LDG Update

- LDG role and composition
- Accelerator R&D progress
- Sustainability assessment
- Community meetings

- LDG: forum / representative body / working group of major labs
- Coming years will bring challenge and opportunities
  - European Strategy update process first steps in 2024 – LDG has a ‘structural’ role
  - Major challenges to operations and delivery for all major labs
  - Positioning / delivery for next generation of large science infrastructures
    - Including, but not limited to, the next particle colliders
    - Some of these infrastructures are becoming ‘global projects’
  - Practical support for the detector and accelerator R&D programmes

LDG Remit

- Remit approved by CERN Council
  - Facilitate informal dialogue among the Directors of the LNLs and CERN
  - Provide direct input to the European Strategy for Particle Physics
  - Liaise with the European Commission and national funding agencies, research institutes and universities, ensuring that LNLs speak with a single voice
  - Maximise the regional and national benefits of investment in fundamental research and in CERN
  - Keep abreast of the activities … being undertaken in laboratories outside CERN's Member States, and of other coordinating groups in particle physics and related fields, and foster dialogue with them
  - Draw up and maintain a prioritised accelerator R&D roadmap towards future large-scale facilities for particle physics
  - Coordinate the accelerator R&D activities on the roadmap, with the aim of strengthening cooperation and ensuring effective use of complementary capabilities

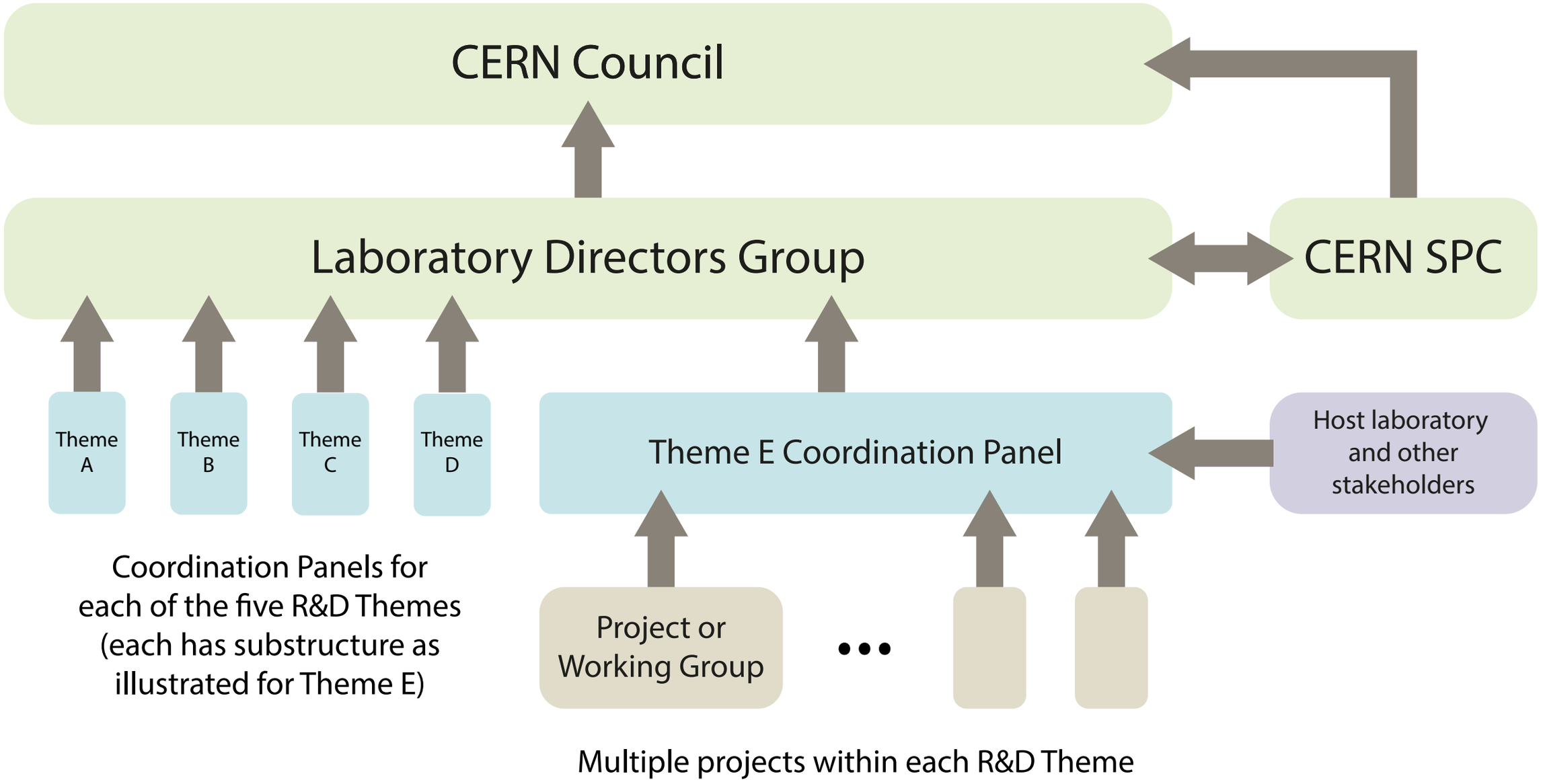
LDG Composition

- Laboratory representatives
  - S. Bentvelsen (NIKHEF)
  - F. Bossi (LNF)
  - J. Clarke (DL)
  - N. Colino (CIEMAT)
  - F. Gianotti (CERN)
  - B. Heinemann (DESY)
  - D. Newbold (RAL – Chair)
  - E. Previtali (LNGS)
  - F. Sabatie (IRFU)
  - M. Seidel (PSI)
  - A. Stocchi (IJCLab)

Close cooperation between LDG and ECFA continues

- Standing observers
  - K. Jakobs (ECFA Chair)
    - -> P. Sphicas (ECFA Chair-Elect)
  - M. Lamont (CERN Directorate)
  - J. Mnich (CERN Directorate)
  - H. Montgomery (SPC Chair)
- Secretary
  - E. Tsemelis (CERN)
  - Scientific secretary… TBA
- Extended LDG members
  - G. Bisoffi + P. Macintosh (RF)
  - W. Leemans + R. Patahill (Plasma)
  - S. Stapnes + D. Schulte (Muons)
  - J. D'Hondt + M. Klein (ERL)
  - P. Vedrine (HFM)

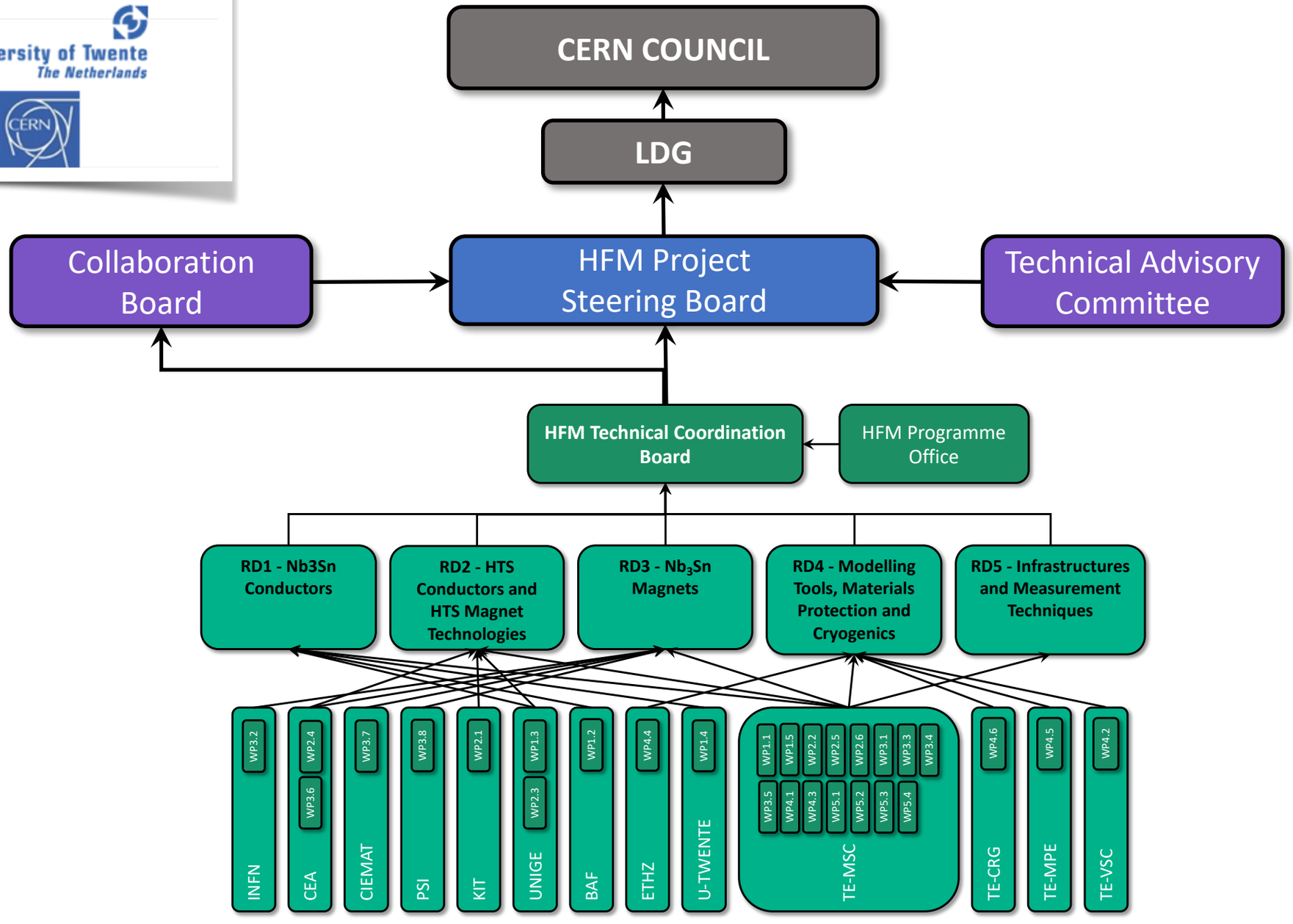
Accelerator R&D Coordination



- Vehicle for cooperative, coordinated, focussed R&D towards the future machines
  - Structure now mature, regular LDG / SPC review cycle in operation
  - Next review and report to Council in November / December 2023

Laboratory Directors Group

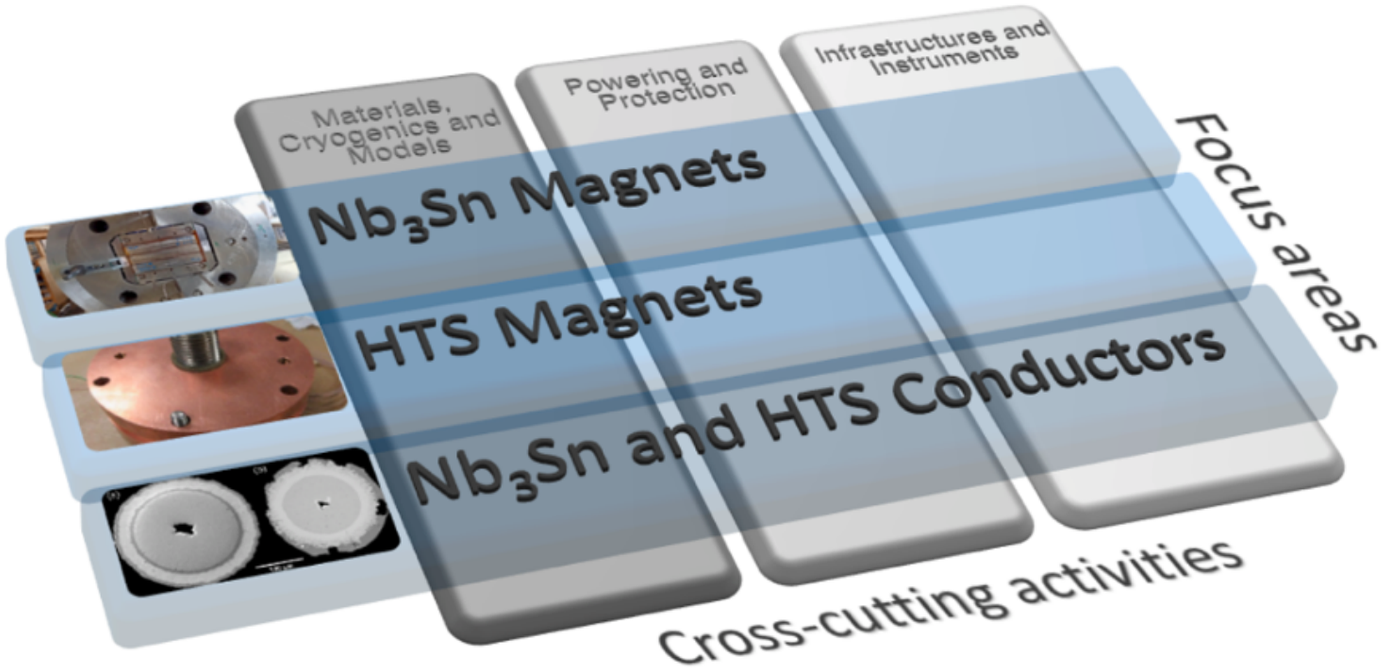
HFM Project



Science and Technology Facilities Council

Laboratory Directors Group

HFM Project

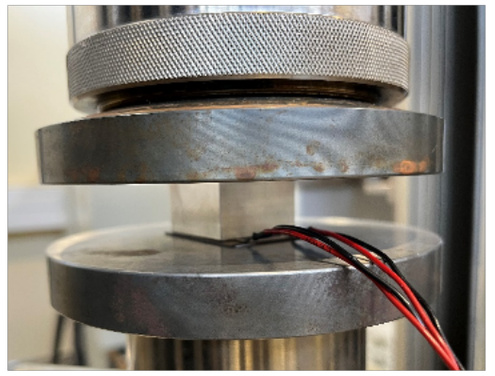


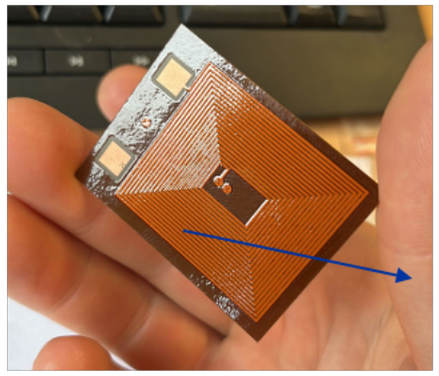
Development of Novel Magnet Protection Method

E-CLIQ: External Coil Coupled Loss Induced Quench

E-CLIQ in development for an SMC magnet demonstrator

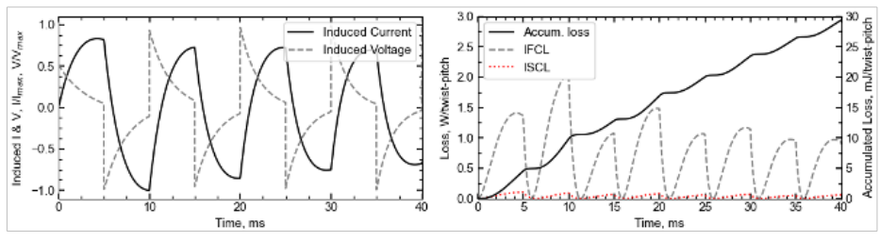
- Able to generate local dB/dt of > 100 T/s
- Compact envelope, width of a Nb_3Sn cable





Design tested to withstand loads of over 200 MPa ✓

Modeling tools further matured

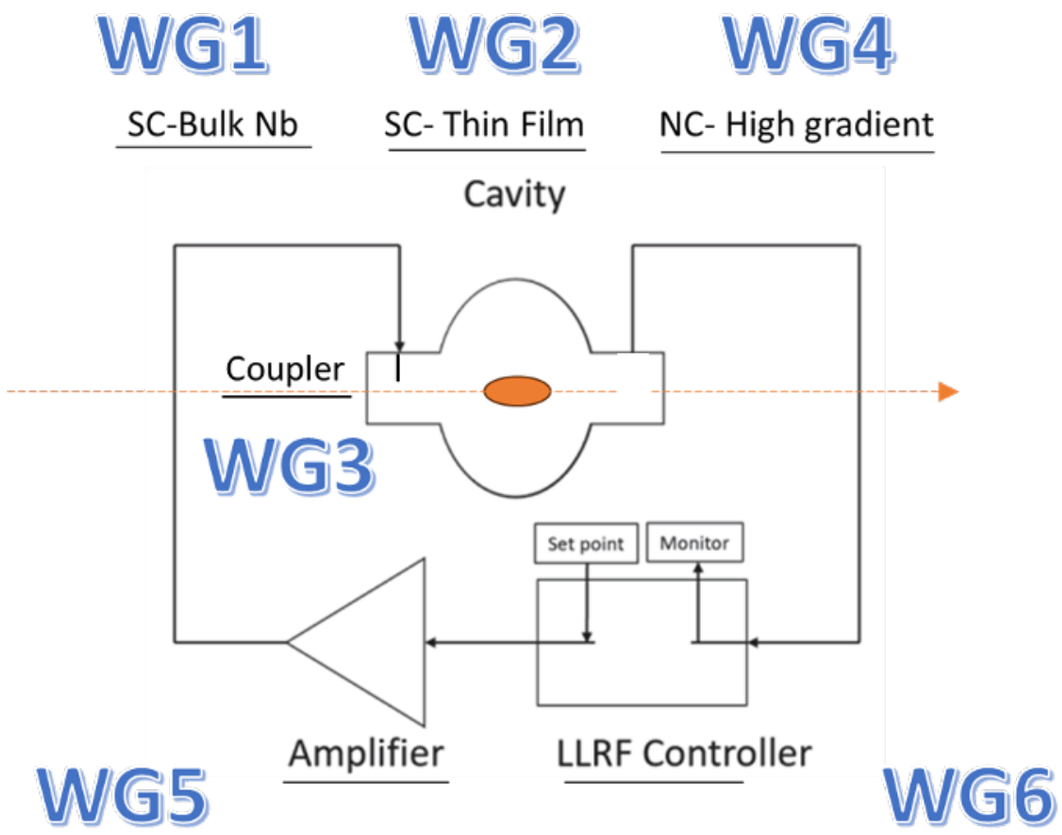


- Comprehensive work plan
  - HLT & LTS – different maturity today
  - Conductors, cables, and prototypes
  - Controls, modelling, and facilities
  - Dipoles and other applications

Science and Technology Facilities Council

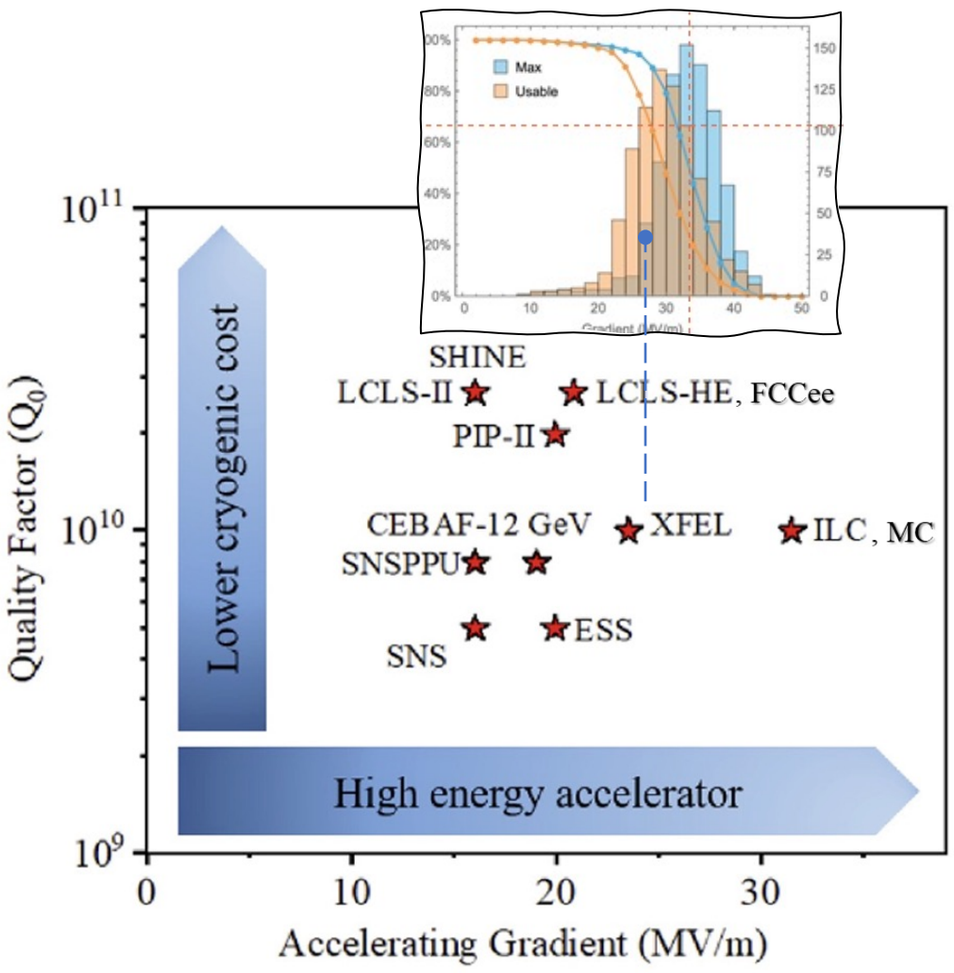
RF Structures

RF Implementation Panel		G. Bisoffi INFN-I, P. McIntosh STFC-UK
WG1	**Bulk Nb**	M. Baylac CNRS-F, C. Madec CEA-F, L. Monaco INFN-I
WG2	**Thin films**	C. Antoine CEA-F, O. Malyshev STFC-UK
WG3	**Couplers**	F. Gerick CERN-CH, E. Montesinos CERN-CH, A. Neumann HZB-D
WG4	**NC High gradient**	W. Wünsch CERN-CH, D. Alesini INFN-I
WG5	**RF Power sources**	I. Syratchev CERN-CH, G. Burt ULAN-UK, M. Jensen ESS-SE
WG6	**LLRF, AI, ML**	Z. Geng PSI-CH, W. Cichalewski U-Lodz-P



RF Structures

WG1: Niobium cavity R&D goals & direction



Most **R&D benefits several** future PP **colliders** (FCC, MC, ILC, ERLC)

HINTS FOR THE FUNDING AGENCIES

1. More funding & HR for treatments:

✓ **FE** studies, **cost** optimisation, **industrial** manufacture.

2. Contributions from other disciplines:

✓ **Robotics** - cavity prep. in cleanrooms.

✓ **Chemistry - Plasma** proc. for FE recovery.

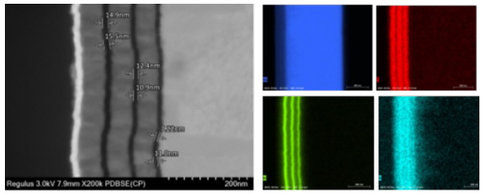
3. Maintain/improve infrastructures:

✓ ISO4 **cleanrooms** for preparation & assembly.

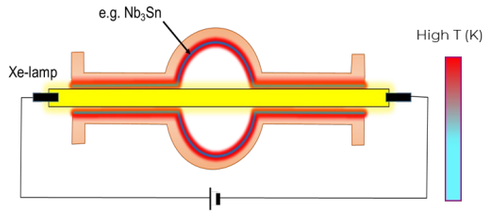
✓ Vertical low power **test stand**

RF Structures

WG2: Thin-film cavities

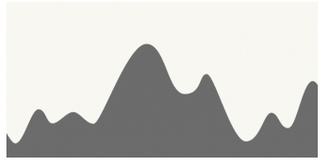


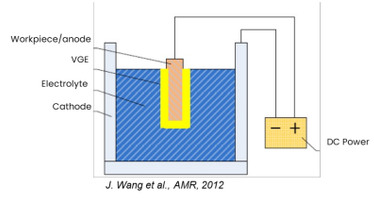
SIS multilayer coating (Nb/AlN/Nb3Sn) on Ta



Flash Lamp Annealing

Same EP set-up
Different regime





Plasma Electrlytic Polishing

Labs: **CEA-Saclay, CERN, HZB, HZDR, INFN, STFC, USI, Hamburg U. (DESY),** (**I.FAST-WP**) JLAB, KeK and FNAL

- Tightly-knit network, very well connected worldwide.
- Small teams, limited budgets, technical support and access to RF tests.

HINTS FOR THE FUNDING AGENCIES

To facilitate expedited multi-cell coated cavity verification, 1.3 GHz and lower

Intensify R&D:

- ✓ **more SC materials** to explore, various **techniques**, **targets**
- ✓ **surface/material characterization** and SC property measurements.
- ✓ **Cu-cavity** production and their polishing.
- ✓ laser and flash-lamp **annealing** on Cu samples/cavities.

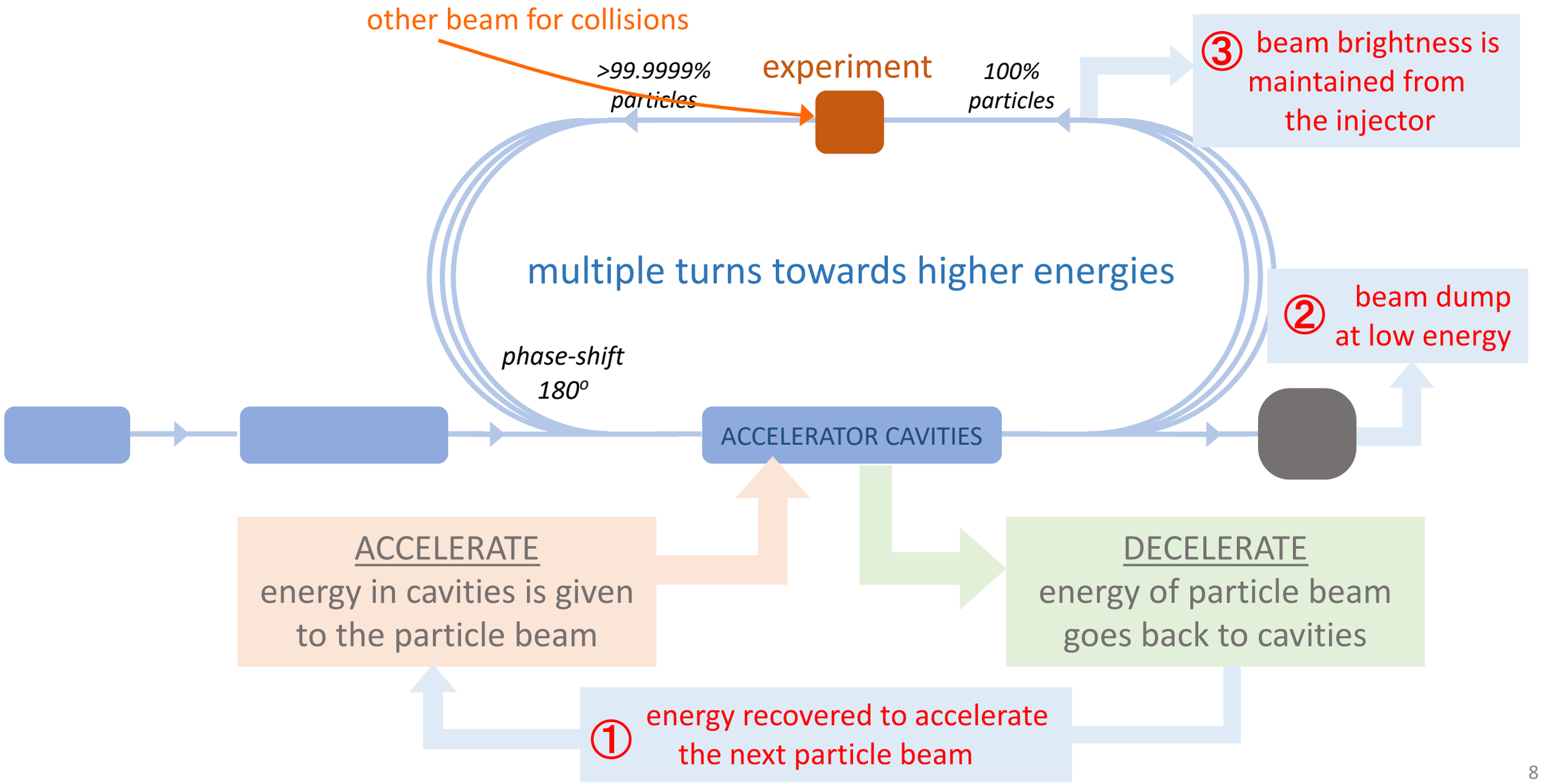
More funds-people/higher priority for:

- ✓ **facilities** (people, liq-He, electricity, …); **for many cells**, various **frequencies**
- ✓ furnace + new **ALD** coating set-up.
- ✓ access to clean rooms.
- Have **more test installations** available (so far some at CERN, HZB and DESY, INFN; in preparation at STFC).
- Have **more sample characterization stations** available.

	Staff	PhD students	Funds/yr (k€)
Present	30	9	870
Ideal	60	18	2100

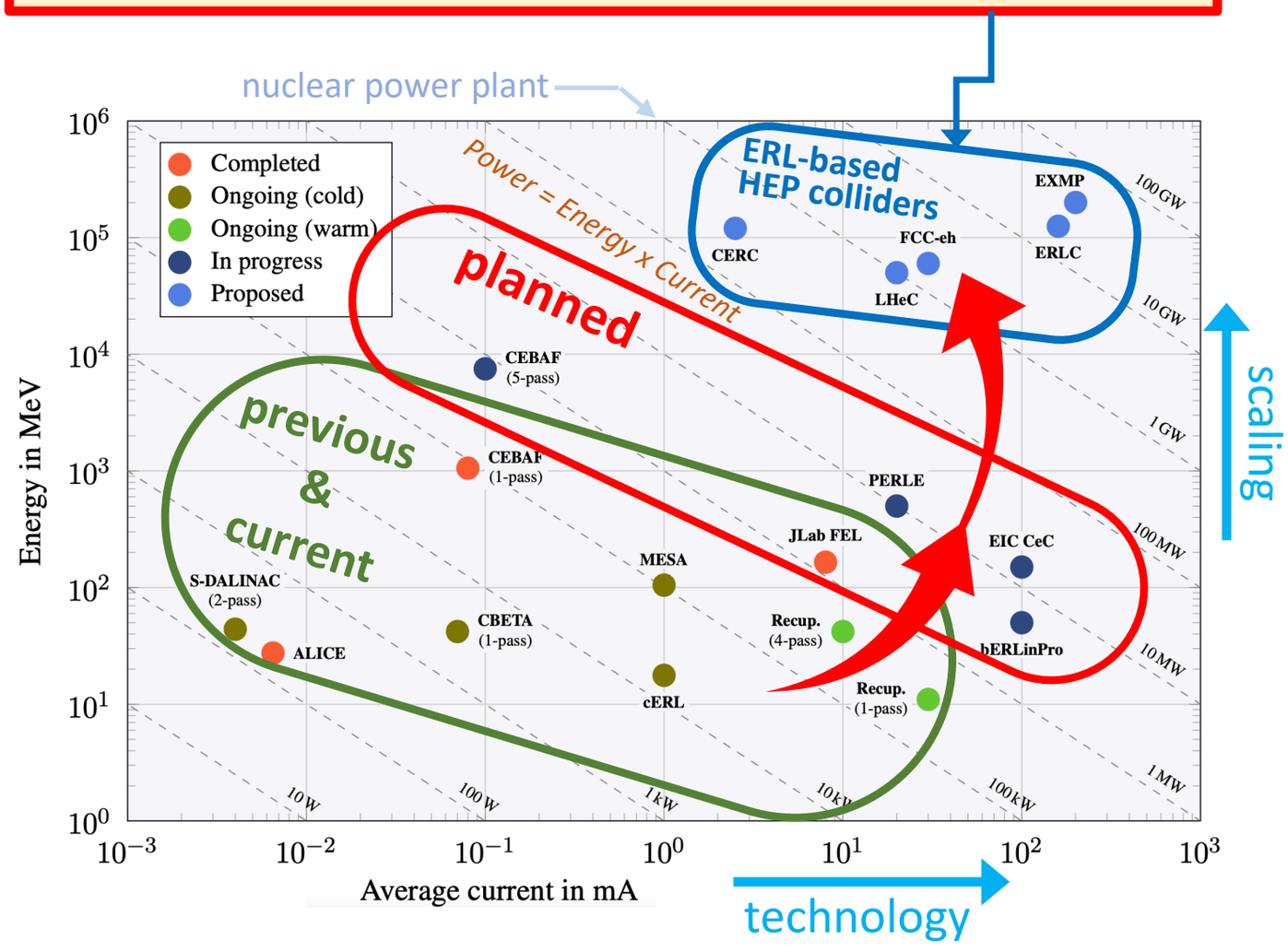
Energy-Recovery Linacs

The principle of Energy Recovery Linacs



Energy-Recovery Linacs

ERL to enable high-power beams that would otherwise require one or more nuclear power plants



Future ERL-based Colliders

H, HH, ep/eA, muons, …

R&D Roadmap

bERLinPro & PERLE

essential accelerator R&D labs with ambitions overlapping with those of the particle physics community

towards high energy & high power

Energy Recovery demonstrated

great achievements on all aspects and large research infrastructures based on Energy Recovery systems have been operated successfully

Energy Recovery Linacs (ERL): reaching higher luminosities with less power requirements

Laboratory Directors Group

ERL: iSAS

iSAS is now an approved Horizon Europe project

Grant Agreement has been signed this week – project starts on March 1, 2024

Spread over 4 years: ~1000 person-months of researchers and ~12.6M EUR

(of which 5M EUR was requested to Horizon Europe)

DESY. · INFN · UK Research and Innovation · HZB Helmholtz Zentrum Berlin · ESS European Spallation Source · Lancaster University · EPFL École Polytechnique Fédérale de Lausanne · cea · VUB Vrije Universiteit Brussel · cnrs · IJCLab Irène Joliot-Curie · CERN

+ industrial companies: *ACS Accelerators and Cryogenic Systems* (France), *RI Research Instruments GmbH* (Germany), *Cryoelectra GmbH* (Germany), *TFE Thin Film equipment srl* (Italy), *Zanon Research* (Italy), *EuclidTechLab* (USA)

R&D aspects for PERLE (at IJCLab) and bERLinPro

Innovate for Sustainable Accelerating Systems (iSAS)

https://indico.ijclab.in2p3.fr/event/9521/

develop a new design of an SRF cryomodule

integrating the most impactful energy saving technologies (incl. RF & ERL aspects)

ELECTRON SOURCES
for higher intensities

BEAM DYNAM & INSTRUMENTATION
for high-power beam different energies & currents

SOURCE → INJECTOR → DUMP

HIGHER-ORDER MODE DAMPING
efficient HOM extraction w/o increasing cryoload

HIGH-TEMPERATURE SC TECHNOLOGY
towards 4.2 K operation

FRT/RF power source
efficient RF operation

ENABLE EFFICIENT ENERGY RECOVERY & FURTHER REDUCE POWER REQUIREMENTS

14

UKRI Science and Technology Facilities Council

ERL: Applications

Potential impact of ERL technology

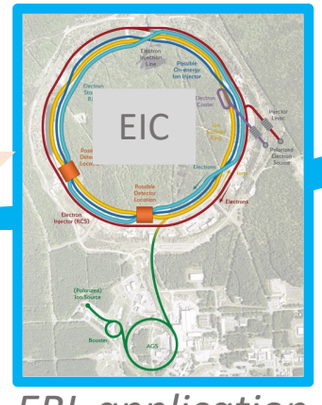
demonstrate multi-turn high-power ERL

2020'ies

high-power ERL demonstrated

enables the ultimate upgrade of the LHC program

2030'ies



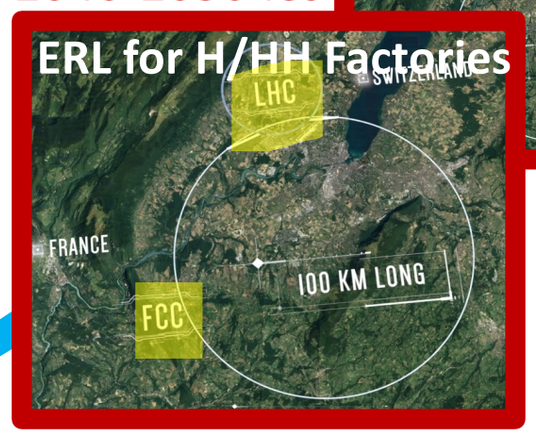
ERL application electron cooling

2030-2040'ies

high-power ERL e⁻ beam in collision (ep/eA @ LHC program)

1 ERL beam

2040-2050'ies



2 ERL beams

2070'ies

reuse ERL

high-power ERL for e^+e^- Higgs Factories (Z/W/H/top/HH program)

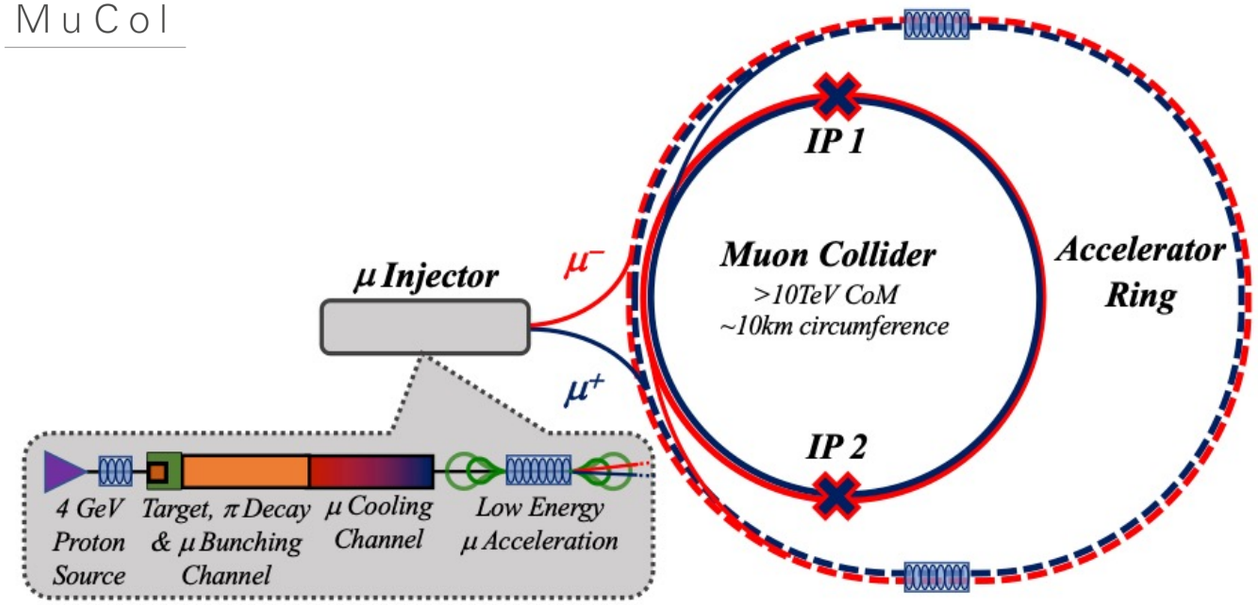
increases the performance of the next major colliders

Muons

MuCol

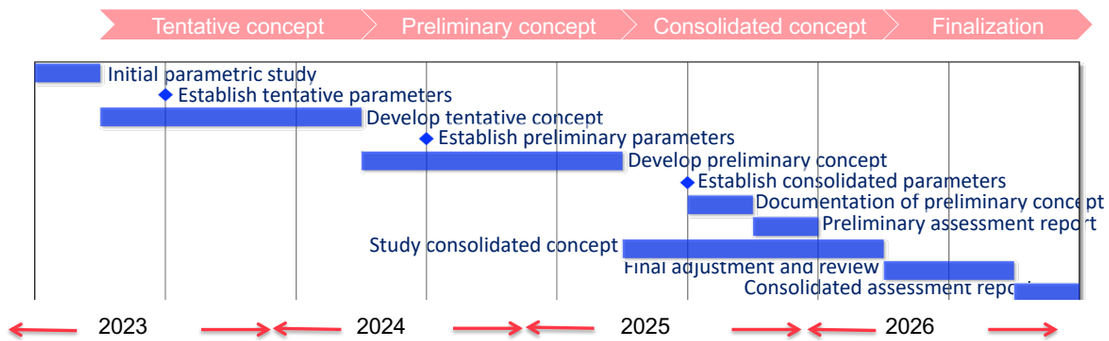
Muon Collider Progress

International MUON Collider Collaboration



Collaboration goals

- Develop muon collider concept
  - Focus on 10 TeV (integrated luminosity 10 ab^{-1})
  - Consider potential initial stage (maybe 3 TeV, integrated luminosity 1 ab^{-1})
- By 2026
  - Assessment report
  - R&D plan toward collider
- Currently writing Interim Report, as promised, ready March 2024
  - Provided tentative parameter document



Collaboration is growing

- 68 signatories, several from US, other partners
- EU co-funded Design Study is now fully active
- Strong US interest: community ask in P5: ramping up to 50 FTE for accelerator, 30 FTE for the detector

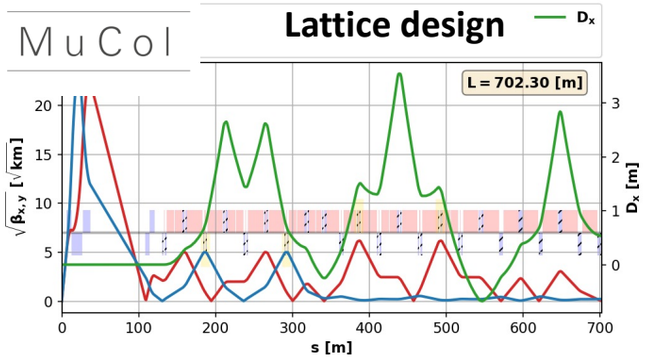
Technical progress

- Make adequate progress on the subjects we are working on
- Progress resource-limited, new collaborators important (in particular larger US contribution)

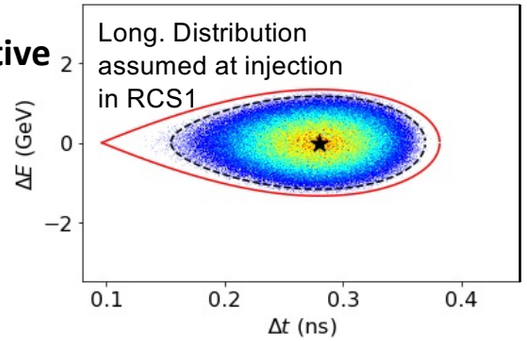
Muon Collider Progress

MuCol

Lattice design

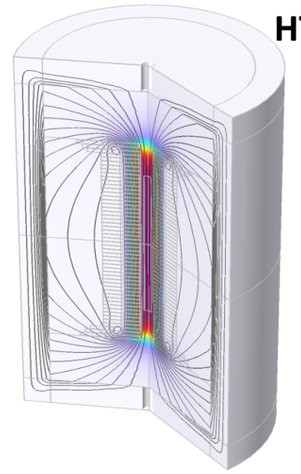


RF and collective effects

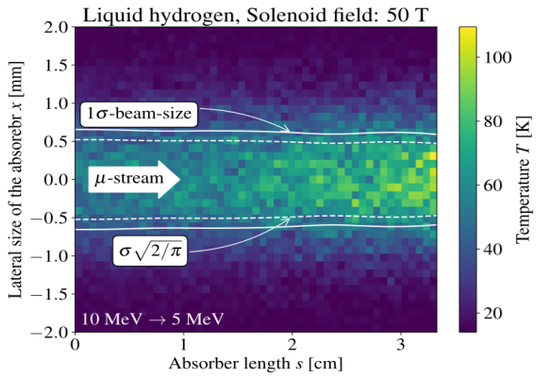


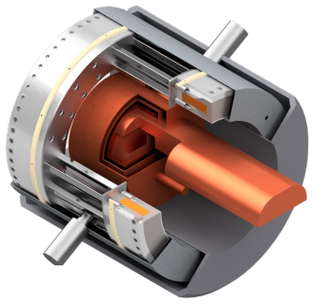
International MUON Collider Collaboration

HTS solenoids

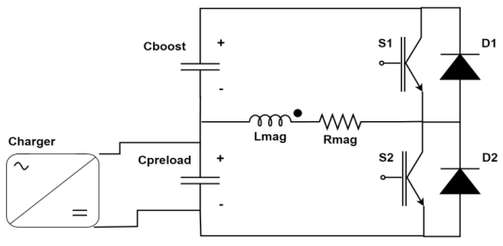


Cooling module model design

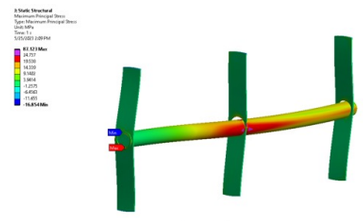


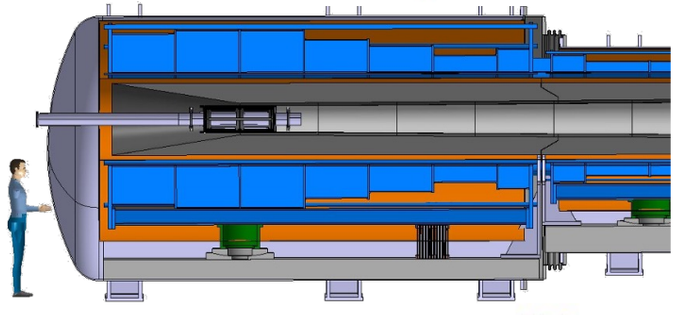


Fast-ramping magnet power converter

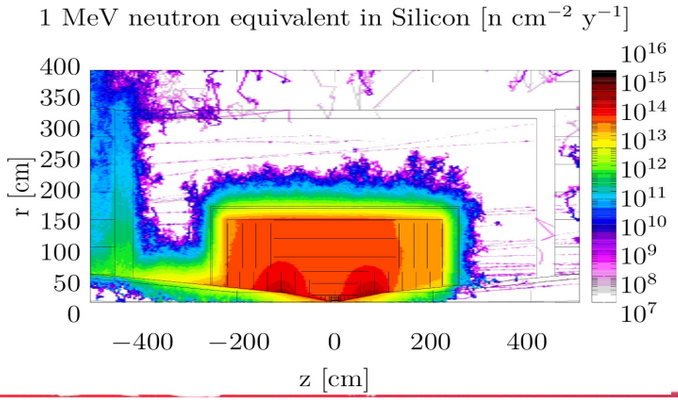


Target





Beam-induced radiation in detector



And more

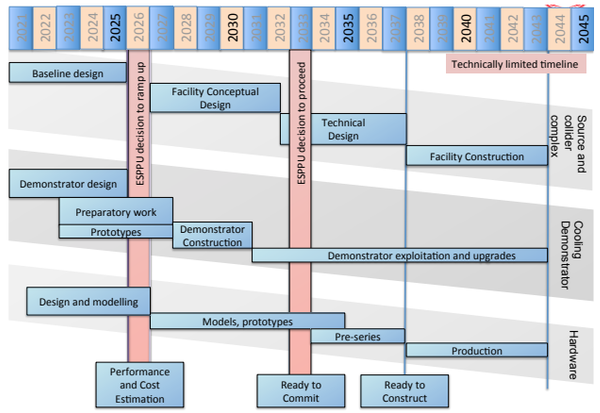
Implementation Considerations

MuCol

International MUON Collider Collaboration

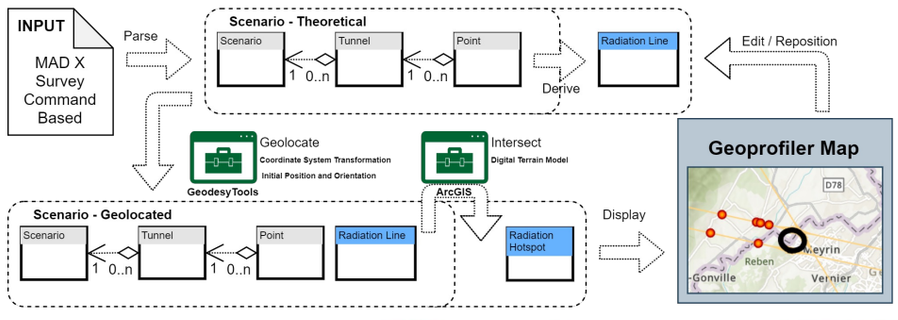
Reviewing timeline (still evolving)

- Uncertainties from physics case (e.g. HL-LHC), budget profile etc.
- On the critical path
  - Muon cooling technologies and integration
  - Magnet technology
  - Detector technologies
- Initial stage to start physics before 2050 appears possible
  - To be confirmed before next ESPPU



Potential site next to CERN identified

- Mitigates neutrino flux
  - Points toward mediterranean and uninhabited area in Jura
- Detailed studies required (280 m deep)
- Will look for other sites, looks promising
- **FNAL** and other sites will also be studied
  - FNAL takes test facility into account in their ACE plans



Neutrino flux mitigation

Magnets

Has been reviewed by expert panel

Experts anticipate technology to be **mature in O(15 years):**

- **HTS solenoids** in muon production target, 6D cooling and final cooling
  - HTS tape can be applied more easily in solenoids
  - Strong synergy with society, e.g. fusion reactors
- **Nb_3Sn 11 T magnets** for collider ring (or HTS if available)

For second stage can use **HTS or hybrid collider ring magnets**

Outcome of the HALHF Collaboration Meeting held at DESY

Hybrid meeting with the HALHF community in Hamburg and online (56 participants, 33 people on site)

Goals of the meeting were:

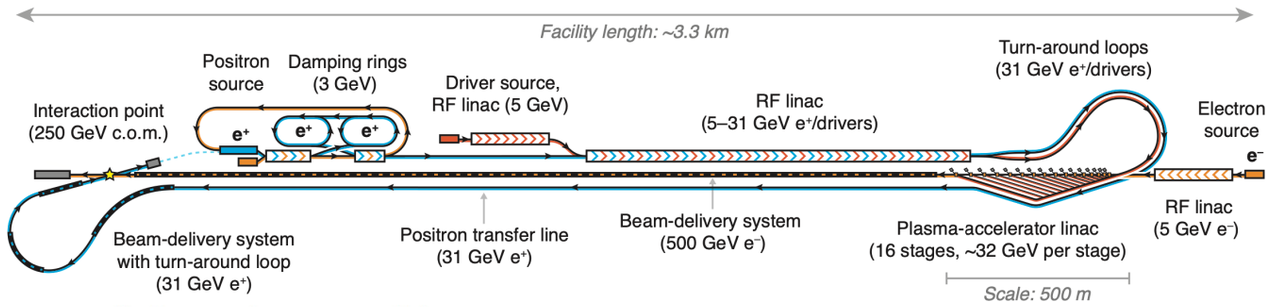
- Update on current status of the HALHF concept
- Plan for staging demo
- Assess impact on detector design
- Assess challenges in
  - Conventional accelerator systems
  - Plasma systems
- Make the HALHF design realistic and realizable

HALHF:

- An end-to-end preliminary collider design presented by Brian Foster, Richard D'Arcy and Carl Lindstrøm
- Asymmetric energy e+e- collider design with a 500 GeV electron arm and a 31 GeV positron arm.
- Plasma-accelerator driven electron arm and a positron-arm based on conventional linac

B. Foster *et al., New J. Phys.* **25**, 093037 (**2023**)
https://iopscience.iop.org/article/10.1088/1367-2630/acf395

https://arxiv.org/pdf/2303.10150.pdf



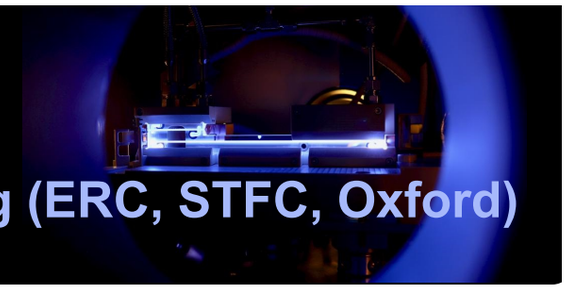
Machine parameters	*Unit*		
Center-of-mass energy	GeV	250	
Center-of-mass boost		2.13	
Bunches per train		100	
Train repetition rate	Hz	100	
Collision rate	kHz	10	
Luminosity	$cm^{-2}\,s^{-1}$	0.81×10^{34}	
Peak luminosity (in top 1%)		57%	
Estimated total power usage	MW	100	
Beam parameters		e^-	e^+
Beam energy	GeV	500	31.25
Bunch population	10^{10}	1	4
Bunch length in linac (rms)	μm	9	75
Bunch length at IP (rms)	μm	75	
Energy spread (rms)	%	0.15	
Horizontal emittance (norm.)	μm	160	10
Vertical emittance (norm.)	μm	0.56	0.035
IP horizontal beta function	mm	3.3	
IP vertical beta function	mm	0.1	
IP horizontal beam size (rms)	nm	729	
IP vertical beam size (rms)	nm	7.7	
Average beam power delivered	MW	8	2
Average beam current	mA	0.016	0.064

RF linac parameters		
Average gradient	MV/m	25
Wall-plug-to-beam efficiency	%	50
RF power usage	MW	47.5
Peak RF power per length	MW/m	21.4
Cooling req. per length	kW/m	20
PWFA linac parameters		
Number of stages		16
Plasma density	cm^{-3}	1.5×10^{16}
In-plasma acceleration gradient	GV/m	6.4
Average gradient (incl. optics)	GV/m	1.2
Length per stage[a]	m	5
Energy gain per stage[a]	GeV	31.9
Initial injection energy	GeV	5
Driver energy	GeV	31.25
Driver bunch population	10^{10}	2.7
Driver bunch length (rms)	μm	27.6
Driver average beam power	MW	21.4
Driver-to-wake efficiency	%	74
Wake-to-beam efficiency	%	53
Driver-to-beam efficiency	%	39
Wall-plug-to-beam efficiency	%	19.5
Cooling req. per stage length	kW/m	100

[a] The first stage is half the length and has half the energy gain of the other stages (see Section V. 4).

Outcome of the discussions

How to continue and push HALHF – prospective funding sources promising (ERC, STFC, Oxford)



- **Start-to-end simulations: high fidelity, full physics modeling**
  - Include non-linear QED effects in extreme regime
- **Need a plan for staging demonstrator:**
  - “Staged approach”:
    - What does a multi-stage demonstrator look like?
    - Are there current facilities that can be used without major (>1M€) investment needed?
    - What investment is needed for a full-fledged demonstrator?
- **Develop base line parameters for drive linac** and collaborate with drive linac experts
- **Work out parameters for ILC-like positron source using spent e^- beam**
- **Detector concept development** needs to continue
- **Produce a “pre-CDR”** in the next few months – a HALHF scheme in which all conventional parts are specified and believably implementable, all PWFA parts clearly defined and coherent machine described.

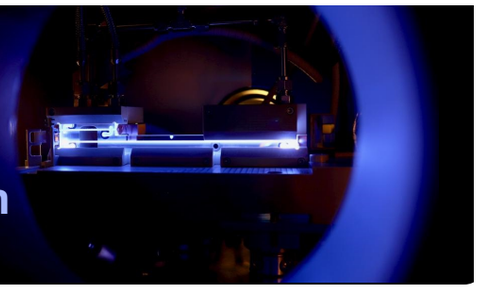
Intermediate milestones:

- Collaboration meeting ~ 6 months from now. Venue: Oslo (tbc)
- “Erice” expert meeting to draft “pre-CDR” 03.-08.10.2024 (tbc) limited to ~30 experts
- Collaboration meeting end of 2024 / early 2025 to “sign off” pre-CDR and launch ”funded” R&D phase.

Plasma

Strategies of PWFA facilities align with pre-CDR work

Plan covers major plasma accelerator challenges – need extra resources for coordination



2018 **Plasma dechirper**
- D'Arcy *et al.*, **PRL** 122, 034801 (2019)

2019 **Energy depletion and energy doubling**

Wakefield sampling
- Schröder *et al.*, **Nat. Commun. 11 5984** (2020)

2020 **Energy spread preservation by beam loading control**
- Lindstrøm *et al.*, **PRL** 126**, 014801** (2021)

Emittance preservation
- Lindstrøm *et al.*, submitted (2022)

2022 **High gain and overall efficiency for sustainable operation**

2024 **kHz-to-GHz plasma response**
- D'Arcy *et al.*, **Nature 603**, 58 (2022)

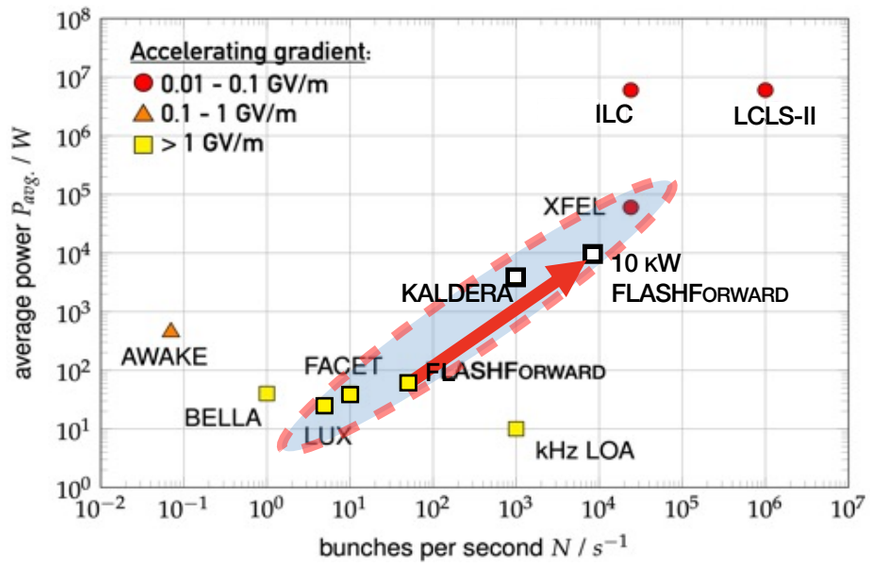
2026 **10 kW avg. power operation**

FLASHFORWARD

DESY.

complete

planned

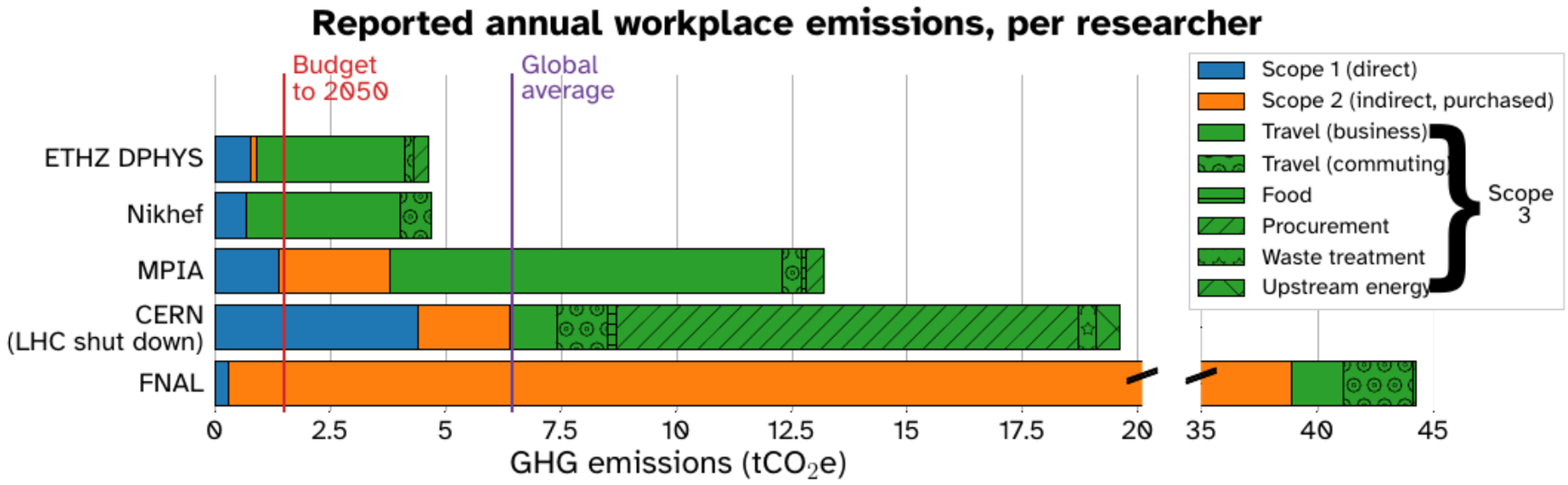


WP 3.1 Electron-beam driven PWFA experiments
Scaling to HALHF-relevant energies and parameters

10 kW stage with 40% efficiency & beam quality conservation

2030
→ FLASH: increase FEL energies,
access oxygen K-edge at 2.33 nm wavelength

Sustainability



2019 data, save MPIA (2018), and ETHZ business travel (average 2016-2018).

- Read HECAP+ report!
  - https://sustainable-hecap-plus.github.io/

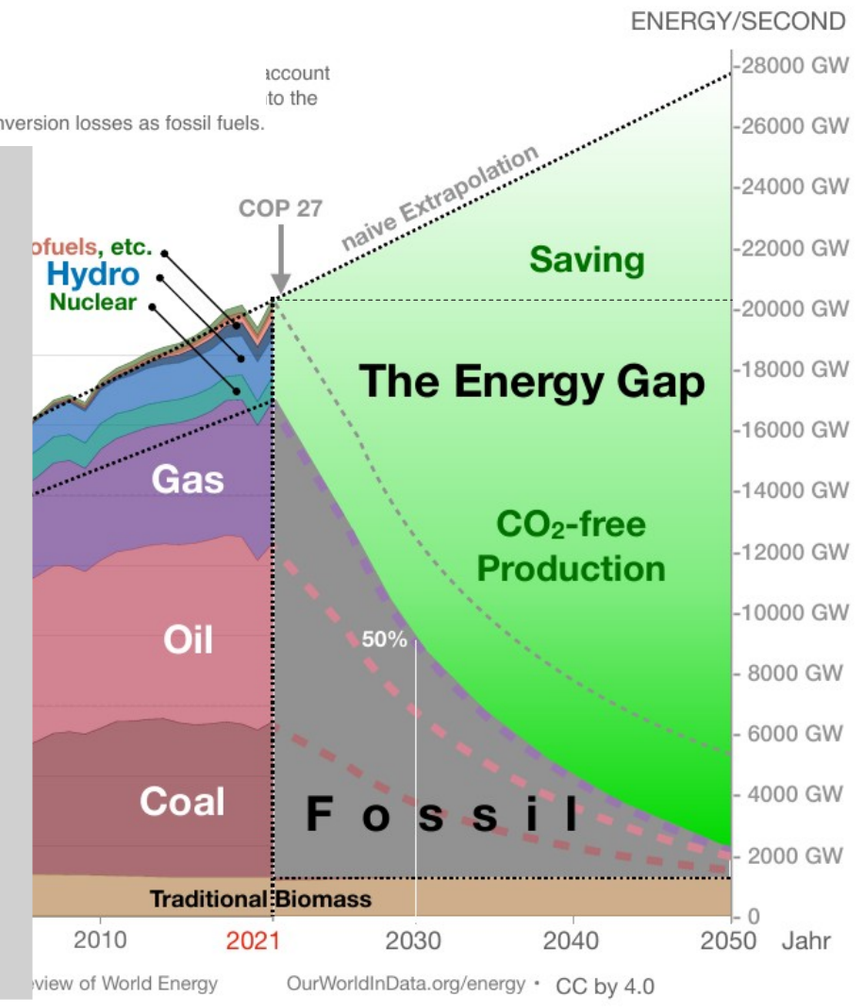
Options:

1) Expand CO2-free energies
→ factor ~12 in 7 years required;

2) Increase energy efficiency
→ factor ~2 in 7 years
e.g. Electrification of engines (factor 3-5 vs. combustion engine)
e.g. LEDs for lighting (factor 10 vs. light bulb)

3) Save energy
→ factor ~2 in 7 years
e.g.Less travel: online conferences, holidays nearby
e.g. Fewer consumer items, more repair options
e.g. Energy priority for essential things

For options 2)+3) an increase in renewables of a factor of 3 needed to cover increase from naive extrapolation is needed



Science and Technology Facilities Council

Sustainability

- LDG Working Group on "Sustainability assessment of accelerators", to define and identify:
  - Key indicators to be reported
    - Peak / instantaneous lifetime- and performance specific (per luminosity) energy consumption
    - Lifetime and specific Global Warming Potential (GWP) including construction
    - Include margins of uncertainty and possibly an assessment of the potential for improvement
  - Methodology and assumptions allowing a transparent and objective determination and comparison of these metrics across the proposals.
    - The maturity of a proposal should be determined, for example early concept phase, CDR, TDR or TRL levels
  - Other high level environmental impacts that may be relevant for all or specific collider proposals.
  - Application to accelerators of European best practices for defining GWP
- Convenor to be appointed at the upcoming LDG meeting
  - Will work closely with – and draw upon – internal sustainability projects of individual labs

Sustainability

- Other (more technical) objectives:
  - Treatment of future carbon intensity of electricity and materials: what scenarios should be assumed?
  - Assessing the potential for dynamic operation of the various facilities, i.e. the ability to adapt to a fluctuating energy supply
  - Treatment of regional vs global parameters: How to treat differences e.g. in carbon intensity between different host countries?
  - Carbon intensity / lifecycle inventory (LCI) studies of materials specific to accelerator projects: high-purity niobium, permanent magnet alloys etc
  - Use of open-source LCI databases and Lifecycle Assessment (LCA) tools to ease/automate the assessment for future research infrastructures
  - Extending the recommendations for colliders to other scientific endeavours related to HEP
  - How HEP labs can share/build up expertise jointly
- Connects directly to R&D work on sustainable technologies

Community Engagement

- Two ‘new’ events held in Frascati this summer
  - First open meeting of the LDG, with involvement of international labs
    - Nineteen major laboratories involved on three continents – can improve!
    - https://agenda.infn.it/event/35700/
  - Community report on accelerator roadmap
    - Intended to bring HEP community and accelerator R&D experts together
    - https://agenda.infn.it/event/35579/
    - Limited attendance by the HEP community
- Engagement is crucial
  - Scope and scale of the acceleartor R&D is growing
  - This is the crucial supporting activity for long-term new machines
    - With obvious relevance to the performance and sustainability of shorter-term machines
  - HEP community involvement makes sure that the goals of the European Strategy are kept ‘front and centre’
- Next open LDG meeting / workshop – please plan to attend!
  - Brookhaven, June 6-7, 2024 (FCC workshop in US is following week)
  - Great opportunity to reflect on alignment of P5 priorities and European Strategy
    - At the start of the next phase of the US programme, and just as we enter the update process

Laboratory Directors Group

Additional Material