Future Circular and Linear Colliders

J. Faltová (Charles University)

15/01/2021

CZ HEP

European Strategy of Particle Physics 2020

High-priority future initiatives (part 3. A of EPPSU 2020 document)

This is the topic of my talk

"**An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy.** Accomplishing these compelling goals will require innovation and cutting-edge technology:

- the particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors;
- Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update.

The timely realisation of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate."

European Strategy of Particle Physics 2020

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My understanding:

1. New e^+e^- collider as the highest-priority
2. Longer term: hadron collider with E_{CMS}>=10 TeV at CERN
3. Support of ILC

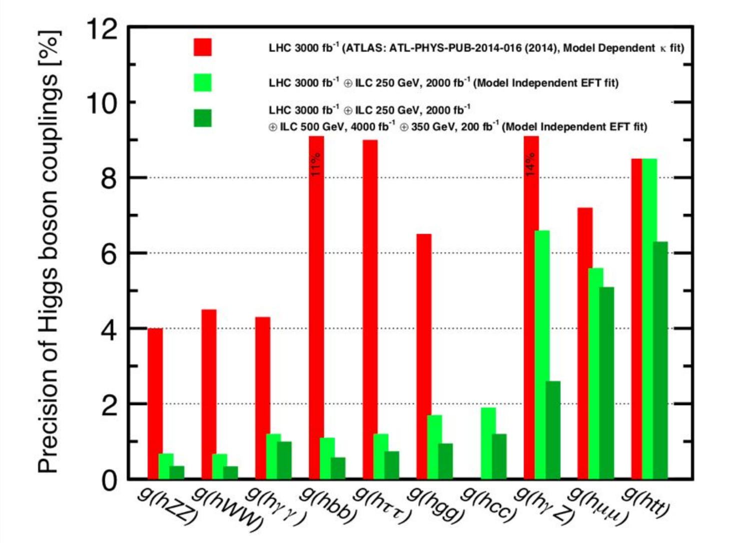
Why do we need new e^+e^- collider?

Motivation: Very precise measurements of the electroweak sector as a hint of new physics

arXiv:1710.07621

Highlights from the physics programme

- Top quark and Higgs boson masses
- Higgs boson couplings
- Flavour physics (b, c, τ)



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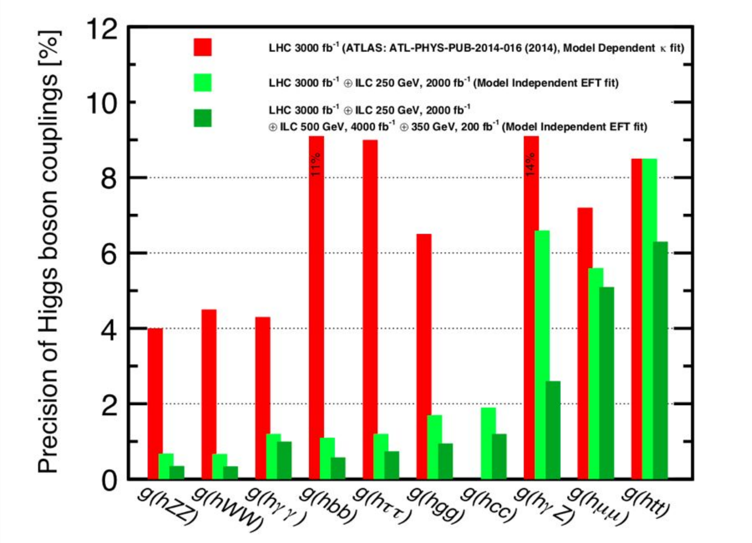

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Advantages of e^+e^- colliders

- Clean environment -> measurements of unprecedented precision
    - Theoretical uncertainties could easily become the dominant one
- We can starting building the collider (almost) now

Electron-positron colliders

Linear collider

- **ILC (International Linear Collider, Japan)**
- **CLIC (Compact Linear Collider, CERN)**

Circular collider

- **FCC (Future Circular Collider, CERN)**
- CEPC (Circular Electron Positron Collider, China)

Electron-positron colliders

Linear collider

- **ILC (International Linear Collider, Japan)**
- **CLIC (Compact Linear Collider, CERN)**

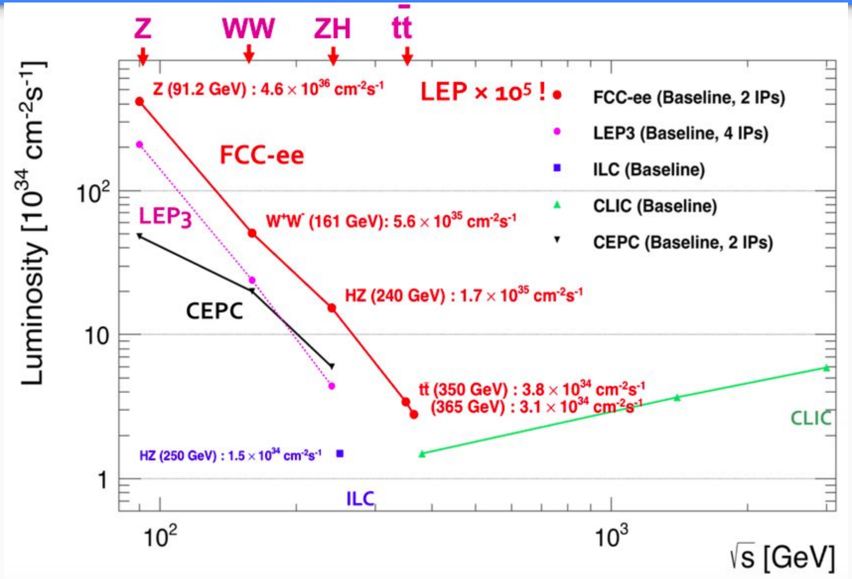
Circular collider

- **FCC (Future Circular Collider, CERN)**
- CEPC (Circular Electron Positron Collider, China)

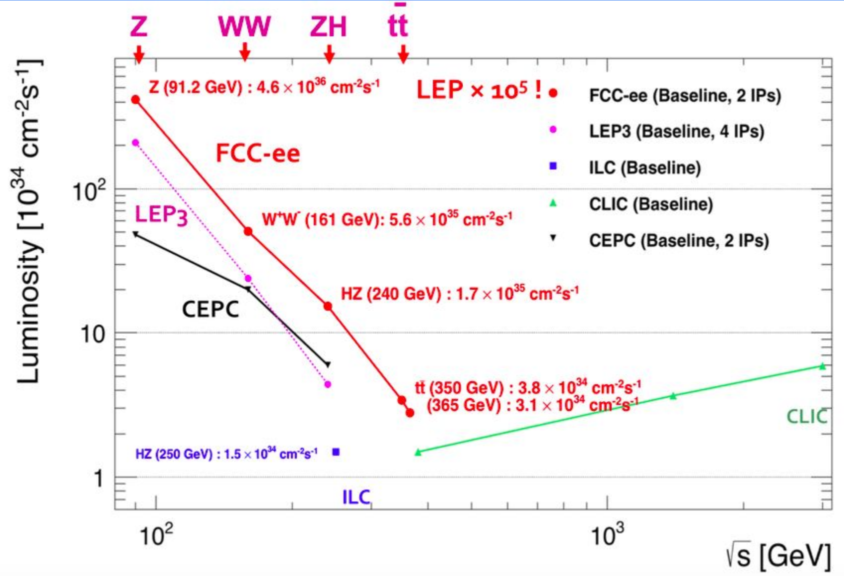
My comments

- CERN “needs” a new accelerator on site after HL-LHC
- ILC supported by European Strategy
- Chinese accelerator in hands of China (mostly)

Circular vs linear colliders



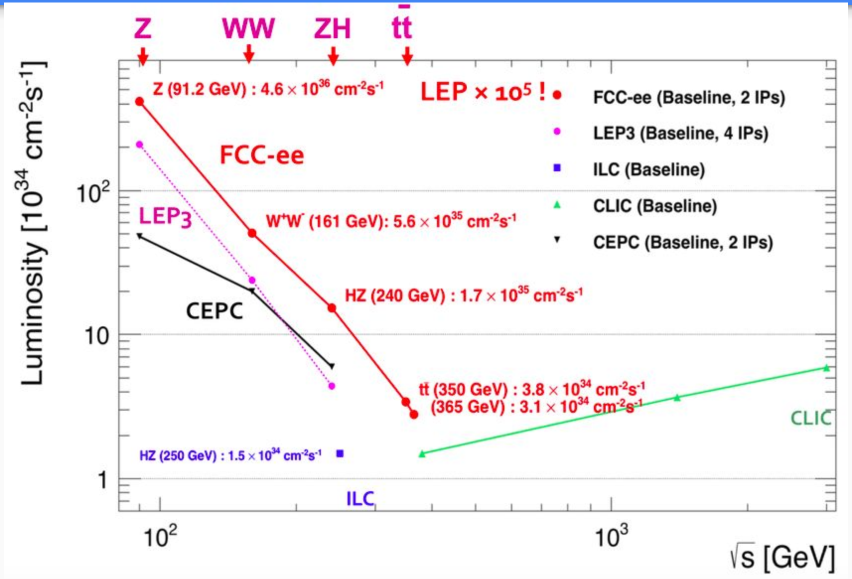
Circular vs linear colliders



Linear colliders

- High energy (extendable)
- No synchrotron radiation, but large beamstrahlung
- Beams not reusable

Circular vs linear colliders



Linear colliders

- High energy (extendable)
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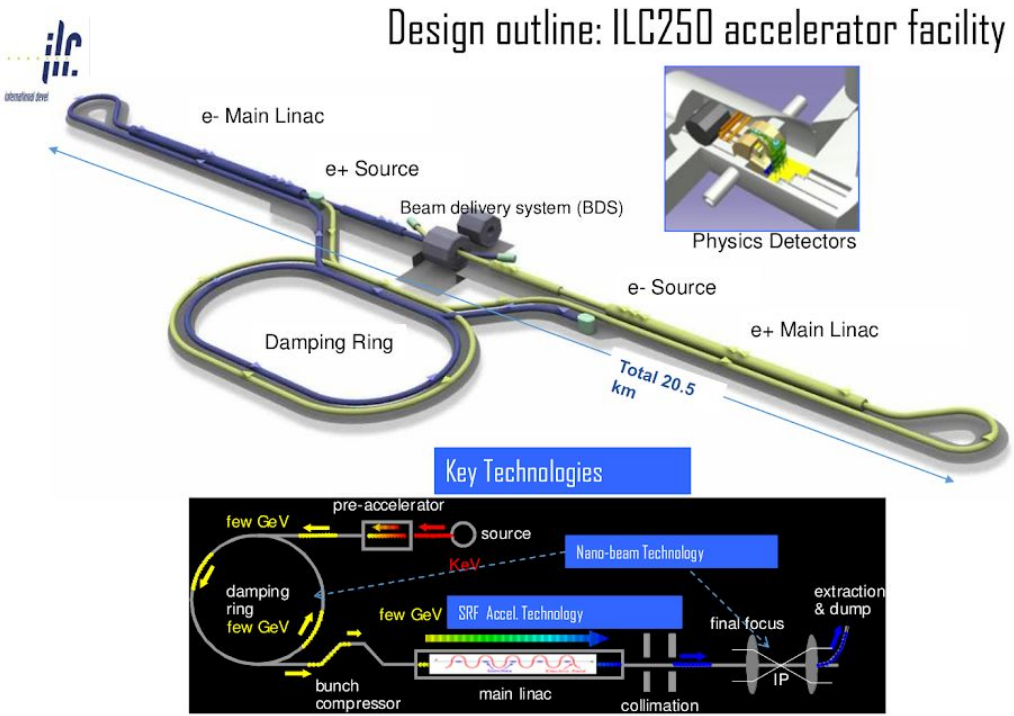
Circular colliders

- High luminosity, several interaction points
- Energy limited by synchrotron radiation
- Circulating beams
- Synergy with next generation of pp colliders

ILC



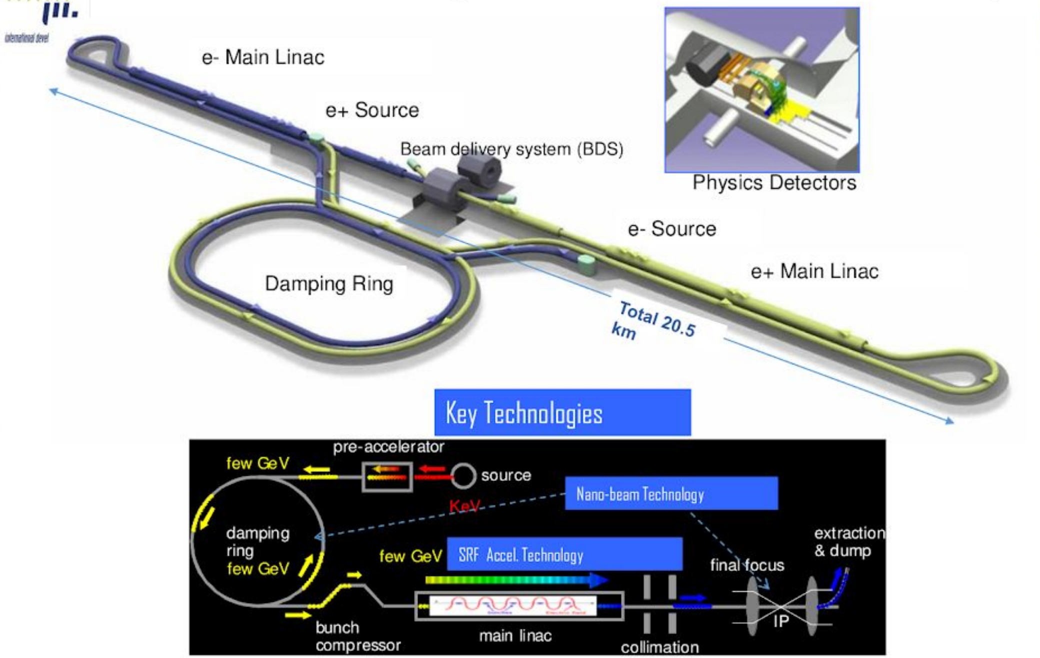
Item	Parameters
C.M. Energy	250 GeV
Length	20km
Luminosity	1.35 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	7.7 nm@250GeV
SRF Cavity G. Q_0	31.5 MV/m (35 MV/m) Q_0 = 1x10^{10}

S. Stapnes,
ECFA meeting, Nov 19 2020

The ILC upgradable to higher energy (500 GeV, 1 TeV) and luminosity (5.4 x 10^{34} $cm^{-2}s^{-1}$)

ILC

Design outline: ILC250 accelerator facility



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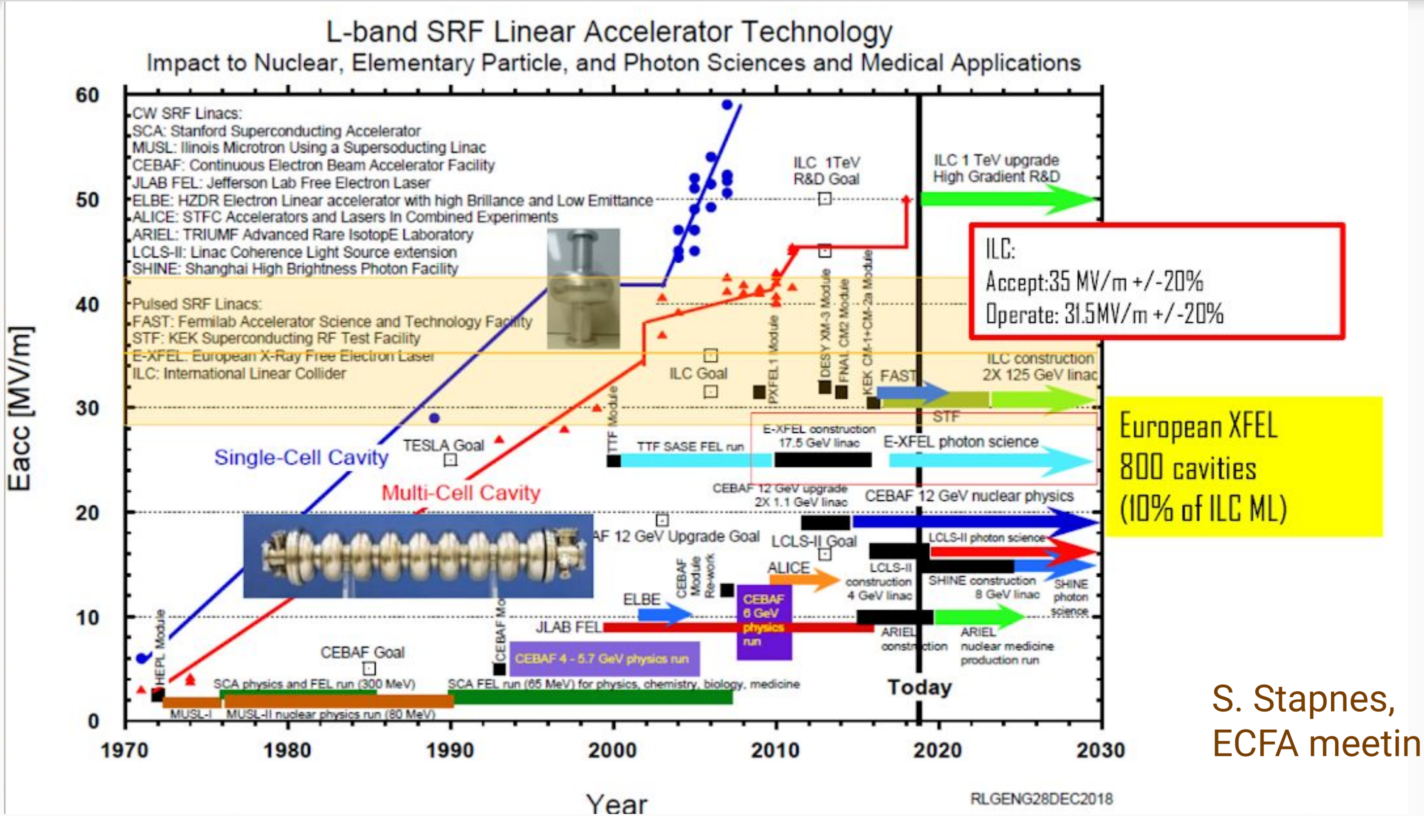
Czech rep. involvement: FZU in ILD (International Large Detector for ILC) and CALICE (highly granular calorimeters)

J. Cvach
J. Kvasnicka
I. Polak
J. Zalesak

ILC key technologies



S. Stapnes,
ECFA meeting, Nov 19 2020

Superconducting radiofrequency (SRF) cavities

ILC timeline

S. Stapnes,
ECFA meeting, Nov 19 2020

ILC IDT (~1.5 years)

- Prepare the work and deliverables of the ILC Pre-laboratory and work out, with national and regional laboratories, a scenario for their contributions
- Prepare a proposal for the organisation and governance of the ILC Pre-laboratory

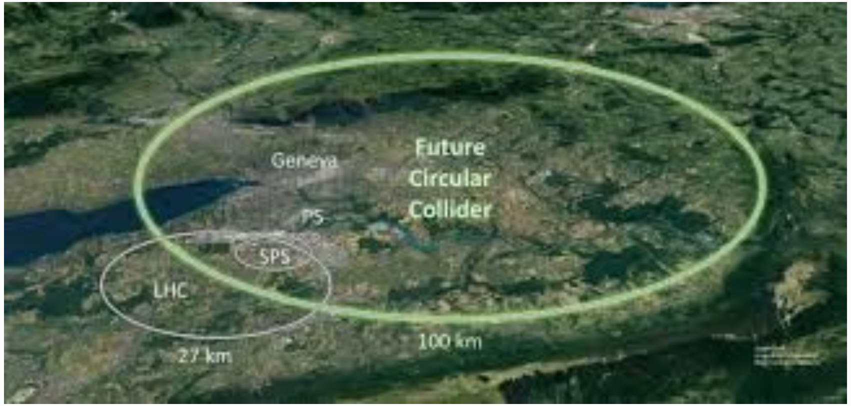
ILC Pre-laboratory (~4 years)

- Complete all the technical preparation necessary to start the ILC project (infrastructure, environmental impact and accelerator facility)
- Prepare scenarios for the regional contributions to and organisation for the ILC.

ILC laboratory

- Construction and commissioning of the ILC (~9-10 years)
- Followed by the operation of the ILC
- Managing the scientific programme of the ILC

FCC



parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1390	147	29	5.4
no. bunches/beam	16640	2000	393	48
bunch intensity [10^{11}]	1.7	1.5	1.5	2.3
SR energy loss / turn [GeV]	0.036	0.34	1.72	9.21
total RF voltage [GV]	0.1	0.44	2.0	10.9
long. damping time [turns]	1281	235	70	20
horizontal beta* [m]	0.15	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horiz. geometric emittance [nm]	0.27	0.28	0.63	1.46
vert. geom. emittance [pm]	1.0	1.7	1.3	2.9
bunch length with SR / BS [mm]	3.5 / 12.1	3.0 / 6.0	3.3 / 5.3	2.0 / 2.5
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	230	28	8.5	1.55
beam lifetime rad Bhabha / BS [min]	68 / >200	49 / >1000	38 / 18	40 / 18

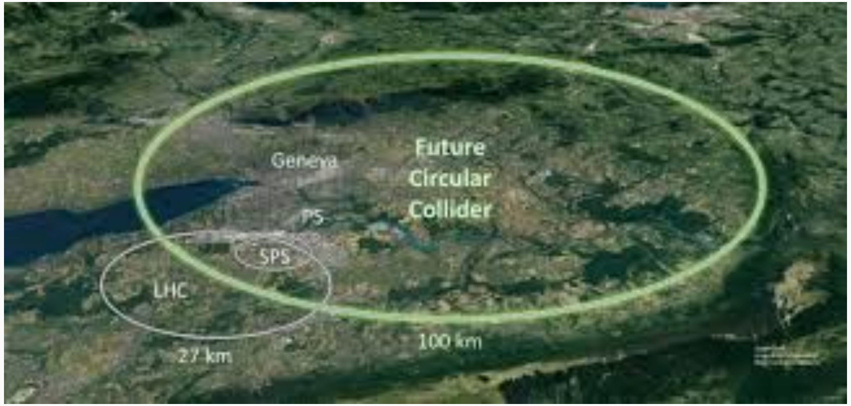
Stage 1: FCC-ee as Higgs factory, electroweak and top factory at highest luminosities

Stage 2: FCC-hh (100 TeV) as a natural continuation, with ion and eh option

Complementary physics, common civil engineering and technical infrastructres

Building on and reusing CERN’s existing infrastructures

FCC



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Building on and reusing CERN's existing infrastructures

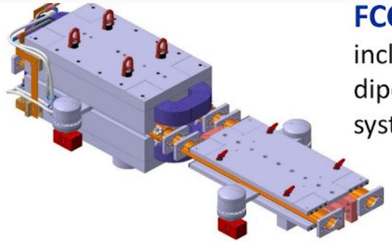
T. Davidek
J. Faltova
J. Smiesko

Czech rep. involvement: Charles Uni (member of FCC collaboration, development of calorimeters)

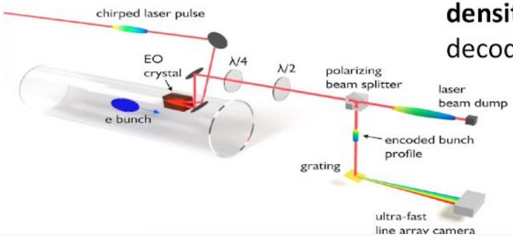
FCC key technologies

FCC Innovation Study (kick-off meeting)

M. Benedikt,
ECFA meeting, Nov 19 2020



FCC-ee complete arc half-cell mock up
including girder, vacuum system with antechamber + pumps, dipole, quadrupole + sext. magnets, BPMs, cooling + alignment systems, technical infrastructure interfaces.



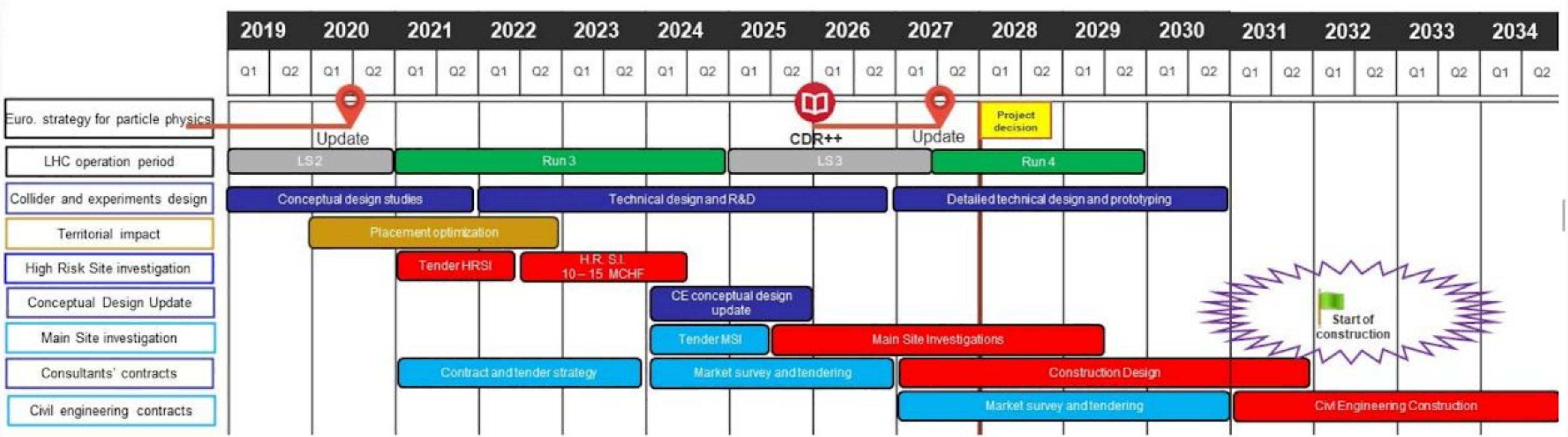
key beam diagnostics elements
bunch-by-bunch turn-by-turn **longitudinal charge density profiles** based on electro-optical spectral decoding (beam tests at KIT/KARA) ;
ultra-low emittance measurement (X-ray interferometer tests at SuperKEKB, ALBA) ;
beam-loss monitors (IJCLab/KEK?) ;
beamstrahlung monitor (KEK);
polarimeter ; **luminometer**

400 MHz SRF cryomodule,
+ prototype multi-cell cavities for FCC ZH operation
High-efficiency RF power sources

positron capture linac
large aperture S-band linac

- Freq : 2.856 GHz
- 90 cells per structure
- Length: 3.254 m
- Distance between two TWs: 45 cm
- Gradient: 20 MV/m
- Aperture: 30 mm

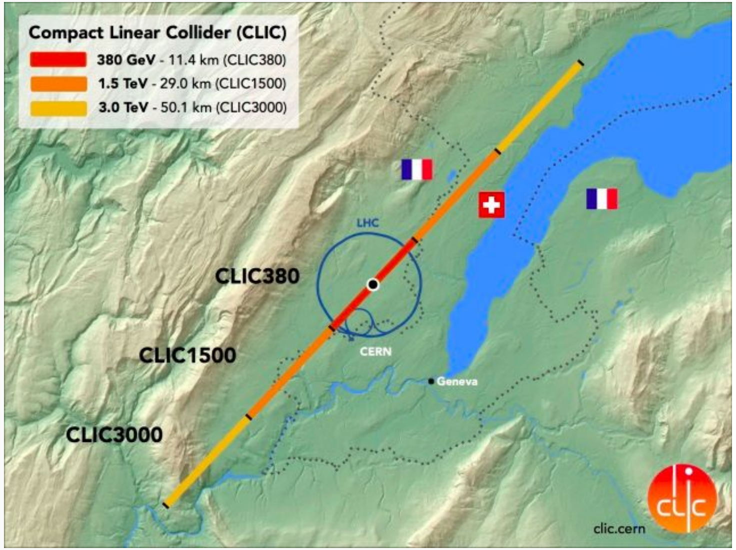
FCC timeline

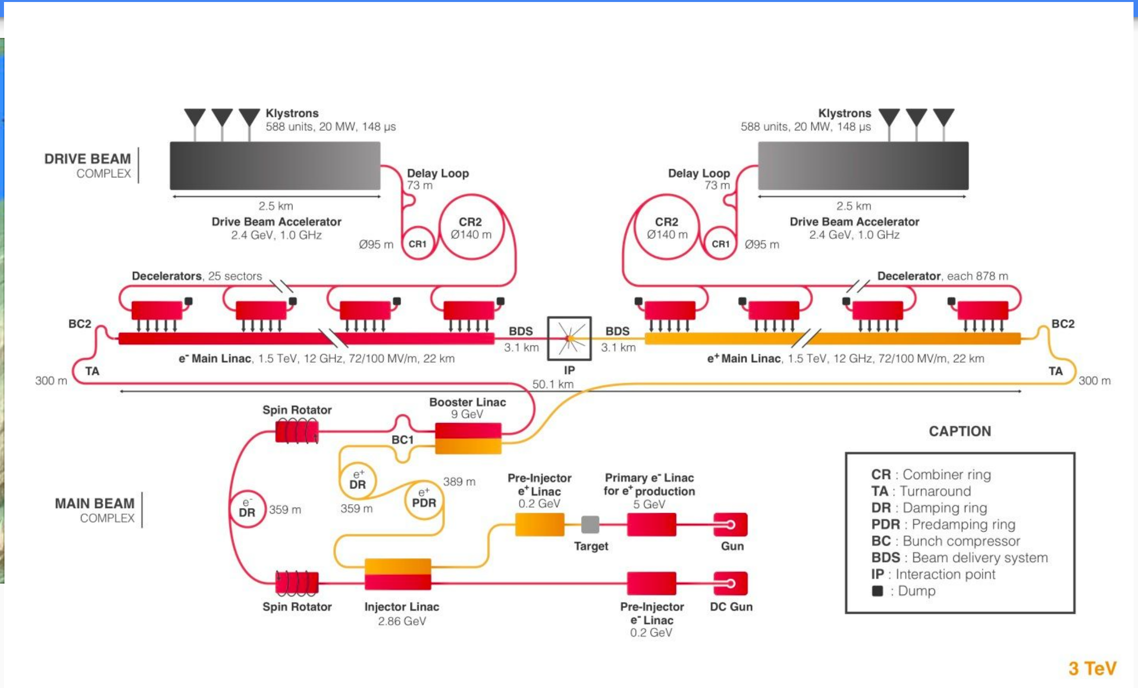


- Technical schedule of main processes leading to start of construction begin 2030ies
- For proof of principle feasibility: High risk area site investigations, 2022 – 2024
- Followed by update of civil engineering conceptual design and CE cost estimate 2025

M. Benedikt,
ECFA meeting, Nov 19 2020

CLIC





Radiofrequency cavities , two-beam acceleration concept

- Accelerating fields 100 MV/m

Possible start of the operation ~2035

Conclusions

Different options under study

Final decision depends on a number of aspects

- Technical feasibility and preparation of the projects
  - Status reports by 2025
- Colliders outside Europe
- Money ...

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Thank you for your attention

BACKUP

ILC

Goal: Pre-lab in Kohoku

Identification and preparation of ILC deliverables – one main one is a European SFR module line

- the accelerator’s beam-delivery system and the Accelerator Test Facility 2 (ATF2)
- high gradient acceleration for linear colliders
- high efficiency klystrons
- detector, physics and software
- cryogenics systems, beam-dumps, superconducting radiofrequency (SC RF) module components and
- technologies, civil engineering (all areas where CERN has provided technical advice as part of the LCC collaboration
- other areas of common interest (e.g.: positron production and beam-dynamics)

FCC Higgs couplings