

# First Measurements of $F_L$ at Low Bjorken $x$

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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  $h_i y$  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**

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

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

**Kinematics from electron**

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

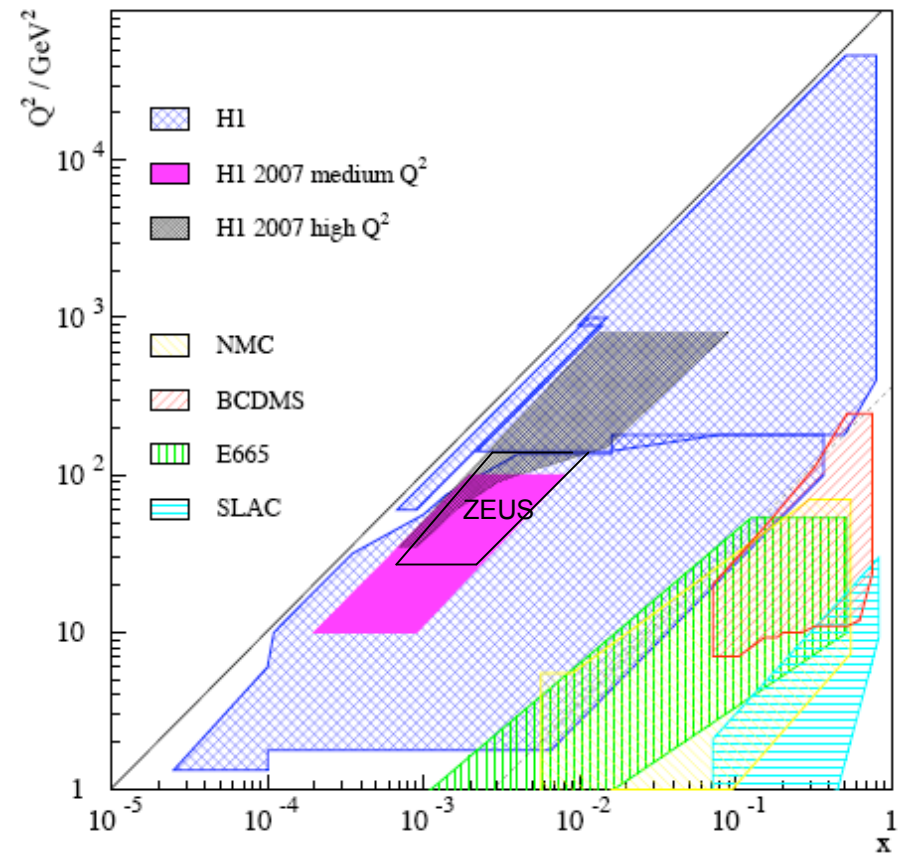
$F_2$  determines sum of quark distributions.

$F_L$ , at low  $x$ , determines gluon distribution.

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

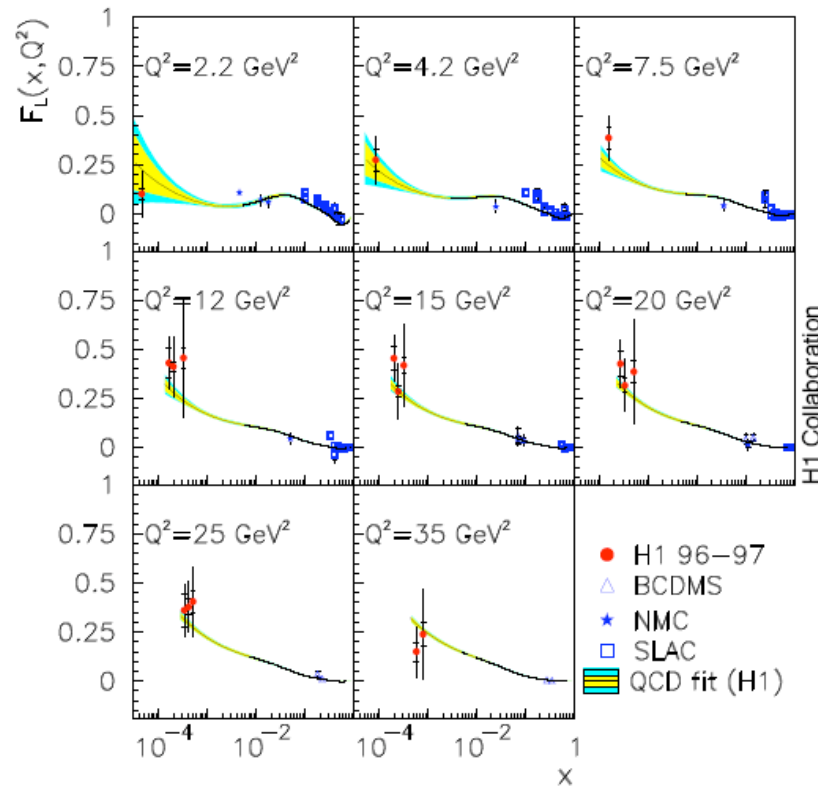
The  $F_L$  term is sizeable only at large values of inelasticity  $y$ . It was directly accessed in the last 4 months of HERA's operation.

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



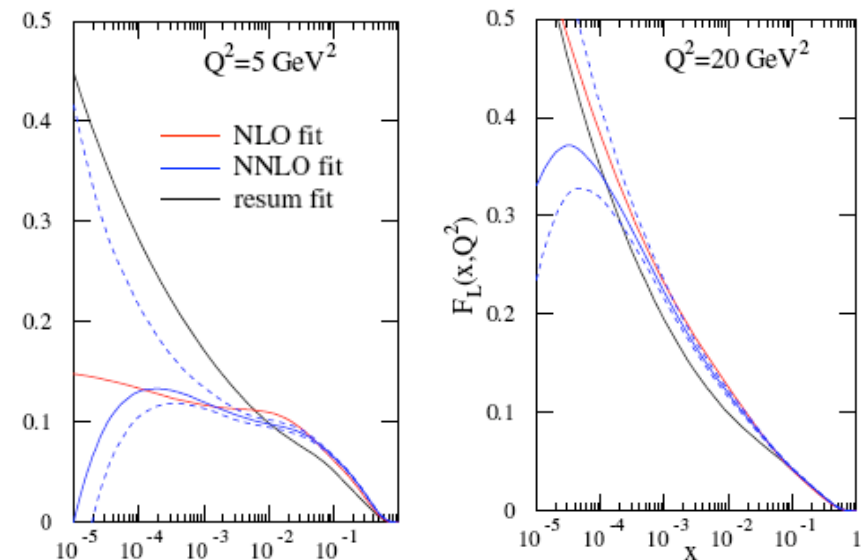
**Fixed target:  $F_L$  is small at large  $x$  (spin 1/2 quarks)**  
**indications for increase towards low  $x$**   
**H1: hints to large  $F_L$  when  $F_2$  is assumed to be known**  
 Eur.Phys.J.C21:33-61,2001

## Theory (pQCD)

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

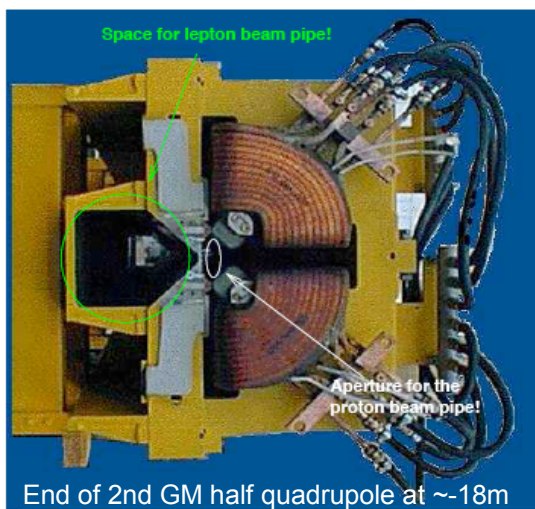
Theory developed to NNLO  
 [W.van Neerven ( $\dagger$ ), J.Vermaseren, et al.]

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



# Measuring $F_L$ in $e^+p$ HERA

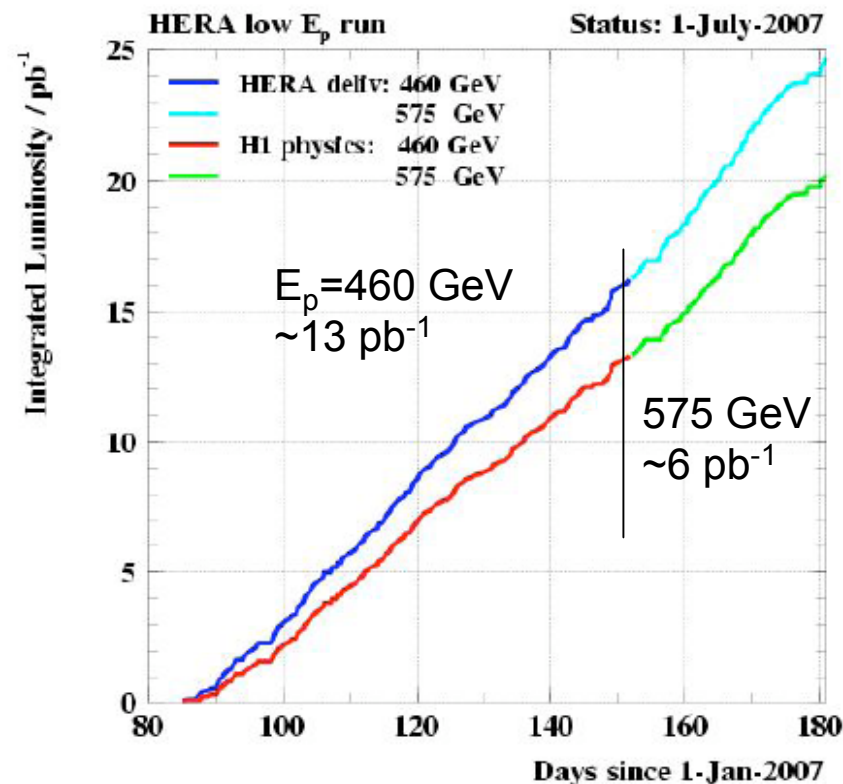
Matched e and p beams: p beam wider  
 Less focussing of e beam: better lifetime:  
 went back to  $60^\circ$  phase advance optics.  
 New optics for both e and p beams. Kept  
 magnet positions despite narrow apertures.



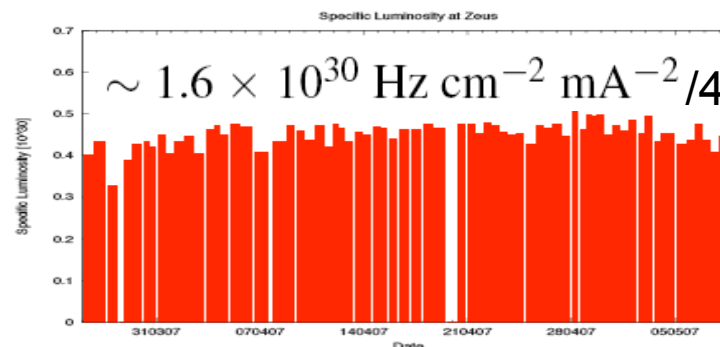
- Set up time of few days only
- Luminosity prompt and as calculated
- Polarisation increased (HERMES)
- Time given for intermediate  $E_p$  run

## The culmination of HERA upgrade

M.Klein  $F_L$  at HERA 30.7.2008 ICHEP Philadelphia



## Luminosity over 4 months at lower $E_p$

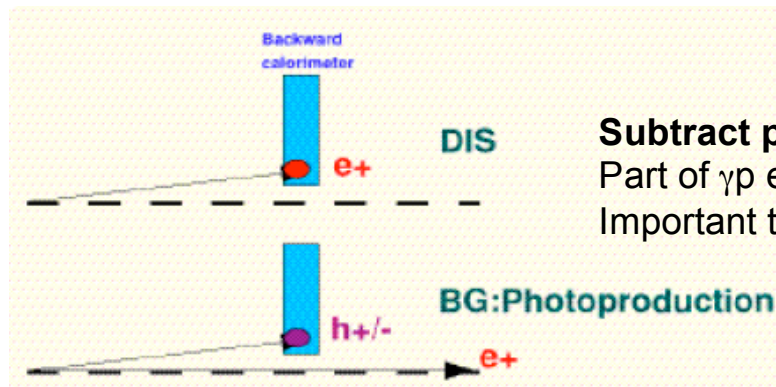
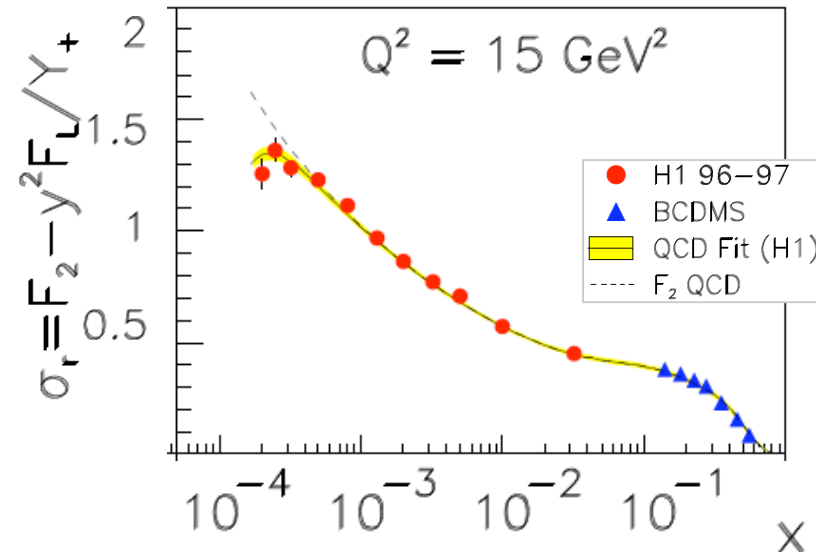


## Specific luminosity over first 2 weeks

# How to Measure $F_L$ ?

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

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



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

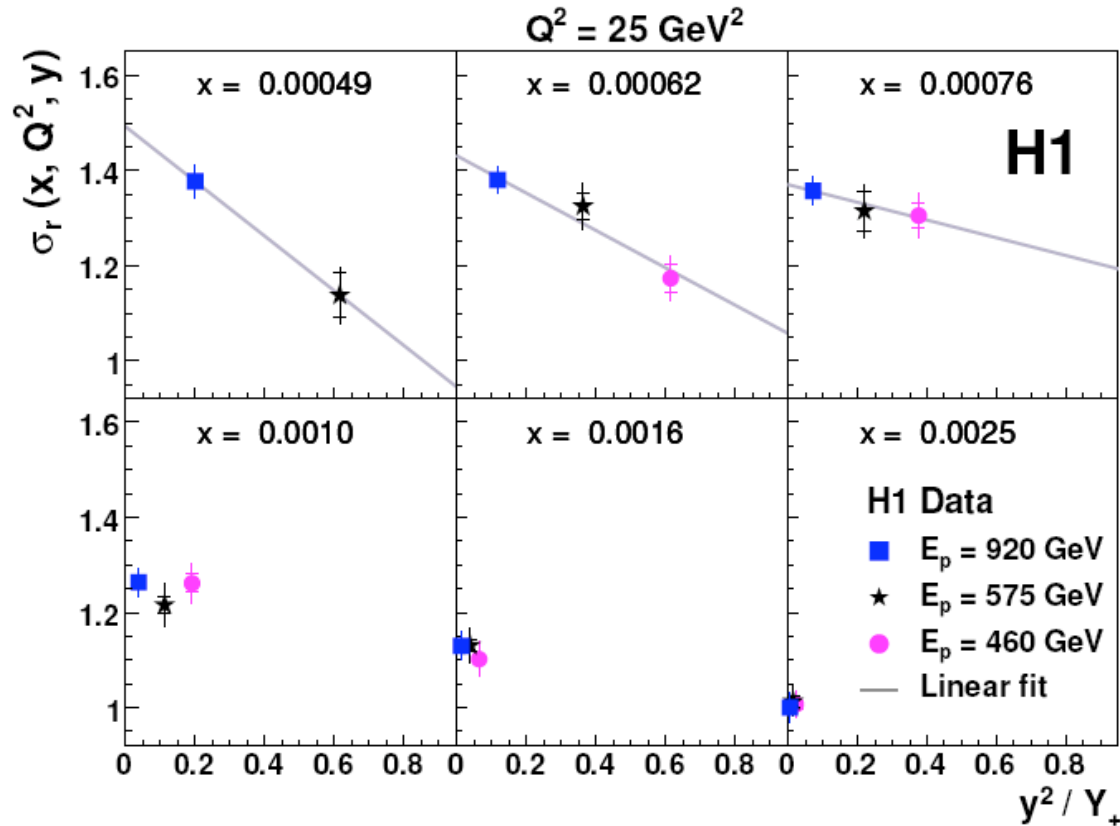
**Measure cross section as accurate as possible**  
cannot measure  $F_L$  at large x (low y) at HERA

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

2% at  $y=0.7$  gives  
 $\sim 0.06$  error on  $F_L$

# How to Measure $F_L$ ?

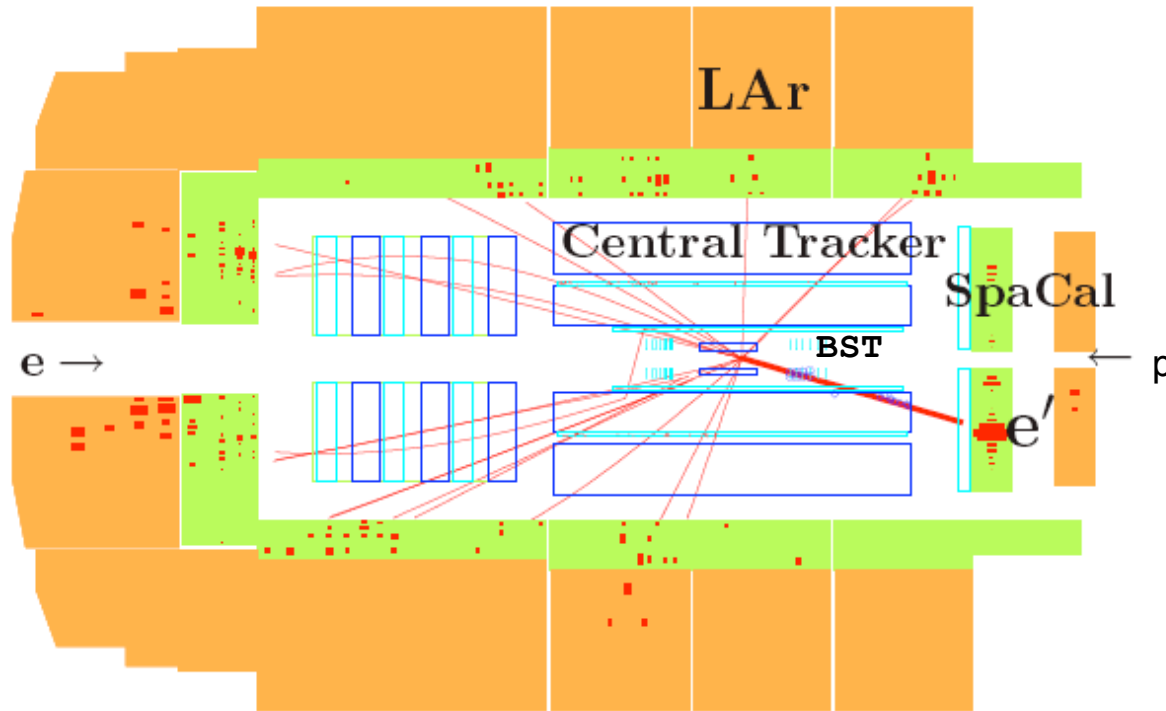
$$\sigma_r(x, Q^2; s) = F_2(x, Q^2) - \frac{y^2}{Y_+} \cdot F_L(x, Q^2)$$



**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  $30 \text{ GeV}^2$  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  $12 \text{ GeV}^2$  SpaCal+BST : in progress  
**12 and  $90 \text{ GeV}^2$  SpaCal+CT: published 6/08**  
**35 and  $800 \text{ GeV}^2$  LAr+CT: preliminary data**

## Event Selection Criteria:

$e$  in SpaCal or LAr (cluster+trigger),  $E_e' > 3 \text{ GeV}$

Track in CT or BST (reject neutrals,  $E/p$ )

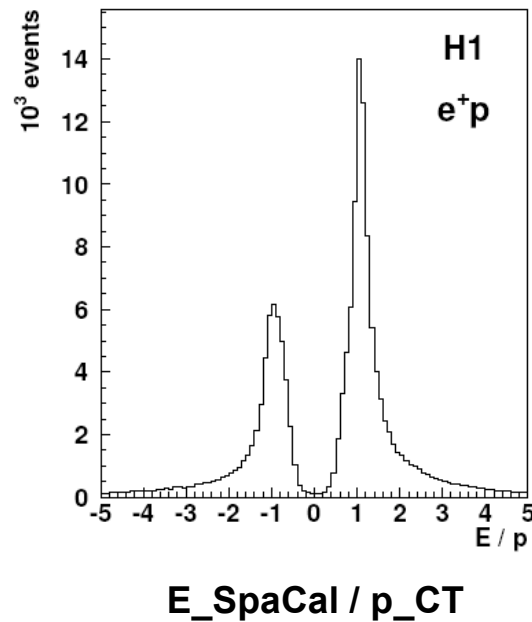
Interaction vertex

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

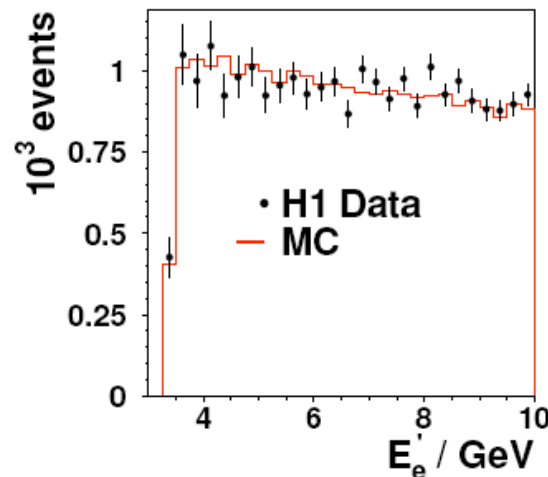
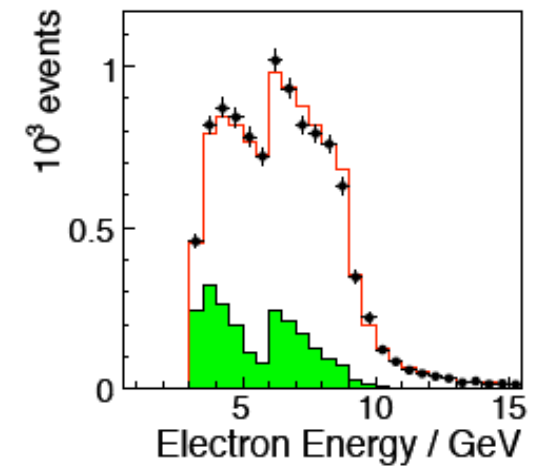
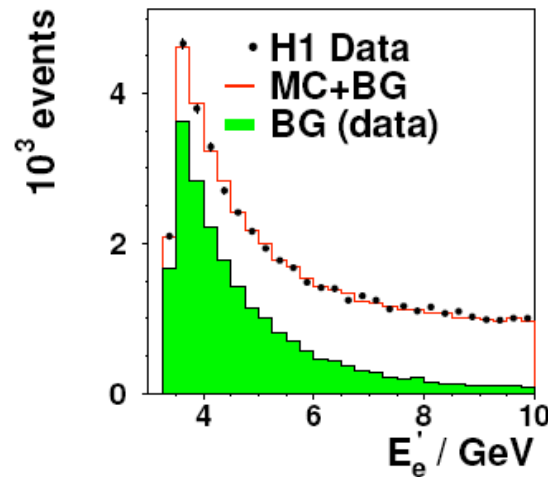
(reduces largely the radiative corrections)

# Background Subtraction - H1

At small energies DIS signal is superimposed by  $\gamma p$  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.

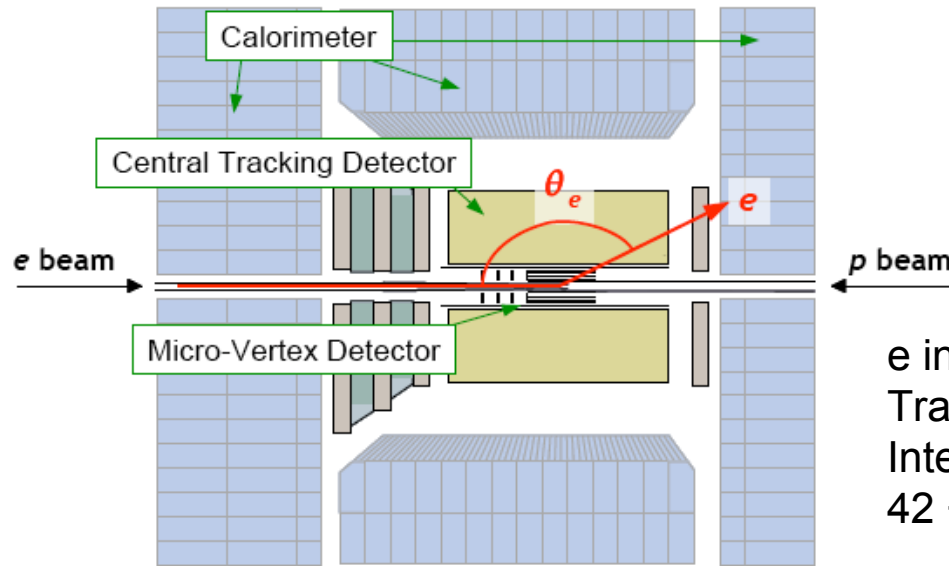


Scattered  $e$  energy distributions at medium and high  $Q^2$   
SpaCal (bwd calo)      Lar (central calo)



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

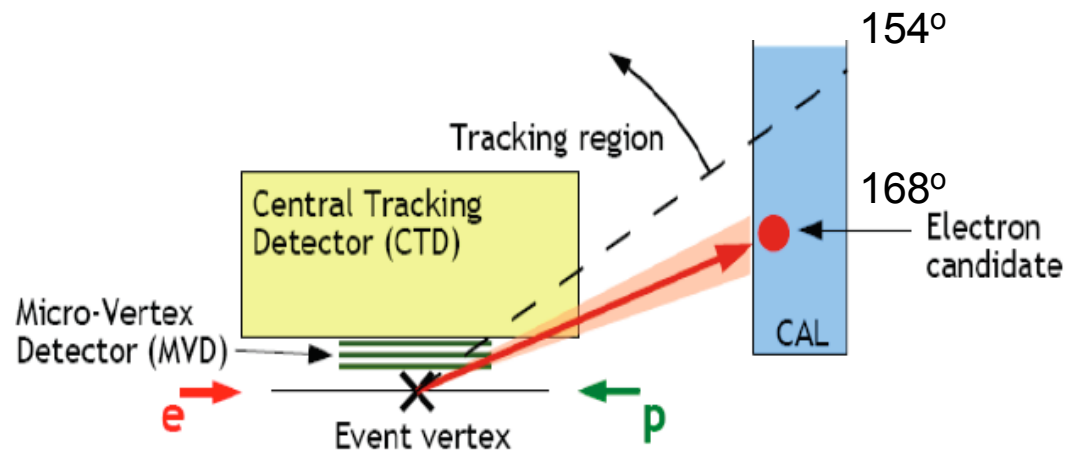
# Measuring $F_L$ with ZEUS



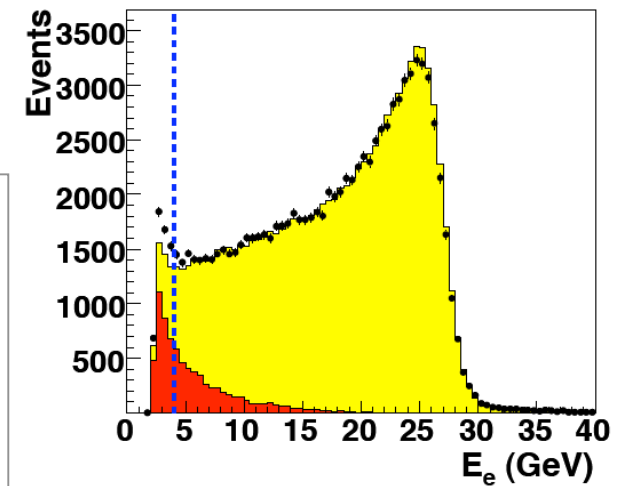
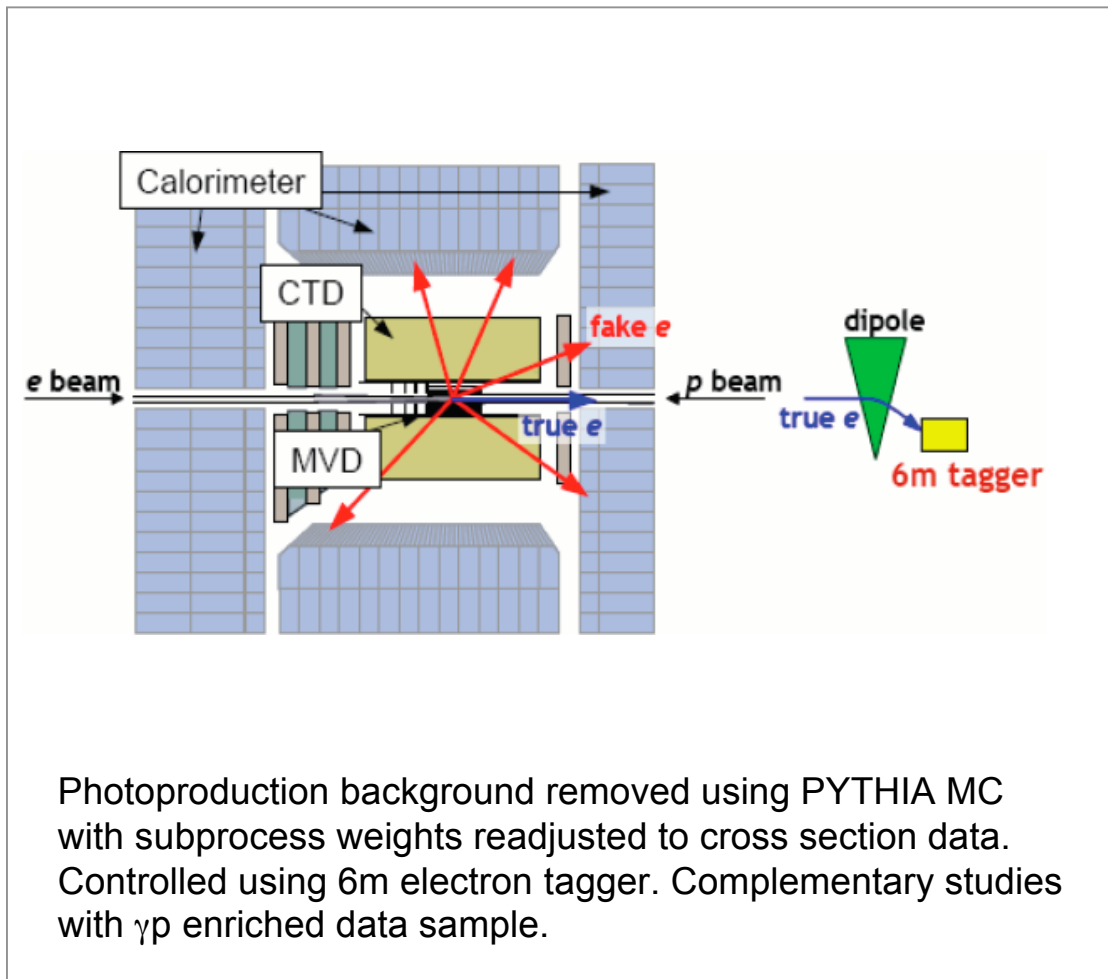
## Event Selection Criteria

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

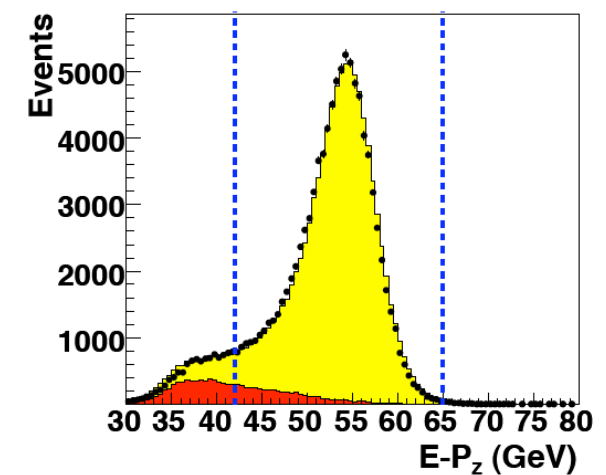
$Q^2$  range between  
 24 and 110 GeV<sup>2</sup>



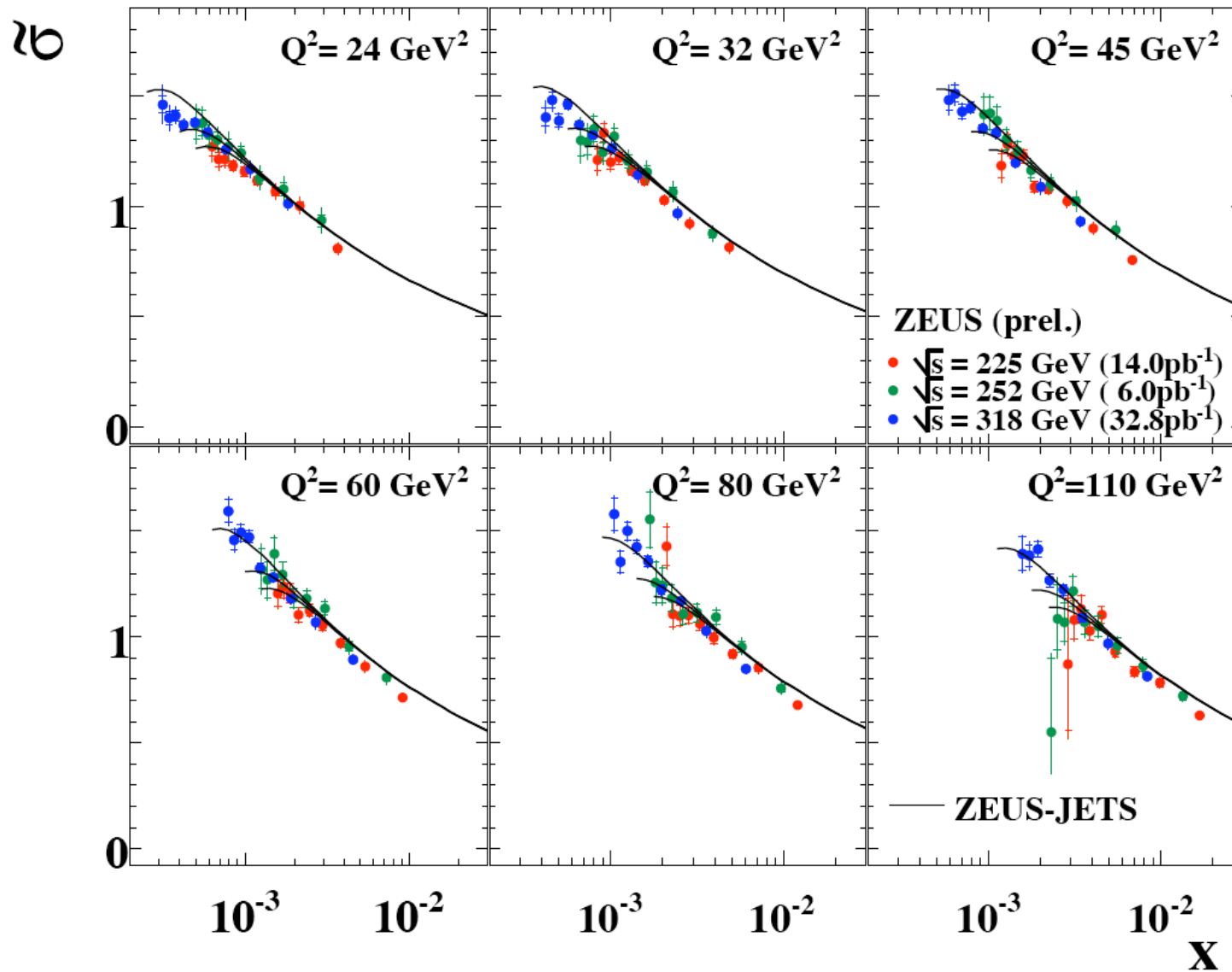
# Background Subtraction - ZEUS



- ZEUS (prel.)
- $\sqrt{s}=252$  GeV ( $6\text{pb}^{-1}$ )
- MC DIS +  $\gamma p$
- MC  $\gamma p$



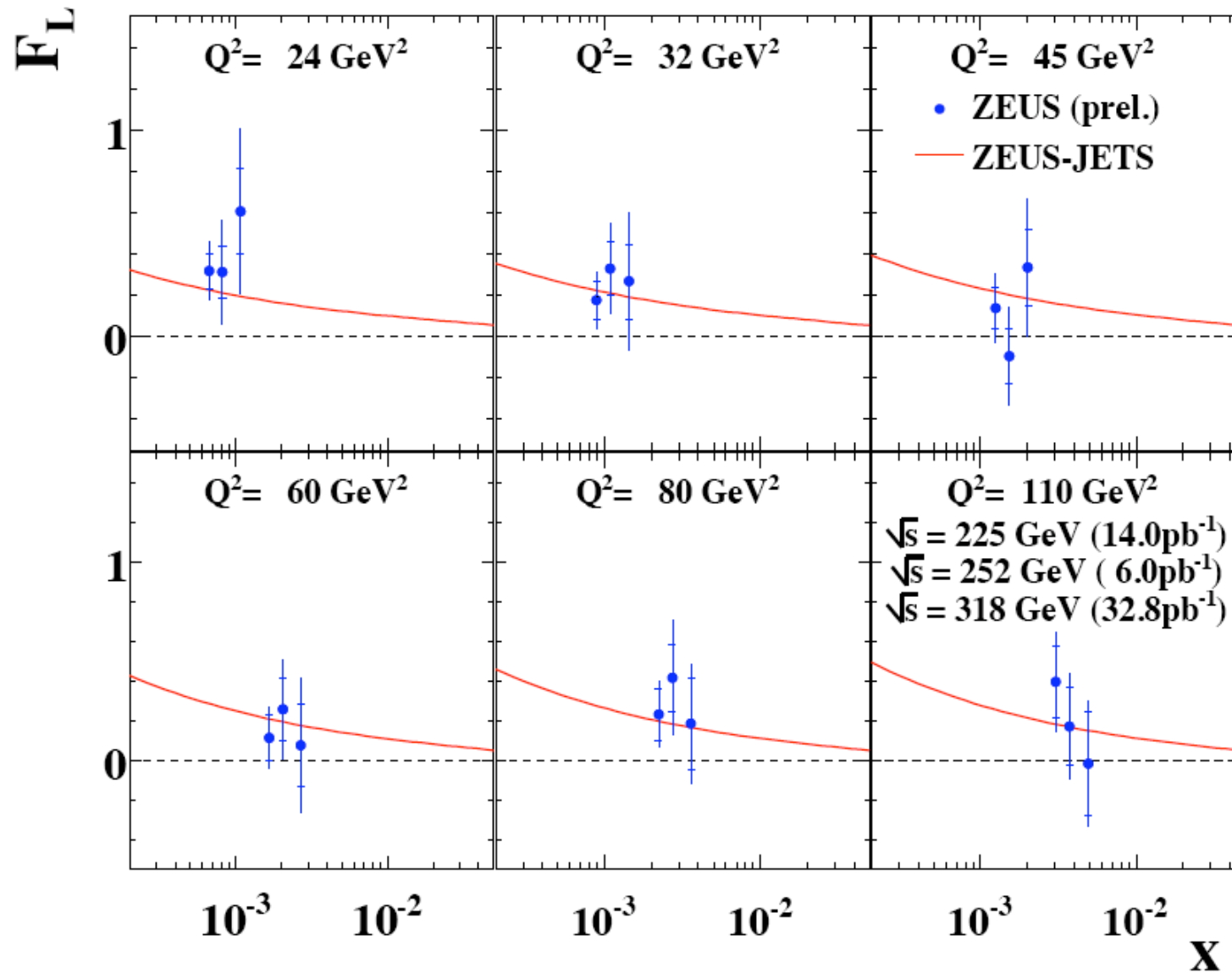
# Cross Section Results - ZEUS



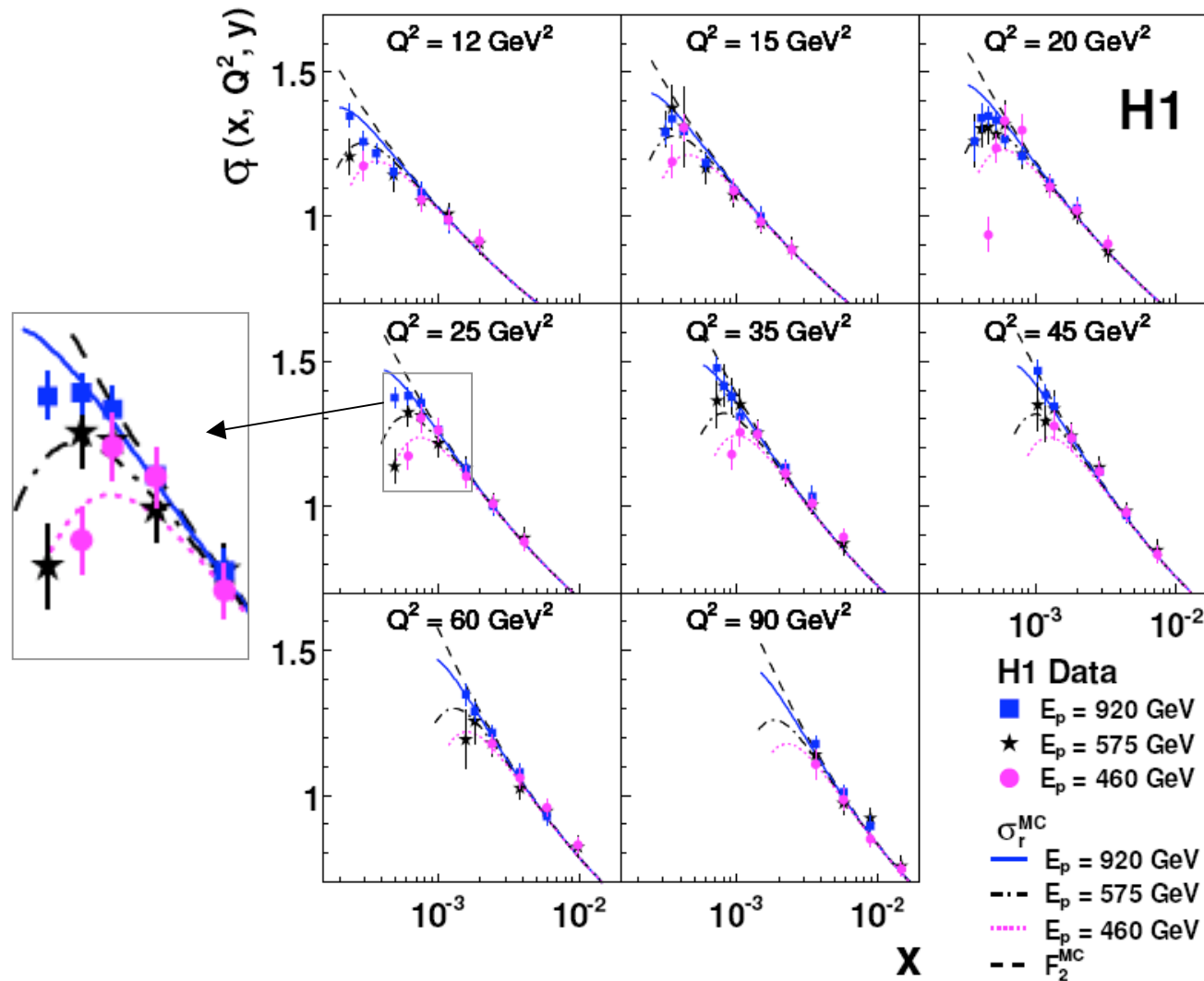
Data at  
460+920 GeV  
were presented  
to DIS08.

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



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

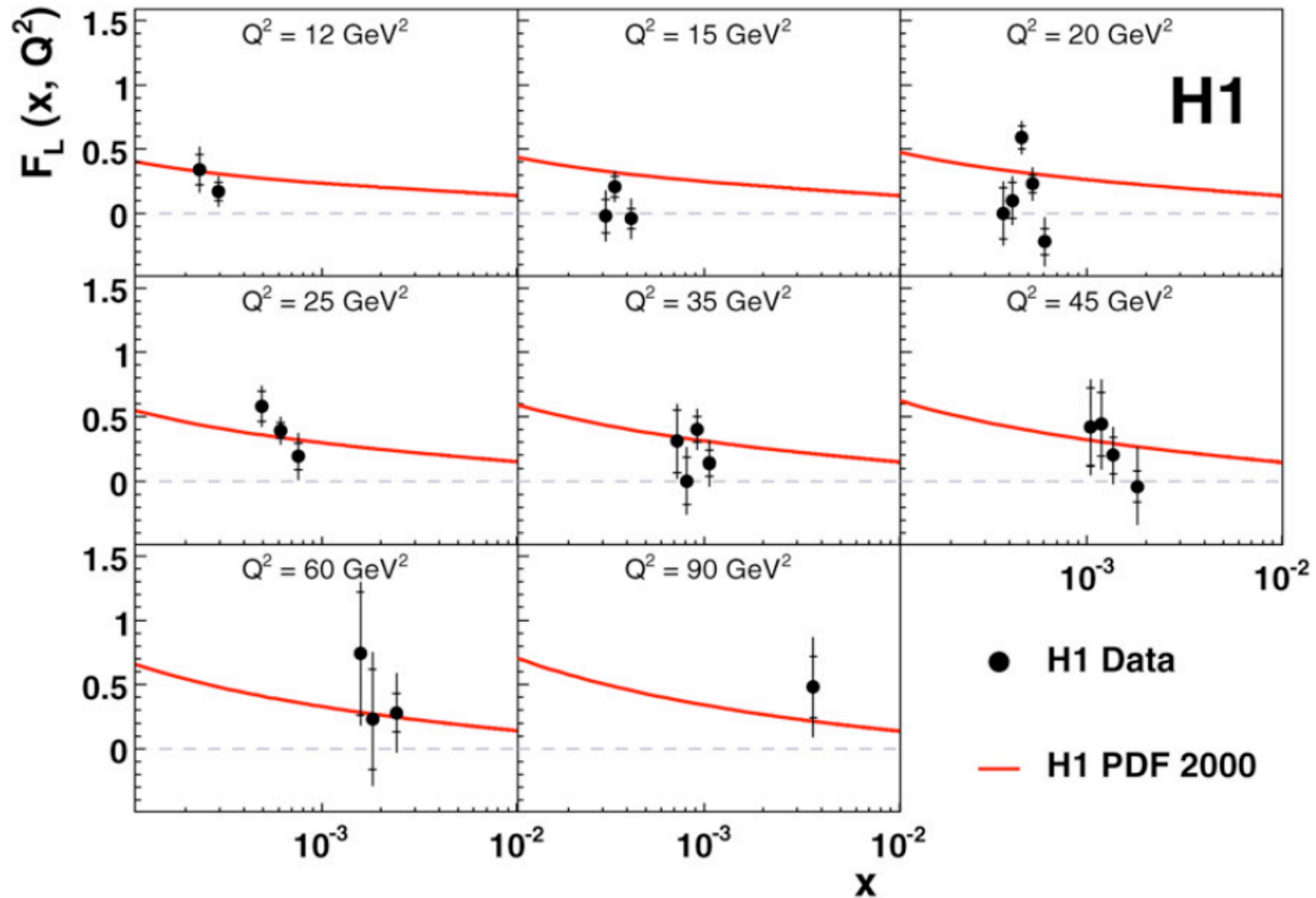


Data presented to DIS08 in preliminary form and published in Phys.Lett in June.

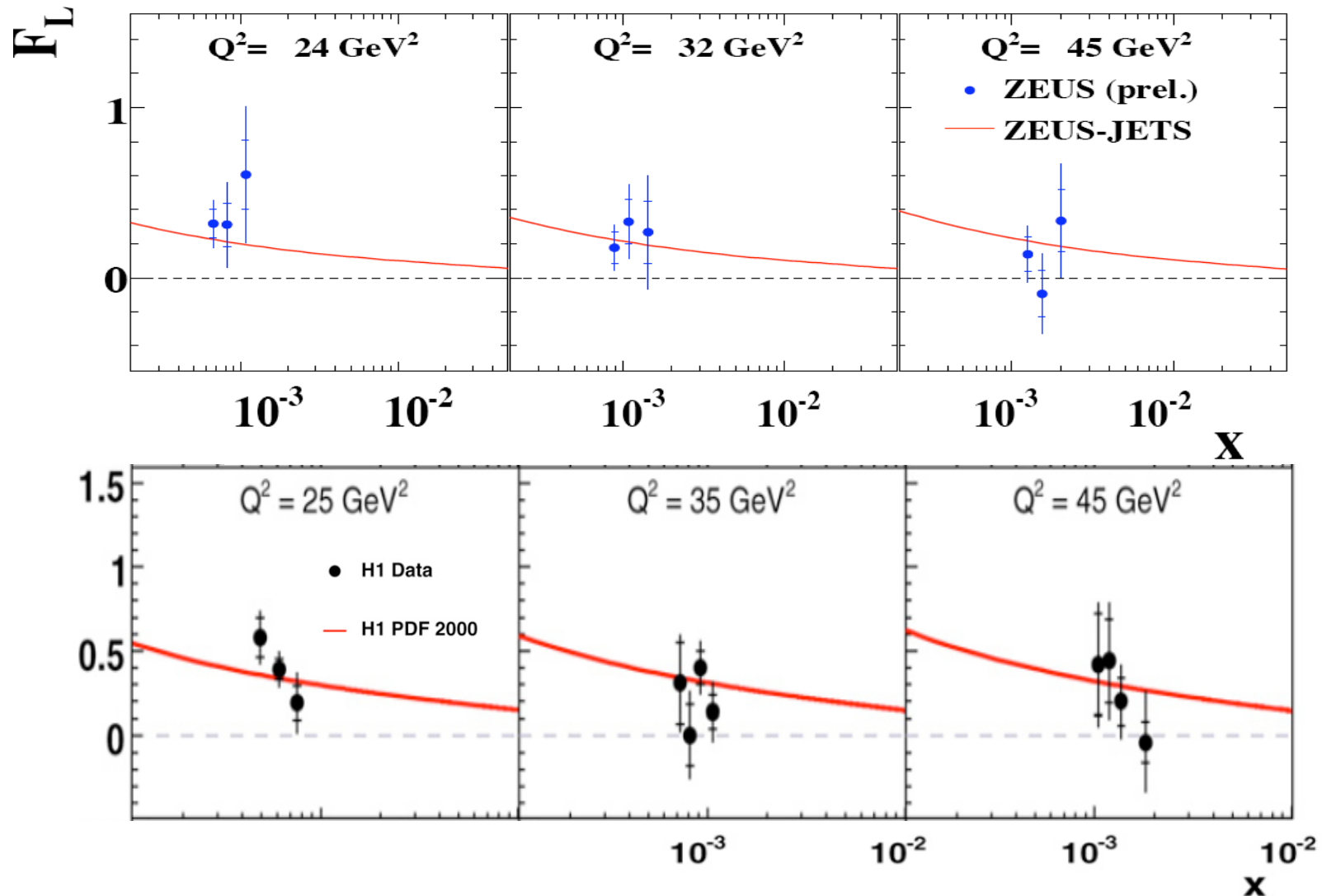
Positron energy measured in SpaCal and its track momentum in the central jet chamber.

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

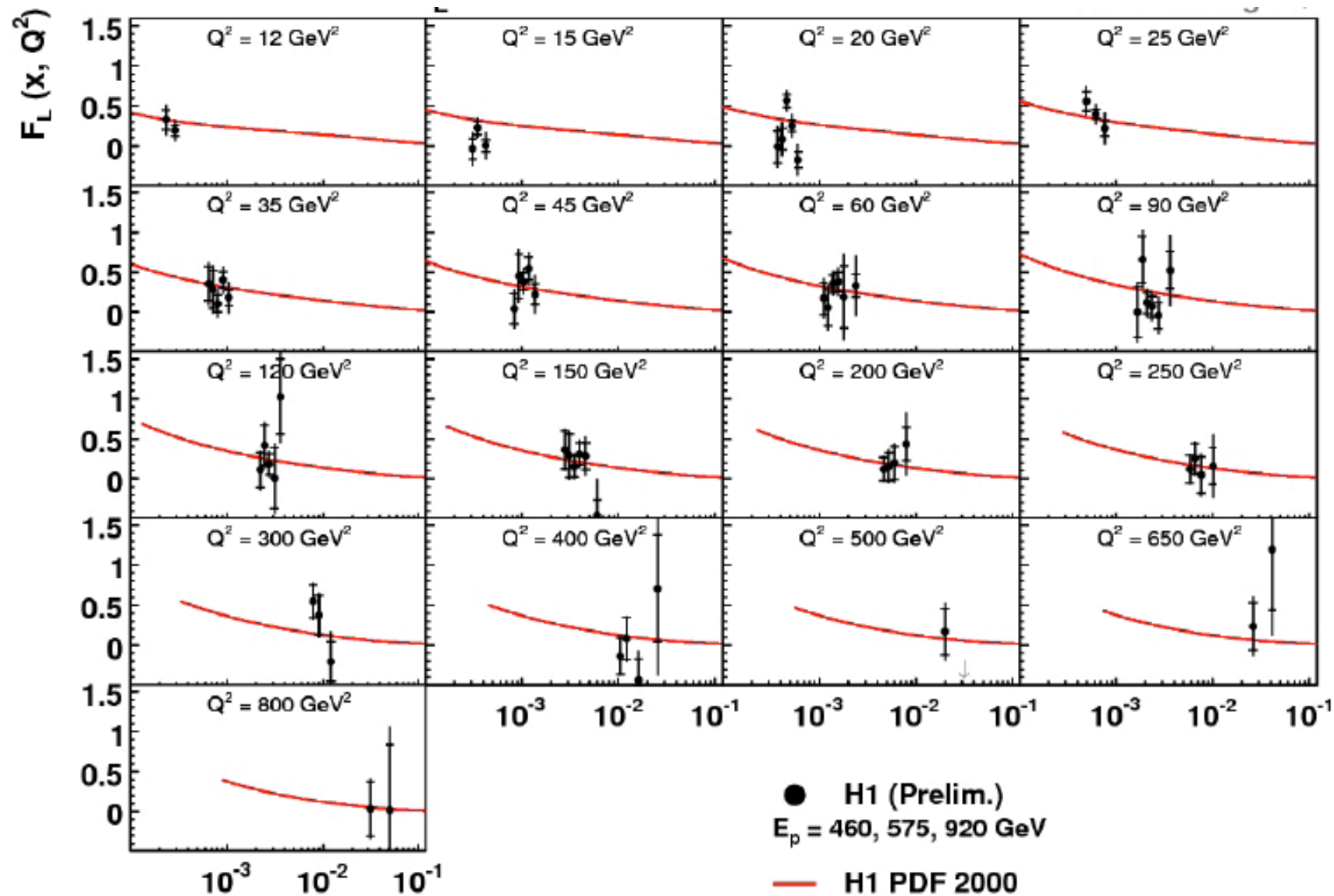
# Overview on $F_L$ Data - H1



# Comparison on $F_L$ Data - ZEUS+H1

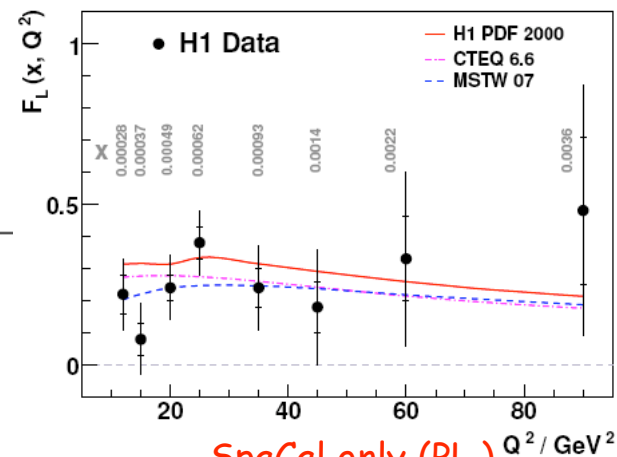
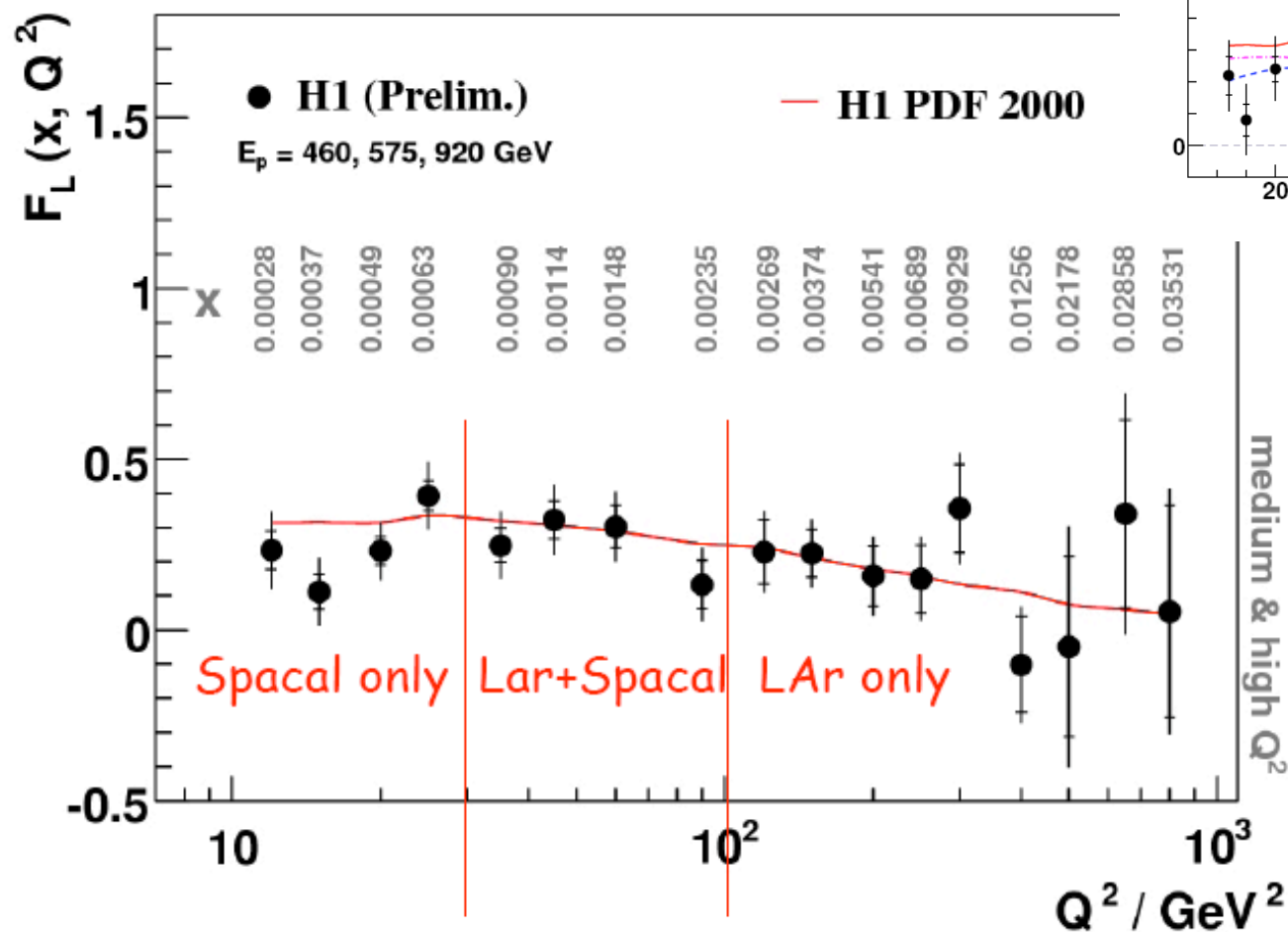


# Overview on all $F_L$ Data - H1



LAr data extend kinematic range and improve accuracy

# Combination of $F_L$ Data - H1



SpaCal only (PL.)

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

**Combination with LAr  
 improves the  
 published SpaCal  
 result for  $Q^2 > 30 \text{ GeV}^2$**

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:

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

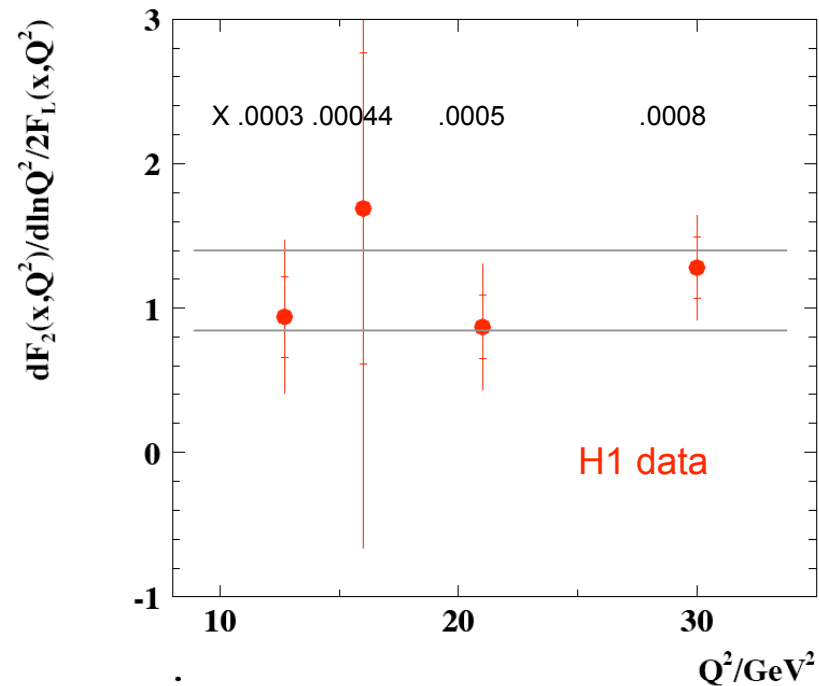
$$F_L(0.4x, Q^2) \approx \frac{10}{54} \cdot \frac{\alpha_s}{\pi} xg(x, Q^2)$$

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  $dF_2/d\ln Q^2 = 2F_L$

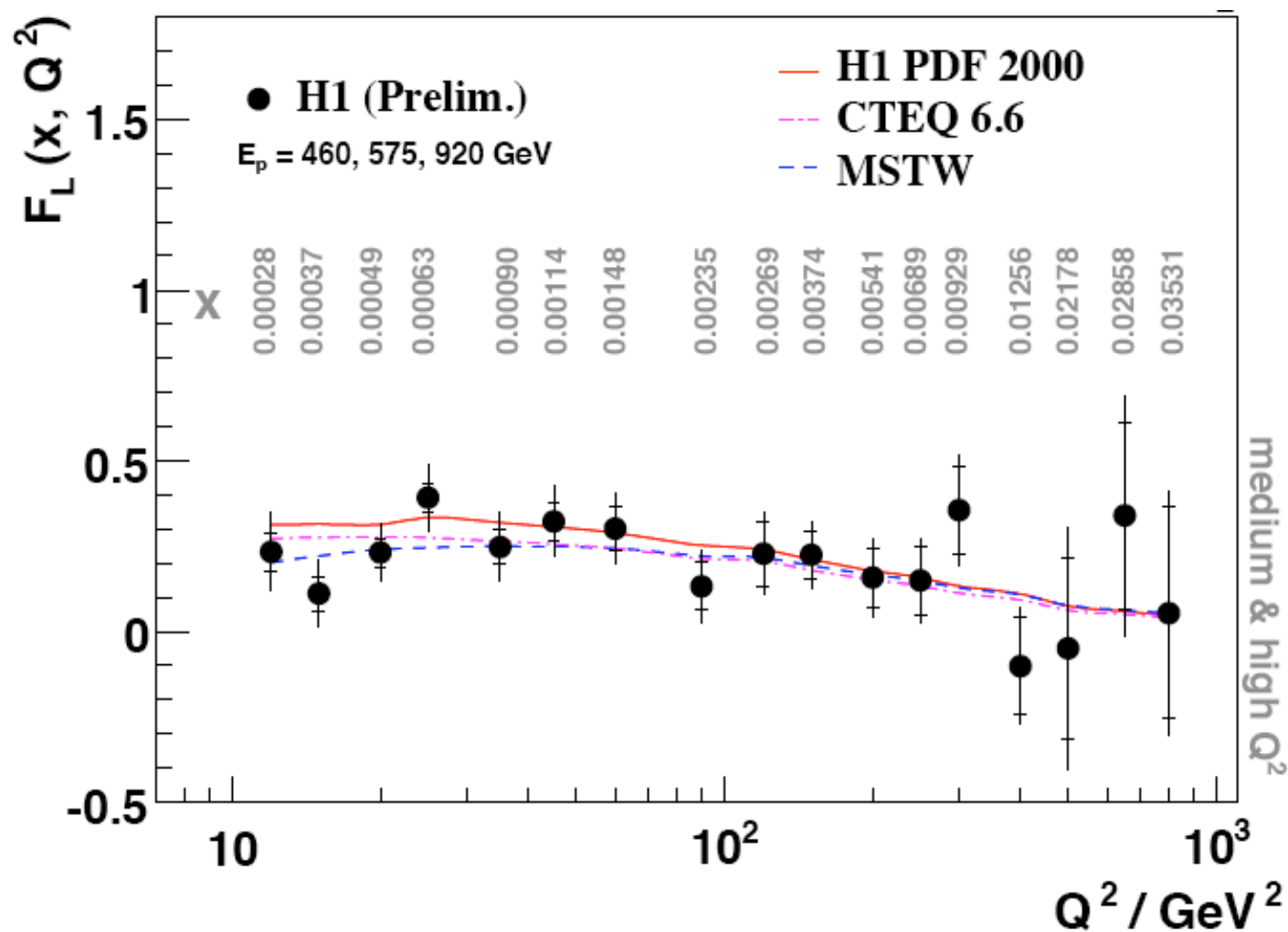
This is observed to hold within 25% and may deserve further study

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



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

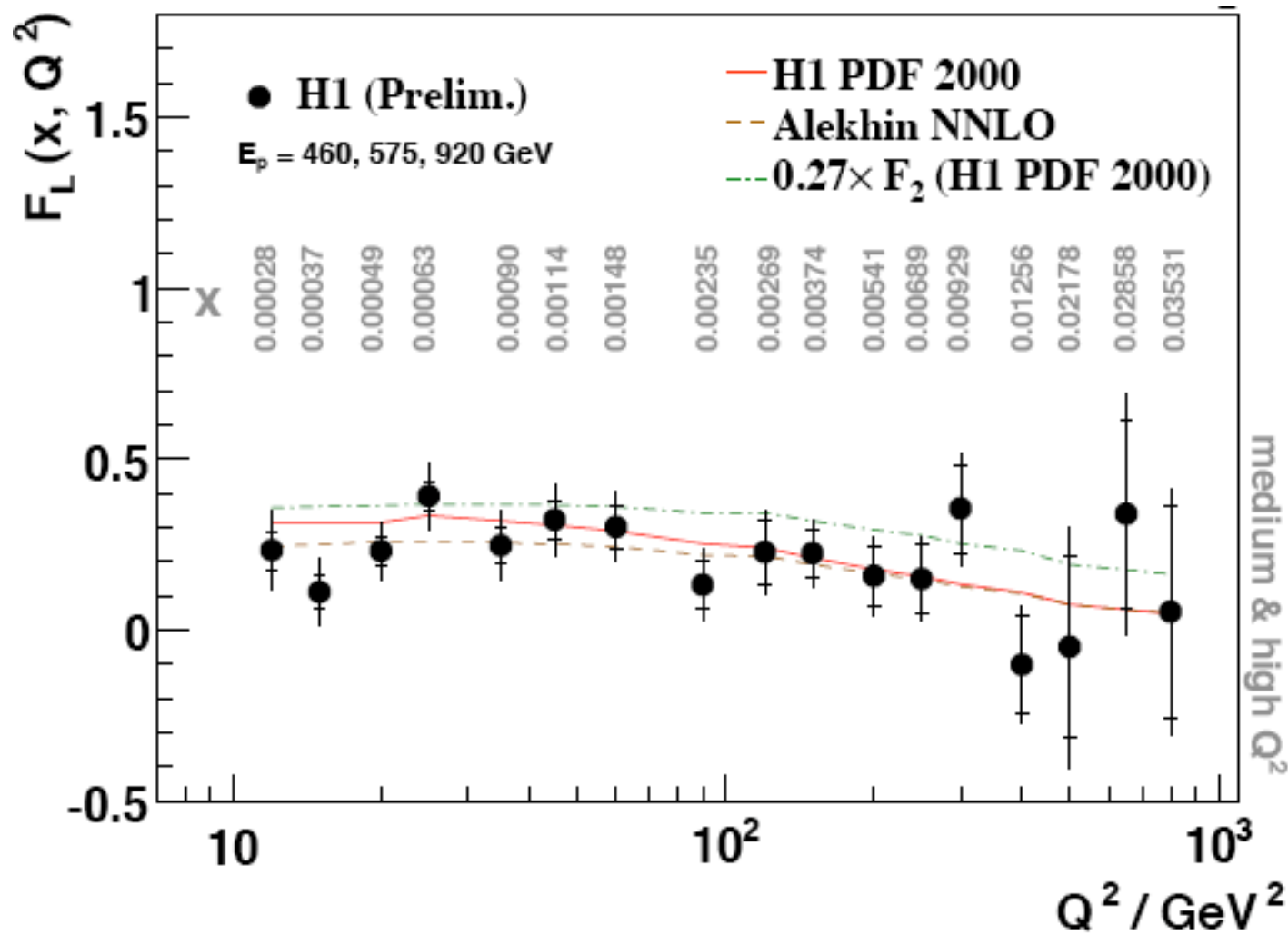
# Comparison of $F_L$ Data with pQCD



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  $12-800 \text{ GeV}^2$  (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.

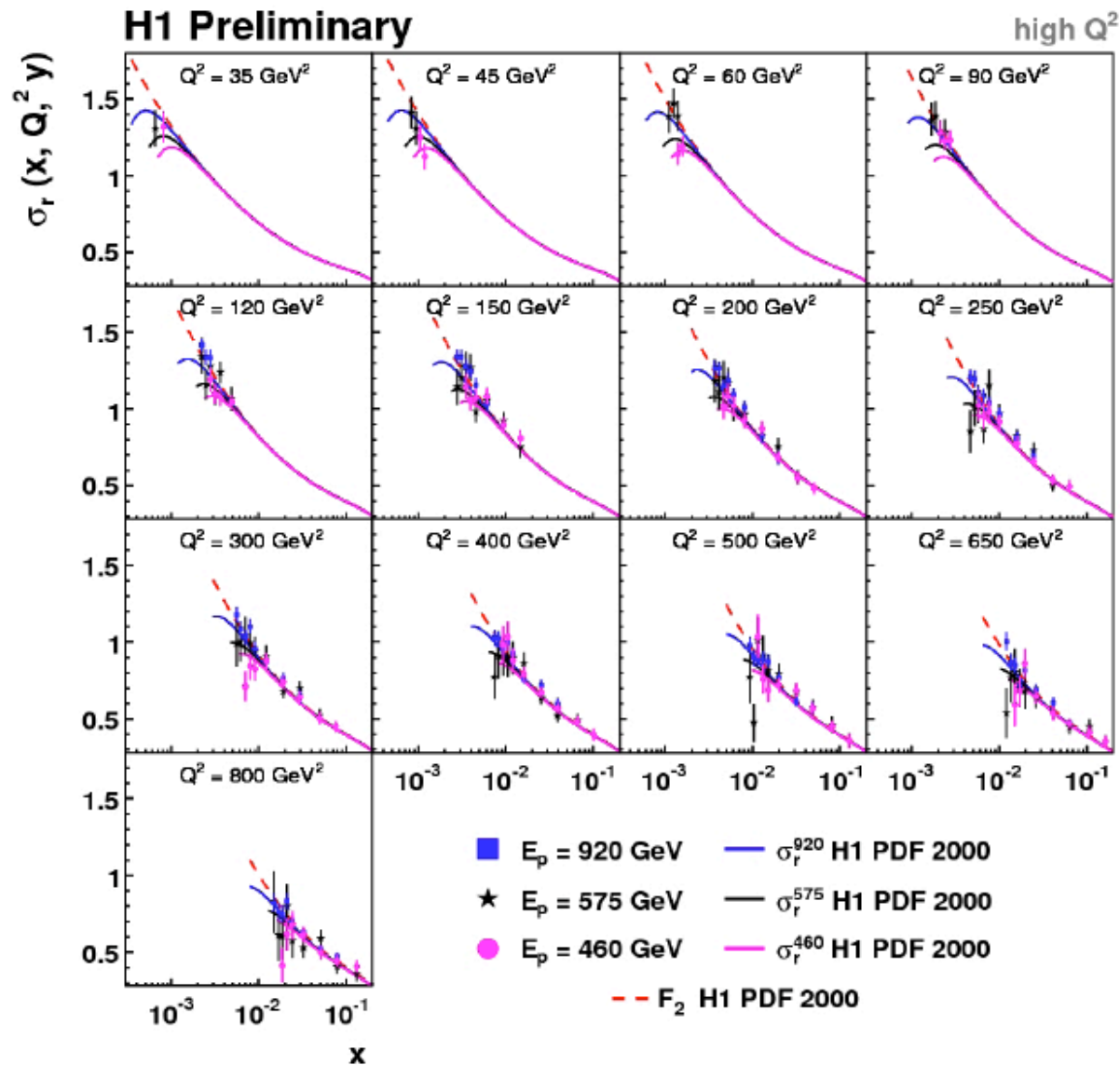
First data of H1 have been published. The analysis is ongoing, with various expected improvements related to:

- 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<sup>2</sup>