HERAにおける 高エネルギー電子・陽子衝突による エクスクルーシブ J/ψ 粒子生成の測定

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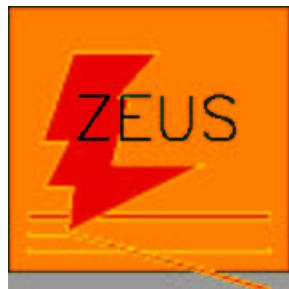
—— Outline ——

[1] Introduction

[2] Event Selection

[3] Results

[4] Summary and Conclusions

[1] Introduction

Neutral Vector Mesons

- $V = \left\{ \rho,\ \omega,\ \phi,\ \underline{\underline{J/\psi}},\ \Upsilon,\ \cdots \right\}$

- the same quantum numbers as photon $\left(J^{PC} = 1^{--} \right)$

- bound states of $q\bar{q}$

Exclusive Production of Neutral Vector Meson (VM) in ep scatterings

$$e\,p \rightarrow e\,V\,p$$
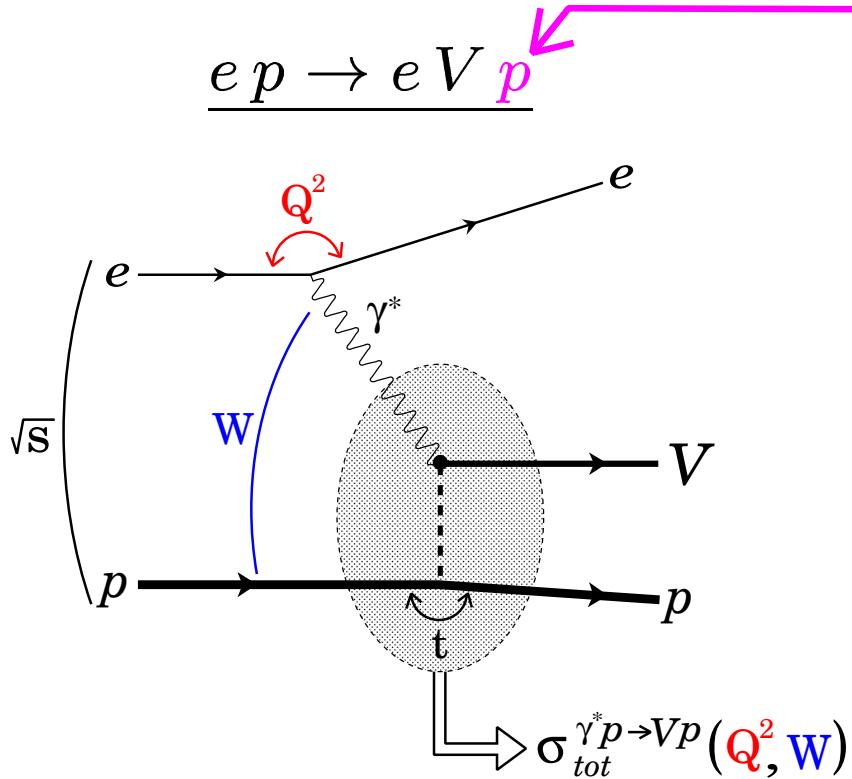
Kinematical Variables to be Measured

W	:	Center-of-mass energy of the $\gamma^* p$ system
Q^2	:	$\left(\text{4-momentum transfer}\right)^2$ at the electron
t	:	$\left(\text{4-momentum transfer}\right)^2$ at the proton

Two Theoretical Approaches

(1) VDM + Regge (**Hadron Physics**)

VDM　**Regge**

γ^*

V → V

$\mathbb{P}$

p → p

- $\sigma_{tot}^{\gamma^* p \to V p}(Q^2) \propto \left(\dfrac{1}{Q^2 + M_V^2} \right)^2$

- $\sigma_{tot}^{\gamma^* p \to V p}(W) \propto W^{0.22}$
  (**Soft Pomeron exchange**)
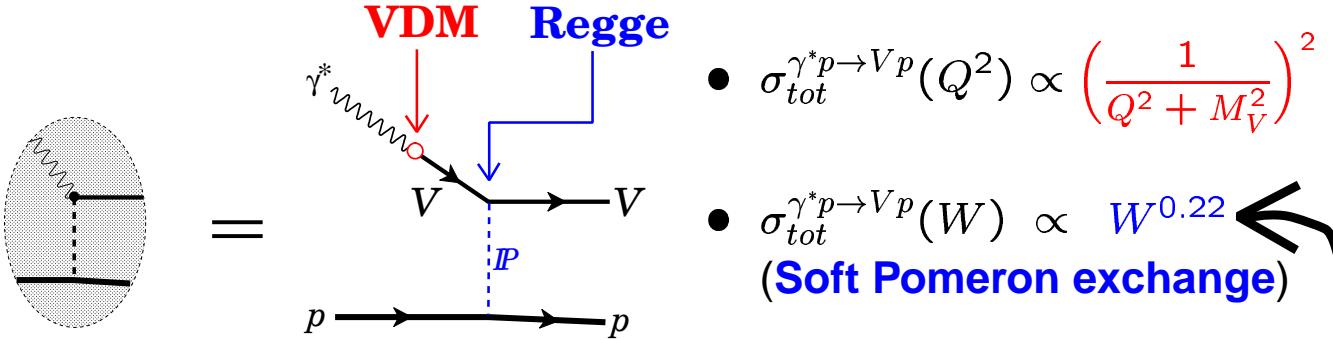
(2) pQCD + Gluon density + VM state (**Parton Dynamics**)

γ^*

Matrix Elements — Vector Meson

Gluon Density

p — p

- Two-gluon Exchange in a color singlet state

- QCD Factorization

★ **Need Hard Scale**
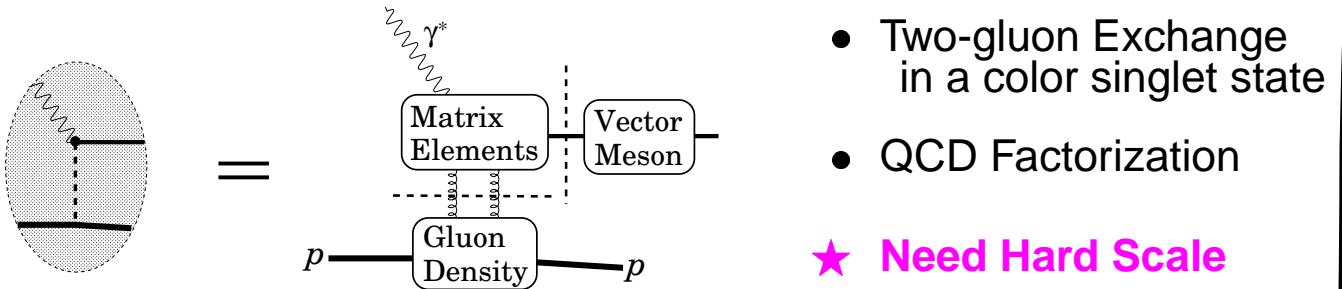
Leading Order (LO) Feynman Diagrams

γ^*　　γ^*　　+
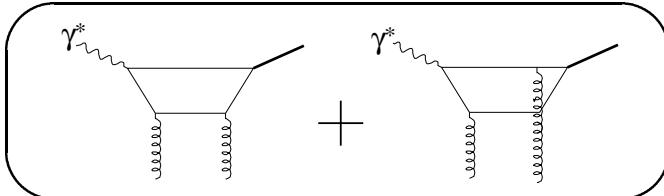
In LO: $\sigma_{tot}^{\gamma^* p \to V p} \propto \left[\bar{x} \cdot g(\bar{x}, \mu^2) \right]^2$ (g : gluon density function)

$\longrightarrow$ **High Sensitivity to Gluon Density in the Proton at low-x** $\left(\bar{x} = \dfrac{Q^2 + M_V^2 + |t|}{W^2} \cong 10^{-4} - 10^{-2} \right)$

$\longrightarrow$ **Steep W-dependence:** $\sigma_{tot}^{\gamma^* p \to V p}(W) \propto W^{0.8 \sim 1.0}$

Exclusive VM Photoproduction ($Q^2 = 0$)
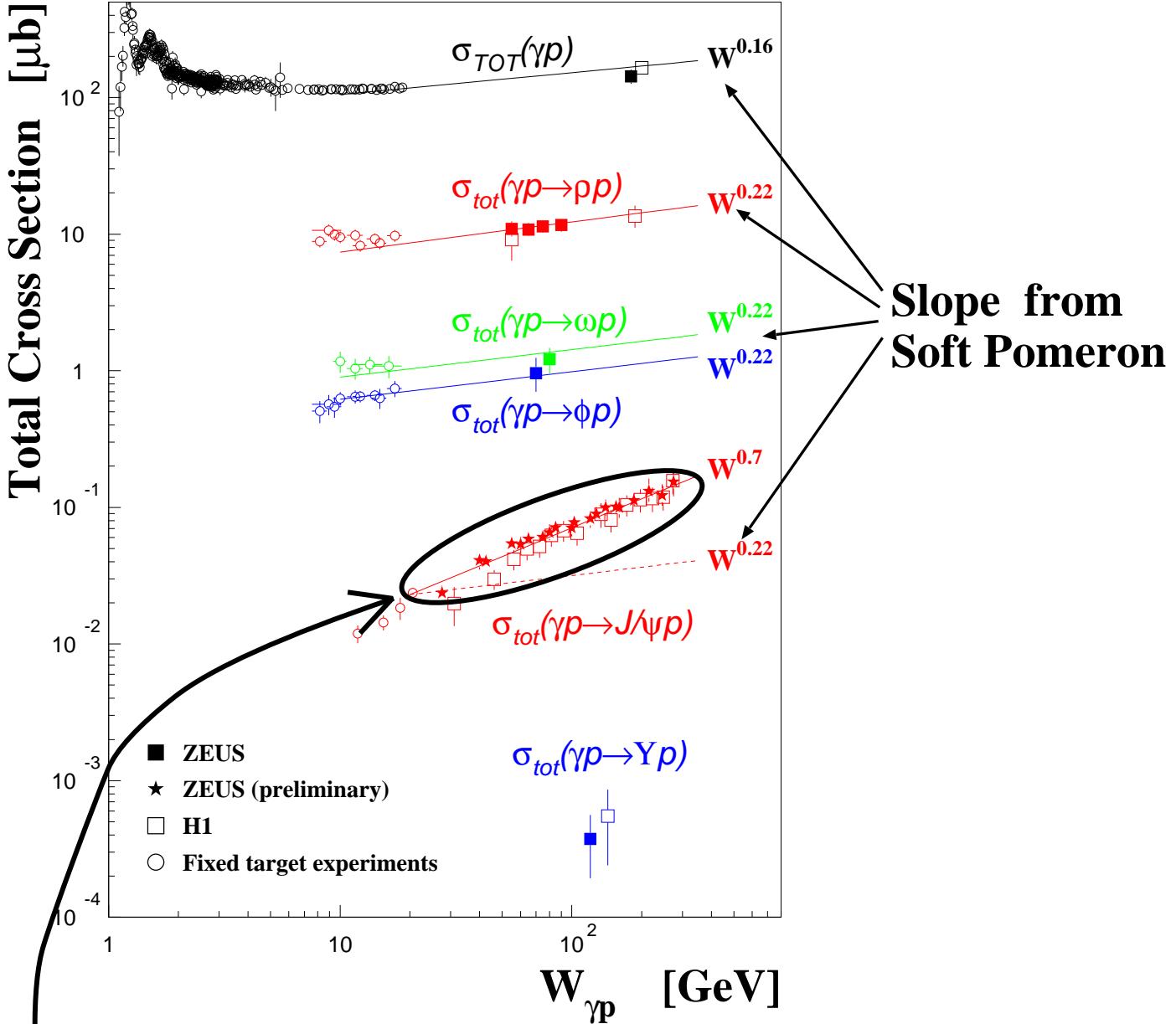
Successful Description with
Soft Pomeron Exchange for light VM PhP

Significantly Steeper W-dependence from J/ψ !

Exclusive ρ^0 Electroproduction at HERA

$$\sigma_{tot}^{\gamma^* p \to \rho p}(W; Q_0^2) \propto W^{\delta(Q_0^2)}$$
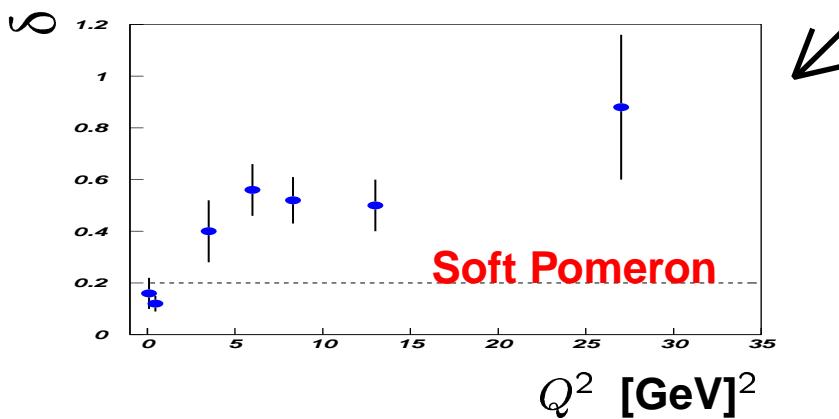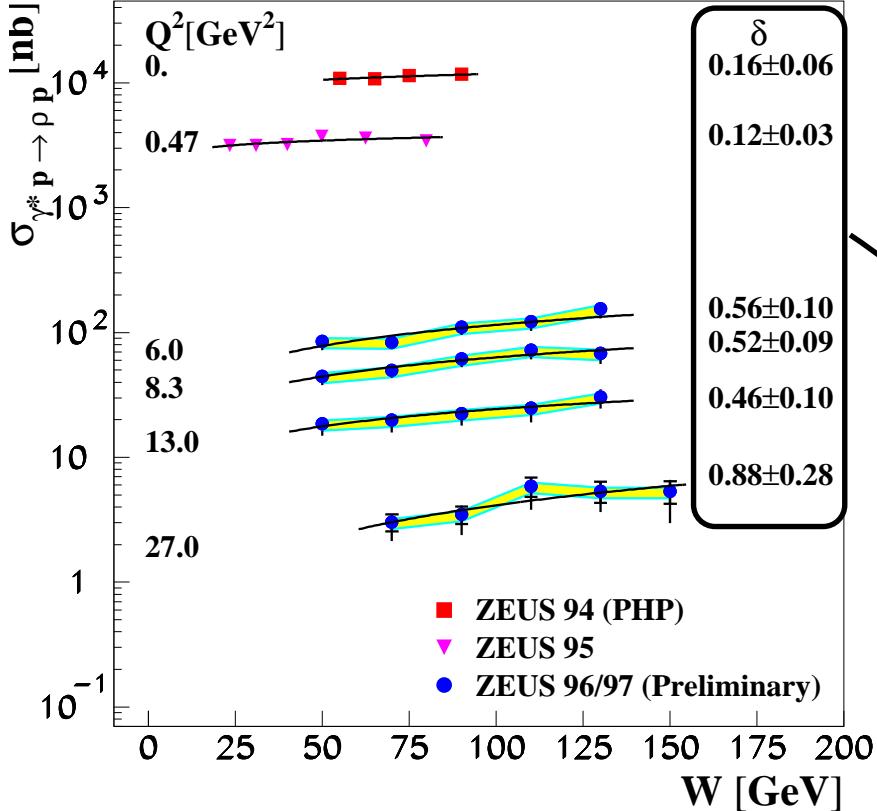
A Marked Increase with Q^2 above Soft Pomeron

This Measurement

Exclusive Electroproduction of J/ψ mesons

$\left(\text{Extension of } J/\psi \text{ Photoproduction} (Q^2 = 0) \longrightarrow Q^2 \gg \Lambda^2_{QCD}\right)$

Detected with Calorimeter

$$e\,p \longrightarrow e\,J/\psi\,p$$
$$\hookrightarrow e^+e^-,\ \mu^+\mu^-$$

using **90.3 pb**$^{-1}$ of the ZEUS data taken in 1996-2000

(Cf. 6.6 pb^{-1} of the previous ZEUS result and
27.3 pb^{-1} of the H1 result)

Qualitative $\longrightarrow$ Quantitative Tests of
pQCD-based Predictions

– $\sigma^{\gamma^* p \to J/\psi\,p}_{tot}(W; Q^2_0) \propto W^{\delta(Q^2_0)}, \ \ \delta(Q^2_0) \uparrow$**?**

– Q^2-dependence of $\sigma^{\gamma^* p \to J/\psi\,p}_{tot}(Q^2; W_0)$

- Clean and simple final state
- The J/ψ state is calculable
  with a small uncertainty (Cf. ρ^0)

**Unique Testing Ground of pQCD
with a clean signal of the leptonic final state**

[2] Event Selection

$$ep \to e' J/\psi \, p', \; J/\psi \to e^+ e^-$$

EM cluster

Decay tracks

Matching clusters

$$ep \to e' J/\psi \, p', \; J/\psi \to \mu^+ \mu^-$$

Nothing else

⇐ 陽子ビーム
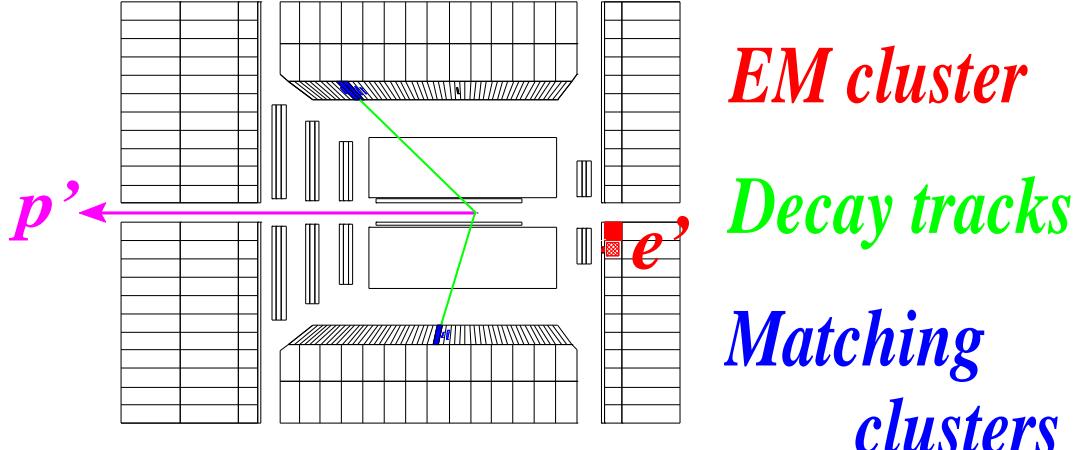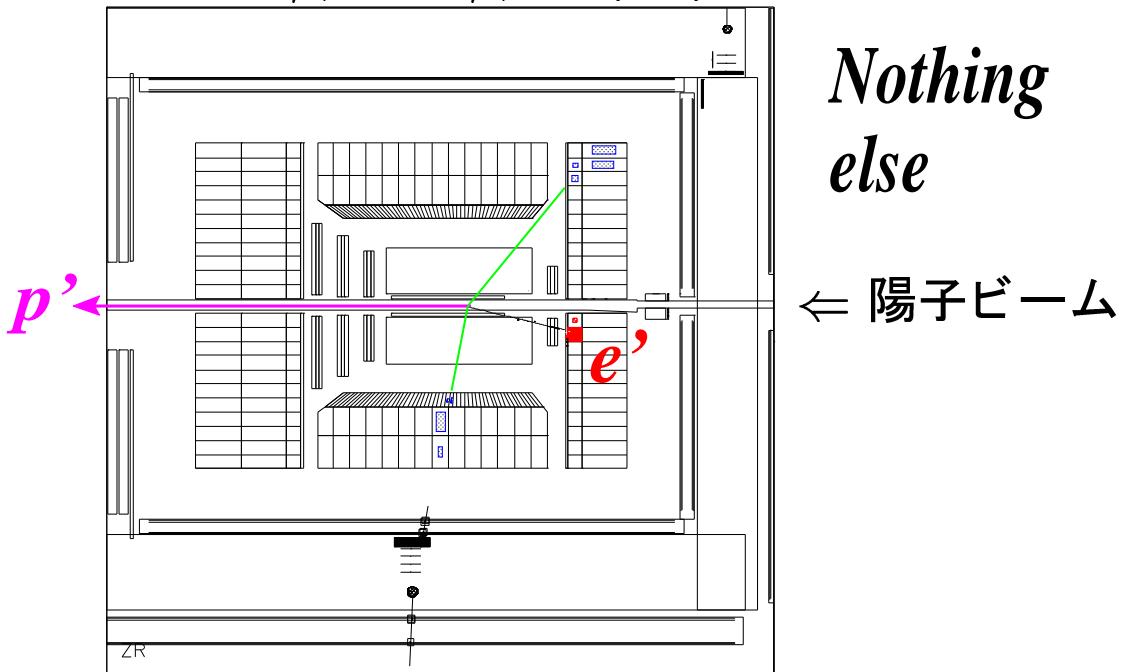
- $E_e > 10\,\text{GeV}$
- Box cut around the beam-pipe hole

- $P_T^{trk} > 0.2\,\text{GeV/c}$
- $20° < \theta_{trk} < 160°$

- No other tracks
- $E_{clus}^{MAX} < 300\,\text{MeV}$

The final data sample : **1649 events**

(a) 615 evts of the medium-W e^+e^-
(b) 776 evts of the medium-W $\mu^+\mu^-$
(c) 258 evts of the   high-W e^+e^-

TWO track sample

$50 \lesssim W \lesssim 150\ \text{GeV}$

$150 \lesssim W \lesssim 220\ \text{GeV}$

● **DATA**

— **MC**

J/ψ

QED
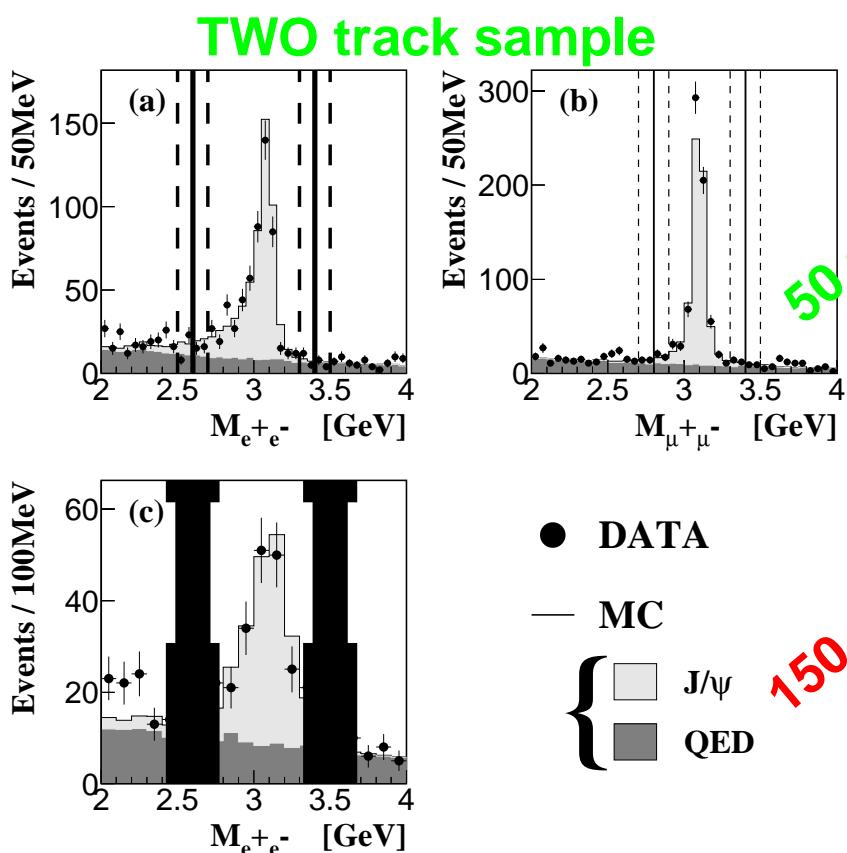
ONE+TWO track sample
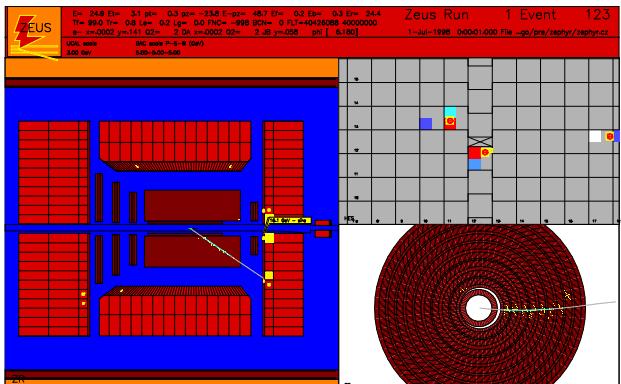
A First Measurement at $W \gtrsim 150$ **GeV**

$\left(W = 200\ \textbf{GeV} \right)$

# Decay Angles

[3] Results

W-**dependence:** W^δ
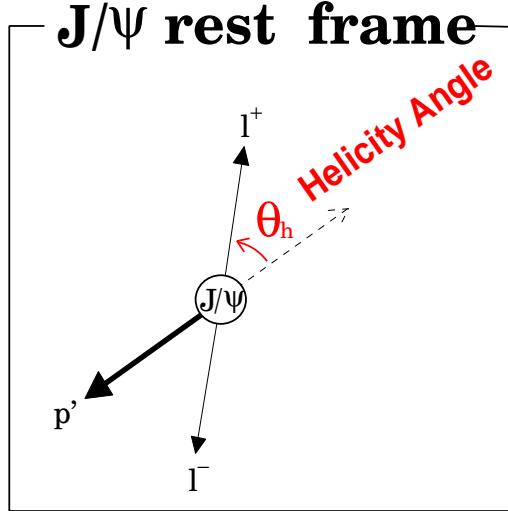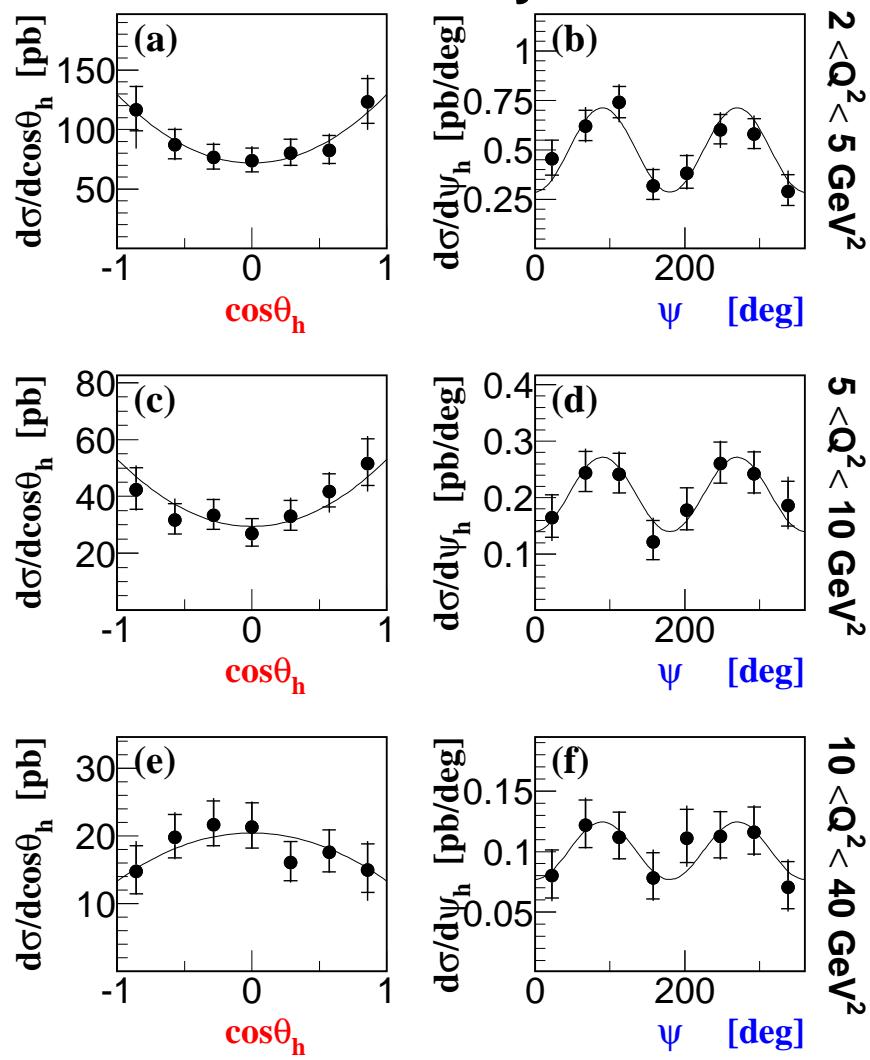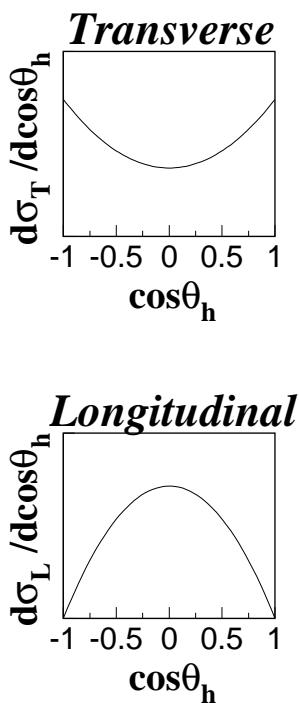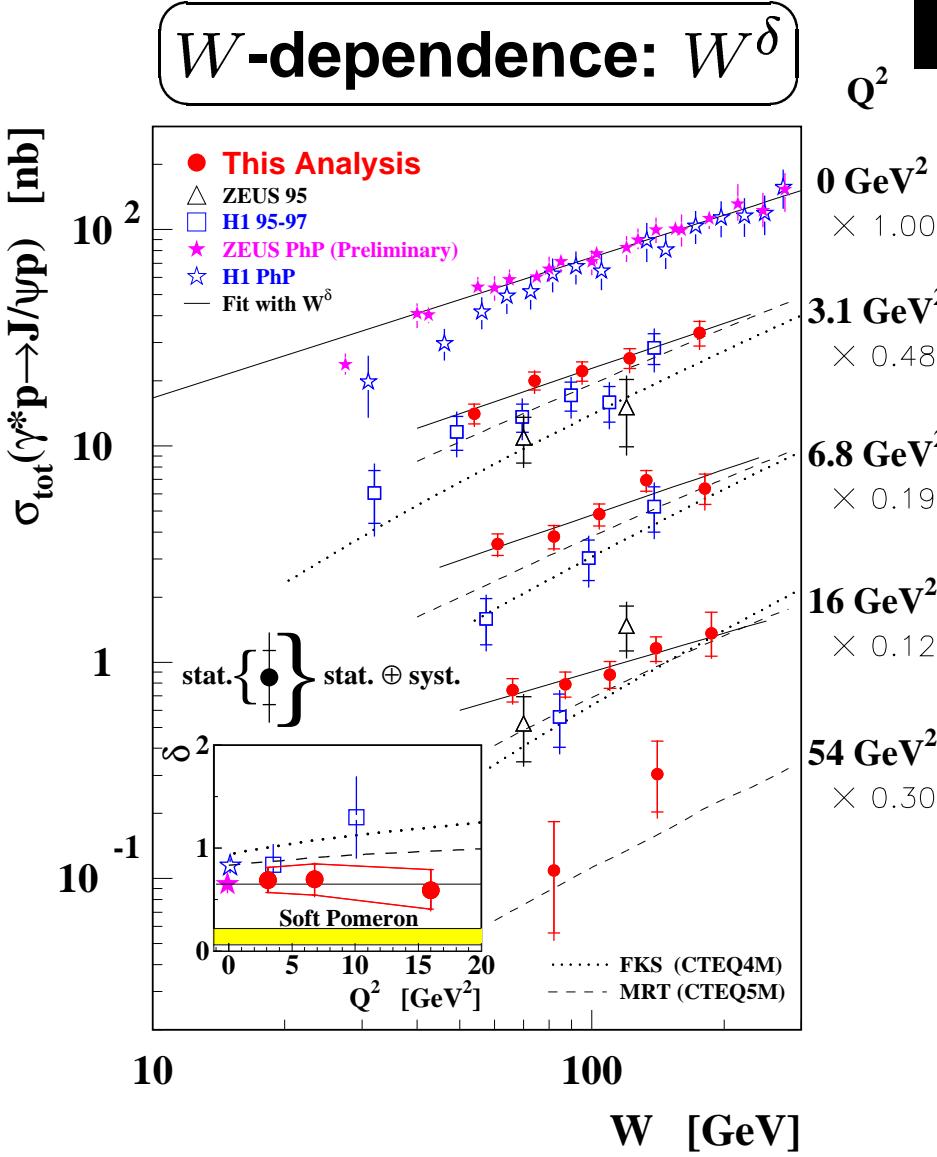
- **First result** from the ZEUS data

- **Significant improvement** compared
  with the H1 result

- Steeper (**harder**) **than**
  Soft Pomeron exchange

- **Consistent with the PhP**-slope,
  and show **no strong increase**.

- Slower rise (**softer**) **than**
  pQCD-based models
  with any parameter and any option

Q^2-dependence

W = 90 GeV

$\sigma_{tot}(\gamma^* p \rightarrow J/\psi p)$ [nb]

- **This Analysis**
- △ **ZEUS 95**
- □ **H1 95-97**
- ★ **ZEUS PhP (Preliminary)**
- ☆ **H1 PhP**
- — **Fit with $(Q^2+M_{J/\psi}^2)^{-n}$**

...... **FKS (CTEQ4M) × 1.6**
--- **MRT (CTEQ5M)** stat. {●} stat. ⊕ syst.

Q^2 [GeV^2]
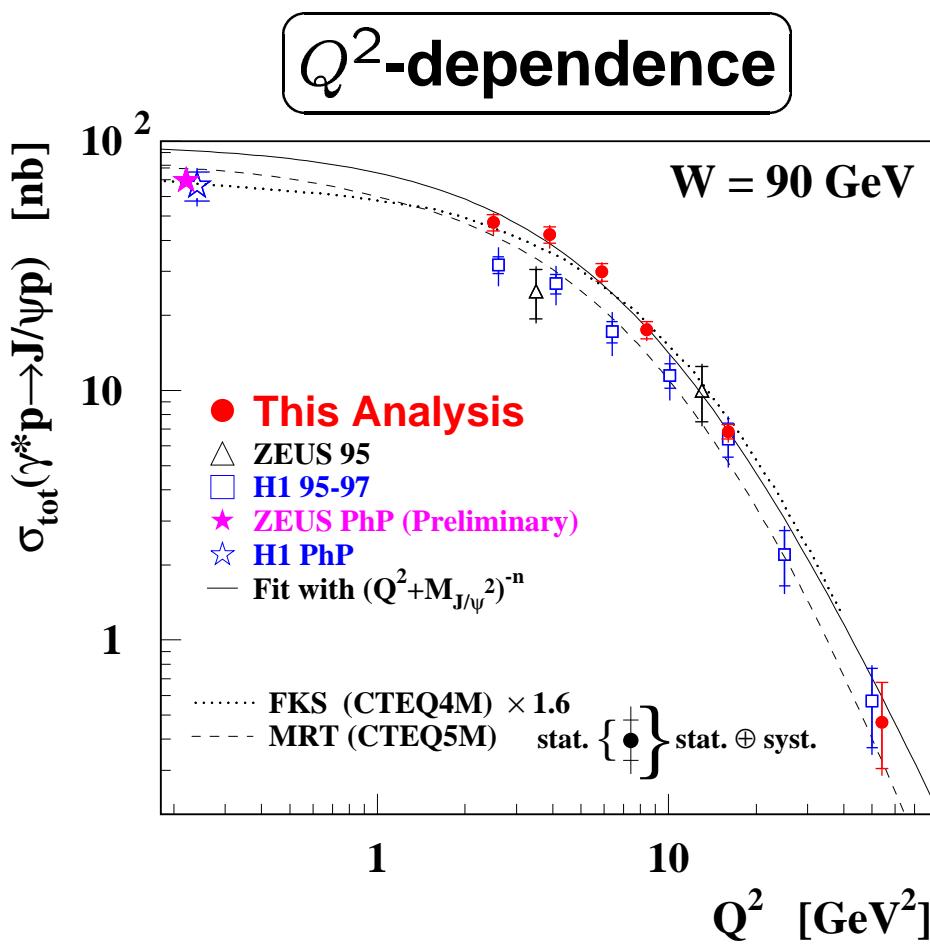
- **First Result** on the Q^2-slope from the ZEUS data

- This result is well-fitted with $1/(Q^2+M_{J/\psi}^2)^n$.
  $\rightarrow n = 2.70\ ^{+0.11}_{-0.10}(stat.)\ ^{+0.06}_{-0.08}(syst.)$

- Significantly **steeper than VDM** prediction ($n = 2$)

- FKS and MRT describe this slope well.

- $\begin{cases} \text{FKS normalization}: 60\,\%\downarrow \\ \text{MRT normalization}: 20\,\%\downarrow \end{cases}$

SU(4) Ratios

SU(4) symmetry

$$
\begin{aligned}
\left|\,\rho\,\right\rangle &= \tfrac{1}{\sqrt{2}}\Big(\left|u\bar{u}\right\rangle - \left|d\bar{d}\right\rangle\Big) & \left|\,\omega\,\right\rangle &= \tfrac{1}{\sqrt{2}}\Big(\left|u\bar{u}\right\rangle + \left|d\bar{d}\right\rangle\Big) \\
\left|\,\phi\,\right\rangle &= \left|s\bar{s}\right\rangle & \left|J/\psi\right\rangle &= \left|c\bar{c}\right\rangle
\end{aligned}
$$
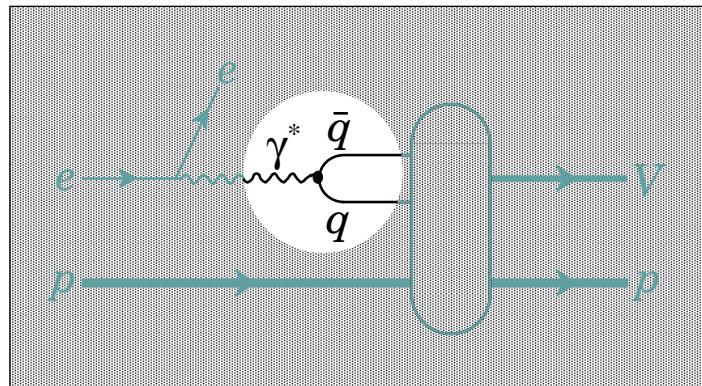
Cross-section Ratios

$\rho : \omega : \phi : J/\psi = \mathbf{9 : 1 : 2 : 8}$

are expected to hold when $Q^2 \gg M_V^2$.
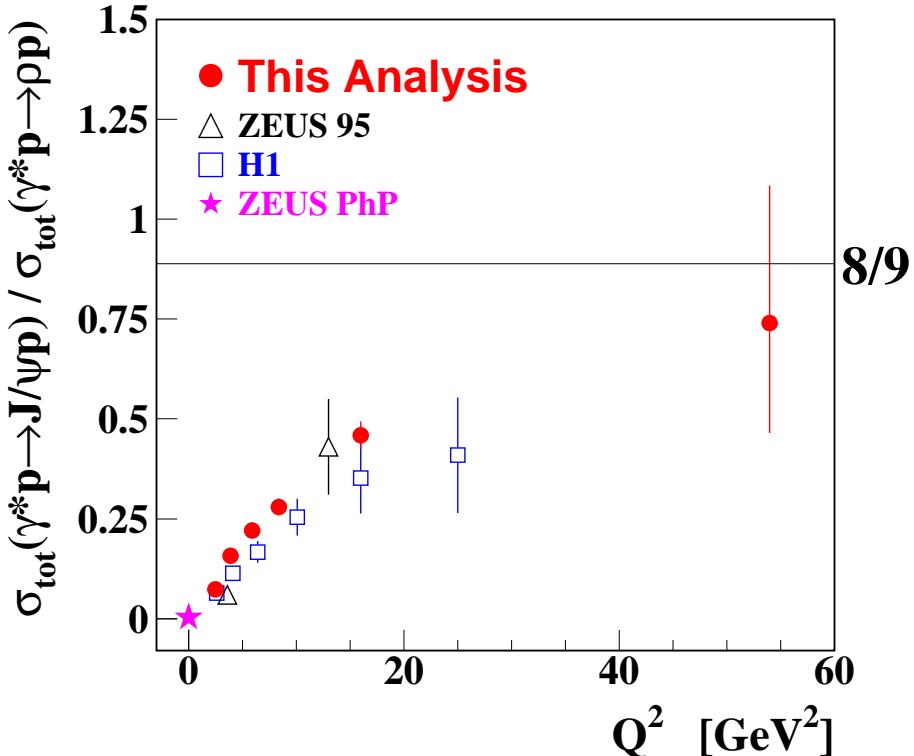
PARTONIC STRUCTURE in VM Production
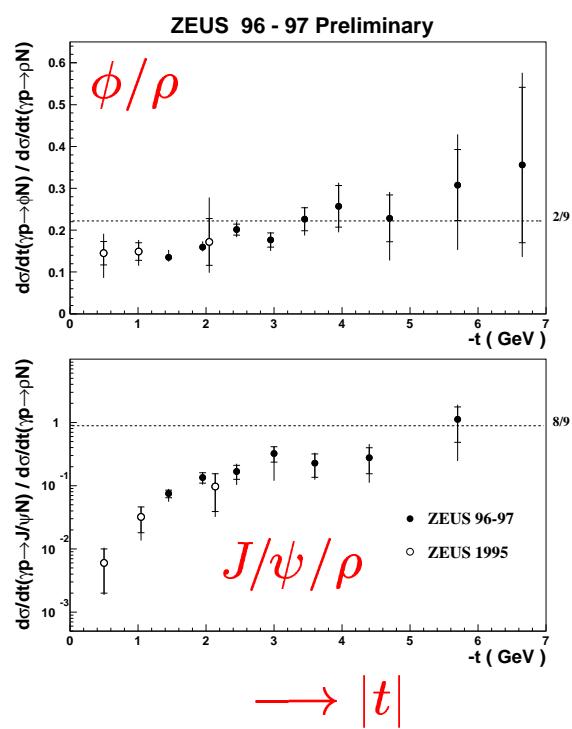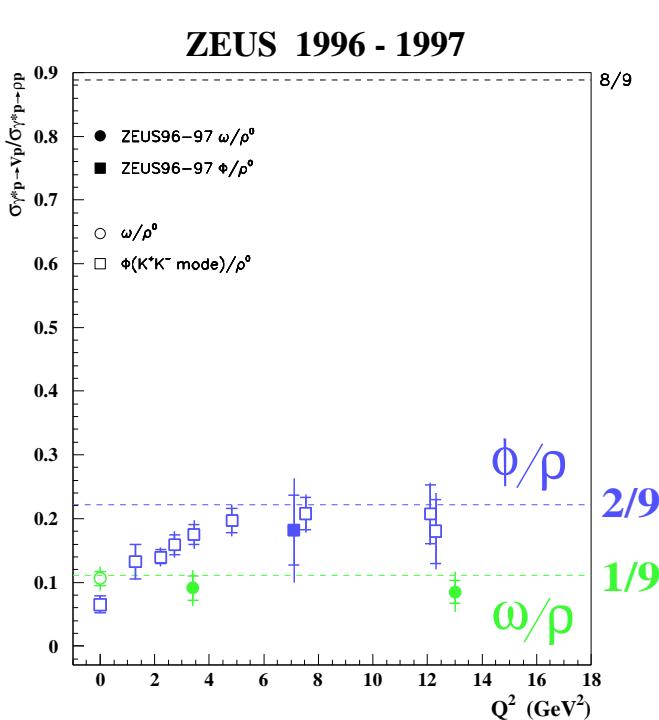
[4] Summary and Conclusions

- With a high statistic, total cross sections for exclusive J/ψ electroproduction have been measured.

- **Quantitative Tests** of the pQCD-based predictions show

  - Q^2-dependence is well-described,
    $\rightarrow$ OK.

  - W-dependence is less steeper.
    - $\rightarrow$ Better theoretical understanding is required in low-x diffraction physics.