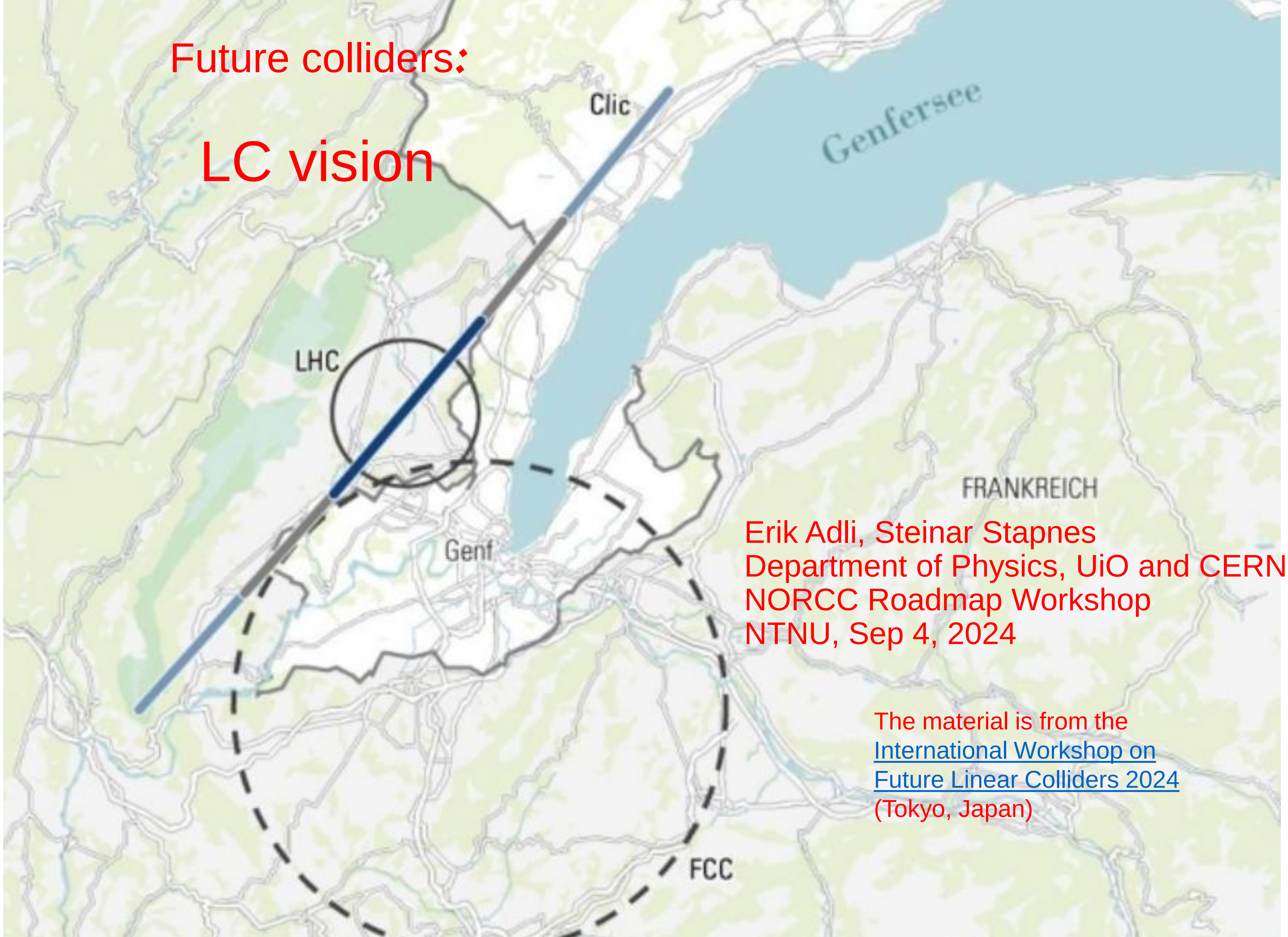
Future colliders:

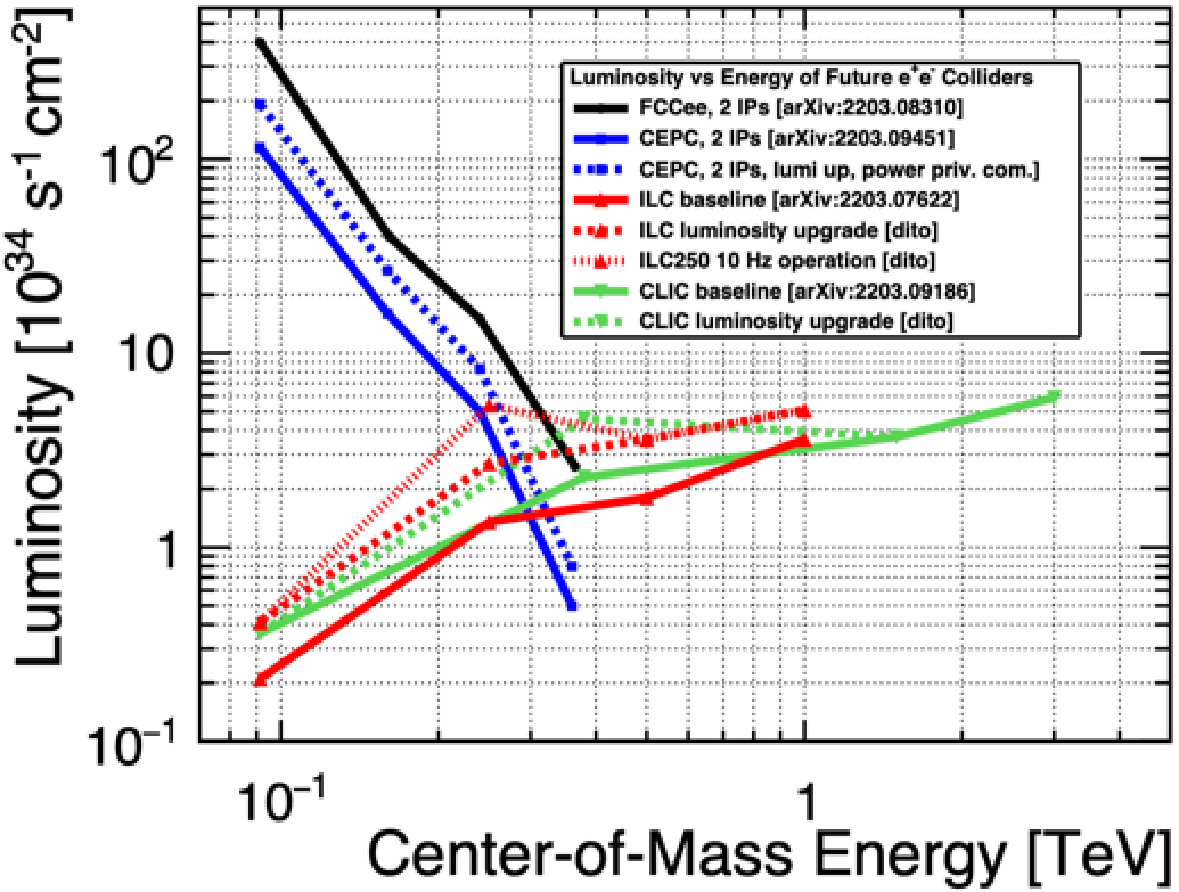
LC vision

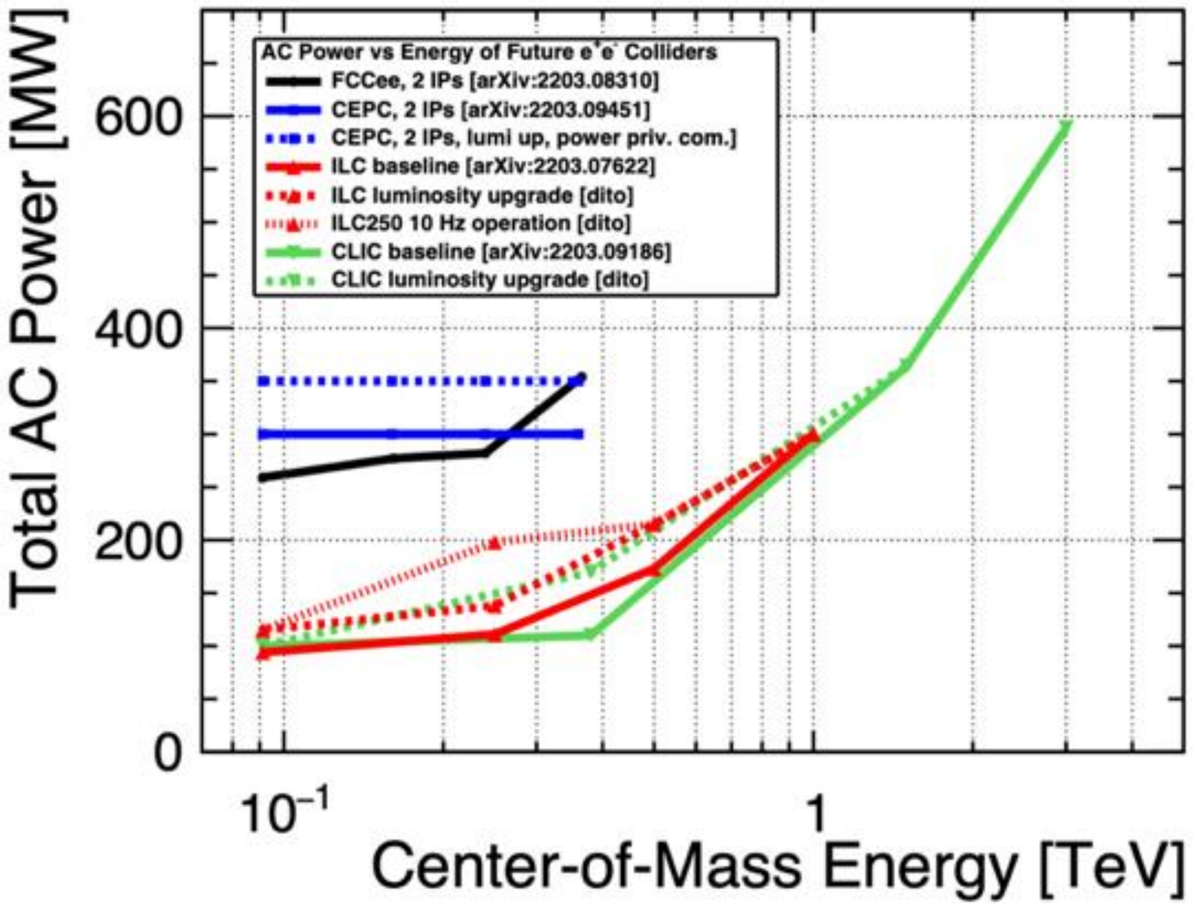


Erik Adli, Steinar Stapnes
Department of Physics, UiO and CERN
NORCC Roadmap Workshop
NTNU, Sep 4, 2024

The material is from the [International Workshop on Future Linear Colliders 2024] (Tokyo, Japan)

Future colliders, luminosity and power





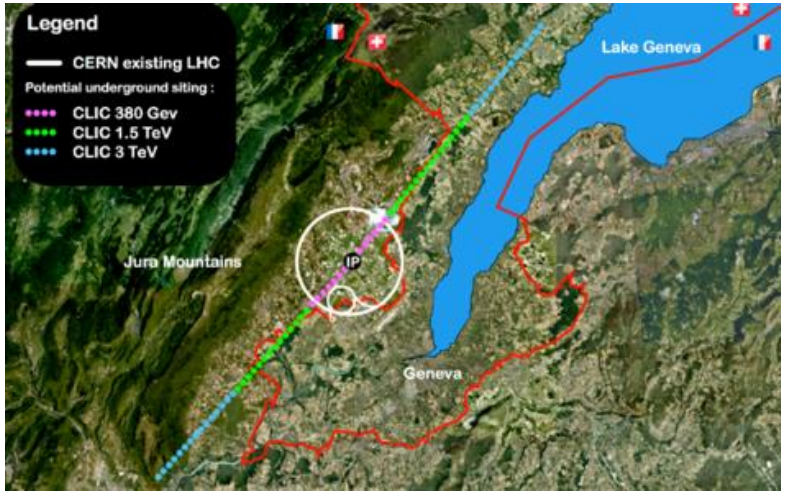
LC projects discussed below

ILC in Japan

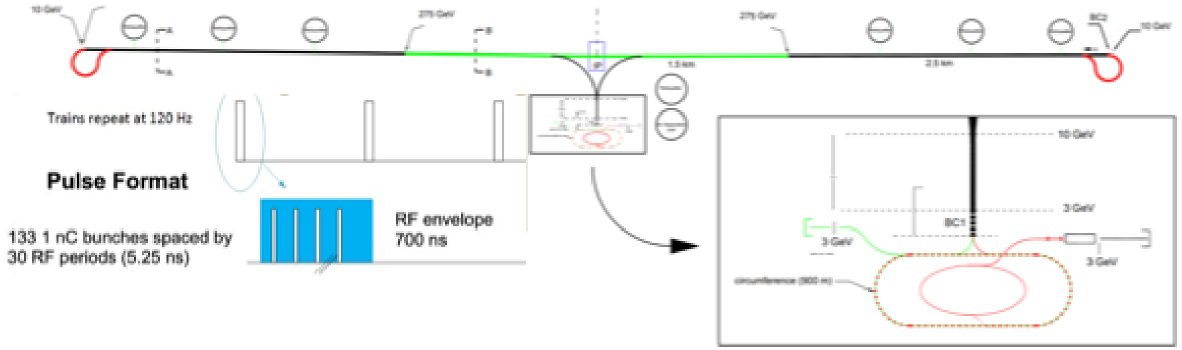
Initially e+e- collisions at least at 250 GeV

- Linear colliders: 11 (Higgs) -> 50 (max) km for higher energies later
- Four different RF solutions drive the designs
- Can be **built anywhere …**

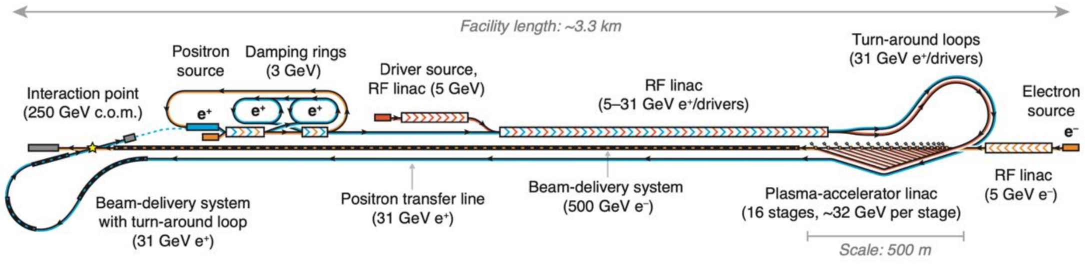
CLIC at CERN



C3 - US based study (initially)



HALHF – anywhere

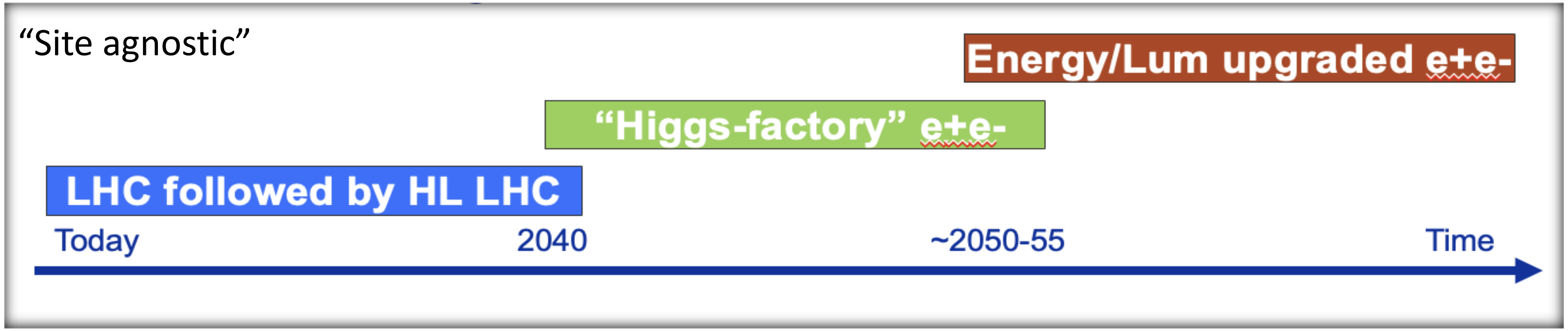


Source: **Foster, D'Arcy & Lindstrøm**, preprint at arXiv:2303.10150 (2023)

>Overall length: ~3.3 km ⇒ **fits in ~any major particle-physics lab**

>Length dominated by e− beam-delivery system

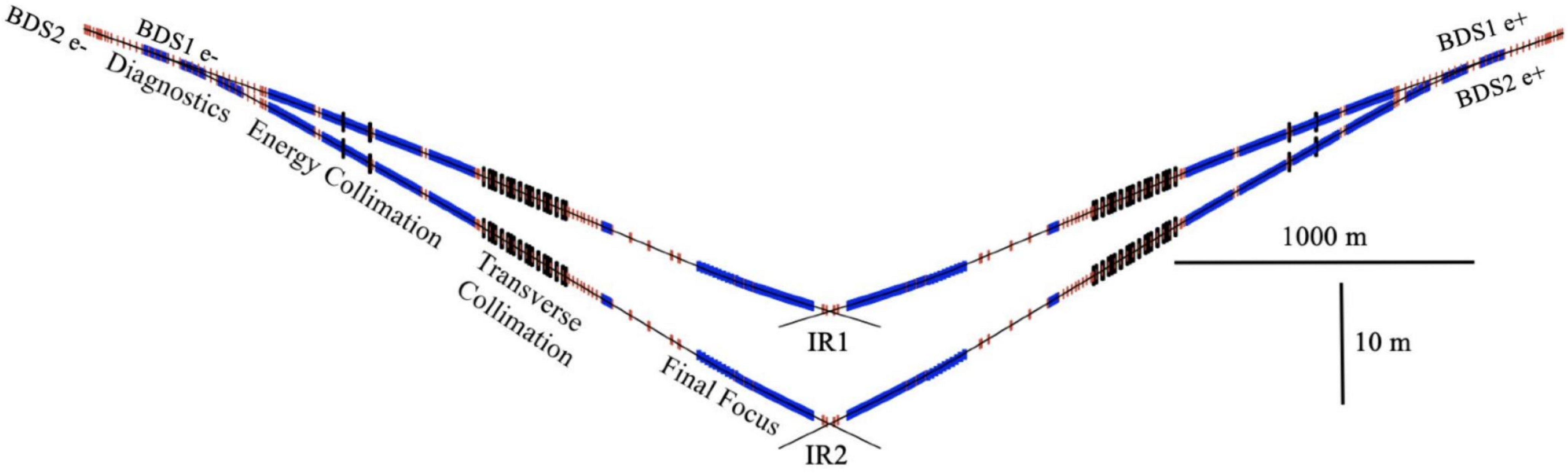
“LC vision” - an adaptable e+e- LC facility for the world



Start with an affordable, technologically-ready initial e+e- collider “Higgs Factory”
Upgrade to higher energy / luminosity as technologies become ready and affordable
using the same or improved versions of the same technology, e.g. as suggested for ILC, CLIC, C3 and HALHF.

- Starting point for fast implementation: ILC has the most mature linac technology for large scale implementation, that is also well established in all regions and in industry - it is based on a 20-21km long and ~6-10m wide tunnel
- The physics at higher energies – Higgs sector and extended models with increased reach and precision, top in detail well above threshold, searches and hopefully new physics – will open for a very exciting long term e+e- programme (see Jenny’s slides)
- Such a programme can run in parallel with future hadron and/or muon colliders that can be developed, optimised and implemented as their key technologies mature
- **...or directly 550...800 GeV if CEPC in China?**

Novel Layout of the Dual BDS for CLIC 380 GeV



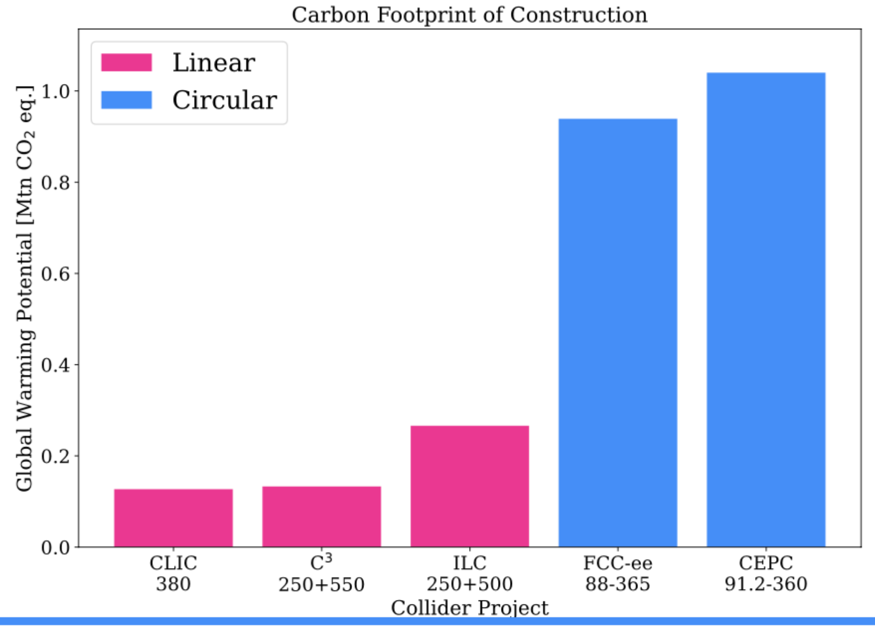
- Four different beam lines have been constructed to provide:
  - Longitudinal separation of ~ 40 m
  - Transverse separation of 10 m
- The θ in the DS of the BDS2 is 4.83 mrad
- **The crossing angles at IR1 and IR2 are respectively 16.5 mrad and 26 mrad**

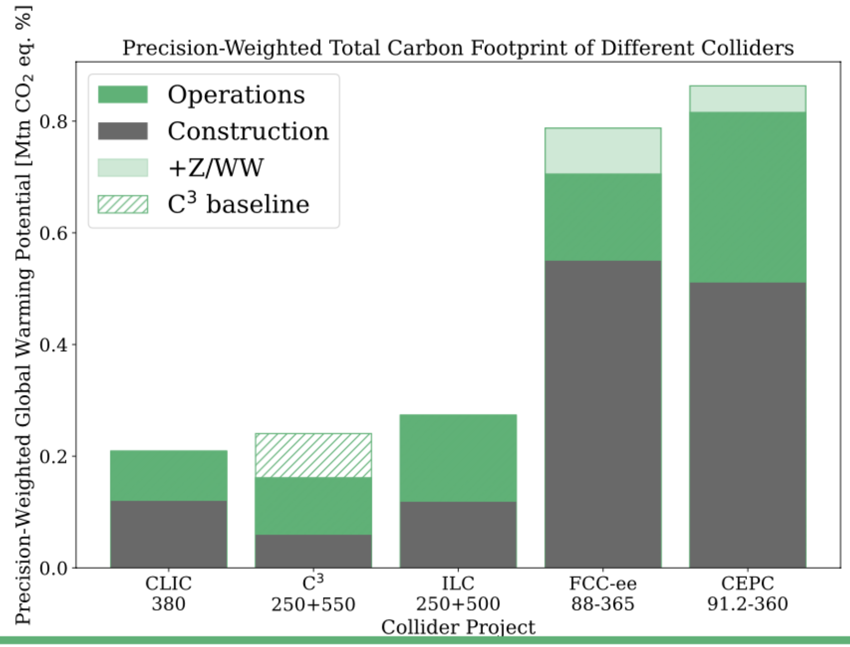
2nd Beam Delivery System (BDS) to 2nd Interaction Region, served "quasi-concurrently", by switching on train-by-train basis have been **designed for ILC & CLIC.**

Global Warming Potential

Study by C3

GWP of construction dominated by CO2 emission from the required concrete & steel => tunnel length (diameter, tunneling technique)





Adding operation GWP

(here weighted by improvement of Higgs couplings over HL-LHC, and with power mix predictions for CERN, US, Japan, China):

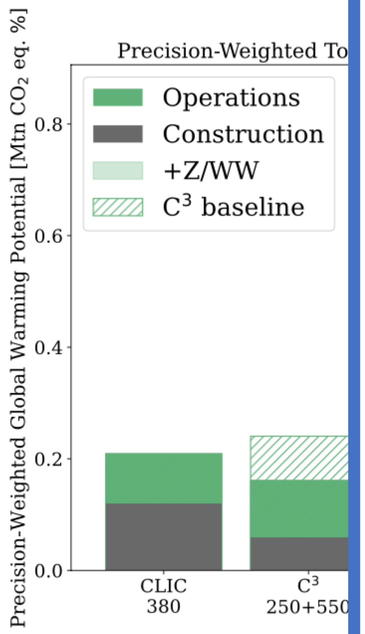
- **Operation dominates for LCs**
- **Construction dominates for CCs**

arXiv:2307.04084

Global War

Study by C3

GWP of cons
from
=> tunnel le



nature > news > article

NEWS | 06 June 2024

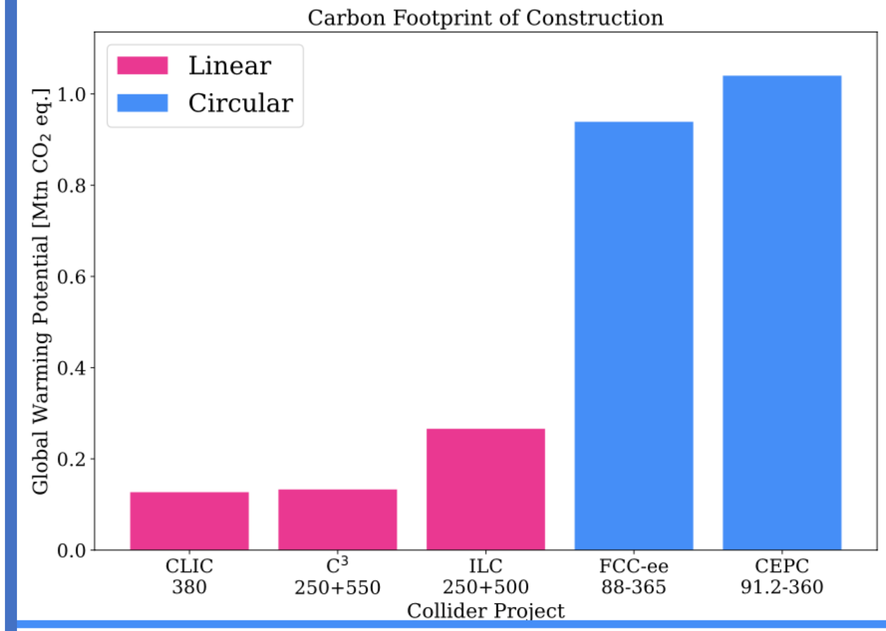
CERN's $17-billion supercollider in question as top funder criticizes cost

Germany has raised doubts about the affordability of the Large Hadron Collider's planned successor.

By Davide Castelvecchi

The Future Circular Collider would occupy a 91-kilometre tunnel (artist's impression). Credit: PIXELRISE/CERN

Plans for a 91-kilometre European particle accelerator are facing a serious challenge after the German government said that the project was unaffordable.



Adding operation GWP

mprovement of Higgs couplings over HL-LHC,
ix predictions for CERN, US, Japan, China):

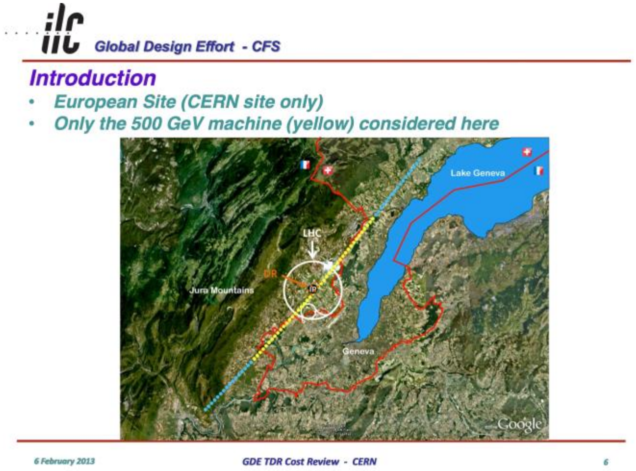
minates for LCs

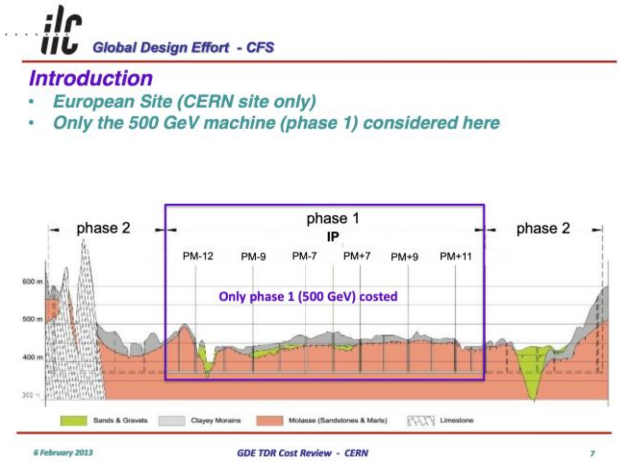
dominates for CCs

arXiv:2307.04084

Linear Collider Inputs to the EPPSU – "LC vision"

- Expect each LC project (ILC, CLIC, C3, HALHF, …) to make "Project Submissions"
  - project overviews with accelerator bias
- Joint LC Submission (physics focus)
  - physics at a LC from 90 GeV to multi-TeV (use references to existing documents, but highlight specifically
    - need for >= 500 GeV and polarised beams
    - new results since Snowmass
  - a joint strategic vision for a Linear Collider Facility incl. upgrades, beyond collider etc — at any location in the world
- Expect some Detector Concepts (ILD, SiD, …) to make a "Detector Concept Submissions"
- "LC facility at CERN" submission (i.e. starting with ILC as outlined)

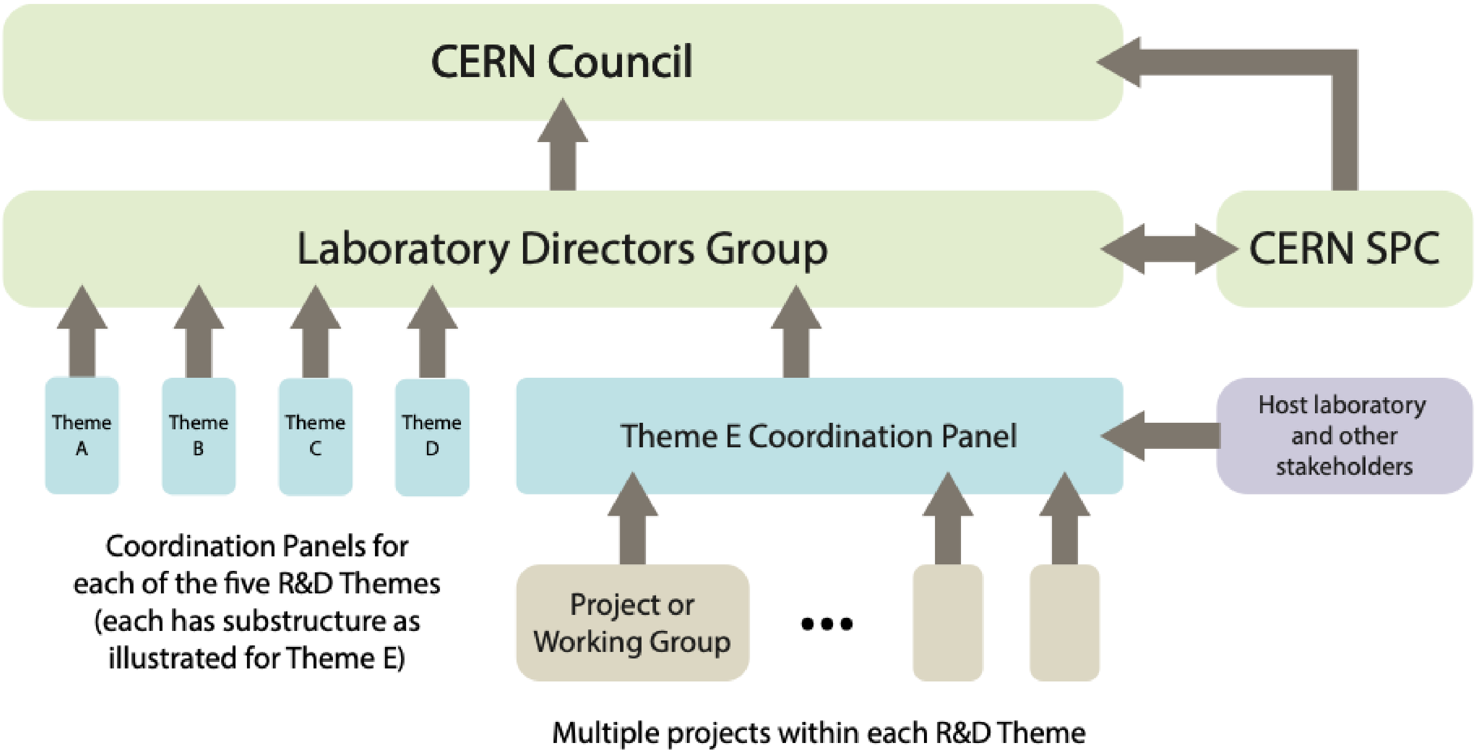




Adapted from Jenny List

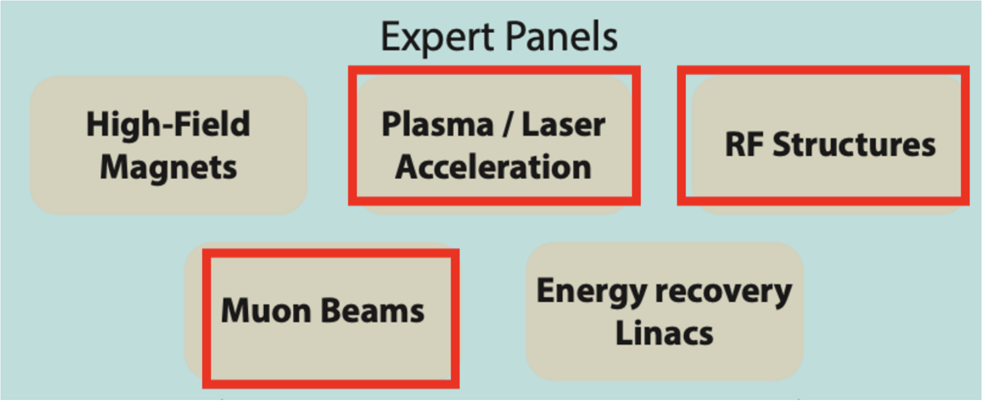
Accelerator R&D Roadmap

Coordination Structure



Coordination Panel Leadership

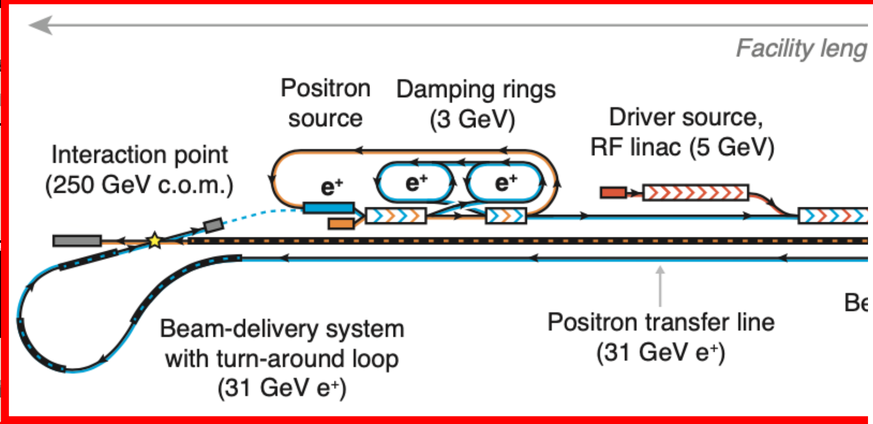
- HFM
  - Mike Lamont (CERN)
  - Pierre Vedrine (IRFU)
- RF
  - Giovanni Bisoffi (INFN Padova)
  - Peter Mcintosh (DL)
- LPA
  - Wim Leemans (DESY)
  - Rajeev Pattahill (RAL)
- Muons
  - Steinar Stapnes (CERN)
  - Daniel Schulte (CERN)
- ERL
  - Jorgen D'Hondt (VUB)
  - Max Klein (U. Liverpool)



- Important that the door is kept open for new participation in coming years
- Becoming clear that communication between panels is also a key aspect
  - e.g. strong overlap between RF, magnets and muons activities

Roadmap, implementation for plasma acceleration (draft)

	Timeline (approximate/aspirational)		
	0-10 years	10-20 years	20-30 years
Single-stage accelerators (proton-driven)	Demonstration of: Preserved beam quality, acceleration in ve… plasma uniformity (longitudinal & t…		
Single/multi-stage accelerators for light sources (electron & laser-driven)	0-10 years Demonstration of: ultra-low emittances, high rep-rate/high effi… laser drivers, Long-term operation, potentia… staging, positrons **(EuPRAXIA)**		



	Timeline (approximate/aspirational)			
	0-5 years	5 - 10 years	10-15 years	
Multi-stage accelerators (Electron-driven or laser-driven)	**Pre-CDR (HALHF)** Simulation study to determine self-consistent parameters (demonstration goals)	Demonstration of: scalabe staging, driver distribution, stabilisation (active and passive)	**Multistage tech demonstrator** Strong-field QED experiment (25-100 GeV e-)	Fa…
		Demonstration of: High wall-plug efficiency(e- -drivers), preserved beam quality & spin polarization, high rep.rate, plasma temporal uniformity & cell cooling		
		Demonstration of: Energy-efficient positron acceleration in plasma, high wall-plug efficiency (laser-drivers… energy recovery schemes, compact beam delivery systems		

Table 1 | Work Packages and coordinators

WP No.	Work package	Coordinators	Main activities
1.1	**Overall collider concepts (Higgs Factory)**	Carl Lindstrøm, Brian Foster, Richard D'Arcy, Deputy: Erik Adli	Ownership of HALHF parameters, informed by expertise in the other WPs and the HEP community. Coordination of HALHF at an overarching level, including seeking input and expertise from the CLIC/ILC communities, identifying critical items in the non-plasma part of HALHF (BDS, DR, e+ production) and first investigations of physics case and detector considerations for HALHF.
1.2	**Beam-driven electron linac – integrated simulations**	Erik Adli Deputy: Carl Lindstrøm	Start-to-end simulations of PWFA linac with HALHF -parameters to underpin HALHF design. This includes: Developing single stage and interstage models, in collaboration with expertise from the other WPs (PIC expertise, experimental results, rep. rate studies etc.), Quantifying the overall length, efficiency and emittance preservation, including tolerances, of the HALHF PWFA linac.
1.3	**Laser-driven electron linac**	Jorge Viera, Brigitte Cros, Maxence Thevenet, Zulfukar Najmudin	Identifying any fundamental showstopper Improving reduced models with additional physics

Implications for Norway?

- No current accelerator and detector activites towards FCC
  - But open to contribute towards FCC, if it goes head

- Most of our accelerator activites related to the LC vision
  - Funded for the next 5+ years
  - R&D towards compact acceleration -> large spin-off potential

- A possible update of the ESU: delayed decisions and “vigourous accelerator R&D needed” ?

- Norwegian roadmap document: currently reflecting the above statements, we are well prepared

- Questions/viewpoints?   *We’ll also have a general discussion at the end)

Extra

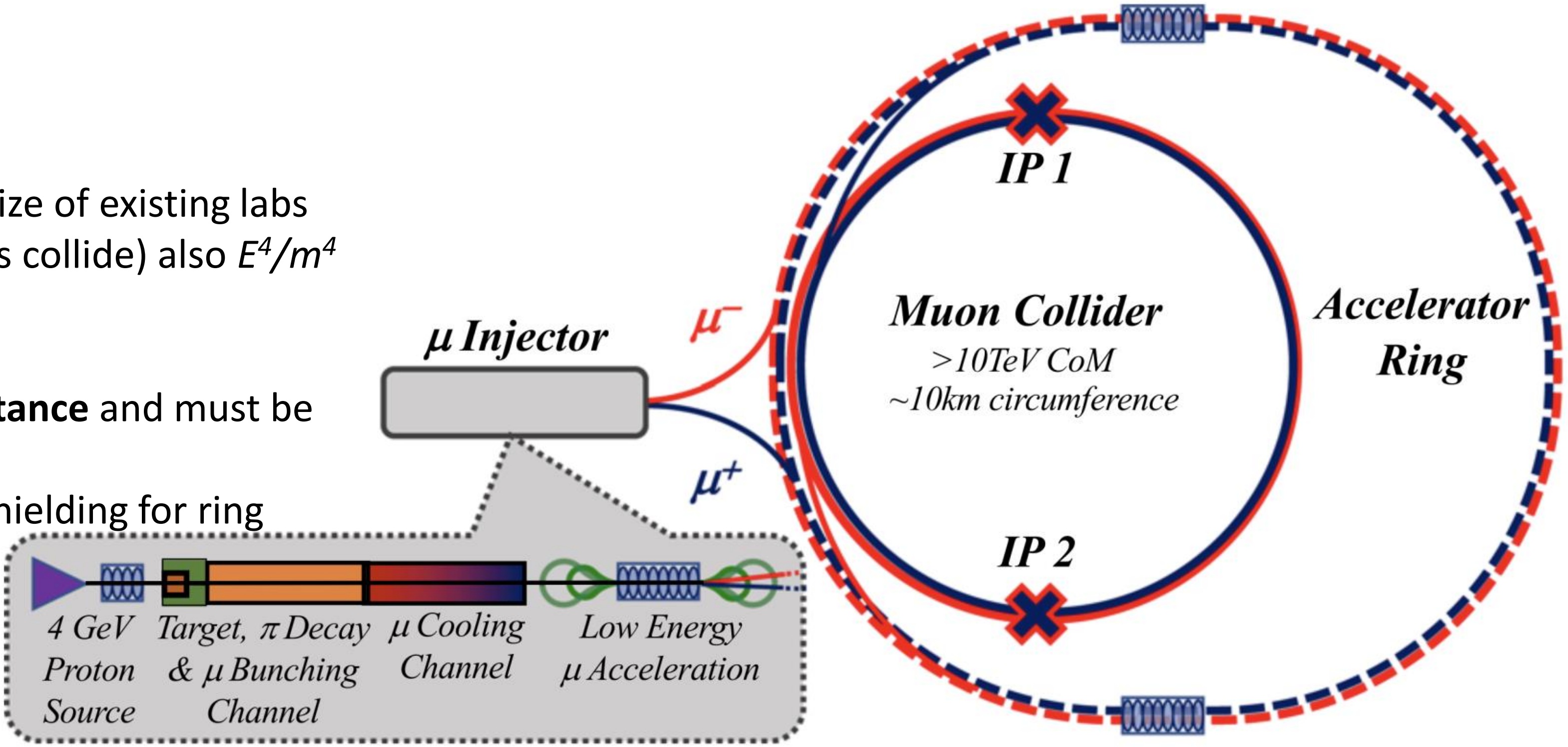
The Muon Collider

Advantages:

- Synchrotron radiation E^4/m^4
- A TeV muon collider ring is small and can fit to the size of existing labs
- Beamstrahlung (synchrotron radiation as two beams collide) also E^4/m^4

Challenges:

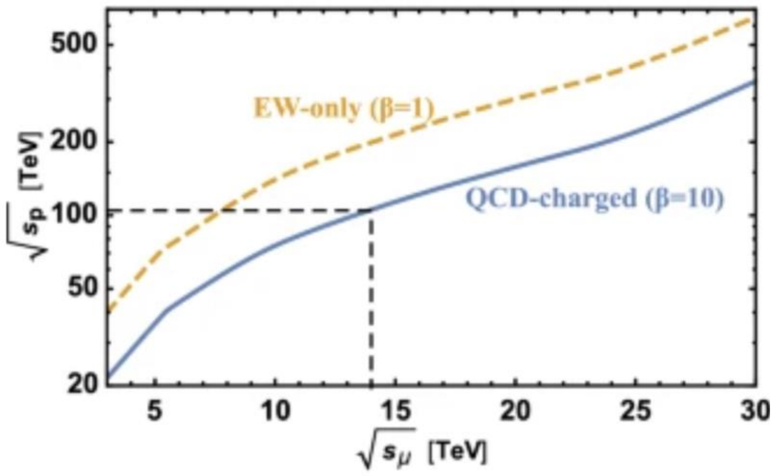
- Cooling and acceleration must be **fast** (<< 2.2 μs)
- Muon beams from proton drivers **has large 6D emittance** and must be cooled by a factor ~100
- Decay electrons leads to **radiation,** imposes heavy shielding for ring magnets and detector

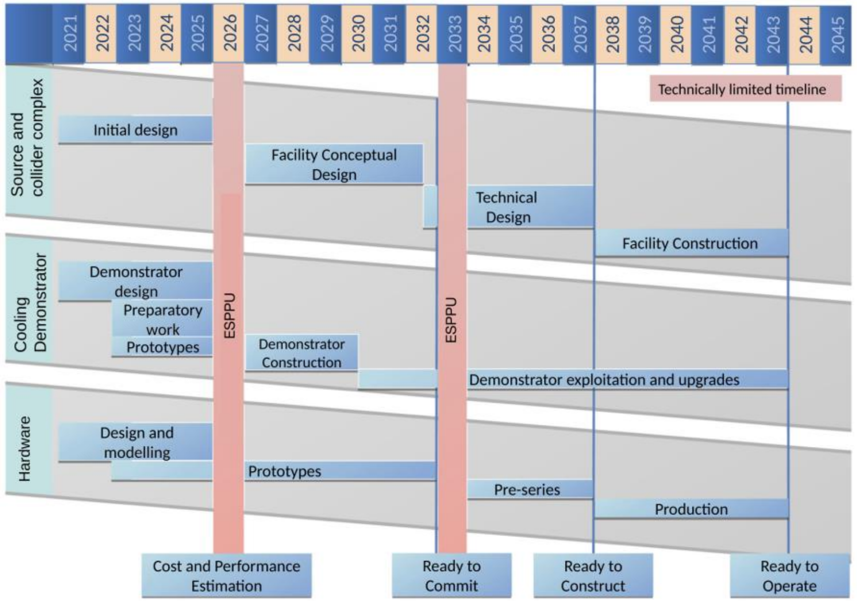


Towards a muon collider, EPJ C, 2023

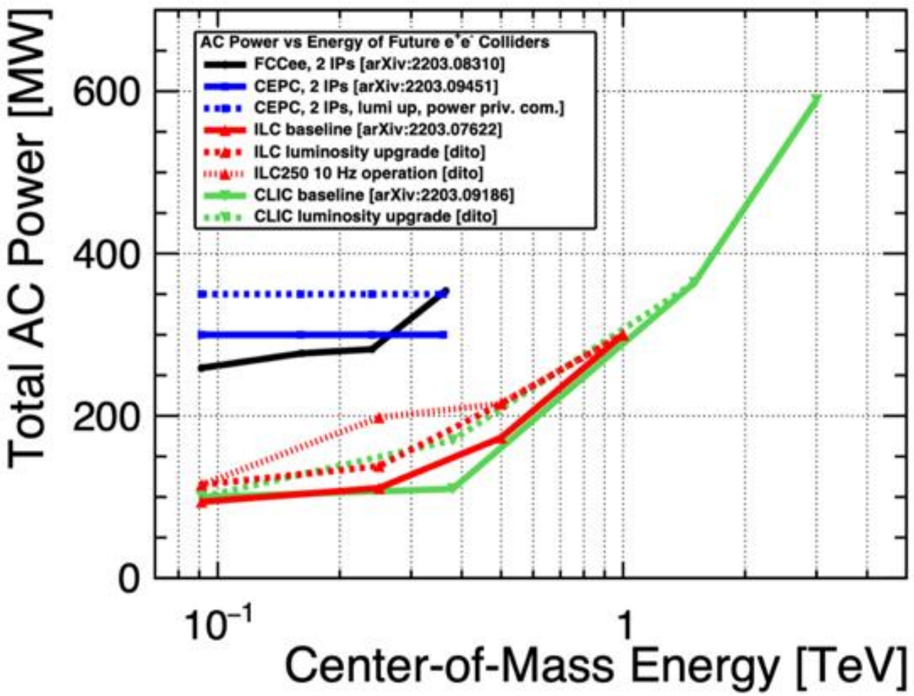
International MUON Collider Collaboration

IMCC





Power and energy

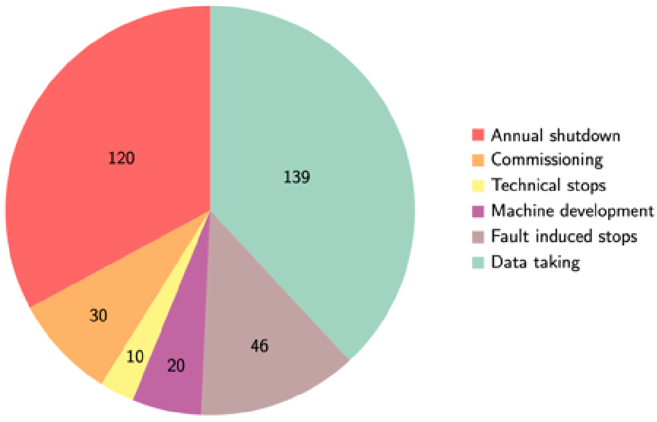


Power at 250-380 GeV in the 100-150 MW range for the projects above, reaching ~500 MW at 3 TeV for CLIC

With a running scenario on the right this corresponds to 0.6-0.8 TWh annually

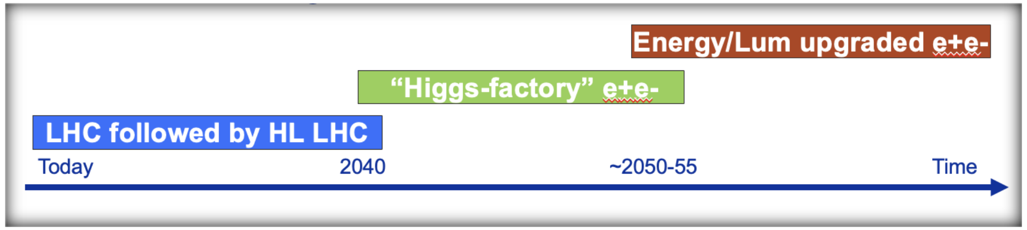
CERN is currently consuming 1.2 – 1.3 TWh annually

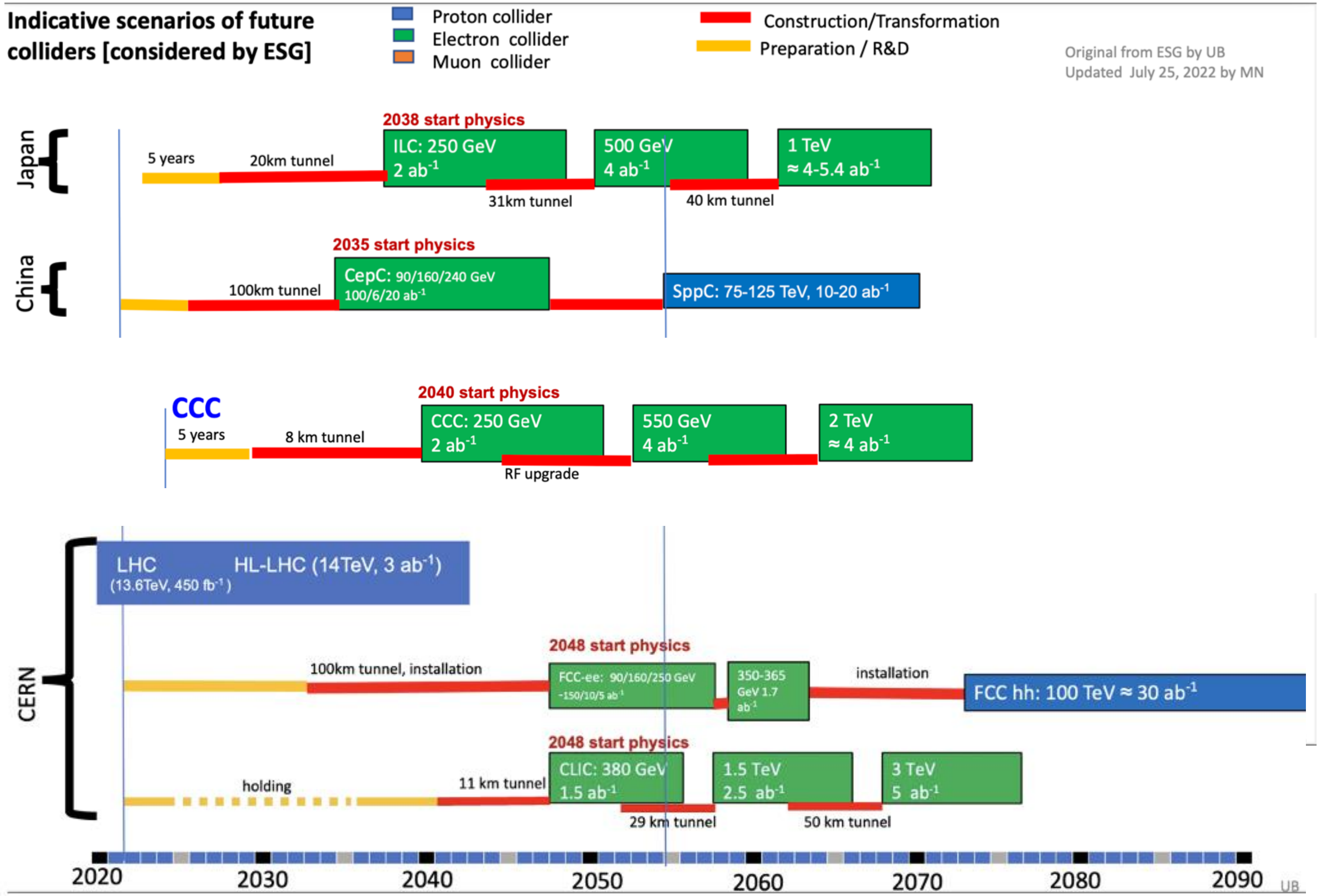
CERN "standard" running scenario used to convert to annual energy use



Includes studies of overall designs optimisation to reduce power, SRF cavities (grad,Q), cryo efficiency, RF power system (klystrons, modulators, components), RF to beam efficiencies, permanent magnets, operation when power is abundant, heat recovery, nanobeam and more.
Recent overview (LINK)

Timelines in Snowmass Energy Frontier summary





Comments:

- Timelines are technologically limited – except the CERN projects that are linked to completion of the HL-LHC
- From Meenakshi Narain EF summary Snowmass