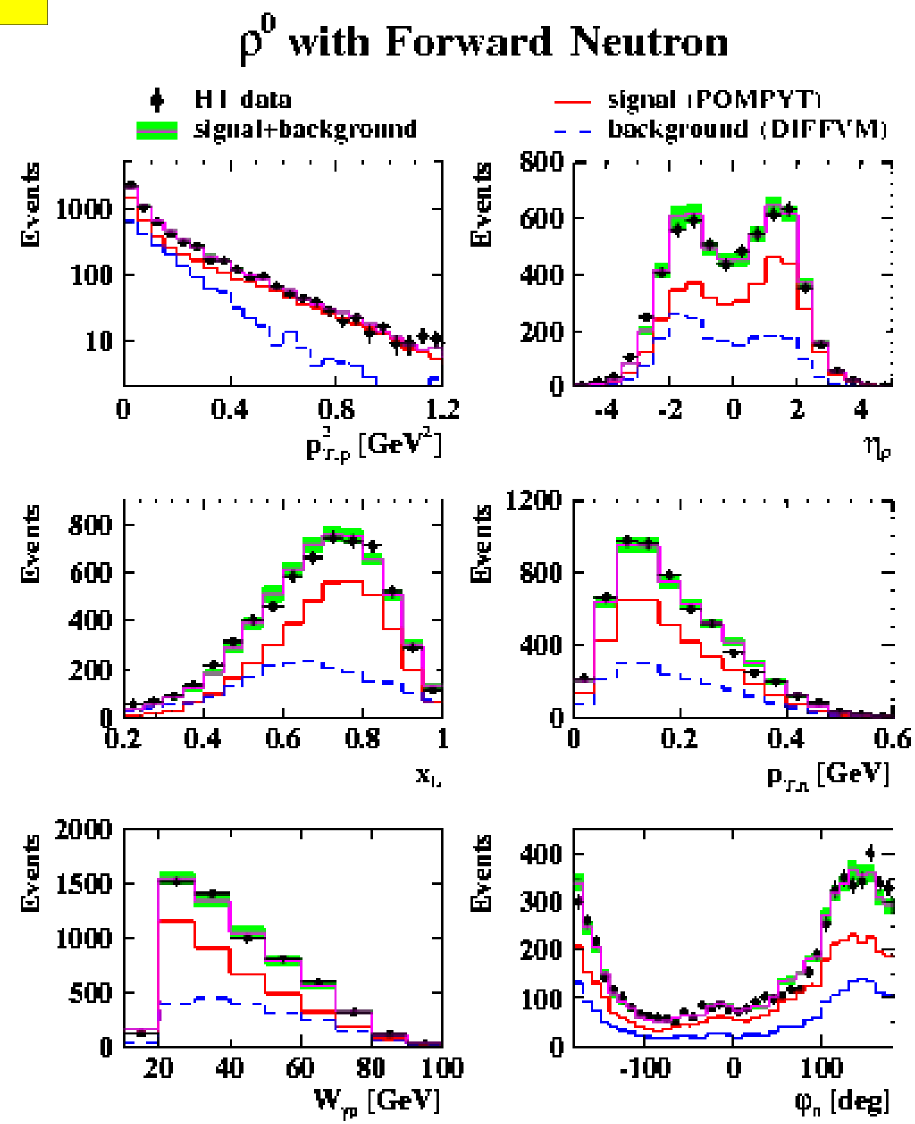
Access to the Spin-Density Matrix Element r^{04}_{00}

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

Selected $\pi^+\pi^-$ sample consistent with ρ° Photoproduction

Signal and Background Separation

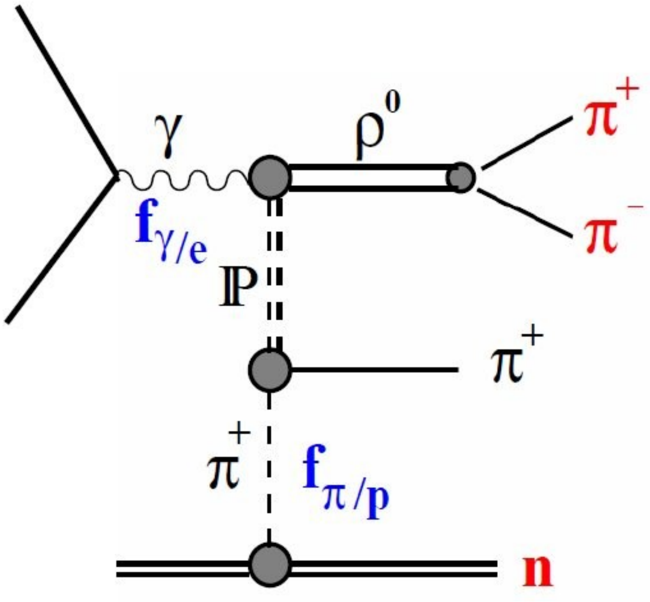




- Signal and background different shapes
- Separation on statistical basis possible
- Fraction fit to the data

  Background Fraction: 0.34 +- 0.05
- Control Plots (shape comparison)

Cross Section Definitions



Photon Flux: VDM (J.J. Sakurai)

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

Pion Flux: H. Holtmann et al.

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

$R_{\pi n}$: **Radius of πn Fock state**

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

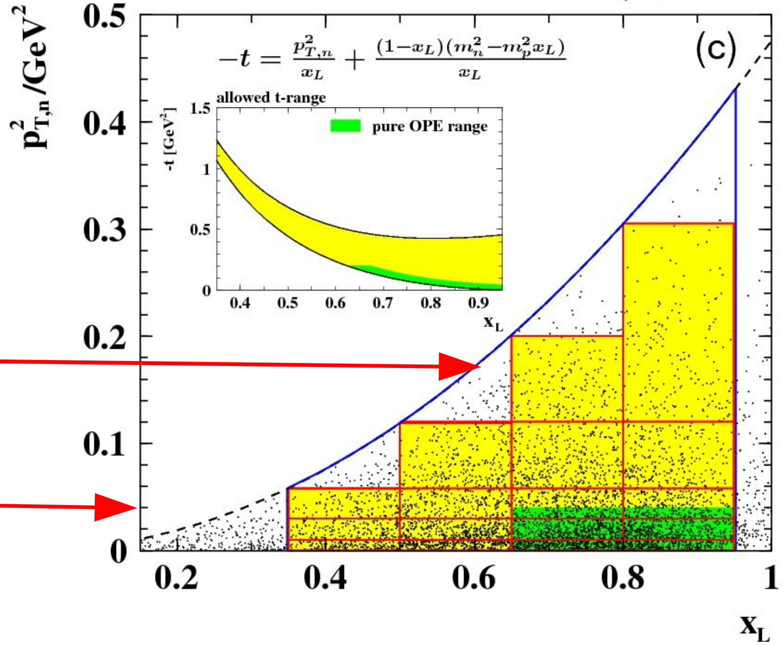
$$\sigma_{\gamma\pi}(\langle W_{\gamma\pi}\rangle) = \frac{\sigma_{\gamma \mathrm{p}}}{\int f_{\pi^+/p}(x_L,t)dx_L dt}$$

RESULTS

Cross section results

γp **Cross Section Phase Space:**

$$0.35 < x_L < 0.95$$
$$-t' < 1 \text{ GeV}^2$$
$$20 < W_{\gamma p} < 100 \text{ GeV}$$



$p_{T,n} < x_L \cdot 0.69$ GeV

OPE domination: $p_{T,n} < 0.2$ GeV

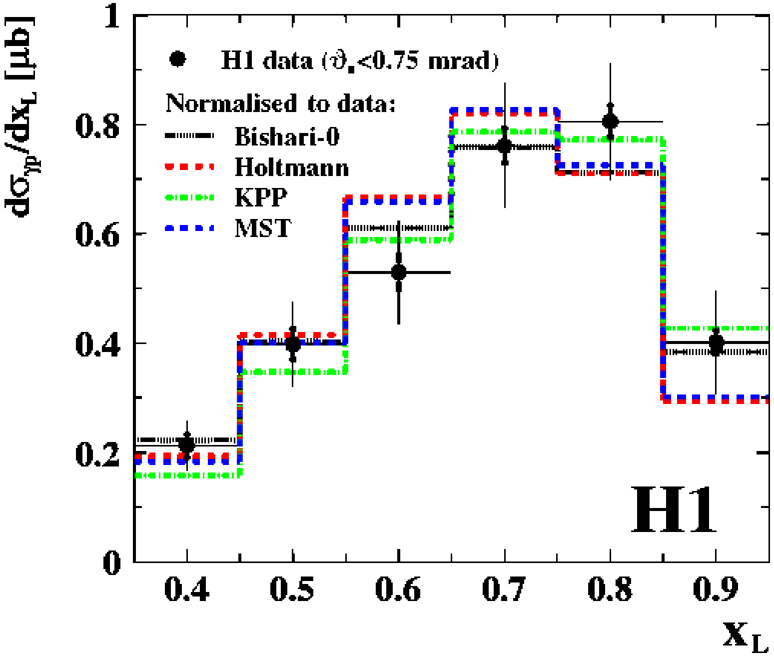
Two intervals of neutron transverse momentum:

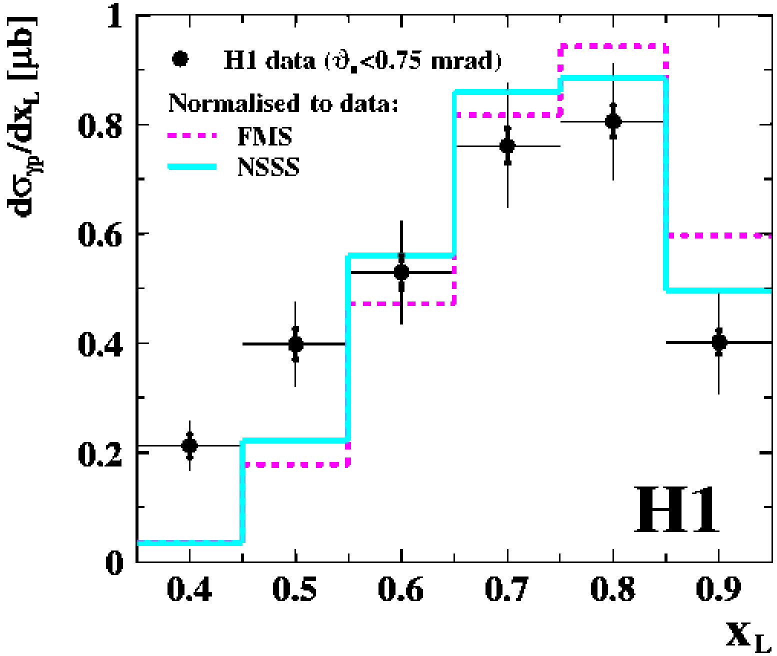
$$\sigma(\gamma p \to \rho^0 n \pi^+) = 310 \pm 6_{\text{stat}} \pm 45_{\text{sys}} \text{ nb} \qquad (\, p_{T,n} < x_L \cdot 0.69 \text{ GeV} \,)$$

$$\sigma(\gamma p \to \rho^0 n \pi^+) = 130 \pm 3_{\text{stat}} \pm 19_{\text{sys}} \text{ nb} \qquad (\, p_{T,n} < 0.2 \text{ GeV} \,)$$

$$\sigma(\gamma \pi^+ \to \rho^0 \pi^+) = 2.33 \pm 0.34(\text{exp})^{+0.47}_{-0.40}(\text{model})\ \mu\text{b} \qquad (\, p_{T,n} < 0.2 \text{ GeV} \,) \quad \langle W_{\gamma\pi} \rangle \simeq 24 \text{ GeV}$$

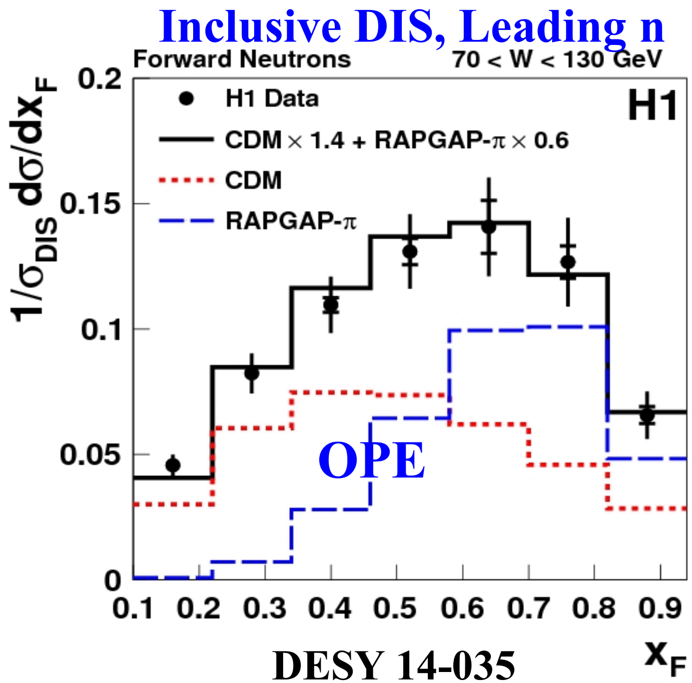
Pion Flux: Data and Models





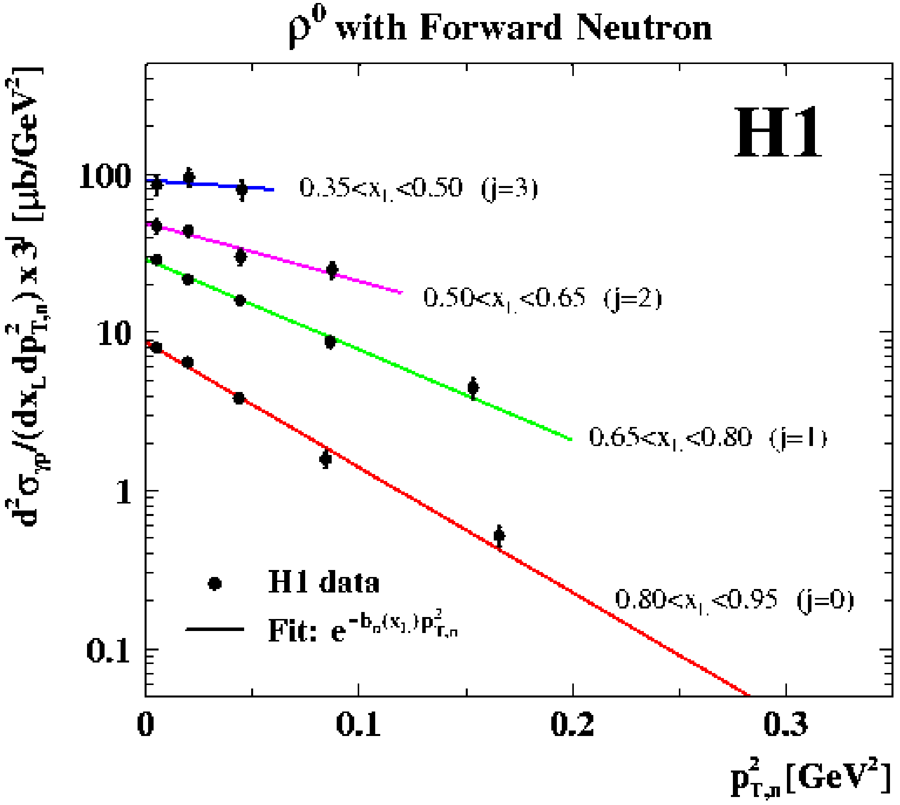
Four pion flux models describe data fairly well

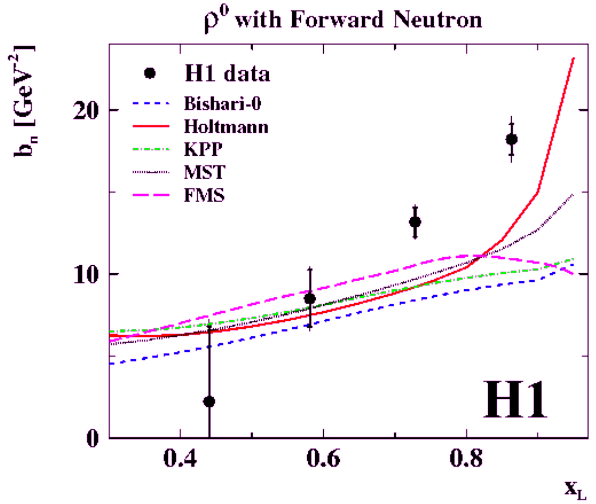
Two models (FMS, NSSS) can be discarded already in the shape comparison

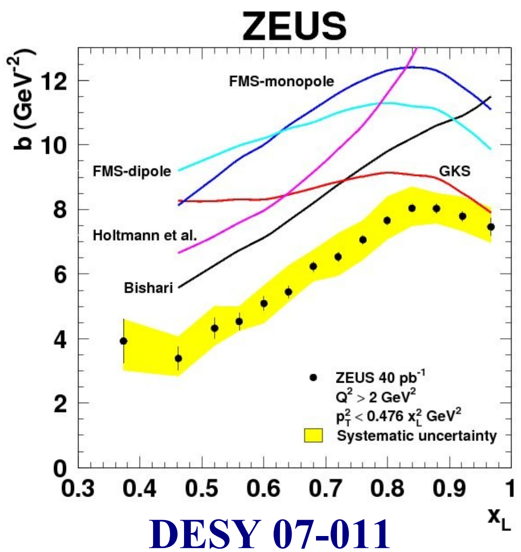


The One Pion Exchange part (RAPGAP-π) of Leading Neutron Production in Inclusive DIS has same shape as in Exclusive ρ Production
==> Supports neutron-proton Vertex Factorisation

Double Differential Cross Section at proton-neutron Vertex







DESY 07-011

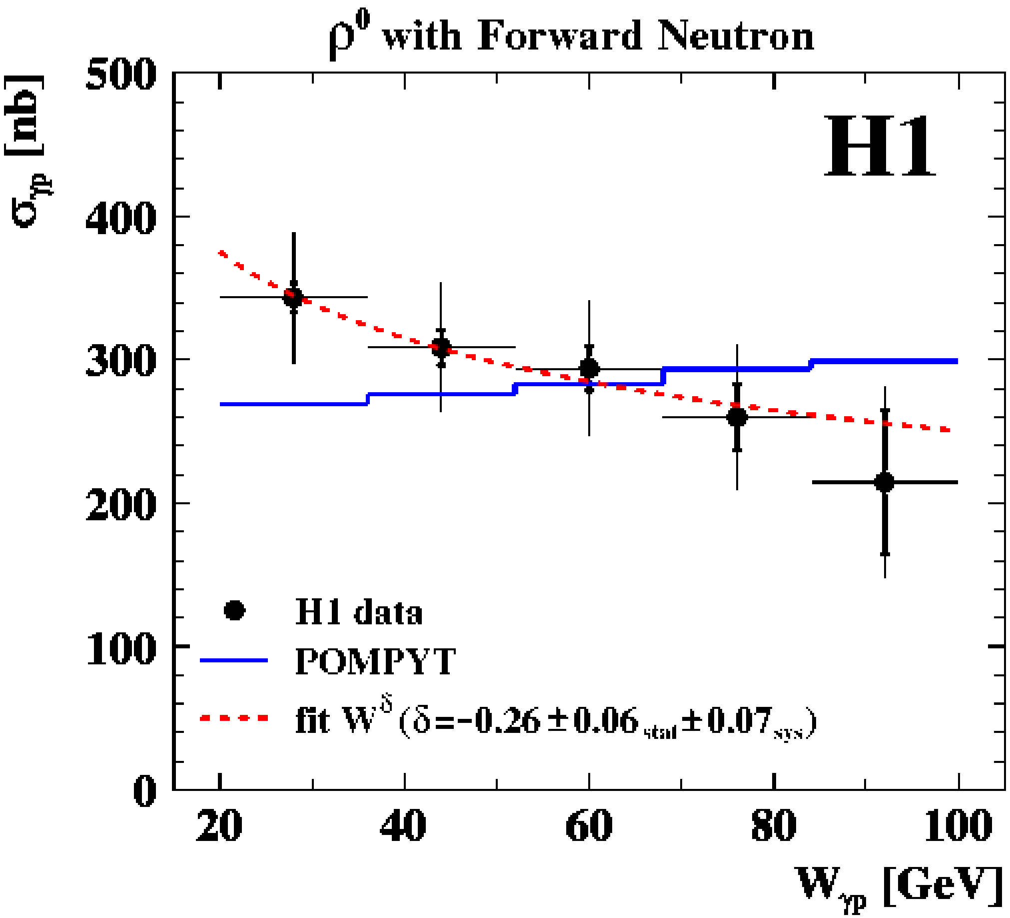
Exponential fit of $d\sigma / dp^2_{T,n}$ in 4 bins of x_L

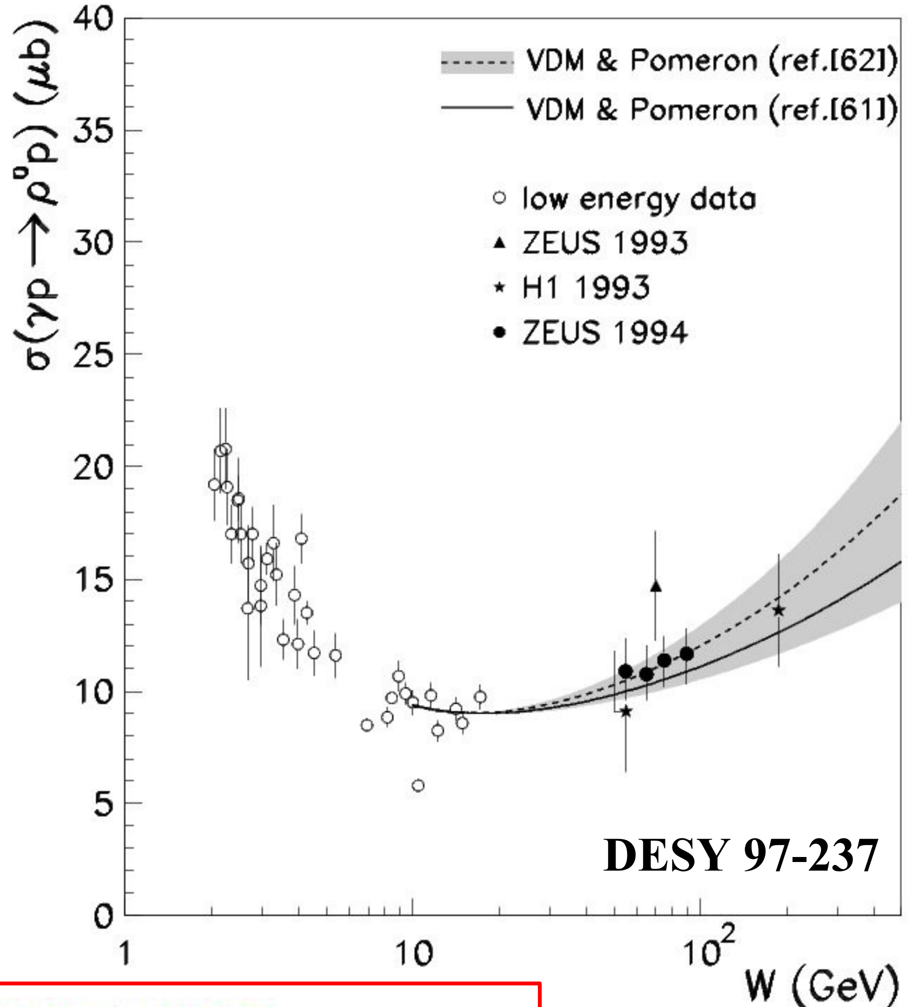
- **Steeply falling distributions at Large x_L**
- **No Flux Model reproduces the Slope Dependence on x_L**

  Possible explanation:

  Absorptive Corrections modify the t-dependence of amplitude ?
- **Compare: Leading neutron in inclusive DIS data (ZEUS)**

W-Dependence of γp Cross Section





Regge type fit of cross section: $\delta = -0.26 \pm 0.06 \pm 0.07$

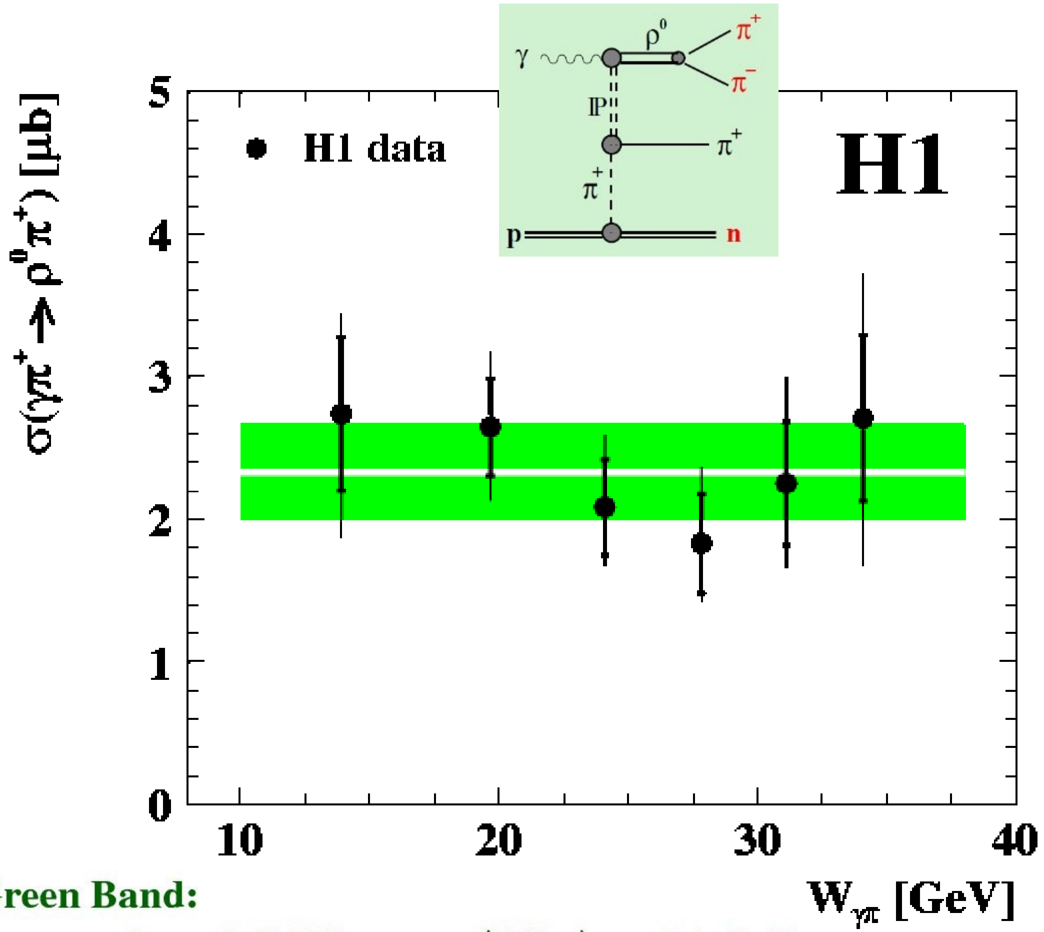
$\sigma(\gamma p \rightarrow \rho^0 npi^+)$ **falls with increasing** W

Compare to slow rise of $\sigma(\gamma p \rightarrow \rho^0 p)$ **Pomeron exchange,** $\delta \sim 0.08$

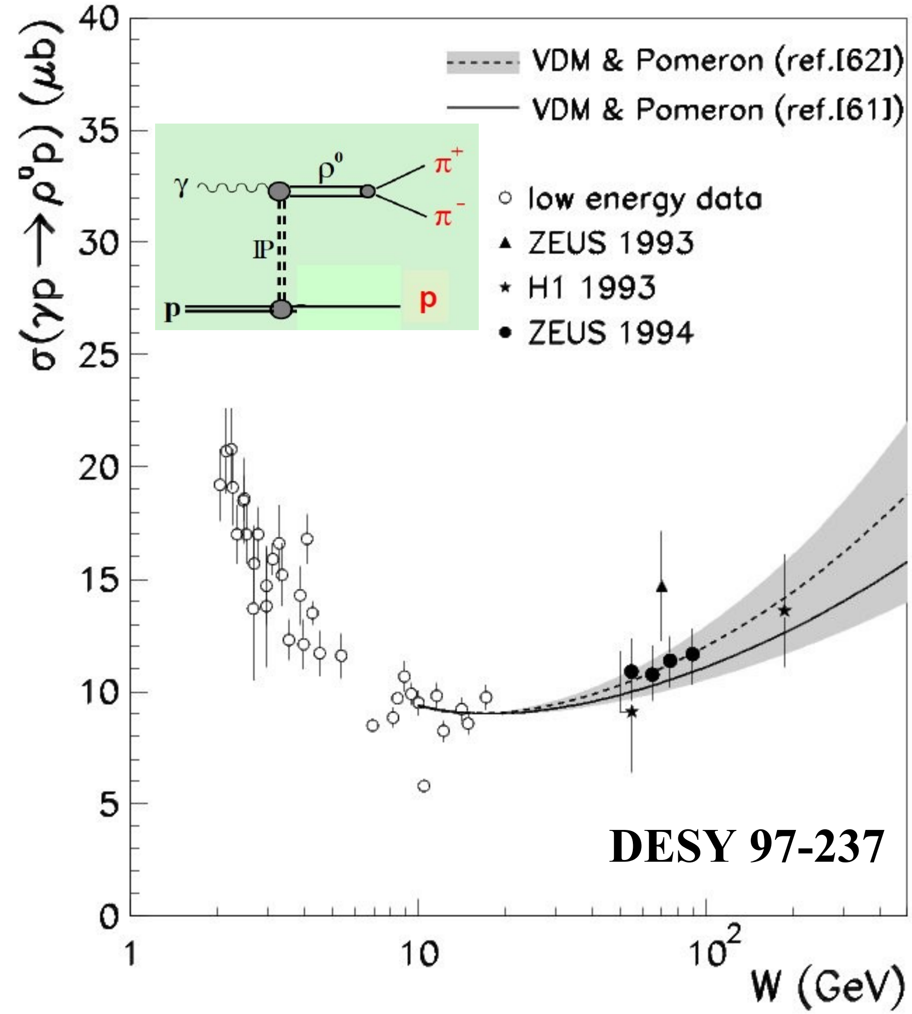
Note: POMPYT with Pomeron exchange only

What about $\sigma(\gamma\pi^+ \rightarrow \rho^0\pi^+)$ **?**

W Dependence of the $\gamma\pi^+$ Cross Section



Green Band:
Average from full W range, $\langle W_{\gamma\pi}\rangle = 24$ GeV



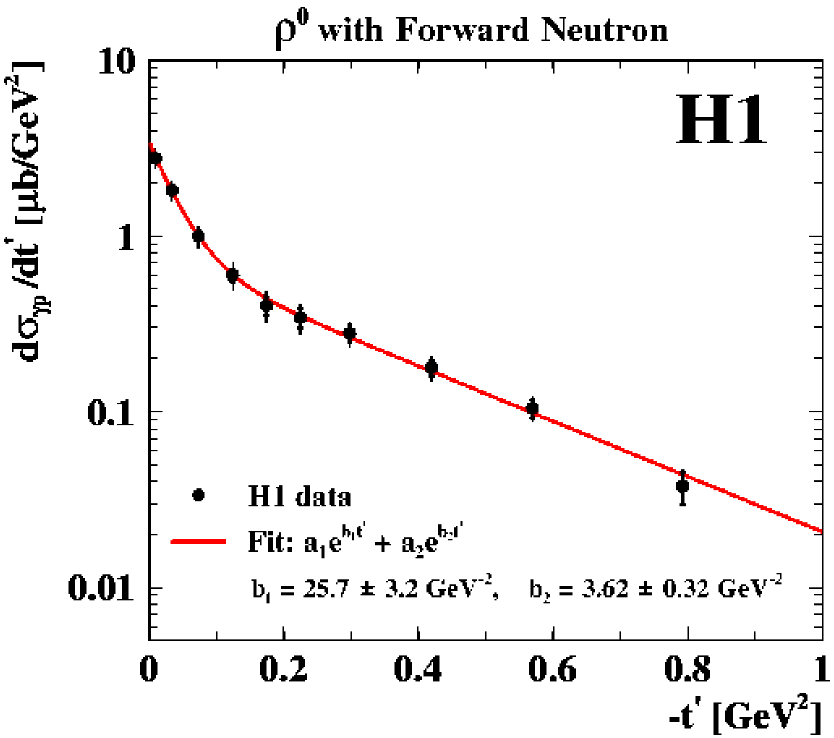
$r_{\rm el} = \sigma_{\rm el}^{\gamma\pi}/\sigma_{\rm el}^{\gamma p} = 0.25 \pm 0.06$ $\ll 2/3$ (AQM naive expectation)

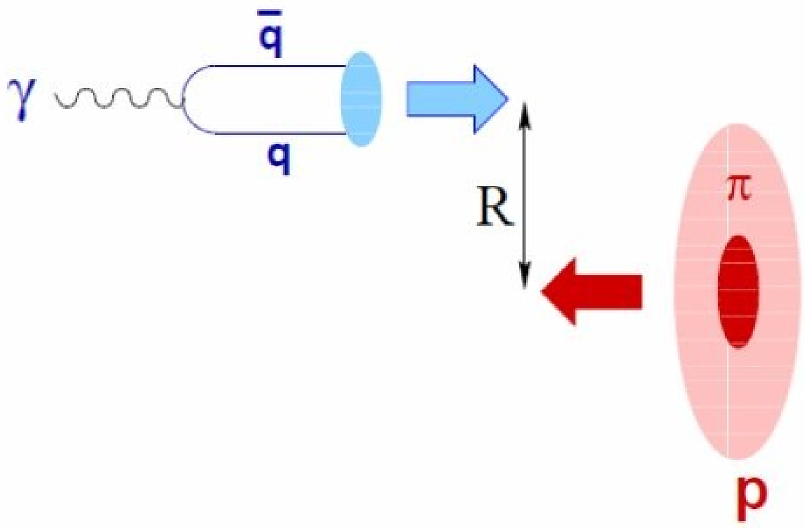
ZEUS obtained $r_{\rm tot} = \sigma_{\rm tot}^{\gamma\pi}/\sigma_{\rm tot}^{\gamma p} = 0.32 \pm 0.03$ at $\langle W\rangle = 107$ GeV (DESY 02-039)

Using Optical Theorem, Eikonal approach and Data, expect $r_{\rm el} = 0.57 \pm 0.03$

Large Absorption Factor for present result: $K_{\rm abs} = 0.44 \pm 0.11$

Cross Section Dependence on t'





Strong change in slope, diffractive peak at small t'

Two exponentials fit: $b_1 = (25.72 \pm 3.22_{unc} \pm 0.26_{cor})\ \mathrm{GeV}^{-2}$

$b_2 = (3.62 \pm 0.30_{unc} \pm 0.10_{cor})\ \mathrm{GeV}^{-2}$

Geometric picture: $\langle r^2 \rangle = 2b_1 \cdot (\hbar c)^2 \simeq 2\mathrm{fm}^2 \approx (1.6 R_\mathrm{p})^2 \quad (b_2 \to 0.6 R_\mathrm{p})$

Ultraperipheral Process: Photon finds pion in cloud, outside of classical p radius

DPP Interpretation: **Diagram interference, t'-slope depends on $M_{n\pi^+}$**

Pion Dissociation component with large mass ?

Cannot be tested, since scattered π^+ not measurable

SUMMARY-1

Exclusive ρ° Photoproduction with Leading Neutron measured for the first time

Elastic Photon-Pion Cross Section $\sigma(\gamma\pi^+ \rightarrow \rho^0\pi^+)$ measured in the OPE Approximation

Single and Double Differential Cross Sections, in variables x_L, $p^2_{T,n}$, t', $W_{\gamma p}$, $W_{\gamma\pi}$

SUMMARY-2

Data sensitive to Pion Flux:

x_L **distribution excludes some models**

x_L **dependence of neutron** p_T**-Slope:**

not reproduced by any Pion Flux Model

$d\sigma/dt'$ **shows typical behaviour of**

DPP, Double Peripheral Processes

Ratio $\sigma_{\rm el}^{\gamma\pi}/\sigma_{\rm el}^{\gamma p} \ll$ **Expectation**

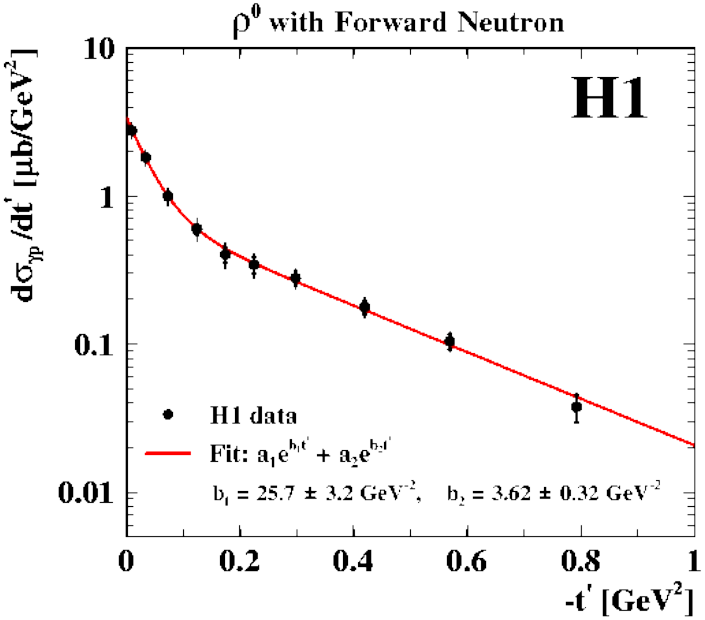
Suggests 60% Reduction

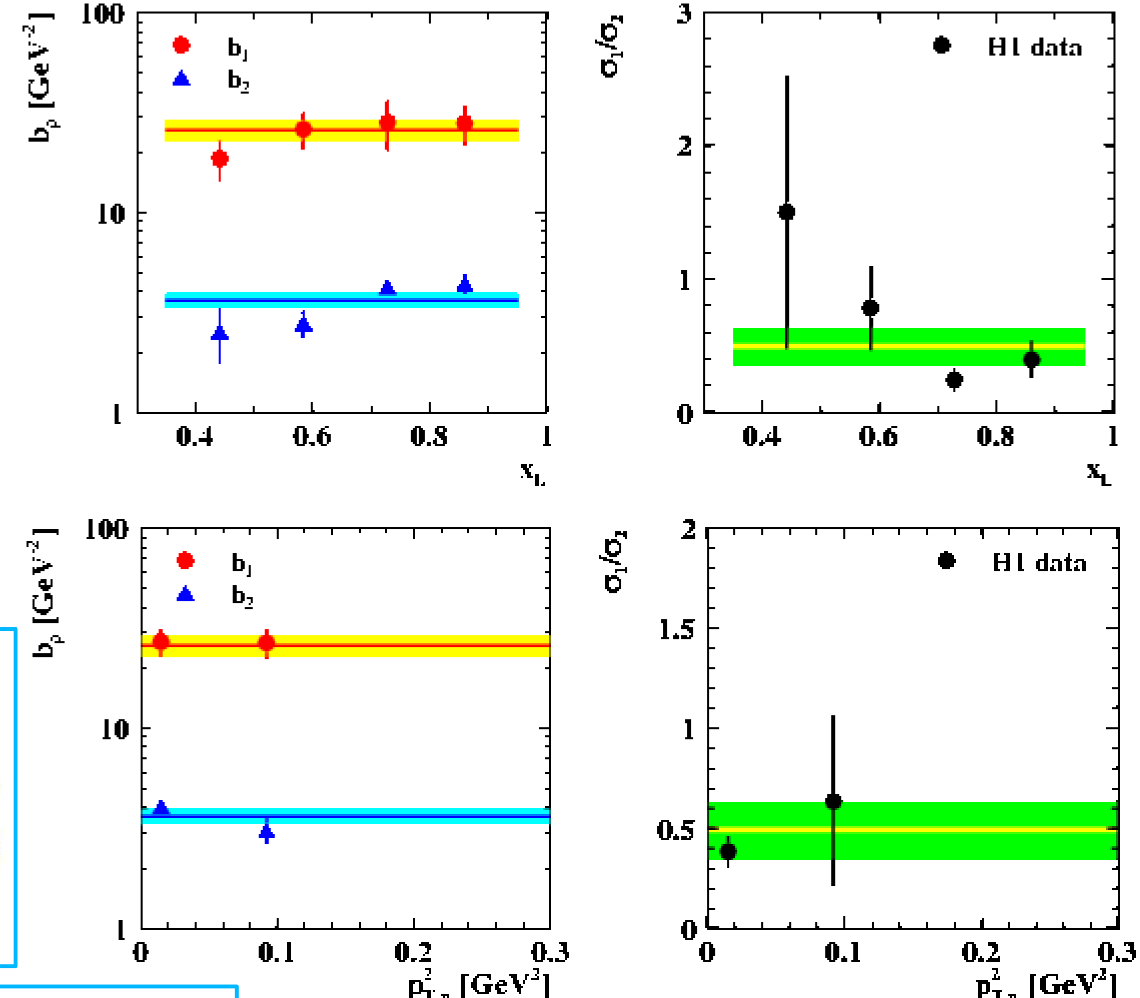
Large Absorptive Corrections?

The HERA data still provide new results,
10 years after End of Data Taking

Backup

Factorisation of the proton- and photon-vertices ?





Redo t'-Fit with 2 Exponentials:

in 4 Bins of x_L, in 2 Bins of $p^2_{T,n}$

Slopes b_1, b_2: Dependence on x_L or on $p^2_{T,n}$?

Horizontal bands:

Average from full range of x_L or $p^2_{T,n}$

Determine $\sigma(\gamma p \to \rho^\circ n \pi^+)$

in 2 Bins of t' $\Rightarrow$ σ_1/σ_2

in 4 Bins of x_L, in 2 Bins of $p^2_{T,n}$

σ_1/σ_2: Dependence on x_L or on $p^2_{T,n}$?

No Conclusions ...