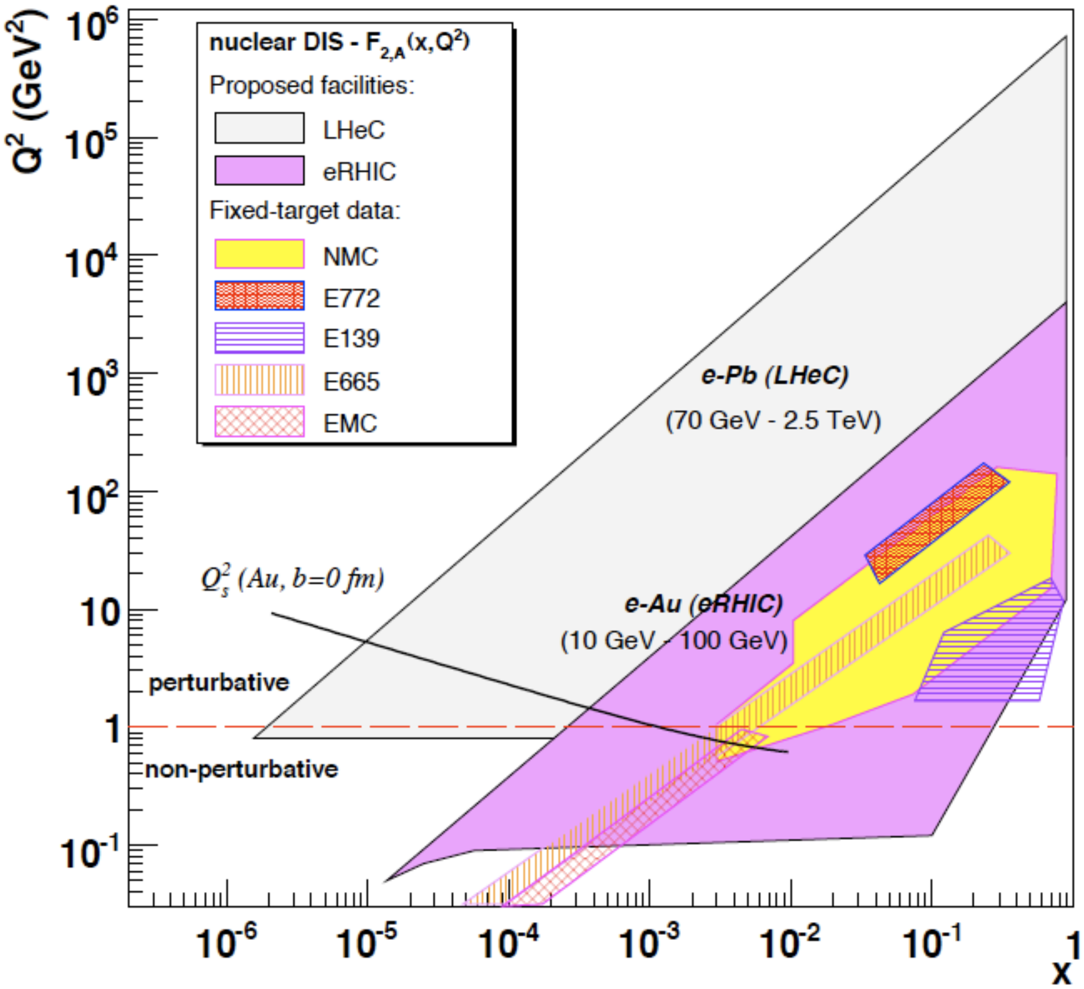
An Electron-Hadron Collider at the LHC

www.lhec.org.uk

50..150 ($e^{\pm}$) GeV on 2.7 (Pb), 3.5 (D), 7(p) TeV



D'Enterria arXiv0707.4182

x: fractional parton momentum
Q^2: -four momentum transfer^2

The LHeC may extend the kinematic range of eA by 4 orders of magnitude.

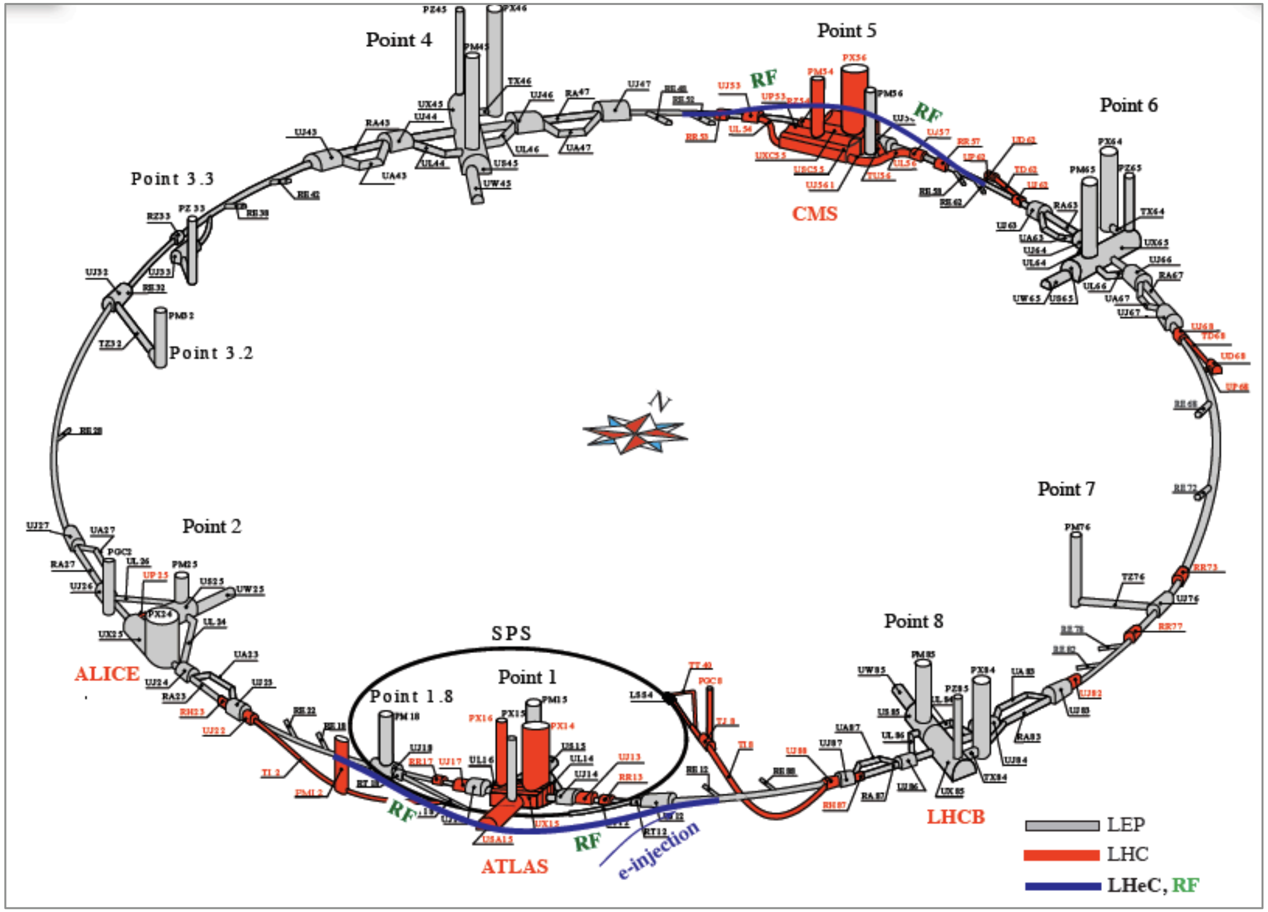
How? When? Why?

HERA missed eA,eD

Max Klein
University of Liverpool
LHeC Steering Group

NuPECC – F/Main 13/10/09

Ring-Ring ep/eA



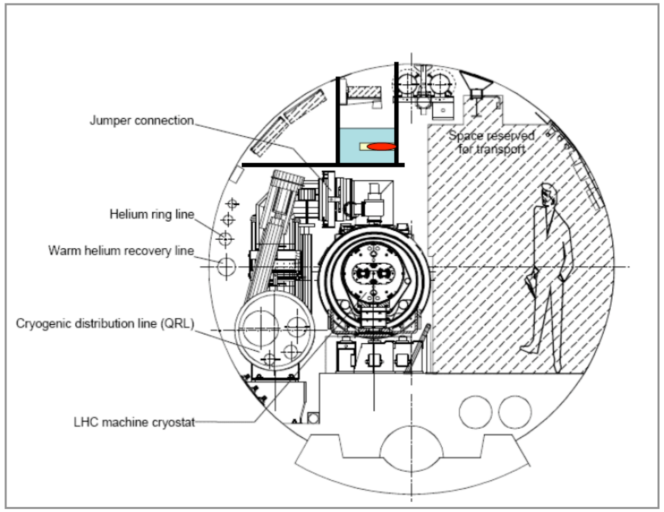
$E_e = E_{inj}$ … 80 GeV. $L_{ep} \sim 10^{33} cm^{-2} s^{-1}$ (100 times HERA)

F.Willeke
B.Holzer
et al

1/x and $Q^2 \sim 10^{4(2)}$ times larger in eA (ep) than so far

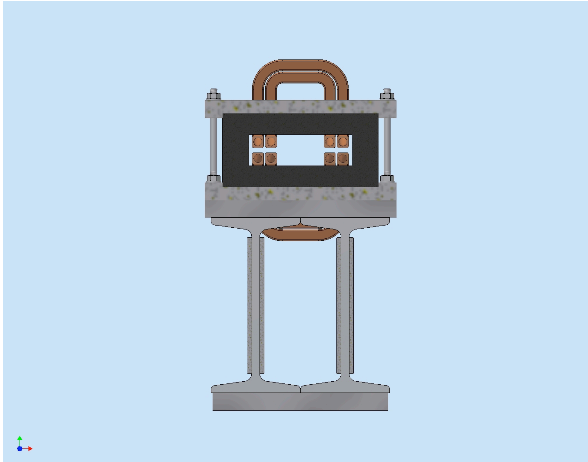
Ring Challenges

Tunnel cross section



F.Willeke, Kh.Mess

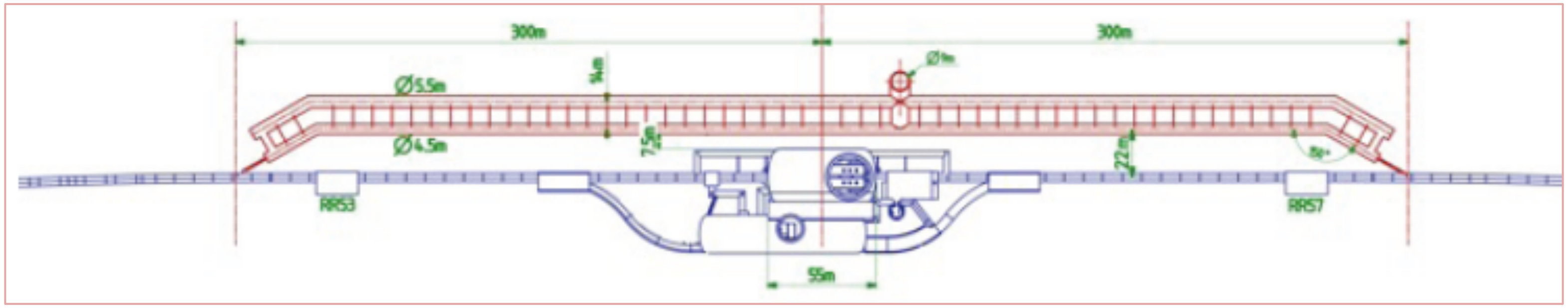
Dipole magnet design (BNP)



O-shaped magnet with ferrite core

P.Wobbly, I.Morosov

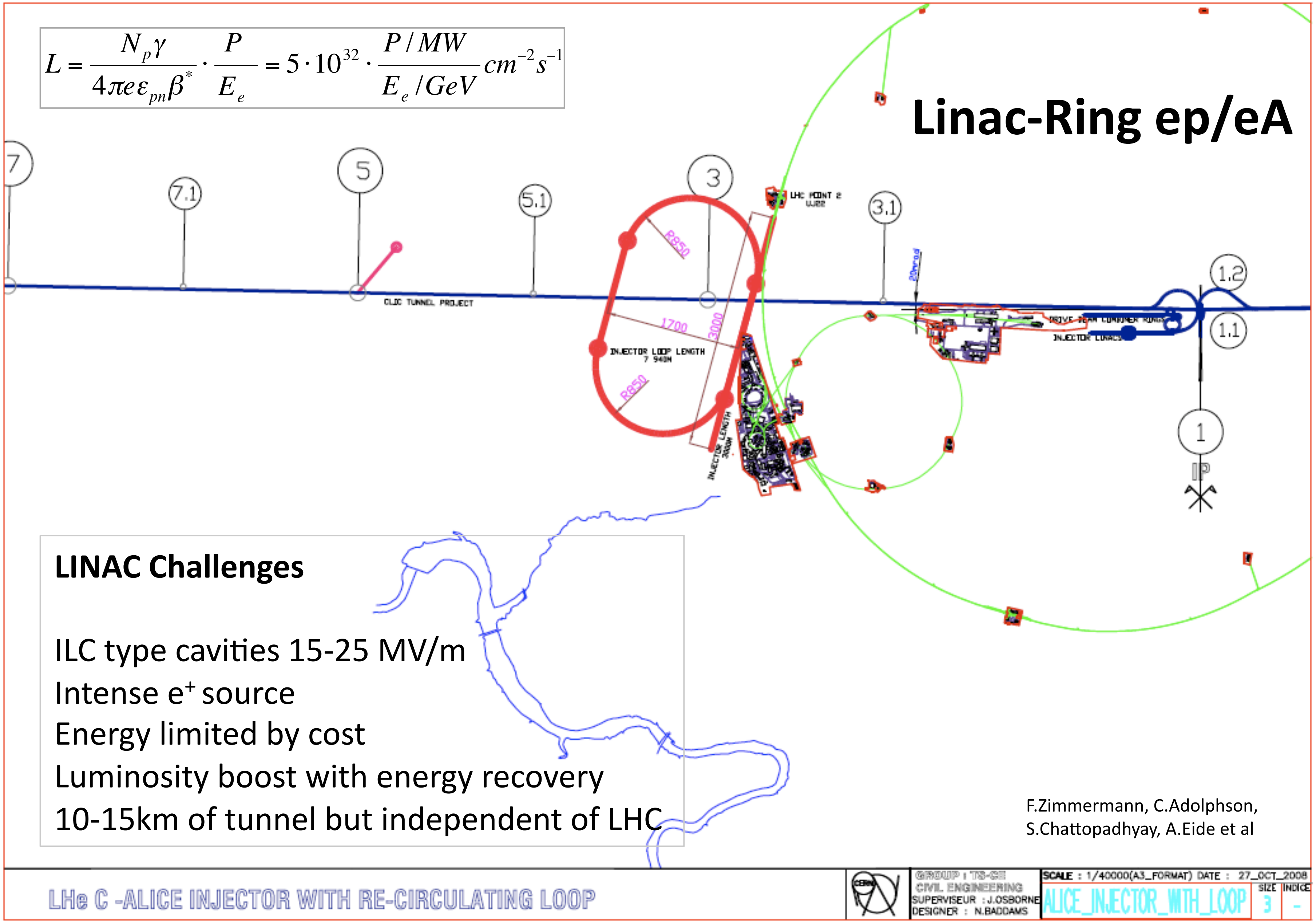
Sketch of bypass tunnel around CMS (double tunnel, 1 shaft, houses rf)



J.Osbourne, S.Myers, H.Burckardt

Linac-Ring ep/eA

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn} \beta^*} \cdot \frac{P}{E_e} = 5 \cdot 10^{32} \cdot \frac{P/MW}{E_e/GeV} cm^{-2} s^{-1}$$



LINAC Challenges

ILC type cavities 15-25 MV/m
Intense e^+ source
Energy limited by cost
Luminosity boost with energy recovery
10-15km of tunnel but independent of LHC

F.Zimmermann, C.Adolphson, S.Chattopadhyay, A.Eide et al

e-A Collisions

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

    $k_b = 592$ bunches of $N_b = 7\times 10^7$ $^{208}Pb^{82+}$ nuclei
- Assume lepton injectors can create matching train of e^-

  $$k_b = 592 \text{ bunches of } N_b = 1.4\times 10^{10}\ e^-$$
- Lepton-nucleus or lepton-nucleon luminosity in ring-ring option at 70 GeV

  $$L = 1.09\times 10^{29}\ \text{cm}^{-2}\text{s}^{-1} \Leftrightarrow L_{en} = 2.2\times 10^{31}\ \text{cm}^{-2}\text{s}^{-1}$$

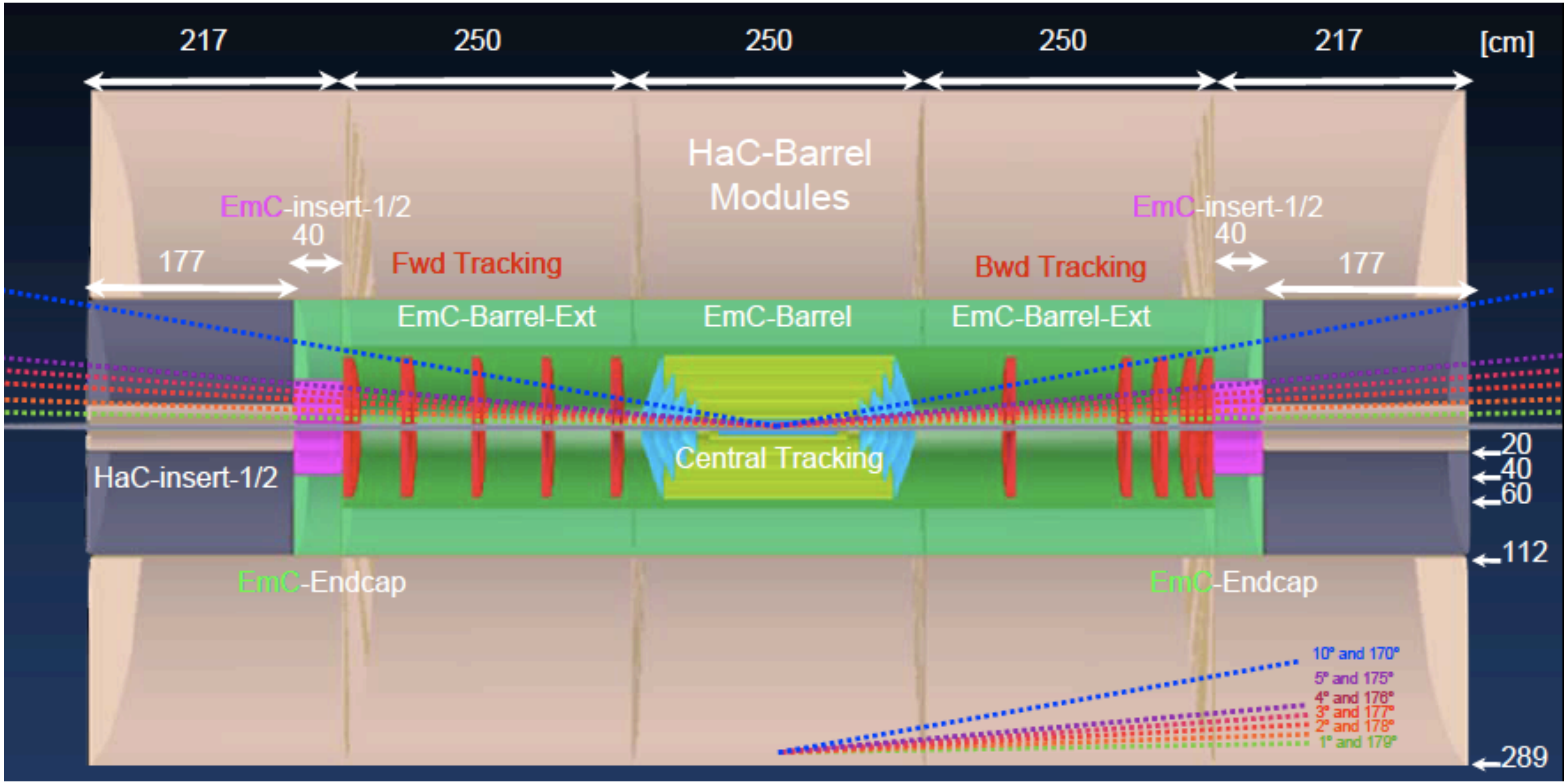
  gives 11 MW radiated power

J.Jowett

eA collisions may be realised at the LHC building on AA,pA: Pb-Pb (in 2010)

Need to maintain ion injector and possibly extend to Ca and Deuterons

Detector under Design (low x, high Q^2, eA)



P.Kostka, A.Pollini, R.Wallny et al, 9/09

New detector: high precision, large acceptance, LHC/ILC/HERA related, fwd. p,n,d, ..

Project Status

2007: (r)ECFA and CERN invite for CDR
2008: Reports to NuPECC (9/08), ICFA (10/08) and ECFA (11/08)
2009: 2nd workshop on the LHeC under auspieces of CERN, ECFA, NuPECC

2010: Conceptual Design Report (CDR)
[machine, interaction region, detector, physics: BSM, QCD+elweak, HPD**]**

Further consideration depends on CDR and LHC

Project may be realised within 10 years and thus fit to the 2nd phase of LHC

www.lhec.org.uk

Physics Programme of the LHeC

Unfolding completely the partonic structure of the proton (neutron and photon) and search for sub-substructure down to scales ten times below HERA's limit

Sensitive exploration of new symmetries and the grand unification of particle interactions with electroweak and strong interaction measurements of unprecedented precision

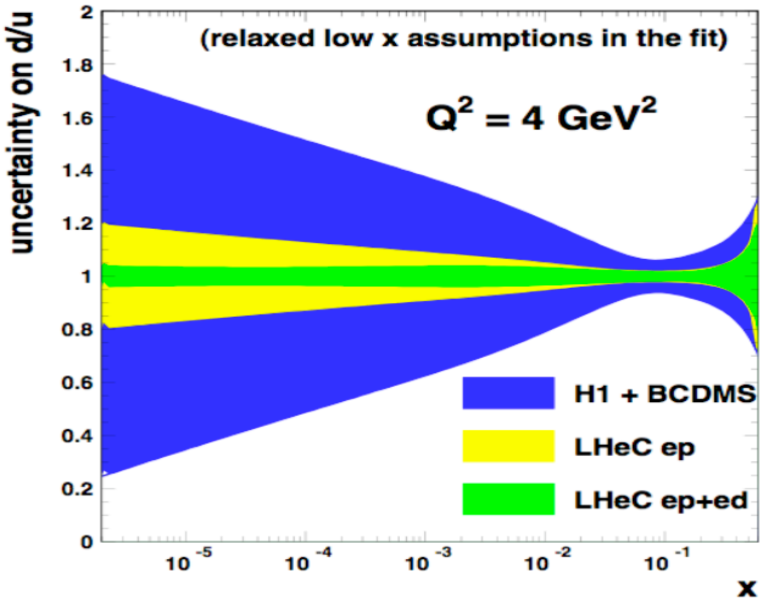
Search for and exploration of new Tera scale physics, in particular for singly produced new states (LQ, RPV SUSY, excited fermions), complementary to the LHC pp program

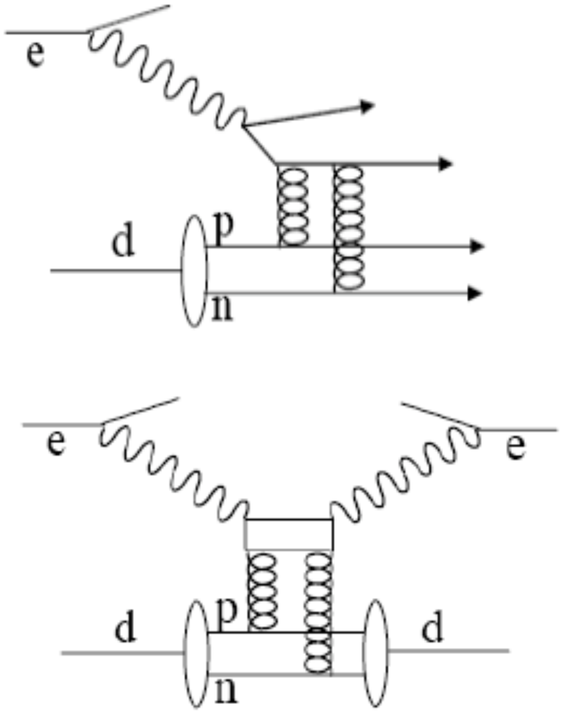
Exploration of high density matter (low x physics beyond the expected unitarity limit for the growth of the gluon density)

Unfolding the substructure and parton dynamics inside nuclei and study of quark-gluon plasma matter, by an extension of the kinematic range of lepton-nucleus scattering by 4 orders of magnitude

Neutron Structure

d/u at low x from deuterons



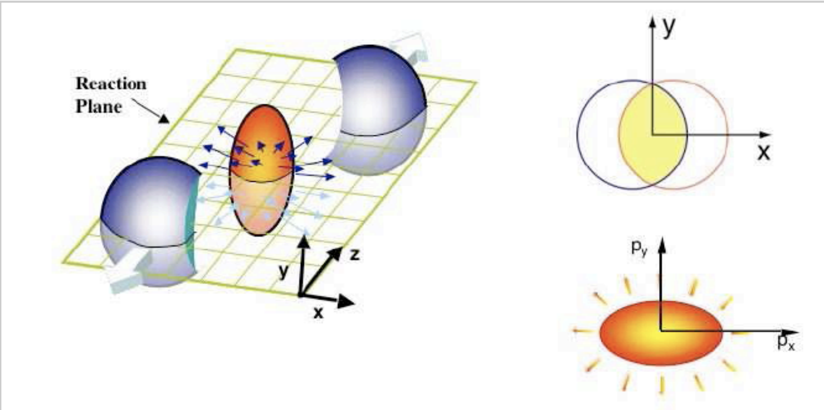


Neutron structure unknown in HERA range and below. Crucial to resolve parton structure and to predict scattering on nucleon rather than proton targets

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

Quark Gluon Plasma

Landau 1953. **RHIC**: QGP strongly coupled plasma with liquid behaviour
instead of weakly interacting gas of partons



M.Tannenbaum, Rept.Prog.Phys 65 (2006) 2005

Related to cold atoms and to superstring theory AdS/CFT

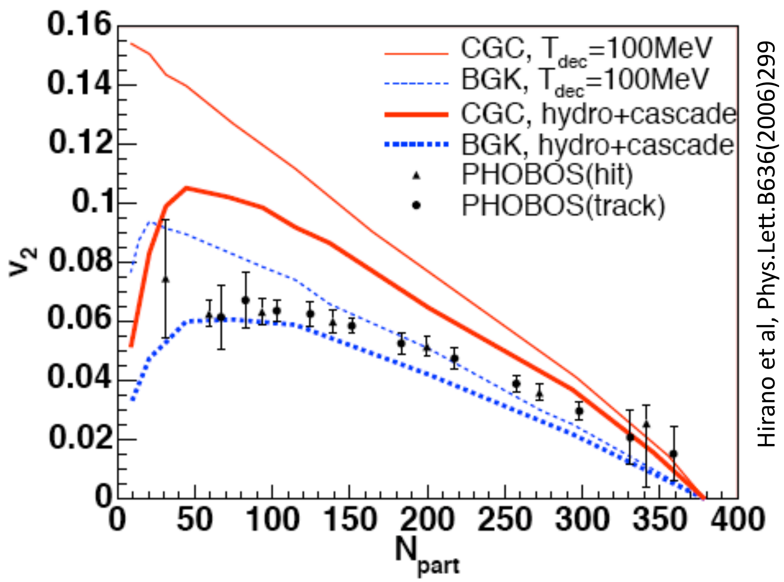
Collective flow in non-central collisions anisotropic

Anisotropy proportional to 1/viscosity of fireball, dominantly elliptic ("v_2" coefficient)

QGP most perfect liquid – smallest shear viscosity/entropy

Conclusions depend on initial fireball eccentricity

eA to measure the initial conditions of QGP.

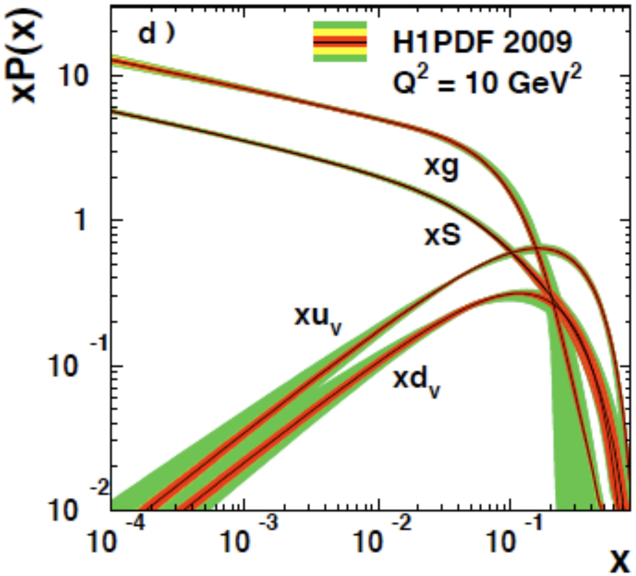


Hirano et al, Phys.Lett.B636(2006)299

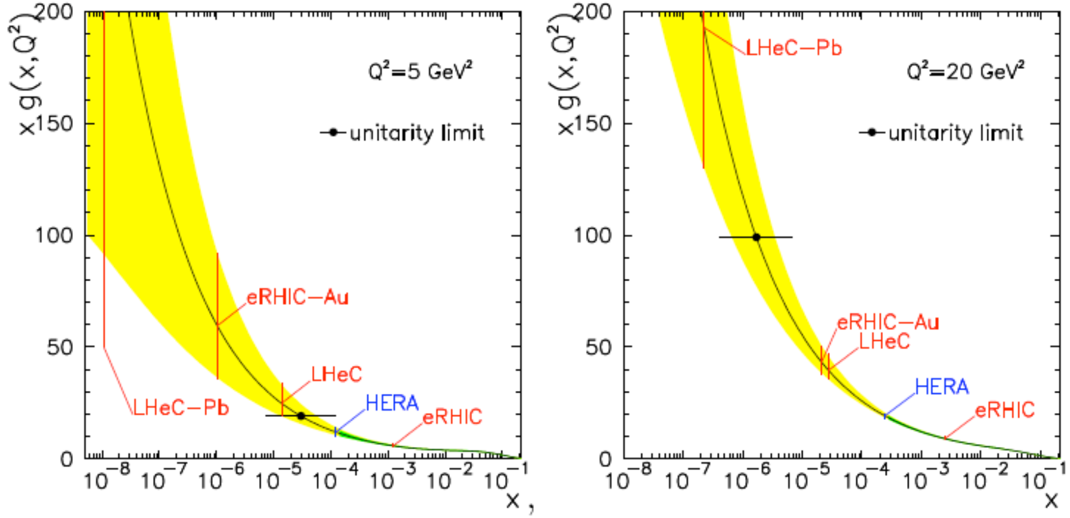
Colour Glass Condensate

Perturbatively calculable via non-linear evolution equations

HERA: Quark and gluon densities rise towards low Bjorken x
gluon dominance in DIS region.



H1 Collaboration, EPJ to appear



T.Lastovicka, M.Klein, DIS06

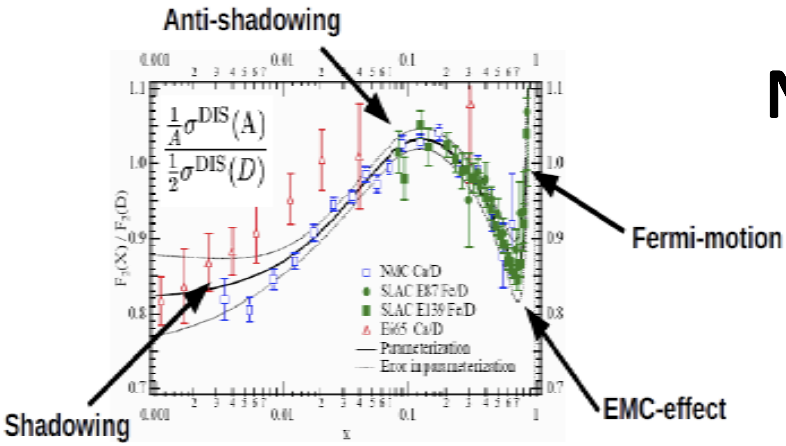
Expect saturation of rise at $\mathbf{Q^2_s \approx xg\,\alpha_s \approx c\,x^{-\lambda}A^{1/3}}$

Qualitative change of scattering behaviour:

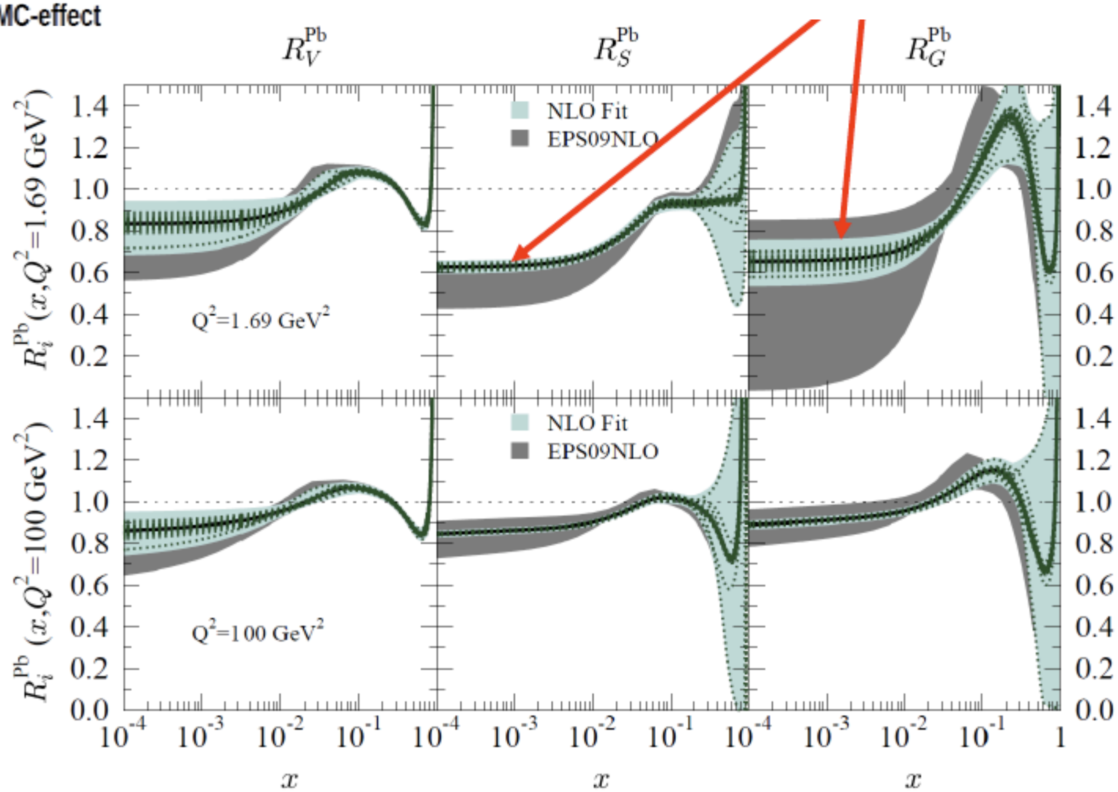
- Saturation of cross sections amplified with $A^{1/3}$
- Rise of diffraction to 50% of cross section
- hot spots of gluons or BDL?

Systematic evaluation of QGC with ep and eA and small α_s

Nuclear Parton Distributions



Quantitative improvement, but based on DIS DATA for the 1st time



K.Eskola, H.Paukkunen, C.Salgado, Divonne09

Shadowing ← diffraction

Fermi motion ← p tagging

p, D, Ca, Pb

LHeC will have immense impact on the partonic structure of nuclei

→ the basis for understanding partonic matter at high densities, complementary to AA, pA

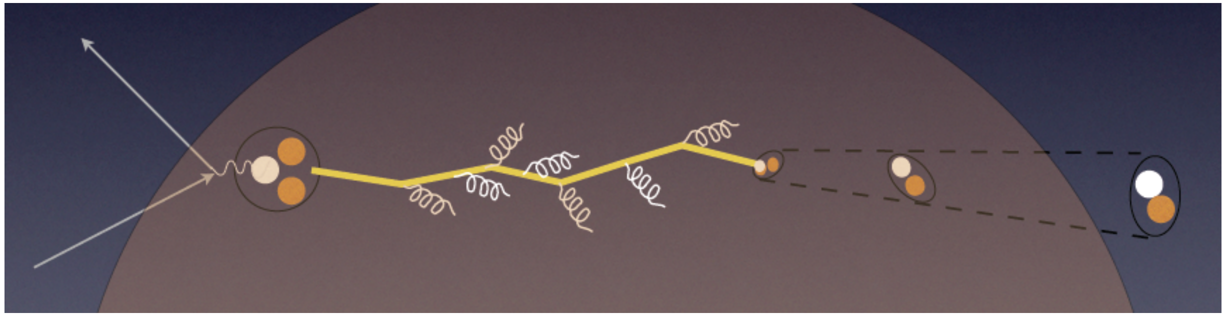
In-medium Hadronisation

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

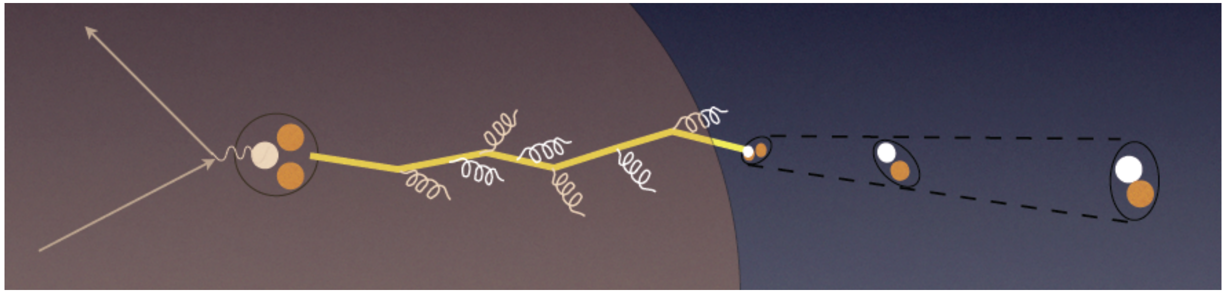
Low energy (ν): need of hadronization inside.

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, testing the energy loss mechanism: crucial for understanding of the medium produced in HIC characterised by jet quenching studies.

Detailed study of heavy quark hadronisation into D, B

Summary

The LHC offers a unique opportunity to build a new electron-hadron collider for which a Conceptual Design Report has been invited by CERN and ECFA. This is being worked out in a series of CERN-ECFA-NuPECC workshops with the aim to deliver the CDR in 2010.

The LHeC promises to exceed HERA by factors of 100 in luminosity and kinematic reach.

As an eA collider, building on the heavy ion programme at the LHC, the LHeC extends the range of lepton-nucleus scattering by 4 orders of magnitude in x and Q^2 .

The physics programme is extremely rich with unique potential in physics beyond the standard model and high precision, thus far reaching, QCD and electroweak measurements. The LHeC may find excited leptons (electrons and neutrinos) or quarks and thus lead to a new layer of matter (below 10^{-19}m) or study unified quarks and leptons.

For proton's and nuclear structure the LHeC offers exciting prospects as on the complete experimental unfolding of the partonic contents of the proton, neutron and nuclei. With a variety of features added, as heavy quark and final state physics or tagged deuteron measurements, the LHeC provides the benchmark information for quark-gluon plasma and high density matter physics as studied in pA and AA.

The project requires addition of a new electron beam to the LHC and building a suitable detector for high precision measurements. It may fit to the LHC upgrade in time and operation.

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=8.5m, 2T)
[Return Fe not drawn,
2 coils w/o return Fe studied]

Central Detector

Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
[Gas on Slimmed Si Pixels]
[0.6m radius for 0.05% * pt in 2T field]
Pixels
Elliptic beam pipe (~3cm)

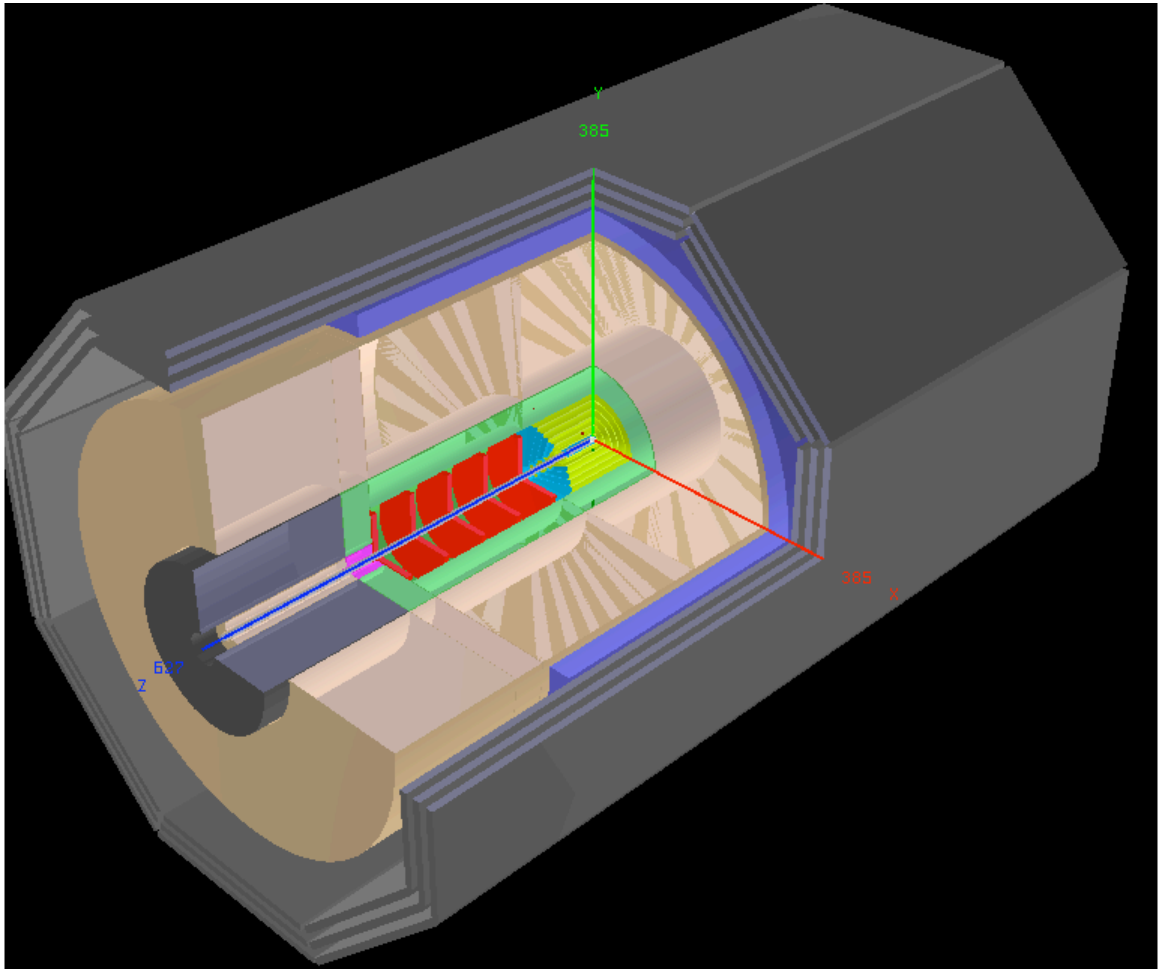
Fwd Spectrometer
(down to 1^o)

Tracker
Calice (W/Si)
FwdHadrCalo

Bwd Spectrometer
(down to 179^o)

Tracker
Spacal (elm, hadr)

LHeC Detector: version for low x and eA



PK et al., April2009

Extensions in fwd direction (tag p,n,d) and backwards (e,γ)