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Diffractive photoproduction of ρ mesons with large momentum transfer at HERA
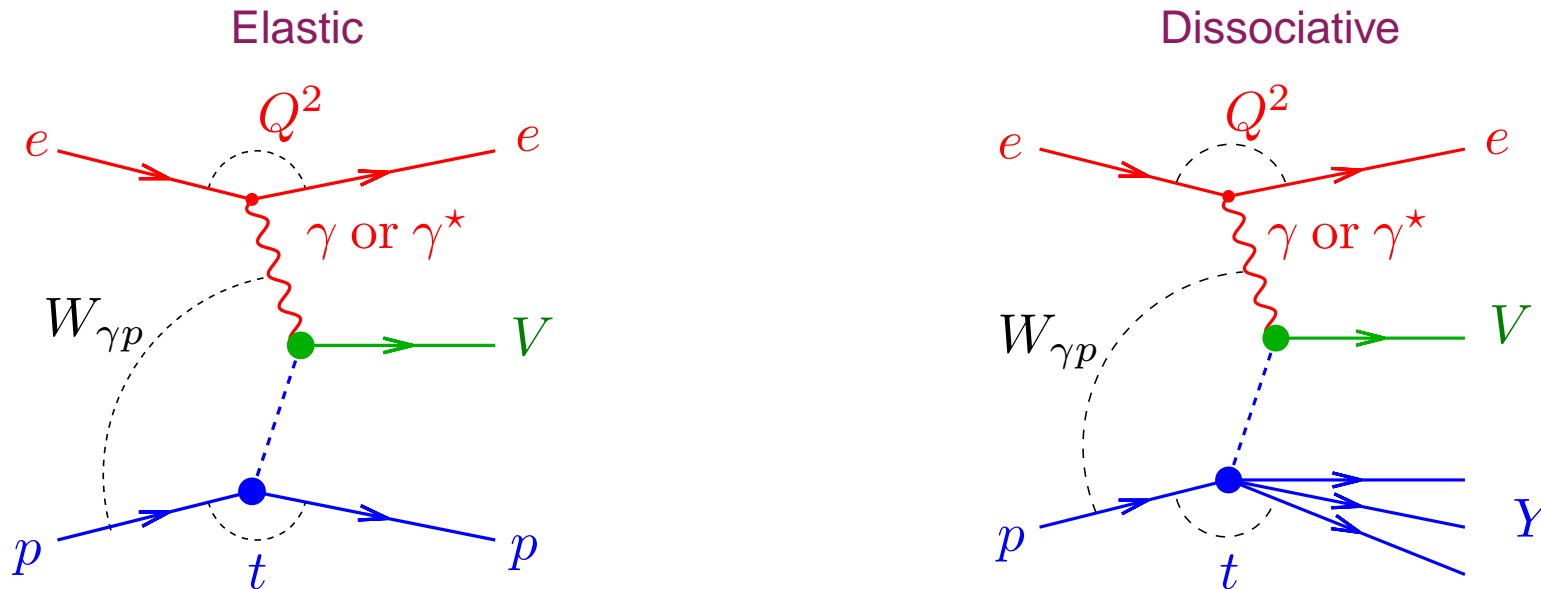
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H1

On behalf of the
H1 Collaboration

XIII International Workshop on Deep Inelastic Scattering

Madison, Wisconsin ● 27th April - 1st May 2005
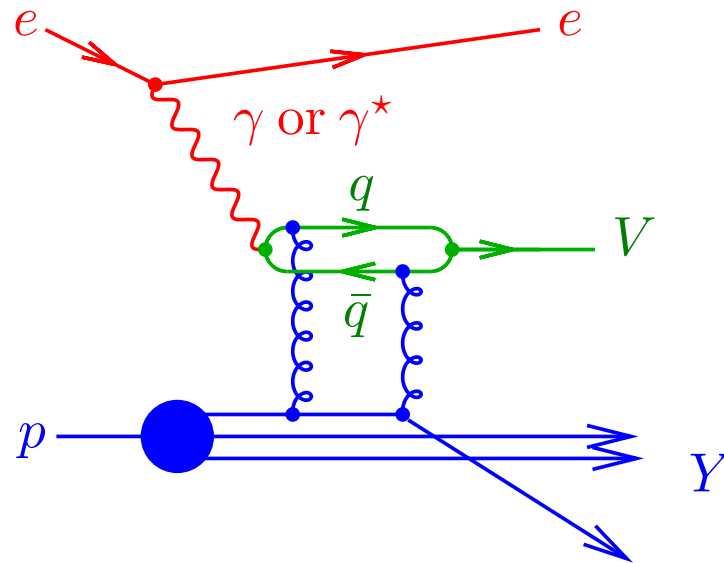
Diffractive Vector Meson Production at HERA

Elastic

Dissociative

Proton dissociation dominates at large $|t|$

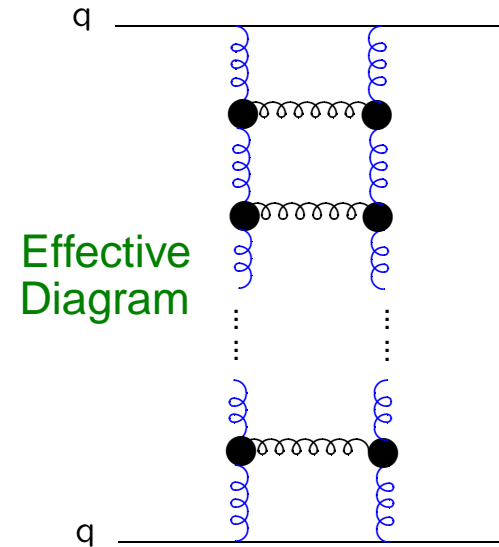|		
Q^2	Virtuality of the $\gamma^\star$	$\sim 0 < Q^2 < 100\,\mathrm{GeV}^2$
$W_{\gamma p}$	CM energy of the γp system	$20 < W_{\gamma p} < 290\,\mathrm{GeV}$
t	(4 momentum transfer at the p vertex)^2	$\sim 0 < |t| < 30\,\mathrm{GeV}^2$
V	Vector meson	$\rho^0, \omega, \phi, J/\psi, \psi(2s), \Upsilon(1s)$

$\Rightarrow$ Simultaneous probe of several different kinematical quantities

Perturbative QCD

Lowest Order Exchange

Higher Order Exchange

Effective Diagram

1. Photon fluctuates into $q\bar{q}$ pair

2. Lowest order exchange = 2 gluons

3. Meson wavefunction is needed to form V

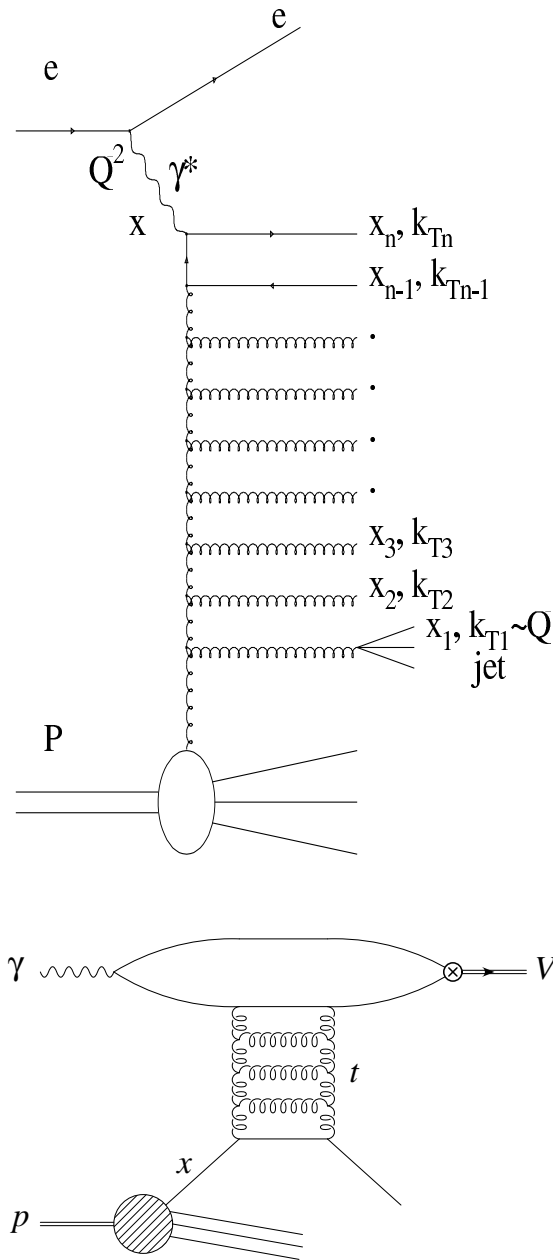Sums perturbative series in α_s

$\Rightarrow$ Effective gluon ladder ("QCD Pomeron")

Can be described by BFKL evolution at low x

Calculations require hard scale $\Rightarrow$ possibilities are: Q^2, $|t|$, M_V^2

BFKL Model

BFKL LL:

- Sums terms in $\alpha_s^n \log^n(1/x)$

- "Random walk" with **no** transverse momentum k_T ordering but **strong** longitudinal momentum ordering: $x_i \gg x_{i+1} \gg \ldots \gg x$

Poludinowski et al.[†]:

- Challenge is to simultaneously describe $|t|$ spectra and SDMEs

- LL BFKL with meson production **factorised** from the hard sub-process using a set of meson **light-cone** wavefunctions [twist-3]

- Free parameters:

  α_s^{IF}: coupling of the two gluons to each impact factor

  α_s^{BFKL}: the gluon couplings inside the gluon ladder

  $\Lambda^2 = m_v^2 - \gamma t$: undefined energy scale

- Naively expect light q mesons to be predominantly longitudinal. Use **constituent** q mass $m = m_V/2$ to introduce large **chiral odd** contribution & enhance production of **transverse** mesons

[†] [1] R. Enberg *et al.*, JHEP **0309** (2003) 008 [hep-ph/0306232]   [2] G. G. Poludniowski *et al.*, JHEP **0312** (2003) 002 [hep-ph/0311017]

Data Selection

$$\gamma + p \longrightarrow \rho^0 + Y \text{ with } \rho^0 \longrightarrow \pi^+ \pi^- (\sim 100\%)$$
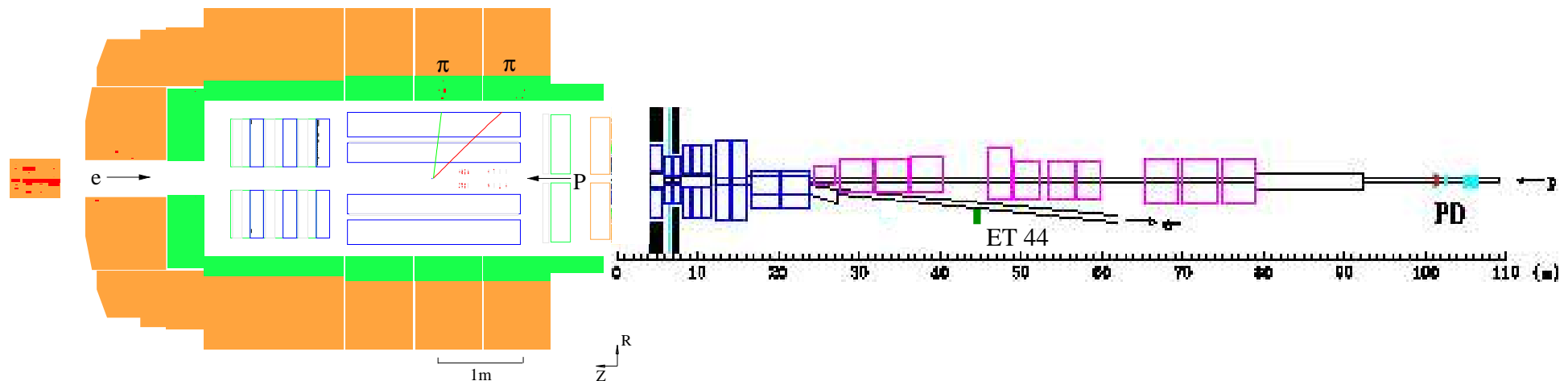
Selection:

- 2000 data period $\Rightarrow \mathcal{L} = 20.1 \text{ pb}^{-1}$

- Two charged tracks (pion candidates)

- No additional neutral clusters

- Electron detected in $44\,\mathrm{m}$ tagger
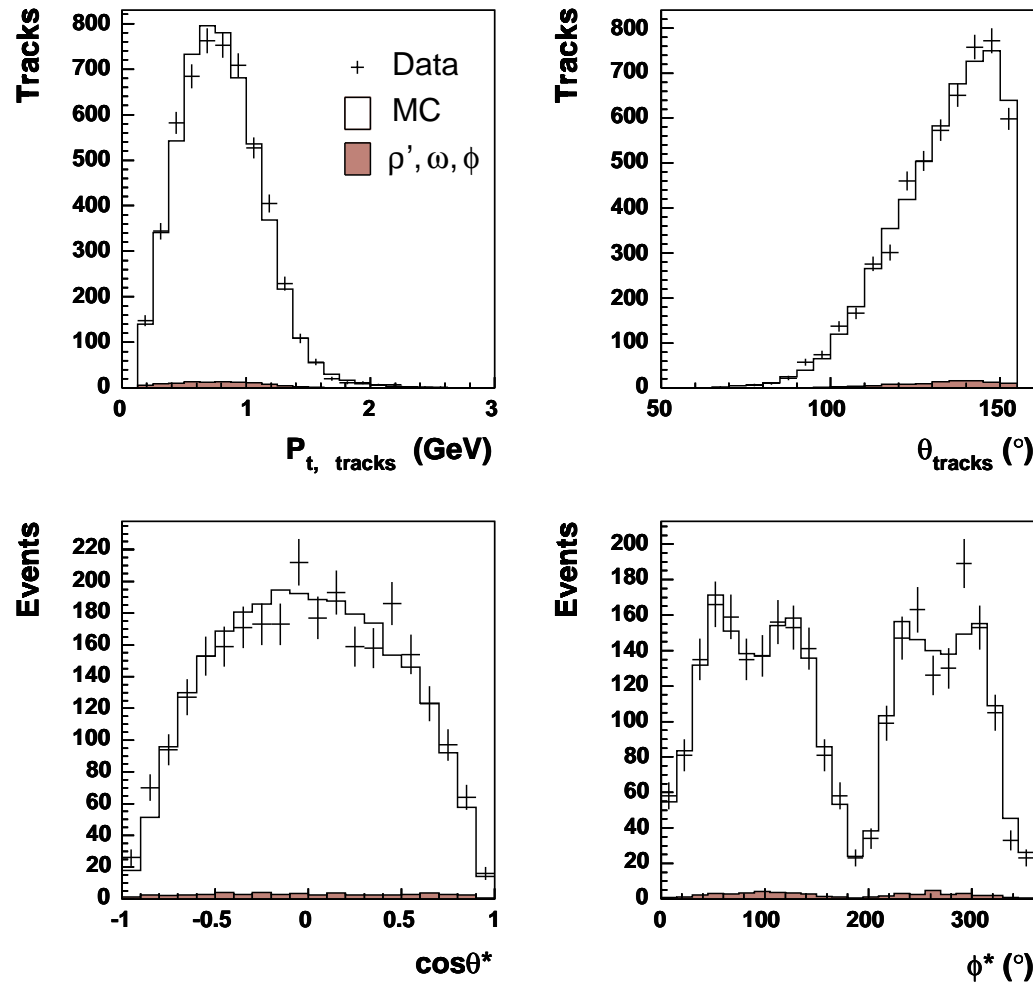
Kinematics:

- Photoproduction $Q^2 < 0.01 \text{ GeV}^2$

- Tagged electron $75 < W < 95 \text{ GeV}$

- $|t|$ range $1.5 < |t| < 10.0 \text{ GeV}^2$

- Proton remnant mass $M_Y < 5 \text{ GeV}$

Number of selected events ≈ 3000

Monte Carlo Simulation
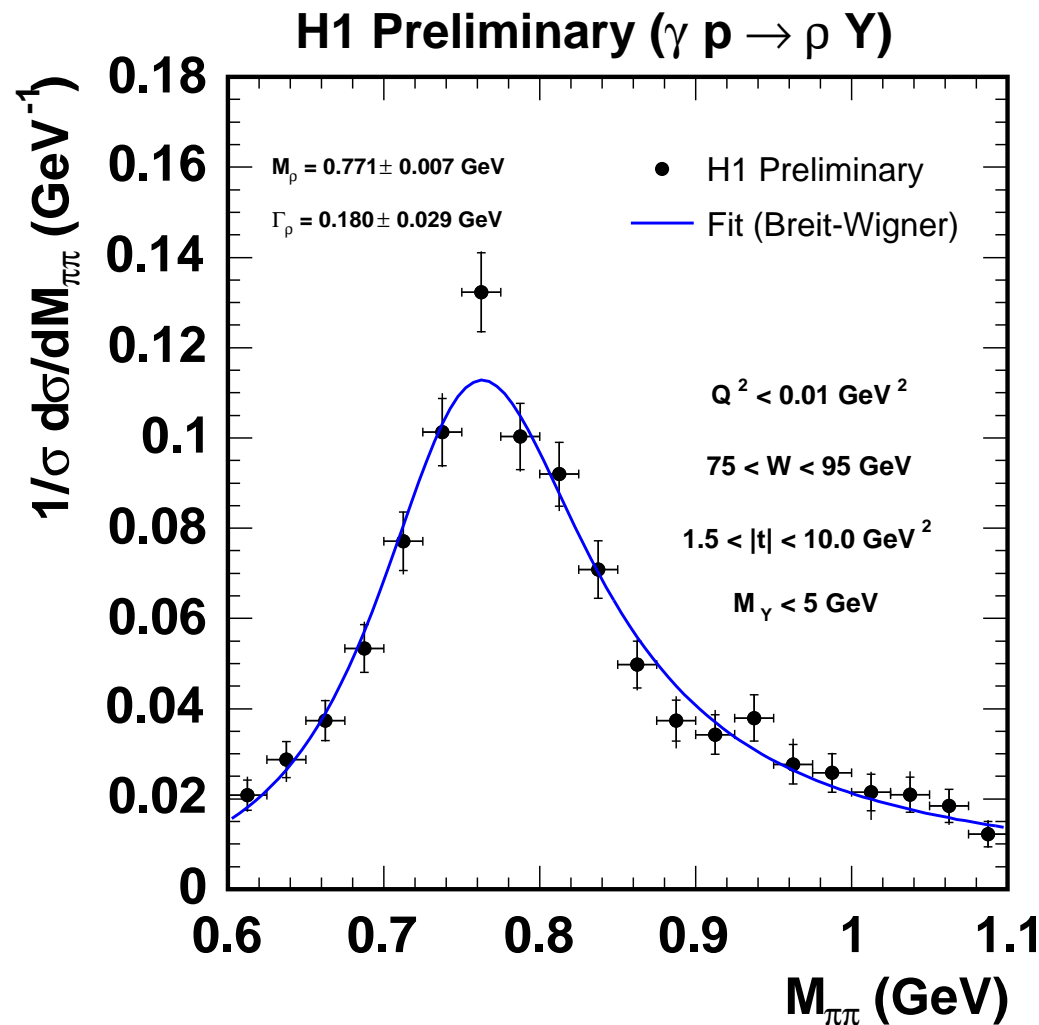
H1 Preliminary (γ p $\rightarrow$ ρ Y)

DiffVM Monte Carlo:

● Diffractive Vector Meson production

● Simulates soft diffraction in ep collisions

● Based on Vector Dominance Model

● Detailed description of p dissociation

● Tuned to describe data $|t|$ dependence

● Re-weighted to take into account

   s-channel helicity non-conservation

Data and Monte Carlo are in good agreement

Invariant Mass Distribution

Clear evidence for a ρ meson mass peak

H1 Preliminary (γ p $\rightarrow$ ρ Y)

$M_\rho = 0.771 \pm 0.007$ GeV

$\Gamma_\rho = 0.180 \pm 0.029$ GeV

● H1 Preliminary

— Fit (Breit-Wigner)

$Q^2 < 0.01$ GeV^2

$75 < W < 95$ GeV

$1.5 < |t| < 10.0$ GeV^2

$M_Y < 5$ GeV

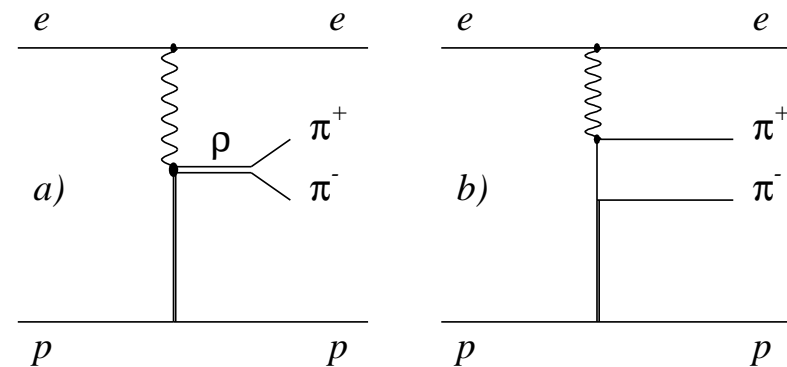(y-axis: $1/\sigma \; d\sigma/dM_{\pi\pi}$ (GeV^{-1}), x-axis: $M_{\pi\pi}$ (GeV))

● Fitted with a relativistic Breit-Wigner

$$BW_\rho(M_{\pi\pi}) = \frac{M_{\pi\pi} m_\rho \Gamma(M_{\pi\pi})}{(m_\rho^2 - M_{\pi\pi}^2)^2 + m_\rho^2 \Gamma^2(M_{\pi\pi})}$$

$$\Gamma(M_{\pi\pi}) = \Gamma_\rho \left(\frac{q^*}{q_0^*} \right)^3 \frac{m_\rho}{M_{\pi\pi}}$$
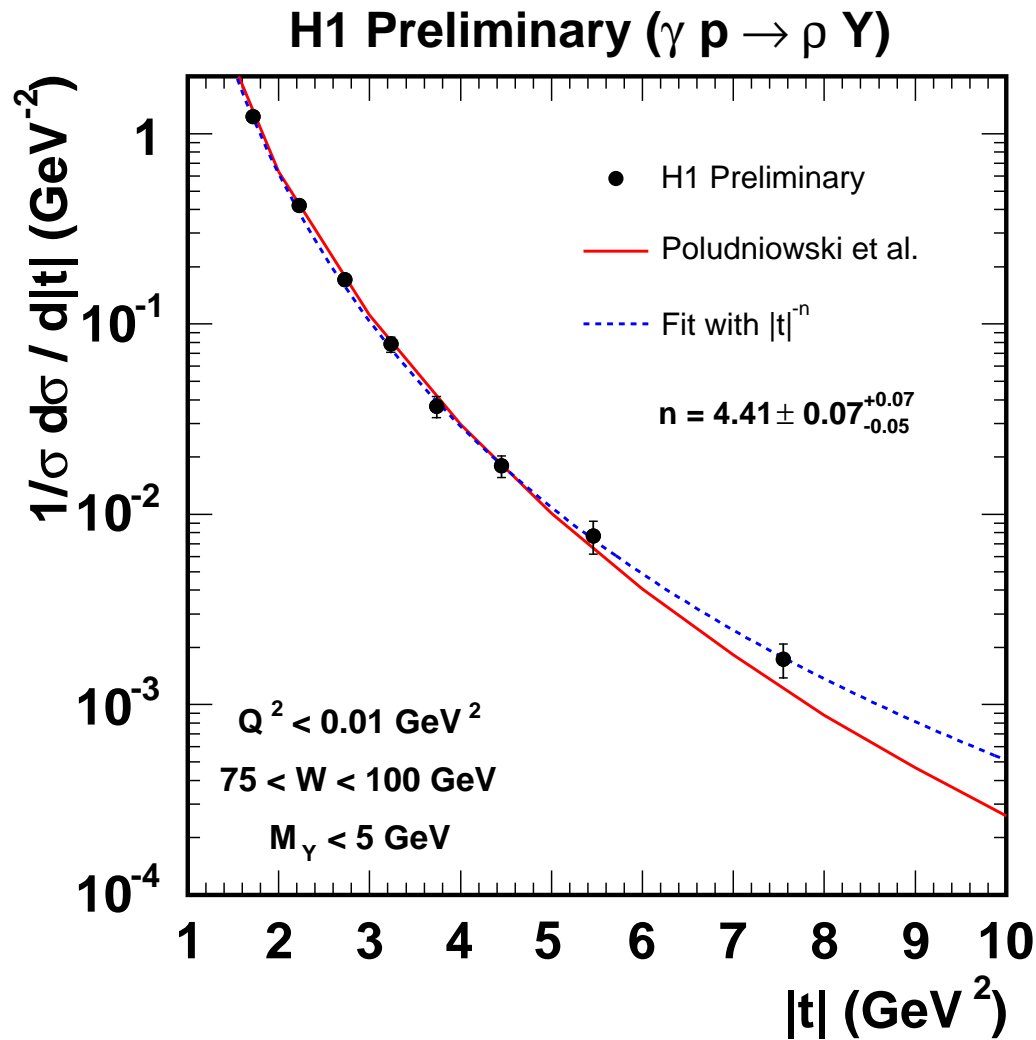
● At lower $|t|$ skewing effects have been observed $\Rightarrow$ E.g. Ross-Stodolsky:

$$\frac{dN}{dM_{\pi\pi}} = f_\rho BW_\rho \left(\frac{m_\rho}{M_{\pi\pi}} \right)^n$$

$a)$ e ... e, ρ, π^+, π^-, p ... p

$b)$ e ... e, π^+, π^-, p ... p

● Here skewing is consistent with zero

Dependence on $|t|$

H1 Preliminary ($\gamma\, p \to \rho\, Y$)

- H1 Preliminary
- Poludniowski et al.
- Fit with $|t|^{-n}$

$$n = 4.41 \pm 0.07^{+0.07}_{-0.05}$$

$Q^2 < 0.01$ GeV^2

$75 < W < 100$ GeV

$M_Y < 5$ GeV

$\dfrac{1}{\sigma}\, d\sigma\, /\, d|t|$ (GeV^{-2})

$|t|$ (GeV^2)

$$n_{ZEUS} = 3.21 \pm 0.04\,(\text{stat.}) \pm 0.15(\text{syst.})$$

Fit:

- Power-like behaviour is expected at large $|t| \Rightarrow$ Data fitted with $|t|^{-n}$

$$n = 4.41 \pm 0.06\,(\text{stat.})^{+0.07}_{-0.05}(\text{syst.})$$

BFKL Model:

- BFKL model well describes data using
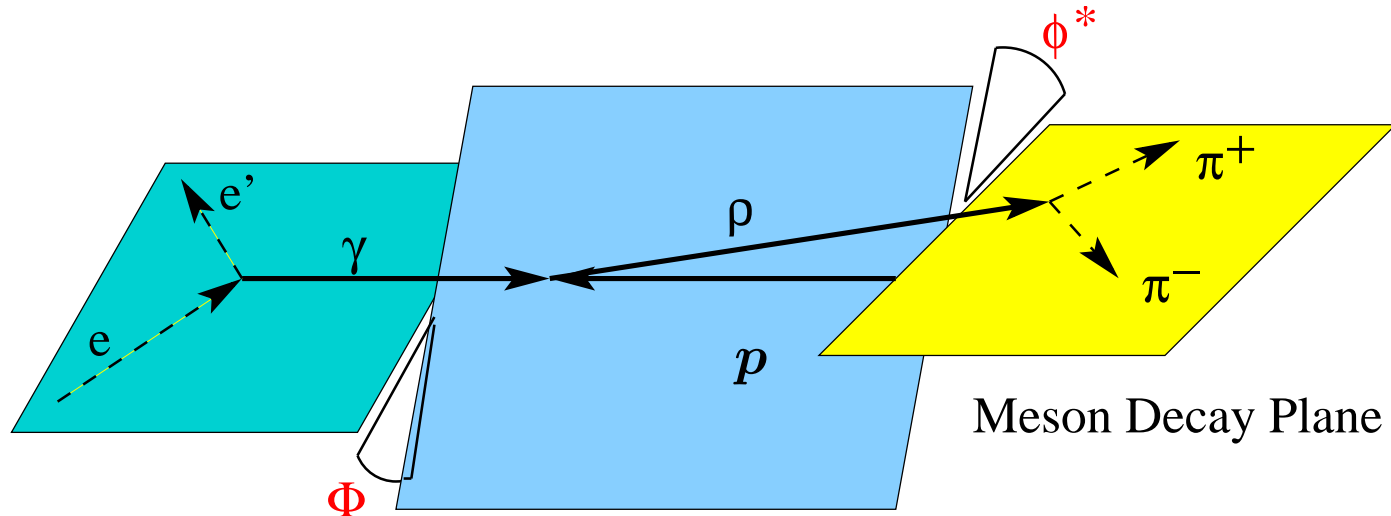
$$\alpha_s^{IF} = 0.17$$
$$\alpha_s^{BFKL} = 0.25$$
$$\gamma = 1$$

at $\langle W \rangle = 87.3$ GeV and $Q^2 = 0$ GeV^2

- t slope quite sensitive to the M_Y cut. Here evaluated for $M_Y < 5$ GeV $\Rightarrow$ theory predicts steeper dependence than for ZEUS, where $M_Y < 25$ GeV

Helicity Angles: Testing the Meson Wavefunction

Perform a boost into the γp CM frame $\Rightarrow$ here we can define three angles: $\theta^\star$, $\phi^\star$ & Φ
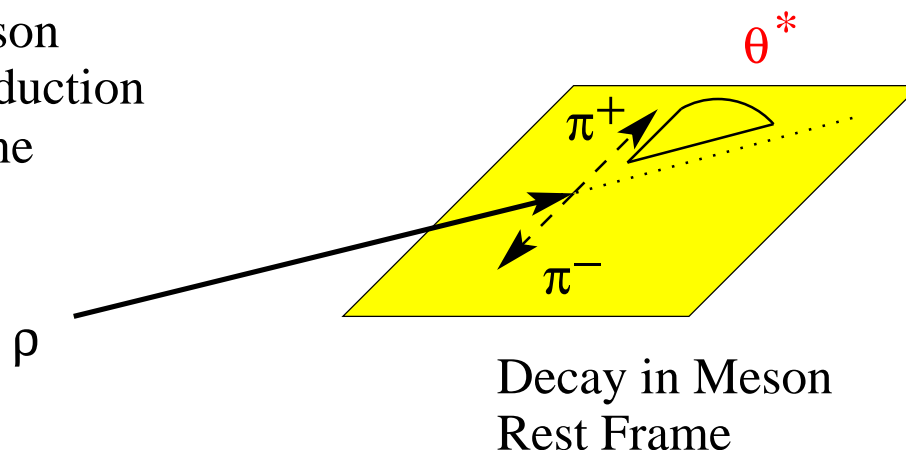
ϕ^*

π^+

ρ

π^-

e'

γ

e

p

Meson Decay Plane

Φ

Lepton Scattering Plane

Meson Production Plane

θ^*

π^+

π^-

Helicity = component of spin along direction of the particle's motion

ρ

Decay in Meson Rest Frame

Can measure angular decay distributions $\Rightarrow$ Provides access to 15 spin density matrix elements

Poludinowski *et al.* model predicts: No Flip (M_{++}) > Double Flip (M_{+-}) > Single Flip (M_{+0})

Previous Measurements of SDMEs

Photoproduction:

- Can only measure 2 angular dists: $\theta^\star$ & $\phi^\star$

  $\Rightarrow$ Allows measurements of 3 of the 15

  spin density matrix elements (SDMEs)

- s channel helicity conservation (SCHC)
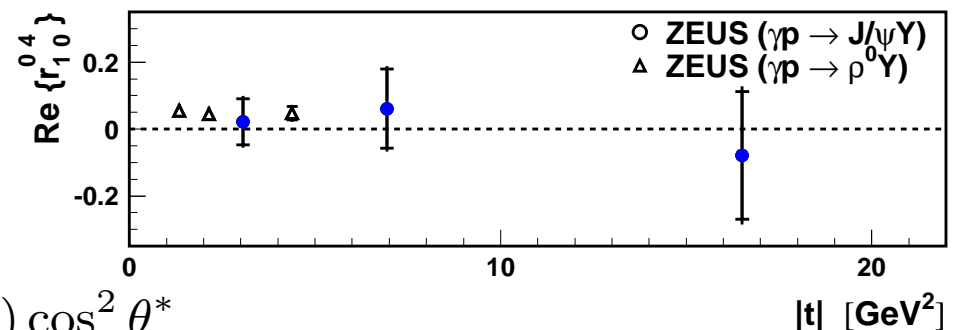
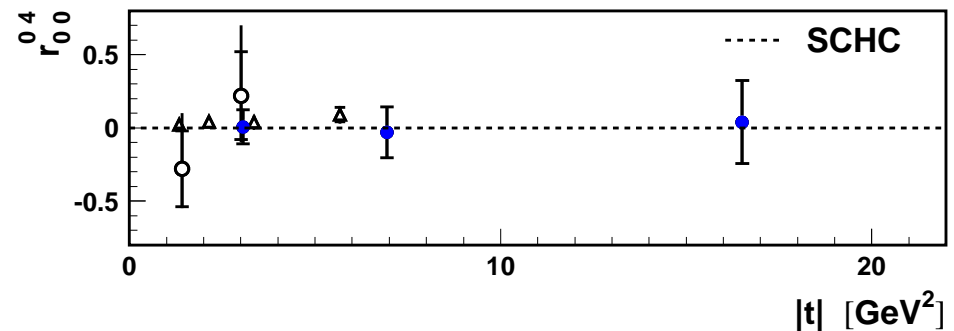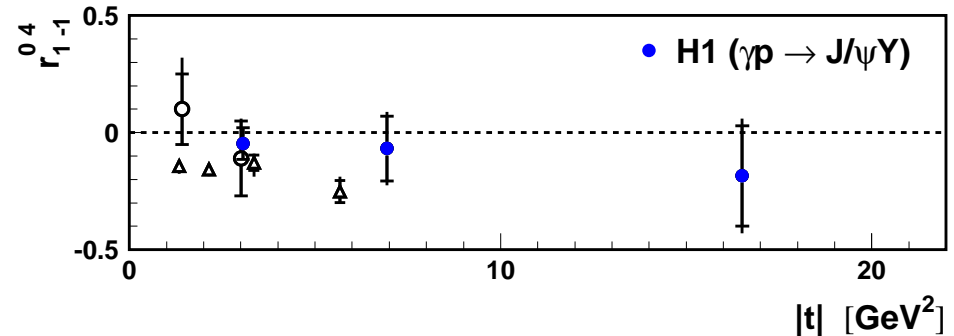 $\Rightarrow$ Vector meson retains helicity of photon

  $\Rightarrow$ All 3 SDMEs are predicted to be zero

- Heavy J/ψ data is consistent with SCHC

- In contrast, lighter ρ meson violates SCHC
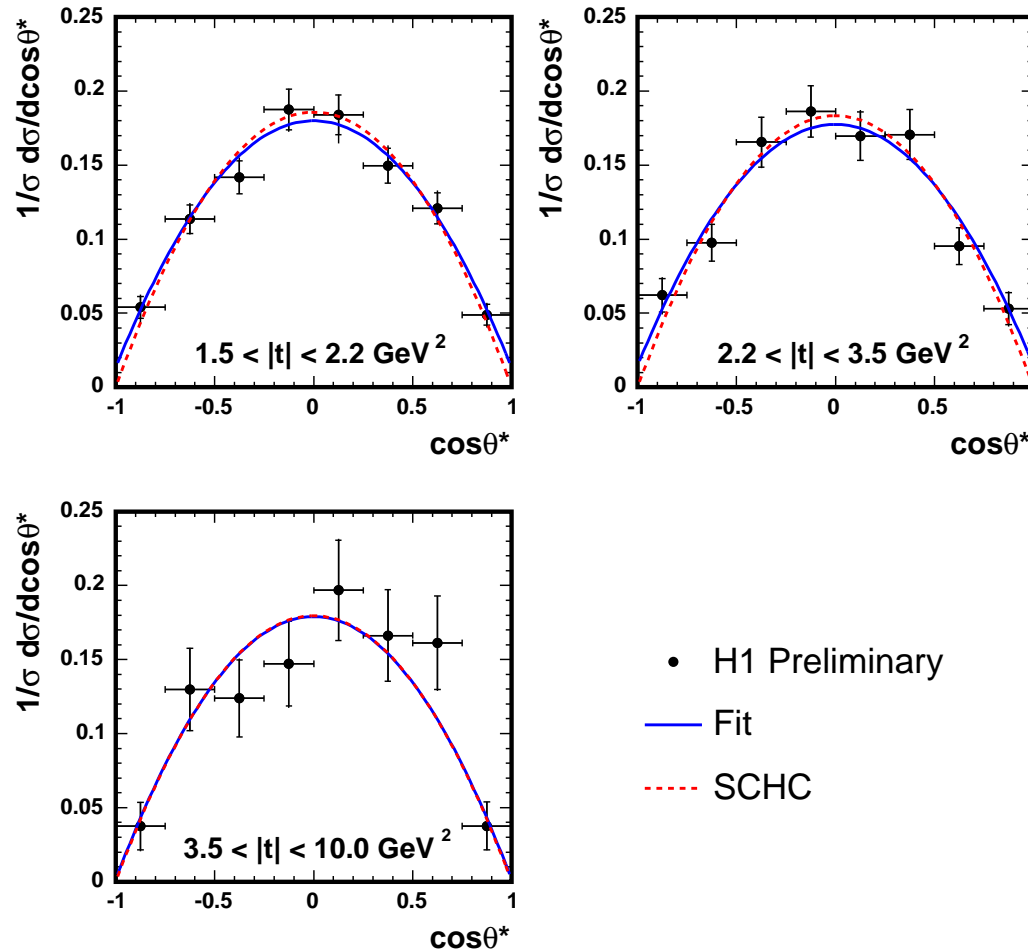
- 2 dimensional fit needed to extract 3 SDMEs:

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta^* d\phi^*} = \frac{3}{4\pi}\left[\frac{1}{2}(1 \mp r_{00}^{04}) \pm \frac{1}{2}(3r_{00}^{04} - 1)\cos^2\theta^*\right.$$
$$\left.\mp\sqrt{2}\mathrm{Re}[r_{00}^{10}]\sin 2\theta^*\cos\phi^* \mp r_{1-1}^{04}\sin^2\theta^*\cos 2\phi^*\right]$$

(plots on right, labeled:)
- r_{1-1}^{04} vs $|t|$ [GeV^2], legend: • H1 ($\gamma p \rightarrow J/\psi Y$)
- r_{00}^{04} vs $|t|$ [GeV^2], legend: ----- SCHC
- Re$\{r_{10}^{04}\}$ vs $|t|$ [GeV^2], legend: ○ ZEUS ($\gamma p \rightarrow J/\psi Y$), △ ZEUS ($\gamma p \rightarrow \rho^0 Y$)

Dependence on $\cos \theta*$

H1 Preliminary ($\gamma\ \mathbf{p} \to \rho\ \mathbf{Y}$)

1 Dimensional Fit:

● Data well described by both full fit

$$\frac{d\sigma}{d\cos\theta*} \propto 1 - r_{00}^{04} + \left(3r_{00}^{04} - 1\right)\cos^2\theta*$$

and the prediction from SCHC

r_{00}^{04}:
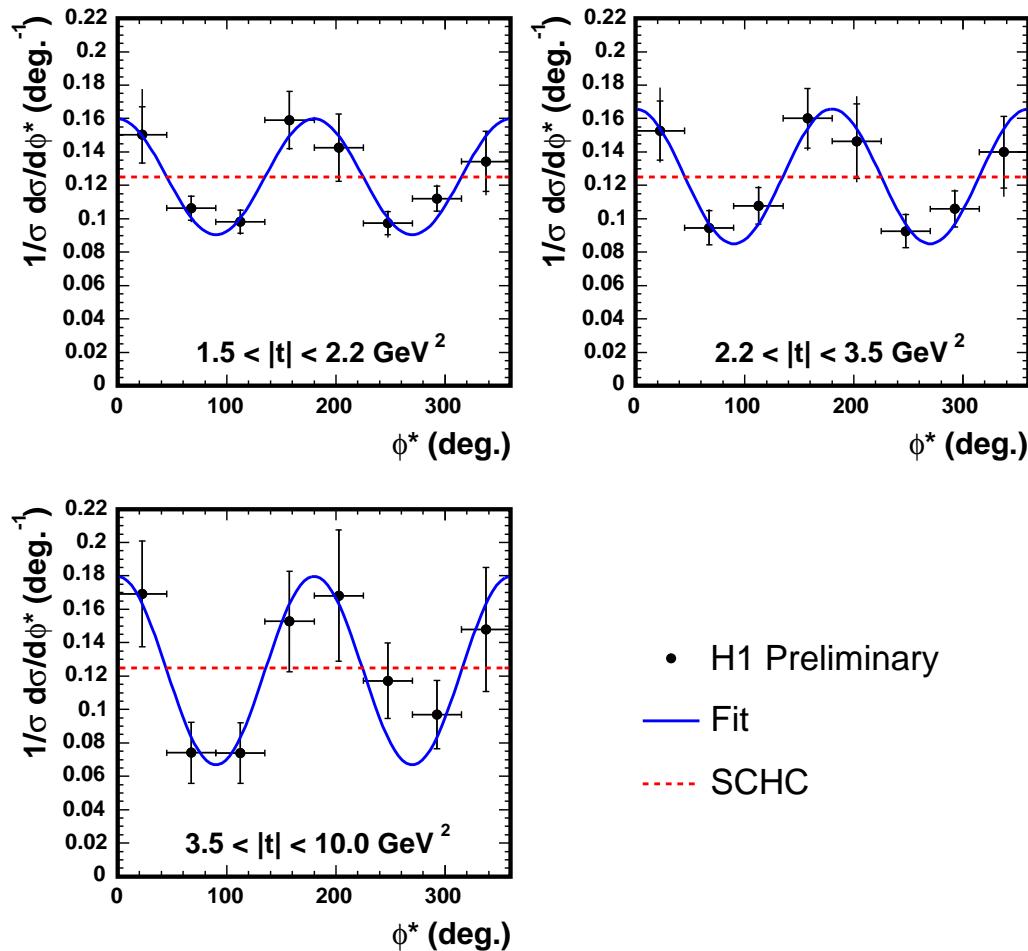
● Production of longitudinally polarised ρ (0) from transversely polarised γ (+)

$$r_{00}^{04} = \frac{\langle|M_{+0}|^2\rangle}{\langle|M_{++}|^2 + |M_{+0}|^2 + |M_{+-}|^2\rangle}$$

● $r_{00}^{04} \neq 0 \Rightarrow$ Helicity "Single Flip"

Dependence on ϕ^*

H1 Preliminary (γ p $\rightarrow$ ρ Y)

1 Dimensional Fit:

- Data well described by the full fit

$$\frac{d\sigma}{d\phi^*} \propto 1 - 2r^{04}_{1-1} \cos 2\phi^*$$

  but differ significantly from SCHC

r^{04}_{1-1}:
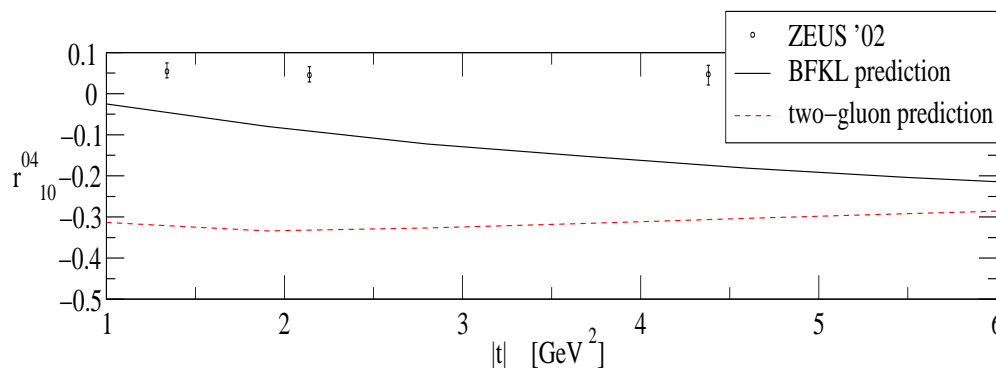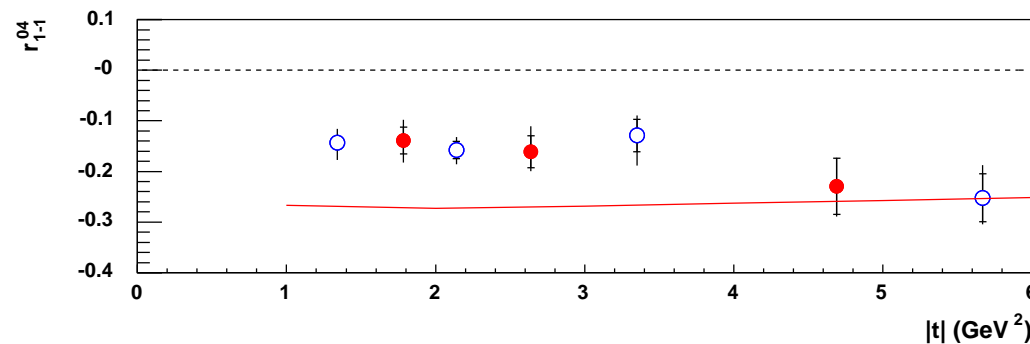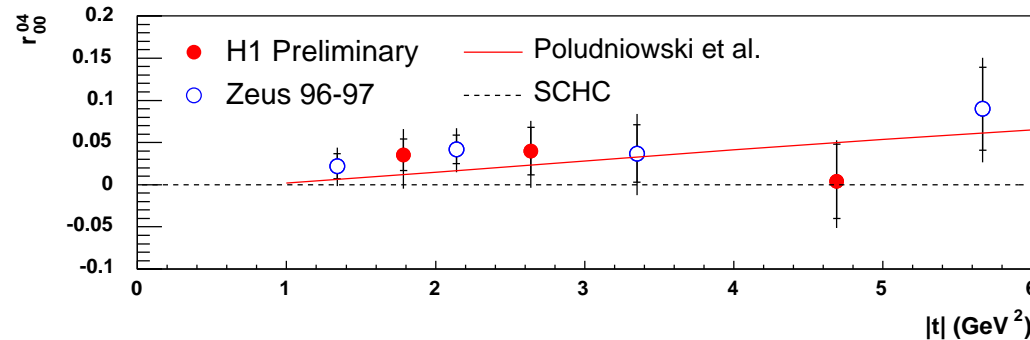
- Production of transversely polarised
  ρ ($\pm$) from oppositely polarised γ ($\mp$)

$$r^{04}_{1-1} = \frac{1}{2} \frac{\langle M_{++}M^*_{+-} + M_{+-}M^*_{++}\rangle}{\langle |M_{++}|^2 + |M_{+0}|^2 + |M_{+-}|^2\rangle}$$

- $r^{04}_{1-1} \neq 0 \Rightarrow$ Helicity "Double Flip"

Dependence of SDMEs on $|t|$

H1 Preliminary (γ p $\rightarrow$ ρ Y)

- Helicity **single flip** amplitude consistent with **zero** $\Rightarrow$ production dominated by **transversely** polarised ρ mesons

- Small r_{00}^{04} well described by model

- **Non-zero** helicity **double flip** amplitude $\Rightarrow$ confirmation of s-channel helicity **non**-conservation in ρ mesons

- Large r_{1-1}^{04} qualitatively agrees with model but prediction too big at lower $|t|$

- ZEUS r_{10}^{04} data differs significantly from zero $\Rightarrow$ production of **longitudinal** ρ meson (+) from **transverse** γ (0)

- BFKL model unable to describe r_{10}^{04} as prediction is too large and negative

Summary

- Photoproduction of ρ mesons measured up to $|t| = 10 \, \mathrm{GeV}^2$

- Power-like $|t|$ dependence with $n = 4.41 \pm 0.06 \, (\mathrm{stat.})^{+0.07}_{-0.05}(\mathrm{syst.})$ observed and is well described by BFKL model of Poludinowski *et al.*

- The single flip r^{04}_{00} and double flip r^{04}_{1-1} SDMEs are measured

  - Small measured single flip amplitude agrees well with BFKL model and indicates transverse production of ρ mesons dominates

  - Large measured double flip amplitude confirms s-channel helicity non-conservation and is in qualitative agreement with BFKL model

- Model unable to describe value of r^{04}_{10} obtained from other measurements since its prediction is both too large and negative