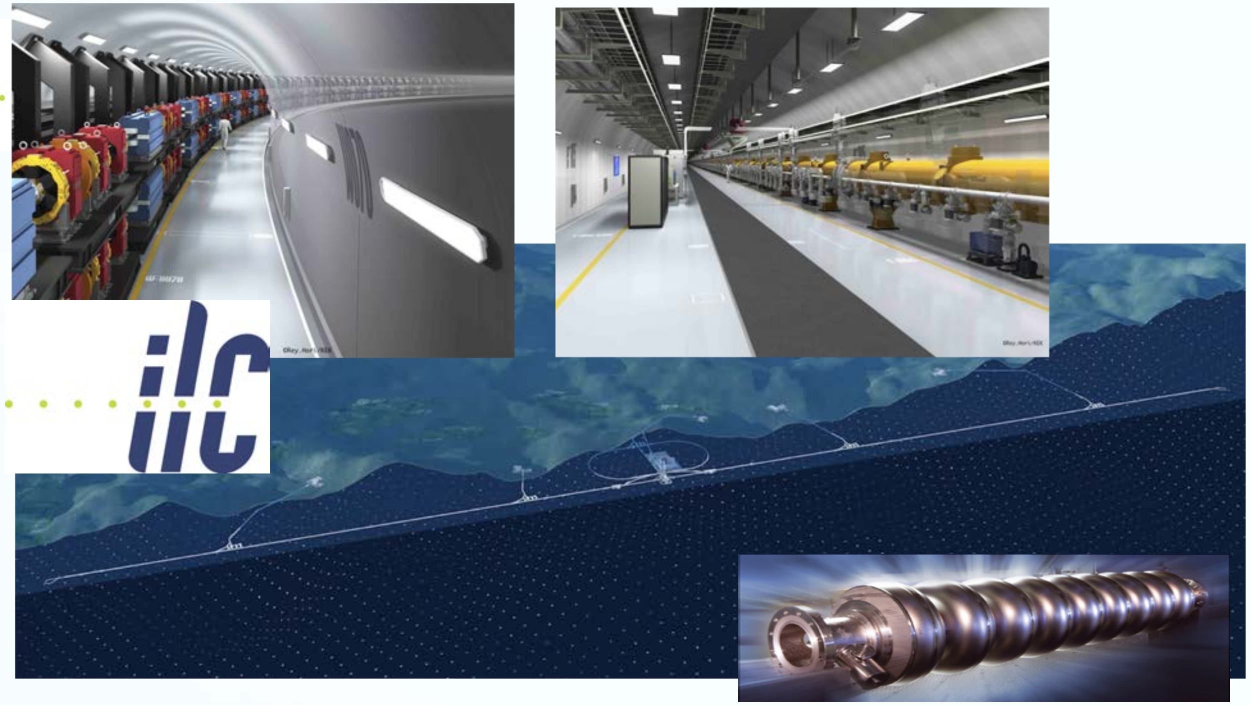


Status and perspectives of ILC and CLIC studies

A. Faus-Golfe

On behalf ILC-IDT and CLIC studies

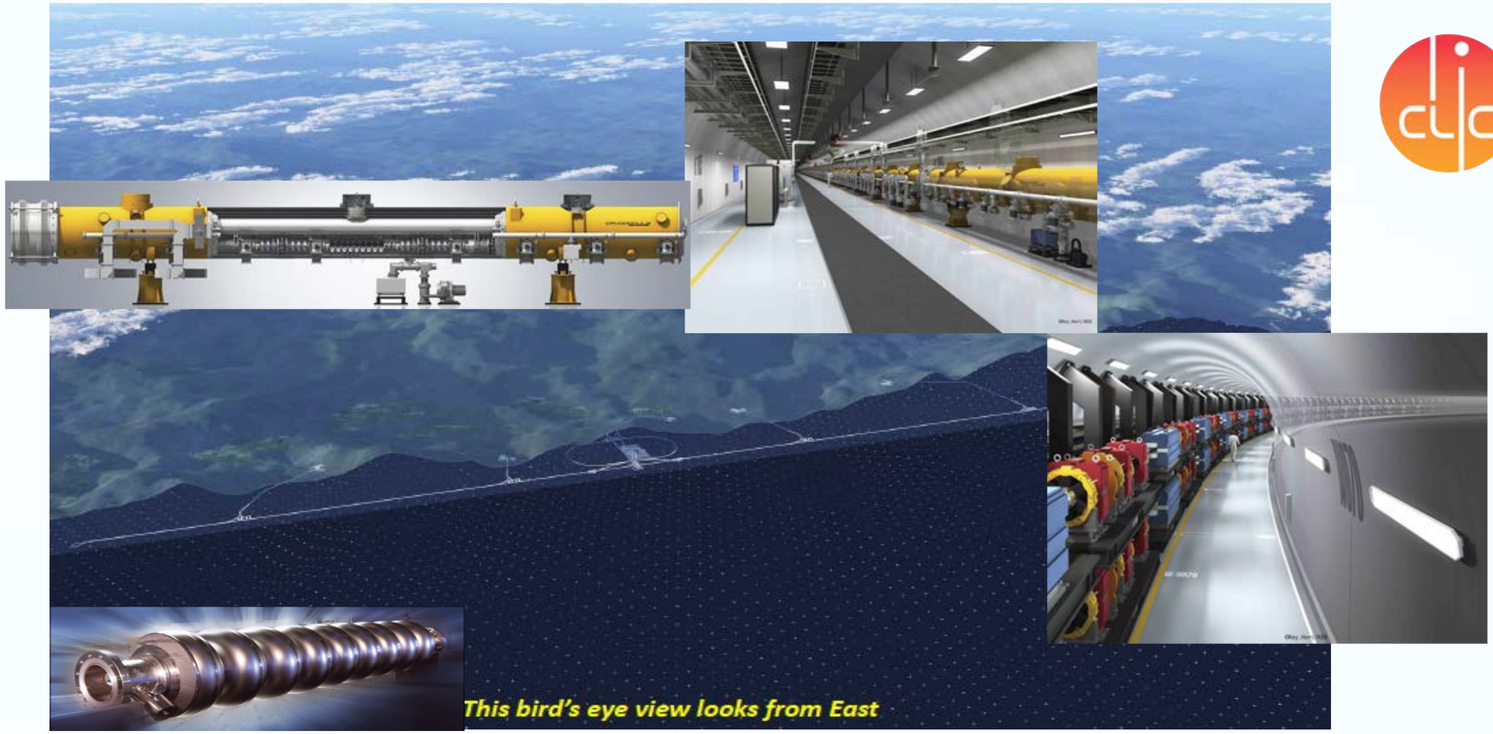
IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis
CNRS IN2P3 Les deux infinis

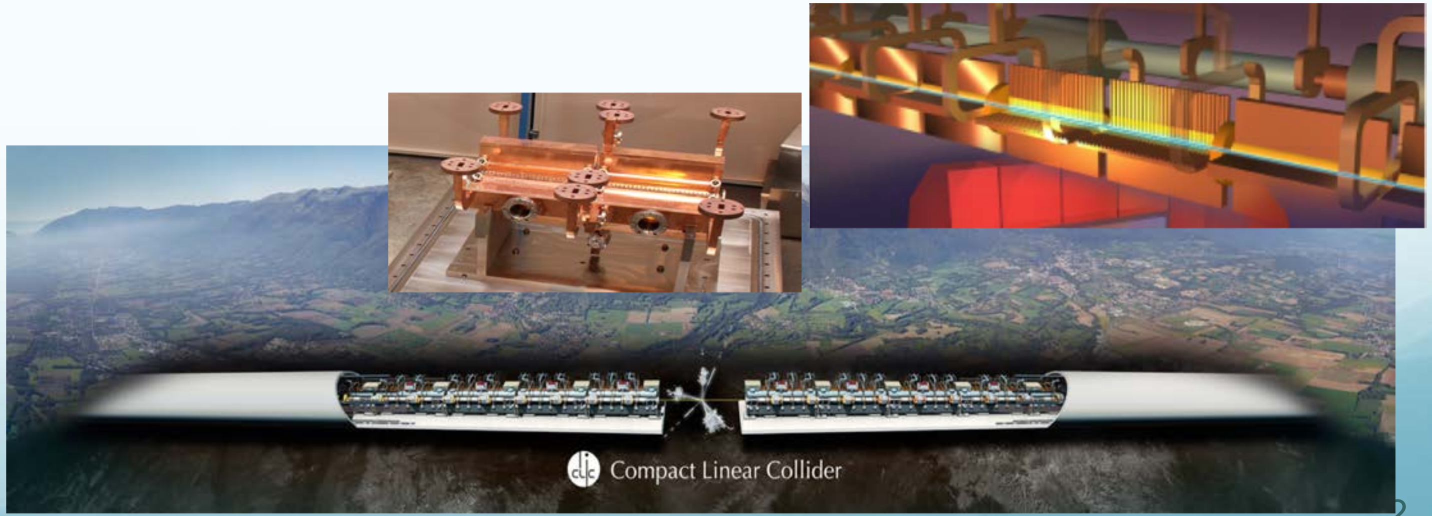
Outline

- Why a linear Higgs factory?

- ILC-IDT: Technology update
- CLIC: Technology update

- Summary and Perspectives





Linear Higgs factories

Note: H. Abramowizc ESG January 2020.

European Strategy Update

2020 Strategy Statements

Guide through the statements

2 statements on Major developments from the 2013 Strategy
a) Maintain focus on successful completion of HL-LHC upgrade
b) Mai...
US...

3 state...
a) Pres...
com...
b) Str...
c) Acknowledge the global nature of PP research

2 statements on High-priority future initiatives
a) Higgs factory as the highest-priority next collider and investigation of the technical and financial feasibility of a future hadron collider at CERN
b) Vigorous R&D on innovative accelerator technologies – through roadmap

Letters for itemizing the statements are introduced for identification, do not imply prioritization

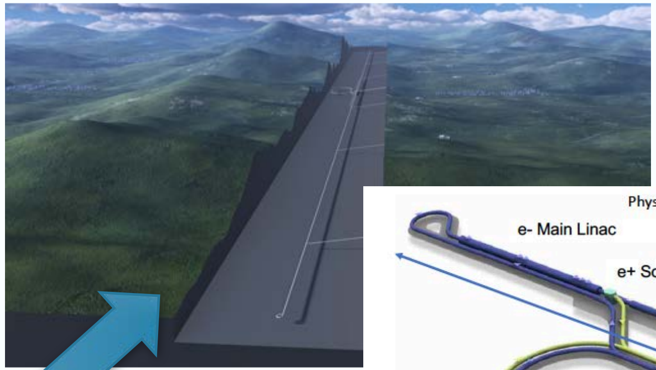
4 statements on Other essential scientific activities
a) Support for high-impact, financially viable ...
...oadmap
...ucture

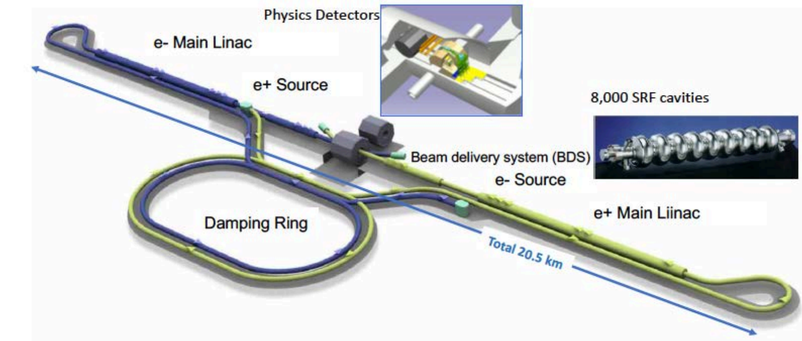
...elds
b) Astroparticle – cooperation with APPEC

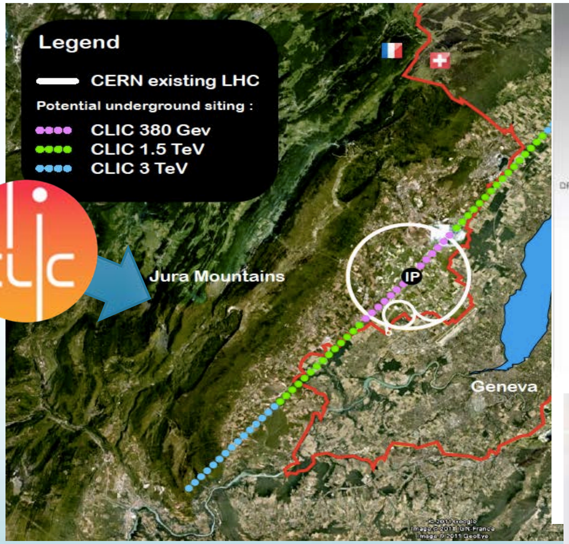
3 statements on Organisational issues
a) Framework for projects in and out of Europe
b) Strengthen relations with European Commission
c) Play active role in supporting Open Science

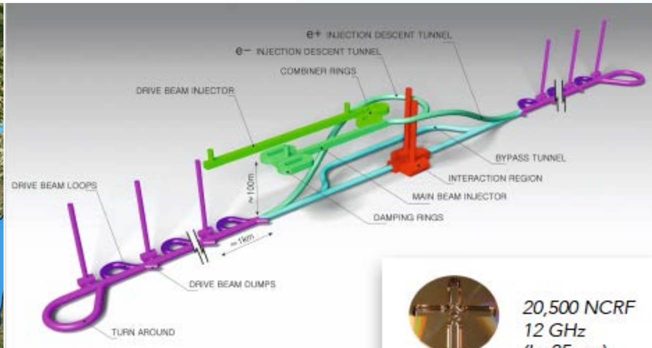
4 statements on Environmental and societal impact
a) Mitigate environmental impact of particle physics
b) Invest in next generation of researchers
c) Support knowledge and technology transfer
d) Spread cultural heritage: public engagement education and communication

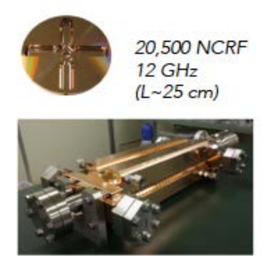
e+e- Higgs factory is highest priority in HEP

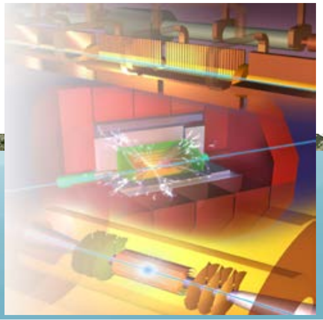












- **Technology View on Relative Timelines**

Timeline	~5	~10	~15	~20	~25	~30	~35
Lepton Colliders – Linear and Circular:							
SRF-LC/CC	Proto/pre-series	Construction		Operation		Upgrade	
NRF – LC	Proto/pre-series	Construction		Operation		Upgrade	
Hadron Collier – Circular :							
14~16T Nb_3Sn	Short-model R&D		Prototype/Pre-series		Construction		
12~14T Nb_3Sn	Short-model R&D	Proto/Pre-series		Construction		Operation	
9~12T Nb_3Sn	Model/Proto/Pre-series	Construction		Operation		Upgrade	
6~8T NbTi	Proto/ Pre-series	Construction		Operation		Upgrade	

Note: LHC experience: NbTi, 10 T R&D started in 1980's and 8.3 T Production started in late 1990's, after ~ 15 years

A. Yamamoto, 190513b/updated 190628a

- **Higgs Factories**

Higgs Factories	Readiness	Power-Eff.	Cost
ee Linear 250 GeV			
ee Rings 240GeV/tt			
μμ Collider 125 GeV			*
ALIC 125 GeV		?	?

F1 "Technology Readiness": Green - TDR; Yellow - CDR; Red - R&D

F2 "Energy Efficiency": Green : 100-200 MW; Yellow : 200-400 MW; Red : > 400 MW

F3 "Cost": Green : < LHC; Yellow : 1-2 x LHC; Red : > 2x LHC

Linear Higgs factories

Note: H. Abramowizc ESG January 2020.


European Strategy Update

2020 Strategy Statements

Guide through the statements

2 statements on Major developments from the 2013 Strategy
a) Maintain focus on successful completion of HL-LHC upgrade
b) Maintain support for long-baseline ν experiments in Japan and US and the Neutrino Platform

3 statements on General considerations for the 2020 update
a) Preserve the leading role of CERN for success of European PP community
b) Strengthen the European PP ecosystem of research centres
c) Acknowledge the global nature of PP research

2 statements on High-priority future initiatives
a) Higgs factory as the highest-priority next collider and inve… futu…
b) Vig… thr…

4 statements on Other essential scientific activities
a) Support for high-impact, financially viable, experimental initiatives world-wide
b) Acknowledge the essential role of theory
c) Support for instrumentation R&D – through roadmap
d) Support for computing and software infrastructure

2 statements on Synergies with neighbouring fields
a) Nuclear physics – cooperation with NuPECC
b) Astroparticle – cooperation with APPEC

3 statements on Organisational issues
a) Framework for projects in and out of Europe
b) Strengthen relations with European Commission

…act …hysics

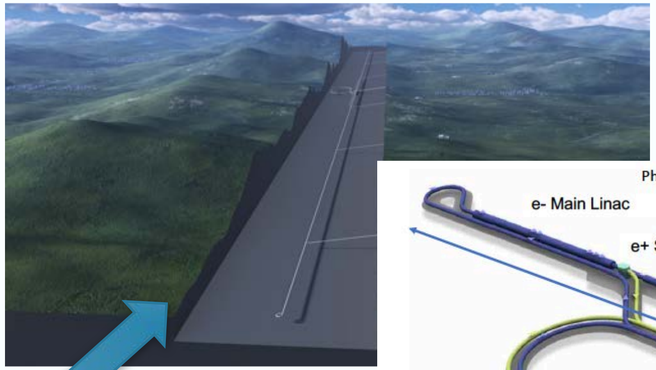
Timeline				
Lepton Colliders				
SRF-LC/CC				
NRF –LC	P…			
Hadron Collier – Circular :				
14~16T Nb_3Sn	Short-model R&D	Prototype/Pre-series	Construction	
12~14T Nb_3Sn	Short-model R&D	Proto/Pre-series	Construction	Operation
9~12T Nb_3Sn	Model/Proto/Pre-series	Construction	Operation	Upgrade
6~8T NbTi	Proto/ Pre-series	Construction	Operation	Upgrade

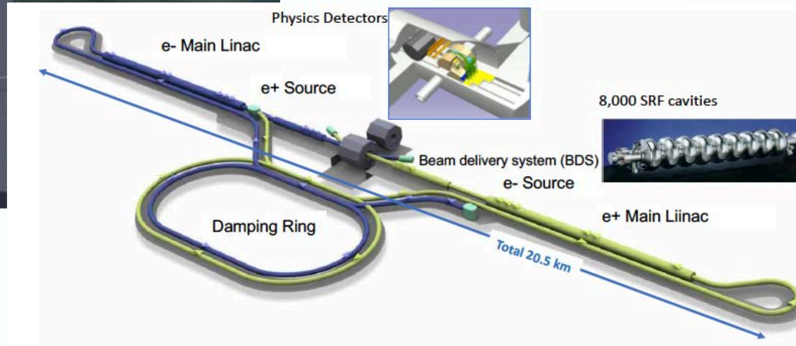
Note: LHC experience: NbTi, 10 T R&D started in 1980's and 8.3 T Production started in late 1990's, after ~ 15 years

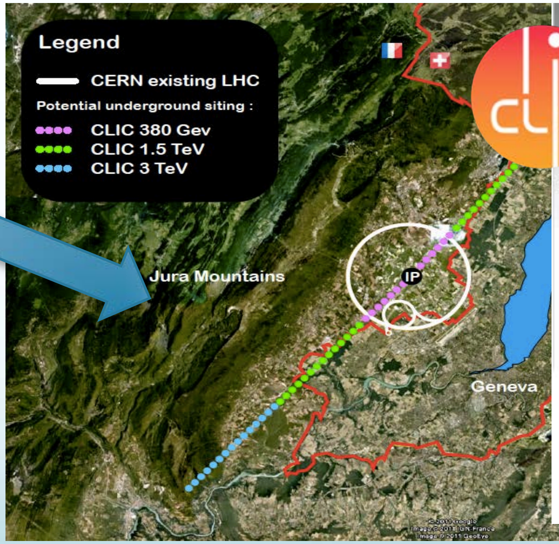
	F1	F2	Cost
ee Rings 240GeV/tt			
μμ Collider 125 GeV			*
ALIC 125 GeV		?	?

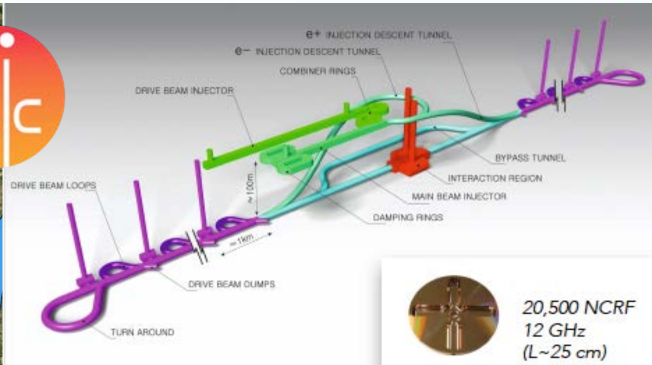
F1 "Technology Readiness": Green - TDR; Yellow - CDR; Red - R&D
F2 "Energy Efficiency": Green: 100-200 MW; Yellow: 200-400 MW; Red: > 400 MW
F3 "Cost": Green: < LHC; Yellow: 1-2 x LHC; Red: > 2x LHC

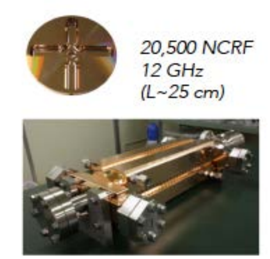
LC Higgs factory technology is ready

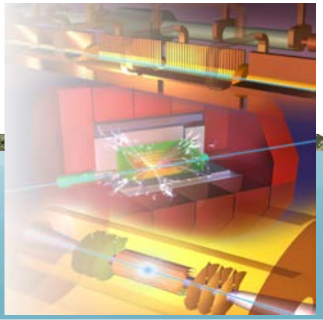




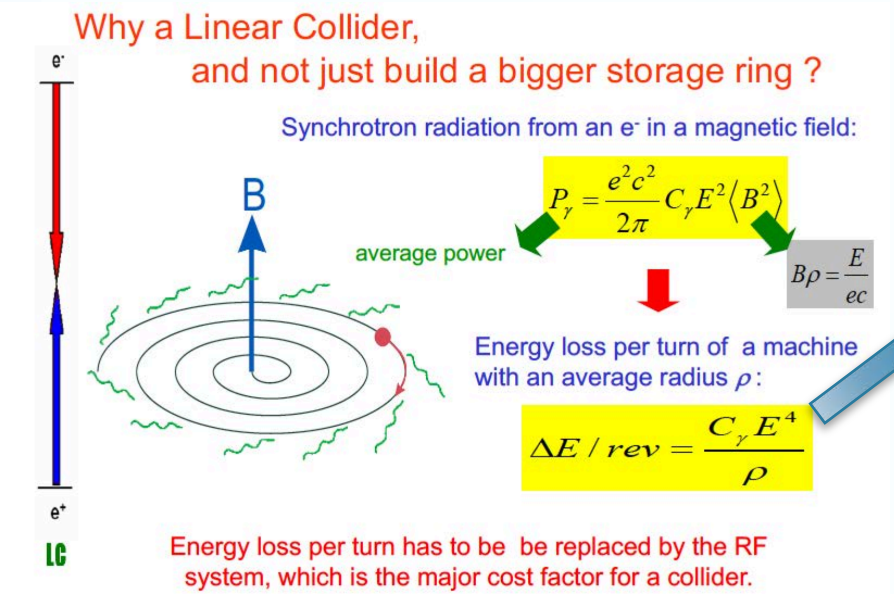


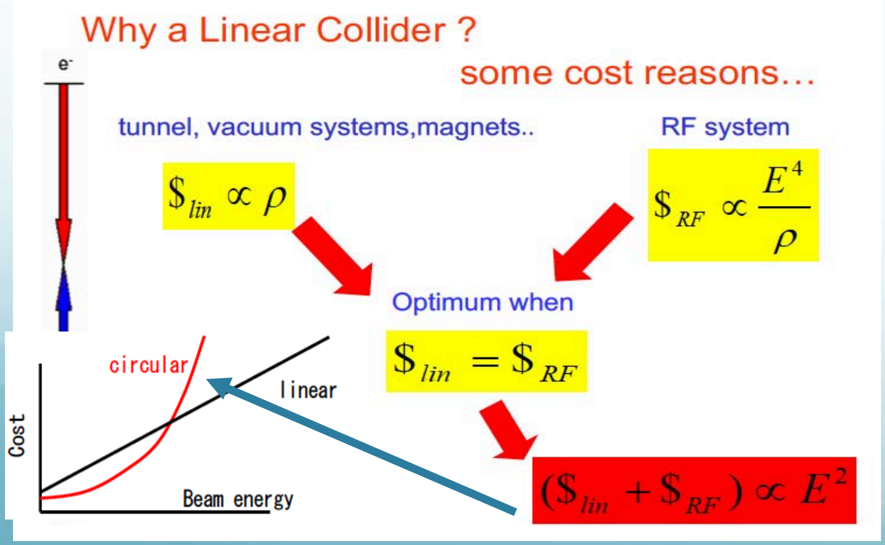






Why a linear Higgs factory?





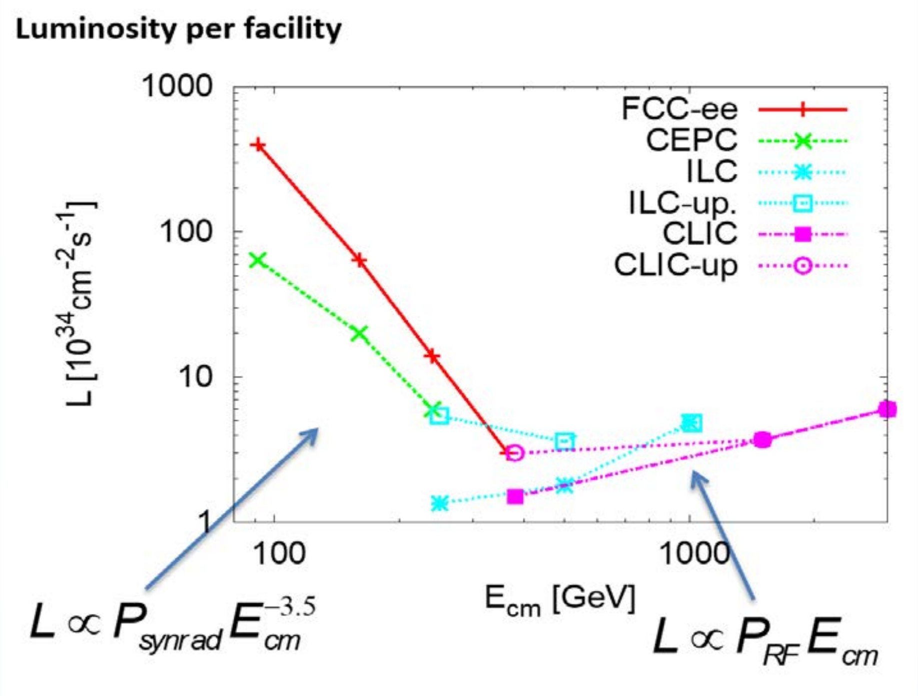
- **Energy dependence:**

At **low energies circular** colliders surpass

- Reduction at high energy due to SR

At **high energies linear** colliders excel

- Luminosity per beam power roughly constant



- **Others LCs advantages:**

- LCs have **polarized beams** (80% e^-, ILC also 30% e^+), the spin of the e^+e^- beam can be maintained during the acceleration and collision. This can help significantly improve measurement precision.
- **Upgradeability**: LCs can extend its collision energy by longer tunnel/ higher gradient

LCs Accelerator Challenges and Key Technologies

Construction cost
$ ~ L

Energy

$$E_{CM} = L \cdot g$$

Luminosity

$$\mathcal{L} = \frac{\eta P_{AC}}{E_{CM}} \cdot \frac{N_e}{4\pi \sigma_x^* \sigma_y^*} H_D$$

Operation cost
$ ~ P_{AC}

High Gradient g

High Efficiency η

Small Beamspot $\sigma^*_x \sigma^*_y$ $\sigma^* = \sqrt{\beta^* \varepsilon}$

Main Linac Technology

Losses in cavity walls

$$\frac{P_{wall}}{L} \propto \frac{g^2 R_s}{\omega}$$

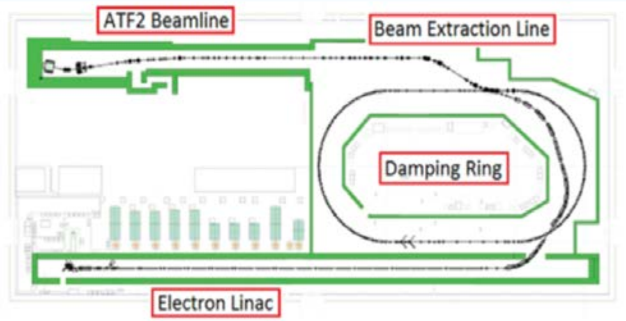
Low resolutivity → ILC SCRF

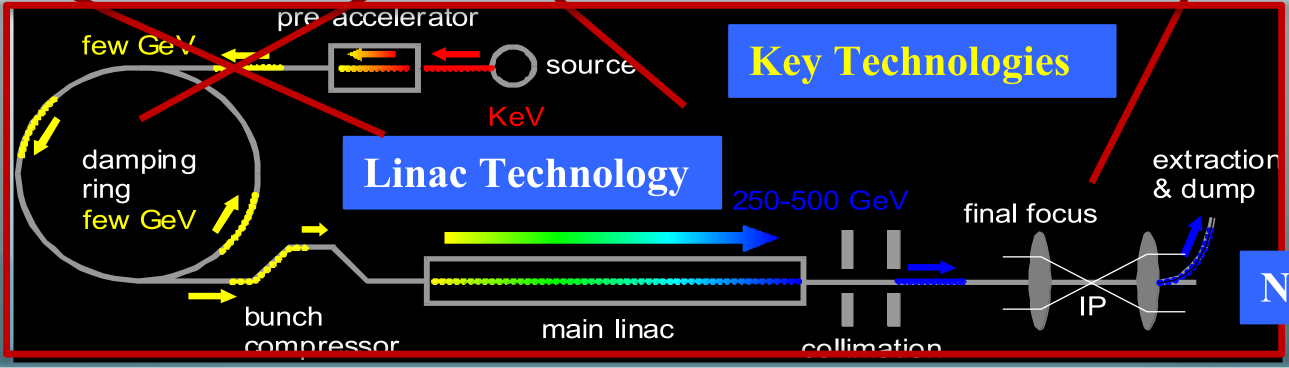
Small duty cycle: Pulsed operation

High frequency & Ultra-short pulses → CLIC 2 beam acceleration

Nanobeam Technology

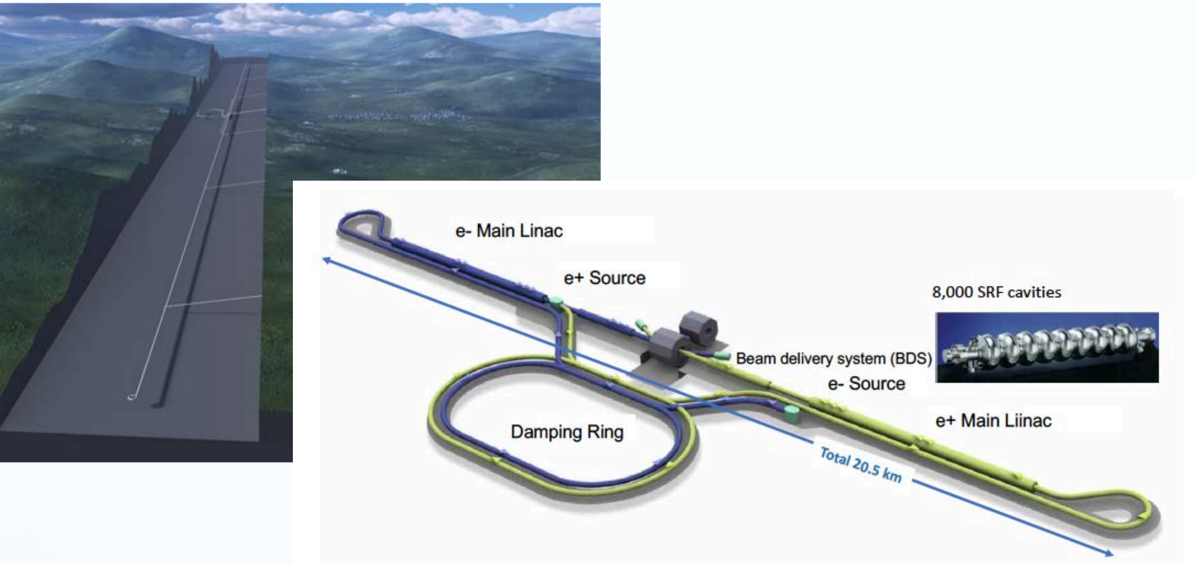
- Damping ring (ε)
- Final focus (β^*)

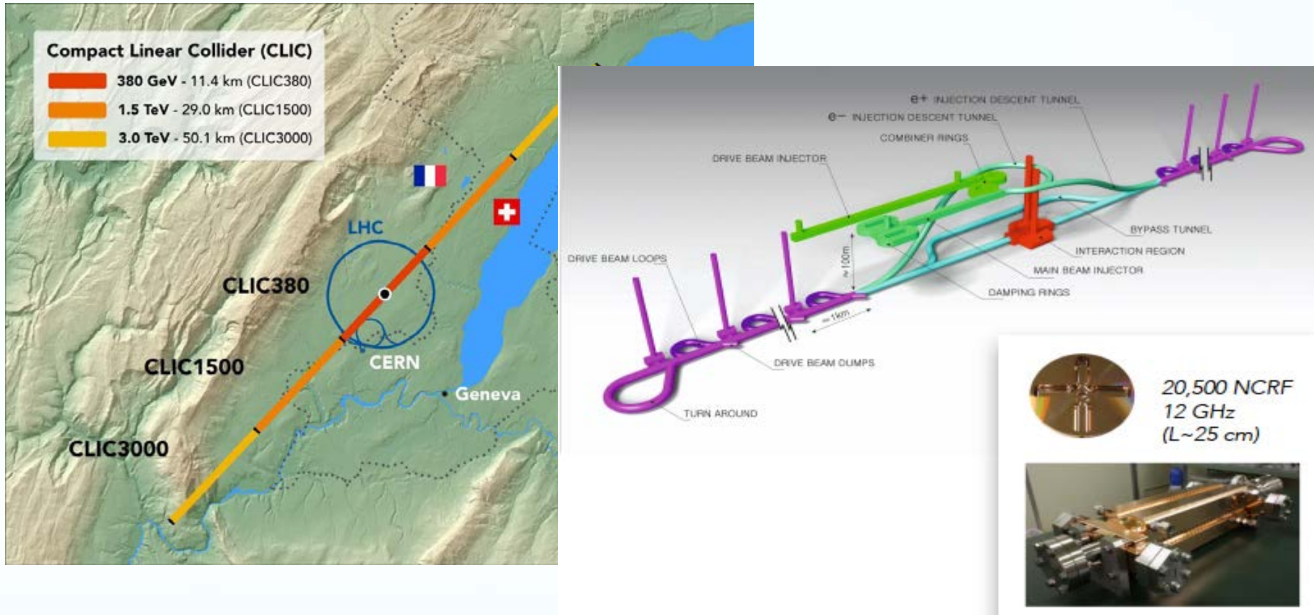




ILC and CLIC in a nutshell

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





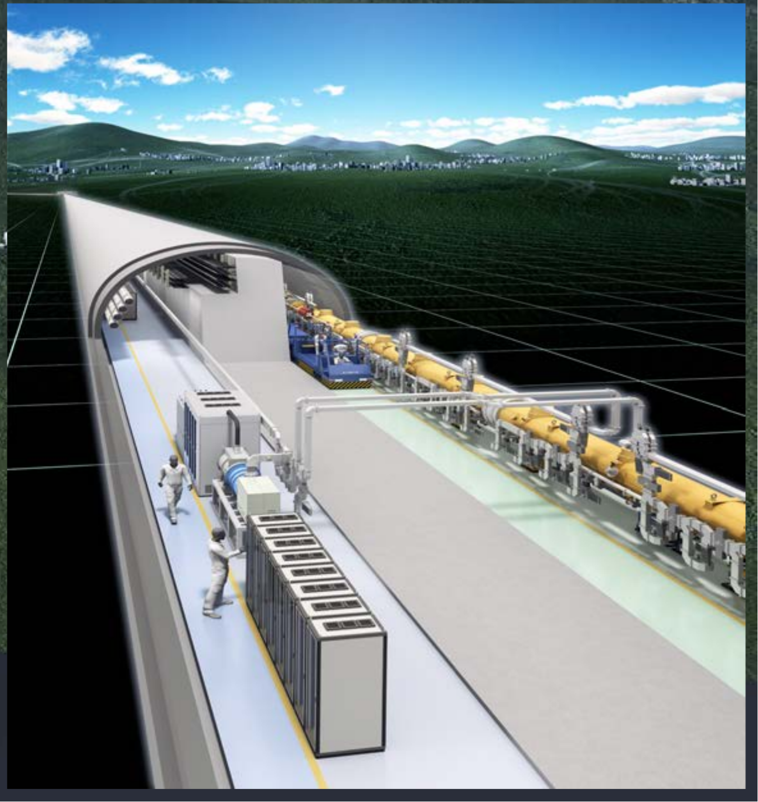
International Linear Collider ILC

- Superconducting Cavities, 1.3GHz, 31.5MV/m
- Klystrons
- 250GeV CME, upgradeable to 500, 1000GeV
- L = 1.35×10^{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 - 100MV/m
- Two-beam acceleration
- 380GeV CME, upgradeable to 1500, 3000GeV
- L = 1.50×10^{34} $cm^{-2}s^{-1}$ (at initial 380GeV)
- 11.4km long, at CERN / France & Switzerland
- Polarisation 80% (e-)

ILC accelerator: Techology update

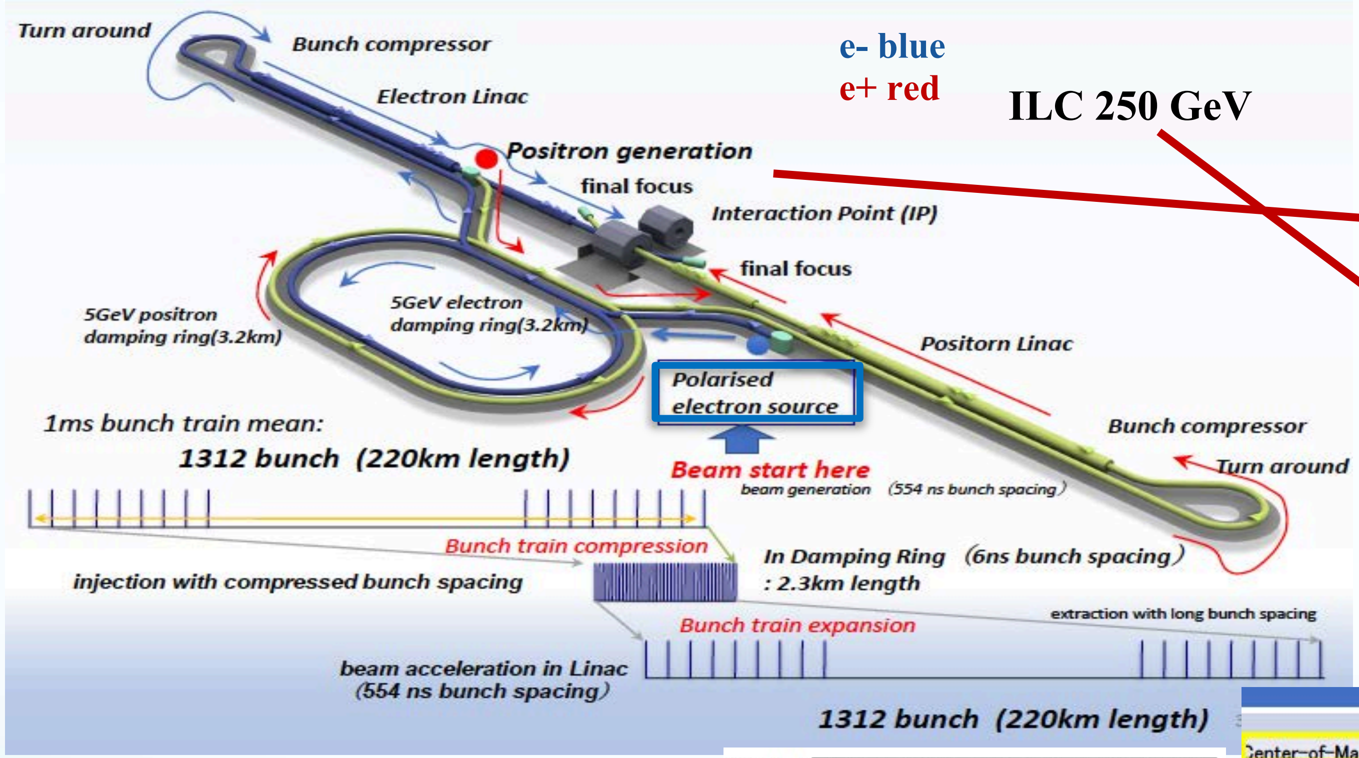


http://www.linearcollider.org/

EPS-HEP 2021

26-30 July 2021

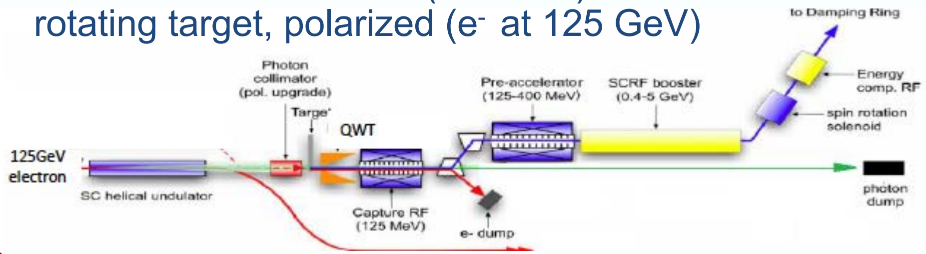
ILC parameters and beam accelerator sequence



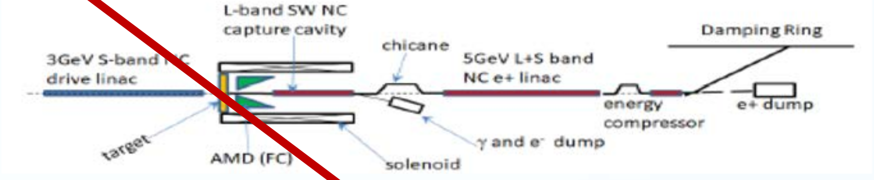
e- blue
e+ red

ILC 250 GeV

- **SC helical undulators** (baseline): rotating target, polarized (e^- at 125 GeV)



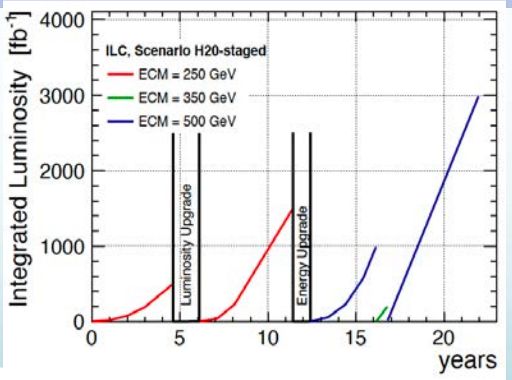
- **Electron driven source**: dedicated 3 GeV NC S-band TW e^- (pair production).



ILC-IDT detailed in Benno List Talk

			Z-Pole [4]		Higgs [2,5]			500GeV [1*]		TeV [1*]
			Baseline	Lum. Up	Baseline	Lum. Up	L Up.10Hz	Baseline	Lum. Up	case B
Center-of-Mass Energy	E_{CM}	GeV	91.2	91.2	250	250	250	500	500	1000
Beam Energy	E_{beam}	GeV	45.6	45.6	125	125	125	250	250	500
Collision rate	f_{col}	Hz	3.7	3.7	5	5	10	5	5	4
Pluse interval in electron main linac		ms	135	135	200	200	100	200	200	200
Number of bunches	n_b		1312	2625	1312	2625	2625	1312	2625	2450
Bunch population	N	10^{10}	2	2	2	2	2	2	2	1.737
Bunch separation	Δt_b	ns	554	554	554	366	366	554	366	366
Beam current		mA	5.79	5.79	5.79	8.75	8.75	5.79	8.75	7.60
Average beam power at IP (2 beams)	P_B	MW	1.42	2.84	5.26	10.5	21.0	10.5	21.0	27.3
RMS bunch length at ML & IP	σ_z	mm	0.41	0.41	0.30	0.30	0.30	0.30	0.30	0.225
Emittance at IP (x)	γe^*_x	µm	6.2	6.2	5.0	5.0	5.0	10.0	10.0	10.0
Emittance at IP (y)	γe^*_y	nm	48.5	48.5	35.0	35.0	35.0	35.0	35.0	30.0
Beam size at IP (x)	σ^*_x	µm	1.118	1.118	0.515	0.515	0.515	0.474	0.474	0.335
Beam size at IP (y)	σ^*_y	nm	14.56	14.56	7.66	7.66	7.66	5.86	5.86	2.66
Luminosity	L	$10^{34}/cm^2/s$	0.205	0.410	1.35	2.70	5.40	1.79	3.60	5.11
Luminosity enhancement factor	H_D		2.16	2.16	2.55	2.55	2.55	2.38	2.39	1.93
Luminosity at top 1%	$L_{0.01}/L$	%	99.0	99.0	74	74	74	58	58	45
Number of beamstrahlung photons	n_γ		0.841	0.841	1.91	1.91	1.91	1.82	1.82	2.05
Beamstrahlung energy loss	δ_{BS}	%	0.157	0.157	2.62	2.62	2.62	4.5	4.5	10.5
AC power [6]	Psite	MW			111	138	198	173	215	300
Site length	Lsite	km	20.5	20.5	20.5	20.5	20.5	31	31	40

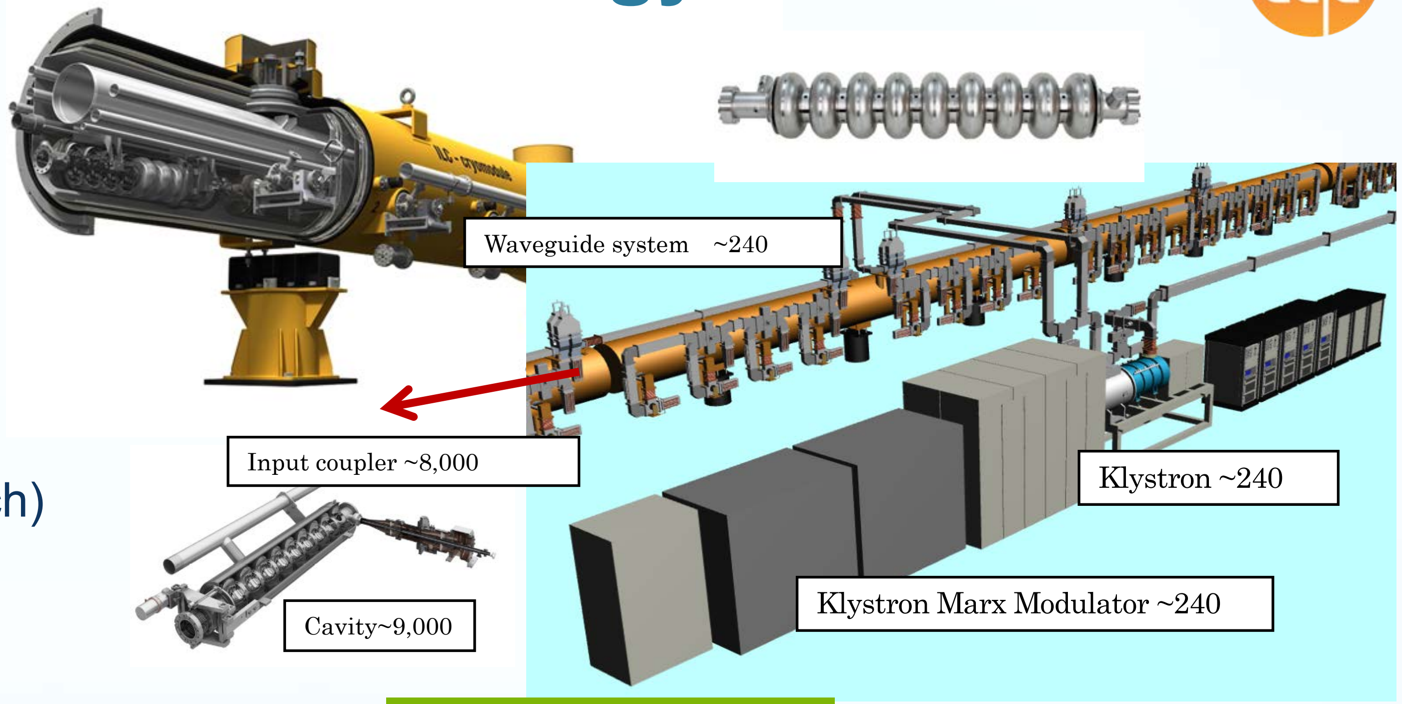
- Possible **energy upgrades**: 500GeV, 1TeV need tunnel extension
- Kitakami site: 50km long, sufficient for 1TeV
- **Luminosity upgrades**:
- More RF: factor 2 (1.35 -> 2.7×10^{34})
- Run = 500GeV machine at 250GeV, 10Hz: factor 2 (2.7×10^{34} -> 5.4×10^{34})
- Improves power efficiency

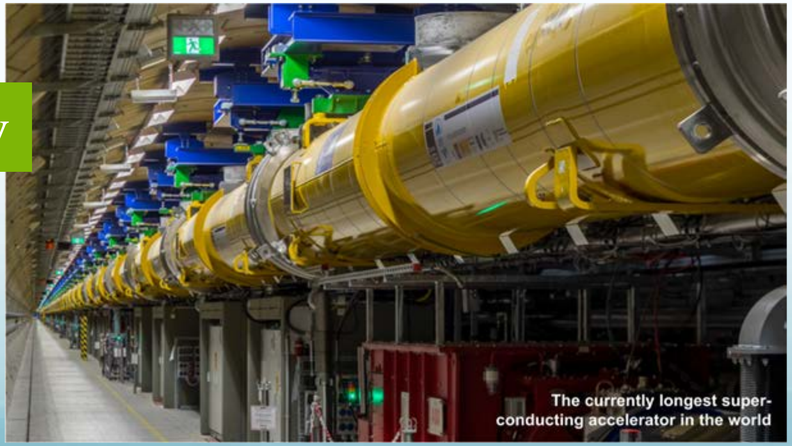


ILC Main Linac: SRF Technology

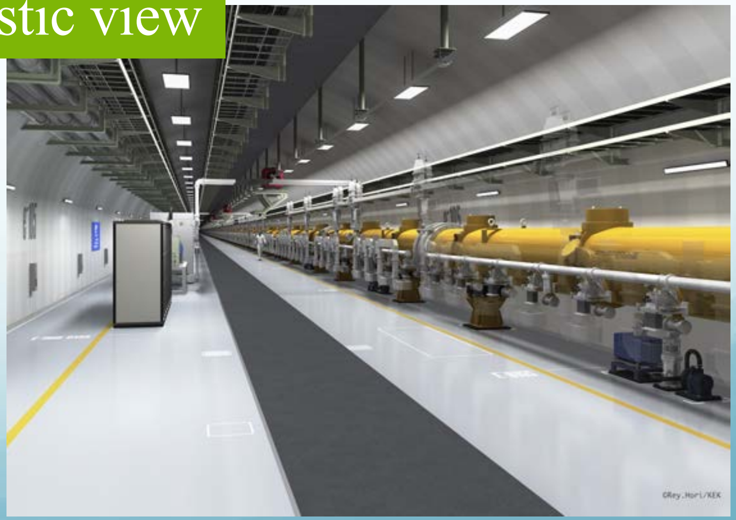
- ~8000 SC 9-cell **cavities**:
  1.3 GHz, 1.038m long, 31.5MV/m
- 9 cavities per 12m long **cryomodule**
- 10MW pulsed **klystron** per 4½ modules
- 2K operating **temperature**:
  4-6 cryo plants 19kW@4.5K
- **Pulsed operation**, 5Hz x 0.73ms (1312 bunch)

- European XFEL in operation
  100 cryomodules, 800 cavities
- LCLS-II, SHINE: Under construction / planned





E-XFEL: Reality



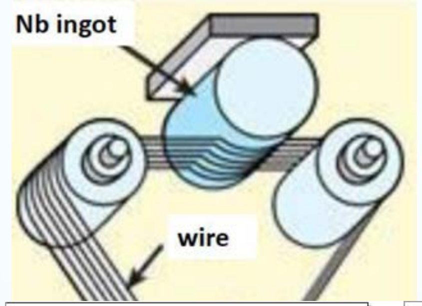
ILC: artistic view

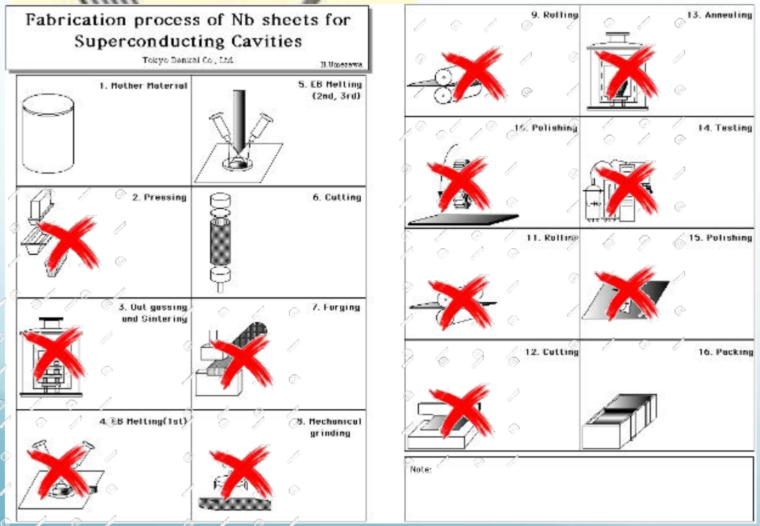
ILC Main Linac: Technology challenge

R&D to reduce cost fabrication and to push performance limits

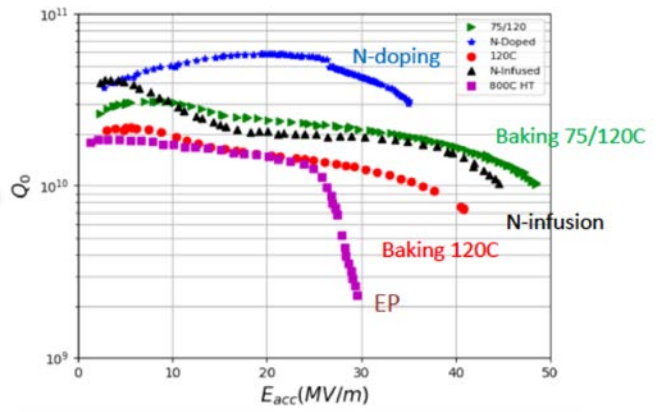
- **Niobium material/sheet preparation**:

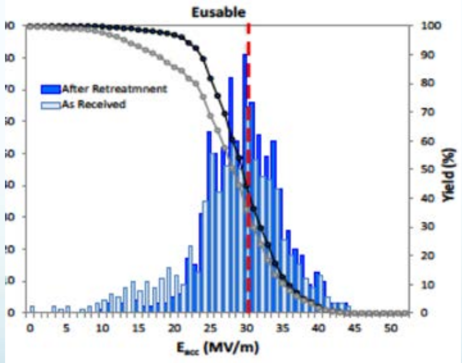
Large grain directly sliced from ingot (cost reduction), **Nb thin-film** coating on Cu based structure (HiPIMS), or Nb_3Sn in Nb or Cu



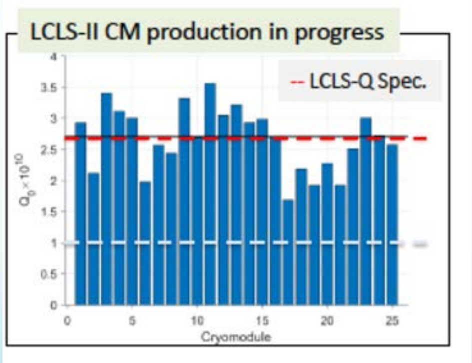


- **SRF cavity fabrication for high-gradient** (N doping well stablished), **high-Q (**N infusion, low-T baking) and **high-yield**.





European XFEL: 29 ± 5.1 MV/m

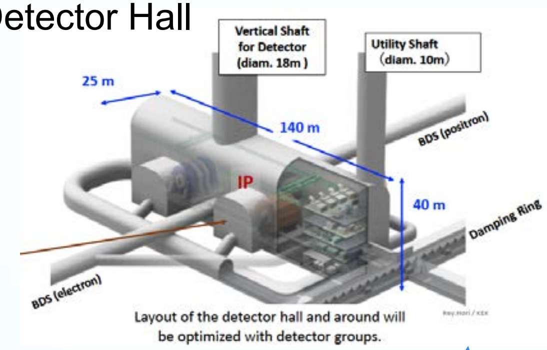


LCLS-II: 18-21 MV/m
Q>2.7 10^{10}

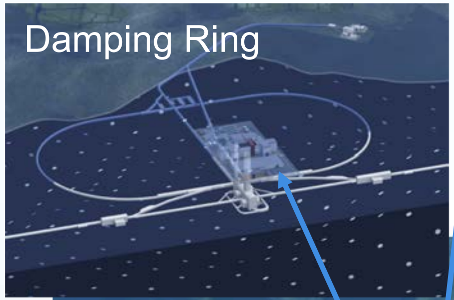
Mass production still a challenge (ILC-IDT talk from B. List)

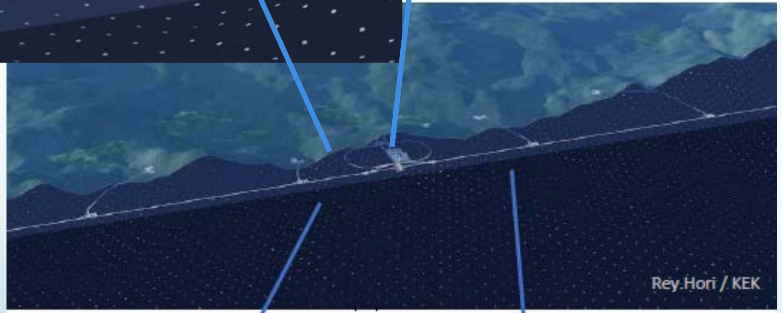
ILC Site Selection and Civil Engineering

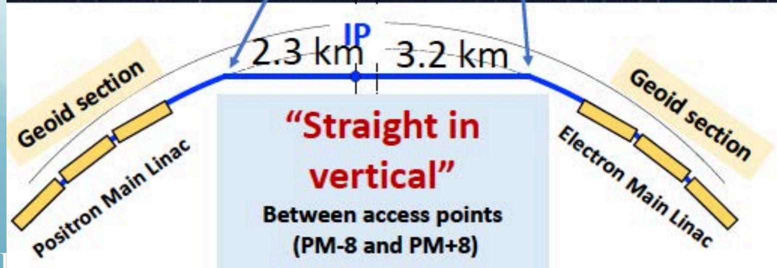
Detector Hall



Damping Ring



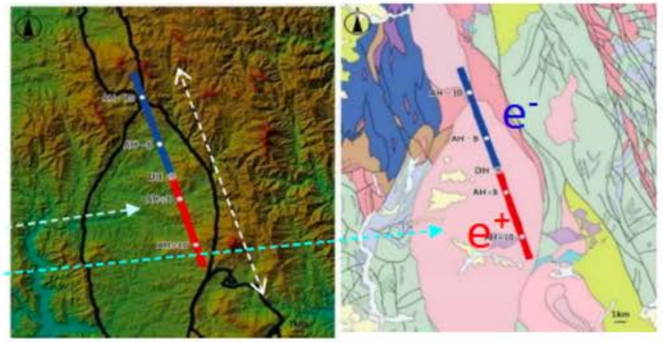




Kitakami mountains

① ILC Location

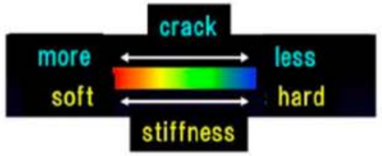
ILC accelerator area : inside the granite rock bodies
→ inside black curves (left)
→ in the pink color (right)
→ possible up to 50 km

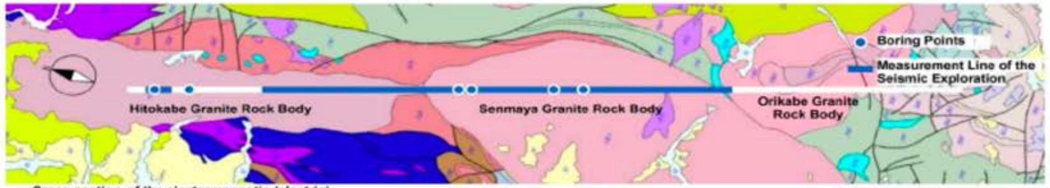


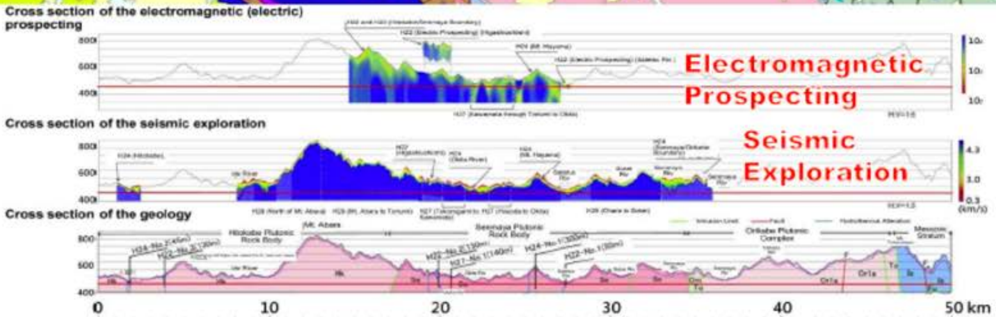
→ On-going jobs : Optimal accelerator placement, considering surface environment, land-use and land-acquisition

② Geological Surveys

- Electric Prospecting (crack)
- Seismic Exploration (stiffness)
- Boring Survey
- Borehole Camera
- Measurement of Initial Stress of the Ground







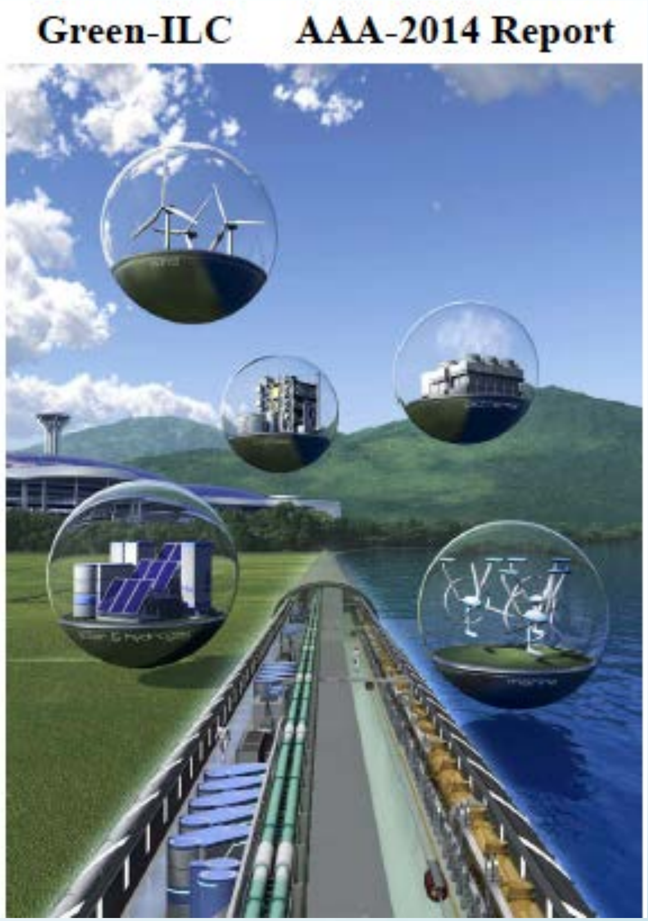
→ no issues from previous surveys
→ requiring : additional surveys around access tunnel head and access tunnel inside for detailed designing

"Green ILC" and Carbon neutrality

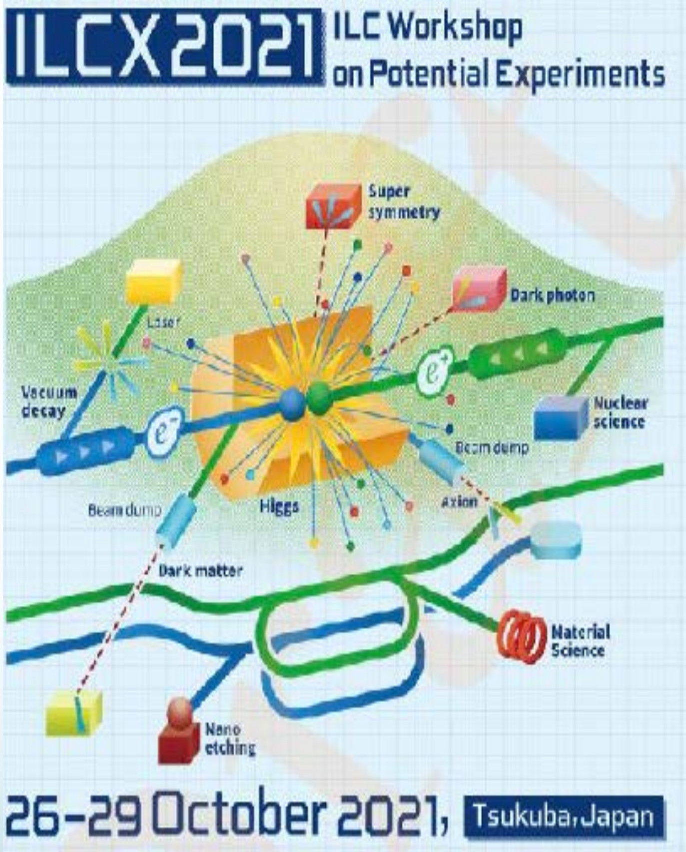
Although SRF has been adopted, the AC power consumption for ML part is <50%, what is a total of 110 MW

- **"Green ILC"**: Past efforts include increasing the efficiency of accelerators (SC, klystron) https://green-ilc.in2p3.fr/documents/
- **Carbon neutrality**: Common challenge for all future HEP accelerators. The use of SC will contribute to carbon neutrality in the future.

Work is ongoing to study these issues



Extending the Physics potentiality of ILC and applications of ILC technology

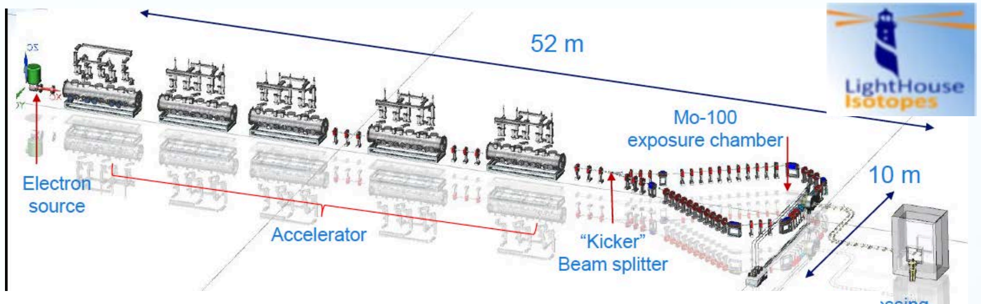


- Experiments using the **main dump**
- Experiments using **Extracted beam**
- **Far detector**

➢ ILC technology for different applications

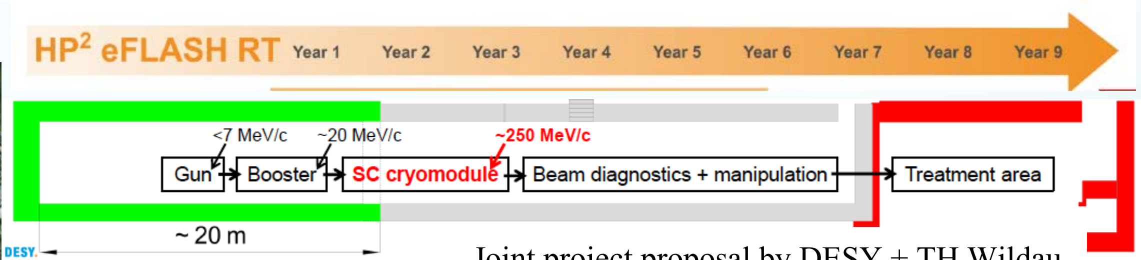
- XFEL accelerators: EuXFEL, LCLSII, SHINE
- Medical linacs
- Industrial linacs
- etc

1.3GHz 9 cell cavity



LightHouse : SC linac Isotope production. ASML-IRE-RI GMbh

SCRF compact for water treatment



Joint project proposal by DESY + TH Wildau

SHINE under construction

ILC Timeline

- **International Development Team** (IDT) prepares **Pre-Lab**
- 4 year Pre-Lab (hosted by KEK, Japan) phase for **R&D**, **Engineering Design Report**, Construction preparation
- **ILC Laboratory** (international): 10 year construction phase

2022 2026

ILC-IDT detailed in Benno List Talk

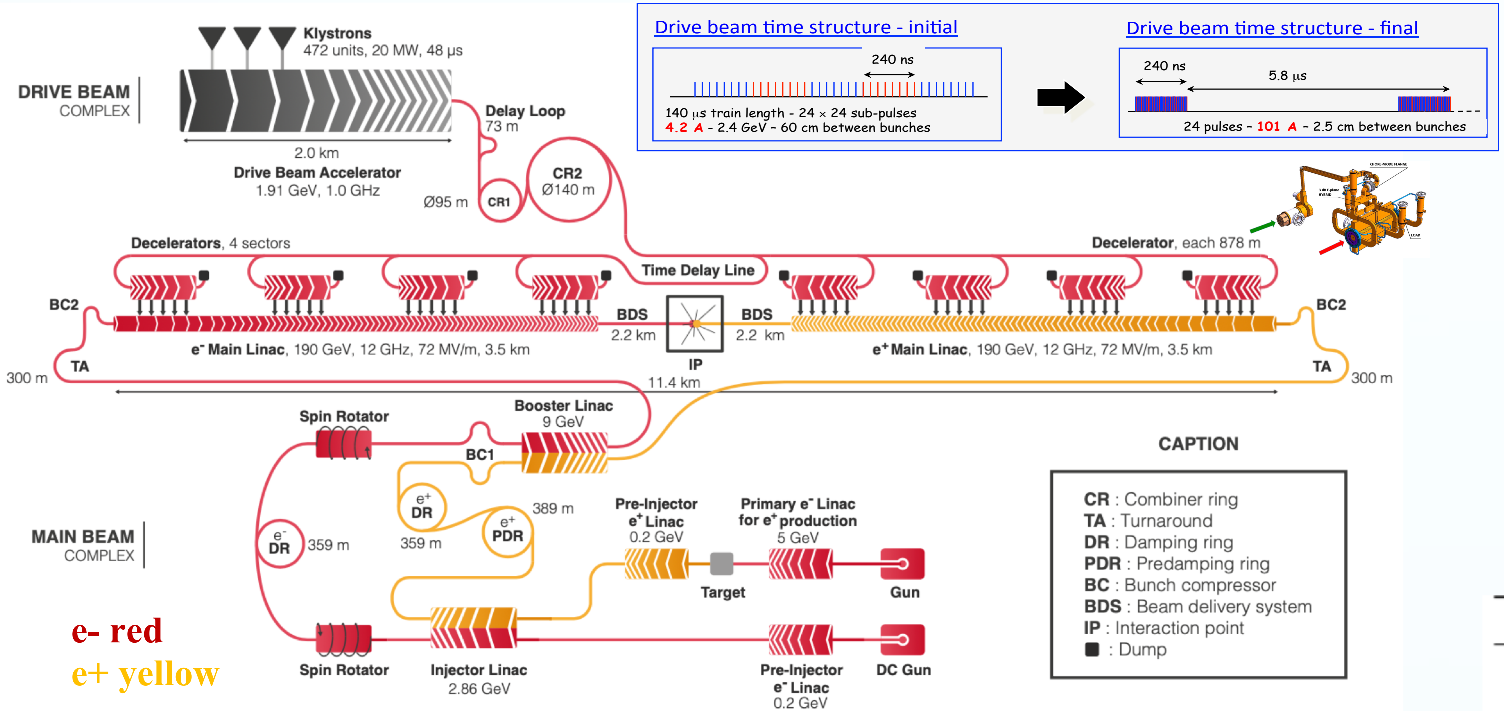
	IDT	ILC Pre-Lab				ILC Lab.										
	PP	P1	P2	P3	P4	1	2	3	4	5	6	7	8	9	10	Phys. Exp.
Preparation CE/Utility, Survey, Design Acc. Industrialization prep.																
Construction																
Civil Eng.																
Building, Utilities																
Acc. Systems																
Installation																
Commissioning																
Physics Exp.																

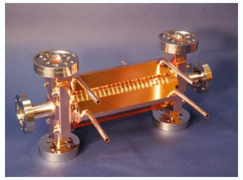
Following a four-year ILC Pre-Lab phase, ILC construction will continue for about ten years.

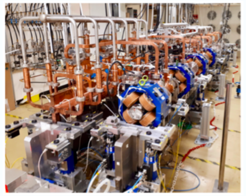
CLIC accelerator: Technology update

http://clic-study.web.cern.ch/

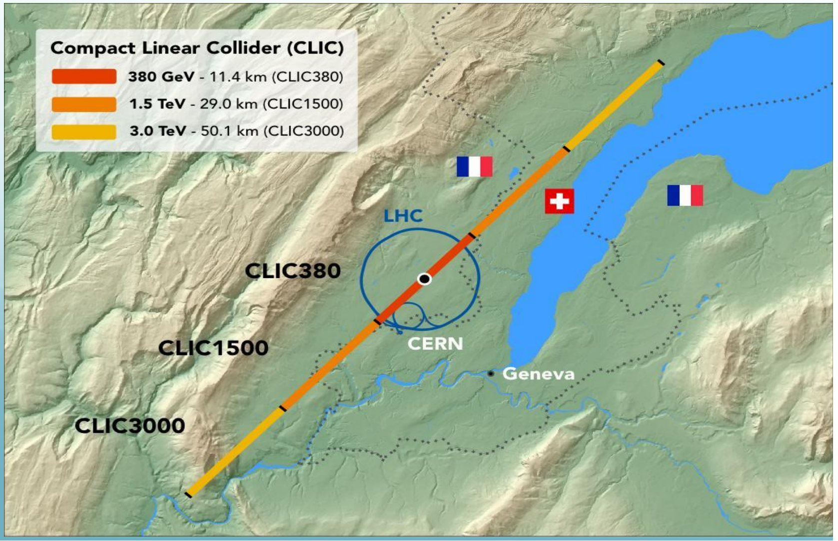
CLIC parameters and beam accelerator sequence

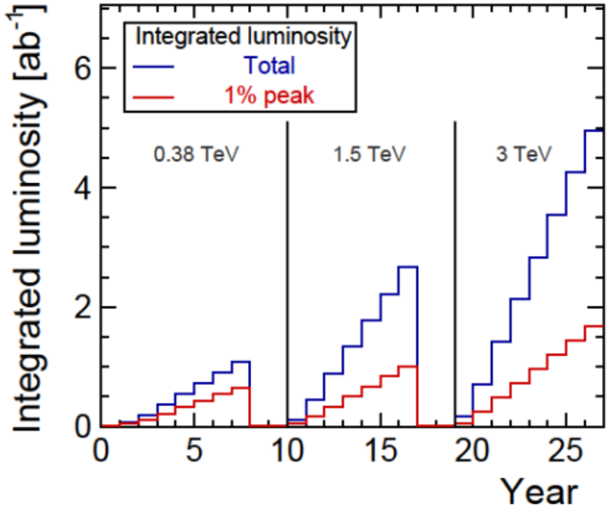






1. **Drive beam** accelerated to ~2 GeV using conventional klystrons
2. **Intensity increased** using a series of delay loops and combiner rings
3. Drive beam **decelerated** and produces high-RF
4. Feed high-RF to the less intense main beam using waveguides





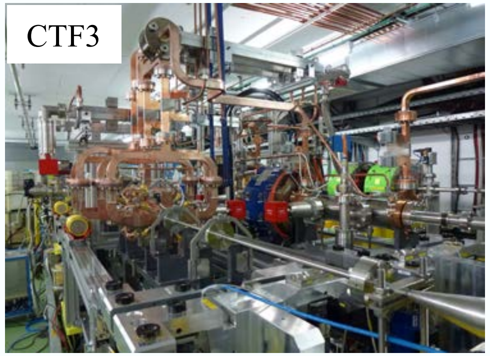
Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	380	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		352	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Pulse length	τ_{RF}	ns	244	244	244
Accelerating gradient	G	MV/m	72	72/100	72/100
Total 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	~ 60/1.5	~ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	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

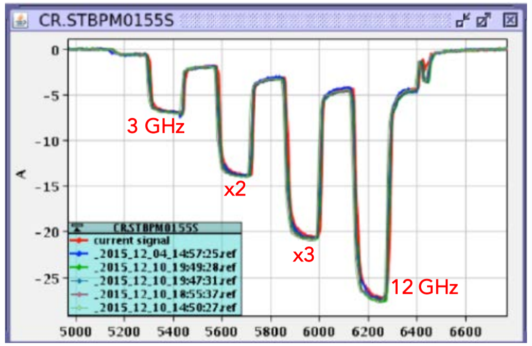
CLIC Main Linac: NCRF Technology

- ML **NC RF X band copper cavities** (20,500 structures)
- **Drive-beam based machine** (PET structures), two beams acceleration demonstrated, CTF3 (CLIC Test Facility at CERN) program addressed all drive-beam production issues.
- **Klystron-powered** option also studied (high-efficiency)
- **High-current drive** beam bunched at 12 GHz
- Achieved **100 MV/m gradient** in main-beam cavities

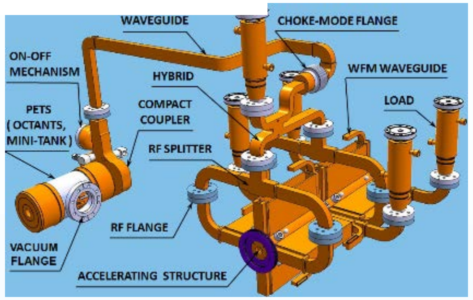
- X-band technology developed and verified with prototyping, test-stands, and use in smaller systems
- Two C-band XFELS (SACLA and SwissFEL – the latter particularly relevant) now operational: large-scale demonstrations of normal-conducting, high-frequency, low-emittance linacs

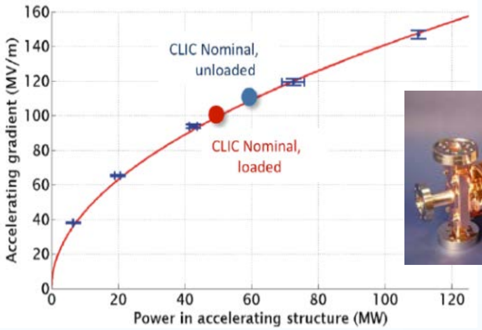
CTF3

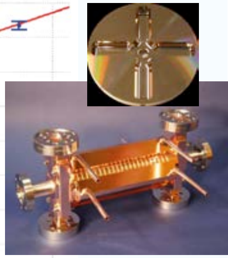




Main linac RF unit

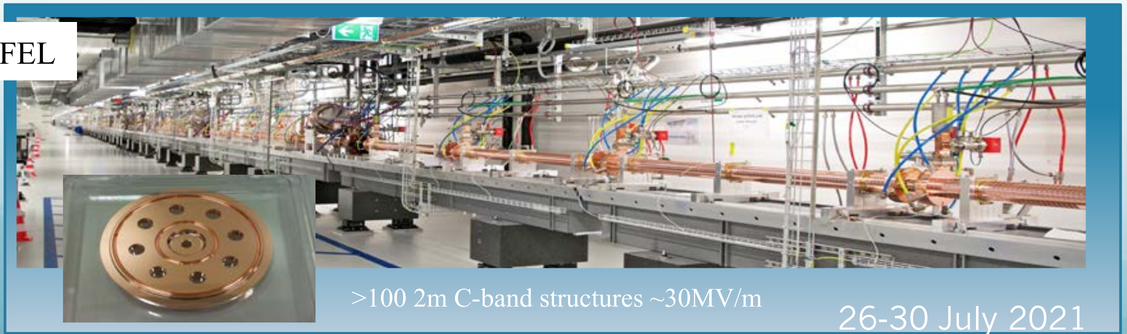






Xboxes test stand

SwissFEL



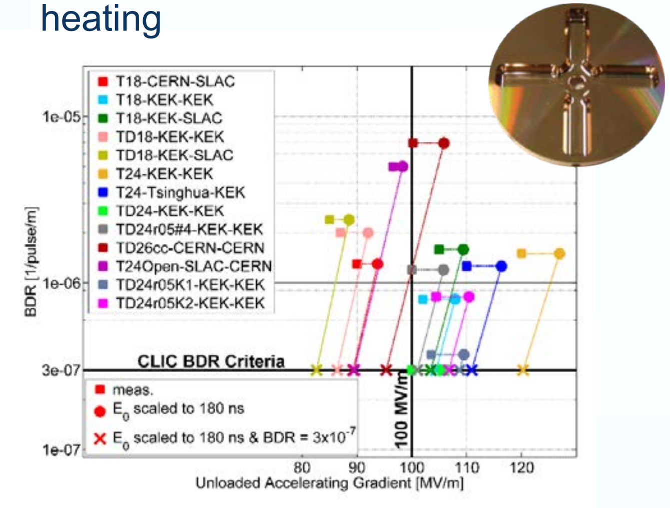
>100 2m C-band structures ~30MV/m

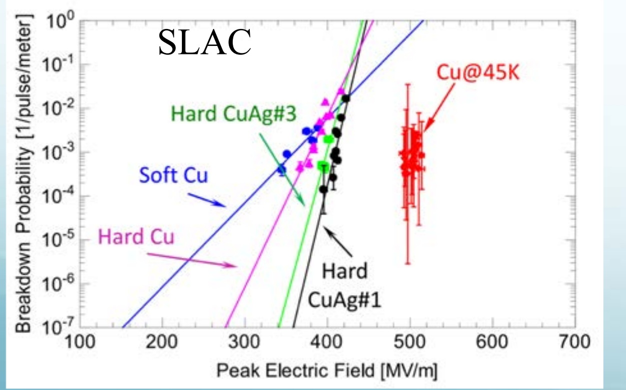
Details in PIP, DOI: http://dx.doi.org/10.23731/CYRM-2018-004

CLIC Main Linac: Technology challenge

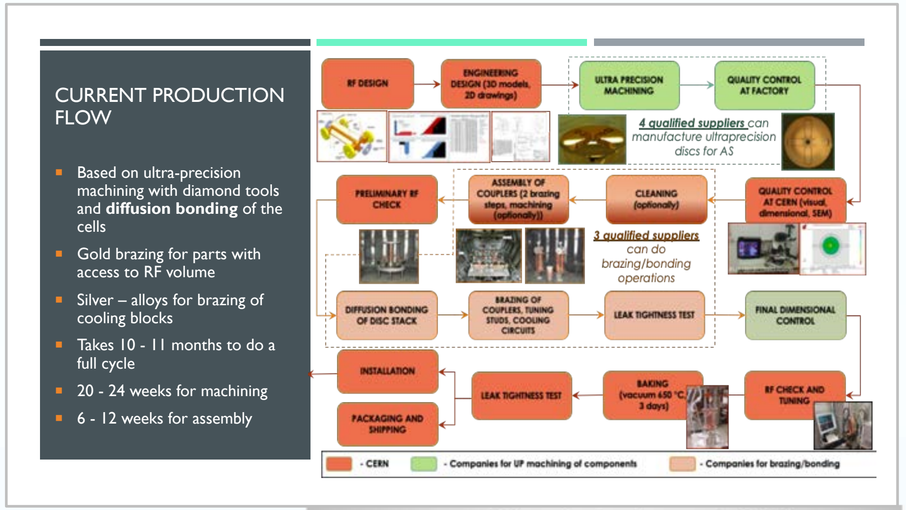
R&D to reduce cost fabrication and to push performance limits

➢ **Fundamental process for high-fields and material dynamics**
Understanding the limits by: Field emission, Vacuum arcing (breakdown) and Fatigue due to pulsed surface heating

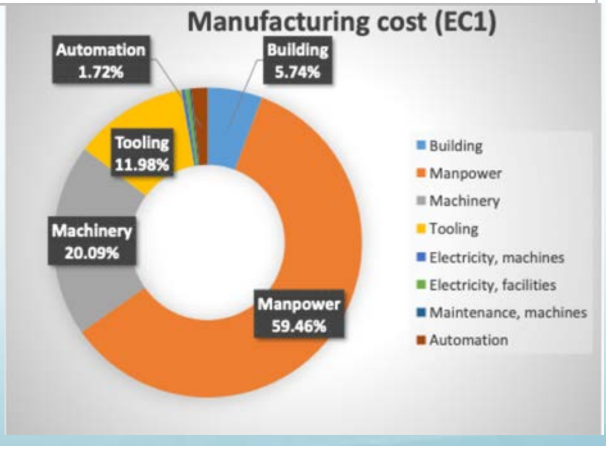




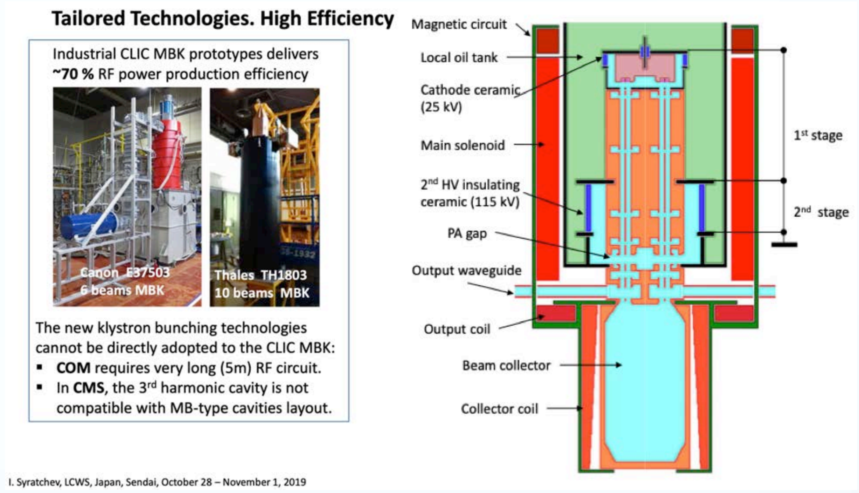
➢ **X band RF structures fabrication:**
Processes, Developments (rectangular disks, brazing, halves), Fabrication capacity and Components for system.



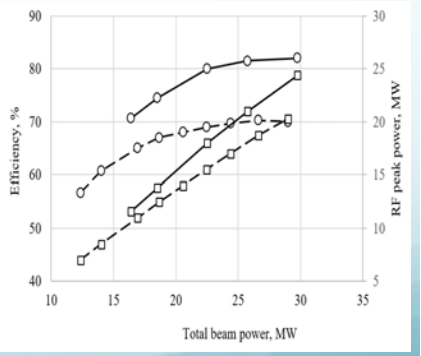
Industrial questionnaire: Based on the companies feedback, the preparation phase to the mass production could take about five years. Capacity clearly available.



➢ **High Efficiency Klystrons:**
for LHC, CLIC, FCC-ee and ILC. For CLIC, this includes the L-band and X-band sources



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.
https://ieeexplore.ieee.org/document/9115885



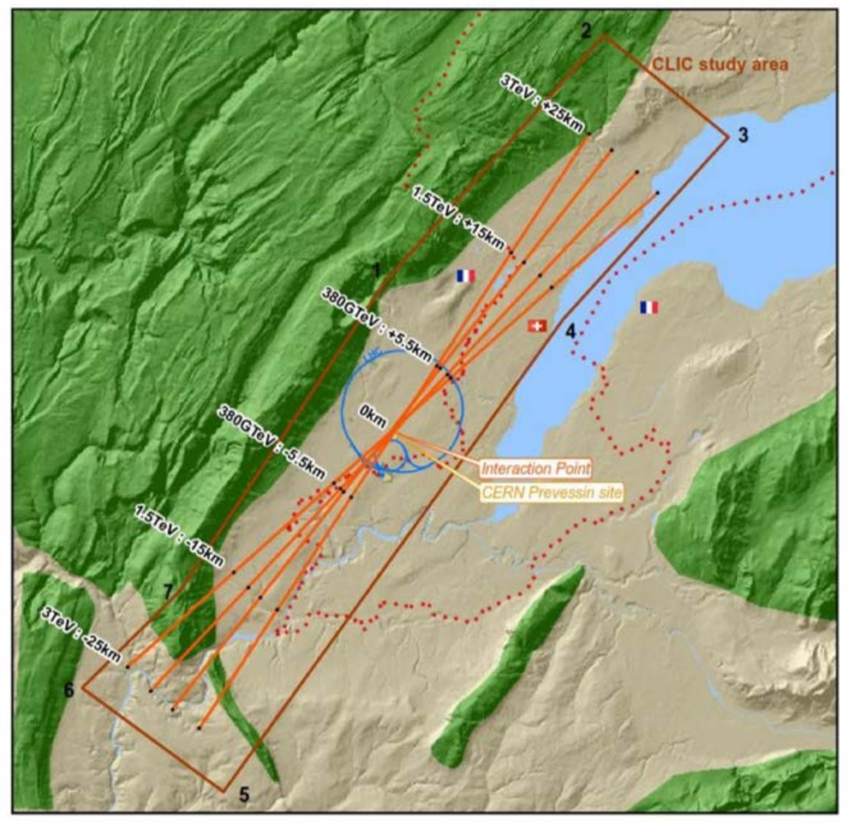
Industrialization and mass production still a challenge

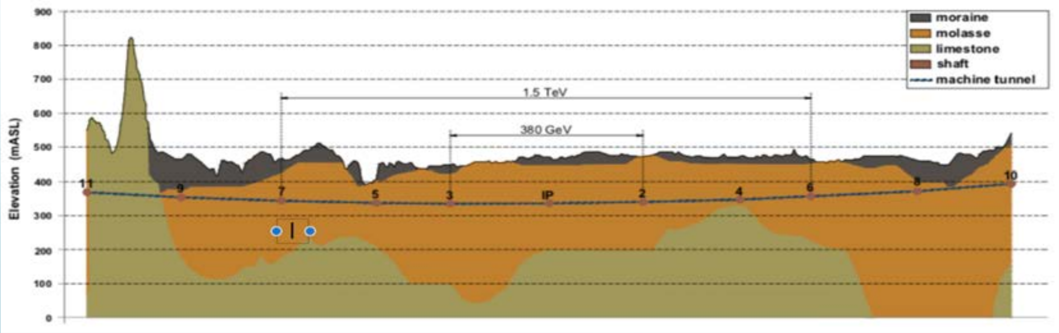
CLIC Site Selection and Civil Engineering

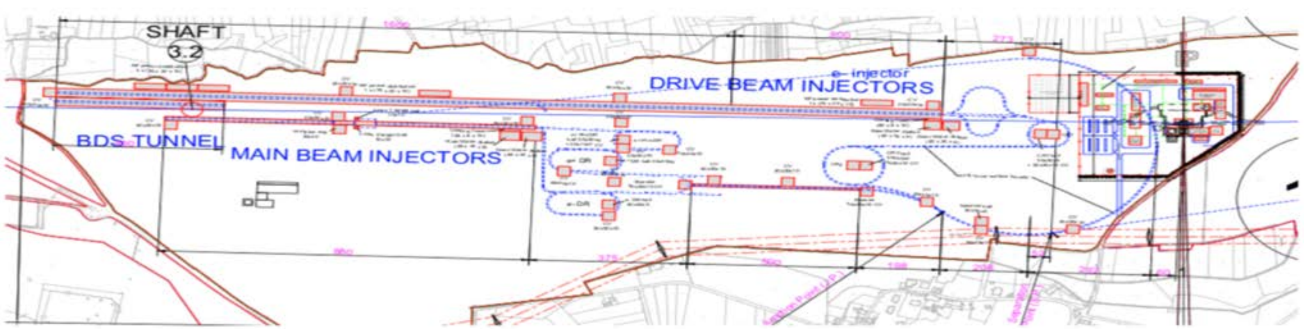
Important effort within:

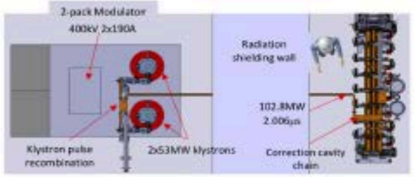
- Civil engineering
- Electrical systems
- Cooling and ventilation
- Transport, logistics and installation
- Safety, access and radiation protection systems

Crucial for cost/power/schedule

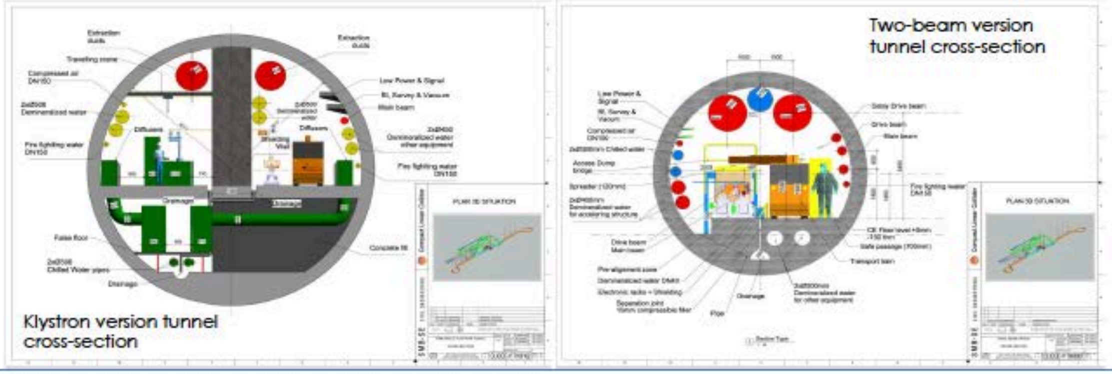






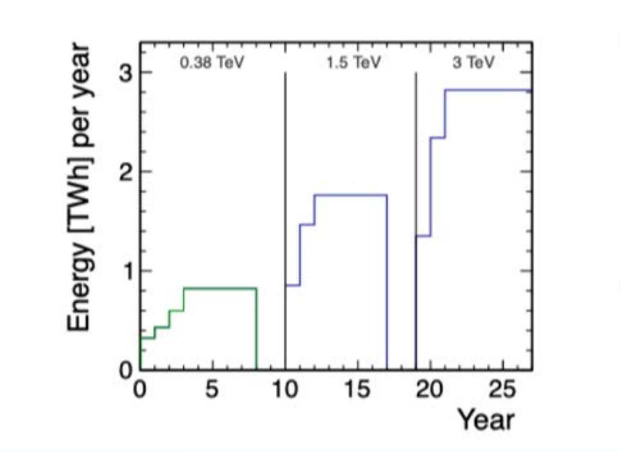


- Klystron-powered version studied and costed for 1st stage (380 GeV c.m.)
- Upgrade to 1 TeV and beyond based in any case on Two-beam scheme (klystron-based sectors re-usable with modifications)



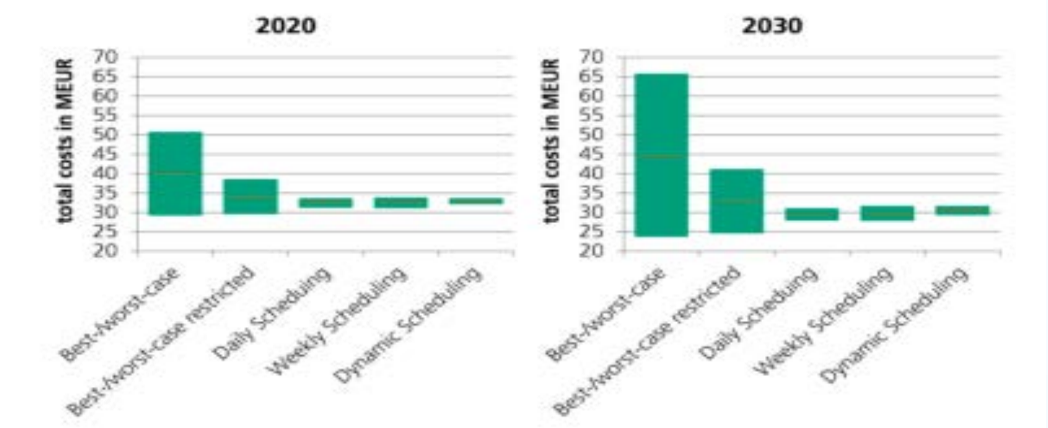
“Green CLIC” and Carbon neutrality

Collision Energy [GeV]	Running [MW]	Standby [MW]	Off [MW]
380	168	25	9
1500	364	38	13
3000	589	46	17

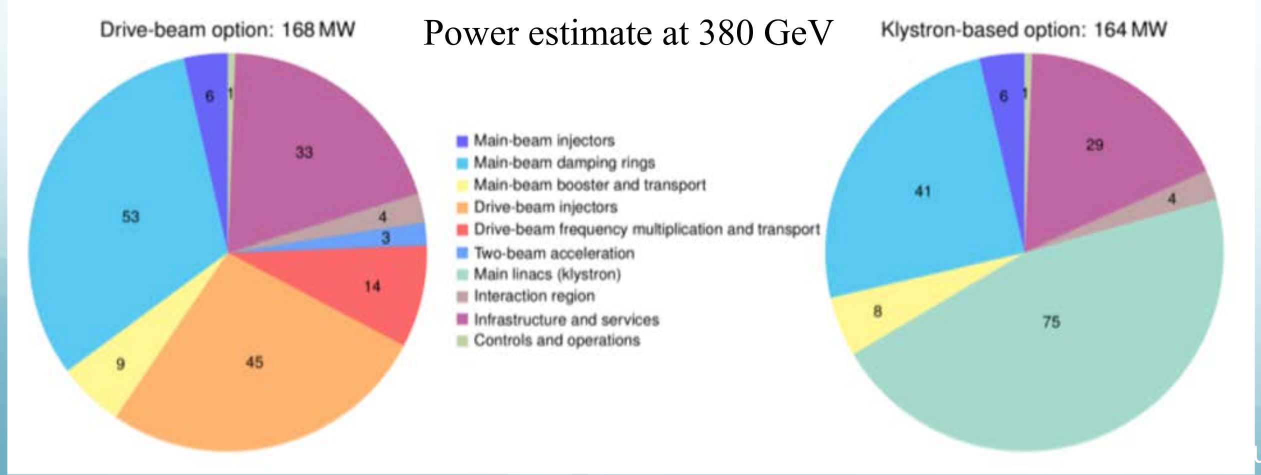


- Very large reductions since CDR, better estimates of nominal settings, much more optimised drivebeam complex and more efficient klystrons, injectors more optimisation, etc
- Further savings possible, main target damping ring RF and improved L-band klystrons for drivebeam

- Energy studies:
- Running when energy is cheap



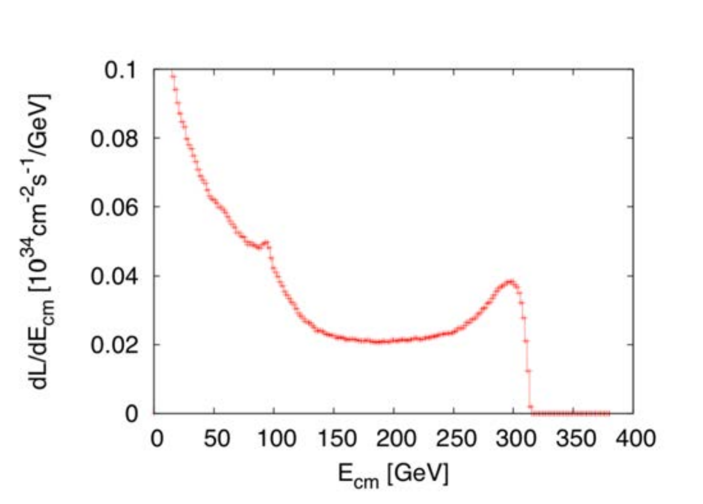
Relative energy cost by no scheduling, avoiding the wintermonths (restricted), daily, weekly and dynamic scheduling. Central values of the ranges shown should be considered best estimates. The absolute cost scale will depend on price, contracts and detailed assumption about running times, but the relative cost differences indicate that significant cost-reductions could be achieved by optimizing the running schedule of CLIC to avoid high-energy cost periods (Fraunhofer)



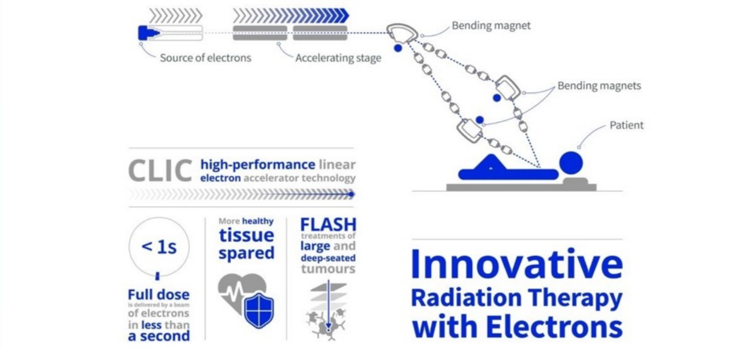
- Renewable energy (carbon footprint)
- Recovering energy

Extending the Physics potentiality of CLIC and applications of CLIC technology

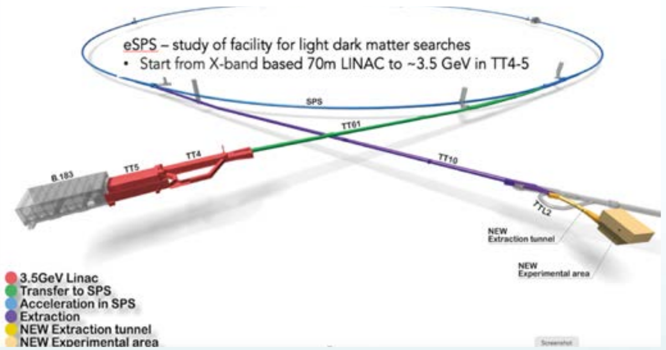
- Further work on luminosity performance, possible improvements and margins, operation at the Z-pole and gamma-gamma are ongoing.



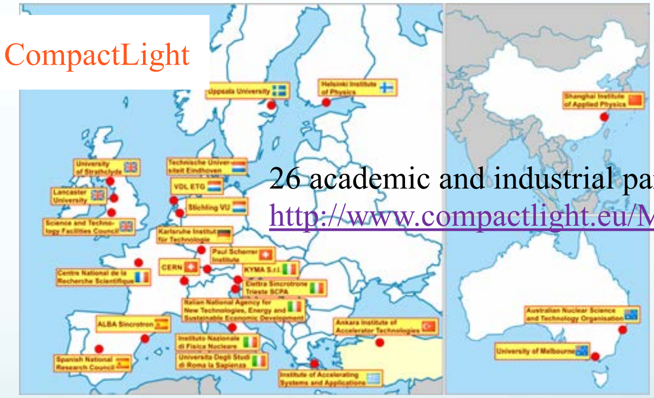
- CLIC technology for different applications
  - EU co-funded FEL design study
  - 1 GeV linac at INFN-LNF
  - Medical linacs
  - ICS
  - etc



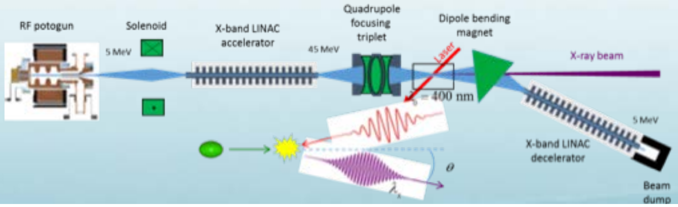
CERN: eSPS study (3.5 GeV X-band linac)



CompactLight



26 academic and industrial partners:
http://www.compactlight.eu/Main/HomePage



Eindhoven University SMART*LIGHT Compton Source

INFN Frascati advanced acceleration facility
EuPRAXIA@SPARC_LAB

CLIC Timeline

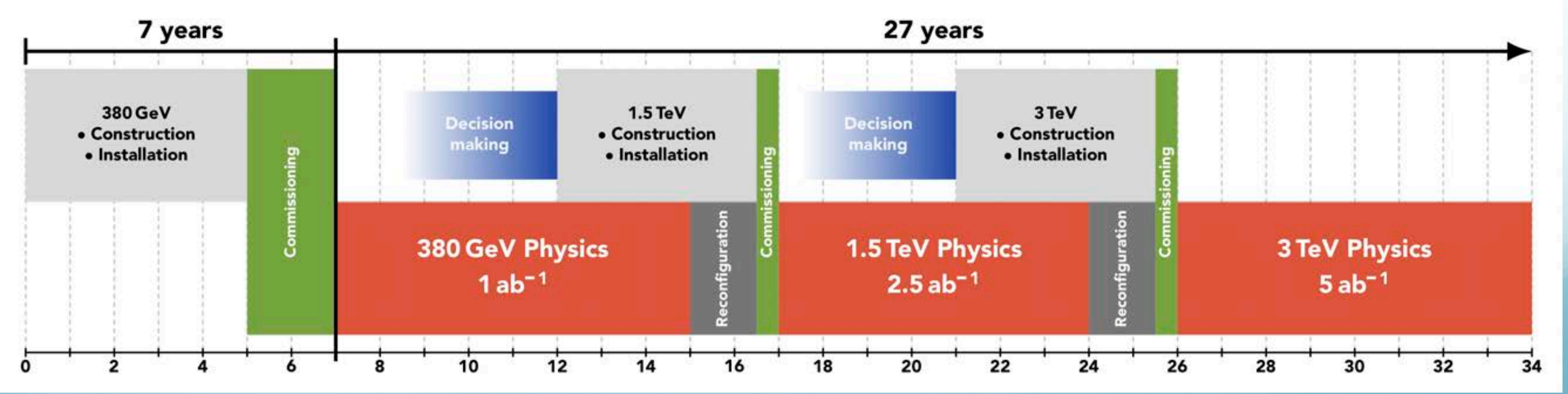
Project Readiness Report as a step toward a TDR – for next ESPP

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

- More details:
- X-band studies: Structure manufacturability and optimized conditioning, interfaces to all connecting systems for large scale production, designs for and support of use in applications from the 1 GeV linac at LNF to medical linacs
- Luminosity: beamdynamics studies and related hardware optimisation for nano beams from damping rings to final focus (mechanical and thermal stability, alignment, instrumentation, vacuum systems, stray field control, magnet stability, etc)
- Improving damping ring and drive beam RF efficiency, study parameter changes to reduce power at multi-TeV energies maintaining high luminosities

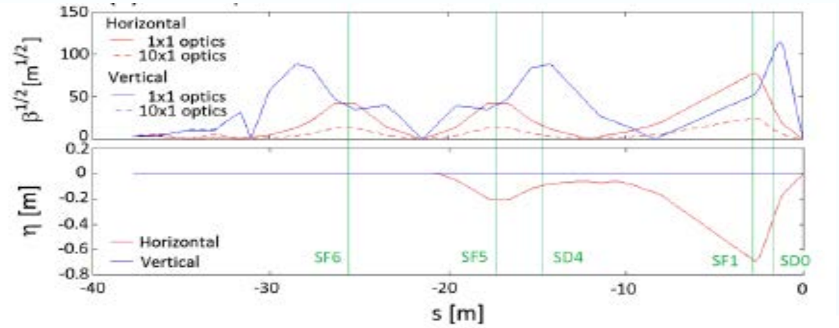
- **Technology Driven Schedule** with a preparation phase of ~5 years is needed before (estimated resource need for this phase is ~4% of overall project costs)



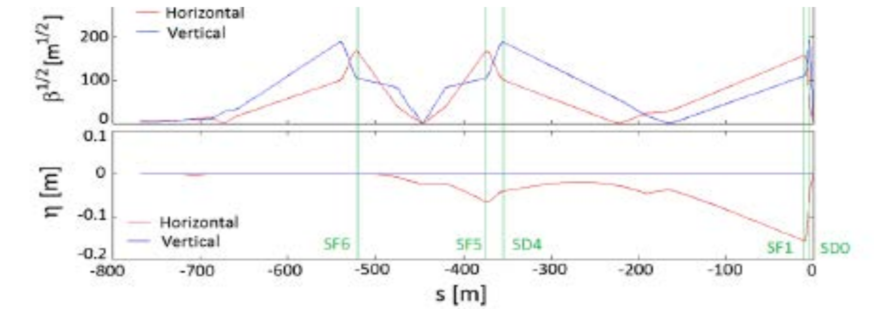
ILC and CLIC FFS: nanobeams Technology

	Units	ATF2	ILC	CLIC
E_{cm}	[GeV]	1.3	250	380
$\mathcal{L}$	[10^{34} cm^{-2} s^{-1}]		1.35	1.5
f_{rep}	[Hz]	3.12	5	50
$n_{bunches}$	1	1 - 20	1312	352
N_e	[10^{10}]	1.0	2.0	0.52
σ_b	[µm]	7000	300	70
Δt_b	[ns]	154	554	0.5
$\gamma\epsilon_x / \gamma\epsilon_y$	[nm]	5000 / 30	5000 / 35	950 / 30
σ_x^* / σ_y^*	[nm]	9000 / 37	516 / 7.7	149 / 2.9
$IP_{Stabilization}$	σ_y^*	< 0.05	< 0.2	< 0.08
L^*	[m]	1	4.1	6
β_x^* / β_y^*	[mm]	40 / 0.1	13 / 0.41	8 / 0.1

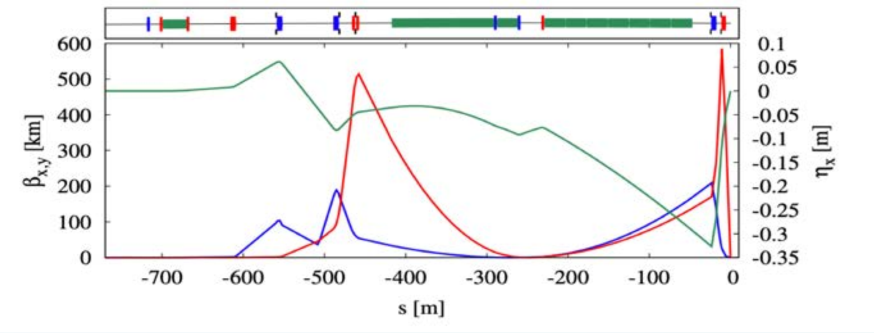
FFS optics



ATF2



ILC



CLIC

ILC and CLIC FFS: nanobeams Technology

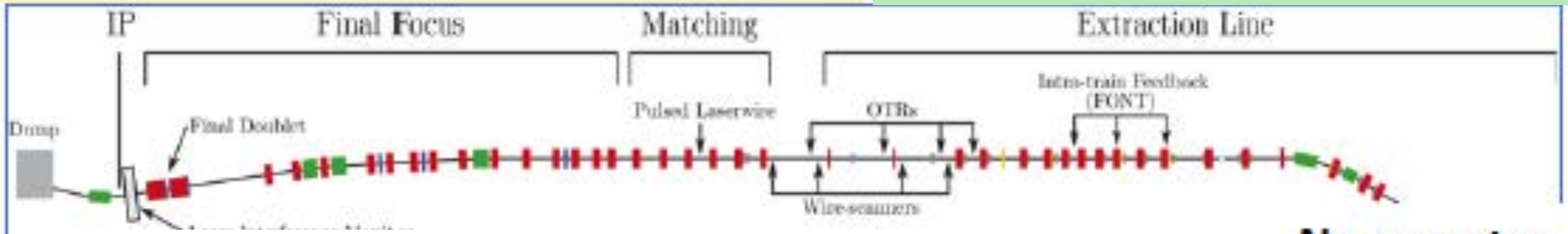
ATF2 goals and achievements

Goal 1: Establish the ILC final focus method with same optics and comparable beamline tolerances

- ATF2 Goal : **37** nm → ILC **7.7** nm (ILC250)
- Achieved **41 nm** (2016)

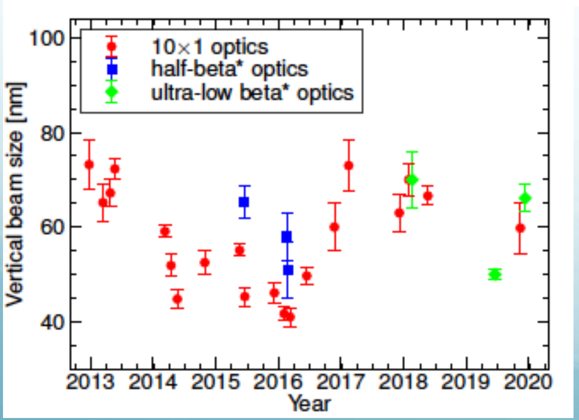
Goal 2: 2 nm beam stabilization at ATF2 IP, (much harder than nm stabilization in collision at ILC).

- **FB latency 133 nsec achieved** (target < 366 nsec)
- **Position jitter at ATF2 IP: 41 nm (2018)** (direct stabilization limited by IPBPMs resolution 20 nm). Upstream FB shows capability for 2nm stabilization. **Demonstrated ILC IPFB system.**

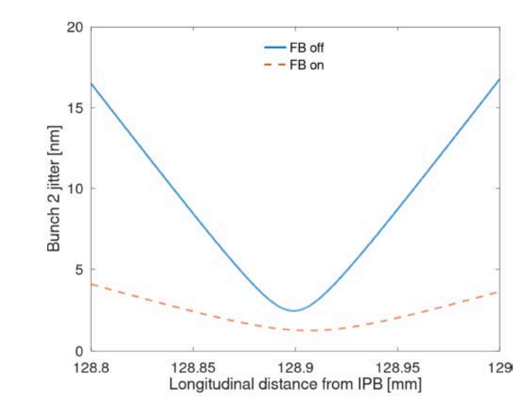


Nanometer beam sizes at IP

Nano-meter stabilization at IP

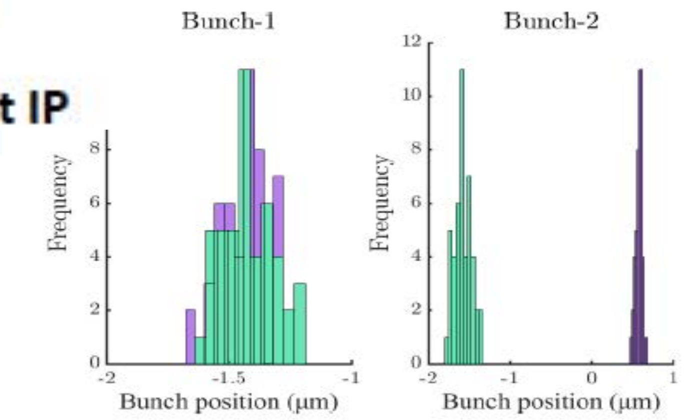


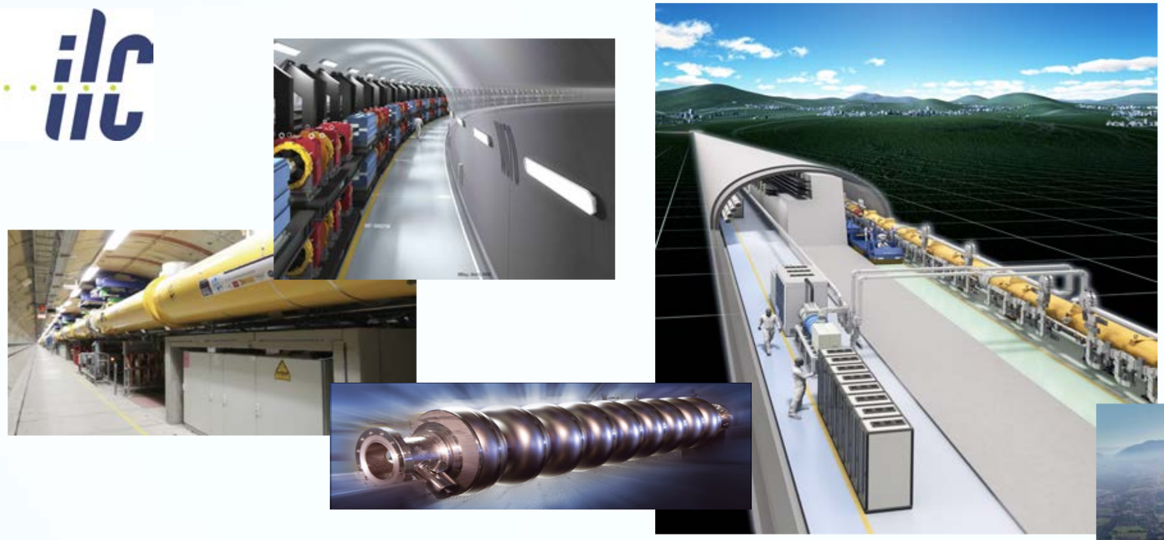
Small beam sizes were obtained with beam intensities of 0.5-1.5 10^9 e^- /bunch (10^{10} design value) and reduced aberration optics ($10\beta_x^* \times \beta_y^*$)

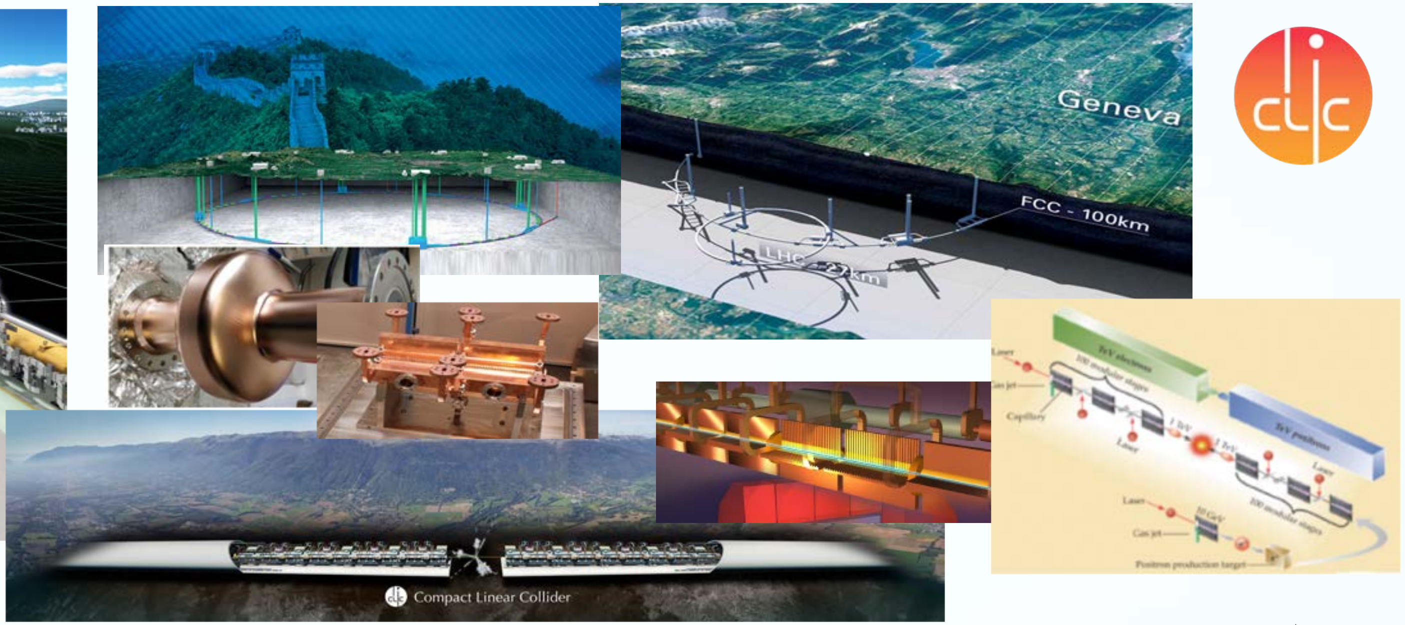


Predicted vertical position jitter with FB on-off

Distribution of bunch positions measured at IPB, with two-BPM FB off (green) and on (purple)







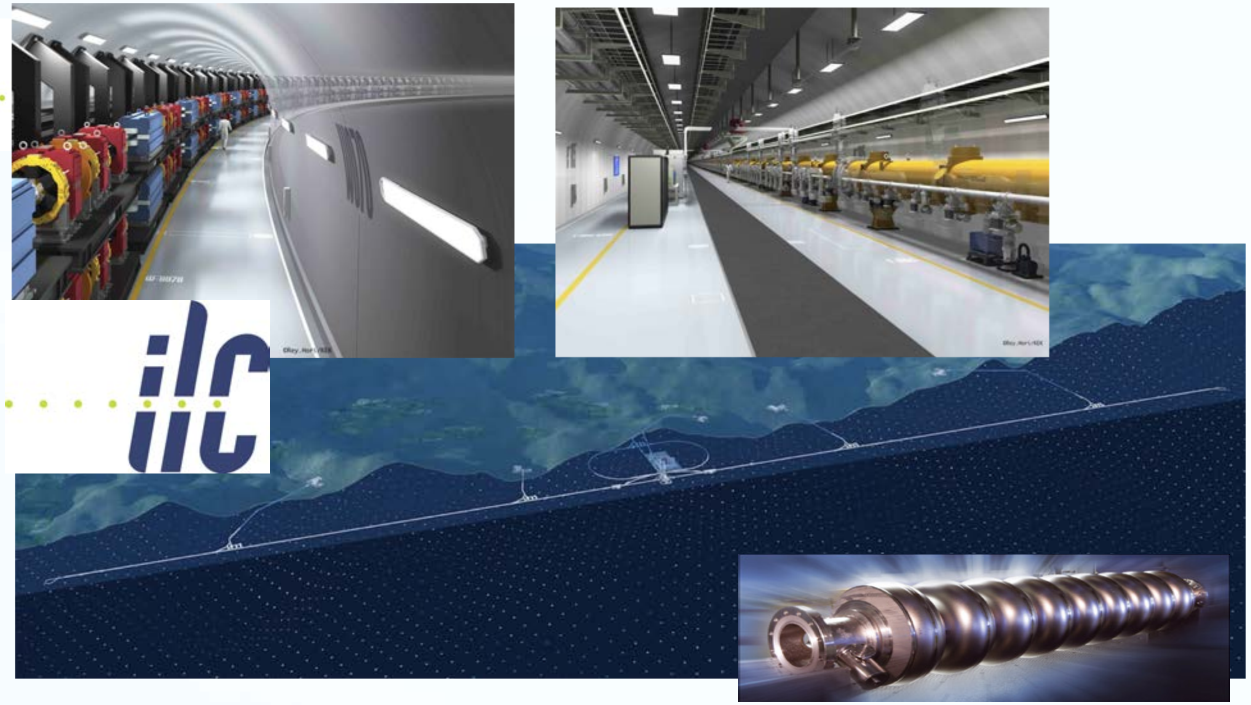
Medium Term Plan

EPPSU ⟵⟶ EPPSU

2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037

- A **LC Higgs factory** is **ready** for start up ~2035: **ILC** hosted in Japan and **CLIC** at CERN, are **mature designs** in both cases promoted and set up as international projects
  - The main accelerator **technologies** have been **demonstrated** (mass production still a challenge)
  - The cost and implementation time are **similar** to **LHC** (~10B$)
  - The physics case is broad and profound, and being further developed
  - The detector concept and detector technologies R&D are well advanced

- Implementing a LC now provides a very attractive, implementable way forward, with a good match between **scientific progress** and **further technology development** – not only for LC technologies ..



Thanks for your attention

Special thanks to

Shin Michuzono, Steinar Stapnes, Benno List

Present and Future Large Accelerator projects

In operation
In construction
Under study

An uncompleted view …

International Large Scale Projects

EPPSU (2020) EPPSU (2026)

2018 2020 2022 2024 2026 2028 2030 2032 2034 2036 2038 2040 2042 2044 2046 2048 2050 2052 2054 2056

LHC
ATF2
Super KEKB
XFEL
…

ESS
SC linac

ATF3

HL-LHC
11T Nb_3Tn

FAIR

LBNF

CepC.
High current
Z-pole

LHeC
ERL

EIC

ILC
1.3GHz SC
nano-beam/stabilization

CLIC
12 GHz
nano-beam/stabilization

FCCee
High current
Z-pole

FCChh
16T Nb_3Tn/NbTn

FCCeh
ERL

HE-LHC (HL-LHC)
16T Nb_3Tn/NbTn

SppC

FCChh (FCCee)
16T Nb_3Tn/NbTn

$\mu^+\mu^-$