Scenarios and Measurements with the LHeC

Luminosity-Energy-Beams
Systematic Errors
Kinematics
Electroweak effects
Pdf's
Detector Requirements

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Divonne , 2.9.2009

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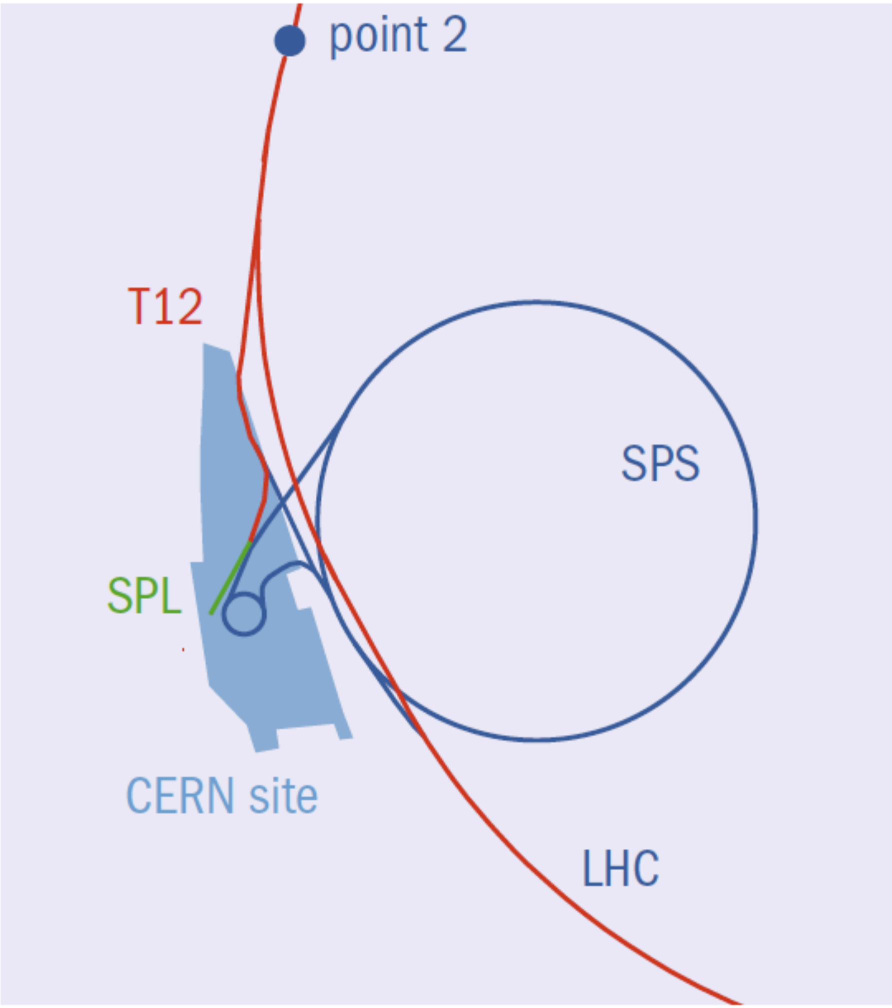


Fig. 4. Sketch of a possible layout to inject an electron beam into the LHC ring, using the SPL and the TI2 connection to the LHC tunnel.

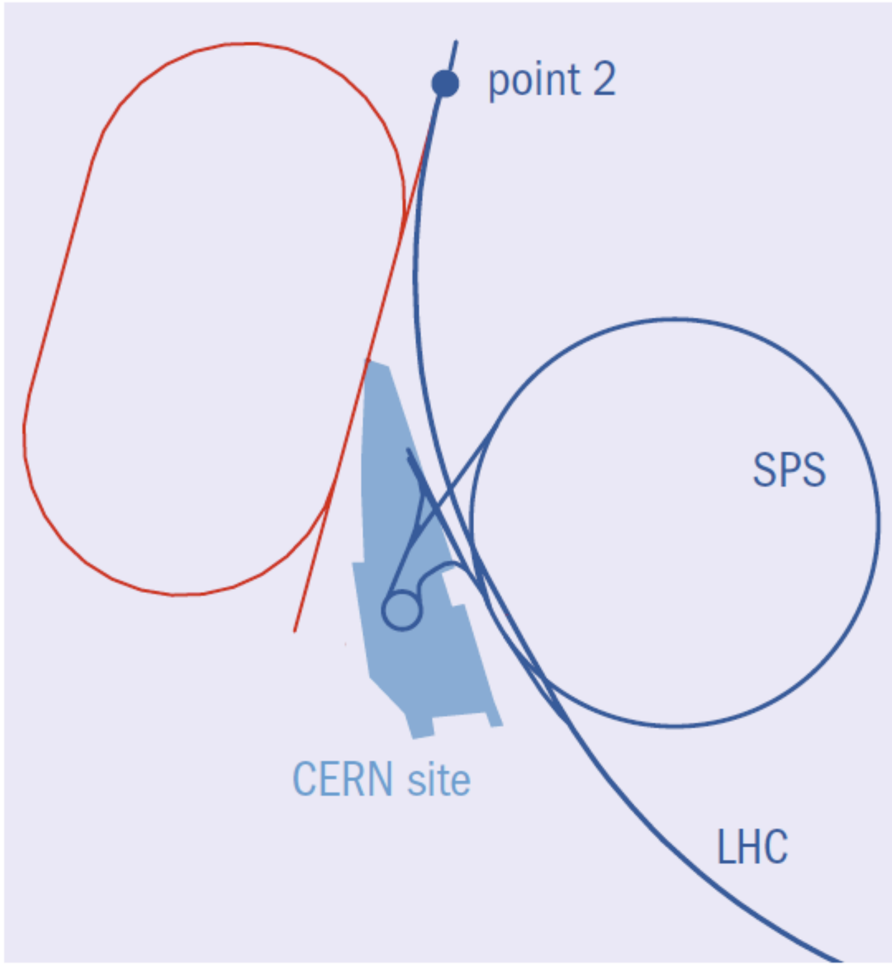


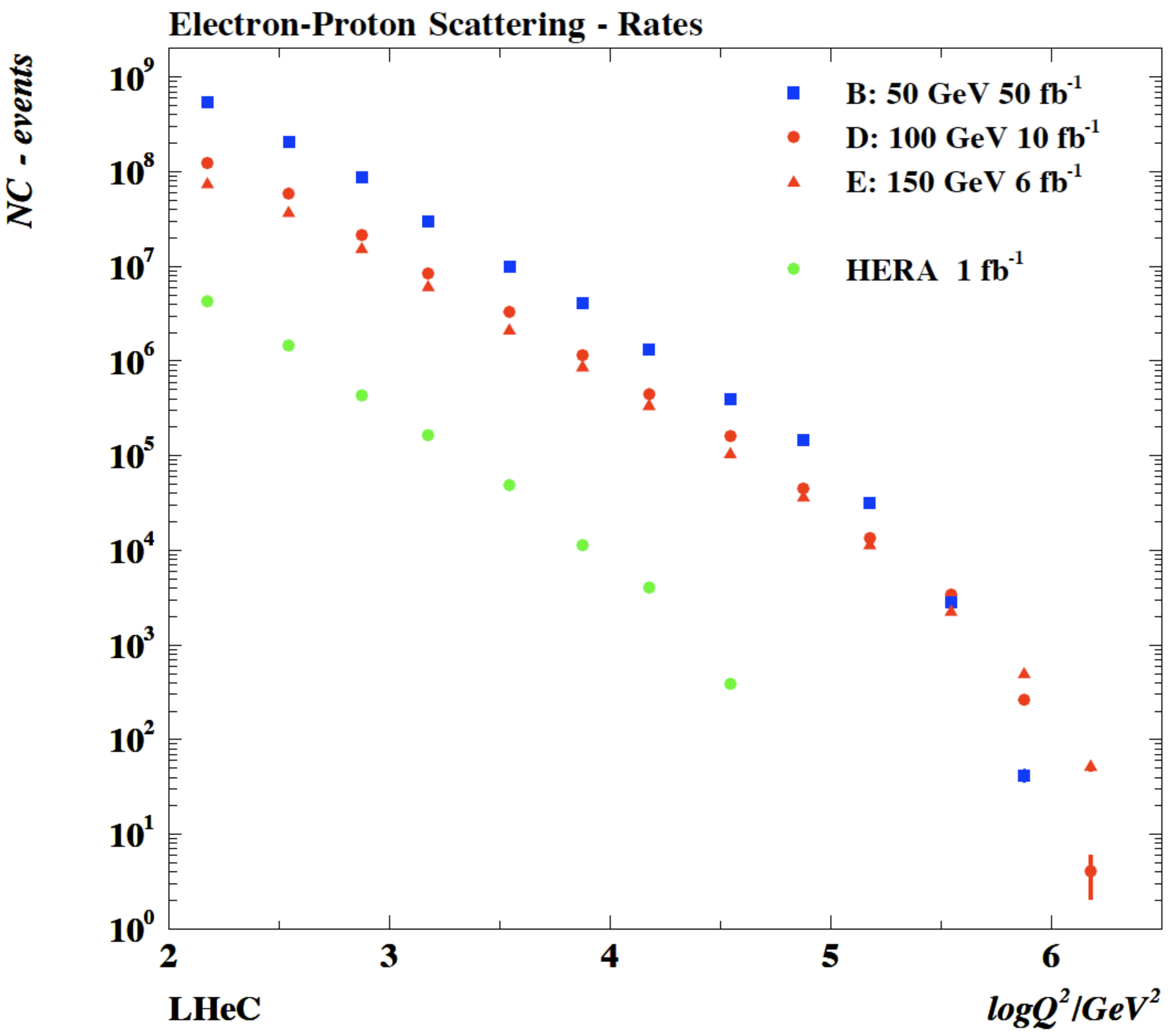
Fig. 5. A possible layout in which an electron linac arrives tangentially to the LHC, after multiple passes around a "racetrack" that makes full use of the linac accelerating structures.

Simulated Default Scenarios, April 2009

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

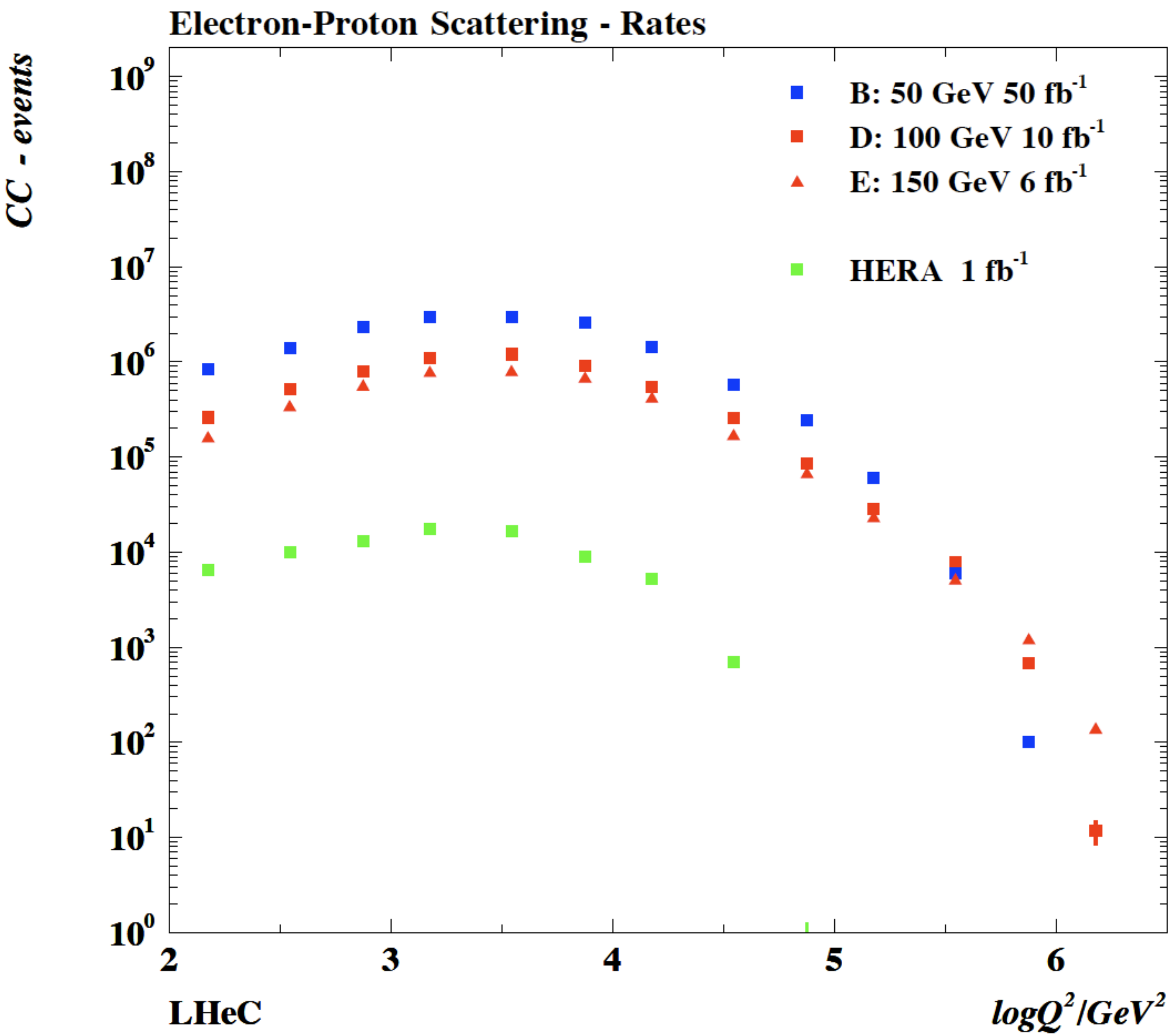
config.	E(e)	E(N)	N	∫L(e^+)	∫L(e^-)	|Pol|	$L/10^{32}$	P/MW	years	type
A	20	7	p	1	1	-	1	10	1	SPL
B	50	7	p	50	50	0.4	25	30	2	RR hiQ^2
C	50	7	p	1	1	0.4	1	30	1	RR lo x
D	100	7	p	5	10	0.9	2.5	40	2	LR
E	150	7	p	3	6	0.9	1.8	40	2	LR
F	50	3.5	D	1	1	--	0.5	30	1	eD
G	50	2.7	Pb	0.1	0.1	0.4	0.1	30	1	ePb
H	50	1	p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

Not simulated (config. G)



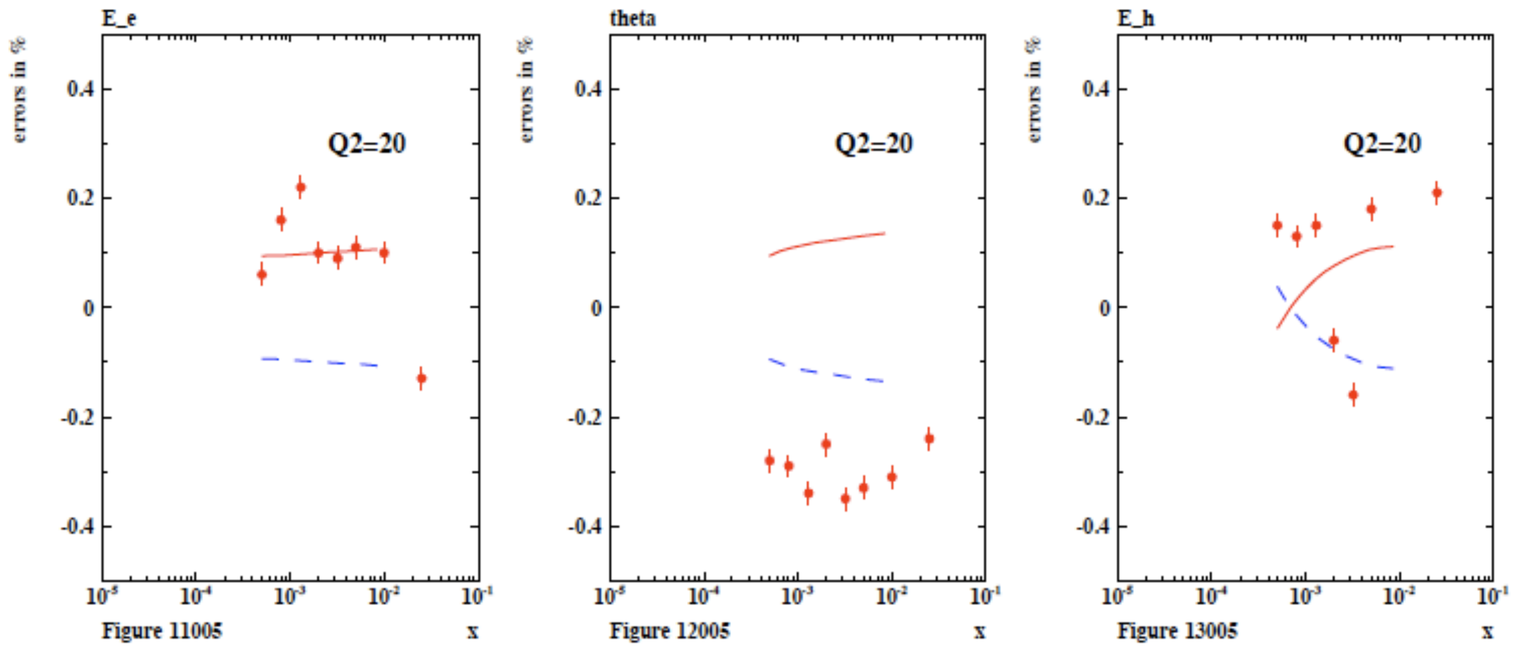
High Luminosity is short running time and high flexibility. Essential for high x, Q^2 and for semiinclusive processes (e.g.DVCS)

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 provides larger s: win-win for CC

Systematic Error Calculation (check for HERA conditions)

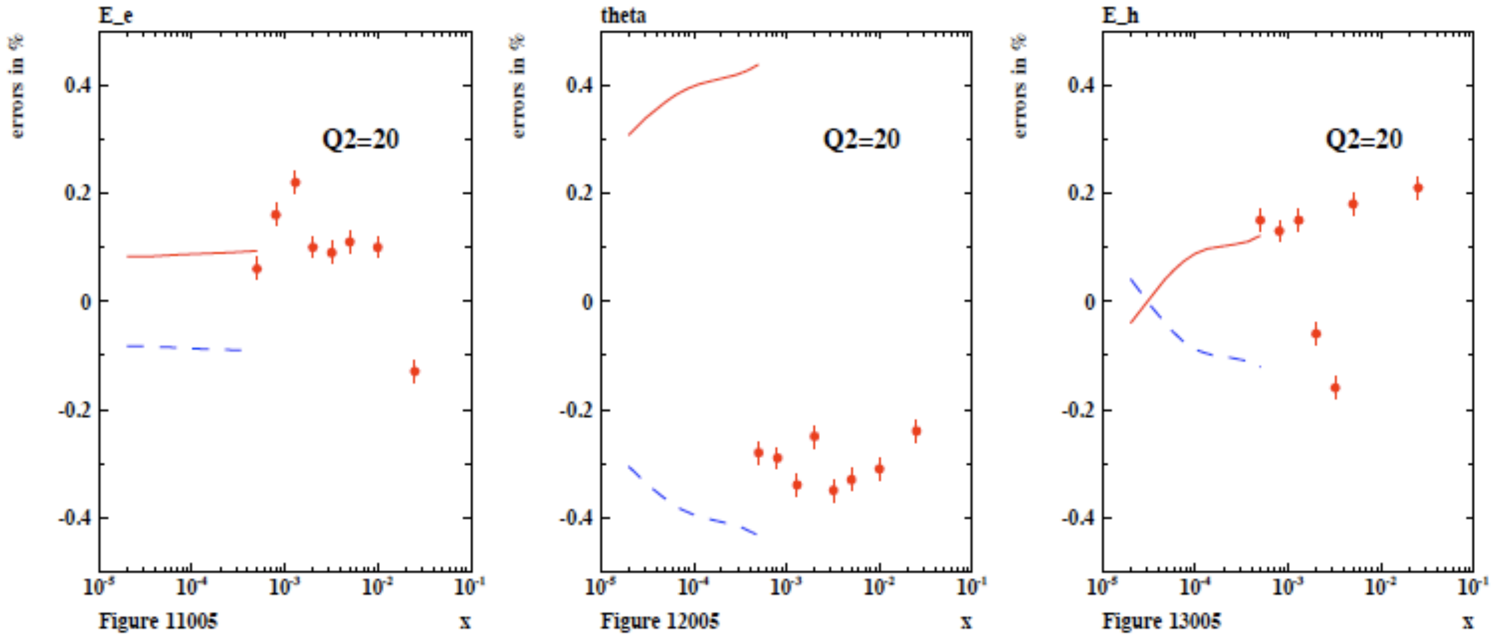


Numeric calculation (J.Bluemlein, MK, 1989) using cross section derivatives to $E_{e,}$’, θ_e,E_h

assume: 0.2 for E’, 1mrad for polar angle and 1% for E_h
compares ok with MC calculation of H12000 paper [just published] (0.2%, 2mrad, 2%)

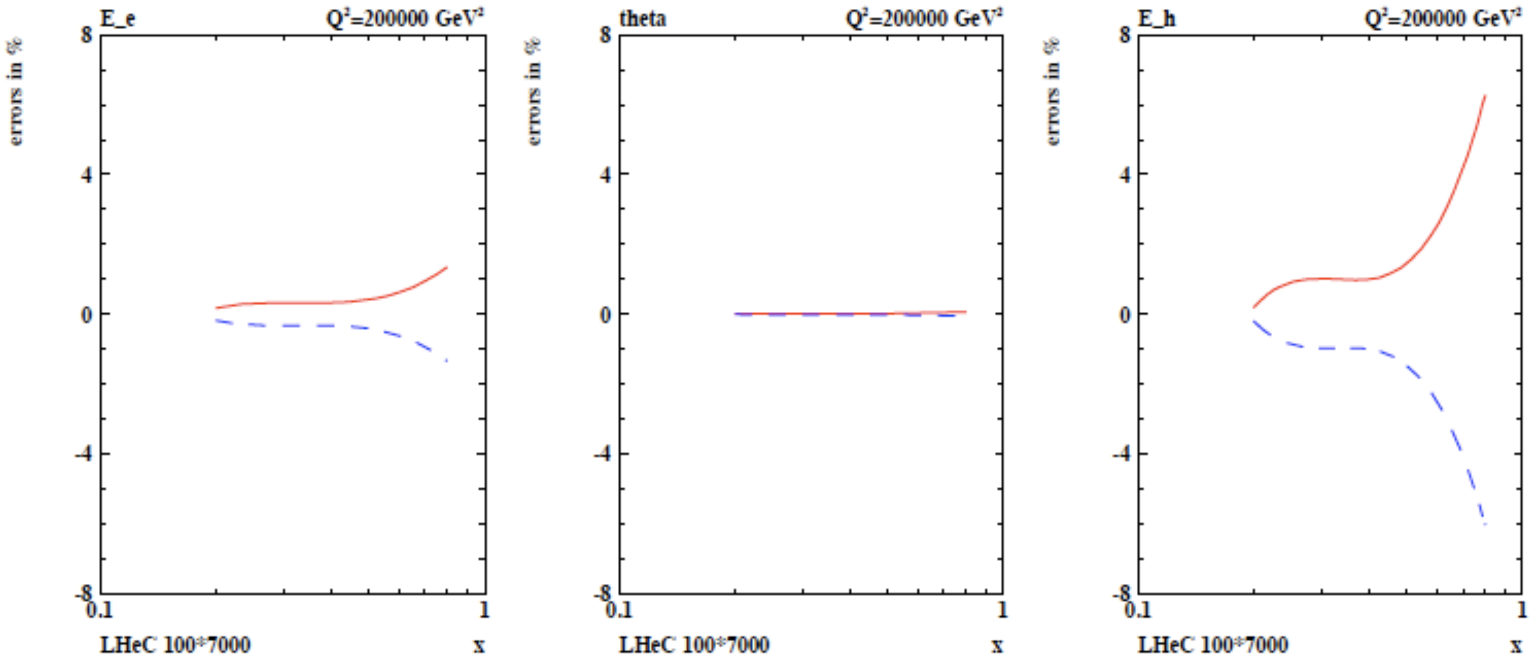
In addition: 0.5% extra efficiency, 1% yp for y>0.7, 0.5% RadCor, noise at y < 0.01

Systematic Error Calculation (LHeC Q^2 = 20)



Same error requirements for D (100 GeV * 7000 GeV): reach lower x
Polar angle error contribution rises. 0.2 mrad would imply 1% error!
→ **Need very accurate polar angle measurement at large bwd angles.**

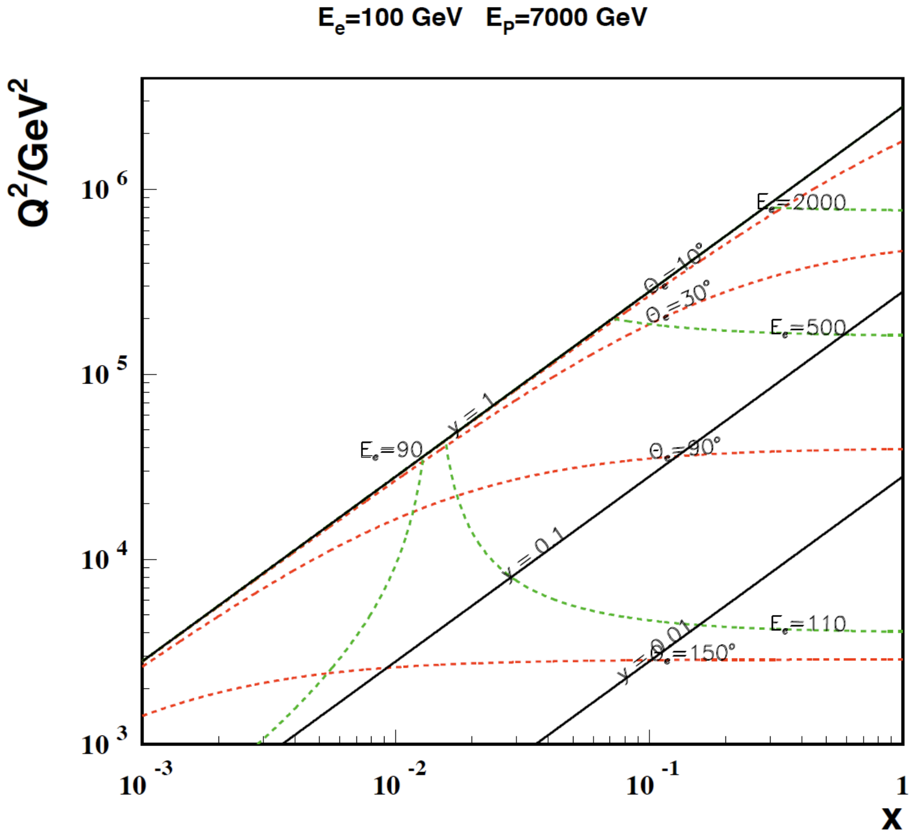
Systematic Error Calculation (LHeC $Q^2 = 2\ 10^5\ GeV^2$)

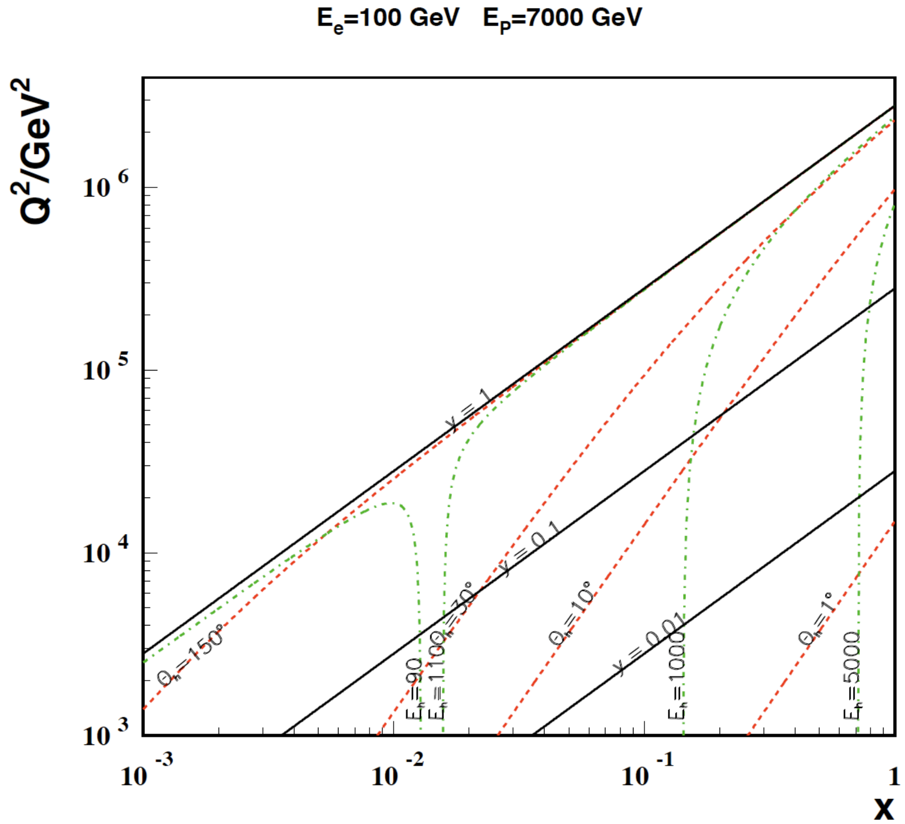


At high Q^2: measure at large x: 0.2% on E_e' may be relaxed a bit. Polar angle may be much worse than 1mrad, but for high x need very accurate hadronic energy measurement (CC in particular).

Need 1% of hadronic energy scales at very large E_h – Accuracy requirements depend on topology!

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.

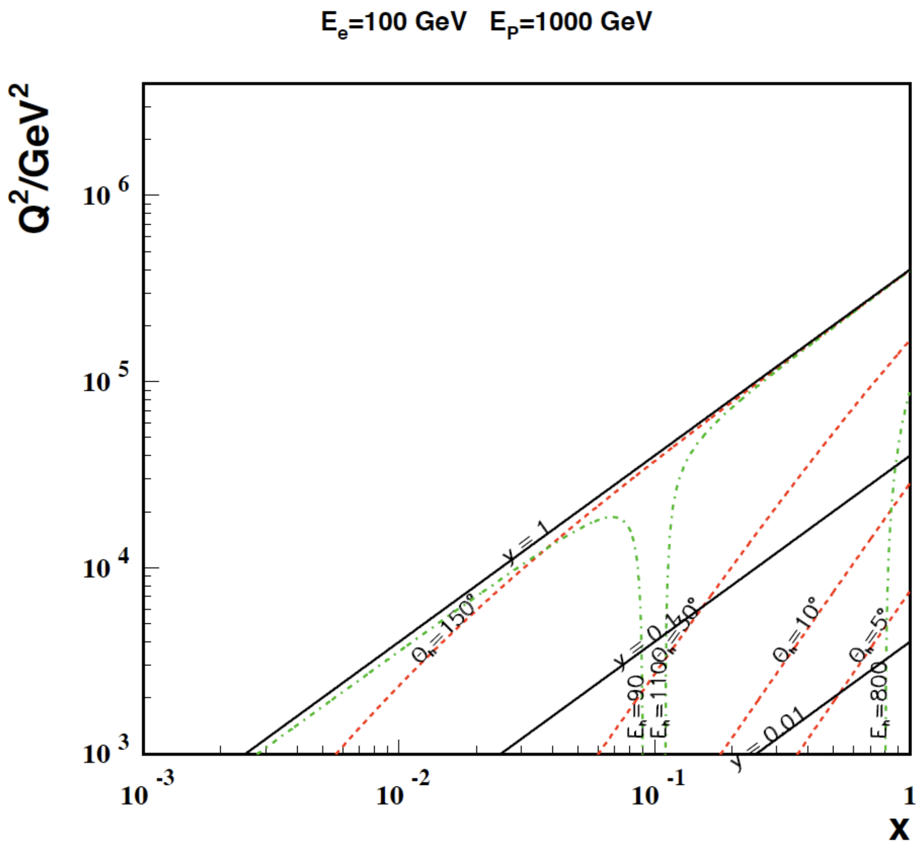
→**Need forward elm. calorimeter of few TeV energy range down to 10°and below with reasonable calibration accuracy.**

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%**

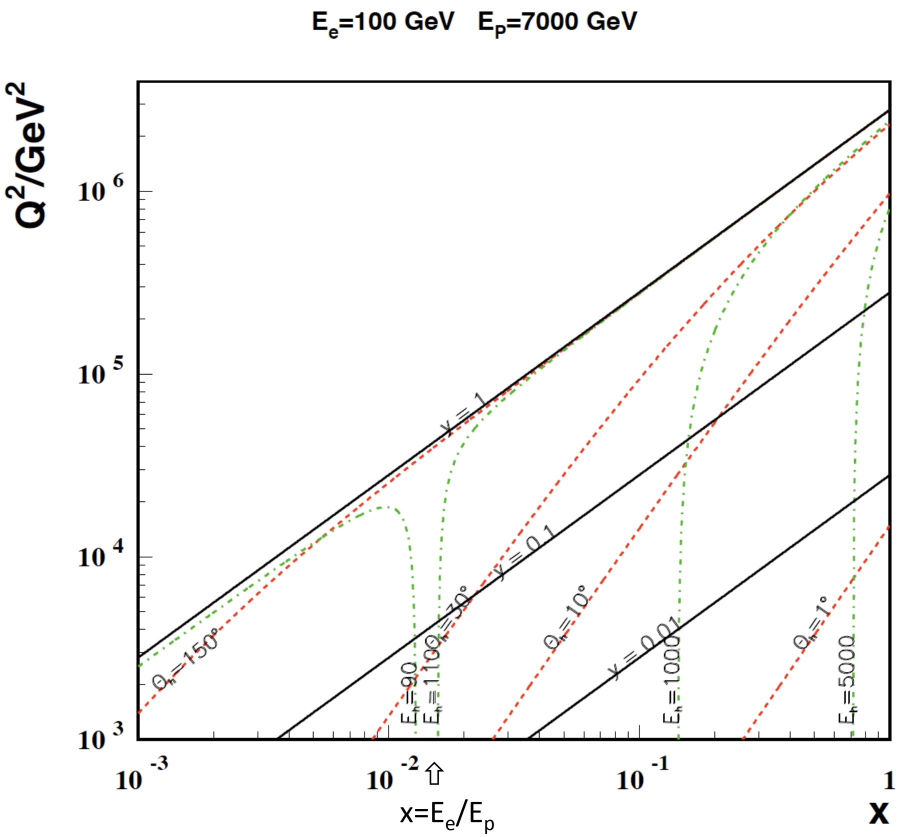
Kinematics – large x

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



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

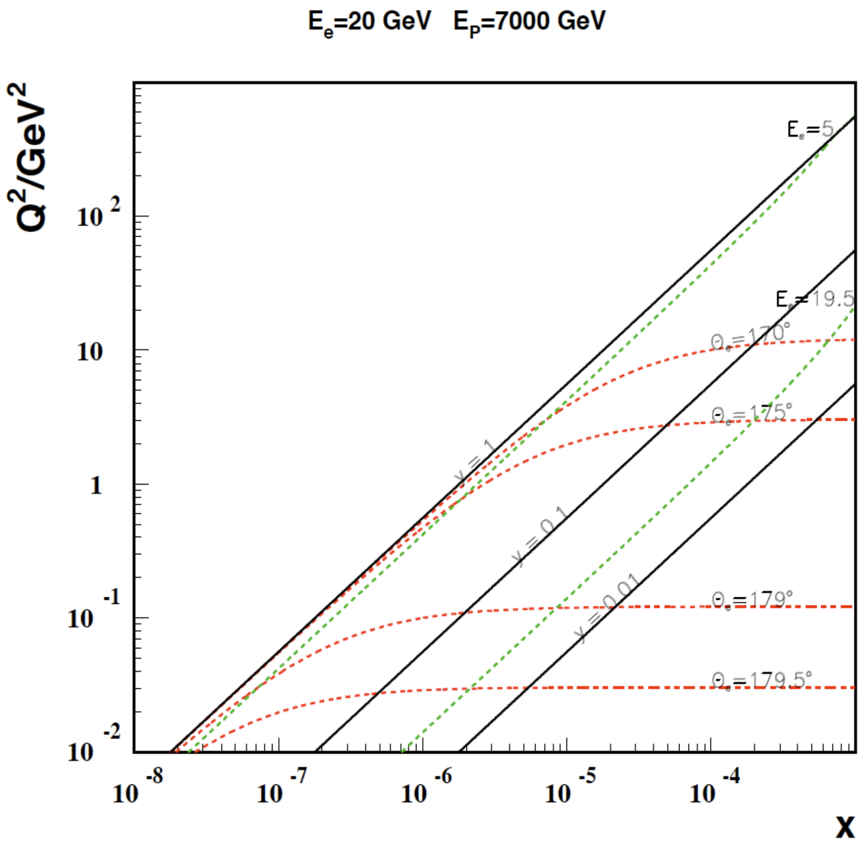
Nominal proton beam energy: need very fwd. angle acceptance for accessing large x

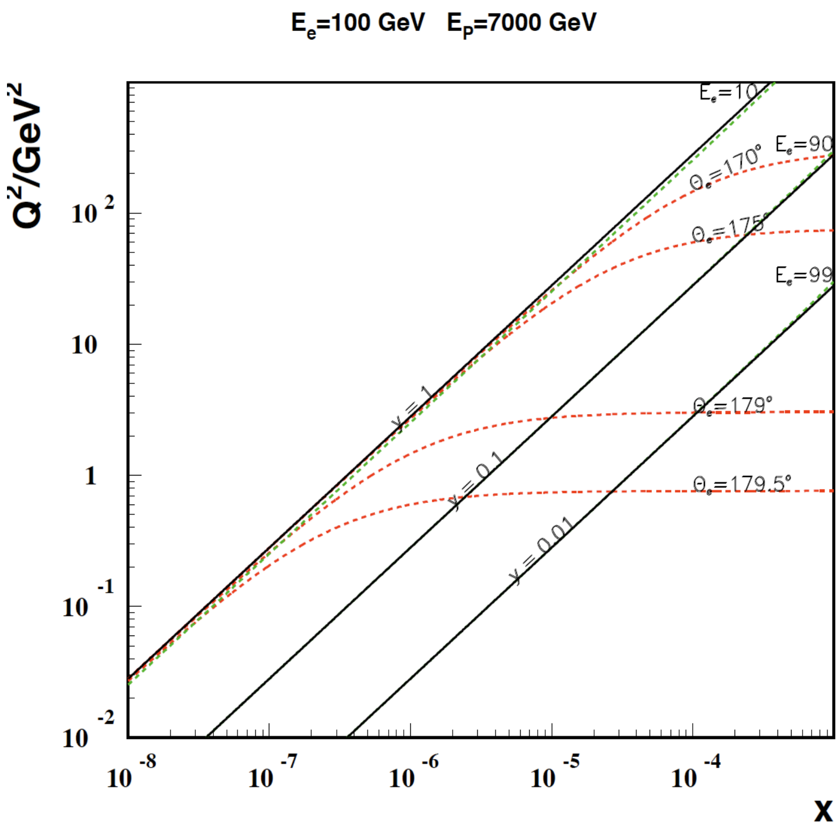


Kinematics – low Q^2,x

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



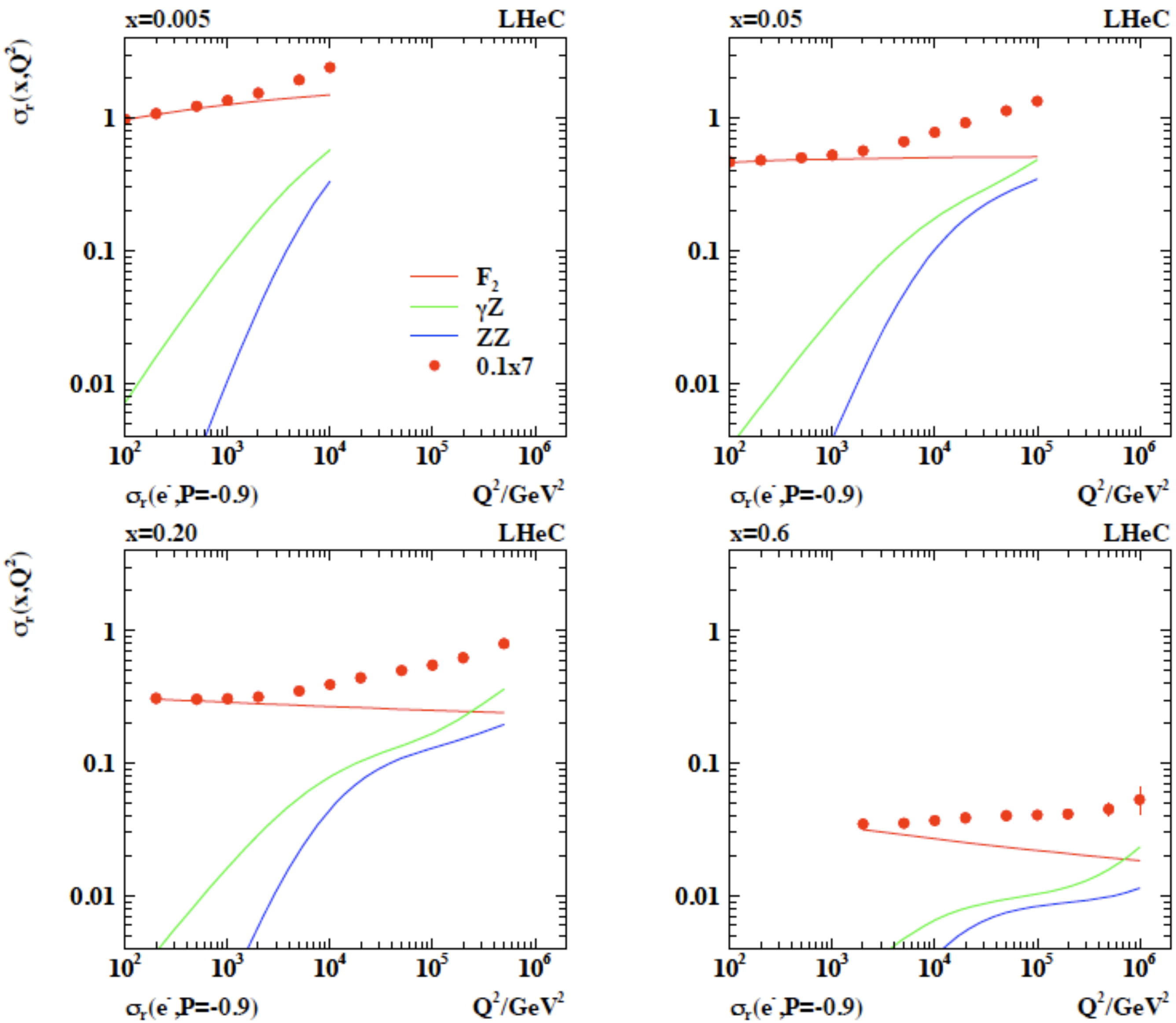


$$Q^2\,(x,\theta_e) = sx/[1 + xE_p cot^2(\theta_e/2)/E_e] \simeq (2E_e cot(\theta_e/2))^2$$

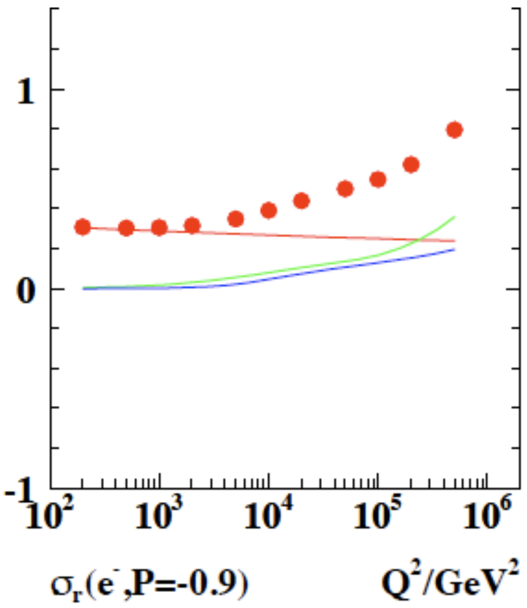
The scenarios and error estimates have been used in a variety of QCD fits (CG, EP, TK, NNPDF).

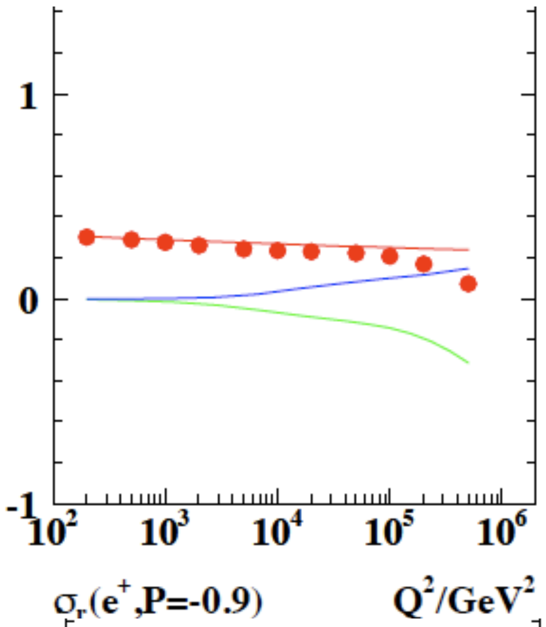
Following are slides on size of electroweak effects and on extraction of all parton distributions (shown previously at DIS07, 08, Divonne 08).

Electroweak Cross Section Measurements



Electroweak Cross Section Measurements

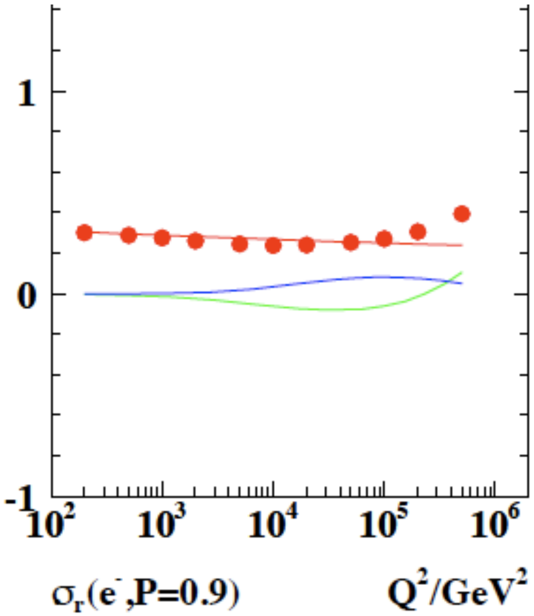


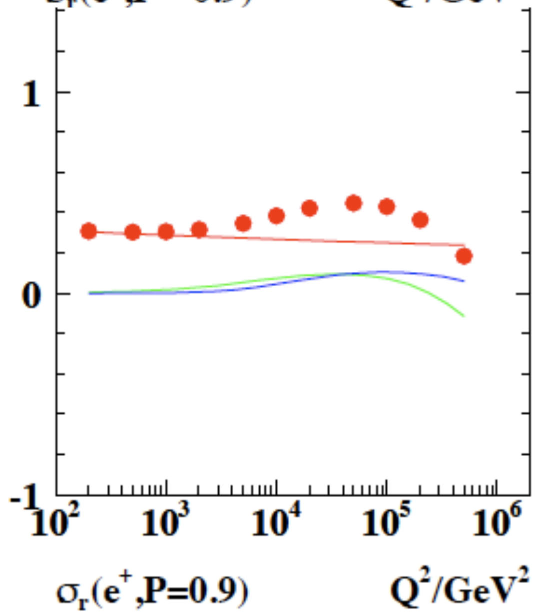


D, x=0.2

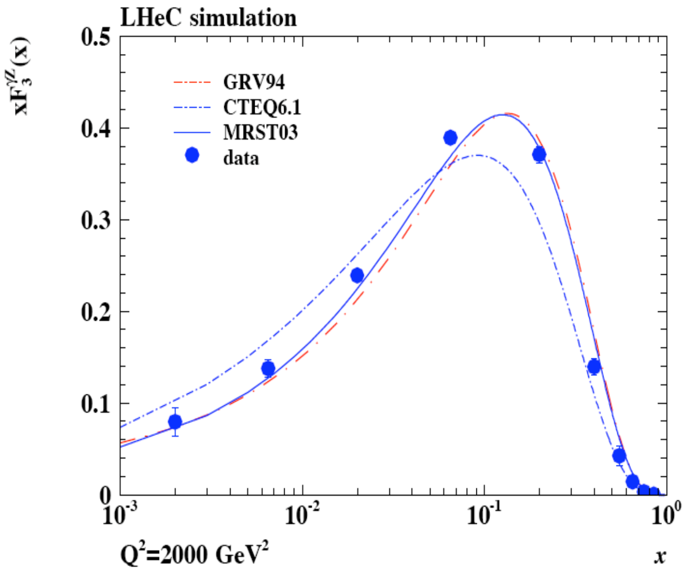
2 charges and
2 polarisations
very desirable
for electroweak
physics and the
new spectroscopy
should that appear.

Z effects depend
on charge and
polarisation.





Structure Functions with the LHeC



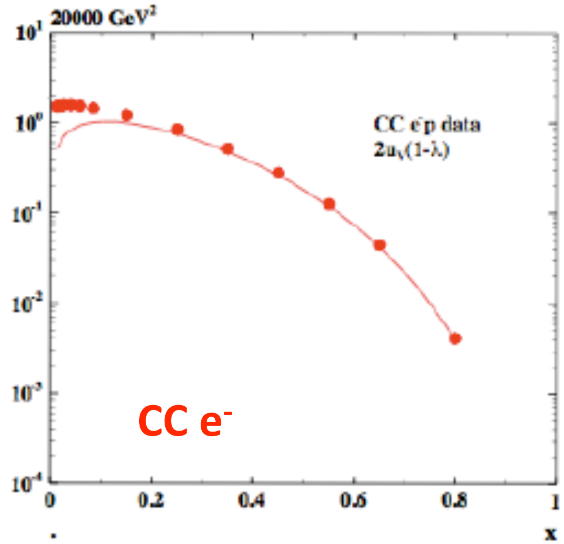
High precision electroweak structure functions.

high Lumi,
high precision,
new detector,
full range:

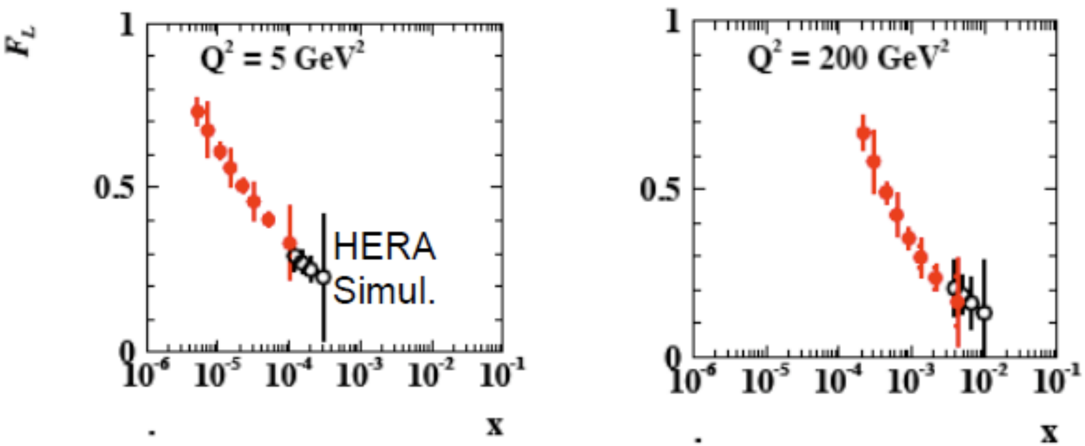
α_s to 0.0002

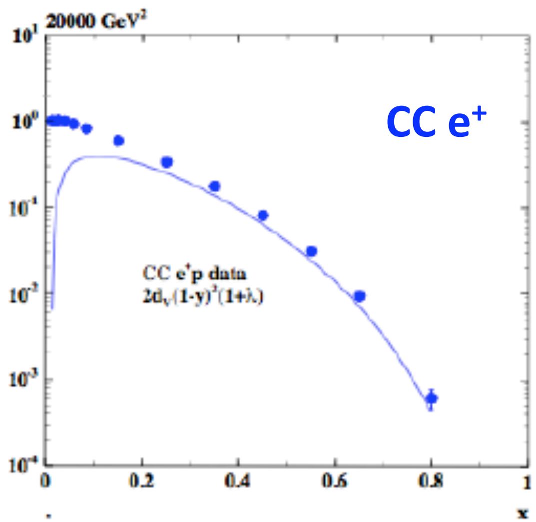
thy challenge

T.Kluge, MK - DIS08



Flavour separation to highest x

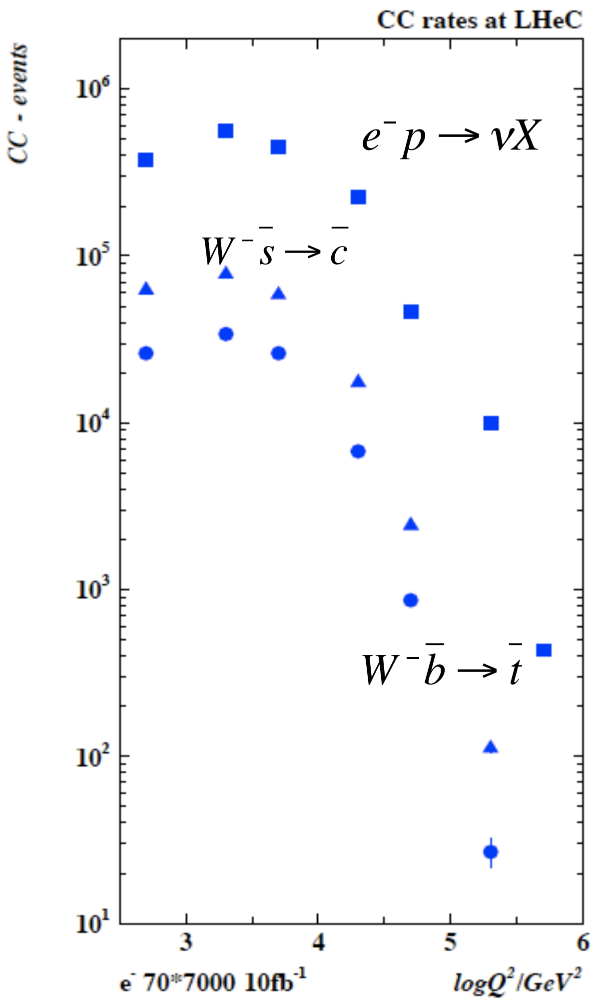


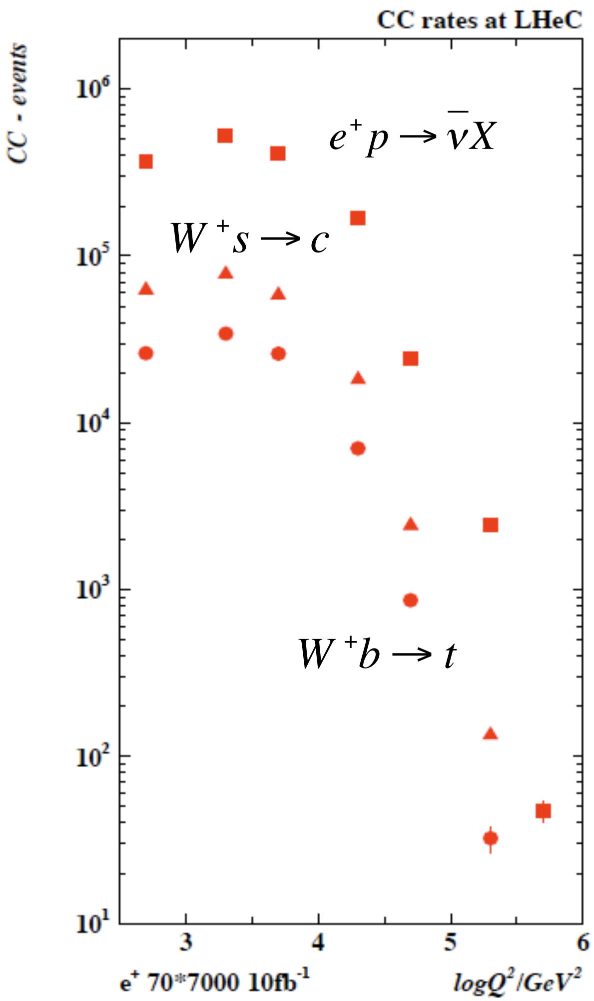


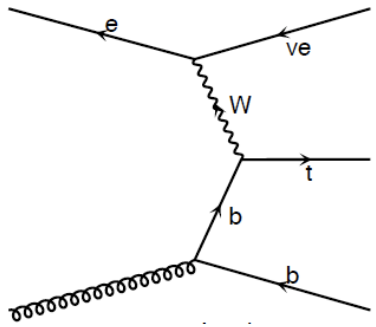
F_2 and F_L: the ultimate challenge to saturation
(Foreshaw et al, NNPDF group)

F_L “data” included in simulation files (now with reduced E_e)

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





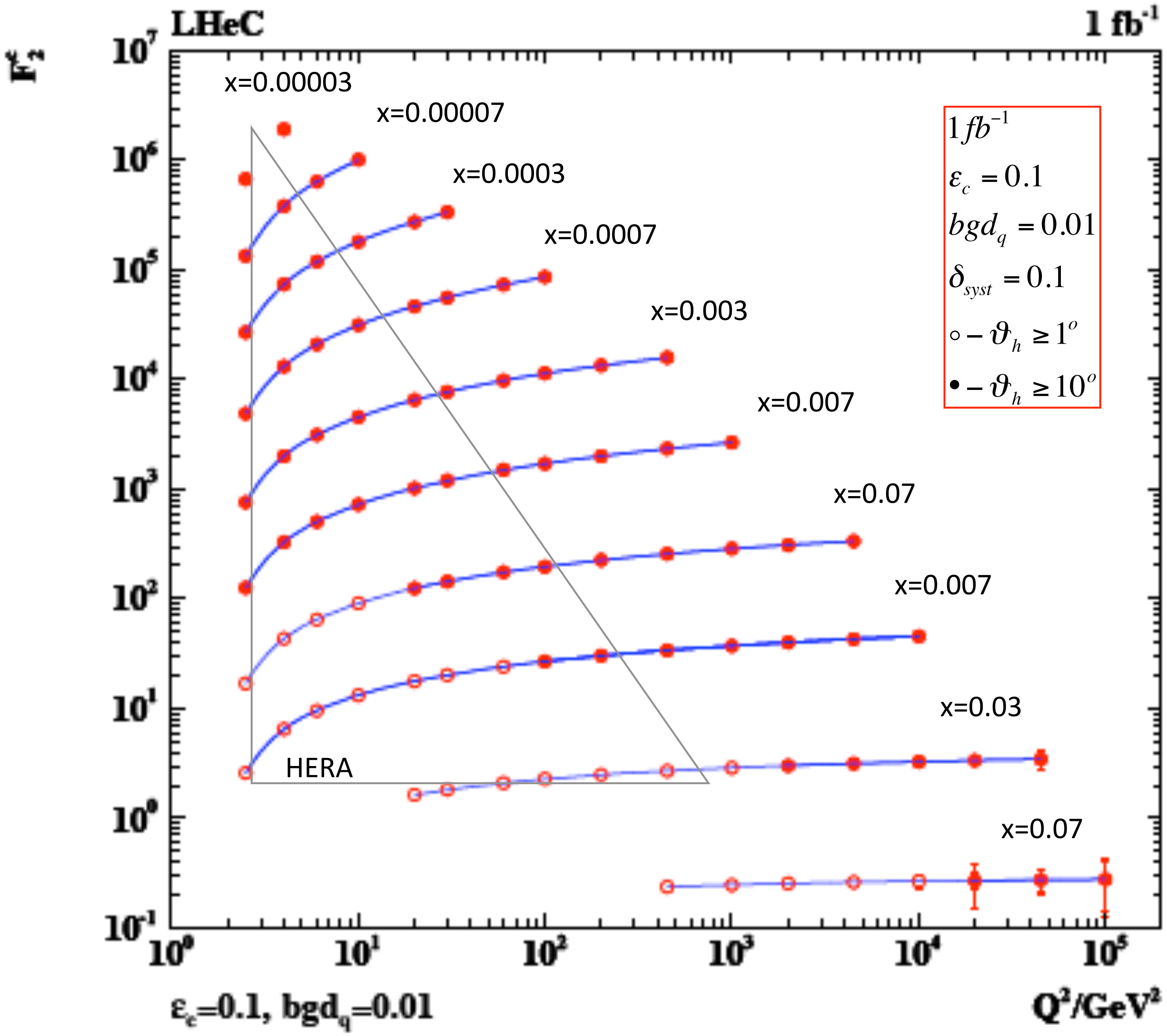


LHeC is a single top and anti-top quark factory

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

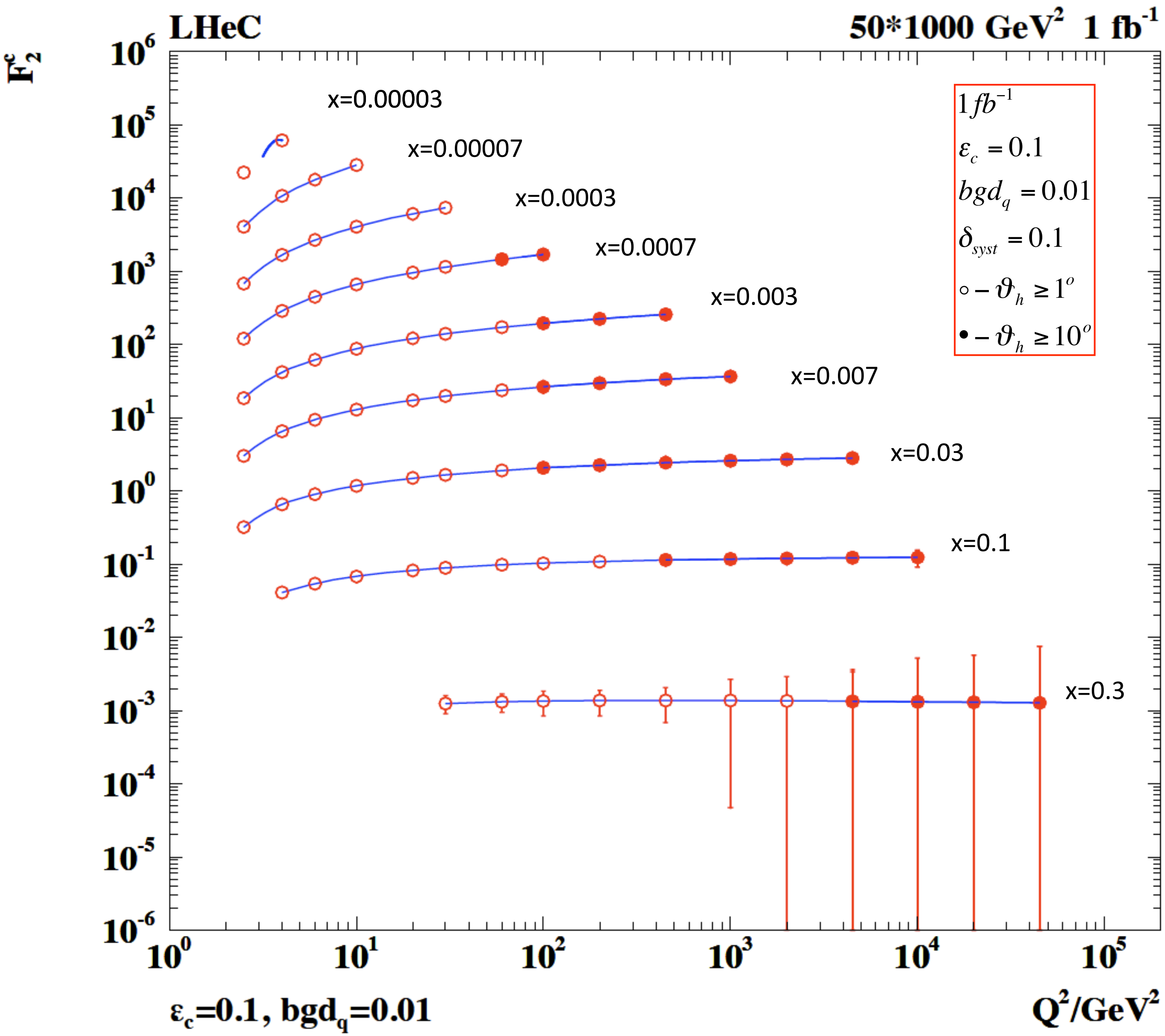
Charm quark distribution



$$\delta_{stat} = \frac{1}{\varepsilon_c N_c} \cdot \sqrt{\varepsilon_c N_c + bgd_{LQ} N_{NC}}$$

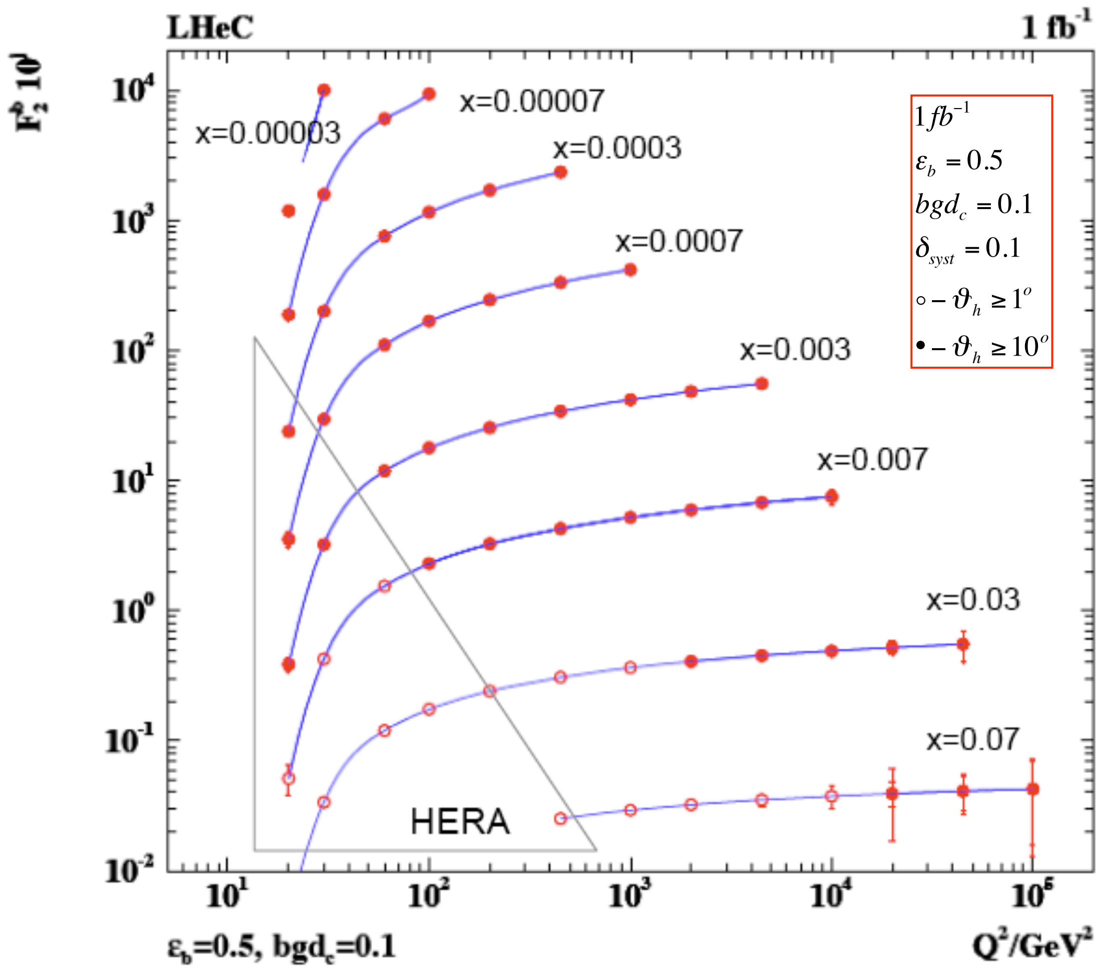
Intrinsic charm requires dedicated forward tagging and low E_p in order to reach large x.

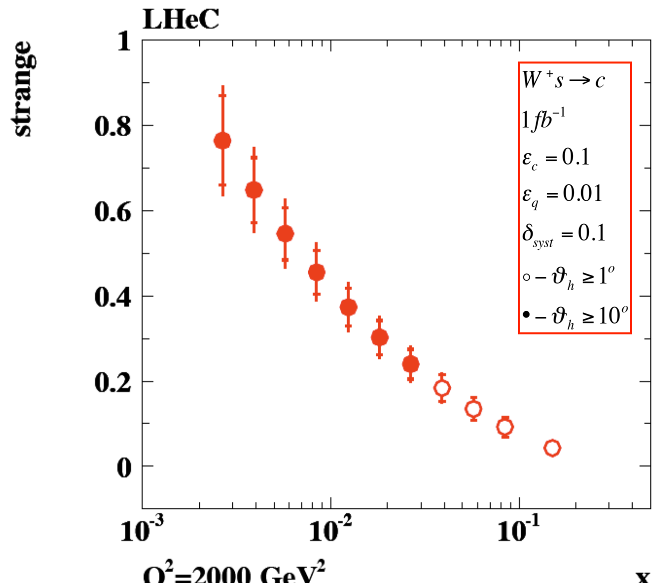
Try to see charm at large x

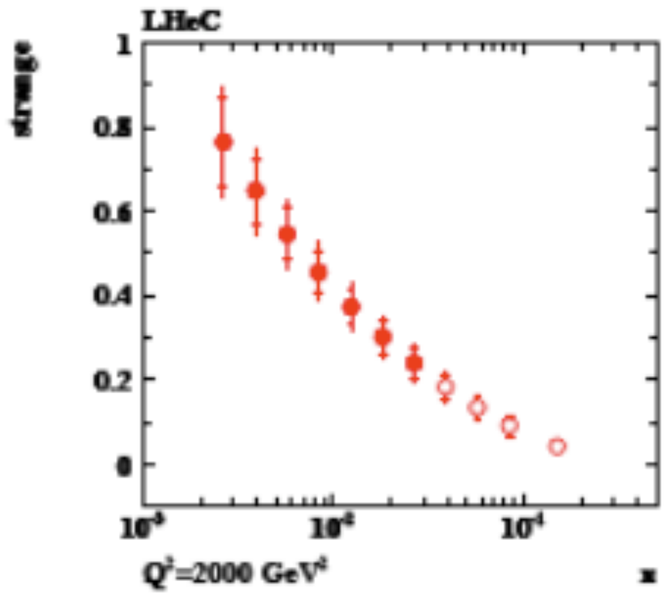


Even in the most favourable beam energy setting, a search for intrinsic charm at x >=0.1 would require charm tagging down to few degrees…

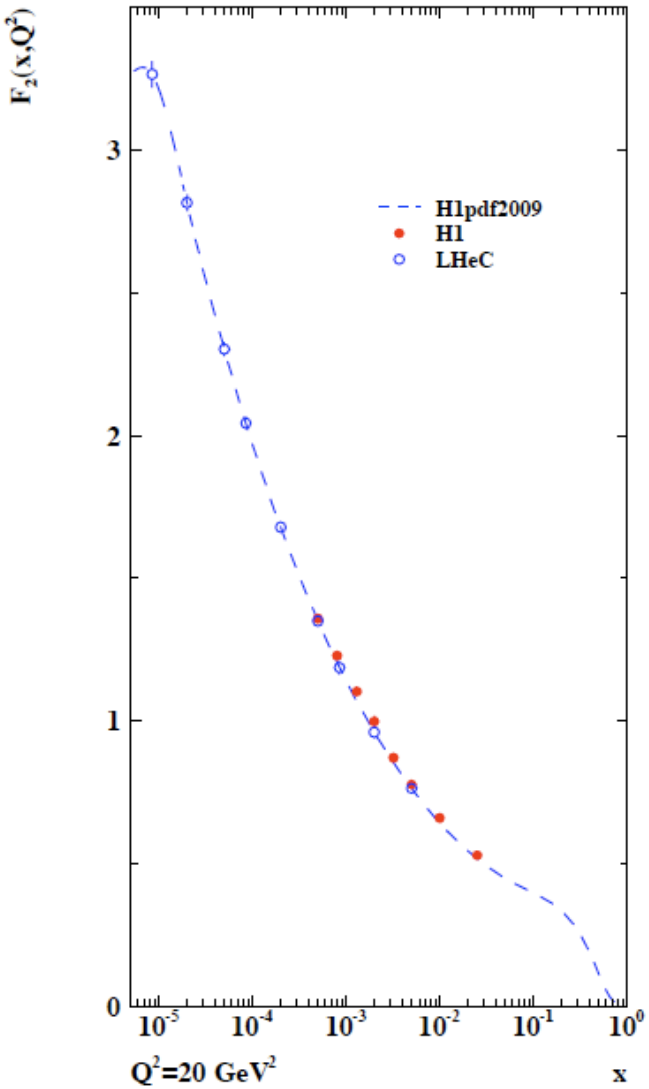
Beauty, s and anti-s measurements with the LHeC







Summary



At mid term of the CDR development the LHeC has 3 options for consideration: RR, LR and LR_{ER}

The energies and luminosities in all cases substantially exceed the HERA values with
RR: 50-80 GeV: 10^{33}; LR:50-150 GeV: 10^{32} times N(ER)

RR will have low polarisation, if any, and the LR will have a particular luminosity problem for positrons, both to be considered for the CDR.

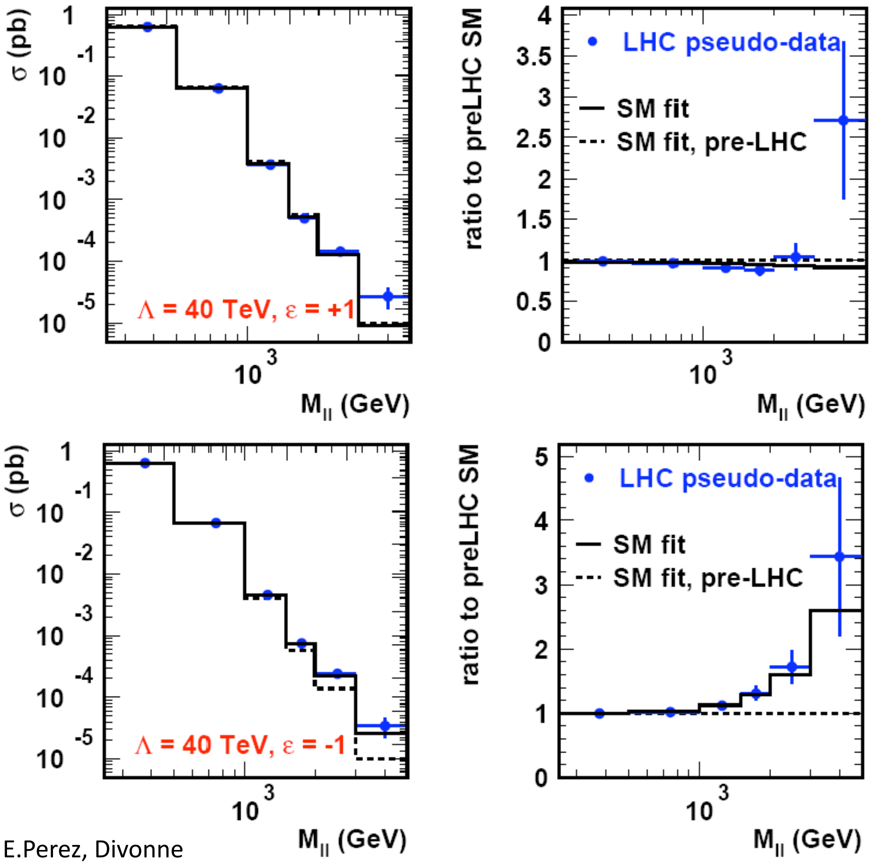
Lower energy options are vital to fill the phase space and for special physics studies as F_L or high x physics.

A set of NC and CC measurements has been simulated which may serve as a CDR basis. For a TDR more detailed MC detector studies will be needed.

The detector needs maximum coverage. In fwd direction a few TeV are scattered and the hadronic energy scale shall be determined to better than 1%. At small Q^2 the angle should be known to 0.1mrad.

New levels of luminosity, beam energy, target variety and measurement accuracy will lead to the full unfolding of the partonic content of p,n,D,A and of course to a much deeper understanding of parton dynamics and if we are lucky of physics BSM , in the electroweak sector, in QCD and/or their interrelation.

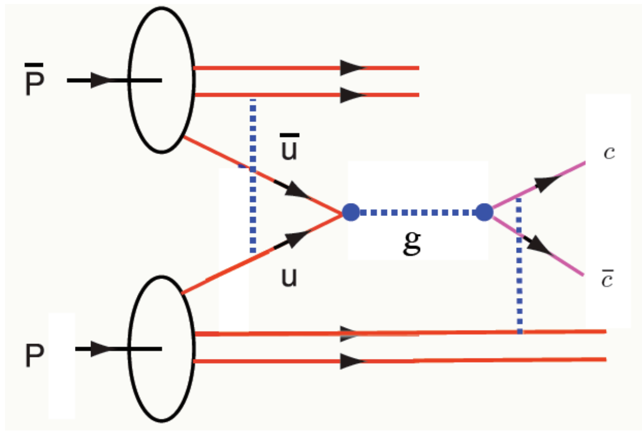
pdf's and New Physics at the LHC



E.Perez, Divonne

NP may be accommodated by HERA/BCDMS DGLAP fit. It can not by the fit to also LHeC.

(recall high E_T excess at the Tevatron which disappeared when xg became modified)



Factorisation is violated in production of high p_T particles (IS and FS i.a.s).

Important, perhaps crucial, to measure pdf's in the kinematic range of the LHC. cf also ED limits vs pdf's.

John Collins, Jian-Wei Qiu . ANL-HEP-PR-07-25, May 2007.

e-Print: **arXiv:0705.2141** [hep-ph]

e-Pb collisions

- Present nominal Pb beam for LHC
  - Same beam size as protons, fewer bunches

$k_b = 592$ bunches of $N_b = 7\times10^7$ ${}^{208}Pb^{82+}$ nuclei

- Assume lepton injectors can create matching train of e^-

$k_b = 592$ bunches of $N_b = 1.4\times10^{10}$ e^-

- Lepton-nucleus or lepton-nucleon luminosity in ring-ring option at 70 GeV

$$L = 1.09\times10^{29}\ \mathrm{cm^{-2}s^{-1}} \Leftrightarrow L_{en} = 2.2\times10^{31}\ \mathrm{cm^{-2}s^{-1}}$$

(gives 11 MW radiated power)

  - May be some scope to exploit additional power by increasing electron single-bunch intensity

J.Jowett (22.4.09). when simply scaled: 11MW, 70 GeV → 30MW, 50GeV: $L_{eN}=10^{32}$

Ca is a candidate for a lighter nucleus, may assume same eN luminosity and L_A ~1/A but lighter ions are not part of CERN's programme so far.

Very(!) tentative e-d luminosity

- Rough guess for beam via Linac3
  - Same beam size as protons, fewer bunches as for Pb

$$k_b = 592 \text{ bunches of } N_b = 1.7\times 10^9 \quad \text{deuterons}$$

- Assume lepton injectors can create matching train of e⁻

$$k_b = 592 \text{ bunches of } N_b = 1.4\times 10^{10} \quad e^-$$

- Lepton-nucleus or lepton-nucleon luminosity in ring-ring option at 70 GeV

$$L = 2\times 10^{30} \text{ cm}^{-2}\text{s}^{-1} \quad (\text{gives 11 MW radiated power})$$

  - Optimist might hope for maybe 10-50 times more if Linac4 and other systems work well.
  - A lot of further study required!!

J.Jowett with Alessandra Lombardi, Detlef Kuchler, Richard Scrivens, 24.4.09
When scaled to 50 GeV and 30MW gives 10^{31}