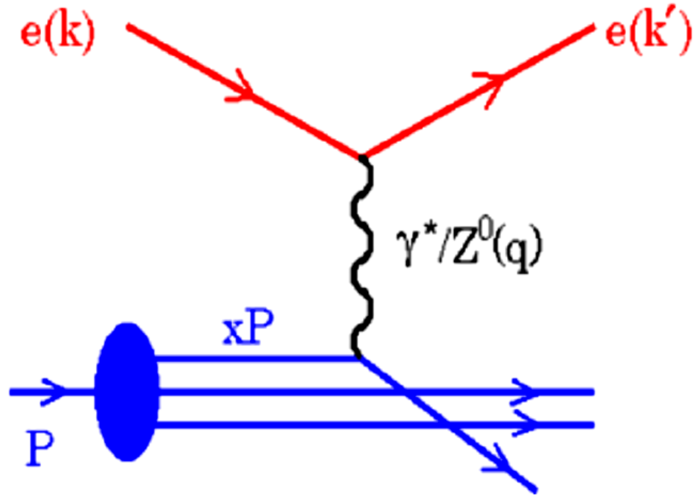
Measurement of F_L at HERA

S. Glazov, DESY, Ringberg 2008

DIS kinematics



Kinematics of inclusive scattering is determined by Q^2 and Bjorken x.
In x “scale parameter” 1/3 - equal sharing among quarks. Proton structure for

- $x \geq 0.05$ — valence quarks
- $x \leq 0.05$ — coupled quark-gluon QCD evolution. Large gluon density.

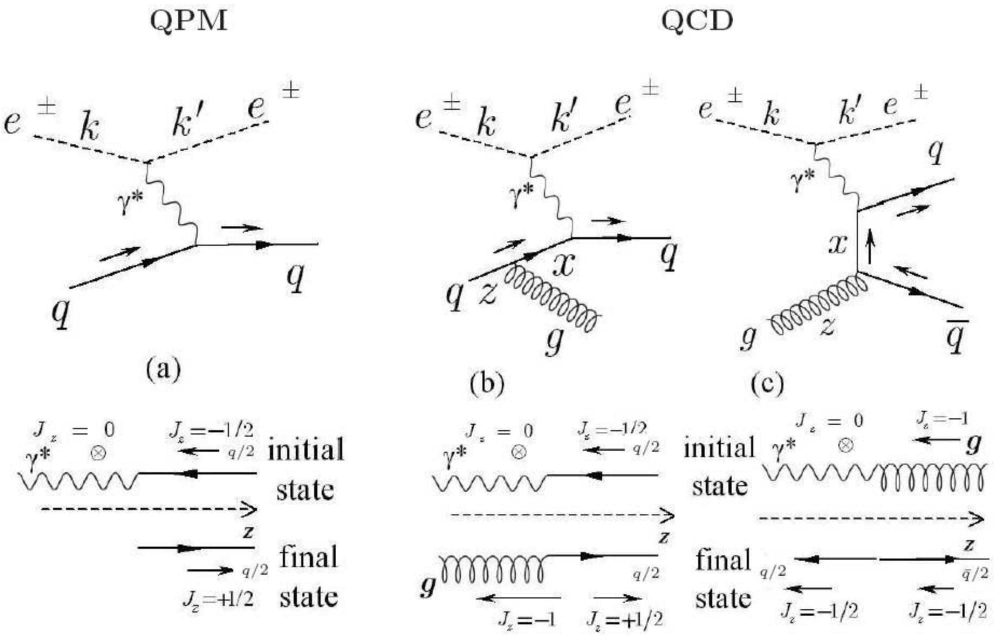
At small x complex dynamics which must obey simple asymptotic solutions (unitarity).

For low Q^2, inclusive cross section is described by two structure functions:

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

where factors $Y_+ = 1 + (1-y)^2$ and y^2 define polarization of the exchanged photon and $y = Q^2/(sx)$.

The Proton Structure Functions at low Q^2



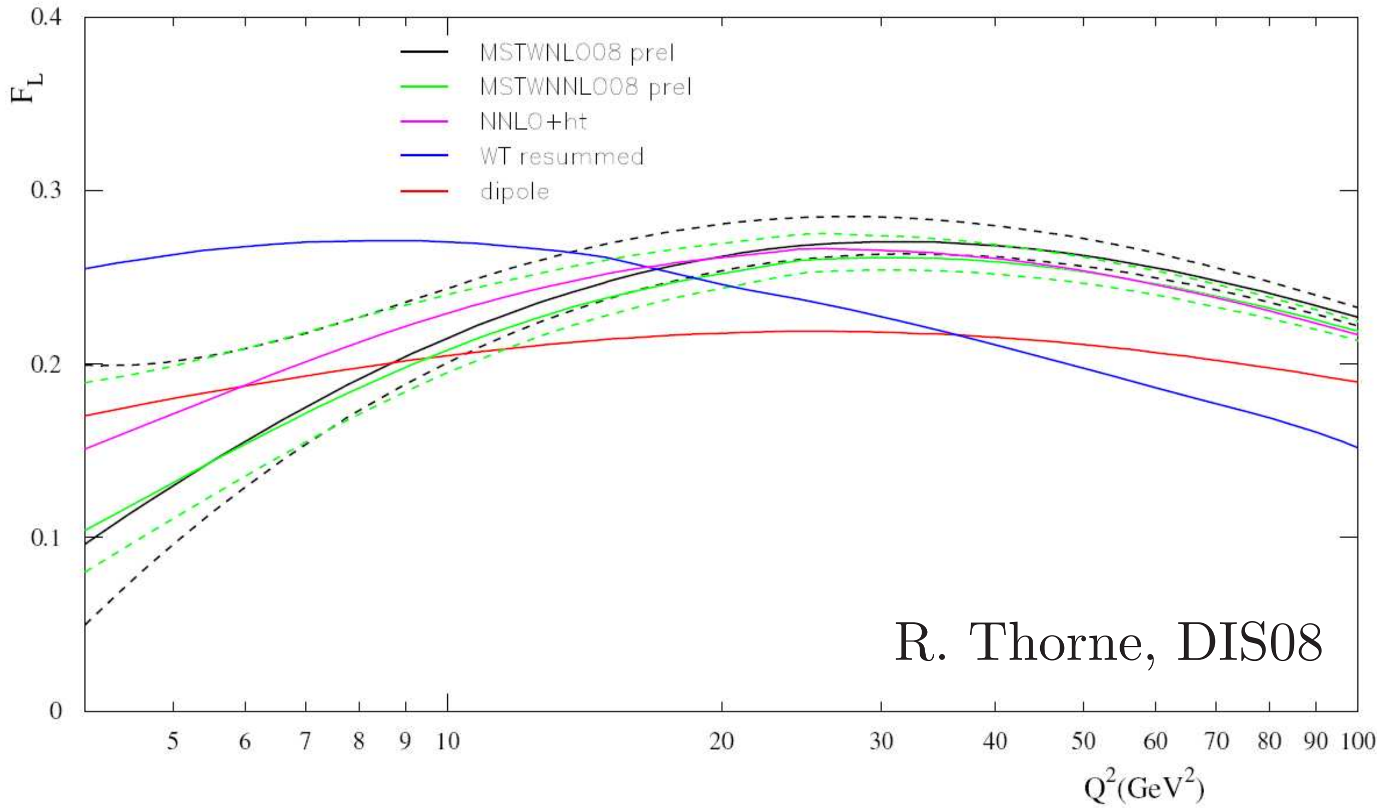
For low Q^2:

$$F_2 \sim \sigma_L + \sigma_T \qquad F_L \sim \sigma_L$$

which implies $0 \leq F_L \leq F_2$.

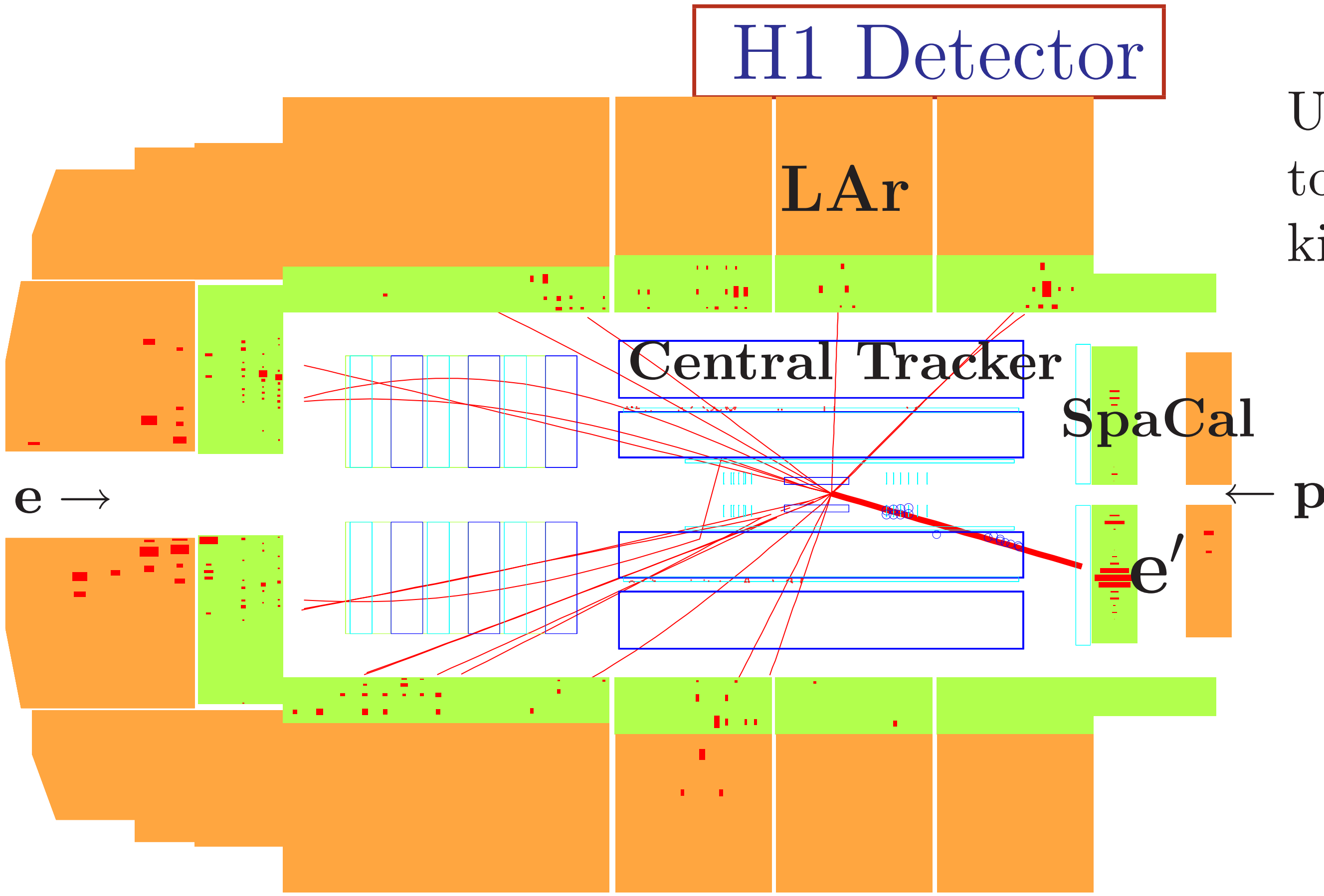
- In Quark-Parton Model $F_L = 0$ for spin $1/2$ quarks.
- In QCD, $F_L > 0$ due to gluon radiation.
- At low x, sea quark and gluon density are measured using F_2 and its scaling violation, $\mathrm{d}F_2/\mathrm{d}\log Q^2$.
  F_L measures gluon via cross section polarization decomposition.

F_L at low x and low Q^2



Significant spread of predictions for low Q^2 and low $x = Q^2/(Sy)$

- Large higher order perturbative corrections.
- Small x resummation.
- Higher twist effects.



Use the scattered electron to reconstruct event kinematics

$$Q^2 = 4E_eE'_e\cos^2\frac{\theta_e}{2}$$

$$y = 1 - \frac{E'_e}{E_e}\sin^2\frac{\theta_e}{2}$$

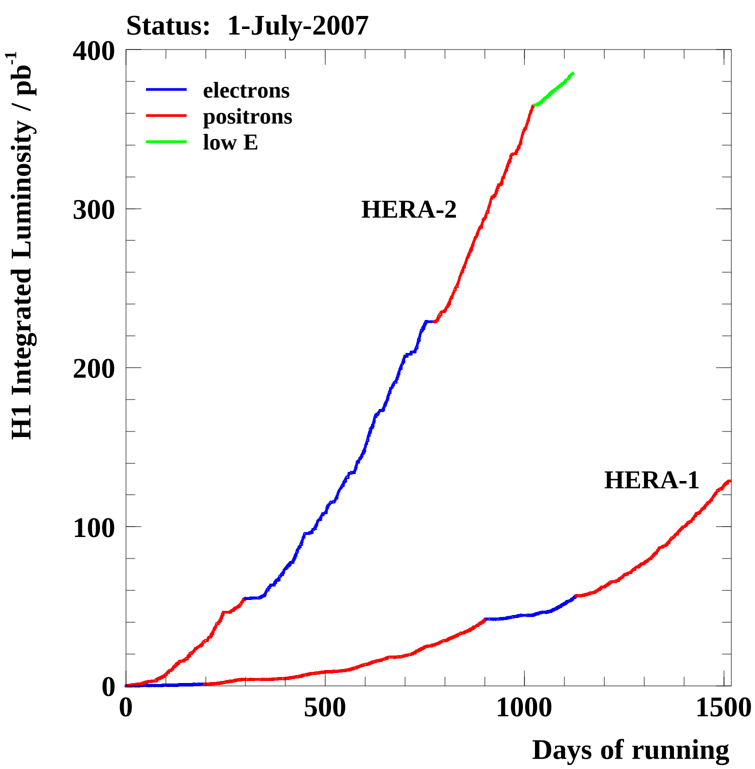
$$x = \frac{Q^2}{Sy}$$

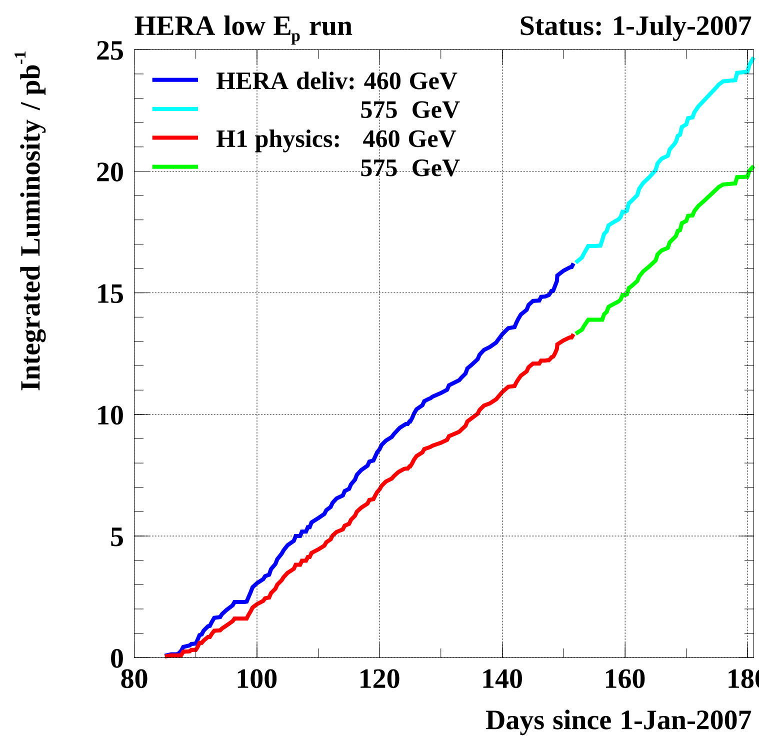
- **H1 Medium Q^2**, $12 \leq Q^2 \leq 90$ GeV^2, SpaCal+CT (DESY-08-053)
- **H1 High Q^2**, $35 \leq Q^2 \leq 800$ GeV^2, LAr + CT (H1 preliminary).
- **ZEUS**, $24 \leq Q^2 \leq 110$ GeV^2, CTD+CAL (ZEUS preliminary)

Measurement Strategy

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

- Measure at the same x, Q^2, different y — use different E_p
- Increase sensitivity by using largest spread in $f(y) = y^2/(1 + (1-y)^2)$: $E_p^{max}/E_p^{min} \to$ max, $y \to 1$.





High y Experimental Challenge

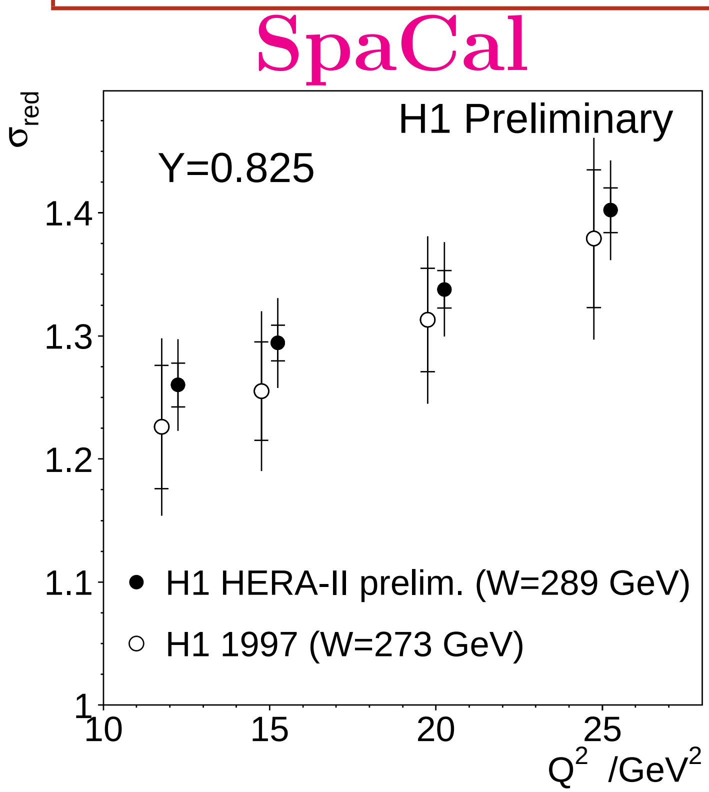
Measurement at both low $y > 0.1$ and high $y < 0.9$ are required. High y is much more difficult.

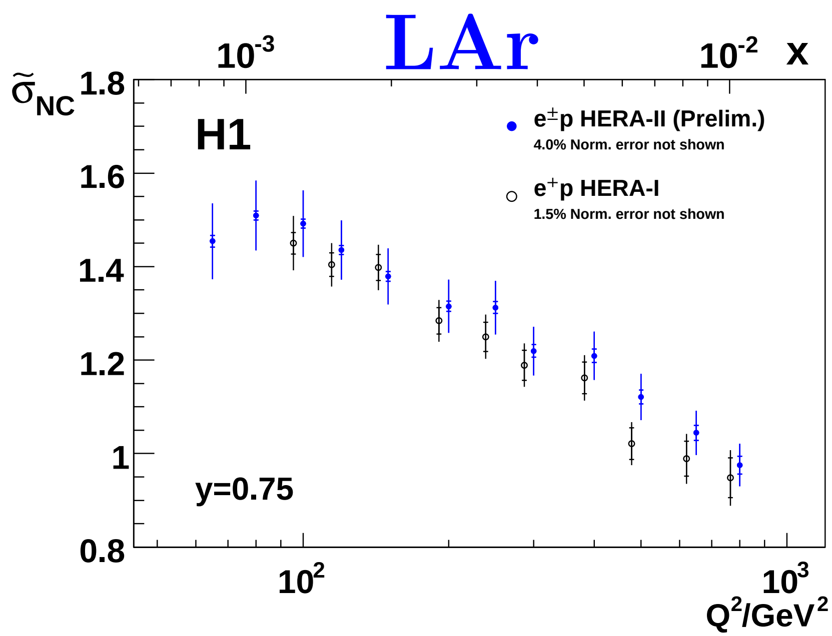
$$y \approx 1 - \frac{E'_e}{E_e}$$

Measurement extends down to $E'_e = 3$ GeV.

- Trigger efficiency/rate
- Electron identification
- Background
- Radiative corrections

Previous H1 High y σ_r Measurements

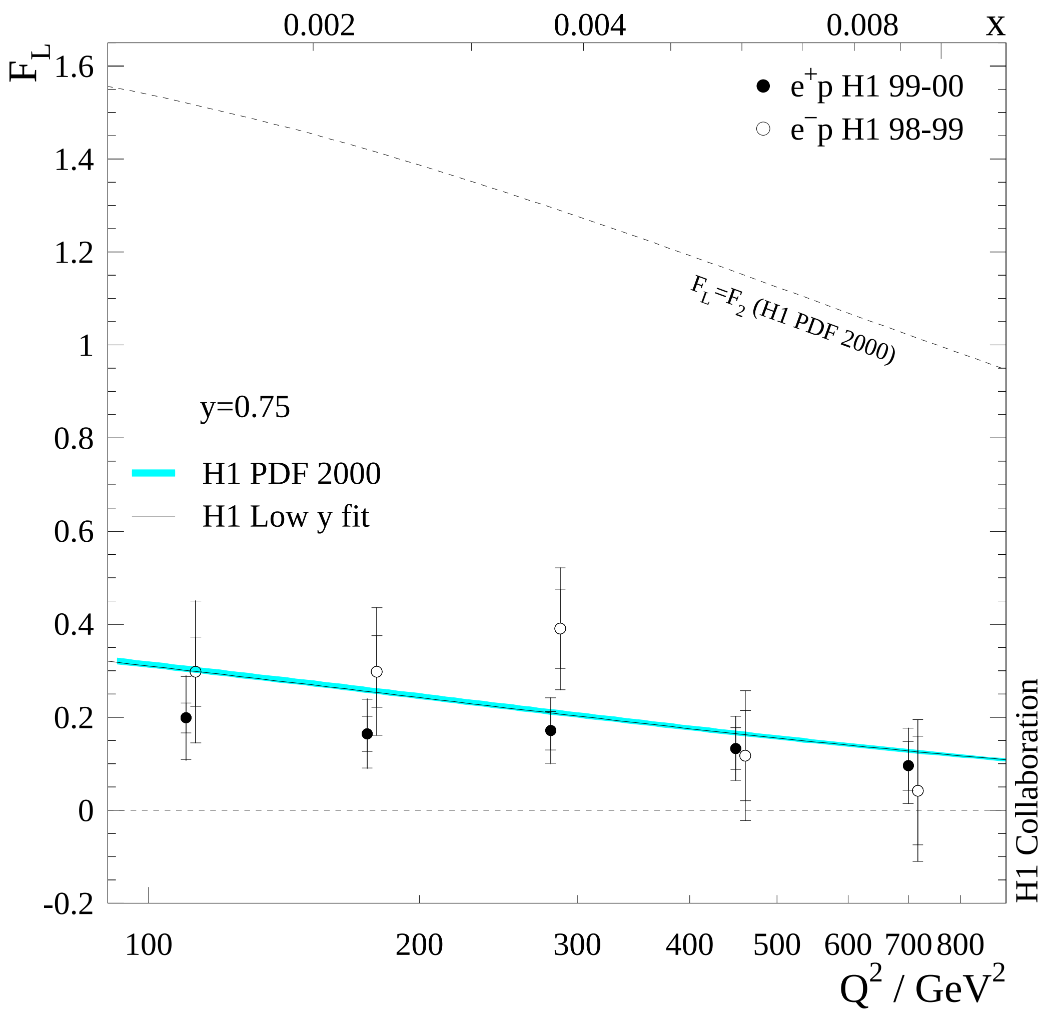




- H1 has already analyzed high y data in both SpaCal and LAr calorimeters.
- HERA-II data allows to reduce errors, due to large e^+ and e^- samples.

For LAr sample, low energy cut was at $E'_e > 5$ GeV.

Consistency check: H1 F_L determination at high Q^2



Determination of F_L as

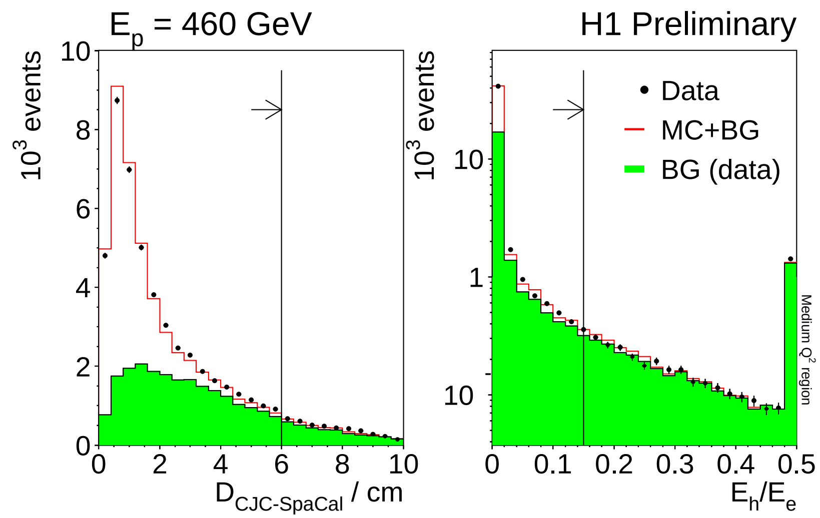
$$F_L = \frac{Y_+}{y^2}\left(F_2^{fit} - \sigma_r\right)$$

Use QCD fit to obtaine F_2^{fit}.

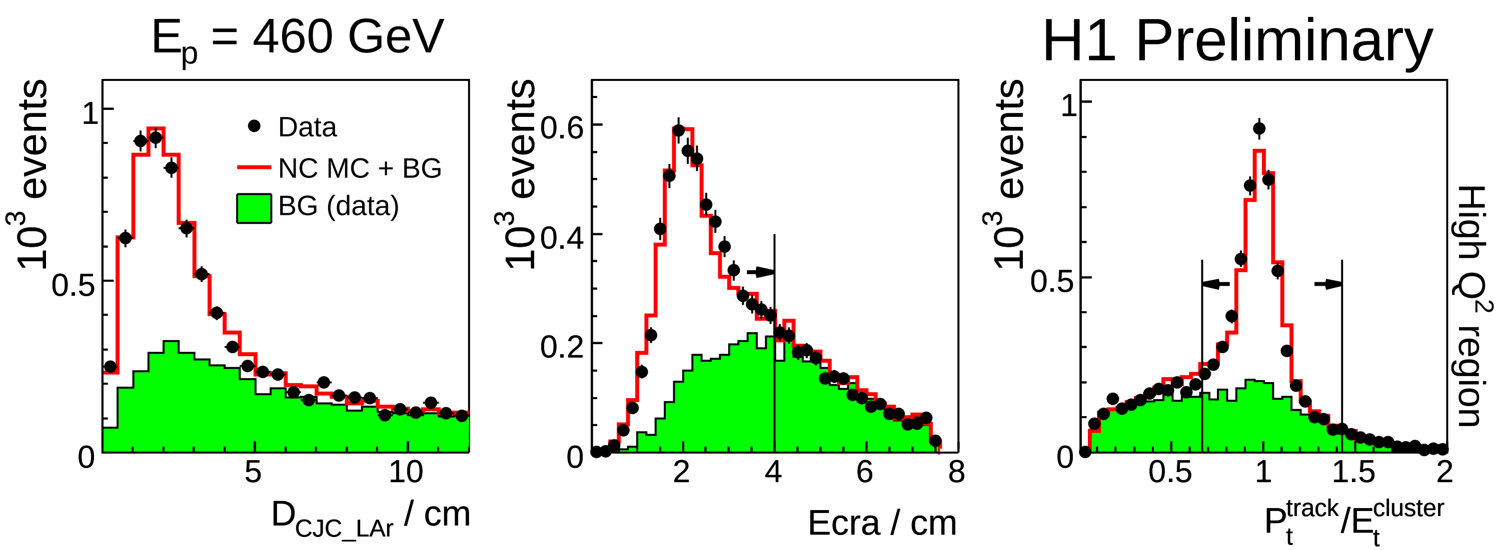
Consistency check of gluon determined from F_2 scaling violation vs X-section decrease at high y.

Electron Identification at High y

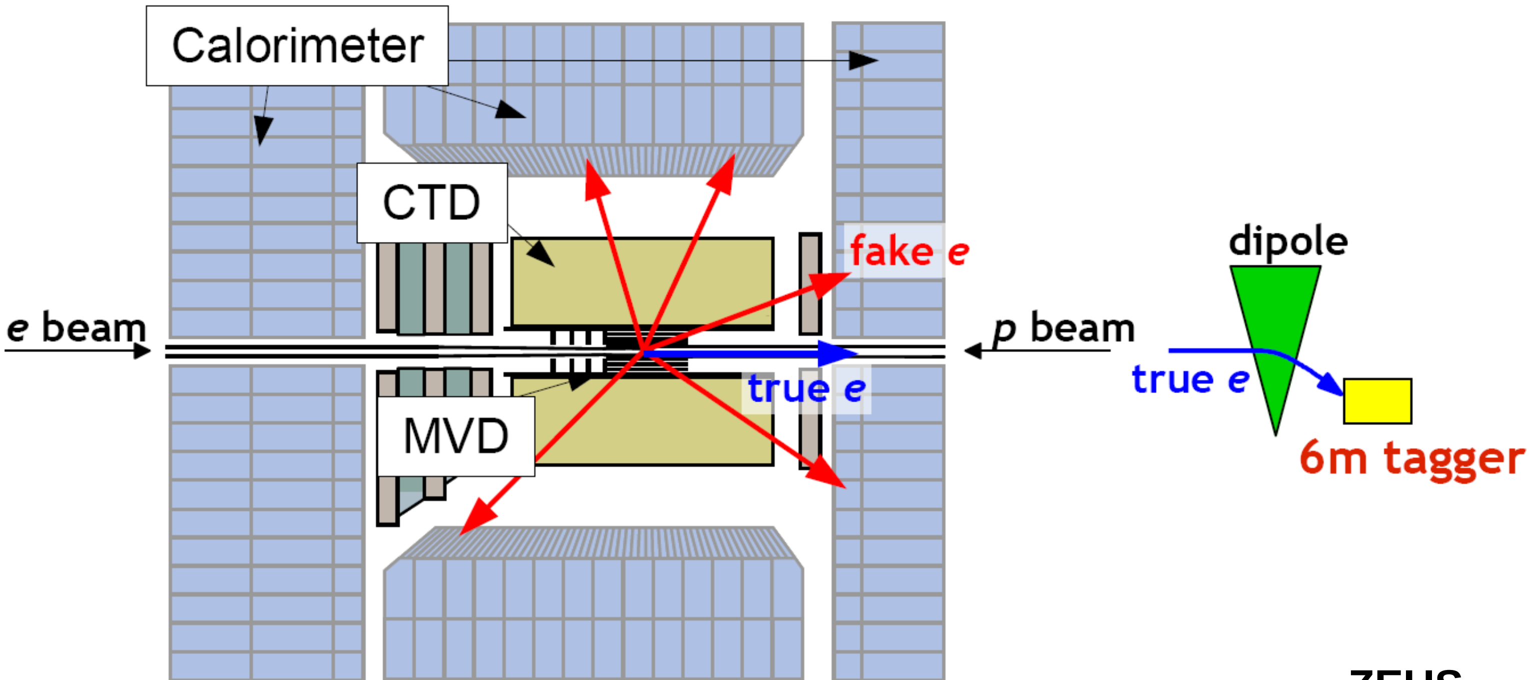
- High efficiency with significant reduction of background.
- Cluster transverse/longitudinal shape requirements.
- Cluster-track geometric matching — to reduce/estimate background directly from data



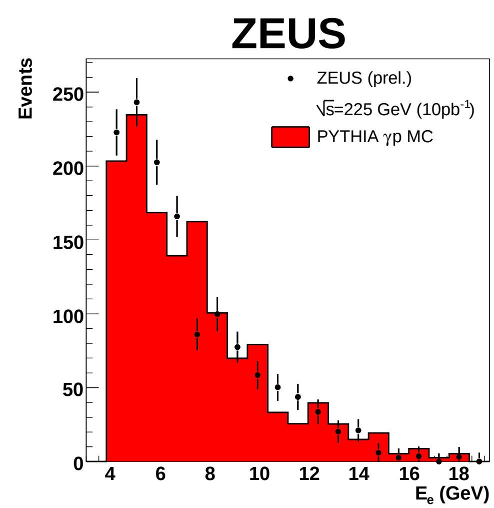
Additionally for H1-LAr sample and $E_e < 6$ GeV require $p_t^{track}/E_t^{cluster}$ kinematic match.



ZEUS background estimation



- MC simulation for photoproduction background.
- Use events with the true scattered e detected in 6m tagger (tagged) to normalize/check.

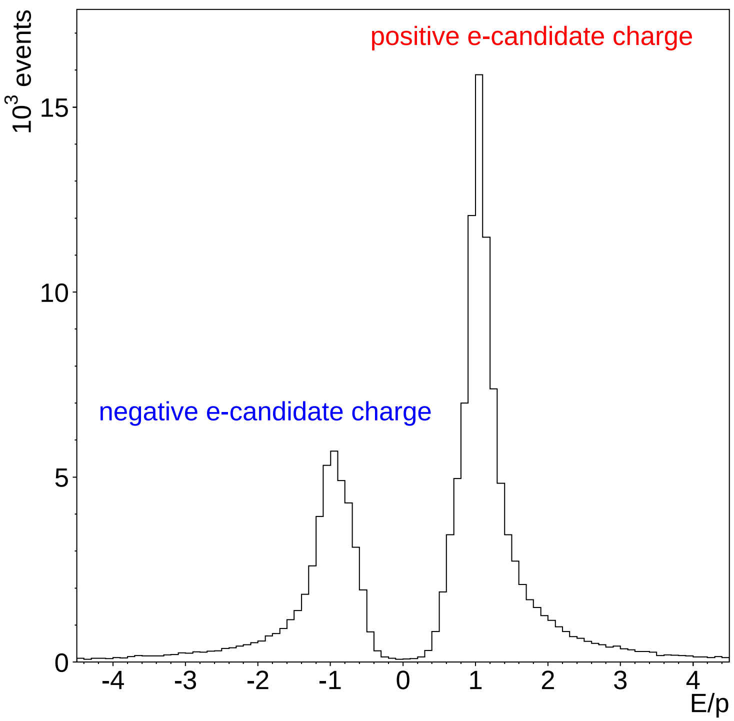


H1 Background Estimation

e^+p scattering:

- $+$ Scattered lepton has the beam charge (positive).
- $-$ Background from hadronic particles, γ conversions is almost charge symmetric: $N_{bg}^+ \approx N_{bg}^-$

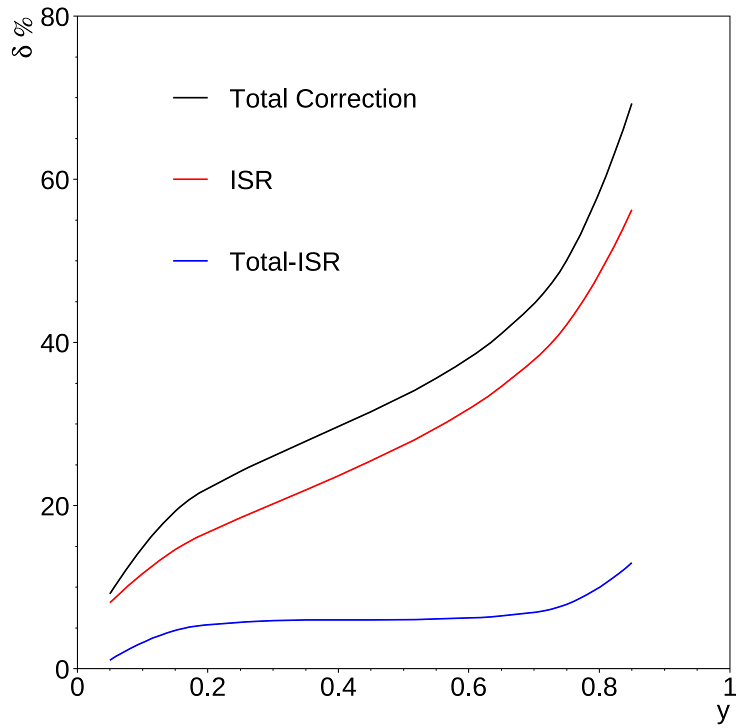
$\rightarrow$ require positive charge for the signal sample. Estimate remaining background using negative sample.



Background charge asymmetry is measured by comparing e^+p, e^-p samples and using tagged photoproduction events.

Radiative Corrections

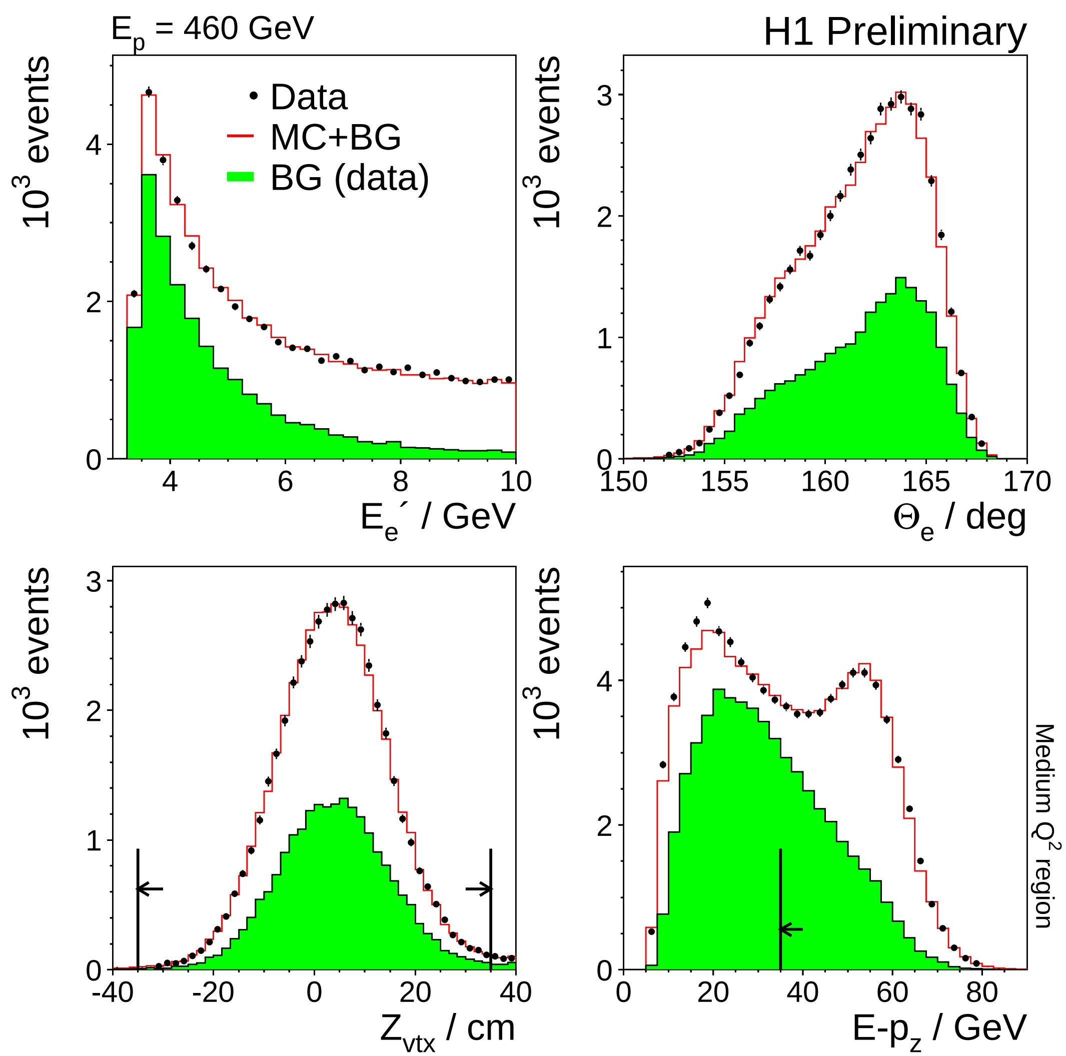
- Radiative corrections are large at high y, $\delta = \frac{\sigma_{\text{total}}}{\sigma_{\text{born}}} - 1 > 50\%$.
- Simulated in DJANGO MC, checked with HECTOR program.
- Mostly from initial state radiation (ISR) - radiative return to low y and low Q^2 ($\sigma \sim 1/y$ and $\sigma \sim 1/Q^4$).



Remove/check ISR radiation using the measured lepton beam energy:

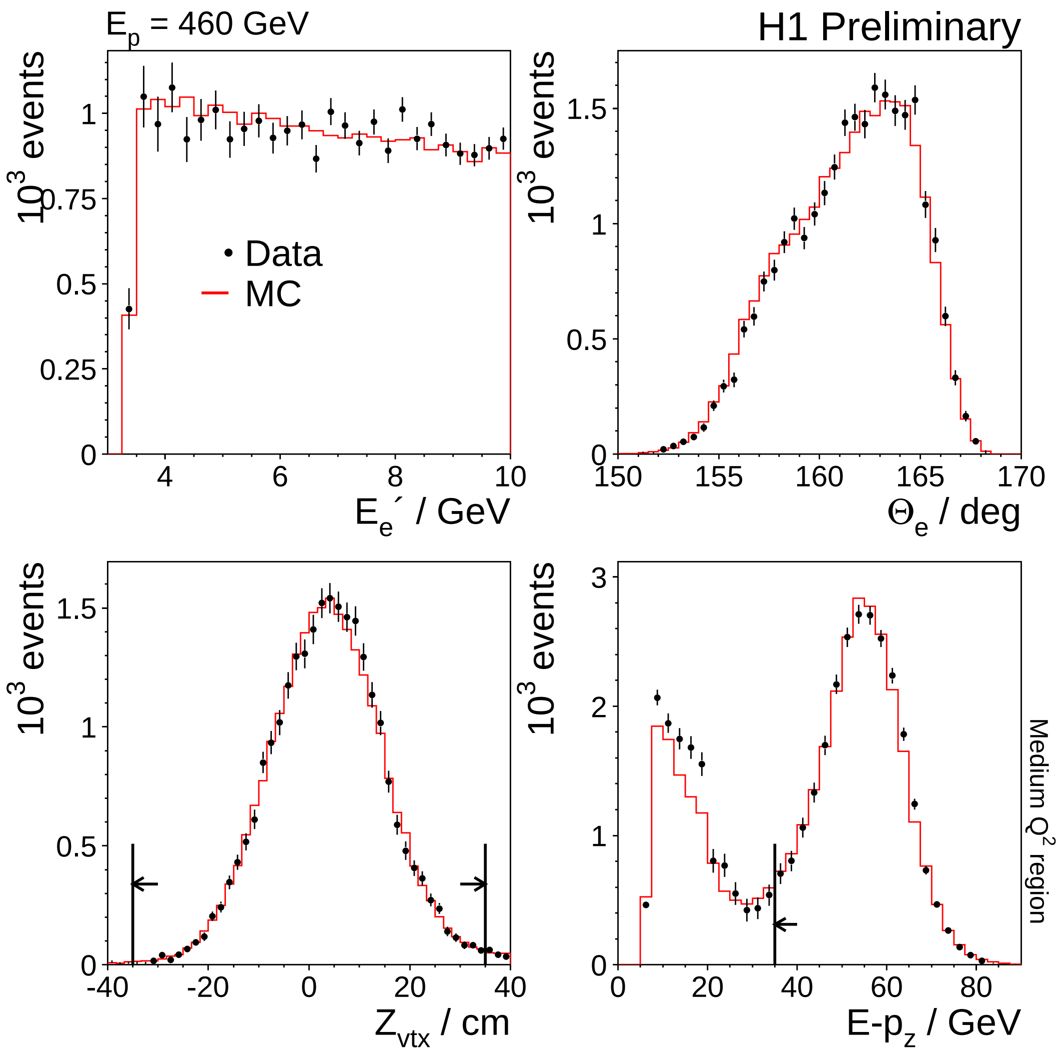
$$2E_e \approx E{-}p_Z|_{in} = E{-}p_Z|_{out} = \sum_h (E^h - p_Z^h) + \sum_e (E^e - p_Z^e) \equiv E{-}p_Z$$

Control plots: High y medium Q^2 (H1 SpaCal)



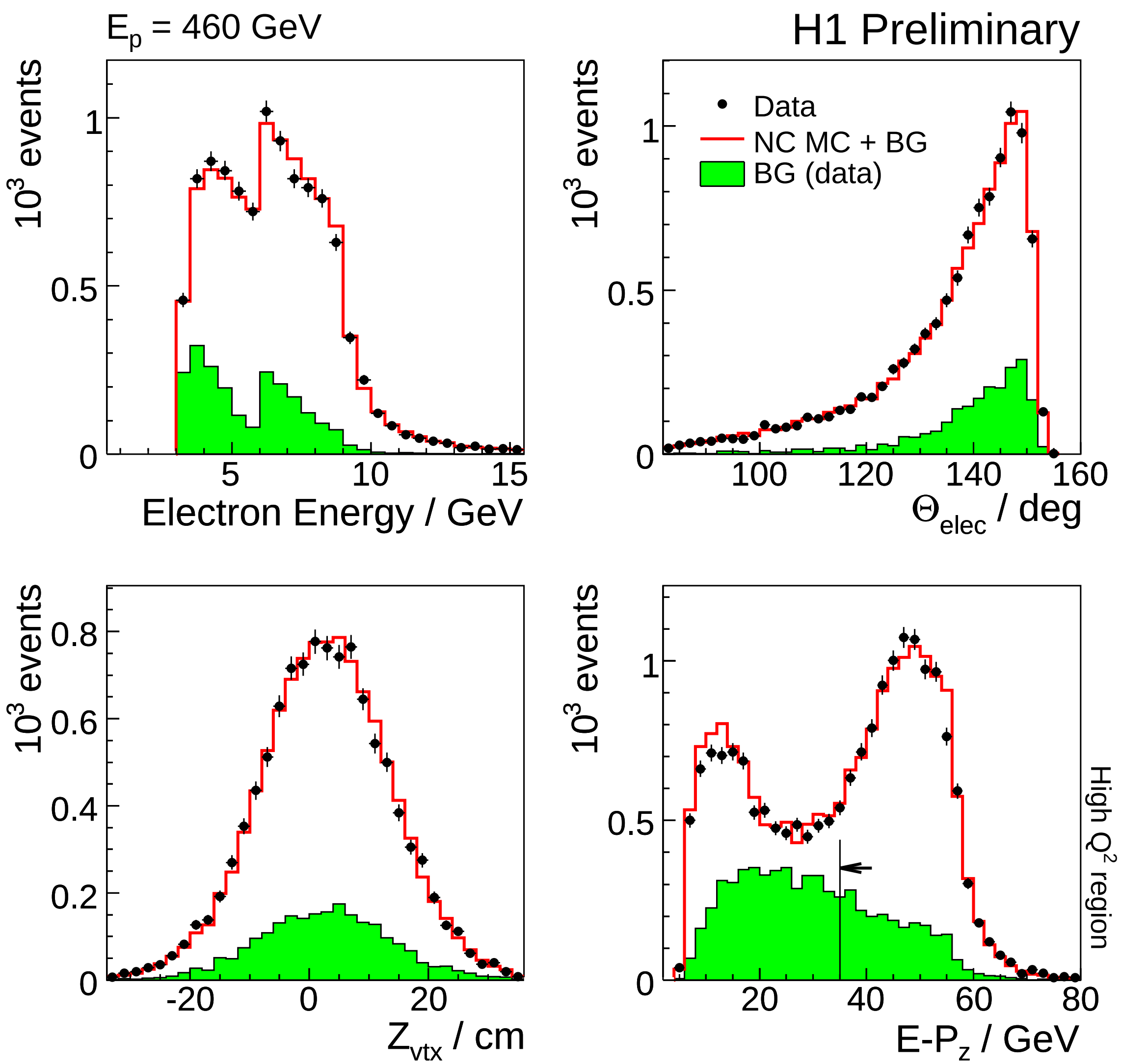
- Before background subtraction
- $E_p = 460$ GeV
- $E_e' > 3.4$ GeV.
- Lines indicate cut values
- $E - p_z$ is effective against background

Control plots: High y medium Q^2 (H1 SpaCal)



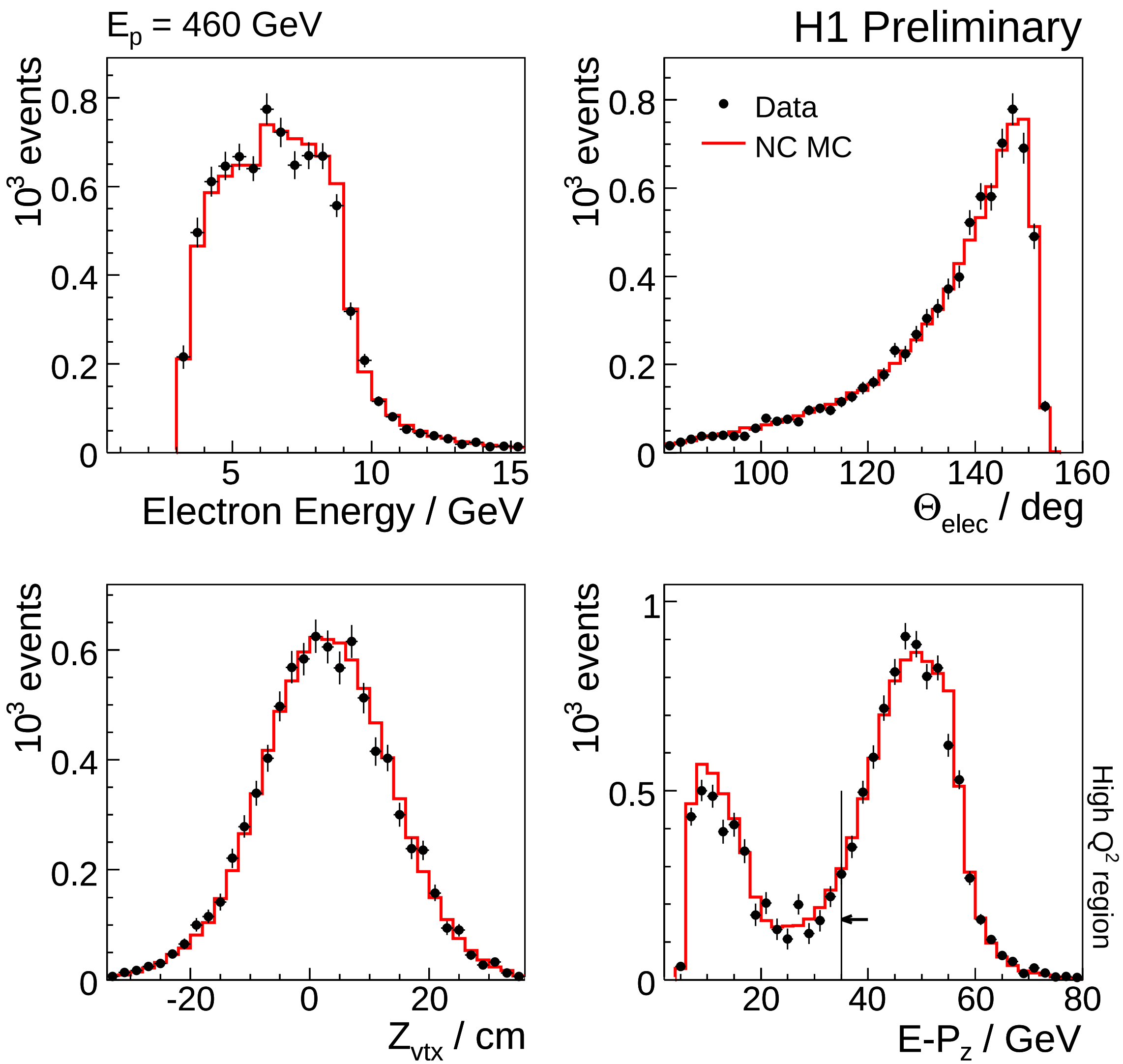
- After background subtraction
- $E_p = 460$ GeV
- $E_e' > 3.4$ GeV.
- Lines indicate cut values
- $E - p_z$ is effective against ISR radiation

Control plots: High y high Q^2 (H1 LAr)



- Before background subtraction
- $E_p = 460$ GeV
- $E'_e > 3$ GeV.
- Additional cuts at $E > 6$ GeV introduce step
- $E - p_z$ is also well described

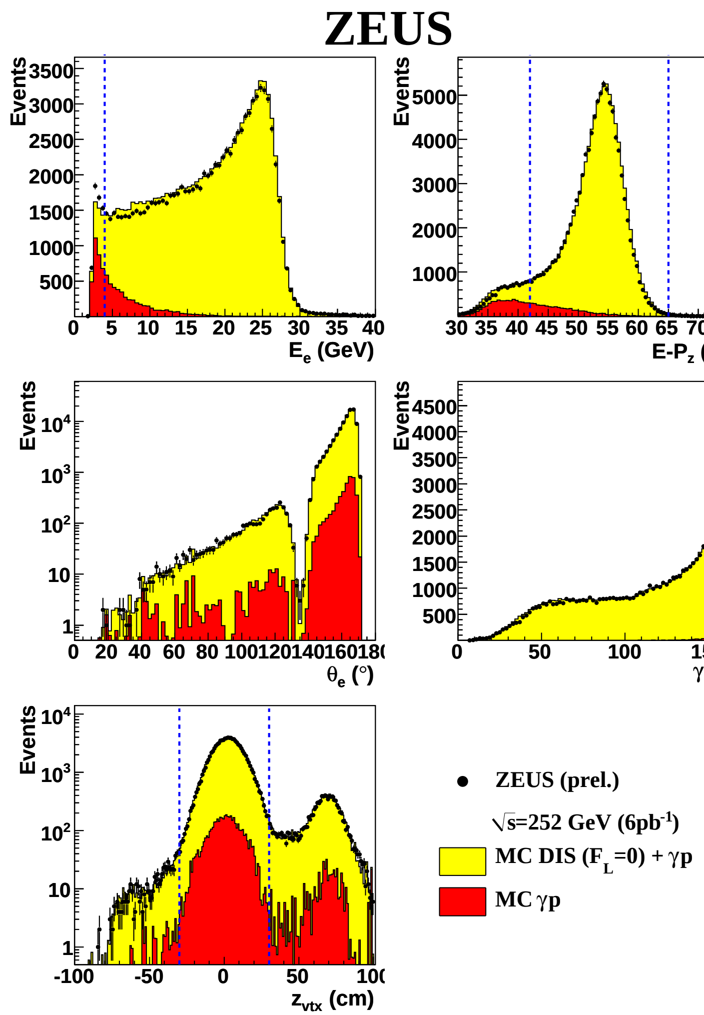
Control plots: High y high Q^2 (H1 LAr)



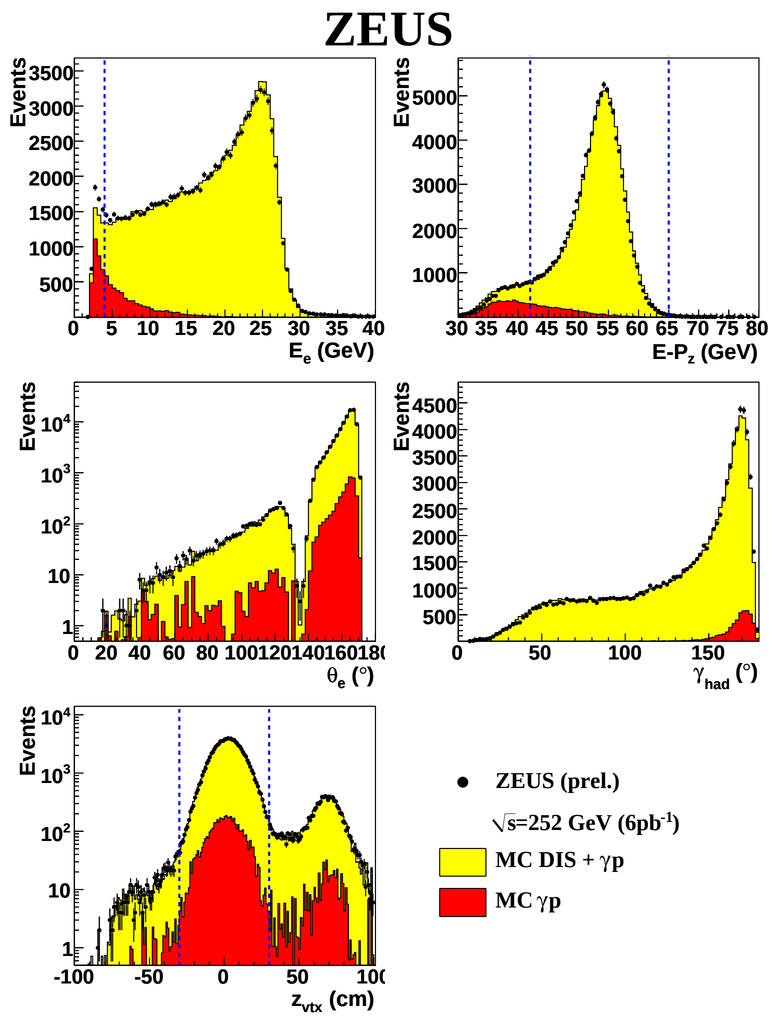
- After background subtraction
- $E_p = 460$ GeV
- $E_e' > 3$ GeV.
- Additional cuts at $E > 6$ GeV introduce step

$\longrightarrow$ Good description of data by MC.

Control plots: ZEUS $E_p = 575$



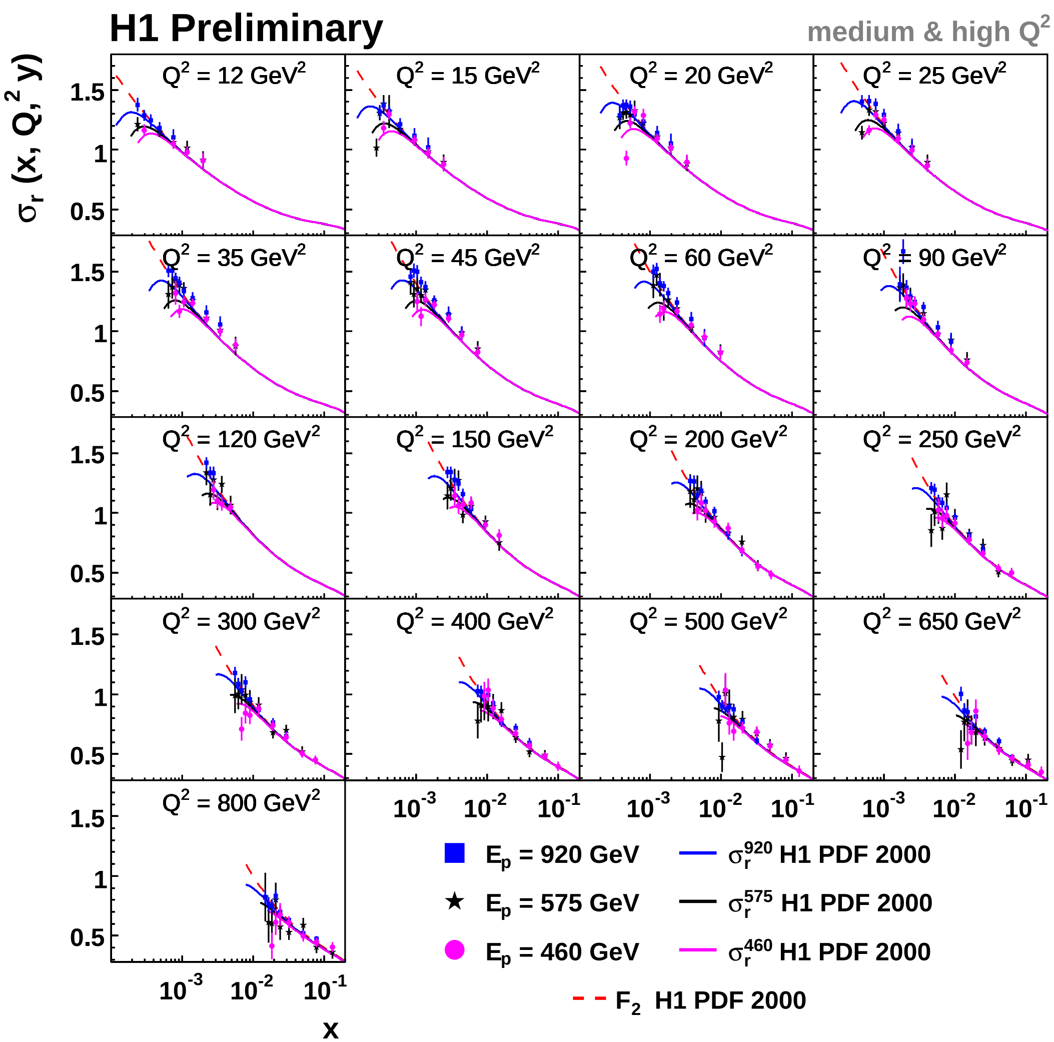
MC uses $F_L = 0$



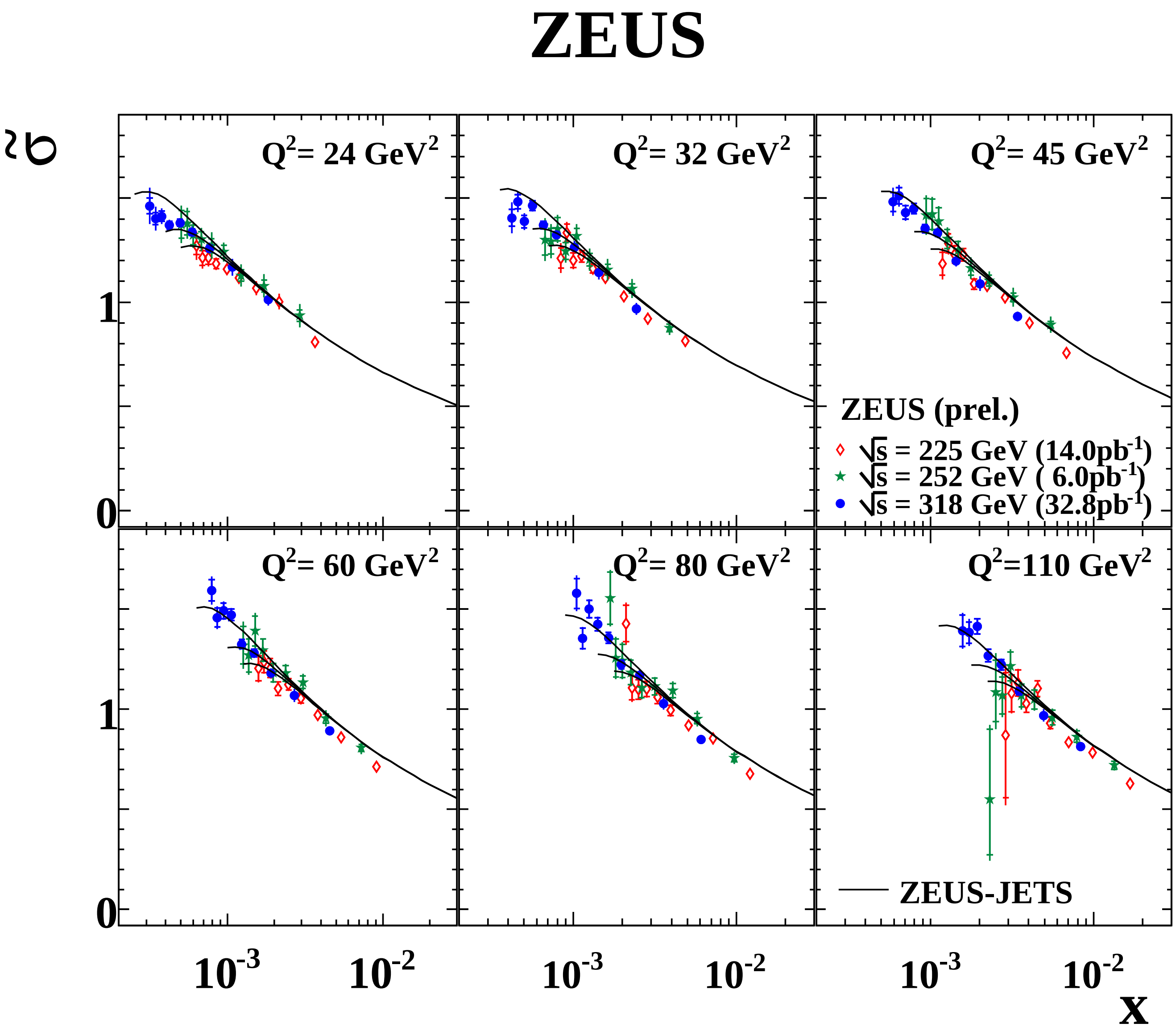
MC reweighted using $F_L = F_{QCD}$

H1 σ_r for $E_P = 460, 575$ and 920 GeV

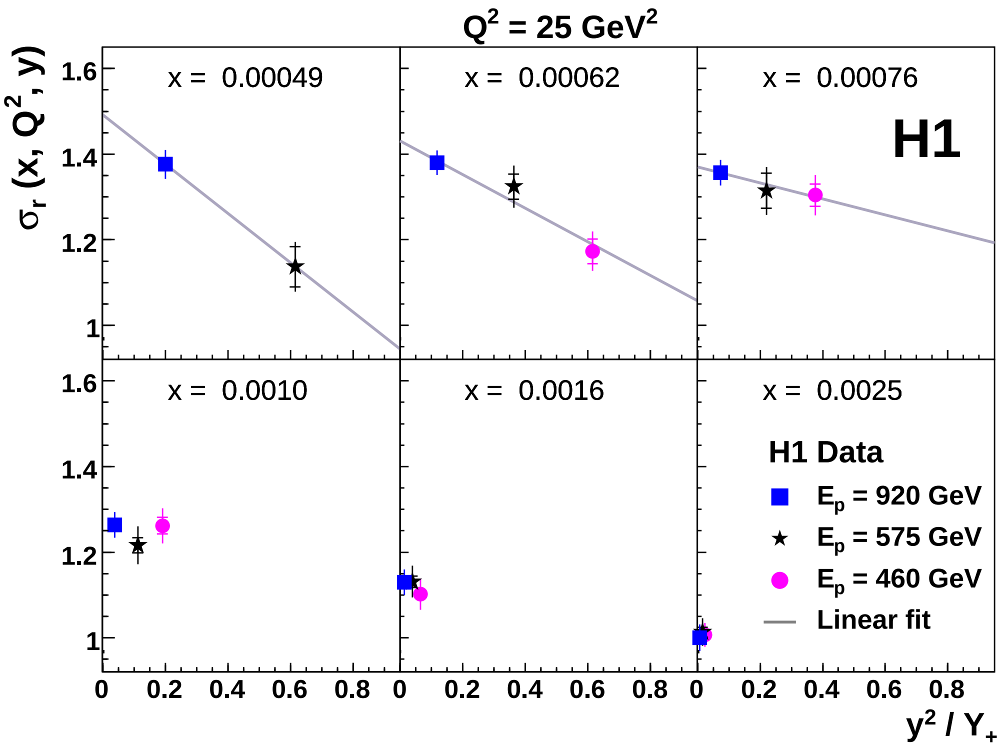
- For (almost) each Q^2, x measurements at three E_p.
- Mix of SpaCal and LAr data
- Turn over of the cross section from F_2 is due to F_L



ZEUS σ_r for $E_P = 460, 575$ and 920 GeV



F_L extraction

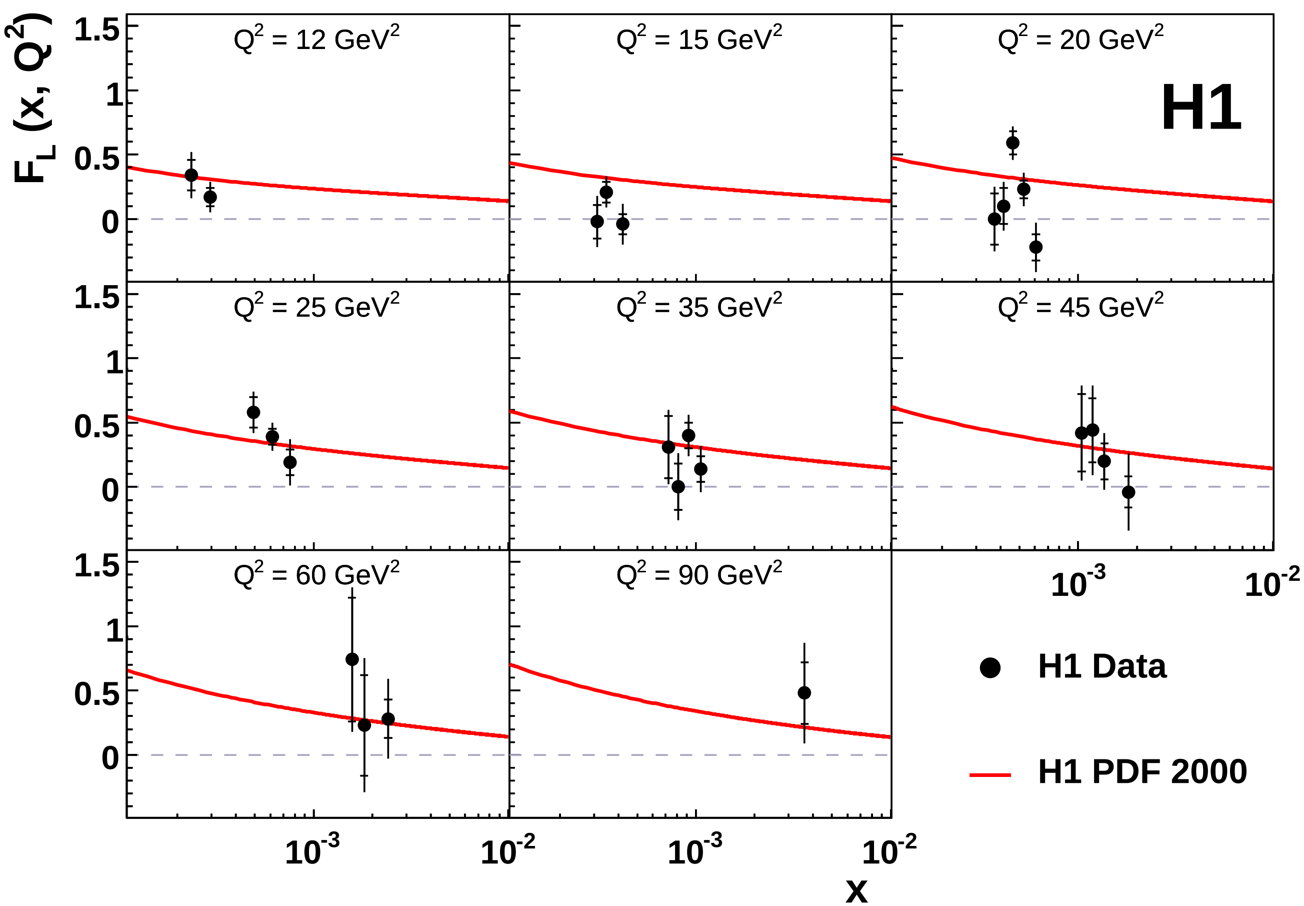


$$\sigma_r(y) = F_2 - \frac{y^2}{1+(1-y)^2} F_L$$

- Linear fit to get F_2 and F_L
- Relative normalization from low y data

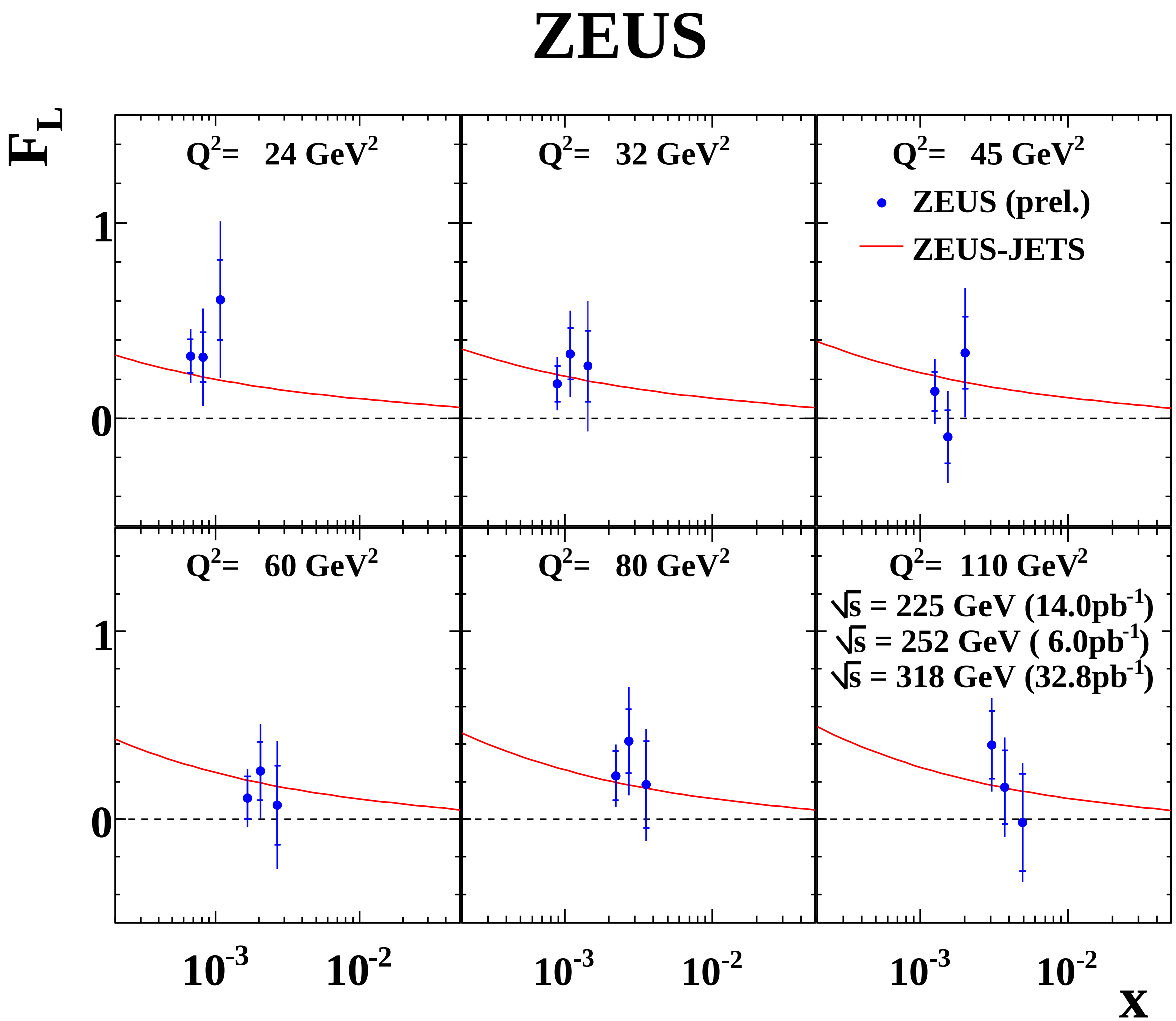
Data at $\mathbf{E_p} = \mathbf{575}$ provides cross check and extends measurement to low x.

The First Measurement of F_L at HERA



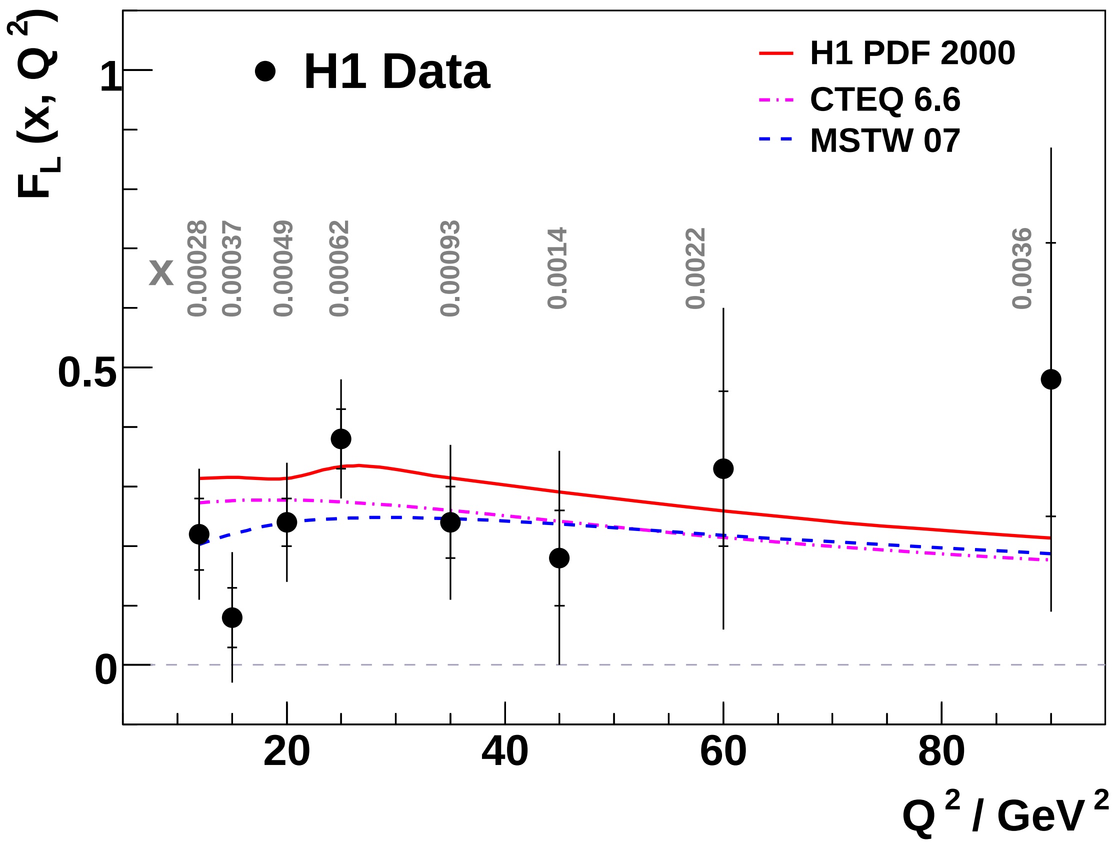
- Agree well with QCD prediction.
- Released for Moriond QCD, March 2008. `DESY-08-053`.

Measurement of F_L by ZEUS



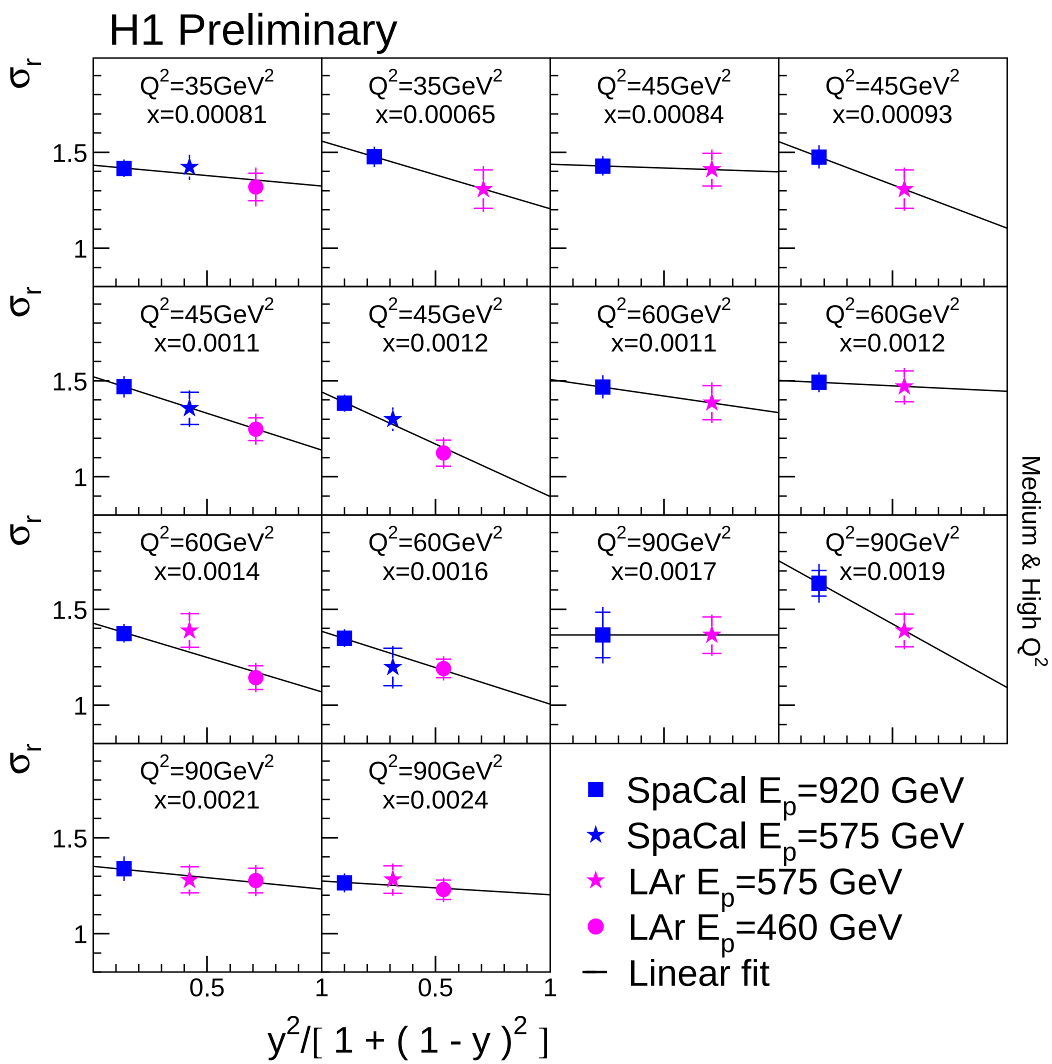
- Updated for ICHEP to include $E_p = 575$ GeV data.
- Consistent with NLO prediction and H1.

H1 F_L measured at medium Q^2



Average data for each Q^2 takinig into account correlated systematic uncertainties. Typical error: total ~ 0.1, uncorrelated ~ 0.05. Agreement with expectations.

F_L extraction: H1 overlap region

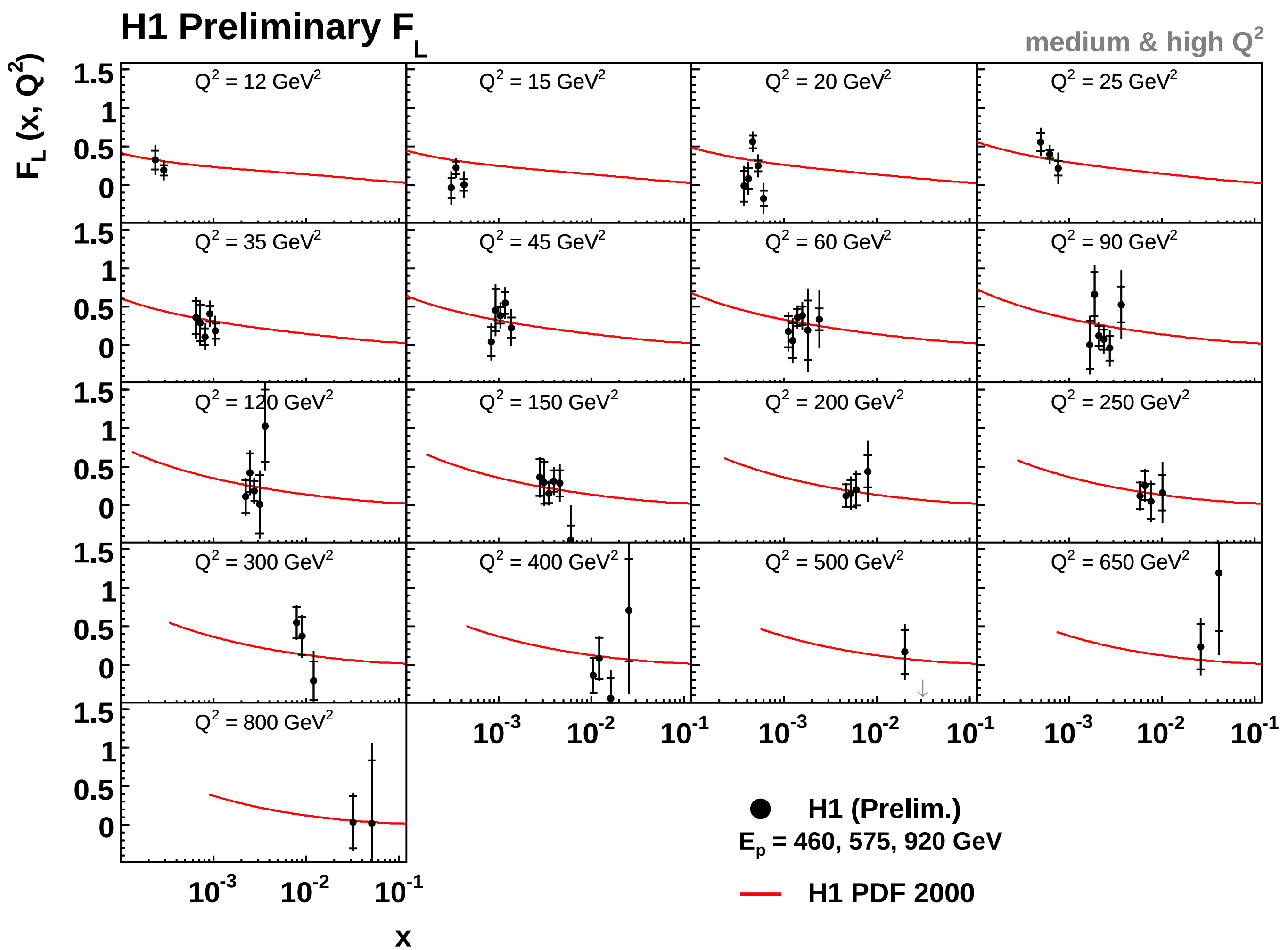


Repeat linear fits to determine F_2 and F_L for the SpaCal/LAr overlap region

Blue points — SpaCal
Magenta points — LAr

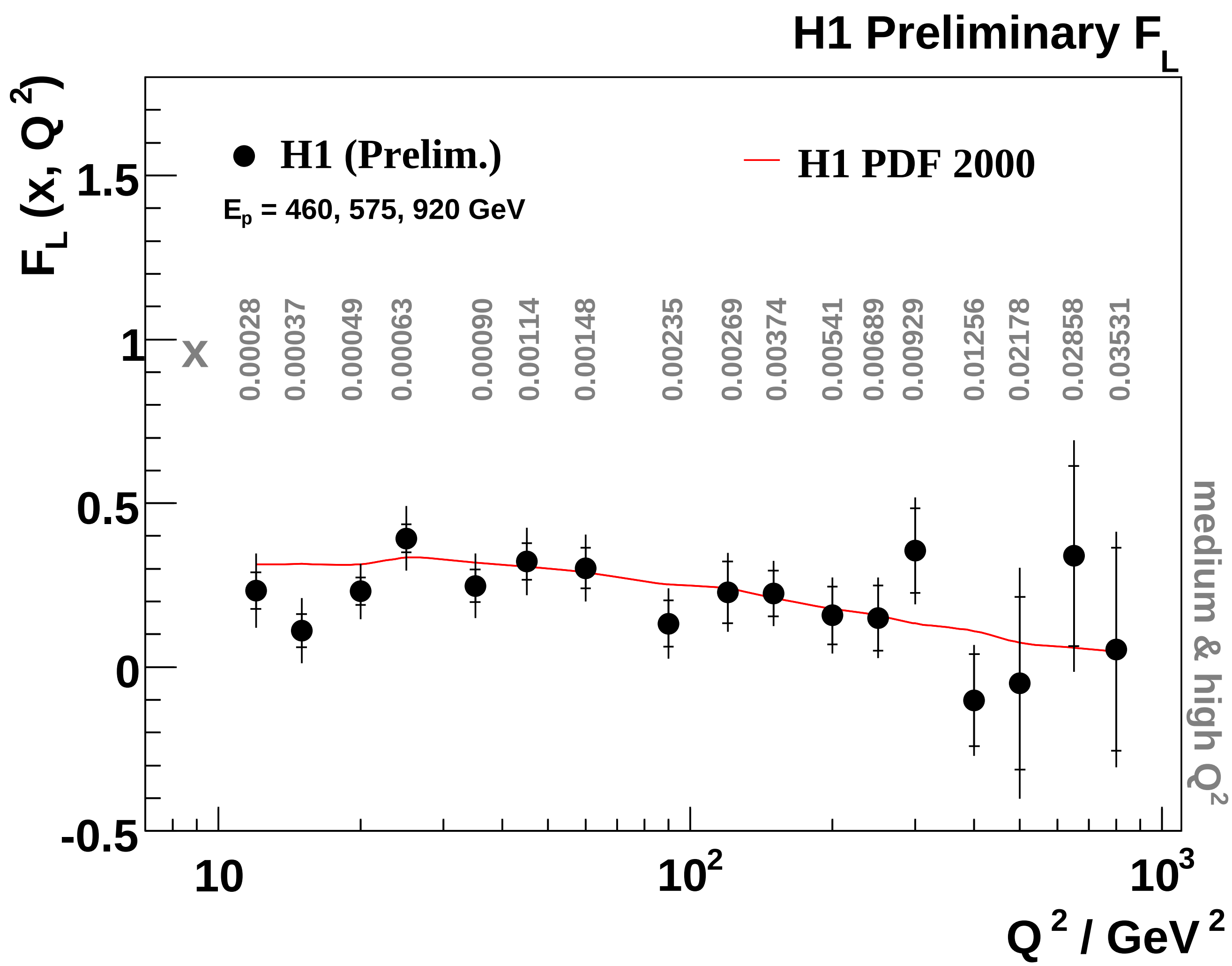
Complementarity of the two fully independent analyzes.

The Combined Measurement of F_L by H1



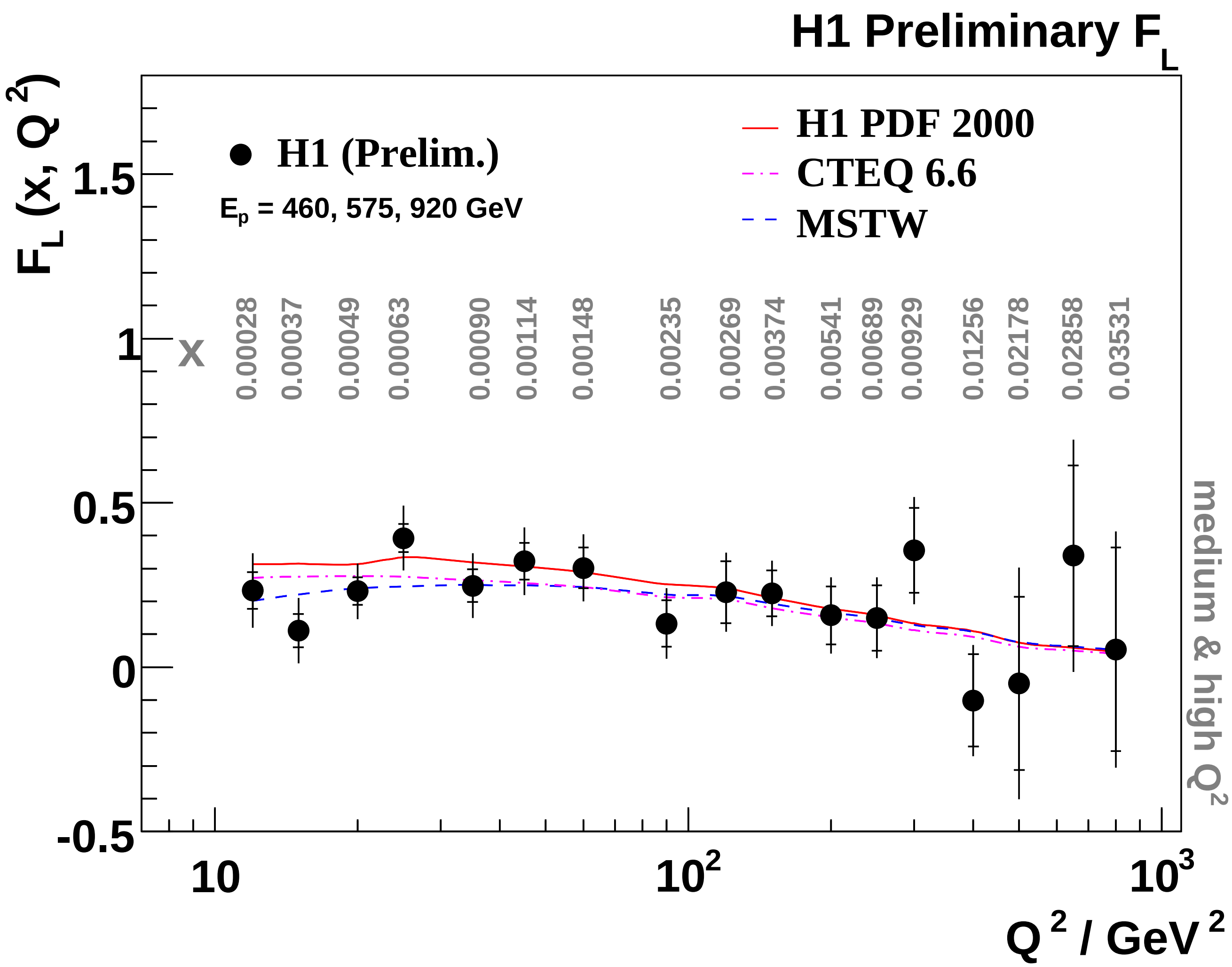
Bins $35 - 90\ \mathrm{GeV}^2$ improved, new bins at $Q^2 \geq 120\ \mathrm{GeV}^2$.

Average F_L by H1



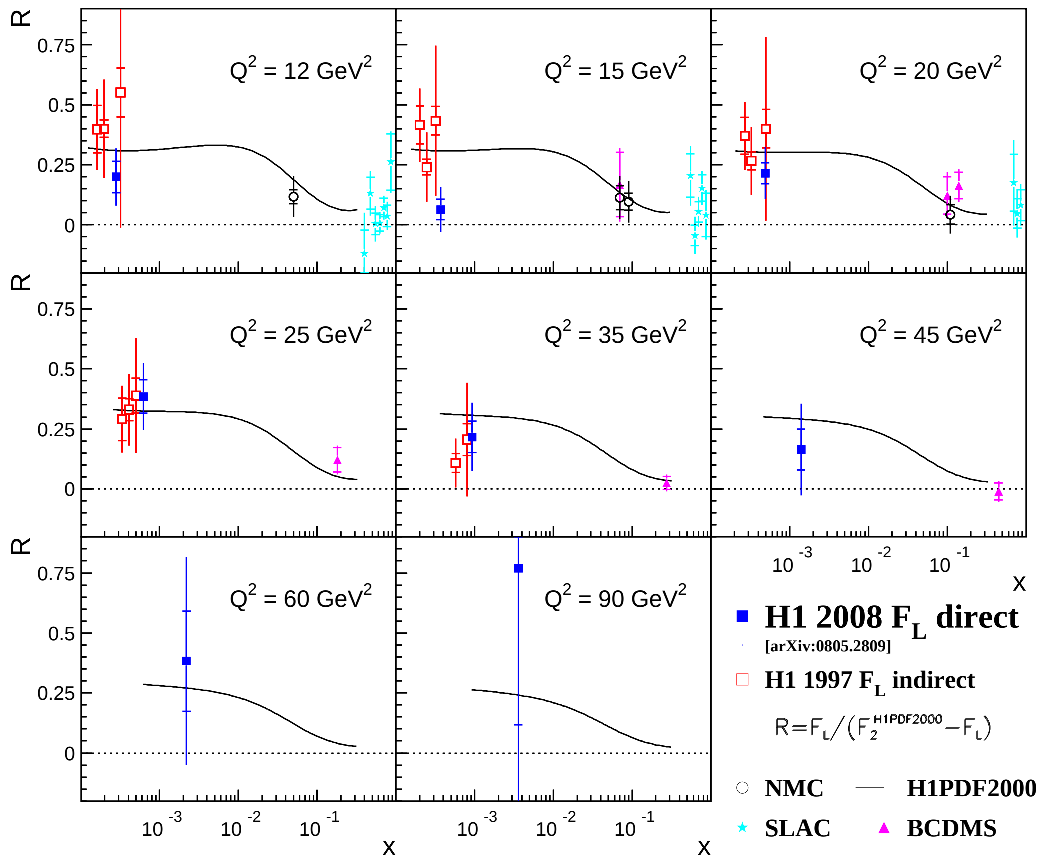
Average using total errors, compare to prediction based on H1 QCD fit to published by H1 DIS cross section data.

Average F_L by H1 vs theory



H1 F_L measurement agrees with QCD calculations.

World measurements of R



Using F_2 from H1 QCD fit F_L can be recalculated to

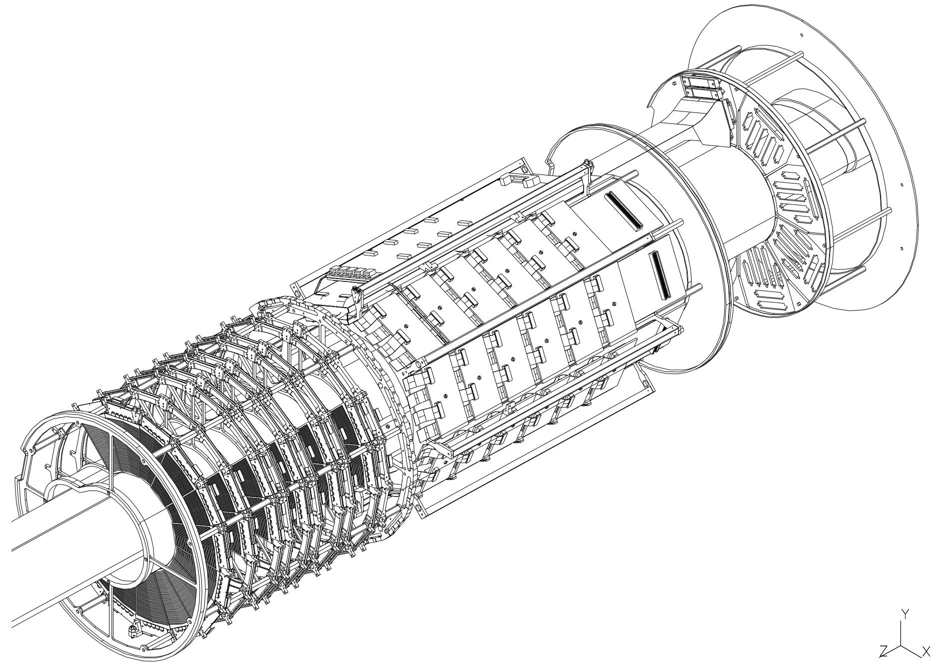
$$R = \frac{F_L}{F_2 - F_L} = \frac{\sigma_L}{\sigma_T}$$

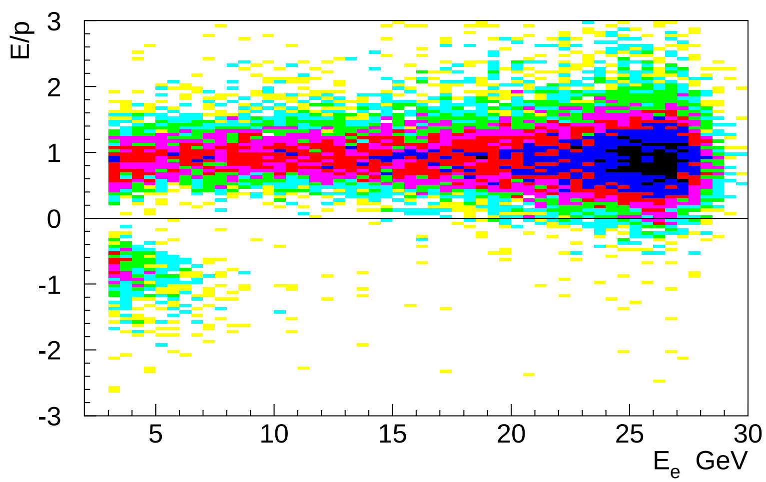
R from indirect F_L determinations and direct measurement can be compared to the fixed target experiment.

Precision on R from HERA is similar to fixed target experiments.

Towards measurement at low Q^2

H1 Backward Silicon Tracker covers $3 < Q^2 < 10\ \mathrm{GeV}^2$ range for $y > 0.6$.





Allows scattered angle reconstruction/charge determination for the electron candidate.

Summary

- First measurement of the longitudinal proton structure function F_L at HERA.
- Good agreement between H1 and ZEUS results.
- The measurements agree with QCD expectations which are based on HERA measurements of the structure function F_2 and its Q^2 dependence.

Still to come: measurement at $Q^2 < 12$ GeV^2 using H1 backward silicon tracker.