DIS97, Chicago, 04/15/97

A Measurement of the Proton Structure Function $F_2(x, Q^2)$ at Low x and Low Q^2 at HERA

H1 Collaboration

DESY-97-042

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- Introduction
- Upgrade of H1 Detector
- Event Selection & Background Subtraction
- Results & Comparison to Models
- Summary

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Cross Section

at low Q^2: single photon exchange approximation $\rightarrow$

$$\boxed{\begin{aligned}\frac{d^2\sigma}{dx dQ^2} &= \frac{2\pi\alpha^2}{xQ^4}\left[(2(1-y)+y^2)F_2(x,Q^2) - y^2 F_L(x,Q^2)\right] \\ &= \Gamma[\sigma_T(x,Q^2)+\epsilon(y)\sigma_L(x,Q^2)] \equiv \Gamma\sigma^{\rm eff}_{\gamma^* p}(x,y,Q^2)\end{aligned}}$$

$$F_L = F_2 - 2xF_1, \qquad R = \frac{\sigma_L}{\sigma_T} = \frac{F_L}{F_2 - F_L}$$

$$\Gamma = \frac{\alpha(2-2y+y^2)}{2\pi Q^2 x}, \qquad \epsilon(y) = \frac{2(1-y)}{2-2y+y^2}$$

- F_L not yet directly measured in the HERA regime

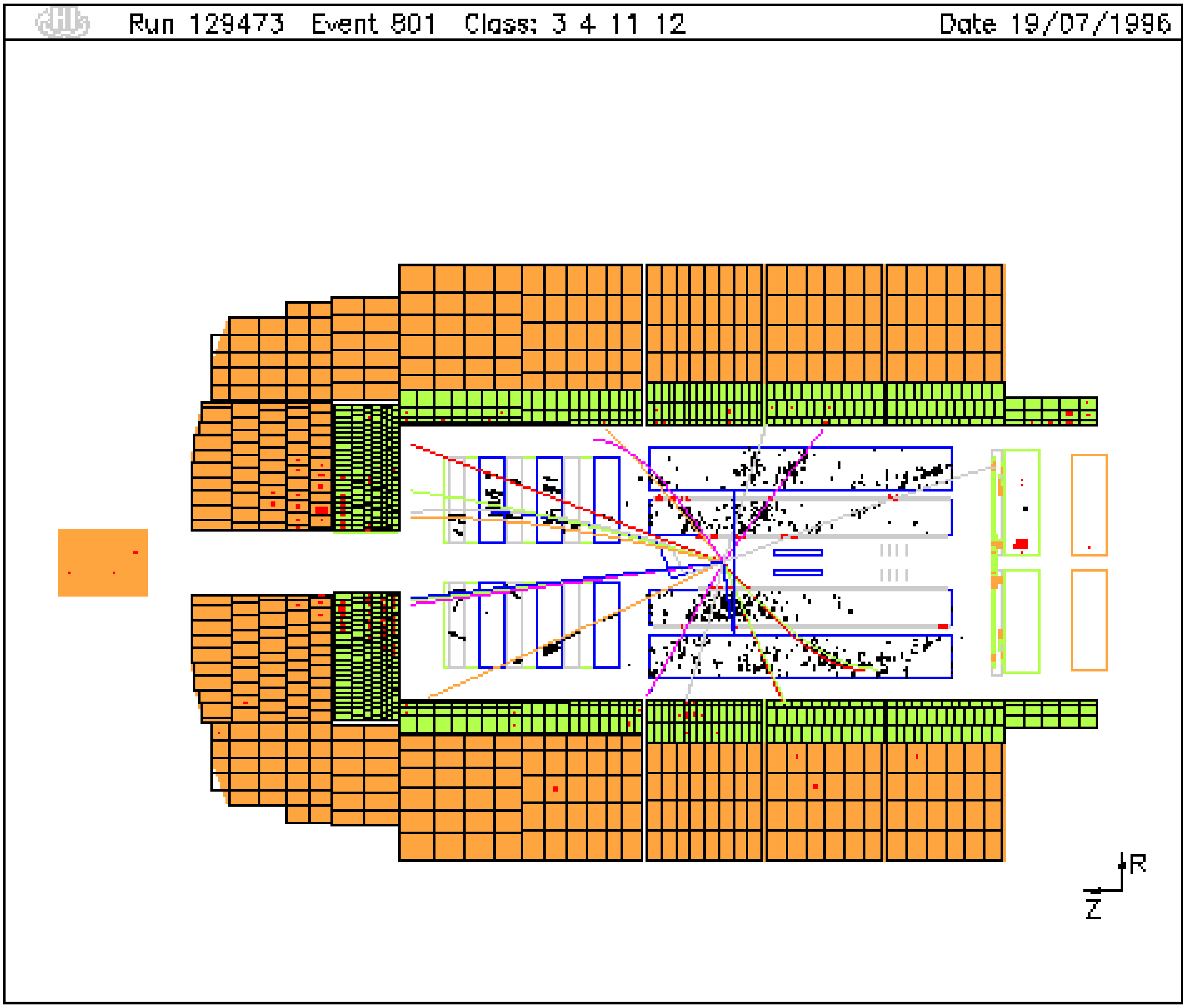
Define total virtual photon-proton cross section:

$$\boxed{\sigma^{tot}_{\gamma^* p} = \sigma_T(x,Q^2) + \sigma_L(x,Q^2) \simeq \frac{4\pi^2\alpha}{Q^2}F_2(x,Q^2)}$$

$\rightarrow$ Comparisons with other experiments and γp data.

H1 Detector

$$E_e = 27.5GeV, \qquad E_p = 820GeV$$
$$Q^2 = 1.35\mathrm{GeV}^2, \qquad x = 3 \cdot 10^{-4}$$

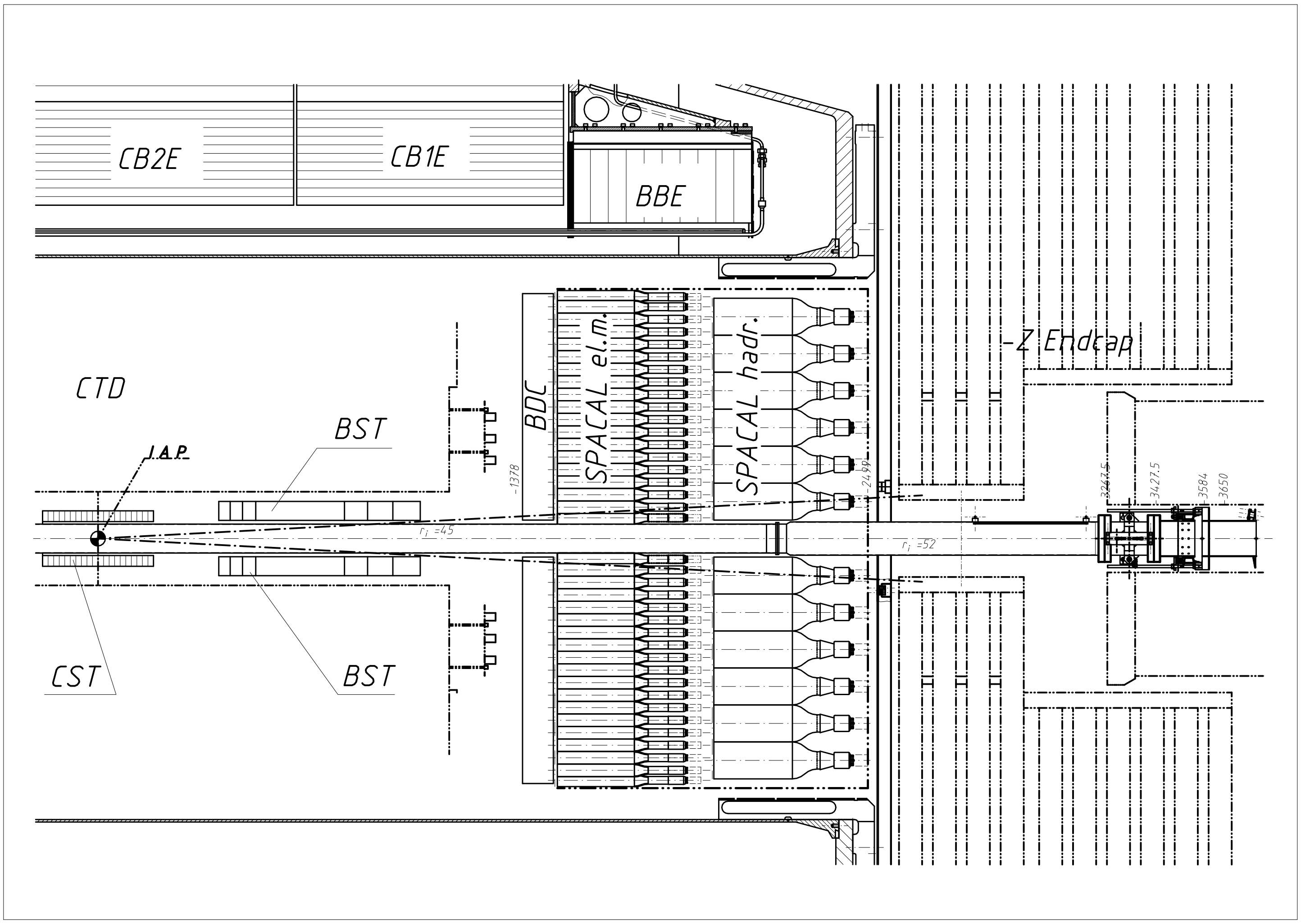


- Polar angle w.r.t. Proton beam: large $\theta_e \Rightarrow$ low Q^2
- Interaction point shifted by +70 cm $\rightarrow$ access lower Q^2.
- 1995: New Detector Components 'Spacal' and 'BDC'. angles

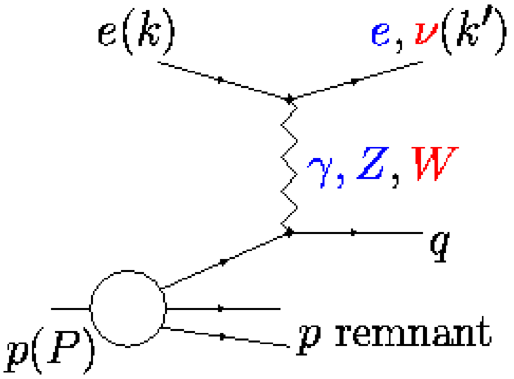
H1 Backward Detectors

1995: High Performance in 1st Year of Operation

Spacal	E'_e Resolution:		$\frac{\sigma_E}{E} = \frac{7.5\%}{\sqrt{E}} \oplus 2.5\%$
		Absolute Scale:	1% at 27.5 GeV
			3% at 7 GeV
BDC	θ_e Resolution:		$\sigma_R = 0.5\text{mm}$
			$\sigma_\phi = 2.5\text{mm}$
		Absolute Scale:	0.5 mrad



Kinematic Reconstruction



$$Q^2 = -(k-k')^2$$

$$x = \frac{Q^2}{2P\cdot(k-k')}$$

$$y = \frac{P\cdot(k-k')}{P\cdot k}$$

- Electron Method:

$$y_e = 1 - \frac{E'_e}{E_e}\sin^2\frac{\theta_e}{2}, \qquad Q_e^2 = 4E'_e E_e \cos^2\frac{\theta_e}{2}$$

- Σ Method:

$$y_\Sigma = \frac{\Sigma}{\underbrace{\Sigma + E'_e(1-\cos\theta_e)}_{2\cdot E_{\text{Incident Electron}}}}, \qquad Q_\Sigma^2 = \frac{E_e'^2\sin^2\theta_e}{1-y_\Sigma}$$

with $\Sigma = \sum_{\text{hadrons}} (E_h - p_{z,h})$

$\rightarrow x = Q^2/ys$

- Different Systematics: e, Σ (e.g. ISR)
- Optimal Resolution for Q^2 and x
- Redundancy used for Consistency Checks

Measurements

data '94: $1.5\mathrm{GeV}^2 \leq Q^2 \leq 5000\mathrm{GeV}^2$

pQCD DGLAP behaviour throughout complete region

data '95: Very low $Q^2 \geq 0.35\mathrm{GeV}^2$

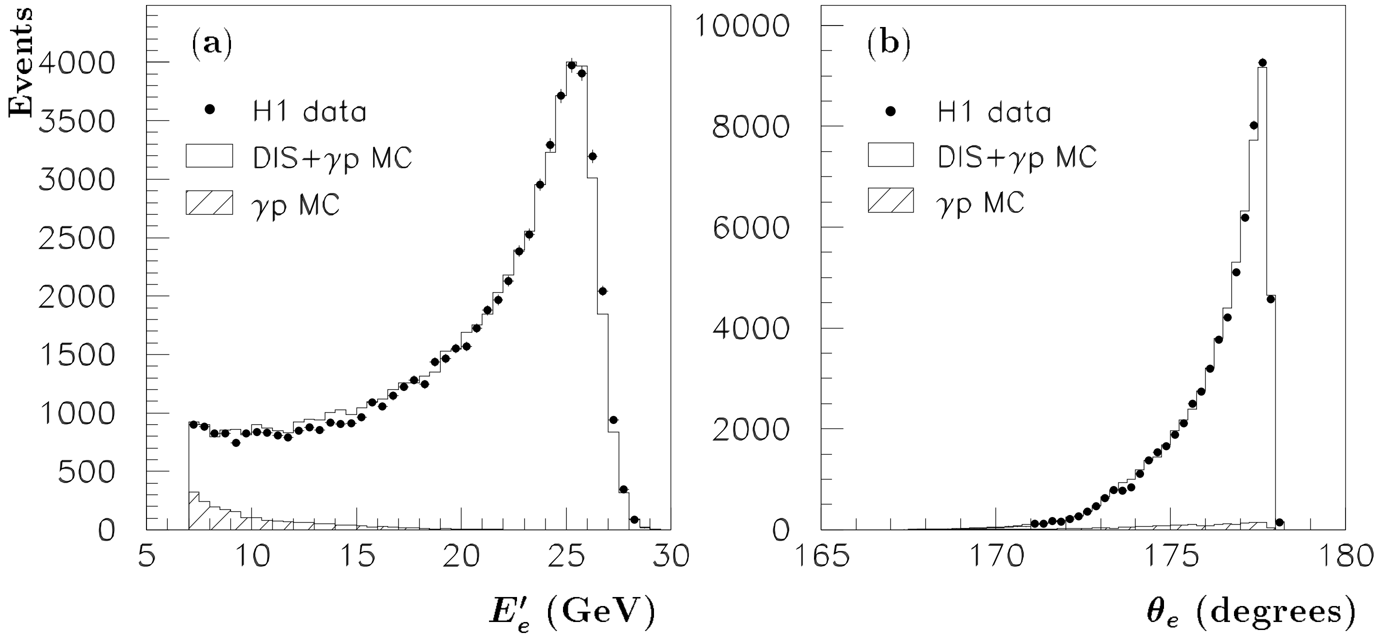
Transition to photoproduction region

DIS ($Q^2 \gtrsim \mathcal{O}(\mathrm{GeV}^2)$) $\leftrightarrow$ photoproduction ($Q^2 \approx 0$)

pQCD DGLAP NLO $\leftrightarrow$ Regge phenomenology

How does the transition take place?

Scattered Electron Candidates



DIS Event Selection

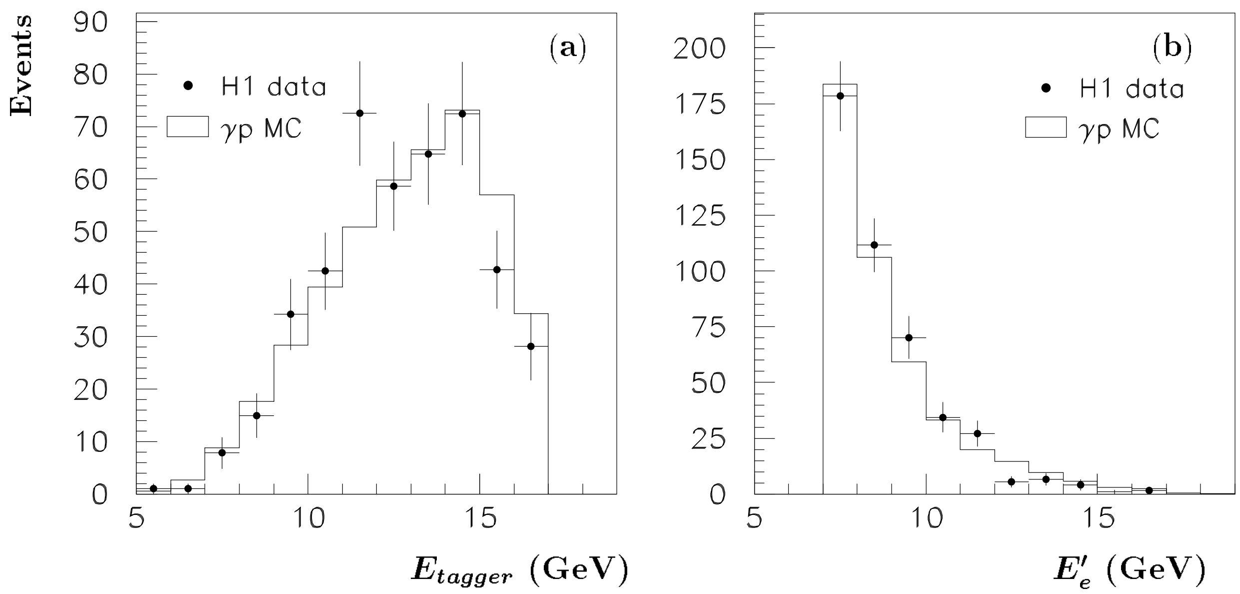
- Most energetic cluster $E'_e > 7\text{GeV}$ $(\Leftrightarrow y \lesssim 0.75)$ fulfills electron identification criteria (Rcl, BDC-Spacal Match,...)
- Polar Angle $\theta_e < 178°$
- Reconstructed vertex
- For Electron Method: $\Sigma(E - p_z) > 35$ GeV

Detector Acceptance correction by Monte Carlo

DIS	DJANGO
γp Background:	PHOJET

- MC events are reweighted to measured cross section
- R according to BK

Determination of γp Background

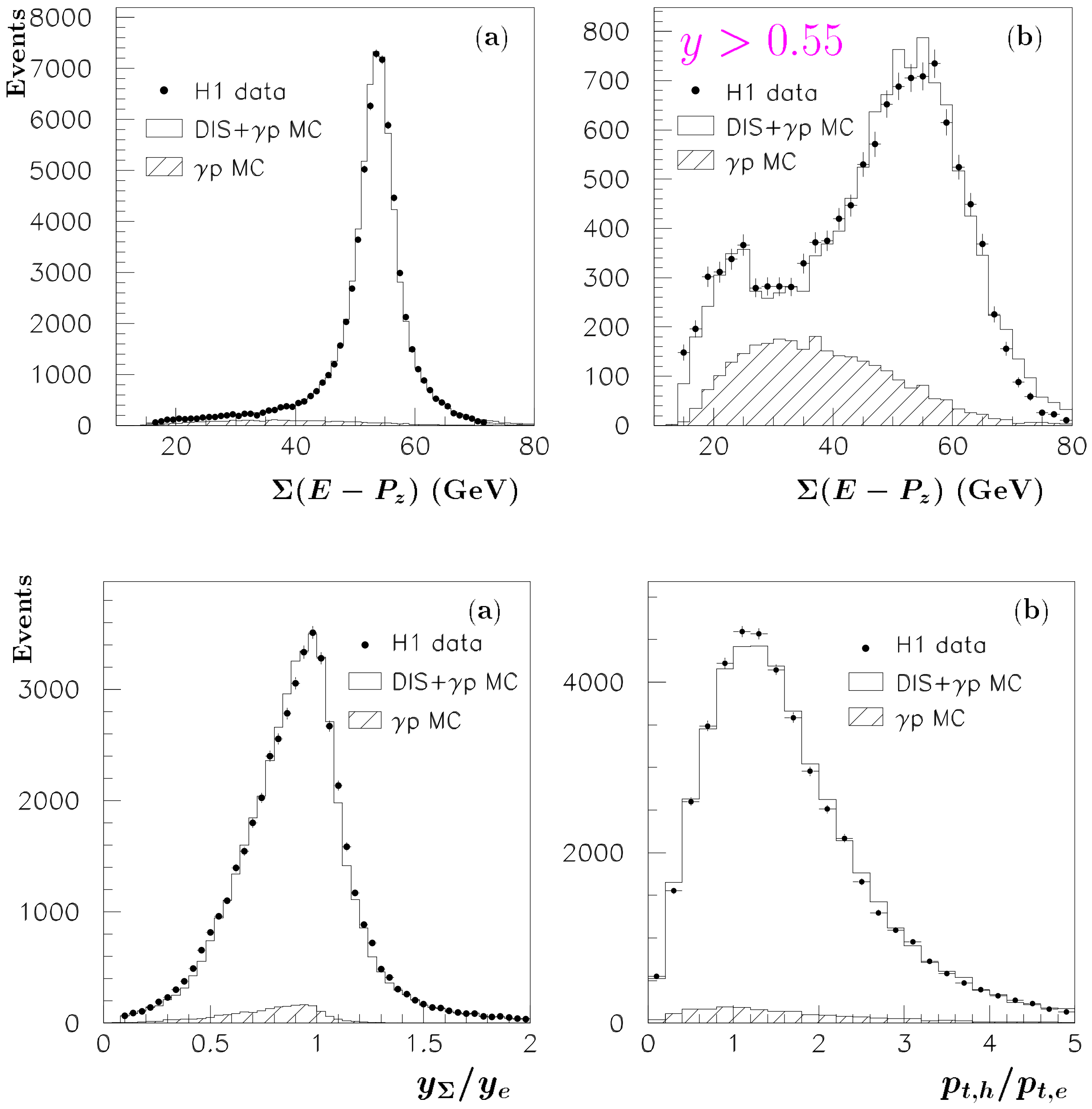


- γp hadronic final state may fake e signature.
- 10% of γp Background tagged by scattered electron.

- γp contamination neglegible at low y.
- Statistical subtraction of background using γp Monte Carlo.

Hadrons vs. Electron

$$\Sigma(E - p_z) = 2E_e \quad (= 55\mathrm{GeV})$$



- Good Description of Data by Monte Carlo

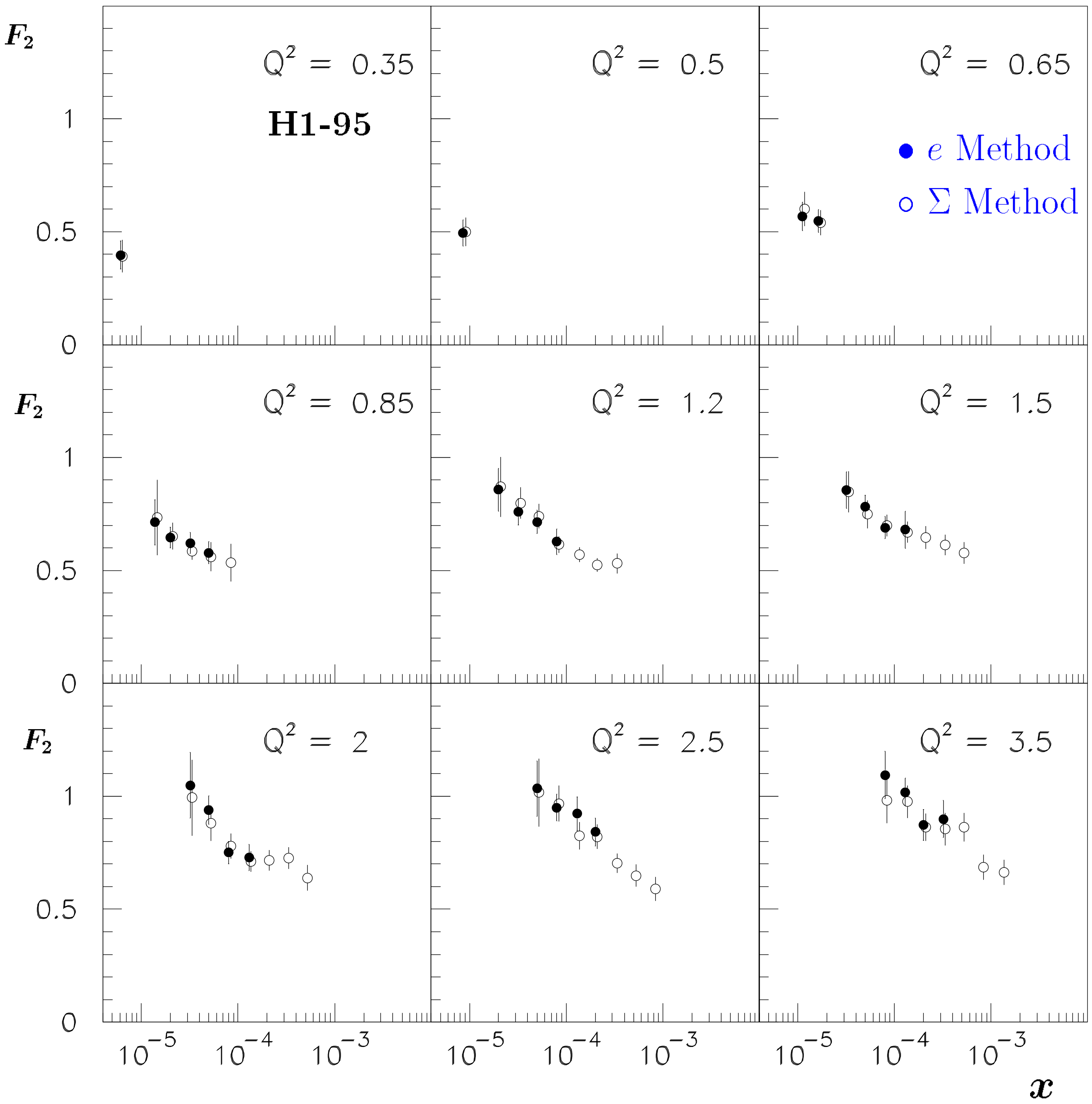
Systematics

- Electron Energy Scale: $\Delta E/E = 1\%$ at 27 GeV, 3% at 7 GeV.
- Polar Angle: ± 0.5 mrad
- Hadronic Energy Scale: $\Delta E/E = 4\%$ LAr, 7% Spacal
- Σ Method only: Simulation of had. final state 3%
- γp Background: 30% of Subtracted Value $\rightarrow < 6\%$.
- Electron Identification: 30% of the fraction of DIS events lost by the selection cuts
- Vertex Reconstruction Efficiency: 2% (5% at $y < 0.05$)
- BDC Efficiency: 2%
- Trigger and Timing Efficiency: 0.5%
- Luminosity Determination: 3%
- Radiative Corrections: 2% (5% at highest y and at $Q^2 \leq 0.65 \mathrm{GeV}^2$)
- Diffractive Processes: up to 6% correction for loss of diffractive events due to vertex existence requirement, $\rightarrow$ 50% error on the correction

Total Systematic Error typically: $\sim 5 - 10\%$

Statistical Error: $\sim 3\%$

Results



- Good Agreement, e, Σ, confirms systematic understanding
- Error bars include statistical and systematic uncertainty
- Uncertainty of overall normalization: 3%
- Use e at high y, Σ at low y

Models at low x, Q^2

- DoLa: Assumption of Q^2-independent Regge behaviour. $\rightarrow$ Contribution from Soft Pomeron Exchange to cross section at $Q^2 > 0$.

- CKMT: Regge-type model with Q^2 dependent slope λ. Screening corrections to the 'bare Pomeron' at low Q^2 ($\rightarrow$ 'soft behaviour') rapidly decreasing with increasing Q^2.

- ALLM: Regge motivated parametrization, logarithmic development towards larger Q^2. Good description of all ('94) data.

- BK: Combination of GVMD Model with pQCD

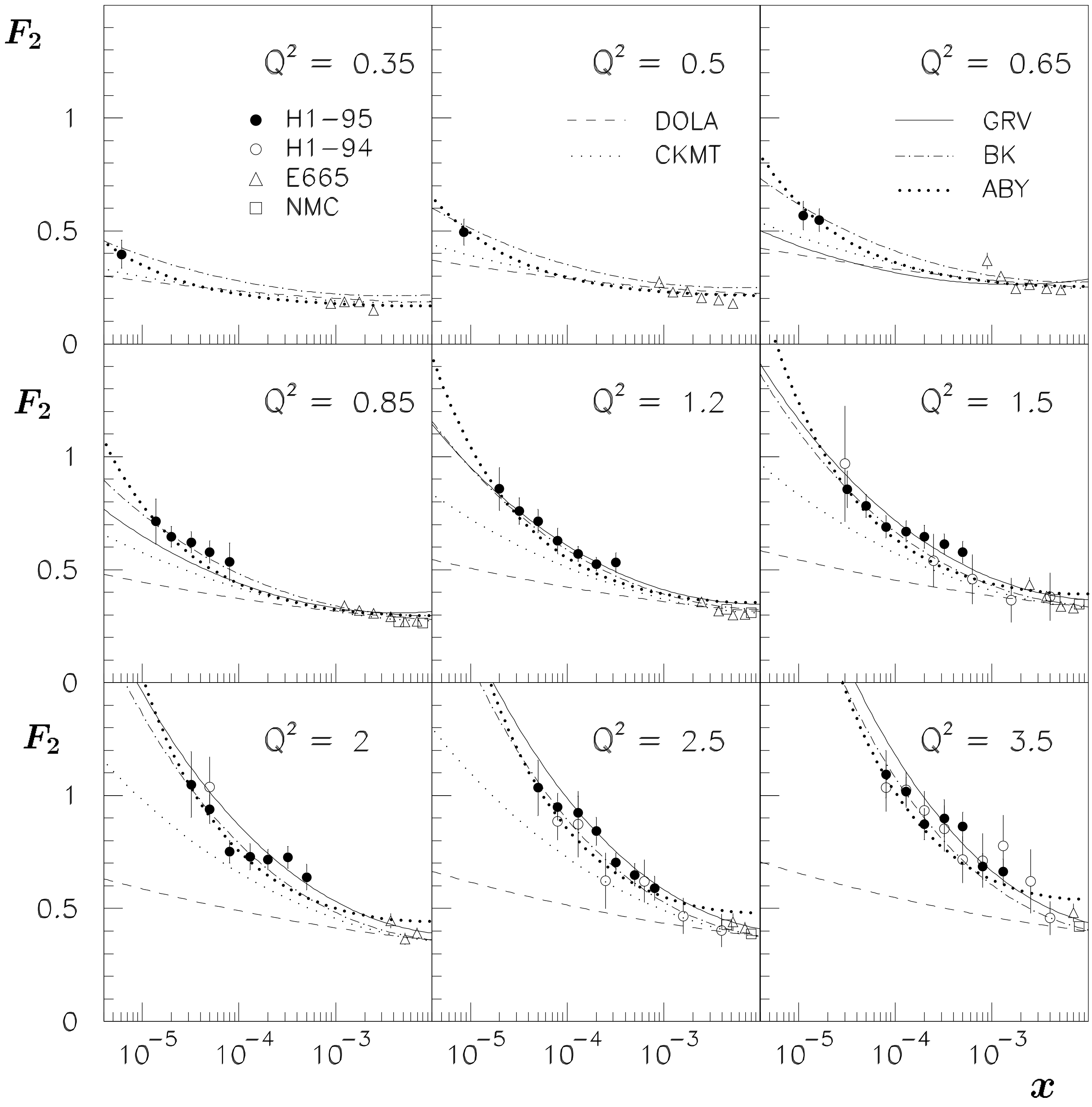
$$F_2(x, Q^2) = F_2^{\mathrm{VMD}}(x, Q^2) + \frac{Q^2}{Q_0^2 + Q^2} F_2^{\mathrm{QCD}}(\overline{x}, Q^2 + Q_0^2)$$

- ABY: Sum of hard and soft contribution to F_2. Saturation of $\alpha_s(Q^2)$ at low Q^2.

- GRV: pQCD evolution, NLO DGLAP.

  Valence like parton distribution at low starting scale 0.34 GeV^2.

Comparisons

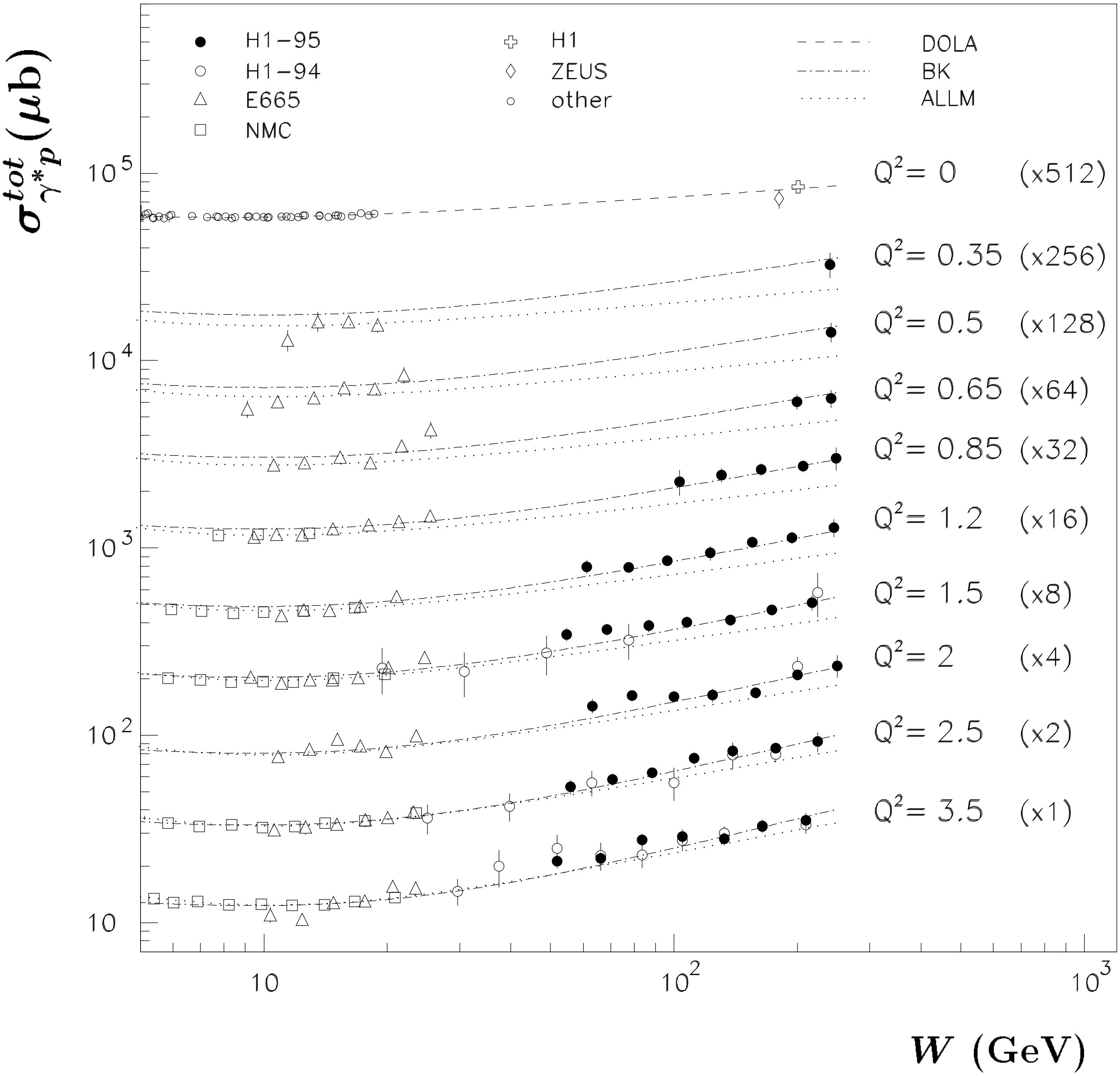


- DoLa: Soft Pomeron (low Q^2)
- GRV: pQCD DGLAP ($Q^2 \gtrsim 1$GeV)
- BK: Combination of GVMD and pQCD ($Q^2 > 0$)

Slope Parameter λ

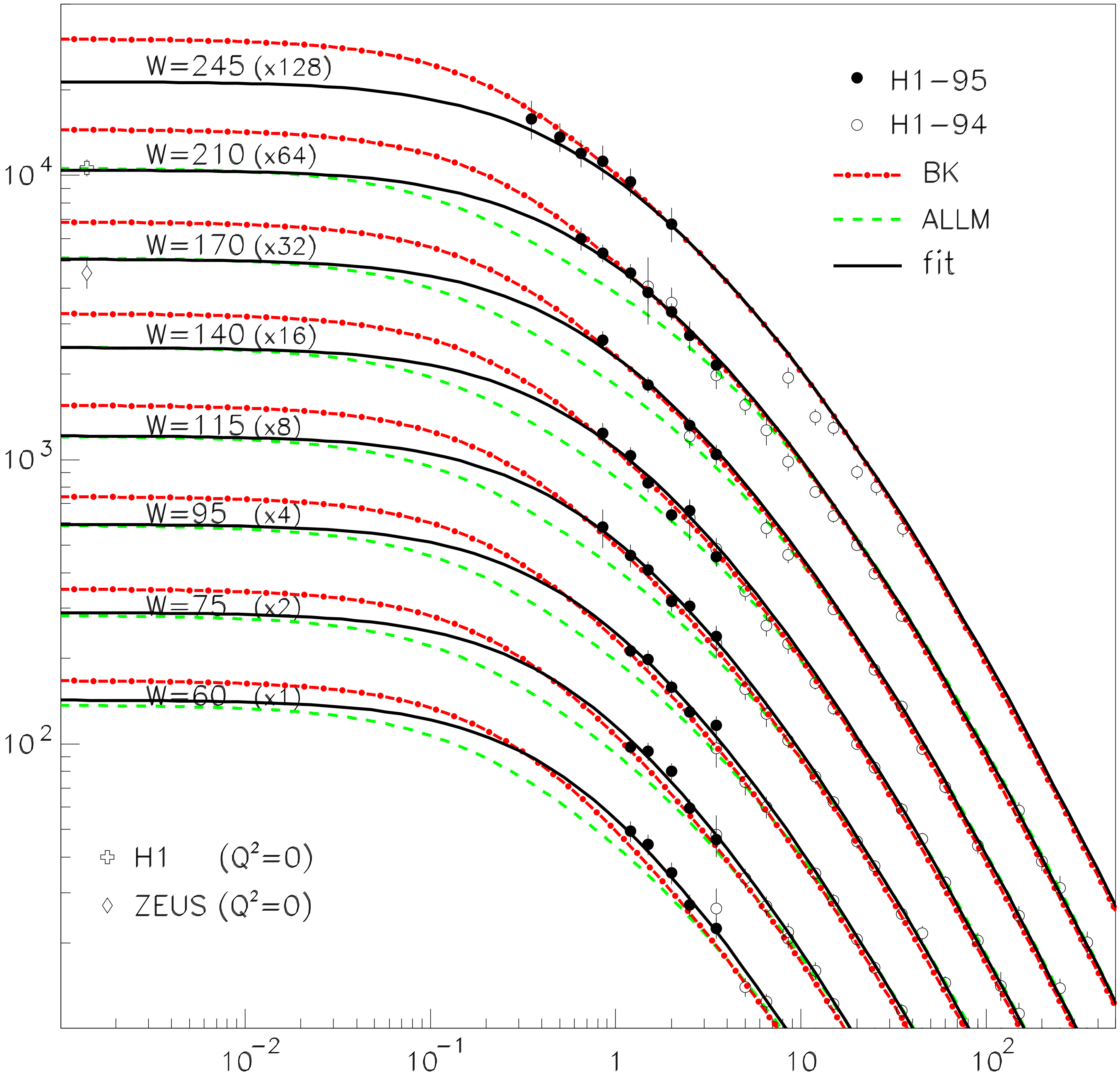
$$F_2(x, Q^2) \propto x^{-\lambda(Q^2)}$$

$\sigma^{\mathrm{tot}}_{\gamma^* p}$: Energy Dependence



- At low x: $W \simeq Q^2/x$.
- Comparison to Fixed Target and γp Measurements

Q^2 Dependence



Q^2 [GeV^2]

- BK: Good description of data at low Q^2.
- Fit to accommodate photoproduction points ($Q^2 = 0$):

$$F_2(x, Q^2) = C_{\mathrm{VMD}} \cdot F_2^{\mathrm{VMD}}(x, Q^2) + \frac{Q^2}{Q_0^2 + Q^2} F_2^{\mathrm{QCD}}(\overline{x}, Q^2 + Q_0^2)$$

$$C_{\mathrm{VMD}} = 0.77, \qquad Q_0^2 = 0.45\mathrm{GeV}^2$$

Summary

- Measurement of $F_2(x, Q^2)$ in a new kinematic regime:

$$Q^2 \geq 0.35\mathrm{GeV}^2 \qquad \text{and} \qquad x \geq 6 \cdot 10^{-6}$$

- First measurement with the new H1 Backward Detectors
- Two Reconstruction Methods e and Σ $\rightarrow$

  Good Resolution, Wide Kinematic Range, Internal Cross Checks
- Transition from pQCD to non-perturbative region explored
- Comparison to low Q^2 models
  - At $Q^2 \gtrsim 1\mathrm{GeV}$: good description of data by pQCD
  - At lowest Q^2 F_2 approaches Regge expectation
- No model yet available describing full kinematic range