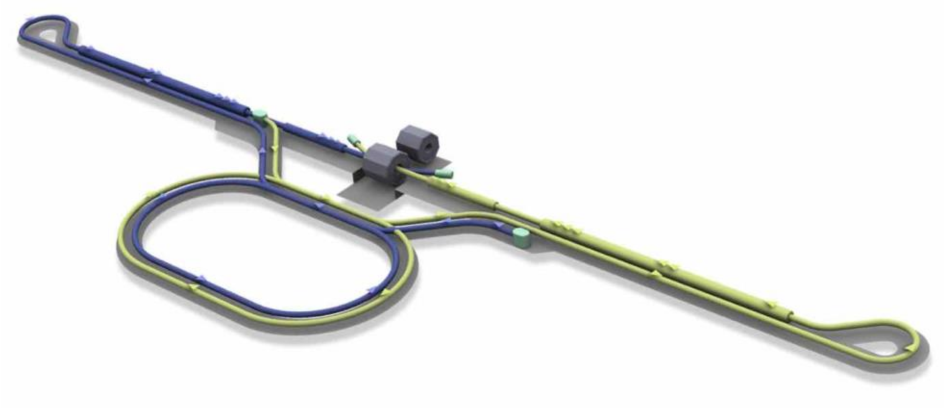
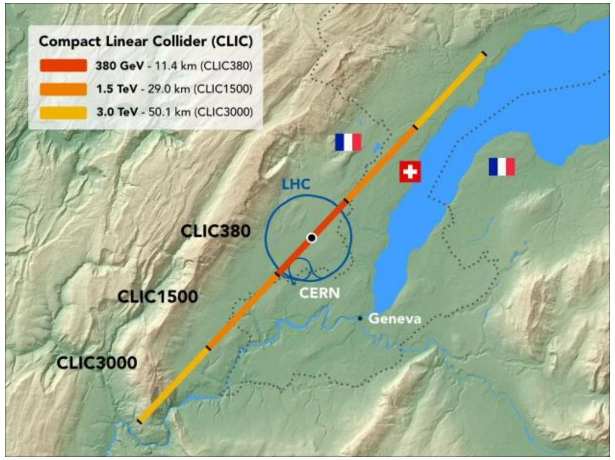

# High energy linear colliders: ILC and CLIC

Steinar Stapnes, CERN





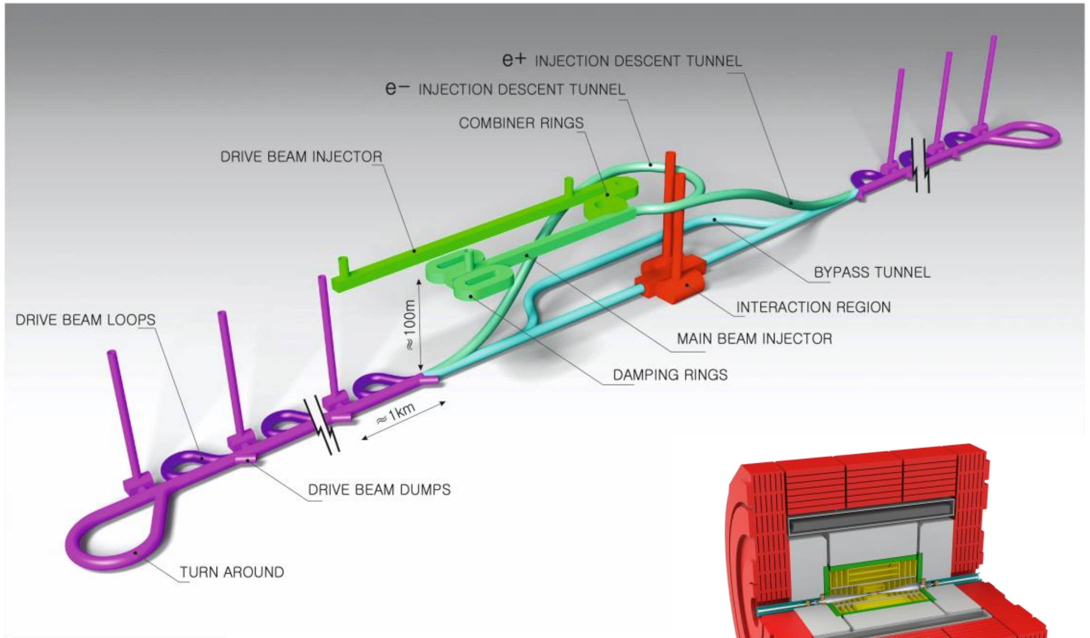

**International Linear Collider ILC**

- Superconducting Cavities, 1.3GHz, 31.5MV/m
- 250GeV CME, upgradeable to 500, 1000 GeV
- L = 1.35E34 $cm^{-2}s^{-1}$
- 20km length, in Tohoku / Japan

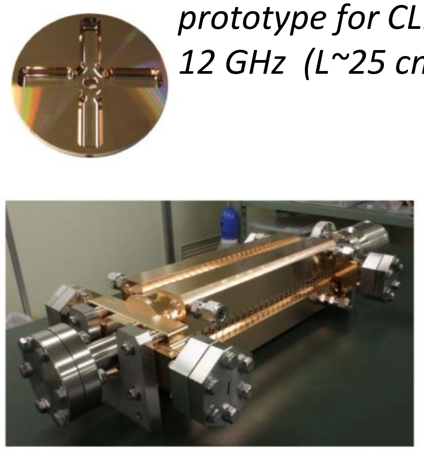
**Compact Linear Collider CLIC**

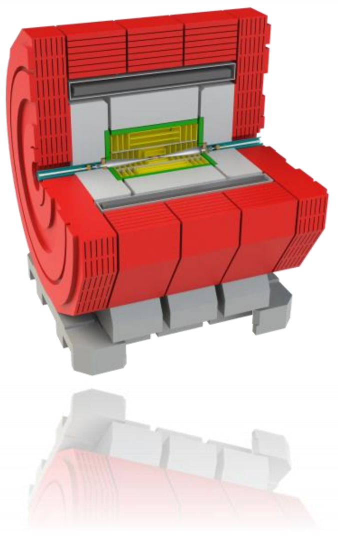
- NC Copper Cavities, 12GHz, 72MV/m, two-beam acceleration
- 380GeV CME, upgradeable to 1500, 3000 GeV
- L = 1.50E34 $cm^{-2}s^{-1}$
- 11.4km long, at CERN / France & Switzerland

# 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:** 168 MW at 380 GeV (reduced wrt 2012), corresponding to 60% of CERN’s energy consumption today

- Comprehensive **Detector and Physics** studies

# Collaborations

CLIC accelerator

- ~50 institutes from 28 countries
- CLIC accelerator studies
- CLIC accelerator design and development
- Construction and operation of CLIC Test Facility, CTF3

CLIC detector and physics (CLICdp)

- 30 institutes from 18 countries
- Physics prospects & simulations studies
- Detector optimisation + R&D for CLIC

+ strong participation in the CALICE and FCAL Collaborations and in AIDA-2020/AIDAinnova

# CLIC parameters

| Parameter | Symbol | Unit | Stage 1 | Stage 2 | Stage 3 |
|---|---|---|---|---|---|
| Centre-of-mass energy | $\sqrt{s}$ | GeV | 380 | 1500 | 3000 |
| Repetition frequency | $f_{\text{rep}}$ | Hz | 50 | 50 | 50 |
| Number of bunches per train | $n_b$ | | 352 | 312 | 312 |
| Bunch separation | $\Delta t$ | ns | 0.5 | 0.5 | 0.5 |
| Pulse length | $\tau_{\text{RF}}$ | ns | 244 | 244 | 244 |
| Accelerating gradient | $G$ | MV/m | 72 | 72/100 | 72/100 |
| Total luminosity | $\mathscr{L}$ | $10^{34}\ \text{cm}^{-2}\ \text{s}^{-1}$ | 1.5 | 3.7 | 5.9 |
| Luminosity above 99% of $\sqrt{s}$ | $\mathscr{L}_{0.01}$ | $10^{34}\ \text{cm}^{-2}\ \text{s}^{-1}$ | 0.9 | 1.4 | 2 |
| Total integrated luminosity per year | $\mathscr{L}_{\text{int}}$ | $\text{fb}^{-1}$ | 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 | $\sigma_z$ | μm | 70 | 44 | 44 |
| IP beam size | $\sigma_x/\sigma_y$ | nm | 149/2.9 | $\sim$ 60/1.5 | $\sim$ 40/1 |
| Normalised emittance (end of linac) | $\epsilon_x/\epsilon_y$ | 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 is a mature design/study

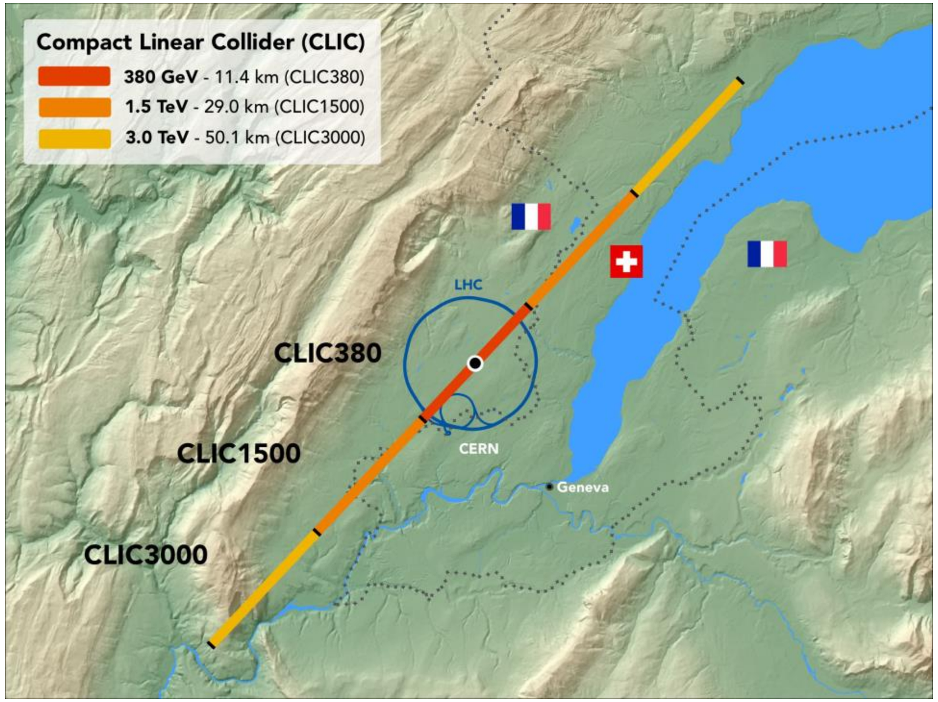

The CLIC accelerator studies are mature:

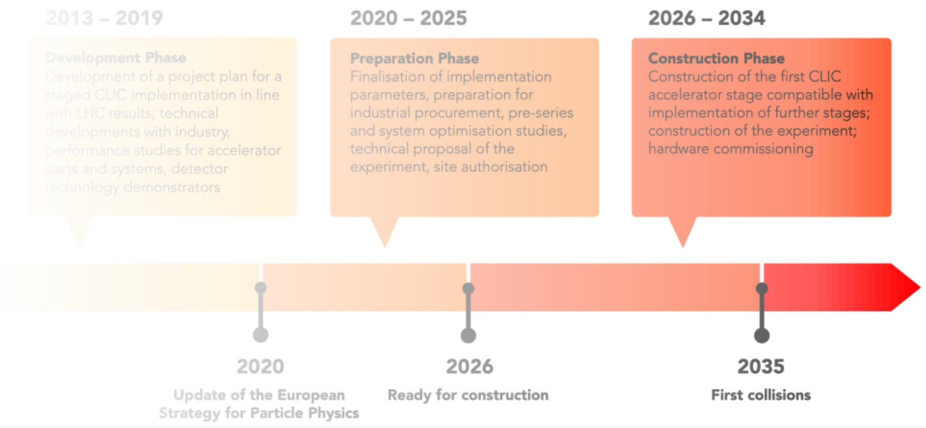
Optimised design for cost and power

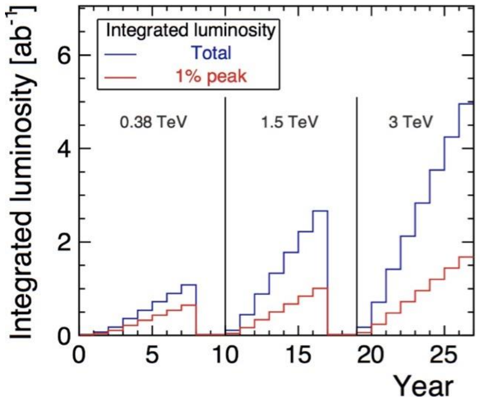
Many tests in CTF3, FELs, lightsources and test-stands

Technical developments of “all” key elements

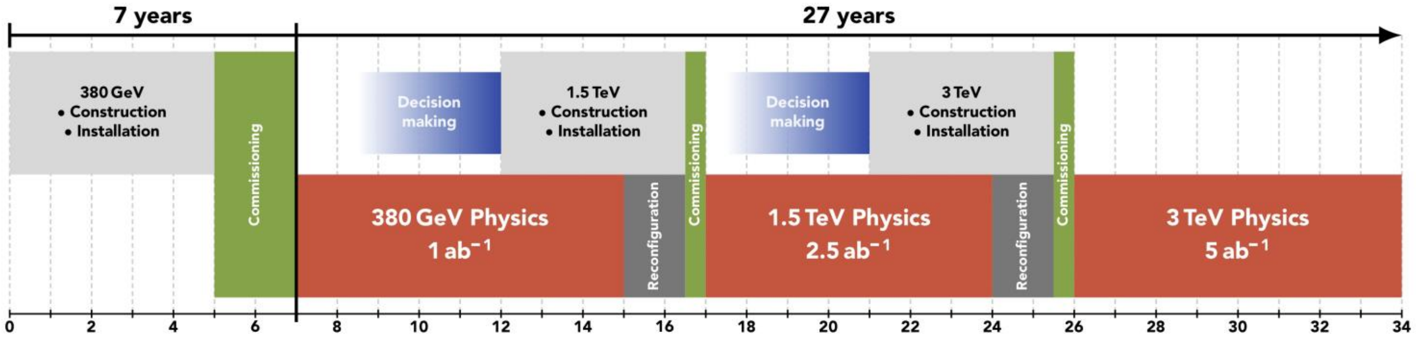
# CLIC timeline




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




Technology Driven Schedule from start of construction shown above.

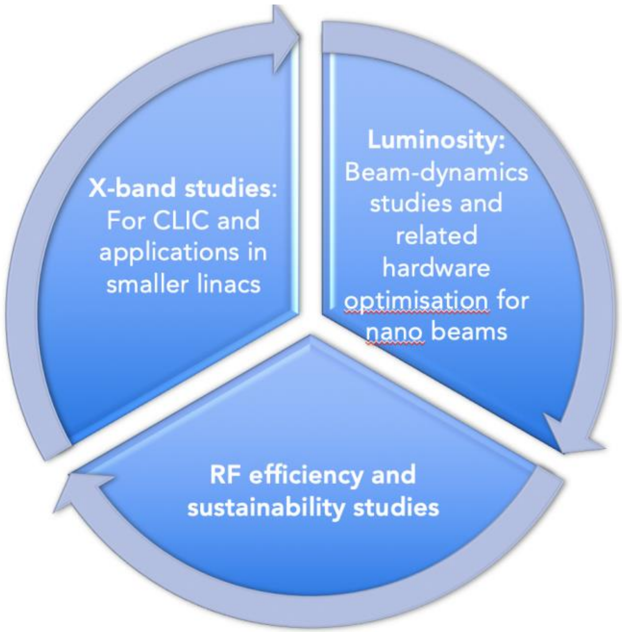
A preparation phase of ~5 years is needed before (estimated resource need for this phase is ~4% of overall project costs)

# CLIC 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:

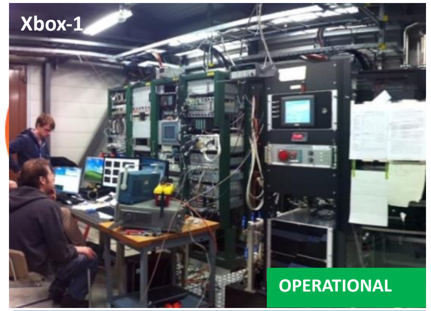
- The X-band technology readiness for the 380 GeV CLIC initial phase
- Optimizing the luminosity at 380 GeV
- Improving the power efficiency for both the initial phase and at high energies




Goals for these studies by ~2025:

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

# 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

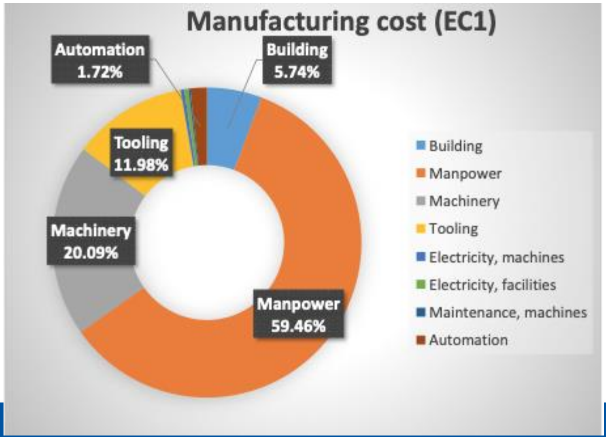
**Ongoing test:**
*CLIC TD26 CLEX SuperStructure*

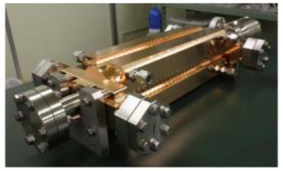

2x Toshiba 6MW 5us klystron
2x Scandinova Modulators
Rep Rate 400Hz

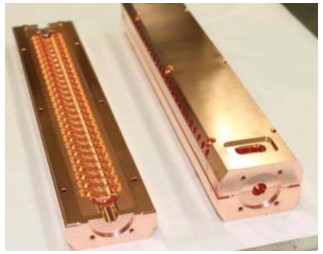
**Ongoing test:**
*SARI X-band deflector*
*High power window*

**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

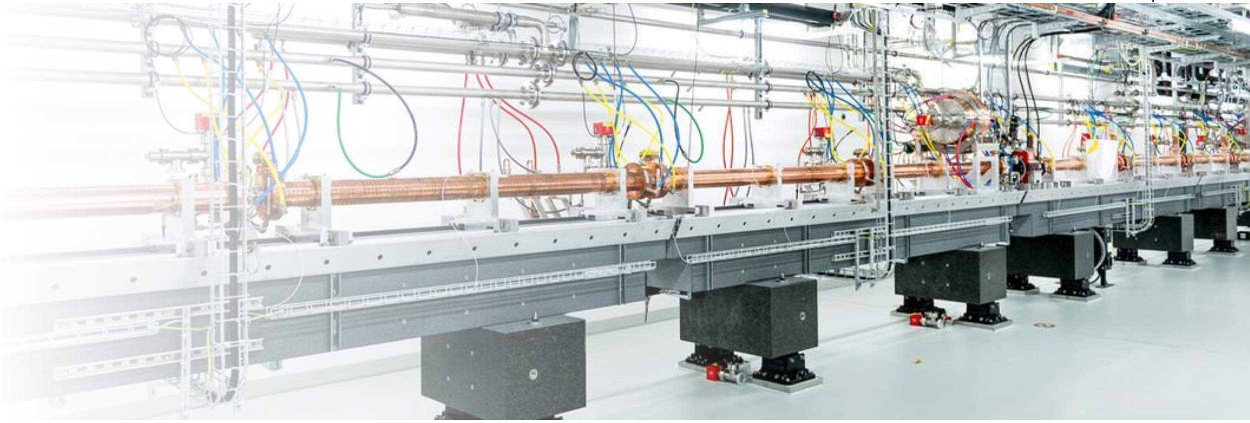
EU projects: ARIES, I-FAST, new TNA

# Use in smaller linacs (C and X-band)

SwissFEL: C-band linac

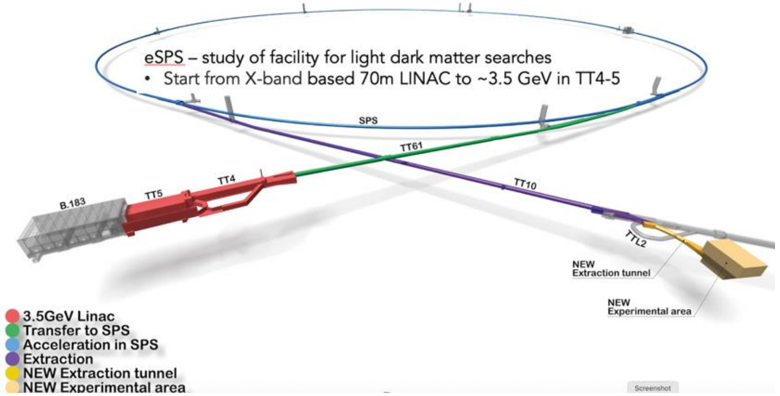
Photo: SwissFEL/PSI

- 104 x 2 m-long C-band (5.7 GHz) structures (beam up to 6 GeV at 100 Hz)
- Similar µm-level tolerance
- Length ~ 800 CLIC structures
- Being commissioned
- X-band structures from PSI perform well



26 academic and industrial partners: [http://www.compactlight.eu/Main/HomePage](http://www.compactlight.eu/Main/HomePage)

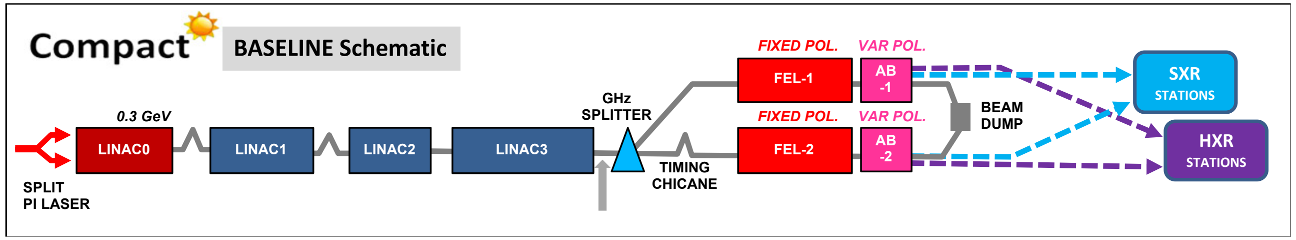
CompactLight Design Studies 2018-21 ([link]())
Compact FEL based on X-band technologies

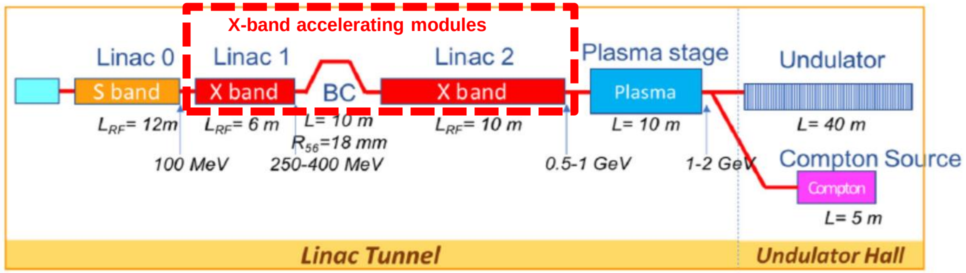


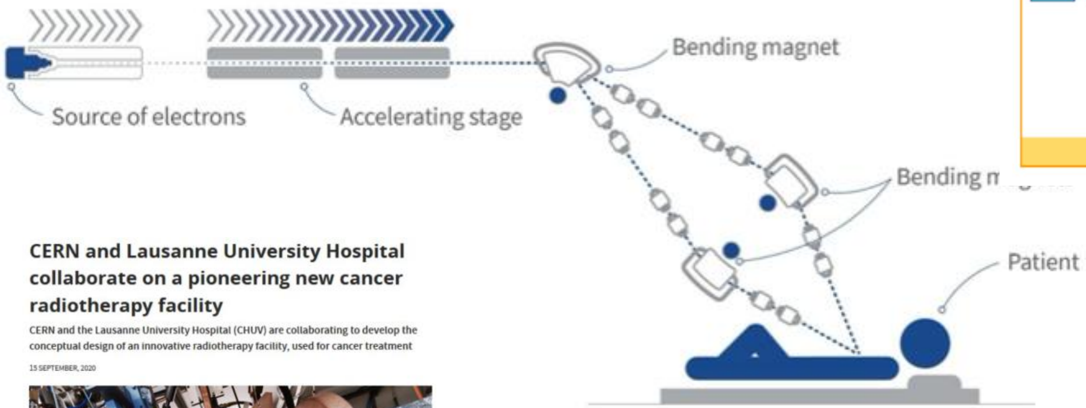

CERN: eSPS study (3.5 GeV X-band linac)

# Applications – injector, X-band modules, RF

- CompactLight Design Studies 2018-21 (right)
- INFN 1 GeV linac
- Flash RT, at CHUV (see talk of M.Cirilli)
- “Design Studies” for ICS
- AERES, IFAST and TNA project



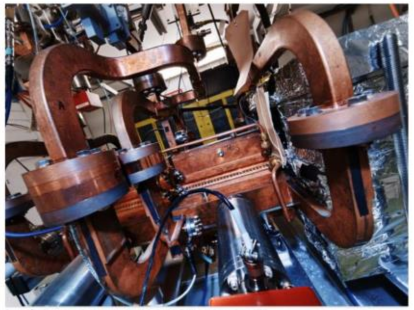



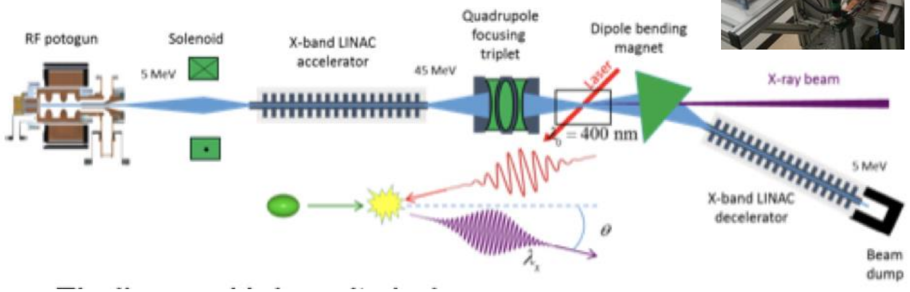



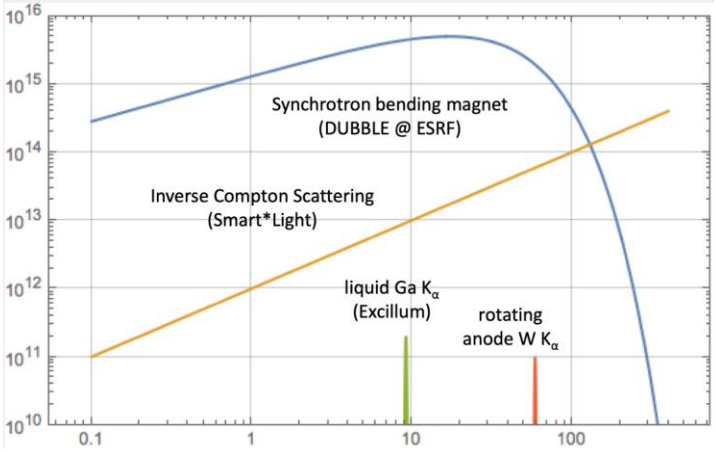

**CERN and Lausanne University Hospital collaborate on a pioneering new cancer radiotherapy facility**

CERN and the Lausanne University Hospital (CHUV) are collaborating to develop the conceptual design of an innovative radiotherapy facility, used for cancer treatment

15 SEPTEMBER, 2020





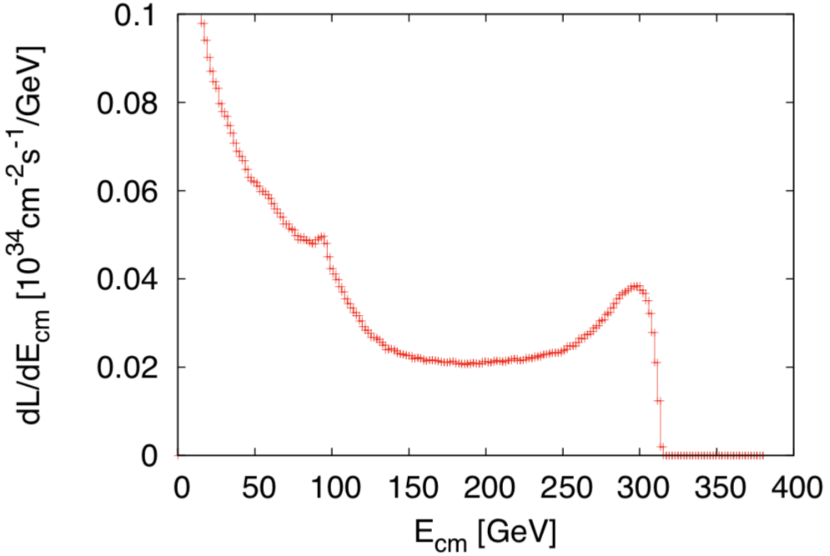
# CLIC acc. studies – luminosities

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

- Z pole performance, $2.3\times10^{32}$ – $0.4\times10^{34}$ 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: $1.5\times10^{34}$ cm$^{-2}$ s$^{-1}$, a "perfect" machine will give : $4.3\times10^{34}$ 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

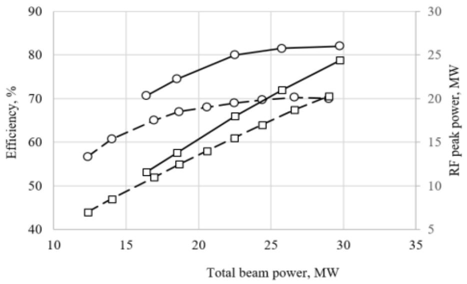
  - **Studies cover from beam-dynamics to technical studies of the required performances of stability, alignment, instrumentation, magnets, BDS, final focus, injectors including positrons, damping rings – priority for next ESU**

- CLIC note and paper about these studies



# High Eff. Klystrons

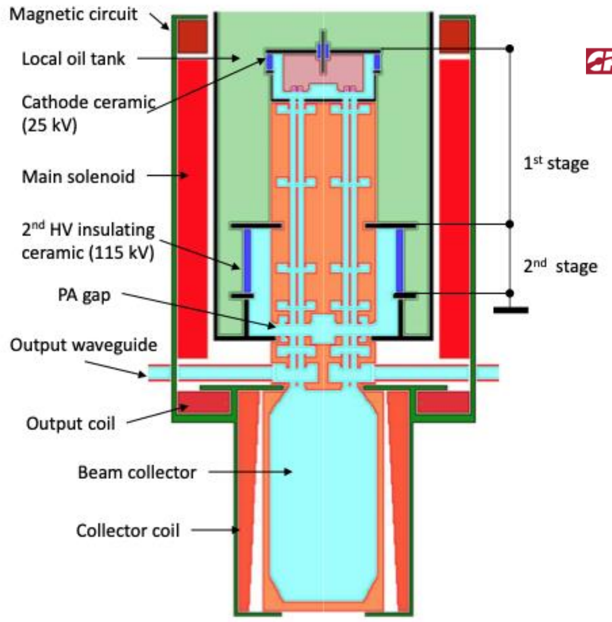
## L-band, X-band (for applications/collaborators and test-stands




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.

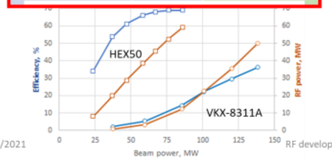
Publication: [https://ieeexplore.ieee.org/document/9115885](https://ieeexplore.ieee.org/document/9115885)

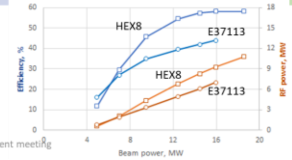



High Efficiency X-band klystrons retrofit upgrades (in collaboration with CPI and Canon).

| 50 MW | VKX-8311A | HEX COM_M (CERN/CPI) |
|---|---|---|
| Voltage, kV | 420 | 420 |
| Current, A | 322 | 204 |
| Frequency, GHz | 11.994 | 11.994 |
| Peak power, MW | 49 | 59 |
| Sat. gain, dB | 48 | 58 |
| Efficiency, % | 36.2 | 68 / KlyC |
| Life time, hours | 30 000 | 85 000 |
| Solenoidal magnetic field, T | 0.6 | 0.35/0.6 |
| RF circuit length, m | **0.32** | **0.32** |

| 8-10 MW | E37113 at factory | HEX COM_M (CERN/Canon) |
|---|---|---|
| Voltage, kV | 154 | 154 |
| Current, A | 93 | 90 |
| Frequency, GHz | 11.994 | 11.994 |
| Peak power, MW | 6.2 | 8.1 |
| Sat. gain, dB | 49 | 58 |
| Efficiency, % | 42 | 57/ FCI |
| Life time, hours | 30 000 | 30 000 |
| Solenoidal magnetic field, T | 0.35 | 0.4 |
| RF circuit length, m | **0.127** | **0.127** |



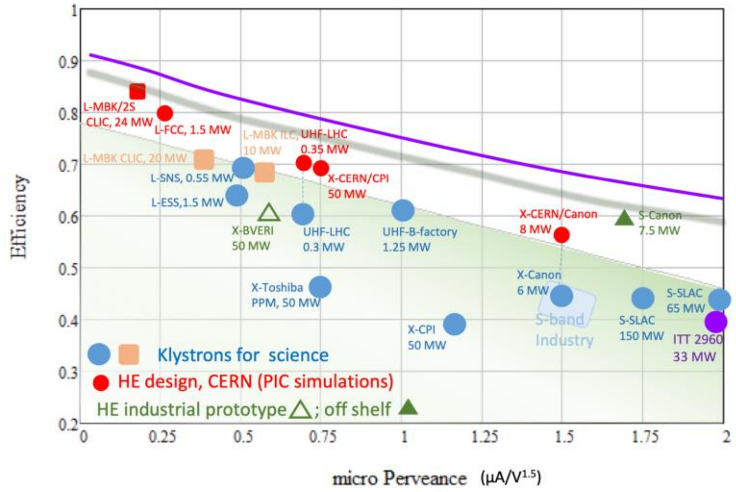




20/1/2021 RF development meeting 15

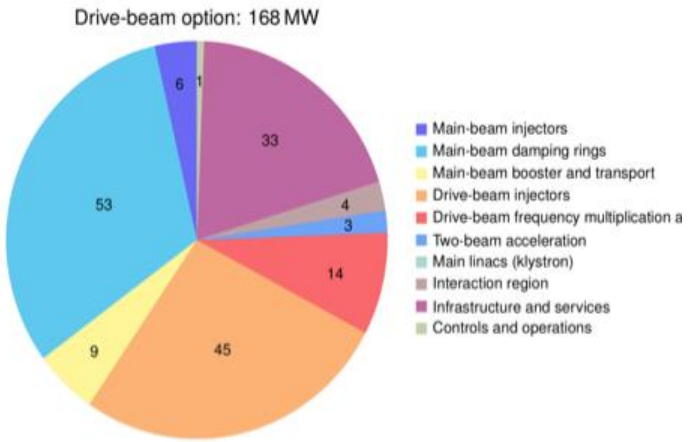
High Efficiency implementations:

- 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



# Power and Energy




Power estimate bottom up (concentrating on 380 GeV systems)

- Very large reductions since CDR, better estimates of nominal settings, much more optimised drivebeam complex and more efficient klystrons, injectors more optimized, etc

Further savings possible, main target damping ring RF, L-band klystron (target 140-150 MW)

Energy consumption ~0.8 TWh yearly (target 0.7)
CERN is currently (when) running at 1.2 TWh (~90% in accelerators)

**Design Optimisation:**

The designs of CLIC, including key performance parameters as accelerating gradients, pulse lengths, bunch-charges and luminosities, have been optimised for cost but also increasingly focussing on reducing power consumption.

**Technical Developments:**

Technical developments targeting reduced power consumptions at system level high efficiency klystrons, and super conducting and permanents magnets for damping rings and linacs.

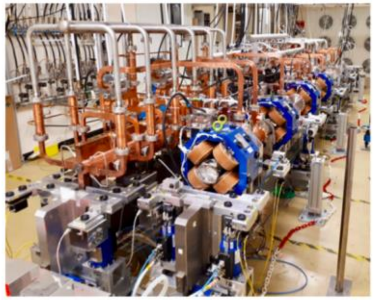
**Running when energy is cheap:**

CLIC is normal conduction, single pass, can change off-on-off quickly, at low power when not pulsed. Specify state-change (off-standby-on) times and power uses for each – see if clever scheduling using low cost periods, can reduce the energy bill

**Renewable energy (carbon footprint):**

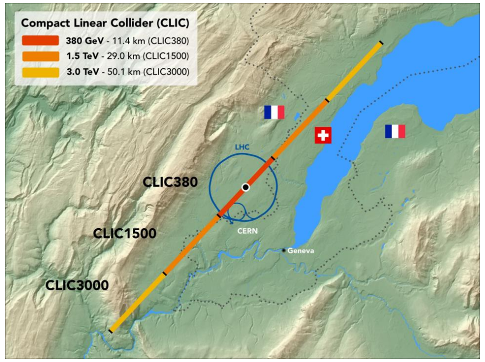
Is it possible to fully supply the annual electricity demand of the CLIC-380 by installing local wind and PV generators (this could be e.g. achieved by 330 MW-peak PV and 220 MW-peak wind generators, at a cost of slightly more than 10% of the CLIC 380 GeV cost)

# CLIC can easily be extended



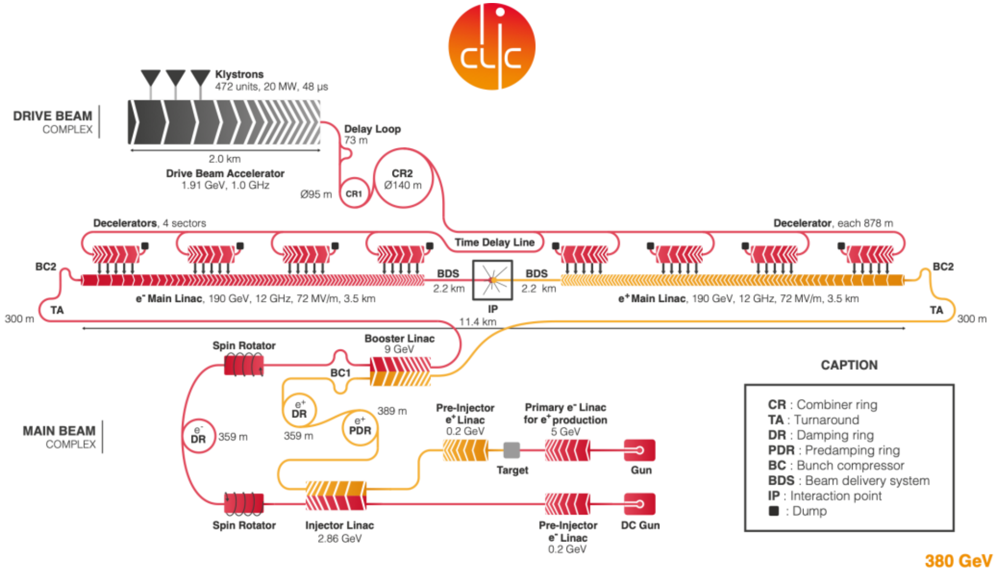
What are the critical elements:

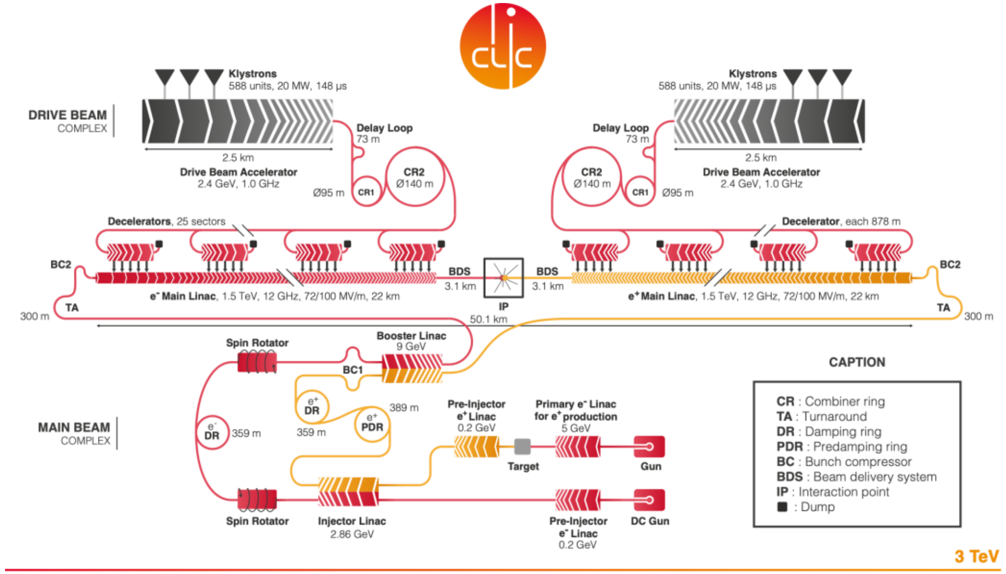
- Physics
- Gradient and power efficiency
- Costs




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

Extend by extending main linacs, increase drivebeam pulse-length and power, and a second drivebeam to get to 3 TeV




CLIC - Scheme of the Compact Linear Collider (CLIC)

# Resources

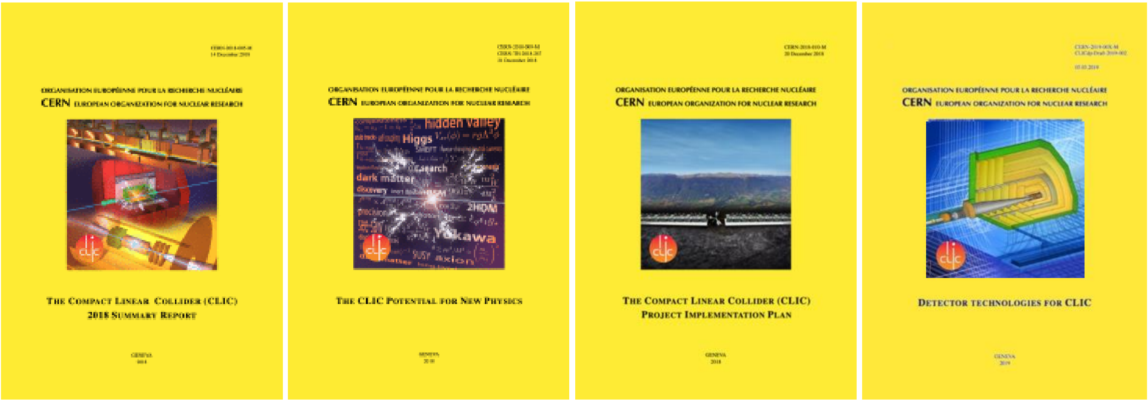
Available at:
[clic.cern/european-strategy](clic.cern/european-strategy)

## 3-volume CDR 2012


## Updated Staging Baseline 2016


*Two formal submissions to the ESPPU 2018*


## 4 CERN Yellow Reports 2018

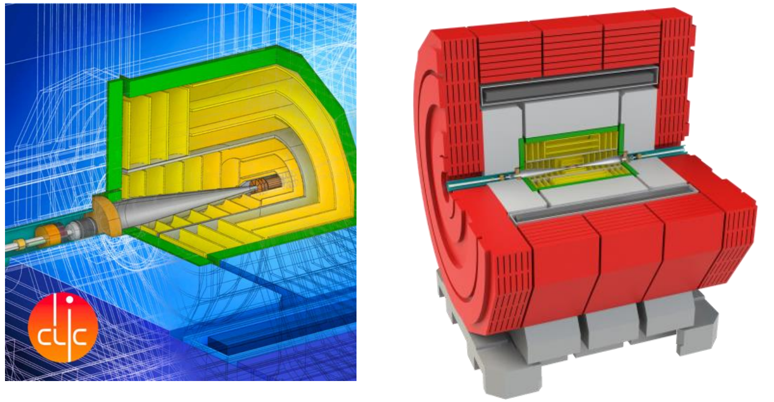



Details about the accelerator, detector R&D, physics studies for Higgs/top and BSM

*Several LoIs have been submitted on behalf of CLIC and CLICdp to the Snowmass process:*

*The CLIC accelerator study: Link*
*Beam-dynamics focused on very high energies: Link*
*The physics potential: Link*
*The detector: Link*

# Detector R&D for CLICdet



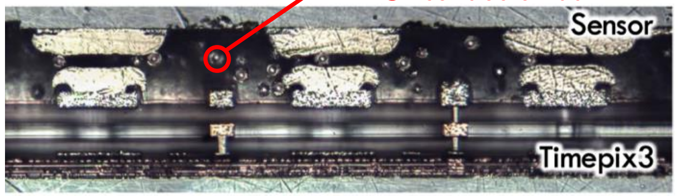
**Calorimeter R&D** => within CALICE and FCAL
**Silicon vertex/tracker R&D:**
- Working Group within CLICdp and strong collaboration with DESY + AIDAinnova
- Now integrated in the CERN EP detector R&D programme

## *A few examples:*

### Hybrid assemblies:

◆ Development of **bump bonding** process for **CLICpix2** hybrid assemblies with 25 µm pitch
https://cds.cern.ch/record/2766510

ACF conductor ball



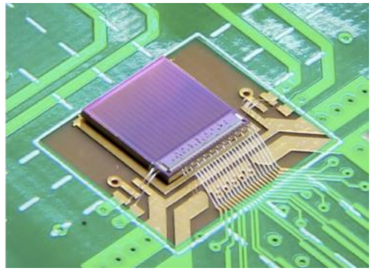

◆ Successful sensor+ASIC bonding using **Anisotropic Conductive Film (ACF)**, e.g. with CLICpix2, Timepix3 ASICs.
ACF now also used for module integration with monolithic sensors.
https://agenda.linearcollider.org/event/9211/contributions/49469/

### Monolithic sensors:

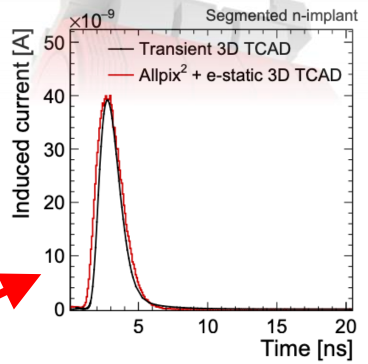
◆ Exploring sub-nanosecond pixel timing with **ATTRACT FASTPIX** demonstrator in 180 nm monolithic CMOS
https://agenda.linearcollider.org/event/9211/contributions/49445/

◆ Now performing qualification of modified **65 nm CMOS** imaging process for further improved performance

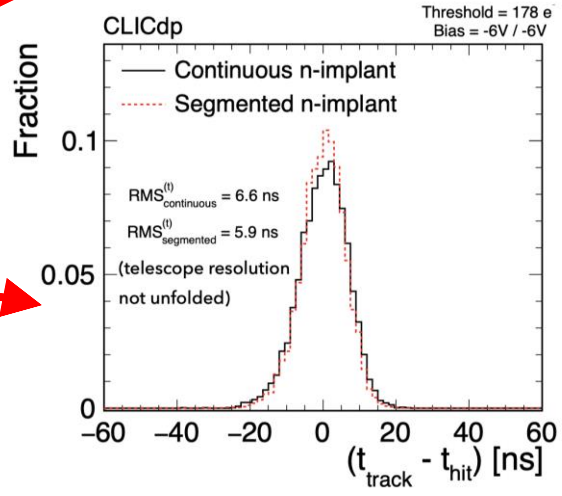
### CLICTD monolithic tracking sensor:



Detailed simulations, Allpix$^2$ transient Monte Carlo combined with electrostatic 3D TCAD.




Beam tests at DESY, e.g. 5.8 ns CLICTD time resolution achieved
https://agenda.linearcollider.org/event/9211/contributions/49443/



# Physics Potential recent highlights:
## Initial energy stage

- **Ongoing studies on Higgs and top-quark precision physics potential**

**Higgs coupling sensitivity:**

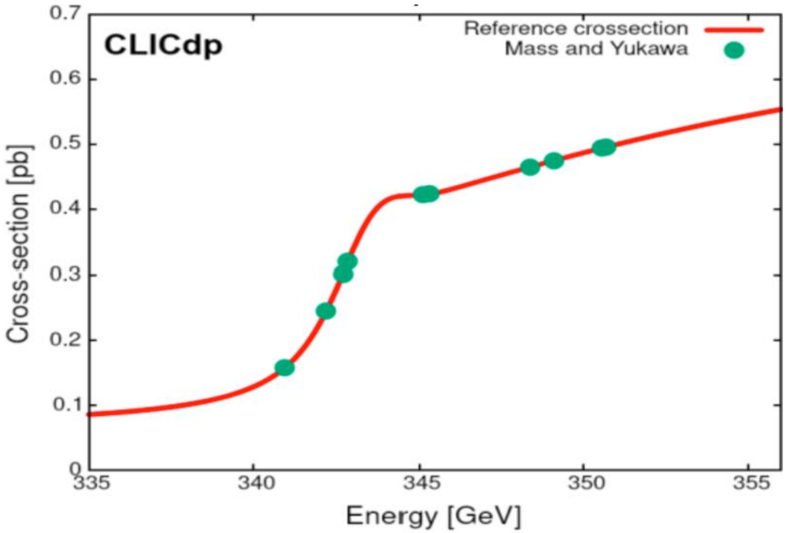
- Sensitivities under different integrated luminosity scenarios to complement accelerator luminosity studies

Increased integrated luminosity at 380 GeV (4ab$^{-1}$)

Baseline: 380 GeV (1ab$^{-1}$) + 1.5 TeV

| | Benchmark | HL-LHC | HL-LHC + CLIC | | HL-LHC + FCC-ee | |
|---|---|---|---|---|---|---|
| | | | 380 (4 ab$^{-1}$) | 380 (1 ab$^{-1}$) + 1500 (2.5 ab$^{-1}$) | 240 | 365 |
| $g_{HZZ}^{\text{eff}}$[%] | SMEFT$_{\text{ND}}$ | 3.6 | 0.3 | 0.2 | 0.5 | 0.3 |
| $g_{HWW}^{\text{eff}}$[%] | SMEFT$_{\text{ND}}$ | 3.2 | 0.3 | 0.2 | 0.5 | 0.3 |
| $g_{H\gamma\gamma}^{\text{eff}}$[%] | SMEFT$_{\text{ND}}$ | 3.6 | 1.3 | 1.3 | 1.3 | 1.2 |
| $g_{HZ\gamma}^{\text{eff}}$[%] | SMEFT$_{\text{ND}}$ | 11. | 9.3 | 4.6 | 9.8 | 9.3 |
| $g_{Hgg}^{\text{eff}}$[%] | SMEFT$_{\text{ND}}$ | 2.3 | 0.9 | 1.0 | 1.0 | 0.8 |
| $g_{Htt}^{\text{eff}}$[%] | SMEFT$_{\text{ND}}$ | 3.5 | 3.1 | 2.2 | 3.1 | 3.1 |
| $g_{Hcc}^{\text{eff}}$[%] | SMEFT$_{\text{ND}}$ | – | 2.1 | 1.8 | 1.4 | 1.2 |
| $g_{Hbb}^{\text{eff}}$[%] | SMEFT$_{\text{ND}}$ | 5.3 | 0.6 | 0.4 | 0.7 | 0.6 |
| $g_{H\tau\tau}^{\text{eff}}$[%] | SMEFT$_{\text{ND}}$ | 3.4 | 1.0 | 0.9 | 0.7 | 0.6 |
| $g_{H\mu\mu}^{\text{eff}}$[%] | SMEFT$_{\text{ND}}$ | 5.5 | 4.3 | 4.1 | 4. | 3.8 |
| $\delta g_{1Z}[\times 10^2]$ | SMEFT$_{\text{ND}}$ | 0.66 | 0.027 | 0.013 | 0.085 | 0.036 |
| $\delta \kappa_{\gamma}[\times 10^2]$ | SMEFT$_{\text{ND}}$ | 3.2 | 0.032 | 0.044 | 0.086 | 0.049 |
| $\lambda_Z[\times 10^2]$ | SMEFT$_{\text{ND}}$ | 3.2 | 0.022 | 0.005 | 0.1 | 0.051 |

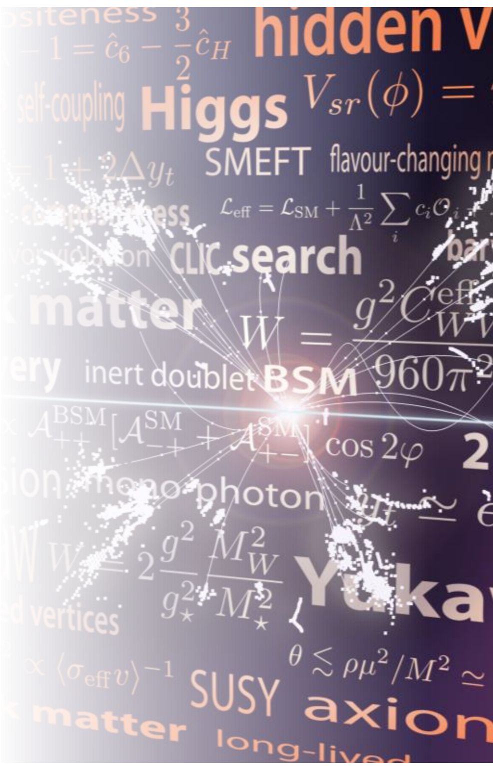
https://arxiv.org/abs/2001.05278
other sensitivities from Briefing Book https://arxiv.org/abs/1910.11775



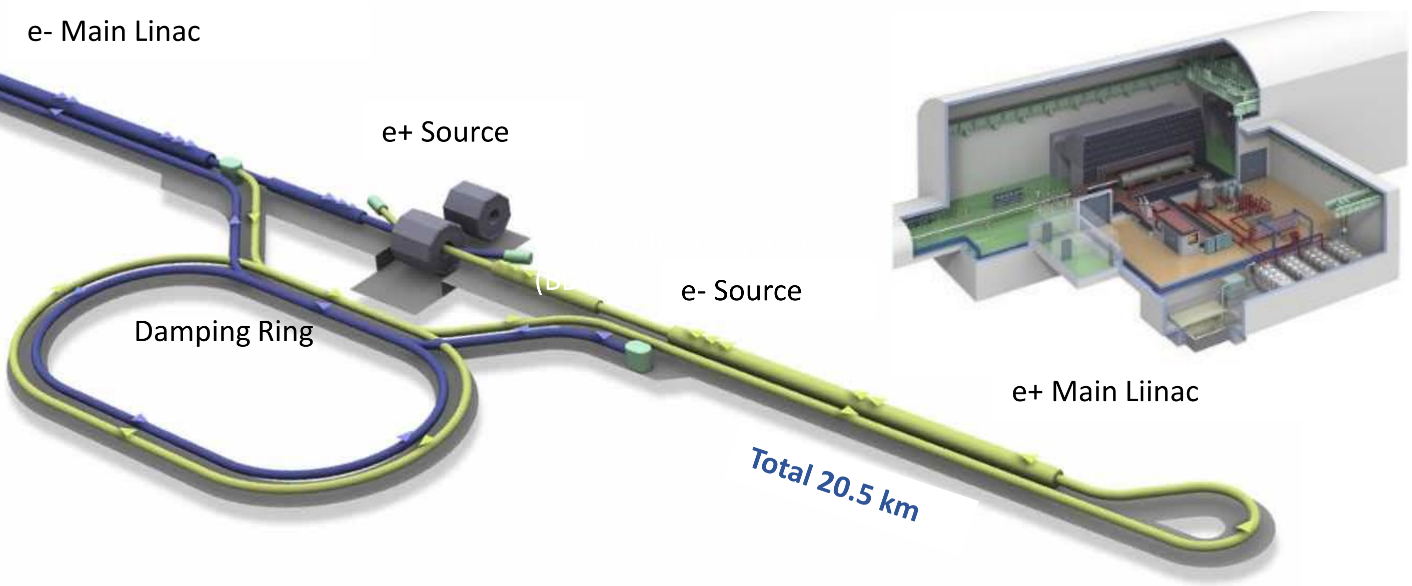

**Top-quark threshold scan**

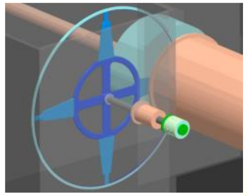
- Optimisation of scan points including beam spectrum; here optimising on mass and Yukawa coupling.
- Expected top-quark mass precision of 25MeV can be improved by 25% without losing precision on width or Yukawa.

https://arxiv.org/abs/2103.00522



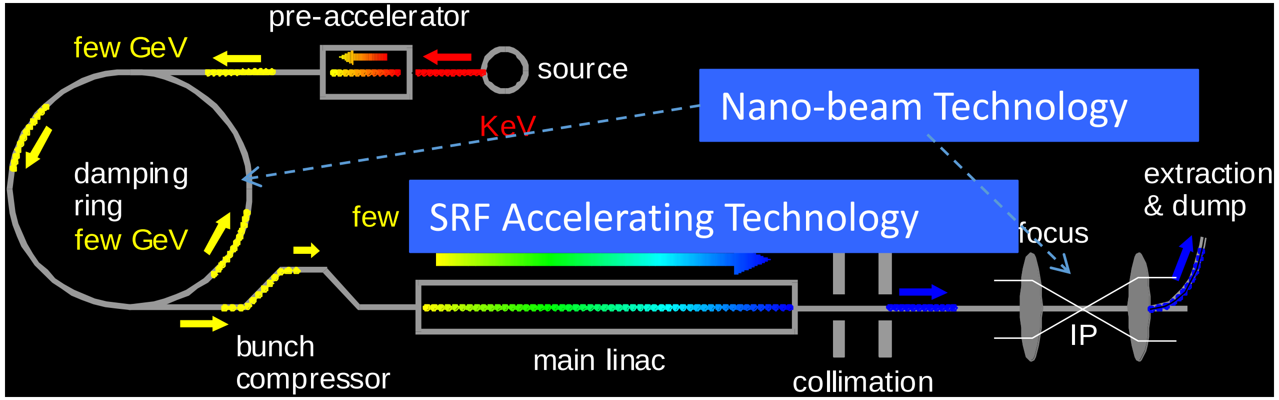
# 250GeV ILC – Japan



Positron source


## Key Technologies




| 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.<br>$Q_0$ | **31.5** MV/m<br>(**35** MV/m)<br>$Q_0$ = 1x10 $^{10}$ |

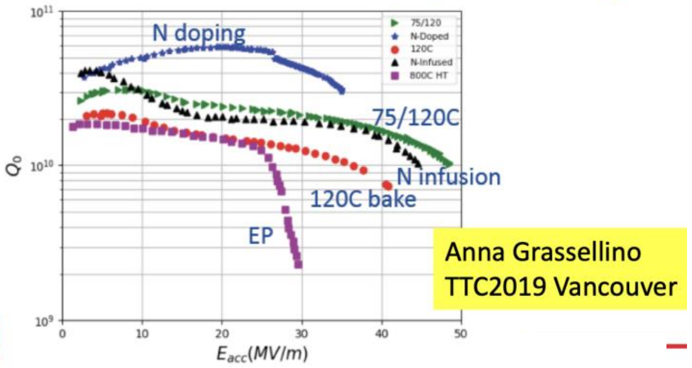
*ILC is foreseen to be upgraded in luminosity and energy (towards ~ 1 TeV)

Costs ~5 B$, power 110 MW

# Potential for upgrades

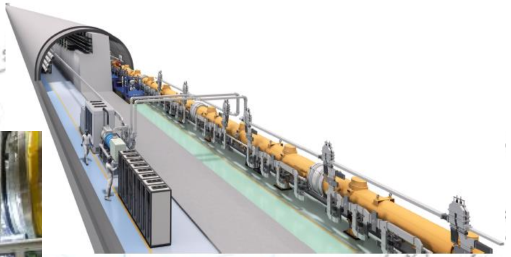
| | | | Z-Pole [4] | | Higgs [2,5] | | | 500GeV [1*] | | TeV [1*] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Baseline | Lum. Up | Baseline | Lum. Up | L Up,10Hz | Baseline | Lum. Up | case B |
| Center-of-Mass Energy | $E_{CM}$ | GeV | 91.2 | 91.2 | 250 | 250 | 250 | 500 | 500 | 1000 |
| 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 | $\Delta t_b$ | 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 | $\sigma_z$ | mm | 0.41 | 0.41 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.225 |
| Emittance at IP (x) | $\gamma e^*_x$ | µm | 6.2 | 6.2 | 5.0 | 5.0 | 5.0 | 10.0 | 10.0 | 10.0 |
| Emittance at IP (y) | $\gamma e^*_y$ | nm | 48.5 | 48.5 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 30.0 |
| Beam size at IP (x) | $\sigma^*_x$ | µm | 1.118 | 1.118 | 0.515 | 0.515 | 0.515 | 0.474 | 0.474 | 0.335 |
| Beam size at IP (y) | $\sigma^*_y$ | 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 | $n_g$ | | 0.841 | 0.841 | 1.91 | 1.91 | 1.91 | 1.82 | 1.82 | 2.05 |
| Beamstrahlung energy loss | $\delta_{BS}$ | % | 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 |

- Surface treatments for high-Q and high-G




https://edmsdirect.desy.de/item/D00000001100895

# Worldwide large scale SRF accelerators



Euro-XFEL

Operation started from 2017

- -100 cryomodules
- -800 cavities
- -17.5 GeV (Pulsed)

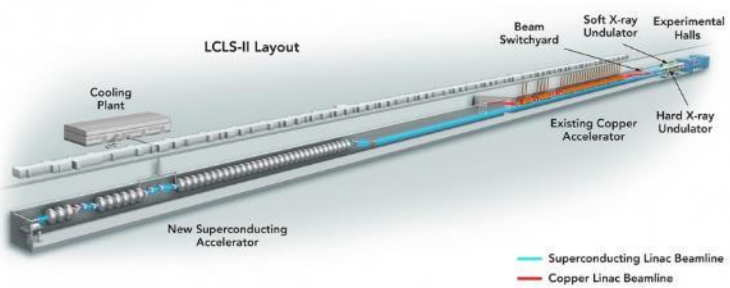
LCLS-II + HE (under construction)

- -35 + 20 cryomodules
- -280 + 160 cavities
- - 4 + 4 GeV (CW)

ILC

- -900 cryomodules
- -8,000 cavities
- -250 GeV (Pulsed)

SLAC FNAL Cornell JLab LAL/Saclay DESY INFN SINAP KEK




SHINE (under construction)

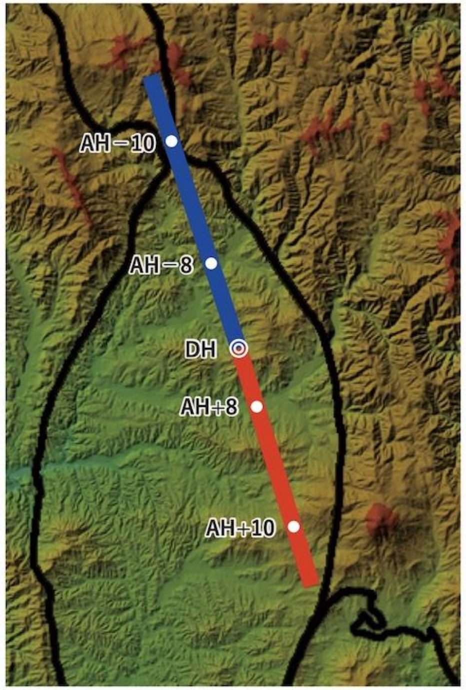
- -75 cryomodules
- -~600 cavities
- - 8 GeV (CW)

1.3GHz 9 cell cavity

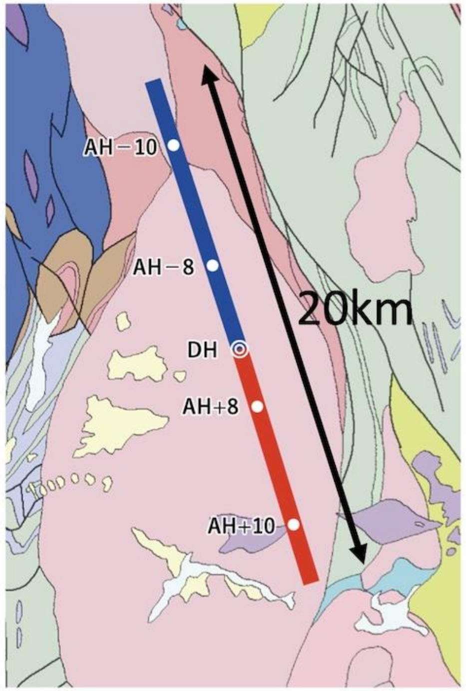
# Topography and geology assumed in civil engineering design of ILC

- Rock mass is generally uniform over a long distance of 50 km
- Solid rock zone is less susceptible to ground vibration
- No "known faults” crosses the site, which is expected to be active faults


Tohoku ILC Project Development
https://tipdc.org/)




granite zone




We evaluated candidate sites by selecting the most suitable geology for construction.

Reduces civil and cost risks due to massive water inflow, etc.

Construction of road tunnels and other projects may pass through areas with poor geology, depending on the conditions of the starting and ending points.
ILC selects candidate sites with priority given to geology, avoiding soft ground in advance.

- Seismic survey (total 30 km), electromagnetic survey (13 km), and borehole survey (7 boreholes) were carried out.
- In the area of the accelerator tunnel, hard and uncracked granite is considered to be widely distributed.

# IDT structure from Summer 2020

**ICFA**

**ILC International Development Team**

**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

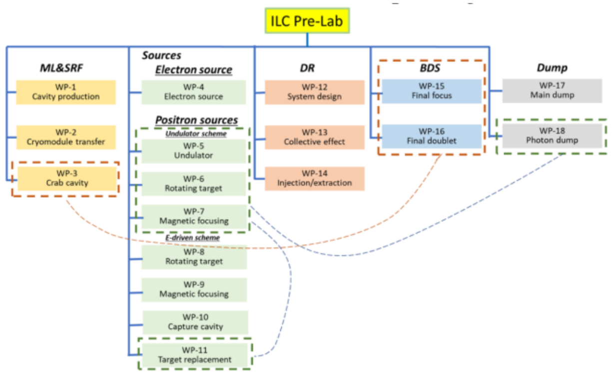
**Working Group 3**
Physics & Detectors

# ILC overall timeline

| Pre-preparatory Phase | | Main Preparatory Phase | | Construction Phase | |
|---|---|---|---|---|---|
| 2020.8 | (2022) | About 4 years | (2026) | About 9 years | (2035) |
| LCB/LCC | International Development Team | ILC Pre-Lab | | ILC Laboratory | |

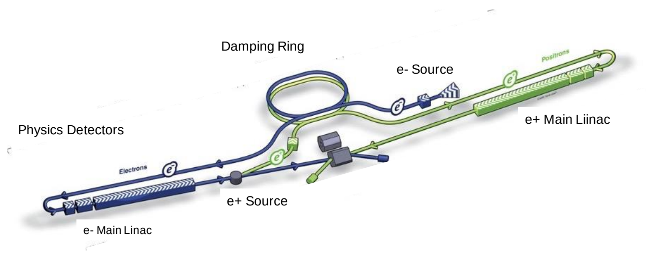
IDT (~1.5 years)
- Prepare the work and deliverables of the ILC Pre-Laboratory and work out, with national and regional laboratories, a scenario for their contributions
- Prepare a proposal for the organisation and governance
  of the ILC Pre-Laboratory

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.




Planning, except to start in 2022 at the earliest

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



# ILC Prelab planning



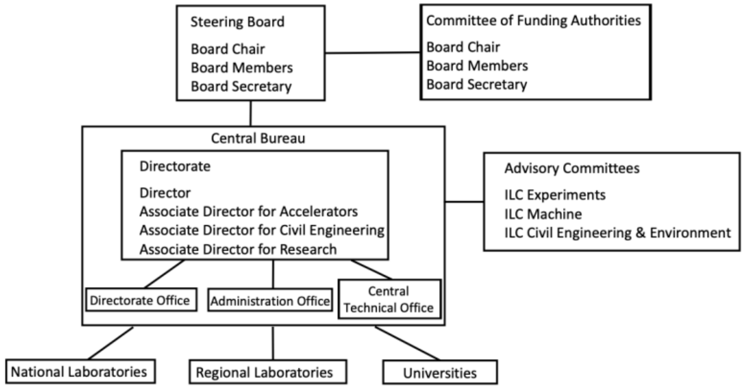



Figure 1: Pre-lab Organisation Chart

https://arxiv.org/abs/2106.00602

# Pre-lab plans

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

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

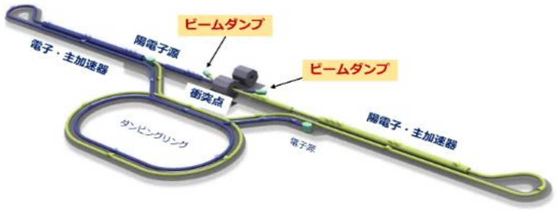
***DR***
～2.5MILCU, 30FTE-yr
- WP-12 System design
- WP-13 Collective effect
- WP-14 Injection/extraction

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

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

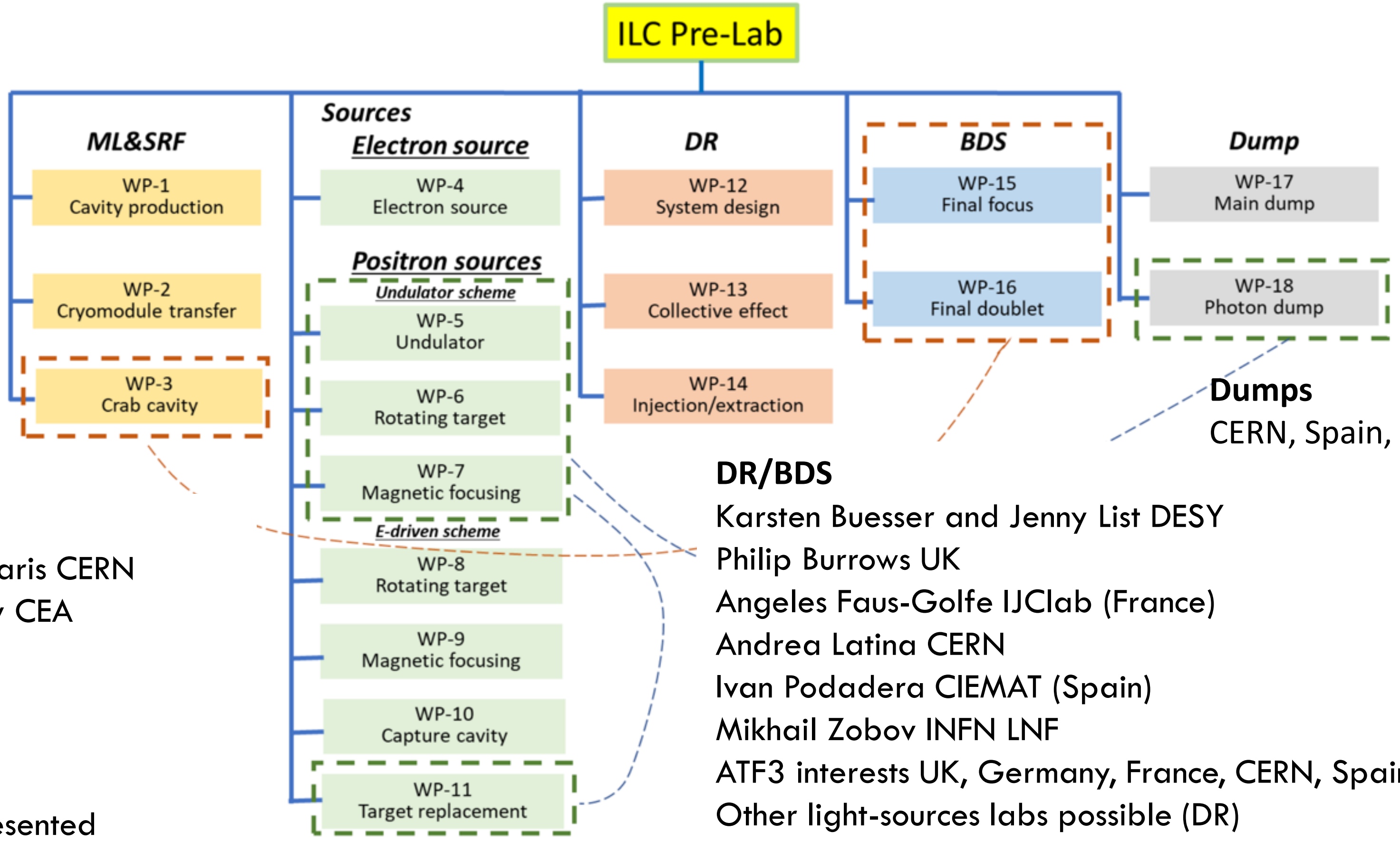
For detail,
http://doi.org/10.5281/ zenodo.4742018

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 Prelab 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.

# A European perspective




**Dumps**
CERN, Spain, CERN

**DR/BDS**
Karsten Buesser and Jenny List DESY
Philip Burrows UK
Angeles Faus-Golfe IJClab (France)
Andrea Latina CERN
Ivan Podadera CIEMAT (Spain)
Mikhail Zobov INFN LNF
ATF3 interests UK, Germany, France, CERN, Spain
Other light-sources labs possible (DR)

**ML & SRF**
Nuria Catalan and Dimitri Delikaris CERN
Enrico Cenni and Olivier Napoly CEA
Luis Garcia-Tabares CIEMAT
Peter McIntosh UK
Laura Monaco INFN Milano
Hans Weise DESY
Not all European SRF labs represented
Additionally:

- Long term cryo collaboration with CERN. HiEff RF another relevant activity
- SRF "basic" R&D for fabrication improvements or long term performance improvements (i.e. for upgrades)

**Sources**
Jim Clarke UK
Steffen Doebert, CERN and Peter Sievers, CERN retired
Benno List, Jenny List, Sabine Riemann, Gudrid Moortgat-Pick DESY
IJCLab also, other groups also possible (FCC-ee, Dafne)

**Engineering Design** working group being set up

**Also in WG2, but related to Civil Engineering**
John Osborne CERN

**Accelerator WP reviewers:**
Erk Jensen CERN
Deepa Angal Kalinin STFC
Nick Walker DESY

WG3

https://linearcollider.org/team/wg3

## Leadership of IDT Working Group 3

| | | | |
|---|---|---|---|
| Coordinator / WG3 Chair | Hitoshi Murayama | UC Berkeley/U. Tokyo | United States/Japan |
| Deputy Coordinators | Jenny List | DESY | Germany |
| | Claude Vallée | CPPM – CNRS/IN2P3 | France |
| Steering Group Members | Ties Behnke | DESY | Germany |
| | James Brau | U. Oregon | United States |
| | Philip Burrows | U. Oxford | United Kingdom |
| | Dmitri Denisov | BNL | United States |
| | Francesco Forti | INFN-Pisa | Italy |
| | Keisuke Fujii | KEK | Japan |
| | Yuanning Gao | Peking U. | China |
| | Kajari Mazumdar | TIFR | India |
| | Patricia McBride | Fermilab | United States |
| | Timothy Nelson | SLAC | United States |
| | Mihoko Nojiri | KEK | Japan |
| | Frank Simon | MPP – MPG | Germany |
| | Phillip Urquijo | U. Melbourne | Australia |
| | Andrew White | UT Arlington | United States |
| | Aleksander Filip Żarnecki | U. Warsaw | Poland |
| Speaker's Bureau | Alain Bellerive | Carleton U. | Canada |
| | Ivanka Božović-Jelisavčić | U. Belgrade | Serbia |
| | Kiyotomo Kawagoe | Kyushu U. | Japan |
| Machine-Detector Interface Subgroup Conveners | Karsten Buesser | DESY | Germany |
| | Roman Pöschl | IJCLab – CNRS/IN2P3 | France |
| | Yasuhiro Sugimoto | KEK | Japan |
| Detector and Technology R&D Subgroup Conveners | Katja Krüger | DESY | Germany |
| | Petra Merkel | Fermilab | United States |
| | David Miller | U. Chicago | United States |
| | Marcel Vos | IFIC – U. Valencia | Spain |
| Software and Computing Subgroup Conveners | Frank Gaede | DESY | Germany |
| | Daniel Jeans | KEK | Japan |
| | Jan Strube | PNNL/U. Oregon | United States |
| Physics Potential and Opportunities Subgroup Conveners | Michael Peskin | SLAC | United States |
| | Aidan Robson | U. Glasgow | United Kingdom |
| | Junping Tian | U. Tokyo | Japan |

# SRF

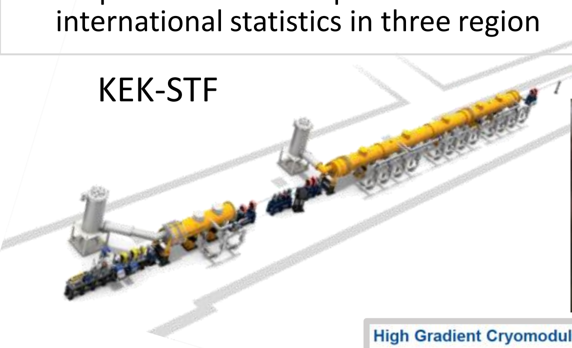
**2018-2021:**

- Achieve stable electric field E > 35 MV/m through US-Japan cooperation
  - Improvement of Nb material manufacturing process and properties (FG, MG, LG)
  - Improvement of surface treatment technology
    - Low temperature (10-20C) EP Two-step baking (75C and 120C) Optimization of cooling speed (flux expulsion)
- Cavity manufacturing efficiency improvement and dust prevention work automation Germany/France-Japan cooperation
- Beam acceleration demonstration KEK-STF, 33 MV/m
- High Gradient Cryomodule (HGC, FNAL) (in progress)
  - Aim to demonstrate 38 MV/m

Demonstration plan at ILC Pre-Lab (2022-)

- Preparation for mass production: Demonstration of international statistics in three region

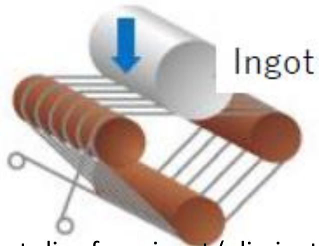
KEK-STF



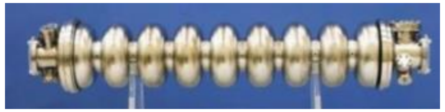
HGC（FNAL） aiming for performance beyond ILC specifications (in progress)

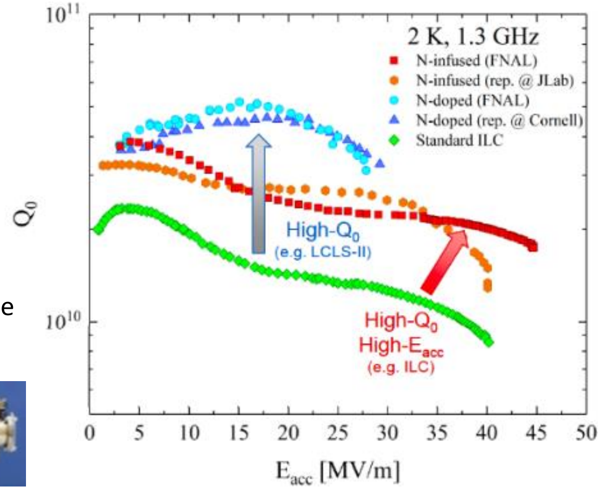

US-Japan: Improving Performance through Surface Treatment

Cost reduction by direct slicing materials

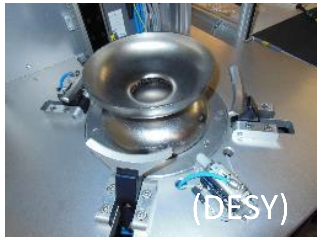



Direct slice from ingot (eliminates the rolling and mechanical polishing)

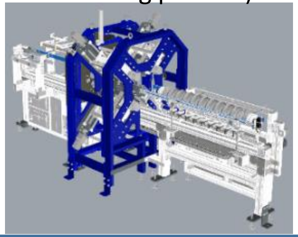




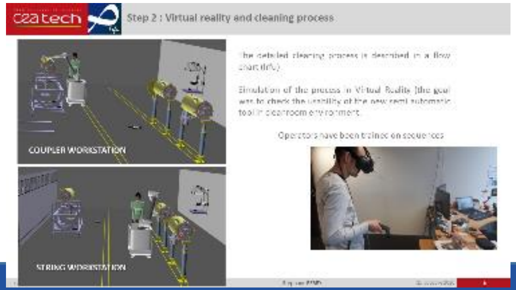

Germany-Japan: Improving efficiency in cavity manufacturing




Cavity Frequency Measurement System(Quality assurance for cavity manufacturing process)



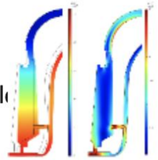
France-Japan ： Automation of Dust Prevention Work

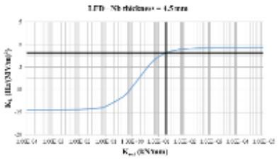


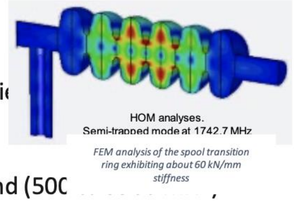
# SRF activities at INFN LASA: overview

Wide European capabilities in SRF – key projects EU-XFEL, ESS, PIP-II, HL-LHC – including Italy of course

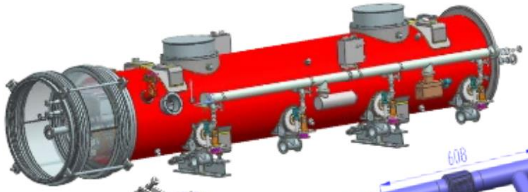
- **Design**
  - Cavities
  - Cryomodul
  - Ancillaries
- **Qualification**
  - Cavities
  - SRF Ancillari
- **Facilities**
  - RF Test Stand (500
  - ISO4-7 Clean Room (HPR, UPW, etc.)
  - Large Vertical Cryostat and advanced quench diagnostic
- **With Industry**
  - Fabrication of cavities and cryomodules
  - Mass Production of **European-XFEL** cavities and cryomodules (1.3 and 3.9 GHz)
    - **QA/QC**
    - **Technology transfer** (within XFEL contract)
  - Large Production of **ESS** Medium Beta Cavities
  - Upcoming Production of **PIP-II** LB650 Cavities

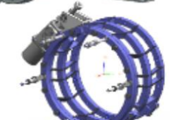


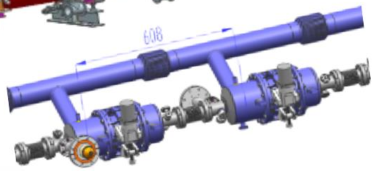


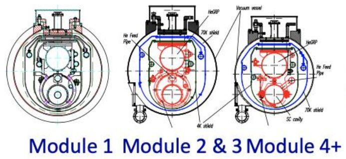


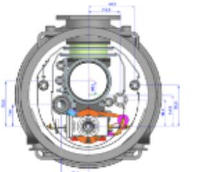

*E-XFEL 3.9 GHz cryomodule & TESLA cryomodule evolution*



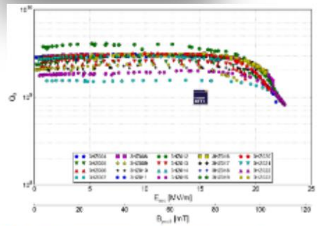




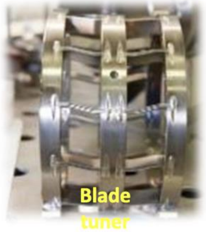

















# Progress in SRF

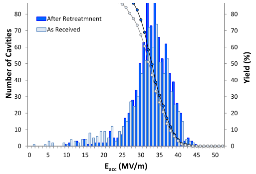
| ~ 2017 | 2018 ~ 2021 | Pre-lab |
|---|---|---|

~41 M$,285 FTE-yr

Cavity

Yield evaluation of cavities based on TDR

The mass production of European XFEL has reached ≥ 83% of the ILC specification yield (90%).



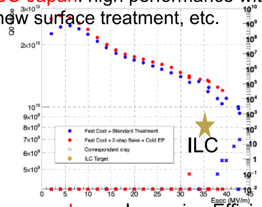

Euro-XFEL Operation (Europe)
~800 cavities/
~100 Modules

LCLS-II Construction (USA)
~280 cavities/
~35 Modules

Realized through international cooperation and procurement

High performance and cost reduction

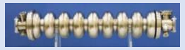
US-Japan: high performance with new surface treatment, etc.




Germany-Japan: Improving Efficiency in Cavity Manufacturing

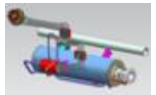
Final design is underway to comply with "High Pressure Gas Safety".

Cavity manufacturing, performance demonstration (Yield demonstration in three areas)

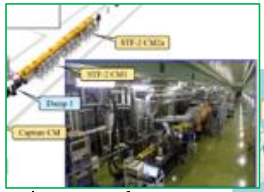


Cryomodule

Eng. design



Module assembly



Accelerator performance verification at KEK-STF2

Demonstration of cryomodule assembly, transfer, and performance

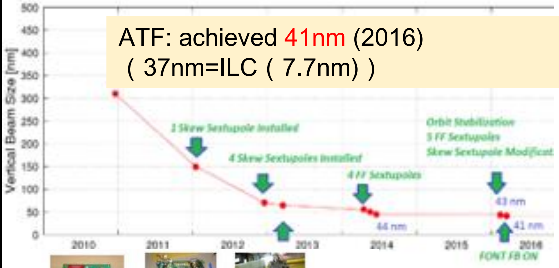

France-Japan: Automation of cavity cleaning

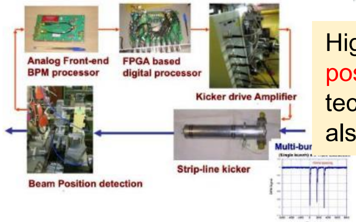
# Progress for final focus

| ~ 2017 | 2018 ~ 2021 | Pre-lab |
|---|---|---|

Tech. design completed
Spec. almost achieved

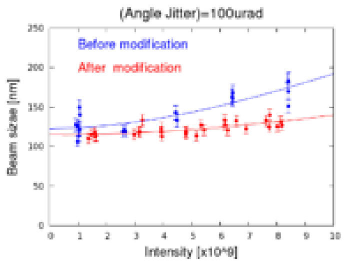
ATF: achieved 41nm (2016)
( 37nm=ILC ( 7.7nm) )




High-speed beam position control technology was also demonstrated.

Wakefield effect



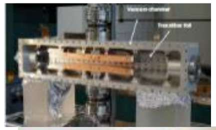

Wakefield effect was evaluated at ATF.
-confirm no serious problem at ILC
-demonstrate a technique to reduce the wakefield effect

ATF International Review (Committee)*
-The committee highly evaluated the achievements of ATF so far.
-The committee pointed out the importance of continuing research to contribute to the detailed design of the ILC final convergence.

* https://agenda.linearcollider.org/event/8626/

~2M$, 16FTE-yr

Detailed design
Stable operation demonstration



Modify the beam monitor system, etc. at ATF to demonstrate stable operation.

# Progress for positron source

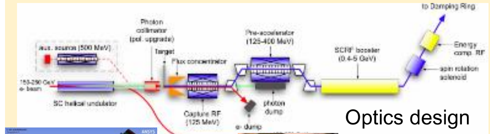
Plan A:Undulator scheme
Plan B:e-driven scheme (same tunnel)
Plan C:e-driven scheme (extra tunnel)

~ 2017 tech. design | 2018 ~ 2021 tech. verification | Pre-lab

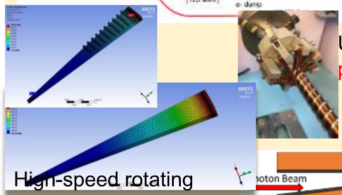
Technology selection

## Undulator scheme to obtain polarization

1.5 M$ 10FTE-yr



Optics design

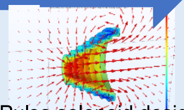


Undulator prototype

Photon dump design

High-speed rotating positron target, Technology Design

Ti target beam test

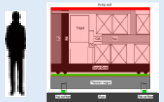



Pulse solenoid design

Next Steps:
evaluate both schemes by international cooperation

Practical Operation of Superconducting Helical Undulator (APS)

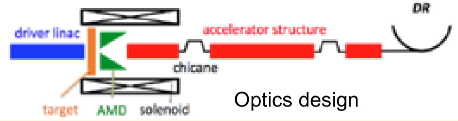
Long undulator operation at European XFEL



Target maintenance

## Conventional e-Driven

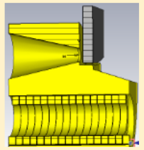
4.4 M$, 5FTE-yr



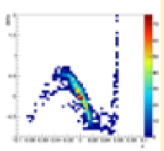

Optics design

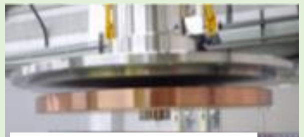
Target thermal simulation

Mag. focusing

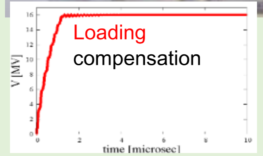


Paricle simulation



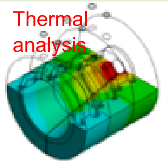


Target Prototyping Vacuum characteristics Testing

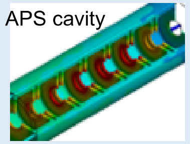



Loading compensation

Thermal analysis



APS cavity



RF stability test

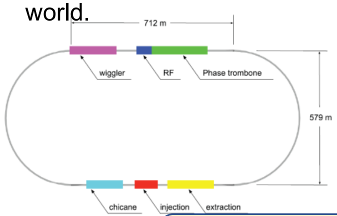
# Progress for DR

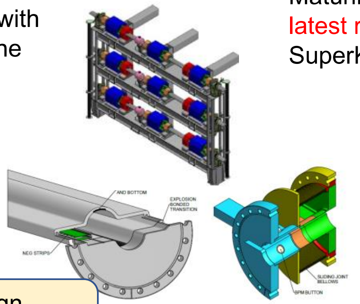
~ 2017 | 2018 ~ 2021 | Pre-lab

~2.5 M$,30 FTE-yr

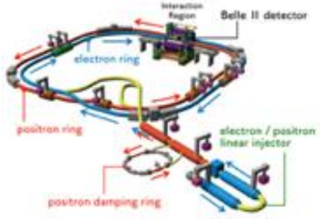
DR — Eng. design

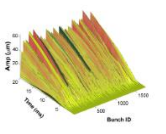
Design based on experience with circular accelerators around the world.

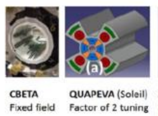


Maturing technology for beams in the latest ring accelerators such as SuperKEKB



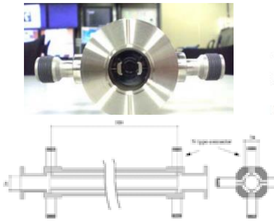



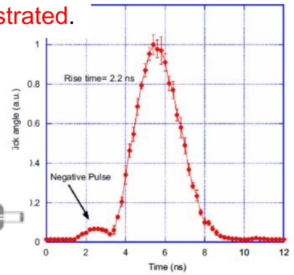



Final design

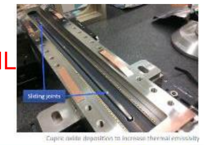
Inj./Ext. — Eng. Design Equipment verification

Beam extraction demonstrated.

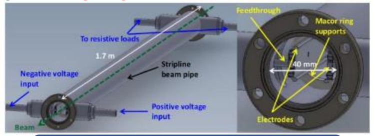




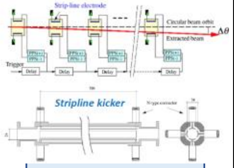

LBNL



CERN-CLIC



Fast kicker technology

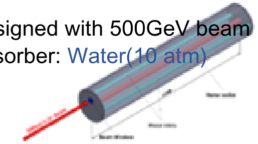



Stable op.

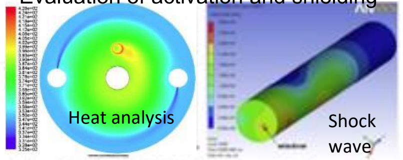
# Progress for beam dump

| ~ 2017 | 2018 ~ 2021 | Pre-lab |
|---|---|---|
| Basic design (by researchers abroad) | Design revalidation and specific facility design | ~3M$, 12FTE-yr Remote Maintenance |

Designed with 500GeV beam
Absorber: Water(10 atm)



Confirmation of safety by simulation
- Heat and stress in beam window, heat and shock waves in water
- Evaluation of activation and shielding

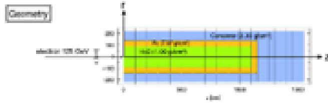


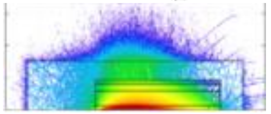

Consultations with beam target/dump experts from around the world beyond

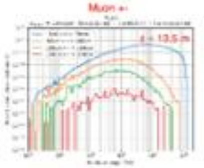
LHC beam dump

RADIATE collaboration

Specific design of radiation shield



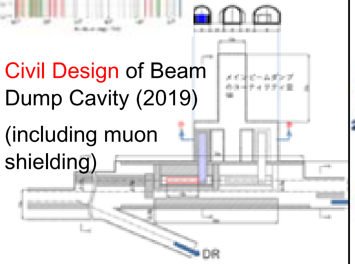





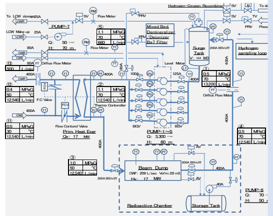
Design for shielding of muon particles generated by beam dump

Civil Design of Beam Dump Cavity (2019)

(including muon shielding)

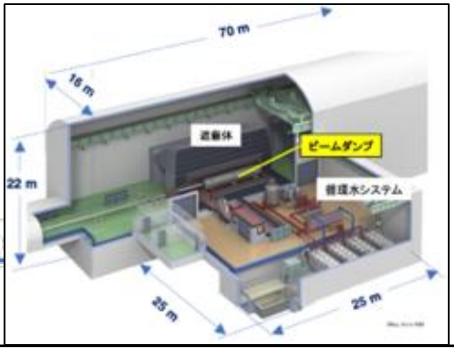



Beam Dump Water Circulation System Design (2020)



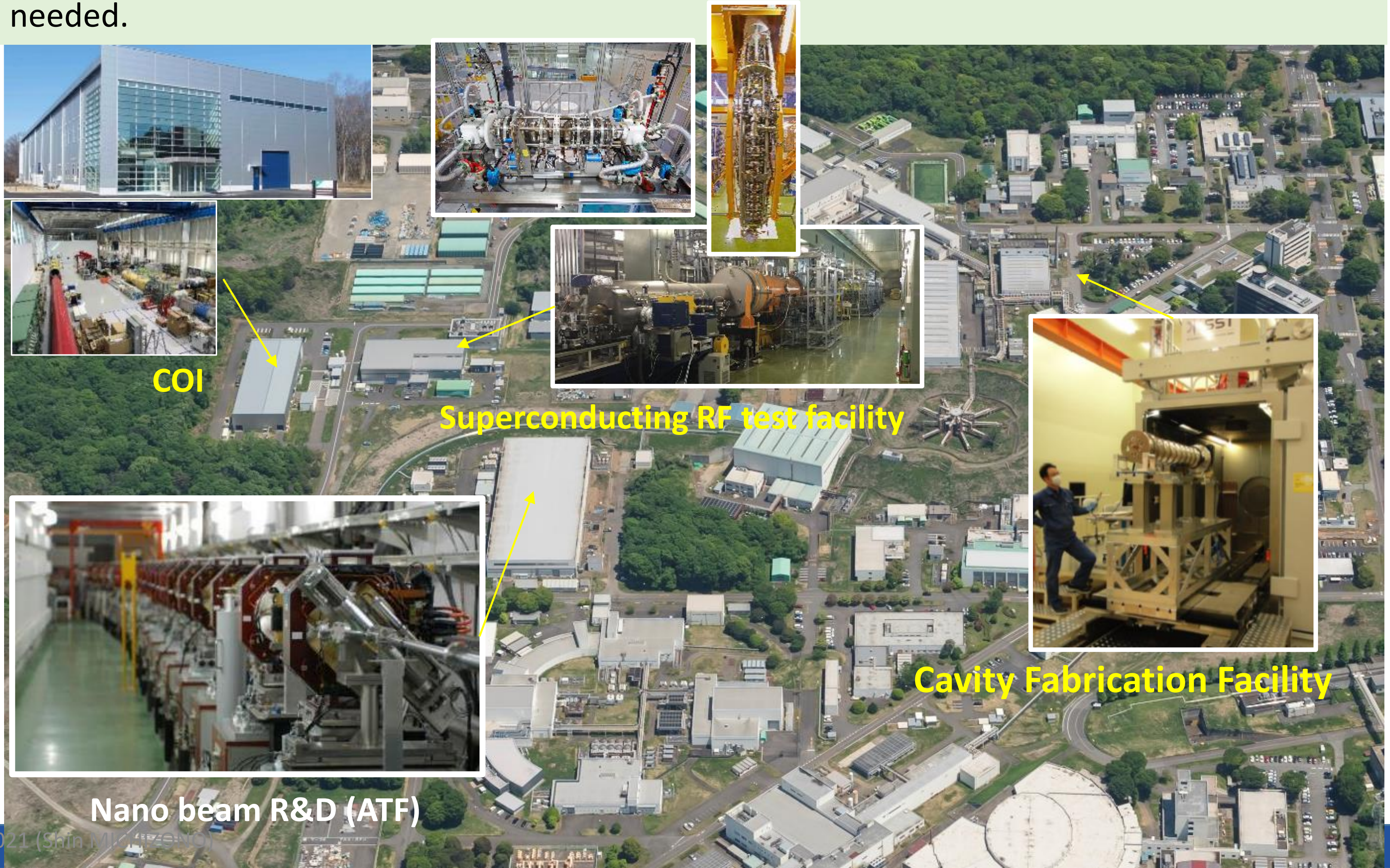
- ●Testing of main components of circulating water system
- ●Beam window replacement device
- ●Leakage countermeasures for radiating dump water
- ●Earthquake resistant design

Detailed system design (pursuit of safety design)



# ILC R&D facilities at KEK

In Europe and the U.S., basic facilities for the evaluation of the superconducting accelerator at the European XFEL and LCLS-II are in place, but in Japan, additional basic facilities are needed.

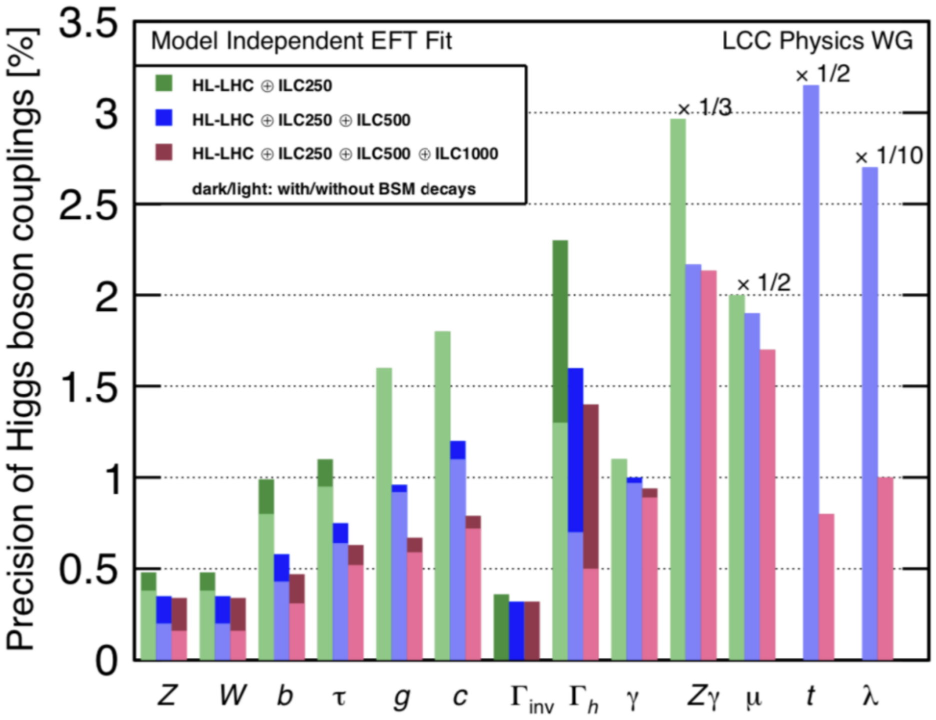


For the Higgs boson couplings, the ILC is expected to reach better than 1% precision on all of the major couplings predicted by the SM.

This potentially gives sensitivity to new particles in the multi-TeV region, beyond the reach of direct searches at the LHC. It is a new window into physics beyond the Standard Model.

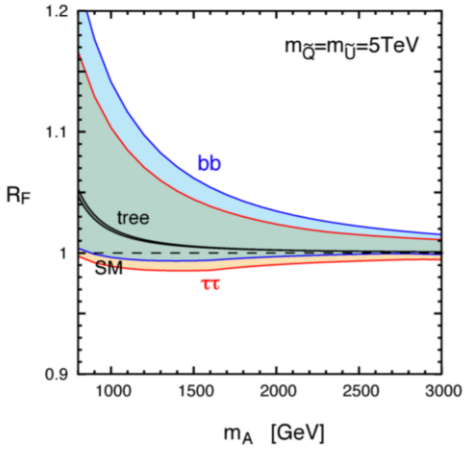
The expectations for linear and circular Higgs factories are almost identical; see arXiv:1903.01629 for a detailed discussion.

ILC projected precision

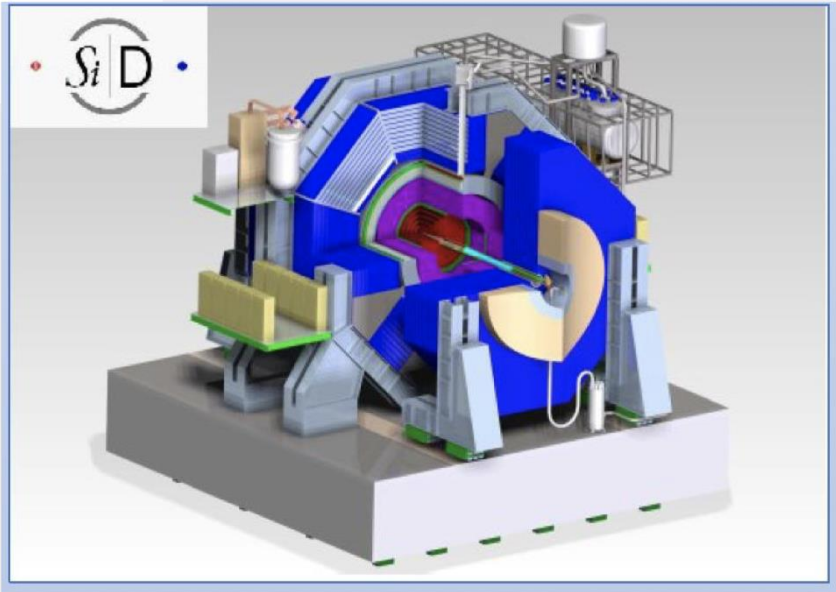


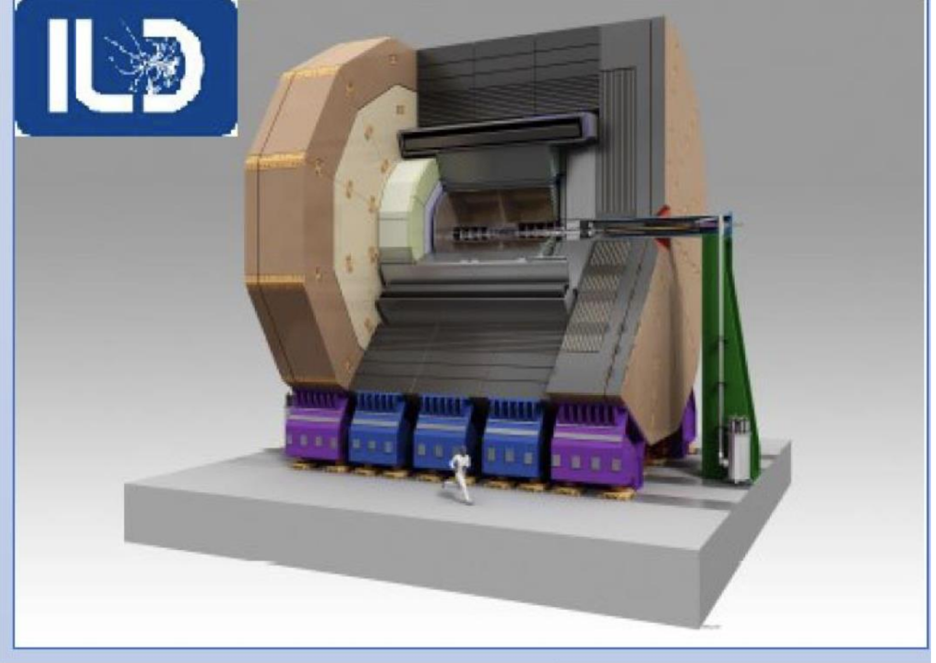

ILC, arXiv:1908.11299

range of predictions for $\Gamma(h \to f\bar{f})/(\mathrm{SM})$ in minimal SUSY




Endo, Moroi, Nojiri arXiv:1502.03959




**SiD Detector**

- 5 T field
- More compact
- All Si

Track momentum resolution: $\sigma_{1/p} < 5 \cdot 10^{-5}\ \mathrm{GeV}^{-1}$ CMS/40

Impact parameter resolution: $\sigma_d < 5\mu m \oplus 10\mu m \frac{1\ \mathrm{GeV}}{p\ \sin^{3/2}\Theta}$ CMS/4

Jet energy resolution: $\sigma_E/E = 3 - 4\%$ (for highest jet energies) ATLAS/2

Hermecity: $\Theta_{min} = 5$ mrad ATLAS/3

**ILD Detector**

- 3.5 T field
- Optimized for CM energies 90 GeV - 1 TeV
- Si/gaseous tracking
- Particle flow calorimetry
- Mature design and available technologies

From CEPC WS 2021, I.Bozovic

# Resources

**The Proposal for the ILC Preparatory Laboratory is now published: https://arxiv.org/abs/2106.00602**

"This proposal is intended to provide information to the laboratories and governmental authorities interested in the ILC project to allow them to consider participation"

- **Several announcements, e.g http://newsline.linearcollider.org/2021/06/01/ilc-preparatory-laboratory-proposal-released/**
- **Endorsed by IFCA, (being) sent to IDT WGs, ICFA, ECFA and Lab directors**
- Sent to MEXT (in translated form)

The Technical Preparation Document describing the 18 WPs is at: (https://zenodo.org/record/4742019#.YLfkLi0RrqY)

And a document (in Japanese) addressing, "key issues related to the ILC project", as identified in various reviews, is also sent

Further information about Japanese funding needs also provided

# Deliberations of Prelab plan

## ILC Expert Panel reopened by MEXT

Preamble of the note to request to reopen the ILC Expert Panel (July 2021)

IDT, a working group of physicists formed by the international research community, has recently published a proposal for the ILC Prelab, and the domestic research community has submitted the status report describing the progress of major issues related to the ILC program. At this occasion, the ILC Expert Panel will be resumed in order to do follow-up discussions from a professional viewpoint regarding the progress in the entire ILC plan and to organize the latest information.

Panel members
14 scientists from various research fields, astronomy, civil engineering, particle accelerator, high energy physics, nuclear physics, journalist, public relations,…

Schedule
July 29 First meeting
Oct. 14 and 18 Presentations by the Japanese ILC community and IDT
Report will be published by the end of 2021 or March 2022 at the latest.

More recent:
- 4th meeting Monday this week (Q/A)
- Summary of meeting MEXT, US, UK, Germany, France that took place 15.10 also released this week

**October 26, 2021**

**Masanori Yamauchi**
**KEK**

MEXT is starting international discussion with the US and European governments

Letter from the MEXT Minister, Hagiuda, to ICFA (May 31, 2021)

Therefore, I recognize that it is appropriate to continue discussions regarding the ILC project between administrative officials of the relevant countries at the right time, as well as to pay attention to researchers' efforts to deal with the remaining challenges.

Message from MEXT to ICFA (July 14, 2021)

Recognizing that the publication of the IDT's report is an opportunity, in order to explain MEXT's position on the ILC project and to exchange views with other participants, MEXT will begin to contact the US and European counterparts this month for having a discussion on the project around autumn. ….. it would be important that communications between particle physicists and their government authorities in the US and European countries improve.

We are expecting that outcome of the first meeting will be announced soon. The international physics community is kindly requested to have opportunities for communications with each government to promote understanding.

# ILCX workshop October 2021

ILCX2021 ILC Workshop on Potential Experiments

ILC Workshop on Potential Experiments (ILCX2021)

26–29 Oct 2021
Fully online format
Asia/Tokyo timezone

Enter your search term

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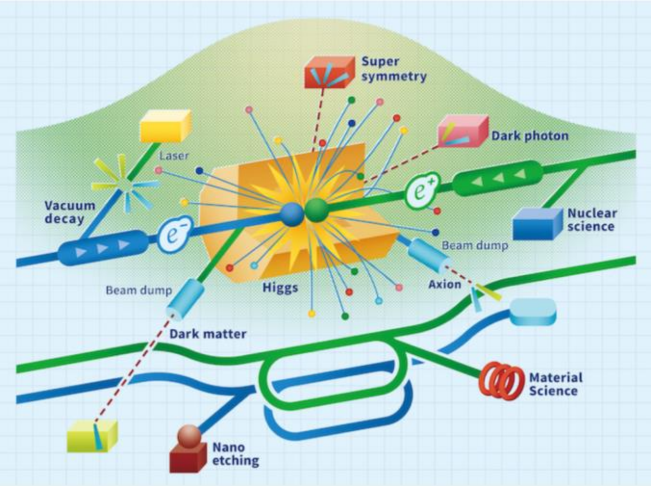
- Scientific Programme
- Timetable
- Sessions and Timezone
  - Zoom Connection
  - SpatialChat Lounge
- Contribution List
- Speaker List
- Participant List
- Workshop Poster
- Information from Iwate
- Organization
- Registration
- Call for Abstracts
- Second Circular
- First Circular

ILCX2021 Local Organizing Committee

ilcx2021@ml.post.kek.jp




The workshop organizing committee is the Executive Board of IDT, and the program committee is the Steering Group of Working Group 3 (Physics and Detectors) of IDT.

ILCX2021 is hosted by IDT, KEK and JAHEP ILC Steering Panel.

## Industry Forum at the ILCX2021: Oct. 26, 2021

**17:00-21:00 JST Japan (10:00 – 14:00 CET Europe, 4:00-8:00 EDT US)**

Indico link: https://agenda.linearcollider.org/event/9211/sessions/5325/#20211026

Zoom: https://us02web.zoom.us/j/87822164767 (passcode: "ilcx2021")

The goal of the event is to strengthen international cooperation between academia and industrial partners involved in the development of advanced accelerator technologies and instrumentation techniques

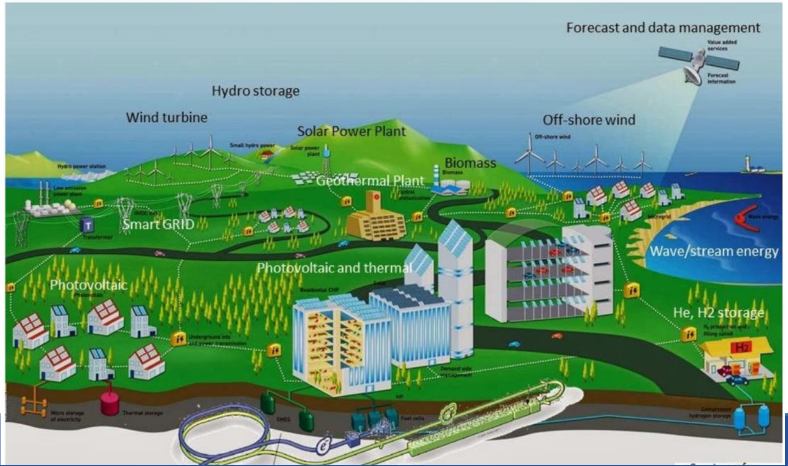
17.00-17.10 - Introduction
17.10-17.30 - Overview of the AAA Activities (Tohru Takahashi, Hiroshima University/AAA)
17.30-17.55 - Development of positron source components using HIP technologies through industry-government-academia collaboration (Yutaka Nagasawa, Metal Technology Co. Ltd.)
17.55-18.15 - The possible collaborations on ILC Pre-lab in accelerator technologies from China from Academic and industries (Jie Gao, IHEP, China)
18.15-18.35 - Acceleration technology: A Sustainable Approach to Cleaner Indian Rivers (Raghava Varma, Indian Institute of Technology Bombay)
18.35-18.50 Coffee Break
18.50-19.10 - ILC industry capabilities in Europe, some examples from recent SRF projects (Steinar Stapnes/CERN - Benno List/DESY)
19.10-19.30 - Document on industrial interests on ILC in Spain (Erik Fernández, INEUSTAR)
19.30-20.00 - CERN Industrial Experience (Christina Lara Arnaud, CERN)
20.00-20.30 - Review of Accelerator Technologies in the US (Eric Colby, US DOE-SC-ARDAP)

## Conclusions

- Fixed-target experiments at ILC beam dumps offer access to a complementary regime: <10 GeV mass scale, <<1 coupling strength
- Motivated physics models populate this landscape: Dark Matter, Axion-Like Particles, flavor gauge bosons, … ILC Experiments have interesting sensitivity
- Electron-laser collisions can be used to probe strong-field QED plasma
- Photon beams (from e-laser or positron source) can be used to search for ALPs
- Far detectors (on or under ground) may extend search for long-lived particles (LLP's) produced at the main IP
- Opportunities to broaden ILC physics program in exciting new directions, often at a modest added fractional cost and parasitic to the main physics program

Beyond collider physics: https://agenda.linearcollider.org/event/9211/contributions/49237/attachments/37575/58892/ILC-X_sessionO_summary.pdf

ILC center futuristic view



# Physics Potential:
# Multi-TeV stages (example from CLIC)

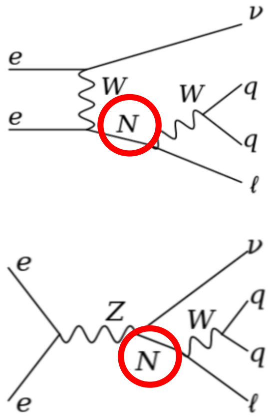
## ◆ Ongoing studies on new physics searches

**Search for heavy neutrinos**

◆ e+e- -> Nν -> qqlν signature allows full reconstruction of N

◆ BDT separates signal from SM; beam backgrounds included.

◆ cross-section limits converted to mass ($m_N$) coupling ($V_{lN}$) plane



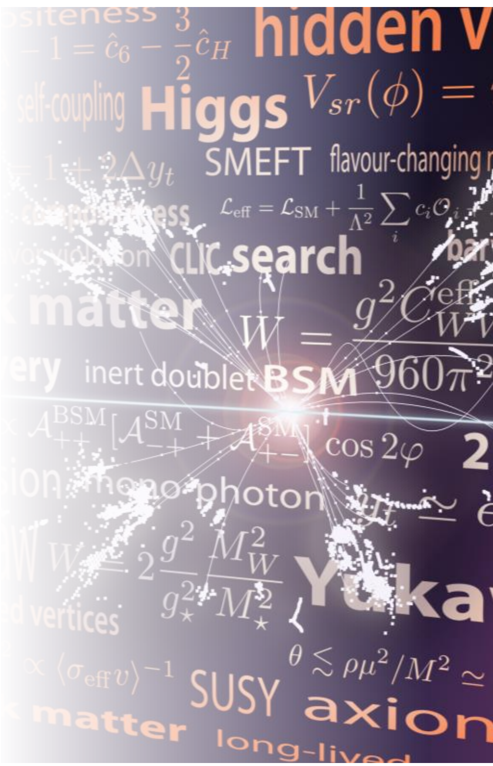

**Dark matter using mono-photon signature at 3TeV,** e+e- -> XXγ

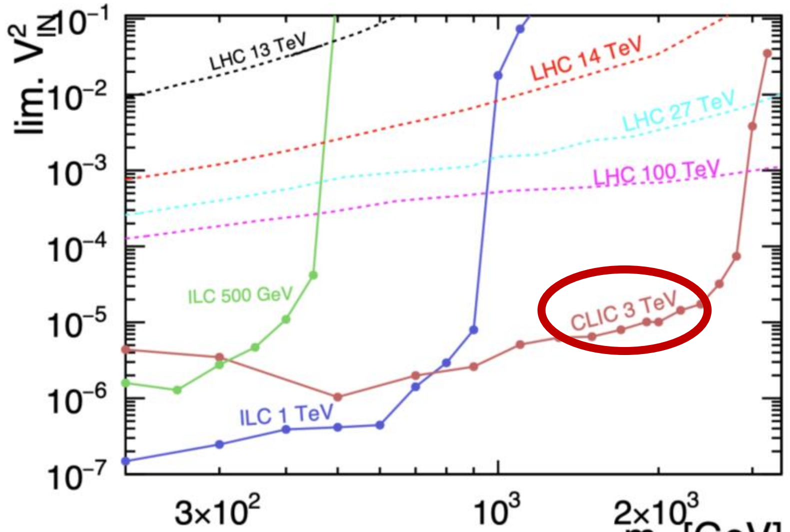
◆ New study using ratio of electron beam polarisations to reduce systematics

◆ Exclusions for simplified model with mediator Y and DM particle X

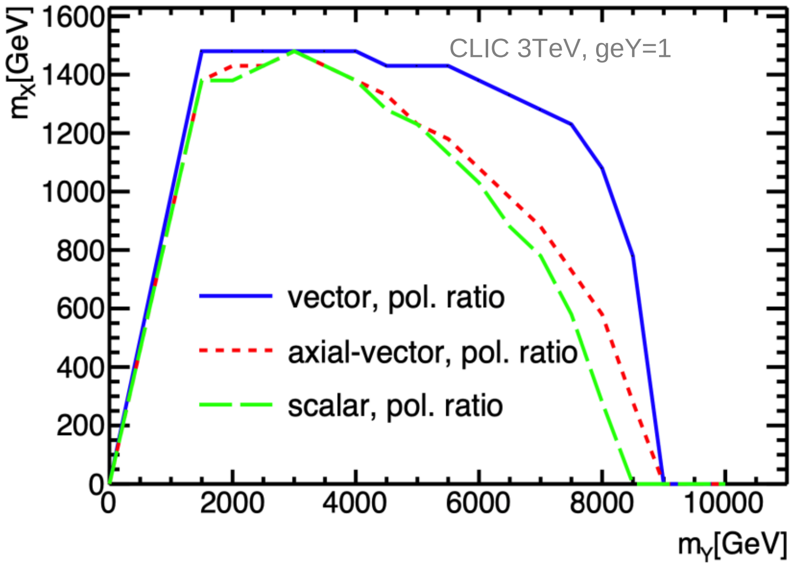
◆ For benchmark mediator of 3.5TeV, photon energy spectrum discriminates different DM mediators & allows 1TeV DM particle mass measurement to ~1%

[https://arxiv.org/abs/2103.06006](https://arxiv.org/abs/2103.06006)

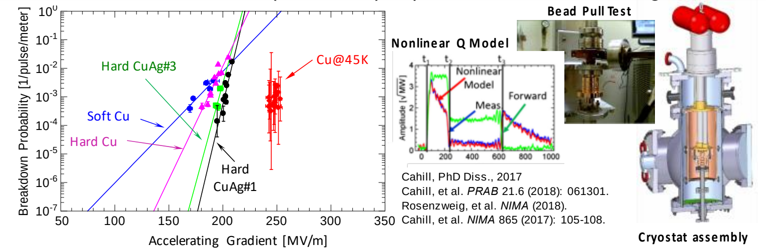




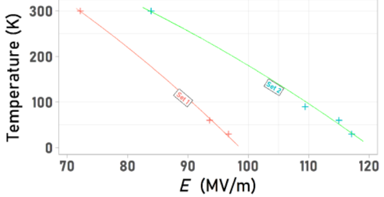

LHC analysis: [1812.08750], different assumption $V_{eN} = V_{mN} \neq V_{\tau N} = 0$

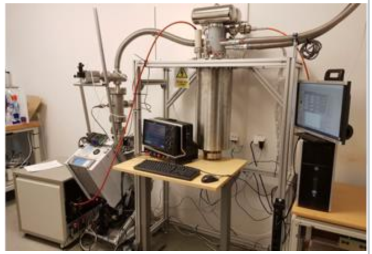


# Pushing the RF technologies – R&D

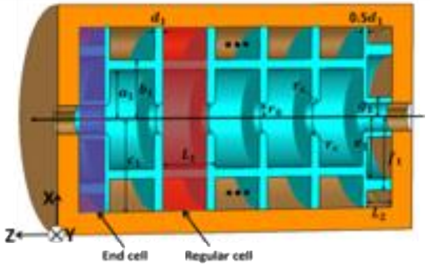



Cryo-cooled copper cavity, SLAC

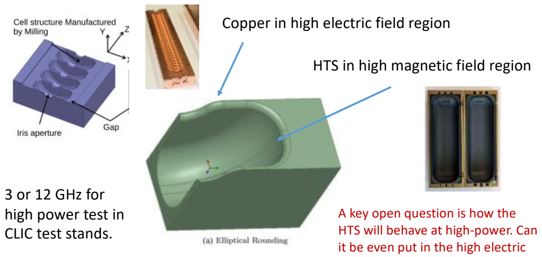


Cryo-cooled copper pulsed dc electrodes, Uppsala/CERN




Implementation



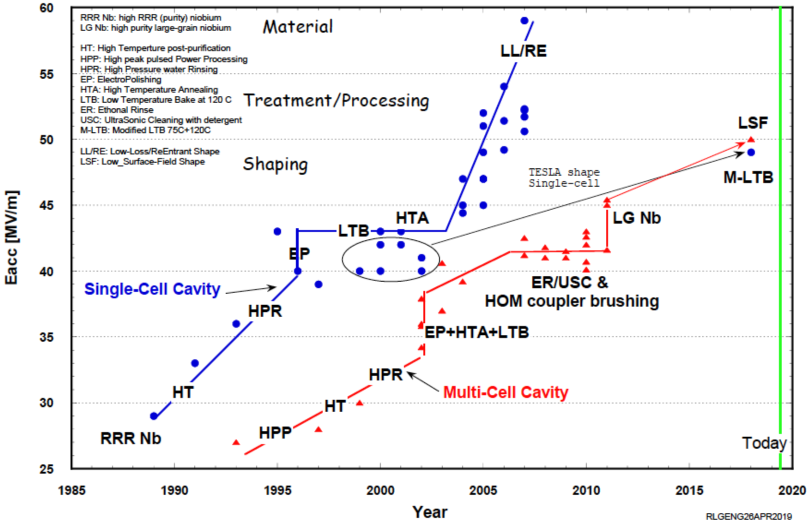

3 or 12 GHz for high power test in CLIC test stands.

A key open question is how the HTS will behave at high-power. Can it be even put in the high electric field region?

Cryogenic systems extended: Combining high-gradients in cryo-copper and high-temperature superconductors for high-efficiency and reduced peak RF power requirements.

**Multi-TeV energies:**

- High gradient
- high wall-plug to beam efficiency
- nanobeam parameters increasingly deman




https://arxiv.org/pdf/2105.12276.pdf

**Optimization of a traveling wave superconducting radiofrequency cavity for upgrading the International Linear Collider**

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*FNAL, Batavia, IL 60510, U.S.A.*

The Standing Wave (SW) TESLA niobium-based superconducting radio frequency structure is limited to an accelerating gradient of about 50 MV/m by the critical RF magnetic field. To break through this barrier, we explore the option of niobium-based traveling wave (TW) structures. Optimization of TW structures was done considering experimentally known limiting electric and magnetic fields. It is shown that a TW structure can have an accelerating gradient above 70 MeV/m

# Summary and thanks

- High Energy Linear Colliders based on cold or warm RF technologies is very feasible (cost, power, interesting timescales, footprint)
- Any region can in principle build a LC (even though we normally associate ILC with Japan and CLIC with Europe) – more precisely: any region can host a LC build as an international project
- Very interesting also in my view because a LC based Higgs-factory keep ALL options and timescales open for the harder problem of reaching multi-TeV lepton colliders (by improved RF in a LC, or with a muon collider) or a ~100 TeV scale hadron collider

- Thanks to many CLIC and ILC accelerator colleagues for slides and input, the ILC slides in most cases from Shin Michizono (but also many others), and the CLICdp slides compiled by Aidan Robson