

# Measurement of $e^+ p$ Scattering Cross Section at low $Q^2$

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DESY  
for H1 collaboration

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## DIS Scattering at low $Q^2$

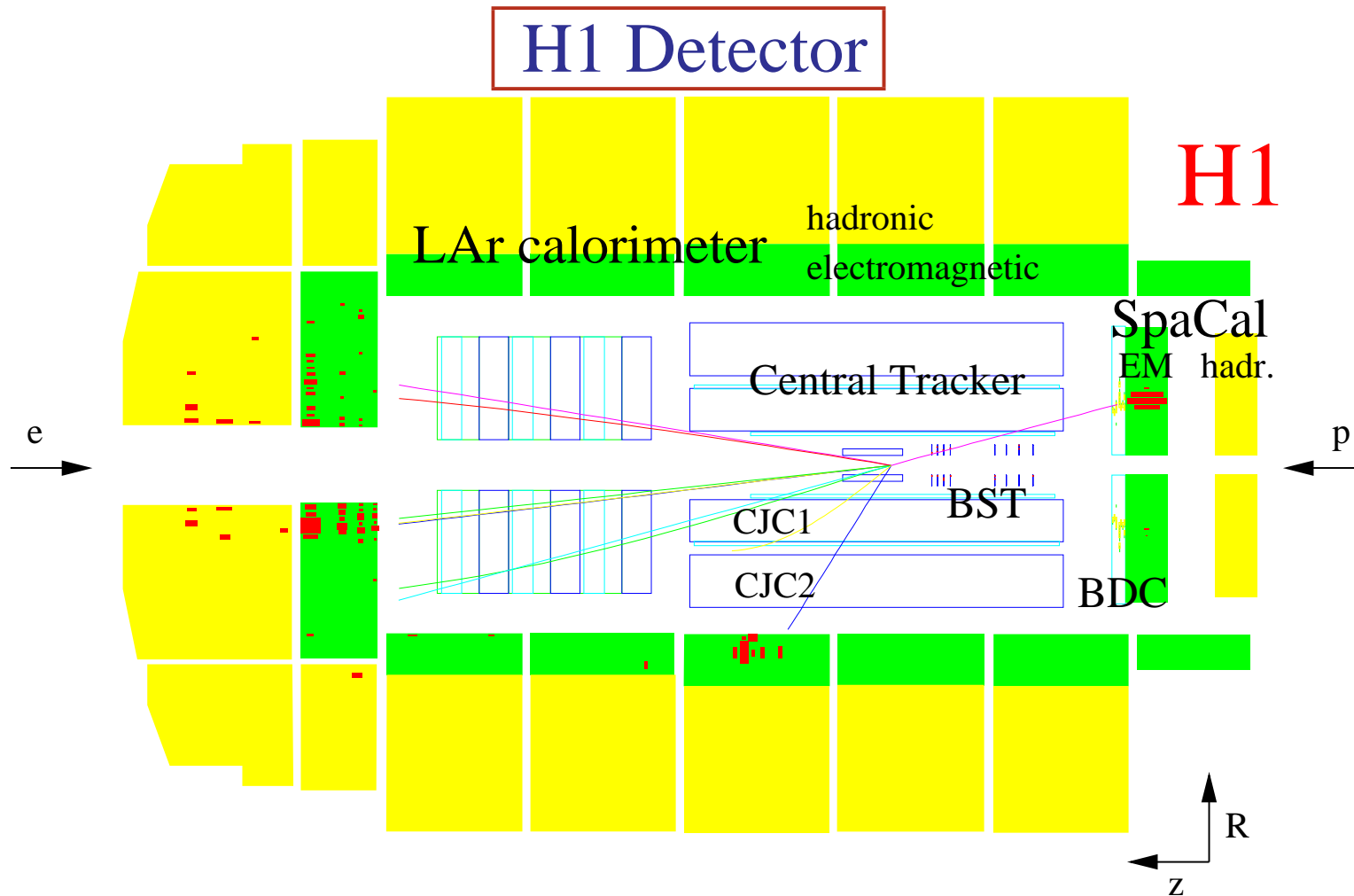
$$\sigma_r = F_2(x, Q^2) - \frac{y}{1 + (1 - y)^2} F_L(x, Q^2)$$

At low  $Q^2$ , only two structure functions contribute which are related to the cross sections for the scattering of longitudinally and transversely polarized photons

$$F_L = \frac{Q^2}{4\pi^2\alpha} (1 - x) \cdot \sigma_L \quad F_2 = \frac{Q^2}{4\pi^2\alpha} (1 - x) \cdot (\sigma_L + \sigma_T).$$

Low  $Q^2$  scattering measures transition from photoproduction to perturbatively calculable QCD. The transition occurs at  $Q^2 \sim 2 \text{ GeV}$ . Phenomenological dipole models describe photoproduction, perturbative and transition regions.

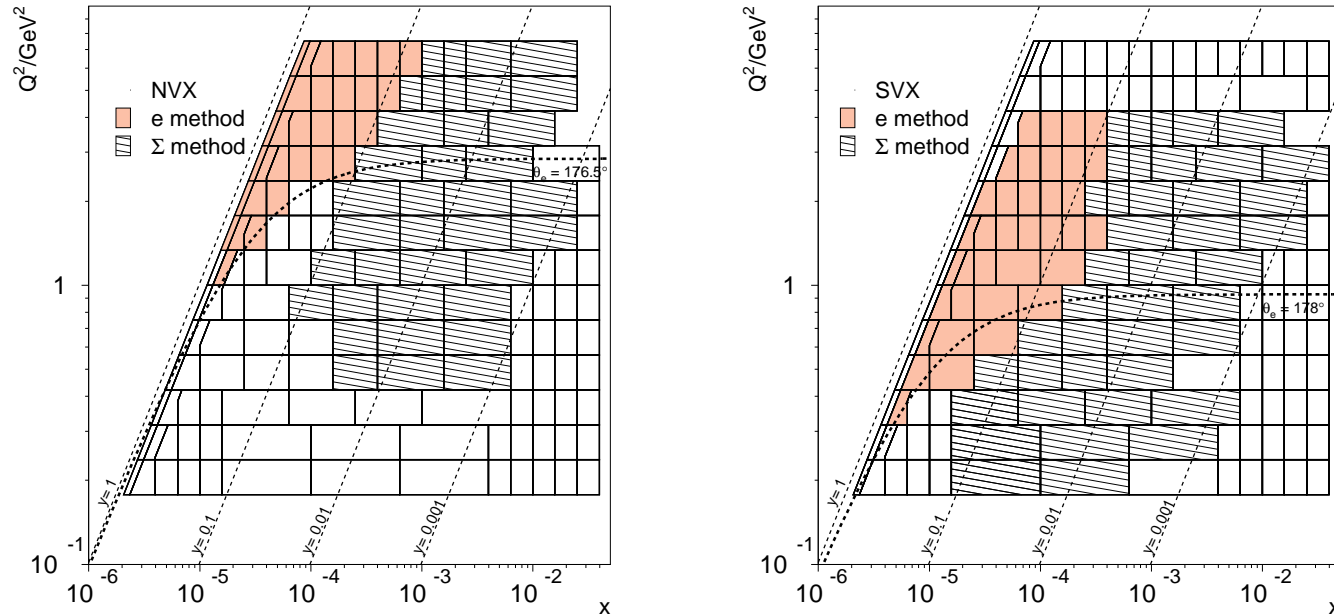
(F.D. Aaron *et al.* [H1 Collaboration], Eur. Phys. J. **C63**, 625 (2009) [[ArXiv 0904.0929](#)].)



Reconstruct event kinematics from the scattered electron measured in the BST and SpaCal as well as from the hadronic final state (HFS) measured in the LAr calorimeter, Central Tracker and SpaCal.

Data collected in 1999-2000.

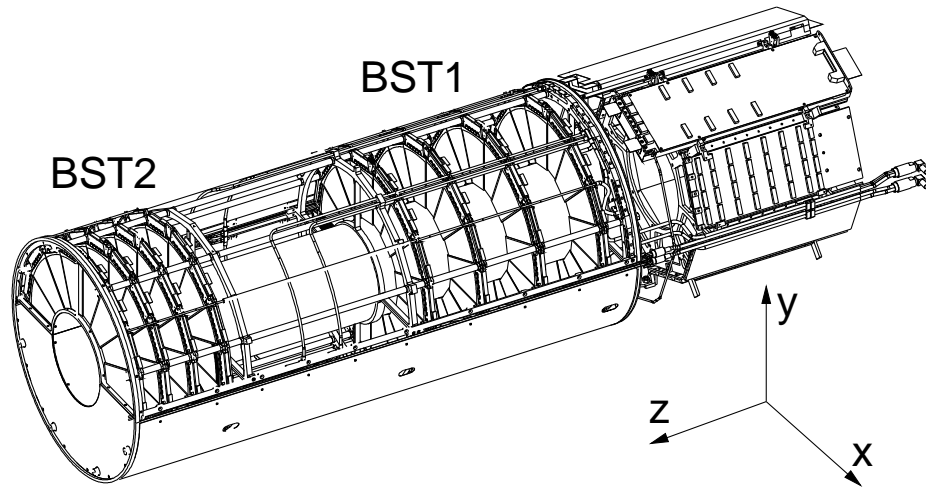
# Kinematic Coverage



$$Q^2 = 2E_e E'_e (1 - \cos \theta_e)$$

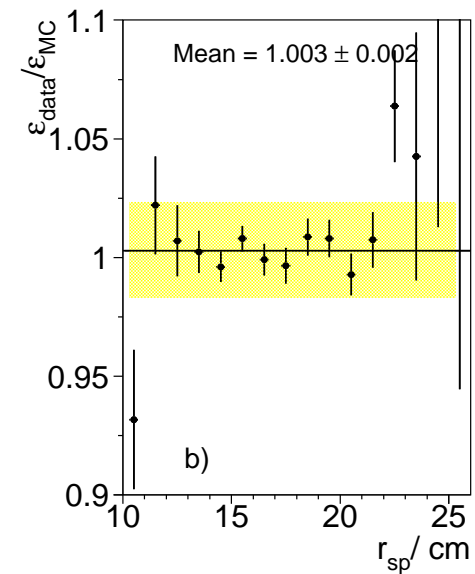
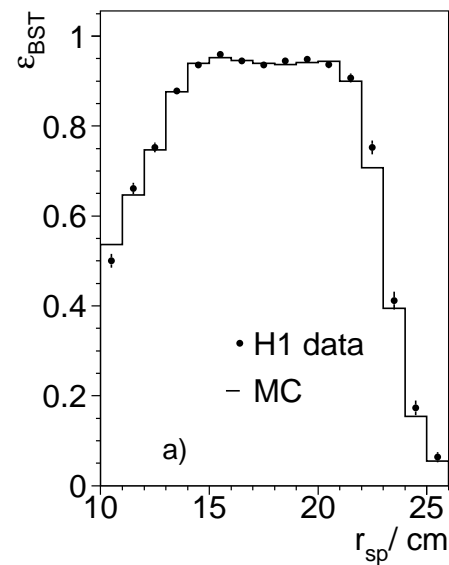
- Use  $505 \text{ nb}^{-1}$  of “shifted” to  $Z = 70 \text{ cm}$  interaction vertex to extend the measurement of the scattered electron from  $\theta_e = 176.5^\circ$  of “nominal” vertex ( $2.1 \text{ pb}^{-1}$ ) to  $\theta_e = 178^\circ$ .
- Use electron to reconstruct kinematics for  $y > 0.1$  and combination of electron and HFS for  $y < 0.1$  ( $\Sigma$ -method).
- Extend measurement beyond  $\theta_e$  kinematic limit by events with initial state radiation.

# Backward Silicon Tracker

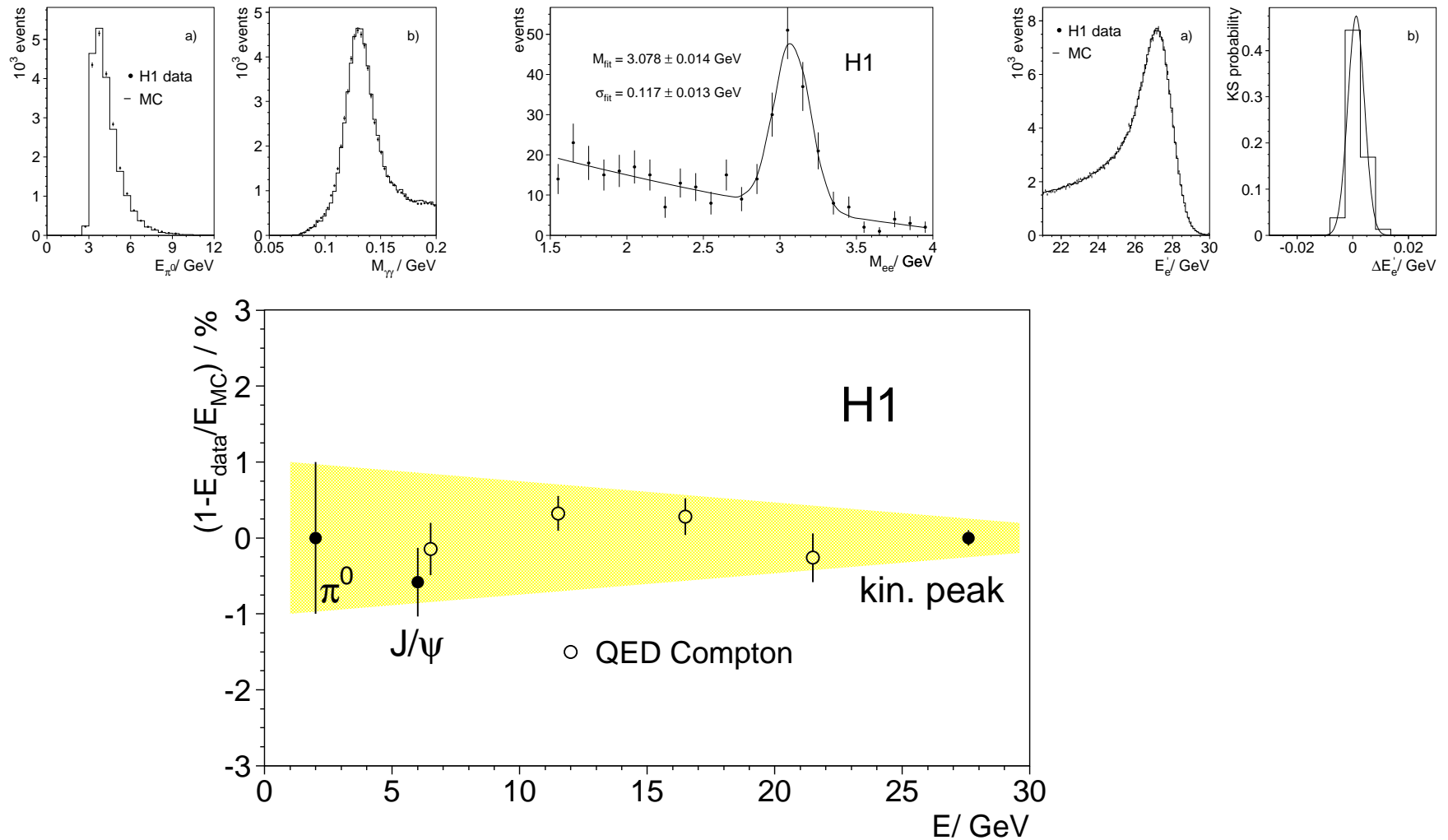


Backward Silicon Tracker in 1999-2000 configuration with 8 discs, 16 sectors measuring  $r$ -coordinate.

High uniform efficiency for  $12 < R < 22$  cm for shifted vertex data.

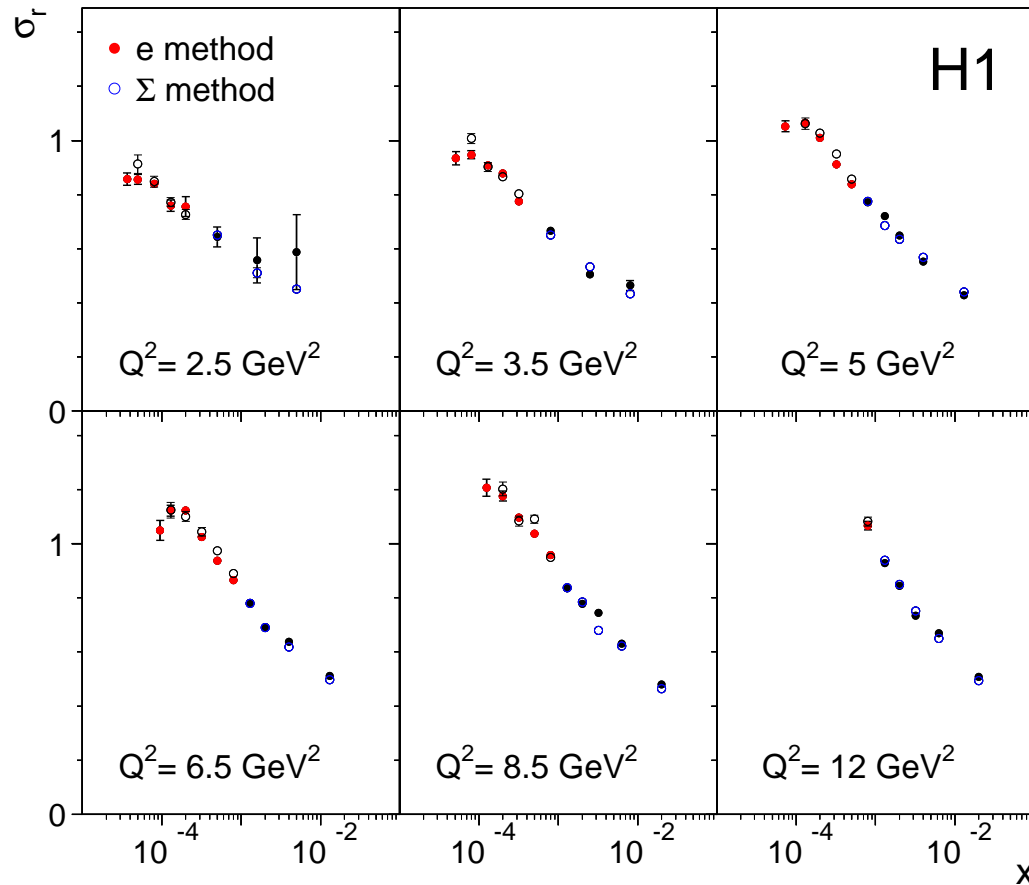


# Calorimeter Energy Scale



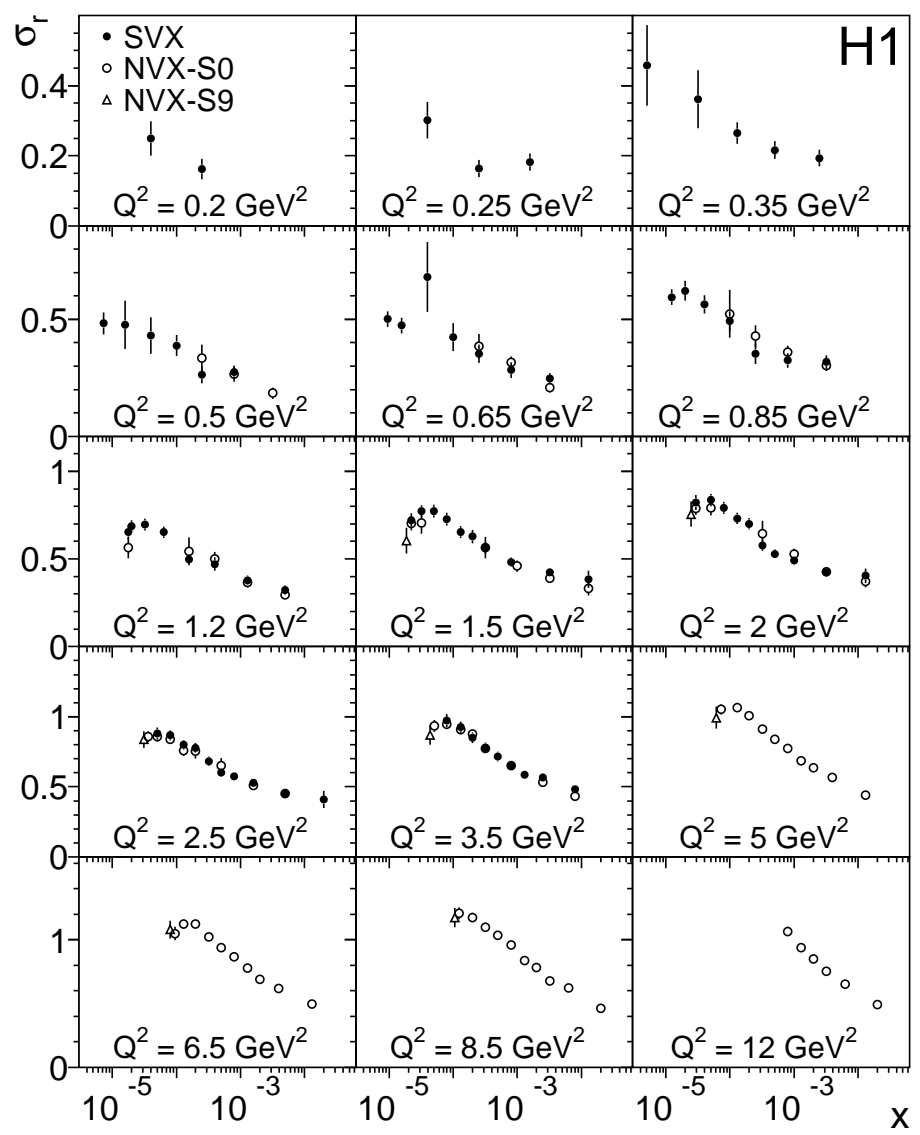
Use  $\pi \rightarrow \gamma\gamma$ , kinematic peak data to fix calibration/linearity. Use QED-Compton and  $J/\psi \rightarrow e^+e^-$  for cross check.

# Cross Checks



The measurement has been verified by several cross checks. An important cross check – compare results obtained using electron and  $\Sigma$ -methods. Different sensitivity to systematic effects checks electromagnetic and hadronic calibration.

# Data Combination I



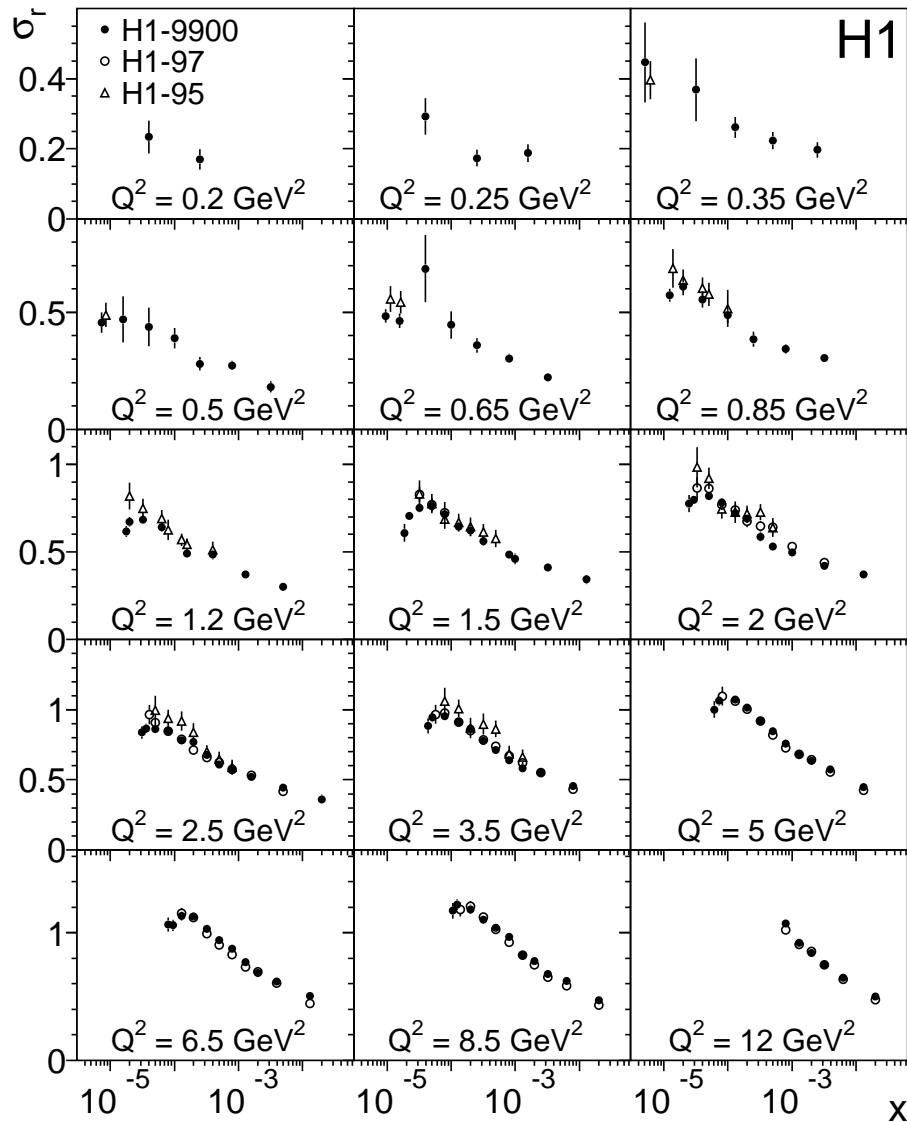
New measurement consists of several data sets, taken with nominal and shifted interaction vertex, with different triggers. The data are combined together following combination procedure which was later used for H1 and ZEUS data combination (see talk of S. Habib.)

There is a large overlap between shifted and nominal vertex data; the data are consistent

$$\chi^2/n_{\text{dof}} = 19.5/39.$$



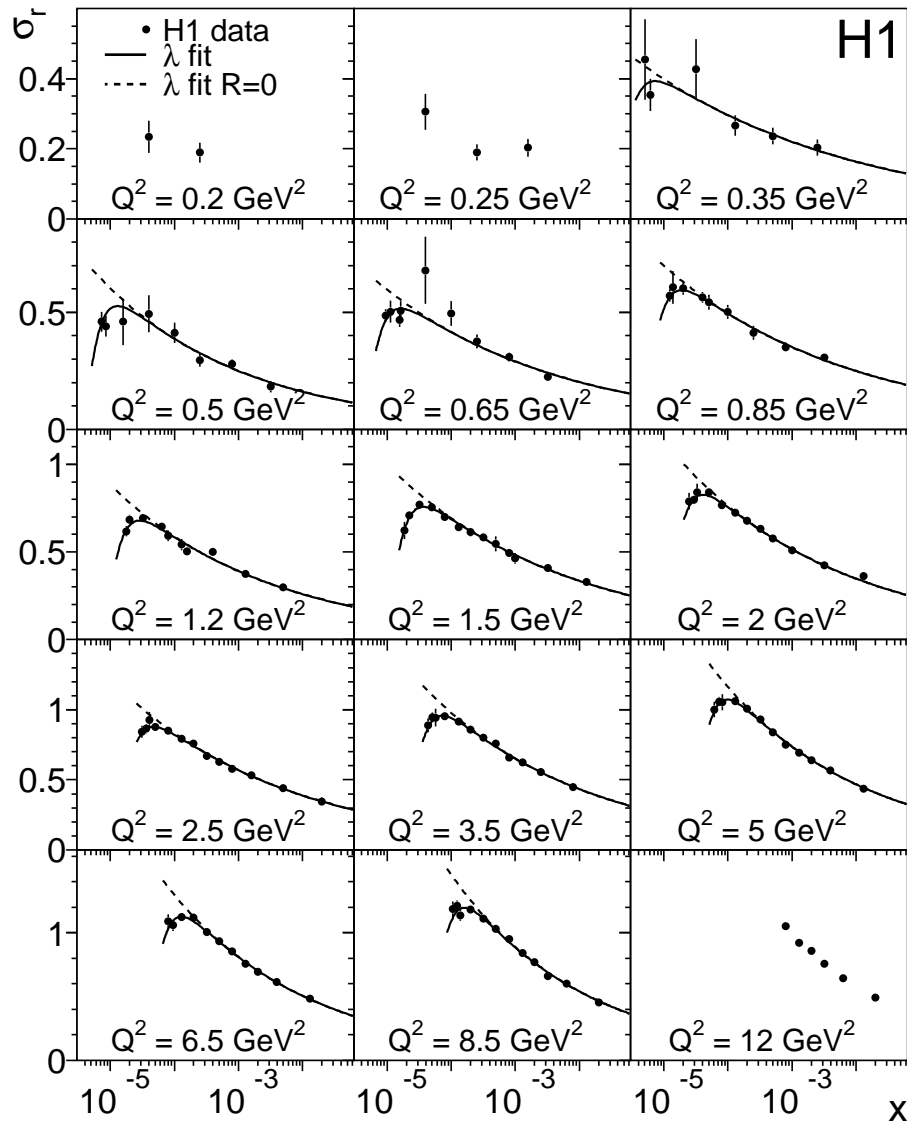
# Data Combination II



The new data from 1999-2000 taken at  $E_p = 920 \text{ GeV}$  are measured in a similar kinematic domain with data collected at  $E_p = 820 \text{ GeV}$  in 1995-1997. Analysis of 1995-1997 data were repeated. A correction is found for global normalization of 1997 sample of +3.4%. Old and new data, taken at different  $E_p$ , are combined for  $y < 0.35$ . The data are consistent with

$$\chi^2/n_{\text{dof}} = 86.2/125.$$

# Combined Data



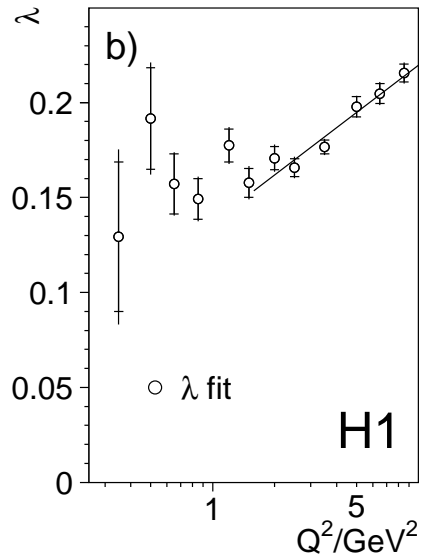
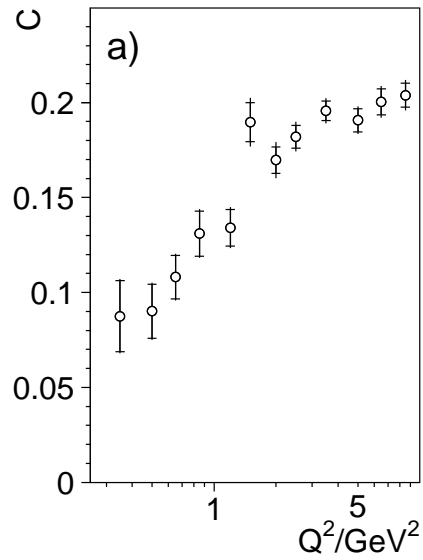
For center of the phase space, precision of the combined measurement is 1.7%.

The data are analyzed assuming power law in  $x$  for  $F_2$  and constant  $R(Q^2) = \sigma_L/\sigma_T$ , for each  $Q^2$  bin:

$$\sigma_r = cx^{-\lambda} \left[ 1 - \frac{y^2}{1 + (1 - y)^2} \frac{R}{1 + R} \right]$$

Turn-over in  $\sigma_r$  at low  $x$  is due to  $R > 0$ , in this model.

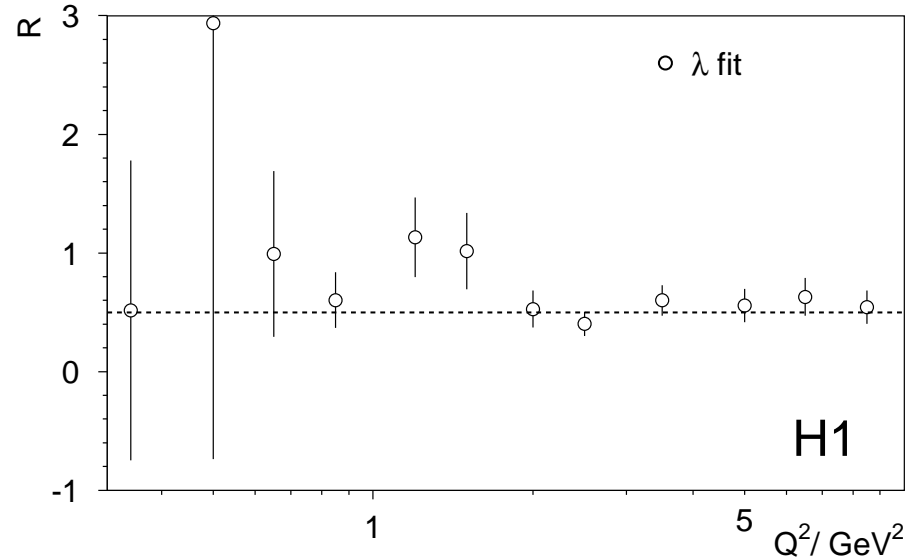
# λ fit results



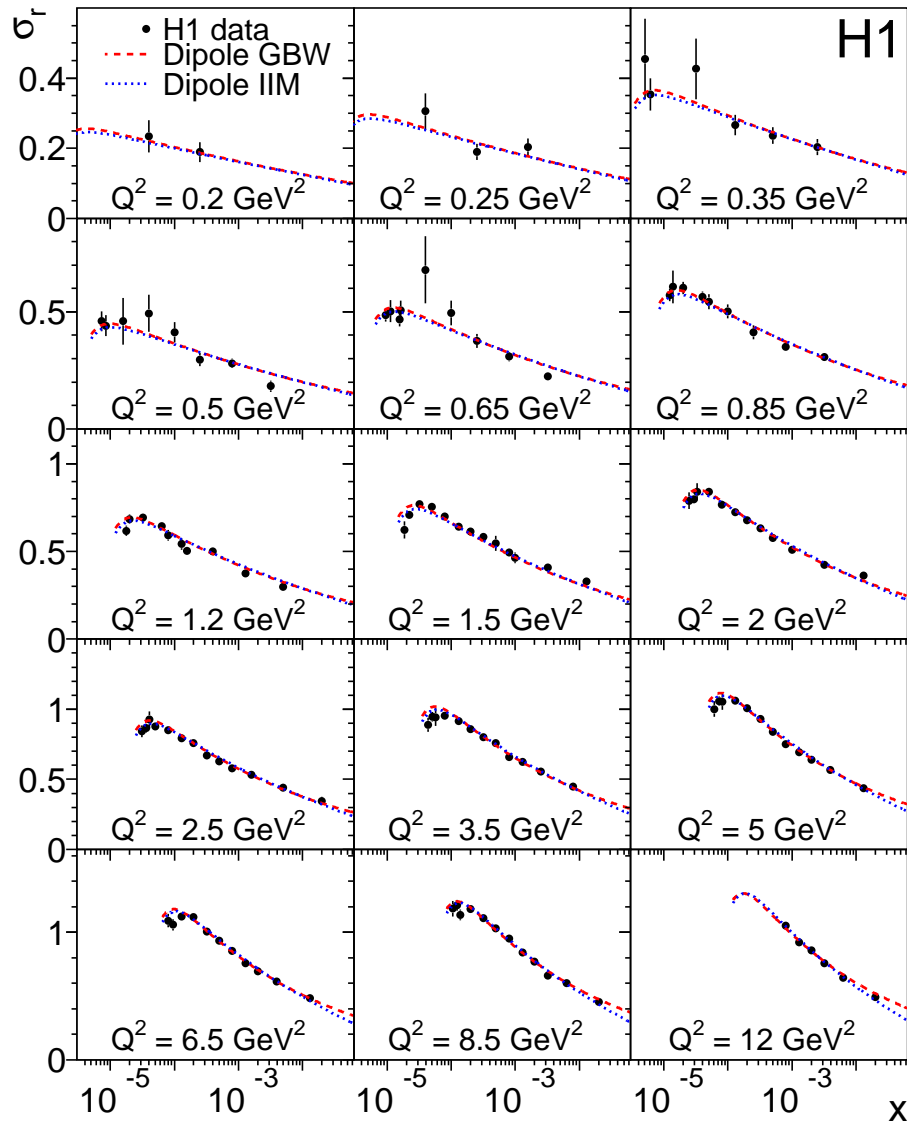
For  $Q^2 \geq 2 \text{ GeV}^2$ , coefficient  $c(Q^2)$  is approximately constant while coefficient  $\lambda(Q^2)$  shows linear rise, as expected from perturbative QCD.

For the  $\lambda$  fit to the data,  $R$  is very large, consistent with

$$R = 0.5.$$



# Dipole Fit



In dipole models,  $ep$  scattering is viewed as fluctuation of the virtual photon to  $q\bar{q}$  dipole which consequently interacts with the proton.

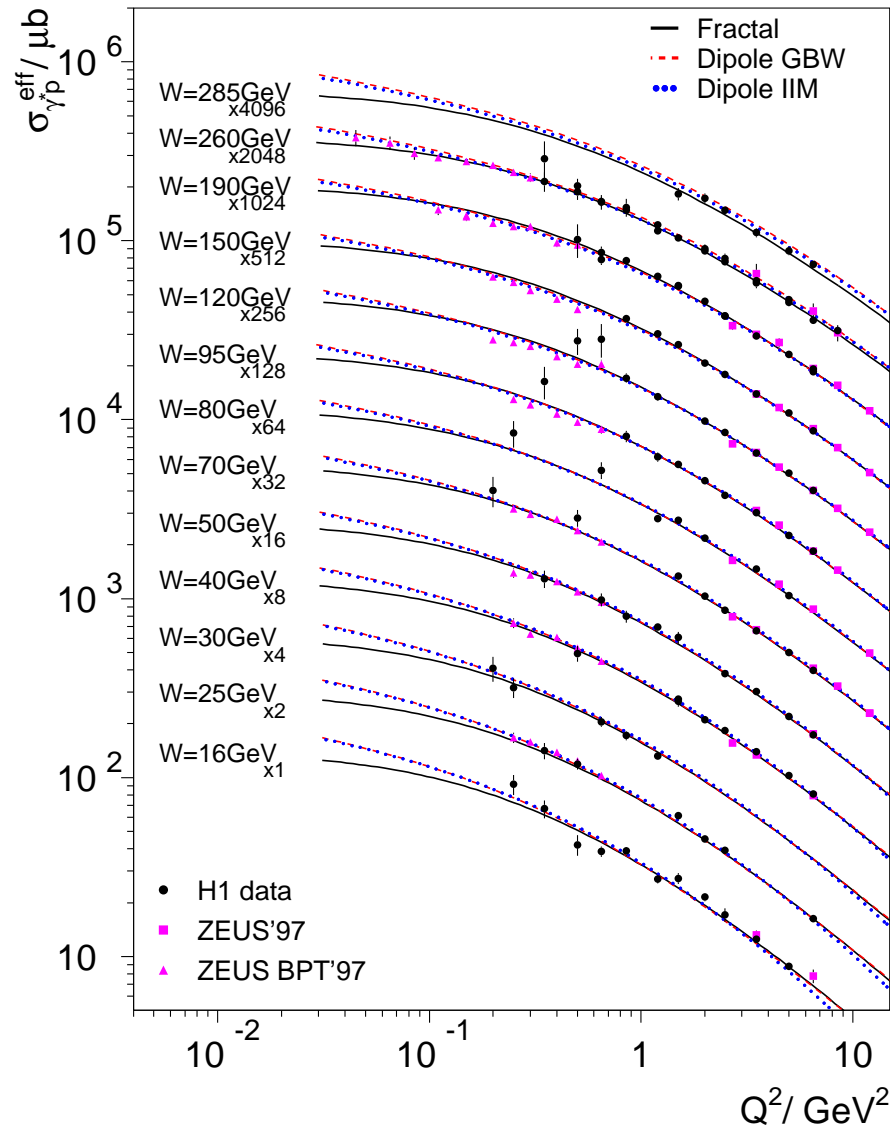
In GBW (Golec-Biernat & Wusthoff) model, the dipole-proton cross section is given by

$$\hat{\sigma} = \sigma_0 \left\{ 1 - \exp \left[ -r^2 / (4r_0^2(x)) \right] \right\}$$

where  $r_0^2 \sim (x/x_0)^\lambda$ . For  $r \gg r_0$ , dipole cross section saturates.

GBW and IIM (Iancu, Itakura & Munier) dipole models give reasonable description of the data with  $\chi^2/n_{\text{dof}} = 183/(149 - 3)$  and  $178.2/(149 - 3)$ , respectively.

# Fractal Fit, $W$ -plot



$$\sigma_{\gamma^*p}^{\text{eff}} = \sigma_T + \left[ 1 - \frac{y^2}{1 + (1-y)^2} \sigma_L \right]$$

At low  $x$ ,  $W^2 \approx Sy$ .

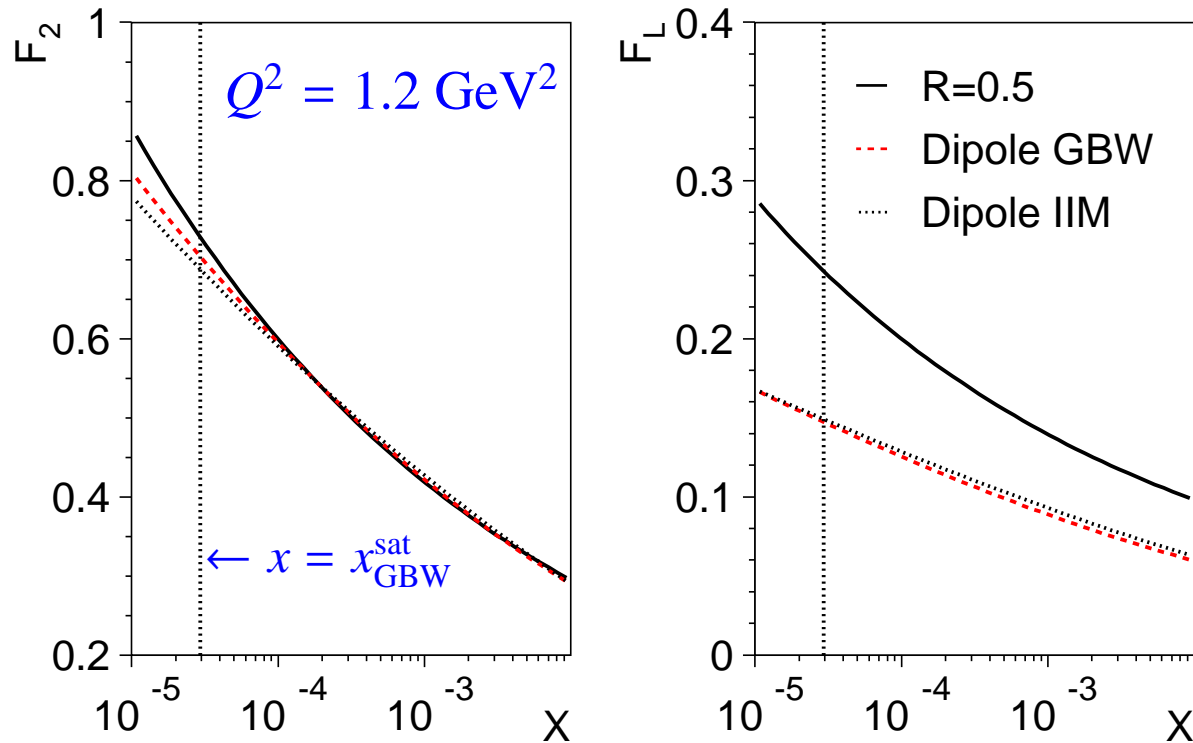
The new low  $Q^2$  H1 data closes the gap to the ZEUS BPT data, which are reported at even lower  $Q^2$ .

The H1 data are also analyzed in terms of fractal ansatz for  $F_2$  and assuming constant  $R$  yielding

$$\chi^2/n_{\text{dof}} = 155/(149 - 5)$$

and very large  $R = 0.56 \pm 0.07$ .

## $F_2$ and $F_L$ in dipole, fractal fits



In dipole model,  $F_2$  and  $F_L$  are predicted together. Formally break this coupling by using free parameter  $B_L$ :  $F_L = F_L^{\text{dipole}}(1 + B_L)$ . For GBW model,  $B_L = 0.54 \pm 0.15$  while for IIM model,  $B_L = 0.15 \pm 0.14$ . Softer  $F_2$  of IIM model describes the data well without requiring large  $F_L$ .

## Summary

- New combined measurement of  $e^+p$  scattering cross section at low  $Q^2$ ,  $0.2 \leq Q^2 \leq 12 \text{ GeV}^2$  and low  $x$ ,  $5 \cdot 10^{-6} \leq x \leq 0.02$ .
- The measurement accuracy is  $\sim 1.7\%$  for the central region of the covered phase space.
- The cross-section data are analyzed in terms of  $\lambda$  and fractal ansätze for the structure function  $F_2$ , assuming constant  $R$ . These fits yield large  $R \sim 0.5$ . Coefficient  $\lambda$  shows linear increase for  $Q^2 \geq 2 \text{ GeV}^2$ , as expected in pQCD.
- Fits with two dipole models, GBW and IIM, give good description of the data. The description of the data by GBW model improves if  $F_L$  is formally allowed to increase. The IIM model  $F_L$  is similar to GBW model. Softer rise of  $F_2$  in IIM model allows to describe data better and no modification of  $F_L$  is suggested by the data.
- The data are included in QCD analysis of H1 (see talk of M. Klein), combination of H1 and ZEUS data (talk of S. Habib), extraction of  $F_L$  (talk of J. Grebenyuk) and QCD analysis of reduced and nominal  $E_p$  data (talk of V. Radescu).