Future Accelerators for ESPP: FCC-ee & Muon Collider &….

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06/11/2024
Meeting on
European Strategy for Particle Physics

INFN FERRARA
Istituto Nazionale di Fisica Nucleare

21 MAGGIO 2024

FCC E MUON COLLIDER AL CENTRO DEL WORSHOP INFN PER LA STRATEGIA EUROPEA DELLA FISICA DELLE PARTICELLE

Si è da poco concluso il workshop *L'INFN e la Strategia Europea per la Fisica delle Particelle*, che si è tenuto a Roma il 6 e 7 maggio scorsi, con una folta partecipazione, anche di giovani ricercatori. Scopo dell'incontro era presentare il lavoro che diversi gruppi di ricerca dell'INFN stanno conducendo per raggiungere gli obiettivi raccomandati dall'ultima edizione dell'*Update of the European Strategy for Particle Physics* (ESPPU) e avviare la discussione sulla preparazione del prossimo aggiornamento della strategia europea per la fisica delle particelle, un appuntamento cruciale per il futuro della fisica delle alte energie.

https://agenda.infn.it/event/39747/contributions/223704/attachments/119196/172718/FCC_VIvarelli_07052024.pdf

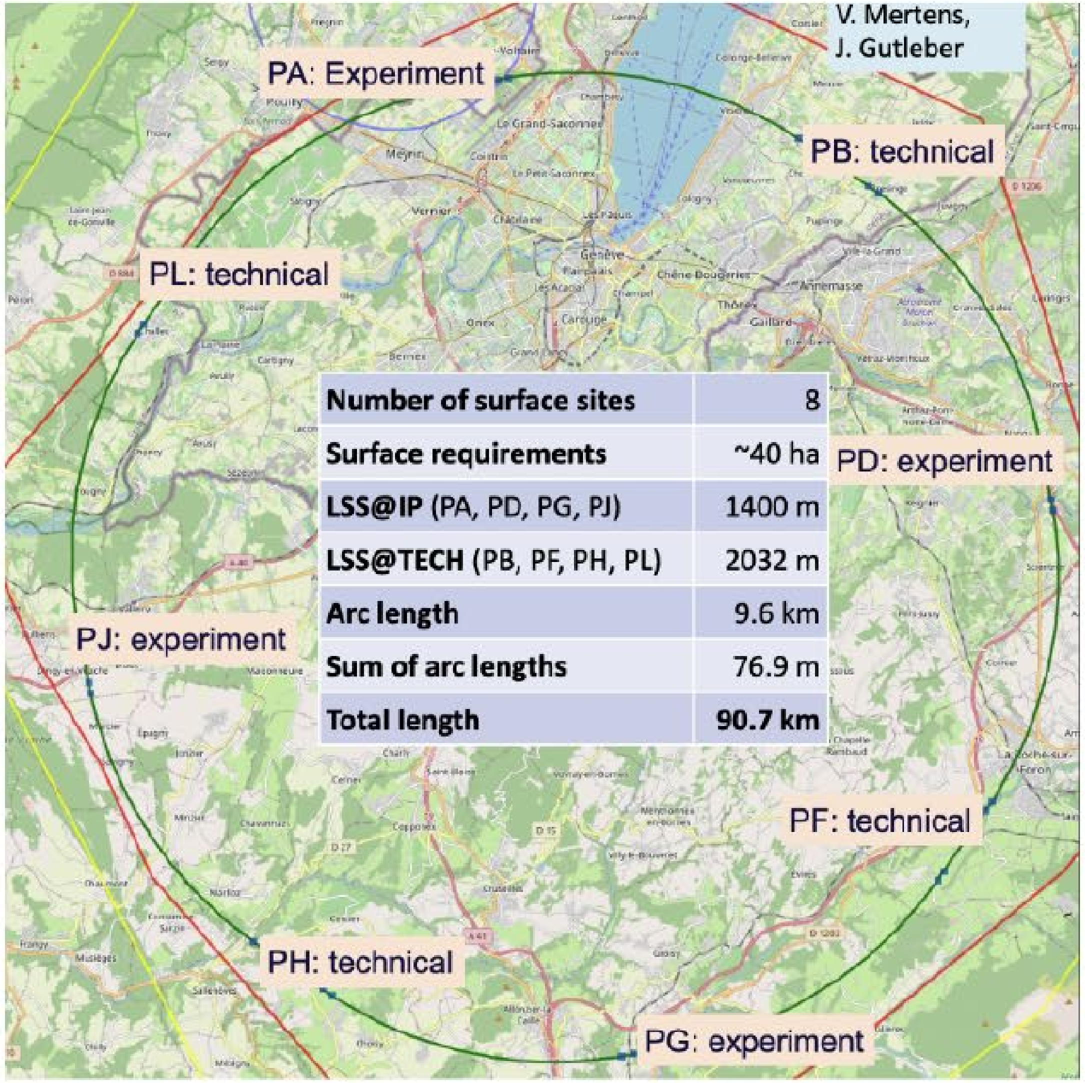
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

FCC-ee in pills

from G. Mezzadri

	Z pole	WW pole	ZH pole	Top pair pole
Beam energy (GeV)	45.6	80	120	182.5
Beam current (mA)	1270	137	26.7	4.9
Number of bunches	11200	1780	440	60
Luminosity (per IP - 10^{34} cm^{-2} s^{-1})	140	20	5	1.25
Integrated luminosity (per IP - ab^{-1}/year)	17	2.4	0.6	0.15
Planned running time (years)	4	2	3	5

Which translates in: 5×10^{12} Z (LEP $\times 10^5$) | $\sim 10^8$ WW (LEP $\times 10^4$) | 2×10^6 H unprecedented at e^+e^- | 2×10^6 $t\bar{t}$ unprecedented at e^+e^-



Number of surface sites	8
Surface requirements	~40 ha
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2032 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	90.7 km

Most demanding positron source

Frank Zimmermann (deputy study leader of FCC-ee) FCCWeek2024

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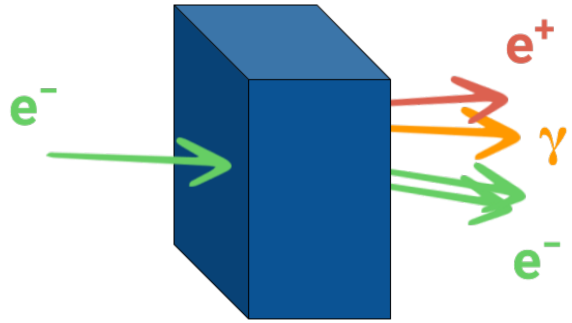
e^+ sources are critical of the future high luminosity colliders

Conventional scheme



Thick amorphous
W target

Current limited by the target heating/melting

e^+ source set a critical constraint for the peak and average current
Luminosity Constraint!
Expecially for future Linacs

FCC-ee positron source and pre-Injector

FCC-ee injector full chain simulation: e+ yield before the dumping ring

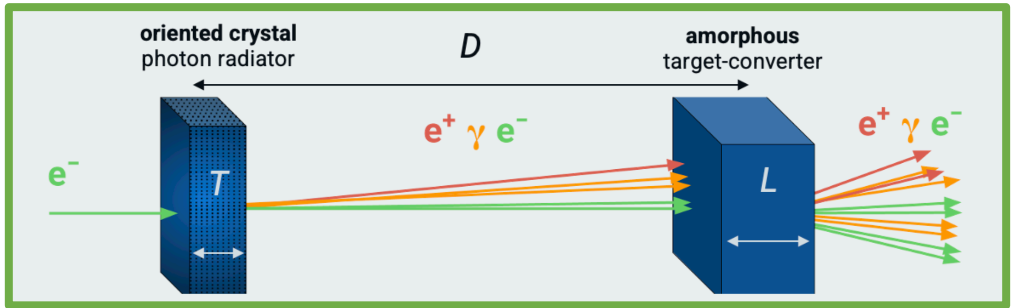
From FCC WEEK 2024

Collaboration with the **FCC-ee Injector Studies**

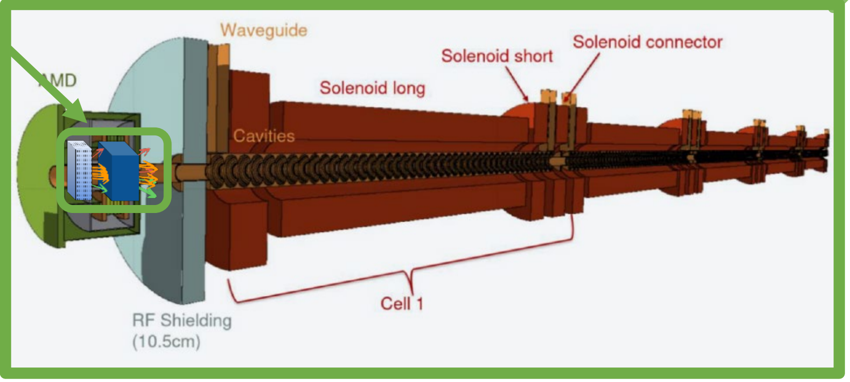
MoU between INFN FE and IJCLab

L. Bandiera et al., Eur. Phys. J. C (2022) 82:699

M. Soldani et al., NIM A 1058 (2024)



Crystal vs Conventional: Intense axial Channeling Radiation in a tungsten crystal results in **higher e+ rate**, with **less deposited energy in the converter!** Possibility to operate at **lower e- current!**



Goals: include the design in the next FCC CDR and test it in the **upgrade of the CHART P³ project on the full FCC-ee injector at PSI**

CHART Swiss Accelerator Research and Technology

PAUL SCHERRER INSTITUT PSI

Funded by the European Union NextGenerationEU

European Commission

Bando PRIN 2022

Trillion

E+BOOST

International Collaboration taks leader: I. Chaikovska, IJCLab

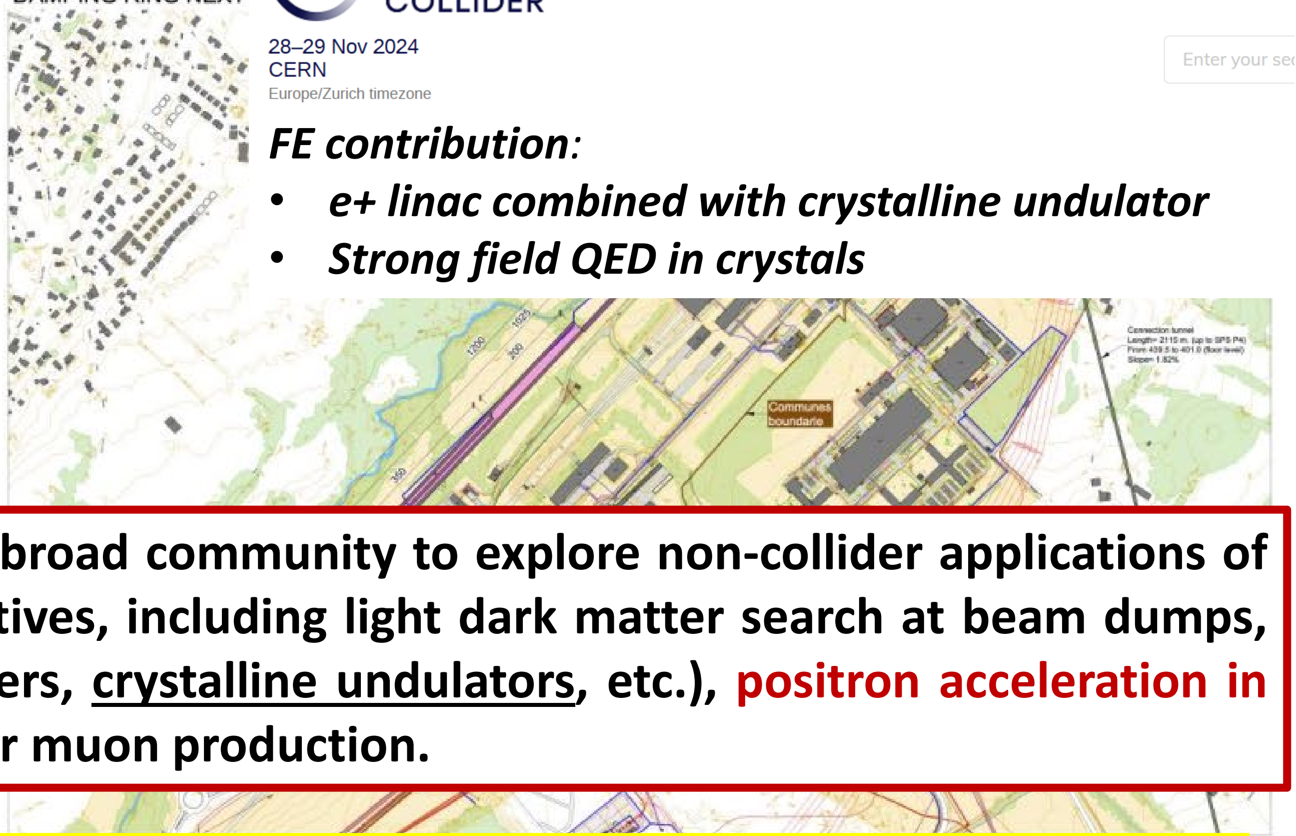
INFN Units involved: Ferrara (coordinator), LNL, Milano, MiB, Naple

Siting of injector complex

20 GeV e+/e-

CERN Physics Beyond Colliders

- Latest proposal: injector complex on the the Prevessin site with damping ring next to the "decheterie"
- High energy linac next to North Area and Beam Dump Facility
- Connection tunnel (2.1 km) to reach BA4 of the SPS, for transfer to the booster



FUTURE CIRCULAR COLLIDER — Other Science Opportunities at the FCC-ee

28–29 Nov 2024
CERN
Europe/Zurich timezone

FE contribution:

- ***e+ linac combined with crystalline undulator***
- ***Strong field QED in crystals***

CERN Physics Beyond Colliders is engaging a broad community to explore non-collider applications of the FCC-ee injector for various physics objectives, including light dark matter search at beam dumps, strong-field QED and light sources (using lasers, crystalline undulators, etc.), positron acceleration in plasma wakefield, and the LEMMA scheme for muon production.

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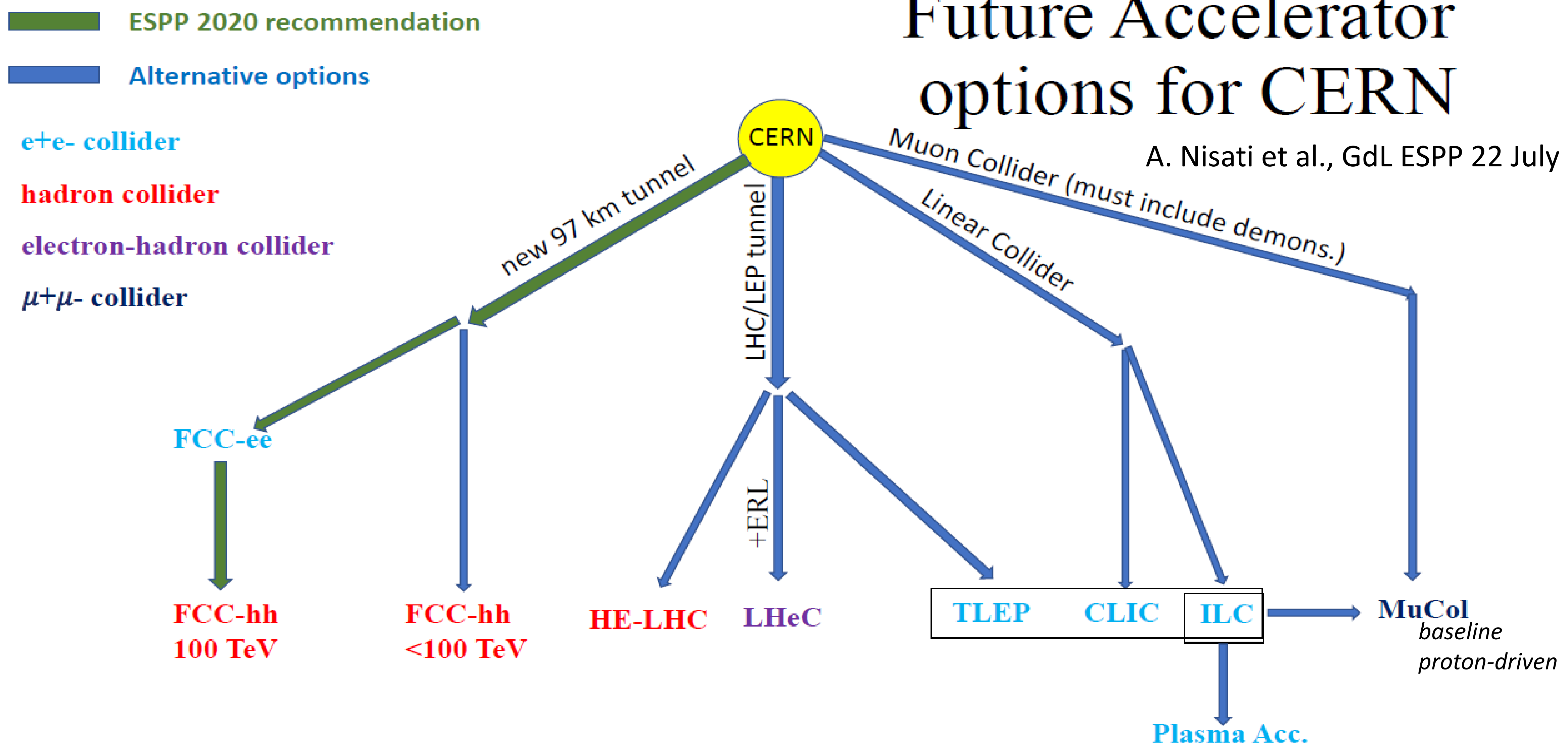
Ferrara involved in the PBC ESPP for the non collider science at the FCC-ee injector

Future Accelerator options for CERN

A. Nisati et al., GdL ESPP 22 July 2024



Future Accelerator options for CERN

ESPP 2020 recommendation

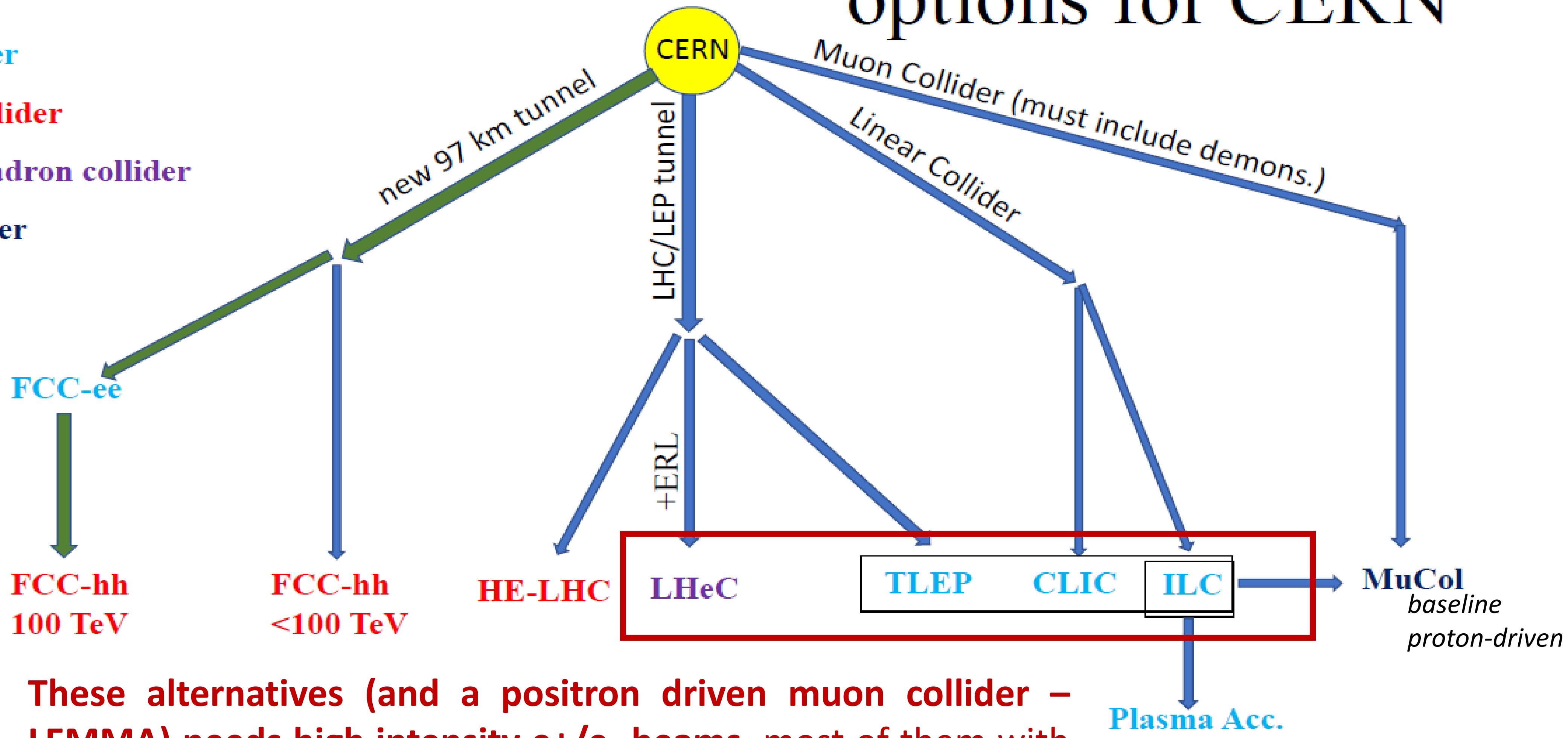
Alternative options

e+e- collider

hadron collider

electron-hadron collider

$\mu+\mu-$ collider



These alternatives (and a positron driven muon collider – LEMMA) needs high intensity e+/e- beams, most of them with requirements even more challenging than FCC-ee*

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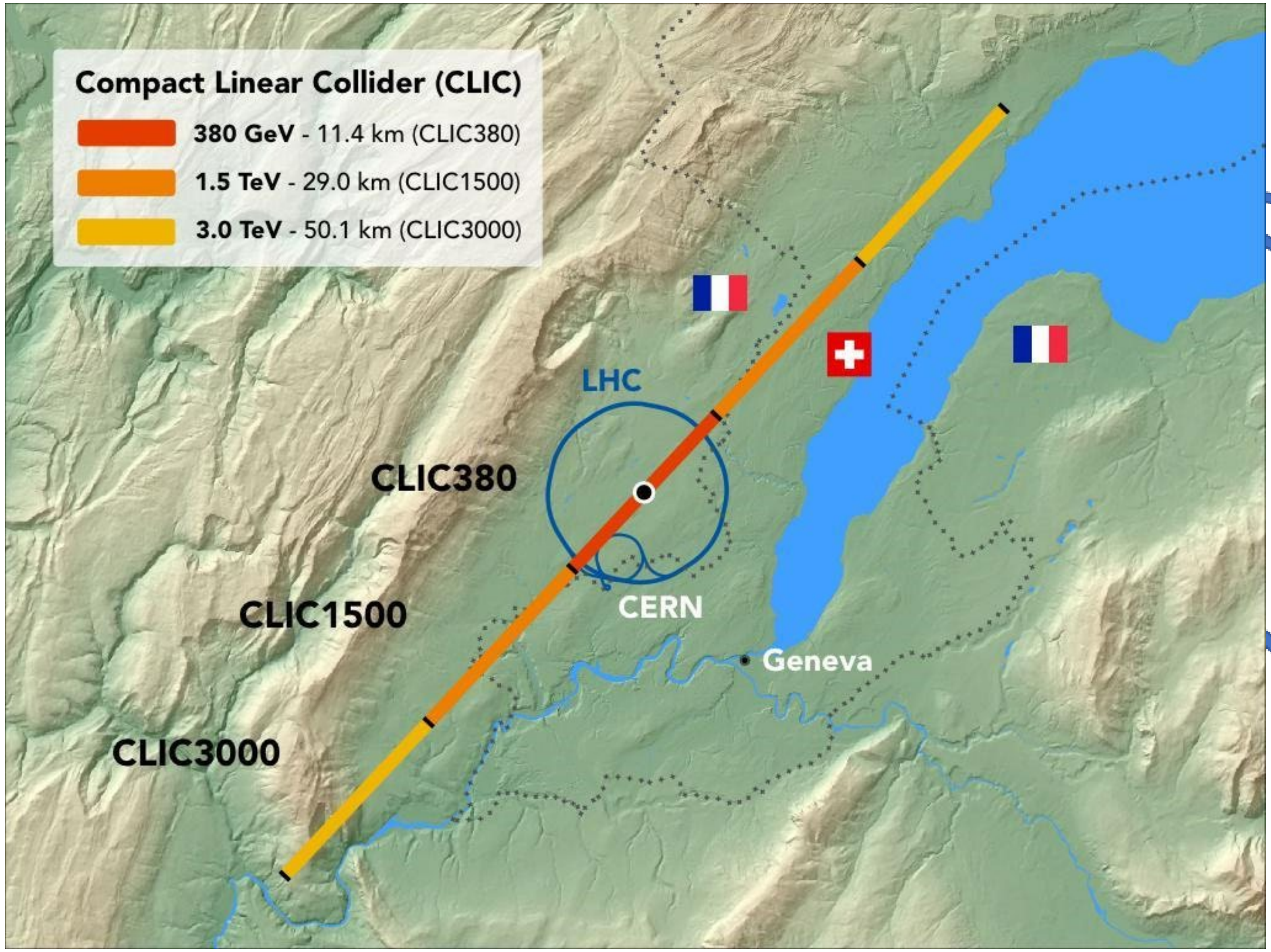
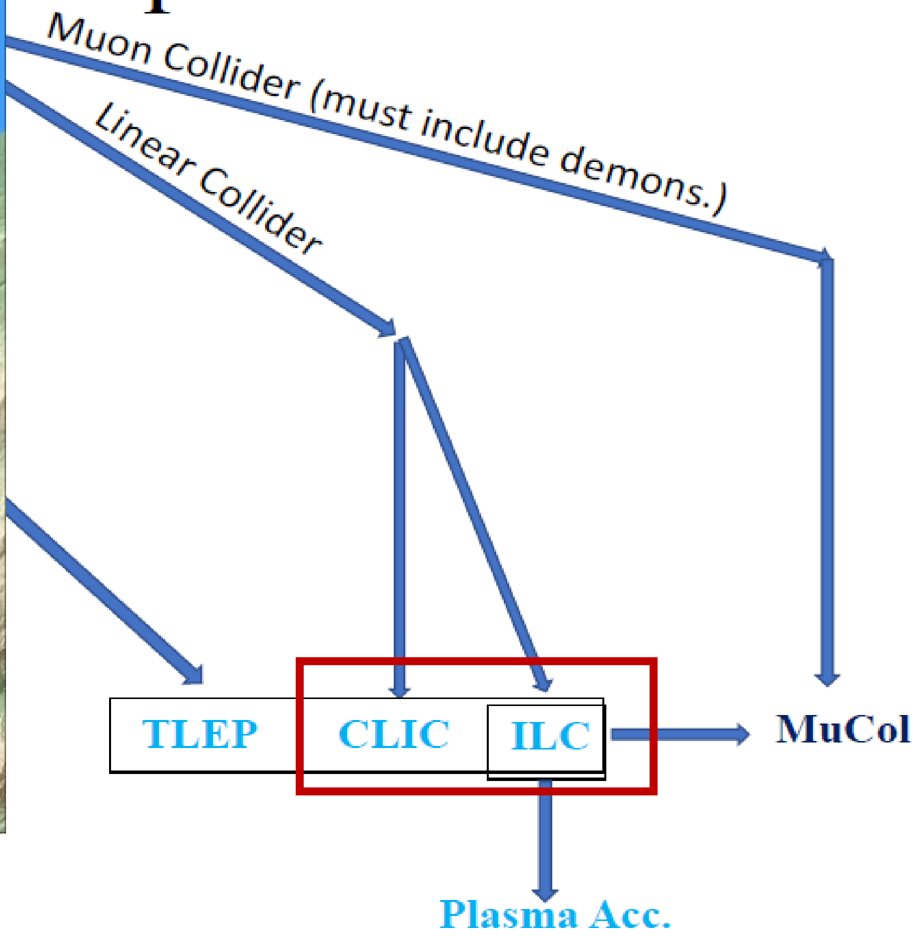
FE proposal on R&D on crystal-based sources for FCC-ee and alternatives options will be included in the **INFN Input document for the ESPP** ***I. Chaikovska et al., 2022 JINST 17 P05015**

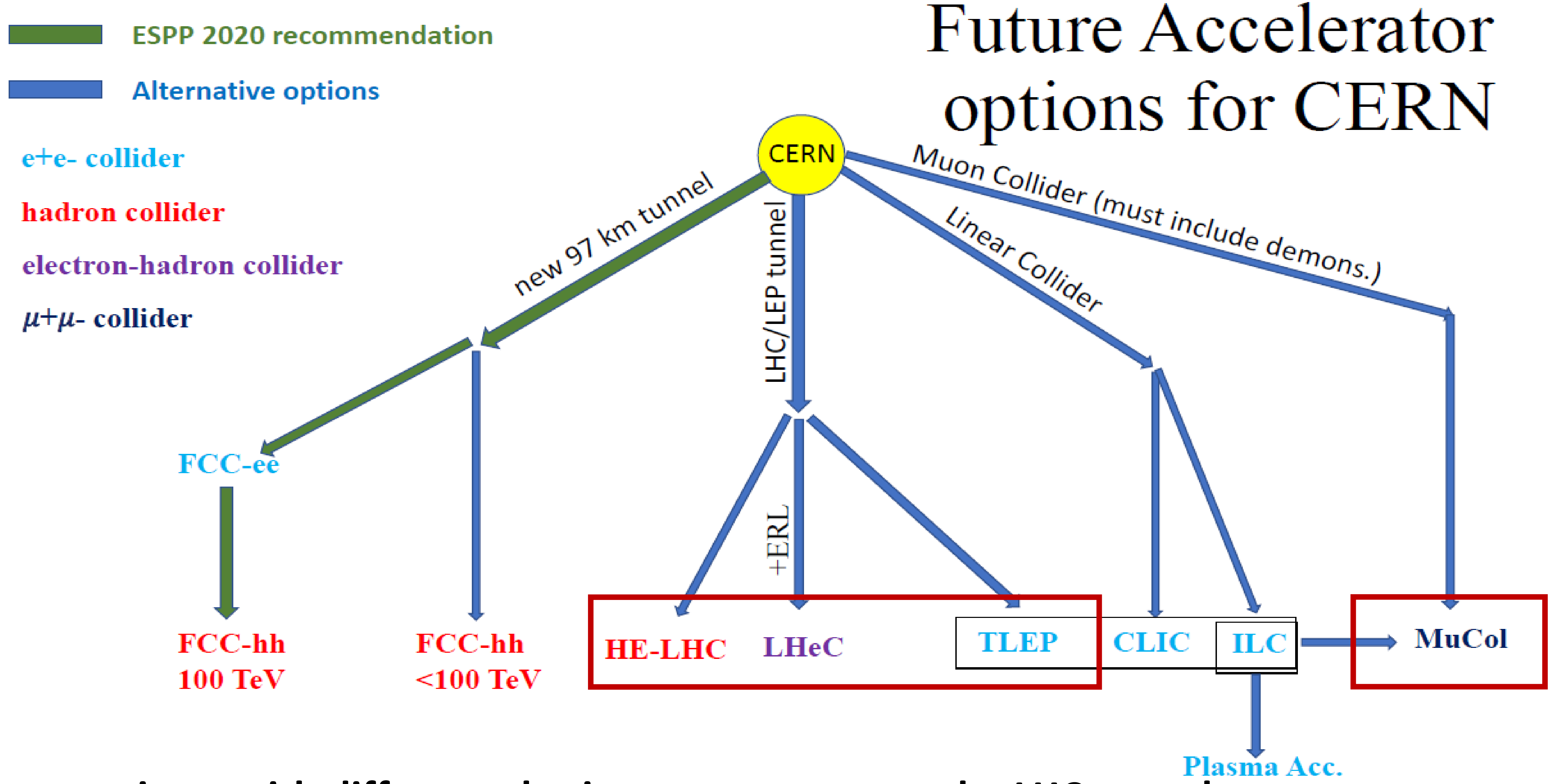
Future Accelerator options for CERN





- ❑ **Linear colliders require a new 10-20 km accelerator**
- ❑ **The technology is more or less ready (CDR) and at a first stage only a Higgs Factory…**
- ❑ **Can be upgraded up to 3 TeV (CLIC), but with a 50 km length**

Future Accelerator options for CERN



These options, with different physics cases, can reuse the LHC tunnel….

- Is the technology ready (magnets etc…) for HE-LHC to reach significant higher energy than LHC?
- LHeC is at the CDR level
- TLEP seems the "old" proposal of e+e- Higgs Factory – 240 GeV COM (beam energy 120 GeV)

And at last.. Why a Muon Collider?

Combining a Higgs/flavor factory with a high-energy accelerator in a single machine could address both the Precision and Energy Frontiers.

- Muons are fundamental particles, and **in μ-μ+ collisions all particle energy is available for the collision**, as with e-e+ colliders. But muons are ≈ 200 times heavier than electrons:
  - **negligible synchrotron radiation** emission;
  - **negligible beamsstrahlung** during collisions.

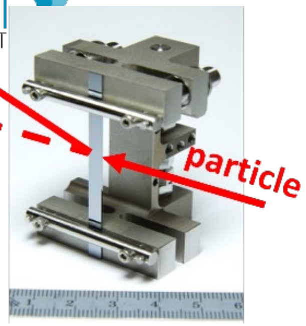
- In other words, this approach could perform the **roles of both an e-e+ colliders and high-energy hadron collider without the need for a 90 km tunnel** (reuse of the LHC tunnel seems feasible for a 10 TeV Muon Collider).

- However, this design faces significant **challenges due to the muons' short 2.2 microsecond lifetime.** We have to **accelerate and collide muons before they decay**, which **makes a demonstrator essential**.

Key Challenges of the facility

Proton driver production
Baseline @ International Design Study
Luminosity = 10^{34}-10^{35} $cm^{-2}s^{-1}$

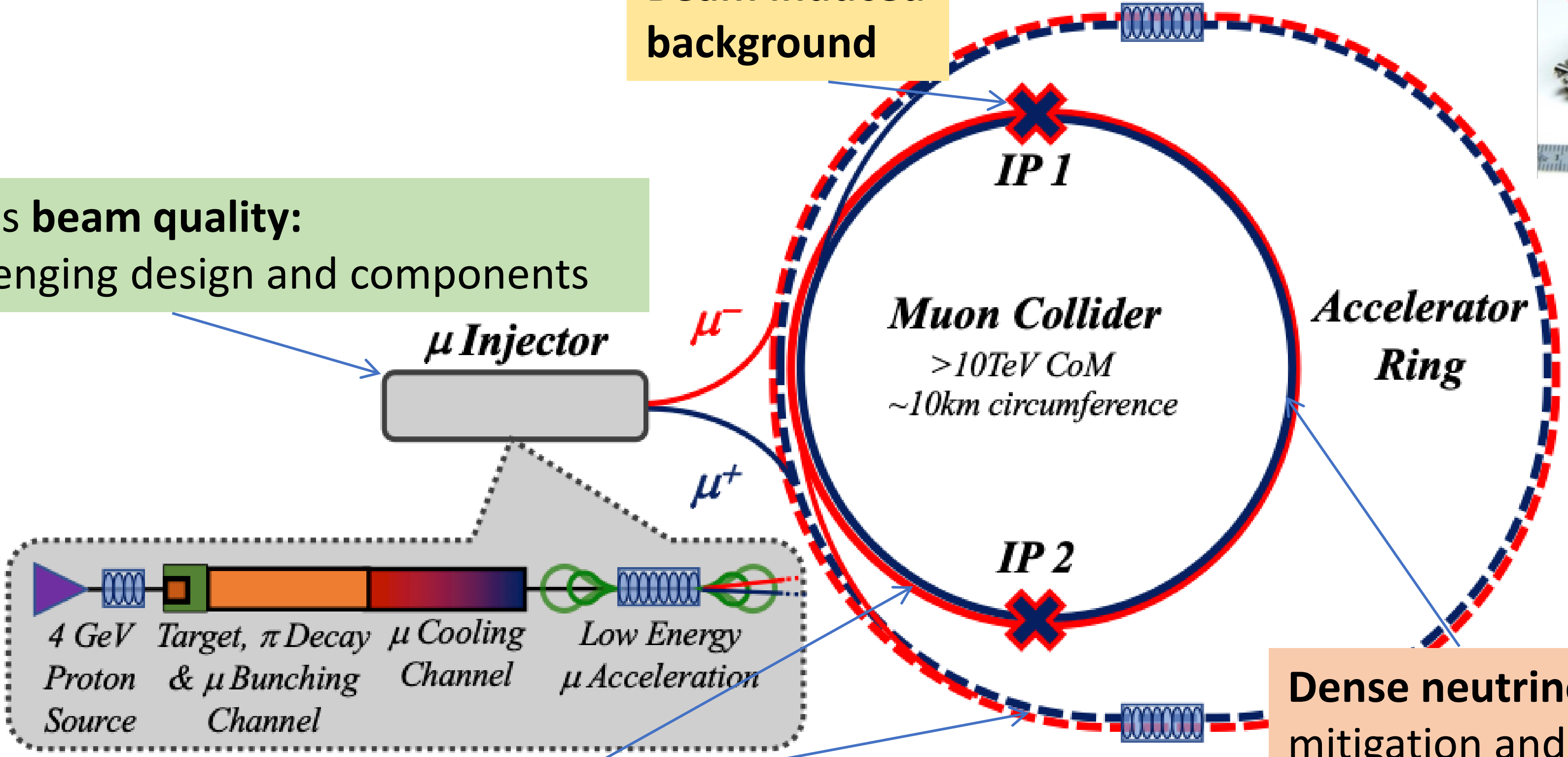
Targets and shielding: for muon production and cooling; collider and detector component shielding and beam collimation (FE bent crystal involvement)



10+ TeV completely new regime to explore!

Drives **beam quality:**
challenging design and components

Beam induced background



$\mathcal{L} = (E_{CM}/10TeV)^2 \times 10\ ab^{-1}$

@ 3 TeV	~	1 ab^{-1}	5 years
@ 10 TeV	~	10 ab^{-1}	5 years
@ 14 TeV	~	20 ab^{-1}	5 years

Dense neutrino flux mitigation and site

Cost and **power** consumption drivers, limit energy reach
e.g. 30 km accelerator for 10/14 TeV, 10/14 km collider ring

[Muon Collider Forum Report]

Courtesy of N. Pastrone
IMCC – ICB Board Chair

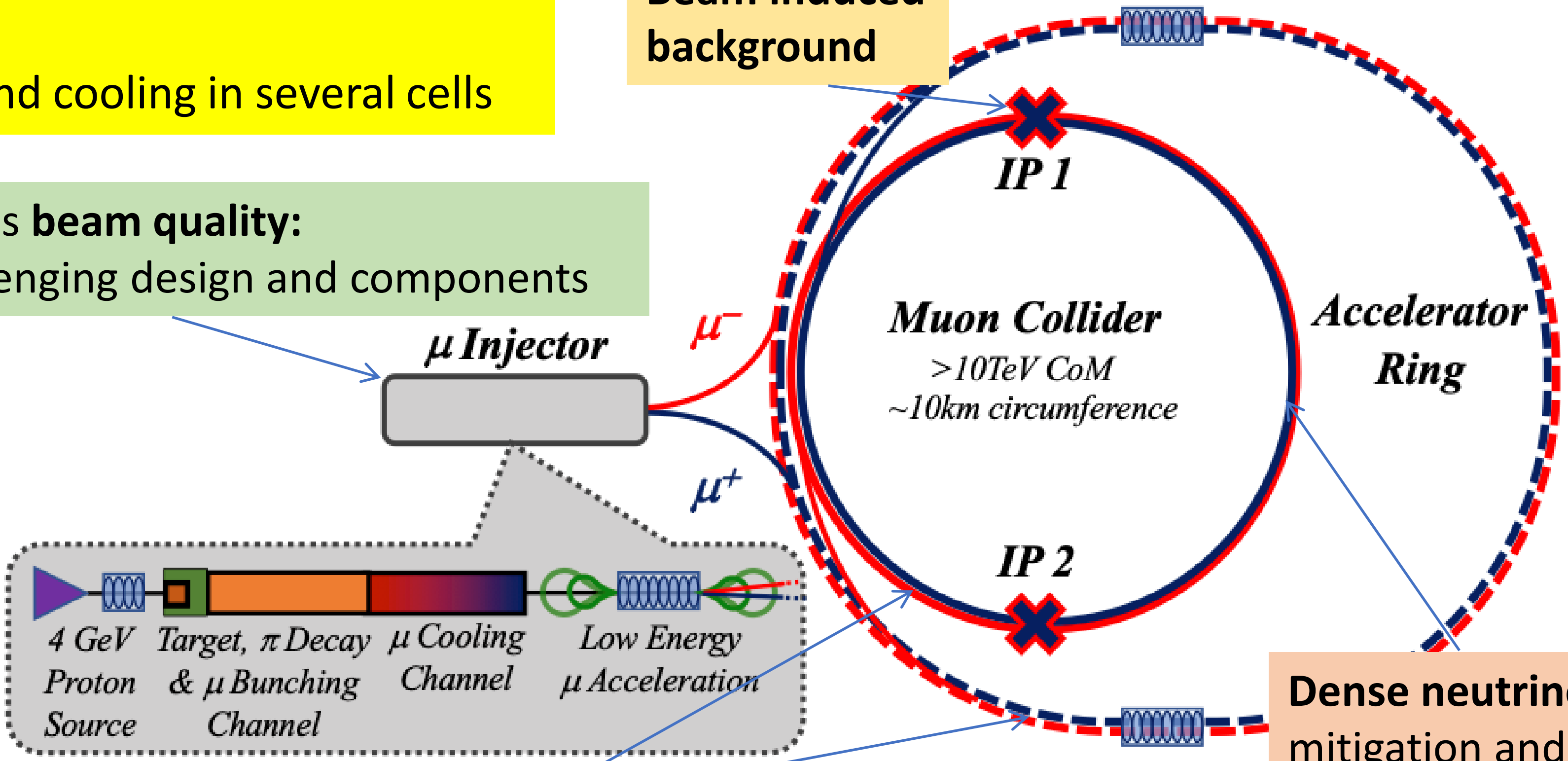
Time-critical Developments

Magnet technology
- HTS solenoids
- Collider ring magnets with Nb3Sn or HTS

Muon cooling technology
- **RF test stand** to test cavities in magnetic field
- **Muon cooling cell** test infrastructure
- **Demonstrator**
  - μ beam production and cooling in several cells

Beam induced background

Drives **beam quality:**
challenging design and components



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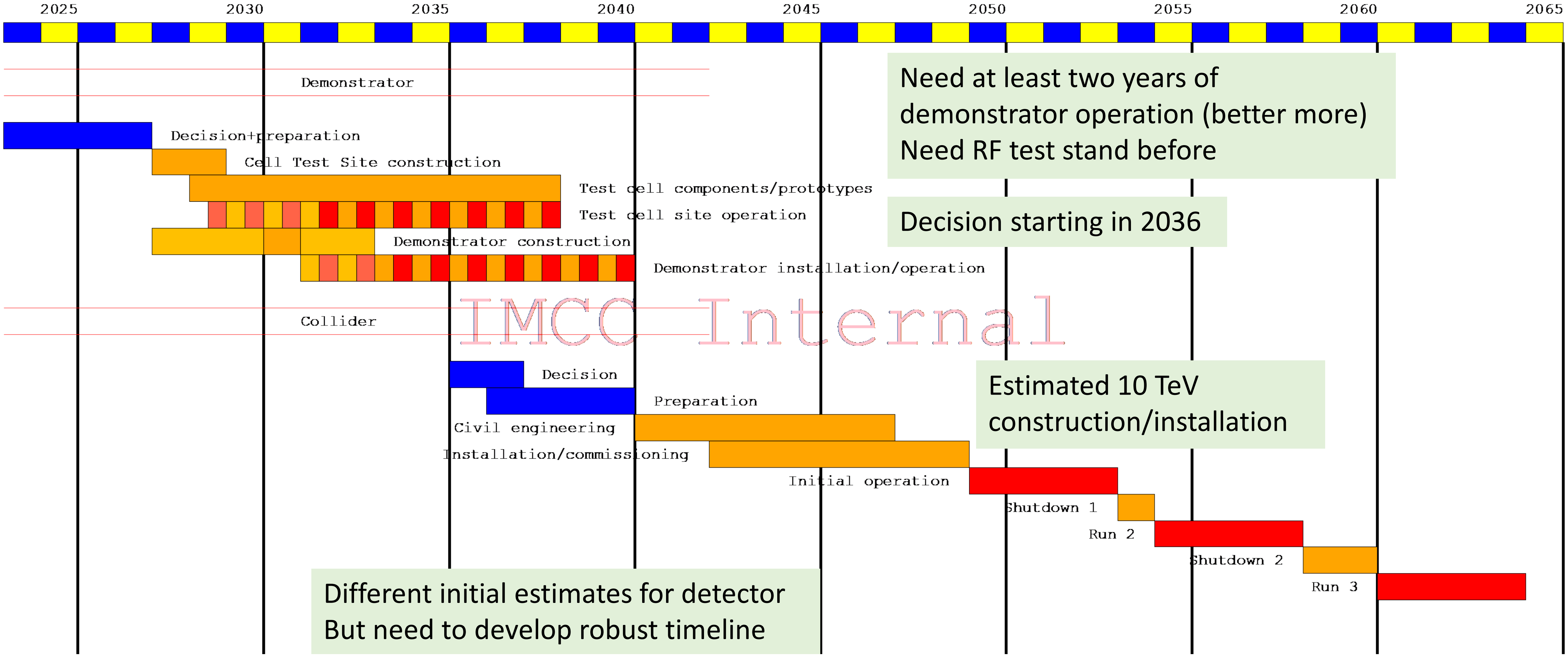
Tentative Timeline (Fast-track 10 TeV)

Only a basis to start the discussion, will be reviewed this year



Need at least two years of demonstrator operation (better more)
Need RF test stand before

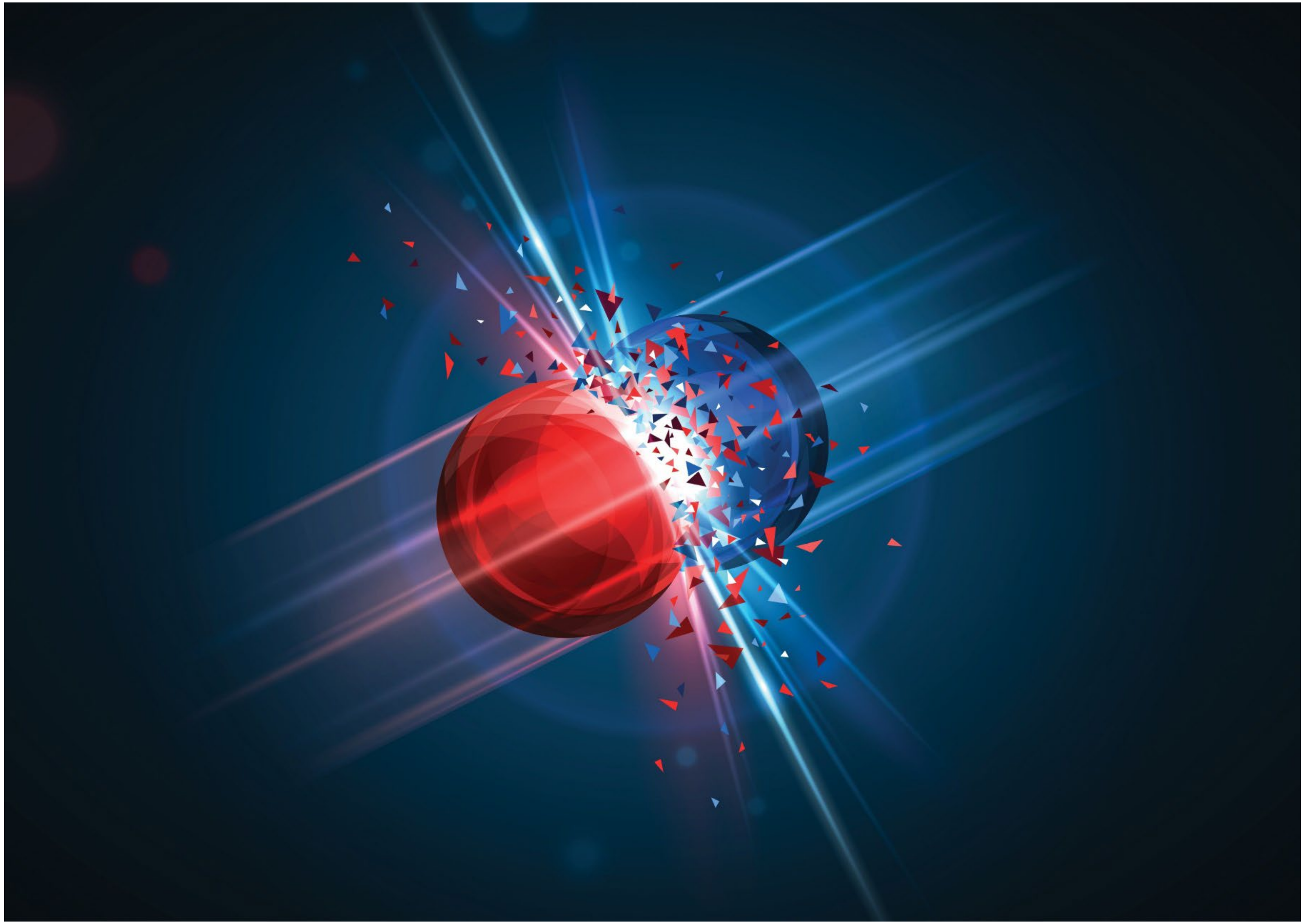
Decision starting in 2036

Estimated 10 TeV construction/installation

Different initial estimates for detector
But need to develop robust timeline

Courtesy of N. Pastrone
IMCC – ICB Board Chair

... And in the end, citing INFN ...
What's Next Collider?

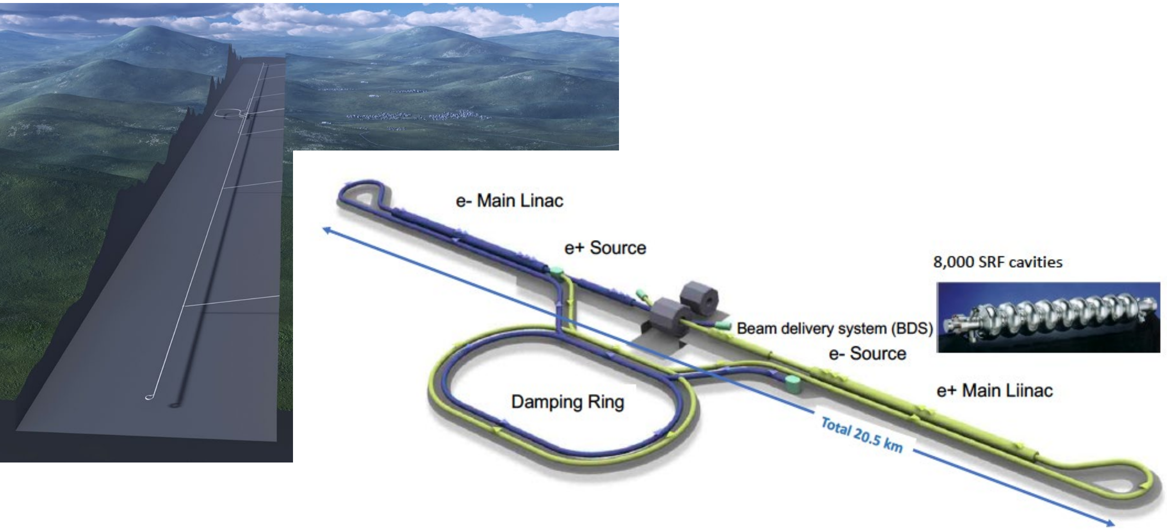


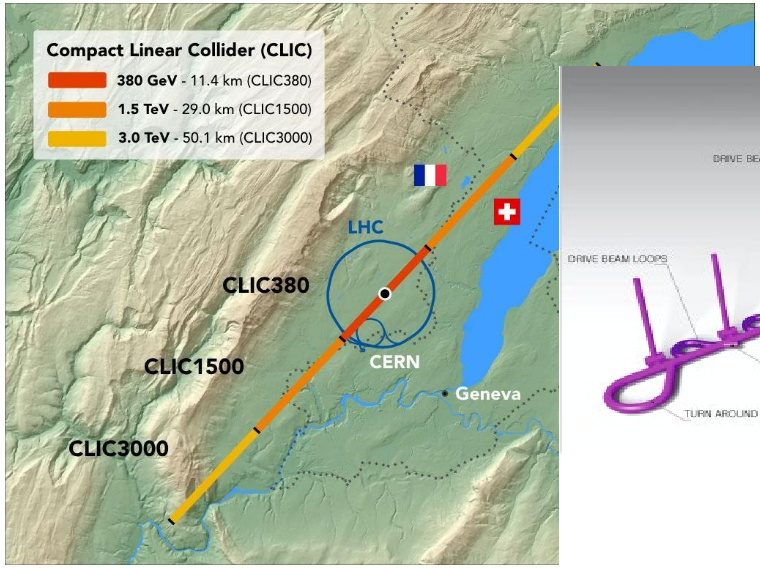
Back up

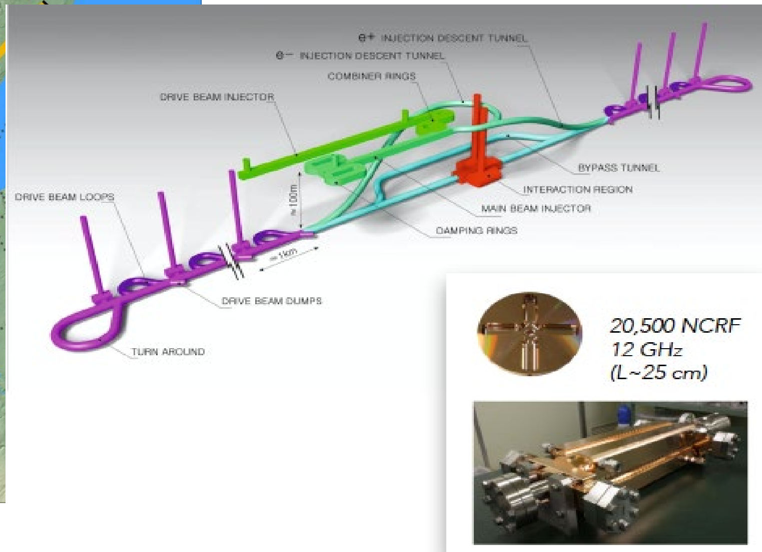
Slide from
A. Faus-Golfe
ICHEP2022

ILC and CLIC in a nutshell

Two e+e- linear collider designs, starting as a Higgs factory







International Linear Collider ILC

- Superconducting Cavities, 1.3GHz, 31.5 (35) MV/m
- Klystrons
- 250GeV CME, upgradeable to 500, 1000GeV
- L = $1.35\text{x}10^{34}$ $cm^{-2}s^{-1}$ (at initial 250GeV)
- 20km length, in Tohoku / Japan
- Polarisation 80%(e-), 30%(e+)

Compact Linear Collider CLIC

- NC Copper Cavities, 12.0GHz, 72 – 100 MV/m
- Two-beam acceleration (Klystrons)
- 380GeV CME, upgradeable to 1500, 3000GeV
- L = $1.50\text{x}10^{34}$ $cm^{-2}s^{-1}$ (at initial 380GeV)
- 11.4km long, at CERN / France & Switzerland
- Polarisation 80% (e-)