Steps Towards the LHeC

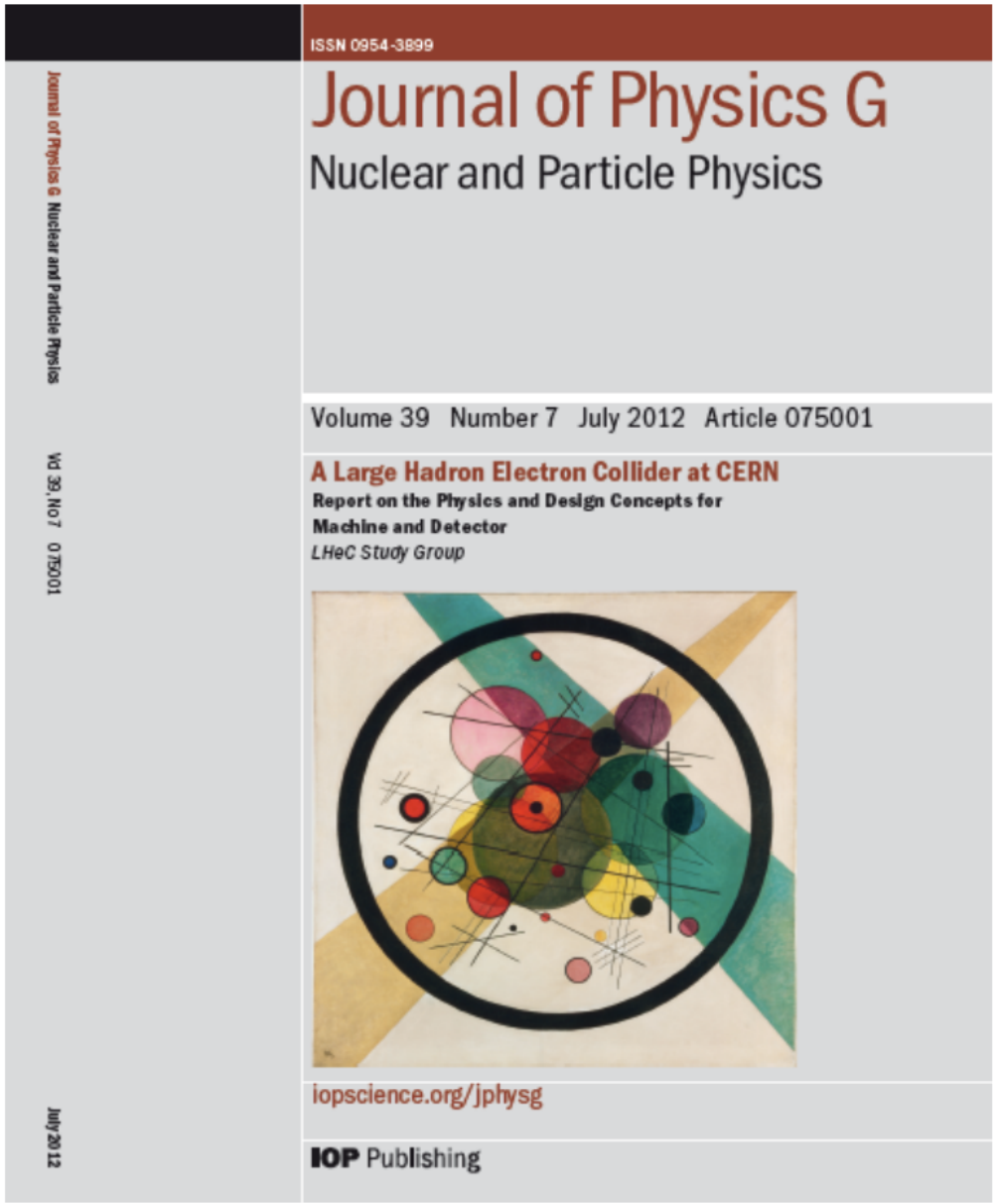
Where do we stand

and the 8 fold way

Wassilij Kandinski. Circles in a Circle. 1923. Philadelphia Museum of Arts : Symbol for gg saturation (2008)

Max Klein
U Liverpool
For the LHeC Coordination Group and Physics Convenors

Contribution to PERLE Collaboration Meeting, Daresbury, UK, 16.1.2018

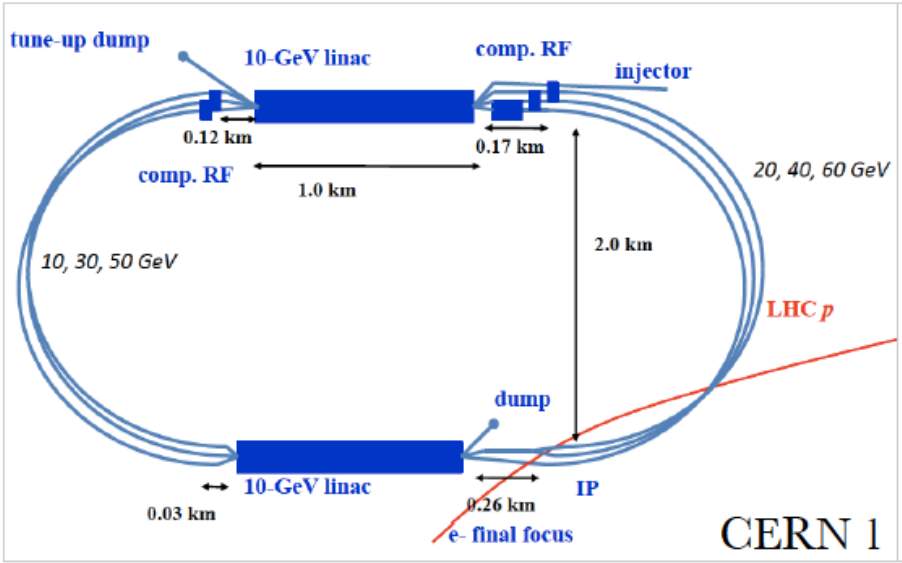


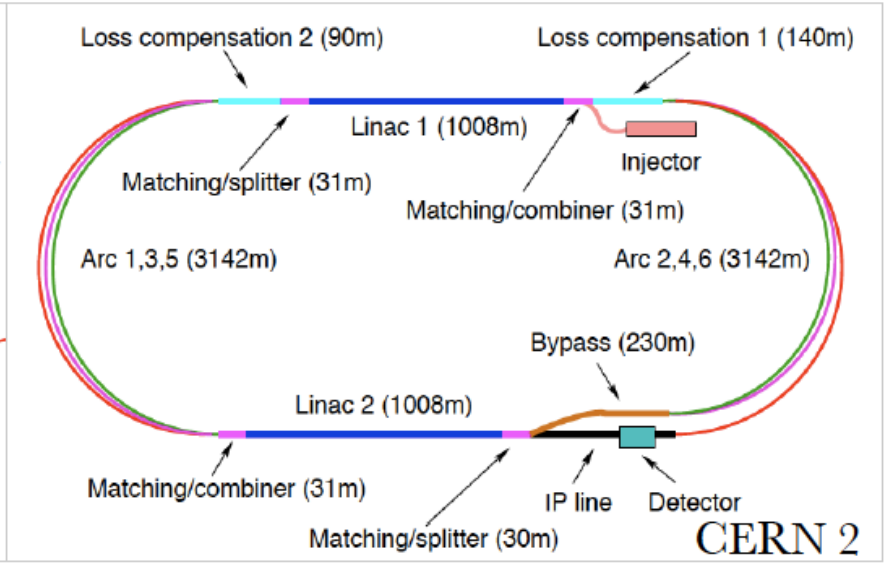
CERN Referees

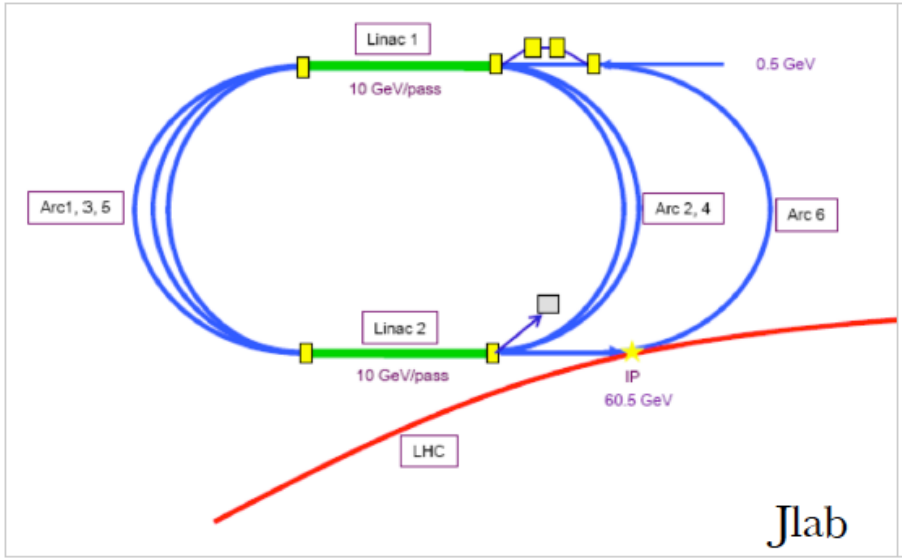
Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
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)

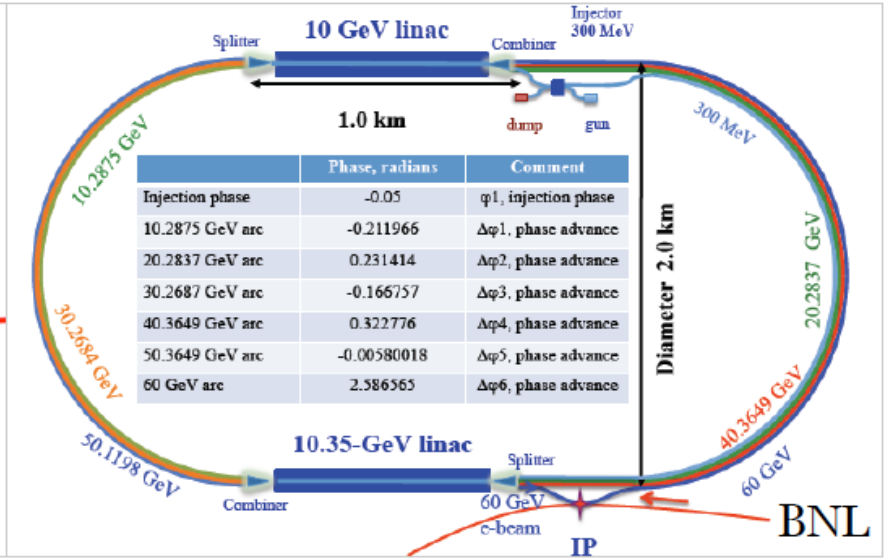
Published 600 pages conceptual design report (CDR) written by 200 authors from 60 Institutes and refereed by 24 world experts on physics, accelerator and detector, which CERN had invited.

60 GeV Energy Recovery Linac





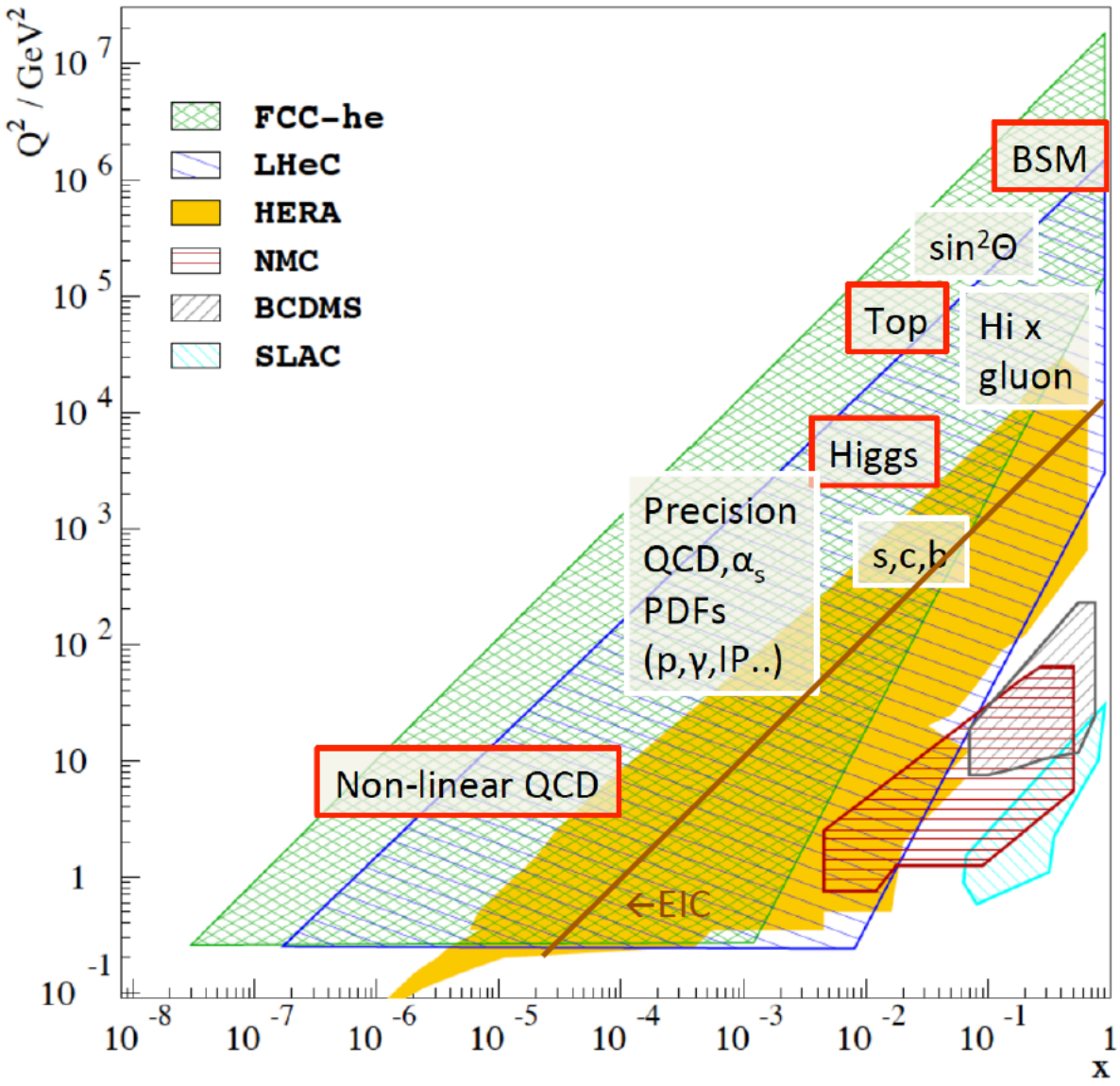




	Phase, radians	Comment
Injection phase	-0.05	φ1, injection phase
10.2875 GeV arc	-0.211966	Δφ1, phase advance
20.2837 GeV arc	0.231414	Δφ2, phase advance
30.2687 GeV arc	-0.166757	Δφ3, phase advance
40.3649 GeV arc	0.322776	Δφ4, phase advance
50.3649 GeV arc	-0.00580018	Δφ5, phase advance
60 GeV arc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

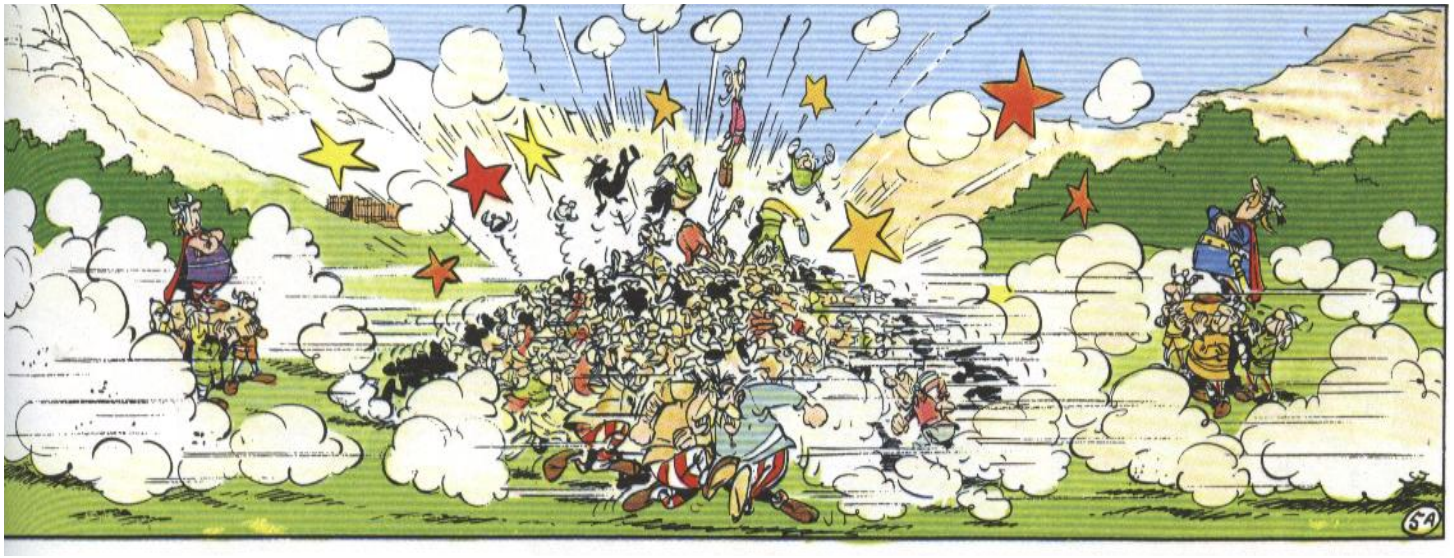
CDR: Default configuration, 60 GeV, 3 passes, 720 MHz, synchronous ep+pp, $L_{ep}=10^{33}$

Pursue **New Physics** of Deep Inelastic Scattering



LHC Physics

Superb LHC performance, reliable detectors and great experimental art



French artist's view on LHC physics – pileup at HL LHC 140-200

- 2000 LHC papers published (ATLAS 100/year). No BSM Physics observed
- Discovery of the Higgs Boson (Mass to W,Z,fermions + portal to BSM??)
- Surprisingly high precision (e.g. ATLAS Wmass to 19 MeV → 0.02%)

- The LHC exploits the large majority of HEP physicists, ATLAS: 1200 PhD's

Motivation

Mandate (ECFA, NuPECC, CERN, PP Community)

HERA's success which is DESY's legacy to a major extent

Technology (ERL − green, high tech accelerator technology, SCRF)

An affordable accelerator for CERN to build, not only design.

Detector (a high tech detector challenge following the lumi upgrade)

New Physics in QCD + BSM, BLHC and ultra high precision (for ep AND pp)

The cleanest high resolution microscope the world can build!

Exploitation of our largest particle physics infrastructure

It can be done (think of 2m SLAC Linac 50 years ago and XFEL at DESY)

… in one word
develop energy frontier collider physics and technology *comme il faut*

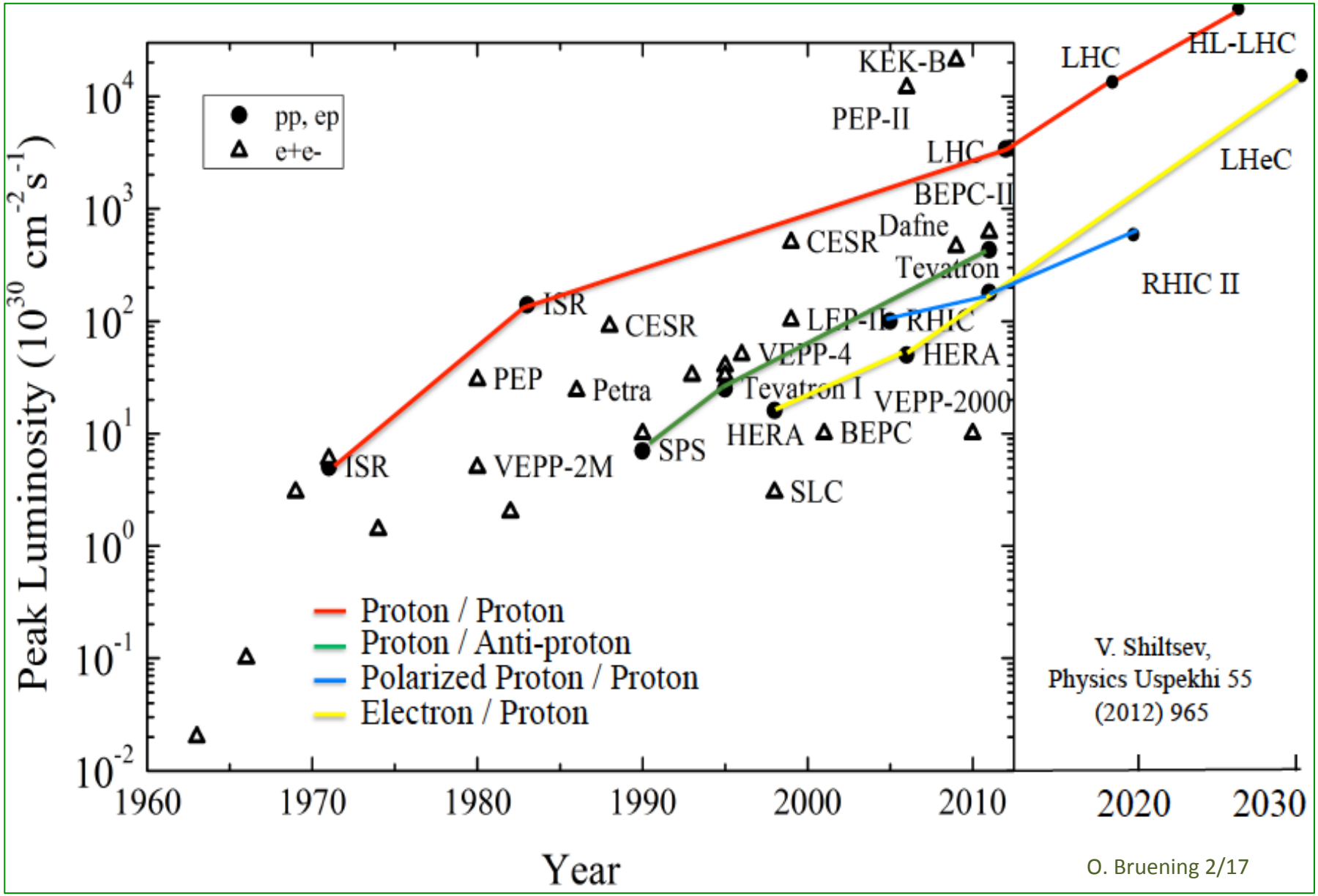
Luminosity for LHeC, HE-LHeC and FCC-ep

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[1,2],
Dario Pellegrini[1], Daniel Schulte[1], Frank Zimmermann[1]
[1] CERN, [2] University of Liverpool
April 6th, 2017

10^{34} in ep, simulated
6 10^{32} in eA for LHeC

Collider Luminosities vs Year (pp and ep)



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

"..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

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(11) are members of the FCC coordination team

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

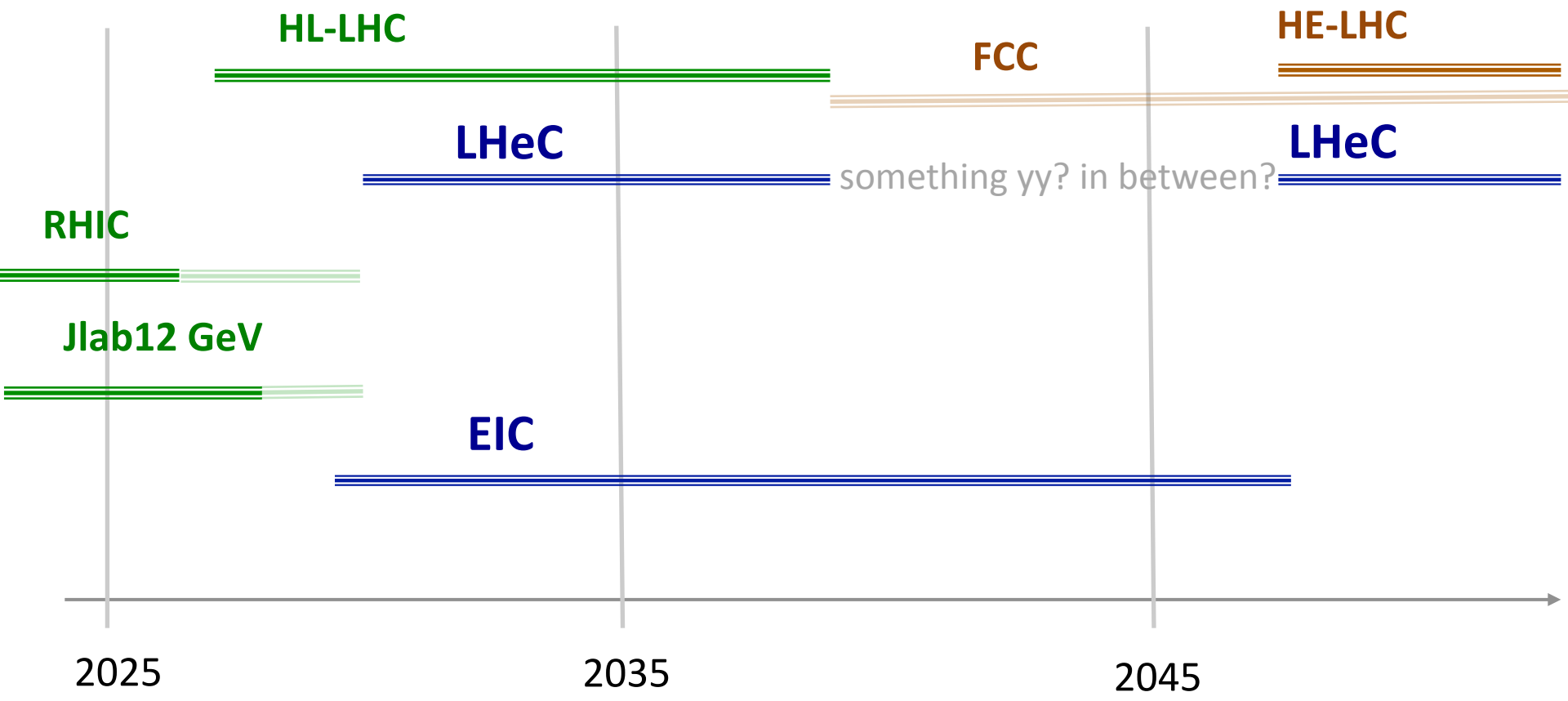
Working Groups

PDFs, QCD
Fred Olness,
Claire Gwenlan
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

*)September 2017

1. New Timeline

Projected Timelines for Future ep/eA Colliders



HERA: Proposal 1984, Data 1992-2007, Publications 1993-2018

VHEep: Plasma e − LHC. **Chinese ep/A** projects: Lanzhou (low E) and CEPC/SPPC

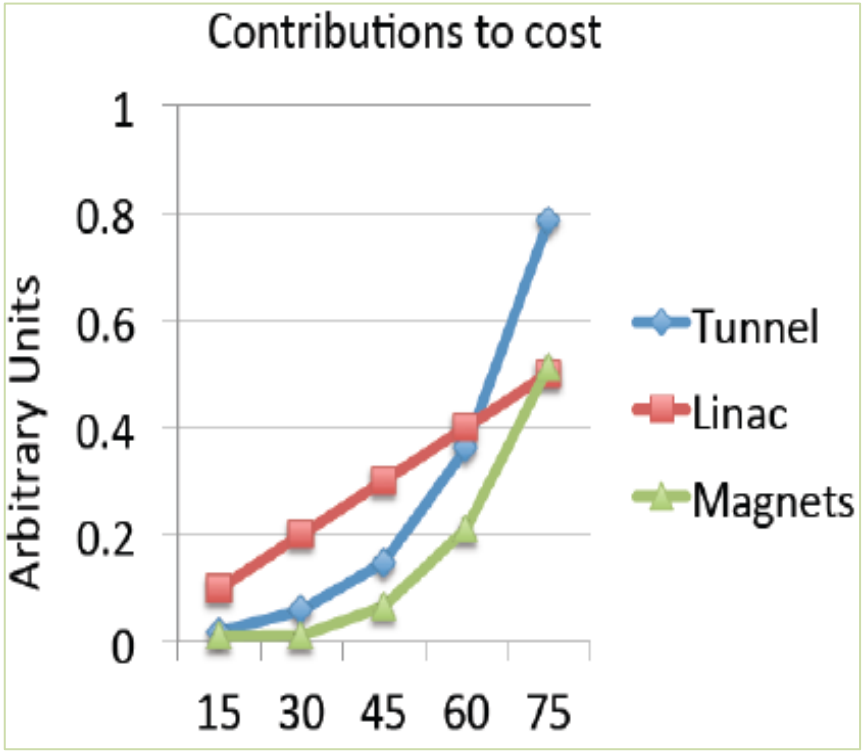
Dislaimer: For discussion and illustration at DIS17 only MK+RY, April 7th, 2017, DIS at Birmingham

2. Cost-Energy-Physics-Configuration Update

We need maximum E_e and 10^{34} and time for the Higgs and BSM programmes

Considerations on the Choice of E_e

Chosen 60 GeV and U(LHeC)=U(LHC)/3 as a supposedly realistic first choice.



MK, F Zimmermann

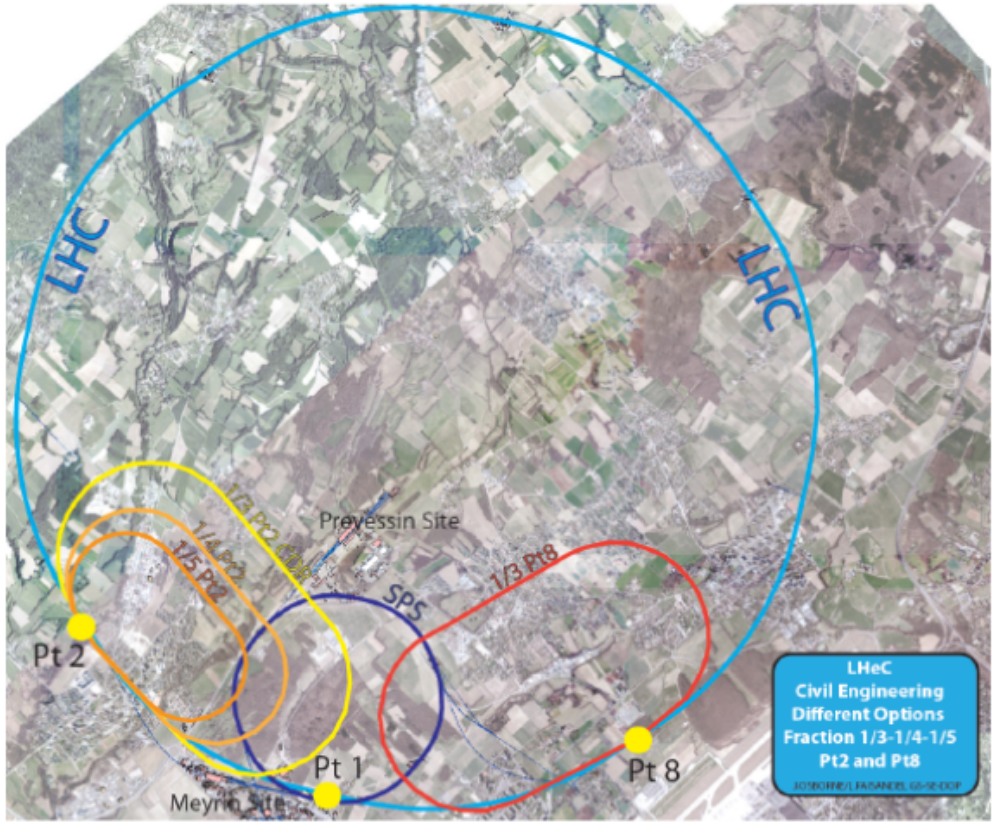
Initial, tentative, rough scaling estimate of basic cost (tunnel, linac (XFEL), magnets
On energy vs physics see MK at September workshop

3. Civil Engineering

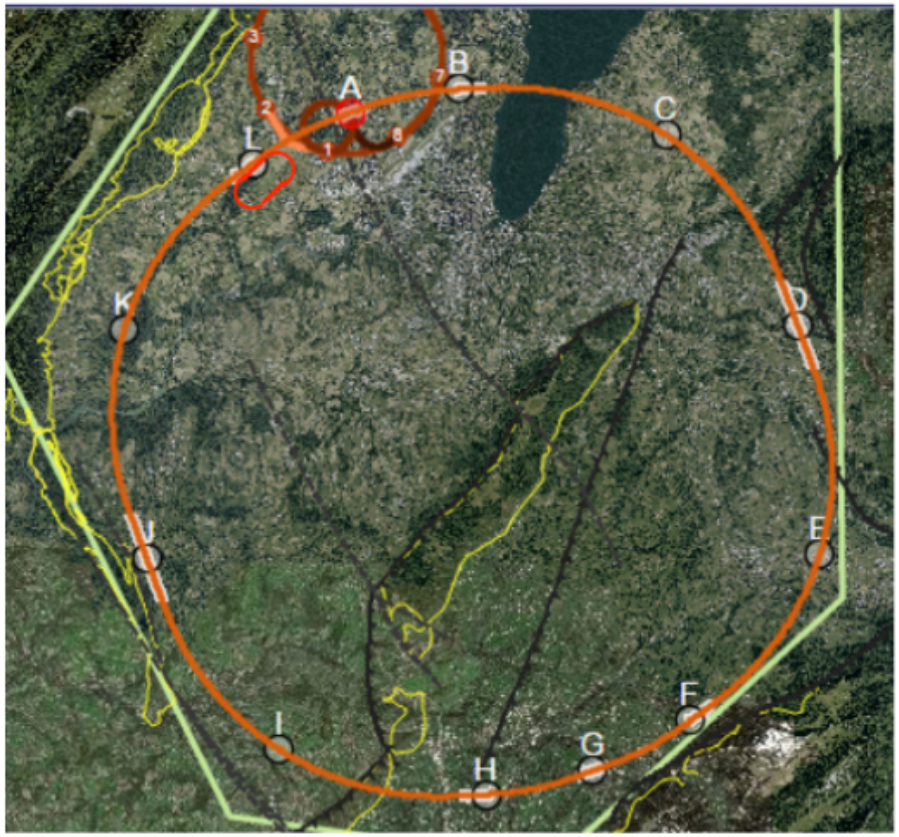
New cost estimate under way. Previously Amberg: fully documented. 4 years

Location + Footprint of the electron ERL

LHC (HL and HE)



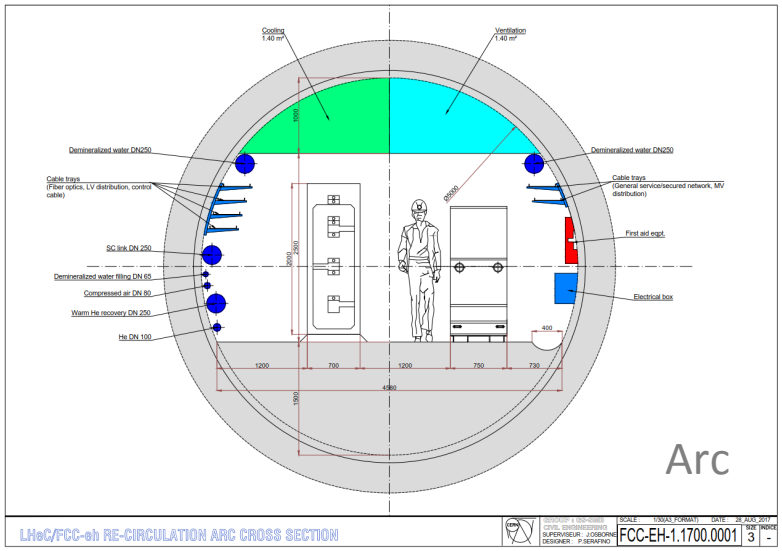
FCC



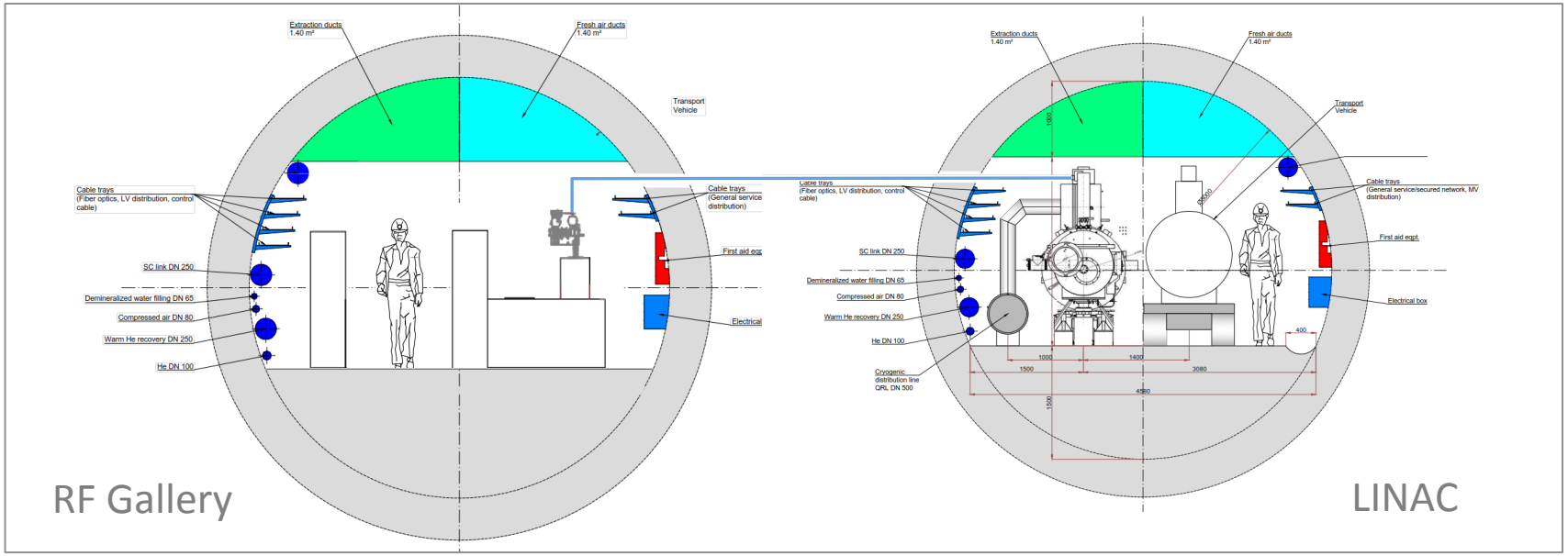
Energy – Cost – Physics – Footprint
are being reinvestigated

A 9km ERL is a small add-on for the FCC
Doubling the energy to 120 GeV hugely increases cost and effort.

Tunnels: Triple Arc and LINACs



DRAFTs
cf Matt Stewart et al. 12.9.

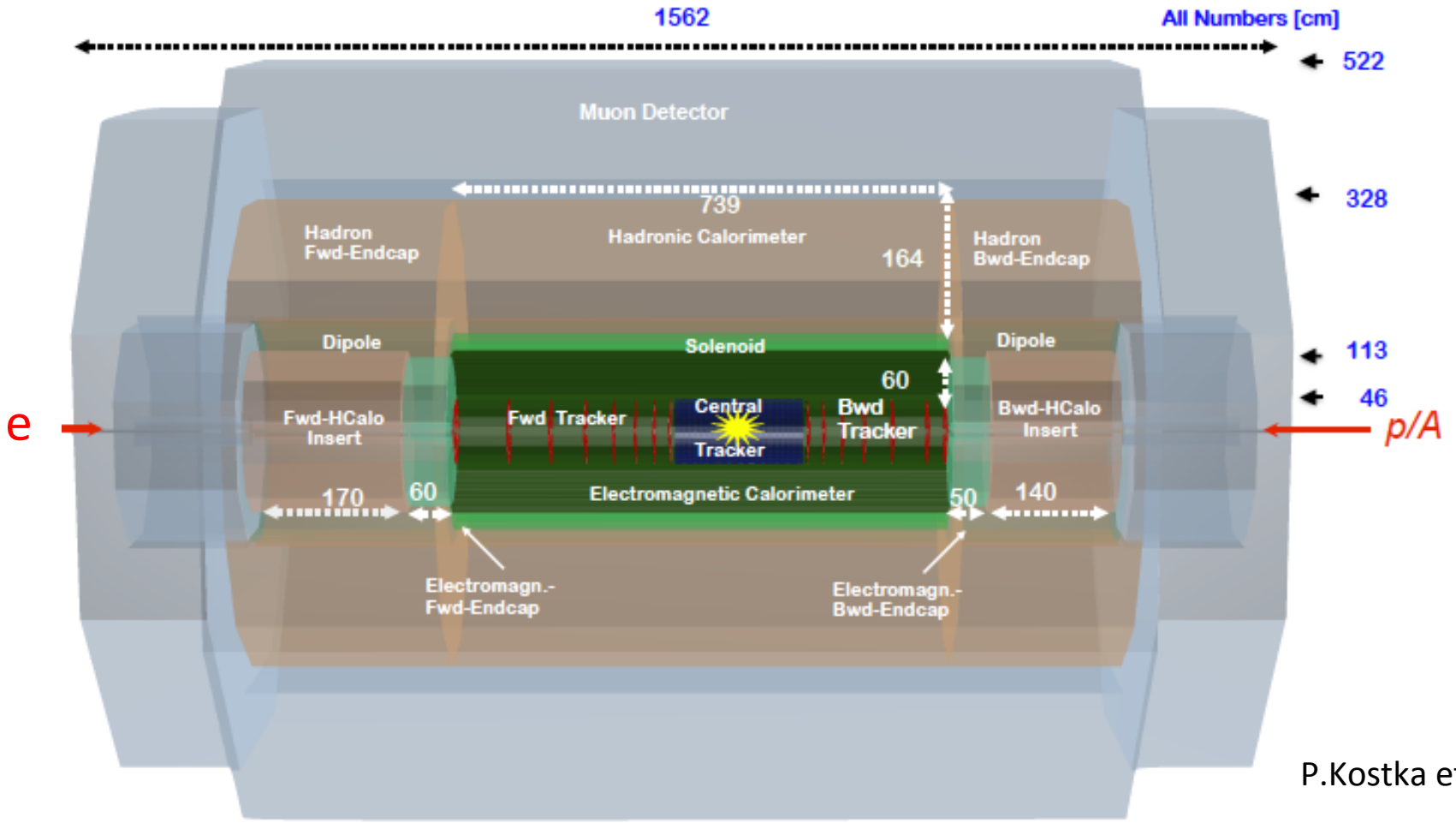


4. Detector Decisions + Flexibility

An invitation to the world community to build a modern collider detector in the 20ties

Installation and ALICE replacement in 2 years, studied (cf A Gaddi)

LHeC Detector for the HE LHC



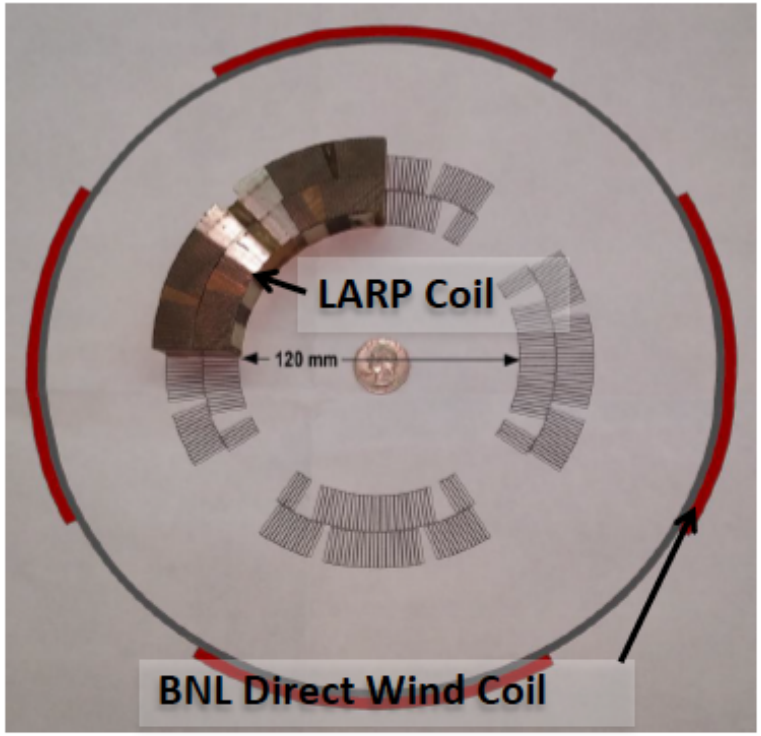
P.Kostka et al

Length x Diameter: LHeC (13.3 x 9 m^2) HE-LHC (15.6 x 10.4) FCCeh (19 x 12)
ATLAS (45 x 25) CMS (21 x 15): [LHeC < CMS, FCC-eh ~ CMS size]
If CERN decides that the HE LHC comes, the LHeC detector should anticipate that

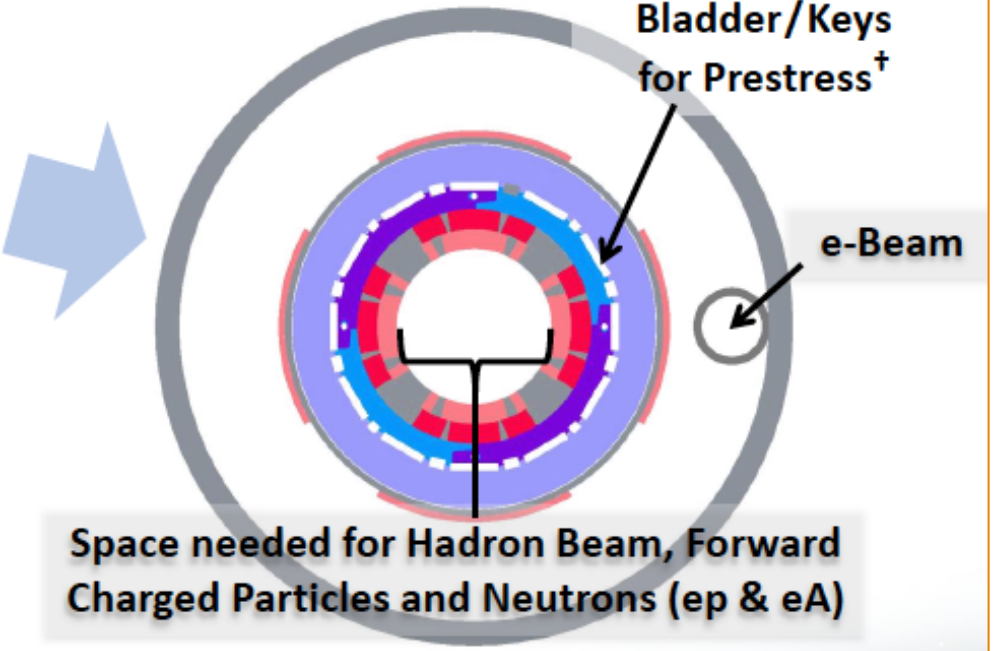
5. Update of the Interaction Region Design

A Fast Track R&D Quadrupole Magnet Concept

R&D Proposal for a "Fast Track" High Field Nb_3Sn Actively Shielded Quadrupole



A compact structure is needed to provide Nb_3Sn coil prestress. Our preliminary modeling results are very encouraging.



Idea is to add active shield around existing Nb_3Sn coil.

†Received funding from "BNL/JLab eRHIC R&D" budget to design, build and test a 15 cm long mechanical model of this compact structure.

Again 9.3 T at coil but few gauss at e-beam!

Brett Parker at September 2017 LHeC Workshop. Replace Q1 of CDR by another design

6. Integration of ep into pp physics (and ions)

Many studies ongoing. Forum: HL-HE Workshop and FCC CDR. Many new papers

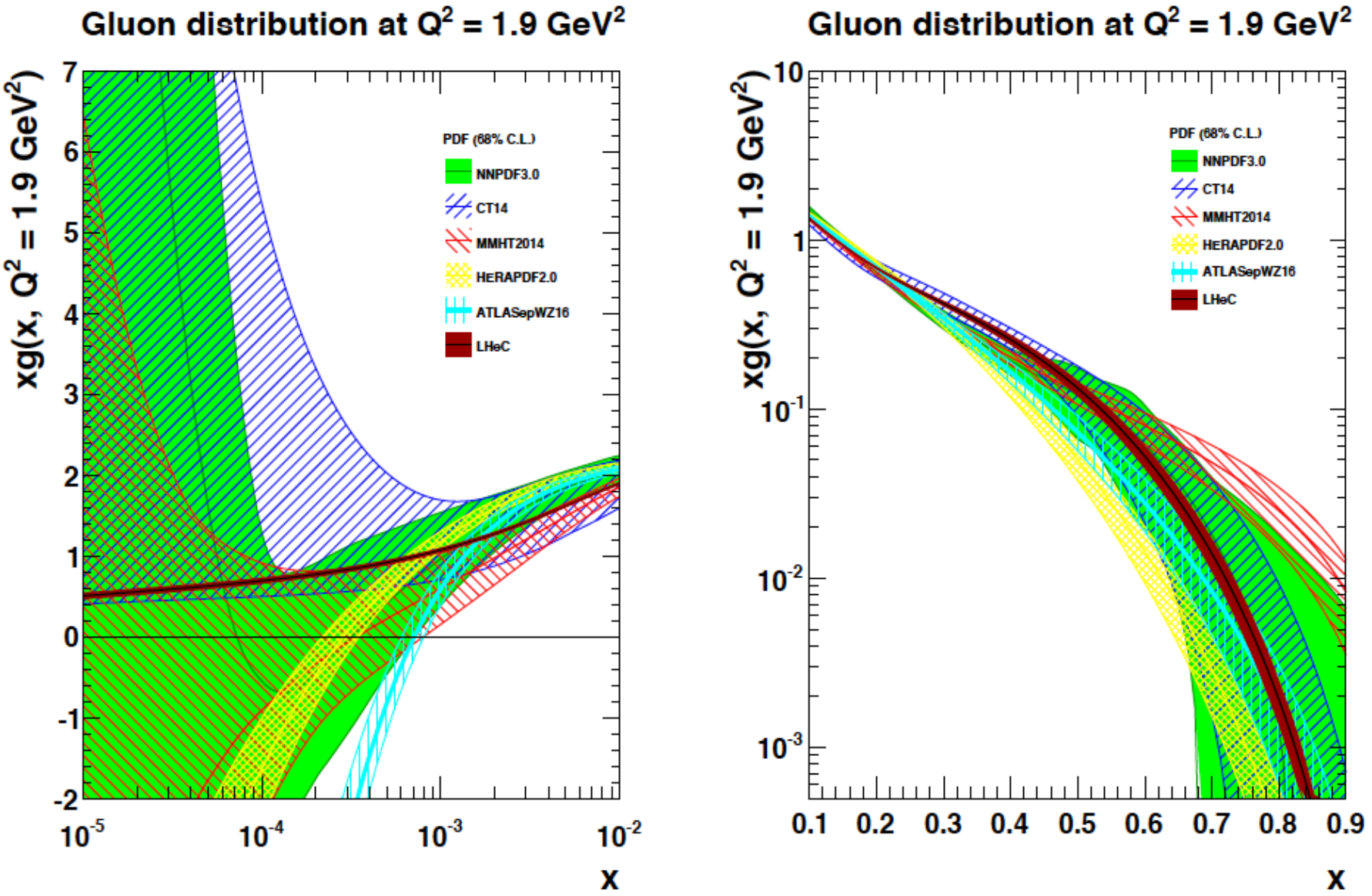
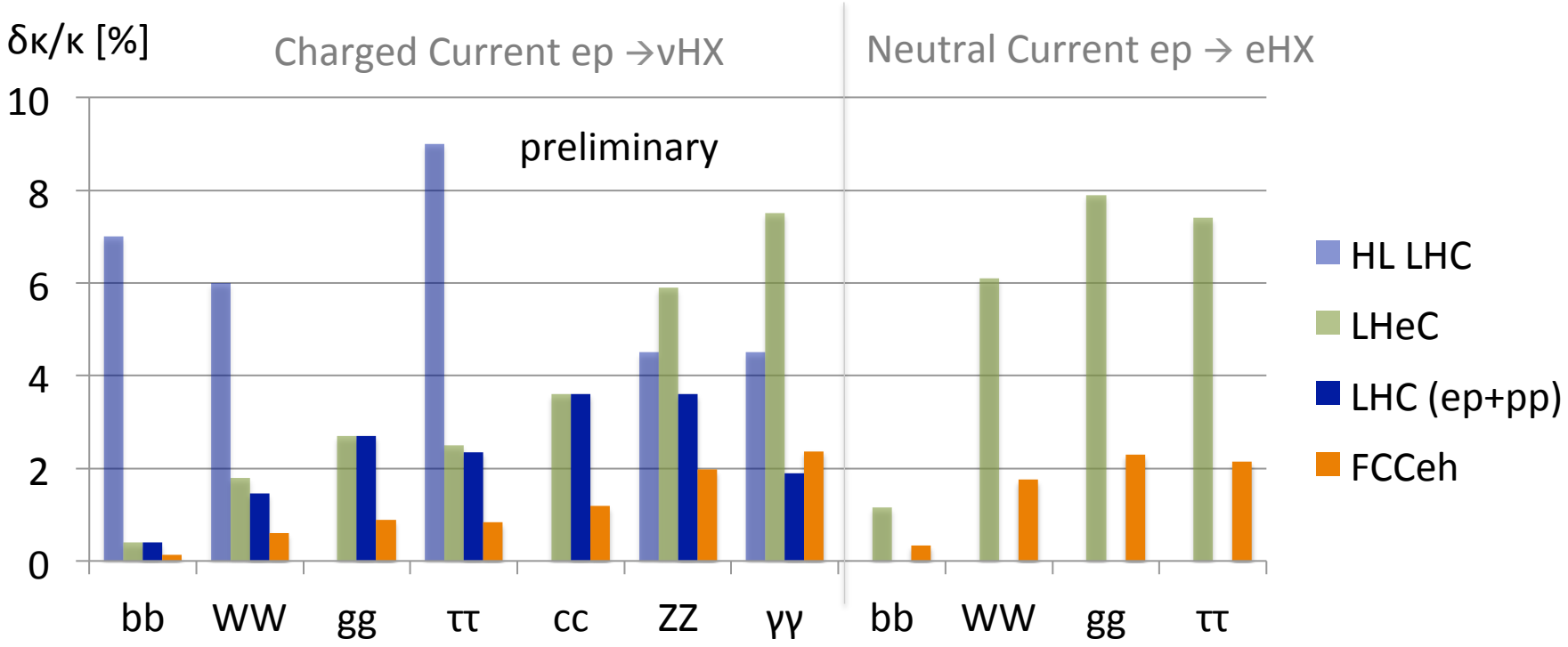


Figure 3: Determination of the gluon momentum distribution in the proton. The expected total experimental uncertainty on xg from the LHeC (dark purple bands) is compared with the most recent global PDF determinations which include the final HERA data, covering for xg a range from $x \simeq 5\ 10^{-4}$ to $x \simeq 0.6$, and much of the LHC data from Run I. Left: xg at small x; Right at large x.

Higgs SM Coupling Prospects



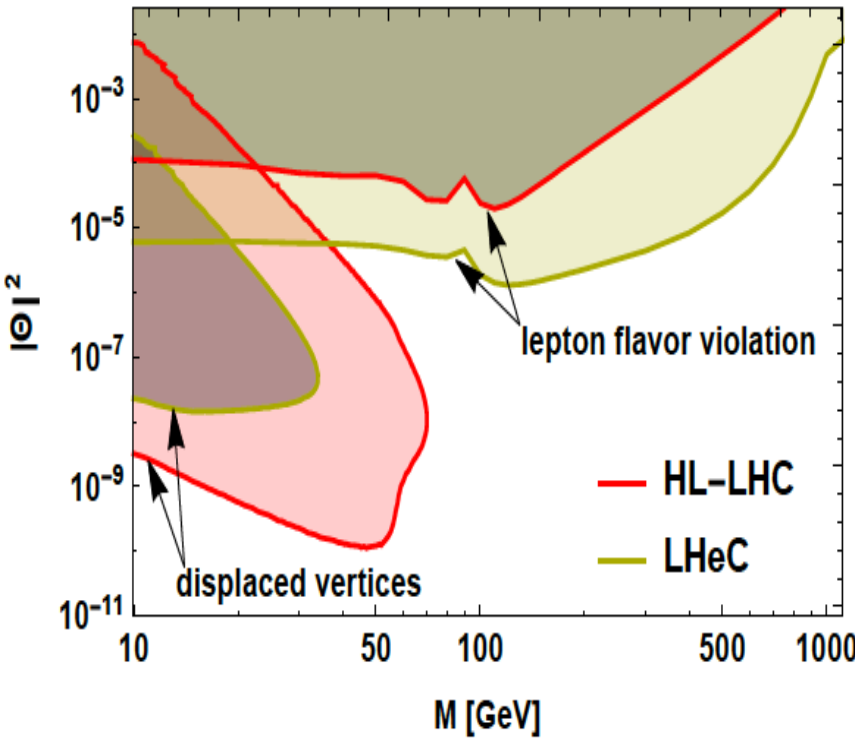
HL LHC: ATLAS-PUB-2014-016 14 TeV 3ab^{-1} – LHC has no gg, no cc, and poor bb, but rare channels as γγ
LHeC: 1ab^{-1}, 60 GeV x 7 TeV - Work in progress. ep also provides precise: xg, α_s and PDFs to N^{3}LO..
LHC (ep+pp): HL LHC with reduced theory uncertainty combined with LHeC
FCCeh: 2ab^{-1}, 60 GeV x 50 TeV - Work in progress. ep also provides precise: xg, α_s and PDFs to N^{3}LO..

Improvements: ATLAS 2014 conservative, no CMS. ep (LHeC/FCCeh) are overconstrained: CC+NC, ratios, sum(br)=1.. → joint coupling determination: especially WW and ZZ should improve

U+M Klein, Contribution to FCC Workshop, 16.1.2018, preliminary

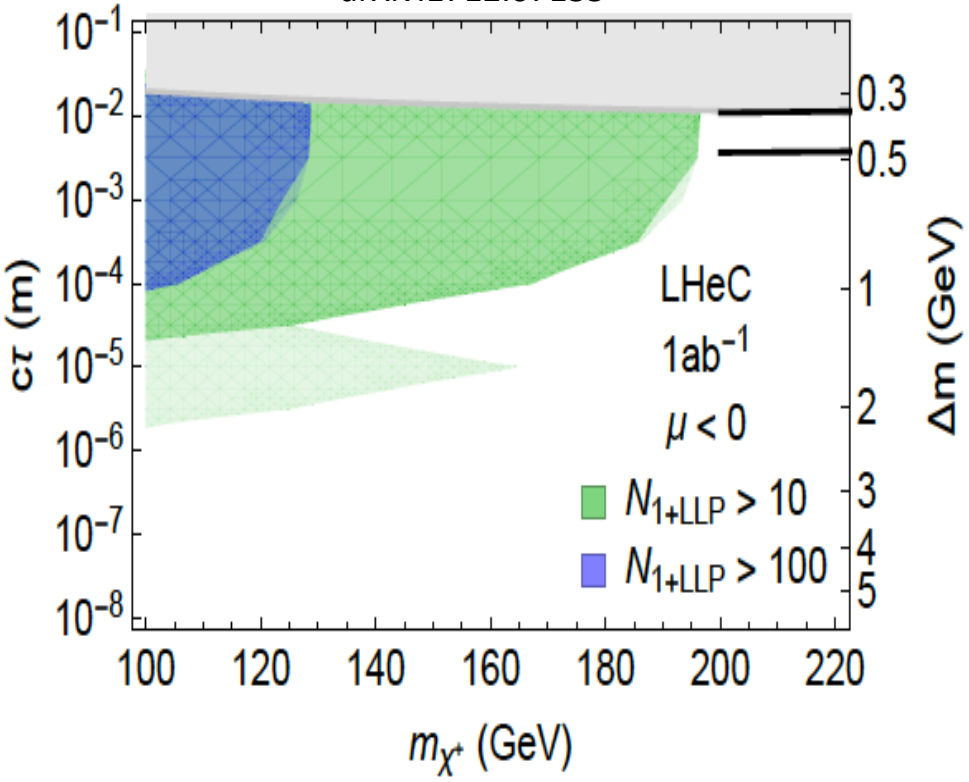
Lots of exciting new papers on BSM in ep

Sterile (heavy) Neutrinos in ep → NX



Search for Higgsino at LHeC

arXiv:1712.07135



This adds significant motivation for the construction of future $e^- p$ colliders. Together with the invaluable proton PDF data, as well as precision measurements of EW parameters, top quark couplings and Higgs couplings, our results make clear that adding a DIS program to a pp collider is necessary to fully exploit its discovery potential for new physics.

7. PERLE

Keep them and many others busy for PERLE

Thank you and many congratulations

TDR by mid 2019 (town meeting of the European PP community)

Technical developments accompanying ERL development (e.g. Jlab's 7 GeV ERL synrad test)

PERLE operational in the early twenties - in time for LHeC in LS4 (2030)

8. Reaching out

- Larger and lasting LHeC/FCCeh/PERLE Workshop in Orsay 27-29.6.18
- 10 pages for EU Strategy Secretariat by fall 2018
- Papers=publications on ALL areas we cover: theory, studies, detector, accelerator, PERLE
- Contributions to Yellow Report on HL-HE LHC Workshop (12/2018)
- Contributions to the FCC CDR Books (eh is part of hh, rightly so)
- Update of the LHeC CDR
- …

Crucial for 2018: Involve and attract new collaborators in support of the LHeC submission

Reach public attention, beyond scientists: funding agencies, interested stable geniuses

Future Deep Inelastic Scattering with the LHeC

Max Klein (University of Liverpool)

Contribution to a Book dedicated to the Memory of Guido Altarelli, December 31, 2017

Abstract

For nearly a decade, Guido Altarelli accompanied the Large Hadron electron Collider project, as invited speaker, referee and member of the International Advisory Committee. This text summarises the status and prospects of the development of the LHeC, with admiration for a one-time scientist and singular leader whom I met first nearly 40 years ago under the sun shining for the "Herceg Novi School" in Kupari, where we both lectured about the beautiful science of Deep Inelastic Scattering and enjoyed life under a yellow moon.

Summary of Physics and Project Status, to be released to arXiv asap.

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]

Expectations

Physics

Strategy

Community

Five Major Themes of Electron-Hadron Physics

at the energy frontier

Cleanest High Resolution Microscope

Joint ep and pp Physics at LHC and FCC

High Precision Higgs Exploration

Discovery Beyond the Standard Model

A Unique Nuclear Physics Facility

CERN has the obligation to utilize its potential fully: the HL LHC programme can and should not "fade away", new discoveries have to be correctly interpreted, and the world's Collider future is with CERN. DIS has to be part of it, as Guido Altarelli and Lev Lipatov had taught us.

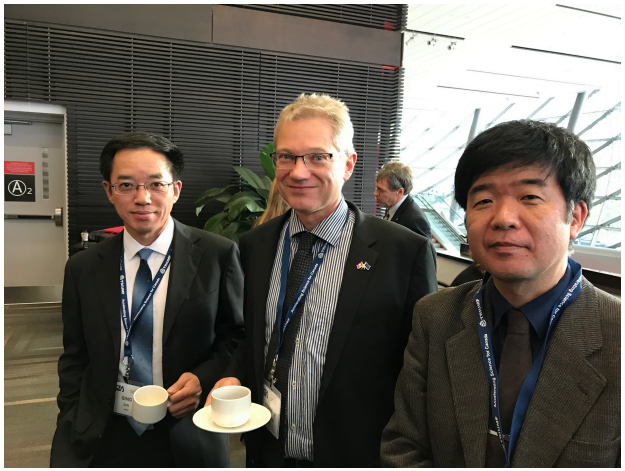
on “the strategy”

The next European strategy will hardly decide anything as it is five years before the 2 BSF HL upgrade takes place, and no one knows how to reach out to O(10)BSF. The demand to make HL LHC a success will be overriding, adding ep and eA is a golden key to this.

Directions may become visible in a global context (an asiatic e+e- machine decision would be important). HEP is remarkably in the hands of the J+Ch governments.

The ERL development and the detector+physics study has a long term future with CERN as we consider this accelerator as a modular addition to HL/HE LHC and the FCC hh.

MK remarks made in the LHeC Coordination June 2017



At ICFA Seminar in Canada 11/17

Quin Qin, Frank Zimmermann
and Shinichiro Michizono

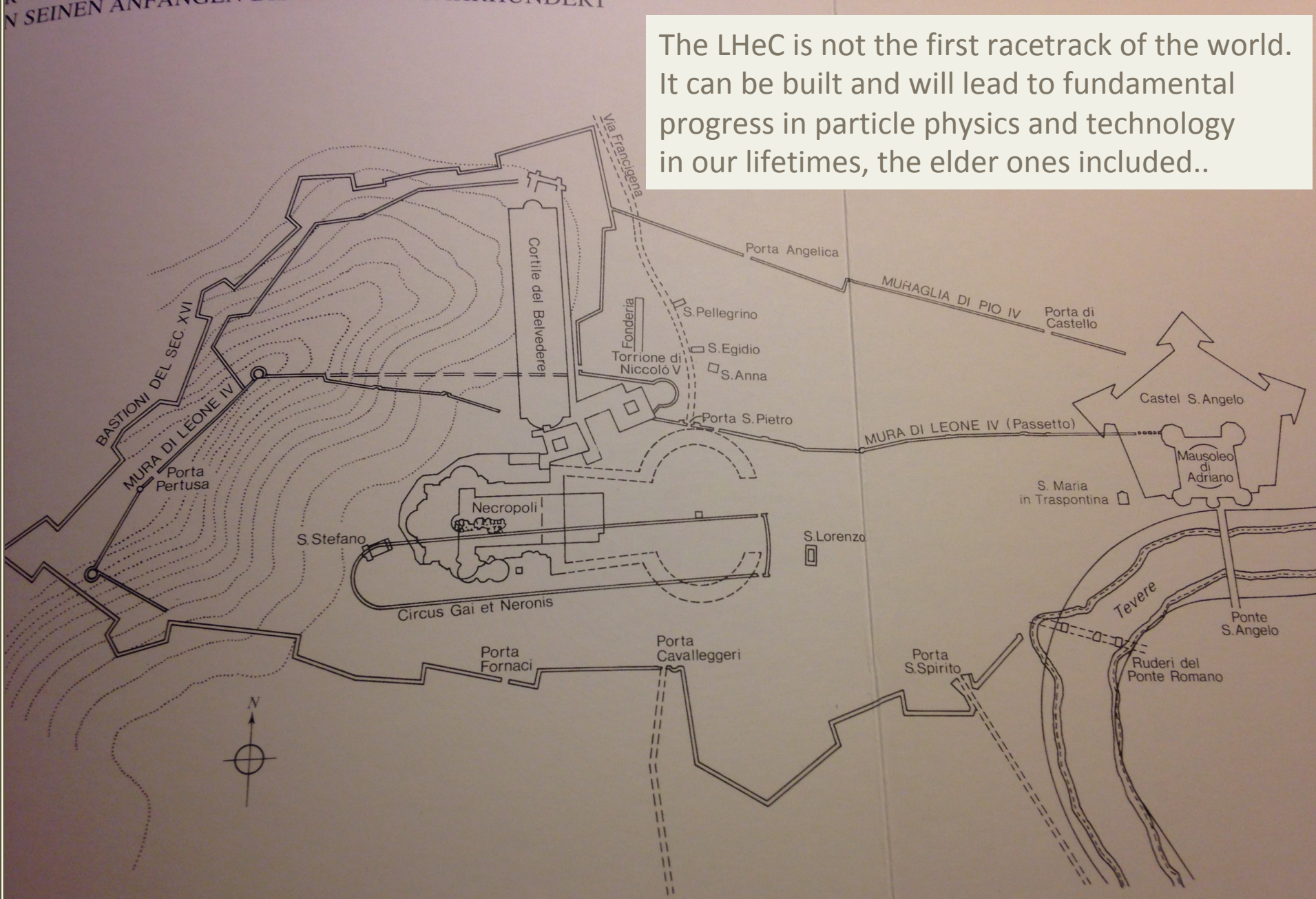
http://lhec.web.cern.ch

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

And further, that we "never walk alone"

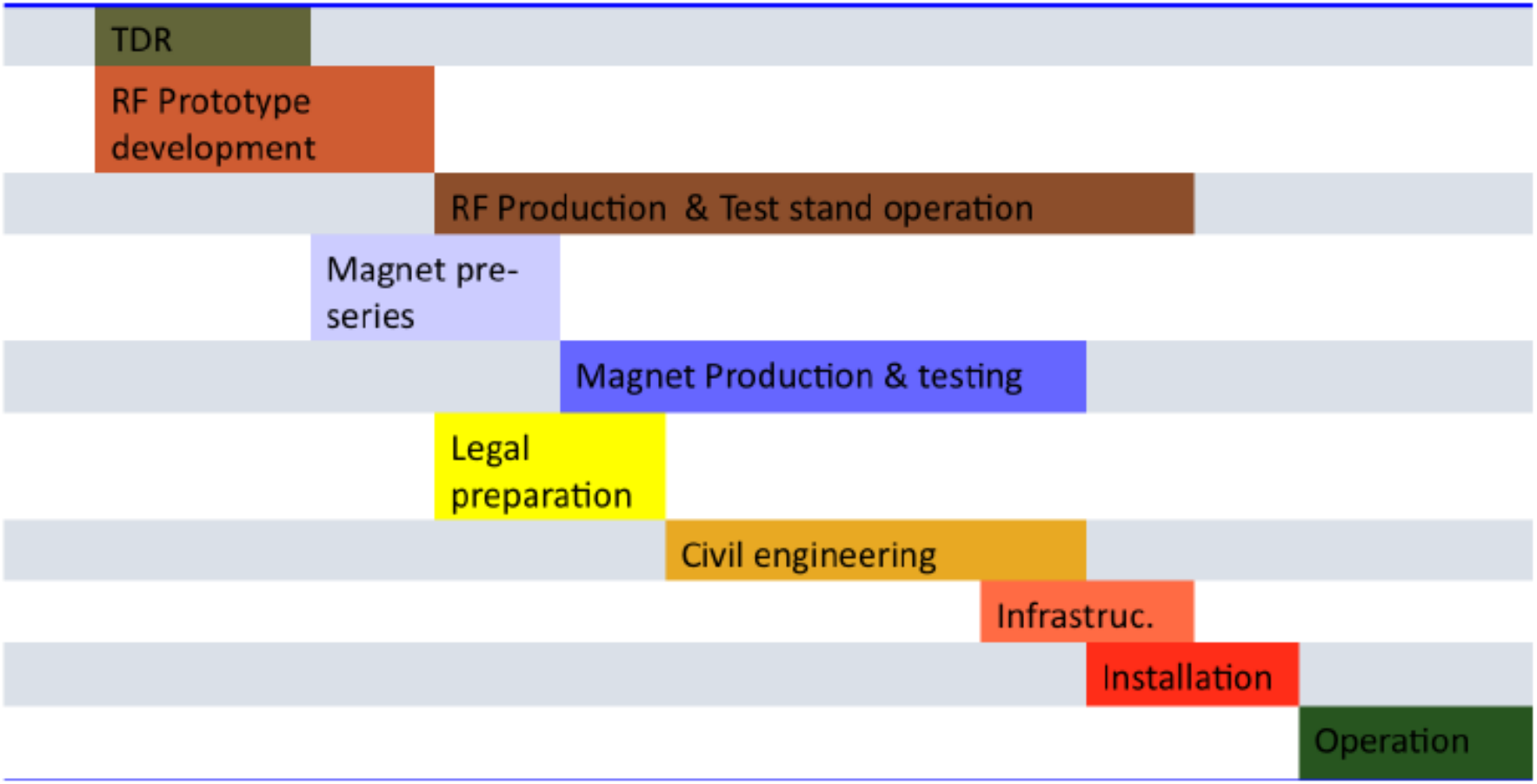
The LHeC is not the first racetrack of the world. It can be built and will lead to fundamental progress in particle physics and technology in our lifetimes, the elder ones included..



An early racetrack embedded in the Vatican (XV century)

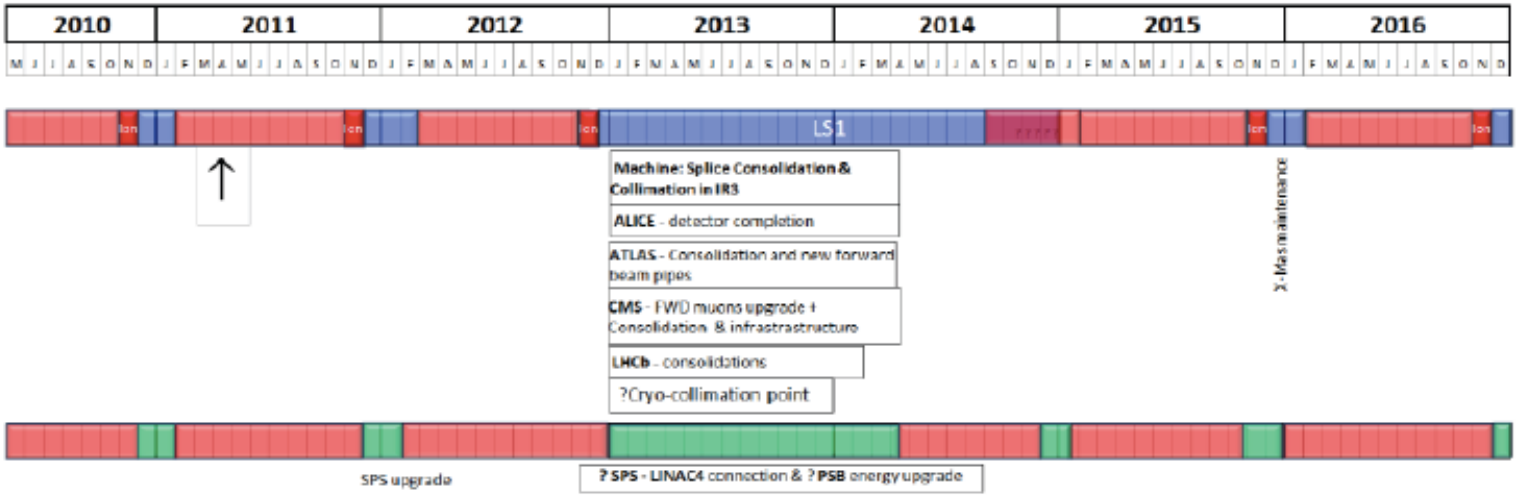
backup

CDR Timeline



2012 Needs update 2022

LHC Schedule for the coming decade



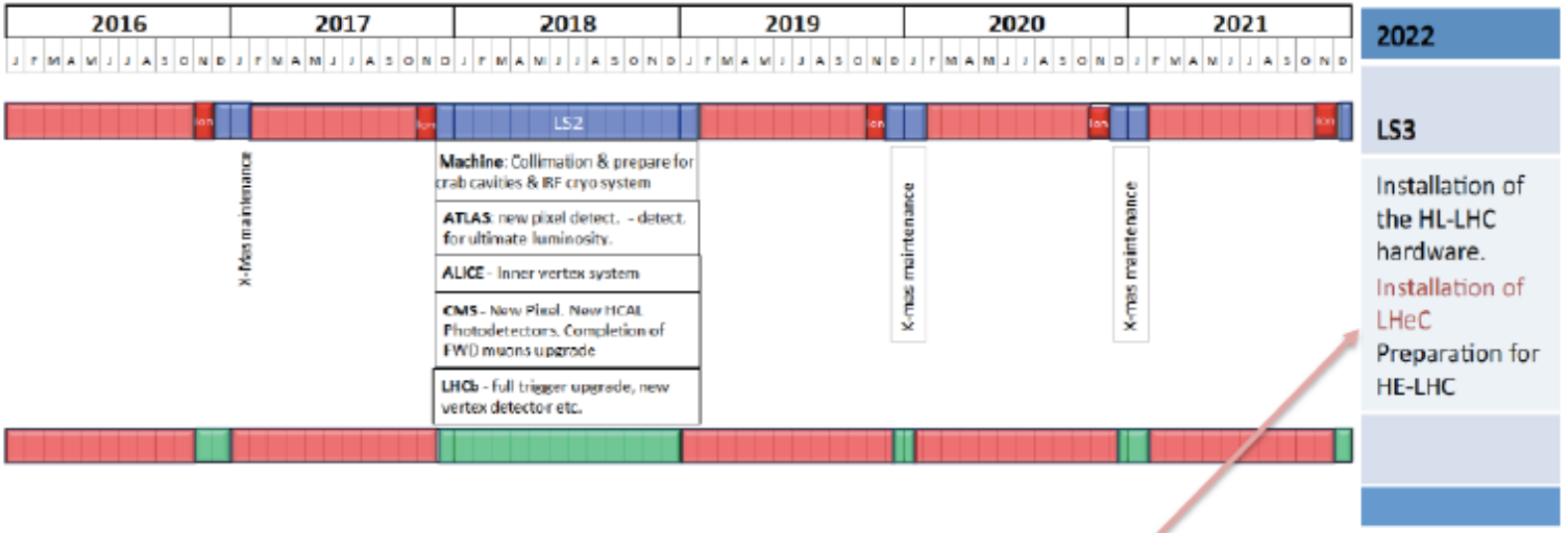


Figure 11.1: CERN medium term plan (MTP), draft as of July 2011

as shown by S. Myers at EPS 2011 Grenoble - Principal guidance of CDR [+N years..]