Structure Function Measurements using Radiative Events at HERA

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- ▷ **Motivation**
- ▷ **Analysis of Initial State Radiative Events**
- ▷ **Measurement of $F_2(x, Q^2)$**
- ▷ **Measurement of $F_L(x, Q^2)$**
- ▷ **Conclusions**

Event kinematics with Initial State Radiation

- $Q^2 = -(k - k')^2$
  - virtuality of exchanged boson
  - Reconstructed using

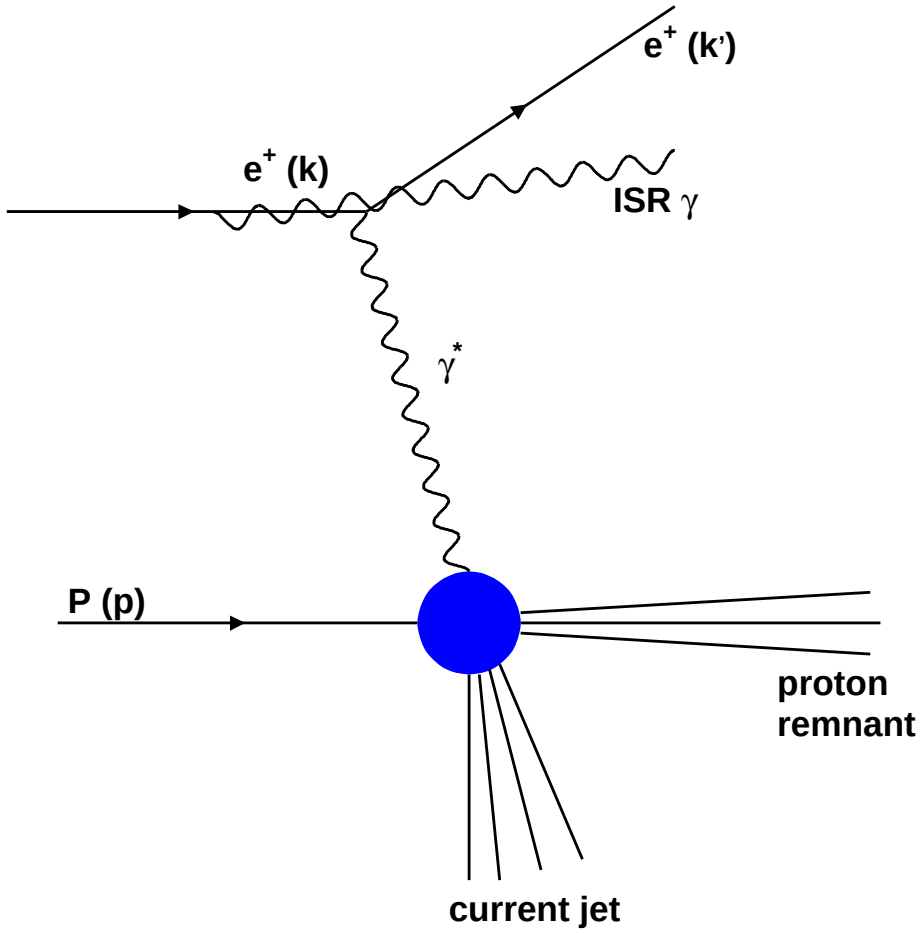
    $$Q^2_e = 2E_e E'_e(1 + \cos\theta)$$

  - $E_e = E_{HERA} - E_\gamma$

- $y = \frac{P \cdot q}{P \cdot k}$
  - inelasticity
  - Reconstructed using

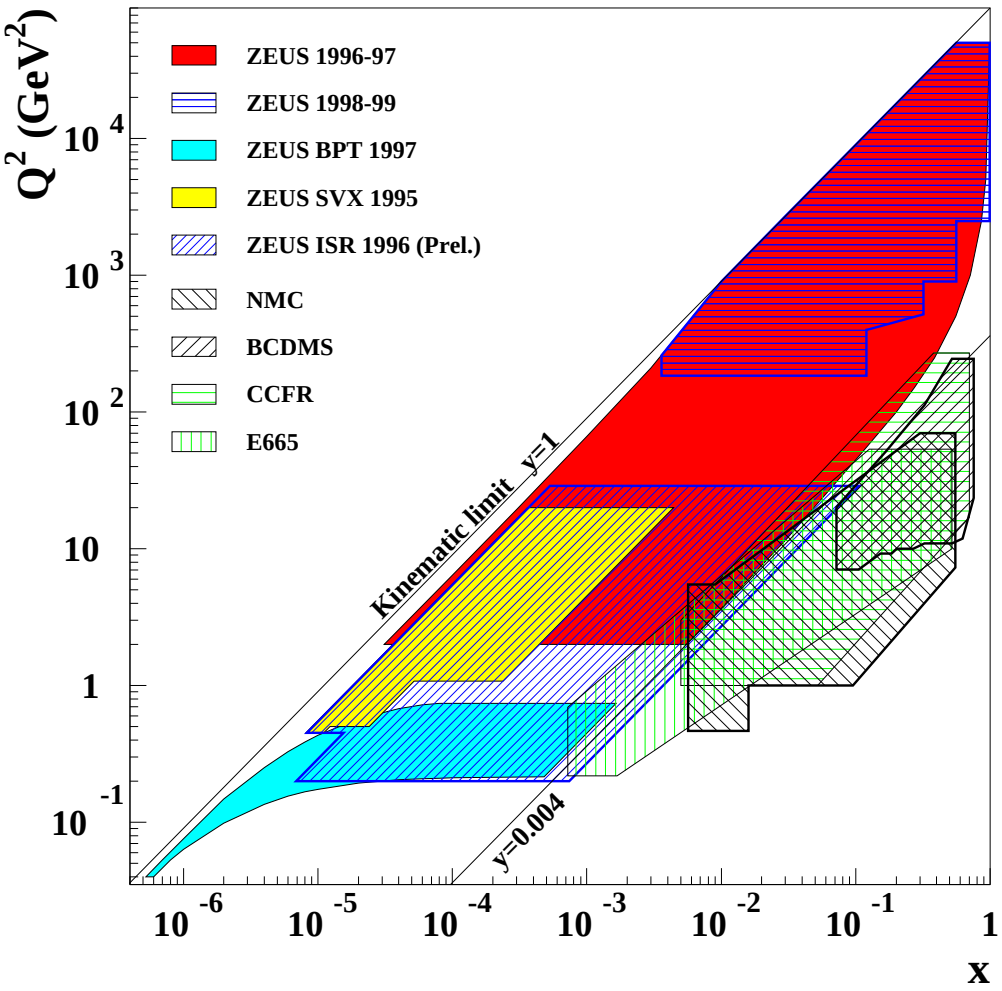
    $$y_\Sigma = \frac{(E - P_z)_H}{(E - P_z)_H + (E - P_z)_e}$$

- $x = \frac{Q^2}{2P \cdot q}$
  - Bjorken scaling variable
  - $Q^2 = xys$



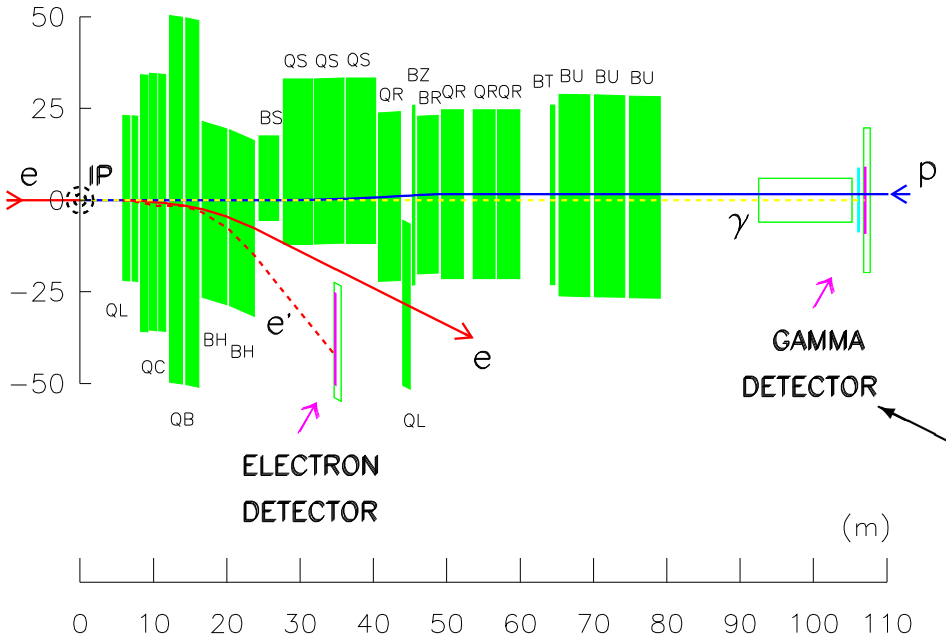
Why measure structure functions using ISR Events ?

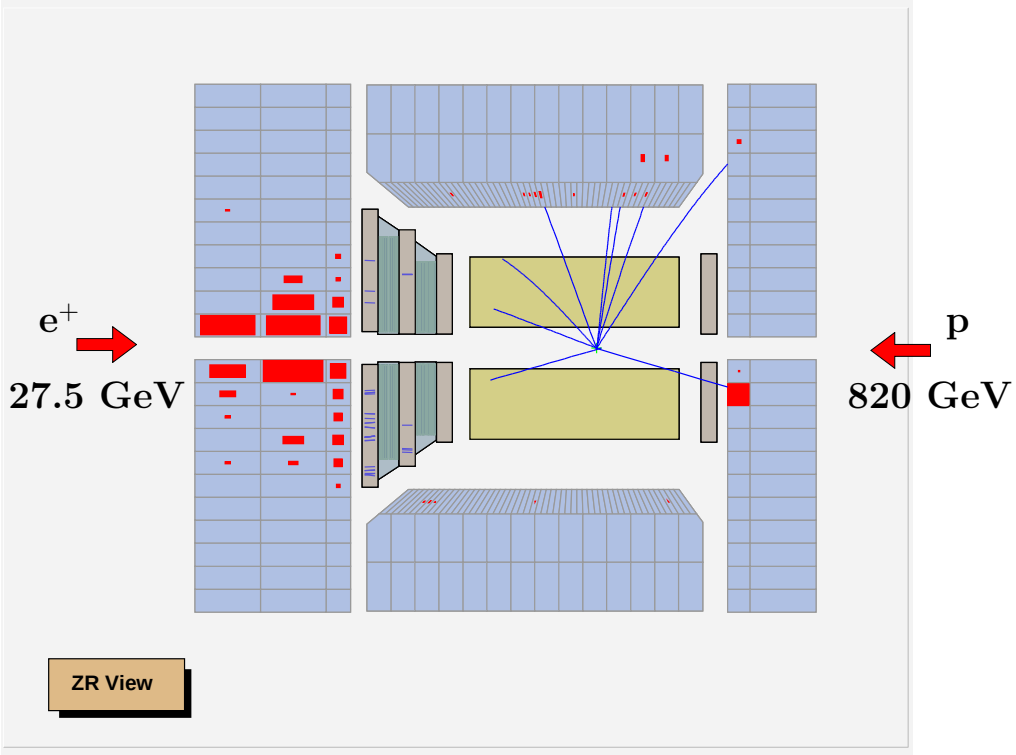
- ▷ Emission of ISR $\gamma \Rightarrow$ reduction of E_e
  - – Lower $E_e \Rightarrow$ lower Q^2
  - – Measure $F_2(x, Q^2)$ is previously unexplored region
- ▷ Emission of ISR $\gamma \Rightarrow$ reduction of $\sqrt{s}$
  - – Access range of y values for fixed (x, Q^2)
  - – Needed for all techniques of measuring F_L



Identifying ISR Events with the ZEUS Detector

- **Standard DIS event selection:**
  - **identify scattered positron in main detector**
- **Identify ISR photon in luminosity monitor**

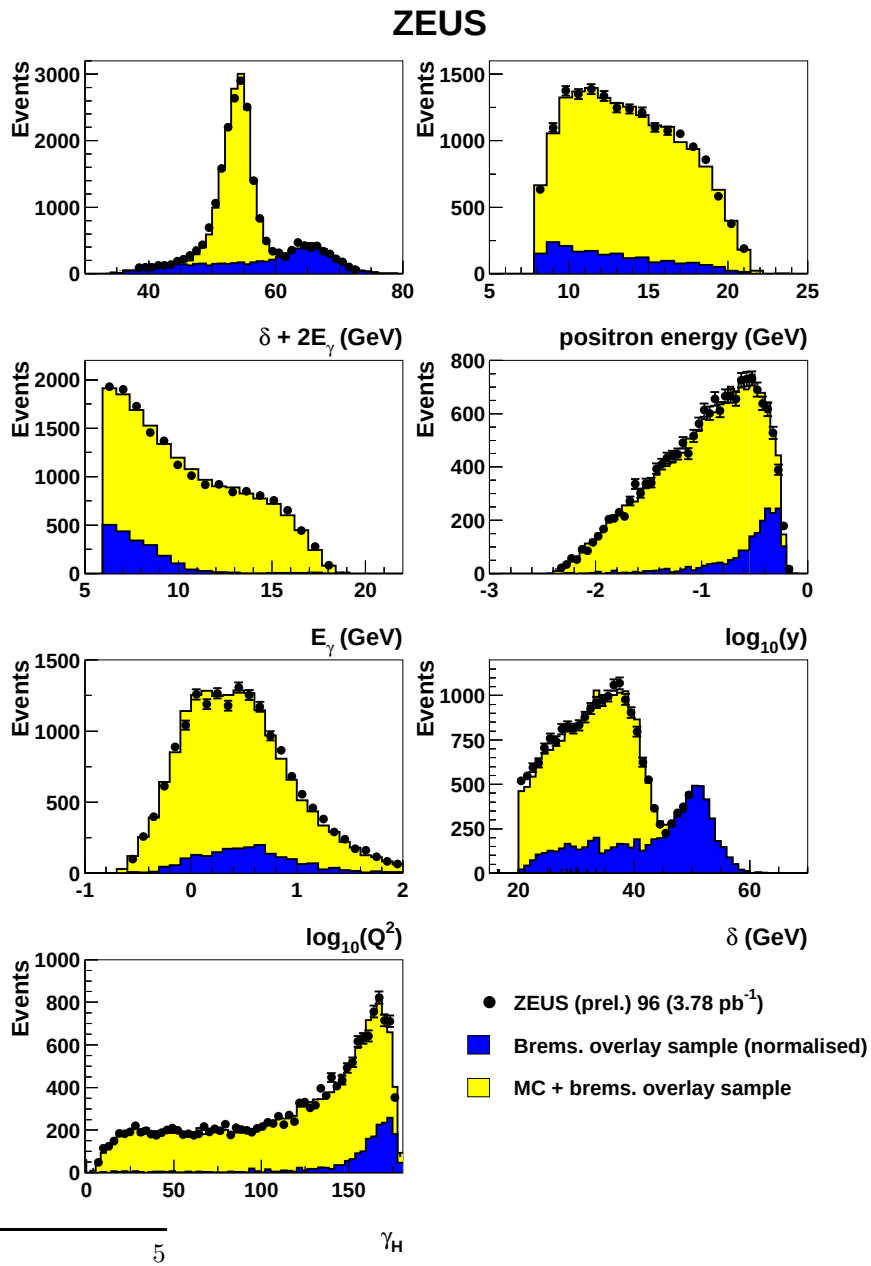




Normally used identify photon in ep → epγ

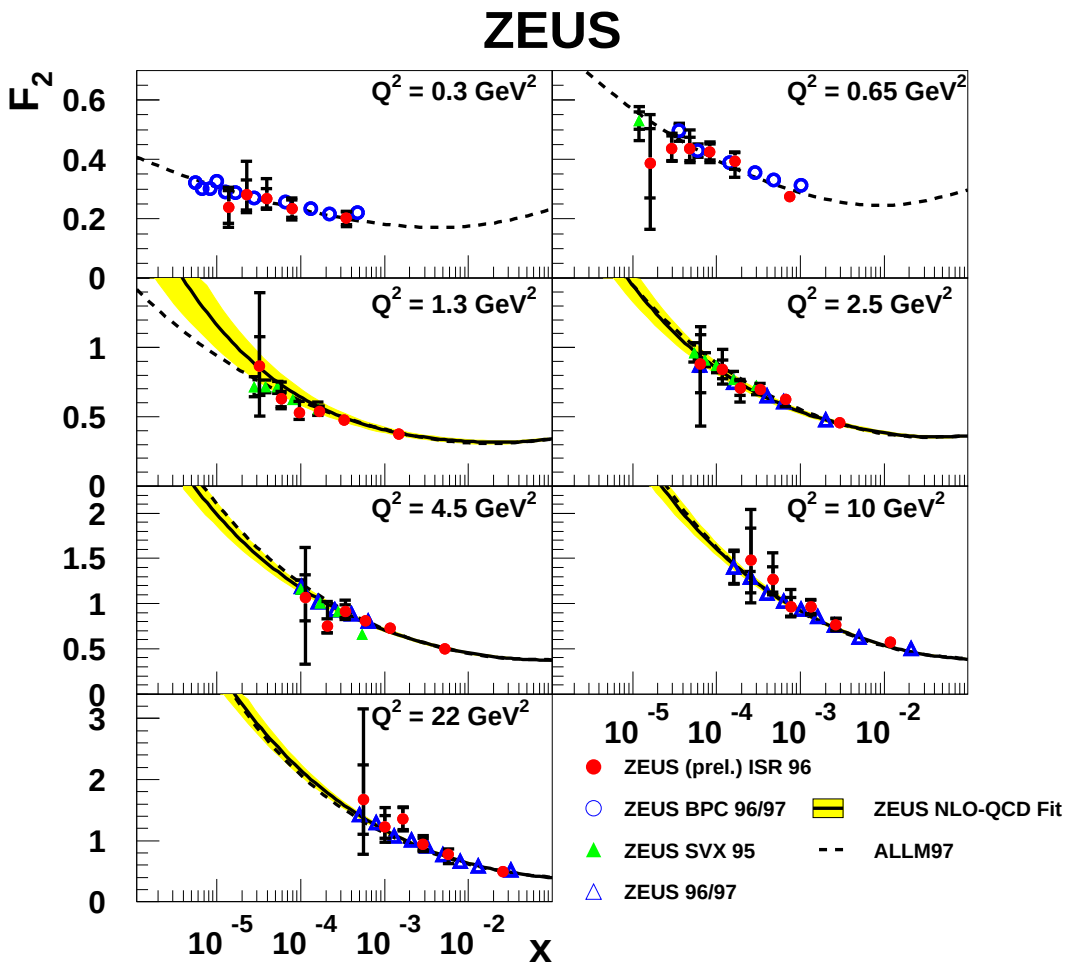
Reconstruction of ISR Events with the ZEUS Detector

- ▷ Detector-level comparisons for F_2
  - – Measured using sub-set of 1996 data (3.78 pb^{-1})
- ▷ Main source of background: bremsstrahlung overlays
  - – Normal DIS events +ep → epγ
- ▷ Estimated using mixture of:
  - – Data DIS events + admixture of photoproduction
  - – "Genuine" bremsstrahlung events
  - – normalise to "signal" sample for $\delta + 2E_\gamma > 62$ GeV
    - ▷ where $\delta = \Sigma_i(E - P_Z)_i$



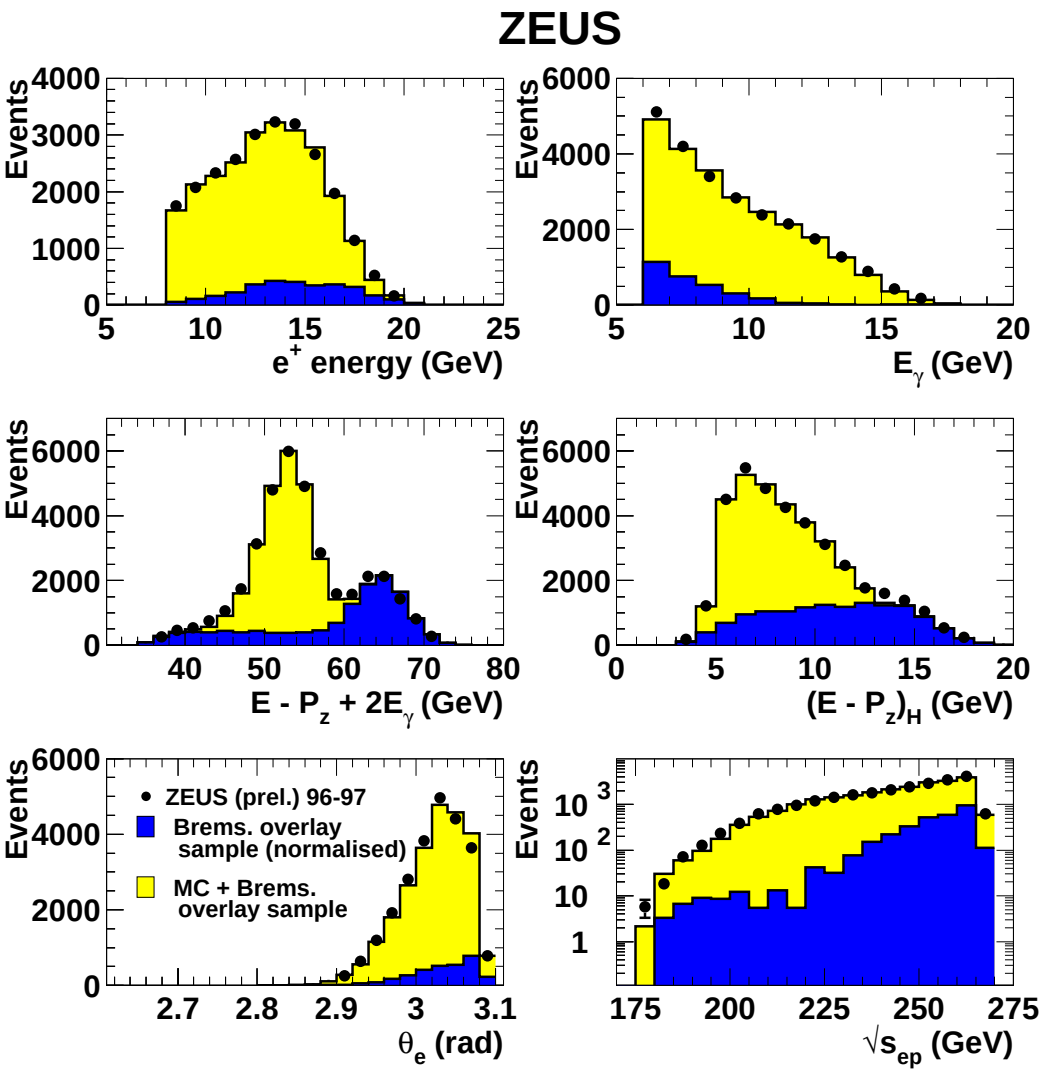
Measurement of $F_2(x, Q^2)$ using ISR Events

- Clear evidence for the rise of F_2 at low x
- Span region in Q^2 between 96/97 F_2 and BPC data
- In some regions, also reach higher x than previous measurements
- Consistent with ZEUS NLO-QCD fit
- ISR events well-understood
  - use to measure F_L



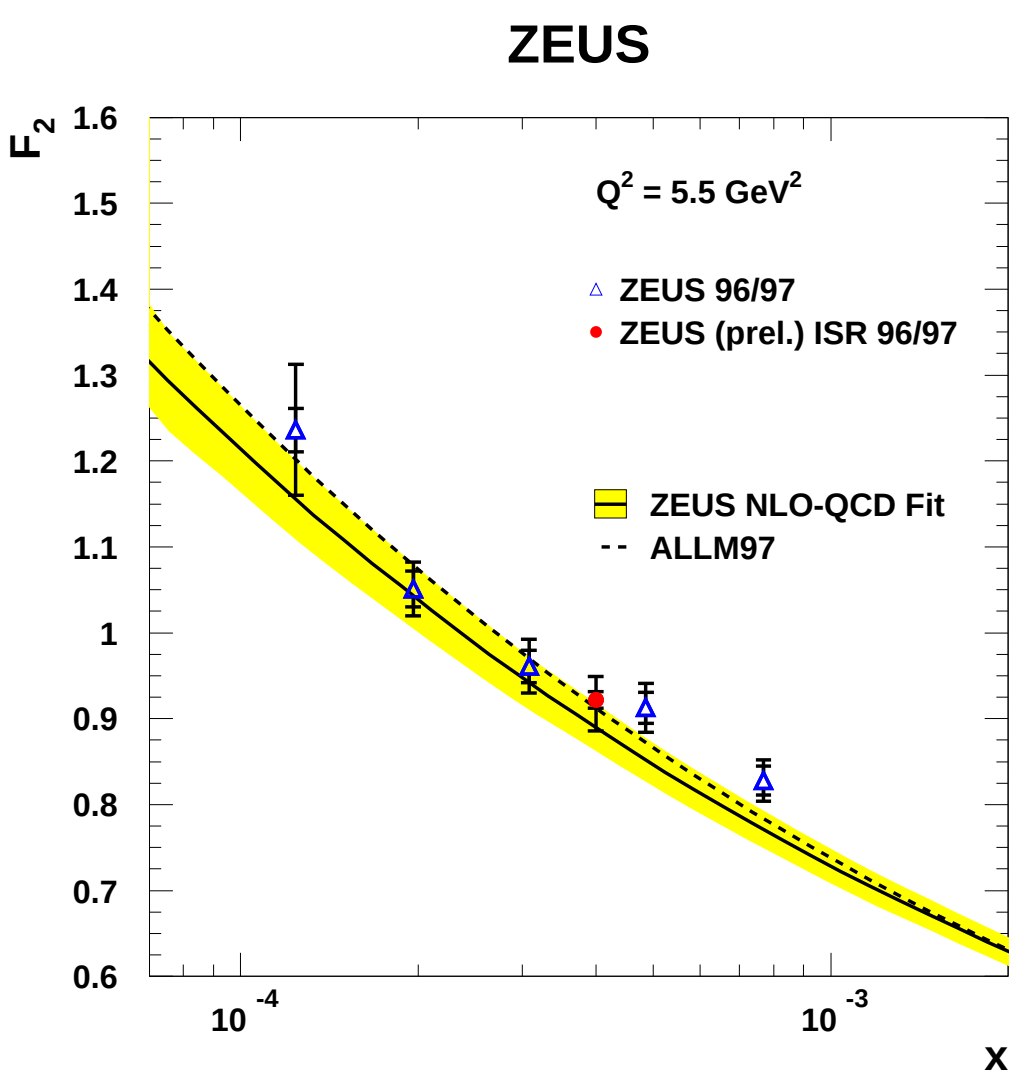
Measurement of $F_L(x, Q^2)$ using ISR Events

- Use 1996 + 1997 data: 35.9 pb^{-1}
- Estimation of bremsstrahlung overlays as before
- Data-MC agreement at detector-level is still reasonable
  - MC has $F_L = 0$
  - perfect agreement not essential



Measurement of $F_2(x, Q^2)$ from F_L Event Sample

- Need $F_2(x, Q^2)$ in order to measure F_L
- Measure in the region:
  - $1 < Q^2 < 30$ GeV^2
  - $0.11 < y_{HERA} < 0.23$
- Compare to published ZEUS values:
  - Agreement is good
  - Further consistency check for data



How to measure F_L using ISR Events

▷ **Re-write double-differential cross section for e^+p scattering as:**

$$\frac{d^2\sigma}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} Y_+ \left(\frac{1+\epsilon R}{1+R}\right) F_2 = \frac{2\pi\alpha^2}{xQ^4} Y_+ \left[F_2 - (1-\epsilon)F_L\right]$$

▷ **where:**

- ▷ $Y_+ = 1 + (1-y)^2$
- ▷ $\epsilon = \frac{2(1-y)}{1+(1-y)^2}$
- ▷ $R = \frac{\sigma_L}{\sigma_T} = \frac{F_L}{F_2 - F_L}$

▷ **Define quantity:**

$$\delta_{F_L} = \frac{1+\epsilon R}{1+R}$$

▷ **Describes shape of cross section as a function of y**

▷ **Effect of F_L only visible at high y**

▷ **Rewrite δ_{F_L} as:**

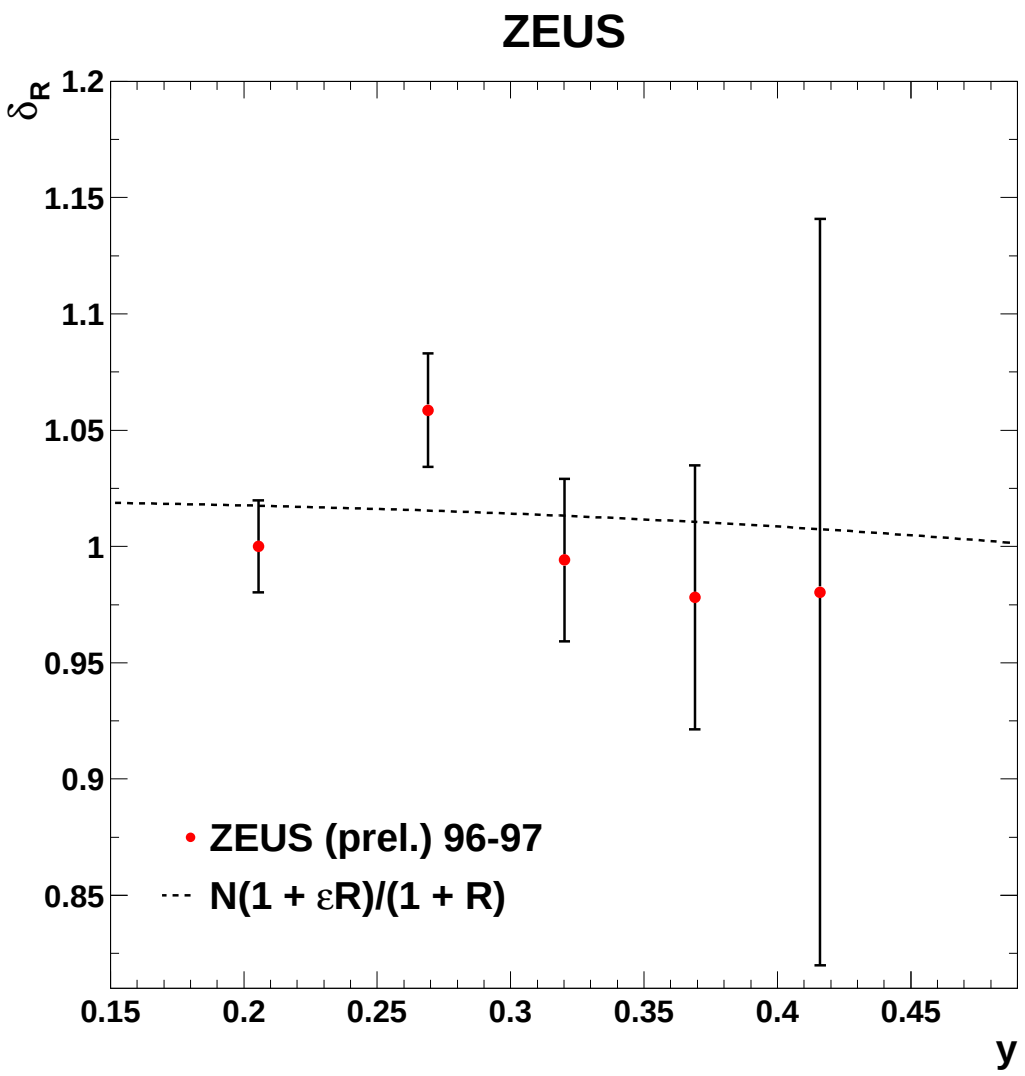
$$\delta_{F_L} = \frac{F_2 - (1-\epsilon)\cdot F_L}{F_2} \equiv \frac{\sigma(F_L \neq 0)}{\sigma(F_L = 0)}$$

▷ **Use δ_{F_L} to determine F_L ...**

Measuring $F_L(x, Q^2)$ using ISR Events

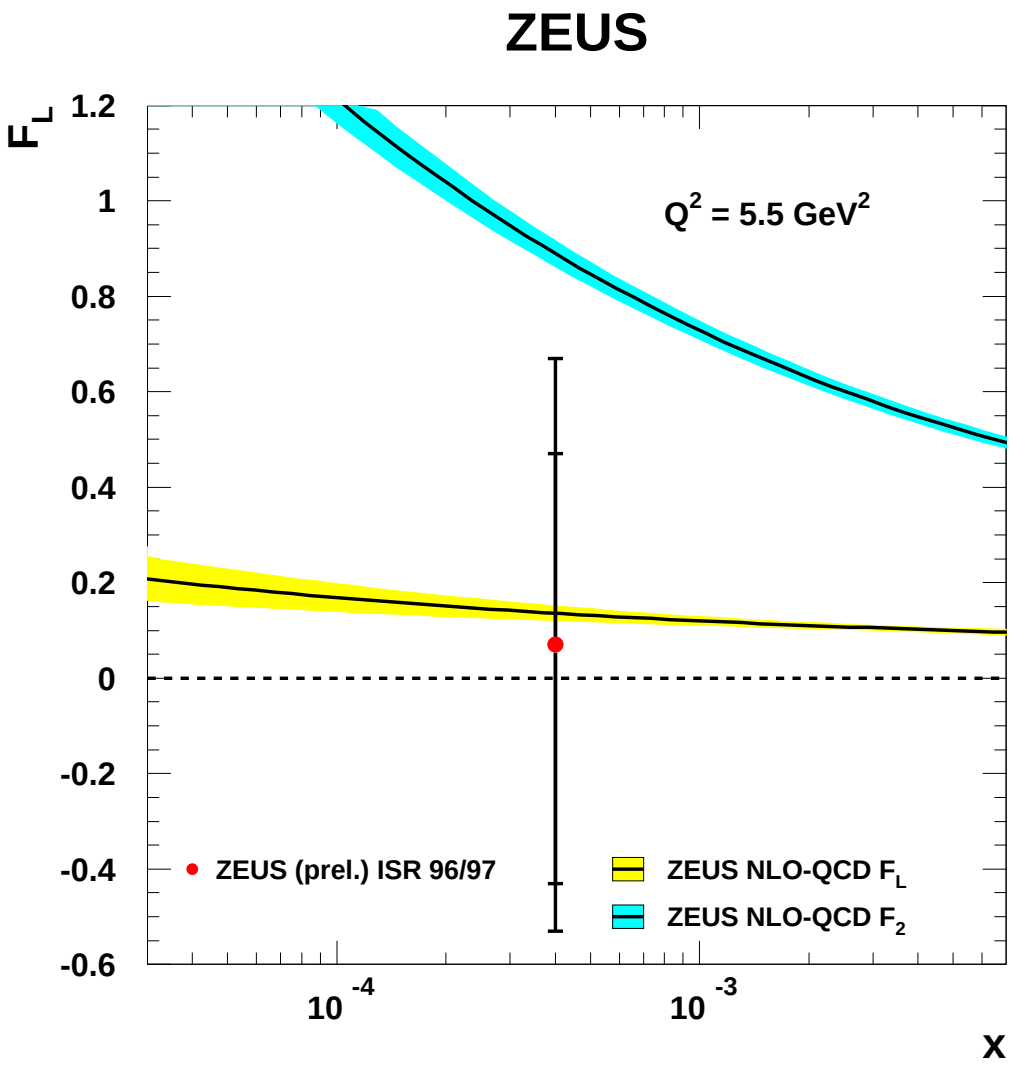
- Measure ratio $\delta_R = \frac{N_{data}}{N_{MC,F_L=0}}$ versus y at detector level
- Shape of y distribution in data and MC determined by σ^{ep}

  $\Rightarrow \delta_R \propto \delta_{F_L}$
- Fit δ_R versus y using
  - $N_{fit} \cdot \delta_{F_L}$
- $\epsilon \rightarrow \epsilon_s = \frac{2(1-S_y y)}{1+(1-S_y y)^2}$
  - S_y = correction factor determined from MC studies
- N_{fit}, F_L free parameters of fit
- Fix σ at measured value



Measurement of $F_L(x, Q^2)$ using ISR Events

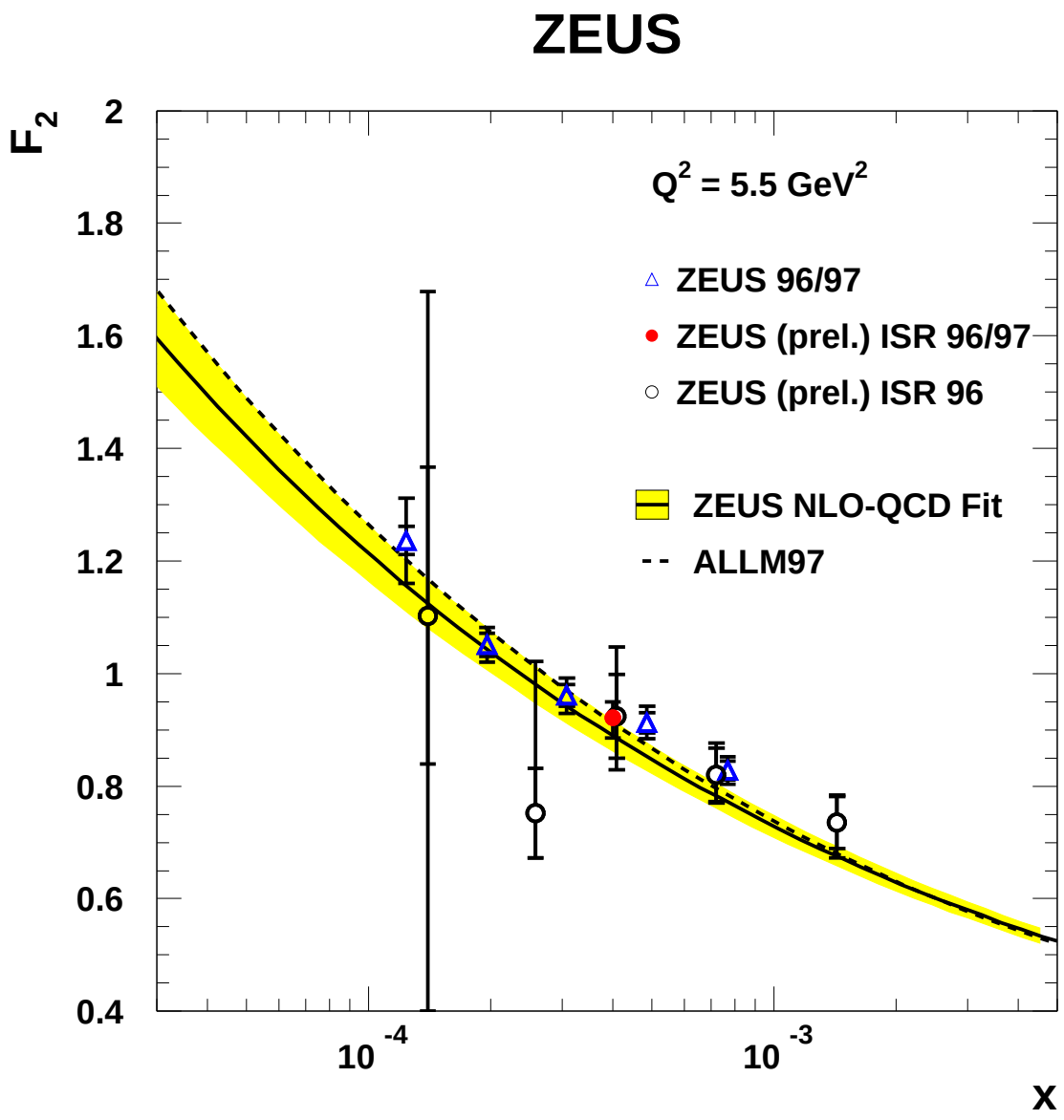
- First direct measurement of F_L at HERA !
- Errors are large, but prefer small value of F_L
- Consistent with F_L predicted by pQCD
  - Nothing really crazy going on ...



Conclusions & Outlook

- **Structure function measurements have been made by ZEUS using ISR events**
- **Measurement of F_2:**
  - **New measurements in previously unexplored region**
  - **consistent results with previously published results**
  - **ISR events are well-understood**
- **Measurement of F_L:**
  - **First ever direct measurement of F_L at HERA !**
  - **Currently not statistically precise, but ...**
    - **Consistent with NLO-QCD**
    - **Proves that ISR events can be used to measure F_L**
- **Several possible improvements in the pipeline**
- **For precision measurement, would need reduced E_p running**

Comparison of F_2 measurements



Comparison of F_L measurement with H1 extraction