# Cross Sections and Structure Functions

**Plan for Section QCD.1**

Definitions
**NC**
$F_2$ and $F_L$
Electroweak
valence quarks low (and high) x
**CC**
valence quarks – high x
single top
**HQ**
s,c,b

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LHeC Workshop Chavannes-de-Bogis, 12.11.10

# DIS Cross Section - NC

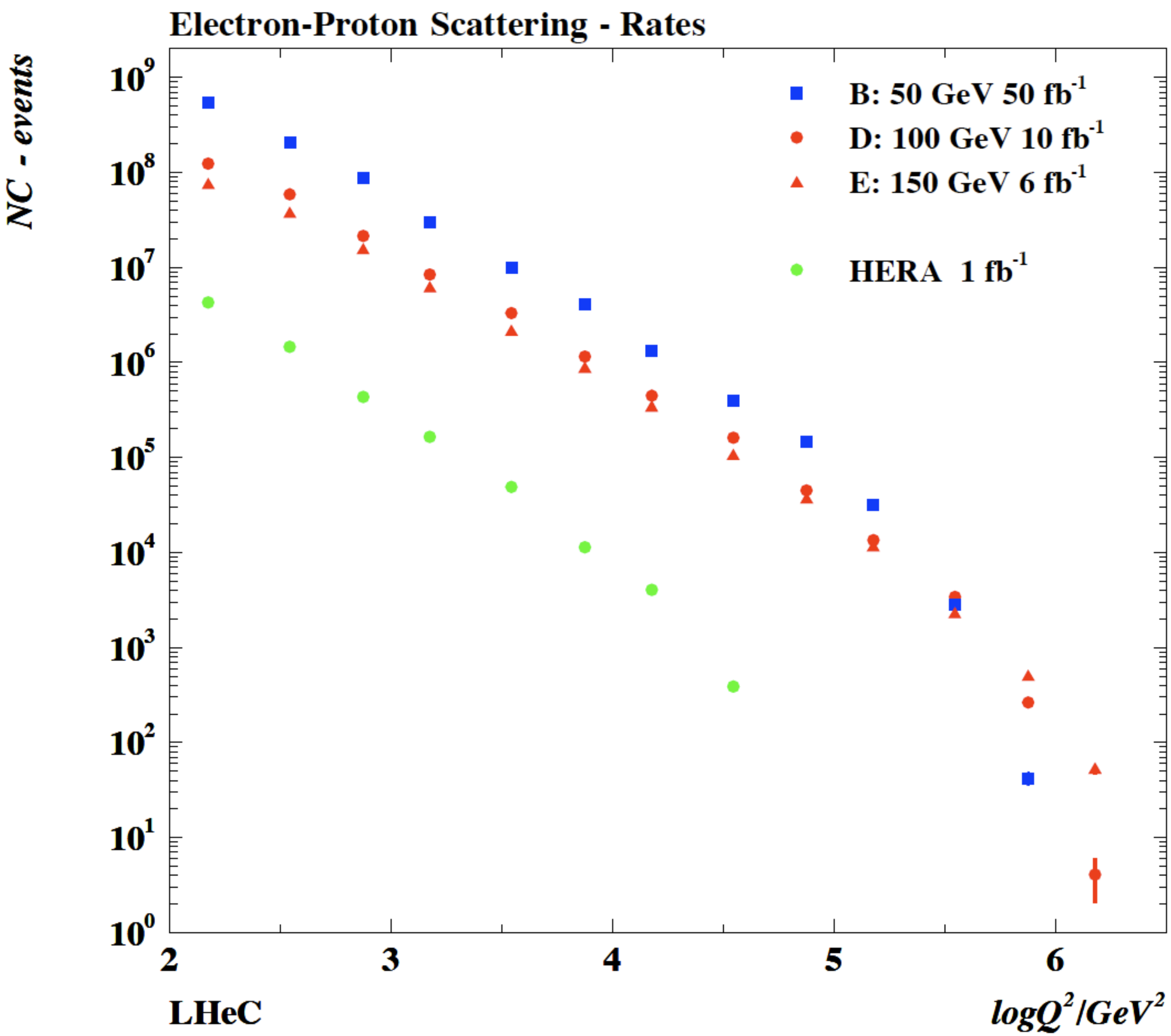
$$\sigma_{r,NC} = \frac{d^2\sigma_{NC}}{dxdQ^2} \cdot \frac{Q^4 x}{2\pi\alpha^2 Y_+} = \mathbf{F_2} + \frac{Y_-}{Y_+}\mathbf{xF_3} - \frac{y^2}{Y_-}\mathbf{F_L}$$

$$\begin{aligned}
\mathbf{F_2^\pm} &= F_2 + \kappa_Z(-v_e \mp P a_e) \cdot F_2^{\gamma Z} + \kappa_Z^2(v_e^2 + a_e^2 \pm 2P v_e a_e) \cdot F_2^Z \\
\mathbf{xF_3^\pm} &= \kappa_Z(\pm a_e + P v_e) \cdot xF_3^{\gamma Z} + \kappa_Z^2(\mp 2 v_e a_e - P(v_e^2 + a_e^2)) \cdot xF_3^Z
\end{aligned}$$

$$\begin{aligned}
(F_2, F_2^{\gamma Z}, F_2^Z) &= x \sum (e_q^2, 2e_q v_q, v_q^2 + a_q^2)(q + \bar{q}) \\
(xF_3^{\gamma Z}, xF_3^Z) &= 2x \sum (e_q a_q, v_q a_q)(q - \bar{q}),
\end{aligned}$$

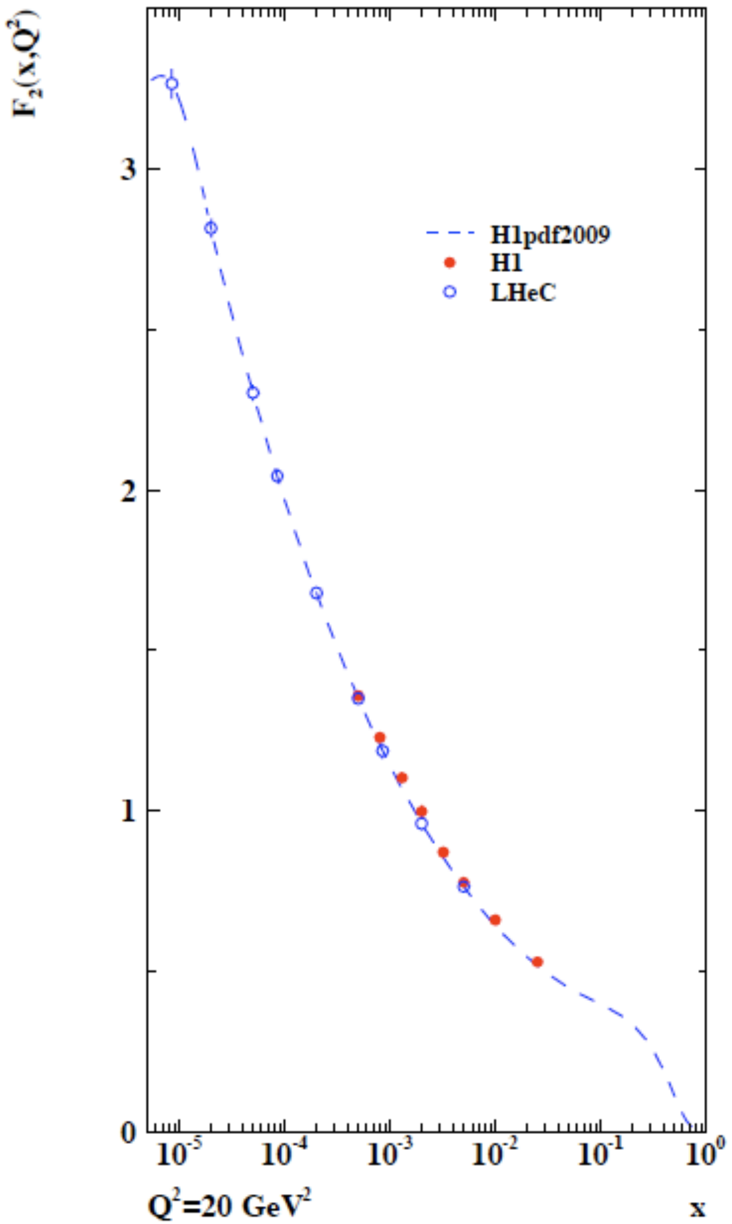
$$F_L(x) = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \cdot \left[\frac{16}{3} F_2(z) + 8 \sum e_q^2 \left(1 - \frac{x}{z}\right) zg(z),\right]$$

Vary charge and polarisation and beam energy to disentangle contributions



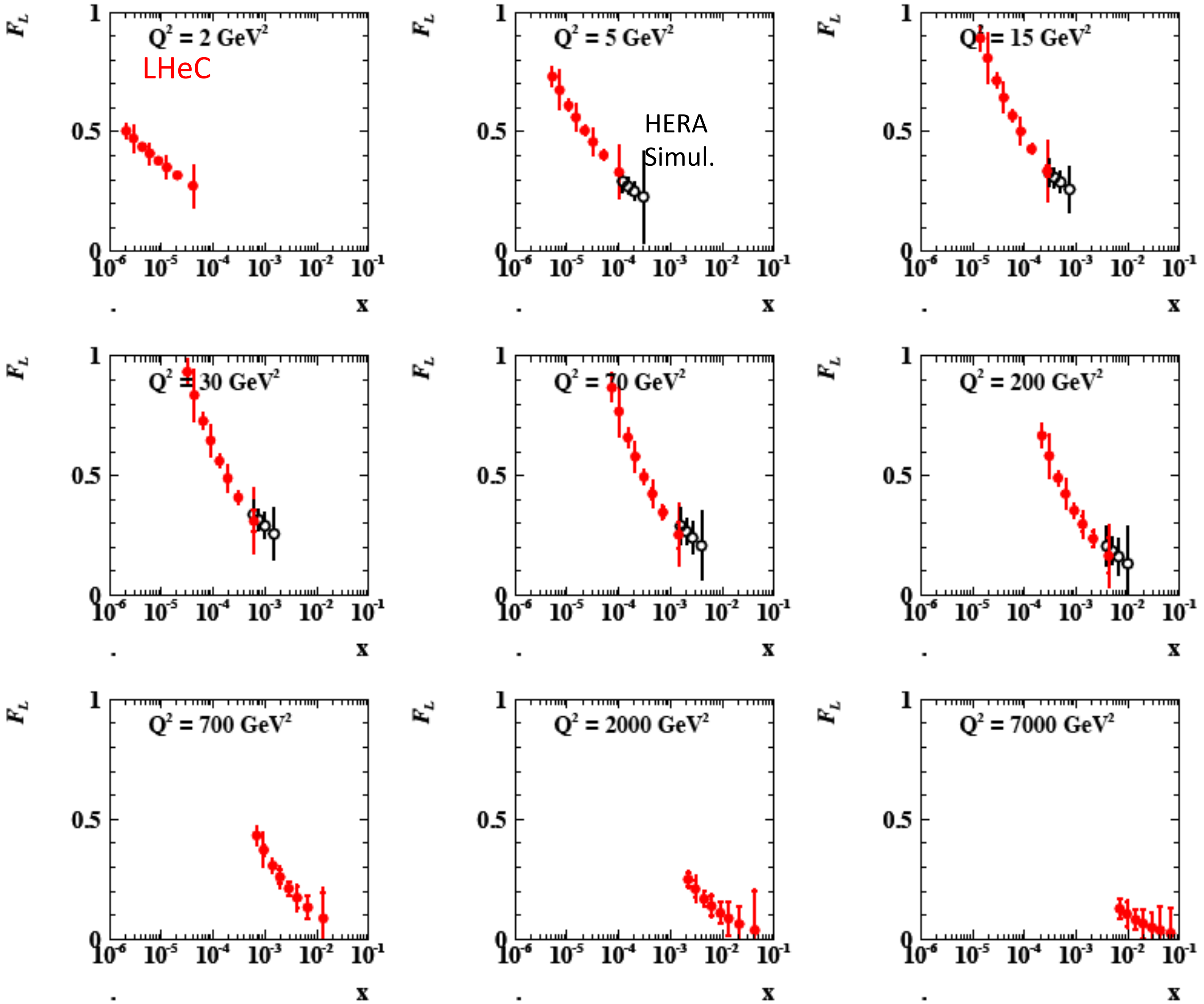

Largest energy is crucial for low x and high masses and high $Q^2$. The LHC may set the scale for everything, perhaps.

# $F_2$



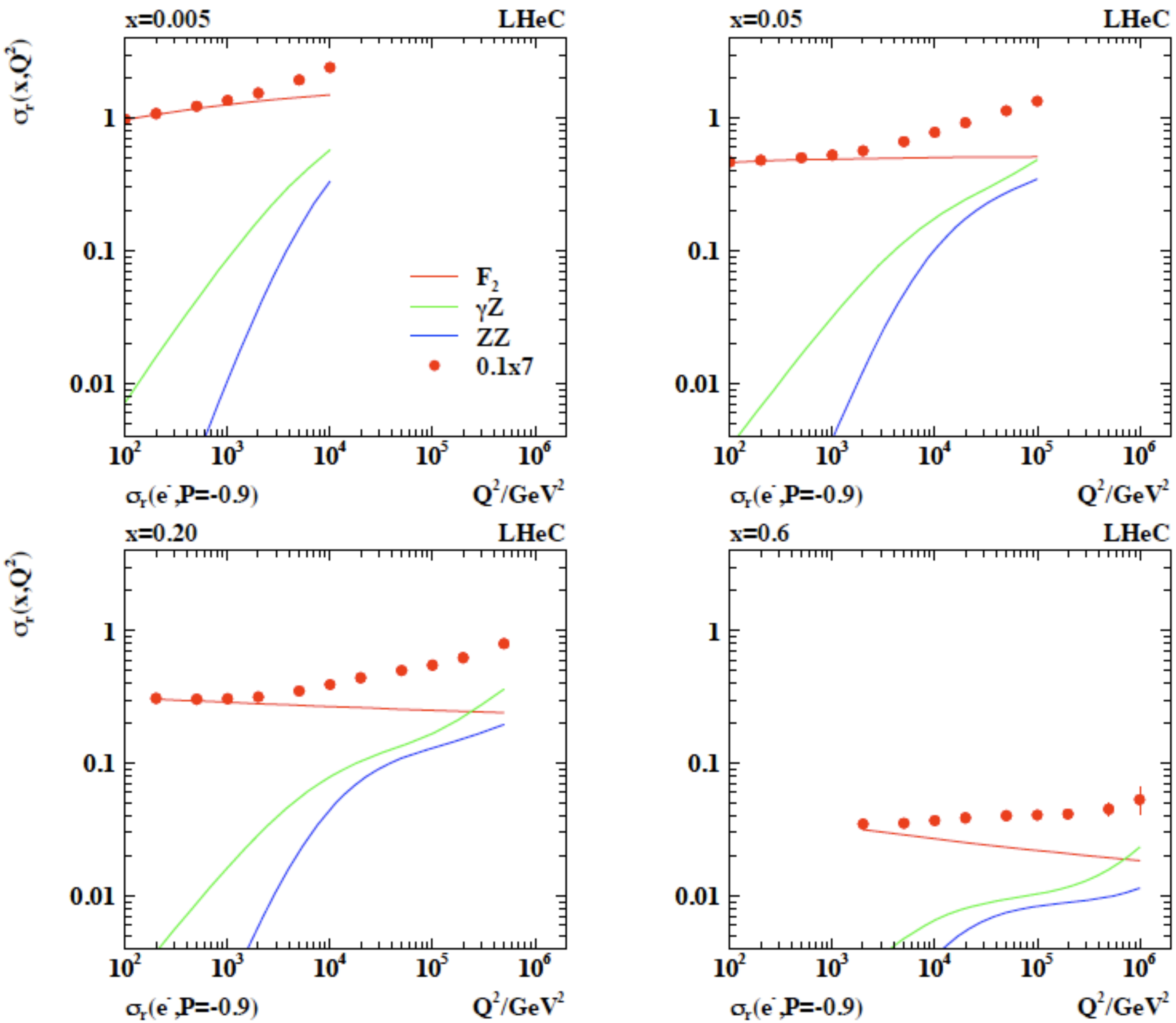

Plot to be made to show the range extension (into saturation) and precision

# $F_L$

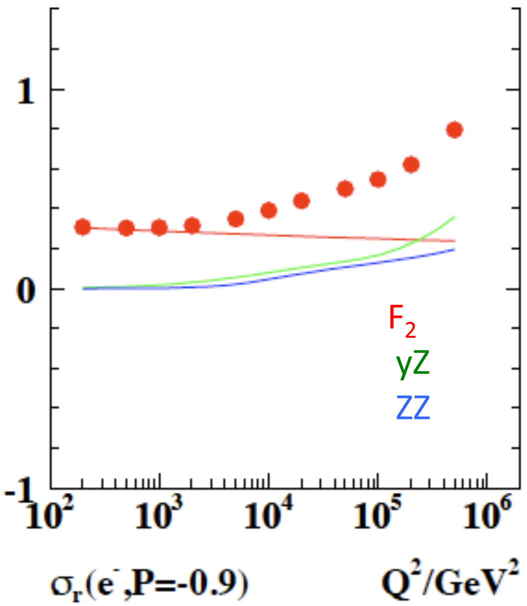



To be redone
with lowered $E_e$
and overlaid
with H1 data

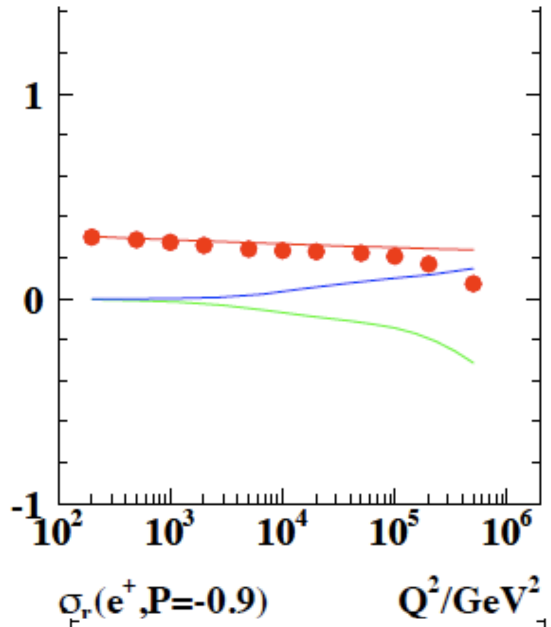
# Electroweak NC Cross Section Measurements



# Photon and Z Exchange are 1:1



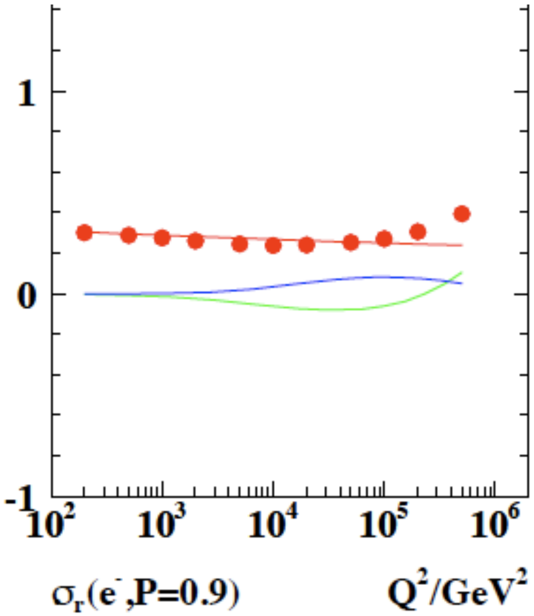

x=0.2
100 GeV
7000 GeV

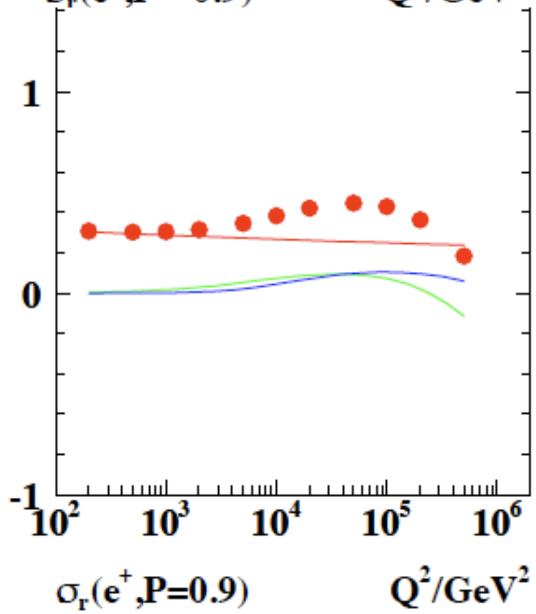



2 charges and
2 polarisations
very desirable

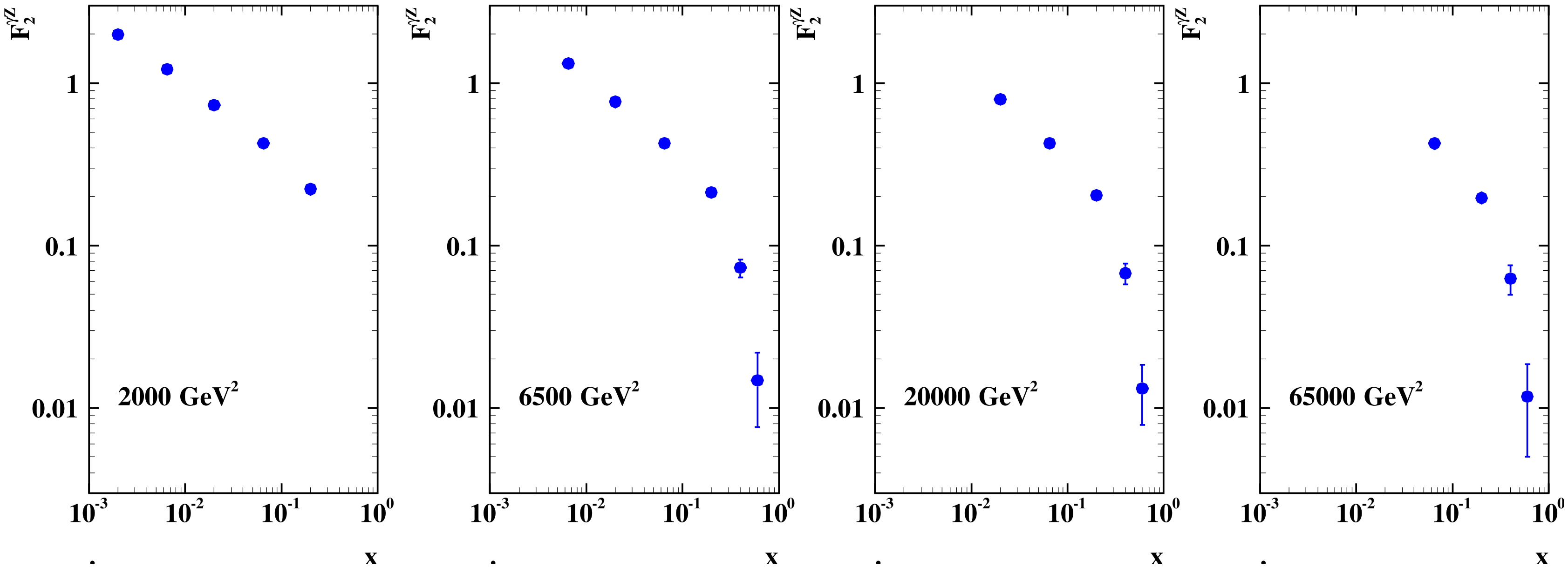
for electroweak
precision physics
and a
new spectroscopy
should that appear.

**Z effects depend on charge and polarisation.**



# Polarisation Asymmetry - $F_2^{\gamma Z}=2x\Sigma v_q e_q(q+qbar)$



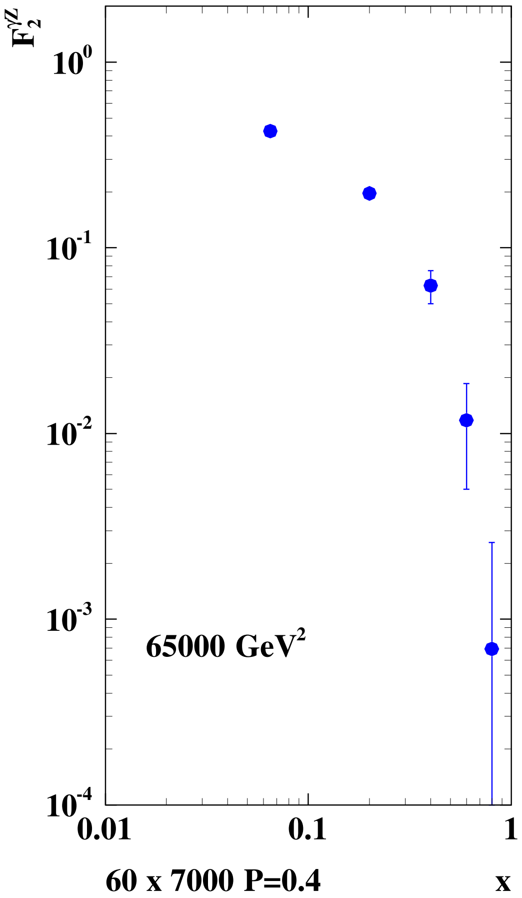

Huge PV effects in polarisation asymmetry

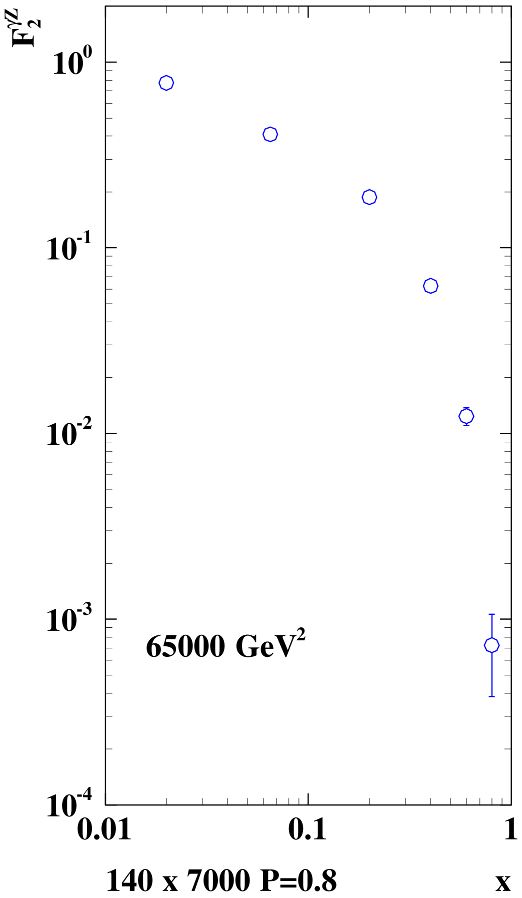
60*7000 GeV$^2$
$e^-$ (P=±0.4)
10fb$^{-1}$

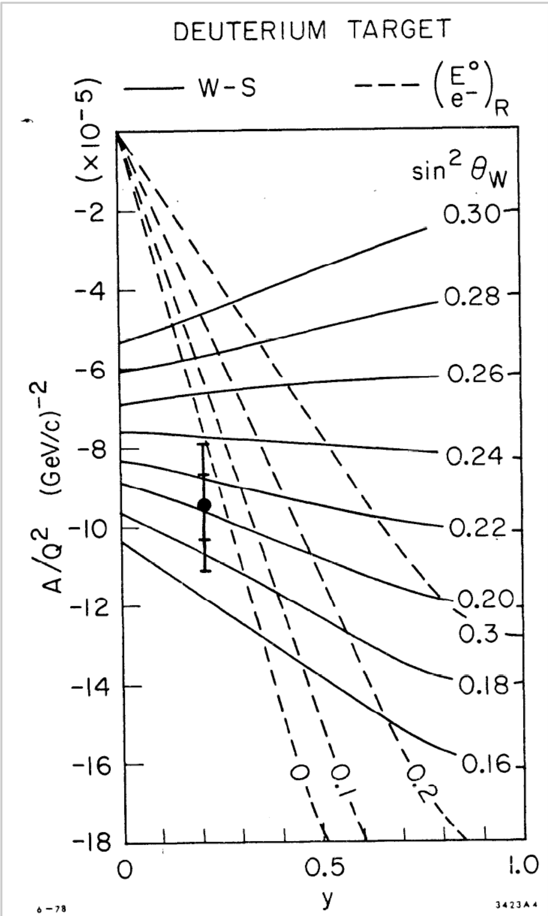
# Comparison of 60 and 140 GeV

$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)}$$

$$A^{\pm} \simeq \mp k a_e \frac{F_2^{\gamma Z}}{F_2}$$

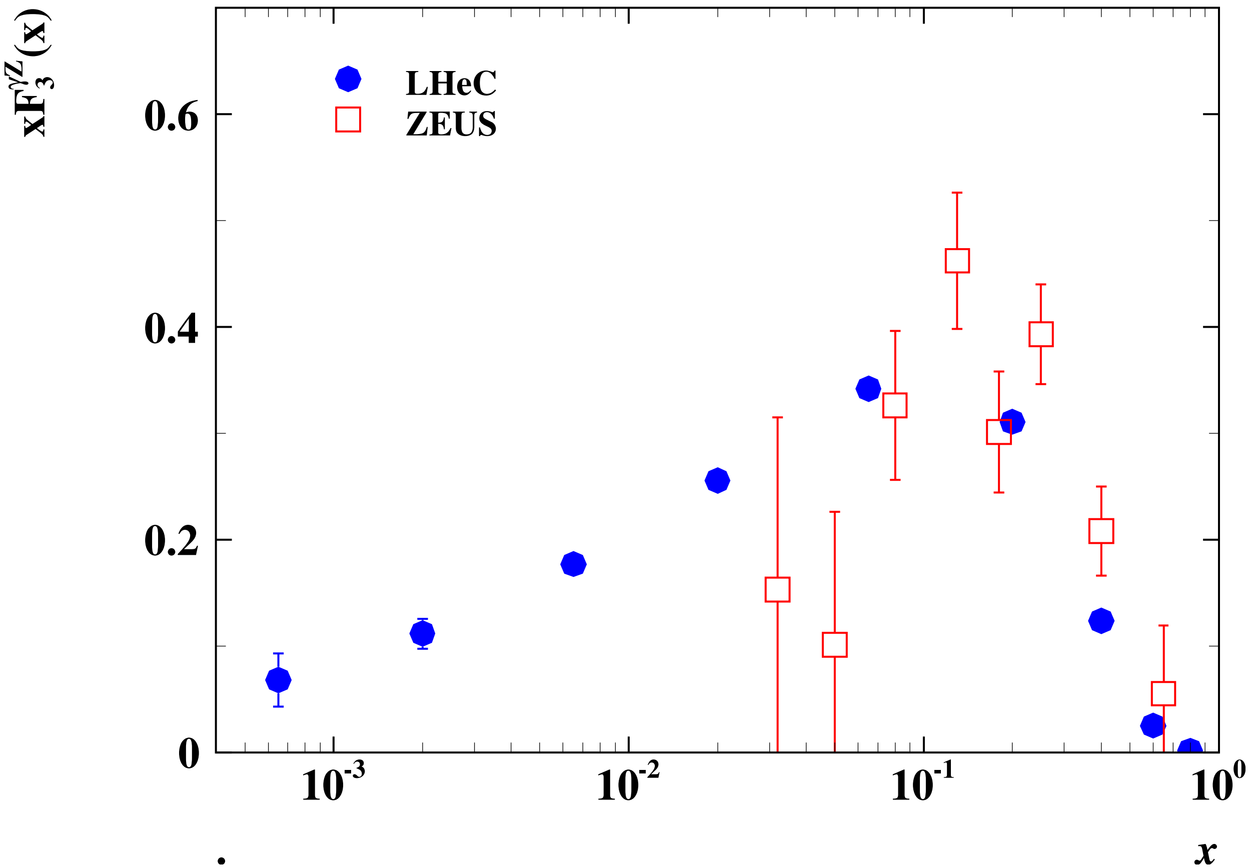



SLAC 1978

# Charge Asymmetry $xF_3^{\gamma Z}$



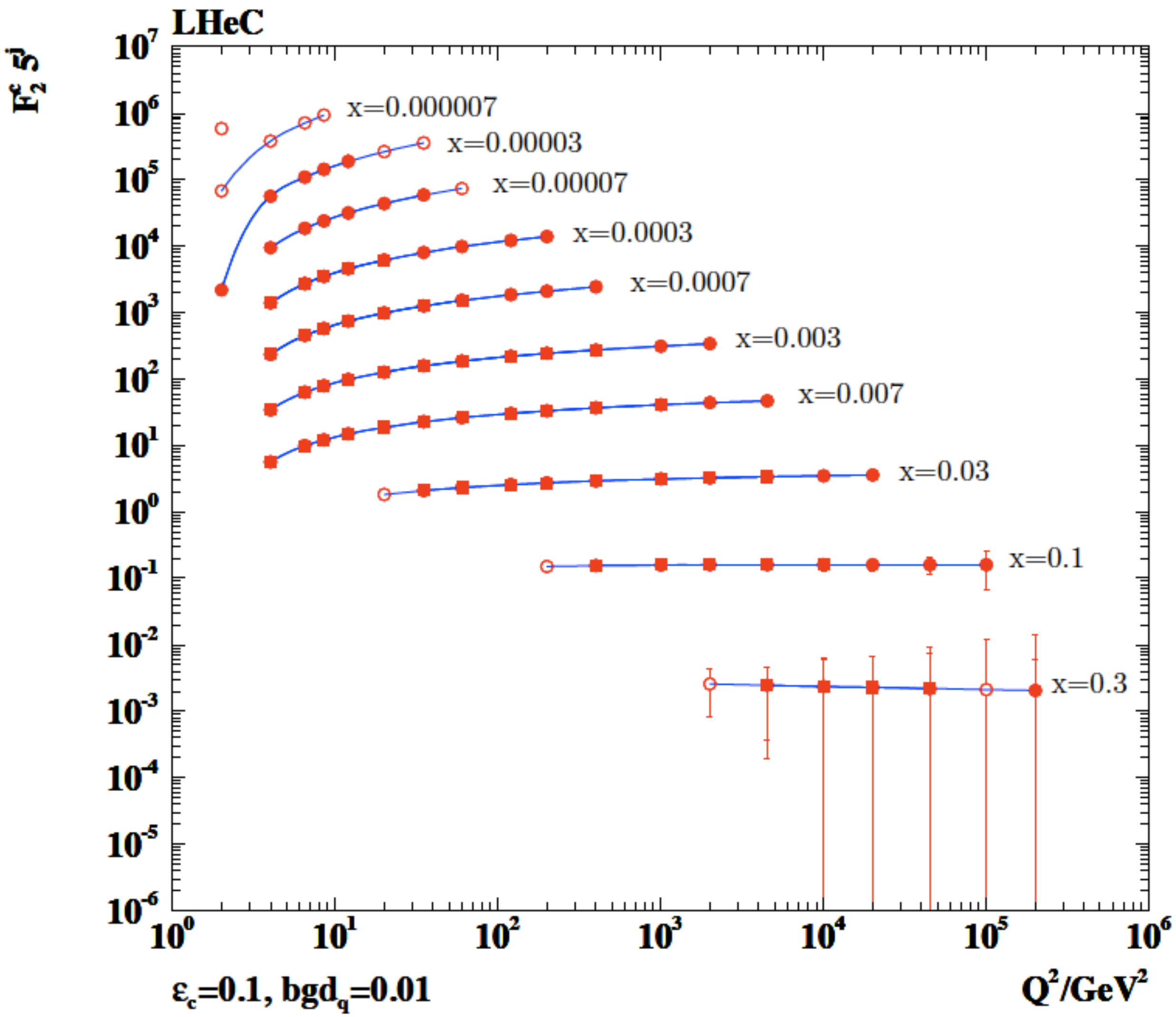

60x7000 GeV$^2$
P=0
10fb$^{-1}$

$$xF_3^{\gamma Z} = 2x[e_u a_u(u_v + \Delta_u) + e_d a_d(d_v + \Delta_d)]$$

$$\Delta_u = (u_{sea} - \overline{u} + c - \overline{c})$$

$$\Delta_d = (d_{sea} - \overline{d} + s - \overline{s})$$

# Charm




Systematic error dominates (so far 3%)

Precise measurement near threshold and up to $10^5$ GeV$^2$

$F_2^{cc}$ will become precision testing ground for QCD and proton structure

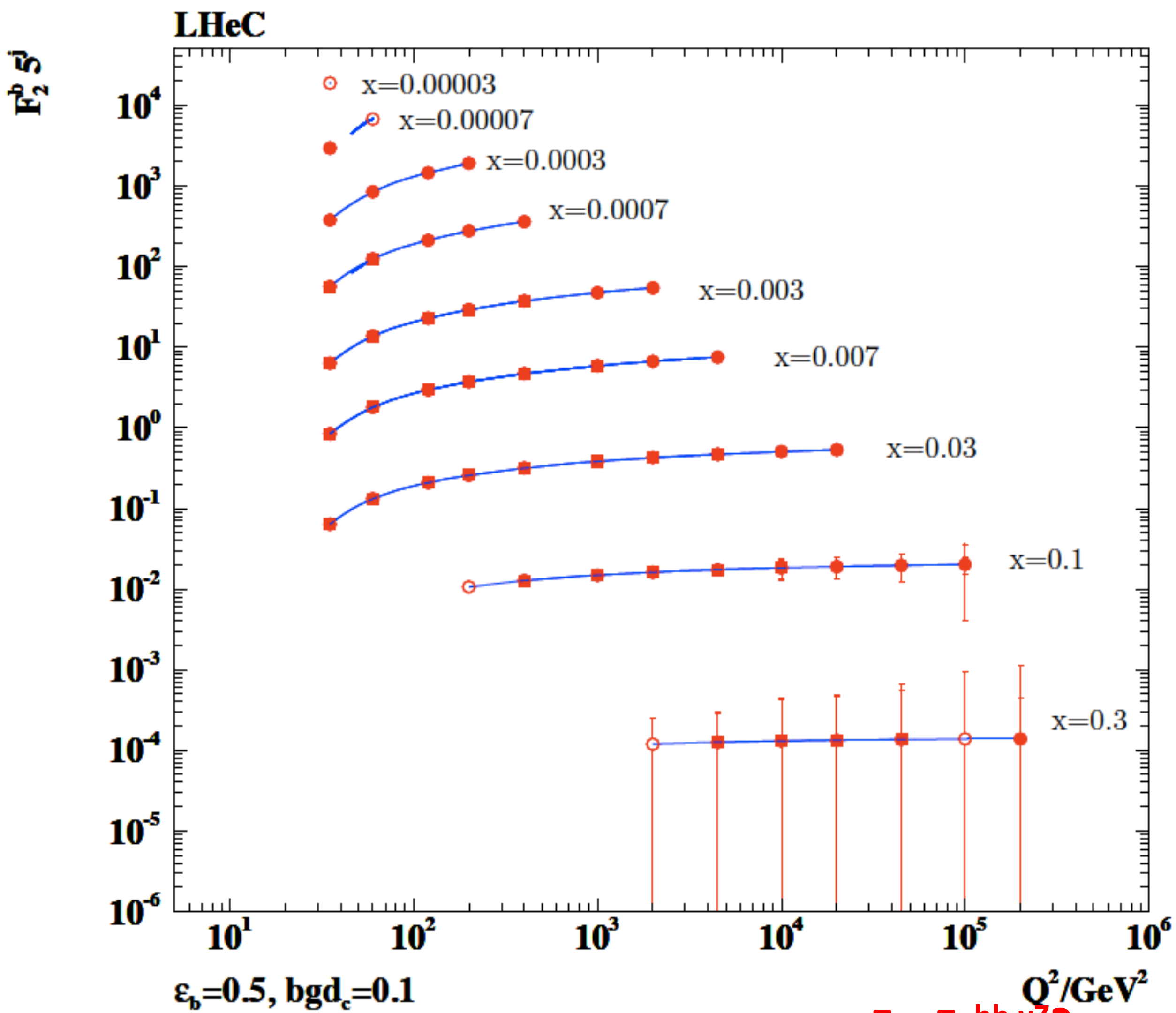
open: $1^O$

closed: $10^o$

box: 1 TeV

**$xF_3$, $F_2^{cc,\gamma Z}$?** → charm NC couplings

# Beauty




$xF_3$, $F_2^{bb,\gamma Z}$?

Systematic error dominates (so far 5%)

Precise measurement near threshold and up to $10^5$ GeV$^2$

Beauty may become crucial if MSSM Higgs is found

open: $1^o$

closed: $10^o$

box: 1 TeV

# Charged Currents

$$\sigma_{r,CC} = \frac{2\pi x}{Y_+ G_F^2}\left[\frac{M_W^2 + Q^2}{M_W^2}\right]^2 \frac{\mathrm{d}^2\sigma_{CC}}{\mathrm{d}x\mathrm{d}Q^2}$$

$$\sigma_{r,CC}^{\pm} = \frac{1 \pm P}{2}(W_2^{\pm} \mp \frac{Y_-}{Y_+} x W_3^{\pm} - \frac{y^2}{Y_+} W_L^{\pm})$$

$$W_2^+ = x(\overline{U} + D),\, xW_3^+ = x(D - \overline{U}),\, W_2^- = x(U + \overline{D}),\, xW_3^- = x(U - \overline{D})$$

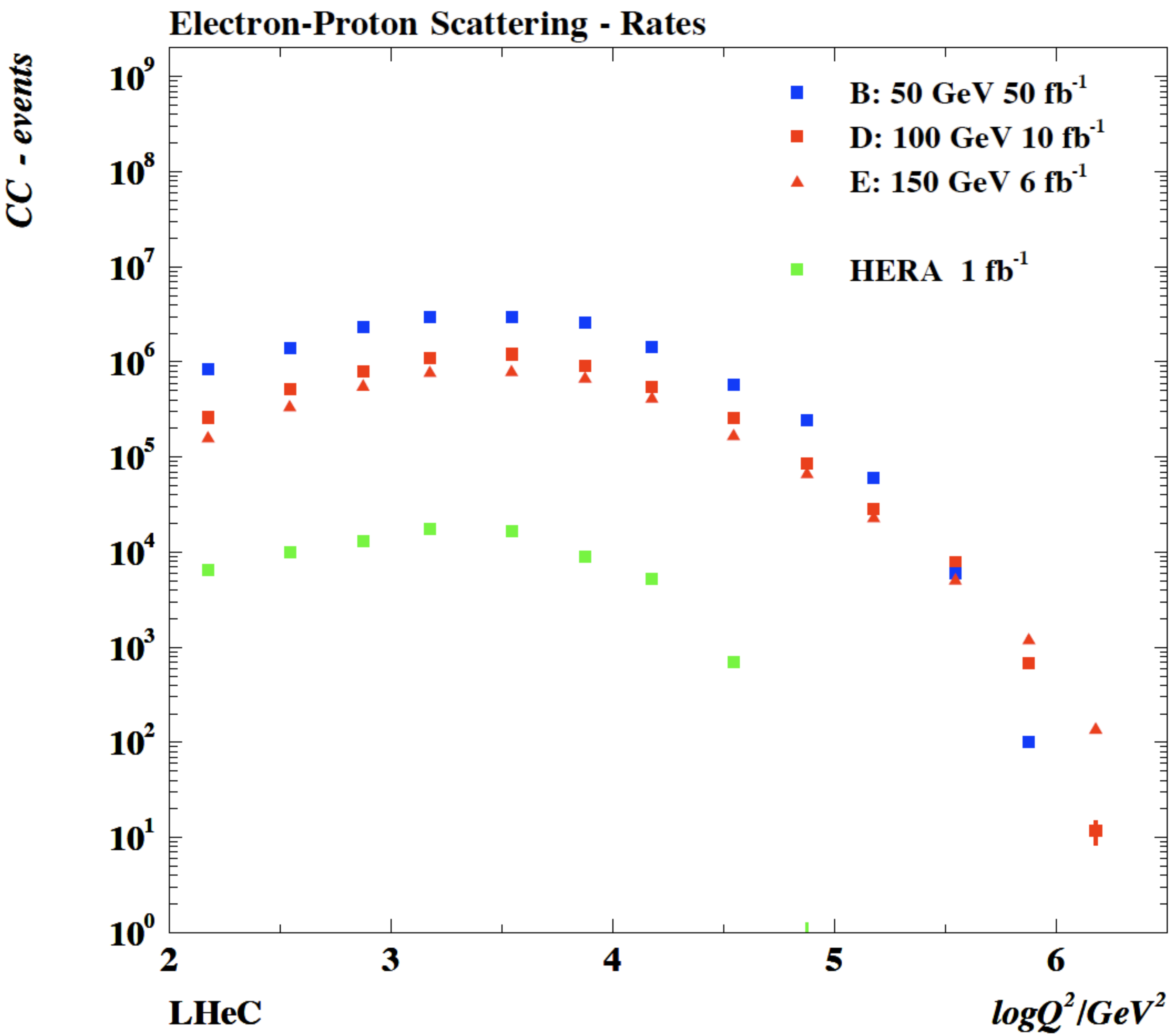
$$U = u + c \qquad \overline{U} = \overline{u} + \overline{c} \qquad D = d + s \qquad \overline{D} = \overline{d} + \overline{s}$$

$$\sigma_{r,CC}^{+} \sim x\overline{U} + (1-y)^2 xD,$$
$$\sigma_{r,CC}^{-} \sim xU + (1-y)^2 x\overline{D}$$

$$\sigma_{r,NC}^{\pm} \simeq [c_u(U + \overline{U}) + c_d(D + \overline{D})] + \kappa_Z[d_u(U - \overline{U}) + d_d(D - \overline{D})]$$

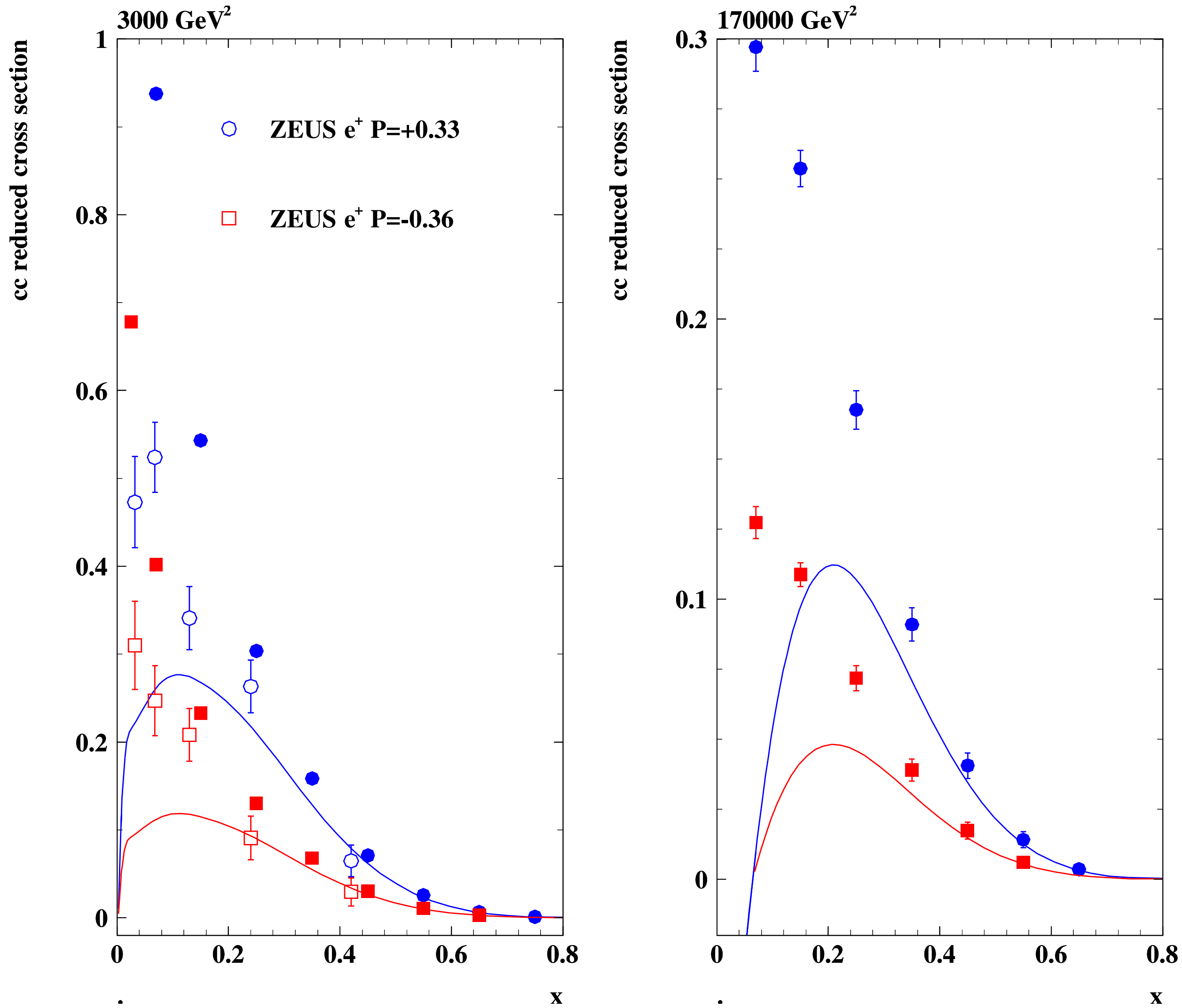
with $c_{u,d} = e_{u,d}^2 + \kappa_Z(-v_e \mp P a_e) e_{u,d} v_{u,d}$ and $d_{u,d} = \pm a_e a_{u,d} e_{u,d}$,

**Complete unfolding of all parton distributions to unprecedented accuracy**

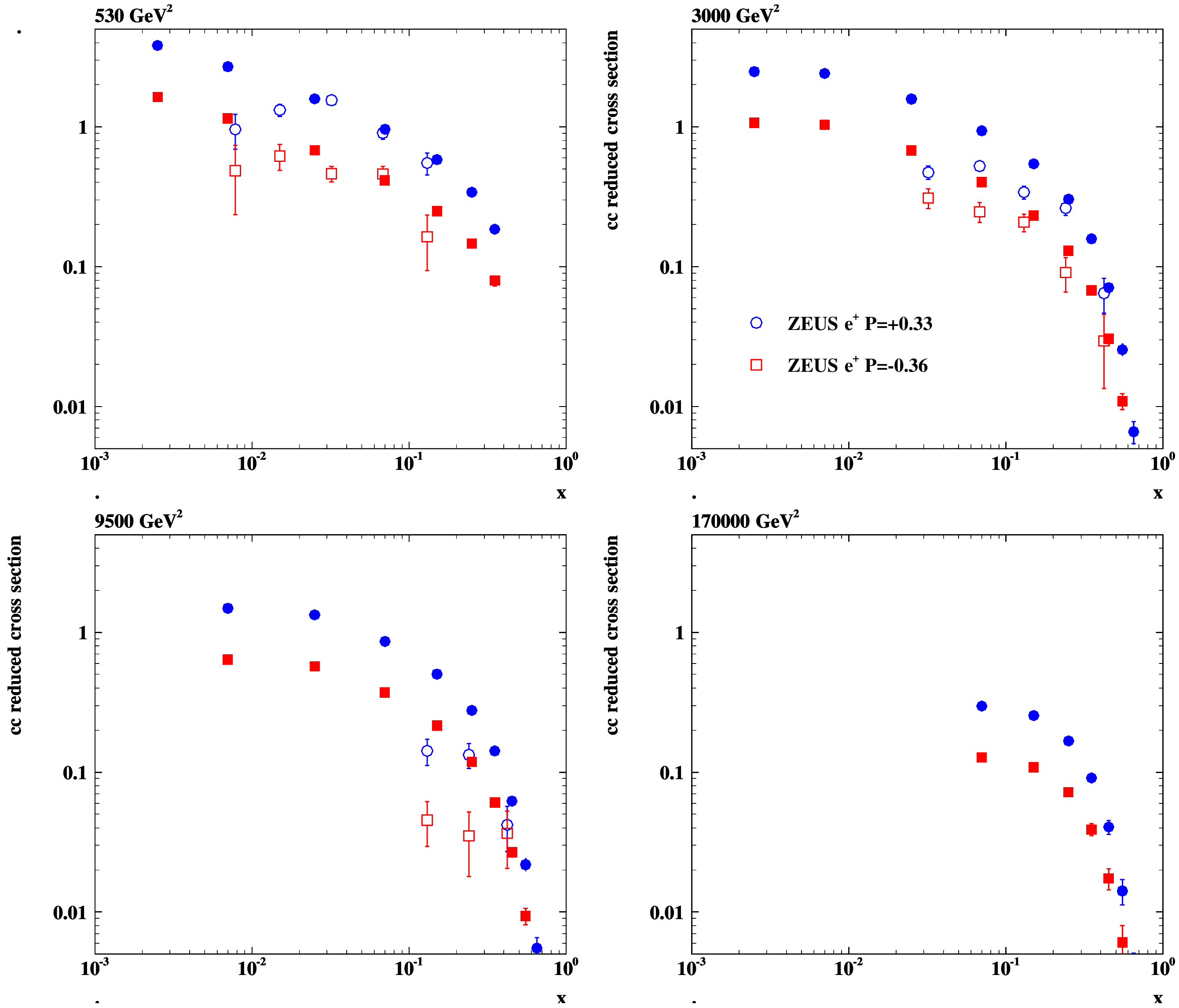



The HERA CC data are restricted to x < 0.5. There follow substantial pdf uncertainties in the (new) HERA pdf QCD fits. High integrated luminosity is thus necessary to unfold partons and study dynamics at large x and high masses. LHeC also provides larger s: win-win for CC

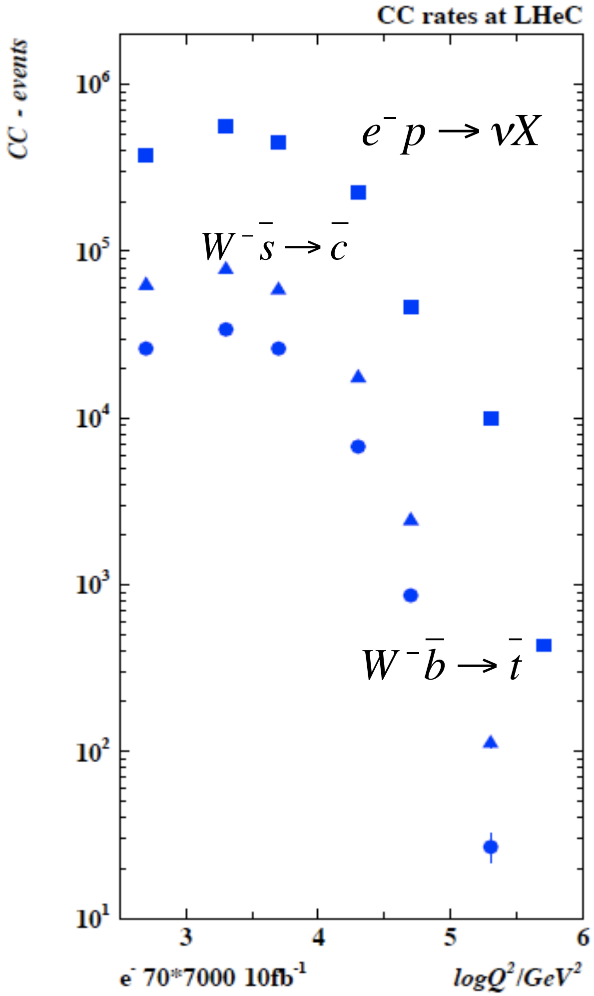
# Charged Currents

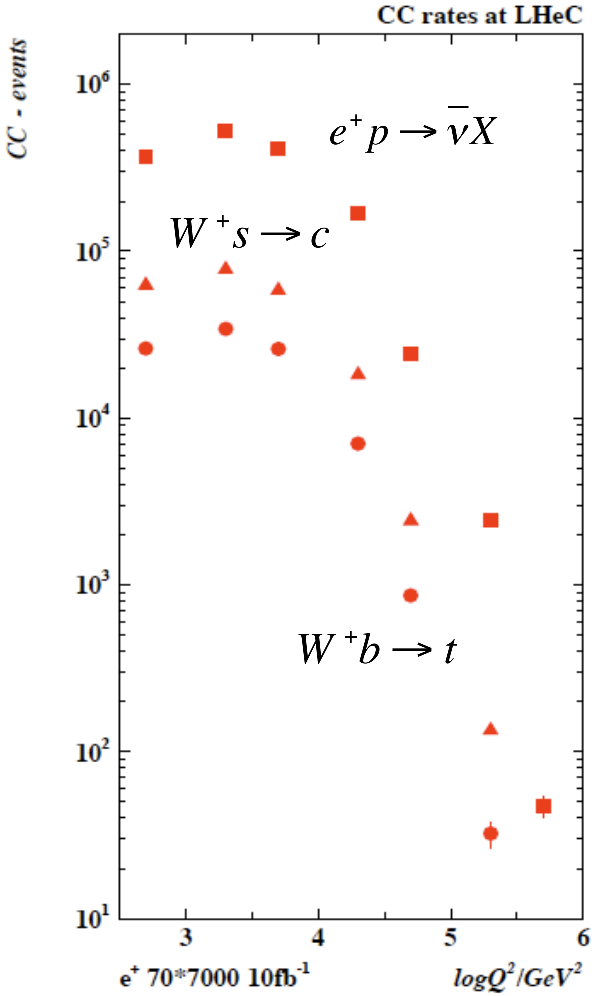


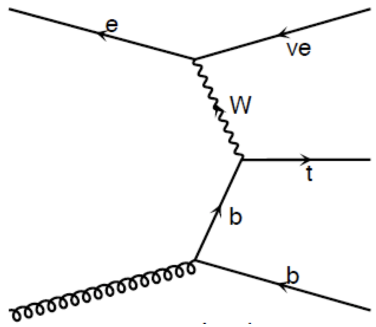
# Charged Currents



# $\overline{\text{Top}}$ and Top Production at the LHeC (CC)



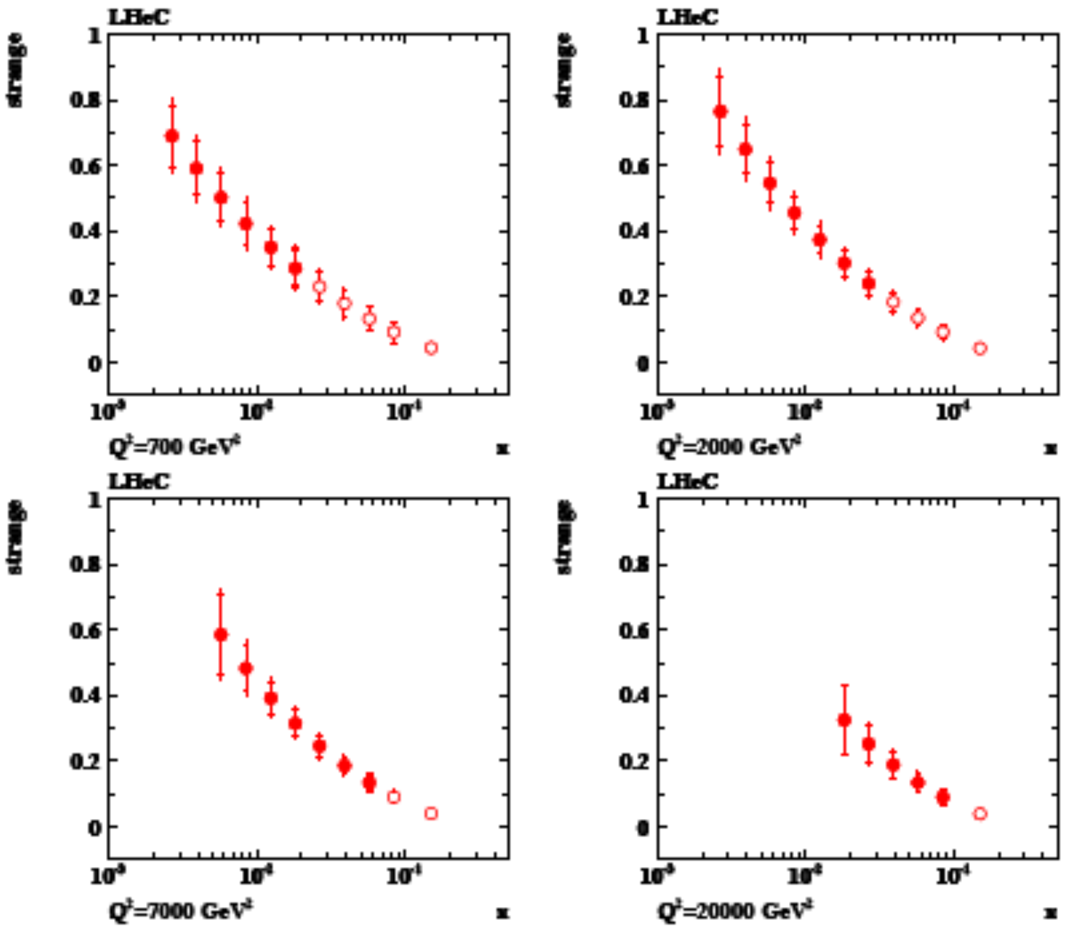




**LHeC is a single top and anti-top quark factory**

with a CC cross section of O(10)pb

Top at HERA essentially impossible to study. Single top at Tevatron barely seen and at LHC very challenging

# Strange Quark




$W^+ s \rightarrow c$

$1\,fb^{-1}$

$\varepsilon_c = 0.1$

$\varepsilon_q = 0.01$

$\delta_{syst} = 0.1$

$\circ - \vartheta_h \geq 1^o$

$\bullet - \vartheta_h \geq 10^o$

# pdf's at LHC

**Constrain up and down sea quarks from W,Z ratios:**

Change of đ [≠ ū] by 50% gives 10% in $W^+/W^-$

**Largely dissident behaviour may be constrained already with Z (y,M)**

in HERAdis the disappearance of d leads to 10% reduced Z cross section due to NC Z weights

**Strange quark distribution**

50% change of s yields 10% difference in W cross sections

**Learn about valence quarks from charge asymmetry**

if $d_v$ at x=0.01 is down by factor 2, W- is down by 6%

→Can constrain some pdf features with WZ but not do precision pdf measurements

# Conclusion

The LHeC is the first DIS machine with the potential to completely unfold the partonic structure of the proton. This should remove all assumptions inherent to QCD fits on the behaviour of the sea quarks (strange, anti-strange, up, down) and provide precision information on the charm and beauty quarks around and much beyond threshold. The valence quarks follow from NC and CC measurements and may be accessed most accurately for x between $10^{-3}$ up to nearly 1.

The detector must cover a maximum range of polar angles, which is much helped by lower energy runs, electron for large $\theta_e$ and protons for small $\theta_h$. For such runs (as for the $F_L$ run at HERA) the luminosity of the machine must be high.

For the CDR a coherent set of plots is being made on the structure function measurements (HERA + LHeC) and the parton distributions (cf Voica R.)

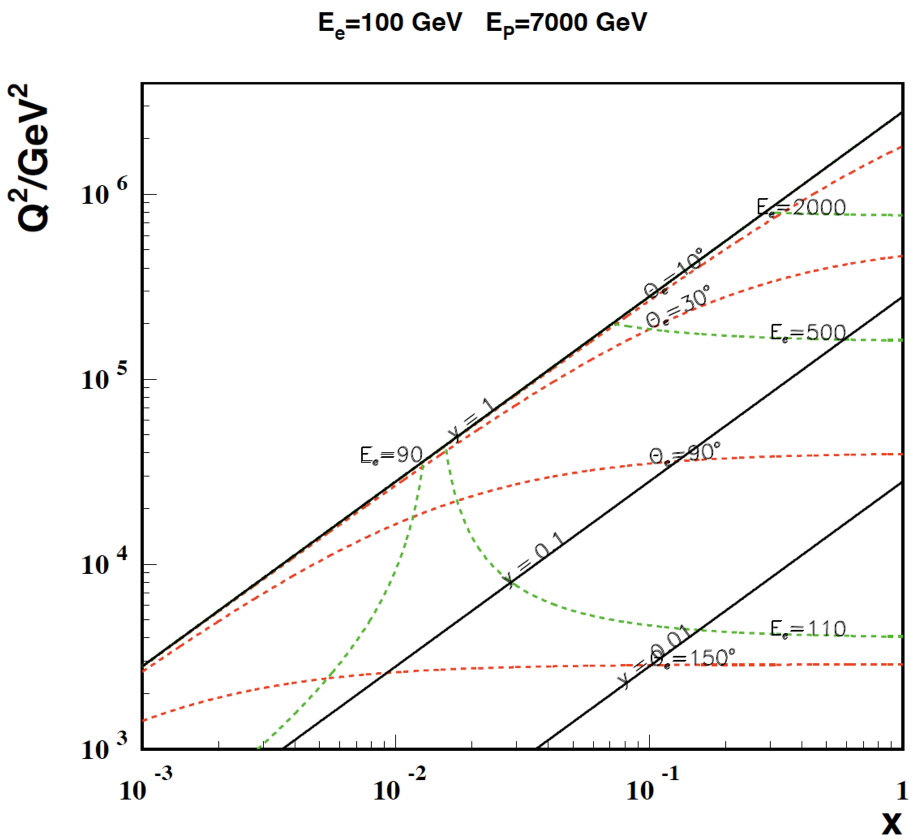
**title**

# **Simulated Default Scenarios**, April 2009

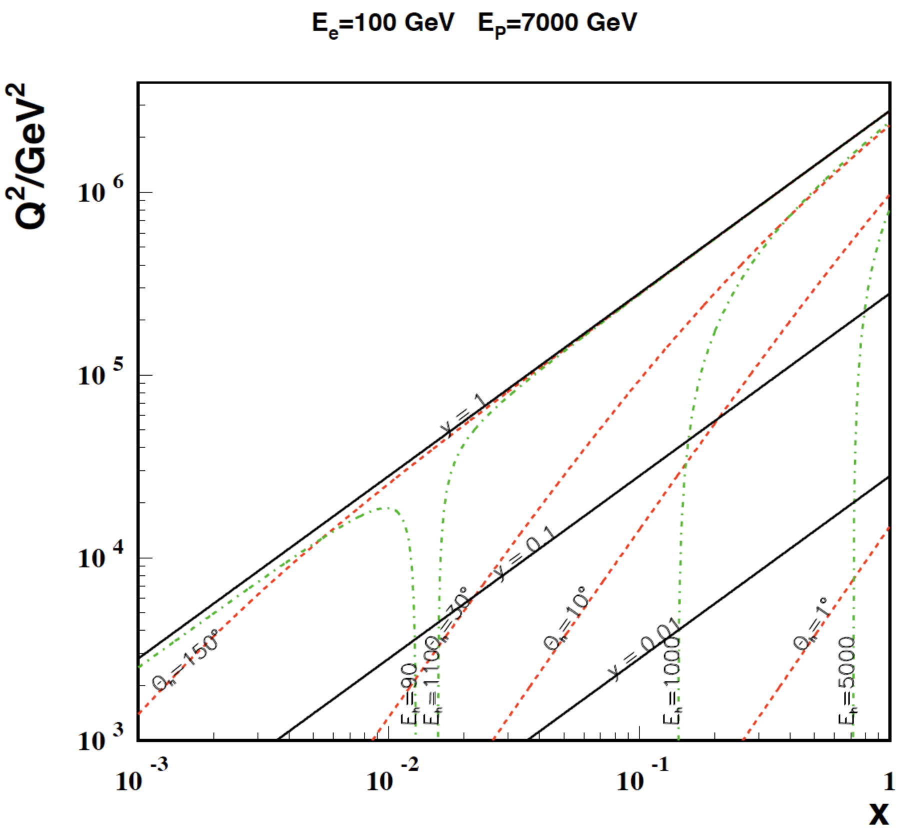
http://hep.ph.liv.ac.uk/~mklein/simdis09/lhecsim.Dmp.CC, readfirst

| config. | E(e) | E(N) | N | ∫L(e$^+$) | ∫L(e$^-$) | \|Pol\| | L/$10^{32}$ | P/MW | years | type |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 20 | 7 | p | 1 | 1 | - | 1 | 10 | 1 | SPL |
| B | 50 | 7 | p | 50 | 50 | 0.4 | 25 | 30 | 2 | RR hiQ$^2$ |
| C | 50 | 7 | p | 1 | 1 | 0.4 | 1 | 30 | 1 | RR lo x |
| D | 100 | 7 | p | 5 | 10 | 0.9 | 2.5 | 40 | 2 | LR |
| E | 150 | 7 | p | 3 | 6 | 0.9 | 1.8 | 40 | 2 | LR |
| F | 50 | 3.5 | D | 1 | 1 | -- | 0.5 | 30 | 1 | eD |
| G | 50 | 2.7 | Pb | 0.1 | 0.1 | 0.4 | 0.1 | 30 | 1 | ePb |
| H | 50 | 1 | p | -- | 1 | -- | 25 | 30 | 1 | lowEp |

# Kinematics – high $Q^2$




The electron kinematics at high $Q^2$
Is no big problem, apart from extreme backscattering at very high $Q^2$ of electrons of a few TeV energy.
→**Need forward elm. calorimeter of few TeV energy range down to 10º and below with reasonable calibration accuracy.**

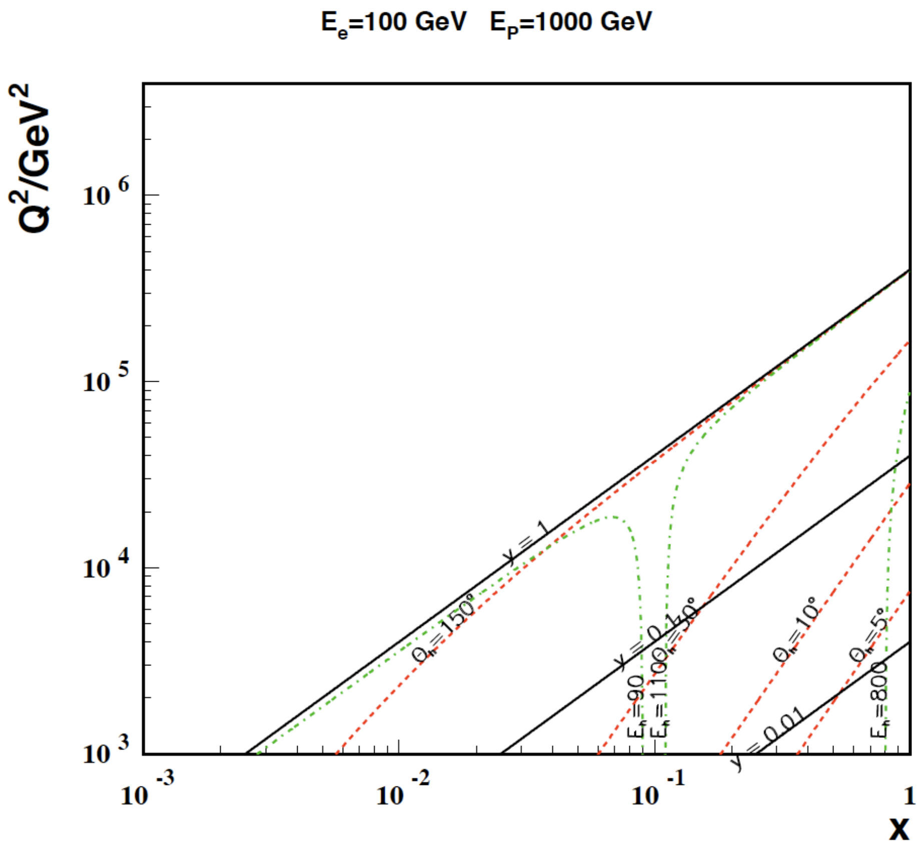


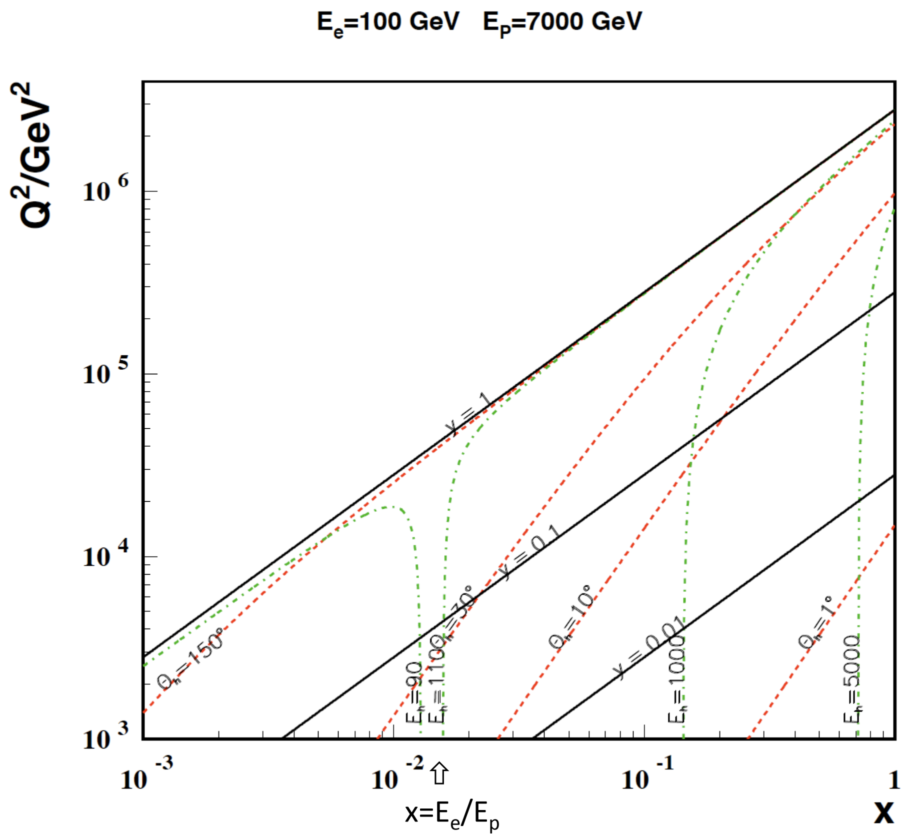

High x and high $Q^2$: few TeV HFS scattered forward:
→**Need forward had. calorimeter of few TeV energy range down to 10º and below. Mandatory for charged currents. Strong variations of cross section at high x demand hadronic energy calibration as good as 1%**

# Kinematics – large x

Low proton beam energy: access large x.
Needs high luminosity: $L \sim 1/E_p^2$

Nominal proton beam energy: need very fwd. angle acceptance for accessing large x



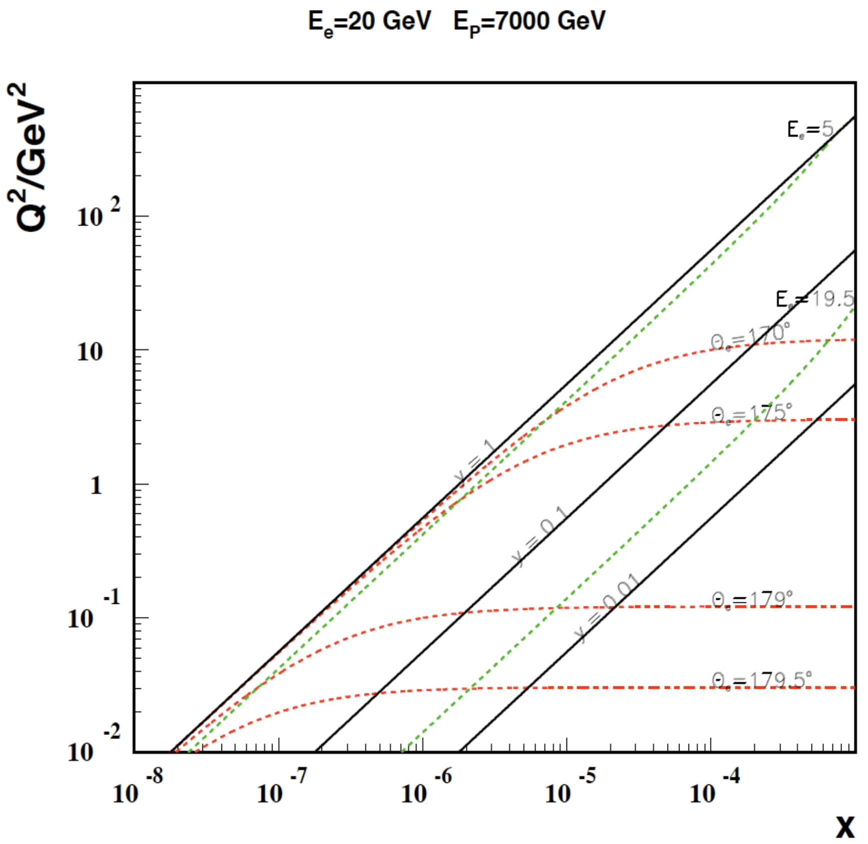



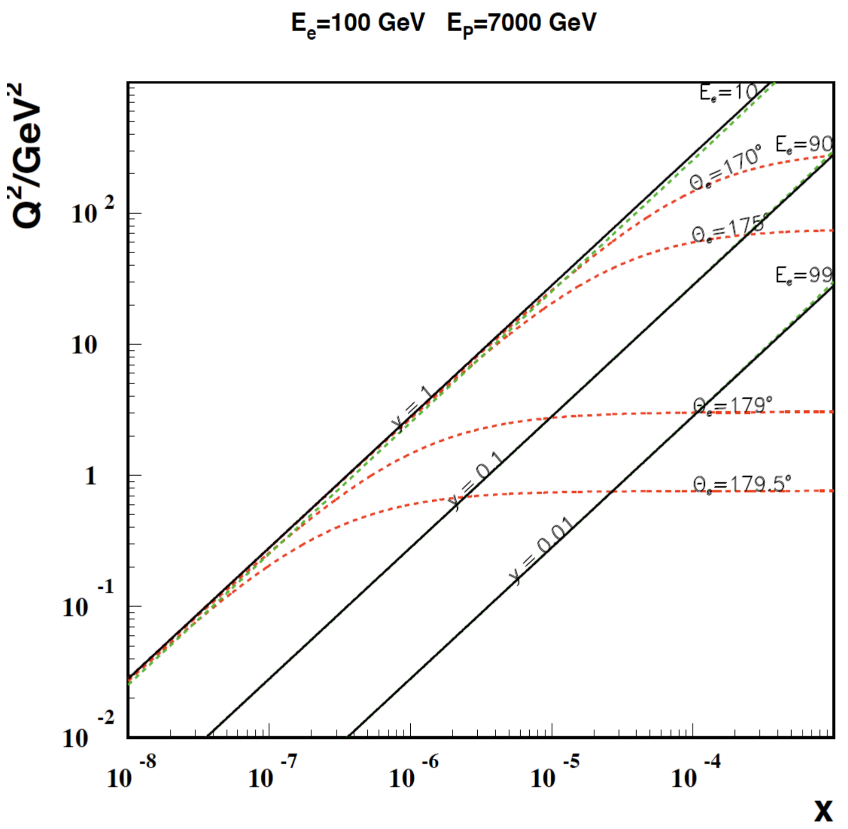

$$Q^2\ (x, \theta_h) = sx/[1 + E_e cot^2(\theta_h/2)/xE_p] \simeq (2xE_p cot(\theta_h/2))^2$$

# Kinematics – low $Q^2$,x

Low electron beam energy: access low x. Needs only small luminosity. SPL for low $Q^2$ physics, however, lowest x require max s.

Nominal proton beam energy: need very bwd angle acceptance for accessing low x and $Q^2$




$$Q^2(x,\theta_e) = sx/[1 + xE_p cot^2(\theta_e/2)/E_e] \simeq (2E_e cot(\theta_e/2))^2$$