CLIC status, plans and outlook

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On behalf of the CLIC Collaborations

Thanks to all colleagues for materials

CLIC Collaborations

31 Countries – over 70 Institutes

Outline

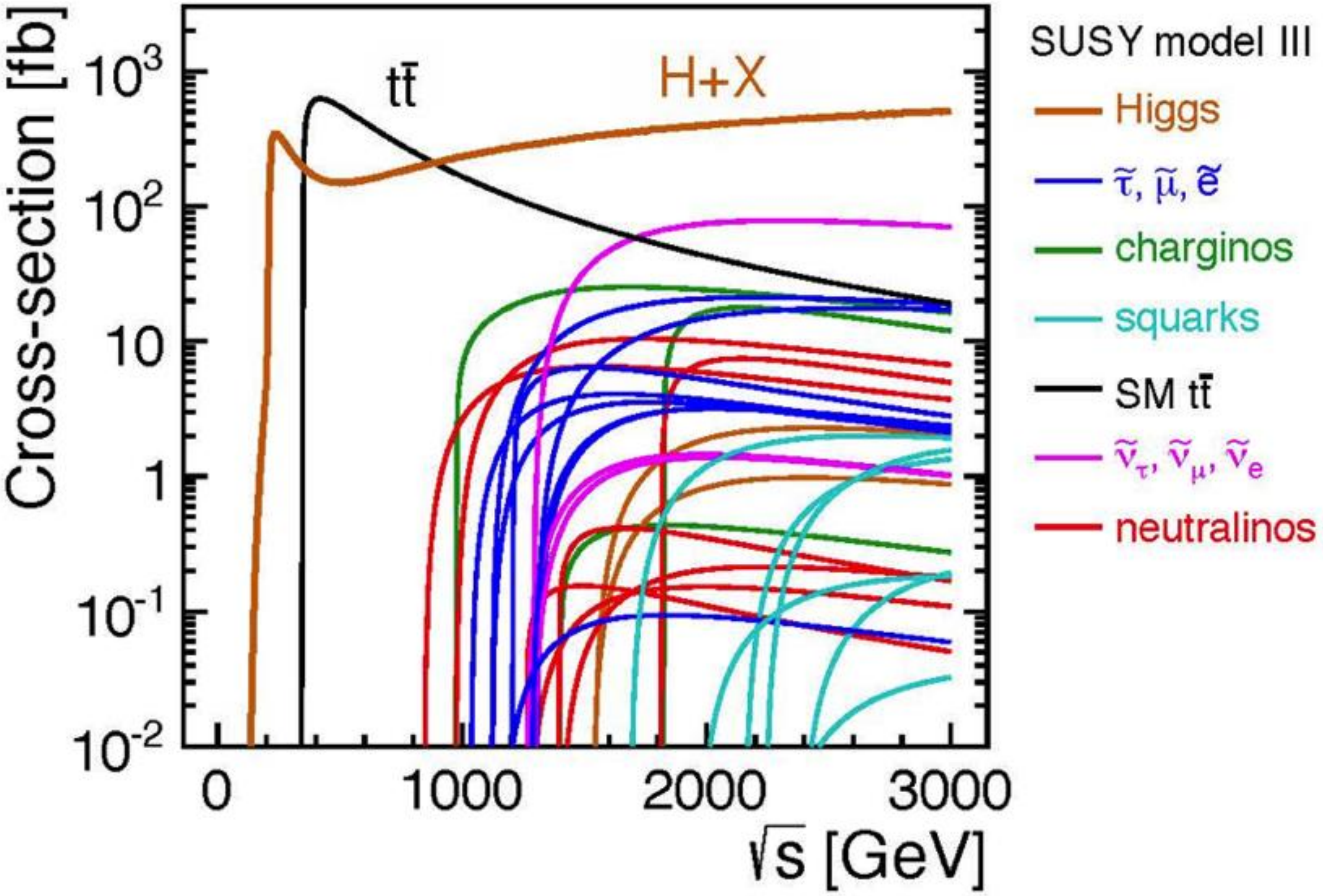
- Brief context and introduction
- CLIC Review
- Rebaselining + project staging
- Strategic plans → 2019 and beyond

Apologies for skipping many results + details

CLIC physics context

Energy-frontier capability for electron-positron collisions,

for precision exploration of potential new physics that may emerge from LHC



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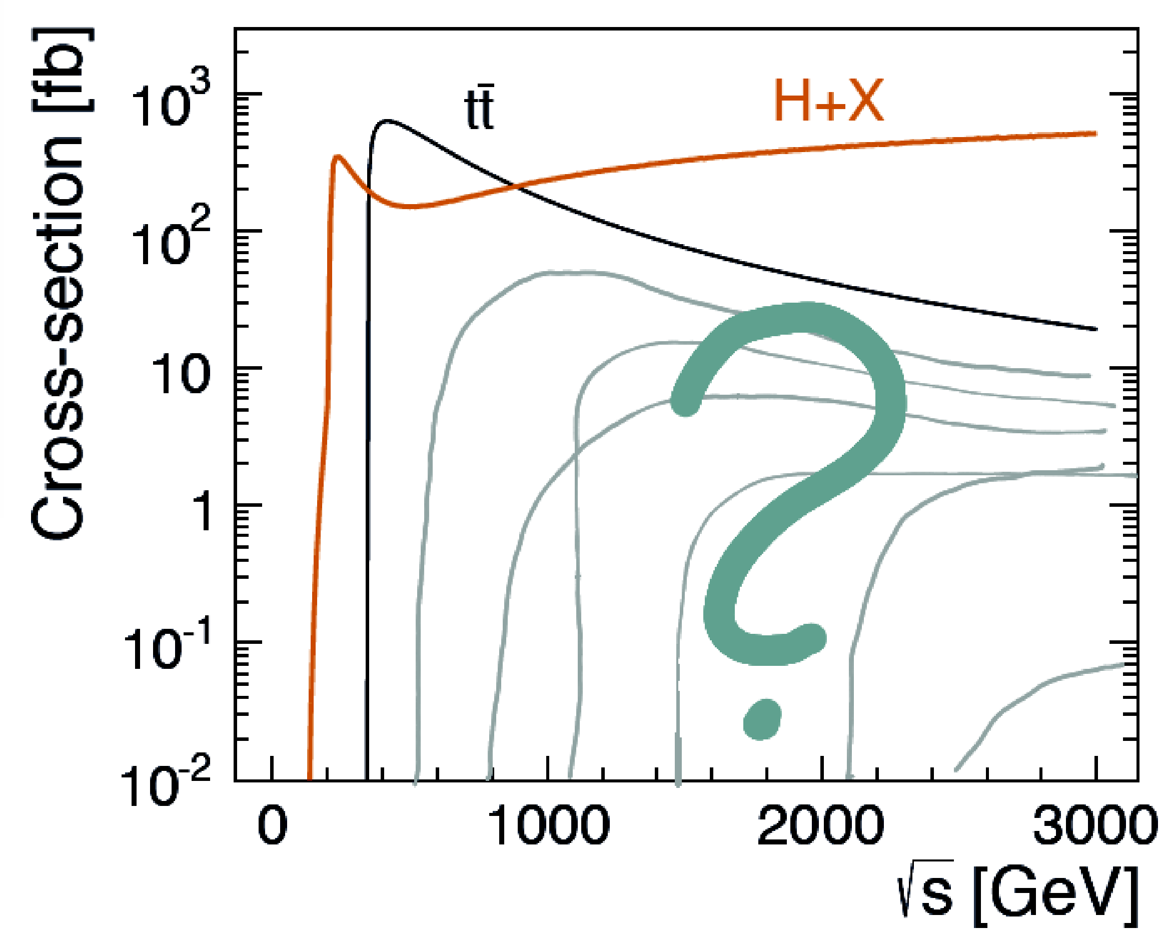

CERN scientific roadmap

Full exploitation of the LHC:

- ☐ Run 2 started last year → goal this year is $L=10^{34}$ at $\sqrt{s}=13$ TeV, ~25 fb^{-1}
- ☐ building upgrade of injectors (LIU), collider (HL-LHC) and detectors (Phase-1 and Phase-2)

Diversity programme serving a broad community:

- ☐ ongoing experiments and facilities at Booster, PS, SPS and their upgrades (ELENA, HIE-ISOLDE)
- ☐ participation in accelerator-based neutrino projects outside Europe (presently mainly LBNF in the US) through the CERN Neutrino Platform

Preparation of CERN's future:

- ☐ vibrant accelerator R&D programme exploiting CERN's strengths and uniqueness (including superconducting high-field magnets, AWAKE, etc.)
- ☐ design studies for future accelerators: CLIC, FCC (includes HE-LHC)
- ☐ future opportunities for scientific diversity programme (new)

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F.Gianotti April 2016

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We are vigorously preparing input for European Strategy Update ~ 2019:

- **Project Plan for CLIC as a credible post-LHC option for CERN**
- **Initial costs compatible with CERN budget**
- **Upgradeable in stages over 20-30 years**

CLIC Review (Spring 2016)

From Review Mandate – called by Frederick Bordry, director of accelerators and technology

Further to recent discussions held in the framework of the MTP, a review is called by the Director for Accelerators and Technology to assess the current status and in particular provide recommendations on the targets to be achieved that will be instrumental for the next European Strategy Update of 2019. The review will concentrate on the CLIC accelerator programme.

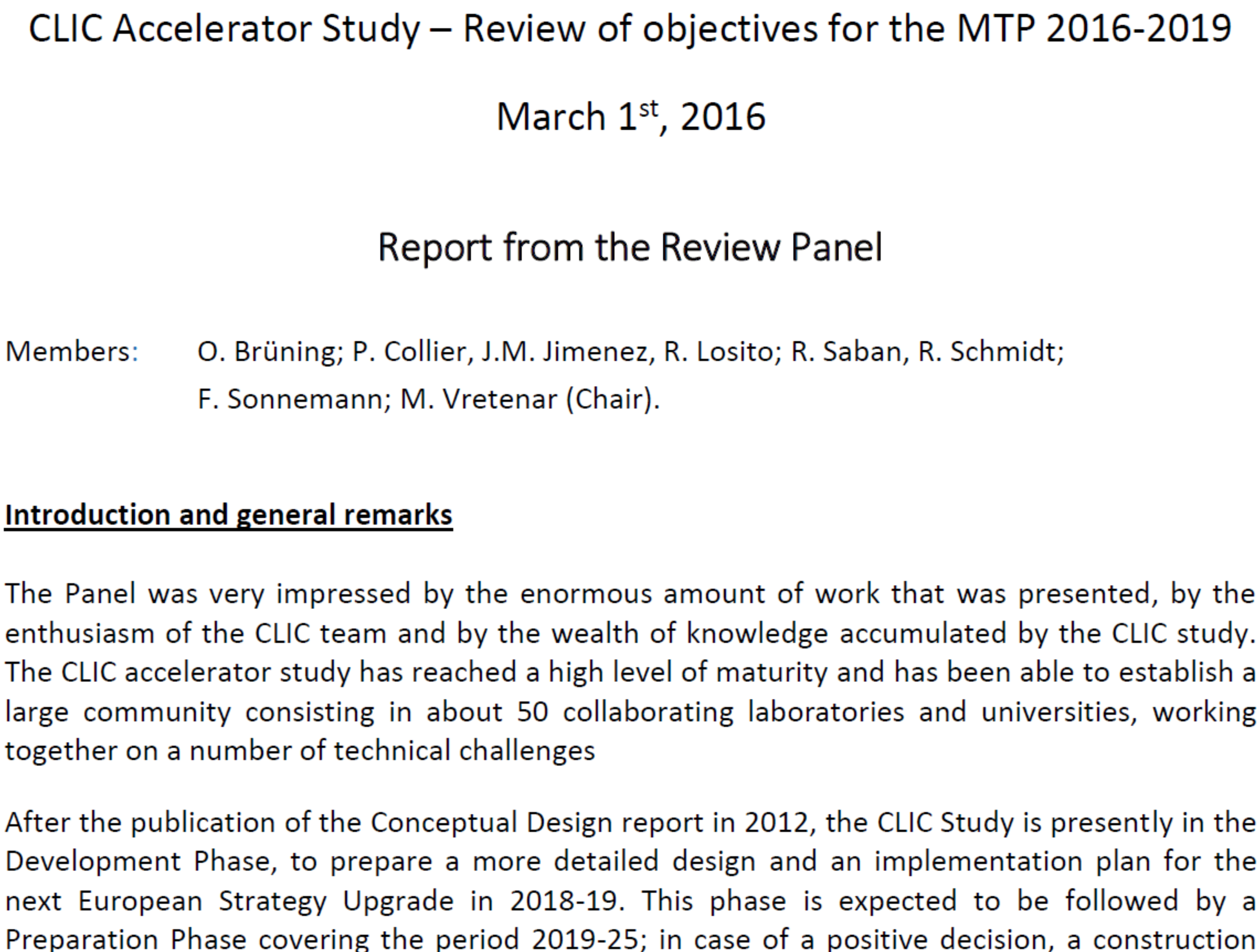
Ranking: High Priority, Some Priority, Low Priority, Terminate

Members of the Review Panel

- **ATS Department Heads: P. Collier, JM. Jimenez, R. Losito;**
- **Oliver Brüning;, Roberto Saban, Rüdiger Schmidt, Florian Sonnemann;**
- **Maurizio Vretenar (Chair).**

Indico link

CLIC Review report



CLIC Accelerator Study – Review of objectives for the MTP 2016-2019

March 1st, 2016

Report from the Review Panel

Members: O. Brüning; P. Collier, J.M. Jimenez, R. Losito; R. Saban, R. Schmidt;
F. Sonnemann; M. Vretenar (Chair).

Introduction and general remarks

The Panel was very impressed by the enormous amount of work that was presented, by the enthusiasm of the CLIC team and by the wealth of knowledge accumulated by the CLIC study. The CLIC accelerator study has reached a high level of maturity and has been able to establish a large community consisting in about 50 collaborating laboratories and universities, working together on a number of technical challenges

After the publication of the Conceptual Design report in 2012, the CLIC Study is presently in the Development Phase, to prepare a more detailed design and an implementation plan for the next European Strategy Upgrade in 2018-19. This phase is expected to be followed by a Preparation Phase covering the period 2019-25; in case of a positive decision, a construction

Report: some key points

- Produce optimized, staged design: 380 GeV → 3 TeV
- Optimise cost and power consumption
- Support efforts to develop high-efficiency klystrons
- Support 380 GeV klystron-only version as alternative
- Consolidate high-gradient structure test results
- Exploit Xboxes + nurture high-gradient test capabilities
- Develop plans for 2020-25 (‘preparation phase’) + structure conditioning strategy
- Continuing and enhanced participation in KEK/ATF2

‘Rebaselining’

Optimize machine design w.r.t. cost and power for a staged approach to reach multi-TeV scales:

~ 380 GeV (optimised for Higgs + top physics)
~ 1500 GeV
~ 3000 GeV
(working assumptions: exact choices of higher c.m. energies depend on LHC findings)

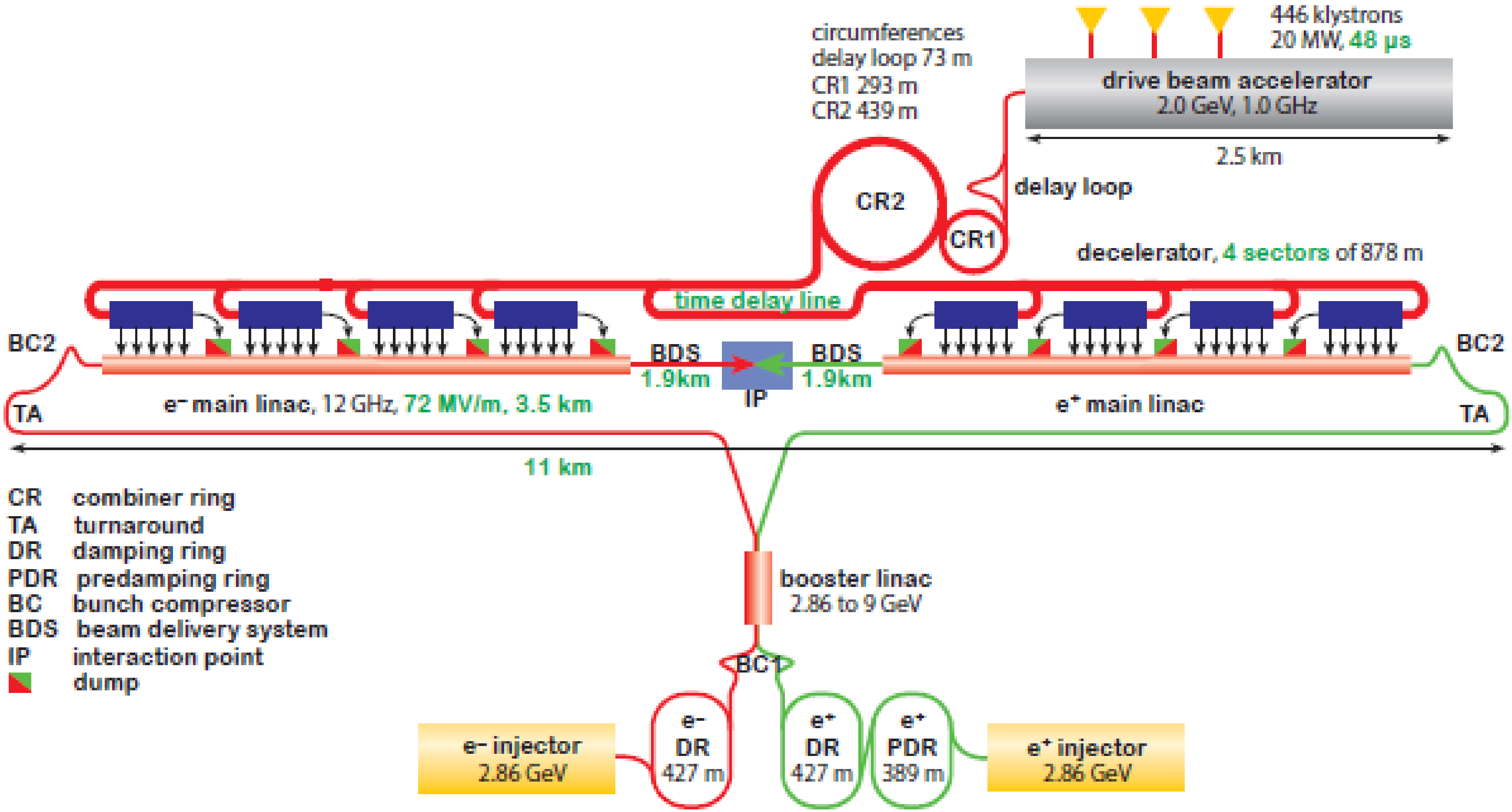
for various luminosities and safety factors

- **Expect to make significant cost and power reductions for the initial stages**
- **Choose new staged parameter sets, with a corresponding consistent upgrade path, also considering the possibility of the initial-stage being klystron-powered**

Rebaselining: first stage energy ~ 380 GeV

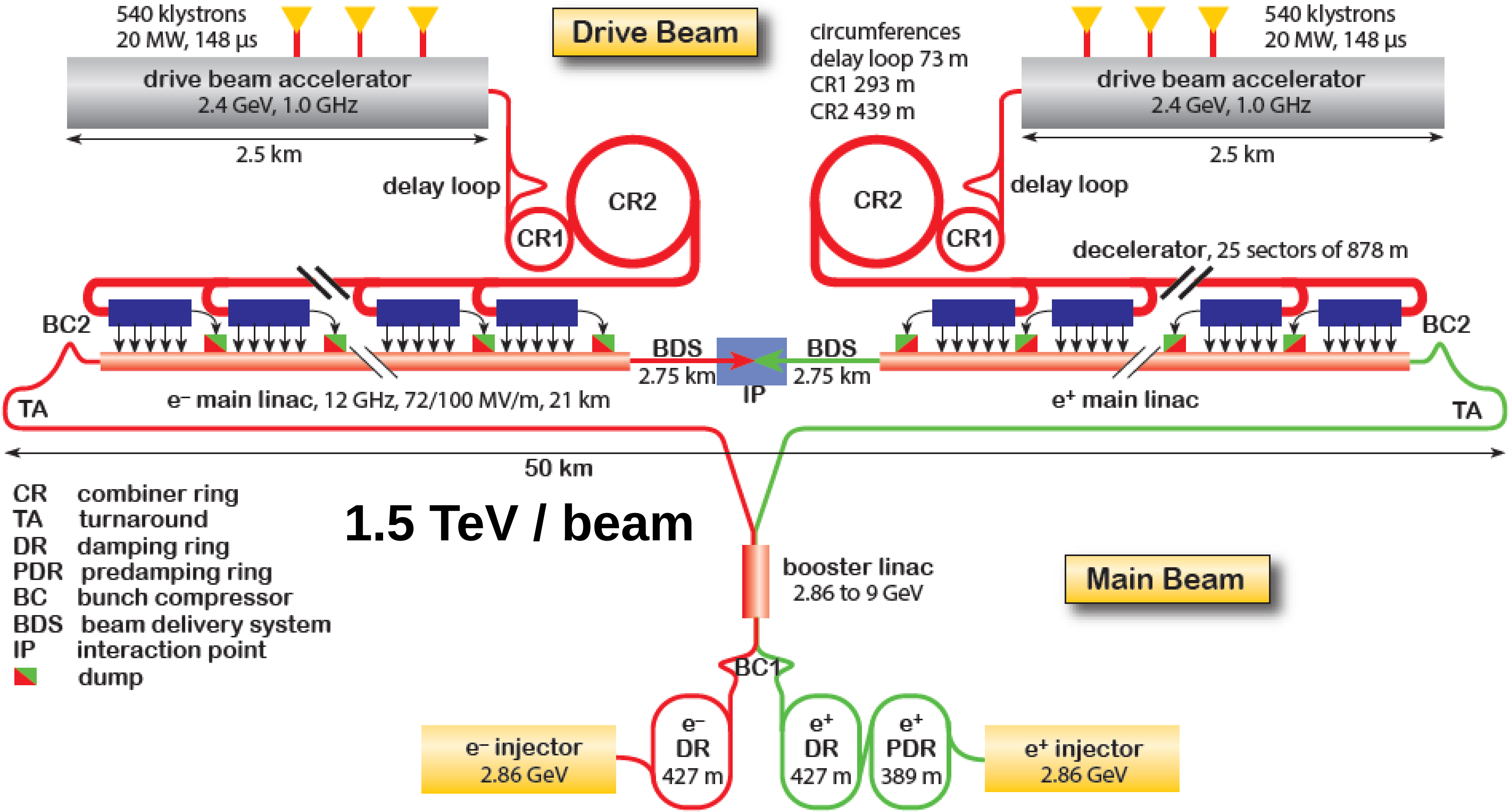
Parameter	Unit	380 GeV	3 TeV
Centre-of-mass energy	TeV	0.38	3
Total luminosity	$10^{34}cm^{-2}s^{-1}$	1.5	5.9
Luminosity above 99% of $\sqrt{s}$	$10^{34}cm^{-2}s^{-1}$	0.9	2.0
Repetition frequency	Hz	50	50
Number of bunches per train		352	312
Bunch separation	ns	0.5	0.5
Acceleration gradient	MV/m	72	100
Site length	km	11	50

New CLIC layout 380 GeV



CR	combiner ring
TA	turnaround
DR	damping ring
PDR	predamping ring
BC	bunch compressor
BDS	beam delivery system
IP	interaction point
🟥	dump

New CLIC layout 3 TeV



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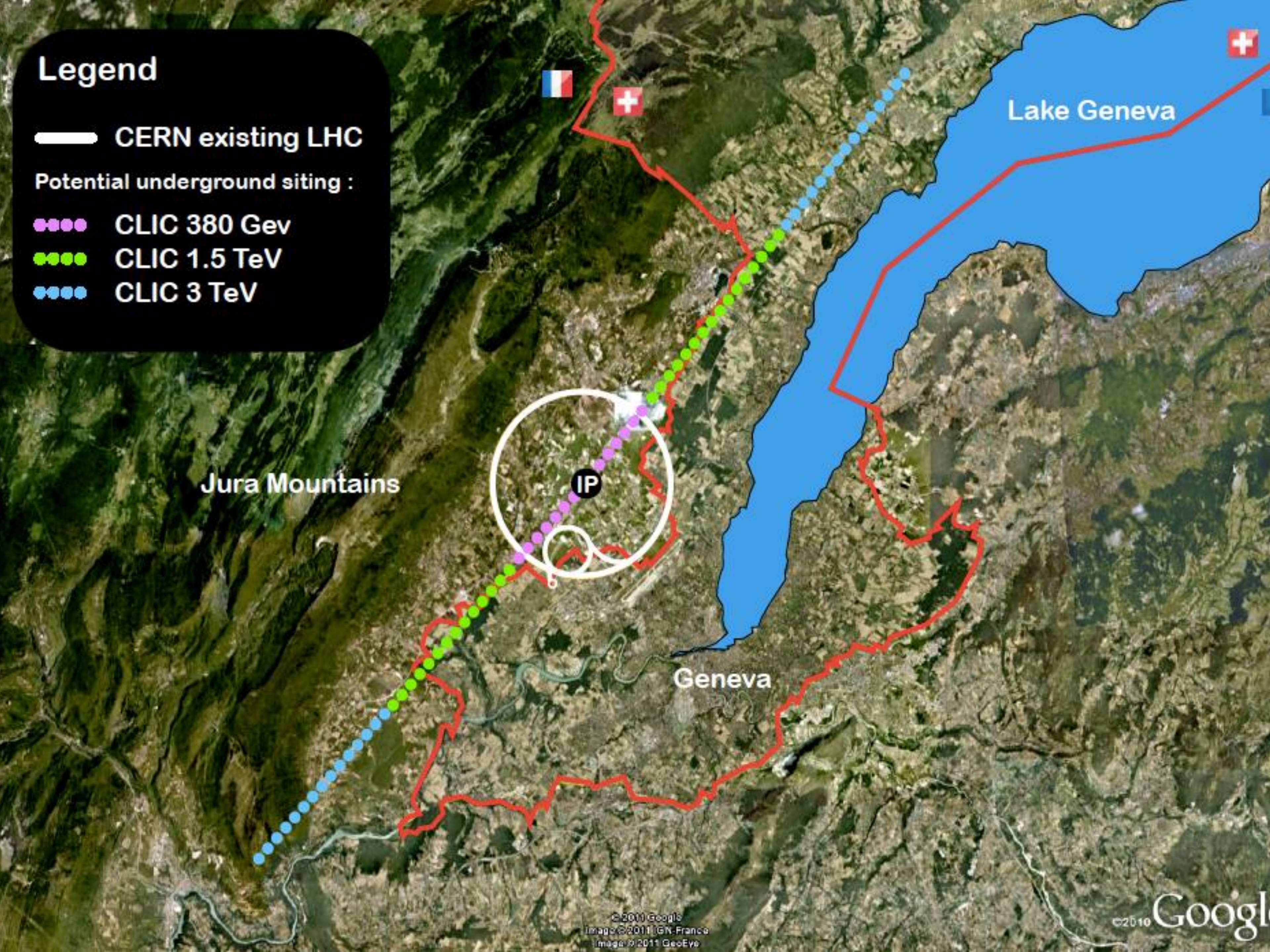
1.5 TeV / beam


Legend
CERN existing LHC
Potential underground siting :
CLIC 380 Gev
CLIC 1.5 TeV
CLIC 3 TeV
Lake Geneva
Jura Mountains
IP
Geneva
©2011 Google
Image ©2011 IGN-France
Image ©2011 GeoEye
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Current rebaselined parameters

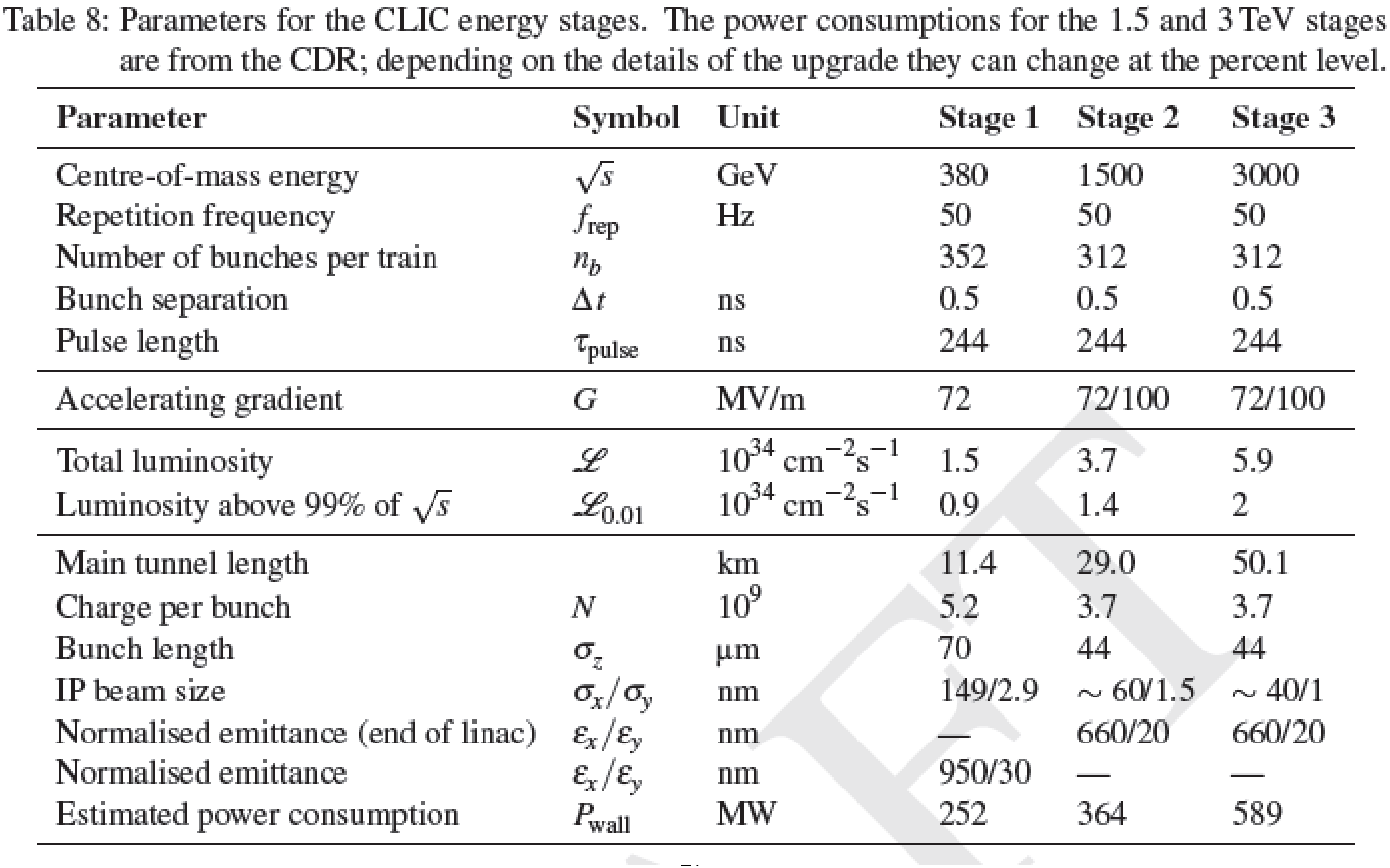
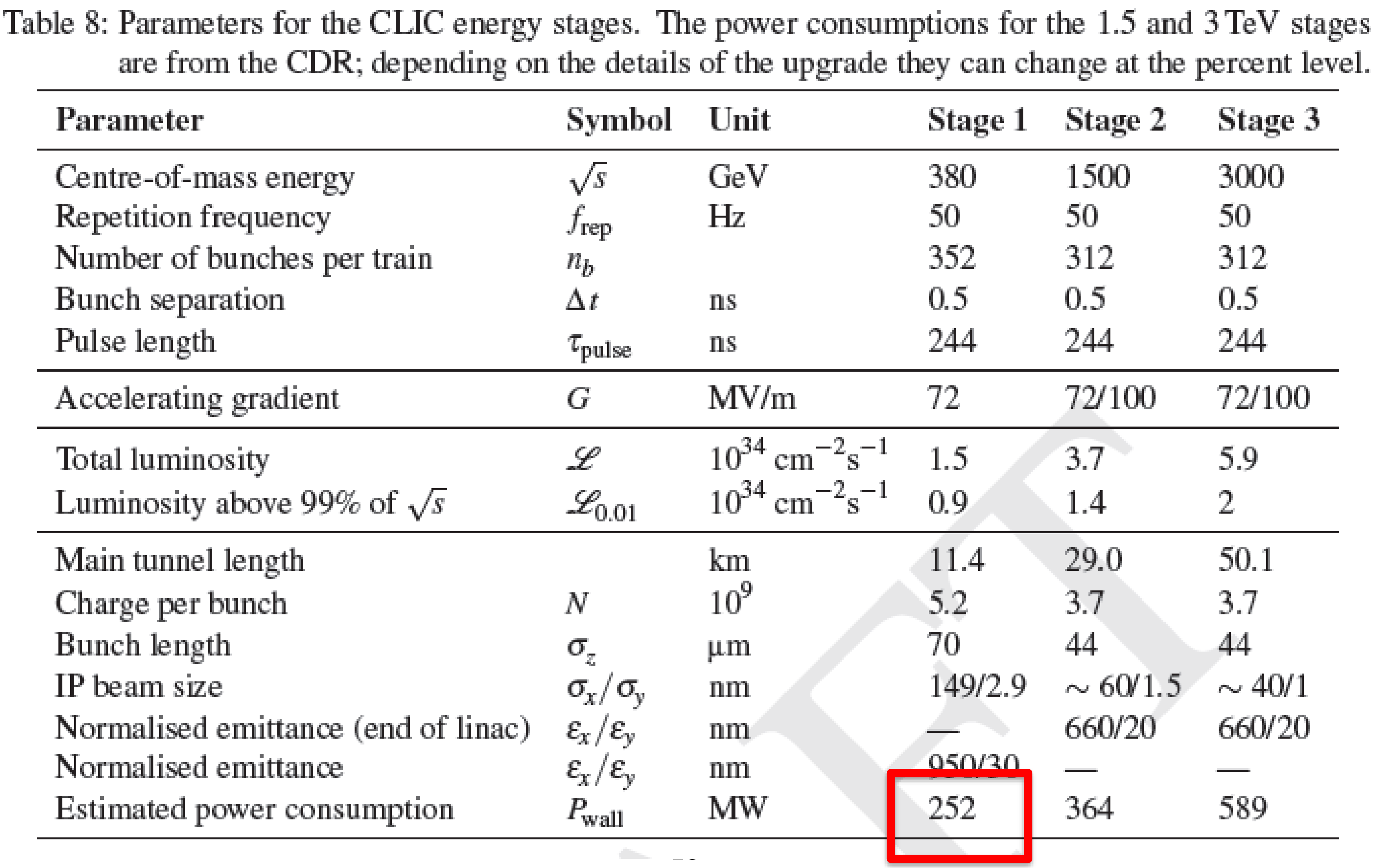


Table 8: Parameters for the CLIC energy stages. The power consumptions for the 1.5 and 3 TeV stages are from the CDR; depending on the details of the upgrade they can change at the percent level.

Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	380	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		352	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Pulse length	τ_{pulse}	ns	244	244	244
Accelerating gradient	G	MV/m	72	72/100	72/100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	1.5	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	0.9	1.4	2
Main tunnel length		km	11.4	29.0	50.1
Charge per bunch	N	10^9	5.2	3.7	3.7
Bunch length	σ_z	µm	70	44	44
IP beam size	σ_x/σ_y	nm	149/2.9	$\sim$ 60/1.5	$\sim$ 40/1
Normalised emittance (end of linac)	ϵ_x/ϵ_y	nm	—	660/20	660/20
Normalised emittance	ϵ_x/ϵ_y	nm	950/30	—	—
Estimated power consumption	P_{wall}	MW	252	364	589

Current rebaselined parameters



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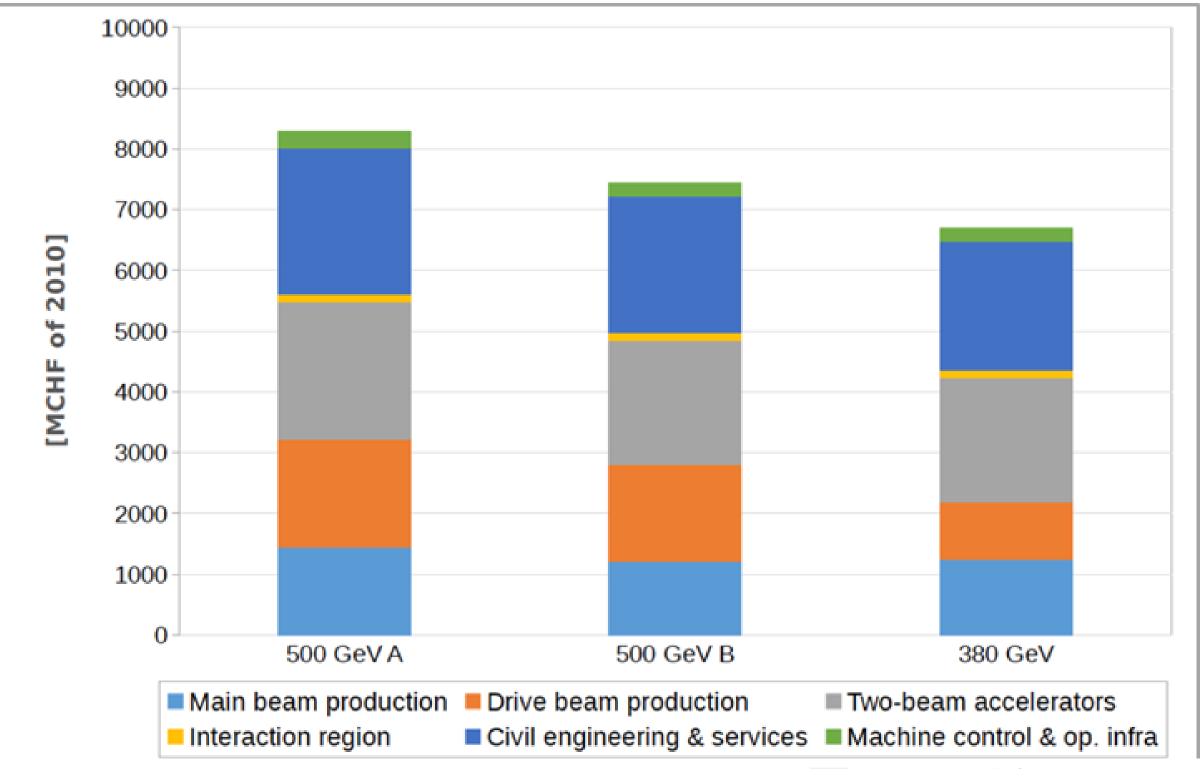
Preliminary cost estimate (380)



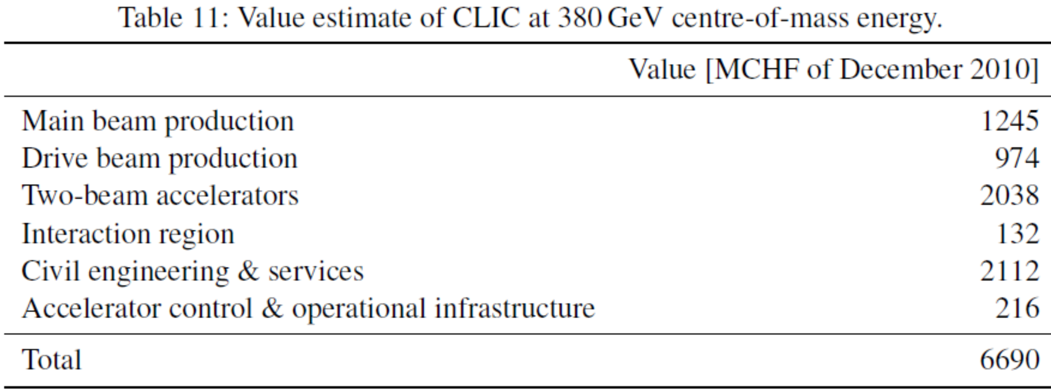
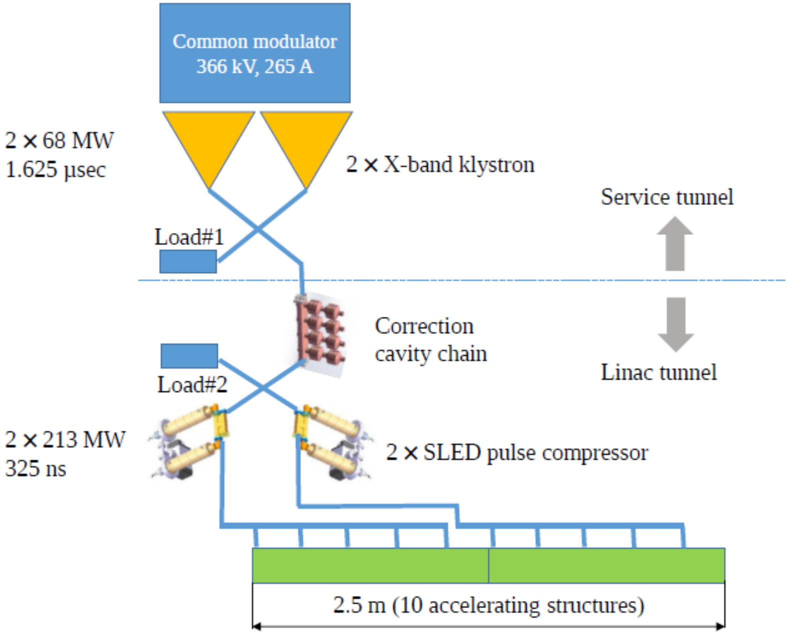


Table 11: Value estimate of CLIC at 380 GeV centre-of-mass energy.

	Value [MCHF of December 2010]
Main beam production	1245
Drive beam production	974
Two-beam accelerators	2038
Interaction region	132
Civil engineering & services	2112
Accelerator control & operational infrastructure	216
Total	6690

Klystron version (380)



Klystron version (380)

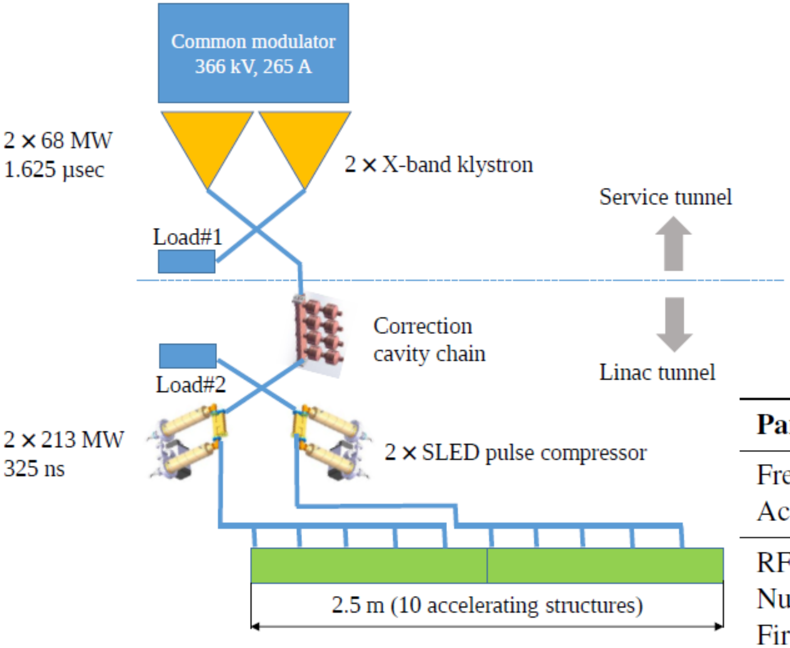
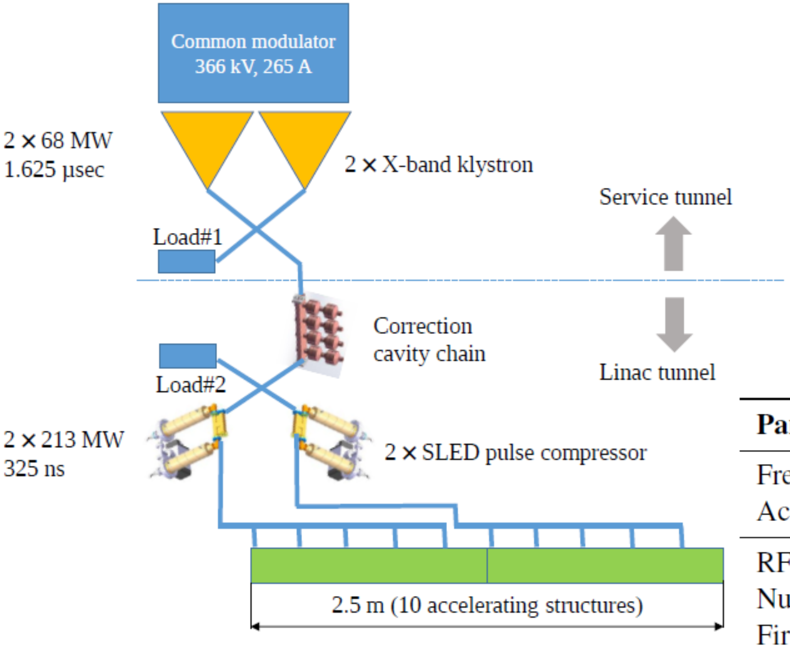
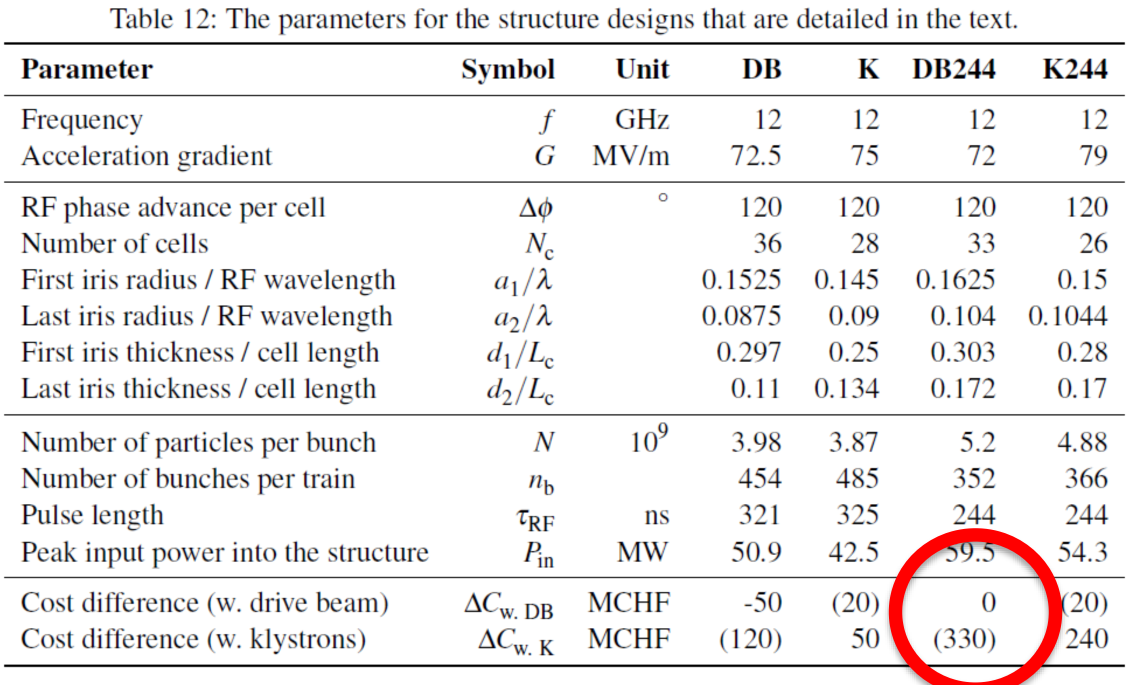


Table 12: The parameters for the structure designs that are detailed in the text.

Parameter	Symbol	Unit	DB	K	DB244	K244
Frequency	f	GHz	12	12	12	12
Acceleration gradient	G	MV/m	72.5	75	72	79
RF phase advance per cell	$\Delta\phi$	°	120	120	120	120
Number of cells	N_c		36	28	33	26
First iris radius / RF wavelength	a_1/λ		0.1525	0.145	0.1625	0.15
Last iris radius / RF wavelength	a_2/λ		0.0875	0.09	0.104	0.1044
First iris thickness / cell length	d_1/L_c		0.297	0.25	0.303	0.28
Last iris thickness / cell length	d_2/L_c		0.11	0.134	0.172	0.17
Number of particles per bunch	N	10^9	3.98	3.87	5.2	4.88
Number of bunches per train	n_b		454	485	352	366
Pulse length	τ_{RF}	ns	321	325	244	244
Peak input power into the structure	P_{in}	MW	50.9	42.5	59.5	54.3
Cost difference (w. drive beam)	$\Delta C_{w.\ DB}$	MCHF	-50	(20)	0	(20)
Cost difference (w. klystrons)	$\Delta C_{w.\ K}$	MCHF	(120)	50	(330)	240

Klystron version (380)





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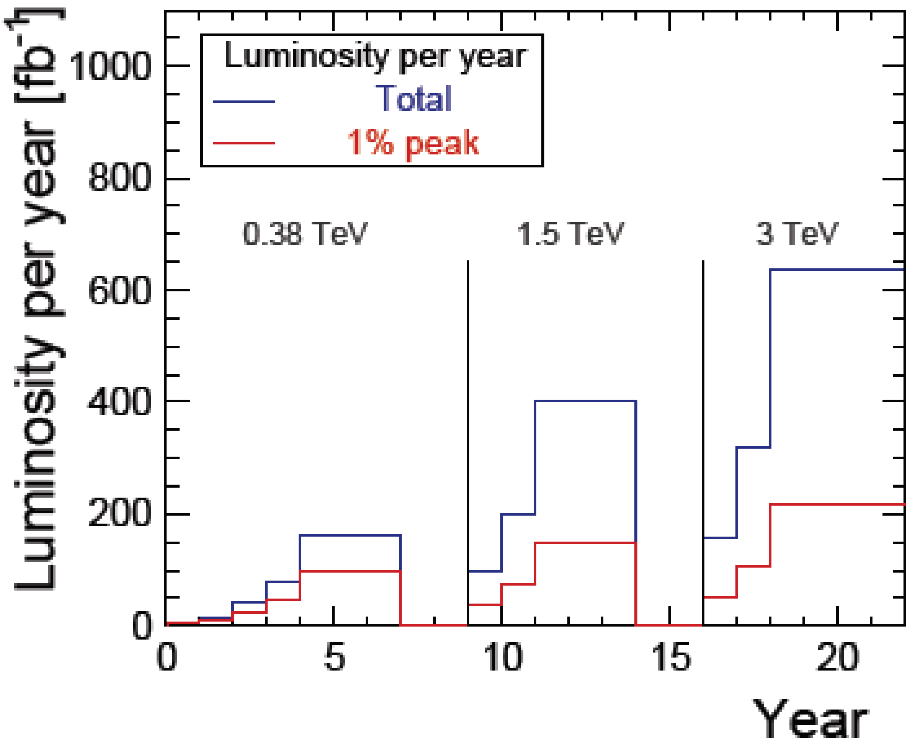
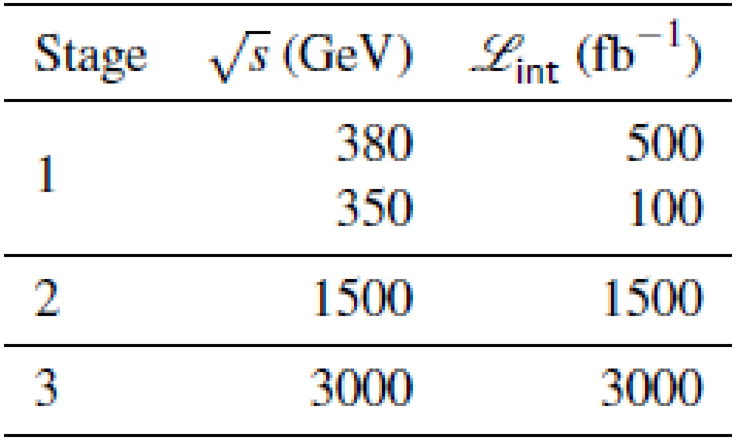
Cost savings may be possible (at the 5% level)

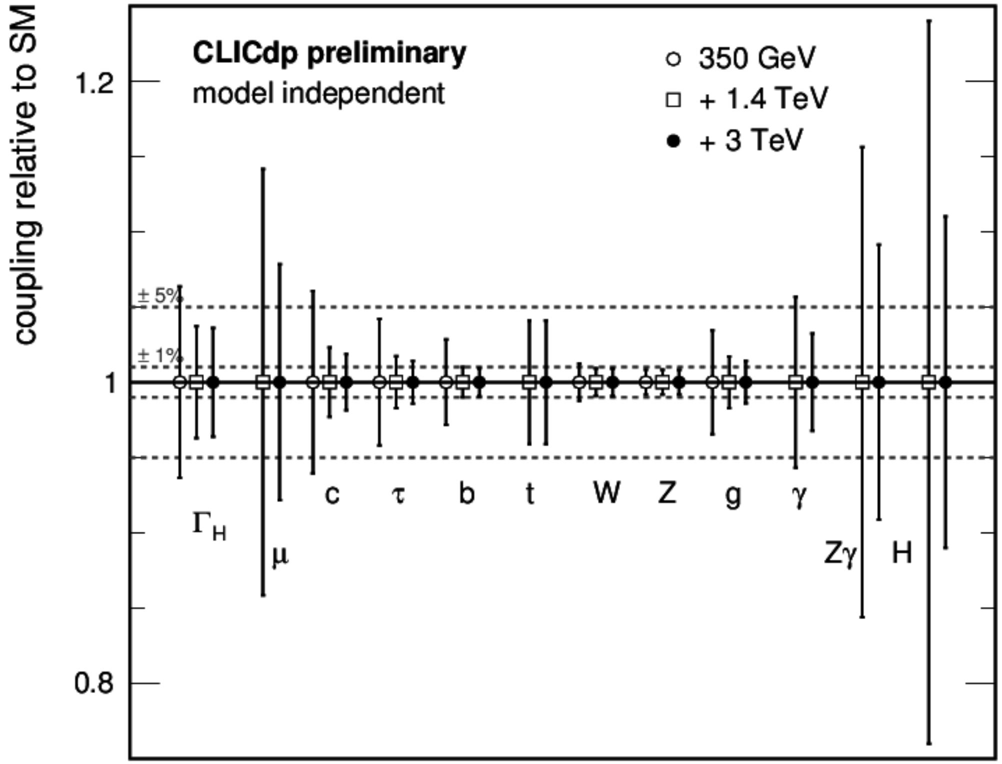
Updated CLIC run model

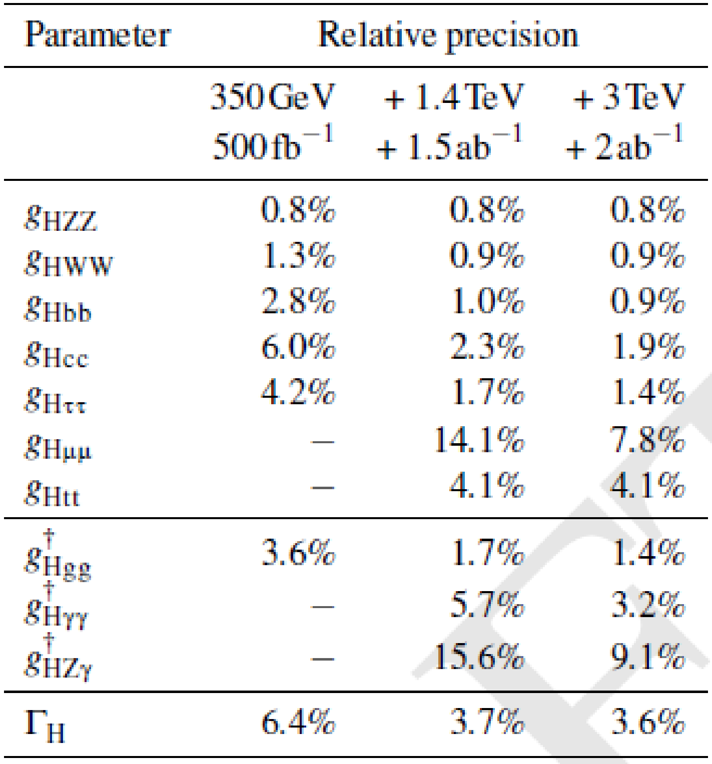




Stage	$\sqrt{s}$ (GeV)	$\mathscr{L}_{\text{int}}$ (fb^{-1})
1	380 350	500 100
2	1500	1500
3	3000	3000

CLIC Higgs physics capabilities





Parameter	Relative precision		
	350 GeV 500 fb^{-1}	+ 1.4 TeV + 1.5 ab^{-1}	+ 3 TeV + 2 ab^{-1}
g_{HZZ}	0.8%	0.8%	0.8%
g_{HWW}	1.3%	0.9%	0.9%
g_{Hbb}	2.8%	1.0%	0.9%
g_{Hcc}	6.0%	2.3%	1.9%
$g_{H\tau\tau}$	4.2%	1.7%	1.4%
$g_{H\mu\mu}$	–	14.1%	7.8%
g_{Htt}	–	4.1%	4.1%
$g^{\dagger}_{Hgg}$	3.6%	1.7%	1.4%
$g^{\dagger}_{H\gamma\gamma}$	–	5.7%	3.2%
$g^{\dagger}_{HZ\gamma}$	–	15.6%	9.1%
Γ_H	6.4%	3.7%	3.6%

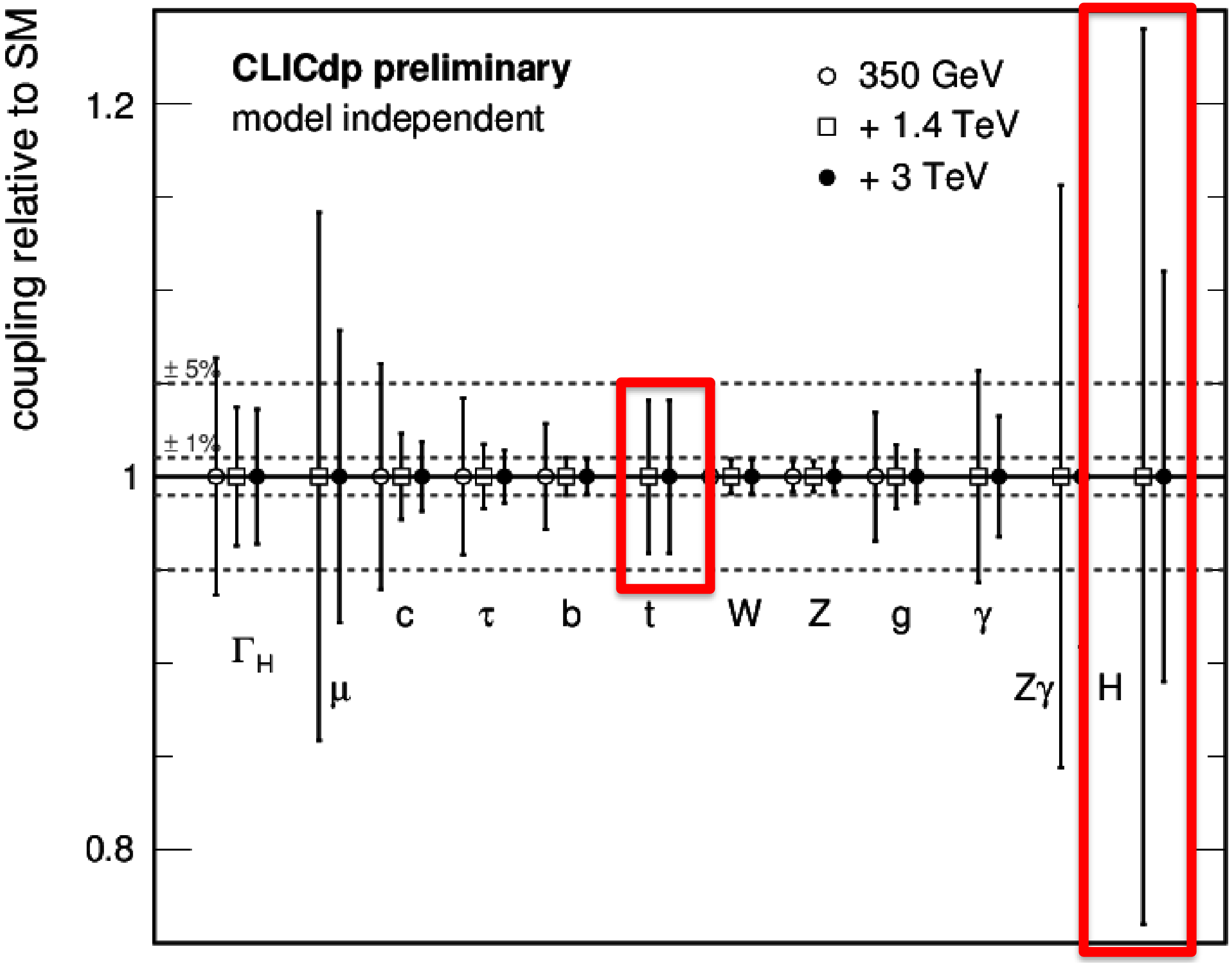
Omnibus paper: about to be submitted for publication

CLIC Higgs physics capabilities

Higgs couplings to heavy particles benefit from higher c.m. energies:

ttH ~ 4%

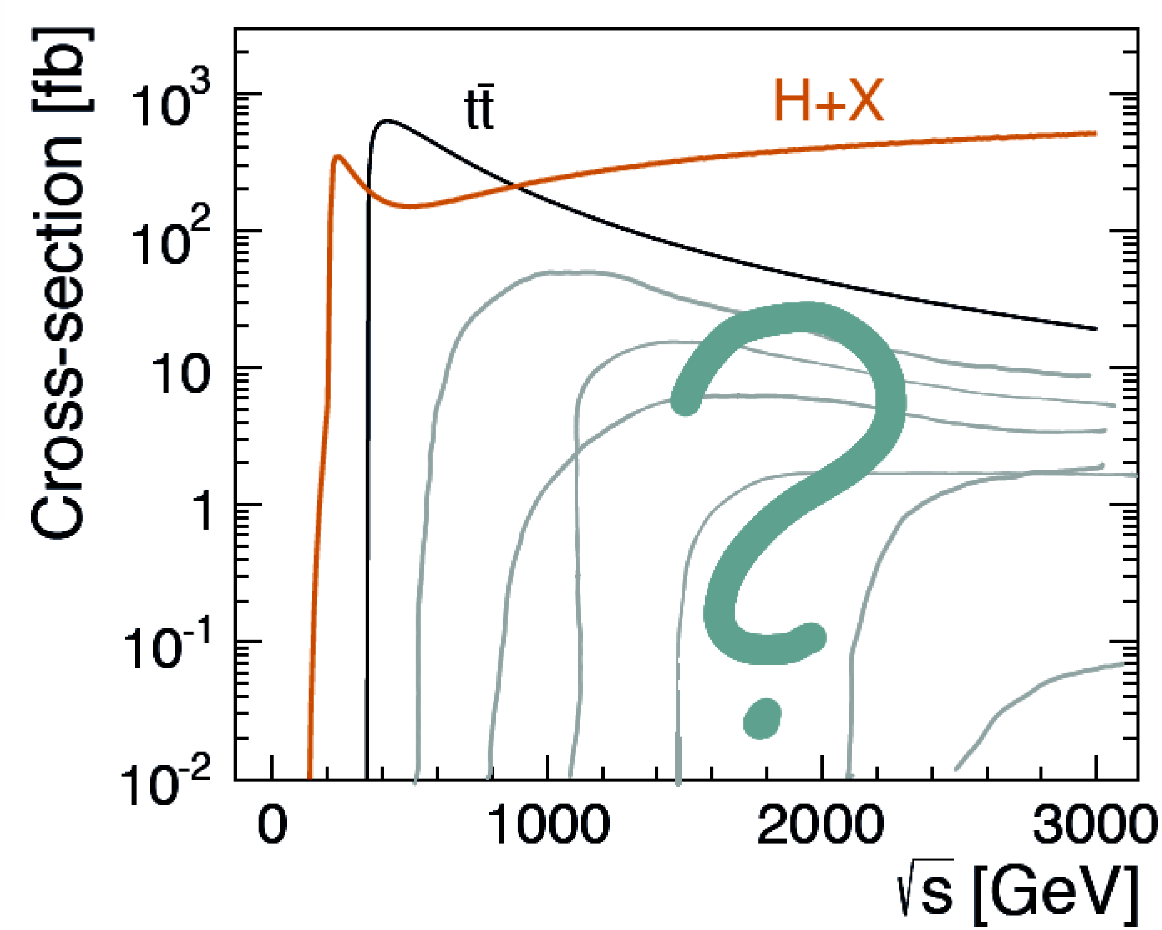
HH ~ 10%



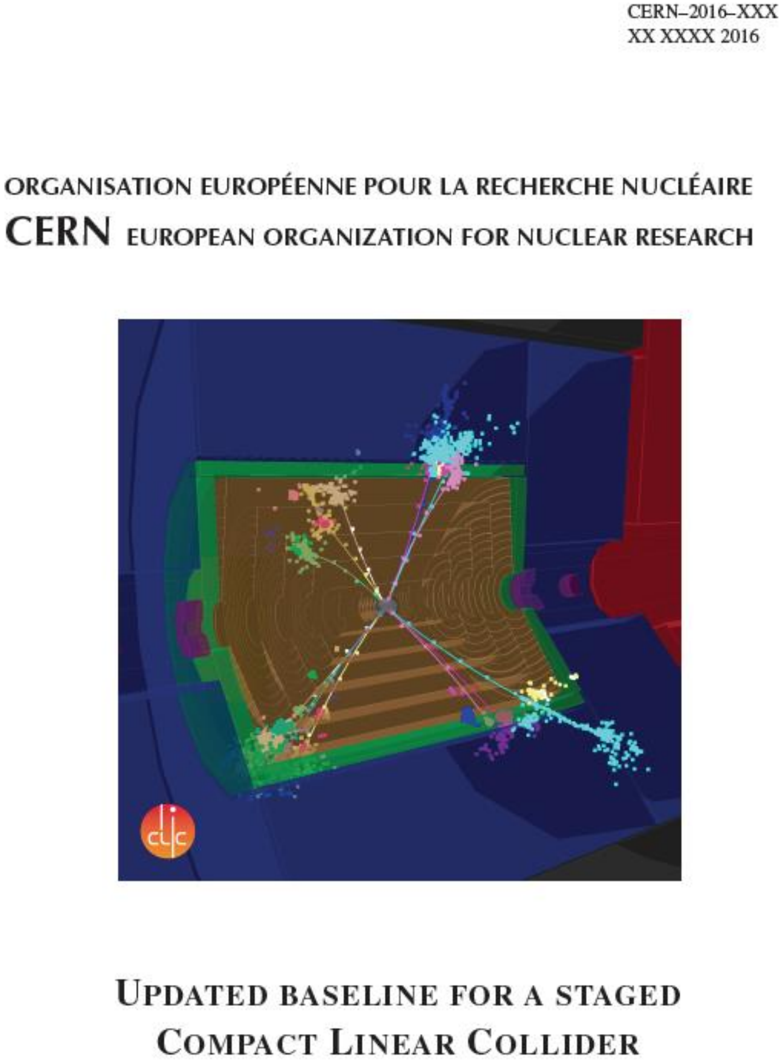
CLIC physics capabilities

Direct new-particle search reach up to 1.5 TeV

Indirect search reach up to O(100 TeV)



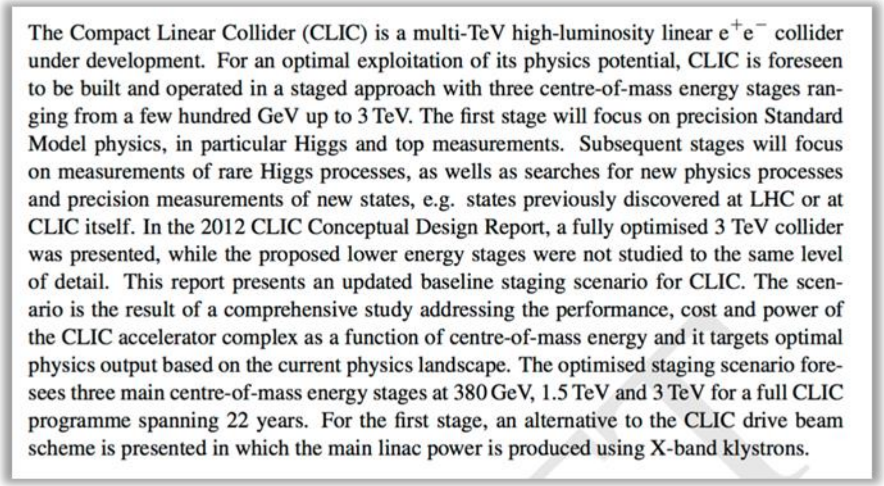
Rebaselining document



CERN–2016–XXX
XX XXXX 2016

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

UPDATED BASELINE FOR A STAGED
COMPACT LINEAR COLLIDER



The Compact Linear Collider (CLIC) is a multi-TeV high-luminosity linear e^+e^- collider under development. For an optimal exploitation of its physics potential, CLIC is foreseen to be built and operated in a staged approach with three centre-of-mass energy stages ranging from a few hundred GeV up to 3 TeV. The first stage will focus on precision Standard Model physics, in particular Higgs and top measurements. Subsequent stages will focus on measurements of rare Higgs processes, as wells as searches for new physics processes and precision measurements of new states, e.g. states previously discovered at LHC or at CLIC itself. In the 2012 CLIC Conceptual Design Report, a fully optimised 3 TeV collider was presented, while the proposed lower energy stages were not studied to the same level of detail. This report presents an updated baseline staging scenario for CLIC. The scenario is the result of a comprehensive study addressing the performance, cost and power of the CLIC accelerator complex as a function of centre-of-mass energy and it targets optimal physics output based on the current physics landscape. The optimised staging scenario foresees three main centre-of-mass energy stages at 380 GeV, 1.5 TeV and 3 TeV for a full CLIC programme spanning 22 years. For the first stage, an alternative to the CLIC drive beam scheme is presented in which the main linac power is produced using X-band klystrons.

‘yellow report’ in preparation

Rebaselining: ongoing studies

Optimize drive beam accelerator klystron system

Eliminated electron pre-damping ring (better e- injector)

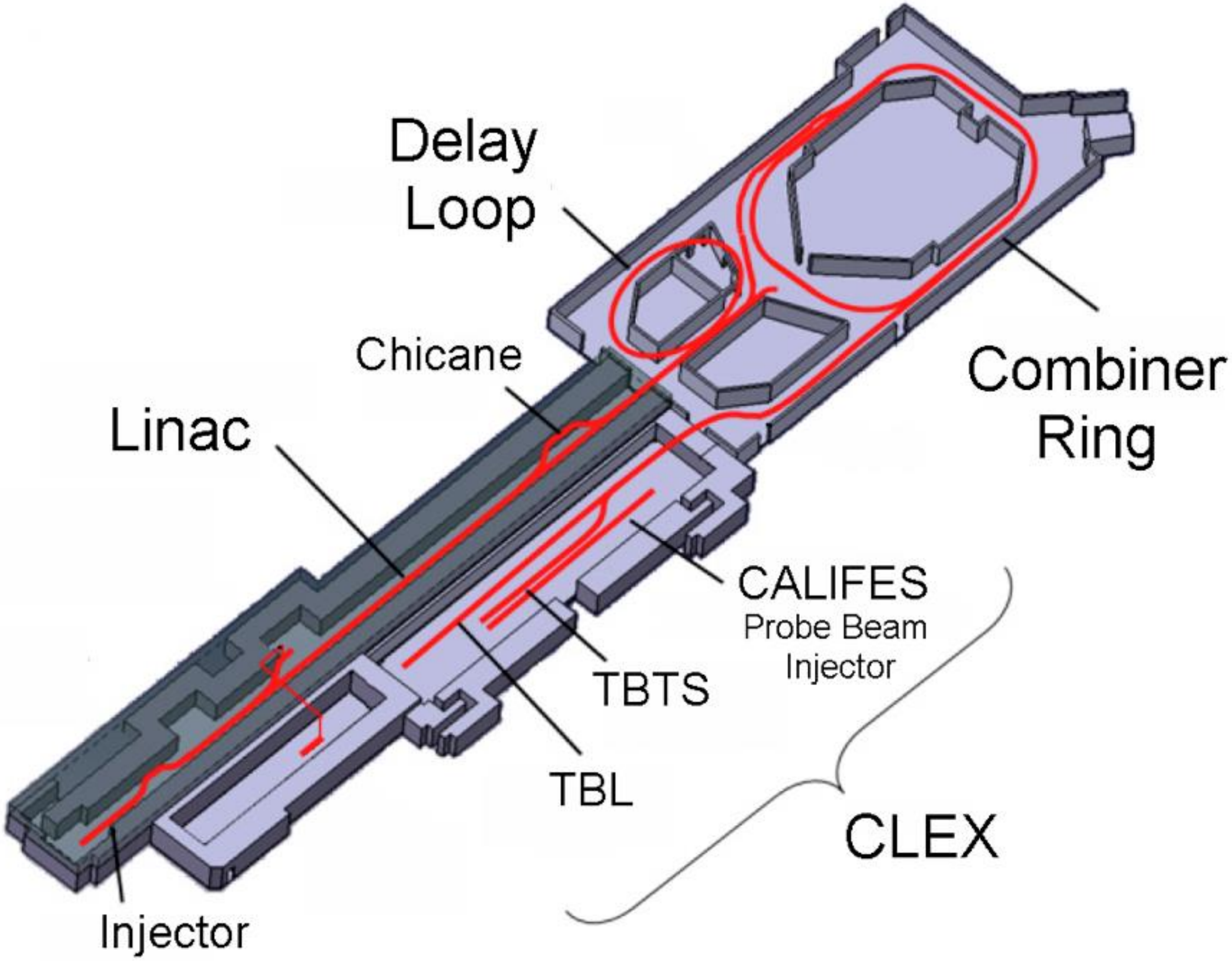
Systematic optimization of injector-complex linacs

Optimize / reduce power overhead estimates

Use of permanent or hybrid magnets for the drive beam
(order of 50,000 magnets)

… … …

CTF3


Delay Loop
Chicane
Linac
Combiner Ring
CALIFES
Probe Beam Injector
TBTS
TBL
CLEX
Injector

Main achievements of CTF3

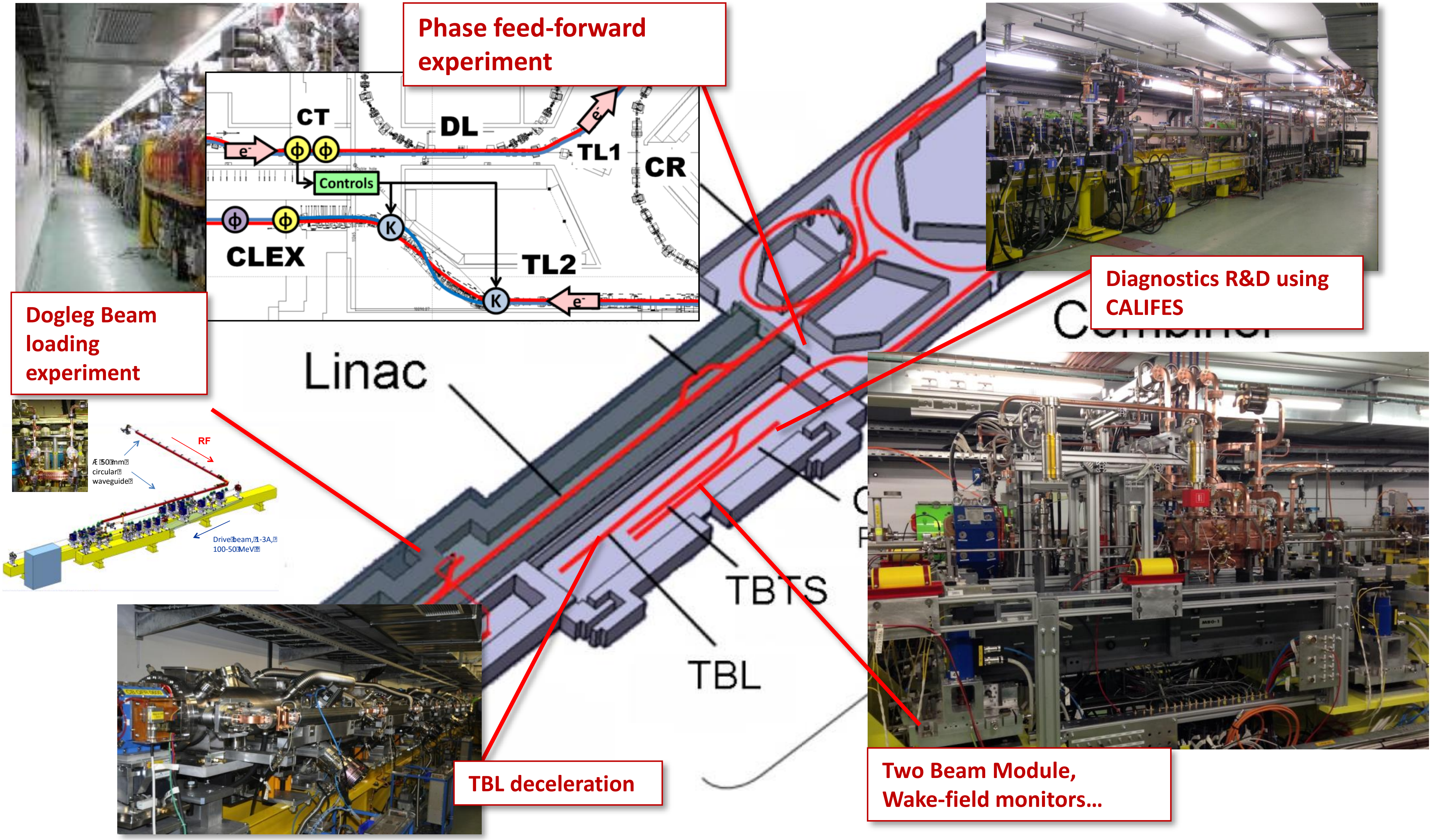
Drive beam generation:

- **Linac operation (4A) with full beam loading**
- **Phase-coding of beam with sub-harmonic buncher system**
- **Factor of ~8 current amplification by beam recombination**
- **Power extraction from drive beam at 2 x CLIC nominal**

Two-beam test stand + TBL:

- **2-beam acceleration in CLIC structures up to 1.5 x nominal**
- **Drive-beam stable deceleration to 35% of initial energy**
- **12 GHz RF power @ ~ 1 GW in string of 13 decelerators**

CTF3: 2016 last year of operation



Phase feed-forward experiment

Dogleg Beam loading experiment

Diagnostics R&D using CALIFES

TBL deceleration

Two Beam Module, Wake-field monitors…

CTF3 programme 2016

Power production:

- **stability + control of RF profile (beam loading comp.)**
- **RF phase/amplitude drifts along TBL**
- **PETS switching at full power**
- **beam deceleration + dispersion-free steering in TBL**
- **routine operation**

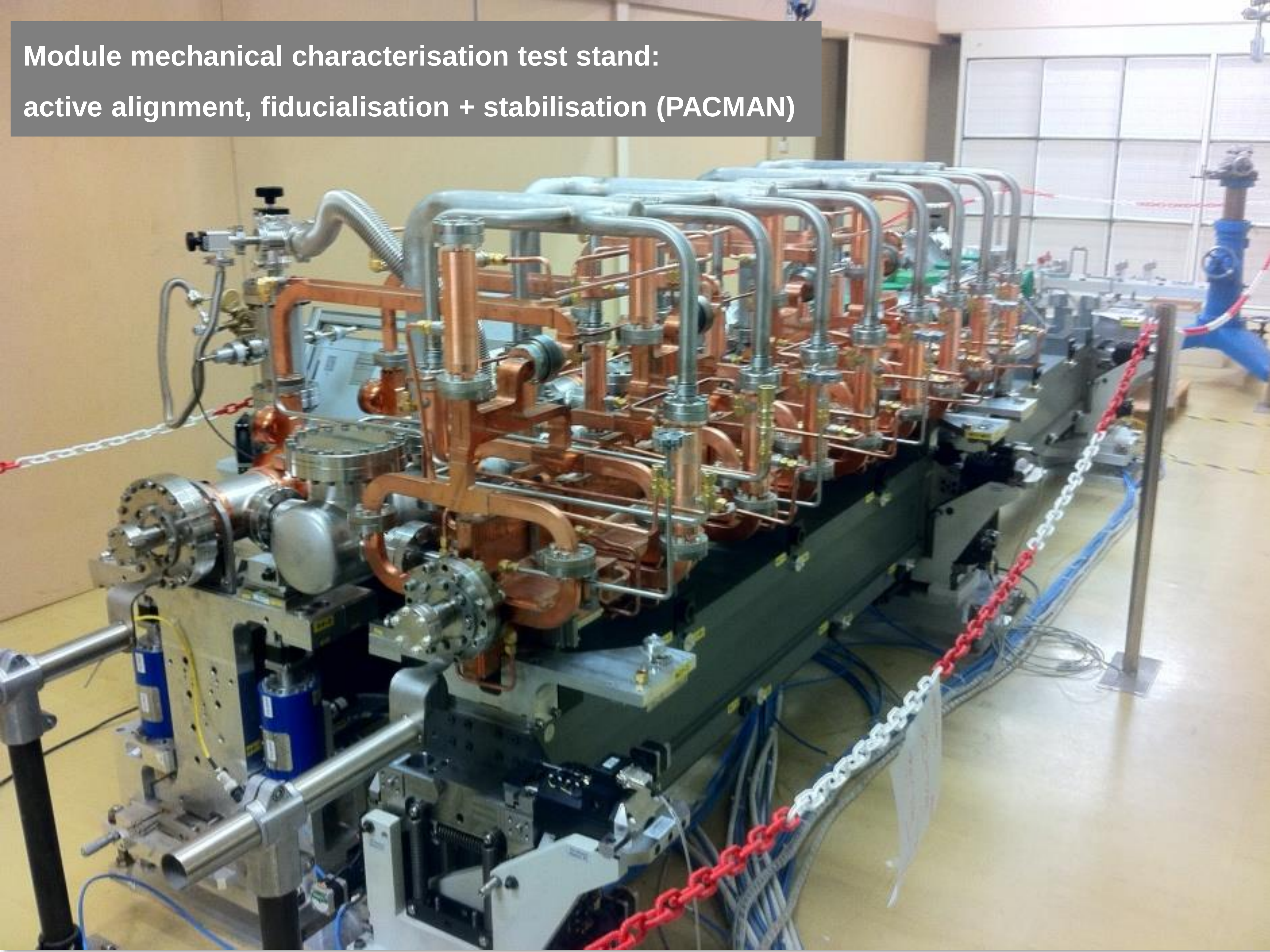
Drive-beam phase feed-forward prototype system

Beam orbit stabilisation/control

…

Recently installed 2-beam acceleration module in CTF3 (according to latest CLIC design)

Module mechanical characterisation test stand:
active alignment, fiducialisation + stabilisation (PACMAN)



CALIFES

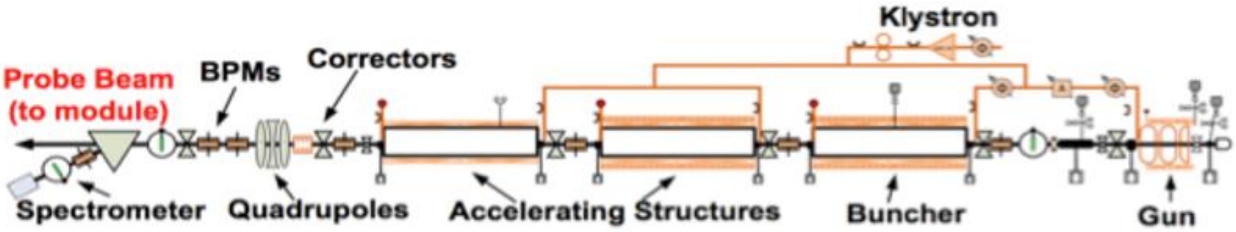
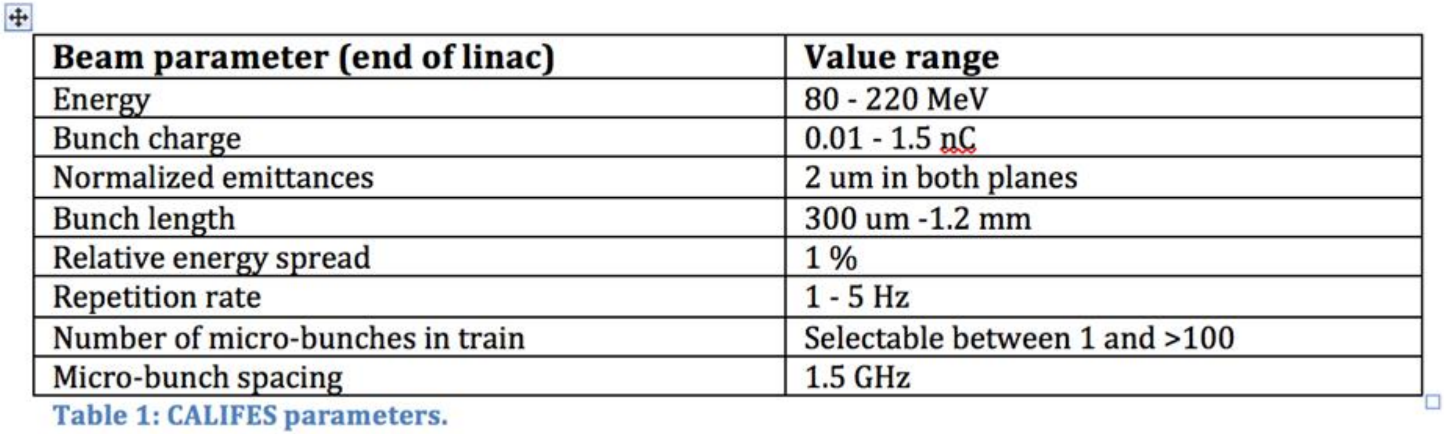


Figure 1: The current CALIFES beam line. The length of the facility (as shown) is ~20m.



Beam parameter (end of linac)	Value range
Energy	80 - 220 MeV
Bunch charge	0.01 - 1.5 nC
Normalized emittances	2 um in both planes
Bunch length	300 um -1.2 mm
Relative energy spread	1 %
Repetition rate	1 - 5 Hz
Number of micro-bunches in train	Selectable between 1 and >100
Micro-bunch spacing	1.5 GHz

Table 1: CALIFES parameters.

- **X-band FEL collaboration (preparation for EU-proposal)**
- **Continuation of the CLIC high-gradient research**
- **Instrumentation tests (including WFMs)**
- **Discharge plasma wakefield experiments**

- **Impedance measurements**
- **Irradiation facility**
- **THz production**
- **General interest from AWAKE (including instrumentation)**

CALIFES workshop

Workshop on exploitation of CALIFES as an e- beam user facility: CERN 10-12 October 2016

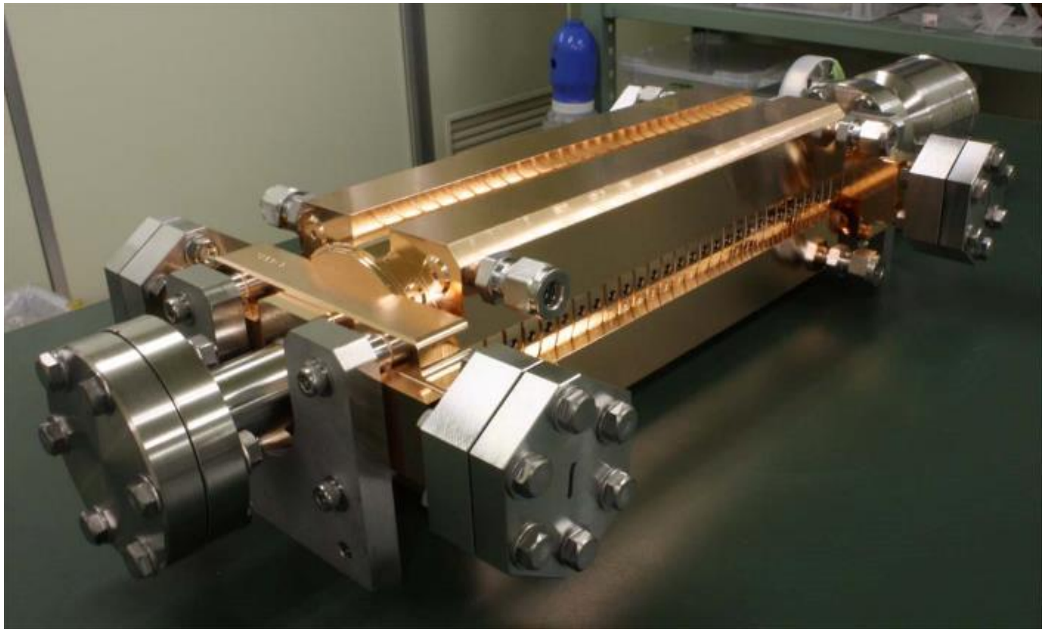
CALIFES Workshop 2016

10-12 October 2016
CERN
Europe/Zurich timezone

https://indico.cern.ch/event/533052/

CLIC accelerating structure

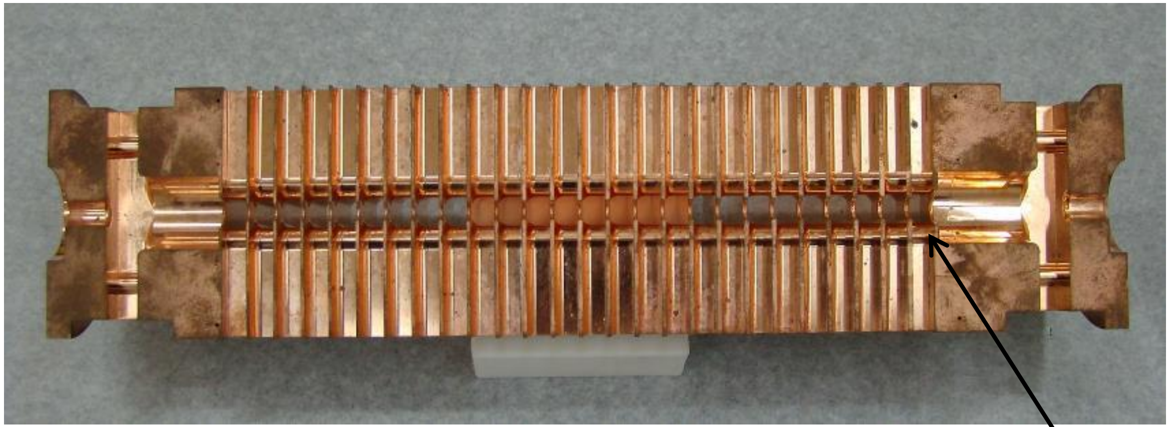
Outside



11.994 GHz X-band
100 MV/m
Input power ≈50 MW
Pulse length ≈200 ns
Repetition rate 50 Hz

HOM damping waveguide

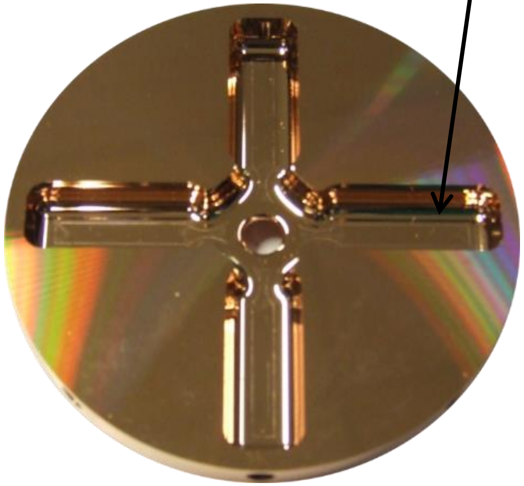
Inside



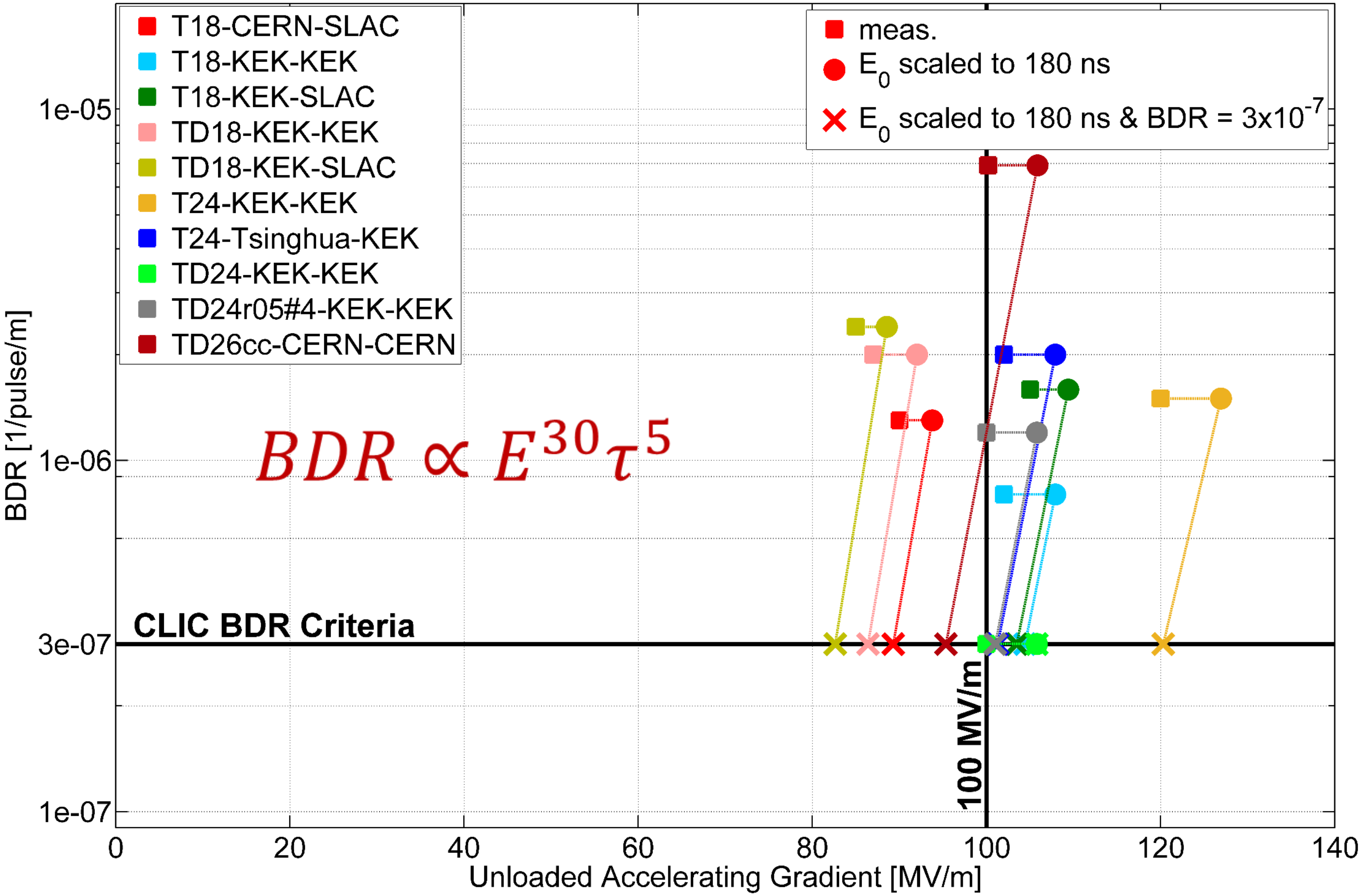
25 cm

6 mm diameter beam aperture

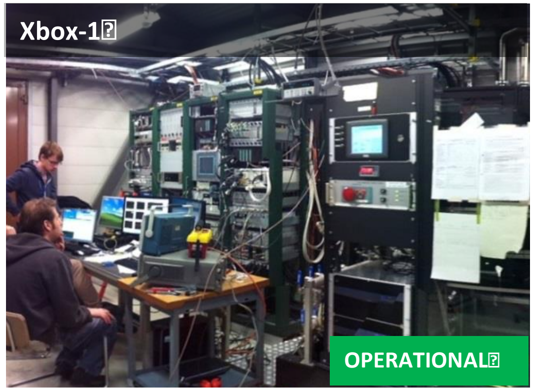
Micron–precision disk



Performance summary at CLIC specifications



X-band test stands (CERN)



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

Previous tests:
2013 TD24R05 (CTF2)
2013 TD26CC-N1 (CTF2)
2014-15 T24 (Dogleg)

Ongoing test:
Aug2015- TD26CC-N1 (Dogleg)

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

Previous tests:
2014-15 CLIC Crab Cavity

Ongoing test:
Sep2015- T24OPEN

4x Toshiba 6MW 5us klystron
4x Scandinova Modulators
Rep Rate 400Hz

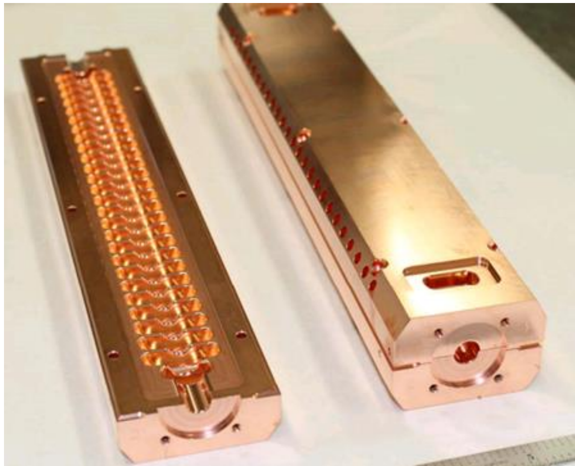
Medium power tests (Xbox-3A):
2015 3D-printed Ti waveguide
2015 X-band RF valve

Major increase in testing capacity!

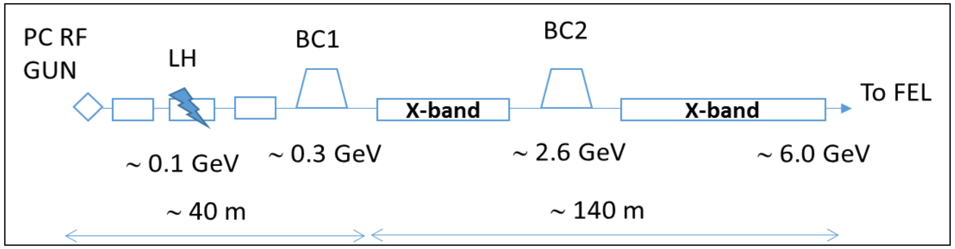
High-gradient structure tests

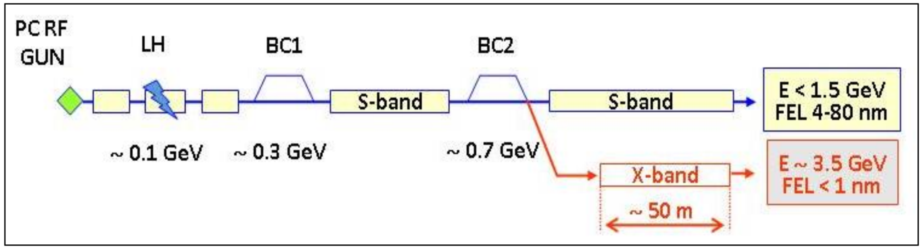
Maximal use of slots in structure test stands:

- **Higher statistics on baseline structure design**
- **Tests of 380 GeV (and FEL) structures**
- **Simplified structure design (halves, brazing vs. bonding)**
- **Qualification of industry-produced structures**
- **7 structures ready for test**
- **6 structures in production**
- **30 - 40 tested structures in next 3 years**



Possible X-band FELs





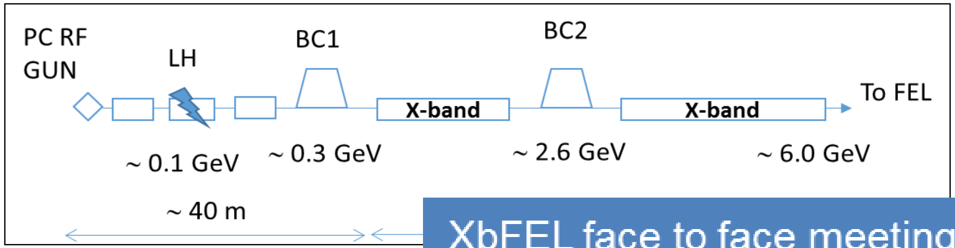
- X-band technology appears interesting for compact, relatively low cost FELs – new or extensions
  - Logical step after S-band and C-band
  - Example similar to SwissFEL: E=6 GeV, Ne=0.25 nC, σ_z=8μm
- Use of X-band in other projects will support industrialisation
  - They will be klystron-based, additional synergy with klystron-based first energy stage
- Collaborating on use of X-band in FELs
  - Australian Light Source, Turkish Accelerator Centre, Elettra, SINAP, Cockcroft Institute, TU Athens, U. Oslo, Uppsala University, CERN
- Share common work between partners
  - Cost model and optimisation
  - Beam dynamics, e.g. beam-based alignment
  - Accelerator systems, e.g. alignment, instrumentation…
- Define common standard solutions
  - Common RF component design, -> industry standard
  - High repetition rate klystrons (200->400 Hz now into test-stands)

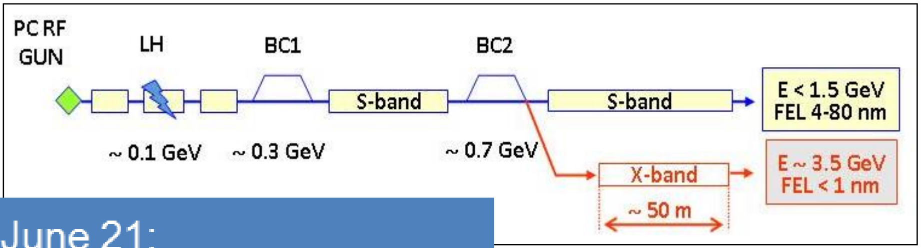

中国科学院上海应用物理研究所
Shanghai Institute of Applied Physics, Chinese Academy of Sciences

Background (Shanghai Photon Science Center)

Important collaboration for X-band technology

Possible X-band FELs





XbFEL face to face meeting, June 21:
https://indico.cern.ch/event/521539/

Preparing Design Study:
The meeting will be devoted to the extension of the scope of the X-band FEL collaboration. In the morning sessions, the four projects of interest (Xbox system, Compton Back Scattering, Soft X-ray, Hard X-ray) will be discussed among the stakeholders. In the afternoon sessions, the actions necessary to advance these projects will be structures within six work packages.

- X-band technology appears cost FELs – new or extensio
  - Logical step after S-b
  - Example similar to S
- Use of X-band in other proj
  - They will be klystron based first energy st
- Collaborating on use of X-b
  - Australian Light Sour SINAP, Cockcroft Inst University, CERN
- Share common work between partners
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  - Beam dynamics, e.g. beam-based alignment
  - Accelerator systems, e.g. alignment, instrumentation…
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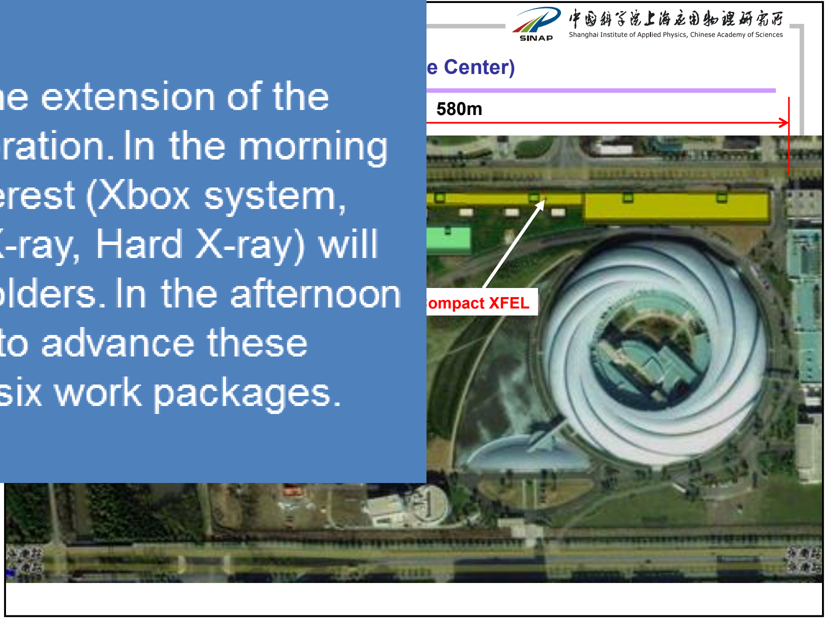


Important collaboration for X-band technology

Outlook → European Strategy

Aim to:

- Present CLIC as a credible post-LHC option for CERN
- Provide optimized, staged approach starting at 380 GeV, with costs and power not excessive compared with LHC, and leading to 3 TeV
- Upgrades in 2-3 stages over 20-30 year horizon
- Maintain flexibility and align with LHC physics outcomes

CLIC roadmap

2013 - 2019 Development Phase

Development of a Project Plan for a staged CLIC implementation in line with LHC results; technical developments with industry, performance studies for accelerator parts and systems, detector technology demonstrators

2020 - 2025 Preparation Phase

Finalisation of implementation parameters, preparation for industrial procurement, Drive Beam Facility and other system verifications, Technical Proposal of the experiment, site authorisation

2026 - 2034 Construction Phase

Construction of the first CLIC accelerator stage compatible with implementation of further stages; construction of the experiment; hardware commissioning

2019 - 2020 Decisions

Update of the European Strategy for Particle Physics; decision towards a next CERN project at the energy frontier (e.g. CLIC, FCC)

2025 Construction Start

Ready for construction; start of excavations

2035 First Beams

Getting ready for data taking by the time the LHC programme reaches completion

Outlook → European Strategy

Key deliverables:

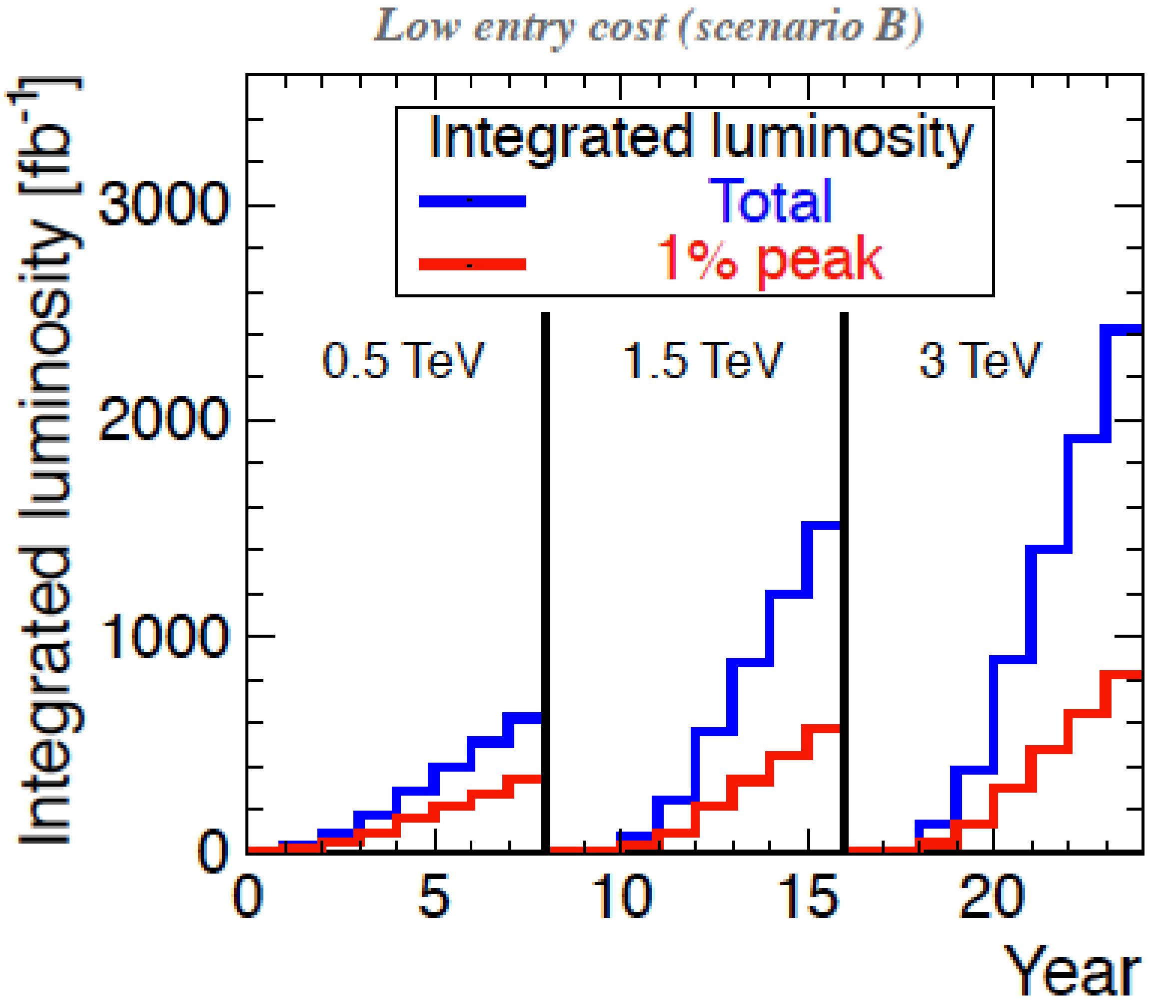
Project plan: physics, machine parameters, cost, power, site, staging, construction schedule, summary of main tech. issues, prep. phase (2019-2025) summary, detector studies

Preparation-phase plan: critical parameters, status and next steps - what is needed before project construction, strategy, risks and how to address them

Backup

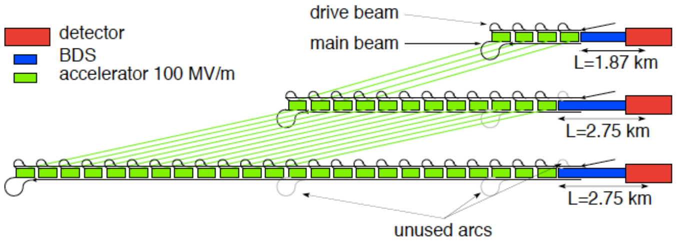
CLIC energy staging (CDR)

Energy-staging exercise started for CDR



CLIC energy staging (CDR)

Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		312	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	100	100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	1.3	3.7	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	0.7	1.4	2
Main tunnel length		km	11.4	27.2	48.3
Charge per bunch	N	10^9	3.7	3.7	3.7
Bunch length	σ_z	µm	44	44	44
IP beam size	σ_x/σ_y	nm	100/2.6	$\sim$ 60/1.5	$\sim$ 40/1
Normalised emittance (end of linac)	ϵ_x/ϵ_y	nm	—	660/20	660/20
Normalised emittance	ϵ_x/ϵ_y	nm	660/25	—	—
Estimated power consumption	P_{wall}	MW	235	364	589



AC power (1.5 TeV)