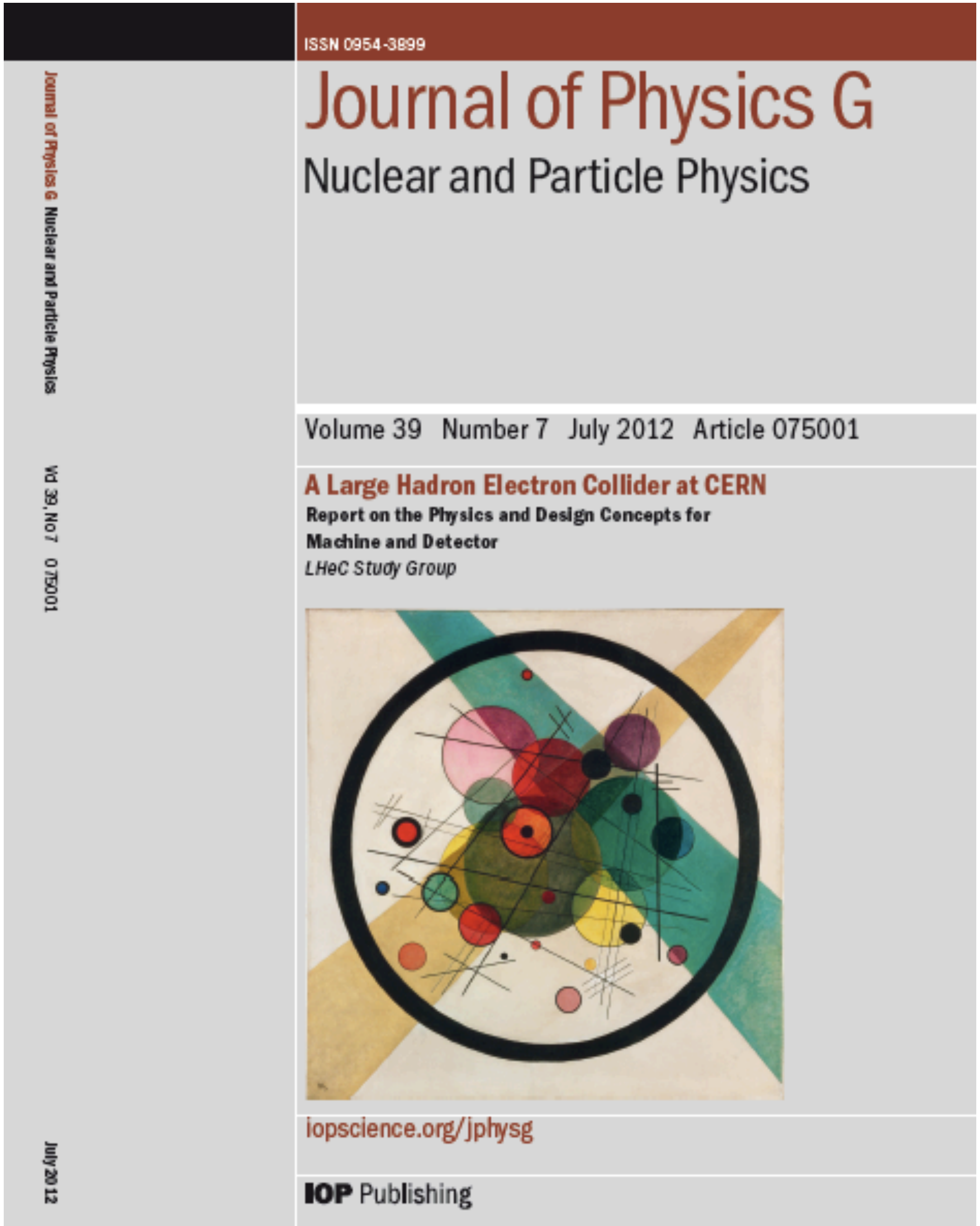



# The LHeC Project

Max Klein
University of Liverpool

For the LHeC Study Group

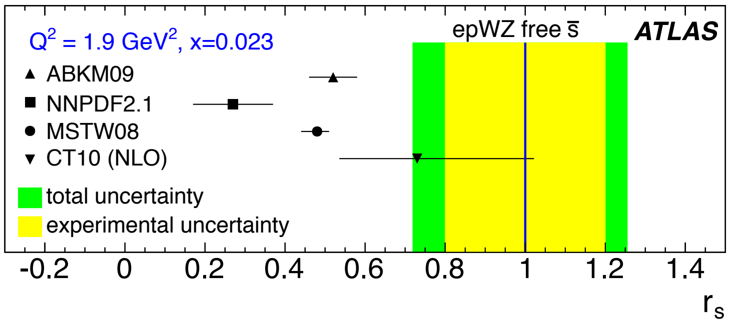
Brief overview on the Status and Prospects

at this conference:
A.Polini – Detector
C.Glasman – QCD
P.Newman – eA
U.Klein – Higgs

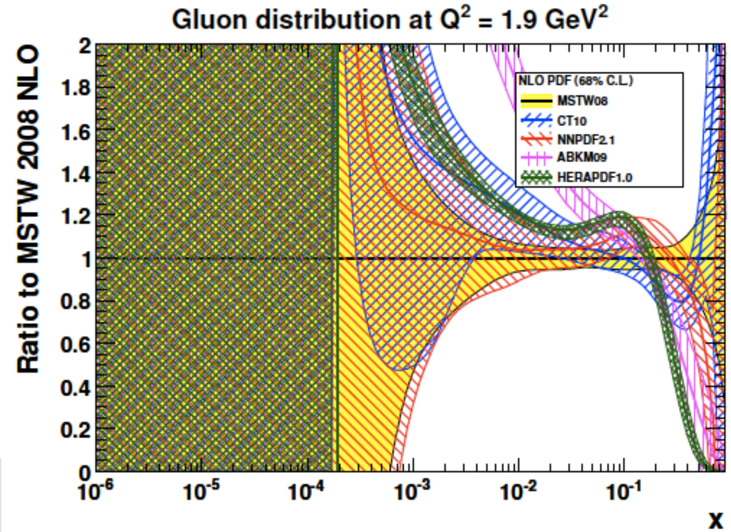
ICHEP 2012 Melbourne 7.7.

**Precision determination of ALL pdfs**

u, $u_v$, d, $d_v$, **s**, c, b and topPDF



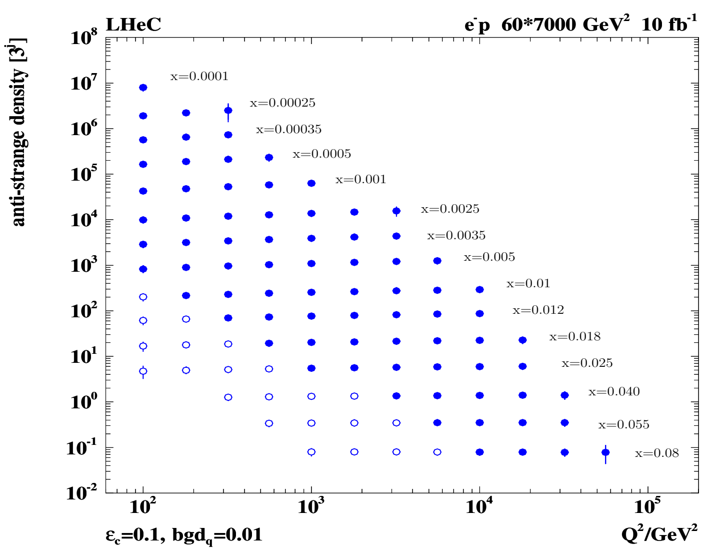

s/d from HERA+ATLAS(W,Z)



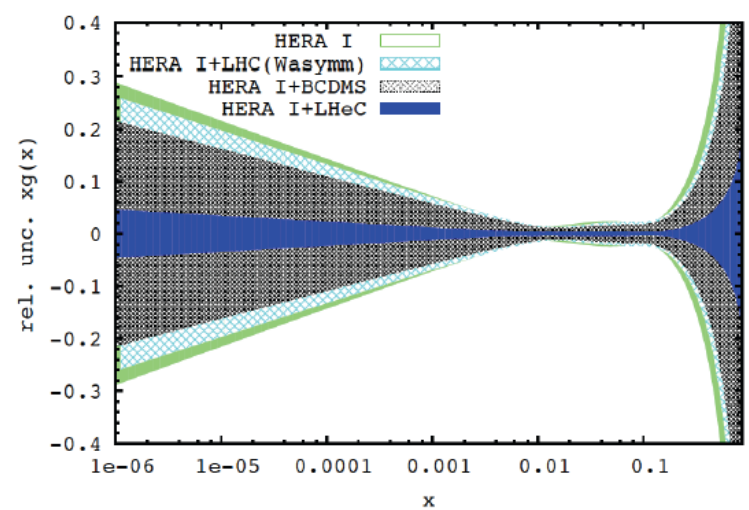

Corner Stones

Mapping of gluon: hi x/M: SUSY at LHC?

Low x: saturation? **End of DGLAP??**




Strange density from Ws →c in CC at LHeC



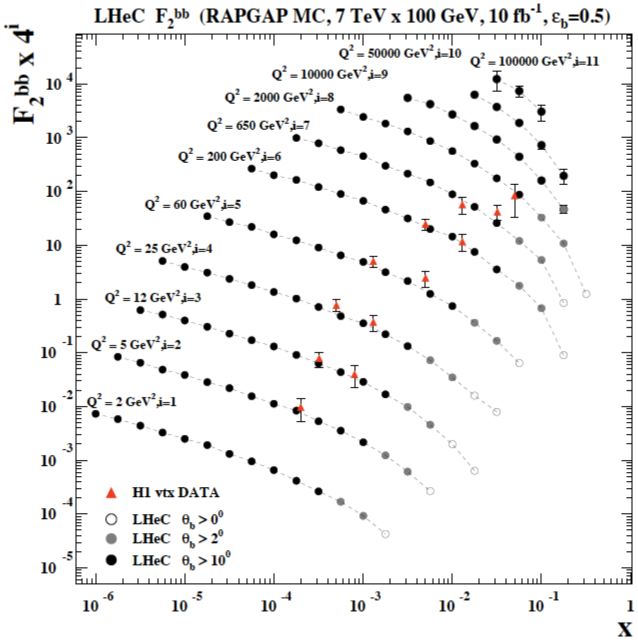

HERA + LHeC

Joint **Electroweak**-QCD precision ($\sin^2\theta(\mu)$,v,a)

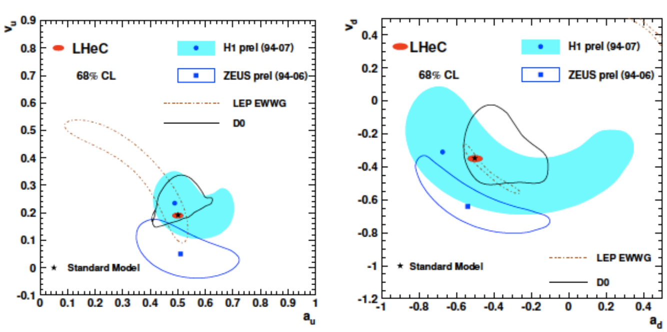
**Factorisation? Generalised, unintegrated, diffractive,γ* partons. Odderon? npQCD-string thy?..**

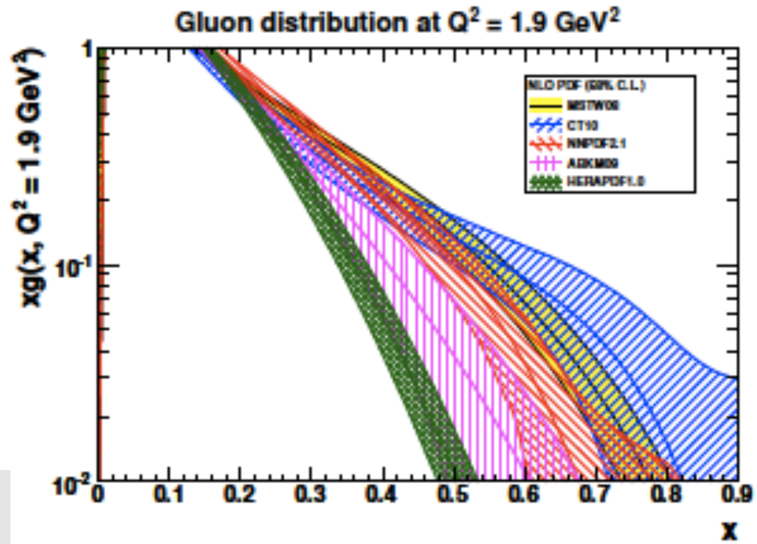
**Precision determination of ALL pdfs**

u, $u_v$, d, $d_v$, s, c, **b** and topPDF




Beauty density from γ/Zb →b in NC at LHeC

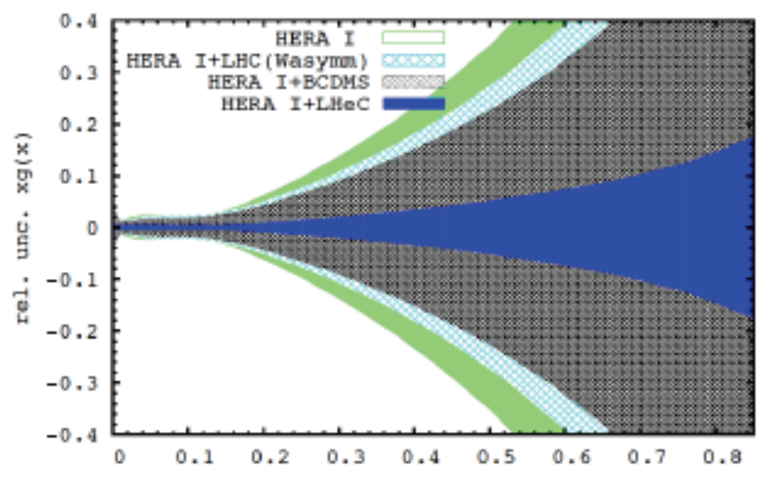



Corner Stones

Mapping of gluon: hi x/M: **SUSY at LHC?**

Low x: saturation? End of DGLAP??



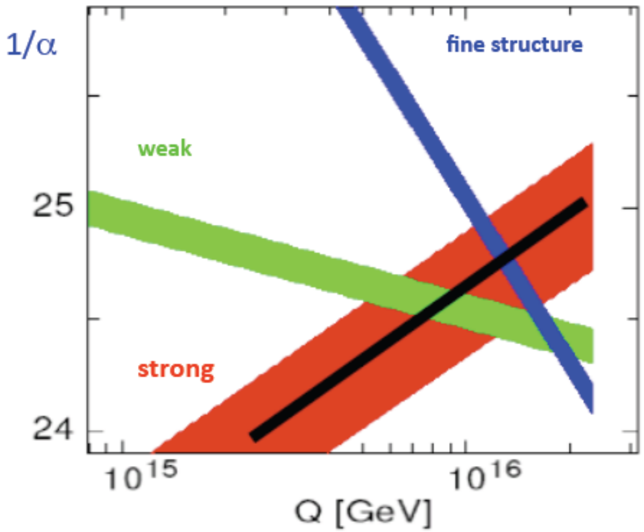

HERA + LHeC

Joint **Electroweak**-QCD precision ($\sin^2\theta(\mu)$,v,a)

**Factorisation? Generalised, unintegrated, diffractive,γ* partons. Odderon? npQCD-string thy?..**

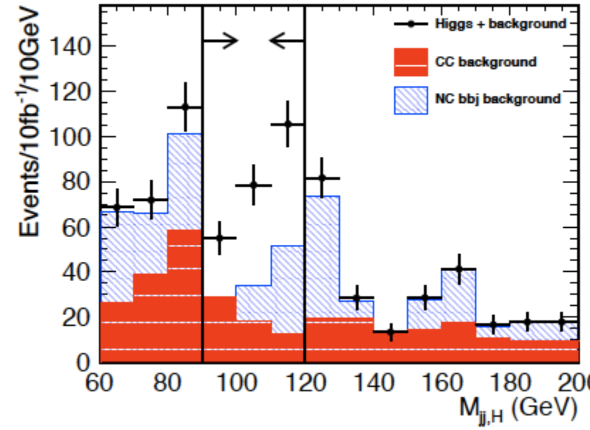
**Grand unification of couplings,**

$\alpha_s$ to 0.1%, $\delta M_c$=3MeV from $F_2^{cc}$




**~4% precise WW-H-bb vertex, CP**

Higgs: even-odd from MET-jet angle

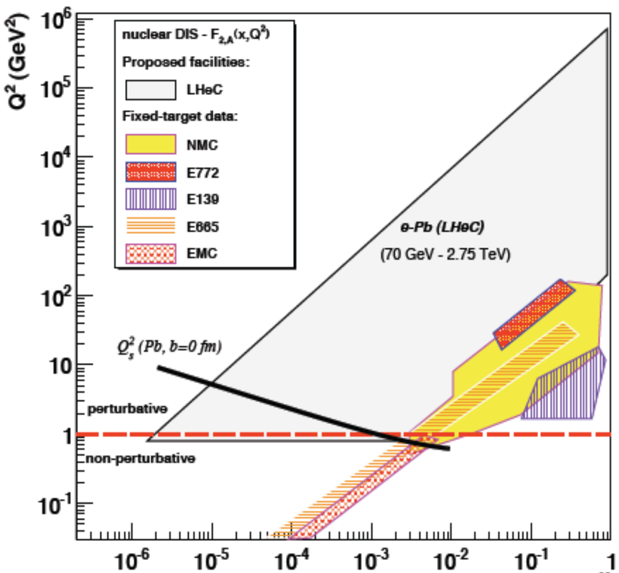



Initial study with non-optimum detector

# New Physics

**Leptoquarks,RPV SUSY**

Determine design of LHeC




**Huge impact on heavy ion physics**:

Black-body limit,

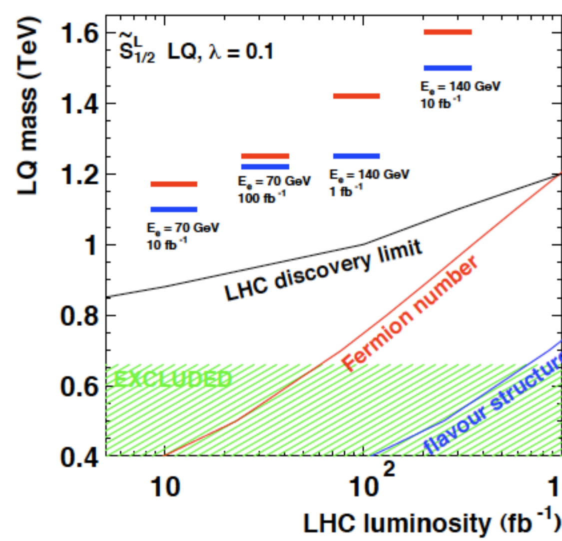
Initial state of QGP,

Nuclear PDFs,

Hadronization

in/outside media..

**Neutron from eD**




**CI to 40 TeV, excited leptons..**

LHeC

# The last year

Journal of Physics G: Nuclear and Particle Physics > Volume 39 > Number 7

J L

Abelleira Fernandez *et al* 2012 *J. Phys. G: Nucl. Part. Phys.* **39** 075001 doi:10.1088/0954-3899/39/7/075001 (http://dx.doi.org/10.1088/0954-3899/39/7/075001)

## A Large Hadron Electron Collider at CERN Report on the Physics and Design Concepts for Machine and Detector

FREE ARTICLE

J L Abelleira Fernandez[16,23], C Adolphsen[57], A N Akay[3], H Aksakal[39], J L Albacete[52], S Alekhin[17,54], P Allport[24], V Andreev[34], R B Appleby[14,30], E Arikan[39], N Armesto[53], 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], G Brandt[44], H Braun[65], S Brodsky[57], O Brüning[16], E Bulyak[12], A Buniatyan[17], H Burkhardt[16], I T Cakir[2], O Cakir[1], R Calaga[16], V Cetinkaya[1], E Ciapala[16], R Ciftci[1], A K Ciftci[1], B A Cole[38], J C Collins[48], O Dadoun[42], J Dainton[24], A De Roeck[16], D d'Enterria[16], A Dudarev[16], A Eide[60], R Enberg[63], E Eroglu[62], K J Eskola[21], L Favart[8], 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], 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], J M Jimenez[16], J M Jowett[16], H Jung[17], H Karadeniz[2], D Kayran[37], A Kilic[62], K Kimura[58], M Klein[24], U Klein[24], T Kluge[24], F Kocak[62], M Korostelev[24], A Kosmicki[16], P Kostka[17], H Kowalski[17], G Kramer[18], D Kuchler[16], M Kuze[58], T Lappi[21], 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], S Moch[17], I I Morozov[40], Y Muttoni[16], S Myers[16], S Nandi[55], Z Nergiz[39], P R Newman[6], 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[7], V Ptitsyn[37], Y Pupkov[40], V Radescu[17], S Raychaudhuri[35], L Rinolfi[16], R Rohini[35], J Rojo[16,31], S Russenschuck[16], M Sahin[3], C A Salgado[53], K Sampei[58], R Sassot[9], E Sauvan[4], 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], H Spiesberger[29], A M Stasto[48], M Strikman[48], M Sullivan[57], S Sultansoy[3], Y P Sun[57], B Surrow[11], L Szymanowski[66], P Taels[5], I Tapan[62], T Tasci[22], E Tassi[10], H Ten Kate[16], J Terron[28], H Thiesen[16], L Thompson[14,30], K Tokushuku[61], R Tomás García[16], D Tommasini[16], D Trbojevic[37], N Tsoupas[37], J Tuckmantel[16], S Turkoz[1], T N Trinh[47], K Tywoniuk[26], G Unel[20], J Urakawa[61], P VanMechelen[5], A Variola[52], R Veness[16], A Vivoli[16], P Vobly[40], J Wagner[66], R Wallny[68], S Wallon[43,46], G Watt[16], 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] and F Zomer[42] (LHeC Study Group)

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)

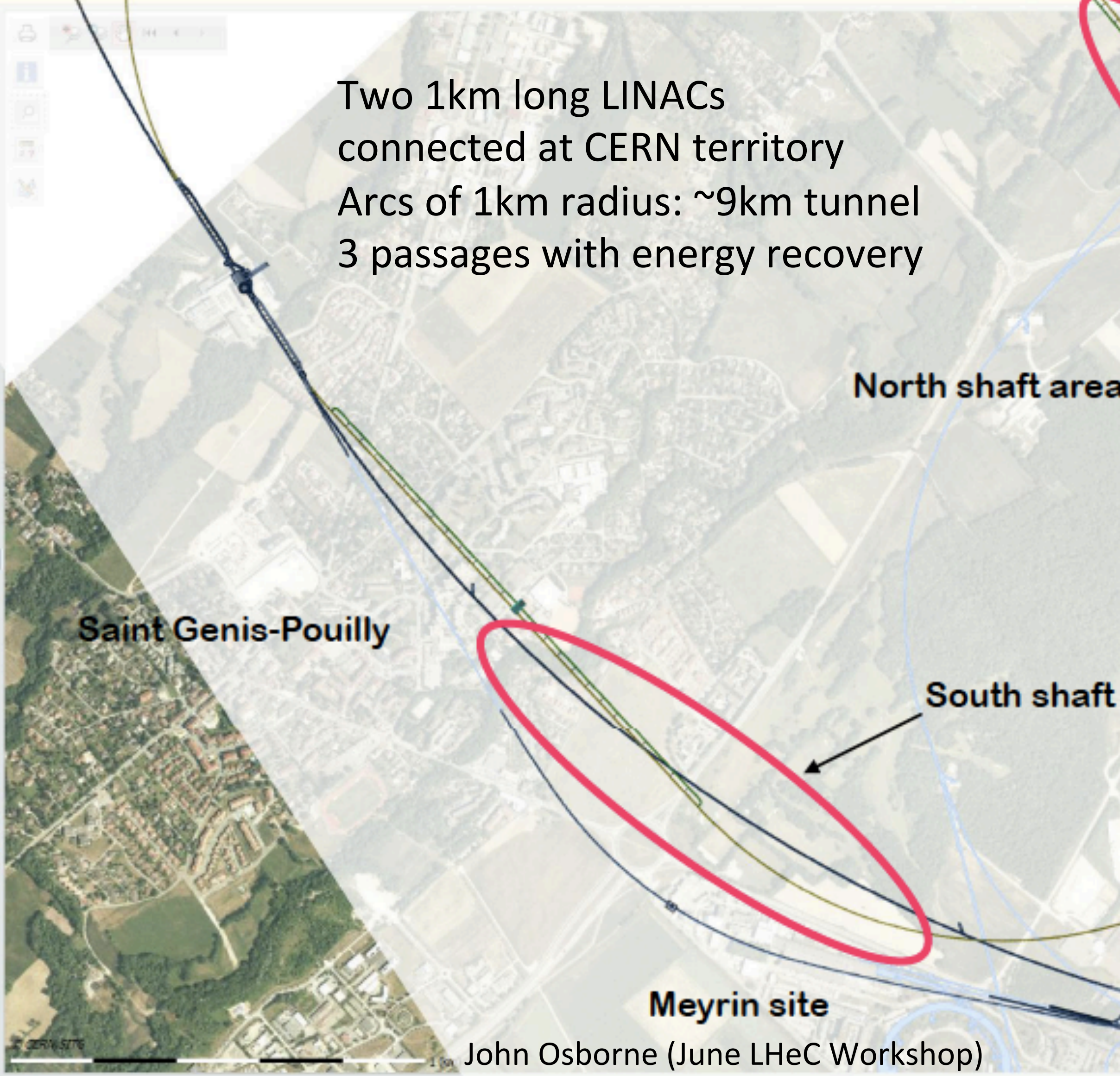
arXiv:1206.2913

CERN-ECFA-NuPECC Workshop 14/15.6 [cern/ch/lhec]

**CERN: Mandate for TDR, ECFA: Report 19.7., NuPECC:Long Range Plan**

# 60 GeV Electron Accelerator

Two 1km long LINACs
connected at CERN territory
Arcs of 1km radius: ~9km tunnel
3 passages with energy recovery

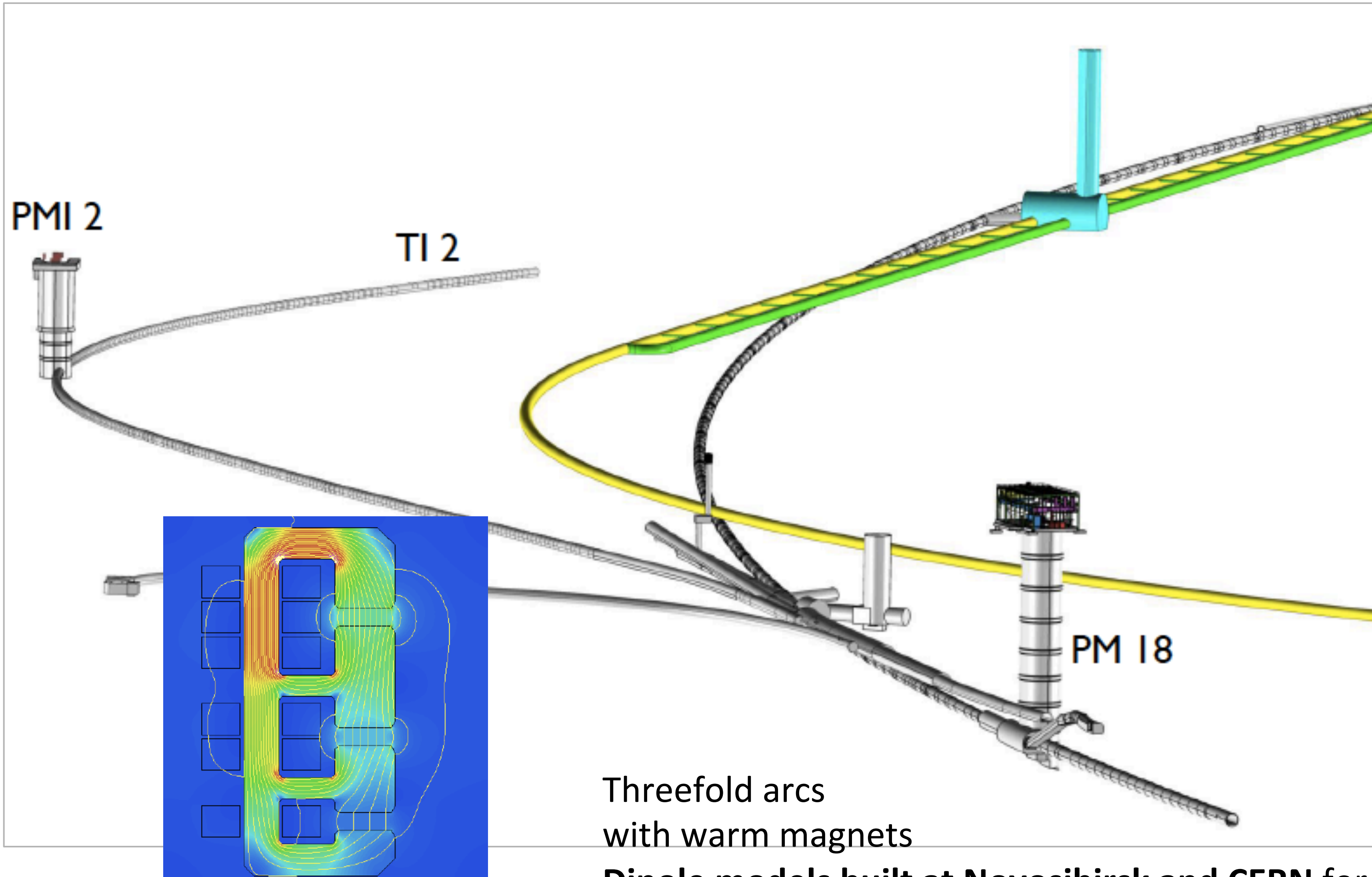



CDR

| | Ring | Linac |
|---|---|---|
| electron beam 60 GeV | | |
| $e^-$ ($e^+$) per bunch $N_e$ [$10^9$] | 20 (20) | 1 (0.1) |
| $e^-$ ($e^+$) polarisation [%] | 40 (40) | 90 (0) |
| bunch length [mm] | 6 | 0.6 |
| tr. emittance at IP $\gamma\epsilon^e_{x,y}$ [ mm] | 0.59, 0.29 | 0.05 |
| IP $\beta$ function $\beta^*_{x,y}$ [m] | 0.4, 0.2 | 0.12 |
| beam current [mA] | 100 | 6.6 |
| energy recovery efficiency [%] | – | 94 |
| total wall plug power [MW] | 100 | 100 |
| critical energy [keV] | 163 | 718 |
| proton beam 7 TeV | | |
| protons per bunch $N_p$ [$10^{11}$] | 1.7 | 1.7 |
| transverse emittance $\gamma\epsilon^p_{x,y}$ [$\mu$m] | 3.75 | 3.75 |
| collider | | |
| Lum $e^-p$ ($e^+p$) [$10^{32}$cm$^{-2}$s$^{-1}$] | 9 (9) | 10 (1) |
| bunch spacing [ns] | 25 | 25 |
| rms beam spot size $\sigma_{x,y}$ [$\mu$m] | 45, 22 | 7 |
| crossing angle $\theta$ [mrad] | 1 | 0 |
| $L_{eN} = A\ L_{eA}$ [$10^{32}$cm$^{-2}$s$^{-1}$] | 0.45 | 1 |

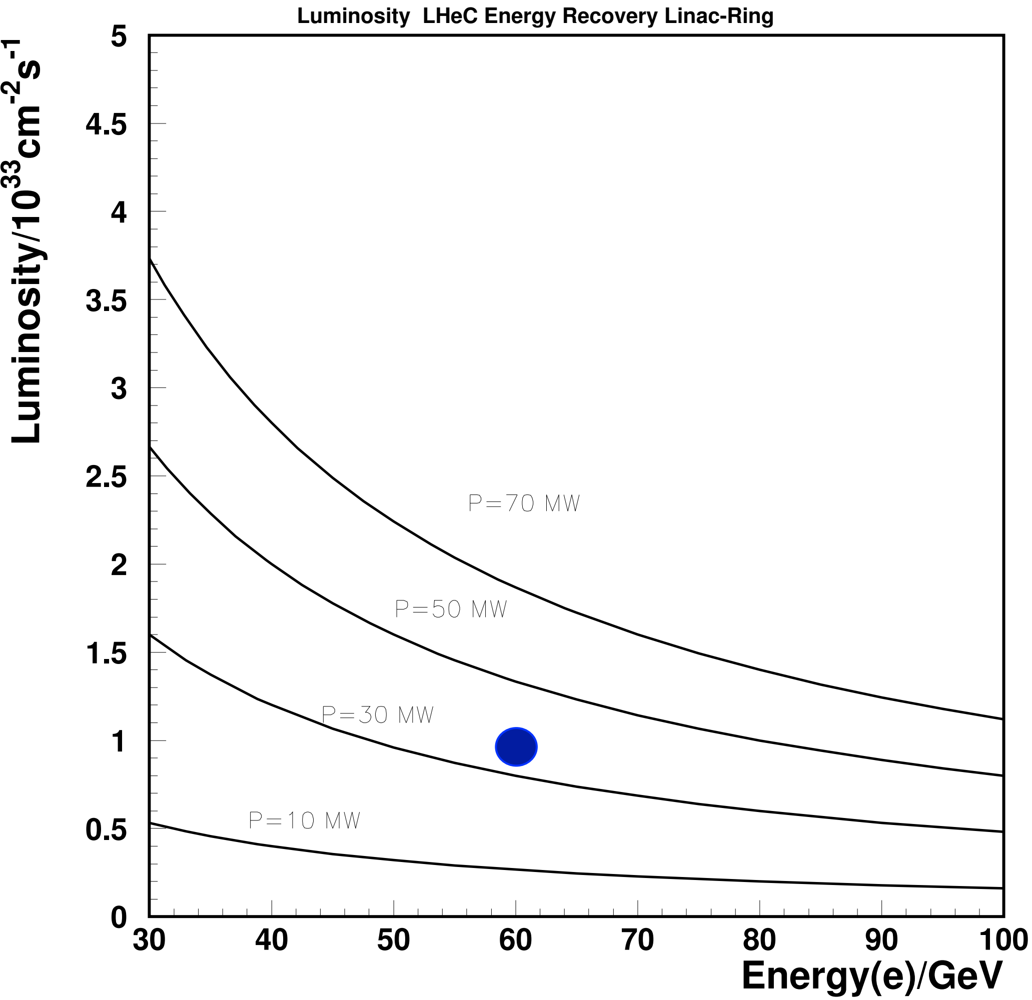
Baseline design parameters of the Ring (RR) and the Linac (RL)

John Osborne (June LHeC Workshop)




Threefold arcs
with warm magnets
**Dipole models built at Novosibirsk and CERN** for RR

# Luminosity




$$L = \frac{1}{4\pi} \cdot \frac{N_p}{\varepsilon_p} \cdot \frac{1}{\beta^*} \cdot \gamma \cdot \frac{I_e}{e}$$

$$N_p = 1.7 \cdot 10^{11}, \varepsilon_p = 3.8 \mu m, \beta^* = 0.2 m, \gamma = 7000 / 0.94$$

$$L = 8 \cdot 10^{31} cm^{-2} s^{-1} \cdot \frac{N_p 10^{-11}}{1.7} \cdot \frac{0.2}{\beta^* / m} \cdot \frac{I_e / mA}{1}$$

$$I_e = mA \frac{P_E / MW}{E_e / GeV}, P_E = P / (1 - \eta), \eta \approx 0.95$$

Wall plug power < 100 MW

Energy recovery efficiency > 90% - test

Hourglass > 0.9
(head-on ep: dipole in detector)

Beam-beam effect - 1.3

Gap for fast ion stability - 2/3 ?

LHC brightness $N_p/\varepsilon$ likely higher

p cooling - towards $10^{35}$ .. V.Litvinenko
(cf June workshop)

Positrons a serious challenge (cf CDR)

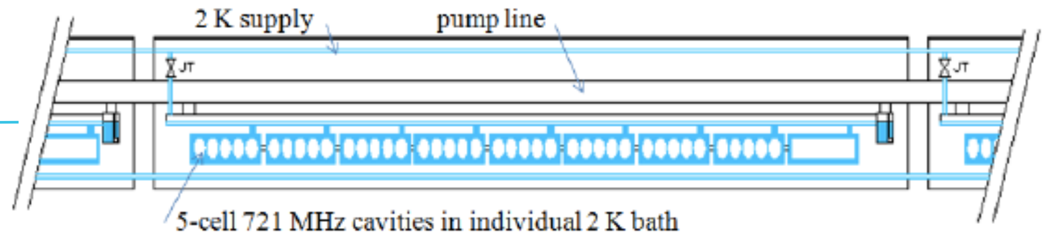
Chapter 9 of CDR

# 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 $R/Q$ [$\Omega$] | 114 | 285 |
| cavity $Q_0$ | – | $2.5\ 10^{10}$ |
| cooling power [kW] | 5.4@4.2 K | 30@2 K |

Jlab: $4\ 10^{11}$



5-cell 721 MHz cavities in individual 2 K bath

Need to develop “own” 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

# Which frequency? 700 MHz vs. 1300 MHz

## Advantages 700 MHz

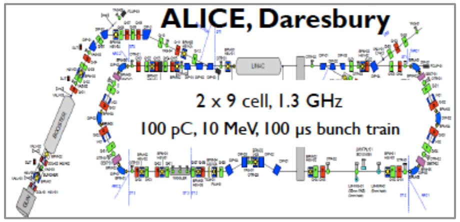
- Synergy SPL, ESS, JLAB, eRHIC
- Smaller BCS resistance
- Less trapped modes
- Smaller HOM power
- Beam stability
- Smaller cryo power
- Power couplers easier

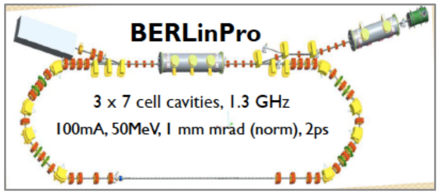
## Advantages 1300 MHz

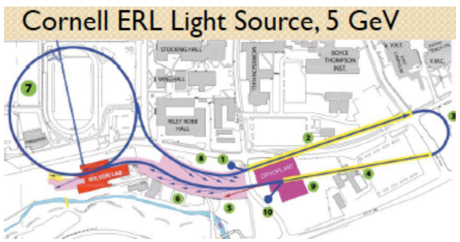
- Synergy ILC, X-FEL
- Cavity smaller
- Larger *R/Q*
- Smaller RF power (assuming same $Q_{ext}$)
- Less Nb material needed

Erk Jensen (LHeC June 12 Workshop)

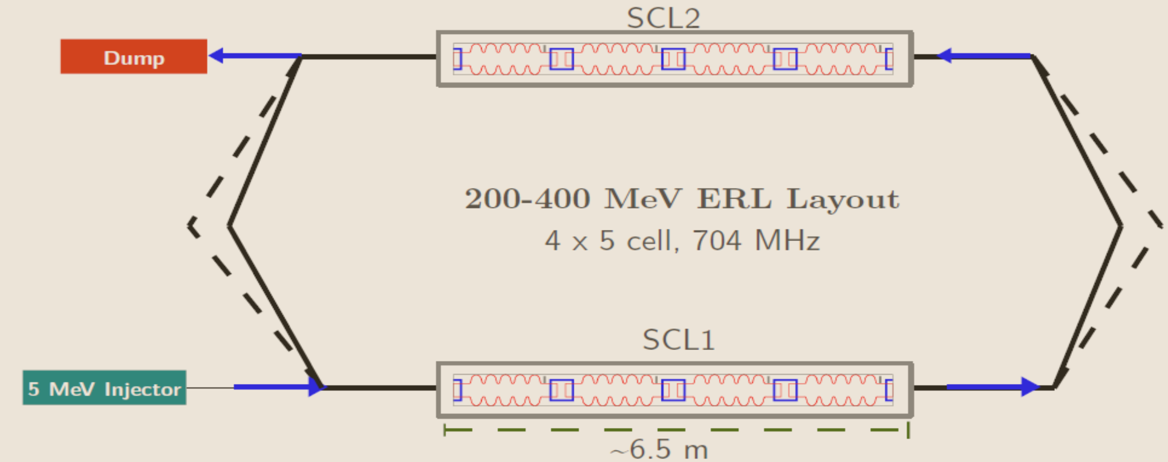
721 much larger stable beam current limit than 1323 MHz.



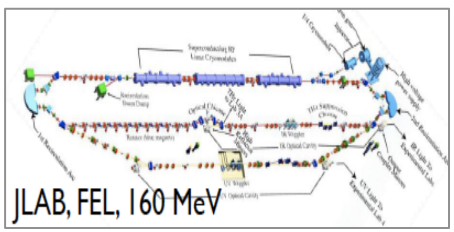



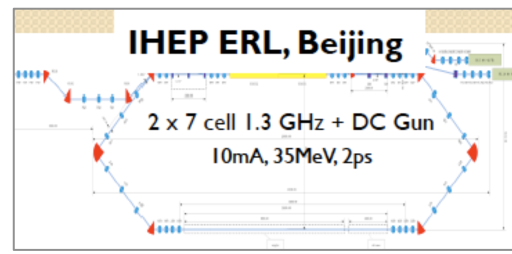

# LHeC Test Facility at CERN

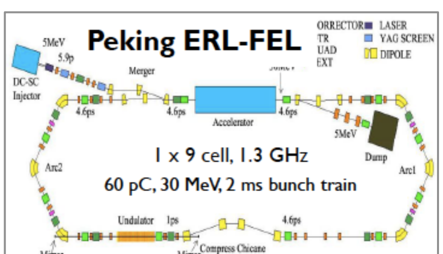


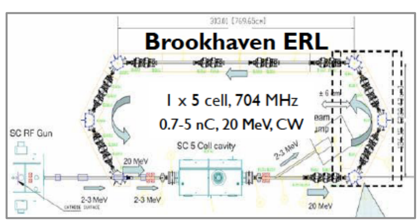

**Draft Plan**. June LHeC Workshop. Rama Calaga, Ed Ciapala, Erk Jensen

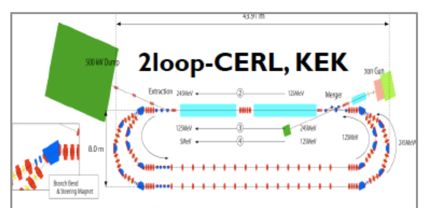




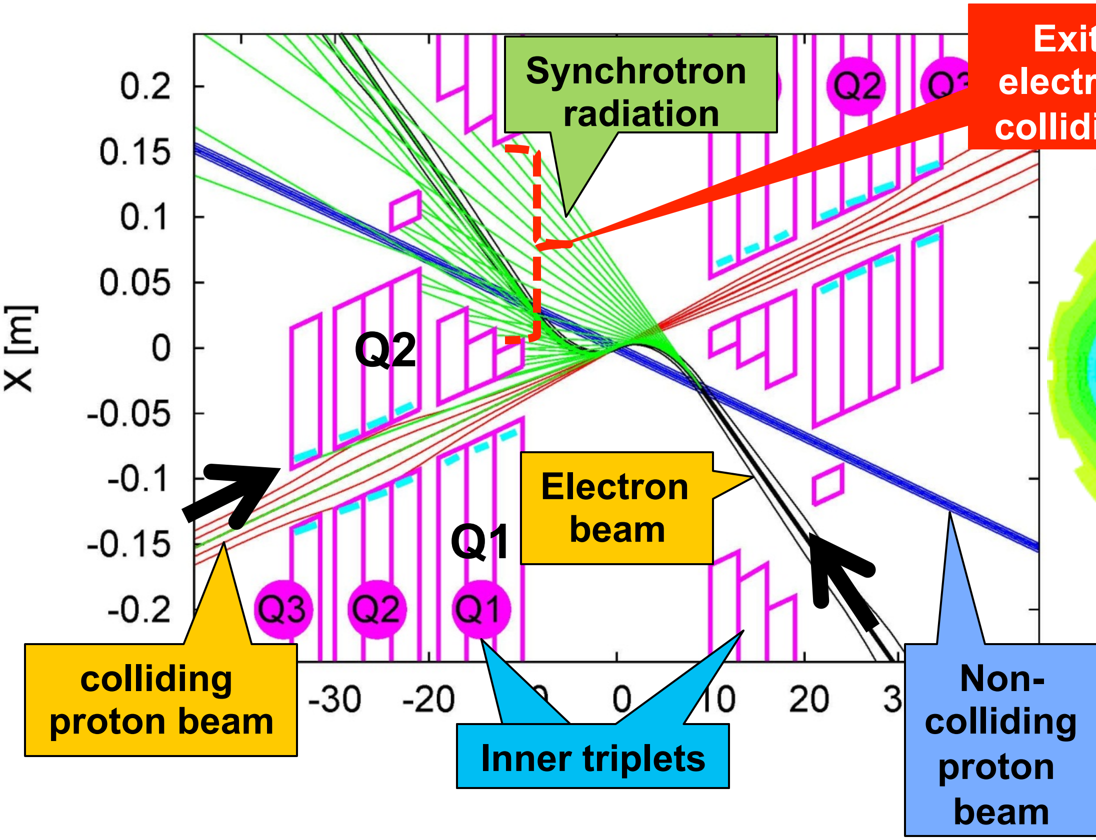


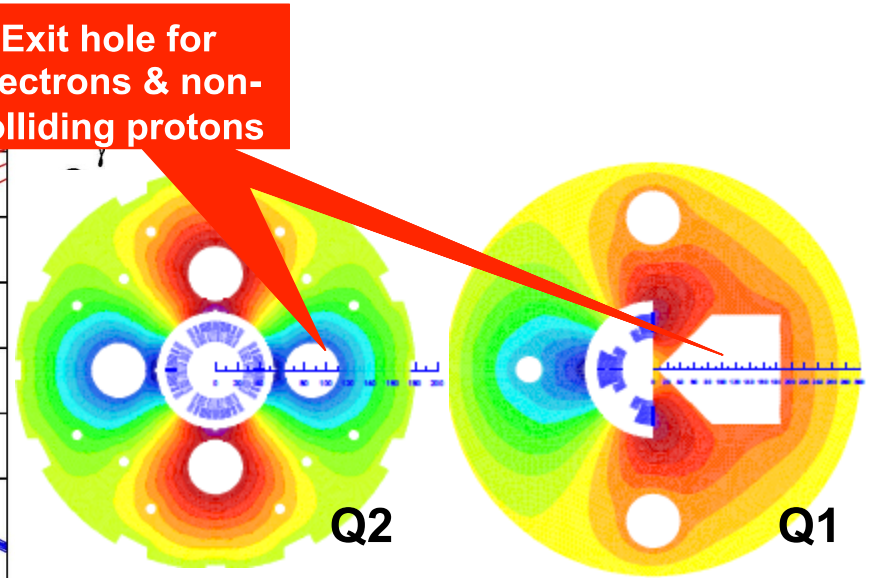




# LR LHeC IR layout & SC IR quadrupoles




| | |
|---|---|
| $Nb_3Sn$ (HFM46): 5700 A, 175 T/m, 4.7 T at 82% on LL (4 layers), 4.2 K | $Nb_3Sn$ (HFM46): 8600 A, 311 T/m, at 83% LL, 4.2 K |
| 46 mm (half) ap., 63 mm beam sep. | 23 mm ap.. 87 mm beam sep. |
| 0.5 T, 25 T/m | 0.09 T, 9 T/m |

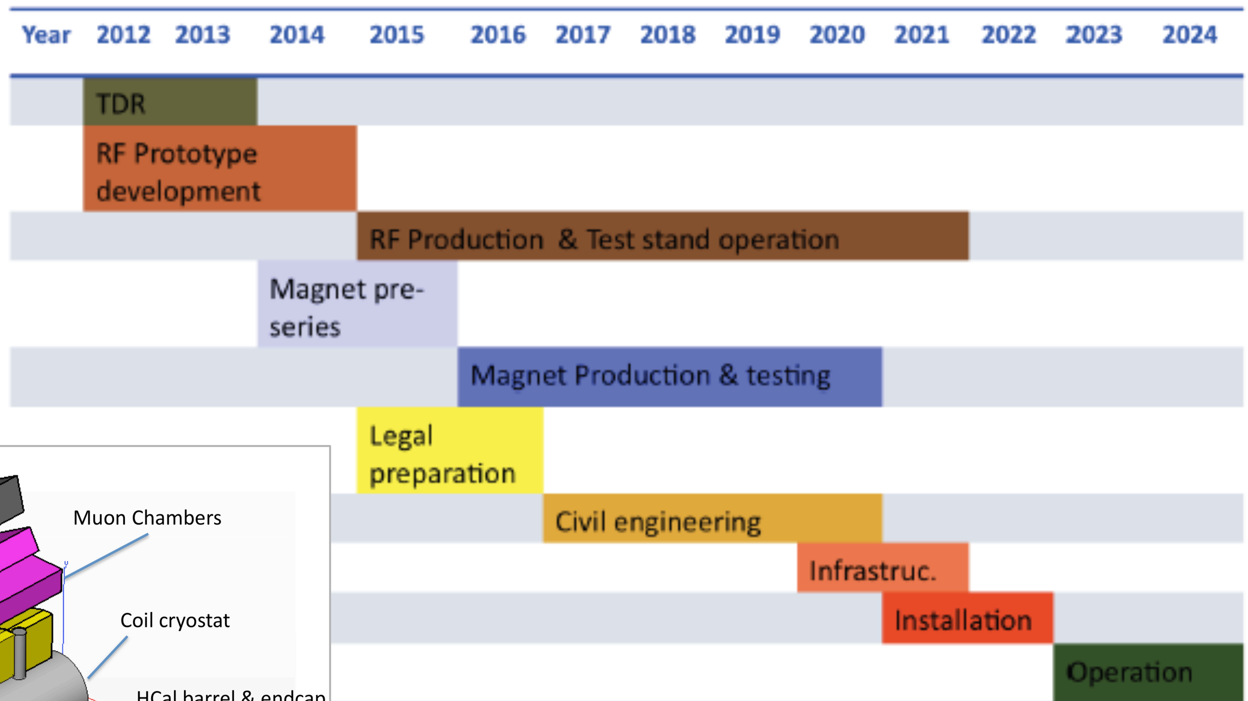
High-gradient SC IR quadrupoles based on $Nb_3Sn$ for colliding proton beam with common low-field

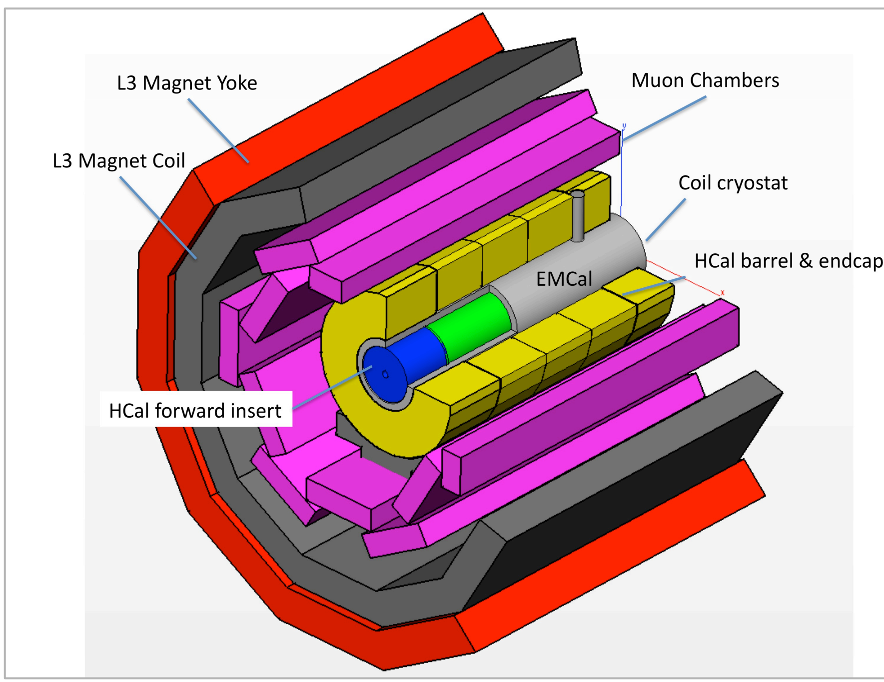
**Q1,2 are considered to prototype, IR challenging!**

As shown by Frank Zimmermann at Chamonix12

# 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

## Synergies

The LHeC represents a natural extension to the LHC, offering maximum exploitation of the existing LHC infrastructure at CERN. This is a unique advantage as compared to when HERA was built, for example. Physics-wise it is part of the exploration of the high energy frontier and as such linked to the LHC and the lepton-lepton colliders under consideration, a relation which resembles the intimate connection of HERA to the physics at Tevatron and LEP for the investigation of physics at the Fermi scale. As an *ep* and *eA* machine, the LHeC unites parts of the particle and nuclear physics communities for a common big project. It has a characteristic electroweak, QCD and nucleon structure physics programme which is related primarily to the LHC but also to lower energy fixed target DIS experiments, as are pursued at CERN and Jlab, and also to plans for realising lower energy electron-ion colliders at BNL and at Jlab. The superconducting IR magnets are related to the HL-LHC superconducting magnet developments by the USLARP, while the LHeC linac appears to be connected to a variety of projects such as the XFEL at DESY, the CEBAF upgrade at Jlab, the SPL at CERN and other projects for high quality cavity developments. Even when its cavity parameters differ (CW vs pulsed, likely 0.72 vs 1.3 GHz), the LHeC would require the industrial production of a thousand cavities, which for the much more ambitious aim of the ILC would seemingly be of interest. With its high energy ERL application to particle physics, the LHeC is related to about ten projects worldwide which are developing the energy recovery concept. The detector technology is linked mainly to the LHC experiments and some of their upgrades. It is thus evident that there are very good prospects for realising the LHeC within dedicated international collaborations at a global scale where mutual benefits can be expected at many levels. The dimension of the LHeC and the technologies involved make it a suitable project for particle physics to develop its collaboration with industry.

**From executive summary of CDR**

# Transition from CDR to R+D Organization

## R+D Tasks for LHeC

LHCC
MAC/LMC

2012-2015

ECFA
NuPECC

| Coordination |
|---|
| Enable decision by 2015 ("TDR") |
| Oversight of Physics, Detector, Accelerator Issues. Finances |
| CERN + International Collaborations on Detector + Accelerator |
| Response to CERN Directorate and Committees, Conferences etc. |

| Physics | Detector | Computing | IR | CE | RF+Cryo | ERL | Magnets |
|---|---|---|---|---|---|---|---|
| Stimulate new DIS physics | Performance (precision, acc.) | Physics processes | Pipe for 1° | Site specific linac design | Cavity-cryo module (Q) | Beam dynamics | Q design and prototypes |
| t,Higgs,RPV.. | Technical design | Computing model, support | Syn.radiation, beam backgrd | Junction of e,p beam lines | Cryogenics system design | Protection, dumps | Return arc magnets |
| Adjust to LHC | Prototypes | Simulations | Masks, collimators.. | Technical integration | Power, coupler | Electron source | Rotator |
| Tool development | Installation model | DAQ and Trigger | Fwd and bwd detectors | Power, GS.. | Test facility | Positron R+D | Integration |

LHeC Project Organisation 2012-2015 [13.6.2012]

Will need time, thoughts and funds

S.Bertolucci LHeC Workshop June 2012

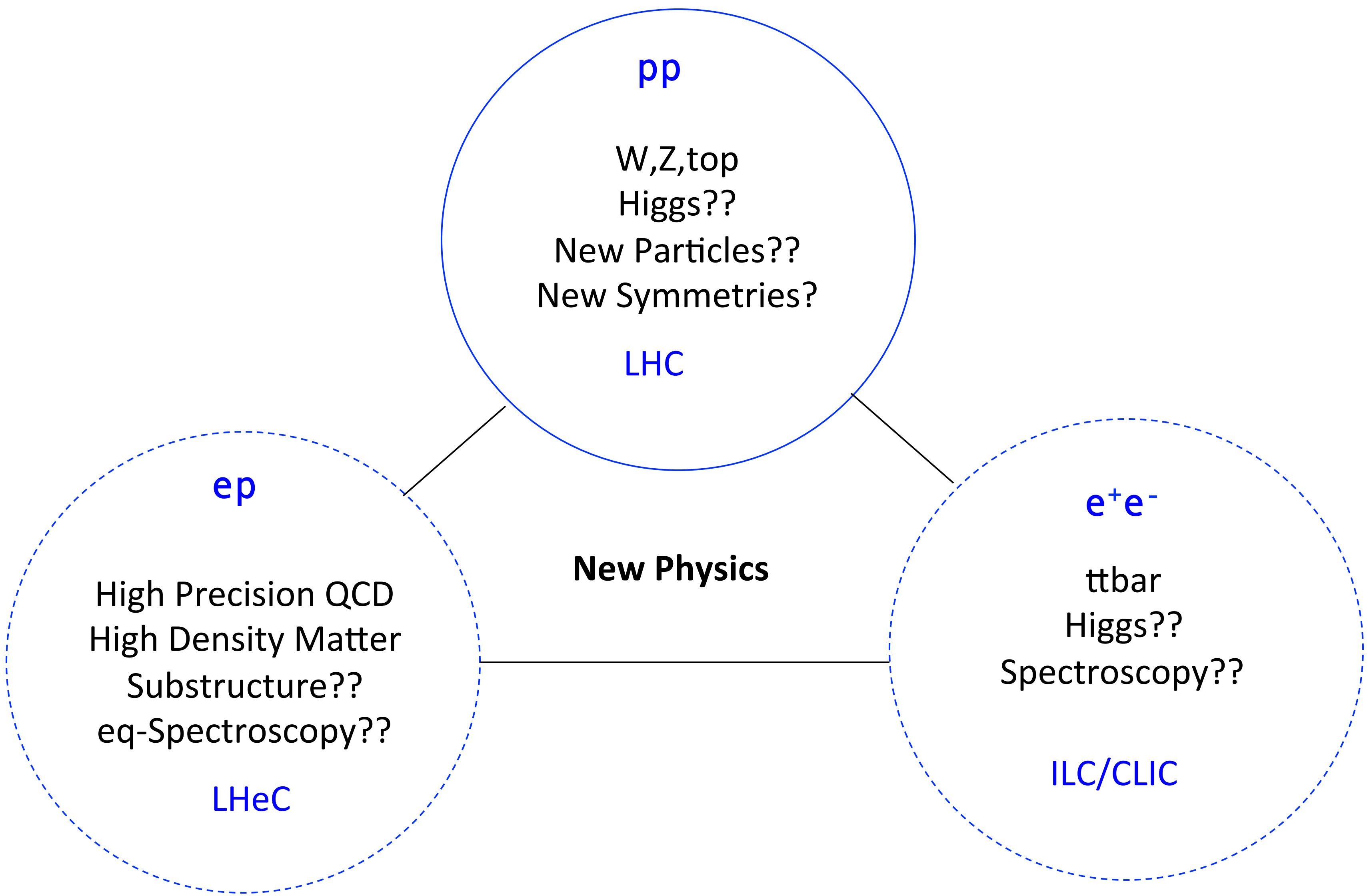
# LHeC Accelerator Design: Participating Institutes

The LHeC design concepts are now published.
The ring-ring configuration is held as a backup for the racetrack ERL which will be developed towards a TDR.
An LHeC test facility will be built and components prototyped.
External laboratories are (being) invited to participate.
The LHeC has all to become the best ep and eA collider ever, which will substantially enrich the physics with the LHC.

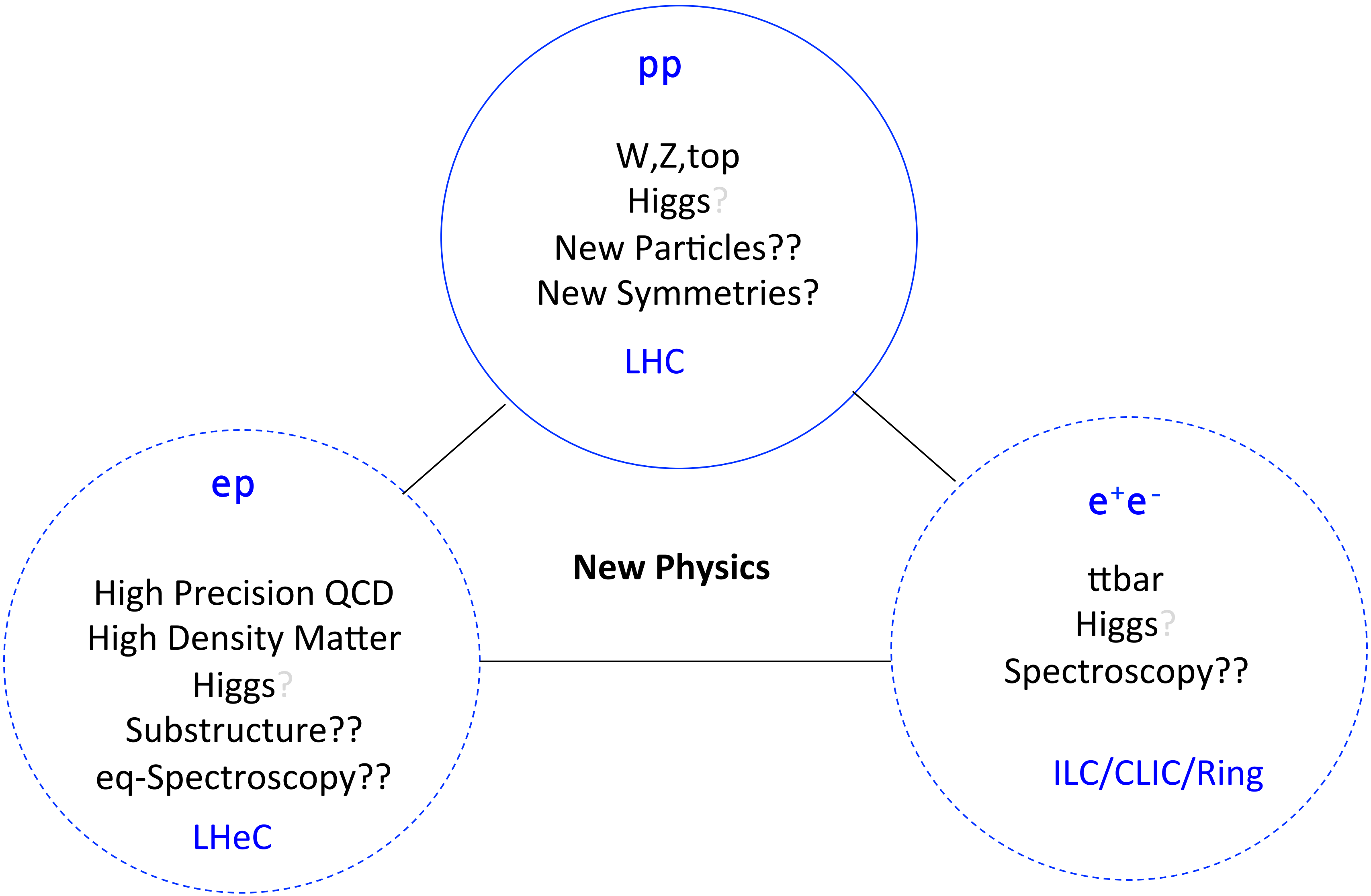
TOBB ETU

KEK

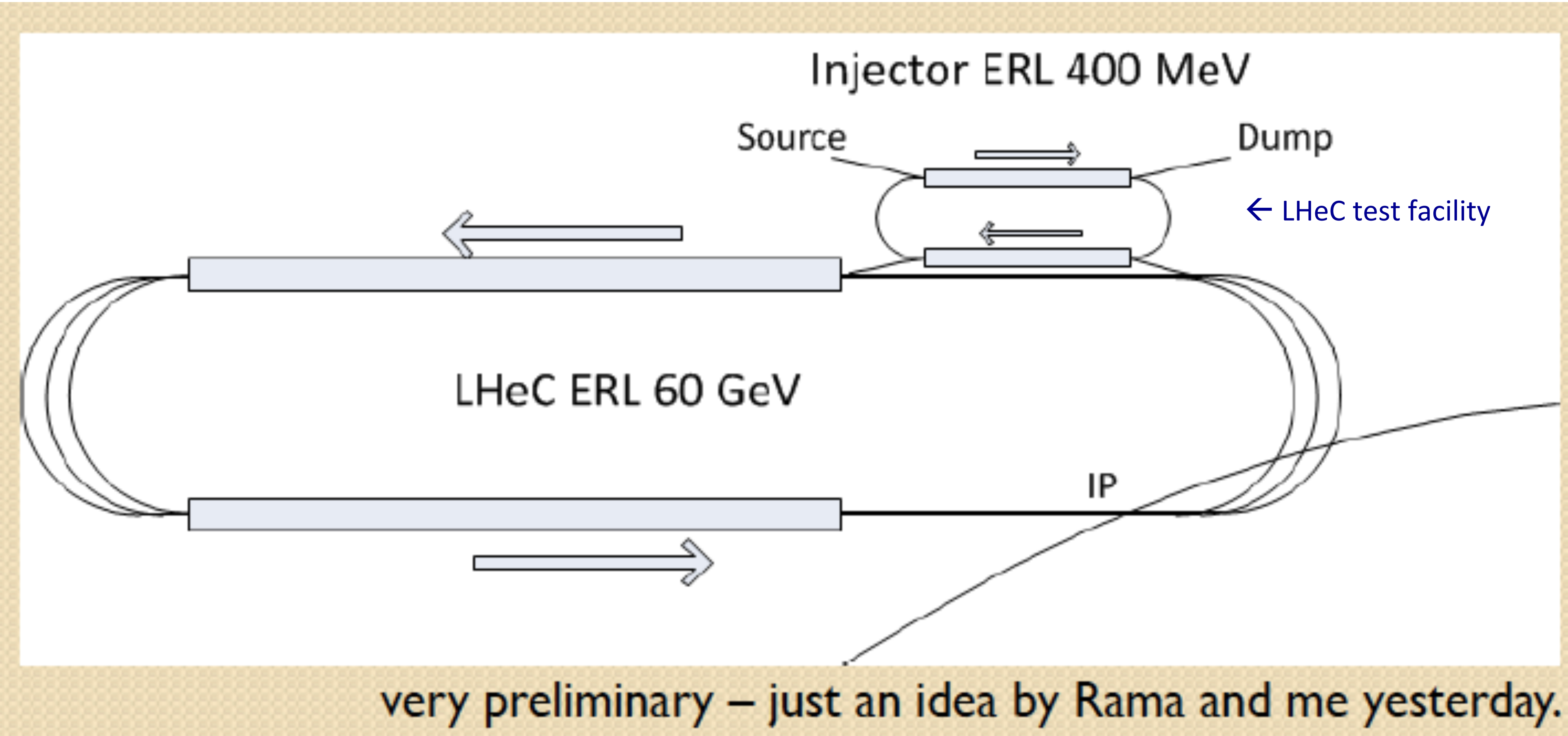
# The TeV Scale [2010-2035..]



# The TeV Scale [2012-2035..]



# Conclusion




Erk 15.6.2012

**The development of the LHeC continues to be very attractive and recent news are supportive..**

Many thanks to all who contributed to this with great enthusiasm, new+old friends, and to CERN, ECFA, NuPECC, the referees, working group convenors, steering group

# backup

# LHeC Accelerator Design: Participating Institutes

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 1946

NİĞDE ÜNİVERSİTESİ 1992

ULUDAĞ ÜNİVERSİTESİ 1975

TOBB ETU

INFN Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali di Legnaro

DESY

LAL Physique des accélérateurs

ECFA

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

UNIVERSITY OF LIVERPOOL

BROOKHAVEN NATIONAL LABORATORY

СИБИРСКОЕ ОТДЕЛЕНИЕ РАН
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KEK

# Candidates for Surprises and Discoveries

PDFs (t, s, $q$-$\bar{q}$, val, xg)
Odderon
Instanton
(no) saturation, QCD
QGP initial state

The study of deep inelastic *ep* scattering is important for the investigation of the nature of the Pomeron and Odderon, which are Regge singularities of the *t*-channel partial waves $f_j(t)$ in the complex plane of the angular momentum $j$. The Pomeron is responsible for a growth of total cross sections with energy. The Odderon describes the behaviour of the difference of the cross sections for particle-particle and particle-antiparticle scattering which obey the Pomeranchuck theorem. In perturbative QCD, the Pomeron and Odderon are the simplest colorless reggeons (families of glueballs) constructed from two and three reggeized gluons, respectively. Their wave functions satisfy the generalized BFKL equation. In the next-to-leading approximation the solution of the BFKL equation contains an infinite number of Pomerons and to verify this prediction of QCD one needs to increase the energy of colliding particles. In the N=4 supersymmetric generalization of QCD, in the t'Hooft limit of large $N_c$, the BFKL Pomeron is equivalent to the reggeized graviton living in the 10-dimensional anti-de-Sitter space. Therefore, the Pomeron interaction describing the screening corrections to the BFKL predictions, at least in this model, should be based on a general covariant effective theory being a generalization of the Einstein-Hilbert action for general relativity. Thus, the investigation of high energy *ep* scattering could be interesting for the construction of a non-perturbative approach to QCD based on an effective string model in high dimensional spaces.

Lev Lipatov in the CDR…

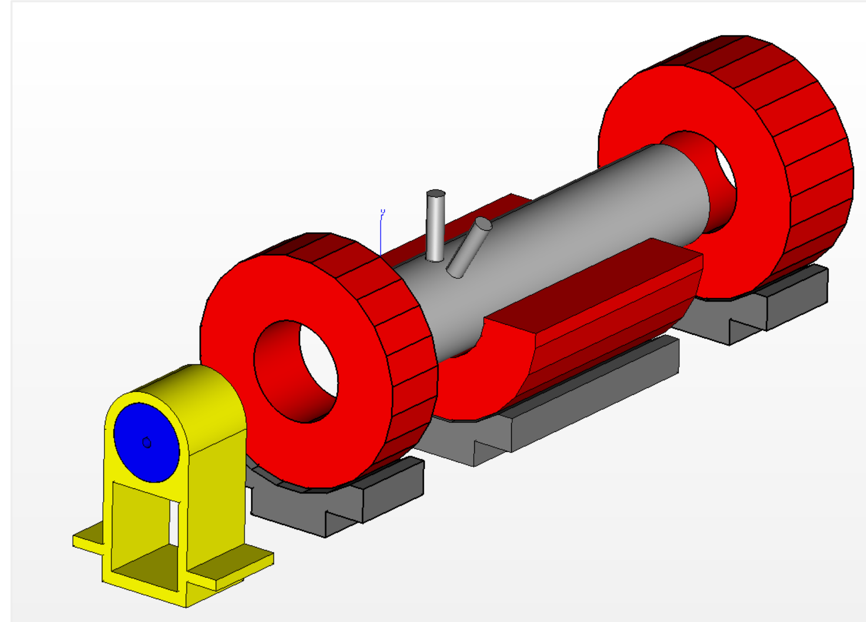
Neutron structure
Factorization pp-ep
LQs, RPV SUSY
$e^*$
Higgs CP
$\alpha_s$ indeed small (GUT)

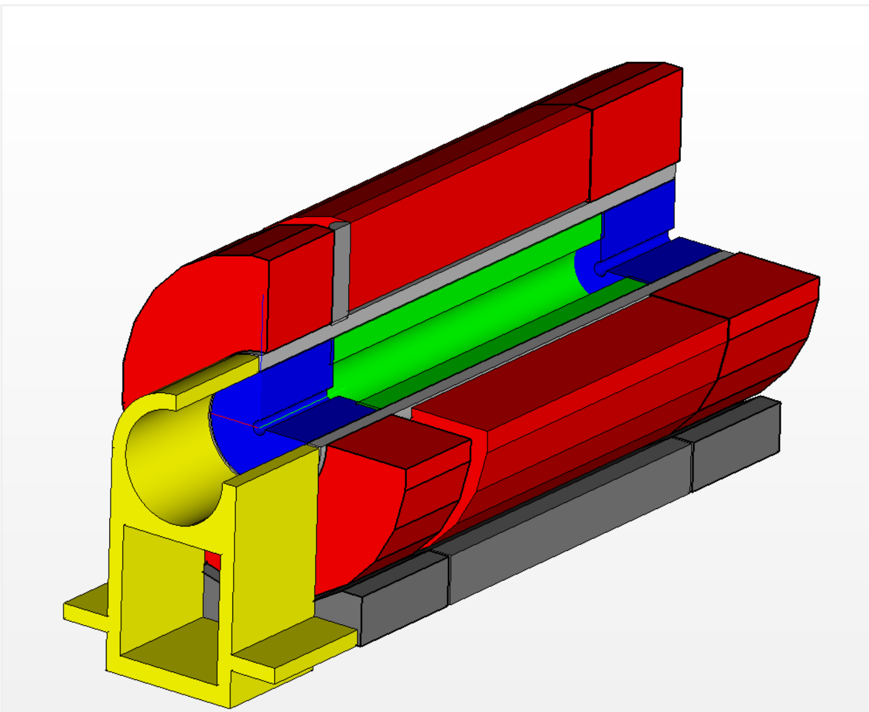
Ultra high precision (detector, e-h redundancy) - new insight
Maximum luminosity and much extended range - rare, new effects
Deep relation to (HL-) LHC (precision+range) - complementarity
→ **LHeC brings a substantial enrichment of LHC physics**

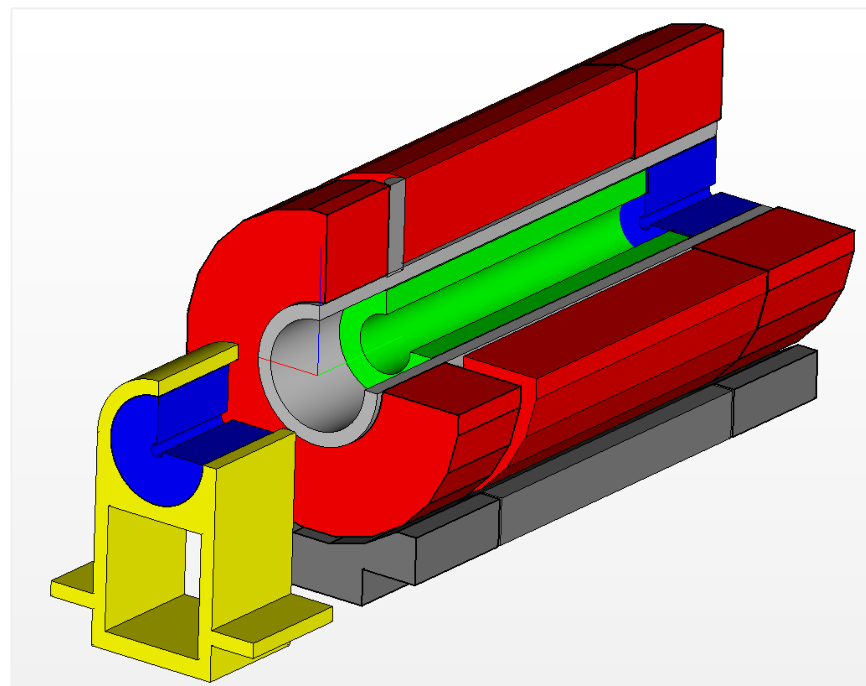
# Introduction

The basic concepts have been developed for an upgrade of the LHC with a new electron beam of 60 GeV energy. Two configurations are considered, a ring-ring layout (RR) with an electron storage ring mounted on top of the LHC magnets, and a linac-ring layout (LR) based on two 10 GeV superconducting linacs arranged in a 9 km recirculating racetrack configuration, where the beam passes three times through each linac during acceleration. Both options are worked out in detail and both are shown to lead to a TeV energy scale collider of very high luminosity, building on the highest energy application of energy recovery techniques for the electron linac. This Large Hadron Electron Collider (LHeC) promises to be the second, high energy frontier electron-proton collider and as such the world's cleanest, extremely high resolution microscope. It is designed to operate synchronously with the LHC in its high-luminosity upgrade phase, the HL-LHC. A concept is also presented for a novel, large acceptance detector, which, using the latest available technology, is a basis for high precision measurements of deep inelastic lepton-hadron scattering processes. The LHeC has an innovative electron-proton physics programme devoted to partonic strong and electroweak interactions, and also to the new phenomena, beyond the Standard Model of particle physics, which are hoped to be discovered with the LHC. The unique heavy ion beams of the LHC provide a third major field of exploration related to the conditions of the initial state of the quark-gluon plasma. This report provides the necessary basis for the technical design of the LHeC to proceed in the coming years. A few key aspects of the present design are summarised below.

From executive summary of CDR







Study of Installation of the LHeC Detector

A.Gaddi, 7.5.2012