Remarks on the Development of the LHeC/PERLE/FCC-eh Project

Bits of History
Particle Physics
Physics with ep/A
Remarks on PERLE
LHeC and its Power
ERL Roadmap
IAC Recommendations
FCC-eh

2008 2009 2010 2012 2014 2015 2017 2018 2019 2022

Max Klein. University of Liverpool. LHeC,PERLE, FCC-eh Workshop at Orsay 26 October 2022

History bits of ep Colliders and LHeC

The realisation of HERA at DESY had followed a number of attempts to realise ep interactions in collider mode, mainly driven by the unforgettable Bjoern Wiik: since the late 1960s, he and his colleagues had considered such machines and proposed to probe the proton's structure more deeply with an ep collider at DORIS [3], later at PETRA (PROPER) [4] and subsequently at the SPS at CERN (CHEEP) [5]. Further ep collider studies were made for PEP [6], TRISTAN [7] and also the Tevatron (CHEER) [8].
In 1990, at a workshop at Aachen, the combination of LEP with the LHC was discussed, with studies [9{11] on the luminosity, interaction region, a detector and the physics as seen with the knowledge of that time, before HERA. Following a request of the CERN Science Policy Committee (SPC), a brief study of the ring-ring ep collider in the LEP tunnel was performed [12] leading to an estimated luminosity of about 1032 cm-2s-1.
At the end of the eighties it had been anticipated that there was a possible end to the increase of the energy of ep colliders in the ring-ring con guration, because of the synchrotron radiation losses of an electron ring accelerator. The classic SLAC fixed target ep experiment had already used a 2 mile linac. For ep linac-ring collider con gurations, two design sketches considering electron beam energies up to a few hundred GeV were published, in 1988 [13] and in 1990 [14]. As part of the TESLA linear collider proposal, an option (THERA) was studied [15] to collide electrons of a few hundred GeV energy with protons and ions from HERA. Later, in 2003, the possibility was evaluated to combine LHC protons with CLIC electrons [16]. It was yet realised, that the bunch structures of the LHC and CLIC were not compliant with the need for high luminosities.
In September 2007, the SPC again asked whether one could realise an ep collider at CERN. Some of us had written a paper [17] in the year before, that had shown in detail, for the first time, that a luminosity of 1033 cm-2s-1 was achievable. This appeared possible in a ring-ring configuration based on the “ultimate" LHC beam, with 1.7 x 1011 protons in bunches 25 ns apart. Thanks to the small beam-beam tune-shift, it was found to be feasible to simultaneously operate pp in the LHC and ep in the new machine, which in 2005 was termed the Large Hadron Electron Collider (LHeC) [18]. Thus it appeared possible to realise an ep collider that was complementary to the LHC, just as HERA was to the Tevatron.

2004: LHC-CLIC 1.1 10^{31} luminosity

DIS2005, Madison, LHeC introduced
F Willeke: RR, 2.4 10^{32} luminosity
JINST paper: hep-ex/0603016 10^{33}

SPC → ECFA 2007

CDR 2012 arXiv:1206.2913

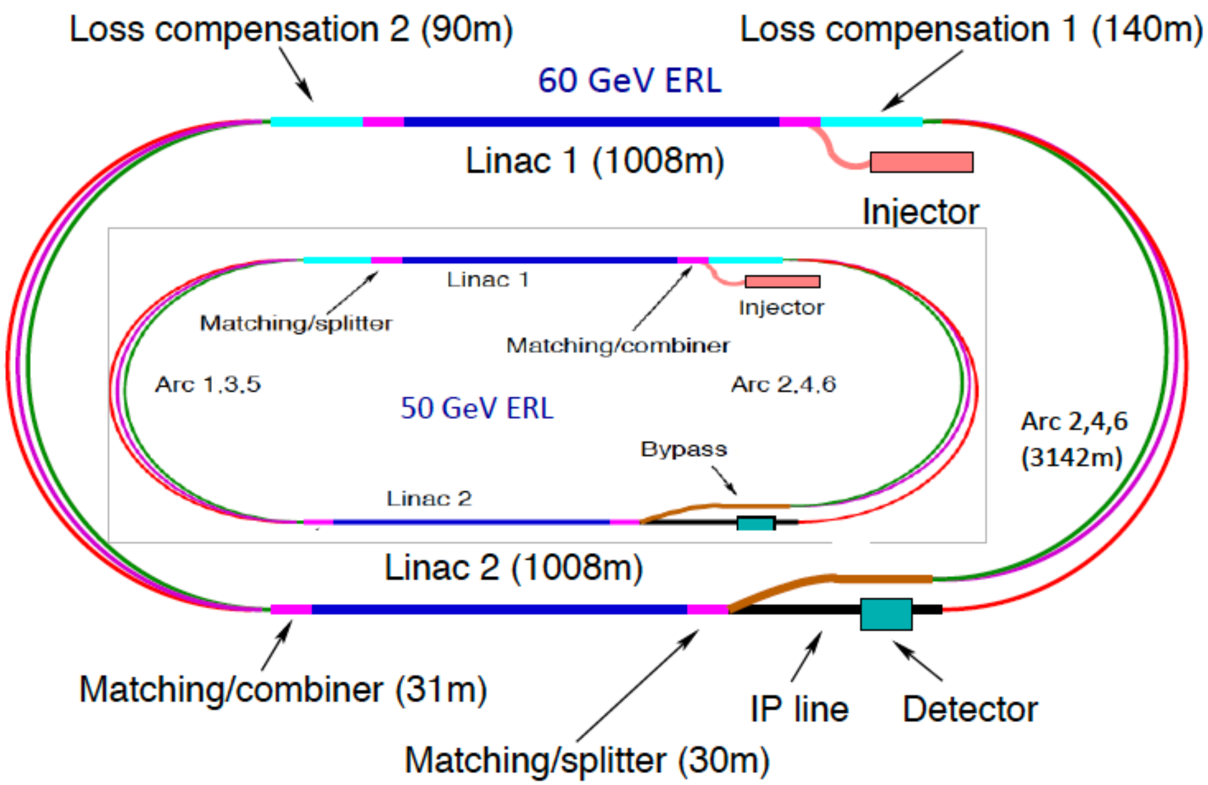
RR and LR: 6.4 mA = I_e , L=10^{33}
RR limited in luminosity by beam beam effects
→ ERL has key advantage

2013: IAC with Herwig Schopper, CERN Mandate
LR default, Higgs and BSM: 10^{34}, I_e up ..

2020: CDR update

← From arXiv:1206.2913. now to add EIC and FCCeh

Electron accelerator for LHeC and FCC-eh: ERL



arXiv:2007.14491, published in J.Phys.G

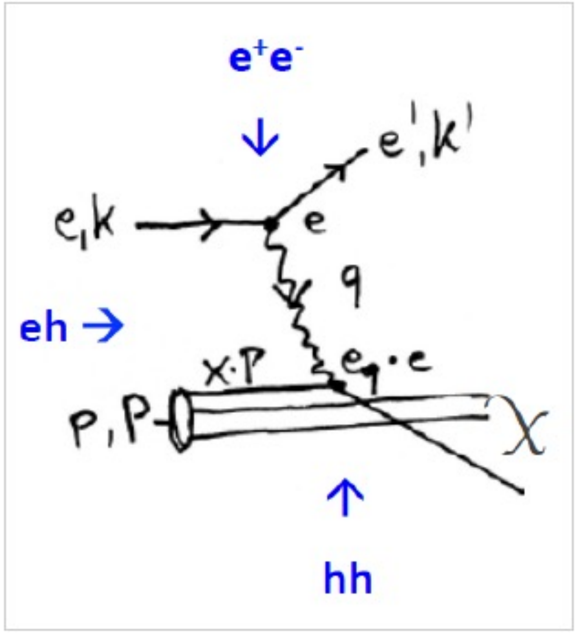
Parameter	Unit	Value
Injector energy	GeV	0.5
Total number of linacs		2
Number of acceleration passes		3
Maximum electron energy	GeV	49.19
Bunch charge	pC	499
Bunch spacing	ns	24.95
Electron current	mA	20
Transverse normalized emittance	µm	30
Total energy gain per linac	GeV	8.114
Frequency	MHz	801.58
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

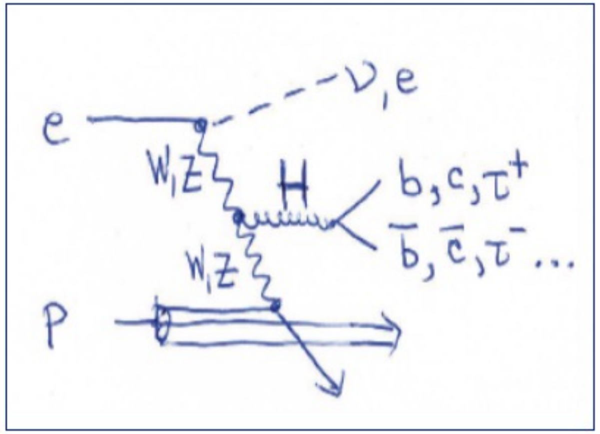
Table 10.1: Parameters of LHeC Energy Recovery Linac (ERL).

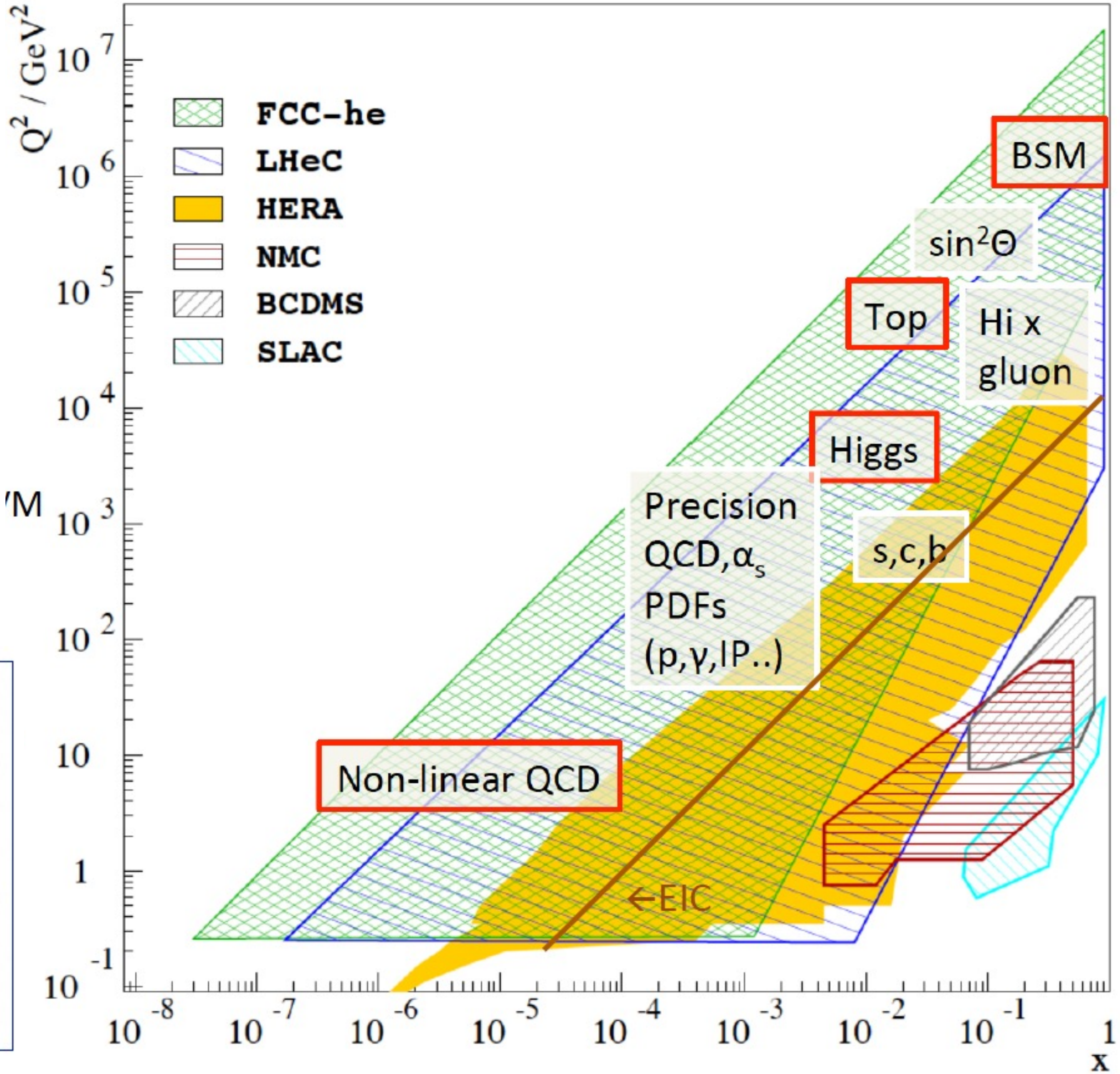
LHeC Version for 50 GeV energy

Physics with Energy Frontier DIS

Deep Inelastic Scattering







Raison(s) d'etre of ep/eA at the energy frontier

Cleanest High Resolution Microscope: QCD Discovery

Empowering the LHC Search Programme

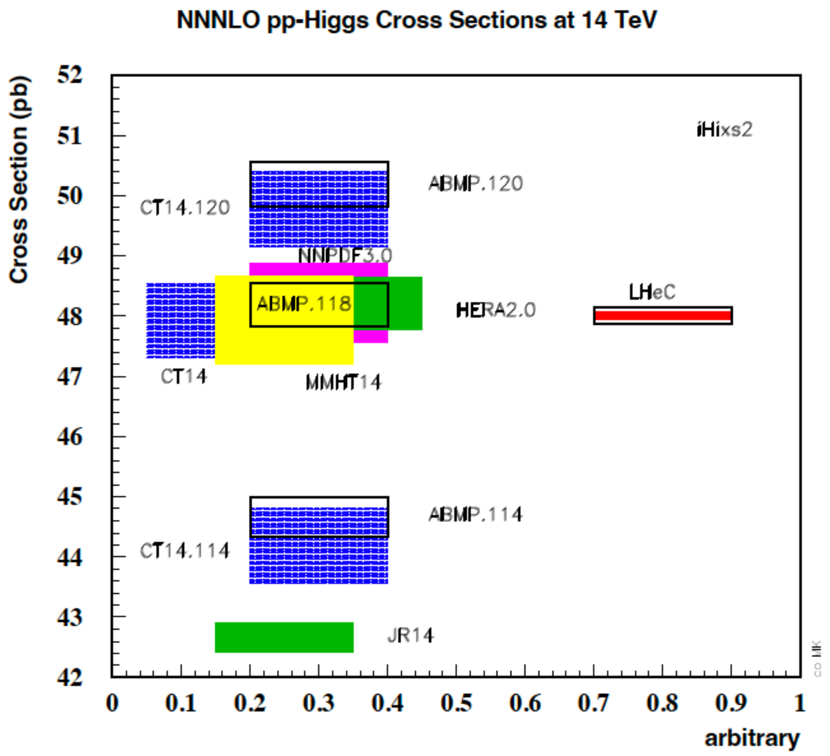
Transformation of LHC into high precision Higgs facility

Discovery (top, H, heavy ν's..) Beyond the Standard Model

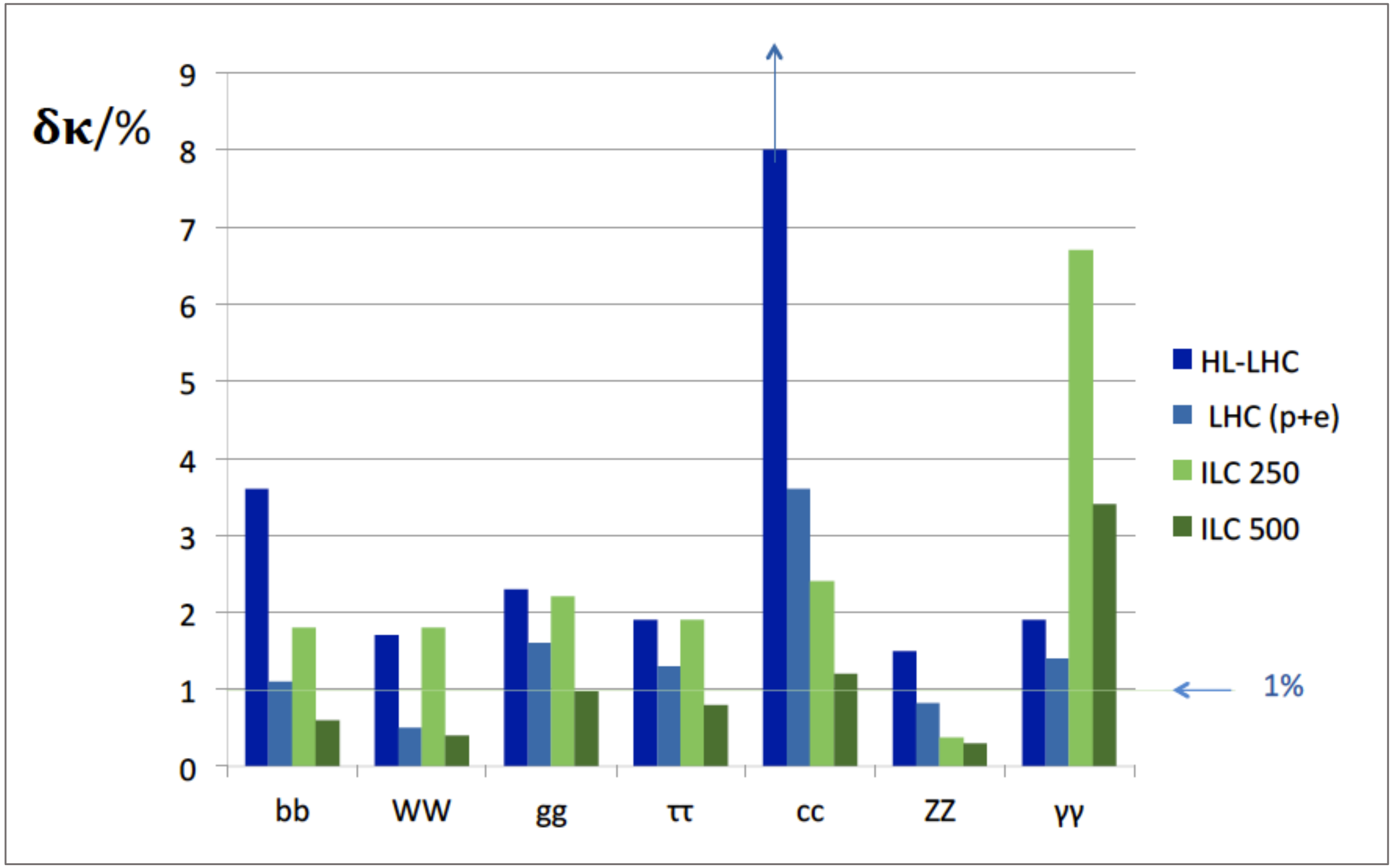
A Unique Nuclear Physics Facility

cf talks this afternoon

Higgs with LHC/LHeC and ILC – a side remark



High precision control of pp→ H



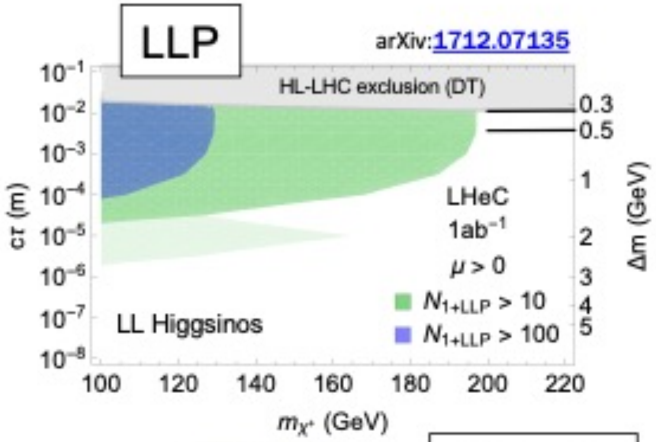
(sub) per cent level determination of Higgs couplings in pp/ep and ILC500 arXiv:2007.14491

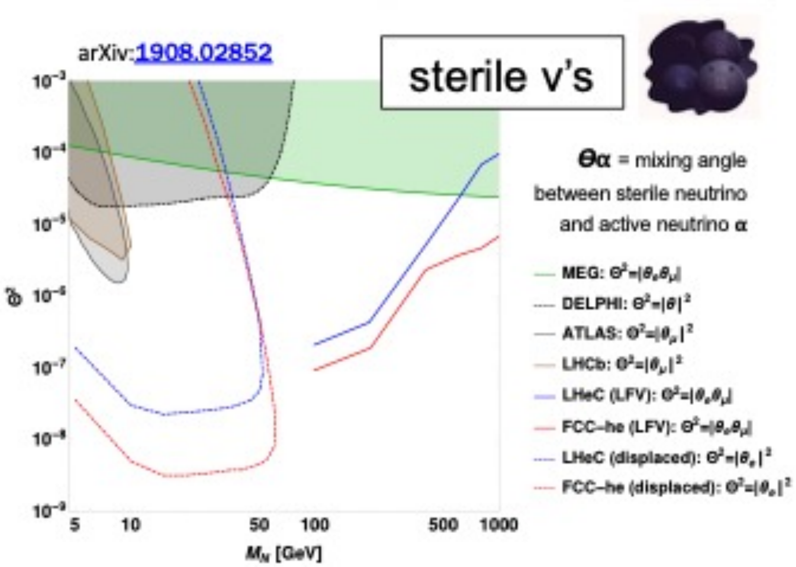
BSM

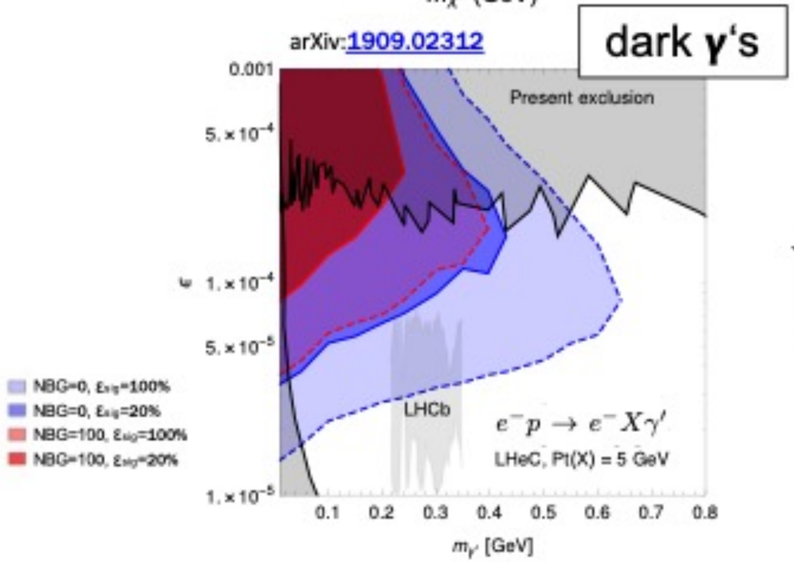
The LHeC has a genuine BSM program [cf O Fischer today]

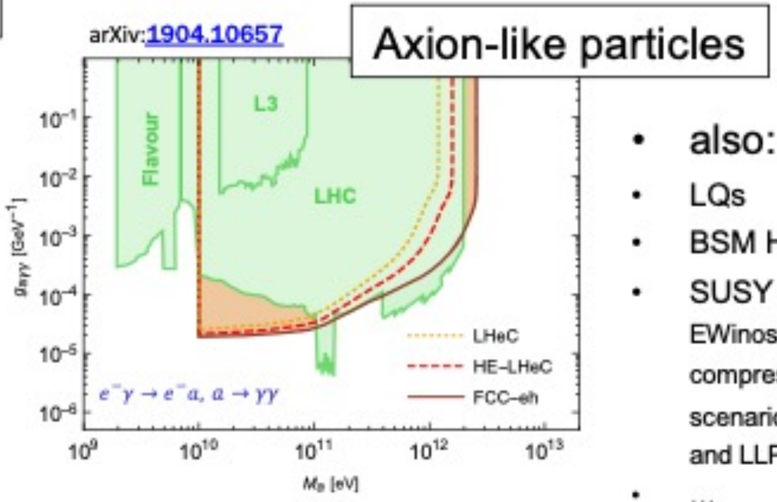
Particle Physics in order to progress needs ee,pp,ep, and not just one of them.

- selected examples:









- also:
- LQs
- BSM Higgs
- SUSY (RPV; EWinos in compressed scenarios, prompt and LLP, ...)
- ...

Claire Gwenlan at ICHEP 2022

R&D Goals and Motivation as described in roadmap 28.10.

-- Sustainability: Limitation of power consumption despite orders of magnitude higher luminosity need in electron based colliders

-- The near term 10 MW, 2K SRF program: 100 mA currents, Niobium SRF at optimum frequency, Q_0 3 10^{10} to 10^{11}, beam based

- **Next step in ERL technology**
- **Crucial development for Europe to stay as recognised partner for US, Russia and Japan**
- **Technology choice for LHeC and FCC-eh, 802 MHz, 5-cell cavity demonstrator, also for FCC-ee development**
- **Low energy particle and nuclear physics: nuclear photonics, exotic isotope spectroscopy, elastic ep (p radius, weak i.a.), dark photons**
- **Industrial applications such as Photolithography at nm scale, FELs (low and high E), inverse gamma sources, pico-second Xray sources**

-- The longer term 4.4K program: R&D for power economy, 20 MV/m, 5 10^{10} Q_0: ambition comparable to high field magnet program

- **Next generation ERL technology: power (heat transfer) efficiency enhanced by factor of three: 300 → 100 MW**
- **Enabling a 500 GeV 10^{36} $cm^{-2}s^{-1}$ luminosity ERL based linear collider for per cent measurement of Higgs self-coupling [backup]**
- **Transfer of superconducting RF technology to smaller labs → revitalisation of the field and its industrial base**

5.5 State of the art and Facility plans—Roadmap Part A

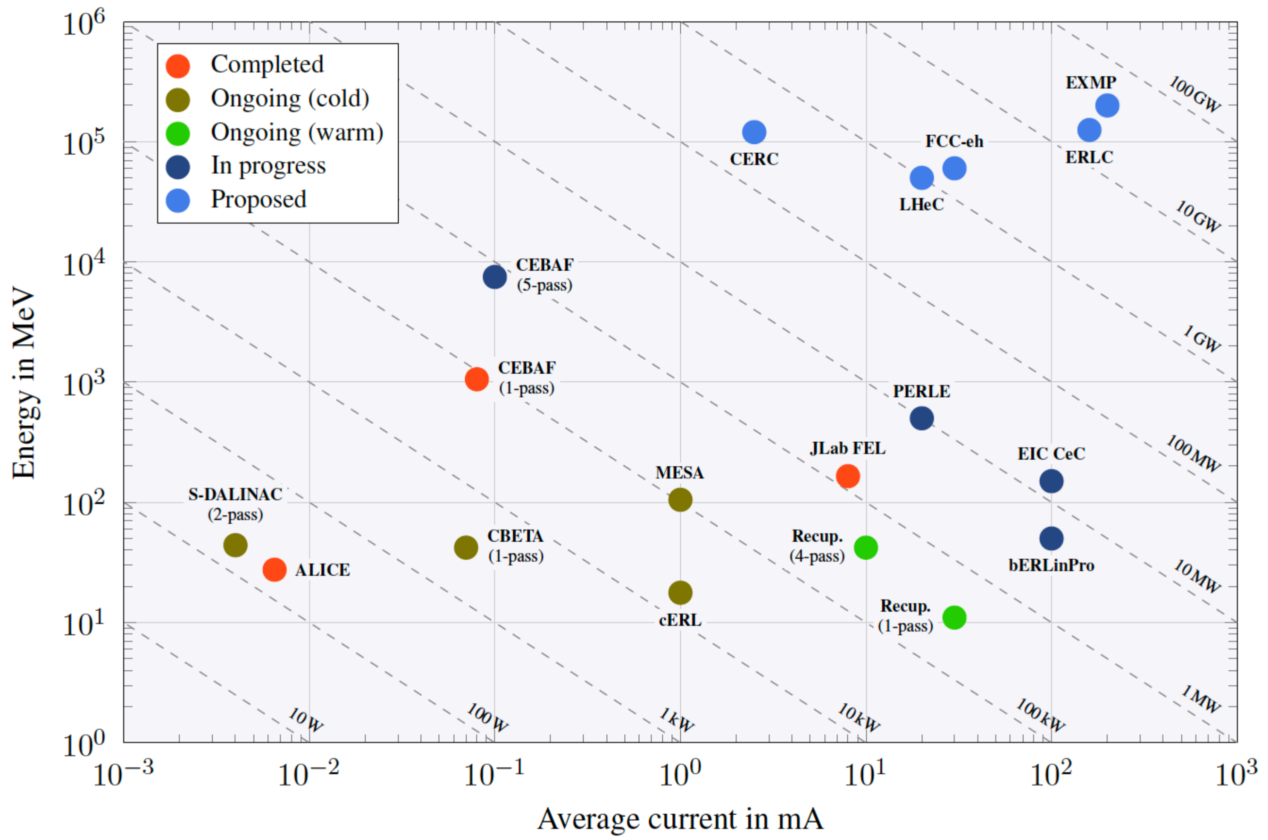


Fig. 6.1: Electron energy E vs. electron source current I for classes of past, present and possible future ERL facilities as are introduced in the text. Dashed diagonal lines represent constant power, $P[\text{kW}] = E[\text{MeV}] \cdot I[\text{mA}]$.

Future HEP colliders need O(100)mA current, multi or single turn

Ongoing/forthcoming facilities

Training, operation — S-DALINAC - Darmstadt

In August 2021, S-DALINAC was successfully operated in a twice-recirculating ERL mode. Full energy-recovery efficiencies of up to 81.8 % had been measured for beam currents of up to 8 µA at a beam energy of 41 MeV. The beam load of the SRF cavities in the two situations— with the beam either being accelerated only once or being accelerated twice and decelerated once— resulted in the same beam load within measurement uncertainties. The measurements, thus, indicate complete energy recovery in the first deceleration passage through the main linac with an efficiency of 100 % within uncertainties.

Support EIC CeC — CBETA - Cornell

After achieving all Key Performance Parameters of CBETA's NYSERDA-funded construction and commissioning phase, operation was interrupted in the spring of 2020. The accelerator is now available to test single-turn and multi-turn ERL technology. Especially tests for the 100 mA hadron-cooling ERL of the EIC are of interest, as several key design parameters of CBETA's main components match that future accelerator well.

Exps, polarised, HOM — MESA- Mainz (from 2024)

It will represent a sustained infrastructure for such experiments but also be available for further research on ERLs for a long time to come. The civil construction for the new machine will be finalised in 2022. Following the installation and commissioning of the machine, first ERL tests are expected in 2025. External-beam experiments are expected to start somewhat earlier. The ERL

– **Improving the higher-order mode damping capabilities** of the cavities.

rents, HOM heating of the damping antennas will lead to a breakdown of superconductivity in the antenna and hence inhibit operation. This can be improved by coating the HOM antennas with layers of material with a high critical temperature, e.g. Nb_3Sn. The MESA research group has recently received funding to start corresponding investigations within a larger joint effort of German universities.

Industry, 10mA, Nb_3Sn — cERL – KEK (50 years..)

– Realization of energy-recovery operation with 100 % efficiency at a beam current of 10 mA at cERL and the FEL light production experiment.
– Development of an irradiation line for industrial applications (carbon nanofibers, polymers, and asphalt production) based on the CW cERL operation.
– Realization of a high-efficiency, high-gradient Nb_3Sn accelerating cavity to produce a superconducting cryomodule based on the compact freezer. We are targeting a general-purpose compact superconducting accelerator system that that can be operated at universities, companies, hospitals,

90MHz, FEL — Recuperator – BINP (warm)

The current of the Novosibirsk ERL is now limited by the electron gun. A new RF gun was built and tested recently [41]. It operates at a frequency of 90 MHz. An average beam current of more than 100 mA was achieved. In brief, the following work is planned for the next years:

– Installation of the RF gun in the injector, while the existing electrostatic gun will be kept there. The RF gun beamline has already been manufactured and assembled in the test setup. It includes an RF chopper for the beam from the electrostatic gun.

See roadmap 2201.07895 and 2207.02095 for more info.

Mission

PERLE at Orsay

1. Demonstration of high current (20mA) multi (3) turn ERL operation and low energy nuclear/particle physis

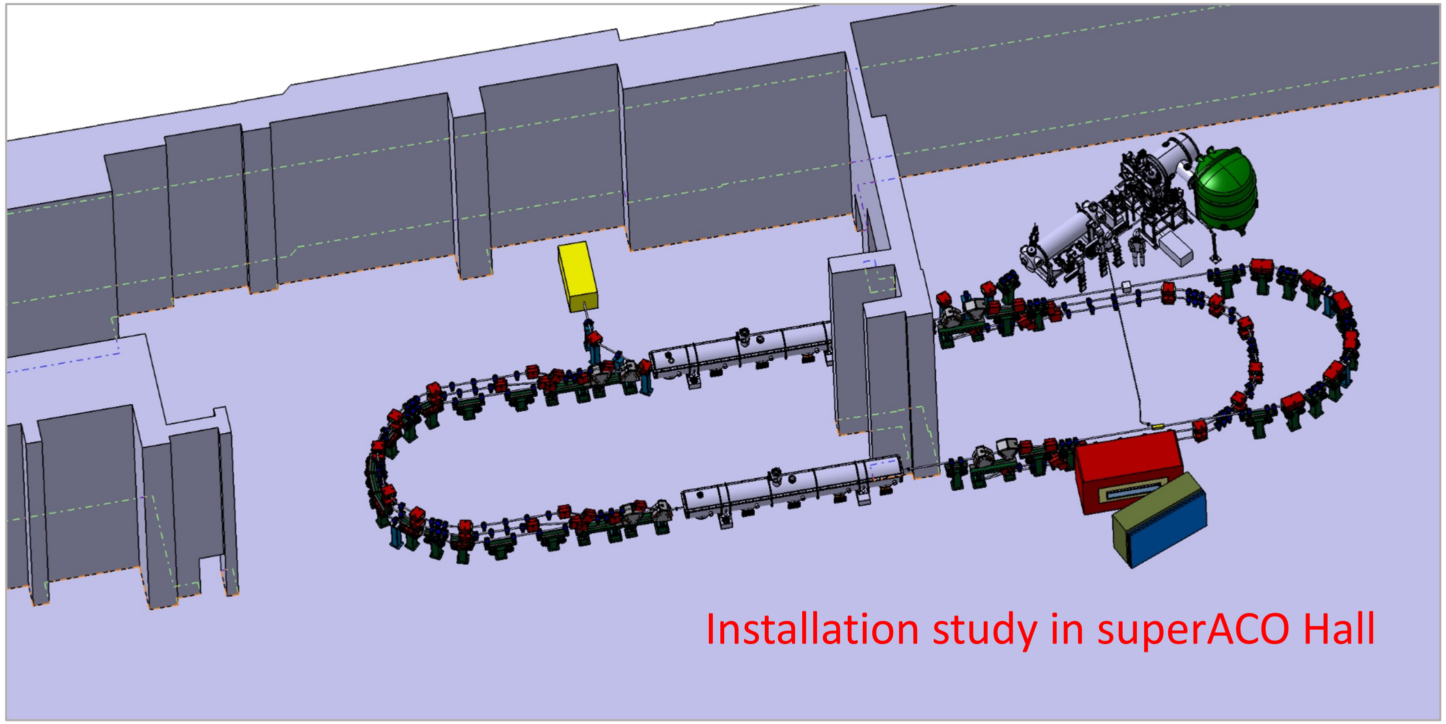
CDR in 2017 (J.*Phys.G* 45 (2018) 6, 065003 and arXiv:1705.08783)

current **Composition of PERLE Collaboration:**

IJCLab (host), AsTEC, BINP (on hold), CERN, Cockcroft, U Cornell, Grenoble, Jlab, U Liverpool, U Nablus, open to further partners

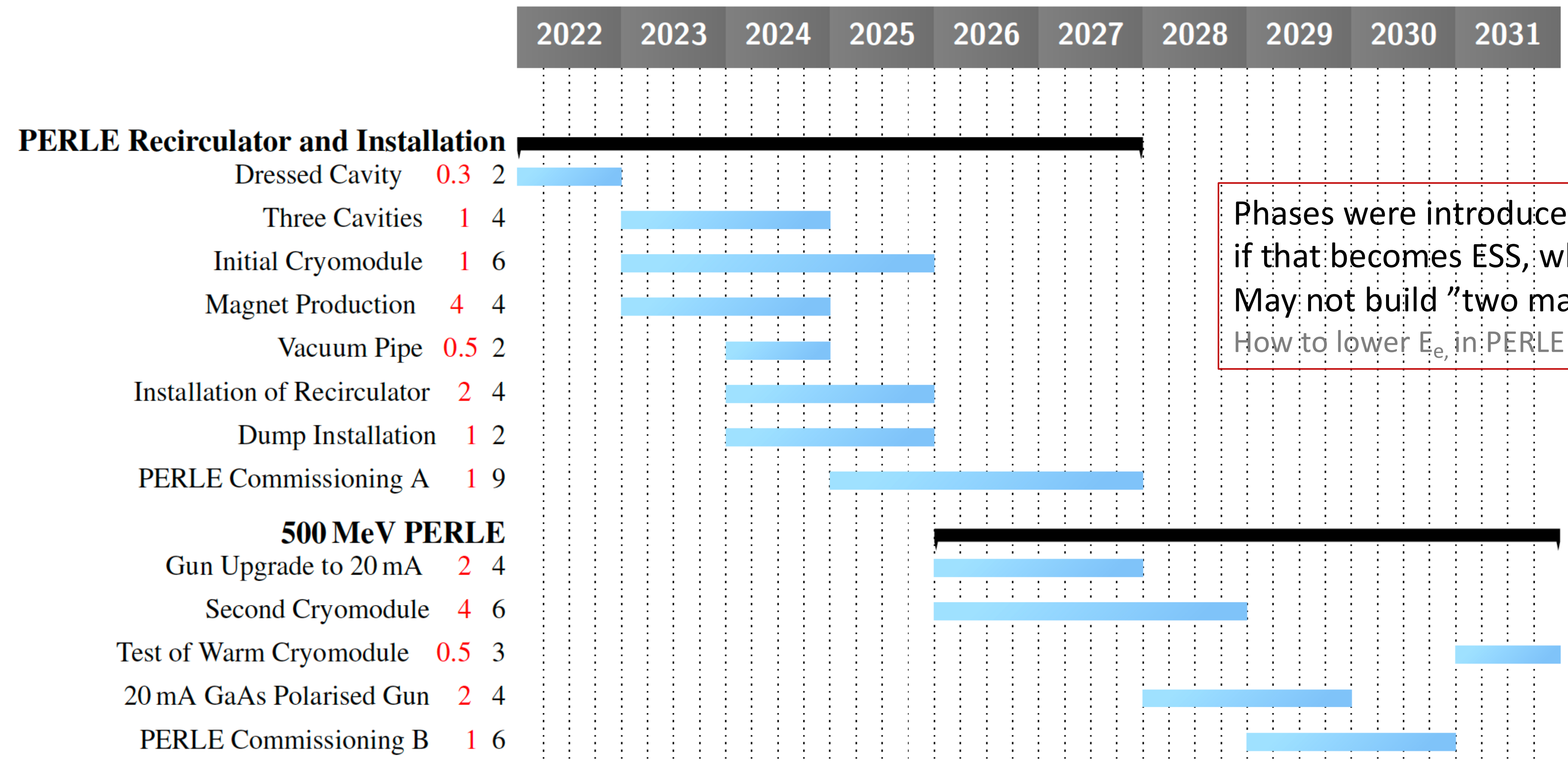
2. Technology (802 MHz, high Q_0, 20MV/m, ESS cryomodule, 4K..)

Synergy with FCC-ee: cavity development, racetrack as injector (Yannis)



HV vessel tightness test 9/22

PERLE profile in the ERL Roadmap, 12/21



Phases were introduced for SPL
if that becomes ESS, why two?
May not build "two machines".
How to lower E_e, in PERLE and LHeC?

Fig. 6.10: PERLE completion in two steps: The 250 MeV phase with beam in the mid-twenties (**ERL.PER.PE1**); and the 500 MeV stage towards the end of the decade (**ERL.PER.PE2**). Resources for the first part, including funding of the TDR and injector phase: 14.6 MCHF (red), 64 FTEy (black). Resources for the 500 MeV stage: 9.5 MCHF, 23 FTEy.

ERL Roadmap and the Power Balance of the LHeC

Thanks to
Akira Yamamotu
Kaoru Yokoya
Bernhard +Kevin

Assumptions and [Variations]

arXiv:2007.14491 - Tabs 10.1, .6, .15

E_e = 50 GeV (8.3 GeV per linac)

U=1/4 of U(LHC) [1/3]
dE_{syn}= 1.5 GeV [0.8 GeV]

2 x 112 Cryomodules, 4 cav/CM
→ 19.73 MV/m * 0.918m =
→ 18.1 MV = V_{ac}
→ 896 cavities = N_{cav}
→ L_{act} = 4.9km

R_{cav} = 130/2 = 65mm

R/Q = 524 shunt impedance

$Q_0 = 3\ 10^{10}$ [10^{10}]

I_e = 20 mA [10 mA]

T_2 = 1.8 K [4.2] RF cryo loss

T_2 = 1.8 K [77K] dyn HOM loss

Main components of power balance : Linac Syn Loss (LSL), Injector (INJ)
Cryo Loads: cavity surface loss rf (CSL), HOM static (HST) and HOM dynamic (HDY)

LSL	90 MW for 1/5 → 60 MW for 1/4 → 30 MW for 1/3 or 10mA	given as Loss × I_e / 0.5
INJ	20 MW → 10 MW for 10 mA	no recovery, calculated as 500 MeV × I_e / 0.5
CSL	10 MW → 4 MW for 4.2 K but 30 MW for $Q_0=10^{10}$	proportional to $N_{cav}/ Q_0\, \eta$; $\eta=\varepsilon T_2/(T_1-T_2)$, ε=0.3
HST	3 MW	proportional to $V_{ac}^2\, N_{cav}$
HDY	10 MW → 1 MW for 77K	proportional to I_e^2 / η ; $\eta=\varepsilon T_2/(T_1-T_2)$, ε=0.3

All numbers preliminary but indicative

- The default power sum is ∑=103 MV + ¼ for Utility = 129 MW, compare with 1 GW/ε w/o ERL!
- LSL: Dominant power requirement is from the Synrad loss, 1/5 yields 90 MW, 1/3 30 MW
  → one must newly balance CE economy against energy prices, possibly return to 1/3 – as for FCCeh
- HDY: HOM damping to higher temperature (77K) reduces the power by 10% wrt ∑
- CSL: The 4.2K cavity technology gains just 5% of ∑, because N_{cav} is 900. *It yet is vital for ERLC.*
- If $Q_0 = 10^{10}$ instead of $3\ 10^{10}$ then ∑ increases by 20% (adds 20 MW)
- Variations: 77K, 4.2K, 1/3, $3\ 10^{10}$ → ∑ =58 MW +1/4 for utility gives 70 MW (38 for 10mA)

The LHeC needs between 40 or 130 MW of power. Reductions are achieved with:
reducing I_e, enlarging U, maximum Q_0, HOM to higher T, 4.2 K technology [in that order of importance]
The LHeC depends on multi-turn ERL (PERLE) with high quality RF but not (much) on the ERL R&D

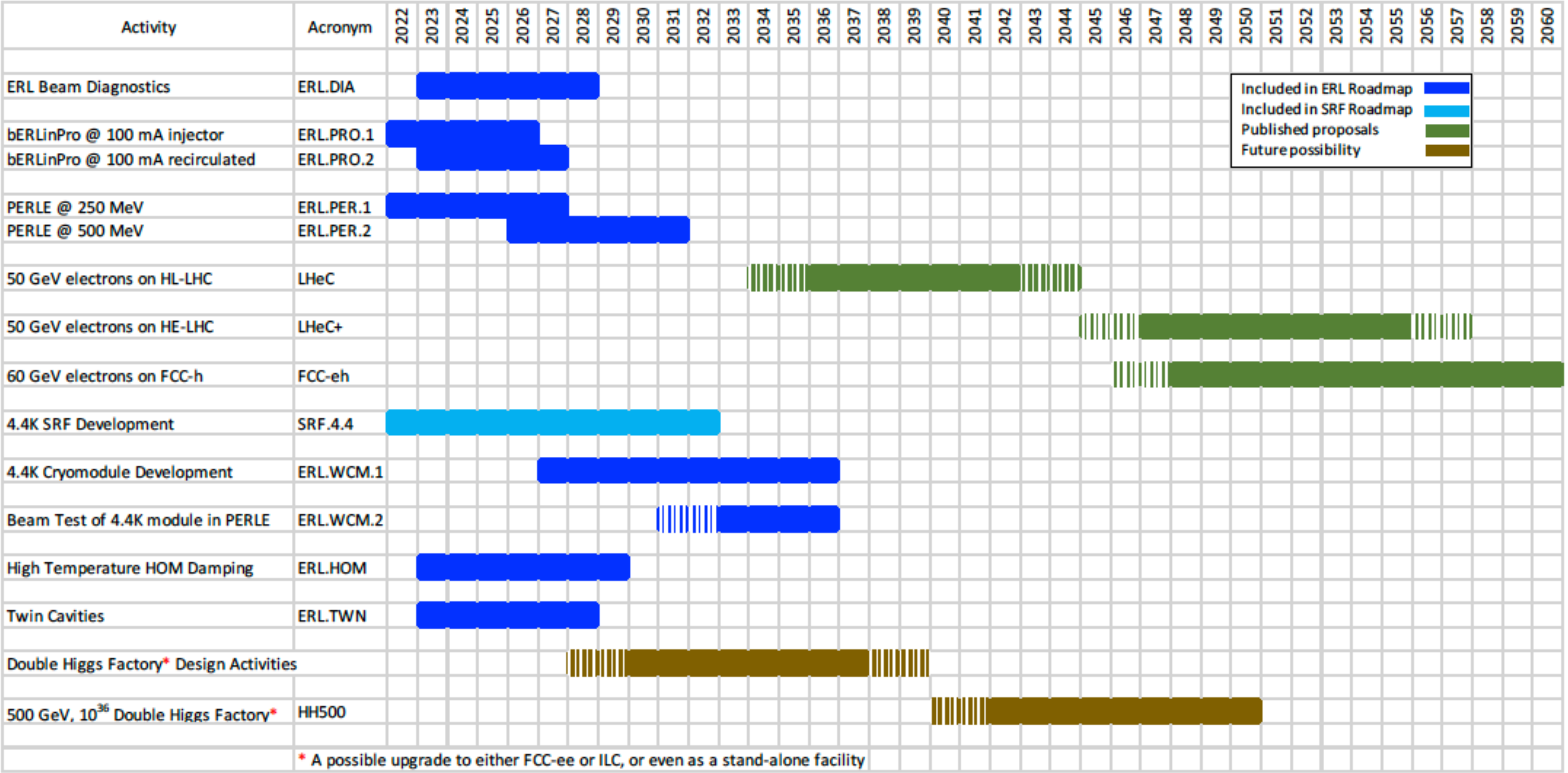


Fig. 6.12: Long-term vision for the ERL Roadmap showing how the activities in the next five to ten years lead to multiple options for future HEP Colliders.

ERL Concepts presented for ILC (ERLC, Telnov) and FCCee (CERC, Litvinenko et al) – evaluated by subpanel, chaired by Andrew Hutton

IAC Recommendations

Recommendations

i) It is recommended to further develop the ERL based ep/A scattering plans, both at LHC and FCC, as attractive options for the mid and long term programme of CERN, resp. Before a decision on such a project can be taken, further development work is necessary, and should be supported, possibly within existing CERN frameworks (e.g. development of SC cavities and high field IR magnets).

ii) The development of the promising high-power beam-recovery technology ERL should be intensified in Europe. This could be done mainly in national laboratories, in particular with the PERLE project at Orsay. To facilitate such a collaboration, CERN should express its interest and continue to take part.

iii) It is recommended to keep the LHeC option open until further decisions have been taken. An investigation should be started on the compatibility between the LHeC and a new heavy ion experiment in Interaction Point 2, which is currently under discussion.

After the final results of the European Strategy Process will be made known, the IAC considers its task to be completed. A new decision will then have to be taken for how to continue these activities.

Herwig Schopper, Chair of the Committee, Geneva, November 4, 2019

Members of the Committee

Sergio Bertolucci (U Bologna)
Nichola Bianchi (INFN, now Singapore)
Frederick Bordy (CERN)
Stan Brodsky (SLAC)
Oliver Brüning (CERN, coordinator)
Hesheng Chen (IHEP Beijing)
Eckhard Elsen (CERN)
Stefano Forte (U Milano)
Andrew Hutton (Jefferson Lab)
Young-Kee Kim (U Chicago)
Max Klein (U Liverpool, coordinator)
Shin-Ichi Kurokawa (KEK)
Victor Matveev (JINR Dubna)
Aleandro Nisati (Rome I)
Leonid Rivkin (PSI Villigen)
Herwig Schopper (CERN, em.DG, Chair)
Jürgen Schukraft (CERN)
Achille Stocchi (IJCLab Orsay)
John Womersley (ESS Lund)

Many thanks to Herwig and the IAC

IAC: High Field IR Magnets and SC Cavity Developments

Magnet parameter	Unit	Magnet type			
		Q1A	Q1B	Q2 type	Q3 type
Superconductor type		Nb-Ti	Nb-Ti	Nb_3Sn	Nb_3Sn
Coil aperture radius R	mm	20	32	40	45
Nominal current I_{nom}	A	7080	6260	7890	9260
Nominal gradient g	T/m	252	164	186	175
Percentage on the load line	%	78	64	71	75
Beam separation distance S_{beam}	mm	106-143	148-180	233-272	414-452

Table 10.28: Main triplet magnet parameters

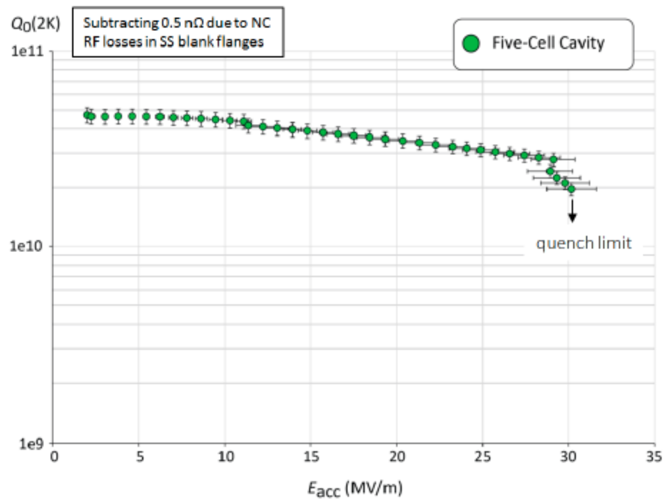


Figure 10.20: Vertical test result of the five-cell 802 MHz niobium cavity prototype.

For Kevin and Oliver to explain

but to stay on time:

Requires design and built of a short model
of an asymmetric quadrupole with field free region
Decide whether one needs Nb_3Sn or can do with NbTi
Contact to Magnet R&D to possibly include a small project

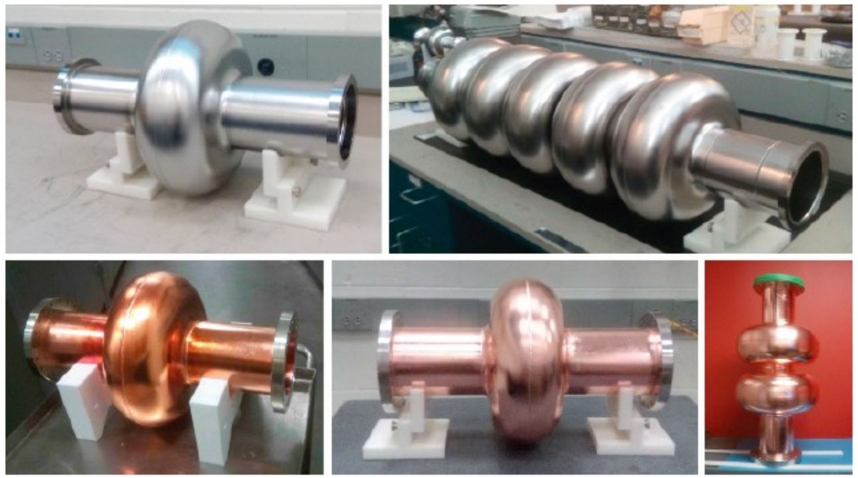


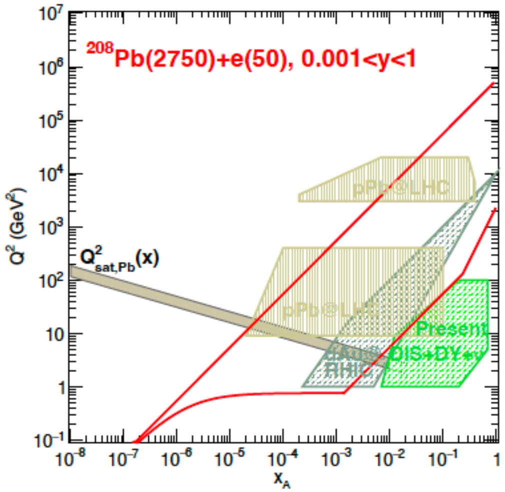
Figure 10.19: Ensemble of 802 MHz cavities designed and built at JLab for CERN. The Nb cavities have been tested vertically at 2 Kelvin in JLab's vertical test area.

Much progress to be reported at this workshop

Concept of a Joint eh/hh Experiment at IP2

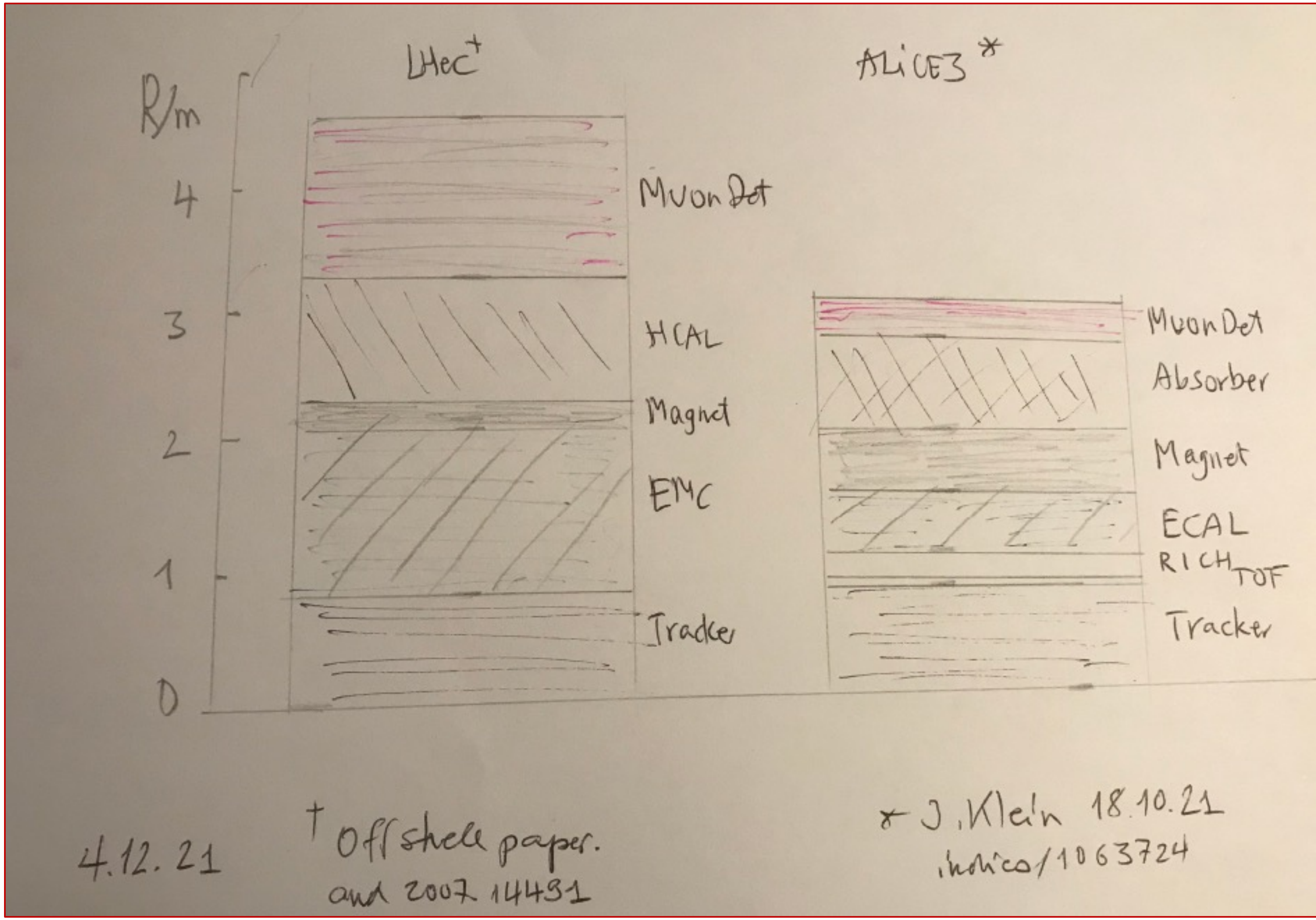
Offshell conference 2021 →2201.02436 EPJ published

K. D. J. André[1,2], L. Aperio Bella[3], N. Armesto[a,4], S. A. Bogacz[5], D. Britzger[6], O. S. Brüning[1], M. D'Onofrio[2], E. G. Ferreiro[4], O. Fischer[2], C. Gwenlan[7], B. J. Holzer[1], M. Klein[2], U. Klein[2], F. Kocak[8], P. Kostka[2], M. Kumar[9], B. Mellado[9,10], J. G. Milhano[11,12], P. R. Newman[13], K. Piotrzkowski[14], A. Polini[15], X. Ruan[9], S. Russenschuk[1], C. Schwanenberger[3], E. Vilella-Figueras[2], Y. Yamazaki[16]



Add eA DIS of unprecedent coverage to A3
Unique potential to exploit LHC facility,
worth indeed jointly studying deeper.

A first configuration has been developed of an IR which may alternately serve *eh* and *hh* collisions while the other experiments at the HL-LHC stay in *hh* collision mode concurrently. The feasibility of realising a common *eh*/*hh* IR implies that one may realistically consider an apparatus which would permit both electron-hadron and hadron-hadron collisions to be registered.



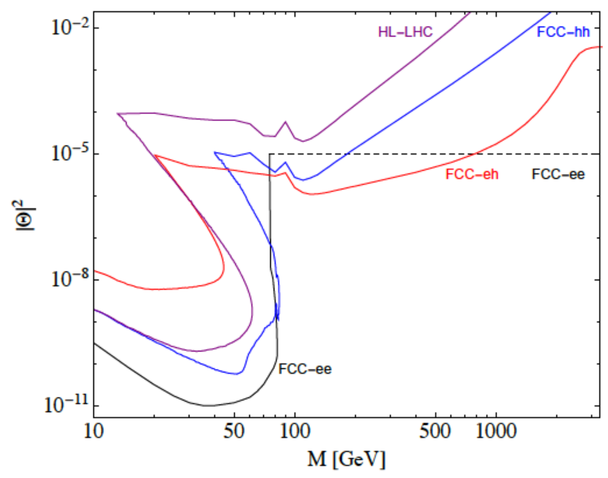
This work goes beyond LH(e)C as it opens a novel avenue to optimum physics and shared cost at FCC

FCC-eh

FCC-eh in the CDR [V1 Physics and V3 hh]

Volume 1 had been the collaborative effort to present **the entity of FCC physics, in ee, pp and ep, including AA and eA**
Volume 3 on FCC hh contains a short summary of **the main characteristics of FCC-eh and the detector concept**

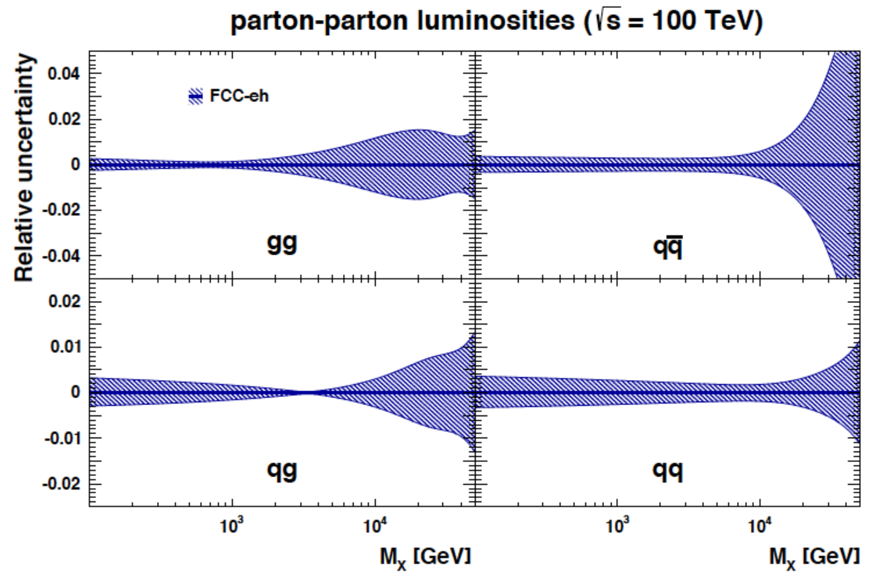
Some striking physics eh prospects are on searches and the high precision measurements on Higgs and proton structure:



Complementary prospects to **discover rh massive neutrinos** in ee, ep and pp [mixing angle vs mass]

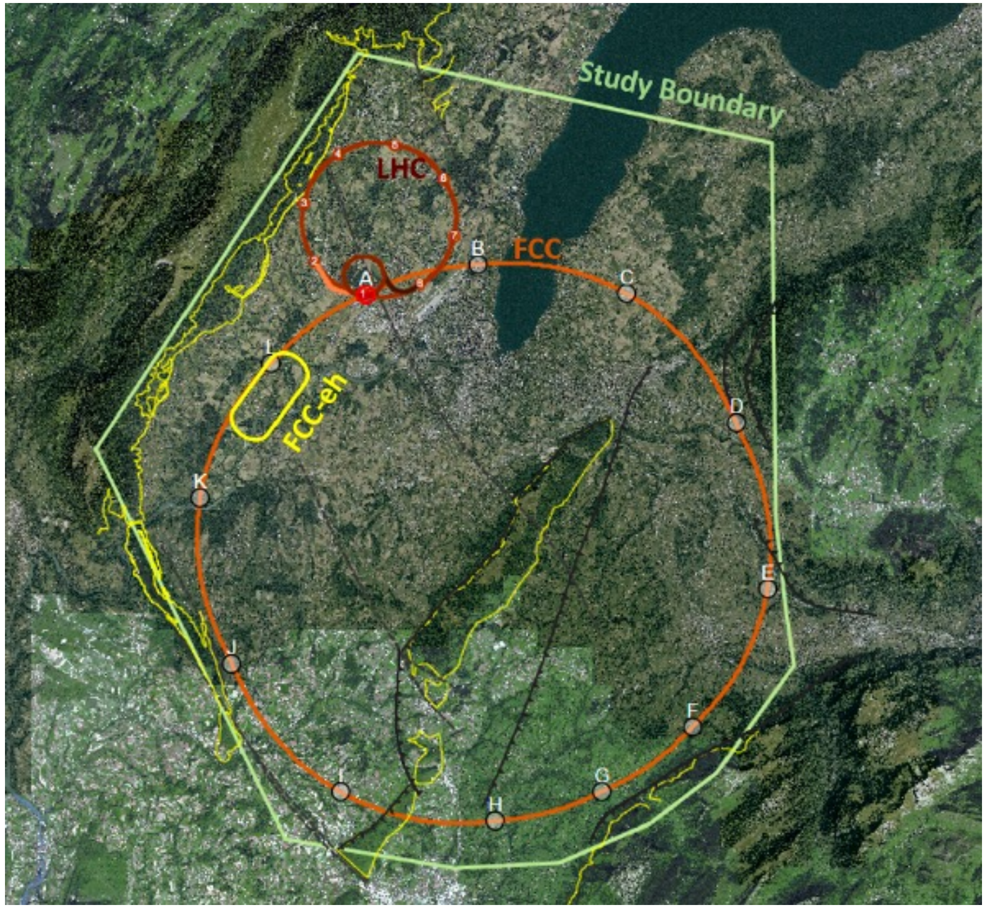
Collider	FCC-ee	FCC-eh
Luminosity (ab^{-1})	+1.5 @ 365 GeV	2
Years	3+4	20
$\delta\Gamma_H/\Gamma_H$ (%)	**1.3**	SM
$\delta g_{HZZ}/g_{HZZ}$ (%)	**0.17**	0.43
$\delta g_{HWW}/g_{HWW}$ (%)	**0.43**	0.26
$\delta g_{Hbb}/g_{Hbb}$ (%)	**0.61**	0.74
$\delta g_{Hcc}/g_{Hcc}$ (%)	**1.21**	1.35
$\delta g_{Hgg}/g_{Hgg}$ (%)	**1.01**	1.17
$\delta g_{H\tau\tau}/g_{H\tau\tau}$ (%)	**0.74**	1.10
$\delta g_{H\mu\mu}/g_{H\mu\mu}$ (%)	**9.0**	n.a.
$\delta g_{H\gamma\gamma}/g_{H\gamma\gamma}$ (%)	**3.9**	2.3
$\delta g_{Htt}/g_{Htt}$ (%)	–	1.7
BR_{EXO} (%)	$<$ **1.0**	n.a.

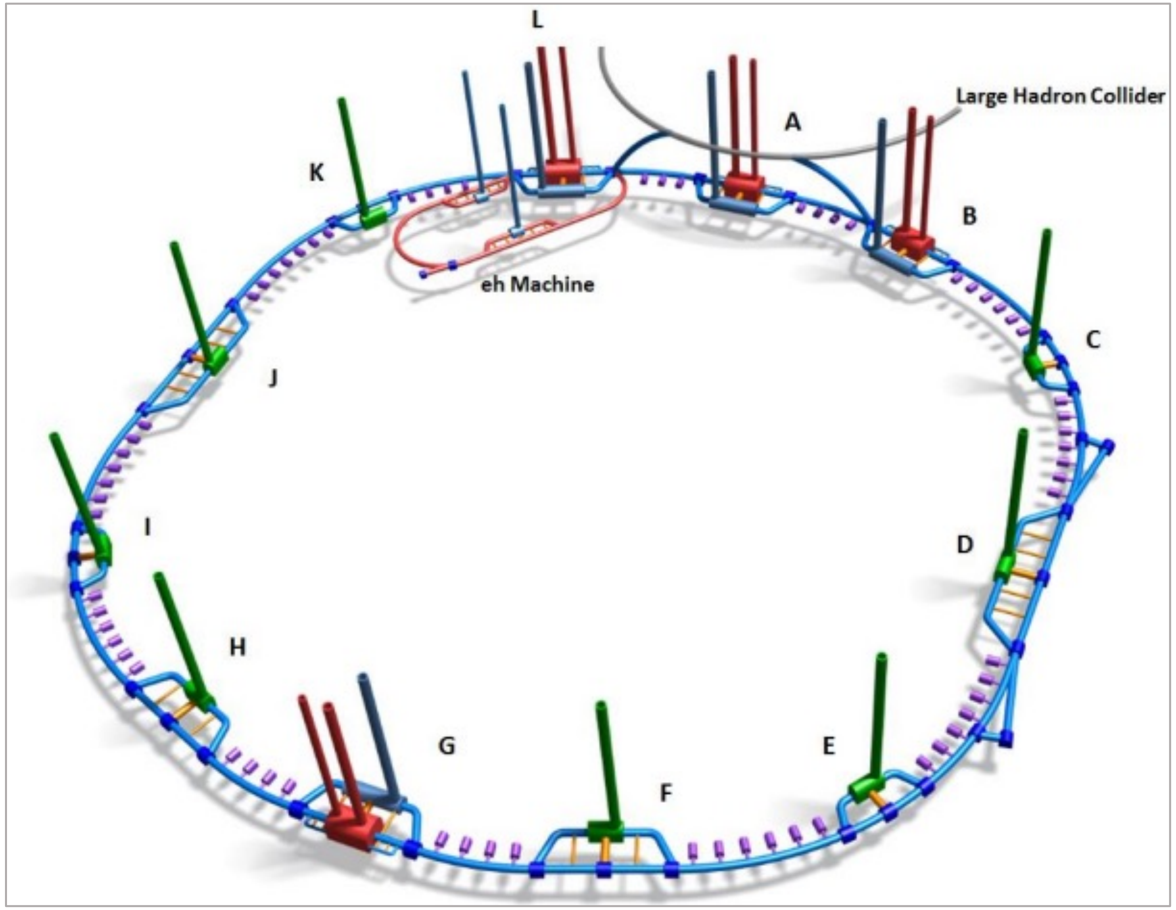
Prospects for high precision measurements of **Higgs couplings at FCC ee and ep**. Note ee gets the width with Z recoil. ee is mainly ZHZ, while ep is mainly WWH: complementary also to pp



Unique resolution of partonic contents of and dynamics inside the proton, providing precise and independent parton luminosities for interpretation and searches on FCC-hh

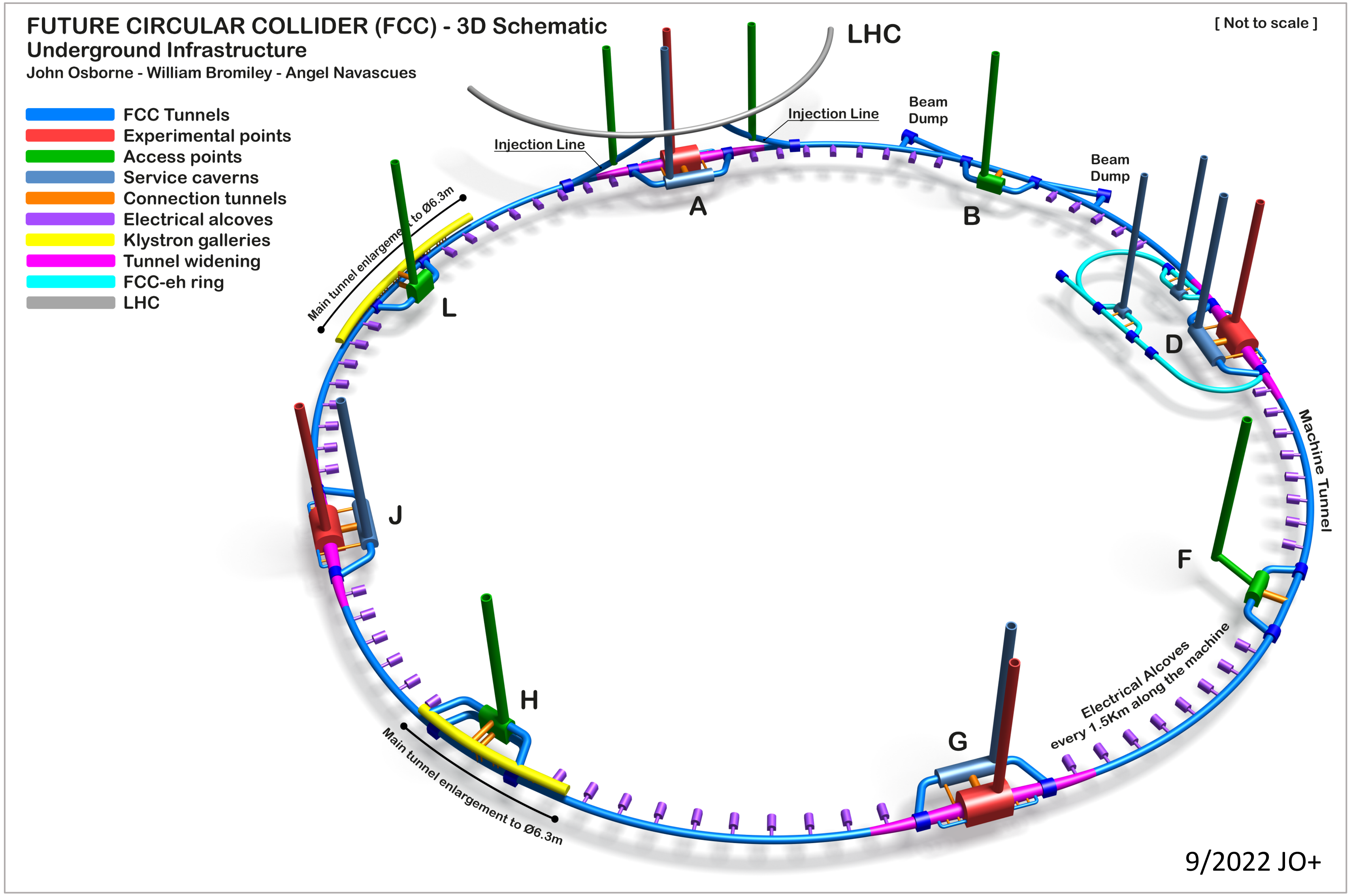
CDR: 12 point FCC





outdated

CDR: 8 point FCC: point D



FCC-eh

FCC-eh Detector Concept Design

Remarks/questions:

- Suitable design for precision DIS

- Muon tagger or spectrometer

- LAr or warm calo

- Beam pipe and Machine-detector Interface

- Final choices not now but later by a collaboration

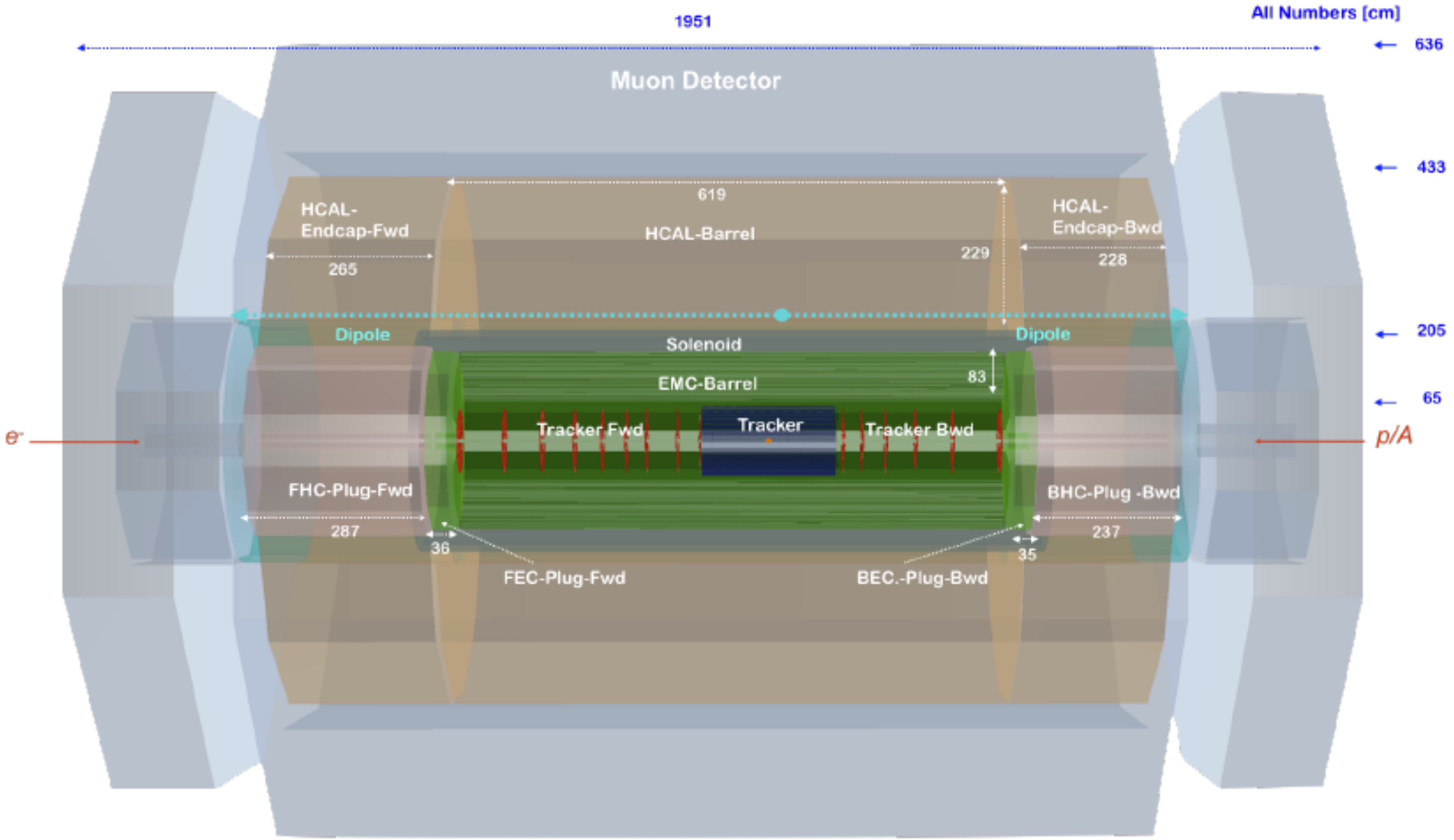


Figure 12.21: Side view of a low energy FCCeh (E_p = 20 TeV) concept detector, designed using the DD4hep framework [891], showing the essential features. The solenoid is again placed between the ECAL-Barrel and Hadronic-Barrel calorimeters and is housed in a cryostat in common with the beam steering dipoles extending over the full length of the barrel and plug hadronic calorimeters. The sizes have been chosen such that the solenoid/dipoles and ECAL-Barrel systems as well as the whole tracker are also suitable to operate after an upgrade of the beam energy to $E_p = 50$ TeV.

Clean FS

No pile-up

NC-CC-yp clearly separated

Radiation 1000 less than in pp

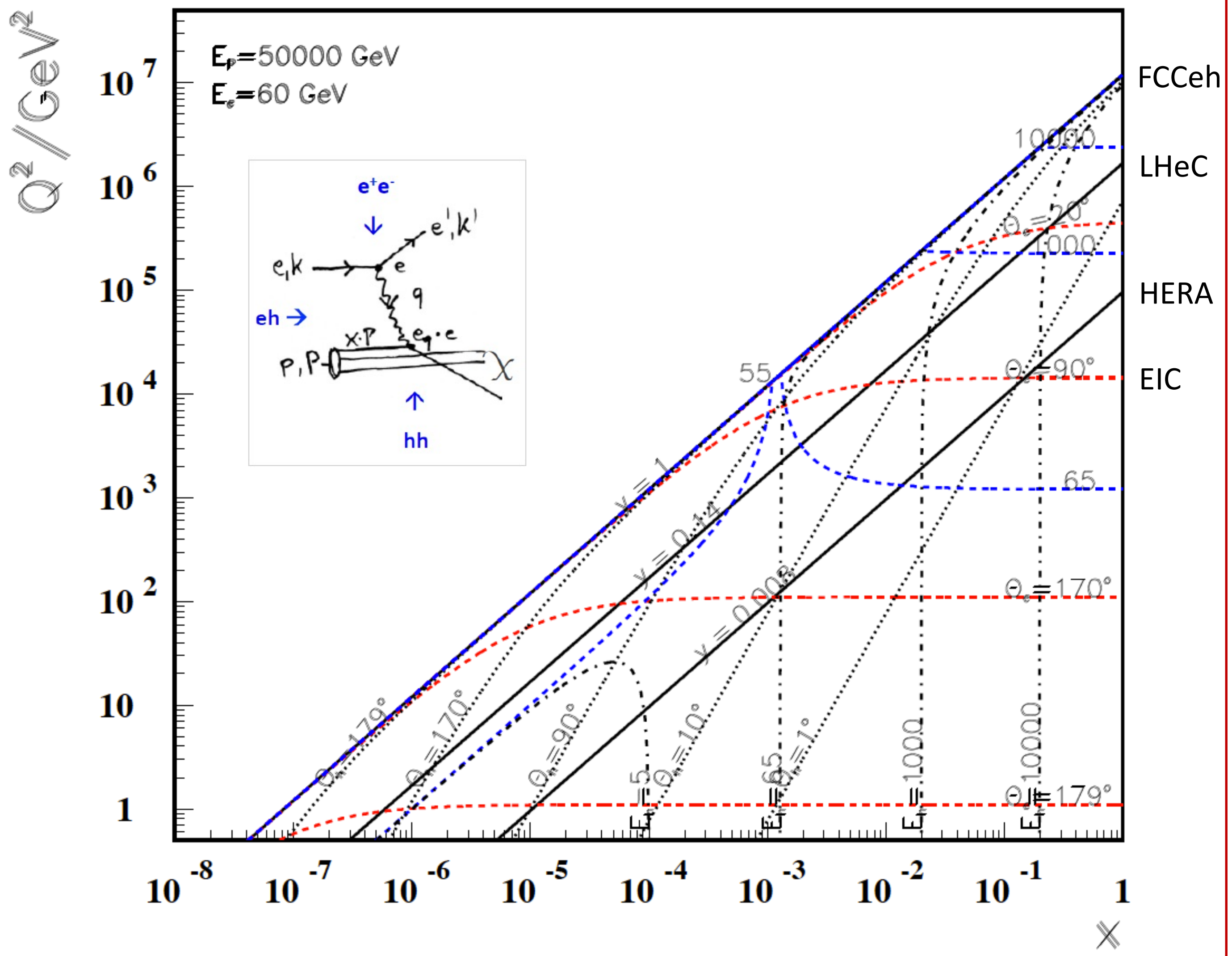
… "easy"

Challenge: IR and e-h

fwd region

From new paper: arXiv:2007.14491

FCCeh How to Proceed?



The most gigantic DIS experiment under consideration
Newton Microscope (Phil Yock) - Outreach on DIS !!

The FCC-eh Development may move towards a dedicated Conceptual Design Report (by 2025)

Physics: TeV Scale DIS and its Importance for hh

A Next Generation DIS Detector [of CMS size]

Accelerator: CE, Lattice, Parameters, Infrastructure..

- A useful base for the FCC-eh development
- Strong relation to LHeC and PERLE
- Emphasis on Unity of Physics

There is a scenario where FCC-hh comes without FCC-ee, in a 100 km or the LHC tunnel. There comes a next strategy discussion which is prepared to include the DIS future.

Comprehensive papers last longer than conferences.. :
The LHeC CDR arXiv:1206.2913 has by now 632 citations.

Needs careful thoughts and preparation and a human base..
Decision with next LHeC/PERLE/FCCeh workshop

Max Klein (U Liverpool) and Oliver Bruening (CERN)

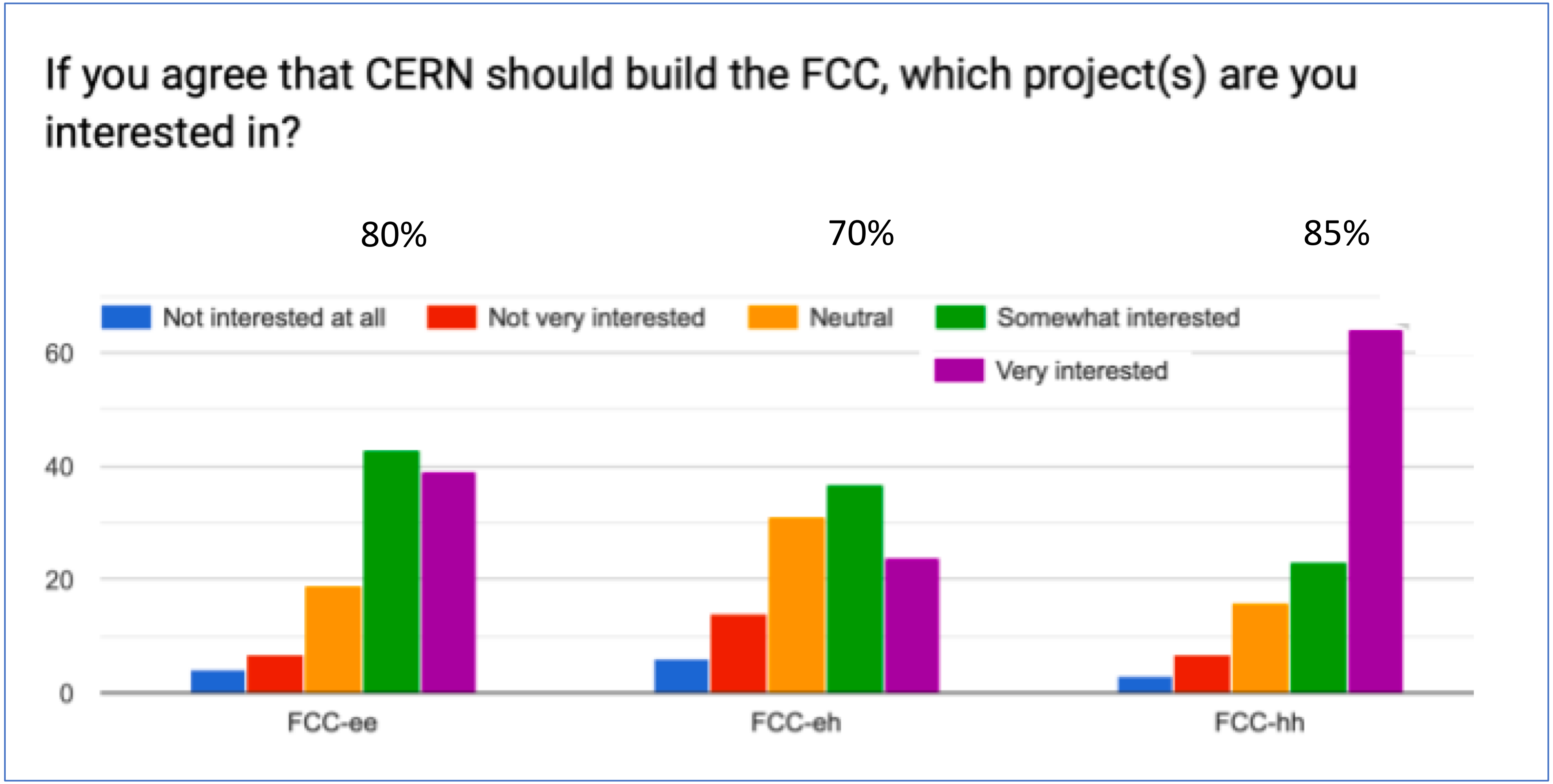
Session on FCC-eh, 30.6.21, FCC Week June/July 2021

Report on the ECFA Early-Career Researchers Debate on the 2020 European Strategy Update for Particle Physics

The ECFA Early-Career Researchers

February 6, 2020

arXiv:2002.02837



Our Philosophy

Beyond the LHC/LHeC: FCC

The far future is least defined
There big questions will remain
and new ones shall be posed
Crucial:
LHC and 1 TeV exploration
Developments of
Accelerator Technology
Experiments
Theoretical Physics
→ Peace for world collaboration

Particle Physics has a long term future,
many of its quests are unresolved,
Nr of families, GUT, substructure, DM..

It has been and will be science at a global scale, with many question marks for USA, China, Japan +CERN at present.

pp

FCC - hh

Higgs Potential
Rare H Decays
SUSY
GUT
??

ep

FCC - eh

High Precision Higgs
BSM in multi TeV range
DIS of top, g saturation
Leptoquarks and GUT

l^+l^-

CLIC, FCC - ee

High Precision Higgs
Top and BSM
Rh Neutrinos

Muon Collider ?

Neutrino Physics
Factory, Proton Decay

lh-hh-ee coexistence former times:

CDHS,BCDMS../SppS/PETRA,PEP

HERA/Tevatron/LEP,SLC

Nearer future, perhaps

LHeC/LHC/ILC,CepC

Colourful, rich 15 years since 2007
thank you to hundreds of colleagues,
from very young to wise.
As Frank Z once cited E Roosevelt:

“The future belongs to those who believe in the beauty of their dreams”

A cordial welcome to Jorgen D'Hondt

JDH

Artist, physicist, former chair of ECFA, new chair of the ERL coordination group, friend and, since Sunday 23.10.22, LHeC/FCCeh coordinator

backup

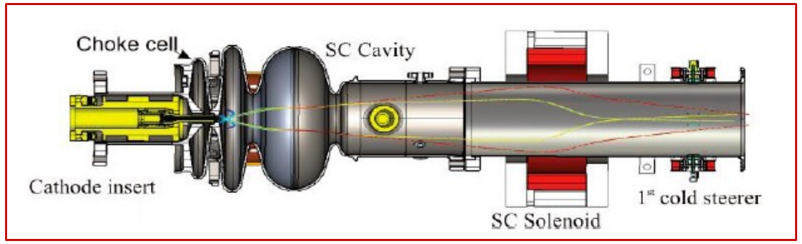
5.6 R&D objectives - Key technologies - ERL Roadmap Part B

5.6.2 SRF Technology and the 4.4 K Perspective

Near-Term 2 K Developments

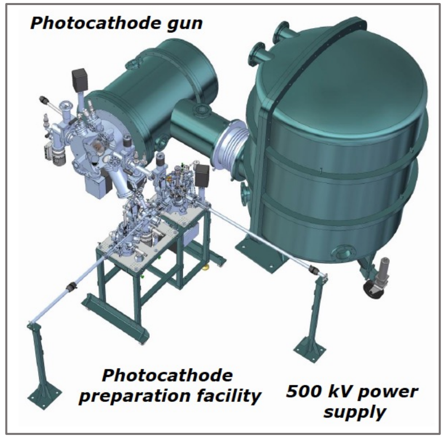
- Operation at 20 MV/m with $Q_0 > 3\ 10^{10}$
- Extraction of HOM power from Helium bath
- Damping of HOMs to prevent beam break up
- Reduction of RF power via Fast Reactive Tuners (FRT)
- 100mA sources (SRF and DC photocathode)

5.6.1 High-Current Electron Sources



SRF elliptical cavity gun at bERLinPro: new 100mA module

ALICE (20mA) PERLE:



Roadmap integrates high current current source and 2K developments into the two facilities (part C):

bERLinPRO: 1.3 GHz, 100mA, 1-pass & PERLE: 802 MHz, 20mA, 3 passes

Towards 4.4 K

A significant part of the power consumption of ERLs is related to the dynamic cavity load in CW operation, which can be estimated by

$$P = \frac{V_{\text{acc}}^2}{(R/Q) \cdot Q_0} \cdot N_{\text{cav}} \cdot \eta_T \tag{5.1}$$

where V_{acc} is the acceleration of a cavity, R/Q the shunt impedance, Q_0 the cavity quality factor, N_{cav} the number of cavities and η_T the heat transfer, i.e. combined technical and Carnot, efficiency, which is proportional to the ratio of the cryo temperature, T, and its difference to room temperature, 300 K − T.

Boost cryogenic efficiency and chill cavities with cryocoolers, no lHe

- Nb_3SN coating via vapour infusion, sputtering or ALD
- Evaluation of other superconductors as NbN, NbTiN, V3S
- Cavity tuners to avoid detachment of coating

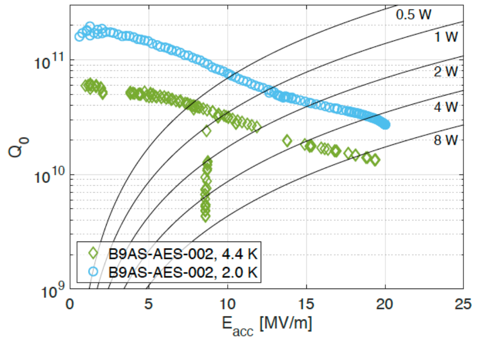


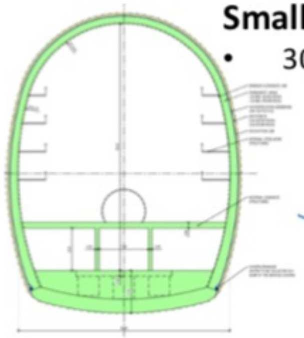
Fig. 13: Performance of 650 MHz single cell cavity B9AS-AES-002. The multipacting at 9 MV/m was processed during the test.

arXiv:2008.00599

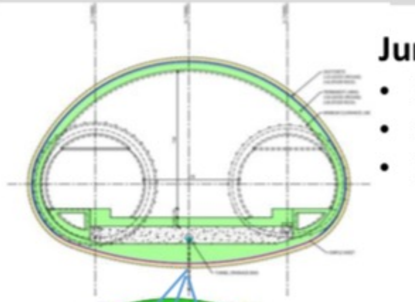
In parallel: nitrogen diffusion and doping to reach 10^{11}

Roadmap: long term cavity R&D towards 4.4K: SRF Panel
ERL: full module in beam test (2030?) PERLE or bERLinPRO

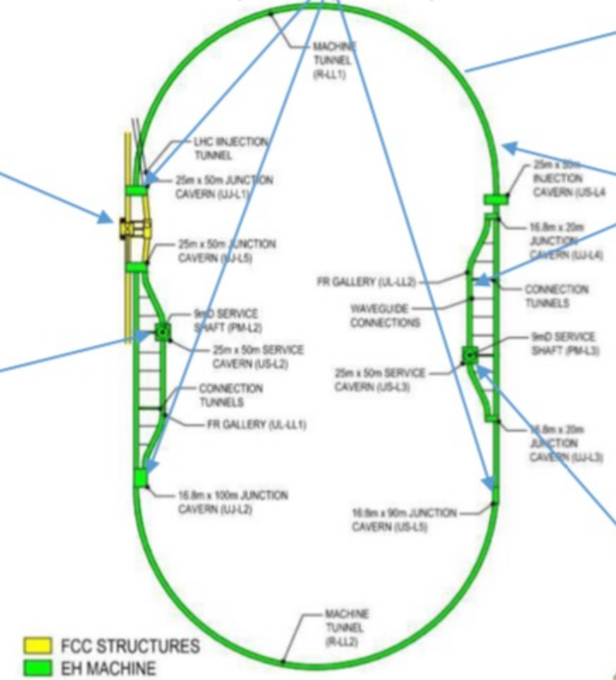
Scope of FCC-eh Structures

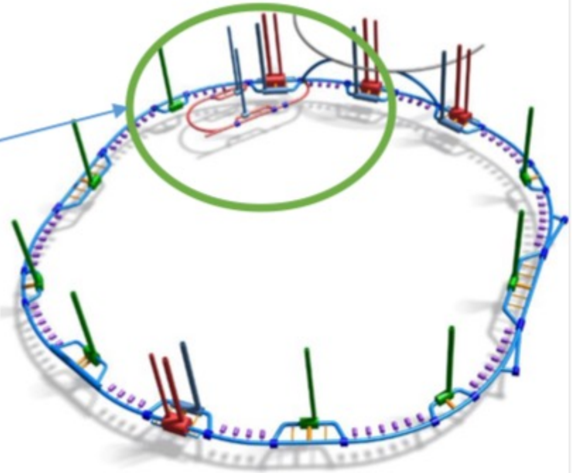


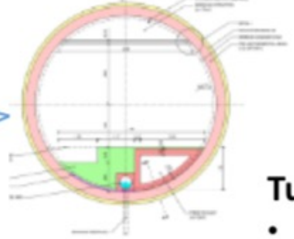
Small Experimental Caverns
- 30 m x 35 m x 66m



Junction Caverns
- 16.8 m x 15 m x 100 m
- 25 m x 15 m x 50 m
- 16.8 m x 15 m x 90 m

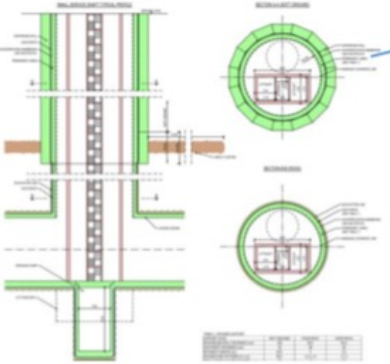


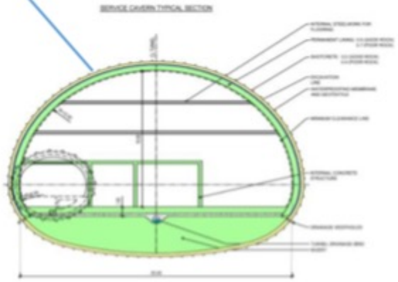




Tunnels:
- 9.091 km of 5.5m dia. machine tunnel.
- 2 x 1.04 km of 5.5m dia RF tunnel.

Shafts:
2 x Service shafts:
9 m dia. x 175 m depth





Service Caverns
- 25 m x 15 m x 50 m

Conclusion (of introduction to PERLE Collaboration Meeting 1/22)

Unprecedentedly high beam intensities open new fields of low energy physics such as nuclear photonics, elastic ep scattering, dark photon searches and exotic isotope spectroscopy. This technology also has a significant future in other fields such as FELs, EUV Lithography, Inverse Compton Scattering, etc. ERL technology is inherently energy-sustainable, which will be an important requirement for all future accelerator projects. As an innovative field, it is bound to attract new generations of accelerator physicists and engineers.

The year 2021 was a very important milestone year for energy recovery linacs, leading to much hope and high expectations. As part of a global development, with CEBAF, CEIC in the US, cERL in Japan and the Recuperator in Russia, Europe's ERL future goes with MESA, the upgrade of bERLinPro and PERLE, which has a key role as a high current, multi-turn facility, are essential. The support of CNRS/IN2P3/IJCLab and a very experienced collaboration offer the unique chance to open a new chapter, not least for linear accelerators at Orsay. This opportunity poses severe demands on all of us, as the ESP process is set to progress based on results by the mid twenties.