LHeC with emphasis to LHC and PDFs

Project Overview
Detector and Simulations
PDF Measurements
Relations to LHC

Max Klein

UNIVERSITY OF LIVERPOOL

For the LHeC Study Group

Talk at a Preparatory QCD Meeting for “Snowmass” 2013 FNAL/CERN, January 31st , 2013

Design Parameters

parameter [unit]	LHeC	
species	e	p, $^{208}Pb^{82+}$
beam energy (/nucleon) [GeV]	60	7000, 2760
bunch spacing [ns]	25, 100	25, 100
bunch intensity (nucleon) [10^{10}]	0.1 (0.2), 0.4	17 (22), 2.5
beam current [mA]	6.4 (12.8)	860 (1110), 6
rms bunch length [mm]	0.6	75.5
polarization [%]	90 (e^+ none)	none, none
normalized rms emittance [μm]	50	3.75 (2.0), 1.5
geometric rms emittance [nm]	0.43	0.50 (0.31)
IP beta function $\beta^*_{x,y}$ [m]	0.12 (0.032)	0.1 (0.05)
IP spot size [μm]	7.2 (3.7)	7.2 (3.7)
synchrotron tune Q_s	—	1.9×10^{-3}
hadron beam-beam parameter	0.0001 (0.0002)	
lepton disruption parameter D	6 (30)	
crossing angle	0 (detector-integrated dipole)	
hourglass reduction factor H_{hg}	0.91 (0.67)	
pinch enhancement factor H_D	1.35 (0.3 for e^+)	
CM energy [TeV]	1.3, 0.81	
luminosity / nucleon [10^{33} cm^{-2}s^{-1}]	1 (10), 0.2	

arXiv:1211:5102

Designed for synchronous ep and pp operation during the HL-LHC phase.

Energy Recovery Linac (3 pass)

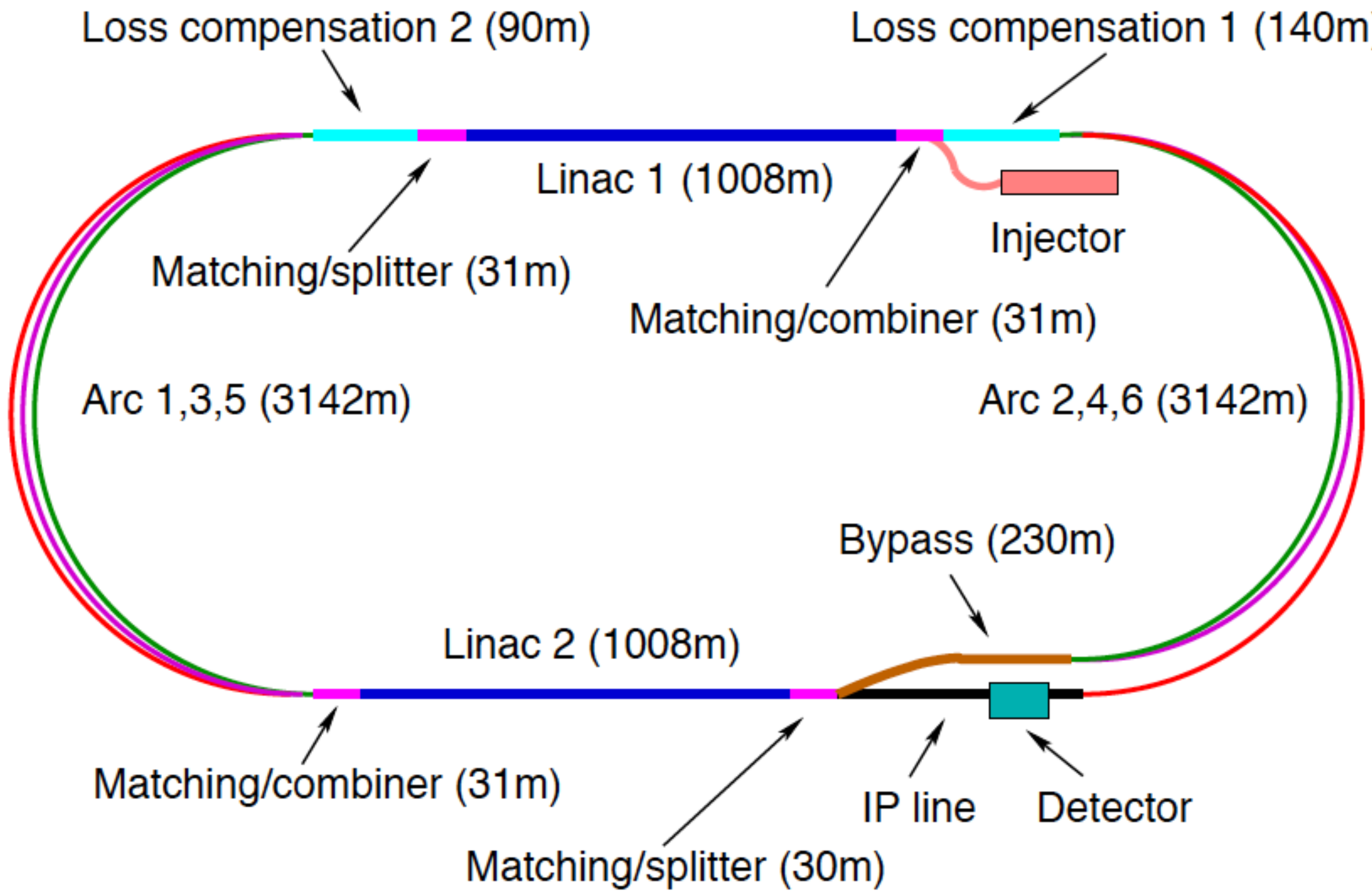
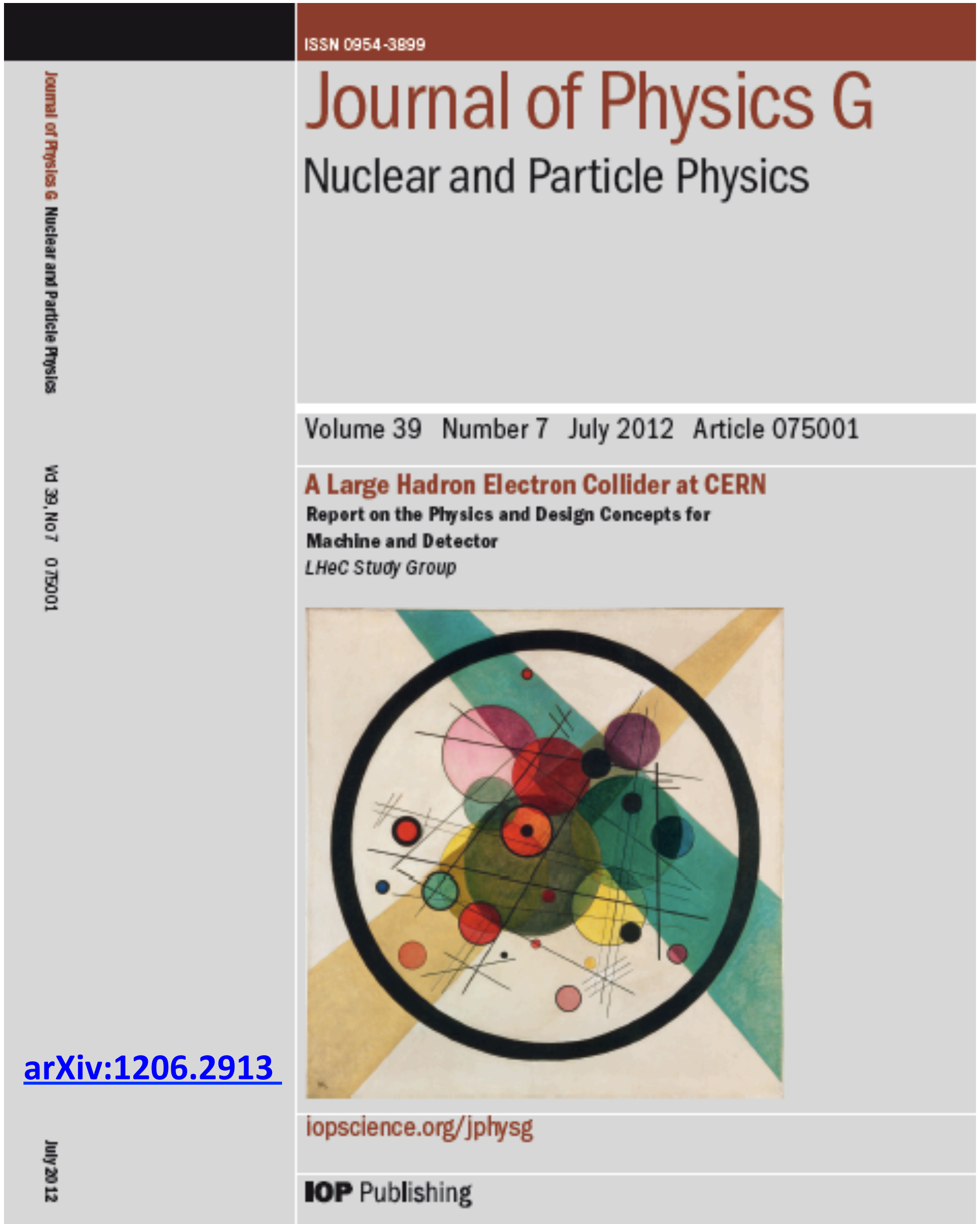


Figure 1: Schematic view on the LHeC racetrack configuration. Each linac accelerates the beam to 10 GeV, which leads to a 60 GeV electron energy at the collision point with three passes through the opposite linear structures of 60 cavity-cryo modules each. The arc radius is about 1 km, mainly determined by the synchrotron radiation loss of the 60 GeV beam which is returned from the IP and decelerated for recovering the beam power. Comprehensive design studies of the lattice, optics, beam (beam) dynamics, dump, IR and return arc magnets, as well as auxiliary systems such as RF, cryogenics or spin rotators are contained in the CDR [1], which as for physics and detector had been reviewed by 24 referees appointed by CERN.

Ring-Ring option as fall back; Photon-photon collider – 4 pass, pulsed, 80 GeV ("SAPHIRE")



arXiv:1206.2913

CERN Referees

Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
Interaction Region
Daniel Pitzl (DESY)
Mike Sullivan (SLAC)
Detector Design
Philippe Bloch (CERN)
Roland Horisberger (PSI)
Installation and Infrastructure
Sylvain Weisz (CERN)
New Physics at Large Scales
Cristinel Diaconu (IN2P3 Marseille)
Gian Giudice (CERN)
Michelangelo Mangano (CERN)
Precision QCD and Electroweak
Guido Altarelli (Roma)
Vladimir Chekelian (MPI Munich)
Alan Martin (Durham)
Physics at High Parton Densities
Alfred Mueller (Columbia)
Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)

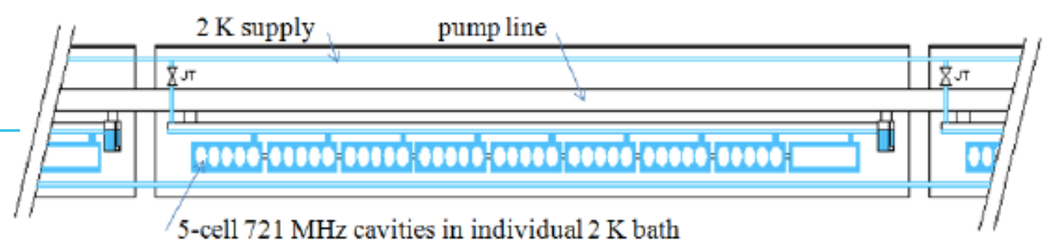
Published 600 pages conceptual design report (CDR) written by 200 authors from 60 Institutes and refereed by 24 world experts on physics, accelerator and detector, which were invited by CERN.

Chapter 9 of CDR

Components and Cryogenics

	Ring	Linac
magnets		
number of dipoles	3080	3504
dipole field [T]	0.013 – 0.076	0.046 – 0.264
number of quadrupoles	968	1514
RF and cryogenics		
number of cavities	112	960
gradient [MV/m]	11.9	20
linac grid power [MW]	–	24
synchrotron loss compensation [MW]	49	23
cavity voltage [MV]	5	20.8
cavity R/Q [Ω]	114	285
cavity Q_0	–	2.5 10^{10}
cooling power [kW]	5.4@4.2 K	30@2 K

Jlab: 4 10^{11}



Need to develop LHeC cavity (cryo-module)

systems will consist of a complex task. Further cavities and cryomodules will require a limited R&D program. From this we expect improved quality factors with respect to today's state of the art. The cryogenics of the L-R version consists of a formidable engineering challenge, however, it is feasible and, CERN disposes of the respective know-how.

from CDR LHeC

LHeC Accelerator Design: Participating Institutes-CDR

CERN

SLAC NATIONAL ACCELERATOR LABORATORY

NTNU
Norwegian University of Science and Technology

CLIC

The Cockcroft Institute of Accelerator Science and Technology

Jefferson Lab
Thomas Jefferson National Accelerator Facility

ANKARA ÜNİVERSİTESİ

NİĞDE ÜNİVERSİTESİ 1992

ULUDAĞ ÜNİVERSİTESİ 1975

TOBB ETU

INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

DESY

LAL Physique des accélérateurs

ECFA

UNIVERSITY OF LIVERPOOL

KEK

EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

СИБИРСКОЕ ОТДЕЛЕНИЕ РАН
ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
им. Г.И.Будкера

BROOKHAVEN NATIONAL LABORATORY

Next: LHeC ERL Testfacility at CERN

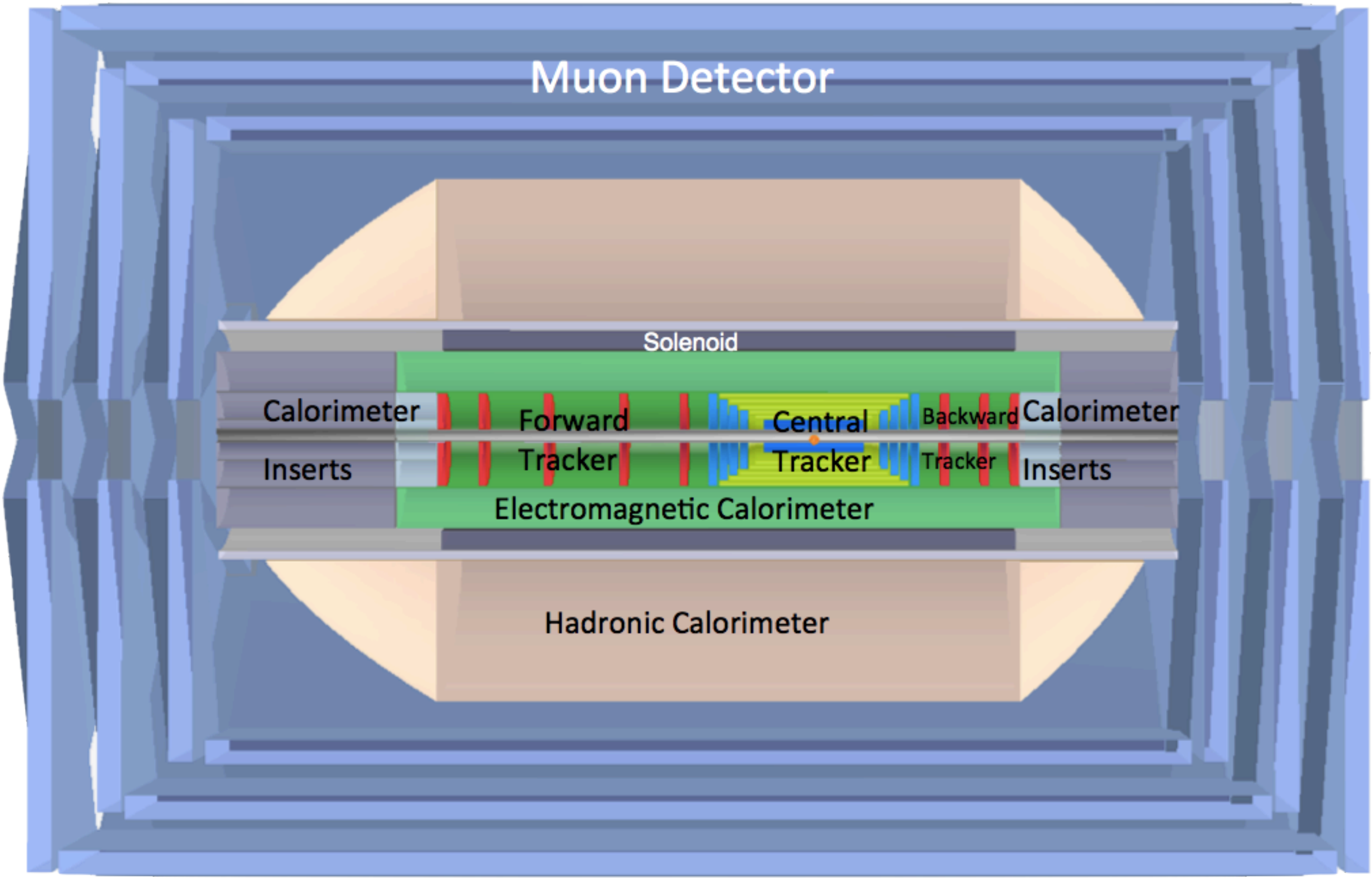
Summary of LHeC Physics [arXiv:1211:4831+5102]

The LHeC represents a new laboratory for exploring a hugely extended region of phase space with an unprecedented high luminosity in high energy DIS. It builds the link to the LHC and a future pure lepton collider, similar to the complementarity between HERA and the Tevatron and LEP, yet with much higher precision in an extended energy range. Its physics is fundamentally new, and it also is complementary especially to the LHC, for which the electron beam is an upgrade. Given the broad range of physics questions, there are various ways to classify these, partially overlapping. An attempt for a schematic overview on the LHeC physics programme as seen from today is presented in Tab. 3. The conquest of new regions of phase space and intensity has often lead to surprises, which tend to be difficult to tabulate.

QCD Discoveries	$\alpha_s < 0.12$, $q_{sea} \neq \overline{q}$, instanton, odderon, low x: (n0) saturation, $\overline{u} \neq \overline{d}$
Higgs	WW and ZZ production, $H \to b\overline{b}$, $H \to 4l$, CP eigenstate
Substructure	electromagnetic quark radius, e^*, ν^*, W?, Z?, top?, H?
New and BSM Physics	leptoquarks, RPV SUSY, Higgs CP, contact interactions, GUT through α_s
Top Quark	top PDF, $xt = x\overline{t}$?, single top in DIS, anomalous top
Relations to LHC	SUSY, high x partons and high mass SUSY, Higgs, LQs, QCD, precision PDFs
Gluon Distribution	saturation, $x \approx 1$, J/ψ, Υ, Pomeron, local spots?, F_L, F_2^c
Precision DIS	$\delta\alpha_s \simeq 0.1\,\%$, $\delta M_c \simeq 3\,\mathrm{MeV}$, $v_{u,d}$, $a_{u,d}$ to $2-3\,\%$, $\sin^2\Theta(\mu)$, F_L, F_2^b
Parton Structure	Proton, Deuteron, Neutron, Ions, Photon
Quark Distributions	valence $10^{-4} \lesssim x \lesssim 1$, light sea, d/u, $s = \overline{s}$?, charm, beauty, top
QCD	$\mathrm{N^3LO}$, factorisation, resummation, emission, AdS/CFT, BFKL evolution
Deuteron	singlet evolution, light sea, hidden colour, neutron, diffraction-shadowing
Heavy Ions	initial QGP, nPDFs, hadronization inside media, black limit, saturation
Modified Partons	PDFs "independent" of fits, unintegrated, generalised, photonic, diffractive
HERA continuation	F_L, xF_3, $F_2^{\gamma Z}$, high x partons, α_s, nuclear structure, ..

Table 3: Schematic overview on key physics topics for investigation with the LHeC.

LHeC Detector Overview



Detector option 1 for LR and full acceptance coverage

Forward/backward asymmetry in energy deposited and thus in geometry and technology
Present dimensions: LxD =14x9m^2 [CMS 21 x 15m^2 , ATLAS 45 x 25 m^2]
Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

Measurement Simulations

source of uncertainty	error on the source or cross section
scattered electron energy scale $\Delta E'_e/E'_e$	0.1 %
scattered electron polar angle	0.1 mrad
hadronic energy scale $\Delta E_h/E_h$	0.5 %
calorimeter noise (only $y < 0.01$)	1-3 %
radiative corrections	0.5%
photoproduction background (only $y > 0.5$)	1 %
global efficiency error	0.7 %

Table 3.1: Assumptions used in the simulation of the NC cross sections on the size of uncertainties from various sources. These assumptions correspond to typical best values achieved in the H1 experiment. Note that in the cross section measurement, the energy scale and angular uncertainties are relative to the Monte Carlo and not to be confused with resolution effects which determine the purity and stability of binned cross sections. The total cross section error due to these uncertainties, e.g. for $Q^2 = 100\,\mathrm{GeV}^2$, is about 1.2, 0.7 and 2.0 % for $y = 0.84,\ 0.1,\ 0.004$.

Full simulation of NC and CC inclusive cross section measurements including statistics, uncorrelated and correlated uncertainties – checked against H1 MC

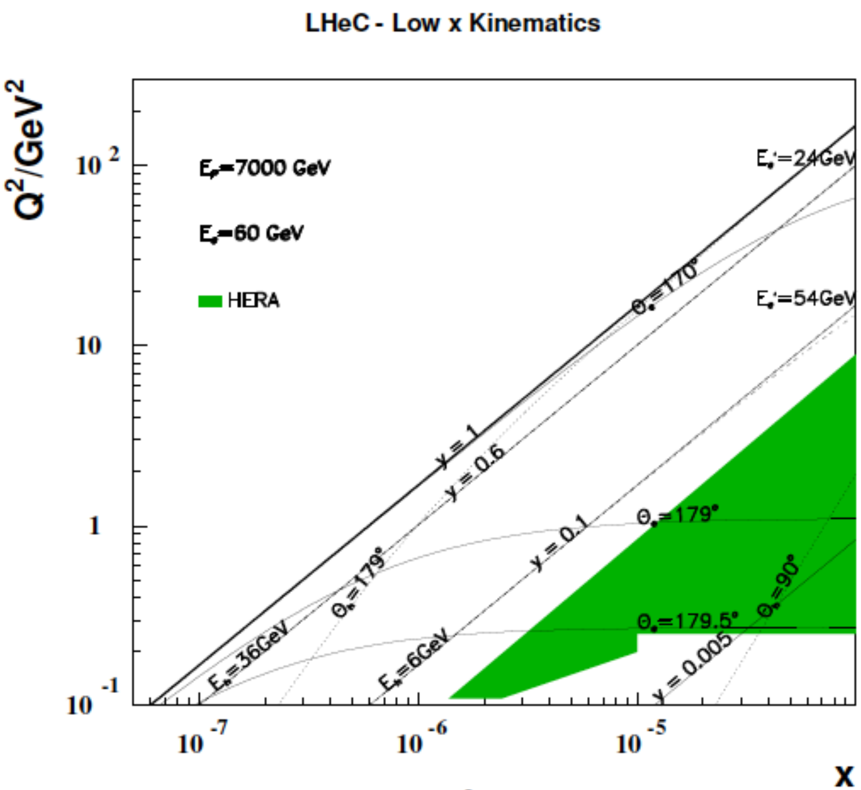
PDF Related Measurements

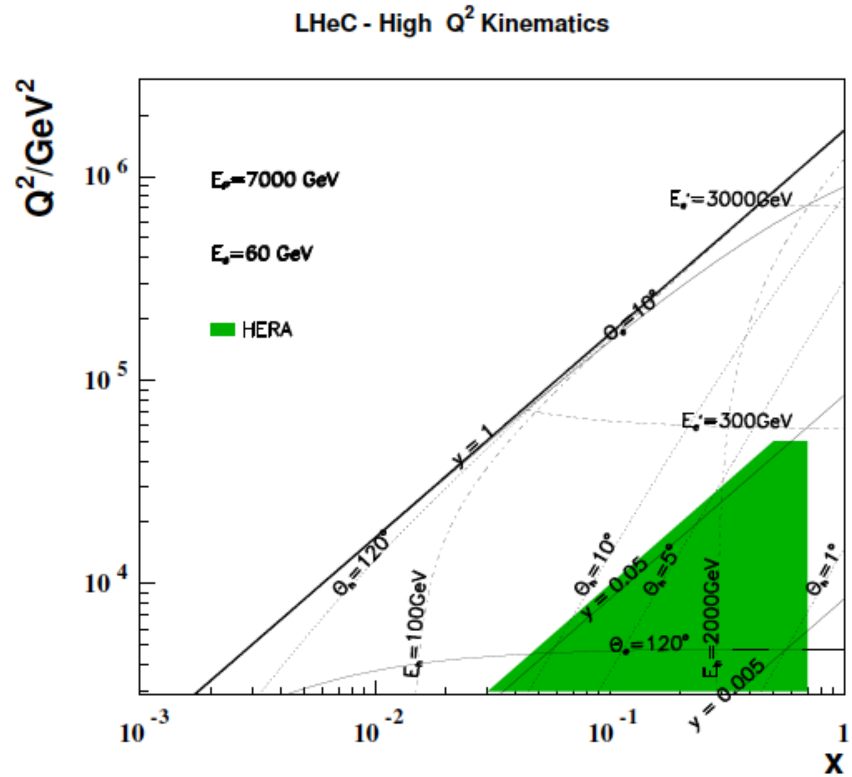
The LHeC provides for the first time a complete data base to determine ALL parton distributions, independently of parameterisation (approximately) and of symmetry assumptions. Given its kinematic range and the anticipated precision, it therefore will completely change the way we do PDF analyses, and it will be a most important means to convert the LHC facility into a high precision QCD, search and Higgs machine. The golden twenties are not far..

This is illustrated/sketched subsequently, making use of the CDR, the EU strategy contributions as of recent results.

Kinematics - LHeC and HERA

Access to “saturation” (?) region in DIS ($Q^2 > 1$ GeV^2) and ep

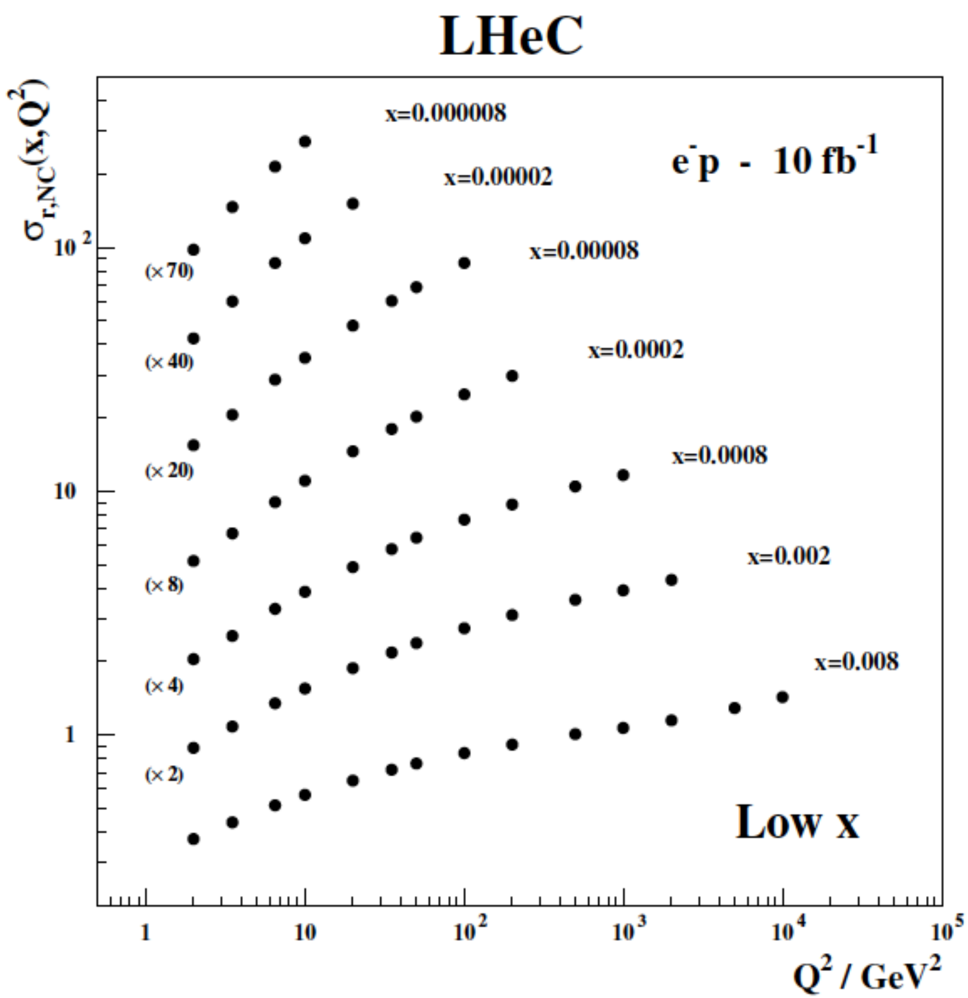


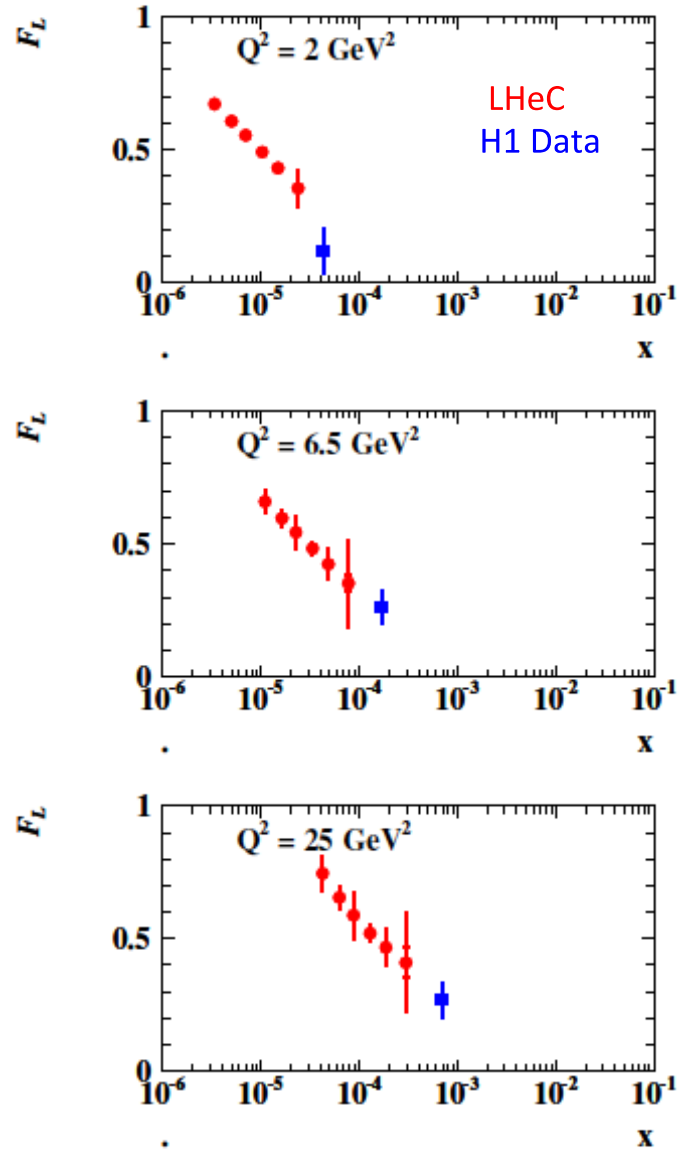


Extending beyond the Fermi scale with precision Z and W exchange data → high x, top PDF, flavour & new physics,

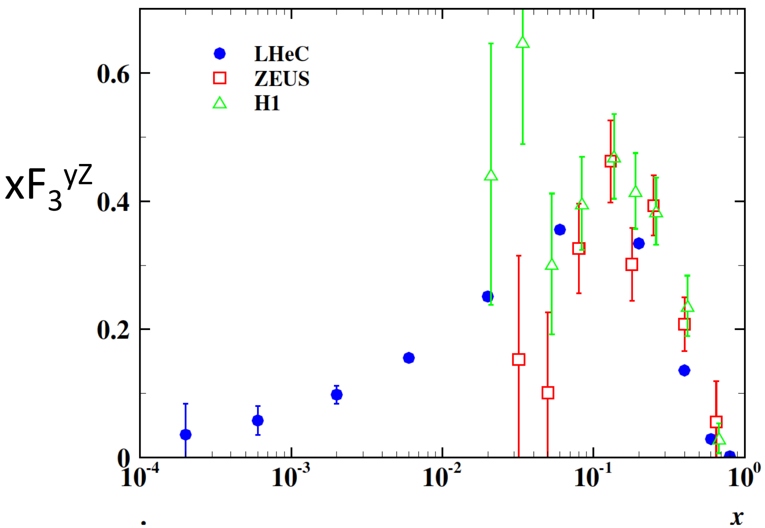
Primary measurements – simulated – low x

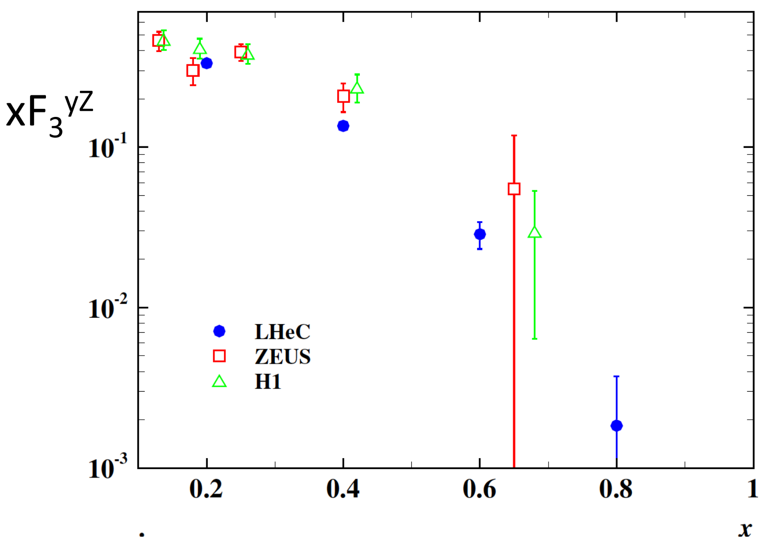
Data down to $x=10^{-6}$, superior F_L measurement,
Saturation? Non-linear evolution? Sea asymmetry?..
New base for GPDs, VMs, diffraction, unintegrated PDFs..





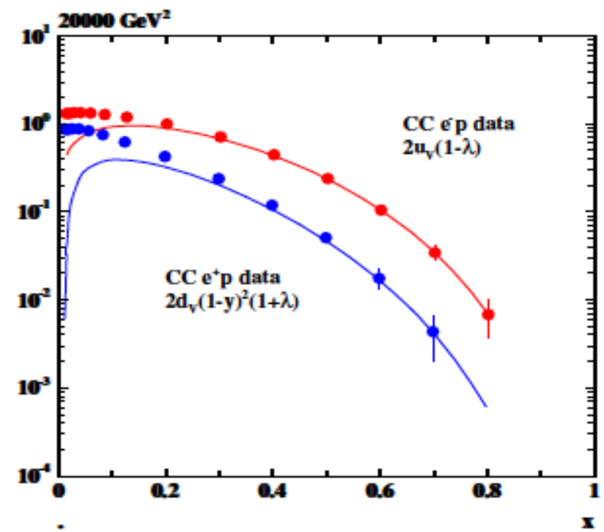
Primary measurements – simulated – high Q^2

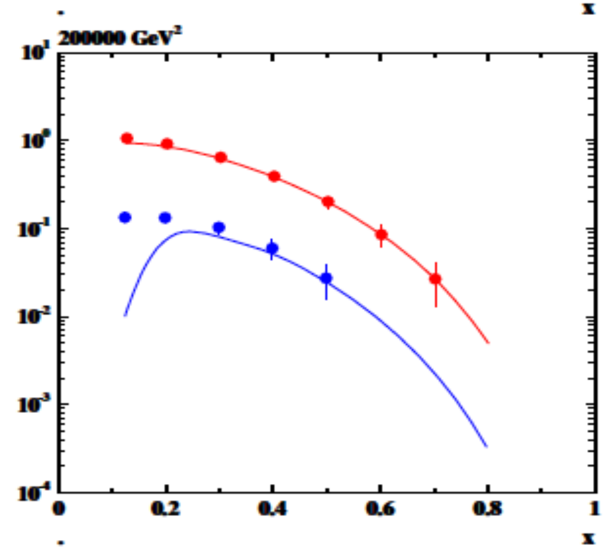




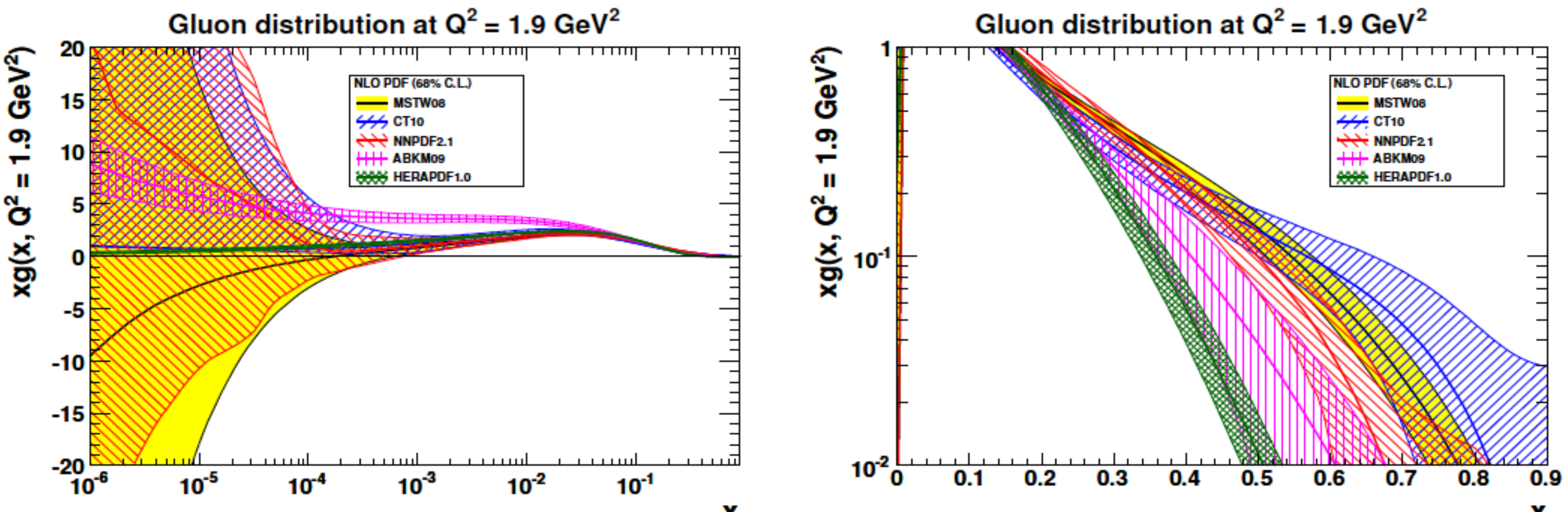
Precision electroweak measurements
PV with polarisation, $F_2^{b,Z}$, NC couplings..

Precision CC measurements: top [10pb]
valence quarks, high x, V_{tb}, strange, ..

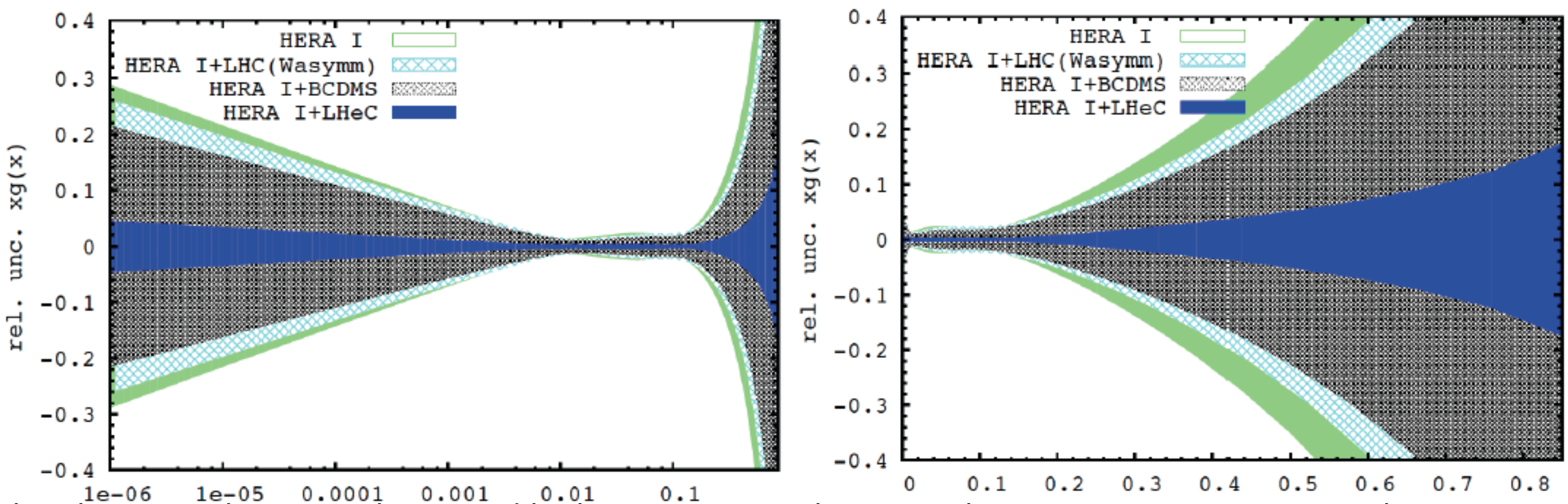




Mapping the Gluon Distribution

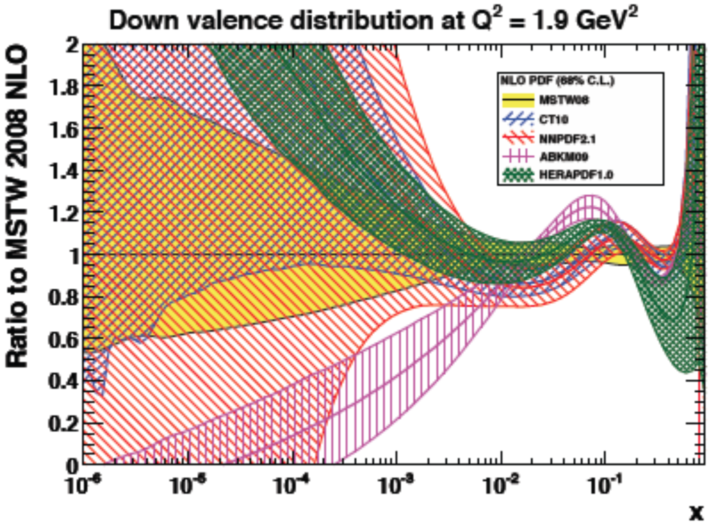


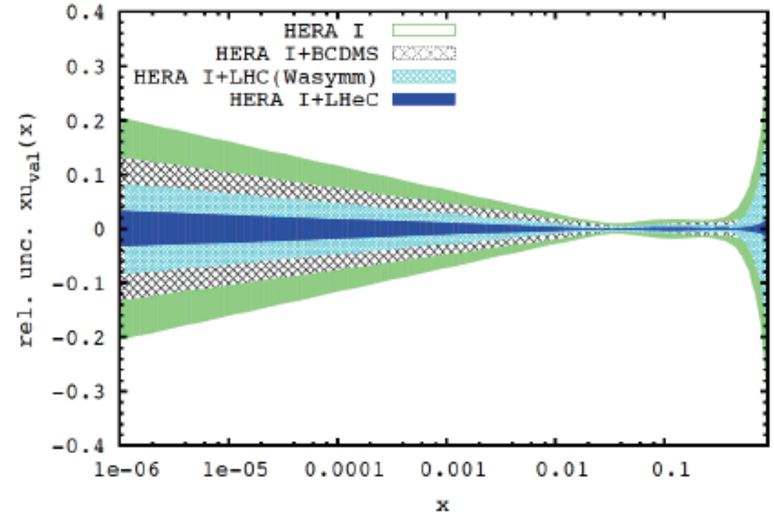
QCD fit analysis (default: NC,CC, LHeC only, following HERAPDF) with full experimental errors

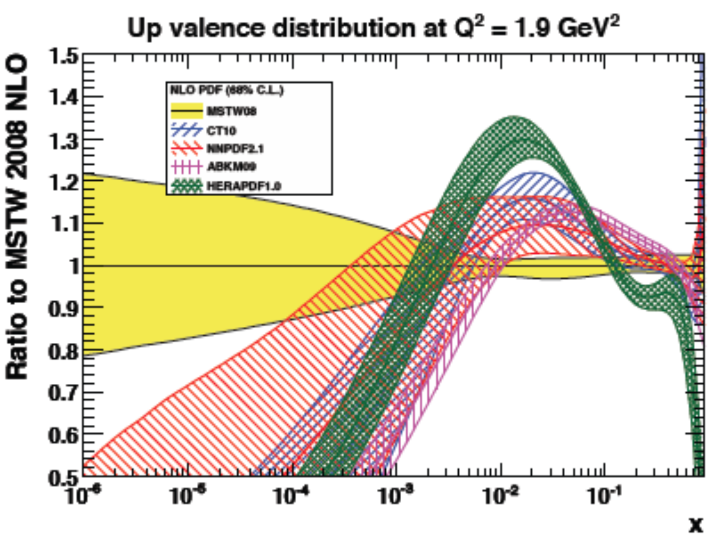


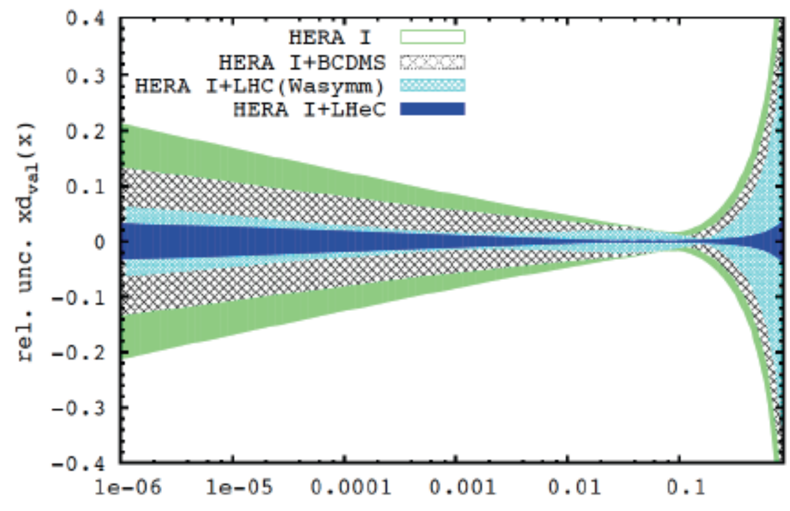
The gluon is unknown at low x and high x – QCD: non-linear evolution, resummation. BSM: hi M – HL-LHC!

Valence Quarks



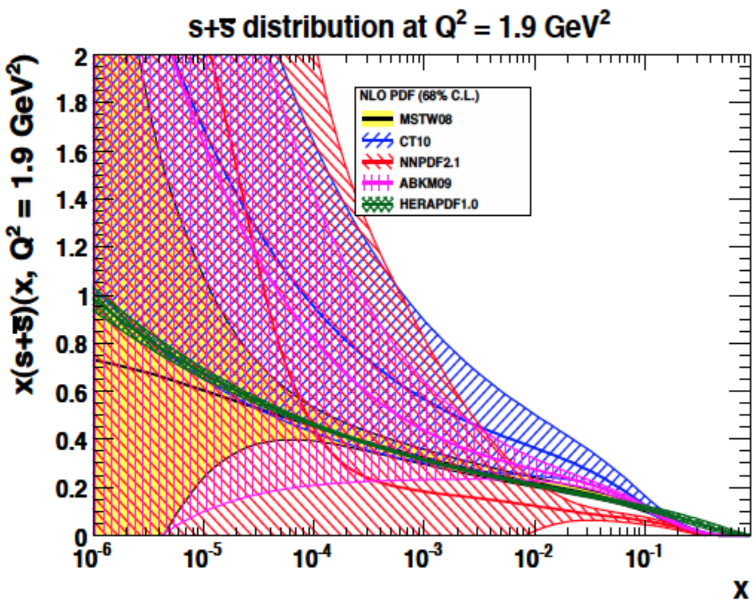


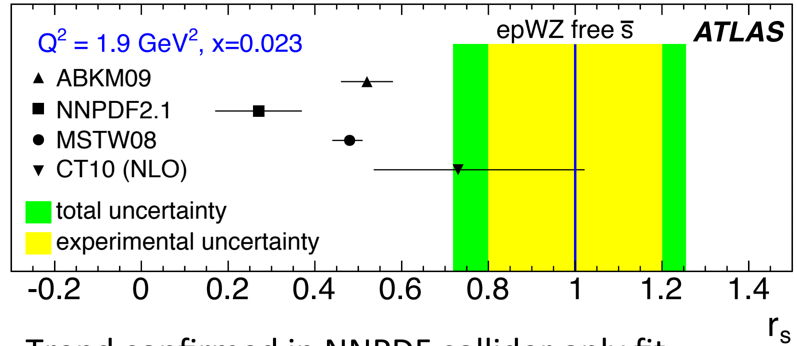




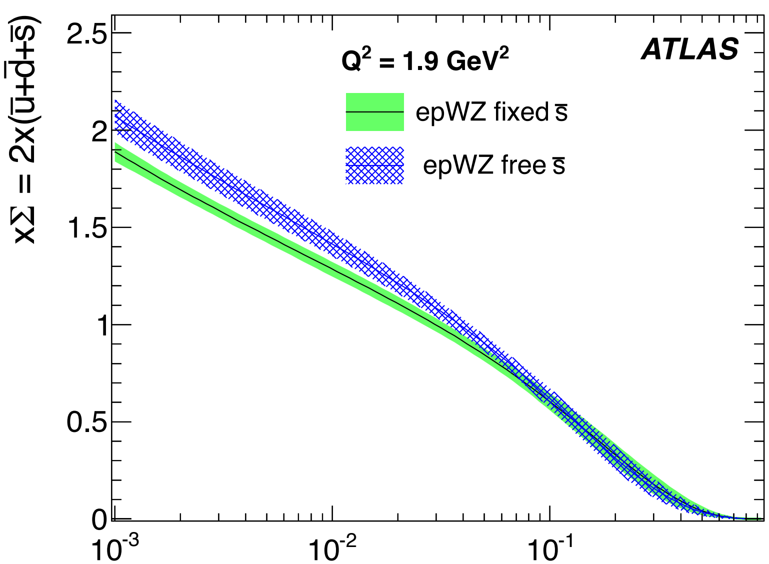
Long time to understand d/u. LHeC: free of higher twist and nuclear corrections, Q_V ??

Constraints on Strange Quark Distribution - LHC

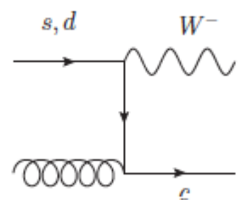




Trend confirmed in NNPDF collider only fit



Change of strange affects sea - UHE ν



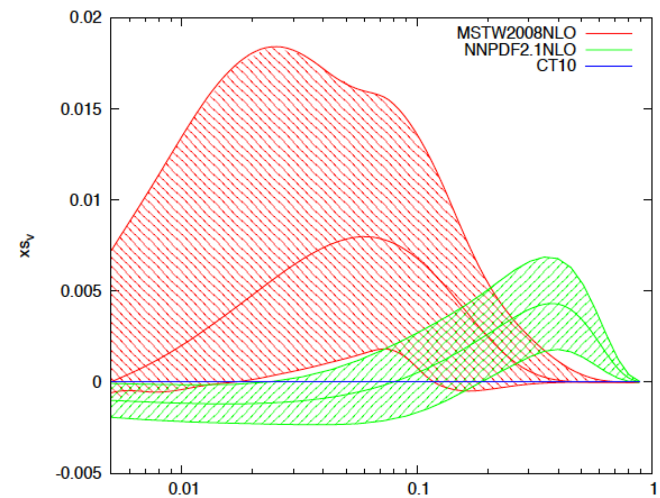
- Large non-perturbative effects to control
- Ratios (W+c/W+j)
- Use charges to access **valence strange**

Scale

$Q^2 = M^2_{W,Z}$

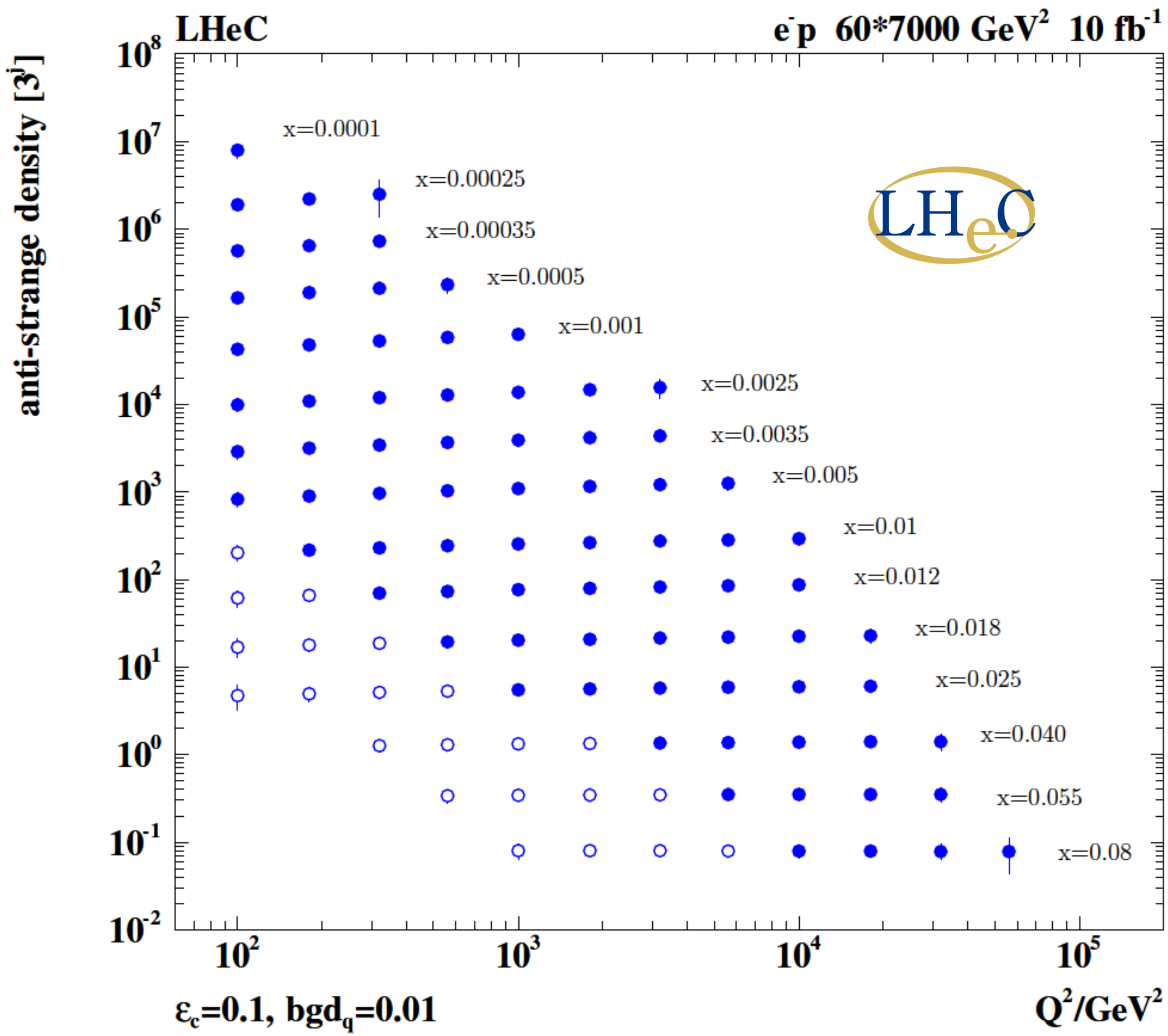
CMS:

PAS-EWK-11-03



W.Stirling, E.Vryonidou, Phys.Rev.Lett. 109 (2012) 082002

Strange Quark Distribution



High luminosity

High Q^2

Small beam spot

Modern Silicon

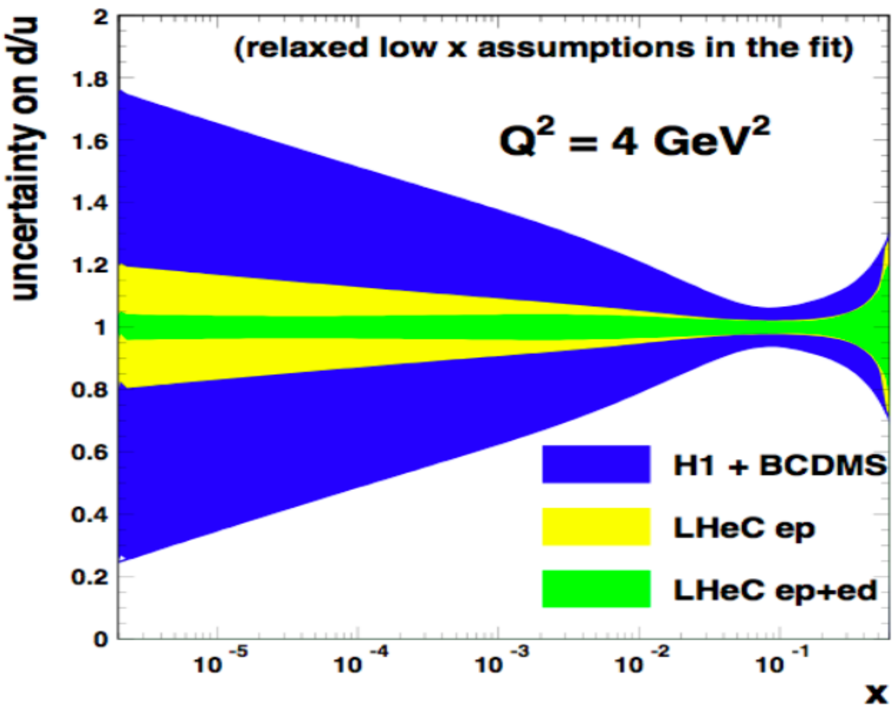
NO pile-up..

→ First (x,Q^2) Measurement of (anti-)strange density.
x 10^{-4} .. 0.05
Q^2 100 - 10^5

Initial study (CDR) Charm tagging efficiency of 10% and 1% light quark background in impact parameter

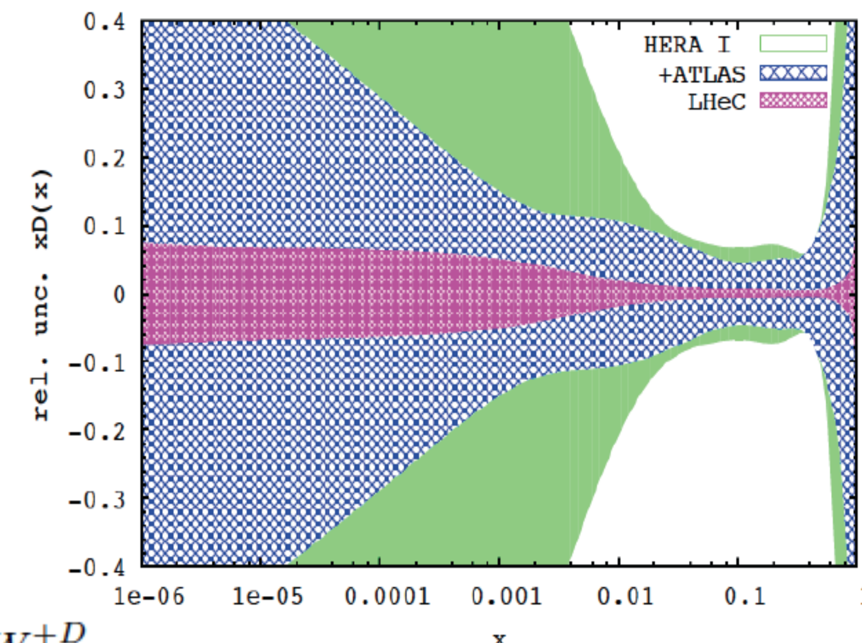
Deuterons and Light Sea Quark Asymmetry

d/u at low x from deuterons



D="total down" from LHeC (ep) fit with FREE d-u difference, including simulated high precision LHC W,Z

CDR

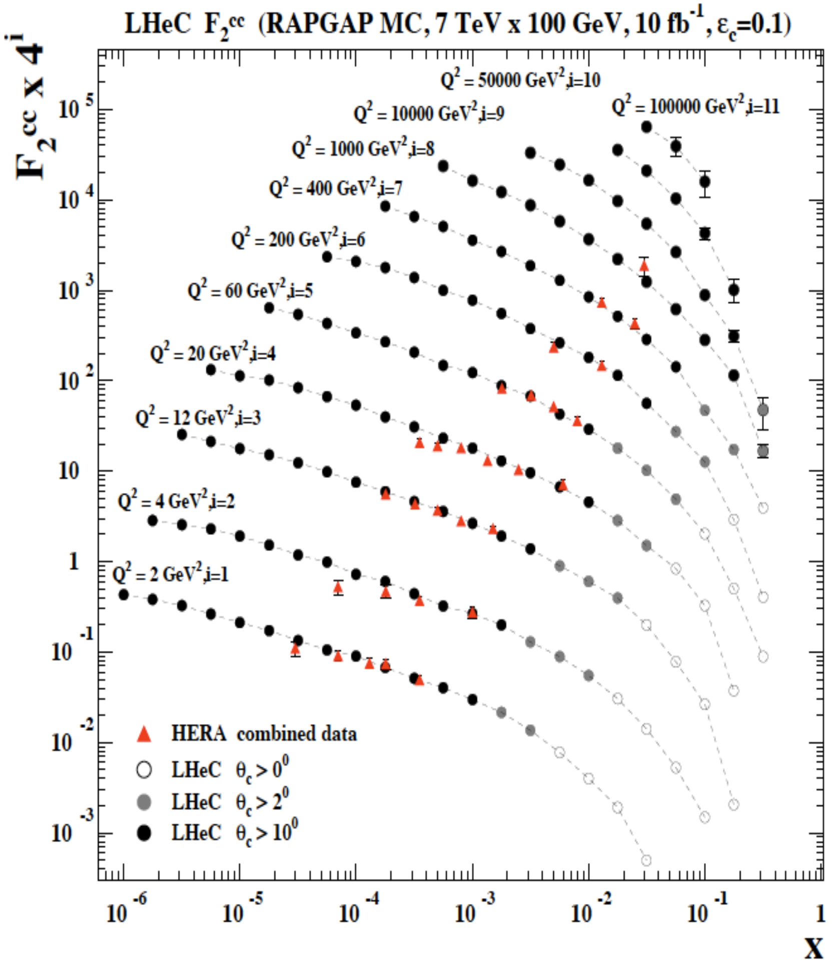


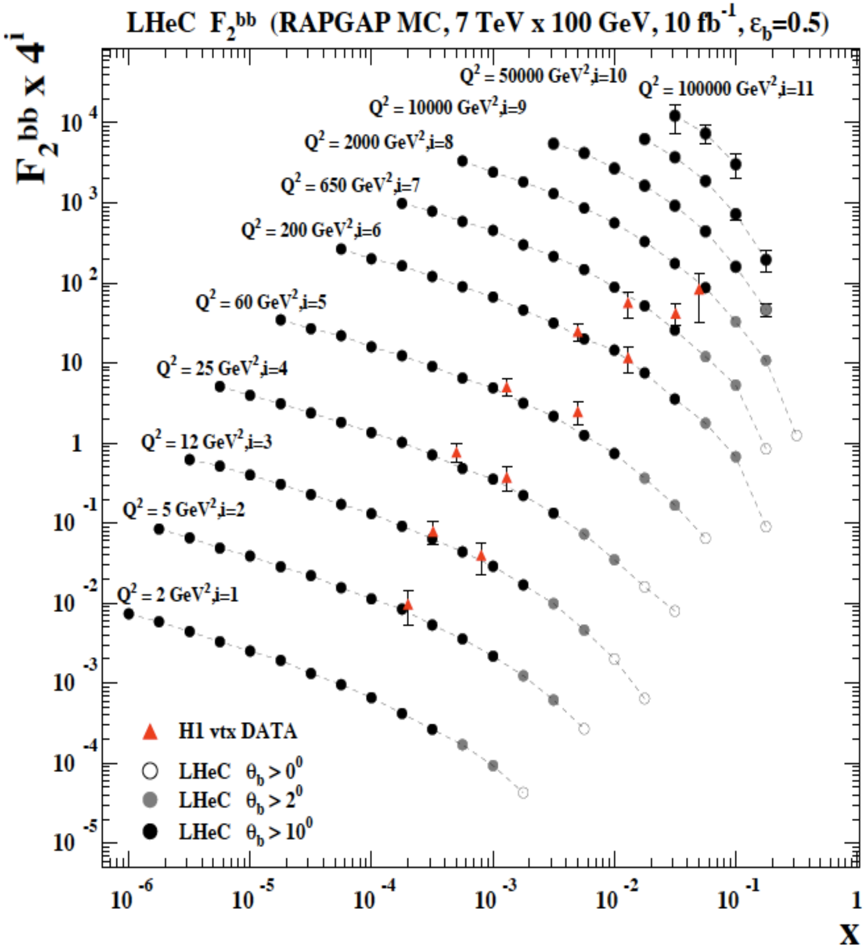
Deuterons: Crucial for
- NS-S decomposition
- Neutron structure
- Flavour separation

$$R^- = 2\frac{W_2^{-D} - W_2^{+D}}{W_2^{-p} + W_2^{+p}}$$

Nice: Gribov relation and spectator tagging to get rid off shadowing and Fermi motion!!

F_2^{charm} and F_2^{beauty} from LHeC



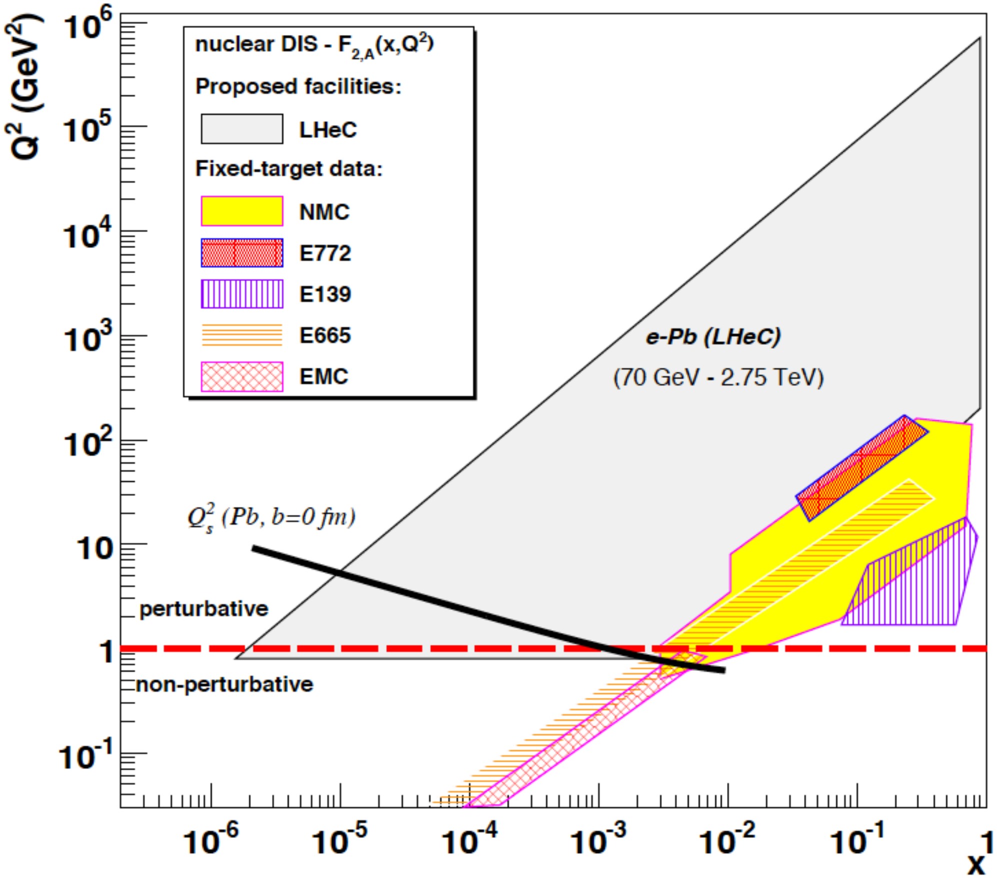


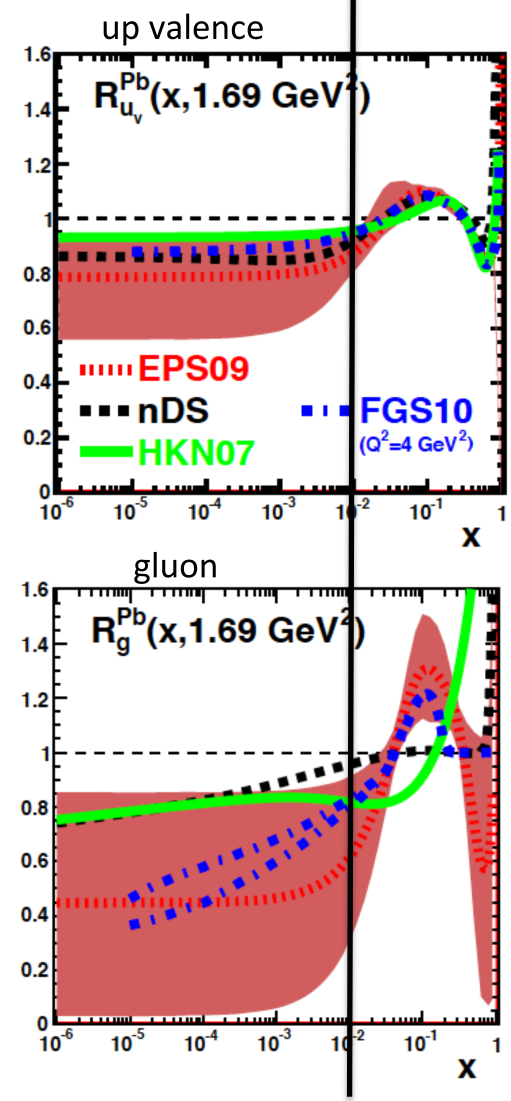
Hugely extended range and much improved precision (δM_c=60 HERA → 3 MeV)

will pin down heavy quark behaviour at and far away from thresholds, crucial for precision t,H..

In MSSM, Higgs is produced dominantly via bb → H (Pumplin et al) , but where is the MSSM..

Nuclear Parton Distributions





unmeasured | known?

eA physics is essentially not done yet (no eA at HERA!)
→ LHeC has huge discovery potential for new HI physics
(bb limit, saturation, deconfinement, hadronisation,QGP..)
and will put nPDFs on completely new ground

eRHIC/EIC would be an important step beyond fixed targets..

Examples for LHC-LHeC Relations*)

Higgs, Strong Coupling, SUSY, Contact Interactions

Why Precision? J. Blümlein arXiv:1205.4991

*) LHeC CDR and arXiv:1211:5102 and extensions

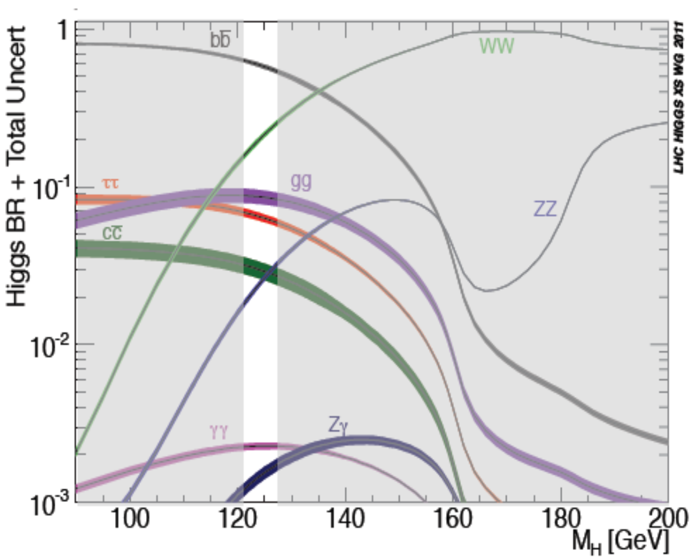
Higgs and LHeC

Precision measurements of couplings **in WW and ZZ production** (CDR: bb study in CC)
Measurement of CP properties ($J^{PC}=0^{++}$ in SM; MSSM has 2 CP-even and 1 CP-odd states)

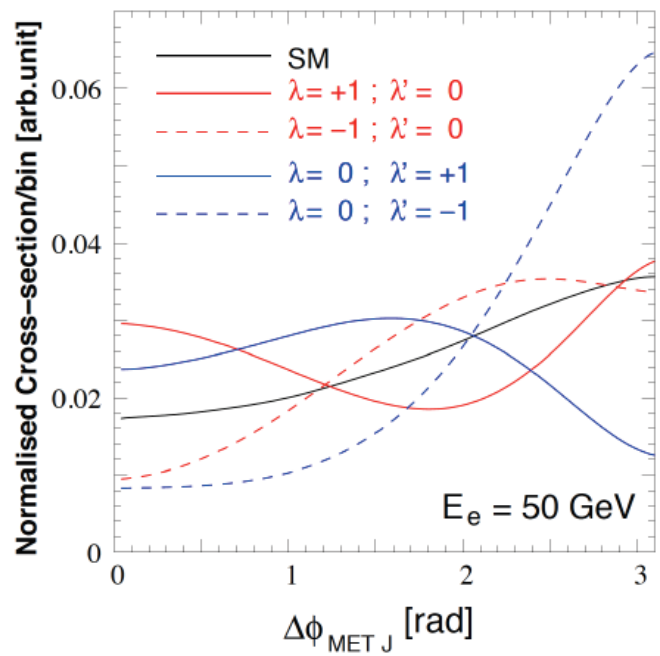
First LHeC Higgs study: WW → H → bb

PGS for detector, cut based analysis, S/B =1, 500 H-bb events for $100fb^{-1}$
→ **2-3% H-bb coupling precision**

thy corrections small:
J.Blümlein et al, NP B395(1993)35

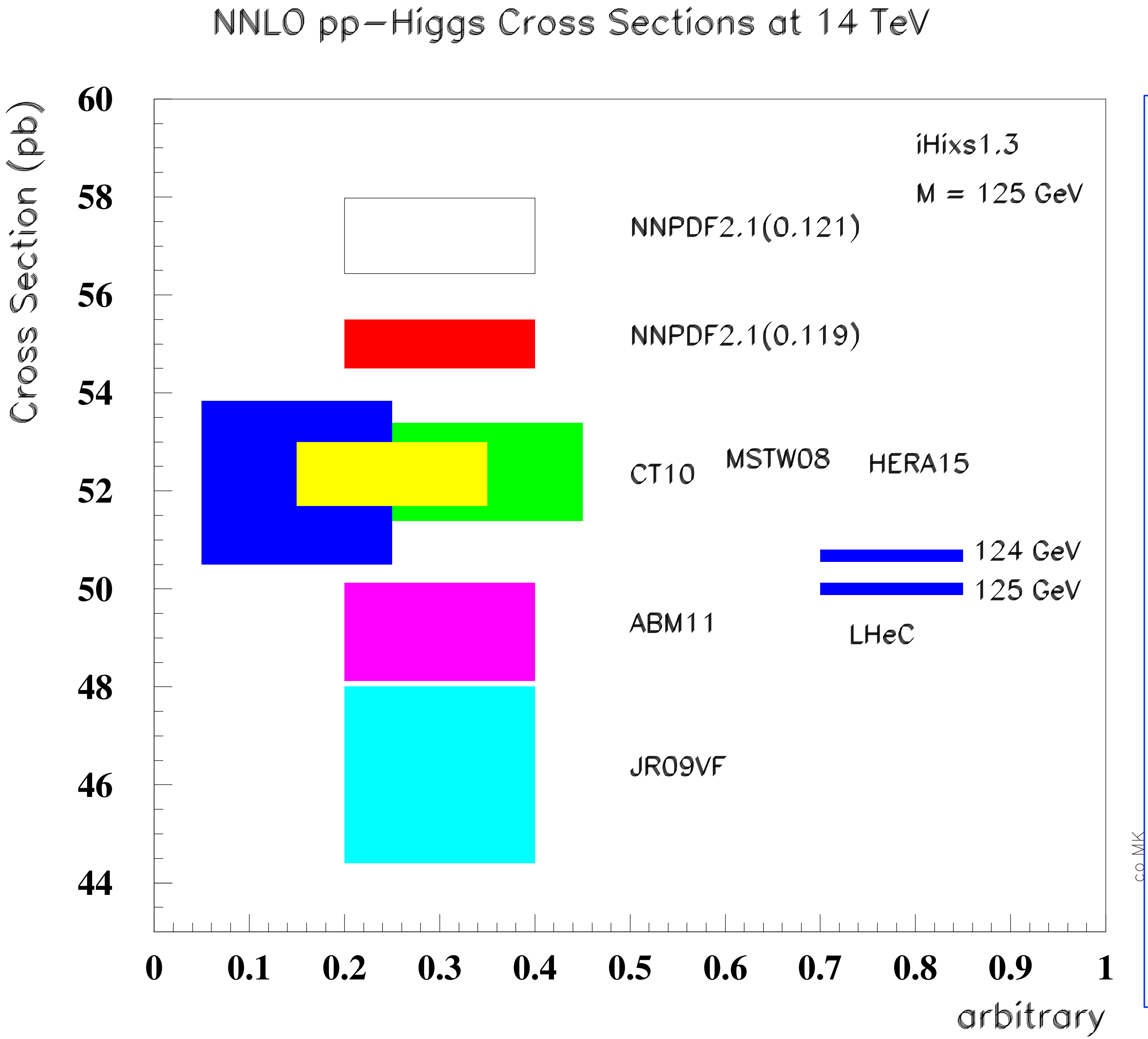


$$\Gamma^{(\mathrm{BSM})}_{\mu\nu}(p,q) = \frac{-g}{M_W}\left[\lambda\,(p.q\,g_{\mu\nu} - p_\nu q_\mu) + i\,\lambda'\,\epsilon_{\mu\nu\rho\sigma}p^\rho q^\sigma\right]$$



ICHEP12: J Campbell: ultimate limitation of Higgs measurements from LHC by PDFs/QCD →

With high luminosity the LHeC has a huge potential for precision Higgs physics, which is being further evaluated.



Exp uncertainty of LHeC Higgs cross section is 0.25% (sys+sta), using LHeC only.

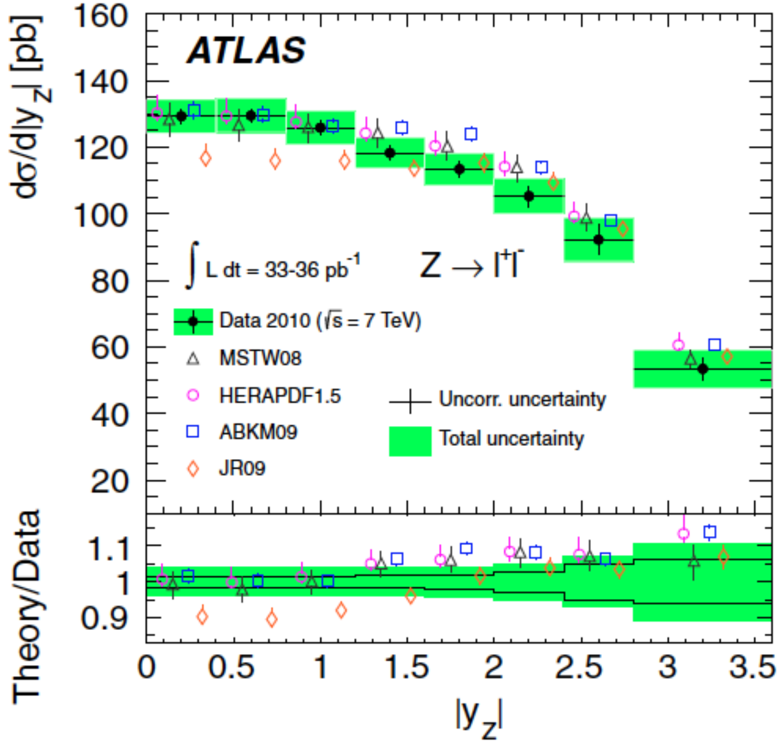
Leads to mass sensitivity..

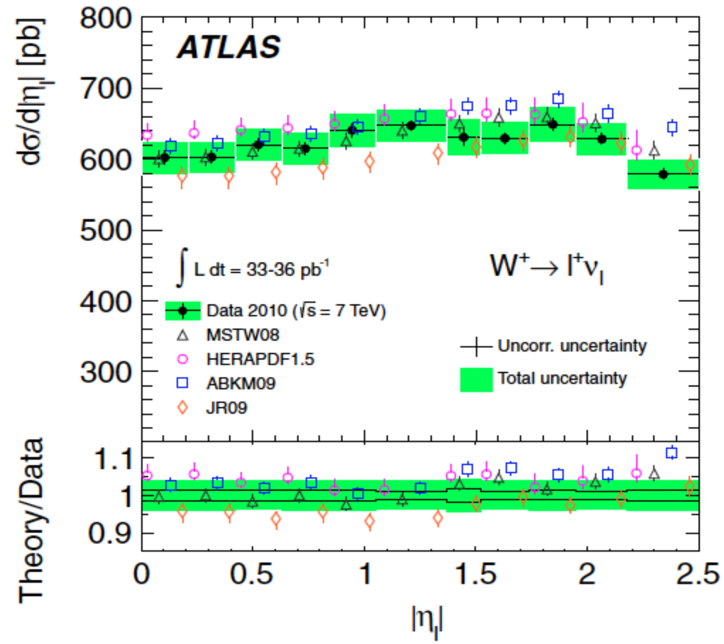
Strong coupling underlying parameter (0.005 – 10%). LHeC – nxt slide

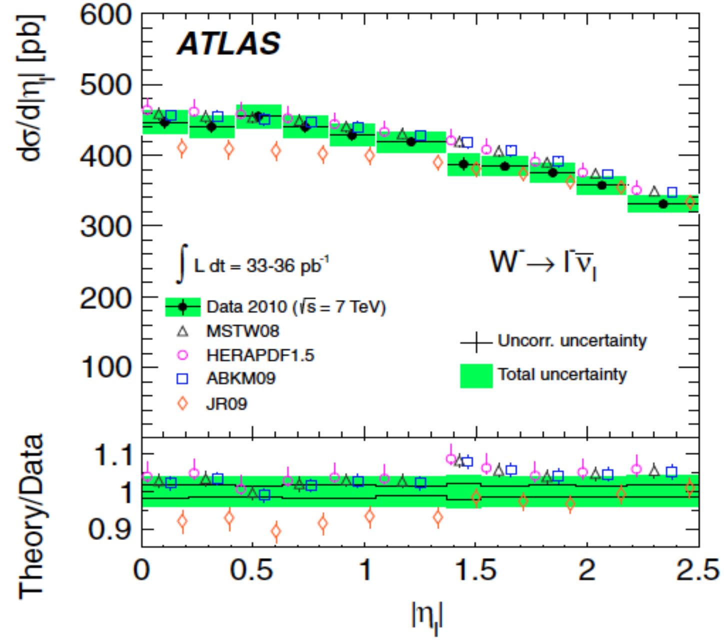
HQ treatment important – LHeC precision!

PRECISION σ(H)

W,Z at the LHC







Constraints from precision W,Z LHC data

For example JR09 a bit low. New data to come. Extraordinary requirement for precision as the measurement is at high Q^2.

2010 data have lead to the suggestion of an unsuppressed strange sea vs anti-down ..

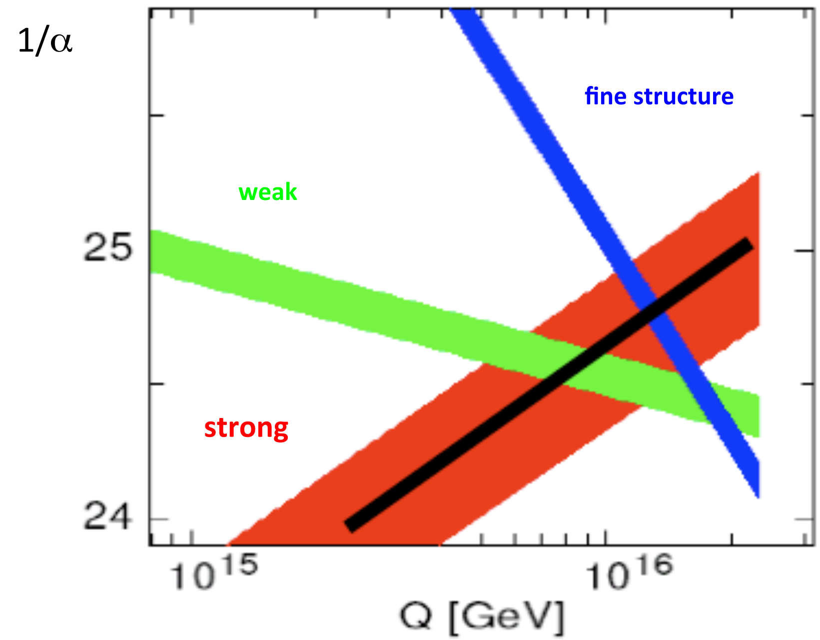
Strong Coupling Constant

α_s least known of coupling constants
Grand Unification predictions suffer from $\delta\alpha_s$

DIS tends to be lower than world average (?)

LHeC: per mille - independent of BCDMS.

Challenge to experiment and to h.o. QCD →
A genuine DIS research programme rather than one outstanding measurement only.

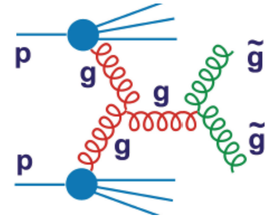


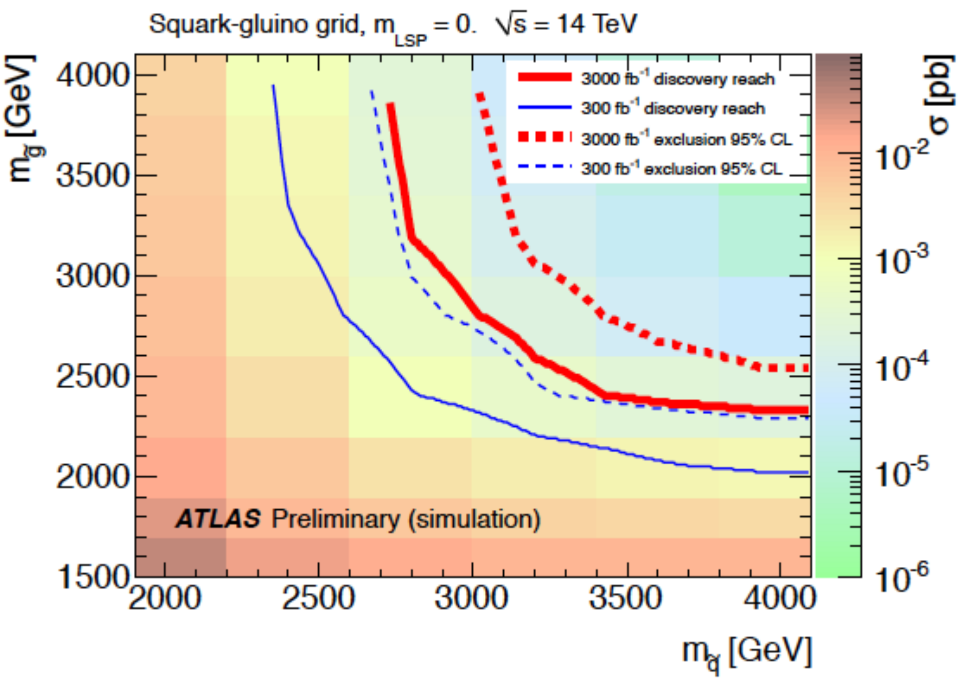
case	cut [Q^2 in GeV^2]	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.17
LHeC only (14p)	$Q^2 > 20.$	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.20
LHeC+HERA (10p)	$Q^2 > 10.$	0.26

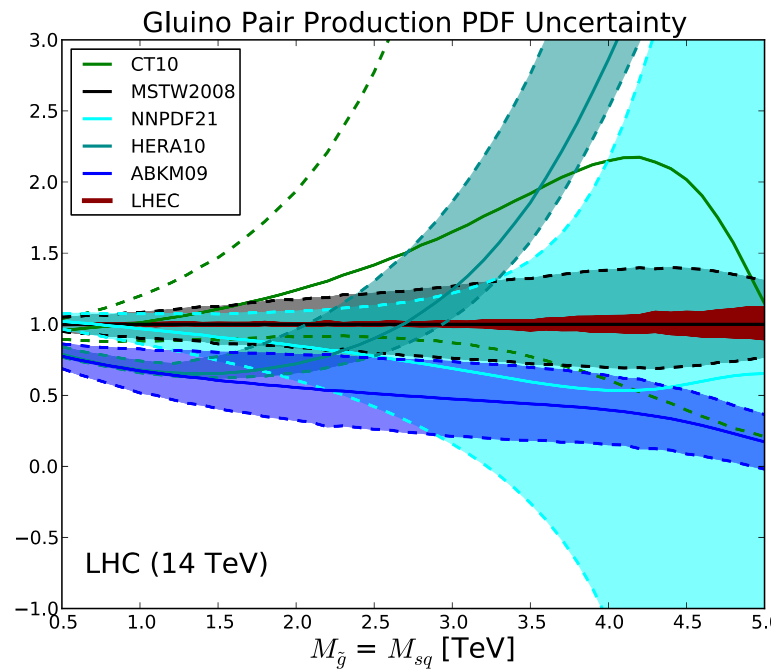
Two independent QCD analyses using LHeC+HERA/BCDMS

DATA	exp. error on α_s
NC e^+ only	0.48%
NC	0.41%
NC & CC	**0.23% :=(1)**
(1) $\gamma_h > 5°$	0.36% :=(2)
(1) +BCDMS	0.22%
(2) +BCDMS	0.22%
(1) stat. *= 2	0.35%

Searching for High Mass SUSY

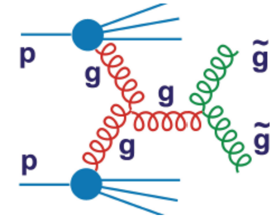


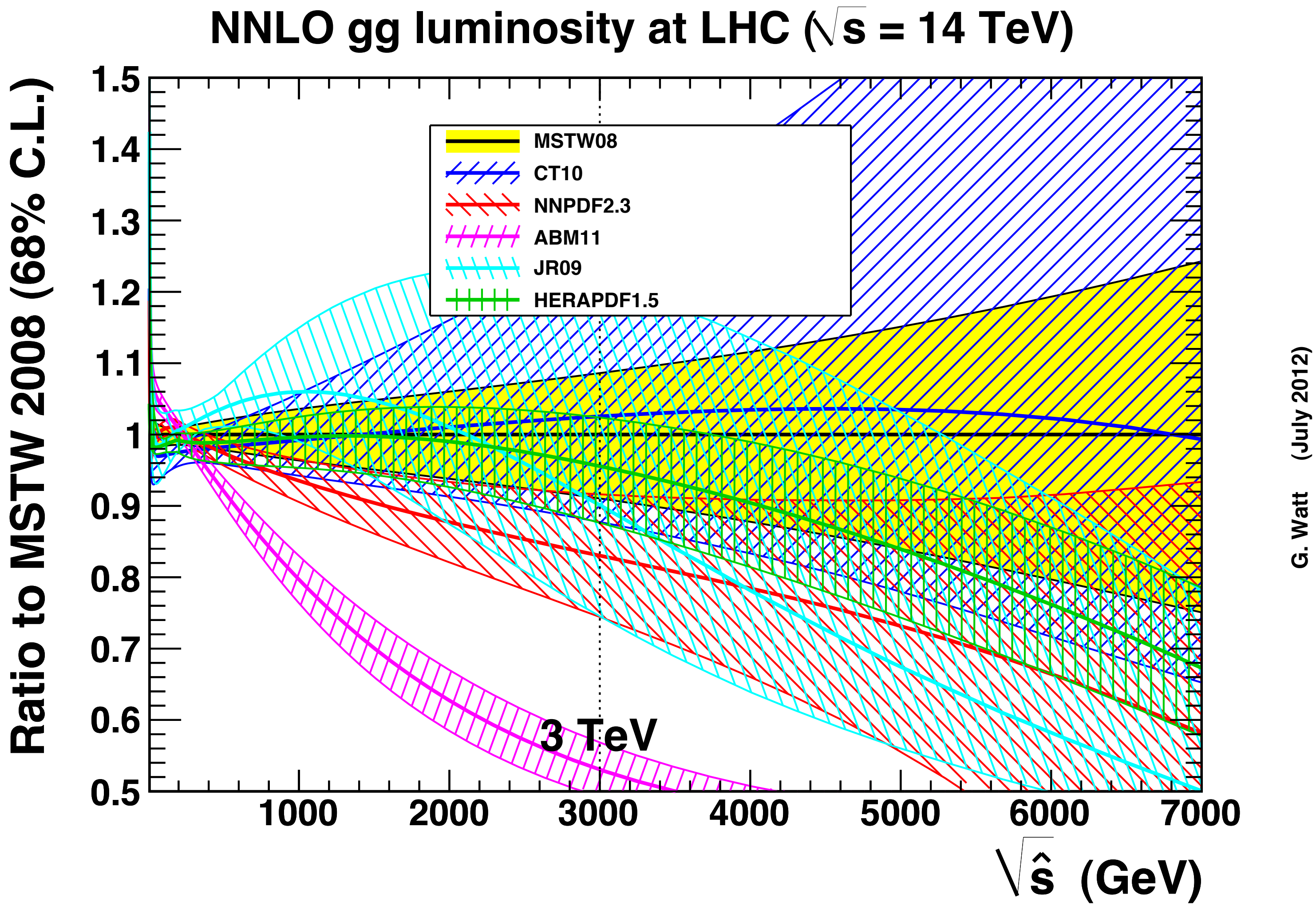




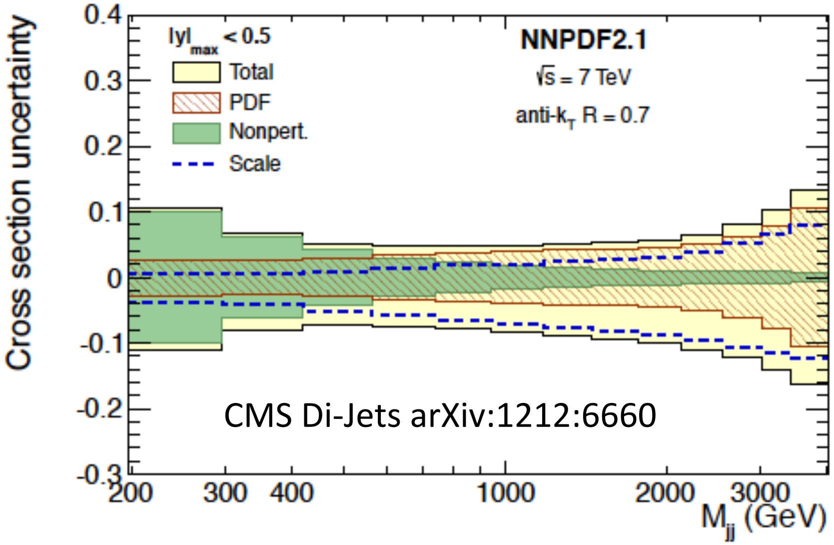
With high energy and luminosity, the LHC search range will be extended to high masses, up to ~5 TeV in pair production, and PDF uncertainties come in ~ 1/(1-x).

Gluon-Gluon Luminosity





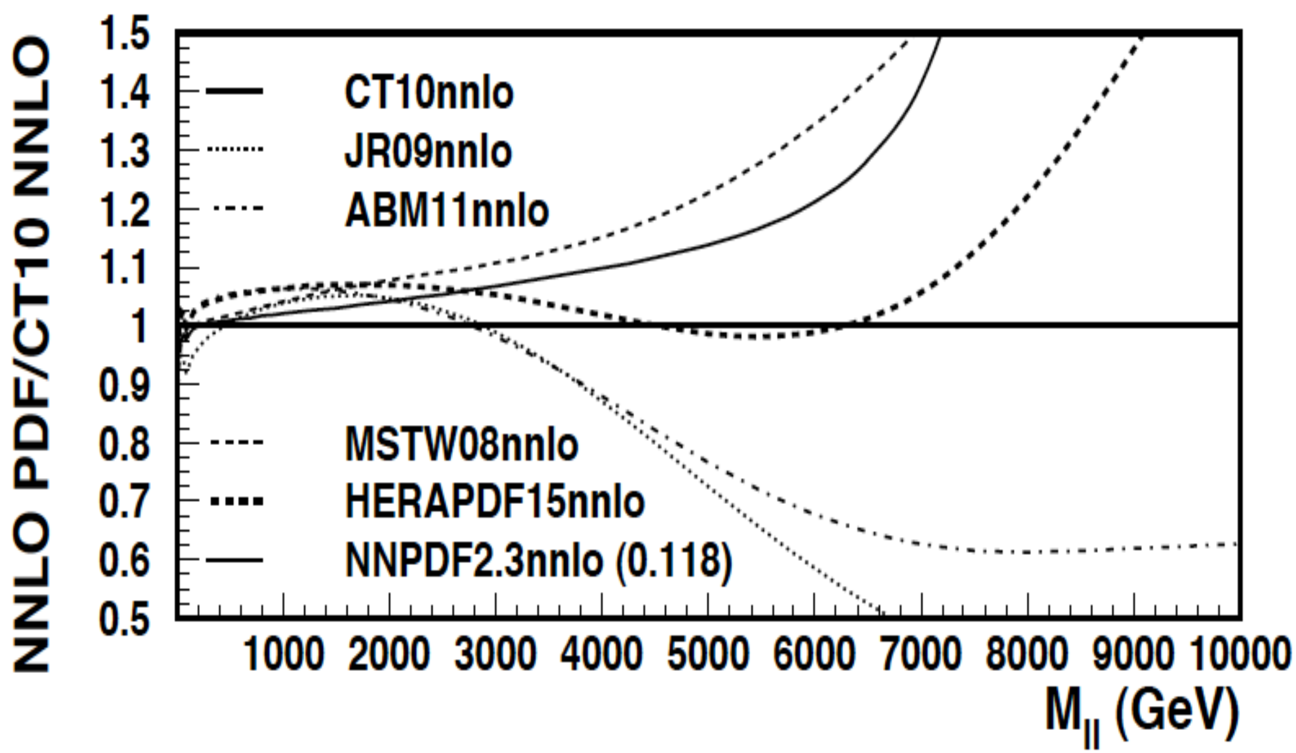
High Mass Drell Yan



Towards high mass the PDF uncertainties rise, dramatically towards the edge (√s) $x \to 1$…

Expected LHeC uncertainty being calculated

14 TeV, VRAP L.Dixon et al, U.Klein



For HL-LHC:
Need to study limits in context with energy calibrations, and thy uncertainties, + PDFs vs BSM expectations

Few Concluding Remarks

The LHeC is a challenging but realistic project with many attractive features in its physics programme, its accelerator and detector developments.

The LHeC development goes ahead towards key component design, an ERL test facility at CERN and the formation of a detector Collaboration.

It is desirable (and has been suggested also by ECFA) that the relation of this ep/eA collider to the LHC programme be studied more thoroughly.

This requires to both evaluate the LHC (pp, pA and AA) future potential, and the LHeC and their combination (as for the precision Higgs physics with the LHC *facility*) deeper than hitherto. The first simulations point to important and possibly crucial relations, as the LHC leaves x ~ 0.01..

The LHeC potential is being further evaluated (increased luminosity, comprehensive detector simulation, independent ep/A physics, etc.).

For the PDFs, the LHeC is a truly exciting prospect, not 'just' for precision but for releasing the constraints, nuclei .. and thus accessing the unknown.

In this endeavo(u)r, an intense collaboration of exp + theory is vital for the future for deep inelastic scattering at the energy frontier - with the LHC.

http://cern.ch/lhec

J.L.Abelleira Fernandez[16,23], C.Adolphsen[57], P.Adzic[74], A.N.Akay[03], H.Aksakal[39], J.L.Albacete[52], B.Allanach[73], S.Alekhin[17,54], P.Allport[24], V.Andreev[34], R.B.Appleby[14,30], E.Arikan[39], N.Armesto[53,a], G.Azuelos[33,64], M.Bai[37], D.Barber[14,17,24], J.Bartels[18], O.Behnke[17], J.Behr[17], A.S.Belyaev[15,56], I.Ben-Zvi[37], N.Bernard[25], S.Bertolucci[16], S.Bettoni[16], S.Biswal[41], J.Blümlein[17], H.Böttcher[17], A.Bogacz[36], C.Bracco[16], J.Bracinik[06], G.Brandt[44], H.Braun[65], S.Brodsky[57,b], O.Brüning[16], E.Bulyak[12], A.Buniatyan[17], H.Burkhardt[16], I.T.Cakir[02], O.Cakir[01], R.Calaga[16], A.Caldwell[70], V.Cetinkaya[01], V.Chekelian[70], E.Ciapala[16], R.Ciftci[01], A.K.Ciftci[01], B.A.Cole[38], J.C.Collins[48], O.Dadoun[42], J.Dainton[24], A.De.Roeck[16], D.d'Enterria[16], P.DiNezza[72], M.D'Onofrio[24], A.Dudarev[16], A.Eide[60], R.Enberg[63], E.Eroglu[62], K.J.Eskola[21], L.Favart[08], M.Fitterer[16], S.Forte[32], A.Gaddi[16], P.Gambino[59], H.García Morales[16], T.Gehrmann[69], P.Gladkikh[12], C.Glasman[28], A.Glazov[17], R.Godbole[35], B.Goddard[16], T.Greenshaw[24], A.Guffanti[13], V.Guzey[19,36], C.Gwenlan[44], T.Han[50], Y.Hao[37], F.Haug[16], W.Herr[16], A.Hervé[27], B.J.Holzer[16], M.Ishitsuka[58], M.Jacquet[42], B.Jeanneret[16], E.Jensen[16], J.M.Jimenez[16], J.M.Jowett[16], H.Jung[17], H.Karadeniz[02], D.Kayran[37], A.Kilic[62], K.Kimura[58], R.Klees[75], M.Klein[24], U.Klein[24], T.Kluge[24], F.Kocak[62], M.Korostelev[24], A.Kosmicki[16], P.Kostka[17], H.Kowalski[17], M.Kraemer[75], G.Kramer[18], D.Kuchler[16], M.Kuze[58], T.Lappi[21,c], P.Laycock[24], E.Levichev[40], S.Levonian[17], V.N.Litvinenko[37], A.Lombardi[16], J.Maeda[58], C.Marquet[16], B.Mellado[27], K.H.Mess[16], A.Milanese[16], J.G.Milhano[76], S.Moch[17], I.I.Morozov[40], Y.Muttoni[16], S.Myers[16], S.Nandi[55], Z.Nergiz[39], P.R.Newman[06], T.Omori[61], J.Osborne[16], E.Paoloni[49], Y.Papaphilippou[16], C.Pascaud[42], H.Paukkunen[53], E.Perez[16], T.Pieloni[23], E.Pilicer[62], B.Pire[45], R.Placakyte[17], A.Polini[07], V.Ptitsyn[37], Y.Pupkov[40], V.Radescu[17], S.Raychaudhuri[35], L.Rinolfi[16], E.Rizvi[71], R.Rohini[35], J.Rojo[16,31], S.Russenschuck[16], M.Sahin[03], C.A.Salgado[53,a], K.Sampei[58], R.Sassot[09], E.Sauvan[04], M.Schaefer[75], U.Schneekloth[17], T.Schörner-Sadenius[17], D.Schulte[16], A.Senol[22], A.Seryi[44], P.Sievers[16], A.N.Skrinsky[40], W.Smith[27], D.South[17], H.Spiesberger[29], A.M.Stasto[48,d], M.Strikman[48], M.Sullivan[57], S.Sultansoy[03,e], Y.P.Sun[57], B.Surrow[11], L.Szymanowski[66,f], P.Taels[05], I.Tapan[62], T.Tasci[22], E.Tassi[10], H.Ten.Kate[16], J.Terron[28], H.Thiesen[16], L.Thompson[14,30], P.Thompson[06], K.Tokushuku[61], R.Tomás García[16], D.Tommasini[16], D.Trbojevic[37], N.Tsoupas[37], J.Tuckmantel[16], S.Turkoz[01], T.N.Trinh[47], K.Tywoniuk[26], G.Unel[20], T.Ullrich[37], J.Urakawa[61], P.VanMechelen[05], A.Variola[52], R.Veness[16], A.Vivoli[16], P.Vobly[40], J.Wagner[66], R.Wallny[68], S.Wallon[43,46,f], G.Watt[69], C.Weiss[36], U.A.Wiedemann[16], U.Wienands[57], F.Willeke[37], B.-W.Xiao[48], V.Yakimenko[37], A.F.Zarnecki[67], Z.Zhang[42], F.Zimmermann[16], R.Zlebcik[51], F.Zomer[42]

Present LHeC Study group and CDR authors

About 200 Experimentalists and Theorists from 76 Institutes

Supported by
CERN, ECFA, NuPECC

backup

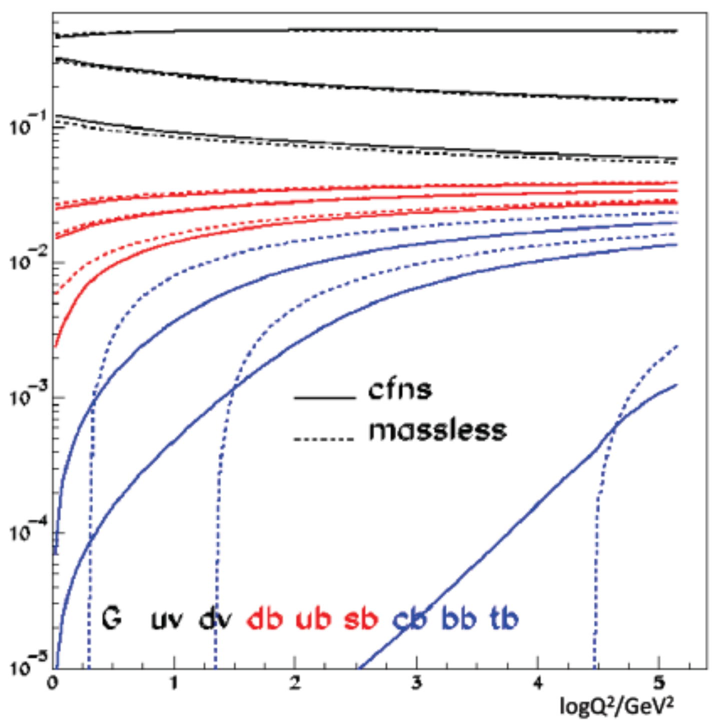
Strong Coupling Determinations

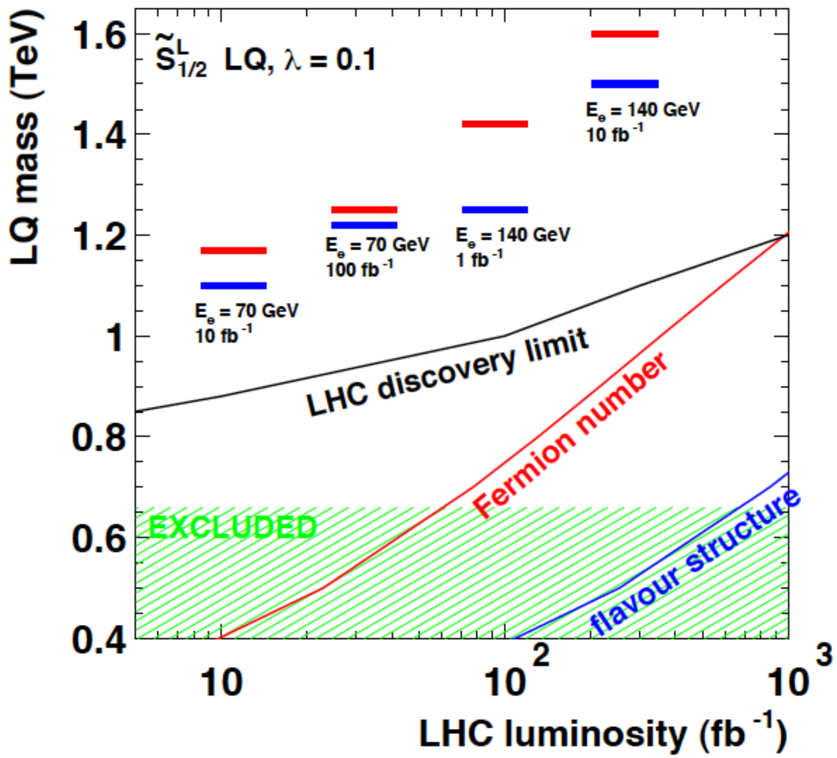
	$\alpha_s(M_Z)$	
BBG	$0.1134\ ^{+\ 0.0019}_{-\ 0.0021}$	valence analysis, NNLO [235, 236]
BB	0.1132 ± 0.0022	valence analysis, NNLO [237]
GRS	0.112	valence analysis, NNLO [238]
ABKM	0.1135 ± 0.0014	HQ: FFNS $n_f = 3$ [228]
ABKM	0.1129 ± 0.0014	HQ: BSMN-approach [228]
JR	0.1124 ± 0.0020	dynamical approach [231]
JR	0.1158 ± 0.0035	standard fit [231]
ABM11	0.1134 ± 0.0011	[229]
MSTW	0.1171 ± 0.0014	[239]
NN21	0.1173 ± 0.0007	[233]
CT10	0.118 ± 0.005	[240]
Gehrmann et al.	$0.1153 \pm 0.0017 \pm 0.0023$	e^+e^- thrust [241]
Abbate et al.	$0.1135 \pm 0.0011 \pm 0.0006$	e^+e^- thrust [242]
3 jet rate	0.1175 ± 0.0025	Dissertori et al. 2009 [243]
Z-decay	0.1189 ± 0.0026	BCK 2008/12 (N^3LO) [121, 244]
τ decay	0.1212 ± 0.0019	BCK 2008 [244]
τ decay	0.1204 ± 0.0016	Pich 2011 [20]
τ decay	0.1180 ± 0.0008	Beneke, Jamin 2008 [245]
lattice	0.1205 ± 0.0010	PACS-CS 2009 (2+1 fl.) [246]
lattice	0.1184 ± 0.0006	HPQCD 2010 [247]
lattice	0.1200 ± 0.0014	ETM 2012 (2+1+1 fl.) [248]
BBG	$0.1141\ ^{+\ 0.0020}_{-\ 0.0022}$	valence analysis, $N^3LO(*)$ [235]
BB	0.1137 ± 0.0022	valence analysis, $N^3LO(*)$ [237]
world average	0.1184 ± 0.0007	[249] (2009)
	0.1183 ± 0.0010	[20] (2011)

Table 1: Summary of recent NNLO QCD analyses of the DIS world data, supplemented by related measurements using other processes; from [229].

Top Quark and Leptoquarks

The LHeC is a (single) top quark production factory, via Wb → t. Top was never observed in DIS. With ep: top-PDF → 6 flavour VFNS, precision M_t direct and from cross section, anomalous couplings

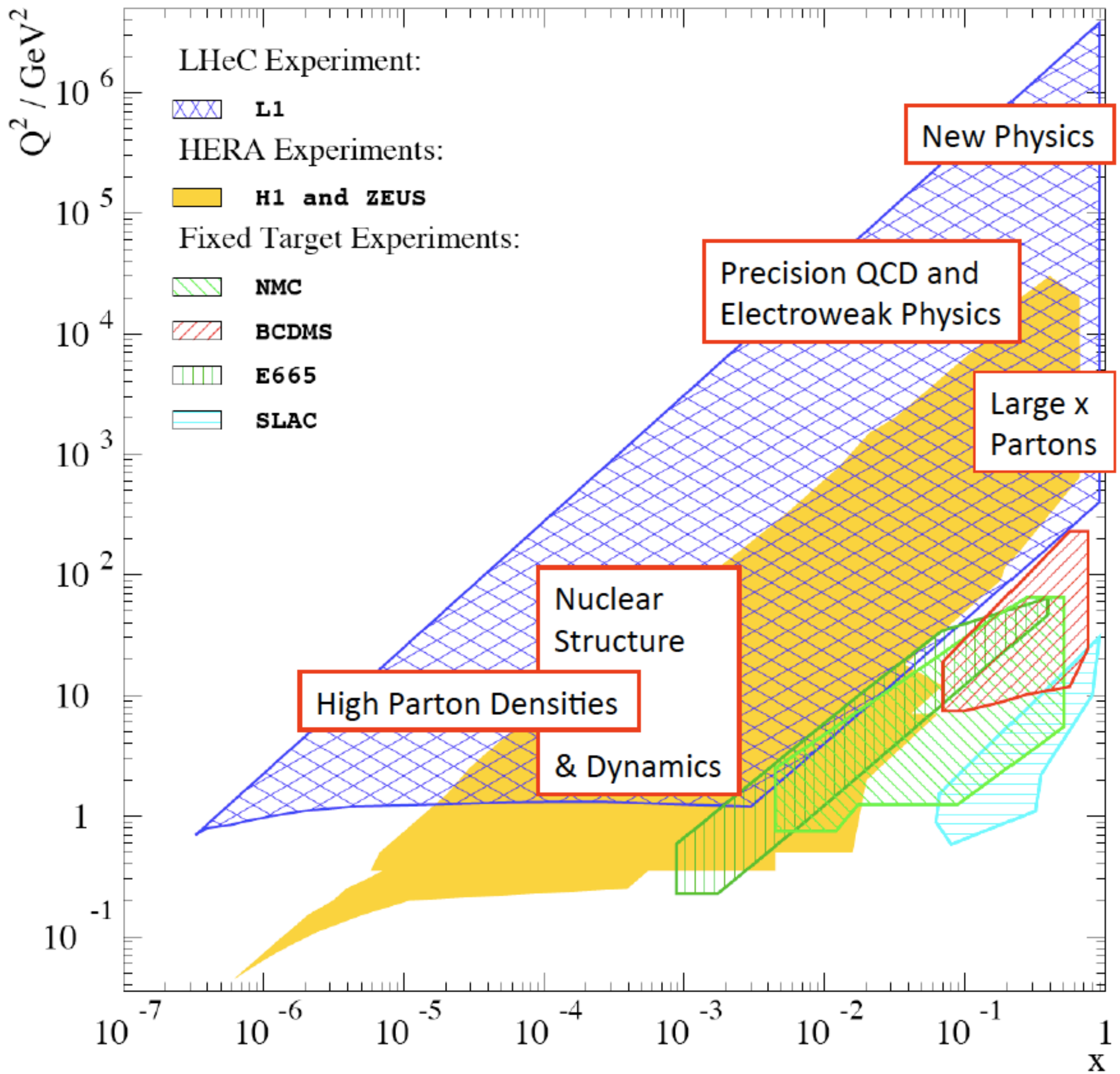




Leptoquarks (-gluons) are predicted in RPV SUSY, E6, extended technicolour theories or Pati-Salam.

The LHeC is the appropriate configuration to do their spectroscopy, should they be discovered at the LHC.

Deep Inelastic e/μ p Scattering



What HERA could not do or has not done

HERA in one box
the first ep collider

$E_p * E_e =$
$920 * 27.6 GeV^2$
$\sqrt{s} = 2\sqrt{E_e E_p} = 320$ GeV

$L = 1..4\ 10^{31} cm^{-2} s^{-1}$
→ $\Sigma L = 0.5 fb^{-1}$
1992-2000 & 2003-2007

$Q^2 = [0.1 -- 3 * 10^4]\ GeV^2$
-4-momentum transfer^2

$x = Q^2/(sy) \cong 10^{-4} .. 0.7$
Bjorken x

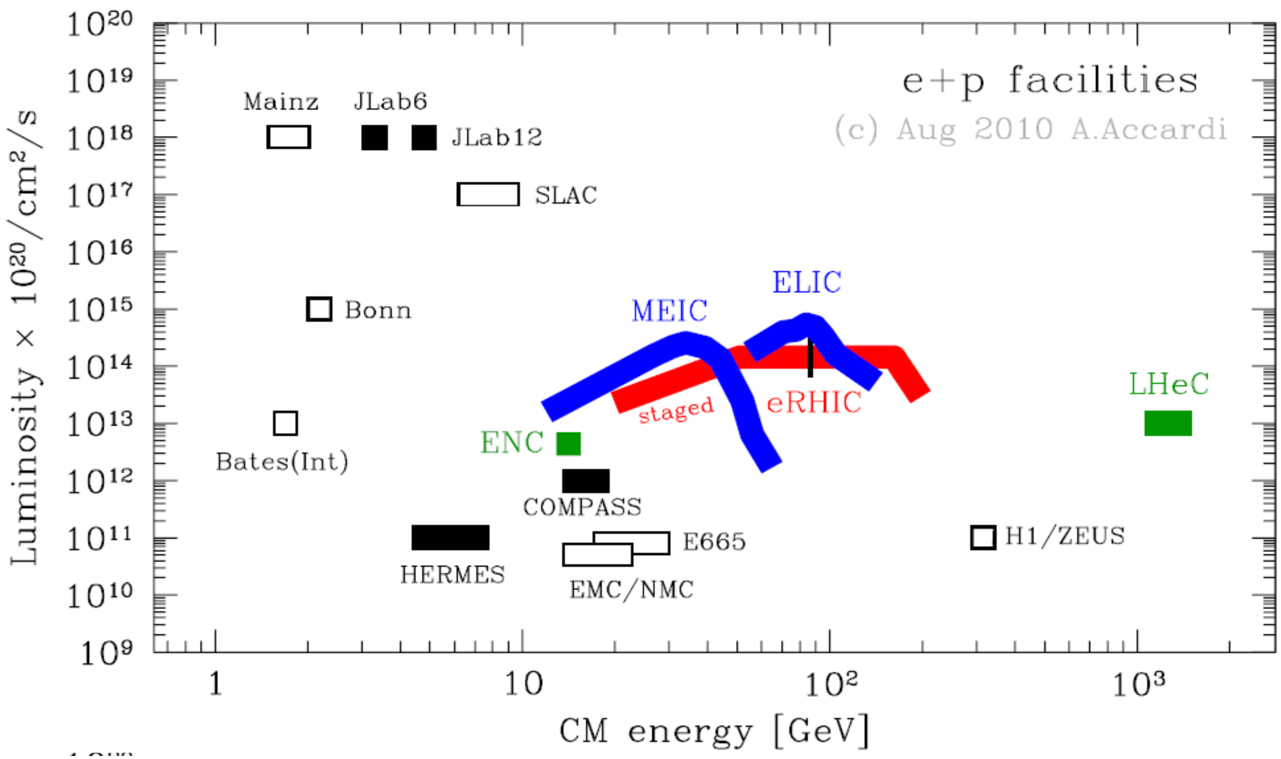
$y \cong 0.005 .. 0.9$
inelasticity

Test of **the isospin symmetry** (u-d) with eD - no deuterons
Investigation of the q-g dynamics in **nuclei** - no time for eA
Verification of **saturation** prediction at low x – too low s
Measurement of the **strange** quark distribution – too low L
Discovery of **Higgs** in WW fusion in CC – too low cross section
Study of **top** quark distribution in the proton – too low s
Precise measurement of **F_L** – too short running time left
Resolving d/u question at **large Bjorken x** – too low L
Determination of **gluon distribution at hi/lo x** – too small range
High precision measurement of **α_s** – overall not precise enough
Discovering **instantons, odderons** – don't know why not
Finding **RPV SUSY** and/or leptoquarks – may reside higher up
…

The H1 and ZEUS apparatus were basically well suited
The machine had too low luminosity and running time

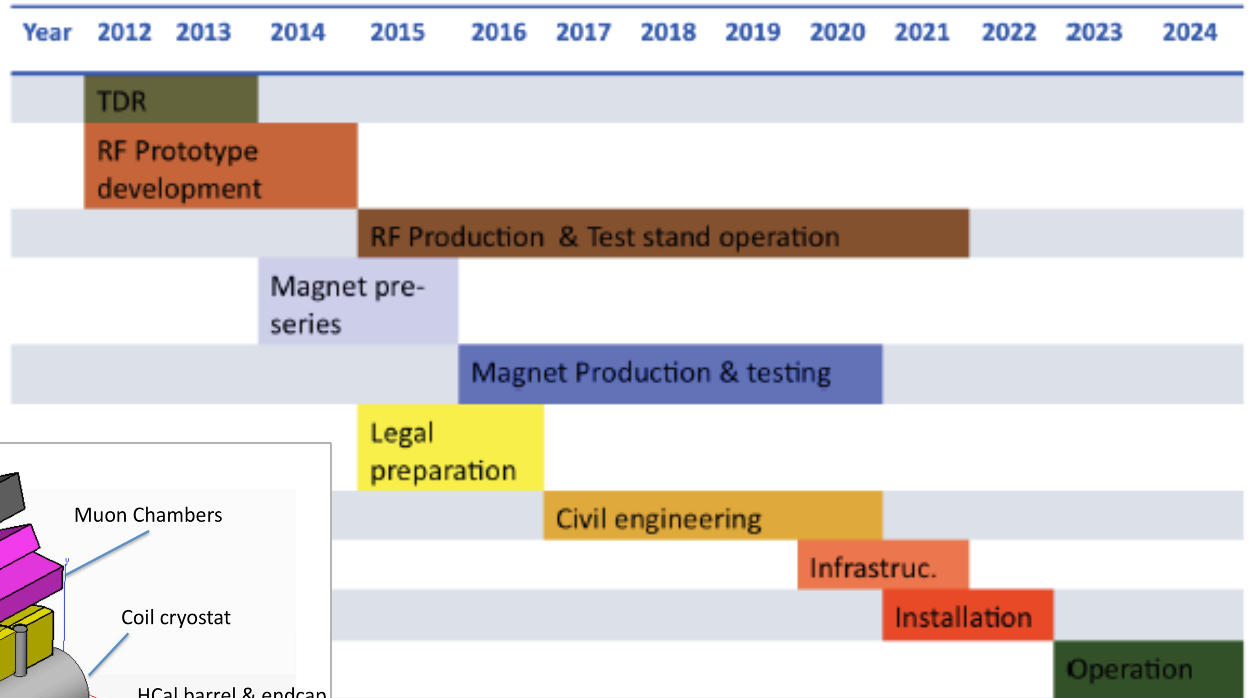
HEP needs a TeV energy scale machine with 100 times higher luminosity than HERA to develop DIS physics further and to complement the physics at the LHC. The **Large Hadron Collider p and A beams offer a unique opportunity to build a second ep and first eA collider** at the energy frontier [discussed at DIS since Madison 2005]

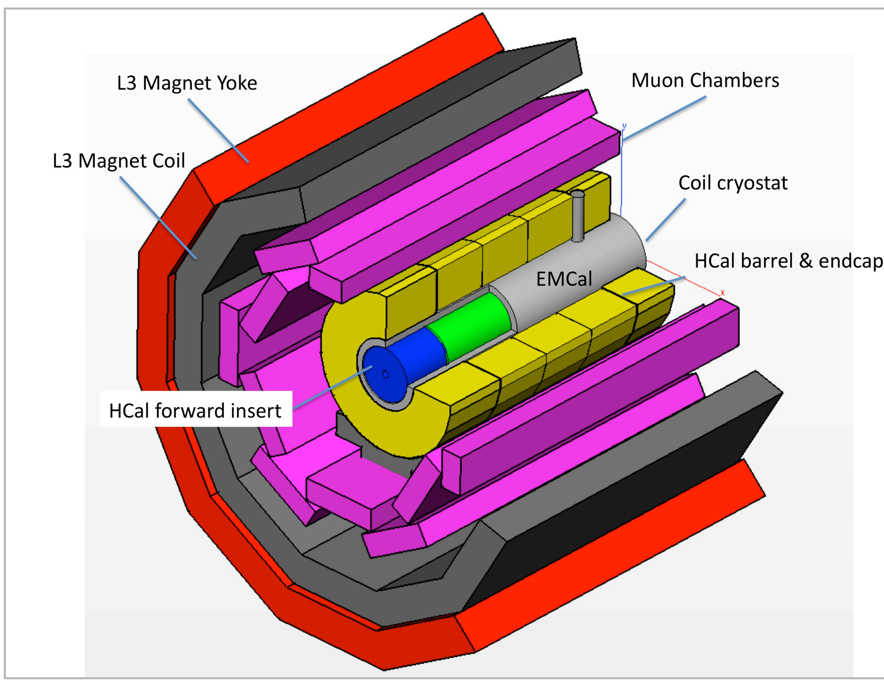
EIC


e+p facilities
(c) Aug 2010 A.Accardi
Luminosity × 10^{20}/cm²/s
CM energy [GeV]
Mainz
JLab6
JLab12
SLAC
Bonn
Bates(Int)
HERMES
COMPASS
ENC
E665
EMC/NMC
MEIC
ELIC
staged
eRHIC
LHeC
H1/ZEUS

CDR - Time Schedule*)

Detector installation study for IP2, reuse of L3 magnet as support for LHeC. Estimated 30 months





LHeC is to operate synchronous with HL-LHC

LS3 requires 2-3 years for ATLAS+. It is the one extended time period, which will allow installation and connection of LHeC

*) LS3 → schedule most likely shifted by +2 years