MANCHESTER 1824

The University of Manchester

Diffractive photoproduction of ρ mesons with large momentum transfer at HERA

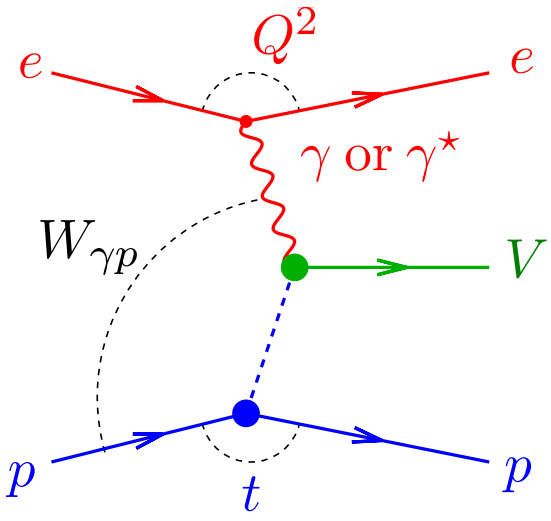
Carl Gwilliam
Manchester University

On behalf of the
H1 Collaboration

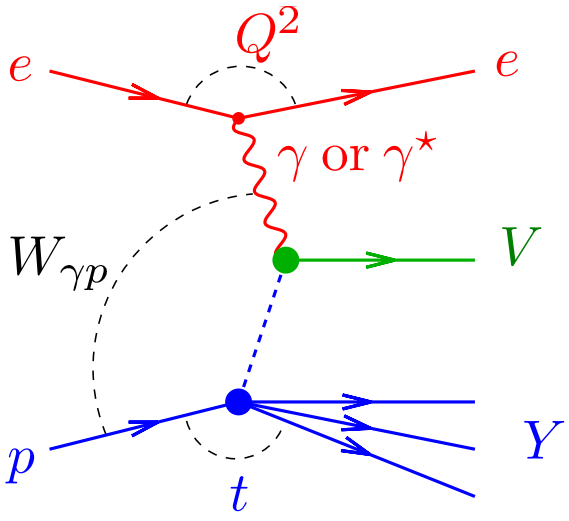
XIII International Workshop on Deep Inelastic Scattering
Madison, Wisconsin ● 27th April - 1st May 2005

Diffractive Vector Meson Production at HERA

Elastic



Dissociative



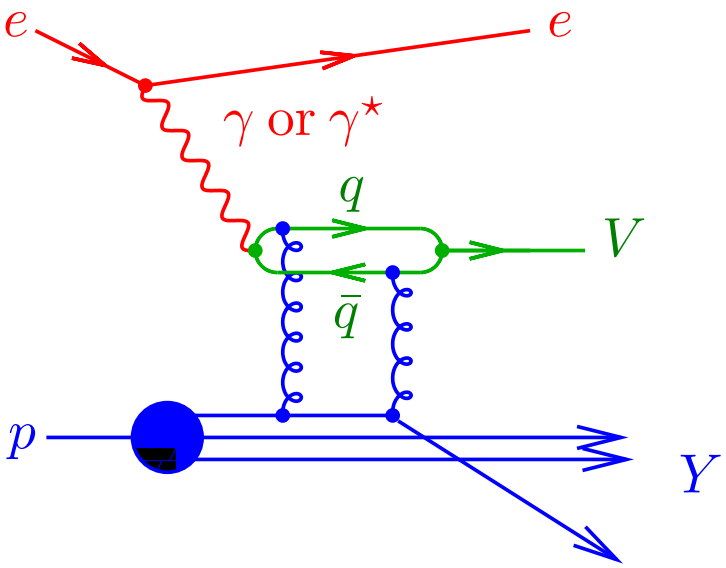
Proton dissociation dominates at large $|t|$

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	$\sim 0 < \lvert t \rvert < 30\ \mathrm{GeV}^2$
V	Vector meson	$\rho^0, \omega, \phi, J/\psi, \psi(2s), \Upsilon(1s)$

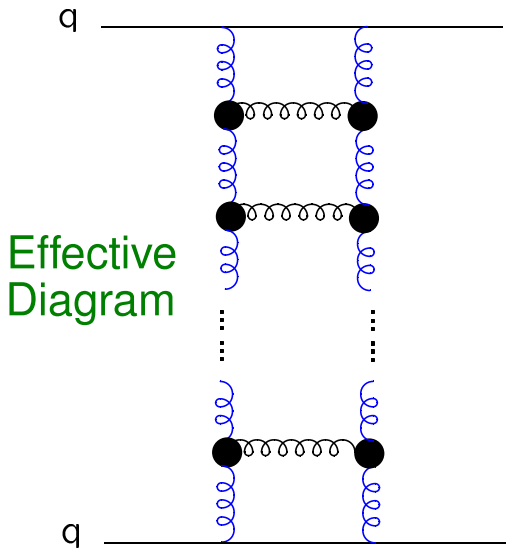
$\Rightarrow$ Simultaneous probe of several different kinematical quantities

Perturbative QCD

Lowest Order Exchange



Higher Order Exchange



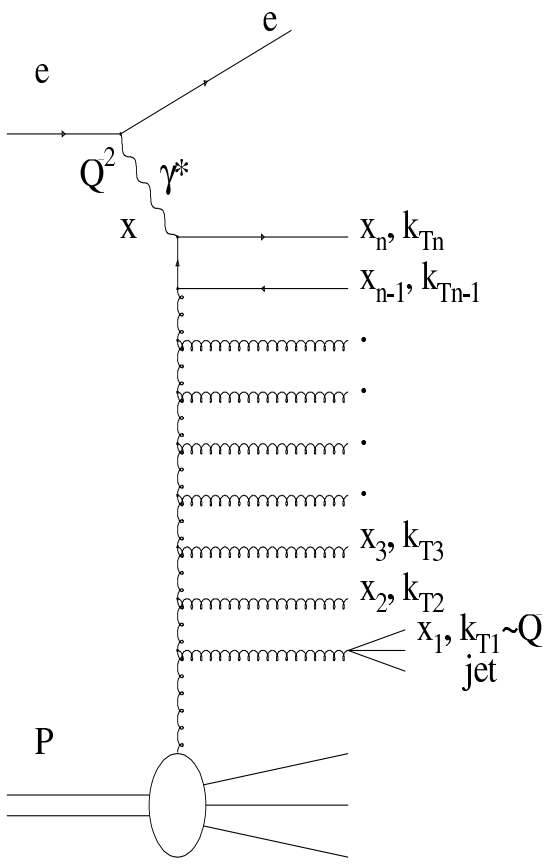
1. Photon fluctuates into $q\bar{q}$ pair
2. Lowest order exchange = 2 gluons
3. Meson wavefunction is needed to form V

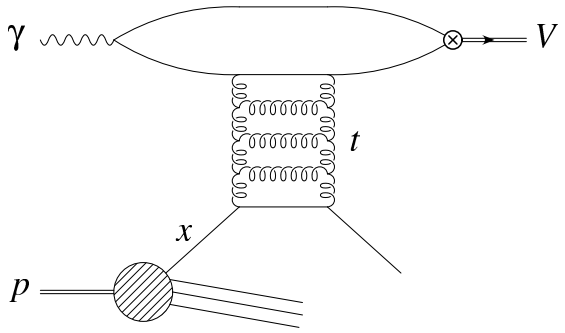
Sums perturbative series in α_s

$\Rightarrow$ 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

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

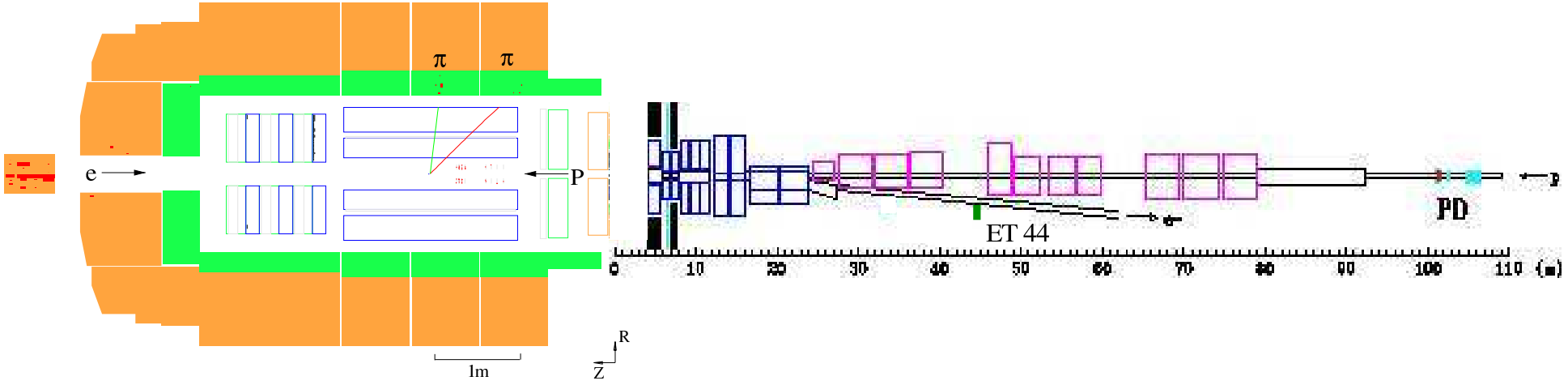
Selection:

- 2000 data period $\Rightarrow \mathcal{L} = 20.1\ \mathrm{pb}^{-1}$
- Two charged tracks (pion candidates)
- No additional neutral clusters
- Electron detected in 44 m tagger

Kinematics:

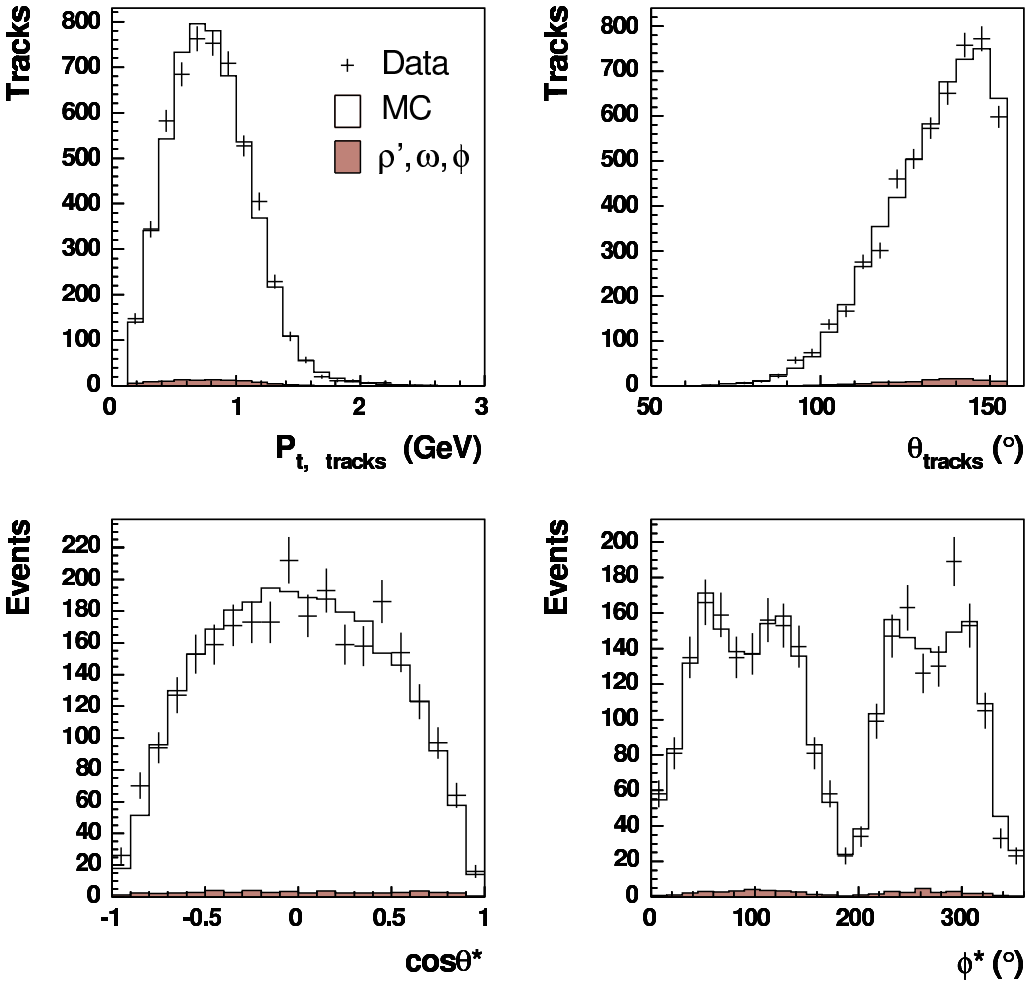
- Photoproduction $Q^2 < 0.01\ \mathrm{GeV}^2$
- Tagged electron $75 < W < 95\ \mathrm{GeV}$
- $|t|$ range $1.5 < |t\,| < 10.0\ \mathrm{GeV}^2$
- Proton remnant mass $M_Y < 5\ \mathrm{GeV}$

Number of selected events ≈ 3000



Monte Carlo Simulation

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



DiffVM Monte Carlo:

- Diffractive Vector Meson production
- Simulates soft diffraction in ep collisions
- Based on Vector Dominance Model
- Detailed description of p dissociation

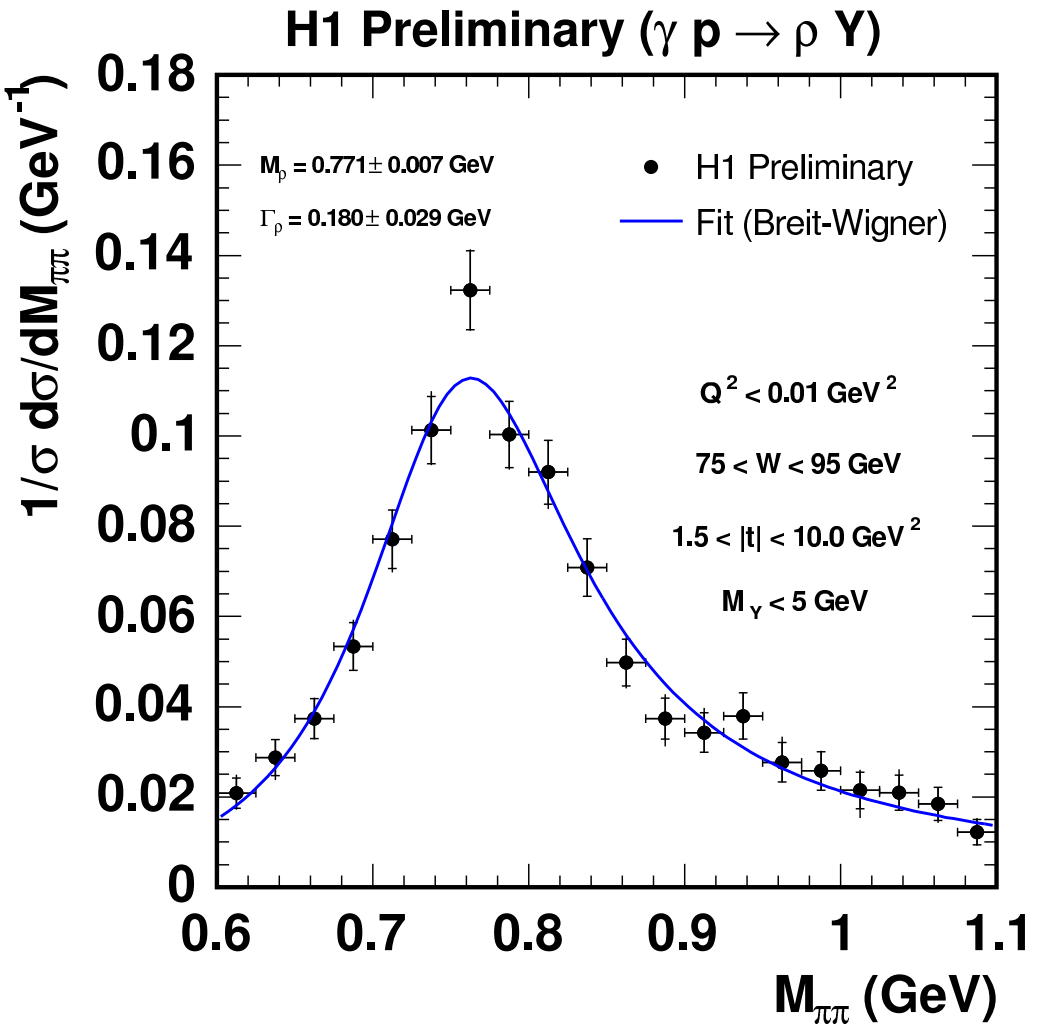
- Tuned to describe data $|t|$ dependence
- Re-weighted to take into account

  s-channel helicity non-conservation

Data and Monte Carlo are in good agreement

Invariant Mass Distribution

Clear evidence for a ρ meson mass peak



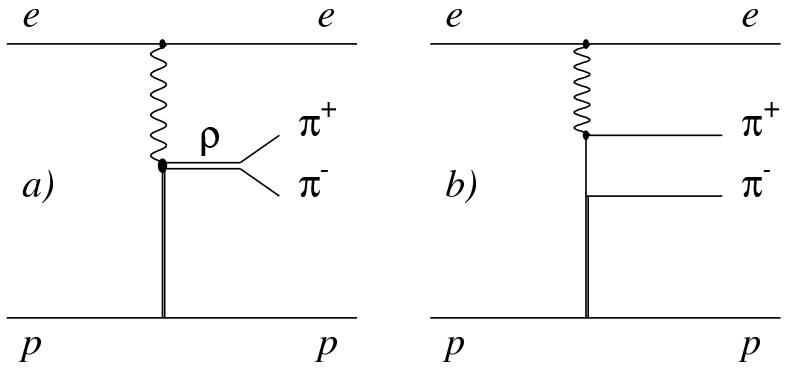
- Fitted with a relativistic Breit-Wigner

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

$$\Gamma(M_{\pi\pi}) = \Gamma_\rho \left(\frac{q^*}{q_0^*}\right)^3 \frac{m_\rho}{M_{\pi\pi}}$$

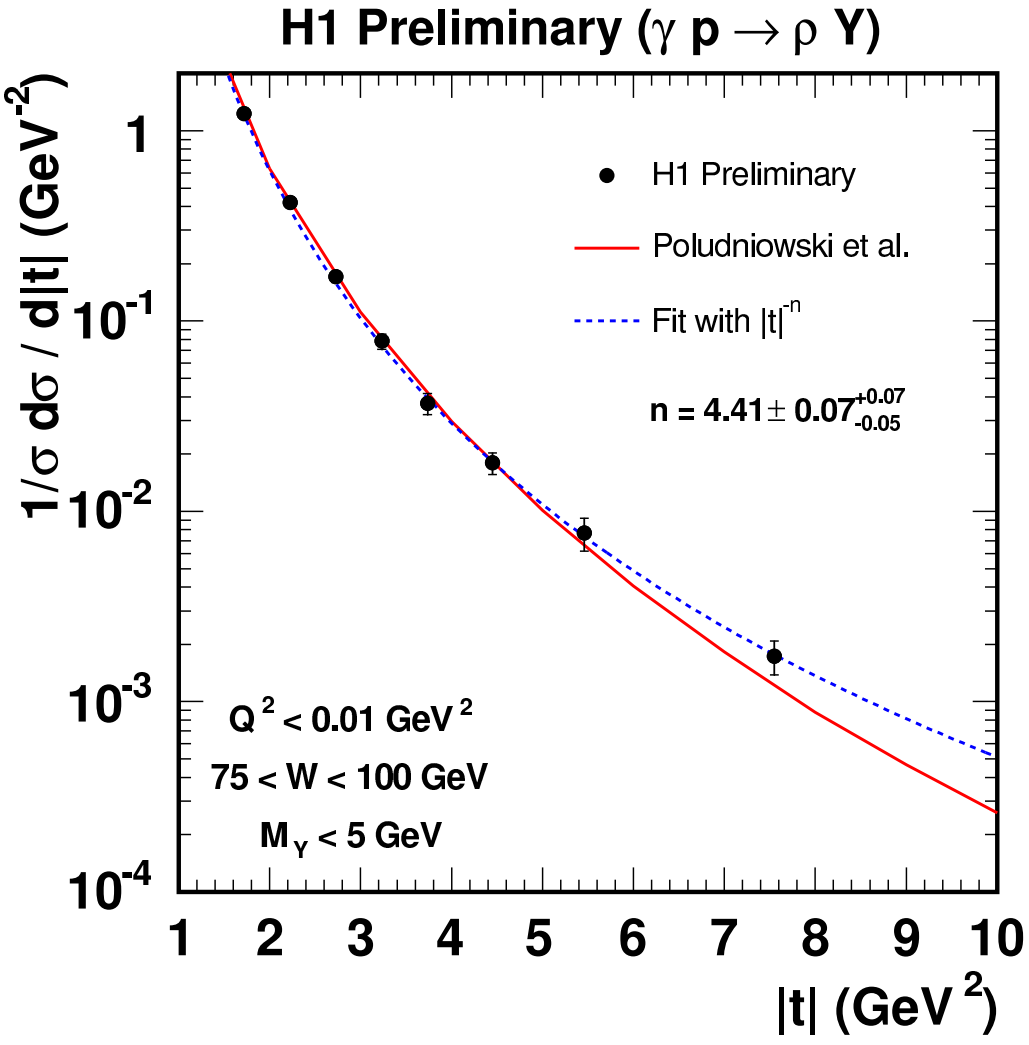
- At lower $|t|$ skewing effects have been observed $\Rightarrow$ E.g. Ross-Stodolsky:

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



- Here skewing is consistent with zero

Dependence on $|t|$



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

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

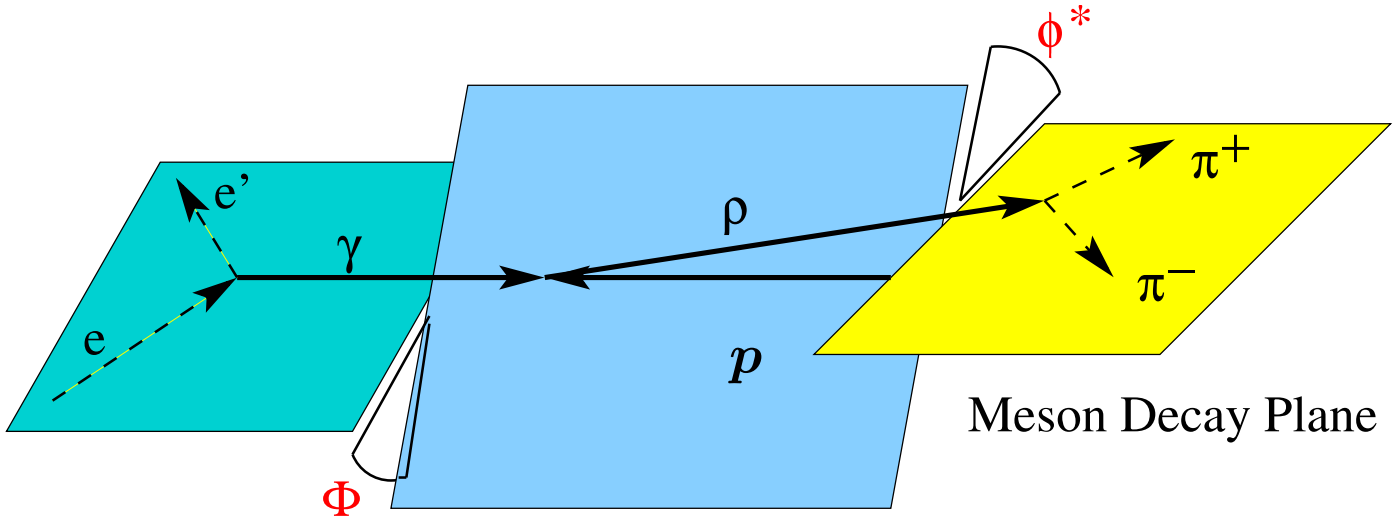
$$\alpha_s^{IF} = 0.17$$
$$\alpha_s^{BFKL} = 0.25$$
$$\gamma = 1$$

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

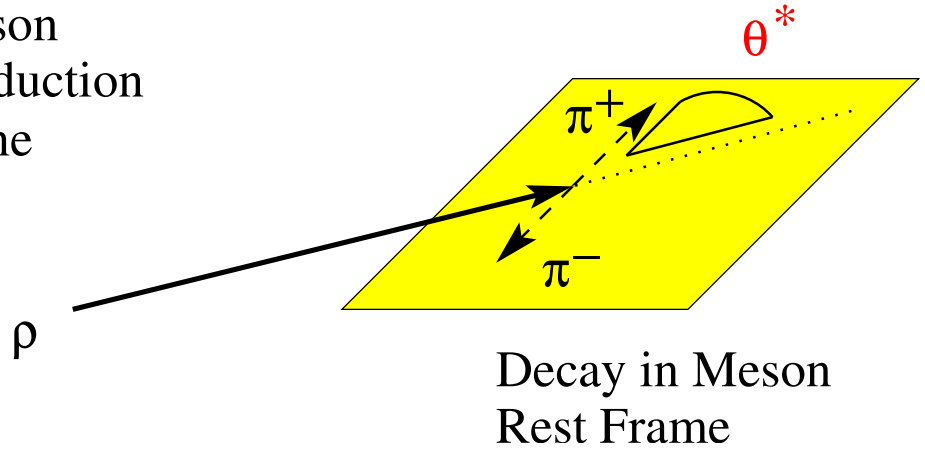
- t slope quite sensitive to the M_Y cut. Here evaluated for $M_Y < 5\ \text{GeV} \Rightarrow$ theory predicts steeper dependence than for ZEUS, where $M_Y < 25\ \text{GeV}$

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



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



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})

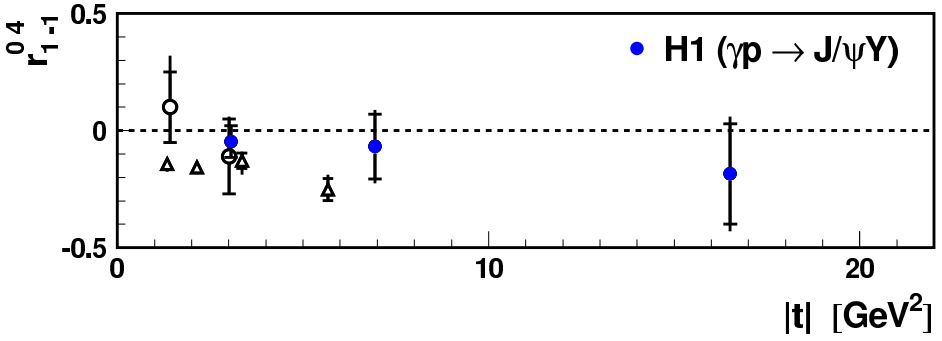
Previous Measurements of SDMEs

Photoproduction:

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

  $\Rightarrow$ Allows measurements of 3 of the 15

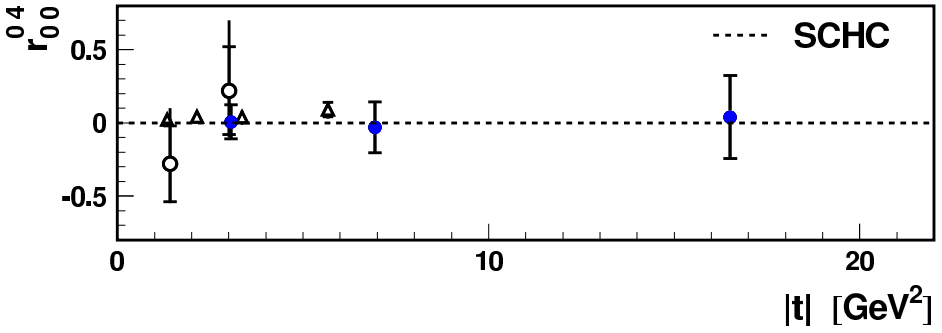
  spin density matrix elements (SDMEs)



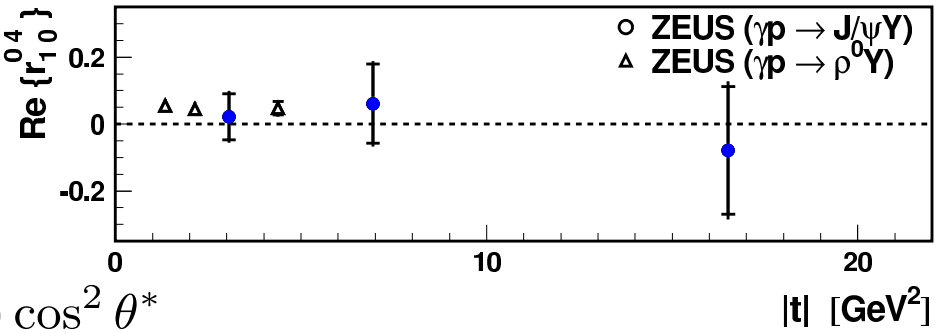
- s channel helicity conservation (SCHC)

  $\Rightarrow$ Vector meson retains helicity of photon

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



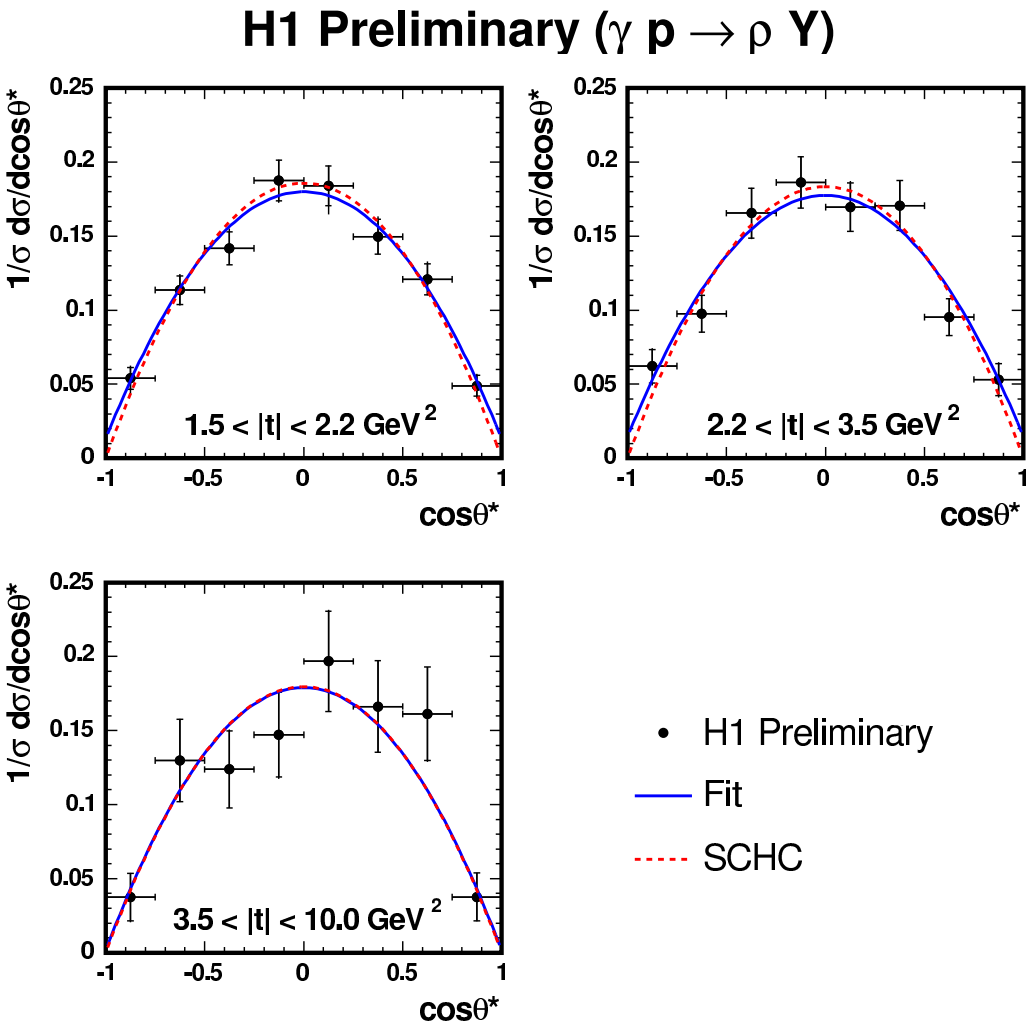
- Heavy J/ψ data is consistent with SCHC
- In contrast, lighter ρ meson violates SCHC



- 2 dimensional fit needed to extract 3 SDMEs:

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

Dependence on $\cos\theta^*$



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

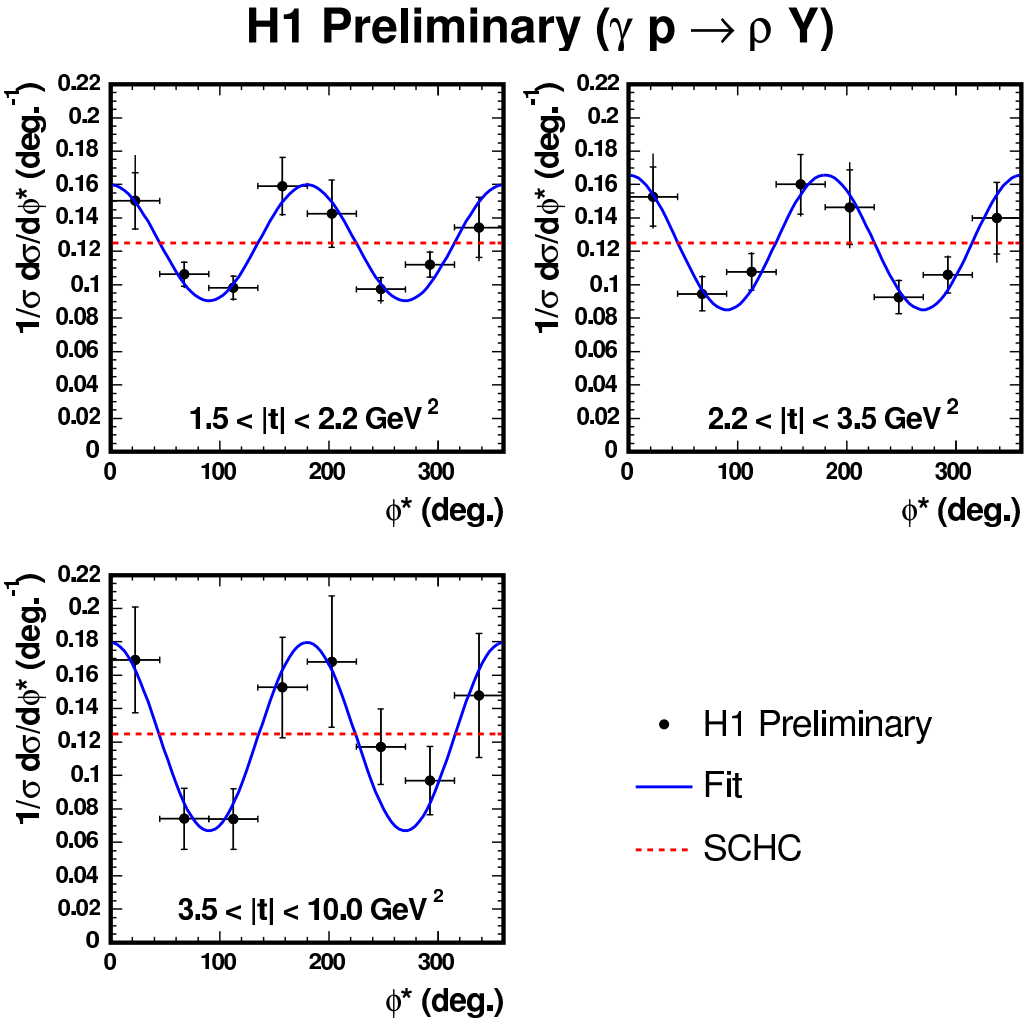
r_{00}^{04}:

- 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^*



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

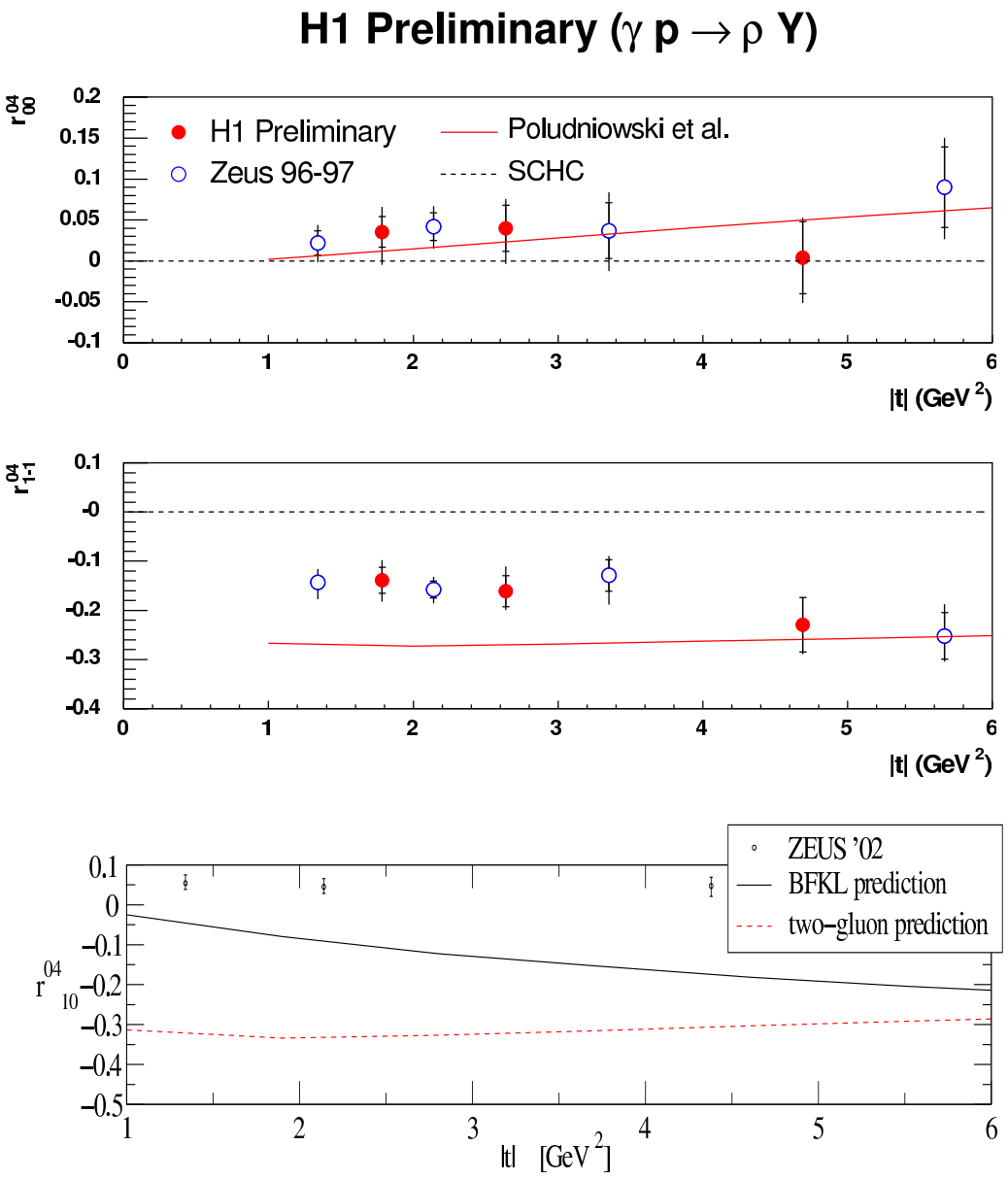
r^{04}_{1-1}:

- Production of transversely polarised $\rho\ (\pm)$ from oppositely polarised $\gamma\ (\mp)$

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

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

Dependence of SDMEs on $|t|$



- Helicity single flip amplitude consistent with zero $\Rightarrow$ production dominated by transversely polarised ρ mesons
- Small r^{04}_{00} well described by model
- Non-zero helicity double flip amplitude $\Rightarrow$ confirmation of s-channel helicity non-conservation in ρ mesons
- Large r^{04}_{1-1} qualitatively agrees with model but prediction too big at lower $|t|$
- ZEUS r^{04}_{10} data differs significantly from zero $\Rightarrow$ production of longitudinal ρ meson (+) from transverse γ (0)
- BFKL model unable to describe r^{04}_{10} 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