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Diffractive photoproduction of ρ mesons with large momentum transfer at HERA

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On behalf of the H1 Collaboration

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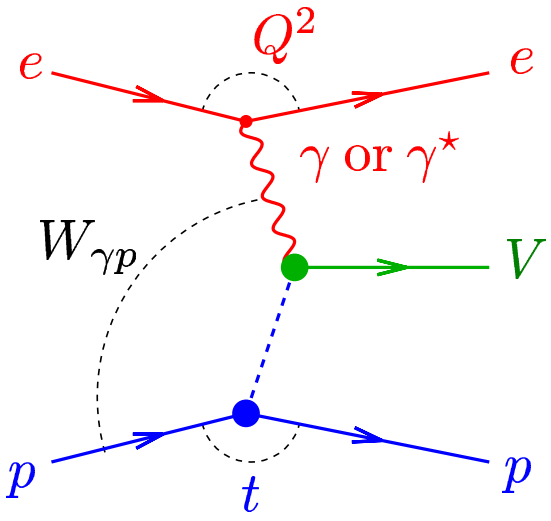
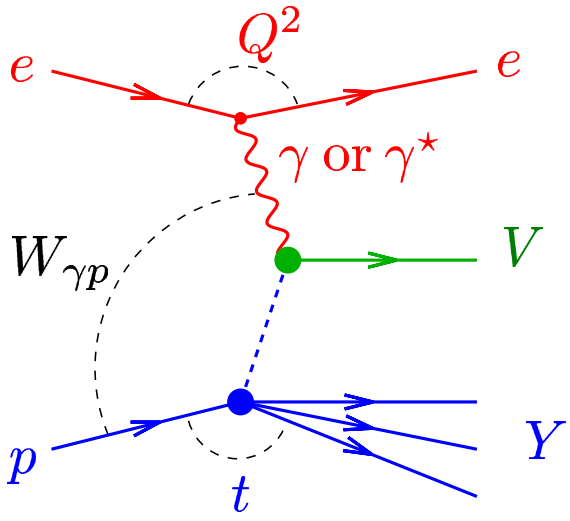
Diffractive Vector Meson Production at HERA

Elastic



Dissociative



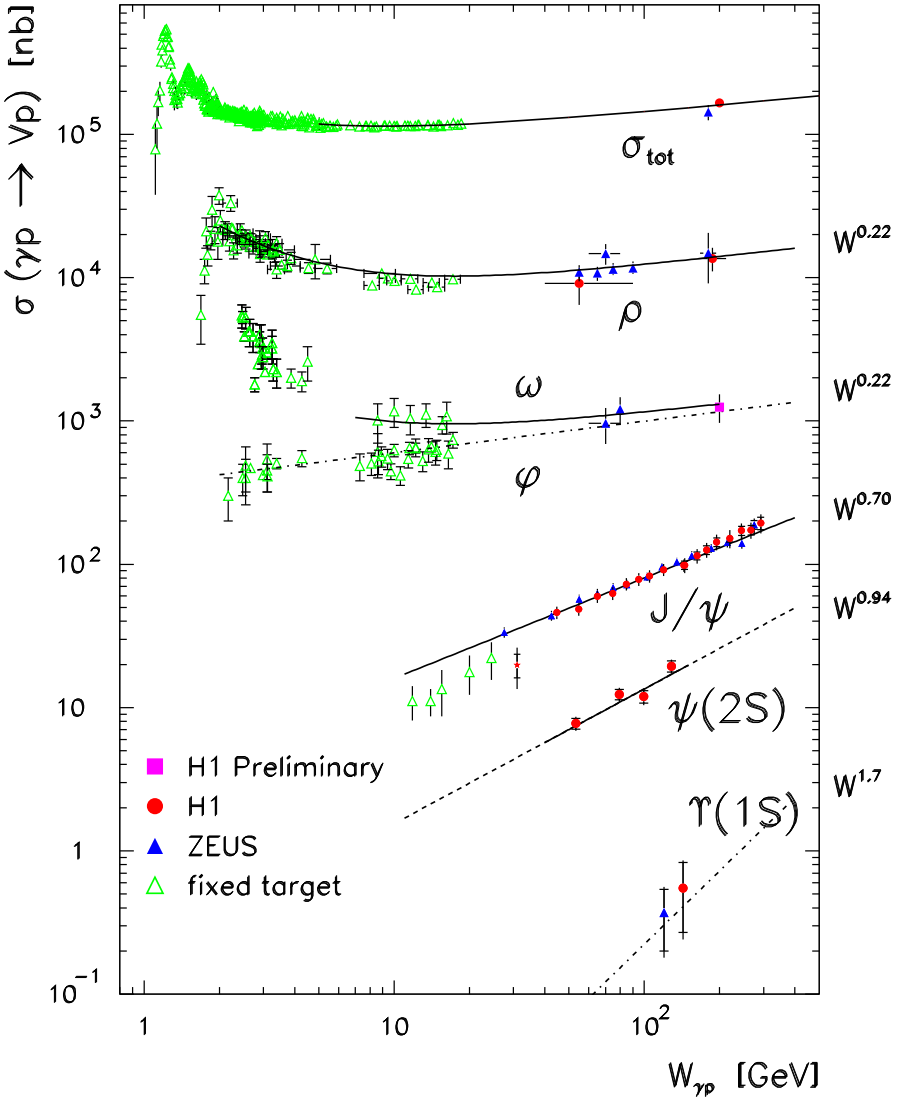
Proton dissociation dominates at large $|t|$

Q^2	Virtuality of the $\gamma^\star$	$\sim 0 < Q^2 < 100\ \mathrm{GeV}^2$
$W_{\gamma p}$	CM energy of the γp system	$20 < W_{\gamma p} < 205\ \mathrm{GeV}$
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

Elastic Vector Mesons in Photoproduction

Photoproduction cross section for elastic VM production (small $|t|$ & Q^2)



Light Vector Mesons (ρ, ω, ϕ):

- Observed dependence goes as $\sigma \sim W^{0.22}$

  $\Rightarrow$ Consistent with Regge soft IP expectation

Heavier Vector Mesons $(J/\psi, \psi(2s))$:

- Steeper rise in cross section is observed $\Rightarrow$

  Need something in addition $=$ pert. QCD

- Break down of pomeron universality $\Rightarrow$ VMs

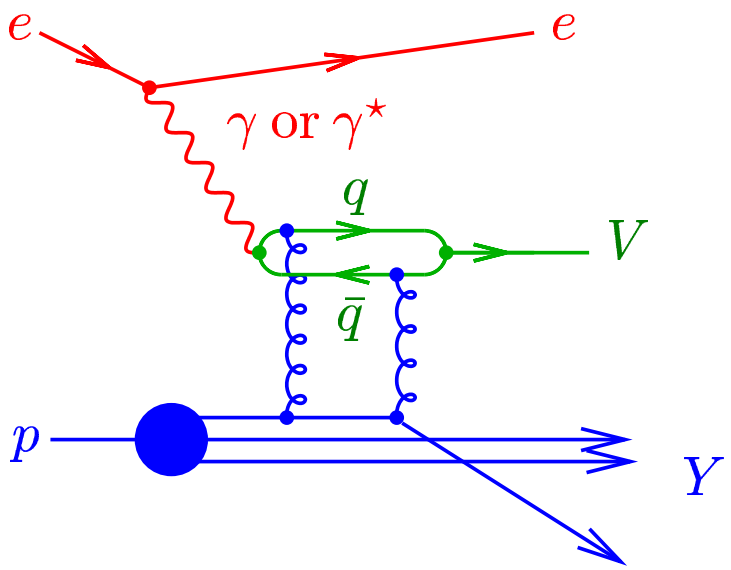
  at HERA provide a test of soft-hard transition

- Similar behaviour with Q^2 – what about $|t|$?

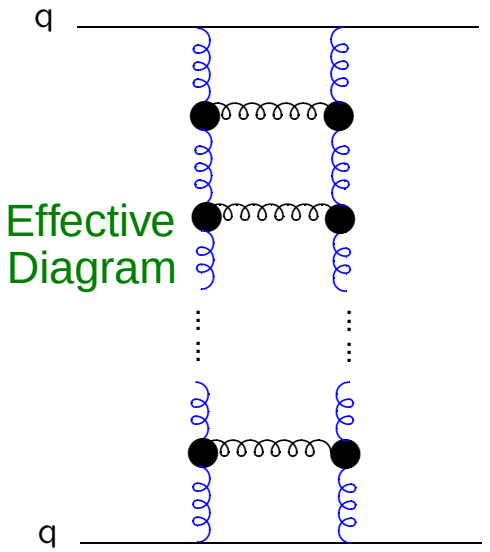
Perturbative QCD

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

Lowest Order (LO) Exchange



Higher Order Exchange



1. Emitted photon fluctuates into $q\bar{q}$ pair
2. Hard interaction of $q\bar{q}$ pair with proton

$\Rightarrow$ 2 gluon exchange (colour singlet) at LO

3. Form bound VM (non pert. meson WF)

- Summation of a perturbative series in α_s

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

- Can be described by BFKL evolution in the region $s \gg |t| \Rightarrow \sum_n \alpha_s^n \ln^n s/|t|$

Diffractive VM photoproduction at large $|t|$ proposed as test of BFKL evolution (Forshaw *et al.*)

Models

Challenge is to simultaneously describe $|t|$ distribution and helicity structure

Two gluon:

- Photon couples to chiral-even $q\bar{q}$ dipole so require $L_z = \pm 1$ onto γ direction
- Hard interaction modifies dipole direction and damps $L'_z = \pm 1$ on VM axis by $\sim \frac{1}{|t|}$
- Reduces prob. of transversely polarised VM and longitudinal production dominates

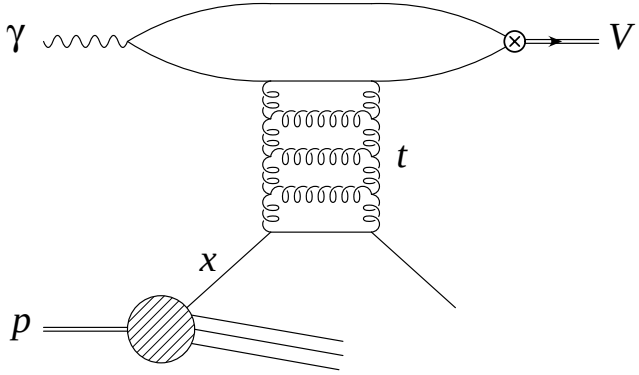
BUT

- Data indicate transverse VMs dominate $\Rightarrow$ requires large chiral-odd coupling
- One way to accommodate this is to use the constituent quark mass $m = \frac{m_V}{2}$

[1] R. Enberg *et al.*, JHEP **0309** (2003) 008 [hep-ph/0306232]

LL BFKL:

- Cures instabilities from the two-gluon prediction
- VM production factorised from hard interaction & uses set of meson light-cone wavefunctions



- Free parameters:

  α_s^{BFKL}: gluon couplings inside gluon ladder

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

  set according to "best fit" to previous data

[2] G. G. Poludniowski *et al.*, JHEP **0312** (2003) 002 [hep-ph/0311017]

Data Selection

$$\gamma + p \to \rho^0 + Y \text{ with } \rho^0 \to \pi^+\pi^- \ (\mathrm{BR} \approx 100\%)$$

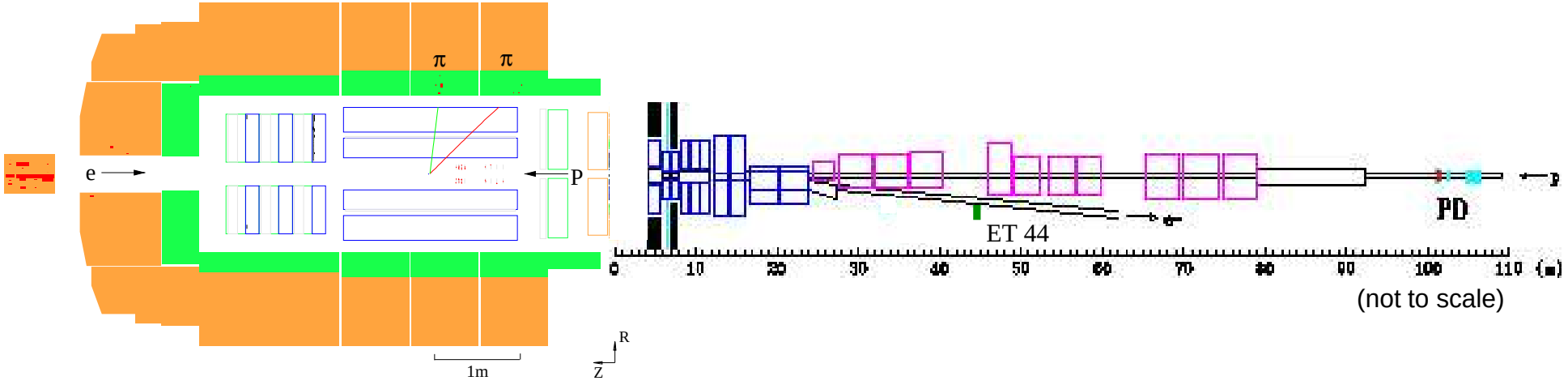
Selection:

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

Kinematics:

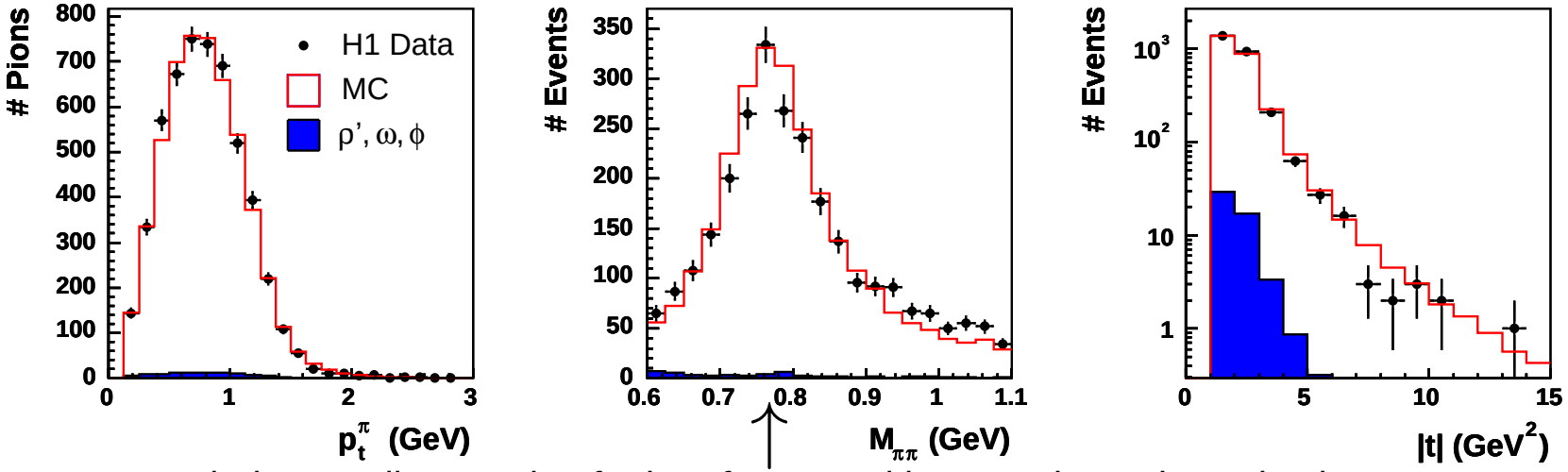
- Photoproduction $Q^2 < 0.01\ \mathrm{GeV}^2$
- Tagged electron $75 < W < 95\ \mathrm{GeV}$
- $|t|$ range $1.5 < |t\,| < 10.0\ \mathrm{GeV}^2$
- Proton remnant mass $M_Y < 5\ \mathrm{GeV}$

Number of selected events ≈ 2600

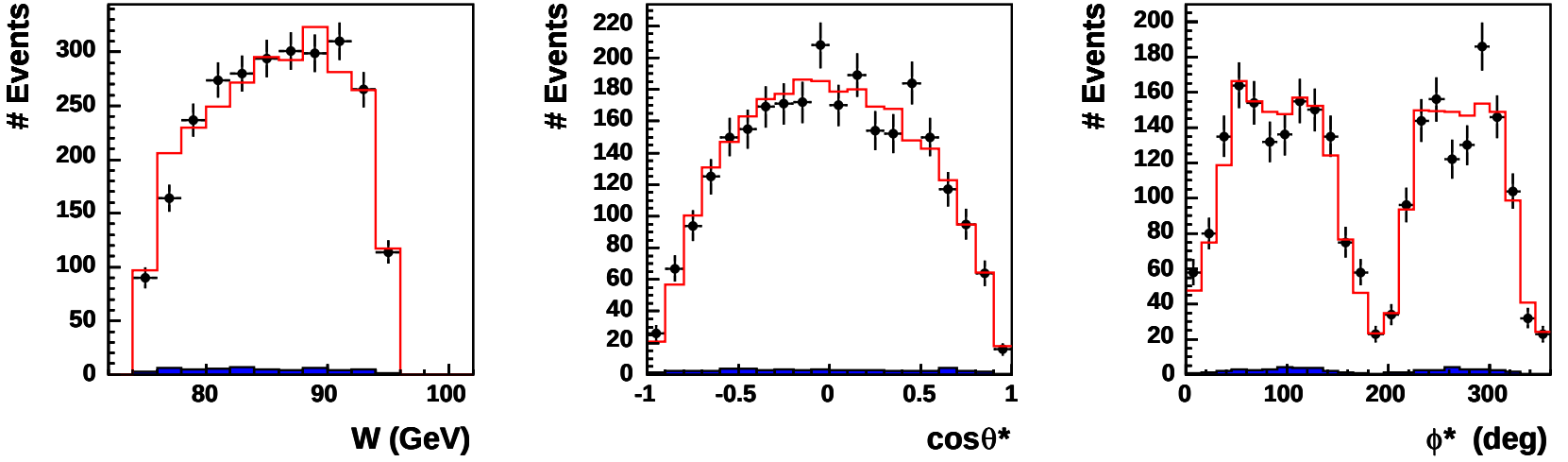


Monte Carlo Description

DIFFVM MC: Based on vector dominance (VDM) with a detailed description of p dissociation

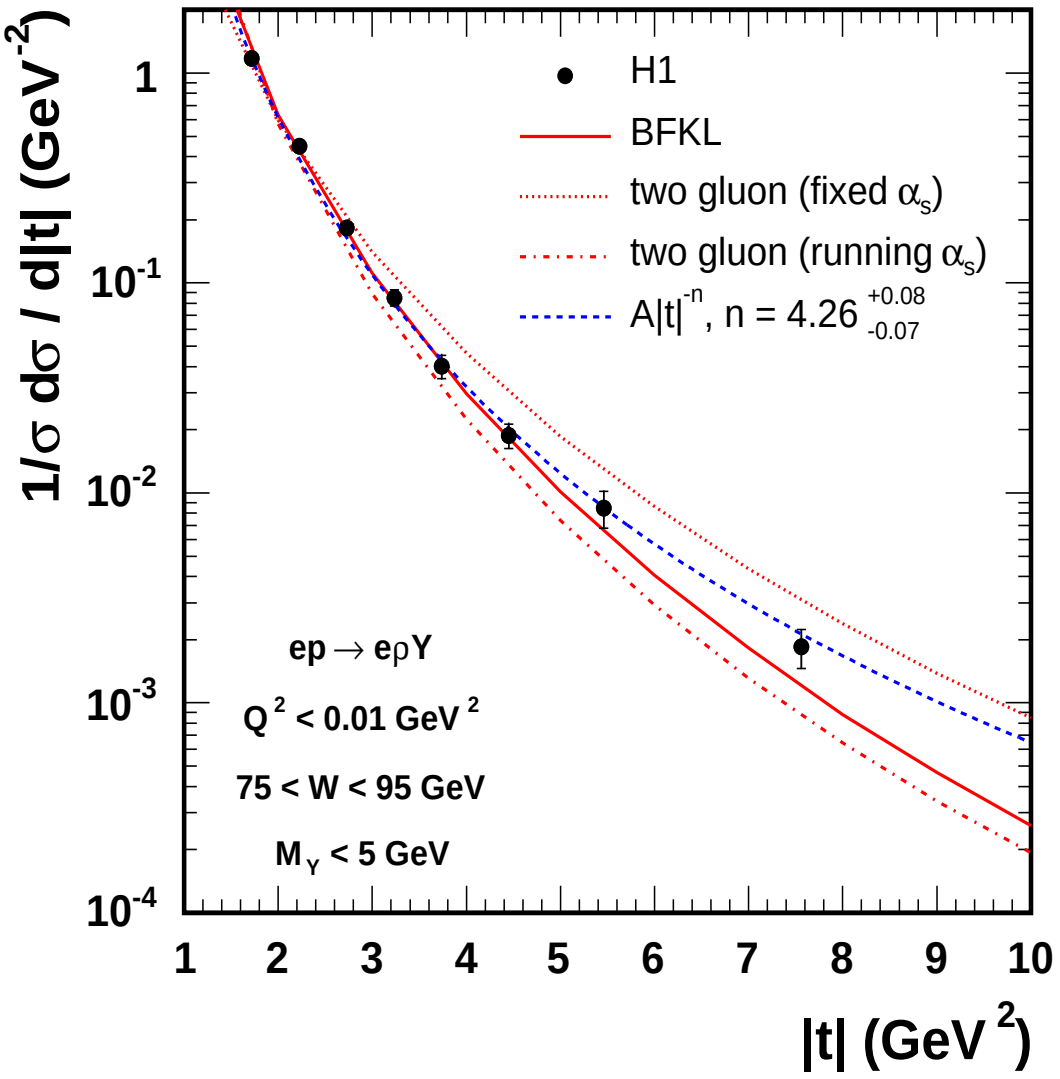


Includes small correction for interference with open pion pair production



Data and Monte Carlo are in good agreement (after tuning for t slope and SCHC violation)

Dependence on $|t|$



Fit:

- Approx. power-like behaviour expected at large $|t| \Rightarrow$ Data fitted with $A|t|^{-n}$:

$$n = 4.26 \pm 0.06\,(\text{stat.})^{+0.06}_{-0.04}(\text{syst.})$$

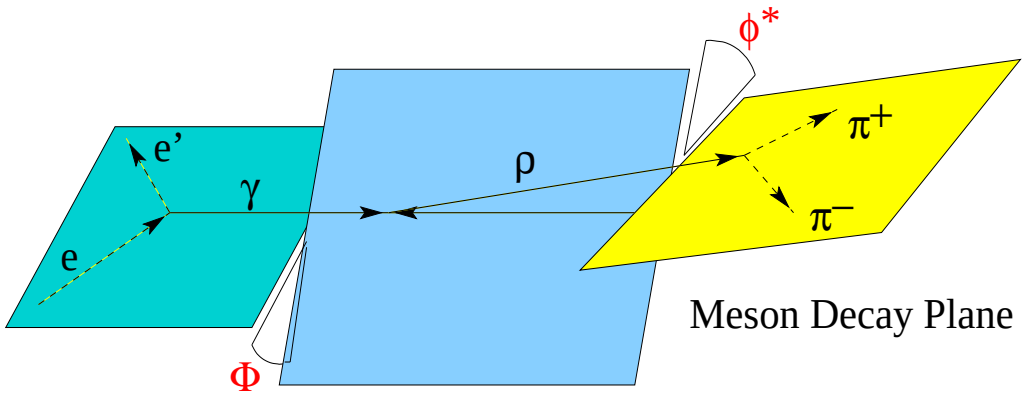
Model:

- Two-gluon model is unable to describe t dependence using either a fixed or running strong coupling (α_s^{BFKL})
- In contrast, BFKL prediction provides a reasonable description of the data
- Steeper t dependence than for ZEUS:

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

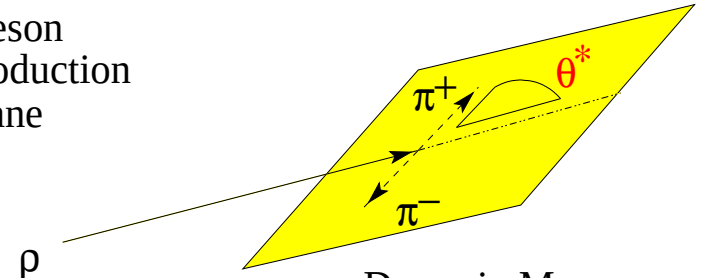
as a result of the differing M_Y ranges

Helicity Angles and Spin Density Matrix Elements



Lepton Scattering Plane

Meson Production Plane



Decay in Meson Rest Frame

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

$$r^{04}_{10} = \frac{1}{2} \frac{\langle M_{++} M^*_{+0} - M_{+-} M^*_{+0} \rangle}{\langle |M_{++}|^2 + |M_{+0}|^2 + |M_{+-}|^2 \rangle}$$

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

- Production & decay angular distributions

  $\Rightarrow$ 15 spin density matrix elements (SDME)

  but only 3 accessible in photoproduction

- SDMEs depend bilinearly on the helicity amplitudes $\Rightarrow r^{ij}_{kl} \propto M_{\lambda_V M \lambda_\gamma} M_{\lambda'_V M \lambda'_\gamma}$

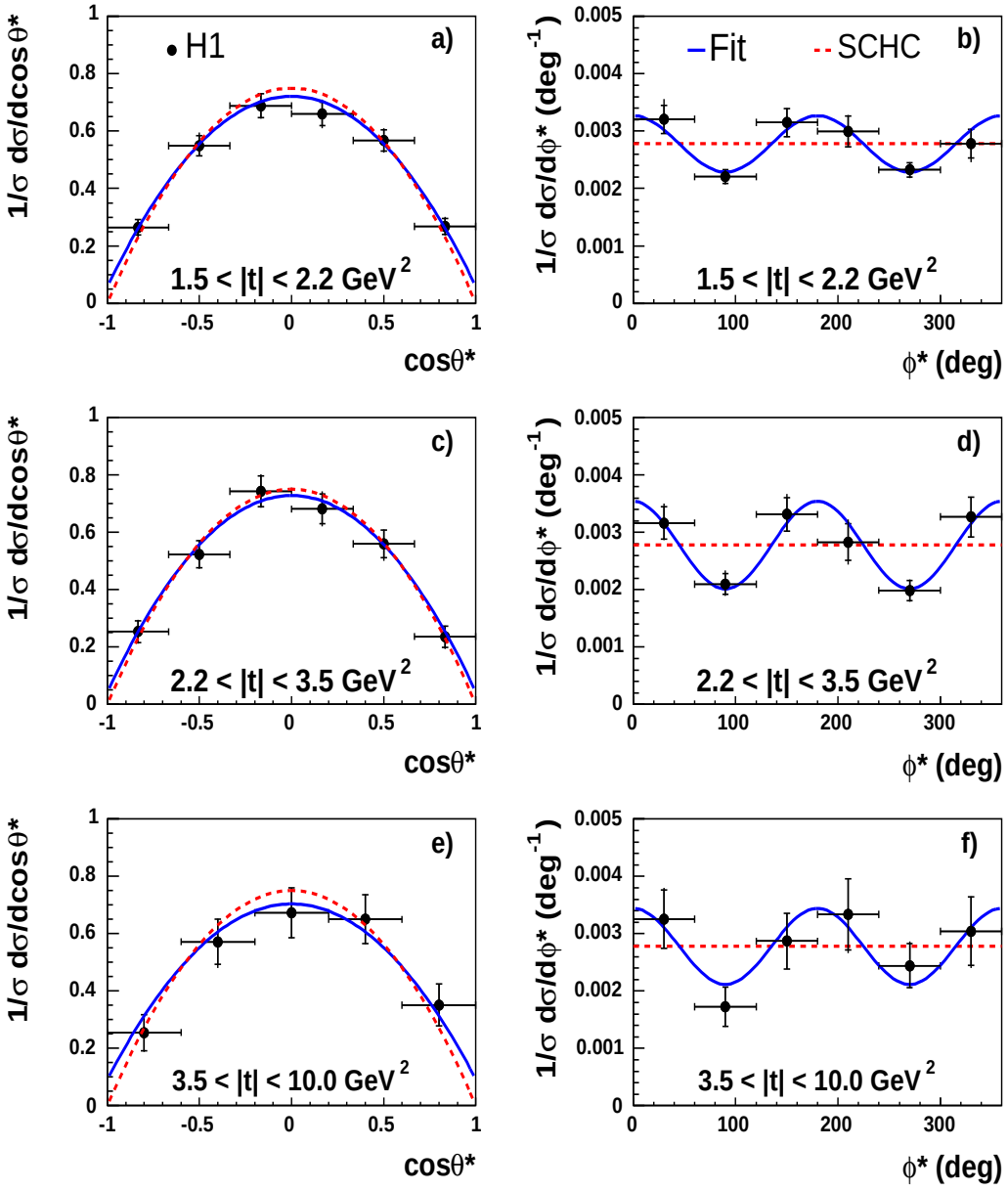
No helicity flip:	M_{++} / M_{--}
Single flip:	M_{+0} / M_{-0}
Double flip:	M_{+-} / M_{-+}

- s-channel helicity conservation (SCHC)

  $=$ Vector meson retains photon helicity

  $\Rightarrow$ All 3 SDMEs predicted to be zero

Helicity Angles: $\cos\theta^*$ and ϕ^*

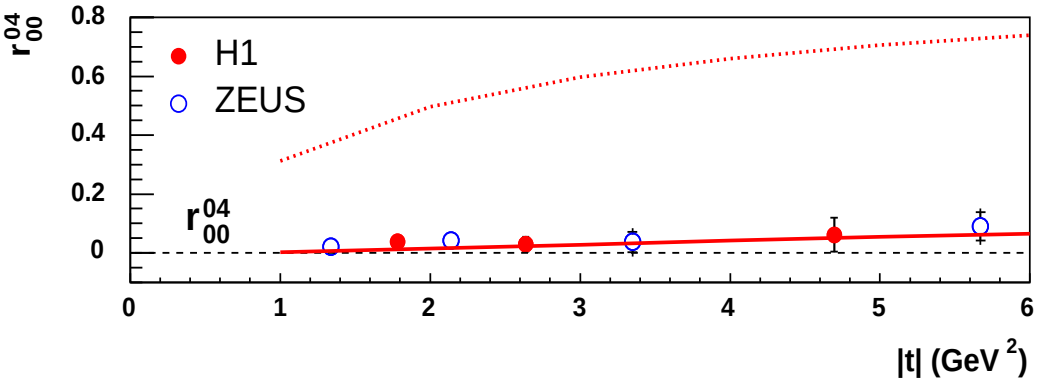


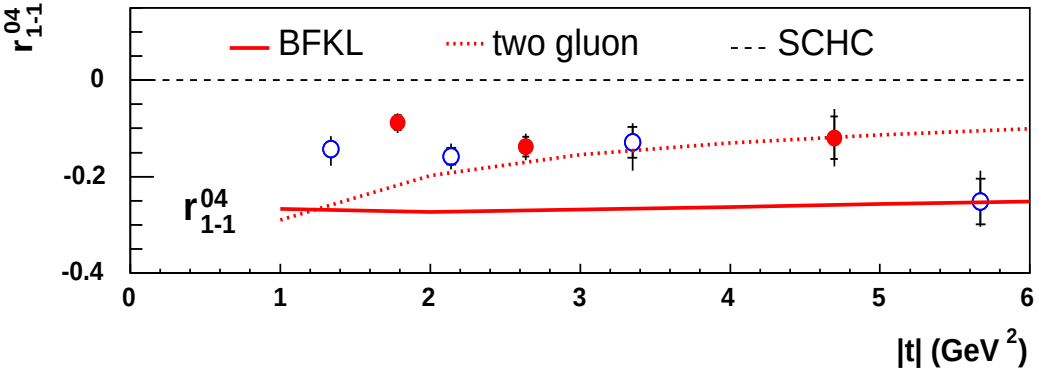
- SDMEs extracted using 2-dimensional log-likelihood fit to angular decay dist.:

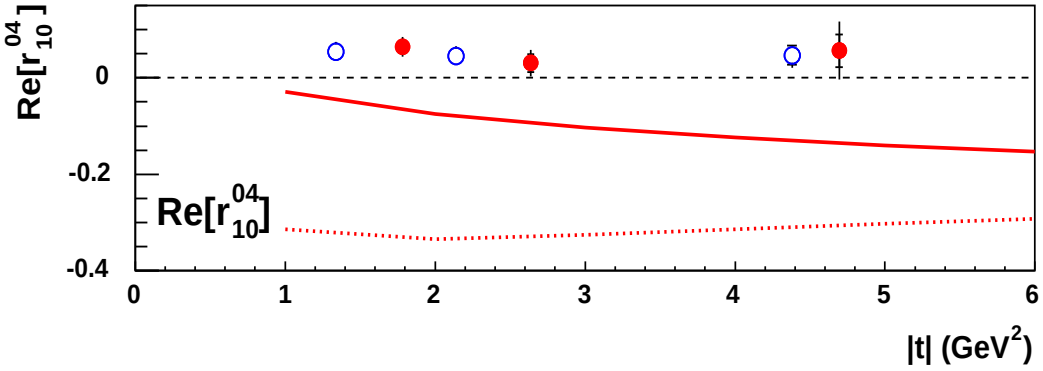
$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta^* d\phi^*} = \frac{3}{4\pi}\left[\frac{1}{2}(1-r^{04}_{00}) + \frac{1}{2}(3r^{04}_{00}-1)\cos^2\theta^* - \sqrt{2}\mathrm{Re}[r^{04}_{10}]\sin 2\theta^*\cos\phi^* - r^{04}_{1-1}\sin^2\theta^*\cos 2\phi^*\right]$$

- $\cos\theta^*$ reasonably described by SCHC
- Flat ϕ^* behaviour clearly disfavoured $\Rightarrow$ indicates a violation of SCHC (in contrast to results for heavier J/Ψ)
- Both the two-gluon and BFKL models predict a violation of SCHC but differ in size of longitudinal VM polarisation

Dependence of SDMEs on $|t|$







- Small r_{00}^{04} value ($\sim$ 5%) $\Rightarrow$ transversely polarised ρ meson production dominates
- Two-gluon model hugely overestimates r_{00}^{04} but BFKL gives a good description
- Large finite value of r_{1-1}^{04} indicates a significant double-flip contribution $\Rightarrow$ clear violation of SCHC in ρ production
- Both models give non-zero prediction with same sign as data
- Non-zero r_{10}^{04} confirms the presence of a single-flip helicity contribution
- Both models unable to describe r_{10}^{04} as predictions are too large and wrong sign

(Sudakov suppression of large $q\bar{q}$ dipoles?)

Summary

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

Dependence on $|t|$:

- The t distribution is well described by a power-like dependence $\mathrm{d}\sigma/\mathrm{d}|t| \sim |t|^{-n} \Rightarrow$

$$n = 4.26 \pm 0.06\ (\mathrm{stat.})^{+0.06}_{-0.04}(\mathrm{syst.})$$

- Two-gluon models with fixed or running strong coupling fail to describe $|t|$ dependence
- In contrast, BFKL model is able to provide a reasonable description of the $|t|$ distribution

Helicity Structure:

- Clear evidence of SCHC violation with contributions from single and double helicity-flip
- Two-gluon model overestimates probability of longitudinally polarised ρ production (r^{04}_{00})
- BFKL model able to describe r^{04}_{00} well, but the prediction for r^{04}_{1-1} is too negative and $\mathrm{Re}[r^{04}_{10}]$ has the wrong sign