D^* and J/ψ

Inelastic Photoproduction at HERA

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1. Introduction

Why Charm ?

- to test pQCD $\Lambda_{QCD} << M_c$
  $\Longrightarrow$ charm mass gives a hard scale
  $$\mu = M_\perp = \sqrt{M_c^2 + p_\perp^2}$$
  $\Longrightarrow$ pQCD expansion is valid

- in the pQCD
  $$\sigma(\gamma^* p) \propto f_p \cdot f_\gamma \cdot \sigma_{hard} \quad \rightarrow$$
  probe Parton Distributions inside $p \, and \, \gamma$ ($f_p and \, f_\gamma$being structure functions of p and photon)

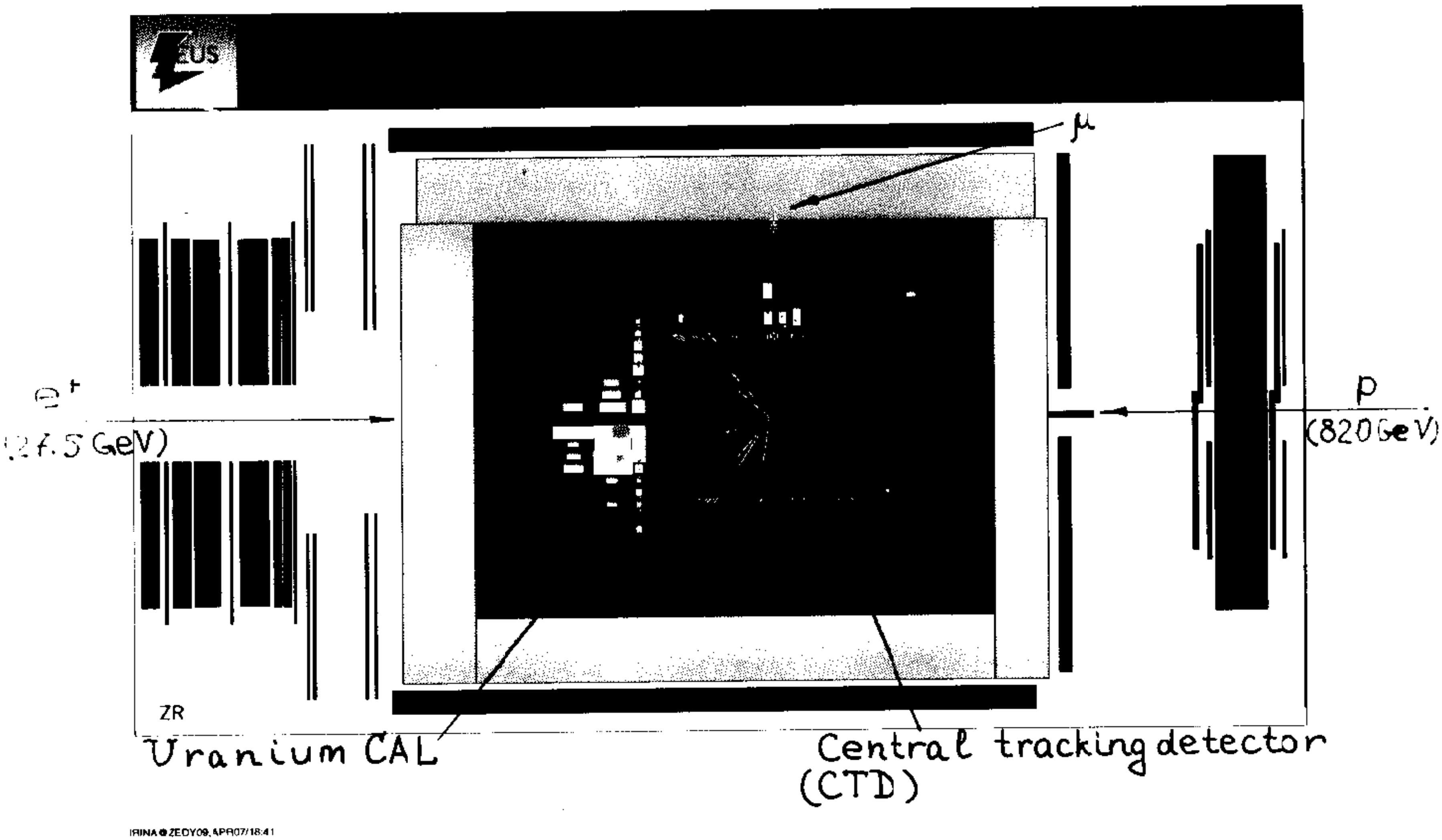
We measure production cross sections of D^* and J/ψ, using

$$L = 2.99 \pm .05 \text{ pb}^{-1},$$

collected by the ZEUS detector during 1994

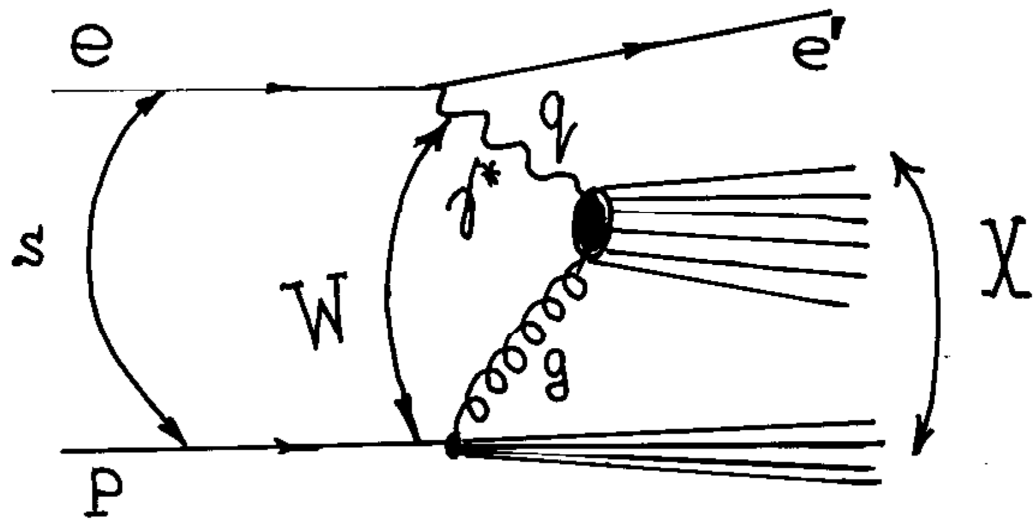
$e^+p \to e^+ D^* X$
$\hookrightarrow (K\pi)\pi_s$

ZEUS '94



Event Global Variables

$ep \rightarrow e'X$



ep c.m.energy $s = (P + e)^2$
$\Longrightarrow$ $\sqrt{s} = 300$ GeV

γ^* virtuality $Q^2 = -q^2 = -(E_e - E_{e'})^2$
$\Longrightarrow$ $Q^2 < 4$ GeV^2, $Q^2_{median} \sim 5 \cdot 10^{-4}$ GeV^2

$\gamma^* p$ c.m.energy $W^2 = (P + q)^2$

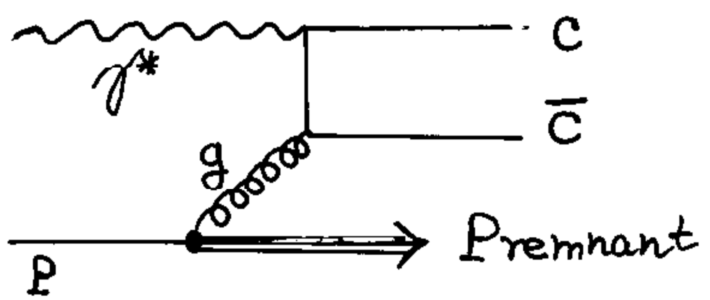
fraction of the E_e lost in the p.r. syst.

$y = \frac{q \cdot P}{e \cdot P} = \frac{E_e - E_{e'}}{E_e} \cong \frac{W^2}{s}$

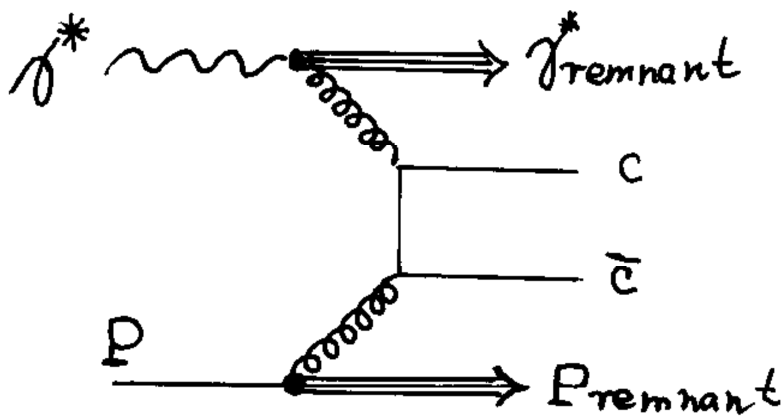
2. D^* Inclusive Photoproduction

In LO pQCD $\sigma^{PhP}(D^*)$ is a superposition of 2 types of $\gamma^* p$ contributions:

- direct γ^* - $\gamma^* g \to c\bar{c}$ (BGF)



- resolved γ^* - $gg \to c\bar{c}$



In NLO pQCD only sum of direct and resolved photon contributions is unambiguously defined

D^* was searched for by its decay modes:

$$D^* \to D^0 \, \pi_s \qquad D^0 \to K\pi \qquad D^0 \to K\pi\pi\pi$$

Both charged states $D^{*\pm}$ were detected

$\Delta M = M(D^*) - M(D^0)$ method

was used to identify $D^{*\pm}$.

PDG :

$M(D^*) = 2.010 \pm .0005$ GeV

$-$

$M(D^0) = 1.8645 \pm .0005$ GeV

$\Delta M = .14542 \pm .00005$ GeV $\sim m_\pi$

– phase space suppressed threshold region

Signature : signals in

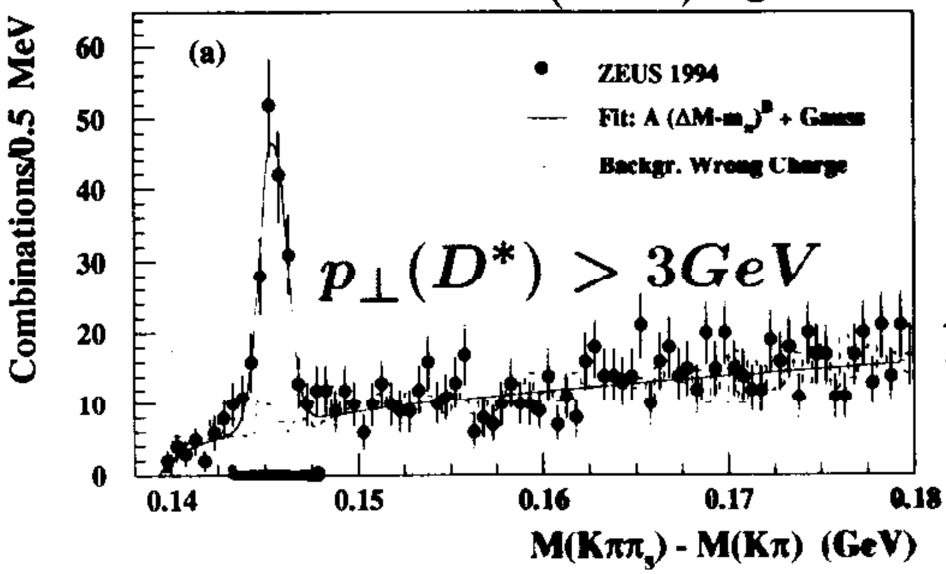
ΔM *and* $M(D^0)$

Kinematic region of the measurement:

$-1.5 < \eta(D^*) < 1.$
$115 < W < 280$ GeV
$Q^2 < 4$ GeV ^{2}

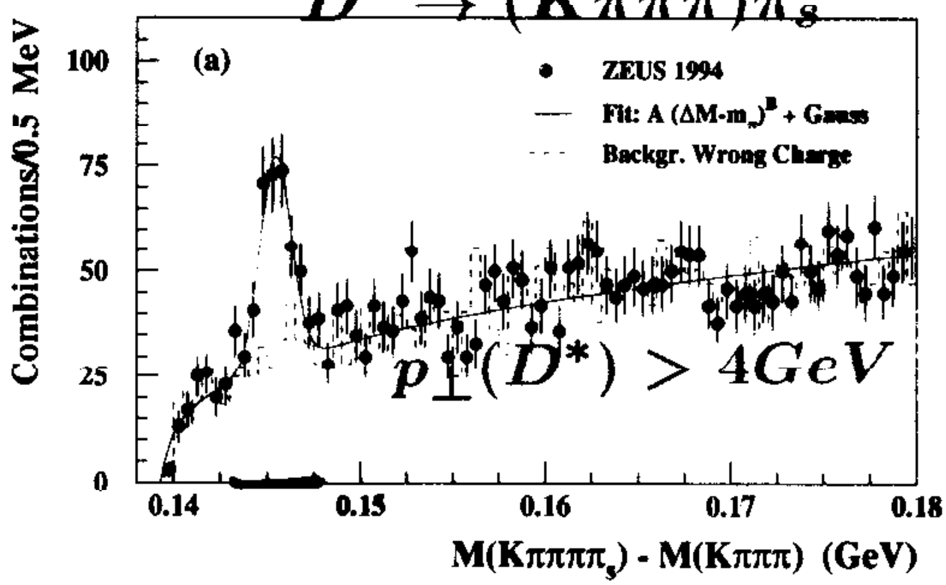
$\eta = -ln(tg(\frac{\theta}{2})$
θ - polar angle
wrt p direction

$D^* \to (K\pi)\pi_s$



$p_\perp(D^*) > 3GeV$ $N^{obs} = 152 \pm 16$

$D^* \to (K\pi\pi\pi)\pi_s$



$p_\perp(D^*) > 4GeV$ $N^{obs} = 167 \pm 25$

ΔM distributions

$ep \rightarrow D^* X$ Cross Sections

In the restricted kinematic region :

$p_\perp(D^*) > 3$ *or* 4 GeV

$-1.5 < \eta(D^*) < 1.$

$115 < W < 280$ GeV and $Q^2 < 4$ GeV^2

Channel	$p_\perp^{D^*}$(GeV)	$\sigma_{ep\rightarrow D^*X}$ (nb)
$K\pi$	> 3	$10.6 \pm 1.7 \pm^{1.6}_{1.3}$
$K\pi$	> 4	$4.5 \pm 0.7 \pm 0.6$
$K\pi\pi\pi$	> 4	$4.8 \pm 0.8 \pm^{1.0}_{0.6}$

$\Longrightarrow$ Cross section measurements by 2 decay modes of D^* gave consistent results in the same range of $p_\perp(D^*) > 4$ GeV

$\Longrightarrow$ systematic uncertainties both in data and theory are strongly reduced

$\Longrightarrow$ more precise comparisons between data and theory are possible

NLO pQCD Calculations:

"massive charm" approach:

S.Frixione et al. Nucl. Phys. B 454(1995)3

$n_f = 3$: (u, d, s) are the active flavours in p and γ

"massless charm" approach:

B.A.Kniehl et. al. DESY 96-210

M.Cacciary et. al. DESY 96-146

$n_f = 4$: (u, d, s) and (c) are the active flavours in p and γ

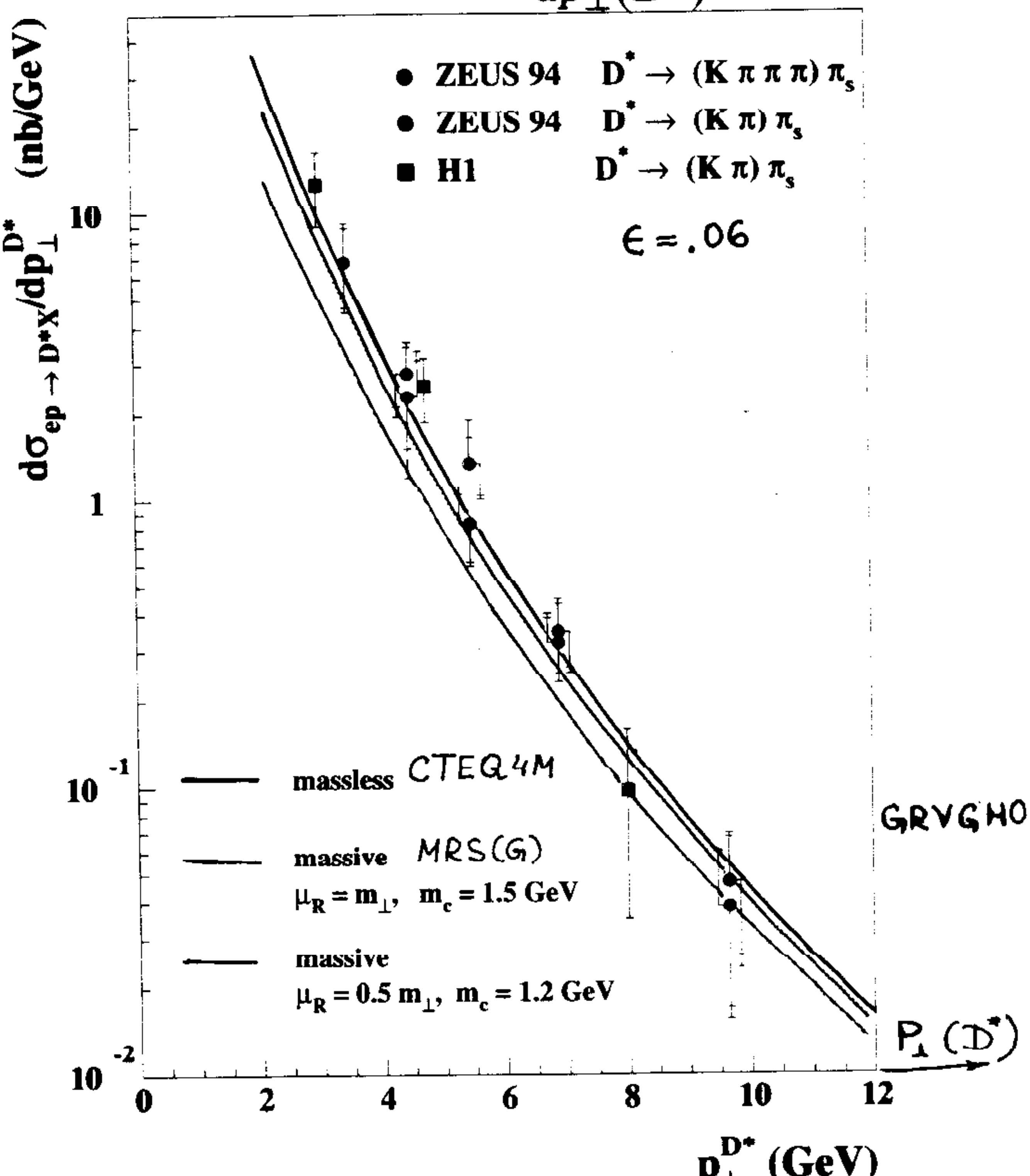
Both approaches:

$FF_{c \to D^*}$ = Peterson function with $\epsilon = .06$

f_p = MRS(G) f_γ = GRV G HO

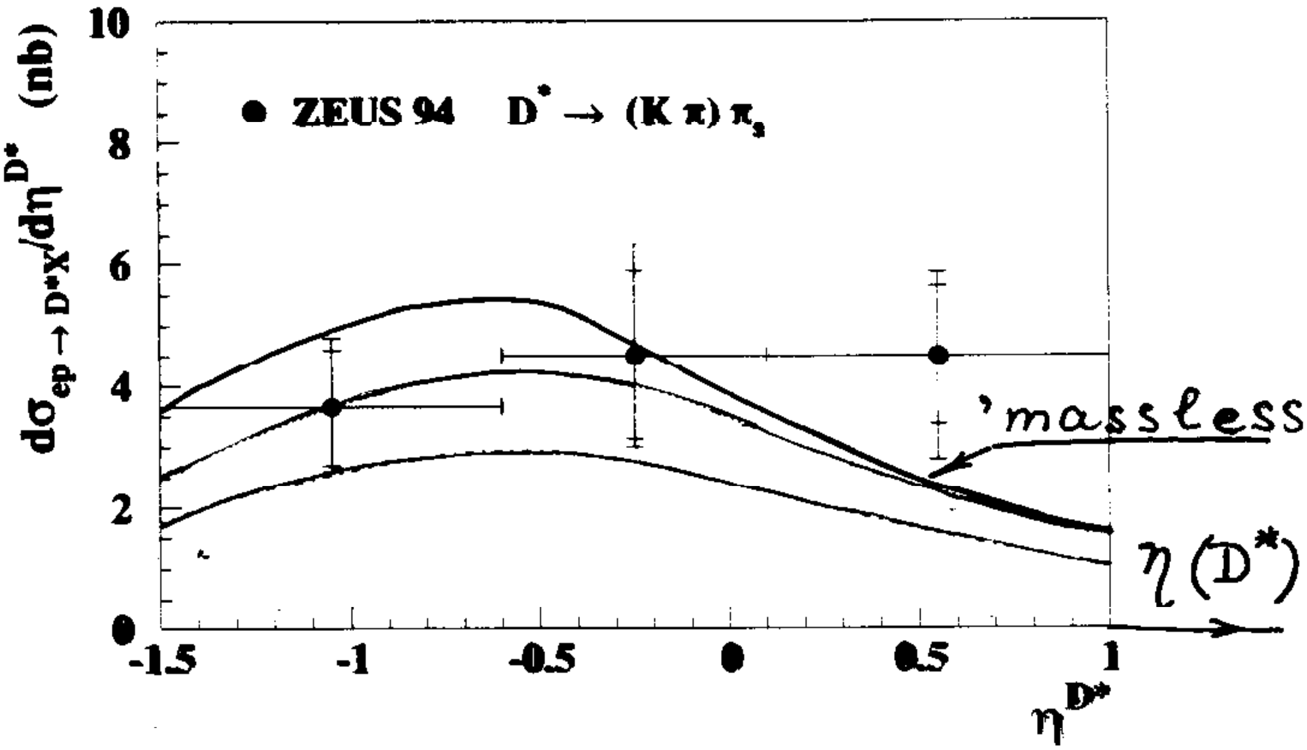
$m_c = 1.5\,GeV$ $\mu = m_\perp$

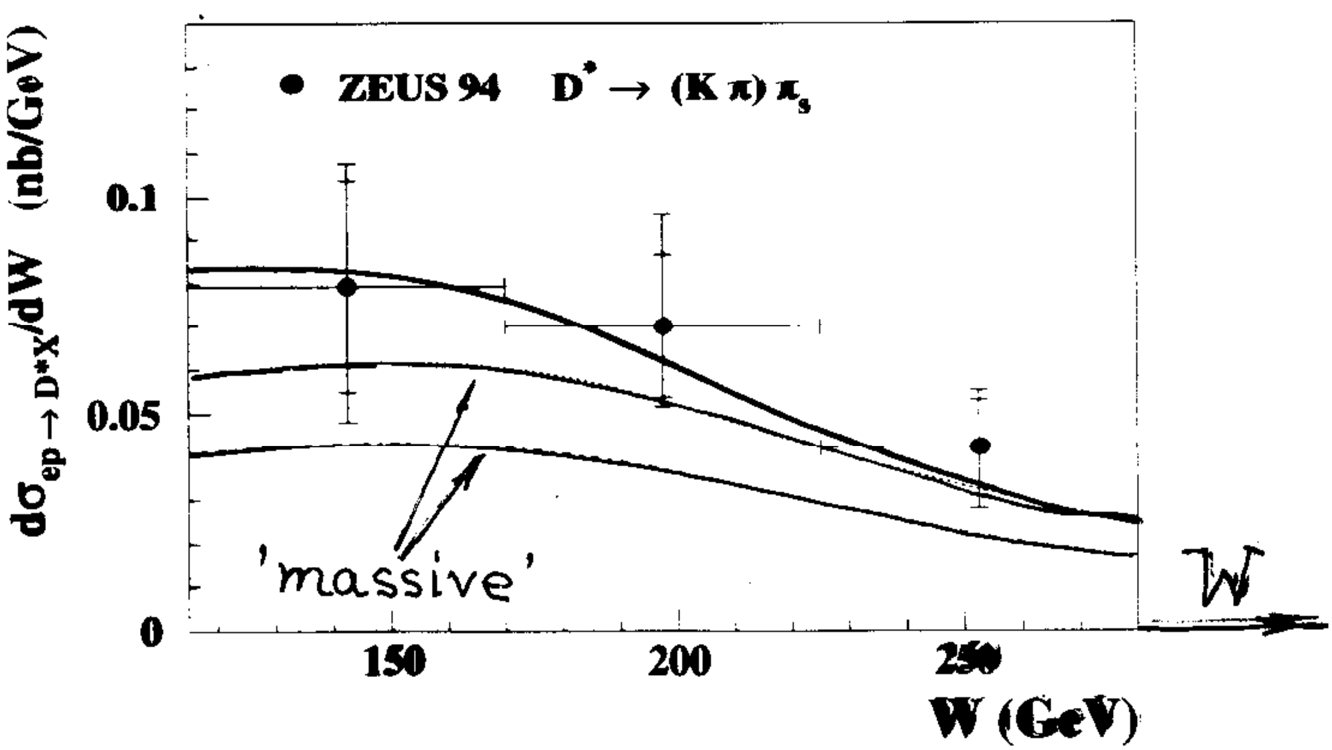
$$\frac{d\sigma(ep\to D^* X)}{dp_\perp(D^*)}$$



⟹ agreement with data in shape and magnitude for "massless charm" approach

$$\frac{d\sigma(ep\to D^*X)}{d\eta(D^*)} \quad and \quad \frac{d\sigma(ep\to D^*X)}{dW}$$





$\Longrightarrow$ agreement with data in shape and magnitude for "massless charm" approach

New pQCD Calculations in "massless charm" approach:

B.A.Kniel et. al. DESY 97-012
M.Cacciari et. al. DESY 97-029

To improve knowledge of $c \to D^*$ fragmentation 2 forms of FF($c \to D^*$) were fitted to the LEP1 data (by ALEPH and OPAL):

(S) - $\mathrm{FF}(c \to D^*) = N \cdot x^{\alpha} \cdot (1-x)^{\beta}$

(M) - $\mathrm{FF}(c \to D^*) = N \frac{\cdot x \cdot (1-x)^2}{[(1-x)^2 + \epsilon \cdot x]^2}$

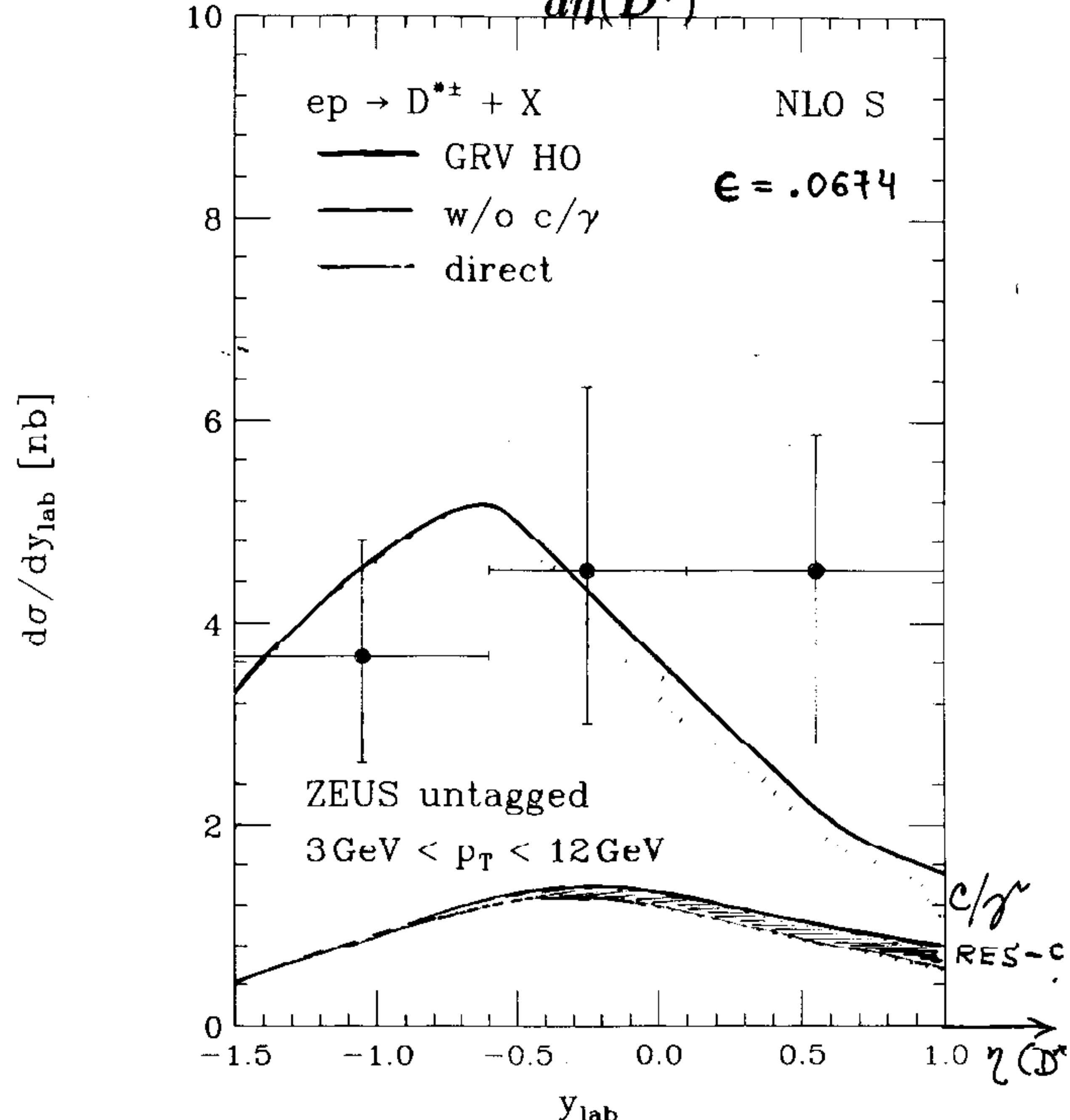
(S) and (M) -

$$\mathrm{FF}(b \to D^*) = N \cdot x^{\alpha} \cdot (1-x)^{\beta}$$

New $\epsilon = .0674 \Longleftrightarrow$ Old $\epsilon = .06$

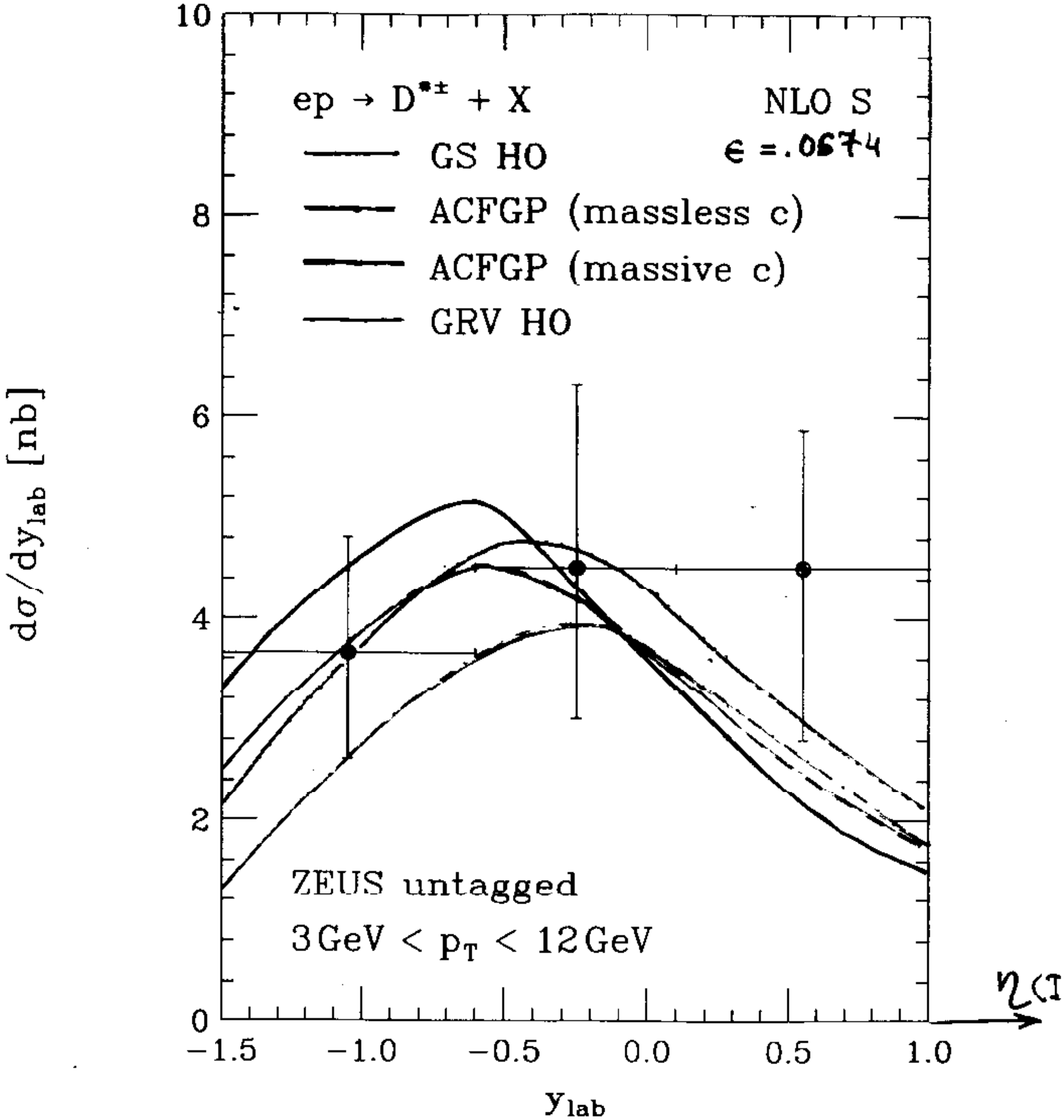
"S" and "M" FF were evolved in LO and NLO algorithms giving close results If FF $c \to D^*$ is reliably measured, then the charm content of the resolved γ is the main uncertainty left in calculations

$$\frac{d\sigma(ep \to D^* X)}{d\eta(D^*)}$$



⟹ in "massless charm" approach strong sensitivity of the $d\sigma(ep \to D^* X)$ to the charm content of γ is predicted

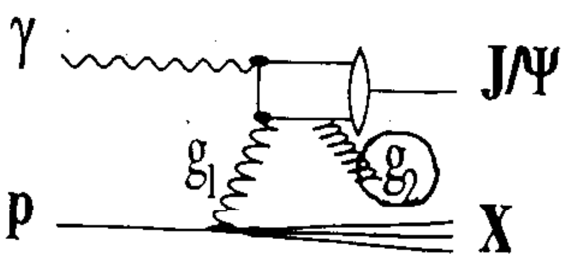
$$\frac{d\sigma(ep\to D^* X)}{d\eta(D^*)}$$



⟹ **At present accuracy HERA data on charm photoproduction are not sensitive to the charm content of γ. ⟹ With improvement of measurement accuracy we may distinguish between different parametrization of PD of γ**

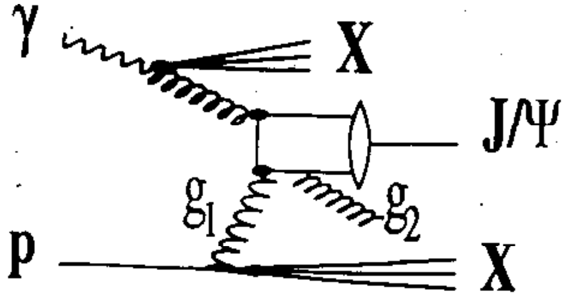
2. J/ψ Inelastic Photoproduction

Measuring inelastic photoproduction cross section of J/ψ we measure the diagram of γg fusion

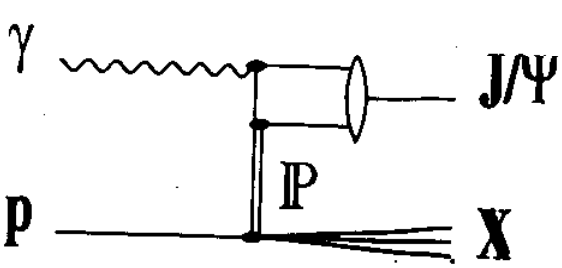


direct (DIR) photon with emission of g_2 → colour singlet J/ψ (color singlet model)

BACKGROUNDS :



resolved (RES) photon



proton diffractive (DIF)

J/ψ was searched for by its leptonic decays:

$$J/\psi \rightarrow e^{+}e^{-}$$
$$J/\psi \rightarrow \mu^{+}\mu^{-}$$

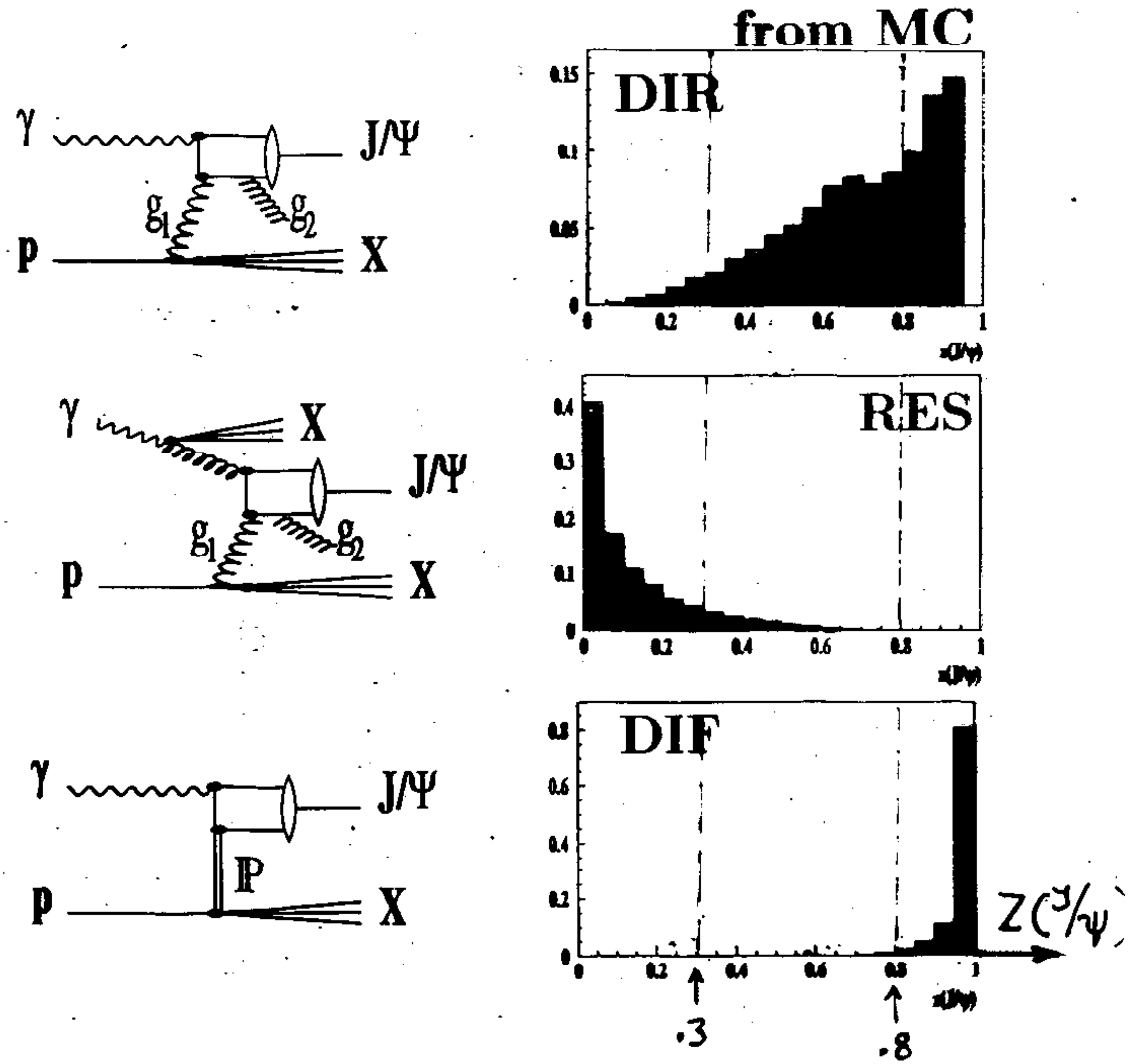
$l\bar{l}$ pairs were identified:

e^{+}, e^{-} by $\frac{dE}{dx}$ in CTD and
$M_{ee} > 2GeV$

μ^{+}, μ^{-} by at least 1 signal in
muon detector and $p_{\perp}(\mu) > 1GeV$

To separate signal from BG define J/ψ inelasticity:

$$z(J/\psi) = \frac{P_p \cdot P\,(J/\psi)}{P_p \cdot P_{\gamma^*}} = \frac{E\ (J/\psi)}{E_{\gamma^*}}$$

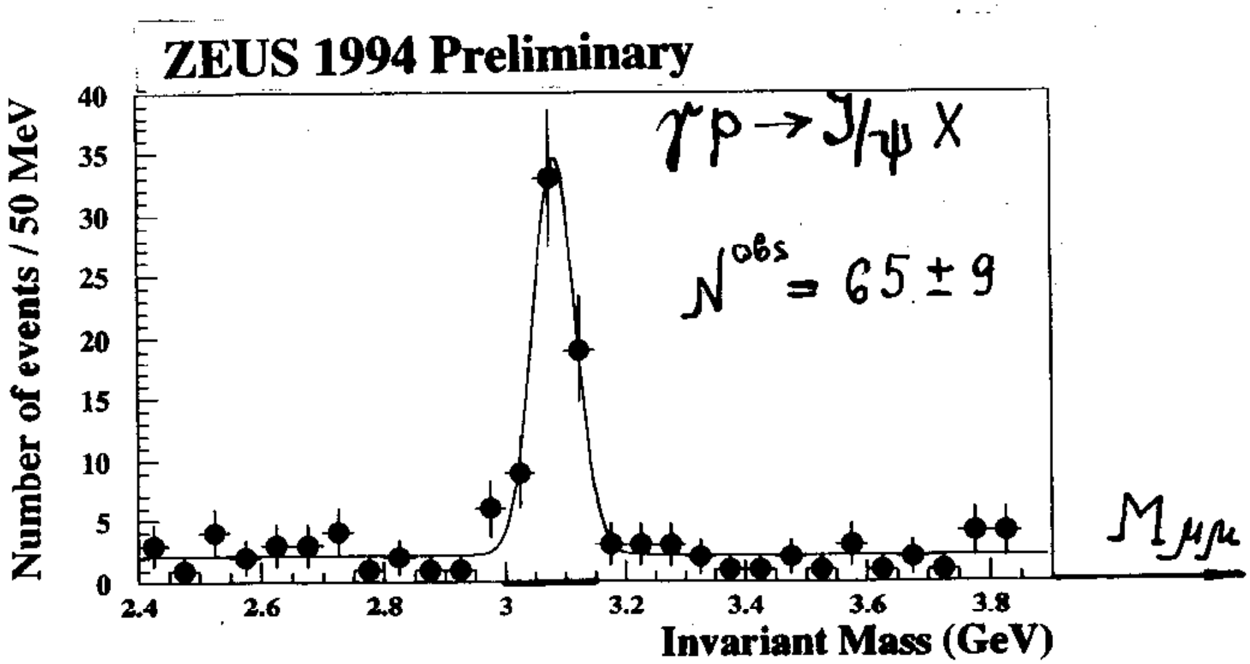


Cross sections were measured in the kinematic region:

$$60 < W < 150\ GeV\ and\ Q^2 < 4 GeV^2$$

$.4 < z < .8\ for\ e^+e^-$
$.3 < z < .8\ for\ \mu^+\mu^-$
to suppress backgrounds

$p_\perp(J/\psi) > 1$ GeV
to compare with NLO pQCD



$N^{obs}(J/\psi) = 25 \pm 6$ in e^+e^- mode
$N^{obs}(J/\psi) = 65 \pm 9$ in $\mu^+\mu^-$ mode
$N^{obs}(J/\psi) = 90 \pm 11$ in total

Data were compared to:

NLO pQCD

M.Krämer et al. Phys. Lett. B 348(1995)6

Nucl. Phys. B 459(1996)3

$m_c = 1.4 GeV$ $\Lambda = 300 MeV$ $\mu = \sqrt{2} \cdot m_c$
$f_p : GRV or MRSA'$

Semihard Approach (SHA) in QCD:

V.A.Saleev, N.P.Zotov.

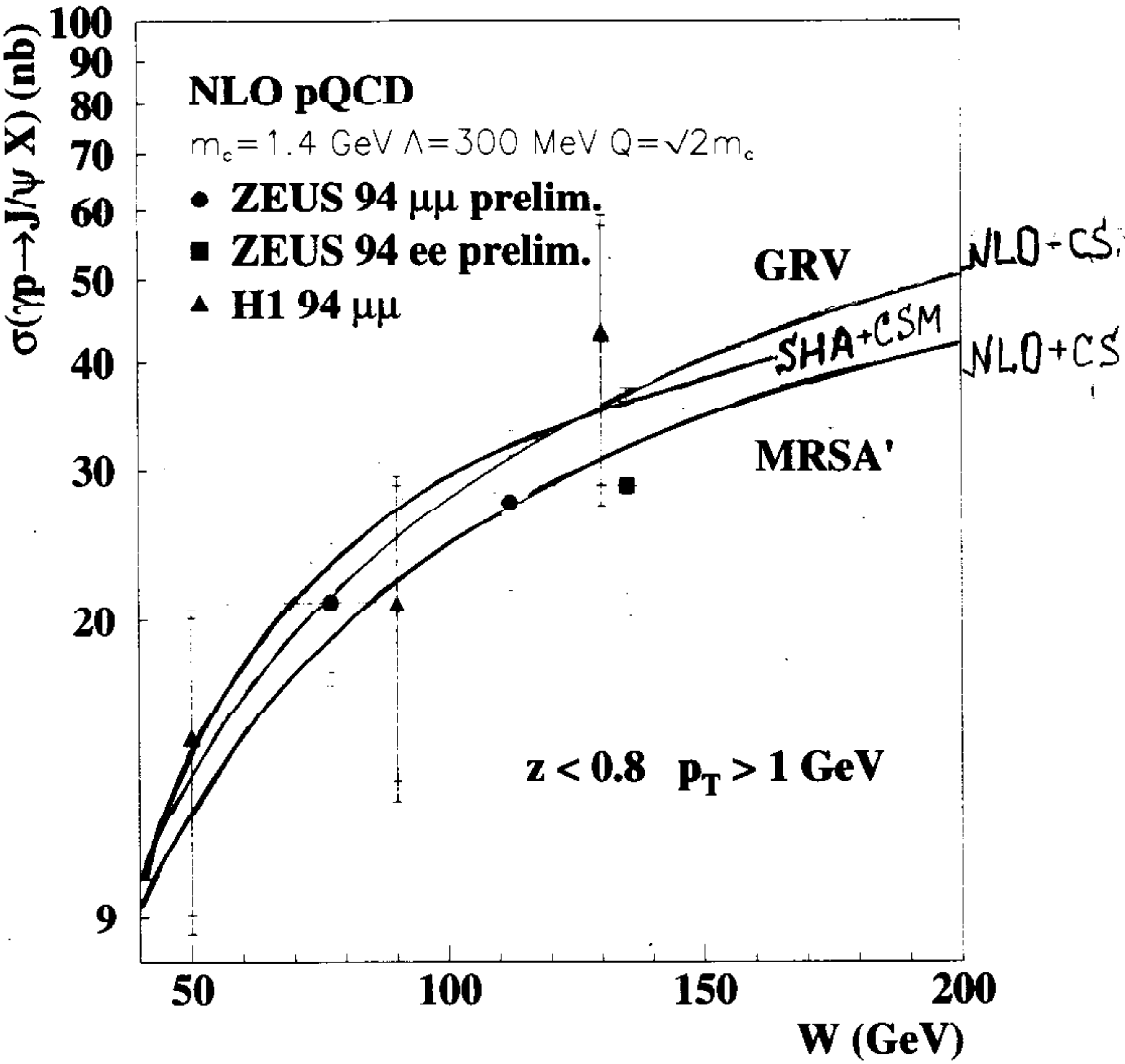
Mod. Phys. Lett A9(1994)151

Mod. Phys. Lett A11(1996)25

g is off-mass shell, $f_{g/p}$unintegrated and 'saturated', $m_c = 1.5\, GeV$

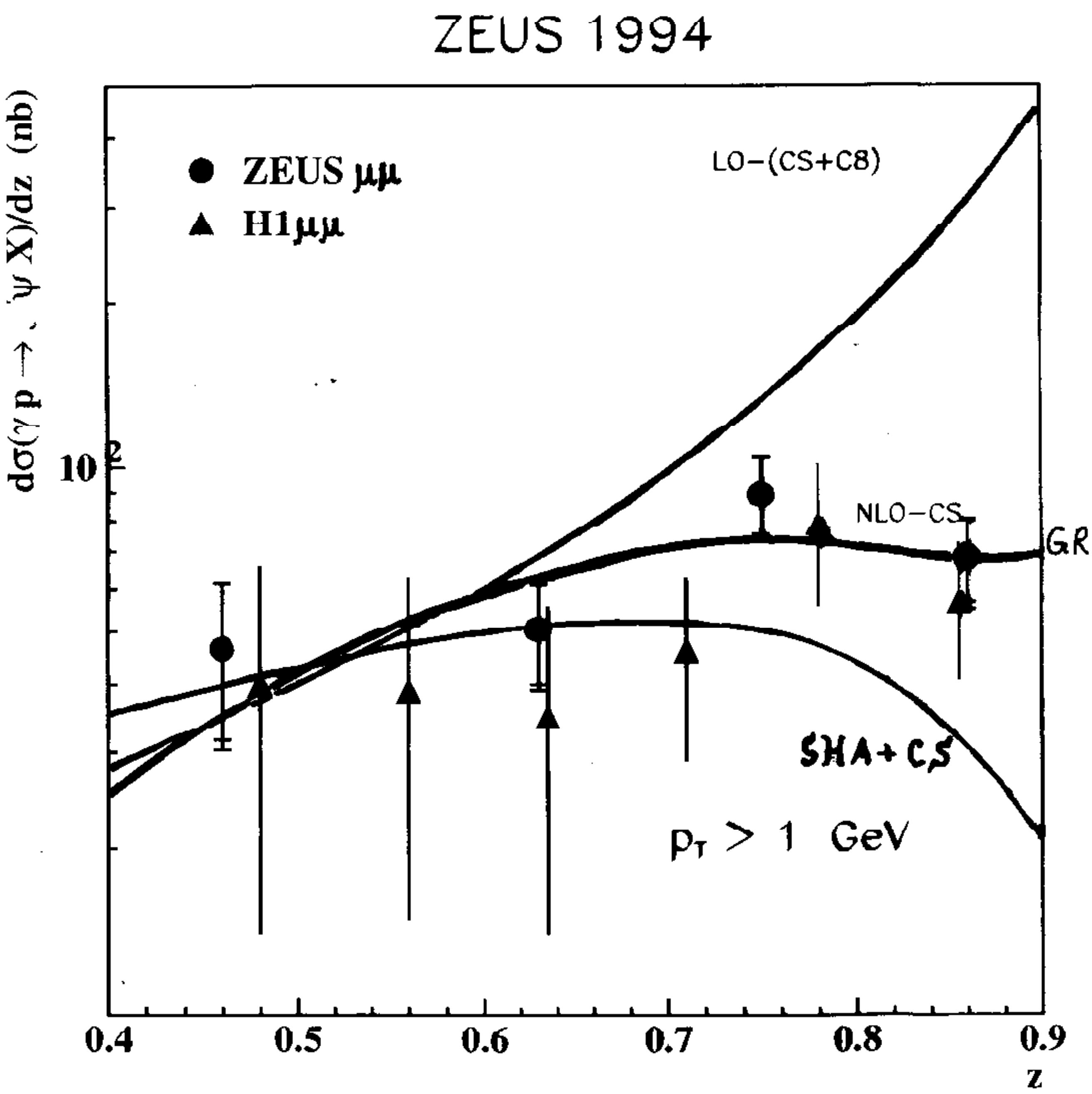
Both: CSModel for $c\bar{c} \to J/\psi$

$$\frac{d\sigma(\gamma p \to J/\psi X)}{dW}$$



Within large errors both approaches agree with data in magnitude and shape. Growth of J/ψ cross sections in W indicates growth of $xG(x)$ with $x \to 0$).

$$\frac{d\sigma(\gamma p \to J/\psi X)}{dz(J/\psi)}$$



4. Summary

D^* *ep* cross sections and J/ψ inelastic photoproduction ones were measured in the limited kinematic regions and comparisons with theory were made.

- D^* inclusive *ep* cross sections were reproduced in shape and magnitude by NLO PQCD calculations in the 'massless charm' approach. 'Massive approach' results are below the data.
- J/ψ inelastic photoproduction cross sections within large errors agree with CSModel calculations in the NLO of pQCD and semi-hard approach (SHA) calculations.