Elastic J/ψ production at HERA

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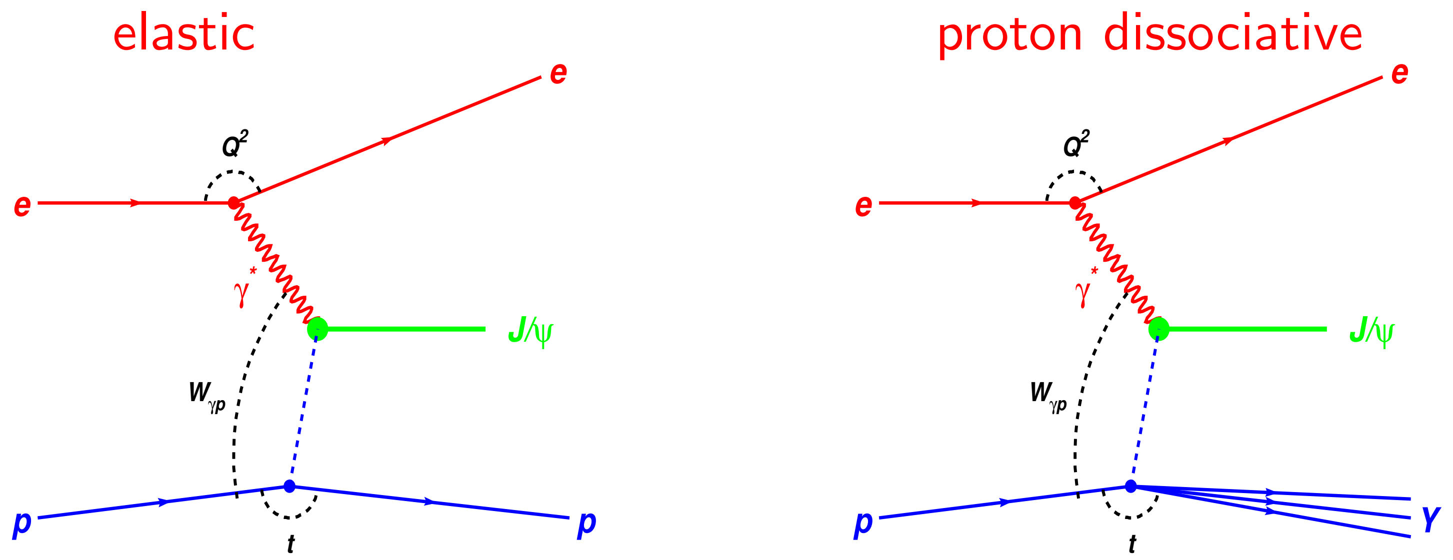
Introduction

Diffractive Vector Meson Production



Q^2 : Photon Virtuality

Photoproduction: $Q^2 \sim 0$

Electroproduction: $2 < Q^2 < 80$ GeV^2

t : (4-momentum transfer)^2 at p vertex $0 < |t| < 1.2$ GeV^2

Proton dissociates: large $|t|$

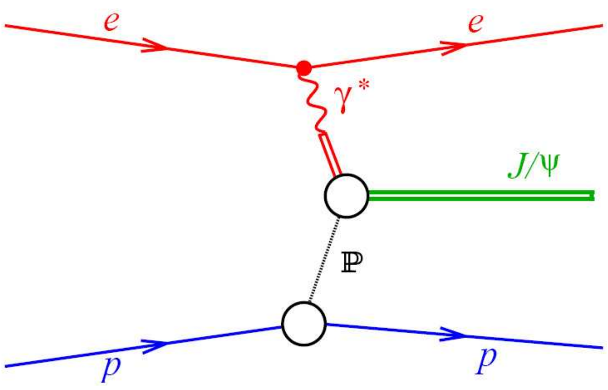
W : CM-energy of γp system

Photoproduction: $40 < W < 305$ GeV

Electroproduction: $40 < W < 160$ GeV

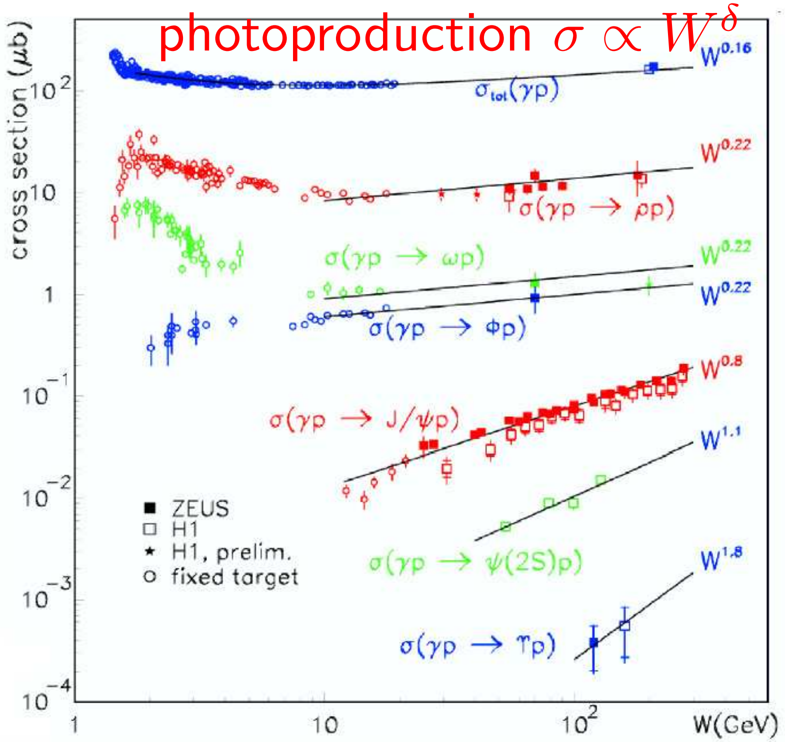
Diffractive Vector Meson Production Models

Regge Model:



- Soft Pomeron exchange
  $\alpha_P(t) = \alpha_{P0} + \alpha'_P \cdot t$
- Slow rise of σ with increasing W
  $\sigma \propto W^{0.22}$
- Shrinkage
  $\frac{d\sigma}{dt} \propto e^{bt}$, $b = b(W_0) + 4\alpha'_P \cdot ln(\frac{W}{W_0})$
- S-channel helicity conservation (SCHC)

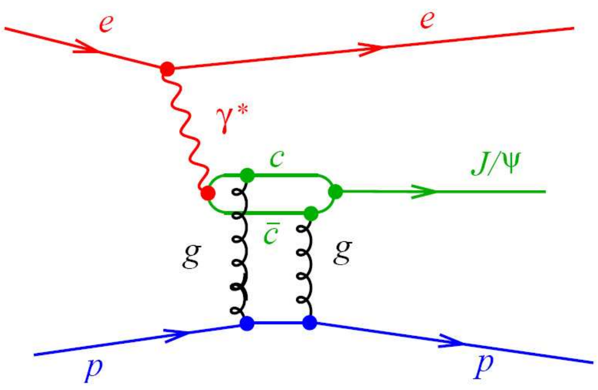
photoproduction $\sigma \propto W^\delta$



- ρ, ω, ϕ show Regge behaviour
  $\sigma \propto W^{0.22}$
- J/ψ is not described by Regge
  $\sigma \propto W^{0.80}$

Increasing M^2_{VM}:
Regge-Model $\longrightarrow$ pQCD Model

pQCD Model:



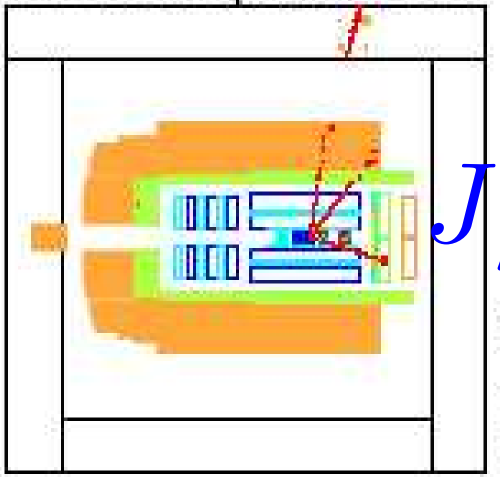
- Exchange of at least 2 gluons
- Steeper rise of σ with increasing W
  $\sigma \propto [x \cdot g(x, Q^2_{eff})]^2$,
  $x = 4Q^2/W^2$, $Q^2_{eff} = (Q^2 + M^2_\psi)/4$
- No or weak shrinkage

pQCD needs hard scale: Q^2, M^2_{VM}, t

- MRT (Martin, Ryskin and Teubner)
  - skewed gluon distribution (x $\neq$ x′)
  - parton-hadron duality approach
  - predicts W and Q^2 dependence
- FMS
  (Frankfurt, McDermott, Strikman)
  - skewed gluon distribution
  - dipole approach
  - predicts W dependence

Data Analysis

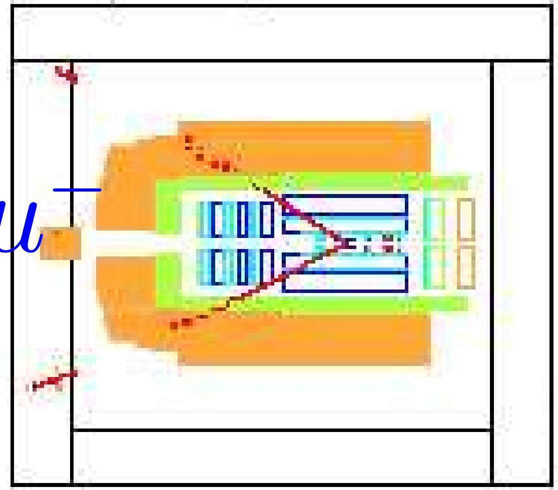
TT electroproduction



2 tracks
≥ 1 muon
scatt. positron

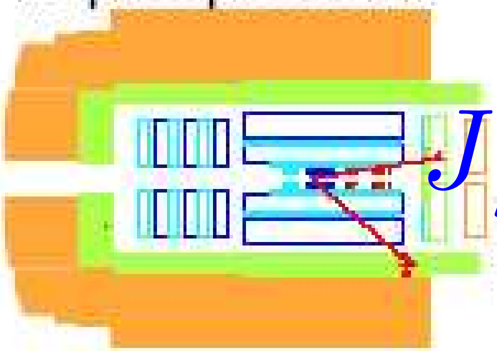
$$J/\psi \rightarrow \mu^+\mu^-$$

TT photoproduction



2 tracks
≥ 1 muon

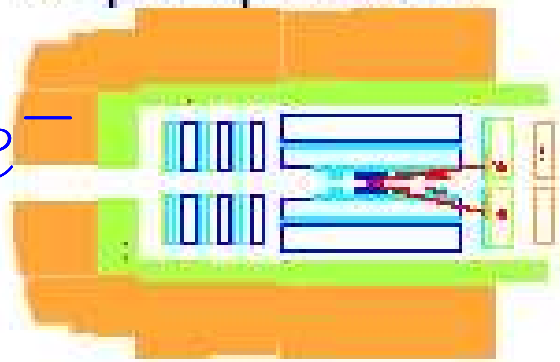
TC photoproduction



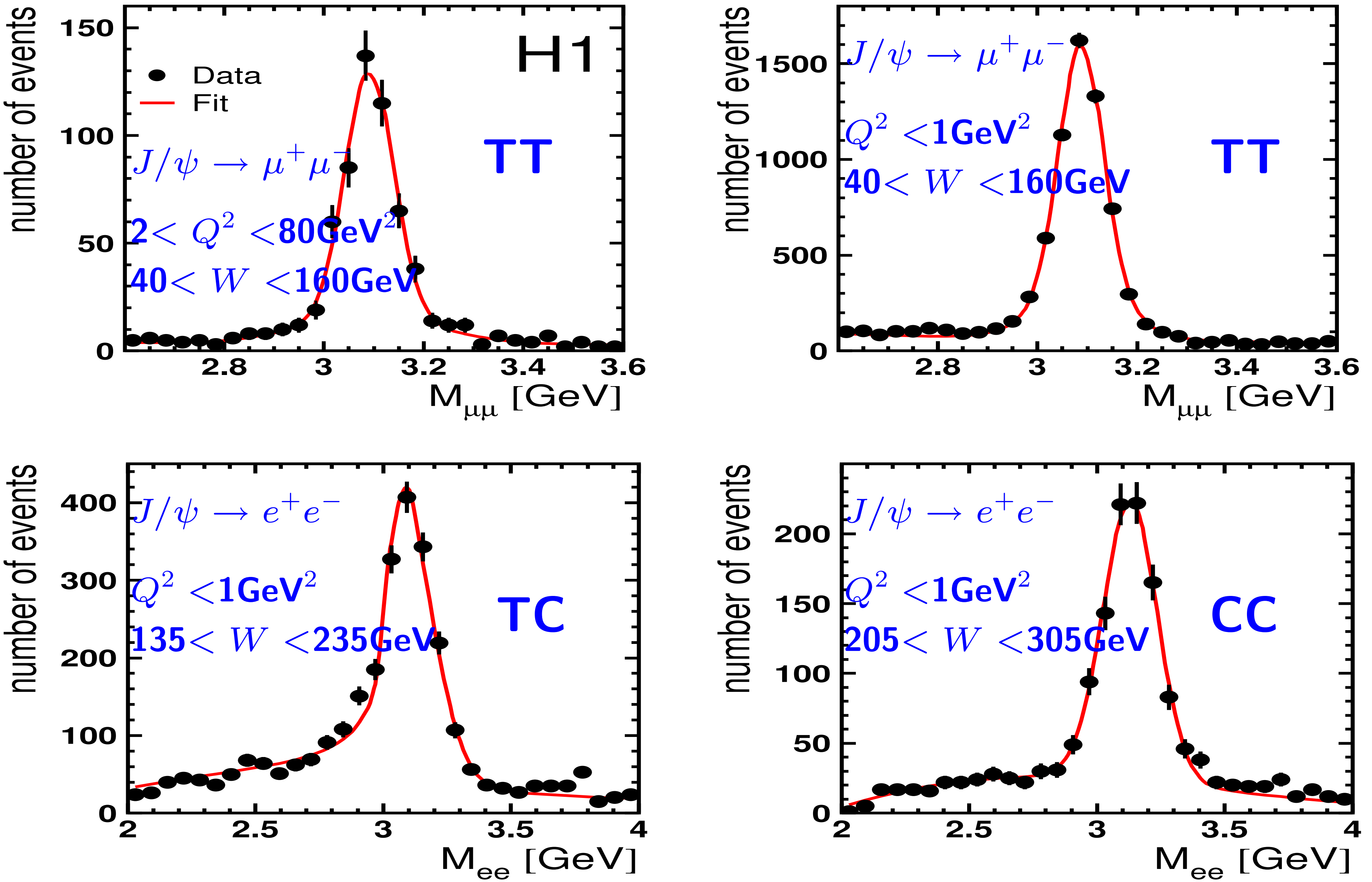
1 track
1 cluster

$$J/\psi \rightarrow e^+e^-$$

CC photoproduction



2 clusters


H1
Data
Fit
number of events
$J/\psi \rightarrow \mu^+\mu^-$
$2< Q^2 <80\mathrm{GeV}^2$
$40< W <160\mathrm{GeV}$
TT
$M_{\mu\mu}$ [GeV]
$J/\psi \rightarrow \mu^+\mu^-$
$Q^2 <1\mathrm{GeV}^2$
$40< W <160\mathrm{GeV}$
TT
$M_{\mu\mu}$ [GeV]
$J/\psi \rightarrow e^+e^-$
$Q^2 <1\mathrm{GeV}^2$
$135< W <235\mathrm{GeV}$
TC
M_{ee} [GeV]
$J/\psi \rightarrow e^+e^-$
$Q^2 <1\mathrm{GeV}^2$
$205< W <305\mathrm{GeV}$
CC
M_{ee} [GeV]

Cross Section Determination

$$\sigma(\gamma p \to J/\psi p) = \frac{N_{notag}\cdot(1-f_{\psi(2S)})\cdot(1-f_{pdis})}{\epsilon\cdot BR\cdot\mathcal{L}\cdot\Phi_\gamma}$$

N_{notag}: the number of signal events without forward tag.

$f_{\psi(2S)}$: contamination from $\psi(2S)$

f_{pdis}: correction from proton dissociation

ϵ : total efficiency

BR : $BR(J/\psi \to \mu\mu) = (5.88 \pm 0.10)\%$

$BR(J/\psi \to ee) = (5.93 \pm 0.10)\%$

$\mathcal{L}$: luminosity

Φ_γ : integrated photon flux

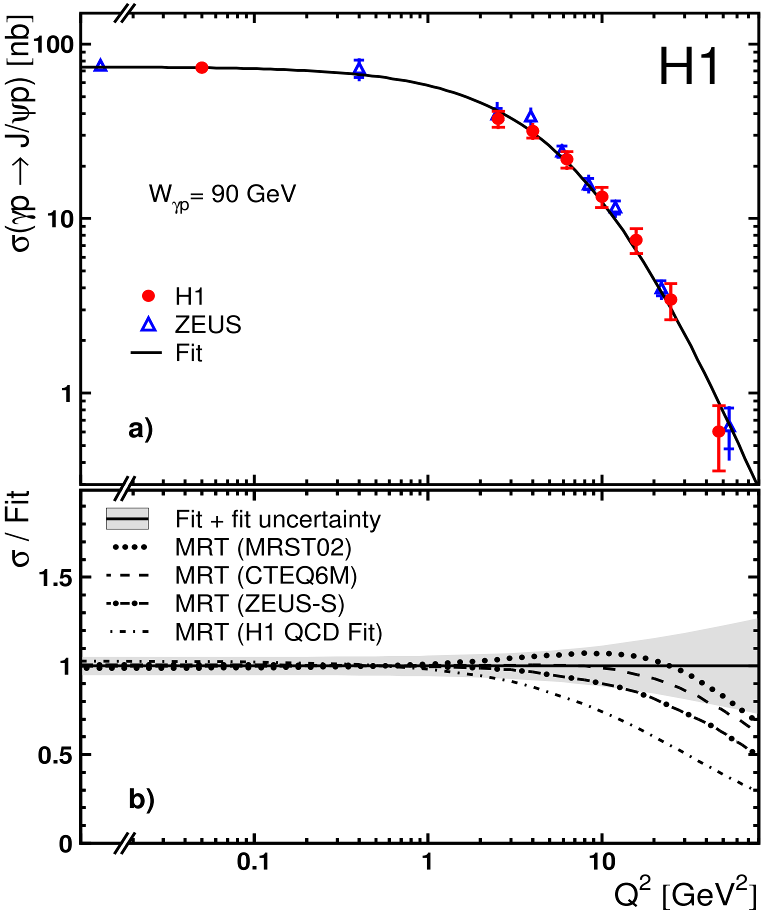
Systematic uncertainties:

- the track reconstruction efficiency
- the lepton identification efficiency
- the trigger efficiency
- the separation of elastic events from proton dissociation
- $\cdots\cdots$

The total systematic uncertainties on the cross section are 8% (TT in electroproduction), 9% (TT in photoproduction), 10% (TC) and 11% (CC), respectively.

Results

Q^2 Dependence



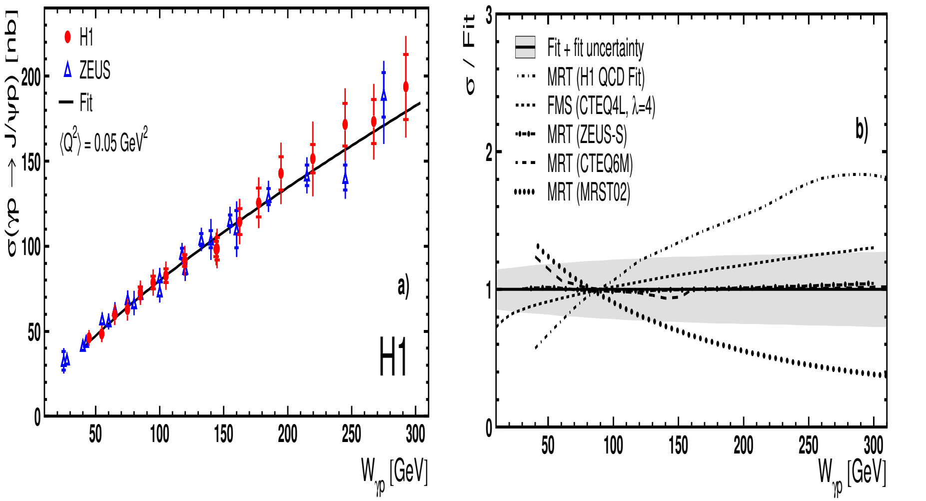
Fit: $\sigma \propto (M_{J/\psi}^2 + Q^2)^{-n}$

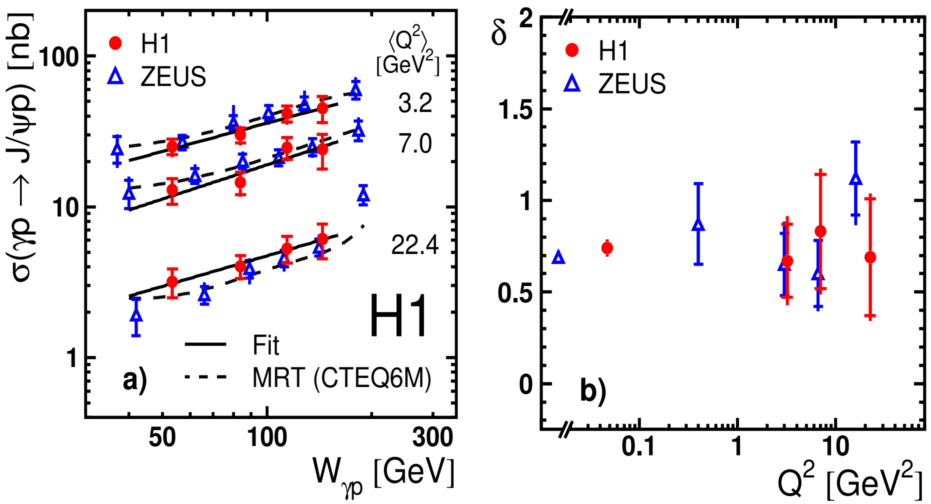
yields: $n = 2.486 \pm 0.080 \pm 0.068$

$$\chi^2/ndf = 0.5$$

- H1 and ZEUS: in good agreement
- At large Q^2, data sensitive to gluon distribution

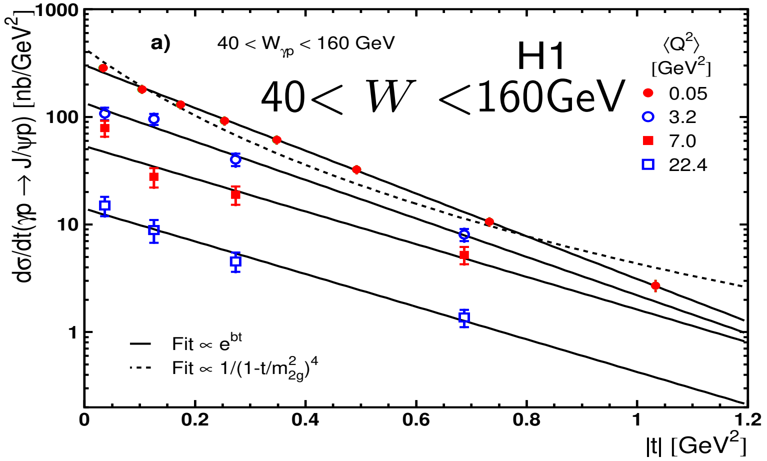
W Dependence

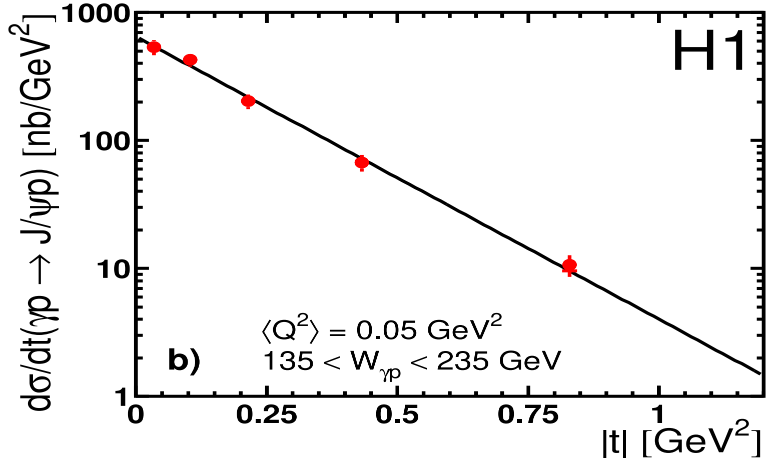


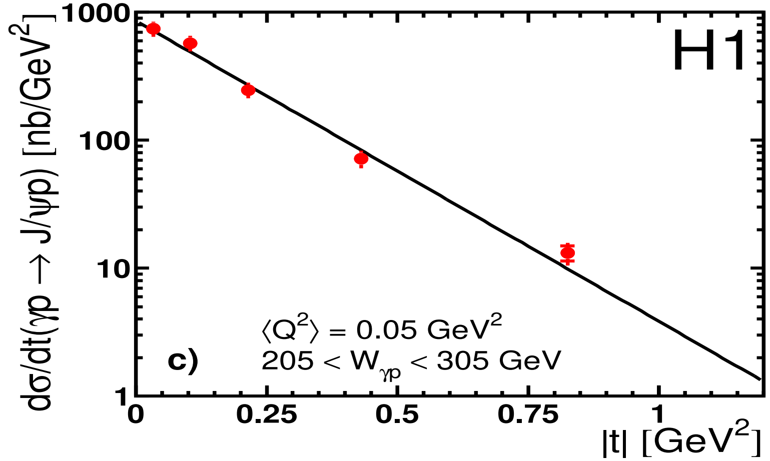


- $\sigma \propto W^{\delta}$
- photoproduction:(40$<W<$305GeV)
  - δ: $\delta = 0.75 \pm 0.03 \pm 0.03$
    $\delta = 0.69 \pm 0.02 \pm 0.03$ (ZEUS)
  - pQCD calculations strongly depend on gluon distribution
- electroproduction: (40$< W <$ 160GeV)
  - The resulting δ is consistent with that in photoproduction
  - pQCD calculation based on CTEQ6M describe data
- No Q^2 dependence of δ is observed

t Dependence (photo- and electroproduction)





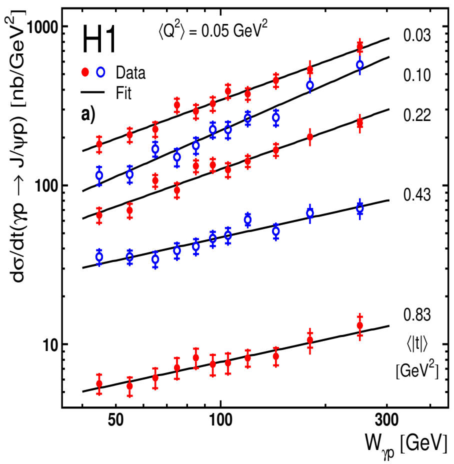


- Date well described by simple exponential
  $\frac{d\sigma}{dt} \propto e^{bt}; \qquad \chi^2/ndf = 0.25$

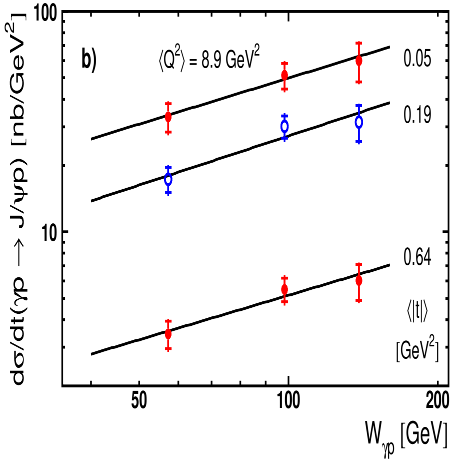
- Dipole form disfavoured
  $\frac{d\sigma}{dt} \propto (1-t/m^2_{2g})^{-4}; \;\; \chi^2/ndf = 5.5$

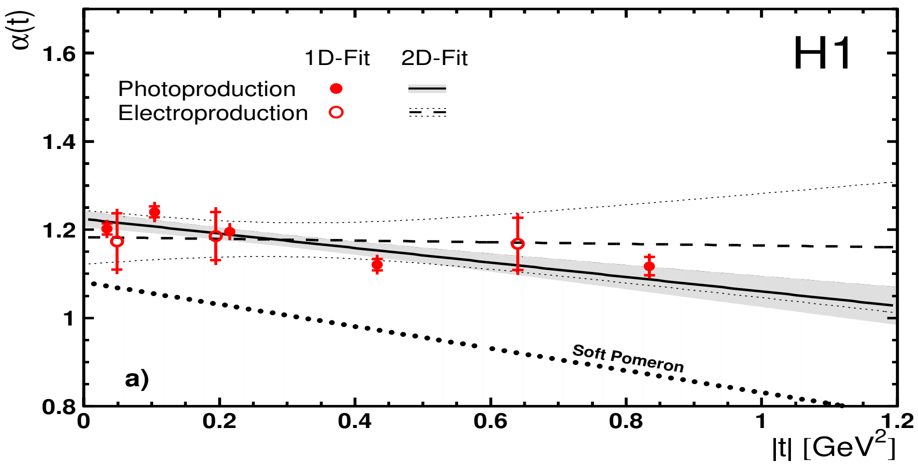
Effective Pomeron Trajectory $\alpha(t) = \alpha_0 + \alpha' \cdot t$

photoproduction



electroproduction



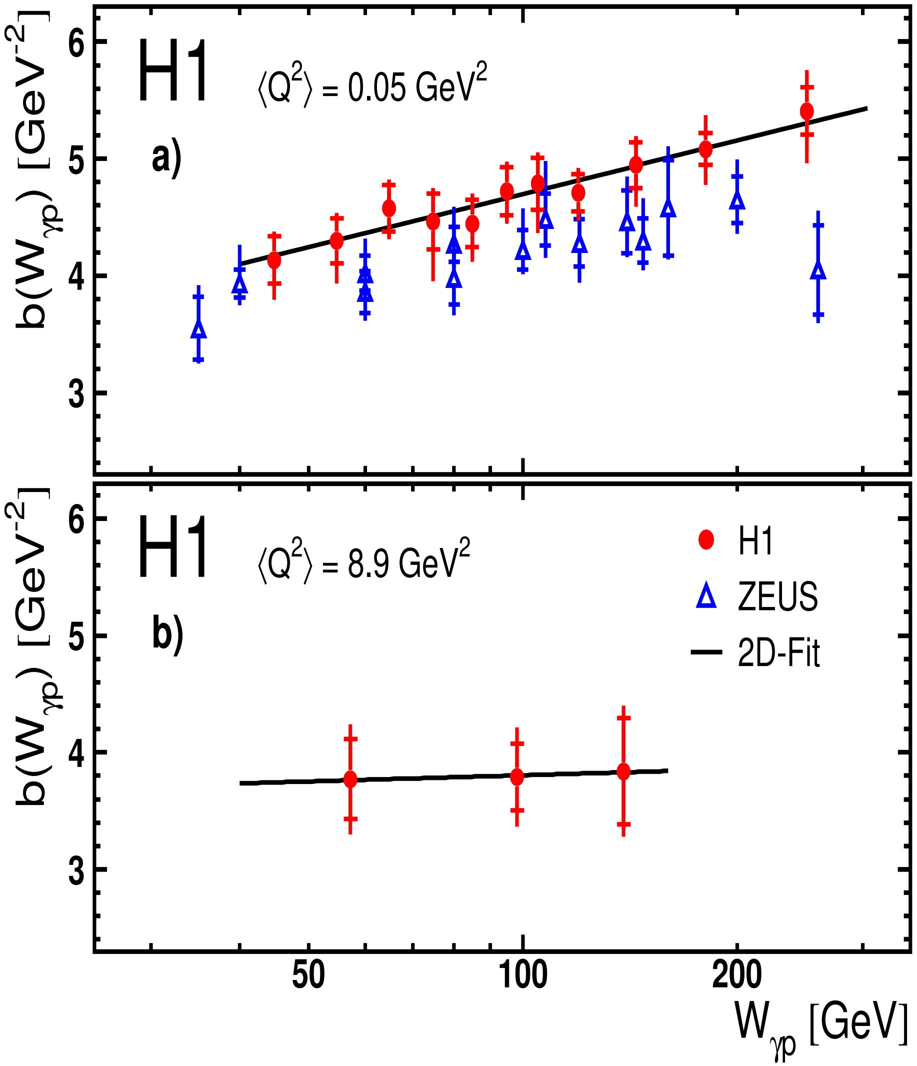


- One-dimensional fit:
  $\frac{d\sigma}{dt}(W) \propto W^{4(\alpha(<t>)-1)}$
  describe the data well
- Two-dimensional fit:
  $\frac{d\sigma}{dt} \propto e^{b_0 t}(\frac{W}{W_0})^{4(\alpha(t)-1)}$
  - photoproduction:
    $\alpha_0 = 1.224 \pm 0.010 \pm 0.012$
    $\alpha' = (0.164 \pm 0.028 \pm 0.030)$ GeV^{-2}
  - electroproduction:
    $\alpha_0 = 1.183 \pm 0.054 \pm 0.030$
    $\alpha' = (0.019 \pm 0.139 \pm 0.076)$ GeV^{-2}

Soft pomeron trajectory:

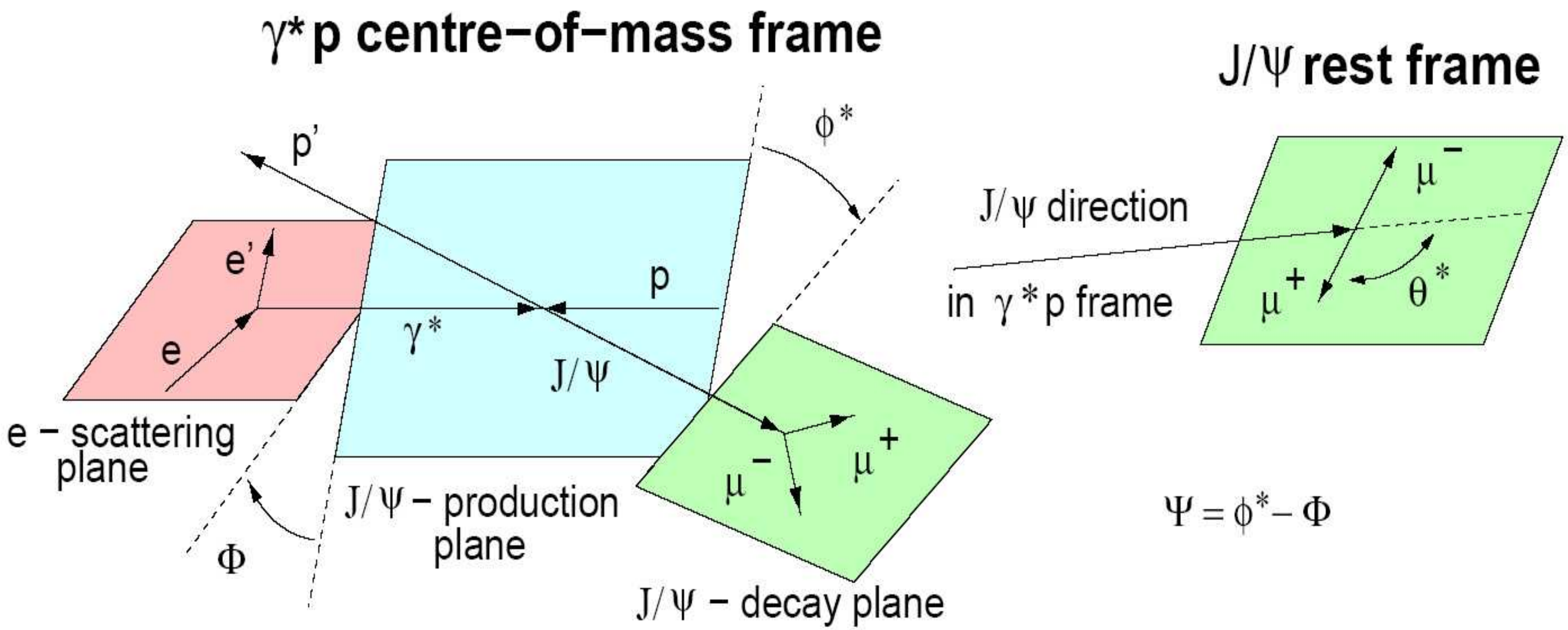
$\alpha(t) = 1.08 + 0.25$ Gev$^{-2} \cdot t$

Shrinkage

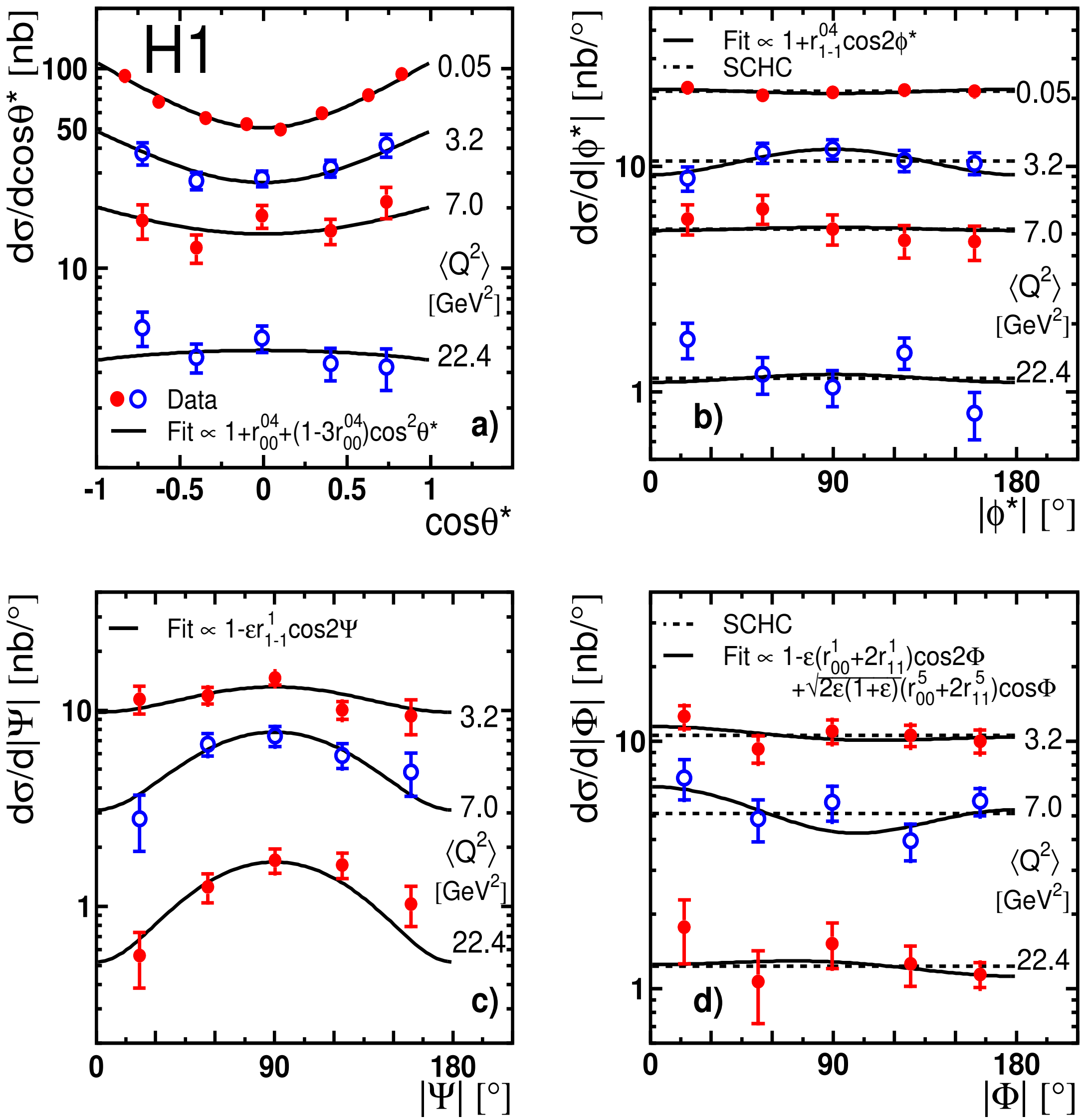


- One-dim. and two-dim. fit:
  one-dim. (data points):
  $$d\sigma/dt \propto e^{bt}$$
  two-dim. (lines):
  $$\frac{d\sigma}{dt} \propto e^{(b_0+4\alpha' ln(W/W_0))\cdot t}$$
- Similar W dependence of b seen from H1 and ZEUS
- Shrinkage seen in photoproduction
  the b values increase with W

Helicity Studies



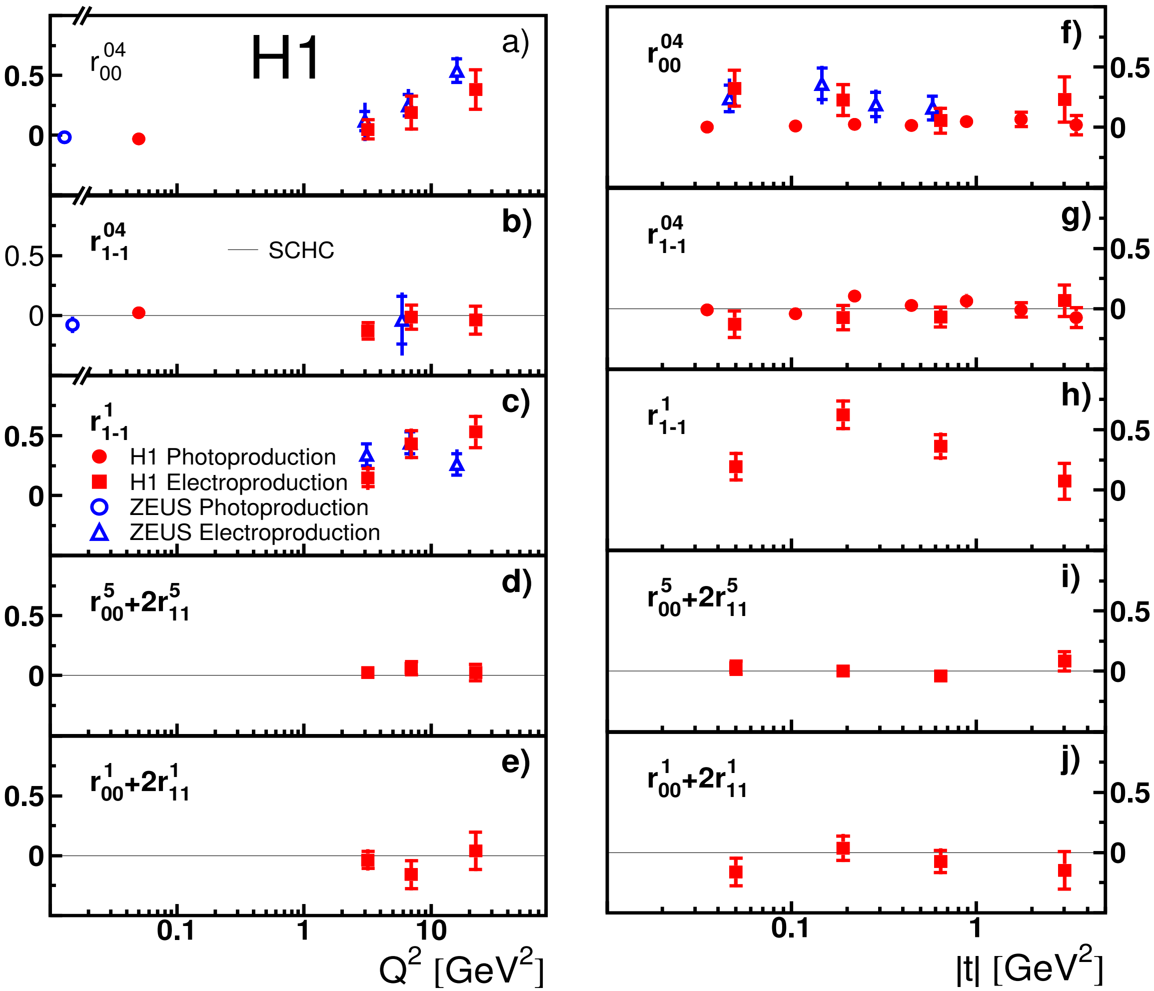
- SCHC: J/ψ keeps the helicity of the photon
- The SCHC can be tested by measurements of the angular distributions, θ^*, ϕ^*, Φ (Φ only measured in electroproduction)



solid line — fit to the data
dash line — SCHC prediction

- For ϕ^* and Φ, SCHC prediction is in agreement with data
- Extract the spin-density matrix elements by fitting the data

Spin-Density Matrix Elements



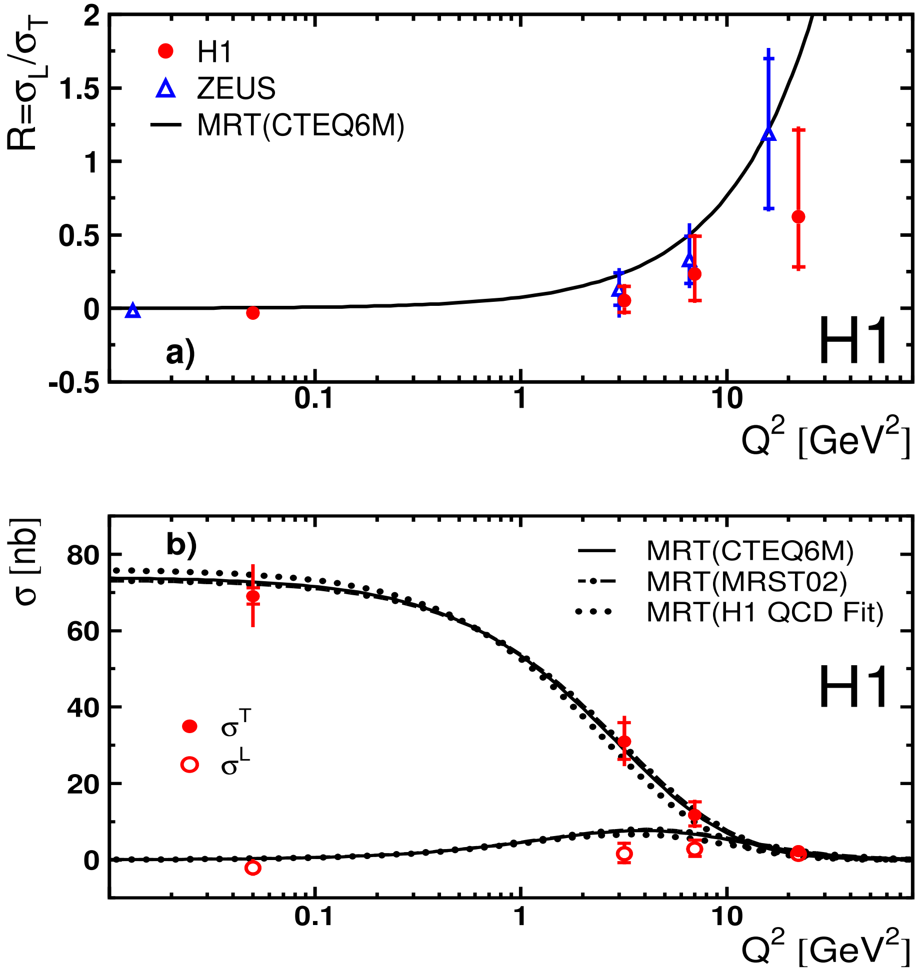
$\Longleftarrow$ Q^2 and t dependence of spin-density matrix elements

- No evidence for SCHC violation:
  r^{04}_{11}, $r^5_{00} + 2r^5_{11}$, and $r^1_{00} + 2r^1_{11}$ expected to be zero.
  $r^1_{11} = (1 - r^{04}_{00})/2$

- use r^{04}_{00} to extract σ_L and σ_T

Helicity studies show consistency with SCHC

Longitudinal and Transverse Cross Sections



- $R = \frac{\sigma_L}{\sigma_T} = \frac{r_{00}^{04}}{\epsilon \cdot (1 - r_{00}^{04})}$ ($\epsilon \approx$ 0.99)

  H1 and ZEUS: agree well

- $\sigma_{\gamma p} = \sigma^T + \epsilon \cdot \sigma^L$

  σ^T dominates at low Q^2
  At large Q^2, $\sigma_L \sim \sigma_T$

- Data reasonably well described by MRT

Summary

Measurements of cross section for J/ψ photoproduction and electroproduction.

- Q^2 dependence: Data sensitive to gluon distribution at large Q^2.
- W dependence: No Q^2 dependence of δ.
  Described by pQCD.
  Data show a high sensitivity to the gluon density of the proton in low x and low Q^2.
- t dependence well described by a simple exponential function.
- Effective pomeron trajectories are determined.
- Shrinkage seen in photoproduction.
- Helicity studies: support SCHC.
  The ratio $R = \frac{\sigma_L}{\sigma_T}$ measured and described by pQCD.