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

Max Klein

UNIVERSITY OF LIVERPOOL

LHeC Workshop Chavannes-de-Bogis, 12.11.10

DIS Cross Section - NC

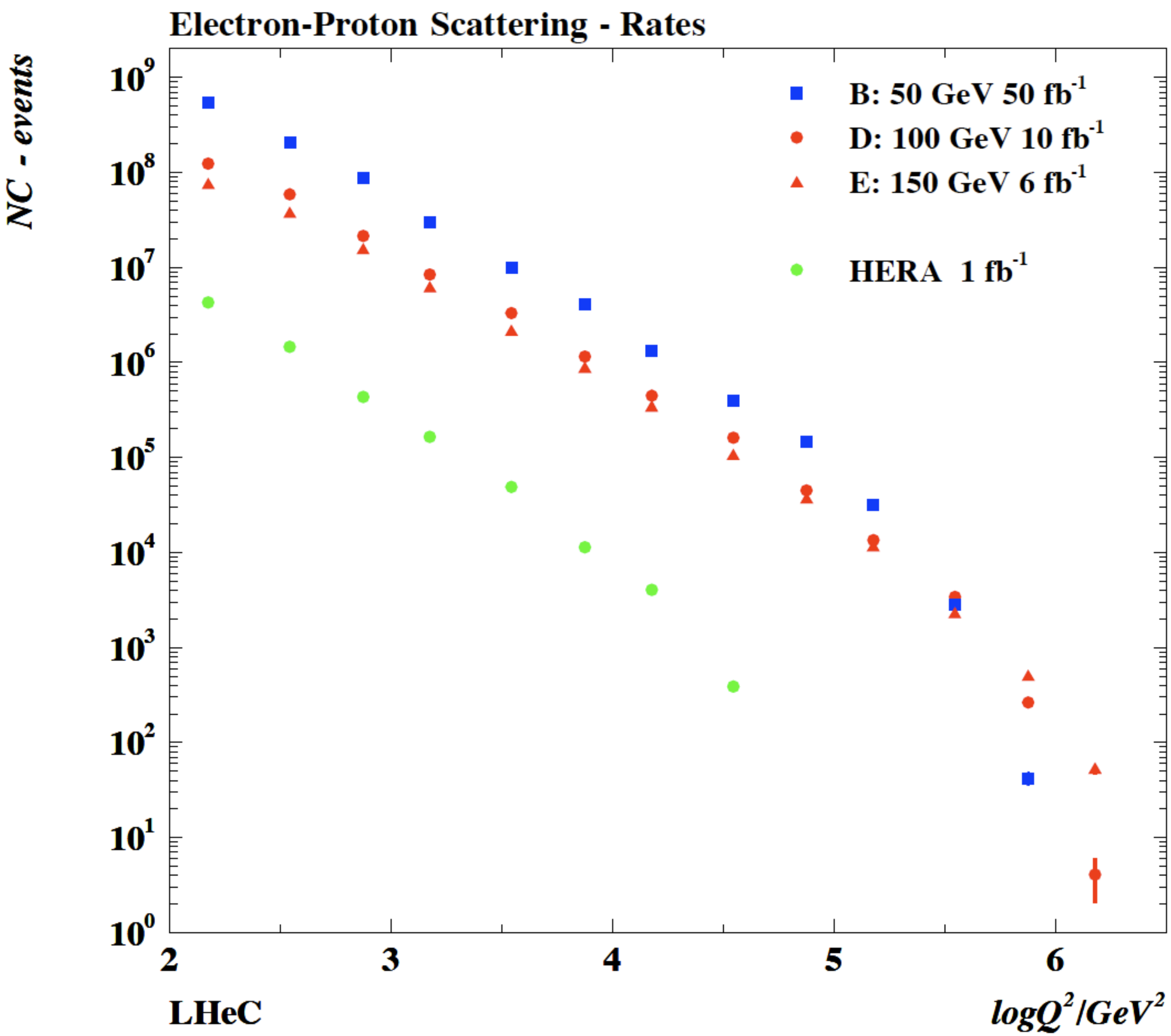
$$\sigma_{r,NC} = \frac{d^2\sigma_{NC}}{dxdQ^2} \cdot \frac{Q^4 x}{2\pi\alpha^2 Y_+} = \mathbf{F_2} + \frac{Y_-}{Y_+}\mathbf{xF_3} - \frac{y^2}{Y_-}\mathbf{F_L}$$

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

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

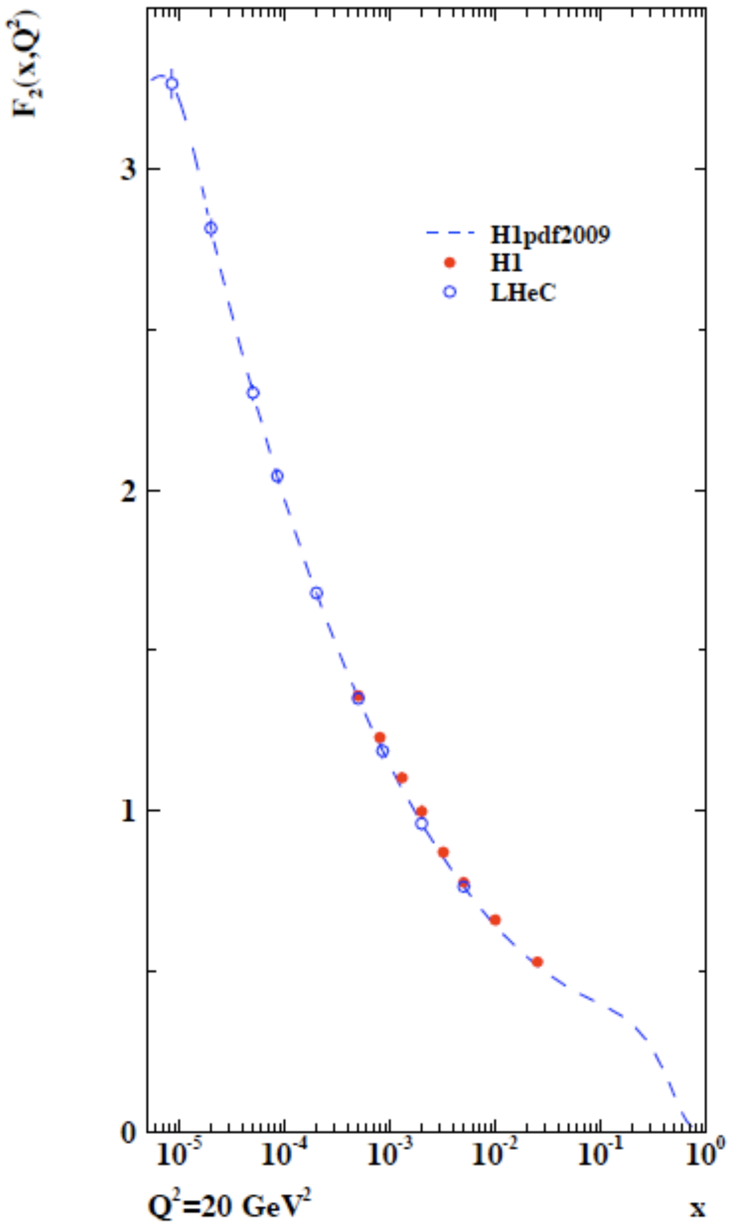
$$F_L(x) = \frac{\alpha_s}{4\pi} x^2 \int_x^1 \frac{dz}{z^3} \cdot \left[\frac{16}{3} F_2(z) + 8 \sum e_q^2 \left(1 - \frac{x}{z}\right) zg(z),\right]$$

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.

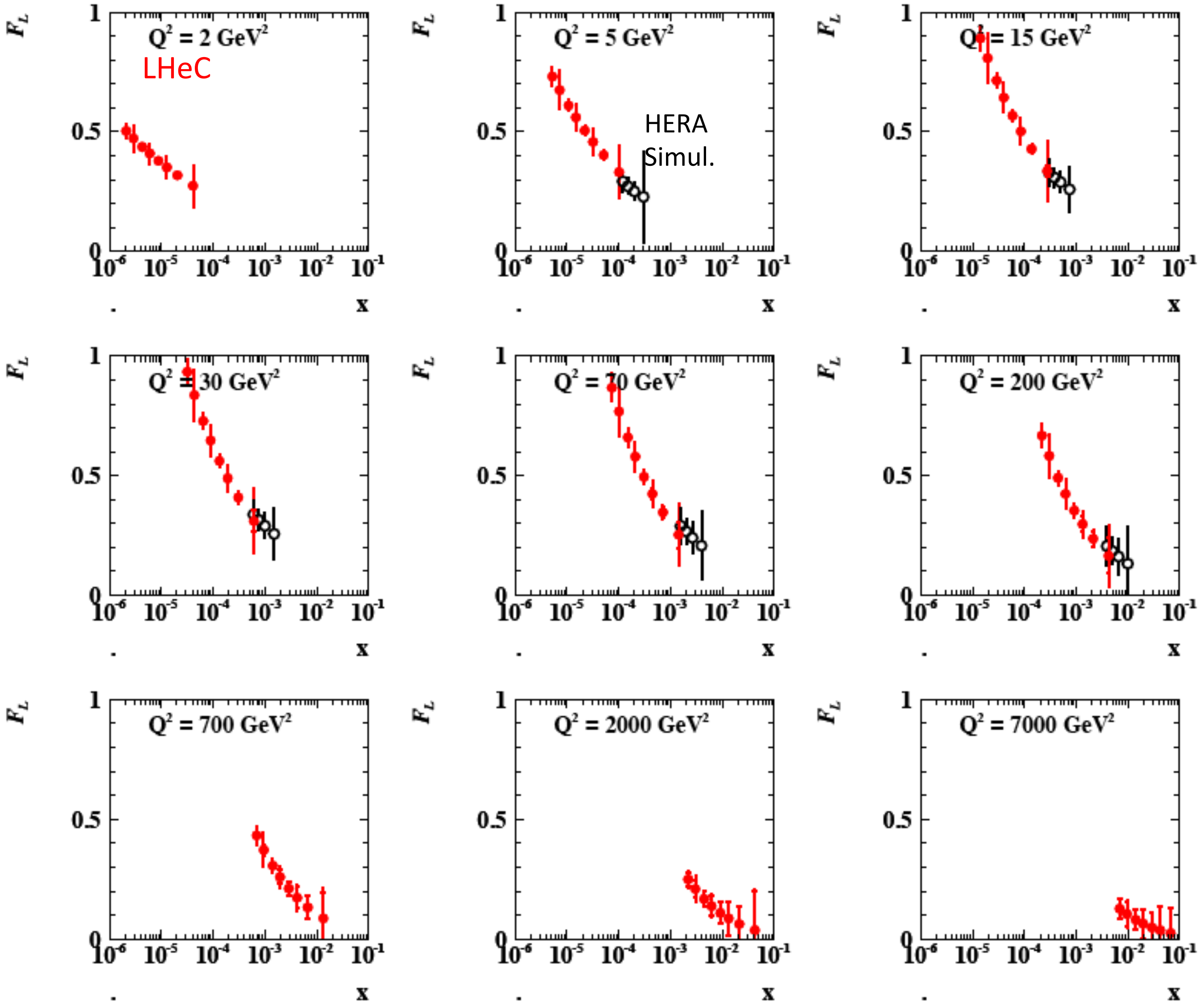
F_2



cf low x session

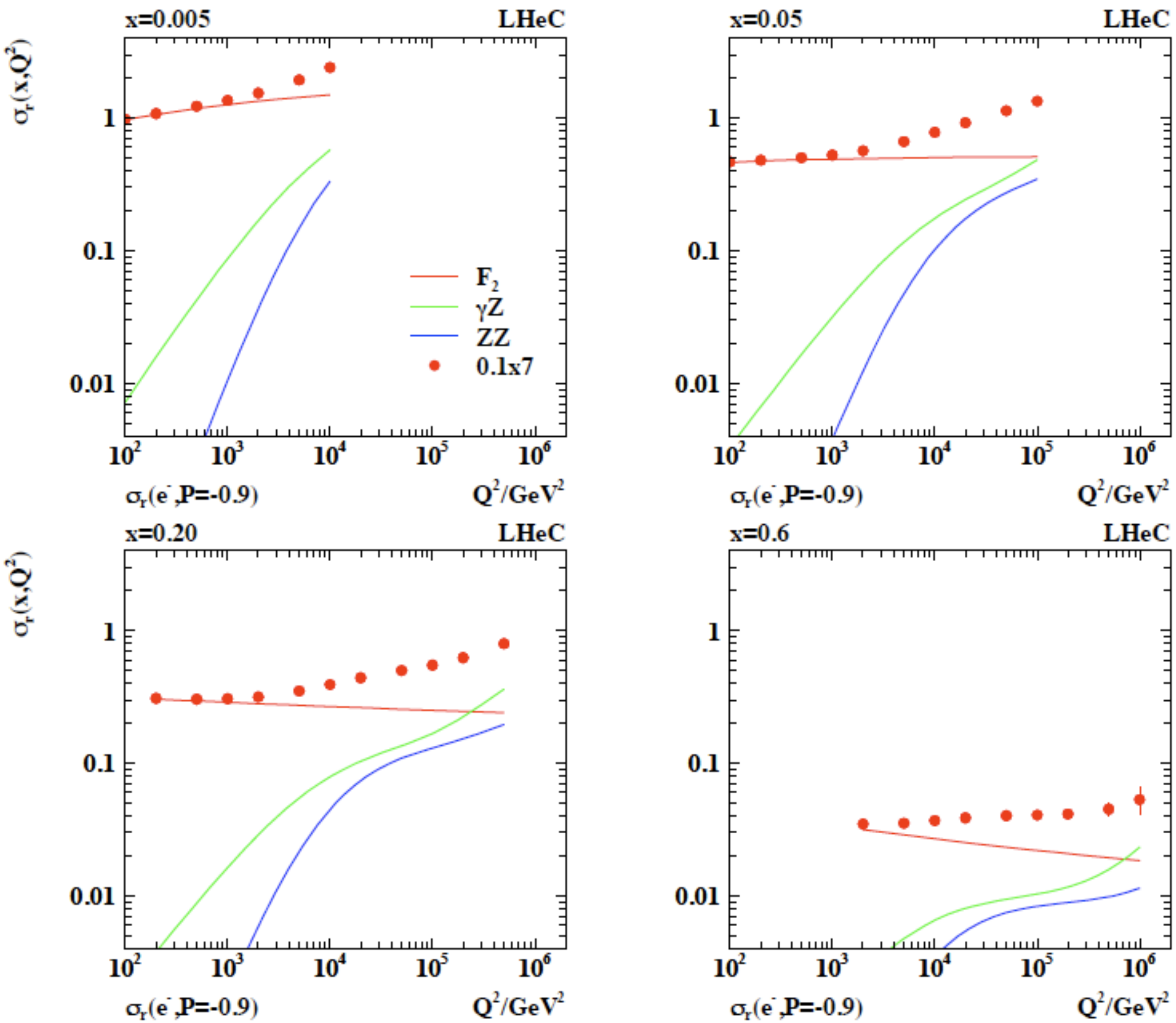
crucial: access saturation region with F_2, dF_2

F_L

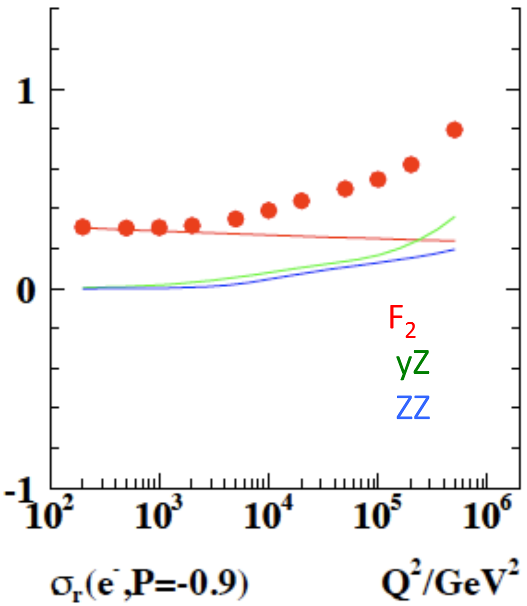


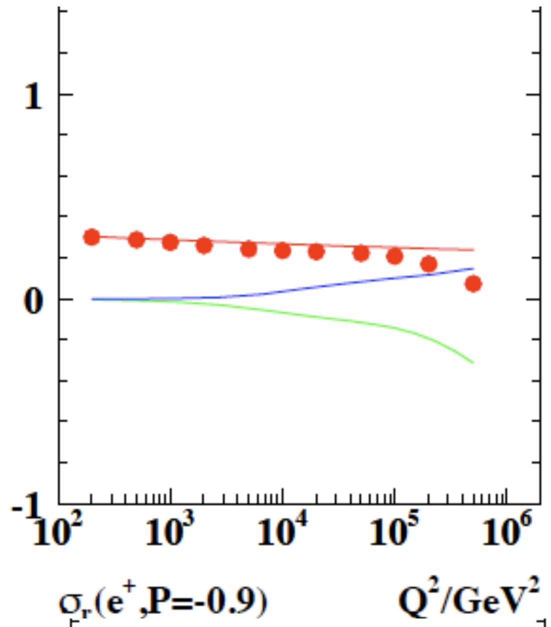
To be redone with lowered E_e and overlaid with H1 data

Electroweak NC Cross Section Measurements



Photon and Z Exchange are 1:1



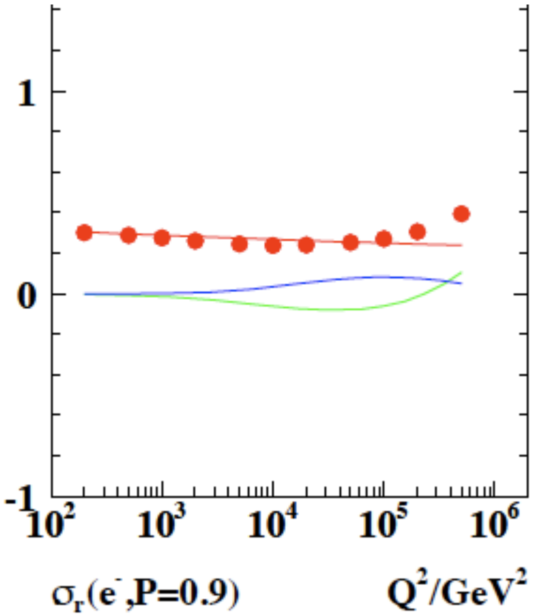


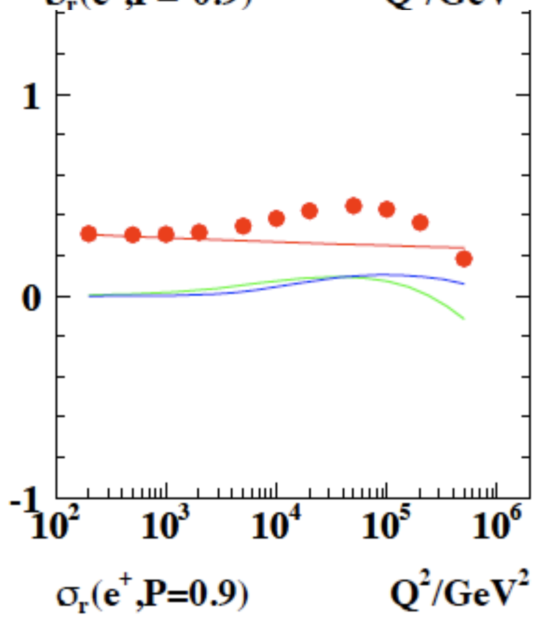
x=0.2
100 GeV
7000 GeV

2 charges and
2 polarisations
very desirable

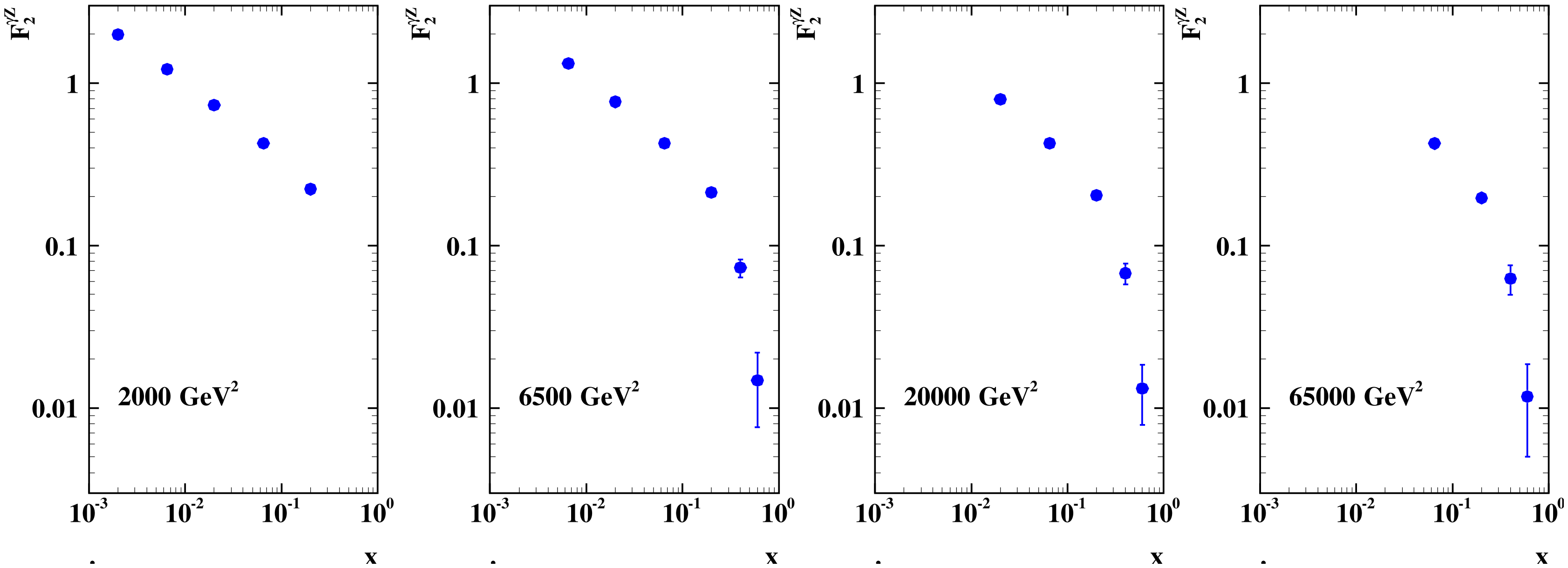
for electroweak
precision physics
and a
new spectroscopy
should that appear.

Z effects depend on charge and polarisation.





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



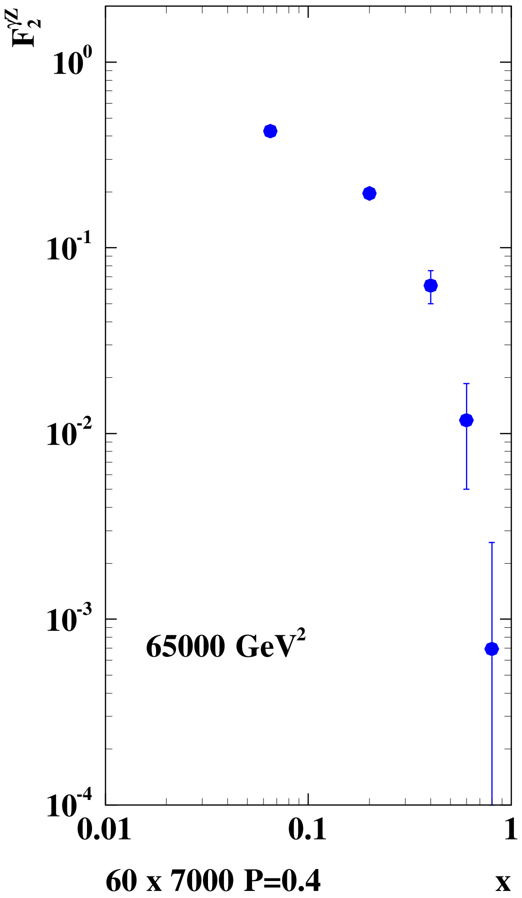
Huge PV effects in polarisation asymmetry

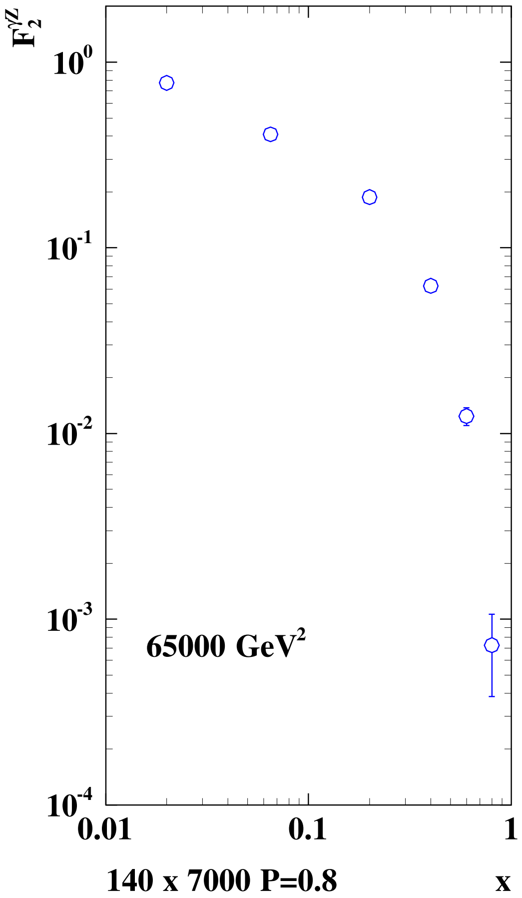
60*7000 GeV^2
e^- (P=±0.4)
10fb^{-1}

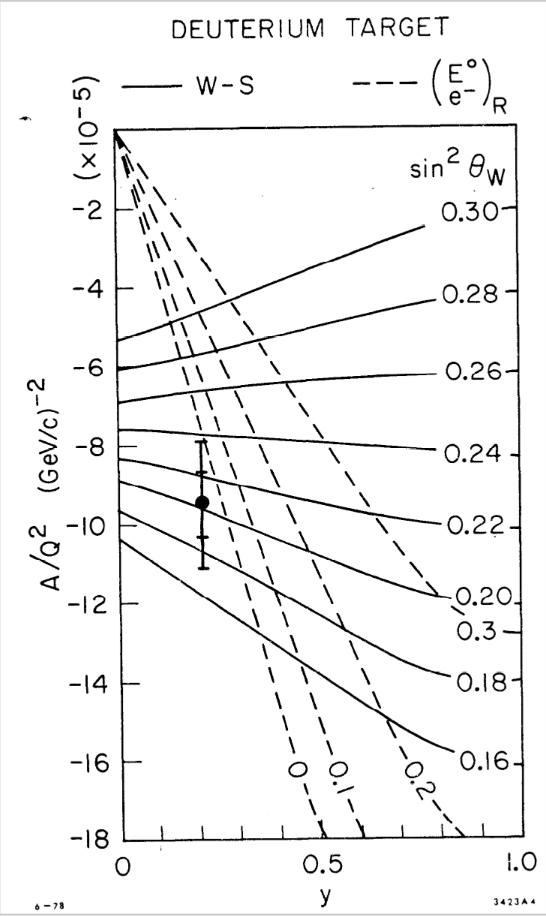
Comparison of 60 and 140 GeV

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

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

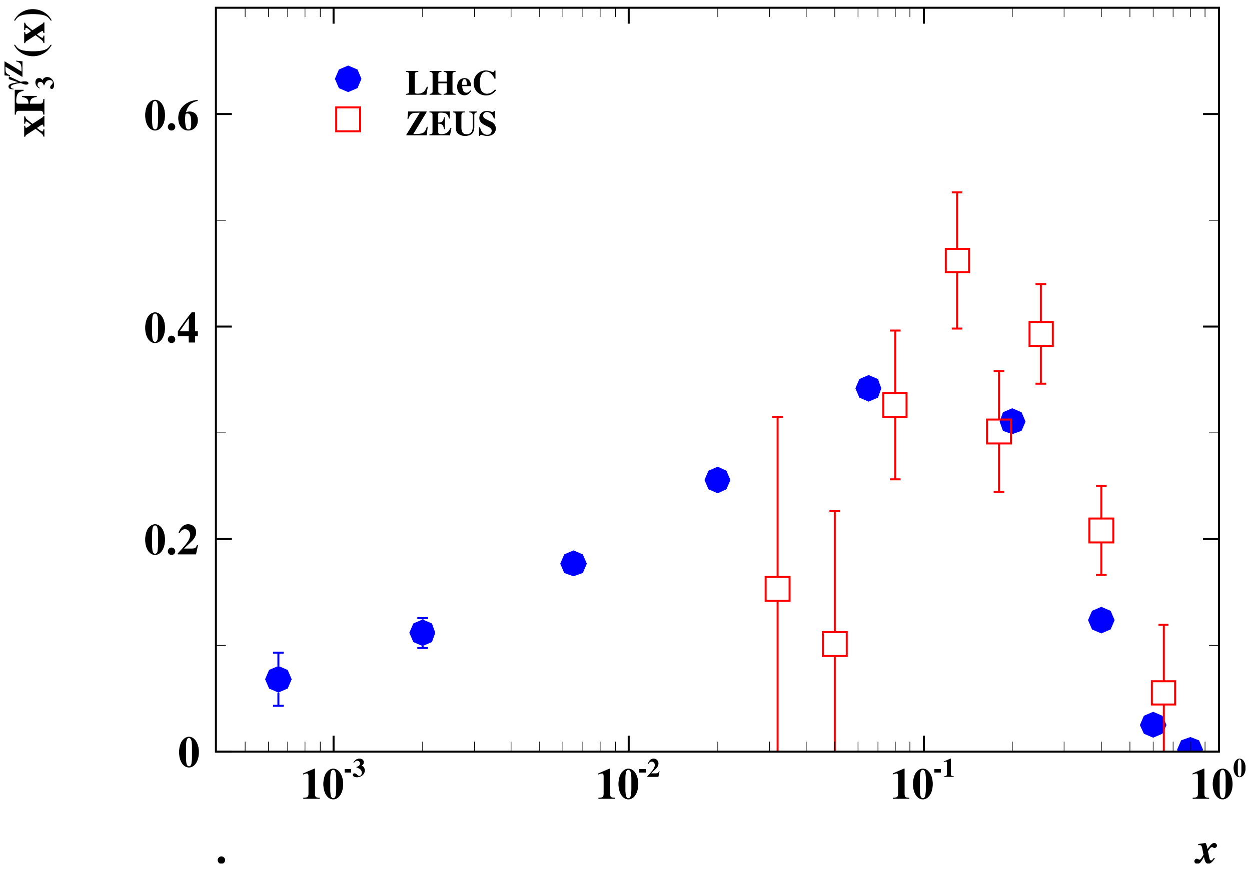






SLAC 1978

Charge Asymmetry $xF_3^{\gamma Z}$



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

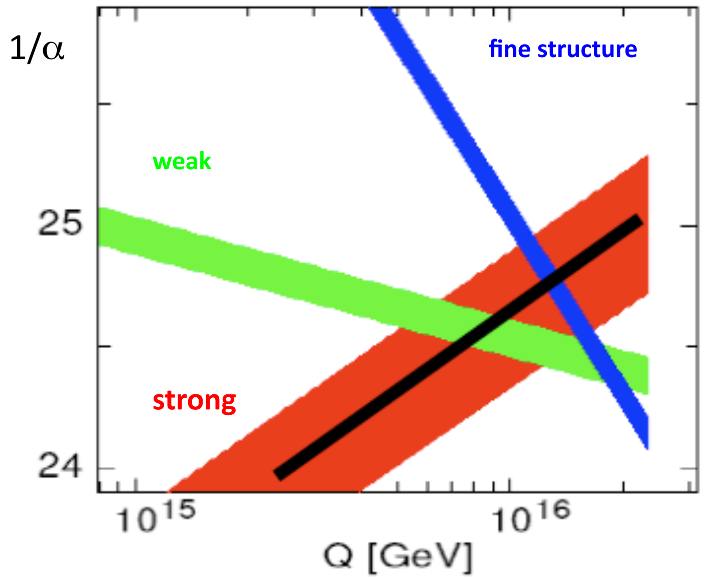
$$xF_3^{\gamma Z} = 2x[e_u a_u(u_v + \Delta_u) + e_d a_d(d_v + \Delta_d)]$$

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

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

Strong Coupling Constant

Simulation of α_s measurement at LHeC



MSSM - B.Allnach et al, hep-ex/0403133

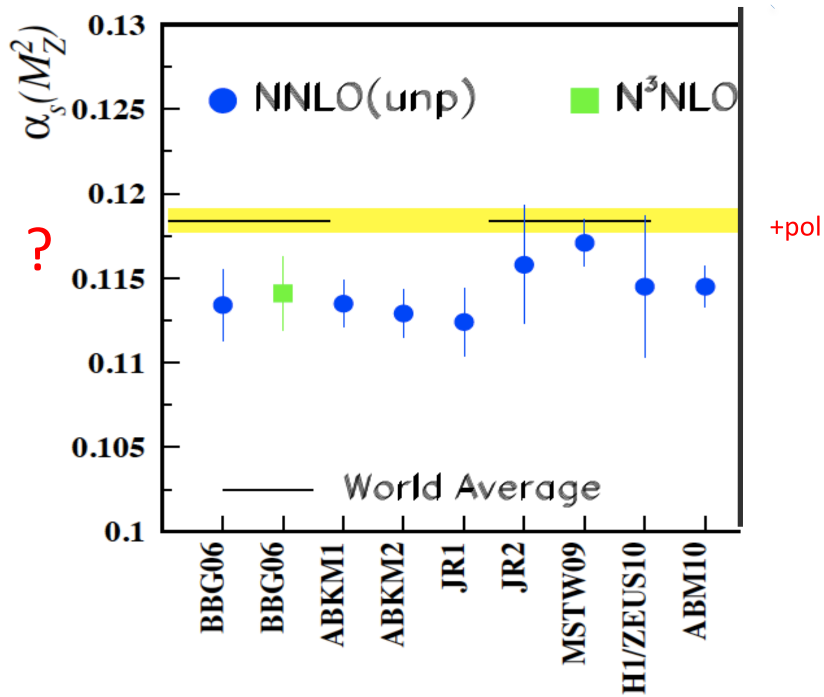
DATA	exp. error on α_s
NC e+ only	0.48%
NC	0.41%
NC & CC	**0.23% :=(1)**
(1) γ_h>5°	0.36% :=(2)
(1) +BCDMS	0.22%
(2) +BCDMS	0.22%
(1) stat. *= 2	0.35%

T.Kluge/M.Klein Divonne 09

α_s least known of coupling constants
Grand Unification predictions suffer from $\delta\alpha_s$

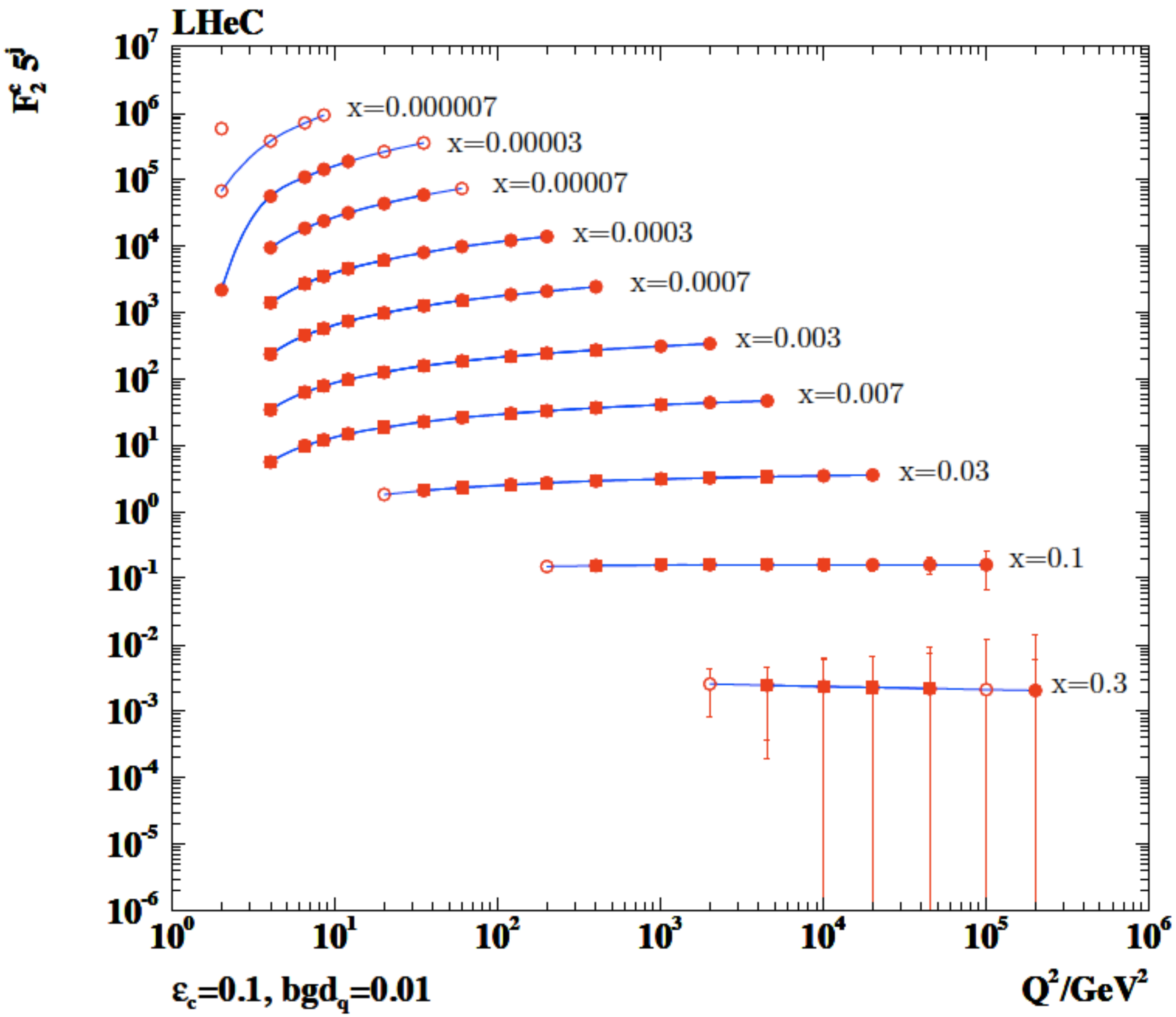
DIS tends to be lower than world average

LHeC: per mille accuracy indep. of BCDMS.
Challenge to experiment and to h.o. QCD



J.Bluemlein and H. Boettcher, arXiv 1005.3013 (2010)

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
Related to α_s

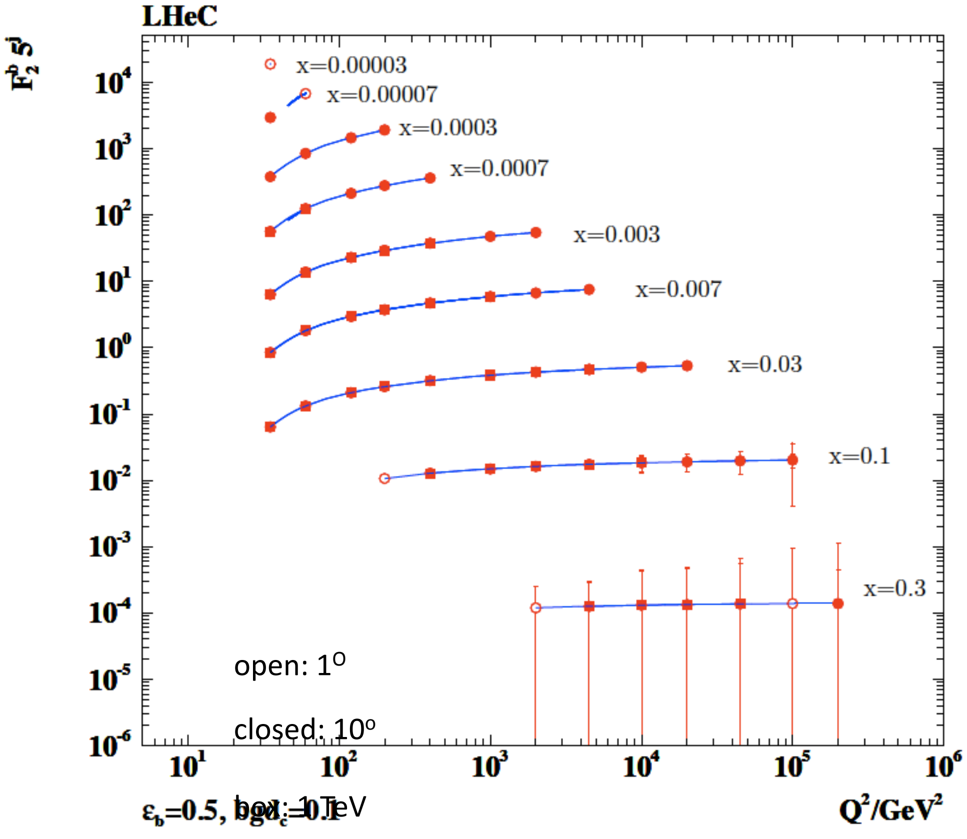
open: 1^O

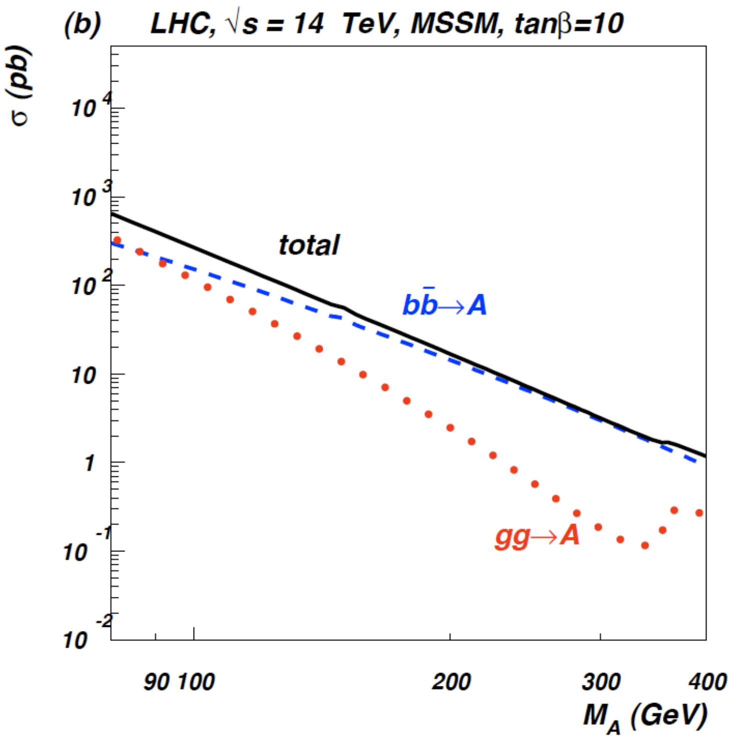
closed: 10^o

box: 1 TeV

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

Beauty





In MSSM Higgs production is b dominated

First measurements of b at HERA can be turned to precision measurement of b-df.

LHeC: higher fraction of b, larger range, smaller beam spot, better Si detectors

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

Charged Currents

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

$$\sigma_{r,CC}^{\pm} = \frac{1 \pm P}{2}\left(W_2^{\pm} \mp \frac{Y_-}{Y_+} xW_3^{\pm} - \frac{y^2}{Y_+} W_L^{\pm}\right)$$

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

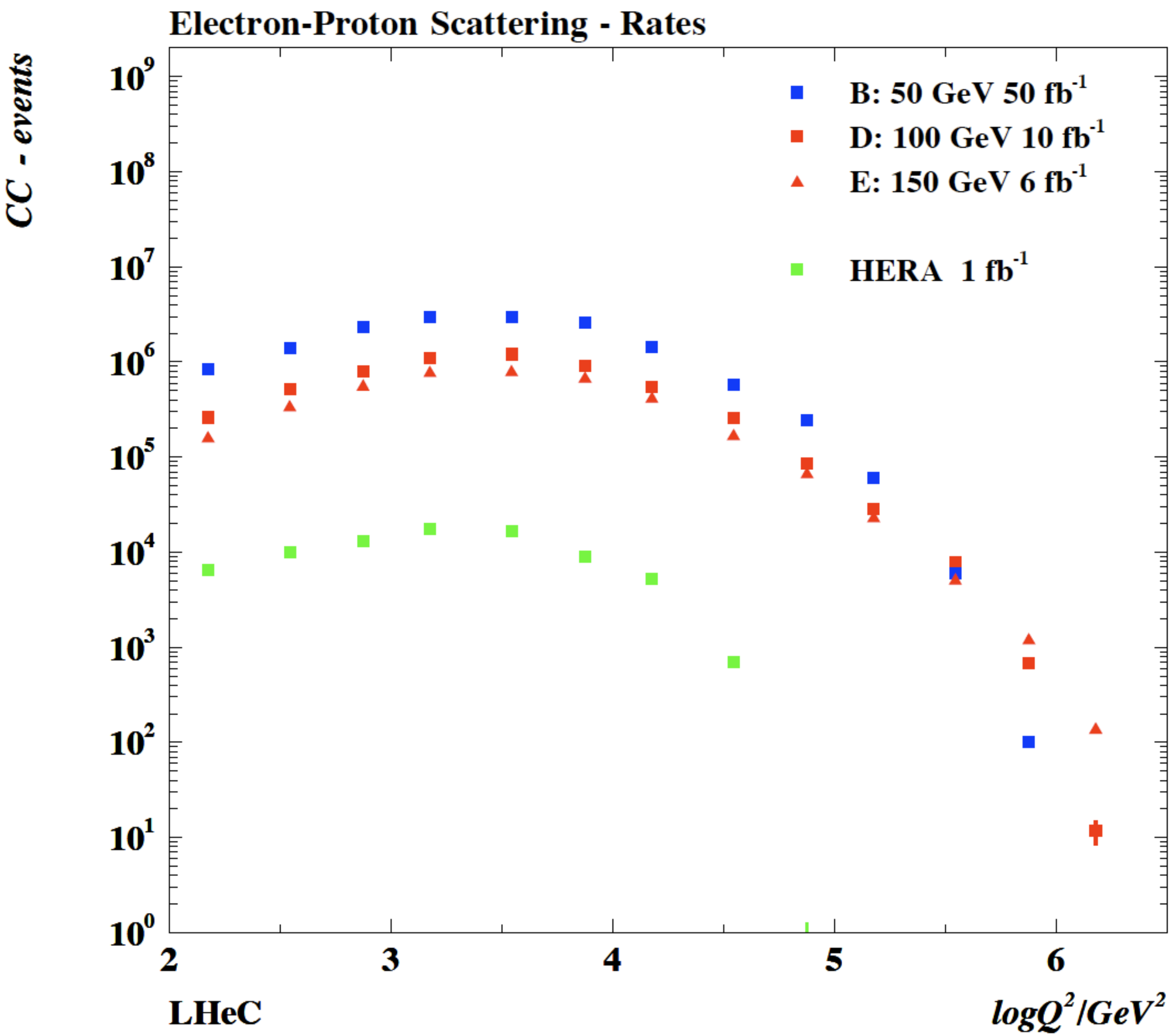
$$U = u + c \qquad \overline{U} = \overline{u} + \overline{c} \qquad D = d + s \qquad \overline{D} = \overline{d} + \overline{s}$$

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

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

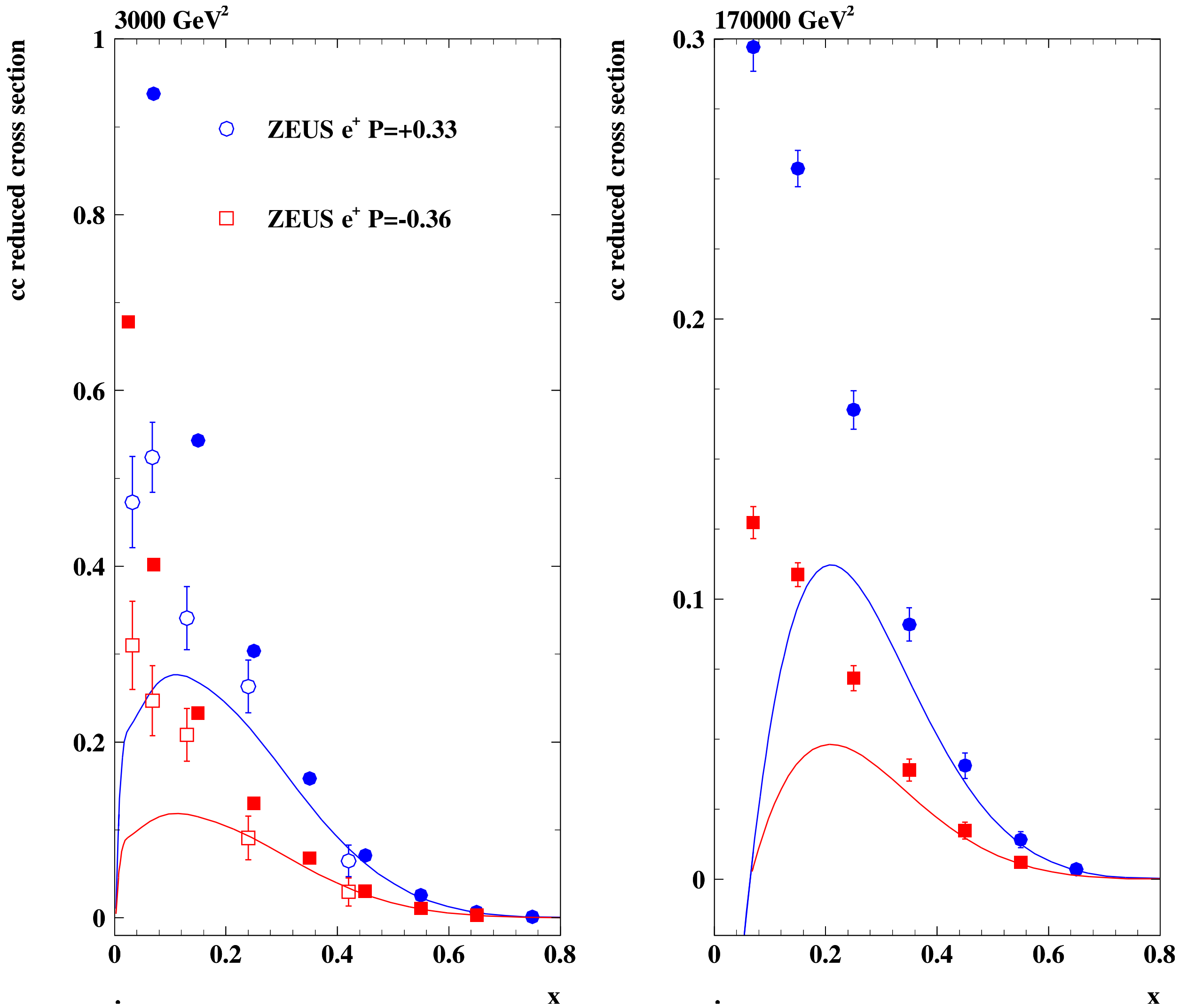
with $c_{u,d} = e_{u,d}^2 + \kappa_Z(-v_e \mp P a_e) e_{u,d} v_{u,d}$ and $d_{u,d} = \pm a_e a_{u,d} e_{u,d}$,

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

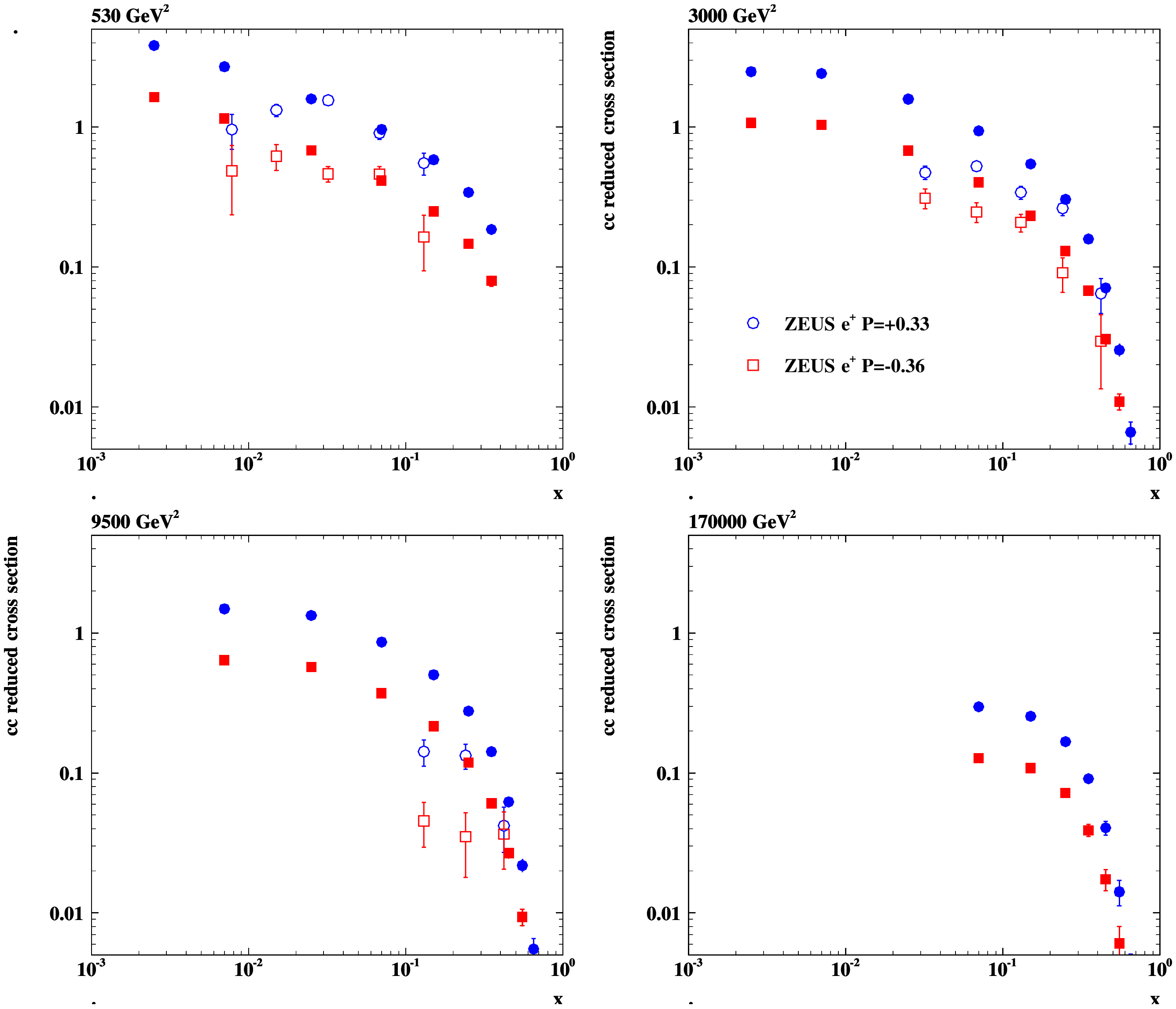
Charged Currents



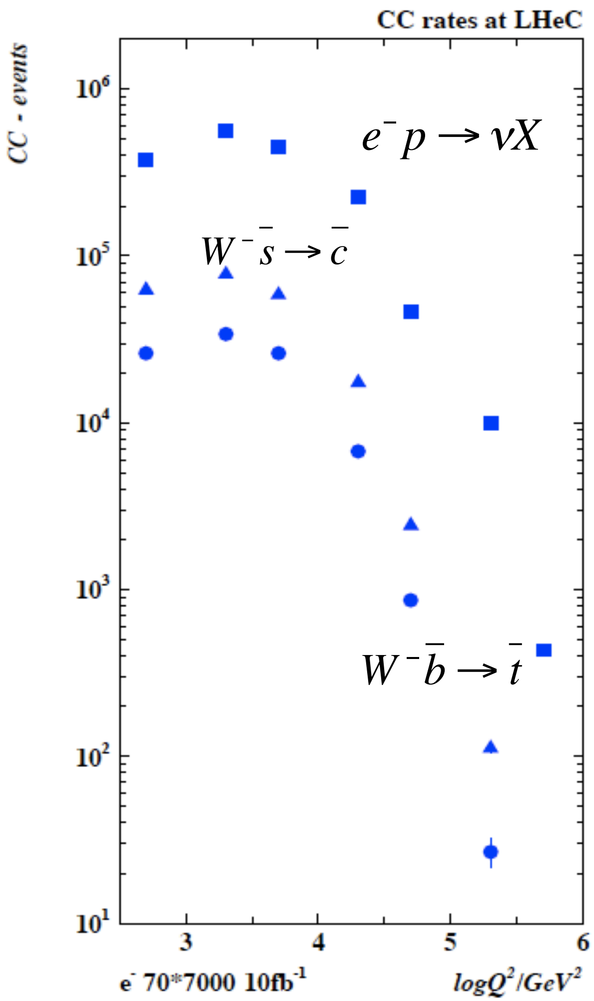
Valence quarks up to x=0.8

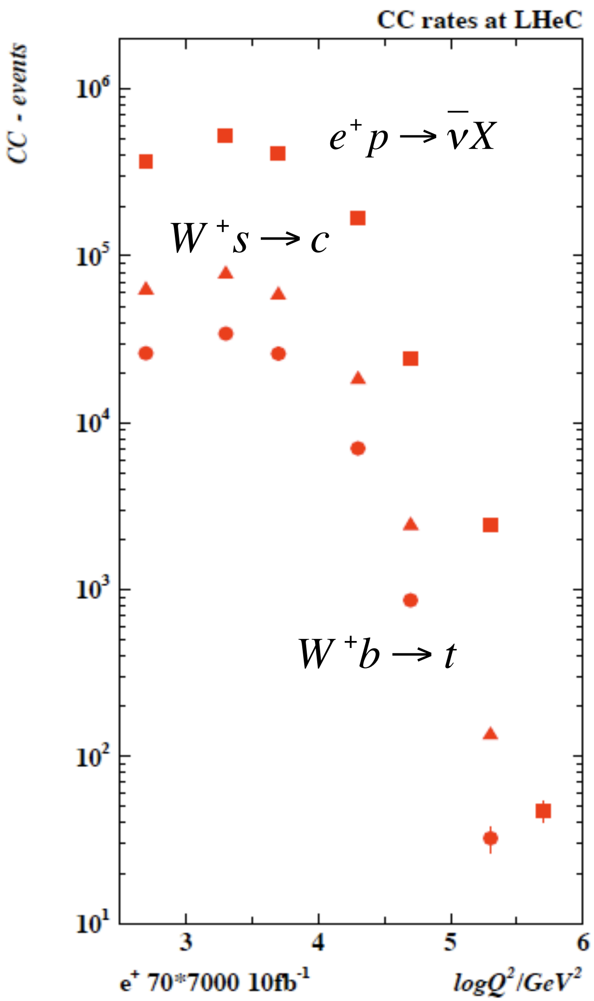
Unfold U,D and anti U,D

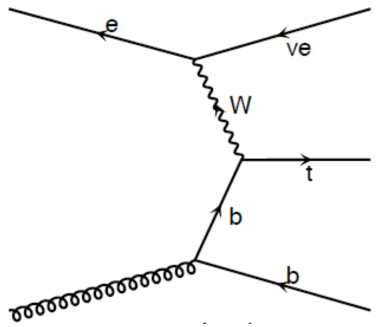
Charged Currents



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





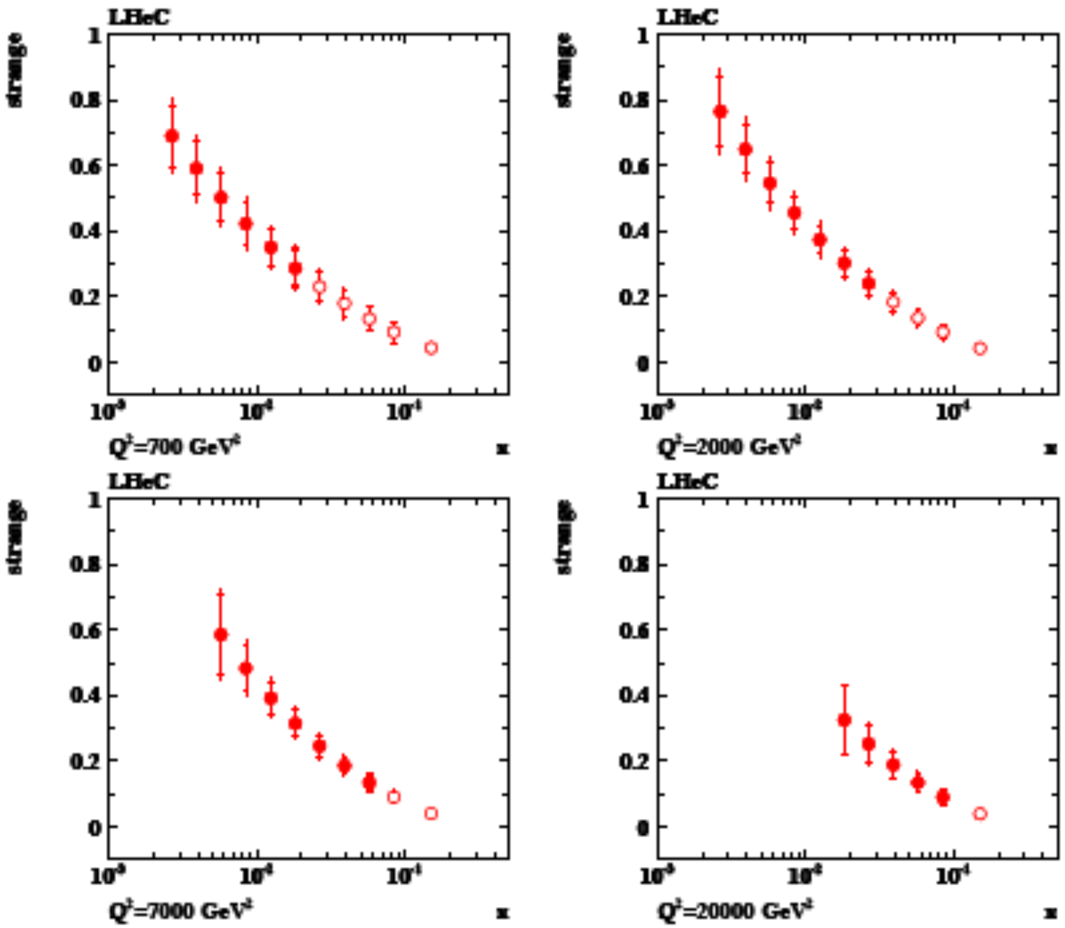


LHeC is a single top and anti-top quark factory

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 (=? anti-strange) Quark



$W^+ s \rightarrow c$

$1\, fb^{-1}$

$\varepsilon_c = 0.1$

$\varepsilon_q = 0.01$

$\delta_{syst} = 0.1$

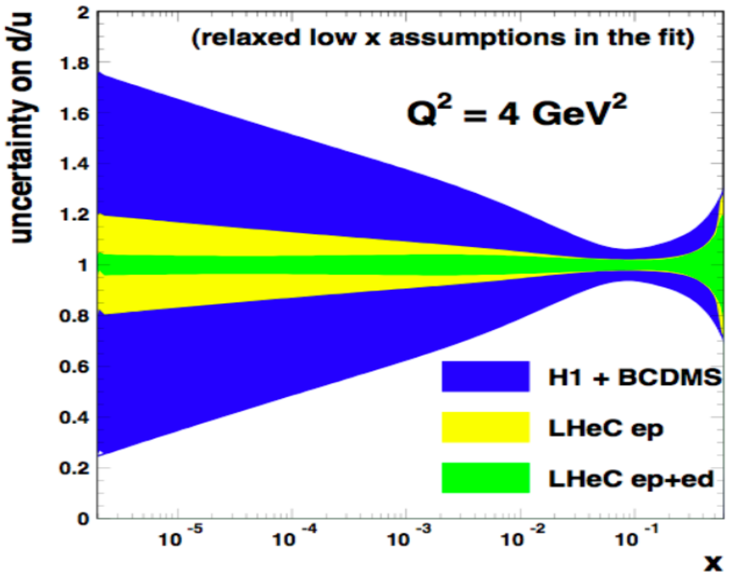
$\circ - \vartheta_h \geq 1^o$

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

Some dimuon and K data
never properly measured

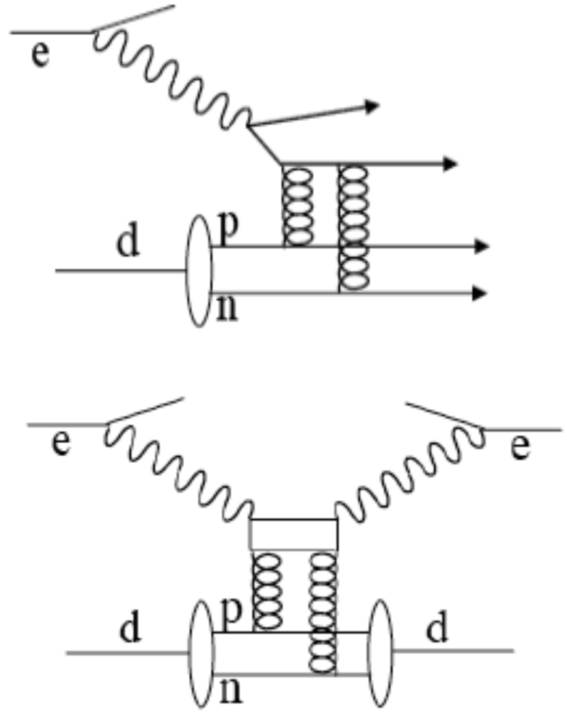
Neutron Structure (ed → eX)

d/u at low x from deuterons



(13) There are five color-singlet combinations of the deuteron wavefunction in QCD, only one of which is the standard proton-neutron state. The "hidden color" [13] components will lead to high multiplicity final states in deep inelastic electron-deuteron scattering.

crucial constraint on evolution (S-NS), improved α_s



In eA at the collider, test Gribovs relation between shadowing and diffraction, control nuclear effects at low Bjorken x to high accuracy

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 θ_e and protons for small θ_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

pdf's from W,Z 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

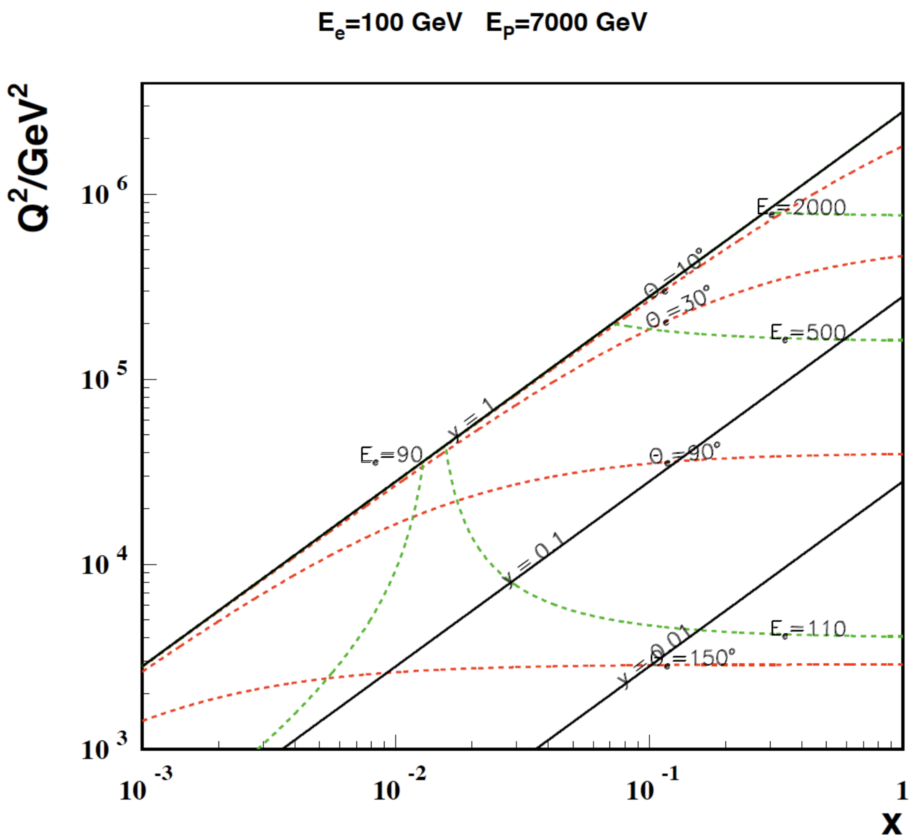
50% change of s yields 10% difference in W cross sections

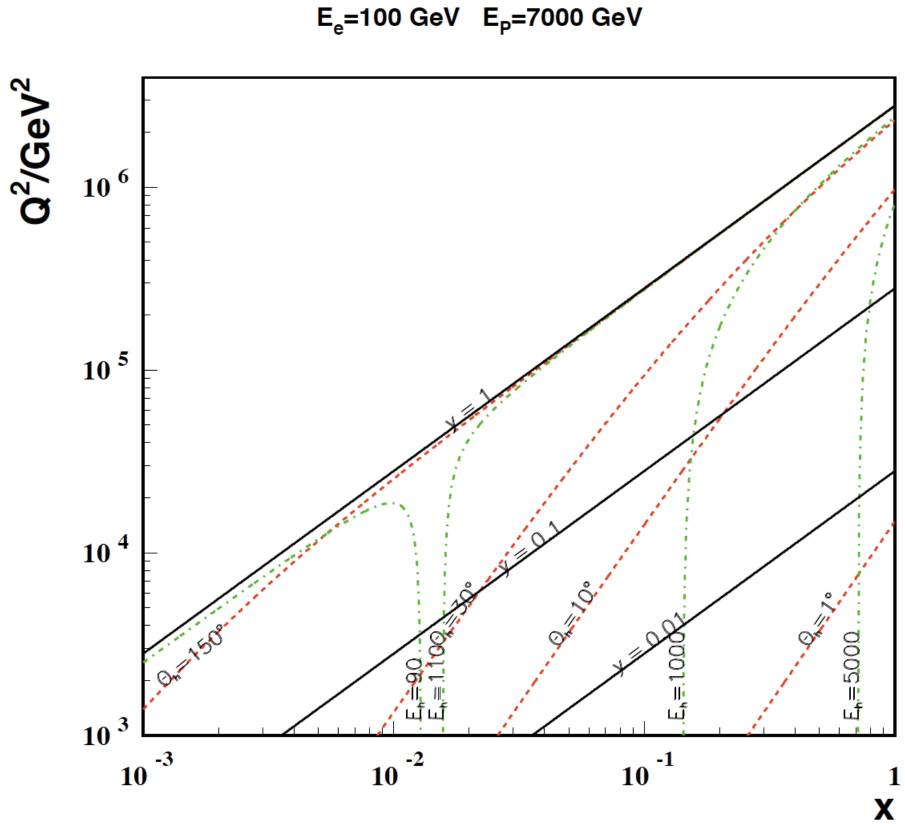
Learn about valence quarks from charge asymmetry

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

Kinematics – high Q^2





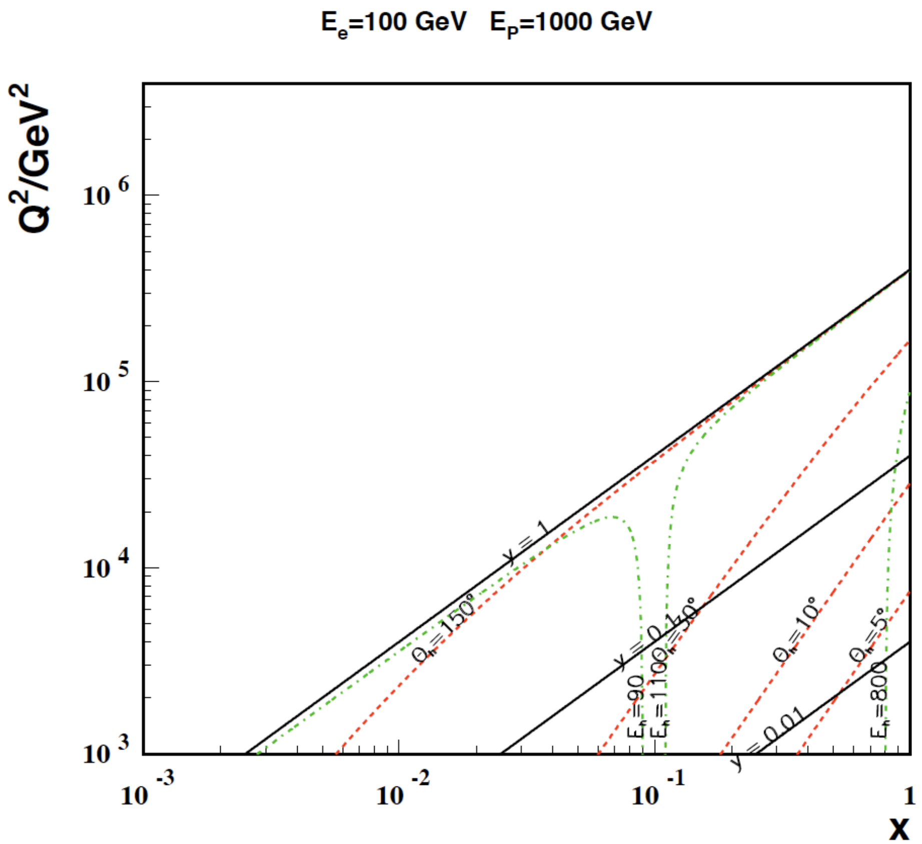
The electron kinematics at high Q^2
Is no big problem, apart from extreme
backscattering at very high Q^2 of electrons
of a few TeV energy.
→**Need forward elm. calorimeter of few TeV energy range down to 10° and below with reasonable calibration accuracy.**

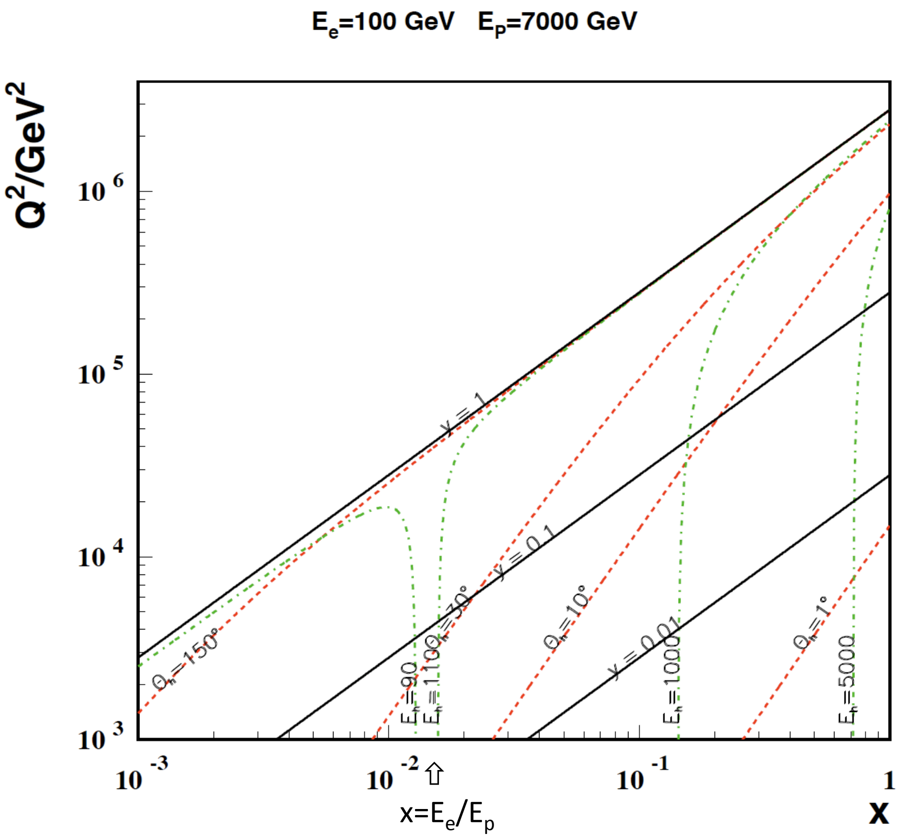
High x and high Q^2: few TeV HFS scattered forward:
→**Need forward had. calorimeter of few TeV energy range down to 10° and below. Mandatory for charged currents. Strong variations of cross section at high x demand hadronic energy calibration as good as 1%**

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



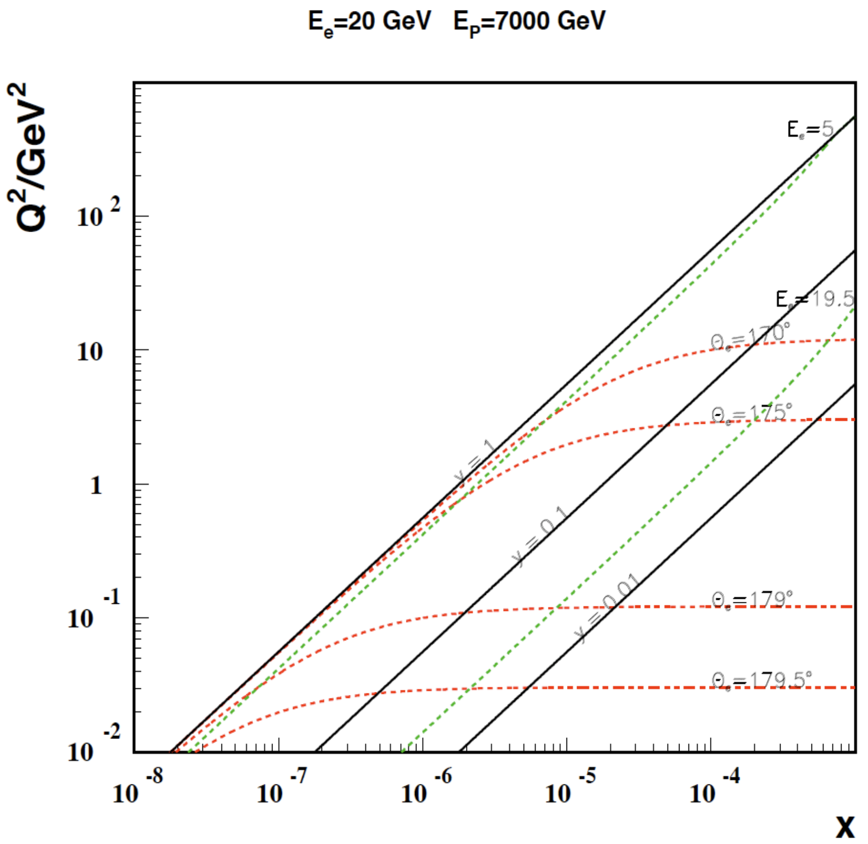


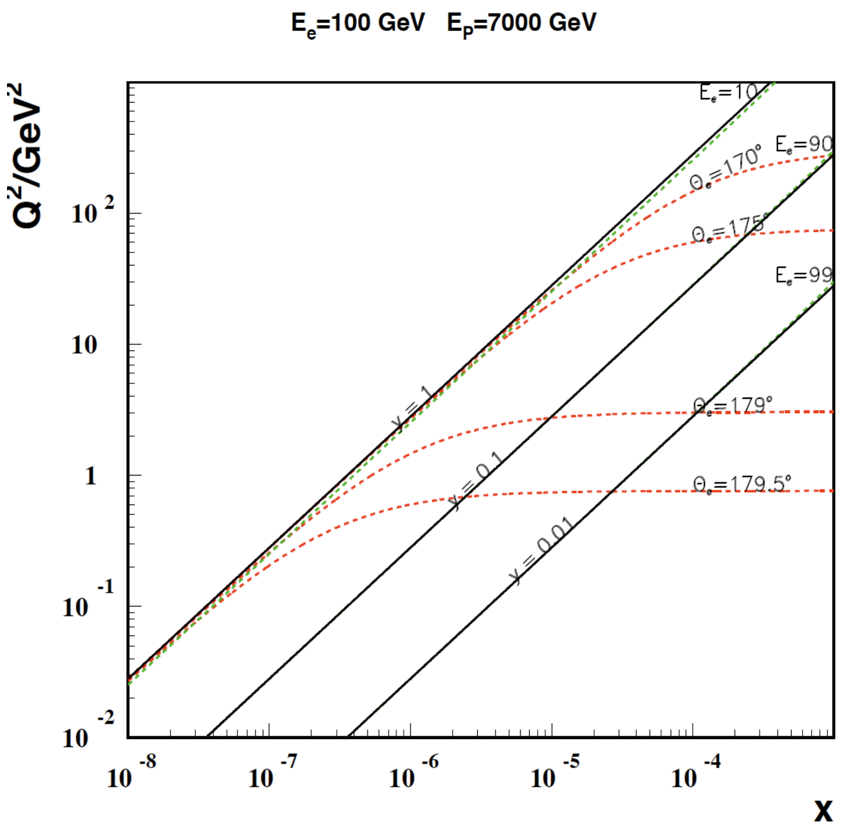
$$Q^2(x,\theta_h) = sx/[1 + E_e cot^2(\theta_h/2)/xE_p] \simeq (2xE_p cot(\theta_h/2))^2$$

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





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