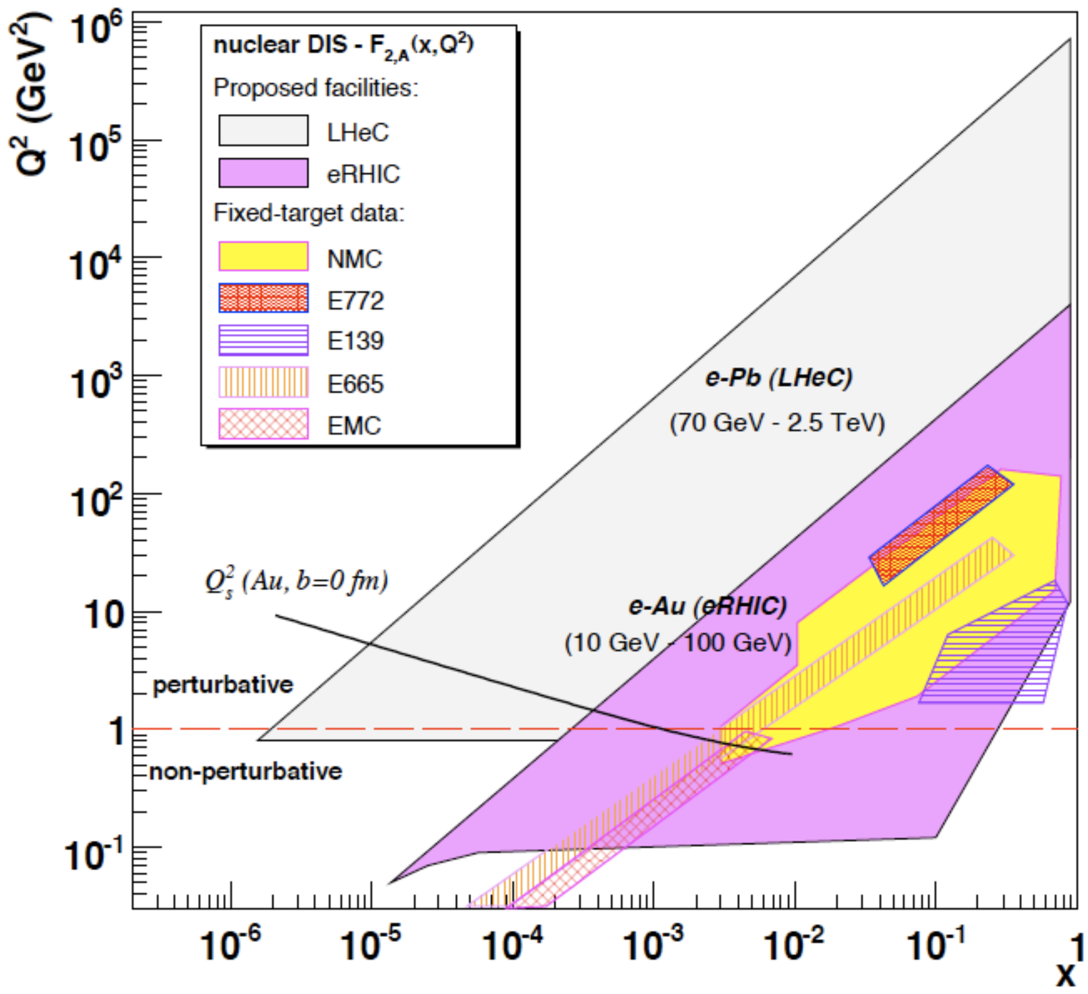
# The LHeC – a New Facility for Nuclear Physics

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 extends the kinematic range of eA by four orders of magnitude.

**Project**
**Accelerator**
**Detector**
**Physics**

**www.lhec.org.uk**

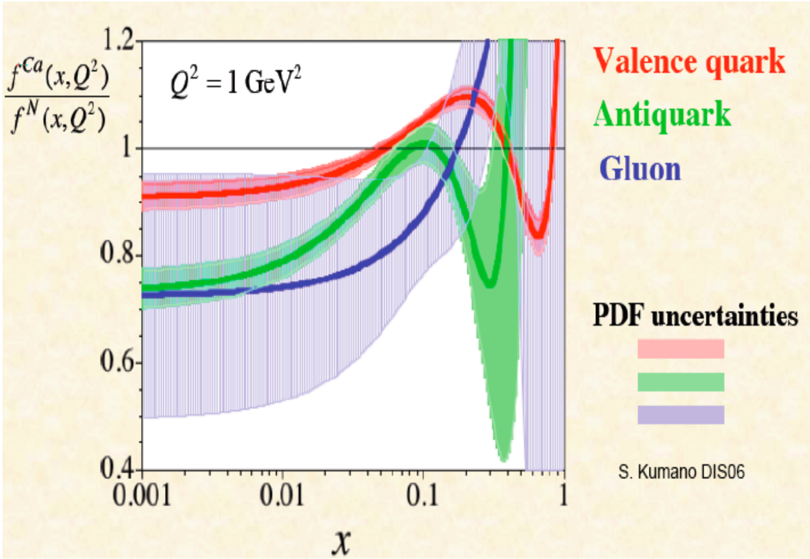

Max Klein
University of Liverpool



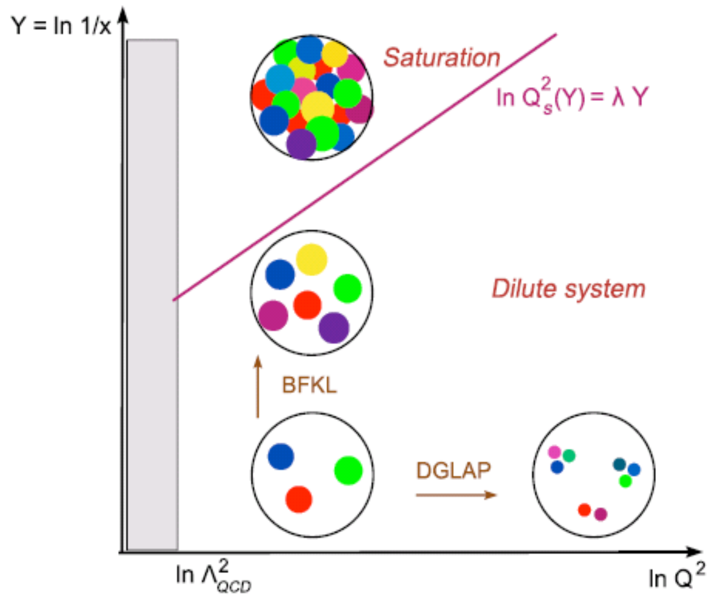
NuPECC Scoping Workshop
Frankfurt/Main 13/10/09

# Nuclear Physics with the LHeC

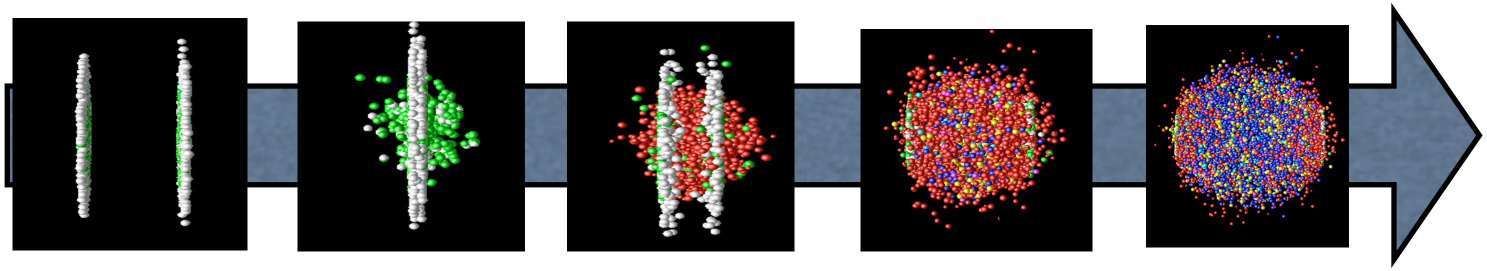
## 1. Nuclear Parton Distribution Functions




## 2. Saturation (low x, nonlinear QCD)




## 3. Quark Gluon Plasma, its initial and final states



Gluon emission from saturated nuclei Glasma? QGP Reconfinement

# Project Development

www.lhec.org.uk

**1990: LEP-LHC Workshop at Aachen**

**2006:** J. Dainton, M.Klein, P.Newman, E.Perez, **F.Willeke** 2006 JINST **1** 10001

**2007: (r)ECFA and CERN invite for CDR.**
organise Steering Group, SAC, six working groups.

**2008: Reports to NuPECC (9/08), ICFA (10/08) and ECFA (11/08)**

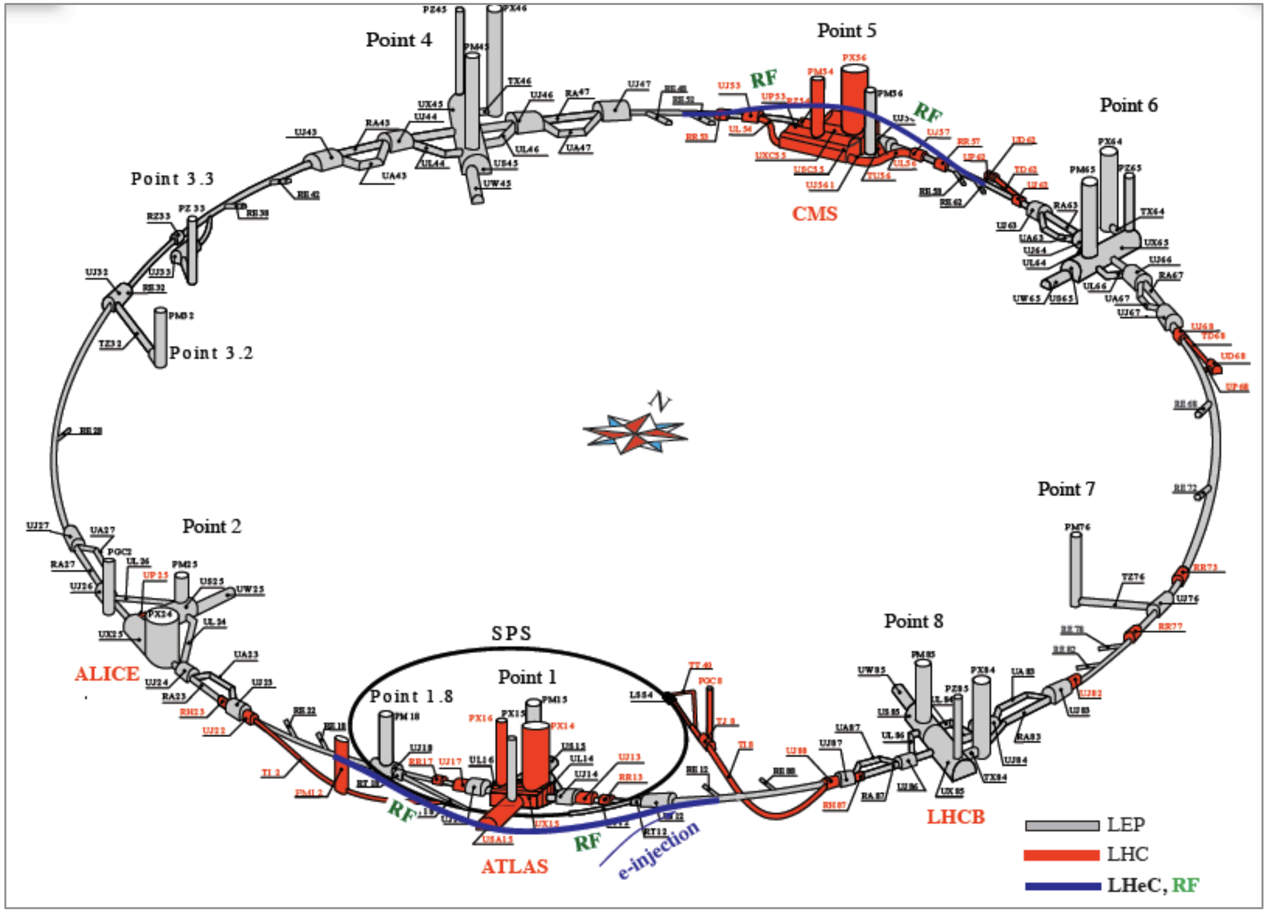
**2009: 2$^{nd}$** CERN-ECFA-NuPECC **workshop on the LHeC at Divonne (9/09)**

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

**Further consideration depends on CDR, on the LHC and on all of us.**

**Project may be realised within 10 years and thus fit to the 2$^{nd}$ phase of LHC**

# Ring-Ring ep/eA



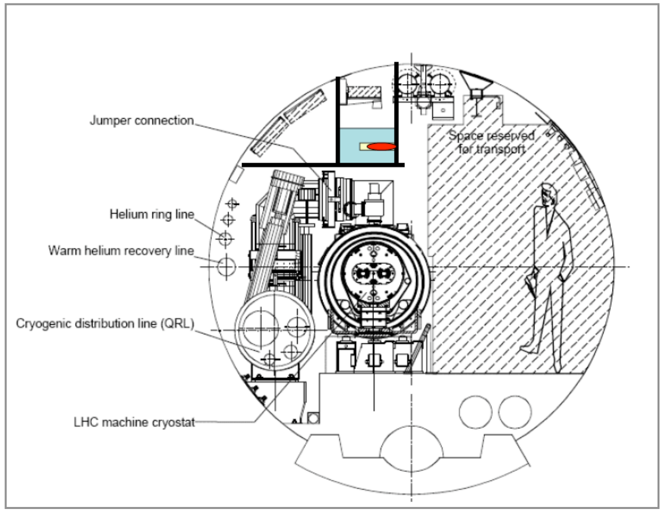

$E_e$=$E_{inj}$ … 80 GeV. $L_{ep}$~$10^{33}cm^{-2}s^{-1}$ (100 times HERA)

F.Willeke
B.Holzer
et al

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

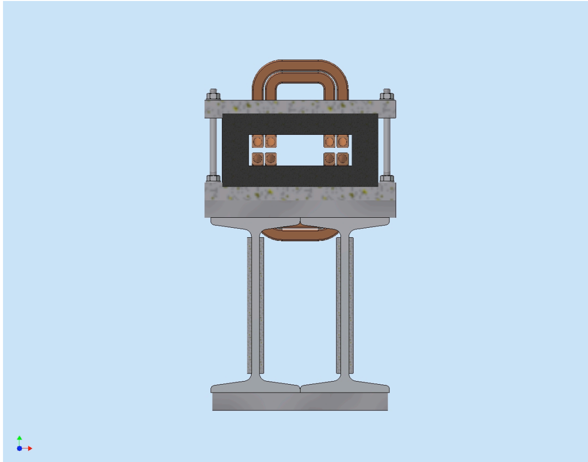
# Major Ring Developments

## Study of machine installation




F.Willeke, Kh.Mess

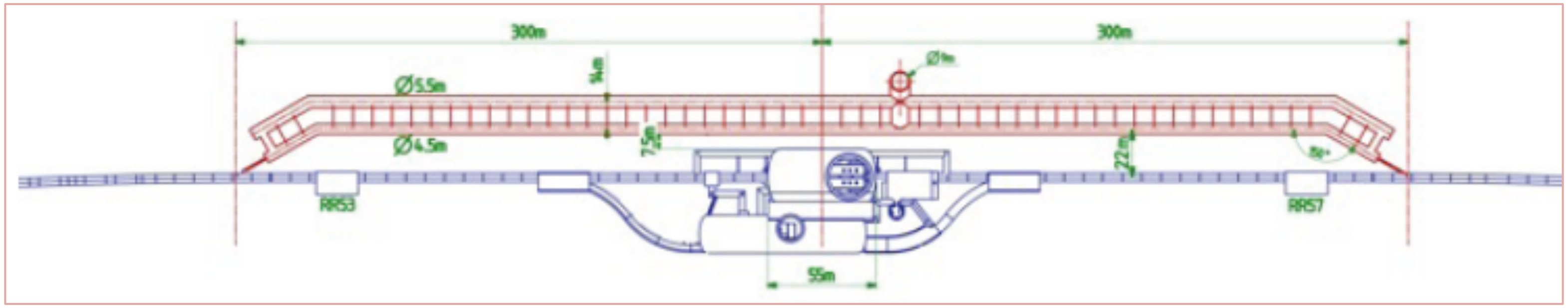
## New dipole magnet (BNP)



O-shaped magnet with ferrite core

P.Wobbly, I.Morosov

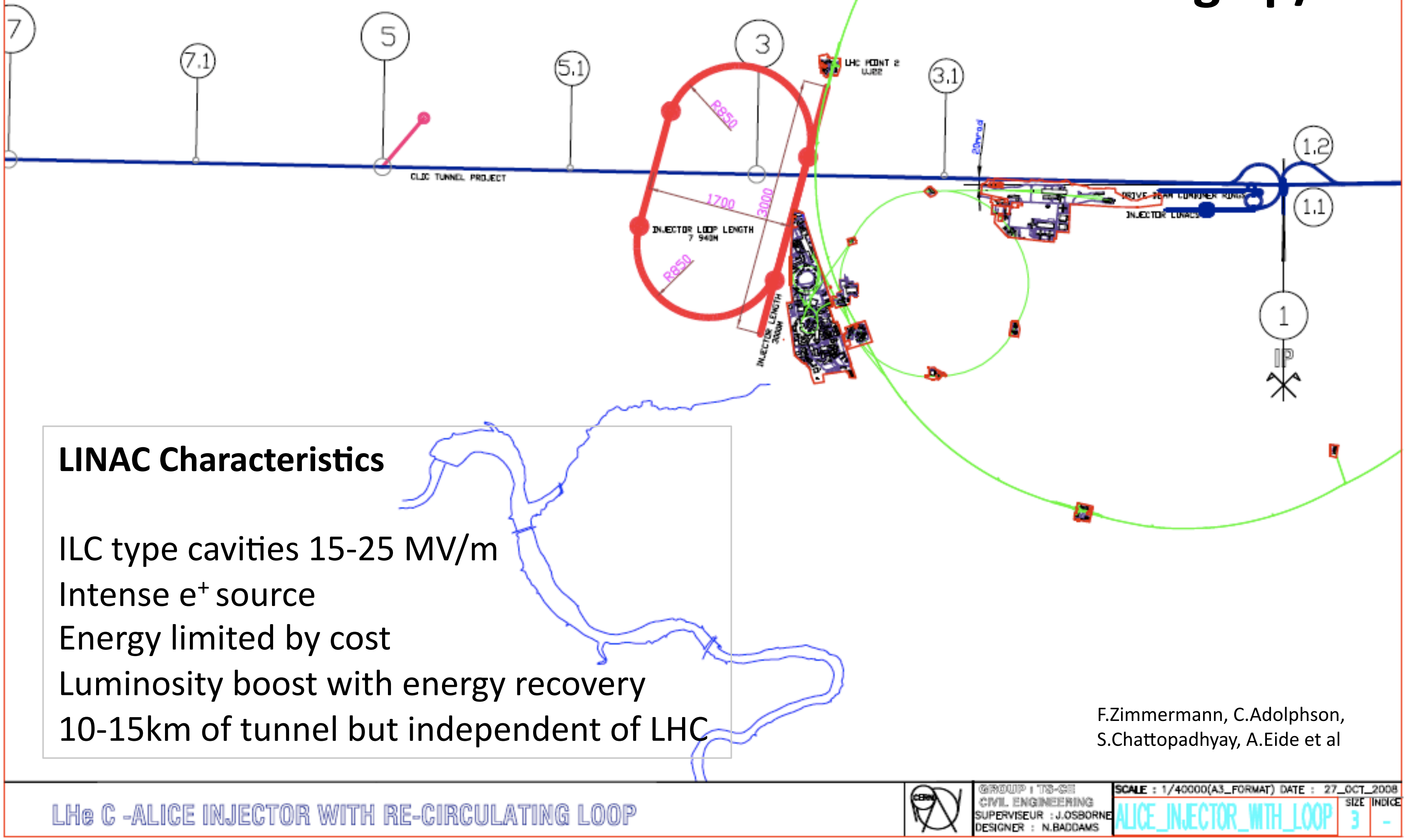
## Sketch of bypass tunnel around CMS (double tunnel, 1 shaft, houses rf)




J.Osbourne, S.Myers, H.Burckardt

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

# Linac-Ring ep/eA




**LINAC Characteristics**

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

$$k_b = 592 \text{ bunches of } N_b = 7\times10^7 \ {}^{208}\mathrm{Pb}^{82+} \text{ nuclei}$$

- Assume lepton injectors can create matching train of $e^-$

$$k_b = 592 \text{ bunches of } N_b = 1.4\times10^{10} \ \mathrm{e}^-$$

- Lepton-nucleus or lepton-nucleon luminosity in ring-ring option at 70 GeV

$$L = 1.09\times10^{29} \ \mathrm{cm}^{-2}\mathrm{s}^{-1} \quad \Leftrightarrow \quad L_{en} = 2.2\times10^{31} \ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

gives 11 MW radiated power

J.Jowett

**L(en) in Pb may be similar or better than L(ep) HERA.**

**Need to maintain ion injector beyond LHC first phase and possibly extend it to Calcium and Deuterons**

# **LHeC Detector:** version for low x and eA

**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**

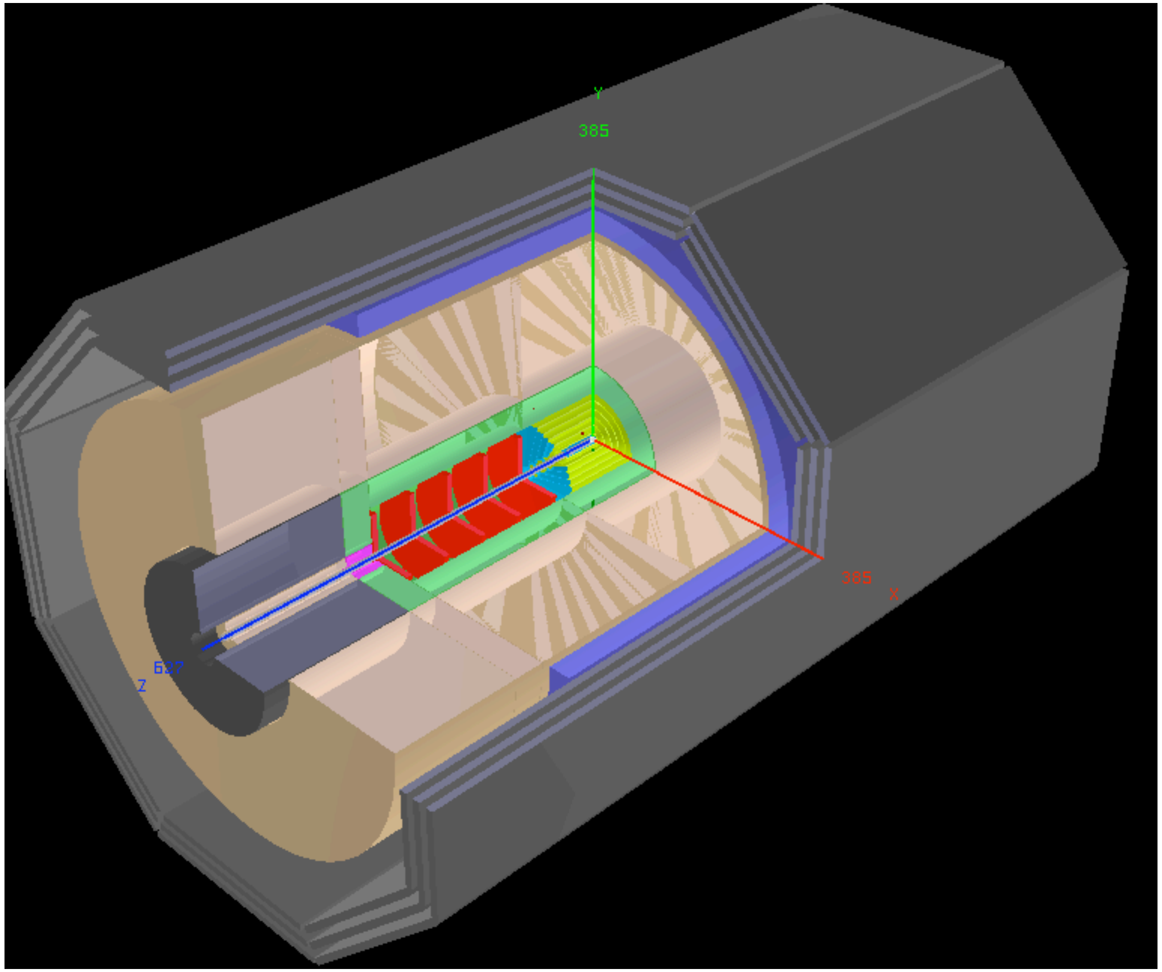
**Hadronic Calo (Fe/LAr)**
**El.magn. Calo (Pb,Sc)**
**GOSSIP (fwd+central)**
**[Gas on Slimmed Si Pixels]**
**[0.6m radius for 0.05% * pt in 2T field]**
Pixels
Elliptic beam pipe (~3cm)

**Fwd Spectrometer**
**(down to 1°)**

**Tracker**
**Calice (W/Si)**
**FwdHadrCalo**

**Bwd Spectrometer**
**(down to 179°)**

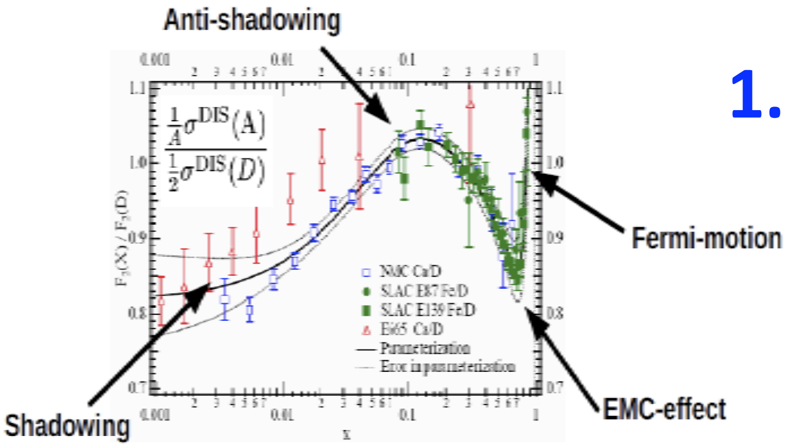
**Tracker**
**Spacal (elm, hadr)**



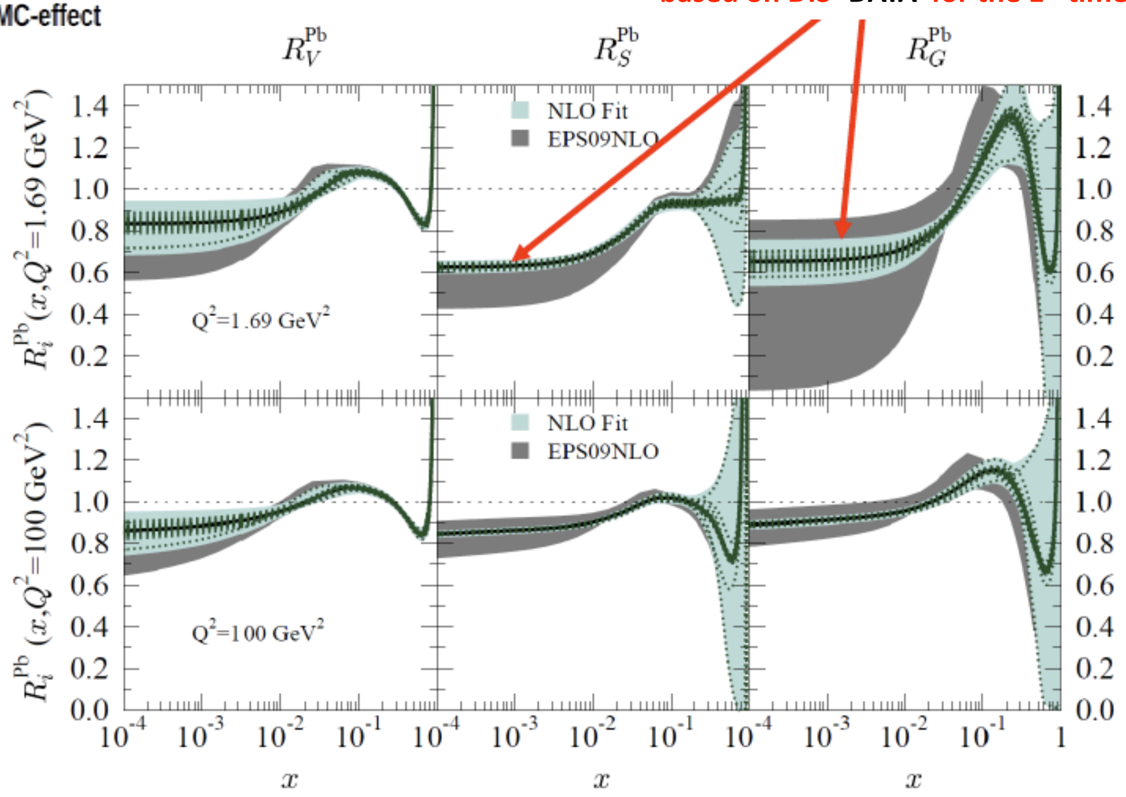

Pkostka, A.Pollini et al., April2009

**Extensions in fwd direction (tag p,n,d) and backwards (e,γ) under study.**

# 1. Nuclear Parton Distributions




Study using eA LHeC pseudodata
Quantitative improvement, but
based on DIS `DATA' for the 1st time




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

Shadowing ← diffraction

Fermi motion ← p tagging

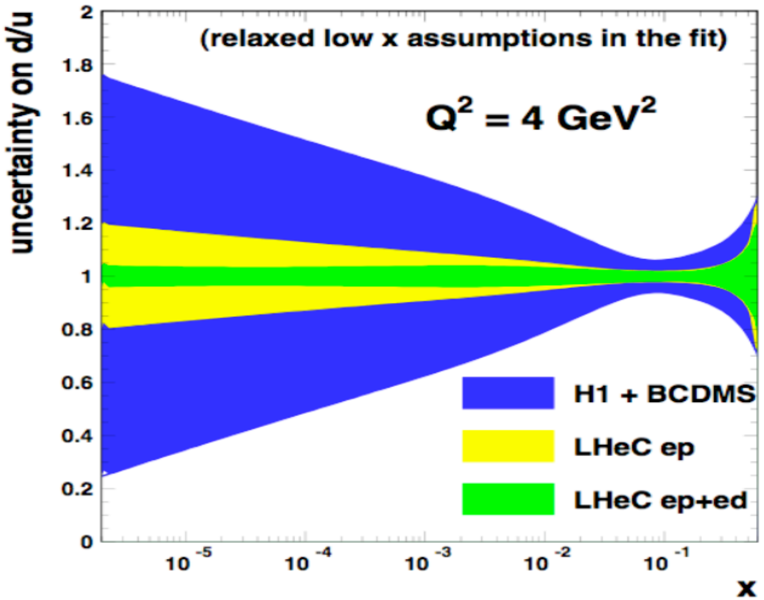
p, D, Ca, Pb

LHeC will have immense impact on the partonic structure of nuclei

**→ A complete determination of nPDFs in grossly extended range, into nonlinear regime**

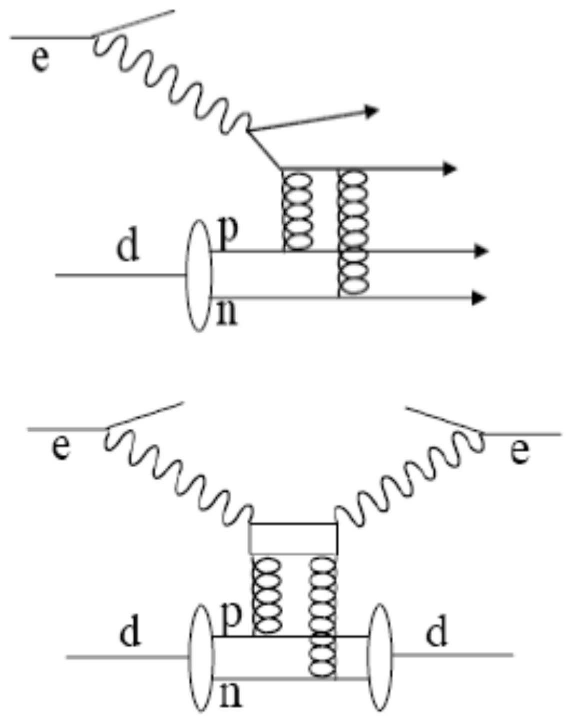
# The ignored Neutron

d/u at low x from deuterons




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

**Collider unique to en (p tag, diffraction)**

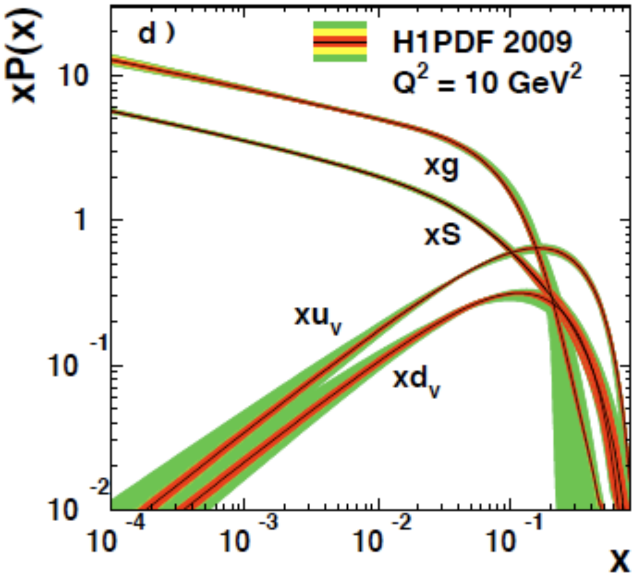



In eA at the collider, test Gribovs relation between shadowing and diffraction, control nuclear effects at low Bjorken x to high accuracy

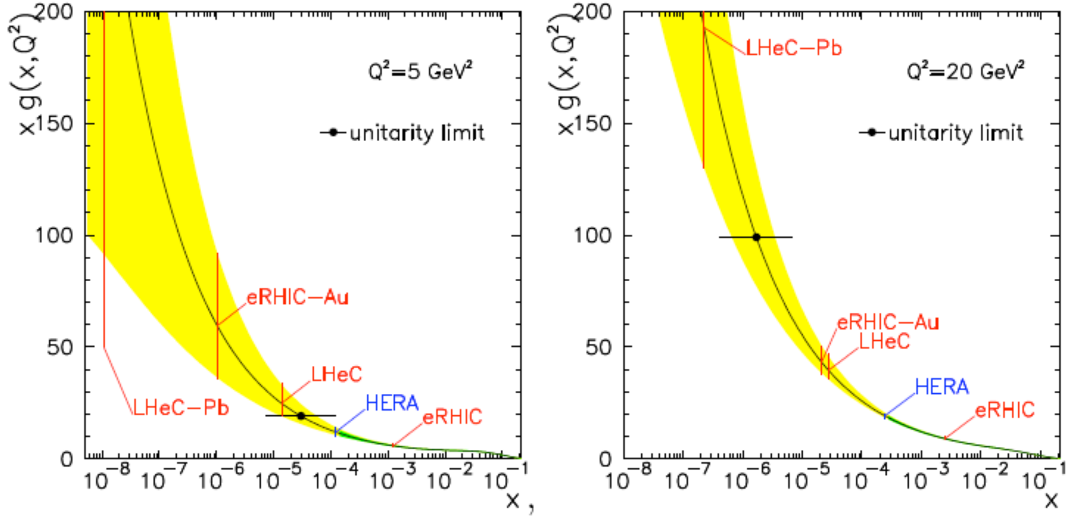
# 2. Colour Glass Condensate - Saturation

Perturbatively calculable via non-linear evolution equations

**HERA**: Quark and gluon densities in p rise towards low Bjorken x. Gluon dominant but no clear proof of nonlinear effects.




H1 Collaboration, EPJ to appear




T.Lastovicka, M.Klein, DIS06

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

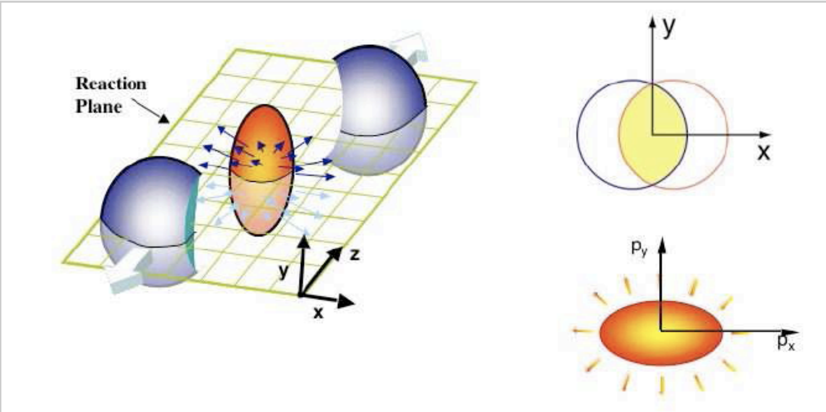
Qualitative change of scattering behaviour:

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

**The LHeC is bound to discover saturation in DIS both in ep and in eA in a region where $\alpha_s$ is small**

# 3. 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]**

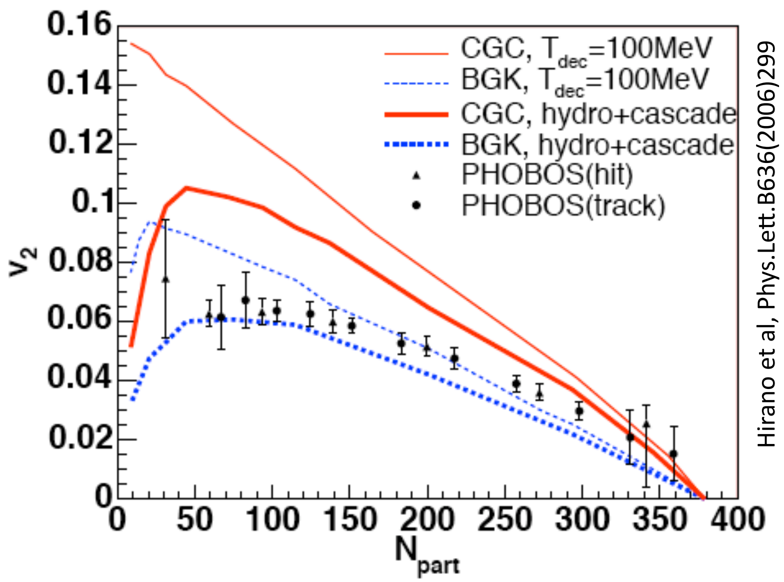
Collective flow in non-central collisions anisotropic

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

U.Heinz arXiv:0907.4256 (nucl.th)

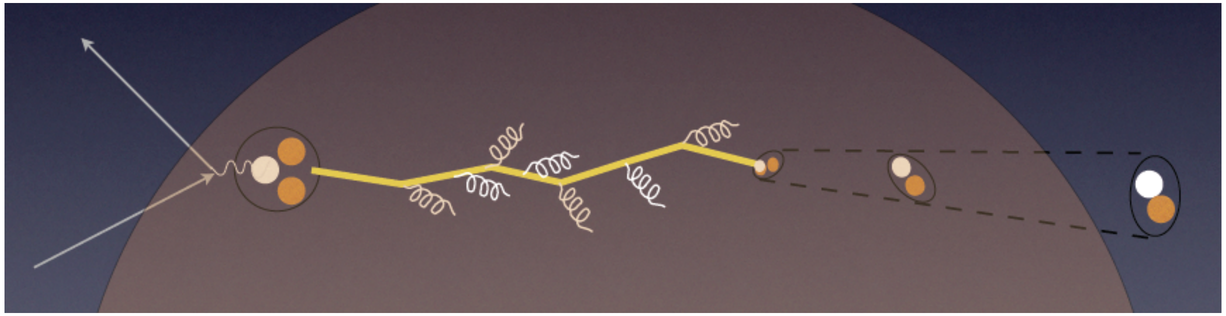
# In-medium Hadronisation

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).

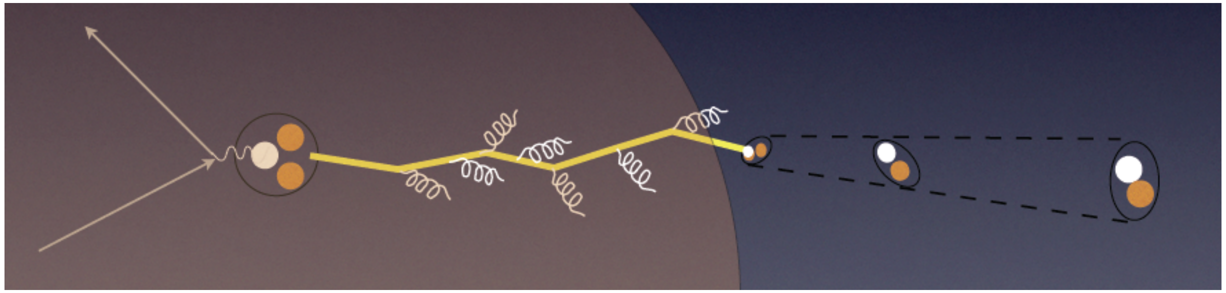
Low energy ($\nu$): need of hadronization inside.

Parton propagation: pt broadening

Hadron formation: attenuation



High energy ($\nu$): partonic evolution altered in the nuclear medium.



W.Brooks, Divonne09

**LHeC :**

**+ study the transition from small to high energies in much extended range wrt. HERMES, Jlab**

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

**+ detailed study of heavy quark hadronisation …**

# 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-A scattering by 4 orders of magnitude in x and $Q^2$ . It has to violate unitarity.

The HEP programme is extremely rich with unique potential in physics beyond the standard model and high precision, thus far reaching, QCD and electroweak measurements and essential complementarity to the LHC pp programme (SM and BSM).
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 quark-lepton states should these exist.

For proton's and nuclear structure, the LHeC offers unique prospects as on the complete experimental unfolding of the partonic contents of the proton, neutron and nuclei.
The LHeC is bound to discover saturation and thus to determine the initial state of the QGP. This has far reaching theoretical (QCD, strings, Hydrodynamics..) and experimental (LHC, neutrino-astrophysics) consequences. The programme is much wider than 1-3.

The project requires addition of a new electron beam to the LHC and building a suitable detector for high precision measurements. It thus represents challenging tasks for the development and maintenance of the technical art of our joint fields (HEP and NP).

The project may fit to the LHC upgrade in time and operation. Ion beams are to be kept.

Special thanks to

N.Armesto
O.Bruening,
B.Cole,
P.Kostka,
P.Newman,
A.Stasto,
U.Wiedemann
and many others spending time on the LHeC,

and to NuPECC for its interest.

**You are invited to take further part in accelerator, detector, physics developments**

# Physics Programme of the LHeC

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

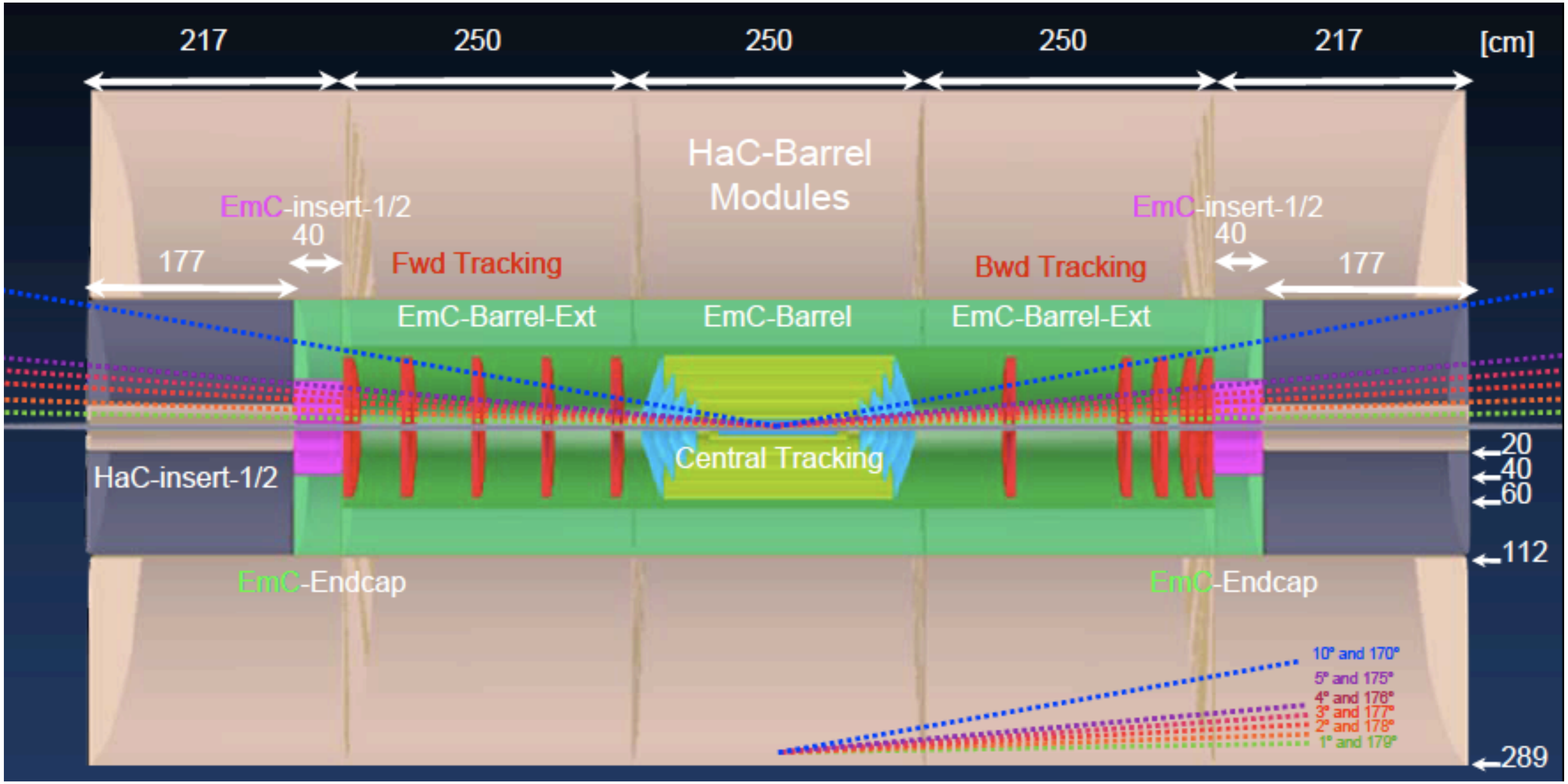
+ Sensitive exploration of new symmetries and the grand unification of particle interactions with electroweak and strong interaction measurements of unprecedented precision.

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

+ 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 the study of quark-gluon plasma matter by an extension of the kinematic range by four orders of magnitude.

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




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

**high precision, large acceptance, LHC/ILC/HERA related, Forward tagging of p, n, d**