UNIVERSITÄT DORTMUND

Olaf Behrendt
University of Dortmund
H1 Collaboration

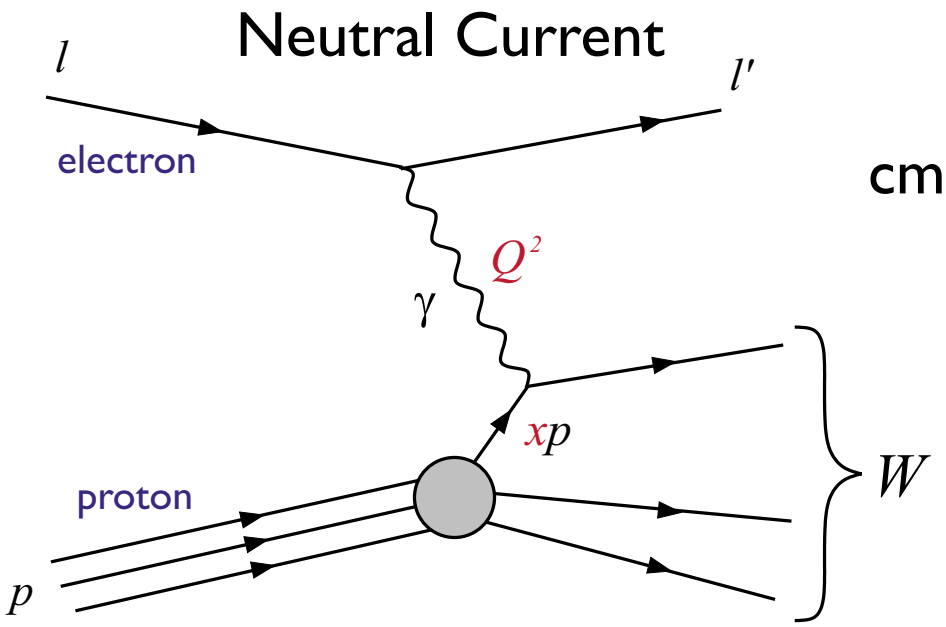
Measurements of Proton Structure Functions at Low Q^2 at HERA

- Deep Inelastic Scattering at HERA
- Measurements of F_2 in Shifted Vertex and Radiative Events
- Extraction of F_L

LOW-X 2004

Prague, 15.09.04

Deep Inelastic Scattering



cms energy $\sqrt{s} = \sqrt{(l+p)^2} \approx 300\,\mathrm{GeV}$

photon virtuality $Q^2 = -(l-l')^2$

Bjorken variable $x = \dfrac{Q^2}{2p \cdot (l-l')}$

Inelasticity $y \approx \dfrac{Q^2}{xs}$

Invariant mass of the $W = \sqrt{Q^2 \dfrac{1-x}{x} + m_p^2}$

Structure Functions in DIS

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{Q^4 x}\left(Y_+ F_2(x,Q^2) - y^2 \cdot F_L(x,Q^2)\right) \qquad Y_+ = 1+(1-y)^2$$

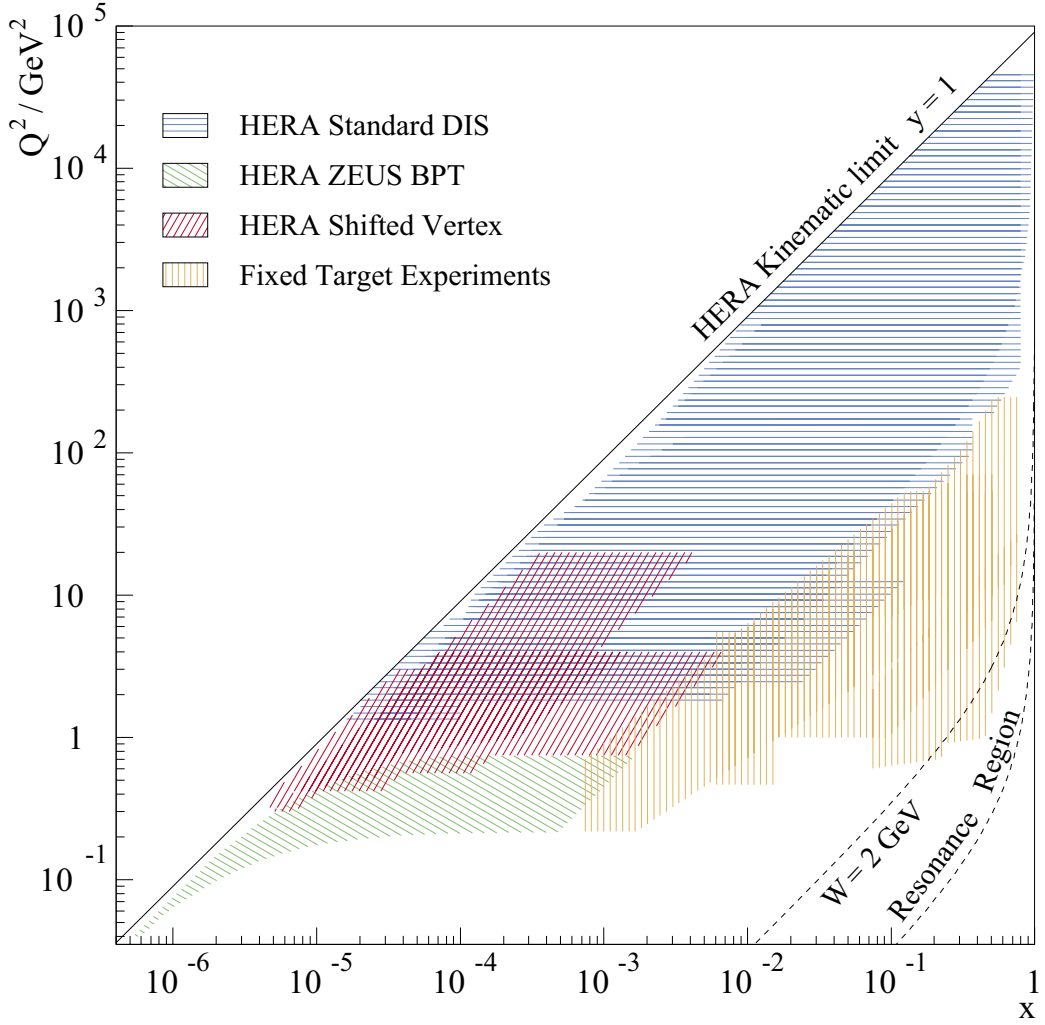
- $F_2(x,Q^2) = x\sum_i e_i^2[q_i(x,Q^2) + \bar{q}_i(x,Q^2)]$

  - dominant contribution
  - sensitive to quark content
    [indirect sensitivity to gluon density via scaling violation]

- $F_L(x,Q^2)$

  - contributes significantly only at high y
  - QPM: $F_L = 0$
    QCD: $F_L \propto \alpha_S g$
  - directly sensitive to gluon density

Accessible Phase Space



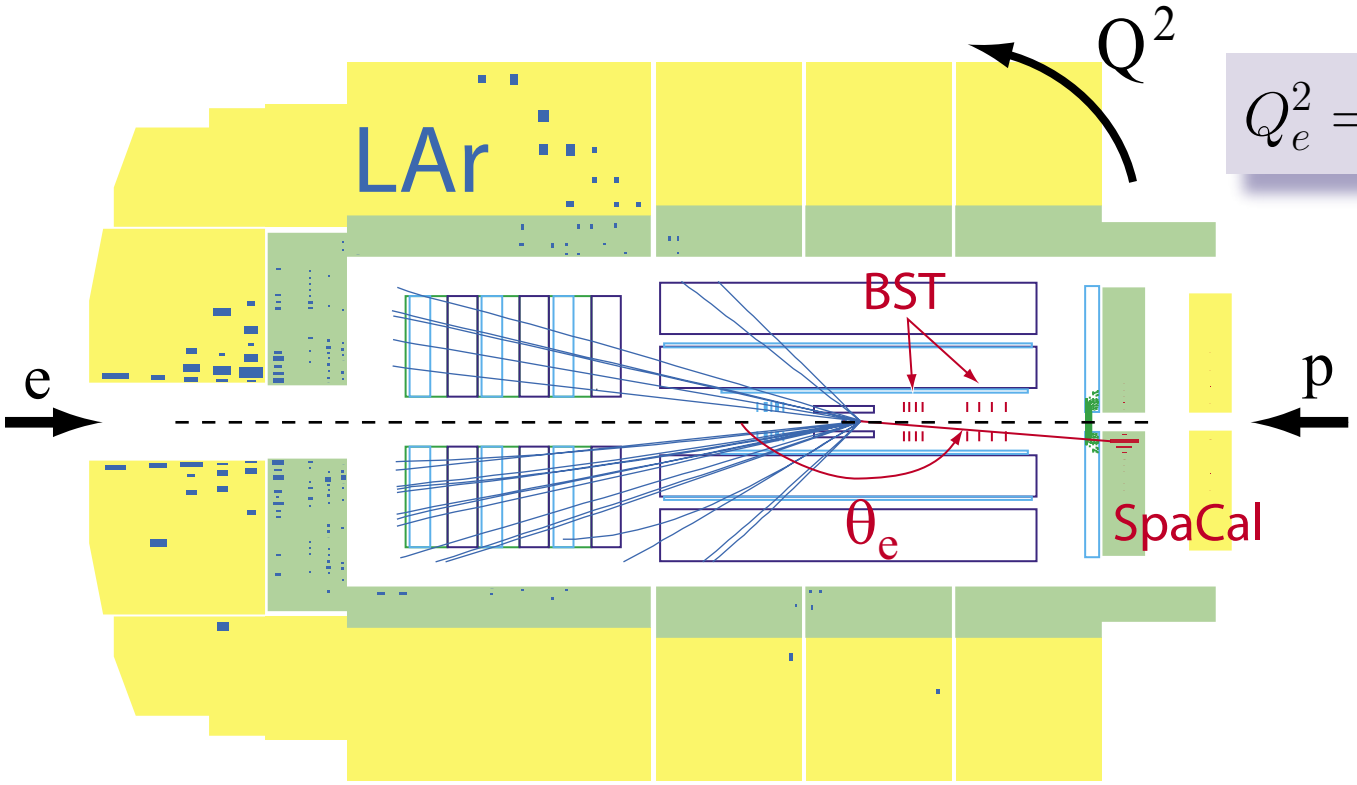
Medium-high Q^2:

- asymptotic freedom
- perturbative QCD

Low Q^2:

- transition to soft hadronic physics
- $\alpha_s(Q^2)$ becomes large
- phenomenological models

Experimental Techniques at Low Q^2



$$Q_e^2 = 2E_e E'_e(1+\cos\theta_e)$$

- standard DIS in main detector:

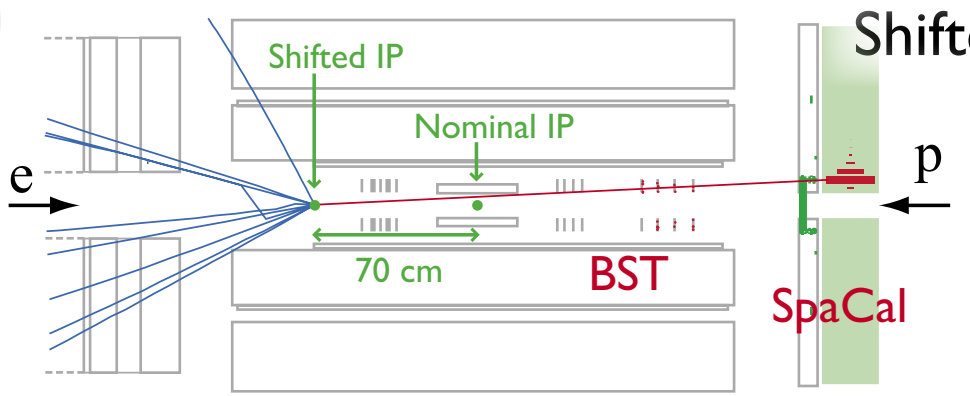
  $Q^2 > 2$ GeV^2

Possibilities to access lower Q^2:

- larger polar angles
- lower initial electron energy

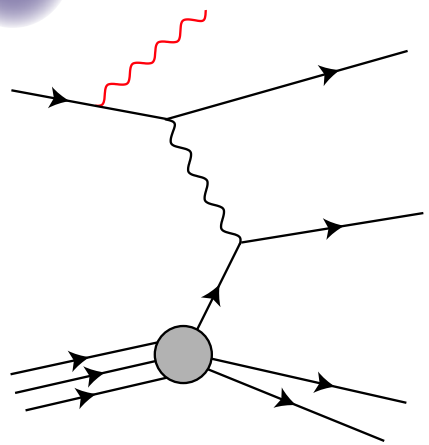
Experimental Techniques at Low Q^2

A



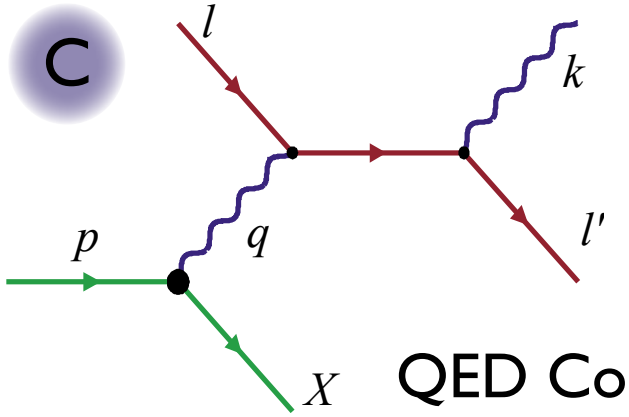
Shifted Vertex Runs

B



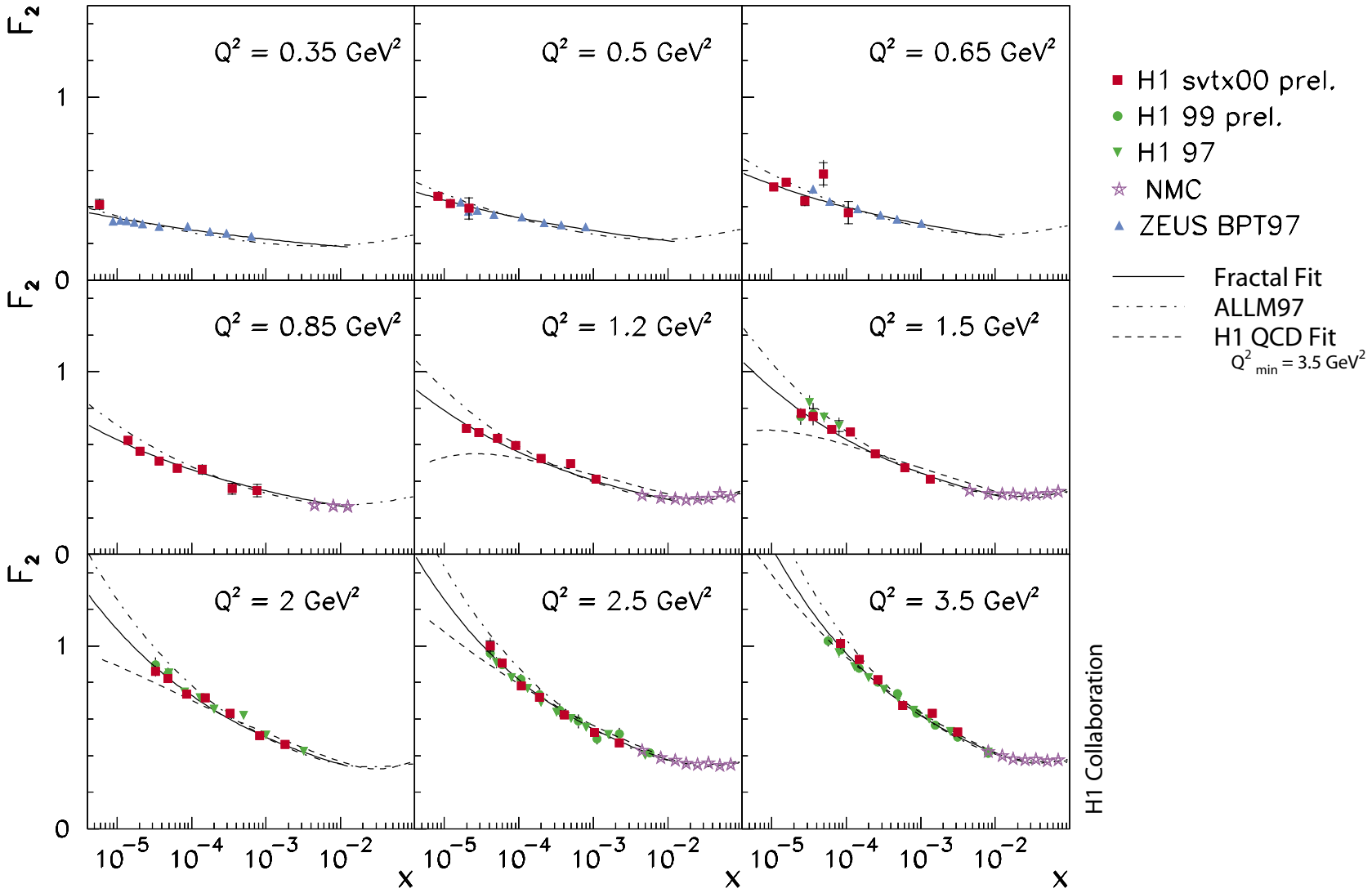
Initial State Radiation (ISR)

C

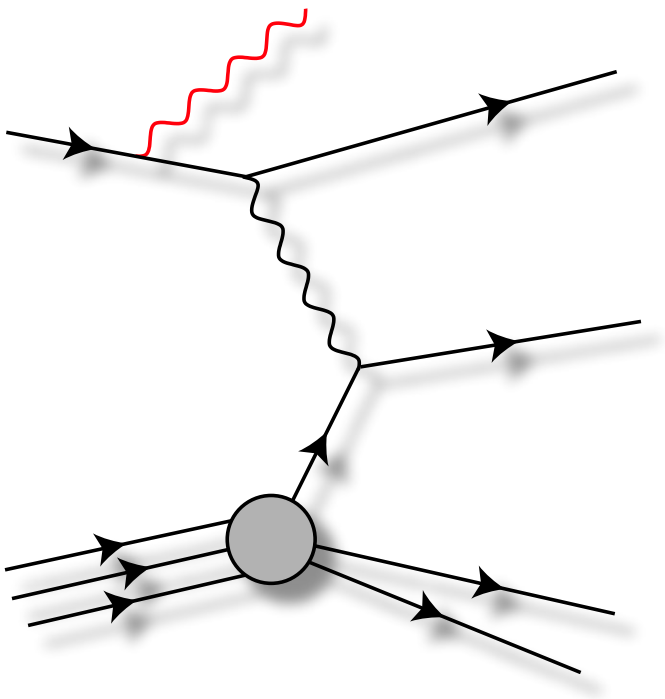


QED Compton (QEDC)

Shifted Vertex and Previous Results at low Q^2



Initial State Radiation (ISR)

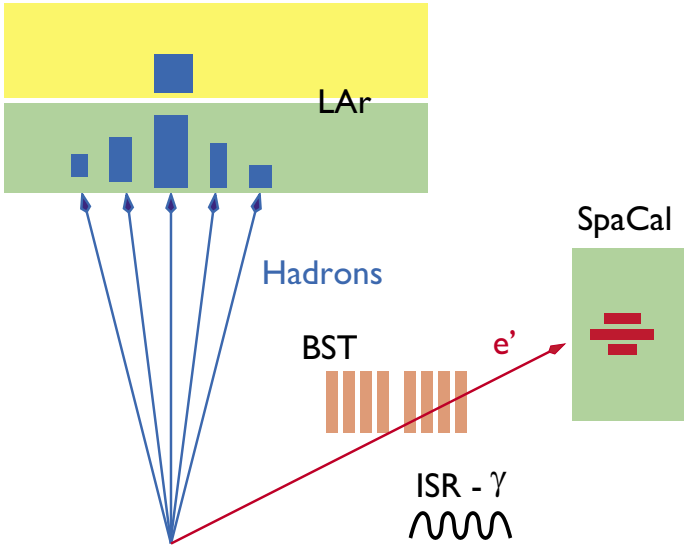


- γ is radiated from incoming e
- equivalent to inclusive DIS at reduced $s = 4E_eE_p$
- $Q^2 = sxy$
  $\Rightarrow$ higher x at fixed Q^2

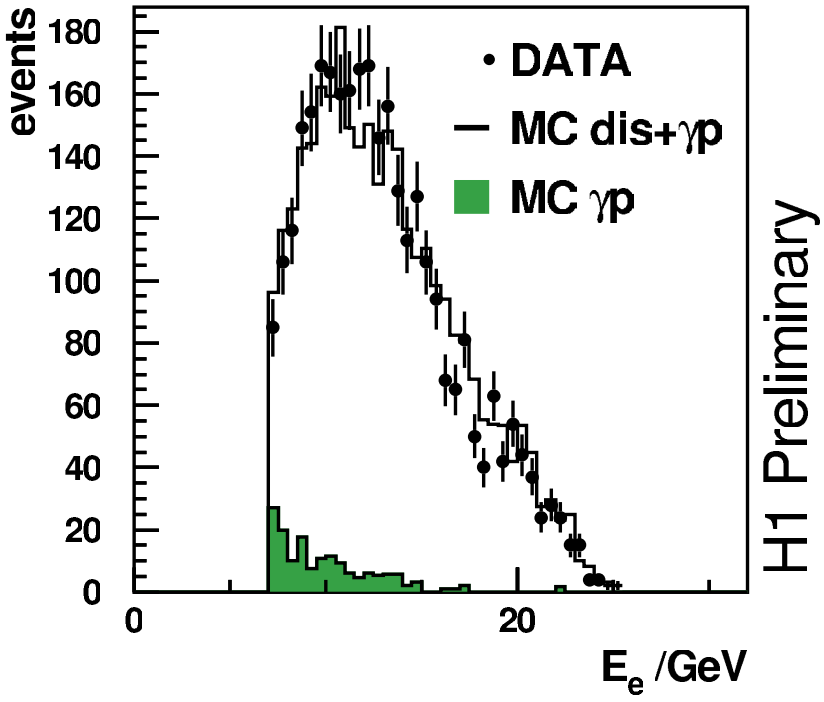
Previous measurements:

- γ directly detected

Untagged ISR in Shifted Vertex (H1)



- γ is undetected
- γp background rejected by BST

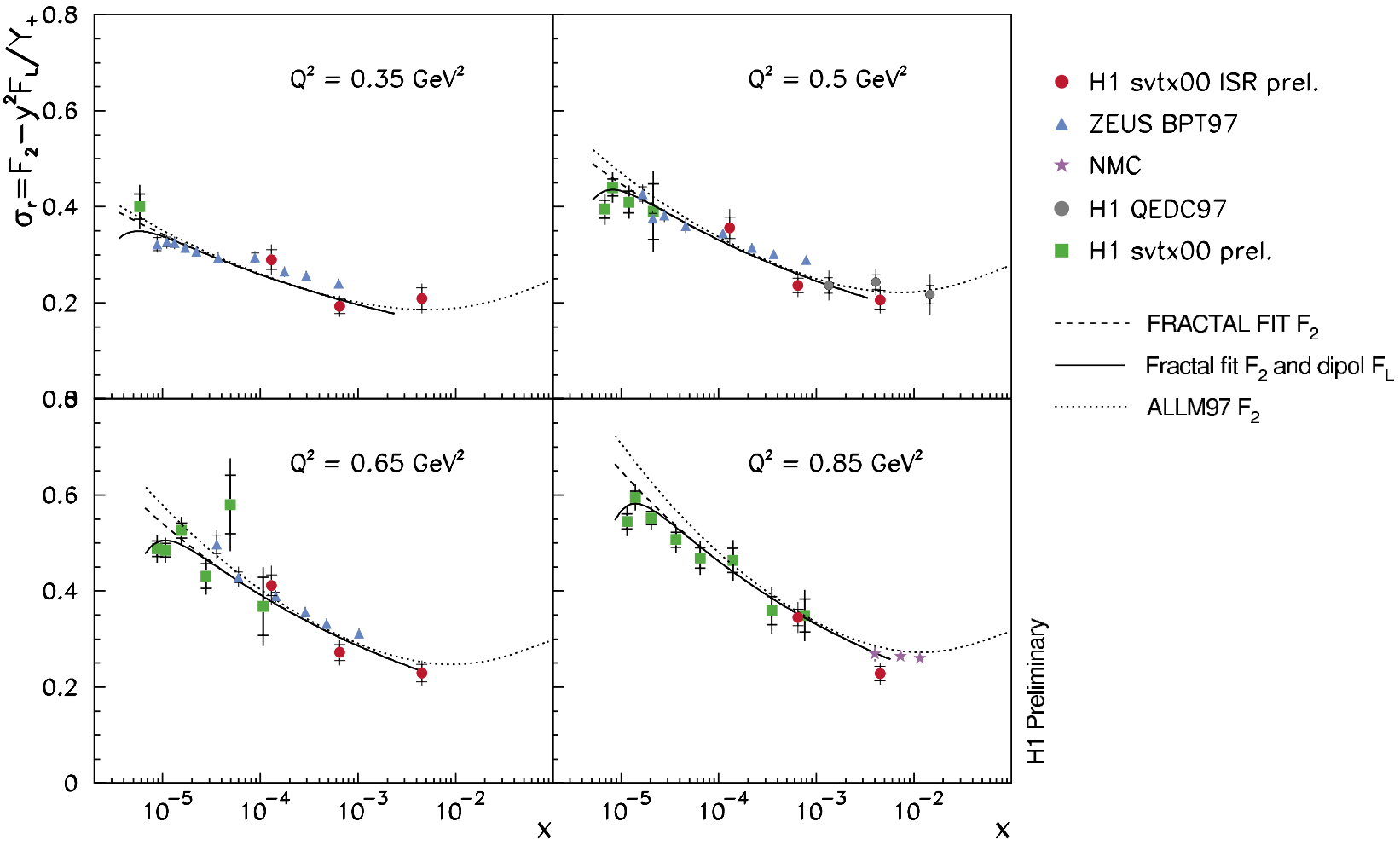


Kinematics:

- E - p_z is used to determine initial electron energy

$$2E_e = (E - p_z)_{had} + (E - p_z)_{e'}$$

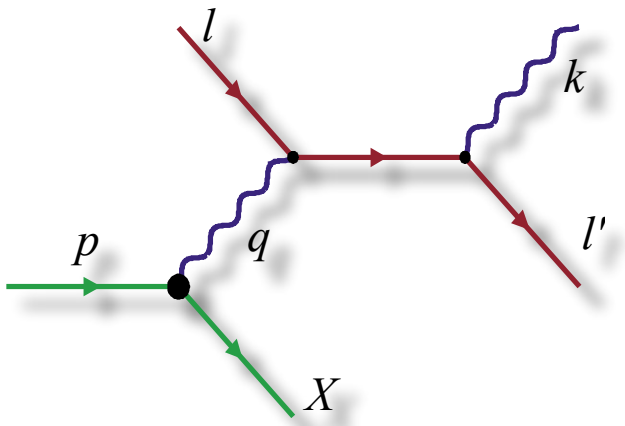
F_2 in Shifted Vertex ISR

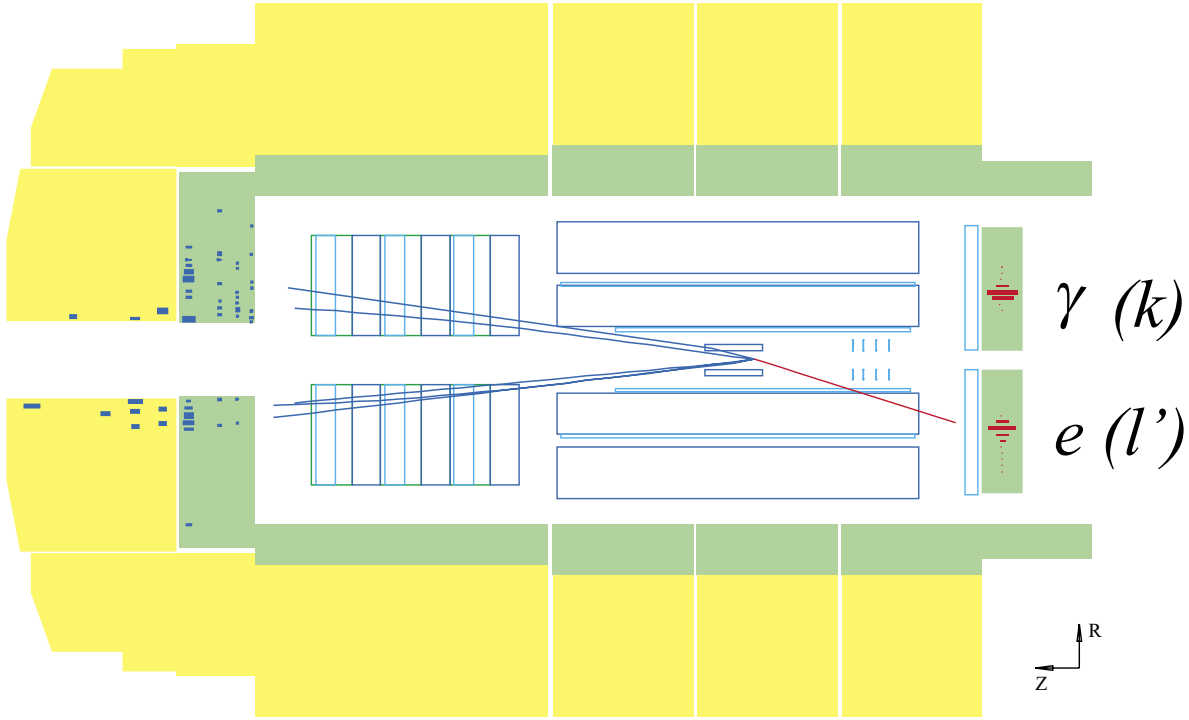


⇒ shifted vertex measurement extended to higher x

Inelastic QED Compton Events

$$e + p \rightarrow e + \gamma + X$$





- low virtuality of the exchanged photon
- high virtuality of the exchanged electron

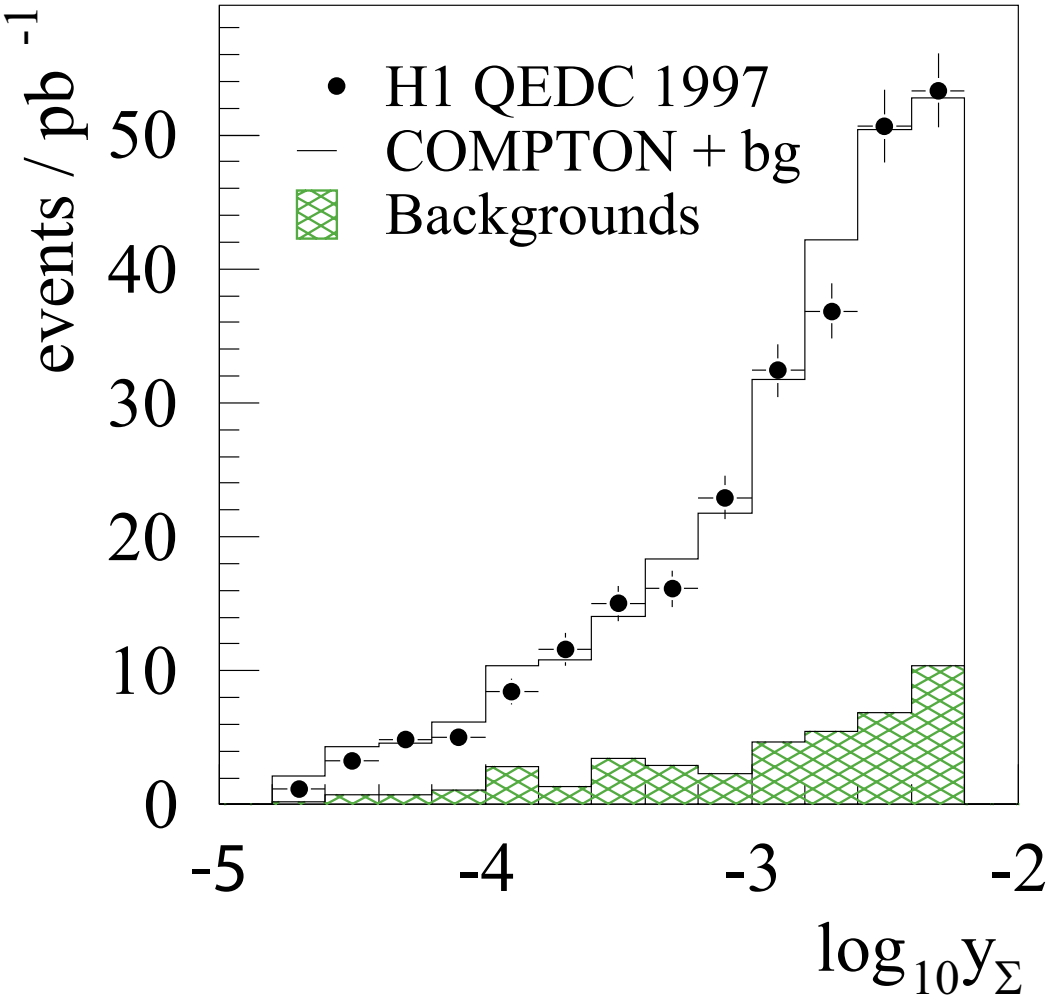
$\Rightarrow$ access to low Q^2

- DIS background: - π^0 fakes QEDC γ
  - dominates QEDC signature at low x

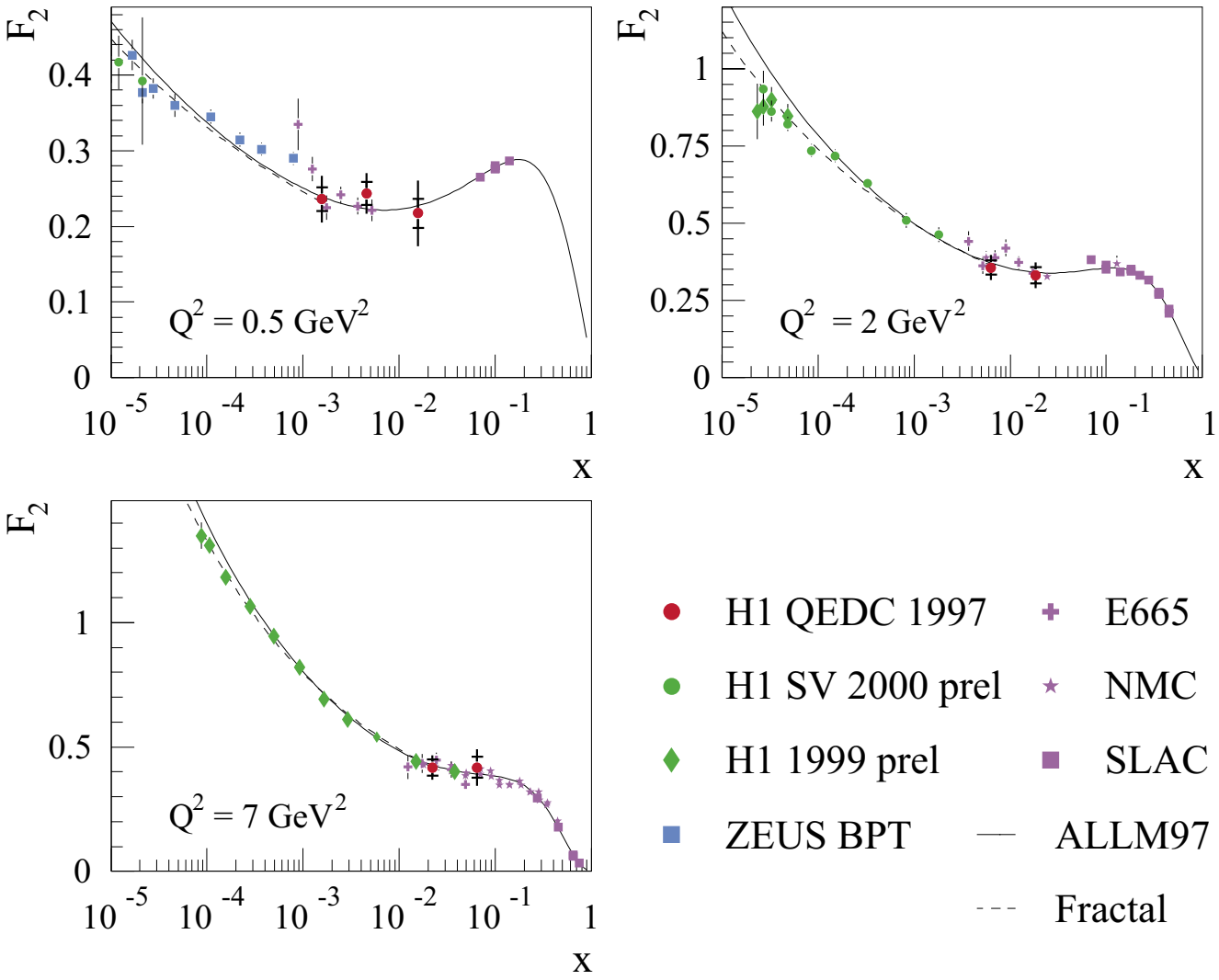
Inelastic QED Compton Events

Medium - high x are measured

- understanding of hadronic final state at low W
- use of SOPHIA Monte Carlo model

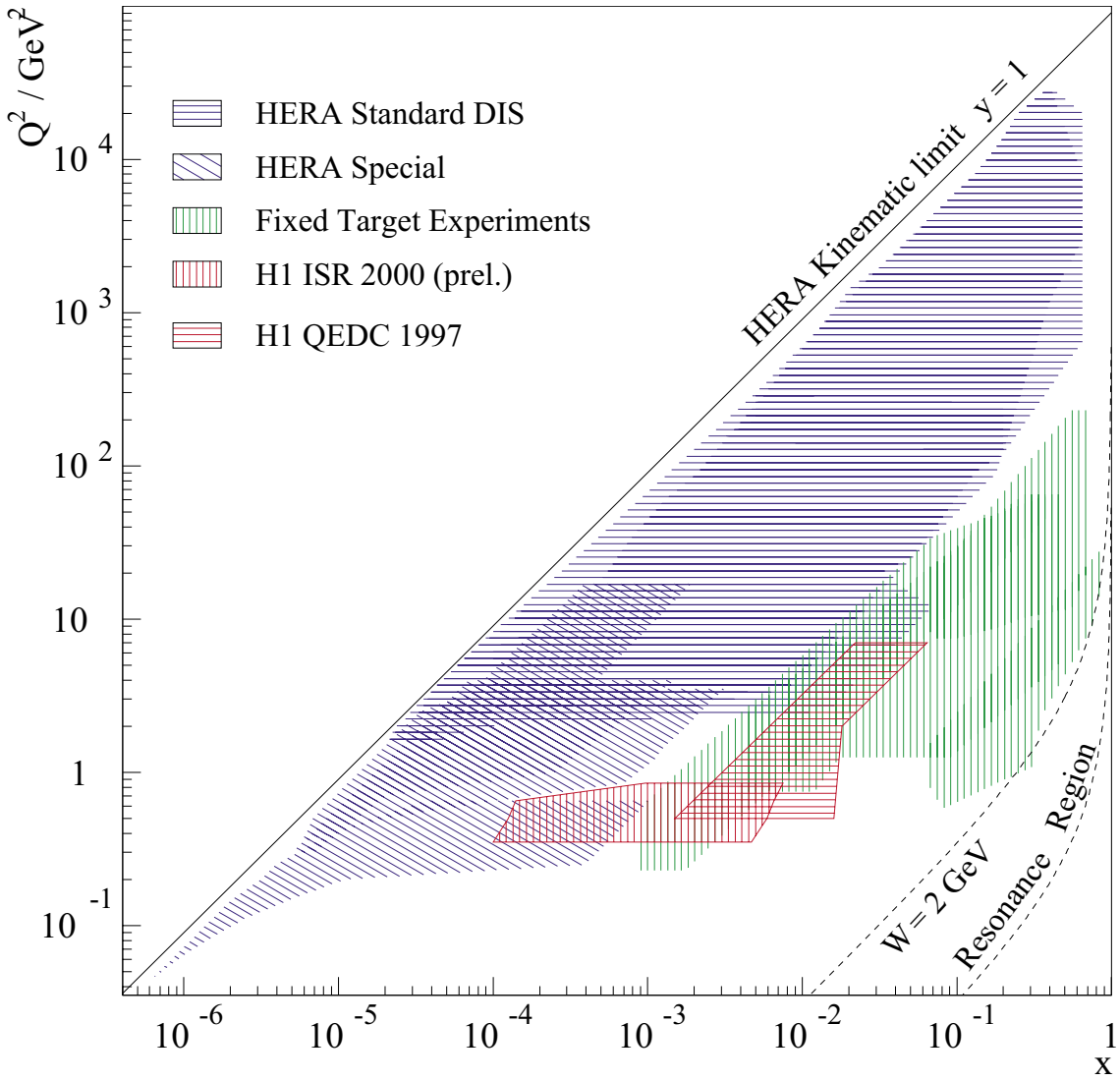


F_2 Measurement with QEDC Events



- good agreement with fixed target experiments

Overview F_2



- QEDC:

$$0.5 < Q^2 < 7\,\mathrm{GeV}^2$$

$$2 \cdot 10^{-3} \lesssim x \lesssim 0.1$$

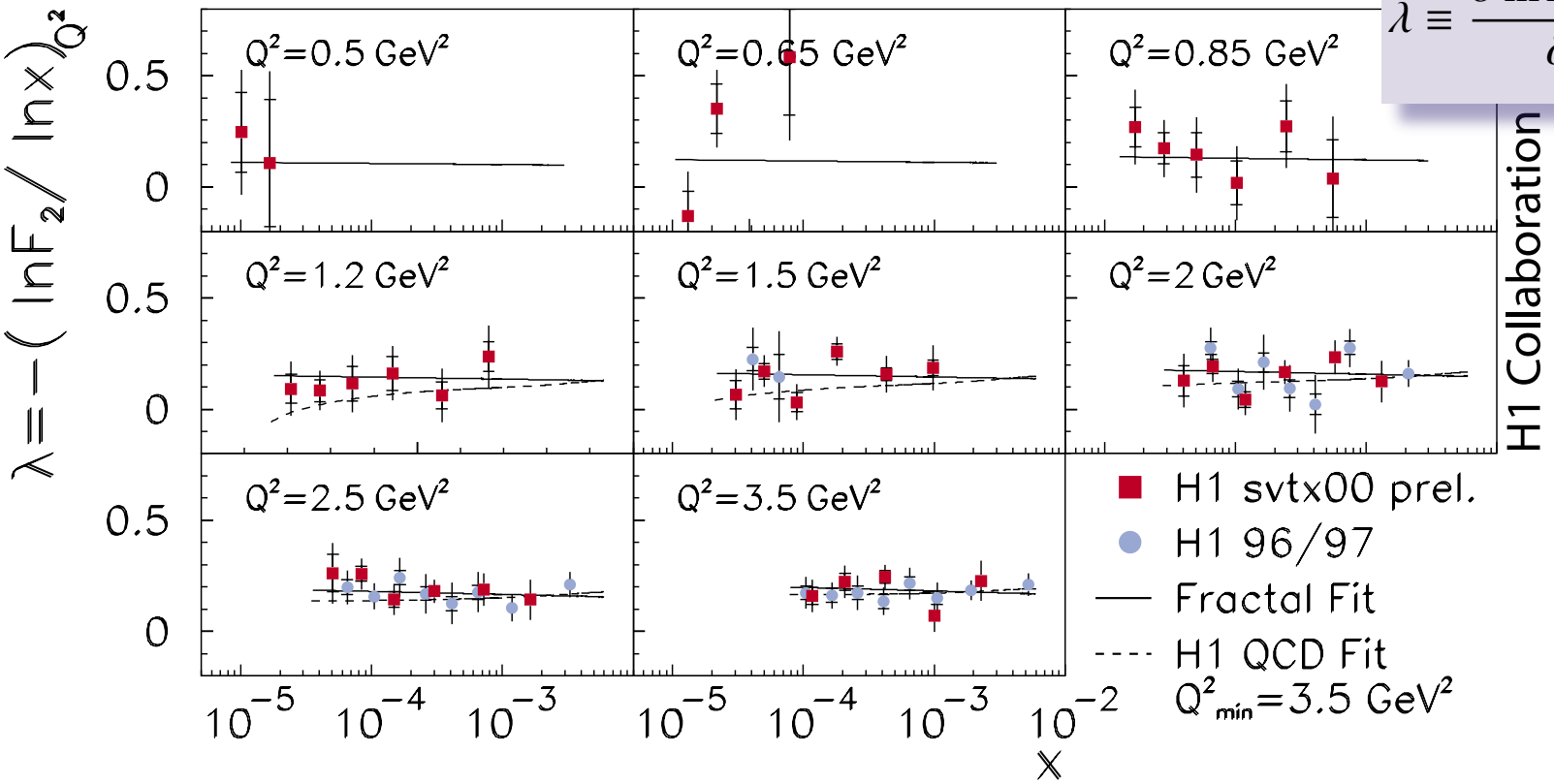
- shifted vertex ISR:

$$0.35 < Q^2 < 0.85\,\mathrm{GeV}^2$$

$$10^{-4} \lesssim x \lesssim 5 \cdot 10^{-3}$$

Rise of F_2 at Low x

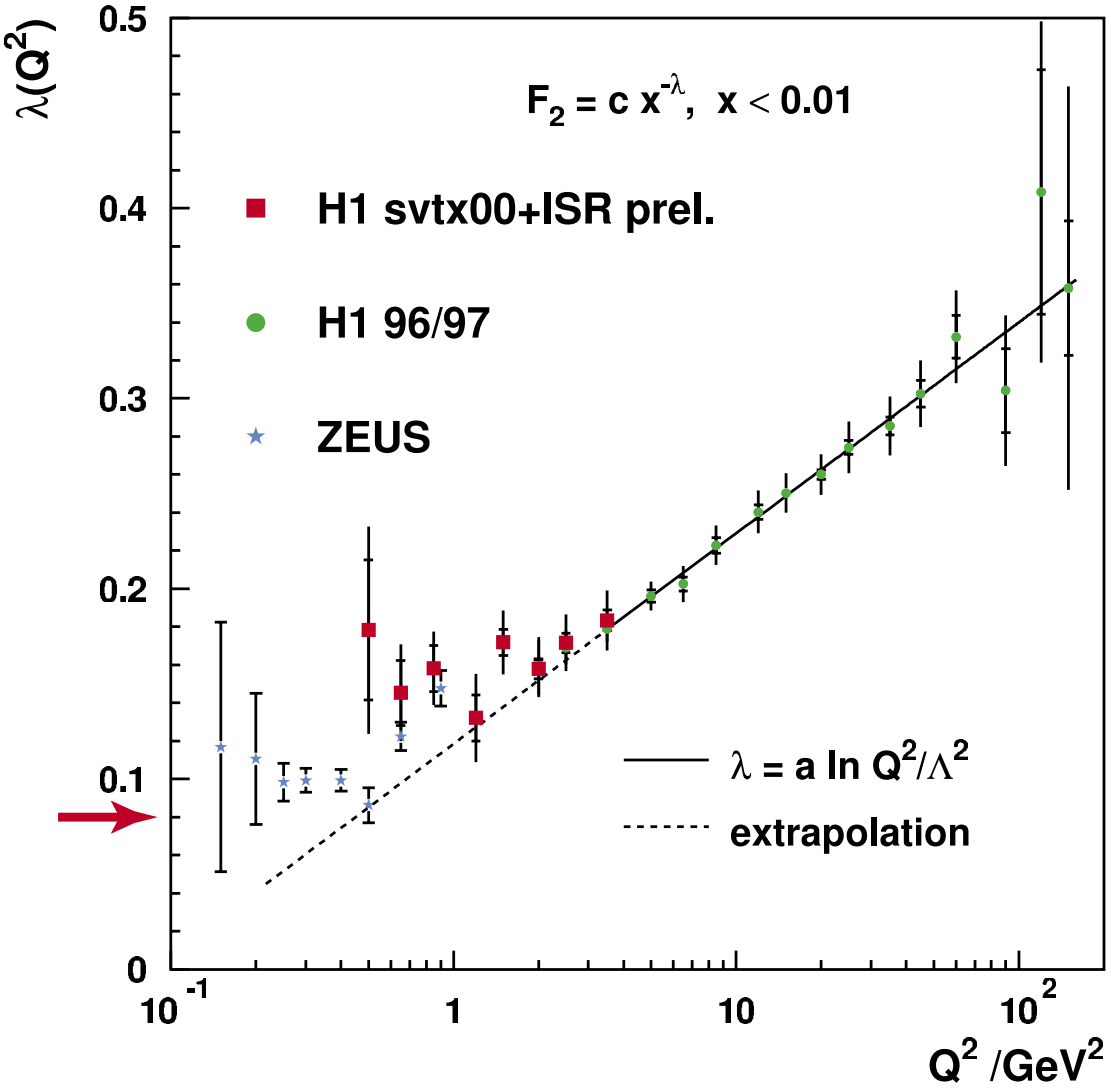
$$\lambda \equiv \left.\frac{\partial \ln F_2(x, Q^2)}{\partial \ln x}\right|_{Q^2}$$



- derivative independent of x for x < 0.01
- rise of F_2 well parameterised by

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

Improved Extraction of $\lambda(Q^2)$



- at $Q^2 \gtrsim 3\,\mathrm{GeV}^2$:

$$\lambda \propto \ln Q^2, c \approx \mathrm{const}$$

partonic degrees of freedom

- at $Q^2 \lesssim 1\,\mathrm{GeV}^2$:

$$\lambda(Q^2) \to 0.08$$

transition to hadronic degrees of freedom

Extraction of F_L

$$\sigma_r = \frac{Q^4 x}{2\pi\alpha^2 Y_+}\cdot\frac{\mathrm{d}^2\sigma}{\mathrm{d}x\mathrm{d}Q^2} = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2) \qquad Y_+ = 1+(1-y)^2$$

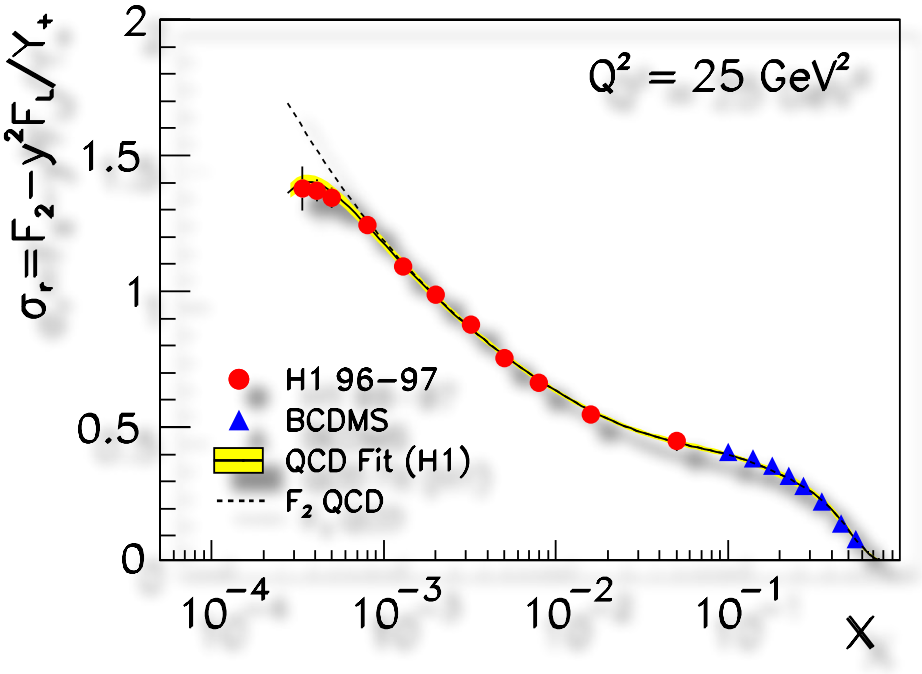
- data sensitive at highest y only
- direct measurement requires data at different s

Indirect determination:

extrapolation of F_2 to higher y:

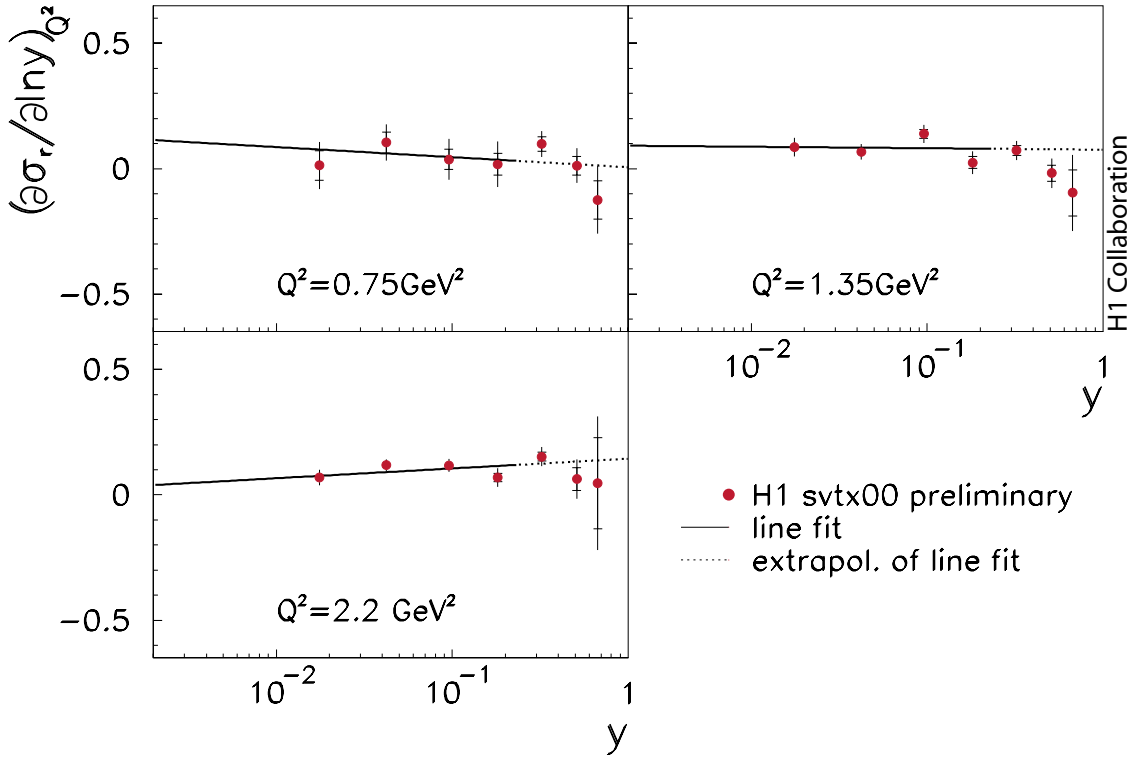
$$F_L \propto F_2 - \sigma_r$$

- derivative method
- shape method



F_L extraction: Derivative Method

$$\left.\frac{\partial \sigma_r}{\partial \ln y}\right|_{Q^2} = \left.\frac{\partial F_2}{\partial \ln y}\right|_{Q^2} - \frac{2y^2(2-y)}{Y_+^2} F_L$$

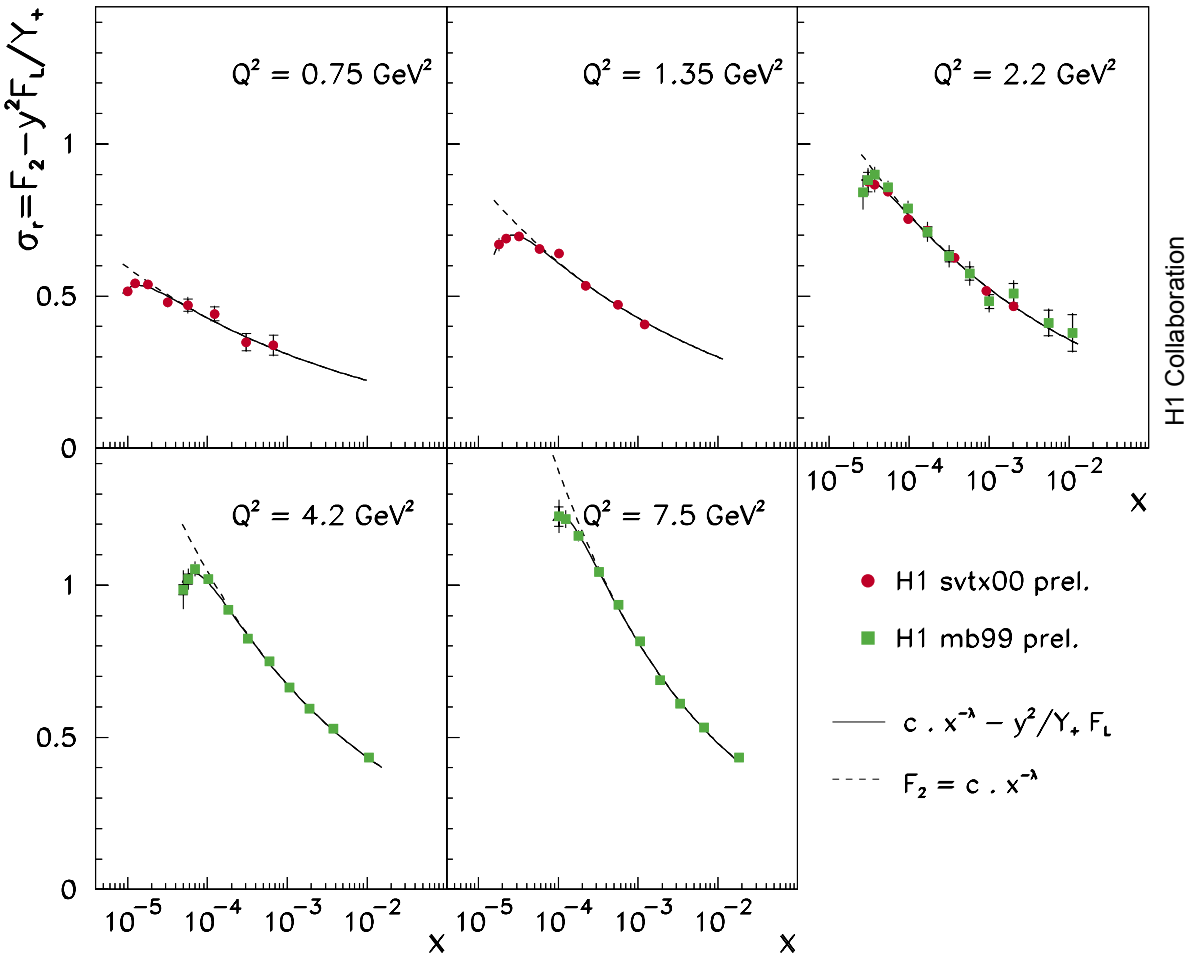


- already shown: $F_2 \propto x^{-\lambda}$ for x < 0.01
- for λ << 1 it follows: $\frac{\partial F_2}{\partial \ln y}$ linear in $\ln y$

⇒ F_2 can be extrapolated from a straight line fit for y < 0.2

⇒ deviation from linear behaviour is attributed to F_L

F_L extraction: Shape Method



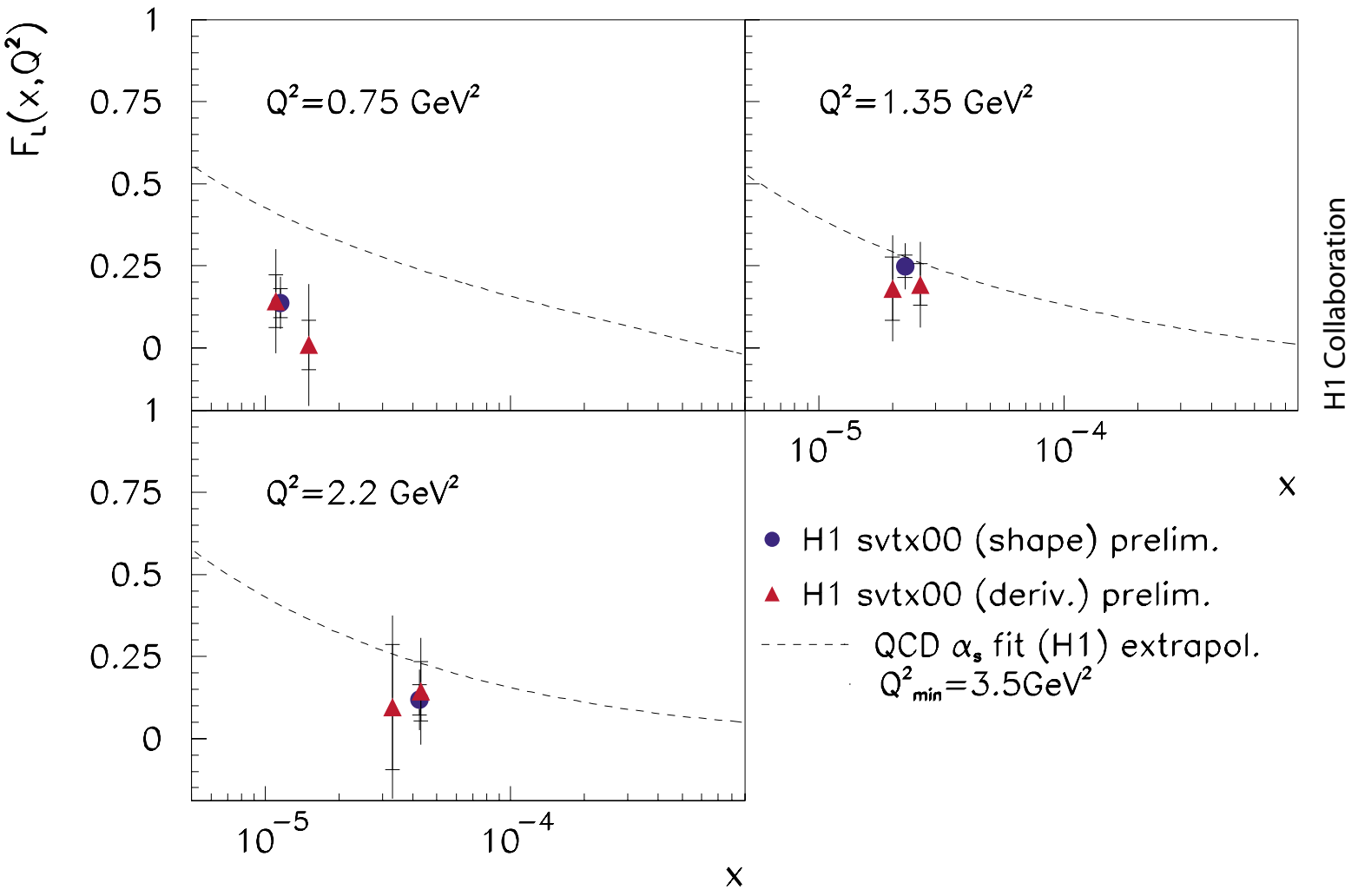
F_L is extracted by fitting σ_r:

$$\sigma_r = cx^{-\lambda} - \frac{y^2}{Y_+} F_L$$

- c, λ and F_L free parameters
- turn-over driven by y^2 / Y^+
- $F_L = F_L(Q^2)$

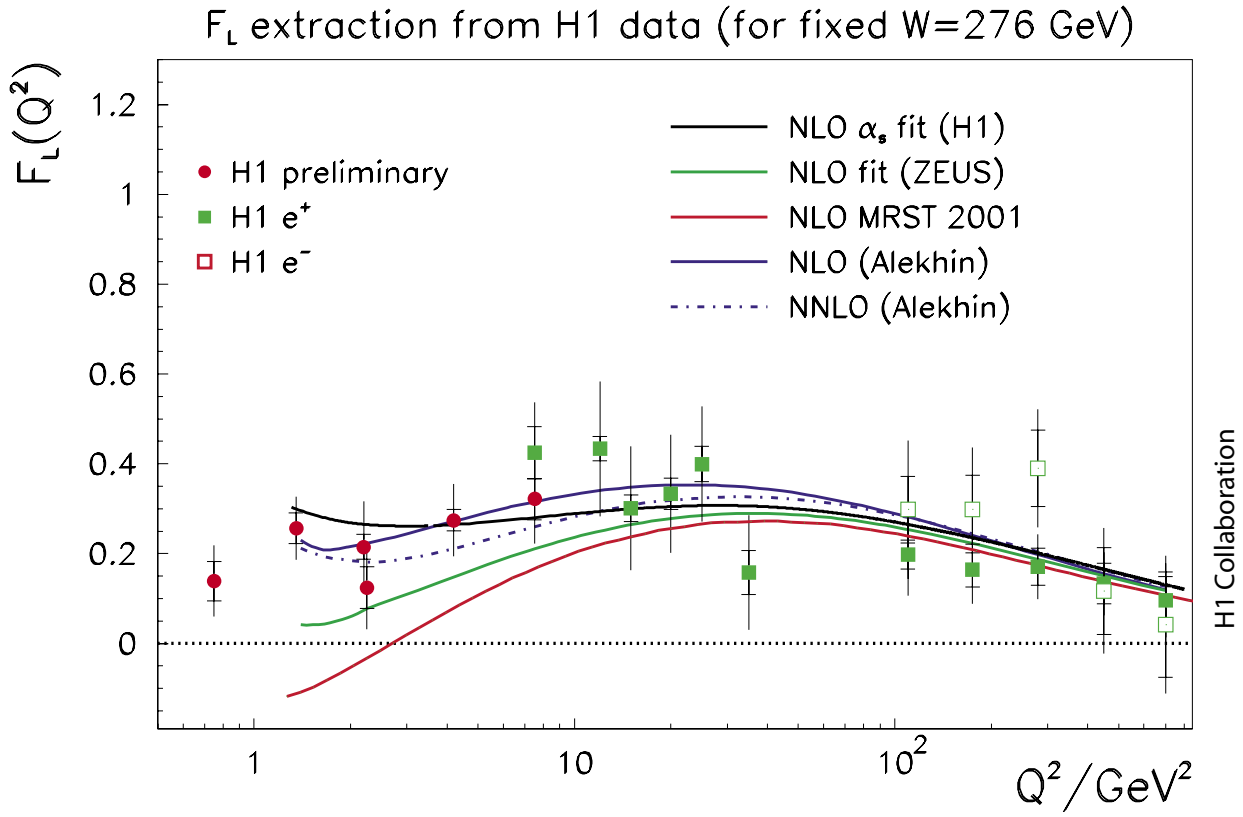
- good description of cross section in full kinematic range

Shape Method vs. Derivative Method



- shape method provides higher precision

$F_L(Q^2)$ at fixed y = 0.75



possible at HERA only with lowered ep cms energy

additional constraint on gluon [positive F_L at low Q^2]

direct F_L measurement important [HERA/LHC workshop]

Summary

New structure function measurements at low Q^2

F_2: phase space extended towards higher x

untagged ISR in shifted vertex

$0.35 < Q^2 < 0.85\,\mathrm{GeV}^2$

$10^{-4} \lesssim x \lesssim 5 \cdot 10^{-3}$

inelastic QEDC scattering

$0.5 < Q^2 < 7\,\mathrm{GeV}^2$

$2 \cdot 10^{-3} \lesssim x \lesssim 0.1$

F_L: positive for $Q^2 > 0.75\,\mathrm{GeV}^2$