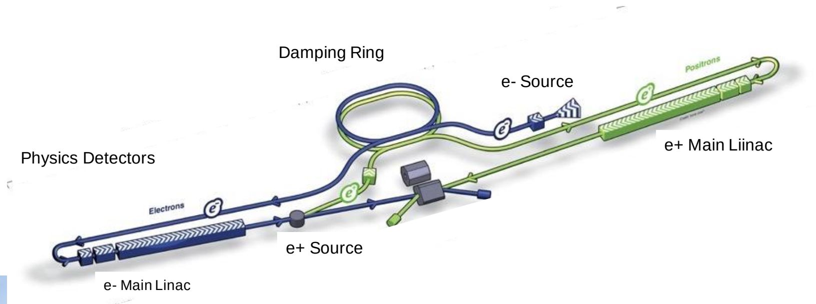
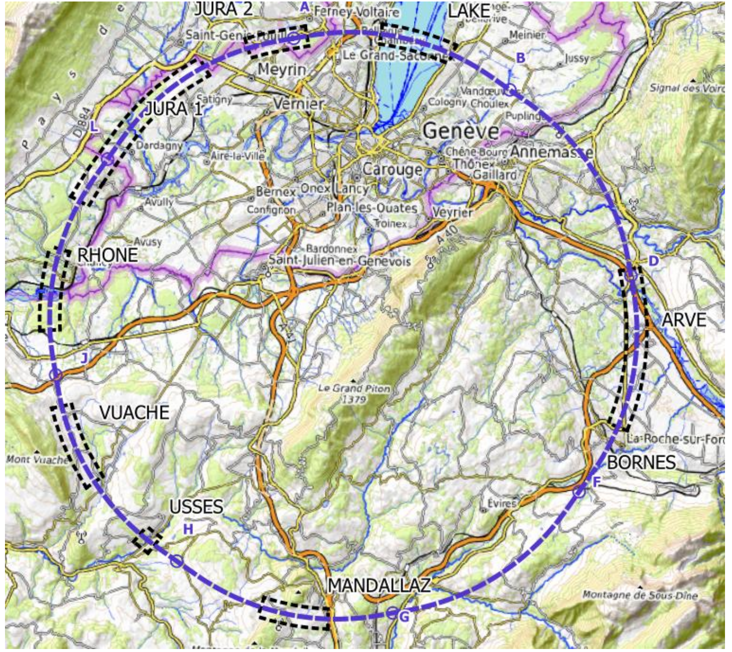
Next: A Higgs factory

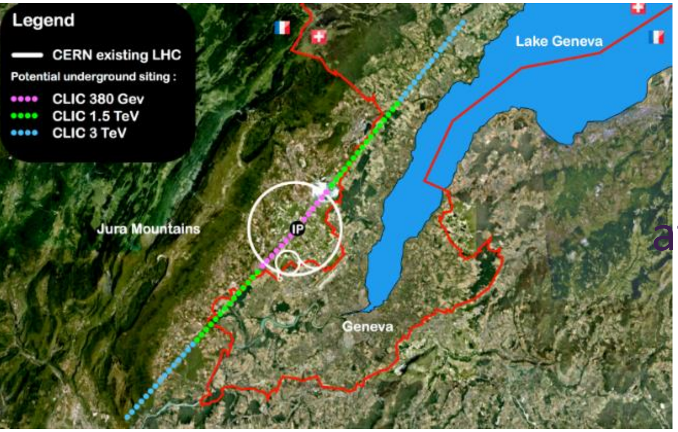




Need e+e- collisions at least at 250 GeV, four main alternatives (plus various less developed ideas):

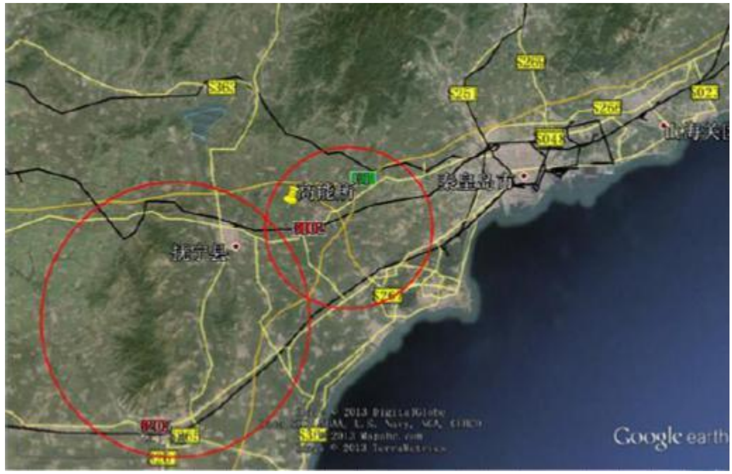
ILC in Japan (linear) FCC at CERN (ring)

CLIC at CERN (linear) CEPC in China (ring)



Linear colliders: 13 (Higgs) -> 50 (max) km to get to 1-3 TeV

Rings ~100km, can be used for protons after



ESPP Update 2020 “High-priority future initiatives”

- 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**.

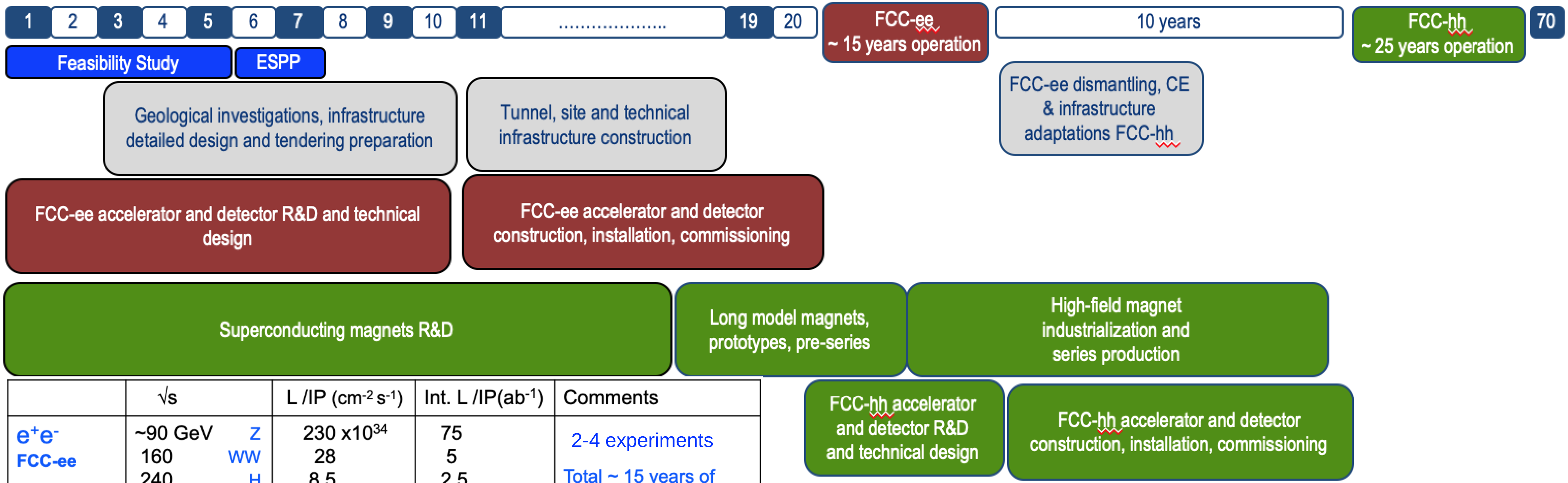
- “Europe, together with its international partners, should investigate the **technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV** and with an **electron-positron Higgs and electroweak factory as a possible first stage**.
- Such a **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**..”

→ launch of Future Circular Collider Feasibility Study in summer 2021

Timeline of the FCC integrated programme

FUTURE CIRCULAR COLLIDER

Technical schedule



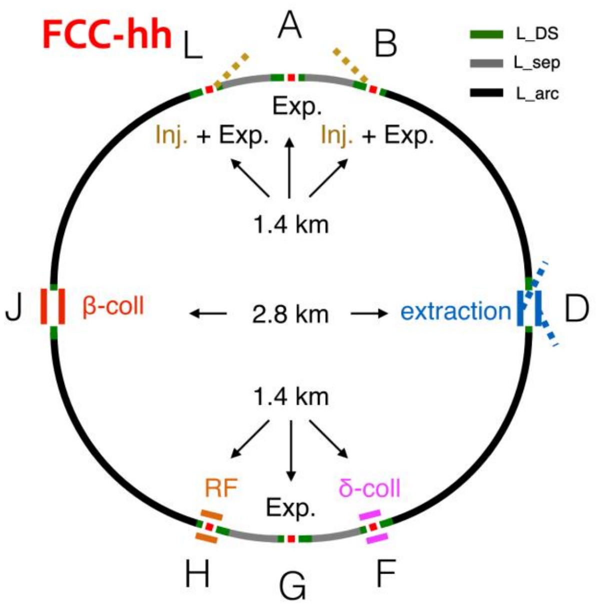
	√s	L /IP ($cm^{-2} s^{-1}$)	Int. L /IP(ab^{-1})	Comments
e^+e^- **FCC-ee**	~90 GeV Z 160 WW 240 H ~365 top	230 $\times 10^{34}$ 28 8.5 1.5	75 5 2.5 0.8	2-4 experiments Total ~ 15 years of operation
pp **FCC-hh**	100 TeV	5 x 10^{34} 30	20-30	2+2 experiments Total ~ 25 years of operation
PbPb **FCC-hh**	$\sqrt{s_{NN}}$ = 39TeV	3 x 10^{29}	100 nb^{-1}/run	1 run = 1 month operation
ep **Fcc-eh**	3.5 TeV	1.5 10^{34}	2 ab^{-1}	60 GeV e- from ERL Concurrent operation with pp for ~ 20 years
e-Pb **Fcc-eh**	$\sqrt{s_{eN}}$ = 2.2 TeV	0.5 10^{34}	1 fb^{-1}	60 GeV e- from ERL Concurrent operation with PbPb

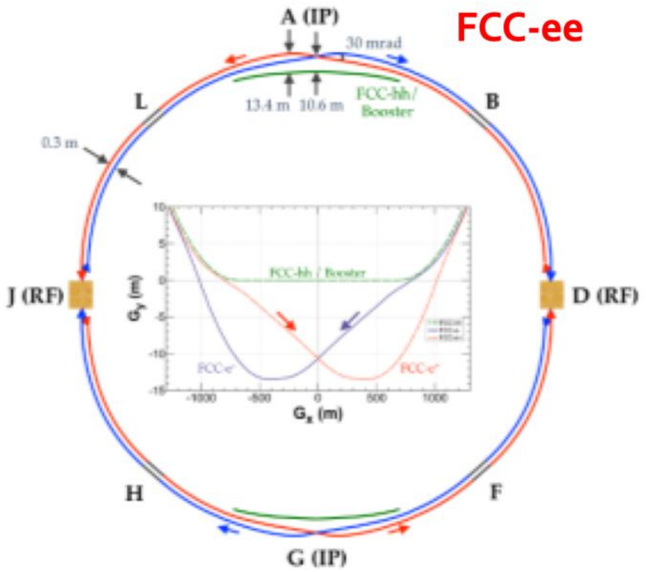
- ❑ Feasibility Study: 2021-2025
- ❑ If project approved before end of decade → construction can start beginning 2030s
- ❑ FCC-ee operation ~2045-2060
- ❑ FCC-hh operation 2070-2090++

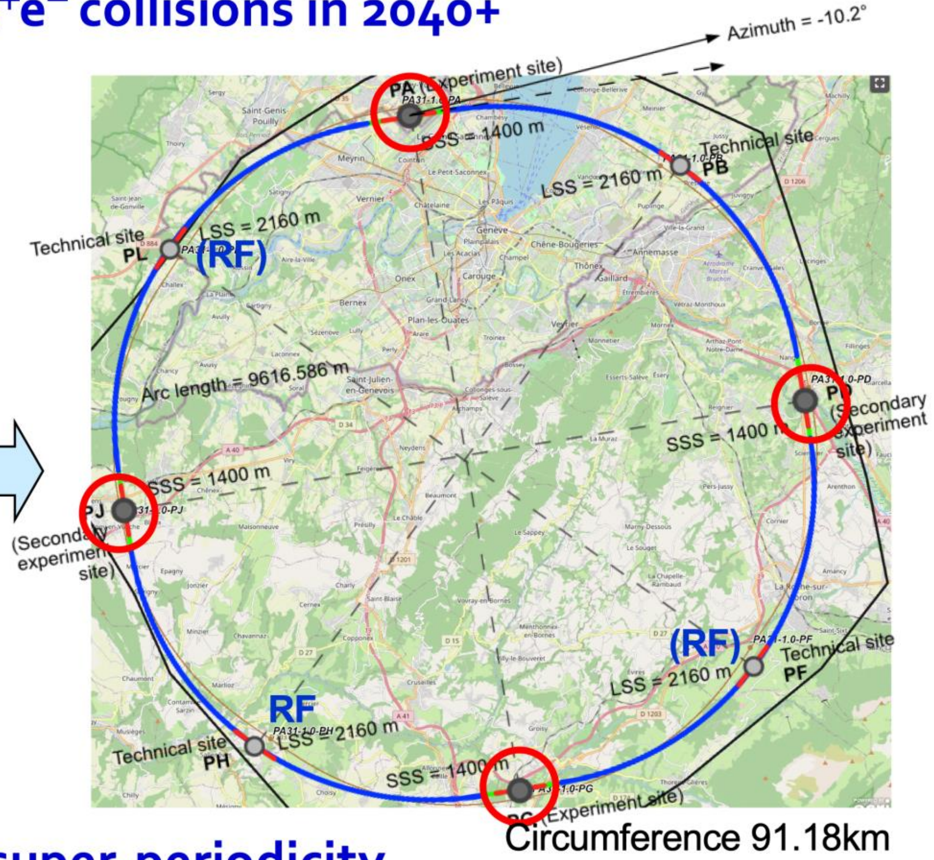
F. Gianotti

Feasibility study launched in July 2021

- **More details in FCC Week 2021:** https://indico.cern.ch/event/995850/
  - **Intermediate review mid 2023 – FSR end 2025 – First e^+e^- collisions in 2040+**
- **Work has started on placement in Geneva area**

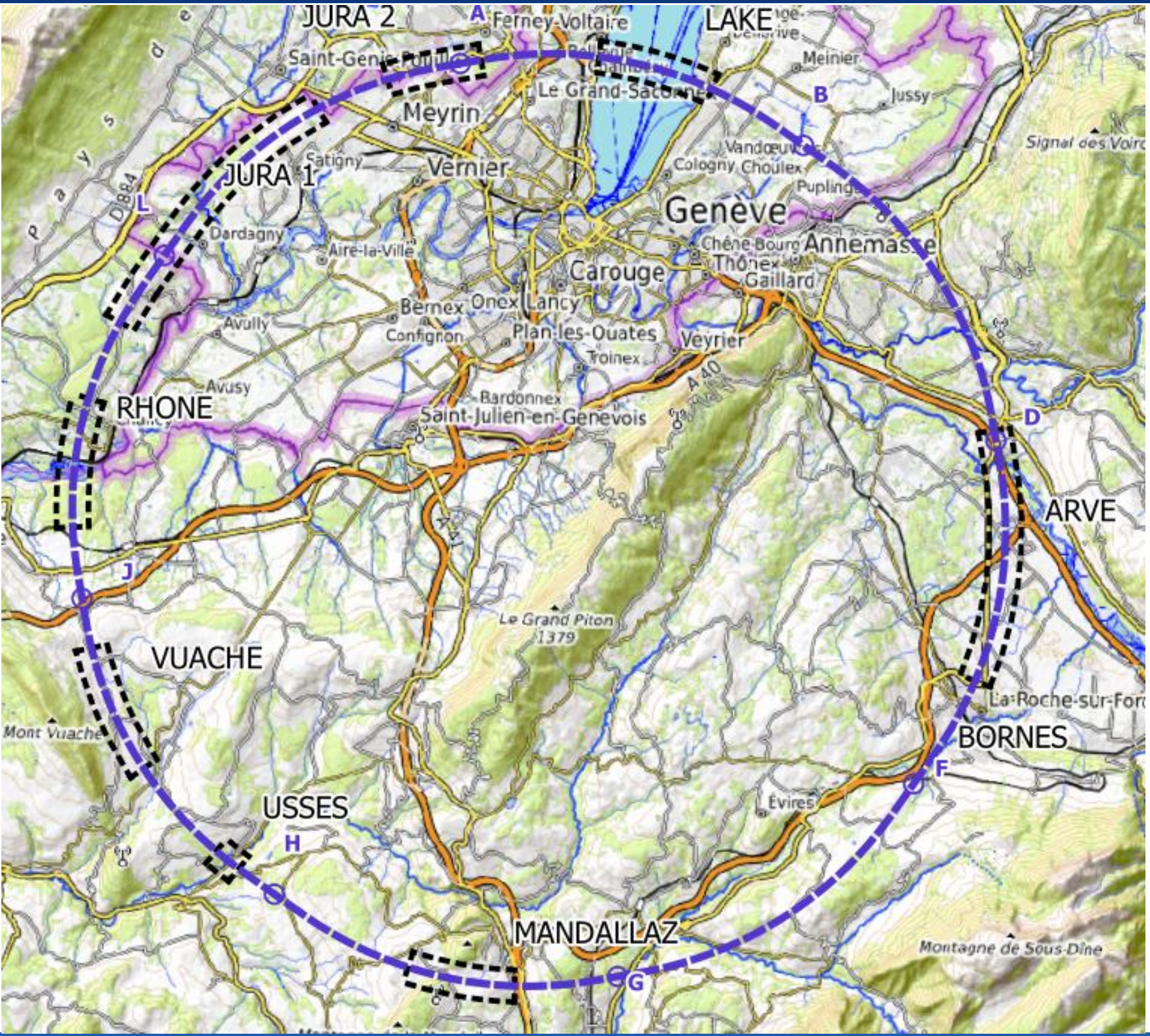






- **Number of surface points reduced to 8, with fourfold super-periodicity**
  - **This new layout is consistent with later choice of 2 or 4 Interaction Points (IP) for FCC-ee**

Plans for high-risk area site investigations



JURA, VUACHE (3 AREAS)
Top of limestone
Karstification and filling-in at the tunnel depth
Water pressure

LAKE, RHÔNE, ARVE AND USSES VALLEY (4 AREAS)
Top of the molasse
Quaternary soft grounds, water bearing layers

MANDALLAZ (1 AREAS)
Water pressure at the tunnel level
Karstification

BORNES (1 AREA)
High overburden molasse properties
Thrust zones

Site investigations planned for mid 2023 – mid 2025: ~40-50 drillings, 100 km of seismic lines

FCC Feasibility Study – coordination team and contact persons

EU Projects
NN

Collaboration building
Emmanuel Tsesmelis

Communications
Panagiotis Charitos, James Gillies

Study Support and Coordination
Study Leader: Michael Benedikt
Deputy Study Leader: Frank Zimmermann

Study Support Unit
IT: Sylvain Girod
Procurement: Adam Horridge
Quality control: NN
Resources: Sylvie Prodon
Scheduling, quality mangement: NN
Secretariat: Julie Hadre

Physics, Experiments and Detectors
Patrick Janot
Gavin Salam

- **Physics programme** – Matthew McCullough, Frank Simon
- **Detector concept** – Mogens Dam
- **Physics performance** – Patrizia Azzi, Emmanuel Perez
- **Software and computing** – Gerardo Ganis, Clément Helsens

Accelerators
Tor Raubenheimer
Frank Zimmermann

- **FCC-ee collider design** – Katsunobu Oide
- **FCC-hh design** – Massimo Giovannozzi
- **Technology R&D** – Roberto Losito
- **FCC-ee booster design** – Antoine Chancé
- **FCC-ee injector** – Paolo Craievich, Alexej Grudiev
- **FCC-ee energy calibration polarization** – Alain Blondel, Jorg Wenninger
- **FCC-ee MDI** – Manuela Boscolo, Mike Sullivan

Technical Infrastructures
Klaus Hanke

- **Integration** – Jean-Pierre Corso
- **Geodesy & survey** – Hélène Mainaud Durand
- **Electricity and energy management** – Jean-Paul Burnet
- **Cooling and ventilation** – Guillermo Peon
- **Cryogenics systems** – Laurent Delprat
- **Computing and controls infrastructure, communication and network** – Dirk Duellmann
- **Safety** – Thomas Otto
- **Operation, maintenance, availability, reliability** – Jesper Nielsen
- **Transport, installation concepts** – Cristiana Colloca

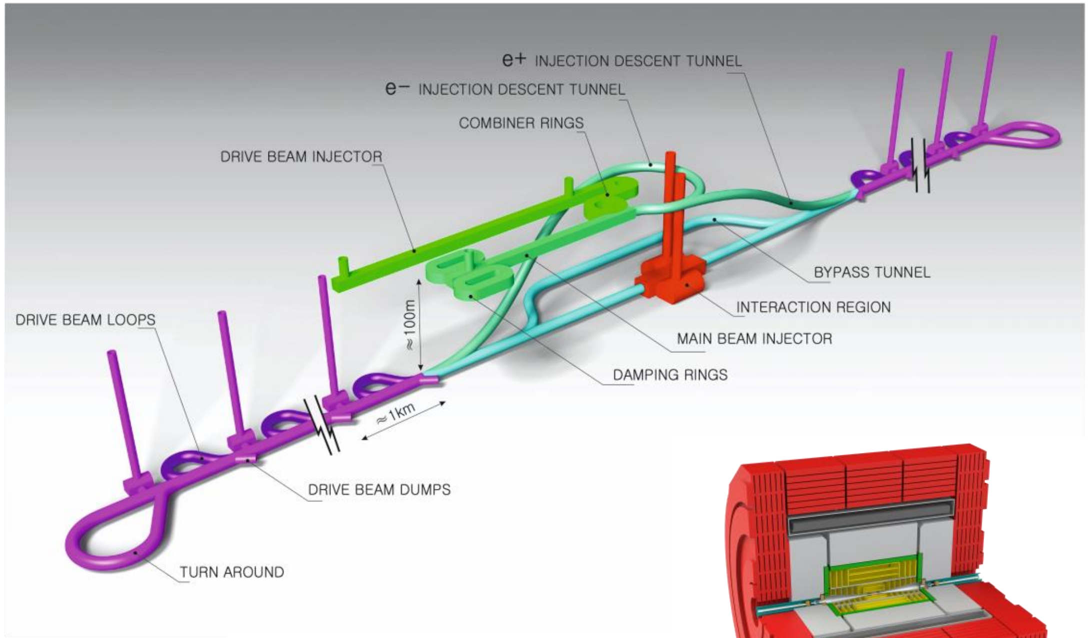
Host State processes and civil engineering
Timothy Watson

- **Administrative processes** – Friedemann Eder
- **Placement studies** – Johannes Gutleber, Volker Mertens
- **Environmental evaluation** – Johannes Gutleber
- **Tunnel, subsurface design** – John Osborne
- **Surface sites layout, access and building design**

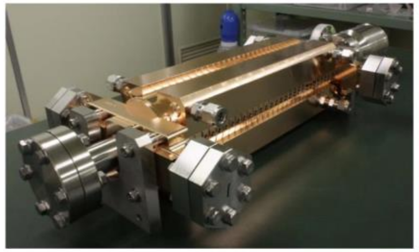
Organisation and financing models
Paul Collier (interim)

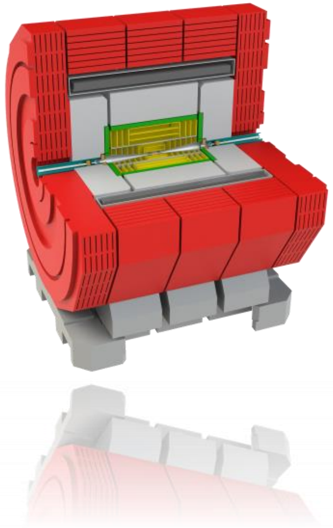
- **Project organisation model**
- **Financing model** – Florian Sonnemann
- **Procurement strategy and rules**
- **In-kind contributions**
- **Operation model** – Paul Collier, Jorg Wenninger

The Compact Linear Collider (CLIC)



Accelerating structure prototype for CLIC: 12 GHz (L~25 cm)





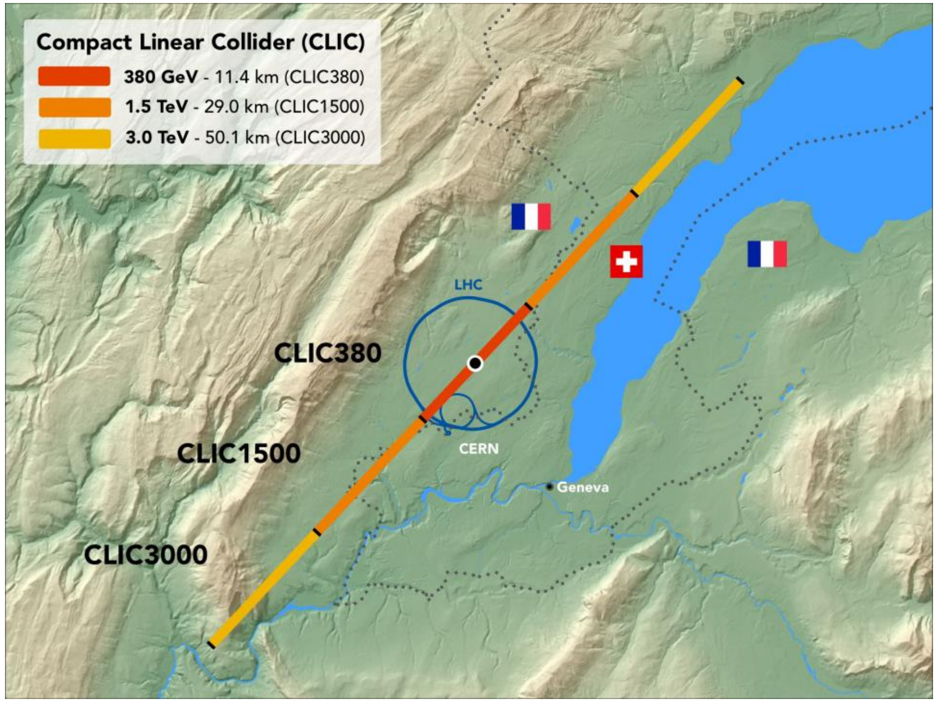
- **Timeline:** Electron-positron linear collider at CERN for the era beyond HL-LHC
- **Compact:** Novel and unique two-beam accelerating technique with high-gradient room temperature RF cavities (~20’500 structures at 380 GeV), ~11km in its initial phase
- **Expandable:** Staged programme with collision energies from 380 GeV (Higgs/top) up to 3 TeV (Energy Frontier)

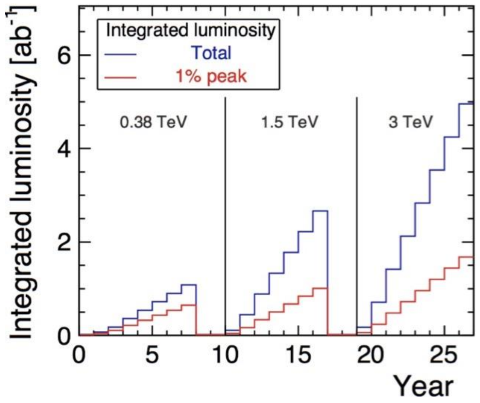
- CDR in 2012 with focus on 3 TeV. Updated project overview documents in 2018 (Project Implementation Plan) with focus 380 GeV for Higgs and top.

- **Cost:** 5.9 BCHF for 380 GeV (stable wrt 2012)
- **Power:** ~110 MW at 380 GeV (reduced wrt 2012), corresponding to 50% of CERN’s energy consumption today

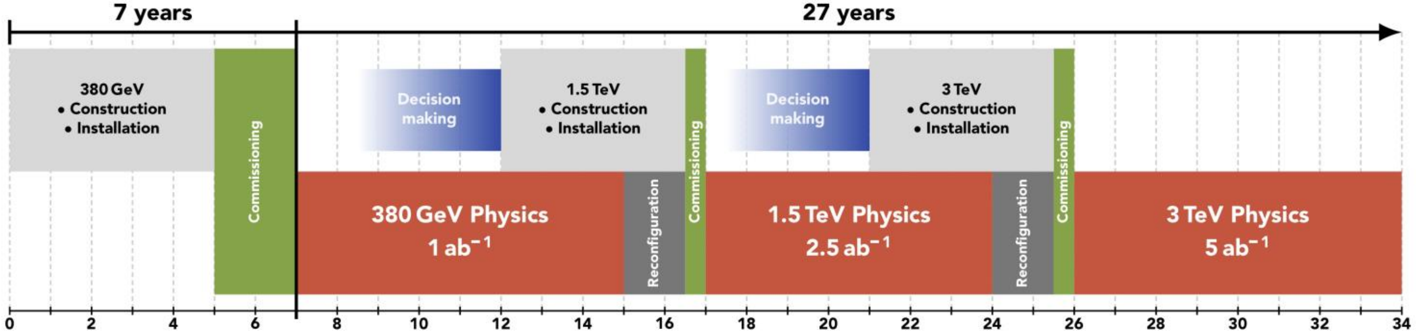
- Comprehensive **Detector and Physics** studies

CLIC timeline





Ramp-up and up-time assumptions: arXiv:1810.13022, Bordry et al.



Technology Driven Schedule from start of construction shown above.

A preparation phase of ~5 years is needed before (estimated resource need for this phase is ~4% of overall project costs)

CLIC is a mature design/study

The CLIC accelerator studies are mature:

Optimised design for cost and power

Many tests in CTF3, FELs, lightsources and test-stands

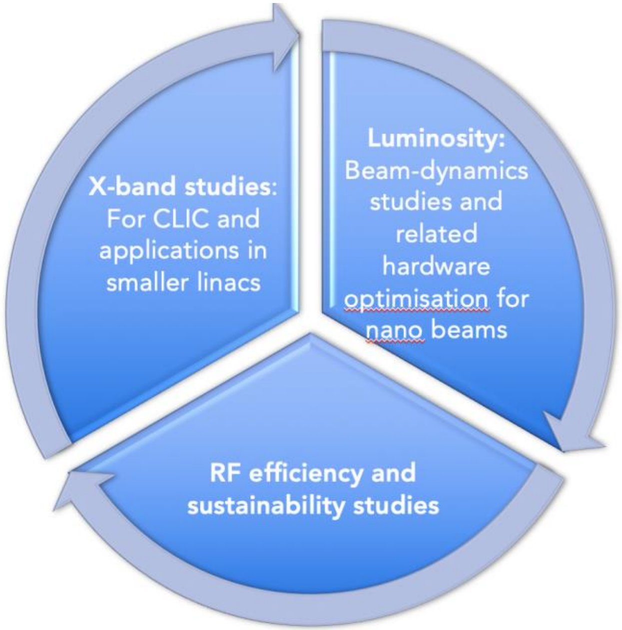
Technical developments of "all" key elements

CLIC Project Readiness

Project Readiness Report as a step toward a TDR – for next ESPP
Assuming ESPP in 2026, Project Approval ~ 2028, Project (tunnel) construction can start in ~ 2030.

Focusing on:

- The X-band technology readiness for the 380 GeV CLIC initial phase
- Optimizing the luminosity at 380 GeV
- Improving the power efficiency for both the initial phase and at high energies



Goals for these studies by ~2025:

- Improved 380 GeV parameters/performance/project plan
- Push multi-TeV options/parameters

CLIC parameters

Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	380	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		352	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Pulse length	τ_{RF}	ns	244	244	244
Accelerating gradient	G	MV/m	72	72/100	72/100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2} s^{-1}	1.5	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2} s^{-1}	0.9	1.4	2
Total integrated luminosity per year	$\mathscr{L}_{int}$	fb^{-1}	180	444	708
Main linac tunnel length		km	11.4	29.0	50.1
Number of particles per bunch	N	10^9	5.2	3.7	3.7
Bunch length	σ_z	μm	70	44	44
IP beam size	σ_x/σ_y	nm	149/2.9	$\sim$ 60/1.5	$\sim$ 40/1
Normalised emittance (end of linac)	ϵ_x/ϵ_y	nm	900/20	660/20	660/20
Final RMS energy spread		%	0.35	0.35	0.35
Crossing angle (at IP)		mrad	16.5	20	20

Examples of R&D

X-band

CPI 50MW 1.5us klystron
Scandinova Modulator
Rep Rate 50Hz
Beam test capabilities

Ongoing test:
CPI2 repair validation and interferometry tests

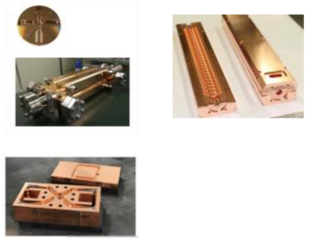
CPI 50MW 1.5us klystron
Scandinova Modulator
Rep Rate 50Hz

Ongoing test:
CLIC TD26 CLEX SuperStructure

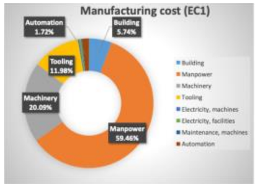
2x Toshiba 6MW 5us klystron
2x Scandinova Modulators
Rep Rate 400Hz

Ongoing test:
SARI X-band deflector
High power window

S-box (3GHz) also being set up again to test KT structure, PROBE and the new injector



Industrial questionnaire: Based on the companies feedback, the preparation phase to the mass production could take about five years. Capacity clearly available.



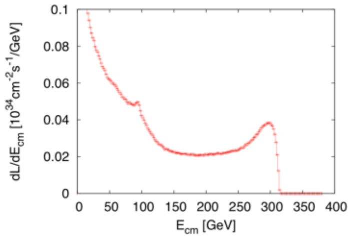
Structures and components production programme to study designs, operation/conditioning, manufacturing, industry qualification/experience

EU projects: ARIES, I-FAST, new TNA

CLIC acc. studies – luminosities

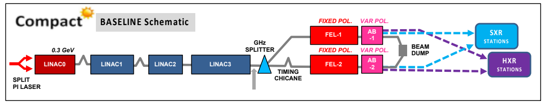
Further work on luminosity performance, possible improvements and margins, operation at the Z-pole and gamma-gamma

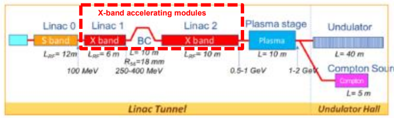
- Z pole performance, $2.3 \times 10^{32} – 0.4 \times 10^{34}$ cm^{-2} s^{-1}
  - The latter number when accelerator configured for Z running (e.g. early or end of first stage)
- Gamma – Gamma spectrum (example)
- Luminosity margins and increases
  - Baseline includes estimates static and dynamic degradations from damping ring to IP: 1.5×10^{34} cm^{-2} s^{-1}, a "perfect" machine will give : 4.3×10^{34} cm^{-2} s^{-1}, so significant upside
  - In addition: doubling the frequency (50 Hz to 100 Hz) would double the luminosity, at a cost of +50 MW and ~5% cost increase
  - **Studies cover from beam-dynamics to technical studies of the required performances of stability, alignment, instrumentation, magnets, BDS, final focus, injectors including positrons, damping rings – priority for next ESU**
- CLIC note and paper about these studies



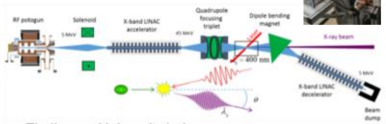
Applications – injector, X-band modules, RF

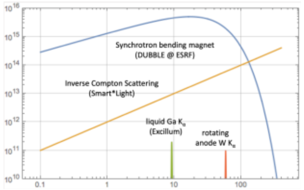
- CompactLight Design Studies 2018-21 (right)
- INFN 1 GeV linac
- Flash RT CDR, next build it at CHUV
- "Design Studies" for ICS
- AERES, IFAST and TNA project





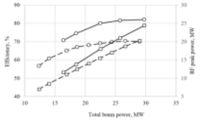
CERN and Lausanne University Hospital collaborate on a pioneering new cancer radiotherapy facility





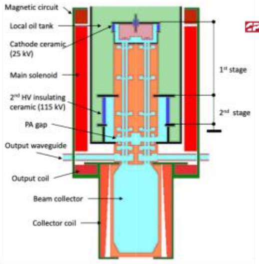
High Eff. Klystrons

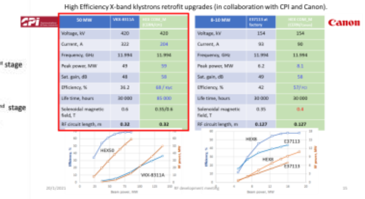
L-band, X-band (for applications/collaborators and test-stands



Location: CERN Bldg: 112

Drivebeam klystron: The klystron efficiency (circles) and the peak RF power (squares) simulated for the CLIC TS MBK (solid lines) and measured for the Canon MBK E37503 (dashed lines) vs total beam power. See more later.
Publication: https://ieeexplore.ieee.org/document/9115885

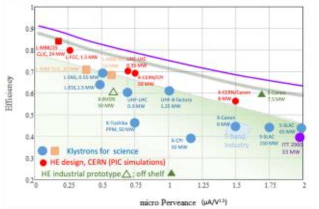




High Efficiency implementations:

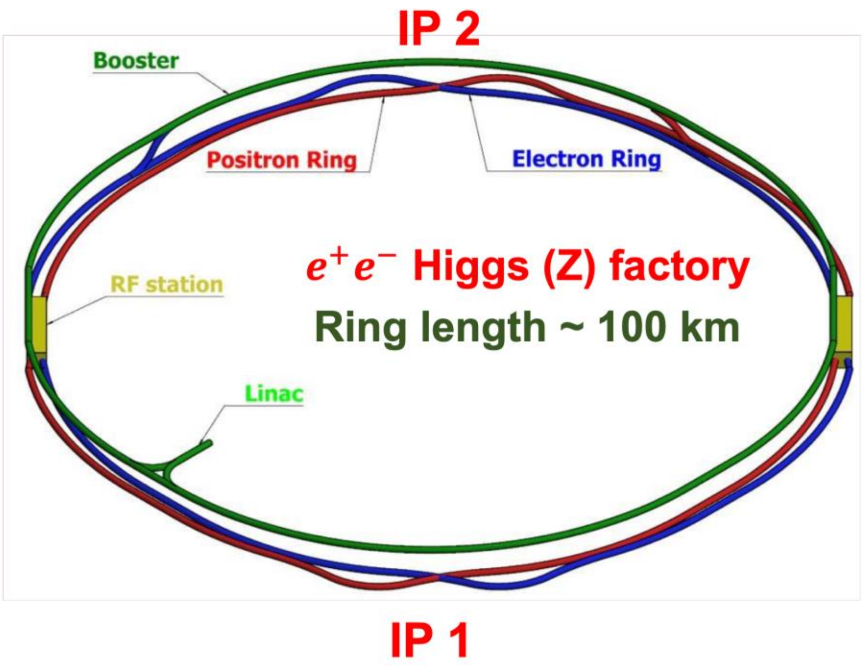
- New small X-band klystron, ordered
- Large with CPI, work with INFN
- L-band two stage, design done, prototyping for FCC

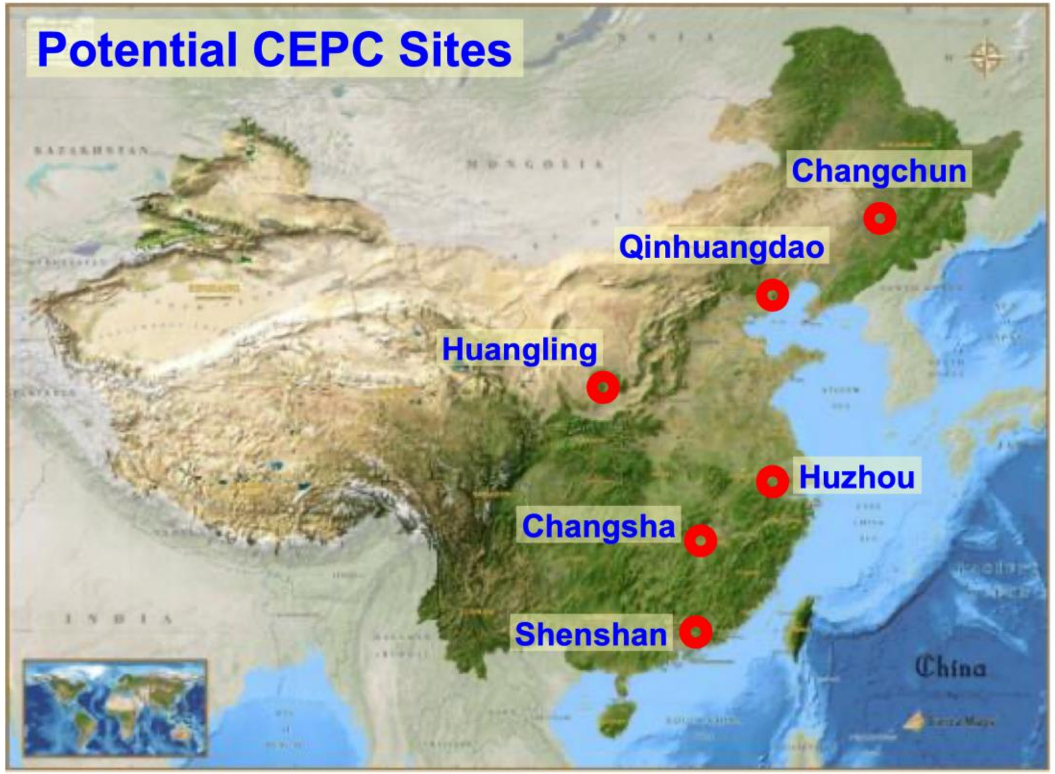
Also important, redesign of damping ring RF system (well underway) – no klystron development foreseen



The Circular Electron Positron Collider

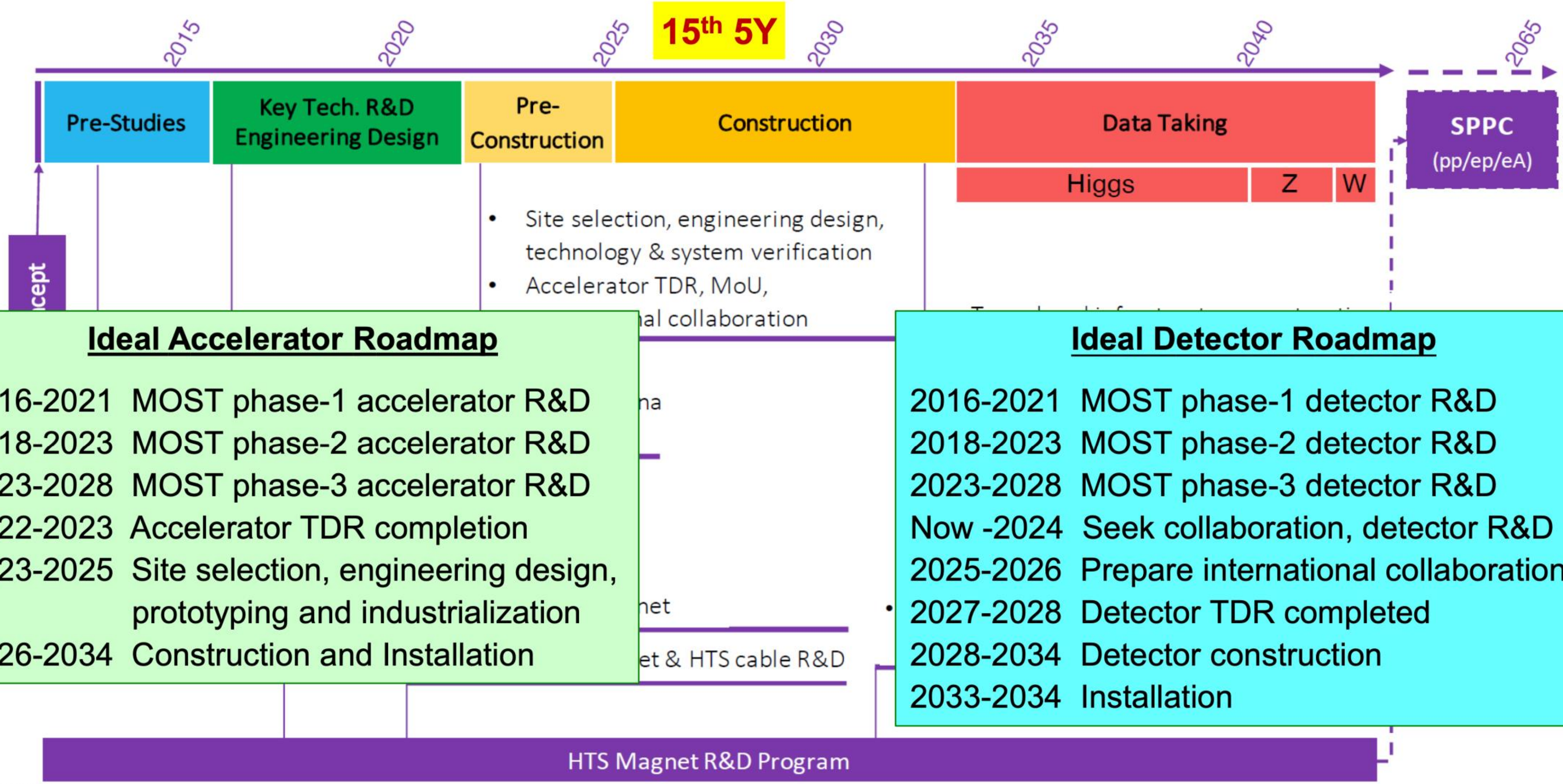
- The CEPC aims to start operation in 2030's, as a Higgs (Z / W) factory in China.
- To run at $\sqrt{s}$ ~ 240 GeV, above the **ZH** production threshold for ~1 M Higgs; at the **Z** pole for ~Tera Z; at the **W⁺W⁻** pair and possible $t\bar{t}$ pair production thresholds.
- Higgs, EW, flavor physics & QCD, probes of physics BSM.
- Possible *pp* collider (SppC) of $\sqrt{s}$ ~ 50–100 TeV in the future.





CEPC Roadmap and Schedule (Ideal)

- 2013-2025: Key technology R&D, from CDR to TDR, site selection, international collaboration etc.
- Ideal case: Approval in the 15th Five-Year Plan, and start construction (~8 years)



Ideal Accelerator Roadmap

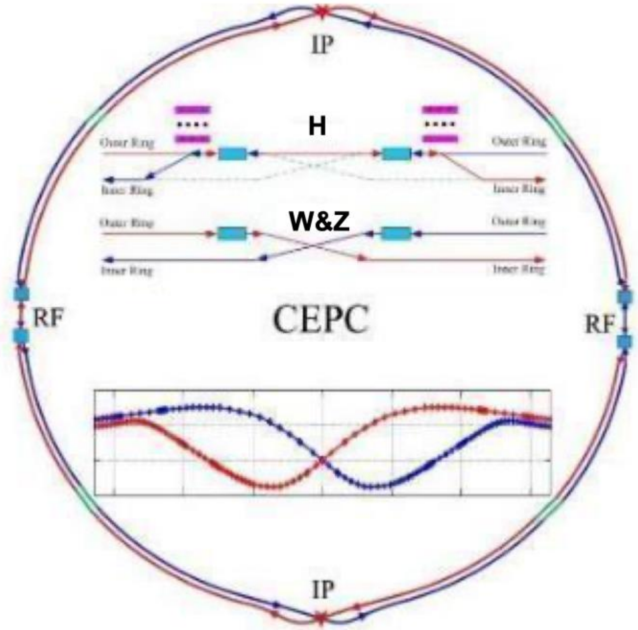
2016-2021 MOST phase-1 accelerator R&D
2018-2023 MOST phase-2 accelerator R&D
2023-2028 MOST phase-3 accelerator R&D
2022-2023 Accelerator TDR completion
2023-2025 Site selection, engineering design, prototyping and industrialization
2026-2034 Construction and Installation

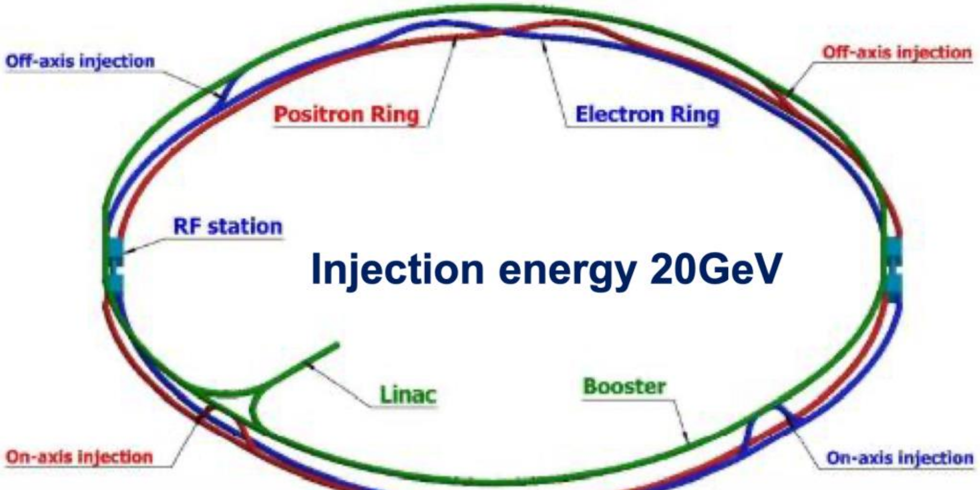
Ideal Detector Roadmap

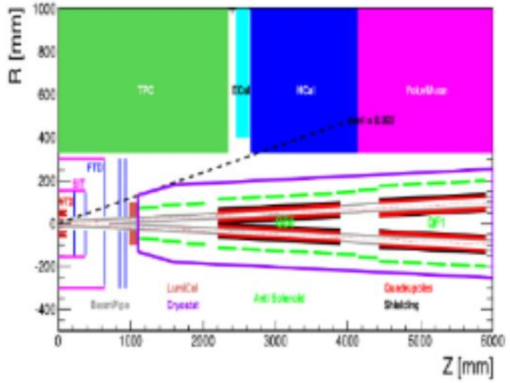
2016-2021 MOST phase-1 detector R&D
2018-2023 MOST phase-2 detector R&D
2023-2028 MOST phase-3 detector R&D
Now -2024 Seek collaboration, detector R&D
2025-2026 Prepare international collaborations
2027-2028 Detector TDR completed
2028-2034 Detector construction
2033-2034 Installation

CEPC High Luminosity TDR Layout

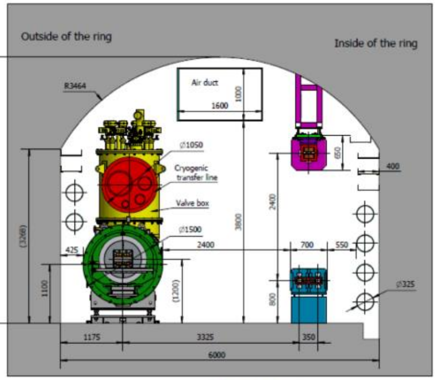
- 100 km double-ring design (30 MW/beam, upgradable to 50).
- New baseline for Linac (C-band, 20GeV) after the CDR.

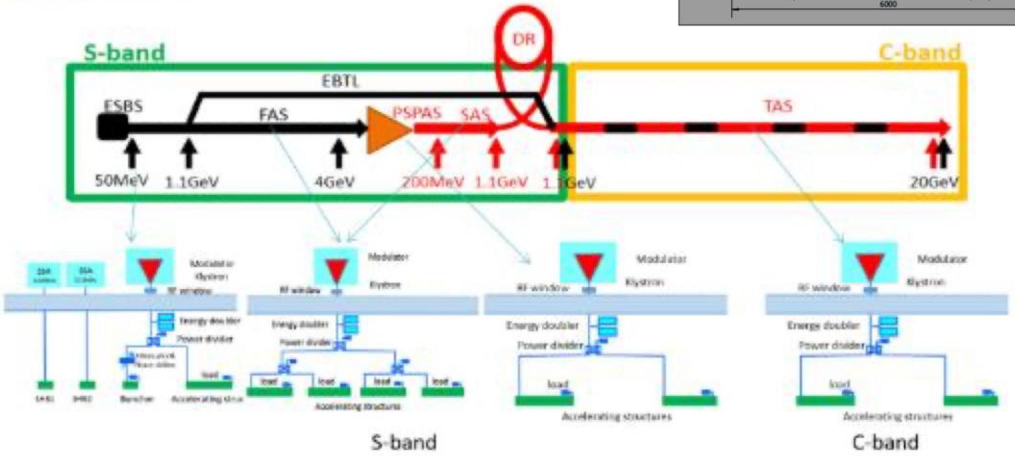






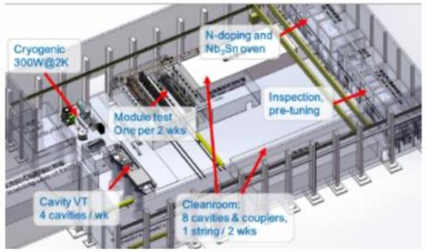
TUNNEL CROSS SECTION OF THE ARC AREA





Operation mode		ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]		~240	~91.2	158-172	360
L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	CDR (2018)	3	32	10	
	Latest	5.0	115	16	0.5

CEPC SCRF Test Facility



New SC Lab Design (4500m²)

SC New Lab is available in 2021

Cryogenic system hall in 2020

Collaboration With Industry

CEPC 650MHz Klystron at Kunshan Co.

CERN HL-LHC CCT SC magnet

CEPC SC QD0 coil winding at KEYE Co.

CIPC (CEPC Industrial Promotion Consortium) was established in Nov 2017. So far 70+ companies have joined.

CEPC Detector SC coil winding tools at KEYE Company (Diameter ~7m)

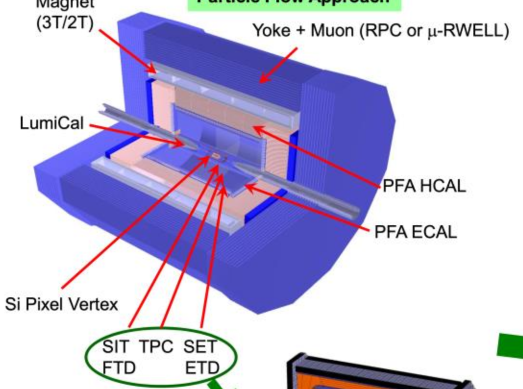
CEPC long magnet measurement coil

1) Superconduting materials (for cavity and for magnets)
2) Superconducting cavities
3) Cryomodules
4) Cryogenics
5) Klystrons
6) Magnet technology
7)Vacuum technologies
8) Mechanical technologies
9)Electronics
10) SRF
11) Power sources
12) Civil engineering
13) Precise machinery
.....

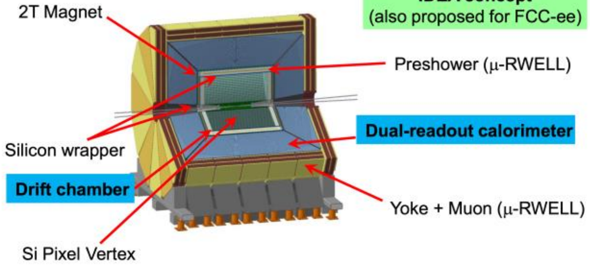
More than 40 companies joined in first phase of CIPC, **and 70 companies now.**

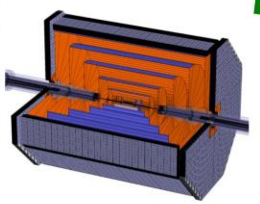
Conceptual Detector Designs

(Baseline Design) Particle Flow Approach



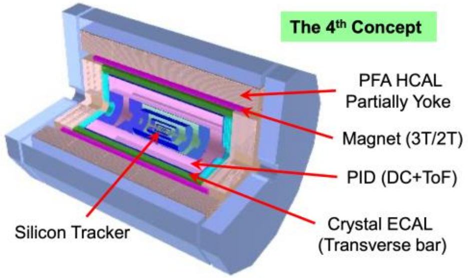
IDEA concept (also proposed for FCC-ee)





FST concept (Full Silicon Tracker)

The 4th Concept



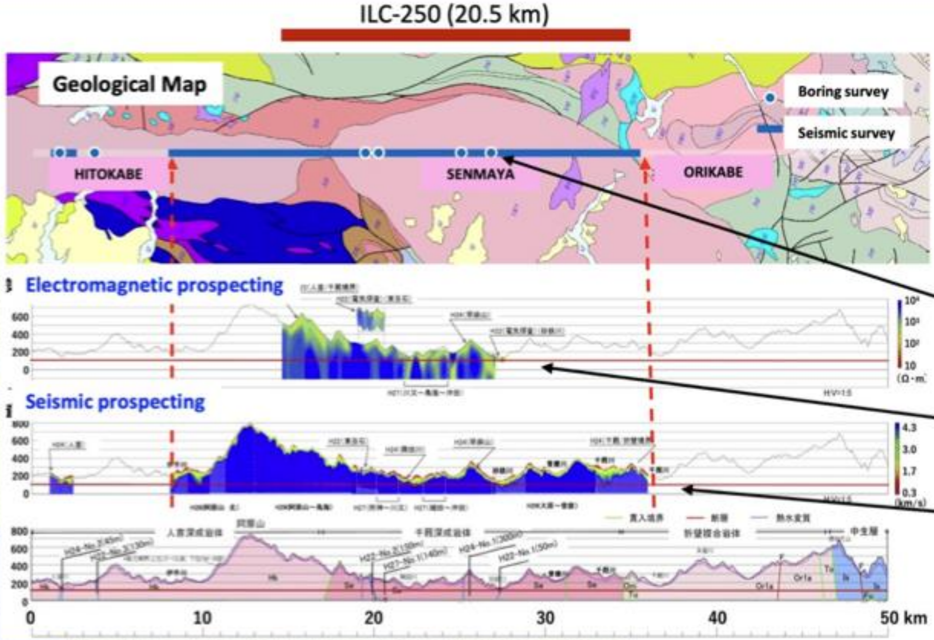
CEPC Physics White Papers

Operation mode		ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]		~240	~91.2	158-172	360
Run time [years]		7	2	1	?
CDR	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	3	32	10	
	$\int L\,dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6	
	Event yields [2 IPs]	1×10^6	7×10^{11}	2×10^7	
Latest	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	5.0	115	16	0.5

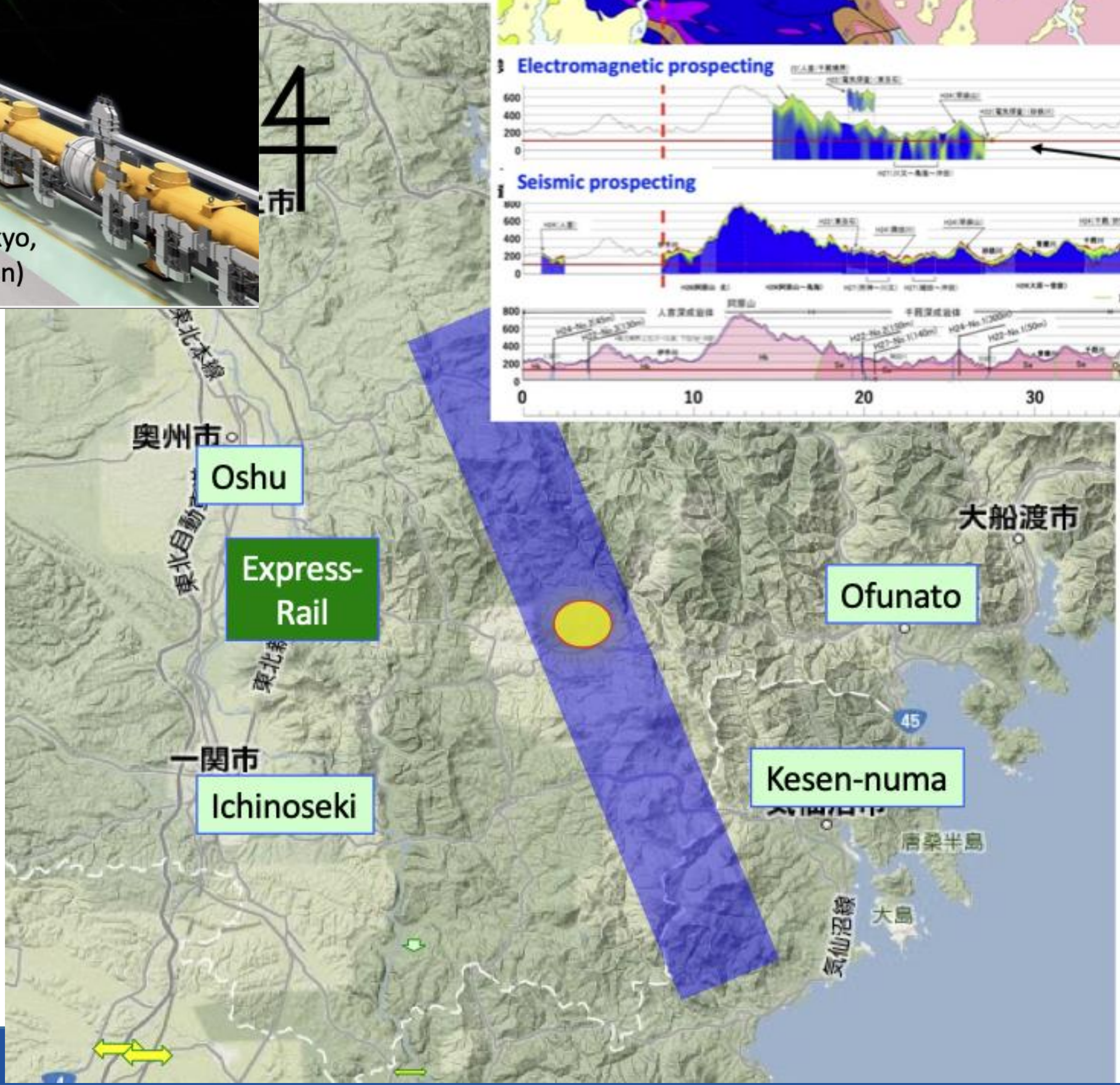
The large samples: ~10^6 Higgs, ~10^{12} Z, and ~10^8 W bosons

- **Physics goals are similar to FCC-ee, ILC, CLIC.**
- 2019.3 **Higgs** White Paper published *(CPC V43, No. 4 (2019) 043002)*
- 2019.7 Workshop@PKU: **EW, Flavor, QCD** working groups formed
- 2020.1 Workshop@HKUST-IAS: Review progress, EW draft ready
- 2021.4 Workshop@Yangzhou: **BSM** working group formed

ILC Site Candidate Location in Japan: Kitakami



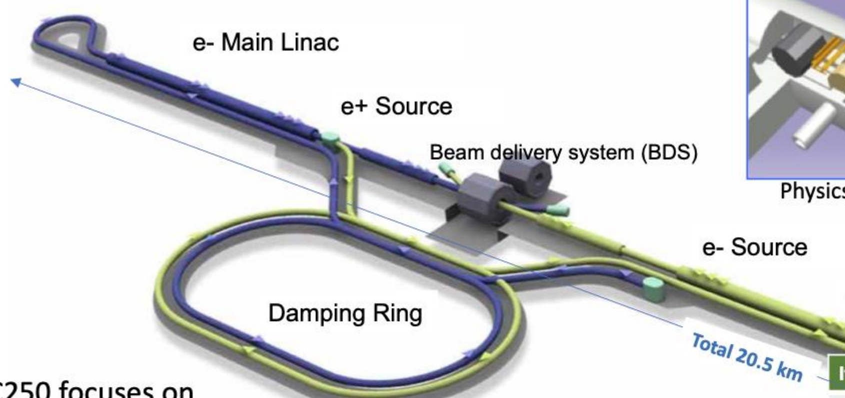
- Continuous **granite region**
  HITOKABE, SENMAYA and **ORIKABE** bedrock
- **Have capability to extend the ILC up to 50 km in future**
- **Boring geological survey**
  → Direct sampling down to the accelerator depth
- **Electromagnetic prospecting**
  → Cracks in the rock
- **Seismic prospecting**
  → Rock hardness

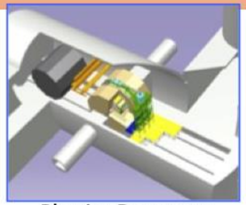


Tohoku ILC Project Development Center is established

Director
Atsuto
Suzuki

[1] Design outline: ILC250 accelerator facility





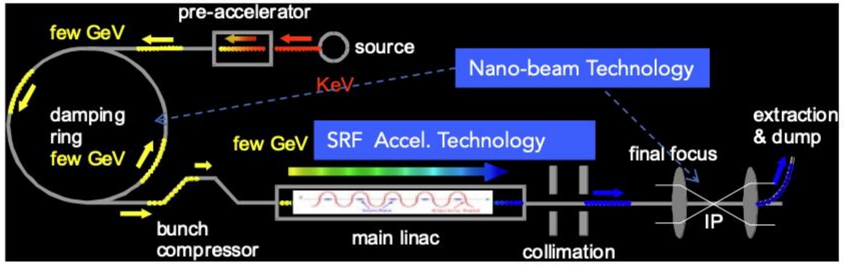
Physics Detectors

ILC250 focuses on
Higgs Factory;
Length becomes 20km

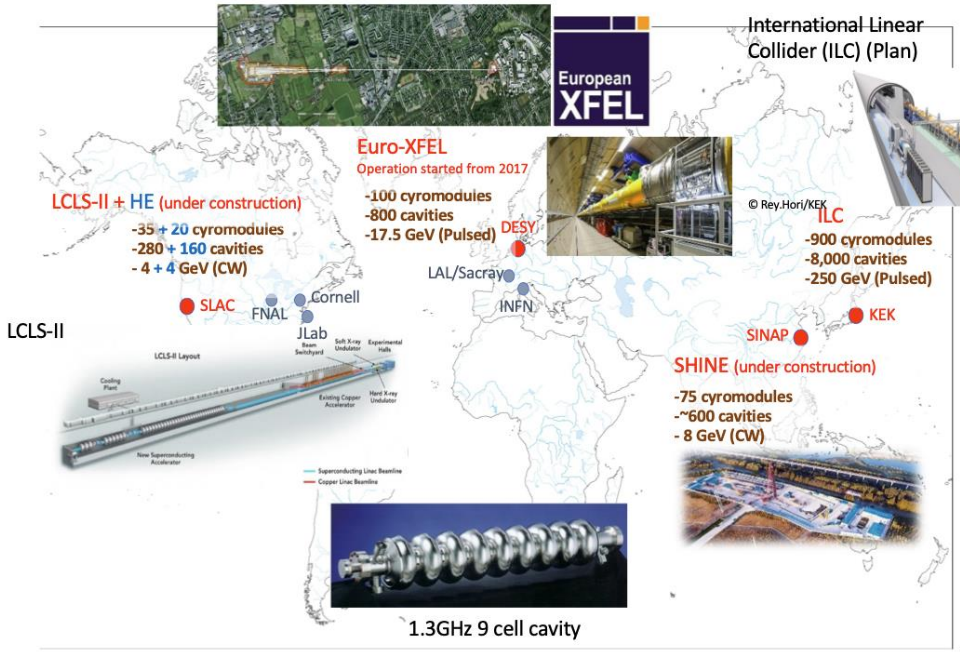
Total Cost of Acc. is ~6BSF including human & Civil Tunnel cost ~ 1.1BSF

Item	Parameters
C.M. Energy	250 GeV
Length	20km
Luminosity	1.35 $\times 10^{34}$ $cm^{-2}s^{-1}$
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.	31.5 MV/m (35 MV/m)
Q_0	Q_0 = 1x10 ^{10}

Key Technologies



SRF accelerators are worldwidely used for light source



ILC SRF technology is well-matured & Cost effective

Just Factor 10 Scale up

[5] IDT and Milestone

Stage 1 International Development Team (~1.5 years)

Stage 2 ILC Pre-Laboratory (4 years)

Stage 3 ILC Laboratory (10 years for construction)

Stage 4 Experiment at ILC!

ILC is the big international project
Pre-Lab Phase is necessary before construction.

Boss is Nakada-san

ICFA

ILC International Development Team

International Org.

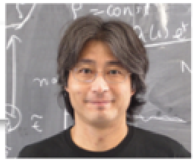
Executive Board

Americas Liaison	Andrew Lankford (UC Irvine)
Working Group 2 Chair	Shinichiro Michizono (KEK)
Working Group 3 Chair	Hitoshi Murayama (UC Berkeley/U. Tokyo)
Executive Board Chair and Working Group 1 Chair	Tatsuya Nakada (EPFL)
KEK Liaison	Yasuhiro Okada (KEK)
Europe Liaison	Steinar Stapnes (CERN)
Asia-Pacific Liaison	Geoffrey Taylor (U. Melbourne)

Working Group 1
Pre-Lab Setup

Working Group 2
Accelerator

Working Group 3
Physics & Detectors



International Development Team (IDT) is established by ICFA

IDT: to prepare for smooth transition to the ILC Pre-lab

- Prepare a proposal for the organization and governance of the ILC Pre-Lab
- Prepare the work and deliverables of the ILC Pre-laboratory and workout a scenario for contributions with national and regional partners

Accelerator : Michizono-sab
Physics: Murayama-san

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Plan for Technical preparation

IDT-WG2 summarized the technical preparation as work packages (WPs) in the technical preparation document.

SRF is dominant, but also there are many interesting topics

Cost & FET are summarized

1 ILCU~ 1 SF

ILC Pre-lab

Actual cavity /CM manufacturing

SRF
~41MILCU
285 FTE-yr
- WP-1 Cavity production
- WP-2 Cryomodule assembly
- WP-3 Crab cavity

e- source
~2.5MILCU, 6 FTE-yr
- WP-4 Electron source

e+ source
~6MILCU, 15FTE-yr

Undulator scheme
- WP-5 Undulator
- WP-6 Rotating target
- WP-7 Magnetic focusing

e-Driven scheme
- WP-8 Rotating target
- WP-9 Magnetic focusing
- WP-10 Capture cavity
- WP-11 Target replacement

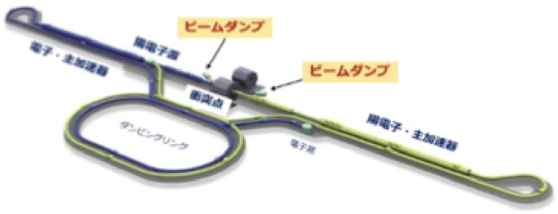
DR
~2.5MILCU, 30FTE-yr
- WP-12 System design
- WP-13 Collective effect
- WP-14 Injection/extraction

BDS
~2MILCU, 16FTE-yr
- WP-15 Final focus
- WP-16 Final doublet

Dump
~3MILCU, 12FTE-yr
- WP-17 Main dump
- WP-18 Photon dump

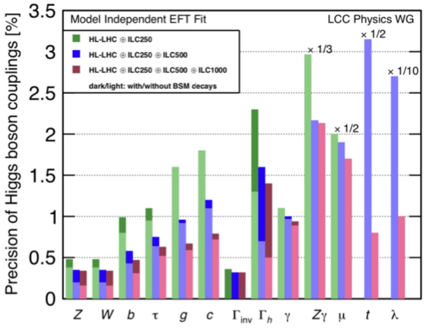
For detail,
http://doi.org/10.5281/ zenodo.4742018

SRF technology is energy-efficient, and its applications are increasing around the world.
These WPs will contribute to the promotion of SRF accelerators in each region.



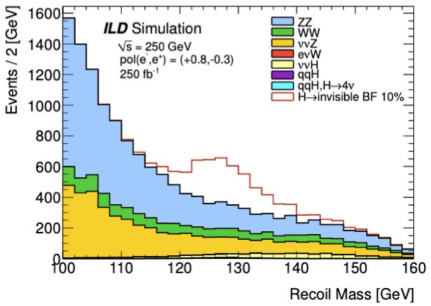
- The technical preparation document was reviewed by the international review committee (chair:Tor Raubenheimer (SLAC)).
- The total global cost of the project is about 60 MILCU and about 360 FTE-year. (This does not include the cost of the infrastructure for the WPs.)
- The cost will be shared internationally as in-kind contribution.

[3] Physics Higgs Factory



arXiv:1908.11299

Higgs coupling can be measured precisely
Accuracy is about 1%
No necessary mention here



This show recoil mass distribution,
We can detect Higgs -> invisible
Higgs portal DM is interesting topics

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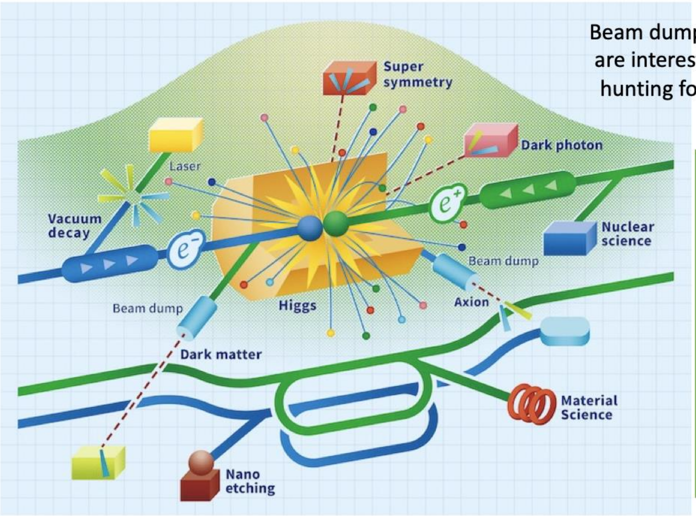
[4] Diversities /applications

Higgs Factory / high energy colliders are very important for us;
But diversities and applications are important for faculty



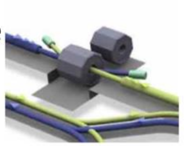
Beam dump experiments
are interesting
hunting for Axion / Paraphoton

Light Source
Laser/XFEL
Nuclear Phys.
Material
Nano beam

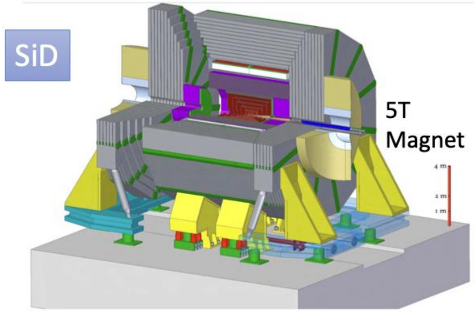
Various
proposals
are welcome

[2] Detectors

Two detectors are
proposed

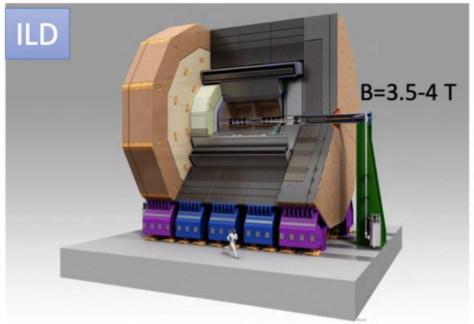


The similar Performance is obtained
in both detectors
Significantly improved from
the LHC detectors



Based on the Silicon pixel and strip detectors
(except for HCAL)

arXiv:2110.09965



TPC/High Granularity Calorimeter
Readout Cell numbers is as larger as
by factor 1000 of LHC

arxiv:2003.01116

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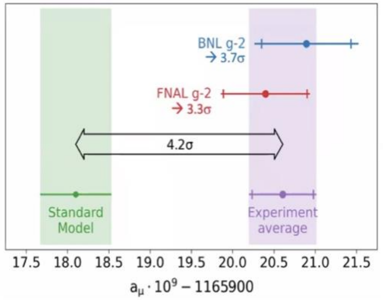
Extendability of ECM is also important

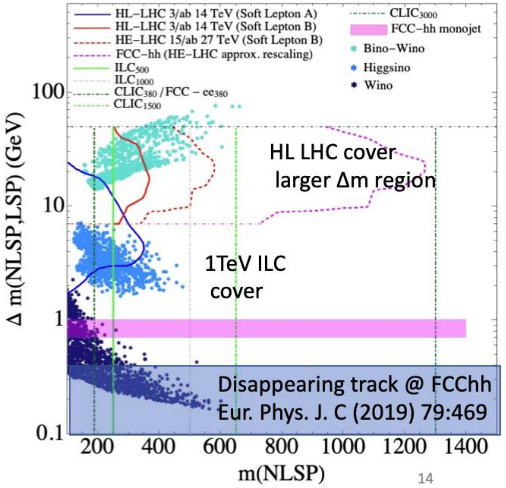
Anomaly in muon g-2 is confirmed.



Light SUSY (color-single SUSY)
particles are expected ~< 500GeV
(Neutralino, chargino, slepton)

With DM/LHC constraint
degenerate case is expected.

arXiv:2103.13403



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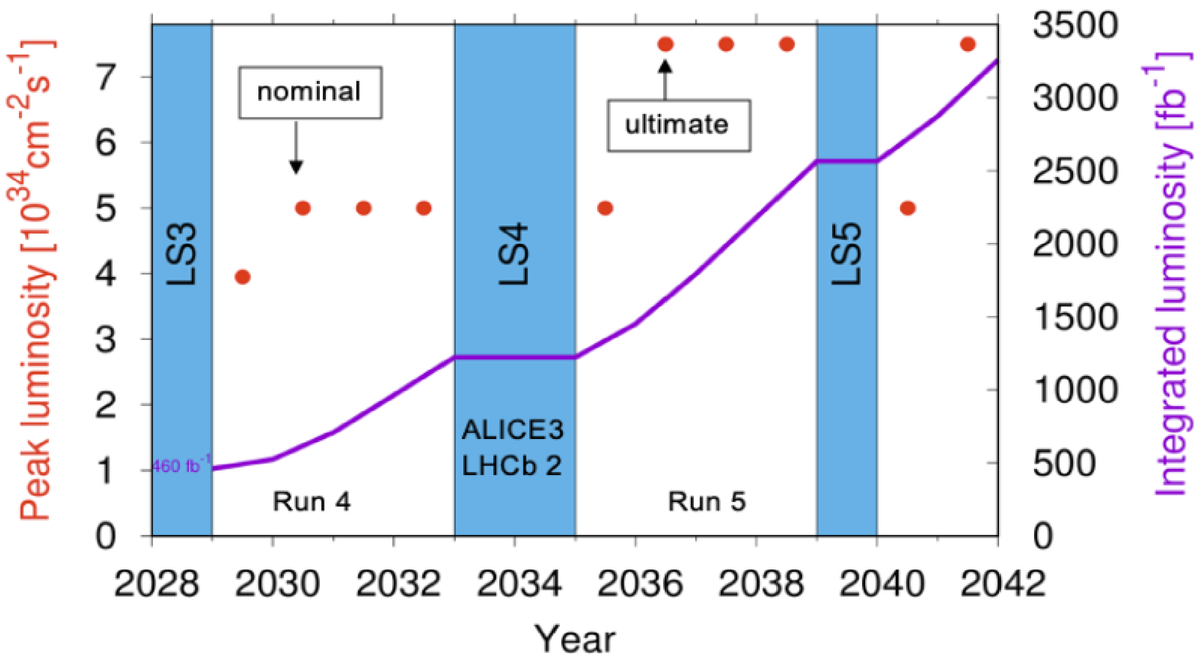
Note on long-term planning

Preliminary (optimistic) schedule of HL-LHC



Shown integrated luminosities include 1 month/year of HI running and no MD or special runs after 2036

LS4 extended from 1 to 2 years (in view of ALICE and LHCb upgrades)

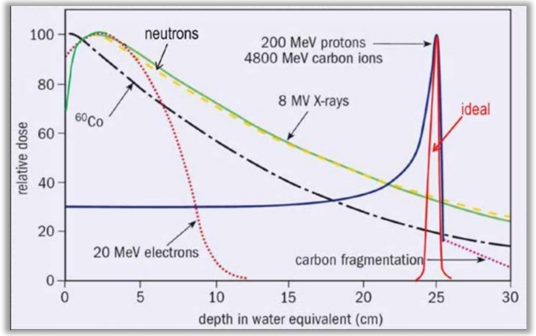
With proposed shift and extension of LS3, and inclusion of HI runs beyond LS3:

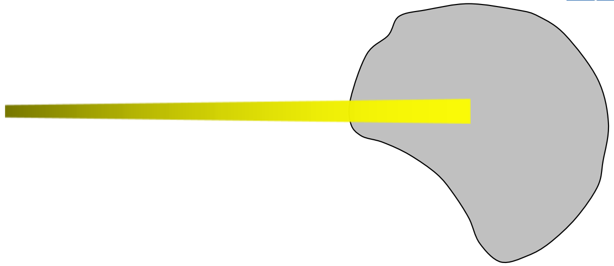
- 2500 fb^{-1} are expected by end 2038 (current end-date of HL-LHC)
- 3000 fb^{-1} (int. luminosity goal) would now be reached in ~ 2041

Note: it should not be assumed that future shifts of LS schedules, or new, ambitious upgrades of the experiments, entail an automatic shift/extension of HL-LHC end date, as this has an impact on the future of the field
(next collider cannot start before ~ 7 years from end of HL-LHC for technical and financial reasons)

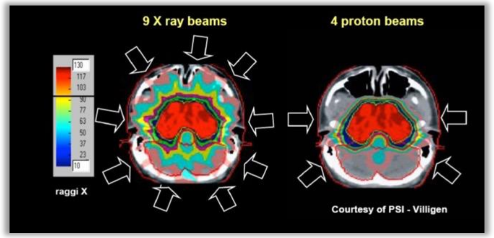
→ next European Strategies will need to optimise the overall planning of the field based on HL-LHC performance and physics results, interest of the community, progress with next facility, etc.

Photon (from electrons) and hadron therapy (protons and ions)



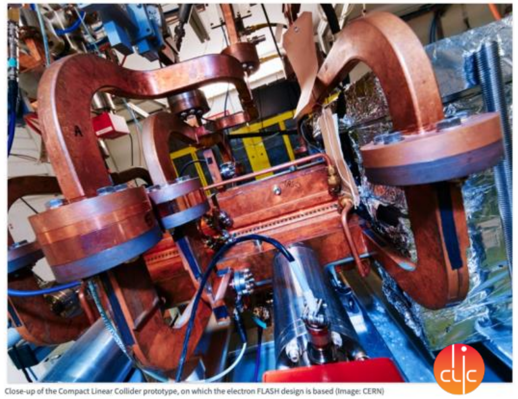


50 mill patients treated with photons

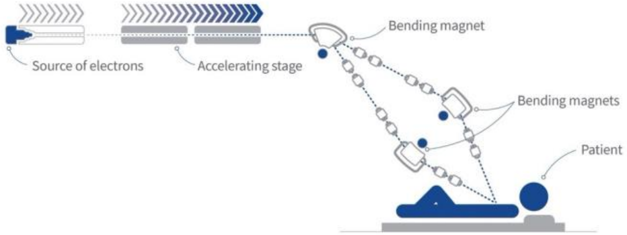


FLASH VHEE (very high energy electron) therapy

CLIC technology for a FLASH VHEE facility being designed in collaboration with Lausanne University Hospital (CHUV)



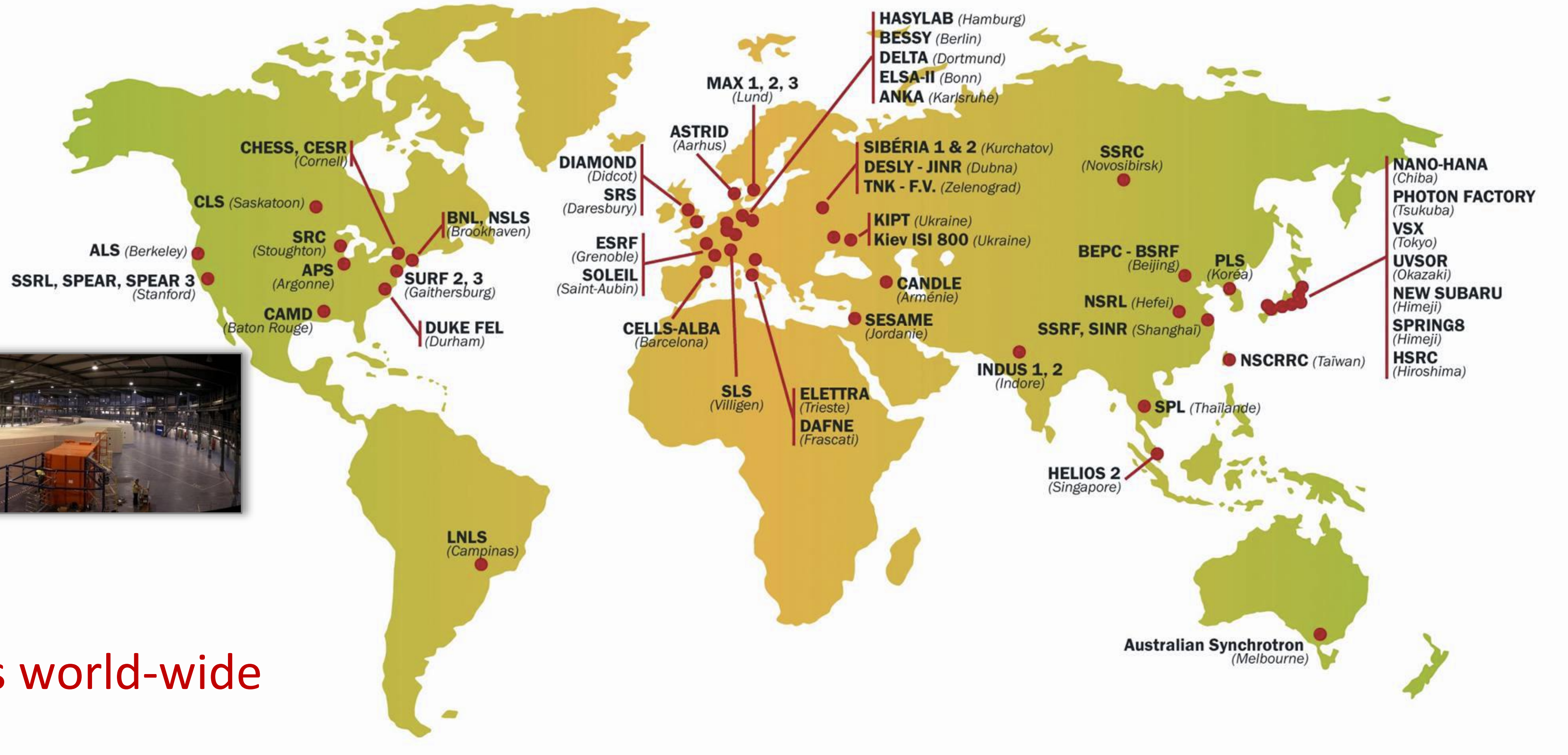
Close-up of the Compact Linear Collider prototype, on which the electron FLASH design is based (Image: CERN)



An intense beam of electrons is produced in a photoinjector, accelerated to around 100 MeV and then is expanded, shaped and guided to the patient.

Flash: Very short and intense radiation, sparing of healthy tissue

Synchrotron Light Sources: about 50 storage ring based



60‘000 users world-wide

Established, mature technology

From L.Rivkin EPFL

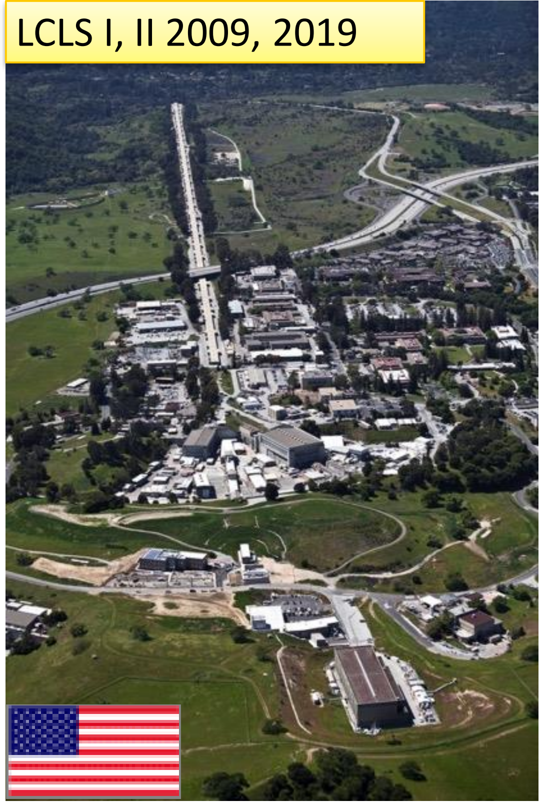
X-Ray Free Electron Lasers

From L.Rivkin EPFL

PAL XFEL 2016

SACLA 2011
8.5 GeV, 60 Hz NC

SwissFEL 2017



LCLS I, II 2009, 2019

European XFEL 2017
DESY, Hamburg

SHINE, Shanghai, under construction