Direct measurement of the longitudinal structure functions at HERA

New Trends in HERA Physics 2005

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Outlook

- Motivation
- Feasibility of a direct measurement
- Undirect determination
- Additionnal benefits from running at low E_p
- A possible strategy and conclusion

Motivations (1/3)

$$\frac{d^2\sigma}{dx dQ^2} = \frac{2\pi\alpha^2 Y_+}{Q^4 x}\left[F_2(x,Q^2) \; - f(y).F_L(x,Q^2)\right]$$

with $f(y) = \frac{y^2}{Y_+}$ and $Y_+ = \left[1 + (1-y)^2\right]$

The structure function F_L is a basic Structure Function which has to be measured.

The measurement is difficult and HERA experiments are probably the best experiments which have ever was to perform it.

It would be a text book measurement.

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Physics motivations (2/3)

F_L simply related to σ_L , the inclusive cross section of longitudinally polarised photons :

$$F_L = \left(\frac{Q^2}{4\pi^2 \alpha} \right) \sigma_L$$

In QPM : $\sigma_L = 0$

F_L gets its value from perturbative QCD,

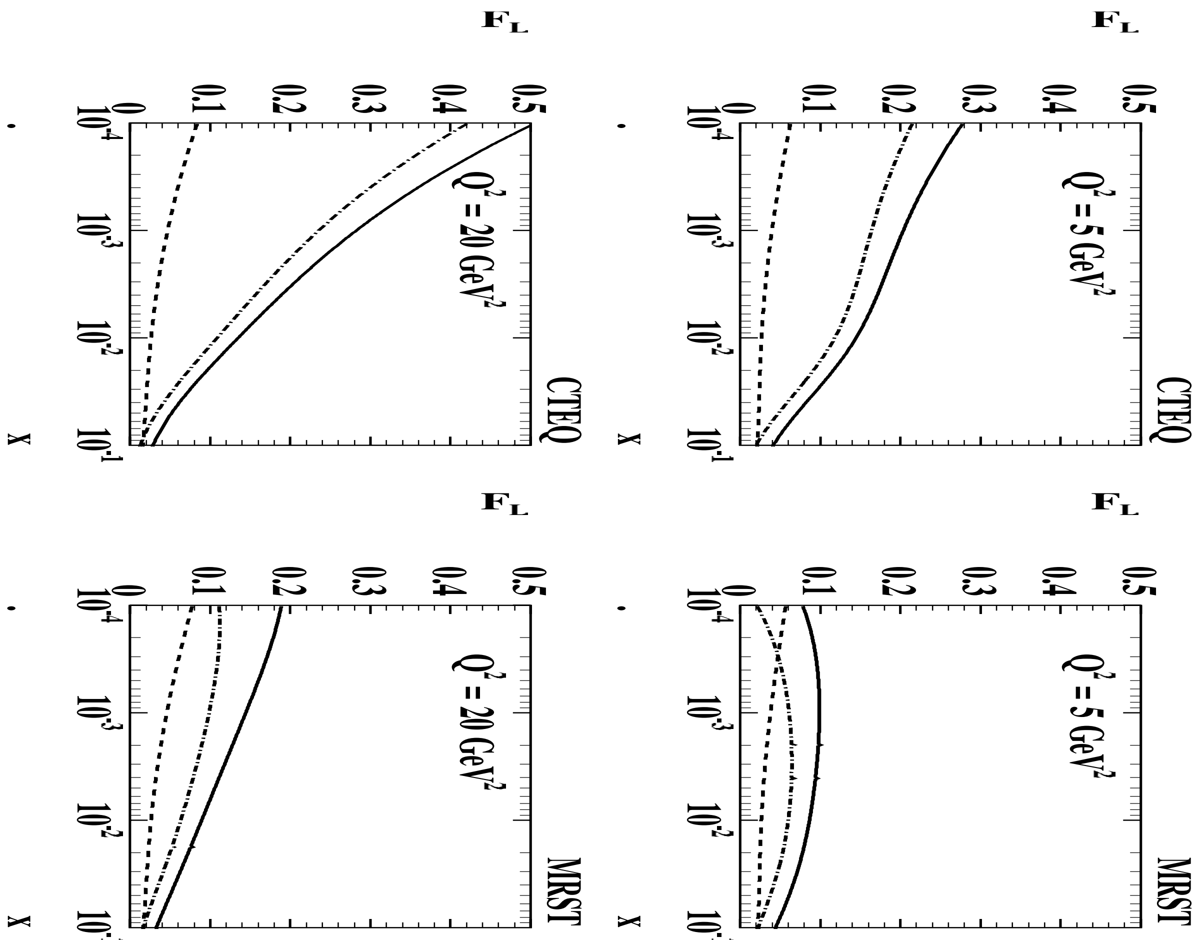
In LO :
$$F_L = \frac{\alpha_S}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \left[\frac{16}{3} F_2 + 8 \sum e_q^2 (1 - \frac{x}{z}) zg \right]$$

At low x, the gluon density dominates. F_L is a clean probe of the gluon distribution .

Measurement of F_L would be an important input to QCD fits of parton distributions and α_s (cf R. Thorne).

Motivations

CTEQ and MRST do fit $F_2(x,Q^2)$ data from H1 at low x but F_L is poorly constrained by present data.



Measuring F_L at x from 10^{-4} to a few 10^{-3} would provide an additional constraint on gluon density for Higgs and W production at LHC

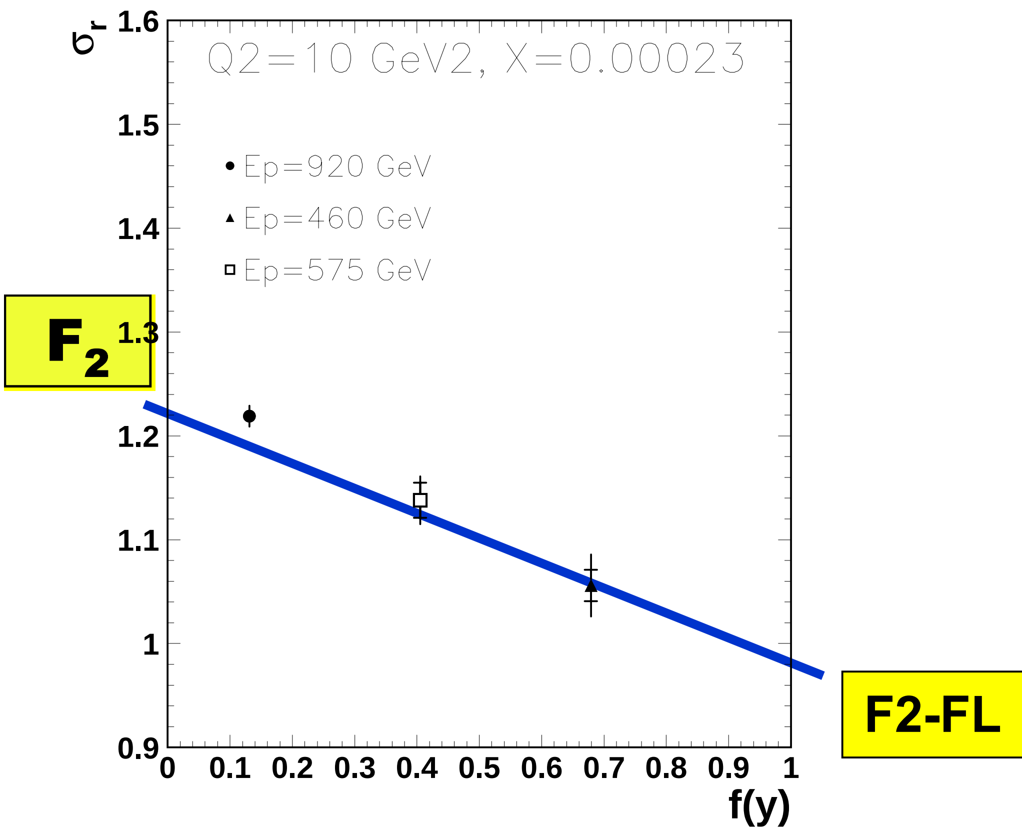
Direct measurement of $F_L(Q^2,x)$

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

Measure at the same (Q2,x) reduced cross sections from different beam energies, i.e. different y.

Perform straight line fit of σ_r to extract F_2 and F_L

F_L is very sensitive to small relative shifts on cross sections



Direct measurement of $F_L(Q^2,x)$

Requirements :

- At least two beam settings which overlap in the (Q^2,x) plane
- A large y difference
- The highest possible y at low beam energies (error on $F_L \sim 1/y^2$)
- Enough luminosity

To have both measurements in the same part of the apparatus,

To access the largest y,

Better to only reduce the proton beam energy

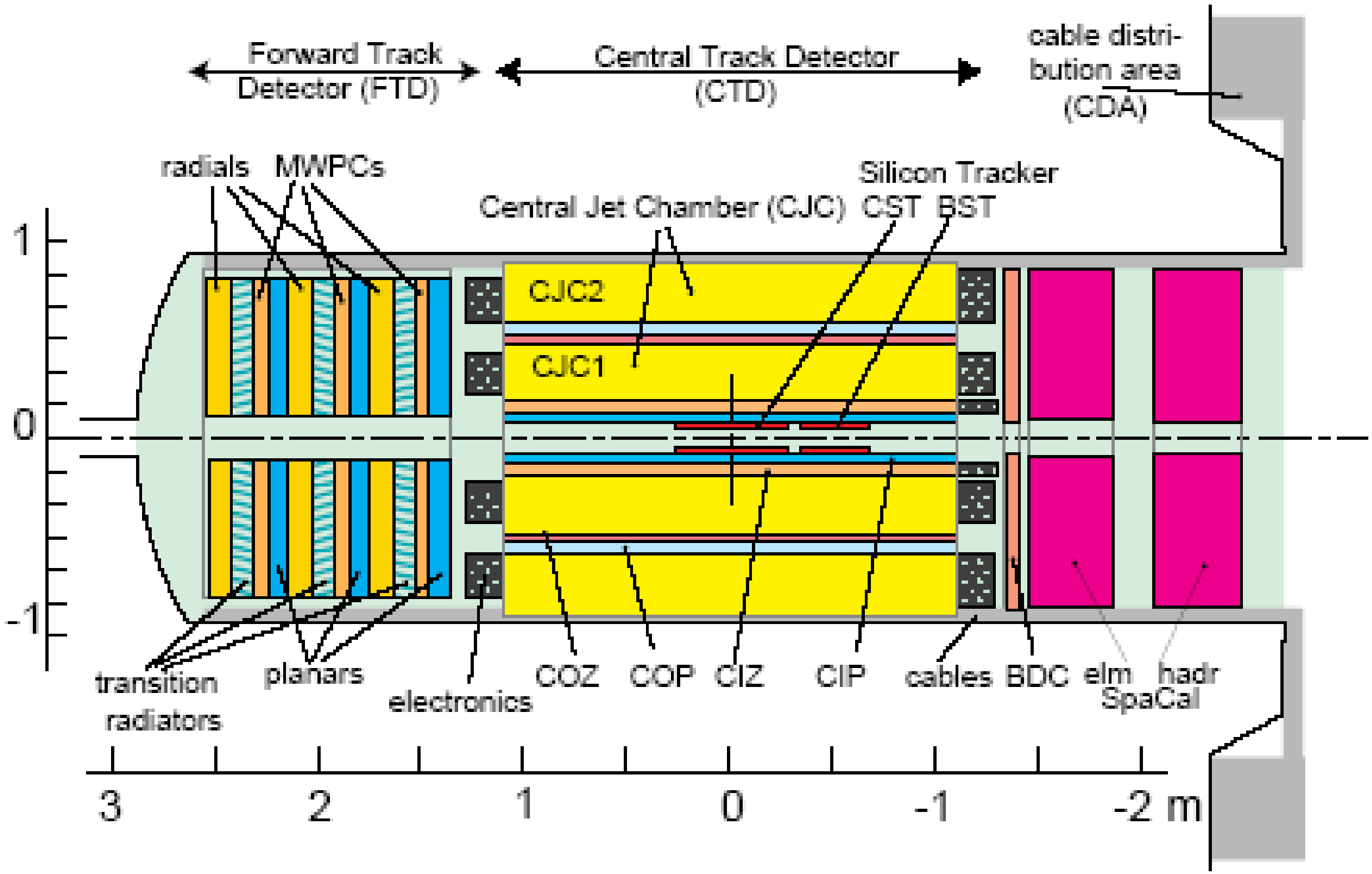
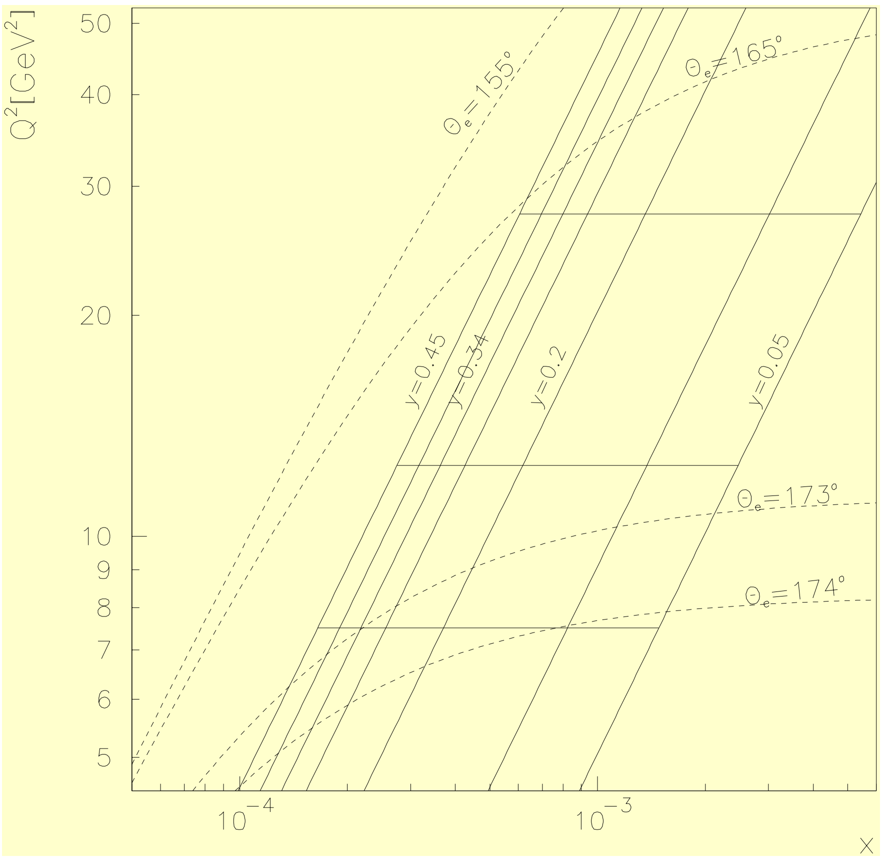
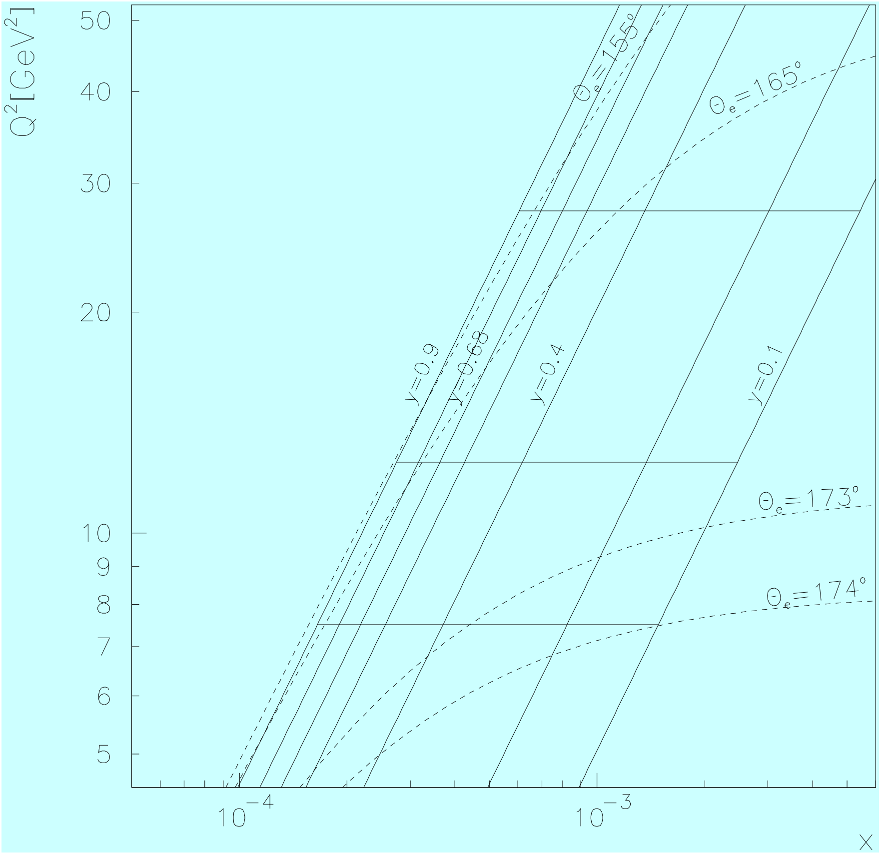


Figure 3.3: The H1 tracking detectors.

E_p = 920 GeV

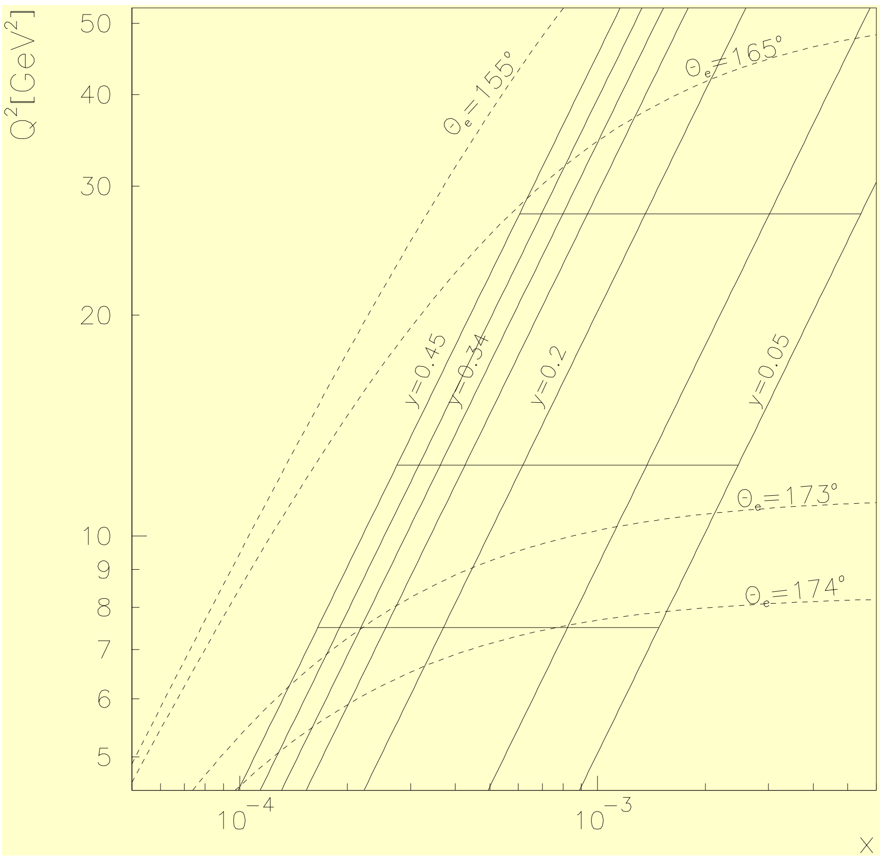


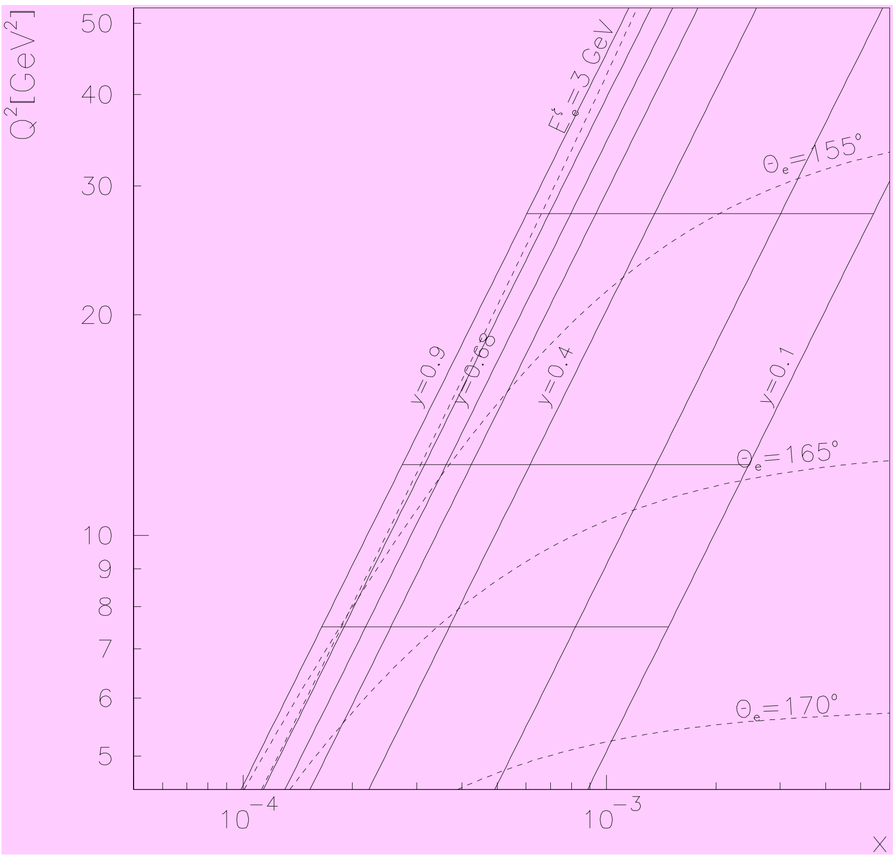
E_p= 460 GeV



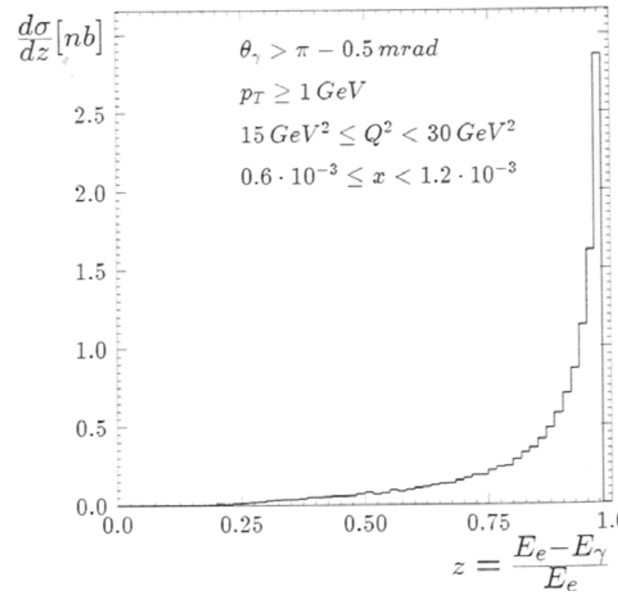
$E_e = 27.6$ GeV

$E_e = 13.8$ GeV





Why not using the radiative events?
$e + p \rightarrow e + \gamma + X$



- We get radiative events fo free !
- Need a huge statistics (~200 pb^{-1})

[Krasny, Placzek, Spiesberger,1991]

- However :
  - For a fixed (Q^2,x) bin, at different y, the overlap in the same part of the detector is quite small
  - No access to very high y (E'_e > 3 GeV)
  - Severe pile up of Bethe-Heitler events (e p→e p γ) in the gamma detector [Favart, Maracek, 1996]

➡ huge errors on F_L ~ 50-100 %!

Direct measurement of $F_L(Q^2,x)$

Present assumptions (to be tuned when Luminosity is better known) :

E_p(GeV)	920	460
L(pb^{-1})	30	10

A possible option :

E_p(GeV)	920	460	575
L(pb^{-1})	30	5	3.5

Systematic errors

F_L is only sensitive to relative shifts of cross section. Errors based on cumulated expertise in analysing F_2 data and anticipation of BST performances.

- Correlated errors
  - Energy of scattered electon : from 2% at 3 GeV to 0.2% at 30 GeV.
  - Angle of scattered electron : 0.2 mrad in BST and 1 mrad at $\Theta_e < 165°$.
  - Residual photoproduction background (from a fit on negative tracks in positron run) $0.267-0.8\,y + 0.6\,y^2$ at $y > 0.65$
- Uncorrelated efficiencies:

electron identification, trigger, vertex, radiative corrections : 1%

Estimates of errors on $F_L(x,Q^2)$

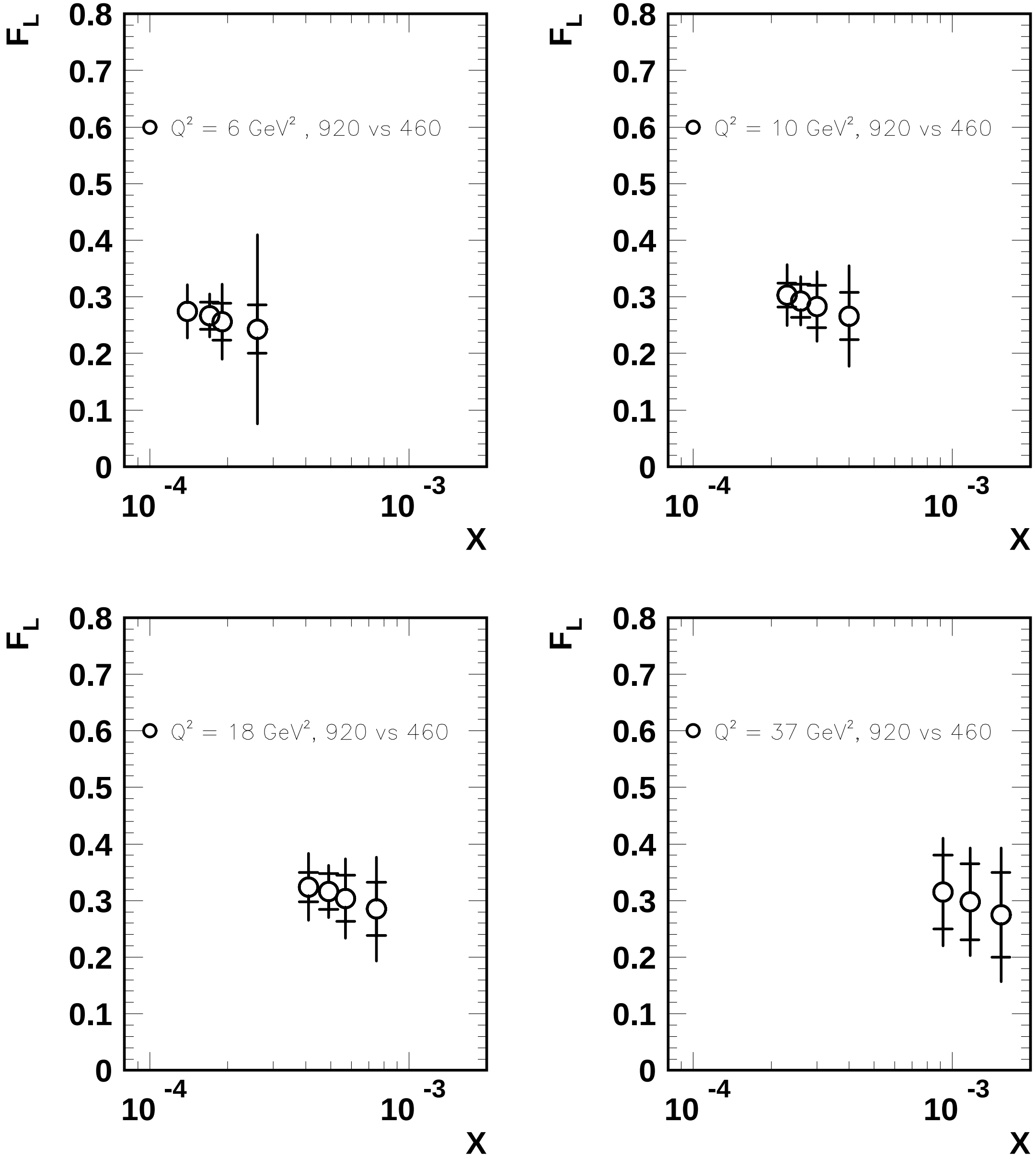
- Fast simulations based on F_2 and F_L parametrizations from H1 QCD fits (2000)

- Two methods have been used :
  - Analytic calculations (MK)
  - Fast montecarlo (JF)

→ Excellent agreement

ERRORS IN PERCENT, Q2 ~ 9.4 GEV2, PROTON BEAM ENERGIES 920 vs 460 GeV

<X>	0.00023	0.00026	0.00030	0.00040
<Y> at 460 GeV	0.835	0.728	0.628	0.483
<FL>	0.303	0.293	0.283	0.266
STATISTICAL ERROR	7.0	9.9	13.1	15.8
SYST: EFFICIENCIES	6.4	9.3	13.8	28.0
SYST: GAMMA-P	13.0	4.6	1.0	0.0
SYST: ELEC. ENERGY	4.7	2.9	9.3	4.7
SYST: ELEC. ANGLE	6.2	0.3	3.2	7.5
SYST: TOTAL	16.4	10.8	17.0	29.4
SYST+STAT	17.9	14.6	21.4	33.4

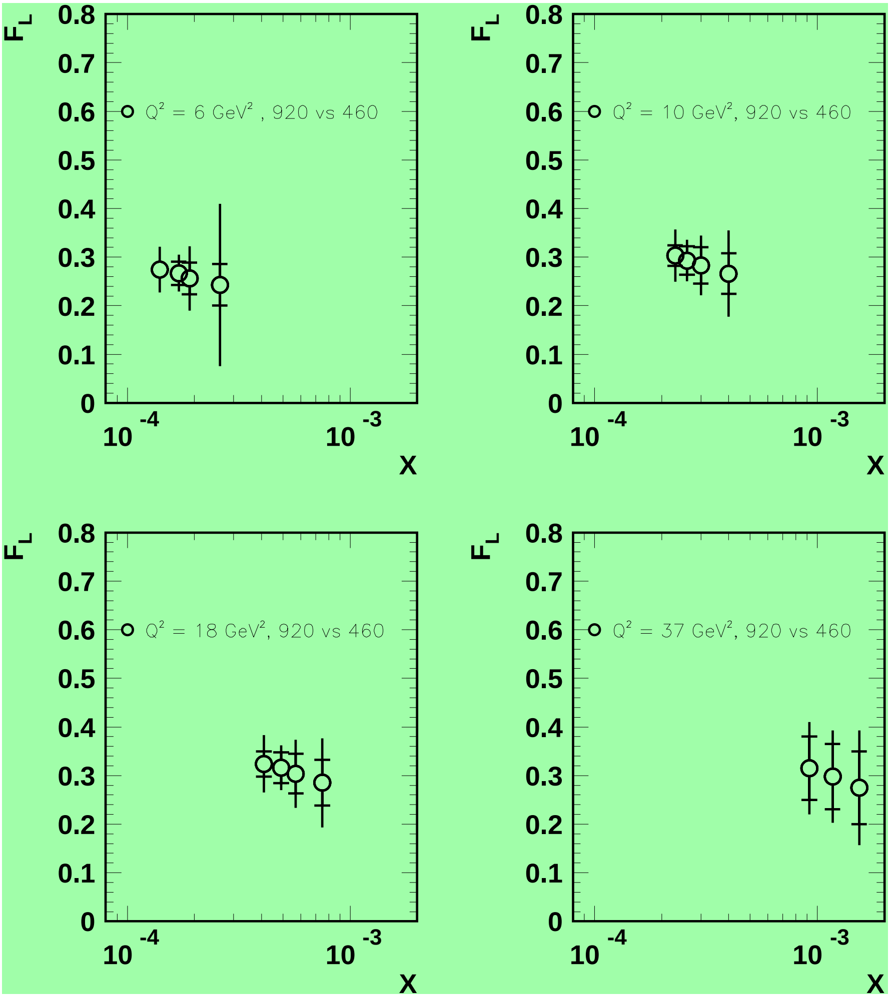


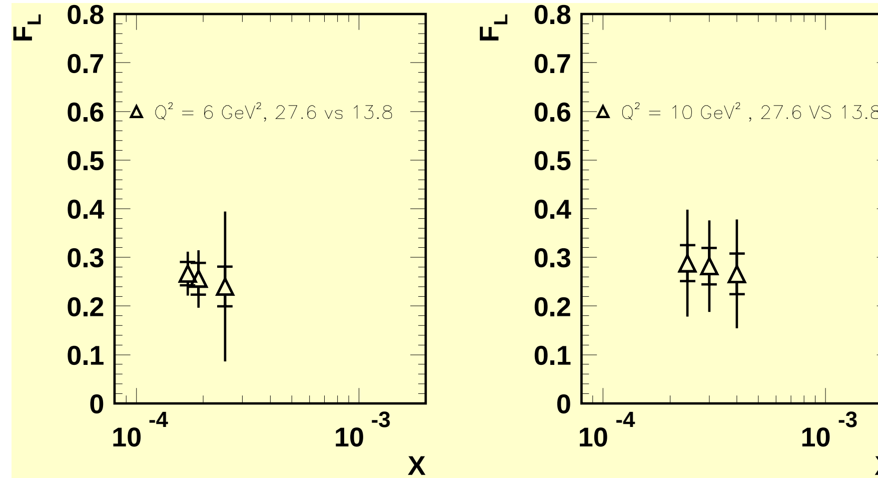
30 pb^{-1}, E_p=920 GeV

10 pb^{-1}, E_p=460 GeV

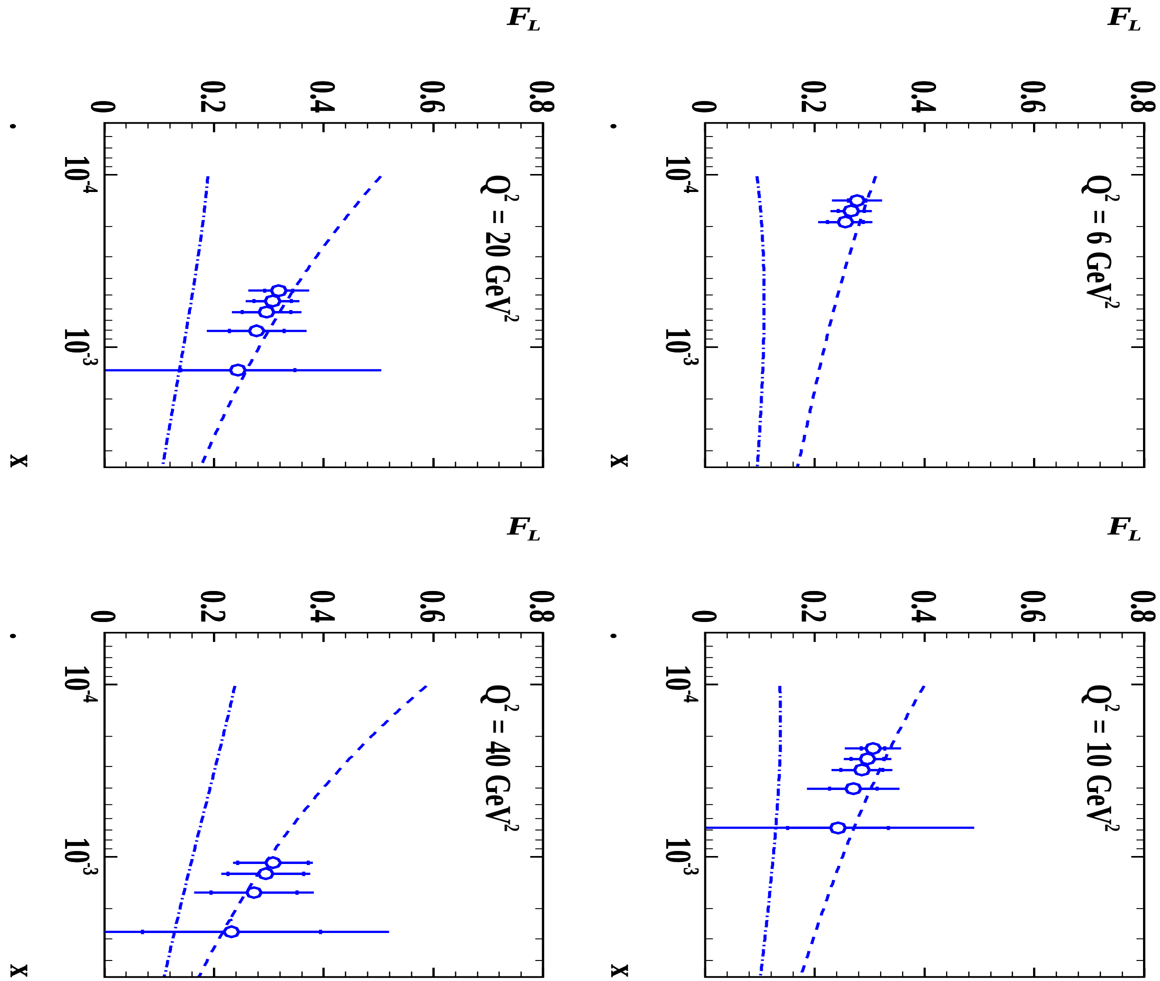
920 x 27.5 vs 460 x 27.5

920 x 27.5 vs 920 x 13.8



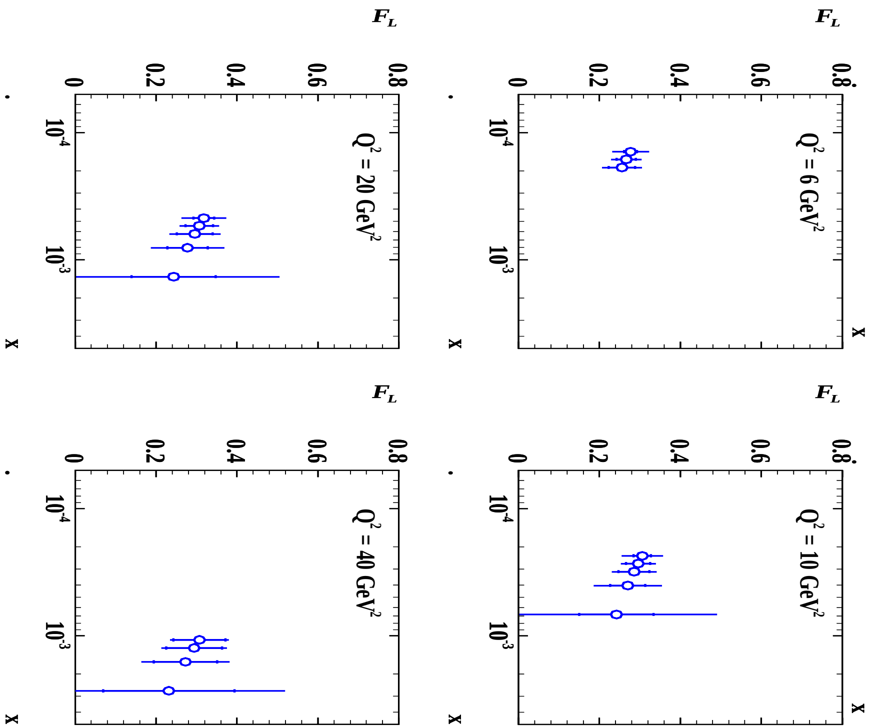


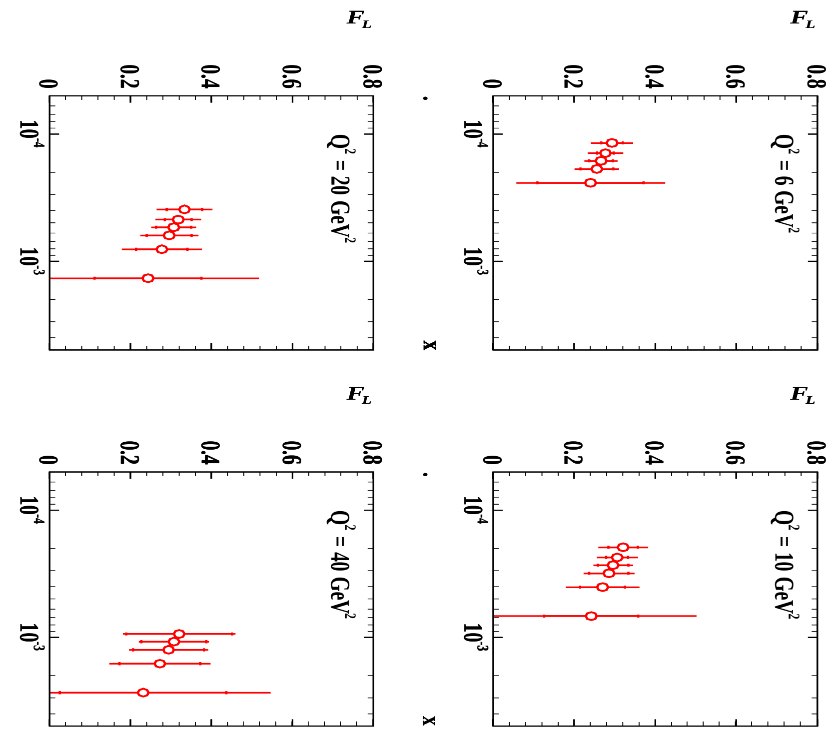
30 pb-1, Ep=920 GeV
10 pb-1, Ep=460 GeV



10 pb^{-1} at E_p=460GeV

5 pb^{-1} at E_p = 460 GeV and
3.5 pb^{-1} at E_p = 575 GeV





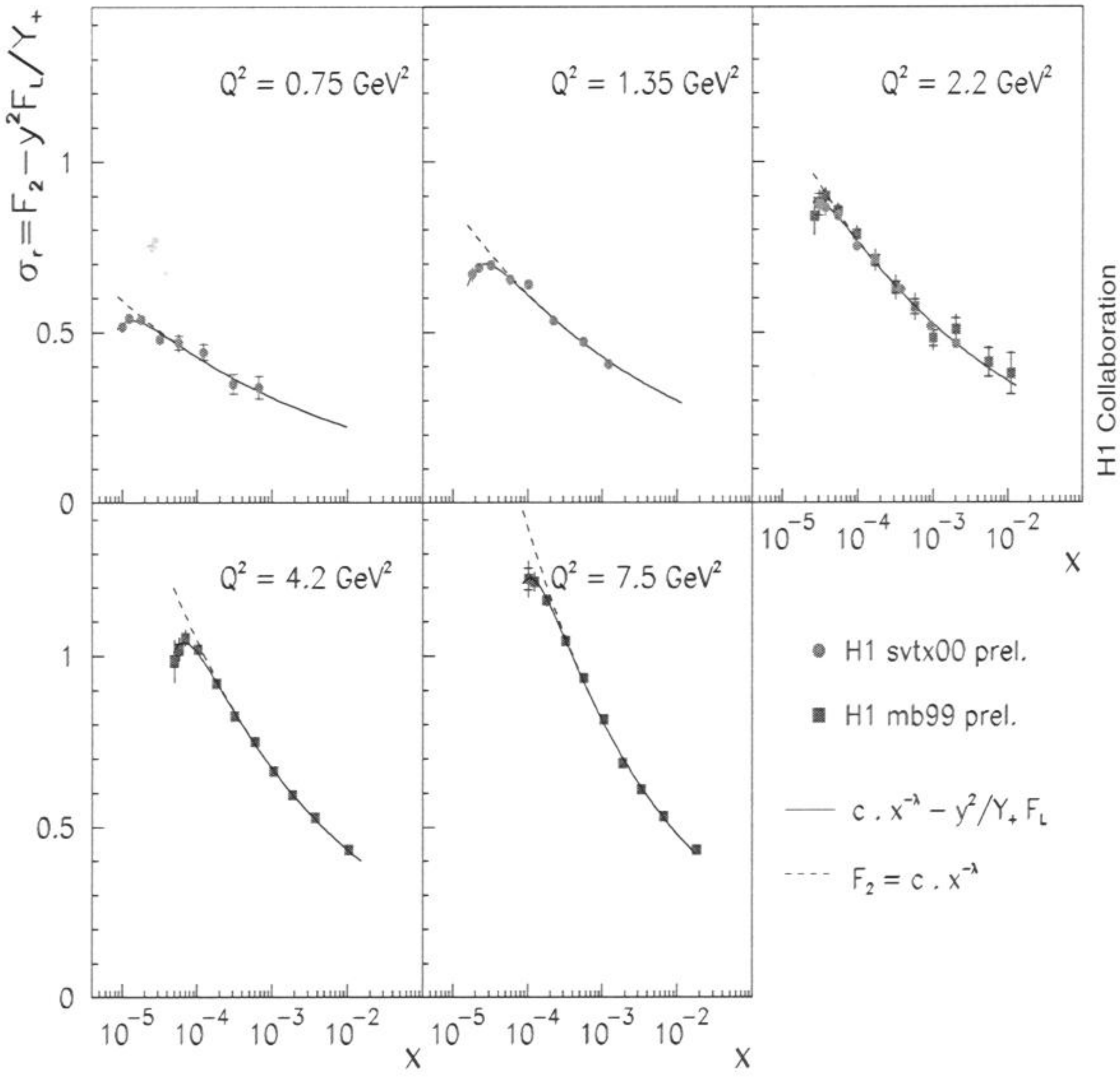
Undirect determination of F_L ?

H1 has invented three methods to determine F_L(not a measurement) at fixed beam energies :

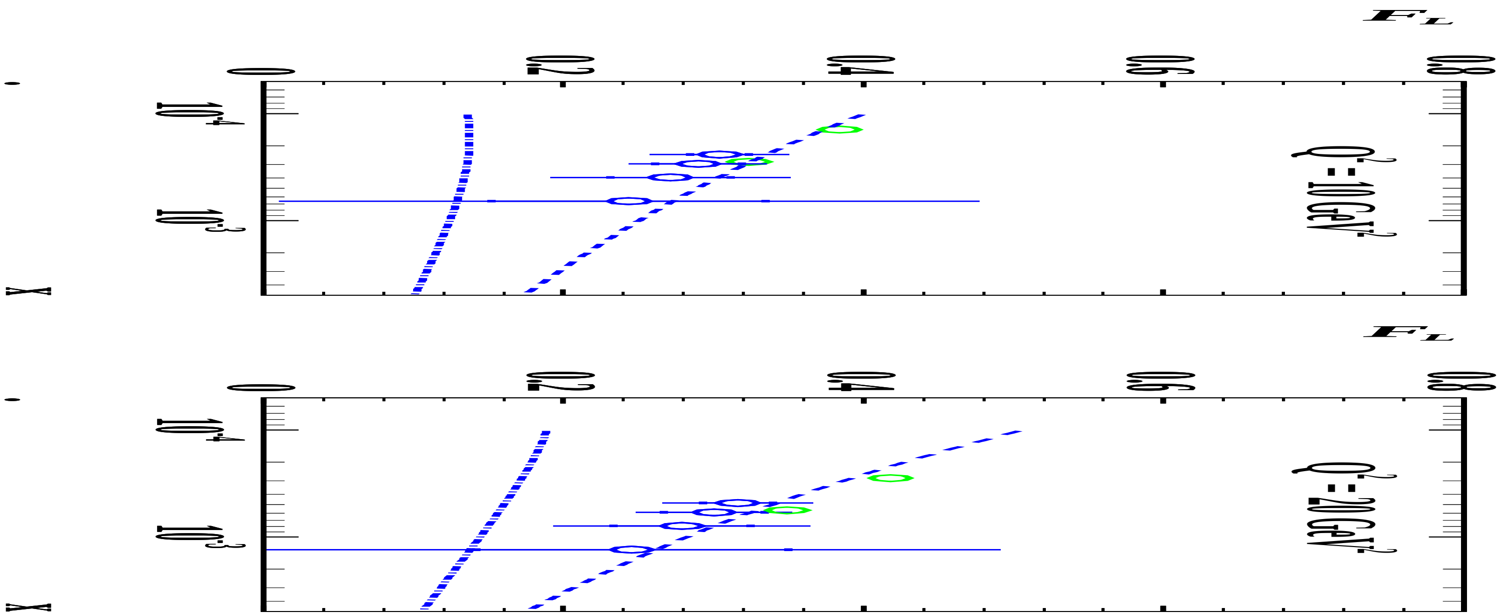
‘extrapolation’, ‘derivative’ and ‘shape’

The methods provide an indirect determination of F_L somewhat model dependent (cf Robert Thorne) and with a modest precision (two to three sigmas).

The shape method is based on a simple parametrization of σ_r at fixed Q^2



Undirect determination of F_L



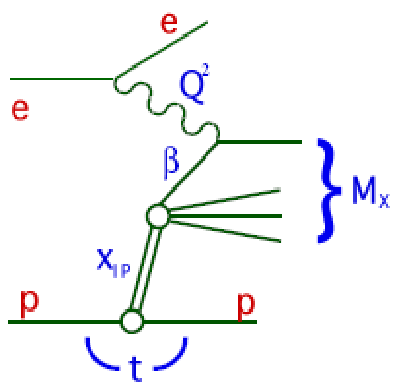
A new undirect determination of F_L at lower proton beam energy would provide an interesting cross check based on quite different systematics.

The Diffractive Longitudinal Structure Function F_L^D

By analogy with inclusive case,

$$\frac{d^3\sigma^{ep\to eXY}}{dx_{I\!P}\, d\beta\, dQ^2} = \frac{2\pi\alpha^2}{\beta Q^4} \cdot Y_+ \cdot \sigma_r^D(x_{I\!P}, x, Q^2)$$

where $\sigma_r^D = F_2^D - \frac{y^2}{Y_+} F_L^D$ and $Y_+ = 1 + (1-y)^2$



Several different measurement possibilities:

- "Shape" method as in inclusive case:

  ...requires knowledge of $x_{I\!P}$ dependence of F_2^D, which is poorly constrained by theory and complicated by meson effects, interference etc.

- Exploit intereference between transverse and longitudinal contributions leading to modulation in $\Delta\phi$ between lepton and proton scattering planes.

  ...Current results (ZEUS) consistent with zero due to poor statistics and large systematics.

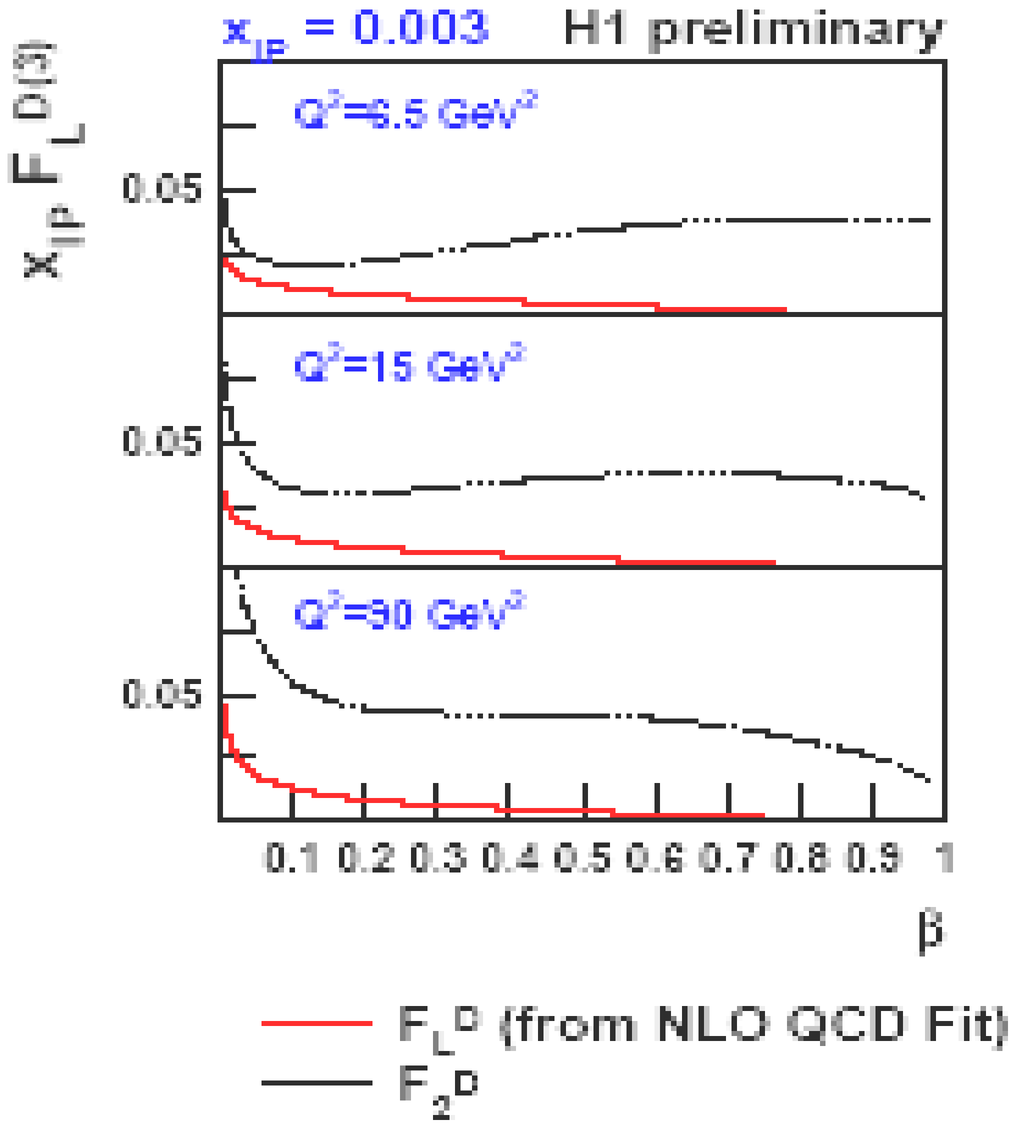
  ...Maybe interesting with VFPS?

- Varying y at fixed Q^2, β, $x_{I\!P}$ by changing $\sqrt{s}$ promises model independent result.

F_L^D has never been measured

F_L^D predicted from QCD fits to be large at low β!

Inclusive diffraction cannot be fully understood without separating out F_L^D contribution.



Results and Uncertainties for $Q^2 = 12\ \mathrm{GeV}^2, \beta = 0.23$

y_{400}	$x_{I\!P}$	δ_{unc}	δ_{pdiss}	$\delta E'_e$	$\delta \theta'_e$	δM_X	$\delta \gamma p$	δ_{syst}	δ_{stat}	δ_{tot}
$0.5 - 0.7$	0.0020	34	6	8	2	7	0	36	20	41
$0.7 - 0.8$	0.0016	19	6	3	2	5	6	22	17	28
$0.8 - 0.9$	0.0014	14	6	6	1	2	13	21	13	25

Uncertainties correlated between beam energies:

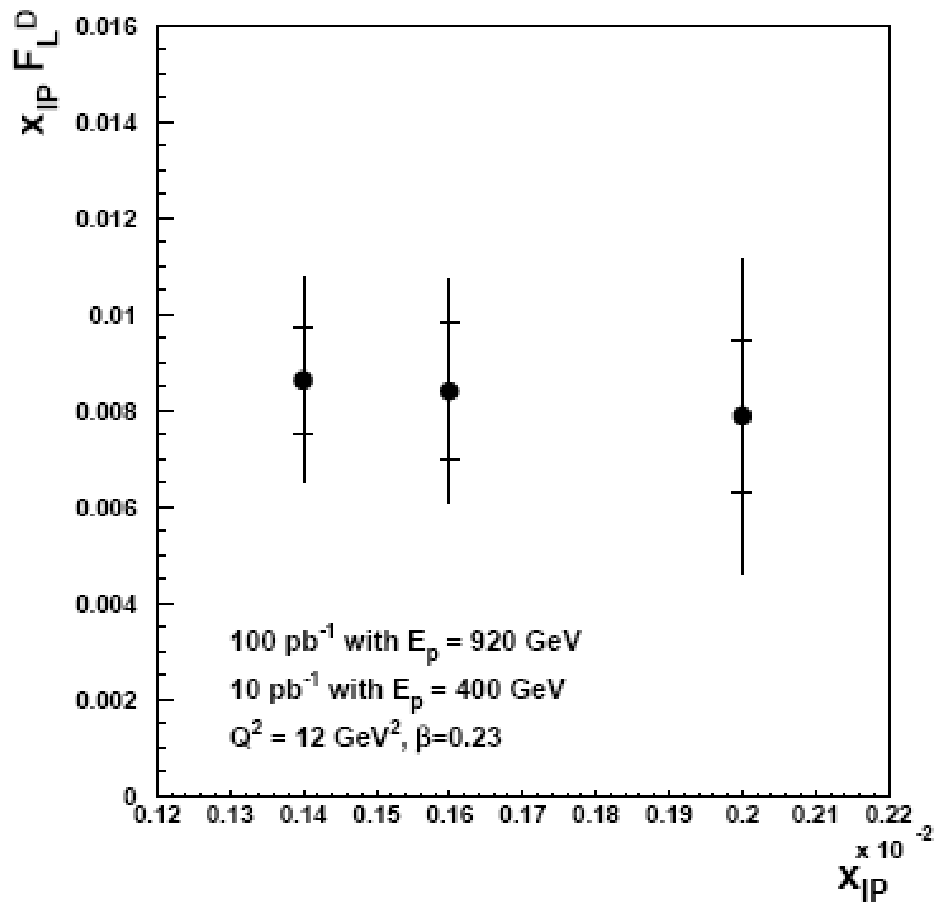
- $\delta E'_e = 0.2\%$ (kinematic peak) $\ldots 2\%$ $(E'_e = 3\ \mathrm{GeV})$
- $\delta \theta'_e = 0.2\ \mathrm{mrad}$
- Hadronic energy scale $\delta M_X = 4\%$ (as now)
- Photoproduction background $\delta \gamma p = 25\%$ (as now)
- Proton dissociation corrections $\delta_{\mathrm{pdiss}} = 6\%$ (as now, assumed 100% correlated)

Uncorrelated uncertainty = 2.4%, mainly from acceptance corrections with RAPGAP

Encouraging result !

F_L^D extracted to 3 – 4 σ in 3 bins

…
What about two bins of t with VFPS?



Possible scenarii for a direct measurement of F_L

Combine 30 pb^{-1} at Ep = 920 GeV with data taken in the last couple of months of HERA running at low proton beam energy(s):

I) 15 pb^{-1} at E_p= 460 GeV :
Estimated time (F.Willeke)):
3 weeks to tune the machine plus 10 weeks of data taking.
$\rightarrow$ 10 pb^{-1} of good data.
More precision at x ~ 10^{-3}. Good safety factor.
Would provide a first measurement of F_L^D .

II) 7pb^{-1}($\rightarrow$ 5pb^{-1}) at Ep = 460 GeV
plus 5 pb-1 ($\rightarrow$ 3.5 pb^{-1}) at E_p= 575 GeV
Estimated time :
(3 + 3) weeks to tune HERA plus (5 + 2.5) weeks of data taking.
An excellent check of the systematics and extension of the x range.

Conclusion

Based on the excellent performance of the HERA detectors and on the cumulated expertise on systematic effects since 1992, a direct measurement of F_L at x from 10^{-4} to 10^{-3} at the 5 sigmas level of precision can be reached by running HERA for a few weeks at low proton beam energy(s).

It could also provide the first measurement of F_L^D at the 3-4 sigmas level.

An attractive added value to the legacy of HERA at small x!

Be open minded and prepared for a final decision by end 2006.