An Energy Recovery Linac for Energy-Frontier eh Scattering at CERN: the LHeC and the FCC-eh

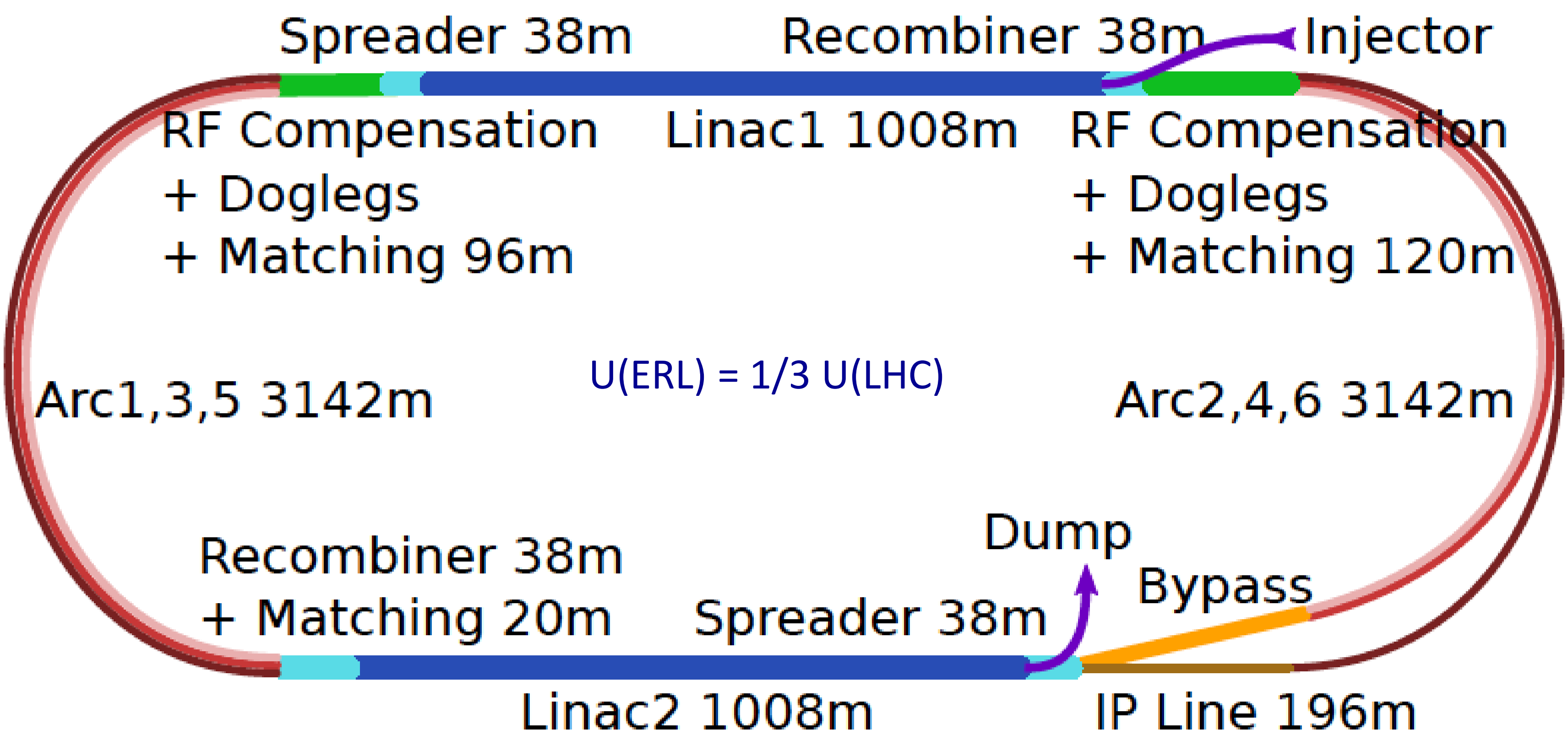
Oliver Brüning (CERN), Max Klein (U Liverpool), Daniel Schulte (CERN), Frank Zimmermann

for the LHeC/PERLE/FCCeh Collaboration

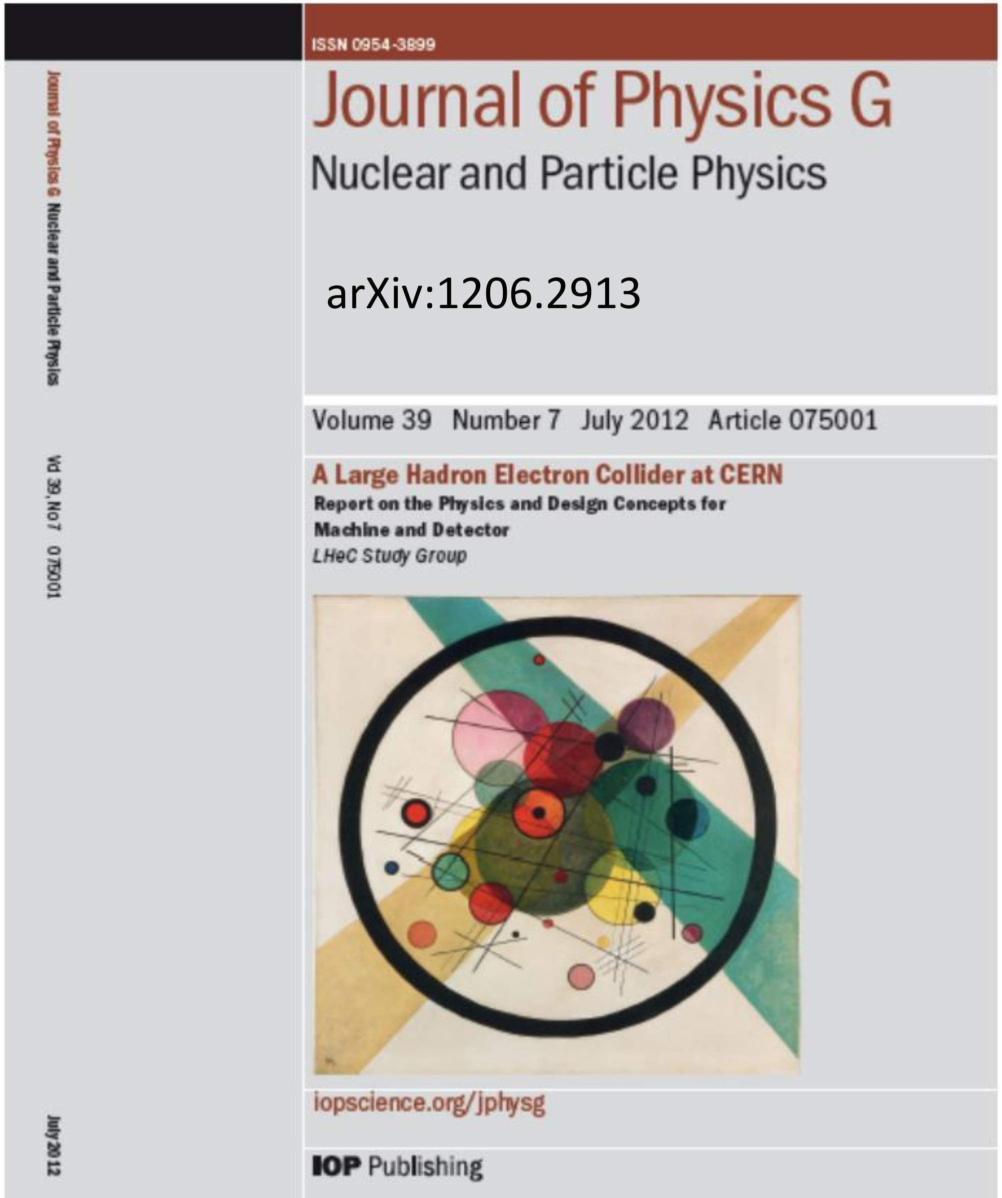
LHeC PERLE FCC hh ee he

Talk at ICHEP Seoul, 6 July, 2018

60 GeV Electron ERL added to LHC



Concurrent operation to pp, LHC/FCC become 3 beam facilities. Power limit: 100 MW
10^{34} cm^{-2} s^{-1} luminosity and factor of 15/120 (LHC/FCCeh) extension of Q^2, 1/x reach
1000 times HERA luminosity. It therefore extends up to x~1.
Four orders of magnitude extension in deep inelastic lepton-nucleus (ion) scattering.



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)

Published 600 pages conceptual design report (CDR) written by 200 authors from 60 Institutes and refereed by 24 world experts on physics, accelerator and detector, which CERN had invited.

Performance

Interaction Region

Optics

Ions

Polarisation (80-90%)

Positrons

CDR: VERY detailed design of the LHeC Linac (and Ring) – Ring Collider, + components, CE..

http://lhec.web.cern.ch

J.L.Abelleira Fernandez[16,23], C.Adolphsen[57], P.Adzic[74], A.N.Akay[03], H.Aksakal[39], J.L.Albacete[52], B.Allanach[73], S.Alekhin[17,54], P.Allport[24], V.Andreev[34], R.B.Appleby[14,30], E.Arikan[39], N.Armesto[53,a], 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], J.Bracinik[06], G.Brandt[44], H.Braun[65], S.Brodsky[57,b], O.Brüning[16], E.Bulyak[12], A.Buniatyan[17], H.Burkhardt[16], I.T.Cakir[02], O.Cakir[01], R.Calaga[16], A.Caldwell[70], V.Cetinkaya[01], V.Chekelian[70], E.Ciapala[16], R.Ciftci[01], A.K.Ciftci[01], B.A.Cole[38], J.C.Collins[48], O.Dadoun[42], J.Dainton[24], A.De.Roeck[16], D.d'Enterria[16], P.DiNezza[72], M.D'Onofrio[24], A.Dudarev[16], A.Eide[60], R.Enberg[63], E.Eroglu[62], K.J.Eskola[21], L.Favart[08], 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], A.Glazov[17], 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], E.Jensen[16], J.M.Jimenez[16], J.M.Jowett[16], H.Jung[17], H.Karadeniz[02], D.Kayran[37], A.Kilic[62], K.Kimura[58], R.Klees[75], M.Klein[24], U.Klein[24], T.Kluge[24], F.Kocak[62], M.Korostelev[24], A.Kosmicki[16], P.Kostka[17], H.Kowalski[17], M.Kraemer[75], G.Kramer[18], D.Kuchler[16], M.Kuze[58], T.Lappi[21,c], 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], J.G.Milhano[76], S.Moch[17], I.I.Morozov[40], Y.Muttoni[16], S.Myers[16], S.Nandi[55], Z.Nergiz[39], P.R.Newman[06], 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[07], V.Ptitsyn[37], Y.Pupkov[40], V.Radescu[17], S.Raychaudhuri[35], L.Rinolfi[16], E.Rizvi[71], R.Rohini[35], J.Rojo[16,31], S.Russenschuck[16], M.Sahin[03], C.A.Salgado[53,a], K.Sampei[58], R.Sassot[09], E.Sauvan[04], M.Schaefer[75], 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], D.South[17], H.Spiesberger[29], A.M.Stasto[48,d], M.Strikman[48], M.Sullivan[57], S.Sultansoy[03,e], Y.P.Sun[57], B.Surrow[11], L.Szymanowski[66,f], P.Taels[05], I.Tapan[62], T.Tasci[22], E.Tassi[10], H.Ten.Kate[16], J.Terron[28], H.Thiesen[16], L.Thompson[14,30], P.Thompson[06], K.Tokushuku[61], R.Tomás García[16], D.Tommasini[16], D.Trbojevic[37], N.Tsoupas[37], J.Tuckmantel[16], S.Turkoz[01], T.N.Trinh[47], K.Tywoniuk[26], G.Unel[20], T.Ullrich[37], J.Urakawa[61], P.VanMechelen[05], A.Variola[52], R.Veness[16], A.Vivoli[16], P.Vobly[40], J.Wagner[66], R.Wallny[68], S.Wallon[43,46,f], G.Watt[69], 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], F.Zomer[42]

LHeC Study group and CDR authors 2014

"you never walk alone"

CERN-OPEN-2019-nnn
LHeC-Note-2019-001 GEN
Geneva, June 25, 2018

CERN

LHeC

A Higgs Facility Resolving the Substructure of Matter

Update on the 2012 LHeC Report
on the Physics and Design Concepts for Machine and Detector

LHeC Collaboration

DRAFT

Submitted to J.Phys. G

New LHeC Document
Reasons: CERN Mandate and

- Higgs: higher luminosity goal
- LHC: no BSM + precision
- New ep/eA Physics prospects
- eh appeared with FCC design
- Updates on IR, CE, …
- Insight from FCC study
- Vision for eh with HE LHC
- Options for ERL based Physics beyond eh scattering.
- Low energy test facility PERLE
- Implementation of ERL at CERN

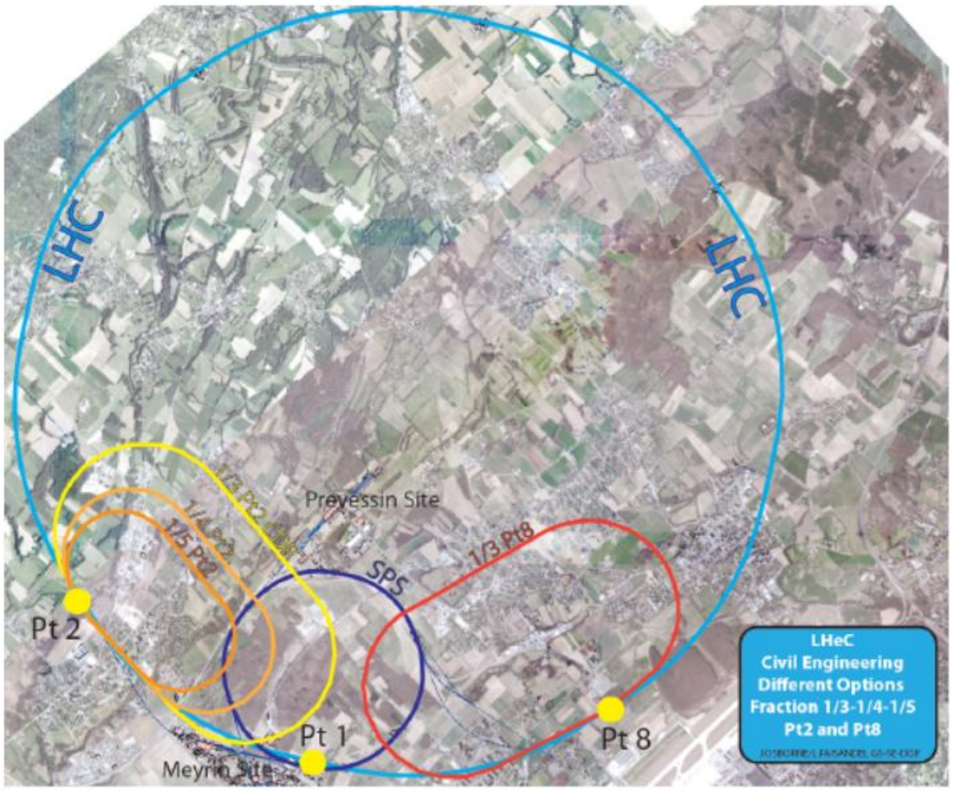
Preparation for early 2019

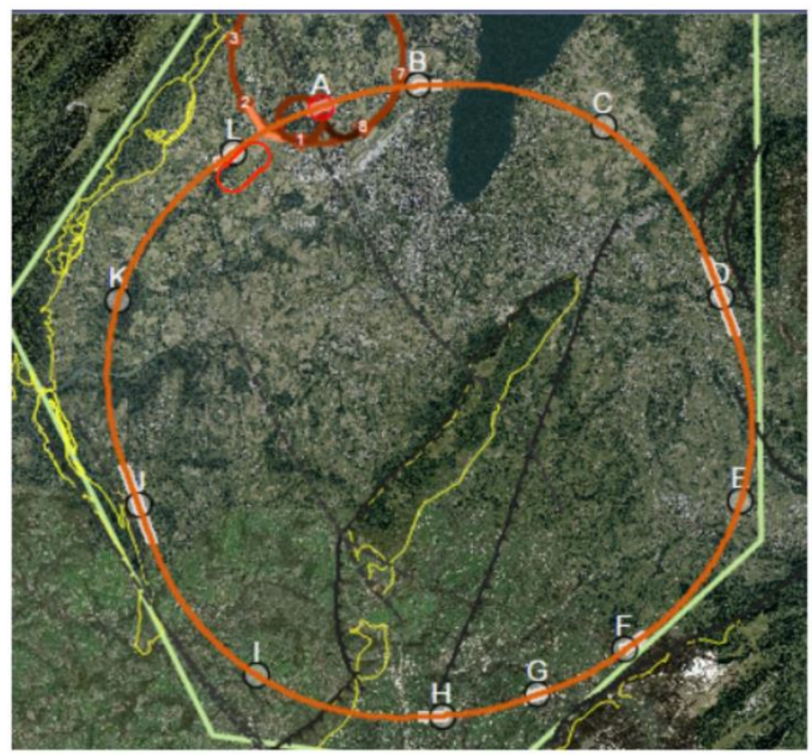
Submissions of eh Papers to European Strategy:

- FCC eh as part of FCC hh
- LHeC with HL
- PERLE technology development

Location, Footprint, Use of the Electron Racetrack

e beam external to LHC. Location suitable for both HL and HE LHC.



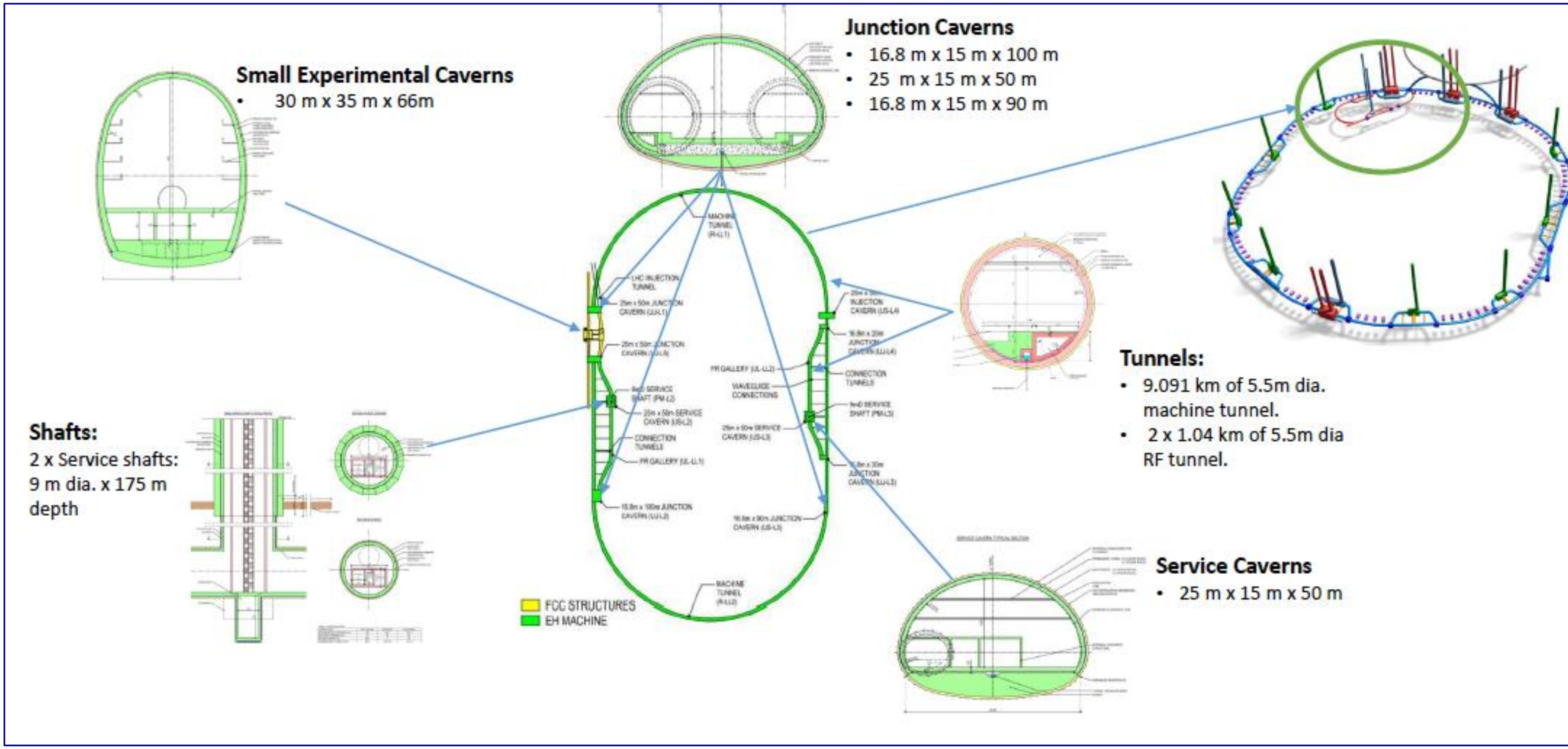


- U(ERL) = 1/n U(LHC): 60 GeV: 1/3
- BSM, top, Higgs, Low x all want maximum E_e
- Cost goes almost linearly down with E_e

For FCC can realise ep/A collisions
With IR at point L, not far from CERN
U(ERL) = 1/11 U(FCC)

Energy – Cost – Physics – Footprint are being reinvestigated for EU strategy

Civil Engineering for ERL



For LHC: re-use IP2. For FCC: deeper shafts, new IP cavern
Refinement of CE study, see J Osborne Amsterdam FCC week
and see Matt Stuart at LHeC Workshop, 28.6.18 at Orsay

Luminosity for LHeC, HE-LHeC and FCC-ep

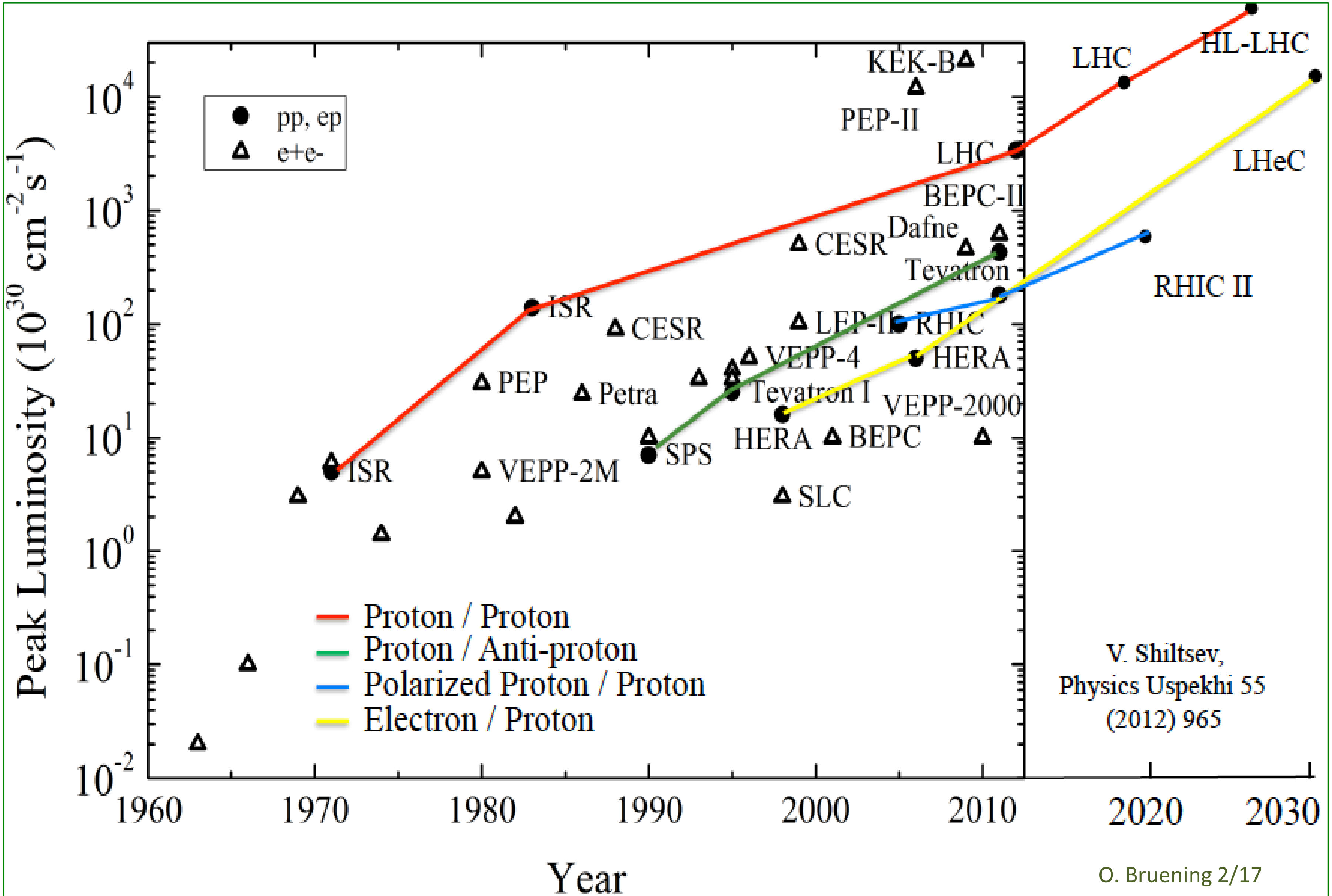
parameter [unit]	LHeC CDR	ep at HL-LHC	ep at HE-LHC	FCC-he
E_p [TeV]	7	7	12.5	50
E_e [GeV]	60	60	60	60
$\sqrt{s}$ [TeV]	1.3	1.3	1.7	3.5
bunch spacing [ns]	25	25	25	25
protons per bunch [10^{11}]	1.7	2.2	2.5	1
$\gamma\epsilon_p$ [μm]	3.7	2	2.5	2.2
electrons per bunch [10^9]	1	2.3	3.0	3.0
electron current [mA]	6.4	15	20	20
IP beta function β_p^* [cm]	10	7	10	15
hourglass factor H_{geom}	0.9	0.9	0.9	0.9
pinch factor H_{b-b}	1.3	1.3	1.3	1.3
proton filling H_{coll}	0.8	0.8	0.8	0.8
luminosity [10^{33}cm^{-2}s^{-1}]	1	8	12	15

Oliver Brüning[1], John Jowett[1], Max Klein[2],
Dario Pellegrini[1], Daniel Schulte[1], Frank Zimmermann[1]

EDMS 17979910 | FCC-ACC-RPT-0012

Contains update on eA:
6 10^{32} in e-Pb for LHeC.

Collider Luminosities vs Year (pp and ep)



FCC-eh ERL Configuration:

[Daniel Schulte]

Performance Simulations for FCC-ep:

Parameter	Unit	Protons	Electrons
Beam energy	GeV	50000	60
Normalised emittance	μm	$2.2 \to 1.1$	10
IP betafunction	mm	150	$42 \to 52$
Nominal RMS beam size	μm	$2.5 \to 1.8$	$1.9 \to 2.1$
Waist shift	mm	0	$65 \to 70$
Bunch population	10^{10}	$10 \to 5$	0.31
Bunch spacing	ns	25	25
Luminosity	$10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	$18.3 \to 14.3$	
Int. luminosity per 10 years	$[\mathrm{ab}^{-1}]$	1.2	

DA and Status of Lattices

LHeC

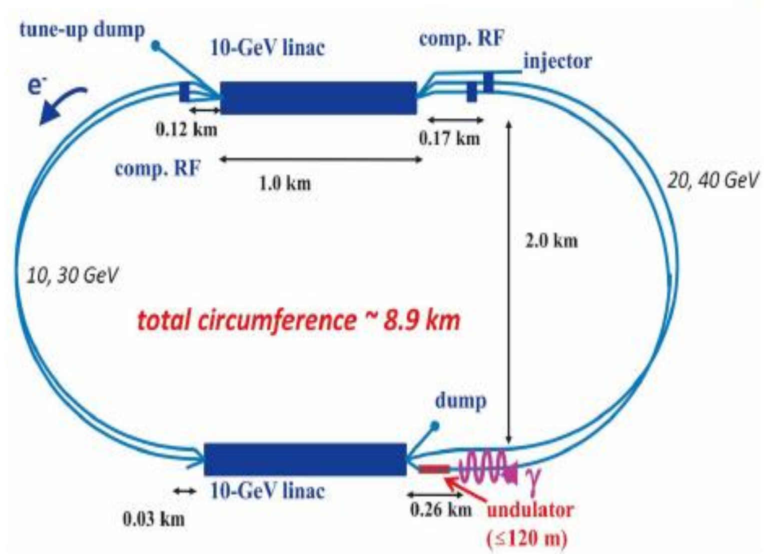
- Based on HL-LHC lattice (round optics β*=15 cm in IR1 and IR5)
- New low-β* IR (IR2)
- ATS-scheme implemented in 3 low-β* IRs
- **Previous DA studies** were implemented for different IR options
- **Update:** Studies with errors in IR1/IR5 magnets and new magnet design for IR2

FCC-eh

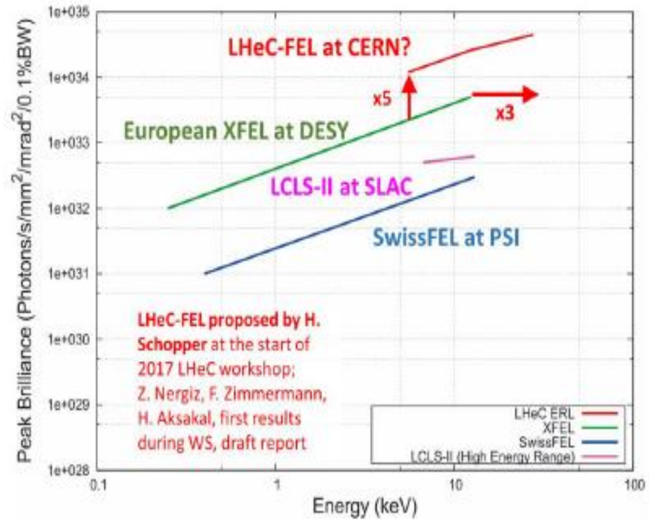
- Based on FCC-hh lattice (β*=30 cm in IRA and IRG)
- New low-β* IR (IRL)
- No ATS-scheme
- Extensive DA studies have been performed for FCC-hh lattice
- **Update**: Implement same techniques for FCC-eh

Update of Lattice and IR Design Study: see E Cruz, R Martin and B Parker at Orsay Workshop

LHeC-FEL – world's best X-ray source

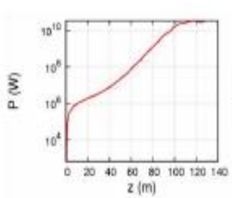


peak brilliance, LHeC-FEL compared with state-of-the-art

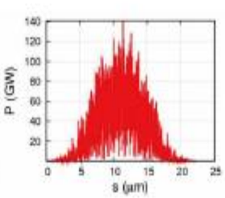


SASE FEL simulation results

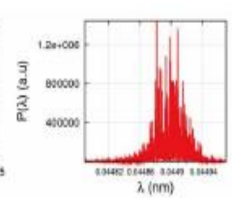
evolution of the pulse power along the undulator



spatial (temporal) profile of the radiation pulse

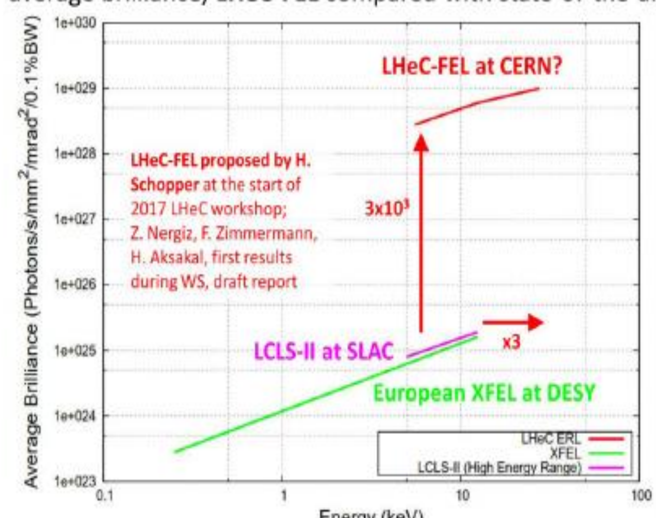


wavelength spectrum of the radiation



for λ=0.45 Å (K = 4.24)

average brilliance, **LHeC-FEL** compared with state-of-the-art



Z. Nergiz, F. Zimmermann, H. Aksakal

APP Template V1.29 Article id: jpgaaa171 Typesetter: MPS Date received by MPS: 14/12/2017 PE: MAC005961 CE : LE:

OPEN ACCESS
IOP Publishing Journal of Physics G: Nuclear and Particle Physics

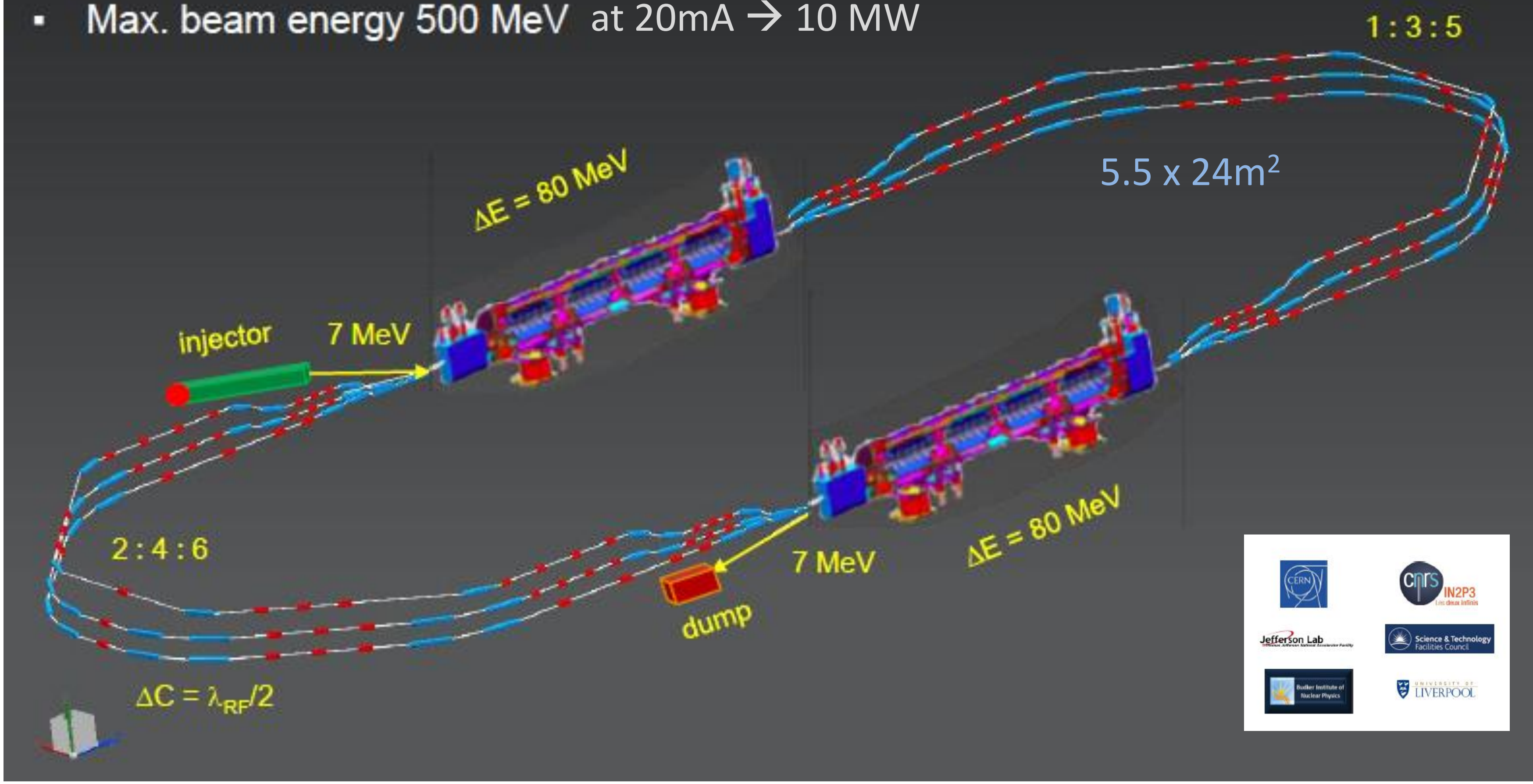
J. Phys. G: Nucl. Part. Phys. **00** (2018) 000000 (71pp)

PERLE. Powerful energy recovery linac for experiments. Conceptual design report

D Angal-Kalinin[1], G Arduini[2], B Auchmann[2], J Bernauer[3], A Bogacz[4], F Bordry[2], S Bousson[5], C Bracco[2], O Brüning[2], R Calaga[2], K Cassou[6], V Chetvertkova[2], E Cormier[7], E Daly[4], D Douglas[4], K Dupraz[6], B Goddard[2], J Henry[4], A Hutton[4], E Jensen[2], W Kaabi[6], M Klein[8], P Kostka[8], N Lasheras[2], E Levichev[9], F Marhauser[4], A Martens[6], A Milanese[2], B Militsyn[1], Y Peinaud[6], D Pellegrini[2], N Pietralla[10], Y Pupkov[9], R Rimmer[4], K Schirm[2], D Schulte[2], S Smith[1], A Stocchi[6], A Valloni[2], C Welsch[8], G Willering[2], D Wollmann[2], F Zimmermann[2] and F Zomer[6]

Powerful ERL for Experiments at Orsay

- 2 Linacs (Four 5-Cell 801.58 MHz SC cavities)
- 3 turns (160 MeV/turn)
- Max. beam energy 500 MeV at 20mA → 10 MW



cf Walid Kaabi at Amsterdam FCC

New SCRF, High Intensity (100 x ELI) ERL Development Facility with unique low E Physics

Why PERLE [as seen from LHeC]?

FUNDAMENTAL MOTIVATION:

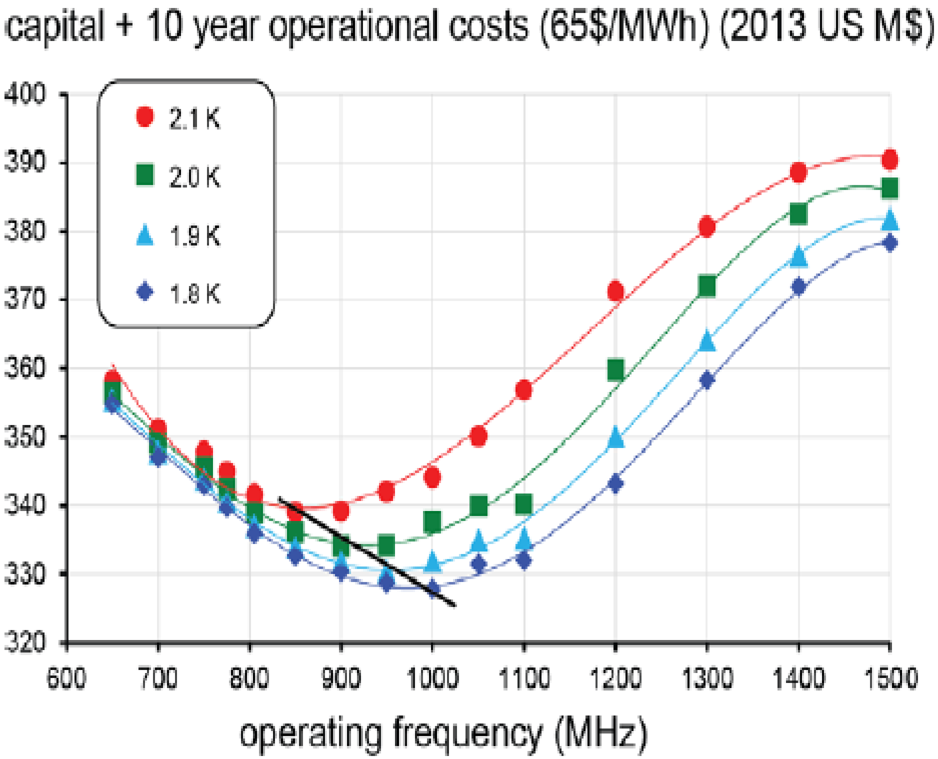
- **Validation of key LHeC Design Choices**

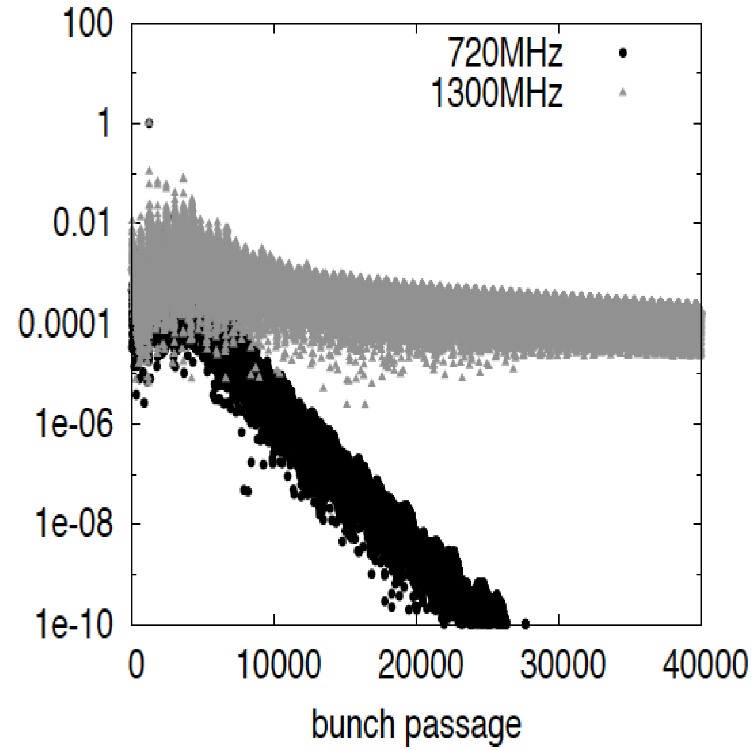
- **Build up expertise in the design and operation for a facility with a fundamentally new operation mode:**
  ERLs are circular machines with tolerances and timing requirements
  similar to linear accelerators (no 'automatic' longitudinal phase stability, etc.)

- **Proof validity of fundamental design choices:**
  Multi-turn recirculation (other existing ERLs have only 1-2 passages)
  Implications of high current operation (2 * 3 * [6mA – 25mA] → 30-150mA!!)

- **Verify and test machine and operation tolerances before designing a large scale facility**
  Tolerances in terms of field quality of the arc magnets and cavity alignment
  Required RF phase stability (RF power) and LLRF requirements
  Halo and beam loss tolerances

Frequency Choice





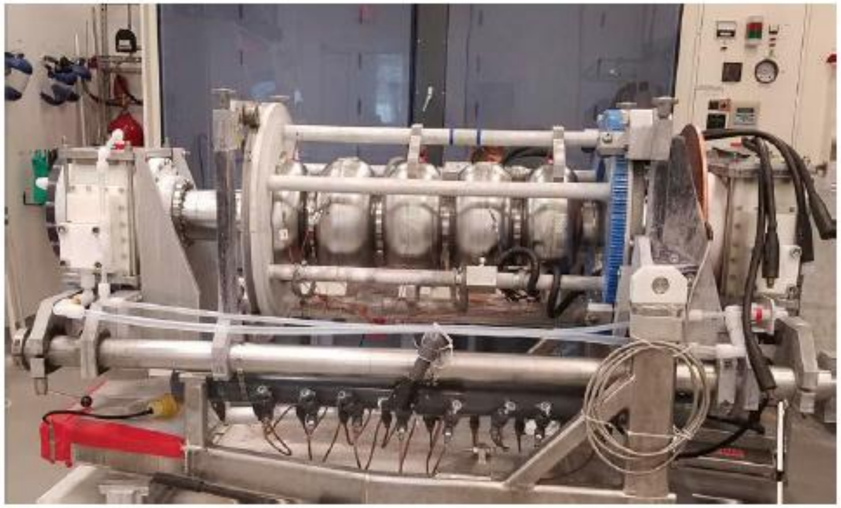
Cost, dynamic heat losses, resistance, Q_0... point to f < 1 GHz (F Marhauser, Orsay 2/17)

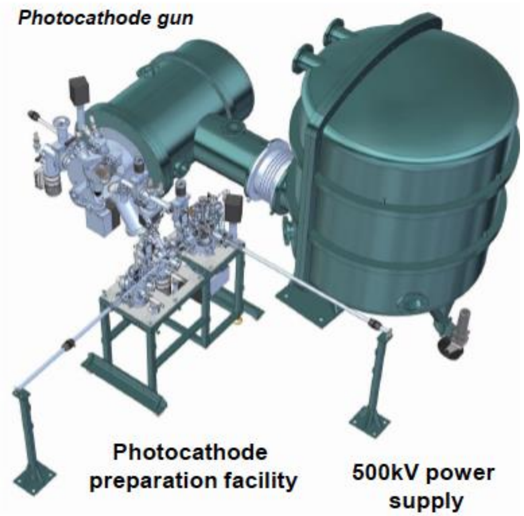
Beam beam interactions unstable for f > 1 GHz (D Schulte, D Pellegrini March 2013)

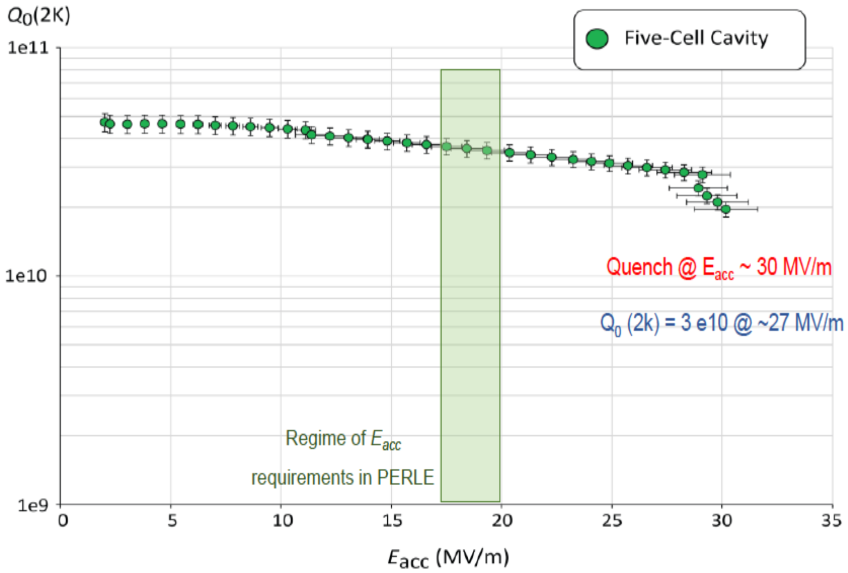
Compatibility with LHC: **Decision for 802 MHz** (E Jensen CI Workshop 1/2015, FM input)

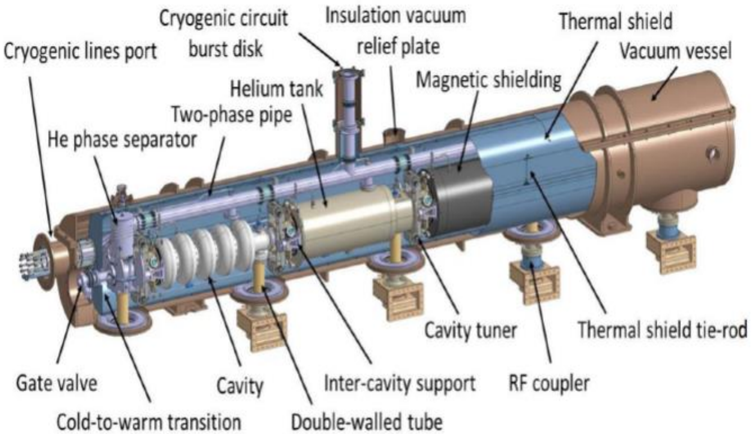
Towards PERLE: 802 MHz cavity, Source, Cryomodule, Magnets

First 802 MHz cavity successfully built (Jlab)



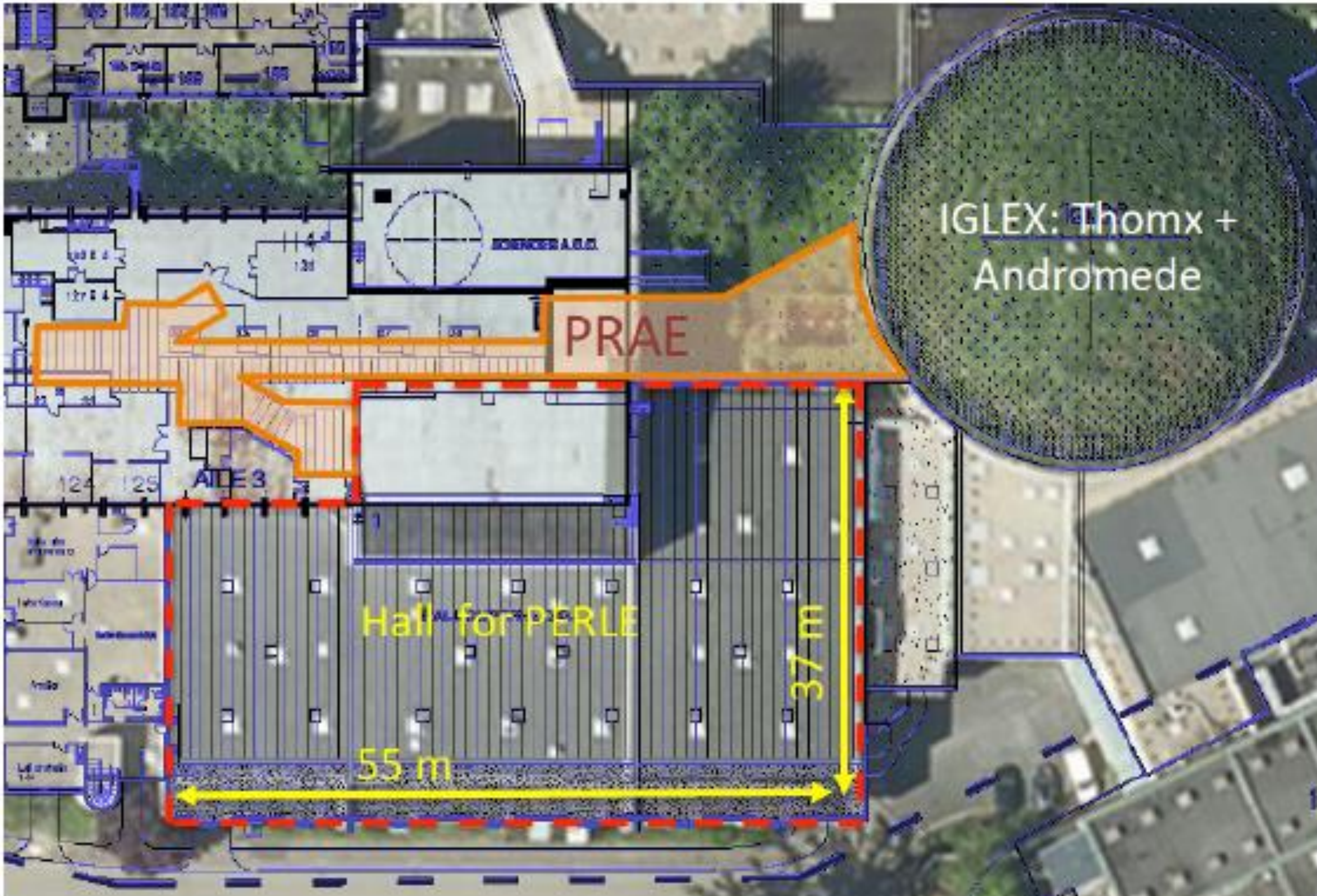






BINP, CERN, Daresbury/Liverpool, Jlab, Orsay, +

CDR 1705.08783 [J.Phys G] → TDR in 2019



IGLEX: Thomx +
Andromede
PRAE
Hall for PERLE
37 m
55 m

Summary and Plans

- Following the CDR and the Higgs Boson Discovery in 2012, Physics from LHC, as well as Technology Developments, the ERL Concept for the LHeC has been updated to design for 10^{34} cm^{-2} s^{-1} ep scattering with the HL LHC, HE LHC and the FCCeh.

- New physics (Higgs, BSM, top) studies have substantially widened the scope.

- The LHeC is designed for concurrent ep operation, with pp, in order to accumulate O(1) ab^{-1} of integrated luminosity, at a power limit of 100 MW.

- New studies on lattice and the IR optics and configuration support this as a realistic goal.

- The heart of ep with HL LHC, HE LHC and FCC-eh is an energy recovery electron linac.

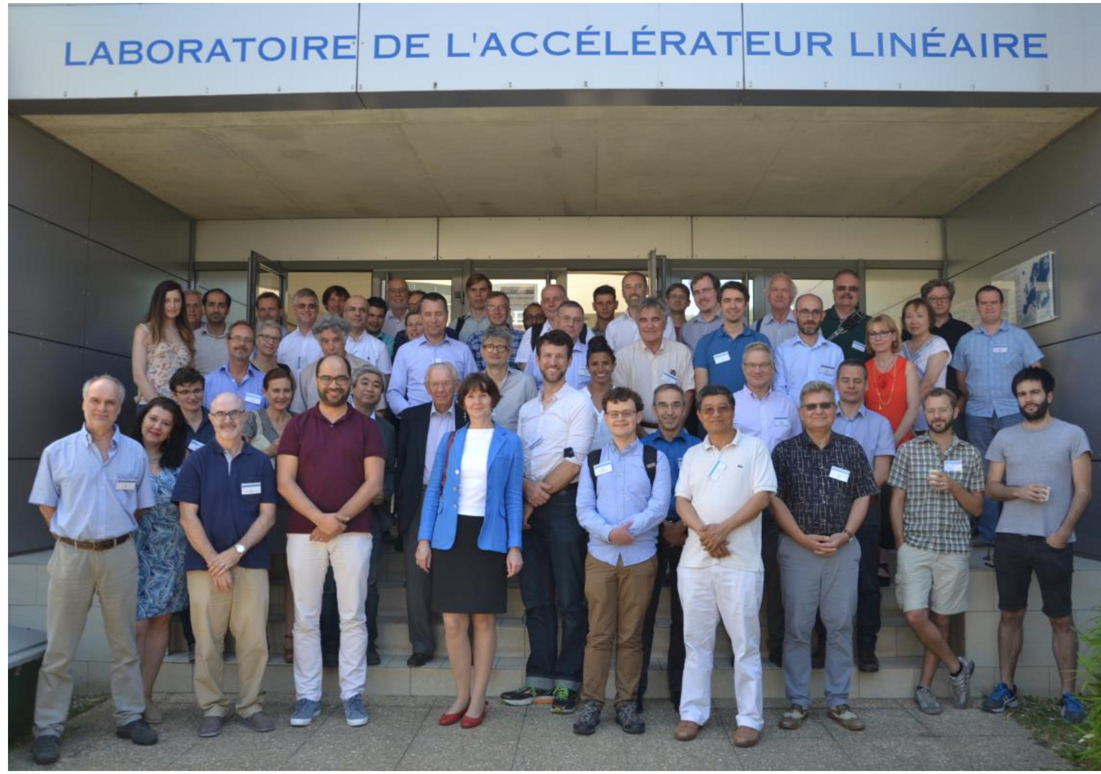
- A first SC cavity of 802 MHz frequency has been designed and successfully tested showing stability of up to 29 MV/m and a weak Q_0-gradient dependence around 3 10^{10}, exceeding the design goal. Single cells will be infused with N, + the CM designed

- A PERLE CDR has been published in 2017 and a TDR is scheduled for 2019. PERLE will be the first 10 MW, multi-turn 802 MHz facility and is suited to accompany the development of the LHeC as a technology development facility, with low E physics.

- PERLE and LHeC (HL/HE) inputs are under preparation for the HEP strategy update + beyond

Most up-to-date Information: https://indico.cern.ch/event/698368/

Workshop: LHeC/FCCeh and PERLE
End of June at Orsay near Paris



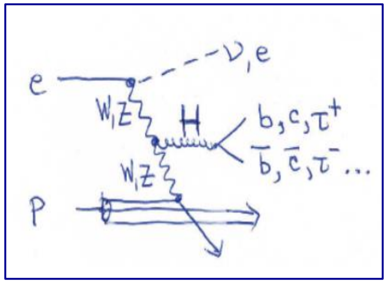
New and Updates on

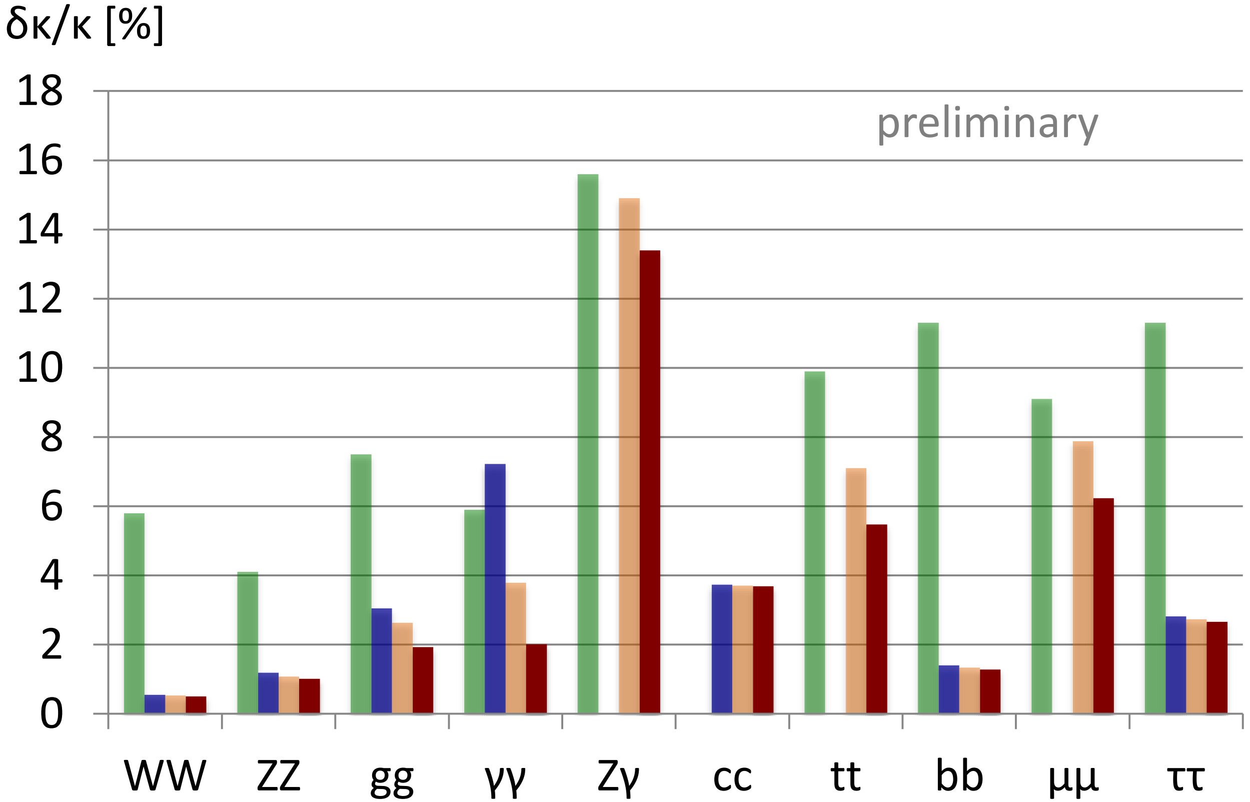
Physics (PDFs, QCD, H, t, BSM, eA + Relation eh-hh..)
Accelerator: IR, Optics, Lattice, Cost-Energy, CE..
Detector: the GPD and its fwd and bwd detectors
PERLE: Source, Injector, Cavity, Cryomodule,.. Physics
Project Development towards the ES2020:
LHeC + FCCeh+ PERLE input 12/18. PERLE TDR in 2019.

http://lhec.web.cern.ch

backup

Determination of SM Higgs Couplings, HL-LHC and LHeC → LHC





J. De Blas, M.+U. Klein, 16.4.2018

LHC: ATLAS prospects PUB Note 2014-016

ttH at LHeC to 15%

The addition of ep to pp (LHeC to LHC (HL,HE) and FCC-eh to FCC-pp) **transforms these machines into precision Higgs facilities. Vital complementarity with e^+e^-** (JdB Amsterdam)

Note that the HL LHC prospects are being updated (HL/HE LHC Physics workshop).

Large Hadron Electron Collider on one page

E_e = 10-60 GeV, E_p =1-7 TeV: √s = 200 – 1300 GeV. **Kinematics**: $0 < Q^2 < s$, $1 > x \geq 10^{-6}$ (DIS)
Electron Polarisation P=±80%. Positrons: significantly lower intensity, unpolarised
Luminosity: O(10^{34}) $cm^{-2} s^{-1}$. integrated O(1) ab^{-1} for HL LHC and 2 ab^{-1} for HE LHC/FCCeh
e-ions 6 10^{32} $cm^{-2} s^{-1}$ O(10)fb^{-1} in ePb . O(1)fb^{-1} for ep F_L measurements

Physics: QCD: develop+break? The worlds best microscope. BSM (H, top, ν, SUSY..)
Transformations: Searches at LHC, LHC as Higgs Precision Facility, QCD of Nuclear Dynamics
The LHeC has a deep, unique QCD, H and BSM precision and discovery physics programme.

1802.04317

Time: Determined by the Large Hadron Collider (HL LHC needs till ~2040 for 3 ab^{-1})
LHeC: Detector Installation in 2 years, earliest in LS4 (2030/31).
HE LHC: re-use ERL. In between HL-HE, 10 years time of ERL Physics (laser, γγ..)
Very long term: FCC-eh

http://lhec.web.cern.ch

Challenges: Demonstration of ERL Technology (high electron current, multi-turn)
Design 3-beam IR for concurrent ep+pp operation, New Detector with Taggers - in 10 years.

The LHeC is a great opportunity to sustain deep inelastic physics within future HEP.
The cost of an ep Higgs event is O(1/10) of that at any of the 4 e^+e^- machines under consideration
It can be done: the Linac is shorter than 2 miles and the time we have longer than HERA had.

CERN and world HEP: Vital to make the High Luminosity LHC programme a success.

LHeC Prospects

- The ep interaction does not disturb pp, i.e. the LHC may become a twin collider, ep and pp operate concurrently and no luminosity loss is planned for pp. This requires a premounted eh detector which may then be inserted in 2 years.

- At LS4 (~2030) the heavy ion LHC operation ends and one may propose a different use of IP2 which currently houses ALICE.

- The electron beam energy (> 50 GeV) and luminosity ($O(10^{34})$ cm^{-2} s^{-1}) goals are derived from Higgs, top and BSM physics, also DIS itself (F_L, low x~1/s).

- The cost of the O(1) TeV ep collider is a small fraction of any other big project currently under discussion. The LHC determines the time frame. This may extend considerably if CERN moves to HE LHC in the fourties.

- The ERL technology is being developed worldwide (Darmstadt, Cornell, Berlin, Novosibirsk, Jefferson Lab). PERLE would be a multi-turn 802 MHZ ERL technology development and test facility which would timely accompany the LHeC progress.

- We celebrate this year the 50th anniversary of the discovery of quarks. This was not planned and achieved by a step in energy with a linac SHORTER than LHeC's

- There is a very long term future for eh as part of hh in the FCC vision

Further use of ERL in between HL and HE LHC

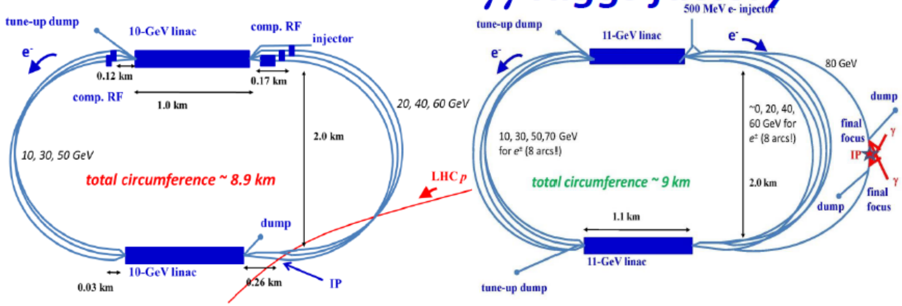
F.Zimmermann at LHeC WS 9/17

Reconfiguring *LHeC → SAPPHiRE*

LHeC-ERL

*SAPPHiRE**

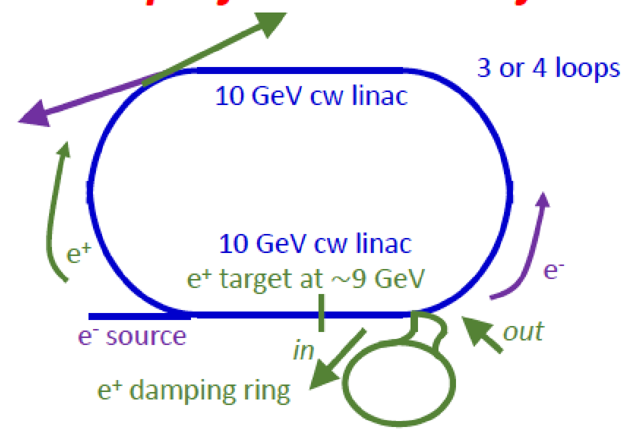
γγ Higgs factory



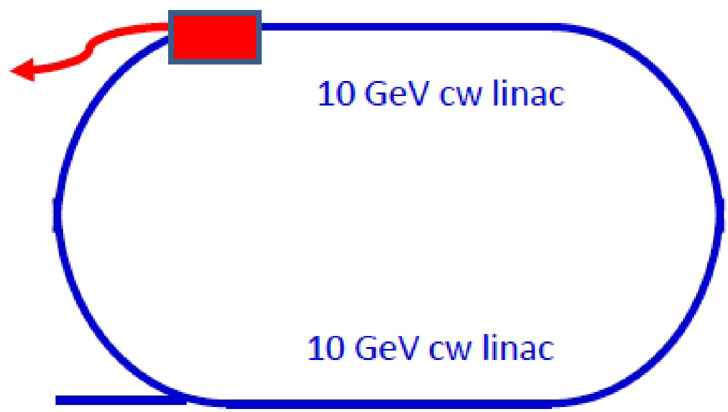
*Small Accelerator for Photon-Photon Higgs production using Recirculating Electrons

S. A. Bogacz, J. Ellis, L. Lusito, D. Schulte, T. Takahashi, M. Velasco, M. Zanetti, F. Zimmermann, 'SAPPHiRE: a Small Gamma-Gamma Higgs Factory,' arXiv:1208.2827

LHeC: perfect FCC-ee injector!



LHeC-FEL



up to 60 GeV,

~25 mA,

1 MeV photons?

3-15x higher beam energy

(10-200x higher γ energies),

300-600x higher current

XFEL: 20GeV e, 0.03mA, 24keV photons. LCLSII: 4 GeV e, 0.06mA, 5 keV photons

DRAFT

Observations post CDR/EUSPP - 2012+ affecting ep at CERN:

LHC lifetime now extended to ~2040 to collect 3 [4] ab^{-1} . LS3 2024-2026+..

Discovery of the Higgs: L(ep): $10^{33} \rightarrow 10^{34}$ $cm^{-2} s^{-1}$ [HERA in days]
LHC brightness N_p/ε about 3 times higher than "ultimately" expected

No further discovery at the LHC, so far

Detector technology developments (LHC Det. Upgrades)

Strong **accelerator technology** developments, notably SCRF
ERL. LHeC: 720 → 802 MHz. enhanced $Q_0 > 10^{10}$

EU strategy 13: exploit LHC, study Higgs, develop SCRF+,
CERN: new accelerators "with emphasis on pp and ee"
Fine with the LHeC cost being a small fraction of ILC,CLIC,FCC

→ CERN in 14 set up a new LHeC organisation with a new mandate
and IAC (H.Schopper et al) to prepare for the next EU strategy 2019+
Two main tasks (IAC): Update of CDR for HL-LHeC/FCCeh + Testfacility

Framework of the Development

Following the CDR in 2012: Mandate issued by CERN:2014 (RH), confirmed in 2016 (FG)

Mandate to the International Advisory Committee

Advice to the LHeC Coordination Group and the CERN directorate by following the development of options of an ep/eA collider at the LHC and at FCC, especially with:

Provision of scientific and technical direction for the physics potential of the ep/eA collider, both at LHC and at FCC, as a function of the machine parameters and of a realistic detector design, as well as for the design and possible approval of an ERL test facility at CERN.

Assistance in building the international case for the accelerator and detector developments as well as guidance to the resource, infrastructure and science policy aspects of the ep/eA collider.

Chair: Herwig Schopper, em. DG of CERN. IAC+CERN have invited four of its members to follow the study with special attention (Stefano Forte, Andrew Hutton, Leandro Nisati and Lenny Rifkin). Collaboration also with the FCC Review Committee chaired by Guenther Dissertori.

LHeC has been a development for and initiated by CERN, ECFA and NuPECC, so far, it’s formal status is that of a community study, not a proposal, which holds for the FCC also, of which ‘eh’ is a part.

Organisation*)

International Advisory Committee

Mandate by CERN to define
“..Direction for ep/A both at LHC+FCC”

Sergio Bertolucci (CERN/Bologna)
Nichola Bianchi (Frascati)
Frederick Bordry (CERN)
Stan Brodsky (SLAC)
Hesheng Chen (IHEP Beijing)
Eckhard Elsen (CERN)
Stefano Forte (Milano)
Andrew Hutton (Jefferson Lab)
Young-Kee Kim (Chicago)
Victor A Matveev (JINR Dubna)
Shin-Ichi Kurokawa (Tsukuba)
Leandro Nisati (Rome)
Leonid Rivkin (Lausanne)
Herwig Schopper (CERN) – Chair
Jurgen Schukraft (CERN)
Achille Stocchi (LAL Orsay)
John Womersley (ESS)

We miss Guido Altarelli.

Coordination Group

Accelerator+Detector+Physics

Gianluigi Arduini
Nestor Armesto
Oliver Brüning – Co-Chair
Andrea Gaddi
Erk Jensen
Walid Kaabi
Max Klein – Co-Chair
Peter Kostka
Bruce Mellado
Paul Newman
Daniel Schulte
Frank Zimmermann

5(12) are members of the FCC coordination team

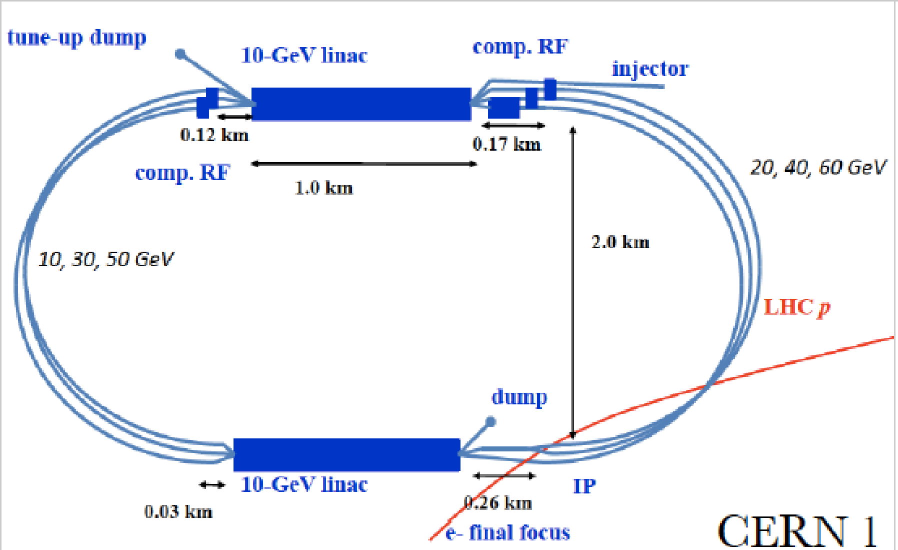
OB+MK: co-coordinate FCCeh

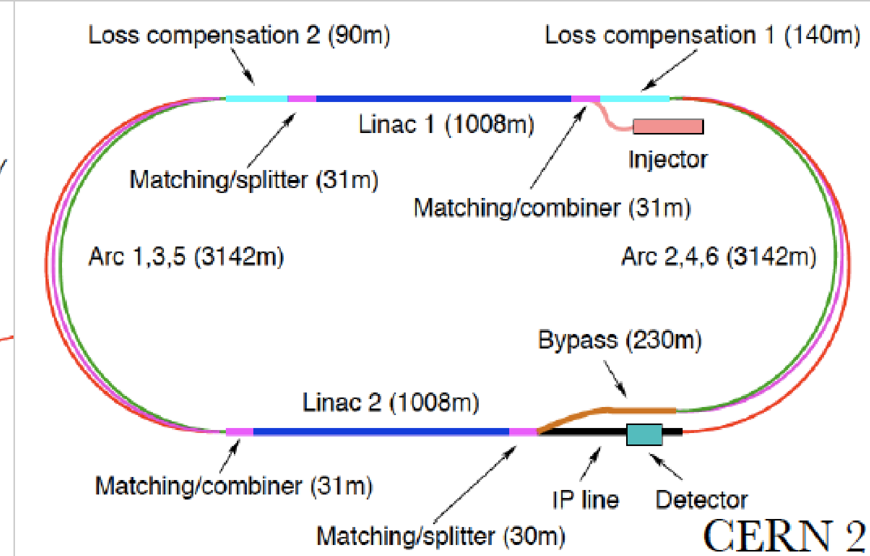
*) April 2018

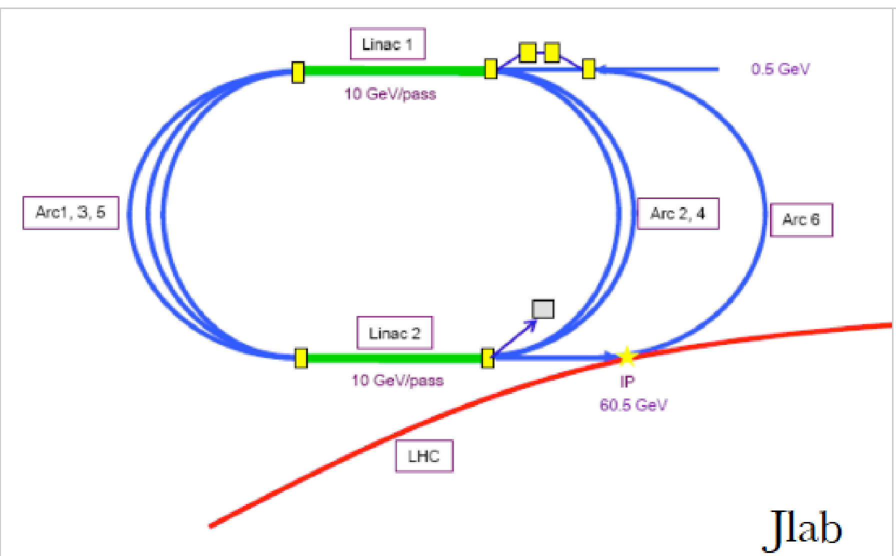
Working Groups

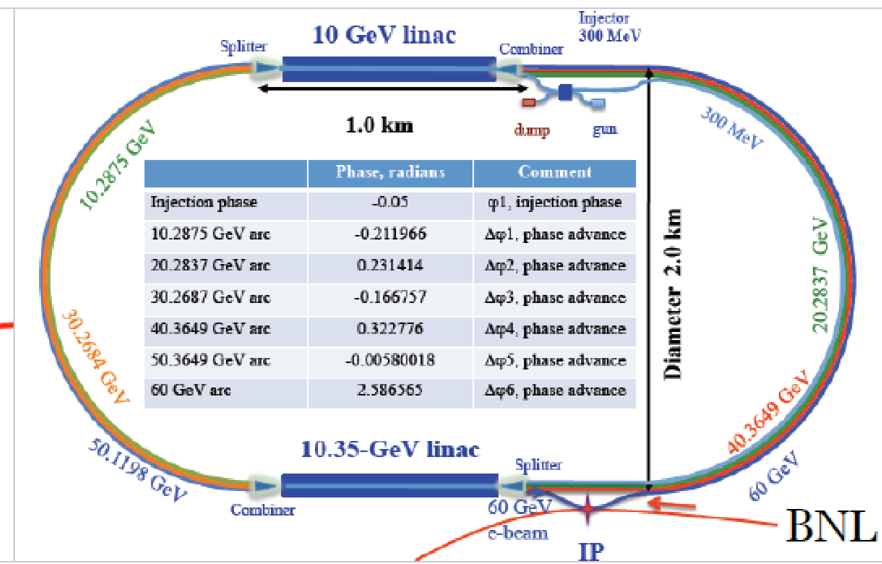
PDFs, QCD
Fred Olness,
Claire Gwenlan
Higgs
Uta Klein,
Masahiro Kuze
BSM
Georges Azuelos,
Monica D’Onofrio
Oliver Fischer
Top
Olaf Behnke,
Christian
Schwanenberger
eA Physics
Nestor Armesto
Small x
Paul Newman,
Anna Stasto
Detector
Alessandro Polini
Peter Kostka

60 GeV Energy Recovery Linac









	Phase, radians	Comment
Injection phase	-0.05	φ1, injection phase
10.2875 GeV arc	-0.211966	Δφ1, phase advance
20.2837 GeV arc	0.231414	Δφ2, phase advance
30.2687 GeV arc	-0.166757	Δφ3, phase advance
40.3649 GeV arc	0.322776	Δφ4, phase advance
50.3649 GeV arc	-0.00580018	Δφ5, phase advance
60 GeV arc	2.586565	Δφ6, phase advance

CDR: Default configuration, 60 GeV, 3 passes, 720 MHz, synchronous ep+pp, $L_{ep}=10^{33}$


8105

Parameter Choice for FCC-he

For matched electron and proton beam sizes:

$$\mathcal{L} \propto \frac{N_p}{\epsilon_p} \frac{1}{\beta_p} I_e H_{geom} H_{b-b} H_{coll}$$

Proton beam brilliance

Proton ring design

Electron beam current

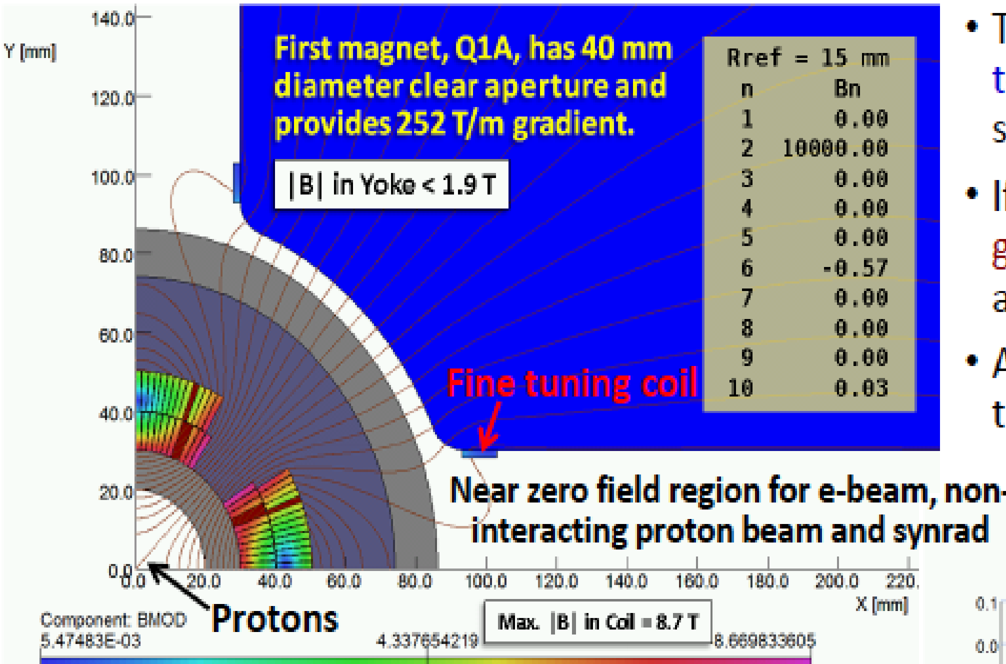
Hourglass effect

Beam-beam effect

Fill pattern matching

→ **O(1ab^{-1}) in a decade of operation,** see D Schulte, FCC week at Rome, 2016

Recent Progress on IR Magnets



- The yoke and a small fine tuning coil add 5% to the bare coil gradient and create zero field sweet spot region just outside coil structure.
- If this were made an actively shielded coil the gradient would have instead dropped by 7% and the "septum region" made 10% thicker.
- A weak fine tuning coil allows to adjust field in the slot and compensate for saturation effects.

- Self-supporting coil structure presents smallest possible "septum" region between the beams.
- Quadrupole symmetric yoke with deep slot cut out regions bypasses magnetic flux around the near zero field space used for beam separation.
- Yoke slots are sized to cleanly pass the synrad fan cleanly to far from IP and thereby avoid adding backscatter background.