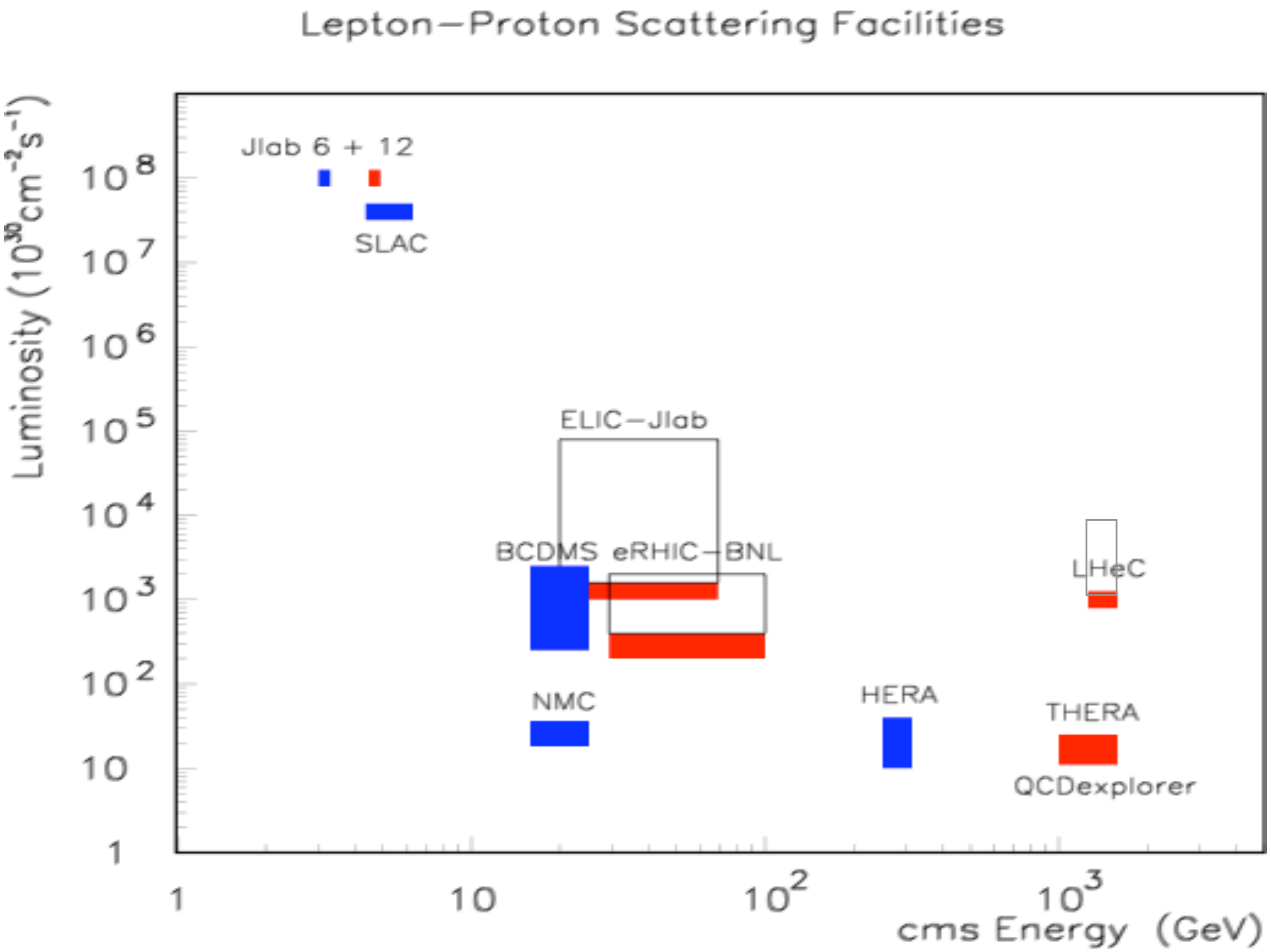
Parton Distributions from the LHeC

Max Klein (U.Liverpool)



Why is an ep collider at TeV scales of interest

E.Perez

P.Newman

this talk

-New Physics in the eq Sector

leptoquarks, contact i.a.'s, RP violating SUSY,..

-Quark-Gluon Dynamics and the Origin of Mass

confinement and diffraction, the gluon

-The Structure of Quantum Chromodynamics

high density (CGC, instantons, odderons..), resumm's

-The Structure of the Proton

substructure, parton correlations, transverse, uPDF's

-Precision for the LHC

heavy flavour (b), strong coupling, partons

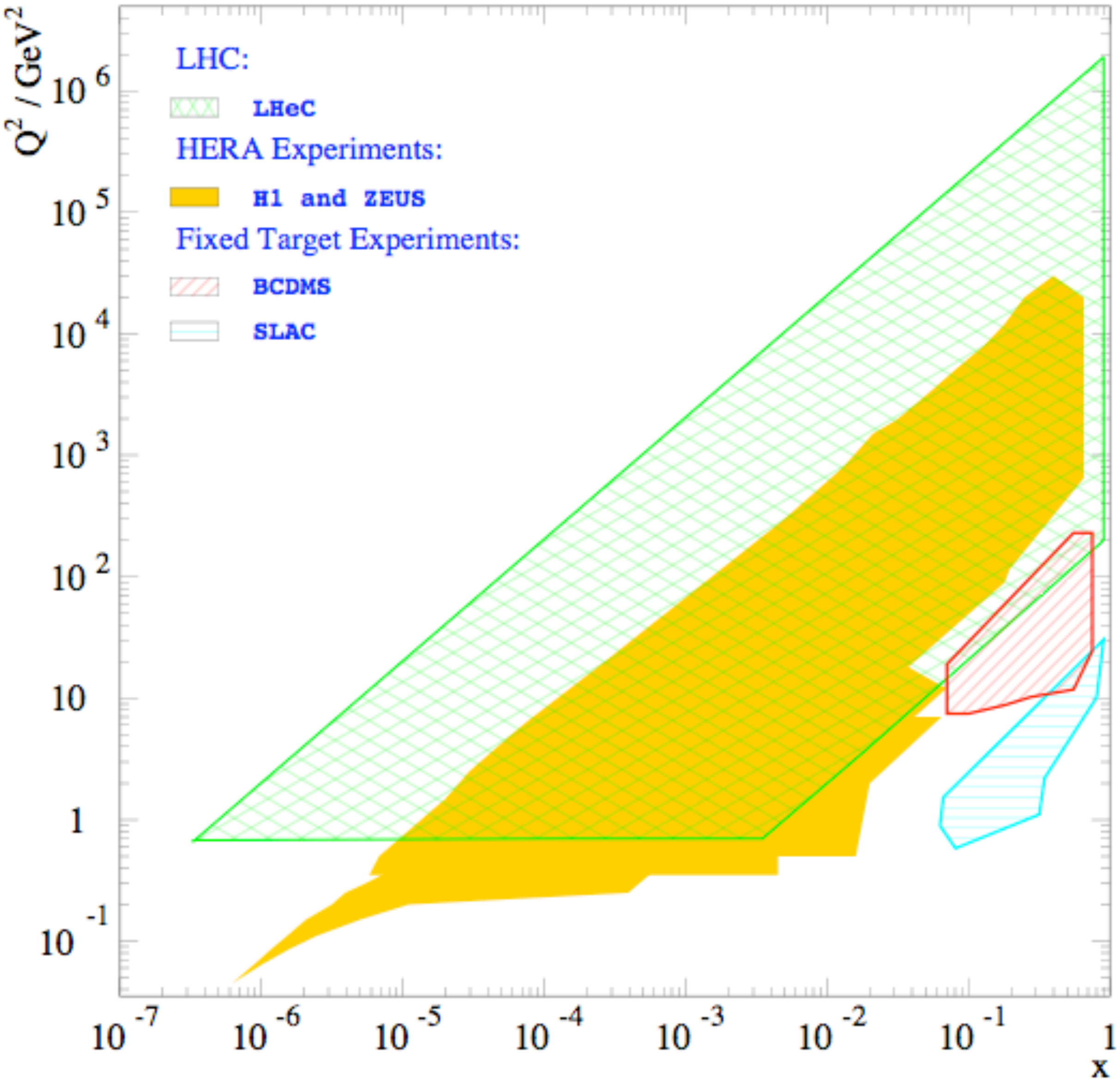
-The Origin of the Quark Gluon Plasma

partons in nuclei, deconfinement phase, CGC

If you bombard protons off each other you better control their structure.
If you scatter electrons off positrons you avoid but also miss p's structure.

ep is the missing link between pp and ee, it has been for decades

Kinematic coverage of lepton proton scattering experiments



$s = 4E_e E_p$

$LHeC: 70 \cdot 7000 \rightarrow 2 \cdot 10^6 GeV^2$

$HERA: 27.6 \cdot 920 \rightarrow 10^5 GeV^2$

$s = 2M_p E_l$

$BCDMS: 280 \rightarrow 500 GeV^2$

$SLAC: 20 \rightarrow 40 GeV^2$

$Q^2 = sxy$

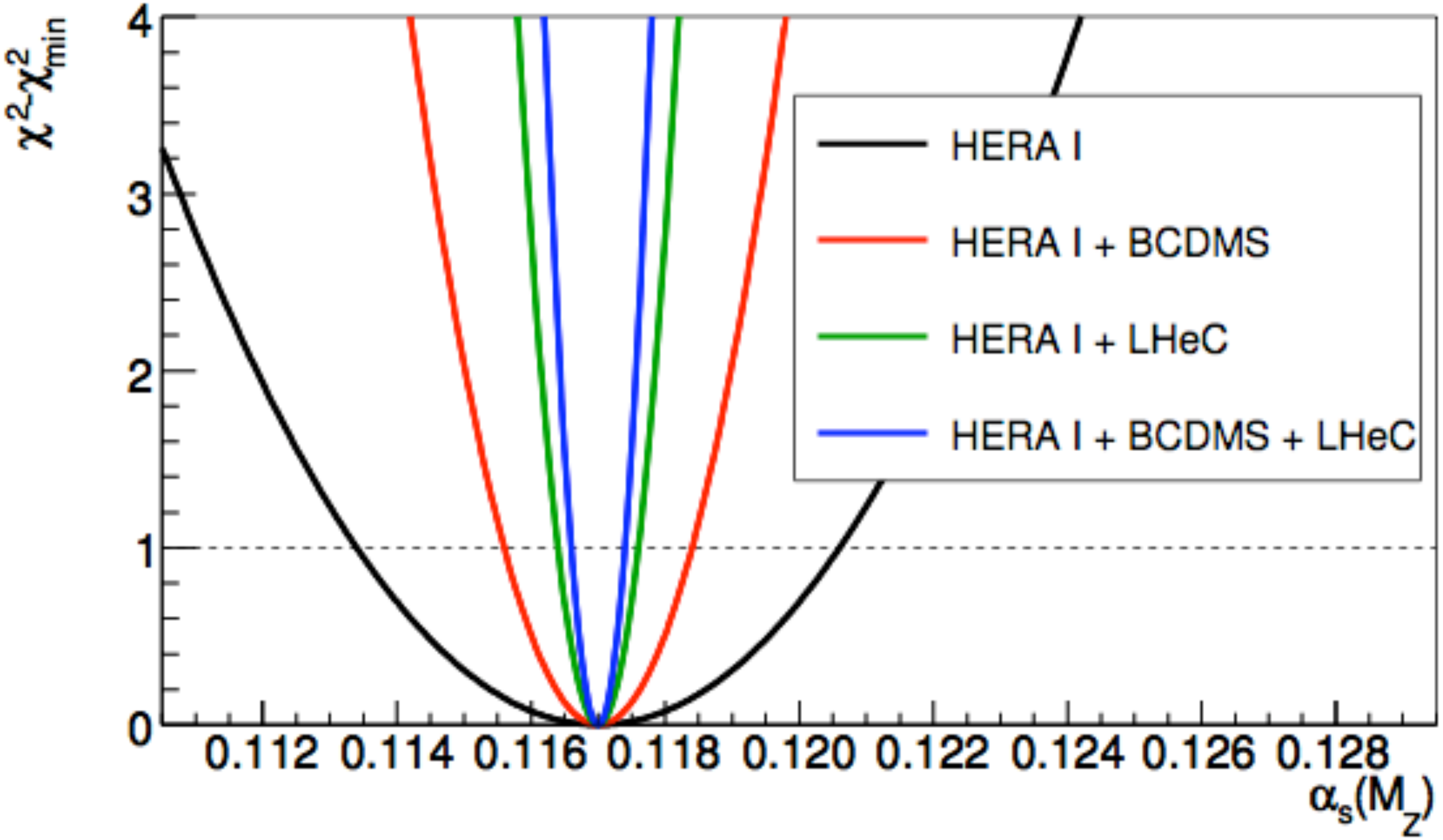
$x = \frac{Q^2}{sy}$

$Bjorken - x \leq 1$

$inelasticity - y \leq 1$

$Q^2 \leq s$

Why precision?



Can one measure the strong coupling constant to per mil accuracy?

Full simulation of NC, CC including systematics and NLO fit

Detector requirements

High luminosity to reach high Q^2 and large x

LHeC	HERA
10^{33} - 10^{34}	1-5 10^{31}

Largest possible acceptance

LHeC	HERA
1-179^o	7-177^o

High resolution tracking

LHeC	HERA
0.1 mrad	0.2-1 mrad

Precision electromagnetic calorimetry

LHeC	HERA
0.1%	0.2-0.5%

Precision hadronic calorimetry

LHeC	HERA
0.5%	1%

High precision luminosity measurement

LHeC	HERA
0.5%	1%

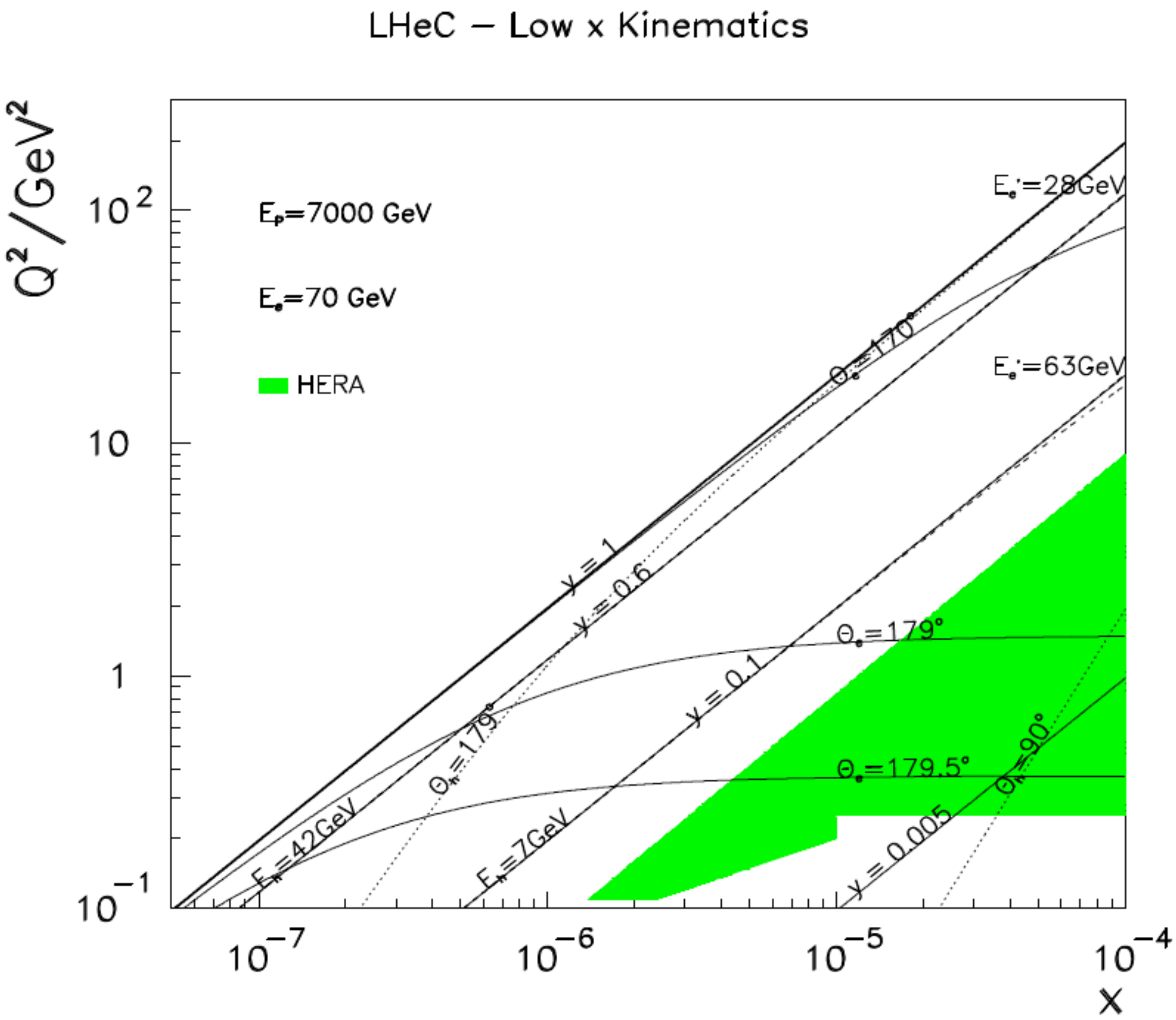
LHeC HERA

The new collider

has to be 100 times more luminous than HERA

The new detector

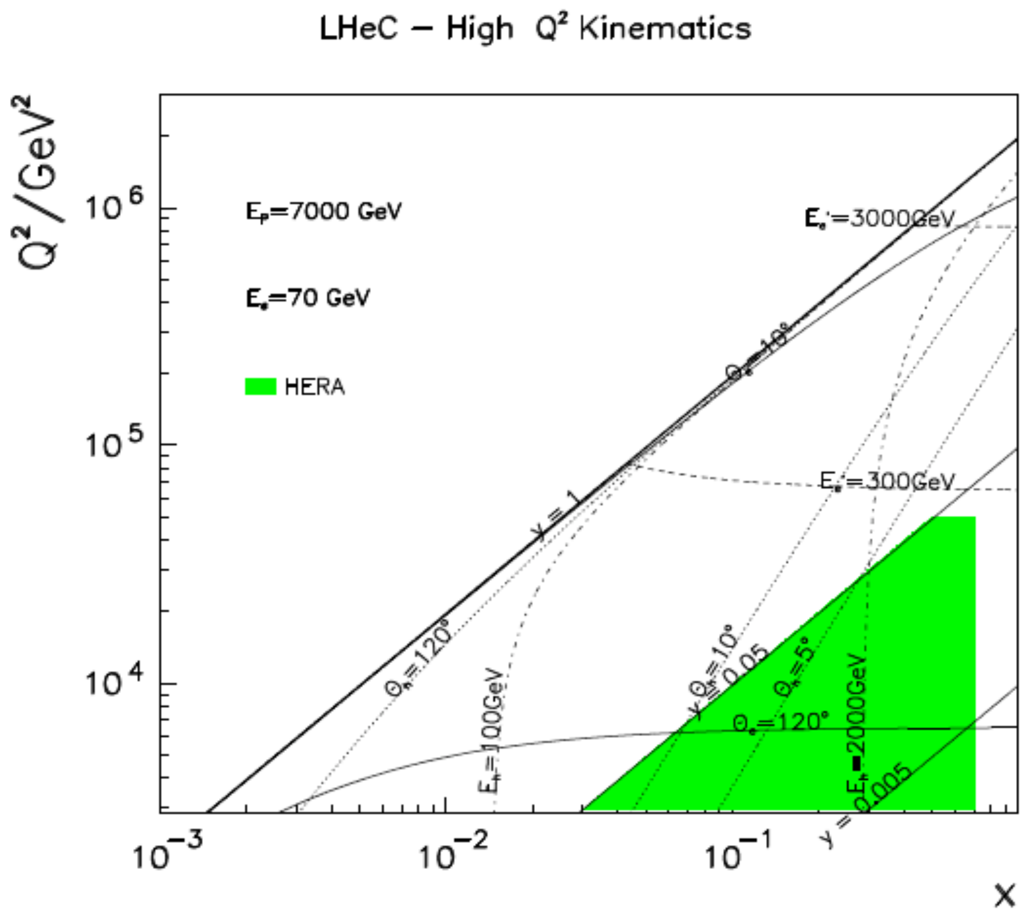
has to be at least 2 times better than the good old H1

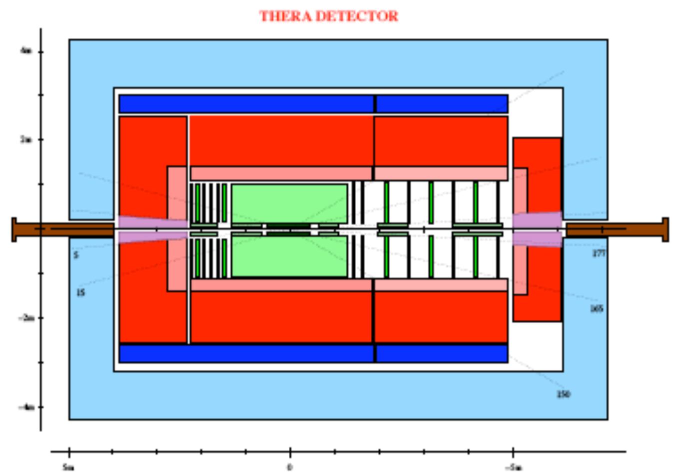


10^5 events per pb^{-1} for Q^2>100
Lumi 'easy'

Small angle spectrometer, favourable over THERA kinematics
cf THERA book for detector concept
[also W.Bartel
Aachen 1990]

Dramatic extension of low x kinematic range



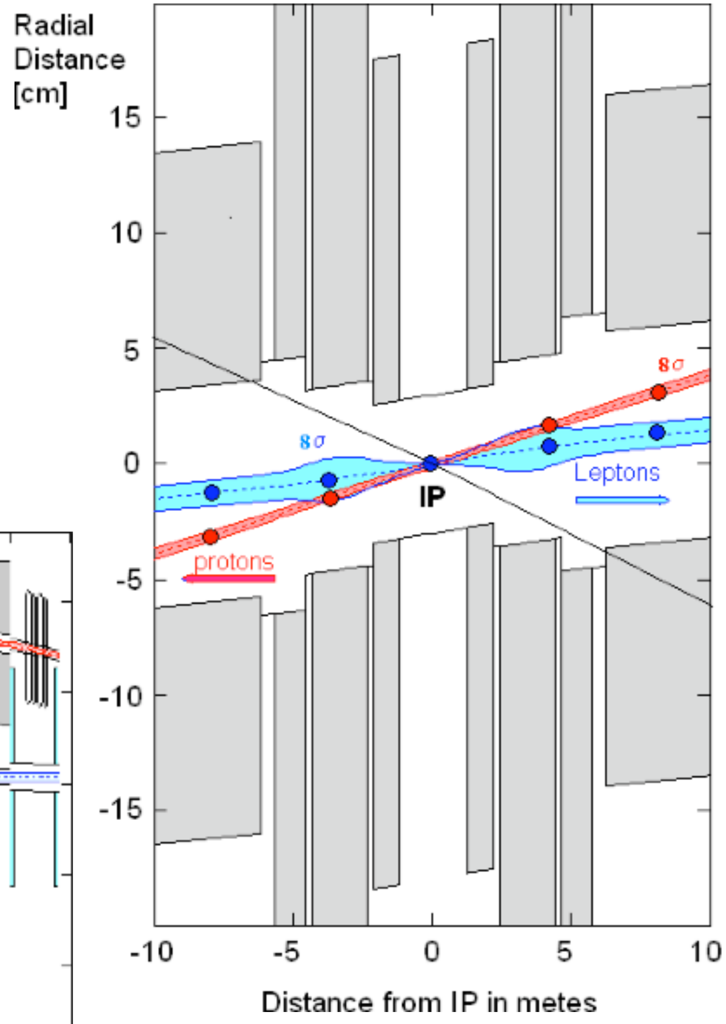


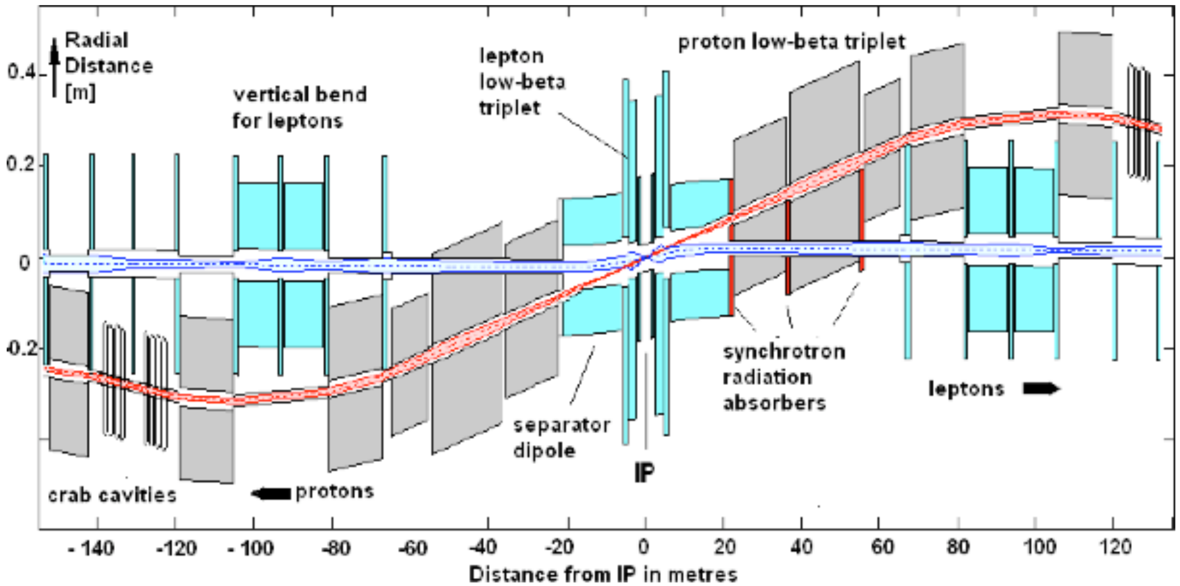
Maximum luminosity in current design achieved with focusing magnets close to IP (9^o cut) two detectors or detector versions required [cf THERA]
Lowx with 10^{32} , highQ with 10^{33} [higher in upgraded LHC]

LHeC Design

Table 3: *Main Parameters of the Lepton-Proton Collider*

Property	Unit	Leptons	Protons
Beam Energies	GeV	70	7000
Total Beam Current	mA	74	544
Number of Particles / bunch	10^{10}	1.04	17.0
Horizontal Beam Emittance	nm	7.6	0.501
Vertical Beam Emittance	nm	3.8	0.501
Horizontal β-functions at IP	cm	12.7	180
Vertical β-function at the IP	cm	7.1	50
Energy loss per turn	GeV	0.707	$6 \cdot 10^{-6}$
Radiated Energy	MW	50	0.003
Bunch frequency / bunch spacing	MHz / ns	40 / 25	
Center of Mass Energy	GeV	1400	
Luminosity	$10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.1	





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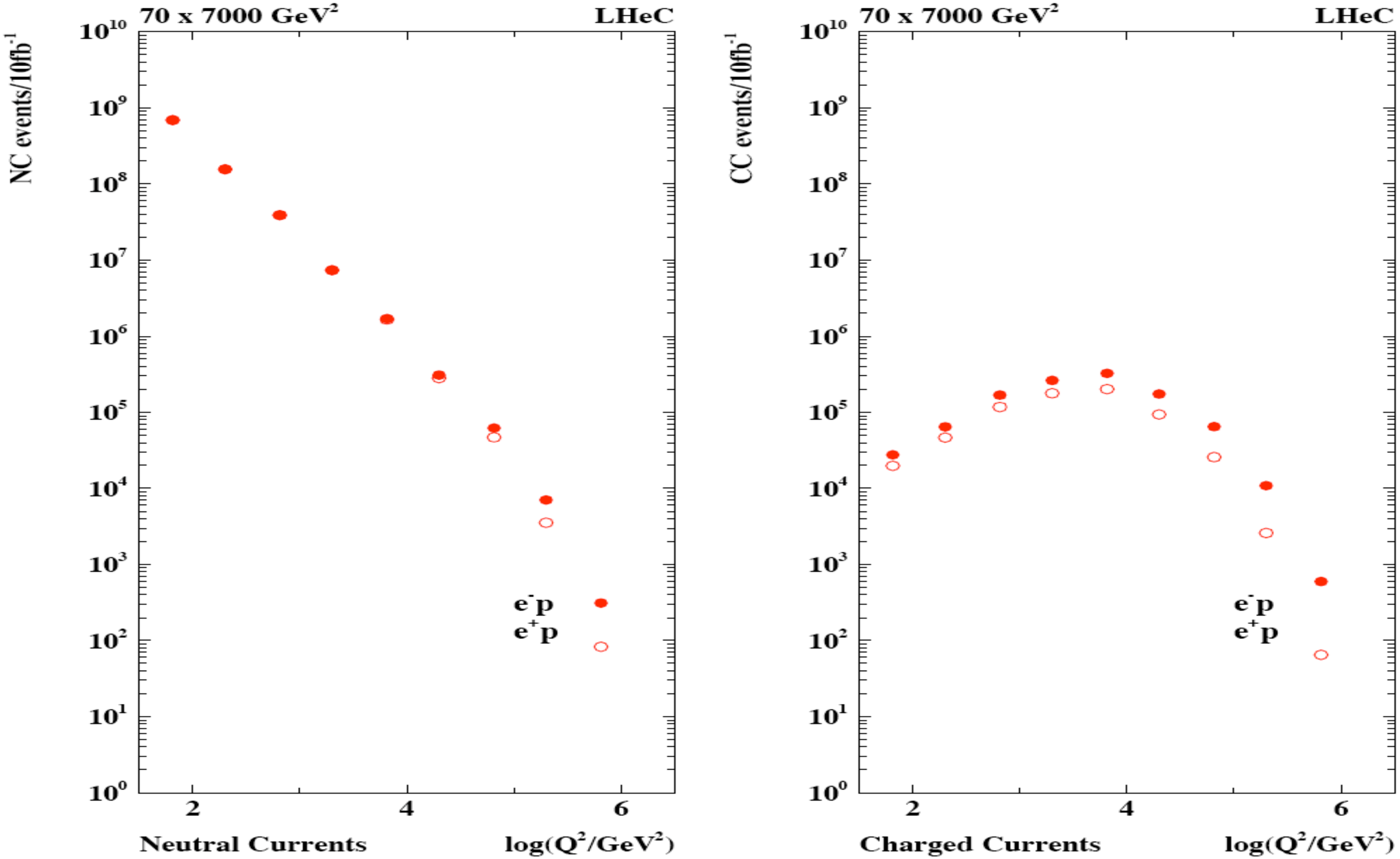
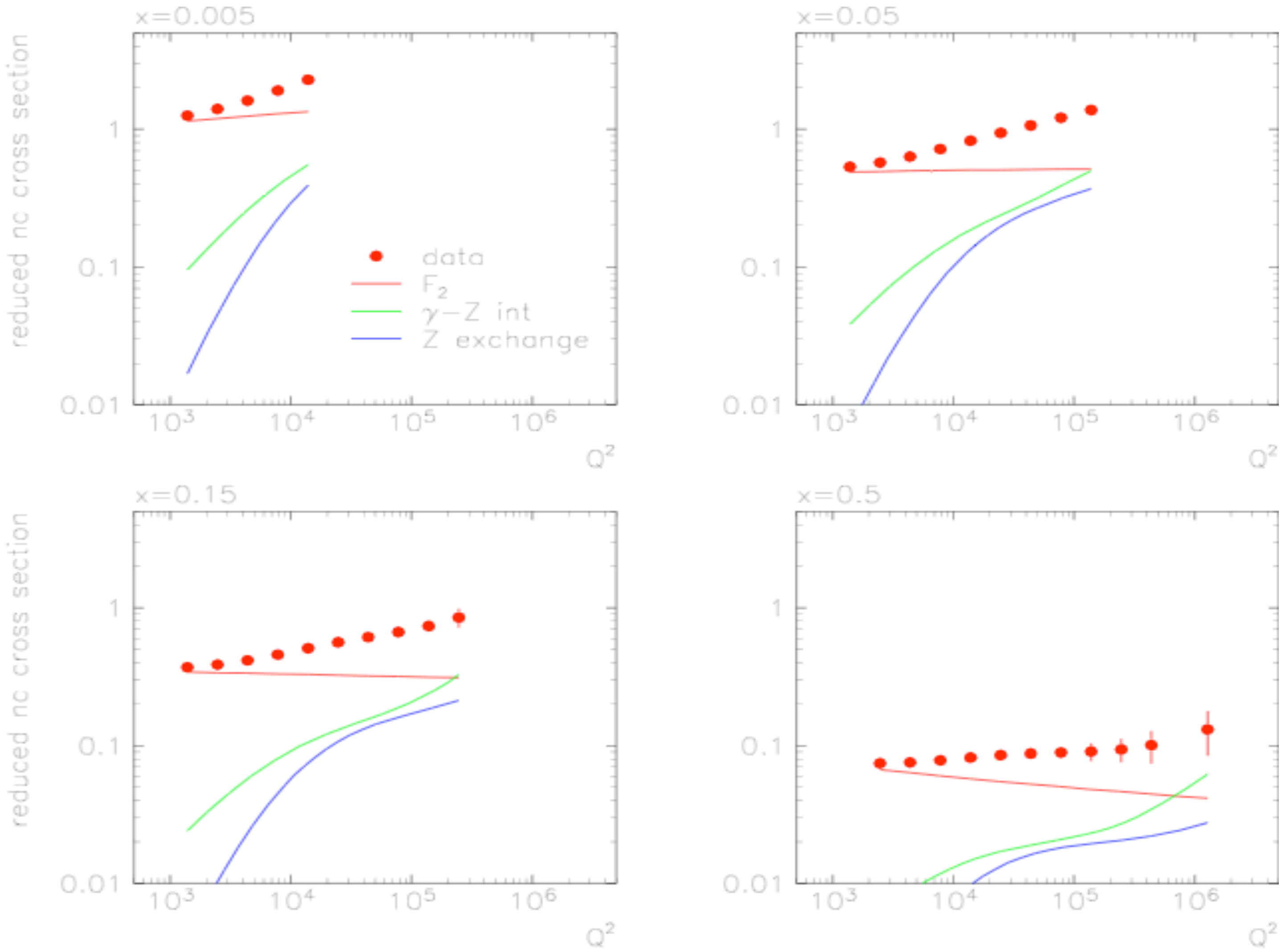
Rates



Simulations done for 10fb-1 and statistical error limited to 0.1% low Q2, acceptance 1-10 degrees

The LHeC is an electroweak machine



Polarisation: not impossible, S/T 1/2 hour, consider from the start (DB)

Lepton Polarisation

Self polarization / depolarization.

- Electrons in storage rings can become spin POLARIZED due to emission of synchrotron radiation: Sokolov–Ternov effect (1964).
- The polarization is perpendicular to the machine plane.
- The maximum value is $P_{st} = 92.4\%$.
- Sync. radn. also excites orbit motion. This leads to DEPOLARIZATION!
- The attainable polarization results from a balance between polarization and depolarization.

$$P_{\infty} \approx P_{st} \frac{1}{1 \; + \; (\frac{\tau_{dep}}{\tau_{st}})^{-1}}$$

- Depolarization is worst at RESONANCES:

$$\nu_s = k_0 + k_1 Q_1 + k_2 Q_2 + k_3 Q_3$$

At high energy the synchrotron sideband resonances take control:

$$\text{Strength scale :} \qquad \xi = (\frac{a\gamma\,\sigma_\delta}{Q_s})^2$$

- Overall, roughly at each energy:

$$\tau_{dep}^{-1} \propto \text{(a polynomial in } \gamma^{2N}) \times \tau_{st}^{-1}$$

- For longitudinal polarization the polarization vector must be rotated into the longitudinal direction before an IP and back to the vertical afterwards ===> spin rotators.
- Depolarization can be strongly enhanced by misalignments, regions where the polarization vector is horizontal between spin rotators etc, etc.....

LEP: 46 GeV 1993. R. Assmann et al. reached 57 percent by tuning the orbit for many hours: $\tau_{pol} \leq 300$ min and $\xi = O(1)$

The good news: at 70 GeV $\tau_{pol} \approx\leq 36$ min (scales like γ^{-5}).

The bad news: depolarization is relatively much stronger than at 46 GeV.

The way forward

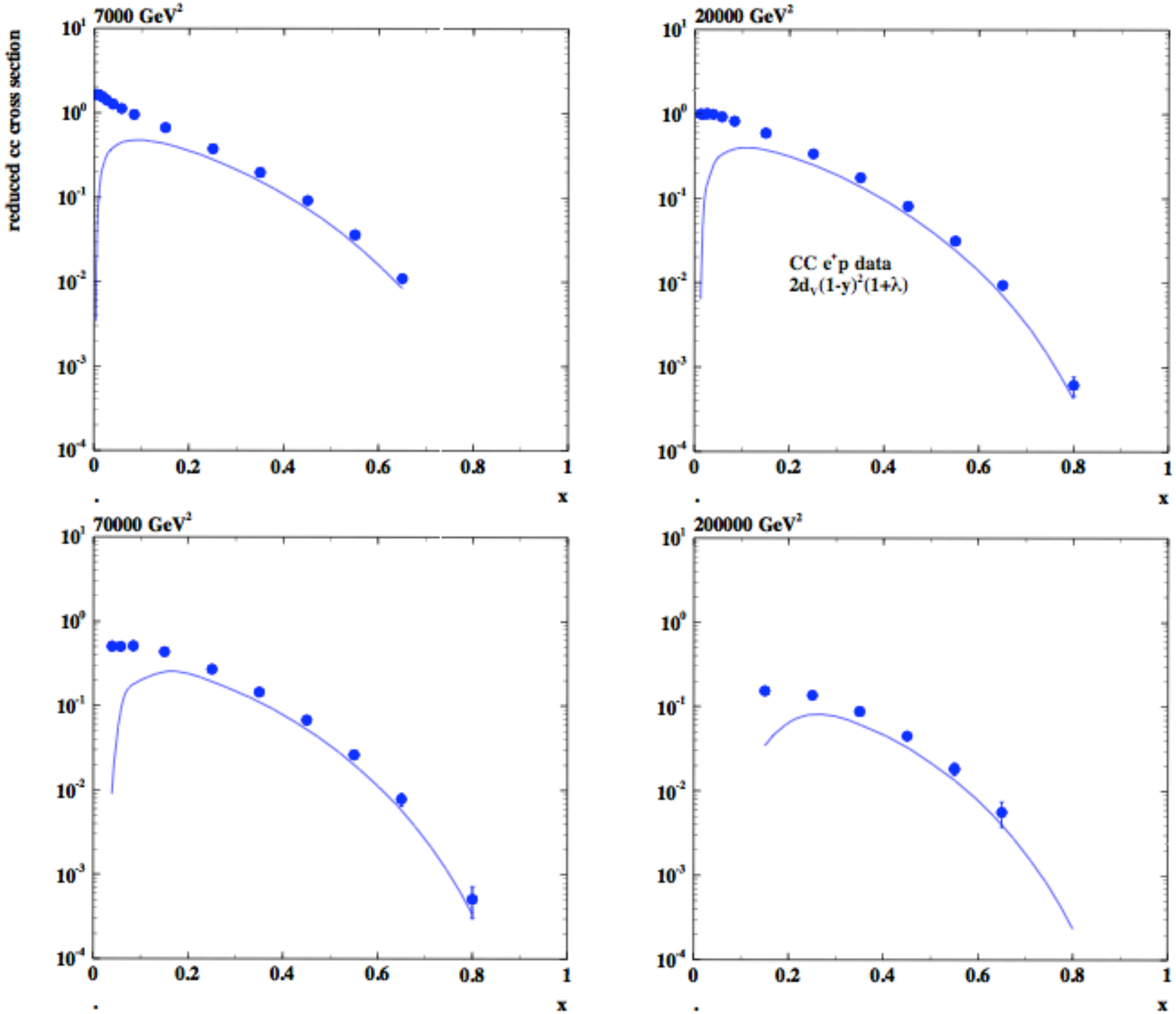
Plan for polarization from the start! Polarization can never be an after thought!

Begin NOW with intense careful study based on experience to investigate tricks.

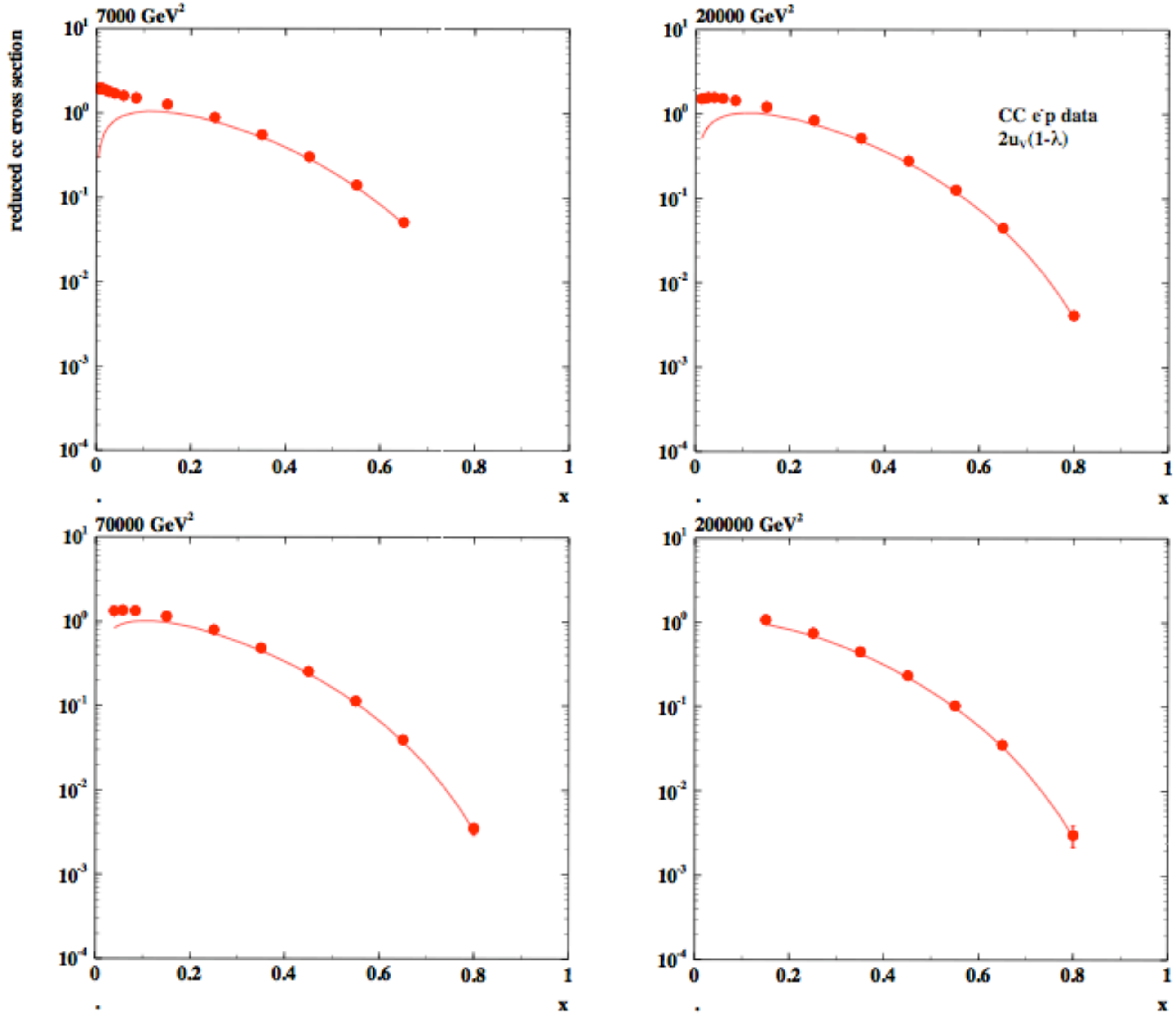
- Need very good alignment – better than at LEP.
- Siberian Snakes to suppress the effect of energy spread and synchrotron motion on spin motion?
  These are essential in proton rings to suppress depolarising resonances during acceleration (e.g., RHIC).
  But in electron rings they kill the S-T effect if the synchrotron radiation is evenly distributed around the ring!!!
- Can an arrangement be found based on a correct snake layout combined with uneven synchrotron radiation from super bends?

D.Barber

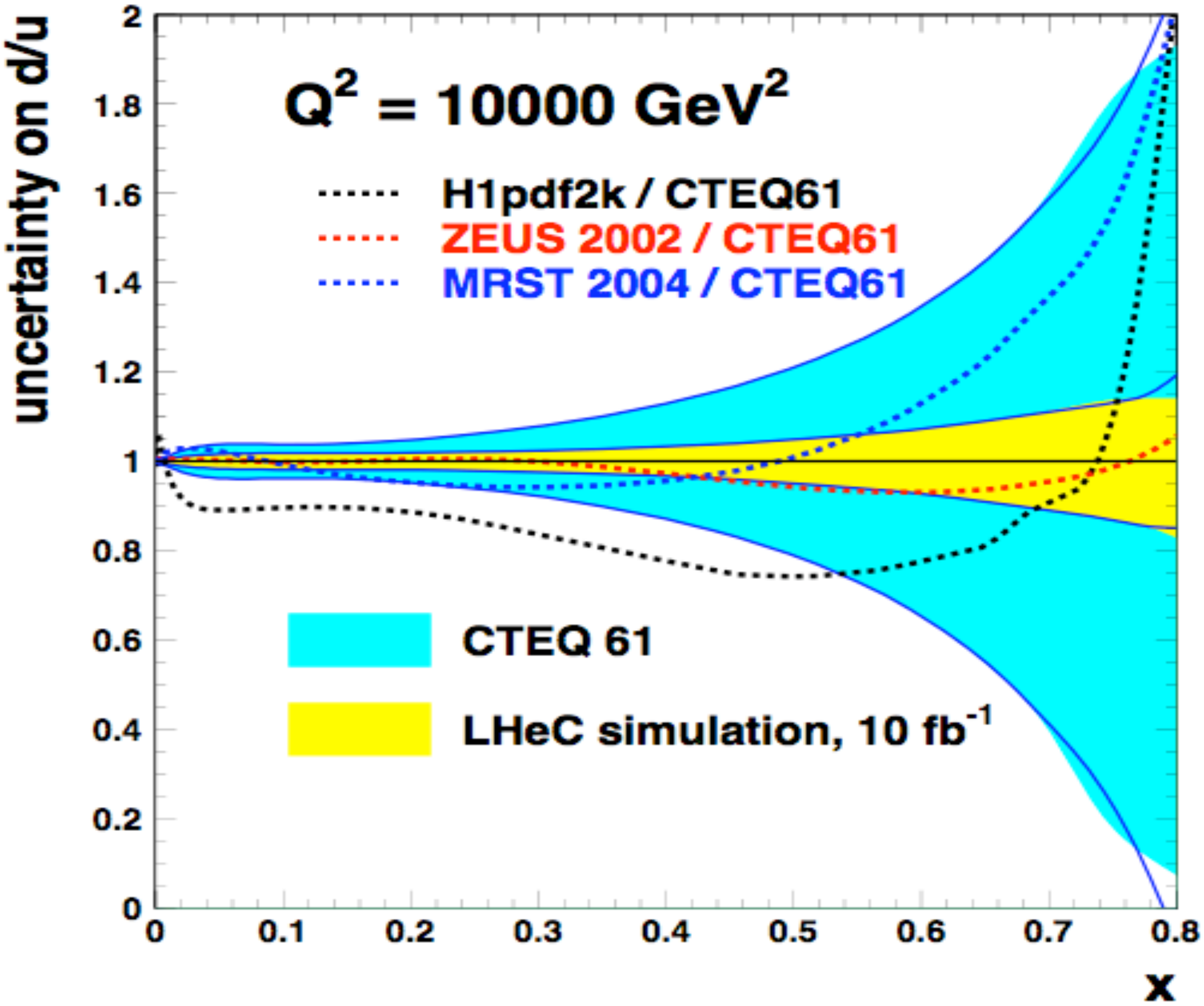
Charged currents (e+)



Charged currents (e-)

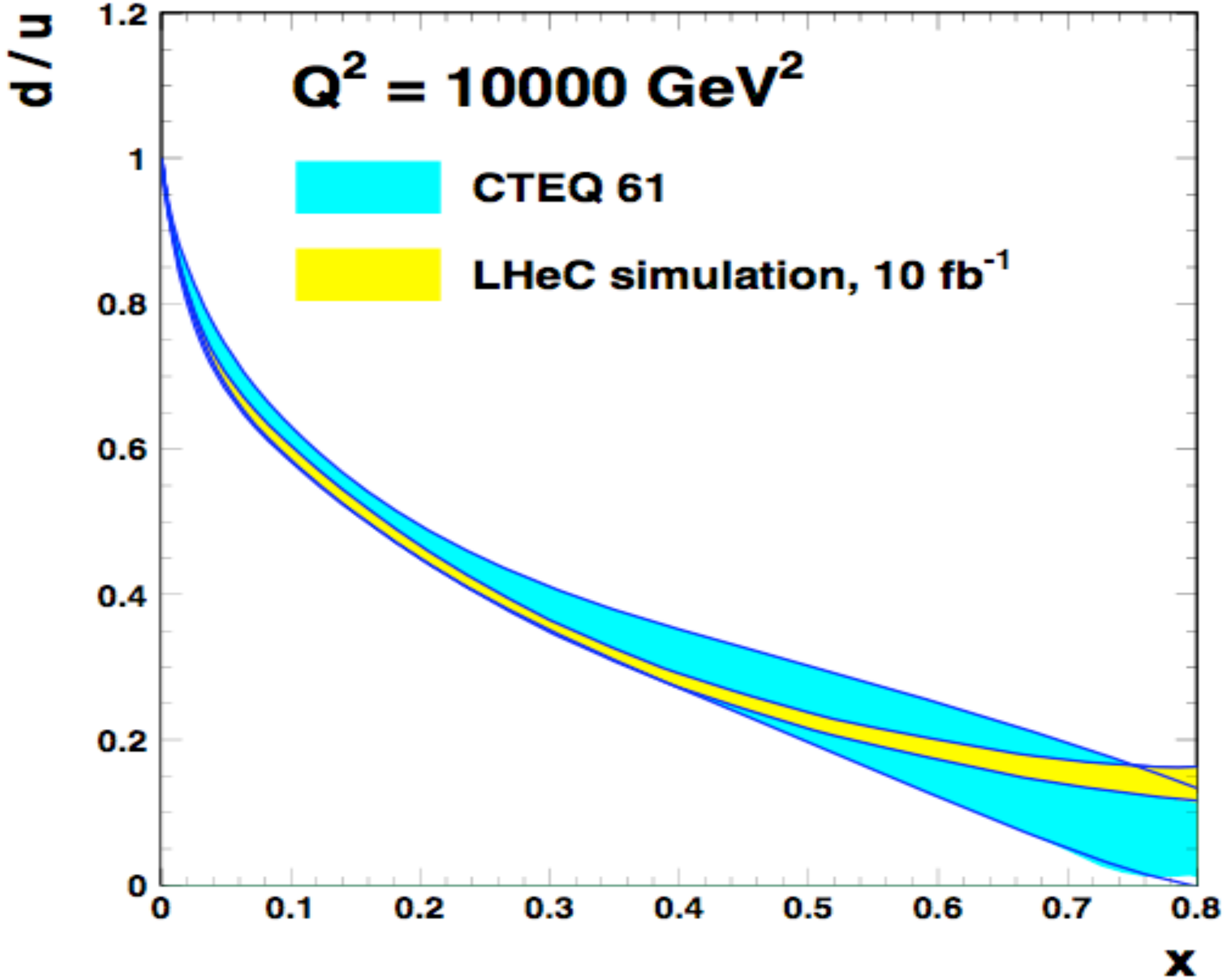


d/u at large x

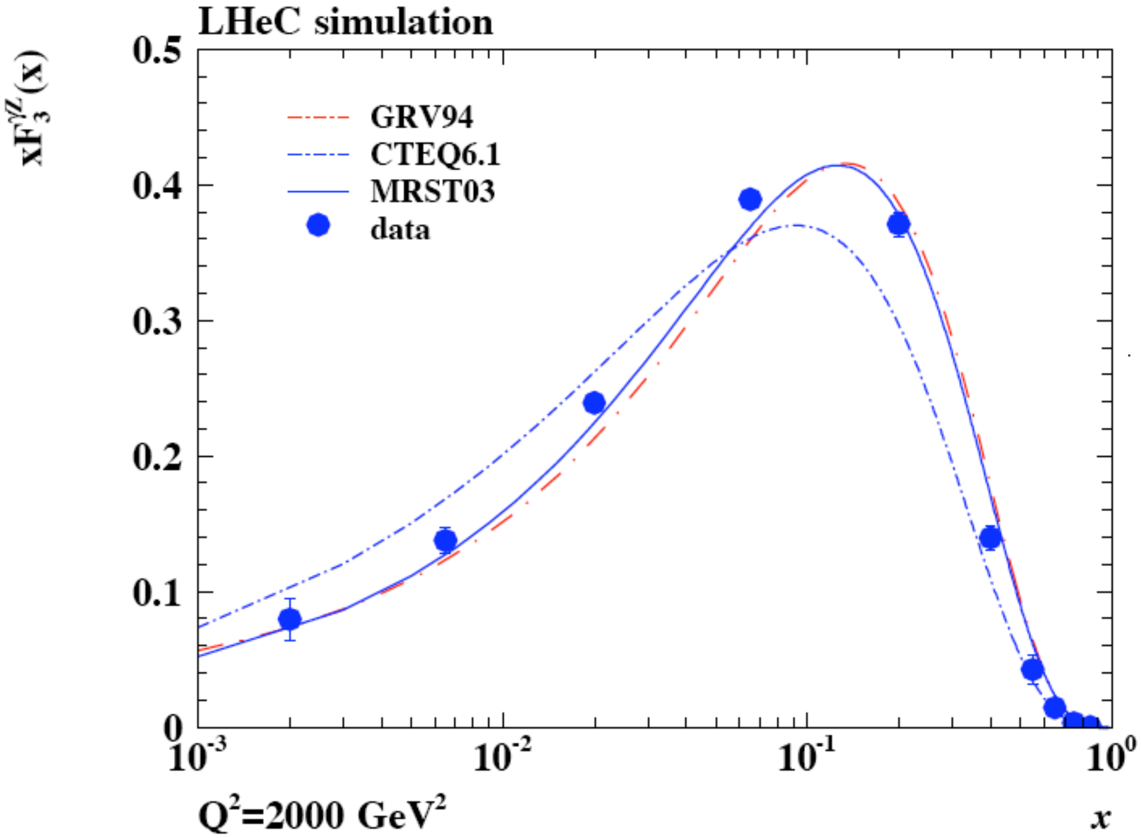


uncertainty on d/u
$Q^2 = 10000\ GeV^2$
H1pdf2k / CTEQ61
ZEUS 2002 / CTEQ61
MRST 2004 / CTEQ61
CTEQ 61
LHeC simulation, 10 fb^{-1}
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
x

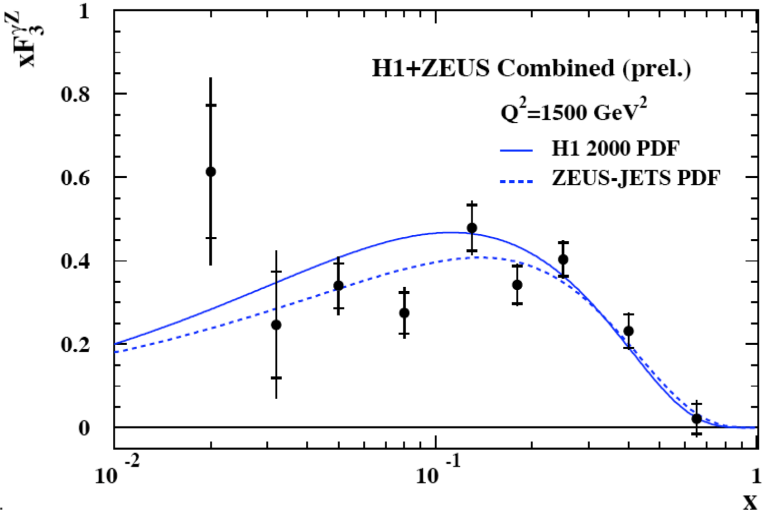
d/u at large x


d / u
1.2
1
0.8
0.6
0.4
0.2
0
Q^2 = 10000 GeV^2
CTEQ 61
LHeC simulation, 10 fb^{-1}
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
x

$xF_3^{\gamma Z}$



HERA I



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

Valence quarks at low x

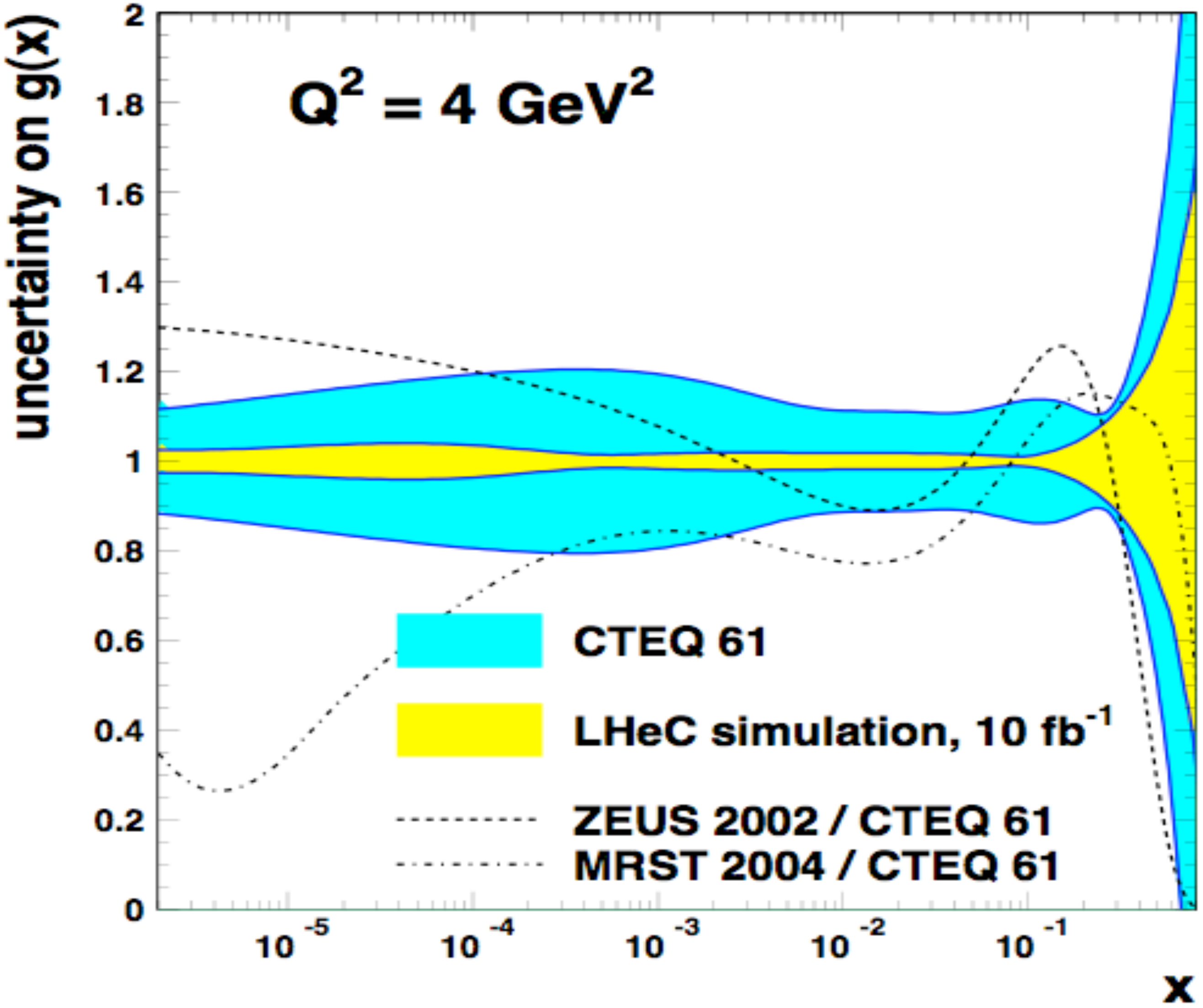
or/and unexpected sea

asymmetries

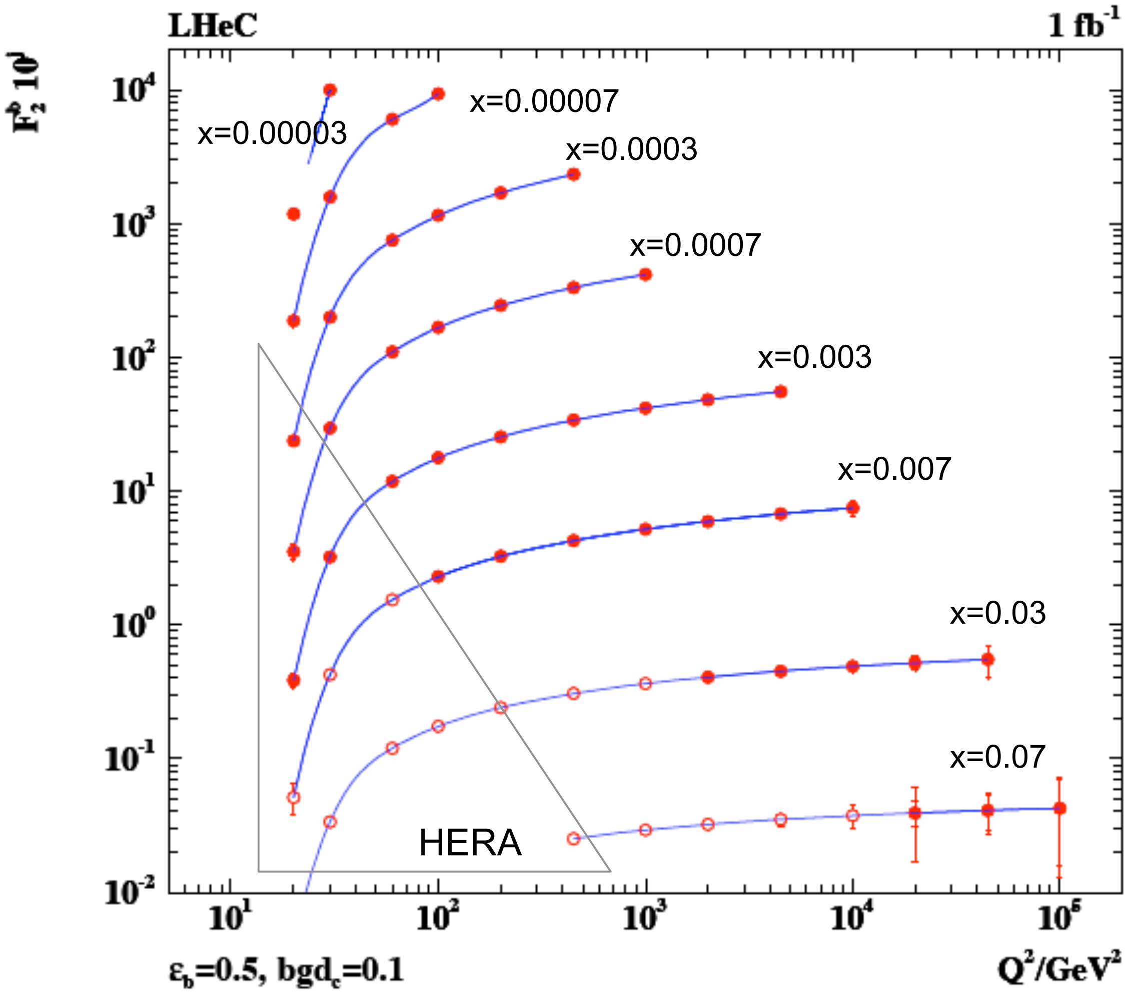
$$\boxed{\begin{aligned} \Delta_u &= (u_{sea} - \overline{u} + c - \overline{c}) \\ \Delta_d &= (d_{sea} - \overline{d} + s - \overline{s}) \end{aligned}}$$

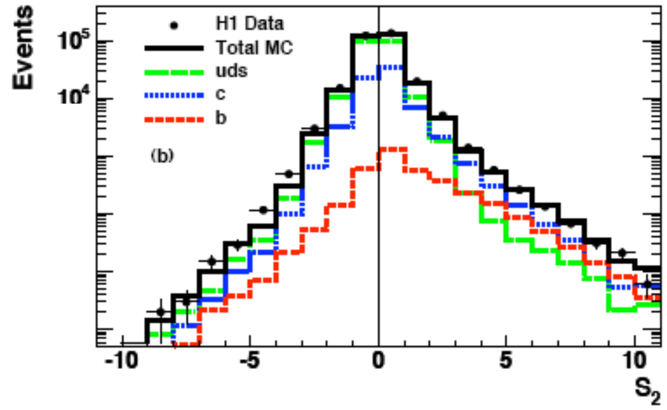
from yZ interference

Gluon Distribution



Beauty quark distribution





$1\,fb^{-1}$

$\varepsilon_b = 0.5$

$bgd_c = 0.1$

$\delta_{syst} = 0.1$

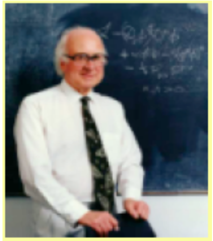
$\circ - \vartheta_h \geq 1^o$

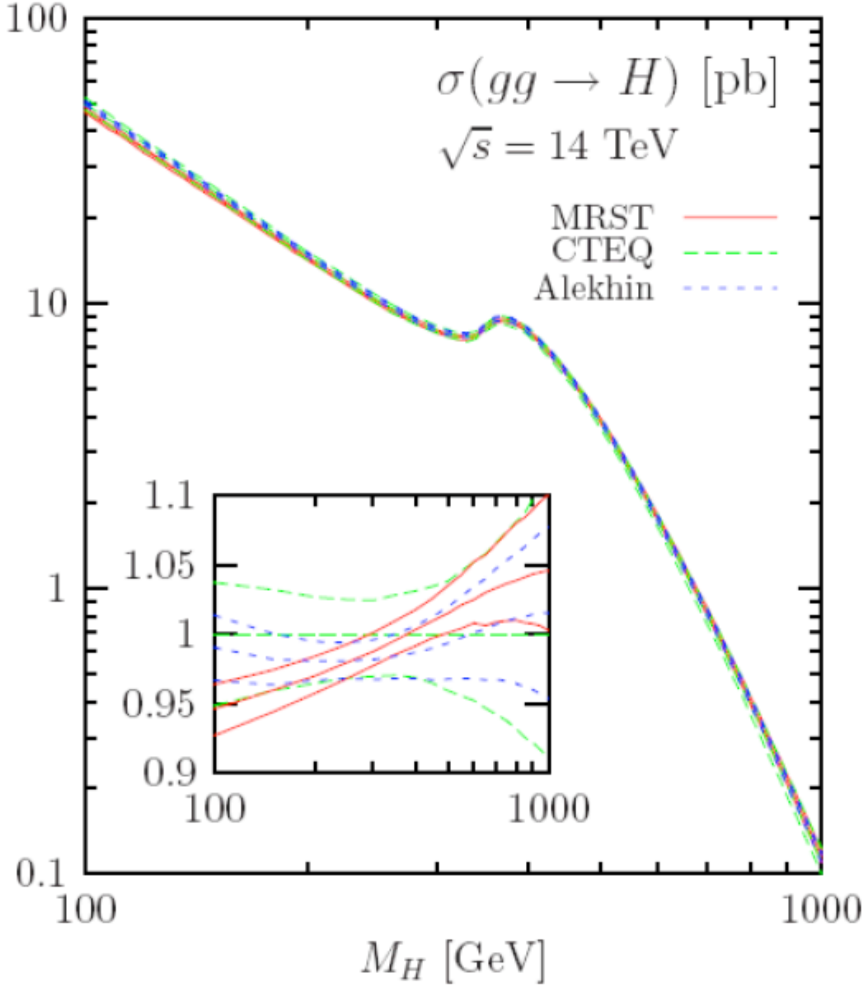
$\bullet - \vartheta_h \geq 10^o$

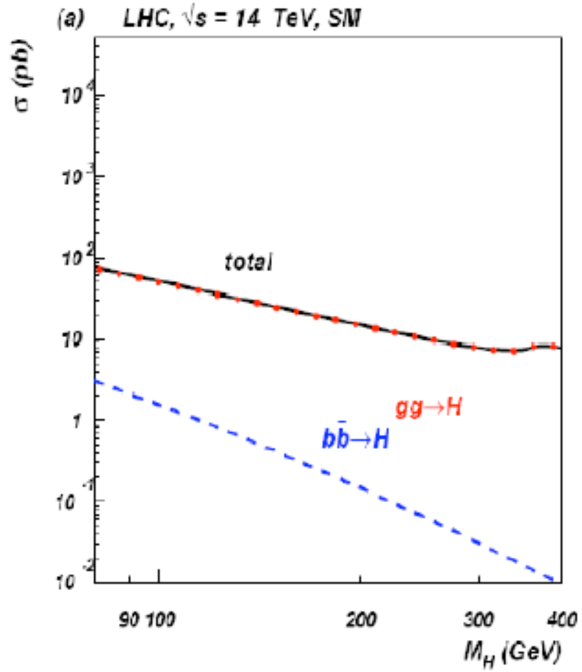
Impact parameter tagging

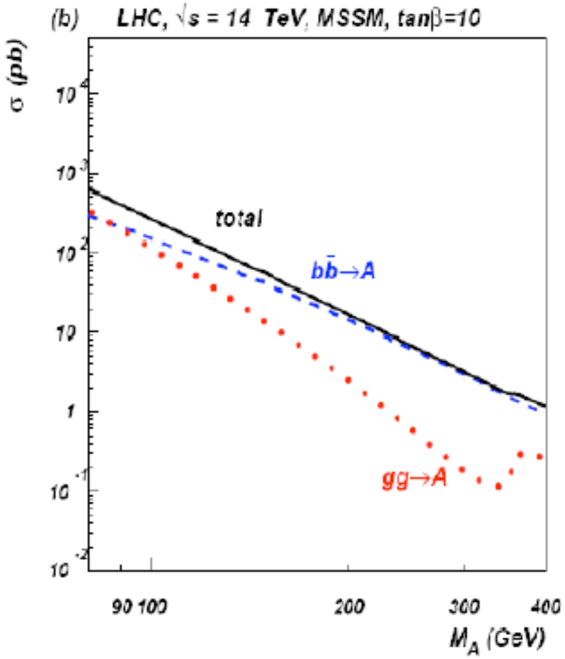
At LHeC may also tag decays with dedicated vertex detector

beam spot 35*15 μm^2



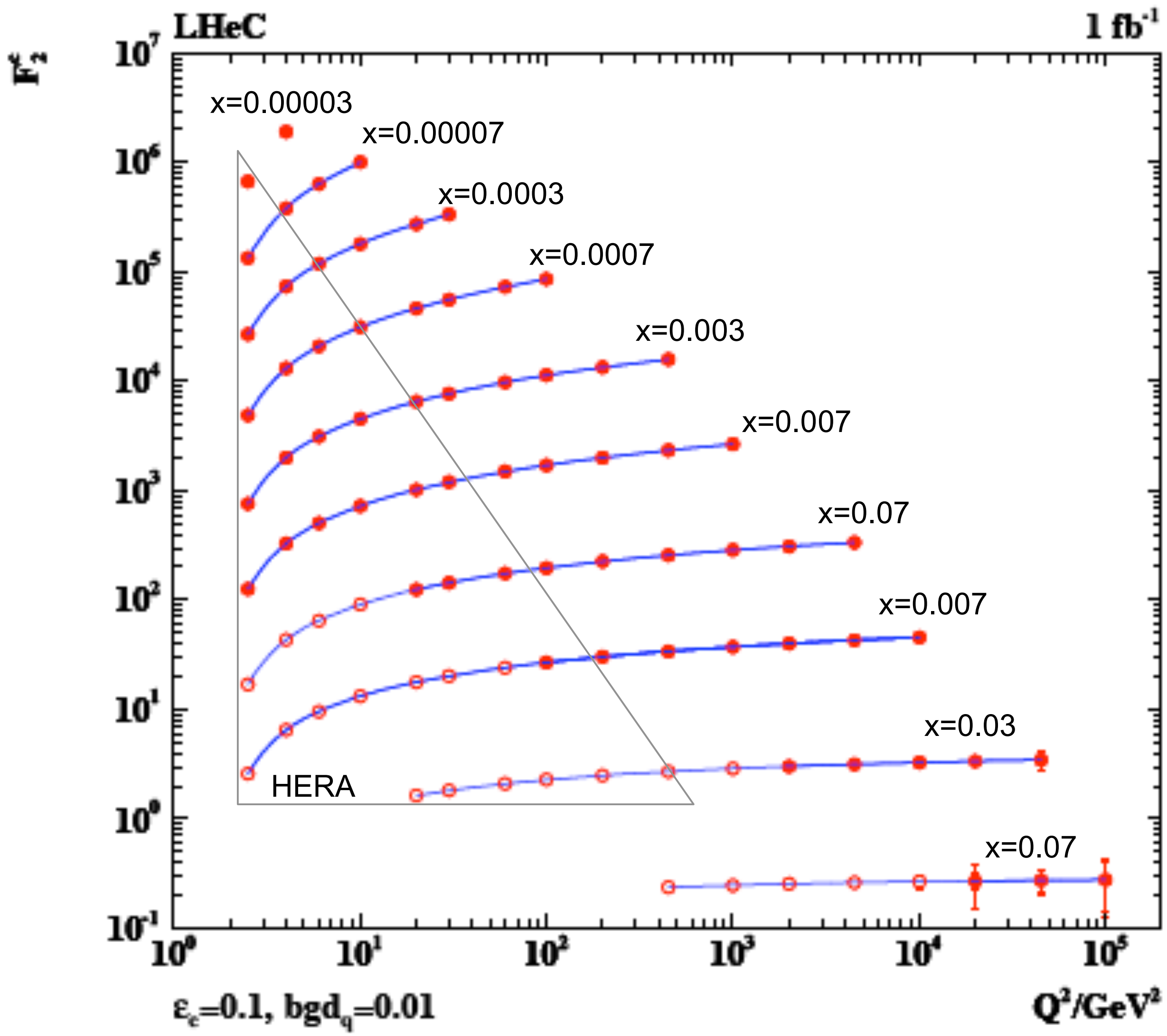






Precision in q,g may become crucial

Charm quark distribution



$1\,fb^{-1}$

$\varepsilon_c = 0.1$

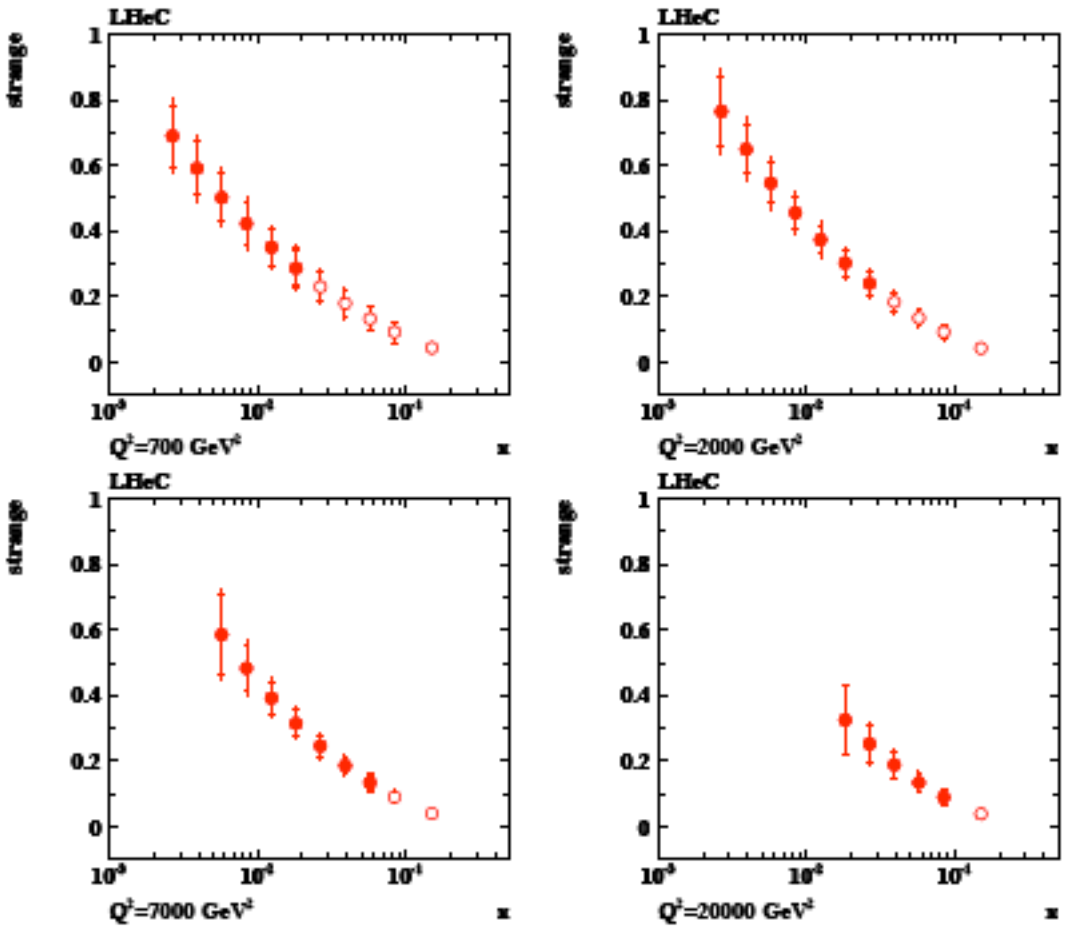
$bgd_q = 0.01$

$\delta_{syst} = 0.1$

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

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

Strange quark distribution



$W^{+}s \rightarrow c$

$1\,fb^{-1}$

$\varepsilon_c = 0.1$

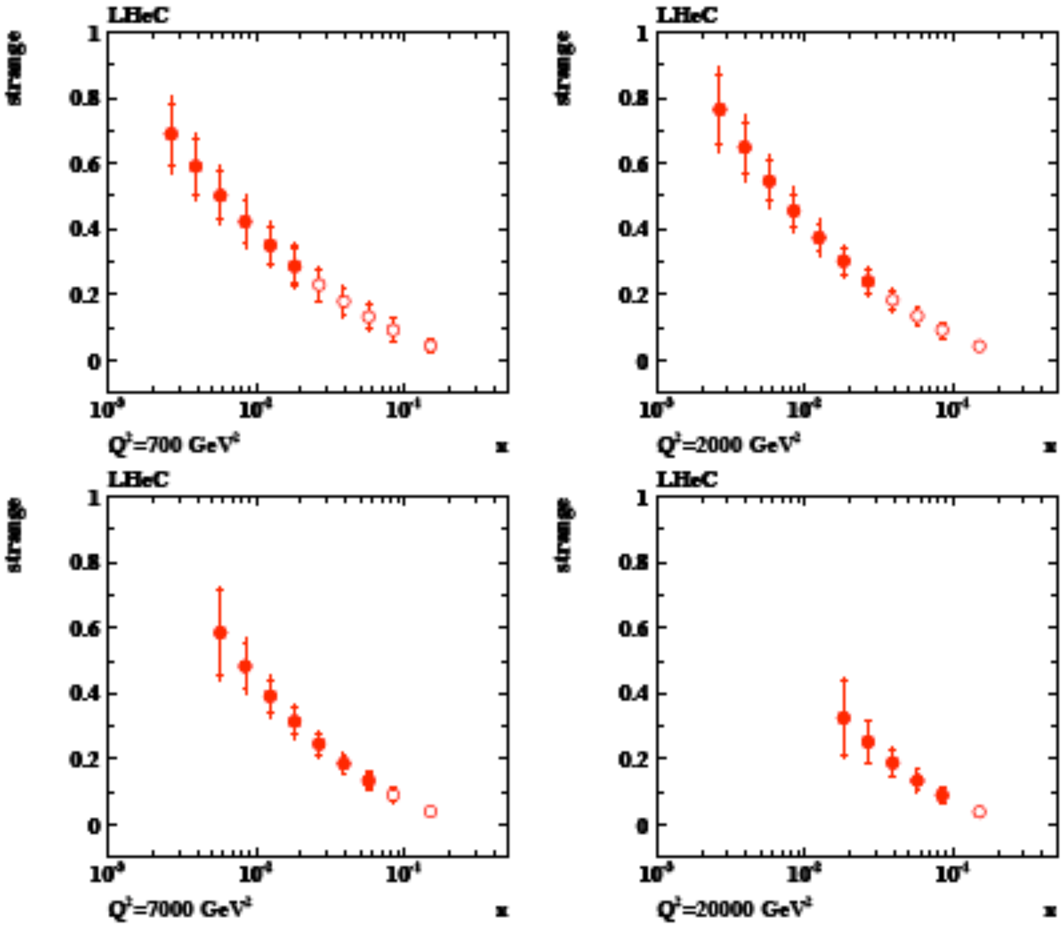
$\varepsilon_q = 0.01$

$\delta_{syst} = 0.1$

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

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

Anti-Strange quark distribution



$W^- sbar \rightarrow cbar$

$1\, fb^{-1}$

$\varepsilon_c = 0.1$

$\varepsilon_q = 0.01$

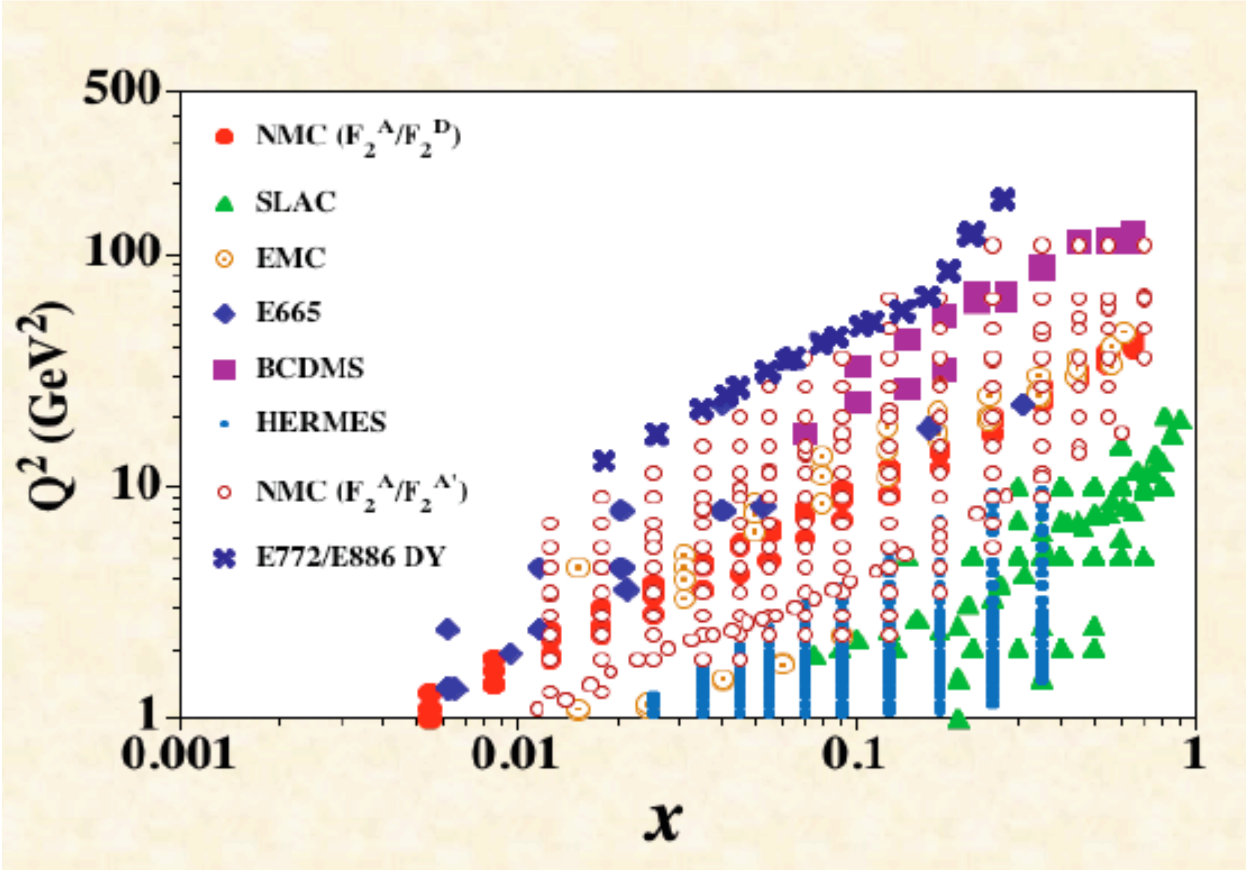
$\delta_{syst} = 0.1$

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

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

The LHC is also the highest energy heavy ion collider

Available data on F_2 in nuclei

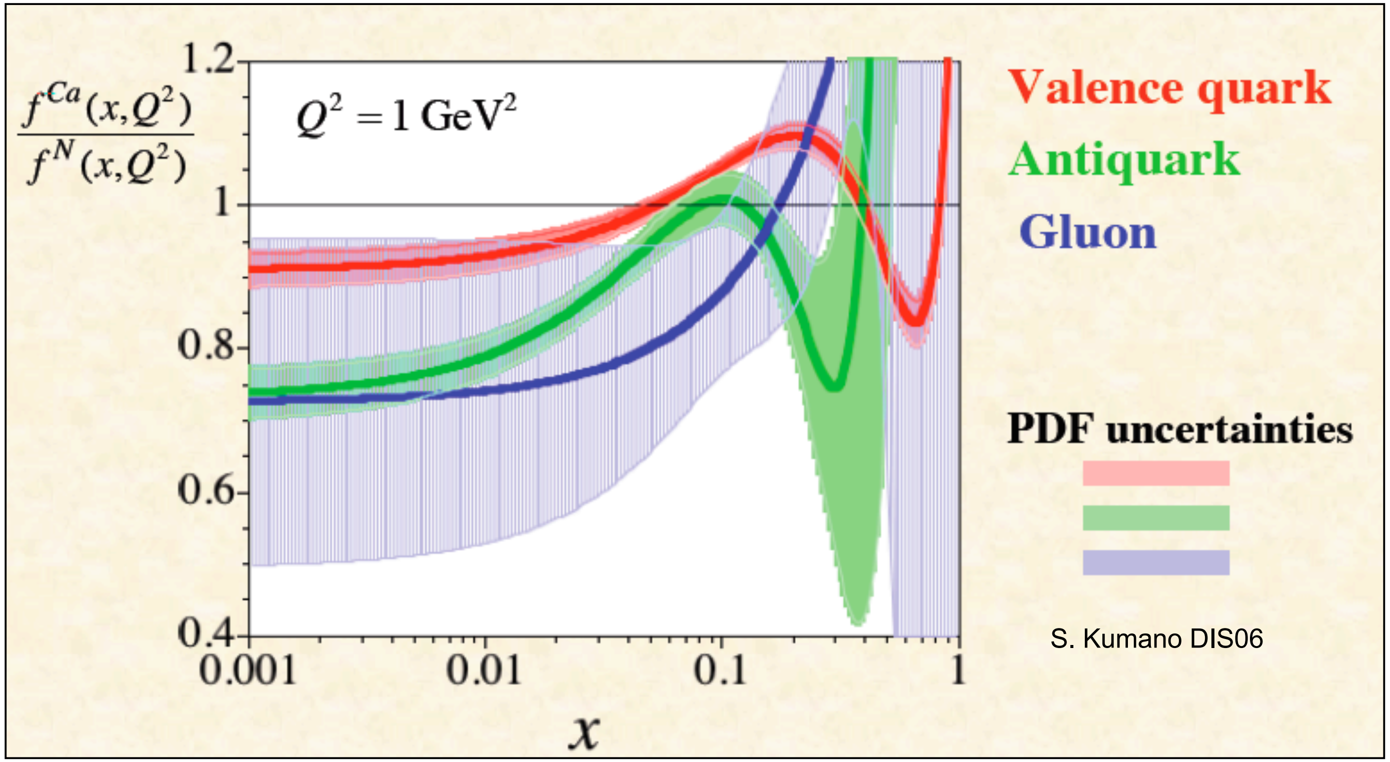


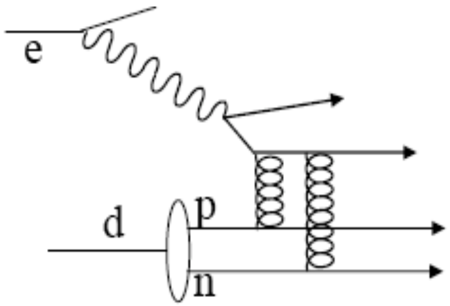
Limited information on quarks and nearly none on gluons

The LHeC extends the eA kinematic range by 4 orders of magnitude

K.Eskola (ed), hep-ph/0308248; S. Kumano DIS06; D.Florian and R. Sassot, hep-ph/0311227; FGS, Phys Rev.D71(05)054001; LMcLerran,Glasma..

Determination of nPDF's





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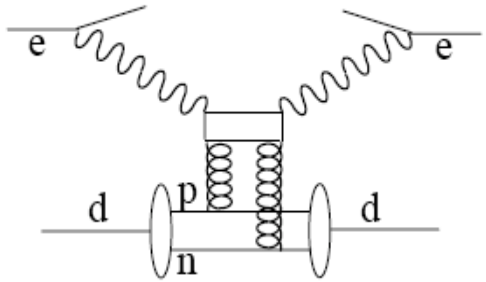
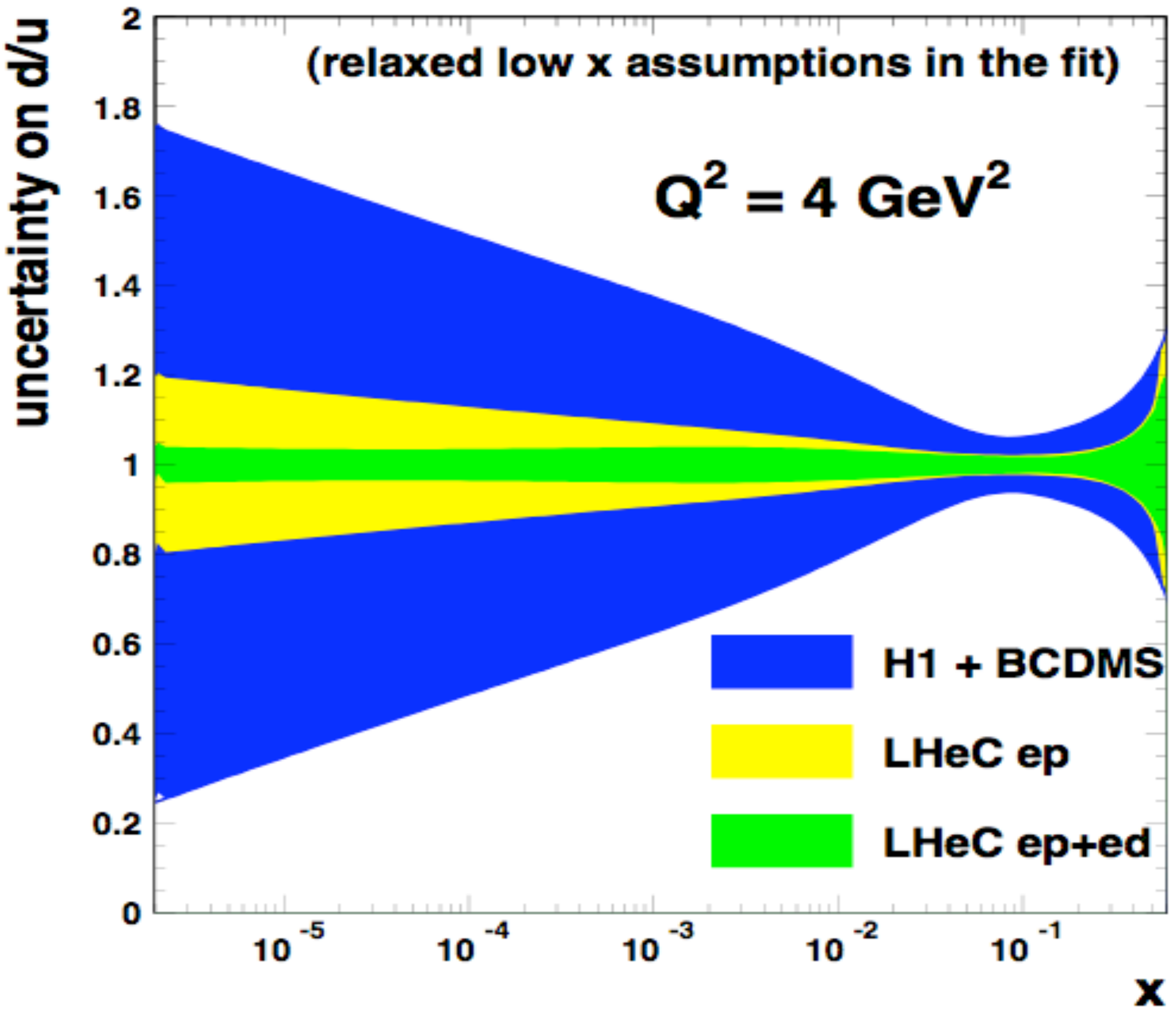
In eA at the collider, test Gribovs relation between shadowing and diffraction, control nuclear effects at low Bjorken x to high accuracy



d/u at low x from deuterons

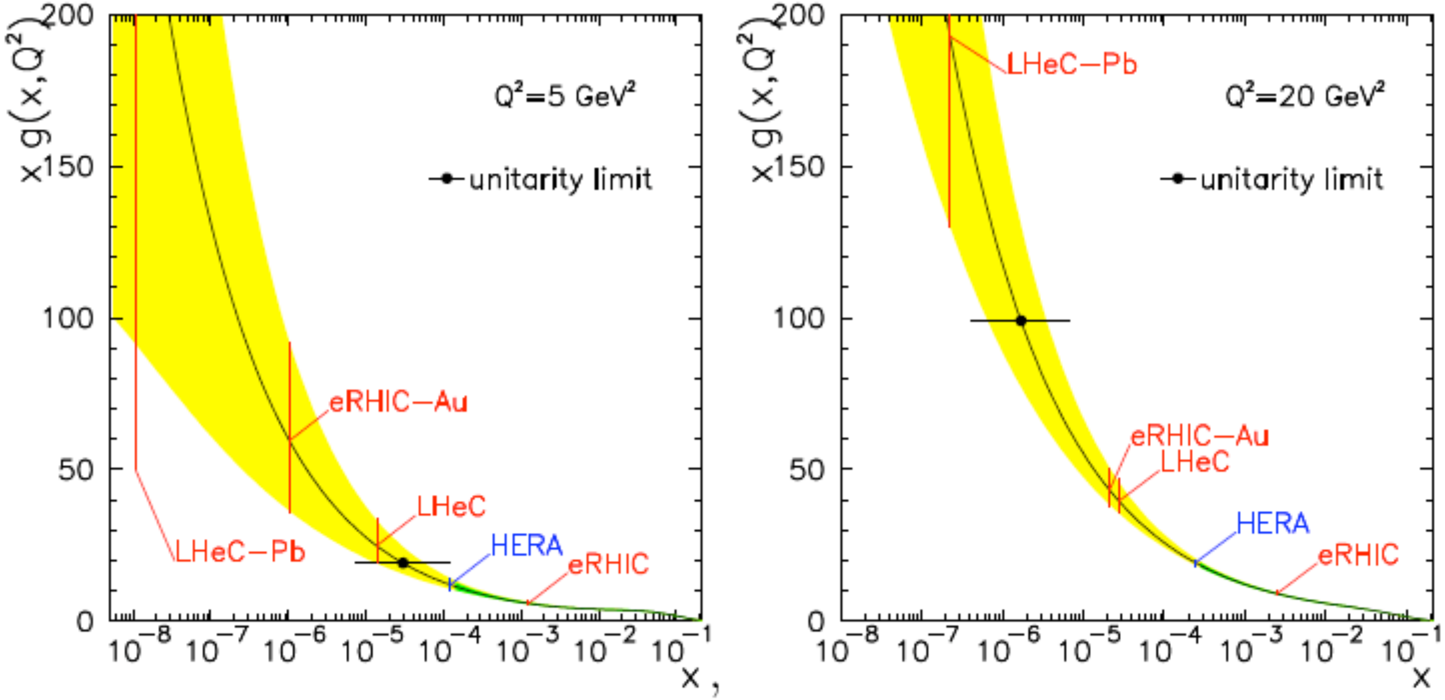


Note
all QCD fits
assume
u=d
at low x

No constraint
from HERA

[W asymmetry]

High density amplification?



High density $\frac{g_A/\pi r_A^2}{g_p/\pi r_p^2} = A^{1/3}\frac{g_A}{Ag_p}$

Unitarity $$\boxed{xg(x,Q^2) \le \frac{1}{\pi N_c \alpha_s(Q^2)} Q^2 R^2 \simeq \frac{Q^2}{\alpha_s}}$$

Striking effects predicted:
bj -> black disc limit $F_2 \to Q^2 \ln(1/x)$
~50% diffraction
colour opacity, change of $J/\Psi(A)$
…

Understanding the possible observation of QGP in AA with eA

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Summary

No surprise: an ep collider at TeV energies has a fascinating potential to explore proton's structure much deeper than hitherto. It will allow pQCD to "live Long" Y.D.

Precision (as for the gluon distribution or the strong coupling constant to ~0.0003) and diversity (as in the complete flavour decomposition [u,d,s,c,b]) make the LHeC the best feasible successor of HERA, thanks to its expected very high luminosity and the very high energy, i.e very high Q^2 and very low x coverage

This could have been demonstrated completely differently with jets, VM's, or deeply virtual Compton scattering DVCS ($1/Q^3$), for example.

Next steps are:
-a much deeper evaluation of the physics potential (cf also E.Perez, P.Newman)
-a thorough evaluation of the LHeC physics in its relation to the LHC
-a draft design of a detector or detectors of high precision and acceptance
-a more detailed design of the IR and study of the injection
This will take 2-3 years. By then the LHC will have shown its potential.

DIS is facing a phase transition and we all are invited to lead this such that lepton-nucleon scattering stays as a recognised part of modern particle physics.

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Deep inelastic electron-nucleon scattering at the LHC

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ABSTRACT: The physics, and a design, of a Large Hadron Electron Collider (LHeC) are sketched. With high luminosity, $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, and high energy, $\sqrt{s} = 1.4\,\mathrm{TeV}$, such a collider can be built in which a 70 GeV electron (positron) beam in the LHC tunnel is in collision with one of the LHC hadron beams and which operates simultaneously with the LHC. The LHeC makes possible deep-inelastic lepton-hadron (*ep*, *eD* and *eA*) scattering for momentum transfers Q^2 beyond $10^6\,\mathrm{GeV}^2$ and for Bjorken x down to the 10^{-6}. New sensitivity to the existence of new states of matter, primarily in the lepton-quark sector and in dense partonic systems, is achieved. The precision possible with an electron-hadron experiment brings in addition crucial accuracy in the determination of hadron structure, as described in Quantum Chromodynamics, and of parton dynamics at the TeV energy scale. The LHeC thus complements the proton-proton and ion programmes, adds substantial new discovery potential to them, and is important for a full understanding of physics in the LHC energy range.

KEYWORDS: Accelerator modelling and simulations (multi-particle dynamics; single-particle dynamics); Large detector systems for particle and astroparticle physics.

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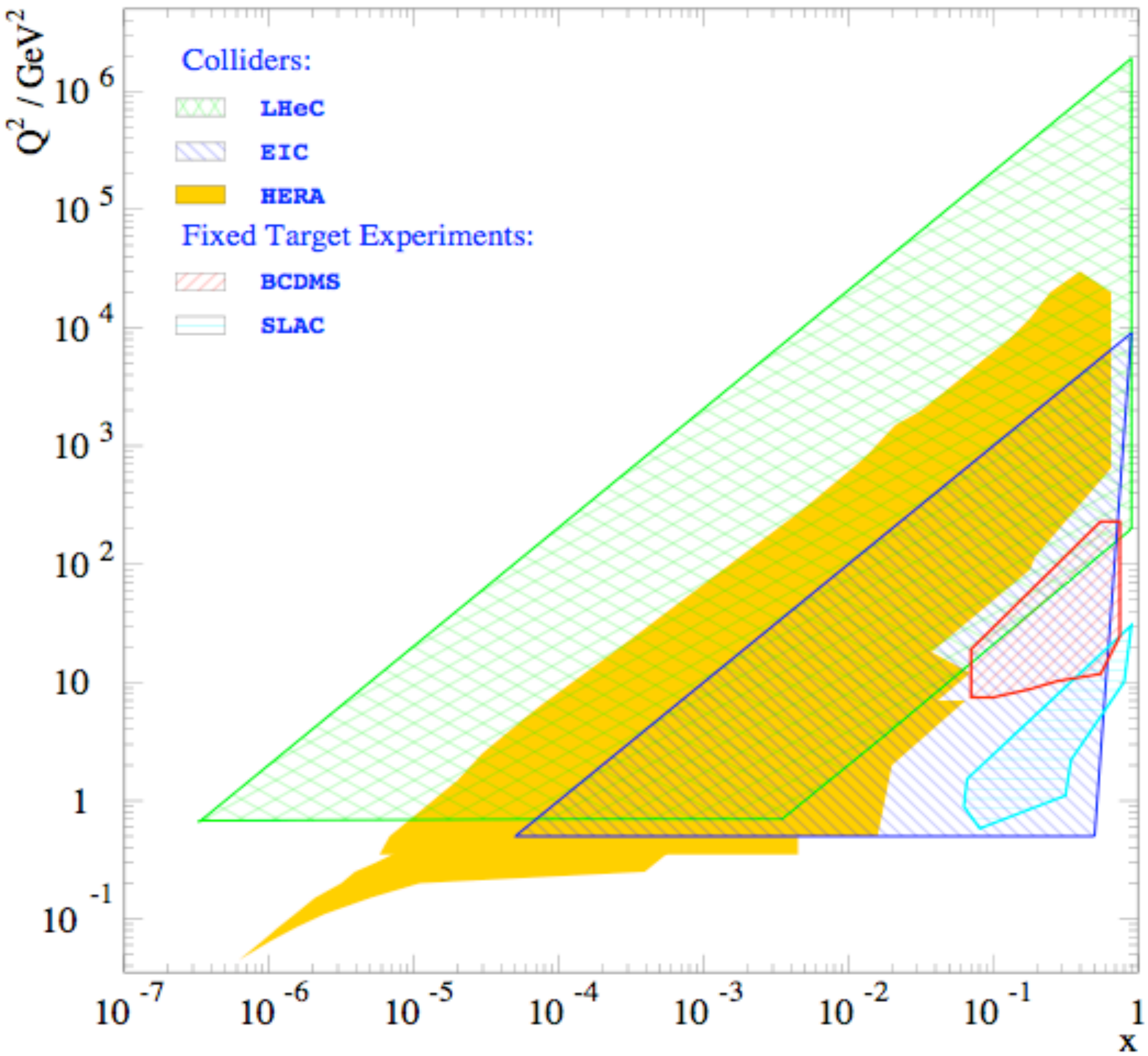
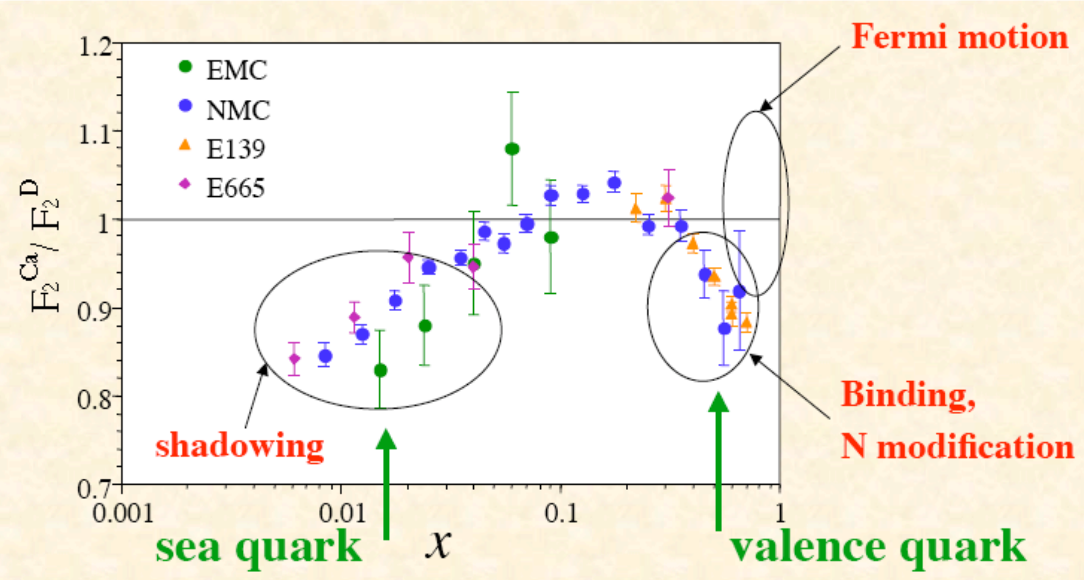
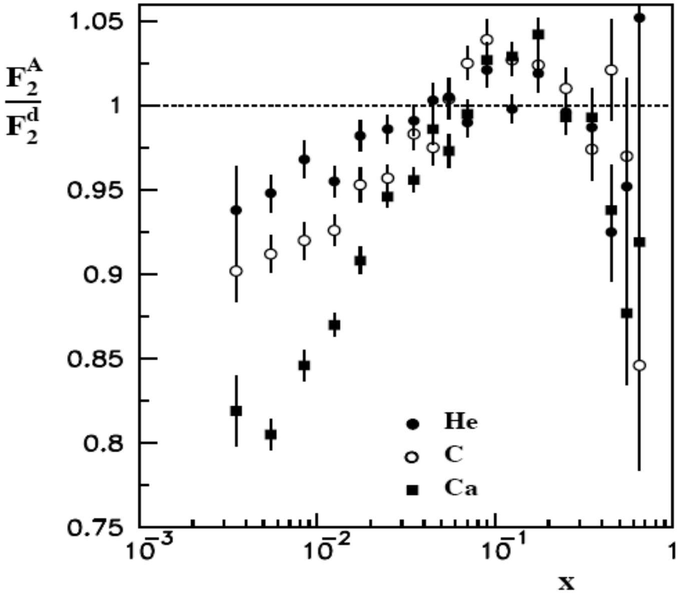
Andy Mehta
Des Barber
for help and the new members of the SAC for encouragement
towards a design study of the LHeC by the end of 2009
cf talk of J.Dainton.

Backup slides

LHeC, HERA and EIC

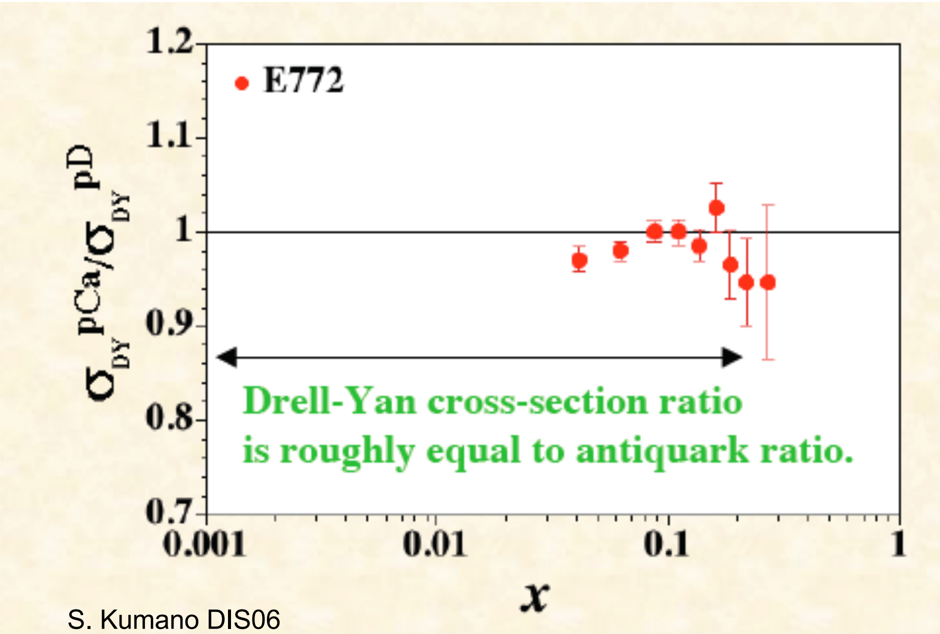






$$f_i^A(x_N, Q_0^2) = R_i(x_N, Q_0^2, A, Z)\, f_i(x_N, Q_0^2)$$

$$f_i^A(x_N, Q_0^2) = \int_{x_N}^{A} \frac{dy}{y} W_i(y, A, Z)\, f_i(\frac{x_N}{y}, Q_0^2)$$



$$\frac{\sigma_{DY}^{pCa}}{\sigma_{DY}^{pD}} \approx \frac{\bar{q}^{Ca}}{\bar{q}^{D}}$$

LHeC provides genuine determination of nuclear quark and gluon distributions based on wide range of data in x,Q²,A

Forward Jet production to discriminate low x evolution

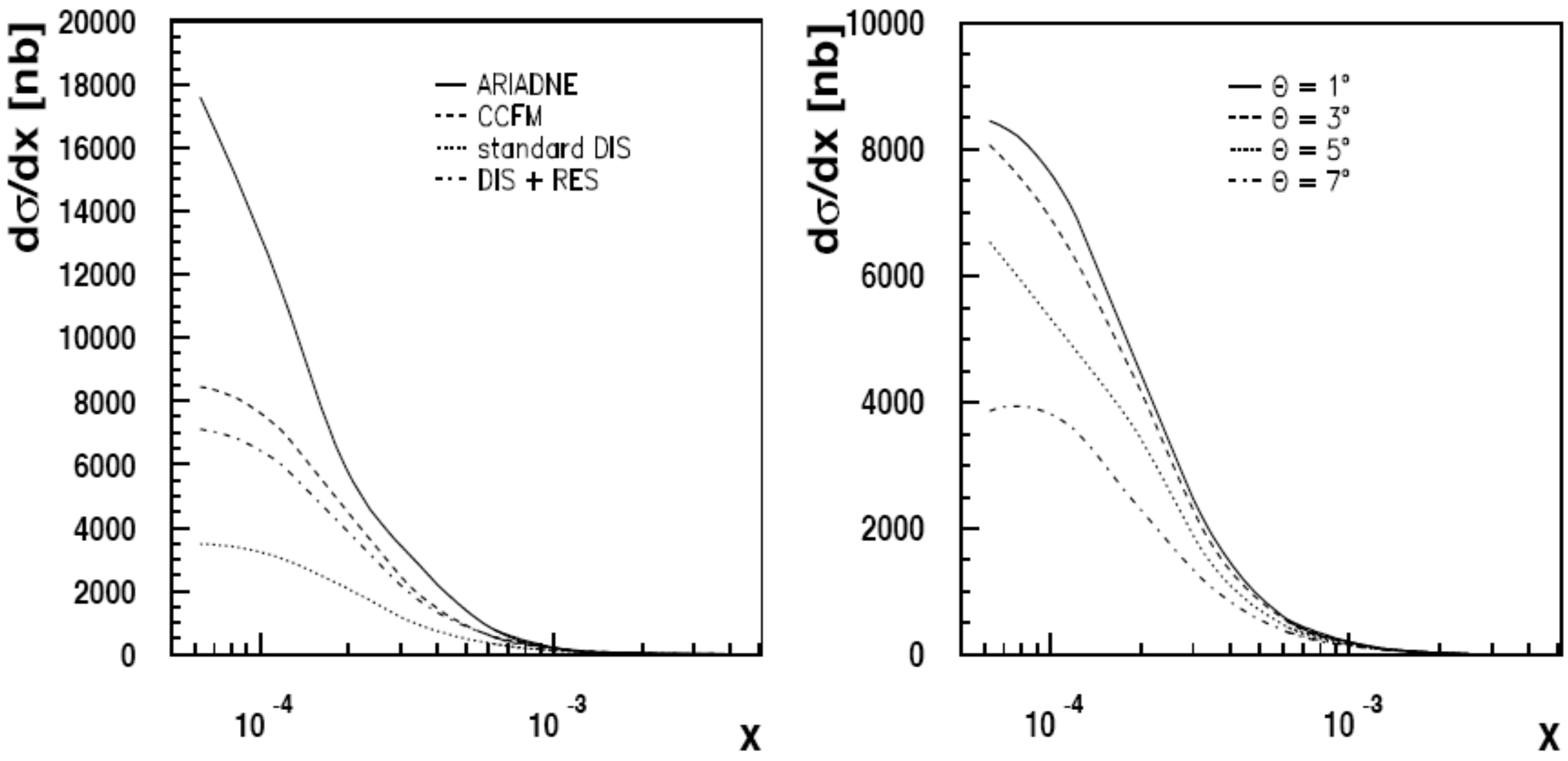


Figure 1.2.9: *Forward-jet cross section as a function of x in different models for $0.5 < p_t^2/Q^2 < 2$ and a minimum polar jet angle of 1°. The measurements at HERA are limited to $x \gtrsim 2 \times 10^{-3}$.*

Figure 1.2.10: *Forward-jet cross section as a function of x obtained from CCFM for $0.5 < p_t^2/Q^2 < 2$, for different values of the minimum jet angle.*

cf Thera Book Jung, Loennblad

title