Remarks on Future Energy Frontier Colliders

Max Klein

A consideration in order of time
UK expressions of interest
Current ECFA and LDG Activities

Recent **Sources of Information**: Strategy Paper, January 21 Hongkong CEPC+ Conference, April 21 DIS Workshop, ECFA Newsletters..
Forthcoming: ZOOM Town Meetings on Detector and Accelerator Developments, EPS Conference, Acc Technology Roadmap 12/21
Further: Snowmass strategy process, .. UK: PPAP, PPTAP and project meetings …

Meeting of the Liverpool Particle Physics Group, April 29, 2021 – on-line

The accelerator energy frontier future as seen by the European Strategy Group (ESG)

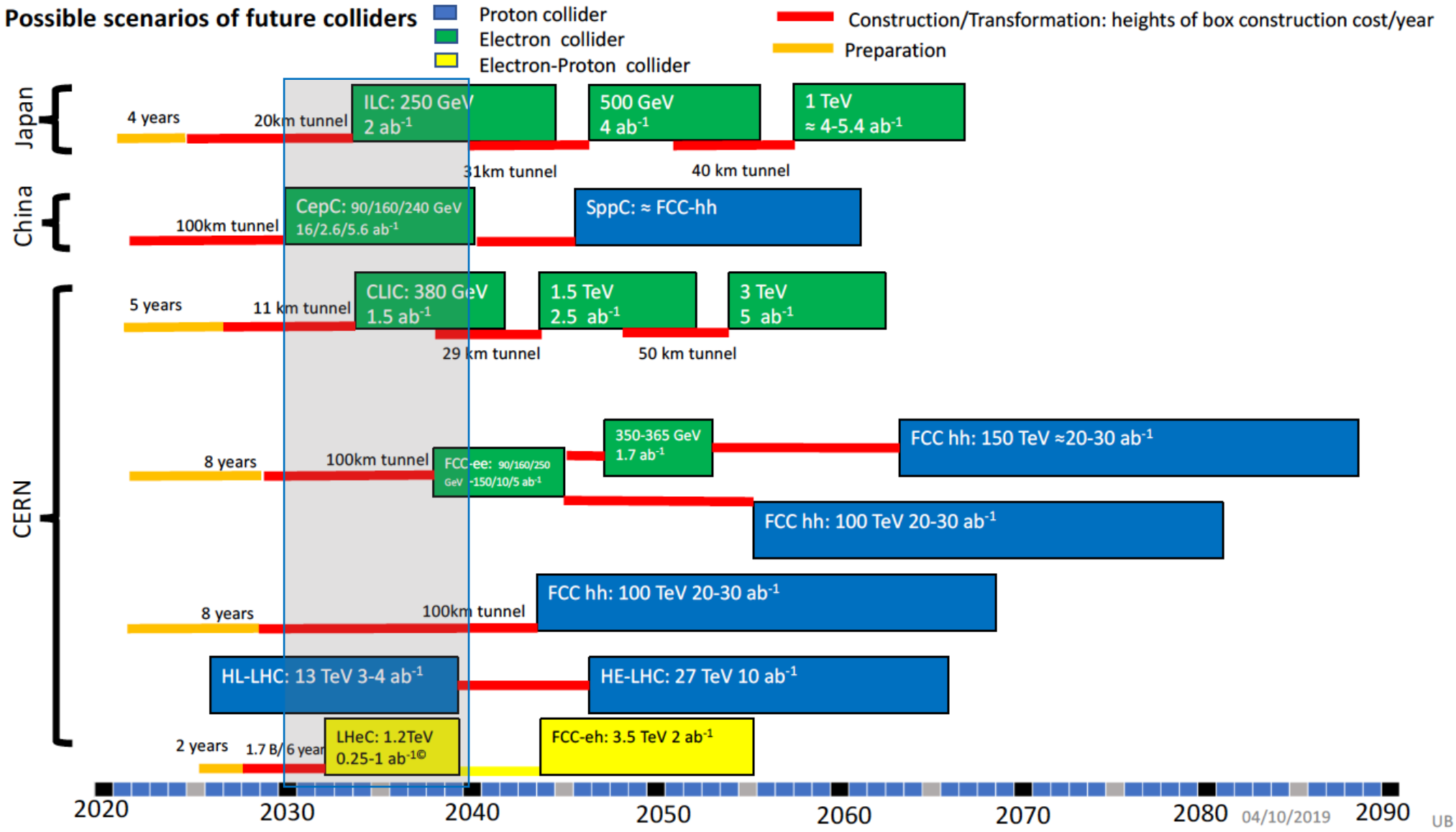
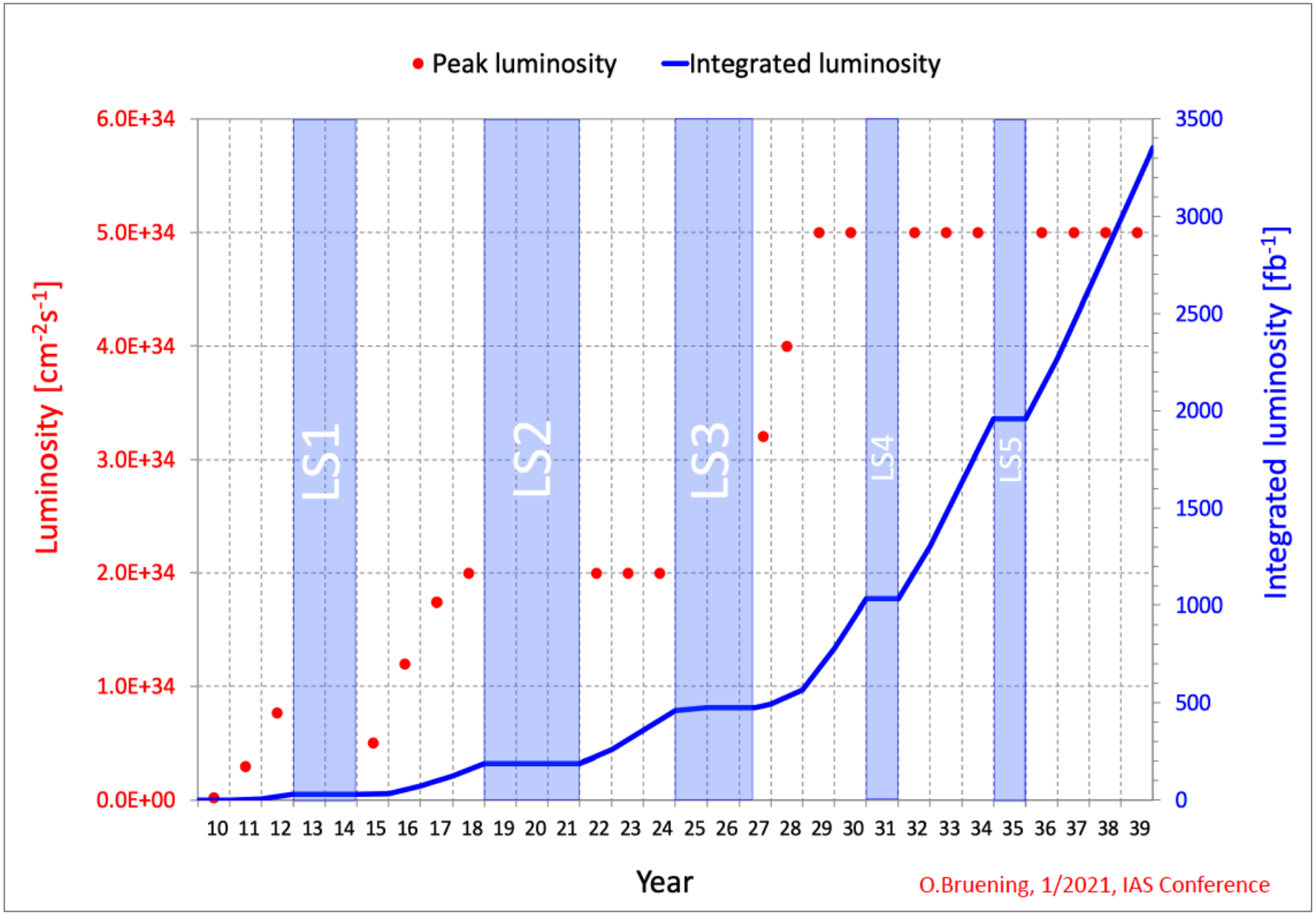


Figure 1 Timeline of Future Colliders as extracted from the submitted inputs (by U. Bassler)

CERN/ESG/05

The nearest future collider: HL-LHC



Some Expectations:

10 fold luminosity should enhance discovery + precision potential

LS3 will move to early 26 as otherwise we have 2+ years in Run 3 after a 3+year LS2

3ab^{-1} rather by 2040 than before Shutdowns last longer than 1 year.

It may run into 2045 and collect 4ab^{-1}

Upgrades:

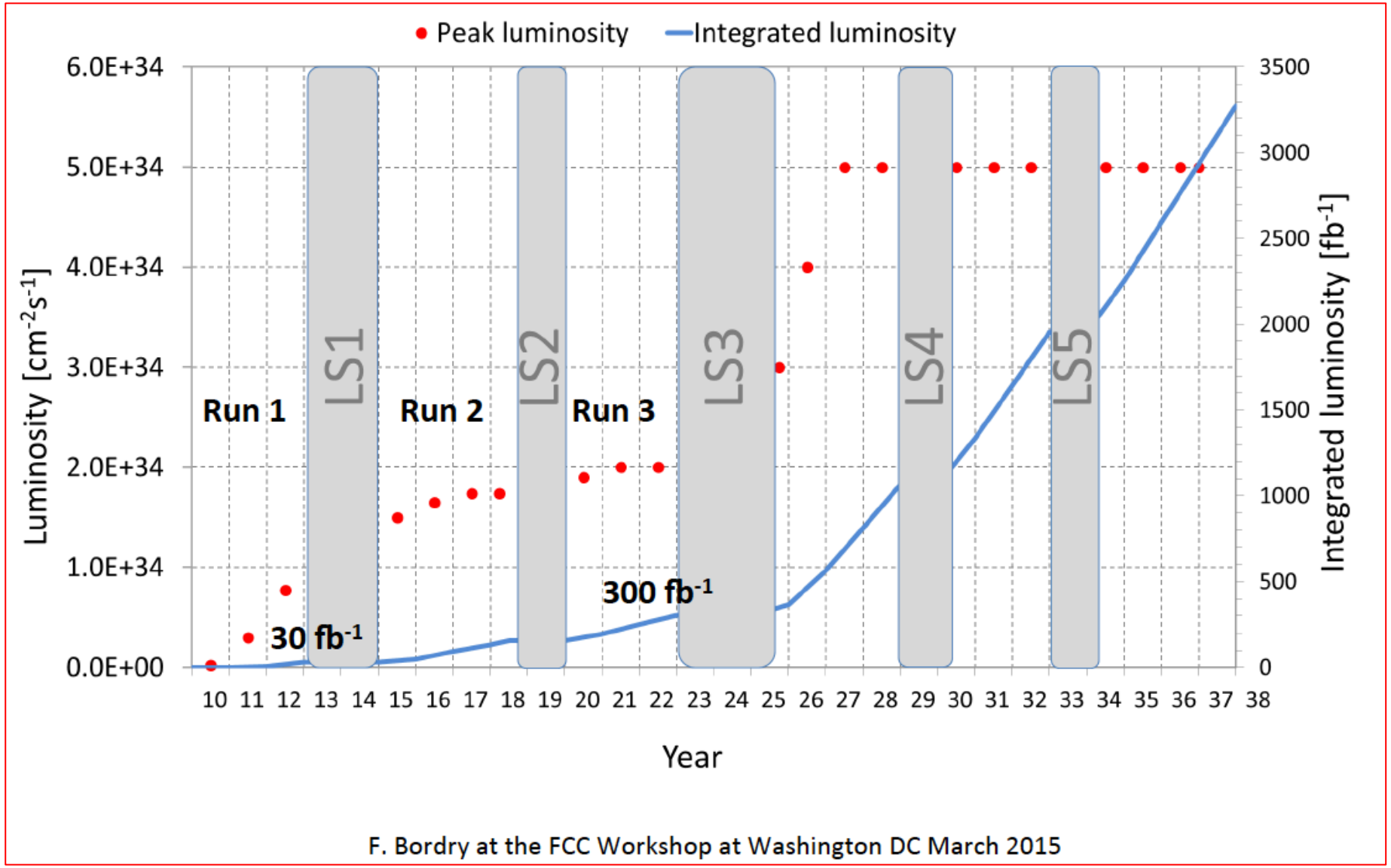
Major for HL-LHC LS3 (Helen+..)
Parts already planned for LS4 and 5

Fixed target experiments

LHeC

…

A look back to the 2015 projection



The change is LS2 with 3+ years vs 1+

LHC yet has been a major success!

The Austrian Railway conductor: we have a plan to be informed how late we are (joke told by Herwig Schopper)

CEPC

CEPC Accelerator TDR R&D Priority, Plan and Test Facilities

Red Color means R&D issues have test facilities

1) CEPC 650MHz 800kW high efficiency klystron (80%) (at the end of 2021 complete the fabriation, finish test in 2022)

2) High precision booster dipole magnet (critical for booster operation) (Complete real size magnet model in 2021)

3) CEPC 650MHz SC accelerator system, including SC cavities and cryomules (Complete test cryomodule in 2022)

4) Collider dual aperture dipole magnets, dual aperture qudrupoles and sextupole magntes(Complete real size model in 2022)

5) Vacuum chamber system (Complete fabrication and costing test in 2022)

6) SC magnets including cryostate (Complete short test model in 2022)

Jia Gao: HK Conference 1/21
https://indico.cern.ch/event/971970/

7) MDI mechanic system (Remote vacuum connection be test in 2022)

8) Collimator (Complete model test in 2022)

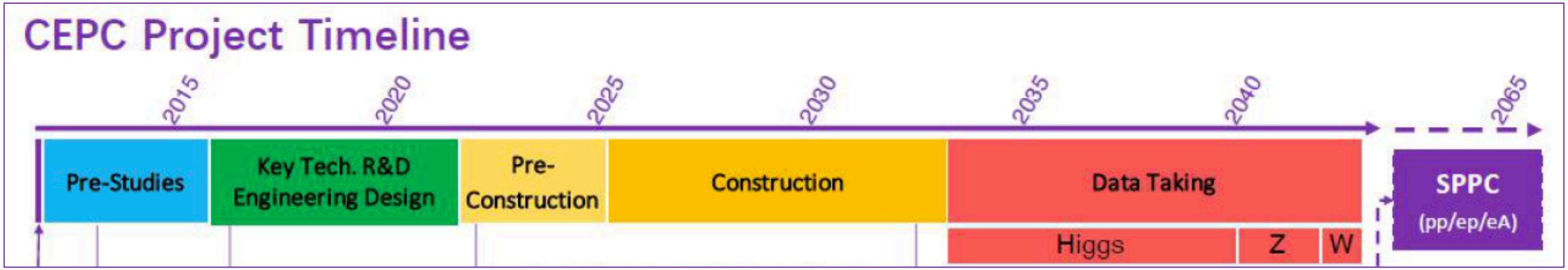
9) Linac components (Complete key components test in 2022)

10) Civil engineering design (Reference implementation design complete in 2022)

11) Plasma injector (Complete electron accelerator test in 2022)

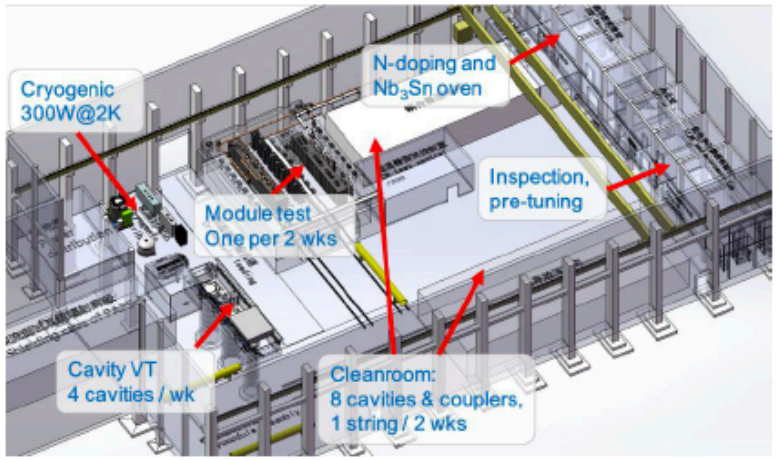
12) 18KW@4.5K cryoplant (Company)

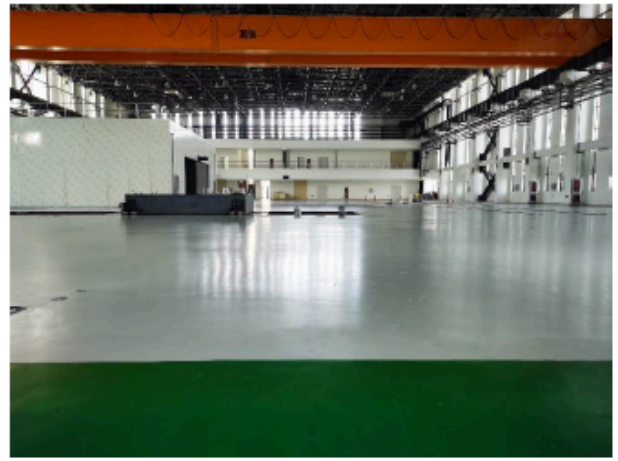
...



IHEP New SC Lab under Construction (Status in Nov. 2019)

Facility: CEPC SCRF test facility (lab) is located in IHEP Huairong Area of 4500m^2





New SC Lab Design (4500m^2)

SC New Lab will be available in 2021

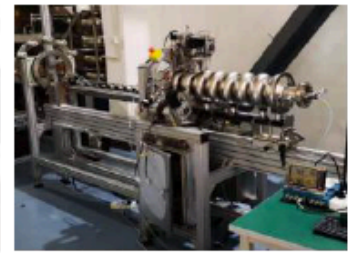
Crygenic system hall in Jan. 16, 2020

Vacuum furnace (doping & annealing)

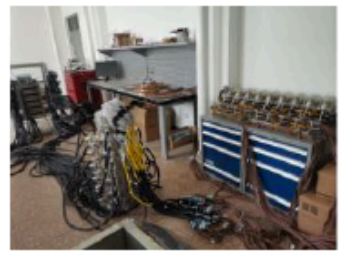
Nb3Sn furnace

Nb/Cu sputtering device

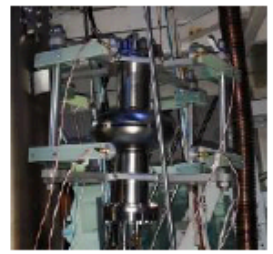
Cavity inspection camera and grinder



9-cell cavity pre-tuning machine



Temperature & X-ray mapping system



Second sound cavity quench detection system

Helmholtz coil for cavity vertical test

Vertical test dewars

Horizontal test cryostat

LHeC

Update of CDR, 7/2021, 156 Institutes
400 pages, J.Phys G to appear

Full **Physics Programme**, QCD,H,BSM,eA with emphasis on DIS + eh-hh Symbiosis

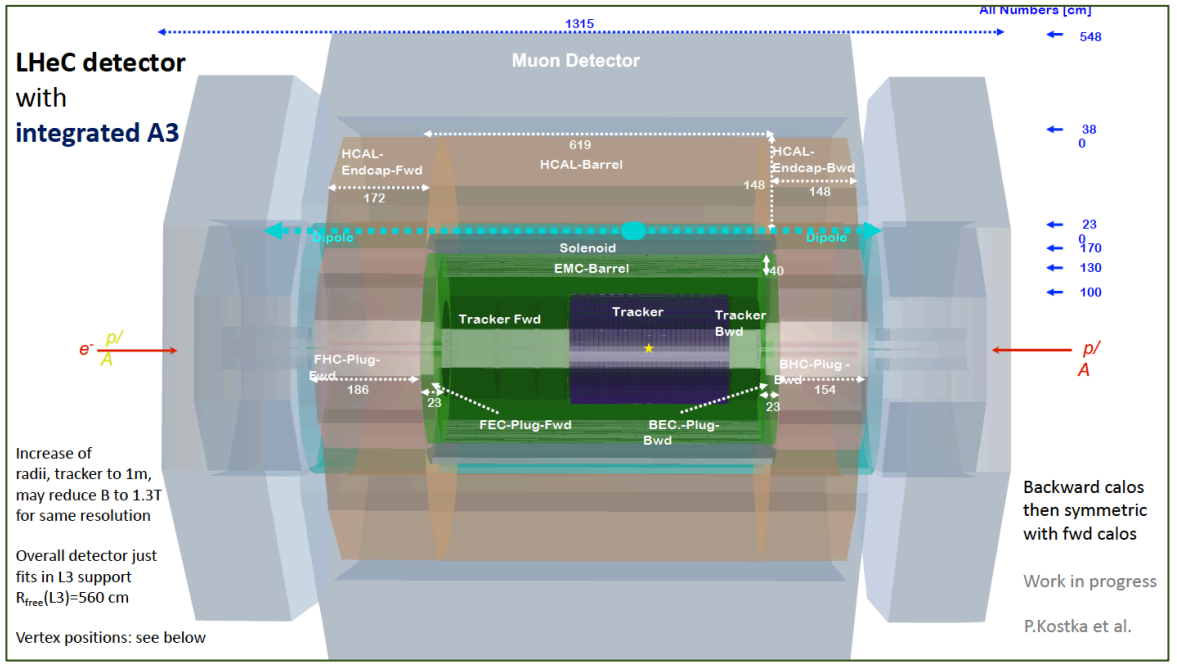
Full **Detector Design** – also for FCC-eh

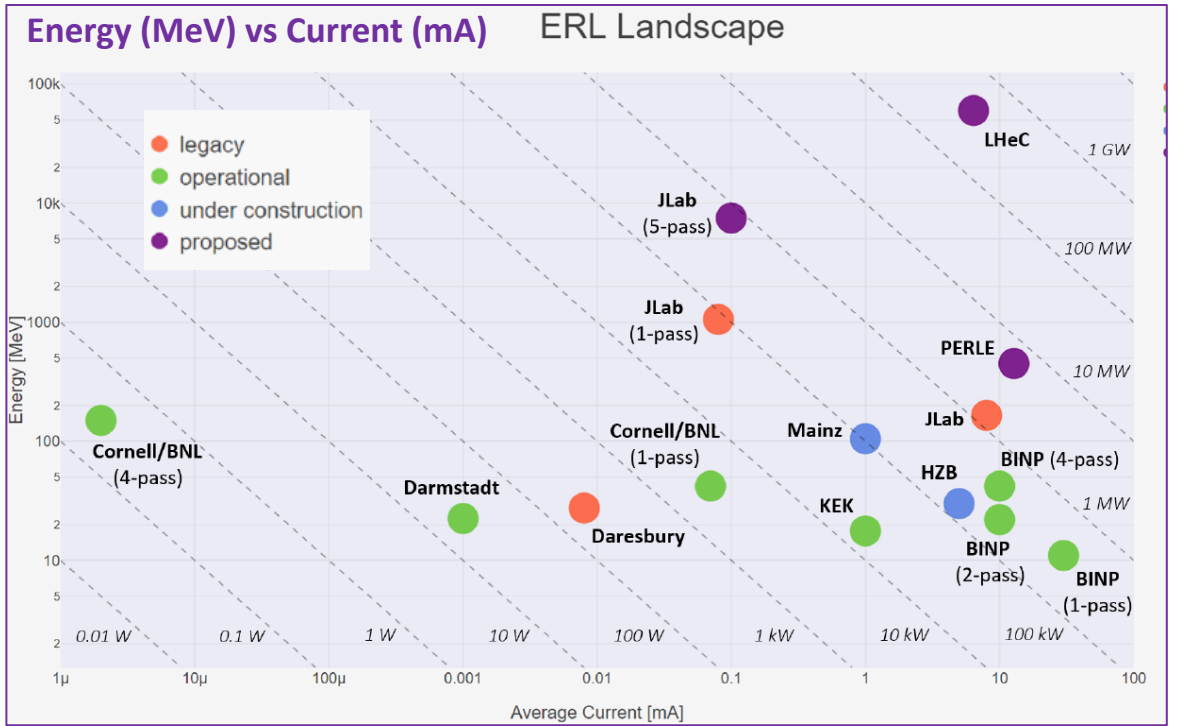
PERLE Collaboration founded: 10MW ERL with LHeC parameters (802MHz, 20mA) and technology (cryomodule, cavities..) [CERN, Cornell, Daresbury, Jlab, Liverpool, Novosibirsk, Orsay]

In kind delivery of source (ALICE/ASTeC), Cryomodule (SPL/CERN) and Booster Cryostate (JLEIC/Jlab) for **250 MeV PERLE**

Opportunity for particle and nuclear **low energy experiments** – under discussion

Project, Physics, Detector, Acc, PERLE – **with outstanding leadership of Liverpool**





ILC

- Still very high international attention →
- Prelab in Japan
- 8000 cavities
- Nanobeam technology
- 1.3 10^{34} luminosity

ICFA

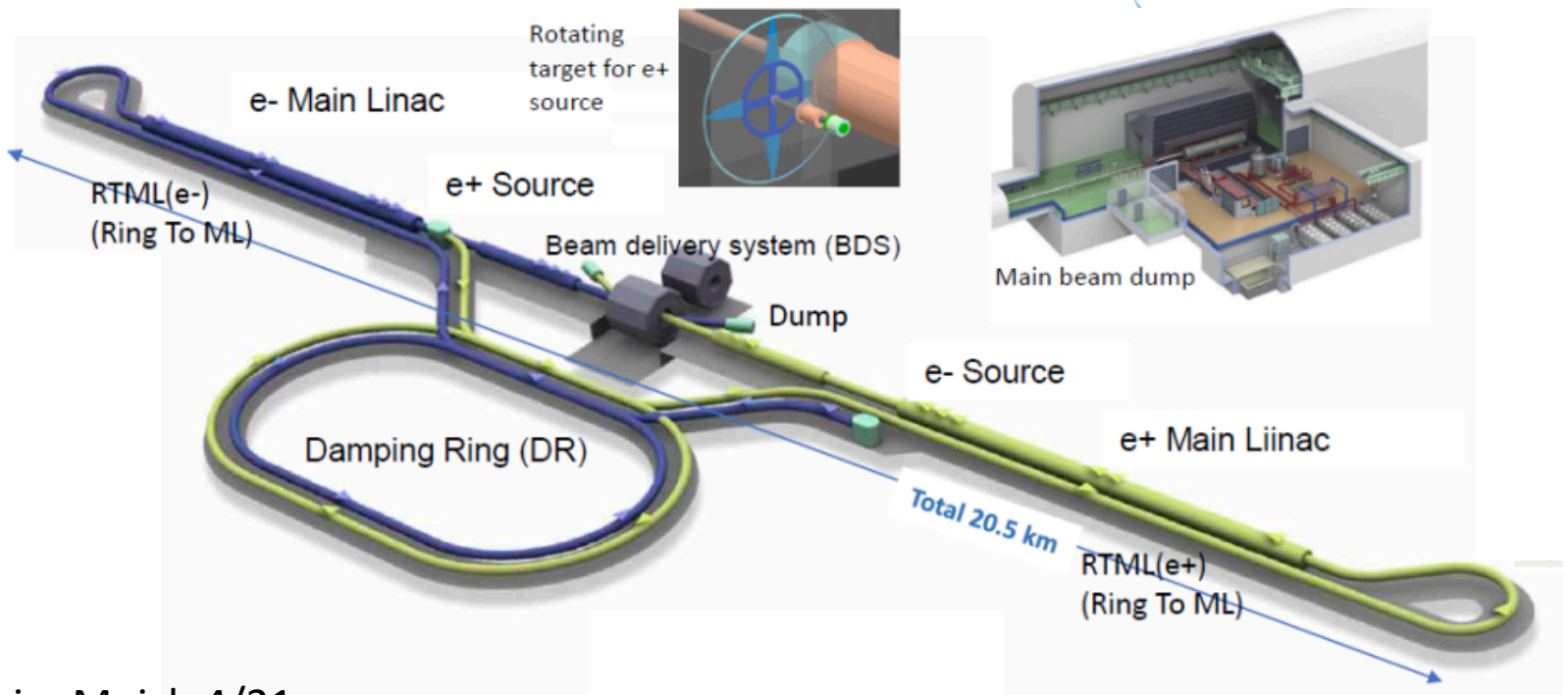
ILC-IDT

Executive Board

Andrew Lankford (UC Irvine): Americas Liaison
Shinichiro Michizono (KEK): Working group 2 Chair
Hitoshi Murayama (UC Berkeley/U. Tokyo): Working group 3 Chair
Tatsuya Nakada (EPFL): Executive Board Chair and Working group 1 Chair
Yasuhiro Okada (KEK): KEK Liaison
Steinar Stapnes (CERN): Europe Liaison
Geoffrey Taylor (U. Melbourne): Asia-Pacific Liaison

Working group 1 Pre-lab set-up	Working group 2 Accelerator	Working group 3 Physics & Detectors

Scientific secretary: Tomohiko Tanabe (KEK)
Communication team led by Rika Takahashi (KEK)



Note: CLIC@CERN is still retained as a possible future option

Joachim Mnich, DIS21

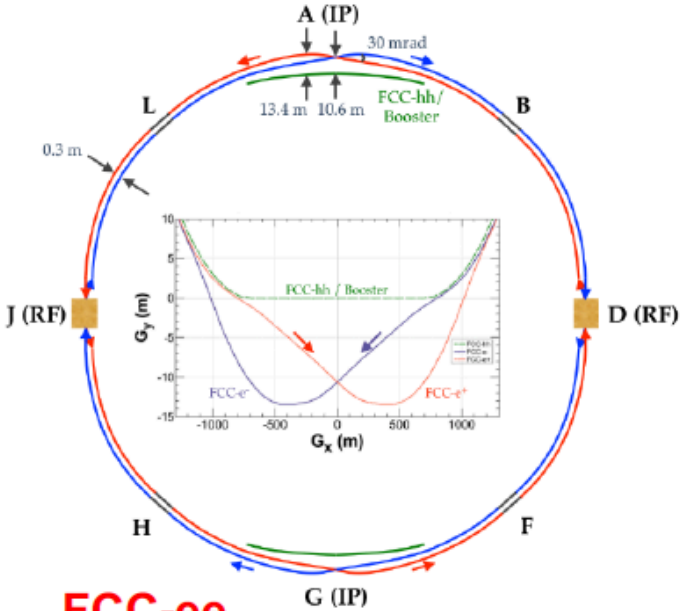
FCC Feasibility Study

CERN is now launching a FCC feasibility study

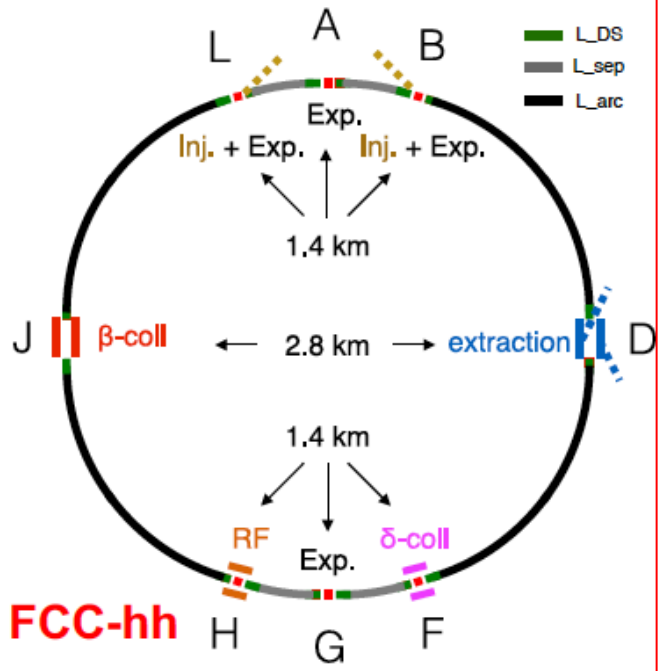
- investigation of the technical and financial feasibility of a future ≥ 100 TeV hadron collider at CERN
  - with e^+e^- Higgs and electroweak factory as possible first stage

- to be completed by the next Strategy Update (≈ 2026)

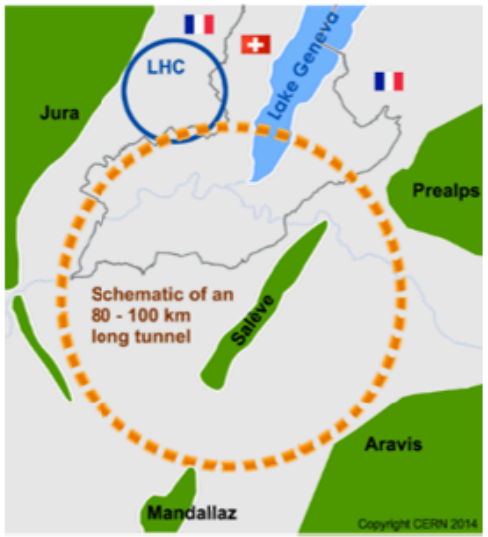
Enable a project decision:
- feasibility study of the 100 km tunnel
- geological aspects and optimisation
- host-state related processes
- CDR+ for colliders and injectors
- high Field Magnetintermediate milestones
- …

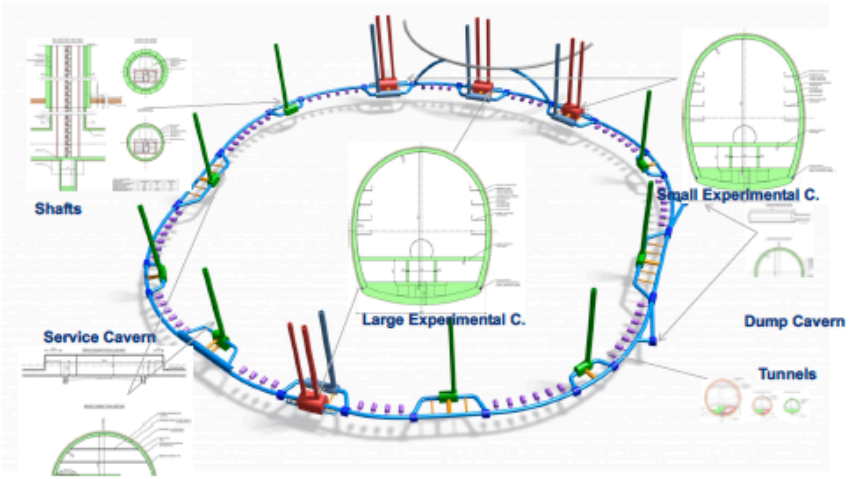


FCC-ee



FCC-hh



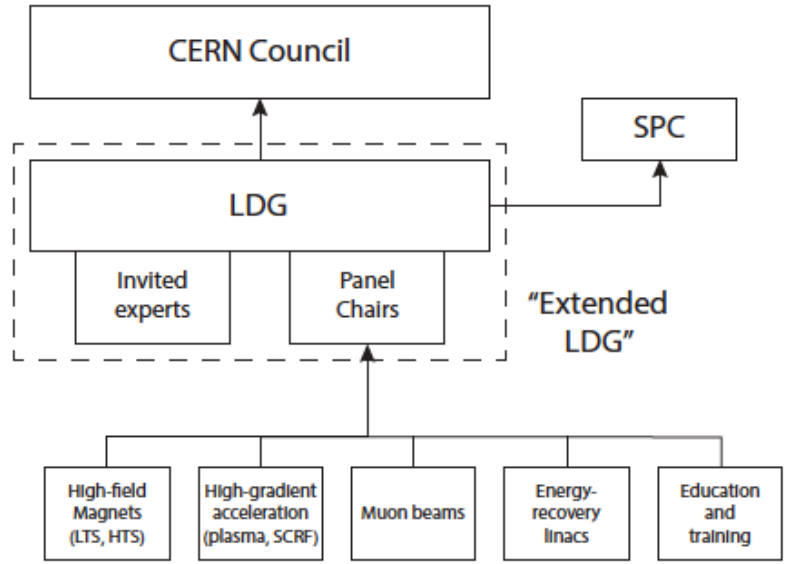


Accelerator Roadmap

CERN and the national laboratories in Europe (LDG) are charged by CERN Council to define a Roadmap for Accelerator R&D

Topics:

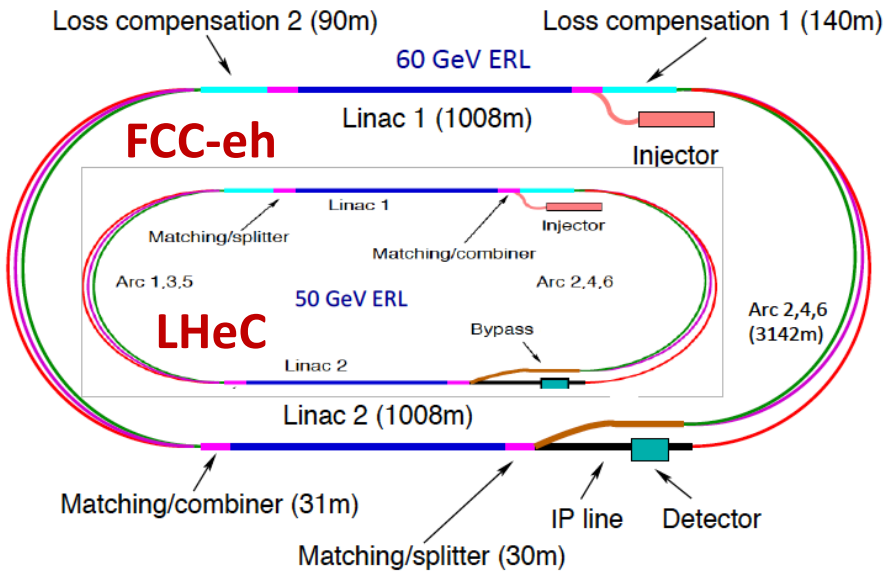
- High-field magnets
- High-gradient accelerations (plasma, SCRF)
- Muon beams/collider
- Energy recovery linacs
- Education and training



	High Field Magnets Low Temp & HTS	High Gradient Acceleration (plasma)	Muon Collider	ERL	High Gradient Accelerating Structures (sc & nc)
chair	Pierre Vedrine, IRFU	Ralph Assmann, DESY & INFN	Daniel Schulte, CERN	Max Klein, Liverpool	Sebastien Bousson, IJCLab
co-chair	Luis Garcia-Tabares Rodriguez, CIEMAT	Edda Gschwendtner, CERN	Nadia Pastrone, INFN	Andrew Hutton, JLAB	Hans Weise, DESY

Goal: viable options which deserve to be pursued can be identified by the next strategy update

Energy Frontier Collider Applications of Energy Recovery Linacs

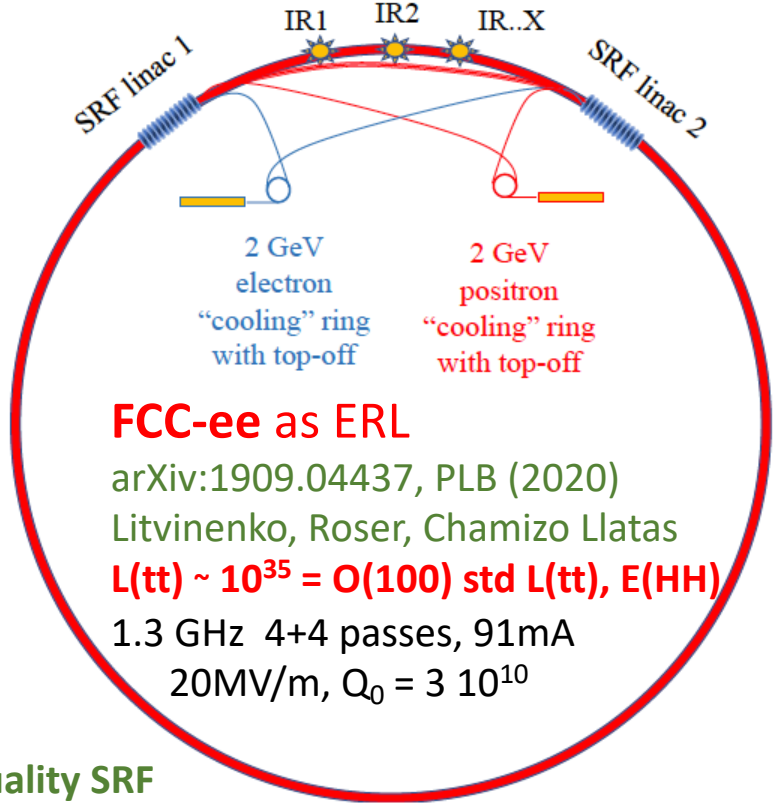


sqrt(s_{ep}) = 1-4 TeV

L(HERA) x 1000
(ERL and LHC)

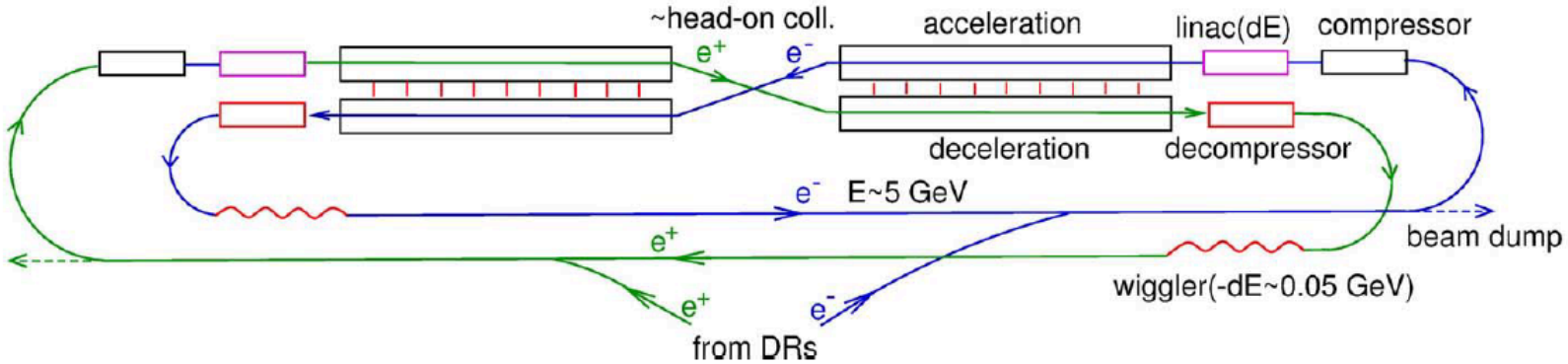
1206.2913, JPhysG
2007.14491, JPhysG

f=802Mz,
3+3 passes: 20mA x 6
20MV/m, $Q_0 > 10^{10}$



FCC-ee as ERL
arXiv:1909.04437, PLB (2020)
Litvinenko, Roser, Chamizo Llatas
L(tt) ~ 10^{35} = O(100) std L(tt), E(HH)
1.3 GHz 4+4 passes, 91mA
20MV/m, $Q_0 = 3\ 10^{10}$

All: ep+ee: major increase in luminosity O(100) for Higgs - at reduced power, via high quality SRF



ILC as ERL
V. Telnov at LCWS 3/2021 in preparation
L(ERL) ~ 10^{36} = O(100) std L(ILC)
This yields O(10^7) HZ events in 3 years.
1+1 passes, l =160m
f=750 MHz, 20MV/m, $Q_0 > 10^{10}$

Slide shown at LDG meeting 23.4.21, MK

ERL Energy Frontier Targets *DRAFT 19.3.21*

[We are writing ~200 pages White Paper on ERL draft May.. Facilities, challenges, PP,NP, industry, sustainability] → Roadmap

Technical Readiness Level*)

			Current Record Achieved	Approved Project Goal	Projects in Progress Goal	LHeC / FCC-eh	FCC-ee ERL	ILC-ERL	TRL now	TRL in 5 Years
ERL	**Top energy**	**GeV**	**1.05**	**7.5**		**50**	**300**	**250**	**6**	**6**
	Beam power	**MW**	**1.3**		**10**	**1000**	**48**	**22.7**	**5**	**5**
Source	Gun Energy	keV	450			220 - 350	N/A		9	9
	Current	mA	9(*20)	100	20	120	0.16	91	3	6
Injector	Beam energy	MeV	6	84	7 - 10	7	2,000		9	9
Acceleration	RF Frequency	MHz	1300 - 1500	591 - 1497	801.58	801.58	750	1300	7	9
	Total Linac current	mA	18 (20*)	100	200	720	0.72	182	3	6
	Bunch charge	pC	270 (1500*)		500	500	19000		4	6
	Normalized emittance	μm	10 @ 270pC		6 @ 500pC	30 @ 500pC	8, 0.008		5	7
	Gradient	MV/m	12	17.5	18	19.73	20	20	9*	9*
	Quality factor	x 10^{10}	1	>1.25	3	>1	~1	3	9*	9*
	Multi-pass		4 + 4	5 + 5	3 + 3	3 + 3	4 + 4	1 + 1	8	8
Interaction Region	βx, βy	cm	6, 6			7 - 10, 7 - 10	small-gap FODO		7	7
	Beam size	μm	50			6, 6	100, 0.2		3	3
Dump	Dump power	kW	100	500		840	N/A		3	5

* Charge reached in low-frequency, copper cavities

Luminosity = $10^{36} cm^{-2} s^{-1}$

* achieved in comercially procured cavities for LCLS II

Common feature: $Q_0 > 10^{10}$ in CW SRF leads to huge luminosity gain (1000 x HERA in ep, 100 x for ILC) with power economy

Major lower energy and industrial applications which are part of the ERL "story".

Expected TRL will require strong (European) effort and appropriate support.

*) TRL: DoE classification, presented last time

FCC – UK[1]

Submissions to PPAP
in the fall 2020

ee

- 2021 - 2025: Physics performance studies
- End of 2025: CDR/TDR (feasibility proof)
- 2025/6: FCC-ee proto collaborations and LoI
- 2026-27: Next ESPPU
- 2028: Project approval
- 2030: Start of tunnel construction
- 2035/36: Tunnel completion
- 2037: Start machine installation
- 2040: First e^+e^- collisions in FCC-ee

Assumptions:
ee collisions 2040
pp collisions 2048
ep goes with pp

hh

- 2021 – 2023: Evaluation studies of machine technology challenges and opportunities, first phase of an advanced detector R&D programme, preliminary physics studies (5FTE, £0.5M capital)
- 2024 – 2027: First phase of HTS magnet programme and machine studies, demonstrator phase of detector R&D programme, detailed physics studies in parallel with LHC LS3 (10FTE, £5M capital)
- 2027: Next update of ESPPU; 'go decision' on detailed design studies for FCC-hh
- 2028 – 2032: Detailed design studies for machine; HTS magnet demonstrator programme; detector design phase towards updated CDR (20FTE, £20M capital)
- 2033: Approval of FCC-hh construction
- 2033 – 2036: Civil construction; industrial magnet pre-series; final detector prototyping phase (50FTE, £20M capital plus direct machine contribution)
- 2036 – 2044: Machine and detector construction, (including software engineering); ramp-up of physics preparations post-LHC, including development of required theory codes and tools (60-80FTE; £100M capital plus direct machine contribution).
- 2044 – 2047: Commissioning
- 2048: Start of physics

eh

9. Programme until about 2025

The following focus points are evident for the coming years:

- Detailed study of the relation of *ep* and *pp*, as well as *eA* with *AA* (*pA*), physics, as e.g. for BSM and Higgs, in close Collaboration with theorists;
- Theory developments as indicated in paragraph 7;
- The realisation of the first phase of PERLE (injector) towards a 250 MeV *e* beam at IJClab Orsay;
- The formation of an international proto-detector Collaboration able to present the LHeC to the LHC(at CERN and to collaborate on detector technology R&D, with strong, leading UK contributions;
- Layout of the machine-detector interface, including a mock-up of the first quadrupole, a plan for absorbers+masks, and a prototype solution of the elliptic beam pipe.

Strong interest in FCC in the UK
Joint FCC-UK Contact Group +
Contacts:

ee NN
hh Sinead Farrington (Edinburgh)
eh Uta Klein (Liverpool)

[1] FCC-UK (along with other FCC national groups from France, Italy, Spain, Poland, etc) report at the Future Circular Collider Physics & Experiments Steering Group about activities and planning at the national level. The UK institute contacts for FCC are: D. Charlton (Birmingham), J. Goldstein (Bristol), C. Potter (Cambridge), P. Ratoff (Cockcroft), R. Lemmon (Daresbury), M. Spannowsky (Durham), C. Leonidopoulos (Edinburgh), A. Buckley (Glasgow), G. Davies (Imperial), P. Burrows (John Adams Institute), J. Ellis (King's College), H. Fox (Lancaster), J. Vossebeld (Liverpool), T. Wyatt (Manchester), G. Wilkinson (Oxford), S. Zenz (QMUL), J. Dopke (STFC Rutherford Appleton Laboratory), V. Boisvert (Royal Holloway), T. Vickey (Sheffield), S. Moretti (Southampton), A. De Santo (Sussex), M. Campanelli (UCL), W. Murray (Warwick).

ILC UK

Science and Technology Facilities Council

PPAP Roadmap Update Proforma 2020/2021

UK Paper on ILC submitted to PPAP

In August 2020 ICFA announced the formation of the 'International Development Team' (IDT) and an indicative timeline for realisation of the ILC project:

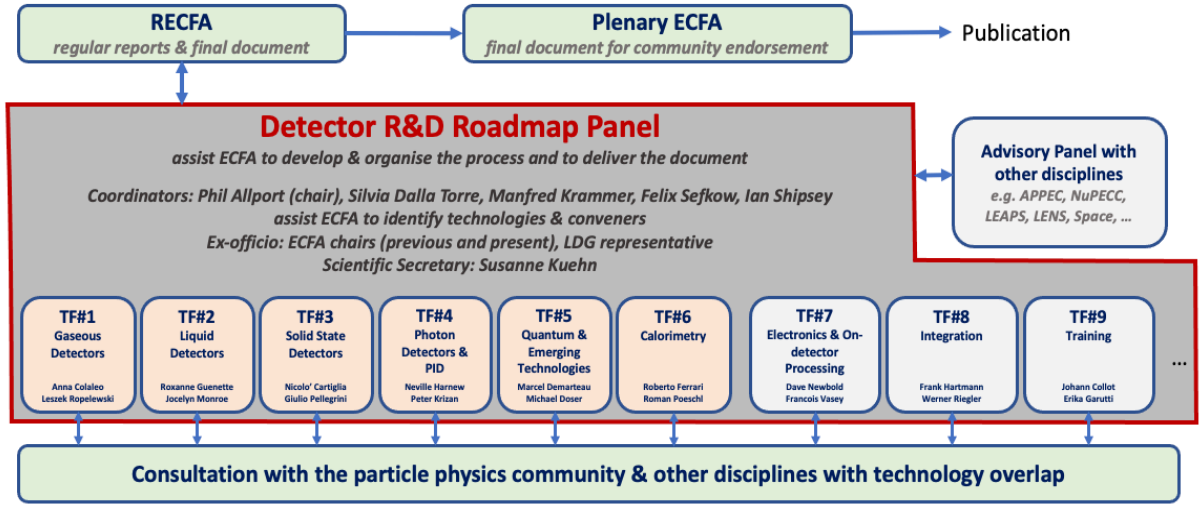
- 2020-21: 'IDT phase': Identify possible partners and their potential contributions during the Preparation Phase.
- 2022-25: 'Preparation Phase': 'Pre-lab' hosted by KEK comprising an international project team. Complete R&D, engineering design and preparatory work for setting up the ILC Laboratory. Conduct negotiations on agreements for technical contributions to ILC construction from international partners.
- 2026-35: 'Construction Phase': Construction under the auspices of the ILC Laboratory, with mostly in-kind contributions from international partners.
- >2035: Commissioning and physics exploitation in parallel with HL-LHC.

CLIC UK: involved in Snowmass

Bascially all UK Groups involved in Accelerator, Detector and/or Physics. Contacts: Phil Burrows (Oxford)
Aidan Robson (Glasgow)

ECFA Activities in 2021

https://ecfa.web.cern.ch/ecfa-newsletters



https://indico.cern.ch/event/957057/program

Draft Roadmap end of May 21 .. EPS .. September feedback..

Early Career Research Panel (19.11.20) NEW

73 Members, 5 pECFA Observers, LB in rECFA

Eleonora Diociaiuti	(Frascati, mu2e)
Gianluca Inguglia	(Austria, BELLE)
Henning Kirschenmann	(Finland, CMS)
Lydia Brenner	(CERN, ATLAS)
Paweł Sznajder	(Poland, theory)

UK: Bryn Roberts, Abbey Waldron, Sara Williams

Physics, Experiments (+Det) Study for an e^+e^- H Factory

Two (so far) main WGs: **Physics Potential and Analysis Tools**.
IAC (19 Members) chaired by K Jakobs. Convenors nominated
Startup end of May/early June. Long term study (~3years)
Directed to explore e^+e^- (mainly) Higgs potential,
related also to hadron (HL-LHC, FCC-hh) and other colliders

Representation of Large Laboratories restructured (LDG)

Accelerator Roadmap (Magnets, Plasma, ERL, SRF, Muons)
accompanied by ECFA, but an LDG/CERN Council process.

rECFA Country Visits 2021 (tbc)

France 10/11. September
Serbia 8/9. October
Denmark 5/6 November

Plenary ECFA Meetings

during EPS (26-30.7.) + November 18-19.11. perhaps at CERN

Joint ECFA-NuPECC-APPEC Seminars

1st JENAS event at Orsay in 2019 (https://jenas-2019.lal.in2p3.fr)

2nd JENAS event planned in Madrid in 2022 (3 – 6 May 2022);

Concluding Remarks

- The future of energy frontier colliders is no less unresolved than before the “Strategy Update” because it is complex
- The HL-LHC deserves maximum support, it is more than challenging, probably further delayed (C19) and no “done deal”.
- Further exploitation of the LHC, beyond and based on HL-LHC, is rather likely, + being considered (new upgrades > LS3, ep)
- Part of the big uncertainty is the new technical dimension, size and overriding cost of the big projects.
- It is visible that the “classic” project handling towards the CEPC leads to an outstanding dynamics. [2m linac Stanford in 3 years]
- The ILC, especially as an ERL twin collider with 10^{36} , may indeed advance, albeit it started 30 years ago (TESLA).
- If Asia builds one [or two] e^+e^- colliders, and decides by ~25, CERN may hardly proceed with FCC-ee nor CLIC [SSC/LHC story]
- This would then lead to a revival of the energy frontier hadron collider which with FCC-ee is deferred to ~2070: hh maybe:
- HE-LHC with eventual HTS/hybrid magnets, FCC-hh (50 TeV with LHC magnets → 150 TeV with HTS/hybrids), SPPC in China
- It will be necessary to globally coordinate how the few TeV scale can be explored, and that needs e^+e^-, pp and ep
- For any of the huge projects, CERN needs an uplift, a perestroika and renewal, based on a clearly defined next goal.

- It is probably wise and realistic if a maximum of useful, generic, synergetic R&D is pursued (R Jones, PPAP)
- The UK has been a leader of the field and there is a task to be pursued and a role to be kept
- This includes a strong collaboration of particle and accelerator physicists, UK and international
- The time scale of the huge projects and the nature of nature implies that a group like ours needs small experiments also.

- In all future collider projects, Liverpool has been engaged: master + PhD students, exp+thy academics, accelerator group
- Andy, Carl, Eva, Jan, Joost, Max, Monica, Nikos, Oliver, Peter, Stephen, Tara, Tim, Uta and others [apologies] and students …
- It needed more time to do justice to these contributions (Science Board, PPAP, PPTAP, LDG, ECFA, papers, HV-CMOS next)

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

Anna Eleanor Roosevelt
(1884-1962)

Universal Declaration of Human Rights (1948)

cited by Frank Zimmermann at the FCC Meeting at Washington DC, March 2015

backup

ECFA Newsletters in 2020

https://ecfa.web.cern.ch/ecfa-newsletters

Nr 5 (July 2020)

Report by Chair Jorgen de Hondt **and Secretary** Carlos Lacasta

Initial Views on the European Strategy Implementation
Fabiola Gianotti

Reports from the Laboratories
CERN Fabiola Gianotti
DESY Joachim Mnich
INFN Frascati Pierluigi Campana

MidTerm Report: Belgium Nick van Remortel

EuPRAXIA A European Plasma Research Accelerator with Excellence in Applications
Maria Weikum, Ralph Assmann, Massimo Ferrario

Electrons for the LHC – on the Update of the LHeC CDR: Physics, Accelerator and Detector Oliver Bruening, Max Klein

Nr 6 (November 2020)

Report by Chair Jorgen de Hondt **and Secretary** Carlos Lacasta

Reports from the Laboratories
CERN Eckhard Elsen DESY Joachim Mnich INFN Frascati Fabio Bossi

MidTerm: Bulgaria Plamen Iaydjiev; **Sweden** David Milstead

Status of the International Linear Collider Steinar Stapness

Status of the Future Circular Collider
Michael Benedikt, Frank Zimmermann

Detector R&D Roadmap Susanne Kuehn

Accelerator R&D Roadmap Leonid Rivkin

Gamma Factory
Dmitry Budker, Yann Dutheil, Mieczyslaw Witold Krasny

EuPRAXIA: Ralph Assmann, Massimo Ferrario

The US Snowmass Process Young-Kee Kim