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

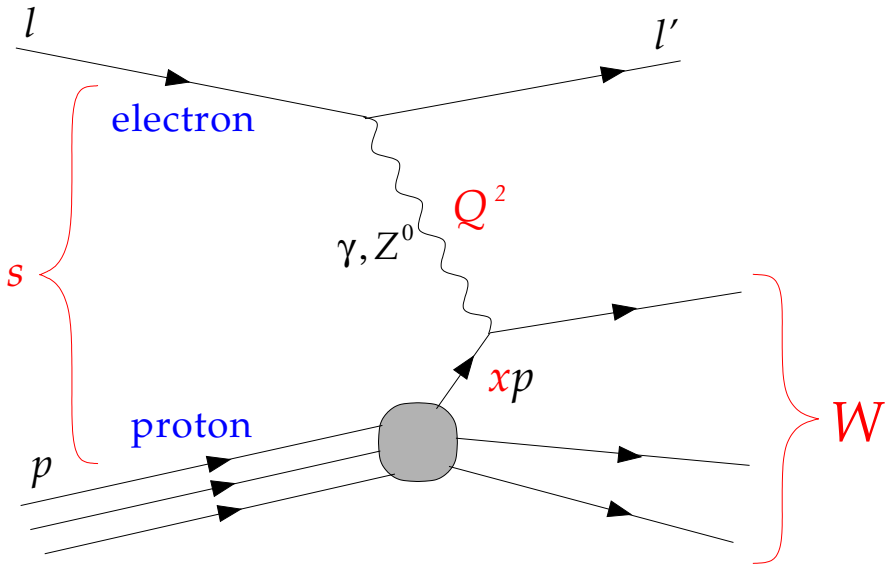
Victor Lendermann
University of Heidelberg
H1 Collaboration

- Deep Inelastic Scattering at HERA
- Measurements of F_2 in shifted vertex and radiative events
- Extraction of F_L

Beijing, 16.08.2004

Inclusive Deep Inelastic Scattering to Study Proton Structure

Neutral Current



- 2 degrees of freedom at fixed

  cms energy $s = (l + p)^2$

boson virtuality (resolution scale) $Q^2 = -(l - l')^2$

fractional momentum of struck quark $x = \dfrac{Q^2}{2p \cdot q}$

- Additional useful variables

inelasticity $y = \dfrac{p \cdot q}{p \cdot l} \approx \dfrac{Q^2}{xs}$

invariant mass of hadronic final state $W = \sqrt{Q^2 \dfrac{1-x}{x} + m_p^2}$

Structure Functions in DIS

- Measure cross section

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{Q^4 x}\left\{\left[1+(1-y)^2\right]F_2(x,Q^2) - y^2 F_L(x,Q^2) \; + \ldots \underset{\text{at high}Q^2}{xF_3}\right\}$$

- Parton distribution functions (PDF) in pQCD

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

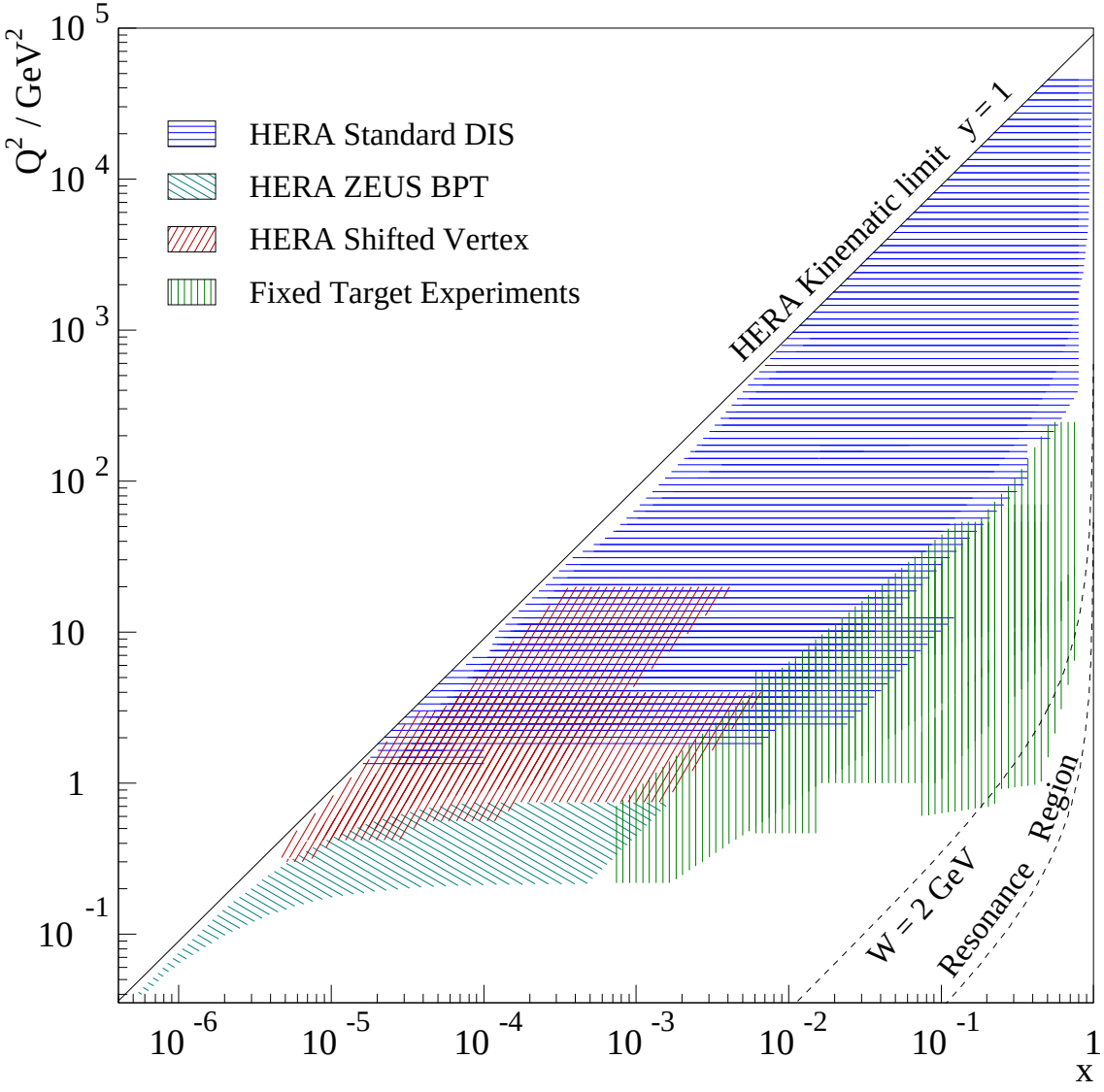
q_i – probability to find quark with flavour i in proton

- $F_L(x,Q^2)$ – longitudinally polarised photons
  - Contribution only at high y
  - Sensitive to QCD higher orders (gluon emission)

    $F_L \sim \alpha_s g$ — constrains gluon density

Kinematic Regions of Measurements

At HERA: $\sqrt{s} \approx 300 - 320\,\text{GeV}$ $\quad 0 < Q^2 < 10^5\,\text{GeV}^2$ $\quad 10^{-6} < x < 1$

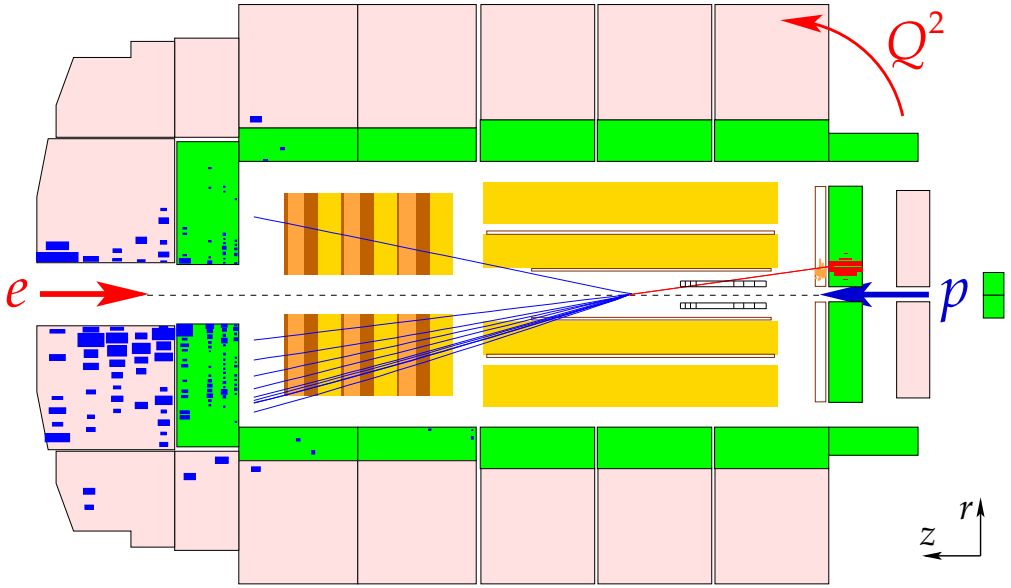


- *Medium – High* Q^2
  asymptotic freedom
  perturbative QCD
  $\longrightarrow$ *talk by Stefan Schmitt*

- *Low* Q^2 – transition to γp
  $\alpha_s(Q^2)$ becomes large $\Longrightarrow$
  quark confinment

Transition from quarks to hadrons
$\longrightarrow$ *theoretical challenge*

Experimental Technique at Low Q^2



H1 main detector – side view

$$Q^2 \propto p_{t,e}^2$$

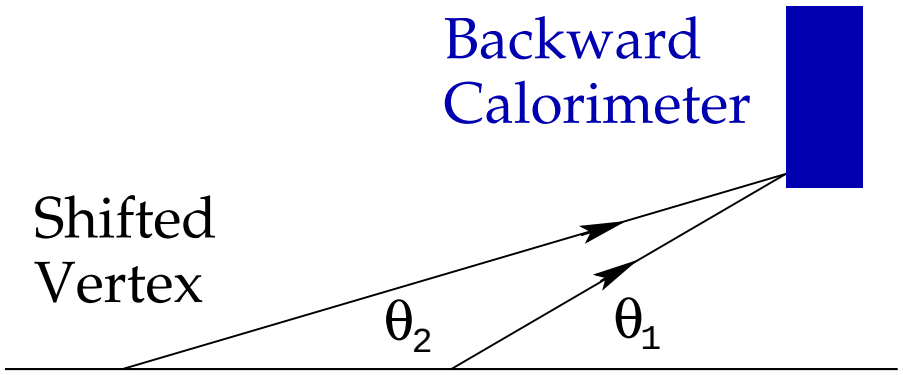
- Low Q^2 – low θ_e in DIS

  Standard DIS in main detector:

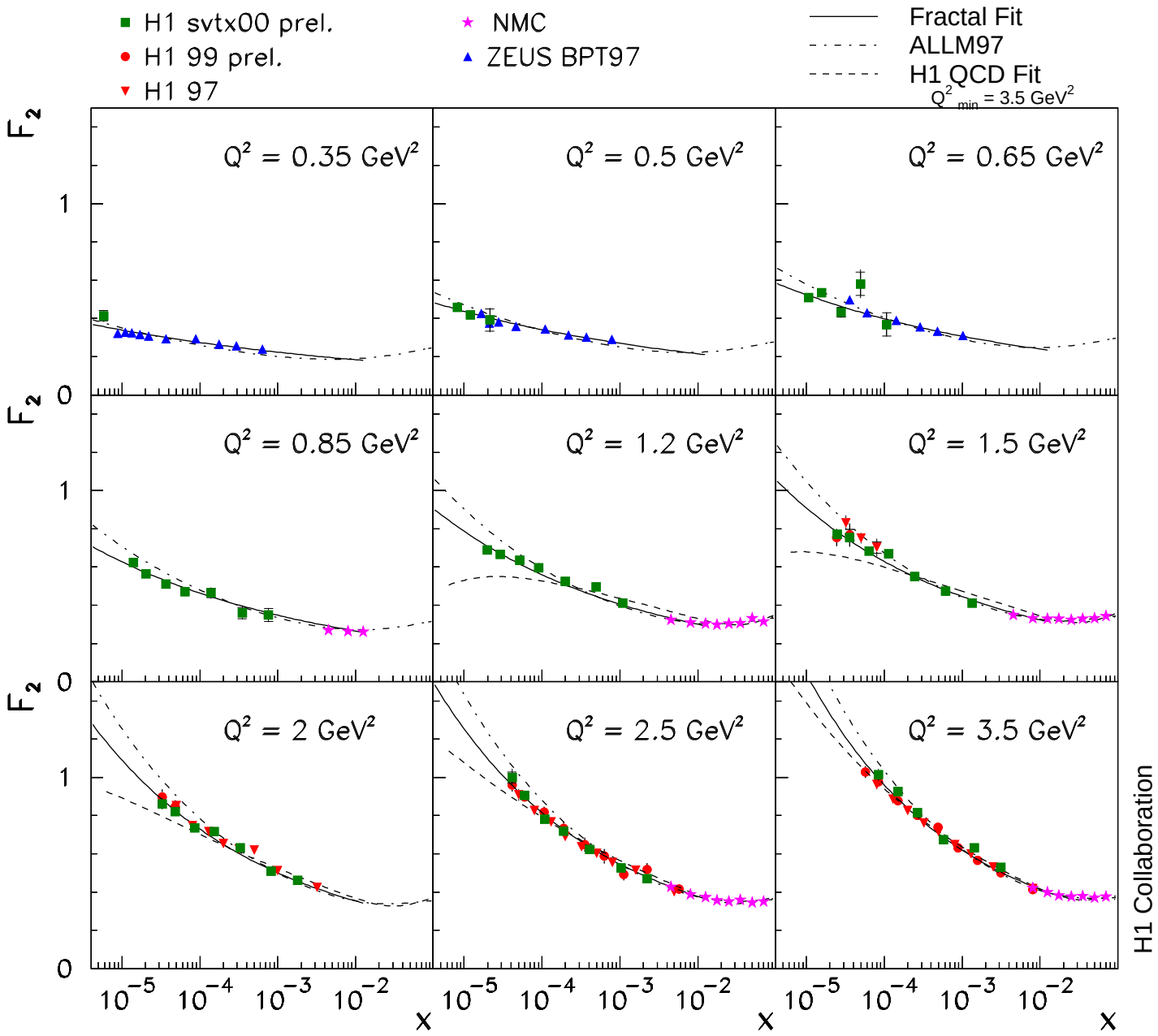
  $Q^2 \gtrsim 2\,\mathrm{GeV}^2$

  $\longrightarrow$ *experimental challenge*

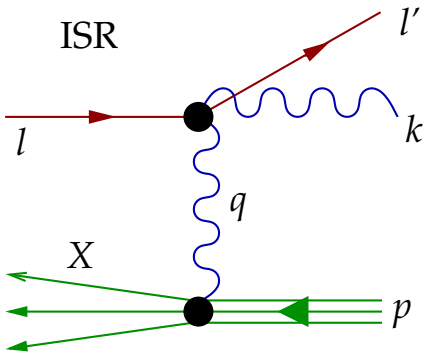
- Approaches
  - Very low Q^2 devices – ZEUS BPC/BPT
  - Shifted vertex runs
  - Radiative events

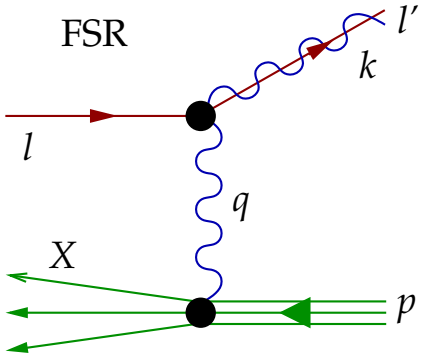


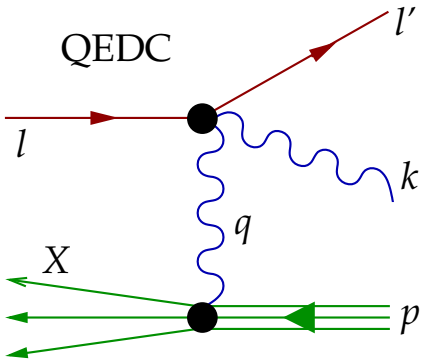
Previous Results at Low Q^2



Photon Radiation from Lepton Line







$$q = l - l' - k$$

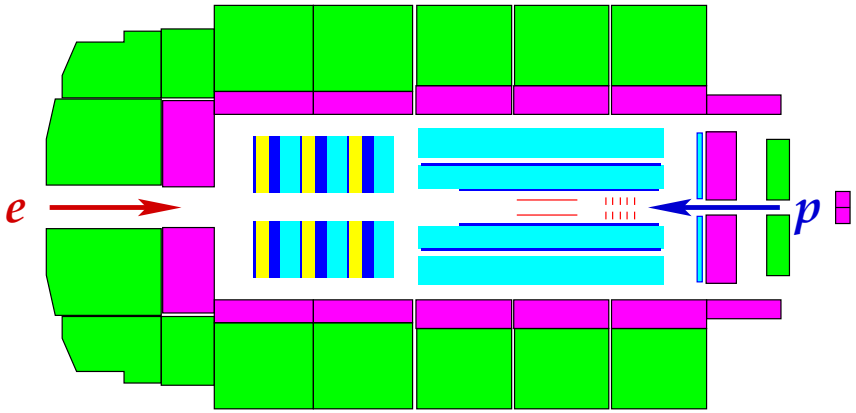
Modified kinematics

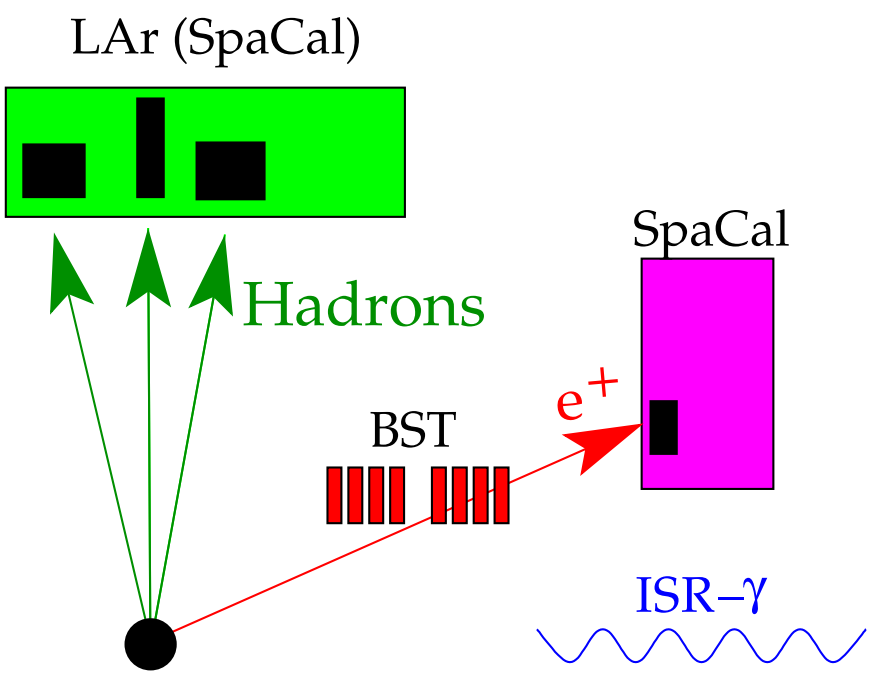
Access lower Q^2 and higher x

Distinct topologies:

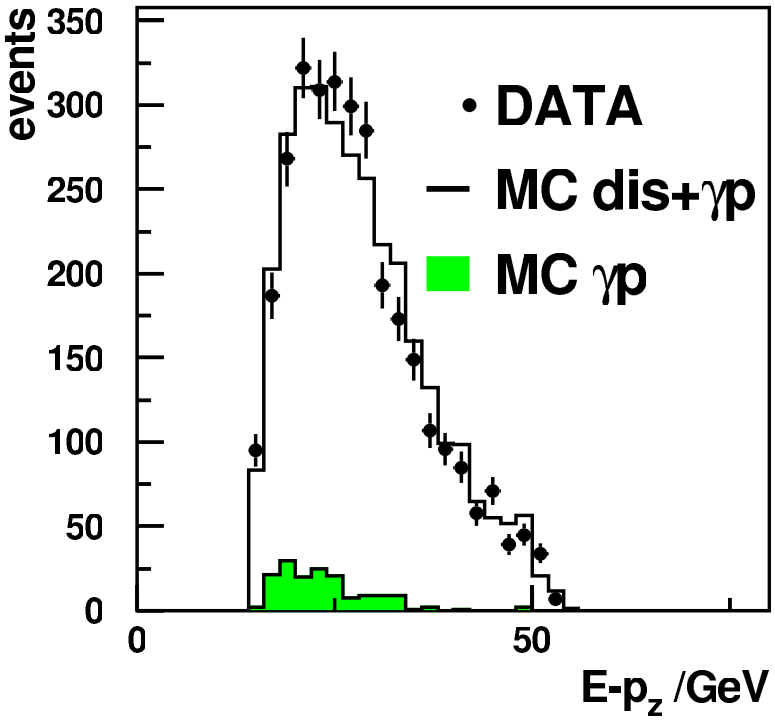
- Initial State Radiation (ISR) : $\vec{k} \parallel \vec{l}$
- Final State Radiation (FSR) : $\vec{k} \parallel \vec{l'}$
- QED Compton (QEDC) : $\vec{q} \parallel \vec{l}$

Untagged ISR Signature



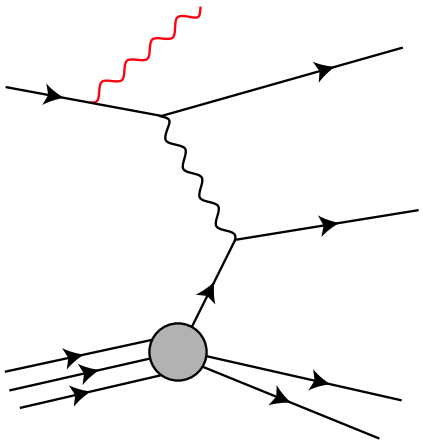


$$\sum (E - P_z)_i < 2E_{e-\text{beam}}$$



γp background rejected by BST

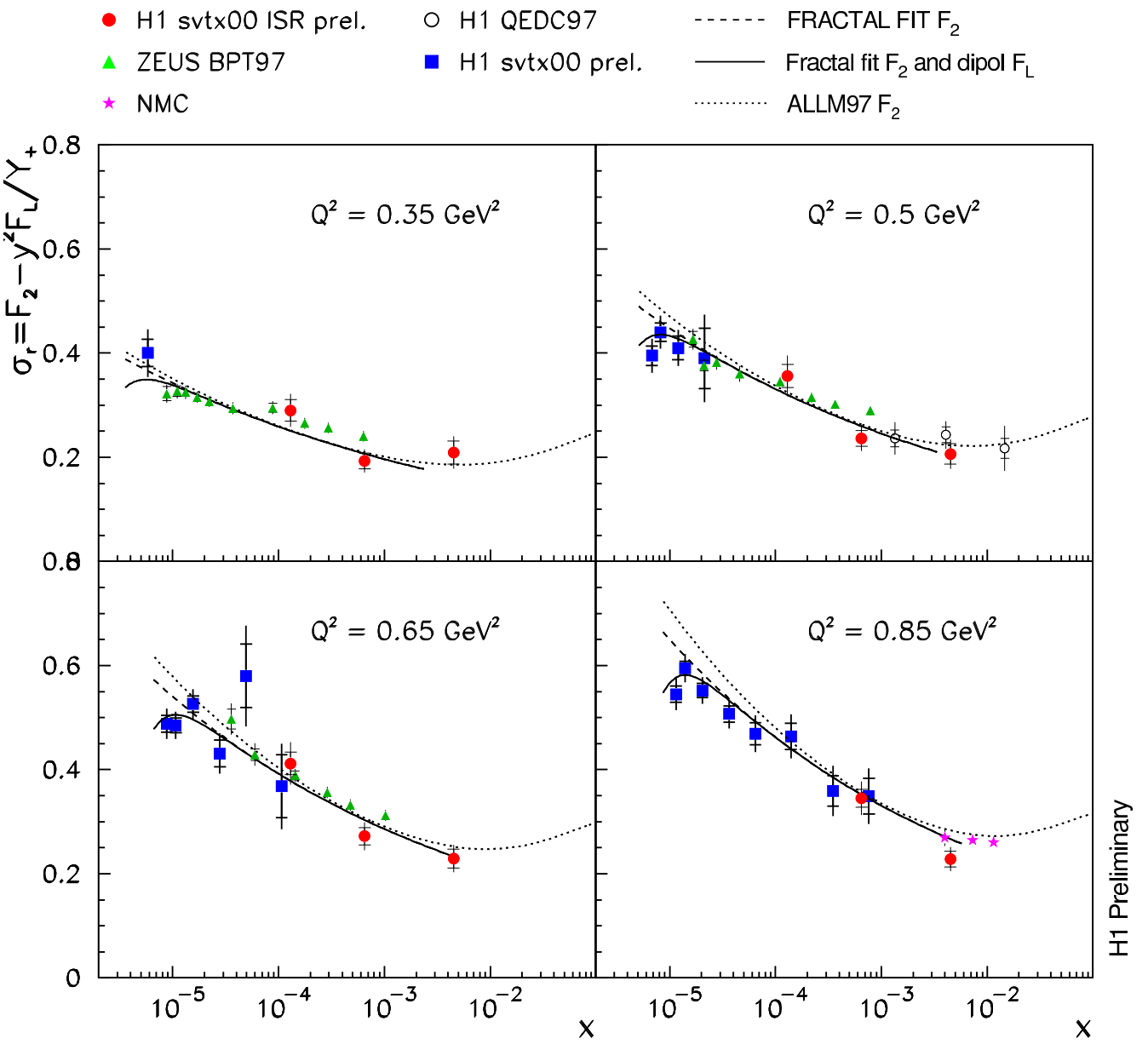
F_2 in Shifted Vertex ISR



Equivalent to inclusive DIS at reduced s

$Q^2 = xys$

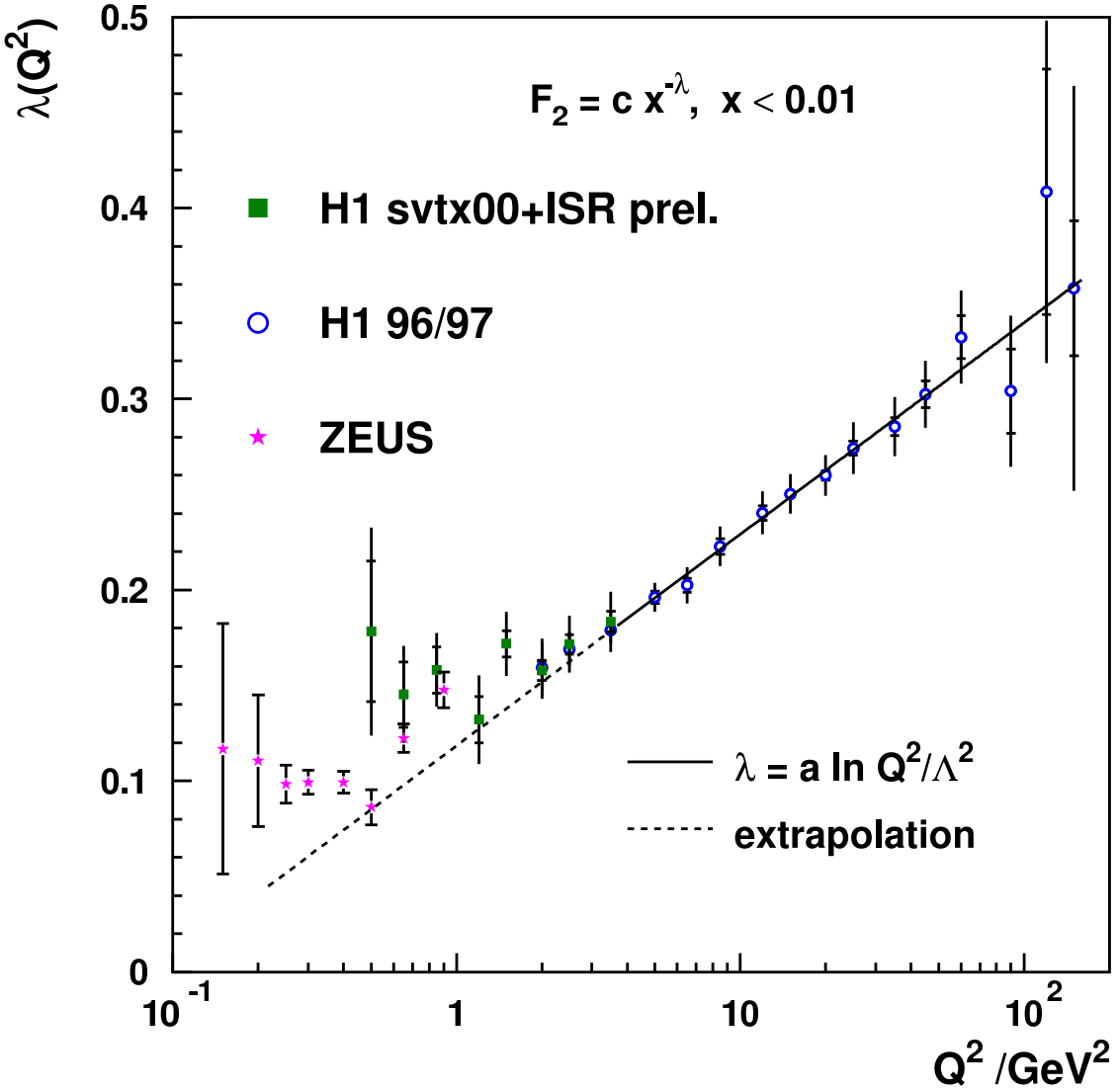
Access higher x



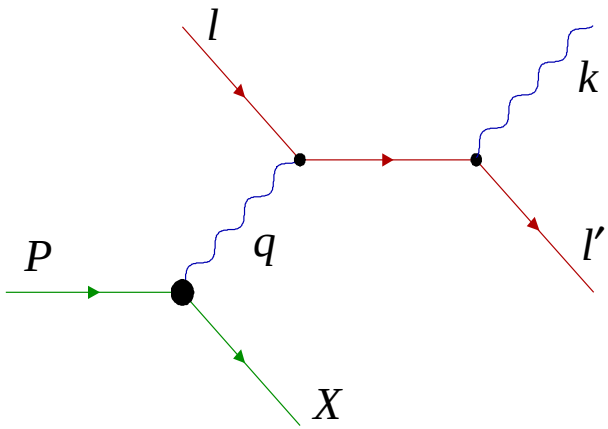
Improved Extraction of $\lambda(Q^2)$

$$\lambda = \frac{\partial \ln F_2}{\partial \ln x}$$

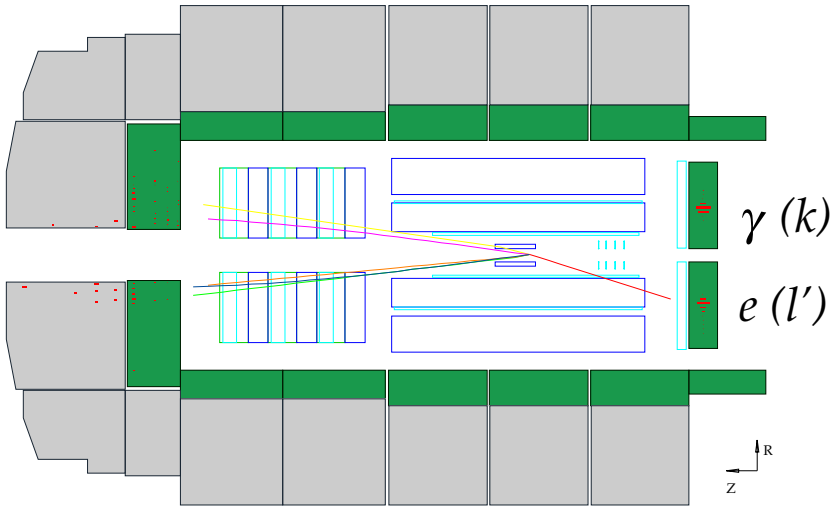
- Rise of F_2 at $x < 10^{-2}$ is well parameterised by
  $$F_2 = c(Q^2) \cdot x^{-\lambda(Q^2)}$$
- At $Q^2 \gtrsim 3\,\mathrm{GeV}^2$:
  $$\lambda \sim \ln Q^2 \,,\; c \sim \text{const}$$
  Partonic degrees of freedom
- At $Q^2 \lesssim 2\,\mathrm{GeV}^2$:
  $$\lambda(Q^2) \to 0.08$$
  Transition to hadronic degrees of freedom



Inelastic QED Compton Events



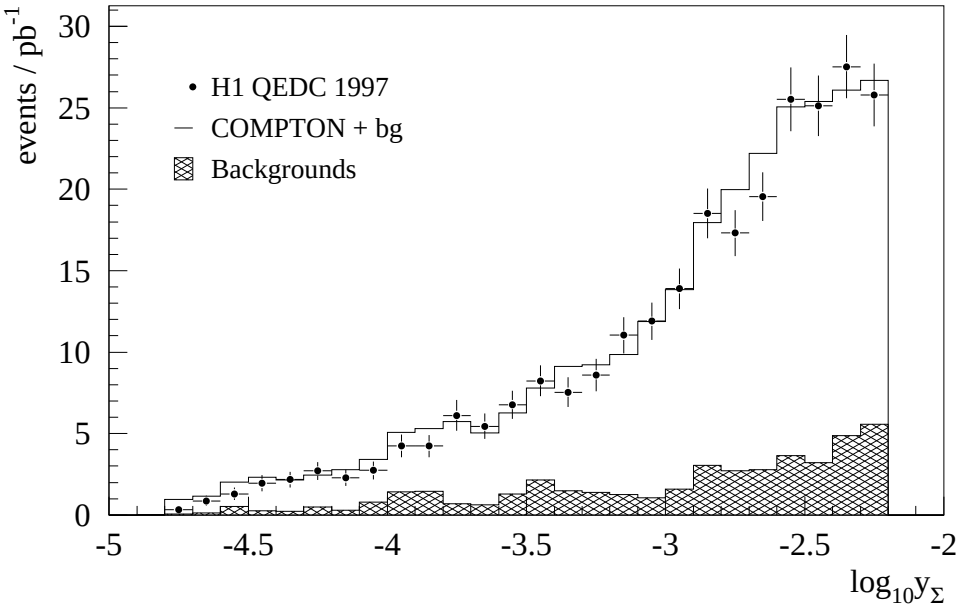
QEDC Event in H1 Detector



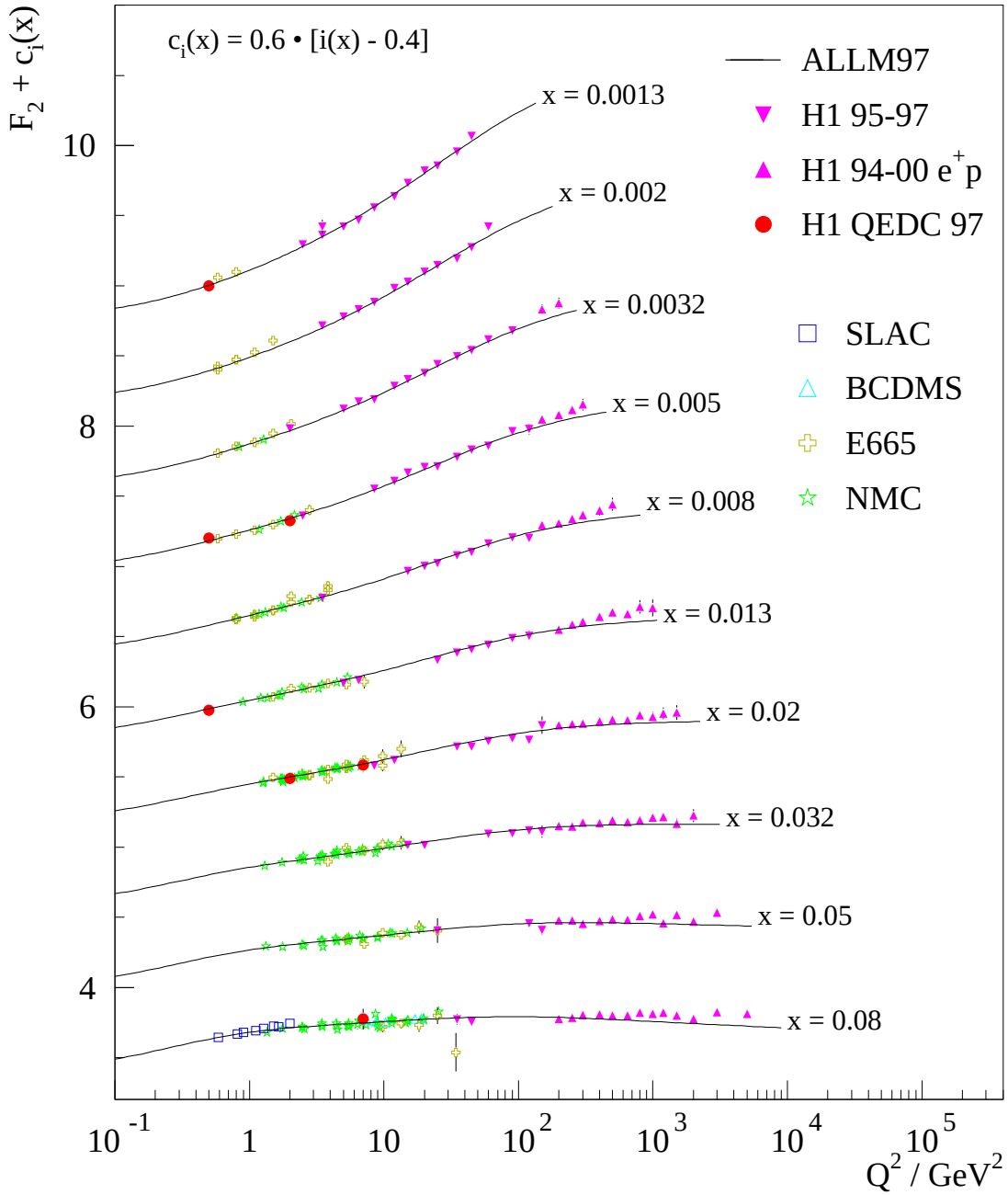
DIS background at low x: π^0 fakes γ

Medium – high x are measured

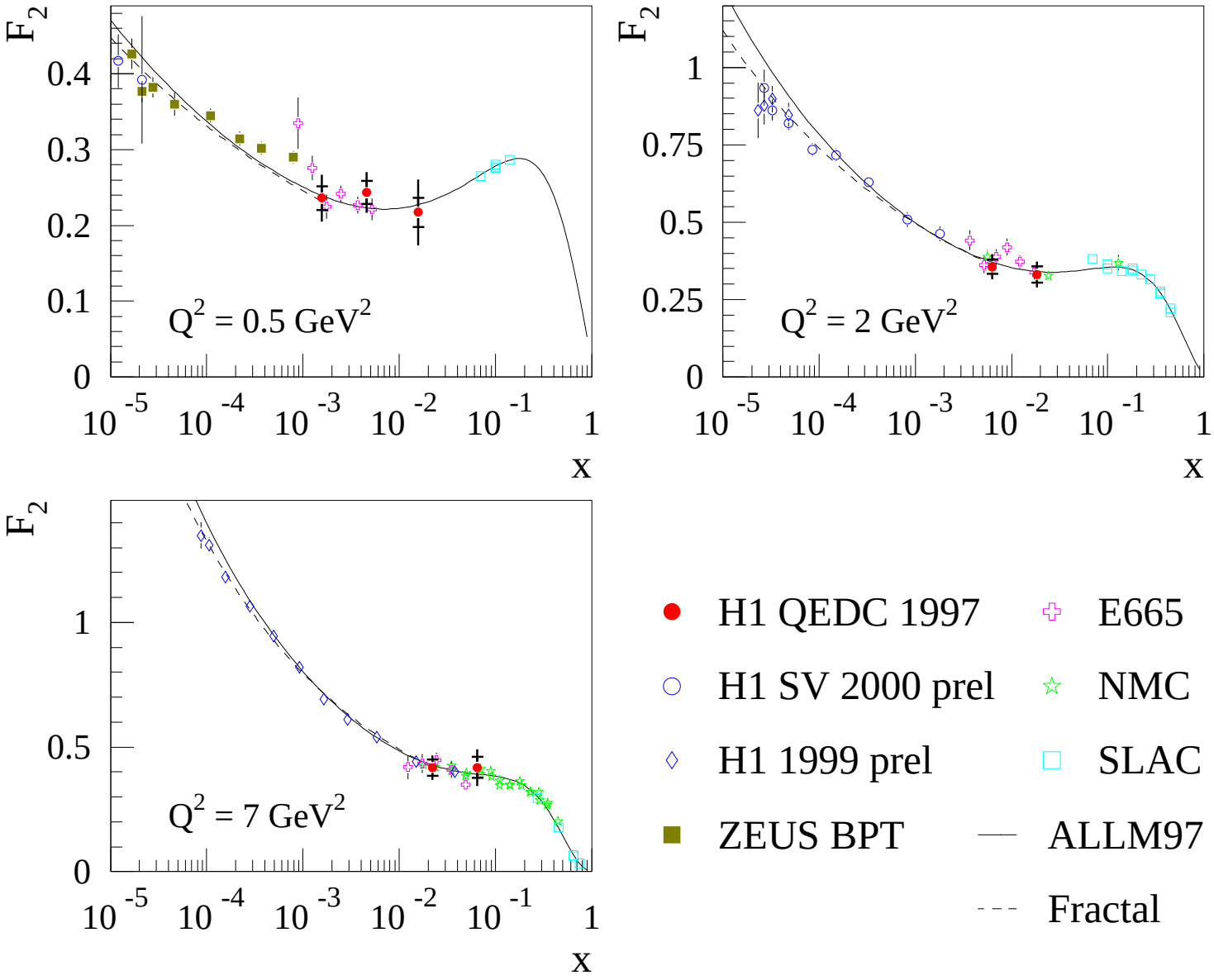
- Understanding of HFS at low W
- Use SOPHIA MC model



Kinematic Region of QEDC Measurement



Results of F_2 Measurement in QEDC



Good agreement with fixed target experiments

Determination of F_L

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{Q^4 x}\left\{\left[1+(1-y)^2\right]F_2(x,Q^2) - y^2 F_L(x,Q^2)\right\}$$

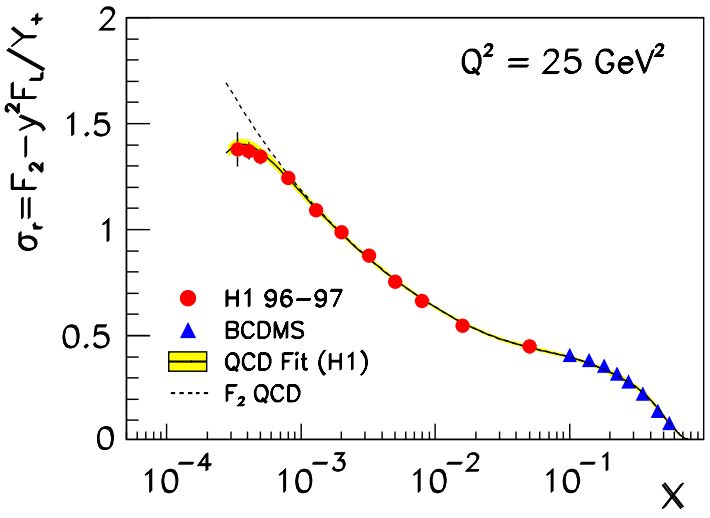
- Data sensitive at highest y only
- Direct measurement requires data at different $s \longrightarrow$ *lower* E_p *runs*
- Indirect determination extrapolating F_2 to higher y

$$F_L \propto F_2 - \sigma_r$$

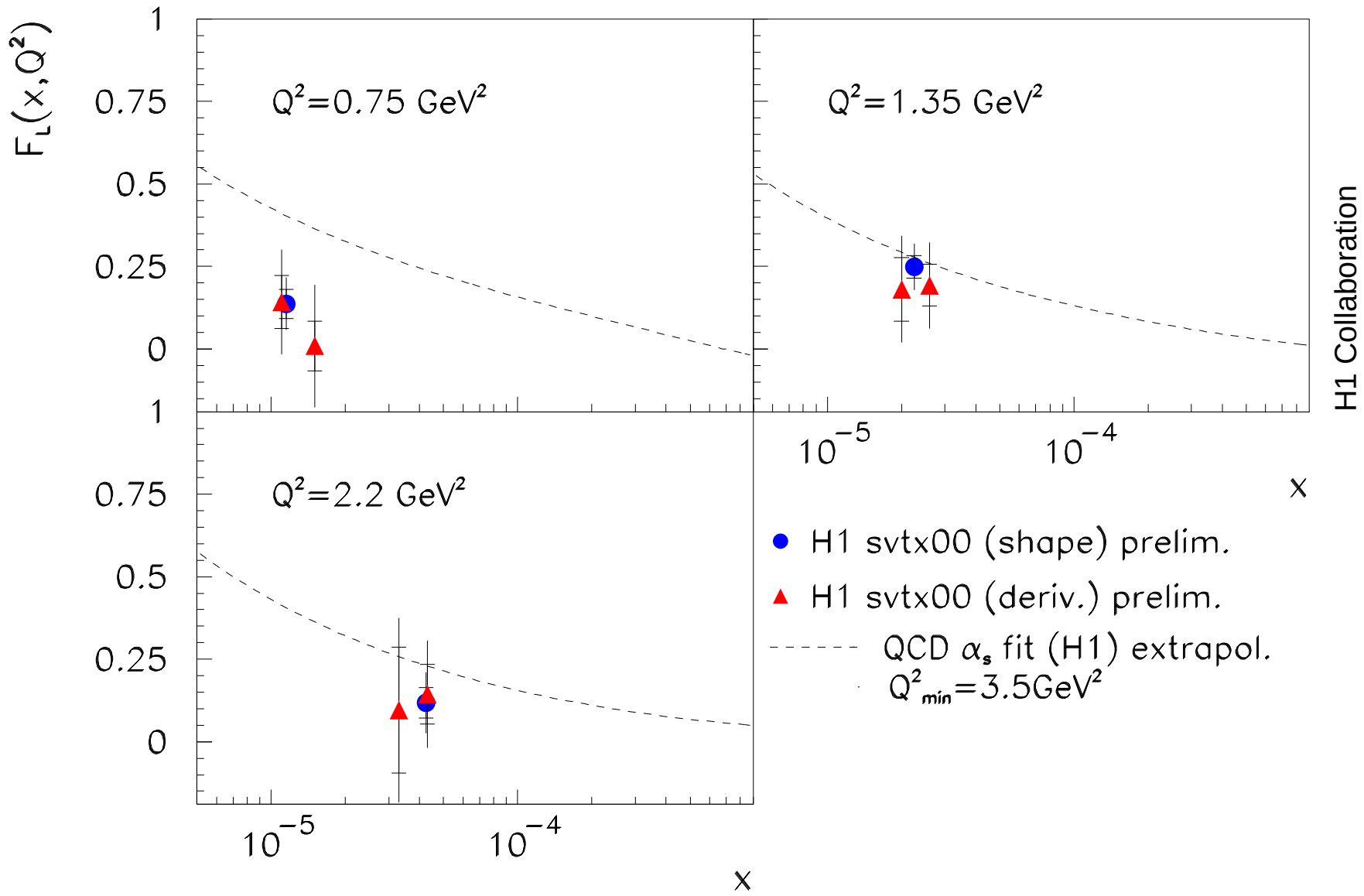
  - derivative method
  - shape method

$$\sigma_{\text{fit}} = cx^{-\lambda} - \frac{y^2}{1+(1-y)^2}F_L$$

Reduced Cross Section

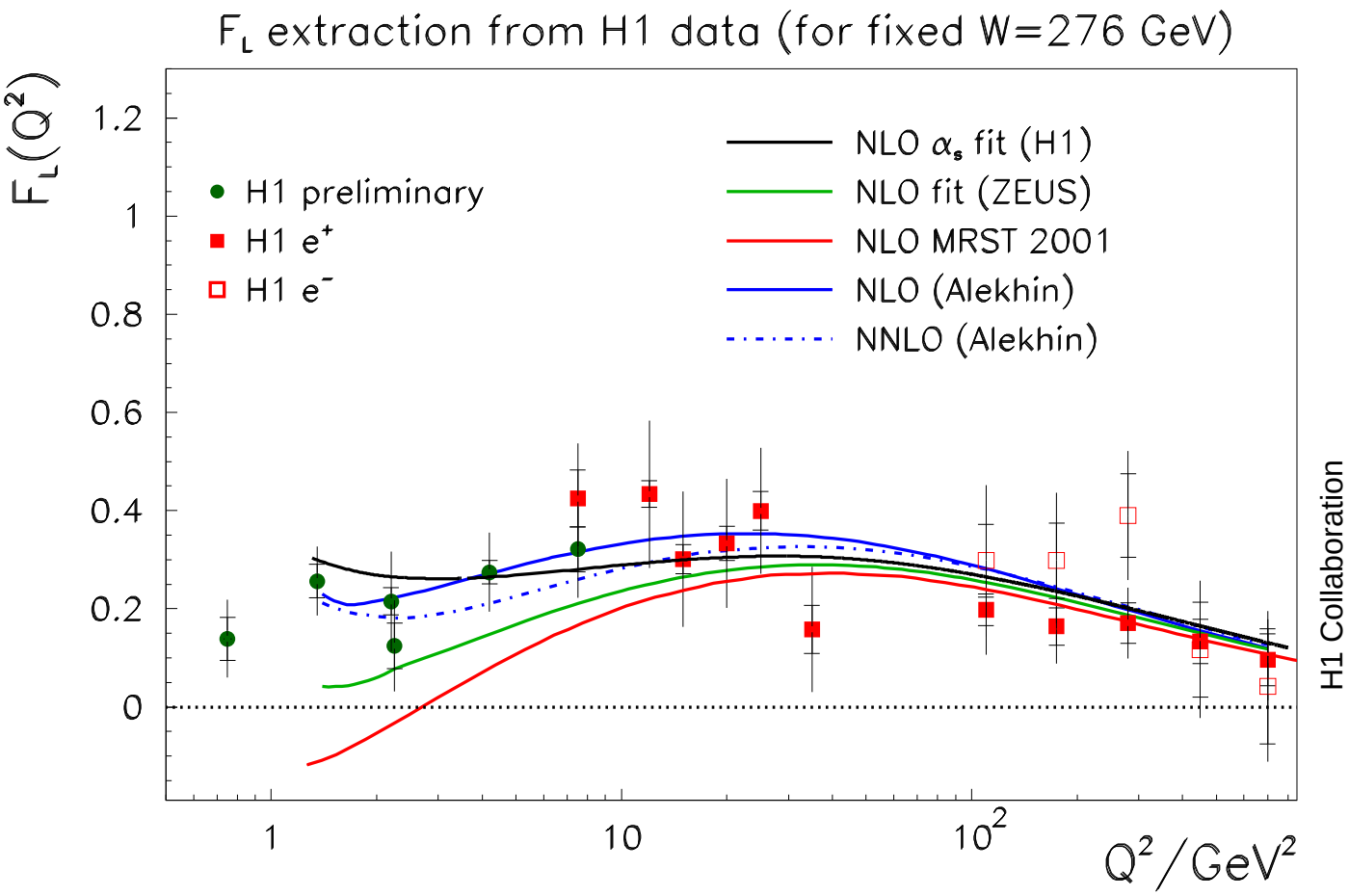


Shape Method vs. Derivative Method



Shape method provides higher precision

F_L at Fixed $y = 0.75$



- New constraints from low Q^2 data
- F_L spans 3 orders of magnitude in Q^2
- Basic agreement with NLO pQCD fits
- H1 non-negligible F_L at low $Q^2 \Longrightarrow$ *positive g*

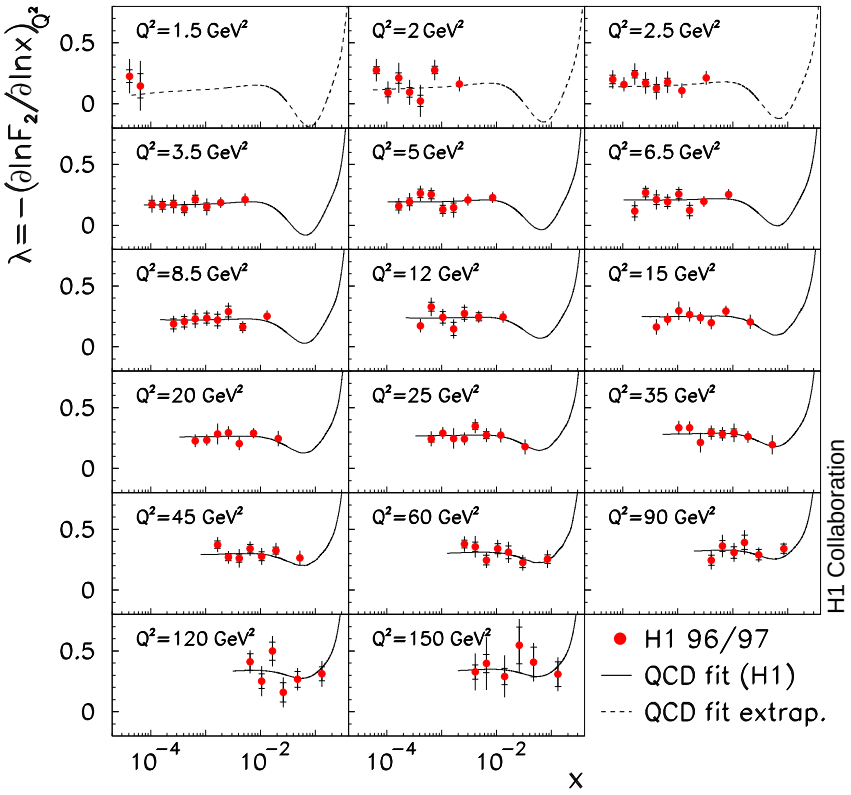
Summary of New Results by H1

New approaches to proton structure function measurements at low Q^2 in transition region from DIS to γp

- $F_2(x, Q^2)$ in QED Compton scattering
  at $Q^2 \to 0.1\,\mathrm{GeV}^2$ and $0.001 \lesssim x \lesssim 0.1$
  - Extended low Q^2 domain of HERA towards higher x
  - Better HFS modelling at low W
  - Good agreement with fixed target data
- Preliminary: $F_2(x, Q^2)$ using shiftex vertex untagged ISR
  at $0.35 < Q^2 < 0.85\,\mathrm{GeV}^2$ and $10^{-4} \lesssim x \lesssim 5 \cdot 10^{-3}$
  - Extended SV domain towards higher x
  - Improved extraction of $\lambda(Q^2)$
- Preliminary: $F_L(Q^2)$ at $W = 276\,\mathrm{GeV}$:
  - Derivative method
  - Shape method — more precise

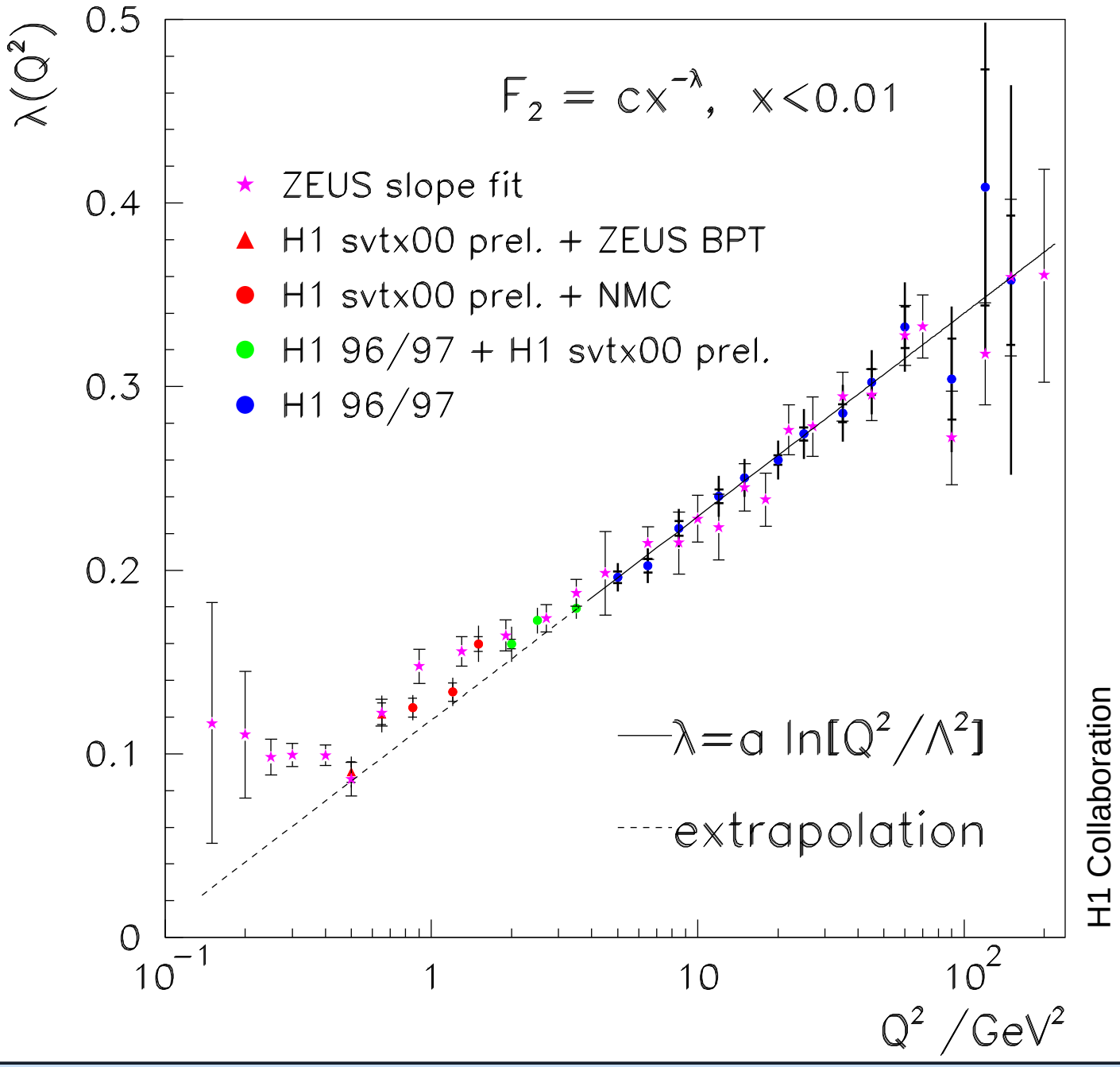
Additional Information

x Dependence of F_2 at Low Q^2

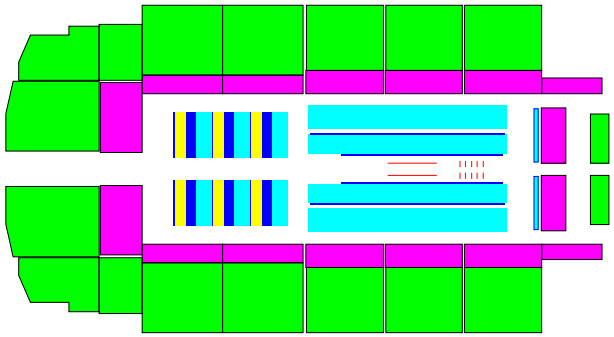


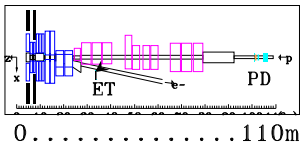
- If unitarisation effects present, expect taming of rise of F_2 at low x
- Extract $\lambda = \dfrac{\partial \ln F_2}{\partial \ln x}$ at fixed Q^2
- Derivative independent of x for $x < 10^{-2}$
  no evidence for saturation

Combined Extraction of λ



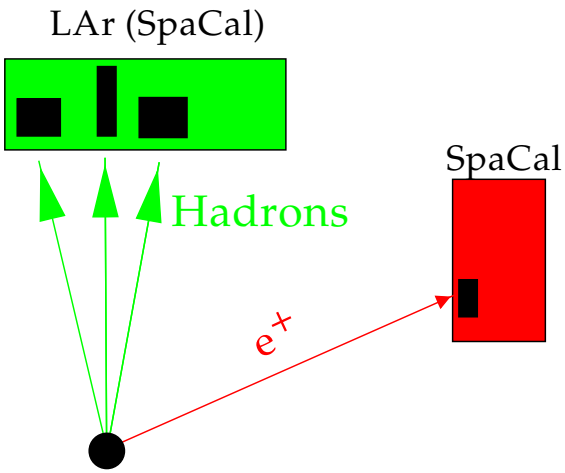
ISR Event in H1 Detector

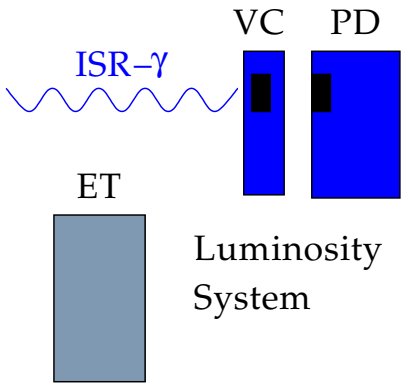




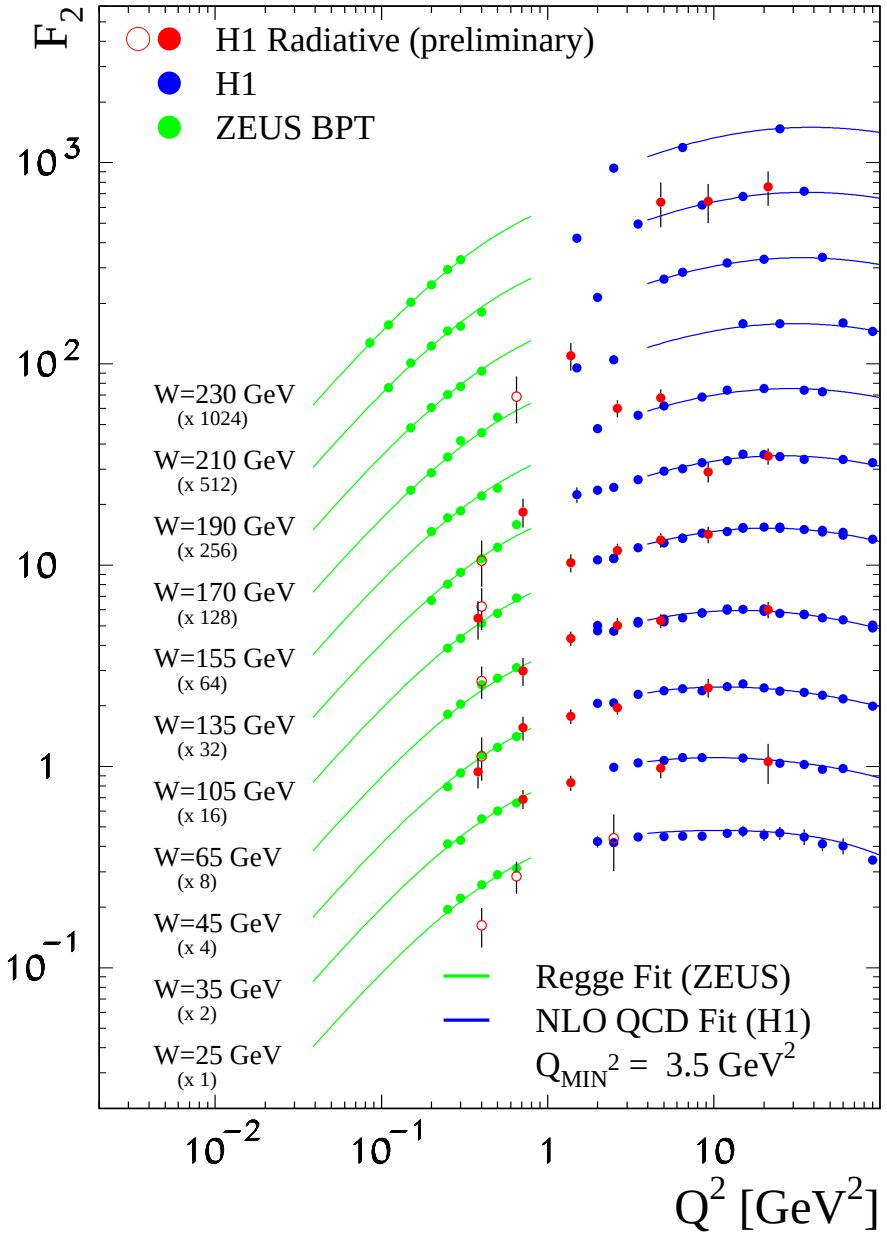
Access lower Q^2

- Additional experimental challenges
  - Detector acceptance and calibration
  - Backgrounds from event overlaps (DIS + BH, γp + BH, ISR + BH)

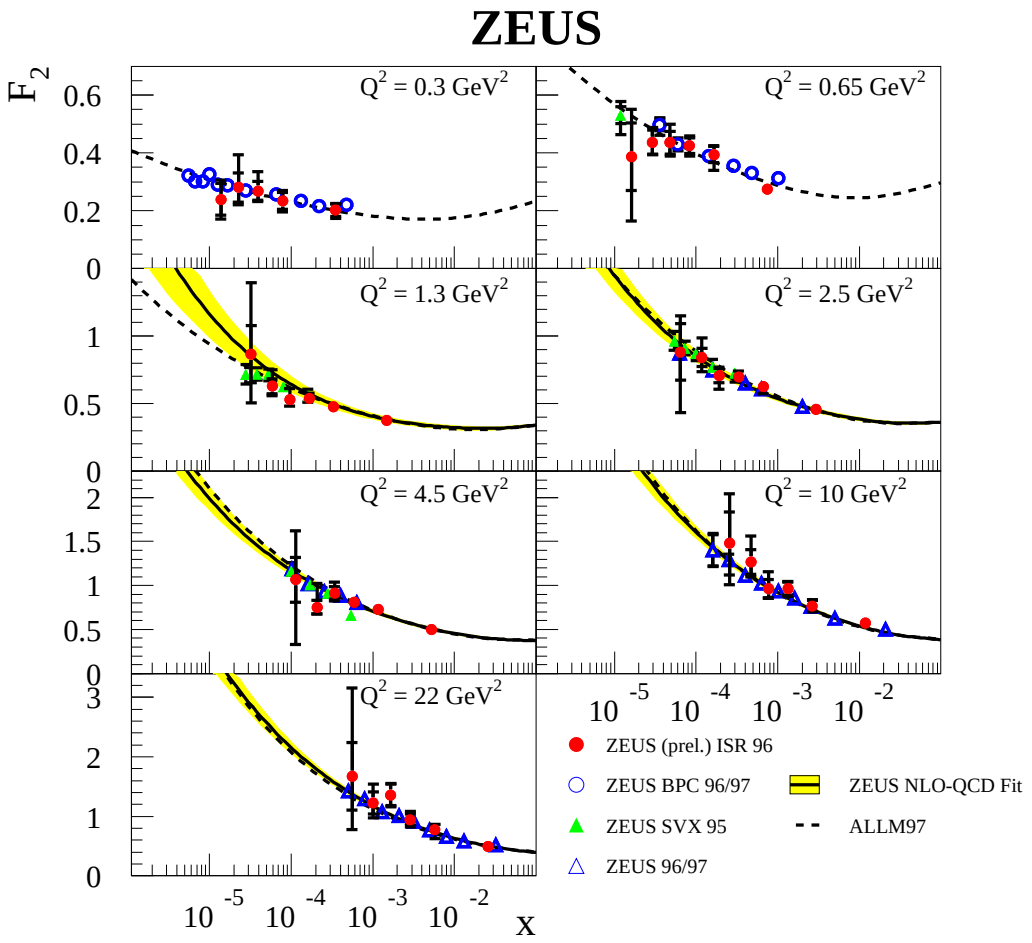




Preliminary Results: F_2 in ISR



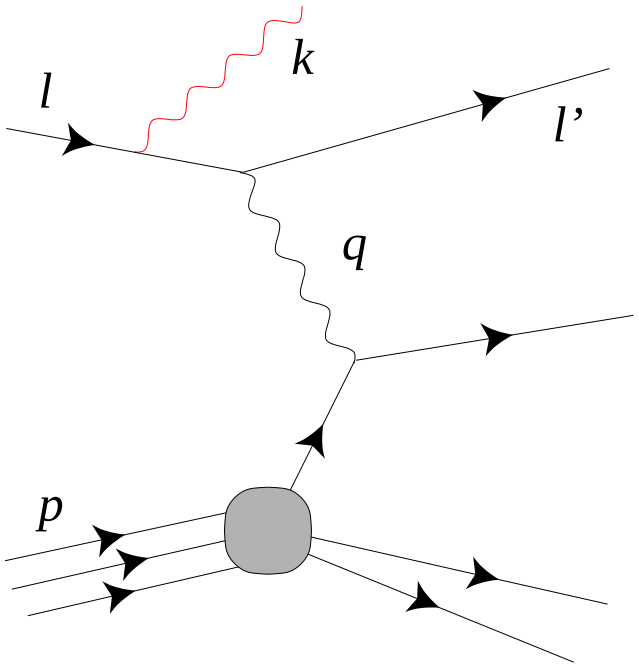
Access both perturbative and non-perturbative domain

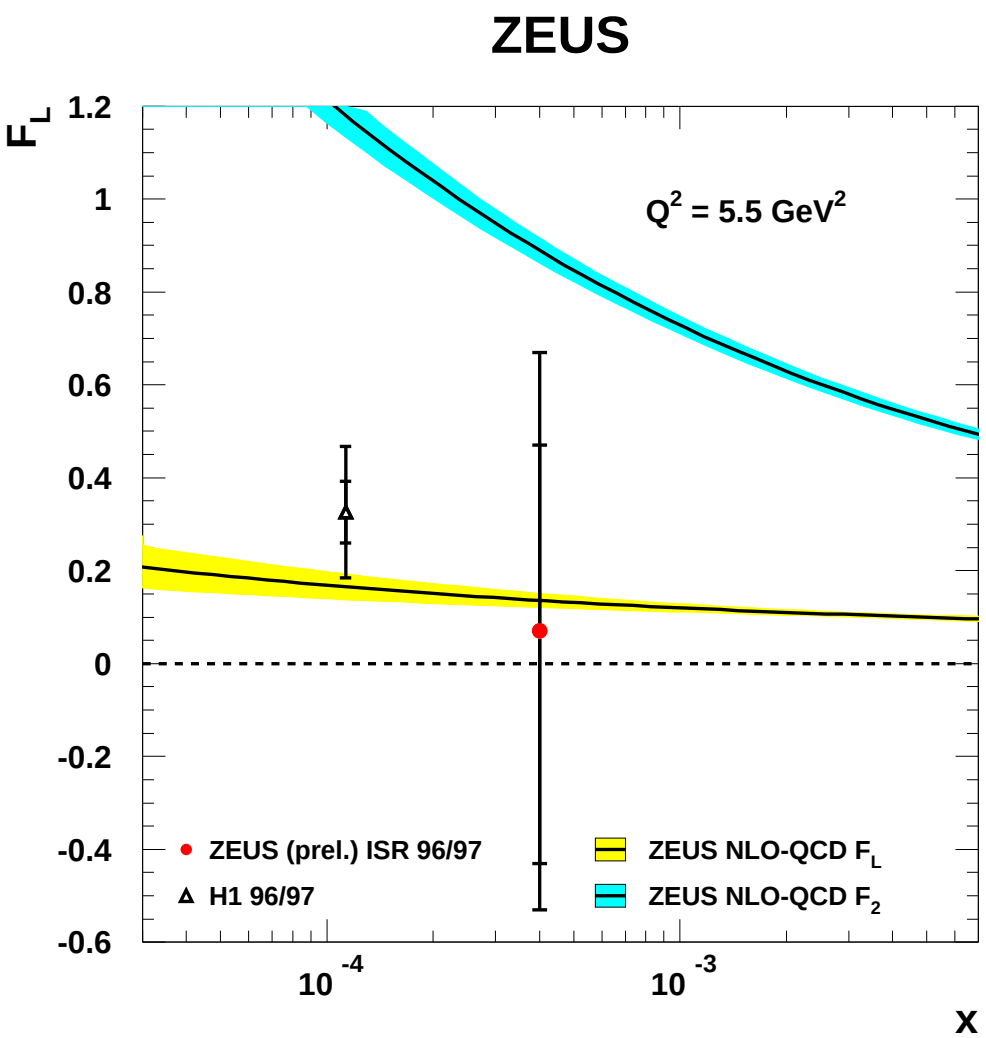


Direct Determination of F_L

- Modified kinematics:
  interpret as incident $E = E_{e-\text{beam}} - E_\gamma \quad \Longrightarrow$ variation of y :

$$y = \frac{p \cdot q}{p \cdot (l - k)}$$





Need much more ISR statistics