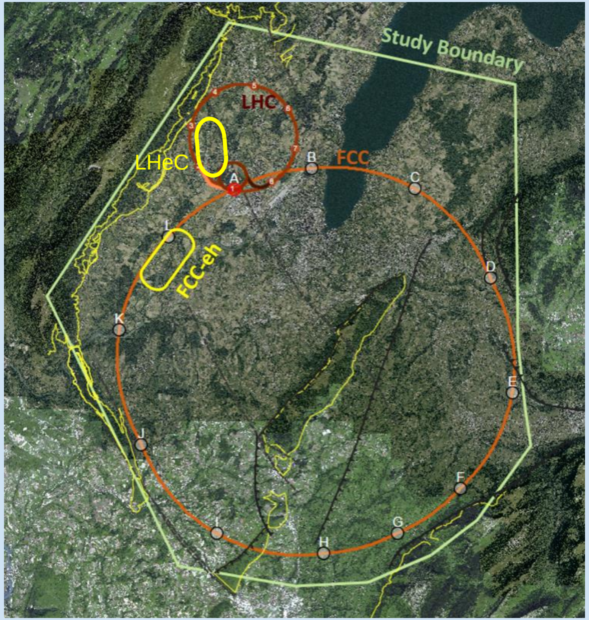
A common eh & hh interaction region and detector for the LHC

K.D.J. André, B. Holzer, M. Klein, P. Kostka for the LHeC study group



LHeC

Energy frontier electron hadron experiment with a luminosity of up to 10^{34} $cm^{-2}s^{-1}$ to complement the HL-LHC physics program with unprecedented TeV scale DIS physics. Featuring an innovative lepton accelerator design based on the energy recovery technology.

CDR (2012) & CDR (2020)

arXiv:1206.2913

arXiv:2007.14491

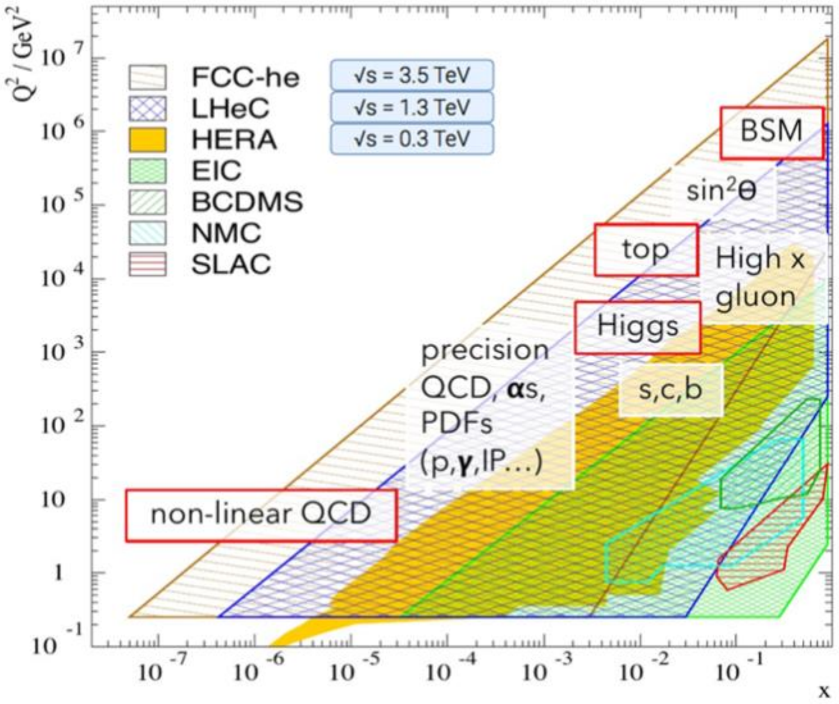
Offshell conference (2021)

Offshell(2021)

EPJC (2022)

EPJC(2022)

LHeC kinematic plane & physics program



- 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 mid 2030s.

The Energy Recovery technology

The energy recovery technology allows to recycle the power given to the beam.

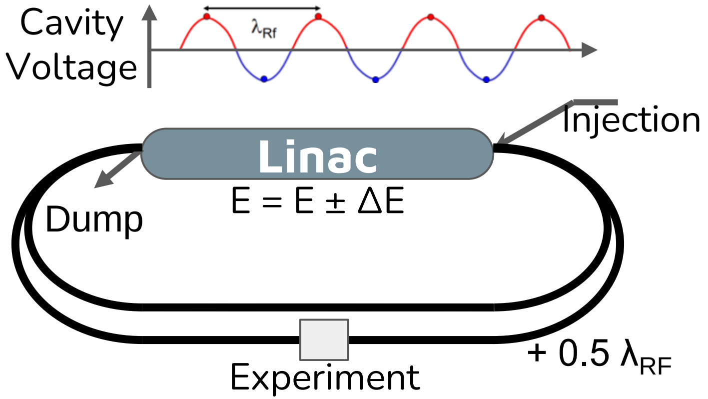
$$\tilde{P_{RF}} = P_{RF}(1 - \eta_{recovery})$$

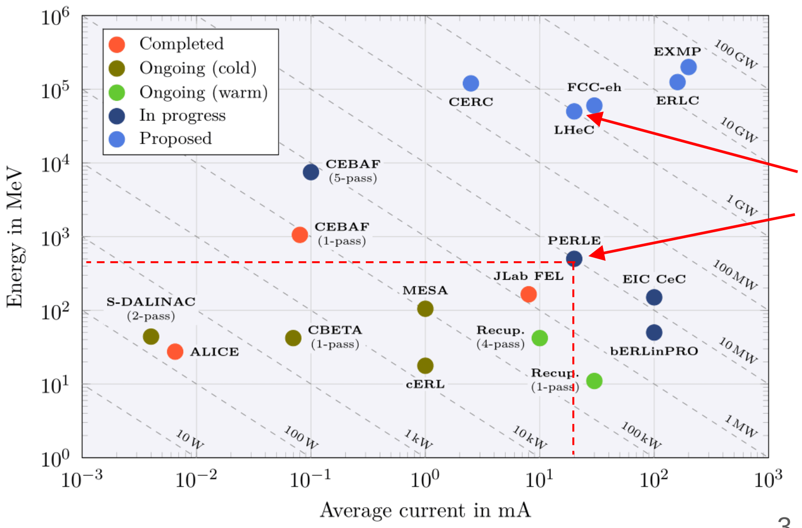
Proven accelerator technology, pushing for higher energy and beam current in view of collider applications.

PERLE demonstrator facility for the LHeC at Orsay to be commissioned in 2025+

with 3-turn, 20mA, 802 MHz SRF cavities

see A. Stocchi's talk

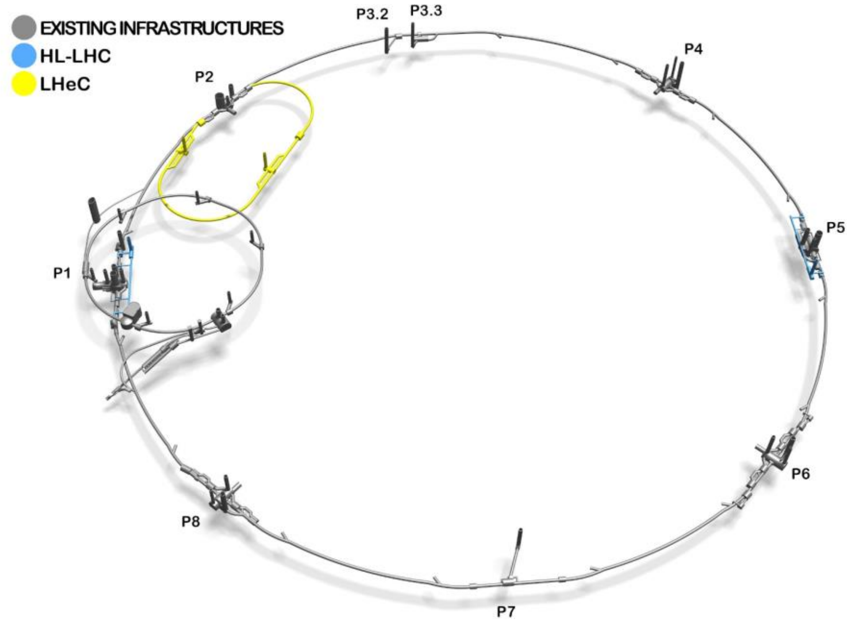




ERL R&D Roadmap

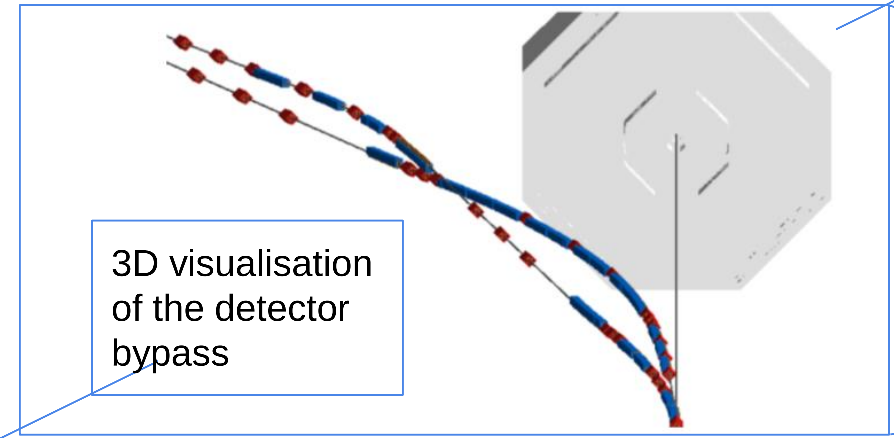
Beam parameters for the LHeC experiment

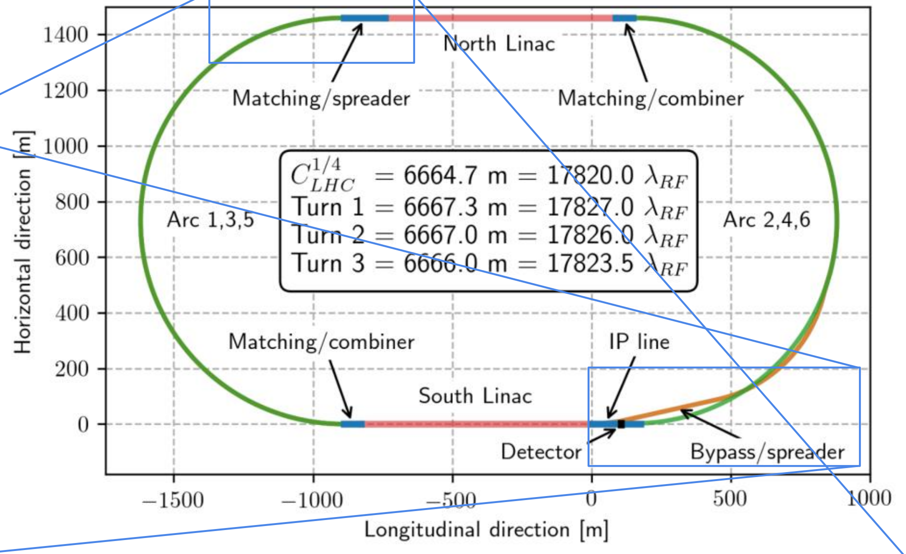
Parameter	Unit	LHeC Electron	LHeC Proton
Beam energy	GeV	50.0	7000.0
Beam current	mA	20.0	1400
Bunches per beam		1188	2808
Bunch population	10^{10}	0.3	22.0
Bunch charge	nC	0.50	35.24
Normalised emittance at IP	mm.mrad	30.0	2.5
Betatron function at IP	cm	10.0	10.0
RMS bunch length	cm	0.06	7.55
Installed RF voltage	GV	17.2*	0.016
Beam-beam disruption		14.3	1×10^{-5}
Luminosity	$cm^{-2}.s^{-1}$	6.5×10^{33}	

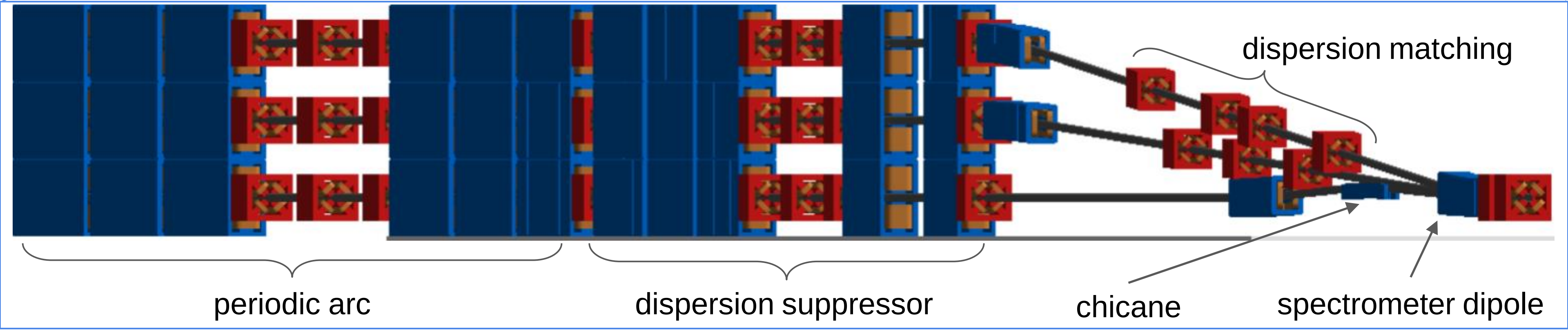


High power electron beam based on three-turn ERL racetrack utilising 100 MW electrical power consumption as a result of the high energy recovery efficiency. ERL circumference equivalent to one-third of the LHC. The ERL could be realised in staged phases.

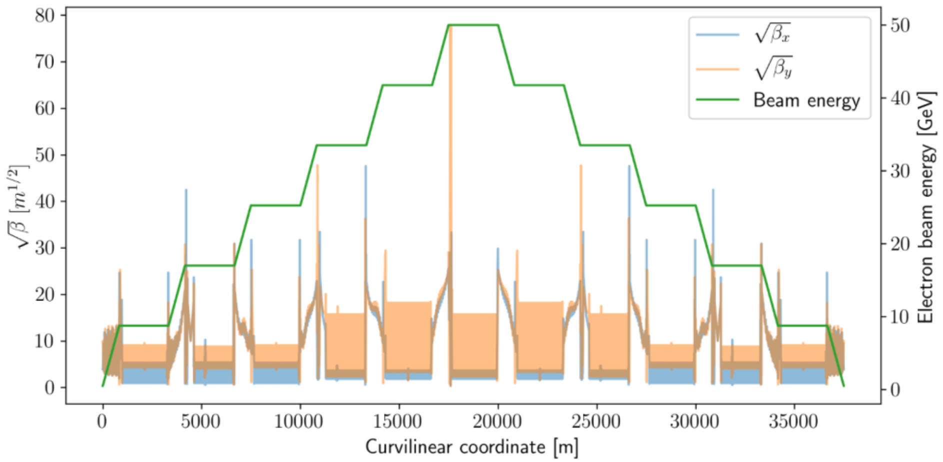
Energy Recovery Linac - I

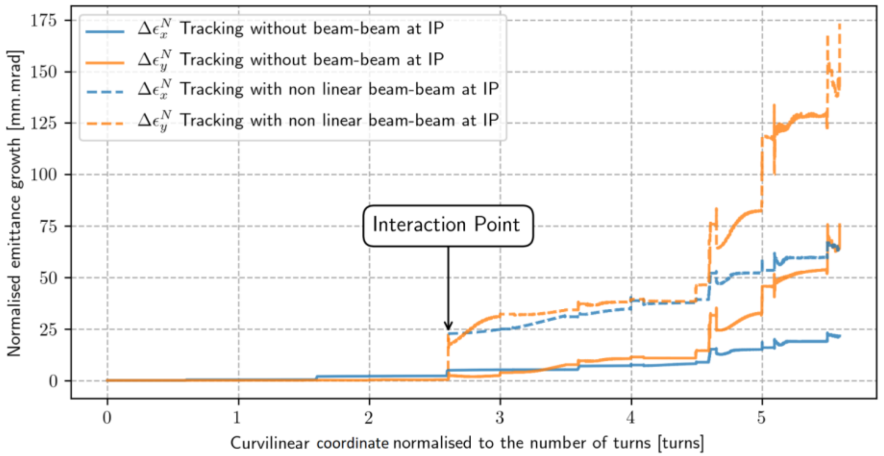






Energy Recovery Linac - II



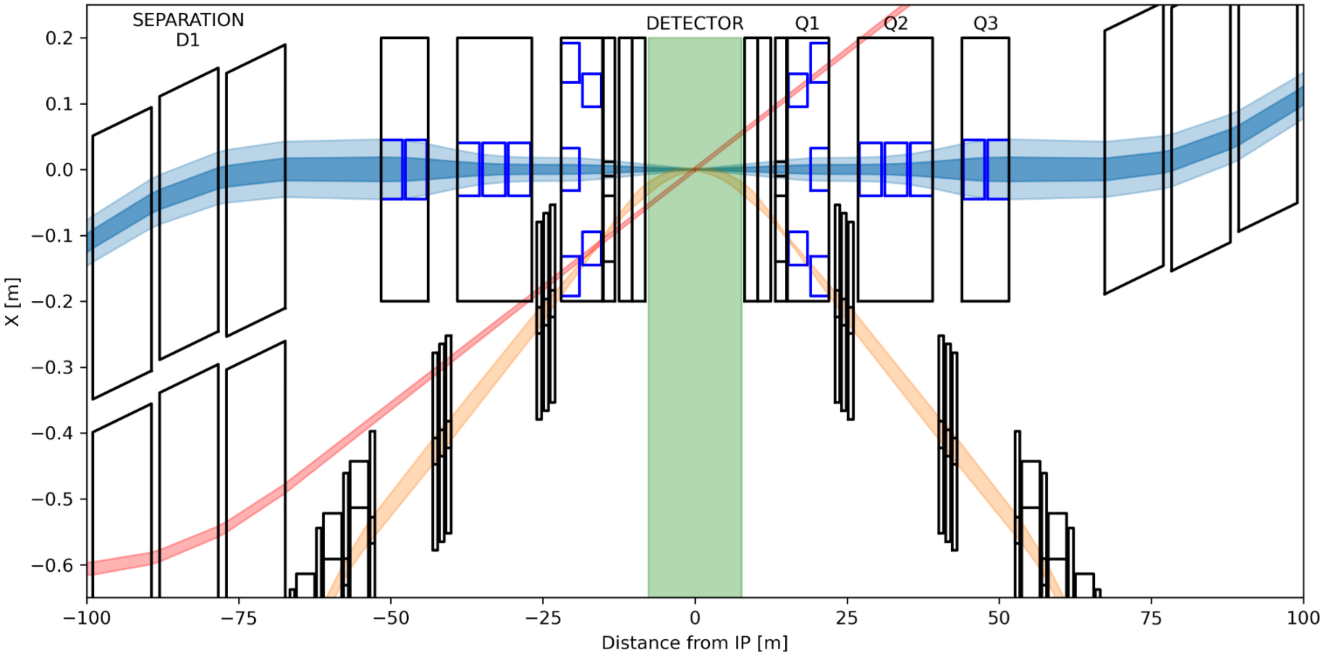


- **Energy gain over 3 turns** to reach 50 GeV,
- Succession of the linacs and arcs with the **RF phase shifted** in the sixth arc following the collision **to initiate the deceleration**,
- Maximum beta function in the junction between arcs and linacs as well as in the mini-beta quadrupoles.

Front-to-end simulations including synchrotron radiation and beam-beam interaction at the IP have shown an excellent transmission and energy recovery efficiency.

	Unit	Inj.	Dump	Trans.	Recov.
ε_x^N	mm mrad	25.4	47.1		
ε_x^N	mm mrad	29.4	525.3	99.98%	97.92%
δ	%	10^{-2}	3.8		

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**.

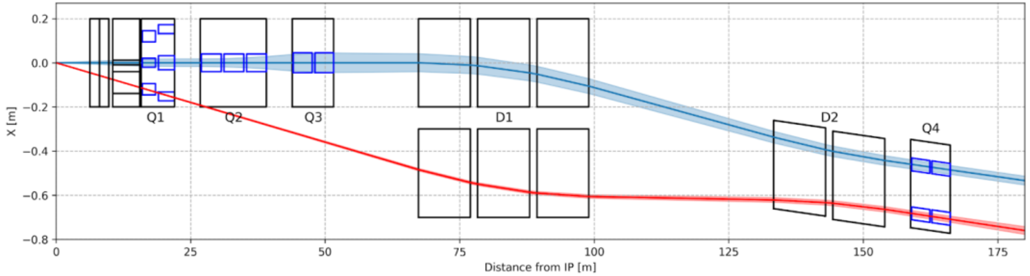
proton optics FCC-eh: **L* = 23 m & β* = 30 cm** || LHeC **L* = 15 m & β* = 10 cm**

Combined hh|eh interaction region

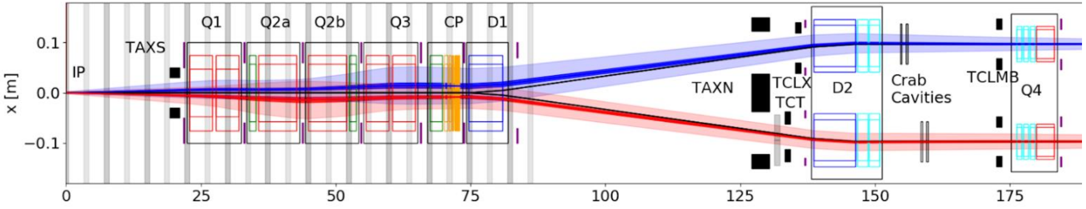
Two modes of operation:

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

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



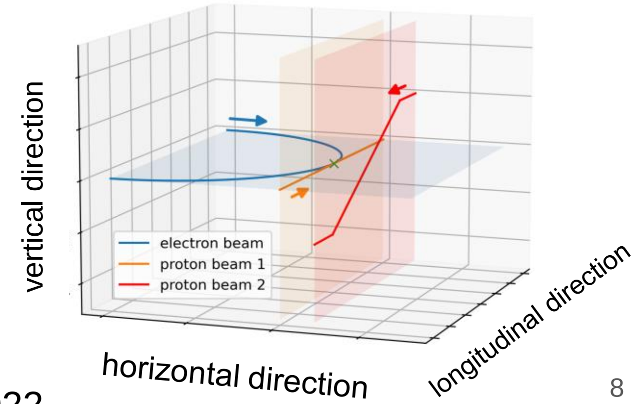
Standard HL-LHC, L* = 23 m, β* = 15 cm, θ = 590 μrad



Courtesy from Massimo Giovannozzi (2019)

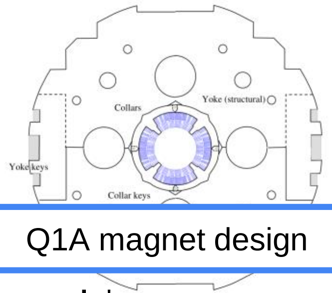
Accelerator considerations to **combine the ALICE and LHeC experiments** at point 2 of the HL-LHC:

- **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.

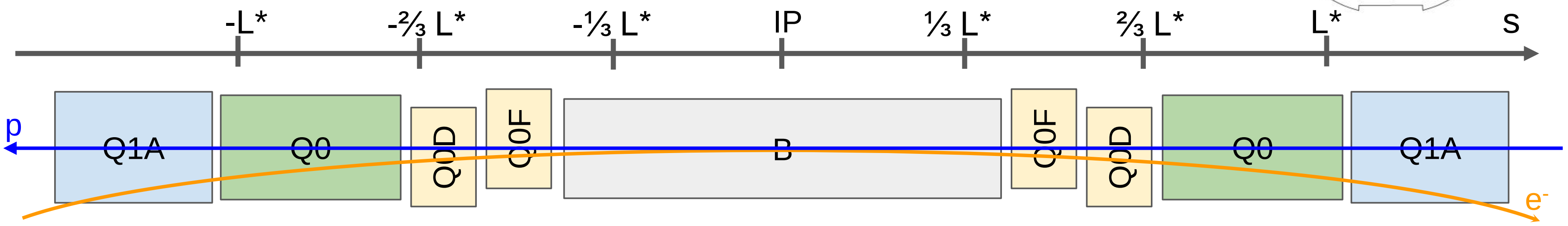


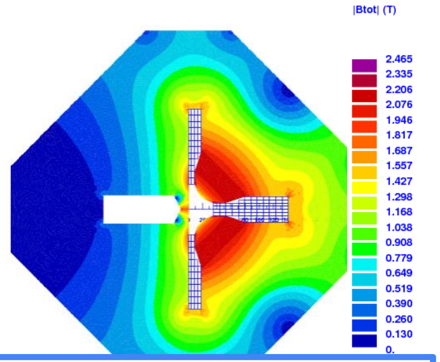
e-p beam separation scheme optimisation

Based on the difference in beam rigidities of the colliding beams.



Q1A magnet design



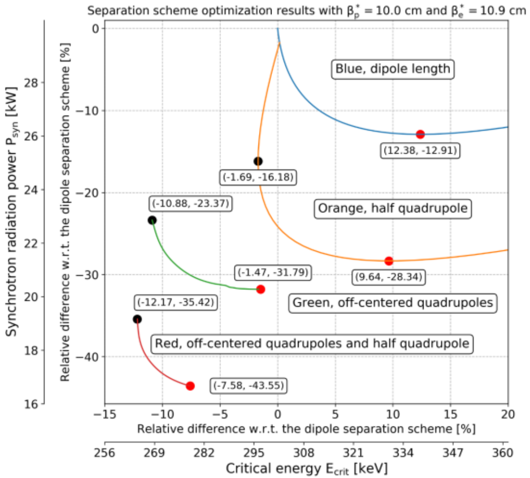


Q0 magnet design

S. Russenschuck & B. Parker

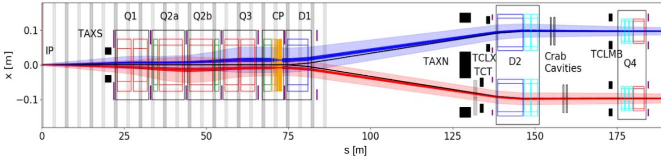
* Optimisation to **extend the distance** to separate the beam with Q0

* Optimisation to **reduce the electron beam size** at Q1A with Q0F & Q0D

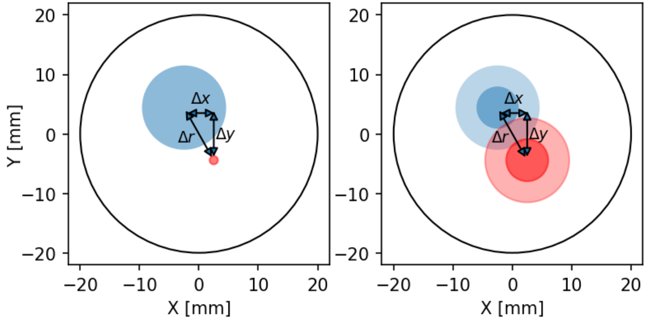


Combined hh|eh interaction region

- Based on HL-LHC optics and lattice design, the **two proton beams must be housed in the same quadrupole aperture** unlike the past LHeC proton interaction design.
- Horizontal separation at the IP and vertical crossing angle to avoid parasitic interactions.
- The second proton beam should have a **flexible optics design**:
  - a **relaxed optics design, during eh operation**, as it acts as a spectator beam with an “injection like optics”,
  - a **collision optics design, during hh operation**, to realise the HL-LHC luminosity
- Tradeoff between quadrupole aperture and achievable beam size at the IP for both eh and hh configurations.



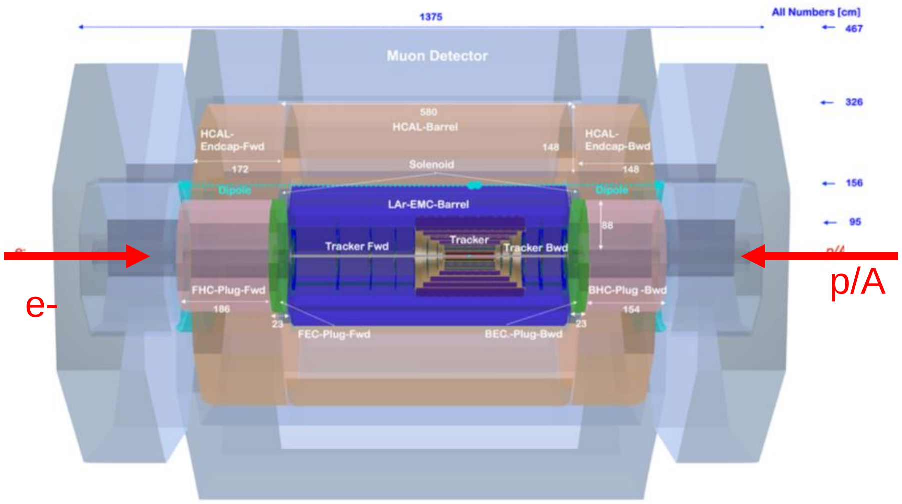
LHC proton beam trajectories from the IP to the matching quadrupole Q4



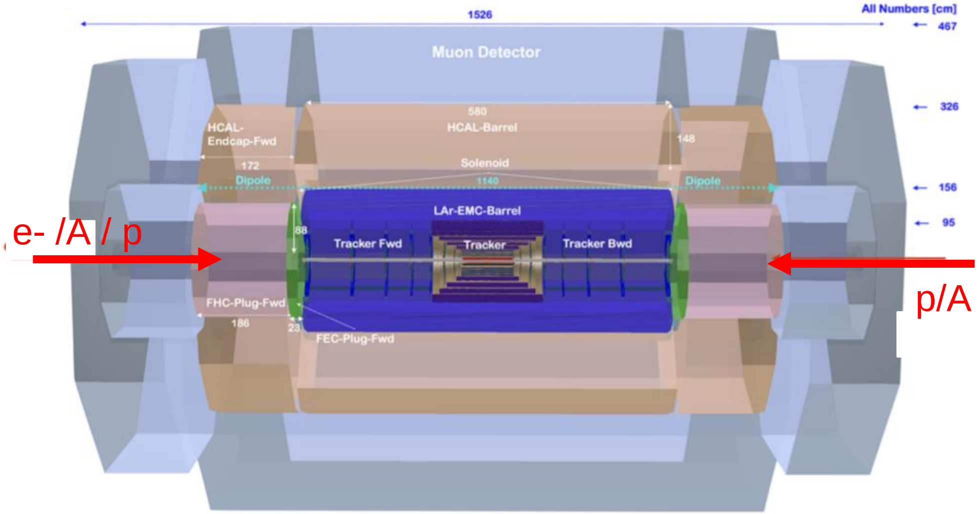
Relaxed (left) and collision optics (right) in a quadrupole aperture

Detector design - EPJC

e-h detector design for the LHeC



e-h & h-h detector design for the LHeC



Silicon tracker, surrounded by an electromagnetic (LAr) calorimeter and a combined solenoid and dipole magnets enclosed by a hadronic calorimeter and muon system. Need of forward-backward symmetry to include hadron-hadron physics.

Summary

* LHeC: 50 GeV electron beam from an ERL colliding with a 7 TeV proton beam from the LHC concurrent to the HL-LHC hadron-hadron operation.

* They are ongoing studies to tackle the challenges to realise a proton lattice and optics design with an interaction region combining e-h & h-h.

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

* The combination of the LHeC and ALICE upgrade would allow to push the energy frontier for electron-ion collisions beyond that of the EIC in Brookhaven providing a synergy of the polarisation studies at BNL and the energy frontier studies at CERN.