A Common eh/hh Interaction Region and Detector for the LHC

K. D. J. André (CERN, U. Liverpool), **N. Armesto** (U. Santiago de Compostela) , **B. J. Holzer** (CERN), **M. Klein** (U. Liverpool), **P. Kostka** (U. Liverpool), **A.Polini** (INFN Bologna), **C. Schwanenberger** (DESY), **Y. Yamazaki** (U. Kobe).
on behalf of the LHeC Collaboration https://lhec.web.cern.ch/

ICHEP 2022 BOLOGNA

The LHeC is the proposal of an upgrade of the High Luminosity-LHC to provide electron-hadron collisions with centre-of-mass energies $O(1)$ TeV and instantaneous luminosities $O(10^{34})$ cm^{-2}s^{-1}. The existing design identifies IP2 as the interaction point. In this talk we present initial accelerator considerations on a common IR to be built which alternately could serve *eh* and *hh* collisions at the HL-LHC, while other experiments would stay on *hh* in either condition [1]. A forward-backward symmetrised option of the LHeC detector is sketched which would permit extending the LHeC physics programme to also include aspects of hadron-hadron and heavy-ion physics.

[1] K. D. J. Andre et al., An experiment for electron-hadron scattering at the LHC, Eur. Phys. J. C 82 (2022) 1, 40, e-Print: 2201.02436 [hep-ex].

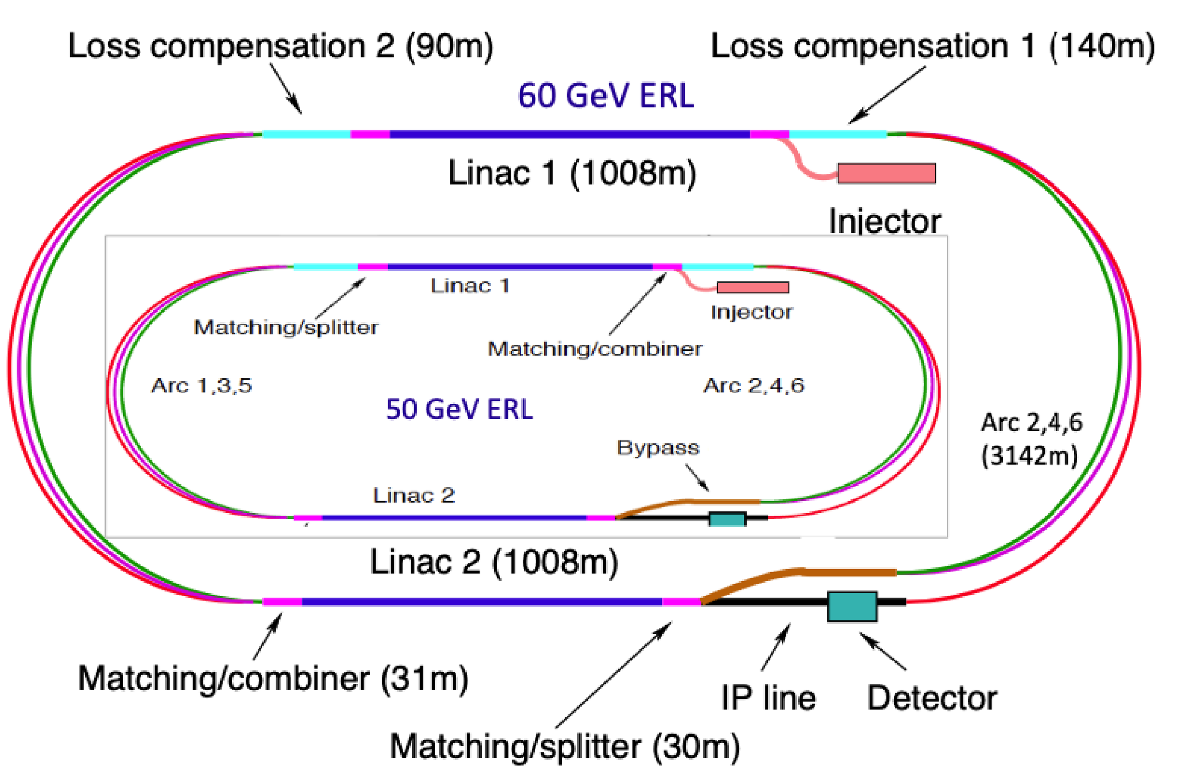
The Basic Concept

Energy $\sqrt{s} = \sqrt{(4 E_e E_p)}$ = 1.2-1.3 TeV

electrons: E_e=50-60 GeV, protons: E_p=7 TeV, ions Pb: E=2.75 TeV

LHeC: a next generation TeV energy electron-proton collider. Large coverage of kinematic DIS range, down to 10^{-6} in *x* owing to high energy and approaching *x*=1 due to high luminosity. Electron-ion collisions extend the kinematic range in electron-ion by several orders of magnitude.HERA missed its electron-ion collider phase.

Default layout of the ERL configuration for the LHeC



An intense electron beam (20mA current) is accelerated in three passes through two 1km linacs in an energy recovery linac racetrack configuration, which is positioned tangentially to the LHC (at IP2, or L for FCC).

The electron-proton interaction does not disturb the proton beams in a noticeable manner. Thus the LHeC may operate synchronously with the LHC. The installation of the ERL is in a separate tunnel, while the detector installation requires a typical LHC shutdown length of two years. The whole project concept therefore is that of adding instrumentation and providing crucial new physics, i.e. of making the LHC physics richer and thus sustaining its HL phase.

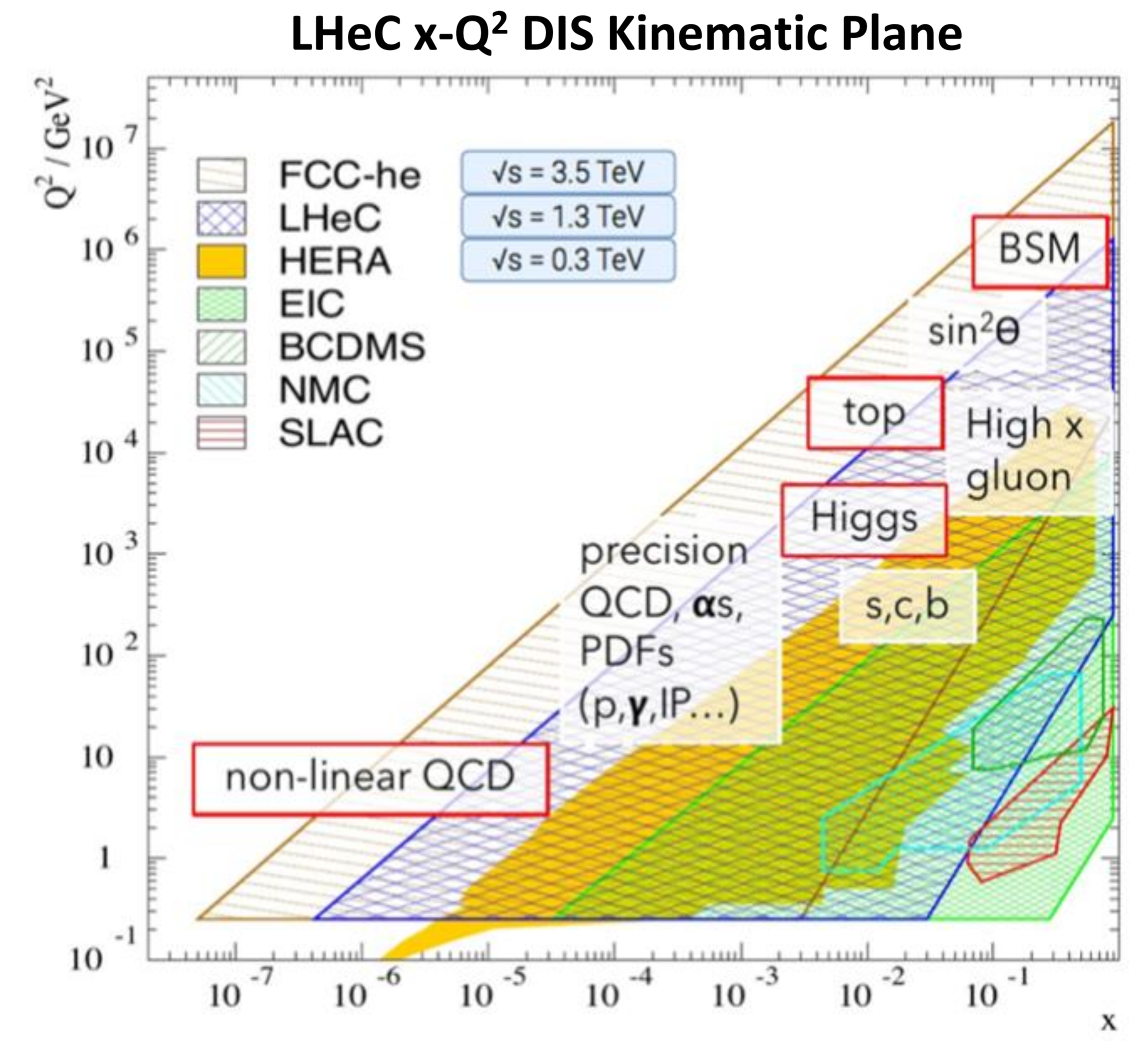
Luminosity:
10^{34} cm^{-2} s^{-1} → O(1) ab^{-1} in 10 years

This is 1000 times higher than HERA, owing to the high beam brightness of the HL-LHC, the large electron current from the ERL and may be achieved through the interaction of matched e and p beams at a β* below 10cm.

LHeC Conceptional Design Report:
arXiv:1206.2913, J. Phys. G 39 075001 (2012)

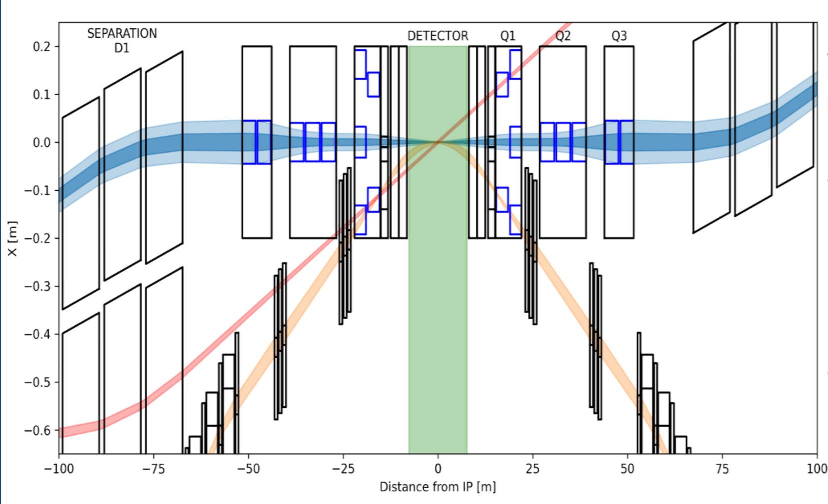
ep - *eh* Physics at TeV Scale

LHeC x-Q² DIS Kinematic Plane



- **Rich physics program at low and high luminosity and low and high-scale physics**
- Polarised electrons are foreseen
- Details on the physics can be found in the references.
- Compared to HERA
  - 100 times the luminosity
  - 4 times larger √s
- *e-p* data in the late 2030s.

LHeC *eh* interaction region



3 beams crossing the interaction region:

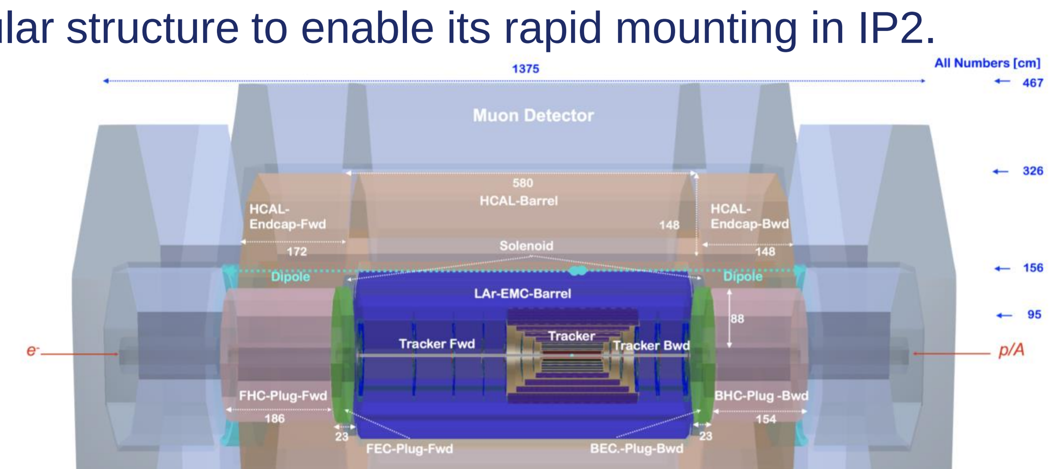
- Colliding electron and proton beams have an optimised separation scheme
- Interaction Point (IP) shifted by **Δt/4 = 6.25 ns or 1.88 m**,
- The non-colliding proton beam is a spectator and both proton beams have a large crossing angle of **7 mrad**

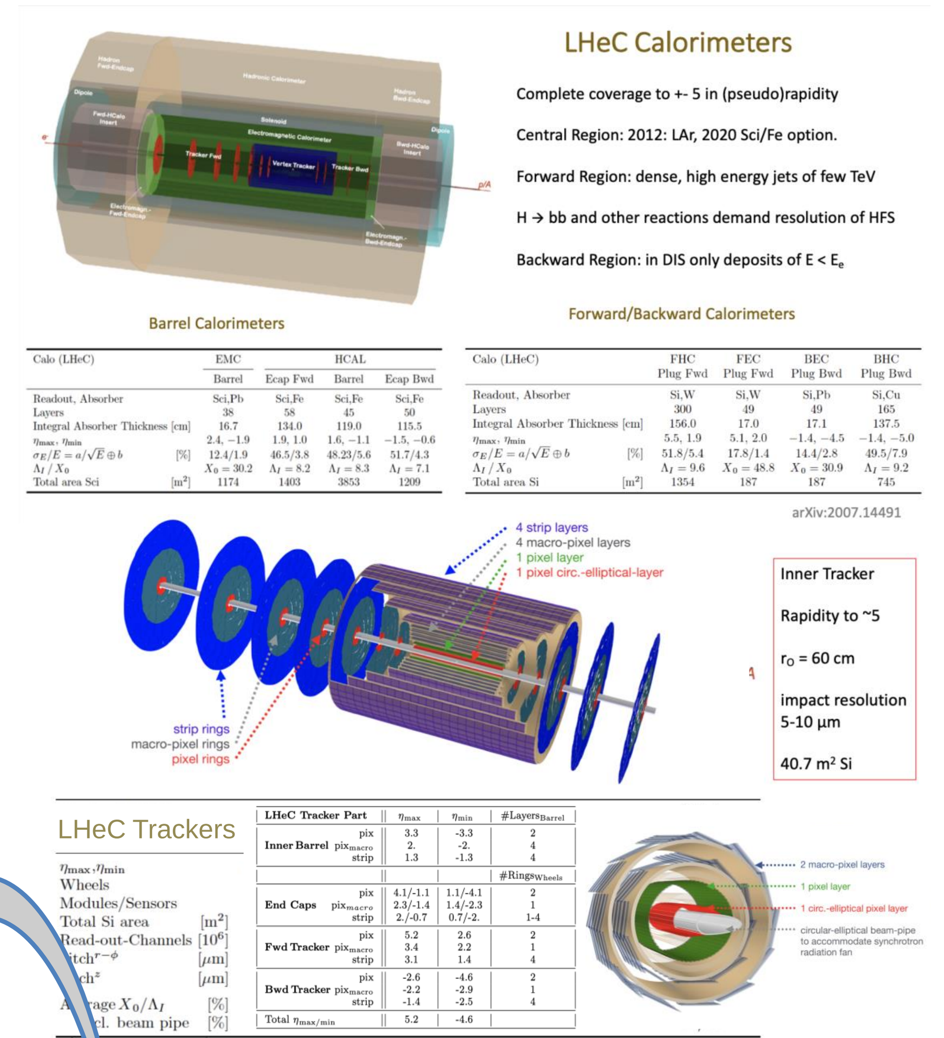
proton optics:

- LHeC: **L* = 15 m & β* = 10 cm**
- FCC-eh: **L* = 23 m & β* = 30 cm**

LHeC Detector Design

The LHeC detector (left below) is a large acceptance, precision device. Its design is determined by kinematics and high precision demands as from the H → bb reaction in CC. The low radiation (1/100 that of pp) enables sensitive technology such as HV CMOS to be used. The need to ensure head-on ep collisions introduces a long, low field dipole to be inserted before the HCAL, the solenoid (right below) is a rather conventional magnet. The detector is complemented by forward (p,n) and backward (e, γ) tagging detectors. Its dimensions are 13 x 9 m² (LxD) which one may compare with CMS: 21 x 15 m². The detector will have a modular structure to enable its rapid mounting in IP2.





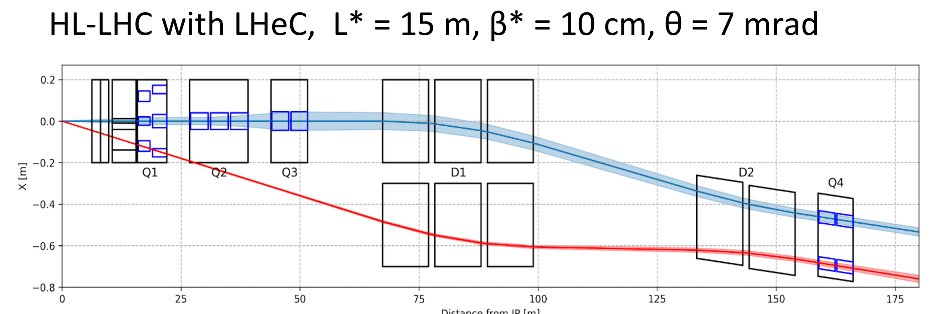
arXiv:2201.02436

Combined *eh* - *hh* IR

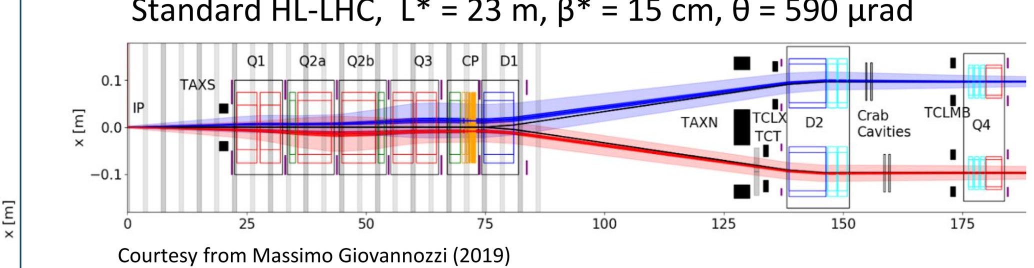
Two modes of operation:

- *hh* collisions in IP 1, 2, 5 and 8, no e⁻ beam
- *eh* collisions in IP 2 and *hh* collisions in IP 1, 5 and 8

HL-LHC with LHeC, L* = 15 m, β* = 10 cm, θ = 7 mrad

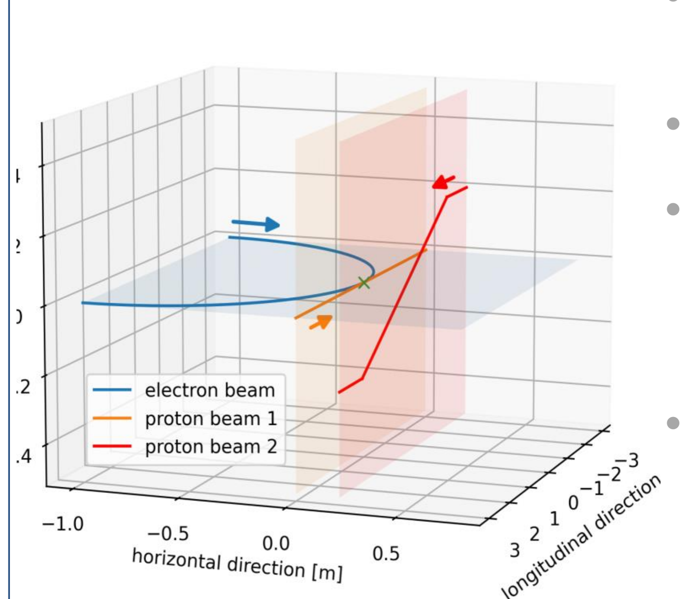


Standard HL-LHC, L* = 23 m, β* = 15 cm, θ = 590 μrad



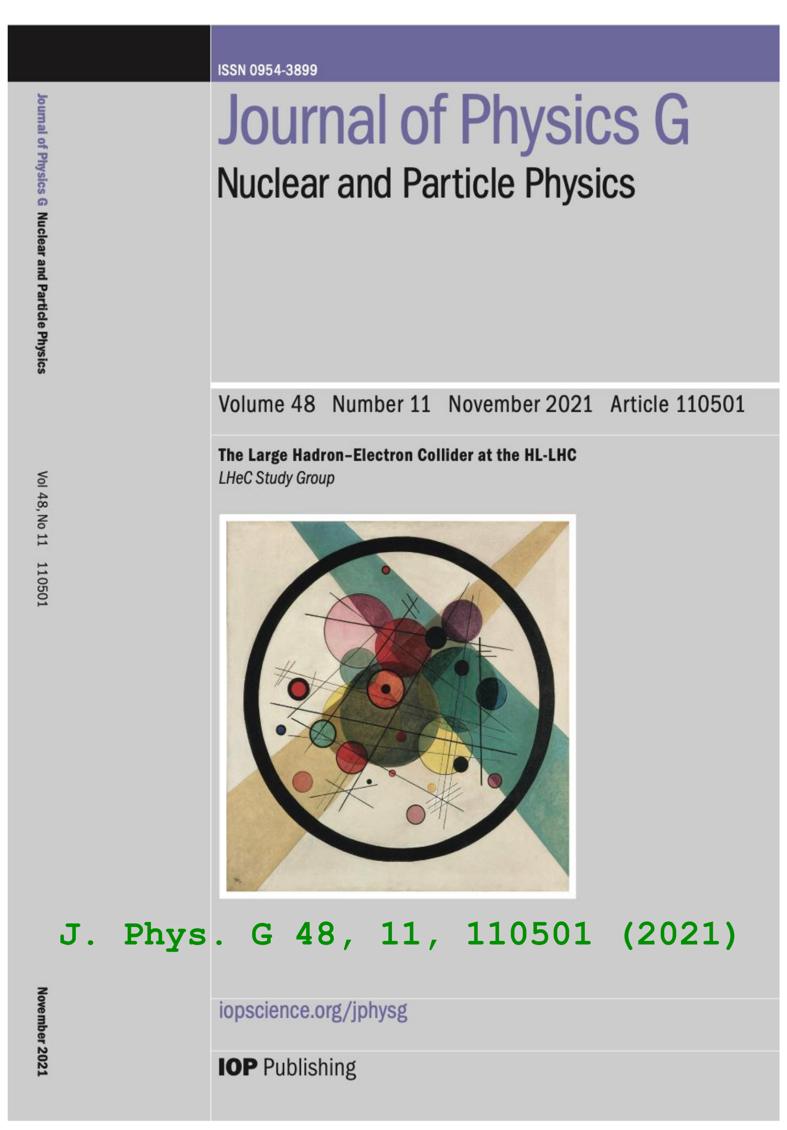
Courtesy from Massimo Giovannozzi (2019)

Accelerator considerations to **combine the ALICE and LHeC experiments** at point 2 of the HL-LHC:

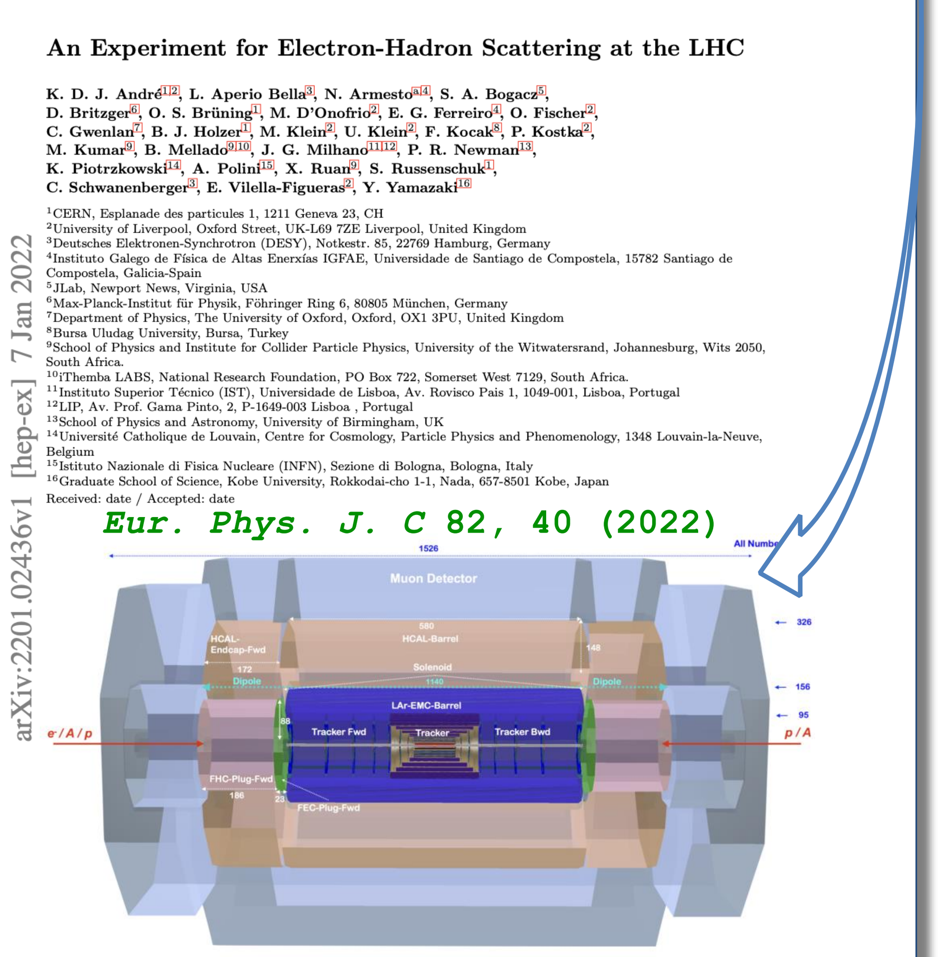


- **Flexible interaction region optics and lattice** to provide e-h and h-h.
- h-h operation: standard HL-LHC optics.
- e-h operation: the compact electron final focus system is embedded in the HL-LHC proton lattice.
- A **beam separation scheme guides the electron beam** after the collision point back to the ERL return arc.

CDR Update and beyond



J. Phys. G 48, 11, 110501 (2021)



An Experiment for Electron-Hadron Scattering at the LHC

arXiv:2201.02436v1 [hep-ex] 7 Jan 2022

Eur. Phys. J. C 82, 40 (2022)

- novel concept of a detector to alternately serve eh and hh collisions/physics
- Forward-backward detector symmetry to include hadron-hadron physics.

Conclusions

* LHeC: 50 GeV electron beam from an ERL colliding with a 7 TeV proton beam, and correspondingly heavy ion beams of several TeV energy, from the LHC concurrent to the HL-LHC hadron-hadron operation.

* First design studies show the feasibility of an IR and optics which alternately can serve eh and hh collisions, providing the seminal opportunity to realise both the LHeC and a new heavy ion detector at IP2, which is currently used by the Alice experiment

* The symmetrisation of the detector design would make possible the study of *eh* and *hh* physics at IP2.