First Measurements of F_L at Low Bjorken x

Max Klein

UNIVERSITY OF LIVERPOOL

on behalf of the HERA Collaborations

History

1986/7: HERA workshop. Estimates on $R = F_L / (F_2 - F_L)$

1994/5: Low x (Backward) upgrade of H1

1995/6: Plans to lower E_p and measure R… LQ's ??
1st indirect measurement of F_L (H1)

LB,AG,MK hep-ex/9609017
H1 PL **B393** (1997) 452.

2002/3: HERA Luminosity upgrade

2004: DIS Workshop: reconsideration to measure F_L
["It is inconceivable to terminate HERA without a measurement of F_L" - A.Martin]

MK@DIS04 (Strebske Pleso)

2005/6: Letters of Intent from H1 and ZEUS
Presentation of high statistics hi y analysis (H1)

2007: Data at E_p =460 and 575, besides 920 GeV, at fixed positron energy E_e =27.5 GeV

2008: Release of preliminary data at DIS08 (April)
Publication of first results from H1

H1 PL **B665** (2008) 139.

This talk presents in 14 min's a 20 years development

Deep Inelastic Scattering (ep → eX)

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

Reduced ep DIS cross section

$$Y_+=1+(1-y)^2; s=4E_eE_p$$

$$Q^2=4E_eE_{e'}\cos^2\frac{\theta_e}{2}, y=1-\frac{E_{e'}}{E_e}\sin^2\frac{\theta_e}{2}, x=\frac{Q^2}{sy}$$

Kinematics from electron

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

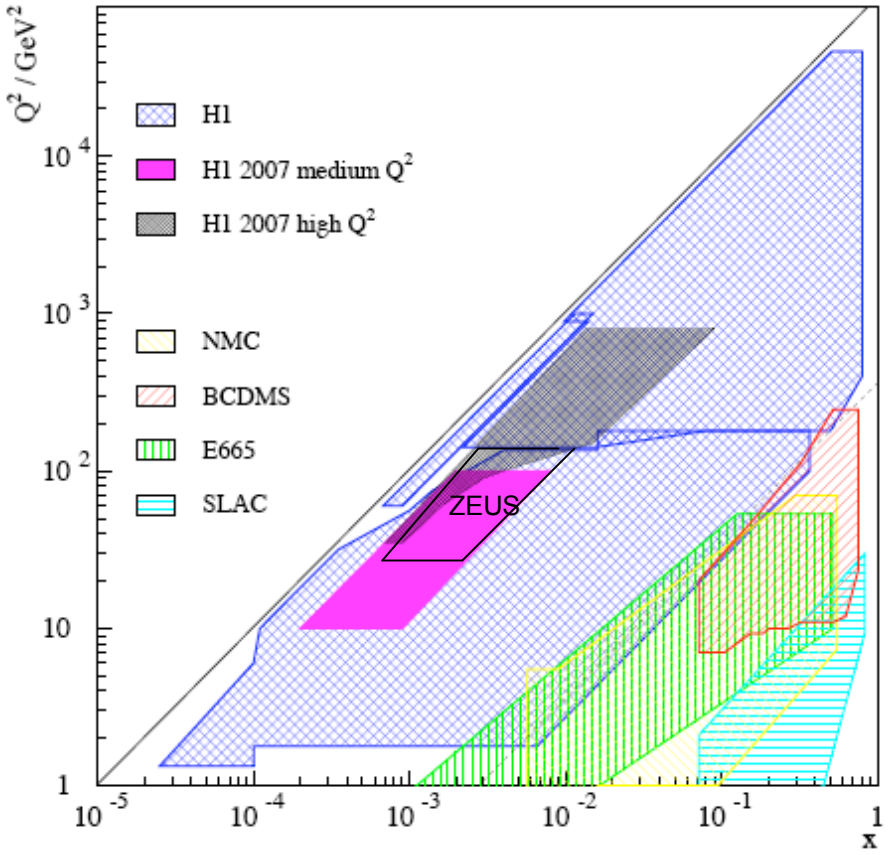
F_2 determines sum of quark distributions.

F_L , at low x, determines gluon distribution.

The F_2 term dominates the cross section, it has been measured for 15 years at HERA.

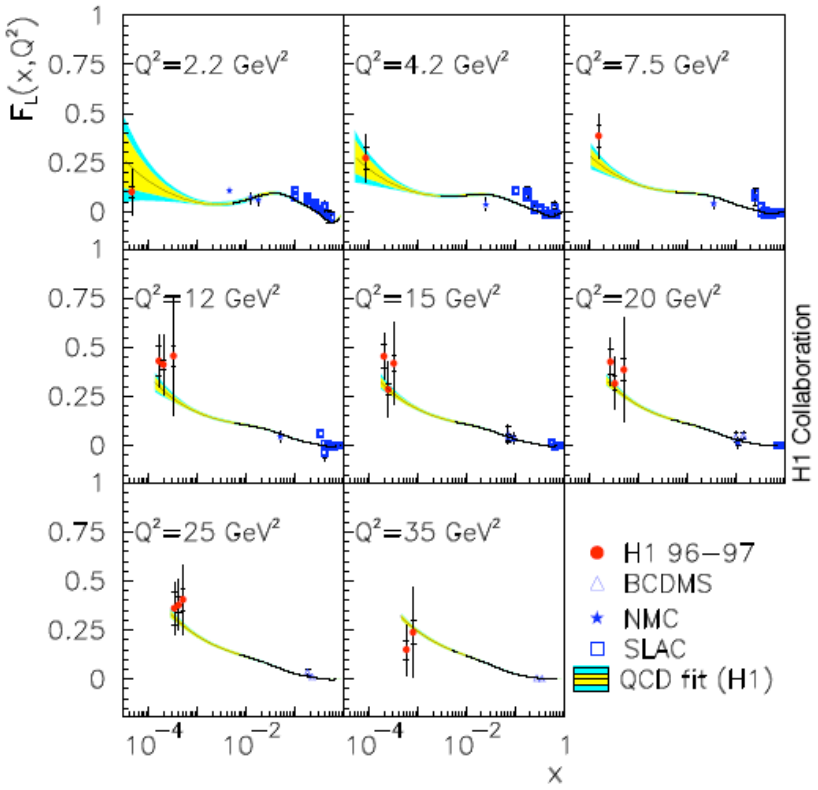
The F_L term is sizeable only at large values of inelasticity y. It was directly accessed in the last 4 months of HERA's operation.

Measuring F_L requires to vary $y=Q^2/sx$ at fixed Q^2 and x. This was achieved by lowering the proton beam energy E_p.



Expectations on F_L

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

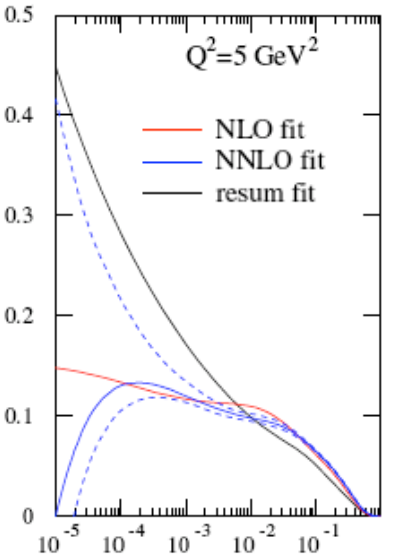
Eur.Phys.J.C21:33-61,2001

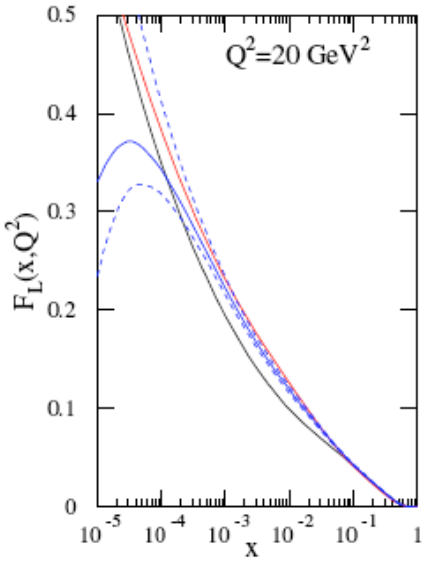
Theory (pQCD)

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, …]

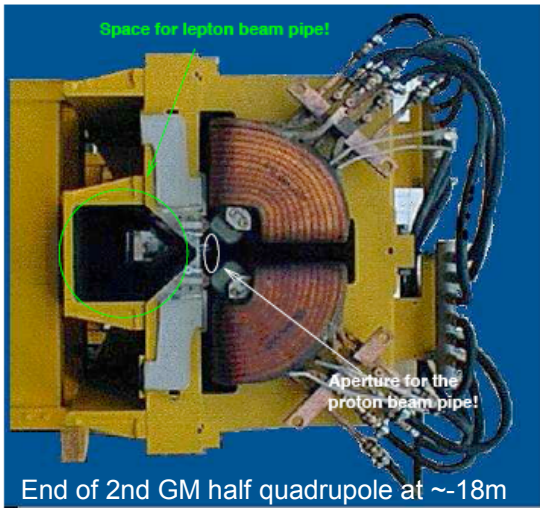




R.Thorne, DIS08

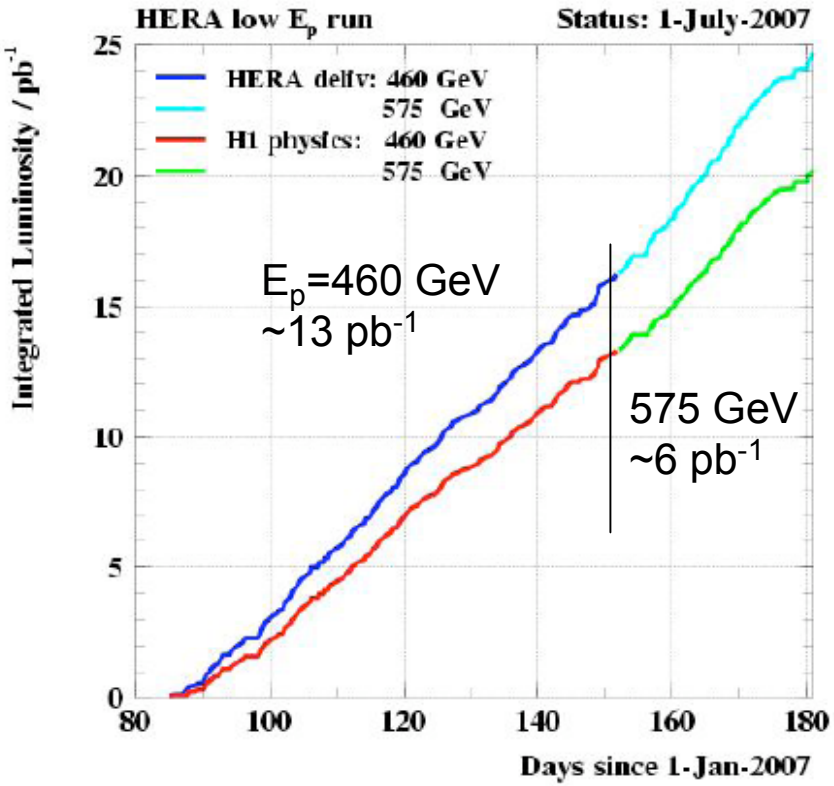
Measuring F_L in e^+p HERA

Matched e and p beams: p beam wider
Less focussing of e beam: better lifetime:
went back to 60° phase advance optics.
New optics for both e and p beams. Kept
magnet positions despite narrow apertures.

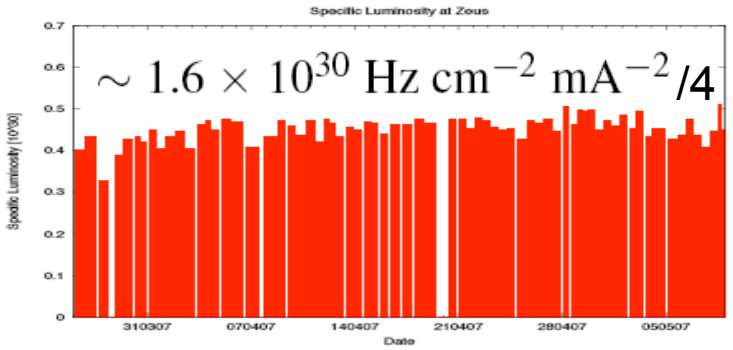


- Set up time of few days only
- Luminosity prompt and as calculated
- Polarisation increased (HERMES)
-Time given for intermediate E_p run

The culmination of HERA upgrade



Luminosity over 4 months at lower E_p

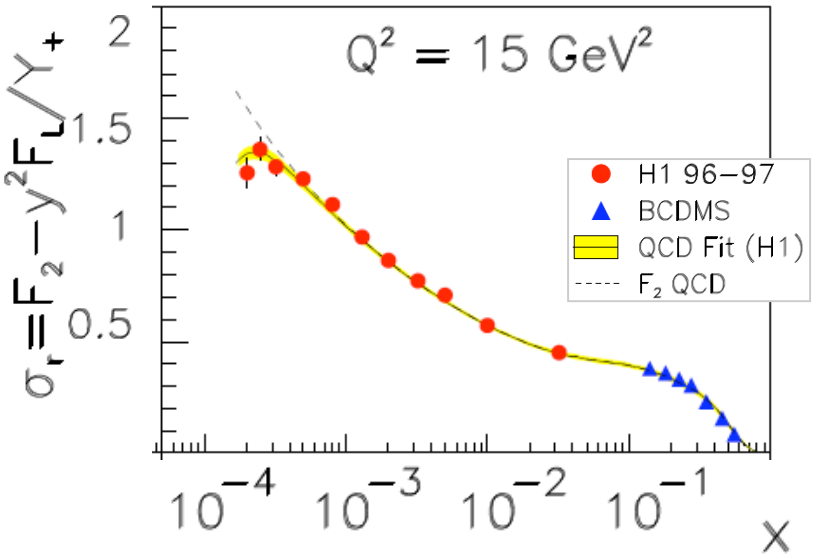


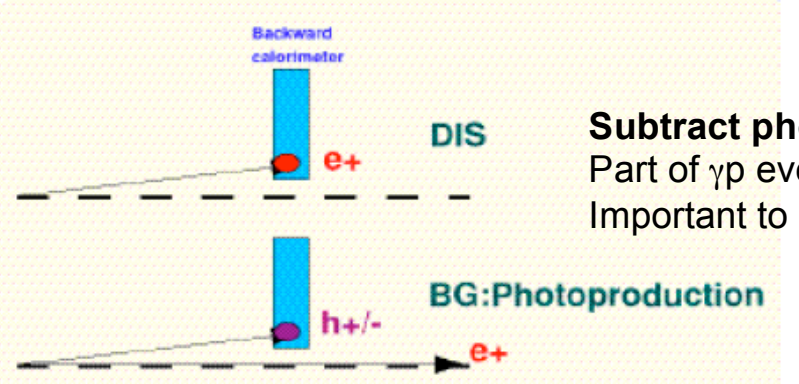
Specific luminosity over first 2 weeks

How to Measure F_L ?

$$y = \frac{Q^2}{sx} \qquad y \approx 1 - \frac{E_e'}{E_e}$$

Measure cross section at high y
Trigger on energy down to a few GeV





Subtract photoproduction background to extract genuine DIS.
Part of γp events is tagged in downstream taggers.
Important to measure charge of e candidate [done in H1]

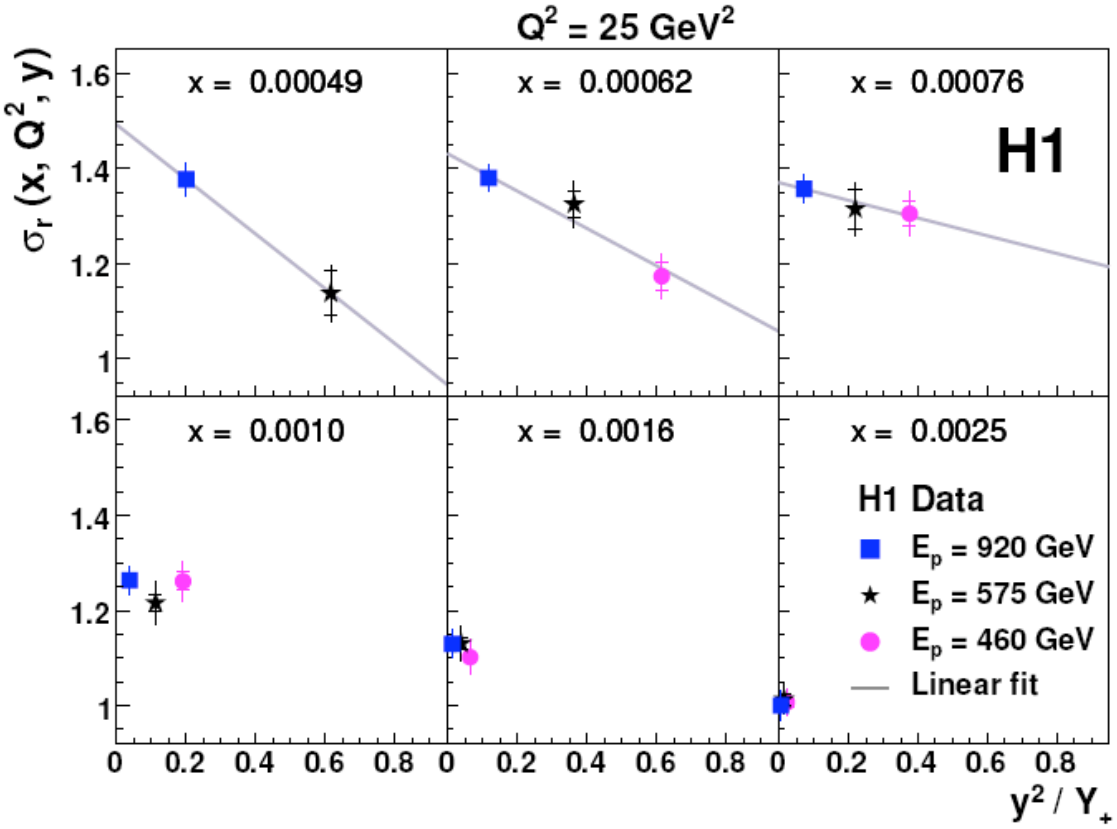
Measure cross section as accurate as possible
cannot measure F_L at large x (low y) at HERA

$$\delta F_L \propto \frac{1}{y^2}\delta\sigma_r$$

2% at y=0.7 gives
~0.06 error on F_L

How to Measure F_L ?

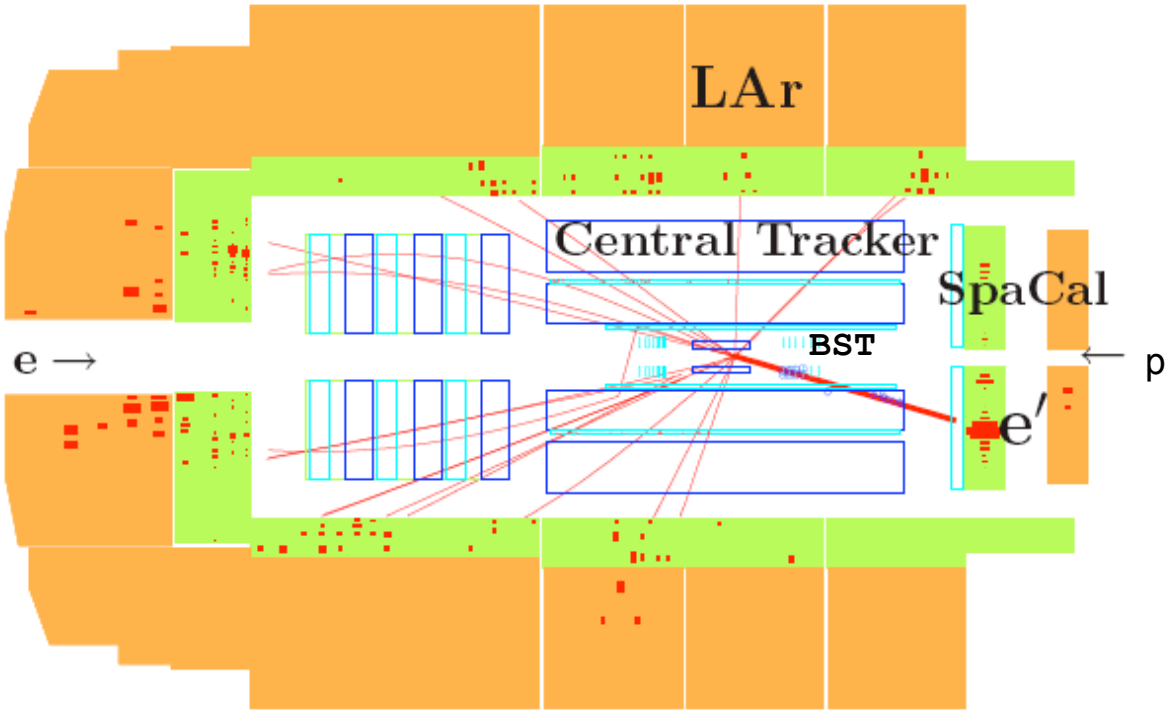
$$\sigma_r(x,Q^2;s) = F_2(x,Q^2) - \frac{y^2}{Y_+} \cdot F_L(x,Q^2)$$



Separate structure functions at given x and Q^2 using straight line fit and error compensation.
Intermediate energy for measurement control. Energy value chosen to interpolate in y^2/Y_+
At low y, fixed x,Q^2 cross sections need to coincide: Renormalisation, used by H1 and by ZEUS.

Measuring F_L with H1

DIS event of Q^2 near 30 GeV^2 in H1



Upgrades for F_L

SpaCal (94)

BST (95+03)

Triggers (03-07)

- -Inner ch. (CIP)
- -SpaCal
- -Fast Tracks (CJC)
- -Jet Trigger (LAr)

…

Three Q^2 ranges

3 and 12 GeV^2 SpaCal+BST : in progress
12 and 90 GeV^2 SpaCal+CT: published 6/08
35 and 800 GeV^2 LAr+CT: preliminary data

Event Selection Criteria:

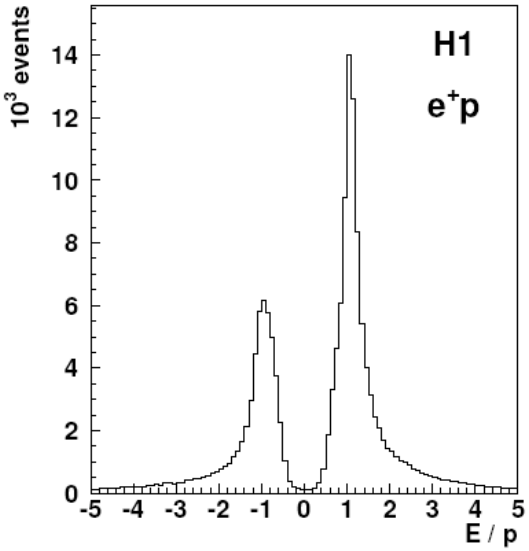
e in SpaCal or LAr (cluster+trigger),E_e'>3 GeV
Track in CT or BST (reject neutrals, E/p)
Interaction vertex

$$E - p_z = \sum_i (E_i - p_{z,i}) + E'_e(1 - \cos\theta_e) \quad > 35 \text{ GeV}$$

(reduces largely the radiative corrections)

Background Subtraction - H1

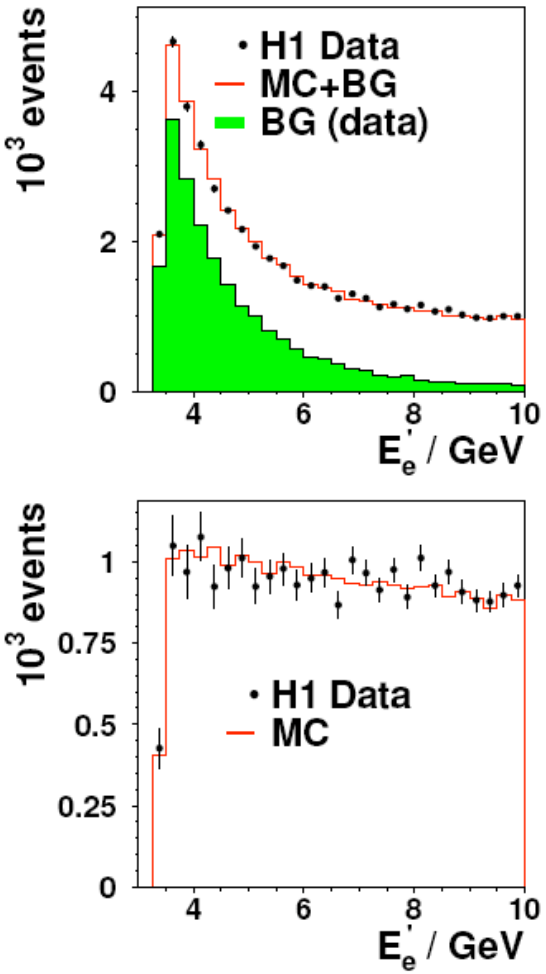
At small energies DIS signal is superimposed by γp events. Those are charge symmetric, apart from small effect due to anti-protons vs protons, which is measured using e+ and e- data, and corrected for. H1 in full range of Q^2 has momentum measurement of e candidate.

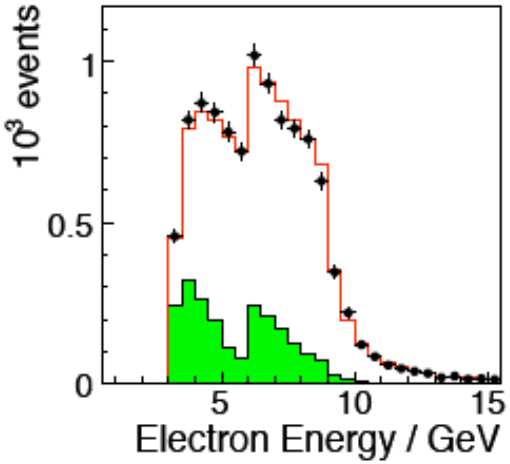


E_SpaCal / p_CT

Scattered e energy distributions at medium and high Q^2

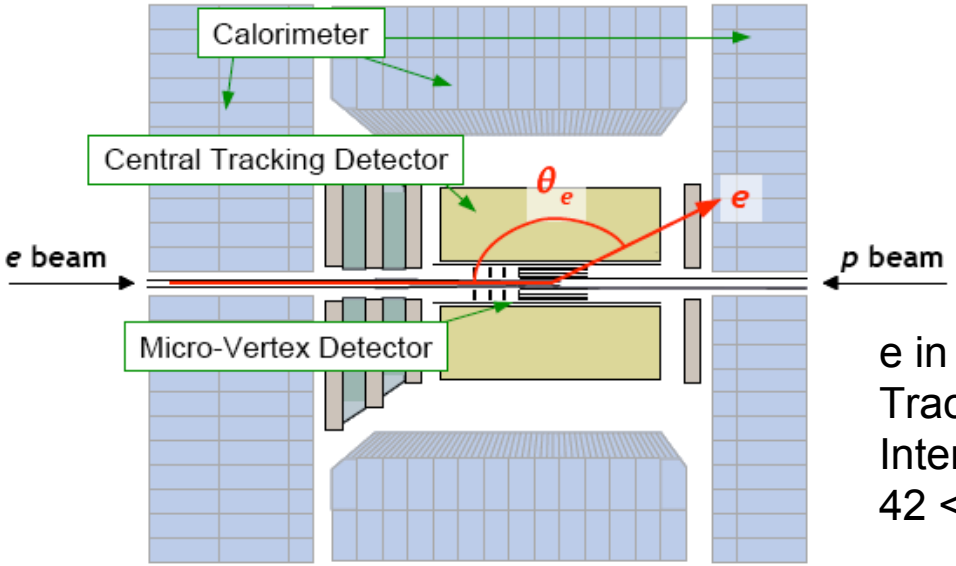
SpaCal (bwd calo) Lar (central calo)





H1 background subtraction based on data. Trade-off between severity of cuts and statistical uncertainty of background (wrong charge data sample).

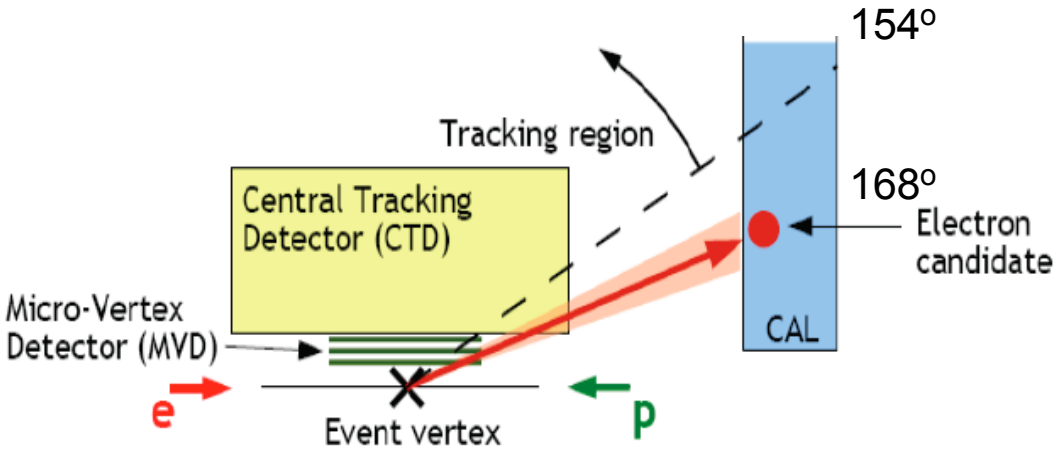
Measuring F_L with ZEUS



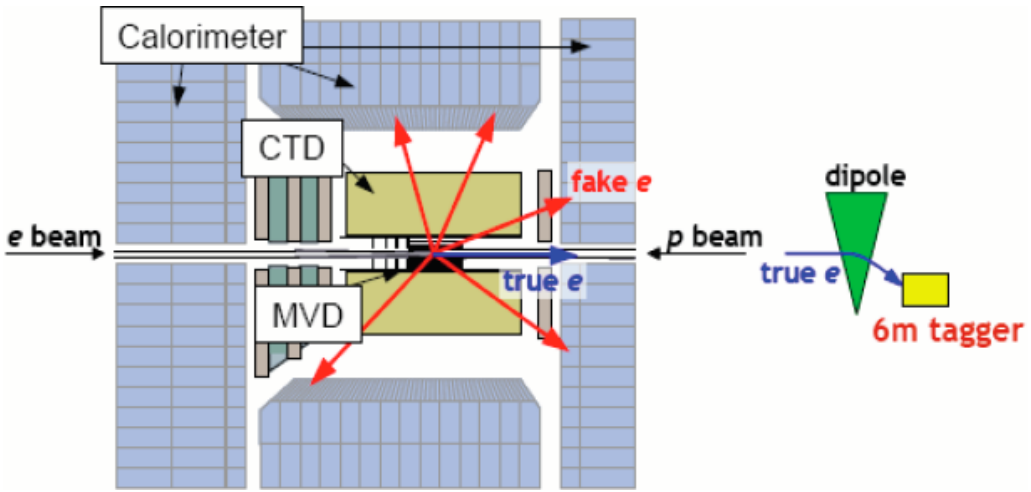
Event Selection Criteria

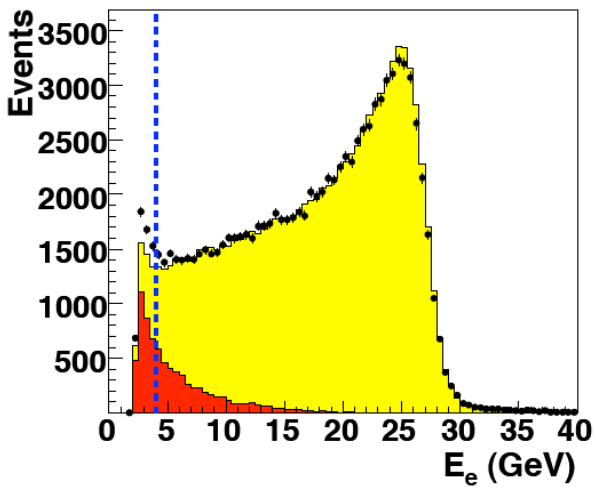
e in Uranium Calo (cluster+trigger), E_e'> 6 GeV
Track or hits in CTD+MVD (reject neutrals)
Interaction vertex
$42 < E\text{-}p_z < 65$ GeV,

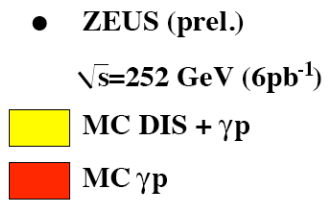
Q^2 range between 24 and 110 GeV^2

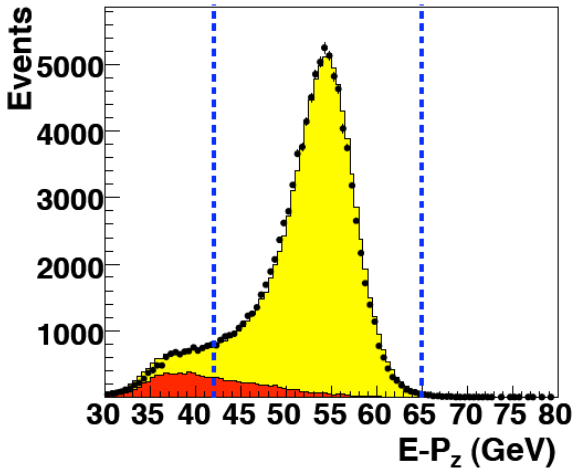


Background Subtraction - ZEUS



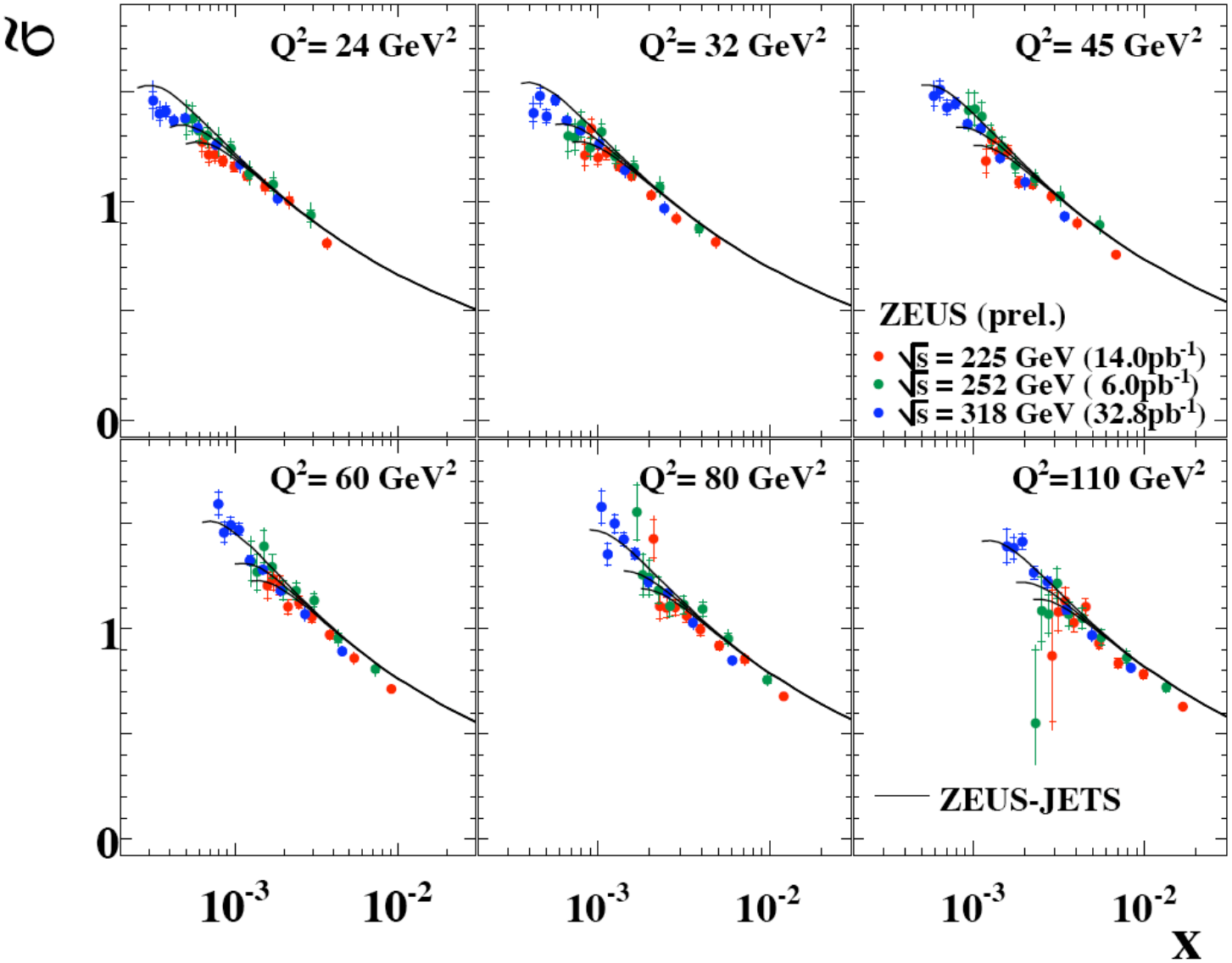






Photoproduction background removed using PYTHIA MC with subprocess weights readjusted to cross section data. Controlled using 6m electron tagger. Complementary studies with γp enriched data sample.

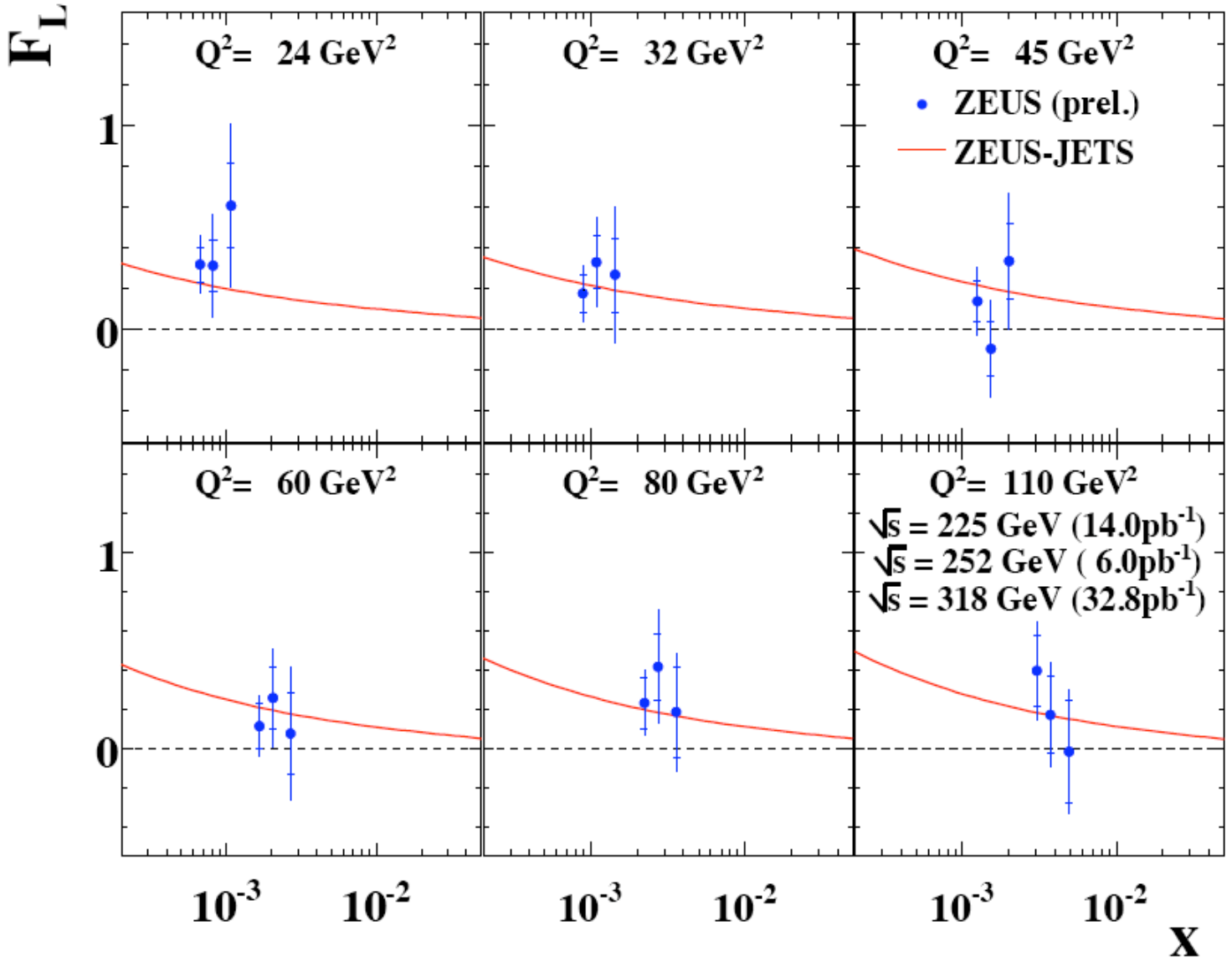
Cross Section Results - ZEUS



Data at 460+920 GeV were presented to DIS08.

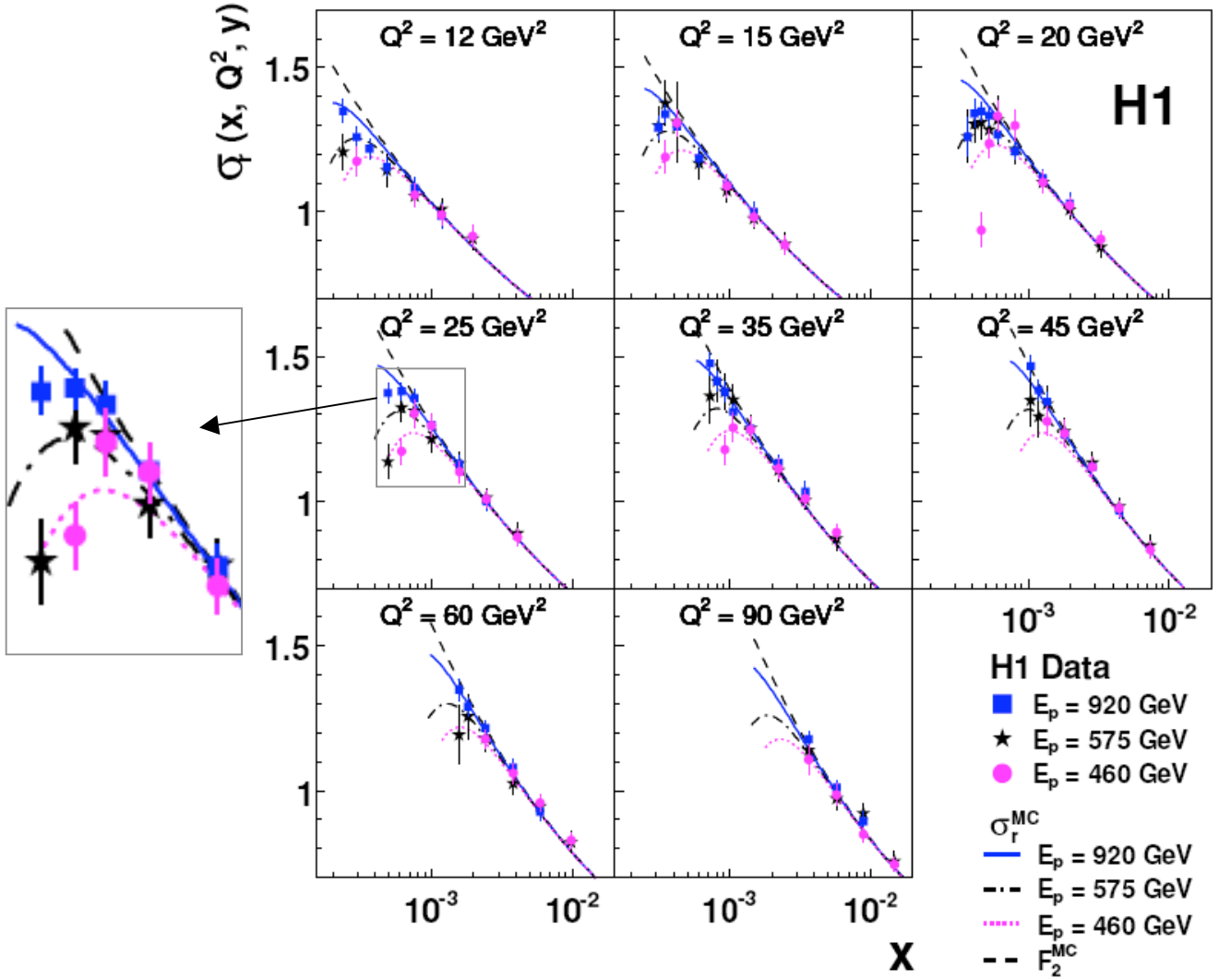
This presentation includes 575 GeV data and thus a complete analysis of all 3 data sets, in preliminary form.

Overview on F_L Data - ZEUS



New to ICHEP08 - includes 575 GeV data.

Cross Section Results - H1 - SpaCal Data - Medium Q^2

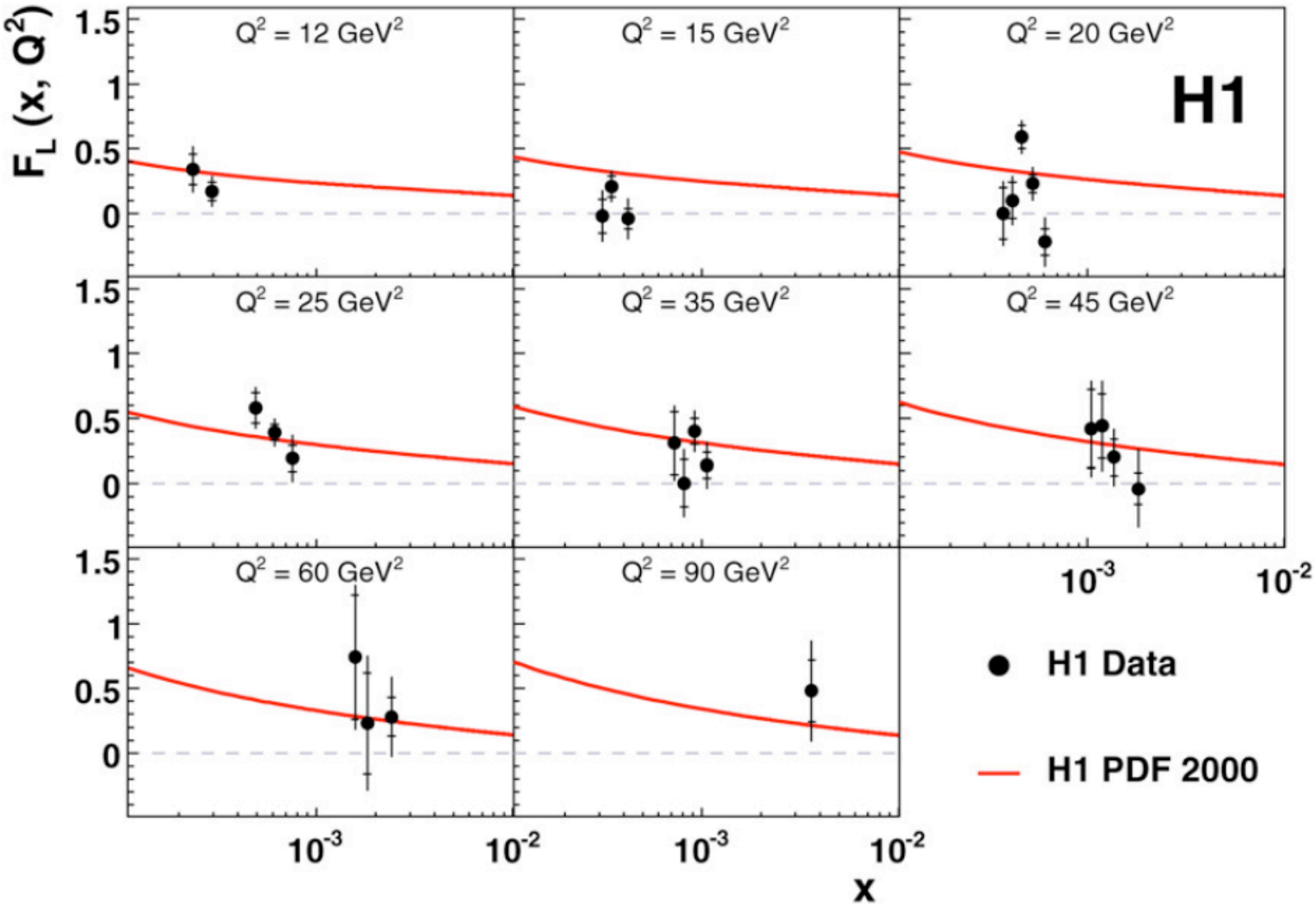


Data presented to DIS08 in preliminary form and published in Phys.Lett in June.

Positron energy measured inSpaCal and its track momentum In the central jet chamber.

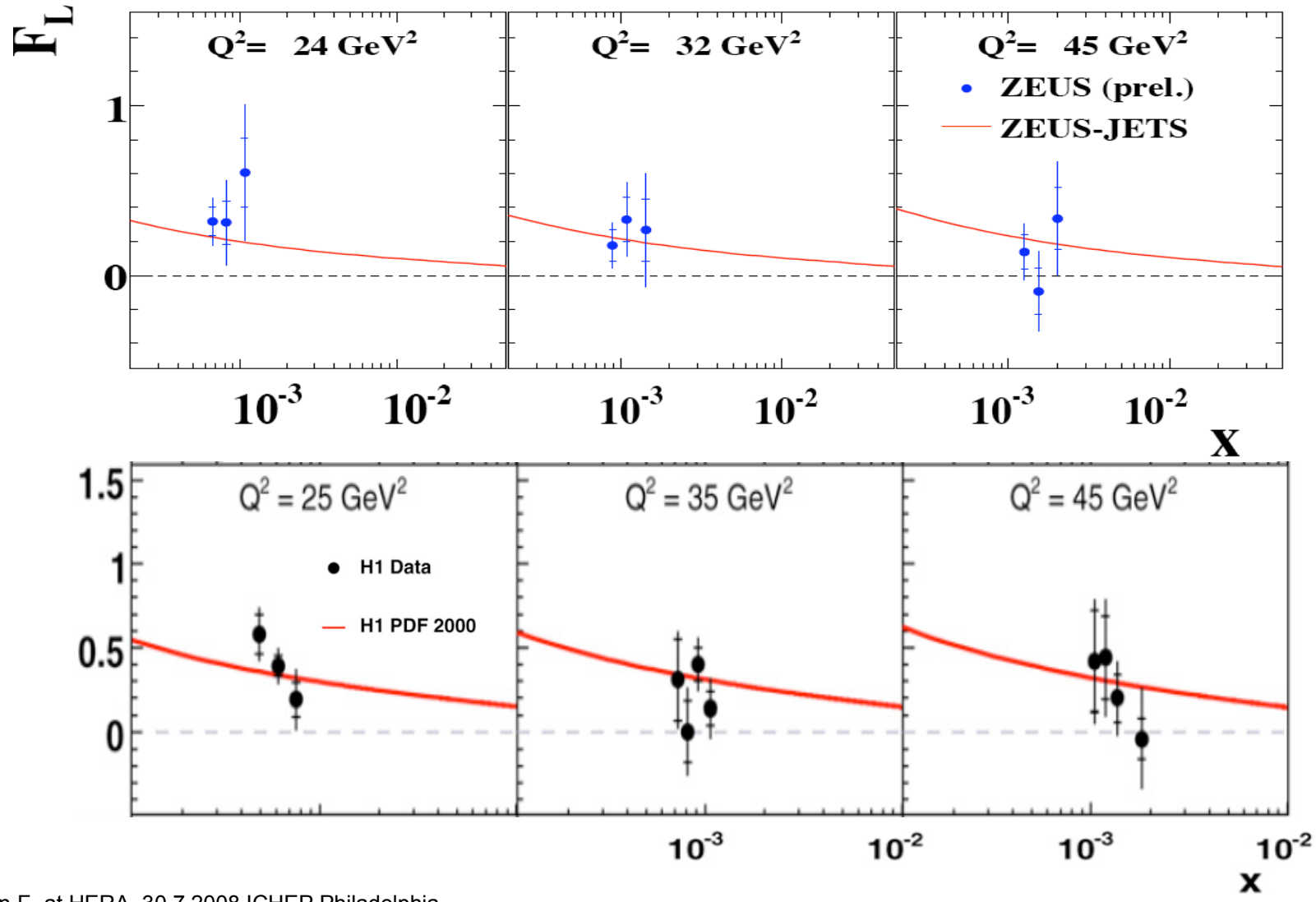
Data at lower Q^2 with track in Backward Silicon Tracker are being analysed.

Overview on F_L Data - H1

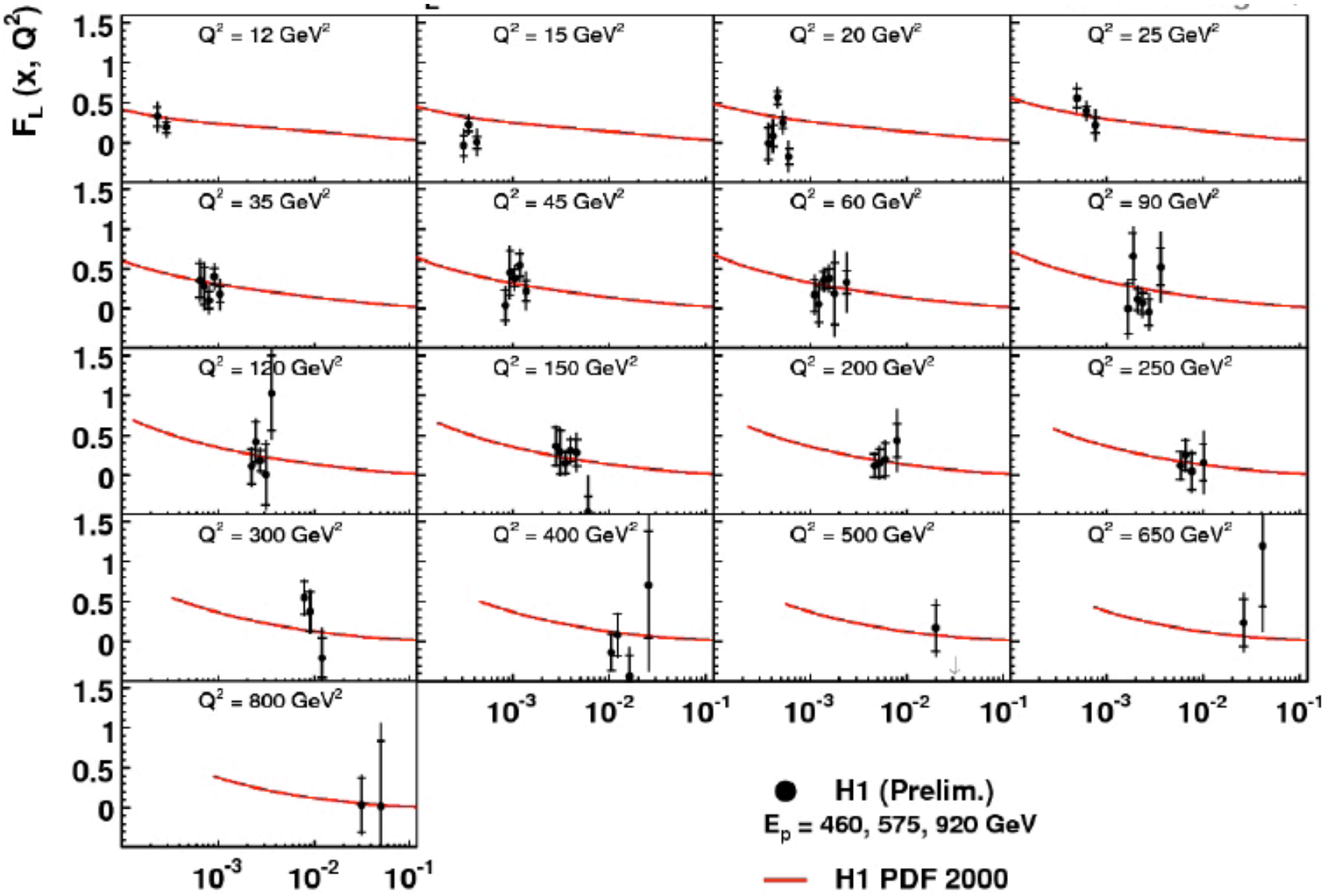


H1 Collaboration Phys.Lett B665(2008)139

Comparison on F_L Data - ZEUS+H1

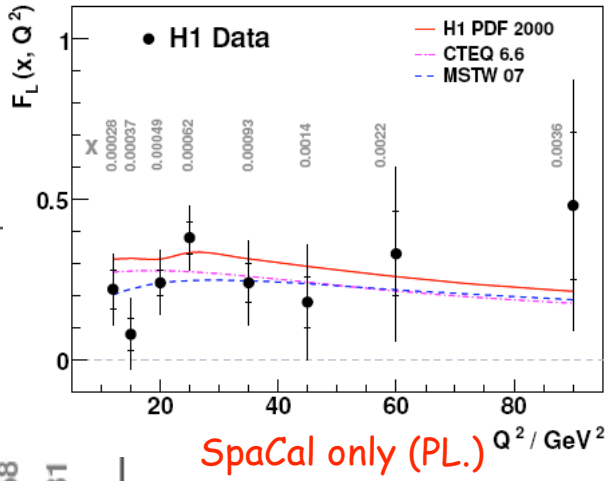


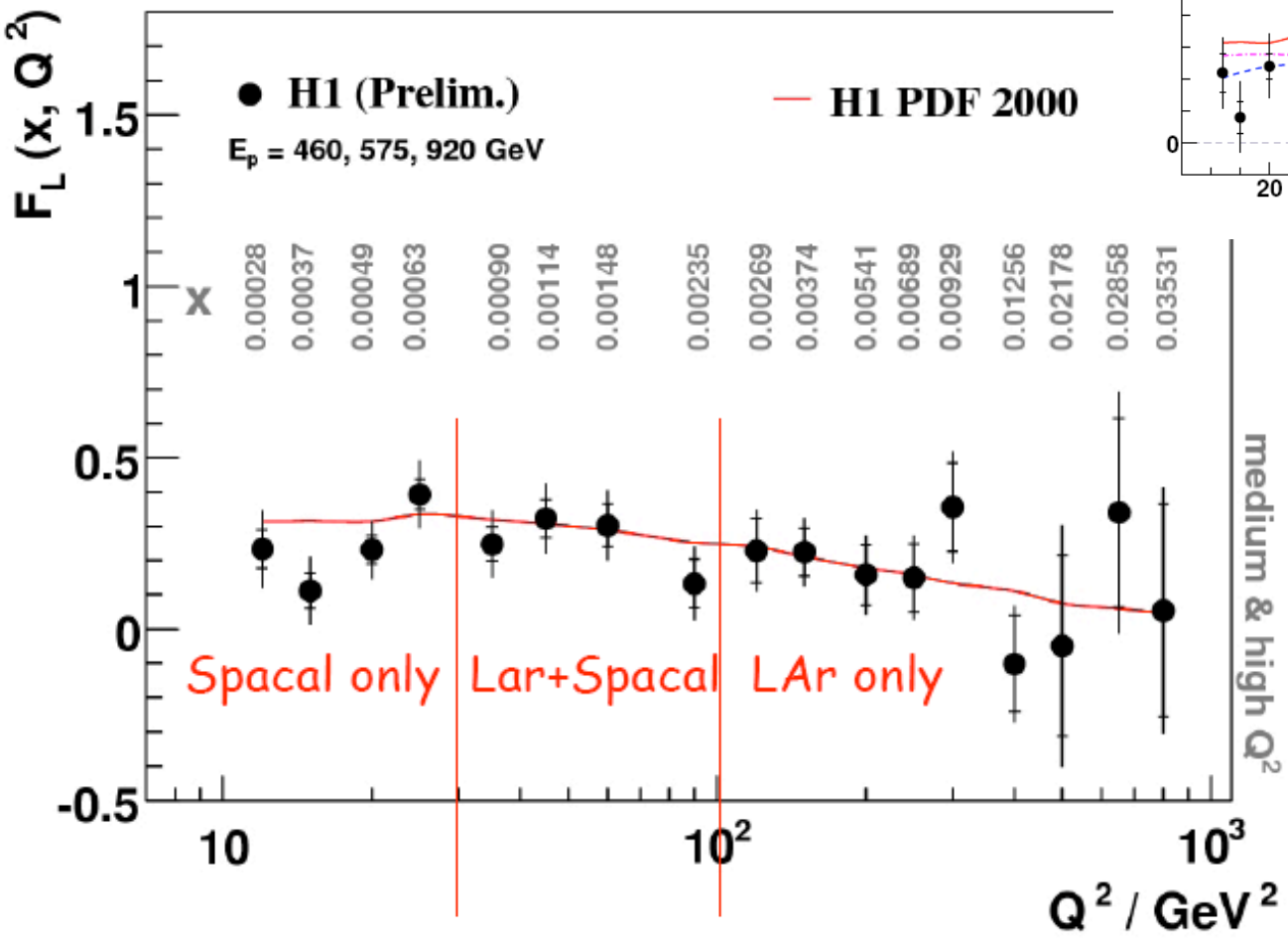
Overview on all F_L Data - H1



LAr data extend kinematic range and improve accuracy

Combination of F_L Data - H1





Data at each Q^2 combined and then averaged vs x.

Combination with LAr improves the published SpaCal result for $Q^2 > 30$ GeV^2

Agrees well with NLO QCD fit to previous H1 data

An Observation

At low x, where xg dominates, both the $\ln Q^2$ derivative of F_2 and F_L determine the gluon distribution.

Approximately, to LO, one has:

$$\frac{\partial F_2(0.5x,Q^2)}{\partial \ln Q^2} \approx \frac{10}{27} \cdot \frac{\alpha_s}{\pi} xg(x,Q^2)$$

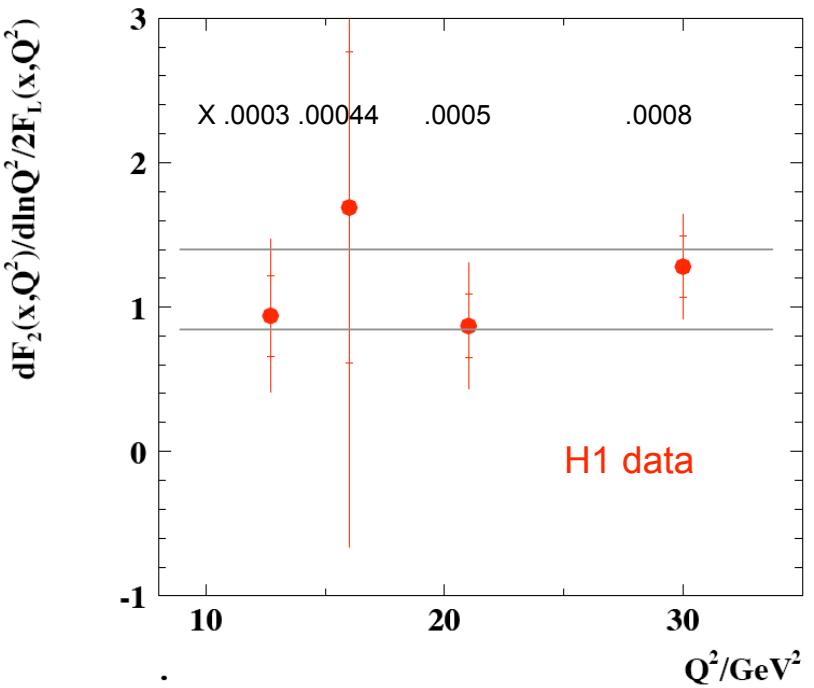
$$F_L(0.4x,Q^2) \approx \frac{10}{54} \cdot \frac{\alpha_s}{\pi} xg(x,Q^2)$$

K.Prytz, Phys.Lett.B311(1993)286
A.Cooper-Sarkar et al, RAL87-112(1987)

One therefore may expect that the F_2 derivative and F_L are directly related as $dF_2/d\ln Q^2 = 2F_L$

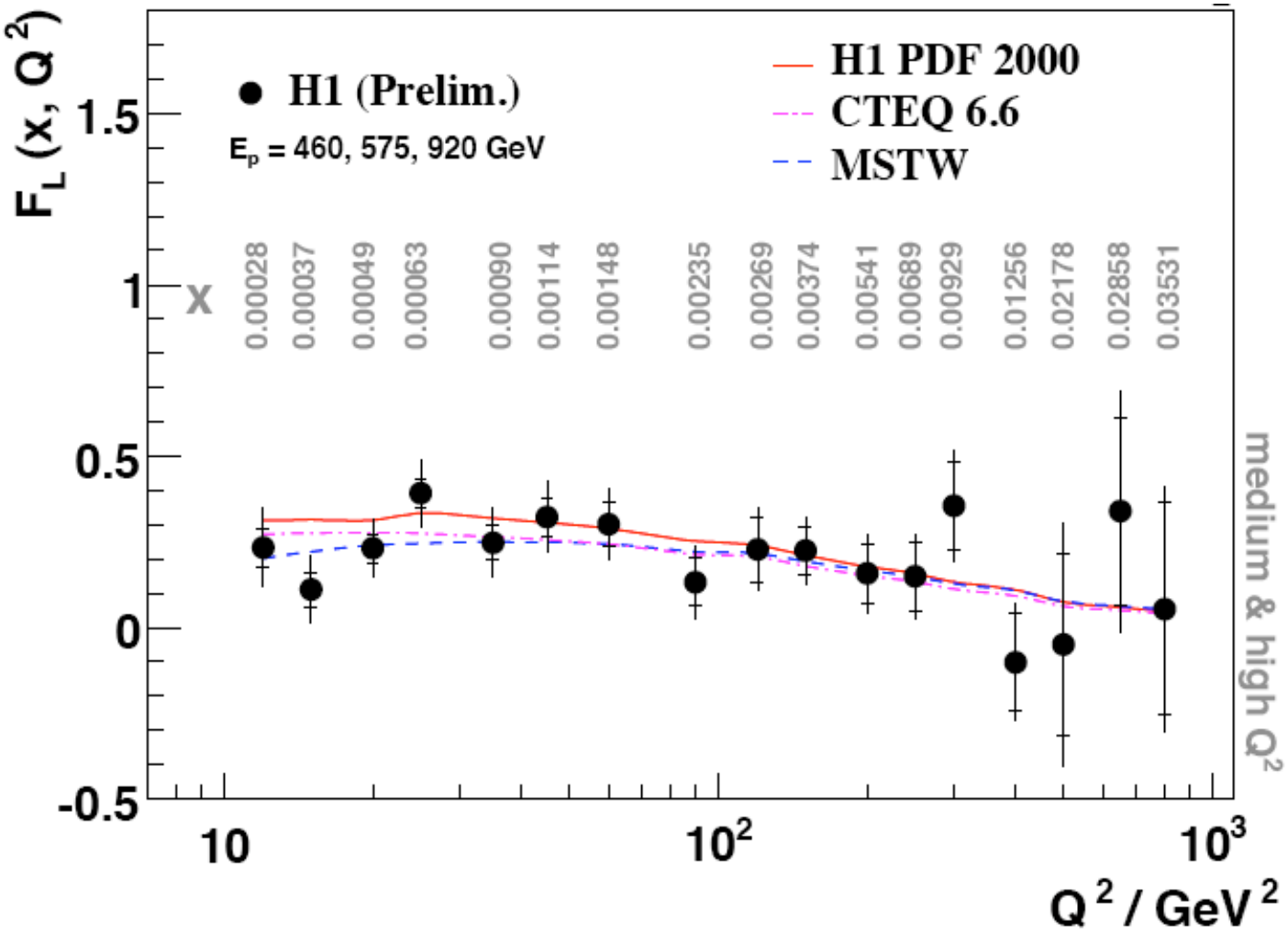
This is observed to hold within 25% and may deserve further study

$$\frac{\partial F_2 / \partial \ln Q^2}{2F_L} = 1.09 \pm 0.13(stat) \pm 0.20(syst)$$



H1 data:
F_2': Eur.Phys.J.C21 (2001) 33; F_L : Phys.Lett.B665 (2008) 139

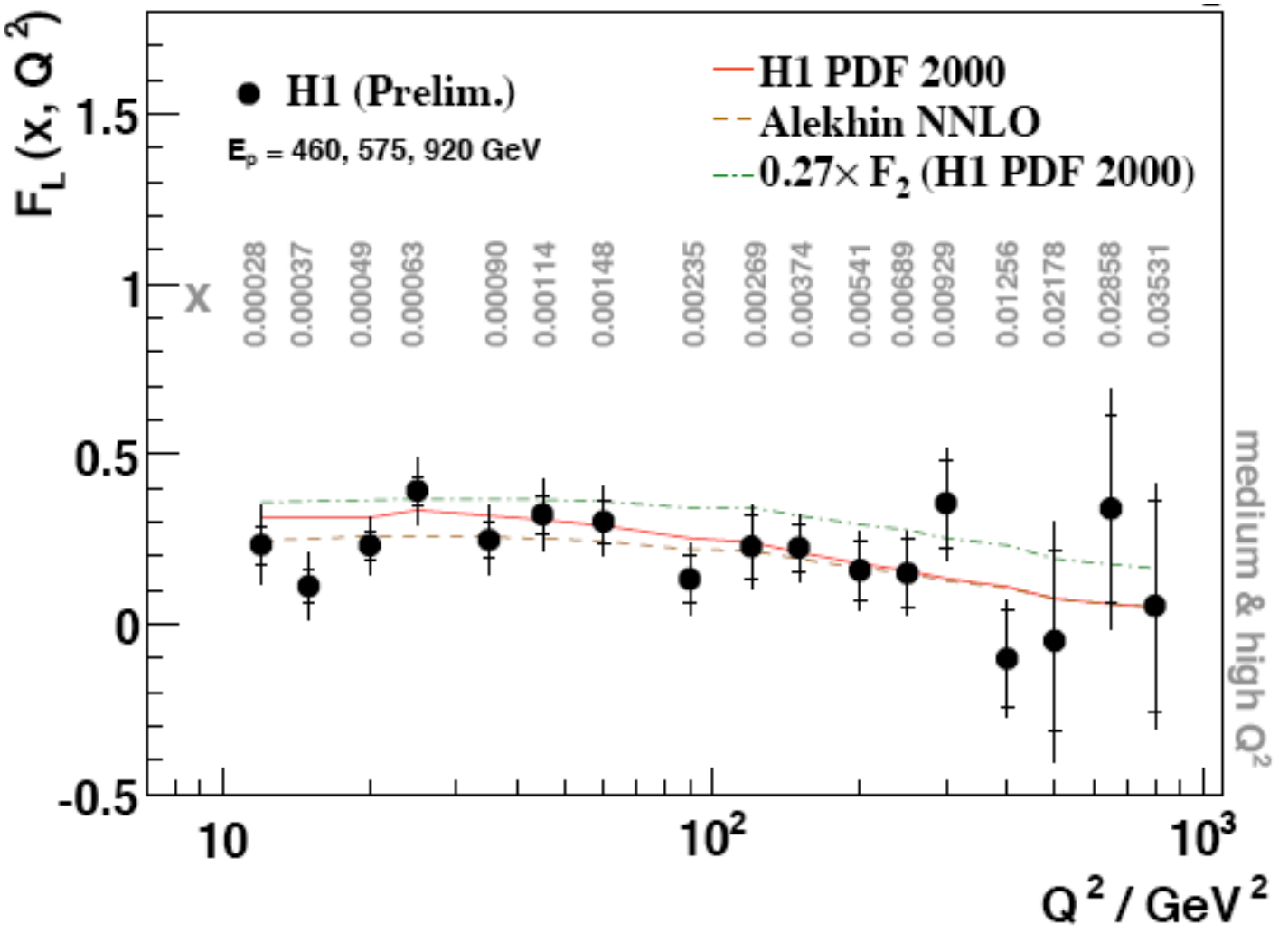
Comparison of F_L Data with pQCD



H1 data in good agreement with perturbative QCD. [CTEQ, MRST,H1, for Alekhin (pto)]

Strong interest in lower Q^2 /x region.

Comparison of F_L Data with Dipole Model



H1 data also consistent with Dipole model predictions:

Transverse qqbar:
F_L=3/11 F_2
arXiv 0806.0202
M.Kuroda, D.Schildknecht

Bound:
$F_L \leq 0.27\ F_2$
Ann.Phys. 322(2007)1635
C.Ewerz, O.Nachtmann

Summary and Outlook

Within less than a year after the end of running, both H1 and ZEUS have presented the first data on the longitudinal structure function.

F_L has thus been measured for the first time in a new kinematic range: for Q^2 = 24-110 (ZEUS) and 12-800 GeV^2 (H1) and Bjorken x = 0.0002 - 0.05

The data are in good agreement with h.o. pQCD predictions and thus confirm the expectations on the behaviour of xg in the DIS kinematic region.

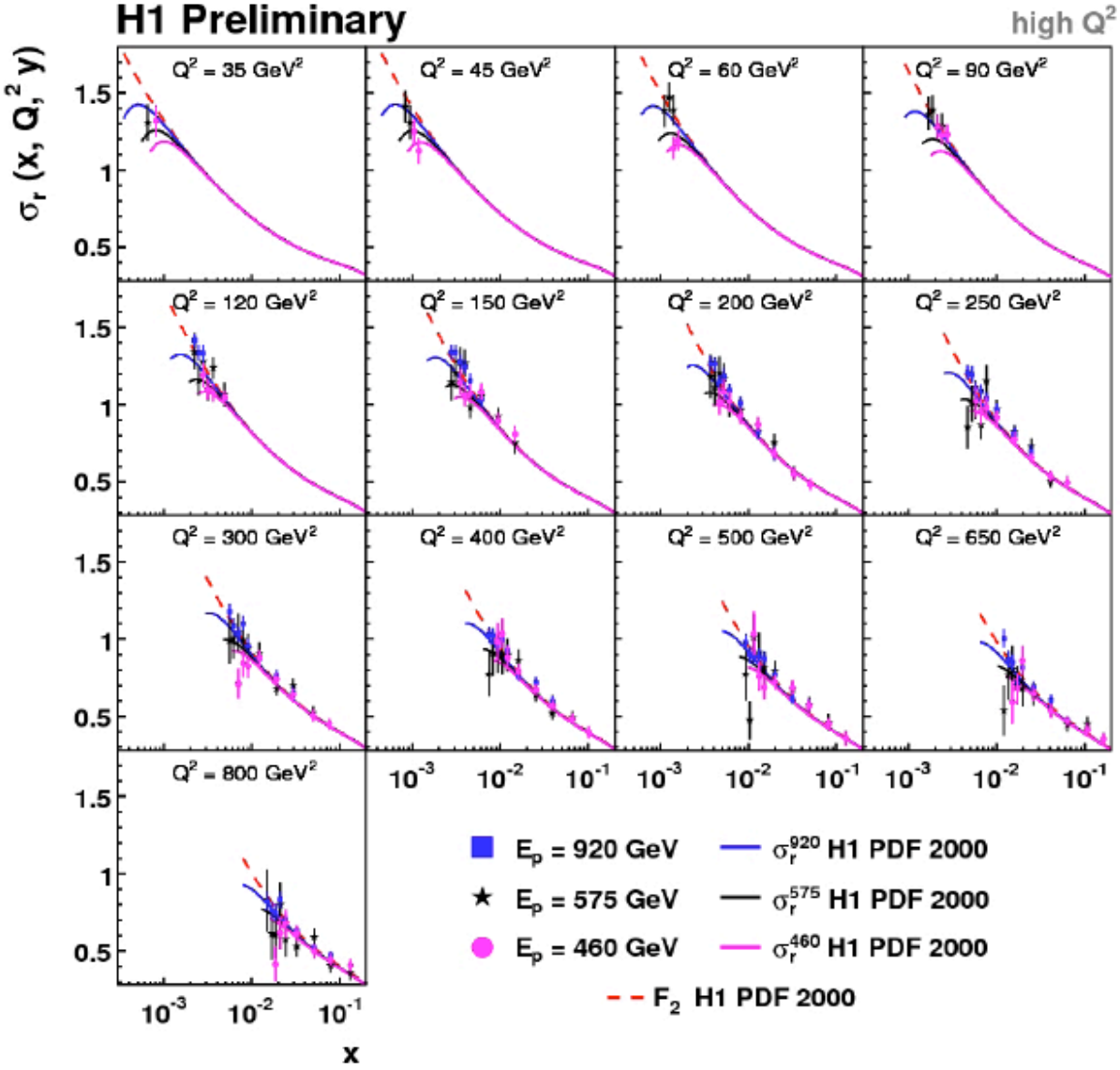
First data of H1 have been published. The analysis is ongoing, with various expected improvements related to:

- understanding the photoproduction background,
- extension of analyses to low y
- combination of and use of further (BST) data
- improved treatment of systematic error correlations.

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

A most remarkable success of HERA and its dedicated crew, thanks!

Cross Section Results - H1 - LAr Data - High Q^2



Data with positron measured in LAr.

Presented to DIS08 as preliminary result, In April 2008.

Overlap with SpaCal data at fixed x,Q^2. Important for cross check and improved measurement accuracy.

Extend to 800 GeV^2