# High $|t|$ Diffractive Photoproduction of $\rho$ Mesons

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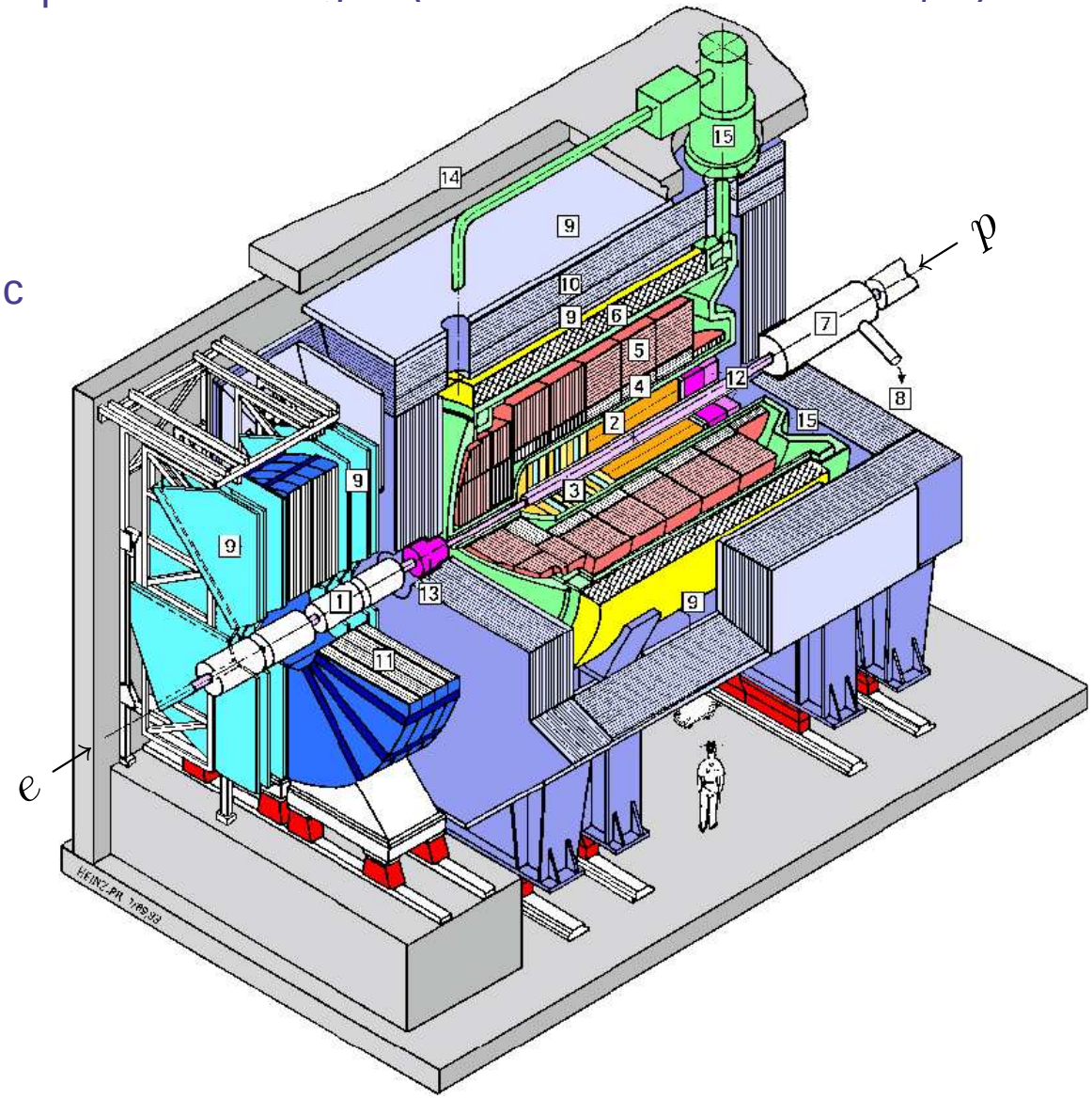
# H1 Detector

Asymmetric detector due to unequal beam energies (27.6 GeV $e$'s on 920 GeV $p$'s)

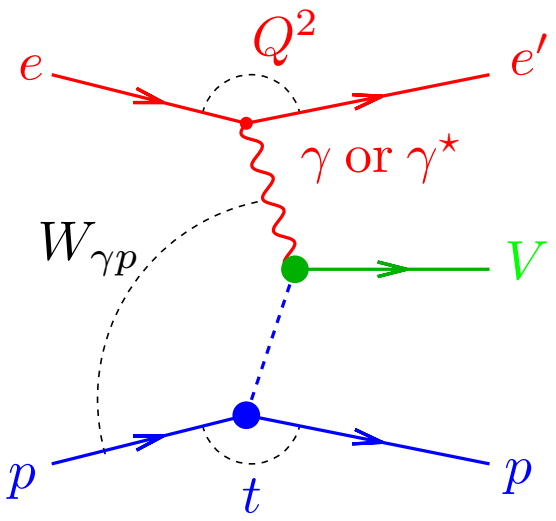
Main Components (2000):

- Tracking provided by 2 concentric drift chambers (CJC1 and 2)
- LAr calorimeter with lead (EM) or steel (Had) showering plates
- Instrumented iron (CMD) & drift chambers (FMD) to detect $\mu$'s
- Taggers for low $Q^2$ physics at 8, 33 and 44 m in $e$ direction

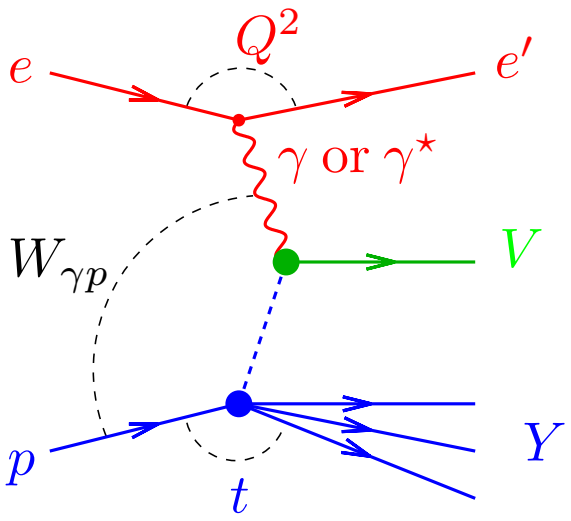


# Diffractive Vector Meson Production at HERA

Elastic




Dissociative




Proton dissociation dominates at large $|t|$

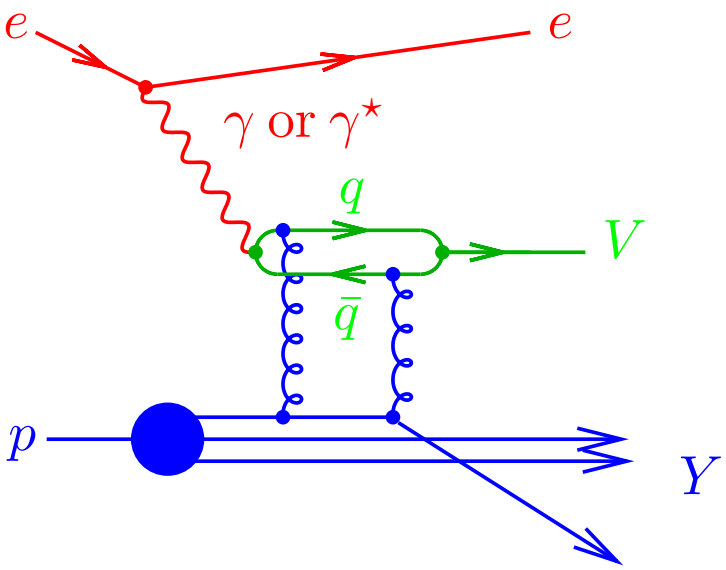
| | | |
|---|---|---|
| $Q^2$ | Virtuality of the $\gamma^\star$ | $\sim 0 < Q^2 < 100\ \mathrm{GeV}^2$ |
| $W_{\gamma p}$ | CoM energy of the $\gamma p$ system | $20 < W_{\gamma p} < 290\ \mathrm{GeV}$ |
| $y$ | Fraction of $E_e$ taken by $\gamma^{(\star)}$ | $\sim 0 < y = W^2_{\gamma p}/s < 0.84$ |
| $t$ | (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

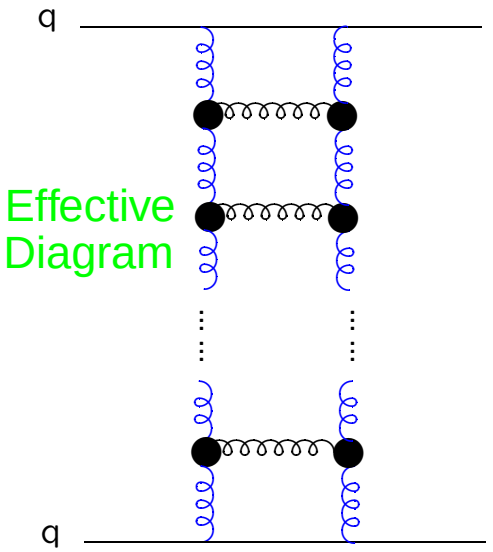
# Perturbative QCD

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

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 $V$

Evolution: a. DGLAP $\Rightarrow \sum_n \alpha_s^n \log^n(Q^2)$

b. BFKL $\Rightarrow \sum_n \alpha_s^n \log^n(1/x)$

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

**High $|t|$ vector mesons $\Rightarrow$ ideal place to study BFKL dynamics**

# High $|t|$ Vector Meson Photoproduction

Two prong vector meson decay signature

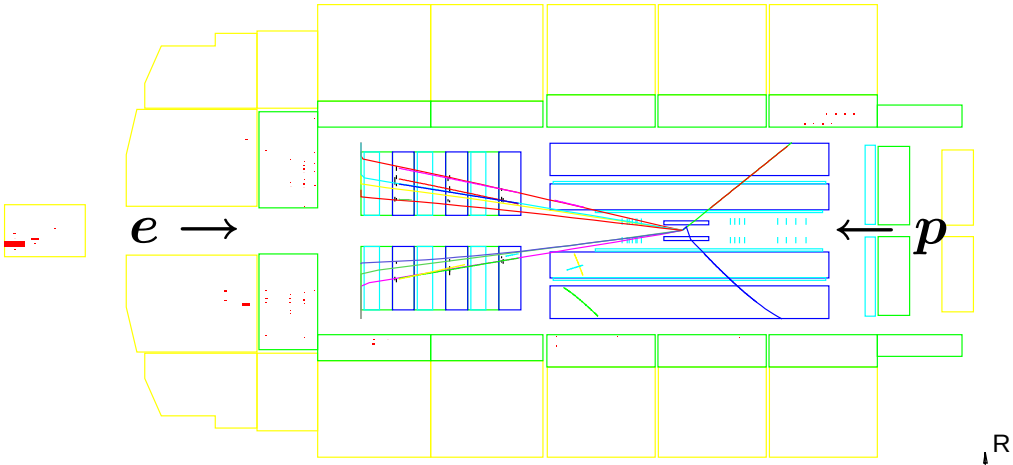
$\Rightarrow$ reconstruct $|t|$ from $P_T$ of tracks

Typically energy deposits in fwd direction

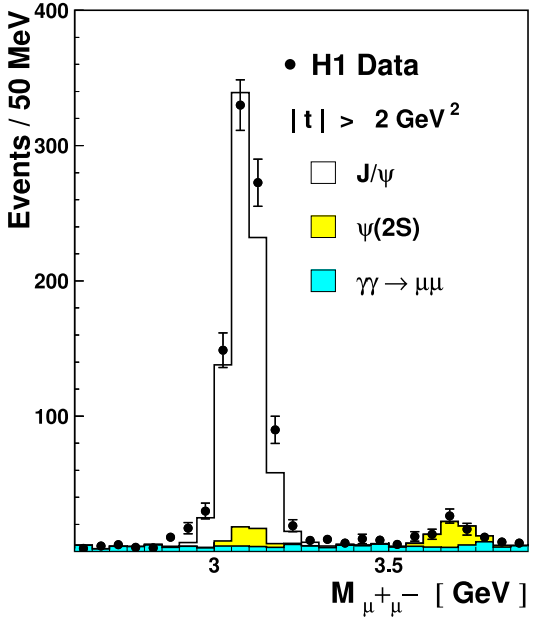
Incoming $e$ scattered through small angle

$\Rightarrow$ Not in main detectors (can be tagged)

$\Rightarrow$ Clean experimental signature!




$\gamma p \rightarrow \rho Y$ candidate




Non-resonant background at large $|t|$ is small

Small contribution from $\psi(2s)$ vector meson

$\Rightarrow$ Backgrounds at large $|t|$ are small!

# Heavy $J/\psi$ Photoproduction at High $|t|$

$J/\psi \to \mu^+\mu^-$ using $\mathcal{L} = 78\,\mathrm{pb}^{-1}$ with $Q^2 < 1\,\mathrm{GeV}^2$ (untagged)

$|t|$ dependence:

Probes region $|t| > M^2_{J/\psi}$ for the first time

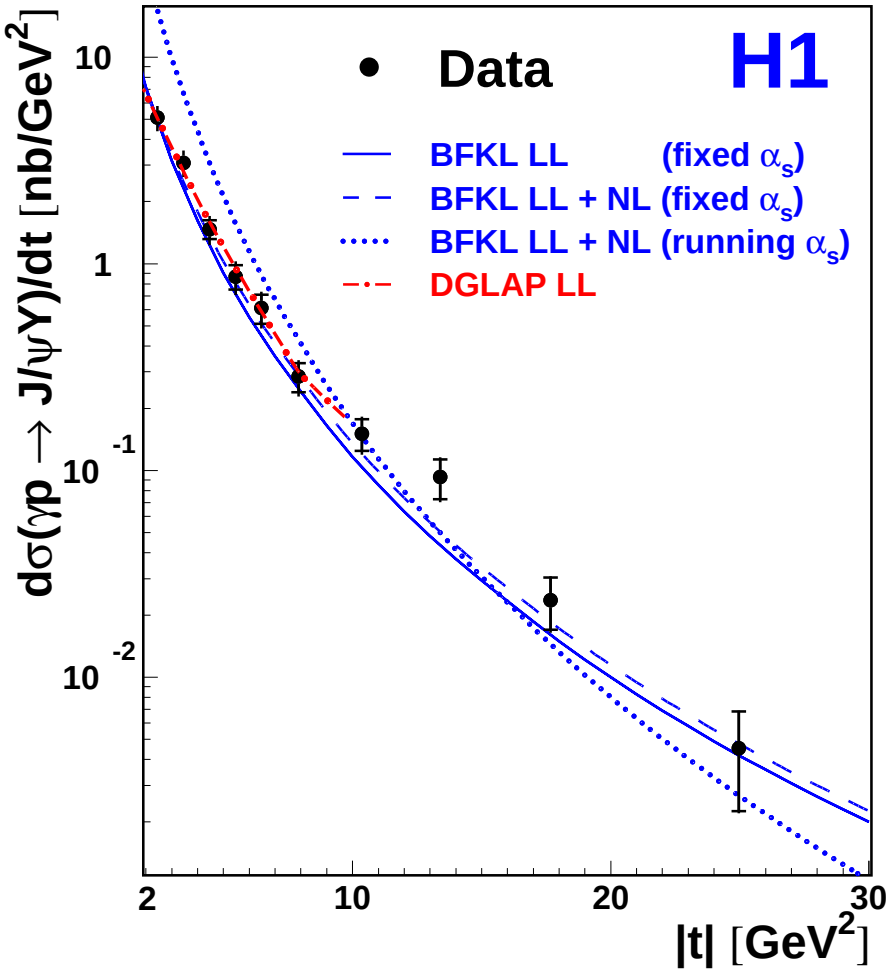
Large $|t|$ dependence: $\frac{d\sigma}{dt} \sim |t|^{-n}$

$\Rightarrow n_{J/\psi} \approx 3.00$ for $|t| > 3.5\,\mathrm{GeV}^2$

Fixed $\alpha_s$ BFKL models well describe the data

But prescription for running $\alpha_s \Rightarrow$ steeper $|t|$

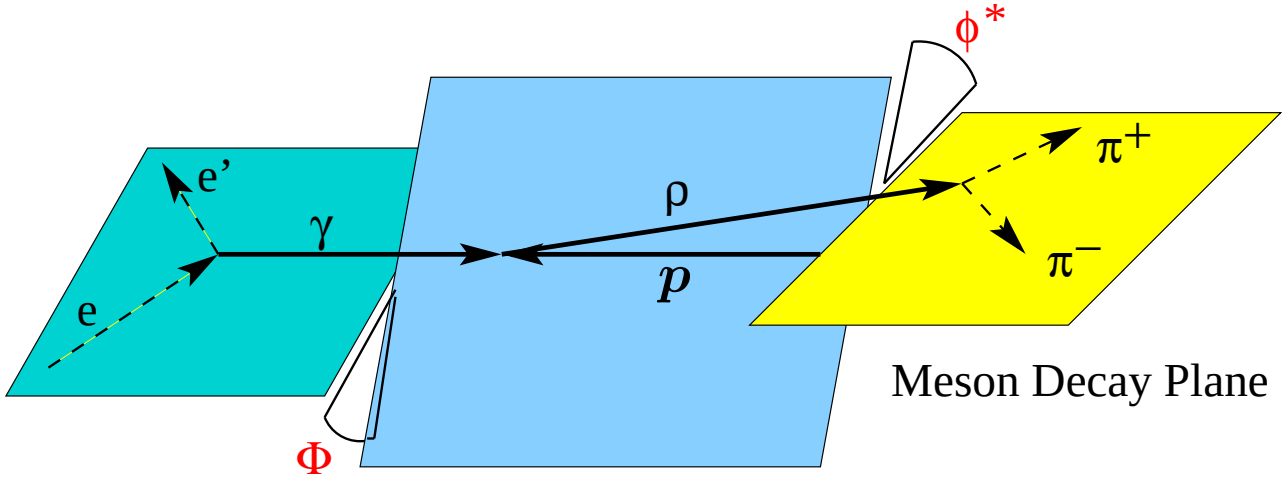
DGLAP describes data where valid $(|t| \leq M_V^2)$

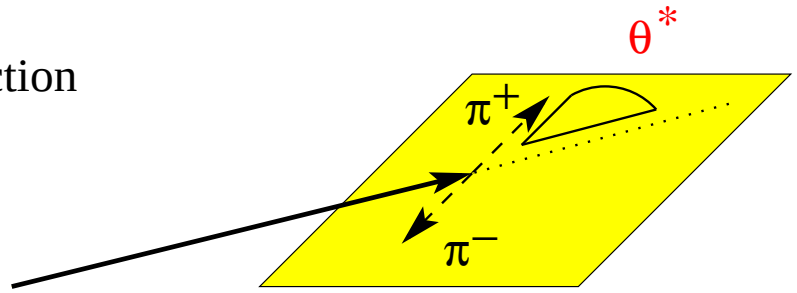


# Helicity Studies: Testing the Meson WF

Perform a boost into $\gamma p$ CoM frame $\Rightarrow$ can measure angular decay distributions ($\theta^\star$, $\phi^\star$ & $\Phi$)

Extracting "spin density matrix elements" (SDMEs) $\Rightarrow$ provides a test of vector meson WF!



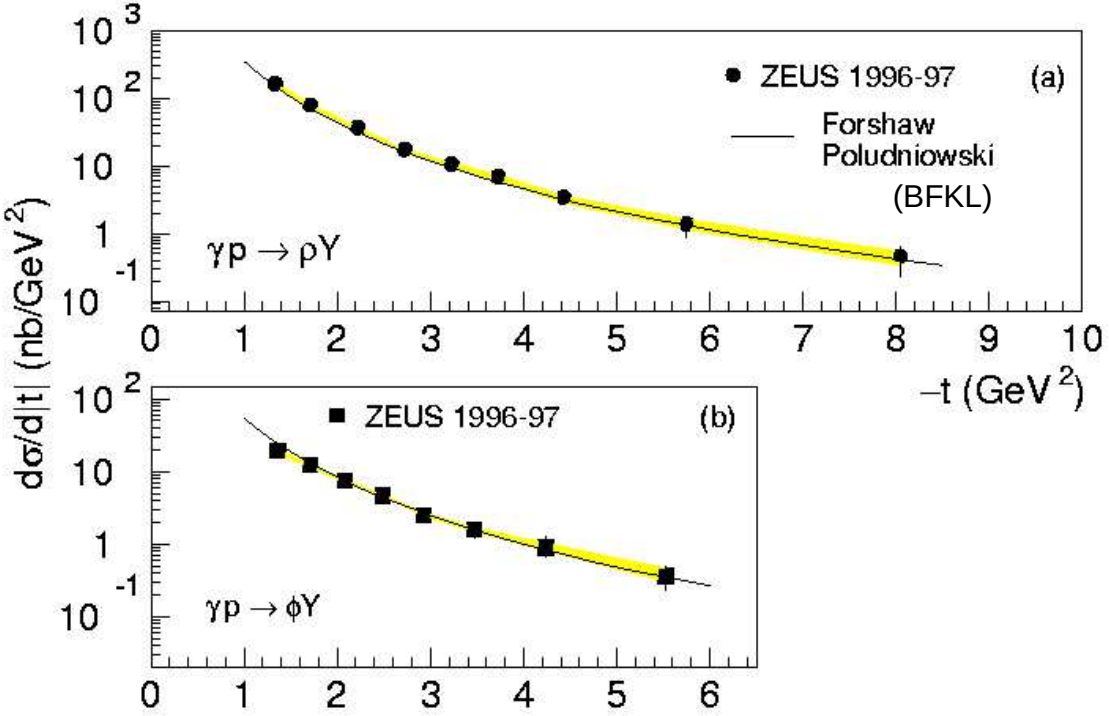

Helicity = component of spin along direction ρ of the particle's motion

Heavy $J/\psi$ consistent with SCHC $\Rightarrow$ Simple meson WF assumptions appear satisfactory

Lighter $\rho$ violates SCHC ($s$ channel helicity conservation) $\Rightarrow$ more complicated WF needed?

# *Light Vector Meson Photoproduction at High $|t|$*

ZEUS have measured $\rho$ & $\phi$ using $\mathcal{L} = 25\,\mathrm{pb}^{-1}$ with $Q^2 < 0.02\,\mathrm{GeV}^2$ (tagged)




$|t|$ dependence:

Large $|t|$ dependence: $\frac{d\sigma}{dt} \sim |t|^{-n}$

$\Rightarrow n \sim 3$ for both $\rho$ & $\phi$

BFKL describes $|t|$ dependence well

(using only simple vector meson WF)

Predictions for the full "lightcone" VM wavefunctions have recently become available

(These are necessary to simultaneously describe the high $|t|$ behaviour and SDMEs)

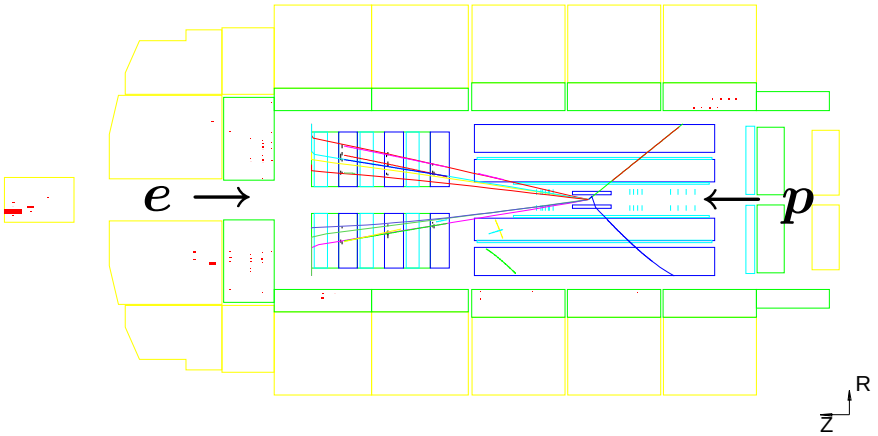
Light VMs can provide important information on these as yet unmeasured WFs!

# High $|t|$ $\rho$ Event Selection

2000 data $\Rightarrow \mathcal{L} \approx 48\,\mathrm{pb}^{-1}$

Photoproduction: $\gamma p \rightarrow \rho Y$

Decay: $\rho \rightarrow \pi^+\pi^-$ (∼100%)




Cuts:

1. Photoproduction with $e'$ detected in 44 m tagger $\Rightarrow Q^2 < 0.01\,\mathrm{GeV}^2$
   $\Rightarrow 70 < W_{\gamma p} < 115\,\mathrm{GeV}$
2. Two good oppositely charged tracks (one with $P_t > 0.4\,\mathrm{GeV}$ to fire trigger)
3. Both must be detected within the central region ($20 < \theta < 160^\circ$)
4. $|t| > 1\,\mathrm{GeV}^2$ (dissociative) where $|t| \approx P_{t,\rho}^2$ in photoproduction
5. Require $\Delta\eta > 2$ for diffractive processes ($\eta = -\ln\left(\tan\frac{\theta}{2}\right)$)
6. No neutral cluster with energy above $0.4\,\mathrm{GeV}$ (noise level)
7. Mass cuts: $0.6 < M_{\pi\pi} < 1.1\,\mathrm{GeV}$ and $M_{KK} > 1.04\,\mathrm{GeV}$ $(\phi \rightarrow K^+K^-)$

Number of events selected $\sim 21000$

# $M_{\pi\pi}$ and $|t|$ Distributions

Invariant mass $(M_{\pi\pi})$:

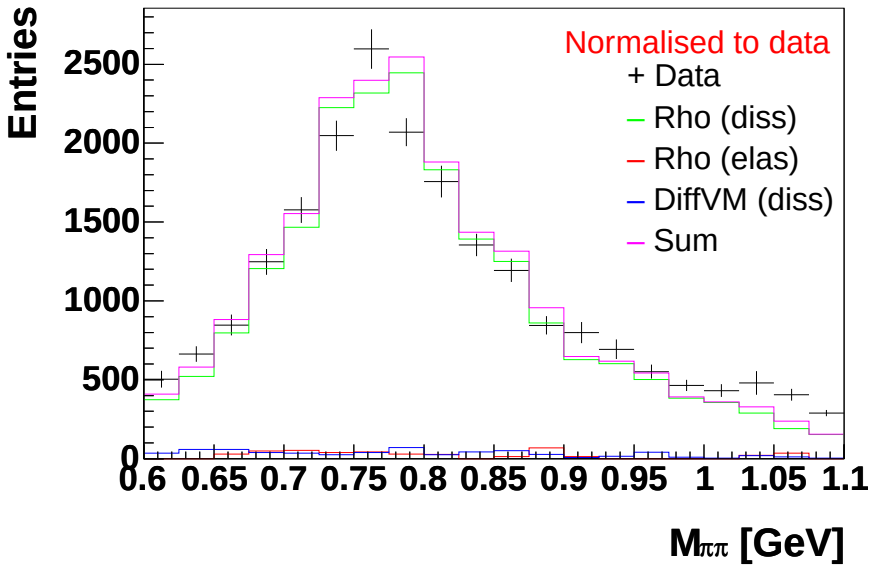
DiffVM uses a non-rel BW for $\rho$ line shape

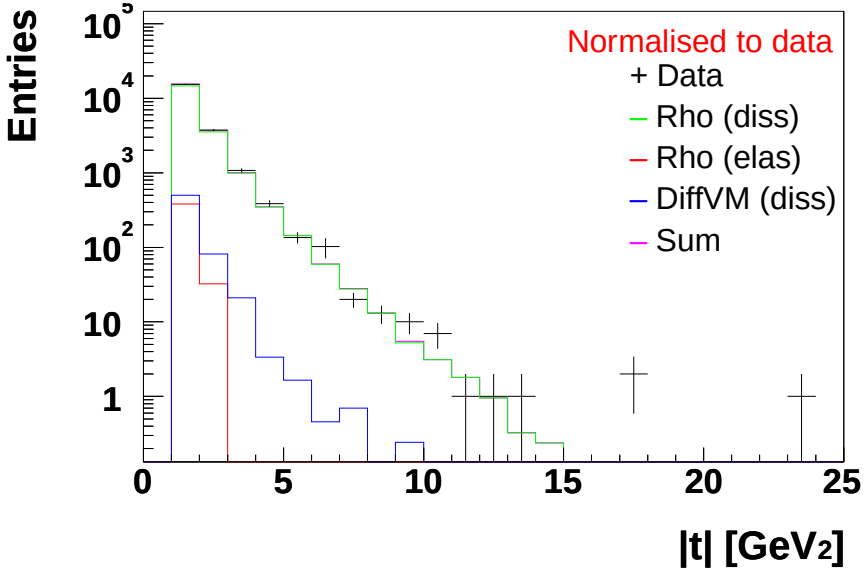
$\Rightarrow$ Convert to a relativistic BW distribution

+

Incorporate skewing effects (Ross-Stodolsky)

$\Rightarrow$Accounts for non-resonant $\pi$ production




$|t|$ slope:

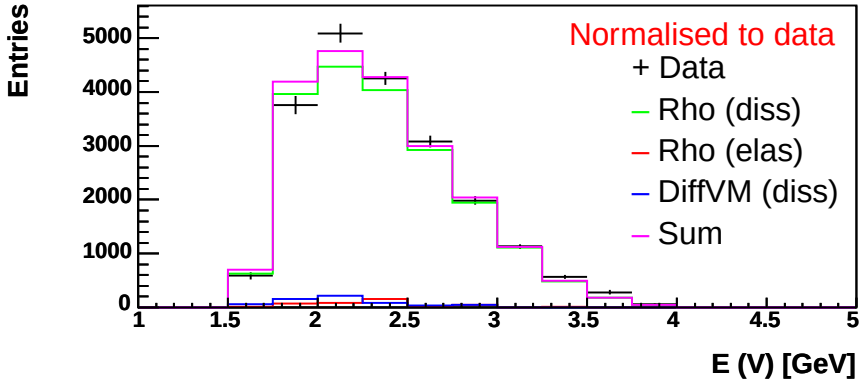
MC generated with a shallow $|t|$ slope

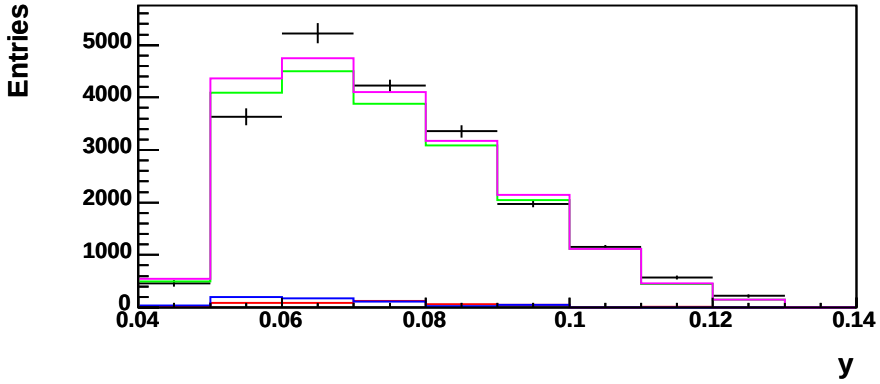
$\Rightarrow$Produces more statistics at high $|t|$

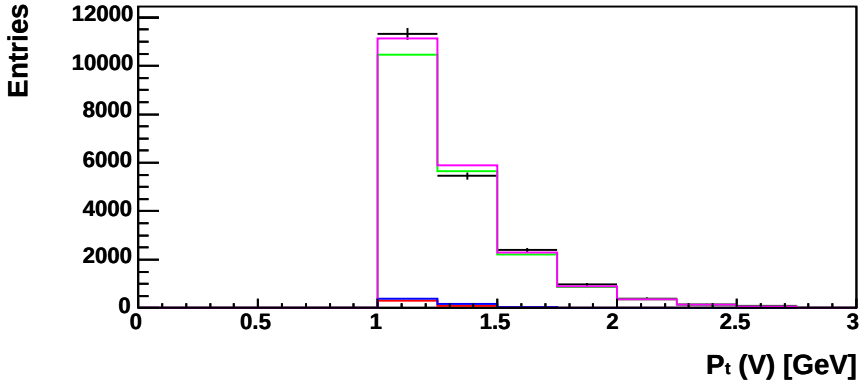
$\Downarrow$

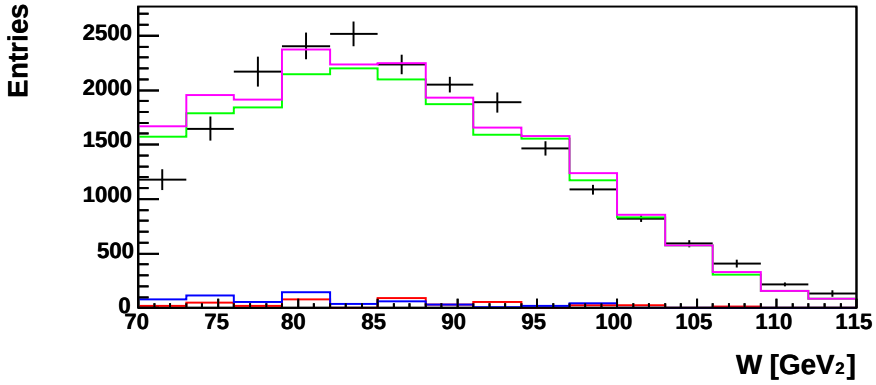
Has been re-weighted to describe the observed $|t|$ distribution of the data

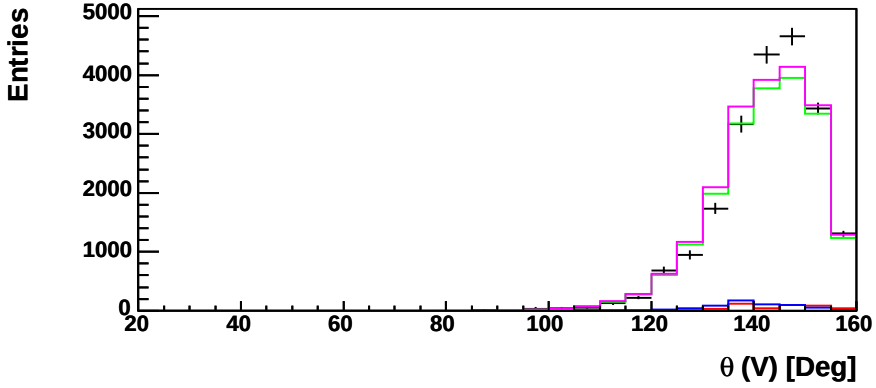
# Control Plots

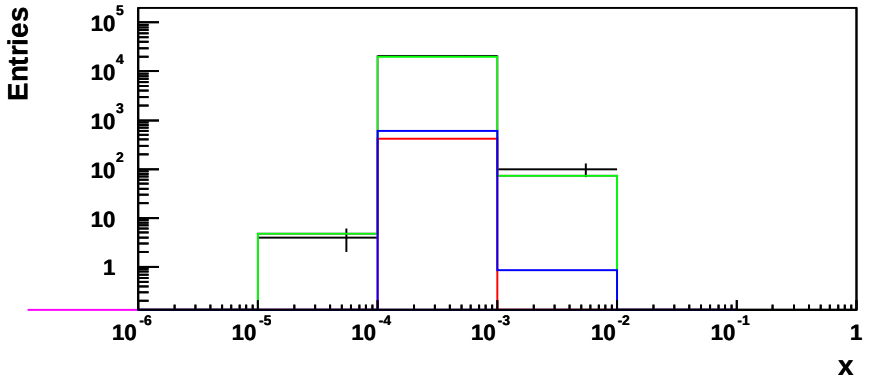


# Preliminary Cross Section

$\gamma p$ cross section:

$$\frac{d\sigma(\gamma p \to \rho Y)}{d|t|} = \frac{1}{F(y,Q^2)} \frac{d\sigma(ep \to \rho Y)}{d|t|}$$

$$= \frac{1}{F(y,Q^2)} \frac{N_{data}(t)}{\mathcal{L} A \Delta t}$$

Weizsäcker-Williams flux:

$F(y,Q^2)$ = Correction for effective $\gamma$ flux =

$$\frac{\alpha}{2\pi} \log\left(\frac{Q^2_{max}}{Q^2_{min}}\right) \left[1 + (1-y)^2\right] \log\left(\frac{y+dy}{y-dy}\right)$$

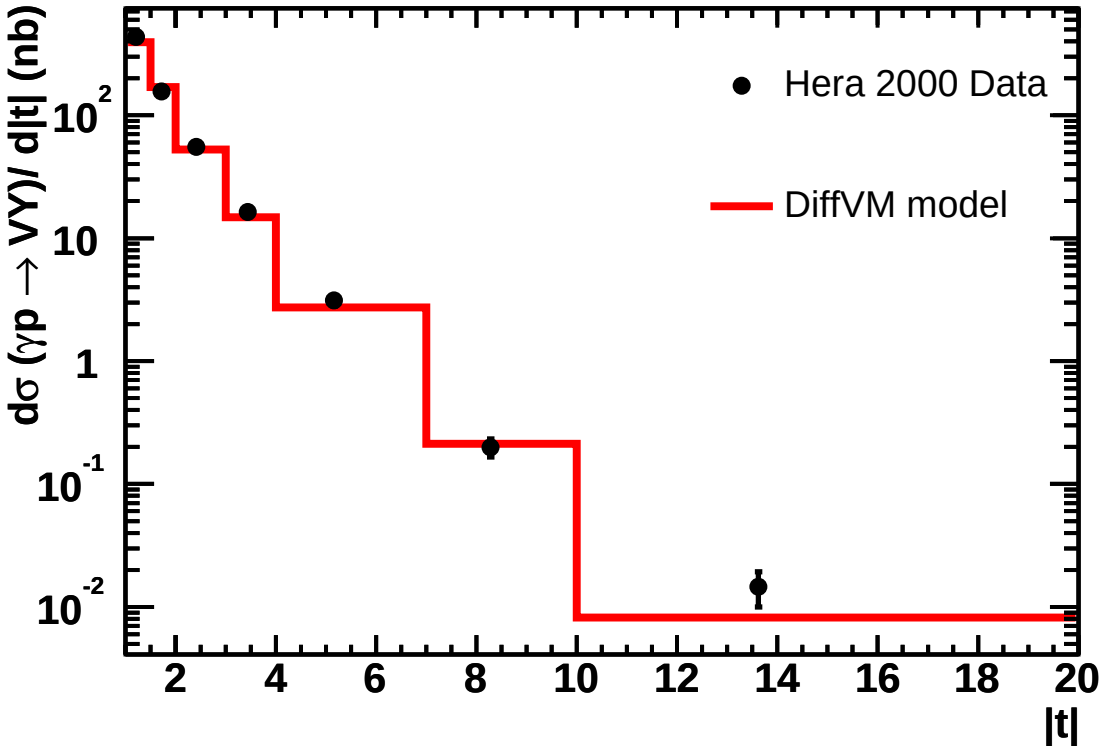
Prescaled luminosity: $\mathcal{L} \approx 23\ \mathrm{pb}^{-1}$

Included:

1. Acceptance correction ($A$)
2. Background subtractions
3. Bin centre corrections

MC tuned to describe $|t|$ dependence

Still to do: Trigger efficiency corrections



# Summary

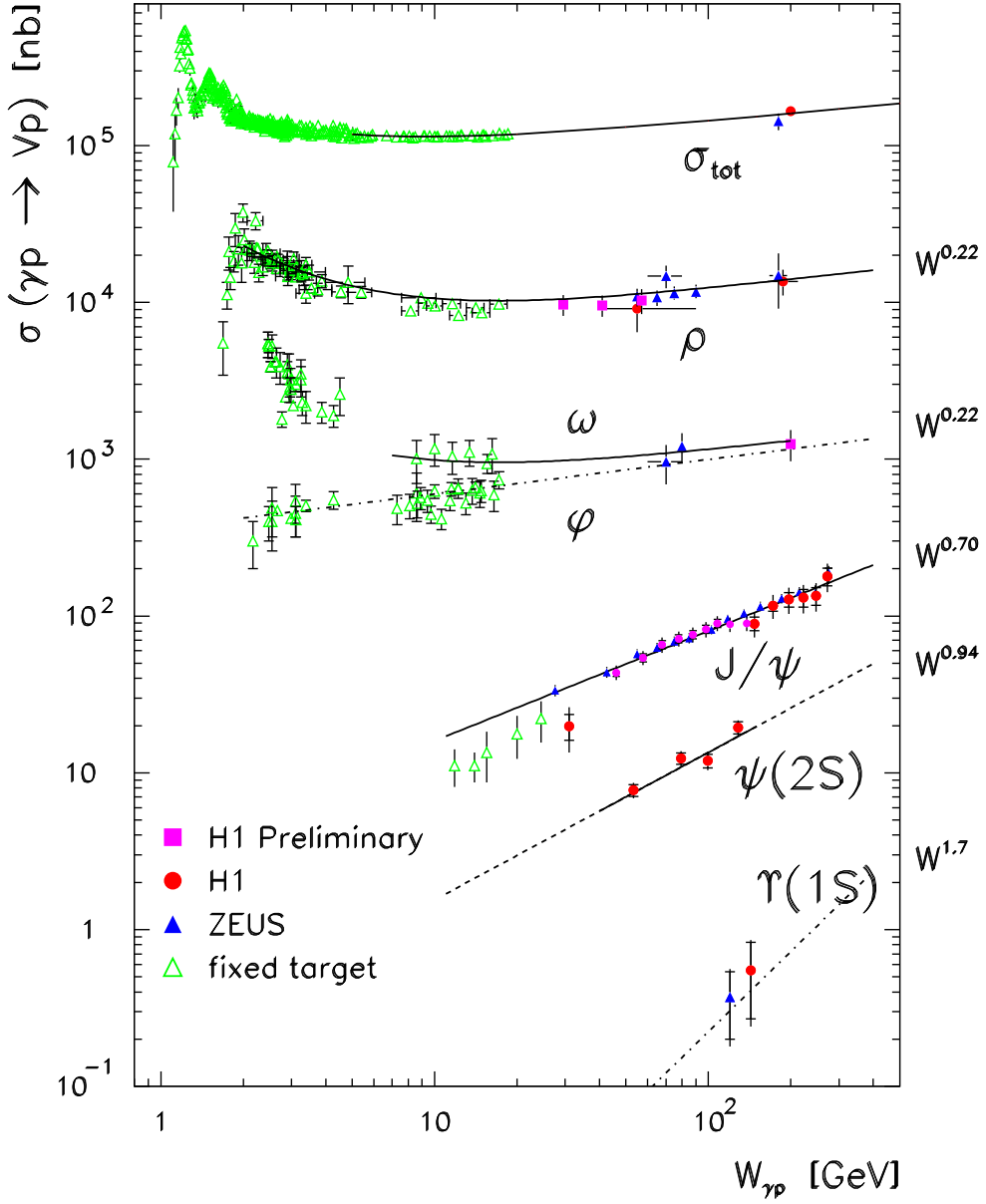
General:

- High $|t|$ VMs are the ideal place to study BFKL dynamics
- Predictions for full "lightcone" VM wavefunction now available
- Light VMs provide information on these as yet unmeasured WFs
- Clean experimental signal with low backgrounds

Analysis:

- A sample of $\sim$ 21000 $\rho$ events $(|t| > 1\ \mathrm{GeV}^2)$ selected
- Initial measurement of differential cross section with $|t|$
- Measurement of SDMEs will test light meson WF assumptions
- Intend to extend analysis to look at $\phi$ mesons in addition

# Elastic Vector Meson Photoproduction




Elastic and photoproduction

$\Rightarrow$ Both $|t|$ and $Q^2$ small

Light Vector Mesons $(\rho, \omega, \phi)$:

Observed dependence $\sigma \sim W^{0.22}$

$\Rightarrow$ Consistent with soft $IP$ expectation which comes out of Regge theory

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

Steeper rise in cross section observed

$\Rightarrow$ Need something in addition to soft $IP$

What about QCD?

# BFKL & DGLAP Evolution

1. DGLAP LL: sums terms in $\alpha_s^n \log^n(Q^2)$

Strong $k_T$ ordering: $k_{T,i}^2 \ll k_{T,i+1}^2 \ll \ldots \ll Q^2$

Weak long. mom ordering: $x_i > x_{i+1} > \ldots > x$

Used to evolve quark and gluon PDFs in $Q^2$

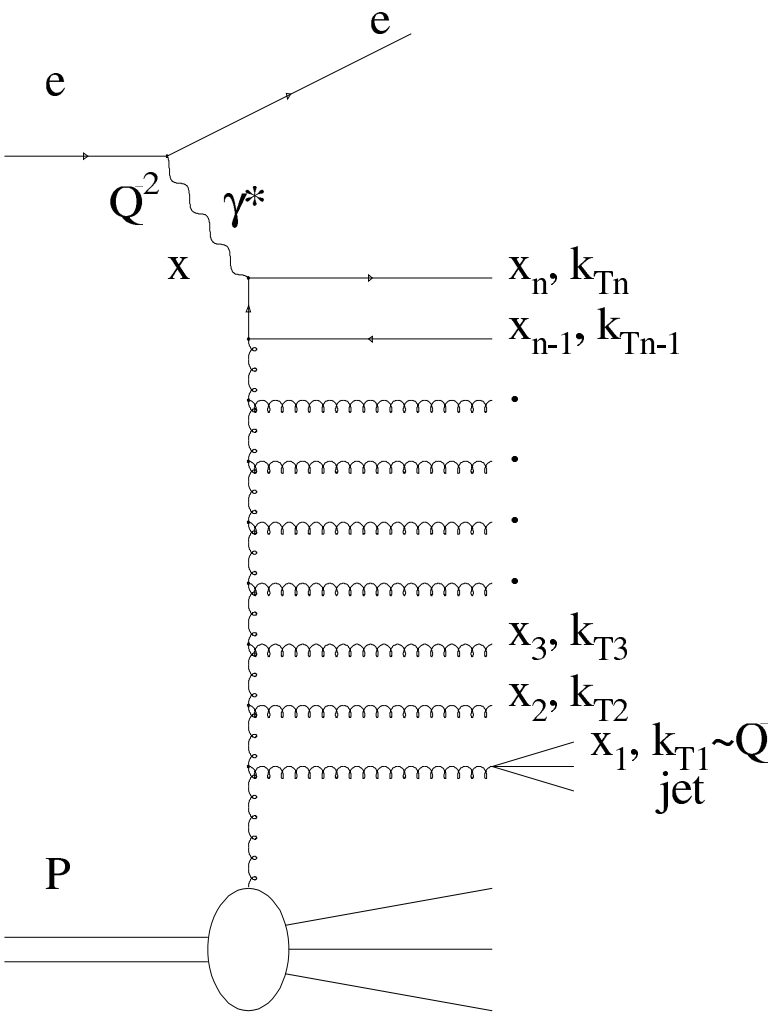
Fails at low $x$!

2. BFKL LL: sums terms in $\alpha_s^n \log^n(1/x)$

No ordering in $k_T \Rightarrow$ "random walk" . . . but . . .

Strong long. mom ordering: $x_i \gg x_{i+1} \gg \ldots \gg x$

Both predict fast rise in cross section with $W$




High $|t|$ vector mesons $\Rightarrow$ ideal place to test BFKL dynamics

# Helicity in High $|t|$ $J/\psi$ Photoproduction

Untagged electron:

Can only measure 2 angular distributions $\theta^\star$ & $\phi^\star$

$\Rightarrow$ Provides access to 3 indep linear combos

of "spin density matrix elements (SDMEs)"

$s$ channel helicity conservation (SCHC)

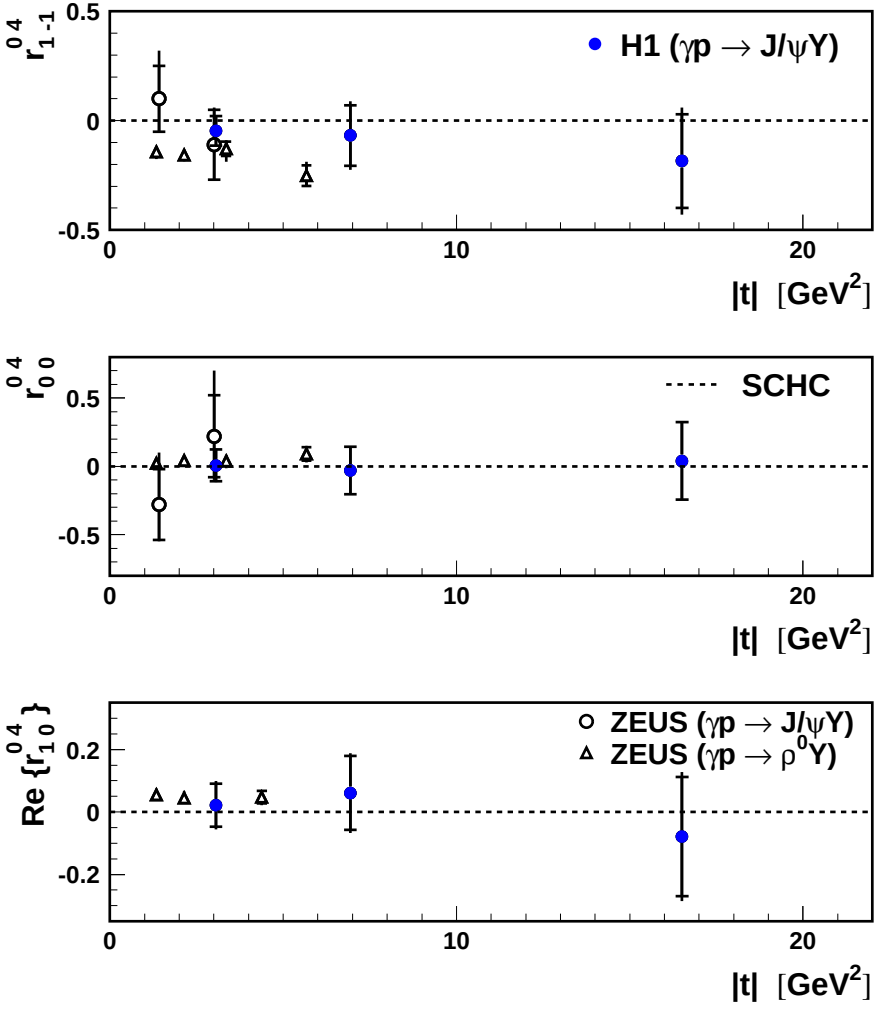
$\Rightarrow$ Vector meson retains helicity of photon

$\Rightarrow$ All 3 combos of SMDEs predicted to be zero

$J/\psi$ data consistent with zero & therefore SCHC

$\Rightarrow$ Simple WF assumptions appear satisfactory

Spin density matrix elements




In contrast $\rho$ is not consistent with zero $\Rightarrow$ SCHC is violated $\therefore$ more complicated WF needed?

# Background Processes

Several possible processes can fake a signal of two oppositely charged tracks:

| | |
|---|---|
| $\phi \longrightarrow K^+K^-$ | Two charged kaons fake pions and therefore $\rho$ |
| $\omega \longrightarrow \pi^+\pi^-\pi^0$ | Neutral pion undetected & charged pions fake $\rho$ |
| $\rho' \longrightarrow \rho^\pm\pi^\mp\pi^0$ | Opp charged pions from two-stage decay fake $\rho$ |
| $\hookrightarrow \pi^\pm\pi^0$ | and both neutral pions remain undetected |

Also treating small ($|t| \leq 3$) elastic $\rho$ contribution as a background