# Scenarios and Measurements with the LHeC

CDR
Luminosity-Energy-Beams
Systematic Errors
Kinematics
Electroweak effects
Could we see intrinsic charm?

… constraints on detector

Max Klein
Madrid, 25.4.2009
LHeC Premeeting


For pdf's and QCD fit
see MK and E.Perez
at DIS07 and Divonne 08

**Thanks to Juan et al!**
¡muchas gracias!

**A Conceptual Design Report (CDR) for a Large Hadron Electron Collider (LHeC) at CERN.**

**DRAFT - February 2009** [~175 pages]

**1. Introduction** [5pages]
a short introduction to the project.

**2. Particle Physics and Deep Inelastic Lepton-Nucleon Scattering** [15]

1. **DIS from 1 to 100 GeV**
   (SLAC, CERN/Fermilab, HERA)
2. **Status of the Exploration of Nucleon Structure**
   (low x, high x, heavy quarks, nuclei and further unknowns)
3. **Tera Scale Physics**
   (the importance of a TeV ep collider to the LHC)

**3. The Physics Programme of the LHeC** [60]

1. **New Physics at Large Scales**
   (SUSY, excited leptons, contact interactions, LQs,ED, Z')
2. **Precision QCD and Electroweak Physics**
   (Higgs, top, beauty, gluon, pdf's, alpha_s..)
3. **Physics at High Parton Densities**
   (low x theory, saturation, ed, nuclear effects and pdf's)

**4. Design Considerations** [10]

1. **Acceptance and Kinematics**
2. **A Series of Measurements**
   (luminosity, beam energy, lepton beam charge and polarisation)
3. **Compatibility with the LHC**
   (operation, installation, radiation, access)
4. **Proton, Deuteron and Ion Beams**

**5. A Ring-Ring Collider Concept** [30]

1. **Injector**
   (the SPL and an initial ep/eA phase, alternative injectors)
2. **Lepton Ring**
   (magnets, rf, bypasses)
3. **Synchrotron Radiation**
4. **Interaction Region**
   (for high luminosity and maximum acceptance)
5. **Installation**
6. **Infrastructure and Cost**

**6. A Linac-Ring Collider Concept** [30]

1. **Electron and Positron Sources, Polarisation**
2. **Linac**
3. **Interaction Region**
4. **Beam Dump**
5. **Infrastructure and Cost**

**7. A Detector for the LHeC** [20]

1. **Dimensions and General Requirements**
   (accuracy, acceptance, beam pipe)
2. **Coil**
3. **Calorimeters**
4. **Tracking**
   (including options as GOSSIP vs full Silicon)
5. **Options for the Inner Detector Region**
6. **Detector Simulation and Performance**

**8. Summary** [5]

1. **Physics Highlights**
2. **Parameters**
3. **Concluding Remarks**

**Appendix** [to be seen]

1. **Tasks for a TDR**
2. **Building and Operating the LHeC**

March 2nd, 2009, The LHeC Steering Committee

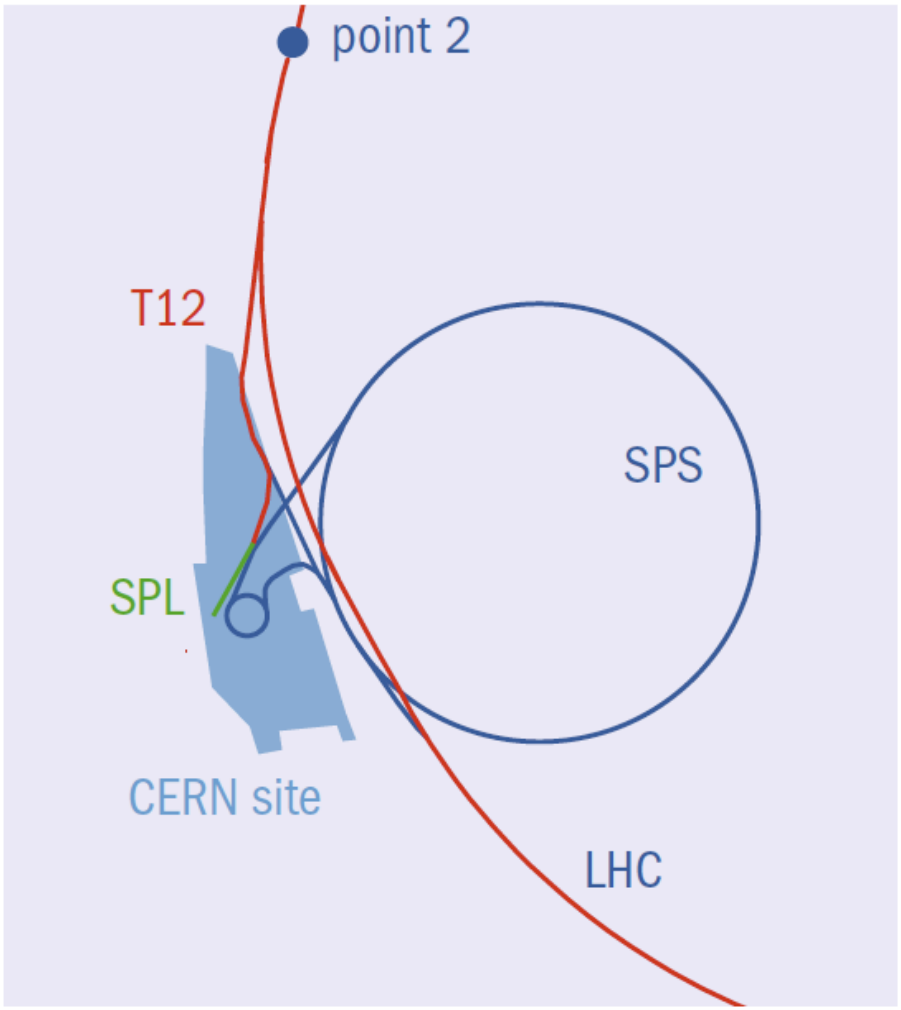



*Fig. 4. Sketch of a possible layout to inject an electron beam into the LHC ring, using the SPL and the TI2 connection to the LHC tunnel.*

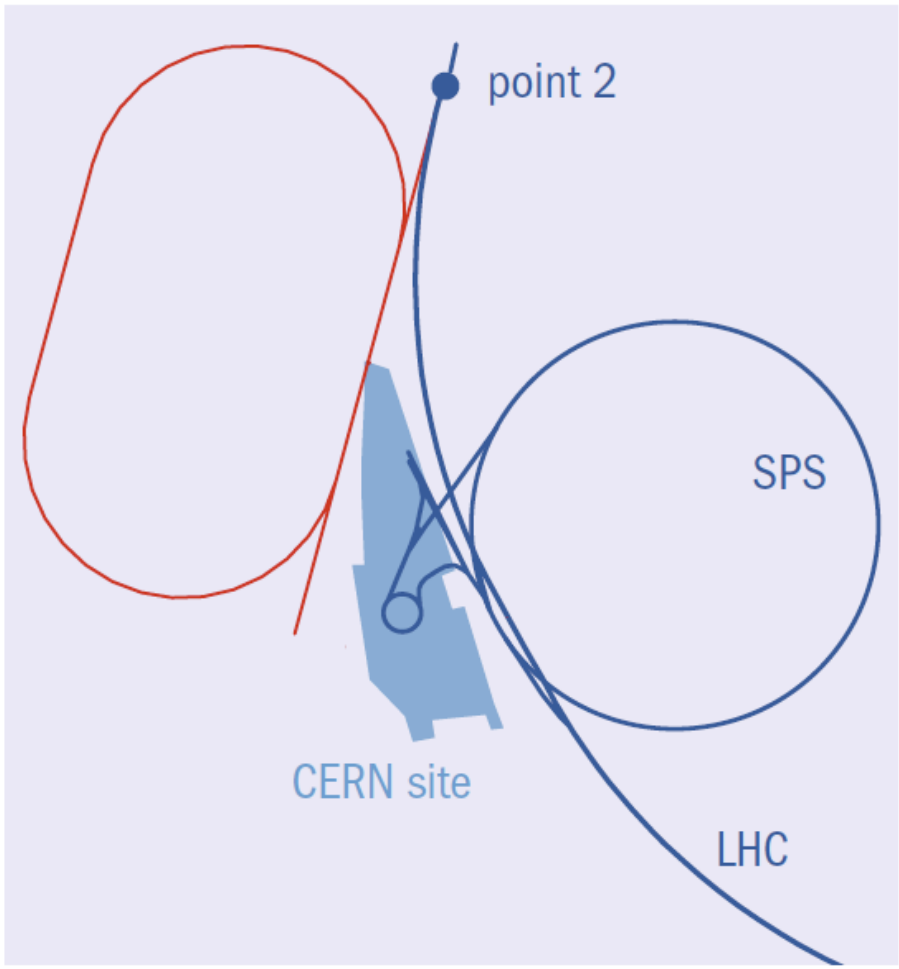
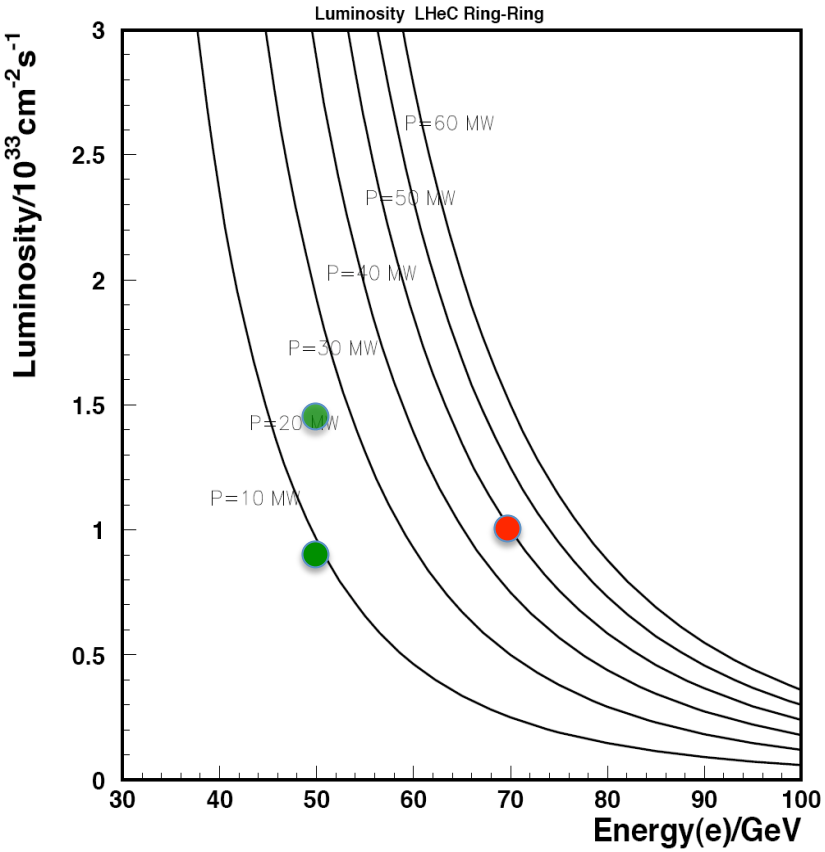



*Fig. 5. A possible layout in which an electron linac arrives tangentially to the LHC, after multiple passes around a "racetrack" that makes full use of the linac accelerating structures.*

# Luminosity Estimates

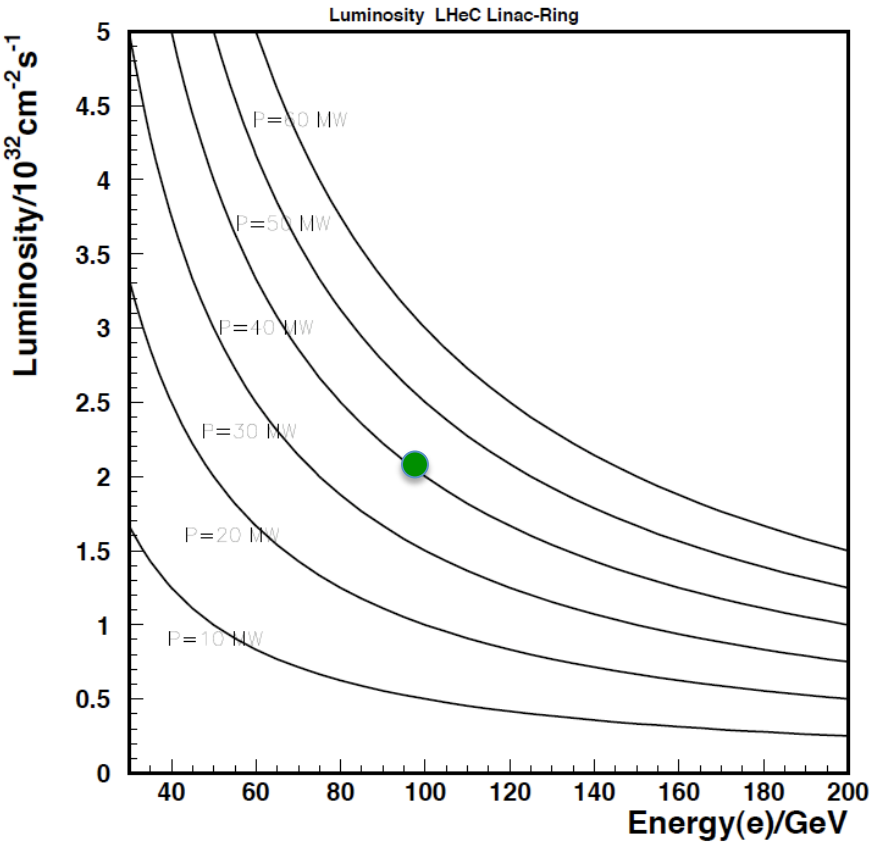
**Ring-Ring:** $L \sim P/E^4$




F.Willeke, 70GeV * 7TeV, 50MW [JINST 2006]
B.Holzer, A.Kling et al, Divonne08,ECFA08

**Scale BH to 50MW: 5 $10^{33}$ at 50 GeV**

**LINAC-Ring:** $L \sim P/E$




F.Zimmermann, ECFA08

**Scale 100 GeV to 50 GeV: 5 $10^{32}$ $cm^{-2}s^{-1}$**

HIgh energy recovery LINAC?

# e-Pb collisions

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

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

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

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

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

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

$$(\text{gives } 11 \text{ MW radiated power})$$

  - 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

$$k_b = 592 \text{ bunches of } N_b = 1.7\times10^{9} \text{ deuterons}$$

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

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

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

$$L = 2\times10^{30} \text{ cm}^{-2}\text{s}^{-1} \quad (\text{gives 11 MW radiated power})$$

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

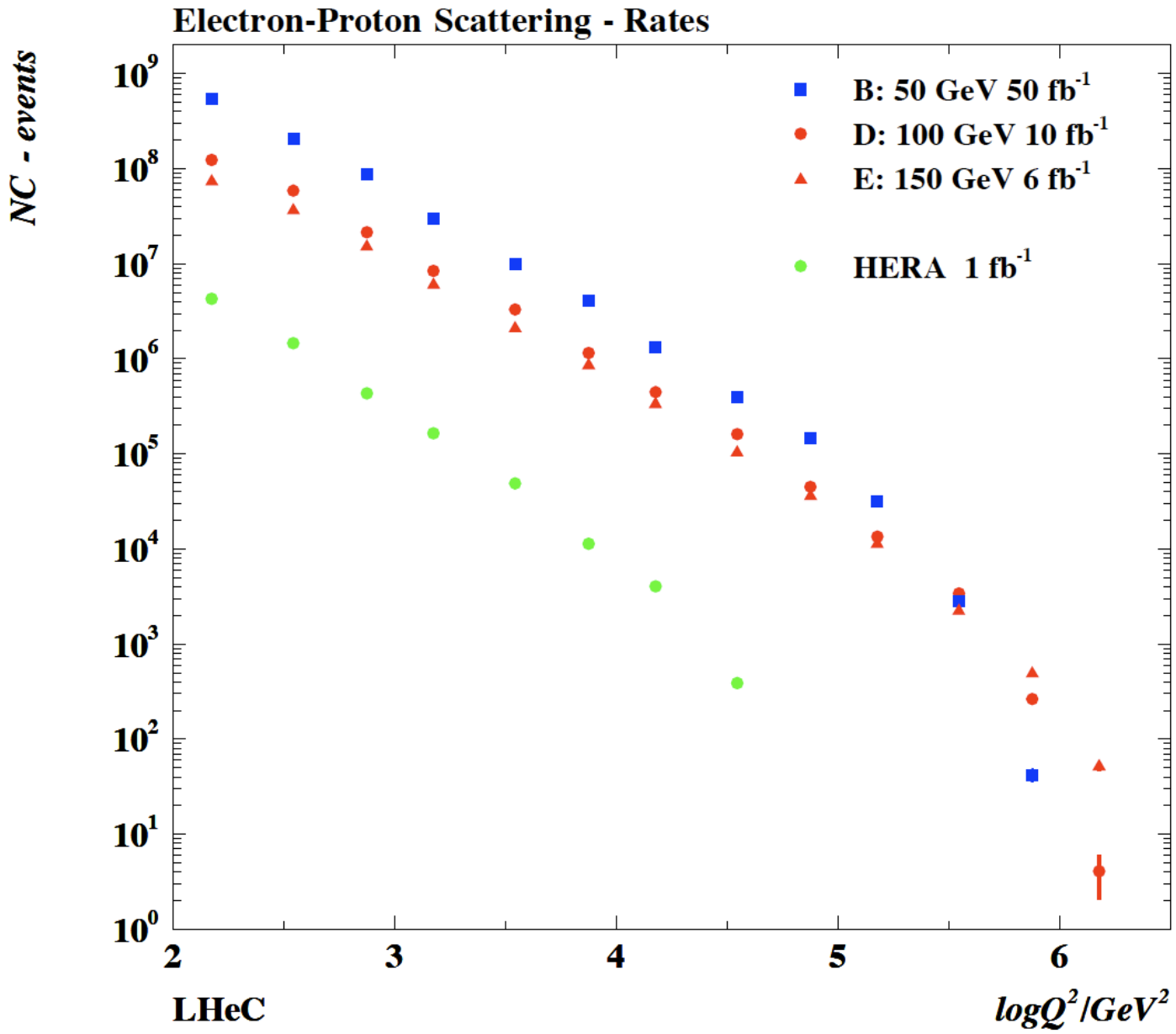
J.Jowett with Alessandra Lombardi, Detlef Kuchler, Richard Scrivens, 24.4.09
When scaled to 50 GeV and 30MW gives $10^{31}$

# **Simulated Default Scenarios**, April 2009

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

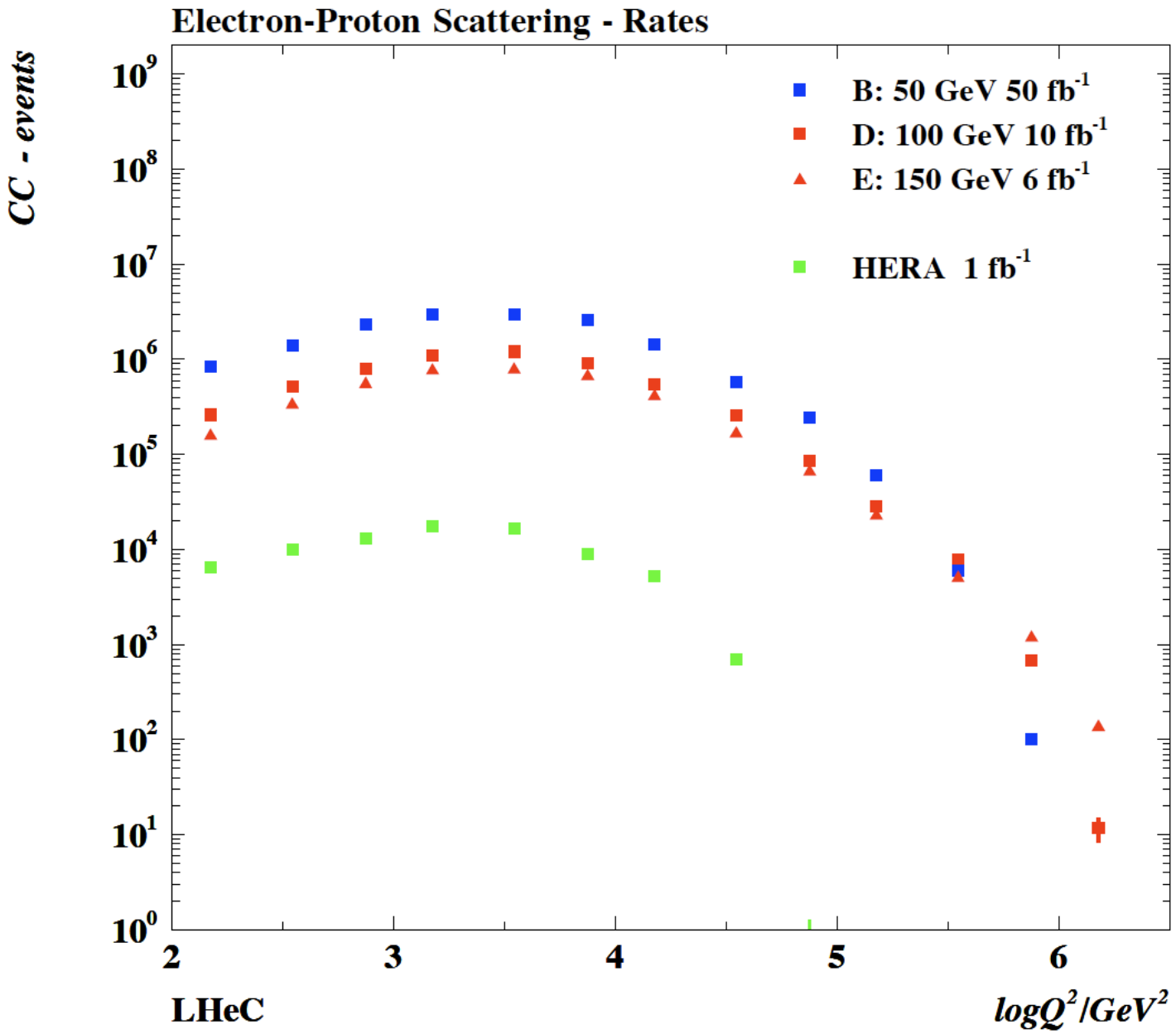
| config. | E(e) | E(N) | N | $\int L(e^+)$ | $\int L(e^-)$ | \|Pol\| | $L/10^{32}$ | P/MW | years | type |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 20 | 7 | p | 1 | 1 | - | 1 | 10 | 1 | SPL |
| B | 50 | 7 | p | 50 | 50 | 0.4 | 25 | 30 | 2 | RR hi$Q^2$ |
| C | 50 | 7 | p | 1 | 1 | 0.4 | 1 | 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




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

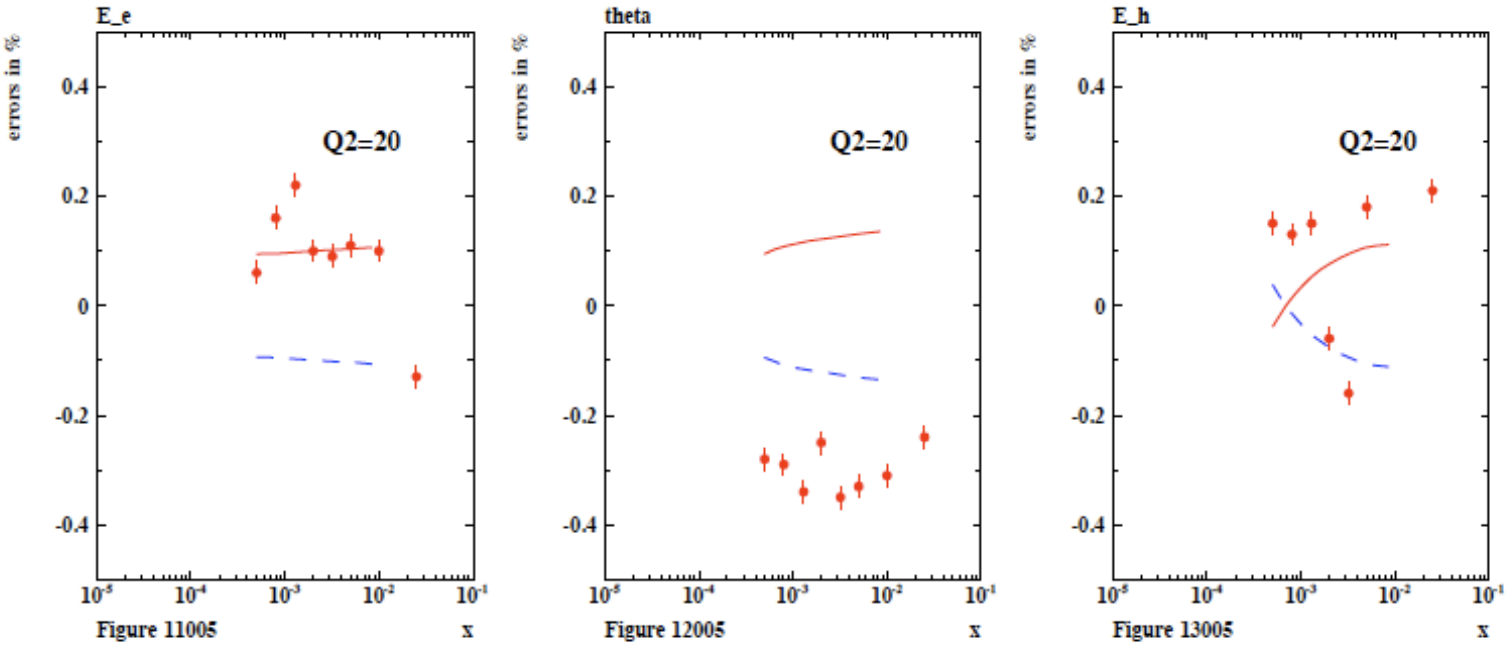
Largest energy is crucial for low x and high masses and high $Q^2$. The LHC may set the scale for everything, perhaps.




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 prrovides larger s:

win-win for CC

# Systematic Error Calculation



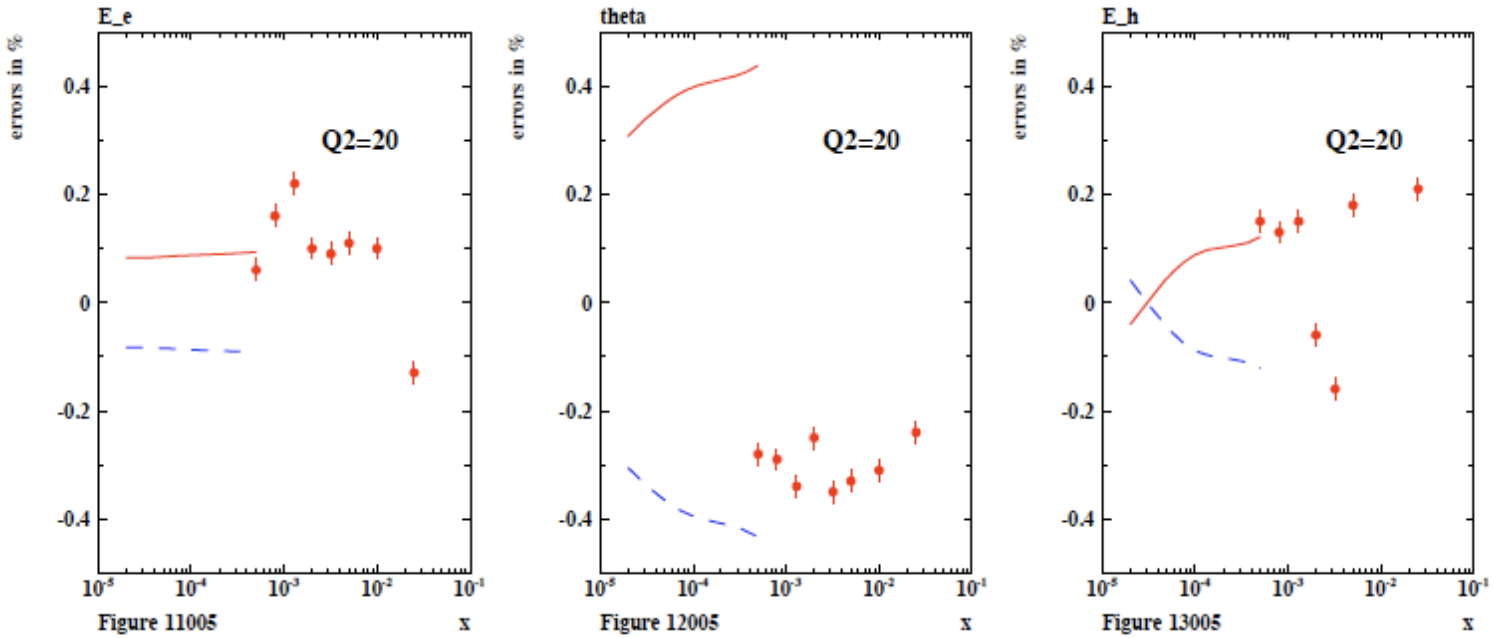

Numeric calculation (J.Bluemlein, MK, 1989) using cross section derivatives to $E_{e,}$', $\theta_e$,$E_h$

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%)

cf talk of Jan Kretzschmar

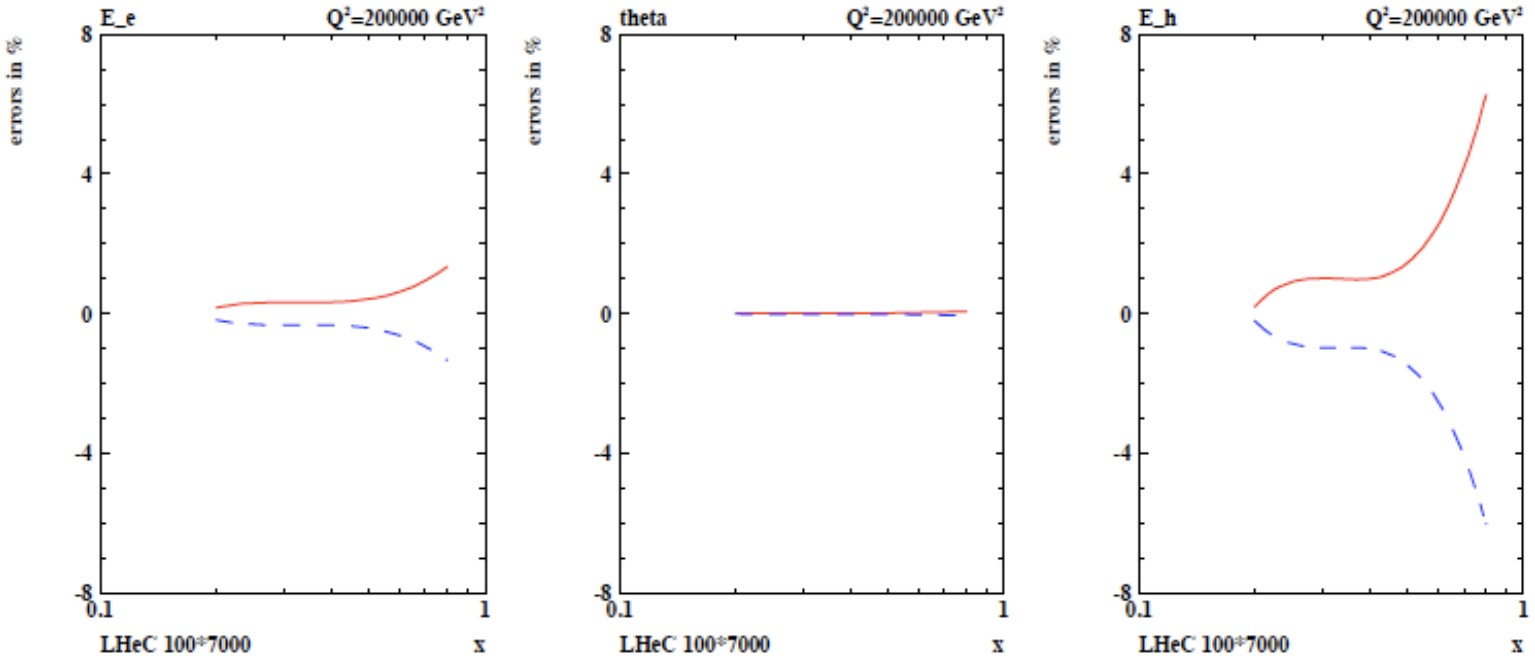
In addition: 0.5% extra efficiency, 1% yp for y>0.7, 0.5% RadCor, noise at y < 0.01

# Systematic Error Calculation



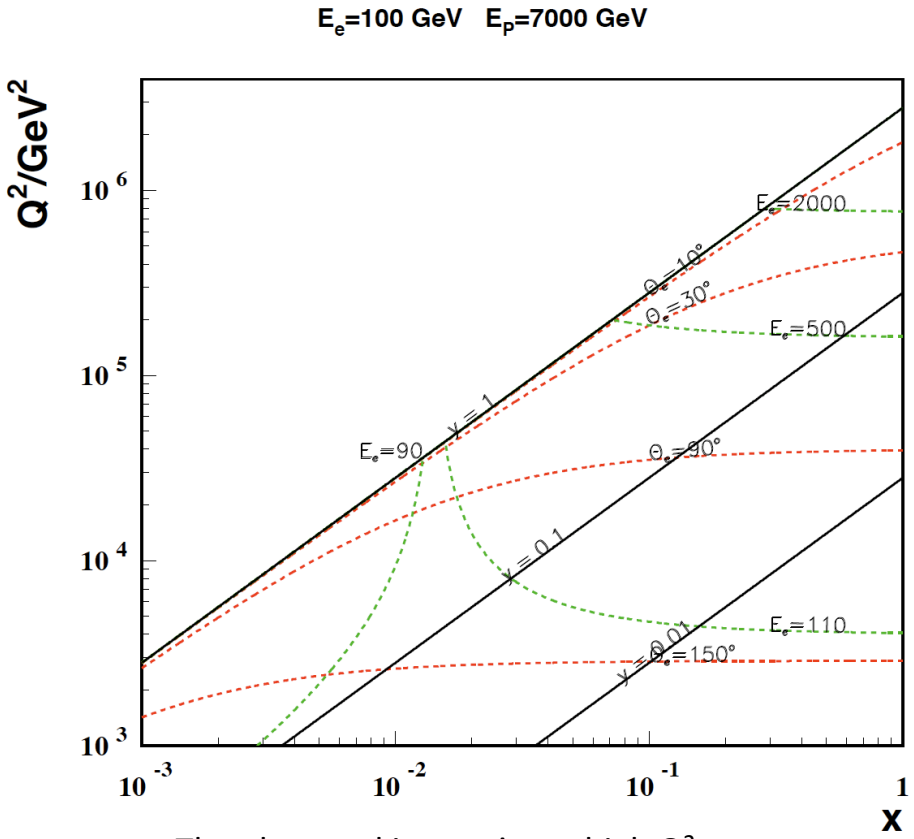

Same error requirements for D (100 GeV * 7000 GeV): reach lower x
Polar angle error contribution rises. 0.2 mrad would imply 1% error!
→ **Need very accurate polar angle measurement at large bwd angles.**

# Systematic Error Calculation



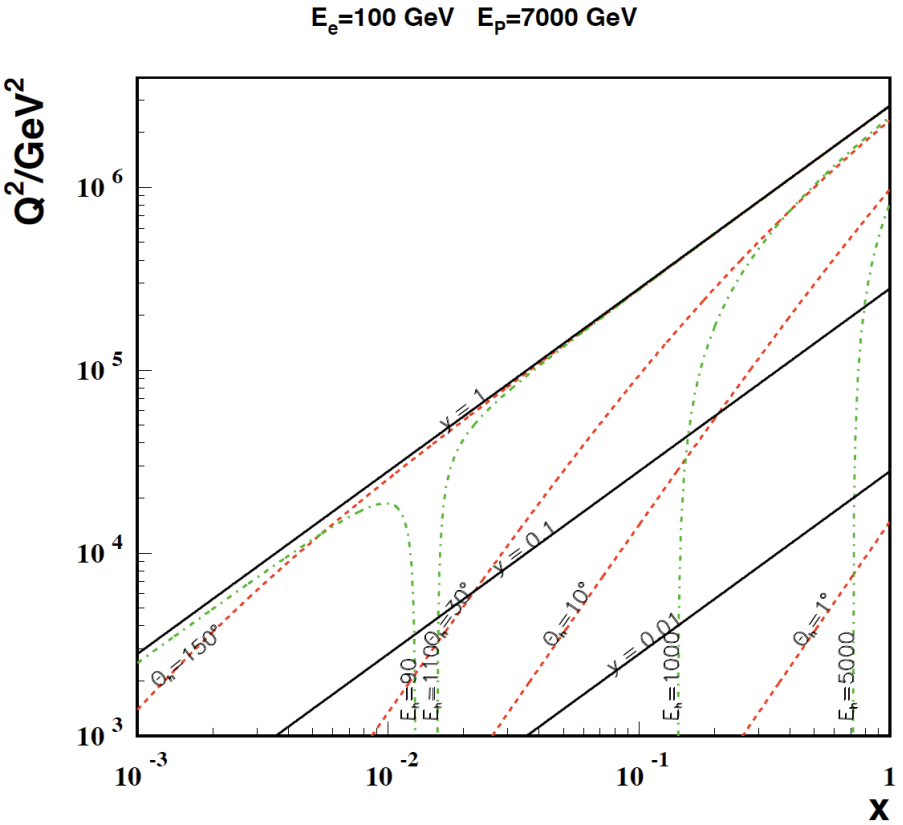

At high $Q^2$: measure at large x: 0.2% on $E_e$' may be relaxed a bit. Polar angle may be much worse than 1mrad, but for high x need very accurate hadronic energy measurement (CC in particular).
**Need 1% of hadronic energy scales at very large $E_h$**

# 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.**

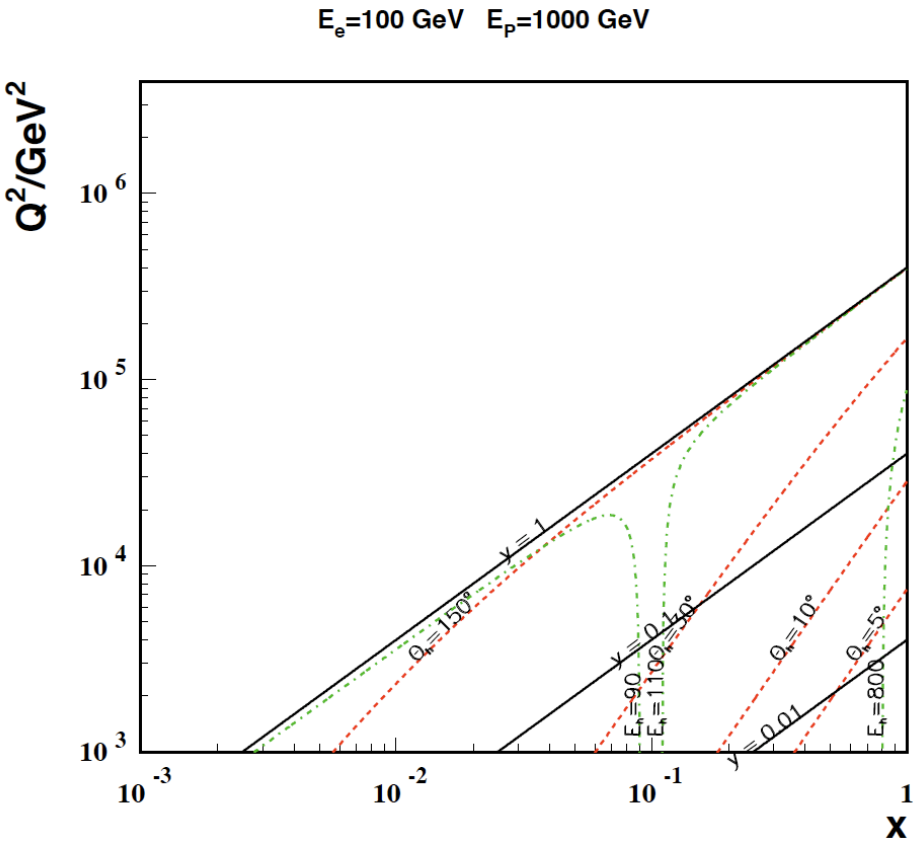



High x and high $Q^2$: few TeV HFS scattered forward:

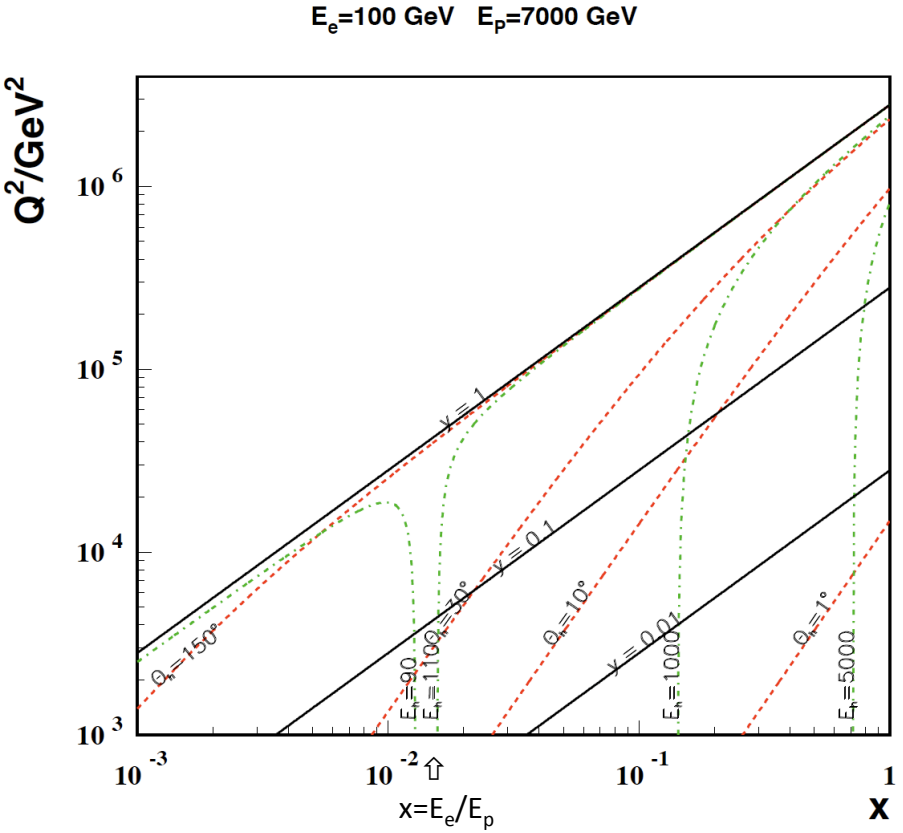
→**Need forward had. calorimeter of few TeV energy range down to 10° and below. Mandatory for charged currents. Strong variations of cross section at high x demand hadronic energy calibration as good as 1%**

# 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

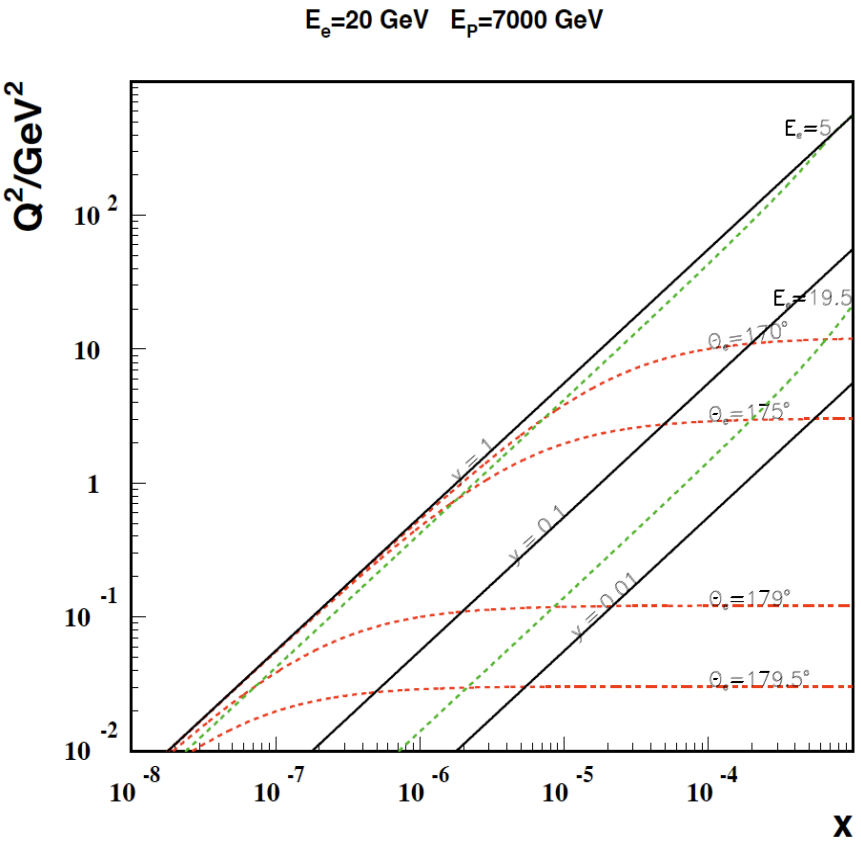


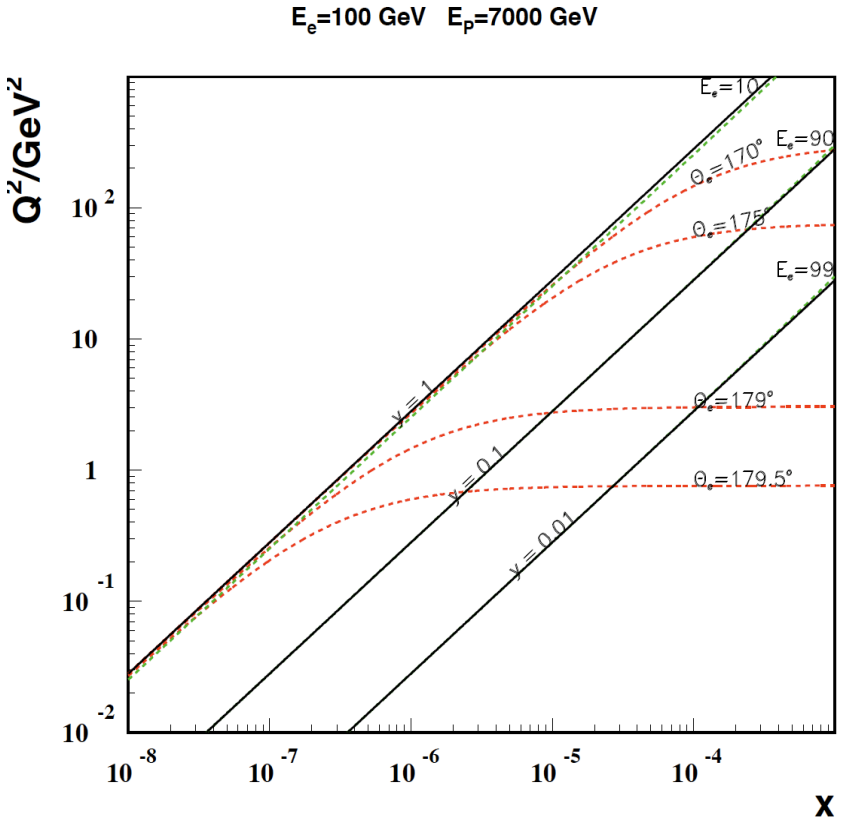

$$Q^2\ (x,\theta_h) = sx/[1 + E_e cot^2(\theta_h/2)/xE_p] \simeq (2xE_p cot(\theta_h/2))^2$$

# 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.

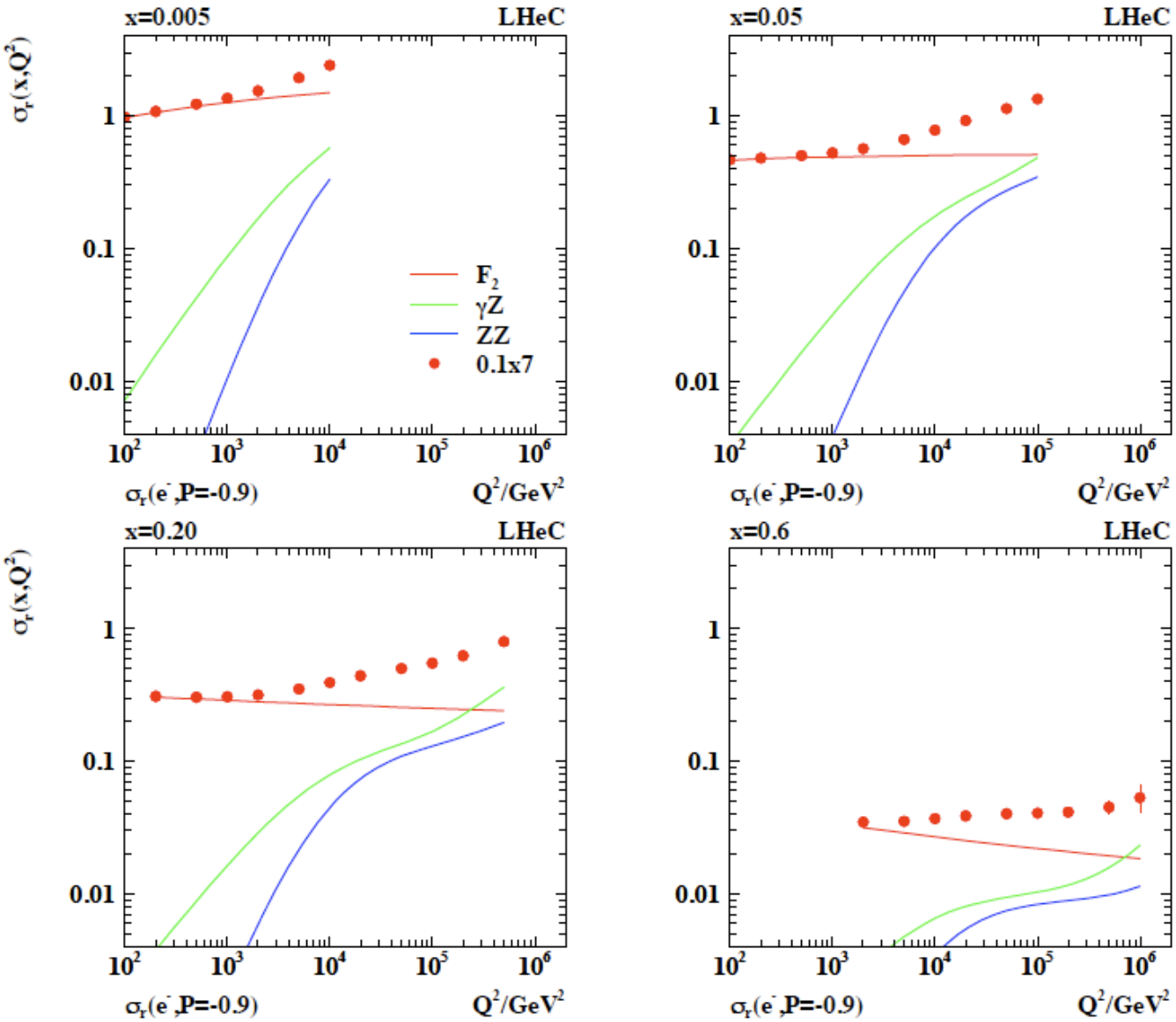
Nominal proton beam energy: need very bwd angle acceptance for accessing low x and $Q^2$



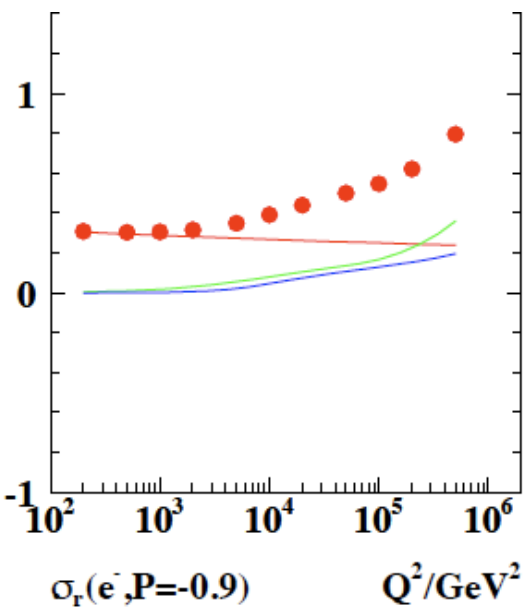



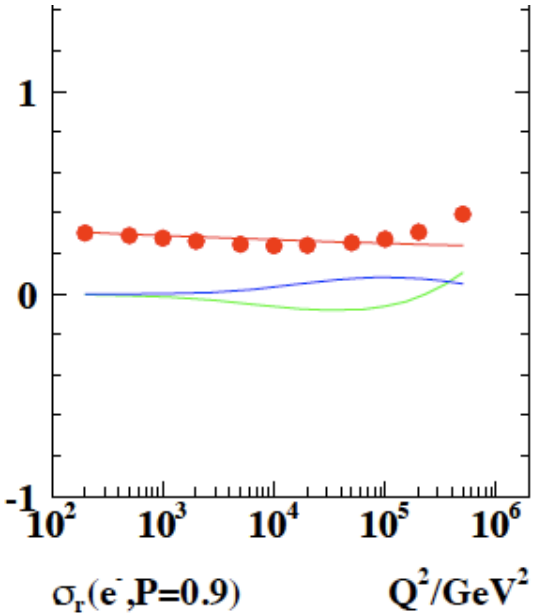

$$Q^2\ (x,\theta_e) = sx/[1 + xE_p cot^2(\theta_e/2)/E_e] \simeq (2E_e cot(\theta_e/2))^2$$

# Electroweak Cross Section Measurements



# Electroweak Cross Section Measurements

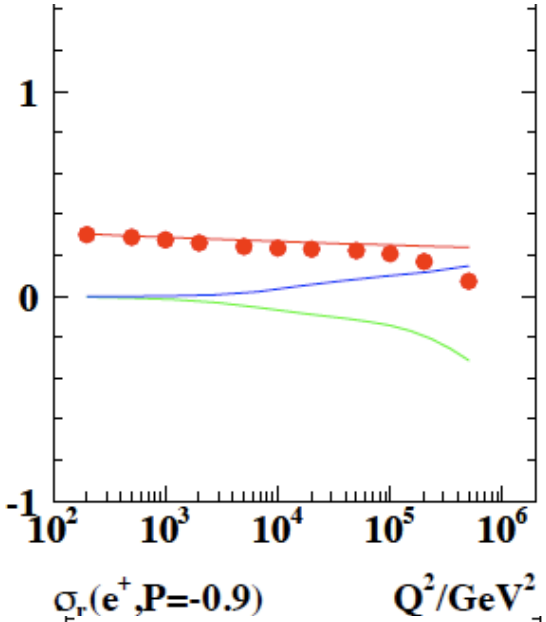


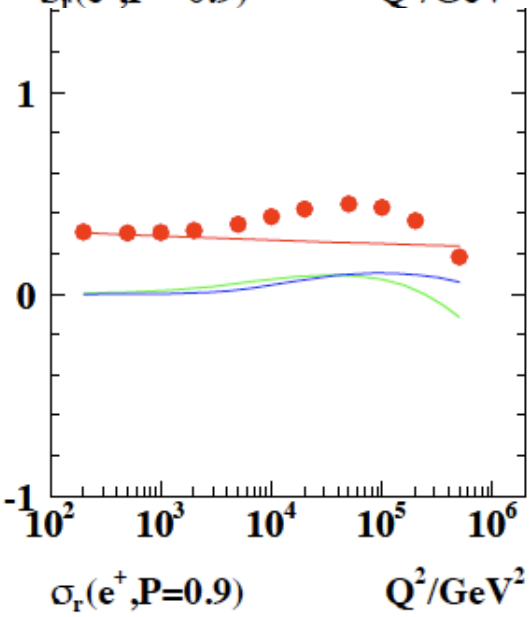




D, x=0.2

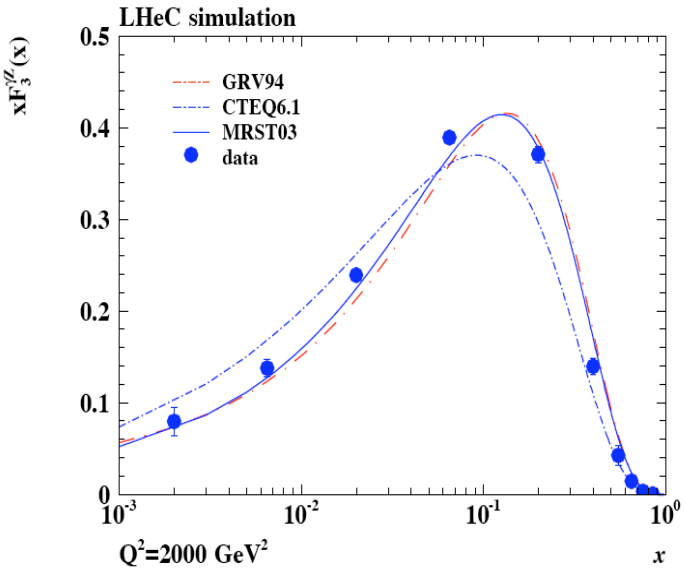
2 charges and 2 polarisations very desirable for electroweak physics and the new spectroscopy should that appear.

Z effects depend on charge and polarisation.



# Structure Functions with the LHeC

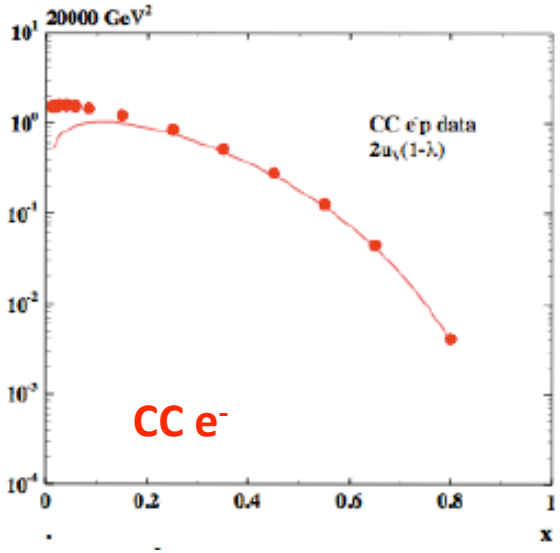



high Lumi,
high precision,
new detector,
full range:

$\alpha_s$ to 0.0001

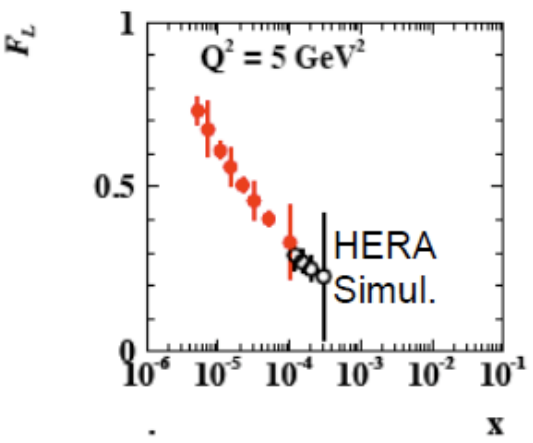
thy challenge

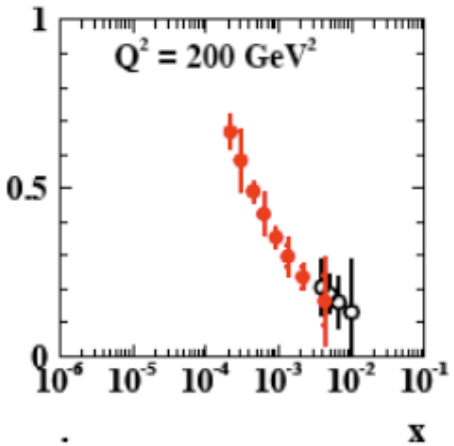
T.Kluge, MK - DIS08

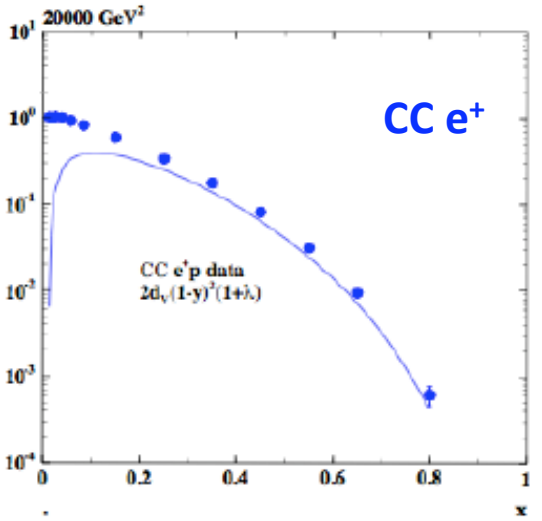



**High precision electroweak structure functions.**

**Flavour separation to highest x**



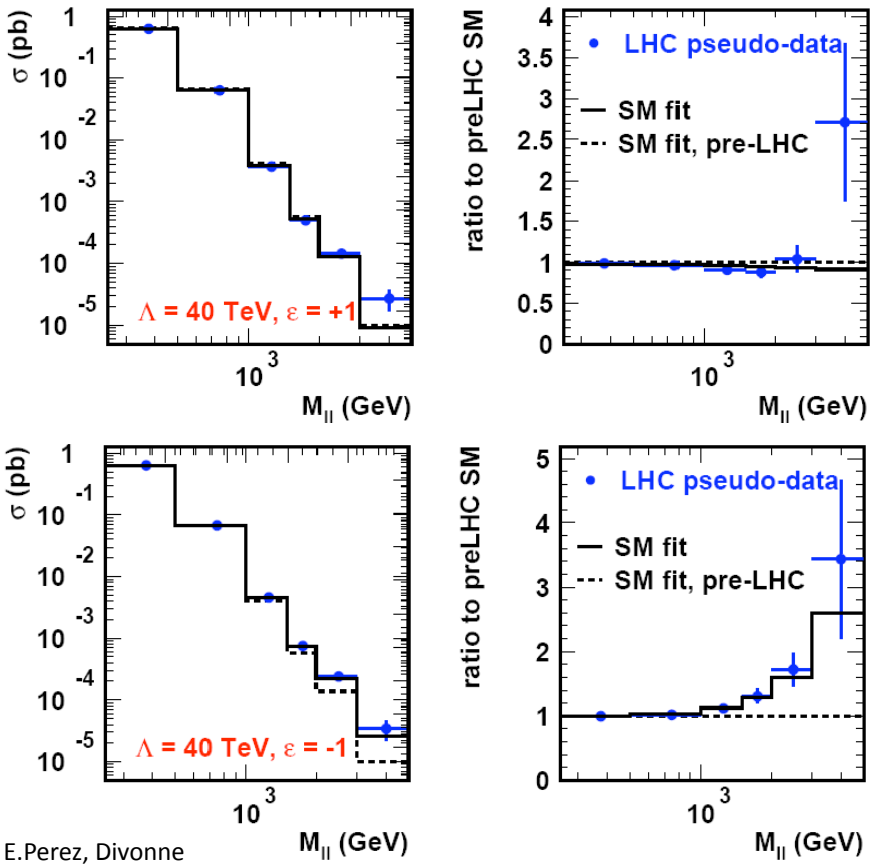




**$F_2$ and $F_L$: the ultimate challenge to saturation**

(Foreshaw et al, NNPDF group)

$F_L$ "data" included in simulation files

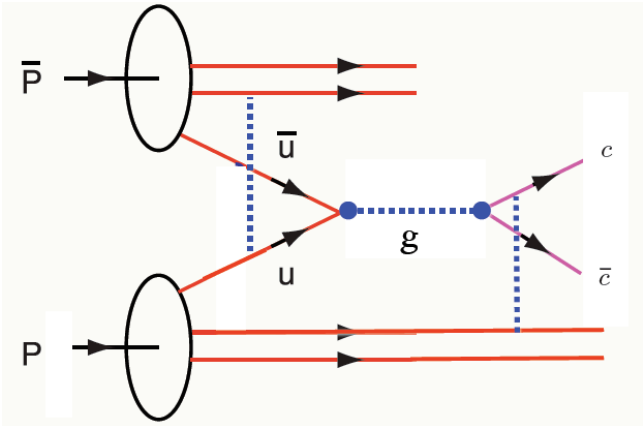
# pdf's and New Physics at the LHC




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)



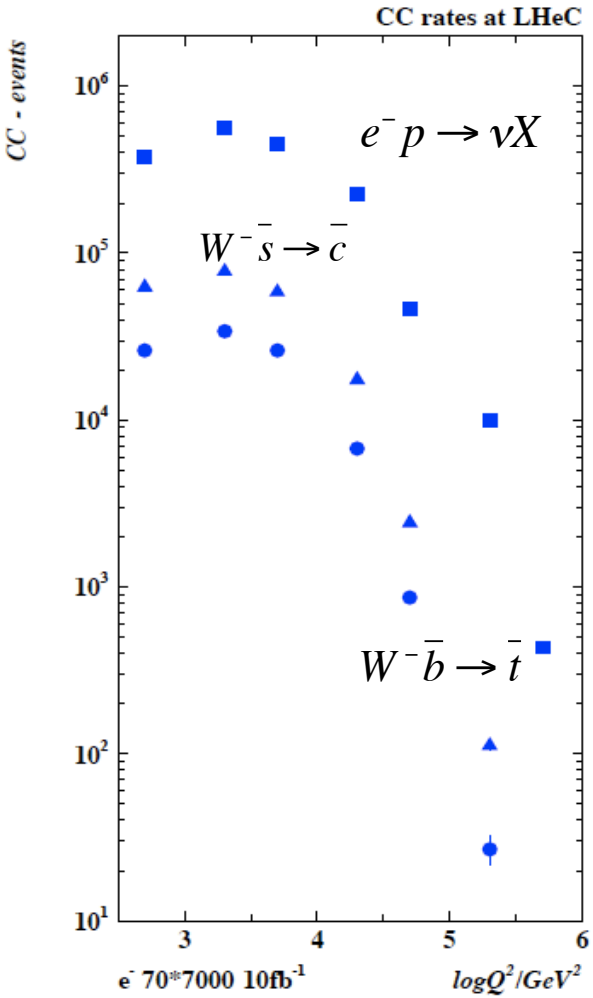

**Factorisation is violated in production of high $p_T$ particles (IS and FS i.a.s).**

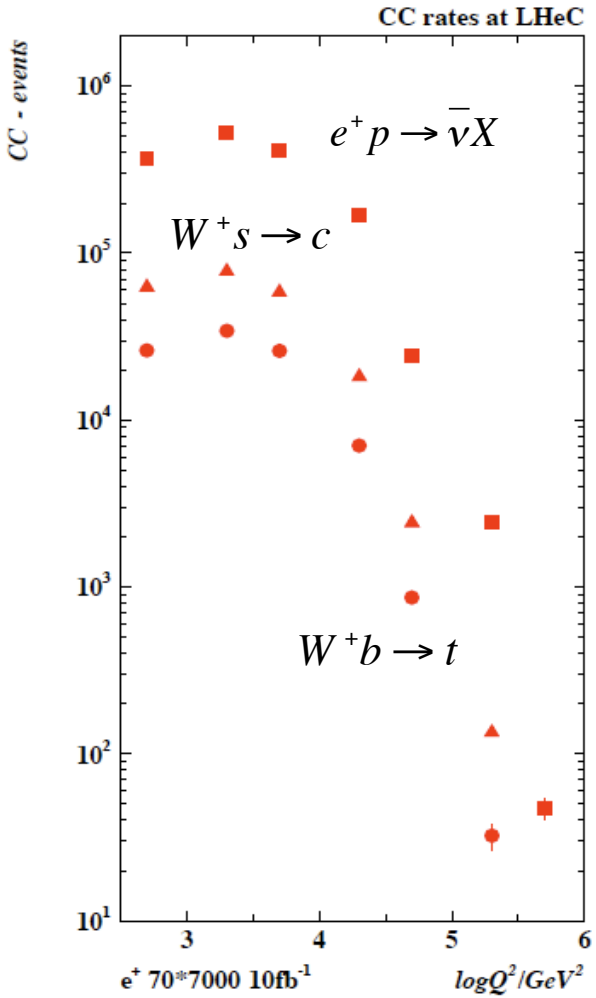
Important, perhaps crucial, to measure pdf's in the kinematic range of the LHC. cf also ED limits vs pdf's.

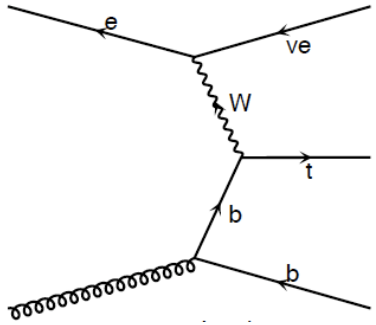
John Collins, Jian-Wei Qiu . ANL-HEP-PR-07-25, May 2007.

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

# Top and Top Production at the LHeC (CC)



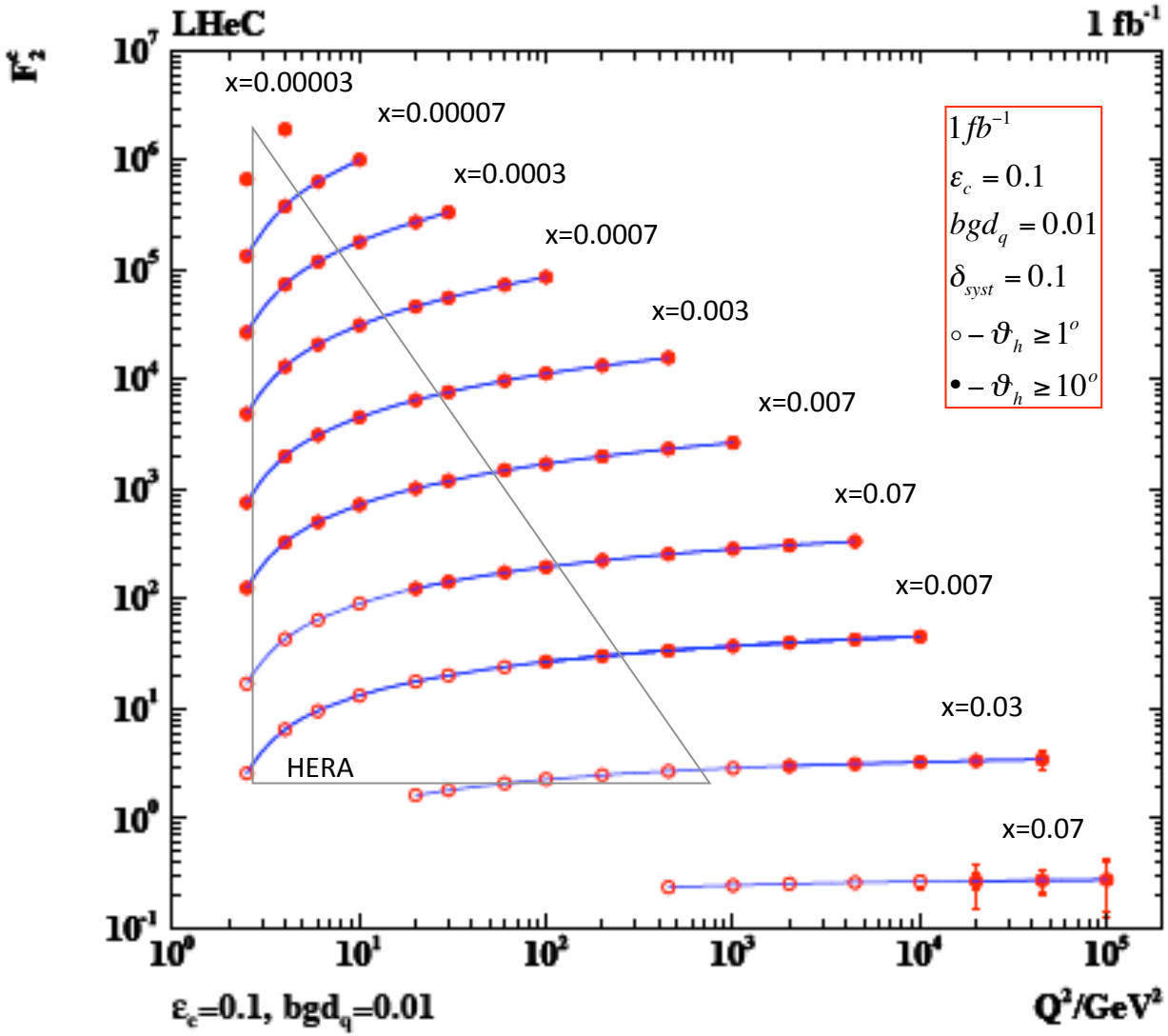




**LHeC is a single top and anti-top quark factory**

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

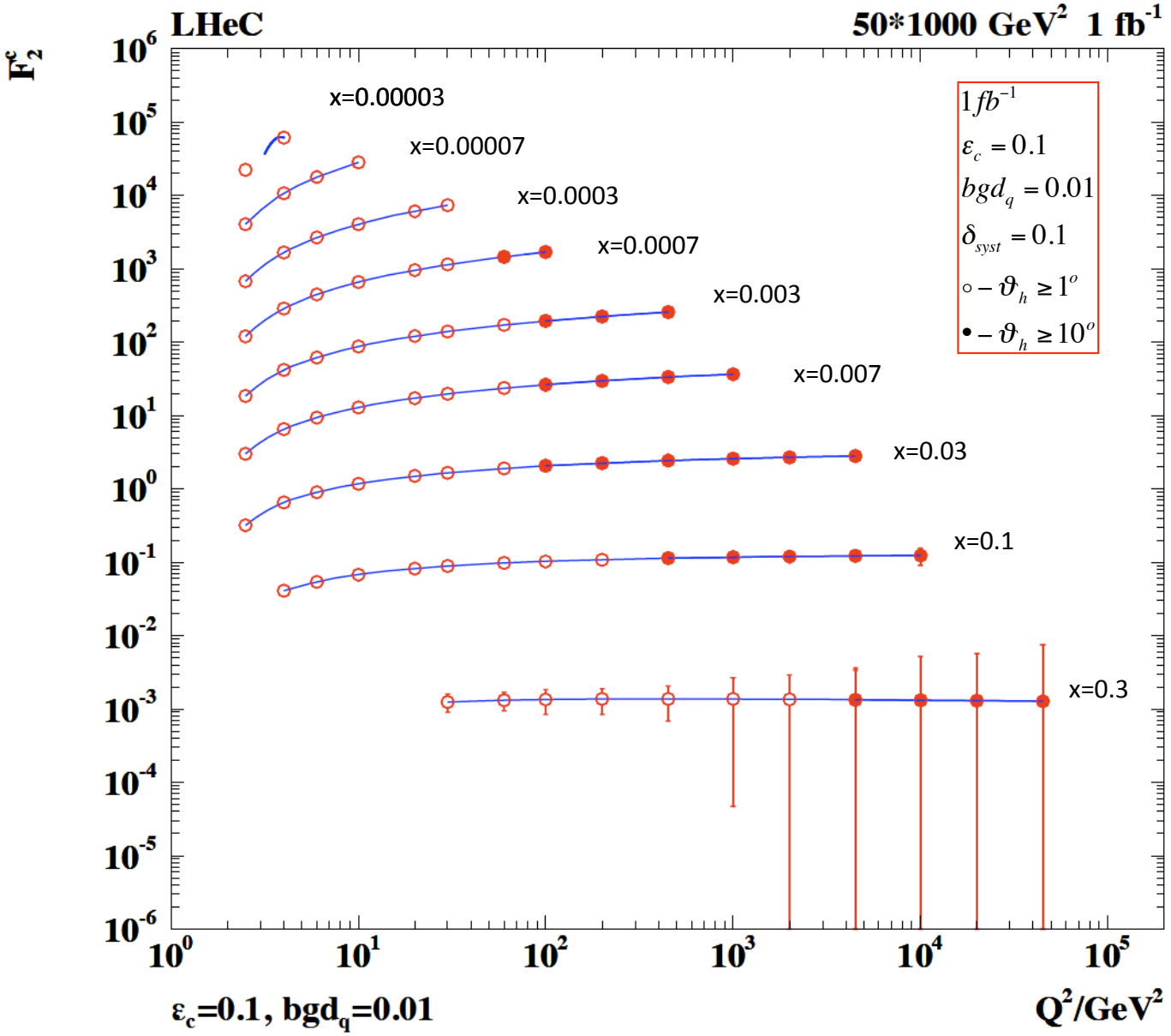
# Charm quark distribution




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

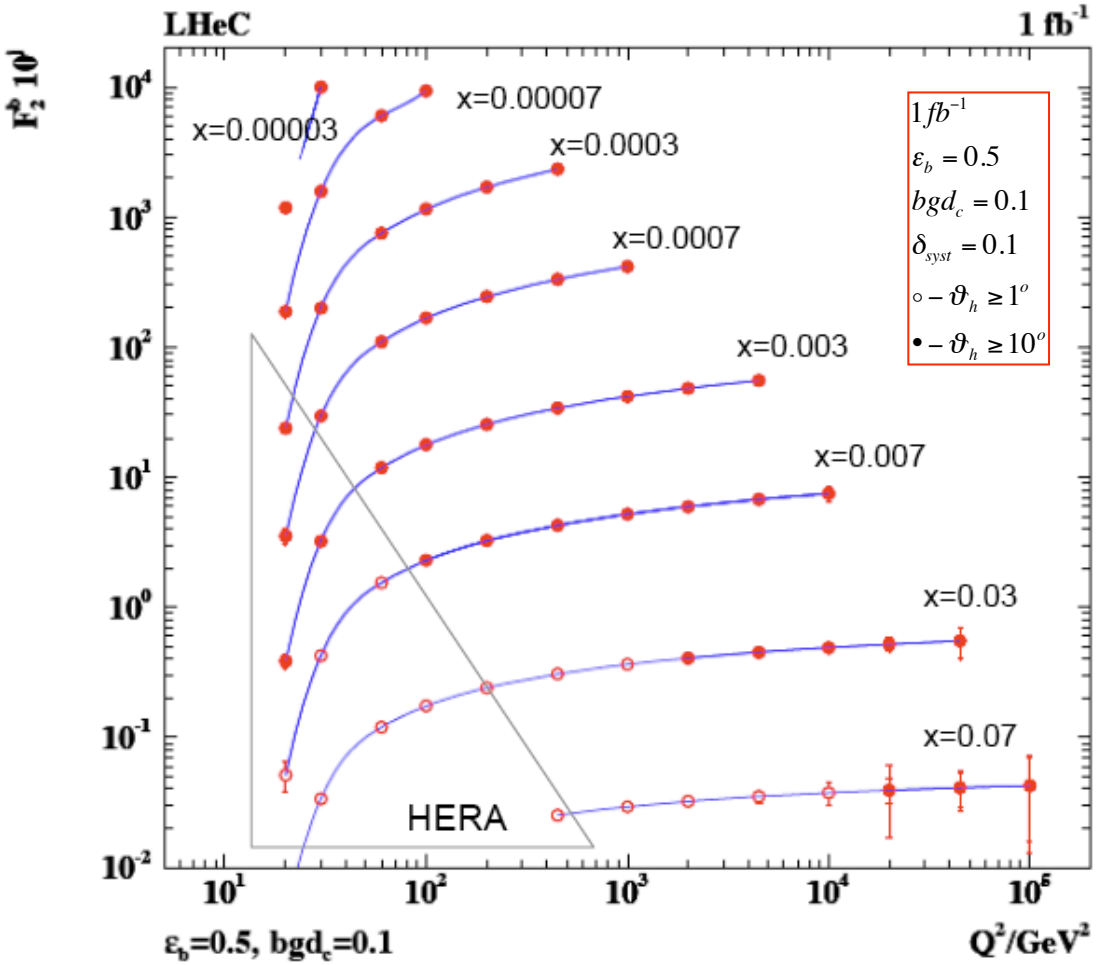
Intrinsic charm requires dedicated forward tagging and low $E_p$ in order to reach large x.

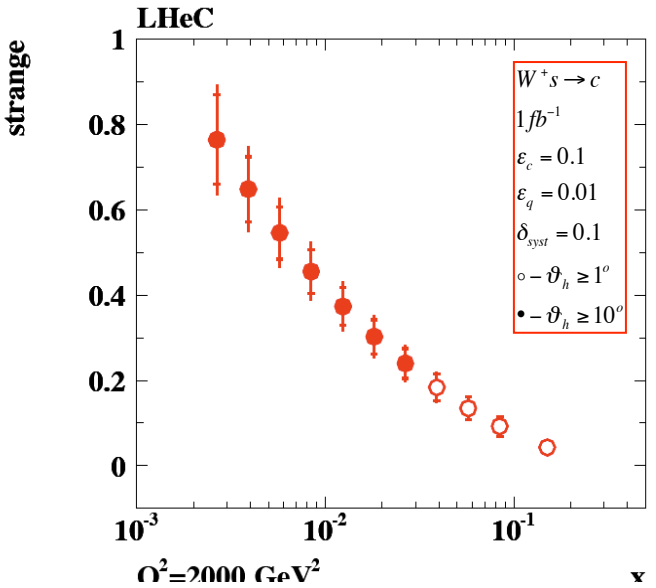
# Try to see charm at large x

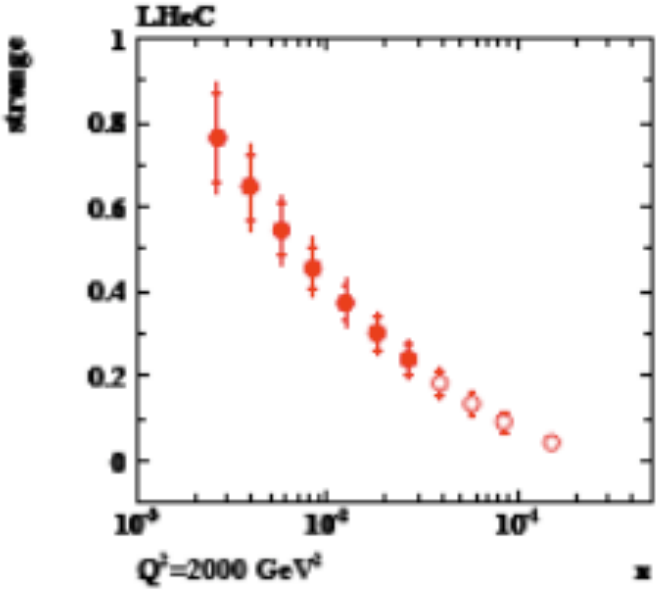



Even in the most favourable beam energy setting, a search for intrinsic charm at x >=0.1 would require charm tagging down to few degrees…

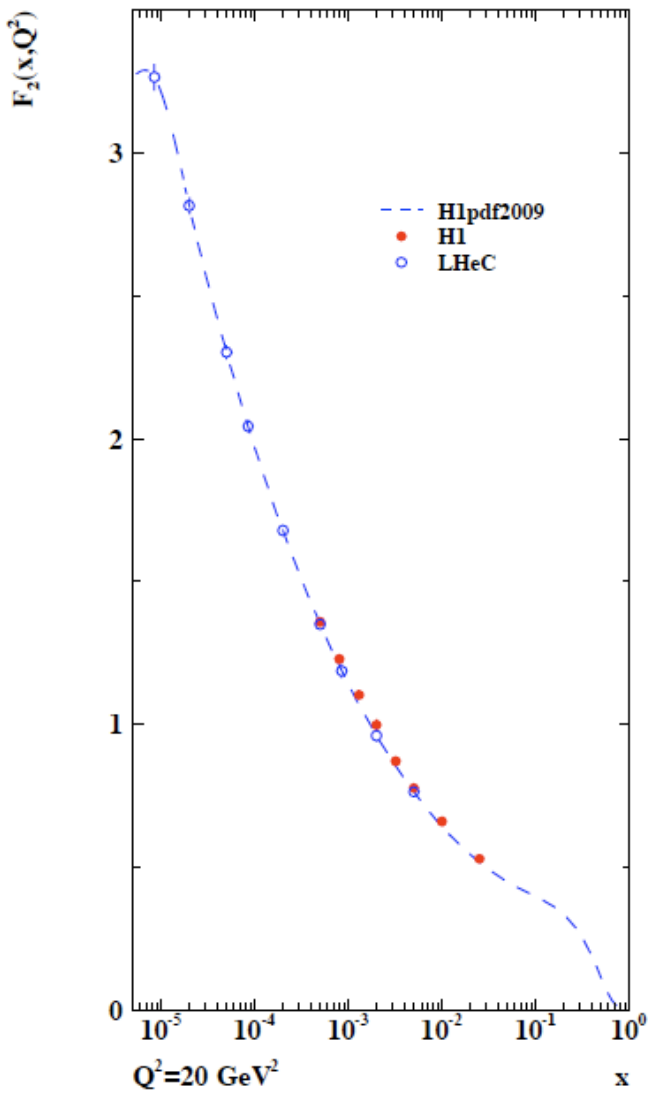
# Beauty, s and anti-s measurements with the LHeC



# 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.

# Backup