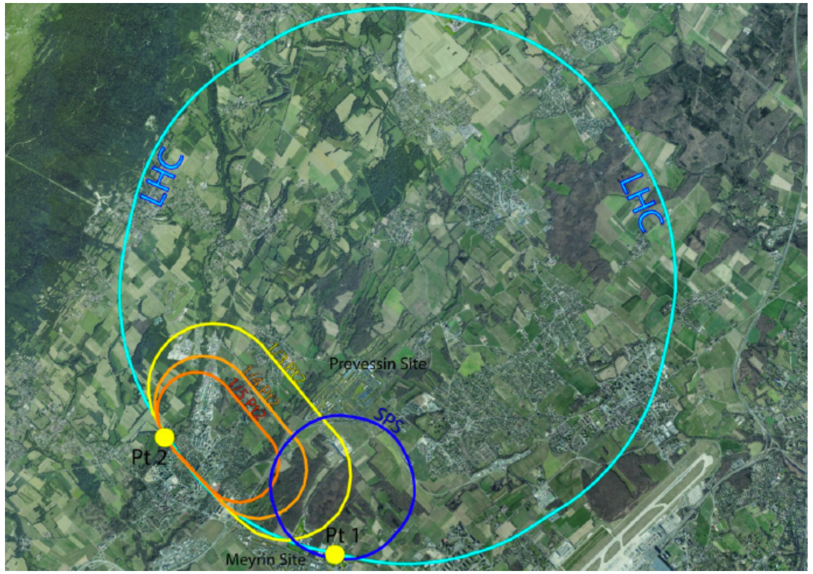
LHeC, PERLE and FCC-eh

M Klein, O Bruening on LoIs for future ep:
Snowmass Meeting on TeV Colliders
8 July 2020, for the LHeC+PERLE+FCCeh



50 x 7000 GeV^2: 1.2 TeV ep collider

Operation: 2035+, Cost: O(1) BCHF

CDR: 1206.2913 J.Phys.G (550 citations)

Upgrade to 10^{34} cm^{-2}s^{-1}, for Higgs, BSM

CERN-ACC-Note-2018-0084 (ESSP)

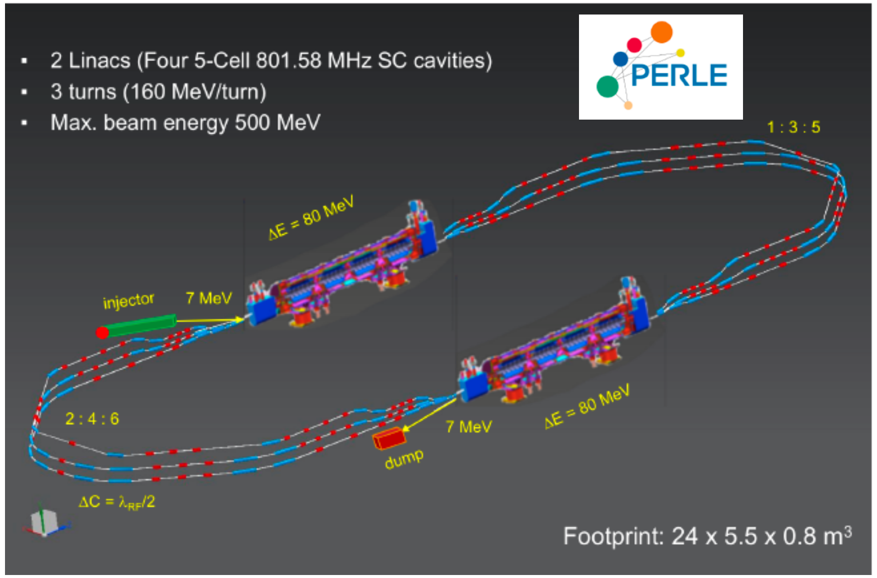
CERN-ACC-Note-2020-0002 →arXiv (July)

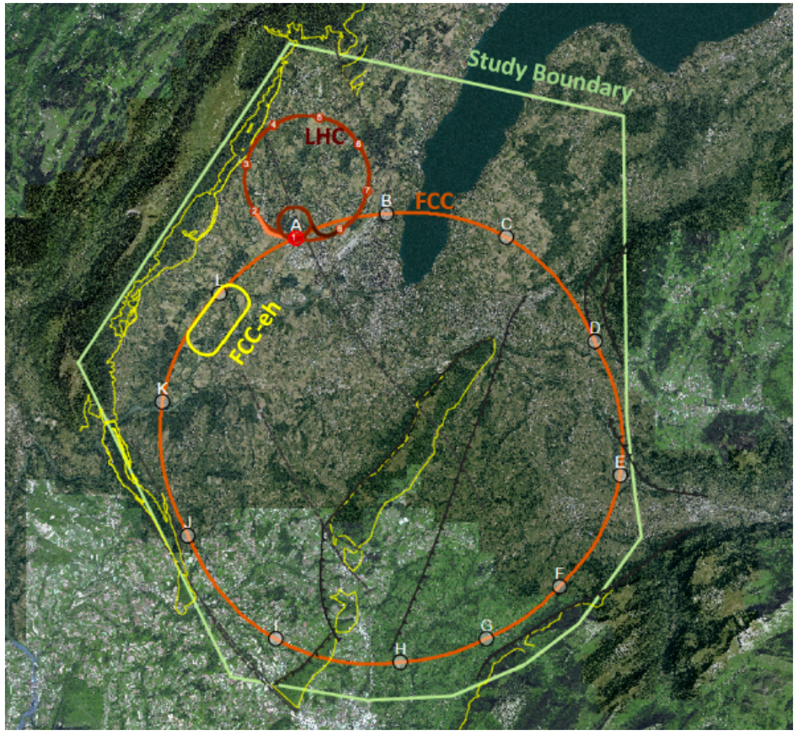
Powerful ERL for Experiments @ Orsay
CDR: 1705.08783 J.Phys.G
CERN-ACC-Note-2018-0086 (ESSP)

Operation: 2025+, Cost: O(20) MEuro

LHeC ERL Parameters and Configuration
I_e=20mA, 802 MHz SRF, 3 turns →
E_e=500 MeV → first 10 MW ERL facility

BINP, CERN, Daresbury, Jlab, Liverpool, Orsay (IJC), +





60 x 50000 GeV^2: 3.5 TeV ep collider

Operation: 2050+, Cost (of ep) O(1-2) BCHF

Concurrent Operation with FCC-hh

FCC CDR:
Eur.Phys.J.ST 228 (2019) 6, 474 Physics
Eur.Phys.J.ST 228 (2019) 4, 755 FCC-hh/eh

Future CERN Colliders: 1810.13022 Bordry+

High Luminosity Electron-Hadron Physics at TeV energy

The LHeC represents a new laboratory for high energy physics.

Its programme comprises five major themes:

MICROSCOPE of substructure

By the nature of the high energy eh interaction, the LHeC is the cleanest high resolution microscope of matter, the Hubble telescope of substructure.

EMPOWERMENT of LHC physics

The LHC lacks crucial input on the proton structure and QCD dynamics. The clean, external input on partons will clarify the high mass predictions, and thus extend the reliablity and range for BSM searches, and provide input required for precision QCD, electroweak and Higgs physics. This way, it empowers the LHC physics and utilises the LHC infrastructure optimally. It is the near detector for the GPDs.

A NOVEL HIGGS PHYSICS FACILITY

The clean final state, the absence of pile-up, the large Higgs production cross section and novel detection and analysis techniques enable precision input in all large decay channels, including H→ cc, which combined with pp, lead to percent level LHC Higgs coupling results, comparable to ee prospects.

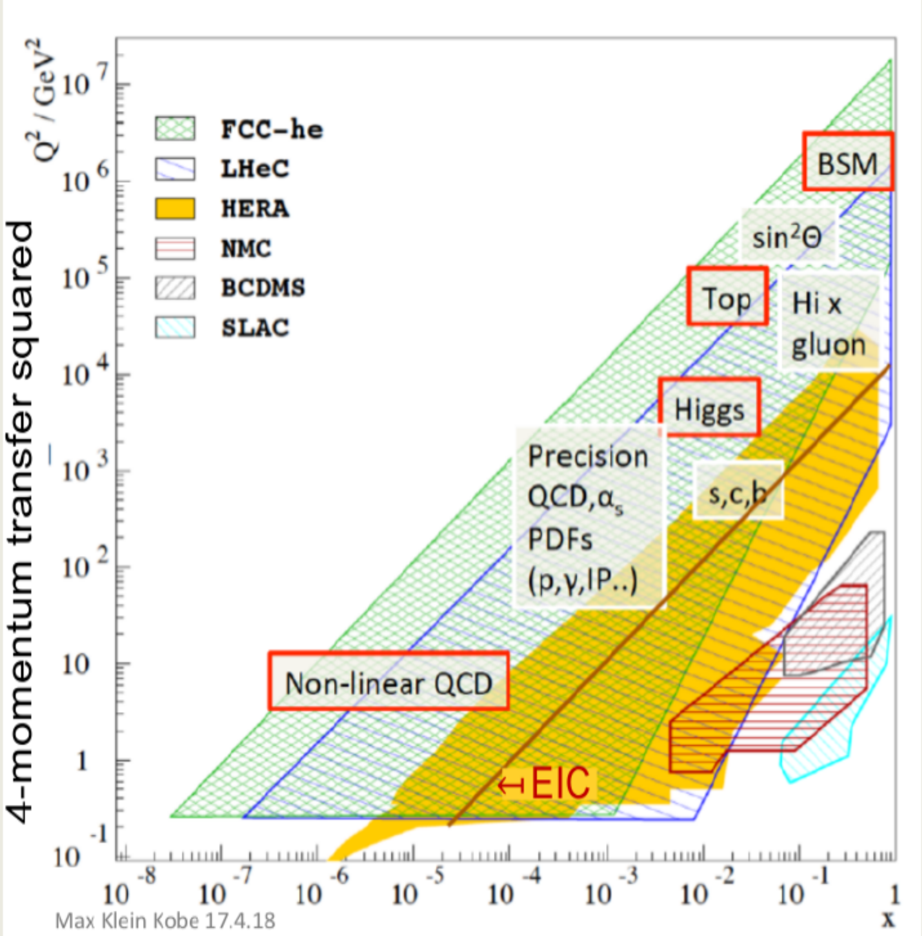
DISCOVERY of new physics

The LHeC is a TeV energy scale new configuration, it has large discovery potential in QCD (saturation), electroweak (Higgsinos, rh neutrinos), top and substructure physics.

REVOLUTION of nuclear particle physics

The partonic structure of nuclei is of an infant status like that of protons before HERA, it will be established in a huge range with stand-alone eA PDF one may then relate to those in ep. The understanding of the Quark-Gluon Plasma needs ep.

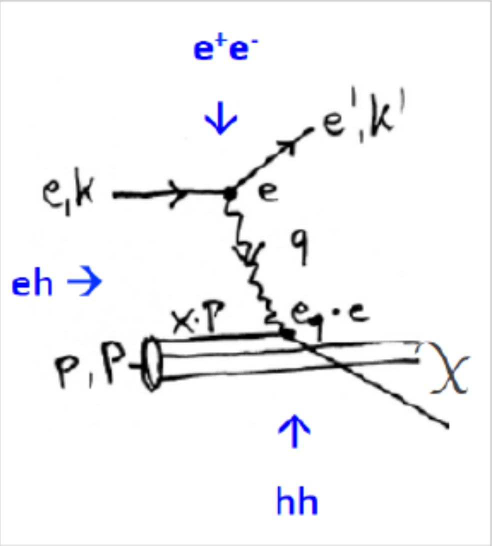
CERN-ACC-Note-2018-084, subm EU strategy, J.Phys.G to appear

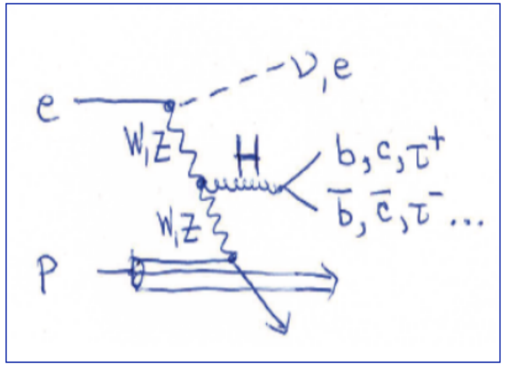


Following HERA, **deep inelastic scattering needs high energy** (and also luminosity) to reach Higgs, top, BSM physics, to use charged currents for unfolding parton structure, independently of nuclear and higher twist effects, to clarify the existence of BFKL dynamics at small x, and prepare for FCC.

With polarised protons, there is **a case for a lower (than HERA) energy eh collider**, which also studies proton structure at medium Bjorken x, the EIC.

DIS: the cleanest high resolution microscope and a laboratory for new particles and new dynamics.





Taken from a poster to Lepton-Photon 2019 MK. See also arXiv:1802.04317

Machine Parameters and Operation - ep

CERN-ACC-Note-2020-0002 →arXiv (July)

Parameter	Unit	LHeC				FCC-eh	
		CDR	Run 5	Run 6	Dedicated	E_p=20 TeV	E_p=50 TeV
E_e	GeV	60	30	50	50	60	60
N_p	10^{11}	1.7	2.2	2.2	2.2	1	1
ϵ_p	μm	3.7	2.5	2.5	2.5	2.2	2.2
I_e	mA	6.4	15	20	50	20	20
N_e	10^9	1	2.3	3.1	7.8	3.1	3.1
β^*	cm	10	10	7	7	12	15
Luminosity	$10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1	5	9	23	8	15

Table 2.3: Summary of luminosity parameter values for the LHeC and FCC-eh. Left: CDR from 2012; Middle: LHeC in three stages, an initial run, possibly during Run 5 of the LHC, the 50 GeV operation during Run 6, both concurrently with the LHC, and a final, dedicated, stand-alone *ep* phase; Right: FCC-eh with a 20 and a 50 TeV proton beam, in synchronous operation.

No pileup

For comparison, HERA I operated at 10^{31}cm^{-2}s^{-1}, and was upgraded by a factor of up to 4 for HERA II
The total luminosity delivered was 1 fb^{-1} over a running period of 15 years, including shutdowns.
LHeC may operate at 20 x 1000 GeV^2 and "repeat" all of HERA in a short running period.

The updated CDR considers a Ring-Ring ep collider as a back-up solution. May be revived for HE-LHC.

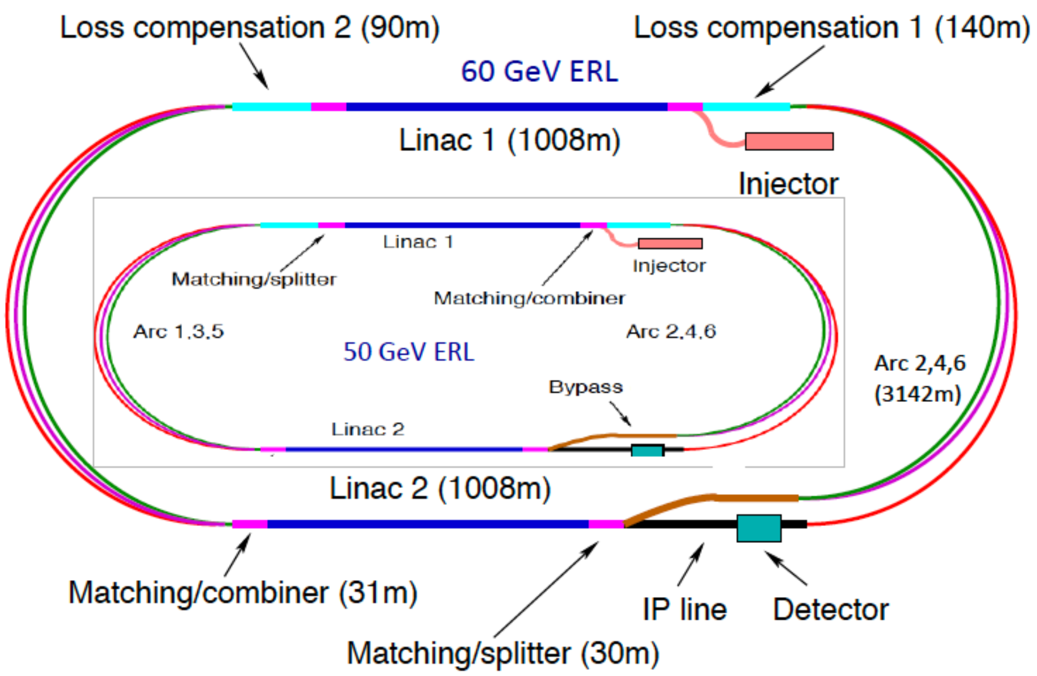
CERN-ACC-Note-2020-0002 →arXiv (July)

LHeC in more Detail

Parameter	Unit	Value
Injector energy	GeV	0.5
Total number of linacs		2
Number of acceleration passes		3
Maximum electron energy	GeV	49.19
Bunch charge	pC	499
Bunch spacing	ns	24.95
Electron current	mA	20
Transverse normalized emittance	µm	30
Total energy gain per linac	GeV	8.114
Frequency	MHz	801.58
Acceleration gradient	MV/m	19.73
Cavity iris diameter	mm	130
Number of cells per cavity		5
Cavity length (active/real estate)	m	0.918/1.5
Cavities per cryomodule		4
Cryomodule length	m	7
Length of 4-CM unit	m	29.6
Acceleration per cryomodule (4-CM unit)	MeV	289.8
Total number of cryomodules (4-CM units) per linac		112 (28)
Total linac length (with with spr/rec matching)	m	828.8 (980.8)
Return arc radius (length)	m	536.4 (1685.1)
Total ERL length	km	5.332

Table 10.1: Parameters of LHeC Energy Recovery Linac (ERL).

Positrons: 500pC is 3 $10^9 e^-$/bunch → 20mA and 1.2 10^{17} e^-/s
LHeC programme needs e^-p predominantly (Higgs) and only smaller e^+p sample, ~fb^{-1} → O(10^{15}) e^+/s, still demanding!
High intensity with γγ or FEL options of LHeC (Frank Z)



- LHeC Configuration reduced from 60 to 50 GeV.
- LINAC: 112 cryomodules with 4 cavities each
  → Total number of cavities: 896 [ILC: O(10^4)]
- Configuration may be staged with less RF
- Tunnel is small part of cost and better not reduced further, synchrotron loss, upgrades..
- ERL reduces power to << GW and dumps at < GeV
  → novel, "green" accelerator technology

Machine Parameters - eA

Parameter	Unit	LHeC	FCC-eh (E_p=20 TeV)	FCC-eh (E_p=50 TeV)
Ion energy E_{Pb}	PeV	0.574	1.64	4.1
Ion energy/nucleon E_{Pb}/A	TeV	2.76	7.88	19.7
Electron beam energy E_e	GeV	50	60	60
Electron-nucleon CMS $\sqrt{s_{eN}}$	TeV	0.74	1.4	2.2
Bunch spacing	ns	50	100	100
Number of bunches		1200	2072	2072
Ions per bunch	10^8	1.8	1.8	1.8
Normalised emittance ϵ_n	μm	1.5	1.5	1.5
Electrons per bunch	10^9	6.2	6.2	6.2
Electron current	mA	20	20	20
IP beta function β^*_A	cm	10	10	15
e-N Luminosity	$10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	7	14	35

Table 2.4: Baseline parameters of future electron-ion collider configurations based on the electron ERL, in concurrent eA and AA operation mode with the LHC and the two versions of a future hadron collider at CERN. Following established convention in this field, the luminosity quoted, at the start of a fill, is the *electron-nucleon* luminosity which is a factor A larger than the usual (i.e. electron-nucleus) luminosity.

CERN-ACC-Note-2020-0002 →arXiv (July)

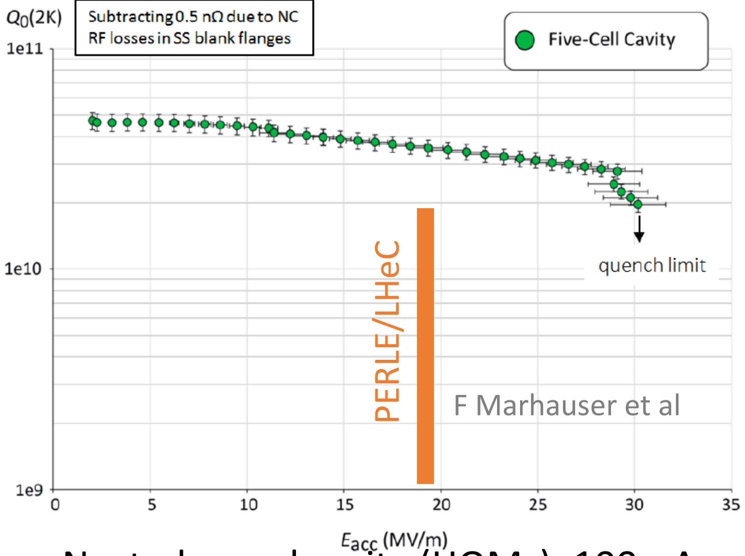
The LHeC and FCC-eh are the highest energy, most powerful electron-ion colliders the world may build.

Developments +Partners

Cf recent meeting: https://indico.cern.ch/event/923021/

SCRF: High Q_0, complete Cryomodule

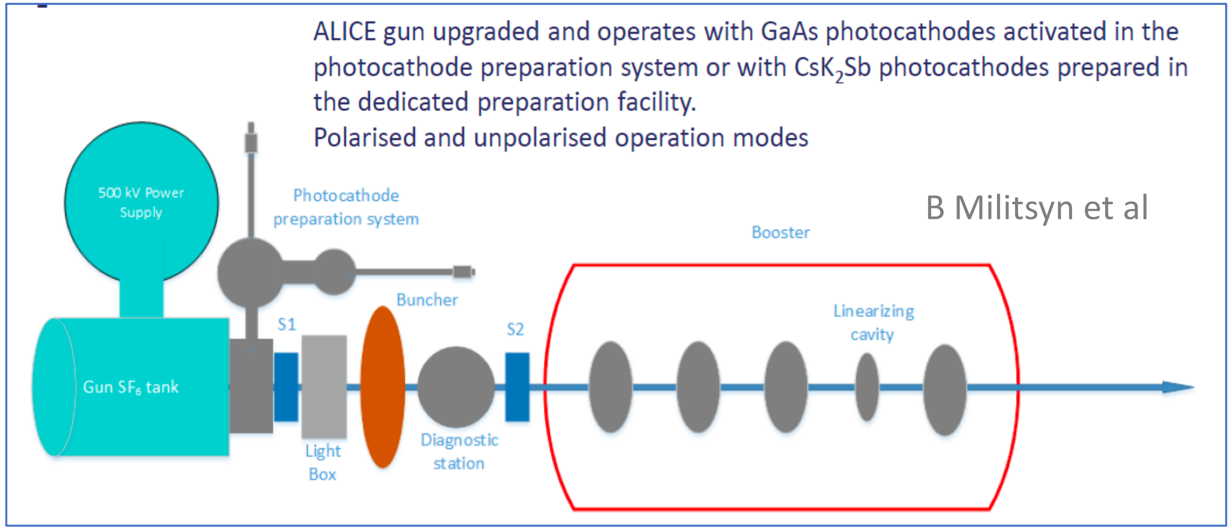
Jointly with FCC-ee



Next: dressed cavity (HOMs), 100mA
Adapt SPL Cryomodule for PERLE

CERN, Jlab, Orsay +

High Current Source (e^-, P, e^+)

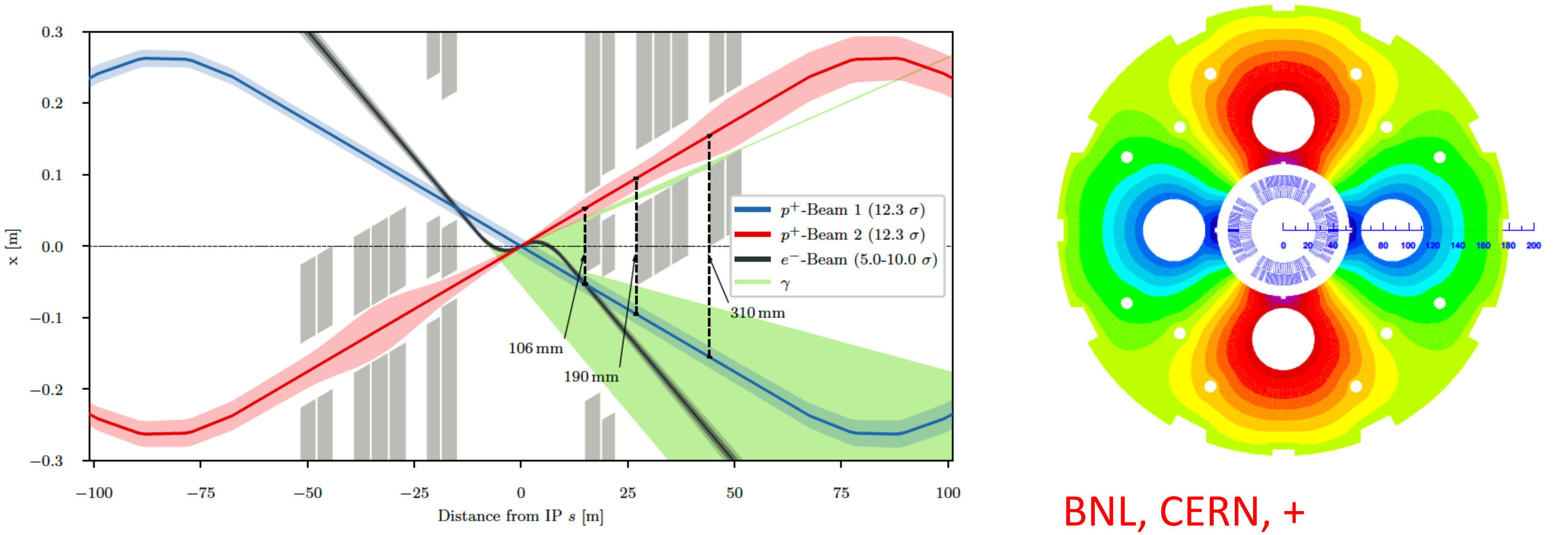


PERLE will begin with 5mA ALICE source, which has been transferred from Daresbury to Orsay while UK was in EU..

BINP, BNL/Cornell (cBETA), Daresbury, IJC, Jlab, +

Interaction Region Design and Q_1 Prototype:

B Holzer, B Parker, S Russenschuck et al



BNL, CERN, +

A few summarising remarks

TeVatron-LEP/SLC-HERA eventually established the SM.

LHeC and FCC-eh Developments have the aim to to restore the hh-eh-ll symmetry as is particularly important for the current situation of particle physics.

The baseline of the LHeC/FCC-eh is a multi-turn, large current energy recovery linac in racetrack configuration.

The luminosity reach is 10^{34} $cm^{-2}s^{-1}$ leading to O(1) ab^{-1} owing to the intense hadron beams of the LHC/FCC.

An ERL demonstrator has been designed and is being developed for built at IJC laboratory at Orsay, by an international collaboration, open for partners.

ERL has been recognized by the ESSP as one of the far reaching new accelerator technologies to be developed.

An informative network exists for exchange of expertise between several ERL facilities, not least CEBAF and CBeta

Specific ep tasks for the next year development are:

- High quality SRF, towards a complete cryomodule [4 cavities of 802 MHz frequency, with FRT possibly]

- High current electron sources (with polarization, e^+)

- ep 3-beam interaction region for concurrent ep and pp operation and head-on ep collision, with special demands on the focusing magnets

We are presenting to EF, QCD and other physics working groups.

The LoI process on accelerator, detector and physics is being discussed for submission end of August, glad to have your input, especially on synergies.

For ep and eA it is of interest to be in contact with the American community and assist in the Snowmass evaluation of its physics and technology.

Thank you for inviting to this process.

LHeC Detector

L=13.2 m [FCCeh:19.3 about CMS size]

R=4.8 m
[6.2 FCCeh]

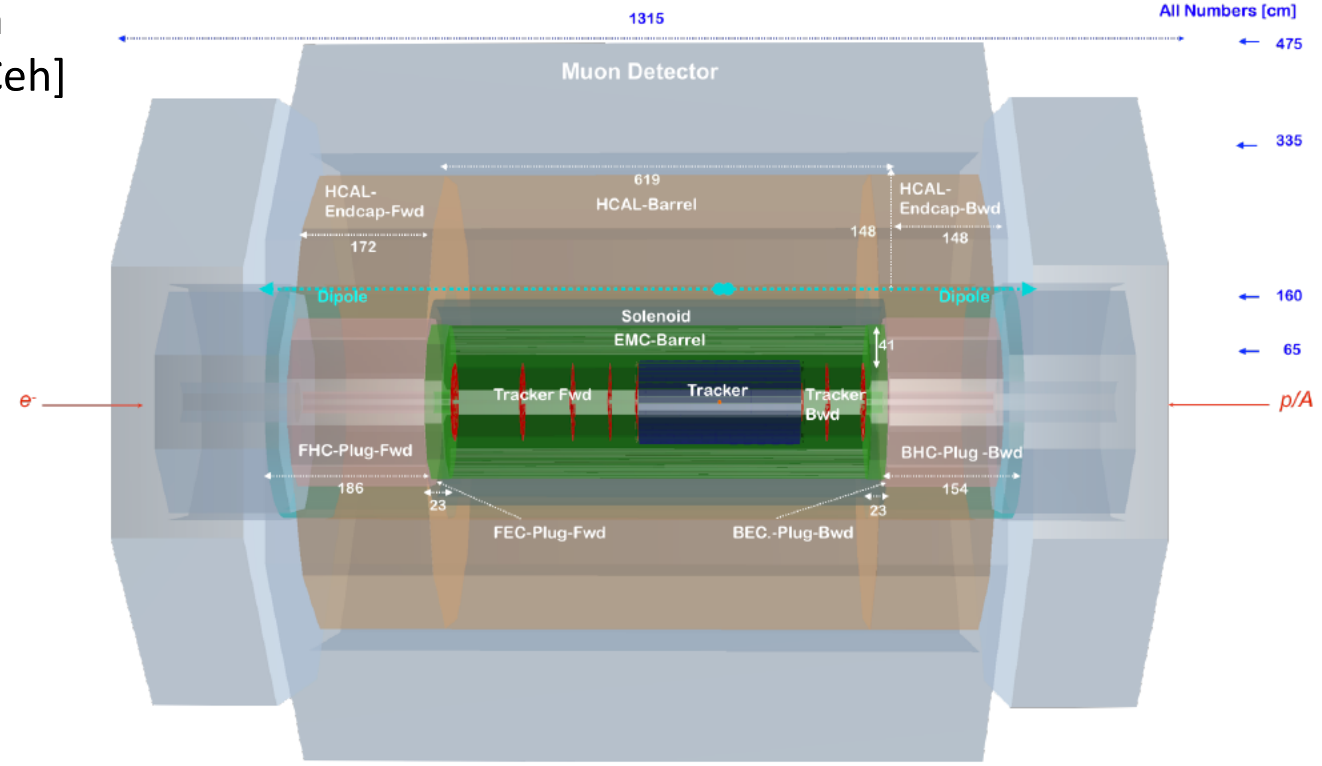
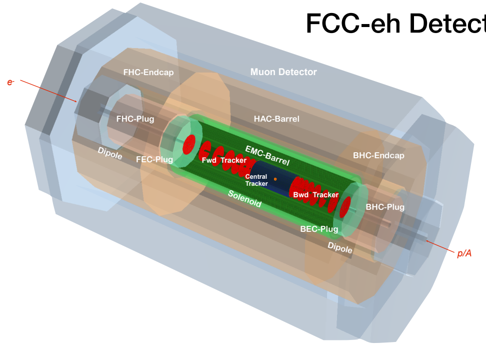


Figure 12.1: Side view of the updated baseline LHeC detector concept, providing an overview of the main detector components and their locations. The detector dimensions are about 13 m length and 9 m diameter. The central detector is complemented with forward $(p,\ n)$ and backward $(e,\ \gamma)$ spectrometers mainly for diffractive physics and for photo-production and luminosity measurements, respectively. See text for details.

CERN-ACC-Note-2020-0002 →arXiv (July)

FCC-eh Detector



Study of installation (sequence) of LHeC detector in IP2 cavern using L3 magnet support structure [commensurate with 2 year shutdown]