Longitudinal structure function measurements from HERA

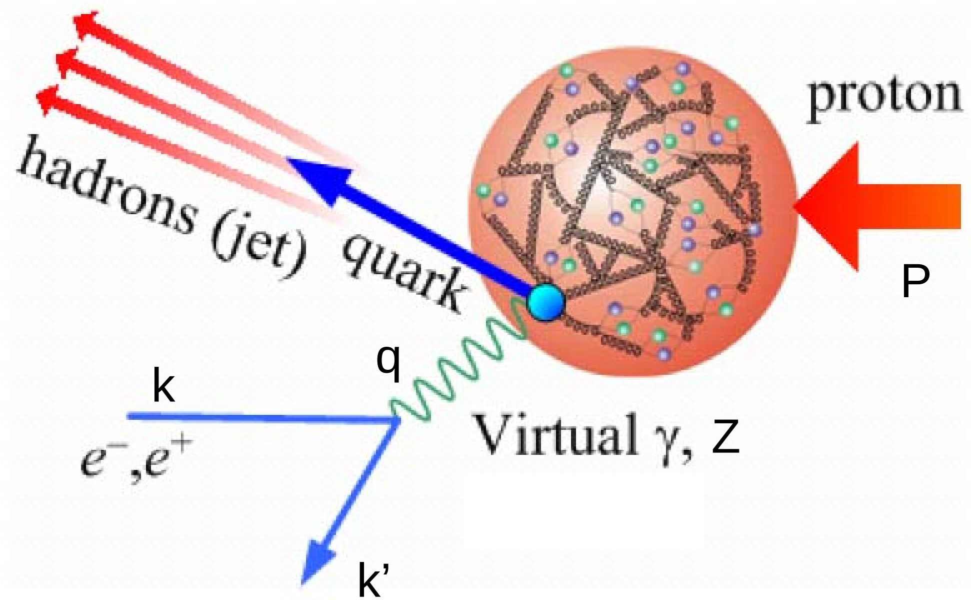
Vladimir Chekelian (MPI for Physics, Minich)

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): $\mathbf{e^{\pm} p \rightarrow e^{\pm} X}$



$\mathbf{Q^2 = -q^2 = -(k-k')^2}$	virtuality of γ^*,Z
$\mathbf{x = Q^2/2(Pq)}$	Bjorken x
$\mathbf{y = (Pq)/(Pk)}$	inelasticity
$\mathbf{Q^2 = sxy}$	$s=(k+P)^2$

Factorisation

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

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

The Proton Structure Functions

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

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

dominant contribution:

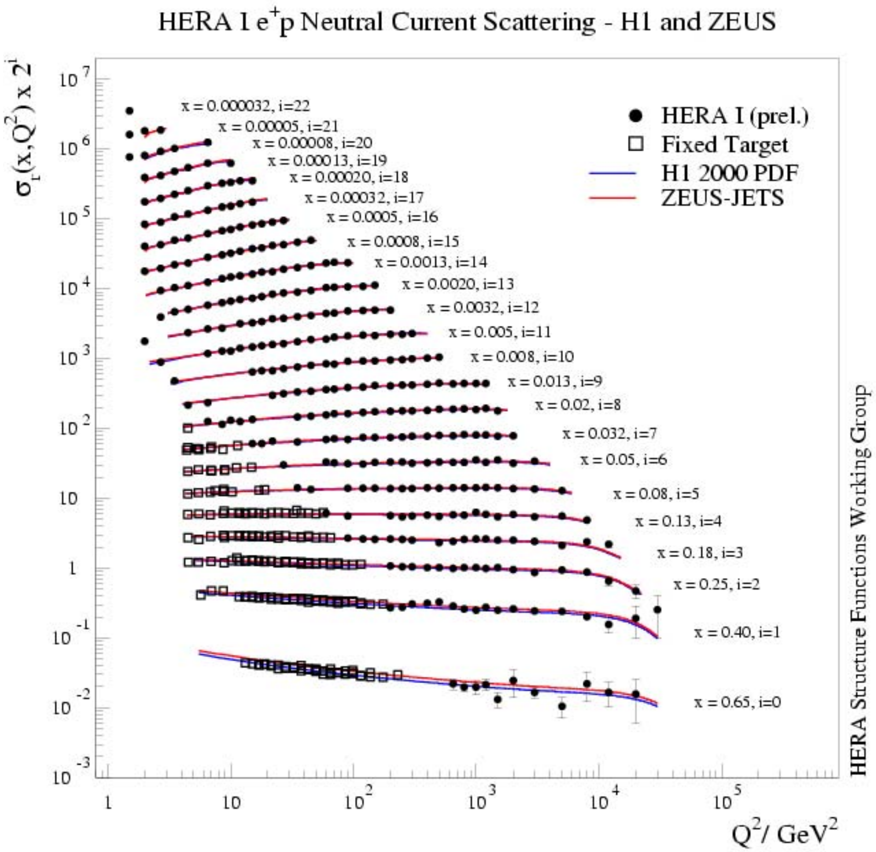
$$F_2(x,Q^2) = \sum e_{q_i}^2 x(q_i + \bar{q}_i)$$

contributes only at high Q^2 ($\gtrsim M_Z^2$)

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

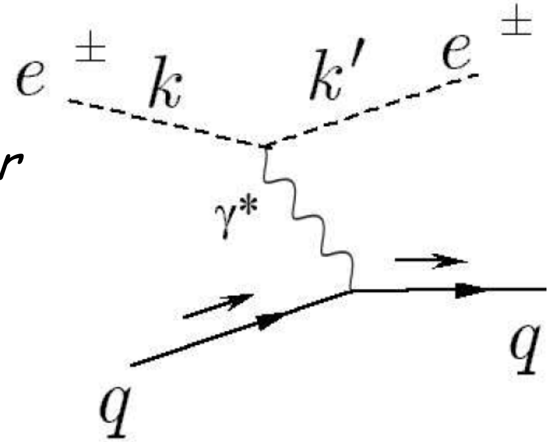
$F_2 \sim \sigma_L^{\gamma p} + \sigma_T^{\gamma p}$, $F_L \sim \sigma_L^{\gamma p}$

→ $0 \leqslant F_L \leqslant F_2$

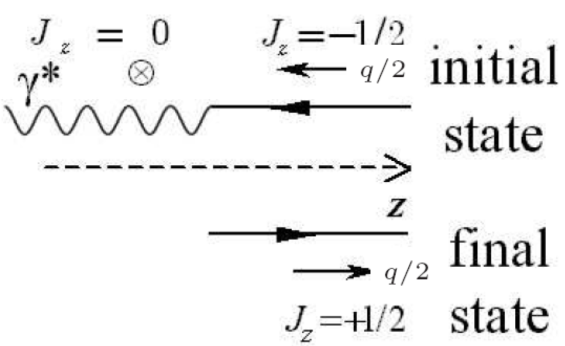


The longitudinal structure function $F_L(x,Q^2)$

- 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



Breit frame:



in QPM

due to helicity and angular momentum conservation for spin ½ quarks

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

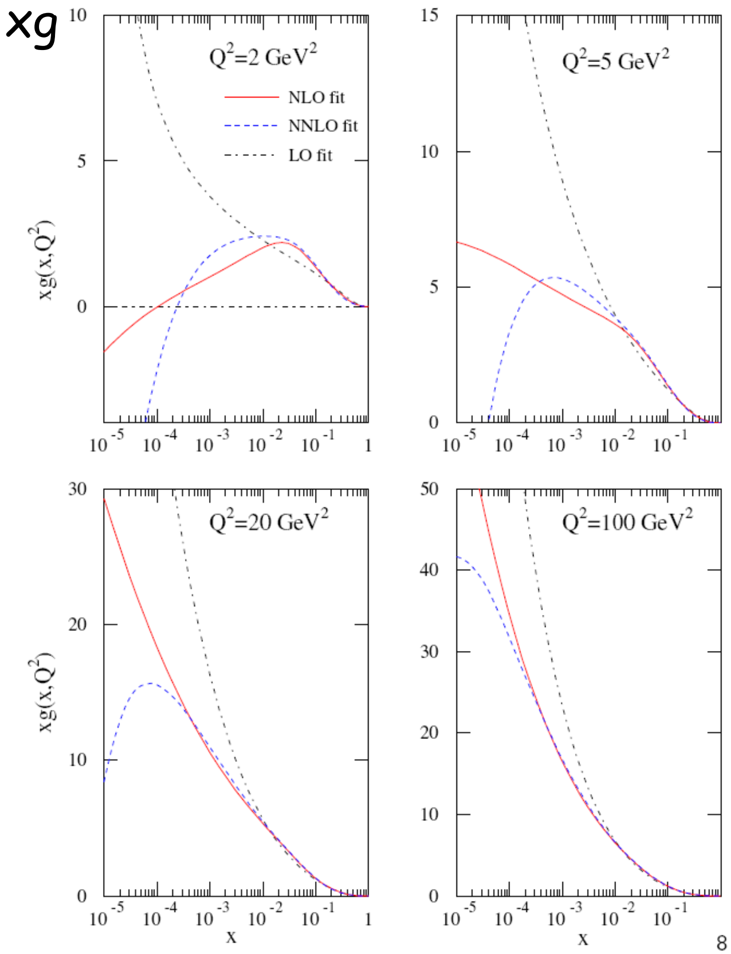
$$F_L = F_2 - 2xF_1 = 0$$

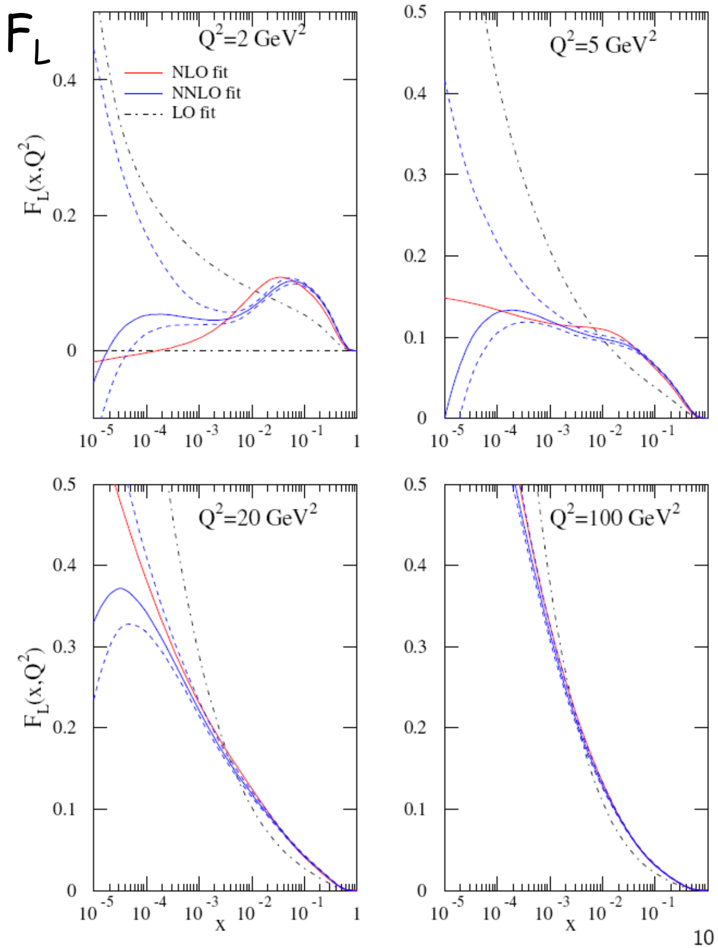
Callan-Gross relation

in QCD:

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

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

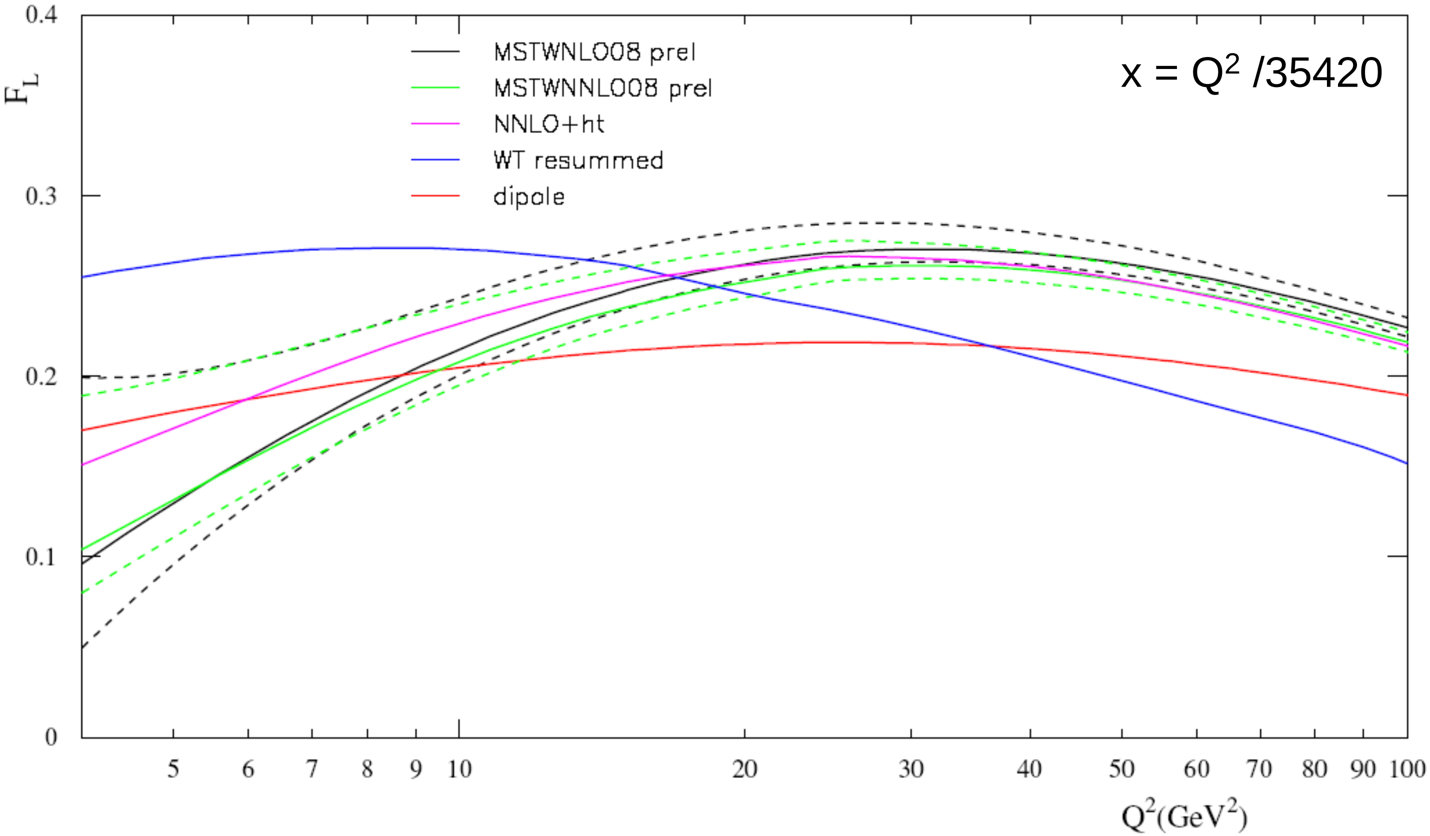




→ poor stability for gluon at small x

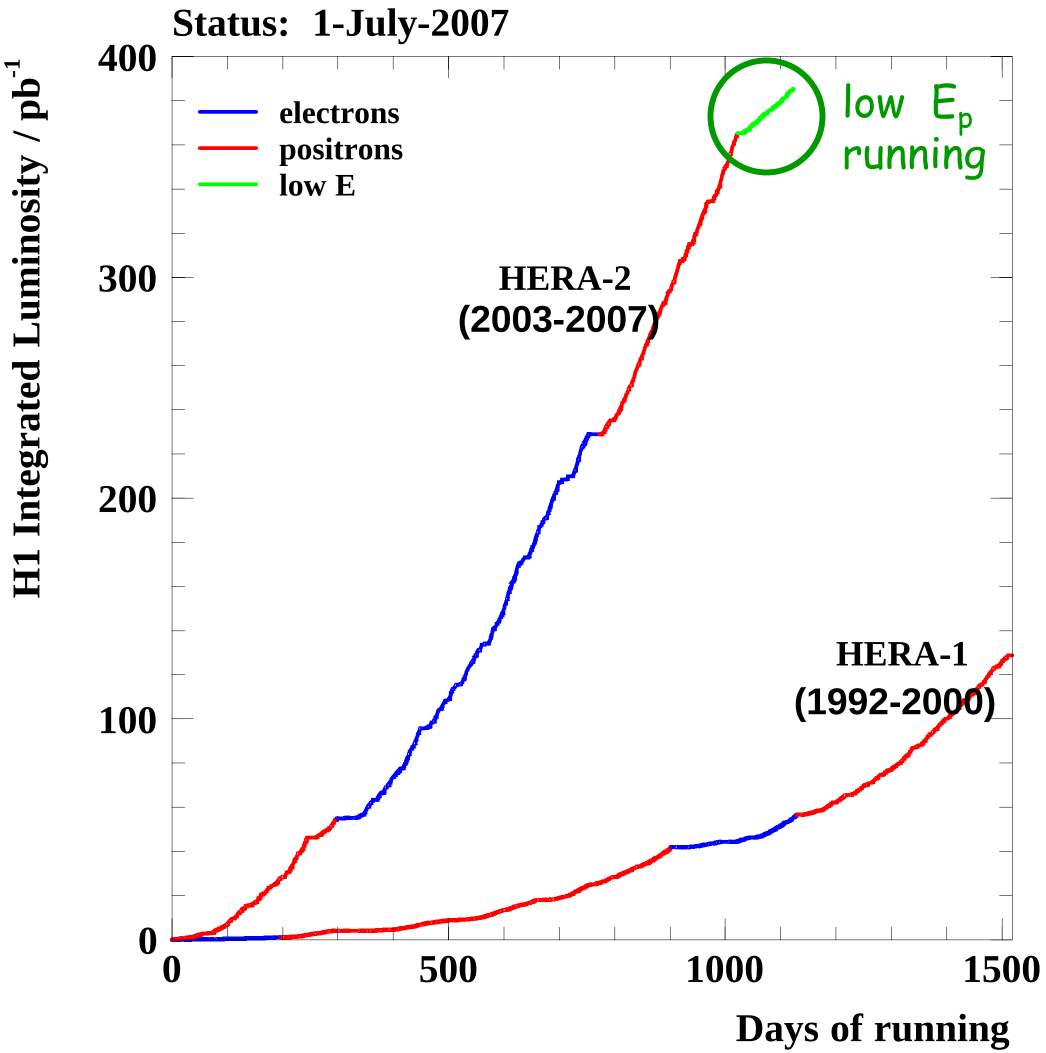
→ similarly for F_L but less prominent

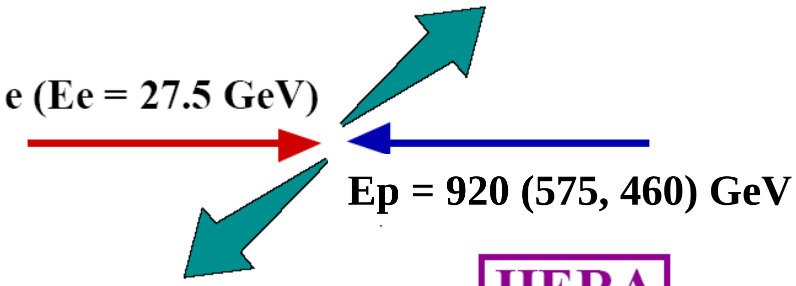
Theory predictions for F_L in the HERA domain



- firm NLO/NNLO QCD predictions for $Q^2 > 10$ GeV^2
- spread of predictions at Q^2 below 10 GeV^2

HERA (1992–2007)





HERA

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

H1+ZEUS in total ~ 1 fb^{-1}

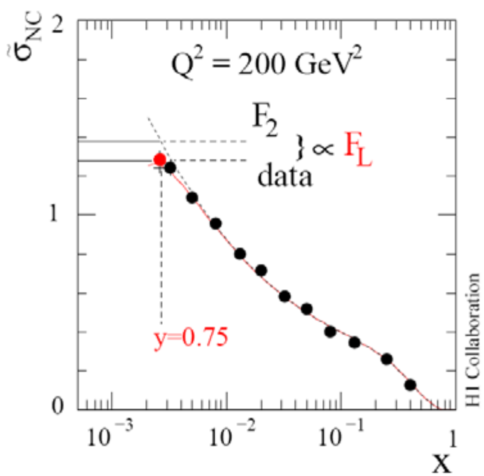
about equally shared between
- experiments (H1, ZEUS)
- e^+ and e^-,
- positive and negative P_e

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

Measurement strategy for F_L

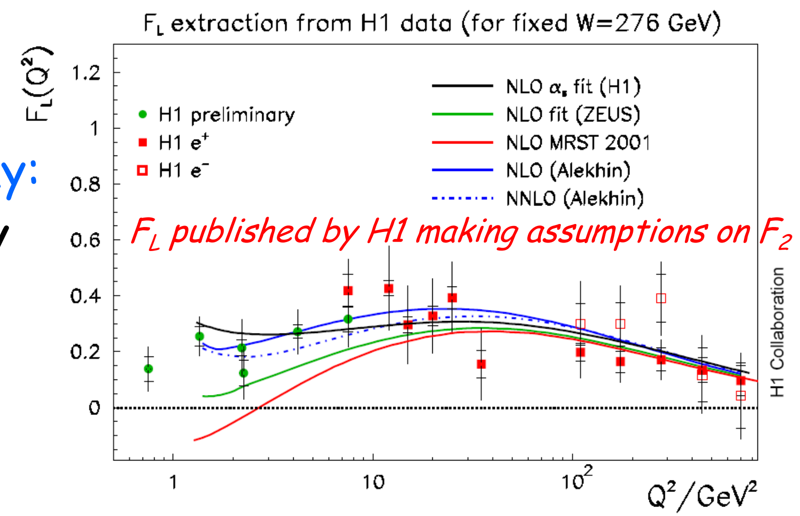
$$\tilde{\sigma}_{NC} = \frac{d^2\sigma^{ep}_{NC}}{dx\,dQ^2} \Big/ \left(\frac{2\pi\alpha^2}{xQ^4}Y_+\right) = F_2 - \frac{y^2}{1+(1-y)^2}F_L$$

sensitivity to F_L only at high y



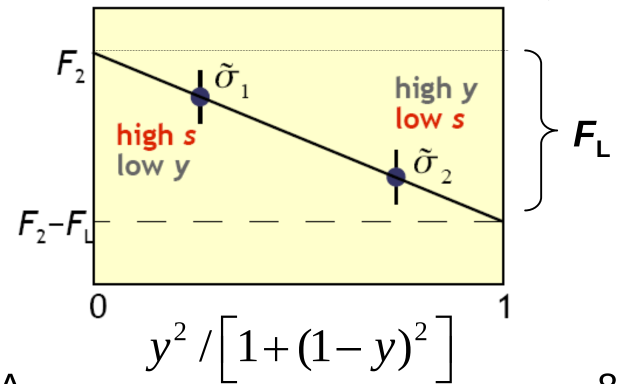
→ one possible way:

measure σ at high y and assume F_2



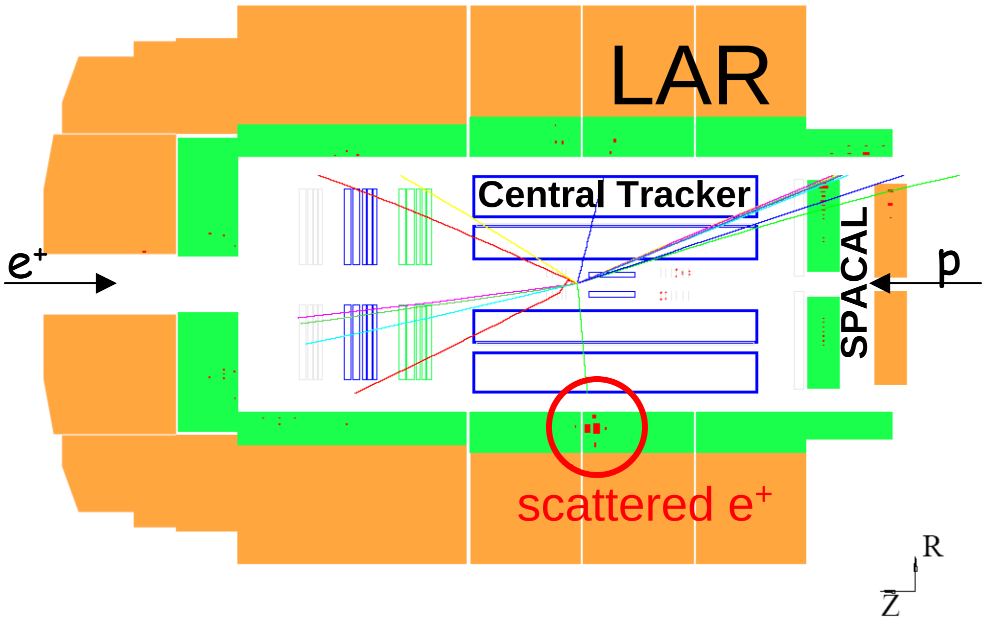
→ *free from theoretical assumption:*

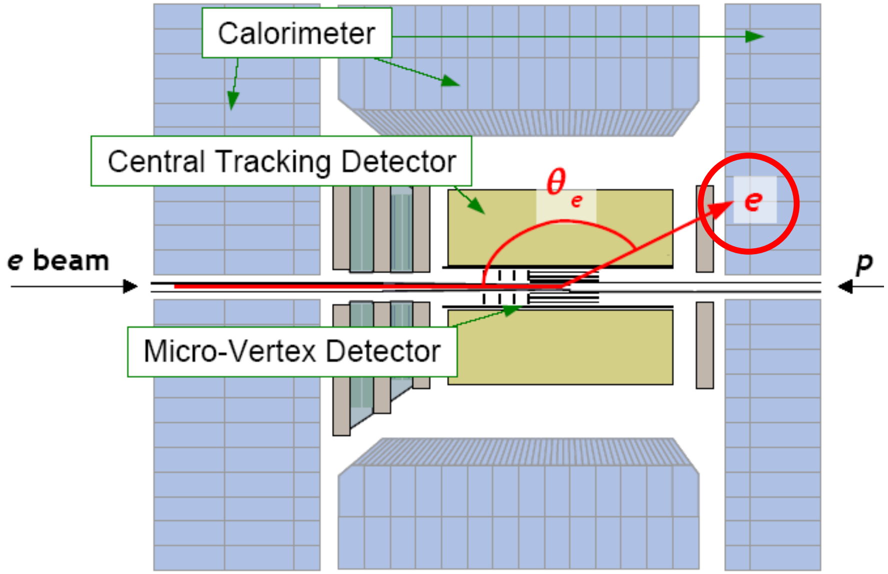
measure σ at the same x & Q^2 and different y by changing the proton beam energy ($y = Q^2/sx$)



H1 and ZEUS

$E'_e > 3$ GeV ($y \approx 0.90$) $y = 1 - (E'_e/E_e)\sin^2(\vartheta_e/2)$ $E'_e > 6$ GeV ($y \approx 0.76$)





F_L measurements in H1

Q^2 range (GeV^2)			
medium Q^2	12-90	Spacal+CT	DESY-08-053
high Q^2	35-800	LAr+CT	H1 prel.
low Q^2	5-15	Spac+BST	to come

F_L measurements in ZEUS

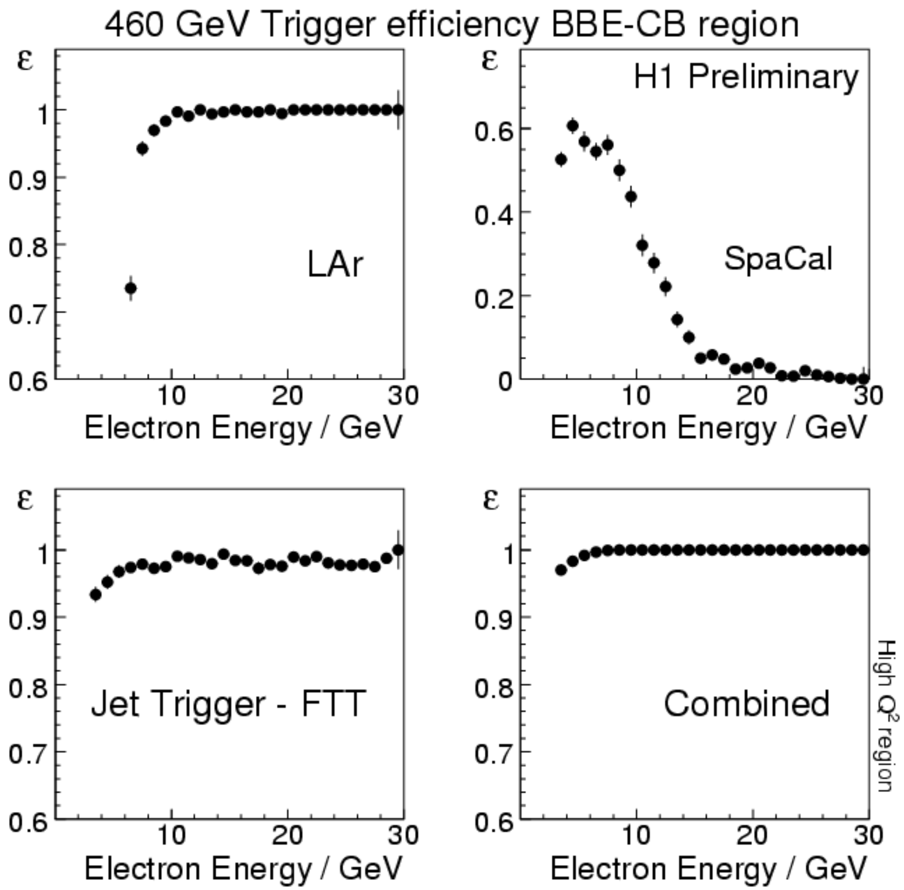
$\vartheta_e < 168^\circ$

$24 \leqslant Q^2 \leqslant 110$ GeV^2

more to come

Hardware & software improvements

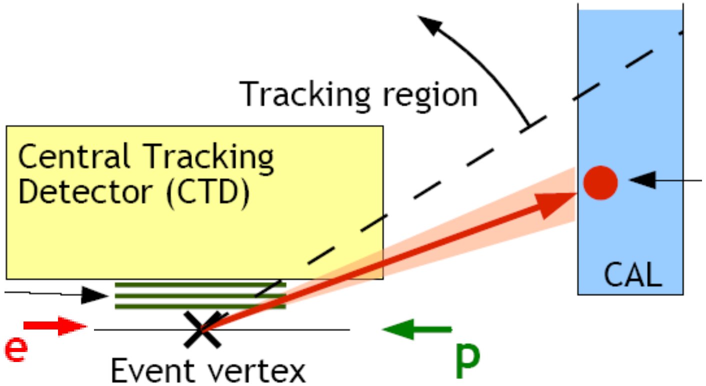
H1: new trigger hardware since fall 2006:
- Jet Trigger (real time clustering in LAr)
- Fast Track Trigger (FTT)



→ **combined trigger eff. ≈ 100% for E_e>3 GeV**

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

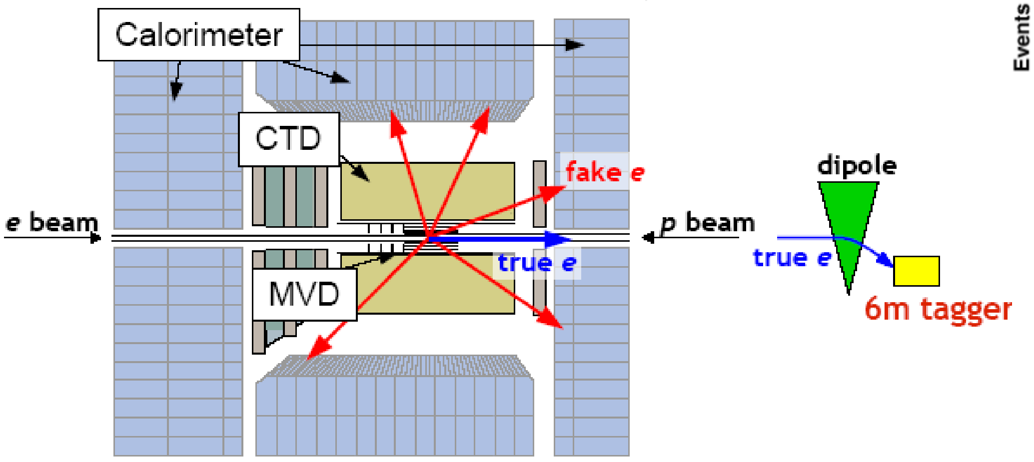
- **acceptance of the track reconstruction is limited to ϑ < 154°**

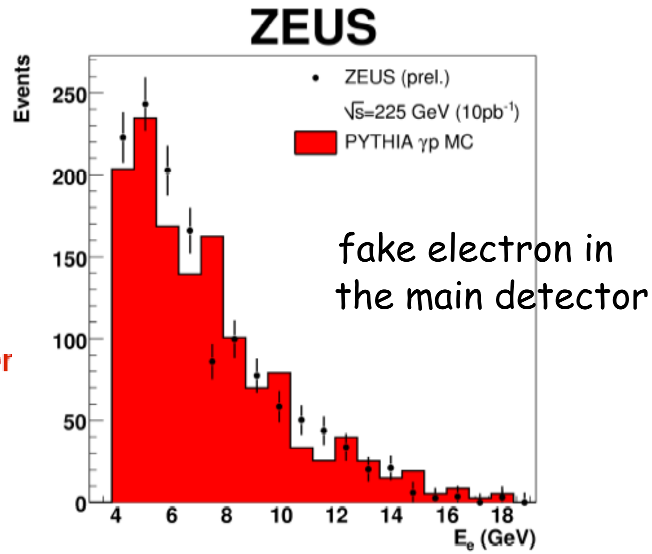


- **use single hits in the tracking detector along a road from primary vertex to el. candidate in CAL taking into account the charge of the scattered electron**

→ **reject neutral particles up to ϑ ≈ 168°**

Photoproduction background estimation using 6m electron tagger (ZEUS)



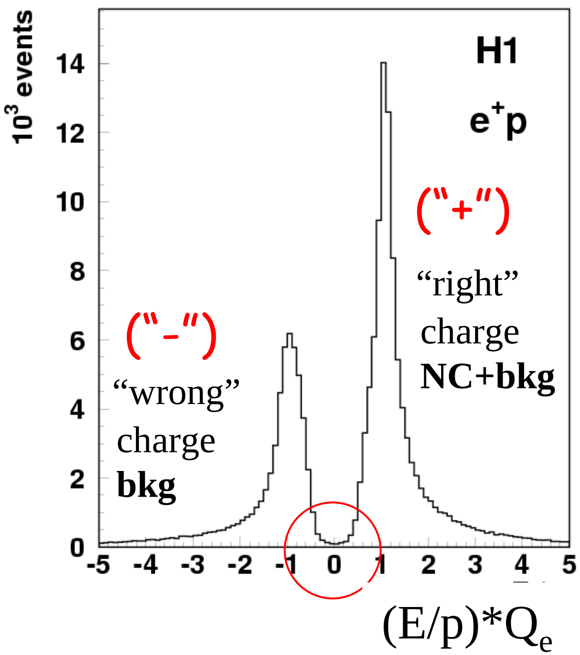


- in photoproduction ($Q^2 \approx 0$) quasi-real photon interacts with the proton
- electron with reduced energy goes along the e beam direction, bends in the dipole magnet and hits the electron tagger located at 6 m

→ fraction of γp events is measured in 6m tagger and used to normalize PYTHIA γp MC for each E_p period

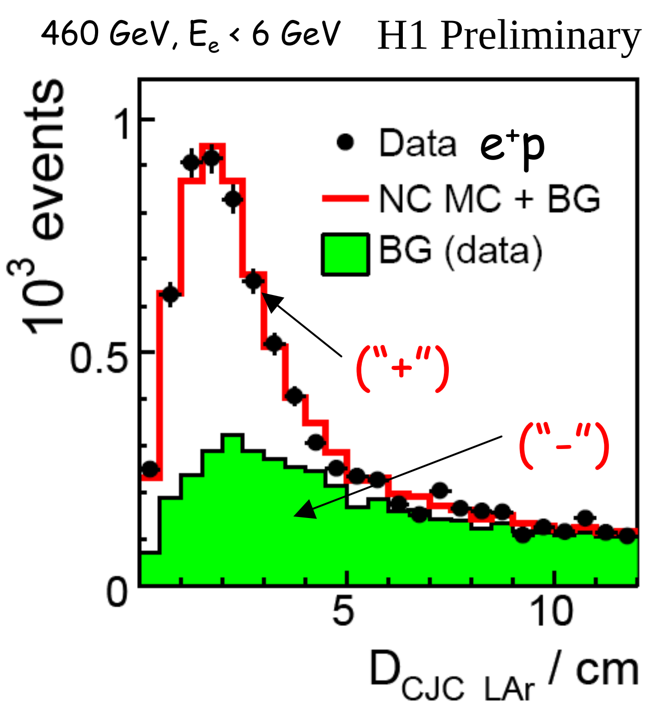
→ H1 uses similar technique for E_p=920 GeV at $y < 0.56$

γp bkg identification up to y=0.90 (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.**



taken into account in statistical subtraction:

- charge asymmerty 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

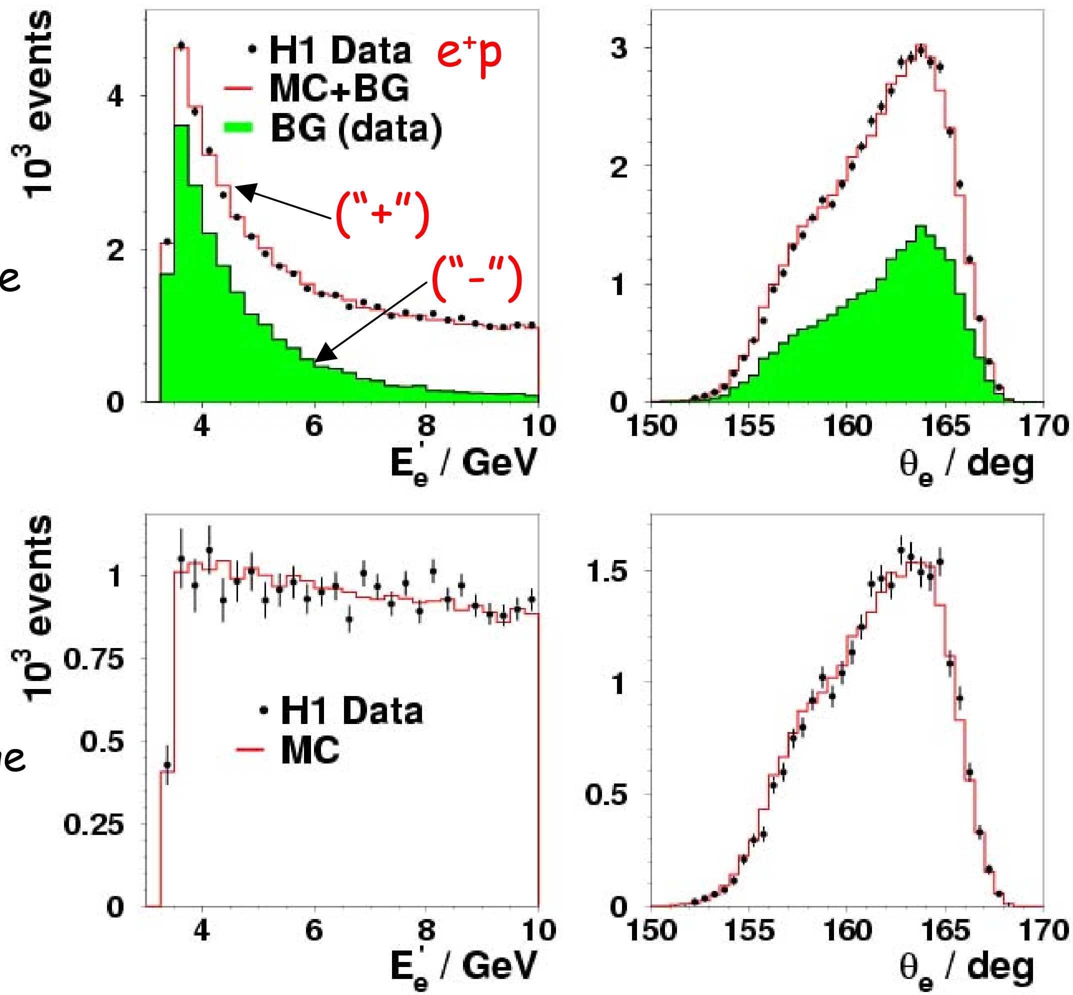
High y region at medium Q^2 (H1)

E_p = 460 GeV

E'_e < 10 GeV

before "wrong" charge subtraction

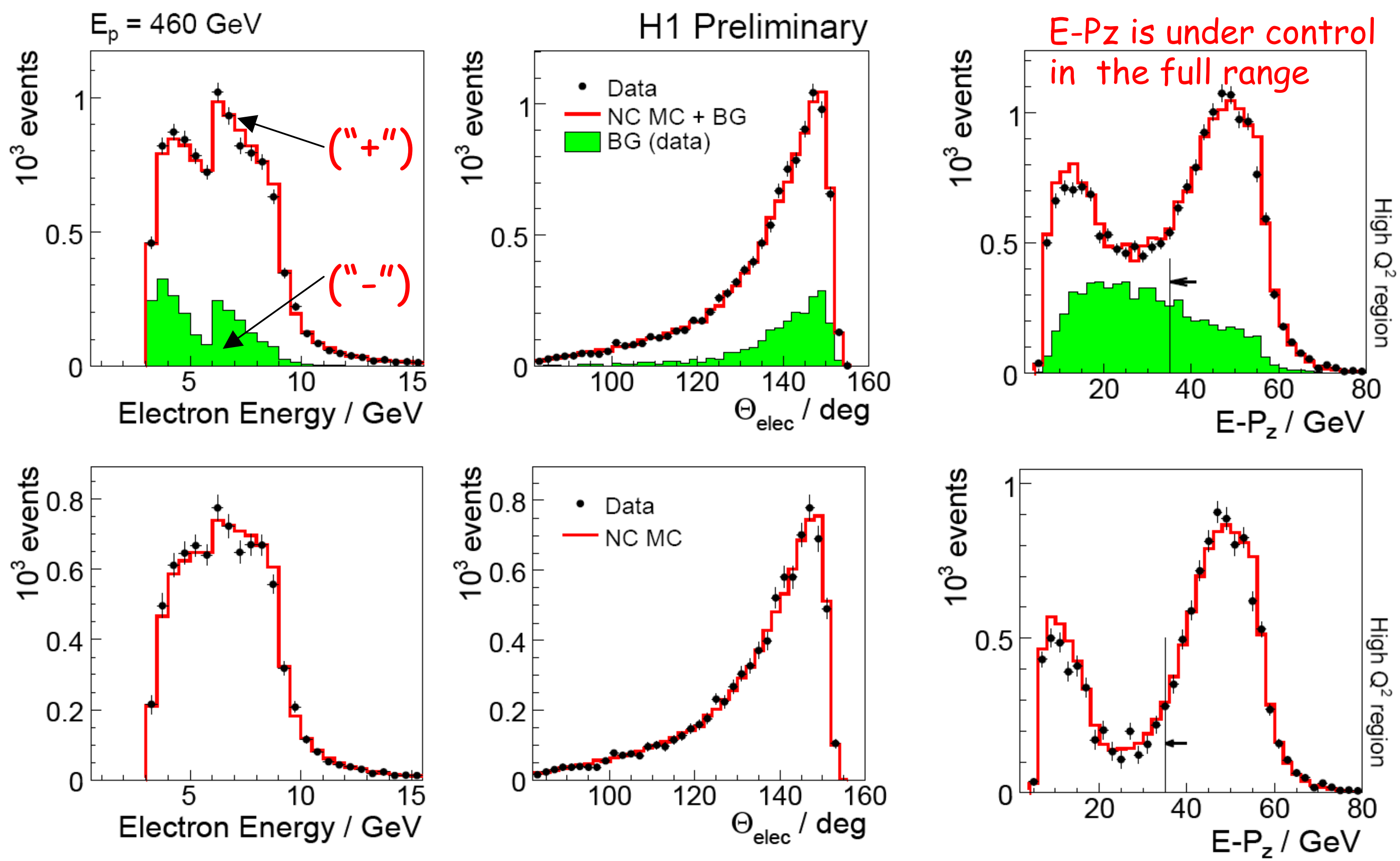
after "wrong" charge subtraction



γp background (green) concentrates at low E_e

the data are well understood in terms of MC

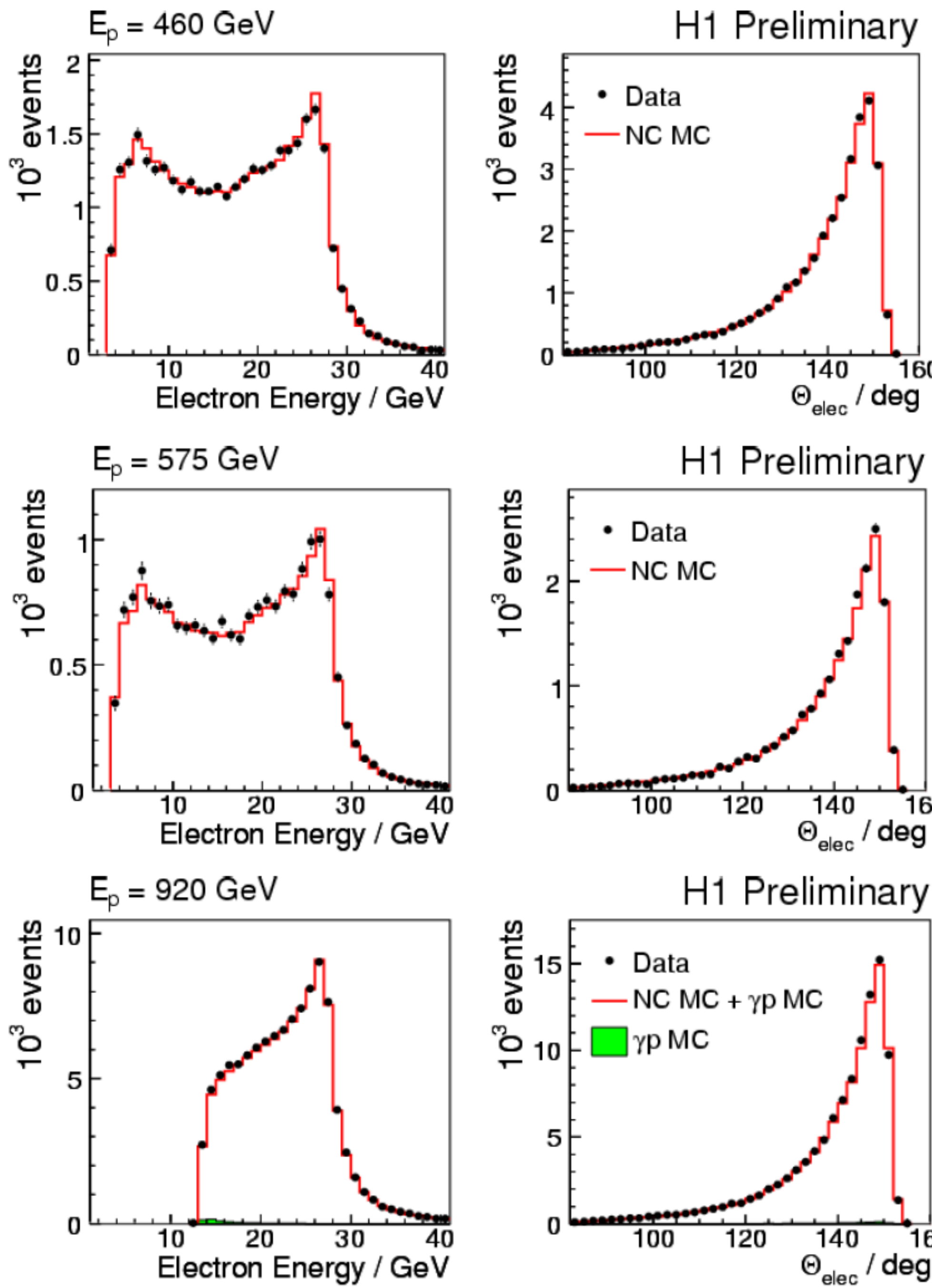
High y region ($0.70<y<0.90$) at high Q^2 (H1)



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

the requirement E-Pz>35 GeV :
- ***rejects γp background***
- ***rejects initial state radiation (ISR)***

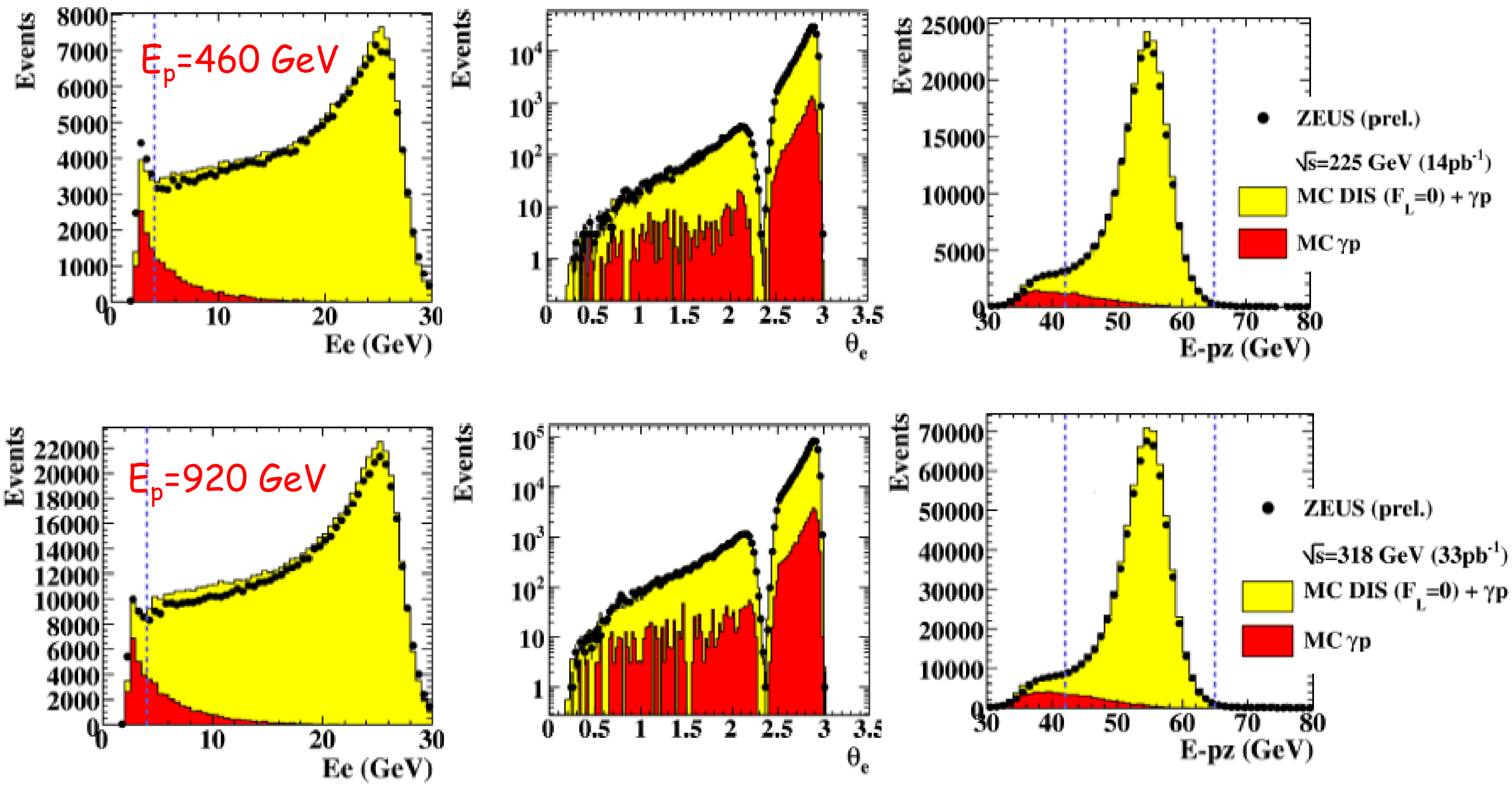
Full y range at high Q^2 after γp background subtraction (H1)



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

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

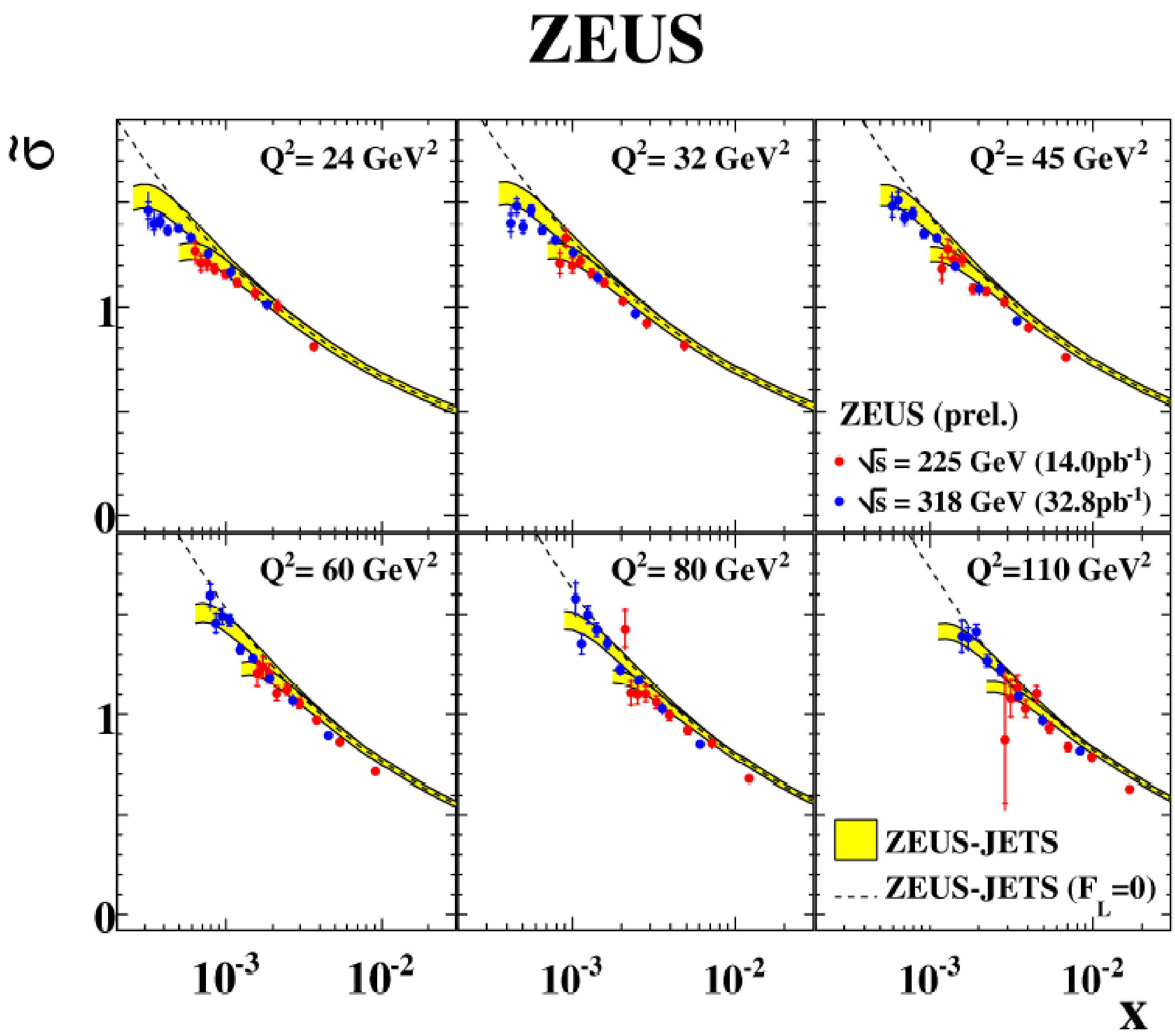
MC is shown without F_L contribution



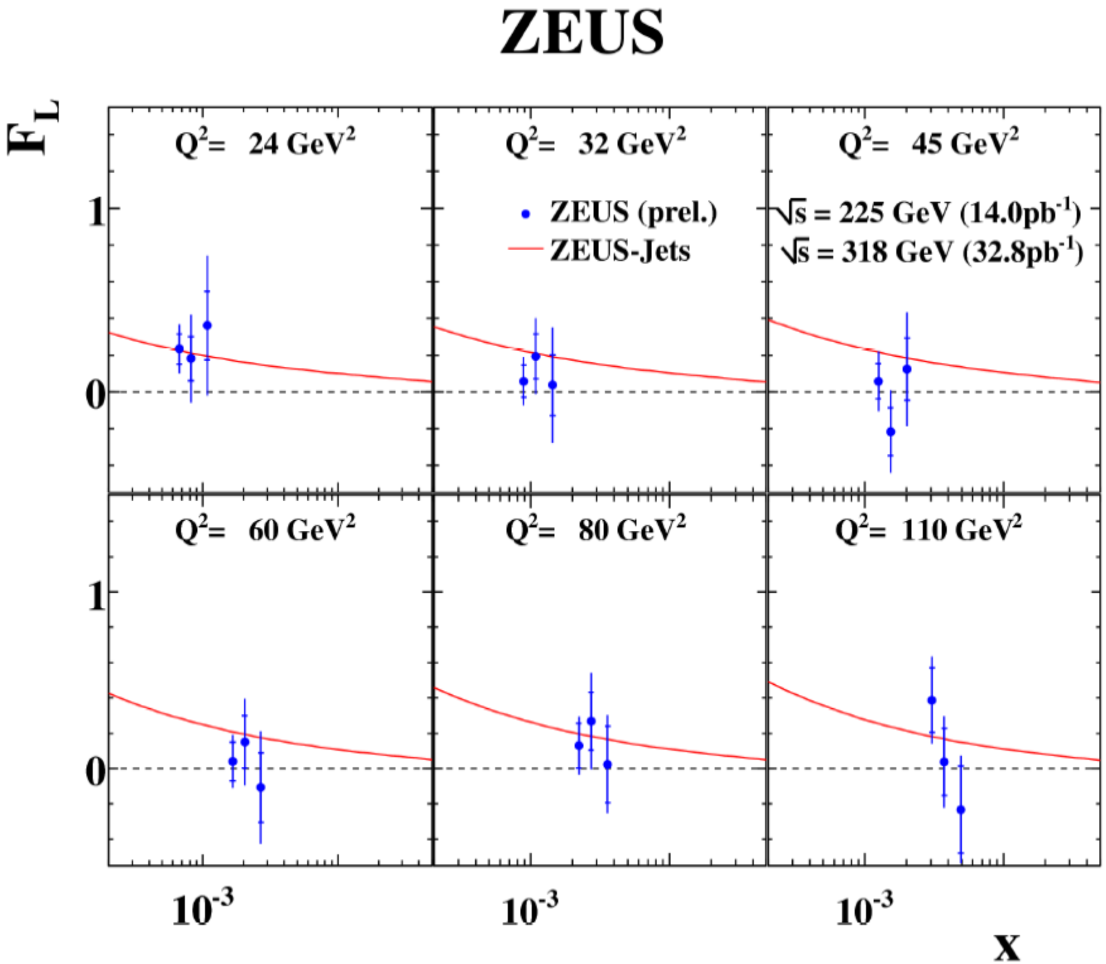
cuts indicated by lines: $E'_e > 6$ GeV

$42 < E\text{-}P_z < 65$ GeV

NC cross sections for E_p= 460, 920 GeV



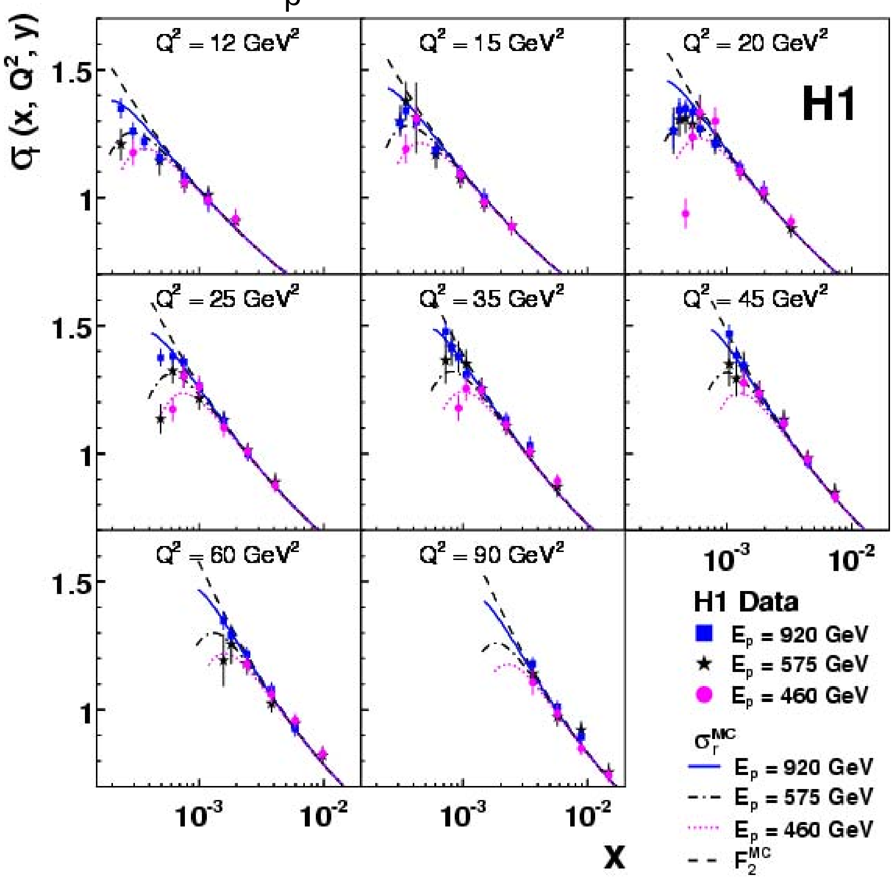
F_L (x, Q^2) from ZEUS



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

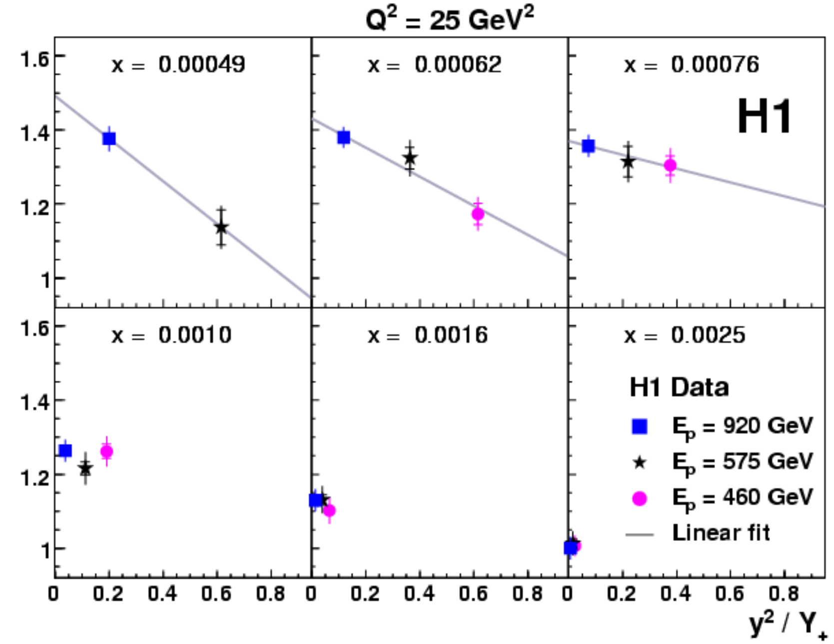
NC cross sections at medium Q^2 (H1)

E_p= 460,575,920 GeV



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

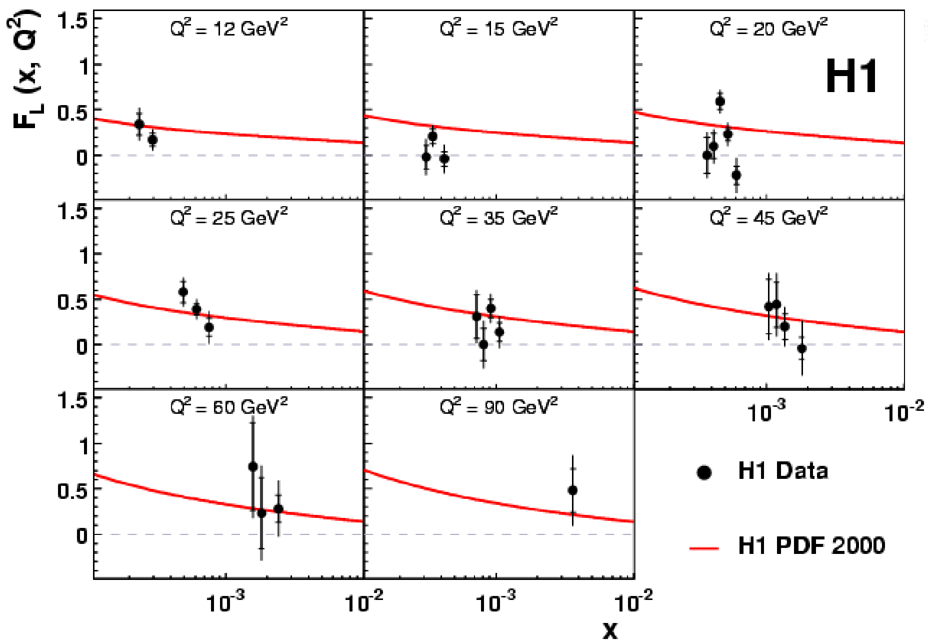
→ determine F_L and F_2 from linear fits at each x and Q^2

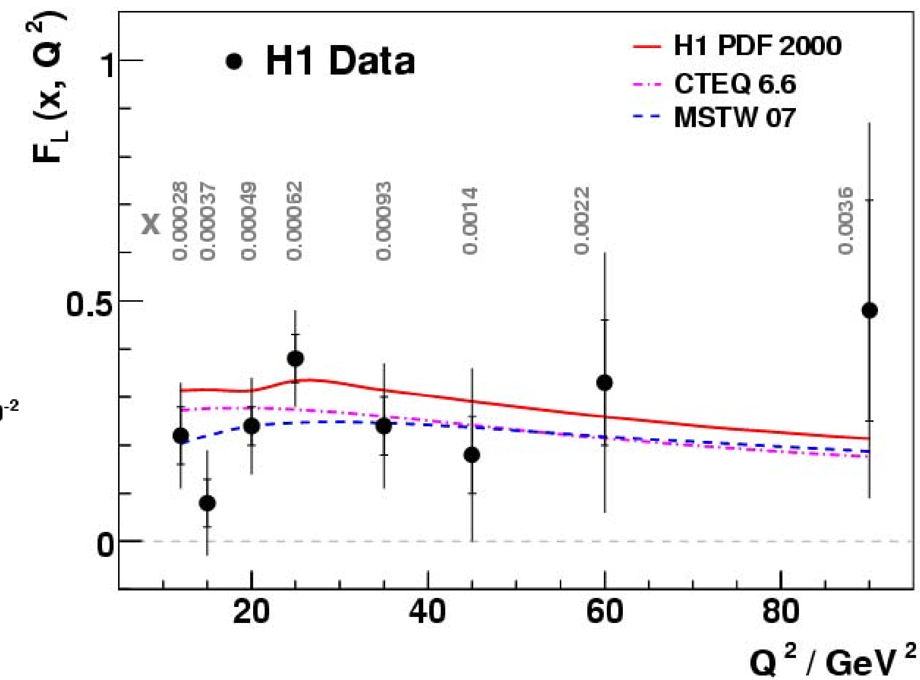


→ use relative normalisation (the same for LAr and Spacal) of E_p = 460, 575, 920 GeV from the low y data for the F_L measurement

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

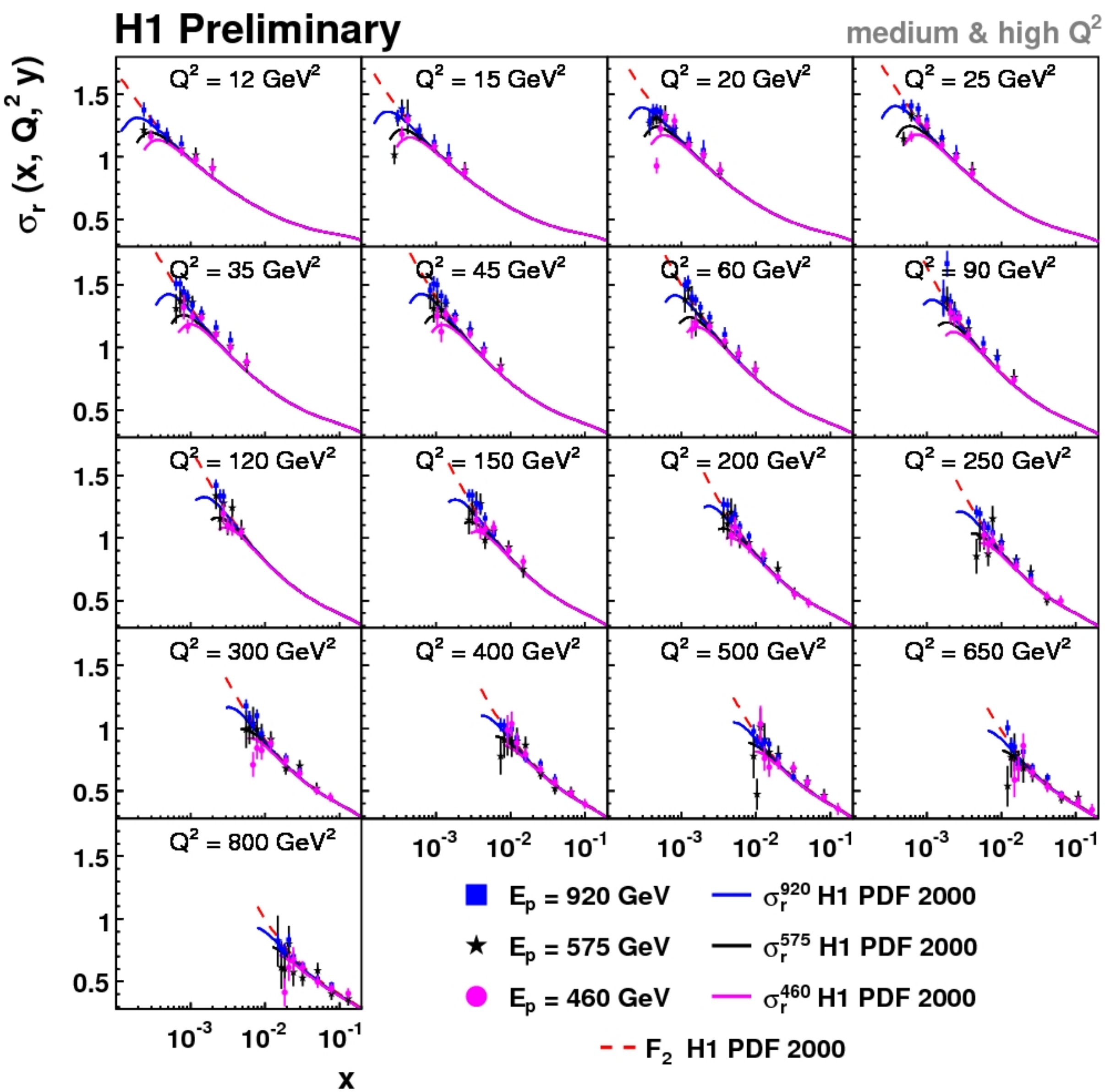
DESY-08-053





→ measured F_L are above zero and consistent with QCD calculations

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

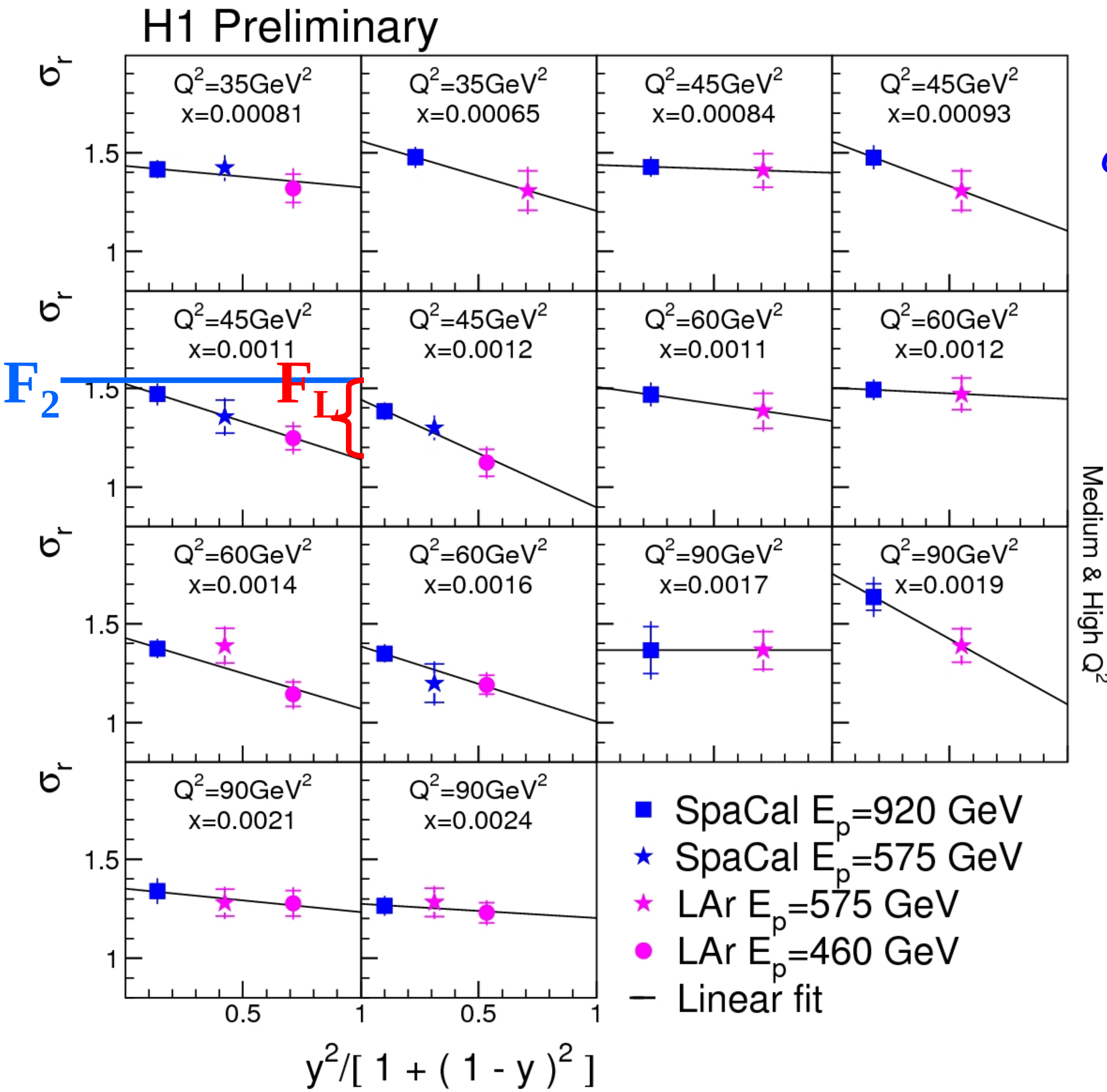


The full range of medium and high Q^2 obtained using Spacal and LAr data

E_p= 460,575,920 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 & Q^2 which involve both the LAr and Spacal data (H1)



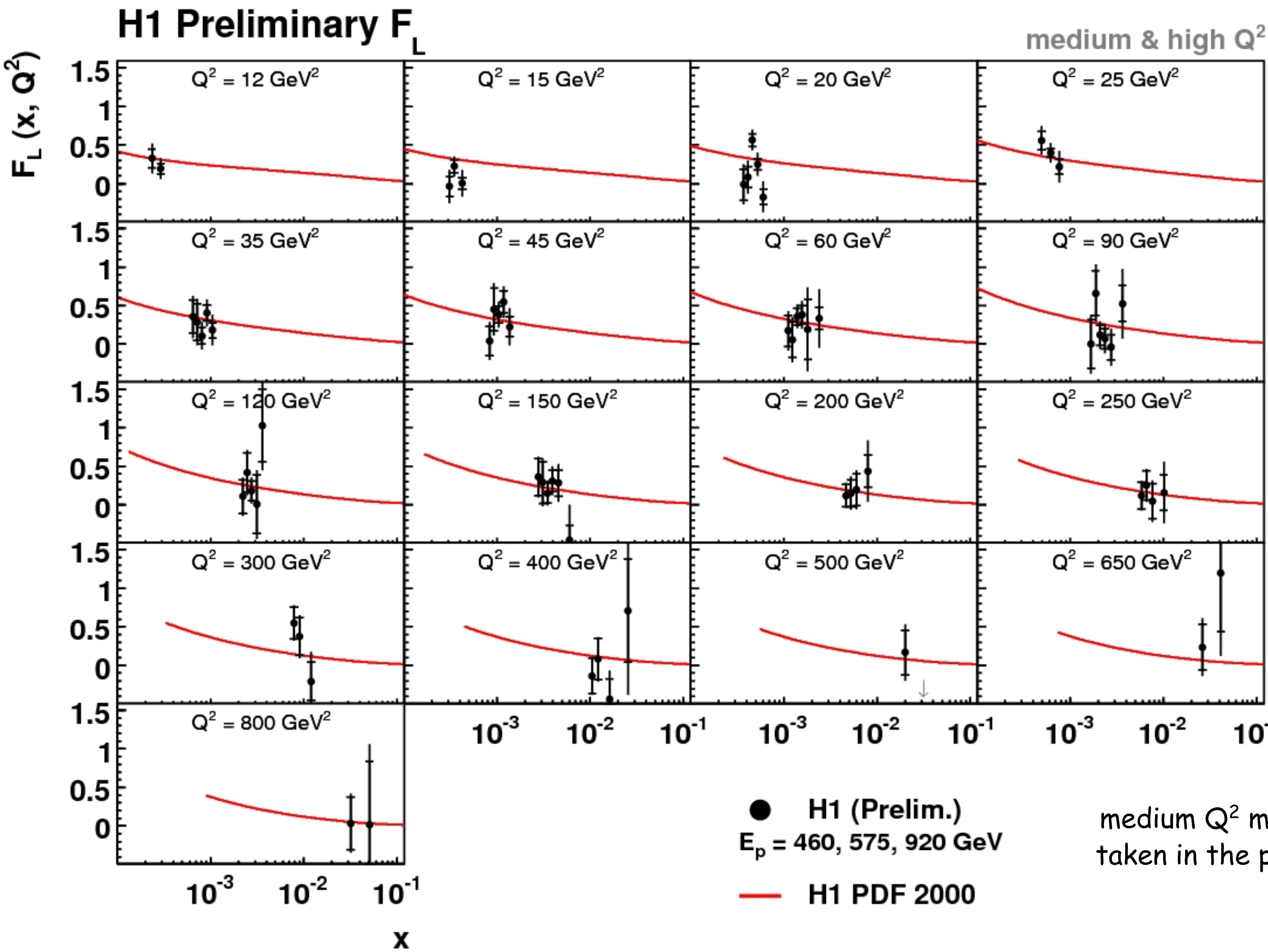
$$\tilde{\sigma}_{NC} = F_2 - \frac{y^2}{1+(1-y)^2} F_L$$

From linear fits at each x and Q^2 one determines F_L and F_2

blue points – Spacal
red points - LAr

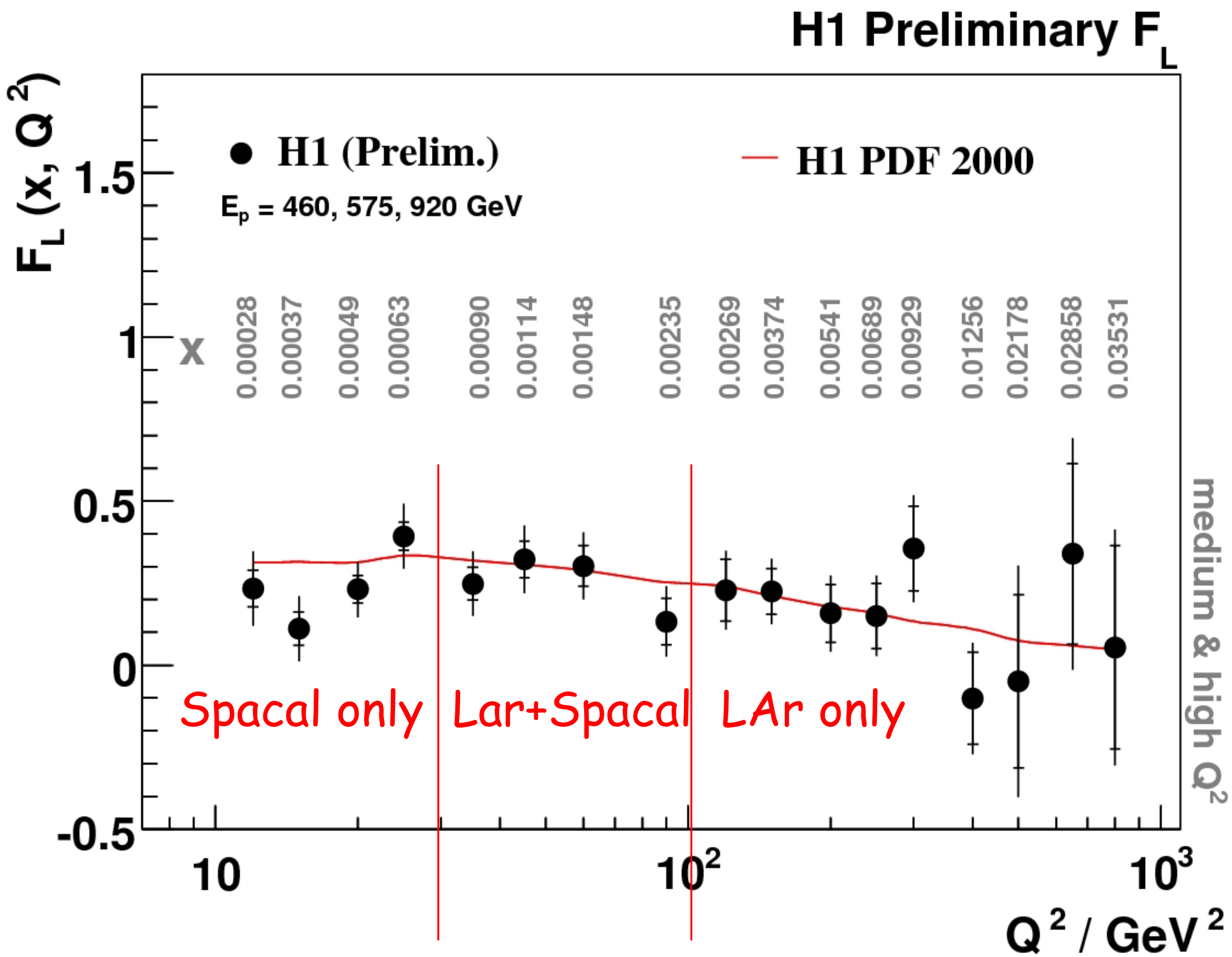
→ *nice interplay of the two fully independent analyses using different detectors: Lar and Spacal*

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



medium Q^2 measurements are taken in the preliminary form

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

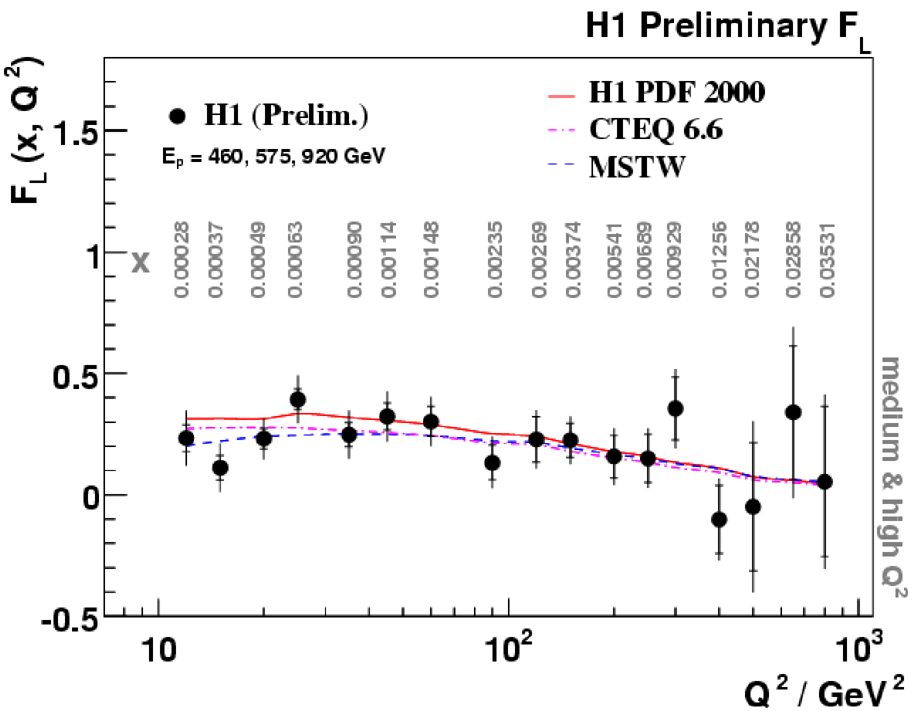


→ Spacal and LAR provide a cross check of the F_L measurements

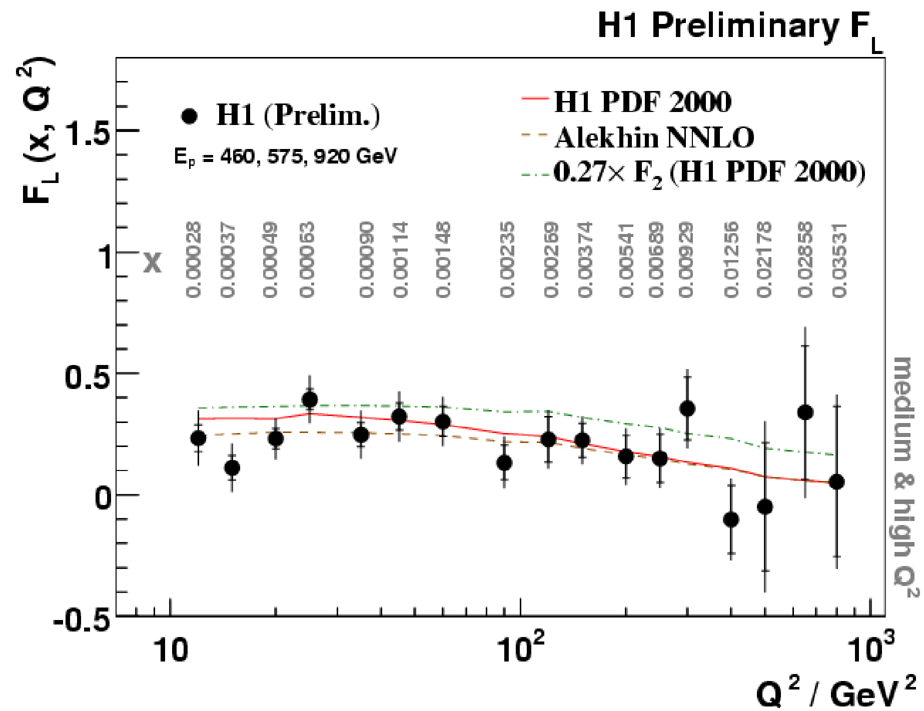
→ overall correlated systematics between F_L points is $\delta F_L \approx$ 0.05-0.10

medium Q^2 measurements are taken in the preliminary form

Comparison of F_L from H1 with recent theory predictions



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



$F_L = 0.27{*}F_2$ is motivated by Schildknecht et al. arXiv:0806.0202

→ F_L measurements are in a good agreement with the NLO/NNLO QCD calculations

→ extension to $Q^2 < 10$ GeV^2 will provide an important constraint

Summary

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

H1:

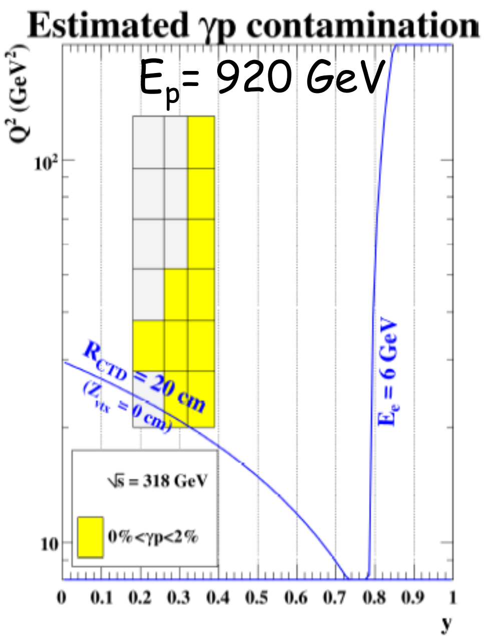
- measured at medium and high Q^2 : $12 \leqslant Q^2 \leqslant 800$ GeV^2 using the e^+p 2007 data collected with E_p = 460, 575 and 920 GeV
- nice interplay of the two fully independent analyses which use two different detectors: LAr and Spacal
- measured $F_L(x,Q^2)$ is in agrement with the recent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

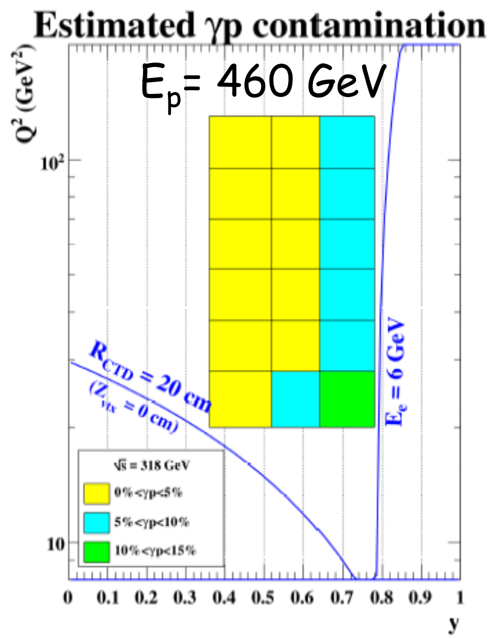
ZEUS:

- measured in the range $24 \leqslant Q^2 \leqslant 110$ 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: F_L at Q^2< 10 GeV^2 (H1), analysis of Ep=575 GeV data (ZEUS), F_L^D, ...*

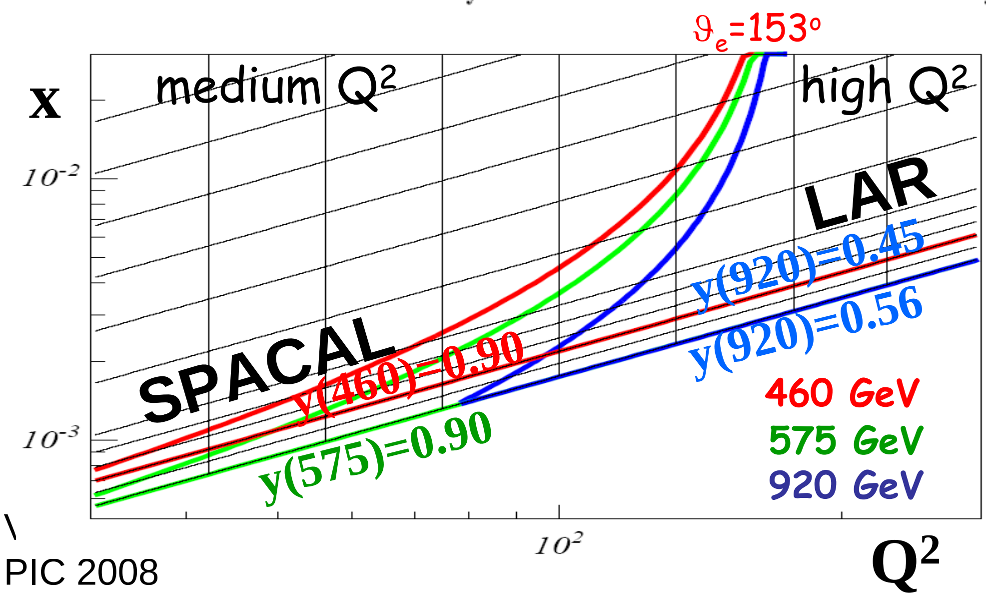
Experimental challenge: γp bkg at high y





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

< 2% for E_p = 920 GeV (y < 0.40)
10-15% for E_p = 460 GeV (y ≈ 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

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: Ecra < 4 cm
- matching between track momentum and cluster energy: $0.7<E_t^{cluster}/P_t^{track}<1.5$