The LHeC as an Electron-Ion Collider

Introduction
Nuclear Parton Distributions
Electron-Deuteron Scattering
Saturation
Project

Max Klein, for the LHeC Study Group

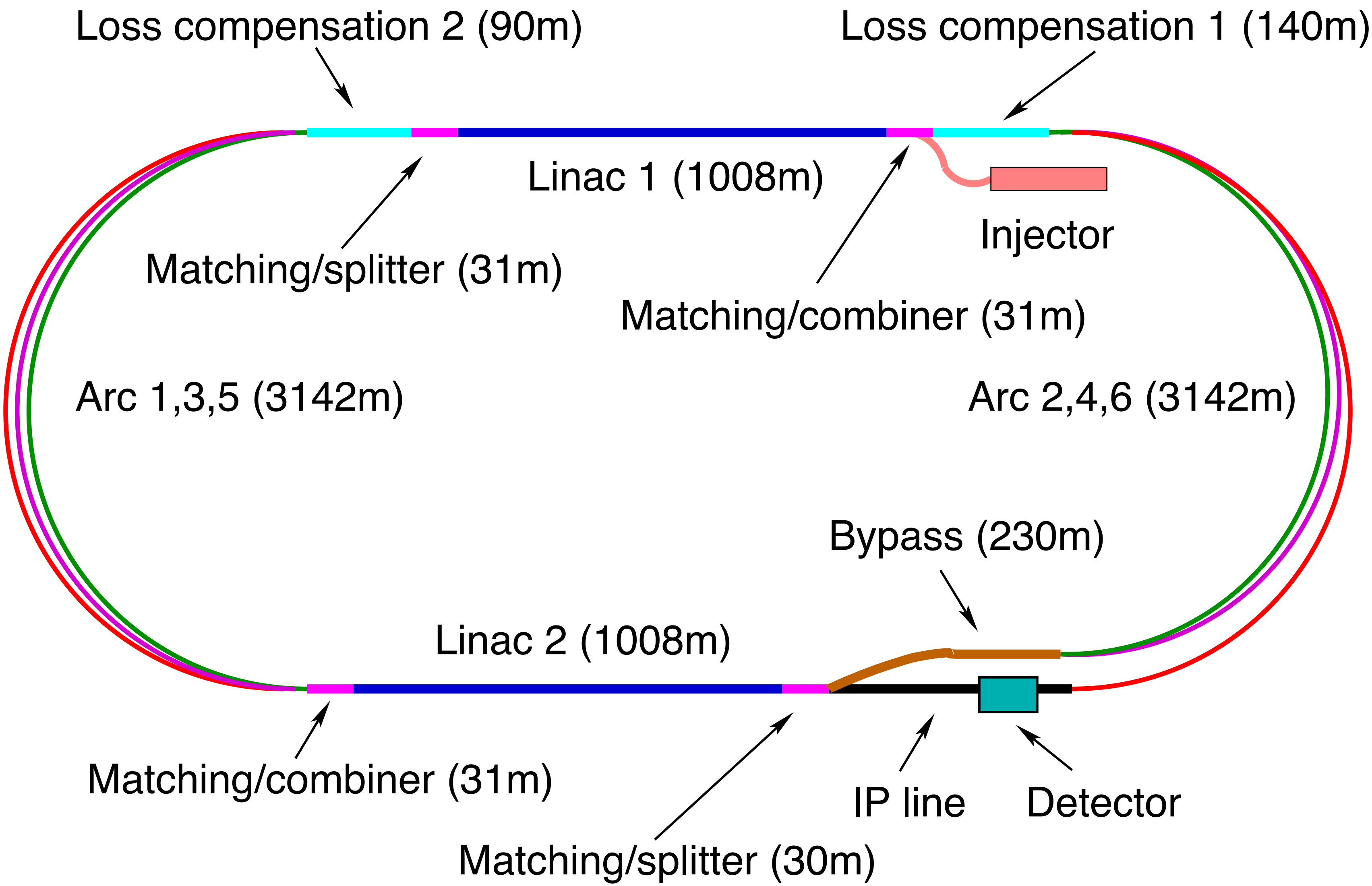
LHeC

UNIVERSITY OF LIVERPOOL

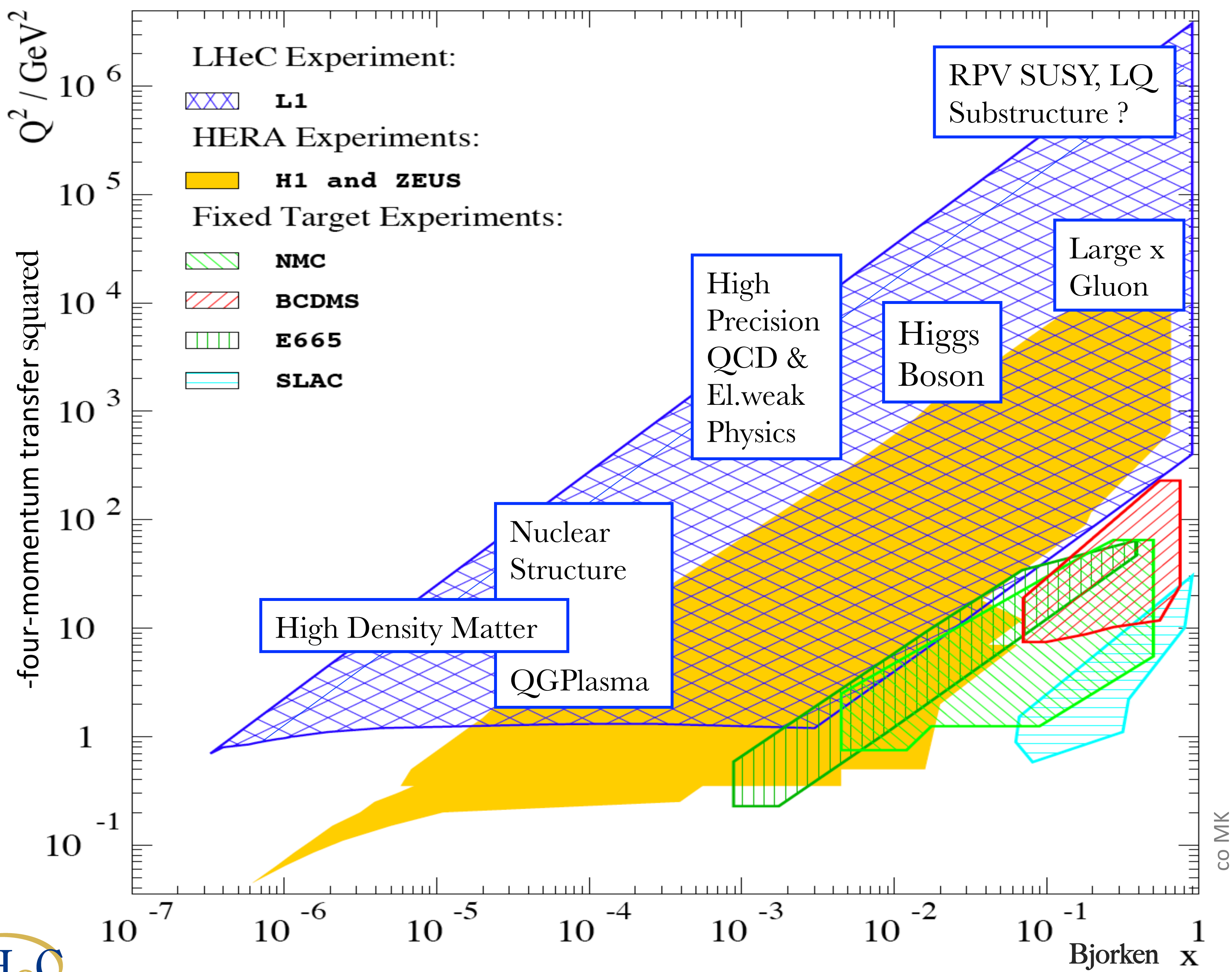
EPS Stockholm, July 19th, 2013

Further Contributions on the LHeC at this Conference

A.Cooper-Sarkar: Precision PDFs; U.Klein: Higgs in ep; D.Schulte: LHeC Collider
Posters: P.Kostka, D.South: Detector; M'D'Onofrio et al: New Physics with LHeC



60 GeV electron beam energy, L= 10^{33} $cm^{-2}s^{-1}$, √s=1.3 TeV: Q^2_{max}= 10^6 GeV^2, 10^{-6} < x< 1
Recirculating linac (2 * 1km, 2*60 cavity cryo modules, 3 passes, energy recovery)
Ring-ring as fall back. "SAPHIRE" 4 pass 80 GeV option to do mainly: γγ→ H



LHeC Experiment:
L1
HERA Experiments:
H1 and ZEUS
Fixed Target Experiments:
NMC
BCDMS
E665
SLAC
RPV SUSY, LQ
Substructure ?
Large x
Gluon
High
Precision
QCD &
El.weak
Physics
Higgs
Boson
Nuclear
Structure
High Density Matter
QGPlasma
Q^2 / GeV^2
-four-momentum transfer squared
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
Bjorken x
co MK
LHeC

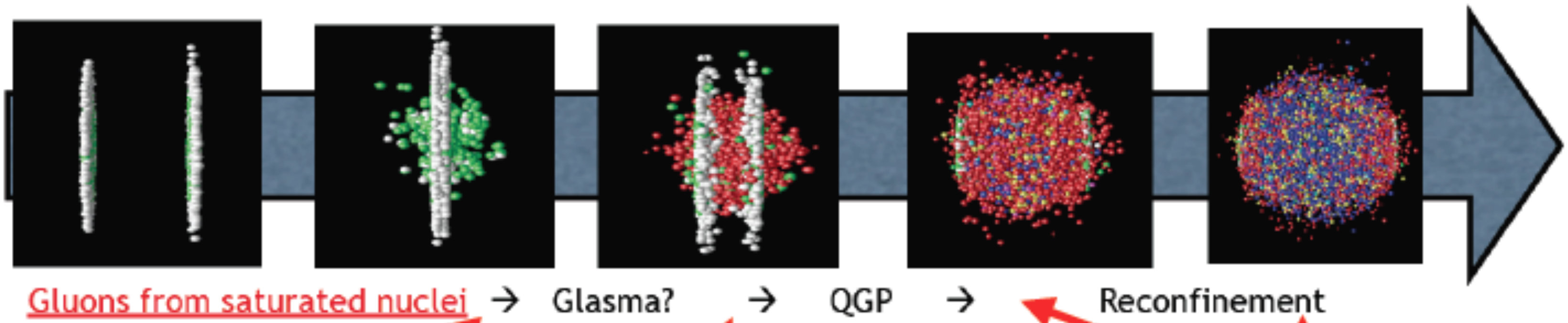
CDR - nuclear parton physics and low x

CDR = LHeC Conceptual Design Report, JHEP 39 (2012) 075001 [1206.2913]

Simulations based on detector performance and luminosities of **$\sim 10^{32}$ cm^{-2} s^{-1} in eN**

This is 10 times higher than at HERA I and uses a conservative LHC wrt recent runs.

Relation of the LHeC and the LHC HI Program



- Nuclear wave function at small x: nuclear structure functions.

- Particle production at the very beginning: which factorisation in eA?

- How does the system behave as ~ isotropised so fast?: initial conditions for plasma formation to be studied in eA.

- Probing the medium through energetic particles (jet quenching etc.): modification of QCD radiation and hadronization in the nuclear medium.

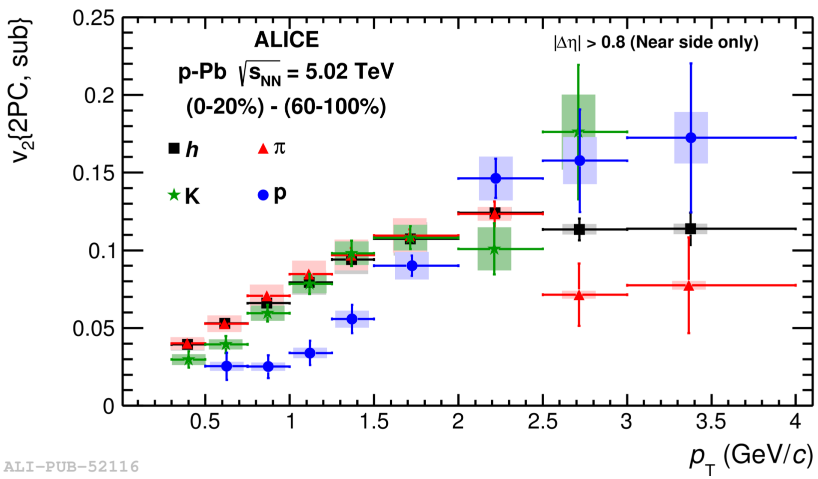
Proton-Lead at the LHC

$$\frac{dN}{d\Phi_Z} \propto \sum_n [1 + v_n \cos(n(\Phi_Z - \Phi_{EP}))]$$

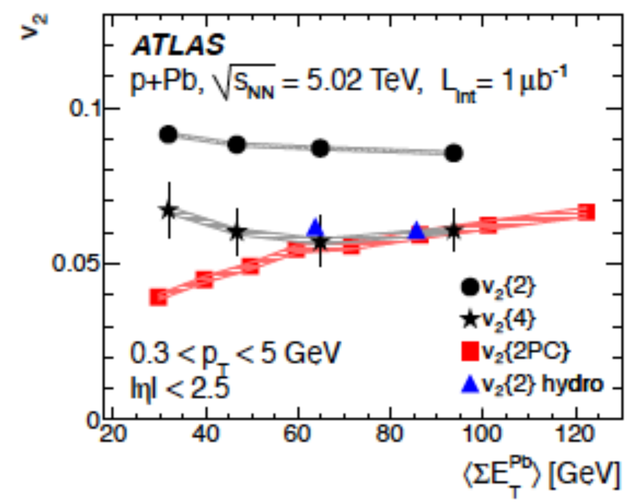
Φ_Z boson azimuthal emission angle
Φ_{EP} event plane azimuth

v_2 for Z is zero, it decays before the plasma is formed ..

1307.3237 – ALICE

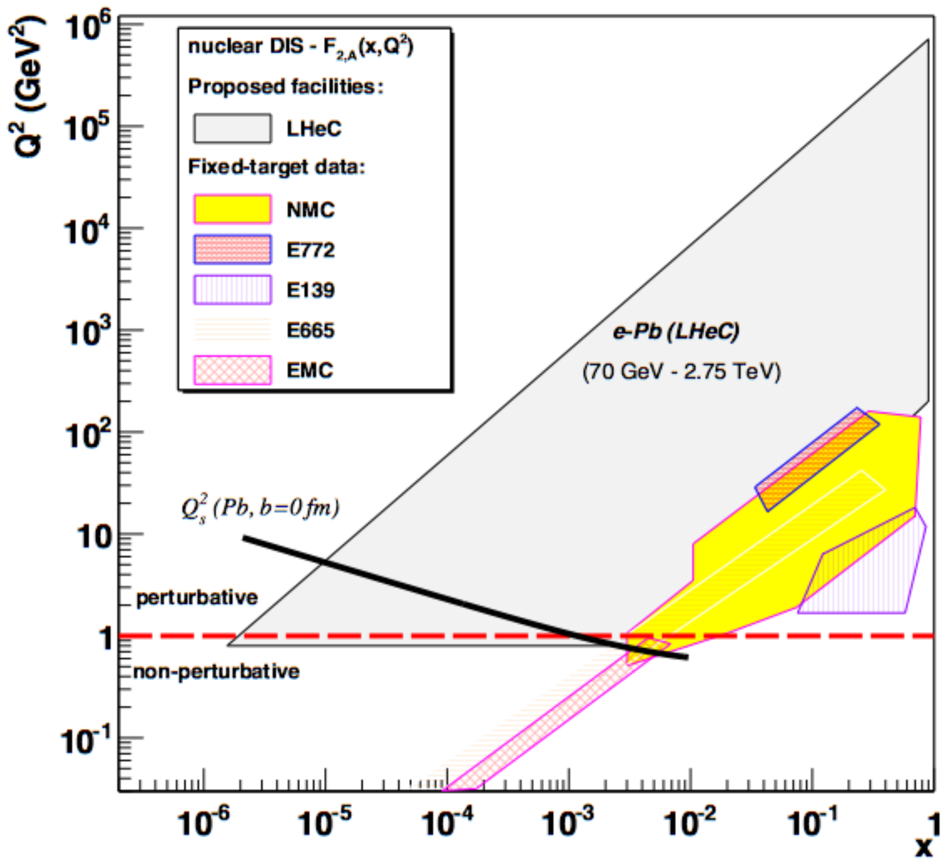


1303.2084 – ATLAS



Perhaps surprising, recent results indicate that the flow in pPb resembles PbPb
Possibly the determination of nPDFs in AA and pA is reduced to W,Z production
[collective effects in final state – rescattering of produced partons – hydrodynamics]

LHeC as Electron Ion Collider



LHeC is part of NuPECCs long range plan since 2010

Extension of kinematic range in lA by FOUR orders of magnitude will change QCD view on nuclear structure and parton dynamics

May lead to genuine surprises…

- No saturation of xg (x,Q^2) ?
- Small fraction of diffraction ?
- Broken isospin invariance ?
- Flavour dependent shadowing ?

Expect saturation of rise at

$$Q^2_s \approx xg\ \alpha_s \approx c\ x^{-\lambda} A^{1/3}$$

Precision QCD study of parton dynamics in nuclei
Investigation of high density matter and QGP
Gluon saturation at low x, in DIS region.

Nuclear Parton Distributions

Data	DIS lA	DIS νA	DY ll	dAu $\pi^{\pm}$	dAu π^{o}	p Base	Ref.
EPS09	+	-	+	-	+	MSTW	JHEP
DSSZ	+	+	+	+	+	CTEQ6	PRD
nCTEQ	+	-	+	-	-	CTEQ6	Prel.

*)

NLO QCD fits of nuclear correction factors with reference to a proton PDF set

Very restricted range of DIS measurements → "no predictive power below x ~ 0.01" FGS

Single pion data used to constrain the gluon – depends on fragmentation fct., thy uncertain

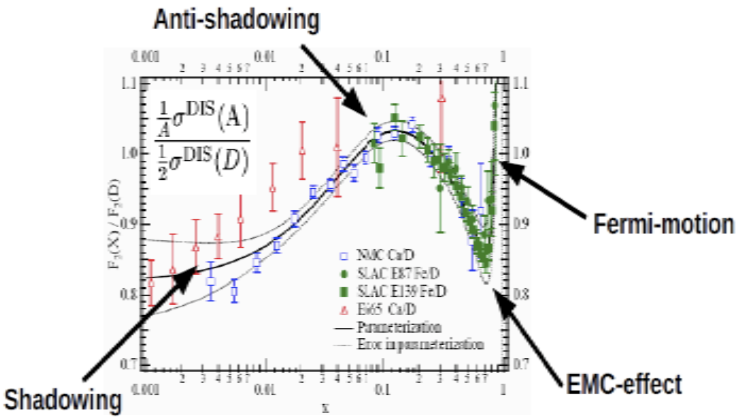
No flavour decomposition (strange may be large, charm, bottom?)

Further assumptions: no nuclear effects in D, isospin invariance, $\Delta\chi^2$ tolerances..

*) see also Hirai, Kumano, Nagai, 0709.3038 (2007)

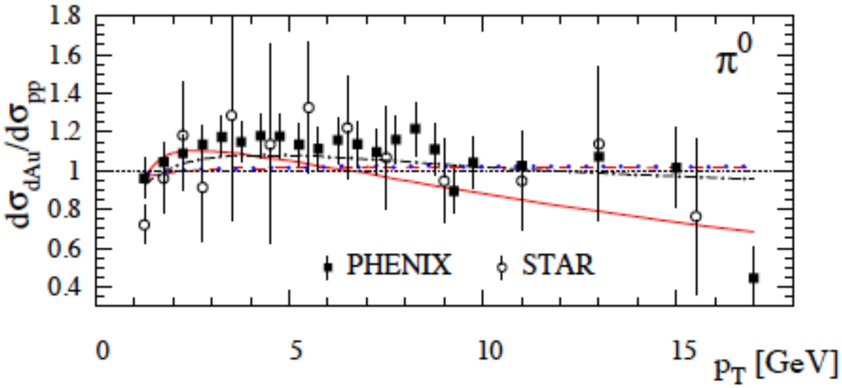
Present nPDFs

DIS input data from NMC and SLAC

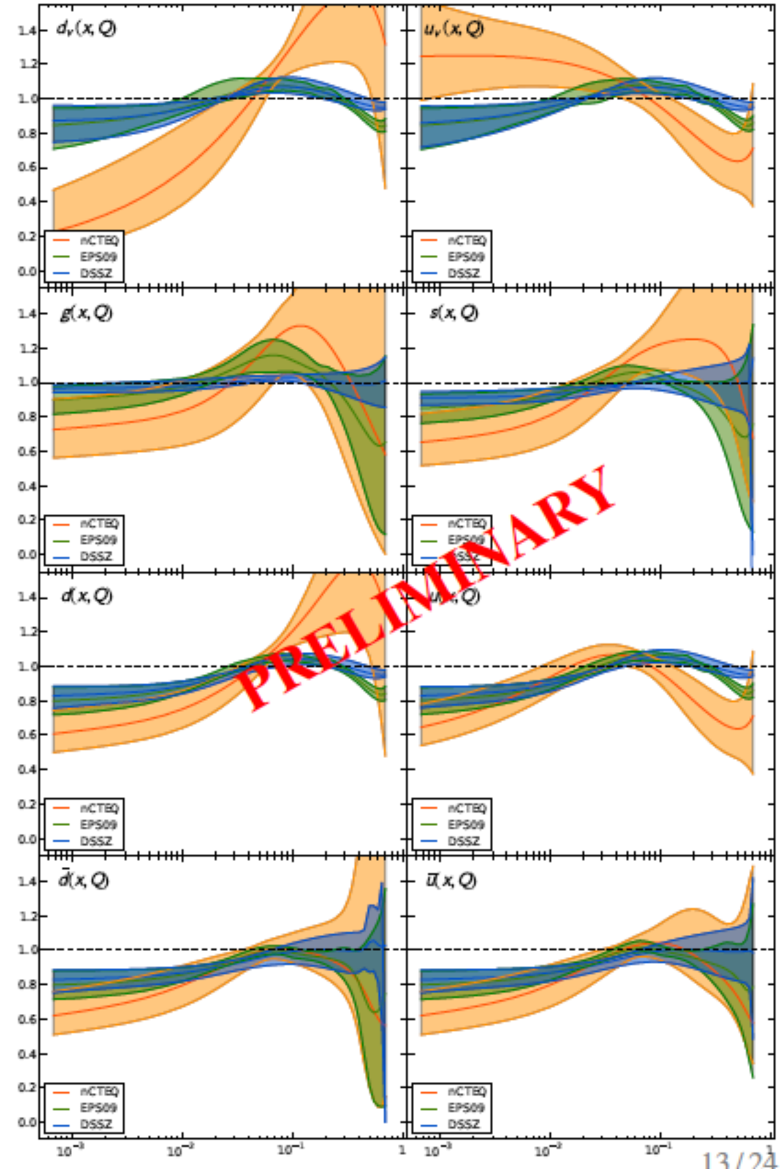


Frankfurt, Guzey, Strikhman, 1106.2091

π^o input from RHIC



For full set of plots cf D.De Florian 1112.6324

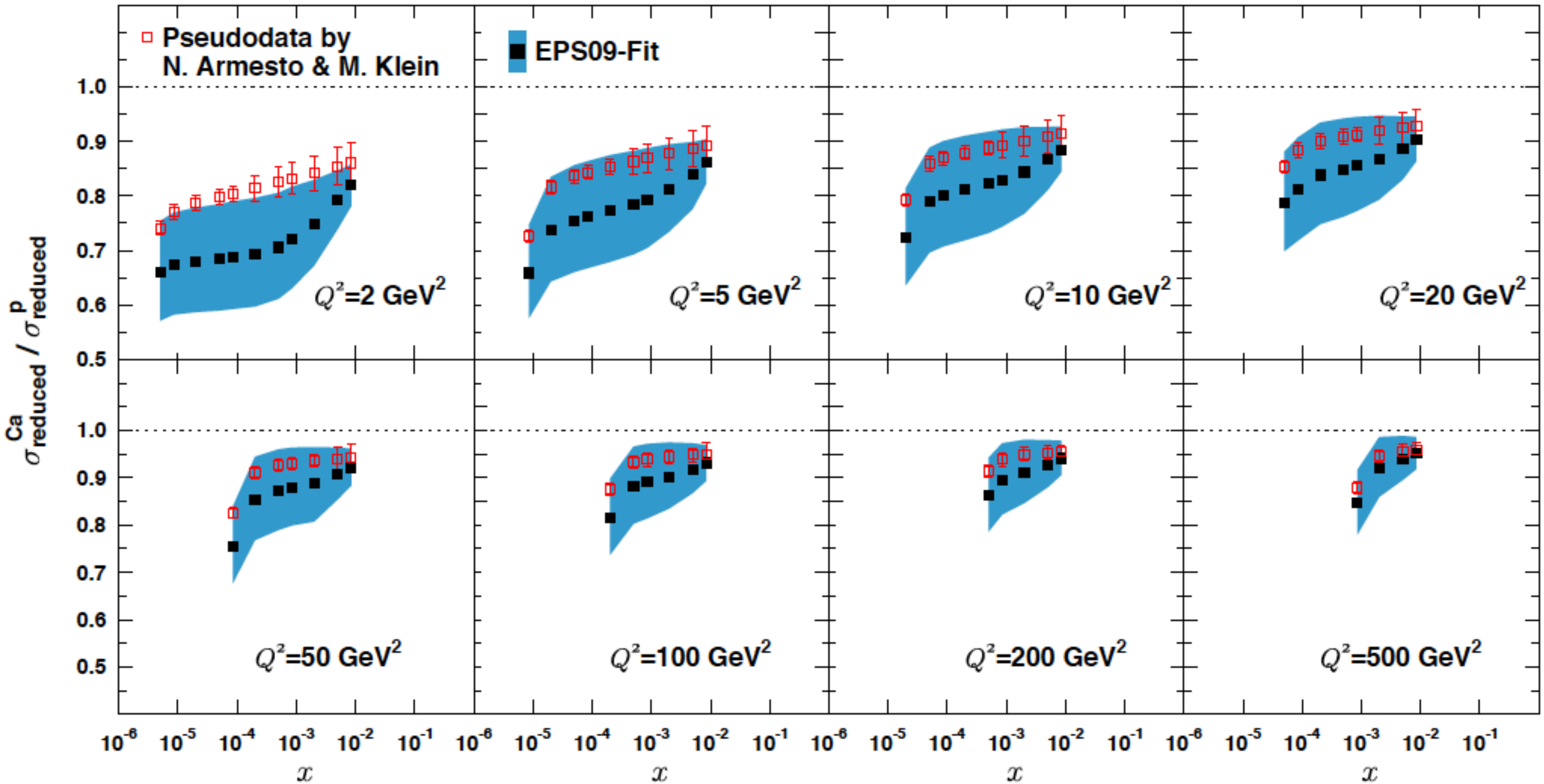


Strong variations of results and just parametric behaviour at x < 0.01

A.Kusina May 2013 Pittsburgh

Low x data from the LHeC

NOW

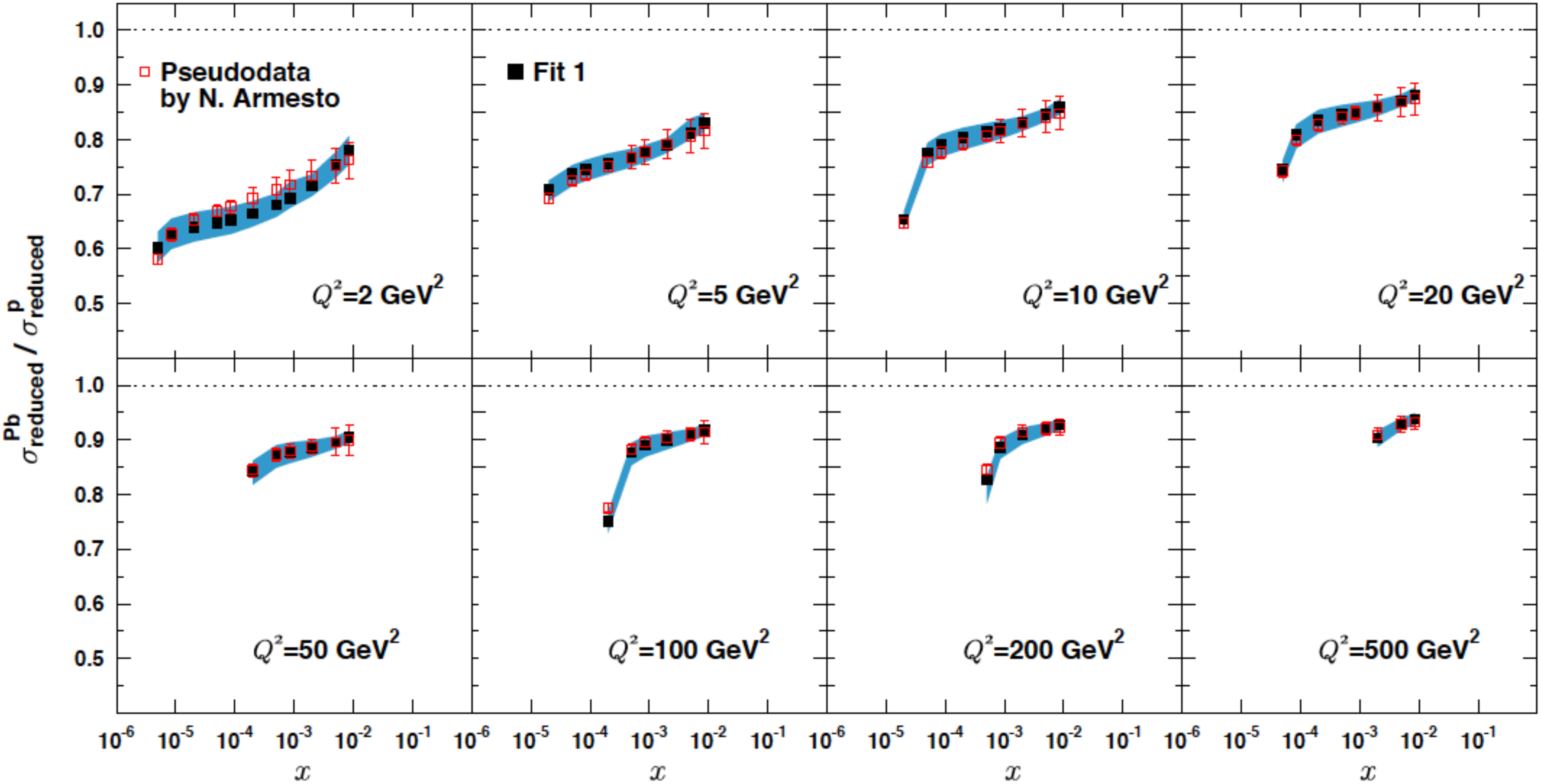


LHeC data simulated: Detector+GBW+Glauber+5Flavours (cf LHeC CDR 2012)

EPS uncertainties are extrapolations to $x < 0.01$

Low x data from the LHeC

THEN

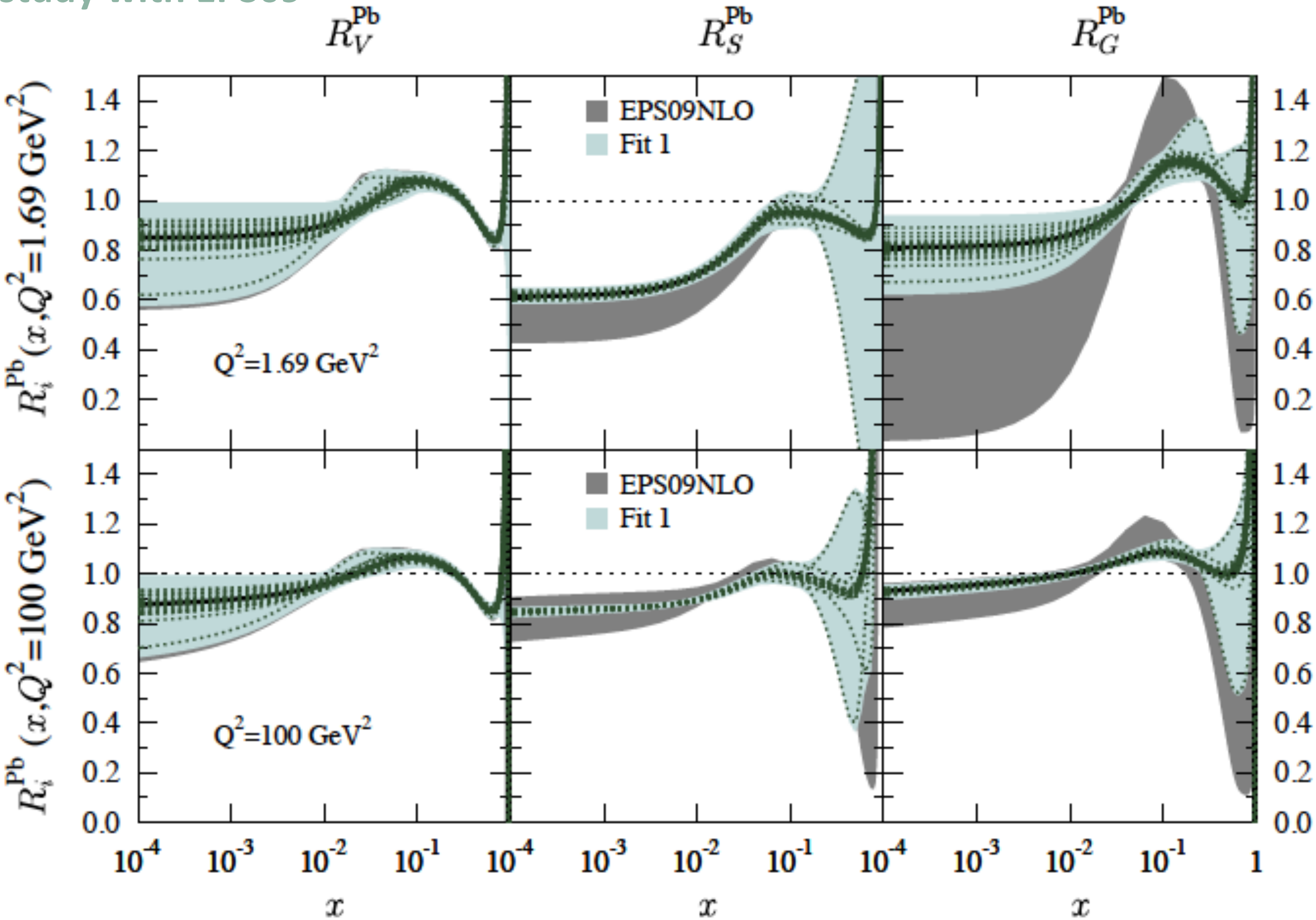


LHeC data simulated: Detector+GBW+Glauber+5Flavours (cf LHeC CDR 2012)

EPS uncertainties are now based on (pseudo) LHeC data + EPS09 input

Determination of Partons in Pb with LHeC

Case study with EPS09

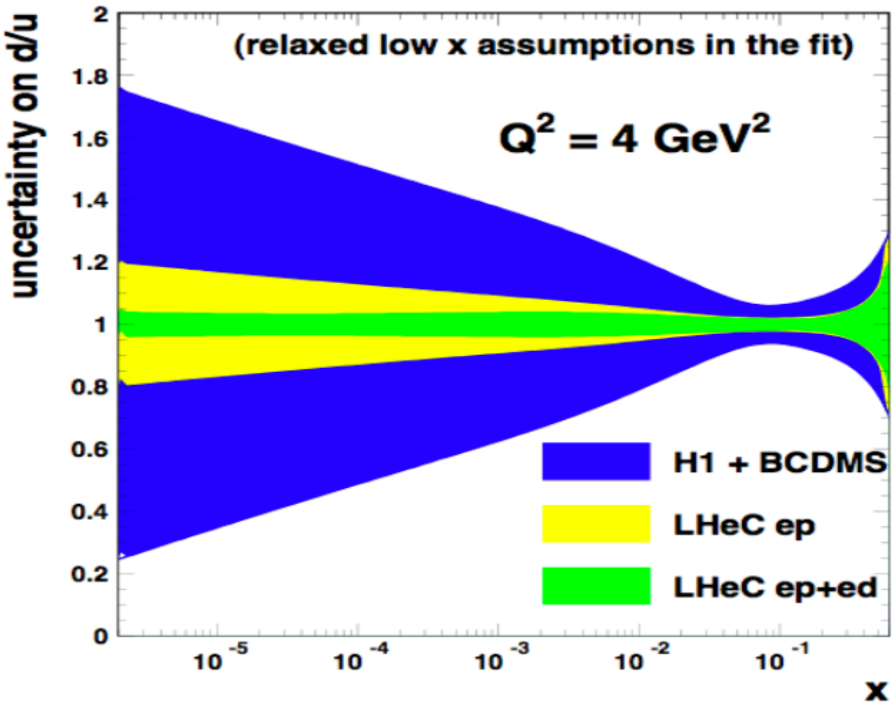


H.Paukkunen, N.Armesto, E.Erskola DIS13, Marseille, Proceedings 1306.2486

A new world of nPDF physics and thus determination of initial state of QGP
A first study. Can do DIS only fit, add further LHeC data constraints as c,b, CC..

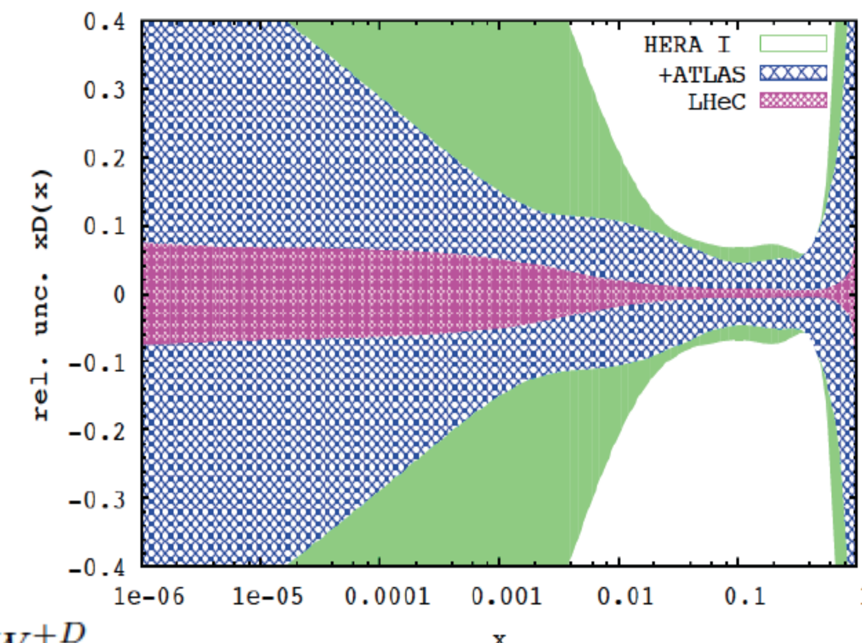
Deuterons and Light Sea Quark Asymmetry

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



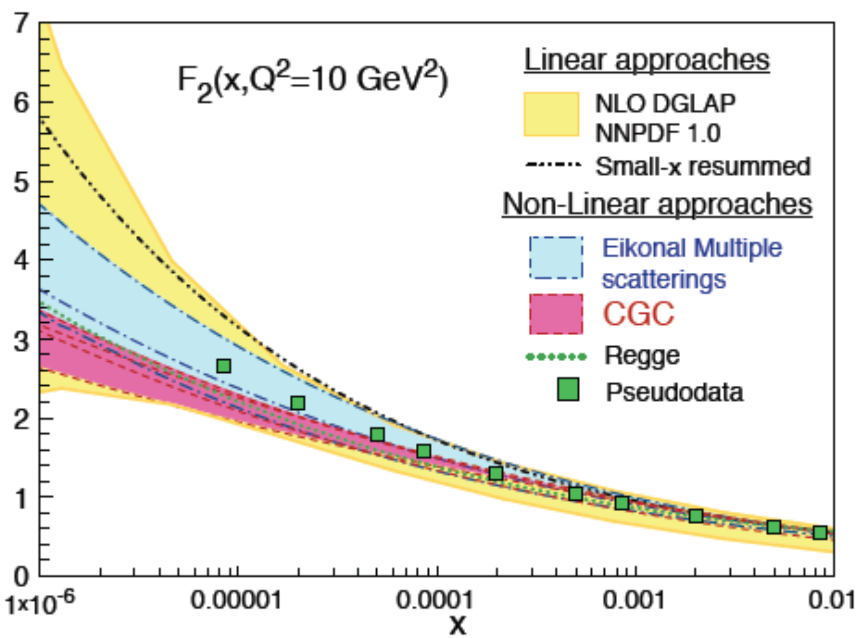
Deuterons: Crucial for

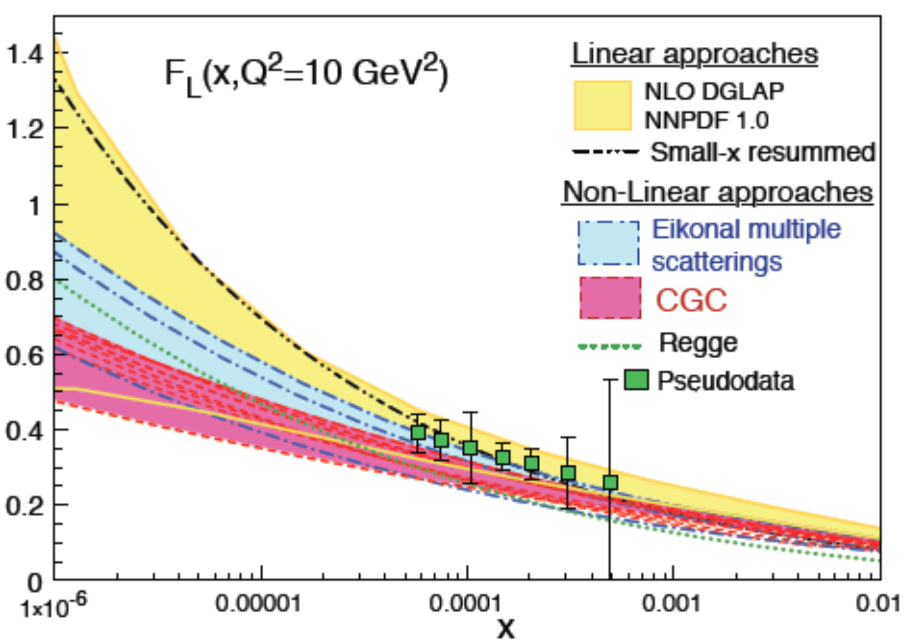
- NS-S decomposition
- Neutron structure
- Flavour separation

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

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

Search for non-linear dynamics at low x - ep





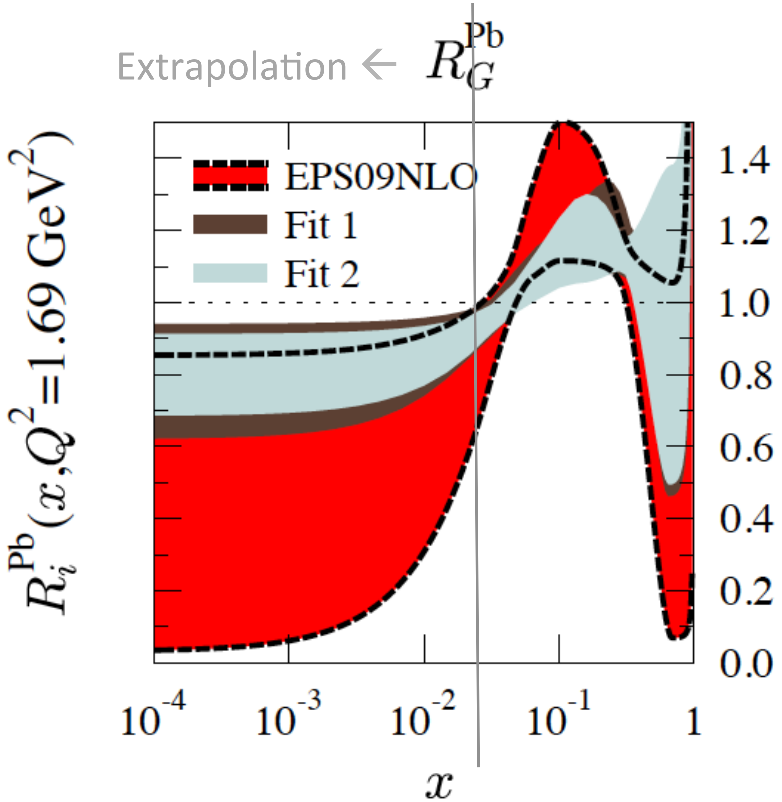
HERA has confirmed DGLAP evolution to surprisingly low x of above 10^{-4}

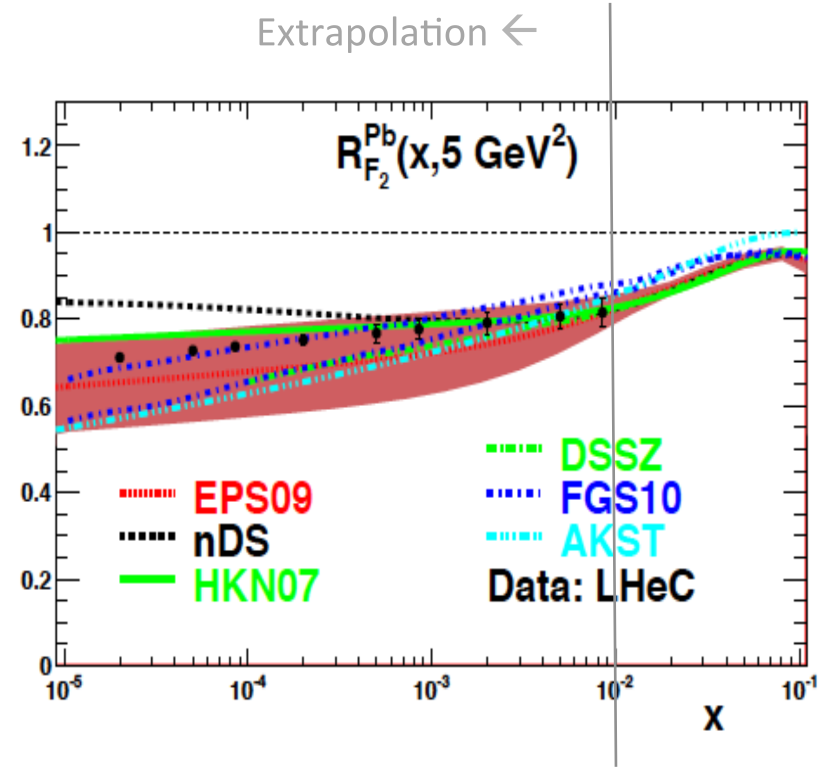
Since long (BFKL, BK, GLR ..) one has considered non-linear effects, as ln(1/x) is large

Requires extreme precision on F_2 AND F_L – full NC (and CC) simulation done

Impossible to describe BOTH structure functions if there are non-DGLAP effects (CDR)

Gluon and Sea at Low x in eA with the LHeC





In eA the gluon density may be enhanced proportional to $A^{1/3}$
A proof of saturation requires: ep AND eA to separate nuclear/collective effects from non-linear parton interactions AND $\alpha_s << 1 \rightarrow Q^2 >> M_P^2$
It is a unique program for the LHC, as it needs high E_A and E_e

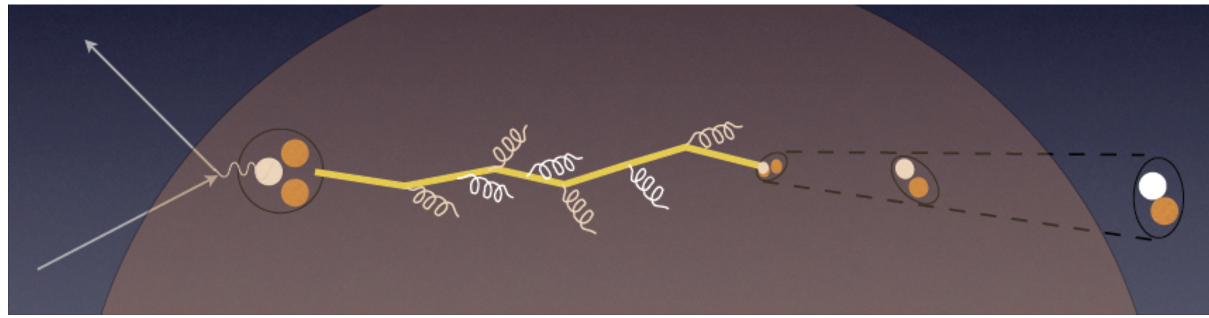
In-medium Hadronisation

The study of particle production in eA (fragmentation functions and hadrochemistry) allows the study of the space-time picture of hadronisation (the final phase of QGP).

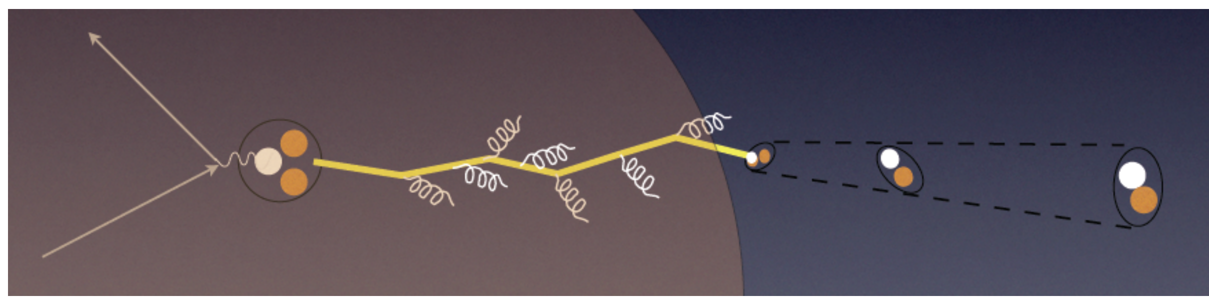
Low energy (ν): need of hadronization inside.

Parton propagation: pt broadening

Hadron formation: attenuation



High energy (ν): partonic evolution altered in the nuclear medium.



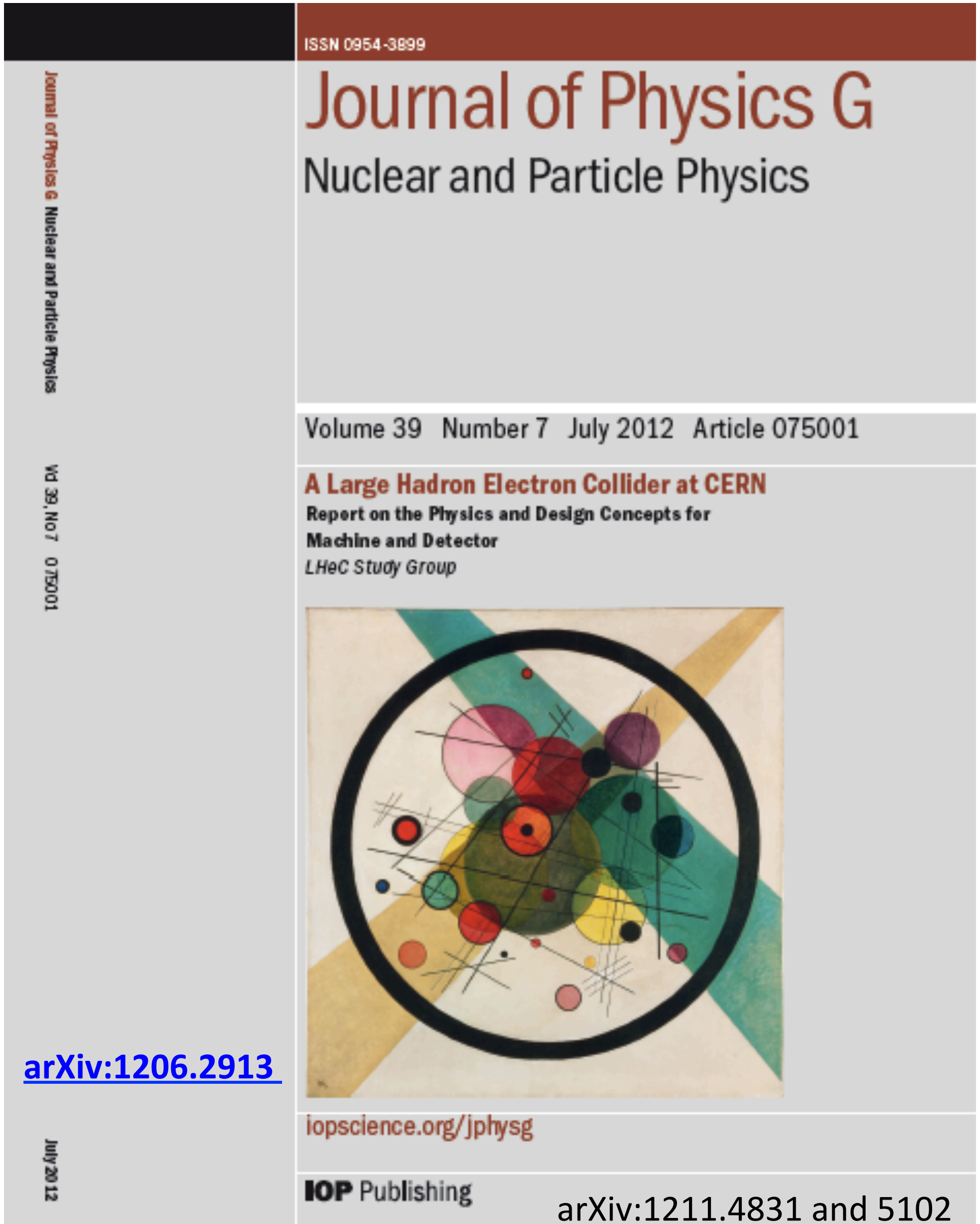
W.Brooks, Divonne09

LHeC :

+ study the transition from small to high energies in much extended range wrt. fixed target data

+ testing the energy loss mechanism crucial for understanding of the medium produced in HIC

+ detailed study of heavy quark hadronisation …



arXiv:1206.2913

arXiv:1211.4831 and 5102

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 150 authors from 60 Institutes. Reviewed by ECFA, NuPECC (long range plan), Referees invited by CERN. Published June 2012.

Project Development

CERN Mandate

LHeC: few years programme -2017

Accelerator

SC RF, LTF, Q1, Optimisation, Lumi,

Detector

IR, Technical Design, Installations

Physics

Higgs, RPV SUSY, top, eA, ..LHC

Project

Workshops, Collaboration..

The LHeC is a challenge worth developing for the future of HEP

LHeC

The mandate for the technology development **includes studies and prototyping of the following key technical components:**

- Superconducting RF system for CW operation in an Energy Recovery Linac, (high Q0 for efficient energy recovery). The studies require design and prototyping of the cavity, couplers and cryostat.
- Superconducting magnet development of the insertion regions of the LHeC with three beams. The studies require the design and construction of short magnet models.
- Studies related to the experimental beam pipes with large beam acceptance in a high synchrotron radiation environment.
- The design and specification of an ERL test facility for the LHeC.
- The finalization of the ERL design for the LHeC including a finalization of the optics design, beam dynamic studies and identification of potential performance limitations.

The above technological developments require close collaboration between the relevant technical groups at CERN and external collaborators.

Given the rather tight personnel resource conditions at CERN **the above studies should exploit where possible synergies within existing CERN studies** (e.g. SPL and ESS SC RF, HL-LHC triplet magnet development and collaboration with ERL test facility outside CERN).

S.Bertolucci at Chavannes workshop 6/12 based on
CERN directorate's decision to include LHeC in the MTP

Summary

The LHeC represents an upgrade project of the LHC as it complements its physics (Higgs, BSM, QCD, eweak) and is designed to operate synchronous. As an eA collider the LHeC extends the kinematic range in lA DIS by 4 orders of magnitude. It therefore has a high discovery potential regarding nuclear structure and dynamics.

The LHeC eA physics is strongly related to all phases of the development of the high density matter, the initial state (nPDFs) up to the hadronisation. It comprises vector meson, diffraction, jet, GPD, unintegrated PDFs.. – cf CDR

The nPDF determinations are at their infancy, worse than pPDFs before HERA. With the LHC AA and pA program new demands will come for precision nPDF information and the LHeC provides these in a complete manner.

Of special interest is eD scattering, both theoretically and experimentally.

The LHeC project is on the long-range map of European Nuclear Physics, as represented by NuPECC, and it can be realised in collaboration with ALICE housed in IP2, which has an upgrade program after LS2.
The LHeC development continues, on the machine, detector and physics
The next workshop tentatively is schedule for the end of January 14 (30/31.)

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]

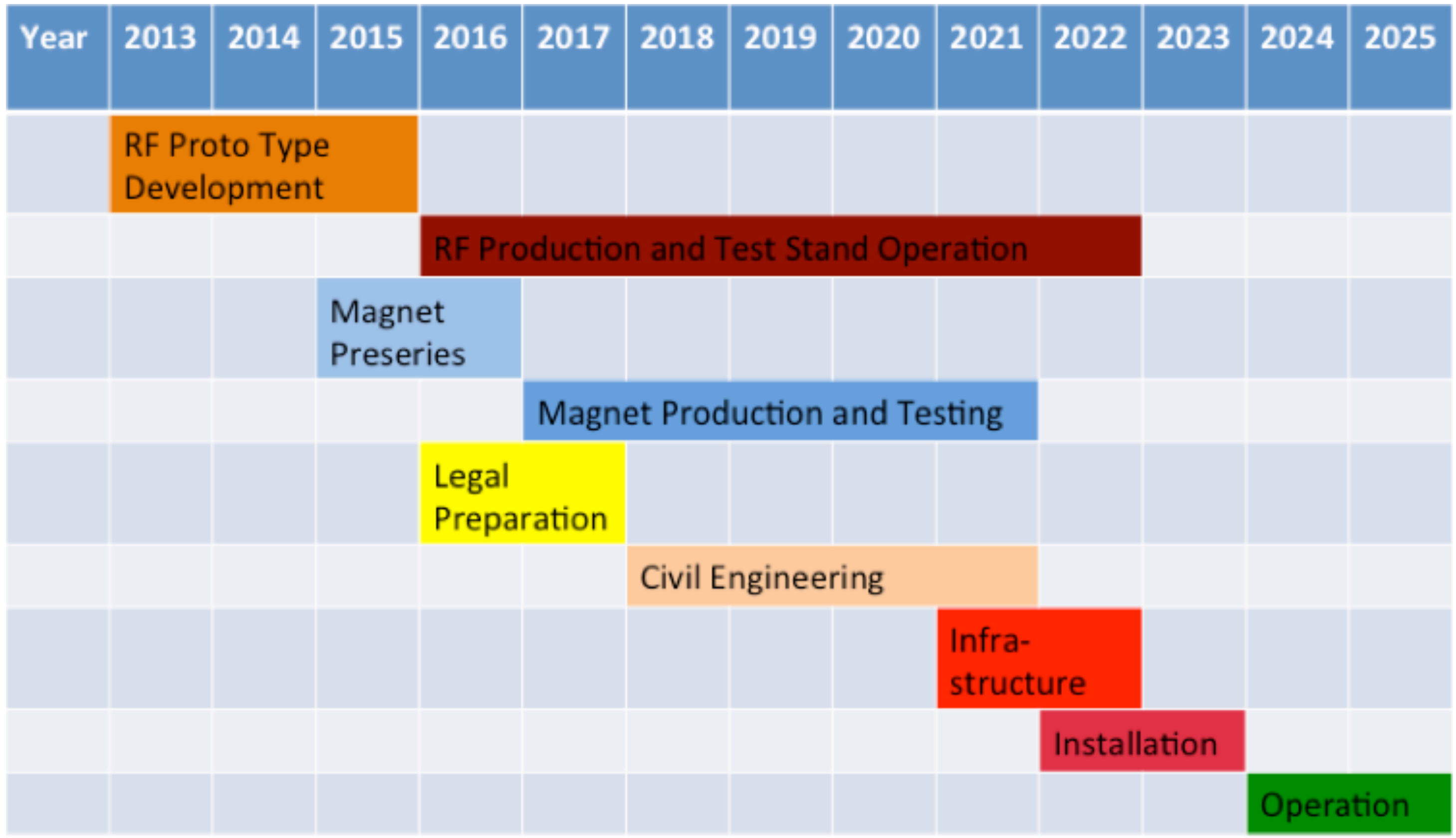
LHeC Study group and CDR authors (Dec.2012)

About 200 Experimentalists and Theorists from 80 Institutes

Special thanks to
Nestor Armesto, Paul Newman,
John Jowett and Anna Stasto

Backup

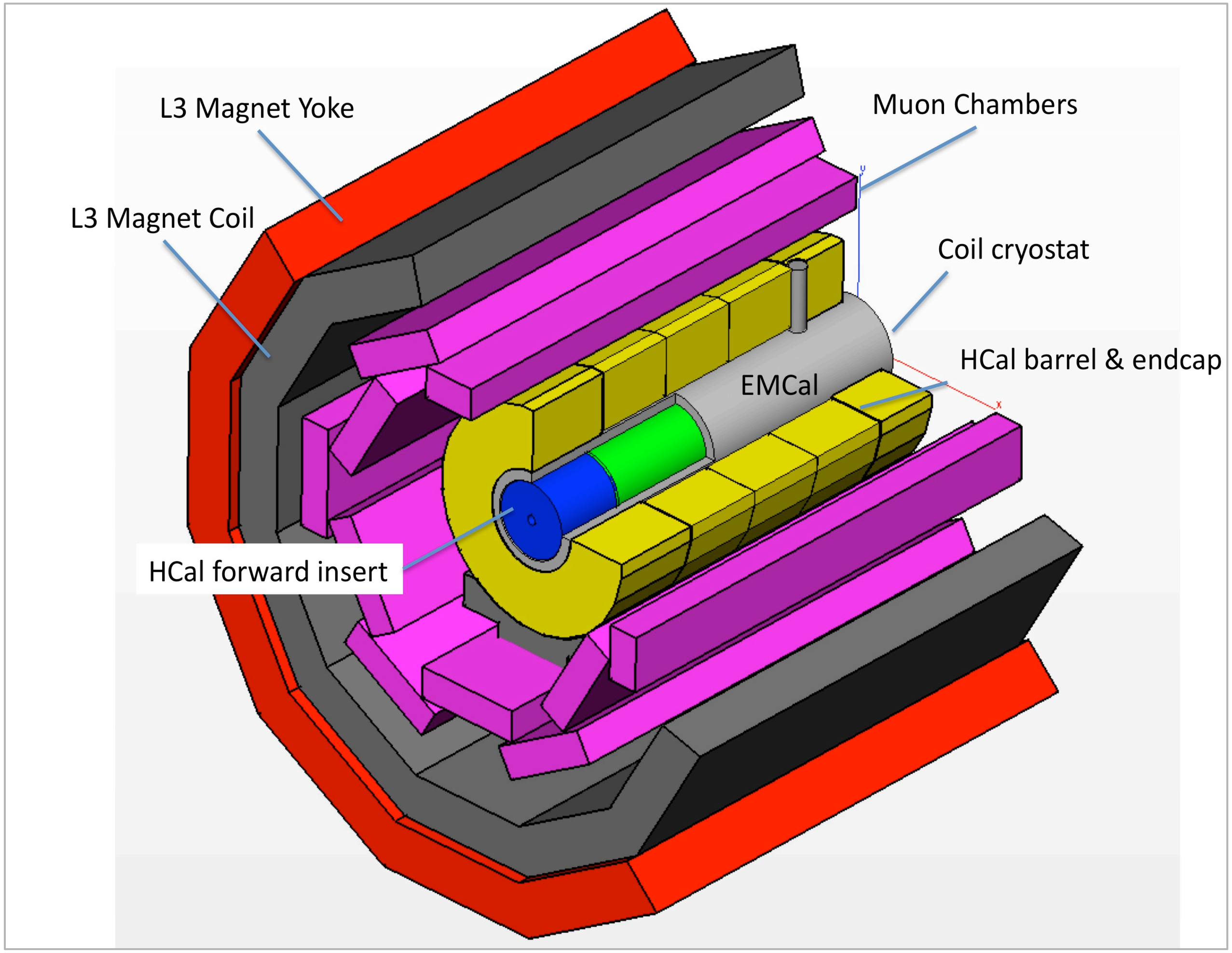
Tentative Time Schedule*)



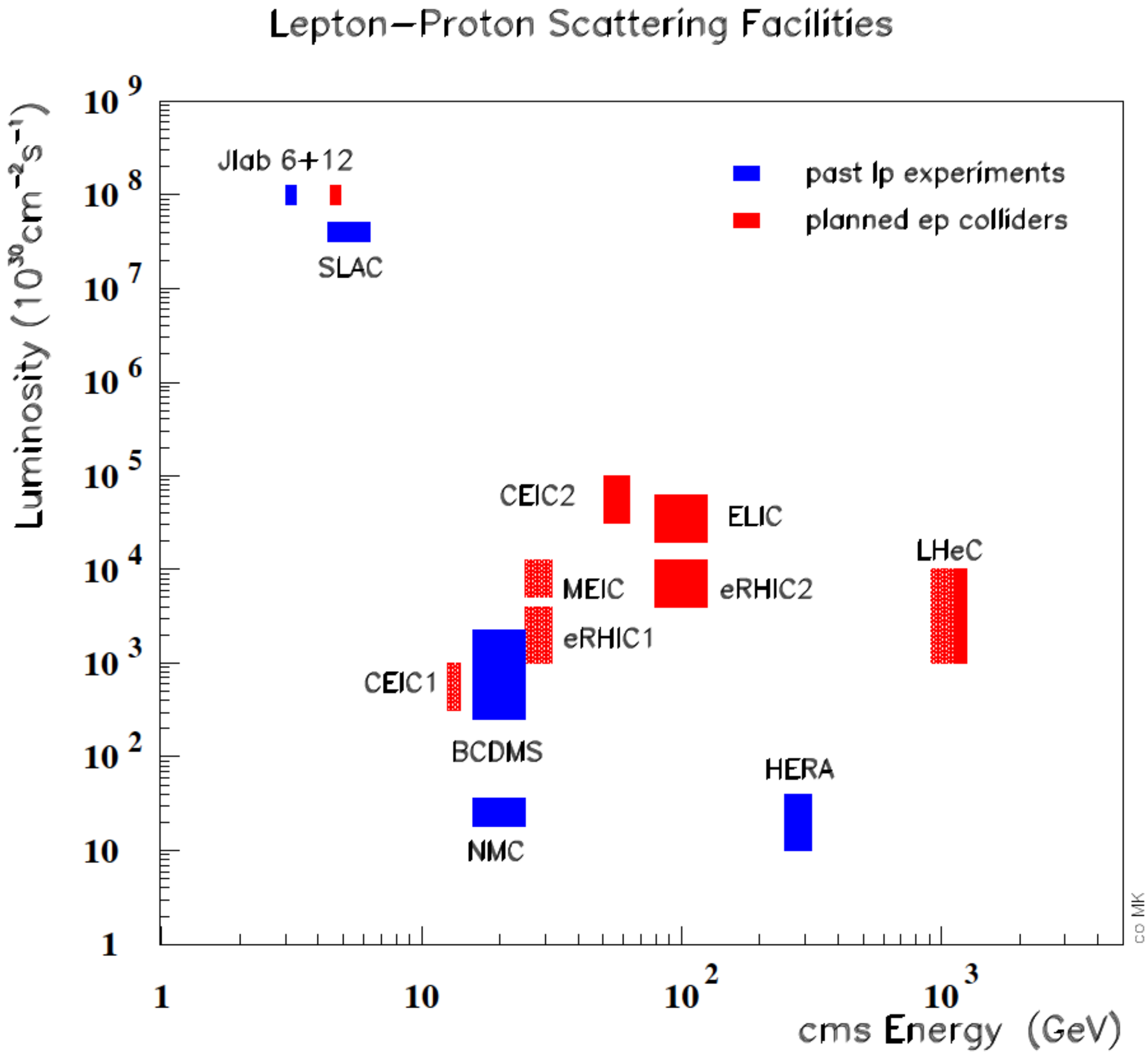
LHeC is to operate synchronous with HL-LHC

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



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



Energy frontier deep inelastic scattering - following HERA with the LHC

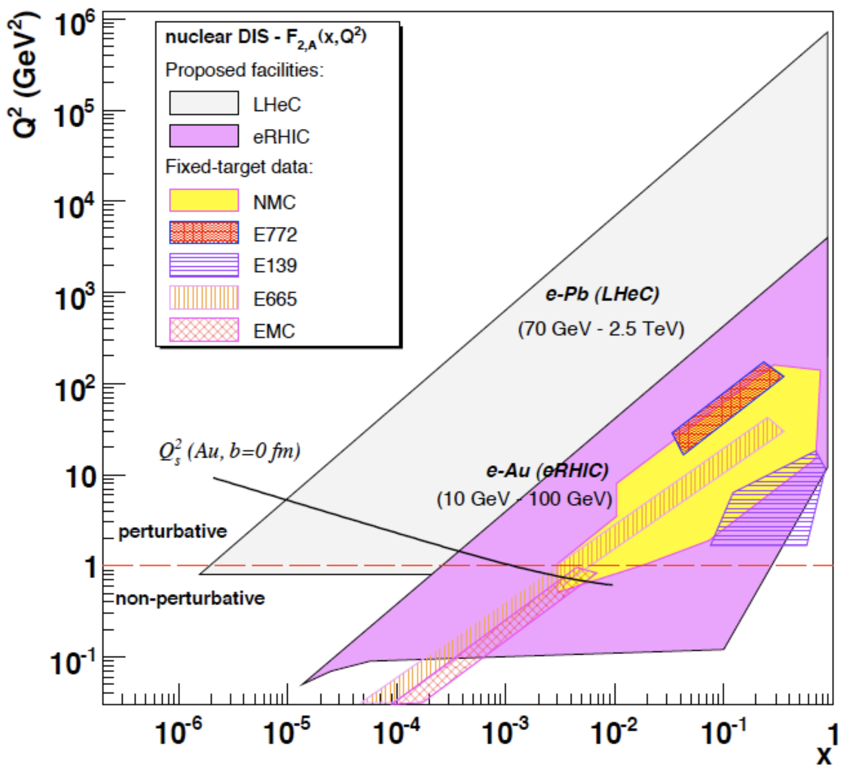
LHeC: A new laboratory for particle physics, a 5th large LHC experiment

HERA's Legacy II – Open Questions

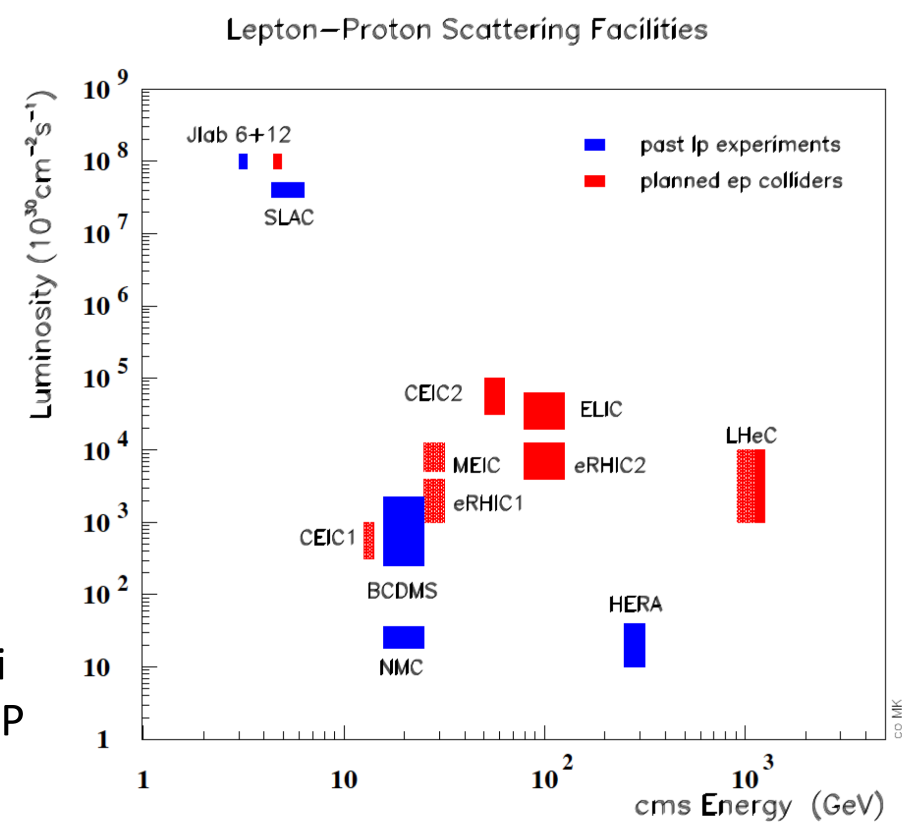
Test of the isospin symmetry (u-d) with eD	- no deuterons
Investigation of the q-g dynamics in nuclei	- no time for eA
Verification of saturation prediction at low x	- too low s
Measurement of the strange quark distribution	- too low L
Discovery of Higgs in WW fusion in CC	- cross section ~0.5fb
Study of top quark distribution in the proton	- too low energy
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
…	

→ Need: much higher luminosity, higher energy, nuclear targets

Electron-Ion-Colliders

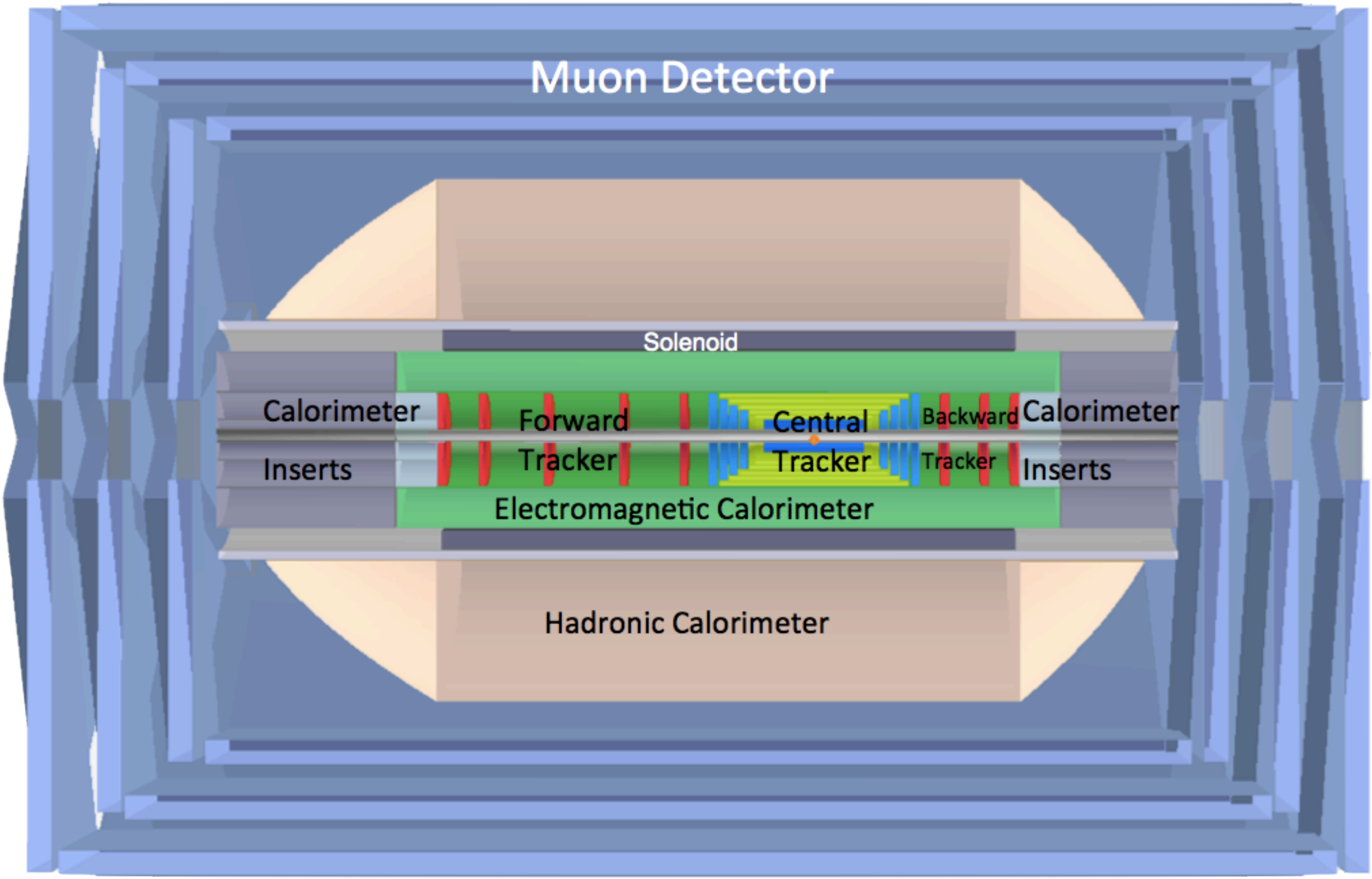


hi Intensity → medium E → E frontier



Precision study of parton dynamics in nuclei
Investigation of high density matter and QGP
Gluon saturation at low x, in DIS region.

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)