Measurement of F_L at HERA by the H1 collaboration

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The Proton Structure Functions at low Q^2

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

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

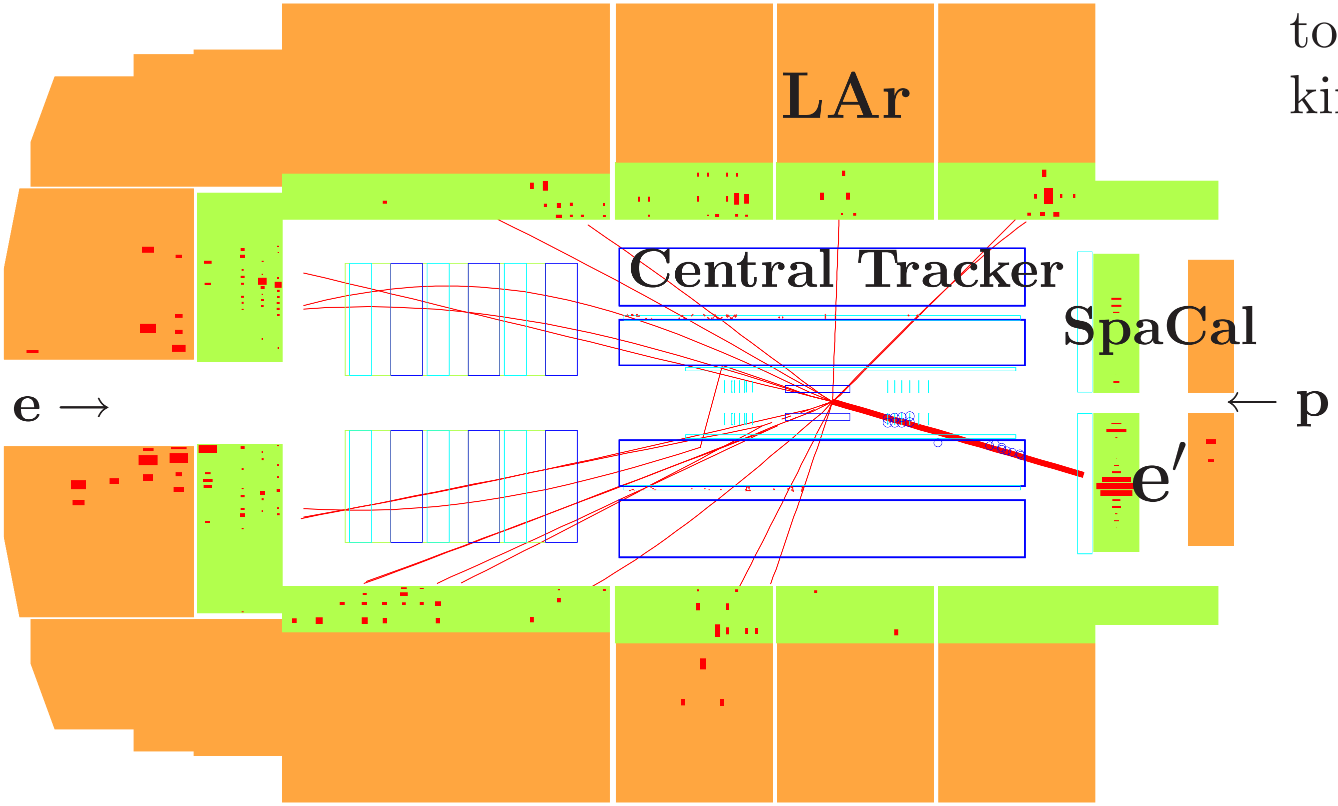
For low x:

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

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.

H1 Detector



Use the scattered electron to reconstruct event kinematics

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

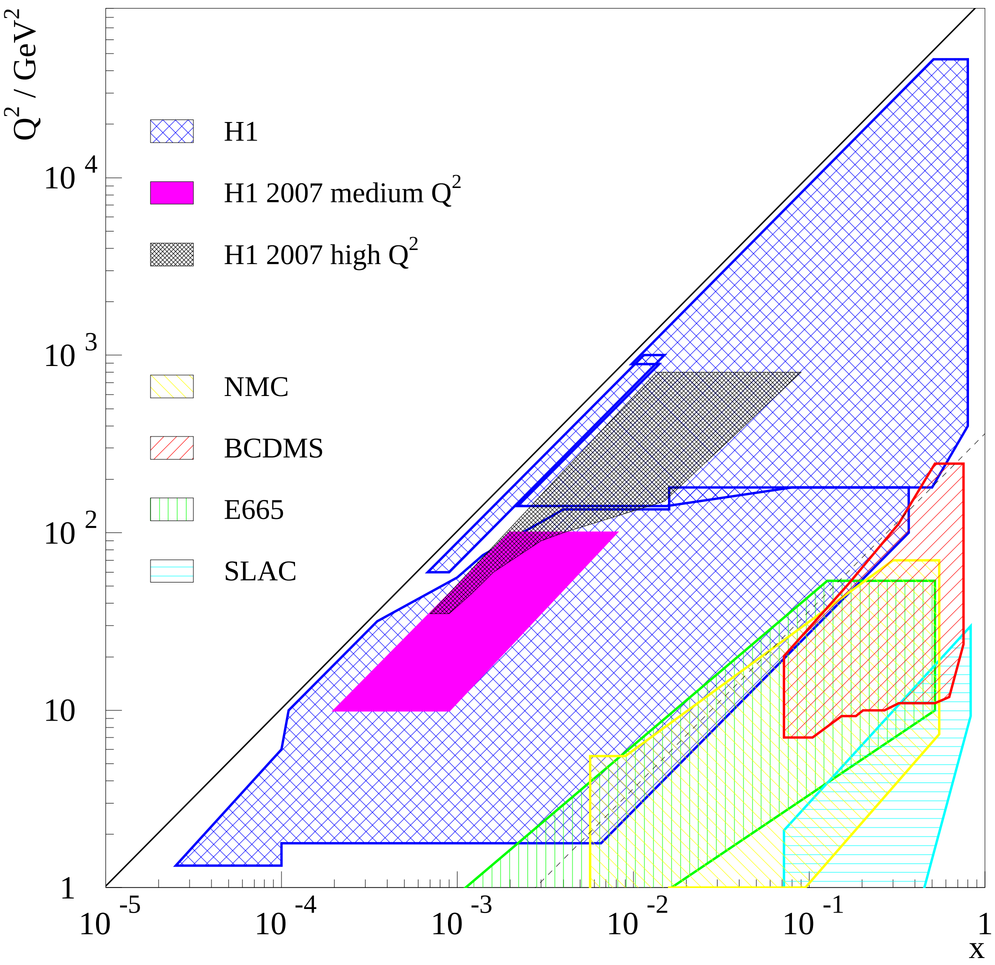
$$y = 1 - \frac{E'_e}{E_e} \sin^2 \frac{\theta_e}{2}$$

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

Two separate measurements, defined by electron measurement techniques:

- Medium Q^2, $12 < Q^2 < 90$ GeV^2, SpaCal + CT
- High Q^2, $35 < Q^2 < 800$ GeV^2, LAr + CT.
- low Q^2, $3 < Q^2 < 12$ GeV^2, SpaCal+BST — to come.

Kinematic Coverage

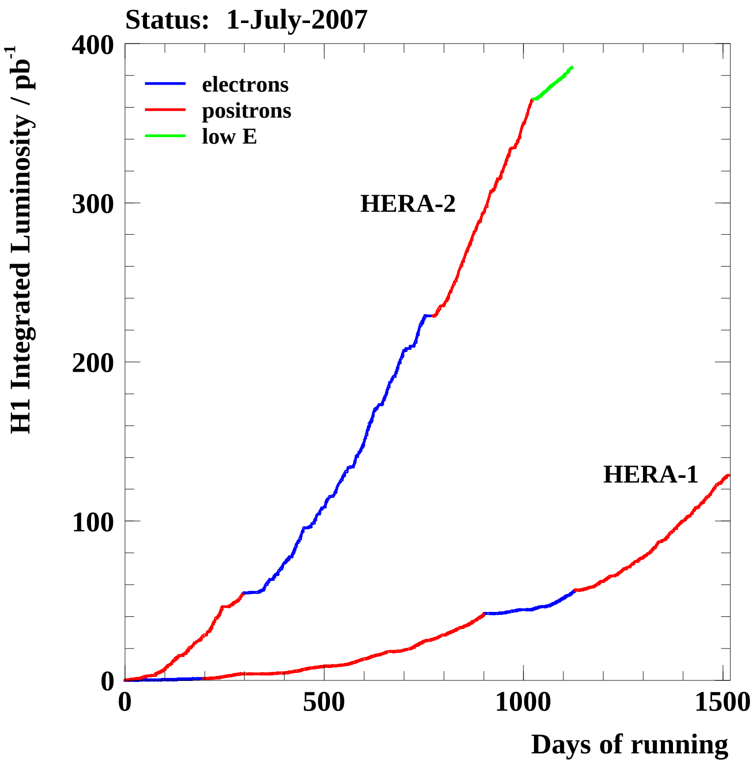


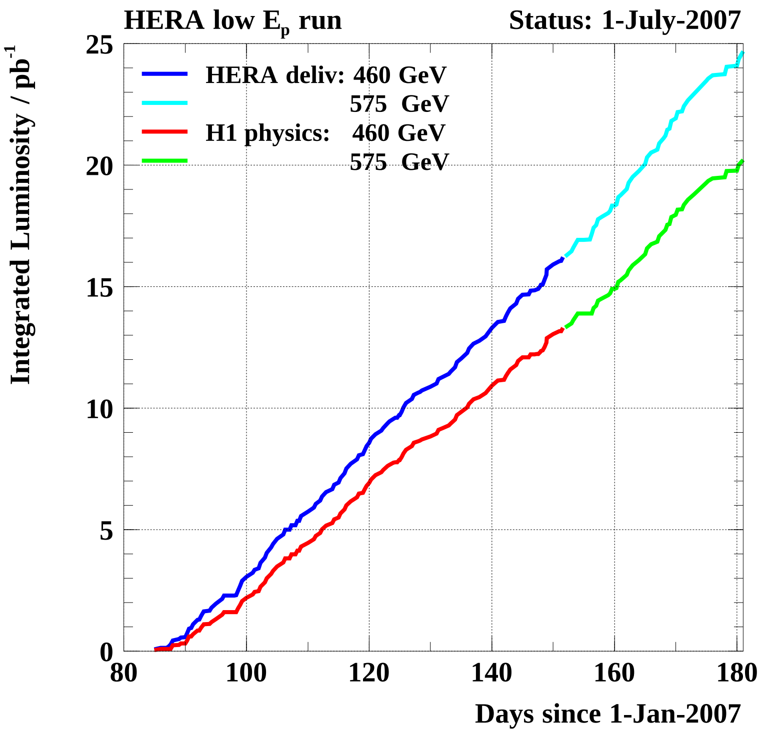
- Measure in the domain already covered by HERA DIS cross section measurements.
- Use data sets with 3 proton beam energies: 460, 575 and 920 GeV.
- Combined measurement using SpaCal and LAr in the $35 < Q^2 < 90$ GeV^2 range.

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.

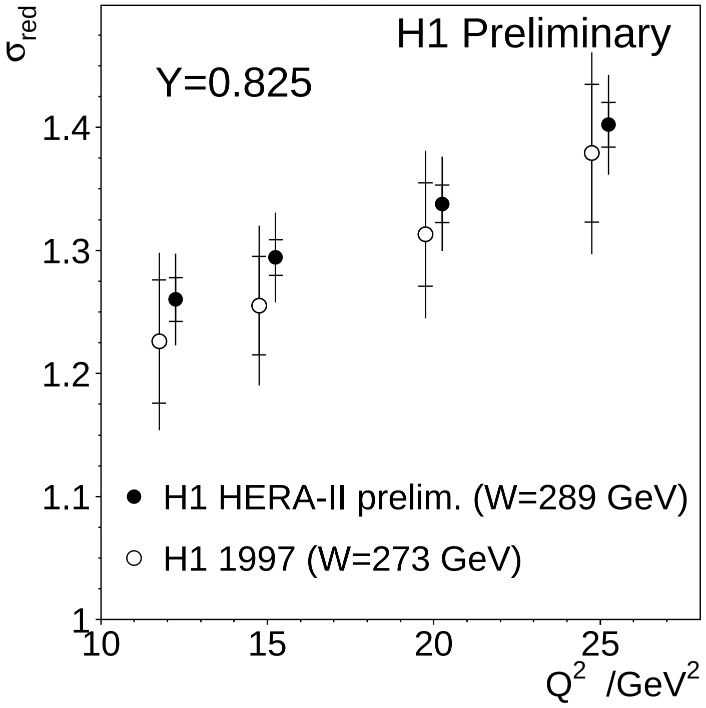
$$y \approx 1 - \frac{E_e'}{E_e}$$

Measurement extends down to $E_e' = 3$ GeV.

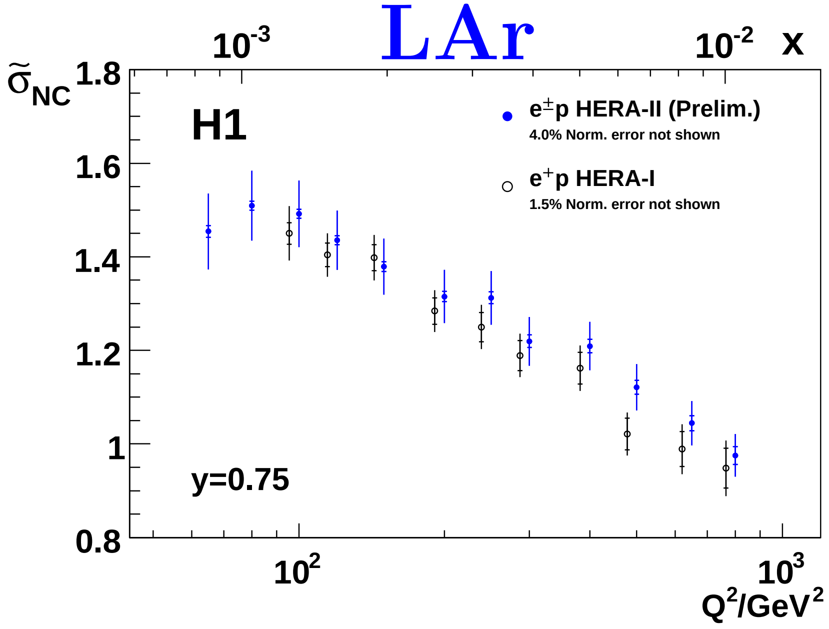
- Trigger efficiency/rate
- Electron identification
- Background
- Radiative corrections

Previous H1 High y σ_r Measurements

SpaCal



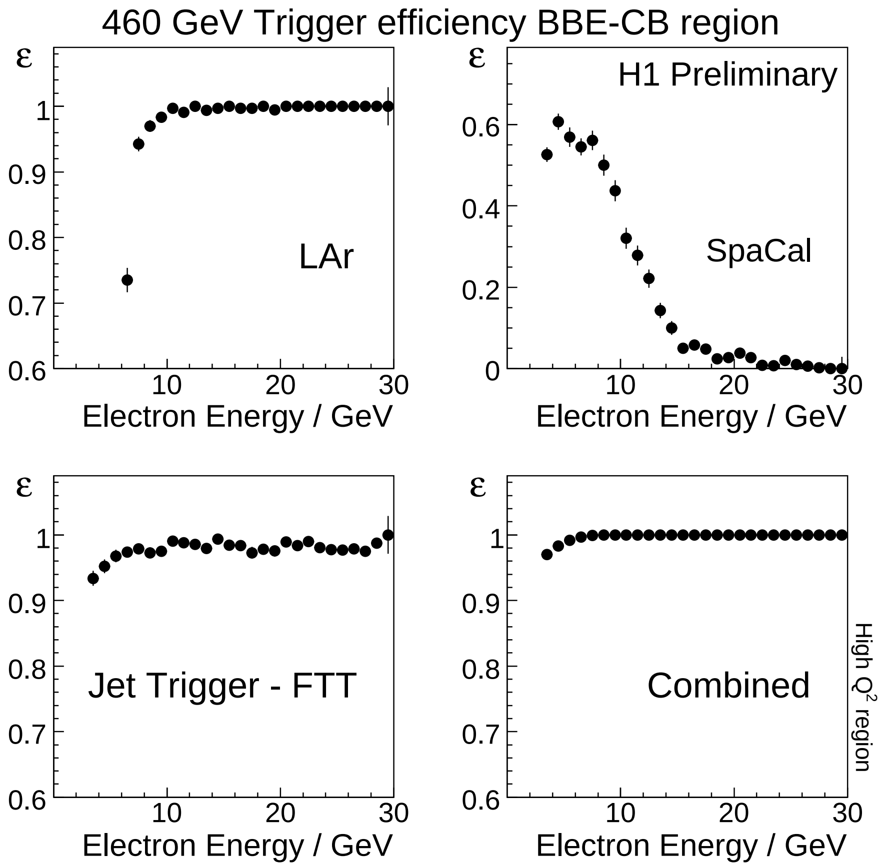
LAr



- 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.

Improvement of LAr Trigger for Low Energy Runs

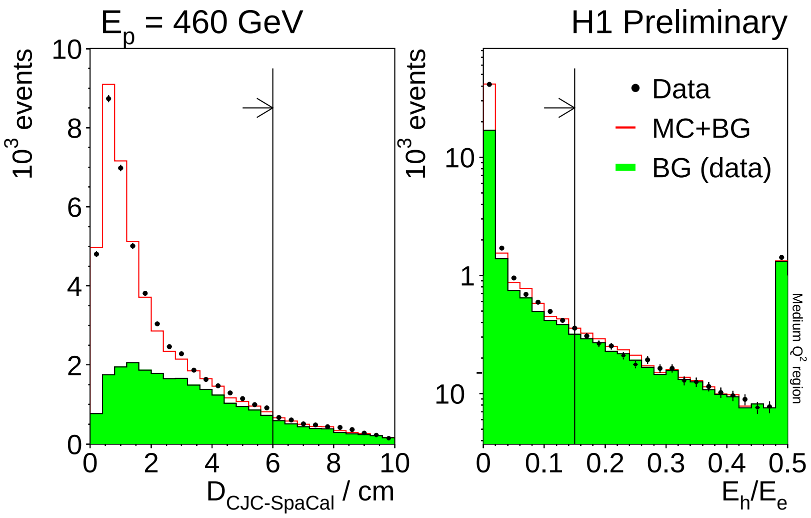


Jet (real time clustering) - FTT (fast track) trigger requires cluster-track match at high level trigger. Jet trigger fully commissioned in 2007.

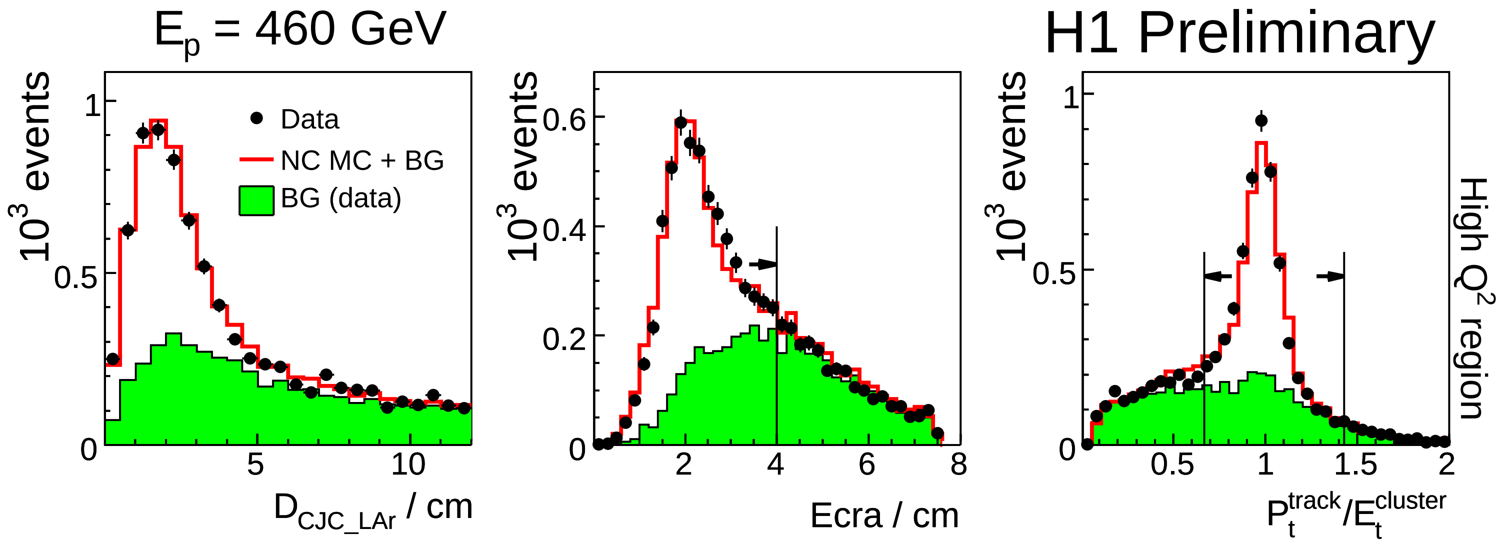
→ Allows to extend measurement in LAr down to 3 GeV

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

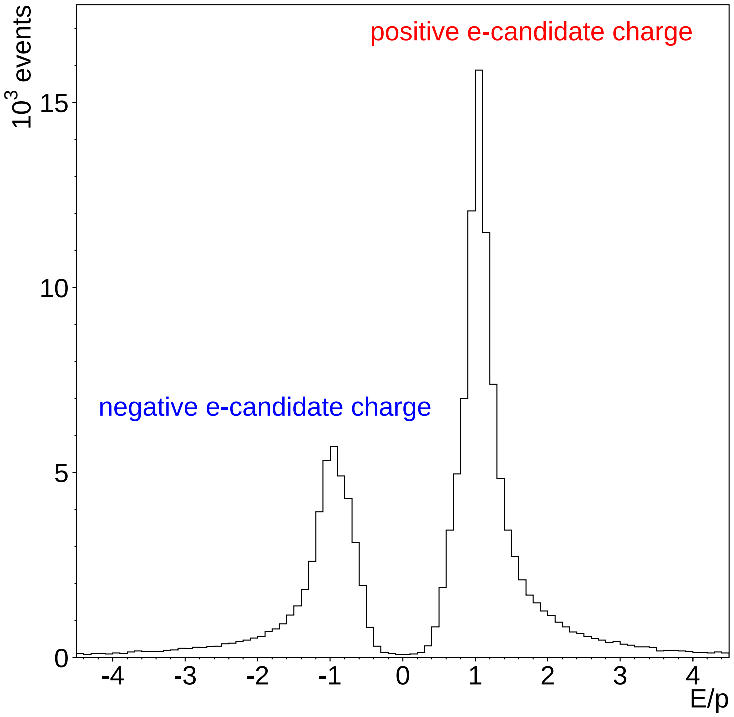


Background Estimation

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.



Good charge resolution, wrong charge determination probability $< 1\%$.

Background charge asymmetry

Background charge asymmetry ($N_{bg}^{+} \neq N_{bg}^{-}$) arises from $\bar{p}$ vs p interaction difference in calorimeters.

$$\kappa = \frac{N_{bg}^{-}}{N_{bg}^{+}}$$

- Measured using $e^{-}p$ vs $e^{+}p$ scattering data. (almost 100 pb^{-1} for SpaCal, complete HERA-II for LAr).
- Checked using a sample with the scattered lepton detected in a electron tagger, located close to the beam line ($Q^2 < 0.01$ GeV^2).

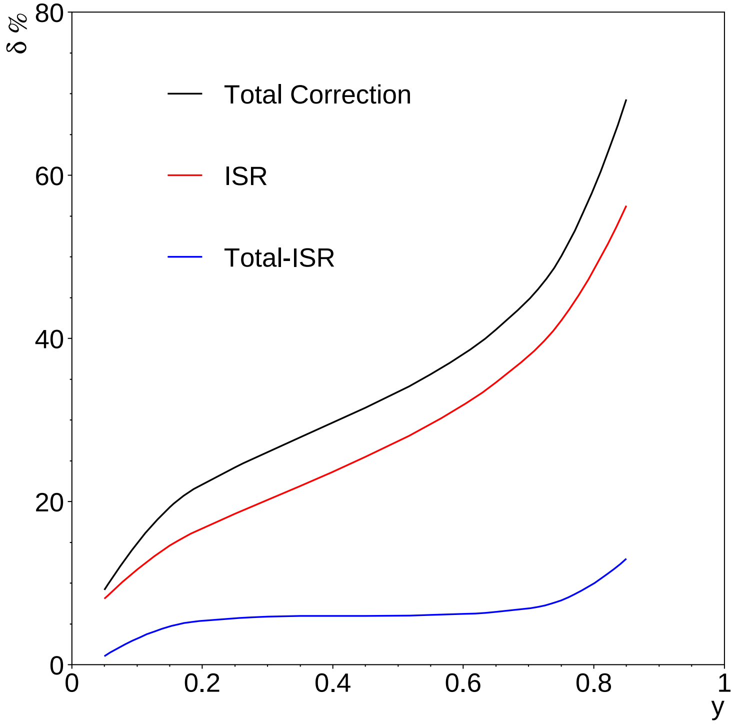
κ depends on electron identification cuts.
$\kappa \approx 1.05$ for both calorimeters.

Statistical subtraction of the background:

$$N_{sig} = N^{+} - N^{-}/\kappa.$$

Radiative Corrections

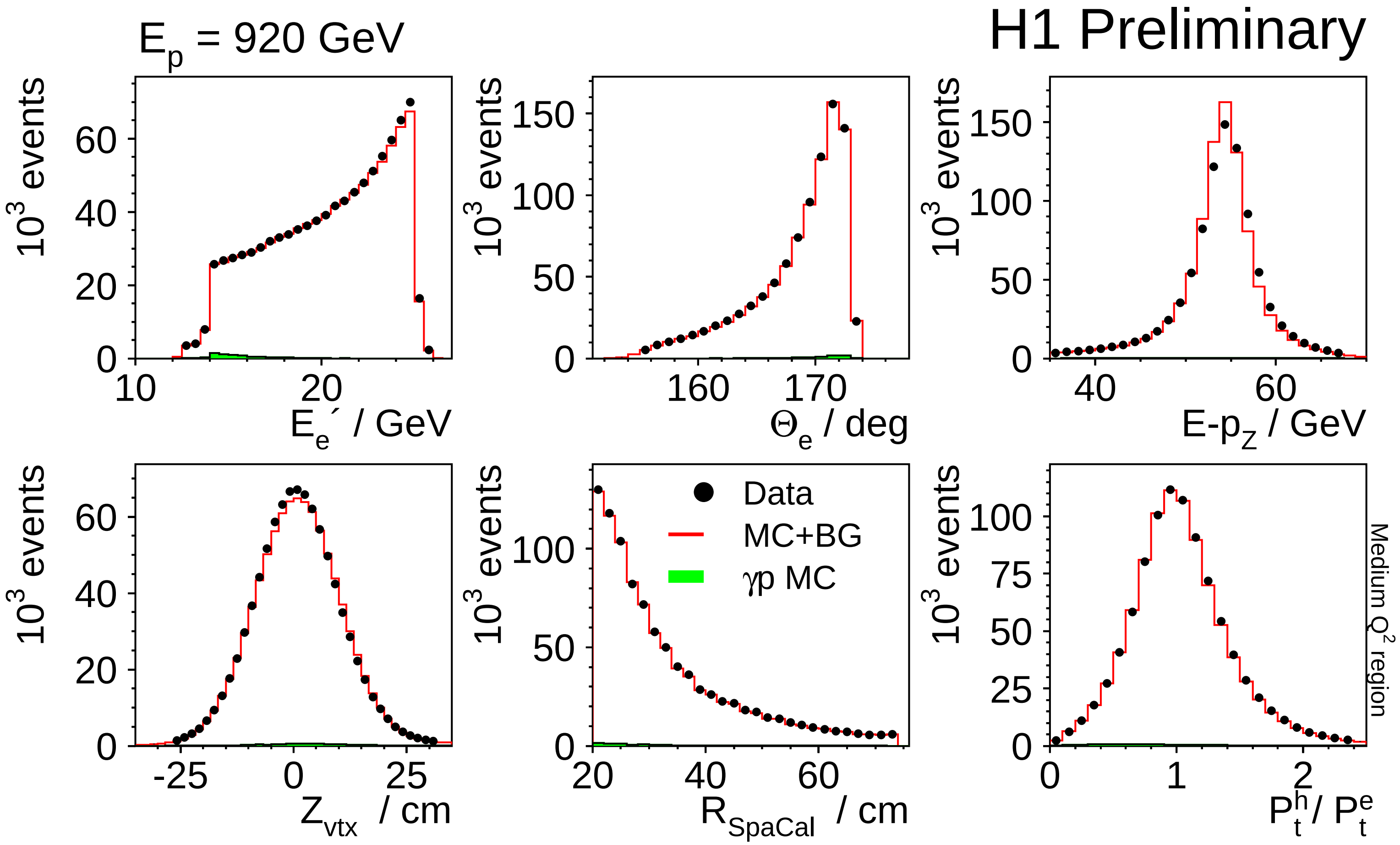
- Radiative corrections are large at high y, $\delta = \frac{\sigma_{\text{total}}}{\sigma_{\text{born}}} - 1 > 50\%$.
- Simulated in DJANGO MC, checked with HECTOR program.
- Mostly from initial state radiation (ISR) - radiative return to low y and low Q^2 ($\sigma \sim 1/y$ and $\sigma \sim 1/Q^4$).



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

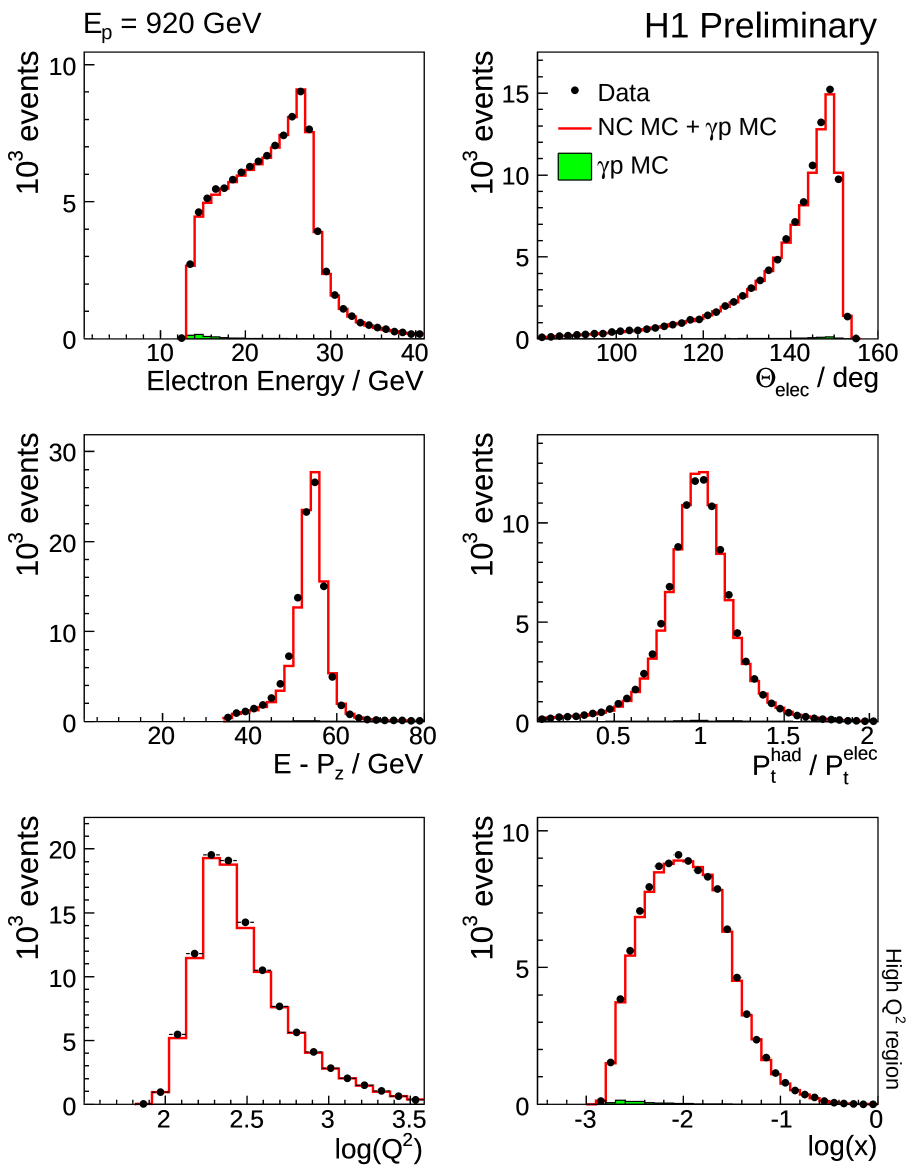
$$2E_e \approx E{-}p_Z|_{in} = E{-}p_Z|_{out} = \sum_h (E^h - p_Z^h) + \sum_e (E^e - p_Z^e) \equiv E{-}p_Z$$

Control plots: 920 GeV, $0.1 < y < 0.56$, medium Q^2



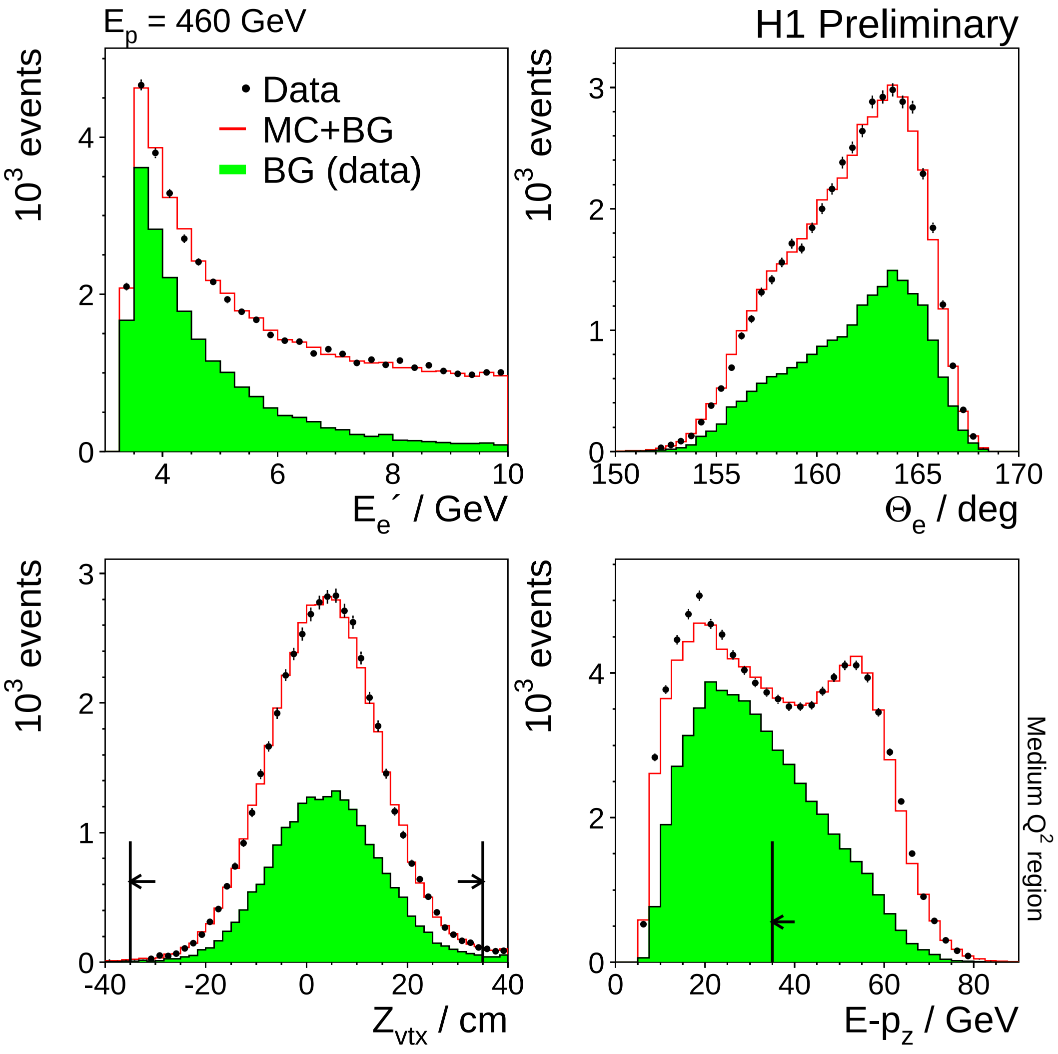
- Energy calibration known to 1%, alignment to 1 mrad
- Residual background is estimated using PHOJET MC

Control plots: 920 GeV, $0.076 < y < 0.56$, high Q^2



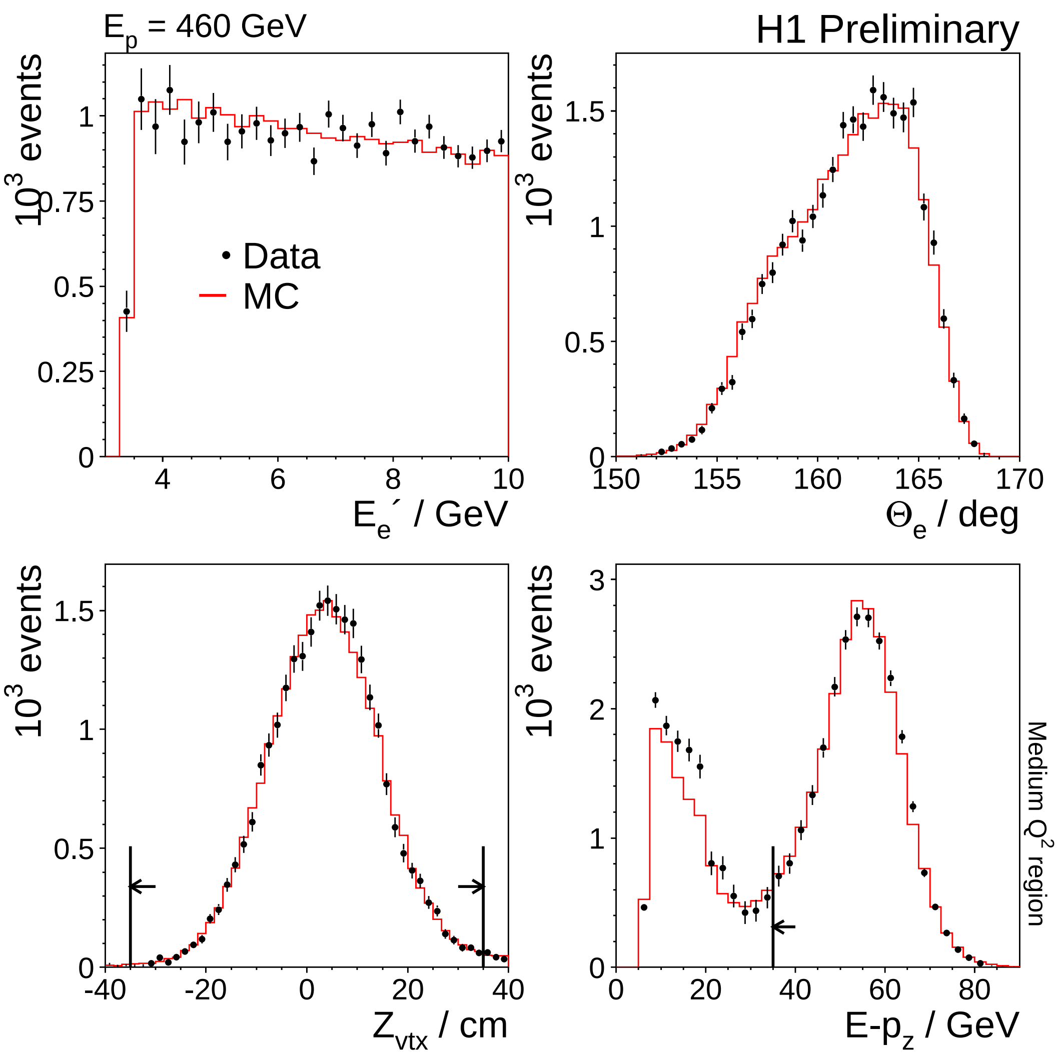
Background is estimated using PYTHIA MC. Good description of data by MC.

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



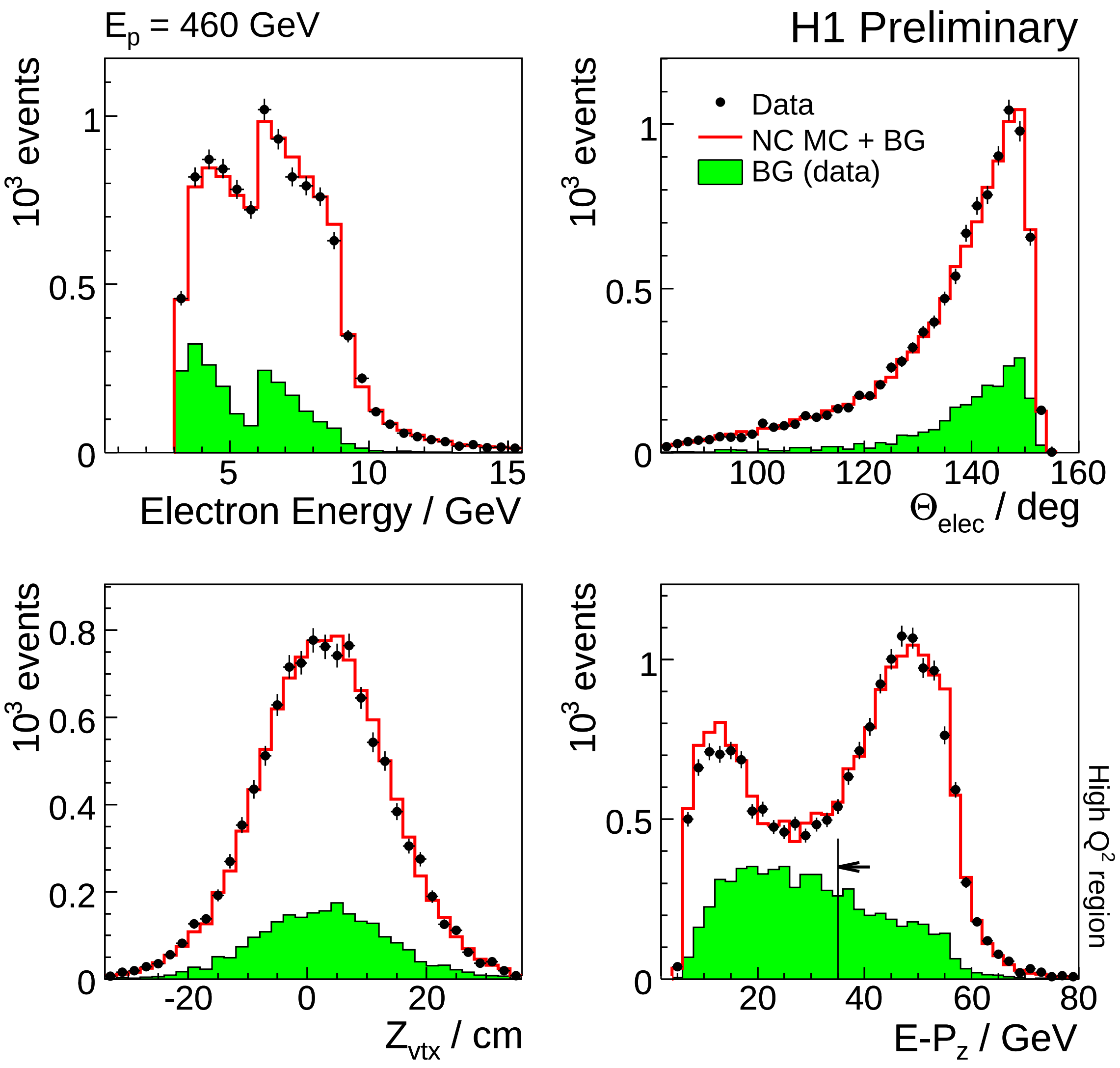
- Before background subtraction
- $E_p = 460$ GeV
- $E_e' > 3.4$ GeV.
- Lines indicate cut values
- $E - p_z$ is effective against background

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



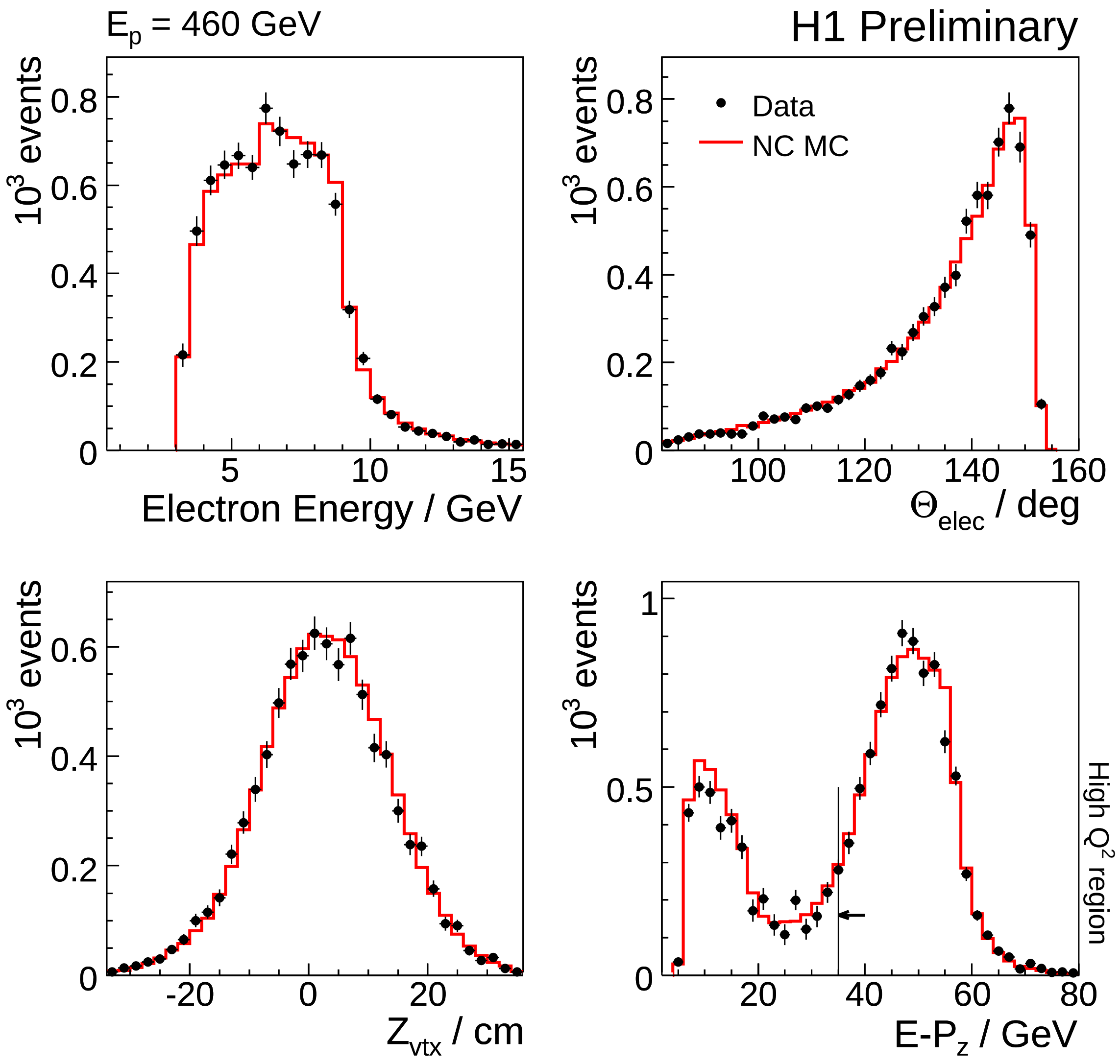
- After background subtraction
- $E_p = 460$ GeV
- $E_e' > 3.4$ GeV.
- Lines indicate cut values
- $E - p_z$ is effective against ISR radiation

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

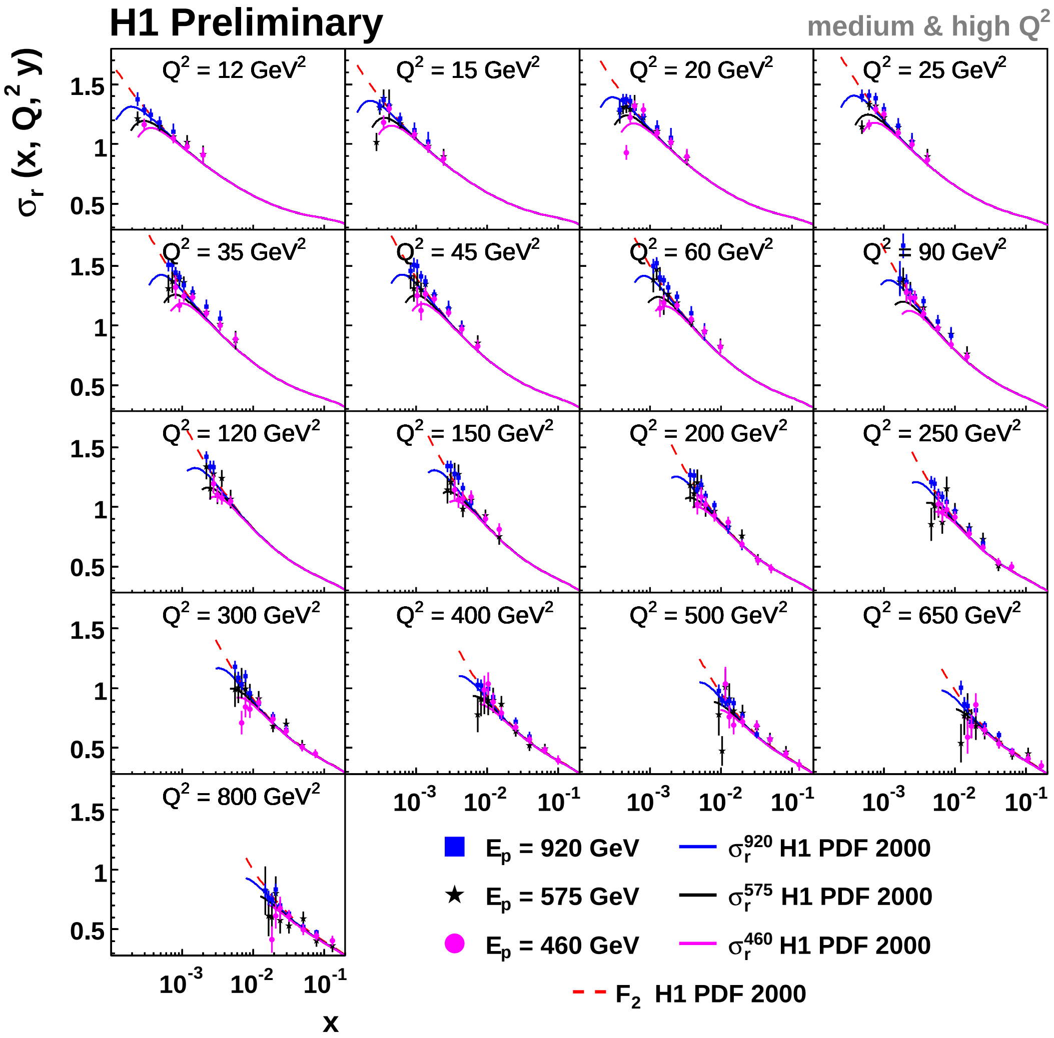


- After background subtraction
- $E_p = 460$ GeV
- $E'_e > 3$ GeV.
- Additional cuts at $E > 6$ GeV introduce step

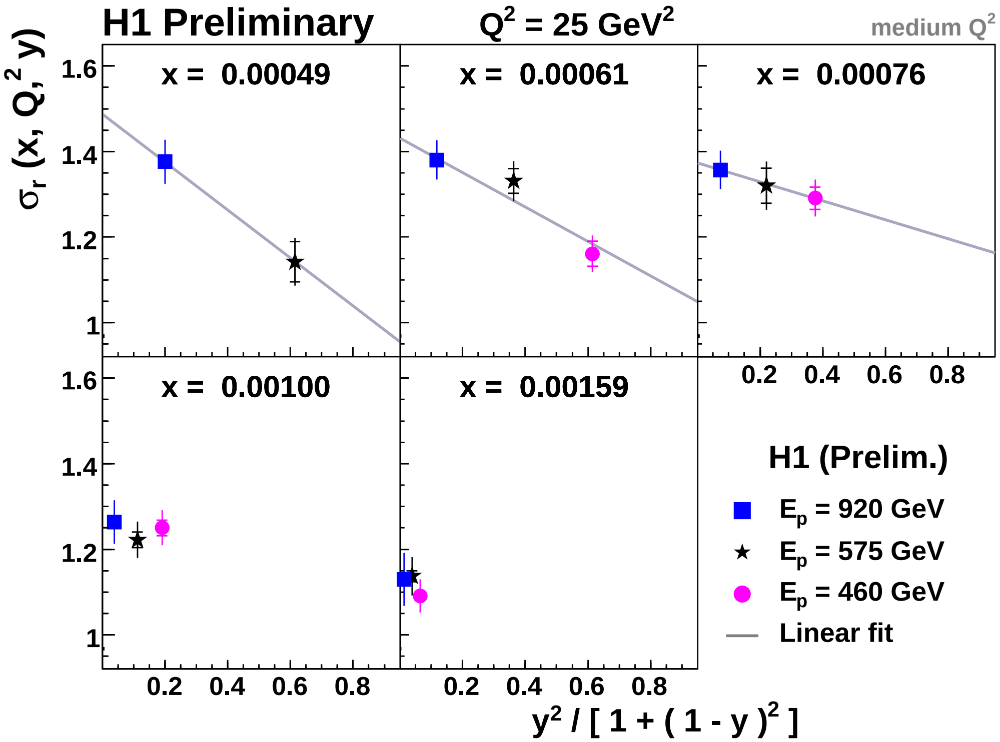
→ Good description of data by MC.

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



F_L extraction

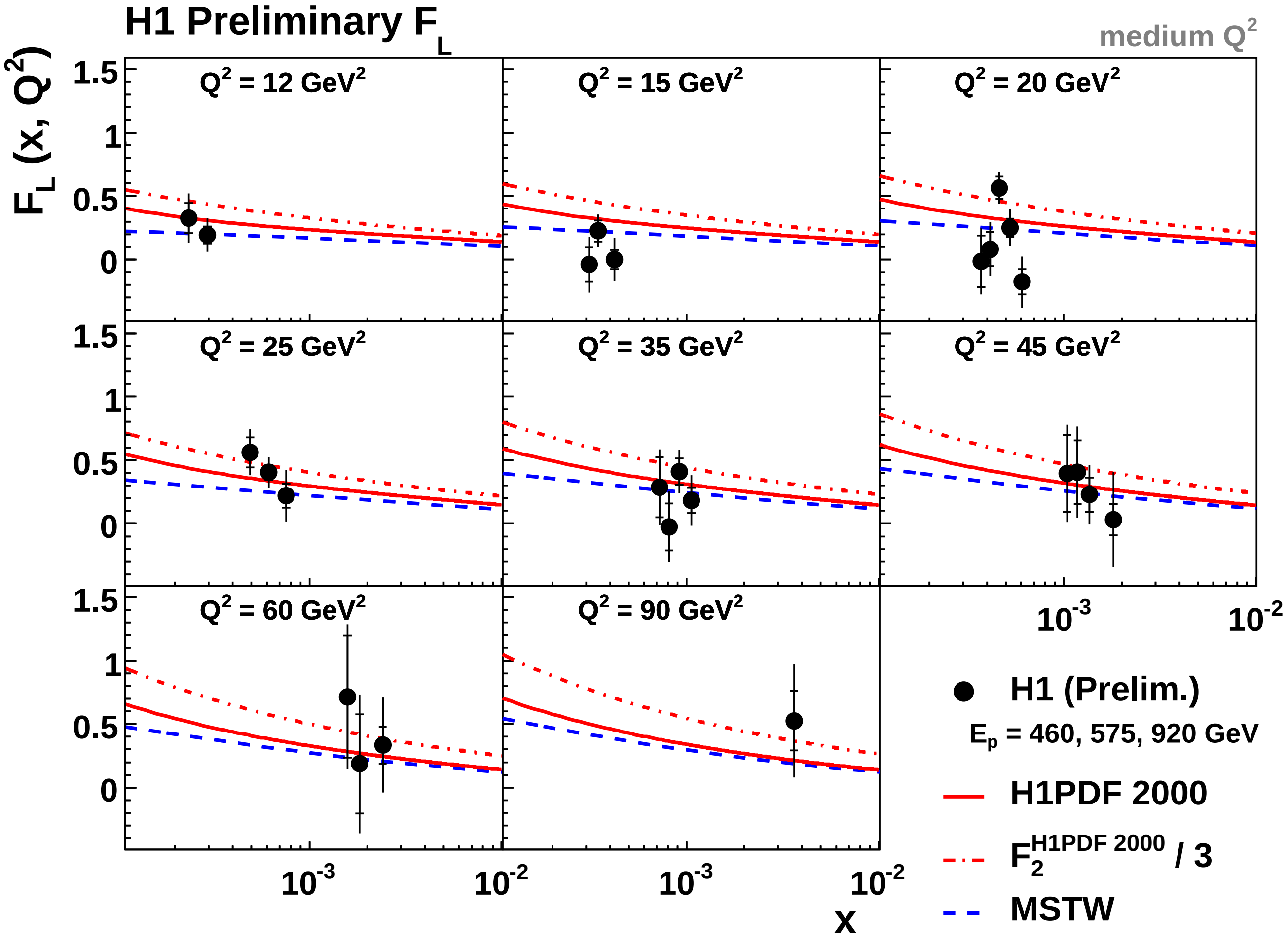


$$\sigma_r(y) = F_2 - \frac{y^2}{1+(1-y)^2} F_L$$

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

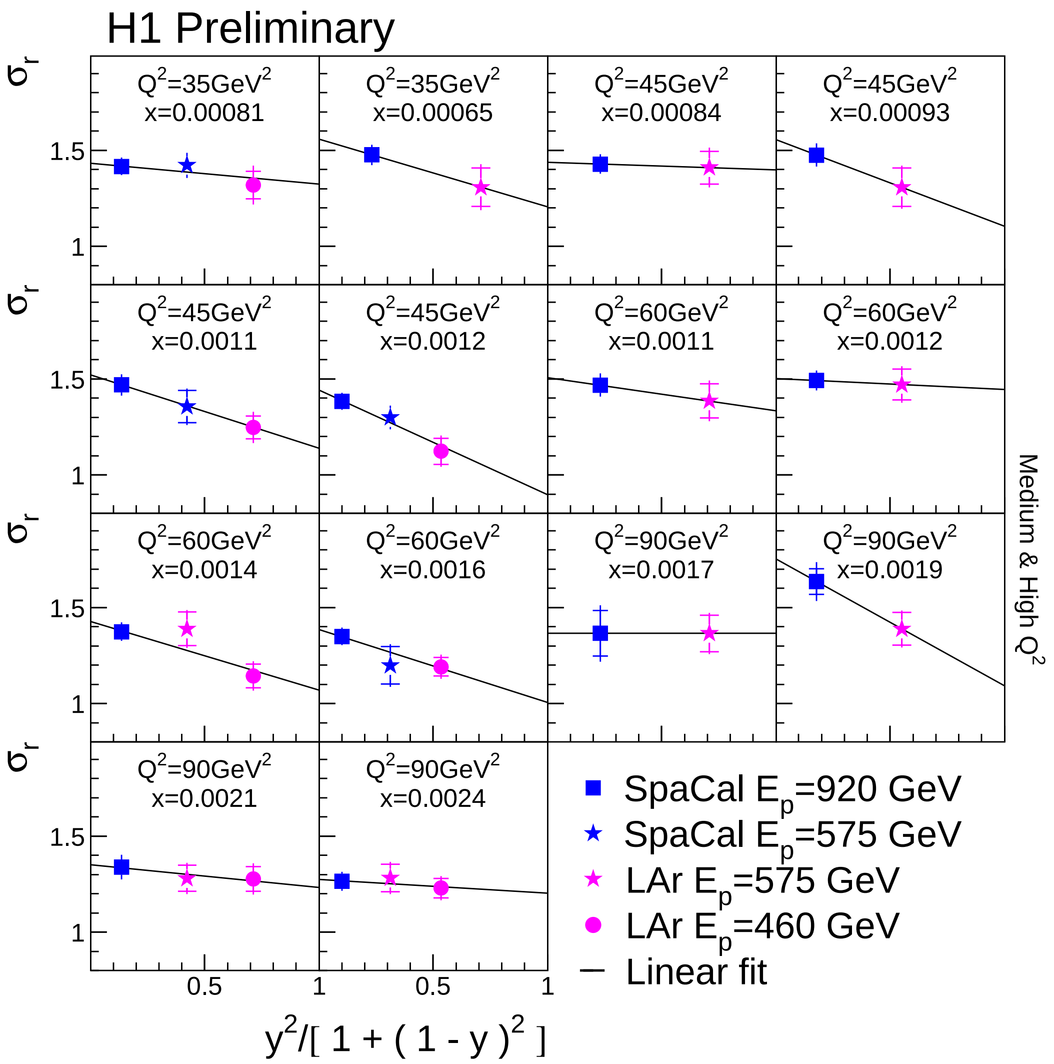
Data at $\mathbf{E_p = 575}$ provides cross check and extends measurement to low x.

The First Measurement of F_L at HERA



- Released for Moriond QCD, March 2008.
- $F_L = F_2/3 \rightarrow R \equiv \sigma_L/\sigma_T = 0.5$, no helicity suppression.

F_L extraction: overlap region



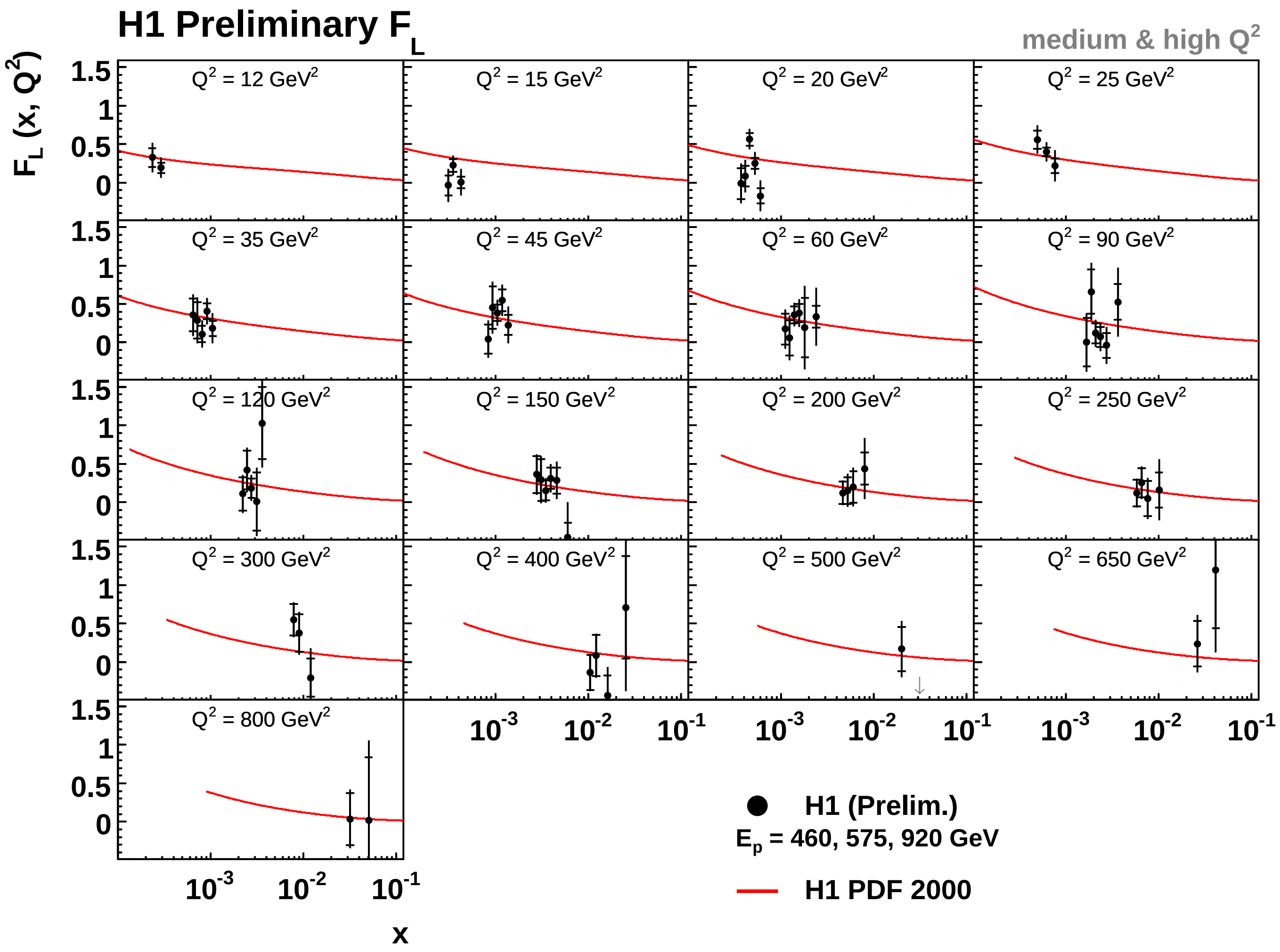
Repeat linear fits to determine F_2 and F_L for the SpaCal/LAr overlap region

Blue points — SpaCal

Magenta points — LAr

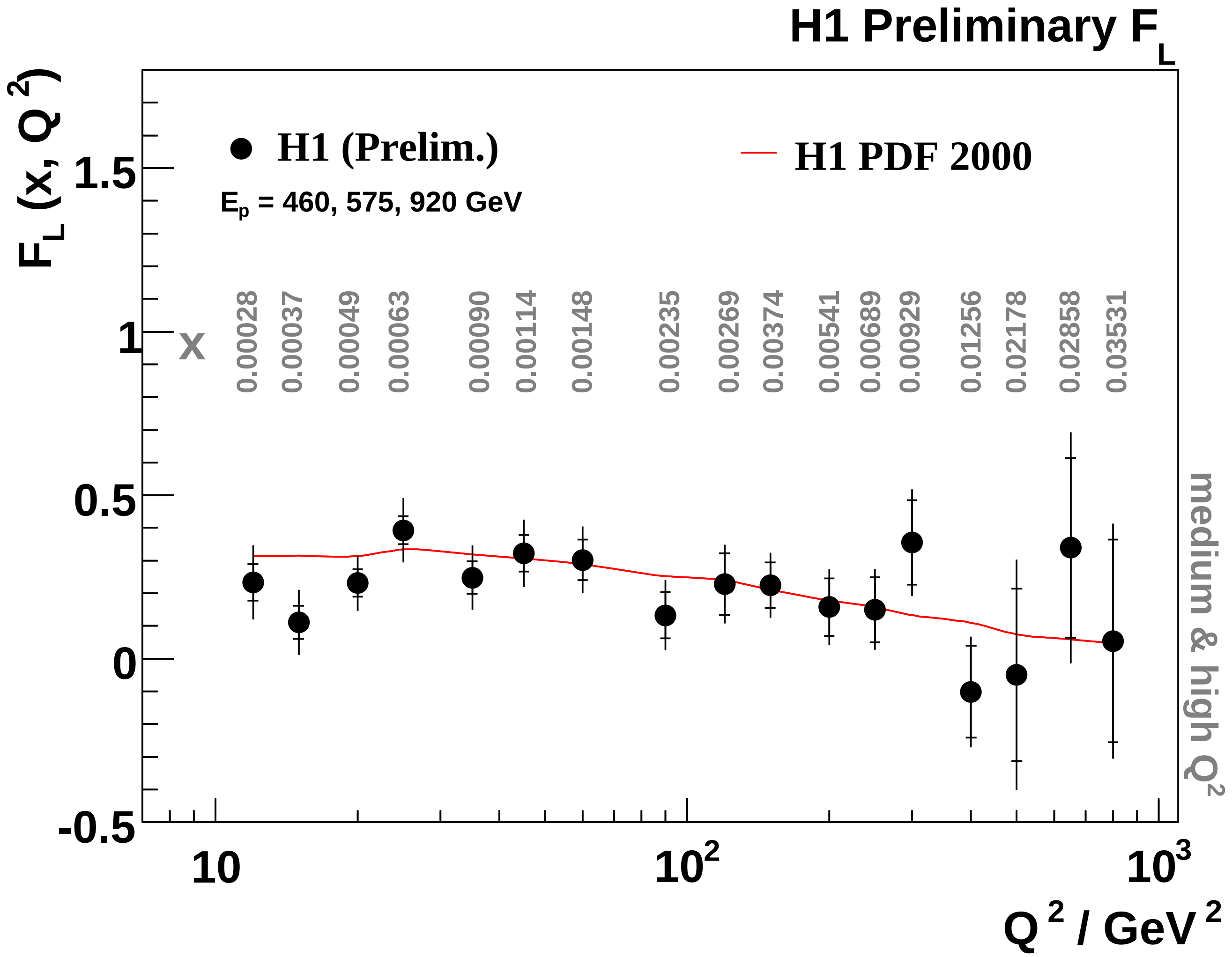
Complementarity of the two fully independent analyzes.

The Combined Measurement of F_L by H1



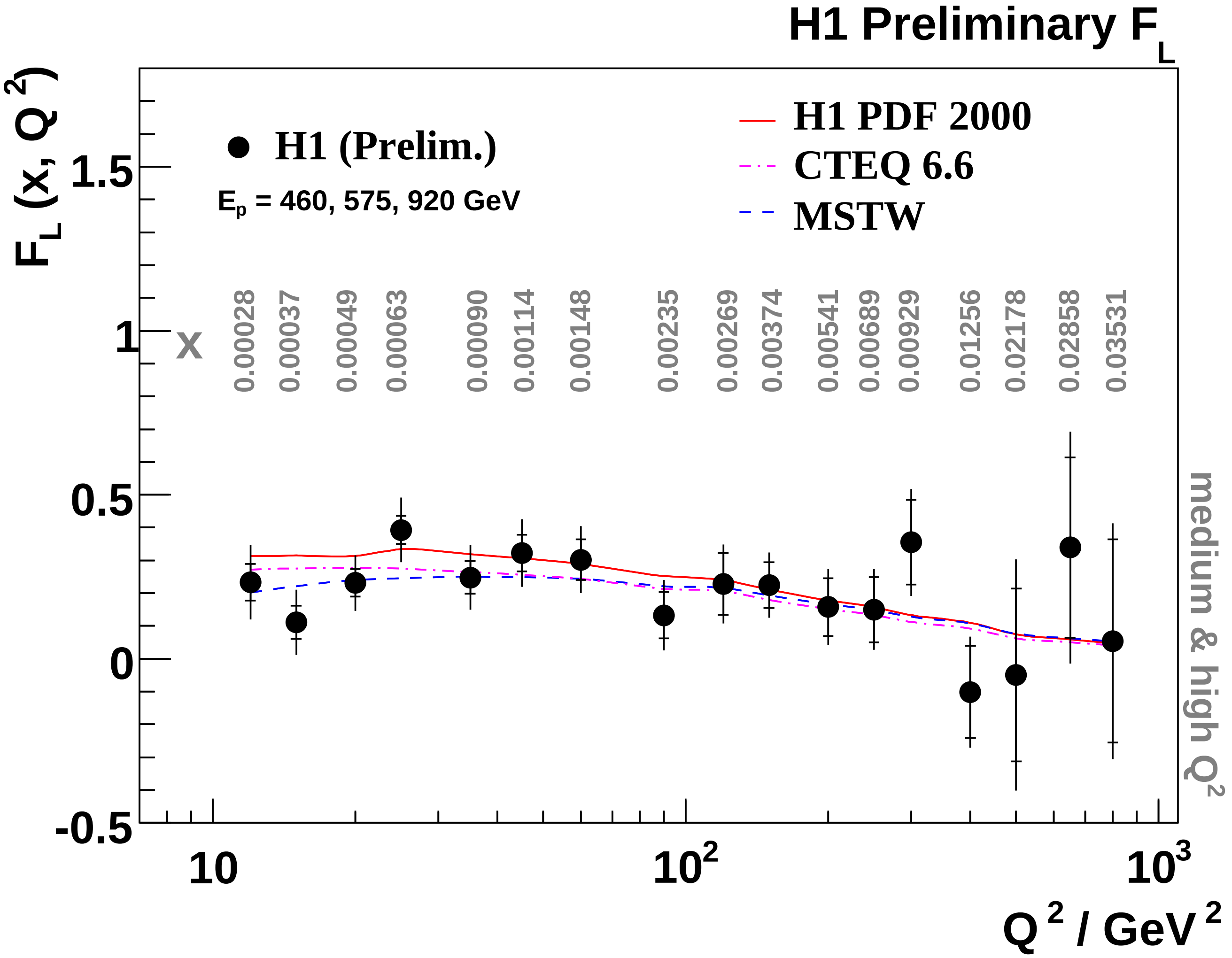
Bins $35 - 90\ \mathrm{GeV}^2$ improved, new bins at $Q^2 \geq 120\ \mathrm{GeV}^2$.

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.

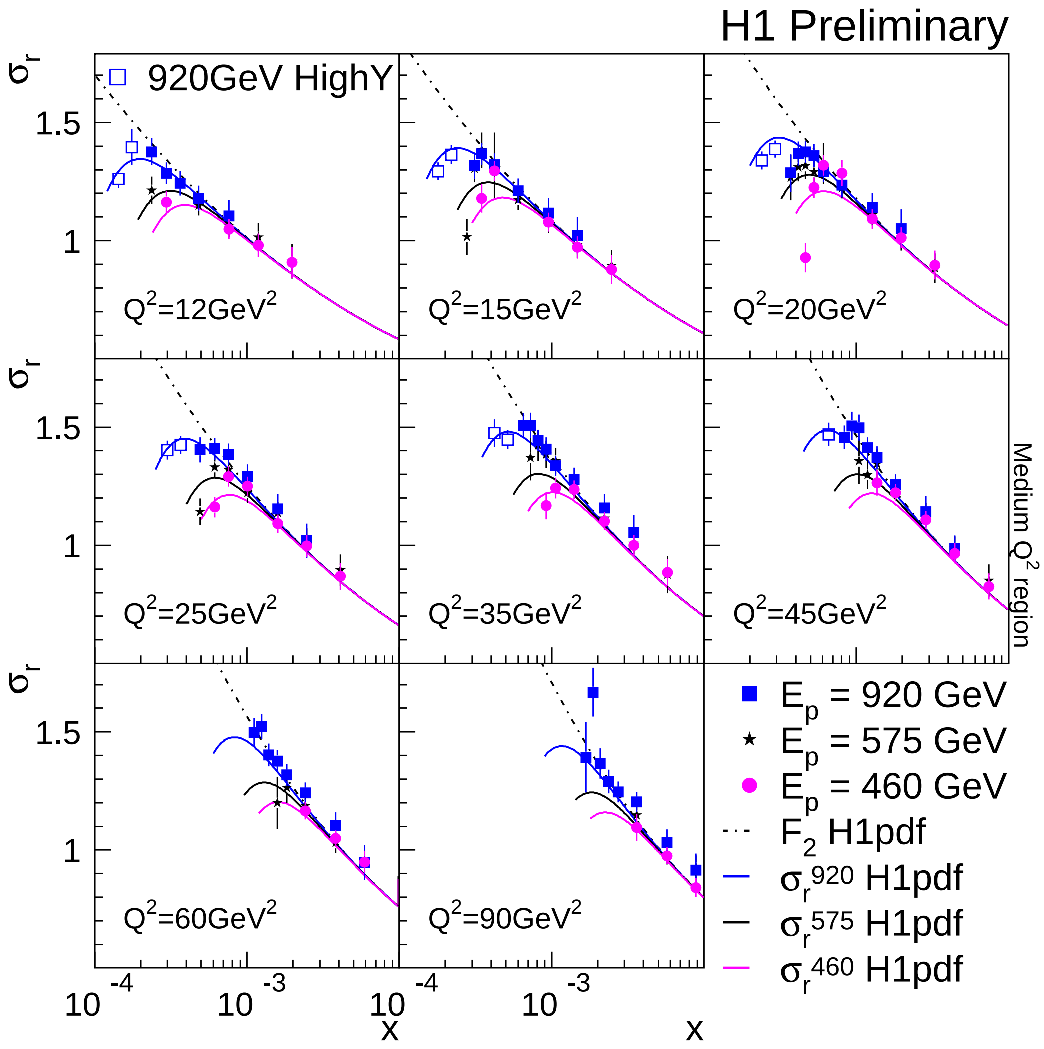
Summary

- First measurement of the longitudinal proton structure function F_L at HERA.
- Complementarity of the measurements based on SpaCal and LAr calorimeters.
- The measurement agrees 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 $Q^2 < 12~\mathrm{GeV}^2$ using H1 backward silicon tracker.

Extras

Comparision of H1 Cross Section Measurements



920 GeV HighY – 96 pb^{-1} of $e^{\pm}p$ HERA-II data