Remarks on the LHeC and PERLE

Raison d’etre de LHeC

Luminosity and Parameters

Status of the LHeC

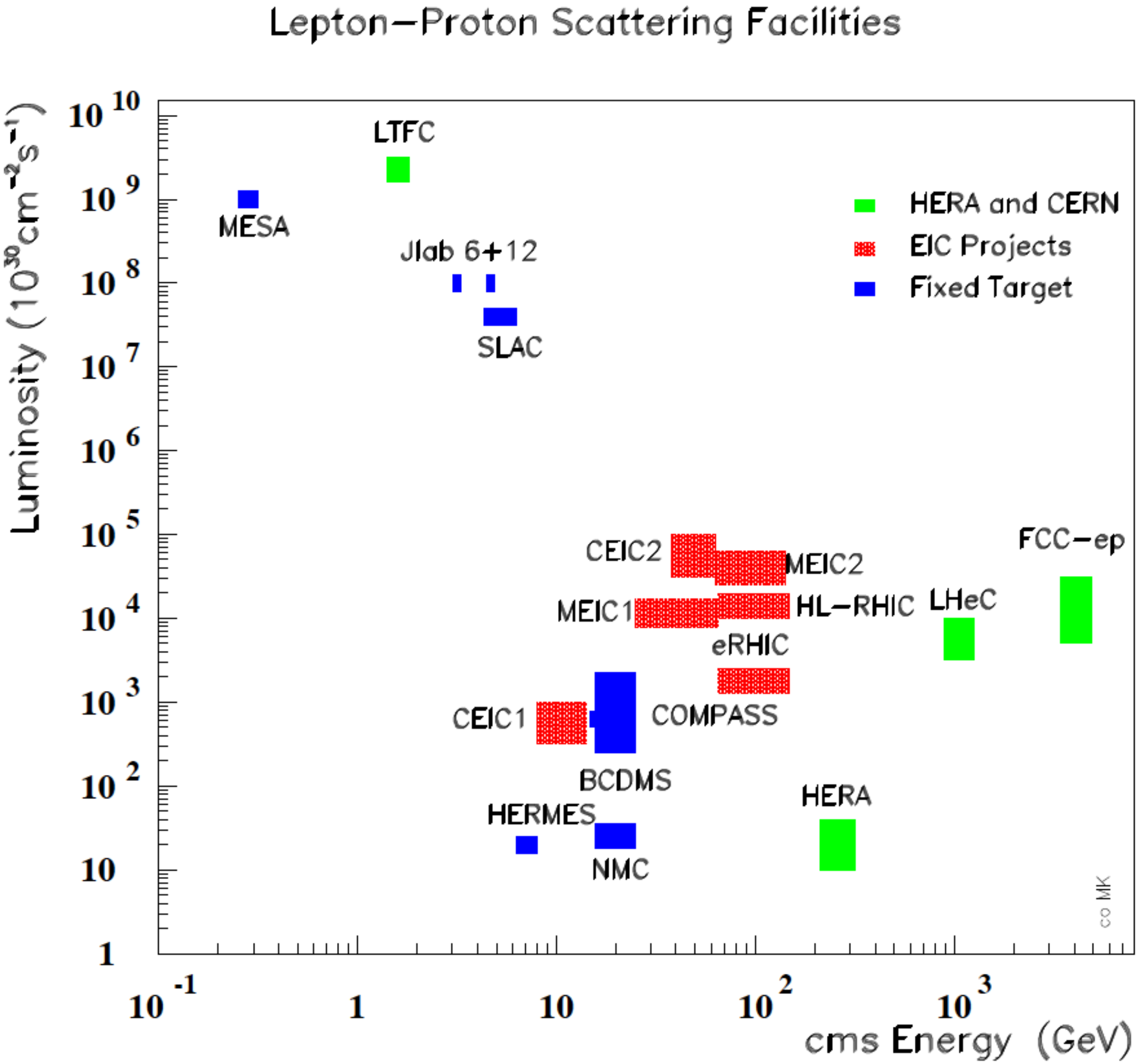
PERLE

ep Physics with PERLE

Max Klein
UNIVERSITY OF LIVERPOOL
For the LHeC Study Group

Kickoff Meeting for the PERLE Technical Design and Report, Orsay, 23.2.2017

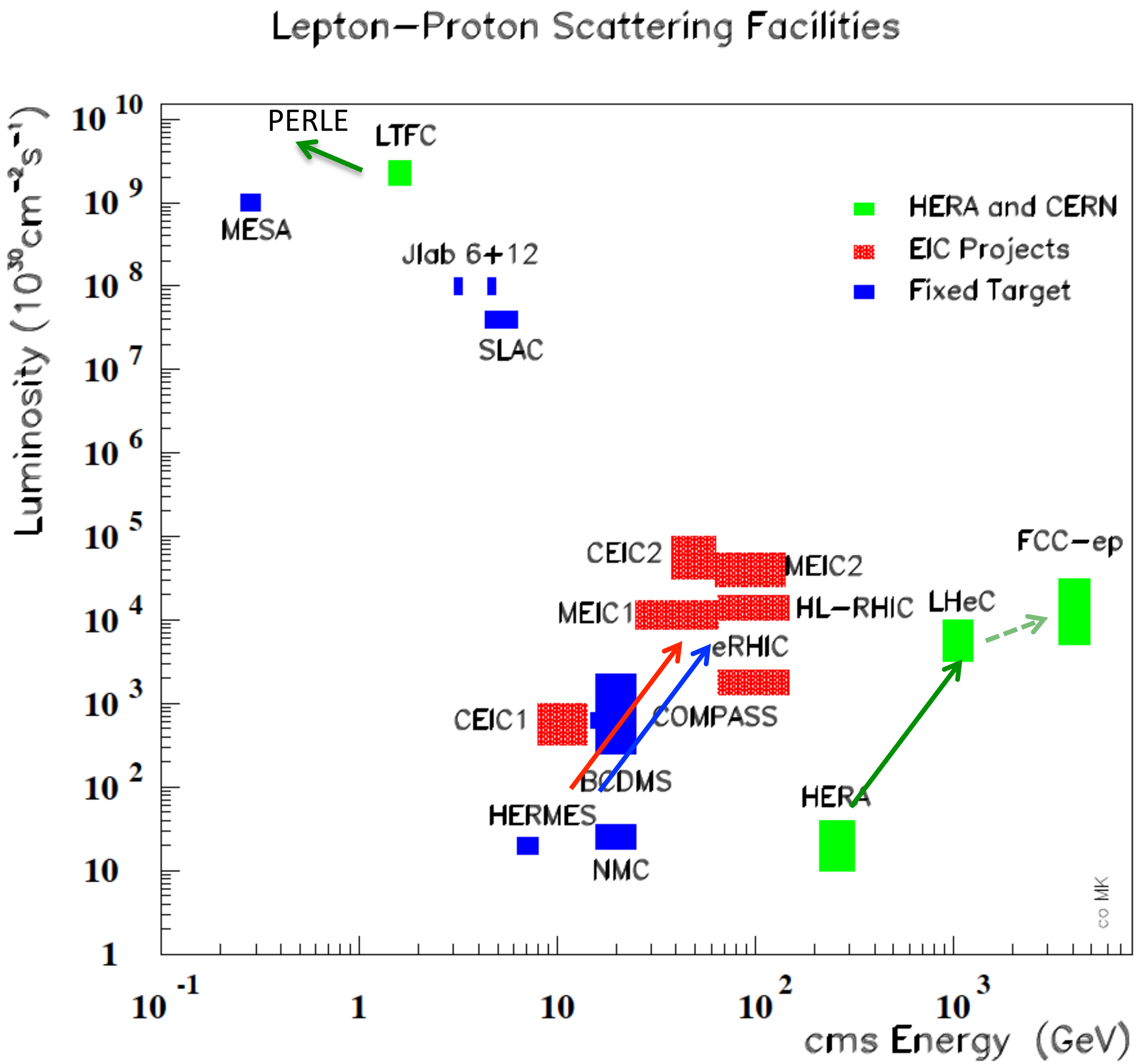
Intensity and Energy Frontier of Future DIS



From CERN Courier
MK, H.Schopper
June 2014

With input from
A.Hutton, R.Ent,
F.Maas, T.Rosner

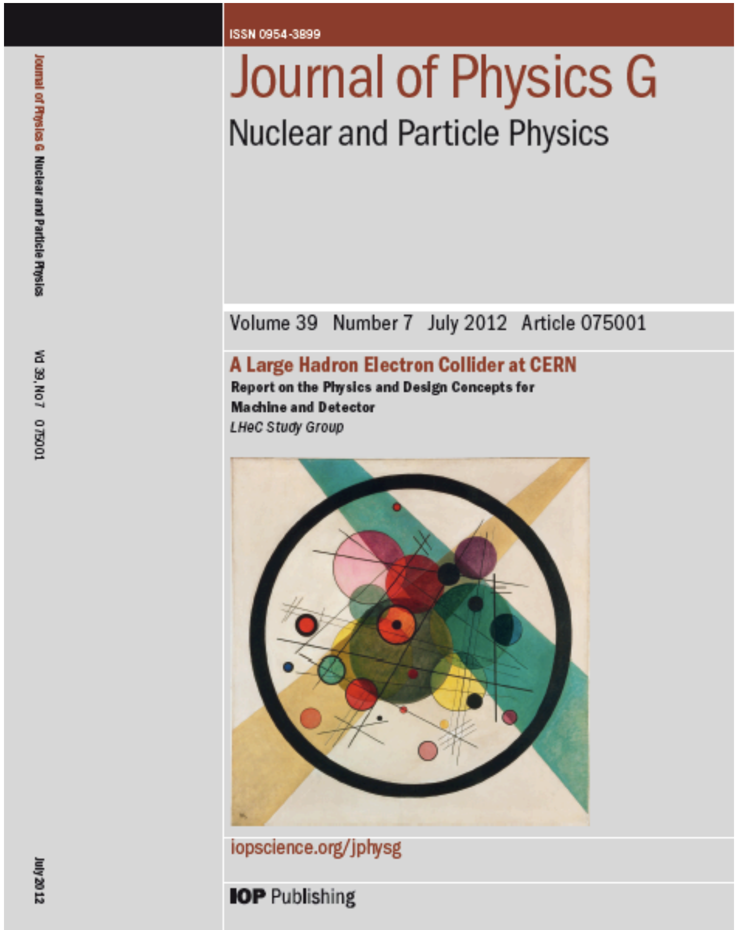
Intensity and Energy Frontier of Future DIS



From CERN Courier
MK, H.Schopper
June 2014

With input from
A.Hutton, R.Ent,
F.Maas, T.Rosner

Design Report 2012



Journal of Physics G Nuclear and Particle Physics   Vol 39, No 7   075001   July 2012

ISSN 0954-3899

Journal of Physics G

Nuclear and Particle Physics

Volume 39 Number 7 July 2012 Article 075001

A Large Hadron Electron Collider at CERN

Report on the Physics and Design Concepts for Machine and Detector

LHeC Study Group

iopscience.org/jphysg

IOP Publishing

arXiv:1206.2913

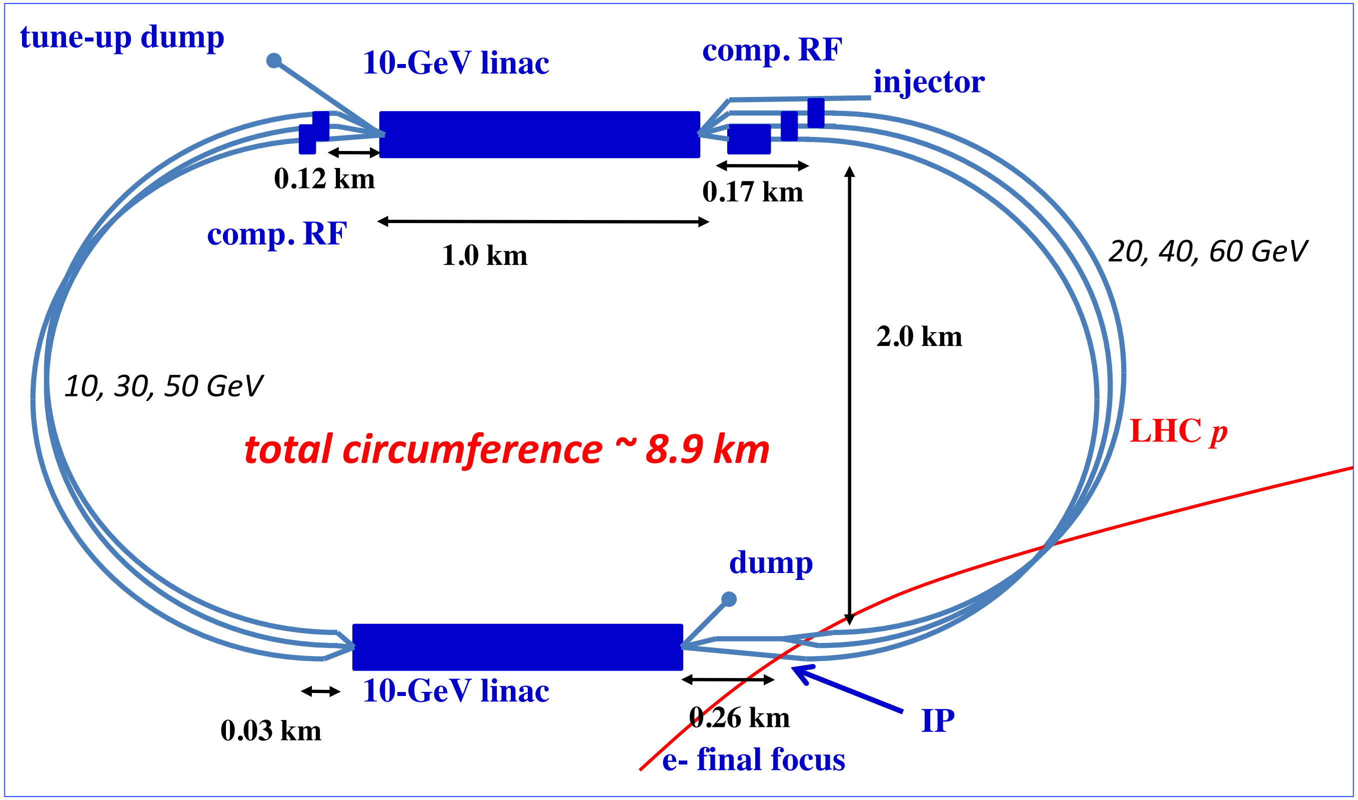
CERN Referees

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)

600 pages. Physics, Detector and Two Accelerator Options
ring-ring which may be of interest in the HE-LHC context and linac-ring, the default LH(e)C

LHeC Default: 60 GeV ERL

Conceptual Design Report: arXiv:1206.2913, published in JPhysG – 20 referees..



total circumference ~ 8.9 km

LHeC: 60 GeV off 7 TeV, L(ep) =10^{34} cm^{-2} s^{-1} (1000 x HERA) in synchronous ep+pp operation

Observations post CDR - 2012+

LHC brightness 2-3 times higher than expected

LHC lifetime now extended to end of 30ies: 3 [4] ab^{-1}

Discovery of the Higgs: L(ep): $10^{33} \rightarrow 10^{34}$ cm^{-2} s^{-1}

No further discovery at the LHC (as yet)

Detector technology developments (LHC Det. Upgrades)

Strong ERL developments (cβ, Jlab, BerlinPRO, MESA..)
SC RF: 802 MHz (LHeC), enhanced Q_0 through Ni doping

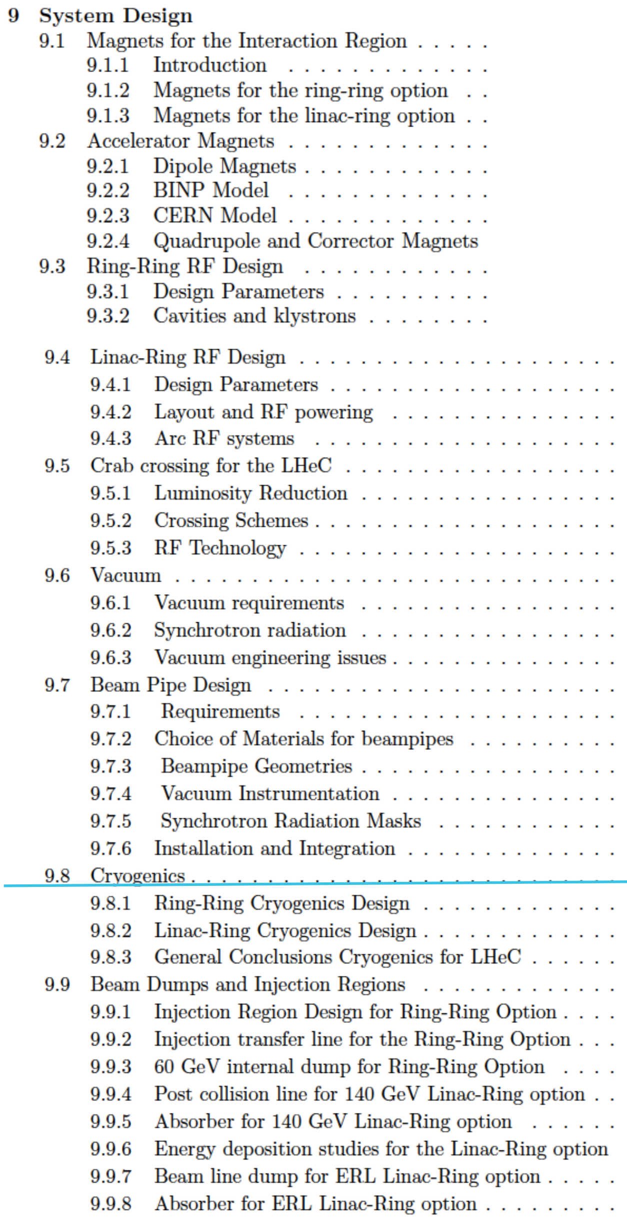
EU strategy 13: exploit LHC, study Higgs, develop SCRF,
CERN: new accelerators "with emphasis on pp and ee"
Fine with the LHeC cost being a small fraction of ILC,CLIC,FCC
No decision on e^+e^- colliders, for how long?

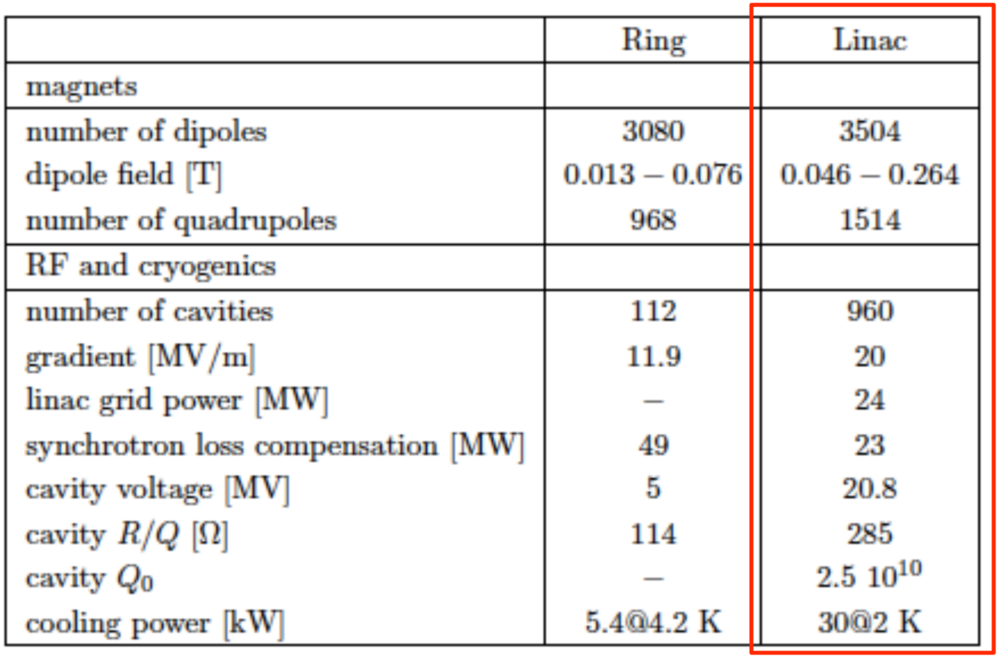
→ CERN in 14 set up a new LHeC organisation with a new mandate to prepare for the next EU strategy 2019

Two main goals: Update of CDR for HL-LHeC + Testfacility

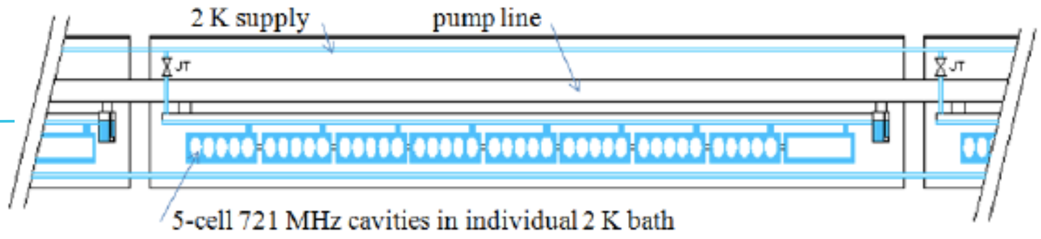
Components and Cryogenics

Chapter 9 of CDR

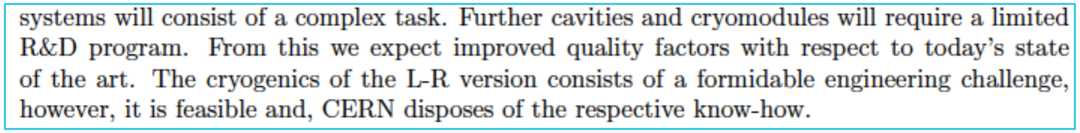




	Ring	Linac
magnets		
number of dipoles	3080	3504
dipole field [T]	0.013 – 0.076	0.046 – 0.264
number of quadrupoles	968	1514
RF and cryogenics		
number of cavities	112	960
gradient [MV/m]	11.9	20
linac grid power [MW]	–	24
synchrotron loss compensation [MW]	49	23
cavity voltage [MV]	5	20.8
cavity R/Q [Ω]	114	285
cavity Q_0	–	$2.5\ 10^{10}$
cooling power [kW]	5.4@4.2 K	30@2 K



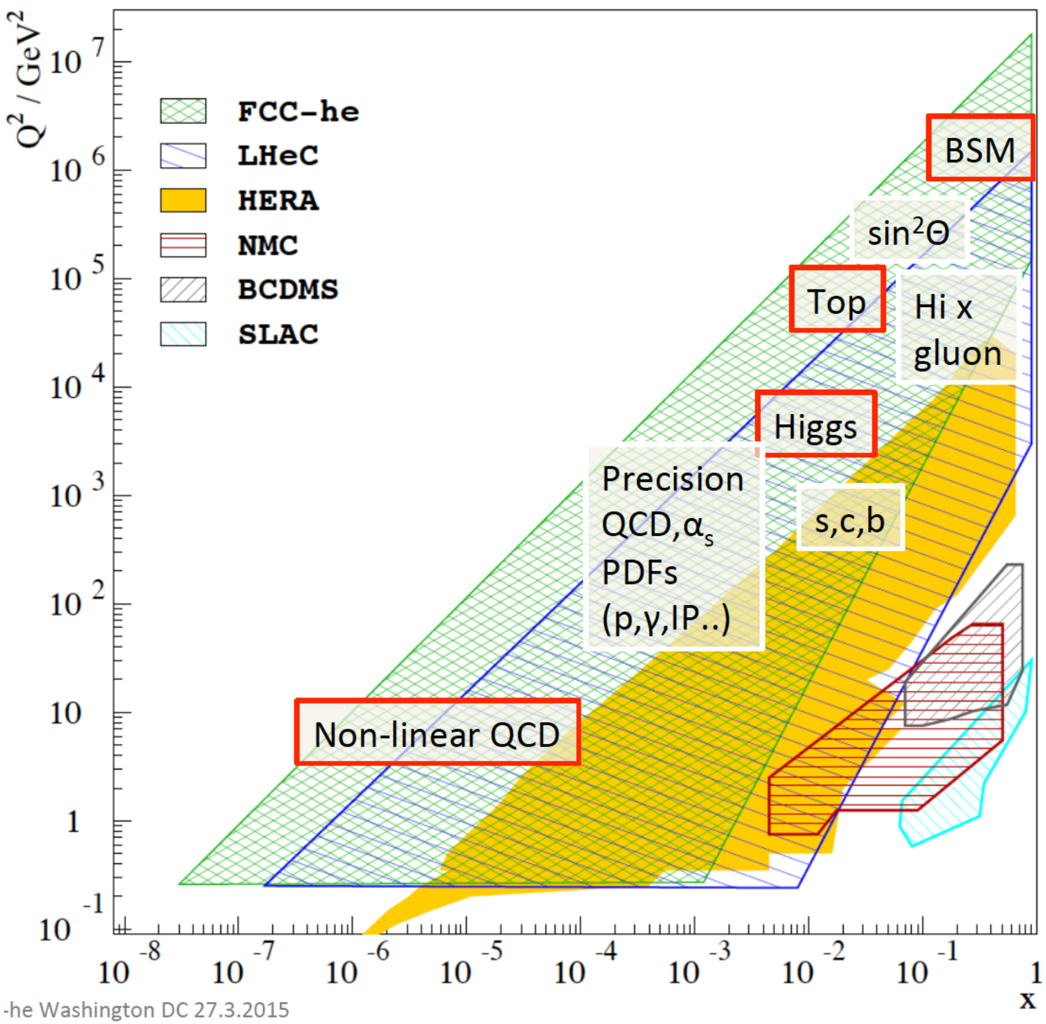
Need to develop LHeC cavity (cryo-module) *[2013]*



systems will consist of a complex task. Further cavities and cryomodules will require a limited R&D program. From this we expect improved quality factors with respect to today's state of the art. The cryogenics of the L-R version consists of a formidable engineering challenge, however, it is feasible and, CERN disposes of the respective know-how.

from CDR LHeC

Physics of the LHeC



-he Washington DC 27.3.2015

Recent highlights:

Higgs to heavy quarks to %

Higgs to invisible

Sterile Neutrinos

Strong Coupling to 0.1%

PDFs to N^{3}LO pQCD
completely unfolded

Low x:
Discover/Disprove Saturation

High x:
Enable searches at HL LHC

Raison d'etre

LHC as Precision Higgs Factory
ep: World'sCleanest Microscope
A Bridge to the 10 TeV + BSM

Huge increase in energy and luminosity enables unique development of physics

For example: parton distributions – all heard about collinear, classic PDFs
LHeC will for the first time determine these, but nature+theory are MUCH richer

Generalised Parton Distributions [DVCS] – "proton in 3D - tomography"

Unintegrated Parton Distributions [Final State] – DGLAP/BFKL?

Diffractive Parton Distributions [Diffraction] – pomeron, confinement??

Photon Parton Distribution [Photoproduction Dijets,QQ; $F_{2,L}$] - fashionable..

Neutron Parton Distributions [Tagged en (eD) Scattering] – ignored at HERA

It is the physics importance and genuine interest which drive the LHeC, directors too:

Next decades

Rolf Heuer at
Aix Les Bains
1. 10. 2013

Road beyond Standard Model

LHC results vital to guide the way at the energy frontier

At the energy frontier through synergy of

hadron - hadron colliders (LHC, (V)HE-LHC?)

lepton - hadron colliders (LHeC ??)

lepton - lepton colliders (LC (**ILC** or CLIC) ?)

Mandate and Goals

LHeC: Following the CDR in 2012: 2014+16: CERN DGs issued Mandate to continue the study:

DG: Mandate to the International Advisory Committee 2015-2018

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.

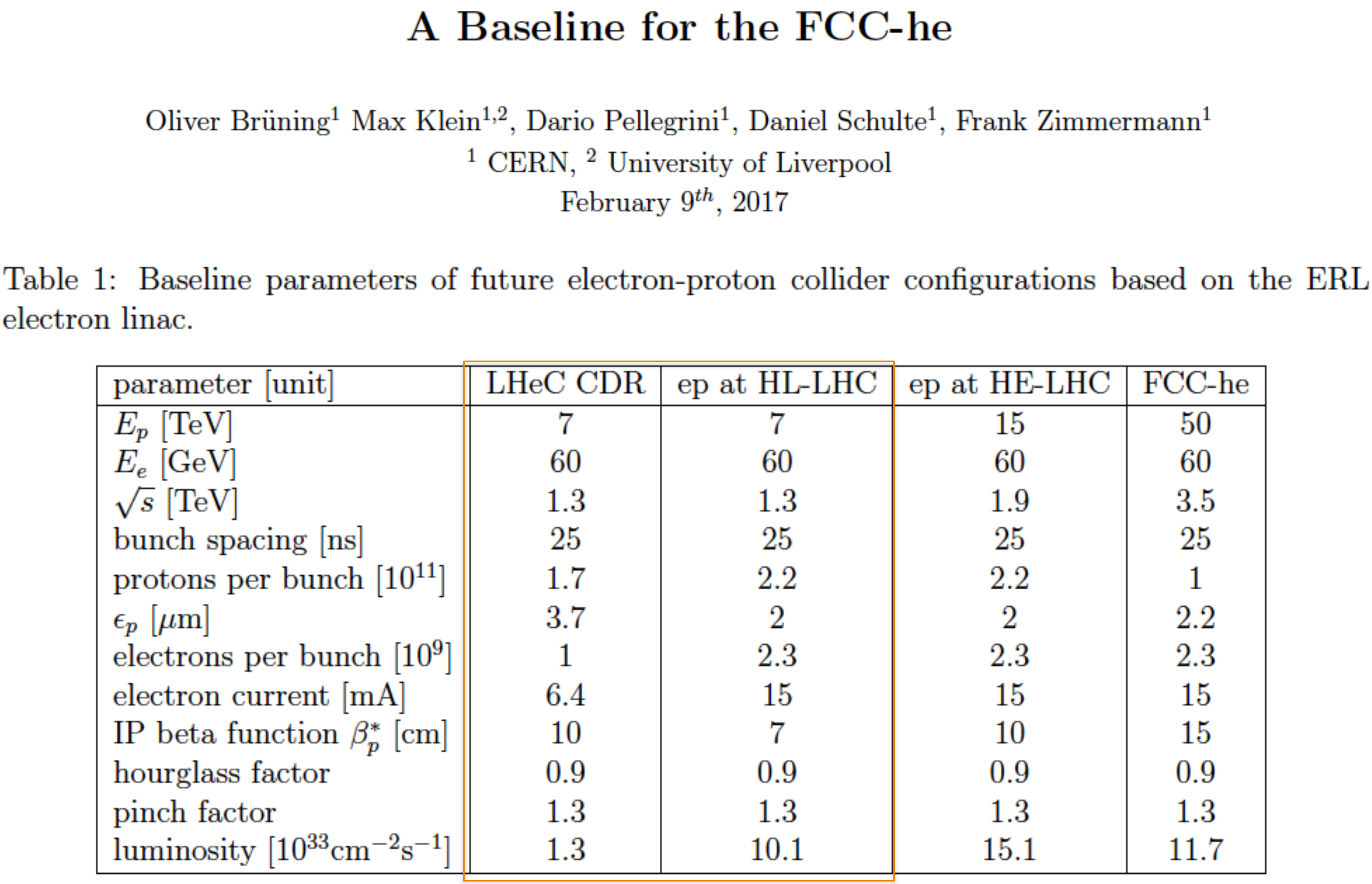
Chair: Herwig Schopper

Two major next goals:

-Design and build an LHeC ERL demonstrator (10mA, 3 turn, 802 MHz)

-Update of the CDR by 2018: LHC physics, 10^{34} lumi, detector and accelerator updates

FCC-eh: Utilize the LHeC design study to describe baseline ep/A option.
Emphasis: 3 TeV physics, IR and Detector: synchronous ep-pp operation.
Open to other configurations and new physics developments (750..)



A Baseline for the FCC-he

Oliver Brüning[1] Max Klein[1,2], Dario Pellegrini[1], Daniel Schulte[1], Frank Zimmermann[1]
[1] CERN, [2] University of Liverpool
February 9th, 2017

Table 1: Baseline parameters of future electron-proton collider configurations based on the ERL electron linac.

parameter [unit]	LHeC CDR	ep at HL-LHC	ep at HE-LHC	FCC-he
E_p [TeV]	7	7	15	50
E_e [GeV]	60	60	60	60
$\sqrt{s}$ [TeV]	1.3	1.3	1.9	3.5
bunch spacing [ns]	25	25	25	25
protons per bunch [10^{11}]	1.7	2.2	2.2	1
ϵ_p [μm]	3.7	2	2	2.2
electrons per bunch [10^9]	1	2.3	2.3	2.3
electron current [mA]	6.4	15	15	15
IP beta function β_p^* [cm]	10	7	10	15
hourglass factor	0.9	0.9	0.9	0.9
pinch factor	1.3	1.3	1.3	1.3
luminosity [10^{33}cm^{-2}s^{-1}]	1.3	10.1	15.1	11.7

Tentative

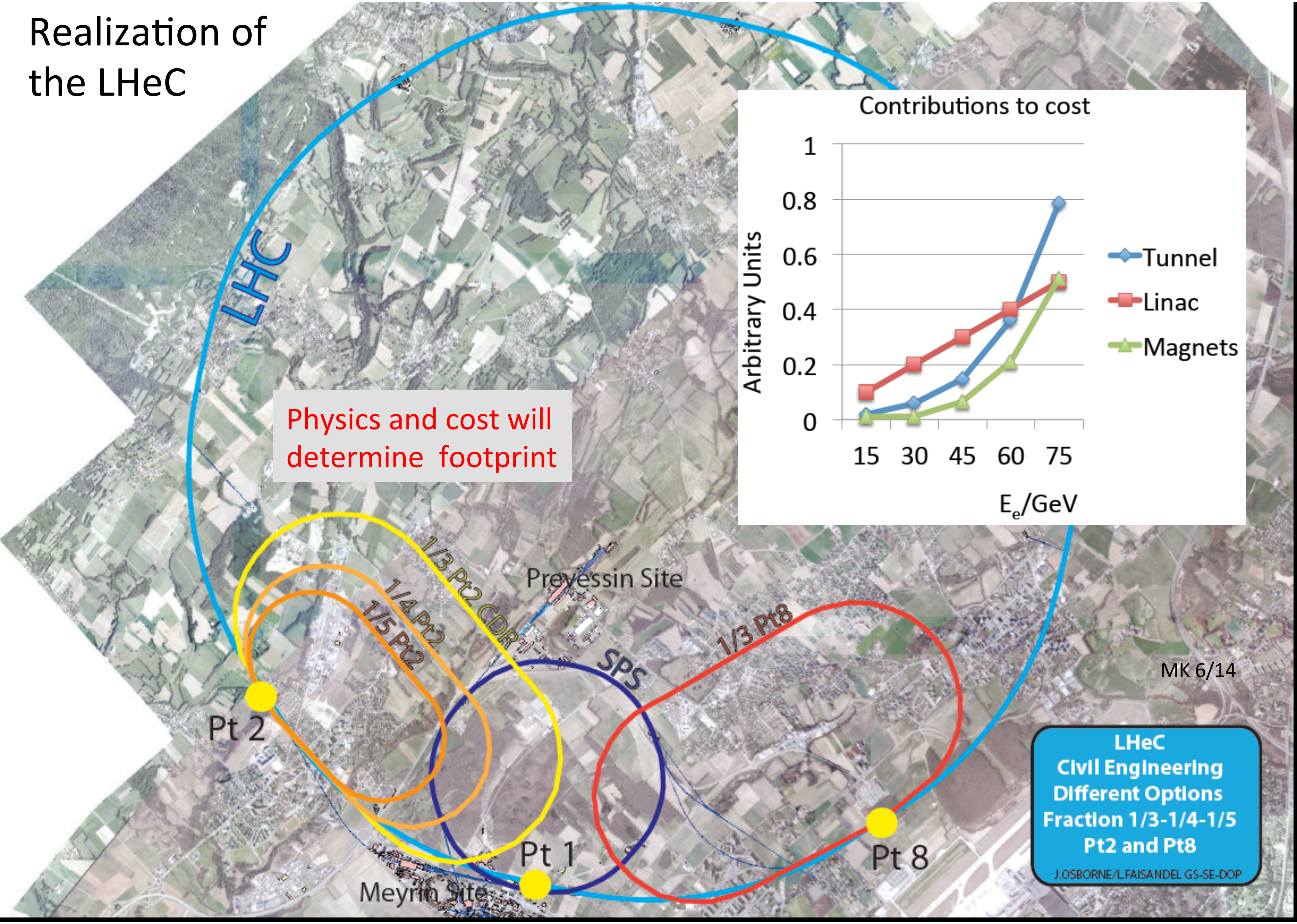
High Energy Electron-Ion Colliders at CERN

F.Zimmermann, January 2017, FCC Physics Week

parameter	FCC-Ae	eA at HE-LHC	LHeC
E_A [TeV]	4100	1025	574
E_e [GeV]	60	60	60
$\sqrt{s}$ [TeV] / nucleon-electron pair	**2.2**	**1.1**	0.8
no. bunches	2215	592	592
ions / bunch [10^8]	1.2	1.2	1.2
$\gamma\varepsilon_A$ [μm]	0.9	1.0	1.5
electrons / bunch [10^9]	11	11	4.7
electron current [mA]	15	15	6.4
IP beta function β_A* [m]	15	10	10
hourglass factor	0.9	0.9	0.9
pinch factor	1.3	1.3	1.3
ion-ring filling factor	0.8	0.8	0.8
e-N luminosity [10^{32} cm^{-2}s^{-1}]	**28**	**9**	1.5

Note: A at injection energy and lower E_e cover EIC range

Realization of the LHeC

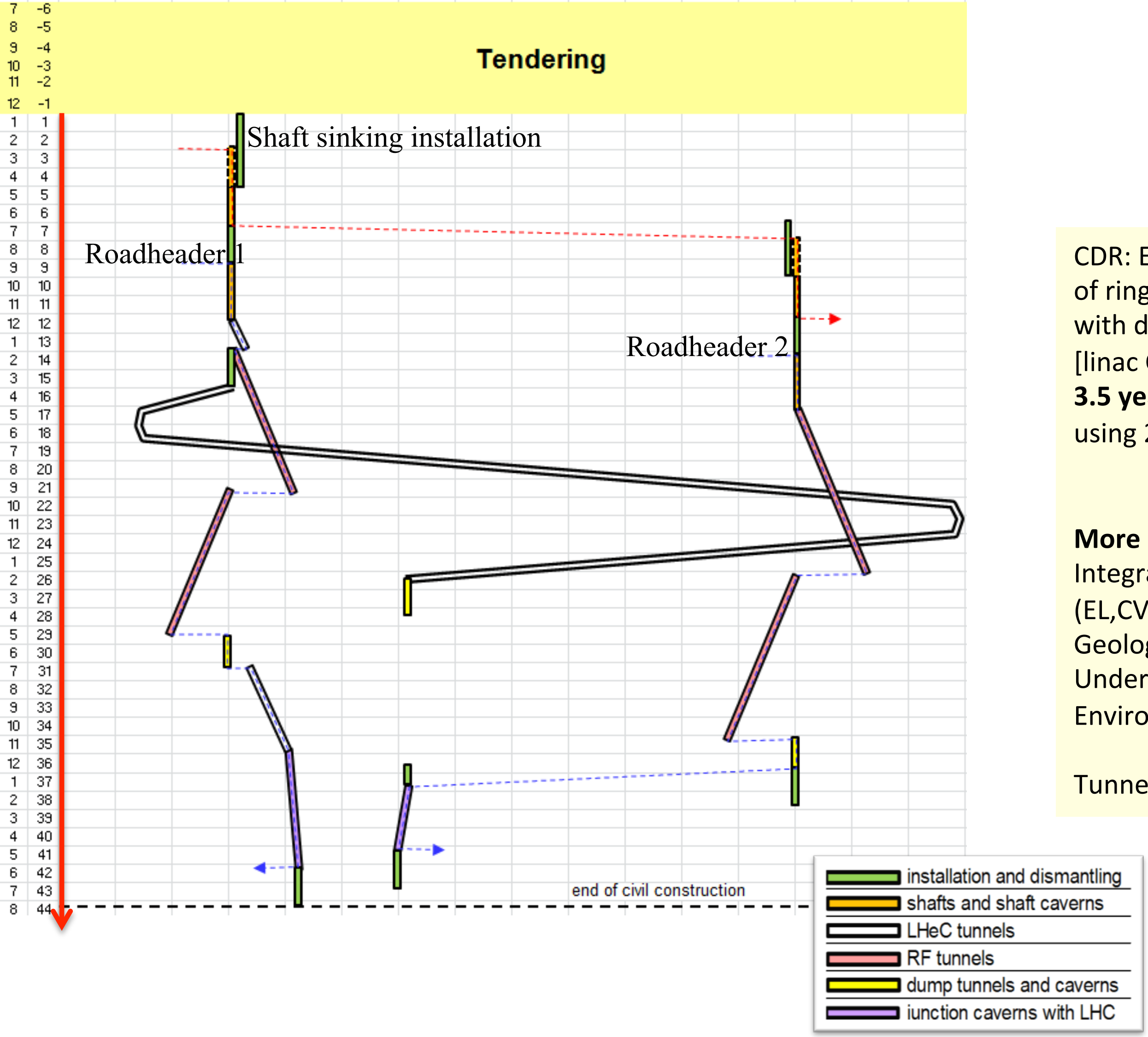


Physics and cost will determine footprint

LHeC
Civil Engineering
Different Options
Fraction 1/3-1/4-1/5
Pt2 and Pt8

J.OSBORNE/L.FAISANDEL GS-SE-DOP

Civil Engineering



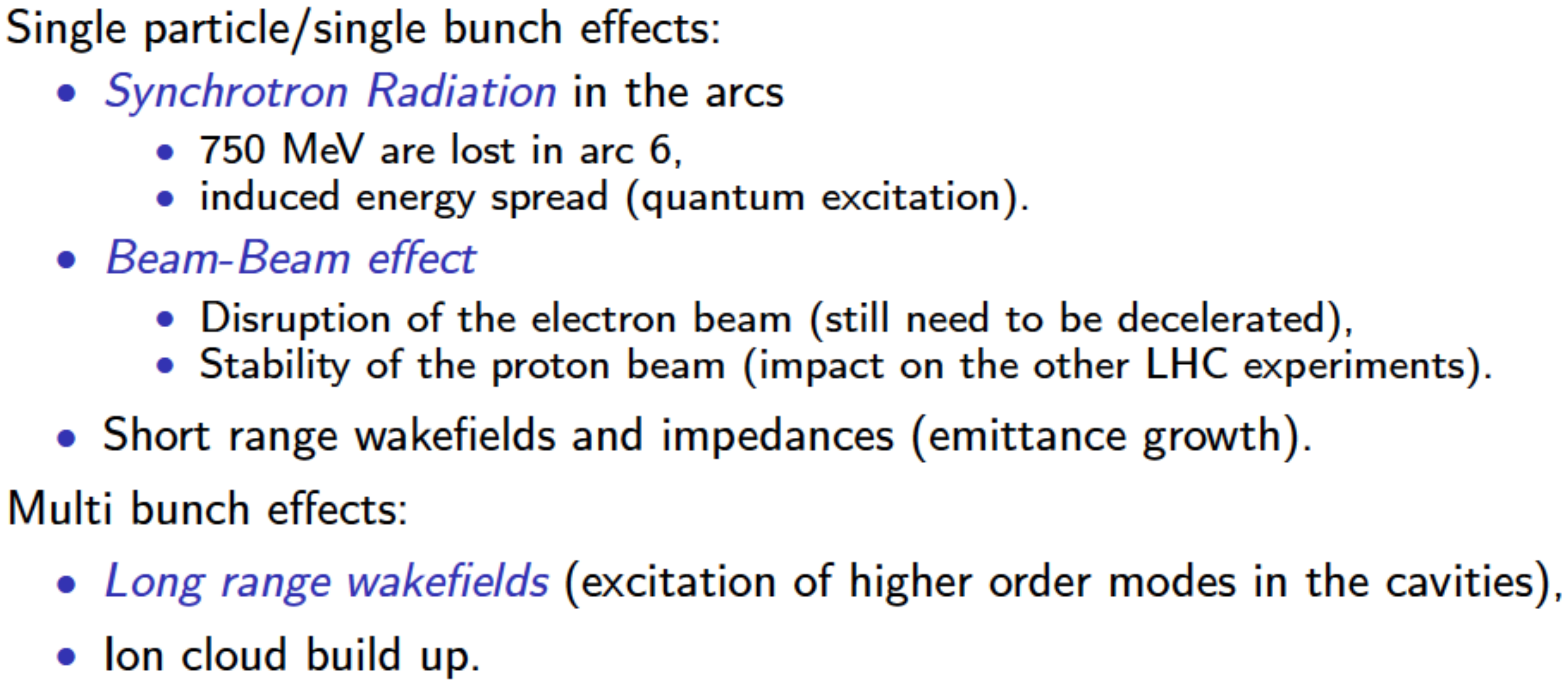
CDR: Evaluation of CE, analysis of ring and linac by Amber Zurich with detailed cost estimate [linac CE: 249,928 kSF..] and time: **3.5 years for underground works** using 2 roadheaders and 1 TBM

More studies needed for
Integration with all services (EL,CV, transport, survey etc).
Geology
Understanding vibration risks
Environmental impact assessment

Tunnel connection in IP2

J.Osborne, Chavannes

Beam dynamics studies



Single particle/single bunch effects:

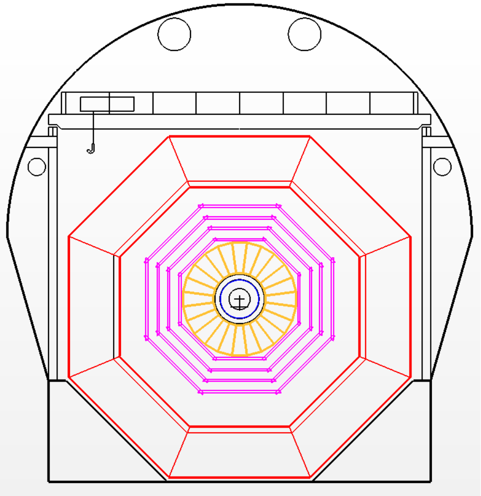
- *Synchrotron Radiation* in the arcs
    - 750 MeV are lost in arc 6,
    - induced energy spread (quantum excitation).
- *Beam-Beam effect*
    - Disruption of the electron beam (still need to be decelerated),
    - Stability of the proton beam (impact on the other LHC experiments).
- Short range wakefields and impedances (emittance growth).

Multi bunch effects:

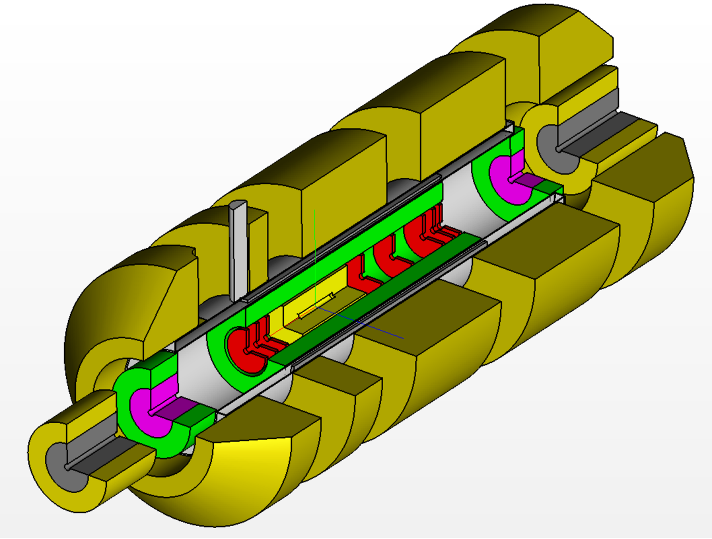
- *Long range wakefields* (excitation of higher order modes in the cavities),
- Ion cloud build up.

cf Dario Pellegrini: Talk in August 2016
Accelerators for QCD, Thessaloniki

Installation Study

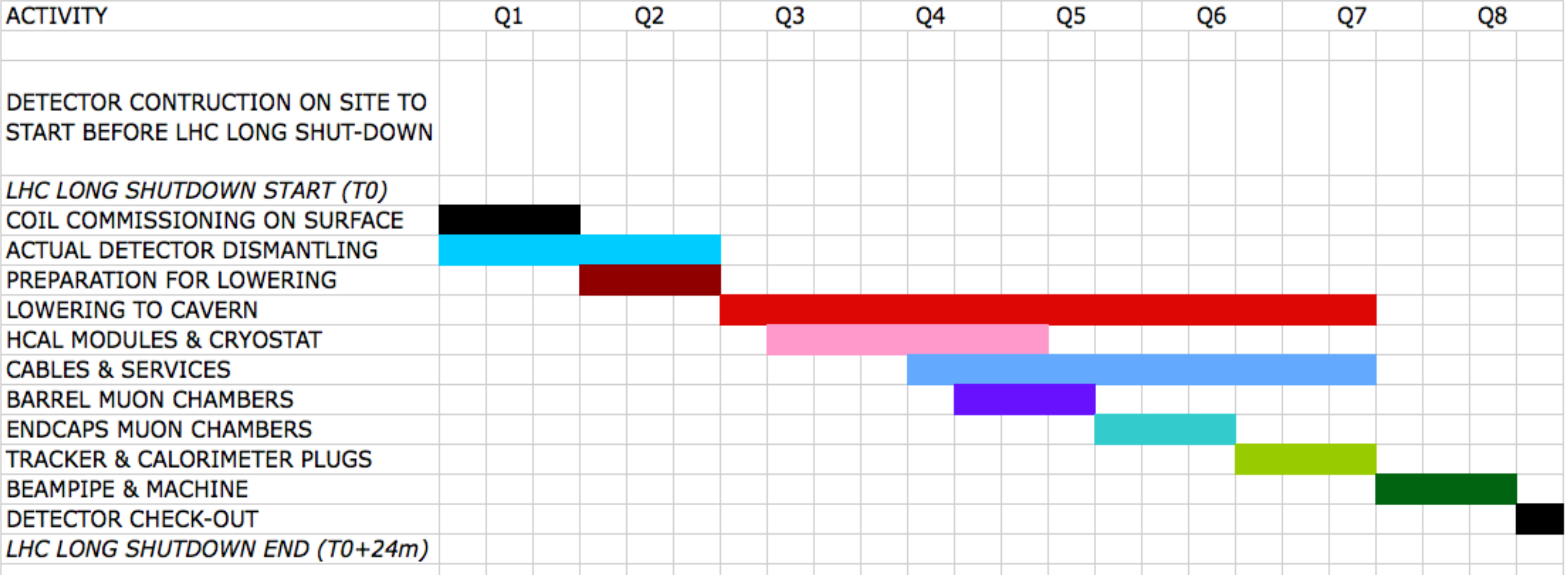


Detector fits in L3 magnet support



Modular structure

LHeC INSTALLATION SCHEDULE



ACTIVITY	Q1			Q2			Q3			Q4			Q5			Q6			Q7			Q8		
DETECTOR CONTRUCTION ON SITE TO START BEFORE LHC LONG SHUT-DOWN																								
LHC LONG SHUTDOWN START (T0)																								
COIL COMMISSIONING ON SURFACE	■	■	■																					
ACTUAL DETECTOR DISMANTLING	■	■	■	■	■	■																		
PREPARATION FOR LOWERING				■	■	■																		
LOWERING TO CAVERN							■	■	■	■	■	■	■	■	■	■	■	■	■	■				
HCAL MODULES & CRYOSTAT								■	■	■	■	■	■											
CABLES & SERVICES											■	■	■	■	■	■	■	■	■	■				
BARREL MUON CHAMBERS												■	■	■										
ENDCAPS MUON CHAMBERS															■	■	■							
TRACKER & CALORIMETER PLUGS																		■	■	■				
BEAMPIPE & MACHINE																					■	■	■	
DETECTOR CHECK-OUT																								■
LHC LONG SHUTDOWN END (T0+24m)																								

Electron-Hadron Scattering at the Energy Frontier – A Higgs Physics Facility Resolving the Substructure of Matter

Draft Table of Contents (9. June 2016)

1. Introduction: The LHC, Modern Particle Physics and the Rôle of ep/eA
2. Physics: QCD/PDFs, Higgs, top, BSM, small x, eA at the LHeC; key items at 1.9/3.4 TeV
3. ERL electron beam: Design, Components, Injector, Dump, Civil Engineering ..
4. LHeC Performance: Collider Parameters, Luminosity, Joint Operation, Infrastructure..
5. Detector: Machine Interface (IR), Design and Performance, Components, Software
6. Installation of the Machine and Detector
7. Summary

Appendix:

- Status of the LHeC Demonstrator and ERL Developments
- Cost-Energy Relation and Cost Estimate for LHeC
- Detector Cost Estimate
- Extensions into the HE LHC Phase
- Electron-Hadron Scattering with the FCC (link to FCC CDR)

LHeC CDR update because:

- Lumi * 10
- LHC results
- Technology progress

Open for any participation

Update of the LHeC CDR$^{*)}$ and input to EU Particle and Nuclear Physics Strategy

*) arXiv:1206.2913

Organisation*)

International Advisory Committee

"..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)
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 (STFC)

IAC being renewed by new DG

We lost Guido Altarelli.

Coordination Group

Accelerator+Detector+Physics

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

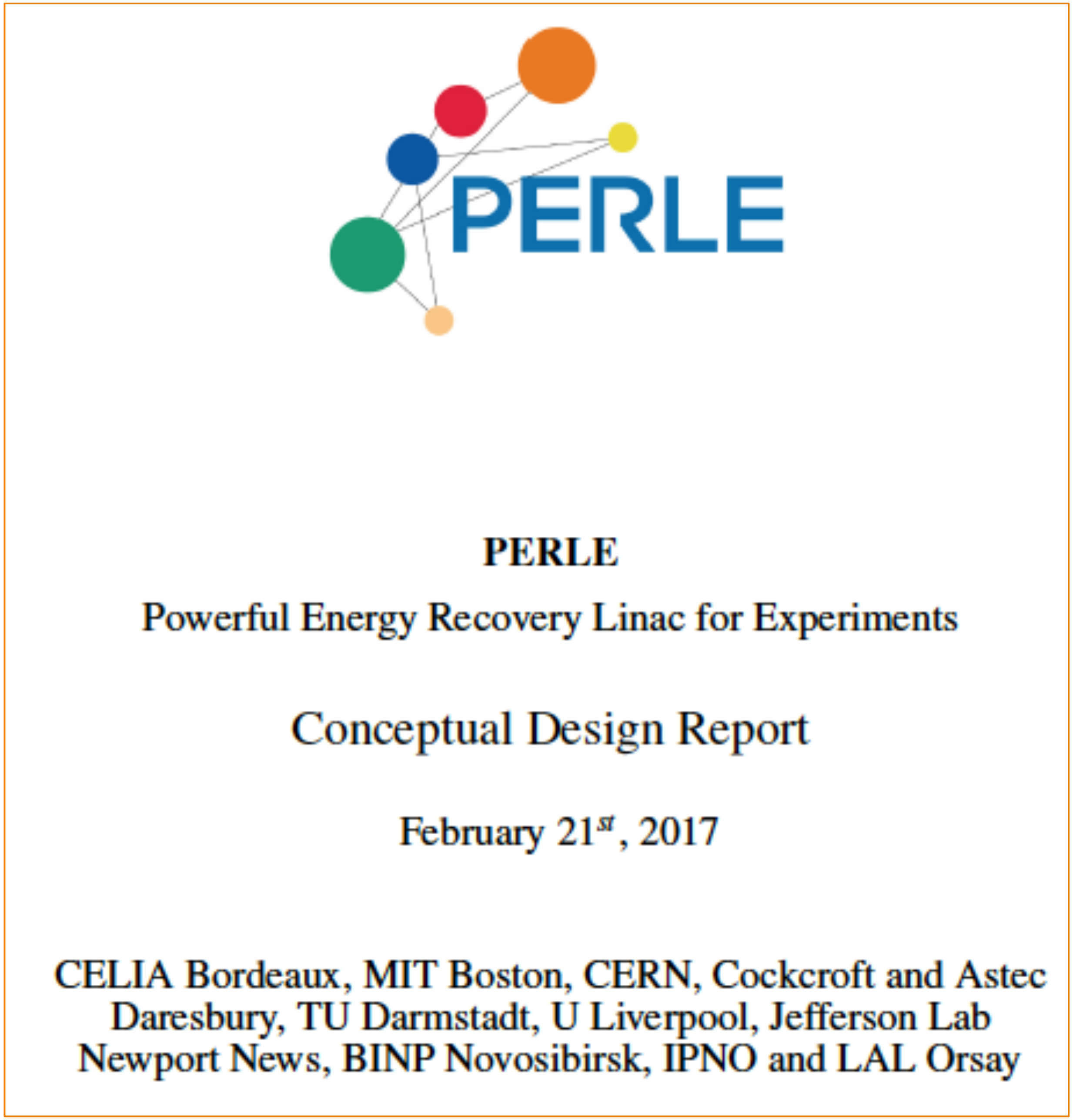
5(11) are members of the FCC coordination team

OB+MK: FCC-eh responsibles
MDO: physics co-convenor

Working Groups

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

*)February 2017



PERLE

PERLE

Powerful Energy Recovery Linac for Experiments

Conceptual Design Report

February 21st, 2017

CELIA Bordeaux, MIT Boston, CERN, Cockcroft and Astec
Daresbury, TU Darmstadt, U Liverpool, Jefferson Lab
Newport News, BINP Novosibirsk, IPNO and LAL Orsay

Ready to go

Comments by

Boris
Frank
Eric
David
Oliver
Erk
Dario
Walid ..

ep Physics with PERLE – proton radius

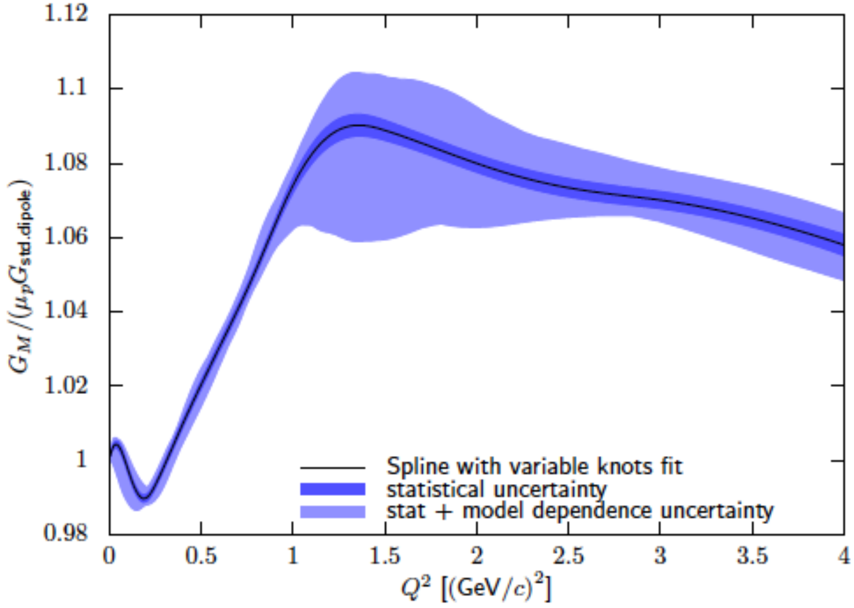
$$Q^2 = \frac{2ME^2(1-\cos\theta)}{M+E(1-\cos\theta)} \qquad E' = \frac{E}{1+\frac{E}{M}(1-\cos\theta)}$$

elastic ep → ep

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{[E(1-\cos\theta)]^2} \cdot \cos^2\frac{\theta}{2} \cdot \frac{1}{1+\frac{E}{M}(1-\cos\theta)} \cdot f(G_E, G_M, \theta)$$

$$f(G_E, G_M, \theta) = \frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2\frac{\theta}{2}$$

Jan Bernauer CDR

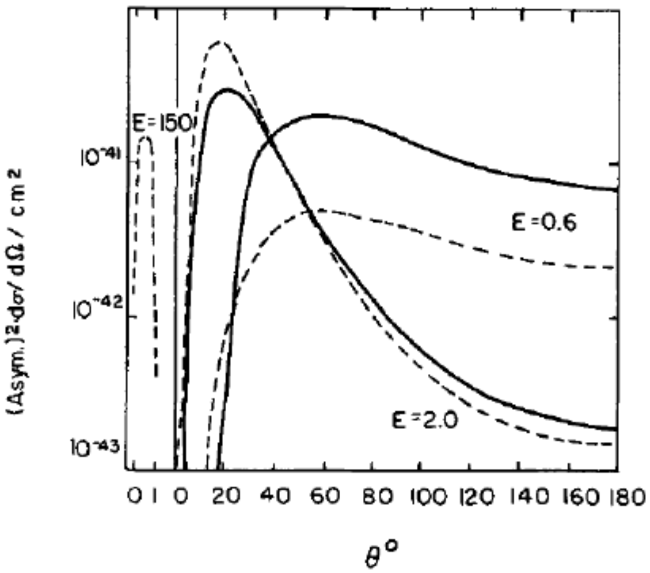


- R_p from Q^2 dependence of G, Q^2=0
- thin target (gas jet), high current
- angular scan with different Ee < 300MeV
- electric and magnetic radius
- h.o. QED corrections

ep Physics with PERLE – $\sin^2\Theta_W$

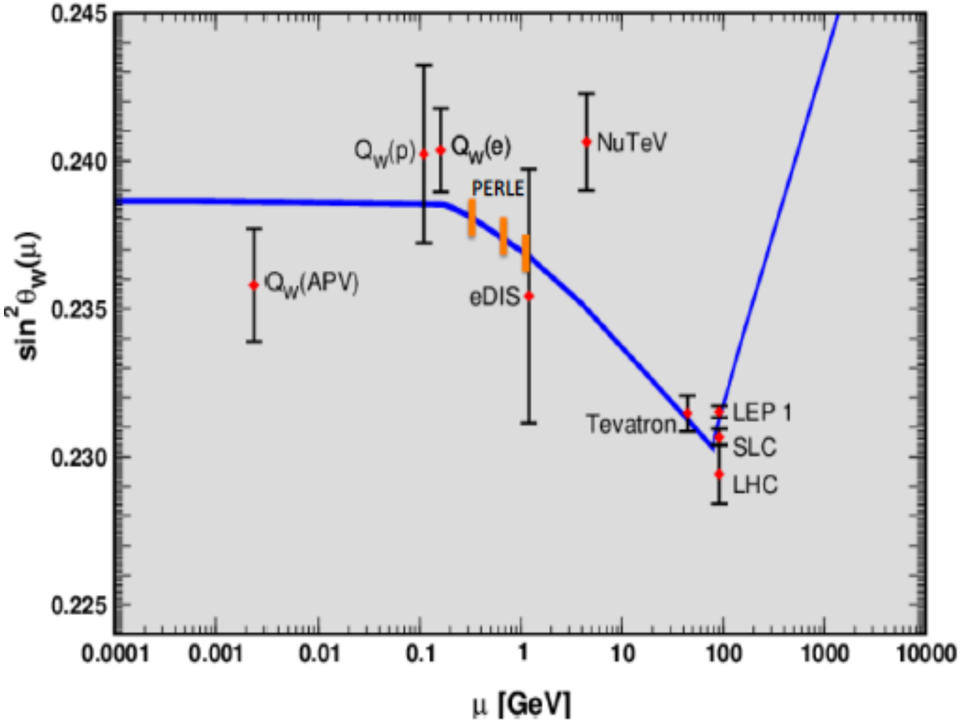
Polarised, elastic ep → ep

$$A^-(P,P') = \frac{\sigma(P)-\sigma(P')}{\sigma(P)+\sigma(P')} = -\kappa\frac{P-P'}{2}\cdot(v_eA - a_eV)$$



: Variation of the statistical accuracy represented as asymmetry squared times cross section in cm^2 for two kinds of asymmetry, solid: beam charge conjugation and dashed: polarisation, from [23].

M.K., T Riemann, PhysLett1978

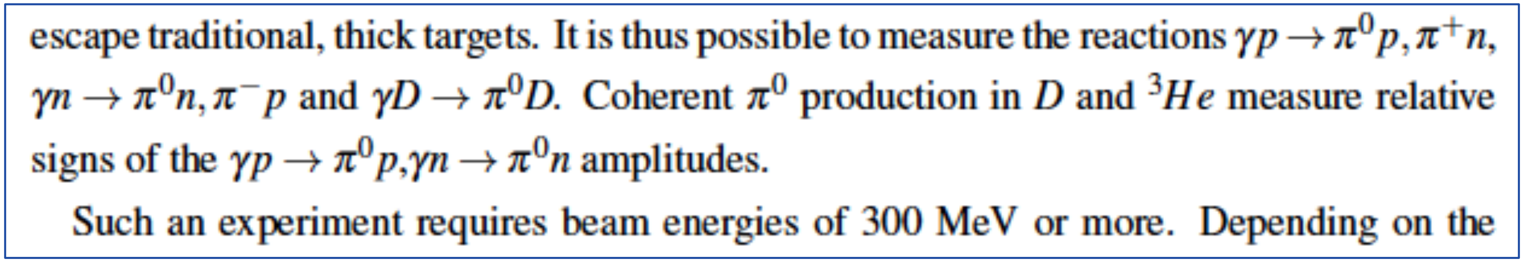


Good acceptance
10mA is 10x the MESA current
Polarisation (and Positrons)

Jlab (Moeller, SOLID)
MESA (beam in 2021)
LHeC 10-1000 GeV

Further ep Physics with PERLE

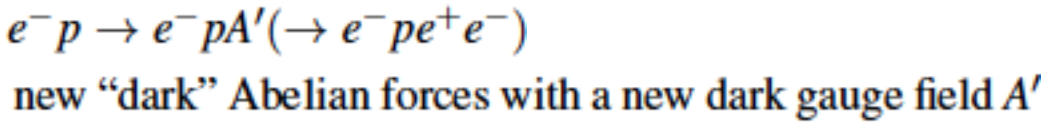
Confinement scale QCD



escape traditional, thick targets. It is thus possible to measure the reactions $\gamma p \to \pi^0 p, \pi^+ n$, $\gamma n \to \pi^0 n, \pi^- p$ and $\gamma D \to \pi^0 D$. Coherent π^0 production in D and ^3He measure relative signs of the $\gamma p \to \pi^0 p, \gamma n \to \pi^0 n$ amplitudes.

Such an experiment requires beam energies of 300 MeV or more. Depending on the

Dark photons



$e^- p \to e^- p A' (\to e^- p e^+ e^-)$

new "dark" Abelian forces with a new dark gauge field A'

Higher luminosity than DarkLight (Jlab)

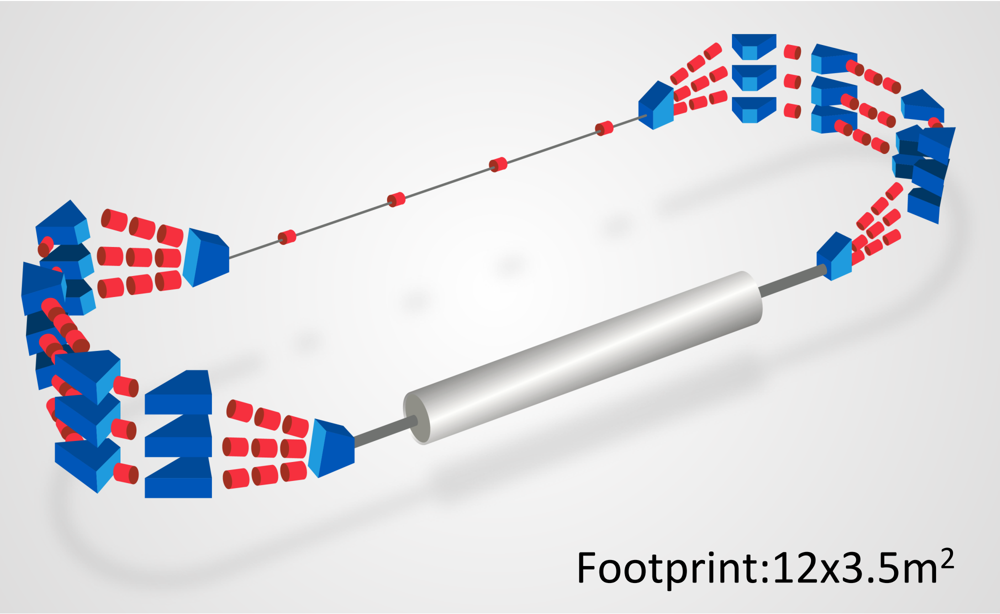
PERLE ("mini")

Demonstration of high current (10mA), multi(3)turn ERL

Test and development of 802MHz SCRF technology

E_e = 200 MeV with cryo module

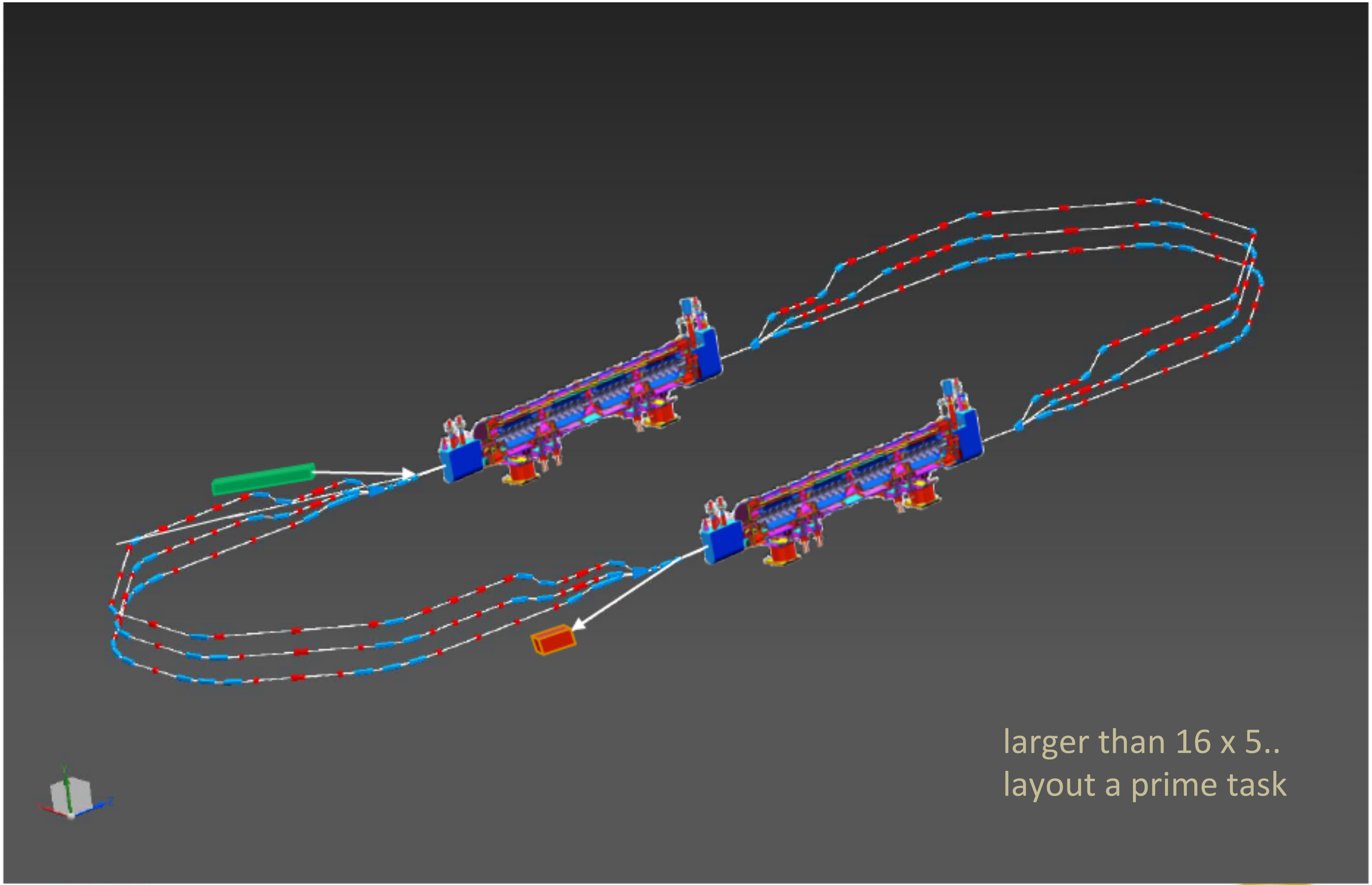
A.Valloni 2/16



Footprint:12x3.5m^2

Parameter	Value
Dipoles per arc Dipole length Max B Field	3/4 50 cm 1.1 T
Quadrupoles per arc Quadrupoles in straight lines	5 4
Dipoles in Spreader/Combiner Quads in Spreader/Combiner	1-3 3
Dipoles for Injection-Extraction	6

PERLE ("centi")
2 modules, 400 MeV
16x5m^2
A.Valloni 6/16



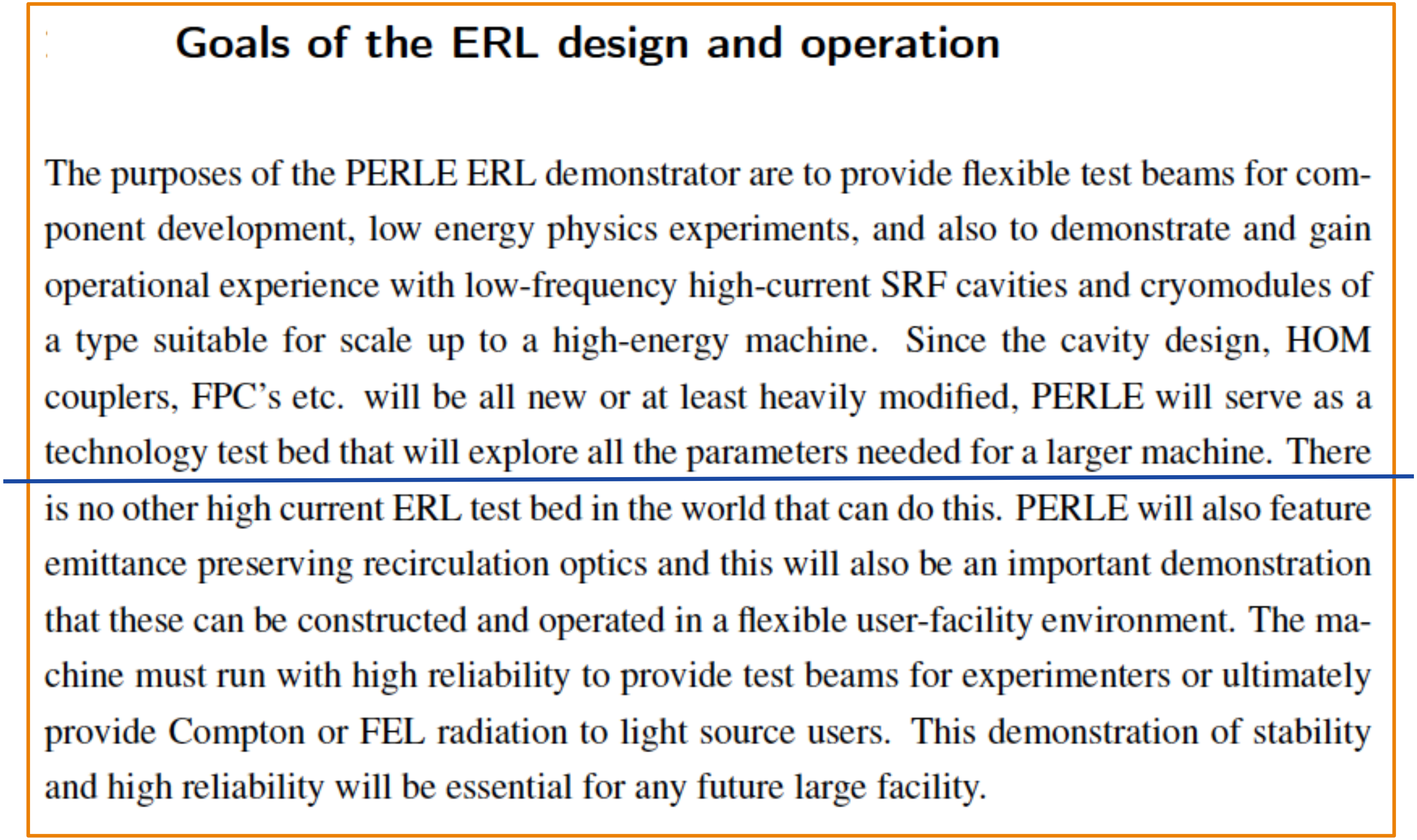
larger than 16 x 5..
layout a prime task

Plan for how to proceed to TDR - *draft*

Achille Stocchi, Walid Kaabi, Sebastien Bousson, Erk Jensen(part time), Max Klein 10/11.10.16

1. Configuration: cPERLE with initially one cryomodule, 2nd optional, termed PERLE [at Orsay]
2. Technical Design Report in International Collaboration, **open to participation**, until 10/2017 building an international collaboration AND cooperation (cf e.g. cβ)
3. Hardware for TDR: a first 802 MHz 5-cell cavity (Bob: May 17), a magnet prototype tested
4. Contributions to TDR (and possibly beyond) currently/tentatively envisaged:
   - Source
   - Injector
   - 4 (8) Cavities
   - 1 (2) cryomodule
   - Magnets
   - Lattice design
   - Dump
   - Diagnostics
   - Cryogenics and Power
   - Shielding
   - H+LV
   - Goals
5. Optional: physics experiments
6. Regular meetings: December 5+6., February, June (ERL workshop), September

Report to the LHeC Coordination Group in October 2016 – For this meeting to assess + develop



Goals of the ERL design and operation

The purposes of the PERLE ERL demonstrator are to provide flexible test beams for component development, low energy physics experiments, and also to demonstrate and gain operational experience with low-frequency high-current SRF cavities and cryomodules of a type suitable for scale up to a high-energy machine. Since the cavity design, HOM couplers, FPC's etc. will be all new or at least heavily modified, PERLE will serve as a technology test bed that will explore all the parameters needed for a larger machine. There is no other high current ERL test bed in the world that can do this. PERLE will also feature emittance preserving recirculation optics and this will also be an important demonstration that these can be constructed and operated in a flexible user-facility environment. The machine must run with high reliability to provide test beams for experimenters or ultimately provide Compton or FEL radiation to light source users. This demonstration of stability and high reliability will be essential for any future large facility.

CDR

Goals reach further out than to the LHeC **(cf Oliver tomorrow)**
in order to be successful, they need to be clear, not just to us

Thank you