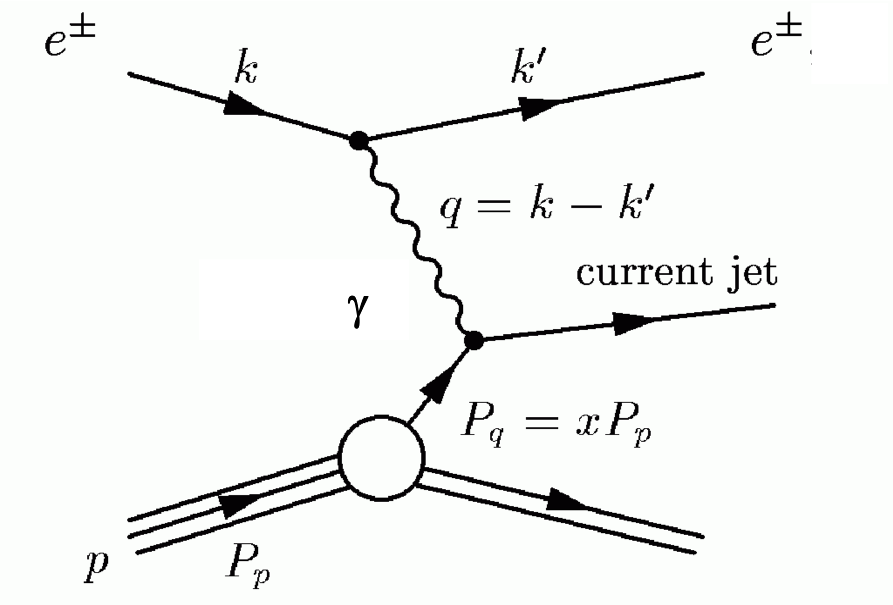
Proton Structure Function F_L at HERA

Burkard Reisert,
Max Planck Institut für Physik,

on behalf of H1 and ZEUS

- **Deep Inelastic Scattering (DIS)**
- **Experimental Setup**
- **Results on FL**
- **Conclusion**

Deep Inelastic Scattering



Center of mass energy $\sqrt{s}$: $s = (k+p)^2$

Kinematic Variables

- **4-momentum transfer resolving power** $Q^2 = -q^2 = -(k-k')^2$
- **Bjørken scaling variable momentum fraction of struck parton** $x = \dfrac{Q^2}{2p \cdot q}$
- **Inelasticity:** $y = \dfrac{p \cdot q}{p \cdot k}$

relation for fixed s: $Q^2 = sxy$

- **Neutral current DIS cross section expressed by structure functions:**

$$\frac{d^2\sigma^{e^\pm p \to e^\pm X}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4} \underbrace{\left(1+(1-y)^2\right)}_{Y_\pm = 1 \pm (1-y)^2} \cdot \left(F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2) \right)$$

reduced cross section

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Deep Inelastic Scattering

Reduced ep DIS
Cross section:

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

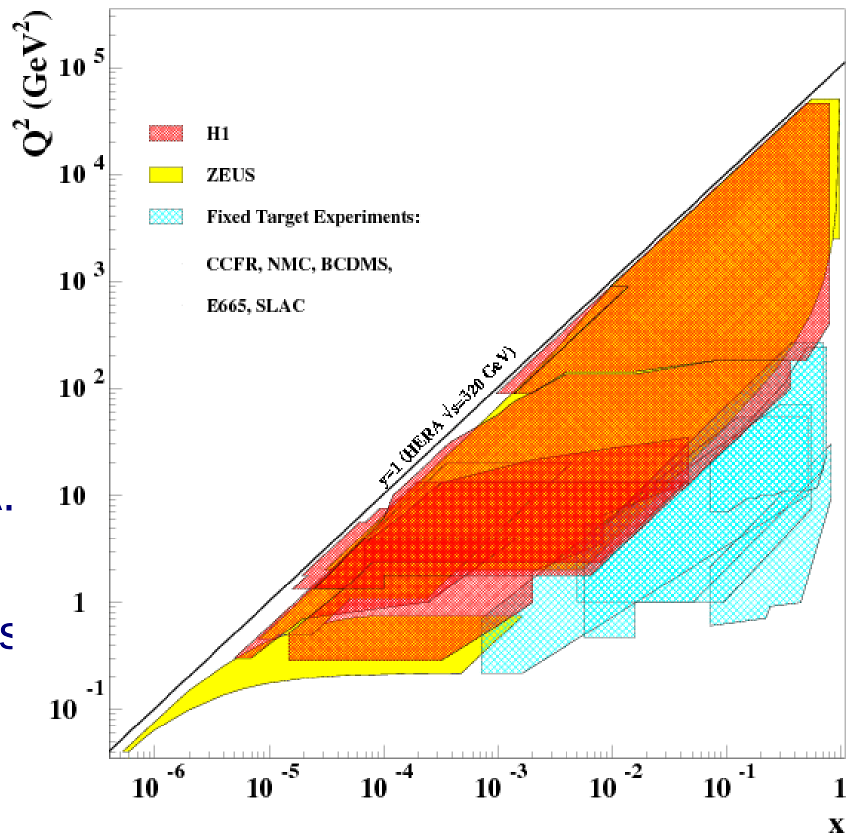
Two proton structure functions define inclusive DIS ep scattering cross section.

F_2 determines sum of quark distributions.

F_L, at low x, determines gluon distribution.

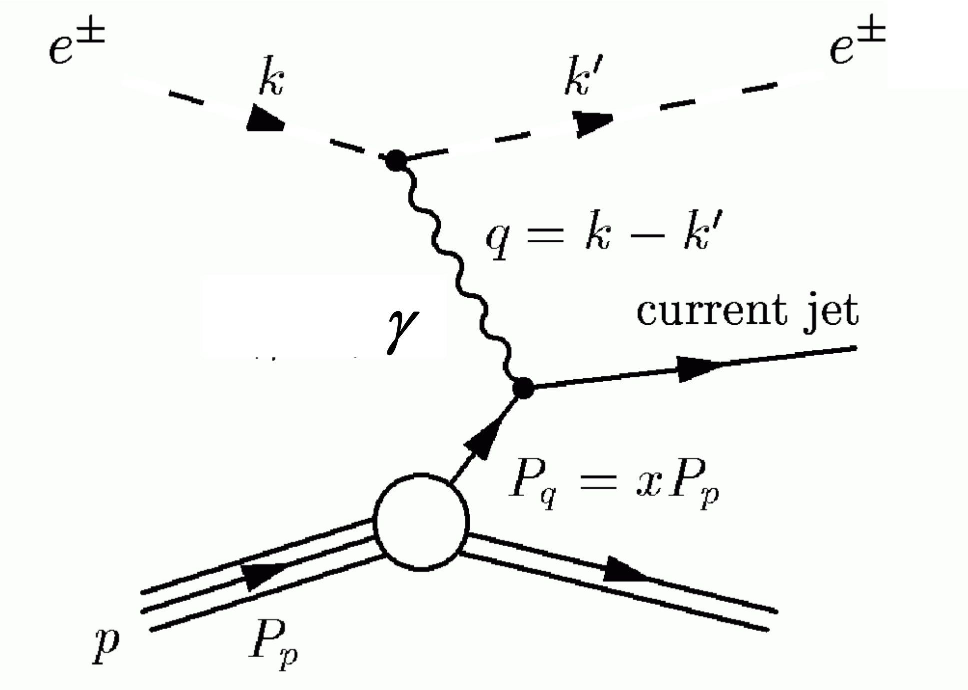
The F2 term dominates the cross section, has been measured for 15 years at HERA.

The F_L term is sizeable only at large values of inelasticity y. It was directly accessed on in the last 4 months of HERA's operation



Photon Proton Scattering

- The same process may be interpreted as scattering of an virtual photon off an proton
- The virtual photon may be transversely or longitudinally polarized



γp Cross Sections:

$$\sigma_T^{\gamma p} = \frac{4\pi\alpha}{Q^2} 2xF_1 = \frac{4\pi\alpha}{Q^2}(F_2 - F_L)$$

$$\sigma_L^{\gamma p} = \frac{4\pi\alpha}{Q^2}(F_2 - 2xF_1) = \frac{4\pi\alpha}{Q^2} F_L$$

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

Quark Parton Model (QPM)

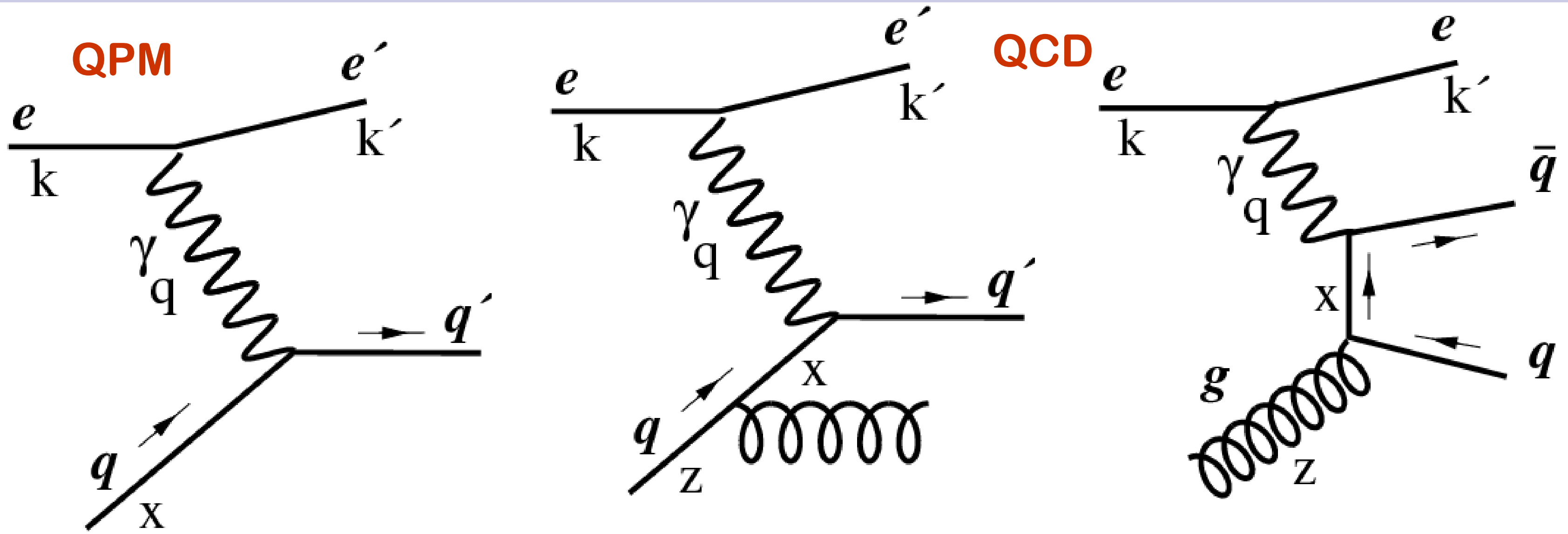
$$F_1(x) = \frac{1}{2x}\sum_q e_q^2 xq(x)$$

$$F_2(x) = \sum_q e_q^2 xq(x)$$

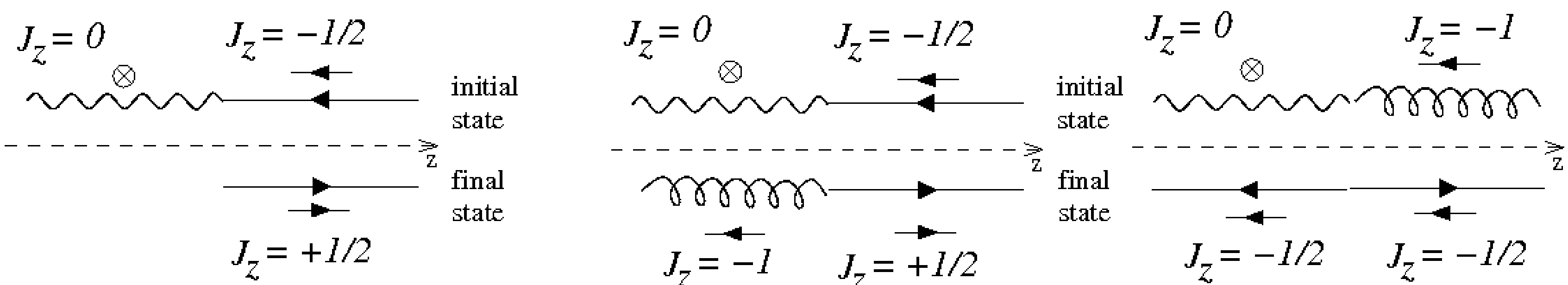
$$F_L(x) = F_2 - 2xF_1 = 0$$

Callan Gross relation

Longitudinal Structure Function F_L



Scattering of longitudinally polarized photons on quarks in helicity frame



J_z conservation not possible

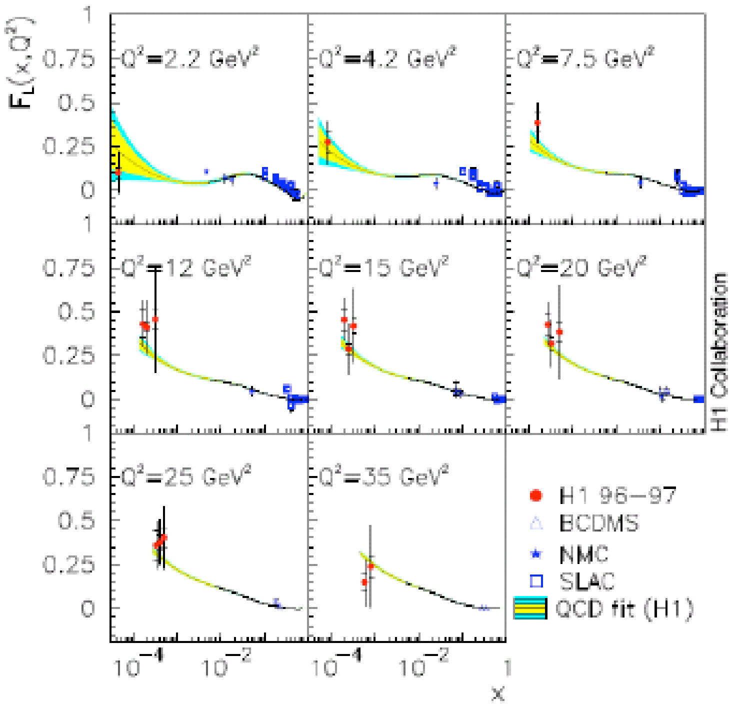
$$F_L \propto \sigma_L = 0$$

$$F_L = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \left[\frac{16}{3} \sum_q z e_q^2 (q + \bar{q}) + 8 \sum_q e_q^2 \left(1 - \frac{x}{z}\right) \cdot z g \right]$$

access to gluon density

Expectations on FL

Experiment



Fixed target: F_L is small at large x (spin 1/2 quarks)
indications for increase towards low x

H1: hints to large F_L when F_2 is assumed to be known

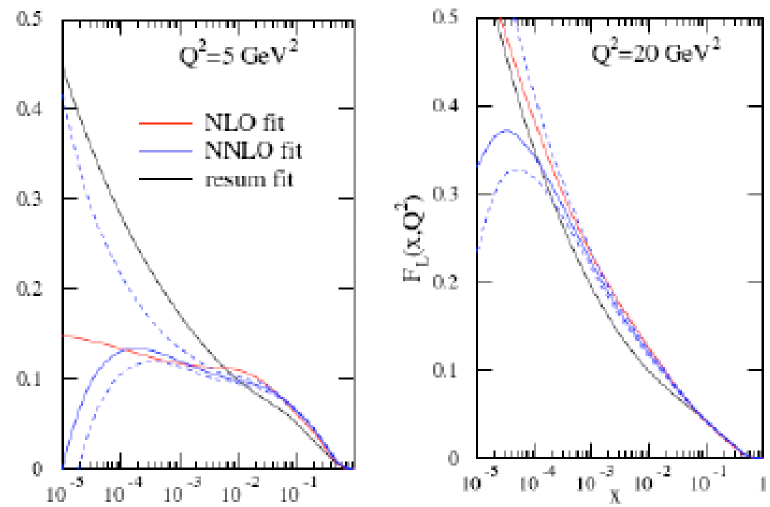
Eur.Phys.J.C21:33-61,2001

Theory (pQCD)

F_L prediction related to the gluon density, the size and the uncertainties on xg - constraints require max accuracy and range

Theory developed to NNLO [W.van Neerven (†), J.Vermaseren, et al.]

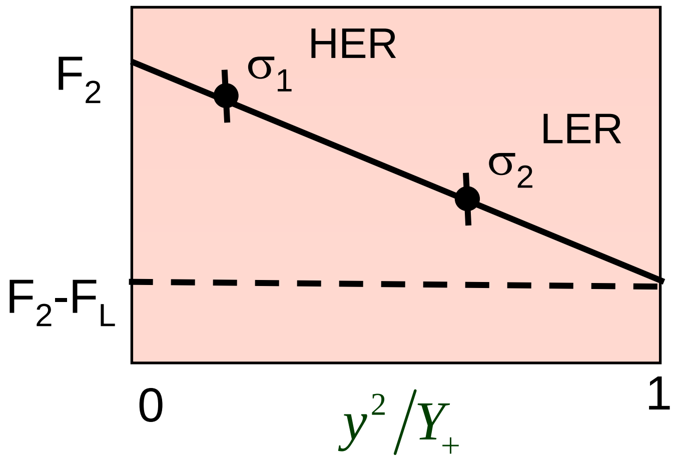
Global/detailed pdf analyses [CTEQ, MRST, Alechin, HERA, …]



R.Thorne, DIS08

How to Measure F_L ?

- **Measure cross sections** $\sigma_r = F_2(x,Q^2) - \frac{y^2}{Y_+} F_L(x,Q^2)$
  at same *x* and Q^2 but different $y = Q^2/x \cdot s$ → vary s



- **Change proton beam energy to change cms energy**
- **Large level arm in y^2/Y_+**
- **Measure at high *y* in LER**

- **Extended measurement to high y region**
  $y = 1 - E'_e/E_e(1-\cos\theta)$ → high *y* means low E'_e

- **Estimate: Need ~10pb^{-1} for measurement**

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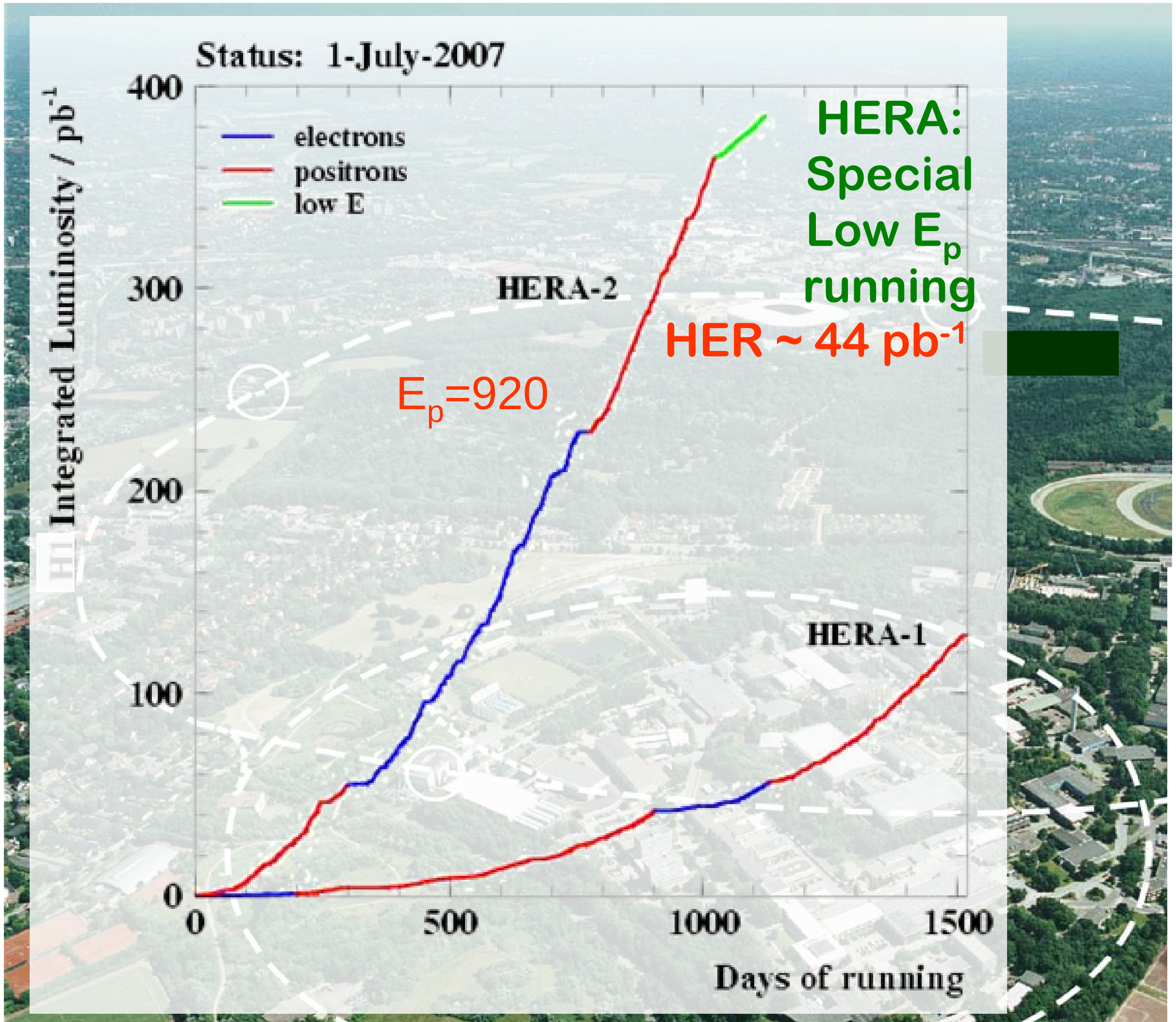
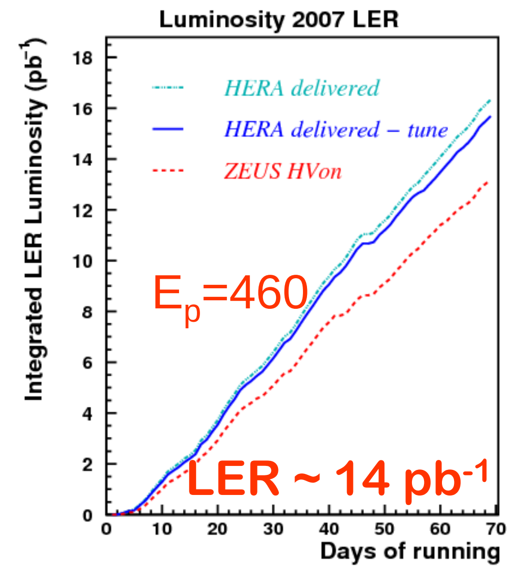
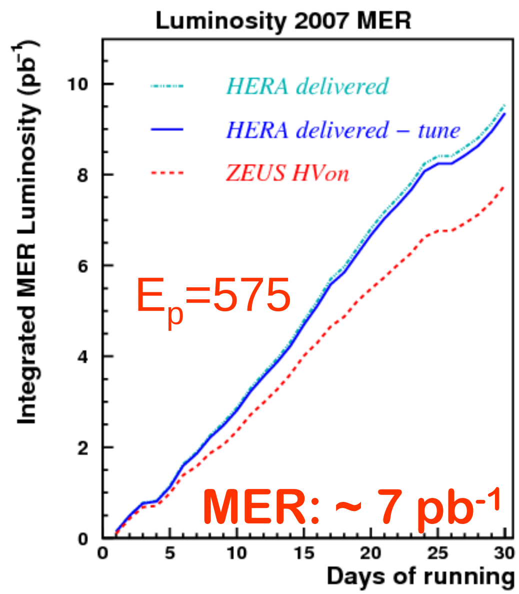
HERA Accelerator Performance



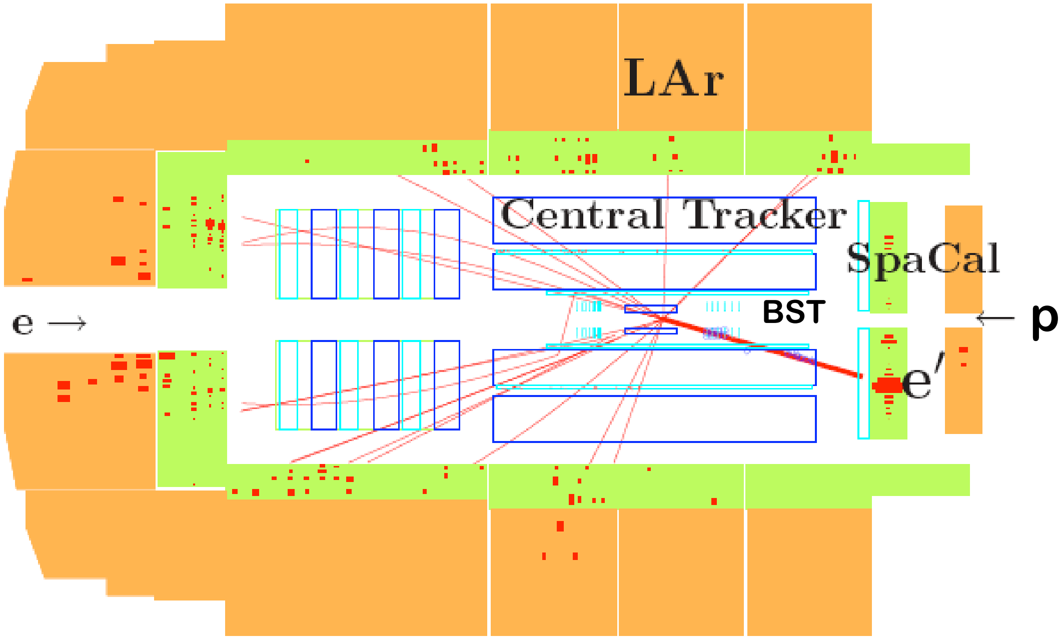




Dedicated data taking for F_L at end of HERA

Measuring F_L with H1

DIS event of Q^2 near 30 GeV^2



Upgrades for FL

SpaCal (94)

BST (95+03)

Triggers (03-07)
- **Inner Chamber (CIP)**
- **SpaCal**
- **Fast Tracking (CJC)**
- **Jet Trigger (LAr)**

Three Q^2 ranges

3 to 12 GeV^2 SpaCal+BST prelim. 04/09
12 to 90 GeV^2 SpaCal+CT: published 08
35 to 800 GeV^2 LAr+CT: prelim. 03/08

Event selection Criteria

El. in SpaCal or LAr (Calo & Trig) E'_e >3 GeV
Track in CT or BST (veto neutrals, e/p)
Interaction vertex
$E\text{-}P_z = \Sigma_i E_i(1-\cos\theta_i)$ >35 GeV
Reduces largely radiative corrections

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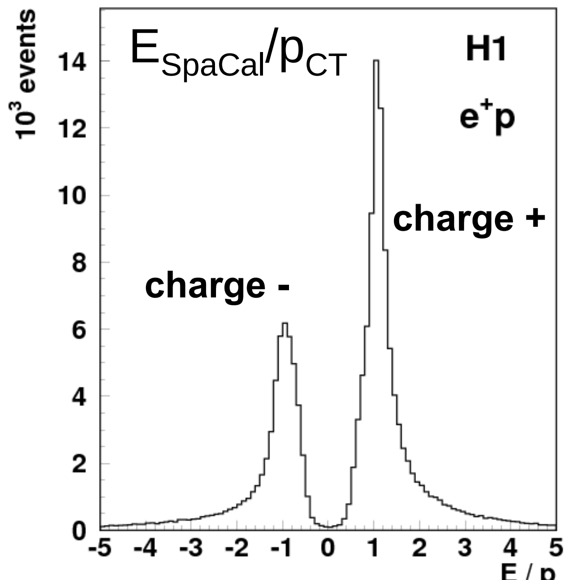
Background Subtraction – H1

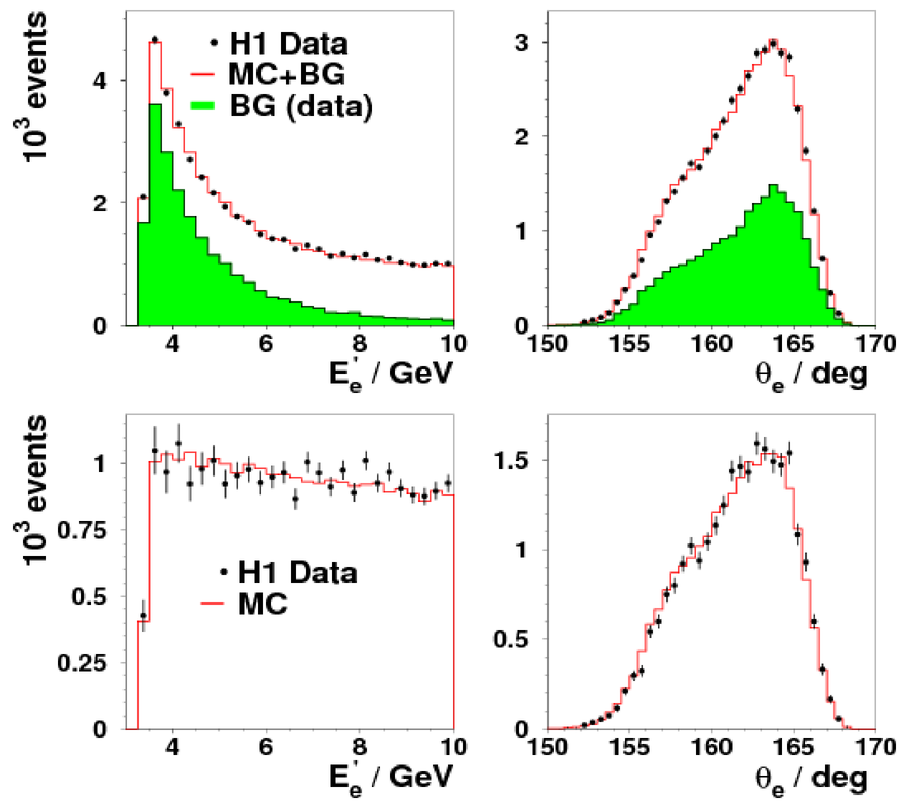
At small energies severe contamination by γp events.

Those are charge symmetric, apart from small effects due to anti-proton vs protons, which is measured using e+p and e-p data, and corrected for



H1 has tracking coverage for the electron candidates for all full Q2 ranges (CT & BST)

Scattered electron distributions (SpaCal + CT)



H1 background subtraction based on data. Trade off between background rejection and stat. unc. of background sample (wrong chrg.)

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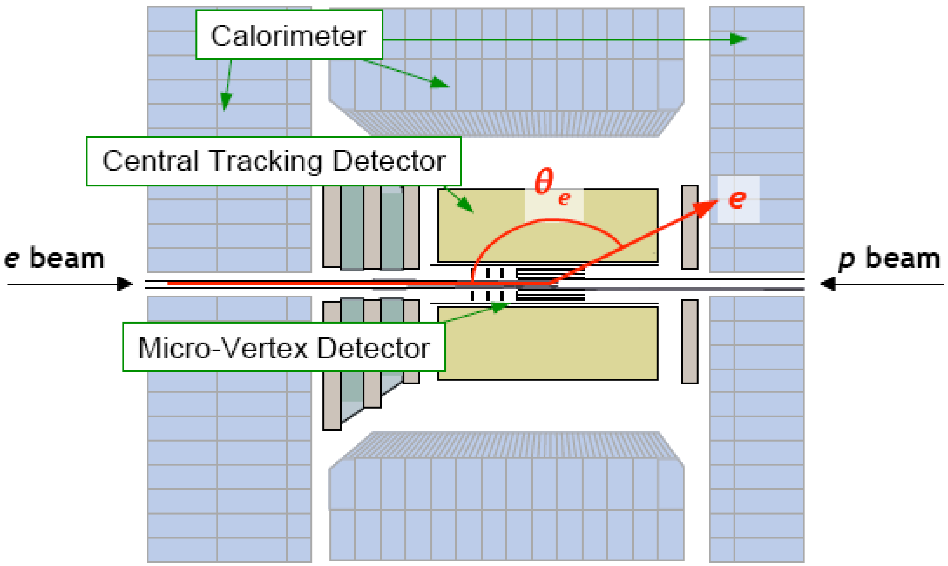
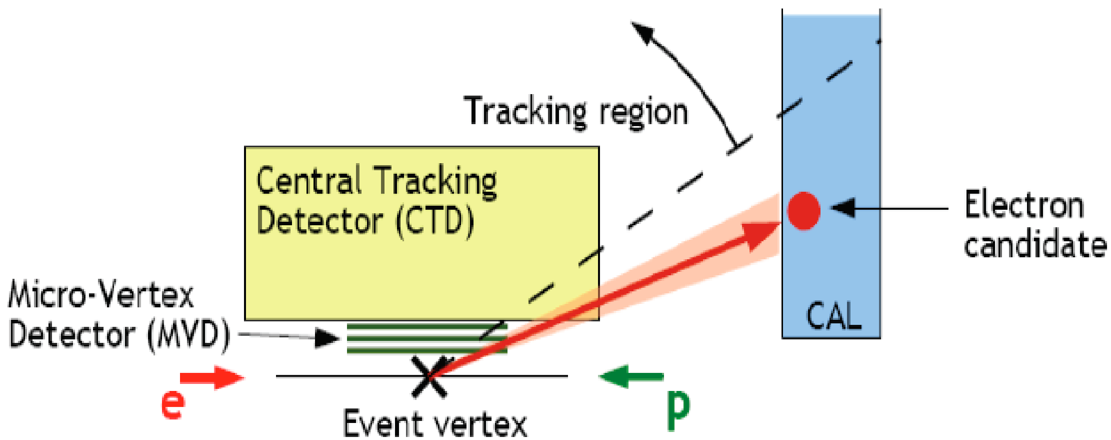
Measuring FL with ZEUS



Event Selection:

Electron in backward Calo
E'$_e$ >6 GeV (Cluster & Trigger)
Hits in CTD & MVD (reject neutrals)
Event vertex
42 < E-p_z < 65 GeV

Q^2 range between 24 and 110 GeV^2



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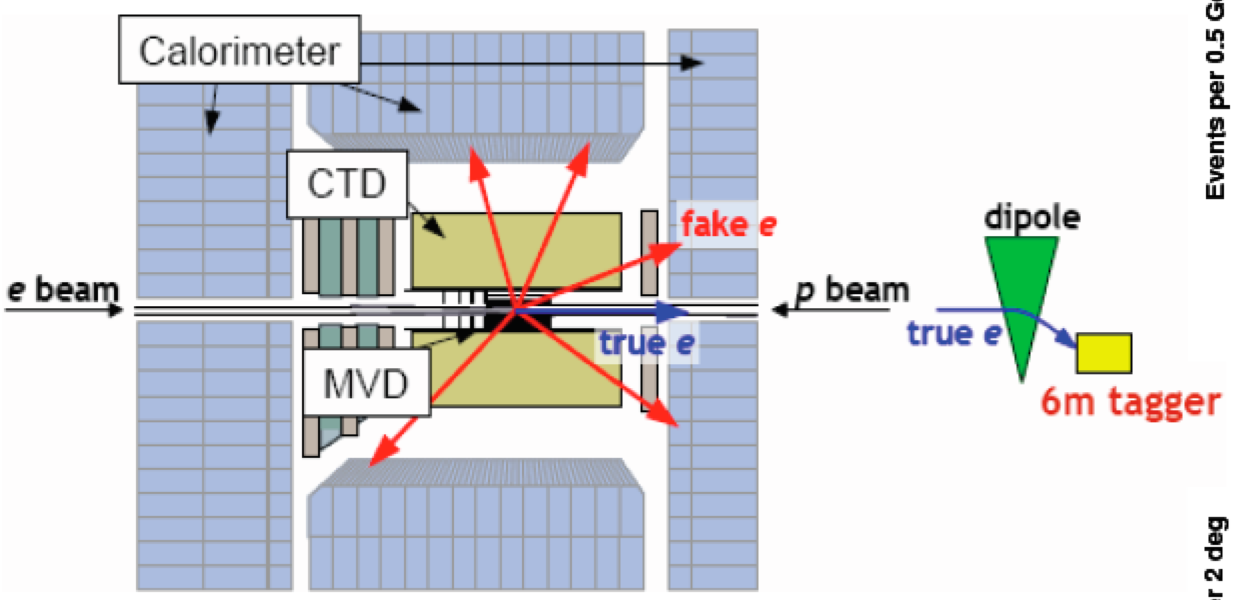
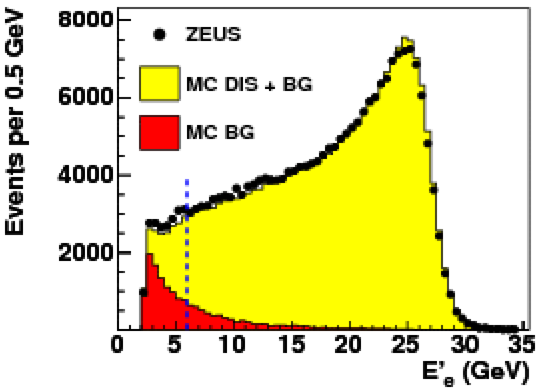
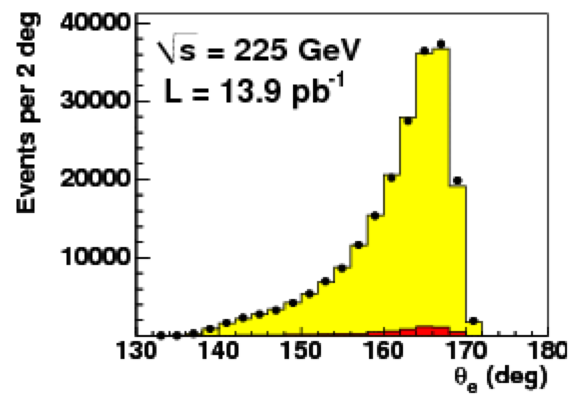
Background Subtraction - ZEUS





ZEUS



Photoproduction BG removed using PYTHIA MC with subprocesses (direct, resolved, diffractive,…) weights Adjusted to γp cross section measurement.
Control using 6m electron tagger. Complimentary studies with γp enriched data sample.

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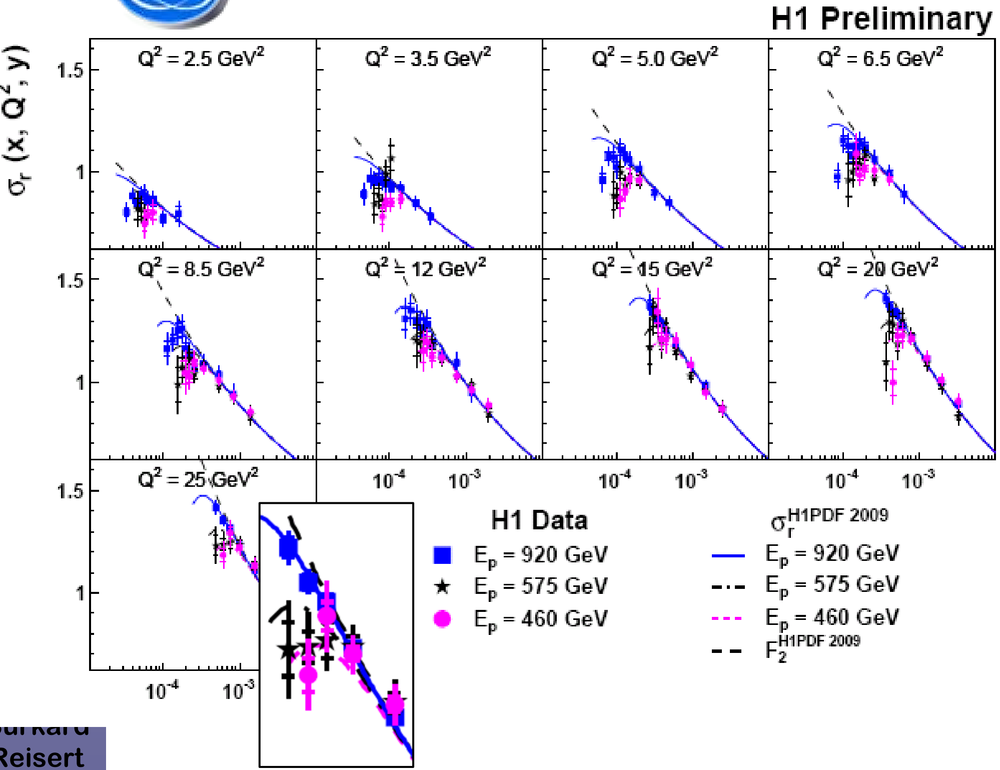
Cross Sections for direct FL extraction

Direct F_L measurement requires measurement of the reduced cross sections at **same x and Q^2 but different y:**

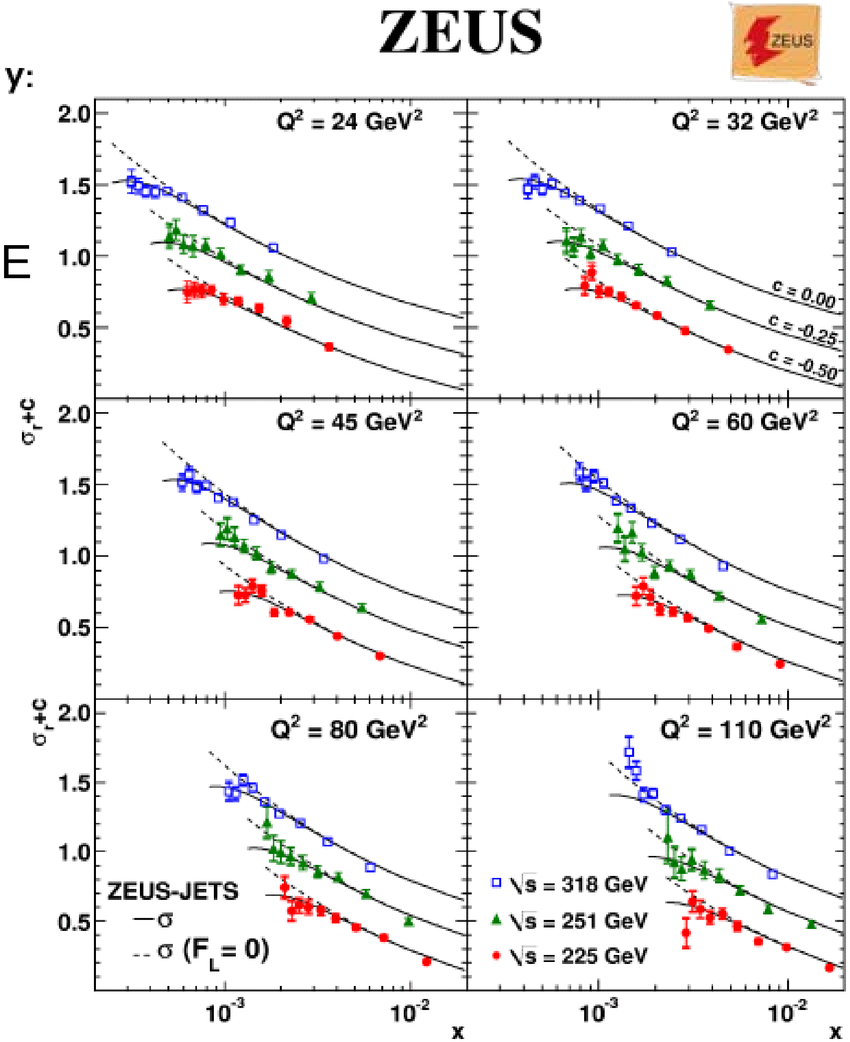
$$\sigma_r(x, Q^2, y) = F_2(x, Q^2) - \frac{y^2}{Y_+} \cdot F_L(x, Q^2)$$

$$y = \frac{Q^2}{x \cdot s}$$

different y → different s → different beam E



Turnover due to F_L small but visible



most precise σ_r from ZEUS

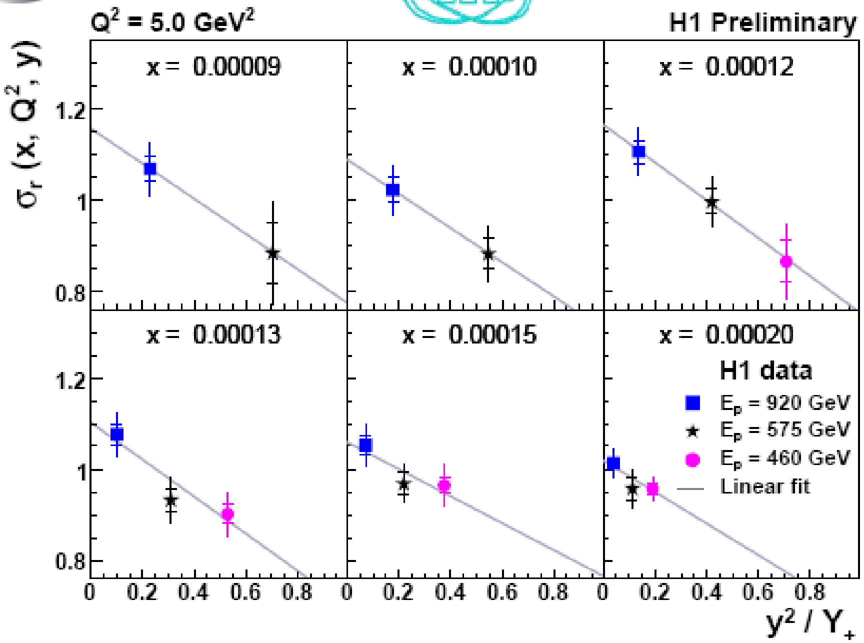
arXiv:0904.1092v1

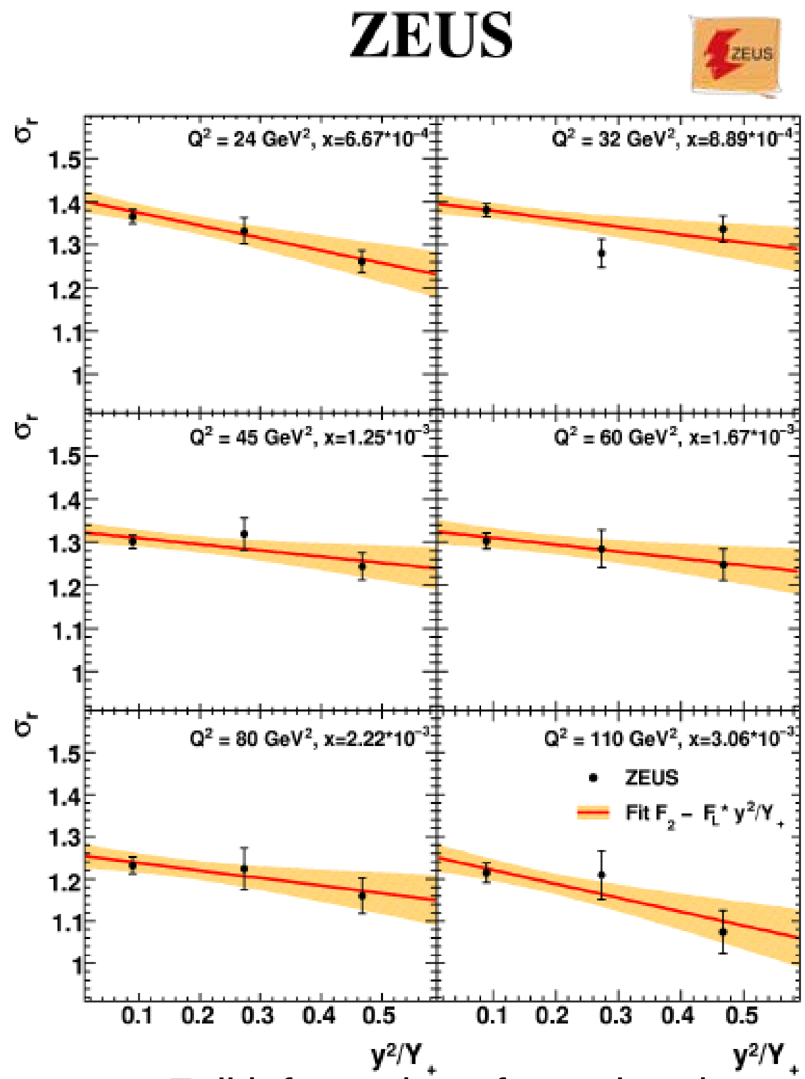
F_L Extraction: Rosenbluth plots

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

Straight line fit of σ_r vs y^2/Y_+

F_L slope, F_2 intercept





Full information of correlated systematics taken into account

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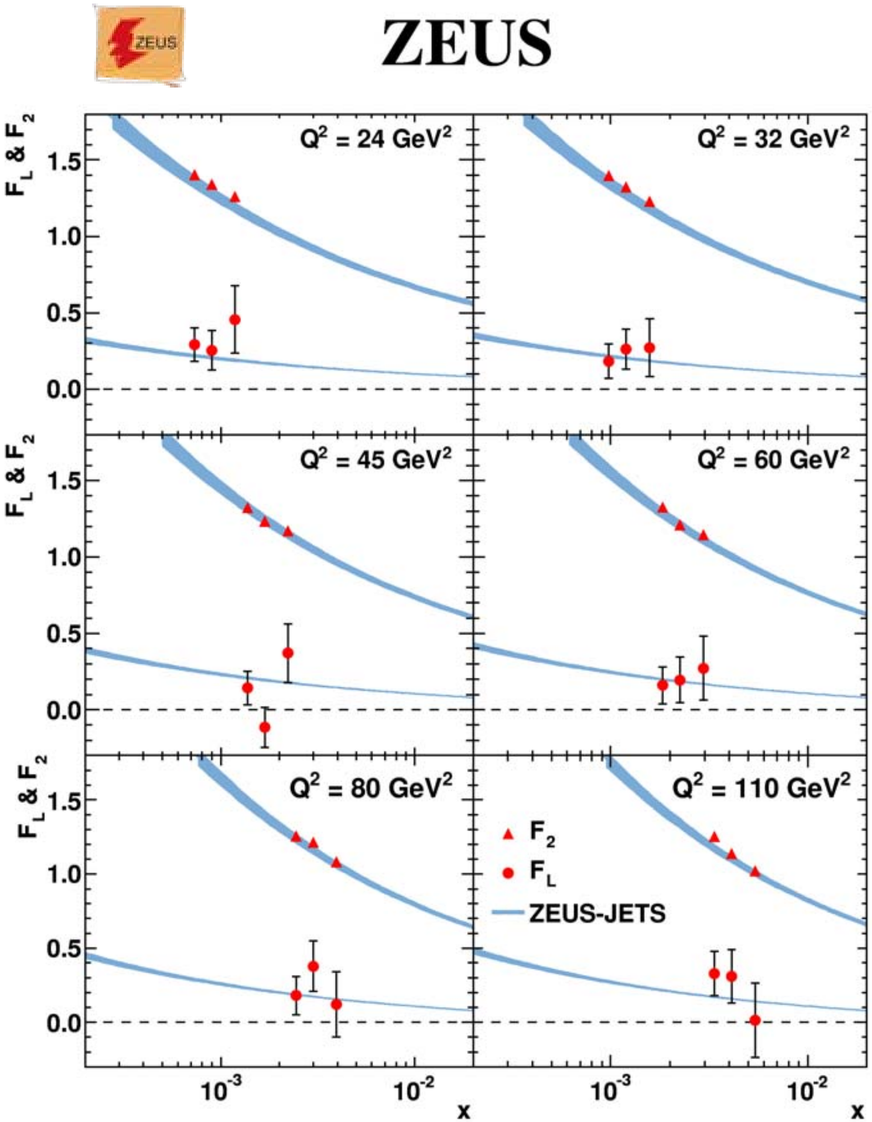
Extracted F_L and F_2 – ZEUS



- Most precise F_2 measurement from ZEUS in kinematic region studied
- First F_2 measurement without assumptions on F_L
- Data support a non-zero F_L
- Predictions for F_2 and F_L are consistent with data

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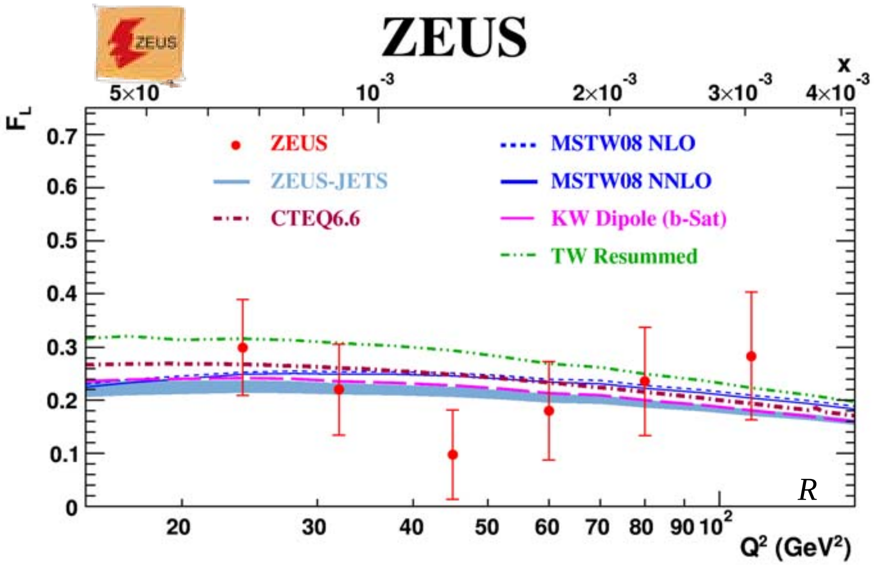
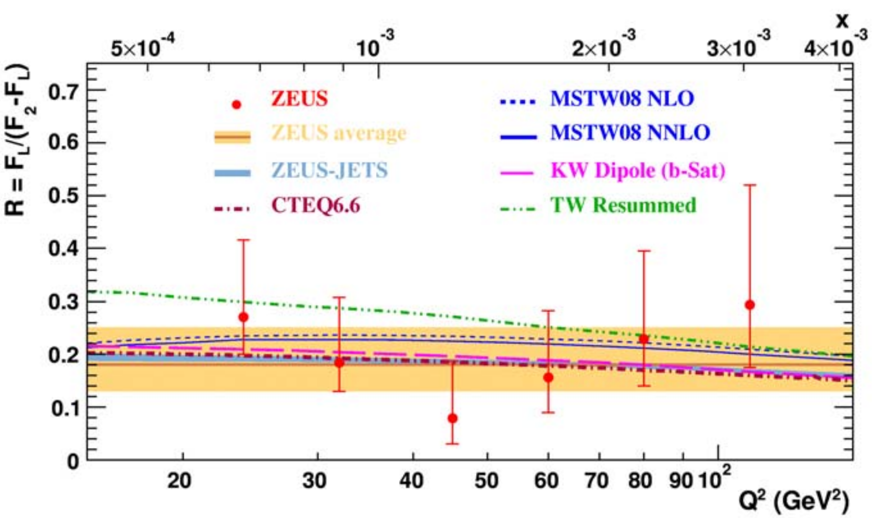
Average F_L and R – ZEUS





Averaged FL

- Data support non-zero FL
- Predictions are consistent with data

Averaged $R = F_L/(F_2-F_L)$

- $R = 0.18^{+0.07}_{-0.05}$

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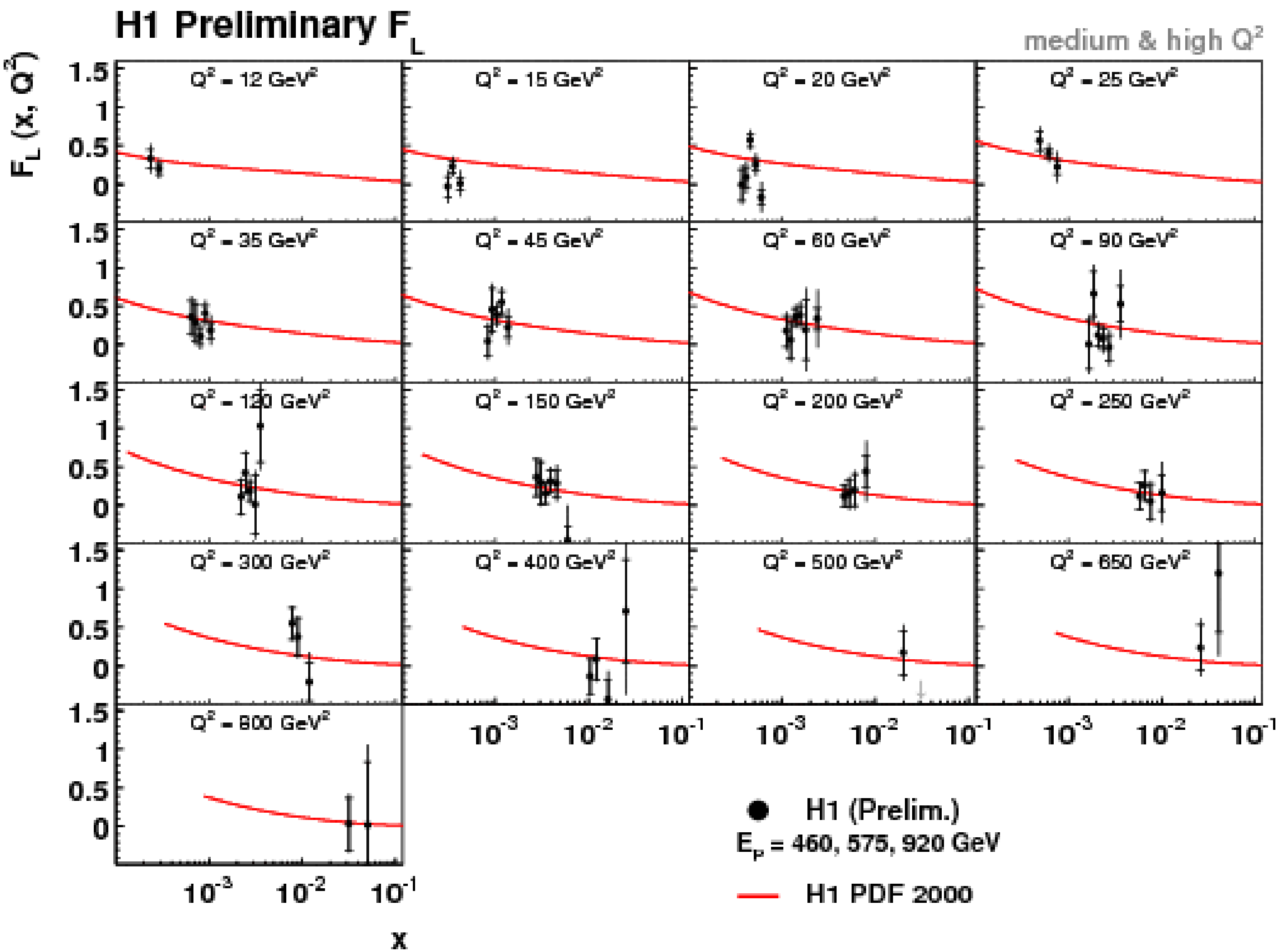
Extracted F_L – medium & high Q^2



Medium Q2 published in Phys. Lett. B665, p. 139

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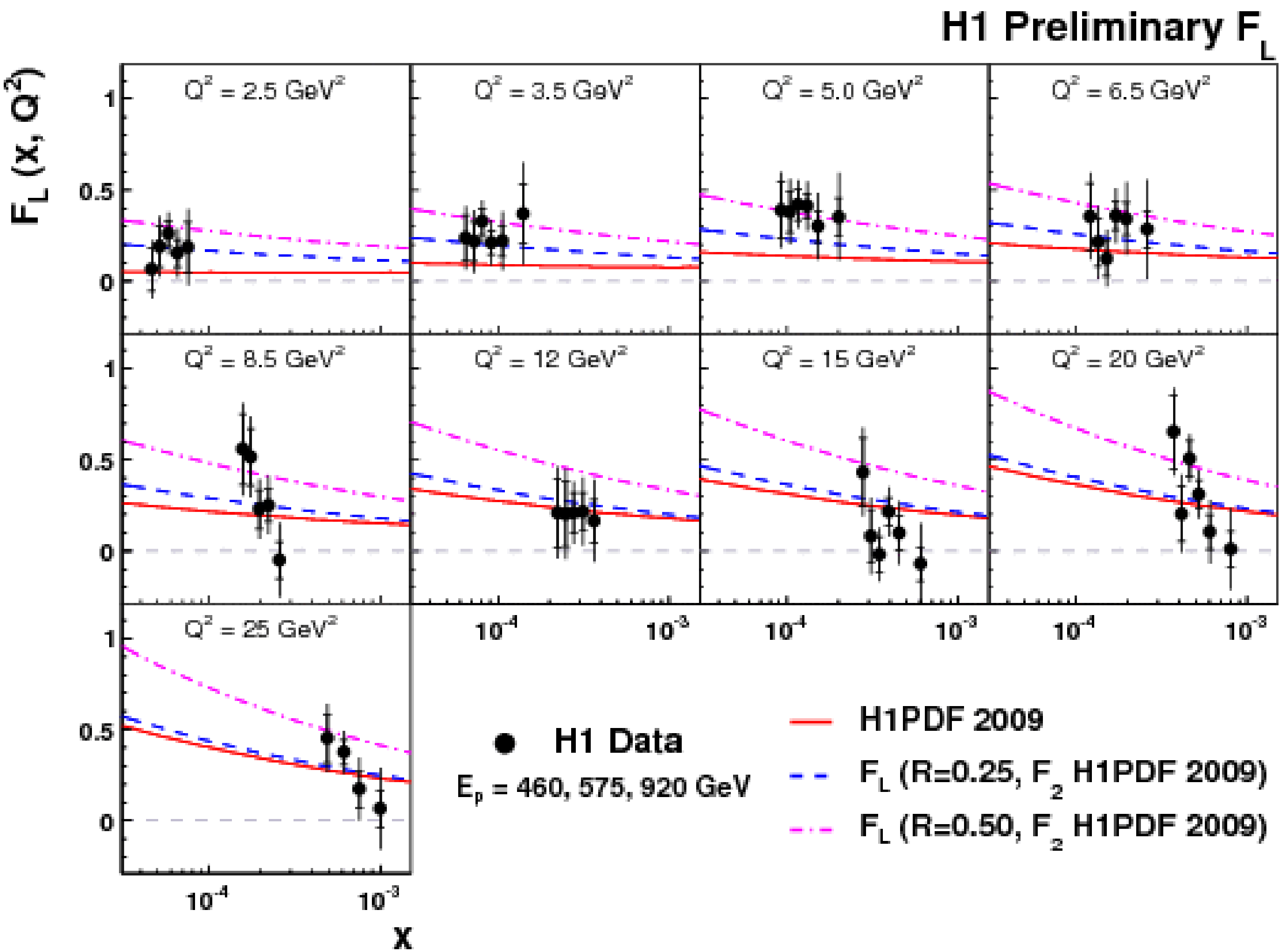
Extracted F_L – Low Q^2



F_L measured down to $Q^2 = 2.5$ GeV^2 !

Data are consistent with R~0.25 ($F_L = 0.2 \cdot F_2$)

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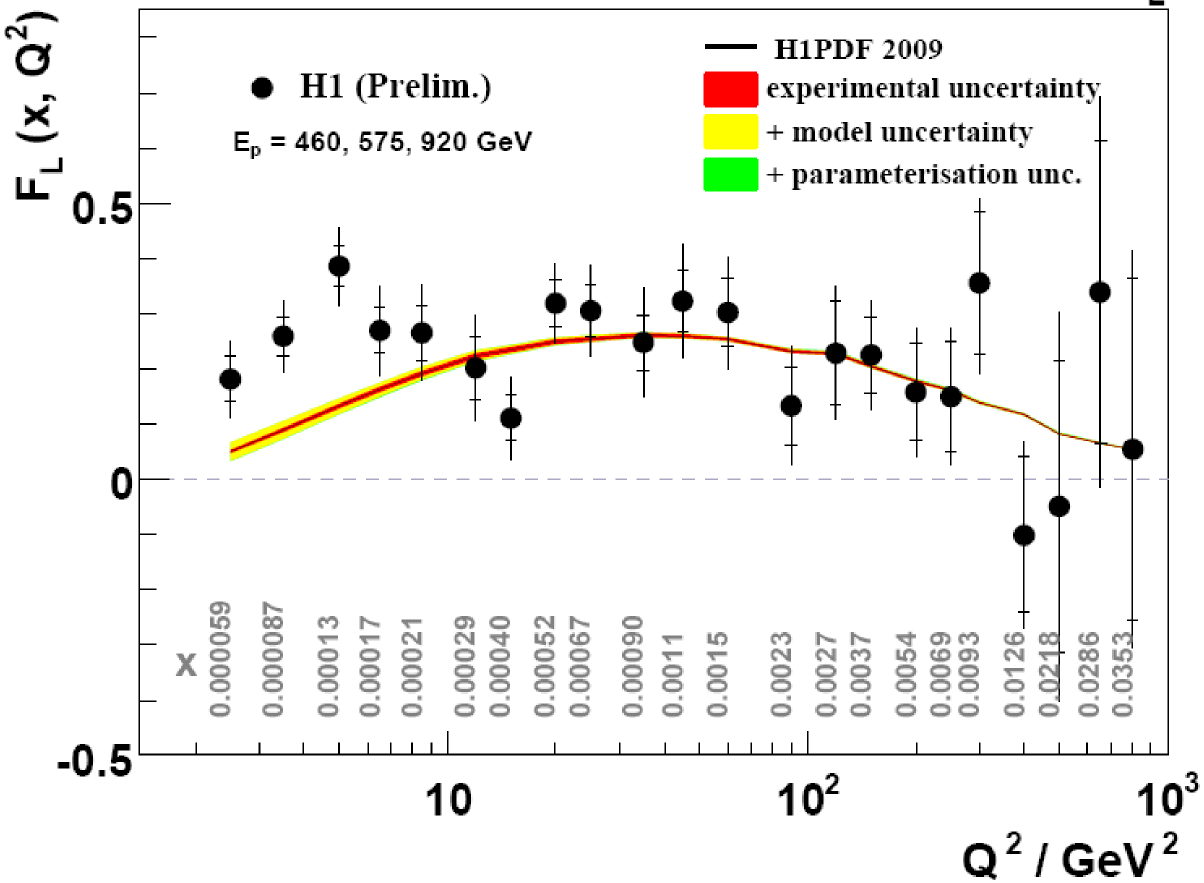
Average F_L – H1



H1 measurements cover $2.5 \leq Q^2 \leq 800$ GeV^2 and $0.00005 \leq x \leq 0.05$
For $Q^2 \geq 10$ GeV^2, agree well with H1PDF 2009 prediction.

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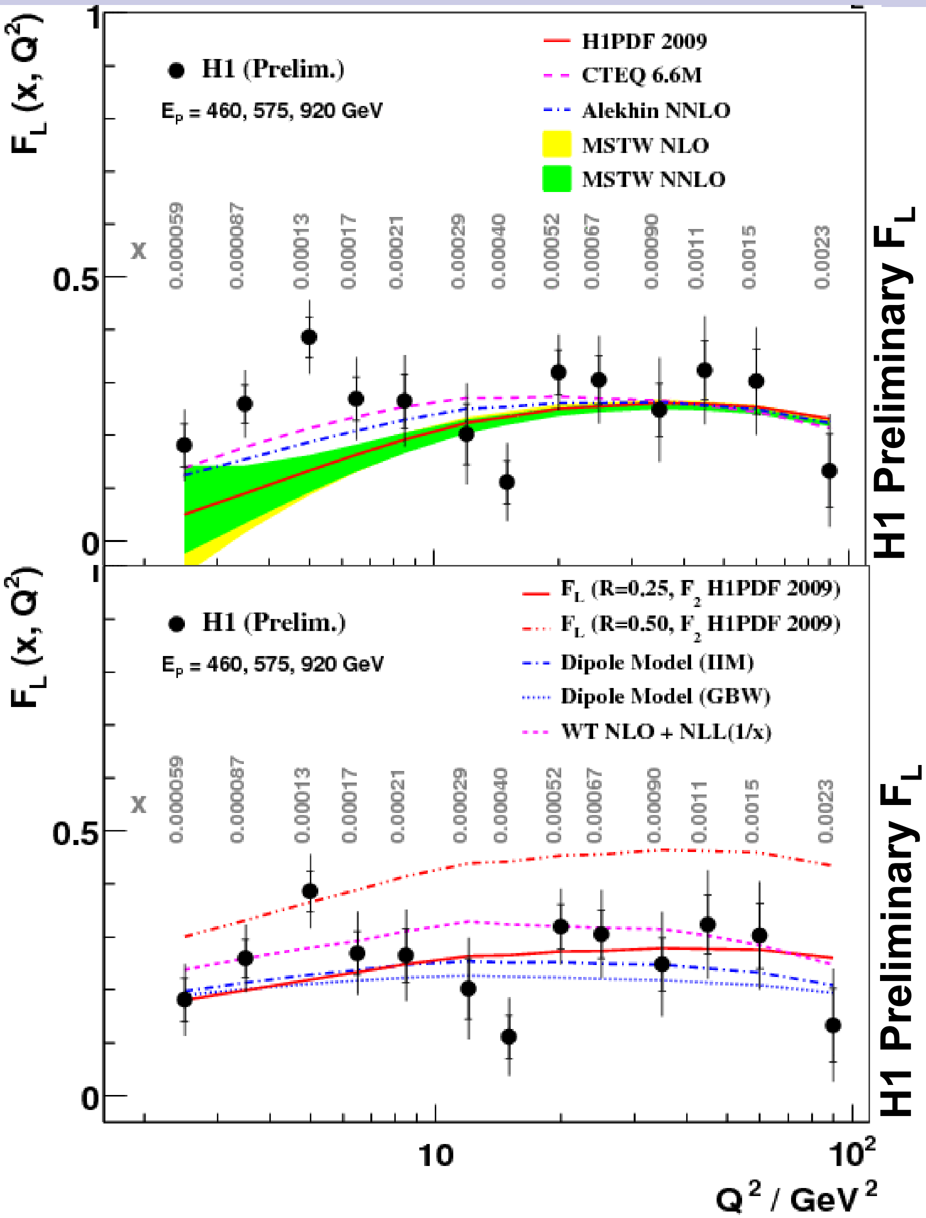
Average F_L < 100 GeV^2



- MSTW and H1PDF 2009 predictions use the same heavy flavour scheme to calculate F_L.
- Data agree better with calculation of CTEQ (and Alekhin)
- Data is consistent with constant $R \sim 0.25$.
- Good agreement with IIM and GBW dipole models, NLL(1/x) prediction.

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Summary and Outlook

Longitudinal structure function F_L has been measured by H1 & ZEUS

FL has thus been measured for the first time in a new kinematic range:
Q^2 = 24 -110 GeV^2 (ZEUS) and 2.5 - 800 GeV^2 (H1), x = 0.00005 - 0.05

Data are consistent with constant R ~ 0.2 (H1), $R = 0.18^{+0.07}_{-0.05}$ (ZEUS)

For $Q^2 > 10$ GeV^2, data are in good agreement with pQCD predictions and thus confirm expectations on the behaviour of *xg* in the DIS kinematic region.

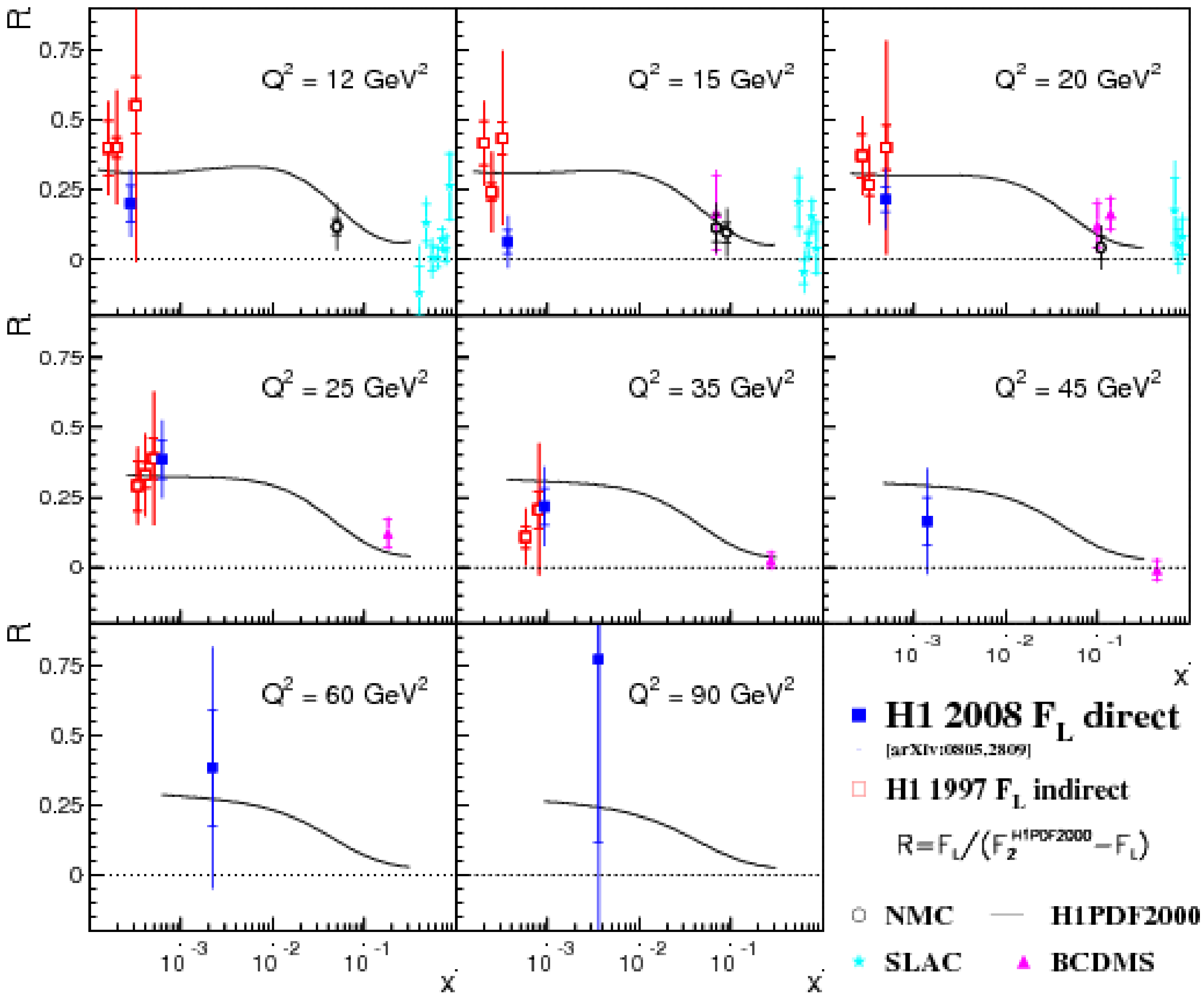
Measured F_L is higher than the predictions of MSTW at NLO and NNLO as well as H1PDF2009 for $Q^2 < 10$ GeV^2, agree better with the CTEQ 6.6M and Alekhin NNLO predictions.

The FL data thus can be expected to further constrain low x theory.

Backupslides

- FL compare direct to indirect measurements
- ZEUS Control Plots
- H1 Control Plots
- H1 cross sections
- H1 FL (x,Q2)
- H1 averaged FL(Q2)

F_L direct vs. indirect Measurements



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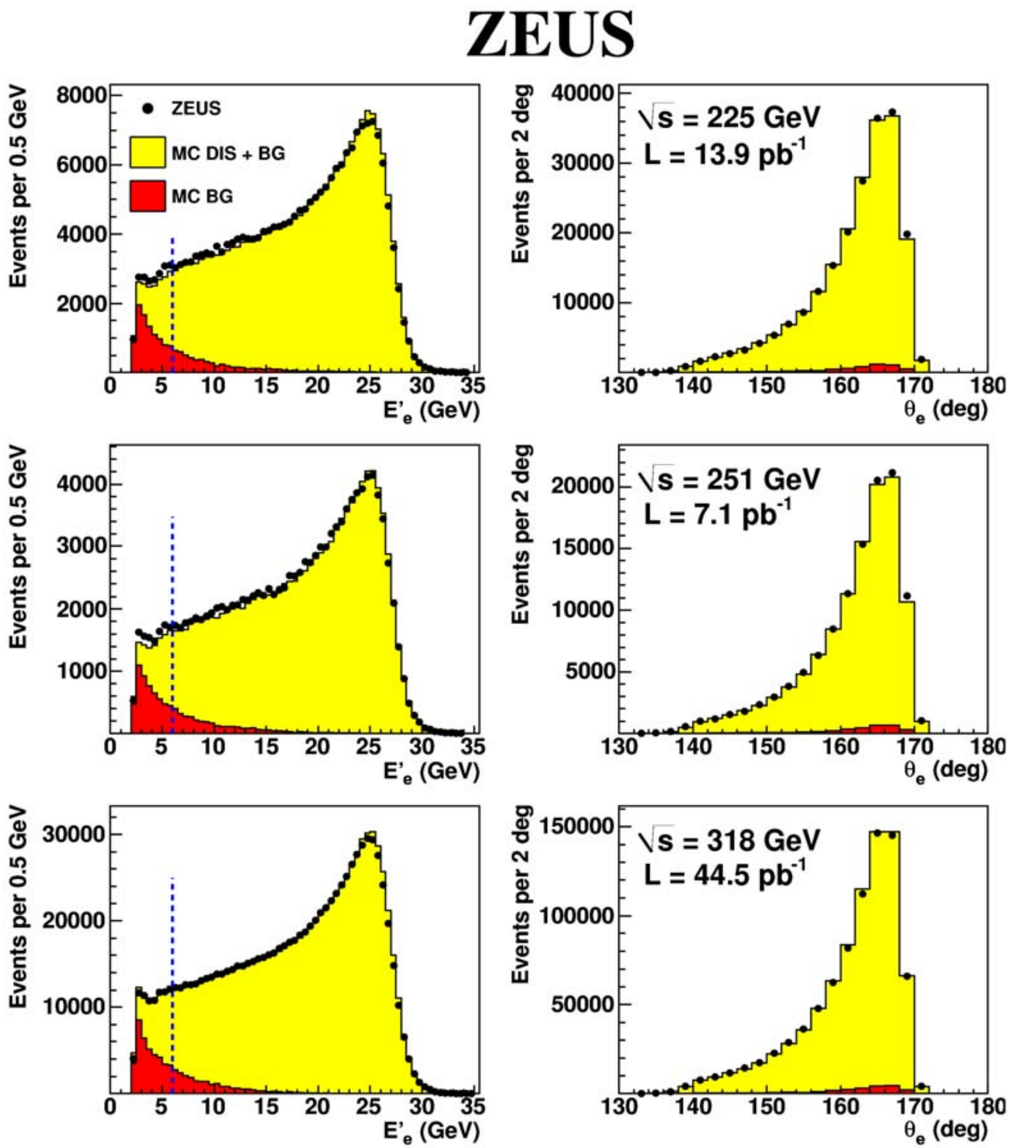
ZEUS Control Plots



Low Energy Run

Ep=460GeV

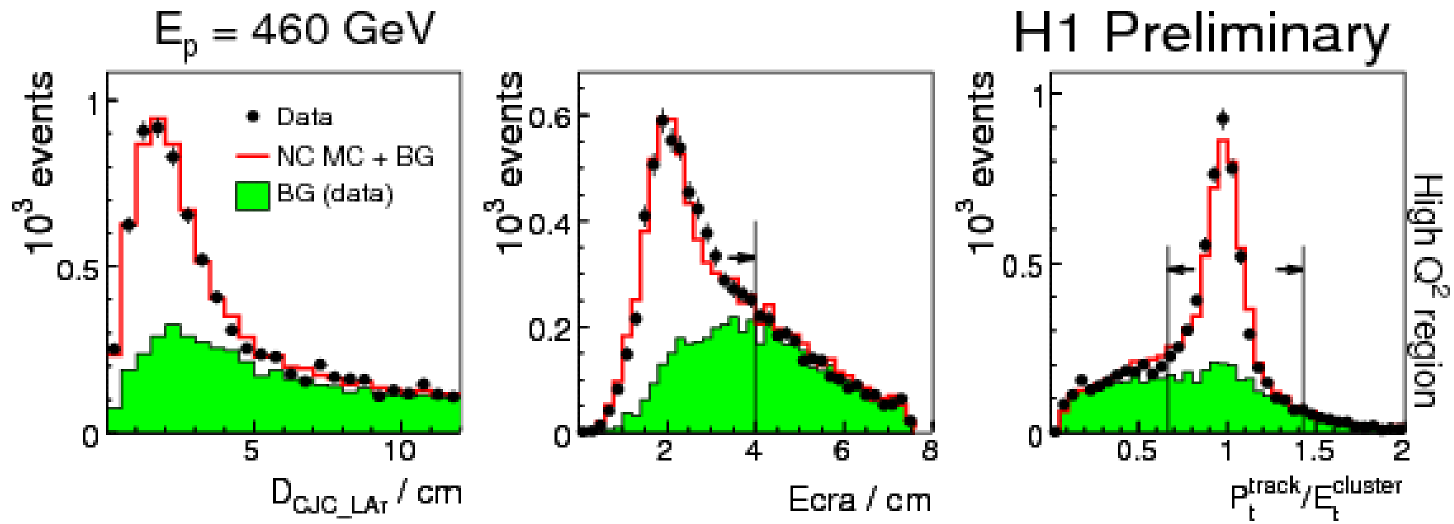
Medium Energy Run

Ep=575GeV

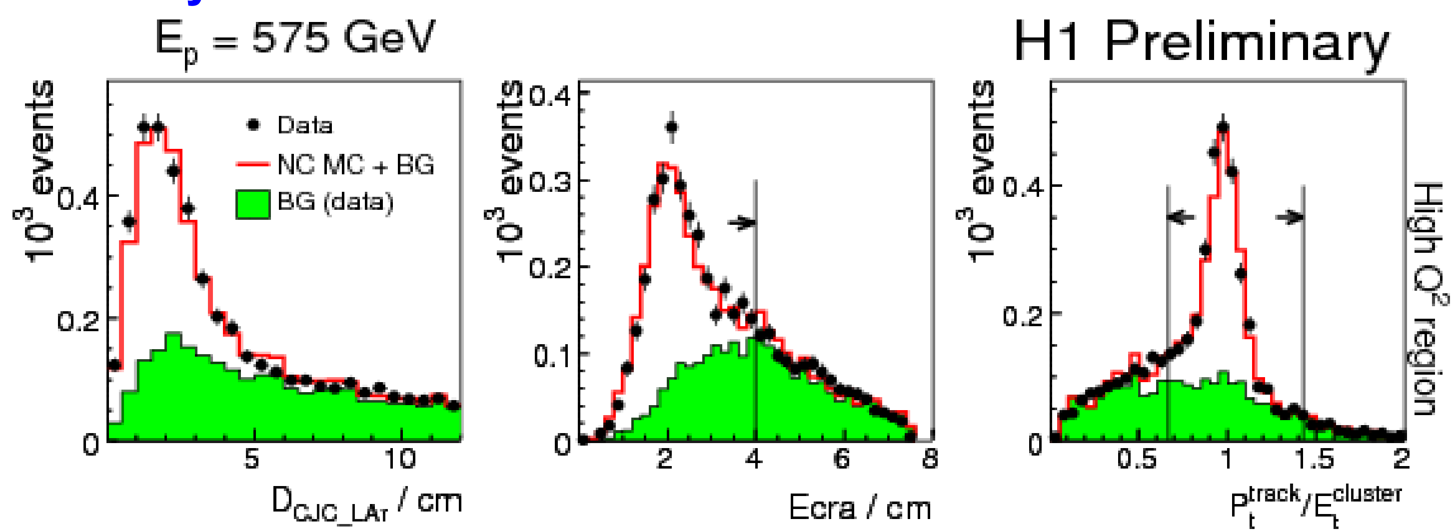
High Energy Run

Ep=920GeV

H1 Control Plots: Electron Variables



High Q2 Analysis



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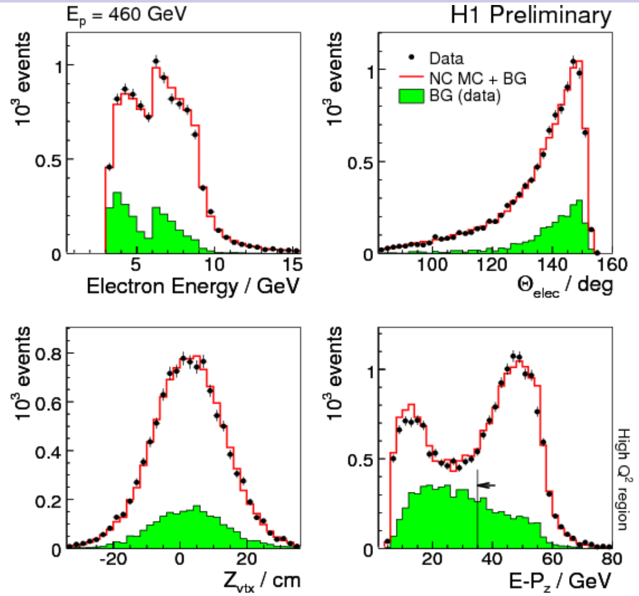
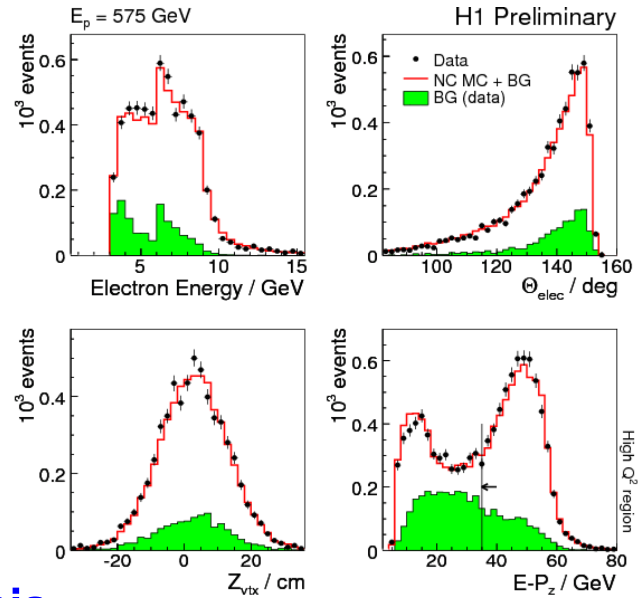
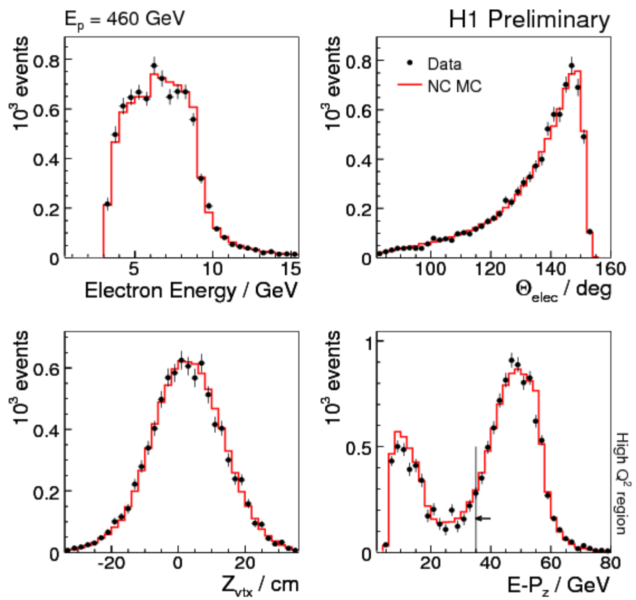
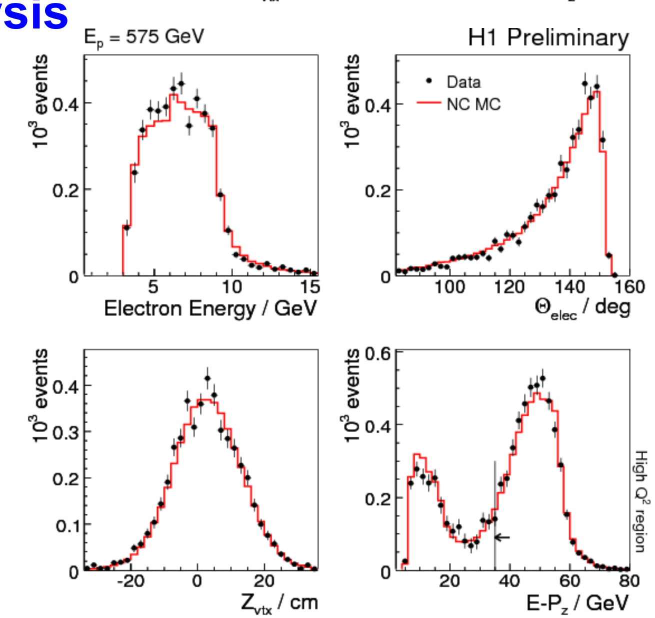
H1 Control Plots: BG Subtraction





High Q2 Analysis





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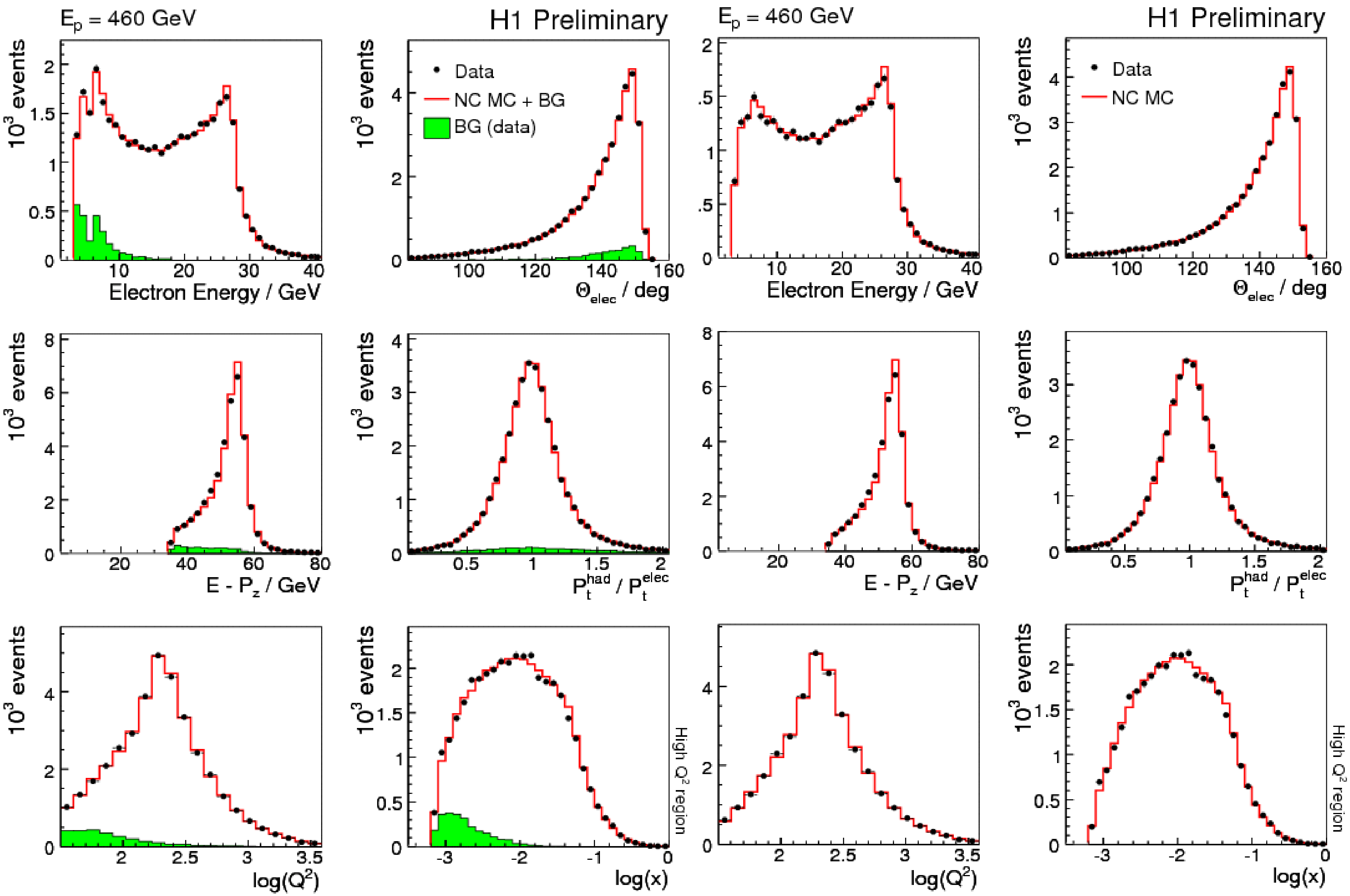
H1 Control Plots: Event Variables



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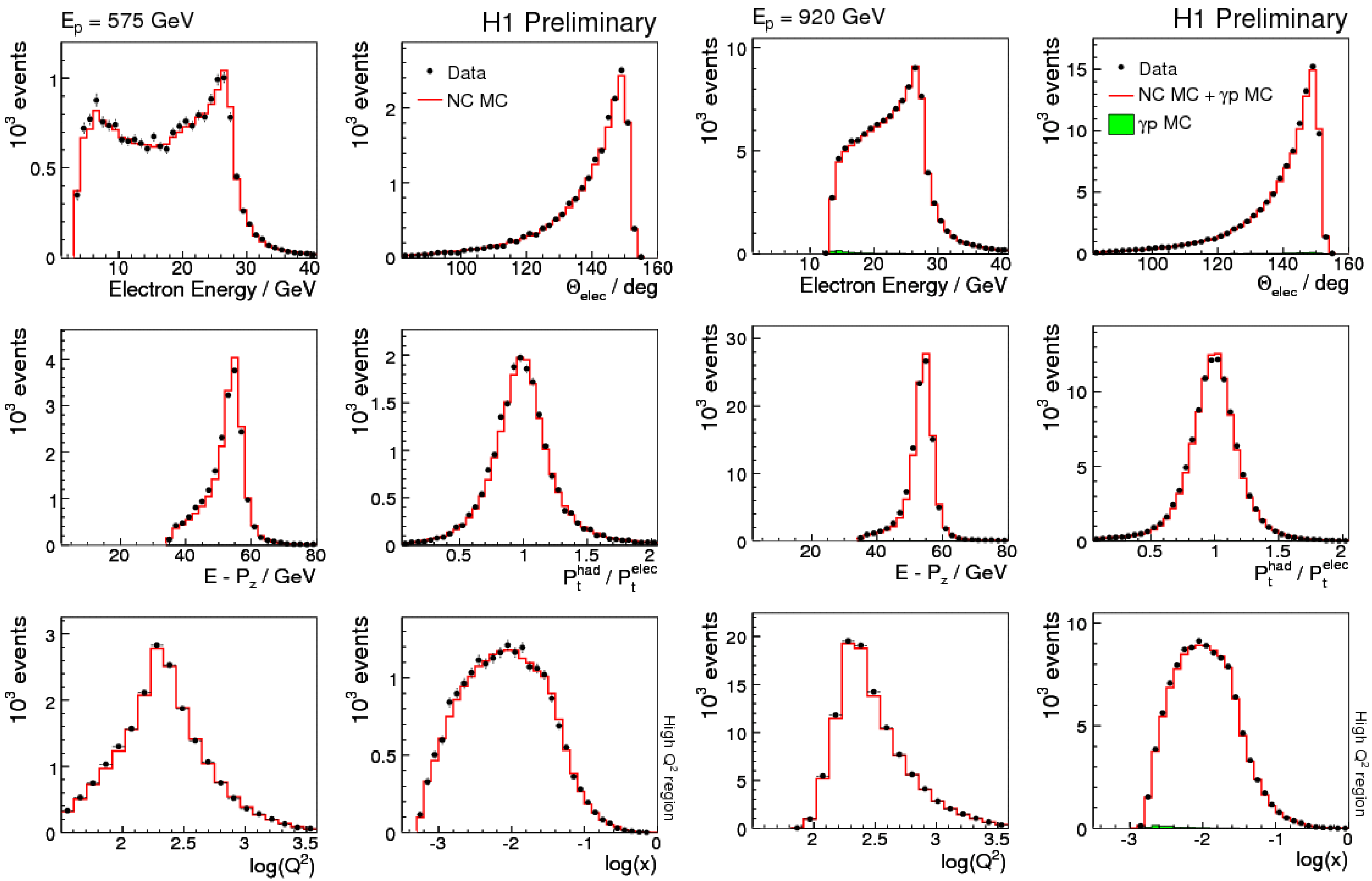
H1 Control Plots: Event Variables



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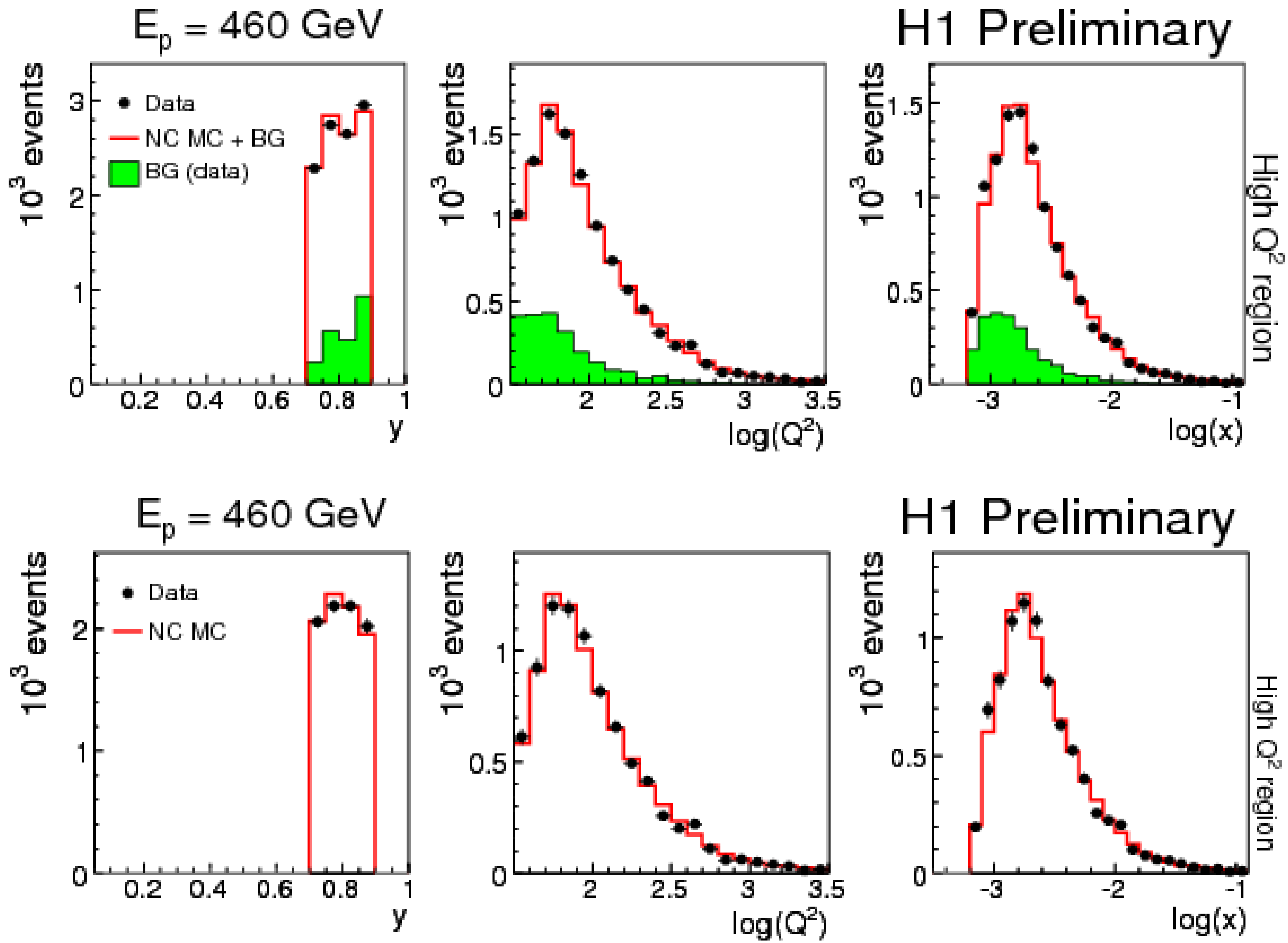
H1: Kinematic Variables



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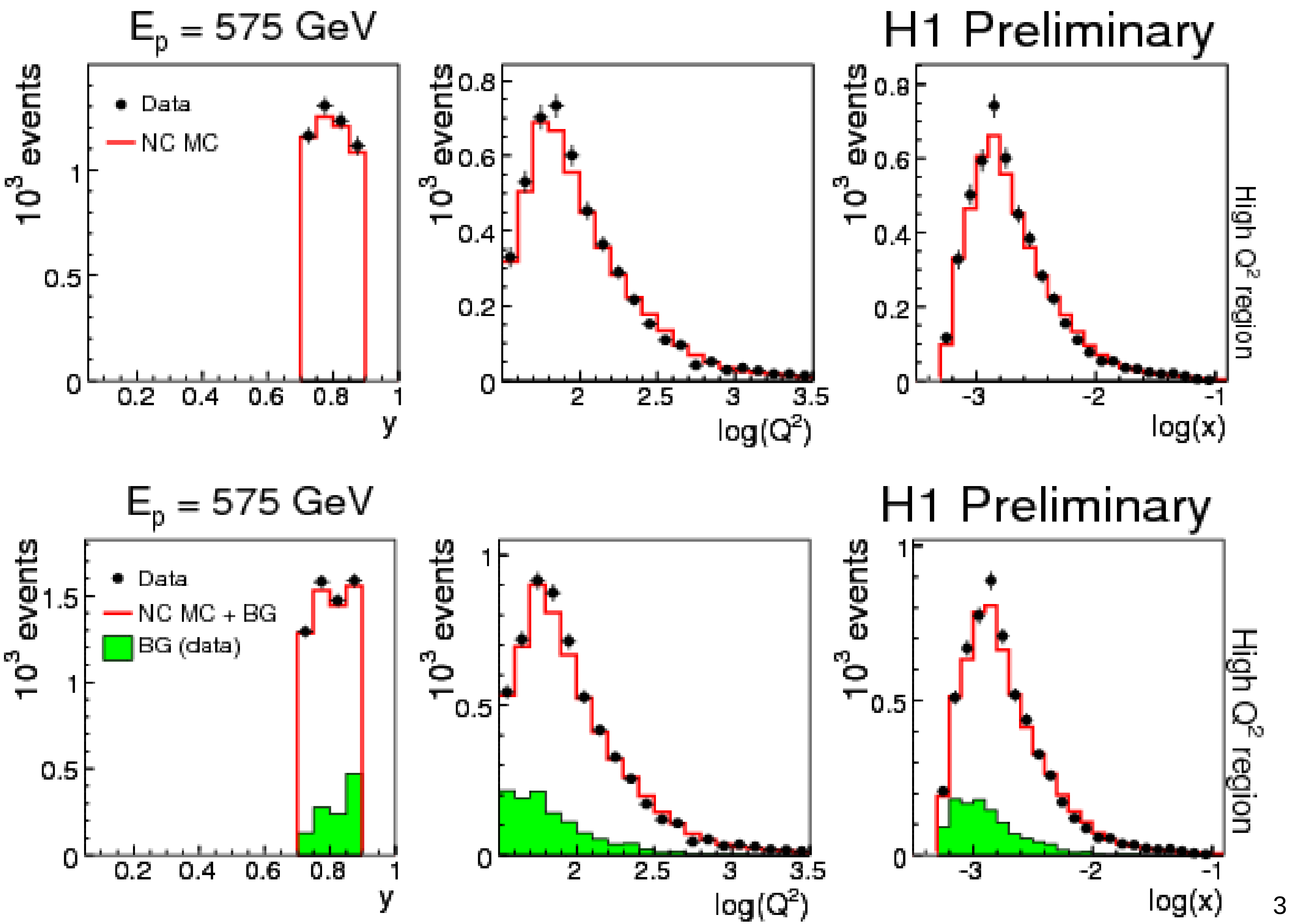
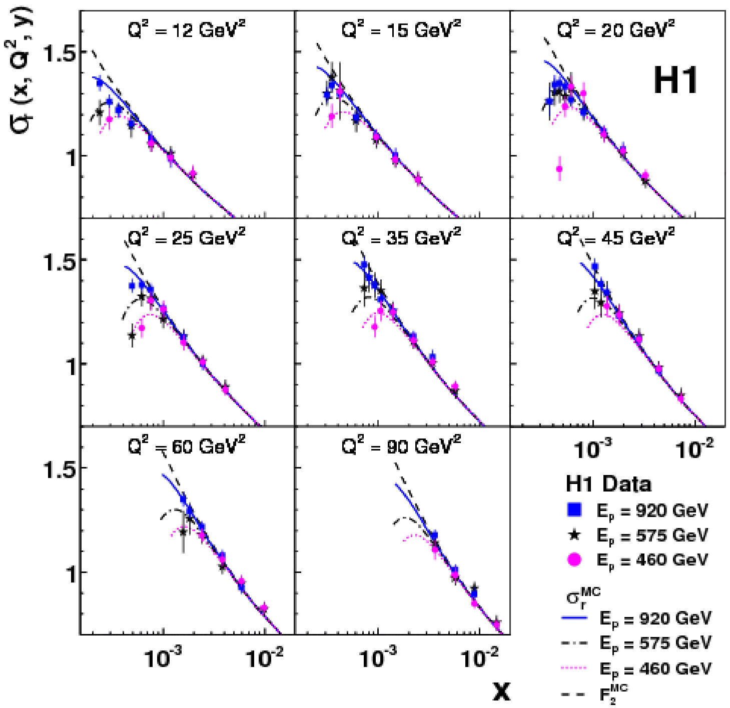
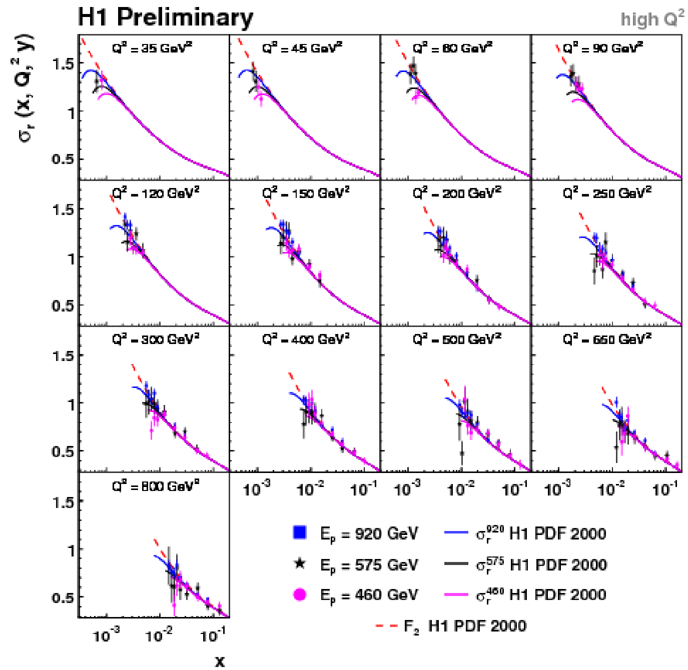
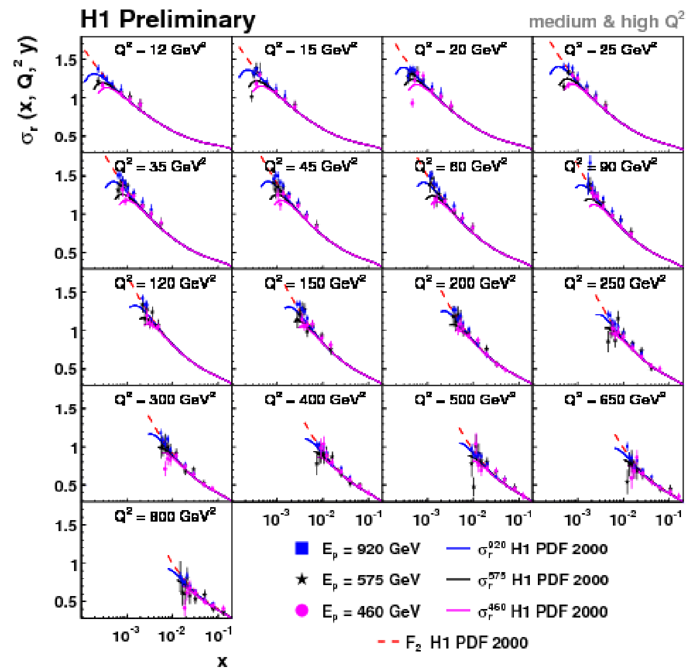
H1: Kinematic Variables



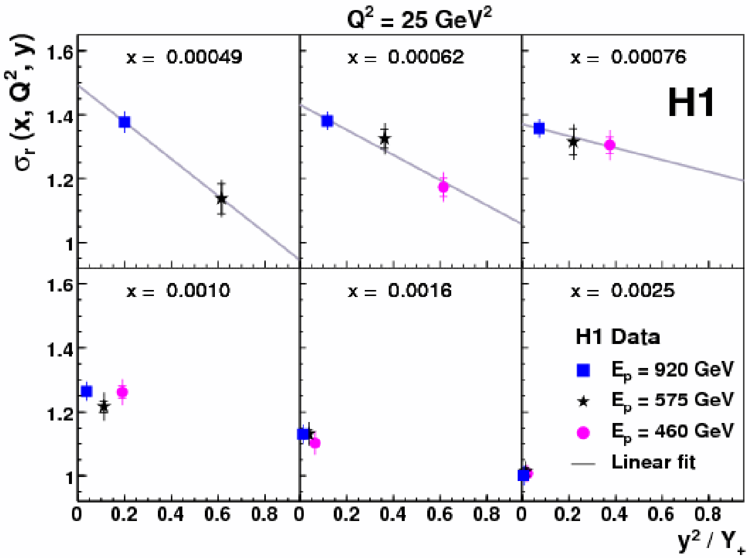
H1: Cross Sect.

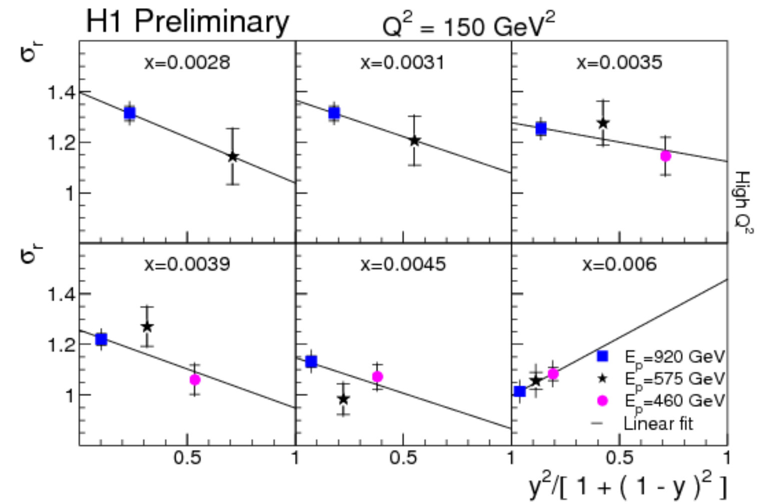


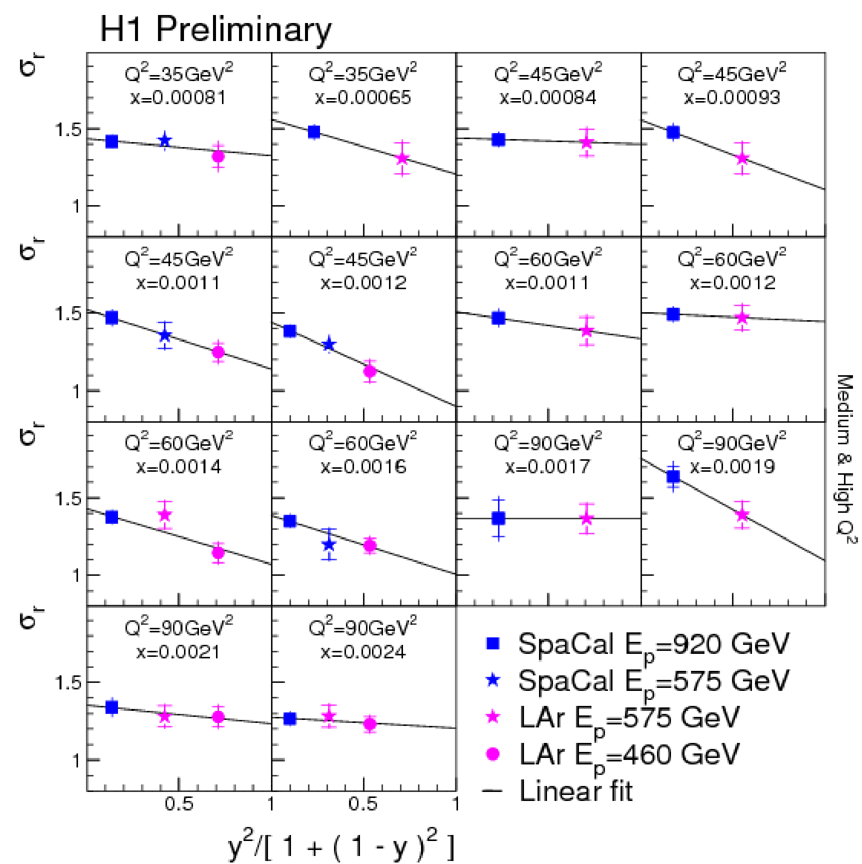


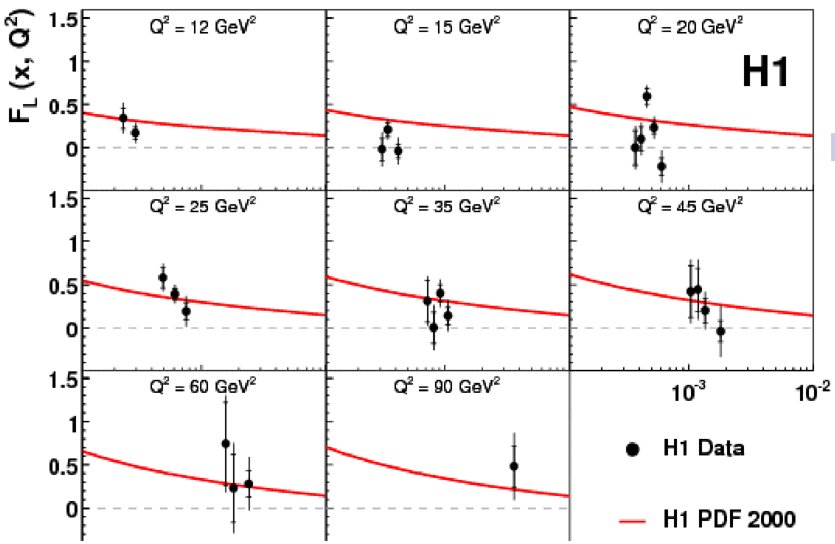


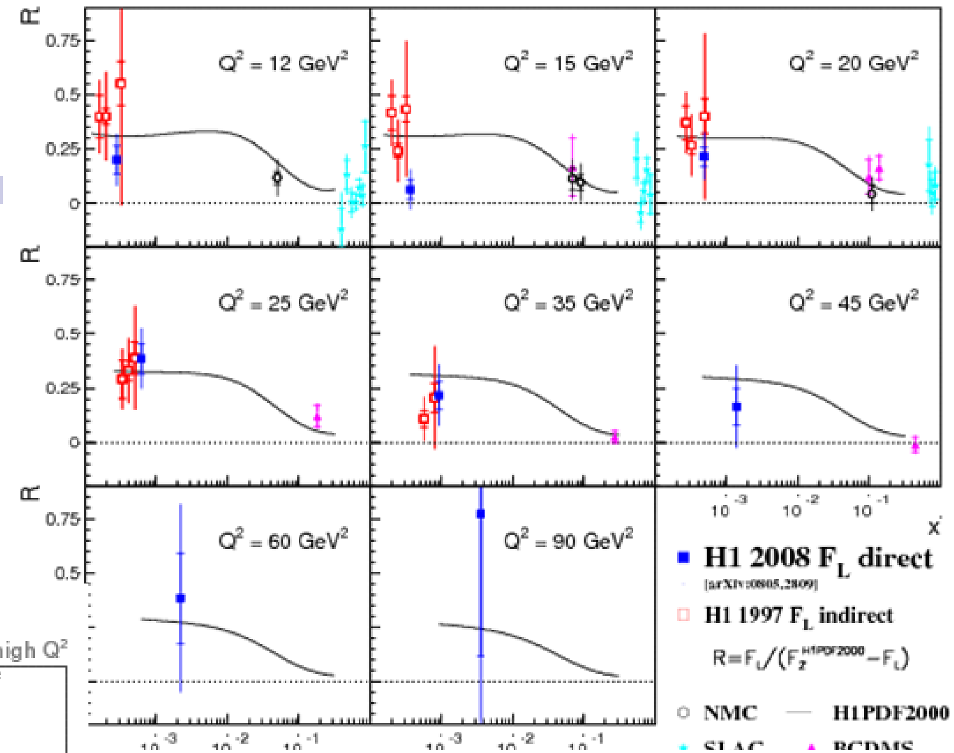
H1 Rosenbuth Plots (Examples)

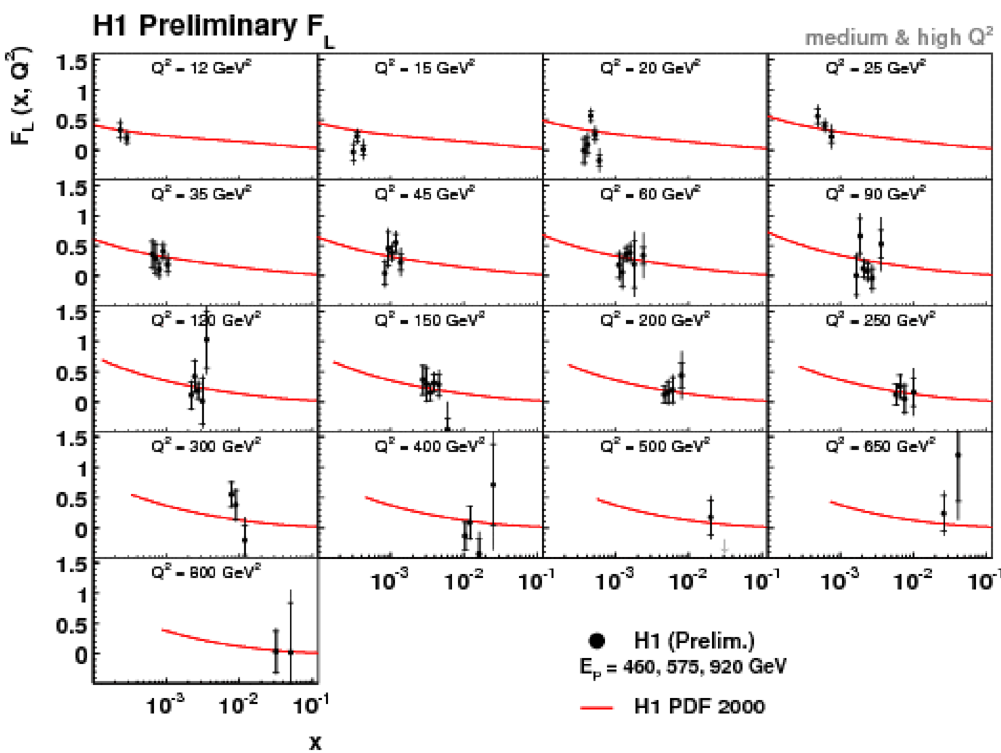


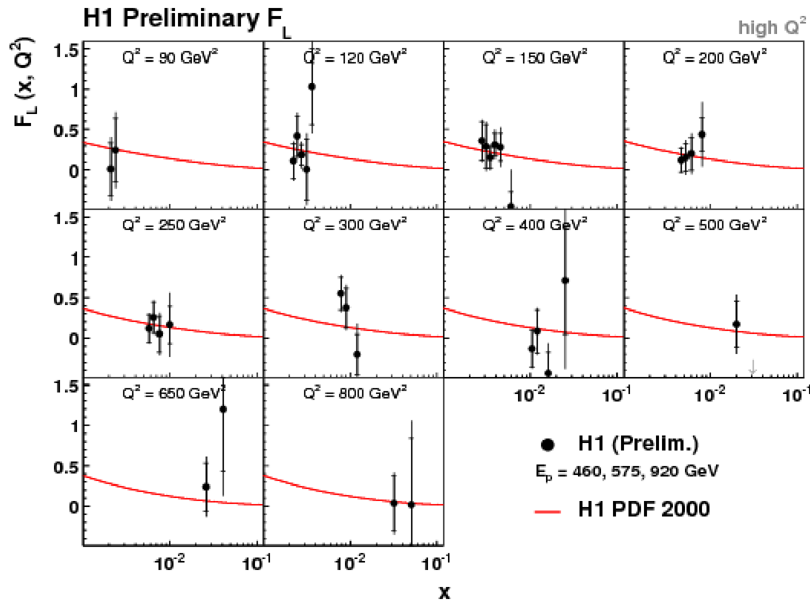




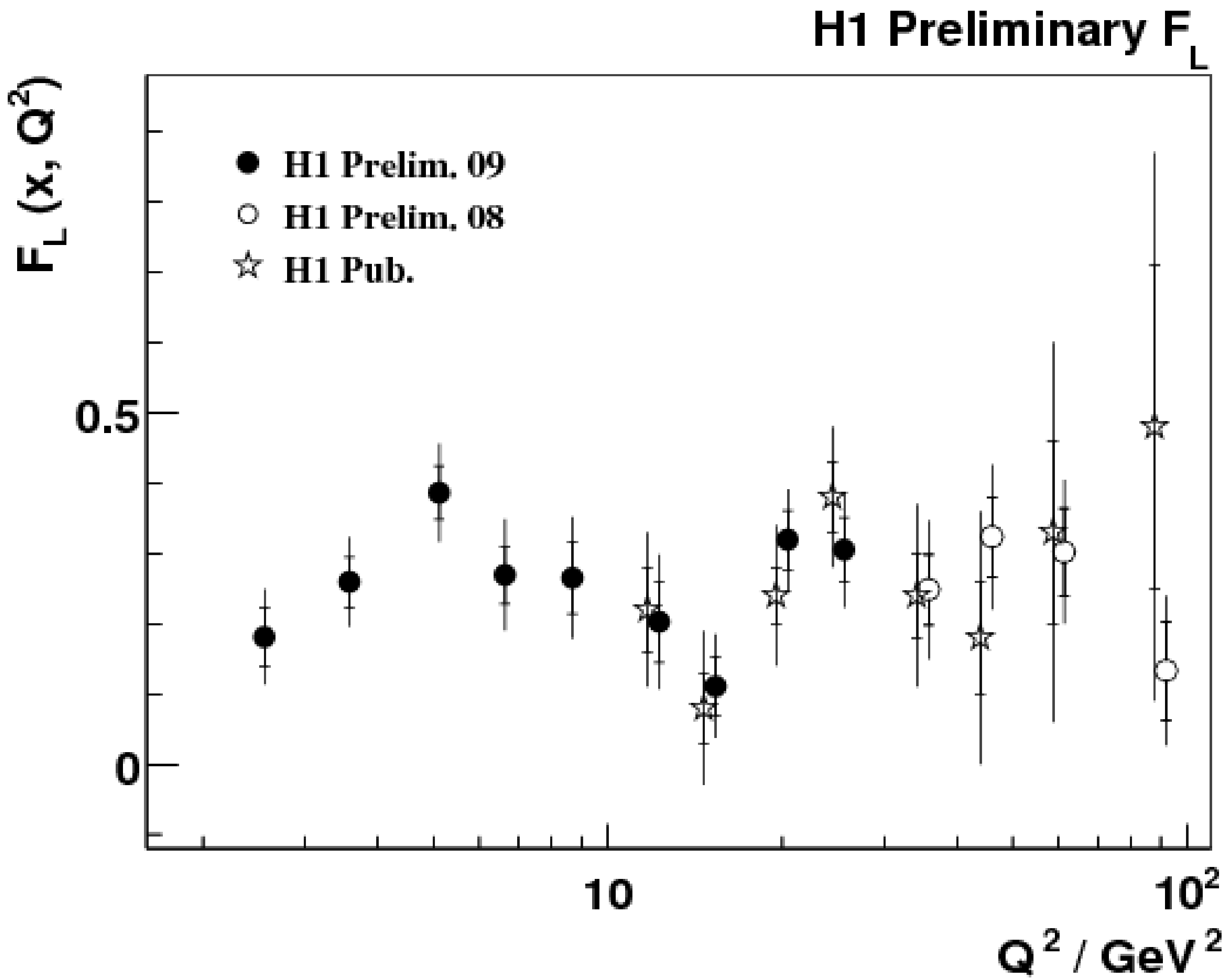

H1
$F_L(x, Q^2)$
Q^2 = 12 GeV^2
Q^2 = 15 GeV^2
Q^2 = 20 GeV^2
Q^2 = 25 GeV^2
Q^2 = 35 GeV^2
Q^2 = 45 GeV^2
Q^2 = 60 GeV^2
Q^2 = 90 GeV^2
H1 Data
H1 PDF 2000


R
Q^2 = 12 GeV^2
Q^2 = 15 GeV^2
Q^2 = 20 GeV^2
Q^2 = 25 GeV^2
Q^2 = 35 GeV^2
Q^2 = 45 GeV^2
Q^2 = 60 GeV^2
Q^2 = 90 GeV^2
x
H1 2008 F_L direct
H1 1997 F_L indirect
$R=F_L/(F_2^{H1PDF2000}-F_L)$
NMC
H1PDF2000


H1 Preliminary F_L
medium & high Q^2
$F_L(x, Q^2)$
Q^2 = 12 GeV^2
Q^2 = 15 GeV^2
Q^2 = 20 GeV^2
Q^2 = 25 GeV^2
Q^2 = 35 GeV^2
Q^2 = 45 GeV^2
Q^2 = 60 GeV^2
Q^2 = 90 GeV^2
Q^2 = 120 GeV^2
Q^2 = 150 GeV^2
Q^2 = 200 GeV^2
Q^2 = 250 GeV^2
Q^2 = 300 GeV^2
Q^2 = 400 GeV^2
Q^2 = 500 GeV^2
Q^2 = 650 GeV^2
Q^2 = 800 GeV^2
x
H1 (Prelim.)
E_p = 460, 575, 920 GeV
H1 PDF 2000


H1 Preliminary F_L
high Q^2
$F_L(x, Q^2)$
Q^2 = 90 GeV^2
Q^2 = 120 GeV^2
Q^2 = 150 GeV^2
Q^2 = 200 GeV^2
Q^2 = 250 GeV^2
Q^2 = 300 GeV^2
Q^2 = 400 GeV^2
Q^2 = 500 GeV^2
Q^2 = 650 GeV^2
Q^2 = 800 GeV^2
x
H1 (Prelim.)
E_p = 460, 575, 920 GeV
H1 PDF 2000

H1 FL vs Q2 (Three Analyses)



MPP Munich
Burkard Reisert