ILC + CLIC status and prospects

Philip Burrows

Oxford University

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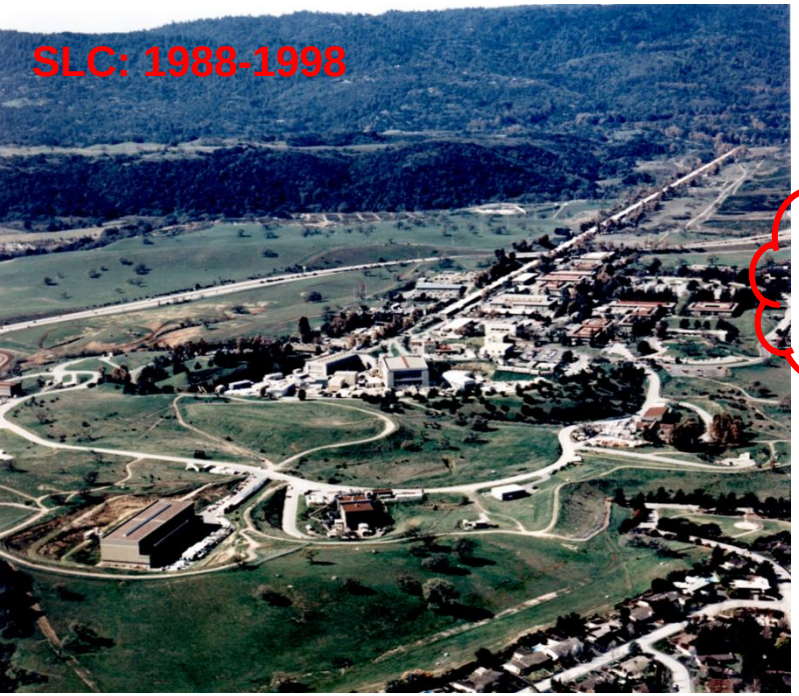
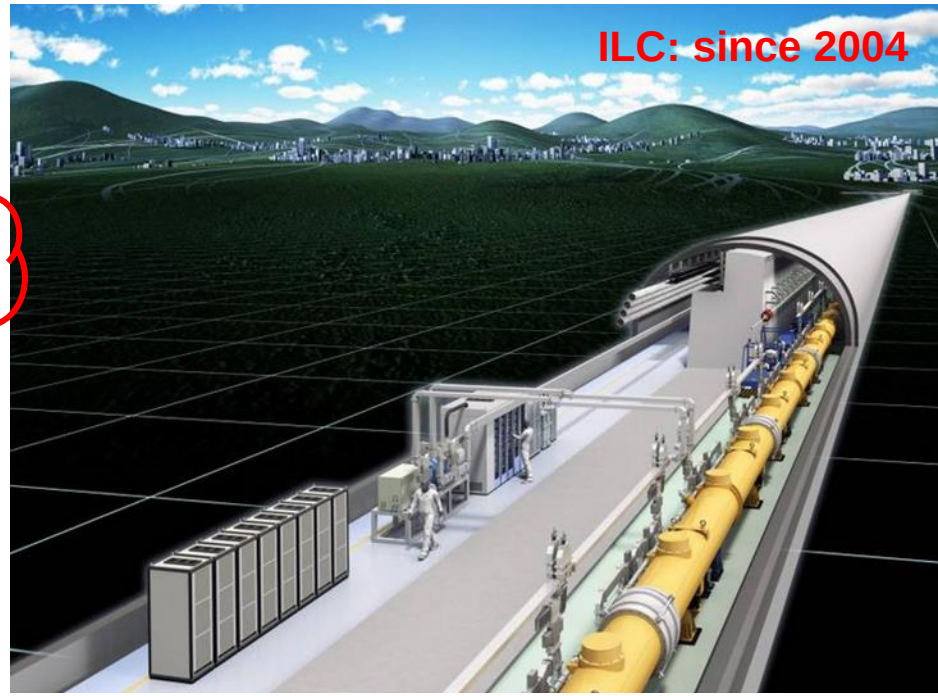
On behalf of the ILC and CLIC teams

ILC: https://linearcollider.org
CLIC: https://clic.cern

Linear Colliders



NLC
JLC
TESLA





Outline

Focus on accelerator projects

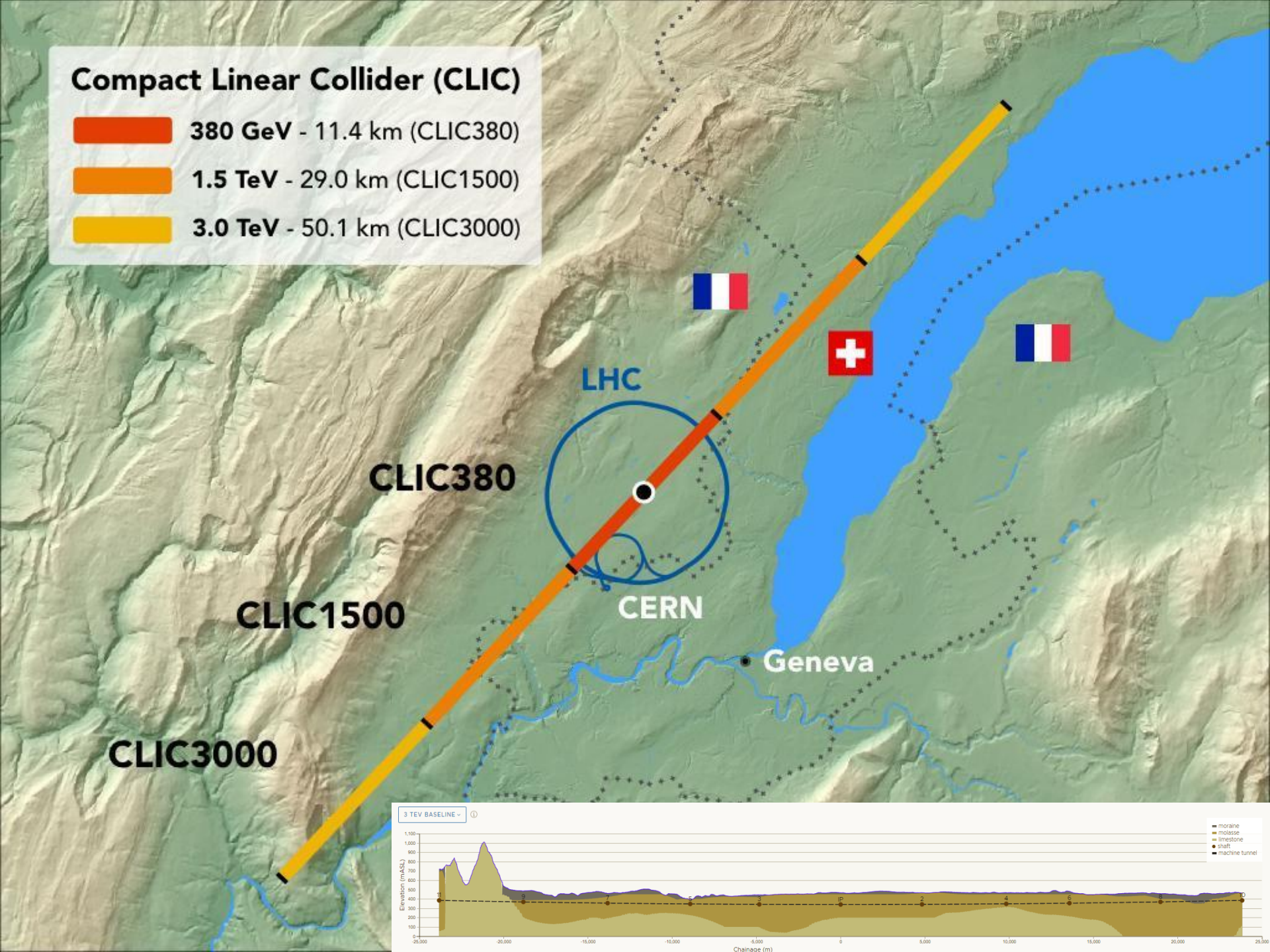
For detector R&D see following talks

- **Project overview**
- **Ongoing developments**
- **Status of project preparation**
- **Summary**

CLIC overview

- **Timeline:** e+e- linear collider at CERN for the era beyond HL-LHC
- **Compact:** novel and unique two-beam accelerating technique based on high-gradient room temperature RF cavities:

  first stage: 380 GeV, ~11km long, 20,500 cavities
- **Expandable:** staged collision energies from 380 GeV (Higgs/top) up to 3 TeV


Compact Linear Collider (CLIC)
380 GeV - 11.4 km (CLIC380)
1.5 TeV - 29.0 km (CLIC1500)
3.0 TeV - 50.1 km (CLIC3000)
LHC
CLIC380
CLIC1500
CLIC3000
CERN
Geneva
3 TEV BASELINE
Elevation (mASL)
Chainage (m)
moraine
molasse
limestone
shaft
machine tunnel

CLIC overview

- **Timeline:** e+e- linear collider at CERN for the era beyond HL-LHC
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  first stage: 380 GeV, ~11km long, 20,500 cavities
- **Expandable:** staged collision energies from 380 GeV (Higgs/top) up to 3 TeV

- Conceptual Design Report published in 2012
- Project Implementation Plan released 2018

  Cost: 5.9 BChF for 380 GeV (stable w.r.t. CDR)

  Power: 168 MW at 380 GeV (significantly reduced since CDR)

- Comprehensive Detector and Physics studies

CLIC Collaborations

https://clic.cern

CLIC accelerator:

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

CLIC detector and physics (CLICdp):

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

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





CLIC Collaborations



CLIC European Strategy Inputs

http://clic.cern/european-strategy


The Compact Linear e+e− Collider (CLIC): Accelerator and Detector

Input to the European Particle Physics Strategy Update on behalf of the CLIC and CLICdp Collaborations

18 December 2018

Abstract


The Compact Linear e+e− Collider (CLIC): Physics Potential

Input to the European Particle Physics Strategy Update on behalf of the CLIC and CLICdp Collaborations

18 December 2018

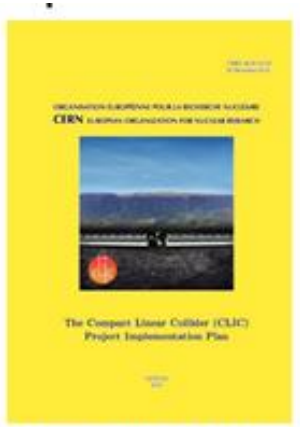
Abstract



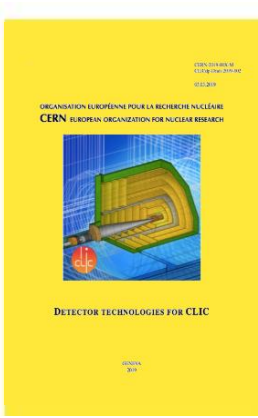
CERN-2018-005-M



CERN-2018-009-M



CERN-2018-010-M



CERN-2019-001

Also engaged with Snowmass planning process

CLIC Snowmass Inputs

Several LoIs have been submitted on behalf of CLIC and CLICdp

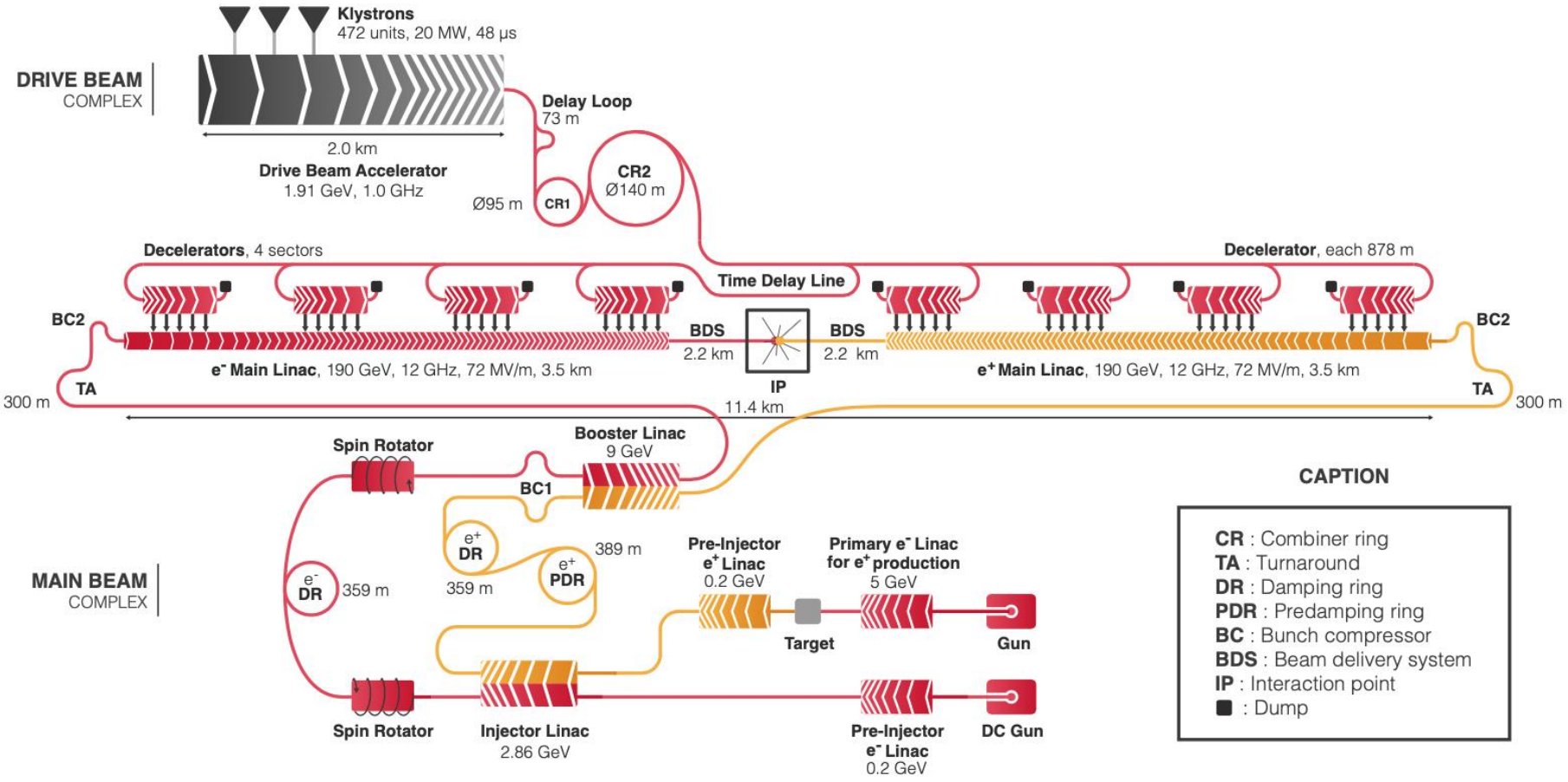
The CLIC accelerator study: Link
Beam-dynamics focused on very high energies: Link
The physics potential: Link
Detector: Link

CLIC parameters

Table 1.1: Key parameters of the CLIC energy stages.

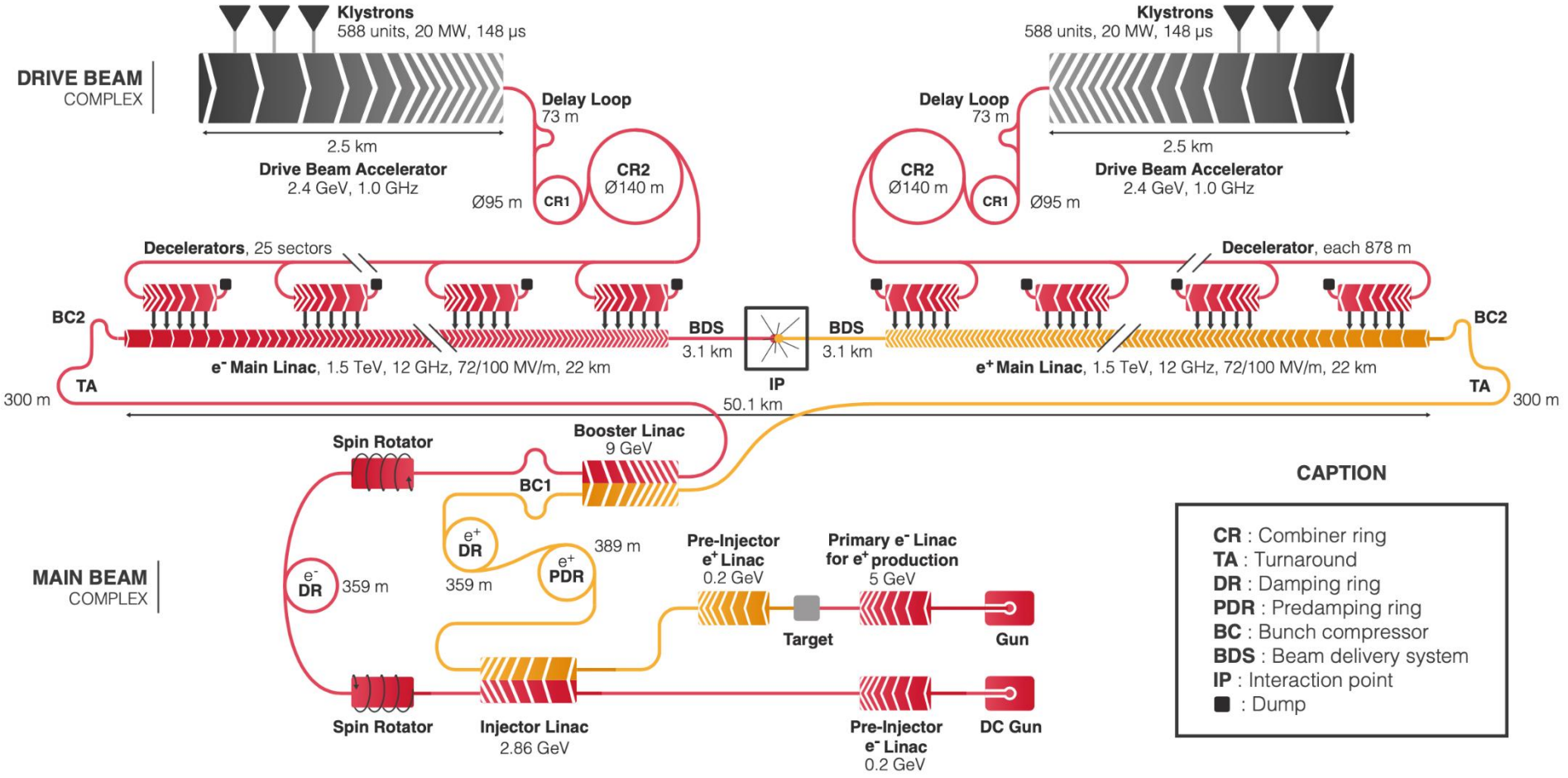
Parameter	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	GeV	380	1500	3000
Repetition frequency	Hz	50	50	50
Nb. of bunches per train		352	312	312
Bunch separation	ns	0.5	0.5	0.5
Pulse length	ns	244	244	244
Accelerating gradient	MV/m	72	72/100	72/100
Total luminosity	$1\times10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$	2.3	3.7	5.9
Lum. above 99 % of $\sqrt{s}$	$1\times10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$	1.3	1.4	2
Total int. lum. per year	fb^{-1}	276	444	708
Main linac tunnel length	km	11.4	29.0	50.1
Nb. of particles per bunch	1×10^{9}	5.2	3.7	3.7
Bunch length	µm	70	44	44
IP beam size	nm	149/2.0	~60/1.5	~40/1
Final RMS energy spread	%	0.35	0.35	0.35
Crossing angle (at IP)	mrad	16.5	20	20

CLIC 380 GeV layout



Baseline electron polarisation ±80%

CLIC 3 TeV layout



Baseline electron polarisation ±80%

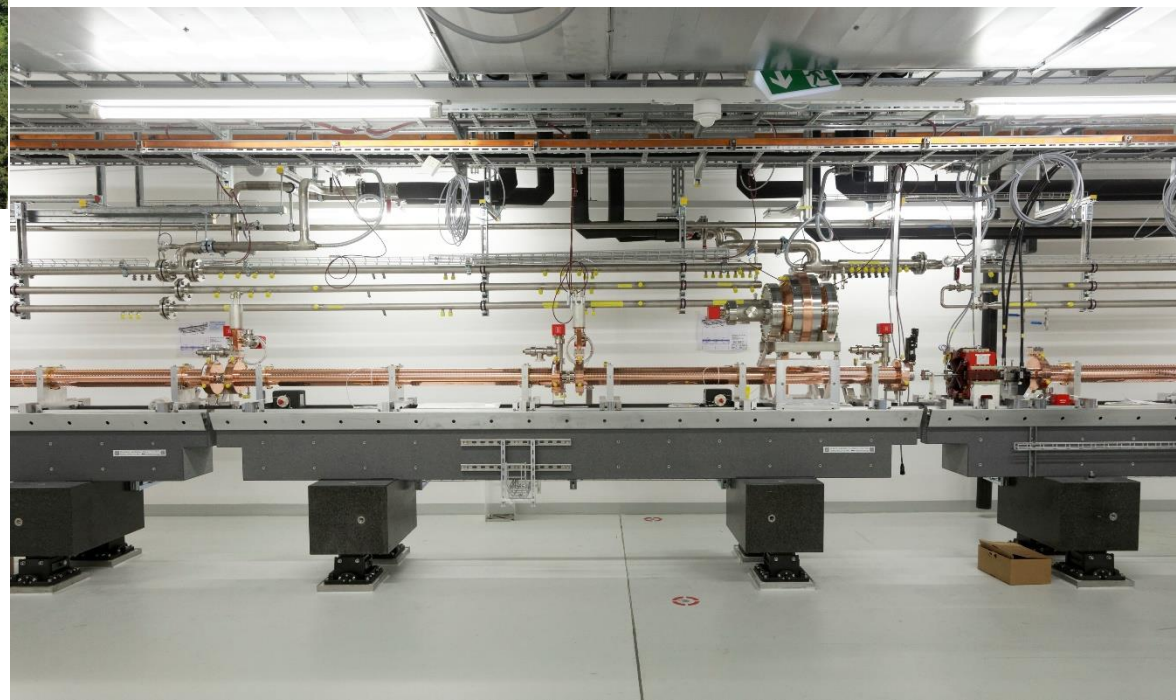
SwissFEL



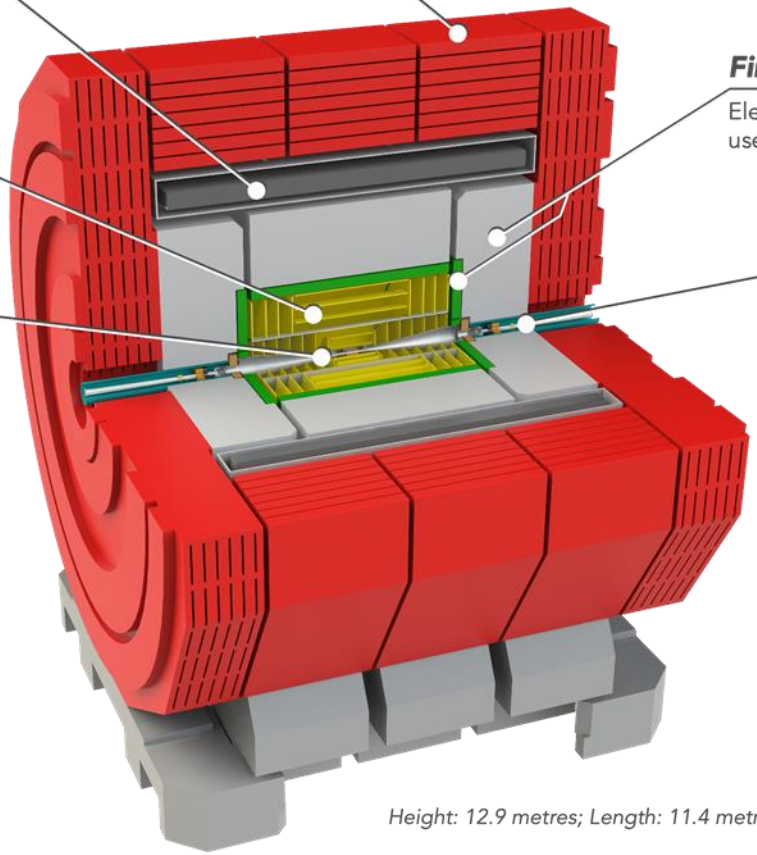




- 104 x 2m-long C-band structures (beam → 6 GeV @ 100 Hz)
- Similar um-level tolerances
- Length ~ 800 CLIC structures



CLIC detector



CLIC accelerator studies 2021-25





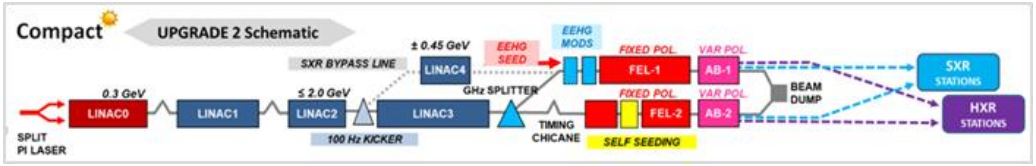
X-band technology:

- Design and manufacturing of X-band structures and components
- Study structures breakdown limits and optimization, operation and conditioning
- Baseline verification and explore new ideas
- Assembly and industry qualification
- Structures for applications, FELs, medical, etc

Technical and experimental studies, design and parameters:

- Module studies (see some targets for development below)
- Beamdynamics and parameters: Nanobeams (focus on beam-delivery), pushing multi TeV region (parameters and beam structure vs energy efficiency)
- Tests in CLEAR (wakefields, instrumentation) and other facilities (e.g. ATF2)
- High efficiency klystrons
- Injector studies suitable for X-band linacs (coll. with Frascati)





Application of X-band technology (examples):

- A compact FEL (CompactLight: EU Design Study 2018-21)
- Compact Medical linacs (proton and electrons)
- Inverse Compton Scattering Source (SmartLight)
- Linearizers and deflectors in FELs (PSI, DESY, more)
- 1 GeV X-band linac at LNF
- eSPS for light dark matter searches (within PBC)

More information: CLIC mini week (1.10.2020)

Power + energy

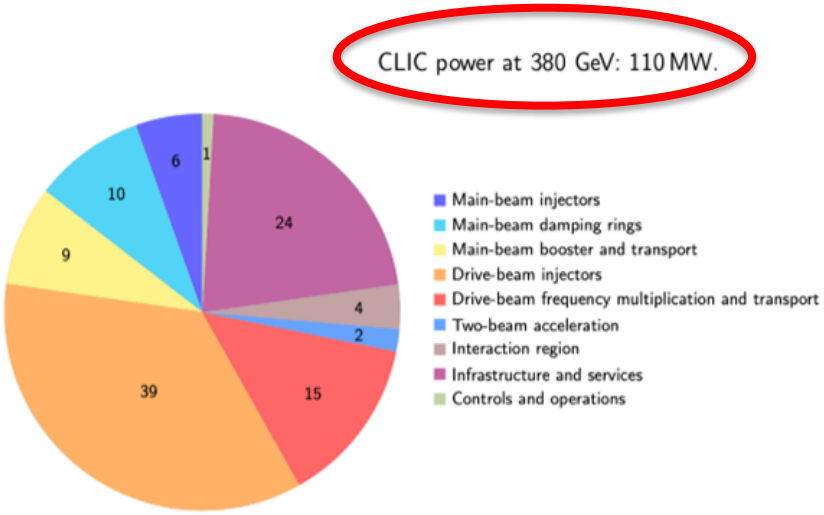


Fig. 4.8: Breakdown of power consumption between different domains of the CLIC accelerator in MW at a centre-of-mass energy of 380 GeV. The contributions add up to a total of 110 MW. (image credit: CLIC)

Table 4.2: Estimated power consumption of CLIC at the three centre-of-mass energy stages and for different operation modes. The 380 GeV numbers are for the drive-beam option and have been updated as described in Section 4.4, whereas the estimates for the higher energy stages are from [57].

Collision energy [GeV]	Running [MW]	Standby [MW]	Off [MW]
380	110	25	9
1500	364	38	13
3000	589	46	17

Power estimate bottom-up (concentrating on 380 GeV systems)

Very large reductions since CDR:

- **better estimates of nominal settings**
- **much more optimised drive-beam complex**
- **more efficient klystrons**
- **optimised injectors**
- **damping ring RF significantly reduced**
- **recent L-band klystron studies**

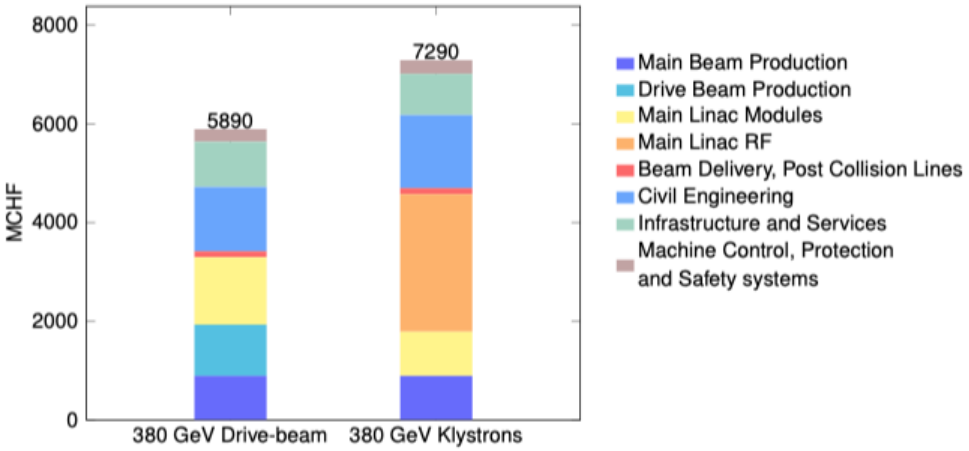
0.6 TWh/yr (50% of current CERN)

Further savings possible: high-efficiency klystrons, permanent magnets …
Looking also more closely at 1.5 and 3 TeV numbers

Cost (380 GeV)

Accelerator re-costed bottom-up

- **Methods and costings validated at review November 2018 – similar to LHC, ILC, CLIC CDR**
- **Technical uncertainty and commercial uncertainty estimated**



Domain	Sub-Domain	Cost [MCHF] Drive-Beam	Klystron
Main Beam Production	Injectors	175	175
	Damping Rings	309	309
	Beam Transport	409	409
Drive Beam Production	Injectors	584	—
	Frequency Multiplication	379	—
	Beam Transport	76	—
Main Linac Modules	Main Linac Modules	1329	895
	Post decelerators	37	—
Main Linac RF	Main Linac Xband RF	—	2788
Beam Delivery and Post Collision Lines	Beam Delivery Systems	52	52
	Final focus, Exp. Area	22	22
	Post-collision lines/dumps	47	47
Civil Engineering	Civil Engineering	1300	1479
Infrastructure and Services	Electrical distribution	243	243
	Survey and Alignment	194	147
	Cooling and ventilation	443	410
	Transport / installation	38	36
Machine Control, Protection and Safety systems	Safety system	72	114
	Machine Control Infrastructure	146	131
	Machine Protection	14	8
	Access Safety & Control System	23	23
Total (rounded)		**5890**	**7290**

CLIC 380 GeV Drive-Beam based: 5890^{+1470}_{-1270} MCHF;

CLIC 380 GeV Klystron based: 7290^{+1800}_{-1540} MCHF.

Cost - II

Other cost estimates:

Construction:

- **Labour estimate: ~11500 FTE for 380 GeV**
- **From 380 GeV to 1.5 TeV, add 5.1 BCHF (drive-beam RF upgrade and lengthening of linacs)**
- **From 1.5 TeV to 3 TeV, add 7.3 BCHF (second drive-beam complex and lengthening of linacs)**

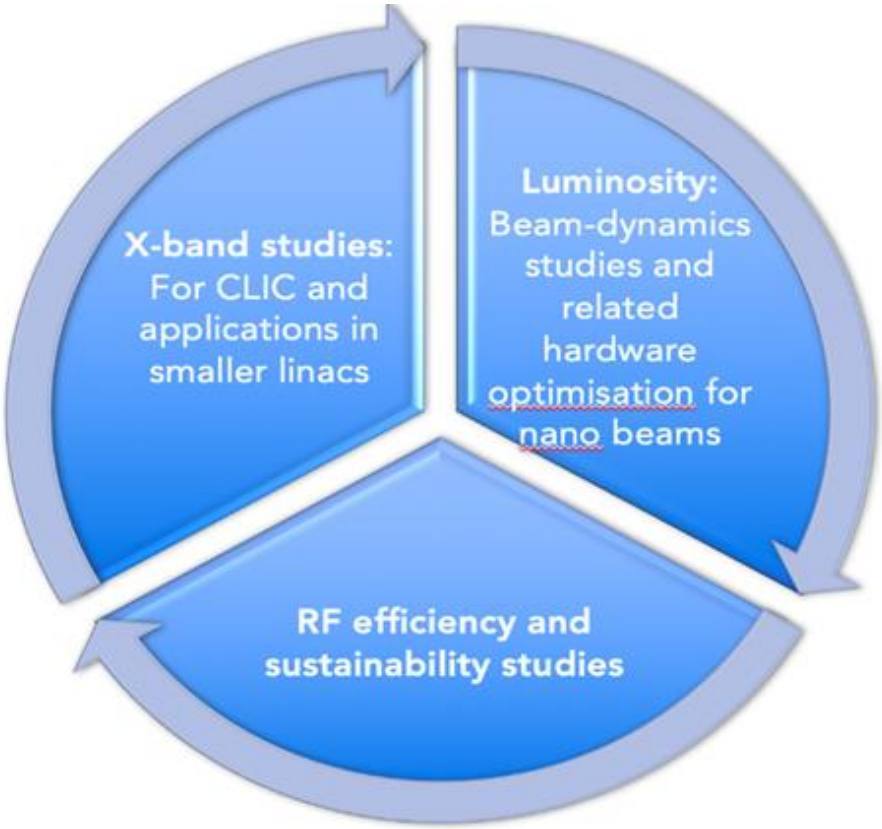
Operation:

- **116 MChF consumables + spares (see below)**
- **Energy costs**

– 1% for accelerator hardware parts (e.g. modules).
– 3% for the RF systems, taking the limited lifetime of these parts into account.
– 5% for cooling, ventilation and electrical infrastructures etc. (includes contract labour and consumables)

These replacement/operation costs represent 116 MCHF per year.

CLIC project readiness → 2025/26



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**

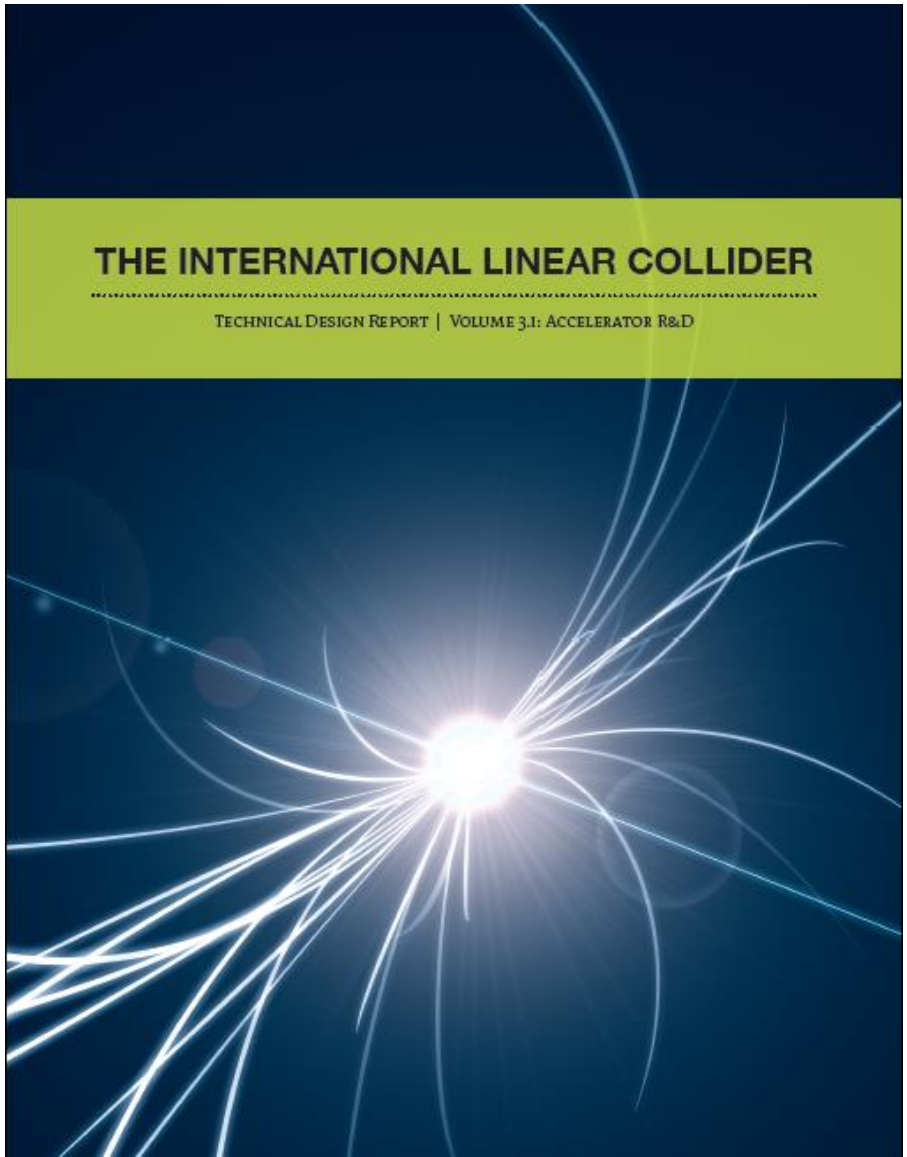
UNIVERSITY OF OXFORD

John Adams Institute for Accelerator Science

ILC: project overview

ILC Technical Design Report (June 2013)

baseline 500 GeV: $6.7B (2010) + 13,000 person-years



https://linearcollider.org/technical-design-report/

Part I:

ILC R&D IN THE TECHNICAL DESIGN PHASE

Part II:

THE ILC BASELINE DESIGN

Editors:

Phil BURROWS, John CARWARDINE, Eckhard ELSEN,
Brian FOSTER, Mike HARRISON, Hitoshi HAYANO,
Nan PHINNEY, Marc ROSS, Nobu TOGE,
Nick WALKER, Akira YAMAMOTO, Kaoru YOKOYA

Technical Editors:

Maura BARONE, Benno LIST

ILC today

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



8,000 1.3GHz
SRF cavities @ 2K



- **Cost ~5 B$**
- **Power ~110 MW**

Ongoing developments

Huge global interest in ILC-like SC RF systems:

eg. European XFEL, LCLS-II, Shanghai XFEL …

European XFEL @ DESY







Largest deployment of SCRF technology

- **100 cryomodules**
- **800 cavities**
- **17.5 GeV**
- **First beams 2016**

Ongoing developments

Huge global interest in ILC-like SC RF systems:

eg. European XFEL, LCLS-II, Shanghai XFEL …

Nb cavity performance advancements made at many labs

New surface treatments + improved fabrication techniques → major improvements in gradient, Q, yield, cost

eg. N-infusion → 45 MV/m @ Q ~ 2 x 1010**

(ILC spec: 31.5 MV/m @ Q ~ 1 x 1010)**

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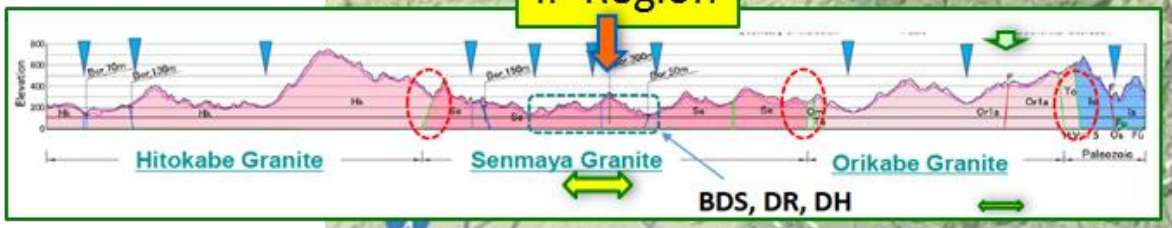
Extensive site studies in Japan: geology, civil, environment, safety …

ILC Candidate Location: Kitakami, Tohoku



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



High-way

Express-Rail

IP Region

Oshu

Ichinoseki

Ofunato

Kesen-numa

北上市

奥州市

一関市

遠野市

陸前高田市

気仙沼市

大船渡市

唐桑半島

大島

45

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(ILC spec: 31.5 MV/m @ Q ~ 1 x 10**10)

Extensive site studies in Japan: geology, civil, environment, safety …

Engineering design studies for beam dumps, positron source …

Ongoing optimisation of nanobeam production at ATF2

Planning for 4-year work programme: engineering prototypes + Engineering Design Report (see later)

ILC upgrade options

Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrade	Z pole	Upgrades		
Centre of mass energy	$\sqrt{s}$	GeV	250	250	91.2	500	250	1000
Luminosity	$\mathcal{L}$	$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.35	2.7	0.21/0.41	1.8/3.6	5.4	5.1
Polarization for e^-/e^+	$P_-(P_+)$	%	80(30)	80(30)	80(30)	80(30)	80(30)	80(20)
Repetition frequency	f_{rep}	Hz	5	5	3.7	5	10	4
Bunches per pulse	n_{bunch}	1	1312	2625	1312/2625	1312/2625	2625	2450
Bunch population	N_{e}	10^{10}	2	2	2	2	2	1.74
Linac bunch interval	Δt_{b}	ns	554	366	554/366	554/366	366	366
Beam current in pulse	I_{pulse}	mA	5.8	8.8	5.8/8.8	5.8/8.8	8.8	7.6
Beam pulse duration	t_{pulse}	μs	727	961	727/961	727/961	961	897
Average beam power	P_{ave}	MW	5.3	10.5	1.42/2.84*)	10.5/21	21	27.2
RMS bunch length	σ_{z}^*	mm	0.3	0.3	0.41	0.3	0.3	0.225
Norm. hor. emitt. at IP	$\gamma\epsilon_{\mathrm{x}}$	μm	5	5	5	5	5	5
Norm. vert. emitt. at IP	$\gamma\epsilon_{\mathrm{y}}$	nm	35	35	35	35	35	30
RMS hor. beam size at IP	σ_{x}^*	nm	516	516	1120	474	516	335
RMS vert. beam size at IP	σ_{y}^*	nm	7.7	7.7	14.6	5.9	7.7	2.7
Luminosity in top 1 %	$\mathcal{L}_{0.01}/\mathcal{L}$		73 %	73 %	99 %	58.3 %	73 %	44.5 %
Beamstrahlung energy loss	δ_{BS}		2.6 %	2.6 %	0.16 %	4.5 %	2.6 %	10.5 %
Site AC power	P_{site}	MW	111	138	94/115	173/215	198	300
Site length	L_{site}	km	20.5	20.5	20.5	31	31	40

Table 4.1: Summary table of the ILC accelerator parameters in the initial 250 GeV staged configuration and possible upgrades. A 500 GeV machine could also be operated at 250 GeV with 10 Hz repetition rate, bringing the maximum luminosity to $5.4 \cdot 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ [26]. *): For operation at the Z-pole additional beam power of 1.94/3.88 MW is necessary for positron production.

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Table 4.1: Summary table of the ILC accelerator parameters in the initial 250 GeV staged configuration and possible upgrades. A 500 GeV machine could also be operated at 250 GeV with 10 Hz repetition rate, bringing the maximum luminosity to $5.4 \cdot 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ [26]. *): For operation at the Z-pole additional beam power of 1.94/3.88 MW is necessary for positron production.

ILC upgrade options

Luminosity

Quantity	Symbol	Unit	Initial	$\mathcal{L}$ Upgrade	Z pole	Upgrades		
Centre of mass energy	$\sqrt{s}$	GeV	250	250	91.2	500	250	1000
Luminosity	$\mathcal{L}$	$10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.35	2.7	0.21/0.41	1.8/3.6	5.4	5.1
Polarization for e^-/e^+	$P_-(P_+)$	%	80(30)	80(30)	80(30)	80(30)	80(30)	80(20)
Repetition frequency	f_{rep}	Hz	5	5	3.7	5	10	4
Bunches per pulse	n_{bunch}	1	1312	2625	1312/2625	1312/2625	2625	2450
Bunch population	N_{e}	10^{10}	2	2	2	2	2	1.74
Linac bunch interval	Δt_{b}	ns	554	366	554/366	554/366	366	366
Beam current in pulse	I_{pulse}	mA	5.8	8.8	5.8/8.8	5.8/8.8	8.8	7.6
Beam pulse duration	t_{pulse}	μs	727	961	727/961	727/961	961	897
Average beam power	P_{ave}	MW	5.3	10.5	1.42/2.84*)	10.5/21	21	27.2
RMS bunch length	σ_{z}^*	mm	0.3	0.3	0.41	0.3	0.3	0.225
Norm. hor. emitt. at IP	$\gamma\epsilon_{\mathrm{x}}$	μm	5	5	5	5	5	5
Norm. vert. emitt. at IP	$\gamma\epsilon_{\mathrm{y}}$	nm	35	35	35	35	35	30
RMS hor. beam size at IP	σ_{x}^*	nm	516	516	1120	474	516	335
RMS vert. beam size at IP	σ_{y}^*	nm	7.7	7.7	14.6	5.9	7.7	2.7
Luminosity in top 1 %	$\mathcal{L}_{0.01}/\mathcal{L}$		73 %	73 %	99 %	58.3 %	73 %	44.5 %
Beamstrahlung energy loss	δ_{BS}		2.6 %	2.6 %	0.16 %	4.5 %	2.6 %	10.5 %
Site AC power	P_{site}	MW	111	138	94/115	173/215	198	300
Site length	L_{site}	km	20.5	20.5	20.5	31	31	40

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ILC upgrade options

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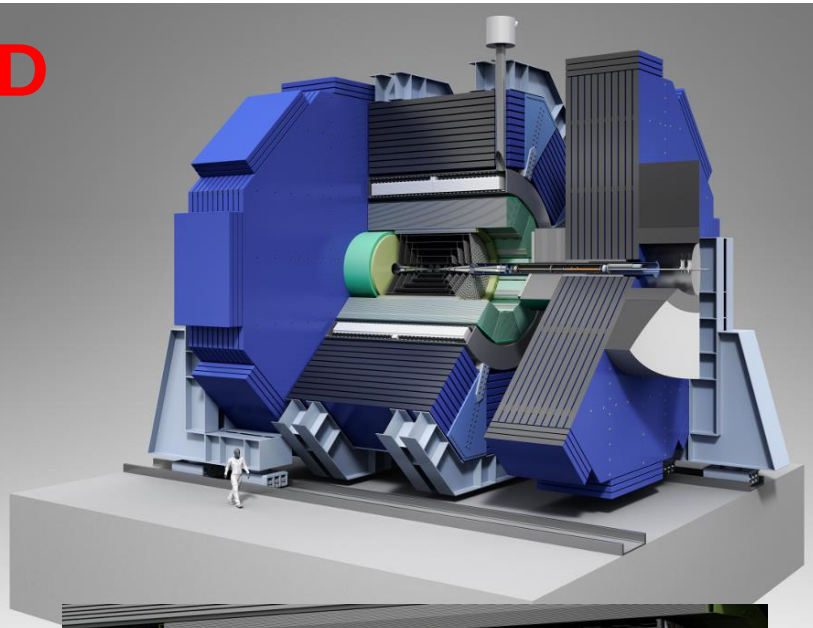
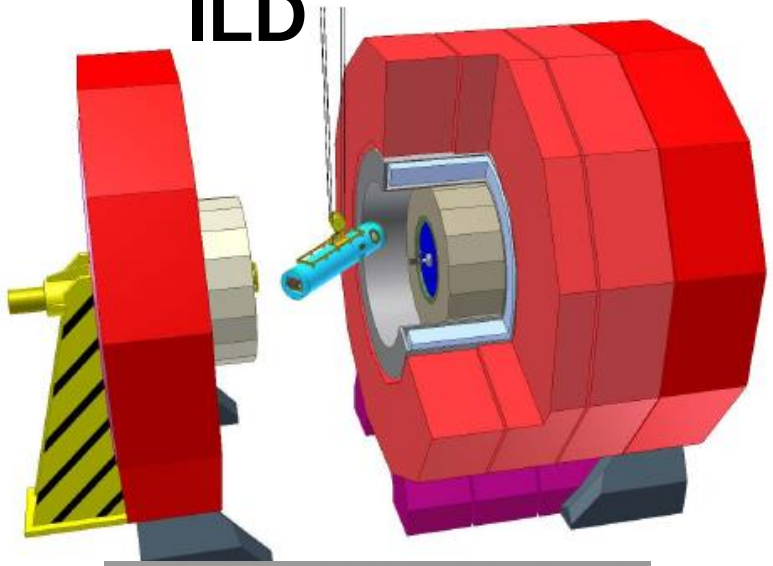
ILC Detectors

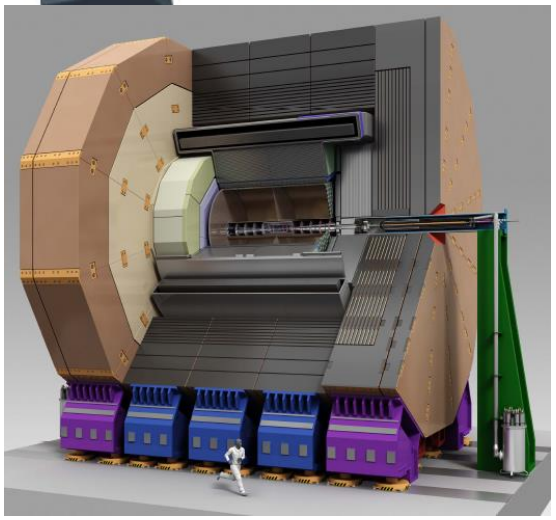
SiD





ILD





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ILC project preparation

ICFA ILC plan

2020: ICFA set up International Development Team (IDT) 'towards … timely realisation of ILC'

1 + 4-year 'Pre-lab' to finalise technical prototypes, prepare Engineering Design Report, secure cooperation among funding agencies, and prepare for construction start



	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	Following a four-year ILC Pre-Lab phase, ILC construction will															
Acc. Systems	continue for about ten years.															
Installation																
Commissioning																
Physics Exp.																

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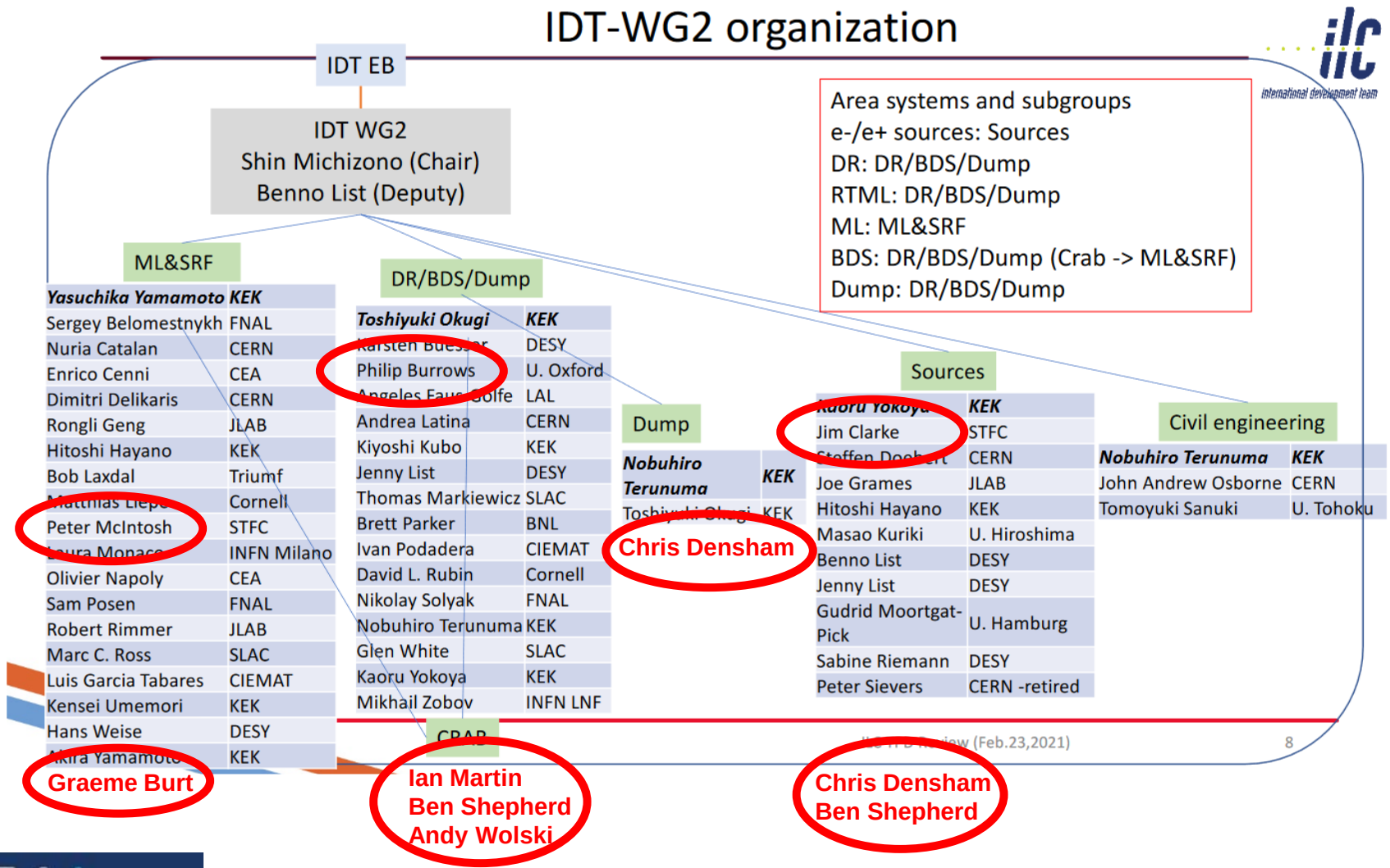
ILC International Development Team



IDT Working Group 2 - Accelerator



ML&SRF	
Yasuchika Yamamoto	***KEK***
Sergey Belomestnykh	FNAL
Nuria Catalan	CERN
Enrico Cenni	CEA
Dimitri Delikaris	CERN
Rongli Geng	JLAB
Hitoshi Hayano	KEK
Bob Laxdal	Triumf
[illegible]	Cornell
Peter McIntosh	STFC
[illegible]	INFN Milano
Olivier Napoly	CEA
Sam Posen	FNAL
Robert Rimmer	JLAB
Marc C. Ross	SLAC
Luis Garcia Tabares	CIEMAT
Kensei Umemori	KEK
Hans Weise	DESY
[illegible]	KEK

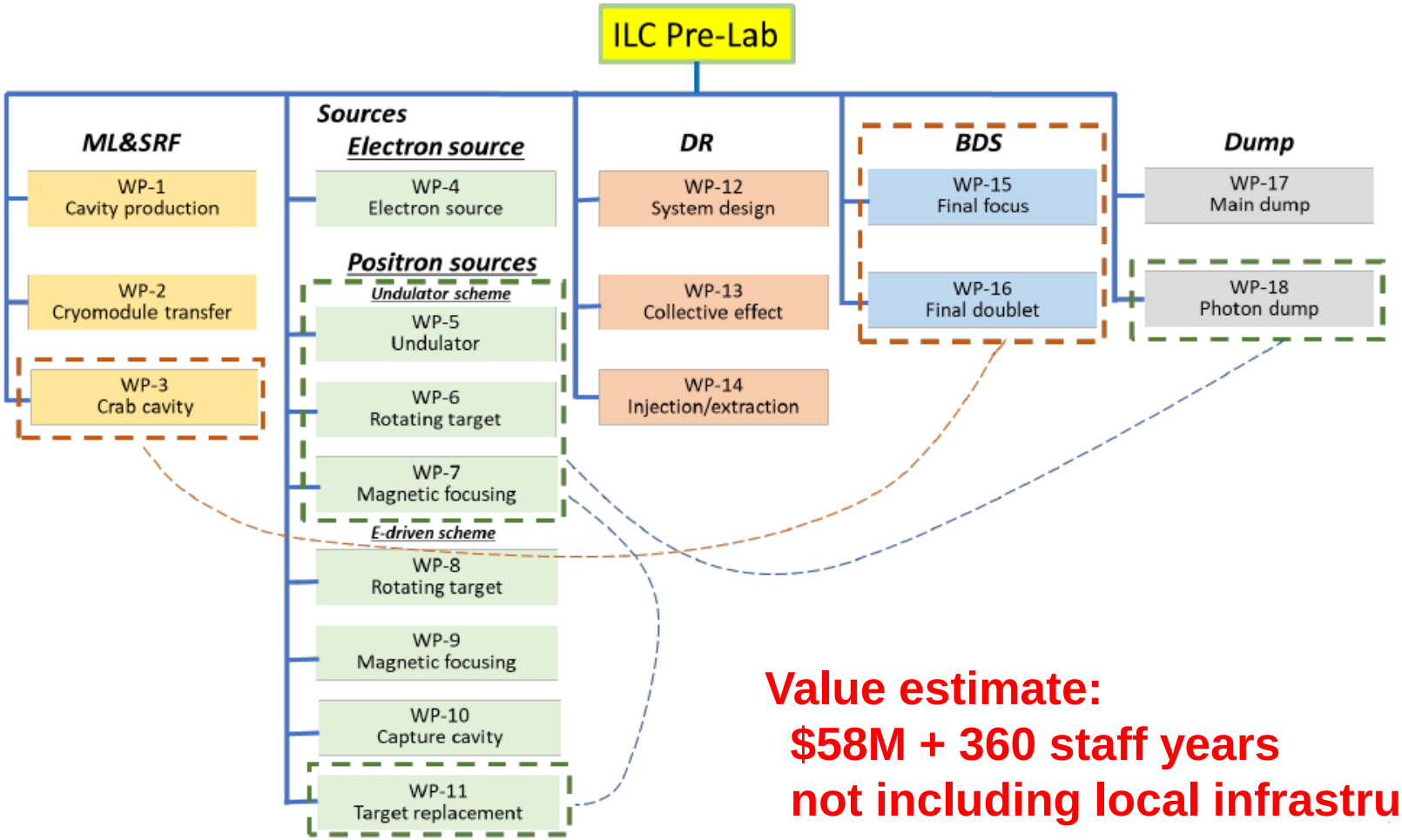
DR/BDS/Dump	
Toshiyuki Okugi	***KEK***
[illegible]	DESY
Philip Burrows	U. Oxford
[illegible]	LAL
Andrea Latina	CERN
Kiyoshi Kubo	KEK
Jenny List	DESY
Thomas Markiewicz	SLAC
Brett Parker	BNL
Ivan Podadera	CIEMAT
David L. Rubin	Cornell
Nikolay Solyak	FNAL
Nobuhiro Terunuma	KEK
Glen White	SLAC
Kaoru Yokoya	KEK
Mikhail Zobov	INFN LNF

Dump	
Nobuhiro Terunuma	***KEK***
Toshiyuki Okugi	KEK

Sources	
Kaoru Yokoya	***KEK***
Jim Clarke	STFC
[illegible]	CERN
Joe Grames	JLAB
Hitoshi Hayano	KEK
Masao Kuriki	U. Hiroshima
Benno List	DESY
Jenny List	DESY
Gudrid Moortgat-Pick	U. Hamburg
Sabine Riemann	DESY
Peter Sievers	CERN -retired

Civil engineering	
Nobuhiro Terunuma	***KEK***
John Andrew Osborne	CERN
Tomoyuki Sanuki	U. Tohoku

WG2: Scope of Pre-lab technical work (TPD)



Value estimate:
$58M + 360 staff years
not including local infrastructure

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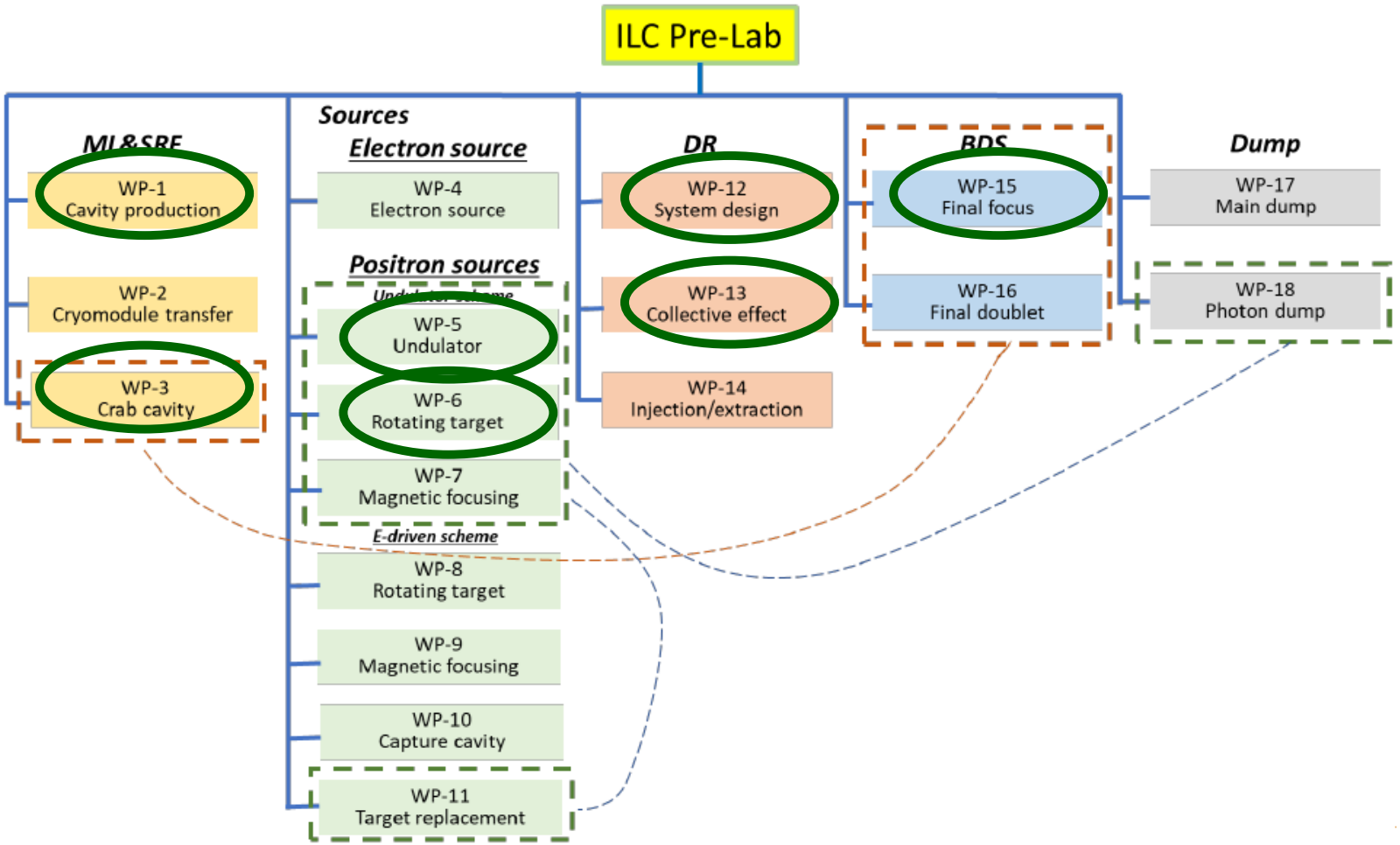
WG2: Scope of Pre-lab technical work (TPD)



MEXT review: ILC Advisory Panel (July 21 – Feb 22)

https://www.mext.go.jp/content/20220401-mxt_kiso-000020463_9.pdf

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Synthesis of findings:

Recognise importance of precision Higgs physics

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Synthesis of findings:

Recognise importance of precision Higgs physics

Premature to transition to ILC Pre-lab on the premise that Japanese Govt. will express an interest to host ILC

Interested countries should continue to work on technical issues

Decouple technical progress from 'hosting issue'

Build relationships between ILC community and stakeholders (government funding agencies) through reinforced collaboration and step-by-step R&D

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Decouple technical progress from 'hosting issue'

Build relationships between ILC community and stakeholders (government funding agencies) through reinforced collaboration and step-by-step R&D

'ILC Japan' set up to coordinate among scientific community, local and regional authorities, Diet members, and industry to promote ILC

ILC project status

April 2022: ICFA re-stated support for ILC

https://icfa.hep.net/wp-content/uploads/ICFA_Statement_April2022_Final.pdf

+ extended IDT mandate:

‘IDT will … further strengthen collaboration among institutes and labs … and expand the broad support from various stakeholders’

‘ICFA continues to encourage inter-governmental discussions between Japan and potential partner nations … toward realisation of an ILC’

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'IDT will … further strengthen collaboration among institutes and labs … and expand the broad support from various stakeholders'

'ICFA continues to encourage inter-governmental discussions between Japan and potential partner nations … toward realisation of an ILC'

IDT has identified 'time-critical' work packages (~ years 1-2 of Pre-lab) and is exploring collaboration among KEK and international partners should significant additional funds appear at KEK in JFY2023

IDT initiating 'International Expert Panel' to develop a model for realising a large global project, such as ILC. Panel members will liaise with respective funding agencies

UK LC interest + investments

UK community strong interest in LC physics potential, and capability in relevant technologies required for the accelerator and detector

Direct major investments in LC R&D from the start (2004):

Accelerator: £18M (2004-11) LC-ABD (PPARC, CCLRC, STFC)

£13M (2011-20) CLIC-UK (CERN/STFC)

+ EUCARD, ARIES, ELAN, EuroTeV, HiGRADE, EJADE …

Detector: £10M (2001-10) LCFI, SPiDeR, CALICE-UK

+ EUDET, AIDA, AIDA2020 …

Plus recent UK investments in SCRF systems/facilities of direct relevance to ILC:

HL-LHC crab cavity cryomodule: £8.5M

ESS, PIP-II, Nb cavity fabrication/test: £9.5M

Plus UK investments in ATLAS, CMS, LHCb …

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LC-UK consortium

Technical system / Institute	Accelerator					Detector			Physics
	BDS/MDI	DR	Beam dumps	e+ source	RF	Si tracker	Calorimetry	DAQ	
Birmingham	X					X	X		X
Bristol						X		X	X
Brunel								X	X
Cambridge							X		X
STFC – Daresbury Laboratory	X			X	X				
Durham IPPP									X
Edinburgh						X			X
Glasgow						X			X
Imperial College							X	X	X
Lancaster				X	X	X			X
Liverpool		X				X			X
Manchester	X				X	X			X
Open University						X			
Oxford	X	X			X	X		X	X
QMUL						X			X
STFC – RAL			X	X		X	X	X	X
RHUL	X							X	X
Sheffield						X			X
Southampton									X
Sussex							X	X	X
UCL	X						X	X	X
Warwick						X			X

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Summary

ILC + CLIC are technically-mature projects

large X-ray FEL systems in operation using both technologies

Concepts have been developed over decades via global efforts

ILC TDR 2013

CLIC CDR 2012, updated 2018

Both are consistent with European PP strategy

European Strategy Update 2020

The vision is to prepare a Higgs factory, followed by a future hadron collider with sensitivity to energy scales an order of magnitude higher than those of the LHC, while addressing the associated technical and environmental challenges

3. **High-priority future initiatives a) An electron-positron Higgs factory is the highest-priority next collider.** For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy ...

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

b) **Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders.** It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other **high-gradient accelerating structures**, bright muon beams, energy recovery linacs.

Summary

ILC + CLIC are technically-mature projects

large X-ray FEL systems in operation using both technologies

Concepts have been developed over decades via global efforts

ILC TDR 2013

CLIC CDR 2012, updated 2018

Both are consistent with European PP strategy

Both affordable: costs comparable with LHC cost (today)

Manageable power: 110 MW (CLIC 380, ILC 250) similar to LHC

Intrinsically upgradeable for both luminosity and energy

LC offers a flexible, staged approach to energy frontier:

energy ~ length

facility reusable as gradient improves, eg. ILC → CLIC → PWFA …

complementary to long-term future hadron or muon colliders

‘A week is a long time in politics’

Harold Wilson, UK Prime Minister



meeting of Lyn Evans and Prime Minister Abe, March 27, 2013

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Thanks to ILC + CLIC colleagues

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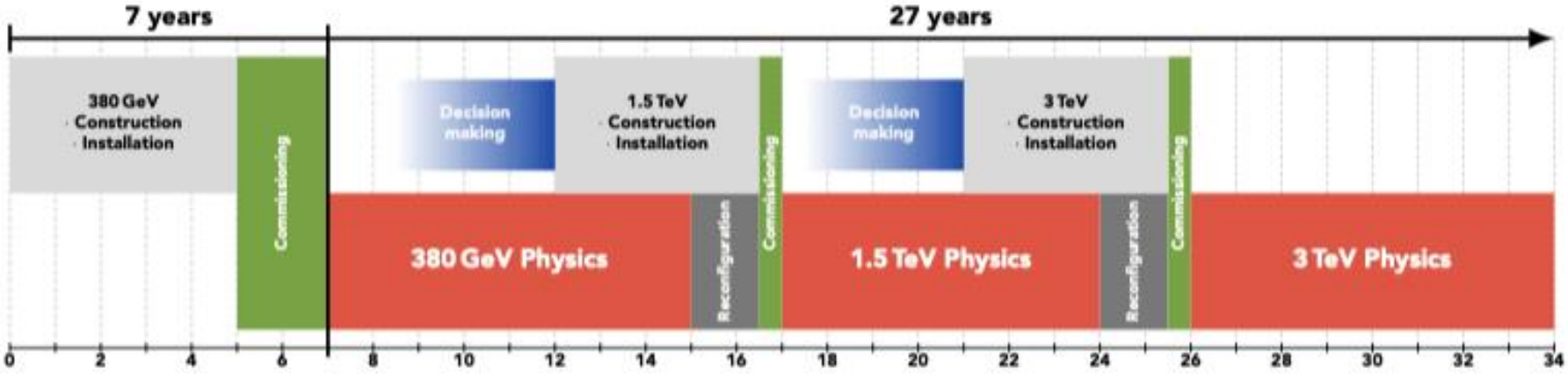
Extra material: CLIC

Timeline



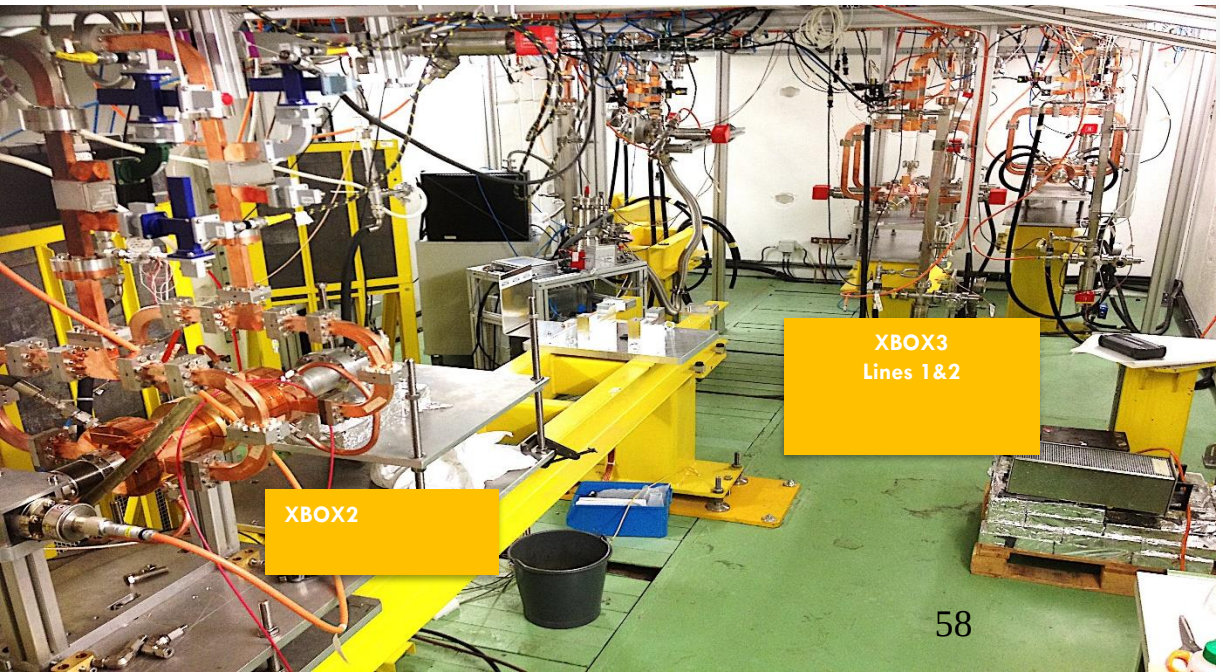
Technology-driven schedule from start of construction shown above.

A preparation phase of ~5 years is needed beforehand
(estimated resource needed ~4% of overall project cost)

X-band Technology

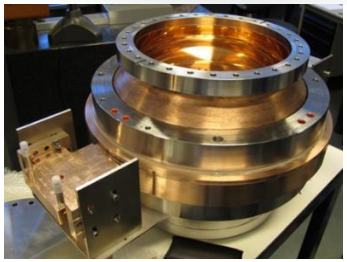
Key area in European 'LDG' accelerator R&D roadmap

- Design and manufacturing of X-band structures and components
- Study structure breakdown limits and optimization, operation and conditioning
- Baseline verification and exploration of new ideas
- Assembly and industry qualification
- Structures for applications: FELs, medical …

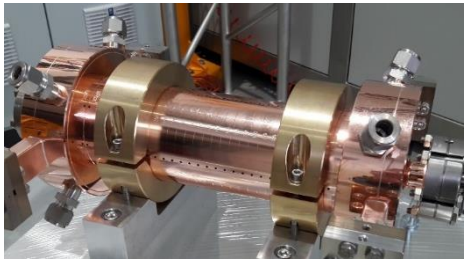






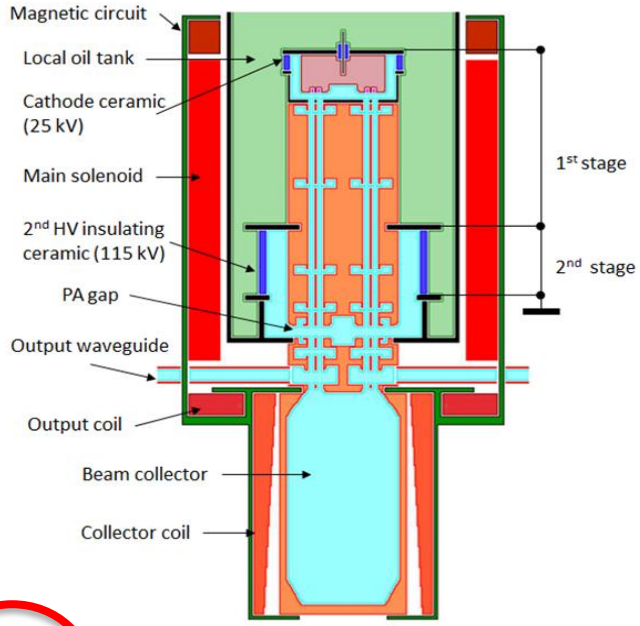


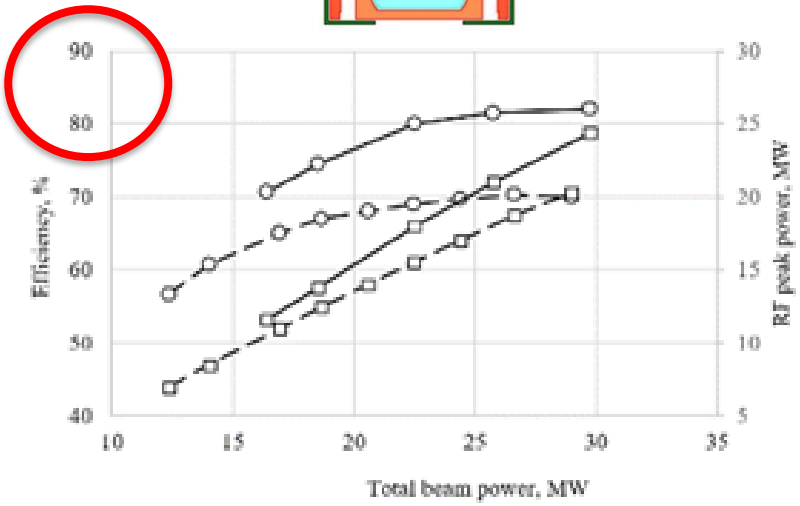




Recent studies

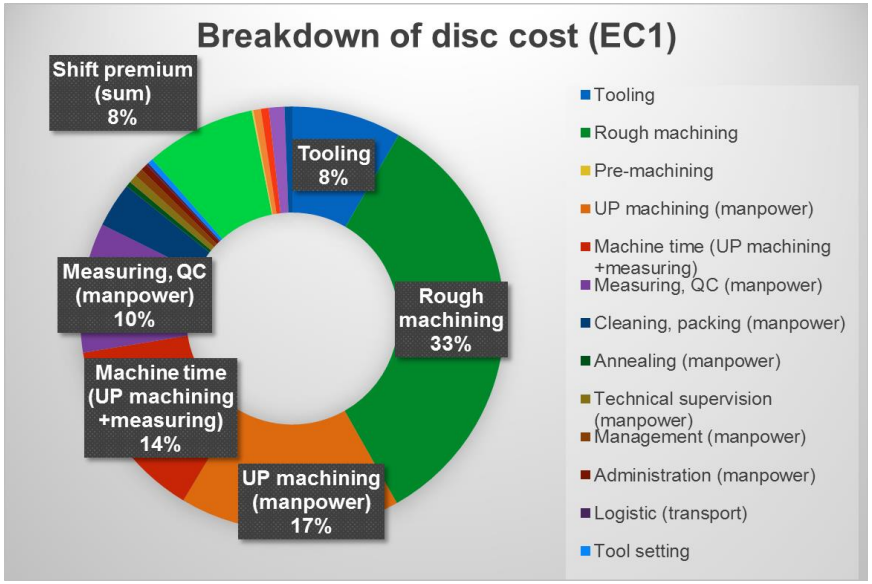
High-efficiency klystron design





Industry survey for CLIC disk production





Industrial questionnaire:

Capacity clearly available.

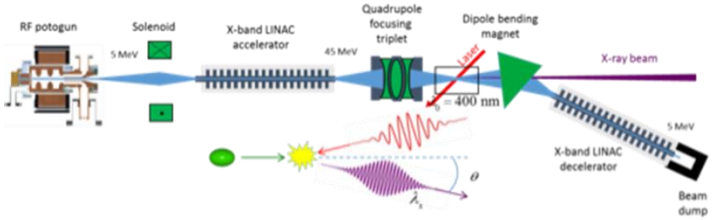
Preparation phase to mass production ~ five years.

Drive-beam 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. Publication: https://ieeexplore.ieee.org/document/9115885

Applications

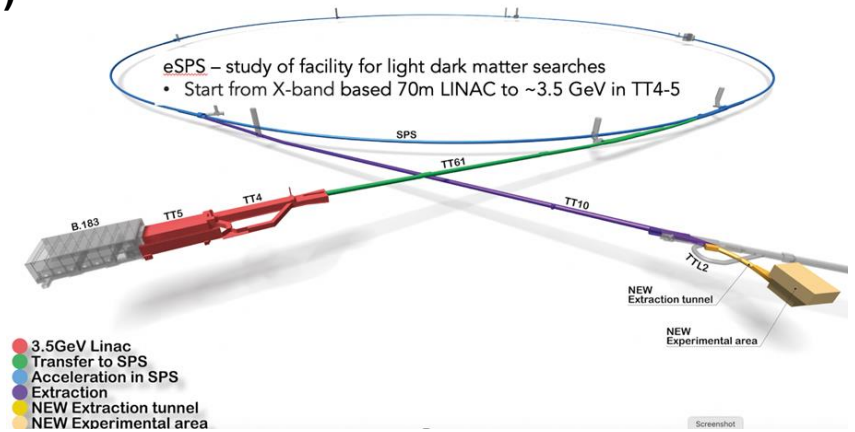
Applications of X-band technology:

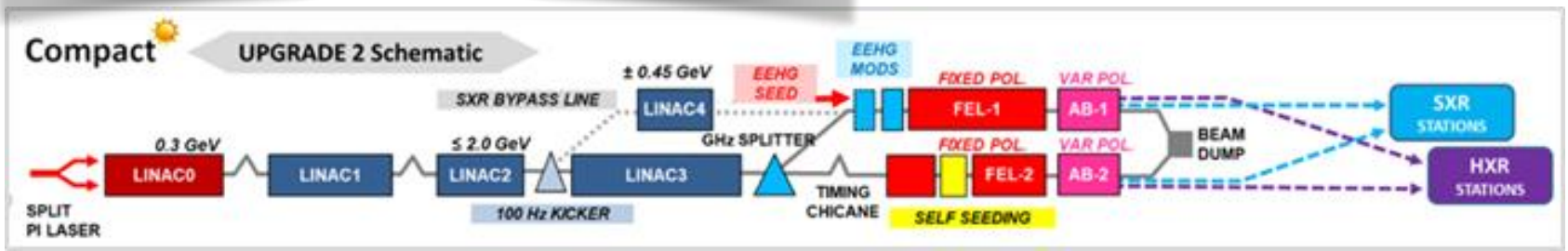
- A compact FEL (CompactLight: EU Design Study 2018-22)
- Compact medical linacs (proton and electrons)
- Inverse Compton Scattering Source (SmartLight)
- 1 GeV X-band linac at LNF
- eSPS for light dark matter searches (PBC)
- Linearizers and deflectors in FELs (PSI, DESY …)



Eindhoven University led
SMART*LIGHT Compton Source

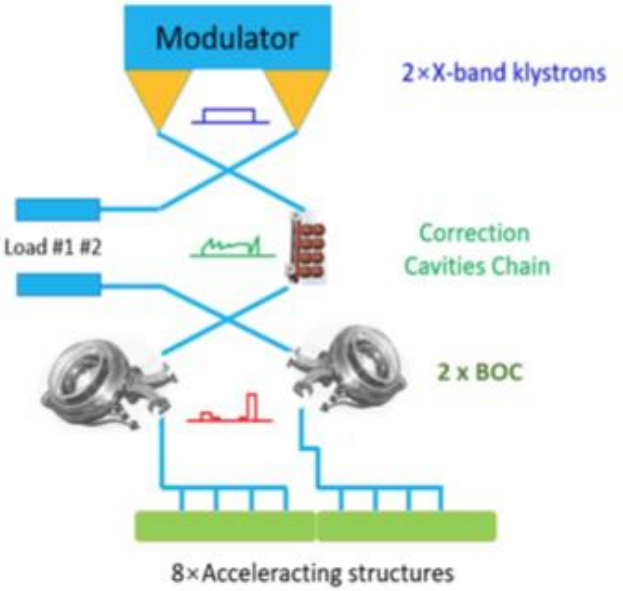


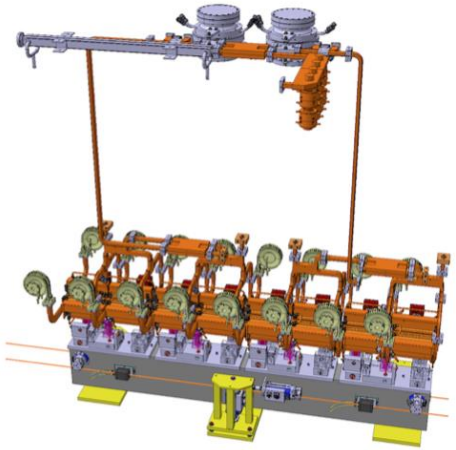





Technical Developments
Capacitor
HV deck
HVPS
Gun
Current transformer
Dump
CBPM 820
CBPM 810
Optical encoder
Reference interferometer

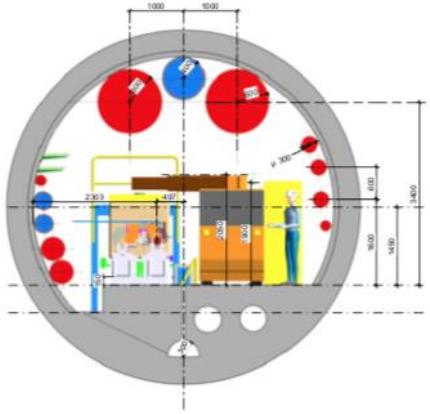
380 GeV klystron option



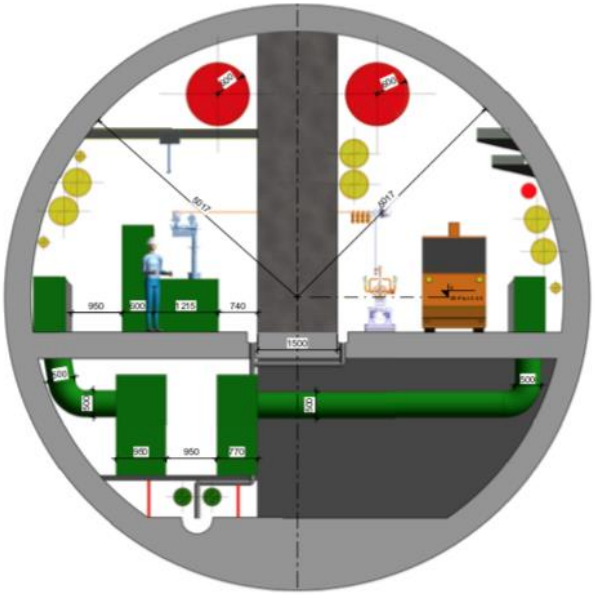


Replace drive-beam complex by local X-band RF power in tunnel

Simpler module, larger tunnel



(a)



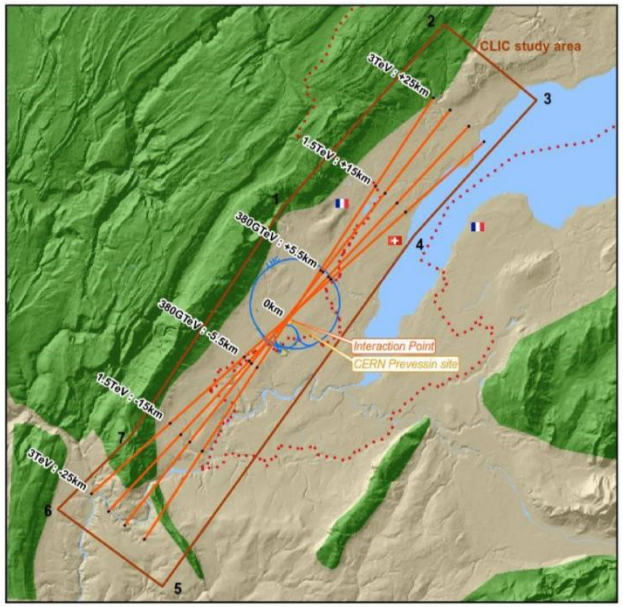
(b)

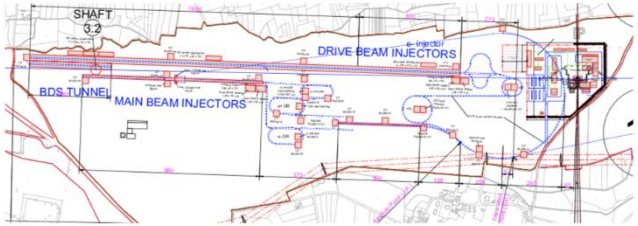
Civil Engineering and Infrastructure Studies

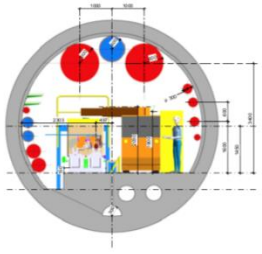
Important effort within:

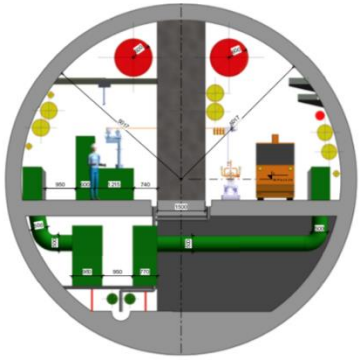
- **Civil engineering**
- **Electrical systems**
- **Cooling and ventilation**
- **Transport, logistics and installation**
- **Safety, access and radiation protection systems**

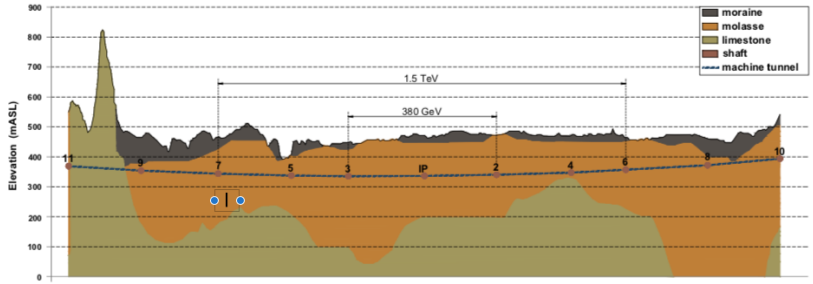
Crucial for cost/power/schedule



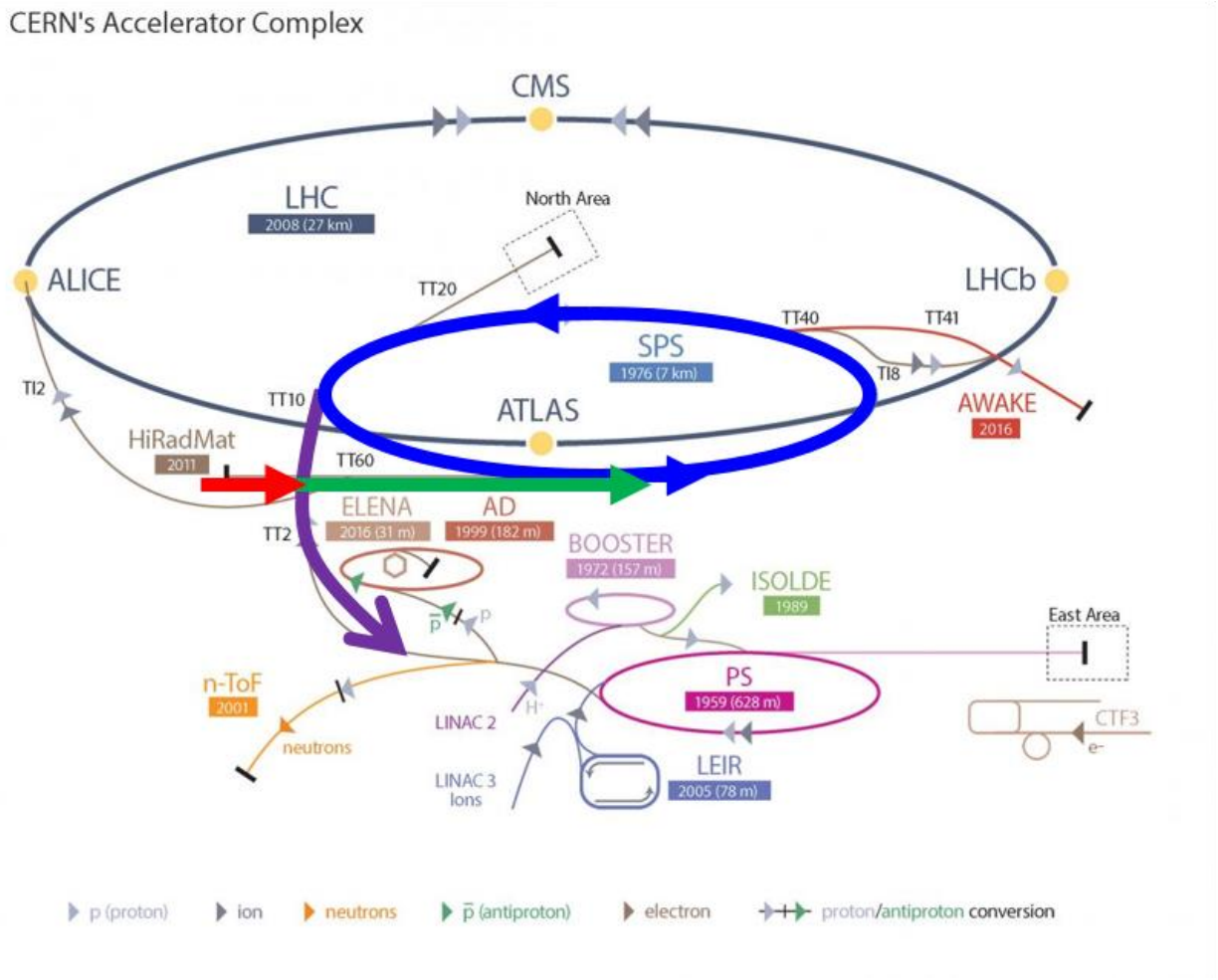



(a)


(b)



eSPS proposal



3.5GeV Linac

Transfer to SPS

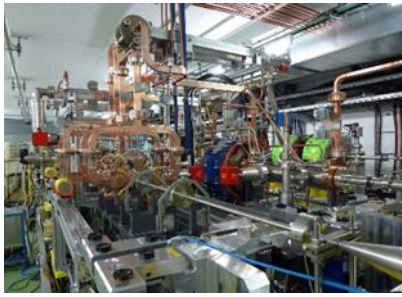
Acceleration to in SPS

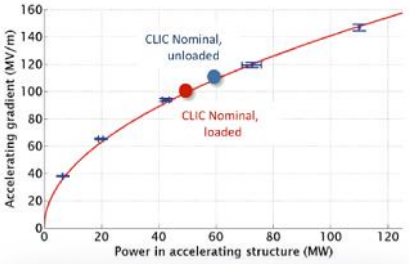
Extraction

Accelerator challenges

1. High-current drive beam bunched at 12 GHz
2. Power transfer and main-beam acceleration
3. Towards 100 MV/m gradient in main-beam cavities
4. Alignment and stability (‘nano-beams’)

- CTF3 (CLIC Test Facility) addressed all drive-beam production issues
- Other critical technical systems (alignment, damping rings, beam delivery, etc.) addressed via design and/or test-facility demonstrations
- X-band technology developed and verified with prototyping, test-stands, and application in smaller-scale systems
- Two C-band XFELS (SACLA and SwissFEL) now operational: large-scale demonstrations of normal-conducting, high-frequency, low-emittance linacs

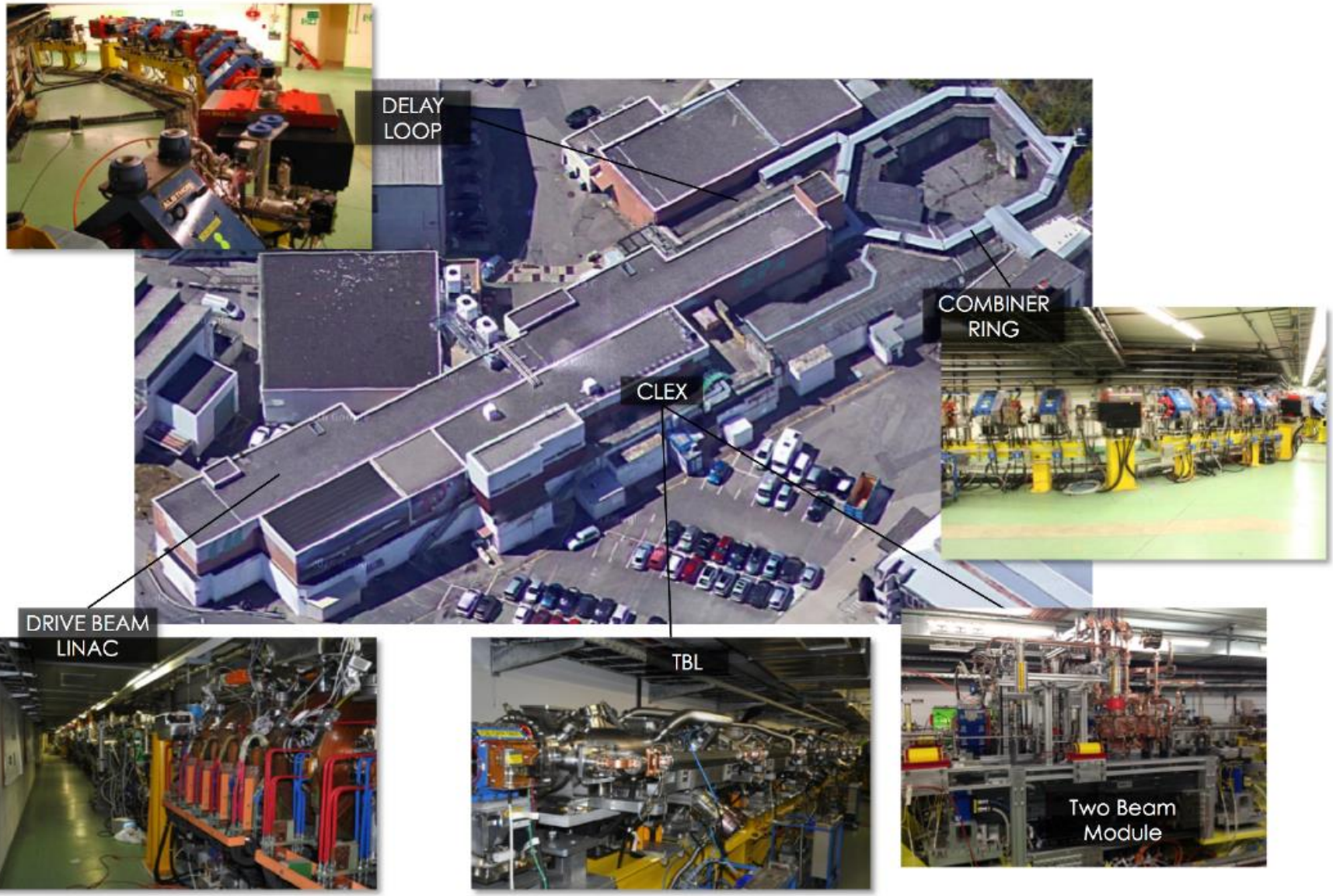






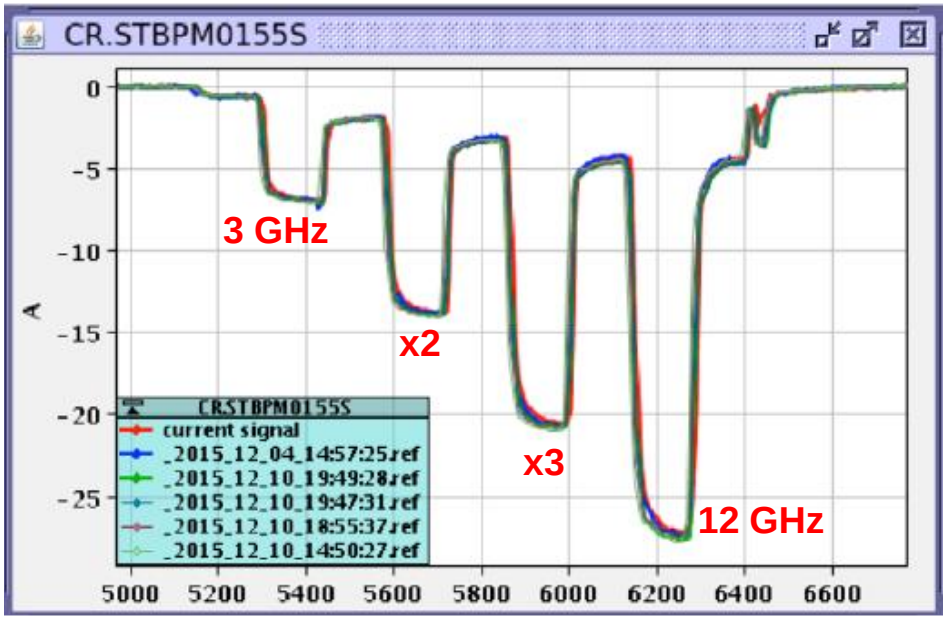


CLIC Test Facility (CTF3)



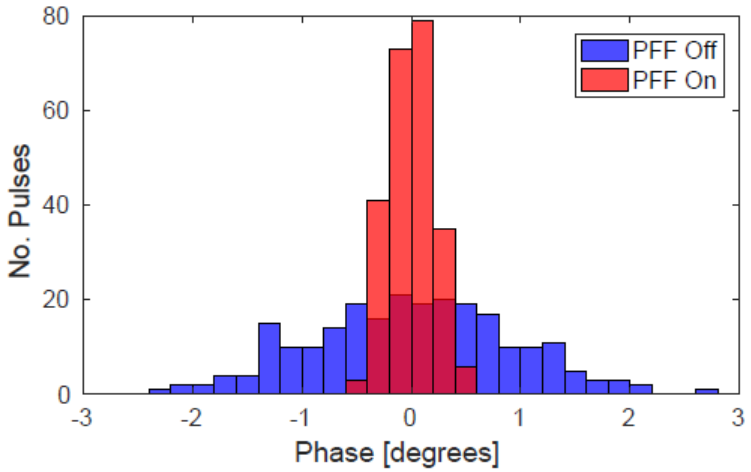
Status

- **Produced high-current drive beam bunched at 12 GHz**



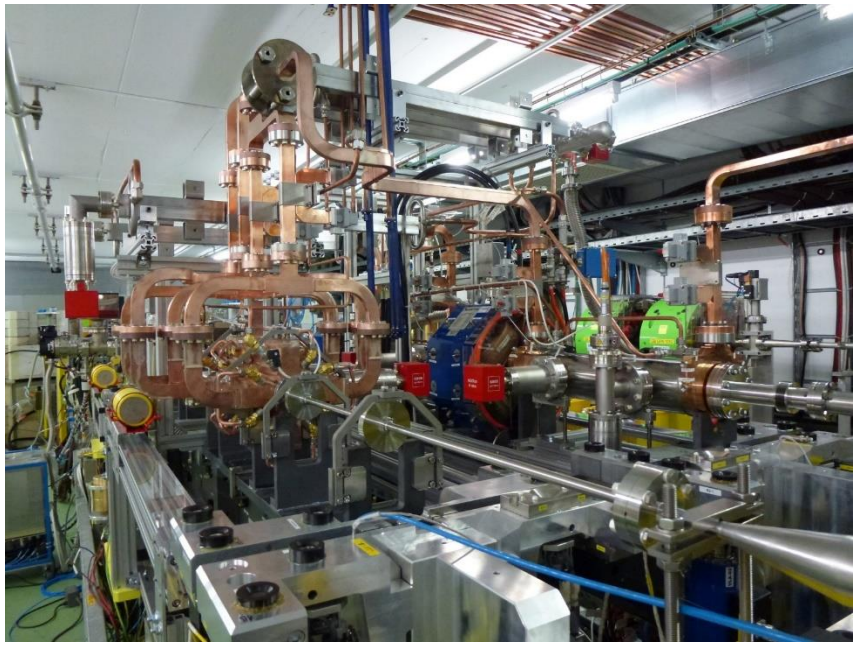
28A

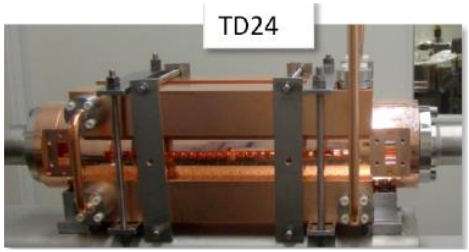
Arrival time stabilised to 50 fs



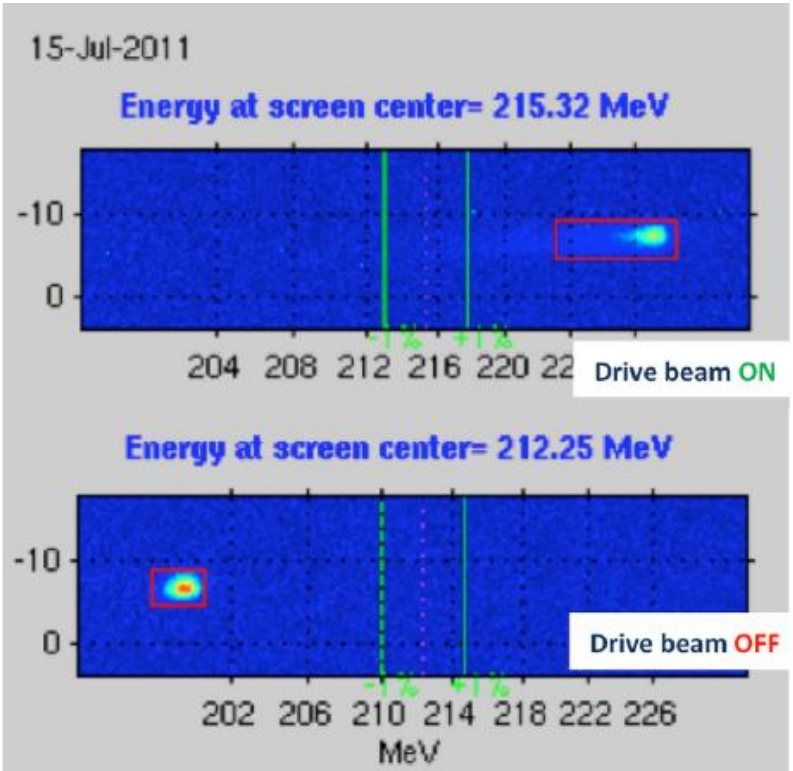
Status

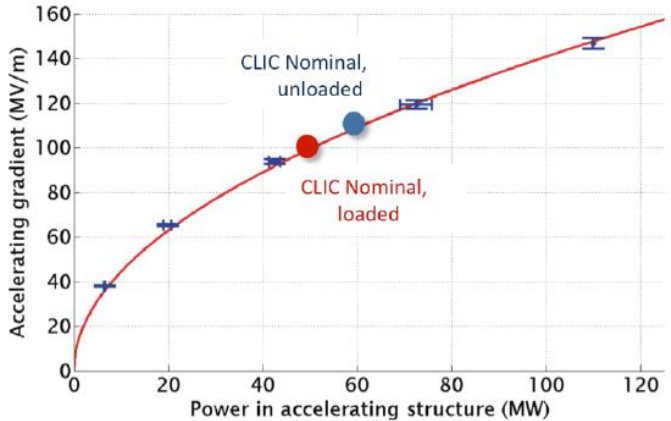
- **Demonstrated two-beam acceleration**





31 MeV = 145 MV/m

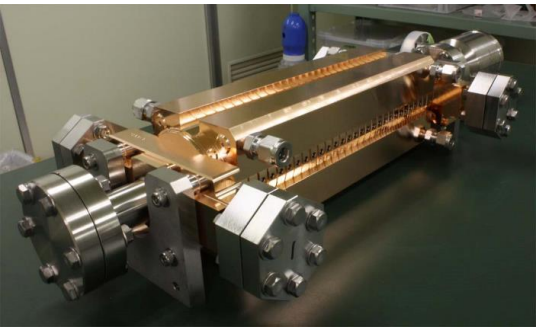




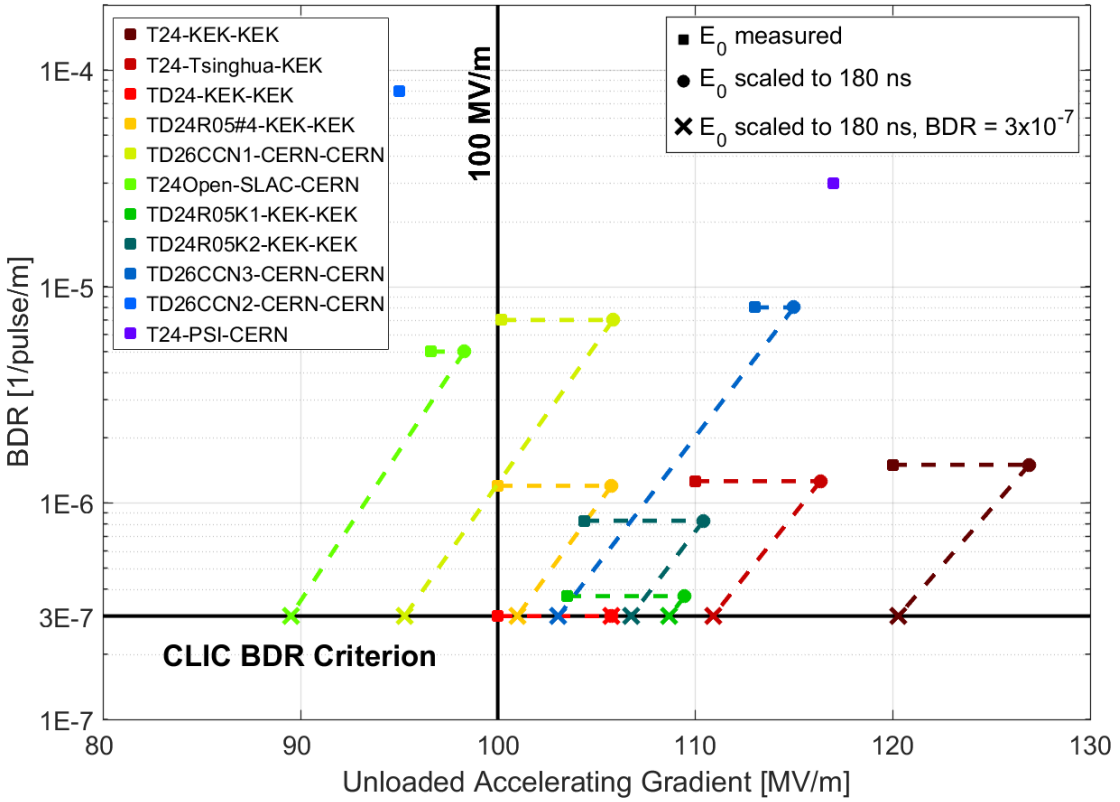
Status

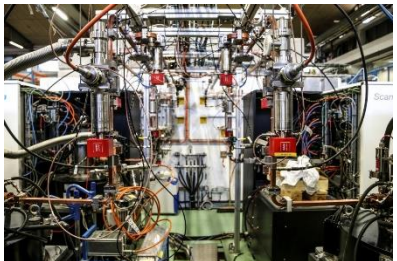
- **Achieved 100 MV/m gradient in main-beam RF cavities**

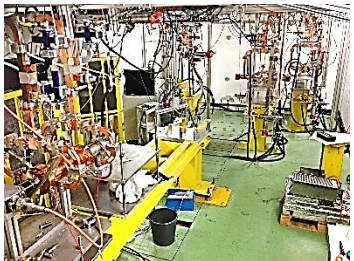




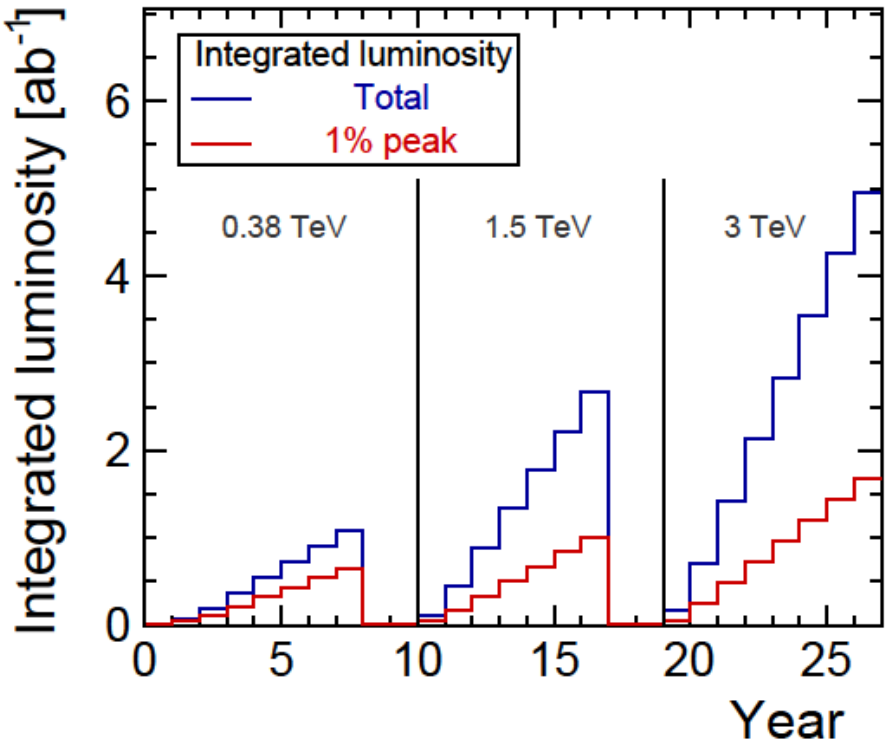








Luminosity staging baseline



Stage	$\sqrt{s}$ [TeV]	$\mathscr{L}_{\text{int}}$ [ab^{-1}]
1	0.38 (and 0.35)	1.0
2	1.5	2.5
3	3.0	5.0

Baseline polarisation scenario adopted:
electron beam (–80%, +80%) polarised in ratio (50:50) at √s=380GeV ; (80:20) at √s=1.5 and 3TeV

Staging and live-time assumptions following guidelines consistent with other future projects:
Machine Parameters and Projected Luminosity Performance of Proposed Future Colliders at CERN arXiv:1810.13022, Bordry et al.

Updated CLIC luminosity model

First-stage construction period ends with one year of beam commissioning with the whole machine before Lumi starts

Luminosity ramp-up:

380 GeV:	**10%, 30%, 60% then nominal L (same as ILC)**
1.5 TeV:	**25%, 75% then nominal L**
3 TeV:	**25%, 75% then nominal L**

Updated CLIC availability model

Task force study of LHC + modern light sources;

→ CLIC availability model common with FCCee

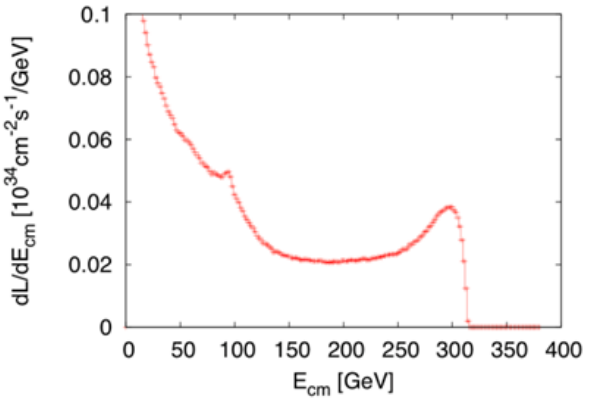
120 days	**winter shutdown (17 weeks)**
30 days	**commissioning**
20 days	**machine development**
10 days	**technical stops**
185 days	**physics @ 75% efficiency**
	→ 1.2 107 s (c.f. ILC 1.6 10**7 s)**

Luminosity studies

- **Z-pole performance (first stage):**

  L (default) 2.3 x 10^{32} → 0.4 x 10^{34} cm^{-2} s^{-1} with accel. configured for Z running

- **Gamma-gamma collisions luminosity (example):**



- **Luminosity margins:**

  baseline 380 GeV design L = 1.5 x 10^{34} cm^{-2} s^{-1}
  'perfect' machine > DR L = 4.3 x 10^{34} cm^{-2} s^{-1}

  → significant margin for improvement

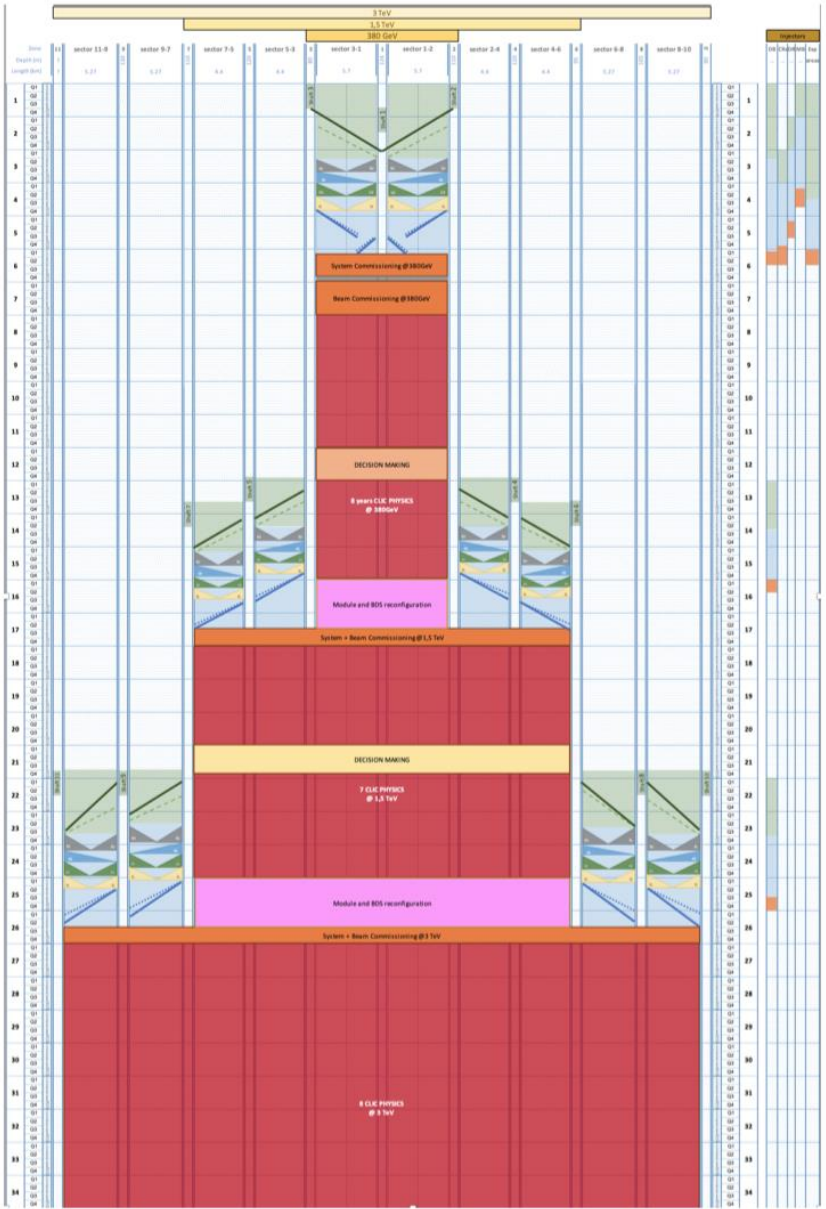
- **Luminosity upgrades:**

  doubling frequency (50 Hz → 100 Hz)

  → double the luminosity, with power +50 MW and cost ~5% increases

CLIC note: http://cds.cern.ch/record/2687090

Full project schedule



Deliberation document

The design, technology, and implementation aspects of CLIC indicate that the first stage (a Higgs factory) could be realised on a timescale of 15 years and could be extended to higher energies subsequently.

Reduction in energy consumption is an important consideration in accelerator design. Substantial progress has been achieved in the development of superconducting and **normal-conducting high-gradient accelerating structures**. This technology, which is needed for the e+e– colliders, is also driven by light source facilities all over the world.

UNIVERSITY OF OXFORD

John Adams Institute for Accelerator Science

Extra material: ILC

Recent documentation:
https://arxiv.org/pdf/2203.07622.pdf

DESY-22-045, IFT–UAM/CSIC–22-028,
KEK Preprint 2021-61, PNNL-SA-160884,
SLAC-PUB-17662
March 2022

arXiv:2203.07622v1 [physics.acc-ph] 15 Mar 2022

The International Linear Collider: Report to Snowmass 2021

THE ILC INTERNATIONAL DEVELOPMENT TEAM AND THE ILC COMMUNITY

ABSTRACT

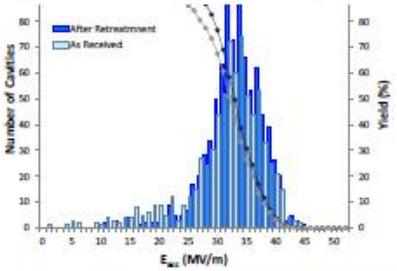
The International Linear Collider (ILC) is on the table now as a new global energy-frontier accelerator laboratory taking data in the 2030's. The ILC addresses key questions for our current understanding of particle physics. It is based on a proven accelerator technology. Its experiments will challenge the Standard Model of particle physics and will provide a new window to look beyond it. This document brings the story of the ILC up to date, emphasizing its strong physics motivation, its readiness for construction, and the opportunity it presents to the US and the global particle physics community.

Progress in SRF

	~ 2017	2018 ~ 2021	Pre-lab
			~41 M$,285 FTE-yr
Cavity	Yield evaluation of cavities based on TDR	High performance and cost reduction	Cavity manufacturing, performance demonstration (Yield demonstration in three areas)
Cryomodule	Eng. design	Module assembly	Demonstration of cryomodule assembly, transfer, and performance



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



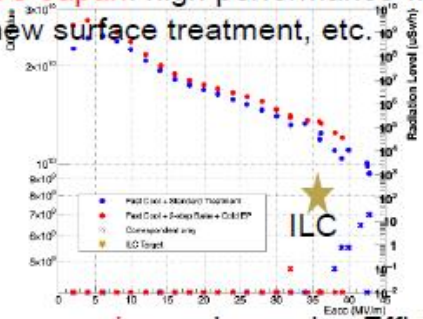


Euro-XFEL Operation (Europe)
~800 cavities/
~100 Modules



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

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

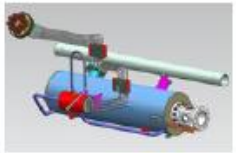


Germany-Japan: Improving Efficiency in Cavity Manufacturing
Final design is underway to comply with "High Pressure Gas Safety".

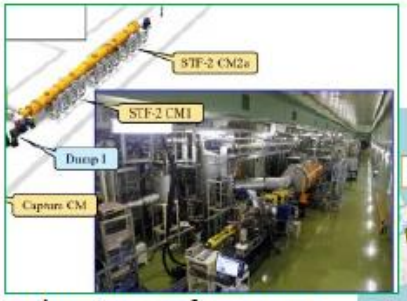




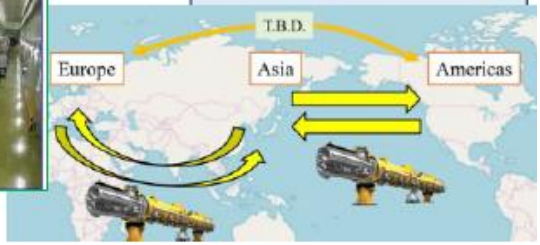




Realized through international cooperation and procurement



Accelerator performance verification at KEK-STF2



France-Japan: Automation of cavity cleaning

International Cooperation in SRF

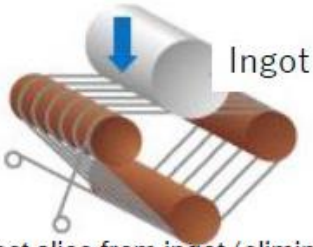
2018-2021:

- 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-)

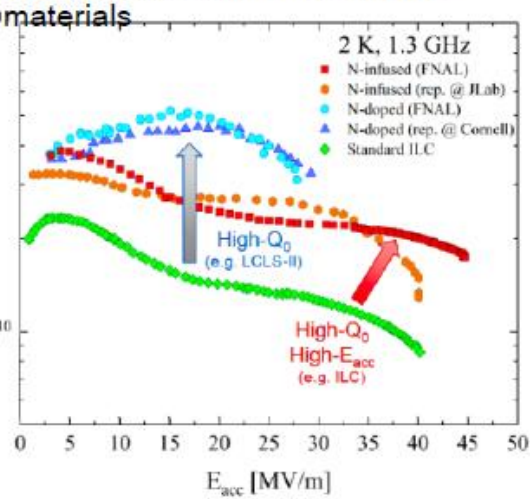
- Preparation for mass production: Demonstration of international statistics in three region

US-Japan: Improving Performance through Surface Treatment
Cost reduction by direct slicing materials



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





KEK-STF

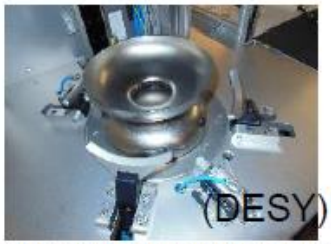


HGC (FNAL) aiming for performance beyond ILC specifications (in progress)

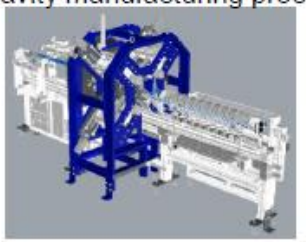




Germany-Japan: Improving efficiency in cavity manufacturing

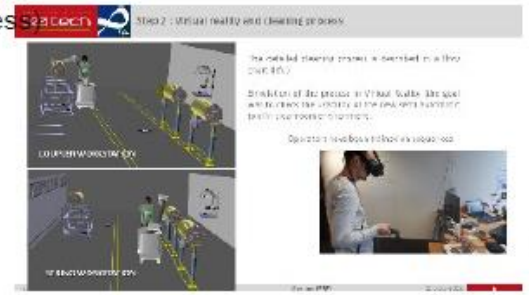


Cavity Frequency Measurement System(Quality assurance for cavity manufacturing process)



France-Japan : Automation of Dust Prevention Work





International Committee for Future Accelerators

August 2, 2020

ICFA announces a new phase towards preparation for the International Linear Collider

At its 86th meeting held today, ICFA approved the formation of the International Linear Collider International Development Team as the first step towards the preparatory phase of the ILC project, with a mandate to make preparations for the ILC Pre-Lab in Japan.

A description of the mandate and structure of the ILC International Development Team was also approved by ICFA today.

The Team will commence its work immediately and is expected to complete it by the end of 2021.

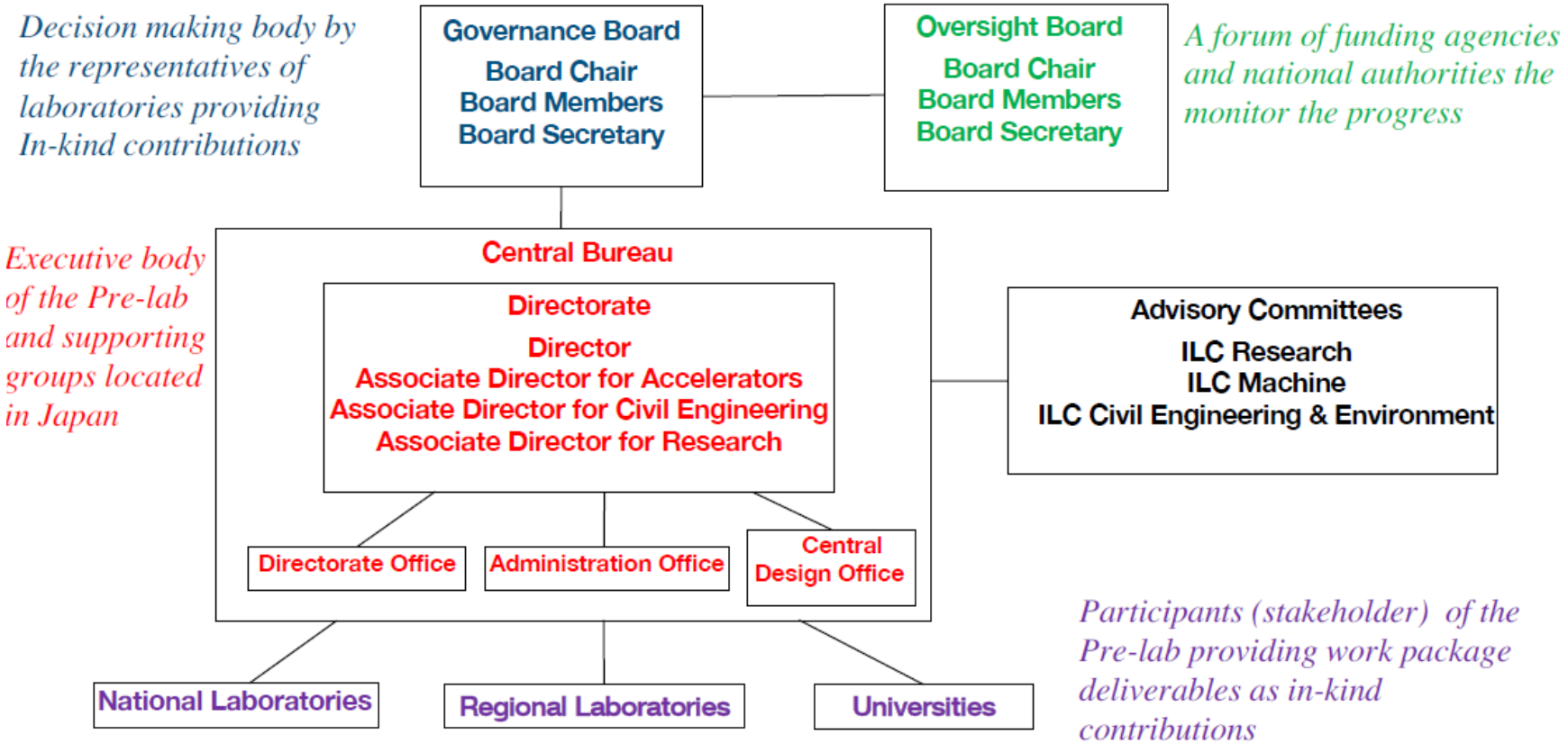
The ILC International Development Team will work towards making a timely realization of the ILC possible.

ICFA thanks the Linear Collider Collaboration led by Dr. Lyn Evans for its excellent work over the past several years.

Contacts:
Geoffrey Taylor (ICFA, Chair) - The University of Melbourne
Tatsuya Nakada (Chair, Executive Board, ILC International Development Team) - EPFL, Lausanne

John Adams Institute for Accelerator Science

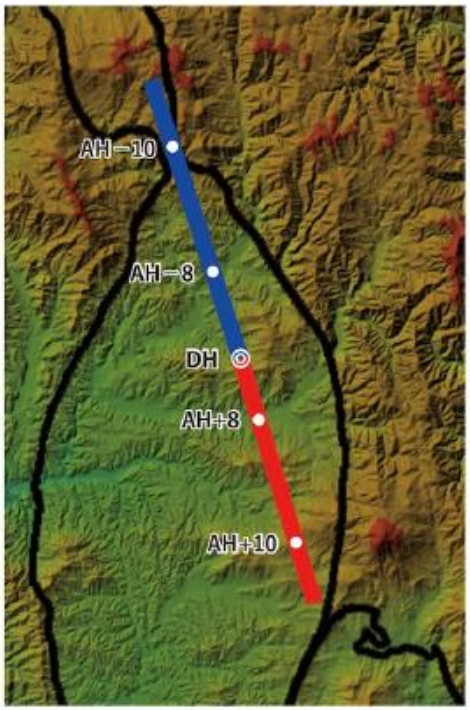
WG1: Draft model for Pre-lab governance



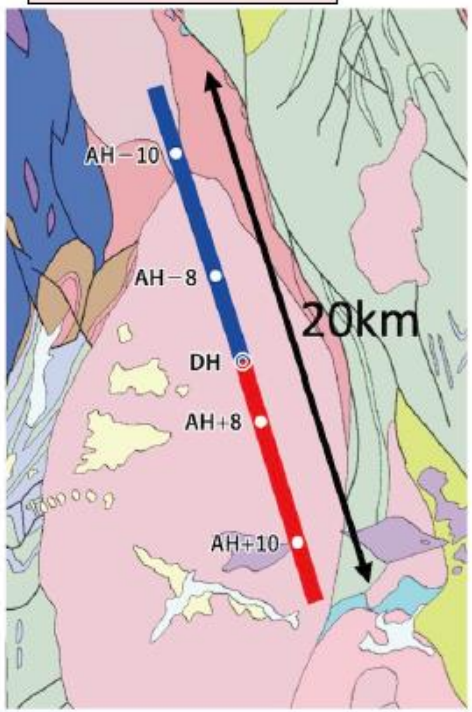
T. Nakada,

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



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.

Radiation safety and community understanding

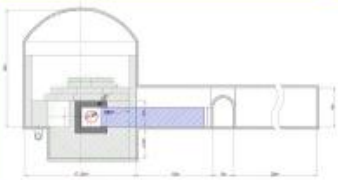
Facility design for radiation safety (radiation protection and long-term maintenance of radioactive materials)

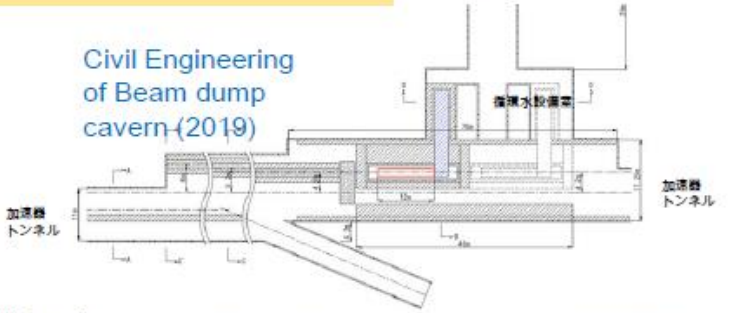
- Experiences with KEK and other large accelerators around the world
  - ✓Experience with proton accelerators with more severe activation (Selection of materials for beam dump windows and positron targets)
- Safety evaluation by simulation

- The final design for safety, including the structure of radiation shielding, maintenance methods for activated components, measures against leakage of beam dump water, and long-term maintenance of activated materials, is being carried out with international cooperation, mainly by KEK.

- Specific design of facilities and equipment through industry-academia collaboration
- Studying measures for drainage, earthquake, and radiation (AAA WG)







Briefing sessions to promote understanding among local residents

- Explanation of safety management and environmental impact measures
- Briefing sessions were held at 11 venues, including the Community Exchange Center, in order to broaden the participation of local residents, and a total of 673 people attended the sessions.
- Questions asked at the briefing sessions and answers to questions and concerns raised by local residents were compiled and made available on the website.

https://tipdc.org/inquiries#qa (in Japanese)

KEK, local Universities and local government



Environmental Initiatives

- Environmental impact assessment policy

  Establishment of the "ILC Environmental Assessment Advisory Board" with external experts (2019)

  Chair: Kenichiro Yanagi (Professor Emeritus, Meiji University), Chairman of Tokyo Olympic and Paralympic Environmental Assessment Committee

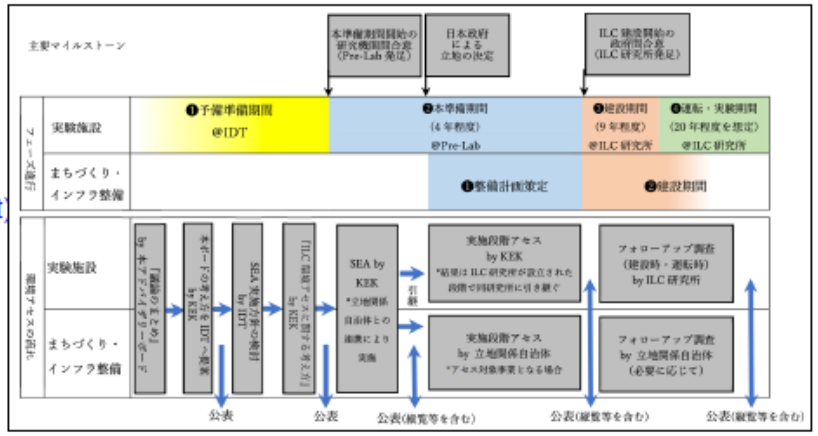
  Based on the project characteristics of ILC,

  - Basic guidelines for assessment, and
  - Implementation structure, process, and
  - Methodology and assessment targets

    (environmental impact, social and economic impact)

  Summary of the Discussion

  https://www2.kek.jp/ilc/ja/contents/docs/Strategic_Environmental_Assessment_of_the_ILC_Project_Summary_of_the_Discussion_r.pdf



Flow of environmental assessment for the ILC project (assumed)

- "Green ILC" for the environment

  (Green ILC WG, AAA)

  https://tipdc.org/assets/uploads/2020/12/guideline03.pdf (in Japanese)
  https://tipdc.org/assets/uploads/2020/12/guideline04.pdf (in Japanese)

  - Energy measures: Biomass, Power-GRID, waste heat utilization
  - Utilization of resources: Use of local wood for ILC-related facilities, use of high-quality granite produced during tunnel excavation