Quark*) Distributions with the LHeC

Project
Scenarios
Statistics
Systematics
Light Quarks
Heavy Quarks

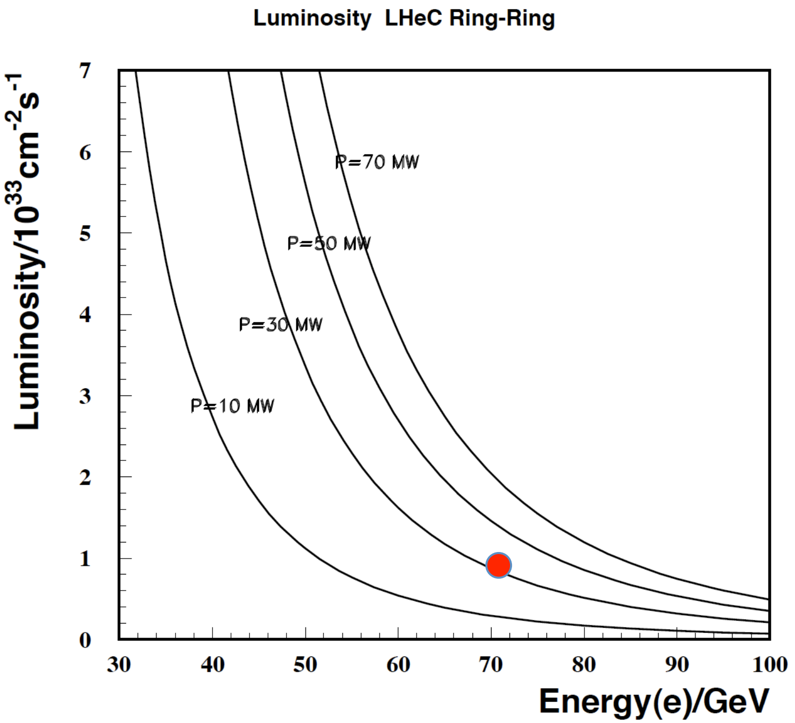
Max Klein
DESY, 7.4.2010
Meeting on QCD at the LHeC

*) For the gluon see previous talks by
E. Perez at DIS07
C. Gwenlan at DIS09

UNIVERSITY OF LIVERPOOL

Some plots old,
some plots new.
All is preliminary
and here shown
for discussion.

Ring-Ring Parameters



Luminosity for $e^{\pm}p$ safely above $10^{33}cm^{-2}s^{-1}$

Used "ultimate" LHC beam parameters

Energy limited by injection and syn.rad losses

Power limit set to 100 MW

Small p tuneshift: simultaneous pp and ep

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}} = 8.3\,10^{32} \cdot \frac{I_e}{50mA} \cdot \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2}s^{-1}$$

$$I_e = 0.35mA \cdot \frac{P}{MW} \cdot \left(\frac{100GeV}{E_e}\right)^4$$

Ultimate Parameter	*Protons*	*Electrons*	
	$Np=1.7*10^{11}$	*$Ne=1.4*10^{10}$*	*nb=2808*
	Ip=860mA	*Ie=71mA*	
Optics	*βxp=230 cm*	*βxe=12.7 cm*	
	βyp= 60 cm	*βye= 7.1 cm*	
	εxp=0.5 nm rad	*εxe=9 nm rad*	
	εyp=0.5 nm rad	*εye=4 nm rad*	
Beamsize	*σx=34 μm*		
	σy=17 μm		
Tuneshift	*Δνx=0.00061*	*Δνx=0.056*	
	Δνy=0.00032	*Δνy=0.062*	
Luminosity	*$L=1.03*10^{33}$*		

LINAC-Ring Parameters

Configuration	60 GeV, pulsed	60 GeV CW ERL	140 GeV pulsed
N_e/bunch/ 10^9/50ns	4	1.9	2
gradient MV/m	32	13	32
normalised ε/ μm	50	50	100
cryo power/MW	3	20	6
effective beam power/MW	50	$40/(1-\eta_{ERL})$	50

An Electron-Proton Collider in the TeV Range

M. Tigner, Cornell Univ., Ithaca, NY
B. Wiik, F. Willeke, DESY, Hamburg, FRG

As the era of e-p colliders begins we need to begin a search for practical schemes for increasing the available center of mass energies. The use of an SC linac on SC proton ring approach may offer a practical possibility while maintaining a favorable electron to proton beam energy ratio.

Luminosity for ultimate beam

$$N_p = 1.7 \cdot 10^{11}, \varepsilon_p = 3.8 \mu m, \beta^* = 0.2 m, \gamma = 7000/0.94$$

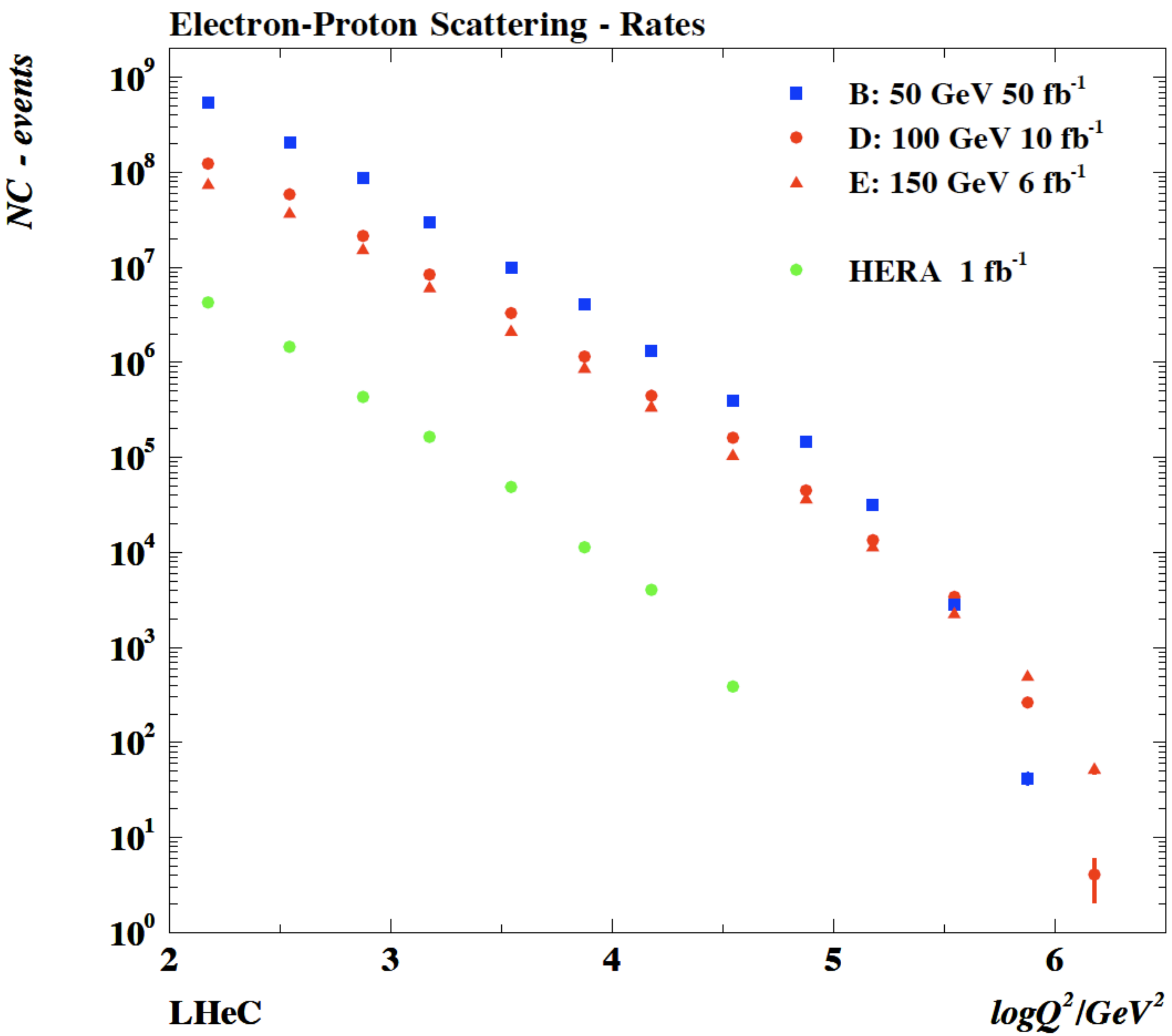
$$L = 8 \cdot 10^{31} cm^{-2} s^{-1} \cdot \frac{N_p 10^{-11}}{1.7} \cdot \frac{0.2}{\beta^* / m} \cdot \frac{P/MW}{E_e/GeV}$$

The LR combination yet requires a still better p beam or/and E_e recovery to come to luminosity beyond $10^{32} cm^{-2} s^{-1}$

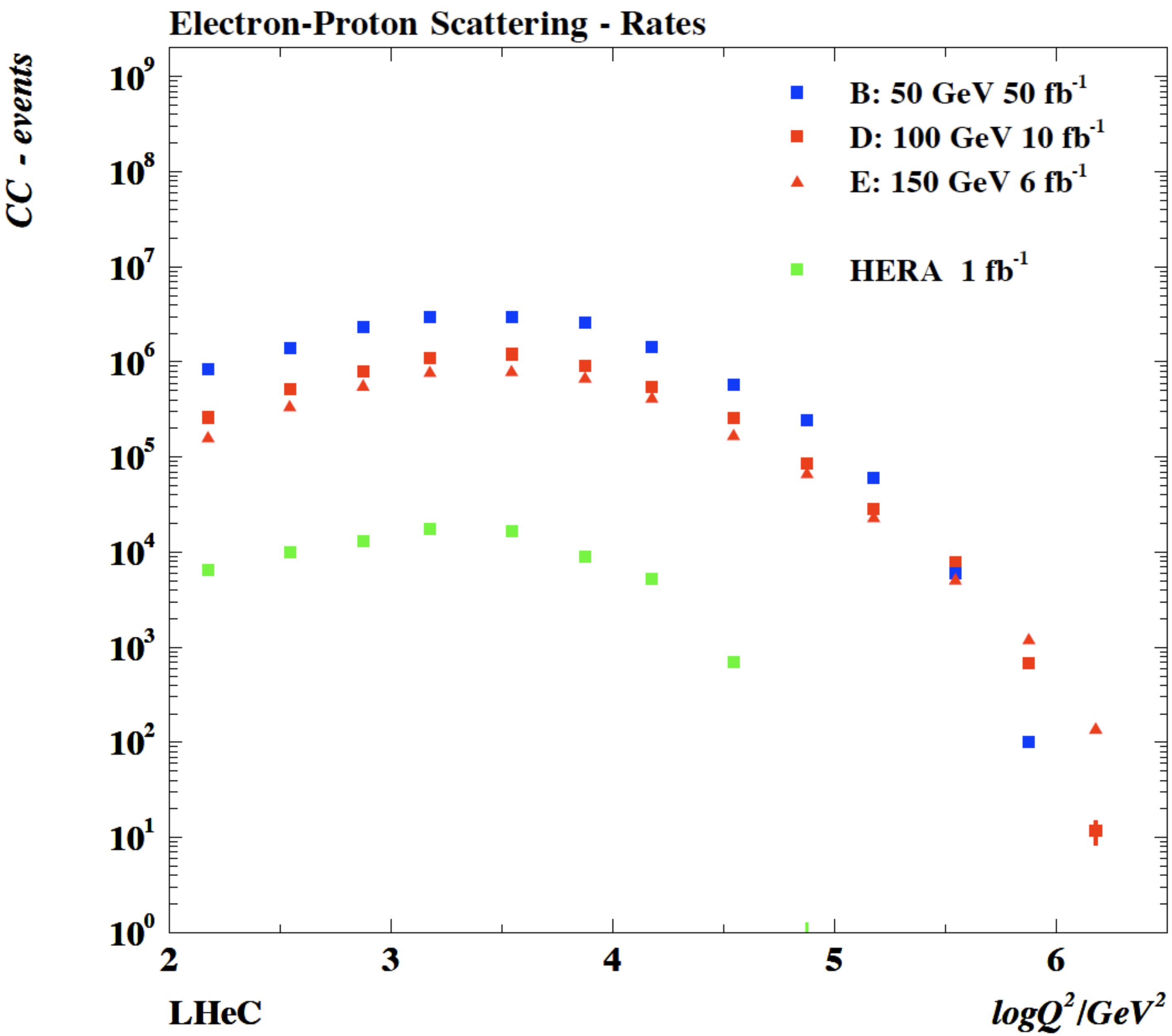
Simulated Default Scenarios, April 2009

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

config.	E(e)	E(N)	N	$\int L(e^+)$	$\int L(e^-)$	|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

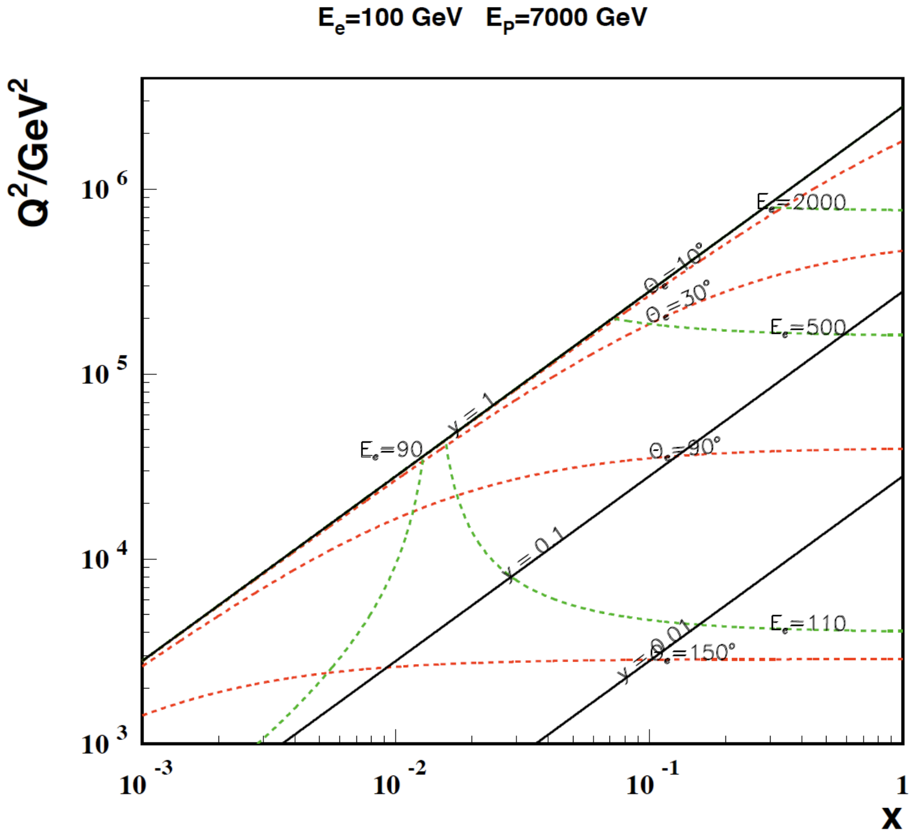


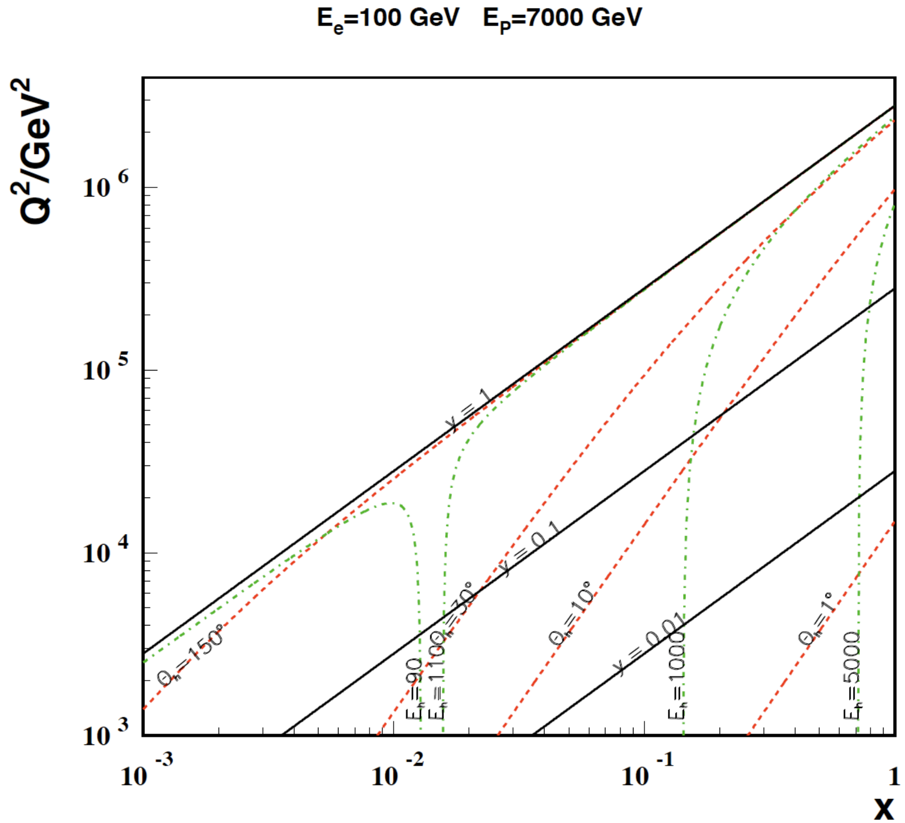
Largest energy is crucial for low x and high masses and high Q^2. The LHC may set the scale for everything, perhaps.



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 prrovides larger s: win-win for CC

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.

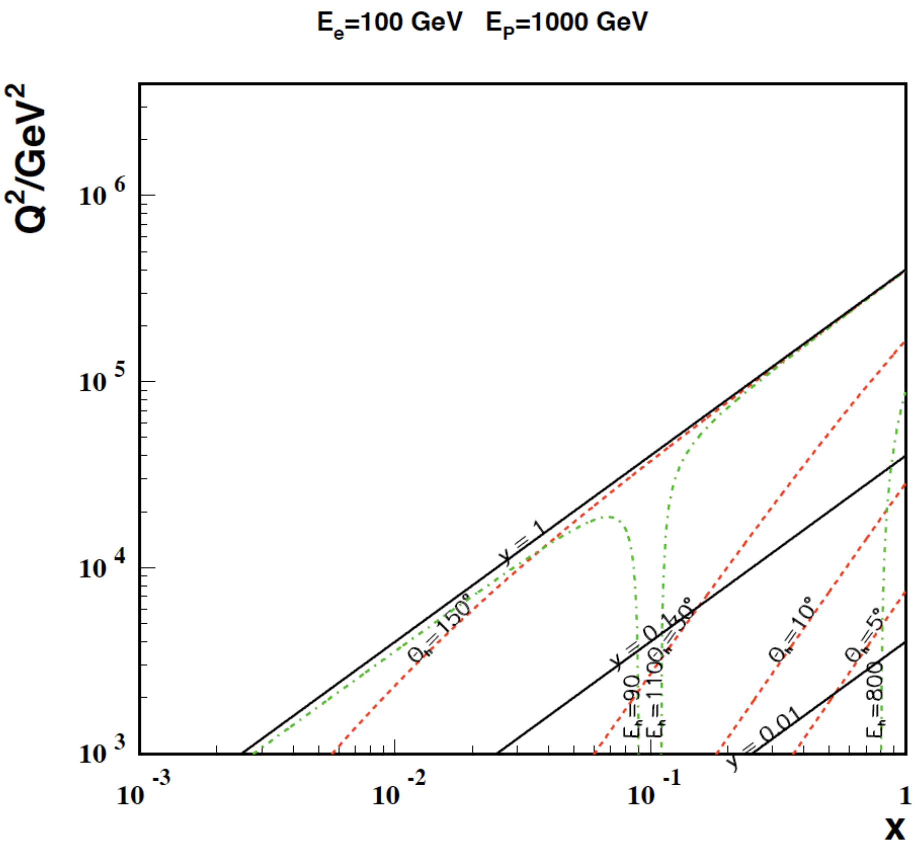
→**Need forward elm. calorimeter of few TeV energy range down to 10° and below with reasonable calibration accuracy.**

High x and high Q^2: few TeV HFS scattered forward:

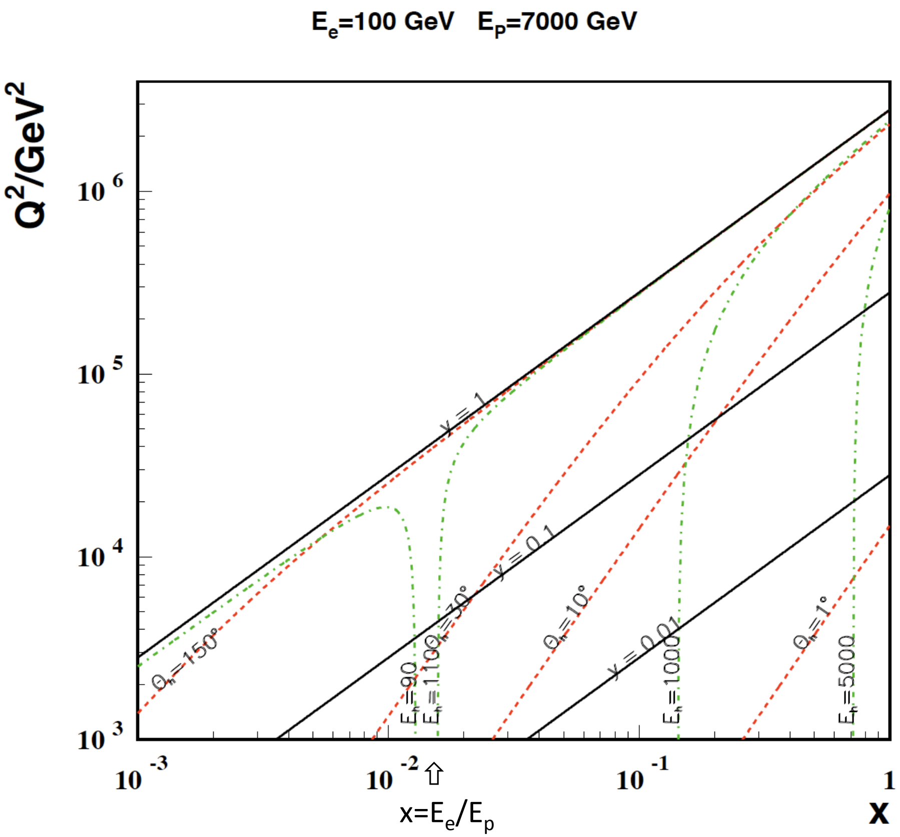
→**Need forward had. calorimeter of few TeV energy range down to 10° and below. Mandatory for charged currents. Strong variations of cross section at high x demand hadronic energy calibration as good as 1%**

Kinematics – large x

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



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

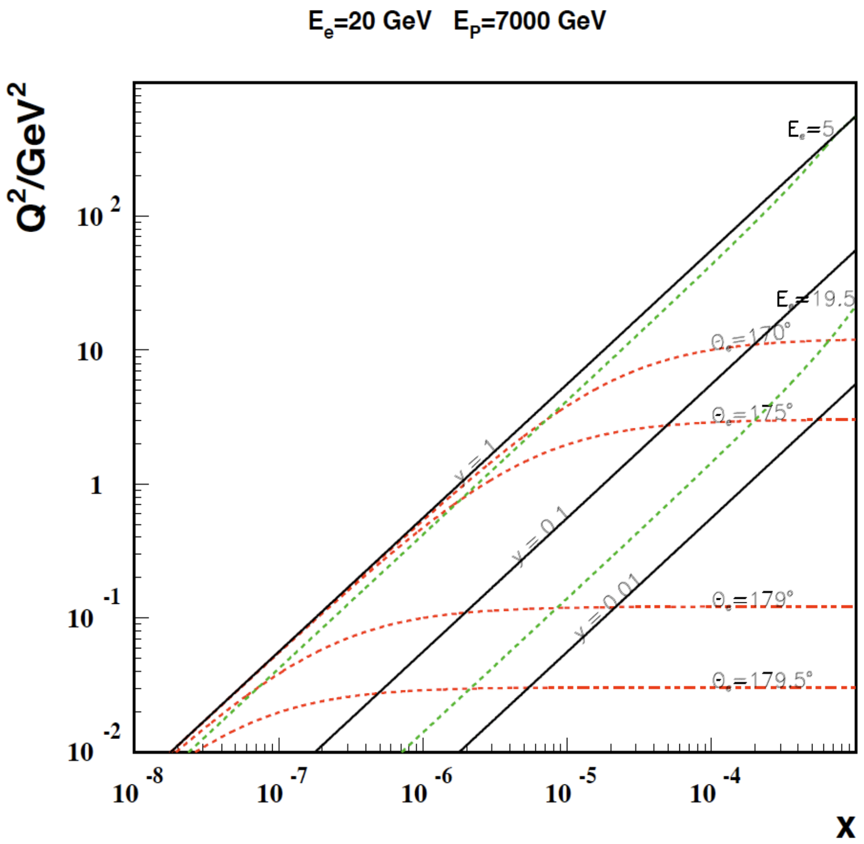


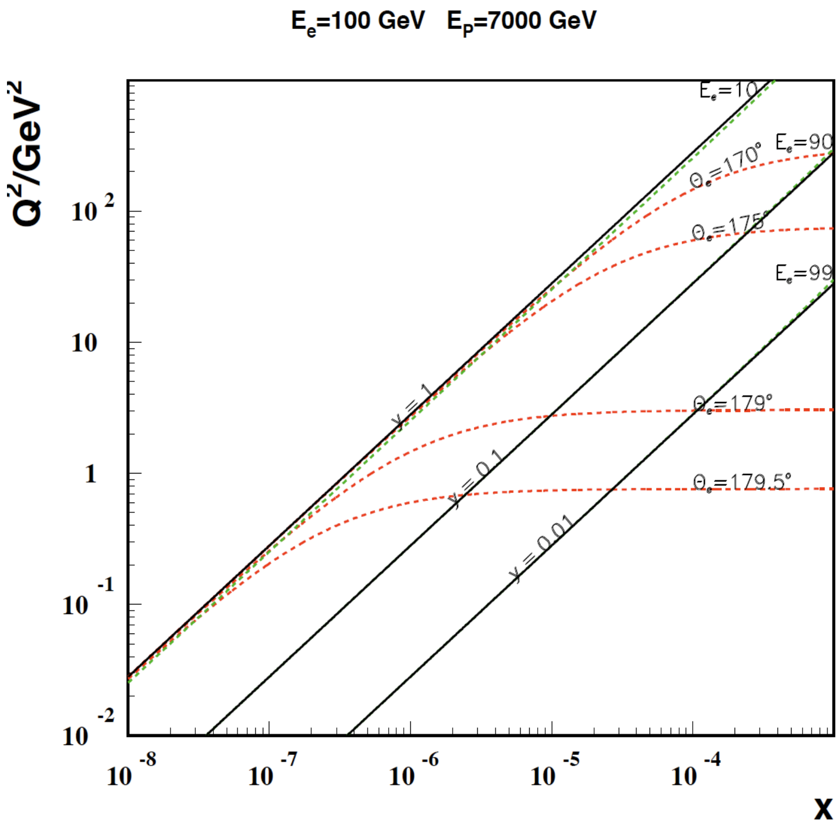
$$Q^2\,(x,\theta_h) = sx/[1 + E_e cot^2(\theta_h/2)/xE_p] \simeq (2xE_p cot(\theta_h/2))^2$$

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





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

Detector requirements

	LHeC	HERA
High luminosity to reach high Q^2 and large x	10^{33} - 10^{34}	1-5 10^{31}
Largest possible acceptance	1-179°	7-177°
High resolution tracking	0.1 mrad	0.2-1 mrad
Precision electromagnetic calorimetry	0.1%	0.2-0.5%
Precision hadronic calorimetry	0.5%	1%
High precision luminosity measurement	0.5%	1%

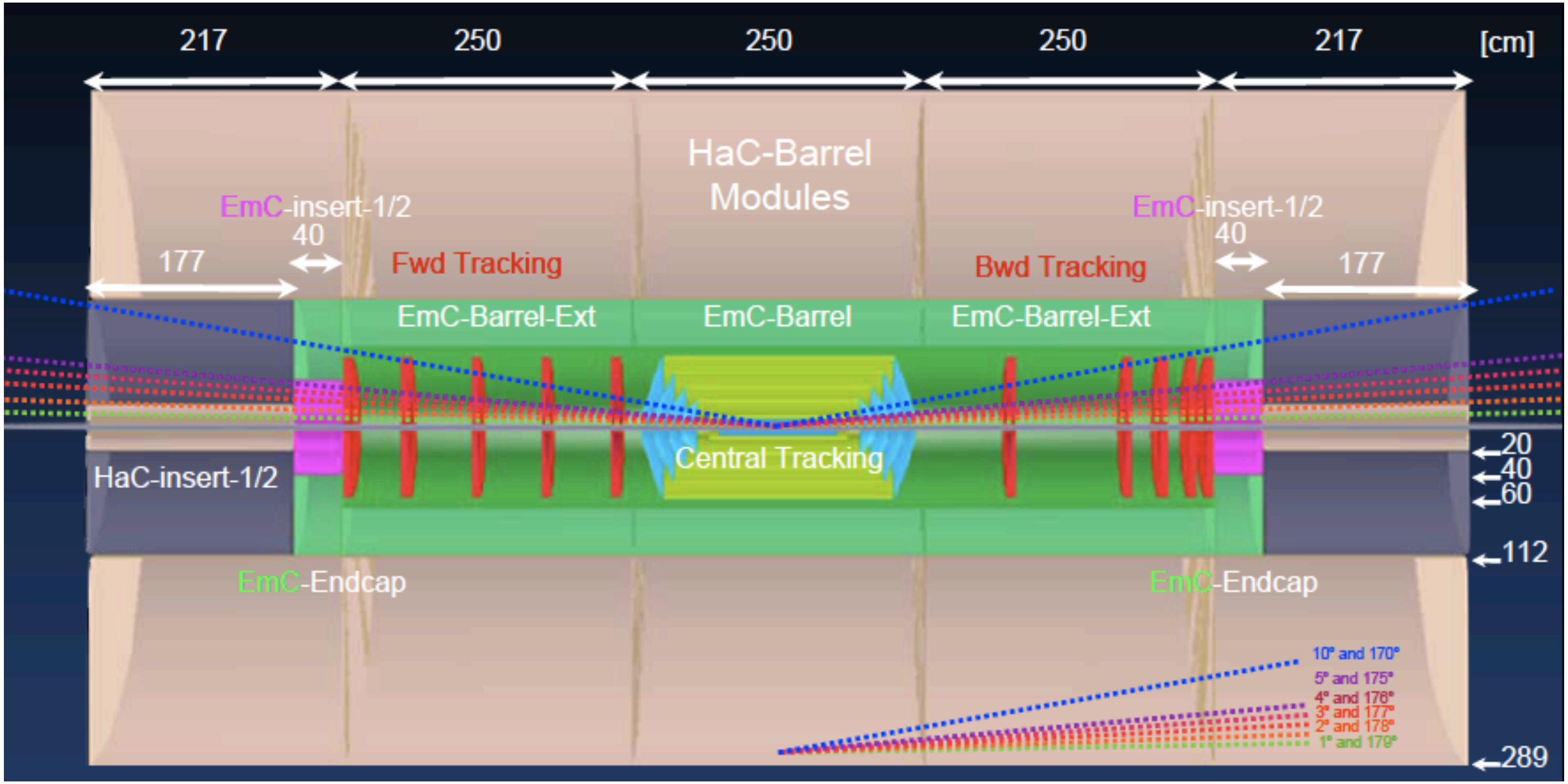
The LHeC detector

has to be at least 2 times better than the good old H1

Detector parameters were put in simulation of NC and CC (LO) cross sections with analytic calculation of systematic uncertainties.

NLO QCD fits to these 'data' were performed, on pdfs by Emmanuelle Perez, on alphas by Thomas Kluge and on electroweak couplings (and pdfs) by Claire Gwenlan

Detector under Design (low x, high Q^2, eA)

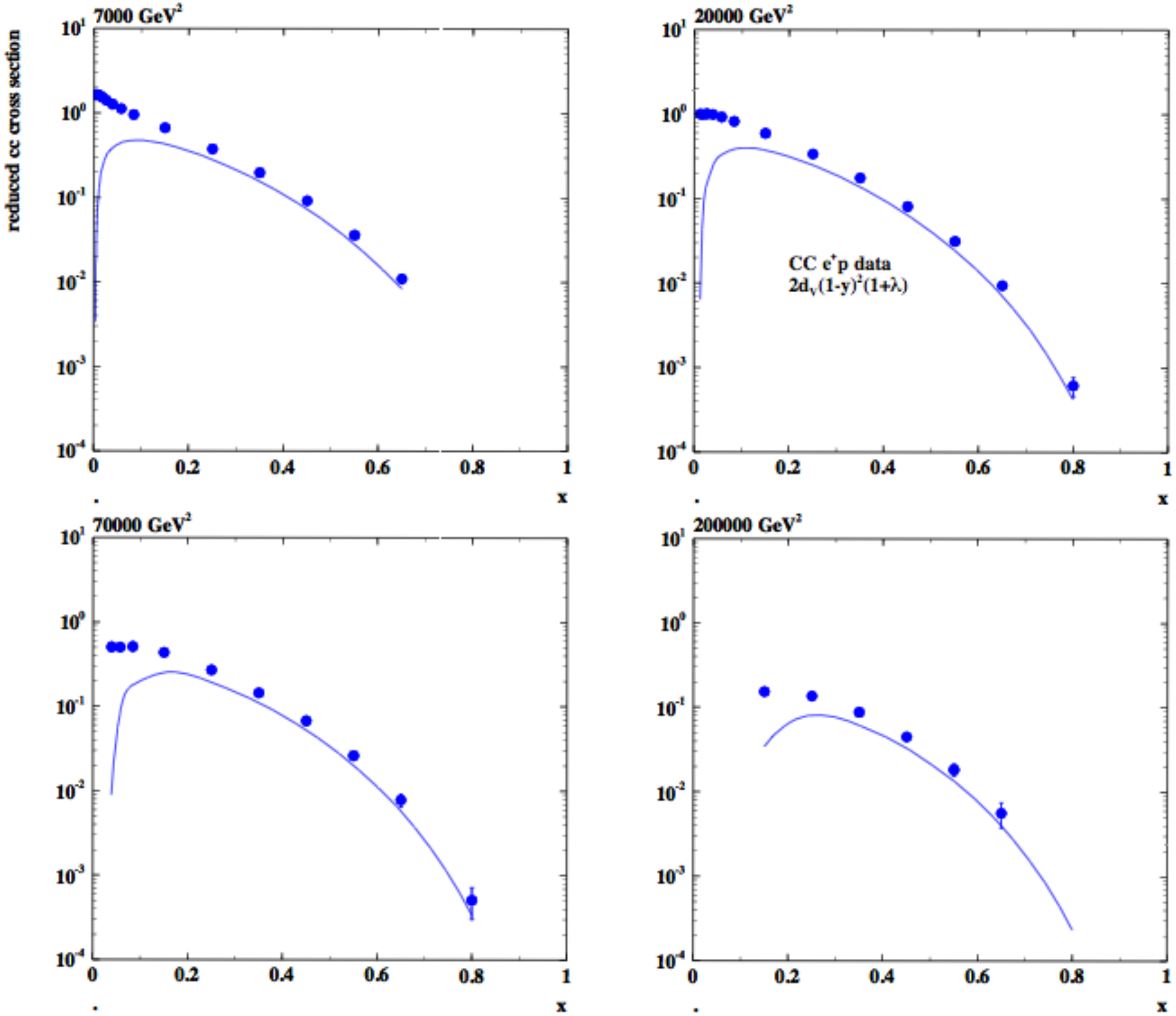


P.Kostka, A.Pollini, R.Wallny et al, 9/09

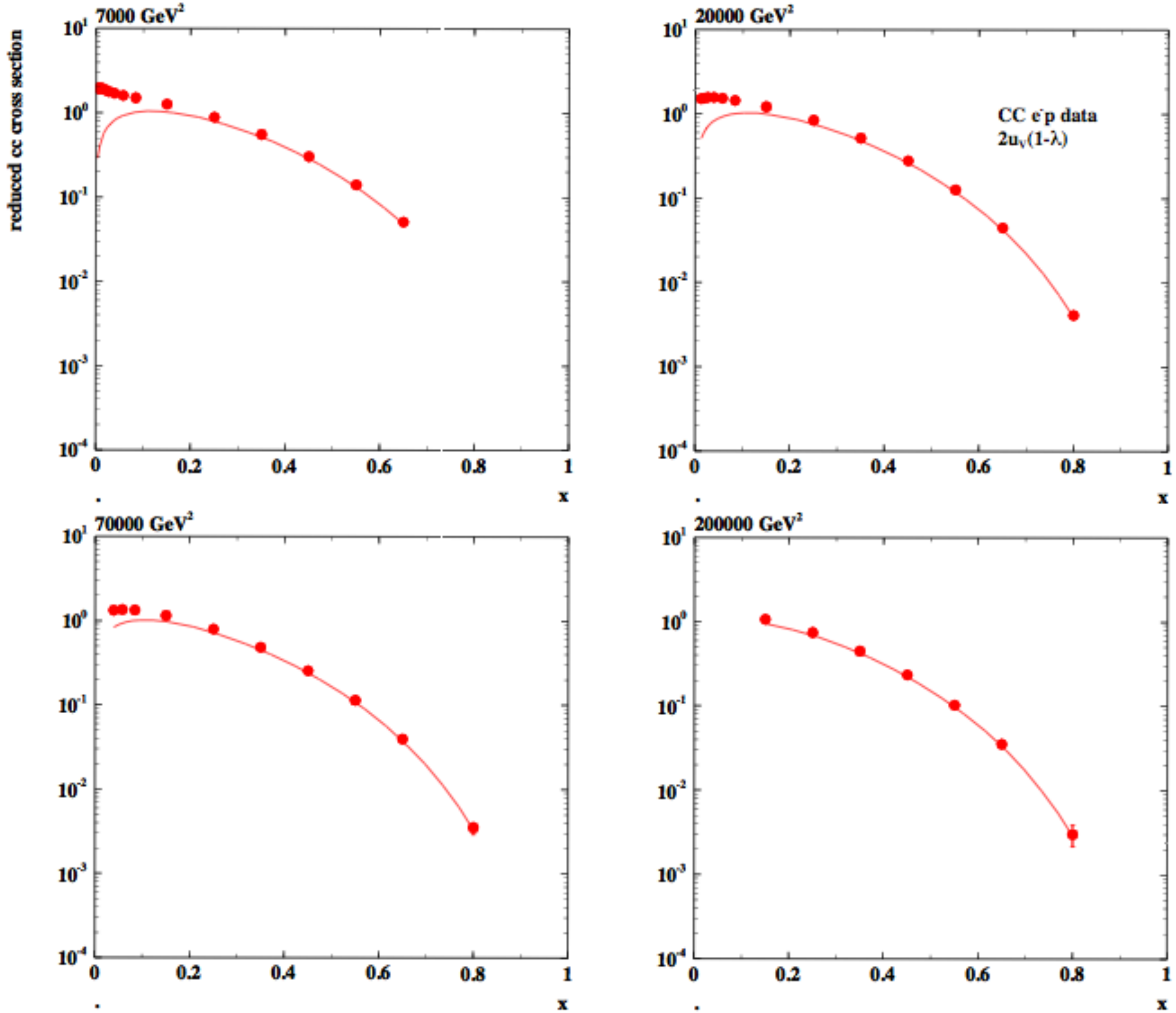
high precision, large acceptance, LHC/ILC/HERA related, Forward tagging of p, n, d

Valence Quarks

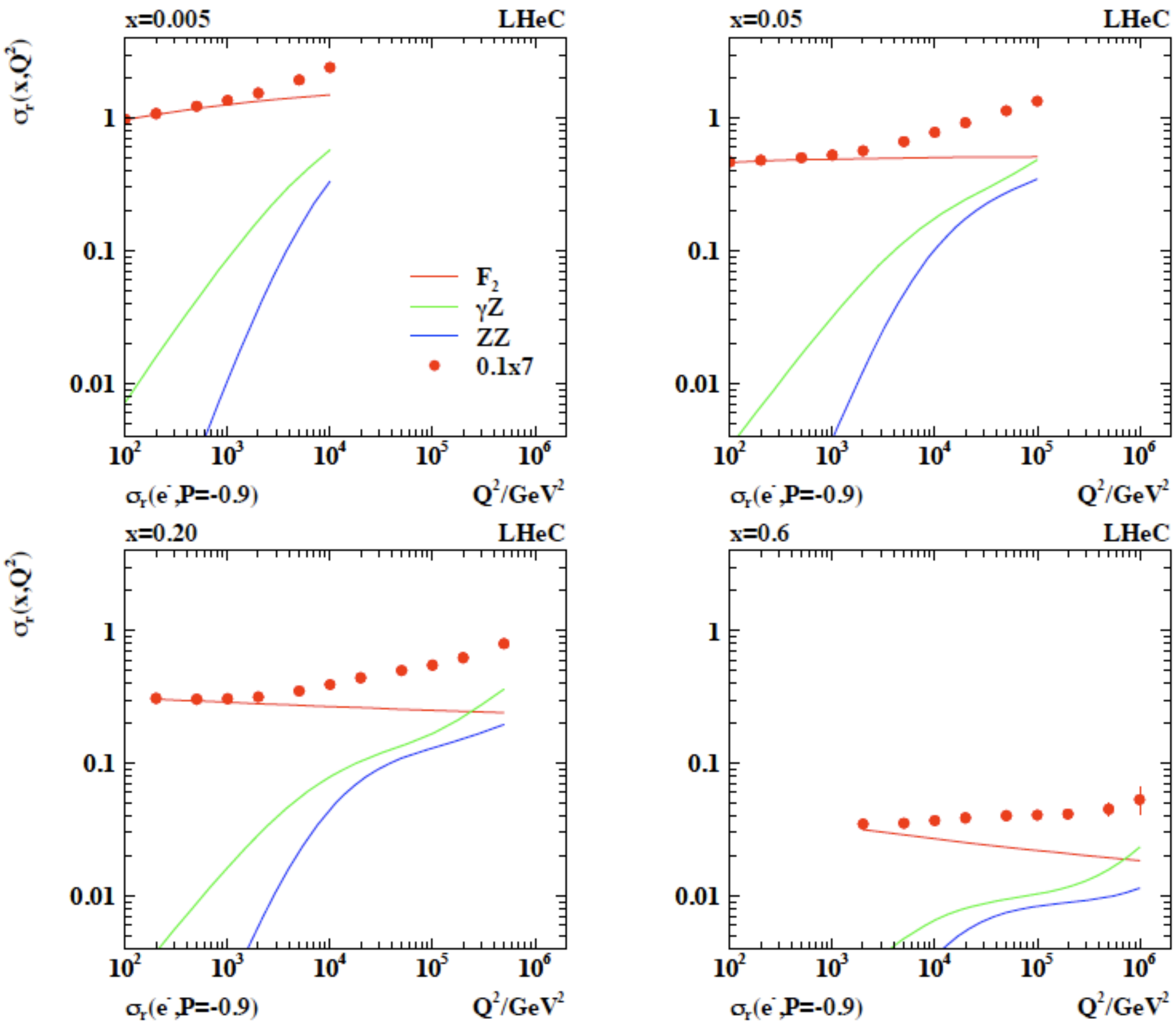
Charged currents (e+)



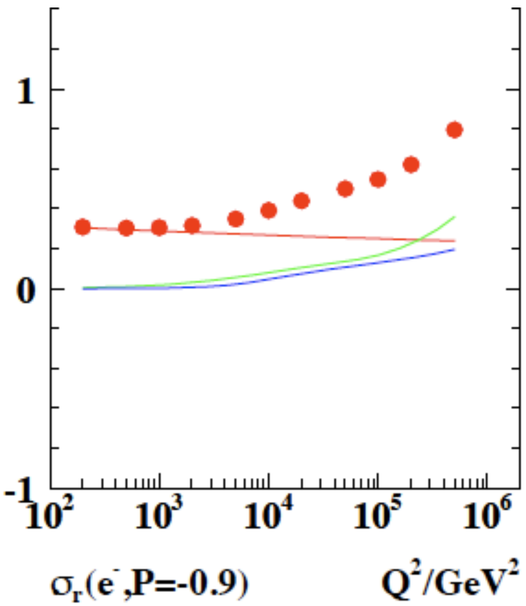
Charged currents (e-)



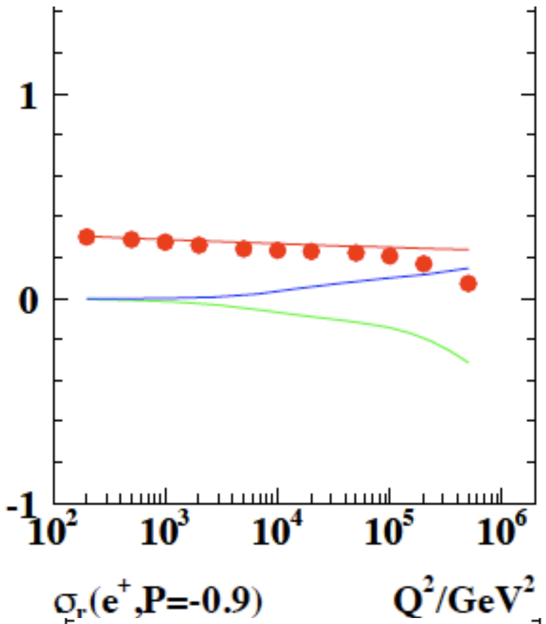
Electroweak NC Cross Section Measurements



Electroweak NC Cross Section Measurements

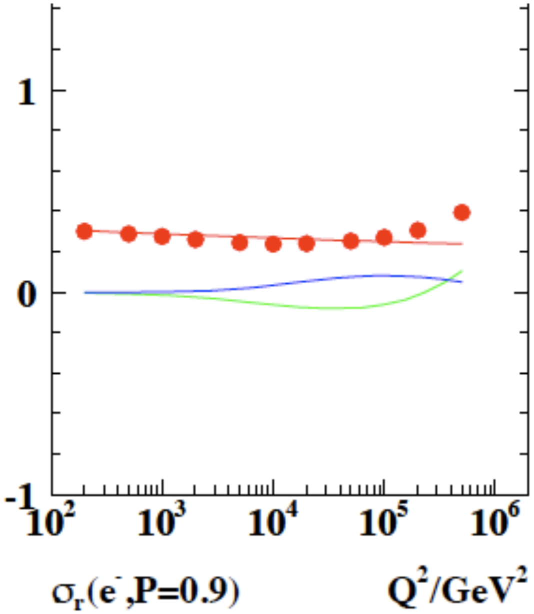


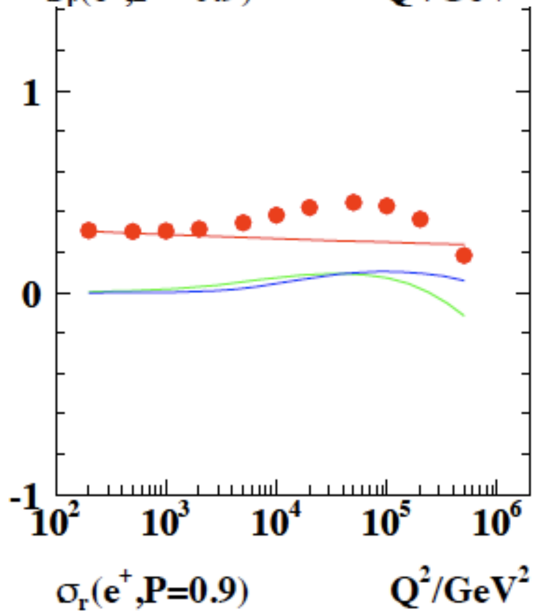
D, x=0.2



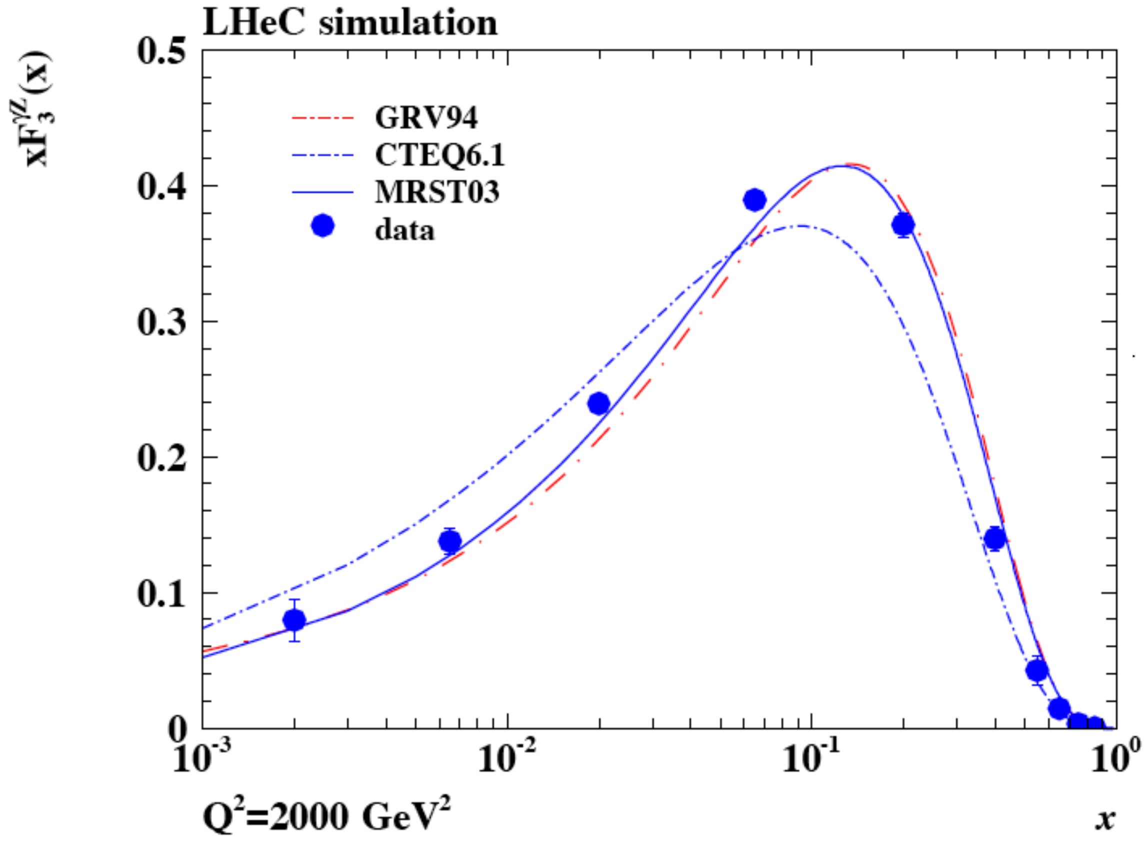
2 charges and
2 polarisations
very desirable
for electroweak
physics and the
new spectroscopy
should that appear.

Z effects depend
on charge and
polarisation.



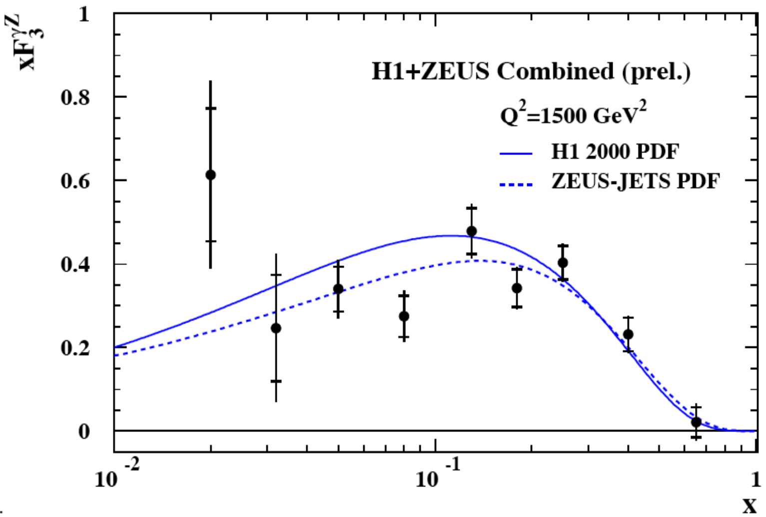


$xF_3^{\gamma Z}$



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

HERA I



Valence quarks at low x

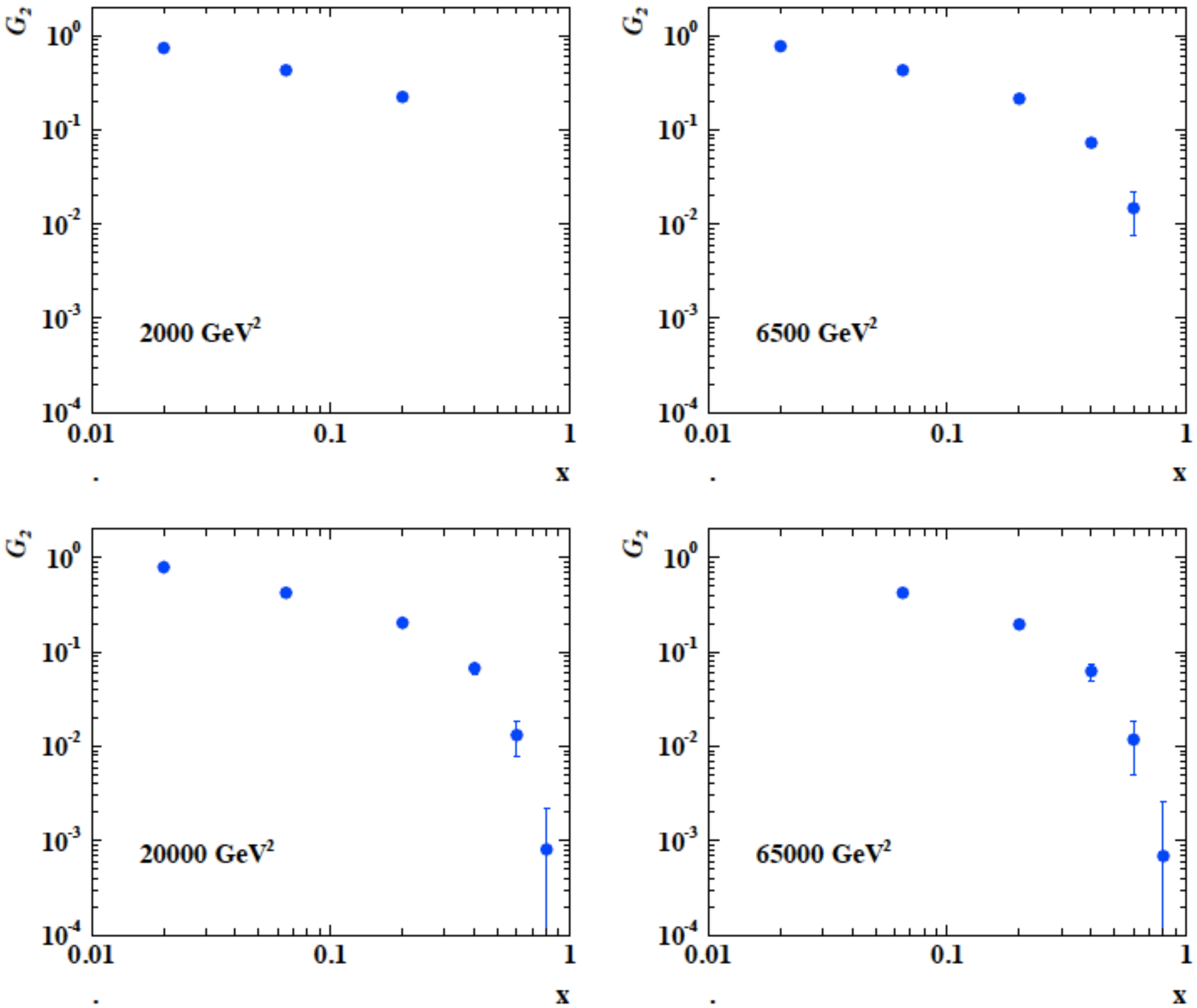
or/and unexpected sea

asymmetries

$$\Delta_u = (u_{sea} - \overline{u} + c - \overline{c})$$
$$\Delta_d = (d_{sea} - \overline{d} + s - \overline{s})$$

from γZ interference

G_2 $=F_2^{\gamma Z}=2x\Sigma v_q e_q(q+qbar)$



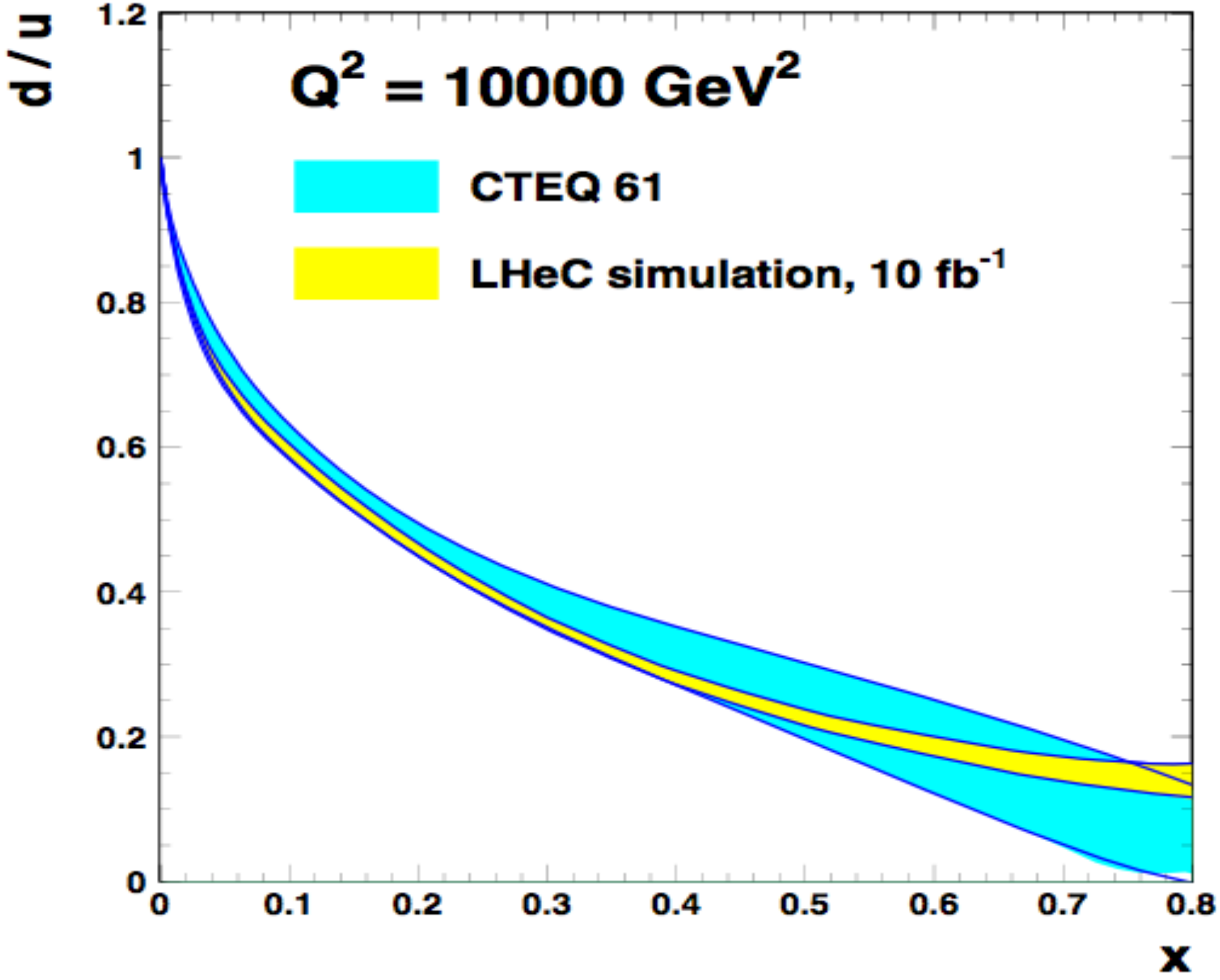
Huge PV effects in polarisation asymmetry

Scenario C:

50*7000 GeV^2
e^- (P=±0.4)
1fb^{-1}

CC and NC provide accurate determination and separation of valence quark distributions

d/u at large x

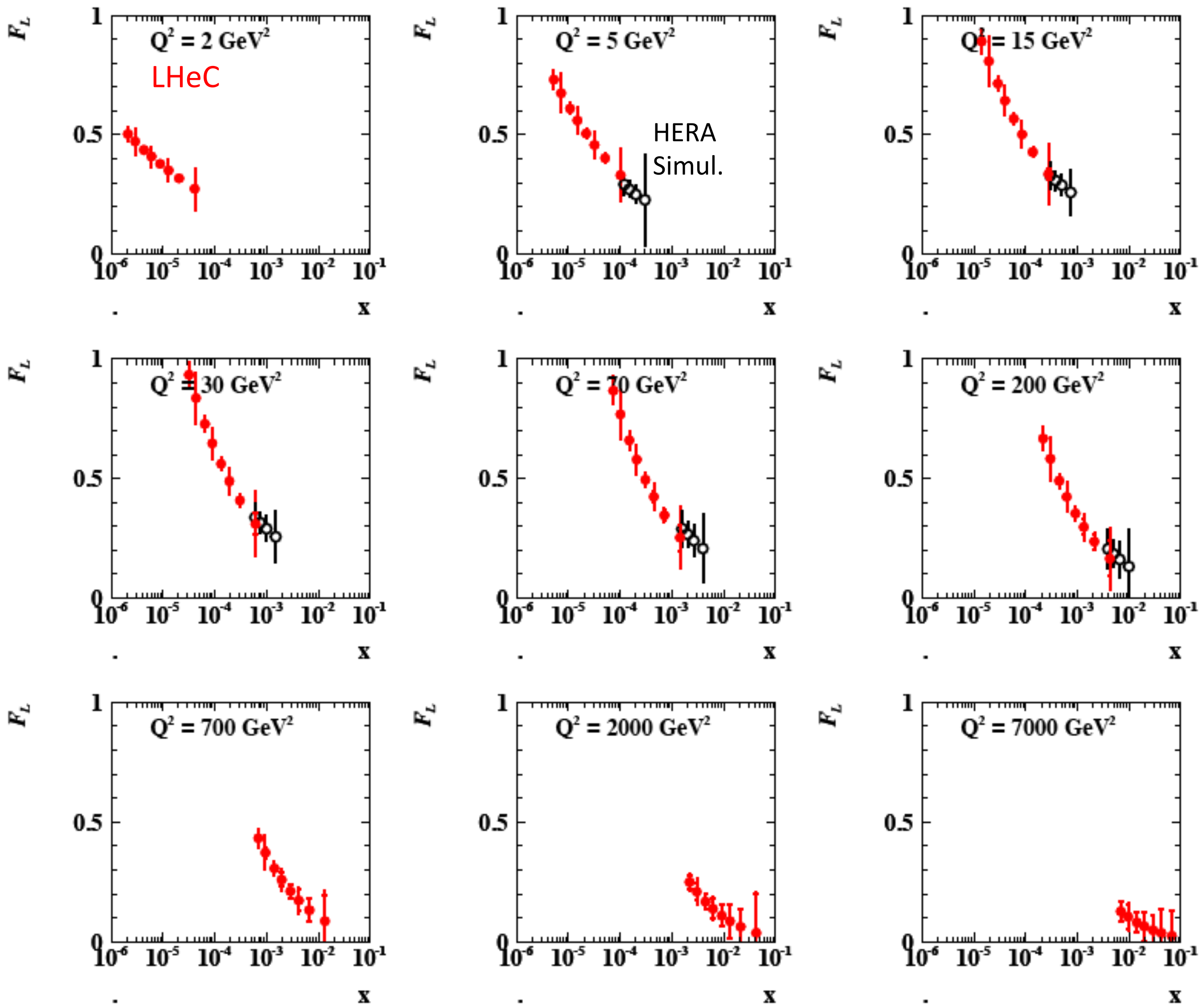


E.Perez

Constraints at Low x

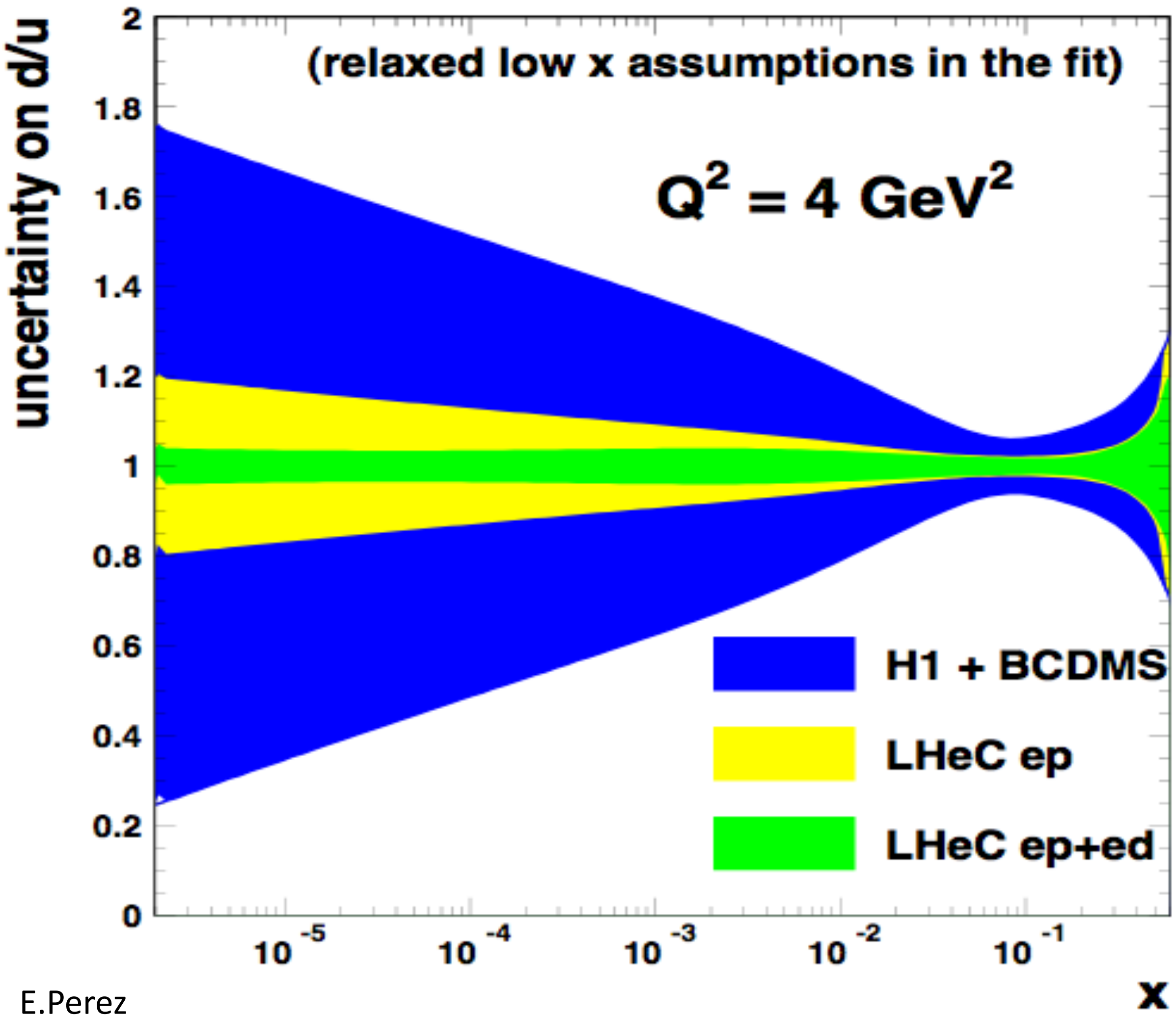
Simulated F_L Measurement at the LHeC

F_L takes long (1986-2010)…



F_L and F_2 provide crucial information at low x → strong constraint on gluon

d/u at low x from deuterons



E.Perez

Note
all QCD fits
assume
u=d
at low x

No constraint
from HERA,
Just

$$F_2 \simeq \frac{2}{9} \cdot (4 + \frac{1}{1-f_s}) \cdot x\bar{u}.$$

[some constraint
from LHC (W,Z)
but at 10^4 GeV^2]

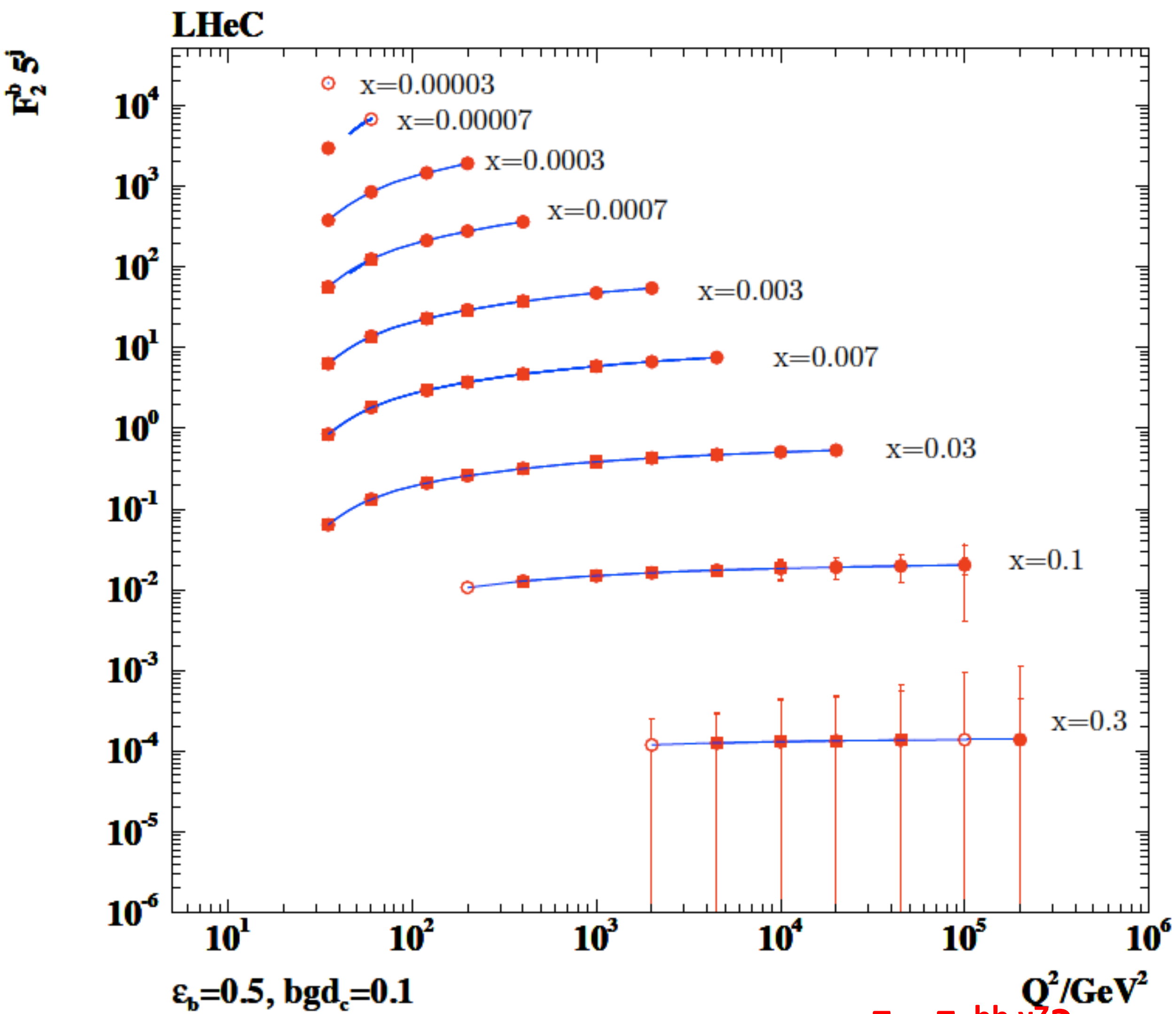
Control shadowing
with diffraction!

Tag spectator
protons in eD=en
collisions!

Heavy Quarks

b-c-t-s

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

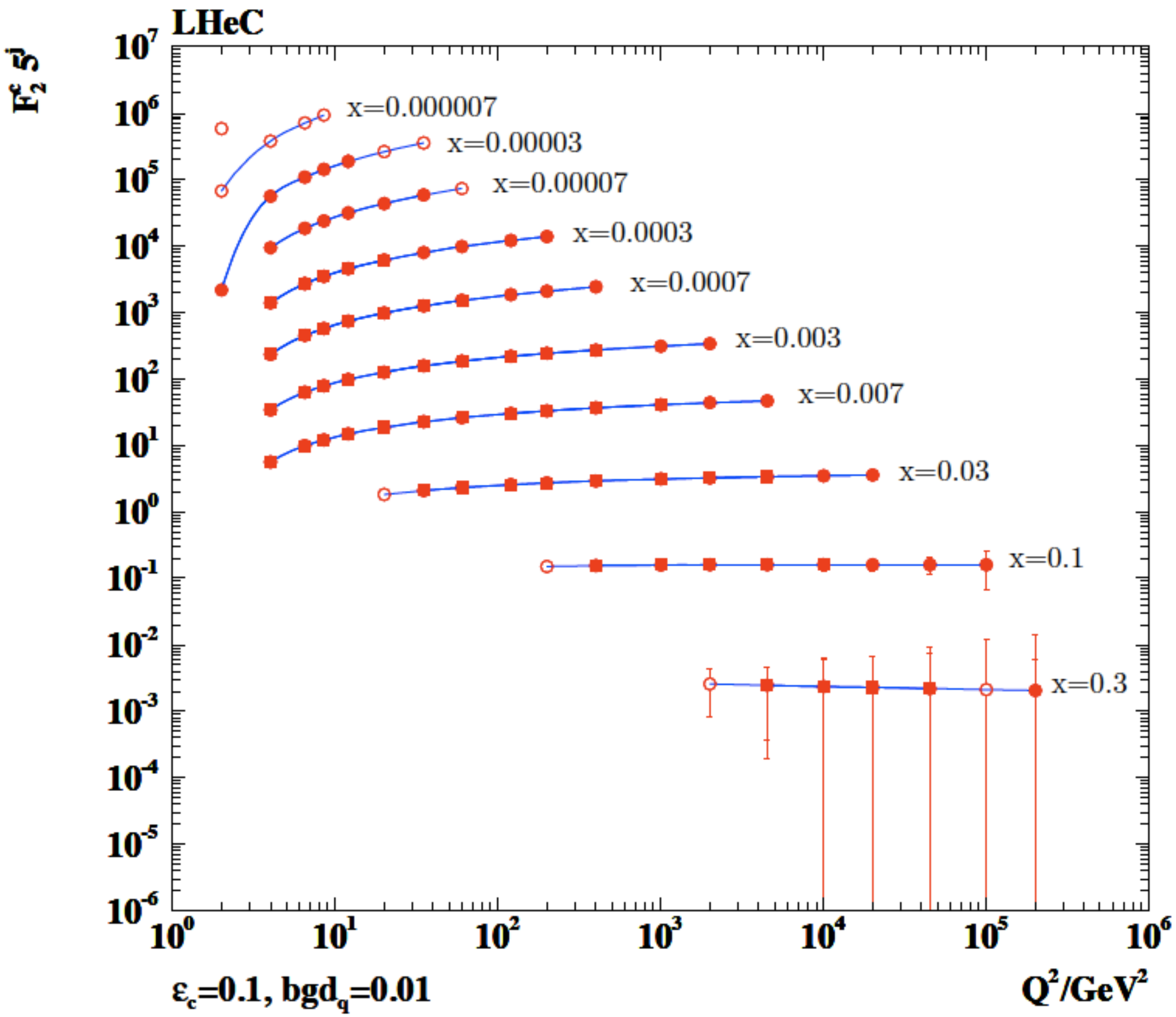
Beauty may become crucial if MSSM Higgs is found

open: 1^o

closed: 10^o

box: 1 TeV

Charm



Systematic error dominates (so far 3%)

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

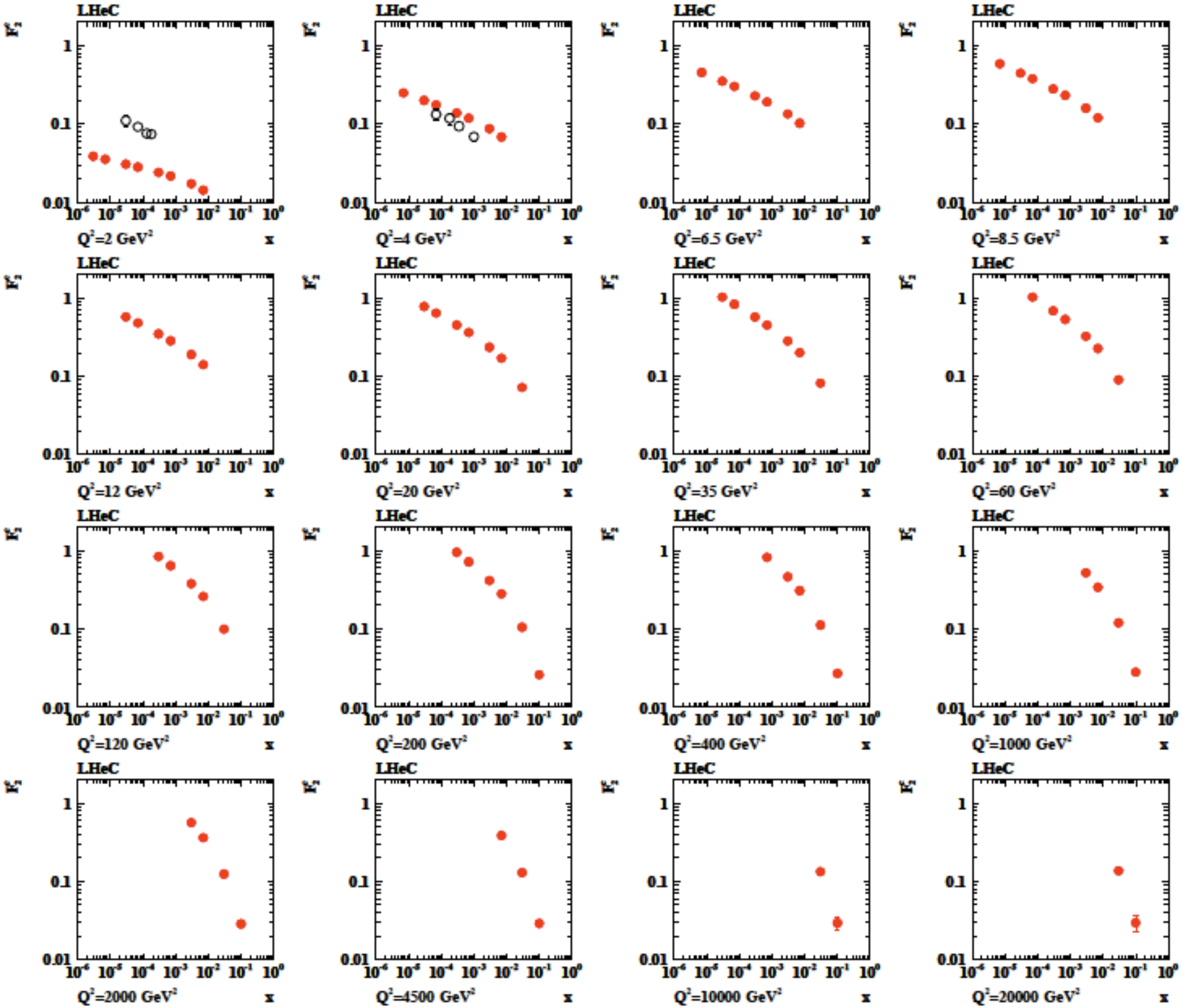
F_2^{cc} will become precision testing ground for QCD and proton structure

open: 1°

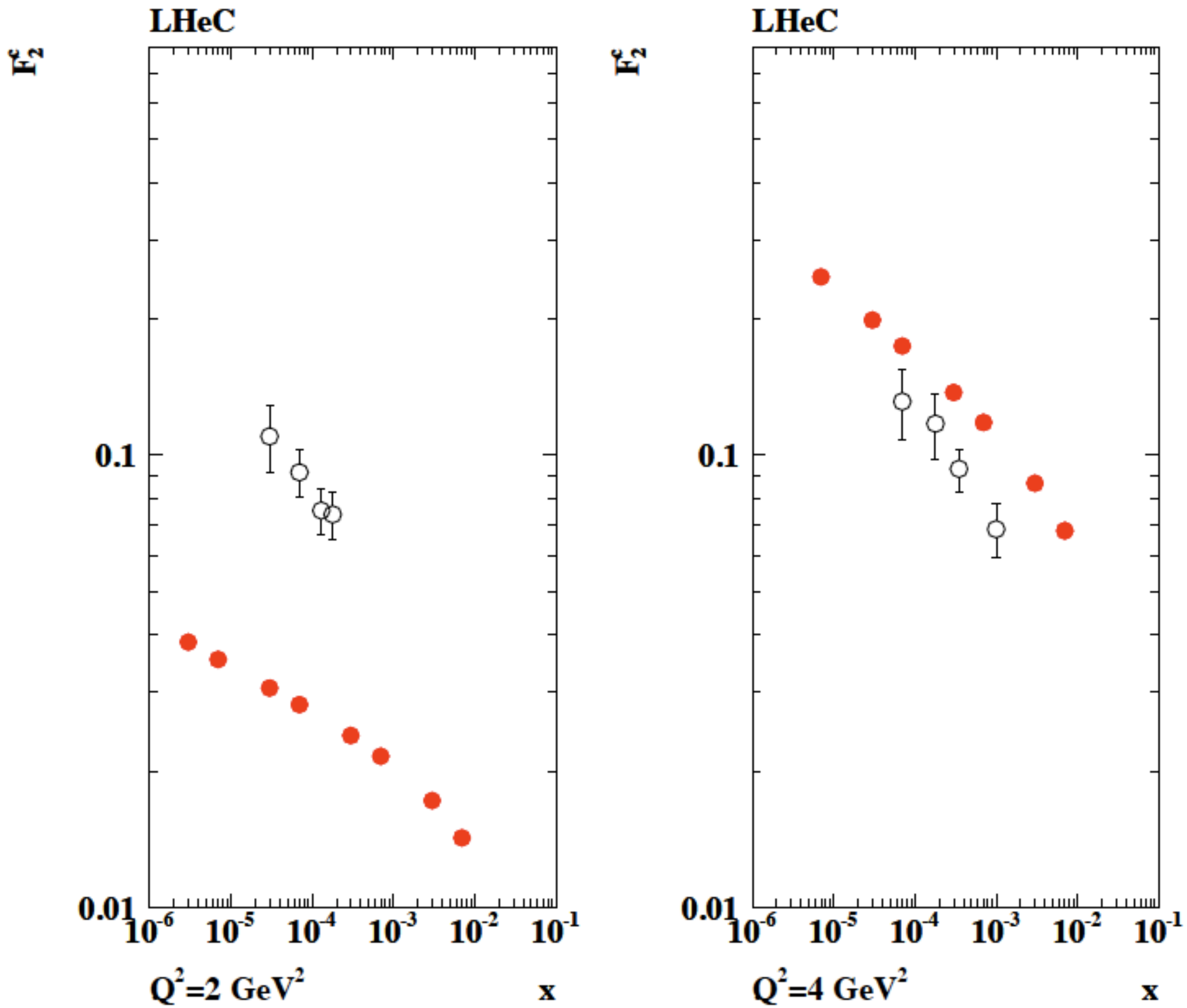
closed: 10°

box: 1 TeV

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


LHeC
F_2
x
Q²=2 GeV²
Q²=4 GeV²
Q²=6.5 GeV²
Q²=8.5 GeV²
Q²=12 GeV²
Q²=20 GeV²
Q²=35 GeV²
Q²=60 GeV²
Q²=120 GeV²
Q²=200 GeV²
Q²=400 GeV²
Q²=1000 GeV²
Q²=2000 GeV²
Q²=4500 GeV²
Q²=10000 GeV²
Q²=20000 GeV²

Charm

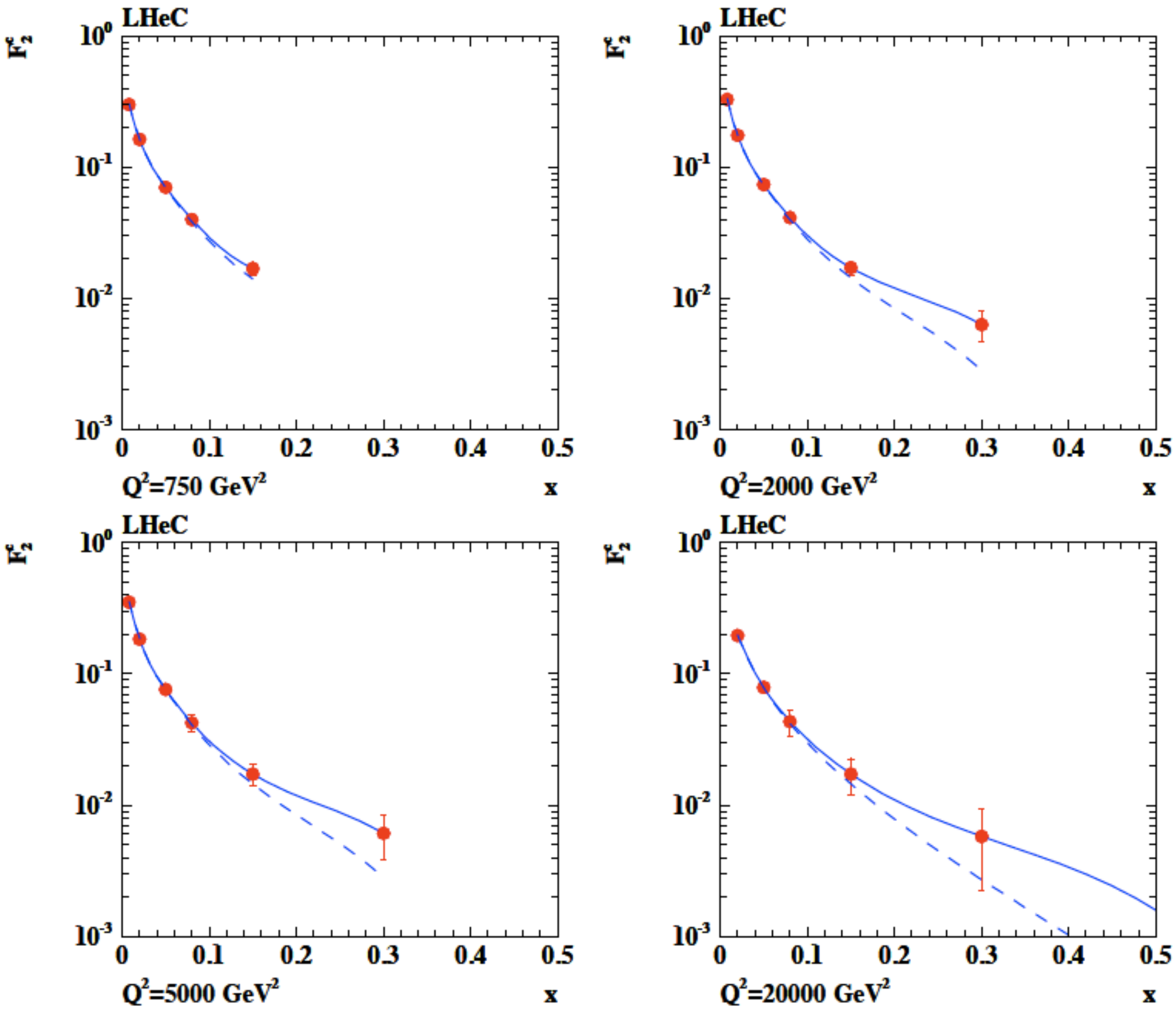


open: H1 ZEUS 2010

closed: LHeC
using H1pdf09 LO
for illustration

Have to make good
i.e. better and complete
plots to demonstrate
potential of LHeC
vs HERA and vs THY

Intrinsic Charm ??

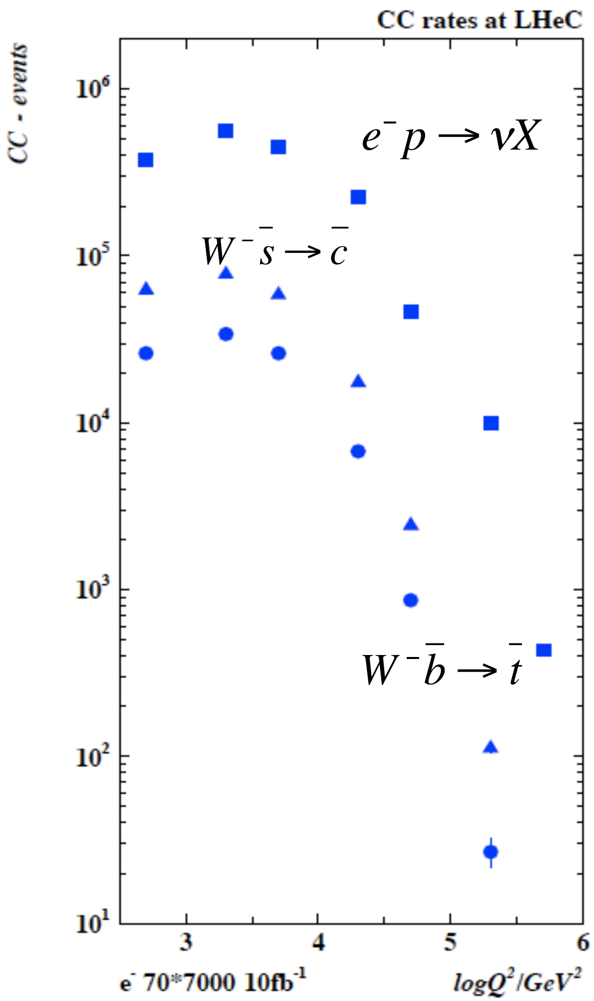


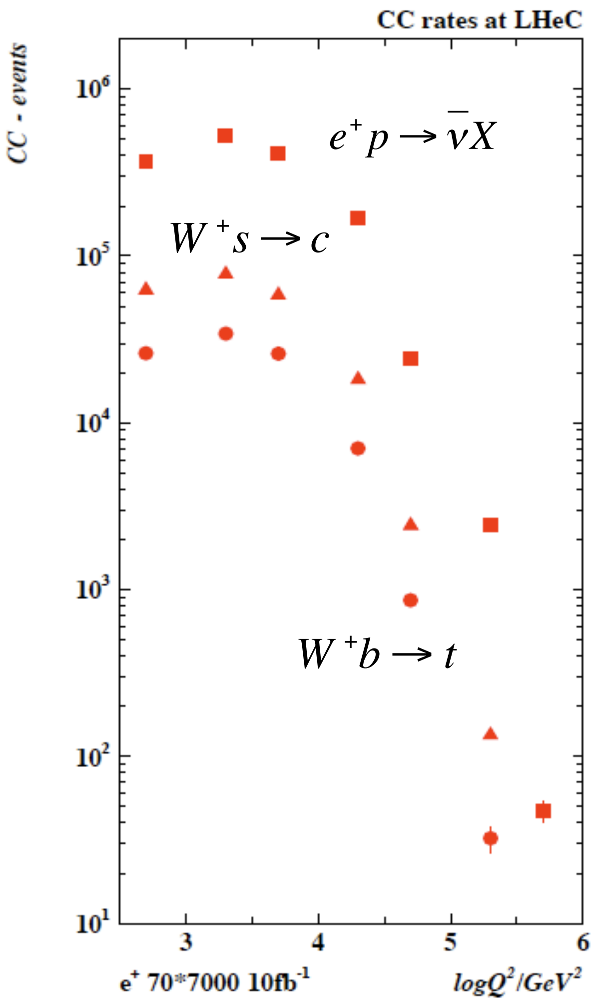
CTEQ6 with (solid) and w/o (dashed) intrinsic charm

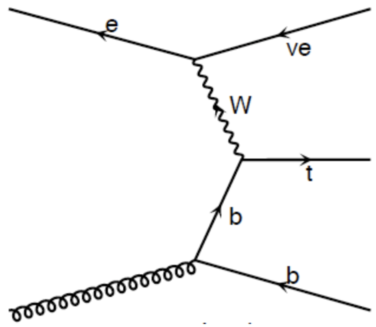
To access the high x region one needs to tag charm in fwd direction and lower the proton beam energy and get high luminosity. Worth a remark in the CDR

Cf D0
PRL 102, 192002 (2009)
Thanks to Stan.

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





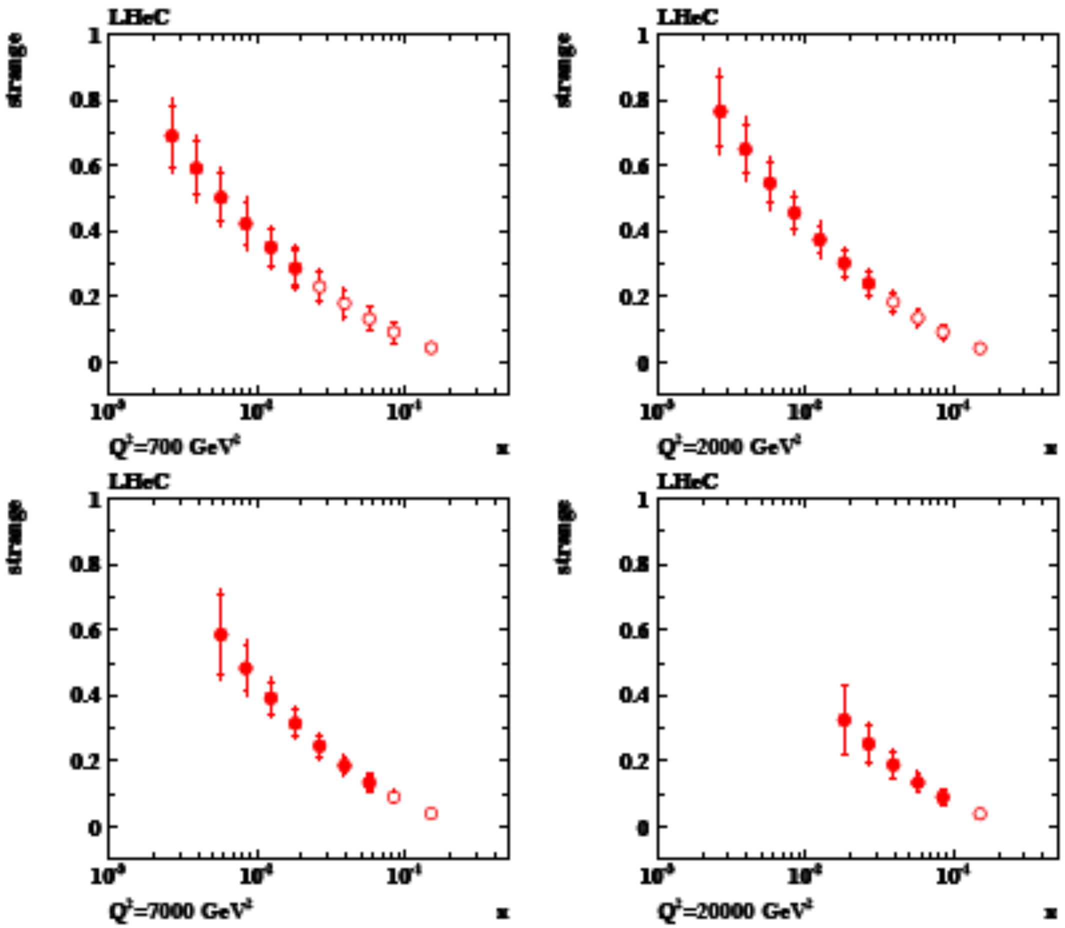


LHeC is a single top and anti-top quark factory

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



$W^+ s \rightarrow c$

$1\, fb^{-1}$

$\varepsilon_c = 0.1$

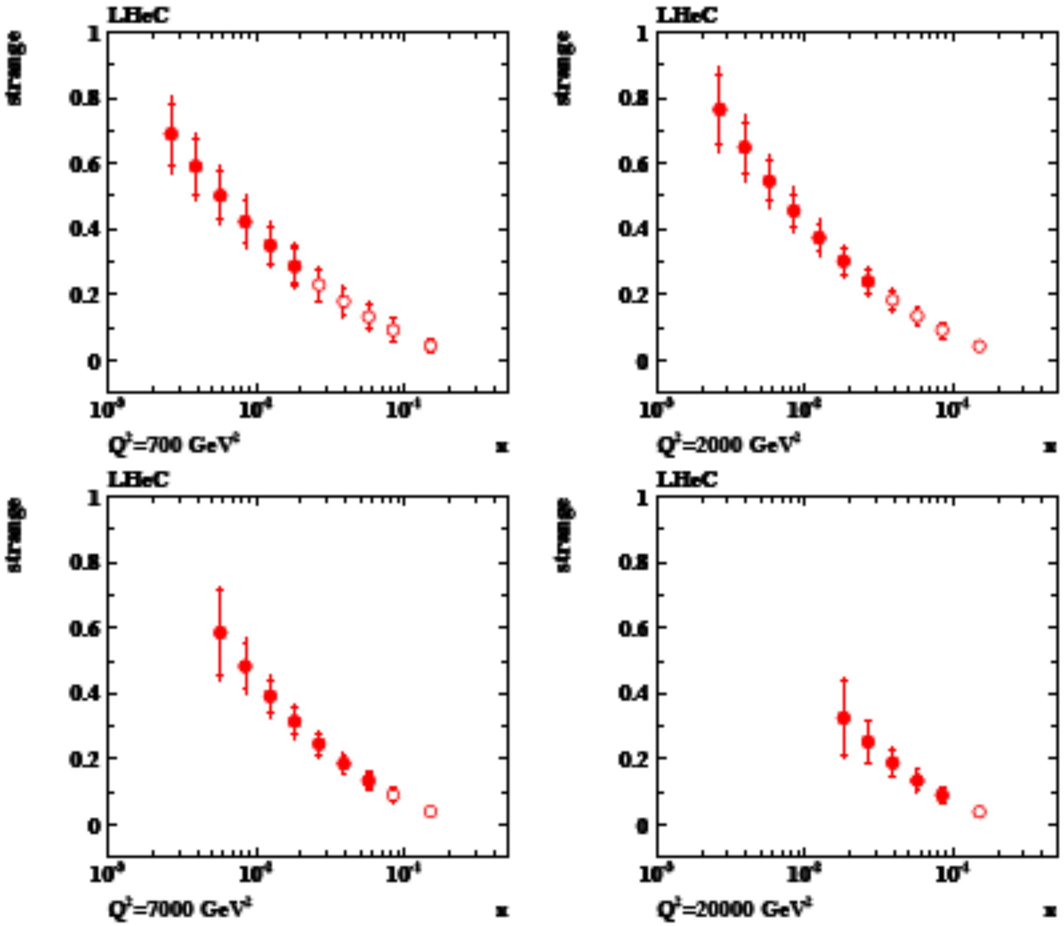
$\varepsilon_q = 0.01$

$\delta_{syst} = 0.1$

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

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

Anti-Strange Quark



$W^{-} sbar \rightarrow cbar$

$1\,fb^{-1}$

$\varepsilon_c = 0.1$

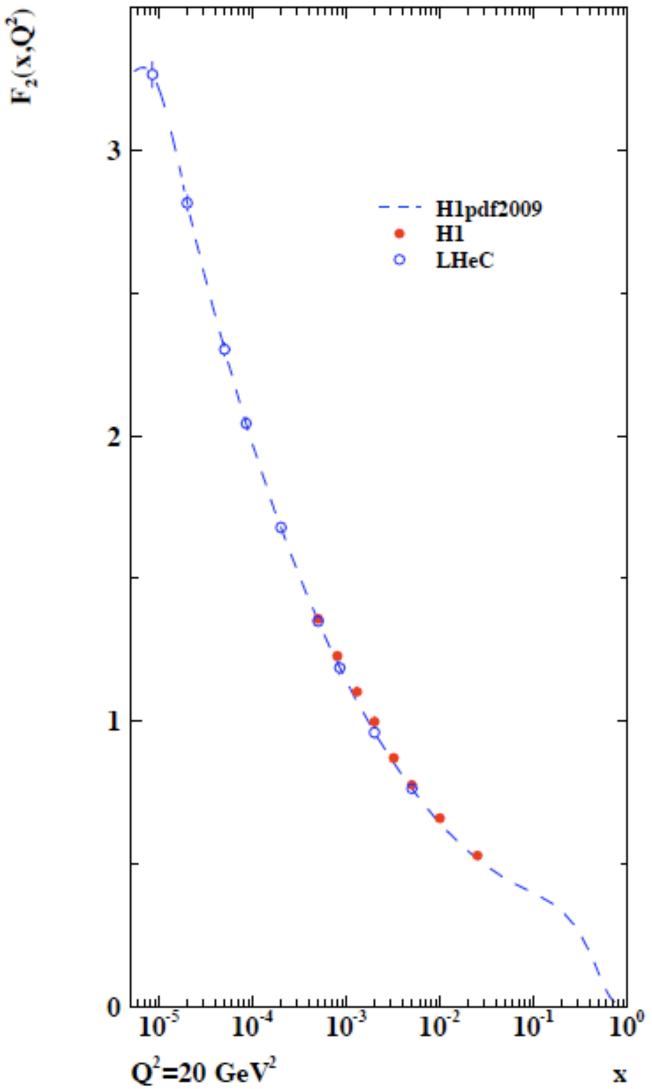
$\varepsilon_q = 0.01$

$\delta_{syst} = 0.1$

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

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

Summary



The LHeC is the first DIS machine with the potential to completely unfold the partonic structure of the proton. This should remove the 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 required on the structure function measurements (HERA + LHeC) and the parton distributions.