7TH INTERNATIONAL WORKSHOP ON
DEEP INELASTIC SCATTERING AND QCD
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New ZEUS Results in the Low Q^2 and Transition Region:

Measurement of the Proton Structure Function F_2 at Very Low Q^2 and Very Low x

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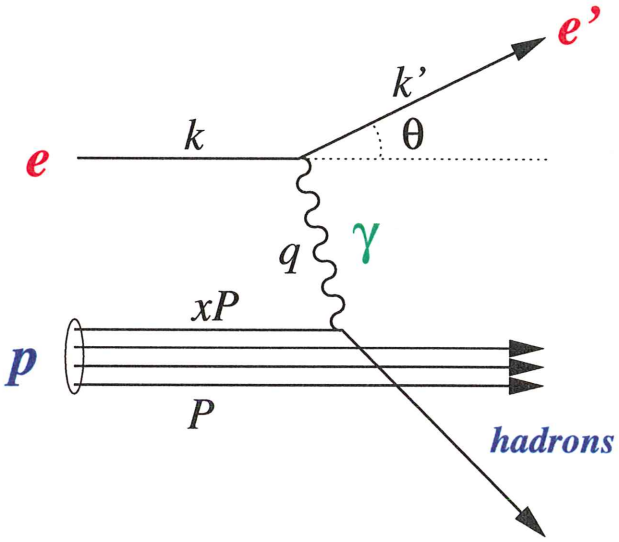
ZEUS Collaboration

- Introduction
- Detectors
- Analysis technique
- Results
- Fits

Deep Inelastic Scattering (1)



HERA (1997):

positrons
$E_e = 27.5$ GeV

protons
$E_p = 820$ GeV

energy in c.m.s.
$\sqrt{s} = 300$ GeV

Kinematic variables:

- $Q^2 = -q^2 = -(k - k')^2 = 4E_e E'_e \sin^2 \frac{\theta}{2}$

  $-$mass^2 of virtual photon

- $x = \frac{Q^2}{2P \cdot q} = \frac{Q^2}{sy}$

  momentum fraction of struck quark in proton

- $y = \frac{P \cdot q}{P \cdot k} = 1 - \frac{E'_e}{2E_e}(1 + \cos\theta)$

  relative energy transfer to proton in proton rest frame

- $W^2 = (P + q)^2 = \frac{Q^2(1-x)}{x}$

  mass^2 of hadronic system

Coordinate system:

- $Z \rightarrow$ incoming proton direction

- $\vartheta = 180^\circ$ for incoming electron: $\theta \equiv 180^\circ - \vartheta$

  handy for small scattering angles

Deep Inelastic Scattering (2)

Differential $e^{\pm}p \to e^{\pm}X$ cross section:

$$\frac{d^2\sigma^{\mathrm{NC}}}{dy\,dQ^2} = \frac{2\pi\alpha^2}{yQ^4}\left(Y_+F_2 - y^2F_L \mp Y_-xF_3\right)$$

- $Y_\pm = 1 \pm (1-y)^2$

factorization in γ^* flux and γ^*p cross section:

$$\frac{d^2\sigma^{\mathrm{NC}}}{dy\,dQ^2} = \Gamma \cdot \left(\sigma_T^{\gamma^*p} + \epsilon\,\sigma_L^{\gamma^*p}\right)$$

- $\Gamma = \alpha Y_+/2\pi yQ^2$ virtual photon flux
- $\epsilon = 2(1-y)/Y_+$ photon polarization

often used (approximation for low x):

$$\sigma_{\mathrm{tot}}^{\gamma^*p} = \sigma_T^{\gamma^*p} + \sigma_L^{\gamma^*p} \approx \frac{4\pi^2\alpha}{Q^2}F_2$$

In leading order & at low Q^2:

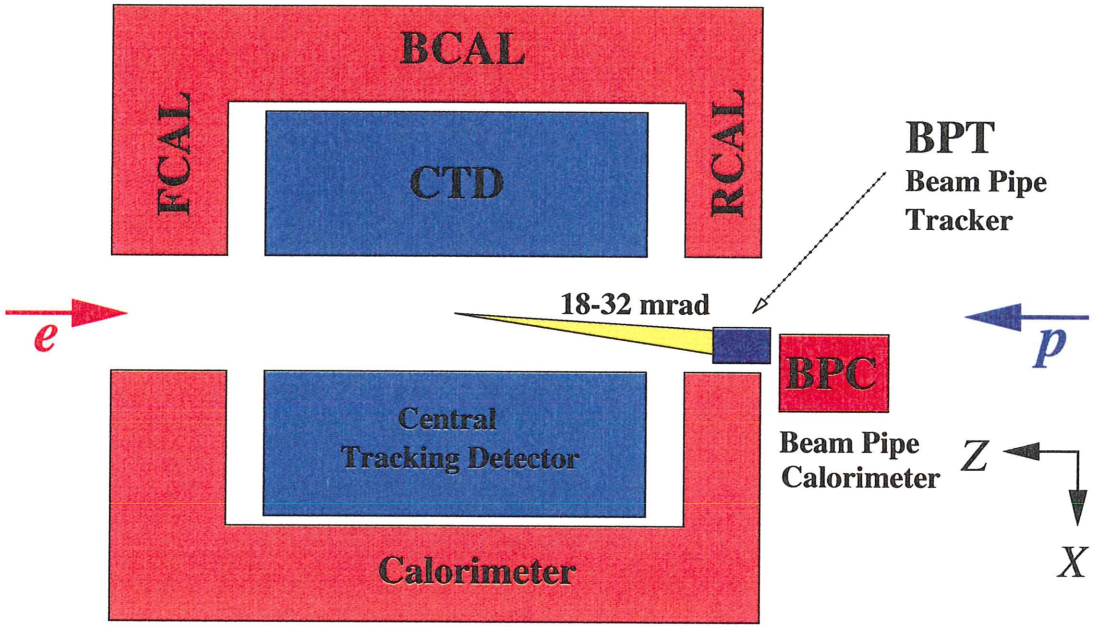
- $F_2 = \sum_{\mathrm{Quarks}} x\,e_q^2\left(q(x,Q^2) + \bar{q}(x,Q^2)\right)$

  "the" structure function of the proton
- $F_L(x,Q^2)$: small correction, relevant at high y

  longitudinal structure function
- $xF_3(x,Q^2)$: negligibly small

  parity violating term

Detectors: ZEUS, BPC, BPT



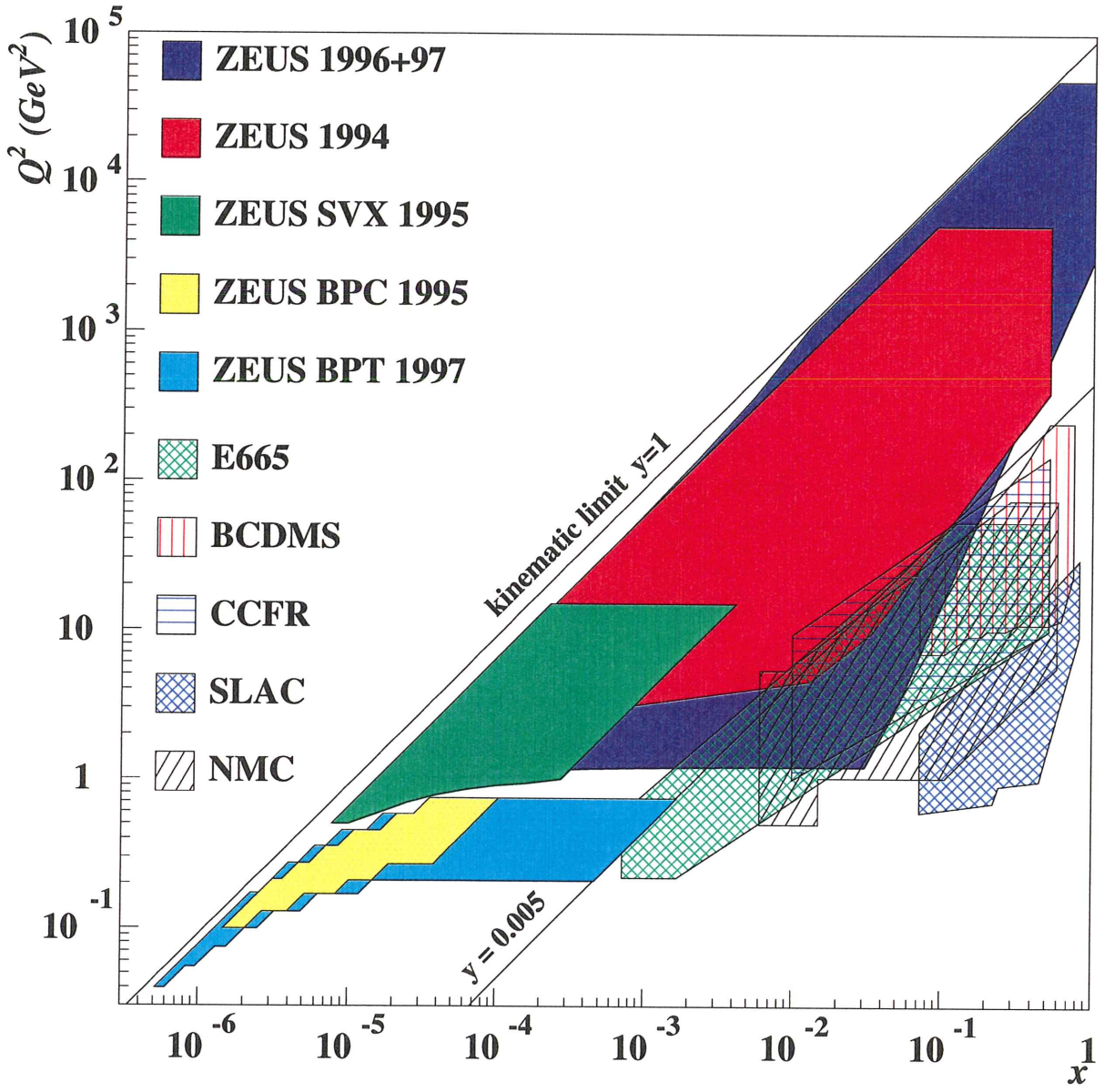
BPC (Beam Pipe Calorimeter, installed 1995)

- tungsten-scintillator sampling calorimeter
- e' energy resolution: $\sigma_E = 0.17\sqrt{E}$
- e' position resolution: $\sigma_{X,Y} = 500\,\mu$m at 27.5 GeV
- energy scale known to $\pm 0.3\%$ at 27.5 GeV
- non-linearity below $\pm 0.5\%$ at 14 GeV

BPT (Beam Pipe Tracker, installed 1997)

- 2 silicon microstrip detectors, 100 μm pitch both planes measure X ($\simeq \theta$), none Y ($\simeq \phi$)
- e' angular resolution: $\sigma_\theta = 0.2$ mrad
- event vertex resolution: $\sigma_Z = 3$ cm
- alignment better than $\pm 200\,\mu$m
- efficiency known to $\pm 1.5\%$

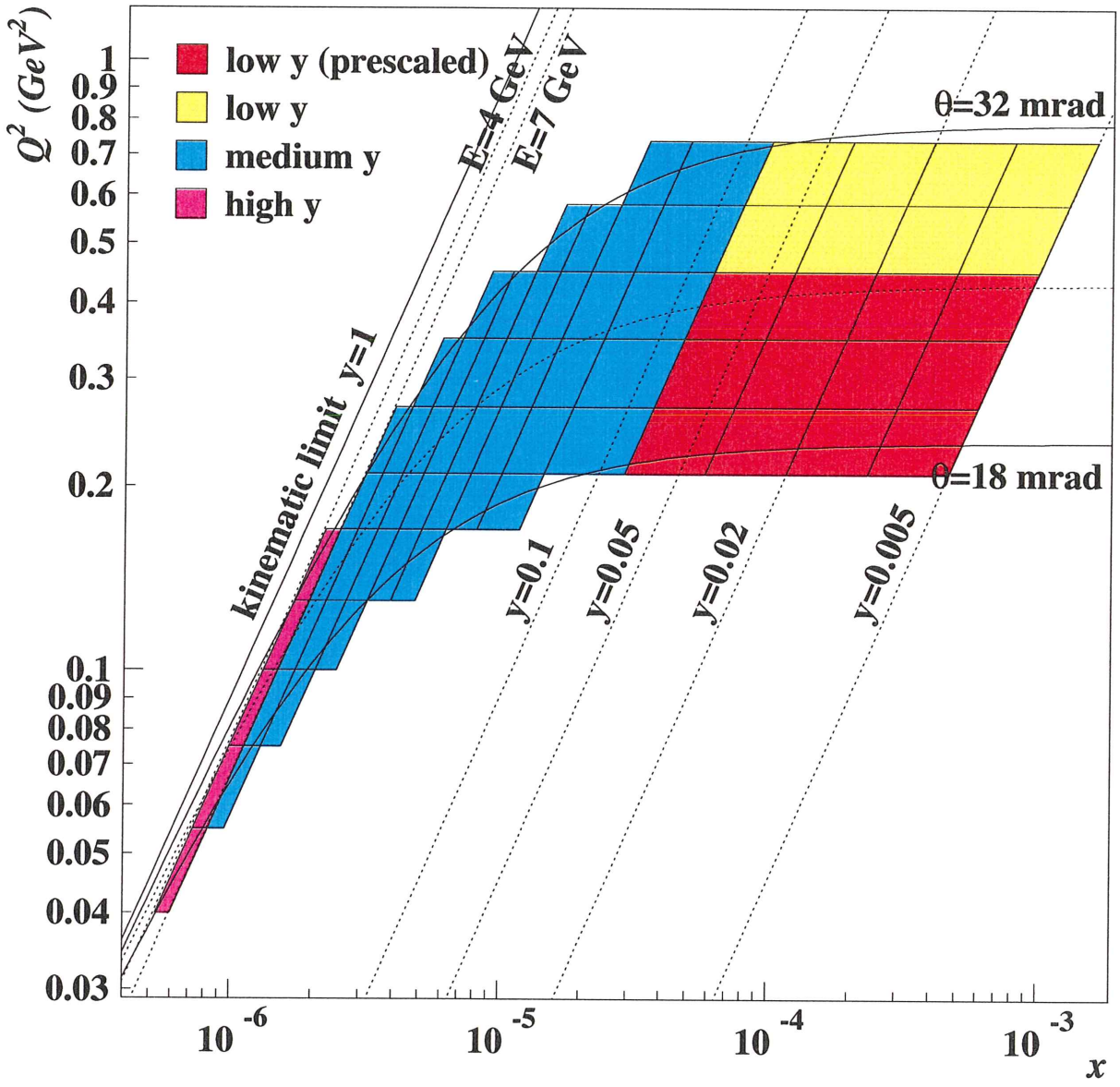
Range in x and Q^2



Kinematic range:

- lowest Q^2 bin: 0.045 GeV^2 (0.11 GeV^2 in 1995)
- highest y: 0.84 (0.74)
- lowest y: 0.005 (0.08) → overlap with E665

Bins and regions



Different triggers & reconstruction methods:

- high y: $E'_e > 4.4$ GeV, electron method
- medium y: $E'_e > 7$ GeV, electron method
- low y: $E'_e > 20$ GeV, e-sigma method
- low y (prescale): $E'_e > 20$ GeV, e-sigma method

Data samples, event selection

Data:

- $\mathcal{L} = 3.9\,\mathrm{pb}^{-1}$, recorded in 6 weeks in 1997
- with typically 4-14% geometrical acceptance

Monte Carlo:

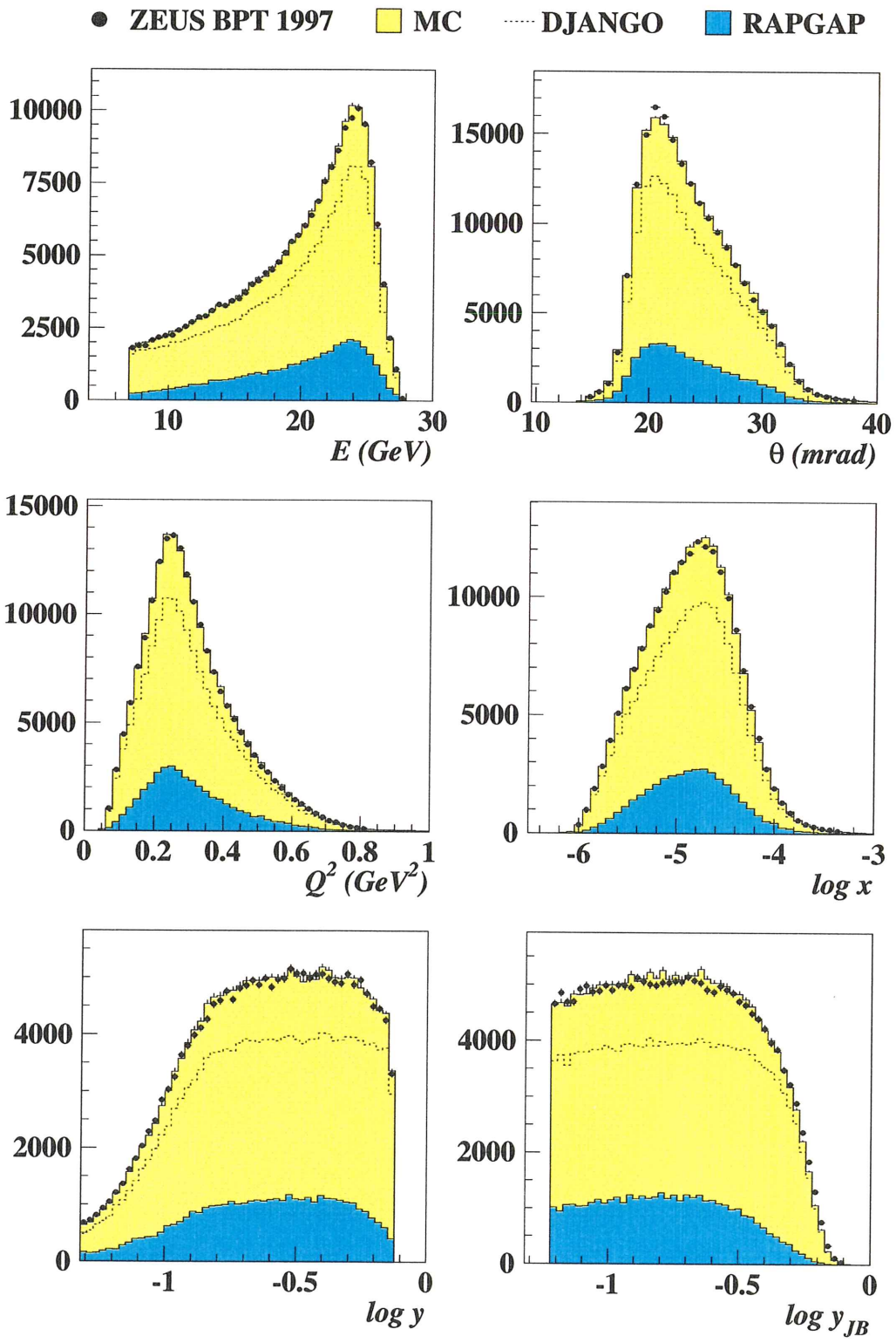
- DJANGO (non-diffractive), $\mathcal{L} = 5.3\,\mathrm{pb}^{-1}$
- RAPGAP (diffractive), $\mathcal{L} = 0.9\,\mathrm{pb}^{-1}$
- mixed in proportion determined from data

Event selection:

- electromagnetic shower in BPC
- track in BPT:
  - matching with BPC (within 5σ)
    reject fake positrons (γ)
  - valid interaction vertex (within $\pm 90\,\mathrm{cm}$)
    reject beam-related background
- cuts on hadronic final state:
  - $\delta \quad = \sum (E - p_Z)_{\mathrm{had}} + (E - p_Z)_e$
  - $y_{\mathrm{JB}} \quad = \sum (E - p_Z)_{\mathrm{had}} / 2E_e$

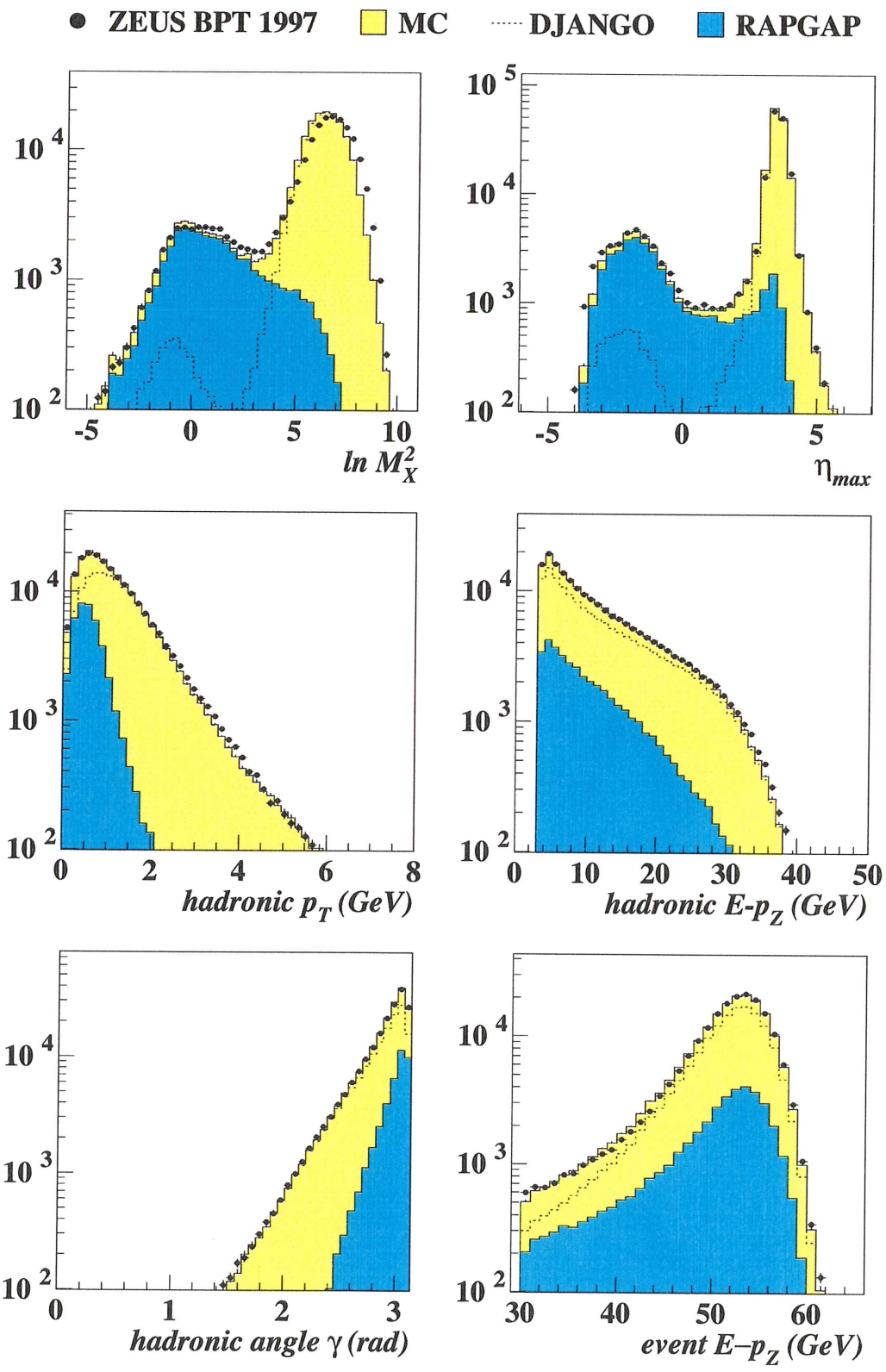
  reduce background, radiative events, migrations

Kinematic variables – medium y

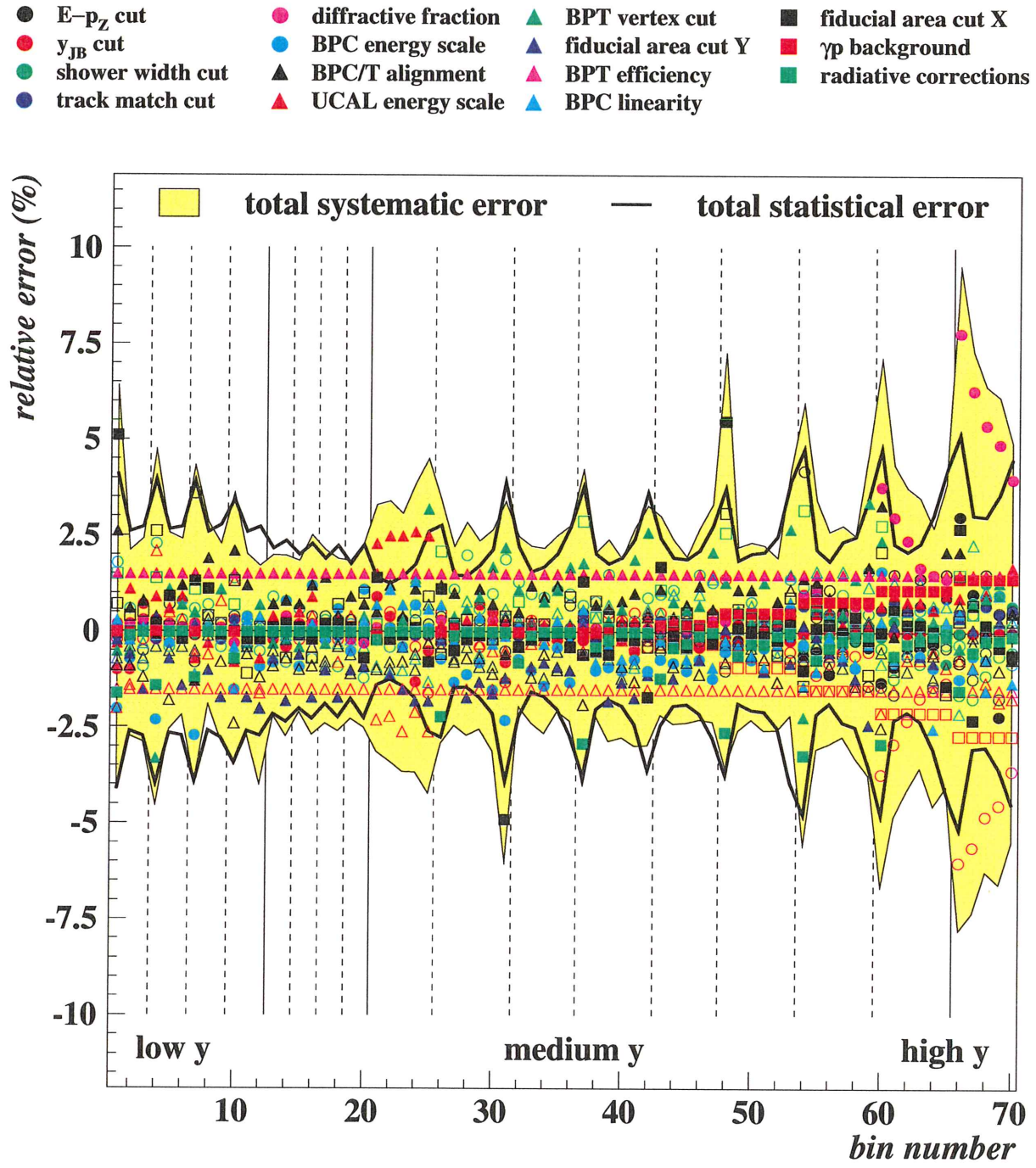


Hadron variables – medium y

ZEUS 1997 (Preliminary)



Stat. & systematic uncertainties

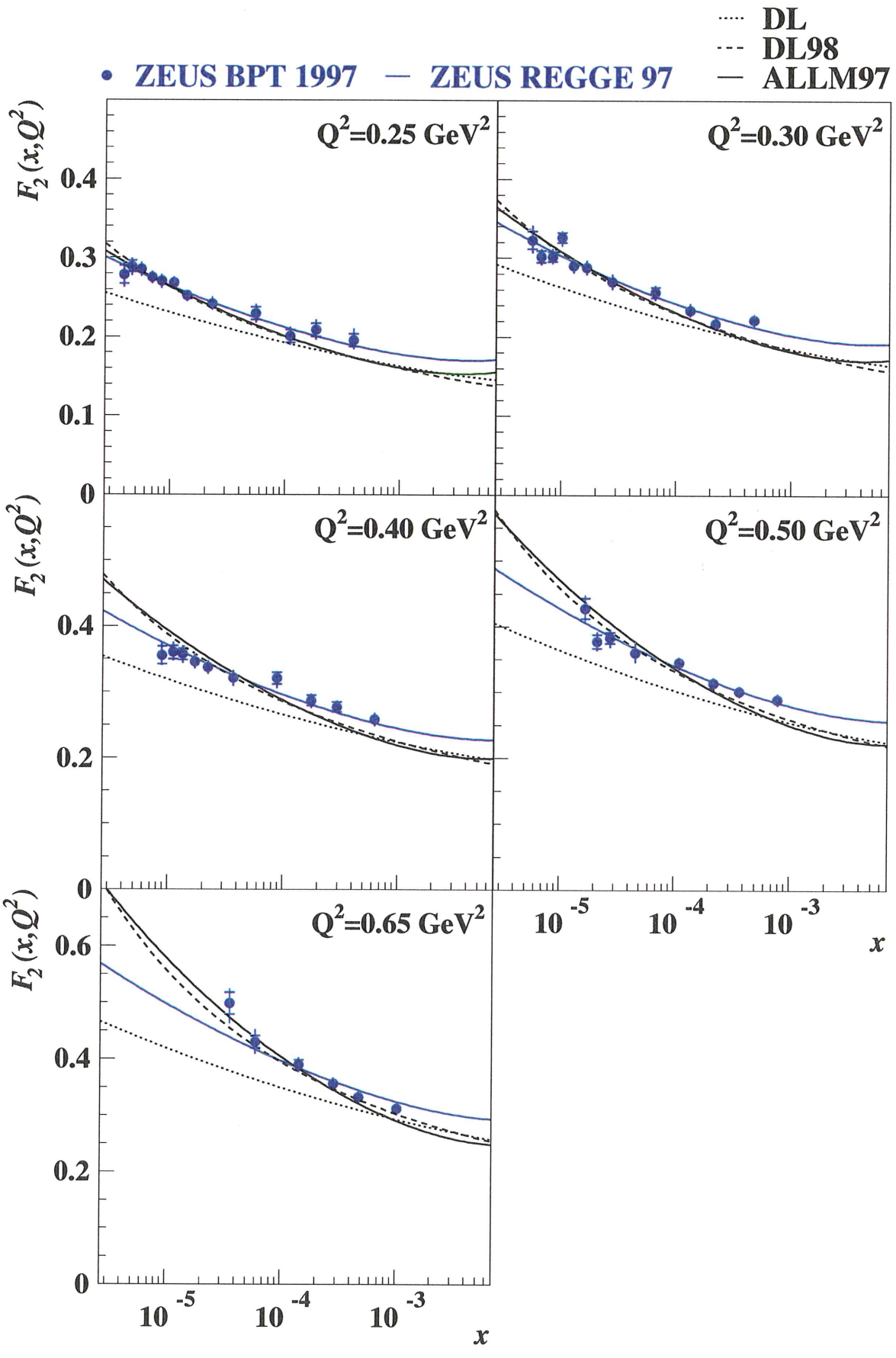


bin number: increasing Q^2 in blocks of increasing y

average error: $\pm 2.6\%(\text{stat}) \pm 3.3\%(\text{sys})$

- statistical and systematic errors very similar
  systematics dominate only at high y
- not shown: overall normalization $\pm 1.8\%$

ZEUS 1997 (Preliminary)



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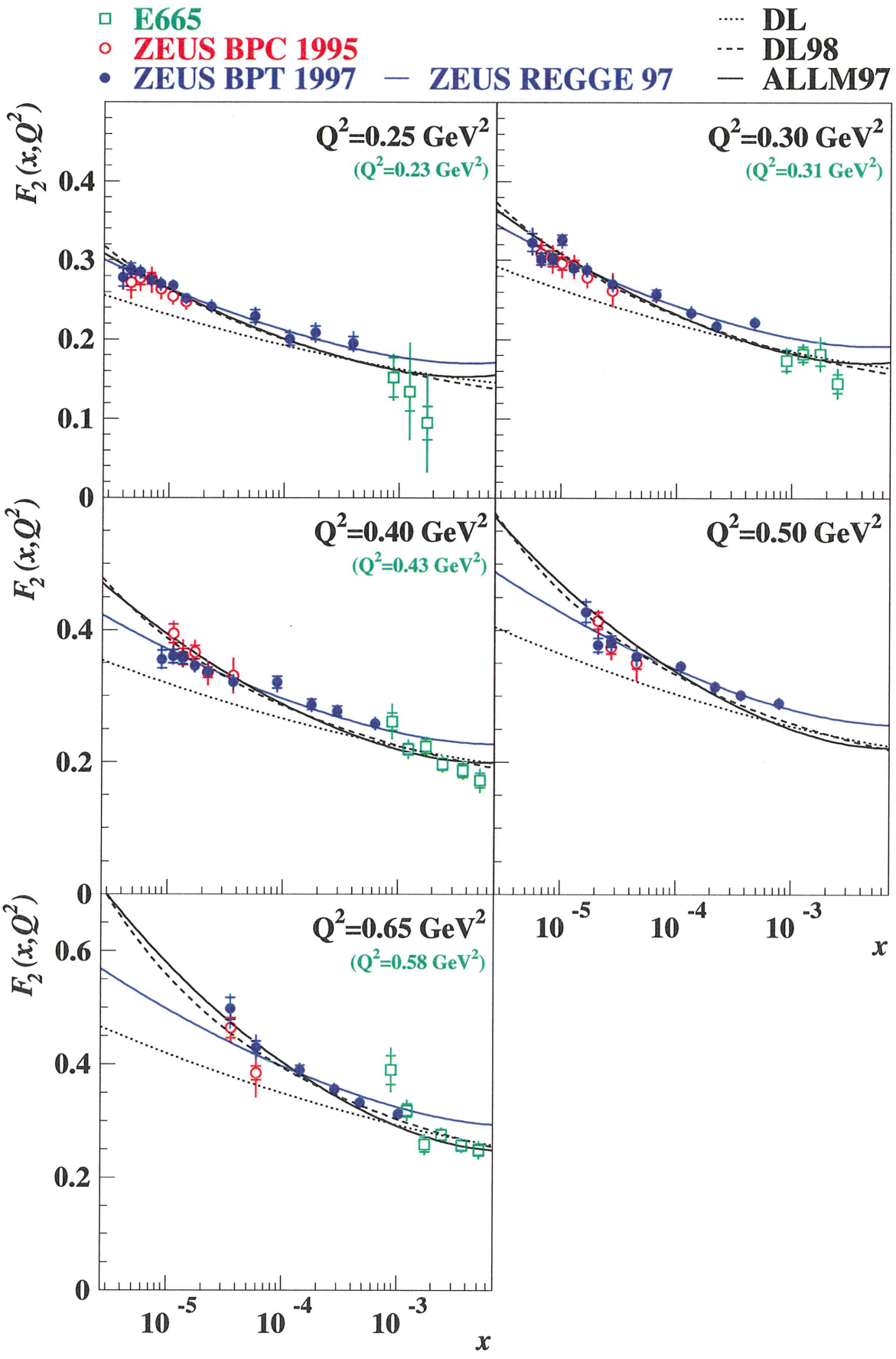

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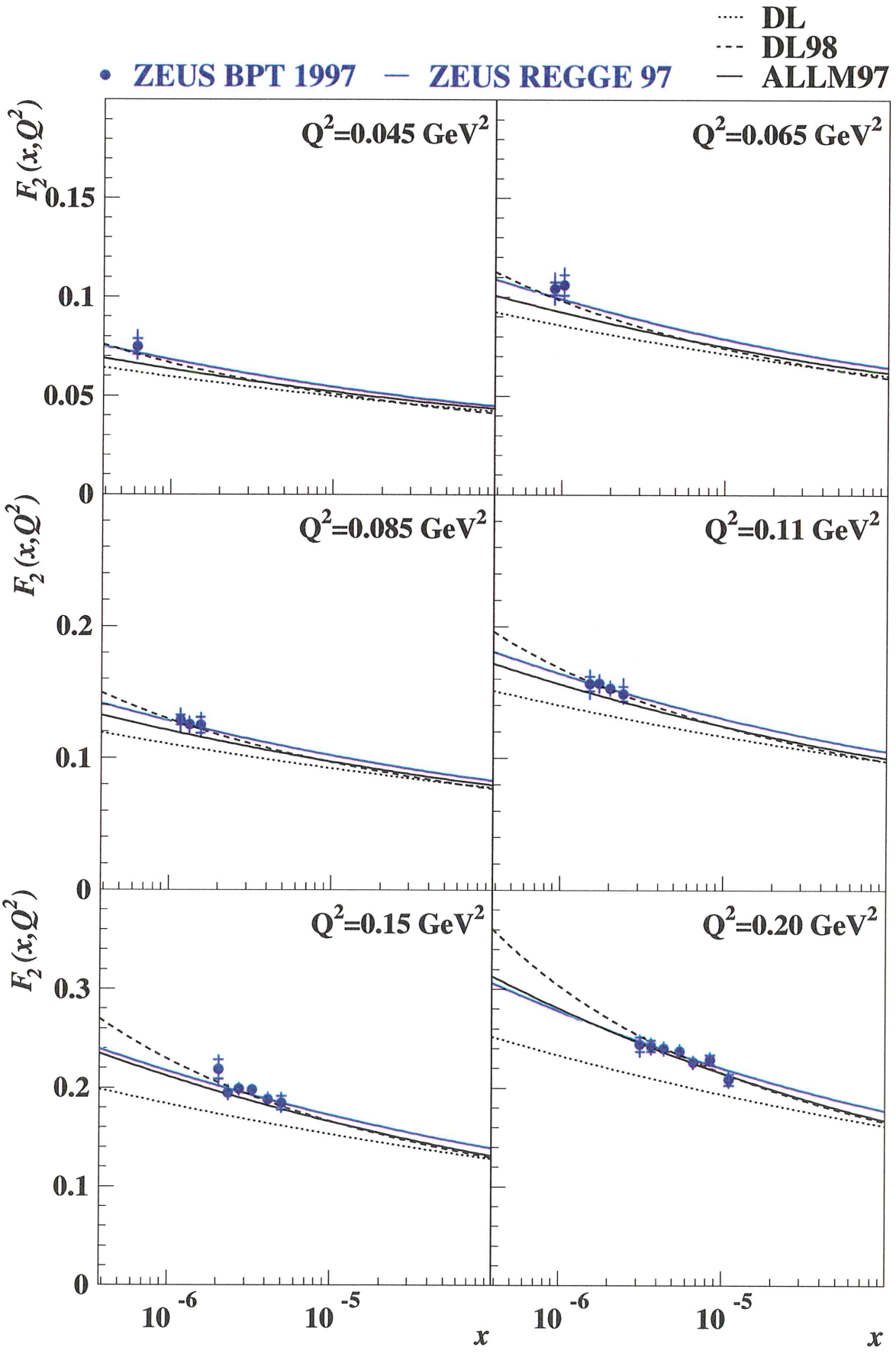

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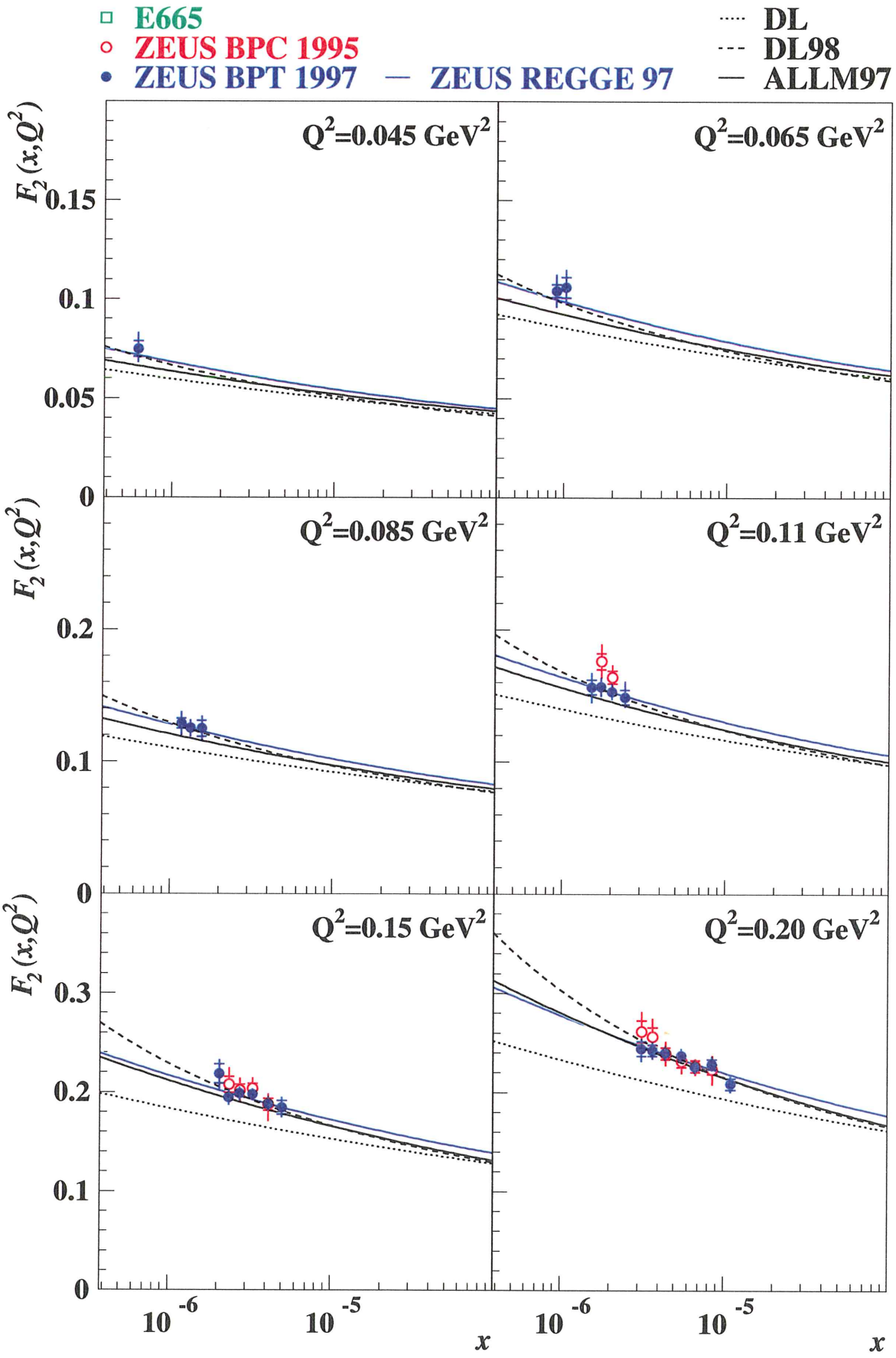

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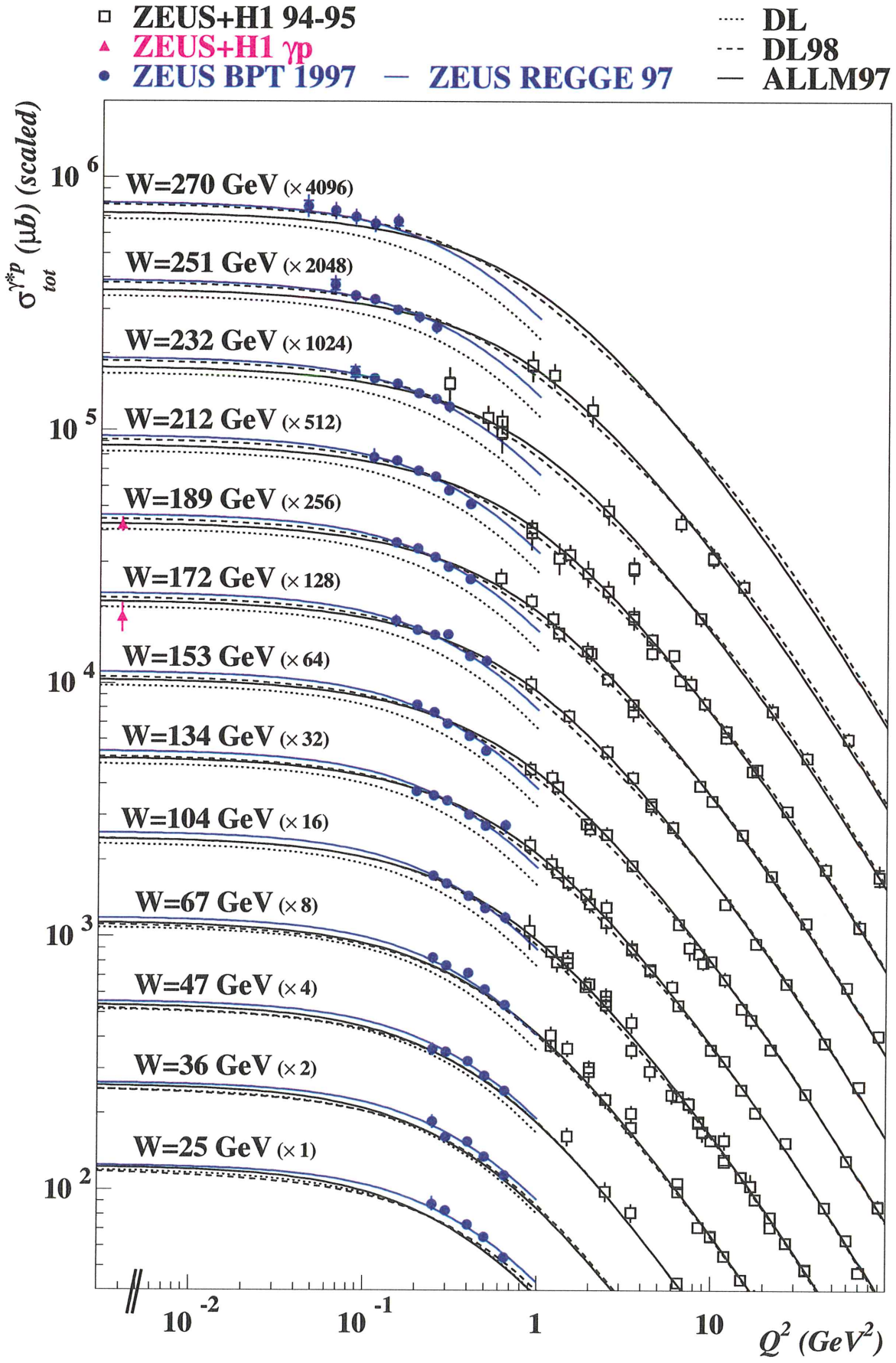
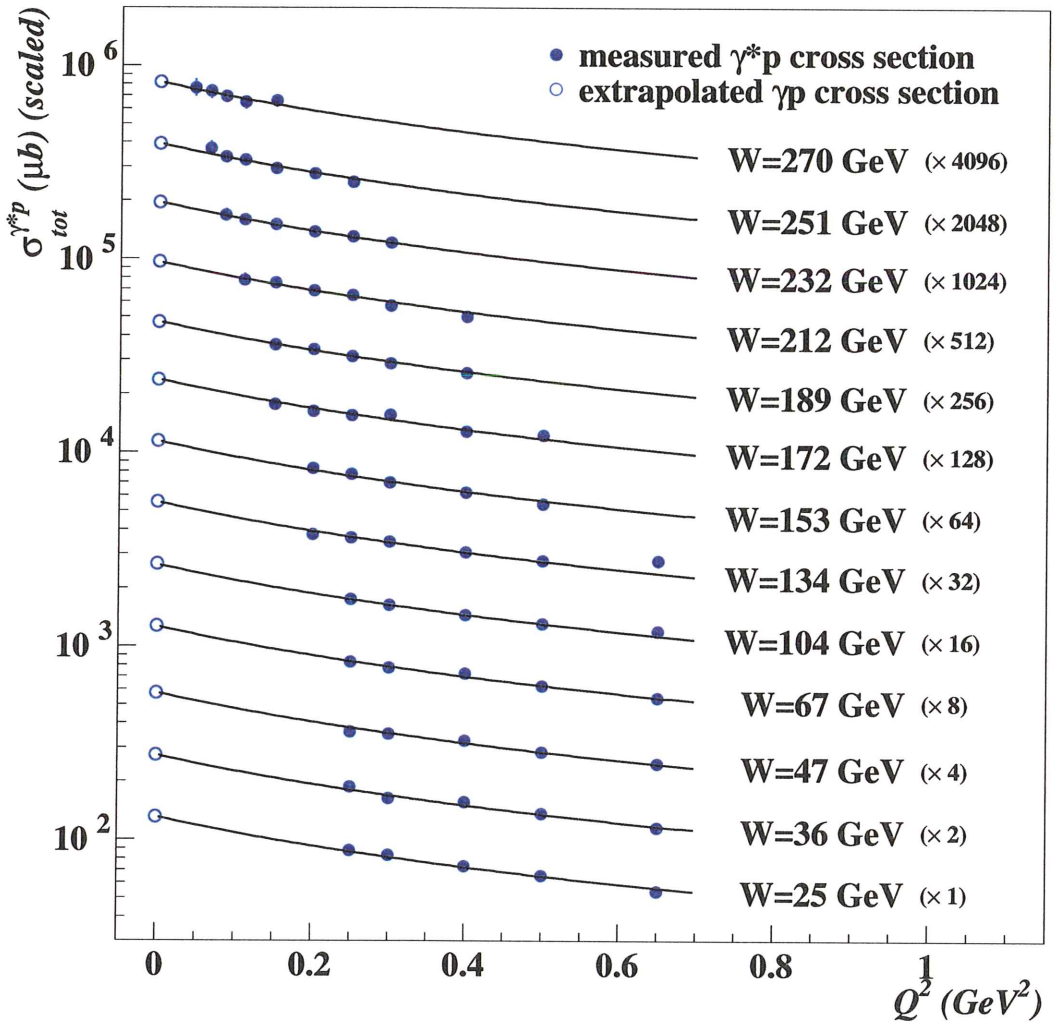


Extrapolation to $Q^2 = 0$

ZEUS 1997 Preliminary



Q^2 dependence of $\sigma^{\gamma^* p}_{\text{tot}}$ à la GVDM:

(simplified: $\sigma_{\text{tot}} \equiv \sigma_T$, σ_L assumed zero)

$$\sigma^{\gamma^* p}_{\text{tot}}(W^2, Q^2) = \frac{m_0^2}{m_0^2 + Q^2} \sigma^{\gamma p}_{\text{tot}}(W^2)$$

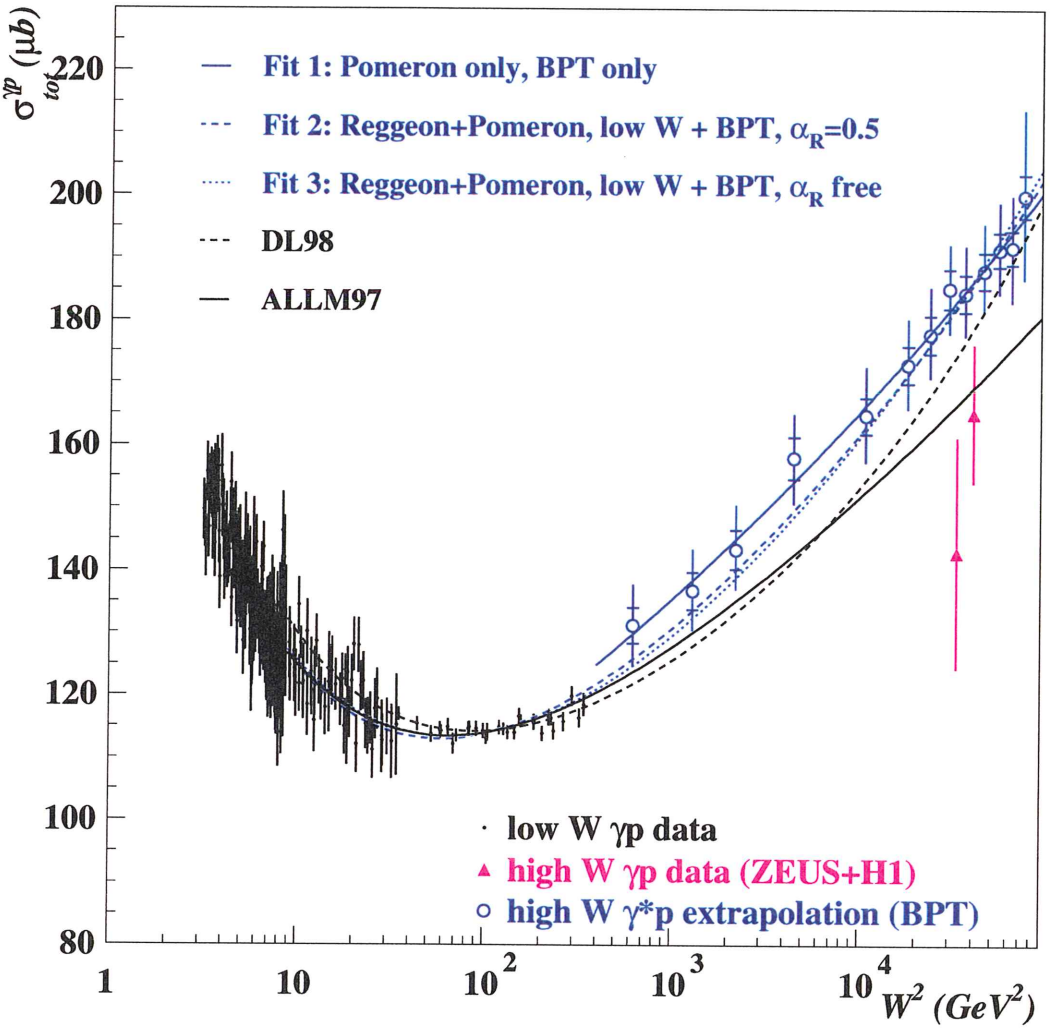
Result: (free parameters: $13 \times \sigma^{\gamma p}_{\text{tot}}(W_i^2)$, m_0^2)

$$m_0^2 = 0.49 \pm 0.02(\text{stat}) \pm 0.04(\text{sys})\ \text{GeV}^2$$

$$\chi^2/\text{ndf} = 71/(70 - 14) = 1.27$$

W dependence

ZEUS 1997 Preliminary



W^2 dependence of $\sigma_{\rm tot}^{\gamma p}$ à la Regge:

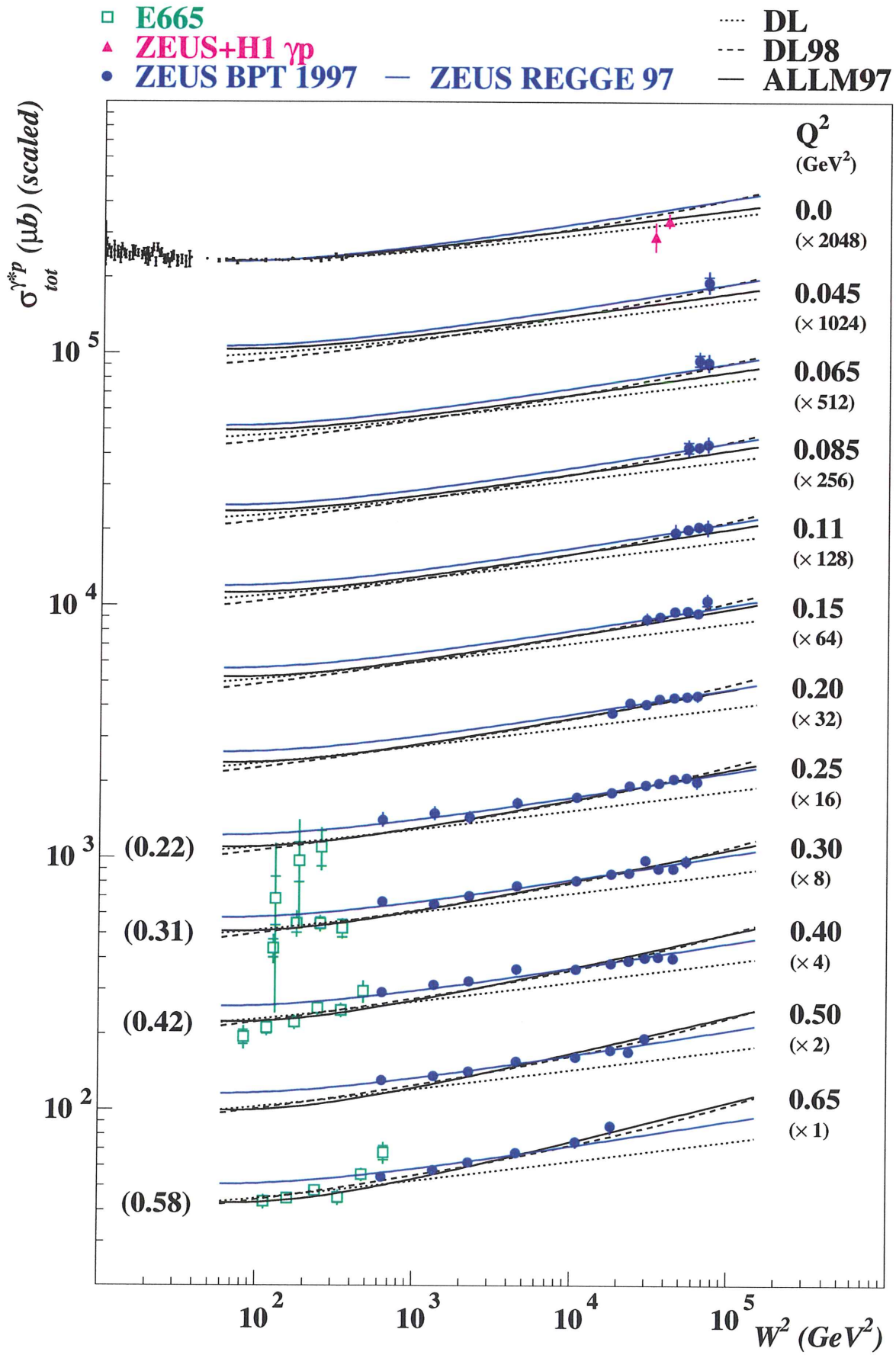
$$\sigma_{\rm tot}^{\gamma p}(W^2) = A_{\mathbb{R}} W^{2(\alpha_{\mathbb{R}}-1)} + A_{\mathbb{P}} W^{2(\alpha_{\mathbb{P}}-1)}$$

Results: (free parameters: $(A_{\mathbb{R}})$, $\alpha_{\mathbb{R}} = 0.5$, $A_{\mathbb{P}}$, $\alpha_{\mathbb{P}}$)

- Fit 1: $\alpha_{\mathbb{P}} = 1.087 \pm 0.004(\text{stat}) \pm 0.008(\text{sys})$
  1995: $\alpha_{\mathbb{P}} = 1.141 \pm 0.020(\text{stat}) \pm 0.044(\text{sys})$
- Fit 2: $\alpha_{\mathbb{P}} = 1.105 \pm 0.001(\text{stat}) \pm 0.007(\text{sys})$
  1995: $\alpha_{\mathbb{P}} = 1.101 \pm 0.002(\text{stat}) \pm 0.012(\text{sys})$

Combined Q^2 and W^2 fit → ZEUS REGGE 97

ZEUS 1997 (Preliminary)



Summary

- In 1997, ZEUS has installed the Beam Pipe Tracker (BPT) to improve the detection of positrons at small scattering angles

- Using the BPT, F_2 and $\sigma_{\mathrm{tot}}^{\gamma^* p}$ have been measured with high precision in the range

$$0.045\,\mathrm{GeV}^2 < Q^2 < 0.65\,\mathrm{GeV}^2$$

$$6 \cdot 10^{-7} < x < 1 \cdot 10^{-3}$$

corresponding to

$$25\,\mathrm{GeV} < W < 270\,\mathrm{GeV}$$

$$0.005 < y < 0.84$$

- The data can be described and extrapolated to $Q^2 = 0$ by a simple GVDM + Regge motivated parameterization