LHeC

Large Hadron Electron Collider

70 * 7000 GeV^2

Max Klein (klein@ifh.de)

DIS to TeV Energies

ep and eA Physics

Ferdinand Willeke (@desy.de)

Machine Design Study

DESY Seminar - May 23rd/24th, 06

hep-ex/0306016 → JINST

DESY 06-006
Cockcroft-06-05

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, $\sqrt{s} = 1.4$ 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.

*Contributed to the Open Symposium on European Strategy for Particle Physics Research, LAL Orsay, France, January 30th to February 1st, 2006.

Why of interest

-New Physics in the eq Sector

leptoquarks, 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 [ED], parton correlations, transverse, uPDF's

-Precision for the LHC

heavy flavour (b), gluon, strong coupling, quarks

-The Origin of the Quark Gluon Plasma

partons in nuclei, deconfinement phase

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:

Parton interaction developments at the energy frontier*)

	1970		2000	2015
DIS	Bjorken scaling – QPM, PV neutral currents asymptotic freedom	….	(high) parton densities diffraction QCD	?
e^+e^-	J/Ψ gluons	…..	3 neutrinos electroweak theory	… ILC
pp	charm, W,Z, bottom top		LHC …	

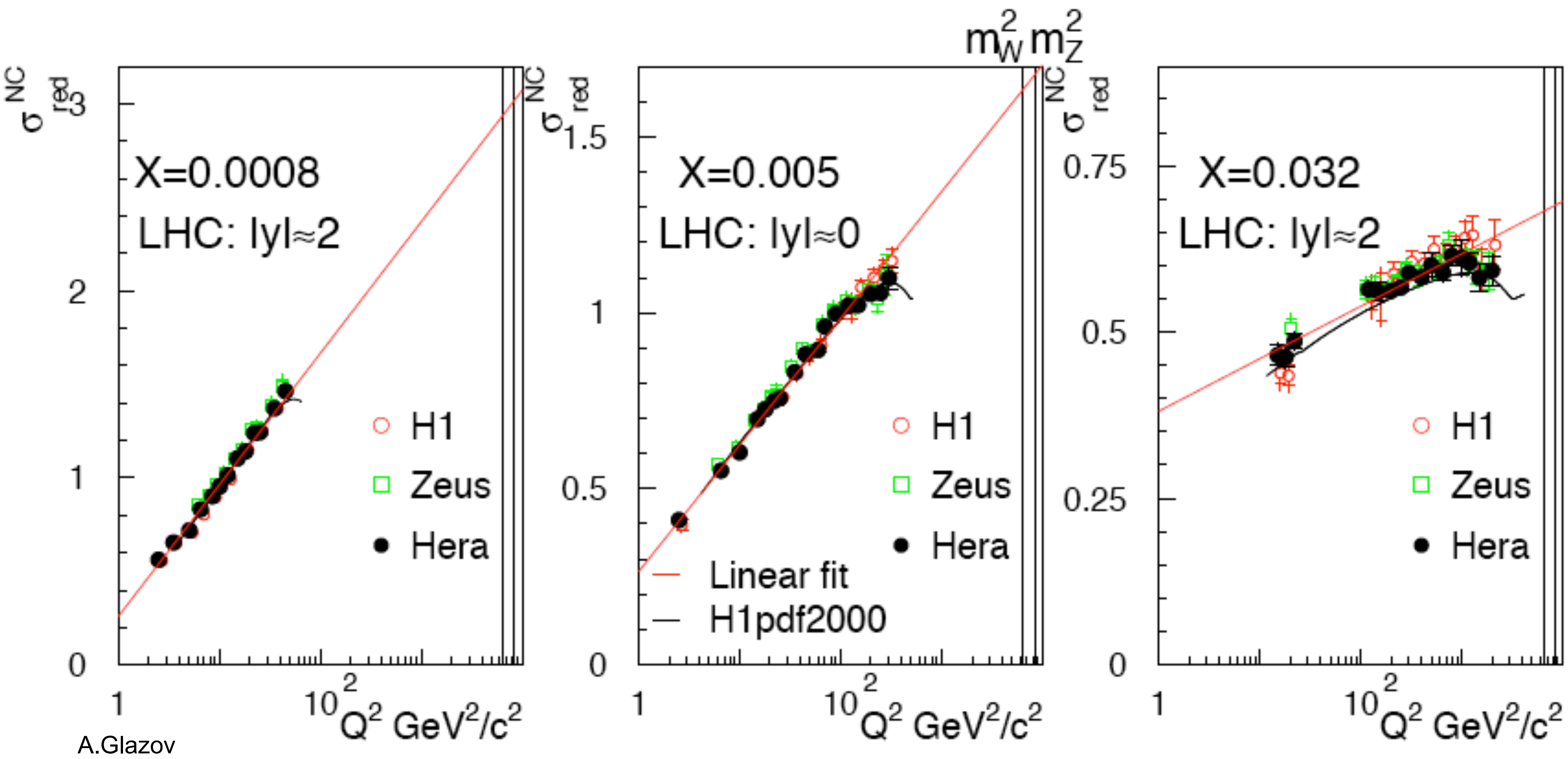
*) incomplete

The standard model emerged as a result of decades of joint research in e^+e^- , ep, pp/hh accelerator experiments, including quark and neutrino mixing.

Low x physics related to AA and to high energy neutrino physics.

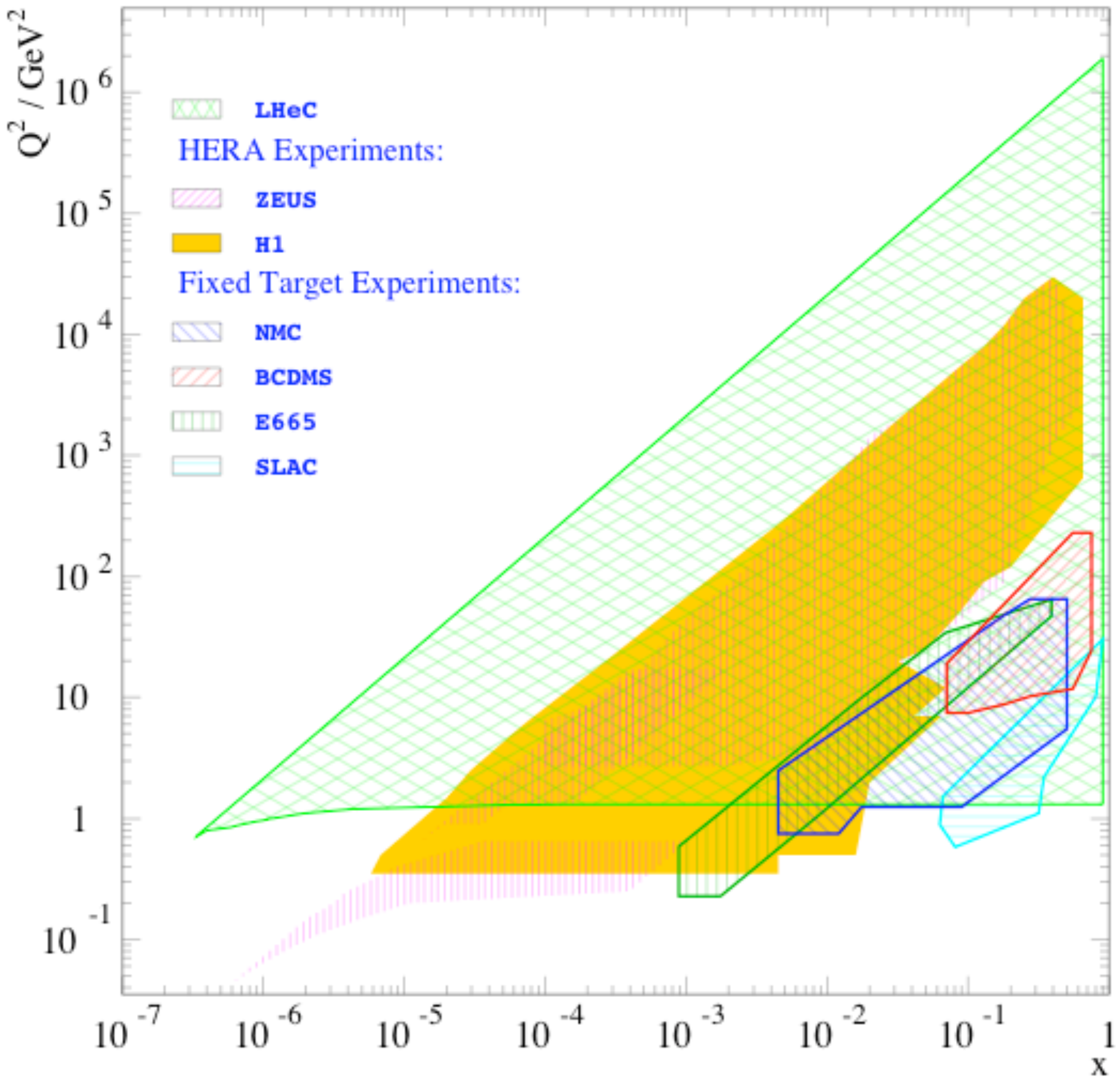
pp has been most successful in discovering quarks and bosons.
There is no quantitative understanding of Tevatron data without HERA.

Have and will use & refine HERA data



but we extrapolate over orders of magnitude in Q^2
and the behaviour at low x below HERA is not known

Particle physics moves to the TeV Scale, how about ep?



$s = 4E_eE_p$

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

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

$s = 2M_pE_l$

$BCDMS: 280 \to 500 GeV^2$

$SLAC: 20 \to 40 GeV^2$

$Q^2 = sxy$

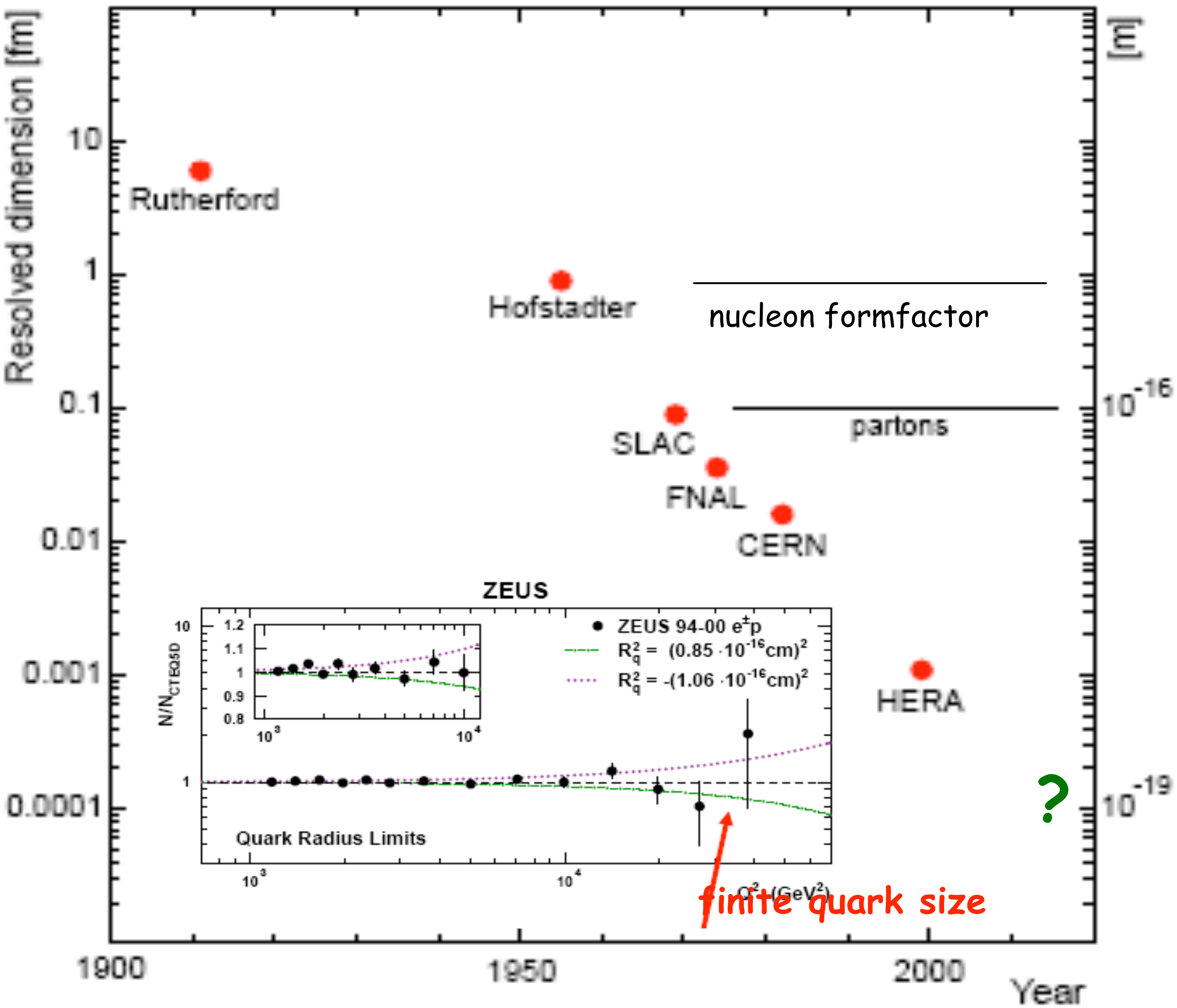
$x = \frac{Q^2}{sy}$

$Bjorken - x \leq 1$

$inelasticity - y \leq 1$

$Q^2 \leq s$

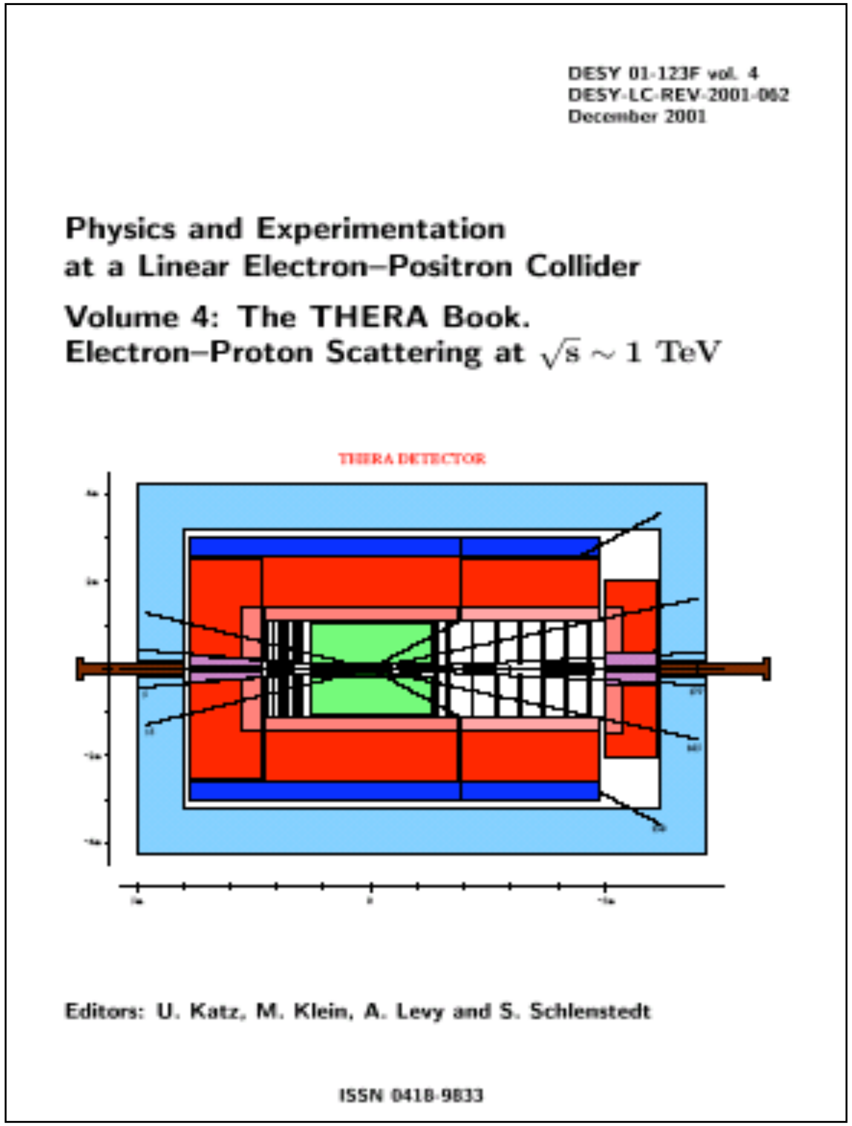
LHeC promises to reach 10^{-19} m, i.e
1/10000 (1000) of proton (quark) radius



present limits

ZEUS r < 0.85
H1 r < 1.0 10^{-18}m

DIS at the TeV Scale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December 2001

Physics and Experimentation
at a Linear Electron–Positron Collider

Volume 4: The THERA Book.
Electron–Proton Scattering at $\sqrt{s} \sim 1$ TeV

Editors: U. Katz, M. Klein, A. Levy and S. Schlenstedt

ISSN 0418-9833

LEP-LHC

A. Verdier LHC Workshop Aachen 90, p.820
E. Keil LHC Project Report 93 (1997)

R. Brinkmann, F. Willeke THERA book
and Proceedings Snowmass 2001

QCD explorer (CLIC-LHC')

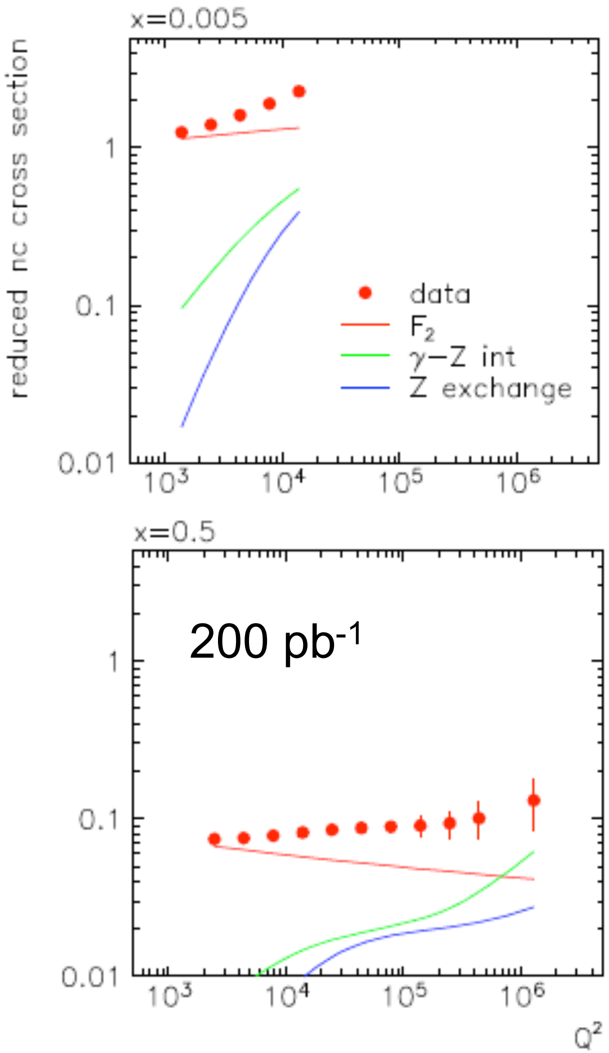
D. Schulte, F. Zimmermann CLIC 608

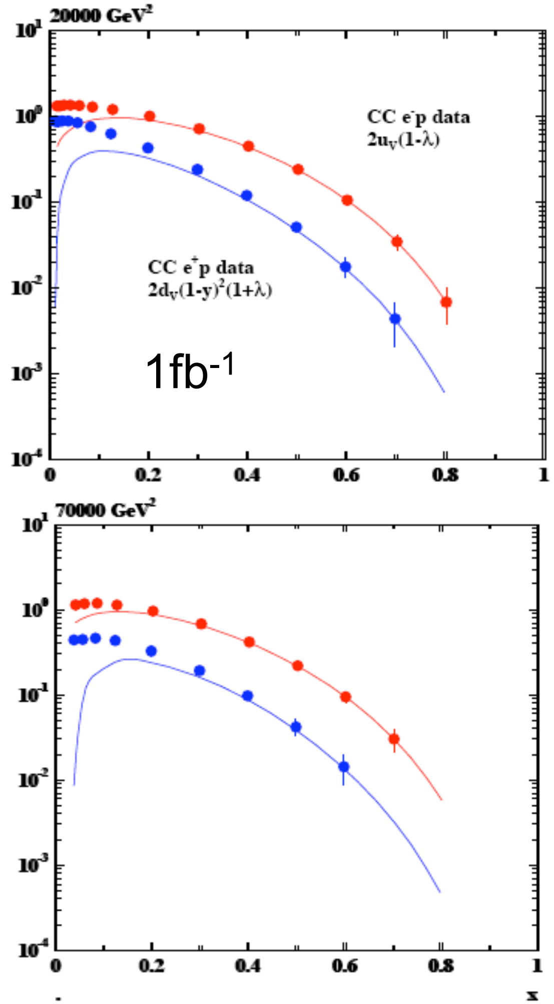
LHeC

F. Willeke (next talk)

All these ep options are 'cost effective'

NC - Cross Sections - CC



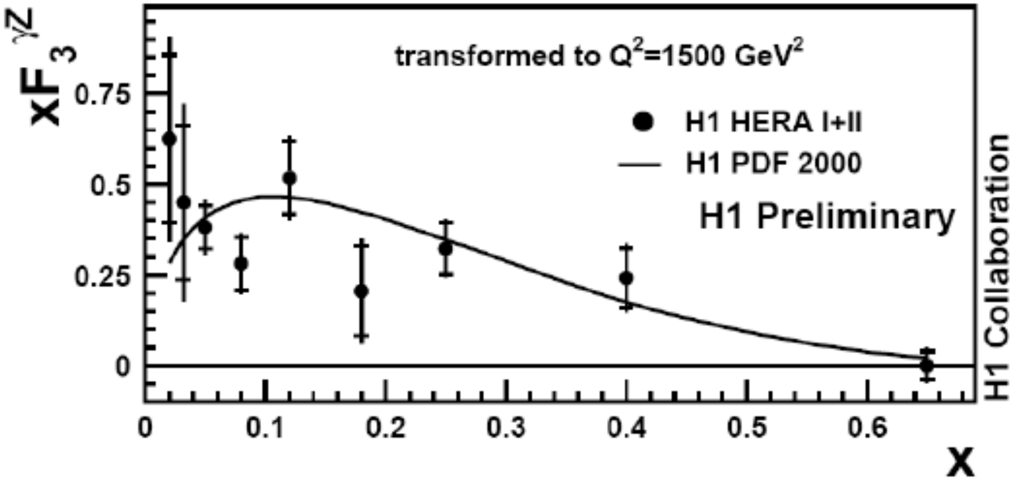


LHeC is genuine electroweak collider

High rate up to large x,

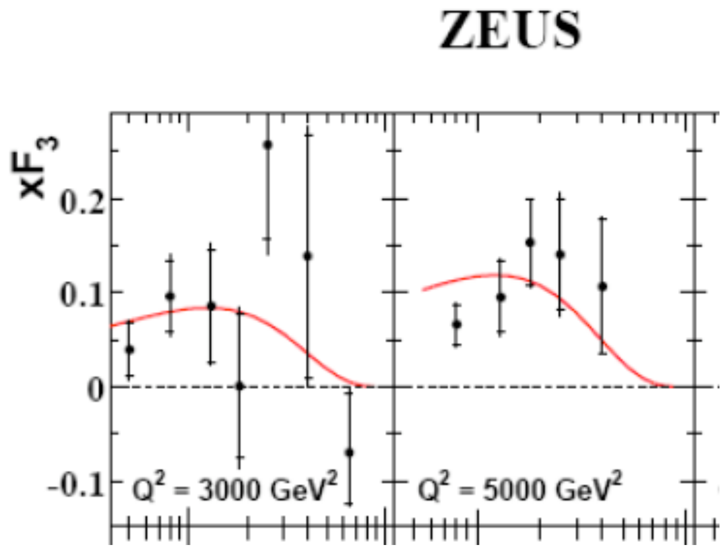
cf eg. sW --> c

xF_3 and the sea quark symmetry

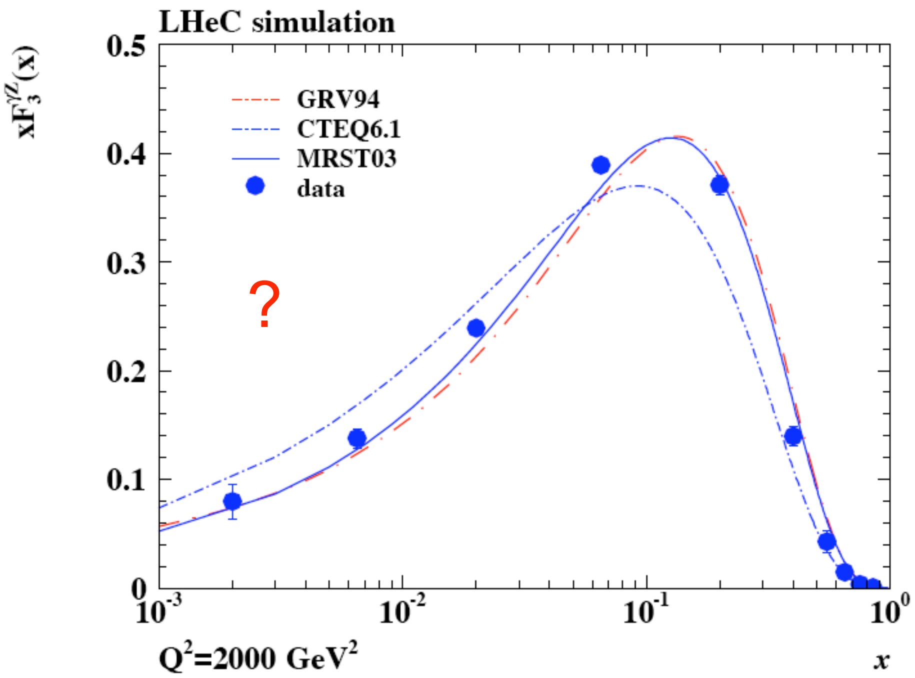


$$2x[a_u e_u(U - \overline{U}) + a_d e_d(D - \overline{D})]$$

$$q_s(x,Q^2) = \bar{q}(x,Q^2)\,?$$

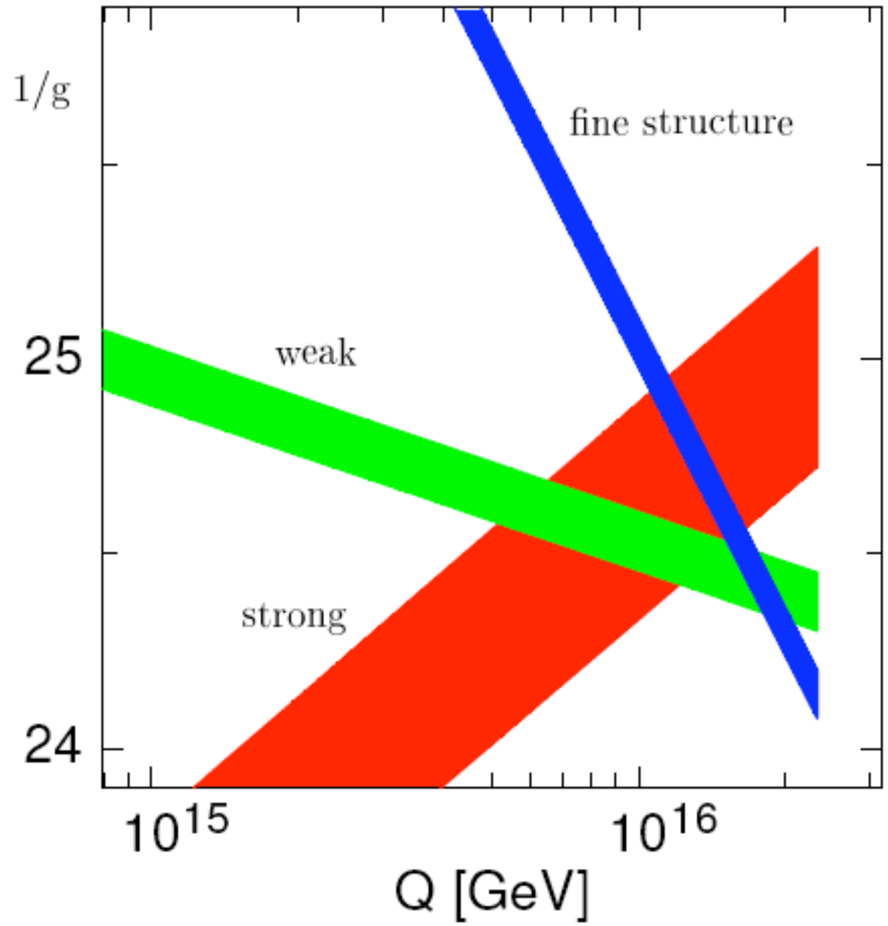


and higher Q^2



The strong coupling constant

- 2006 a @ 10^{-9}
- 2006 G_F @ 10^{-5}
- 2006 G @ 0.1%
- 2006 a_s @ 1-2%
- LHeC ® a_s few/mil



±0.003
HERA
is now
at .001
(exp)

hep-ph/0407067 B.Allanach ... P.Zerwas

Unification?

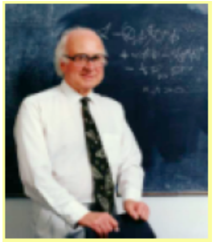
Precision at the LHeC:

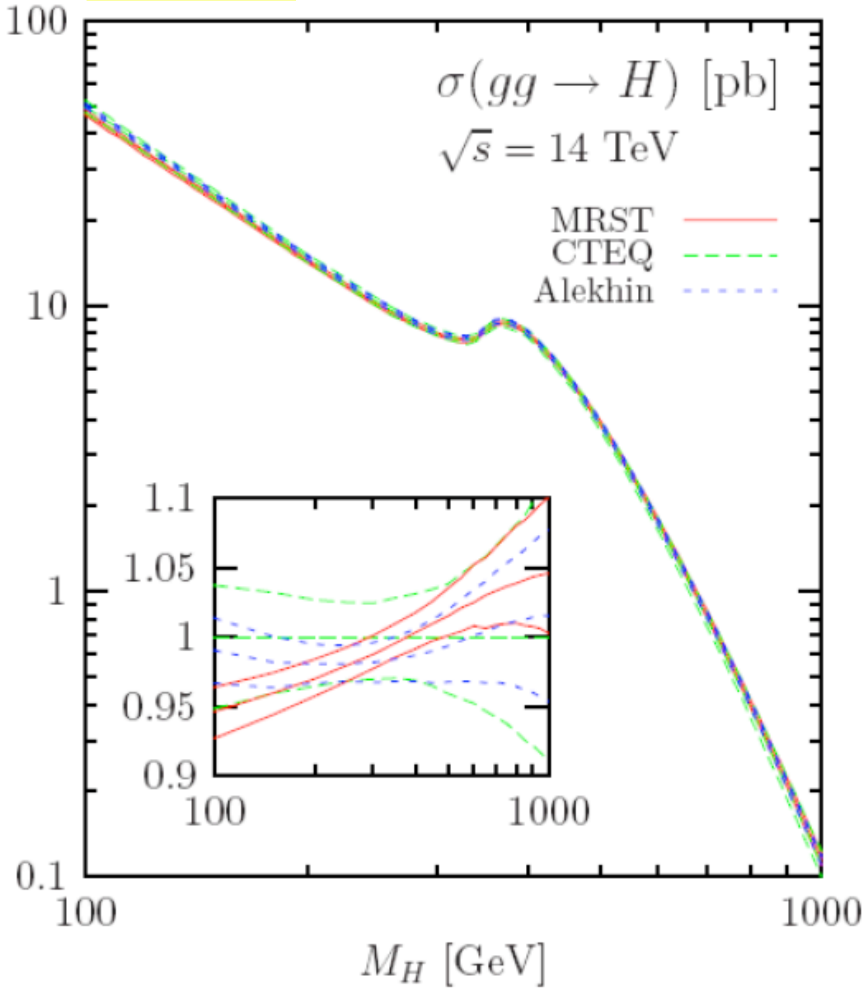
Largest lever arm in x and Q^2

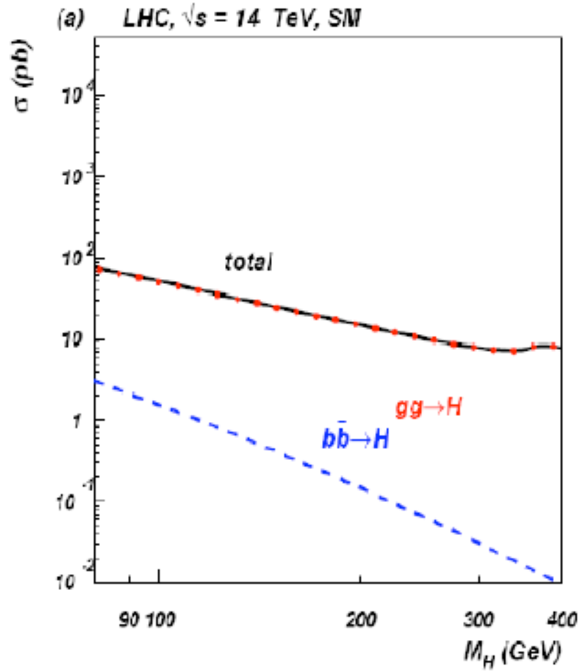
Highest possible accuracy (experiment to < 1% and theory to N^kLO)

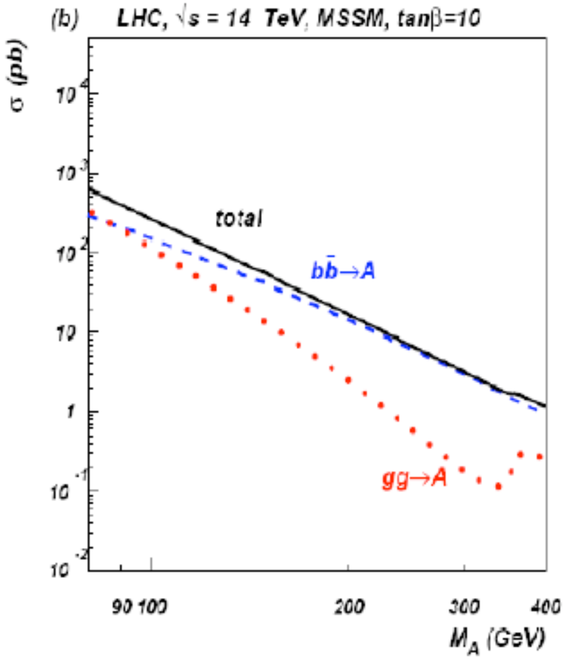
Proton and deuteron data (also for low x evolution, sea asymmetry, n structure)

Get also much more precise determination of gluon density.



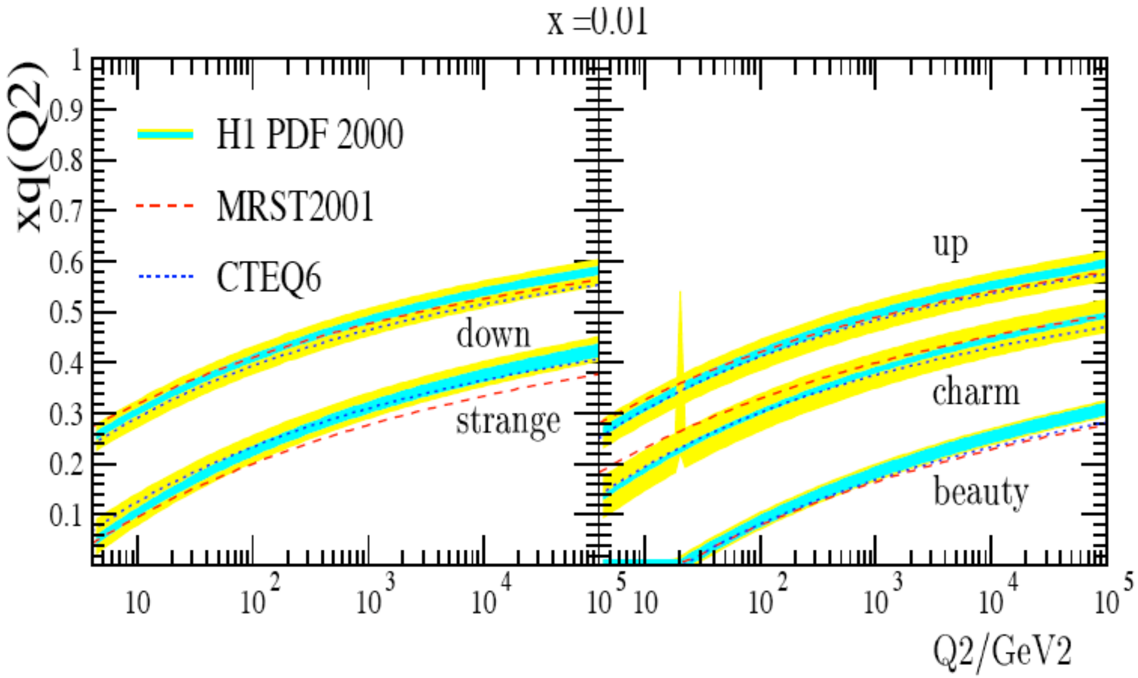




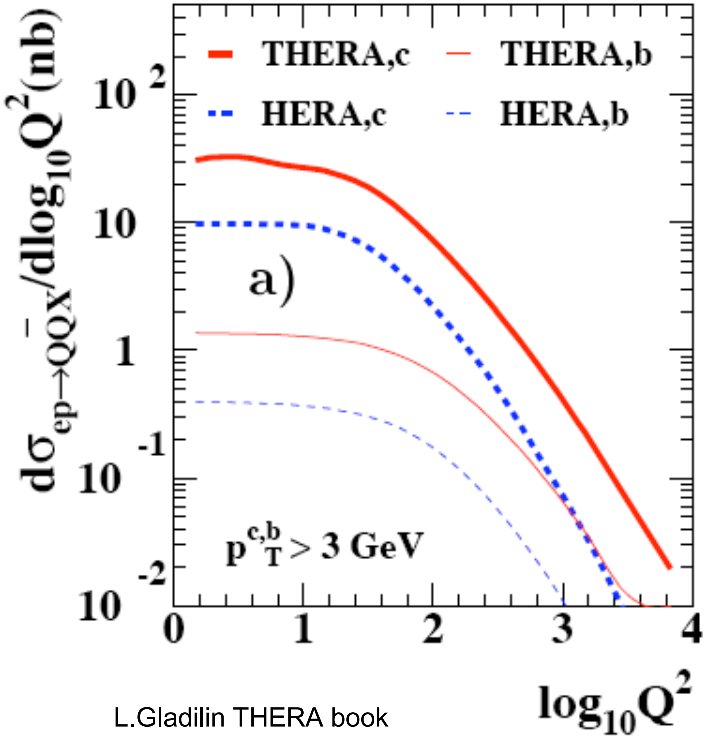


Precision in q,g may become crucial

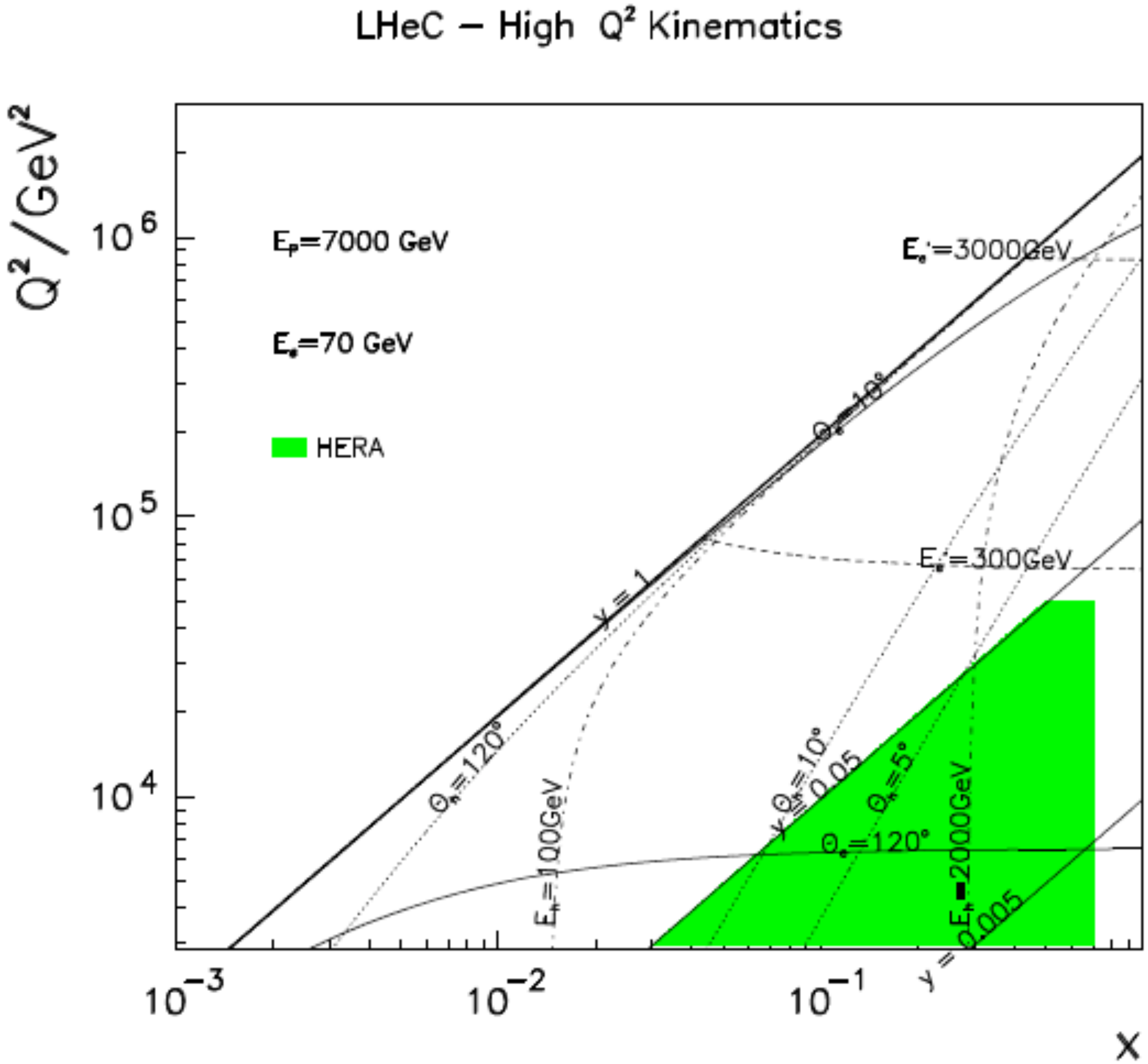
Heavy Flavour (c,b)



Precision measurement of beauty density
and study of production dynamics



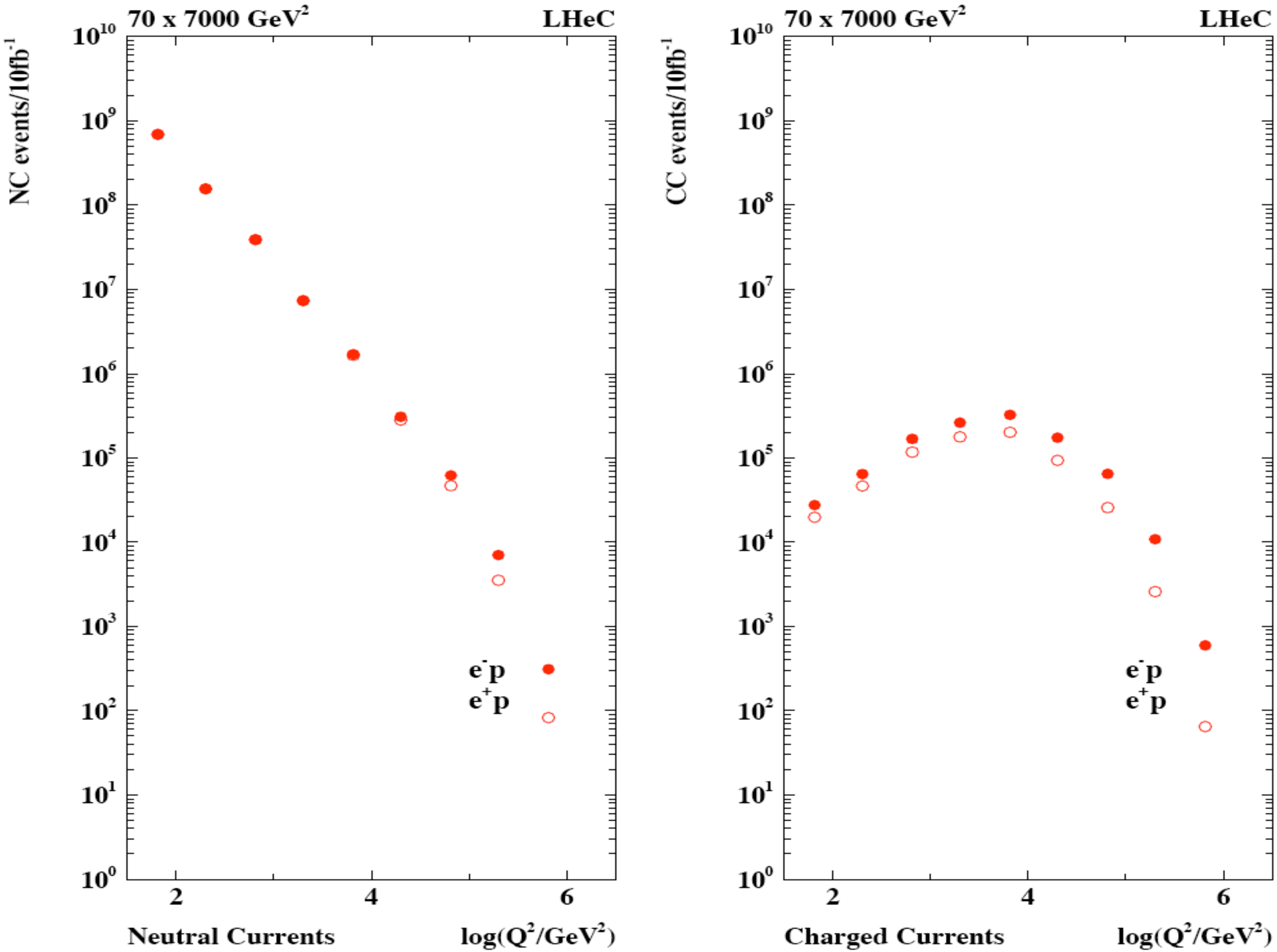
L.Gladilin THERA book



Electron-quark resonance formation M=√(sx) < 1.3 TeV LHeC, 0.3 TeV HERA

Few TeV electron (ctd-fwd) and final state, (fwd-ctd)- detector challenges

Few 100 GeV particles in plateau: both e and final state central in ep detector



70 x 7000 GeV^2
LHeC
NC events/10fb^{-1}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
2
4
6
e^-p
e^+p
Neutral Currents
log(Q^2/GeV^2)
70 x 7000 GeV^2
LHeC
CC events/10fb^{-1}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
2
4
6
e^-p
e^+p
Charged Currents
log(Q^2/GeV^2)

Leptoquarks

Model	Fermion number F	Charge Q	$BR(LQ \to e^{\pm}q)$ β	Coupling		Squark type
S_0^L	2	$-1/3$	$1/2$	$e_L u$	νd	$\tilde{d}_R$
S_0^R	2	$-1/3$	1	$e_R u$		
$\tilde{S}_0$	2	$-4/3$	1	$e_R d$		
$S_{1/2}^L$	0	$-5/3$	1	$e_L \bar{u}$		
		$-2/3$	0		$\nu \bar{u}$	
$S_{1/2}^R$	0	$-5/3$	1	$e_R \bar{u}$		
		$-2/3$	1	$e_R \bar{d}$		
$\tilde{S}_{1/2}$	0	$-2/3$	1	$e_L \bar{d}$		$\overline{\tilde{u}_L}$
		$+1/3$	0		$\nu \bar{d}$	$\overline{\tilde{d}_L}$
S_1	2	$-4/3$	1	$e_L d$		
		$-1/3$	$1/2$	$e_L u$	νd	
		$+2/3$	0		νu	
V_0^L	0	$-2/3$	$1/2$	$e_L \bar{d}$	$\nu \bar{u}$	
V_0^R	0	$-2/3$	1	$e_R \bar{d}$		
$\tilde{V}_0$	0	$-5/3$	1	$e_R \bar{u}$		
$V_{1/2}^L$	2	$-4/3$	1	$e_L d$		
		$-1/3$	0		νd	
$V_{1/2}^R$	2	$-4/3$	1	$e_R d$		
		$-1/3$	1	$e_R u$		
$\tilde{V}_{1/2}$	2	$-1/3$	1	$e_L u$		
		$+2/3$	0		νu	
V_1	0	$-5/3$	1	$e_L \bar{u}$		
		$-2/3$	$1/2$	$e_L \bar{d}$	$\nu \bar{u}$	
		$+1/3$	0		$\nu \bar{d}$	

Buchmueller, Rueckl

$e^{\pm}$ p ideal for LQ spectroscopy

Similar for SUSY - singly produced

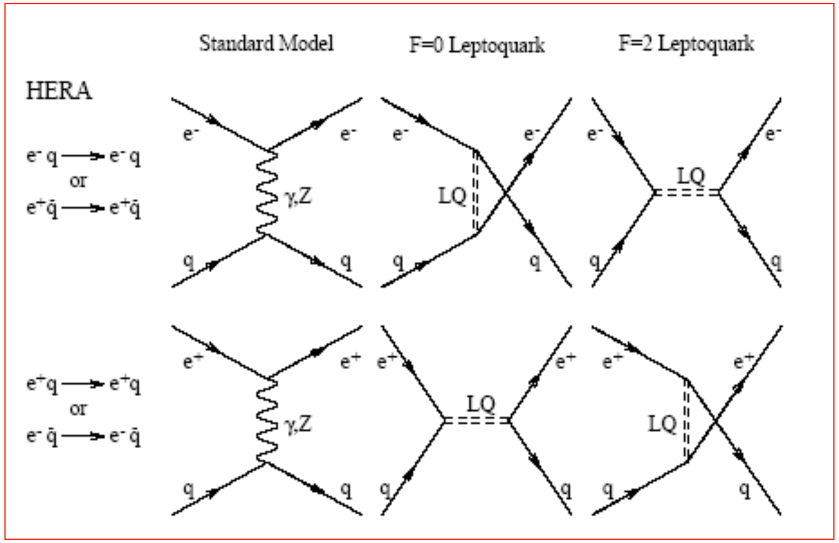
THE UNCONFINED QUARKS AND GLUONS

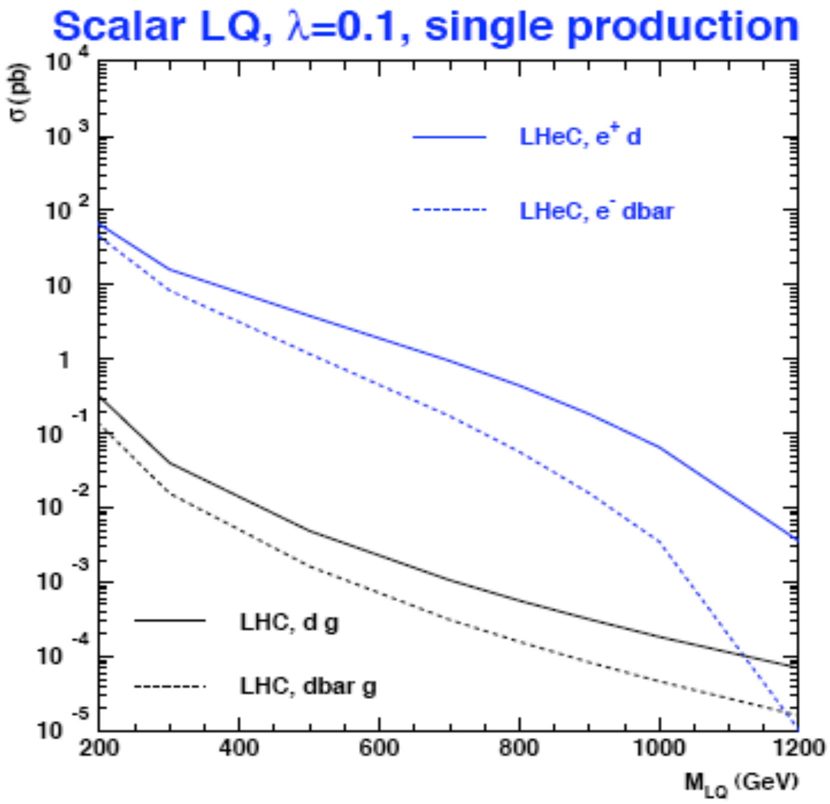
Abdus Salam

International Centre for Theoretical Physics, Trieste, Italy and Imperical College, London, England

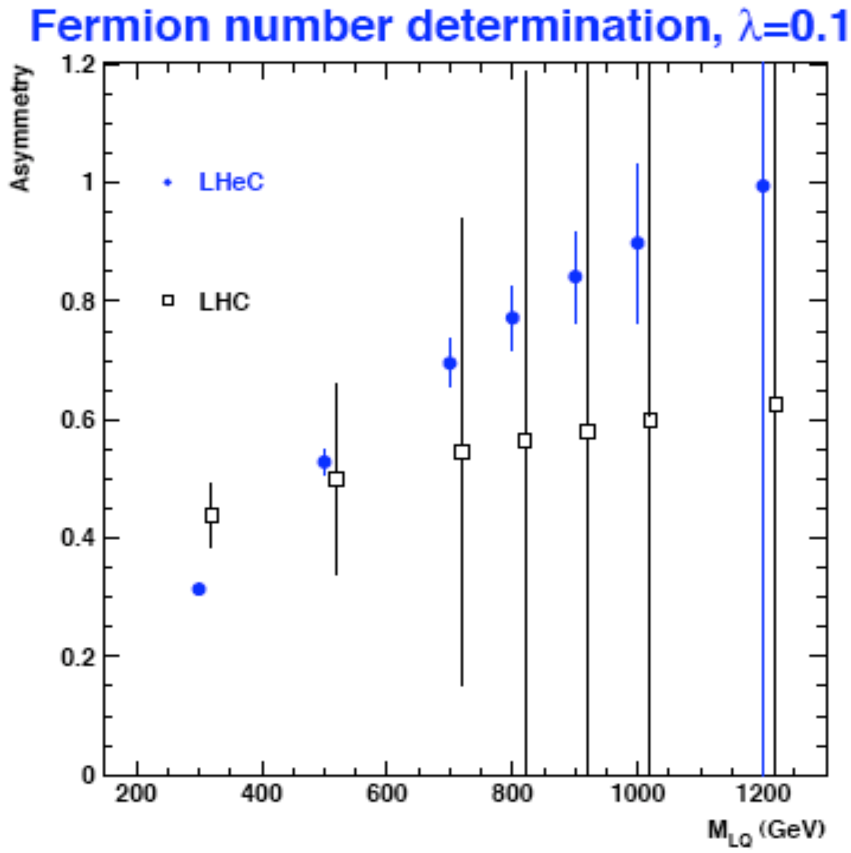
1. Introduction

Leptons and hadrons share equally three of the basic forces of nature: electromagnetic, weak and gravitational. The only force which is supposed to distinguish between them is strong. Could it be that leptons share with hadrons this force also, and that there is just one form of matter, not two?



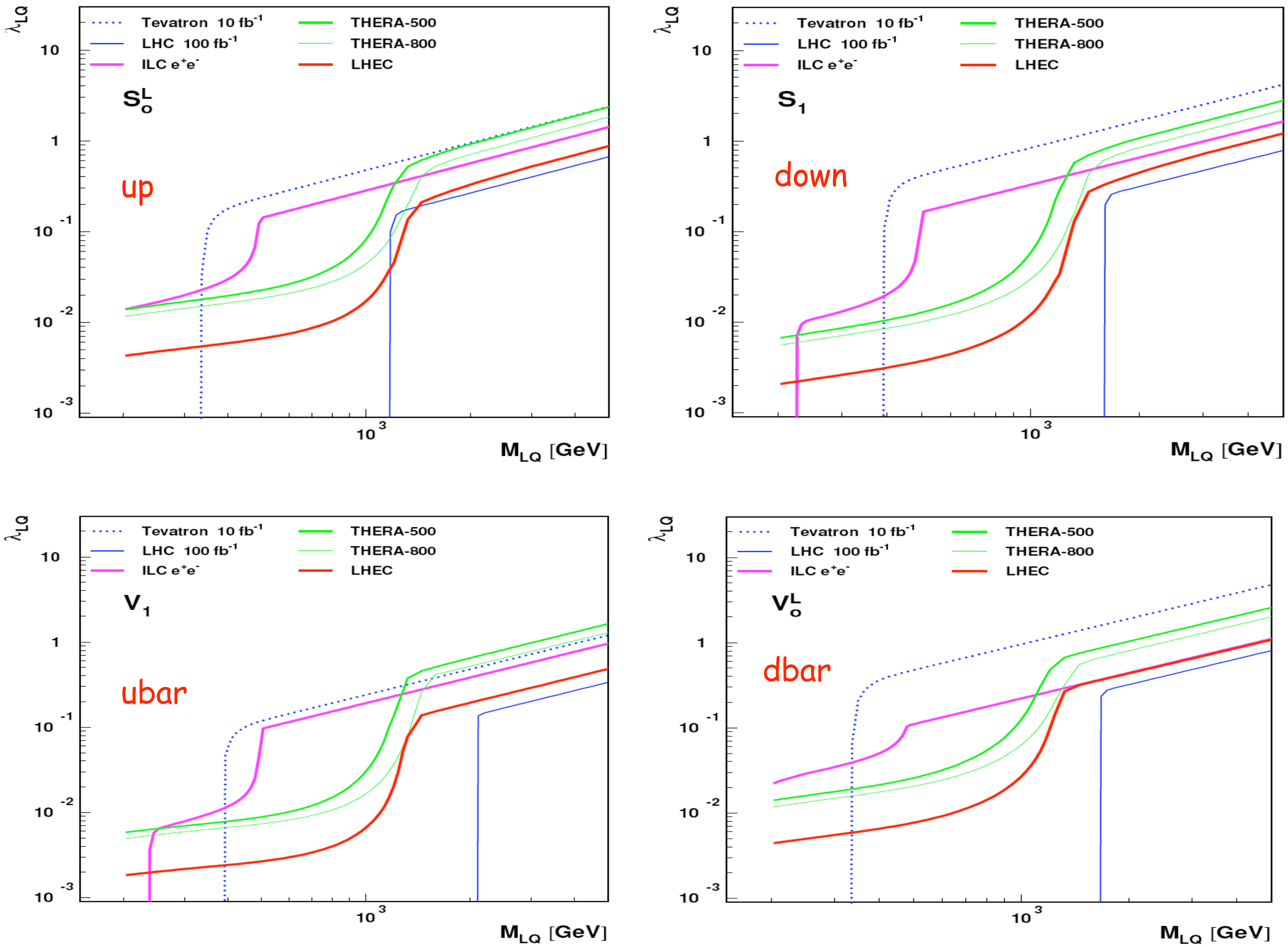


asymmetry determines fermion number (polarisation desirable but 'not impossible')

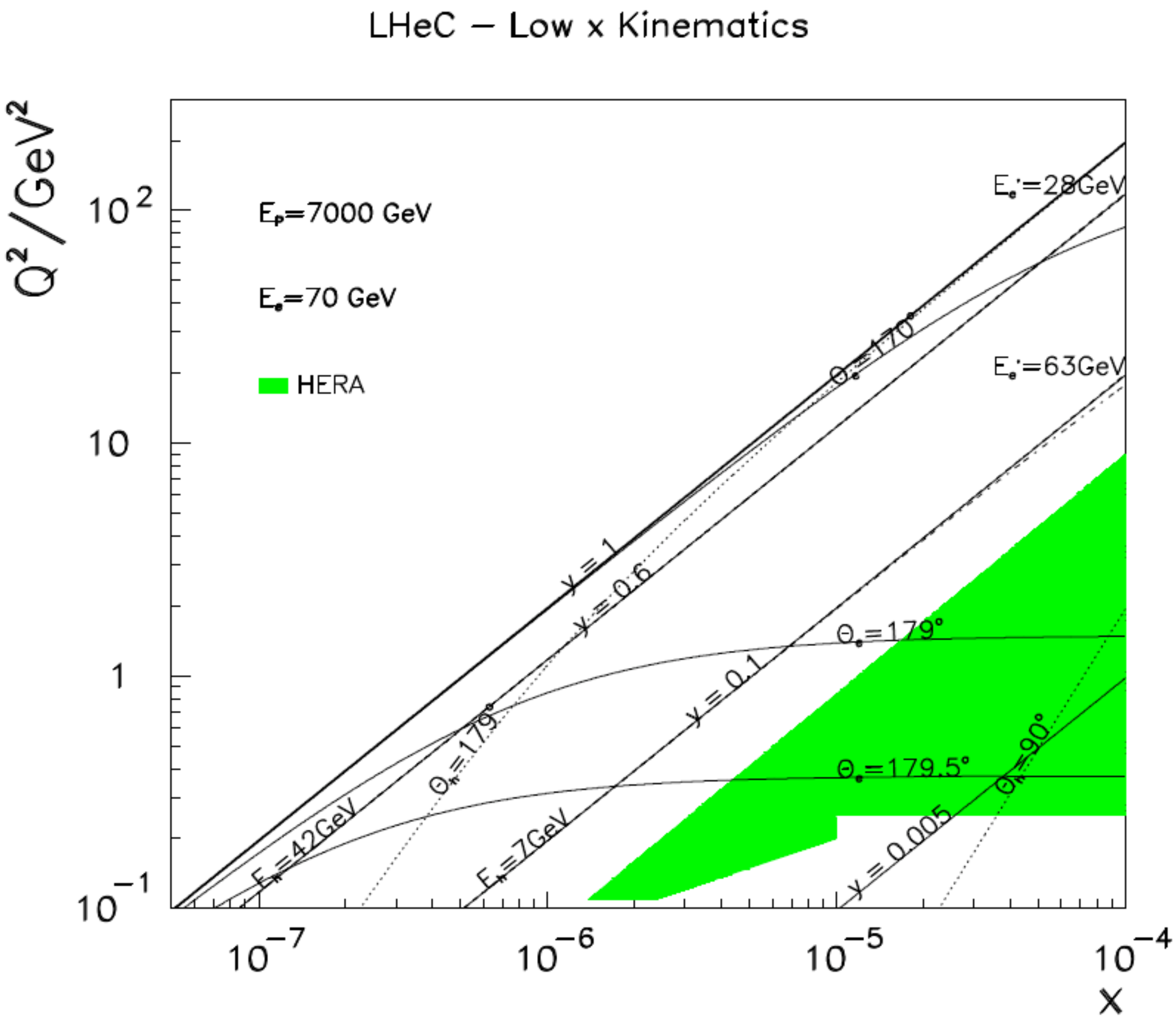


cross sections higher in ep and initial state better defined.

luminosity lower in ep.



F. Zarnecki (prel)



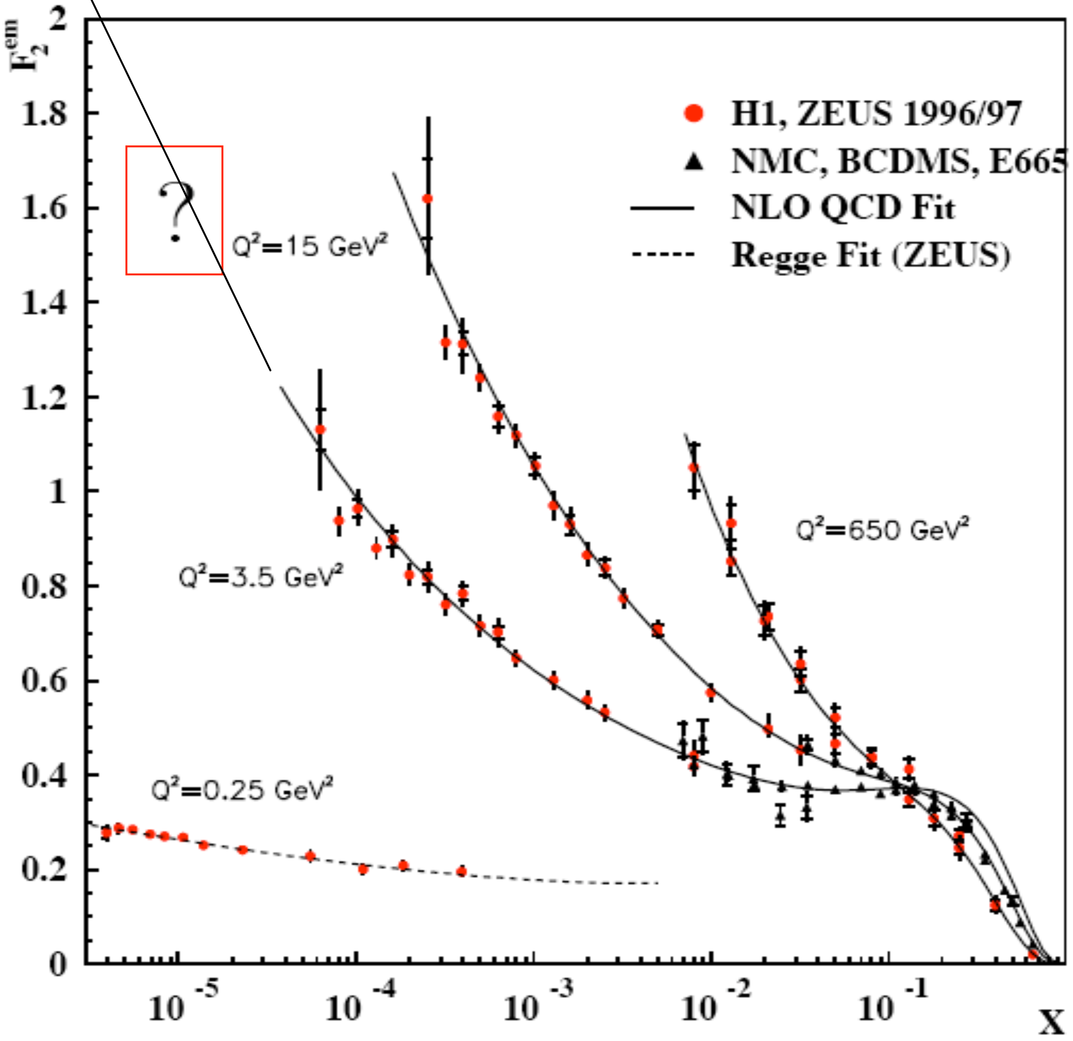
10^5 events per pb^{-1} for Q^2>100
Lumi 'easy'

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

Low x Physics

?



Is the rise limited,
do densities saturate?

Evolution dynamics
(DGLAP, BFKL..)
Final state, diffraction

What is the origin
and range of the
high density phase?
(instantons? CGC,..

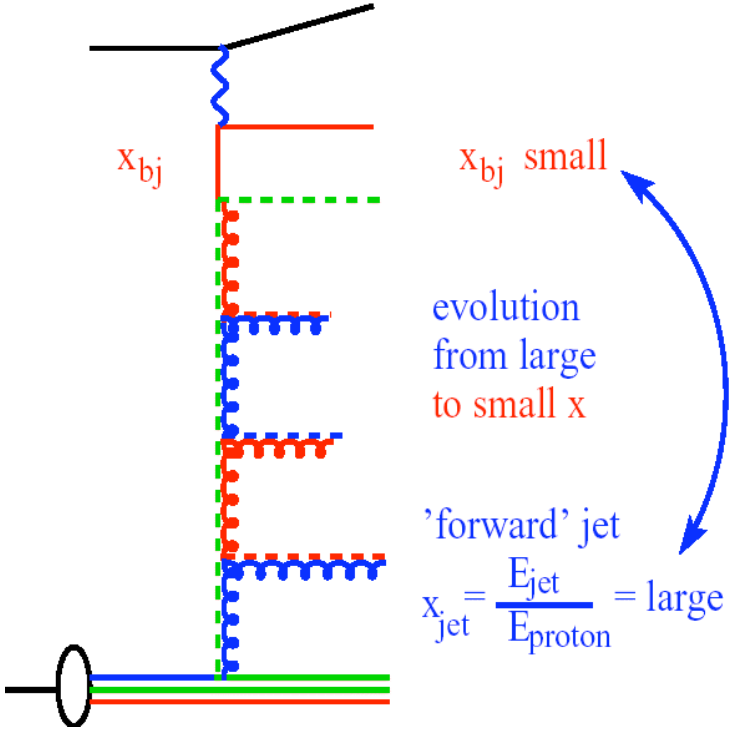
In p restframe:
dipole - p scattering,
transverse p dimension
scanned with 2/Q

LHeC: basis to
understand pp,pA,AA.
Important for superhiE
neutrino and gamma
astrophysics

Low x parton radiation:

forward particle production (in p direction)
hints to departures from conventional DGLAP,
from forward jet and π^0 data of ZEUS&H1
resolved photon? Higher orders?

Needs Phase Space !



How are partons (gluons) emitted?

kt ordered

- DGLAP(Dokshitzer-Gribov-Lipatov-Altarelli-Parisi)
DISENT/NLOJET

angular ordered

- CCFM(Ciafaloni-Catani-Fiorani-Marchesini)
CASCADE

x ordered

- BFKL(Balitsky-Fadin-Kuraev-Lipatov)
ARIADNE (colour dipole. random in kt)

$x_{jet} = E_{jet}/E_{proton} \gg x_{Bj}$ enhances BFKL effect

$E^2_{T,jet} \sim Q^2$ suppress DGLAP evolution

Forward Jet production to discriminate low x evolution

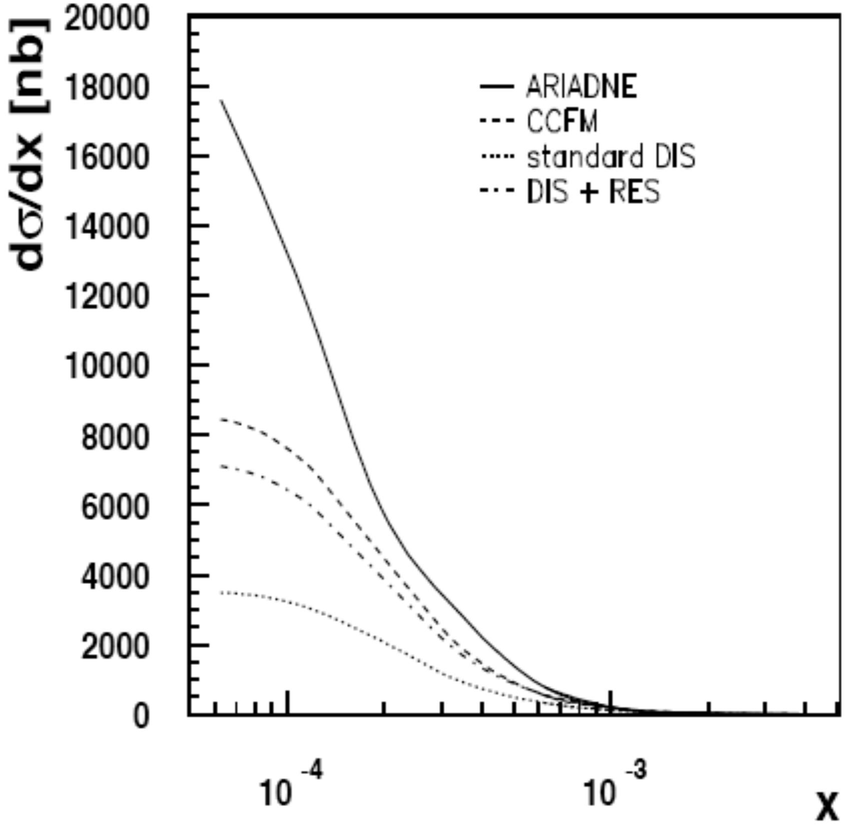


Figure 1.2.9: *Forward-jet cross section as a function of x in different models for $0.5 < p_t^2/Q^2 < 2$ and a minimum polar jet angle of 1°. The measurements at HERA are limited to $x \gtrsim 2 \times 10^{-3}$.*

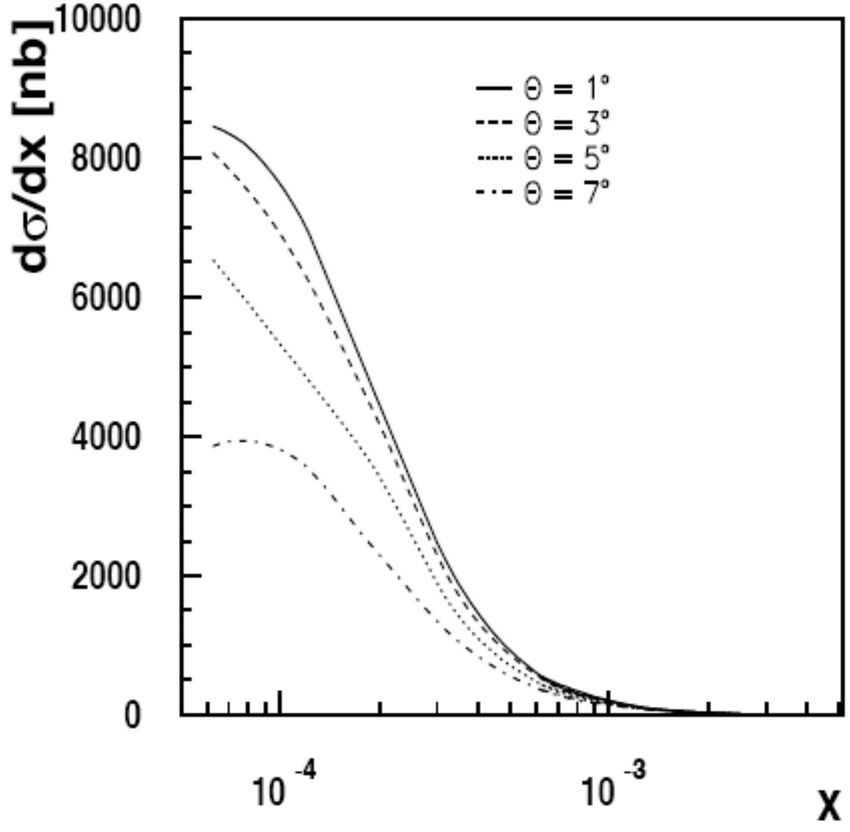
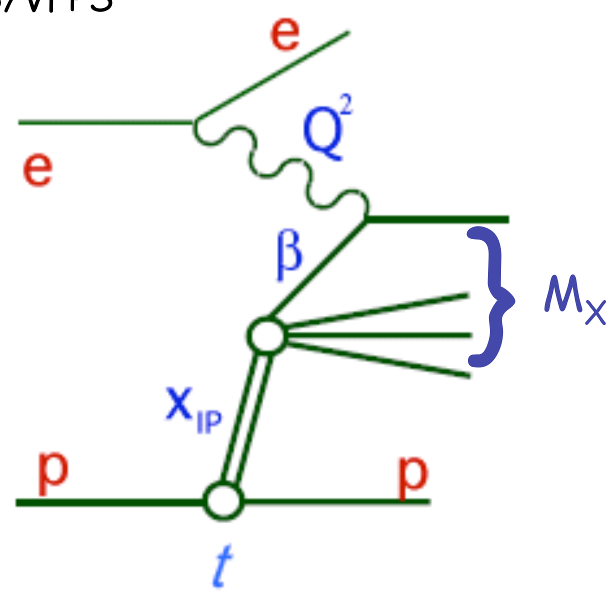


Figure 1.2.10: *Forward-jet cross section as a function of x obtained from CCFM for $0.5 < p_t^2/Q^2 < 2$, for different values of the minimum jet angle.*

cf Thera Book Jung, Loennblad

Hard Diffractive ep Scattering

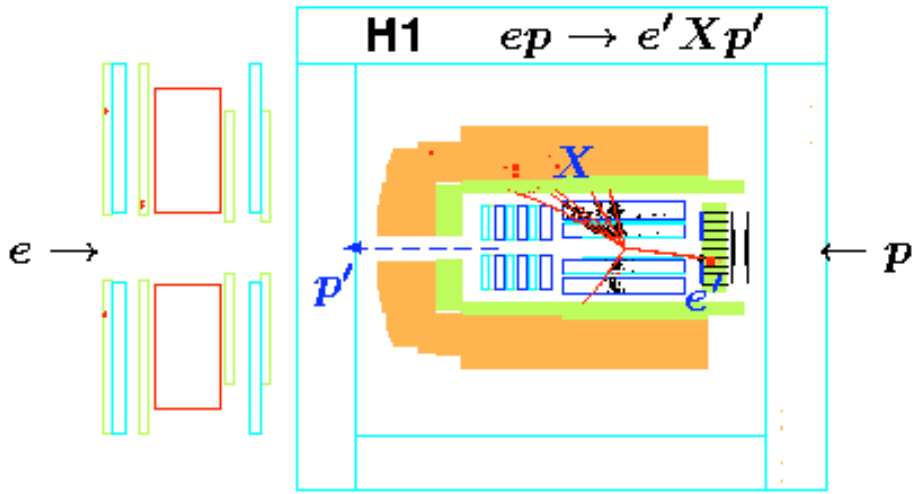
~10% of NC DIS events have gap between p an
central tracks. Measure gap or detect p with
LPS/VFPS



$$\frac{d\sigma^{NC}_{diff}}{dx_{IP}dtd\beta dQ^2} \propto \frac{1}{Q^4} F_2^{D(4)}(x_{IP}, t, \beta, Q^2)$$

Cross section factorises into coefficient functions and diffractive parton distributions

(Trentadue, Veneziano, Berera, Soper, Collins, ...)

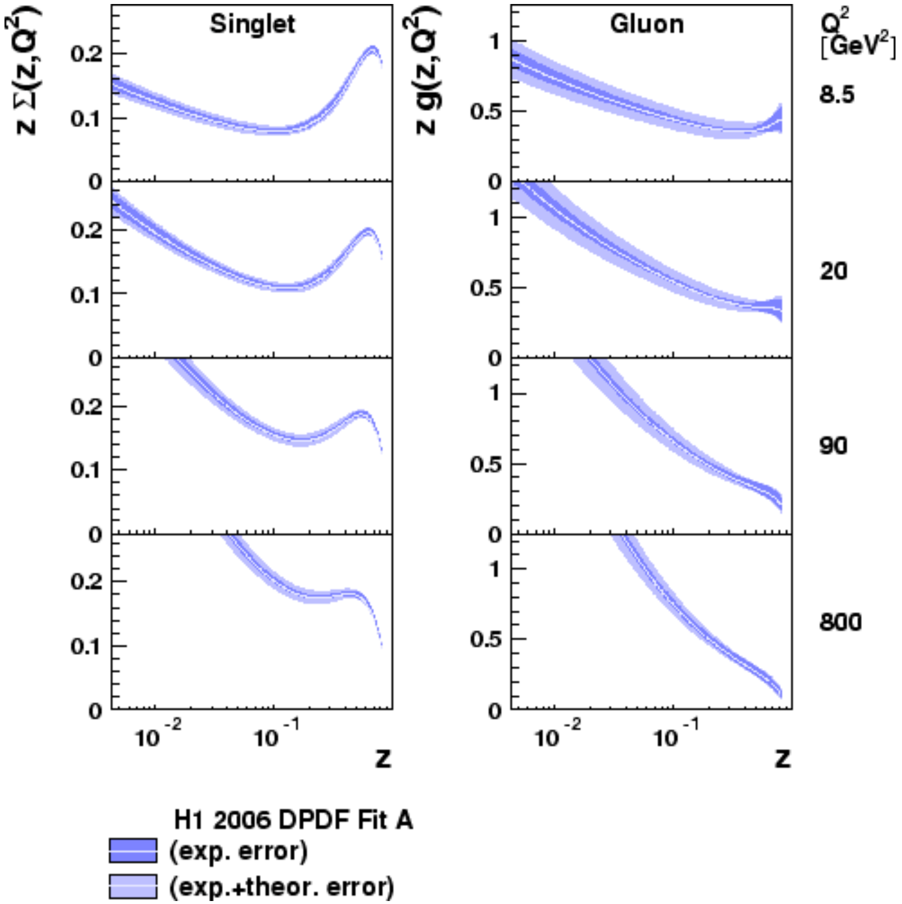


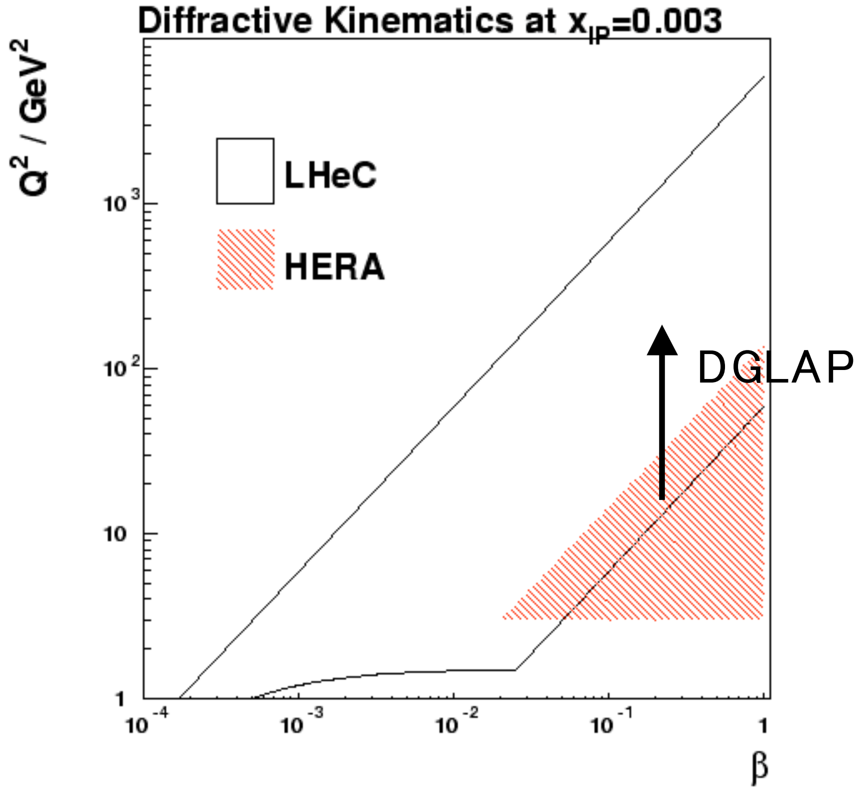
First observations by ZEUS and H1 of diffraction in charged current scattering at high Q^2: 2-3%

Understand nature of diffractive exchange
- Does diffraction affect p PDF's [Martin et al]
- Is diffractive exchange universal, ep – pp?
- 2 g exchange → high gluon density – unitarity?
- Study an old phenomenon at hard scales!

ep allows detailed, quantitative studies.
(inclusive, resolved y, CC, charm, jets..)

Diffraction Kinematics



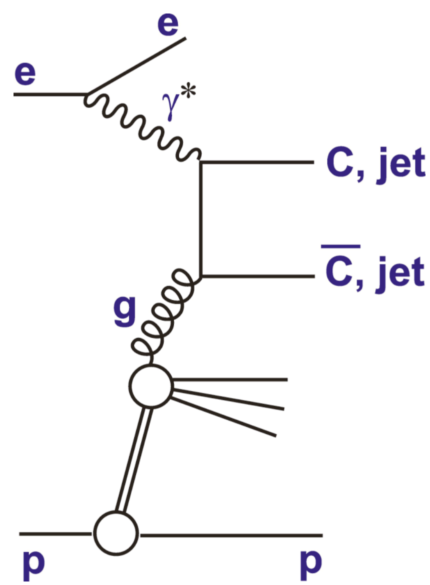


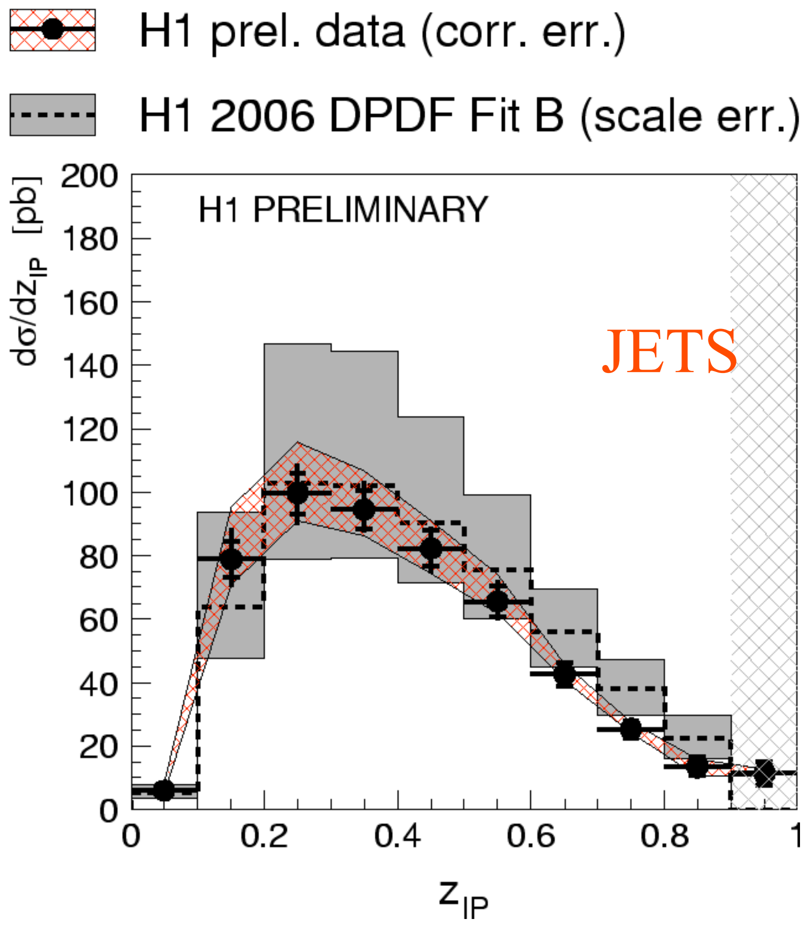
- DPDFs extracted from HERA data predict the LHeC cross section at moderate – large ß, assuming factorisation and DGLAP evolution …..
- Test of these ideas, especially gluon by studying higher Q^2 at similar ß.
- LHeC extends to lower ß – new non-linear dynamics, BFKL etc???

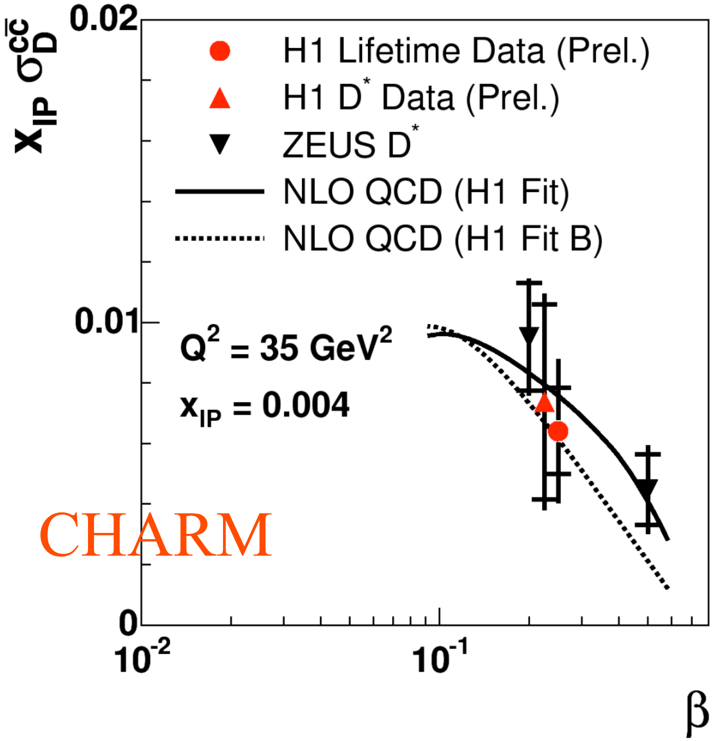
Final States in Diffraction at HERA

- Factorisation tests done at HERA with gluon initiated jet / charm processes…. Success!…

- Restricted to high β region by kinematic constraints

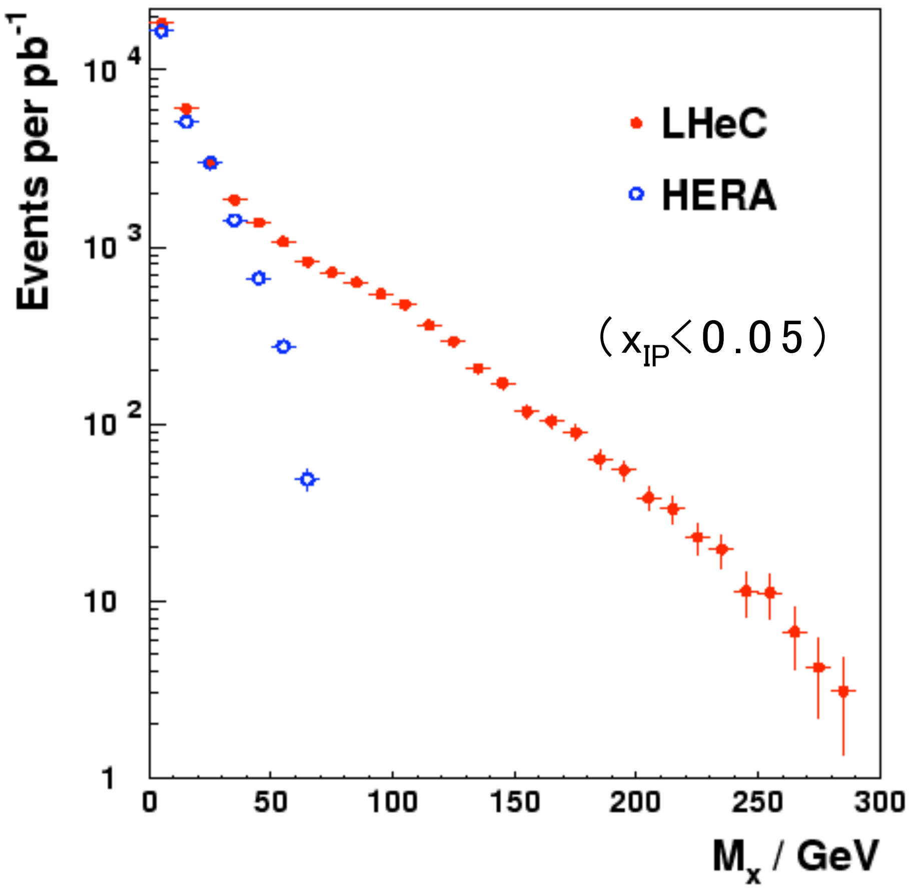






Final States in Diffraction at the LHeC

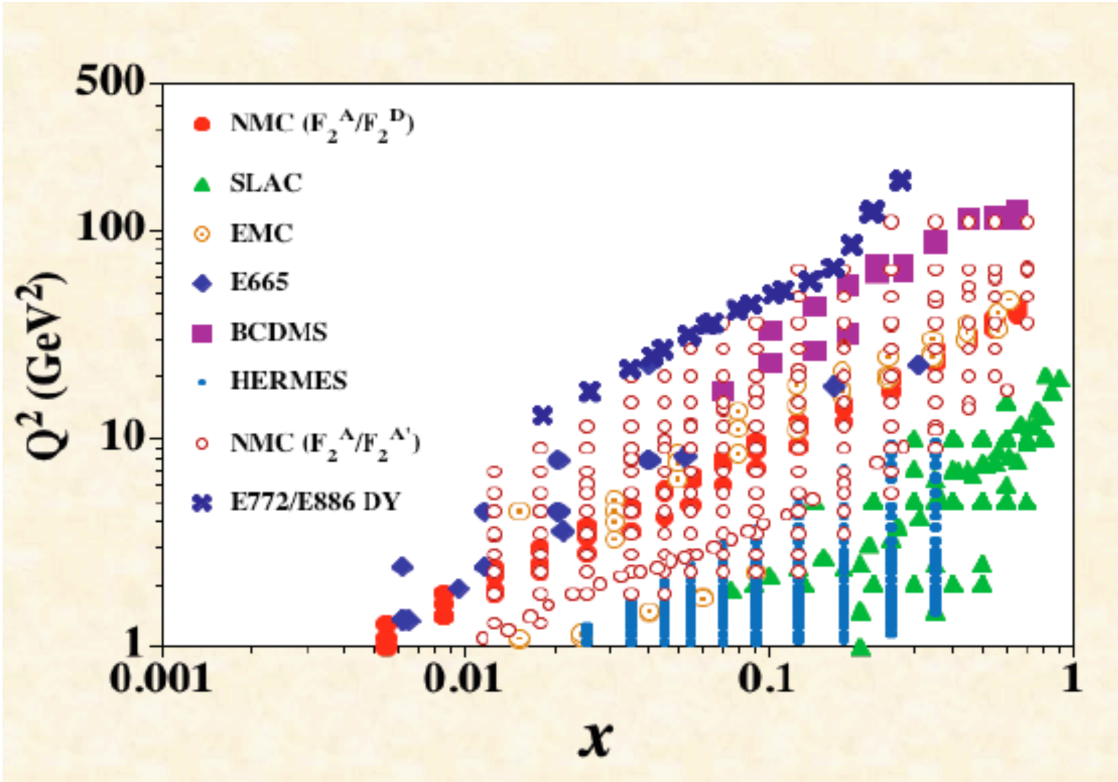
- At LHeC, diffractive masses M_x up to hundreds of GeV can be produced with low x_{IP}
- Low β, low x_{IP} region for jets and charm accessible.
- New diffractive channels … beauty, W / Z bosons
- Unfold quantum numbers / precisely measure exclusively produced new / exotic 1^{--} states



Many further interesting topics to be evaluated …..e.g. VM / DVCS / GPDs …

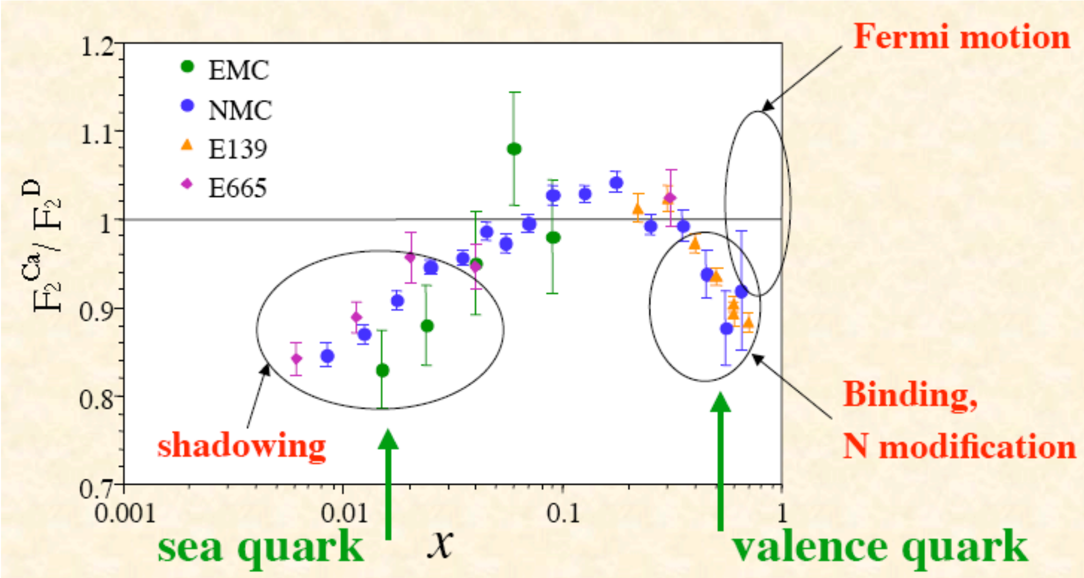
Nuclear Structure

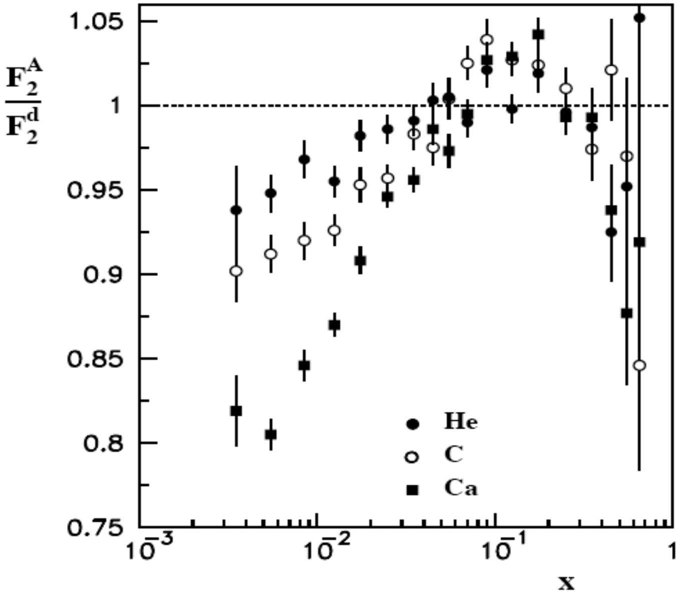
Deconfinement state of partons. Quark-Gluon Plasma
The LHeC extends the eA range by 4 orders of magnitude

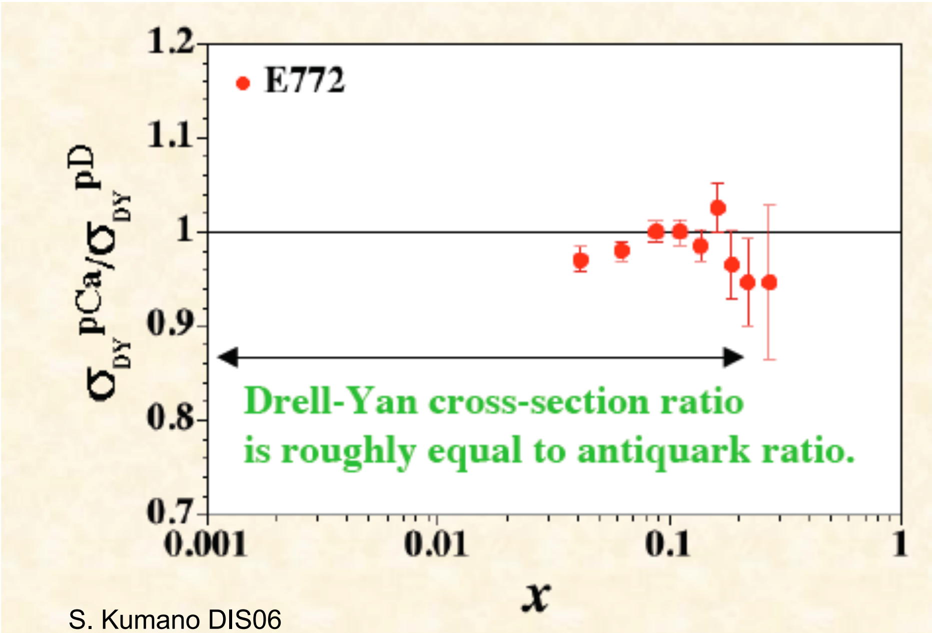


Limited information on quarks and nearly none on gluons

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..







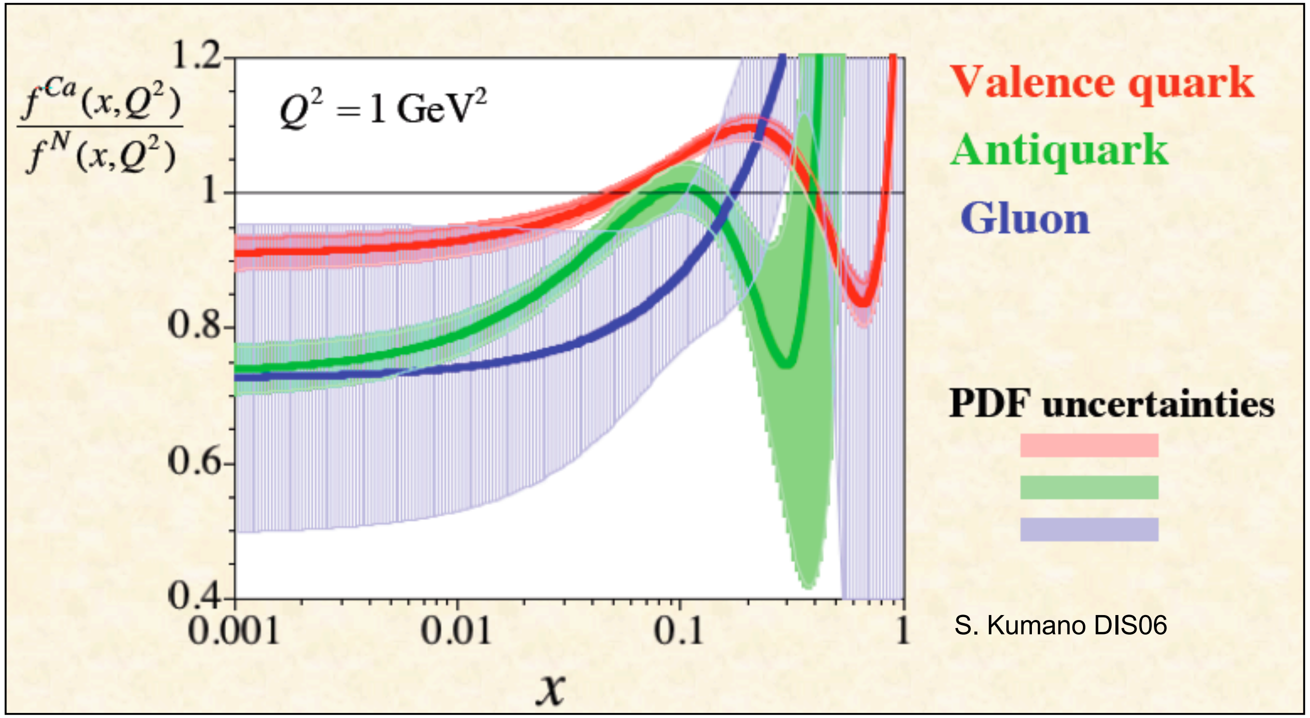
$$\frac{\sigma_{DY}^{pCa}}{\sigma_{DY}^{pD}} \approx \frac{\bar{q}^{Ca}}{\bar{q}^{D}}$$

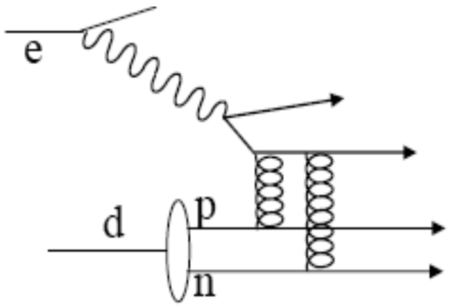
$$f_i^A(x_N, Q_0^2) = R_i(x_N, Q_0^2, A, Z)\, f_i(x_N, Q_0^2)$$

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

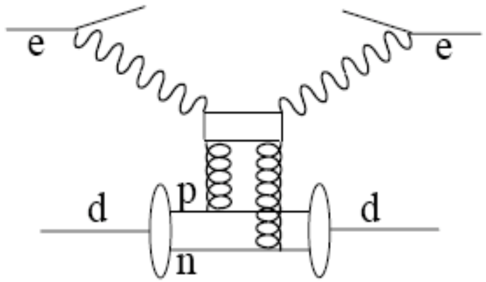
LHeC provides genuine determination of nuclear quark and gluon distributions based on wide range of data in x,Q^2,A

Determination of nPDF's

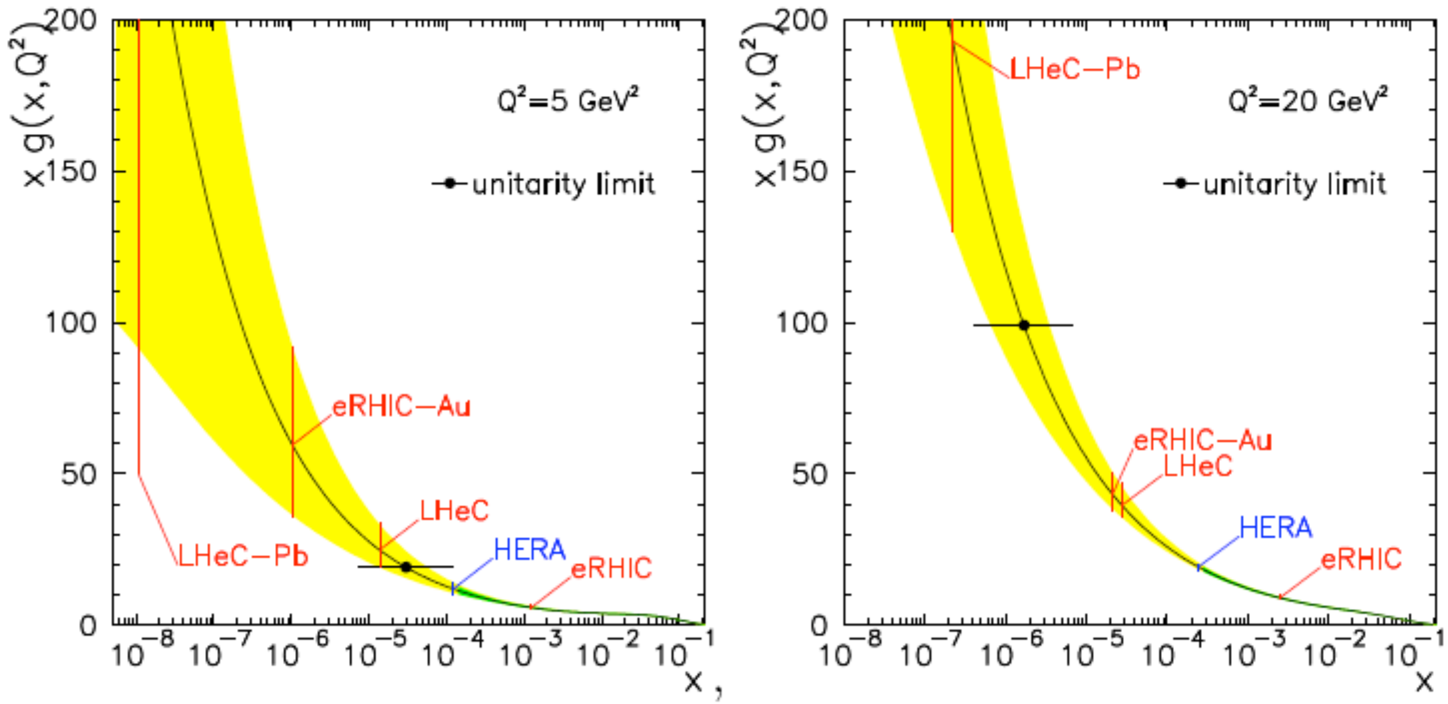




In eA at the collider, test Gribovs relation between shadowing and diffraction, control nuclear effects at low Bjorken x to high accuracy



High density states



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

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

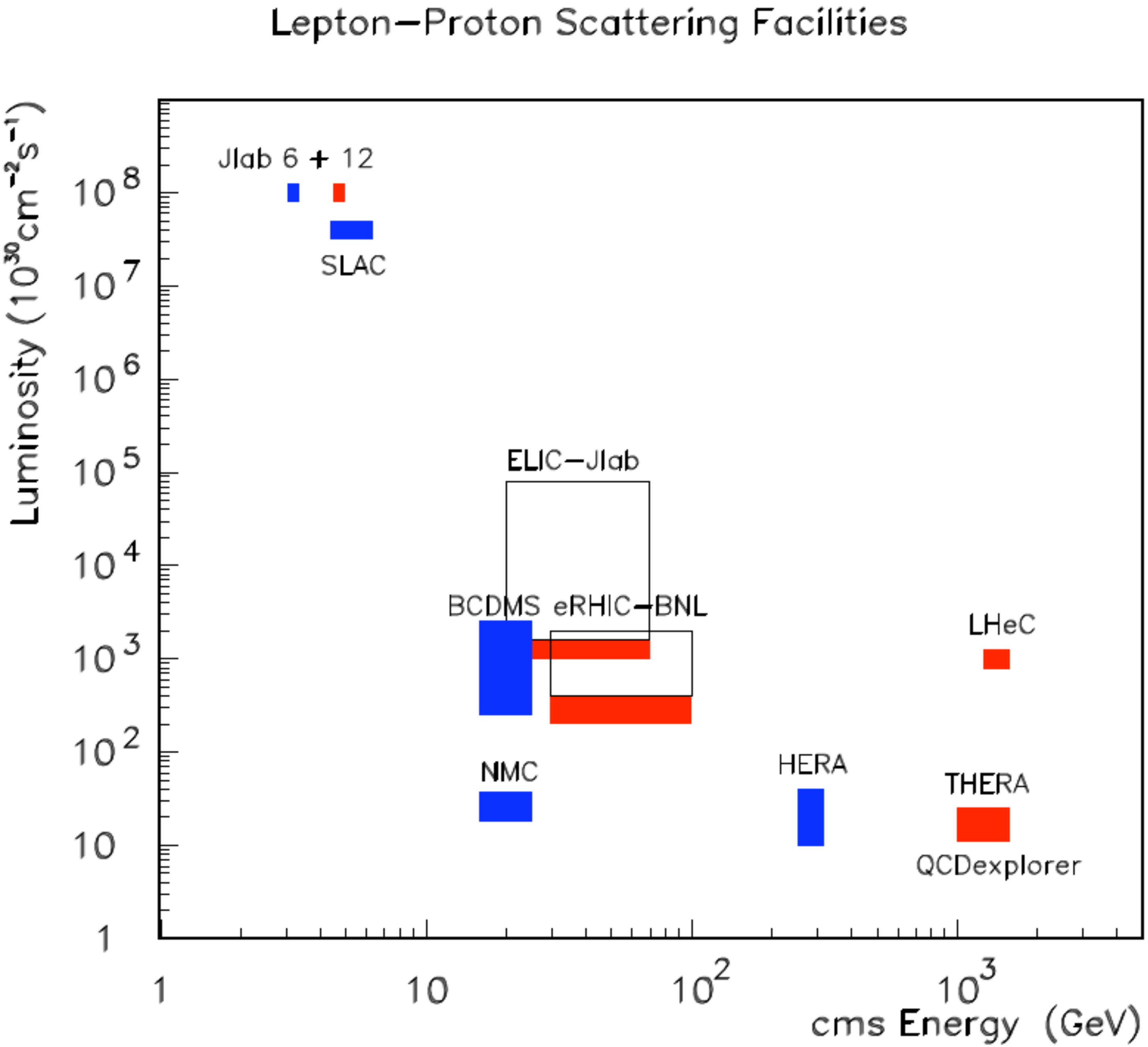
Striking effects predicted:

bj -> black disc limit $F_2 \rightarrow Q^2 \ln(1/x)$

~50% diffraction

colour opacity, change of $J/\Psi(A)$

Understanding the possible observation of QGP in AA with eA



Lepton−Proton Scattering Facilities
Luminosity ($10^{30}cm^{-2}s^{-1}$)
cms Energy (GeV)
Jlab 6 + 12
SLAC
ELIC−Jlab
BCDMS
eRHIC−BNL
LHeC
NMC
HERA
THERA
QCDexplorer

The LHeC has the potential to lead DIS to the TeV scale
"the undisputable next step" JBD : new physics+QCD
as it uses the best hadron beam in the world
accompanied by the highest possible luminosity.

To find out what this machine involves:

Widen+substantiate physics considerations.
Study closer the relations to the LHC (physics + techn)
Design a detector (for hiq2 and for low x).
Further study the machine implications and potential.

LHC may tell that even higher energy is necessary (LC * LHC?)

Aim at workshop this fall, October 26-28 (tentative)..

DIS Contributions to ICHEP86

Proceedings of the
XXIII International Conference
on
High Energy Physics

16–23 July 1986
Berkeley, California USA

A HIGH-STATISTICS MEASUREMENT OF THE NUCLEON STRUCTURE FUNCTION
$F_2(x,Q^2)$ FROM DEEP INELASTIC MUON-CARBON SCATTERING AT HIGH Q^2

Bologna-CERN-Dubna-Munich-Saclay Collaboration

presented by
M. Virchaux
DPhPE, CEN Saclay, France

Preliminary Results from a Precision Measurement of the x, Q^2 and Nuclear Dependence of $R = \sigma_L/\sigma_T$

* Presented by S.E.Rock, The American University

PHYSICS AT FUTURE HIGH ENERGY COLLIDERS

C.H.Llewellyn Smith

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1, Keble Road,
Oxford, OX1 3NP,
England.

To summarize: ep machines are sometimes regarded as poor sisters of e^+e^- and pp machines, but we should remember the story of Cinderella: poor sisters may strike rich and Hera or subsequent ep machines may be spectacularly successful if there are major surprises in the charged current or if lepto-quarks exist.

Backup Slides

Title

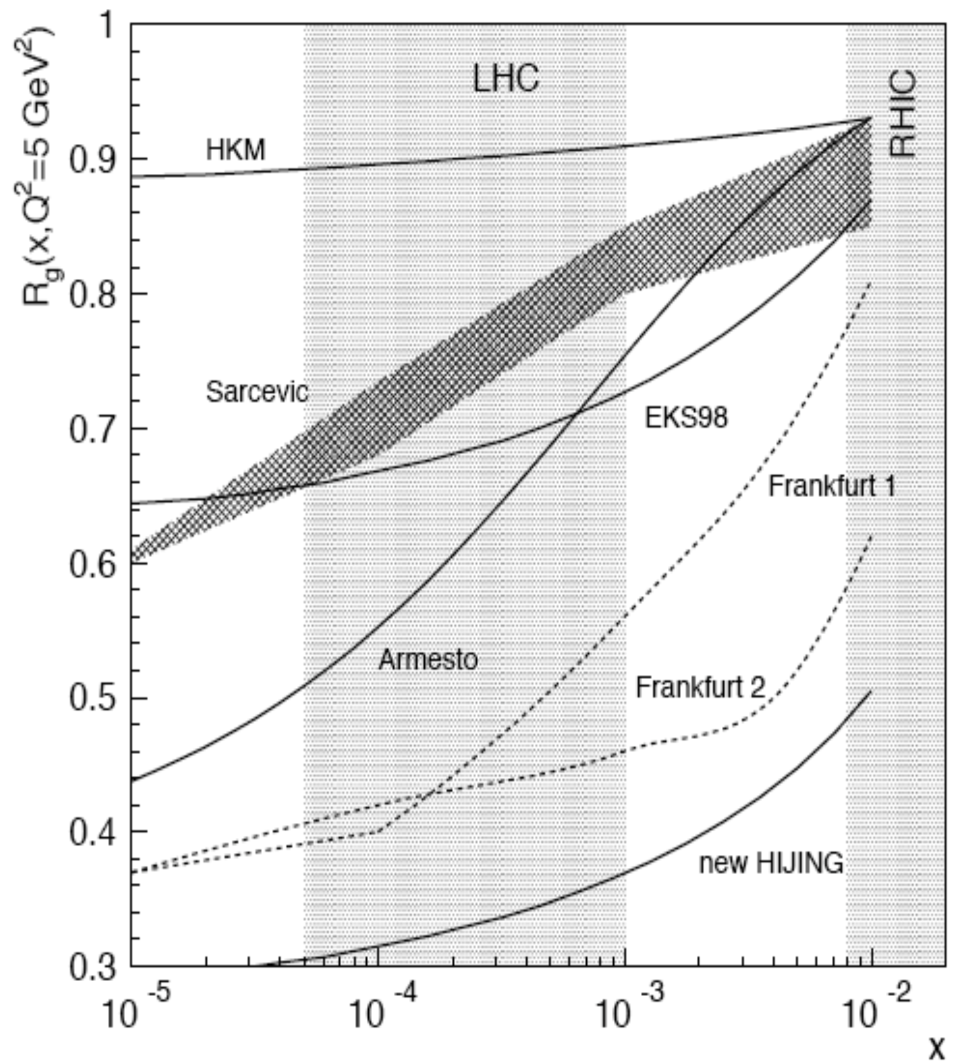

Figure 9: *Ratios of gluon distribution functions in lead (Pb) relative to the gluon distribution in the proton using different models, at* $Q^2 = 5\ GeV^2$.