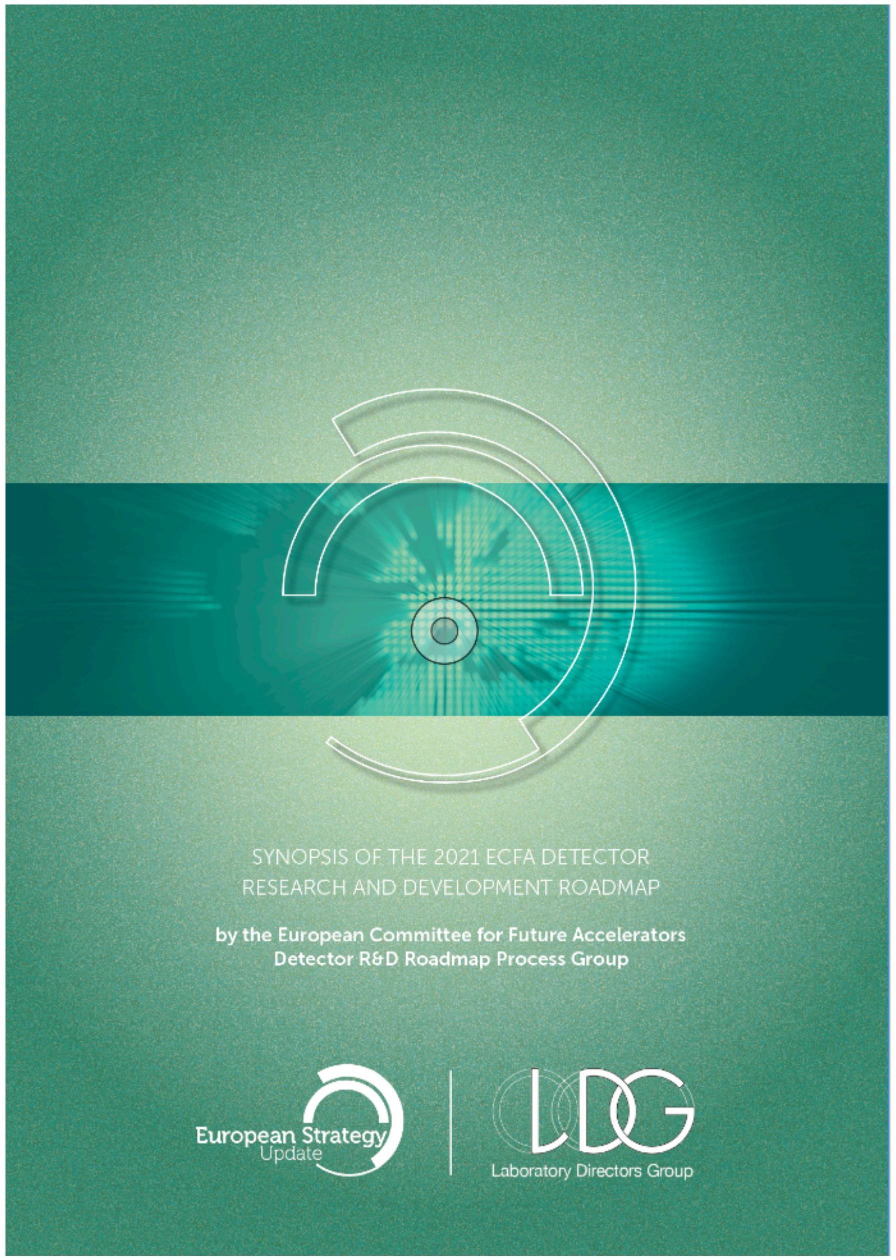
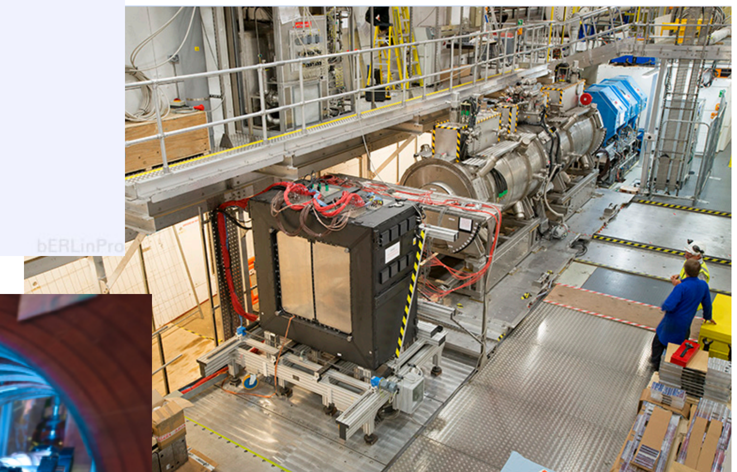
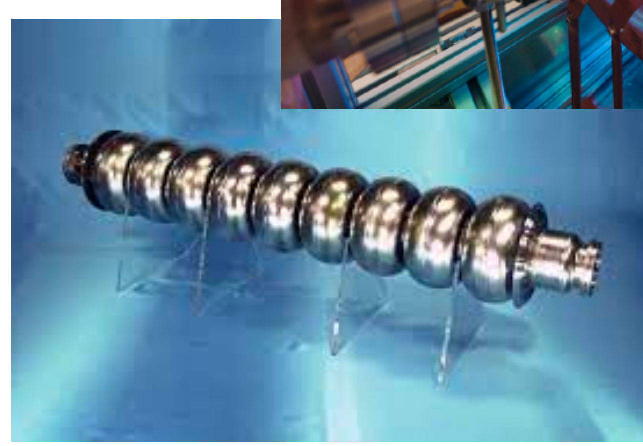
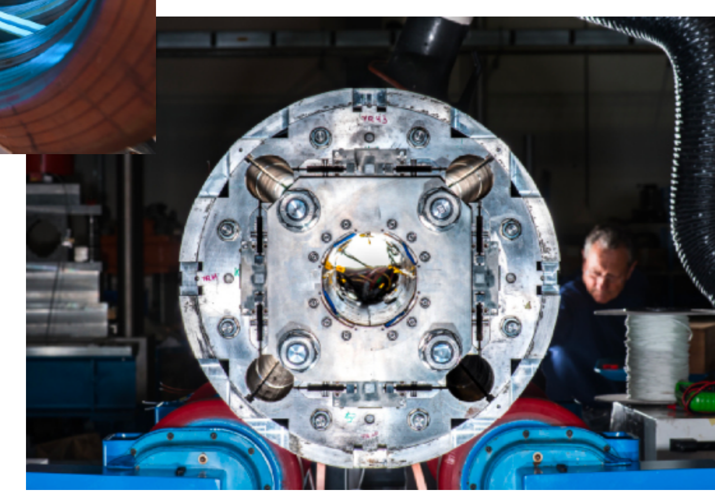
Accelerator R&D Roadmap





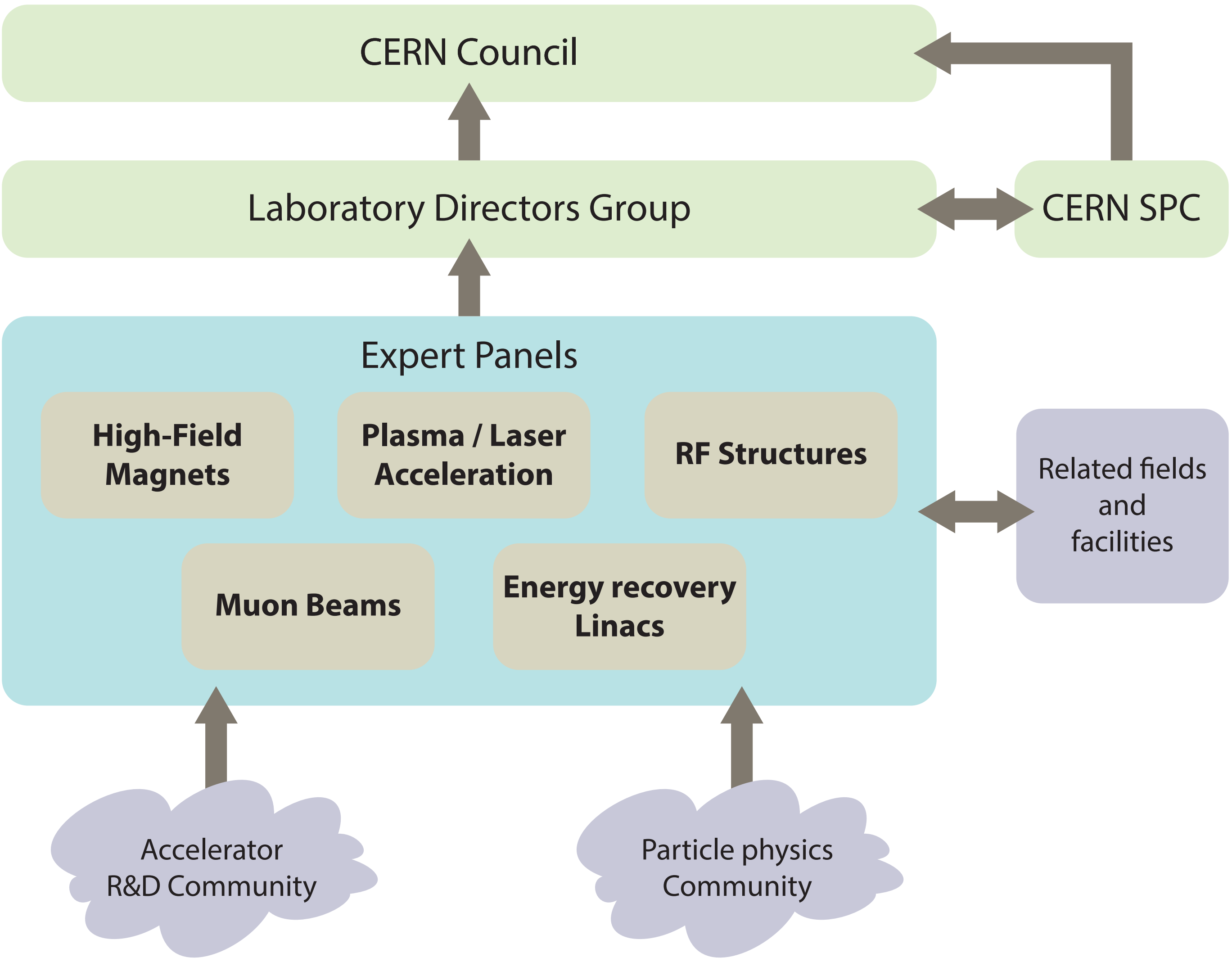




Dave Newbold, STFC
Laboratory Directors Group Chair

Accelerator R&D Roadmap

- European Strategy contains clear recommendations on accelerator R&D:
  - *The particle physics community should ramp up its R&D effort focused on advanced accelerator technologies.*
  - *The European particle physics community must intensify accelerator R&D and sustain it with adequate resources; a roadmap should prioritise the technology.*
  - *Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.*



- Expert panel chairs
  - Magnets: P. Vedrine (IRFU)
  - Plasma: R. Assmann (DESY)
  - RF: S. Bousson (IJCLab)
  - Muons: D. Schulte (CERN)
  - ERL: M. Klein (U. Liverpool)
  - Co-opted authors for additional sections

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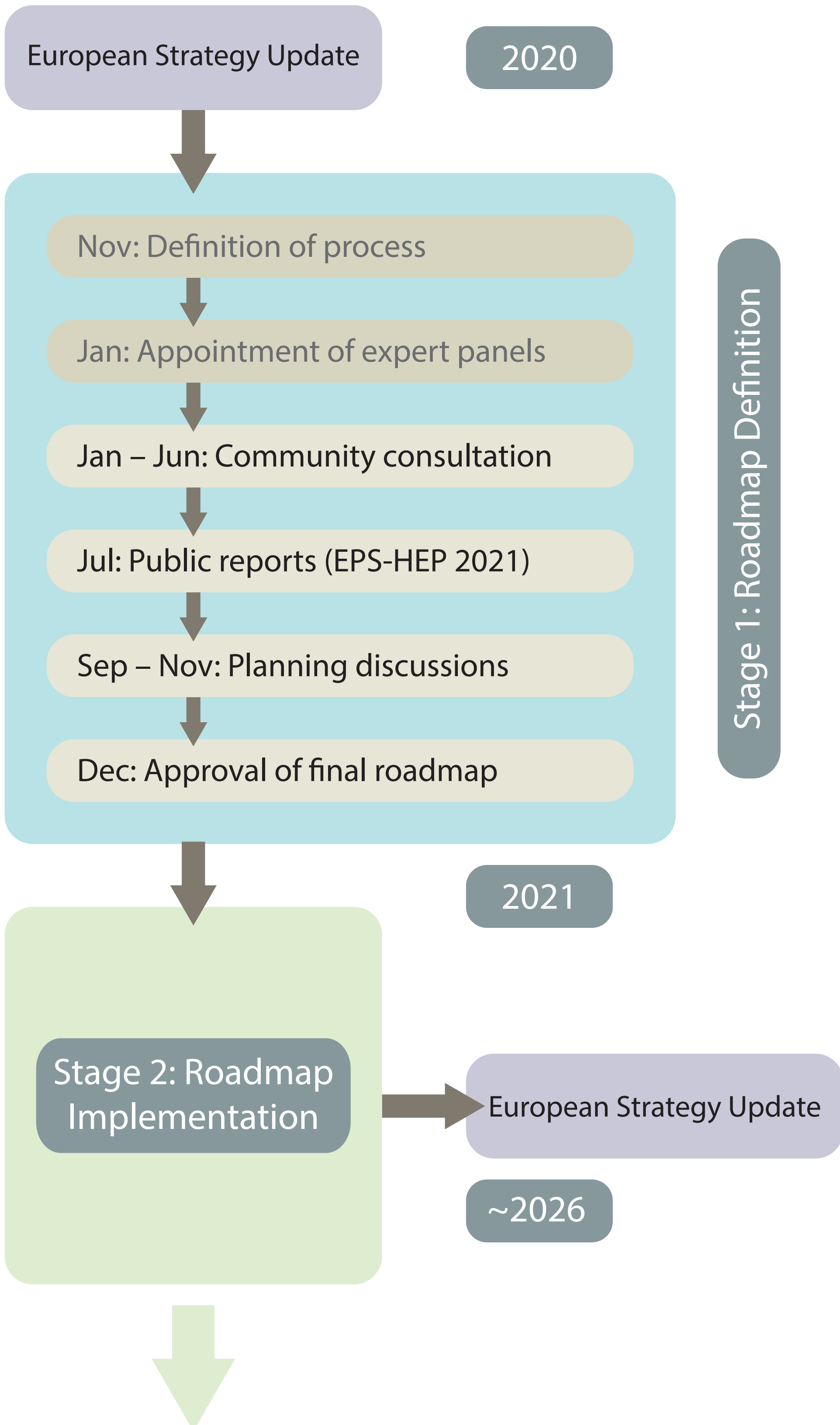
The Questions Asked

- Key questions – raised during the Strategy update process
  - What R&D is necessary for future facilities? What are the priorities?
  - How long might it take? How much will it cost?
  - What are the dependencies, conflicts or choices between activities?
  - What science can be done with demonstrators, or intermediate-scale facilities?
- Goal: provide the concrete evidence to support decision-making by the field at future Strategy updates
- Content of the roadmap
  - Broad and deep survey of each technology area
  - Identification of key R&D objectives for short term and longer term
  - Definition of delivery plans for the next five to ten years
  - Outline estimates of resource needs and the necessary facilities
  - 'Reference' chapters on e+e- programme and sustainability
  - Overarching recommendations on the future R&D programme
- The roadmap provides information, motivation and priorities
  - Decisions on overall scale and balance of the R&D programme are now required

Process



- Expert panels convened in January 2021
  - Wide representation from European institutes
  - International representation on all panels
- Consultation
  - Over fifty panel meetings and workshops held
  - Hundreds of inputs from the accelerator community
  - Workshop for the PP community in July
- Interim reports
  - R&D objectives reported at EPS-HEP, July
  - Feedback gathered from national communities via ECFA delegates
- Planning
  - Closed process for prioritisation, planning and costing
  - Final delivery plans approved in October
- SPC reviews in June, November and December 2021

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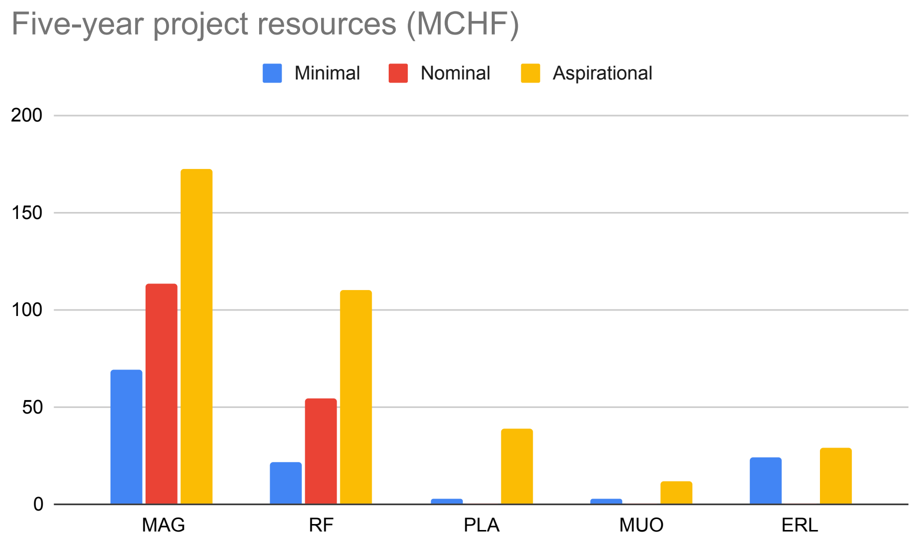
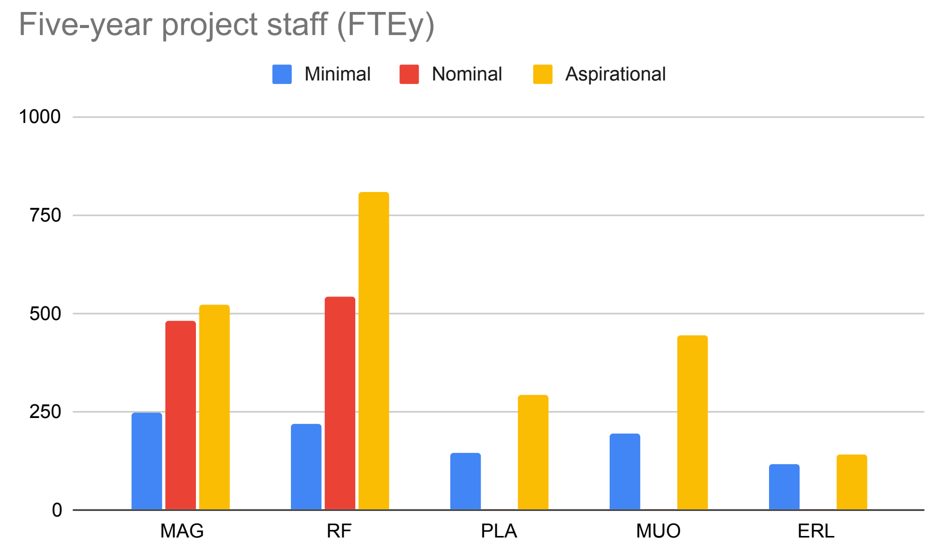
Example of R&D Plan (RF Structures)

- Superconducting RF
  - High quality factor bulk niobium
  - Field emission reduction
  - Thin superconducting films
  - SRF couplers
- Normal-conducting RF
  - Design, modelling and simulations
  - Manufacturing technology
  - mm-wave and higher frequencies
- Powering and LLRF
  - High-efficiency sources
  - mm-wave and gyro devices
  - Power need reduction
  - LLRF
  - Applications of AI / ML

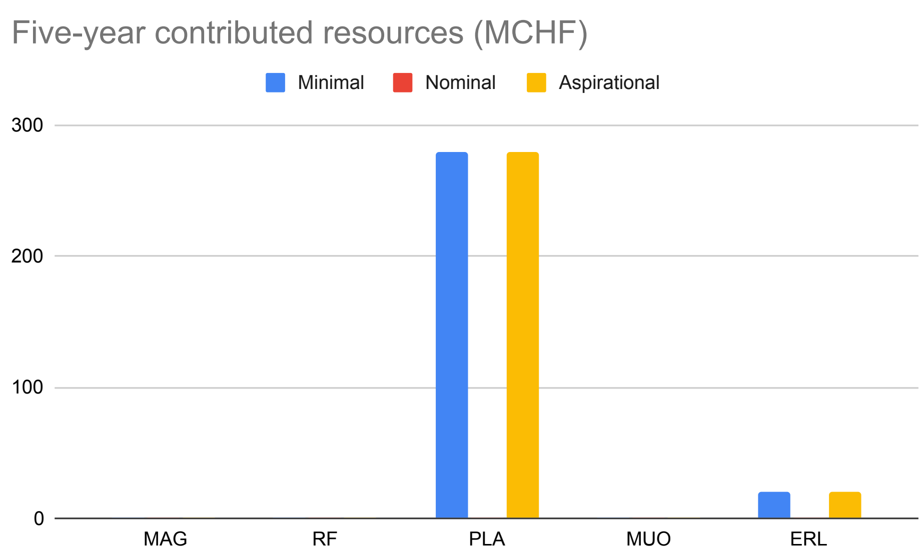
Tasks	Begin	End	Description
RF.SRF.BKNb	2022	2026	Superconducting RF: bulk Nb
RF.SRF.FE	2022	2026	Superconducting RF: field emission
RF.SRF.ThF	2022	2026	Superconducting RF: thin film
RF.SRF.INF	2022	2026	Superconducting RF: infrastructure
RF.SRF.FPC	2022	2026	Superconducting RF: power couplers
RF.SRF			**Total of superconducting RF**
RF.NC.GEN	2022	2026	Normal conducting RF: general NC studies
RF.NC.MAN	2022	2026	Normal conducting RF: NC manufacturing techniques
RF.NC.HF	2022	2026	Normal conducting RF: mm wave & high frequency
			Total of normal conducting RF
RF.HP.HE	2022	2026	High-power RF: high-efficiency klystron & solid state
RF.HP.HF	2022	2026	High-power RF: mm-wave & gyro devices
RF.HP.TUN	2022	2026	High-power RF: reduced RF power needs (tuners)
RF.HP.AI	2022	2026	AI and machine learning
			Total of high-power RF
RF.TS.NCRF	2022	2026	NC RF test stands
RF.TS.MAT	2022	2026	Test stand: new materials
RF.TS.BEAM	2022	2026	Beam test
RF.TS.SRF	2022	2026	Test stand: SRF Horizontal cryostat
			Total for test stand

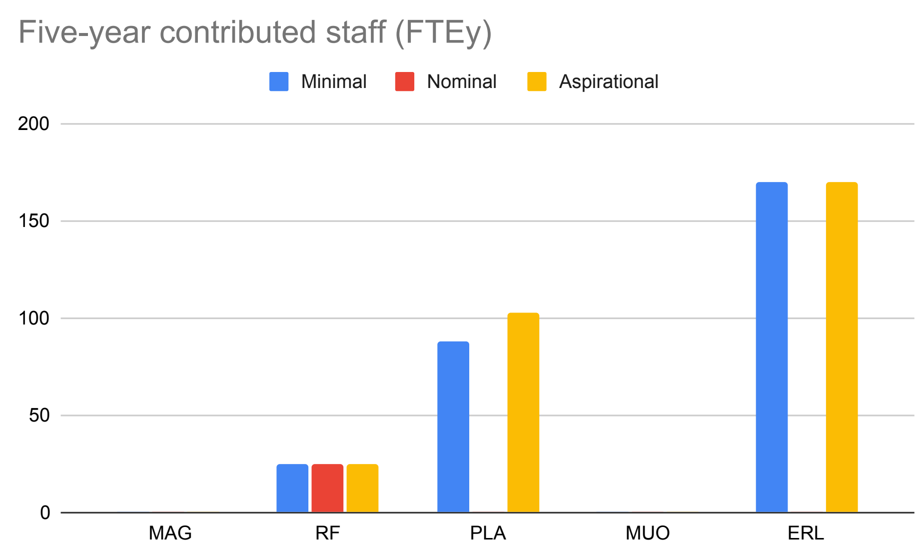
Resources





Costs of approved experimental projects with a link to the R&D programme are included within 'contributed resources'



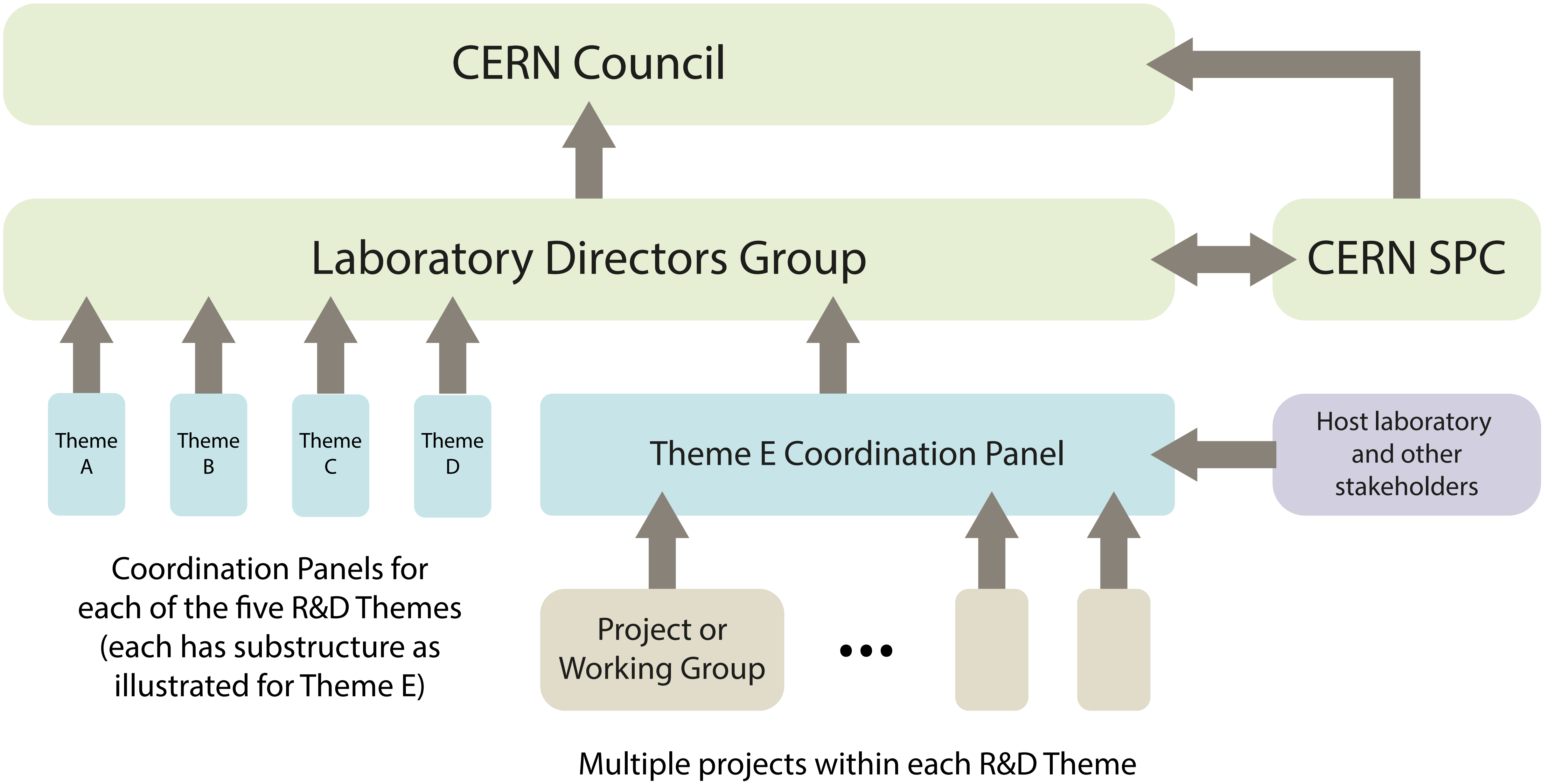


- Panels defined 'nominal', 'minimal' and 'aspirational' planning scenarios
  - 'Nominal' corresponding to the roughly the current level of funding in Europe
- Many pre-existing commitments and plans are in place
  - New funding requests being made regularly; some delivery plans dependent on external investments

General Recommendations

1. Roadmap should be accepted as the collective view of the communities
2. Governance structures should oversee the ongoing R&D ensuring:
   - Proper coordination and balance in their goals and execution
   - Continued focus on implementation of the goals of the European Strategy
   - Regular updates on progress to the community and to CERN Council
3. A broad front of R&D should be maintained, corresponding to at least the minimal resource scenario in each area
4. Provision must be left for 'blue skies' R&D and novel developments
5. Priority should be given to continuity of funding for facilities
6. Environmental sustainability should be a primary consideration
7. Emphasis on prompt scientific exploitation of R&D outputs
8. Practical considerations should factor into the design and parameters of future machines, with the close engagement of industry
9. Close cooperation between European and international labs is required
10. Training and professional development of accelerator physicists is a key factor in sustaining a vibrant and productive field

Proposed Coordination Structure



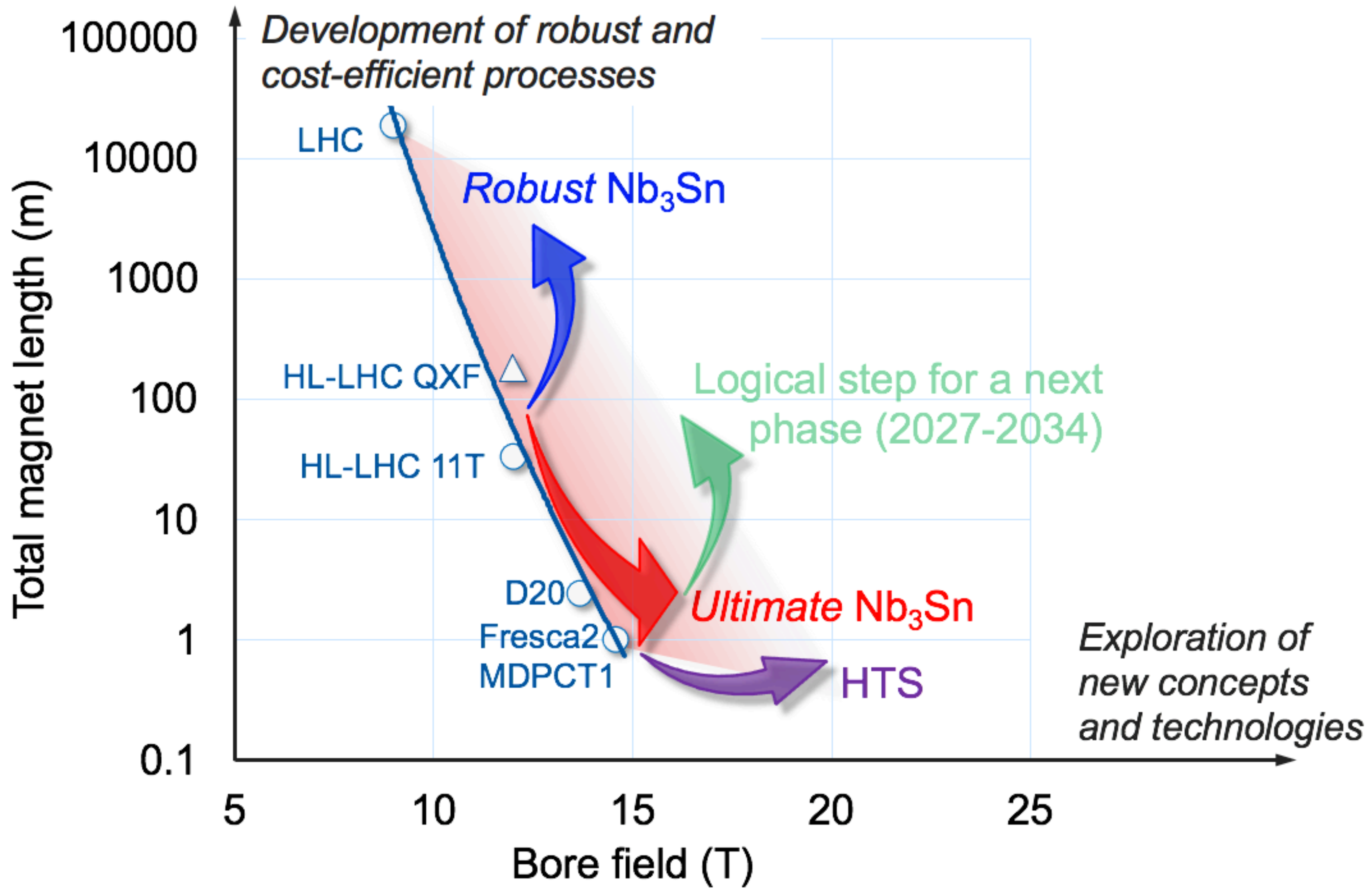
- Intended be 'lightweight', causing minimal disruption / delay to existing projects
- Provide a coherent structure for a community plan in areas still 'ramping up'

Discussions with Funding Agencies

- LDG (and ECFA) now planning in detail for implementation stage
  - Approval for the final mandate at June meeting of CERN Council
  - Practically, our authority relies on the explicit backing of the funding agencies
  - In the coming weeks, we hope to achieve 'buy-in' for the structure and scope of the R&D programme
- In the coming discussions, we hope to:
  - Receive general remarks and feedback on the proposed structure for R&D coordination
  - Identify (in outline) current and near-future FA R&D commitments, projects, and capabilities at national institutes, laboratories and universities
  - Discuss interest in future contributions to the R&D effort, including a first idea of the potential level of investment and any areas of specific interest
  - Receive proposals for leadership of the coordination panels, or other comments on their composition.
- Open Q&A session for funding agencies Thursday 28th April
  - Agenda: https://indico.cern.ch/event/1154156/
  - Both local and remote participation will be possible
  - You private inputs and questions are also extremely welcome

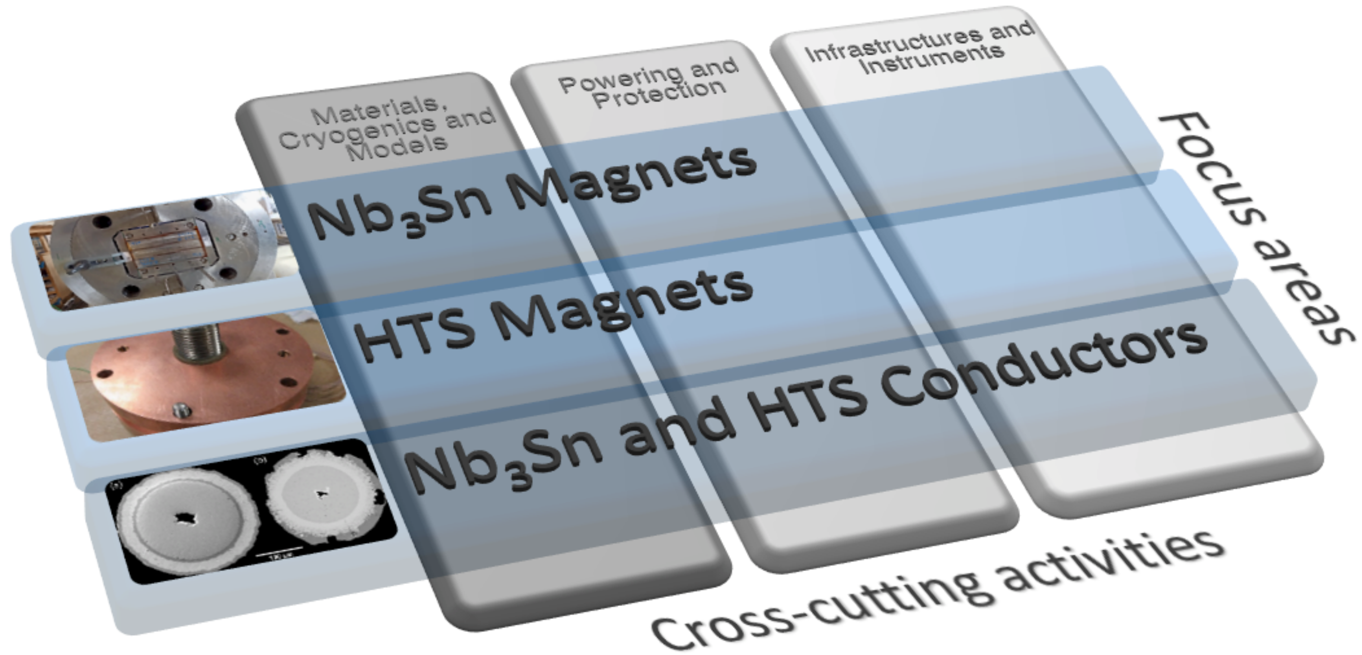
Additional Material

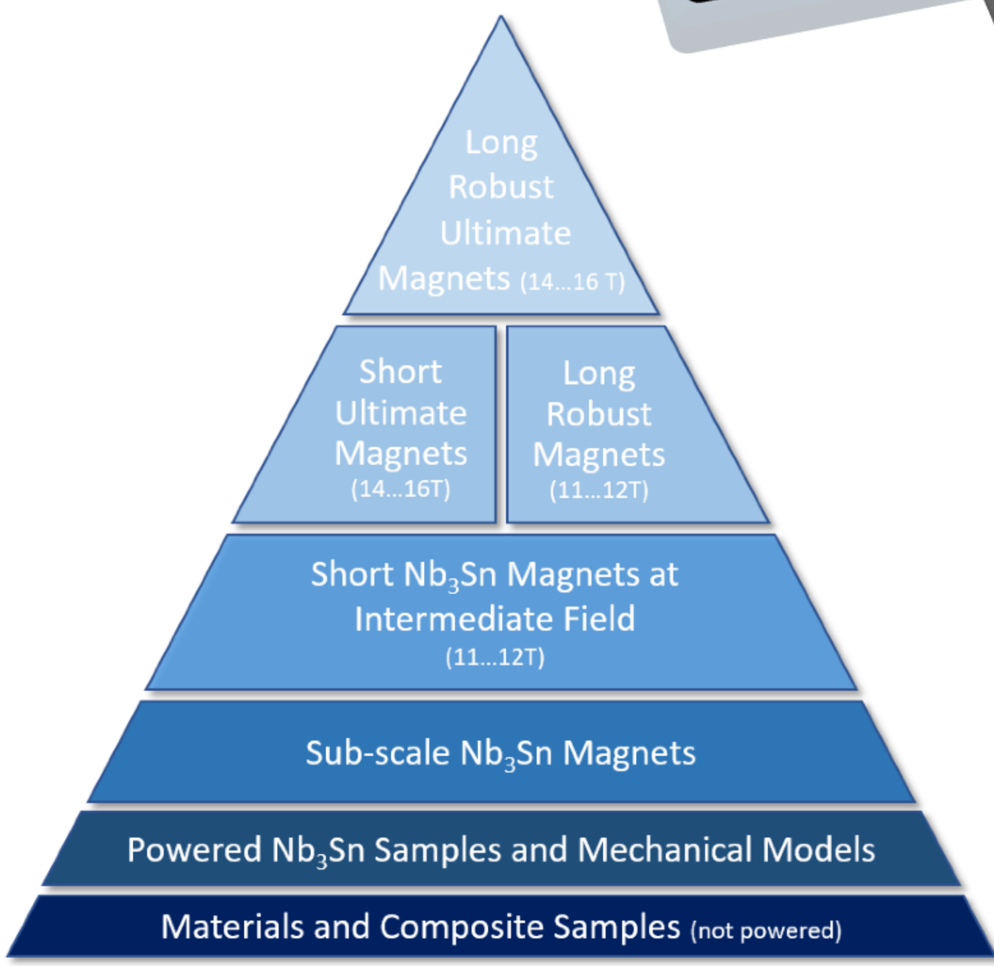
Magnets: Objectives

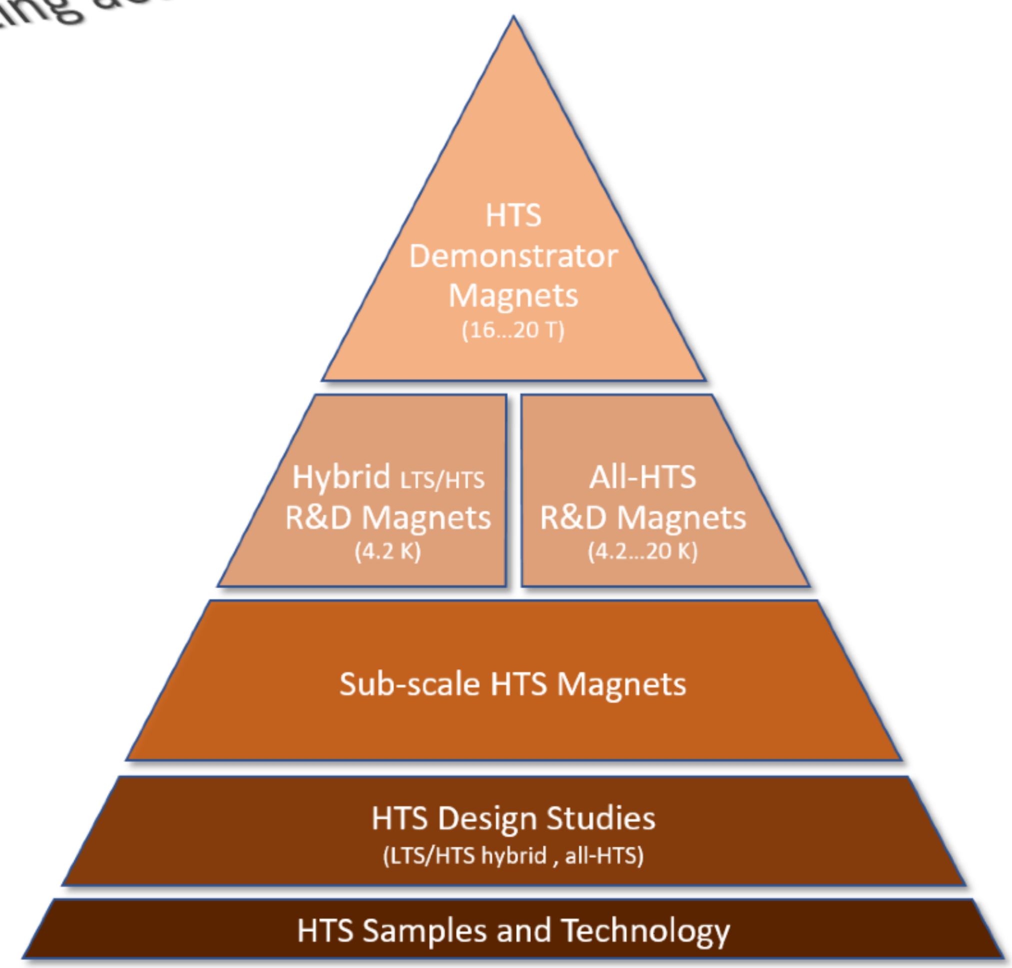


- Encompasses Ni3Sn and HTS (REBCO) developments
- 'Vertically integrated' approach to R&D
  - Development on all aspects from conductors to cables to magnets to systems
  - Emphases: full system optimisation; fast turnaround for R&D; modelling

Magnets: Plan







RF: Objectives

	Particle sources	Magnet and Vacuum systems	High Field SC magnets	Normal Conducting RF structures	Superconducting RF cavities	RF power sources	Cryogenics	Instrumentation
ILC	•				•	•	•	•
FCC	•	•	•		•		•	•
PIP-II, MYRRHA					•	•	•	•
JLEIC	•		•	•		•		•
eRHIC, LHeC					•		•	•
DIAMOND2, SLS2		•				•		•
LCLS2-HE, SHINE		•			•		•	•
DONES	•	•		•	•	•	•	•
DEMOs	•		•			•	•	
PERLE					•	•		•
BELA, compact neutron sources	•			•				•

- Scope covers both SC and NC RF structures
  - Not only cavities, but couplers, tuning elements, power sources, LLRF
- Main objectives
  - Efficiency and optimisation of the end-to-end system
  - Efficient automation / industrialisation for assembly and tuning
  - Diagnostics and rapid feedback mechanisms
  - Development of sources, materials and structures for new wavebands (mm / THz)

RF: Plan

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Laser / Plasma: Objectives

HIGH GRADIENT PLASMA AND LASER ACCELERATORS

Accelerator R&D Roadmap Pillars

FEASIBILITY, PRE-CDR STUDY

Scope: 1st international, coordinated study for self-consistent analysis of novel technologies and their particle physics reach, intermediate HEP steps, collider feasibility, performance, quantitative cost-size-benefit analysis

Concept: Comparative paper study (main concepts included)

Milestones: Report high energy e^- and e^+ linac module case studies, report physics case(s)

Deliverable: Feasibility and pre-CDR report in 2025 for European, national decision makers

TECHNICAL DEMONSTRATION

Scope: Demonstration of critical feasibility parameters for e^+e^- collider and 1st HEP applications

Concept: Prioritised list of R&D that can be performed at existing, planned R&D infrastructures in national, European, international landscape

Milestones: HQ e^- beam by 2025, HQ e^+ beam by 2032, 15 kHz high eff. beam and power sources by 2037 (sustainability)

Deliverable: Technical readiness level (TRL) report in 2025 for European, national decision makers

INTEGRATION & OUTREACH

Synergy and Integration: Benefits for and synergy with other science fields (e.g. structural biology, materials, lasers, health) and projects (e.g. EuPRAXIA, …)

Access: Establishing framework for well-defined access to distributed accelerator R&D landscape

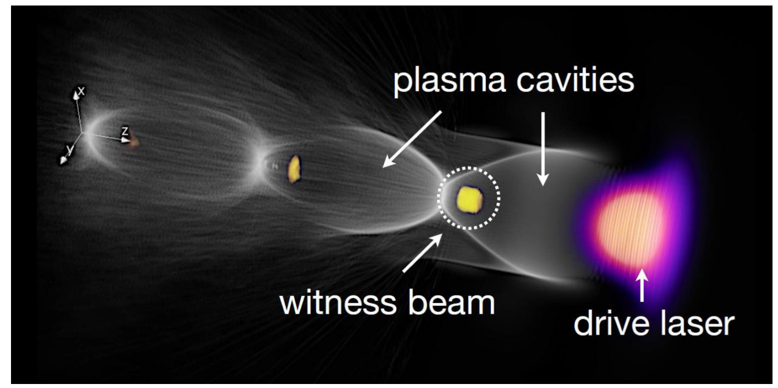
Innovation: Compact accelerator and laser technology spin-offs and synergies with industry

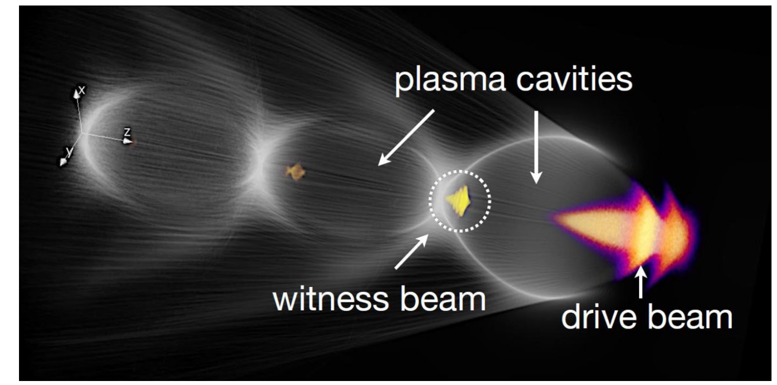
Training: Involvement and education of next generation engineers and scientists

- Goal is to complement large ‘external’ investment in plasmas
  - Ensuring that the HEP-specific aspects are fully covered
  - Drive for (essentially) plausible case for large-scale project at next ESPPU
    - Many ‘fundamental’ questions to be answered on paper, and demonstrated in a later phase

Laser / Plasma: Plan

Tasks	Begin	End	Description
PLA.FEAS.1	2022	2026	Coordination
PLA.FEAS.2	2022	2026	Plasma Theory and Numerical Tools
PLA.FEAS.3	2022	2026	Accelerator Design, Layout and Costing
PLA.FEAS.4	2022	2026	Electron Beam Performance Reach of Advanced Technologies (Simulation Results - Comparisons)
PLA.FEAS.5	2022	2026	Positron Beam Performance Reach of Advanced Technologies (Simulation Results - Comparisons)
PLA.FEAS.6	2022	2026	Spin Polarization Reach with Advanced Accelerators
PLA.FEAS.7	2022	2026	Collider Interaction Point Issues and Opportunities with Advanced Accelerators
PLA.FEAS.8	2022	2026	Reach in Yearly Integrated Luminosity with Advanced Accelerators
PLA.FEAS.9	2022	2026	Intermediate steps, early particle physics experiments and test facilities
PLA.FEAS.10	2022	2026	Study WG: Particle Physics with Advanced Accelerators
PLA.FEAS			**Total of Feasibility and pre-CDR Study**
PLA.HRRP	2022	2026	High-Repetition Rate Plasma Accelerator Module
PLA.HEFP	2022	2026	High-Efficiency, Electron-Driven Plasma Accelerator Module with High beam Quality
PLA.DLTA	2022	2026	Scaling of DLA/THz Accelerators
PLA.SPIN	2022	2026	Spin-Polarised Beams in Plasma Accelerators





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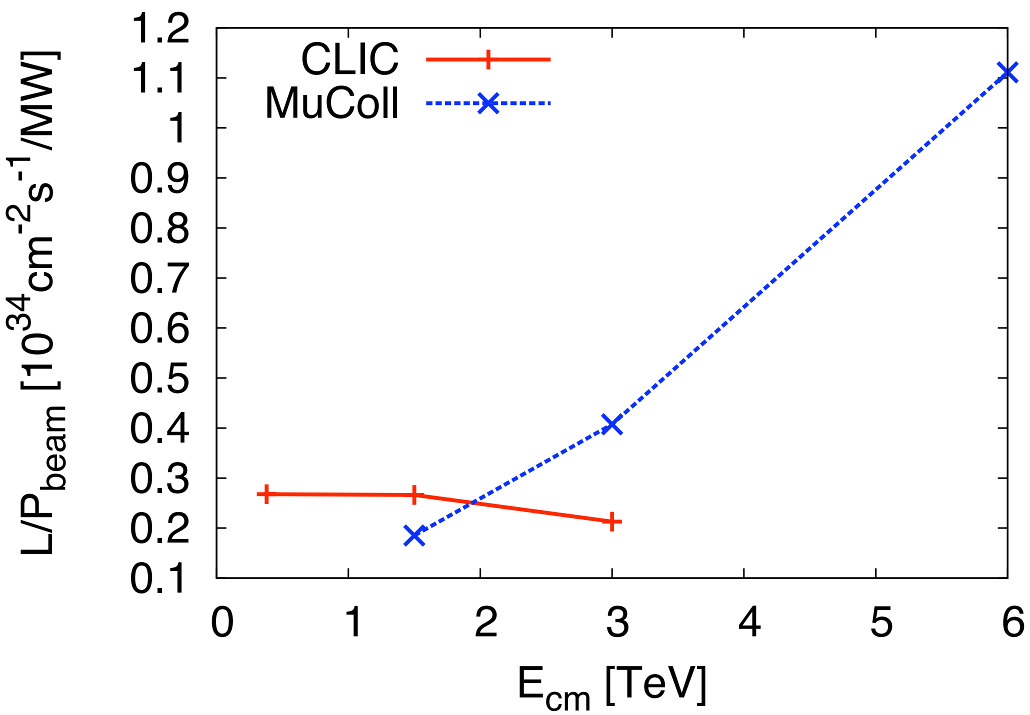
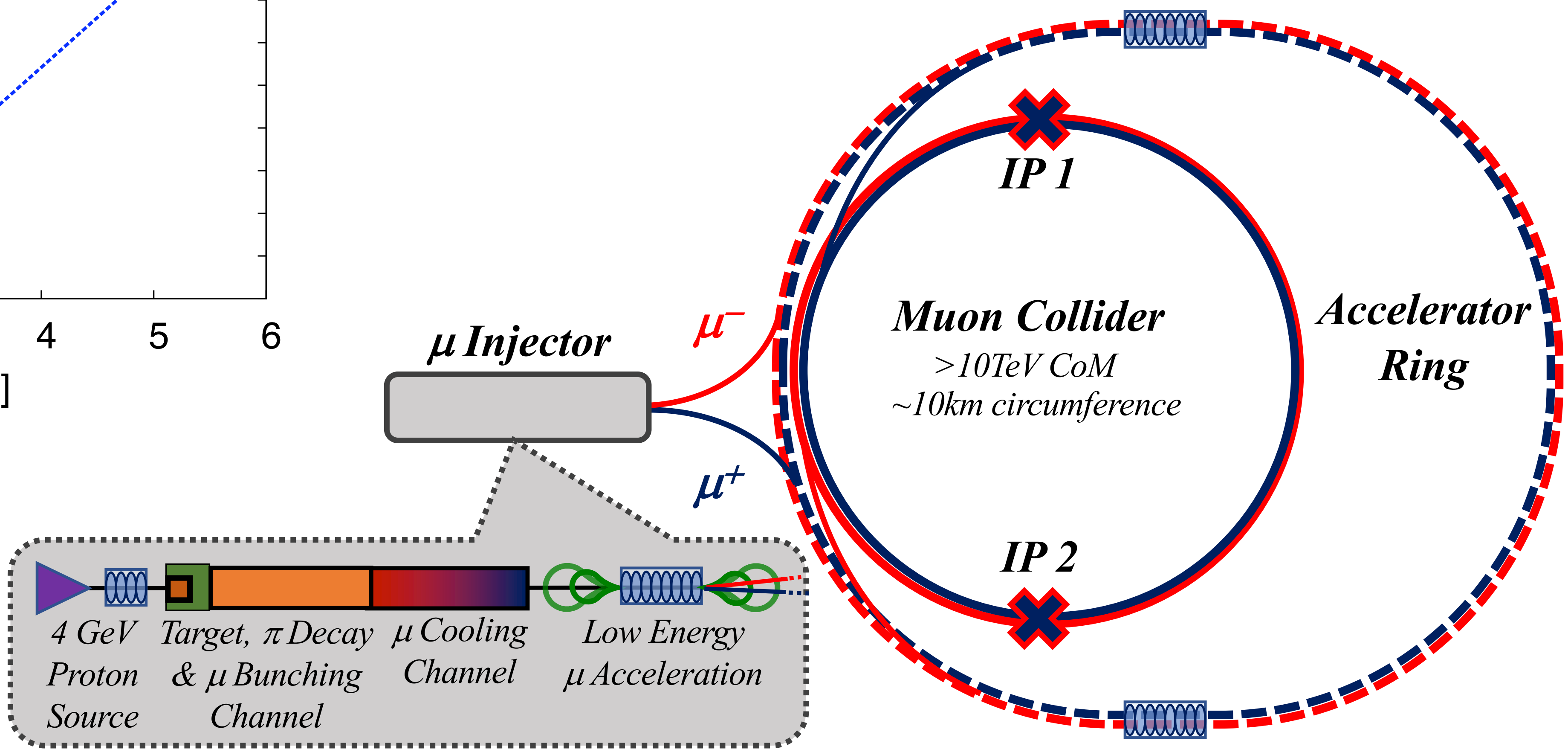
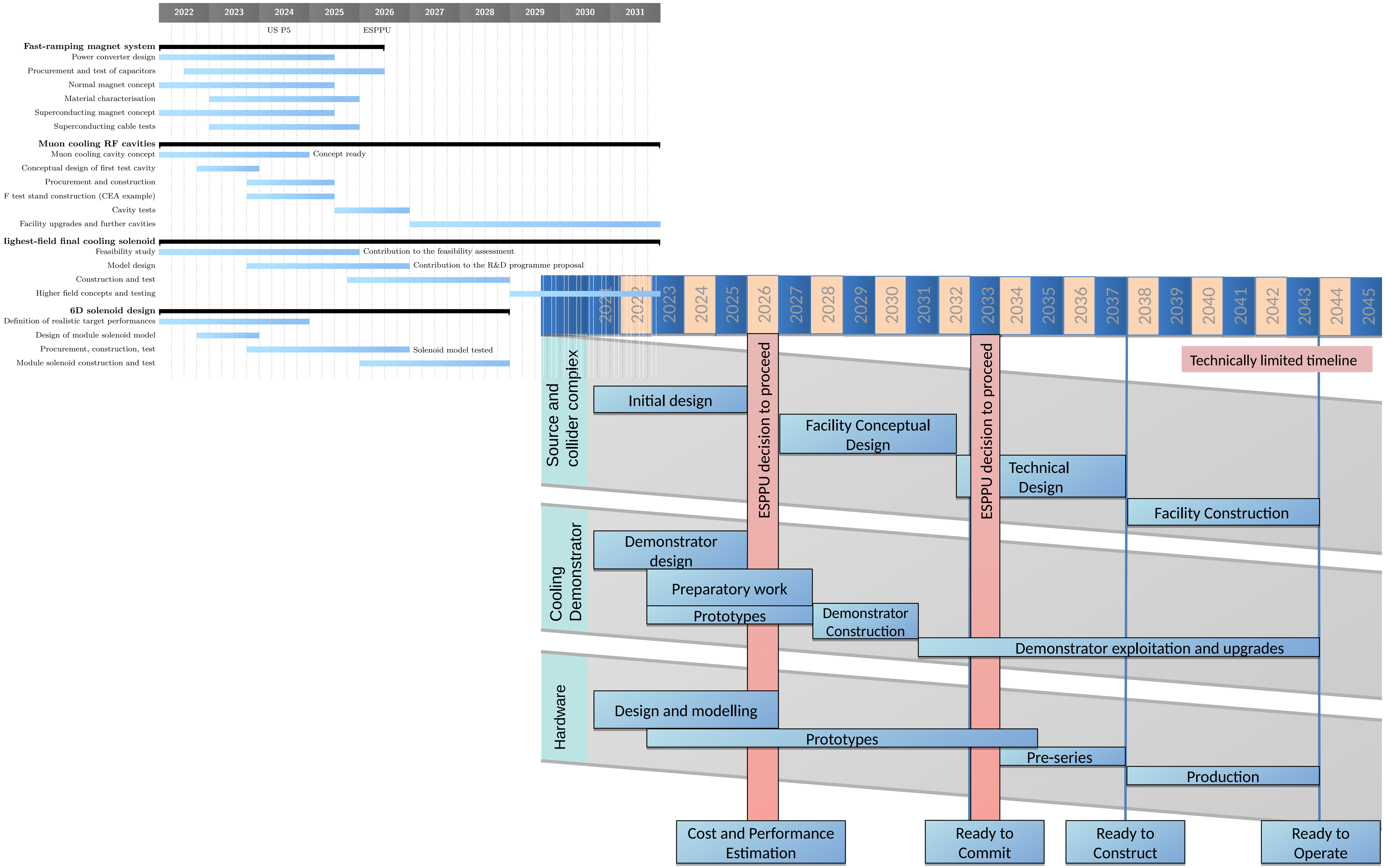
Muons: Objectives





- Objectives are again focussed on the 'plausibility case'
  - Examine the key technical barriers and cost drivers before next EPSSU
  - Planning towards a muon beam demonstrator an optional element
- Key topics
  - Machine parameters; muon cooling cell; siting considerations; neutrino radiation; magnets & RF

Muons: Plan



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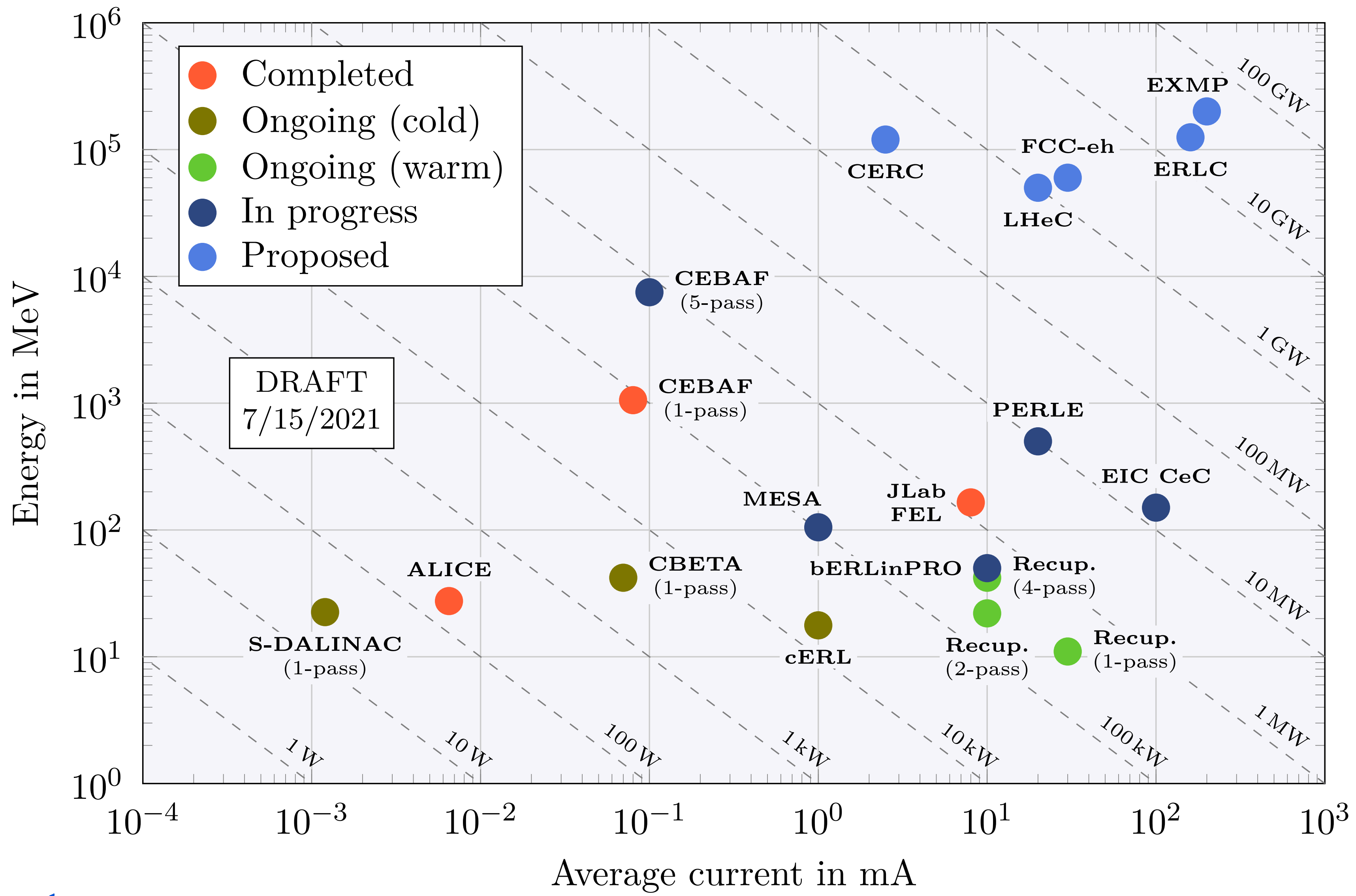
ERL: Objectives



- Three-part programme
  - Support and exploit ongoing facility programmes (worldwide)
  - Focussed technical R&D into key technologies
  - Development or upgrade of European facilities for the mid-2020s
- Relevant to both absolute performance and sustainability of future machines

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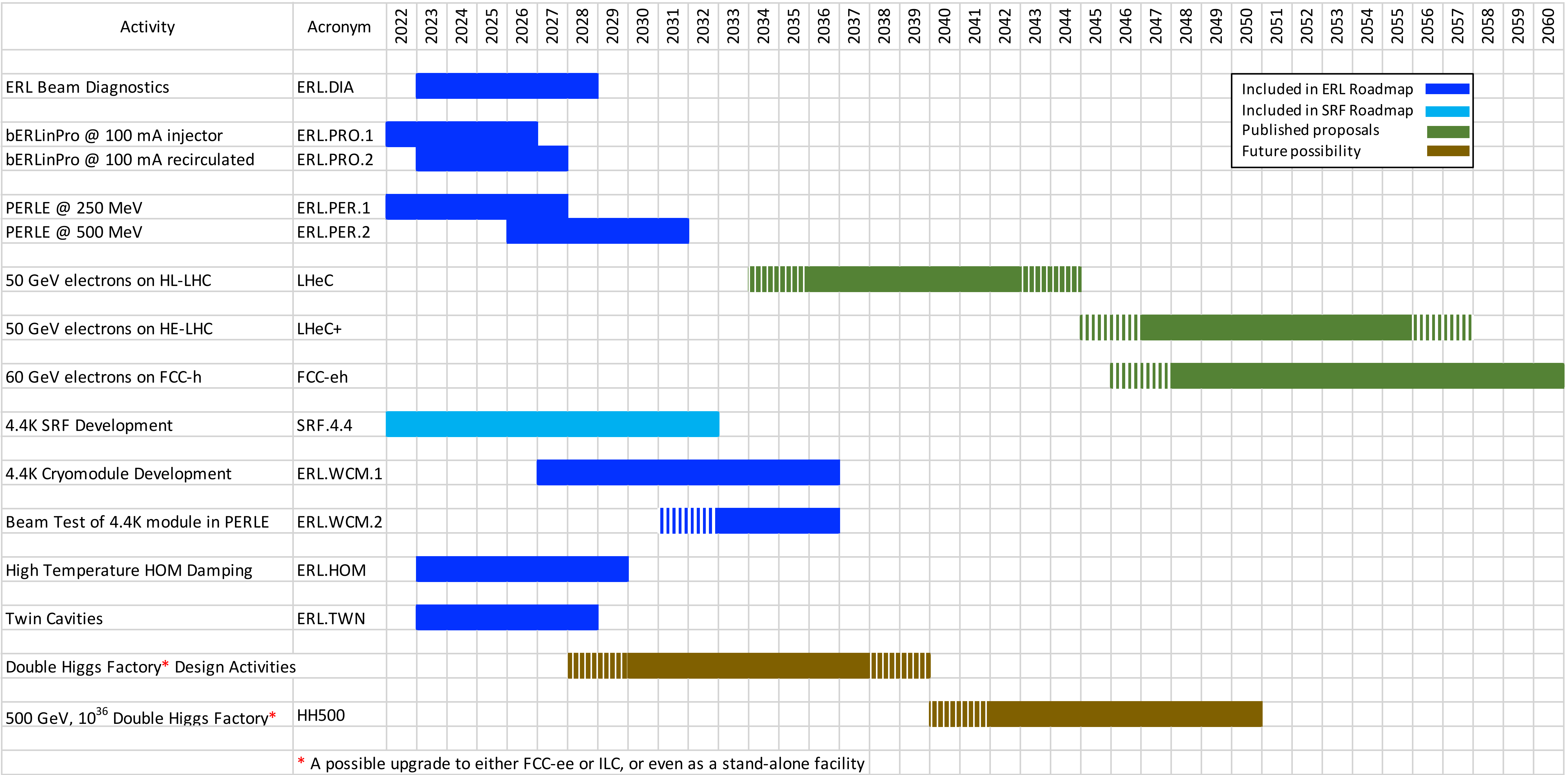
ERL: Plan



- Report includes an assessment of the plausibility / relevance of recent proposals for ERL technology in e+e- machines

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Common Themes in Panel Reports

- Mission-oriented approach
- Staged R&D
  - In many cases, the basic plausibility of some elements is still to be demonstrated
  - Emphasis on covering this ground thoroughly before ESPPU -> then ramp up
- Rapid turn-around
  - Vertically-integrated approach to R&D to achieve fast and regular results
  - Rests upon efficient and common use of test facilities
- Sustainability
  - Many of the key developments are driven by power efficiency
  - Some also have direct impacts on the cost / footprint of civil infrastructure
- Investment needs
  - Investment needed on the five-year timescale in major new facilities
  - Investment in skills and training is of course a continuous requirement
- Industry involvement
  - Early engagement of industry against a clear plan builds trust and cooperation
  - The basic cost of the raw materials of accelerators must be reduced by cooperation with industry
- External and interdisciplinary applications
  - Many scientific and societal applications of the R&D have been highlighted

Future Facilities Timeline

< 2030	2030-2035	2035-2040	2040-2045	> 2045
SPS fixed target Other fixed target; FAIR (hep) Belle II ALICE LS3 PIP-II/DUNE/Hyper-K	ALICE 3 LHCb (≥ LS4) EIC LHeC	ILC	FCC-ee CLIC	FCC-hh FCC-eh Muon Collider Plasma Collider

- ‘Chicken-and-egg’ problem
  - Cannot define an R&D timeline without knowing the approximate dates of future facilities
  - Cannot predict dates of future facilities without knowing R&D needs
- Detector / accelerator roadmaps have used a common timeline
  - Highly approximate, and not to be used out of context
  - Dates represent the ‘earliest feasible date’, driven by both technical considerations and the processes of approval
  - The goal in both cases is that R&D shall not be the rate-limiting step

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