

Longitudinal structure function measurements from HERA

Vladimir Chekelian (MPI for Physics, Minich)



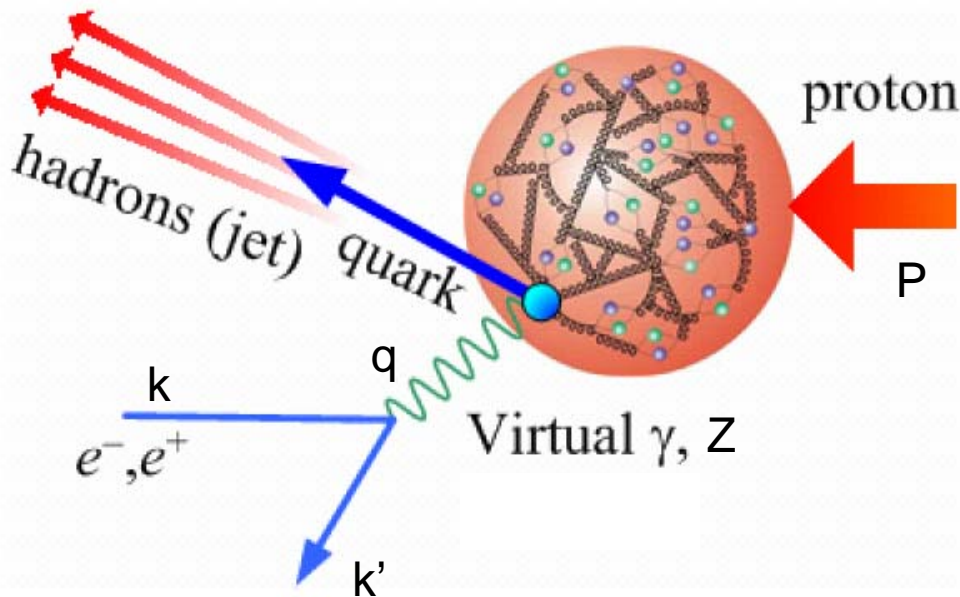
on behalf of H1 and ZEUS



- Deep Inelastic Scattering / Structure functions
- Longitudinal structure function $F_L(x, Q^2)$
- HERA / H1 and ZEUS
- Measurement strategy for F_L
- Experimental details of the F_L analyses
- F_L results
- Summary

Deep Inelastic Scattering

Neutral Current (NC): $e^{\pm} p \rightarrow e^{\pm} X$



$Q^2 = -q^2 = -(k-k')^2$ virtuality of γ^*, Z

$x = Q^2/2(Pq)$ Bjorken x

$y = (Pq)/(Pk)$ inelasticity

$Q^2 = sxy$ $s=(k+P)^2$

Factorisation

$$\sigma_{DIS} \sim \hat{\sigma} \otimes pdf(x)$$

$\hat{\sigma}$ – perturbative QCD cross section
 pdf – universal parton distribution functions

The Proton Structure Functions

$$\frac{d^2\sigma_{NC}^{e^+p}}{dx dQ^2} = \frac{2\pi\alpha^2 Y_+}{xQ^4} \sigma_r^\pm = \frac{2\pi\alpha^2 Y_+}{xQ^4} \left[F_2(x, Q^2) - \frac{y^2}{Y_+} F_L(x, Q^2) \mp \frac{Y_-}{Y_+} xF_3(x, Q^2) \right]$$

helicity factors: $Y_\pm = 1 \pm (1-y)^2$

dominant contribution:

$$F_2(x, Q^2) = \sum e_{q_i}^2 x(q_i + \bar{q}_i)$$

contributes only at high Q^2

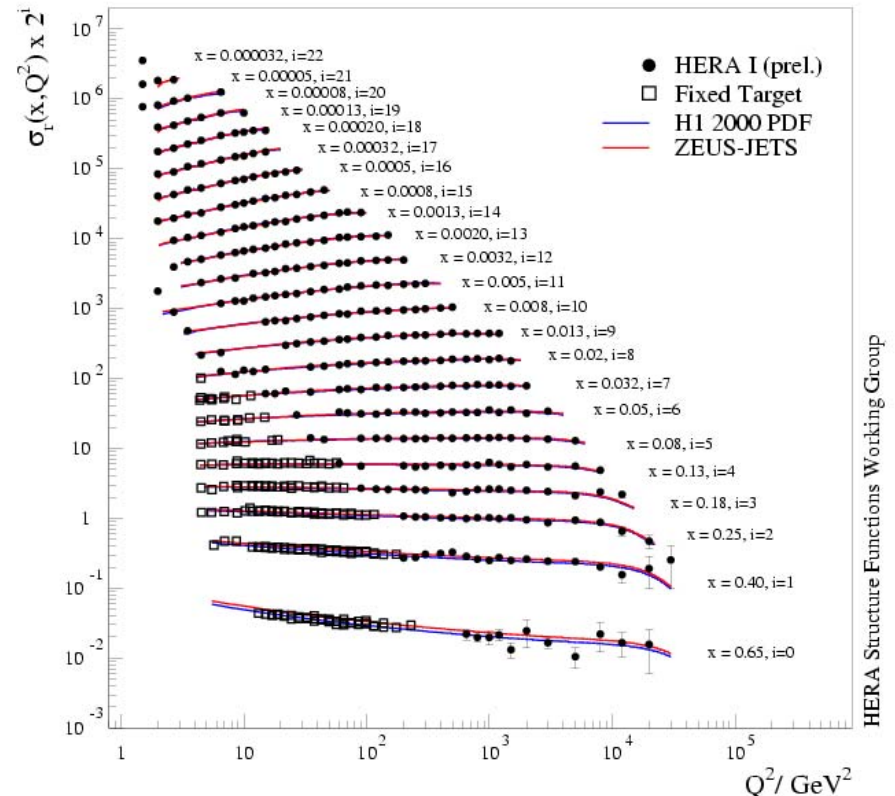
$$xF_3(x, Q^2) = x \sum B_i(q_i - \bar{q}_i)$$

at low x

$$F_2 \sim \sigma_L^{\gamma p} + \sigma_T^{\gamma p}, \quad F_L \sim \sigma_L^{\gamma p}$$

$$\rightarrow 0 \leq F_L \leq F_2$$

HERA 1 e^+p Neutral Current Scattering - H1 and ZEUS



The longitudinal structure function $F_L(x, Q^2)$

- F_L is an independent structure function to be measured at HERA to complete the DIS program
- F_L is a pure QCD effect which allows to make critical tests of the perturbative QCD framework used for pdf determinations
- F_L is directly sensitive to gluon density

in QPM

due to helicity and angular momentum conservation for spin $\frac{1}{2}$ quarks

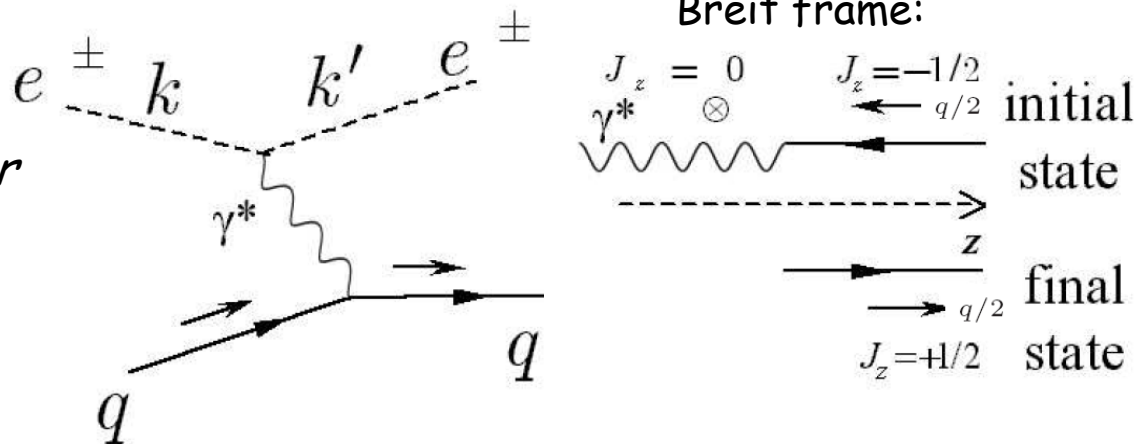
$$F_L \sim \sigma_L^{\gamma p} = 0$$

$$F_L = F_2 - 2xF_1 = 0$$

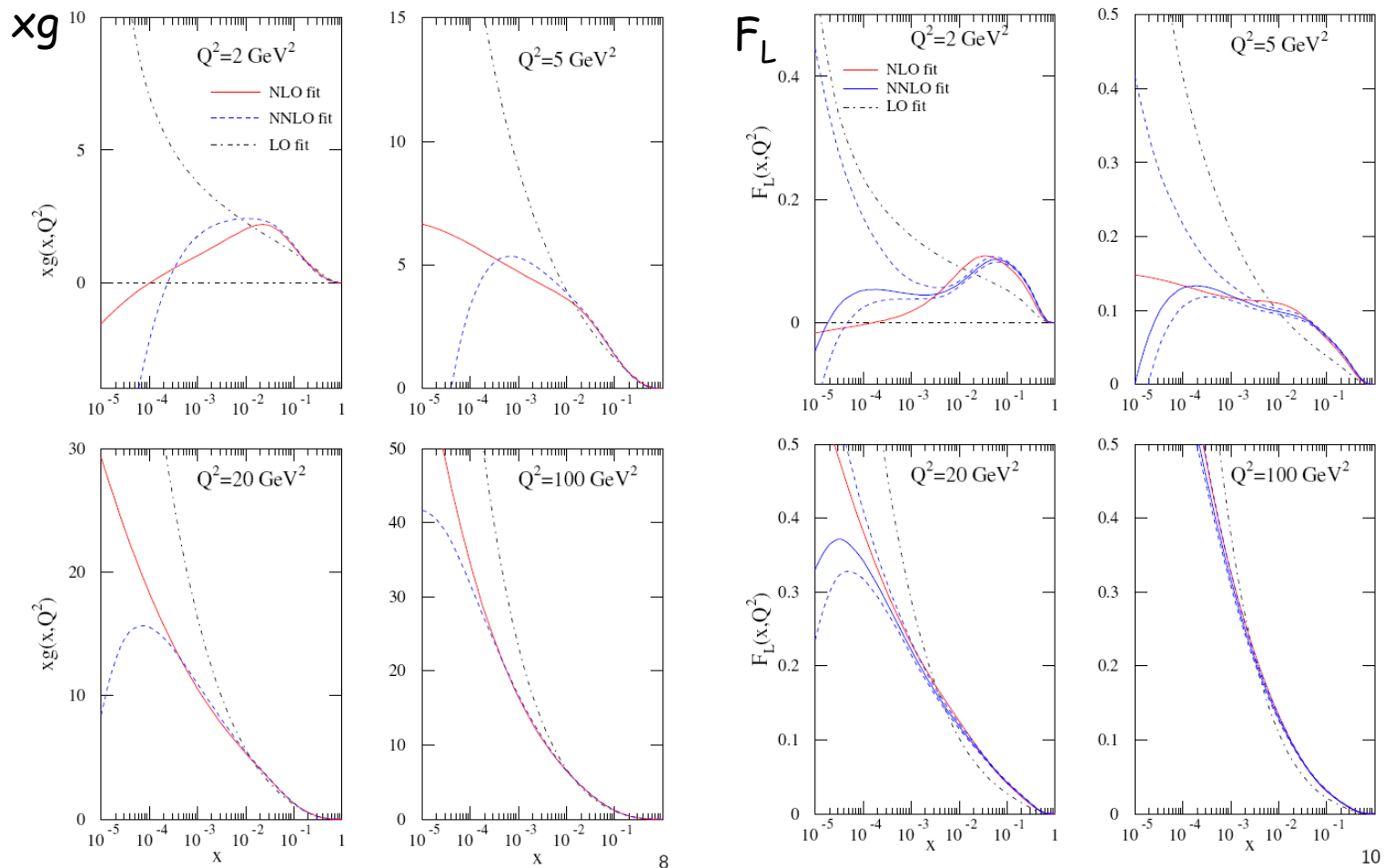
Callan-Gross relation

in QCD:

$$F_L(x, Q^2) = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \left[\frac{16}{3} F_2 + 8 \sum_q e_q^2 \left(1 - \frac{x}{z}\right) \cdot xg \right]$$

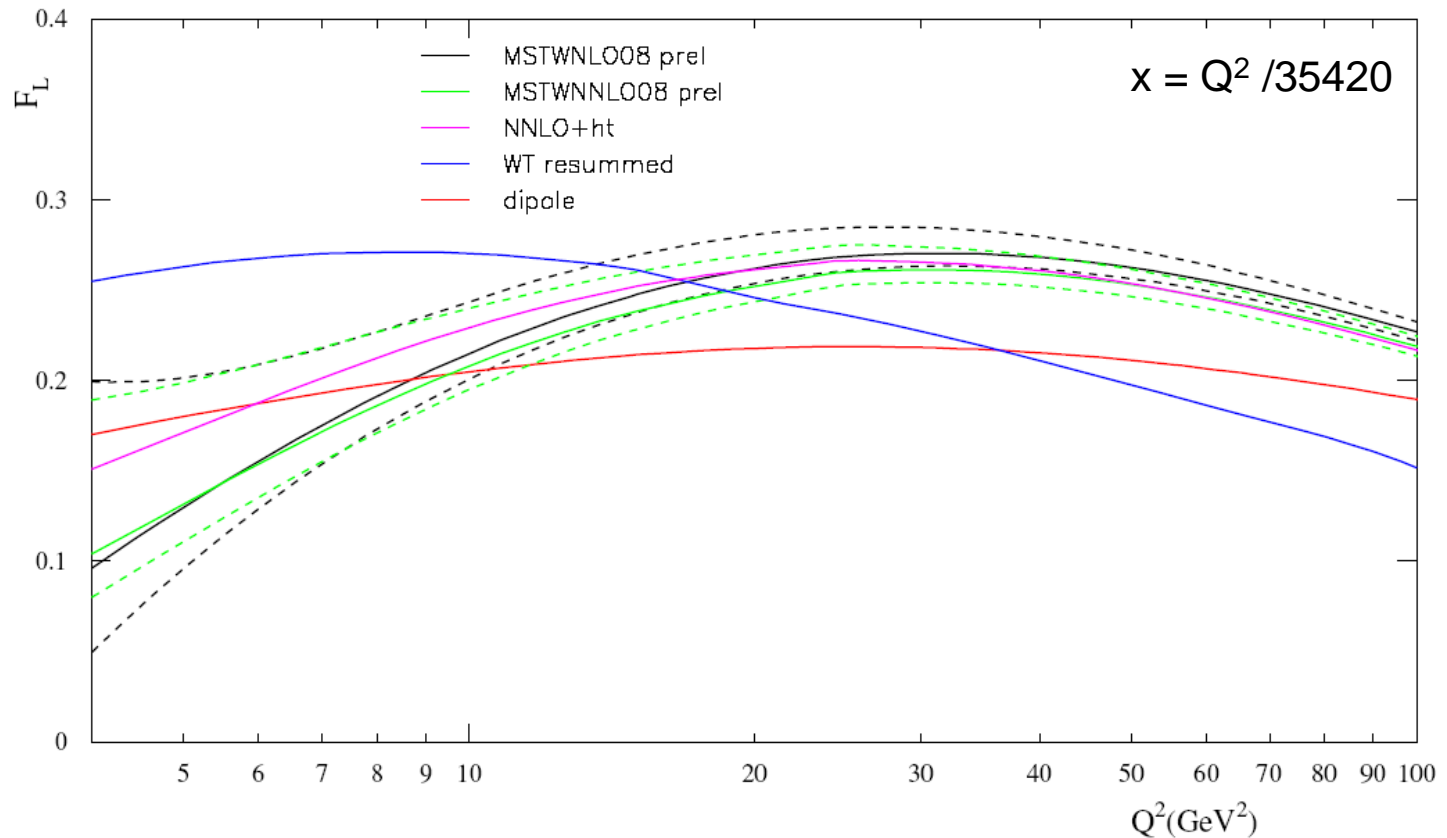


Gluon and F_L in LO – NLO – NNLO (MSTW)



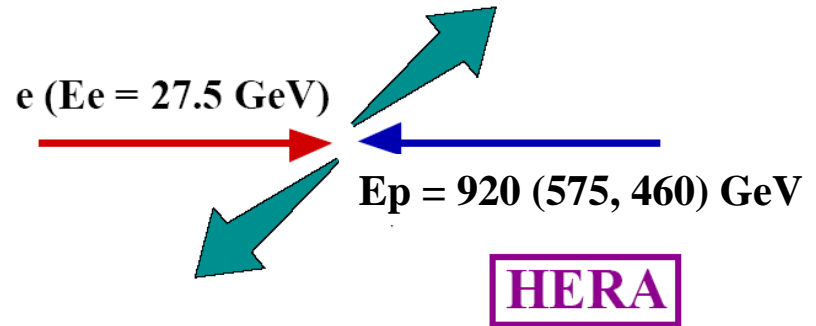
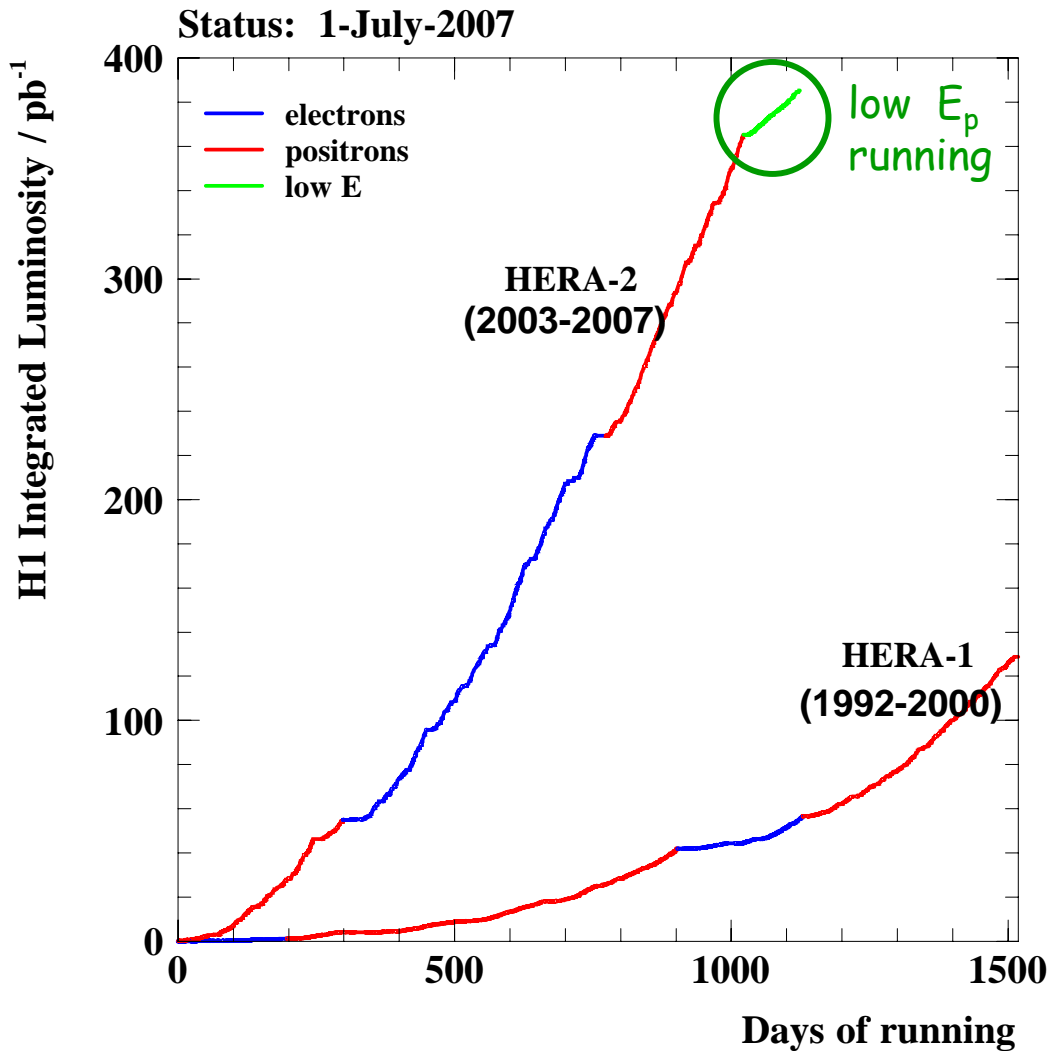
→ poor stability for gluon at small x → similarly for F_L but less prominent

Theory predictions for F_L in the HERA domain



- firm QCD predictions for $Q^2 > 10 \text{ GeV}^2$
- spread of predictions at Q^2 below 10 GeV^2

HERA (1992–2007)



peak luminosity $5 \cdot 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$
 $Q^2_{\text{max}} = 10^5 \text{ GeV}^2$
 $\lambda_{\text{max}} \sim 1/1000 r_{\text{proton}}$
 longitudinal e -beam polarisation

H1+ZEUS in total $\sim 1 \text{ fb}^{-1}$

about equally shared between

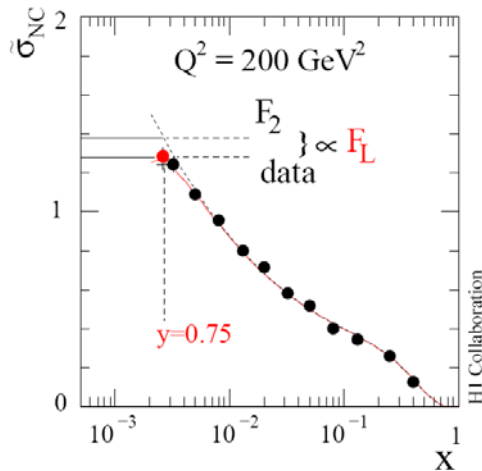
- experiments (H1, ZEUS)
- e^+ and e^- ,
- positive and negative P_e

→ low proton energy run for direct F_L measurements
 $13 \text{ pb}^{-1} E_p = 460 \text{ GeV}$
 $7 \text{ pb}^{-1} E_p = 575 \text{ GeV}$

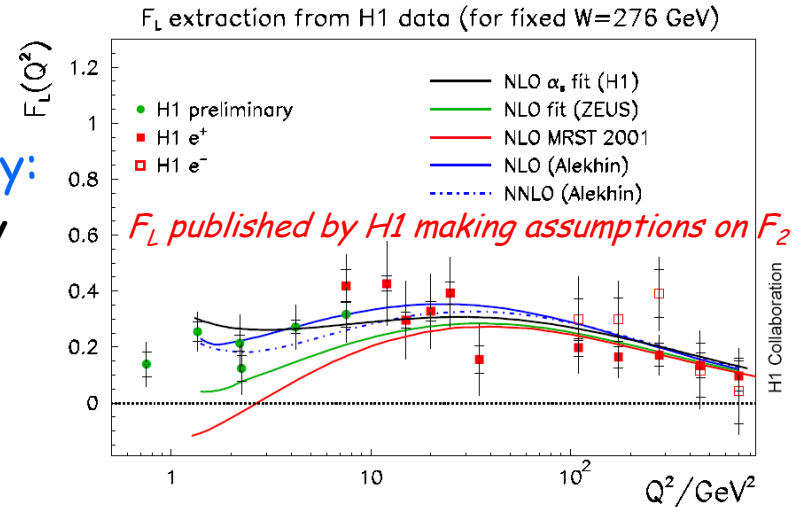
Measurement strategy for F_L

$$\tilde{\sigma}_{NC} = \frac{d^2\sigma_{NC}^{ep}}{dx dQ^2} / \left(\frac{2\pi\alpha^2}{xQ^4} Y_+ \right) = F_2 - \frac{y^2}{1 + (1-y)^2} F_L$$

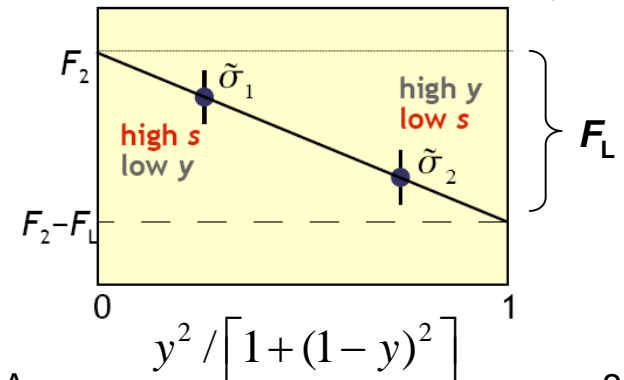
sensitivity to F_L
only at high y



→ one possible way:
measure σ at high y
and assume F_2



→ the way free from theoretical assumption:
measure σ at the same x & Q^2 and different y
by changing the proton beam energy ($y = Q^2/sx$)

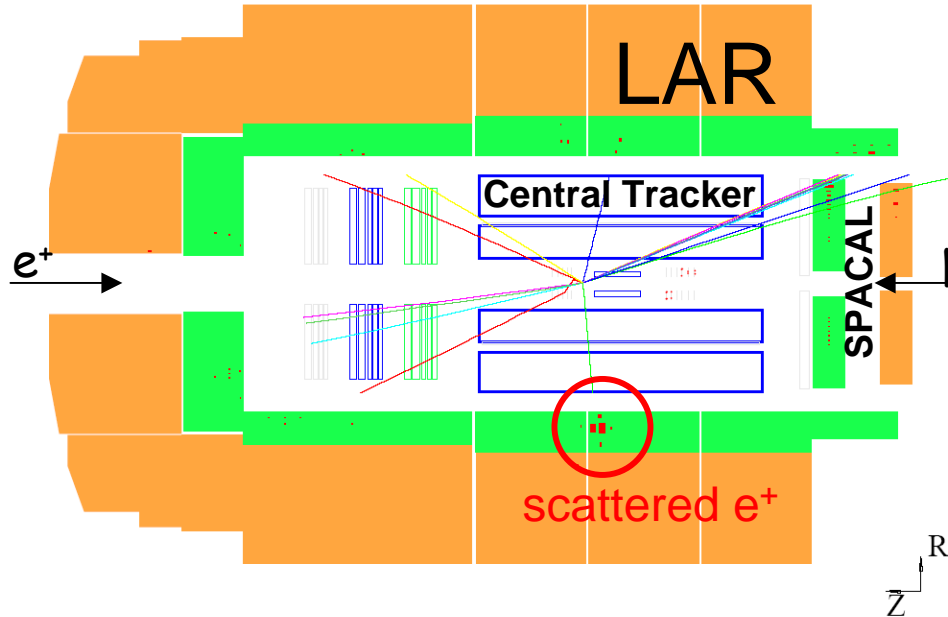


H1 and ZEUS

$E'_e > 3 \text{ GeV}$ ($y \approx 0.90$)

$$y = 1 - (E'_e/E_e) \sin^2(\vartheta_e/2)$$

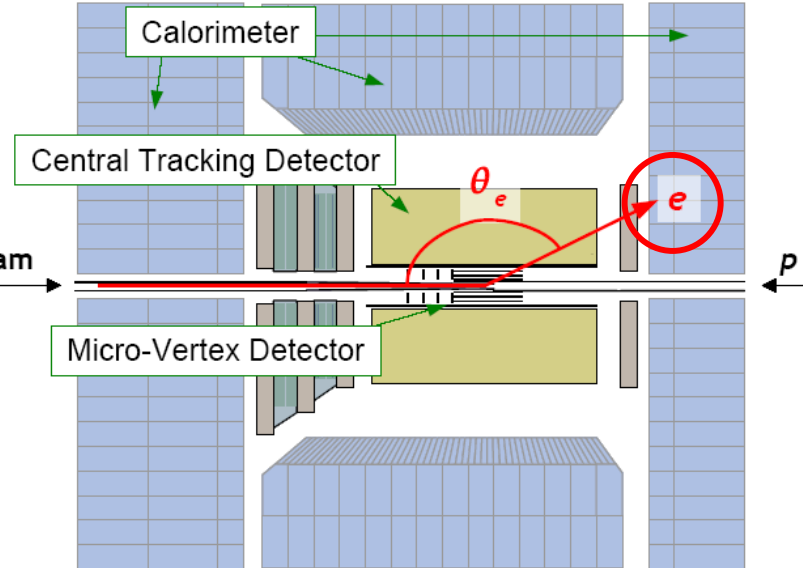
$E'_e > 6 \text{ GeV}$ ($y \approx 0.76$)



F_L measurements in H1

Q^2 range (GeV^2)			
medium Q^2	12-90	Spacal+CT	published
high Q^2	35-800	LAr+CT	H1 prel.
low Q^2	5-15	Spac+BST	to come

V.Chekelian, 28.06.2008
PIC 2008



F_L measurements in ZEUS

$$\vartheta < 168^\circ$$

$$24 \leq Q^2 \leq 110 \text{ GeV}^2$$

more to come

FL measurements from HERA

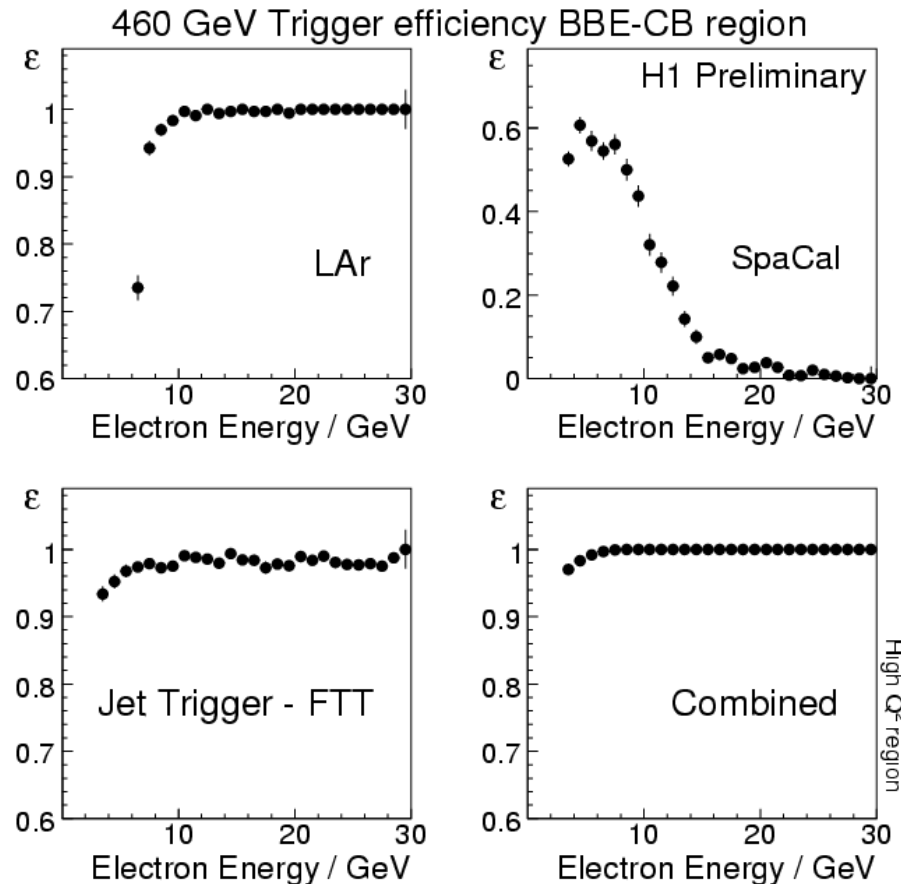
Hardware & software improvements

H1: new trigger hardware since fall 2006:

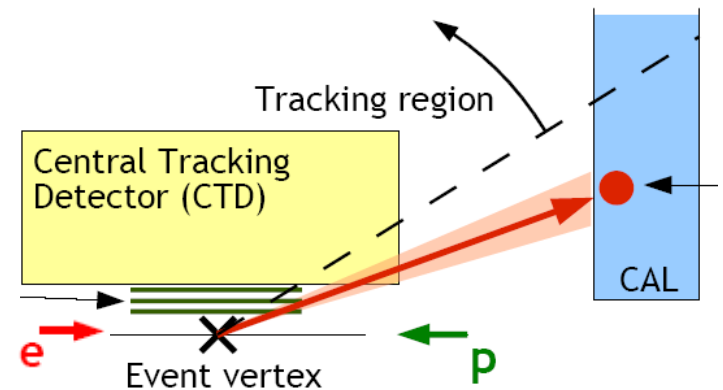
- **Jet Trigger** (real time clustering in LAr)
- **Fast Track Trigger** (FTT)

ZEUS: new tool is developed to extend the tracking region:

- **acceptance of the track reconstruction is limited to $\theta < 154^\circ$**



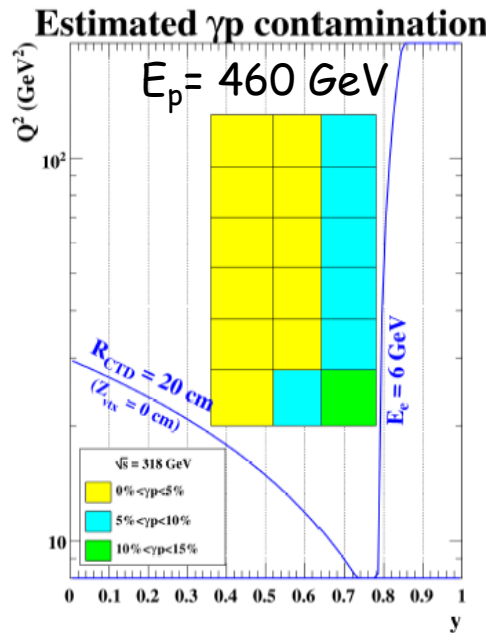
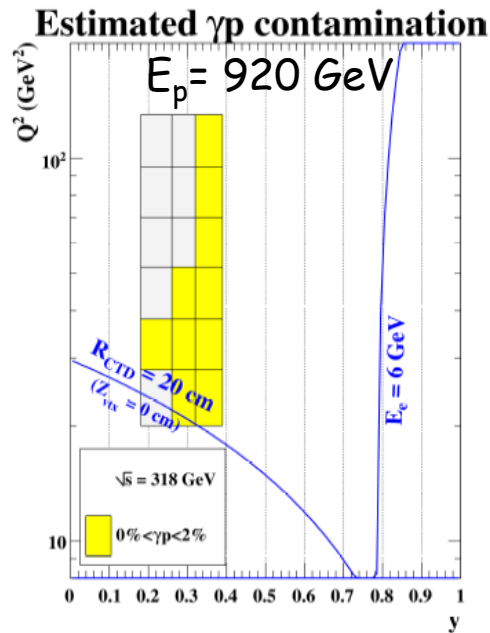
→ **combined trigger eff. $\approx 100\%$**



- **use single hits in the tracking detector along a road from primary vertex to el. candidate in CAL taking into account the charge of the scattered electron**

→ **reject neutral particles up to $\theta \approx 168^\circ$**

Experimental challenge: γp bkg at high y



ZEUS:

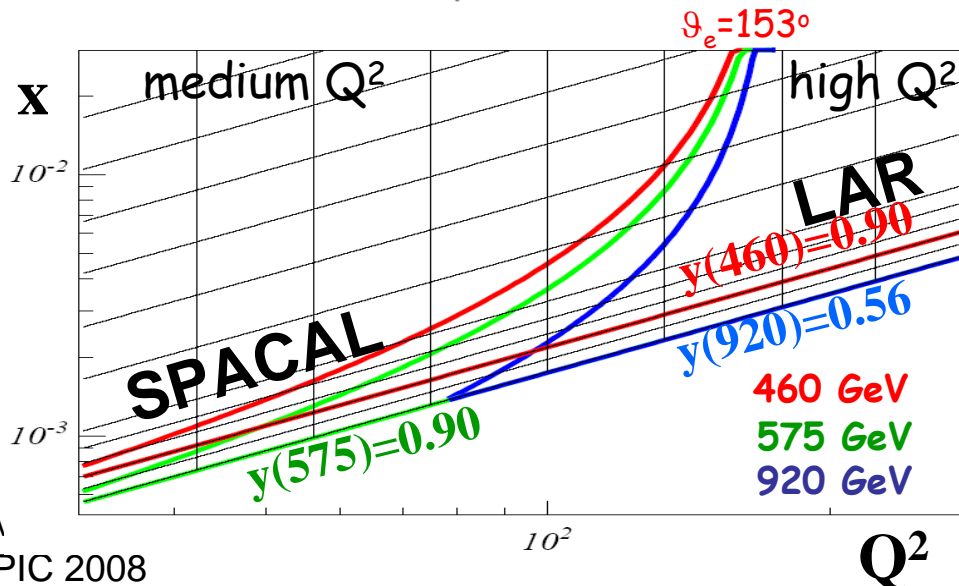
γp background contribution
in the Q^2 - y bins used for FL

< 2% for $E_p = 920 \text{ GeV}$ ($y < 0.40$)
10-15% for $E_p = 460 \text{ GeV}$ ($y \approx 0.76$)

H1:

the same binning in x and Q^2
for all E_p and LAr/Spacal

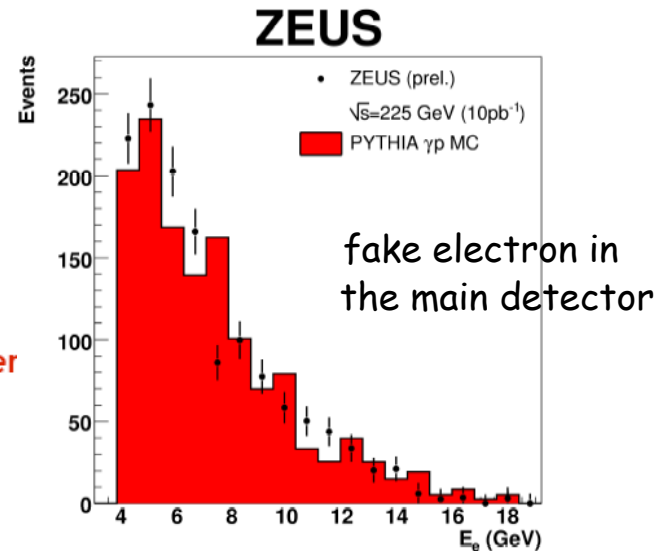
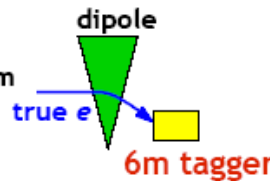
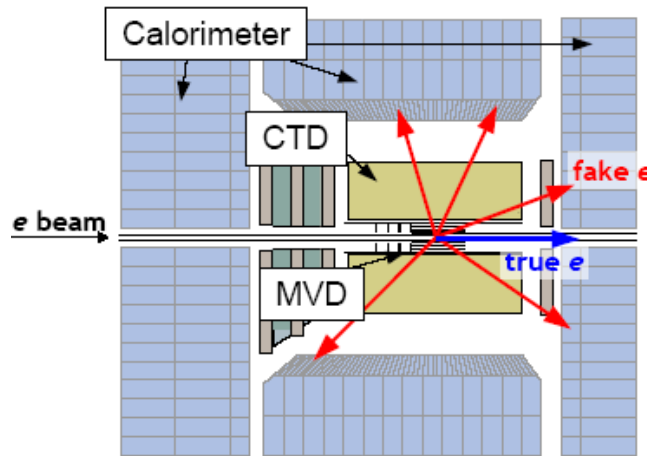
- measurements up to $y = 0.90$
where γp bkg is up to 50% and more



ERA

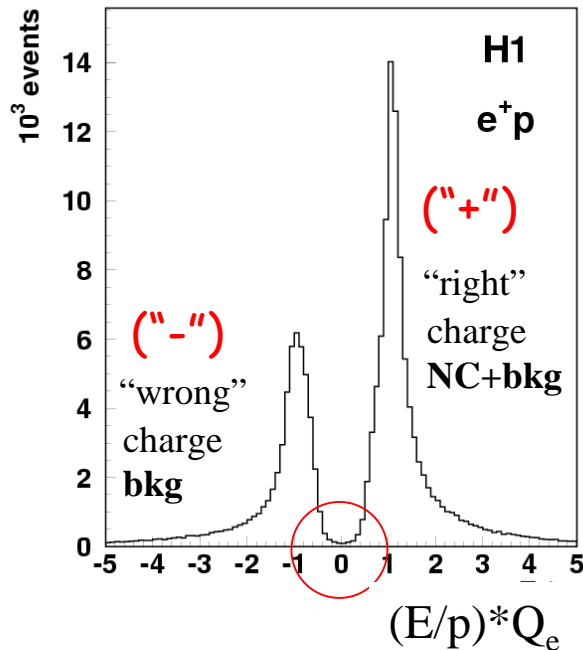
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Photoproduction background estimation using 6m electron tagger (ZEUS)



- in photoproduction ($Q^2 \approx 0$) quasi-real photon interacts with the proton
- electron with reduced energy goes along the e beam direction, bends in the dipole magnet and hits the electron tagger located at 6 m
- fraction of γp events is measured in 6m tagger and used to normalize PYTHIA γp MC for each E_p period
- H1 uses similar technique for $E_p=920 \text{ GeV}$ at $\gamma < 0.56$

γp background identification at high y (H1)



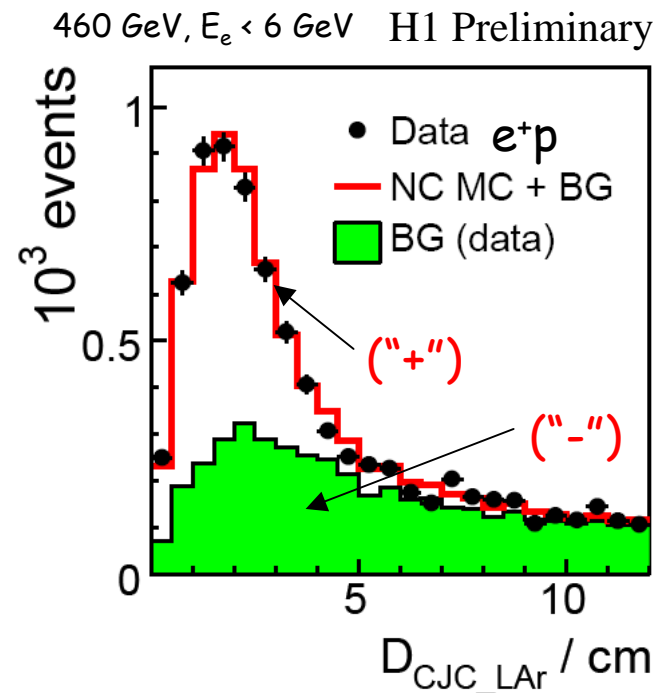
Electric charge of the scattered electron using track from the primary interaction, pointing to the electron cluster:

- good charge measurement resolution
- wrong assignment of the charge $< 1\%$

1. identify and exclude half of γp bkg require the “right” charge for el.
2. estimate and subtract remaining γp bkg using “wrong” charge el.

to be taken into account in statistical subtraction:

- **charge asymmetry in γp data** due to antiprotons determined using “wrong charge” el. candidates in the $e^\pm p$ HERA II data and in γp events identified by the 6 m electron tagger



Electron identification & background suppression at high y

Electron is identified by compactness of the cluster in calorimeter and track pointing to the cluster.

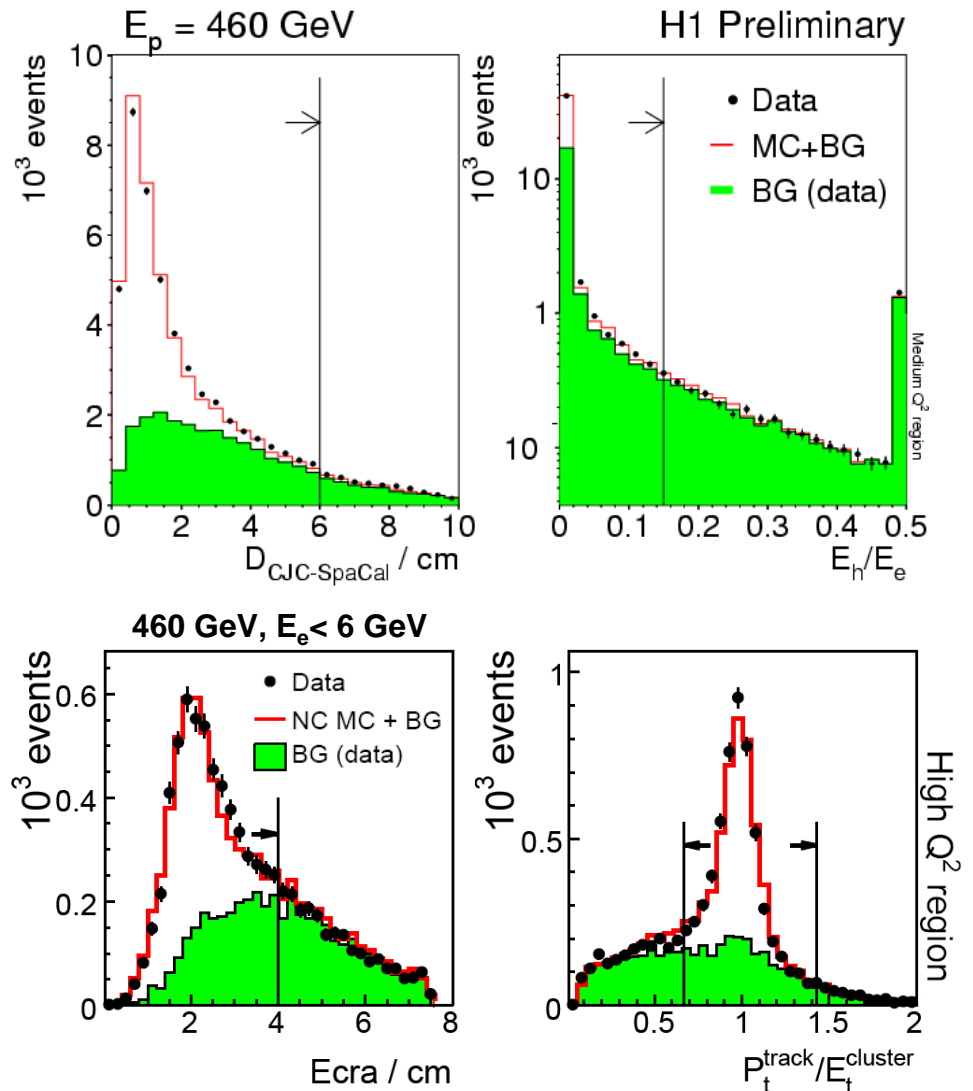
further reduction of γp background keeping high eff. for electron:

Spacal sample

- distance between extrapolated track and the electron cluster $D < 6$ cm
- energy fraction behind the electron cluster $E_h/E_e < 0.15$

LAR sample at $E_e < 6$ GeV

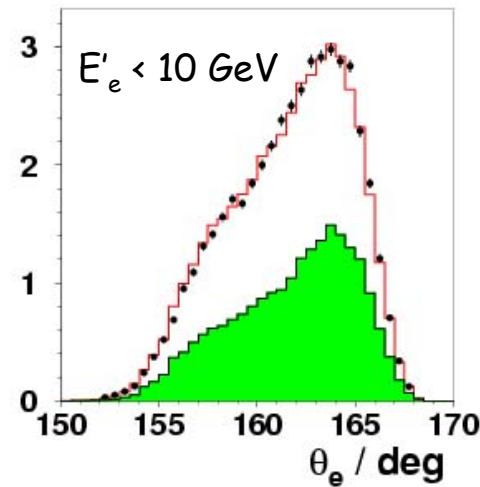
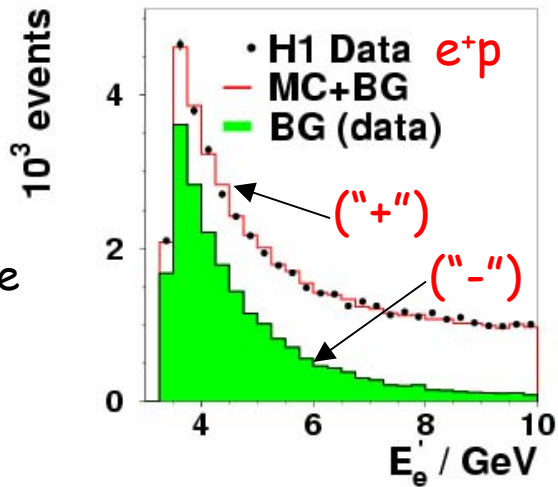
- small transverse size of the electron cluster in LAr: $E_{cra} < 4$ cm
- matching between track momentum and cluster energy: $0.7 < E_t^{cluster}/P_t^{track} < 1.5$



High y region at medium Q^2 (H1)

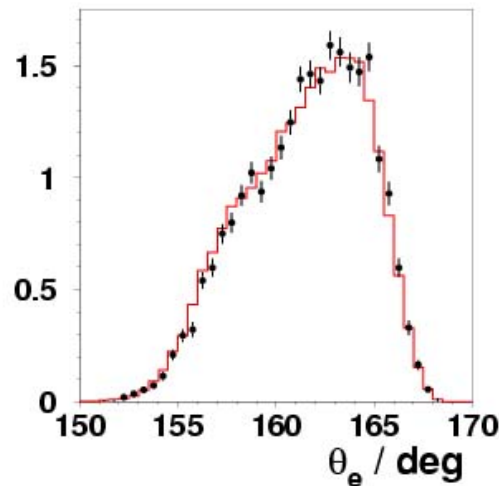
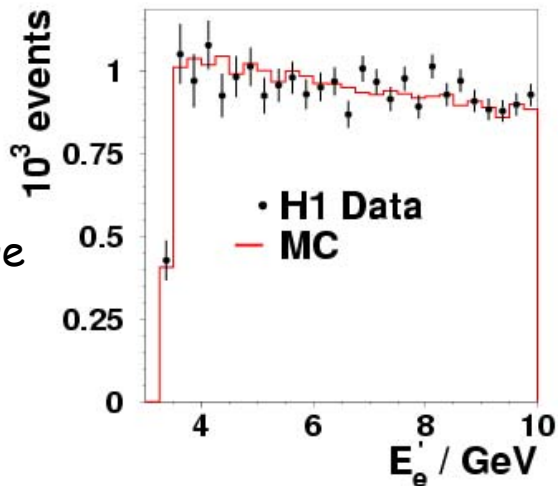
$E_p = 460$ GeV

before
"wrong" charge
subtraction



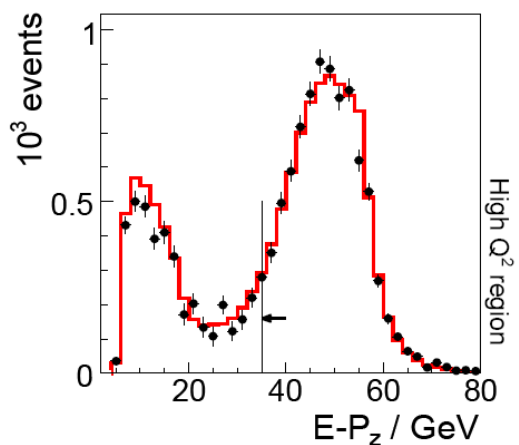
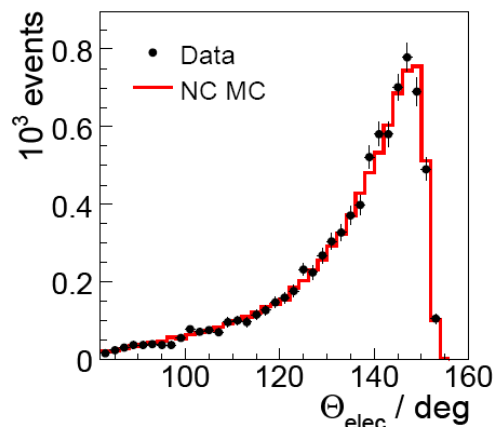
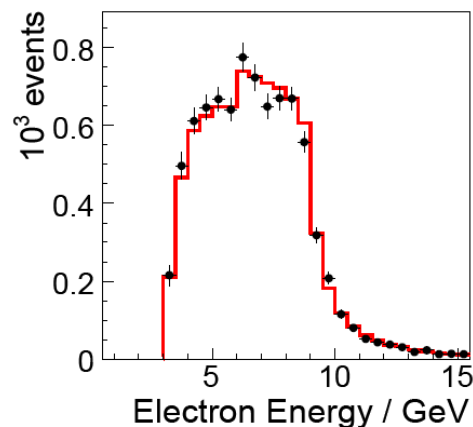
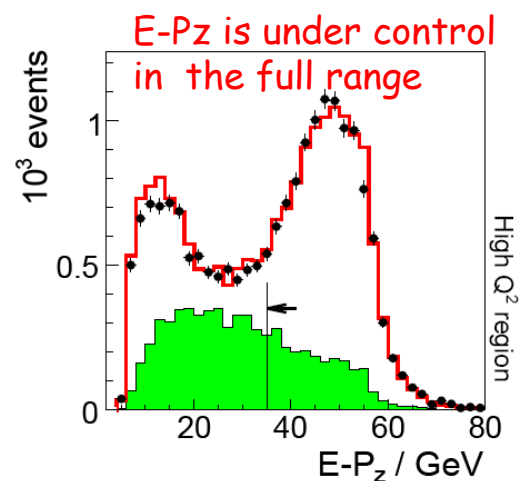
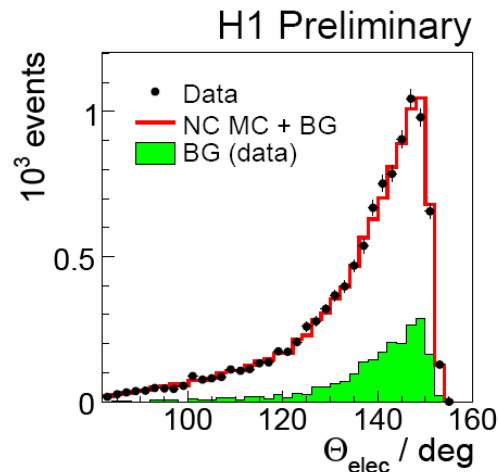
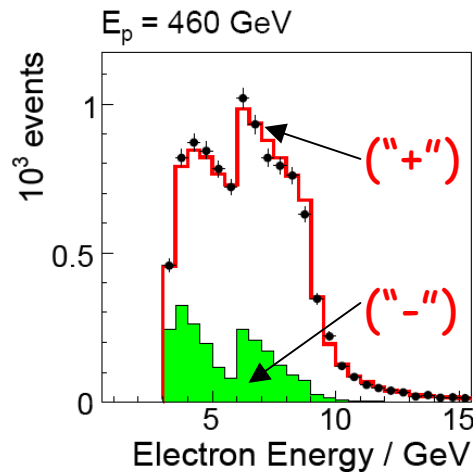
γp background (green)
concentrates at low E_e

after
"wrong" charge
subtraction



the data are well
understood in terms
of MC

High y region at high Q^2 (H1)



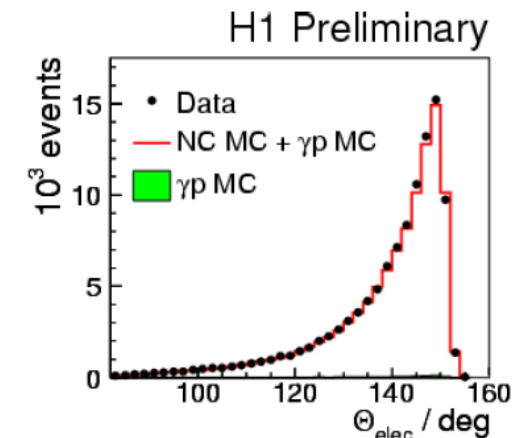
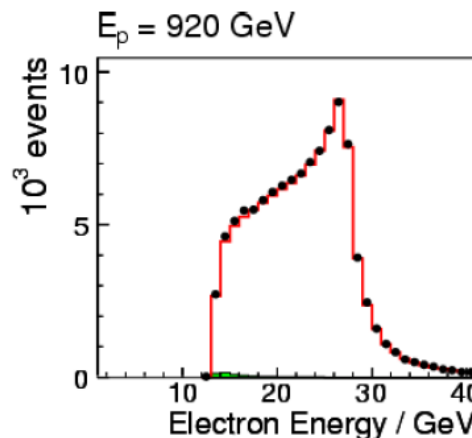
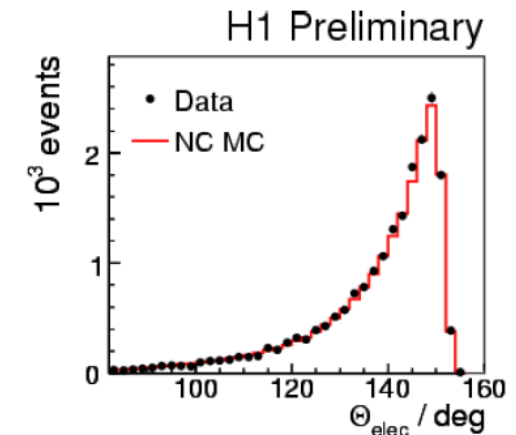
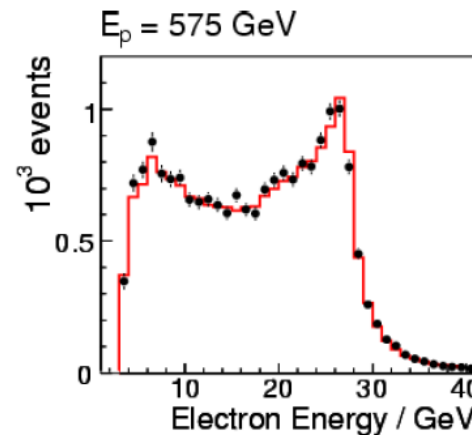
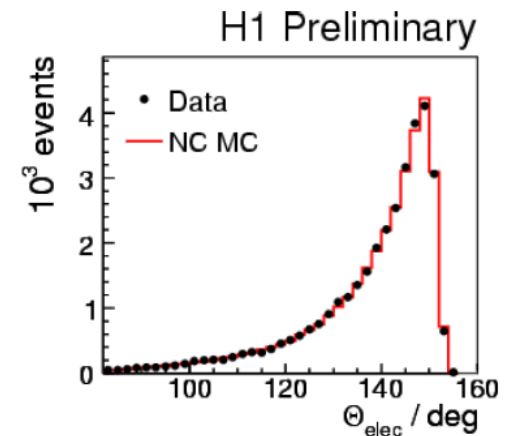
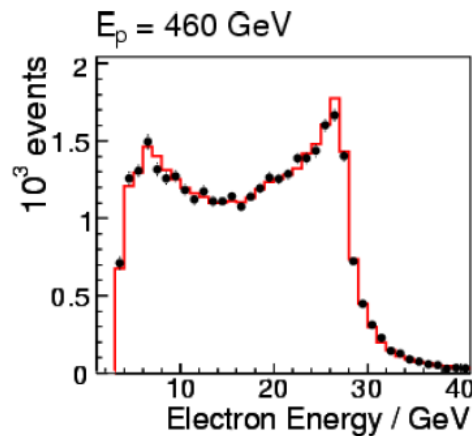
→ step at $E_e = 6$ GeV is due to selection requirements

the requirement $E\text{-}P_z > 35$ GeV :

- rejects γp background
- rejects initial state radiation (ISR)

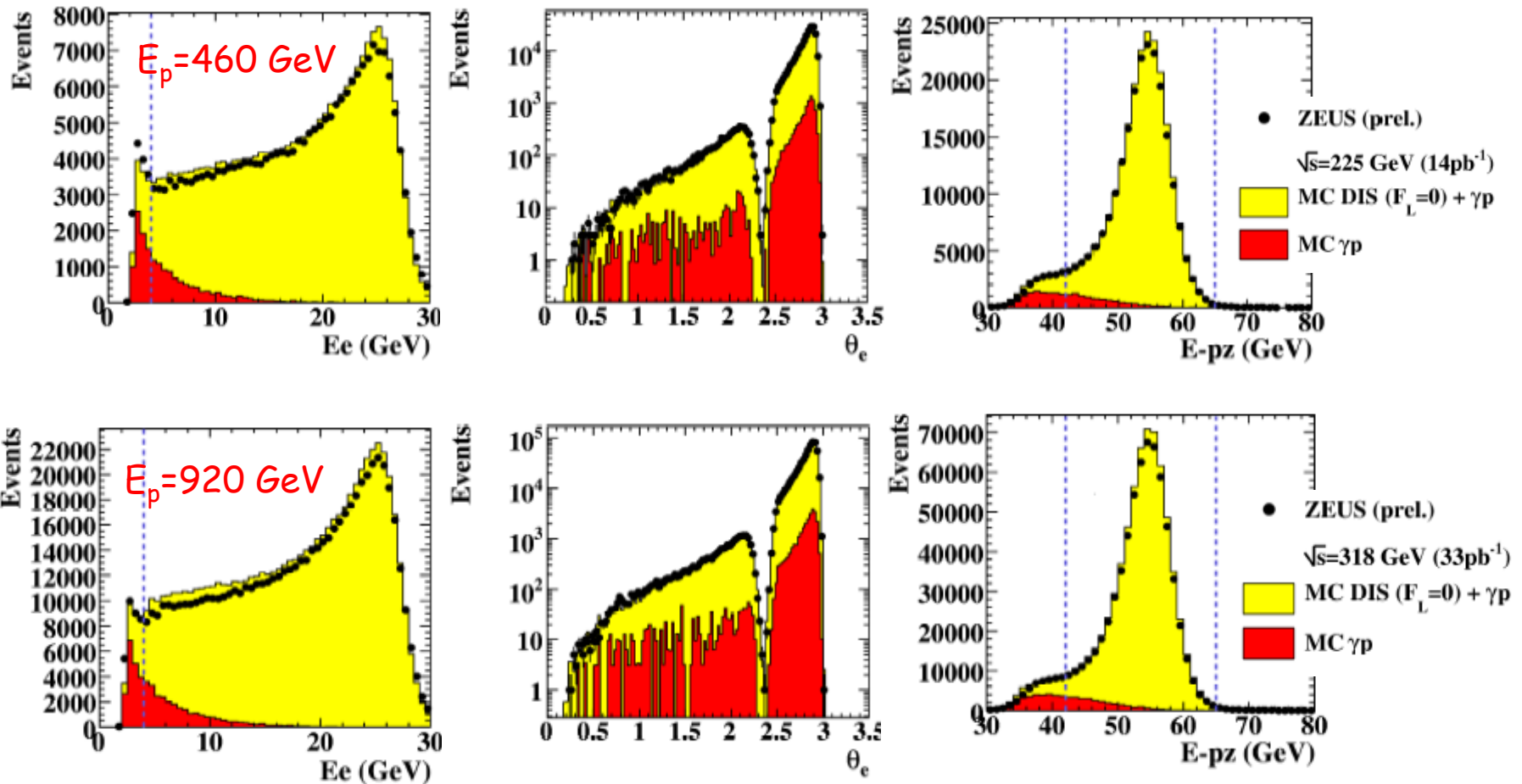
Full y range at high Q^2 after γp background subtraction (H1)

for $E_p = 920 \text{ GeV}$ ($y < 0.56$)
 γp bkg is taken from PYTHIA MC
checked using 6m electron tagger



ZEUS: control plots ($E_p = 460, 920$ GeV)

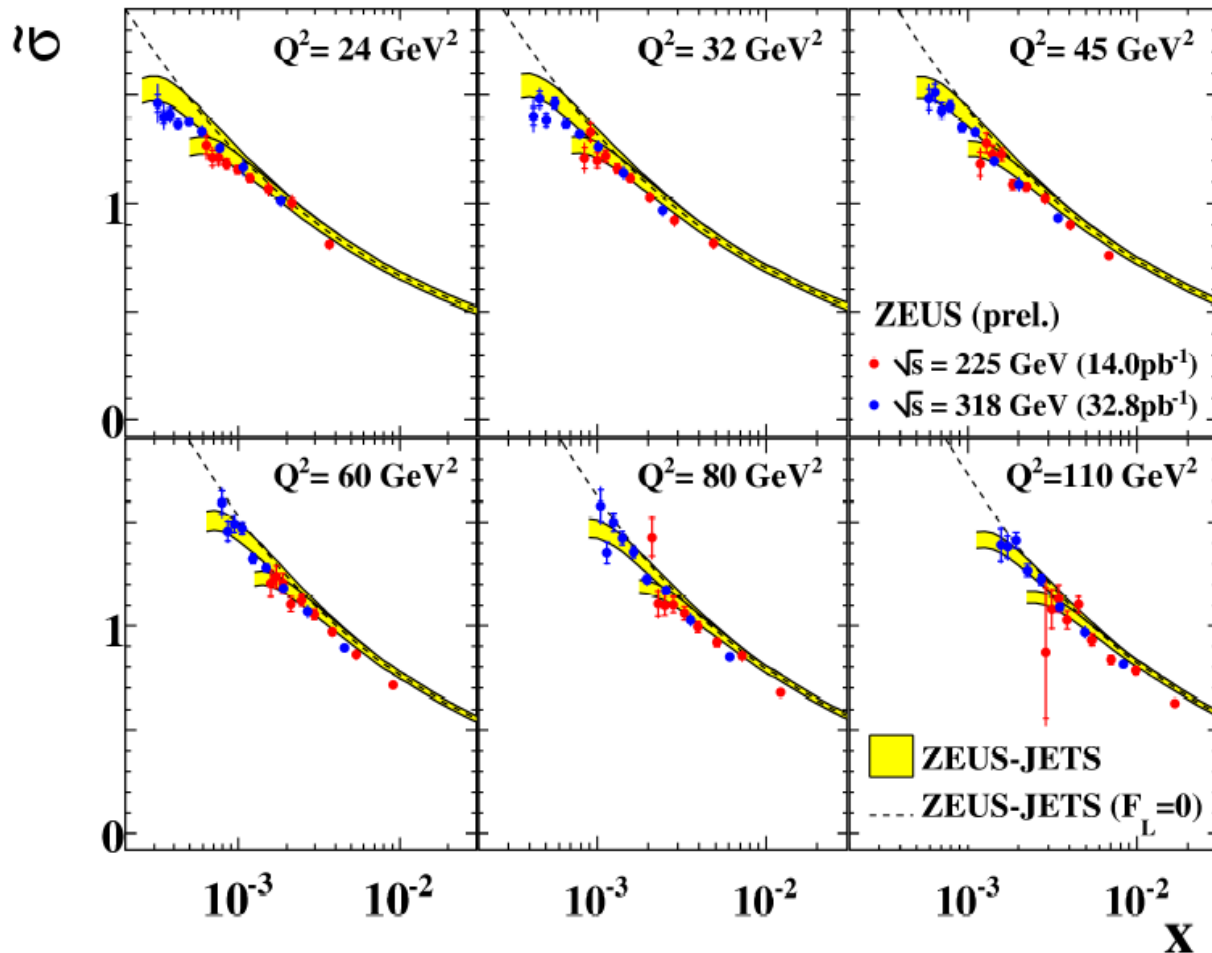
MC is shown without F_L contribution



cuts indicated by lines: $E'_e > 6$ GeV
 $42 < E-Pz < 65$ GeV

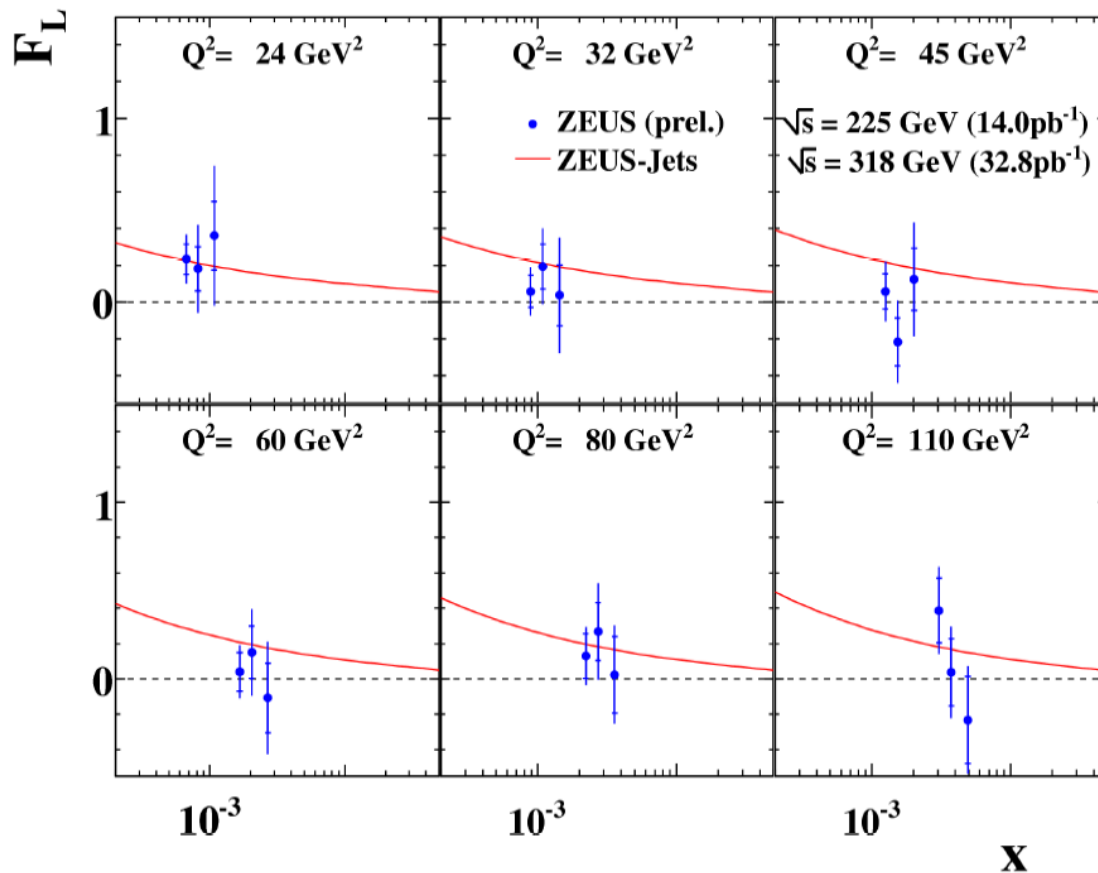
NC cross sections for $E_p = 460, 920$ GeV

ZEUS



$F_L(x, Q^2)$ from ZEUS

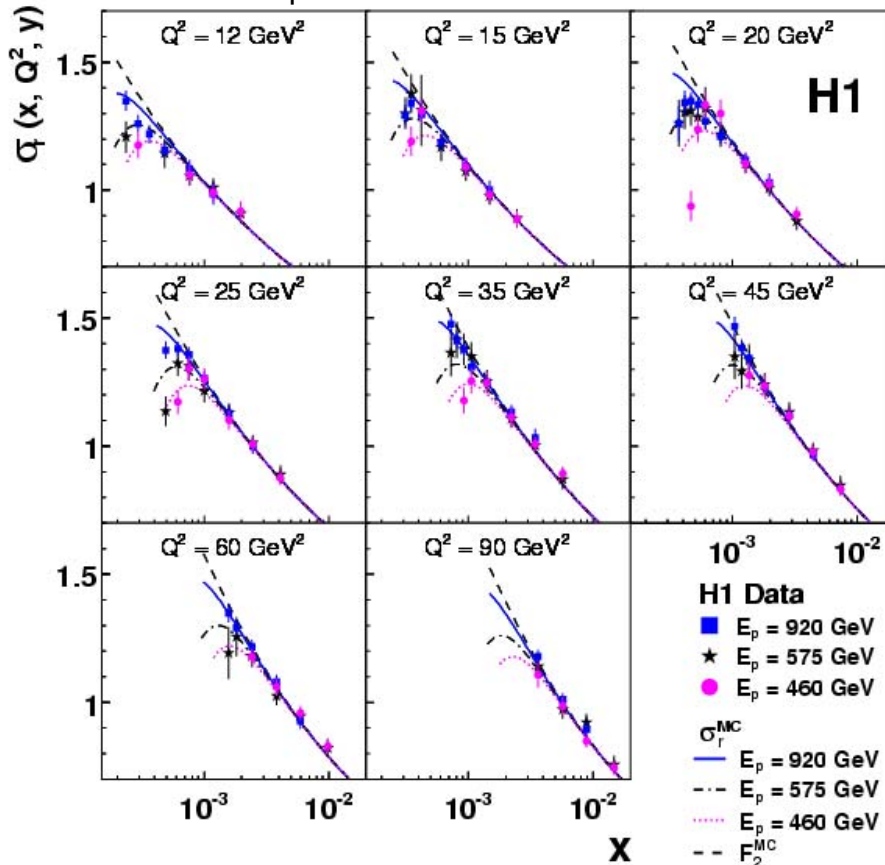
ZEUS



F_L measurements are consistent within errors with QCD calculations and with $F_L=0$

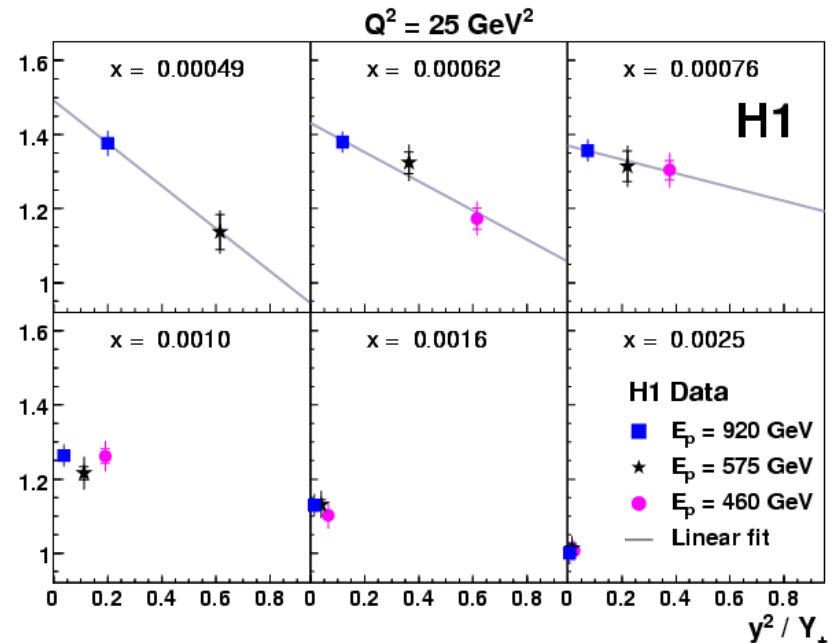
NC cross sections at medium Q^2 (H1)

$E_p = 460, 575, 920$ GeV



$$\tilde{\sigma}_{NC} = F_2 - \frac{y^2}{1 + (1 - y)^2} F_L$$

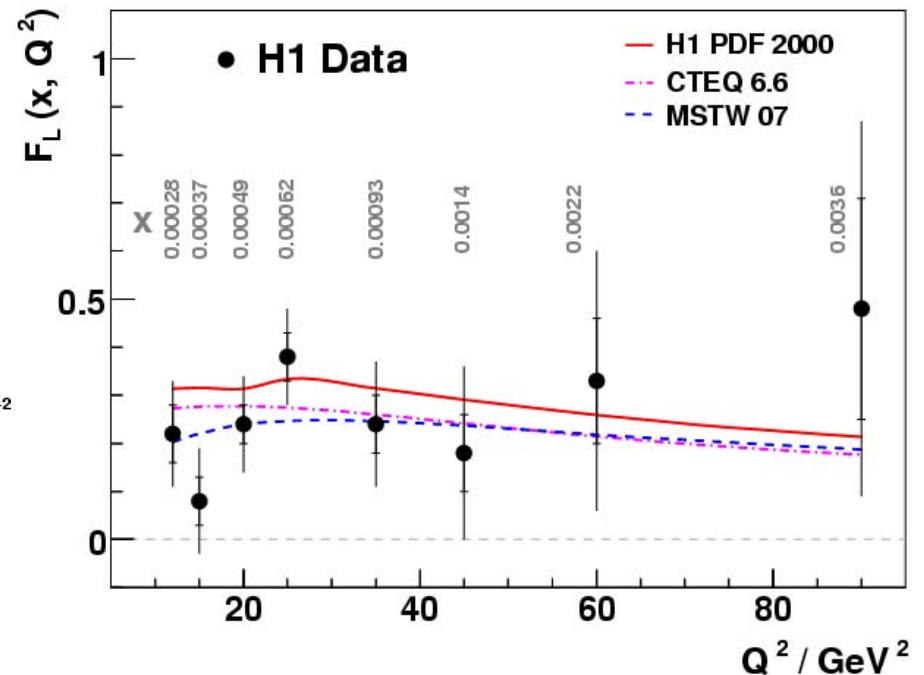
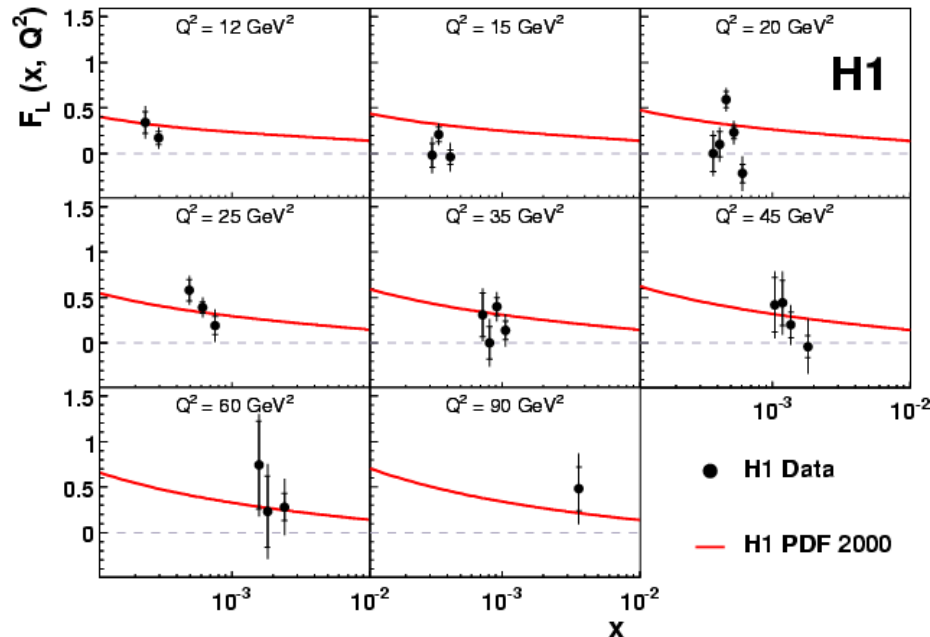
→ determine F_L and F_2 from linear fits at each x and Q^2



→ use relative normalisation (the same for LAr and Spacal) of $E_p = 460, 575, 920$ GeV from the low y data for the F_L measurement

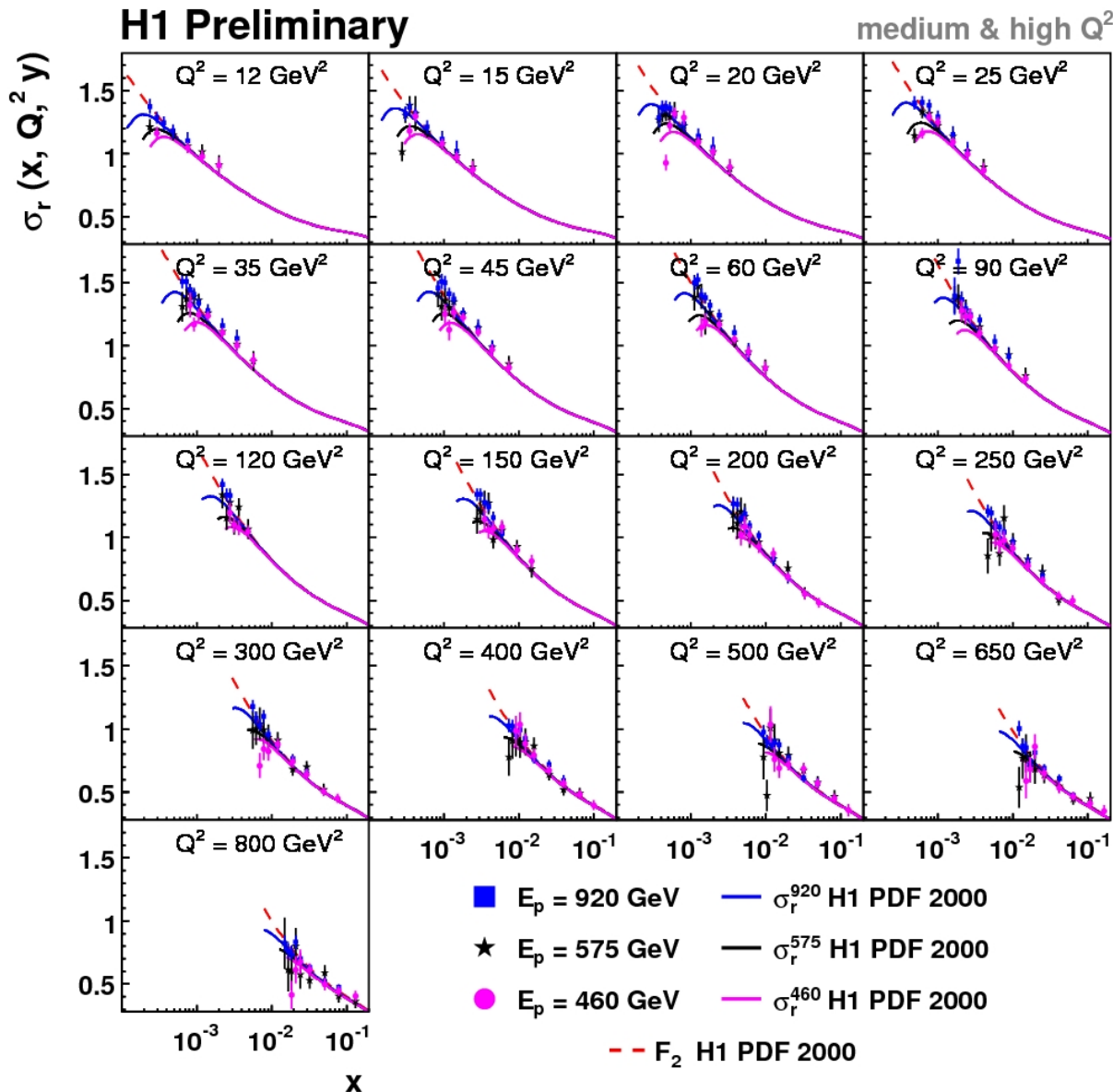
The published $F_L(x, Q^2)$ and averaged $F_L(Q^2)$ at medium Q^2 (H1)

DESY-08-053



→ measured F_L are above zero and consistent with QCD calculations

NC cross section in the full Q^2 range (H1)

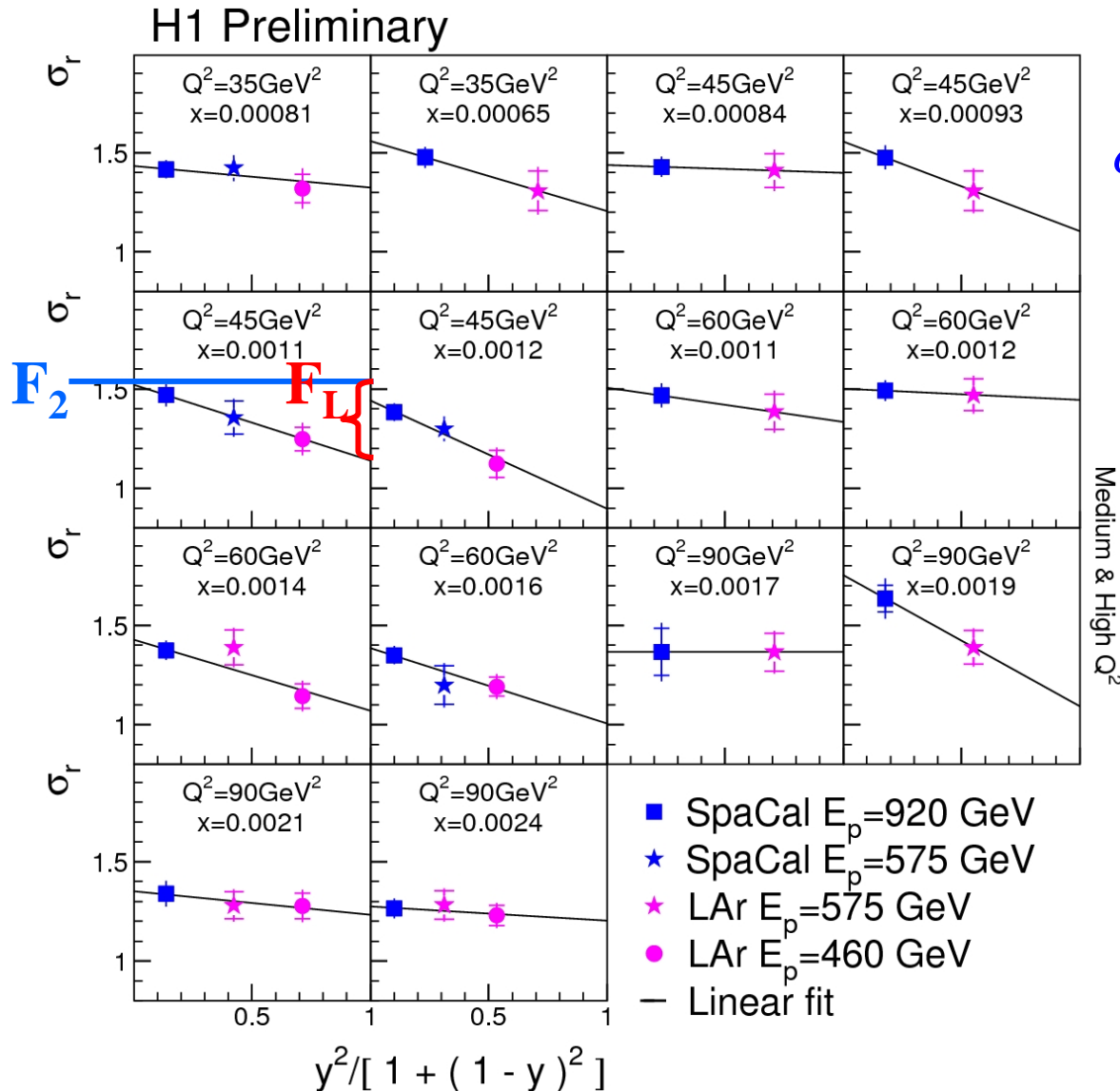


The full range of medium and high Q^2 obtained using Spacal and LAr data

$$E_p = 460, 575, 920 \text{ GeV}$$

use relative normalisation (the same for LAr and Spacal) of $E_p = 460, 575, 920$ GeV from the low y data for the F_L measurement

NC cross sections at the same x & Q² which involve both the LAr and Spacal data (H1)



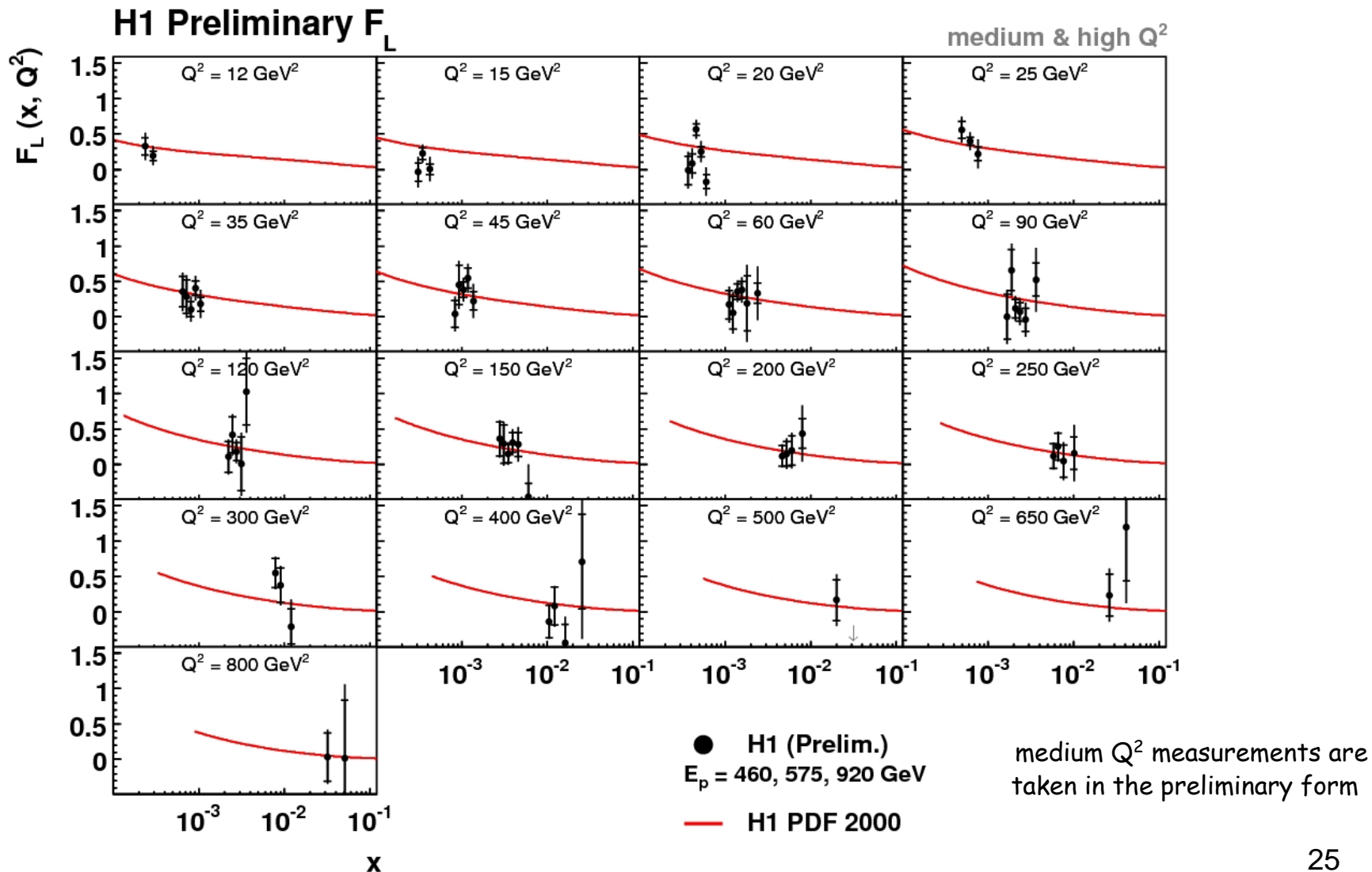
$$\tilde{\sigma}_{NC} = F_2 - \frac{y^2}{1 + (1 - y)^2} F_L$$

From linear fits
at each x and Q²
one determines
F_L and F₂

blue points - Spacal
red points - LAr

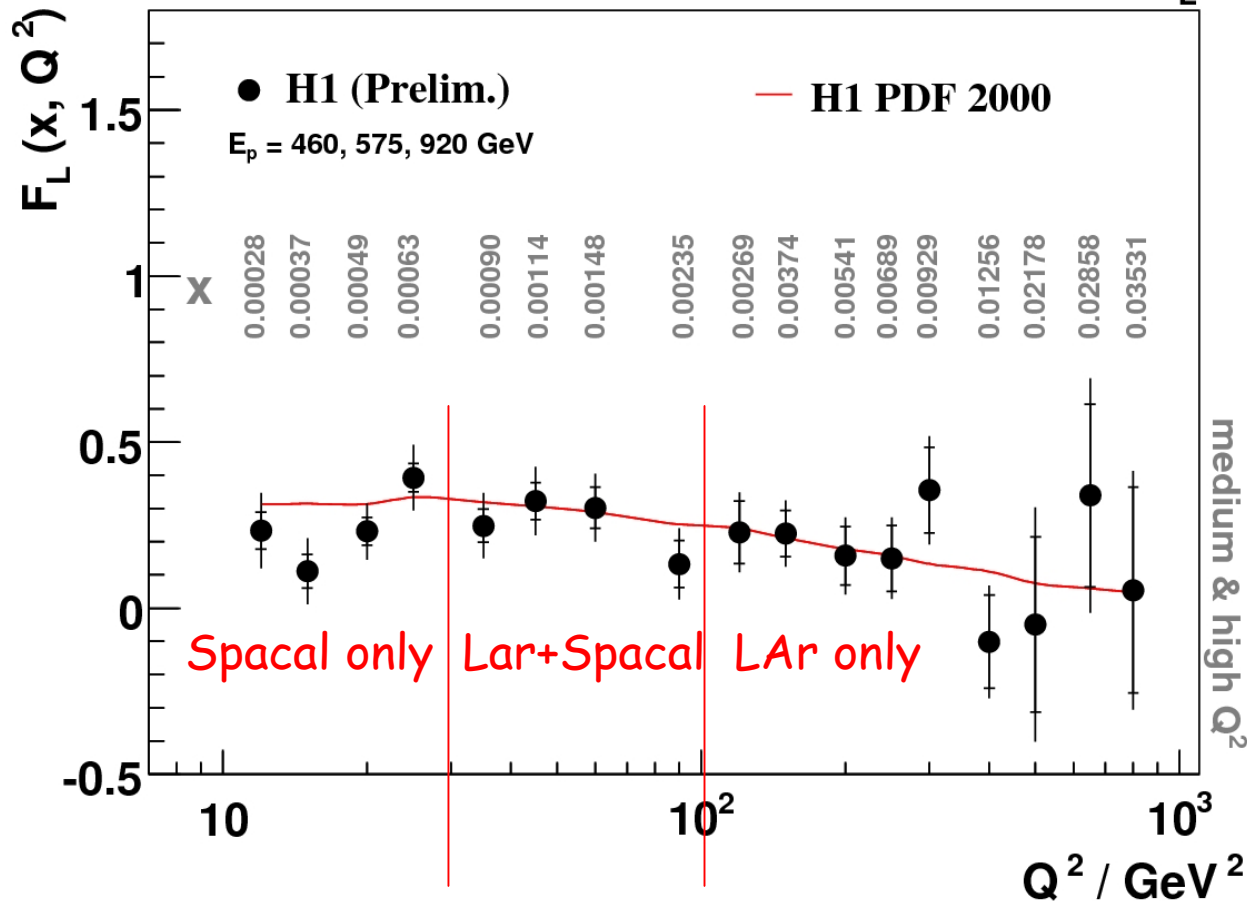
→ nice interplay of the
two fully independent
analyses using different
detectors: Lar and Spacal

$F_L(x, Q^2)$ in the full Q^2 range using the LAr and Spacal data (H1)



Averaged $F_L(Q^2)$ in the full Q^2 range (H1)

H1 Preliminary F_L

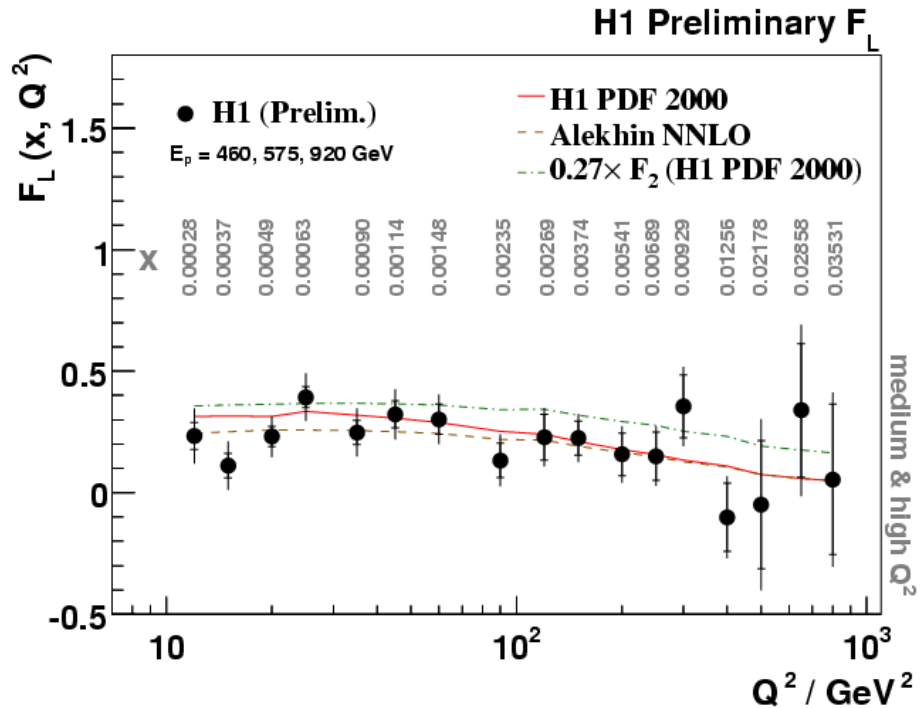
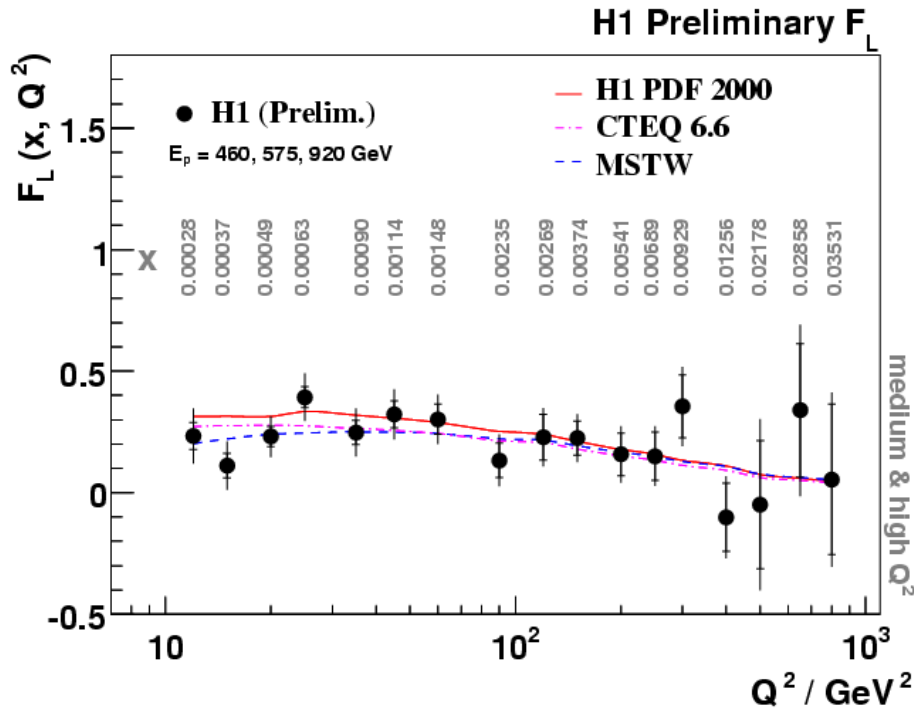


→ Spacal and LAR provide a cross check of the F_L measurements

→ overall correlated systematics between F_L points is $\delta F_L \approx 0.05\text{-}0.10$

medium Q^2 measurements are taken in the preliminary form

Comparison of F_L from H1 with theory predictions



x value for each $F_L(Q^2)$ measurement
 is given in the plot

$F_L = 0.27 \times F_2$ is motivated by
 Schildknecht et al. arXiv:0806.0202

- F_L measurements are in a good agreement with the QCD calculations
- extension to $Q^2 < 10 \text{ GeV}^2$ will provide an important constraint

Summary

The longitudinal structure function $F_L(x, Q^2)$ is measured at HERA in the model independent way using low E_p data

H1:

- measured at medium and high Q^2 : $12 \leq Q^2 \leq 800 \text{ GeV}^2$
using the e^+p 2007 data collected with $E_p = 460, 575$ and 920 GeV
- nice interplay of the two fully independent analyses which use two different detectors: LAr and Spacal
- measured $F_L(x, Q^2)$ is in agreement with the recent theoretical calculations in the QCD framework

ZEUS:

- measured in the range $24 \leq Q^2 \leq 110 \text{ GeV}^2$
using the e^+p 2007 data collected with $E_p = 460$ and 920 GeV
- measured $F_L(x, Q^2)$ consistent within errors with QCD calculations but also with $F_L=0$

→ *more to come: FL at $Q^2 < 10 \text{ GeV}^2$ (H1), analysis of $E_p=575 \text{ GeV}$ data (ZEUS), ...*