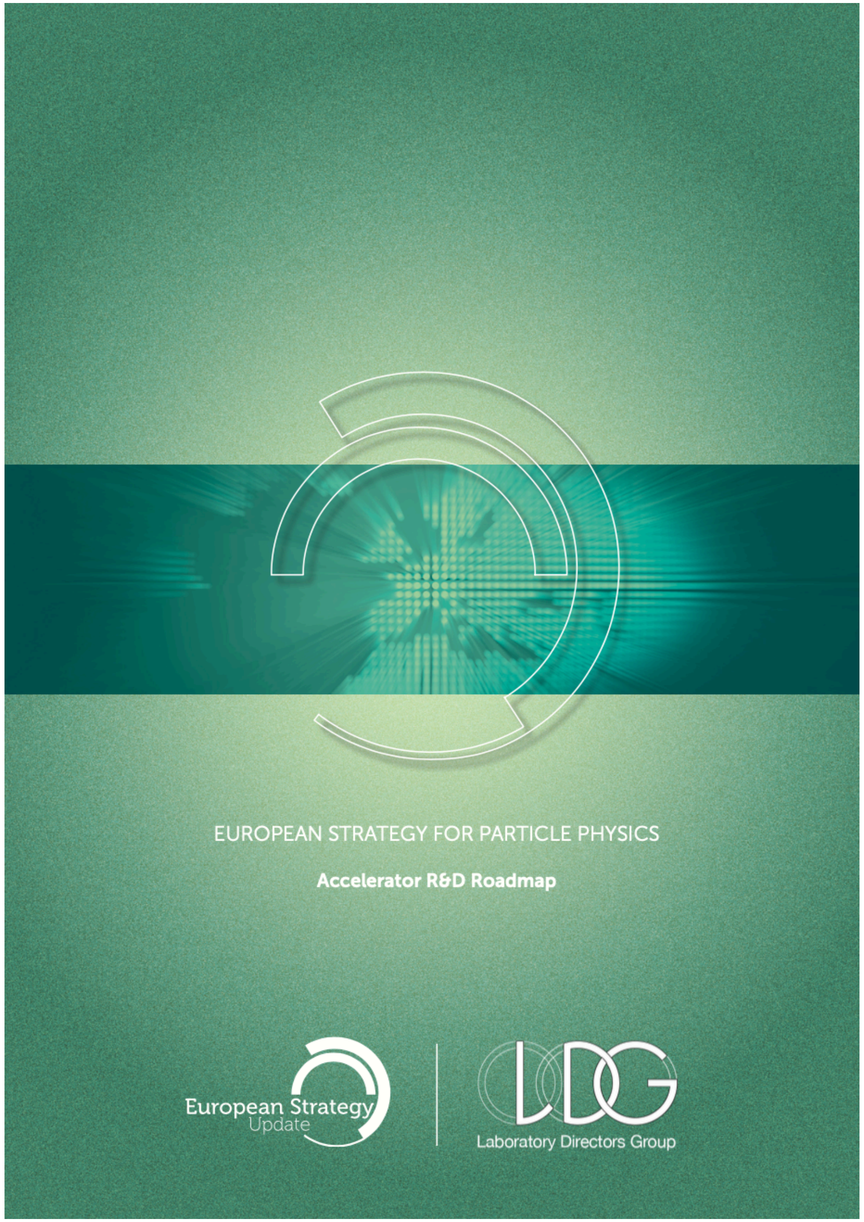


Some thoughs and comments on Accelerator R&D Roadmap (2022)

(slides from ECFA + my comments)

Erik Adli, UiO, NORCC Strategy Kick-off
March 11, 2022

Roadmap for Accelerator R&D

B. Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs.

The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.

Lab Directory Group (LDG) has been Mandated to develop this roadmap
(LDG: Directors of the Large Particle Physics Laboratories and CERN)

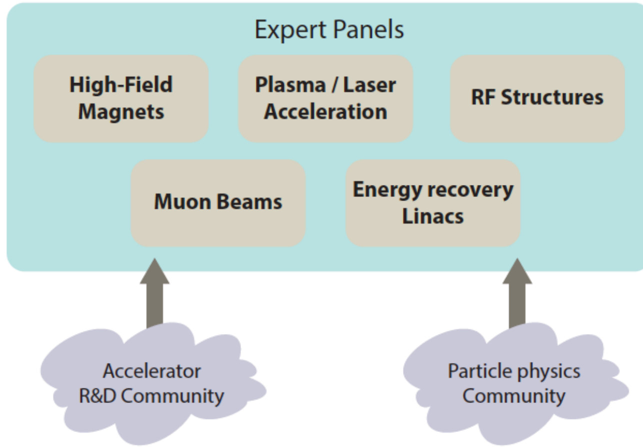
LDG: European "Lab Directors Group" (10 labs)

- CERN, CIEMAT, DESY, IRFU, IJCLAB, NIKHEF, LNF, LNGS, PSI, STFC-RAL
- lab-to-lab communications with a view to address together the ESPP
- current chairperson: Dave Newbold (STFC-RAL)

Deliberation Document:
" … This roadmap should be established as soon as possible in close coordination between the National Laboratories and CERN."

Roadmap for Accelerator R&D (cont.)

- Provide an agreed structure for a coordinated and intensified programme of particle accelerator R&D, including new technologies, **to be coordinated across national laboratories**
- Be based on the goals of the European Strategy, but defined in its implementation through consultation with the community and, where appropriate, through the **work of Expert Panels**
- Take into account, and coordinate with, international activities and work being carried out in other related scientific fields, including development of new large-scale facilities
- **Specify a series of concrete deliverables, including demonstrators, over the next decade;**
- **Designed to inform, through its outcomes, subsequent updates to the European Strategy**



Accelerator R&D Roadmap planned to be released by end of 2021

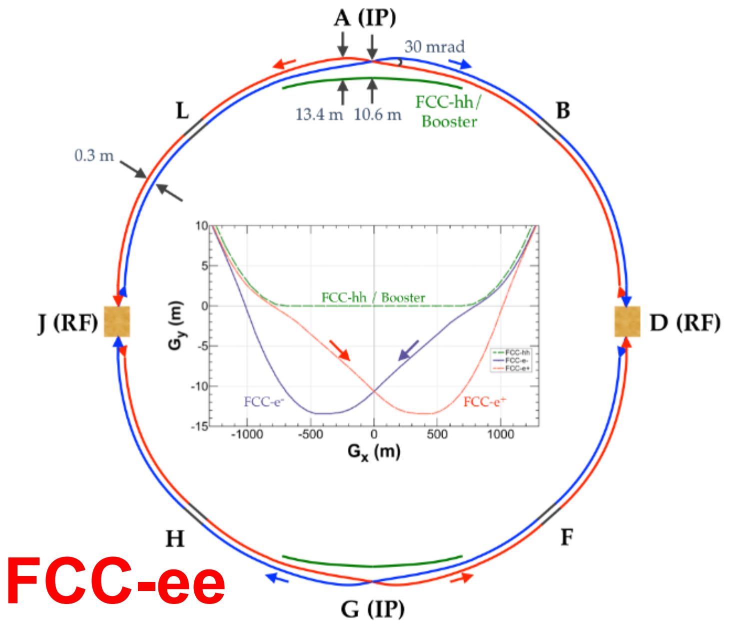
Future Facilities Timeline

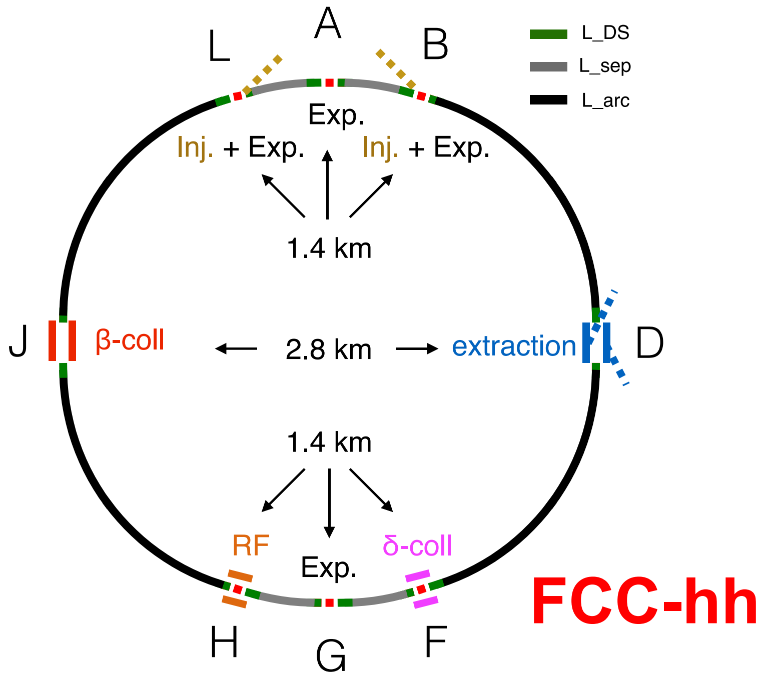
- ‘Chicken-and-egg’ problem
  - Cannot define an R&D timeline without knowing the approximate dates of future facilities
  - Cannot predict dates of future facilities without knowing R&D needs
- Detector / accelerator roadmaps have used a common timeline
  - Highly approximate, and not to be used out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

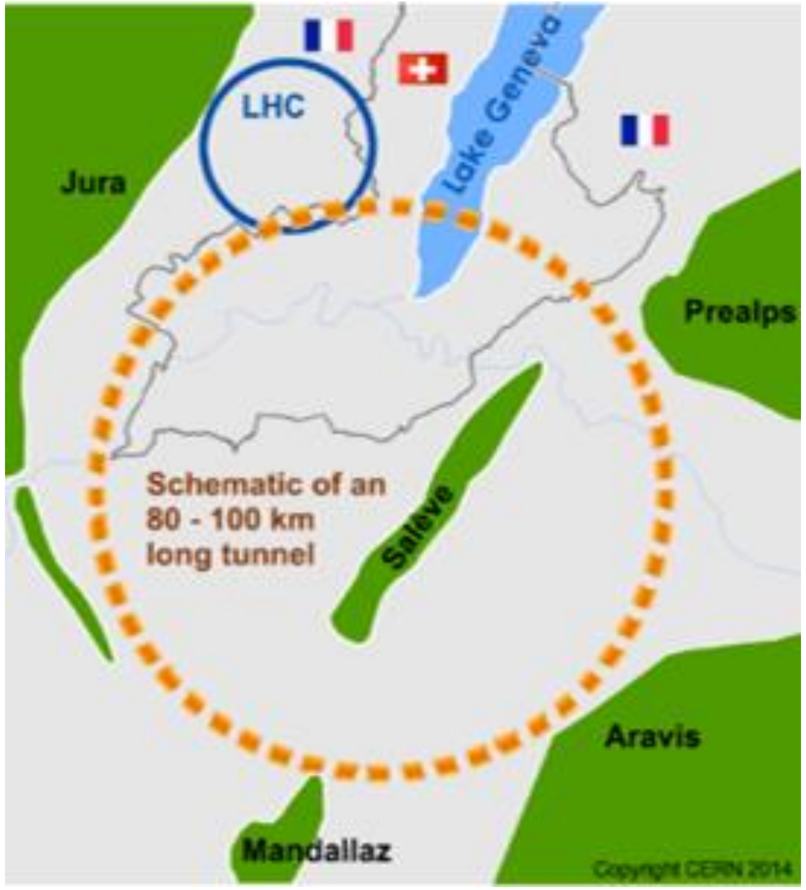
The FCC integrated program inspired by successful LEP – LHC programs at CERN

Comprehensive long-term program, maximizing physics opportunities

- **Stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & and top factory at highest luminosities**
- **Stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options**
- Complementary physics
- Common civil engineering and technical infrastructures
- Building on and reusing CERN's existing infrastructure
- FCC integrated project allows seamless continuation of HEP after HL-LHC







FUTURE CIRCULAR COLLIDER

Status of Global FCC Collaboration

increasing international collaboration as a prerequisite for success:
links with science, research & development and **high-tech industry** will be essential to further advance with the **FCC FS**

34 Countries

EC H2020

30 Companies

147 Institutes

93 member states
16 associate member states
21 non-member states with observer status
17 other non-member states

FCC Feasibility Study Governance approved by June Council.
FCC collaboration board meeting in preparation for September 2021.

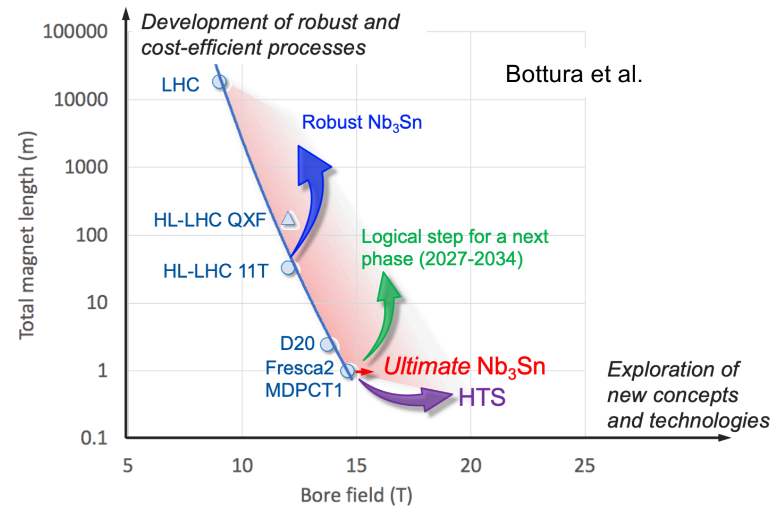
High-field Superconducting Magnets

- Key technology for future accelerators (hadron colliders, muon colliders, neutrino beams, …)
- To reach the required field strength of 16 – 20 T for FCC_hh, new technologies have to be **established and brought into industrial production**

Present candidates: Nb_3Sn or High-Temperature Superconducting (HTS), …)

- So far small magnets have been successfully built and operated, however, scale up to longer magnets is a challenge!
e.g. 11T Nb3Sn magnets will not be installed in Run 3, but needed for HL-LHC

→ a long way to go!
Europe must intensify R&D (more resources (people, money,..), close cooperation with industry)



- HTS magnets interesting beyond HEP / industry
(NMR, fusion, power applications for motors and generators)

My comments: FCC/Magnet development

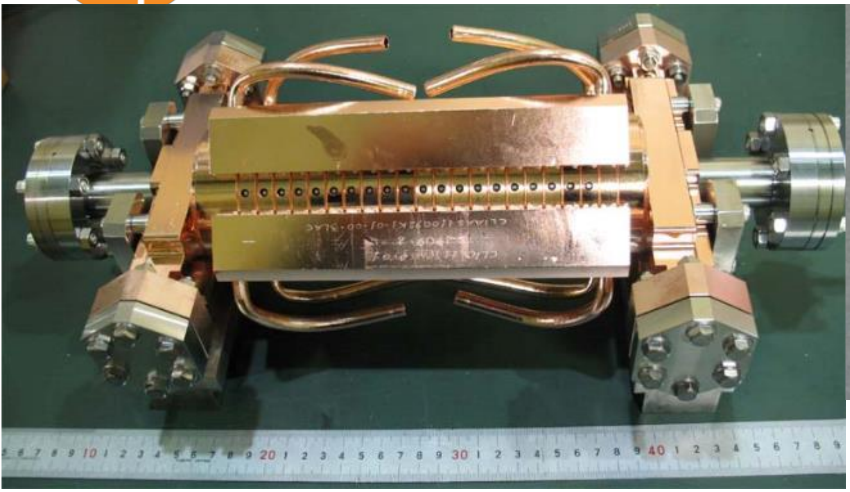
- Cannot contribute to main magnet R&D
- Possible to find other parts where to contribute to (design), in order to formally join the collaboration
  - Would be welcome by CERN/FCC (another country contributing)
  - Will take resources from existing, not only work resources, but formalities/meetings/boards/FCC weeks etc.
  - should only join if we
    - get new resources? (e.g. a dedicated PhD student)
    - profit scientifically?
    - and/or if concerted effort with national FCC physics/detectors?
- If likely that FCC will be approved: important to join, also in the accelerator studies
  - also for future industrial return

RF: Objectives

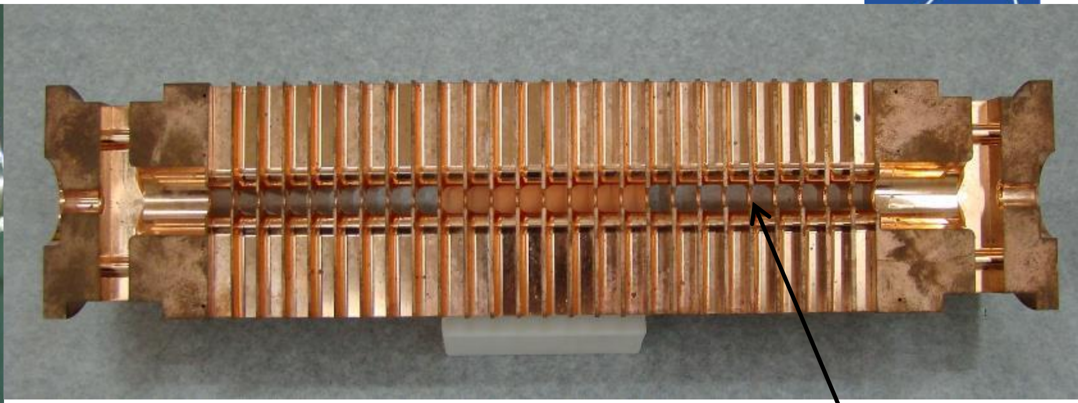
	Particle sources	Magnet and Vacuum systems	High Field SC magnets	Normal Conducting RF structures	Superconducting RF cavities	RF power sources	Cryogenics	Instrumentation
ILC	•				•	•	•	•
FCC	•	•	•		•		•	•
PIP-II, MYRRHA					•	•	•	•
JLEIC	•		•	•		•		•
eRHIC, LHeC					•		•	•
DIAMOND2, SLS2		•				•		•
LCLS2-HE,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

Accelerating structure



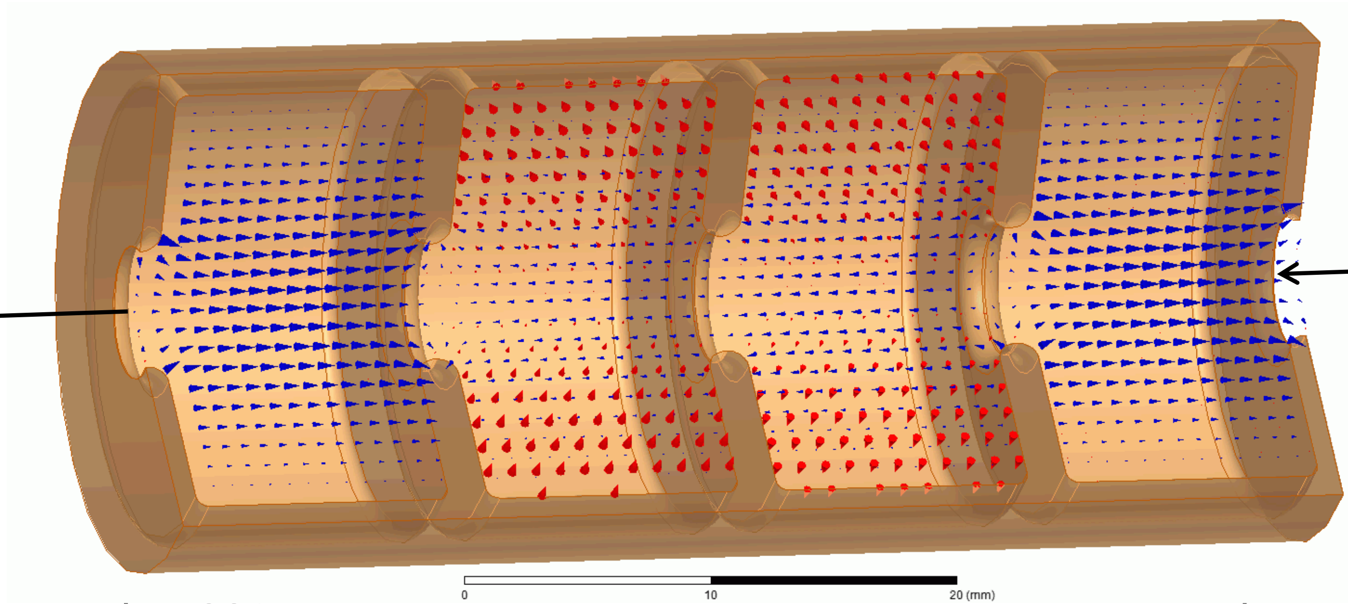
Outside



Inside

11.994 GHz X-band

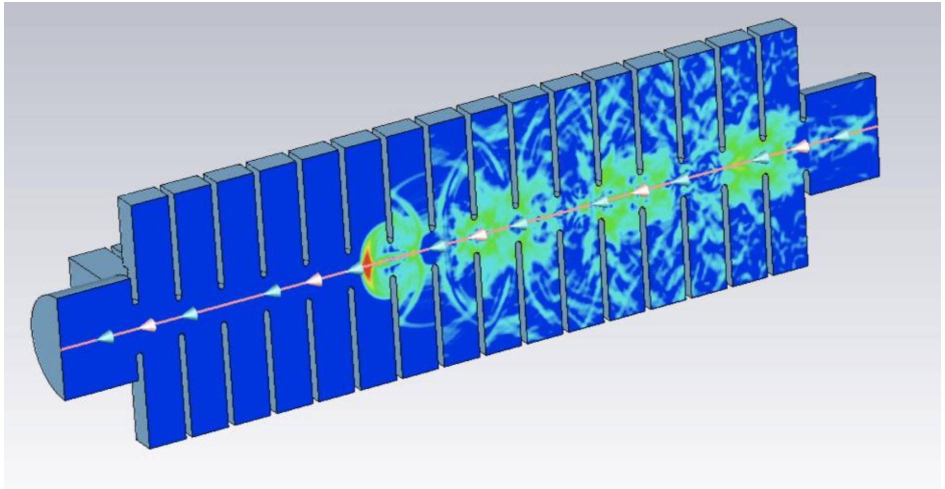
6 mm diameter beam aperture



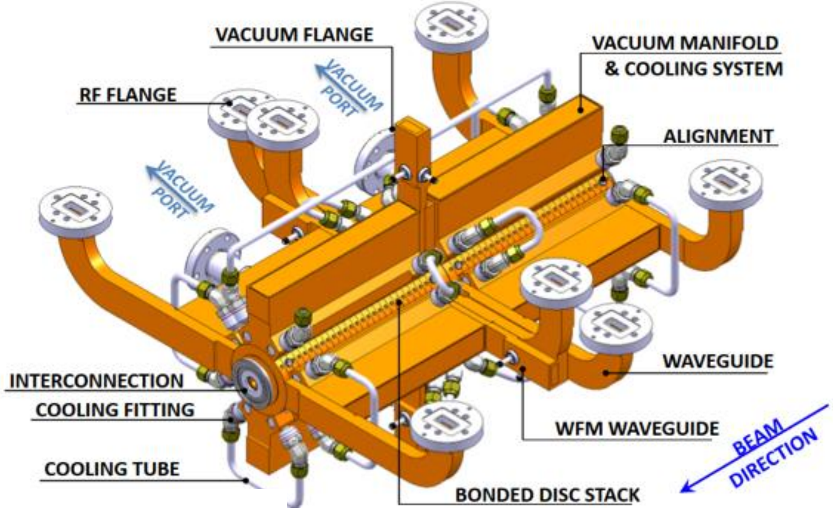
beam propagation direction

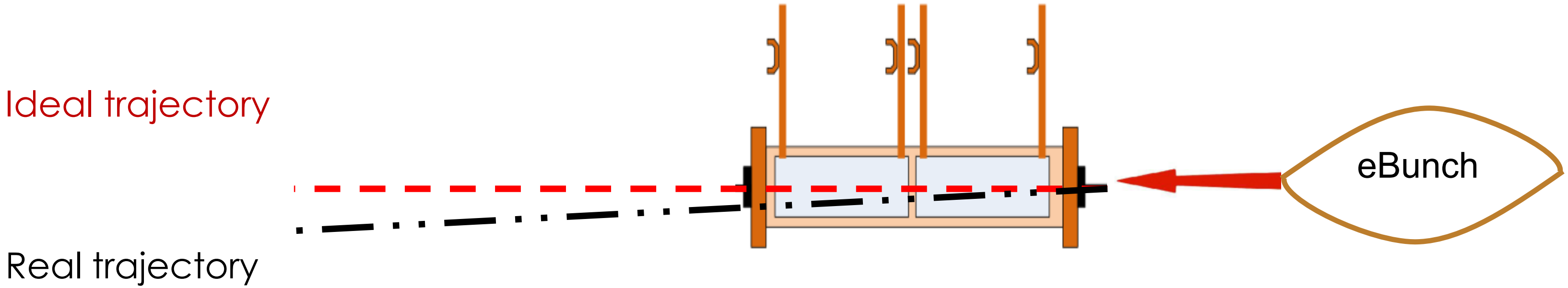
Concept

2x TD26s with Wakefield Monitors



Well known effect, the WAKEFIELD



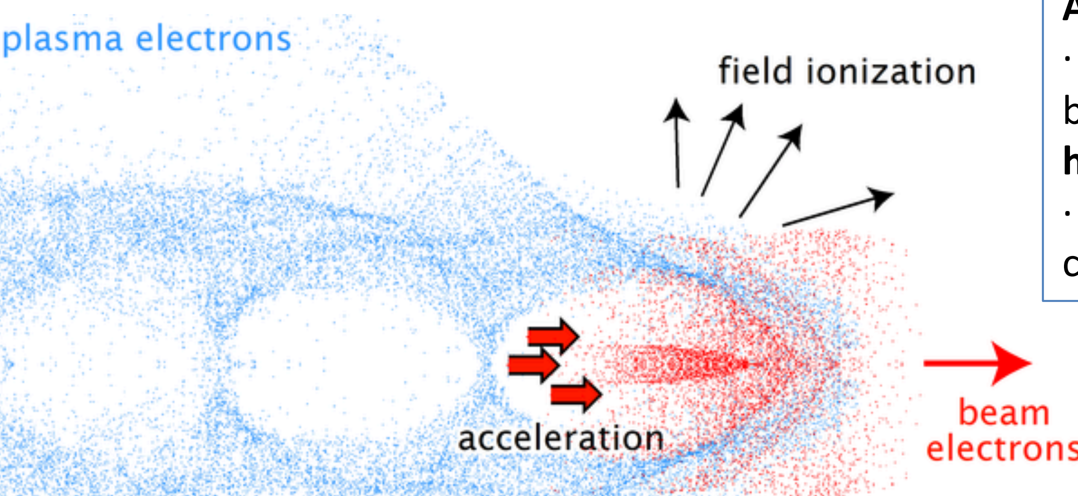


My comments: RF

- Contributing today through CLIC/CLEAR MoU
  - Experts on RF design, instabilities, emittance preservation etc.
- MoU makes easy access to experiments at CLEAR and collaborations for application
  - important to sustain activity, despite the lesser focus on CLIC as an energy frontier machine in this period
- No competence on SC RF hardware, but on design/paper studies
  - in position to contribute to ILC

Novel accelerator concepts: **plasma acceleration**

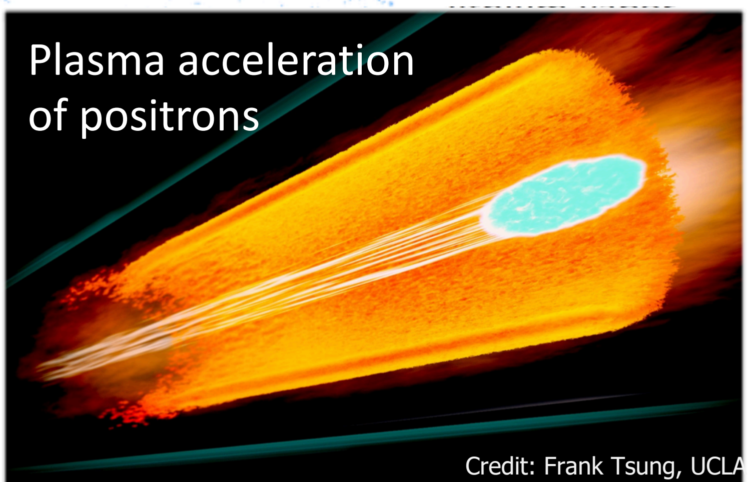
See parallel session talk by Ben Chen (UiO)



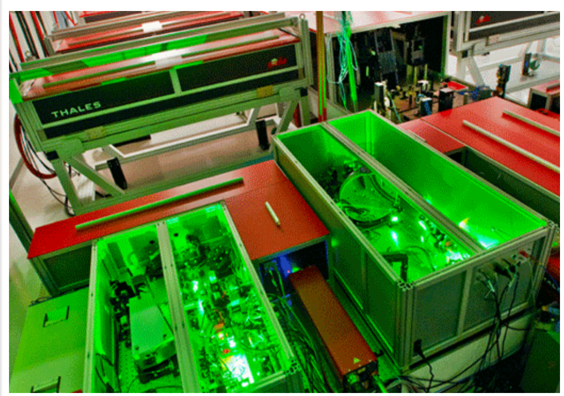
Principle: *drive a wave in plasma with particle or laser beams*

RF cavities: limited by metal surface break down
Alternative: high fields inside plasmas:
· Plasmas of a large range of densities can easily be produced. Fields scale with density. **Very high fields can be generated**.
· Plasmas are already broken down. The plasma can **sustain the very high fields.**

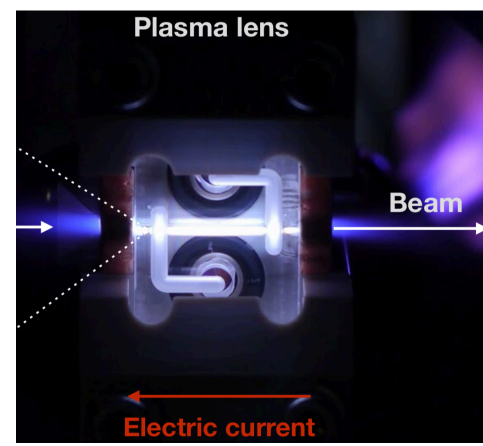
Typical numbers :
Plasma density ~ 10^{16-18}/cm³
Field scale: 10-100 GV/m
Length scale : $\lambda_p/2\pi$=**10-100** μ**m**



Great experimental progress recent years:
50 GV/m accelerating fields, positron acceleration, AWAKE... See UiO-thesis of Carl A. Lindstrøm



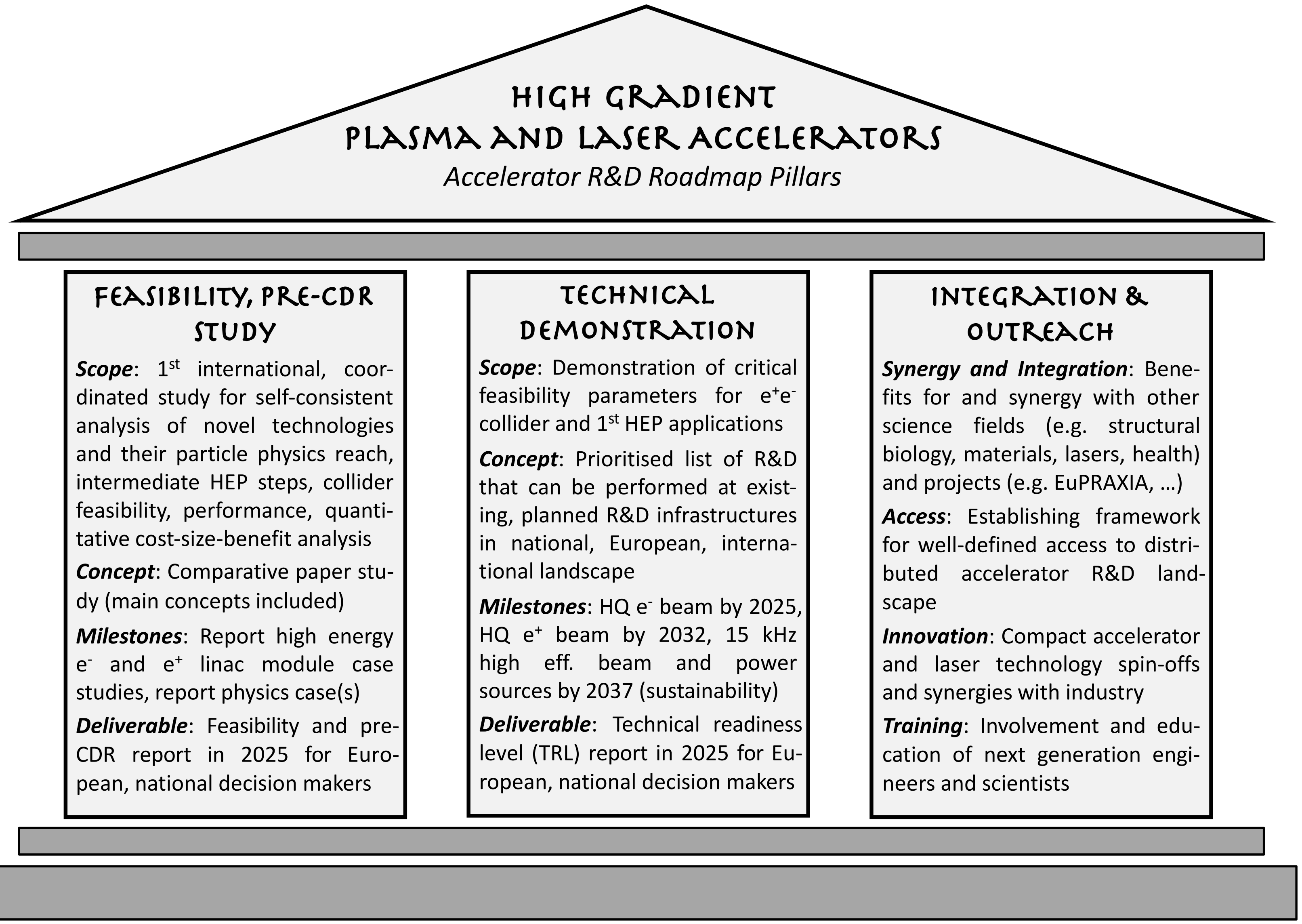
TW-PW laser technology



Plasma lenses for particle beams

See parallel session talk by Kyrre Sjøbæk (UiO)

Laser / Plasma: Objectives

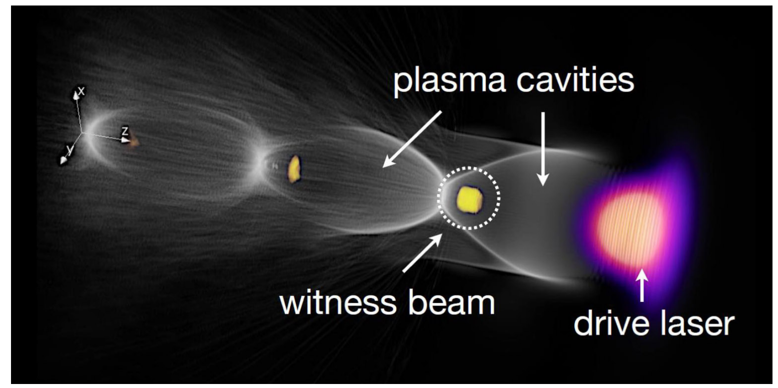


- Goal is to complement large 'external' investment in plasmas
  - Ensuring that the HEP-specific aspects are fully covered
  - Drive for (essentially) plausible case for large-scale project at next ESPPU
    - Many 'fundamental' questions to be answered on paper, and demonstrated in a later phase

Science and Technology Facilities Council

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



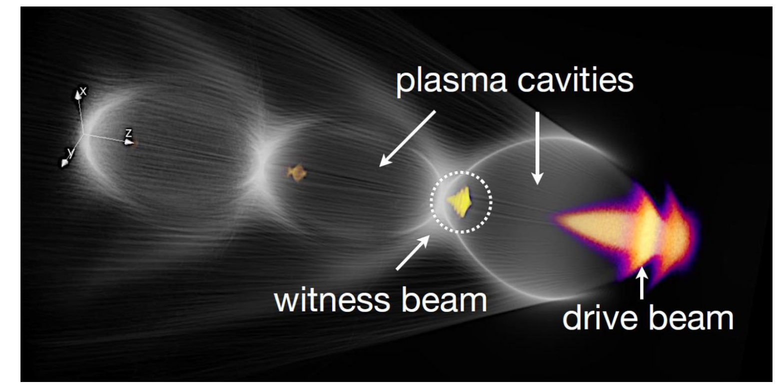
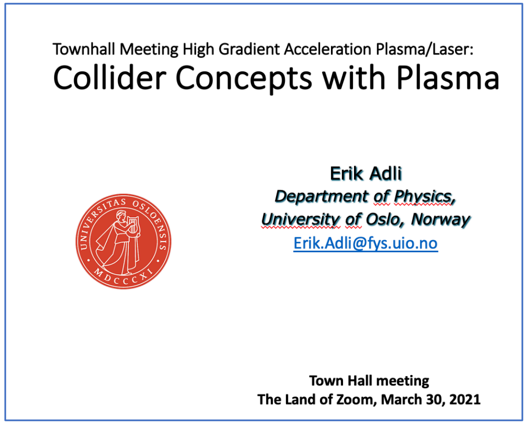


Table 4.4: Work packages and tasks in the minimal plan.

WP	Task	Short Description	Invest Personnel
COOR		Coordination Plasma and Laser Accelerators for Particle Physics	—
FEAS		Feasibility and pre-CDR Study on Plasma and Laser Accelerators for Particle Physics	300 kCHF 75 FTEy
	FEAS.1	Coordination	
	FEAS.2	Plasma Theory and Numerical Tools	
	FEAS.3	Accelerator Design, Layout and Costing	
	FEAS.4	Electron Beam Performance Reach of Advanced Technologies (Simulation Results - Comparisons)	
	FEAS.5	Positron Beam Performance Reach of Advanced Technologies (Simulation Results - Comparisons)	
	FEAS.6	Spin Polarization Reach with Advanced Accelerators	
	FEAS.7	Collider Interaction Point Issues and Opportunities with Advanced Accelerators	
	FEAS.8	Reach in Yearly Integrated Luminosity with Advanced Accelerators	
	FEAS.9	Intermediate steps, early particle physics experiments and test facilities	
	FEAS.10	Study WG: Particle Physics with Advanced Accelerators	
HRRP		Experimental demonstration: High-Repetition Rate Plasma Accelerator Module	1200 kCHF 30 FTEy
HEFP		Experimental demonstration: High-Efficiency, Electron-Driven Plasma Accelerator Module with High beam Quality	800 kCHF 10 FTEy
DLTA		Experimental demonstration: Scaling of DLA/THz Accelerators	500 kCHF 16 FTEy
SPIN		Experimental demonstration: Spin-Polarised Beams in Plasma Accelerators	350 kCHF 16 FTEy
LIAI		Liaison to Ongoing Advanced Accelerator Projects, Facilities, Other Science Fields	—



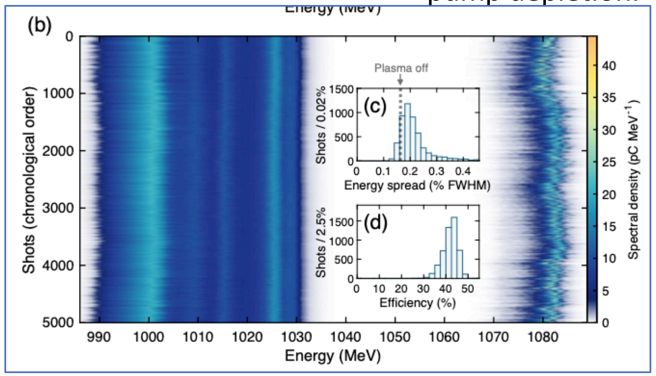
Conclusion

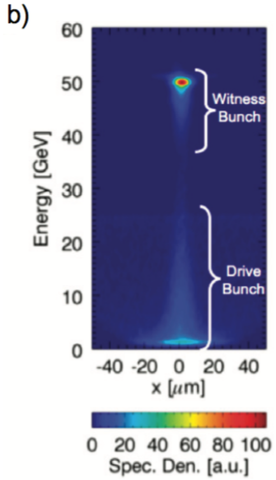
To move towards PLC: a collider parameter "paper" study (not necessary at a CDR level), leading to a consistent global parameters set, and key performance metrics

- needed to understand the promise of a plasma collider, and key parameters
- needed to guide future feasibility demonstrations
- Main input to paper study : performance can be based on theory/simulation, rather than present (non-ideal) experiments. Represents a "a best case".

Example (FlashFoward)

Experiment :
Few MeV energy gain, far from pump depletion.





Simulation :
Energy doubling at 25 GV/m and pump depletion

(see also efficiency example)

Resources for design: a significant number of man-years. Still **small** compared to cost of on-going and proposed experiments and facilities. Some technology choices should be made.

My comments: laser/plasma

- Contributing today, mainly through other NFR projects
  - plasmas: we have expertise, ”sexy” subject for students
  - Possibility to do high impact research
- Path towards a plasma collider unclear
  - Needs a concerted effort, with clear leadership/ownership (muon collider)
  - Collider design: not necessarily high impact research, harder to get funding
  - Contributions to colliders studies: depends on funding schemes

Novel accelerator concepts: **muon collider**

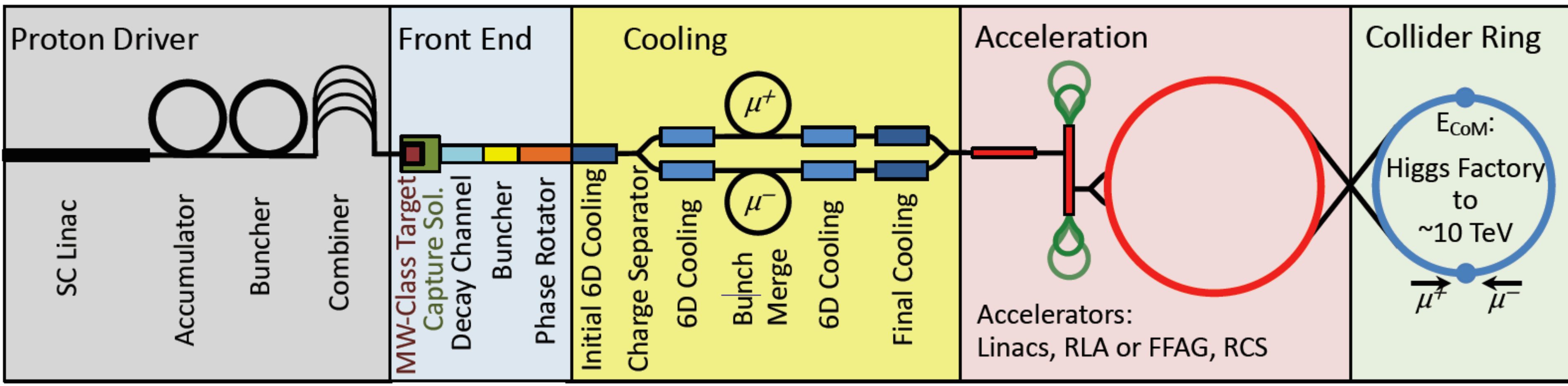
Novel concepts: boost accelerator performance with **radical change in technology**
Very promising and interesting research, many hurdles to overcome before use in a collider.

Muon collider pros and cons

Negligible synchrotron radiation

Main challenge: $\tau_\mu = 2.2\ \mu s$

- Produce sufficiently dense muon beams
- Rapid acceleration
- Mitigate radiation hazards



Protons on target hadronic showers, Pions decay into muons

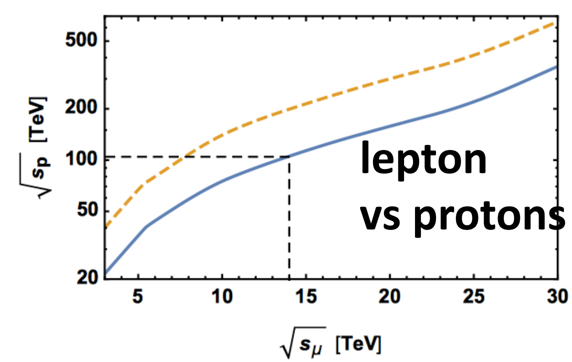
Muon are captured, bunched and then cooled.

Rapid acceleration to collision energy

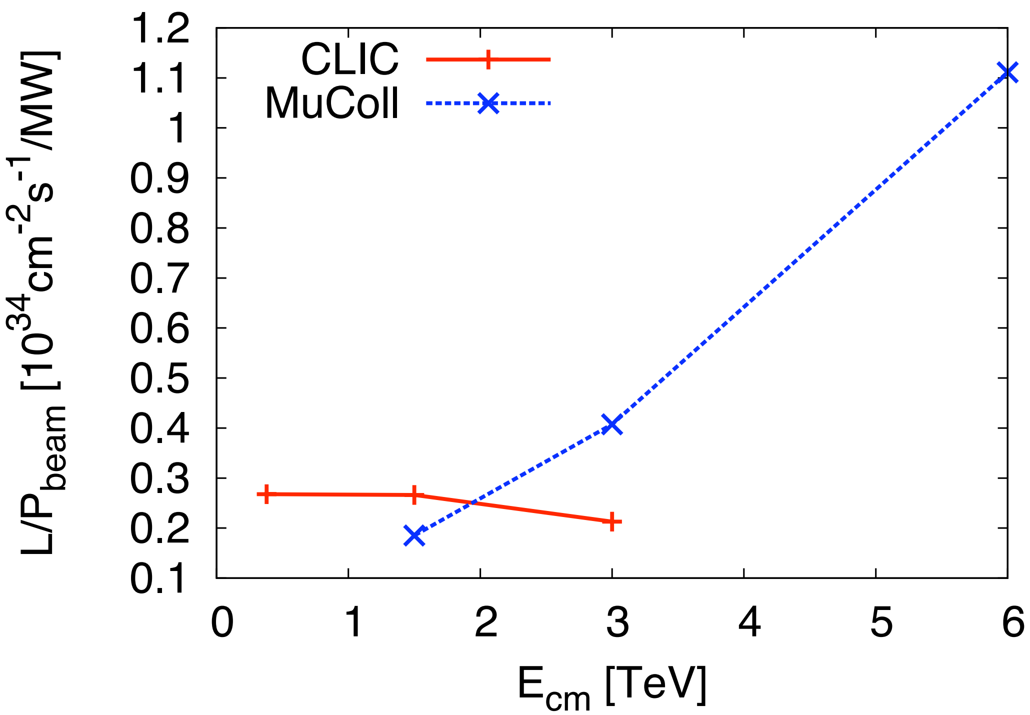
Collision

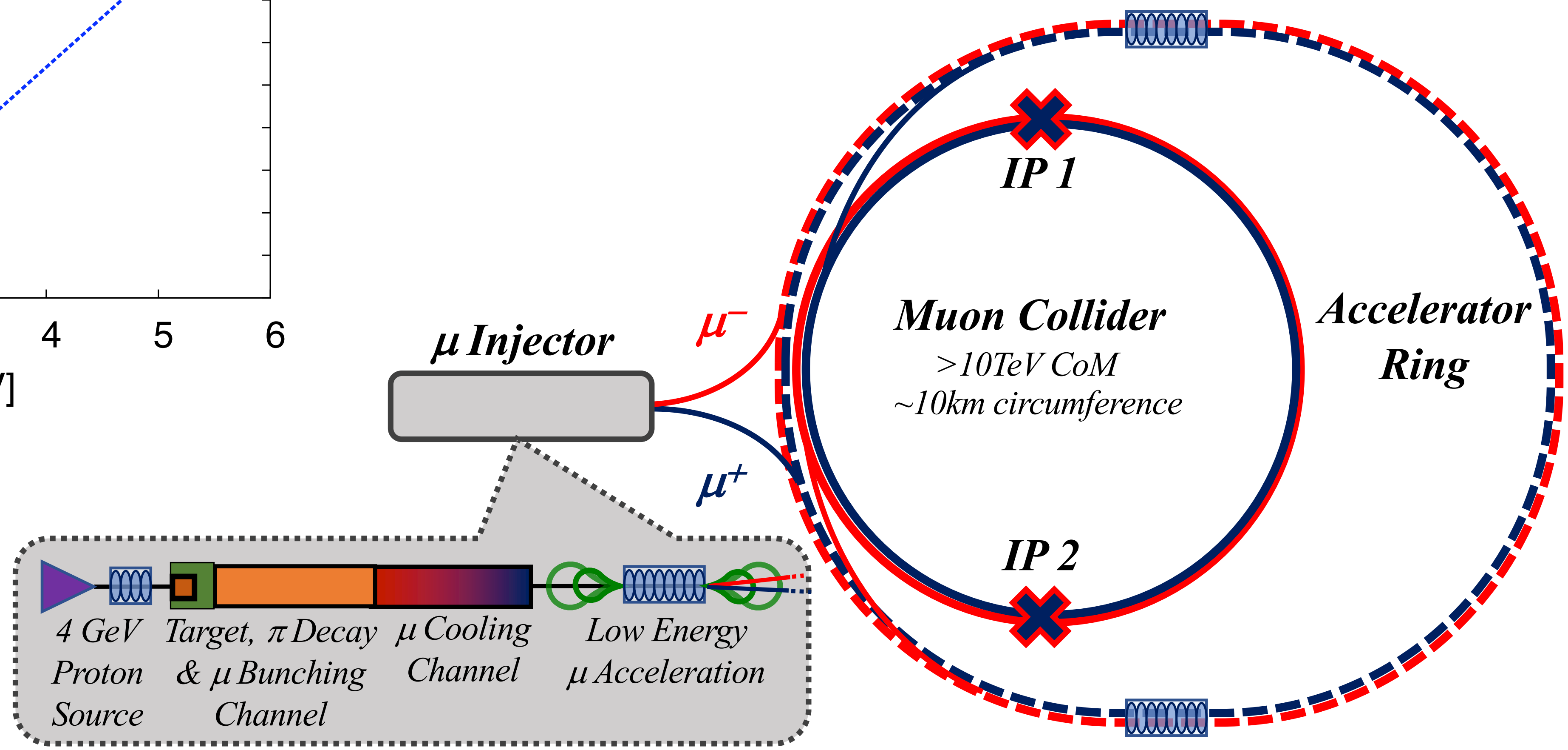
Precision, plus discovery potential!

3 TeV ~ LHC
14 TeV ~ FCC-hh;
30 TeV ~ “amazing"



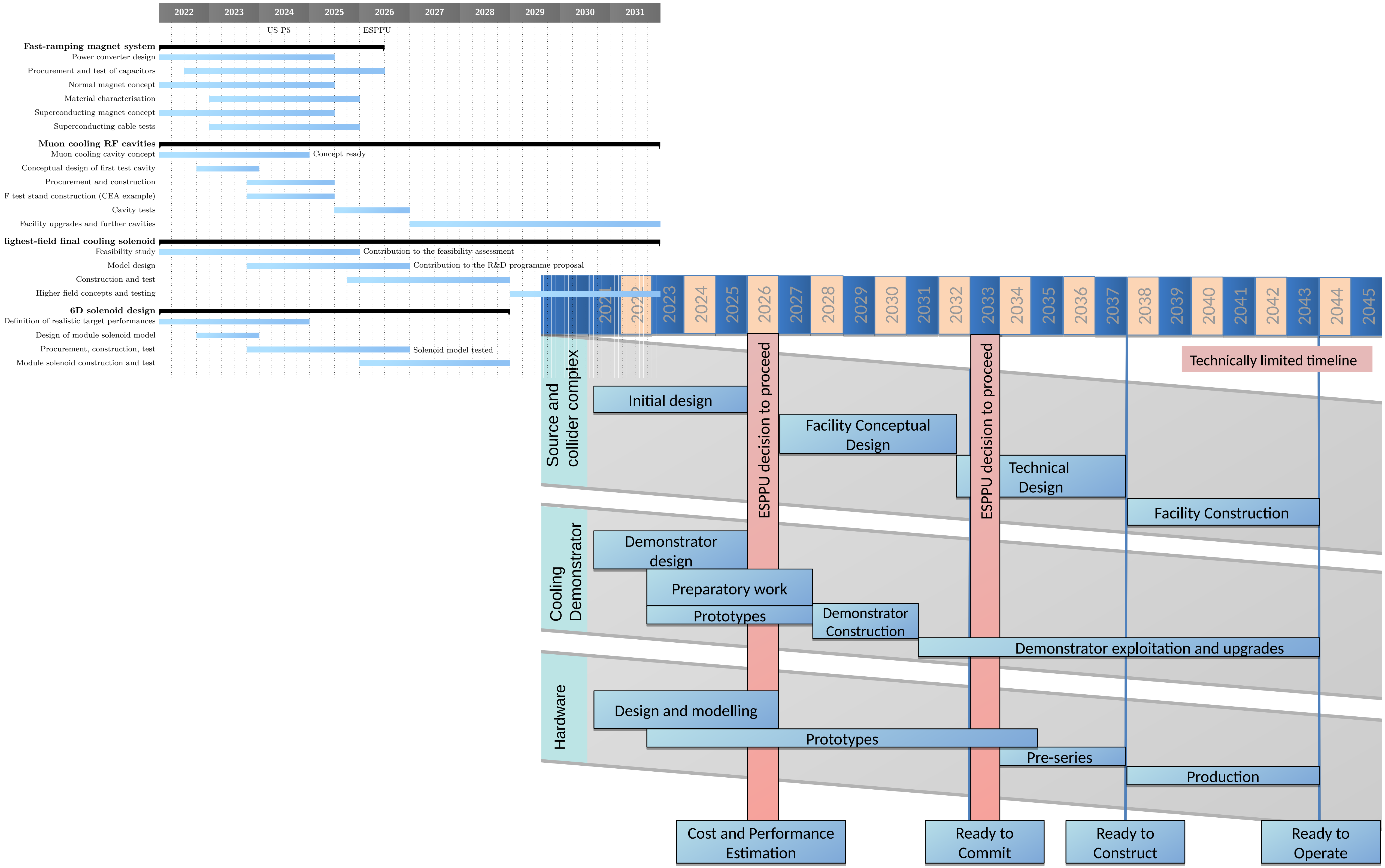
Muons: Objectives





- 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



2022 2023 2024 2025 2026 2027 2028 2029 2030 2031
US P5
ESPPU
Fast-ramping magnet system
Power converter design
Procurement and test of capacitors
Normal magnet concept
Material characterisation
Superconducting magnet concept
Superconducting cable tests
Muon cooling RF cavities
Muon cooling cavity concept
Concept ready
Conceptual design of first test cavity
Procurement and construction
F test stand construction (CEA example)
Cavity tests
Facility upgrades and further cavities
lighest-field final cooling solenoid
Feasibility study
Contribution to the feasibility assessment
Model design
Contribution to the R&D programme proposal
Construction and test
Higher field concepts and testing
6D solenoid design
Definition of realistic target performances
Design of module solenoid model
Procurement, construction, test
Solenoid model tested
Module solenoid construction and test
2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043 2044 2045
Technically limited timeline
Source and collider complex
Initial design
ESPPU decision to proceed
Facility Conceptual Design
ESPPU decision to proceed
Technical Design
Facility Construction
Cooling Demonstrator
Demonstrator design
Preparatory work
Prototypes
Demonstrator Construction
Demonstrator exploitation and upgrades
Hardware
Design and modelling
Prototypes
Pre-series
Production
Cost and Performance Estimation
Ready to Commit
Ready to Construct
Ready to Operate

My comments: muon collider

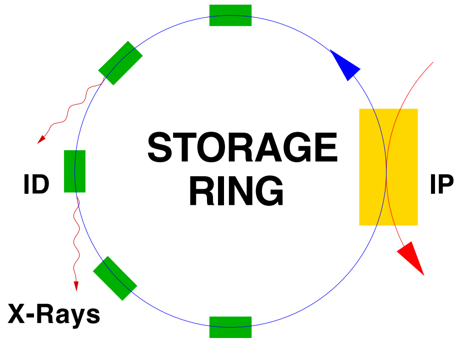
- Norway can contribute to interesting topics (design, application of novel technology)
  - Would be welcome by CERN/MC (another country contributing)
  - Will take resources from existing, not only work resources, but formalities/meetings/boards/workshop weeks etc.
  - from the accelerator point of view: possibly greater scientific interest in MC than in joining the FCC design
  - should only join if we
    - get new resources? (e.g. a dedicated PhD student)

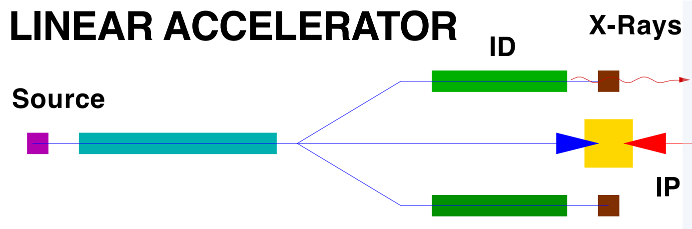
Energy Recovery Linacs – The idea

- high average („virtual“) beam power (up to A, many GeV)
- many user stations
- beam parameter defined by equilibrium
- typical long bunches (20 ps – 200 ps)

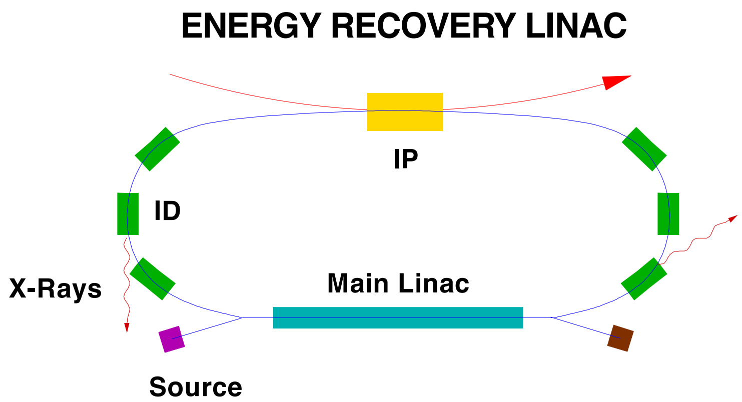
- outstanding beam parameter
- single pass experiments
- high flexibility
- low number of user stations
- limited average beam power (<<mA)

e.g. ESRF:
6 GeV, 200 mA
1.2 GW
virtual power,
stored energy
only 3380 J





e.g. XFEL:
17.5GeV, 33 μA
“only” ~ 600kW,
but real power

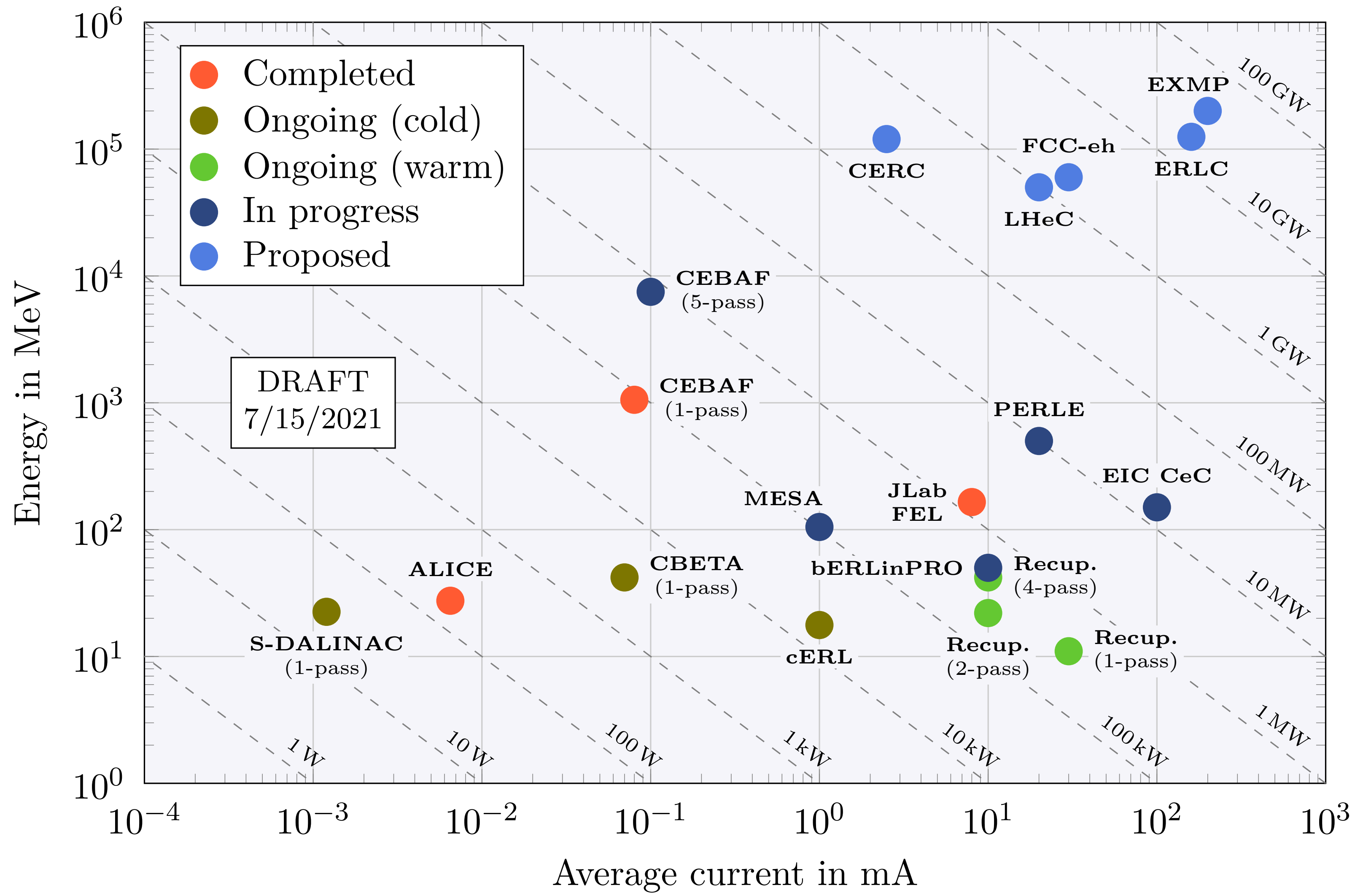


$$\varepsilon \sim \frac{1}{\gamma} \cdot \varepsilon_{source}$$

intrinsic short bunches, high current

high average beam power (multi GeV @ some 100 mA) for single pass experiments, excellent beam parameters, high flexibility, multi user facility

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

Science and Technology Facilities Council

My comments: ERL

- Norway, no particular experience with / interest for ERL

How can we maintain the future of our field?

- Accelerators are large, cost-expensive, funding situation becomes more difficult
- Young generation feels large uncertainty!!

  No concrete future project yet, beyond (HL)-LHC

- We must do all possible to decide soon (latest at the next strategy) on the next project to inject new energy (or keep the momentum) in our field

  → FCC feasibility study essential and must get full support of CERN + ECFA countries!

  Do we only consider an integrated FCC_ee + FCC_hh programme, or are we open as well for an ILC + FCC_hh solution?

  (Load on CERN would be reduced, better distributed world-wide, in Europe more resources could be focussed on key fcc_hh issues, i.e. high-field magnet development; will this be enough to develop magnets in a reasonable timescale?
  In addition, more time to accumulate funding for FCC?
  If ILC decision would be taken soon, e^+e^- machine could be realised earlier!!)

Summary

- We already contribute to Accelerator R&D Roadmap (RF, plasma), through the CERN centre and other NFR project
- With flat budget must cut existing (successful) collaborations/efforts to join new ones – should not spread out too thin
- Design contributions for future machine: hard to sell as high impact research to funding agencies
- If resources are enabled by the R&D roadmap (implementation unclear as of now), we could increase activities towards muon collider, FCC – this will put us in a position to ramp up if e.g. FCC is approved
  - FCC: more interesting to join accelerator, if Norway also joins detector/physics