Future Colliders

Facts and (Science) Fiction

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Meinerzhagen, Feb 14, 2024

Setting the Stage: Snowmass Study

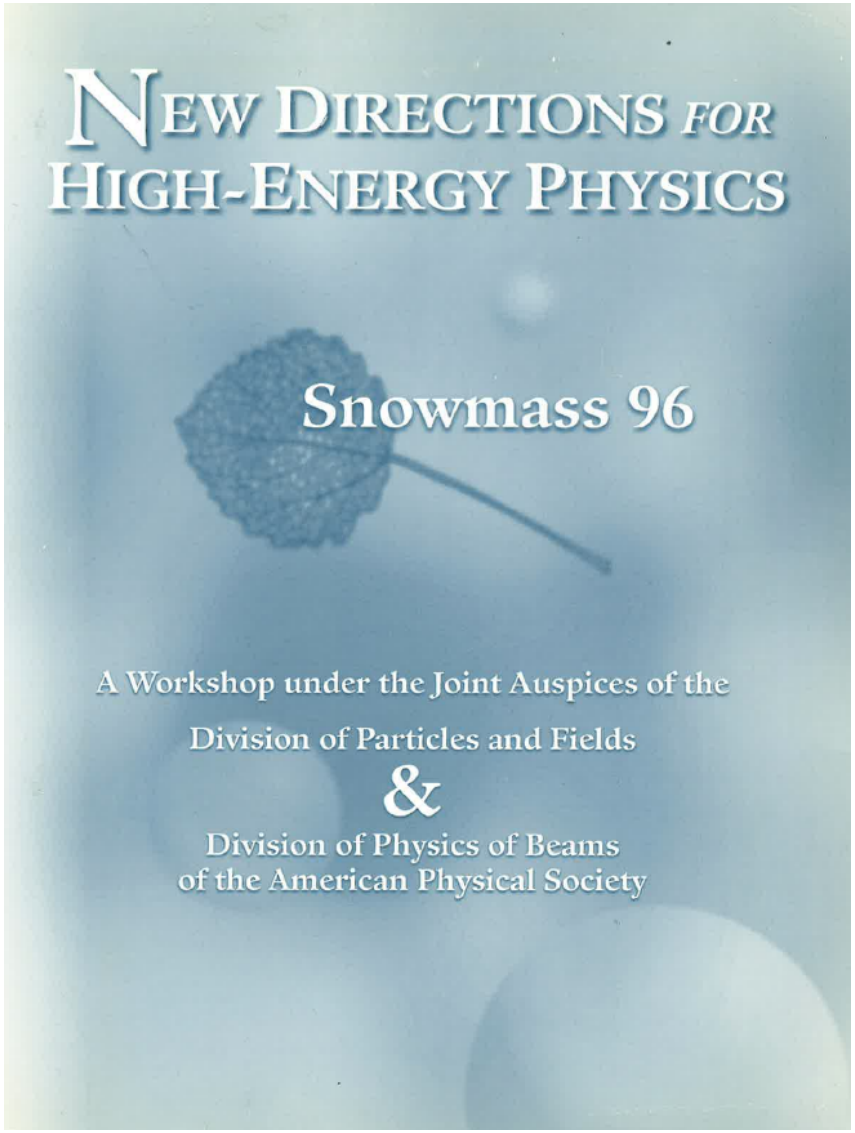
(Recurring community workshop of particle physics: prepare US strategy for future large facilities. Analogue: European Strategy)

From the opening presentation: some bits and quotes

. . . push as hard as possible on the High Energy, High Intensity, and High Precision frontiers

- LHC with very high luminosity . . . besides the Higgs . . . capable of uncovering many scenarios with new physics
- Beyond the LHC: e^+e^- . . . exciting viable possibility . . . superb tool for studying the Higgs
- Hadron collider with 100 TeV . . . technically feasible but is very expensive
- Growing enthusiasm for a muon collider with high energy $\gtrsim 4$ TeV and high luminosity

Source: W. Marciano, A High-Energy Physics Perspective



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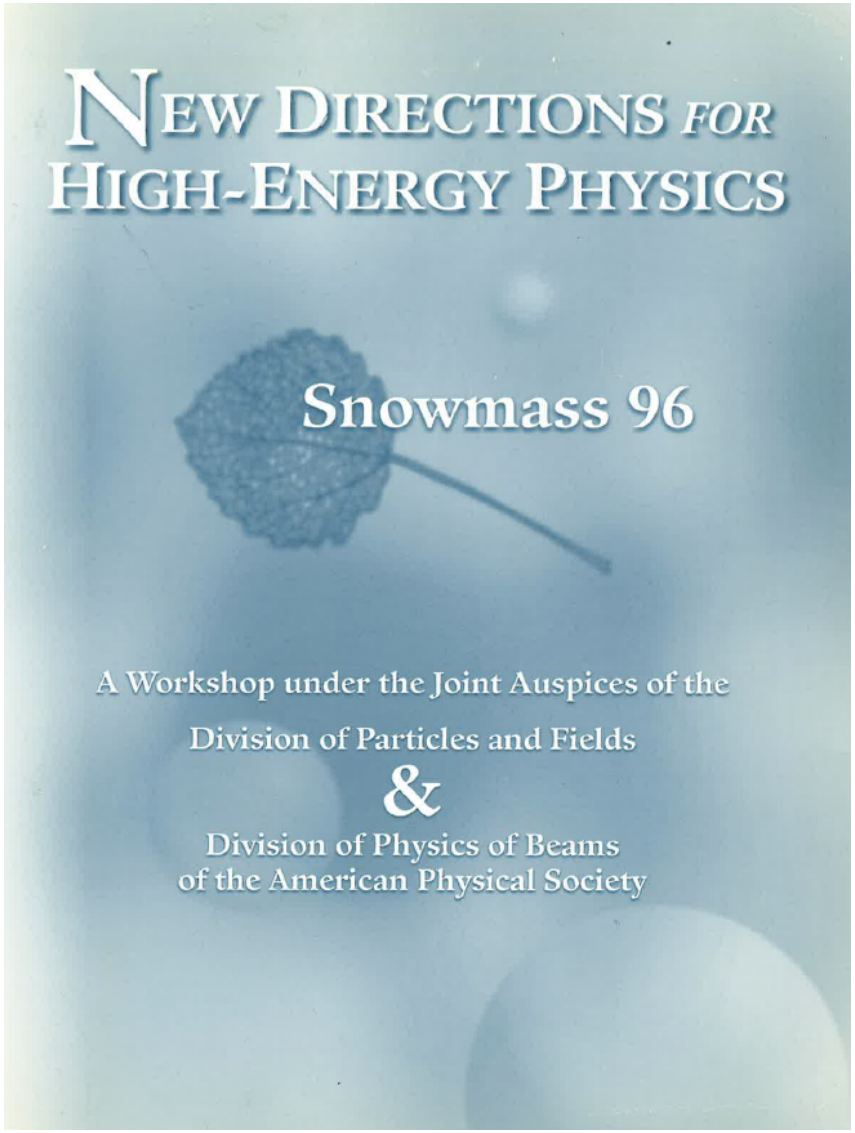

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"Where do we go from here?"

The e^+e^- Collider Story

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Season II (1990s): NLC, JLC: 500 GeV+

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Technology

- Two linear accelerators (e^- and e^+), 20 km total
- Superconducting cavities (TESLA)
- Electron accelerator can fuel positron production
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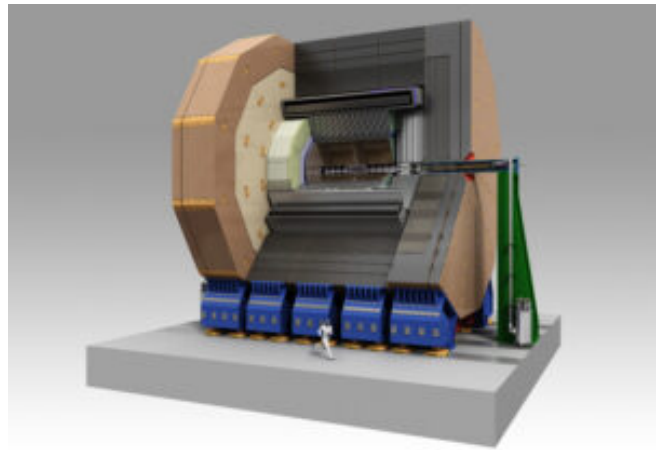
Status

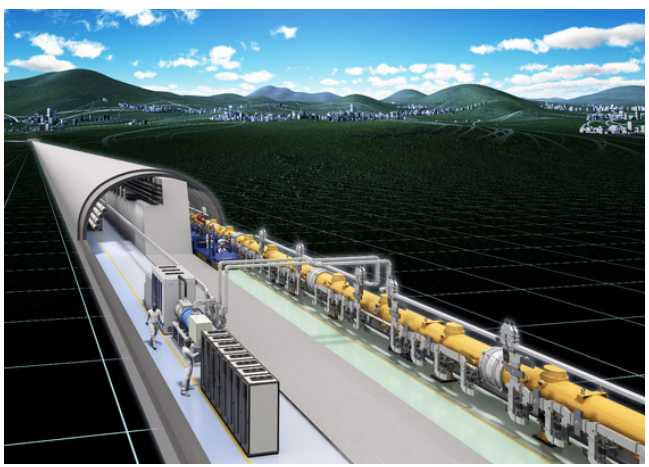
- Proposed: site in northern Japan (Morioka/Iwate)
- Japan: conditional promise of partial funding
- Detector development: DESY, SLAC
- IDT (International Development Team) active, managed via KEK

  $\Rightarrow$ LCWS 2024, Tokyo

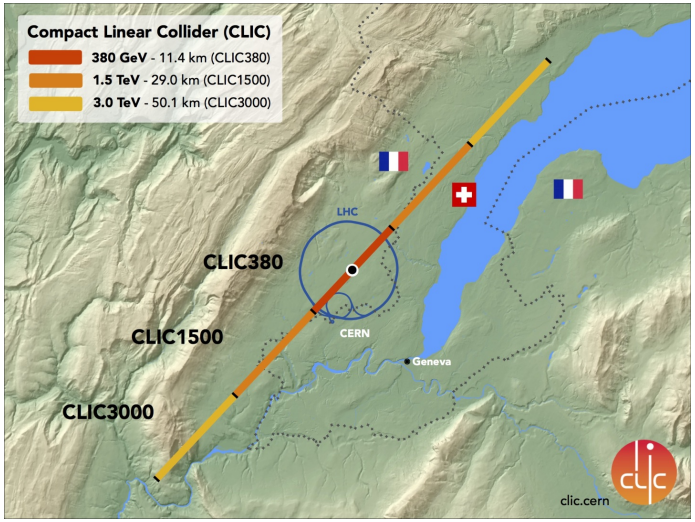
ILC

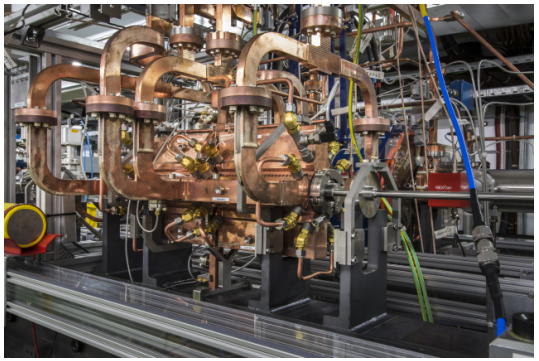


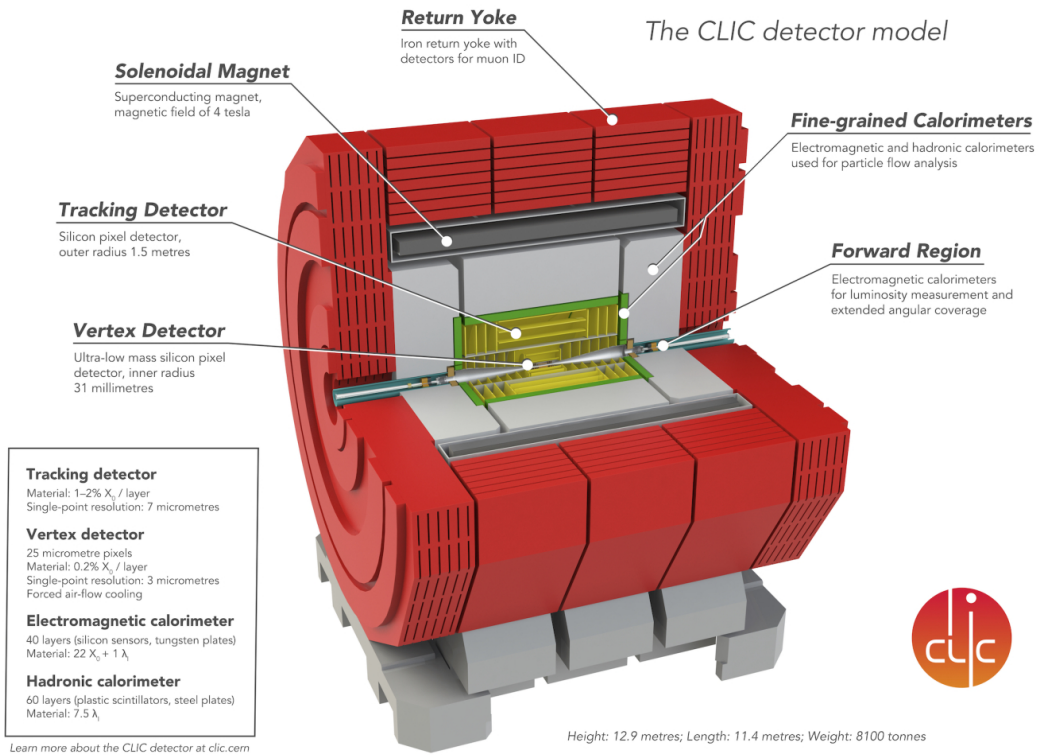
ILC加速器の構成模式図
Schematic illustration of ILC



CLIC



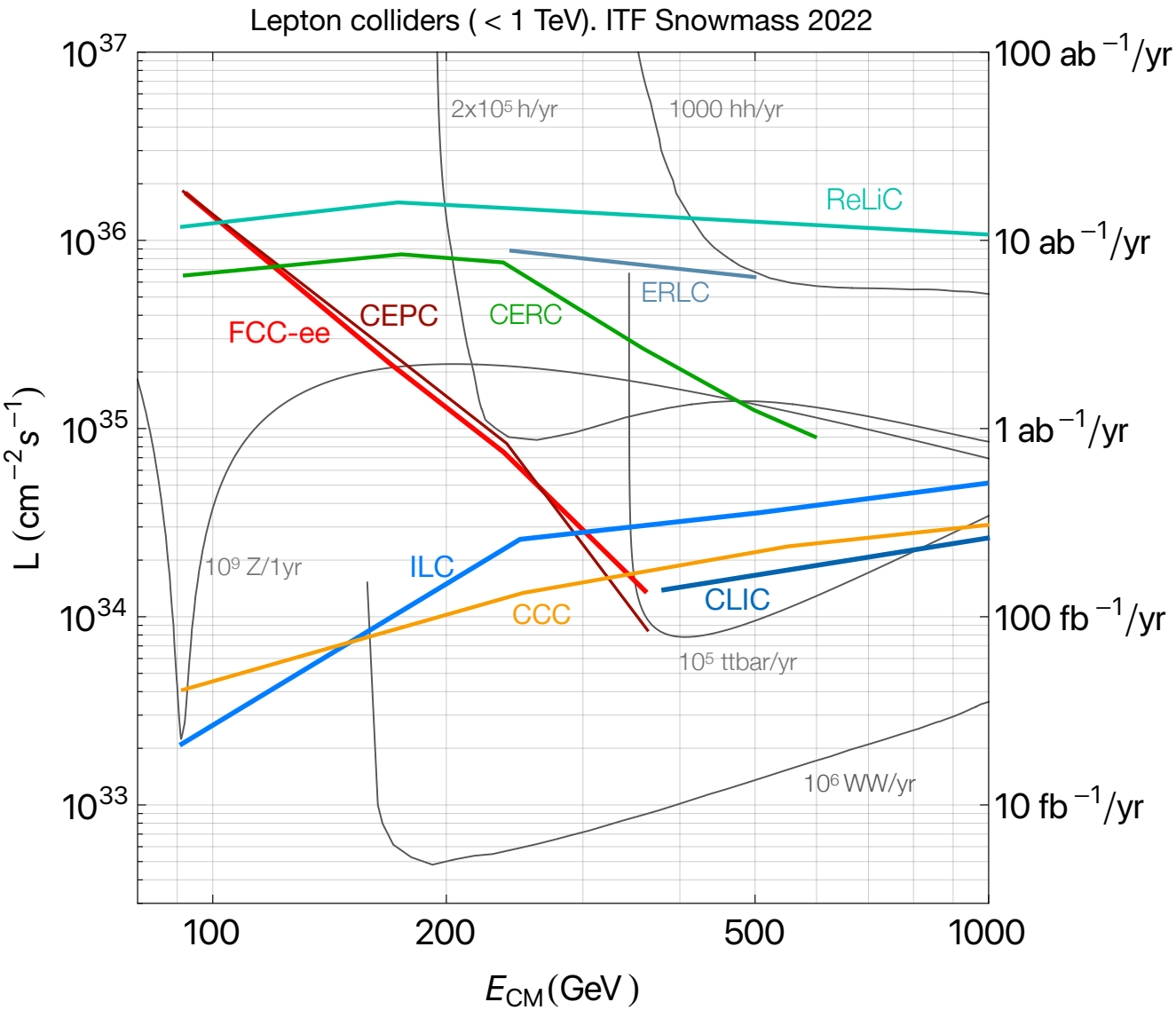




- CERN project
- Copper cavities with drive beam

  $\Rightarrow$ high gradient
- 1st stage: ZH, $t\bar{t}$
- Extensible to 3 TeV
- Accelerator technology study active (applications)
- Currently Plan B for CERN / Europe?

The Case for Higgs Factories



FCC-ee

For maximum Higgs production, 250 GeV is sufficient. Rather invest in highest possible luminosity?

- CERN project #1 after LHC shutdown
- New LEP-like collider with much longer tunnel
- Upgradable up to top-pair threshold energy
- Current: feasibility study
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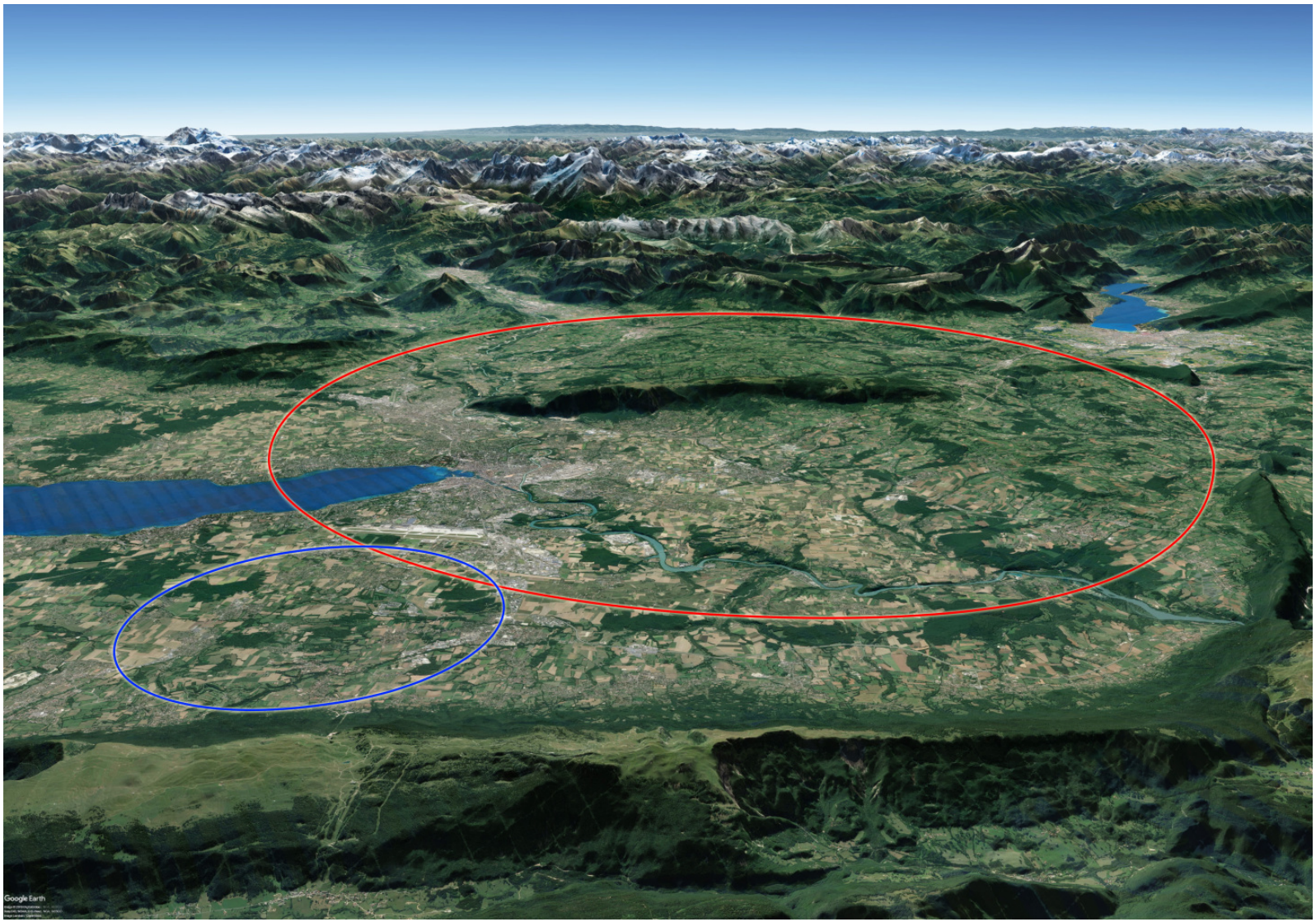
- This tunnel can (will?) host a genuine high-energy proton-proton collider in the far future

FCC



FCC-hh (SPPC)

"The Really Large Hadron Collider with $\sqrt{s} \simeq 100$ TeV looks technically feasible but is very expensive."

- Collision energy: 100 TeV
- Luminosity (integrated): $5\times$ total LHC luminosity
- Technology + cost challenge: superconducting high-field magnets 16 T (current LHC: 12 T)
- Effective $q\bar{q}/gg$ annihilation energy: $O(10\text{ TeV})$

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Timeline (CERN)

assume 2030: preparation – 2038: construction – 2048: operation FCC-ee – 2063: installation FCC-hh – 2073: operation – 2098

FCC

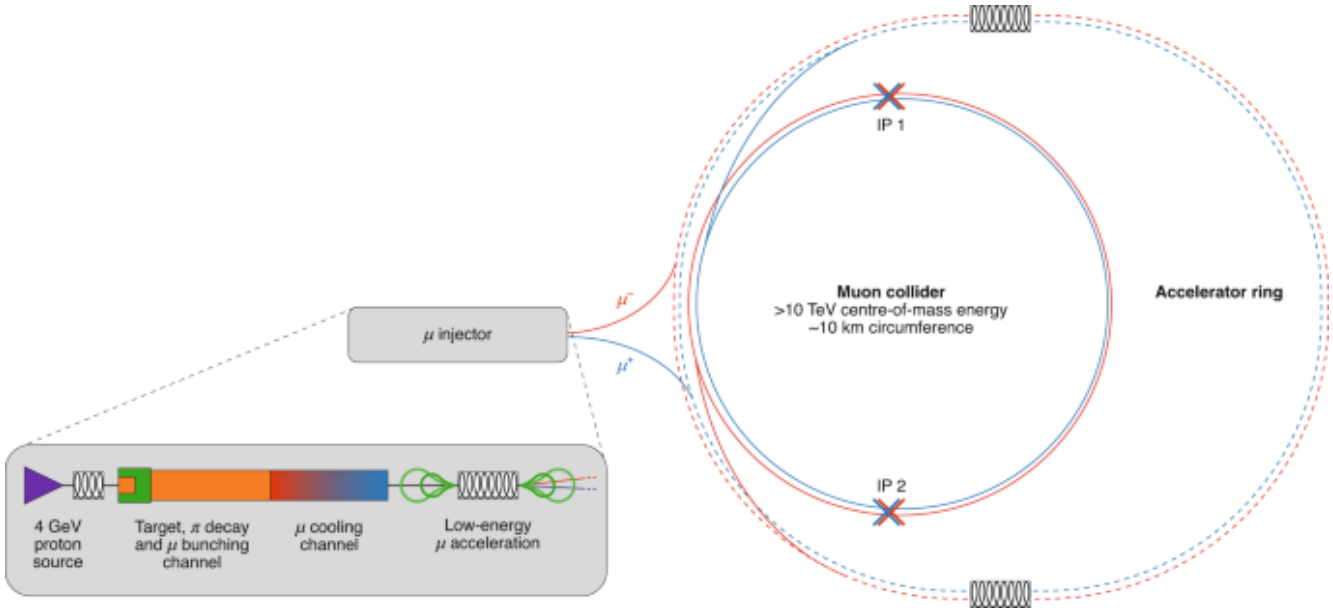
The Muon-Collider Wildcard

Snowmass 1996:
"An interesting study would be a comparison of pp vs. $\mu^+\mu^-$ physics potential."

"The muon collider concept is an idea whose time has come. Now it requires more serious study and R&D. [...] If it can work, it should be built."

P5 Panel 2023 (input from 2021–22 Snowmass):
"**Recommendation 4:** Support a comprehensive effort to develop the resources—theoretical, computational, and technological—essential to our 20-year vision for the field. This includes an aggressive R&D program that, while technologically challenging, could yield revolutionary accelerator designs that chart a realistic path to a 10 TeV pCM collider."

Muon Collider



- Less radiation than electrons
- Less stiffness than protons
- Elementary: 10 TeV in annihilation

- Need to accelerate before decay
- High radiation (neutrinos!)
- Test facilities needed

Honorable mentions

- ep: LHeC, FCC-eh, CEPC+SPPC
- e^+e^-: Fermilab circular *site filler* (Higgs factory)
- e^+e^-: CCC (Higgs factory)
- e^+e^-: energy-recovery: ERCL, ReLiC, CERC
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- pp: *Collider-under-the-sea* (500 TeV, 2000 km)

Colliders & their Physics Case

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Further info: https://arxiv.org/abs/2208.06030