The CLIC Accelerator Project Status and Plans

ICHEP, Seoul, July 2018

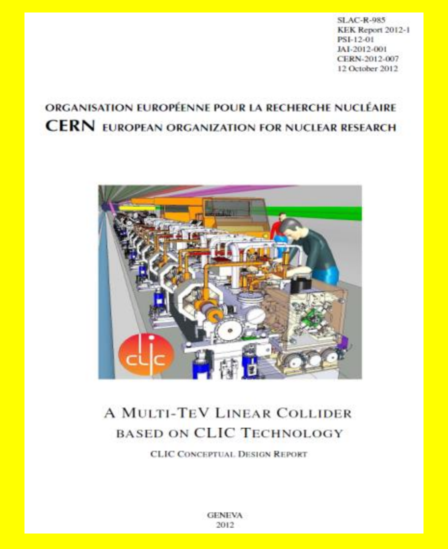
Steinar Stapnes, Daniel Schulte

For the CLIC collaboration

CLIC Introduction

CLIC: **C**ompact **LI**near **C**ollider

CLIC aims to provide **multi-TeV electron-positron** collisions with high luminosity at affordable cost and power consumption


SLAC-R-985
KEK Report 2012-1
PSI-12-01
JAI-2012-001
CERN-2012-007
12 October 2012

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

A MULTI-TEV LINEAR COLLIDER BASED ON CLIC TECHNOLOGY

CLIC CONCEPTUAL DESIGN REPORT

GENEVA
2012

2012 CDR:
Shows feasibility of 3 TeV design

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

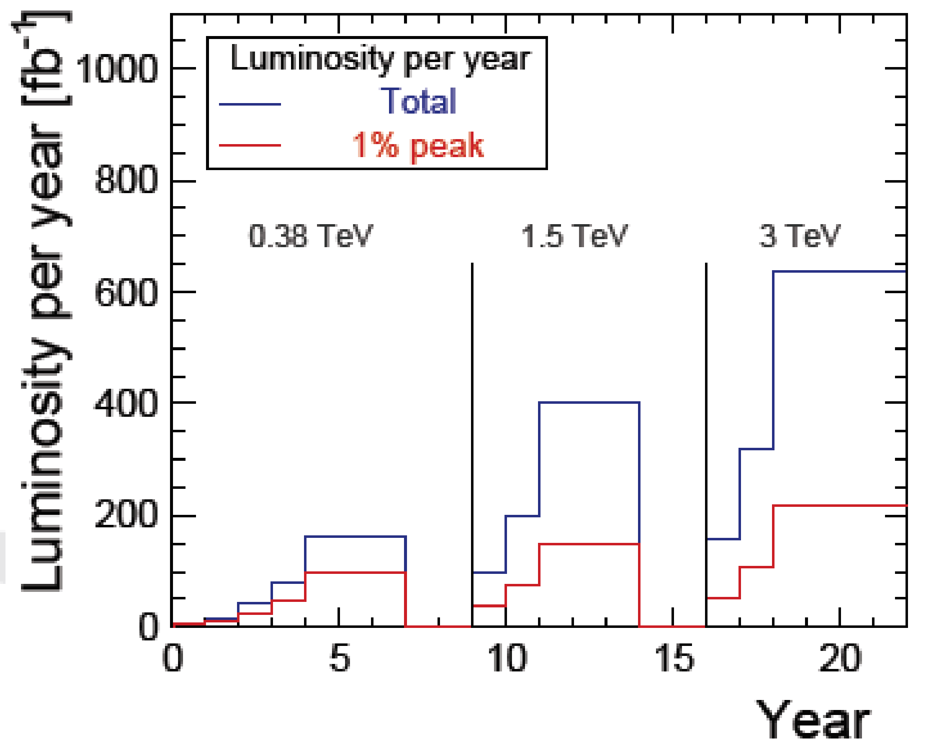
Getting ready for data taking by the time the LHC programme reaches completion

CLIC Collaboration

CLIC Staged Scenario

Plenty of physics at low centre-of-mass energies

Energy and luminosity targets from Physics Study Group



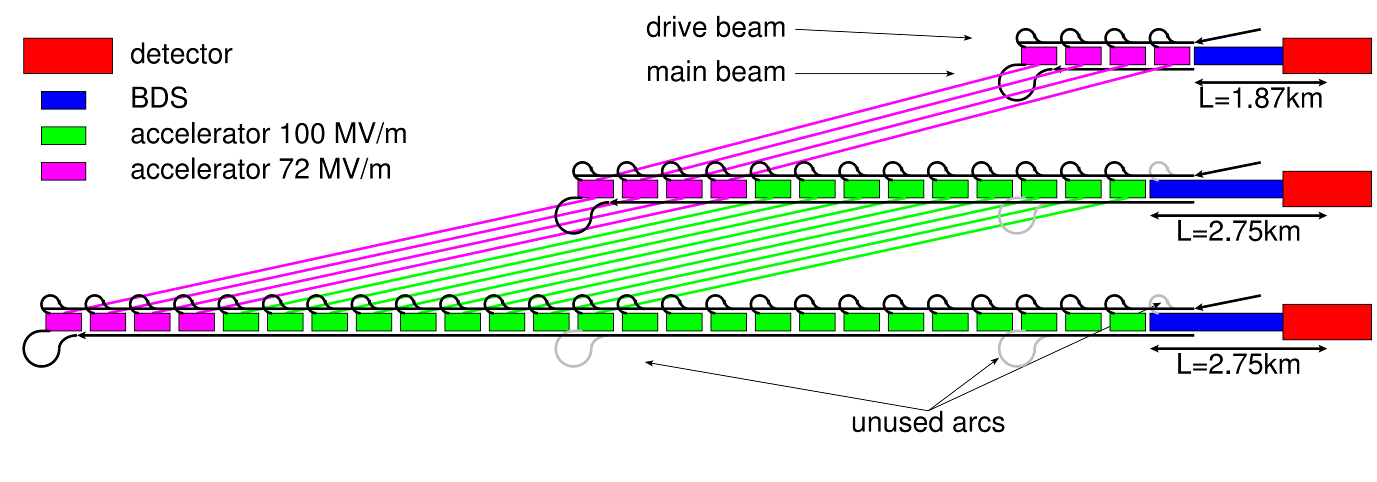
Stage	$\sqrt{s}$ (GeV)	$\mathcal{L}_{int}$ (fb^{-1})
1	380	500
	350	100
2	1500	1500
3	3000	3000

Top above threshold
Higgs via Zh and WW fusion

Study top at threshold

To be updated with more input from LHC and stage 1

Implementation in stages



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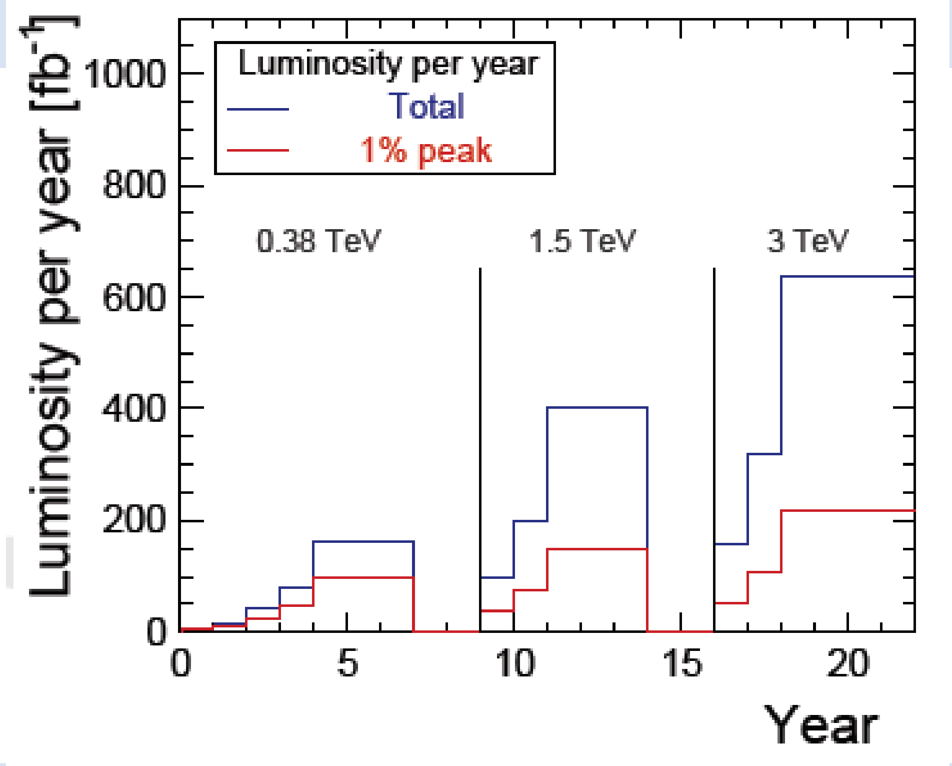


Stage	$\sqrt{s}$ (GeV)	$\mathscr{L}_{int}$ (fb^{-1})
2	1500	1500
3	3000	3000

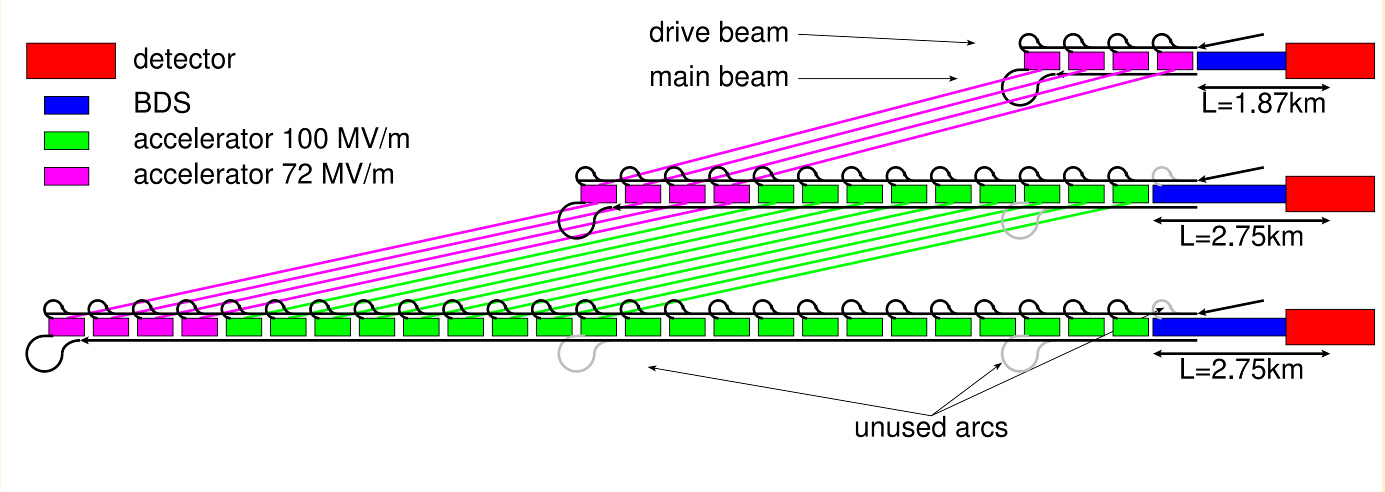
This is being reviewed
Consider larger integrated luminosity
Could further improve physics results

Top above threshold
Higgs via Zh and WW fusion

Study top at threshold

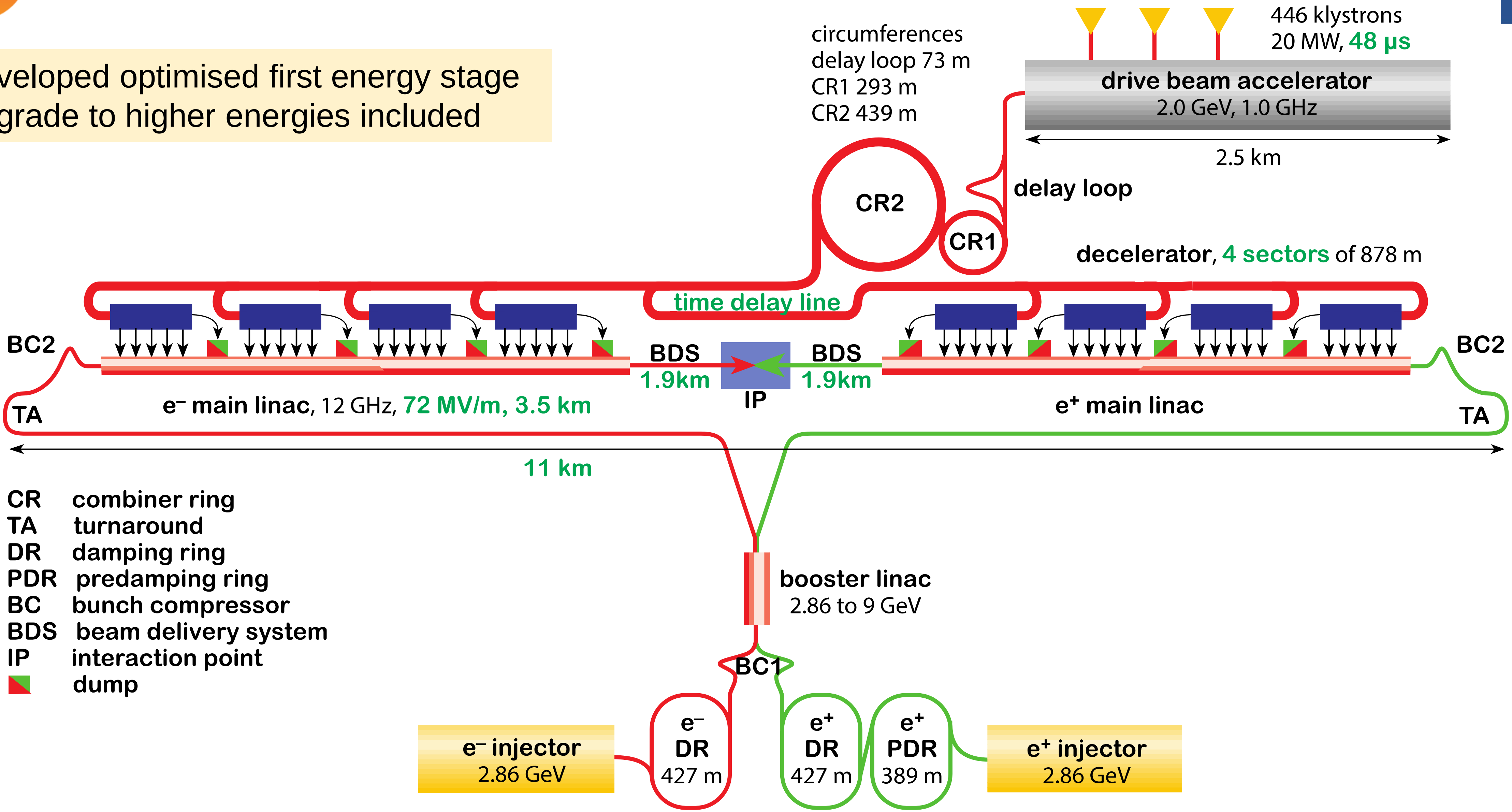
To be updated with more input from LHC and stage 1

Implementation in stages



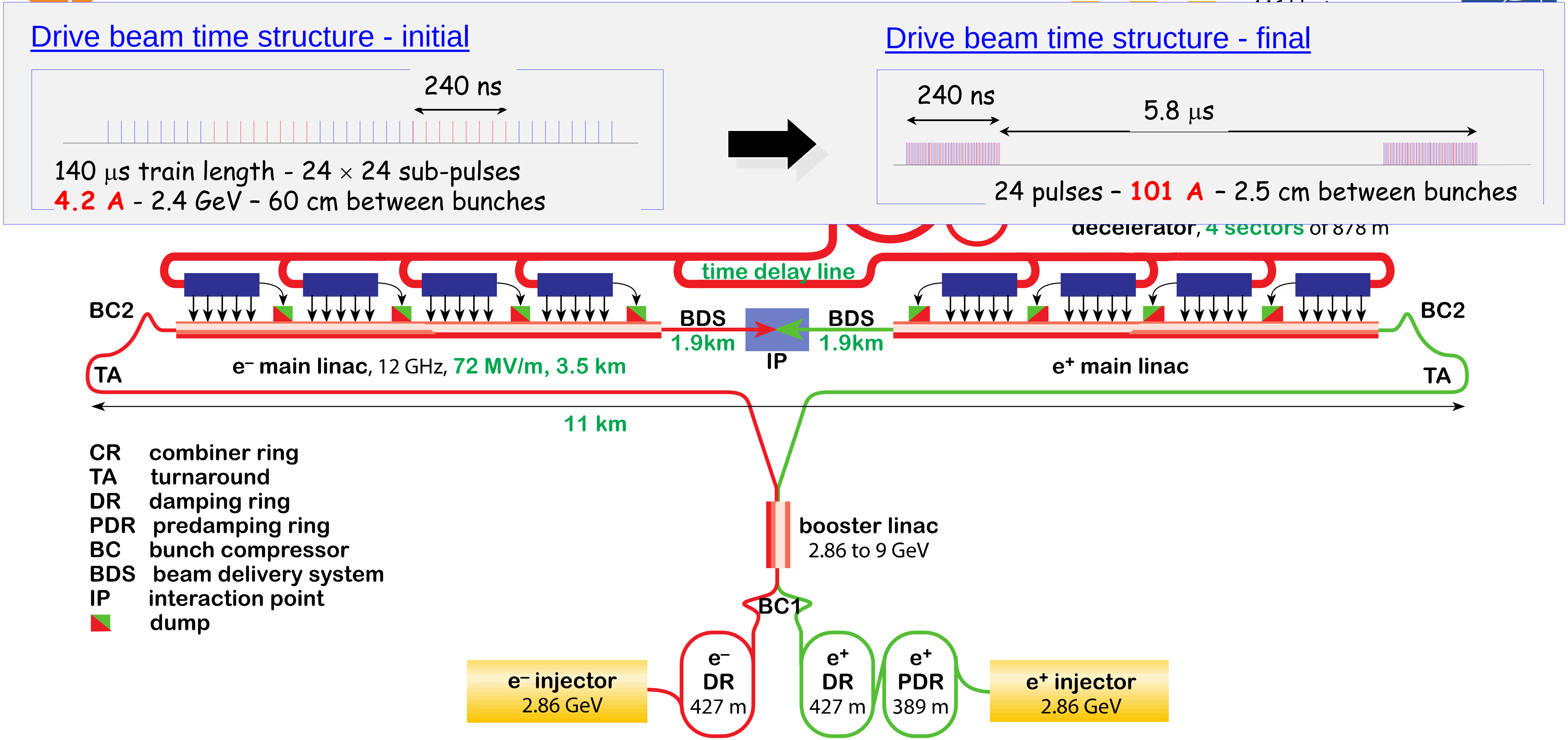
CLIC at 380 GeV

Developed optimised first energy stage
Upgrade to higher energies included



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

CLIC at 380 GeV



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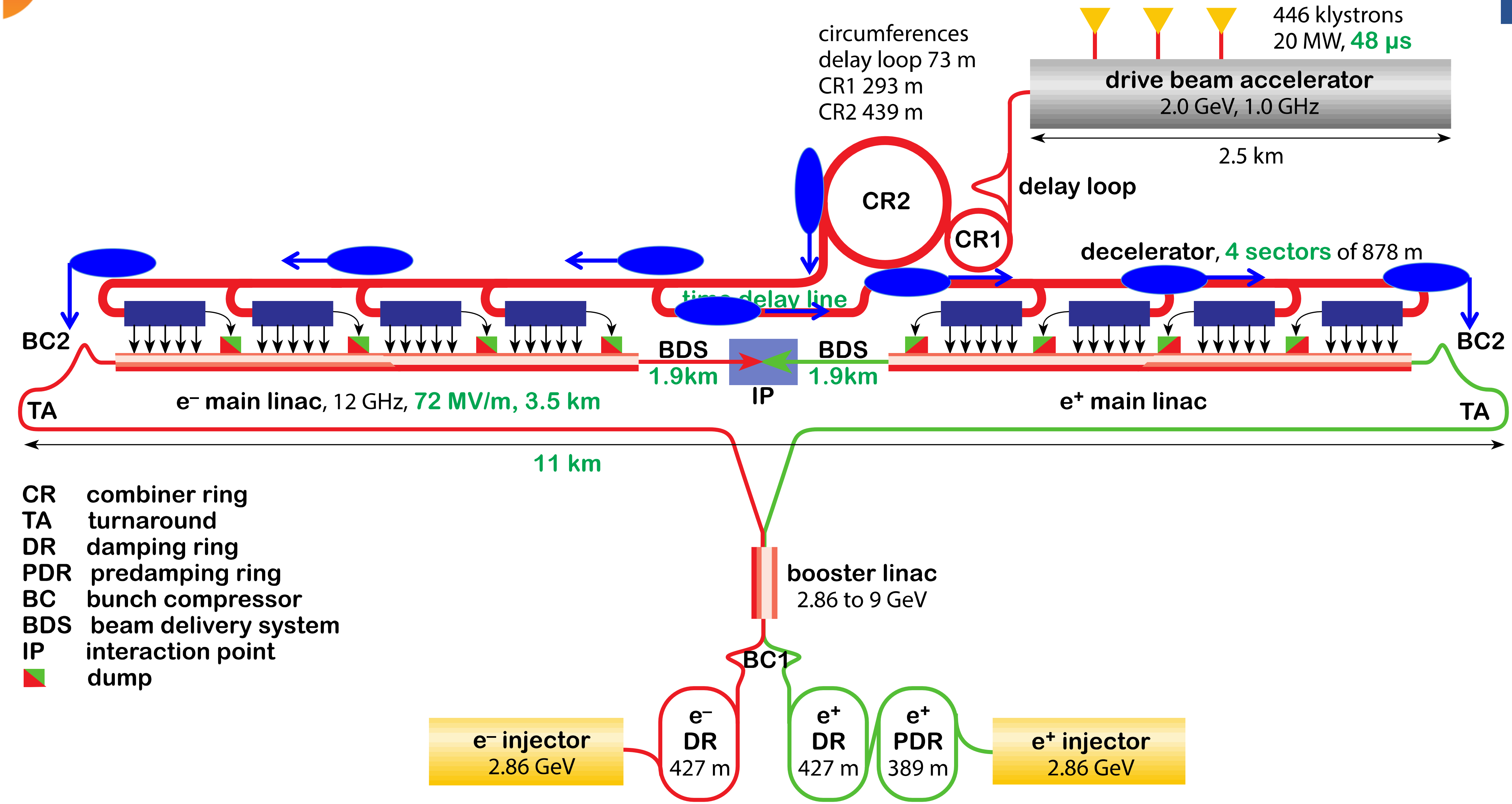
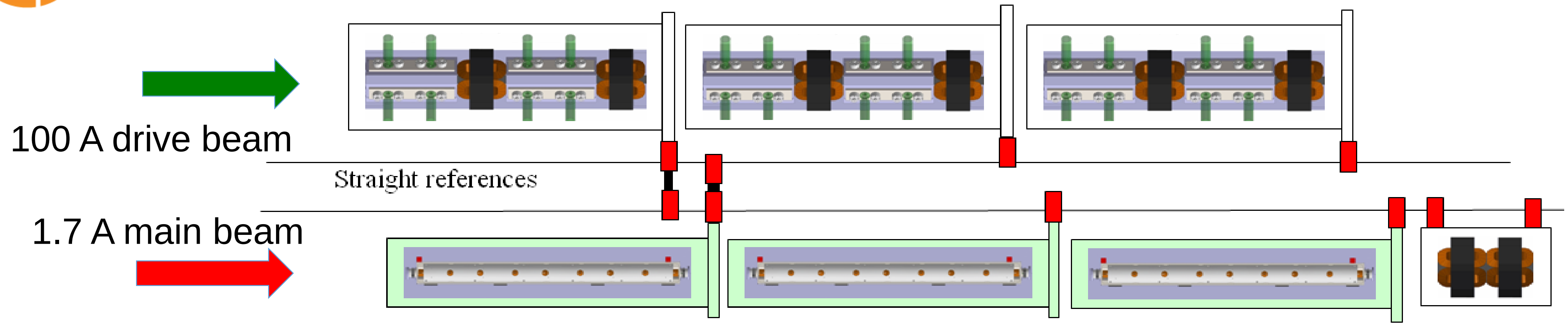
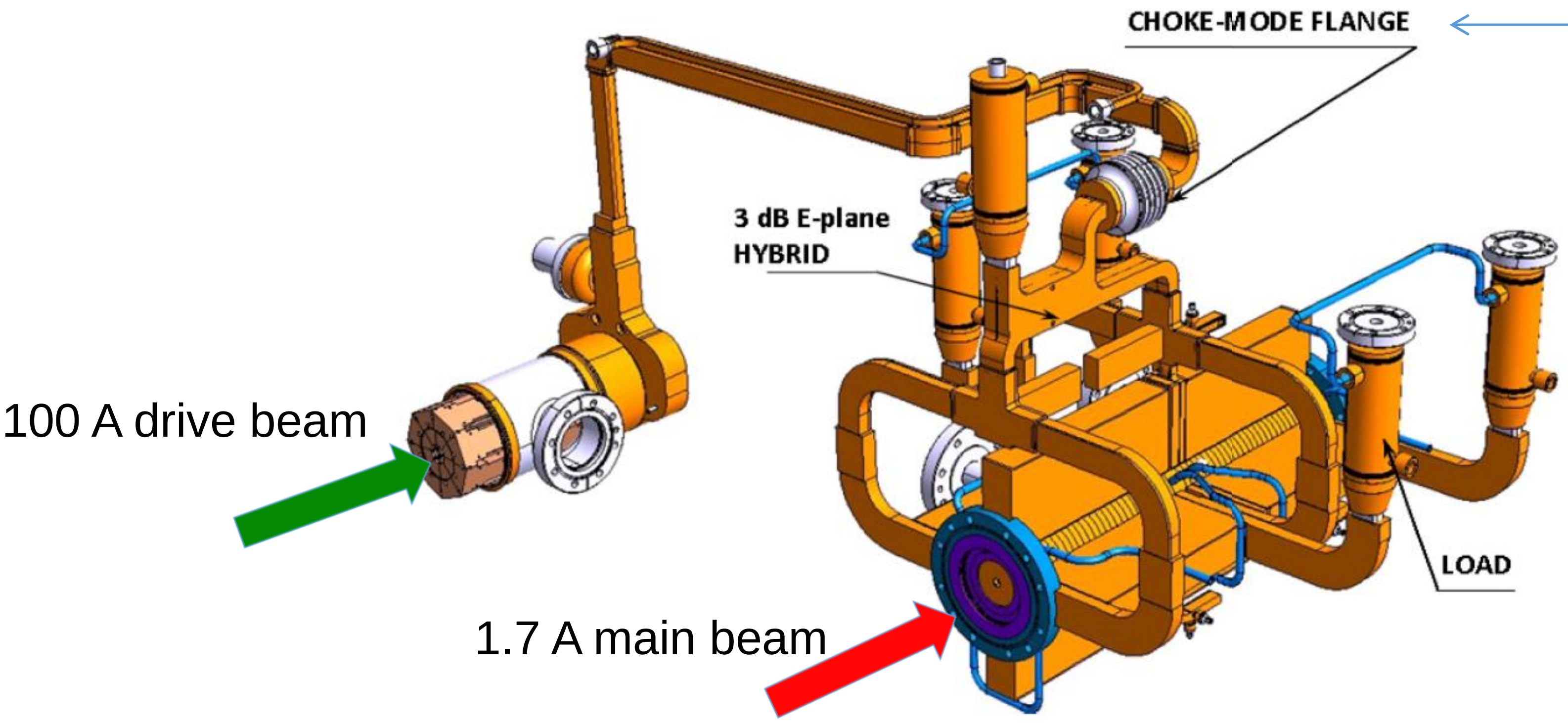
CLIC at 380 GeV



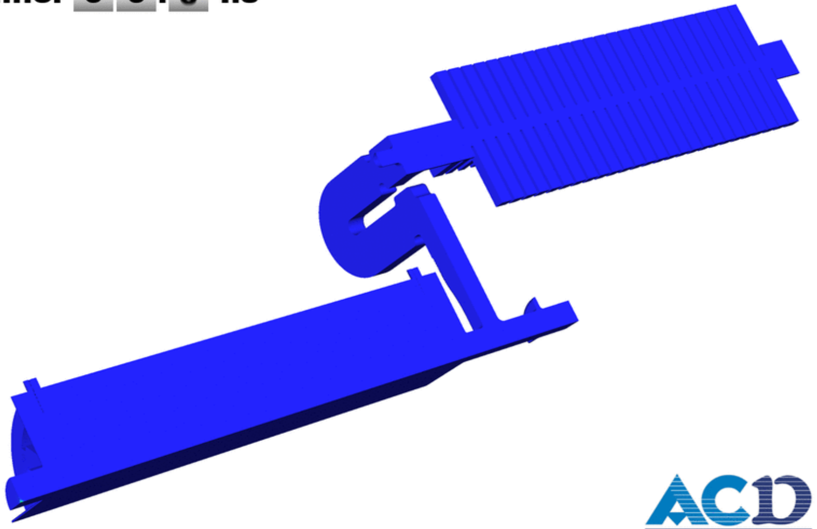
Two-beam Module Concept





2.2m

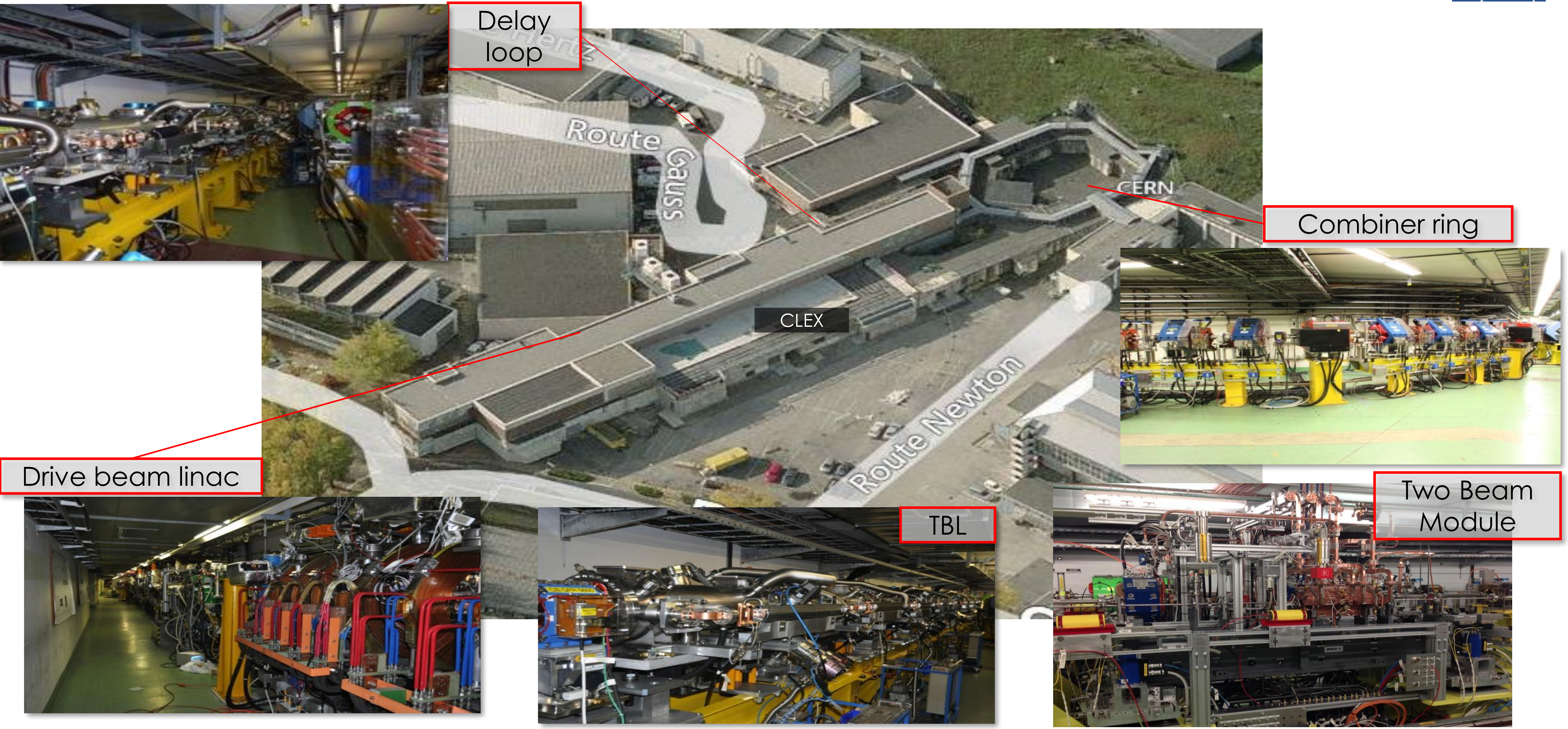
time: 0 0 . 0 ns



Key Parameters

Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	380	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		352	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
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

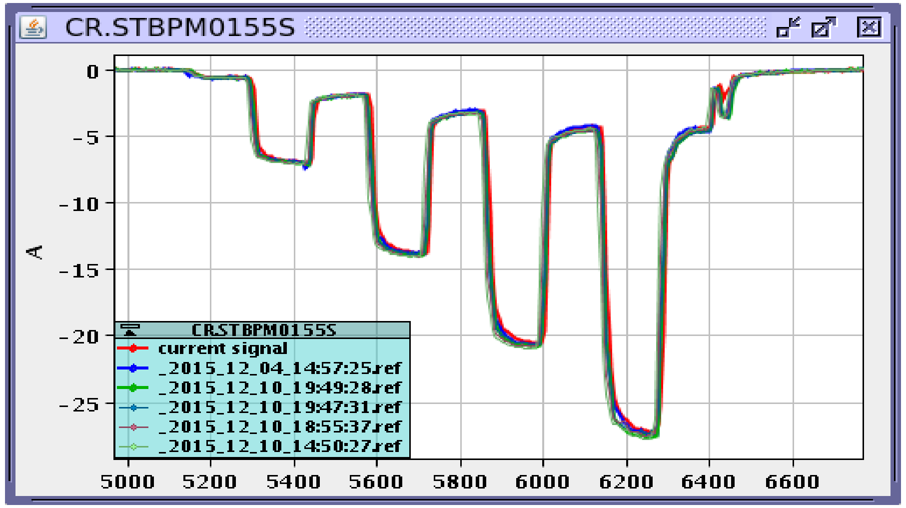
CLIC Test Facility (CTF3)



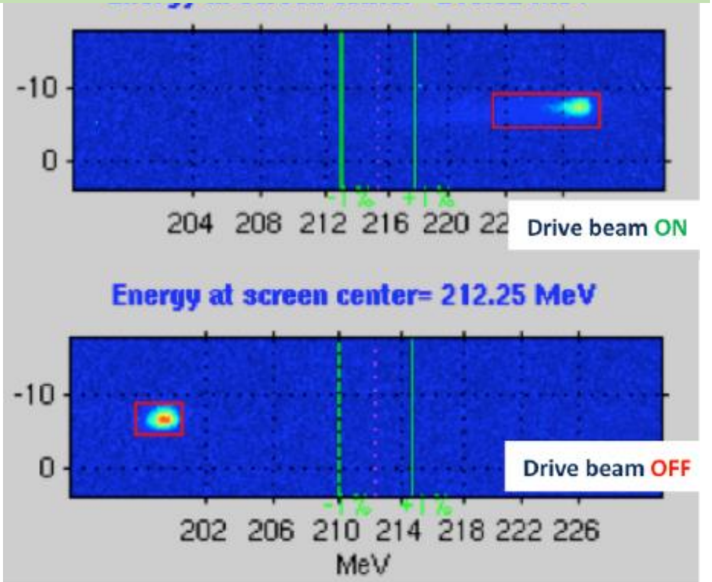
Drive Beam Scheme Performance

CTF3 measurements:
- RF to drive beam efficiency > 95%
- Current multiplication factor 8
- Most of beam quality
- 145 MV/m X-band acceleration

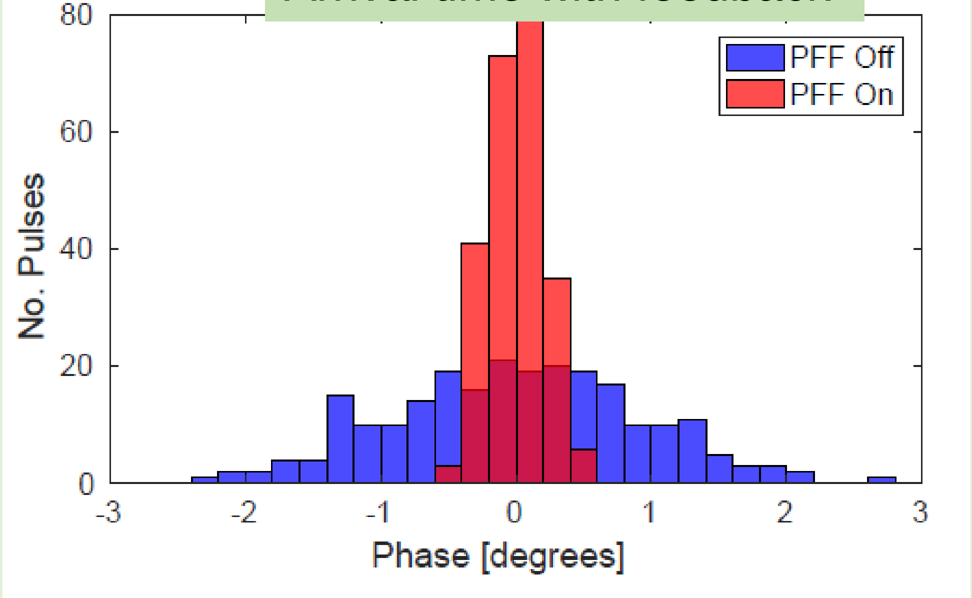
Detailed simulations of drive beam performance in CLIC



Measured 145 MV/m gradient



Arrival time with feedback



Current stability affected by very low CTF3 energy, 3 x larger beam and delay loop design different from CLIC

Parameter	CLIC goal	CTF3 measured
Arrival time	50 fs	50 fs
Current after linac	0.75 x 10^{-3}	0.2-0.4 x 10^{-3}
Energy	1.0 x 10^{-3}	0.7 x 10^{-3}

Drive Beam Scheme Performance

CTF3 measurements:
- RF to drive beam efficiency > 95%
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Deta
perfo

dient

CTF 3 stopped operation
New facility is online: CLEAR
CERN Linear Electron Accelerator for Research

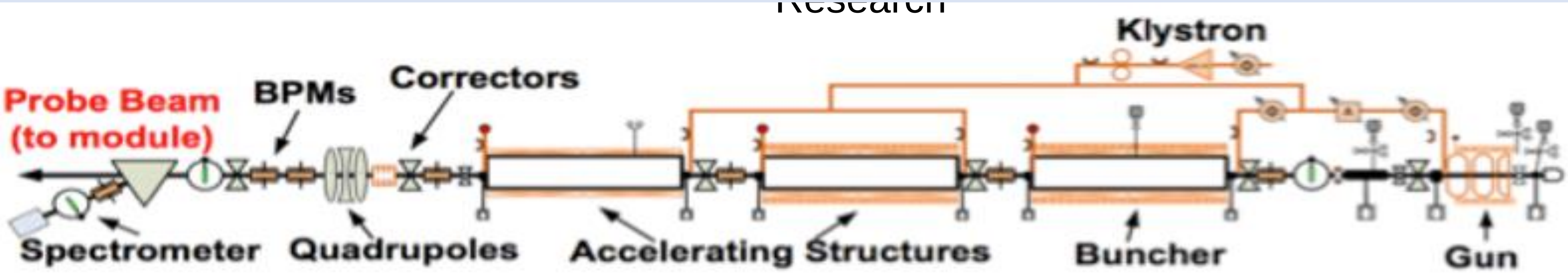
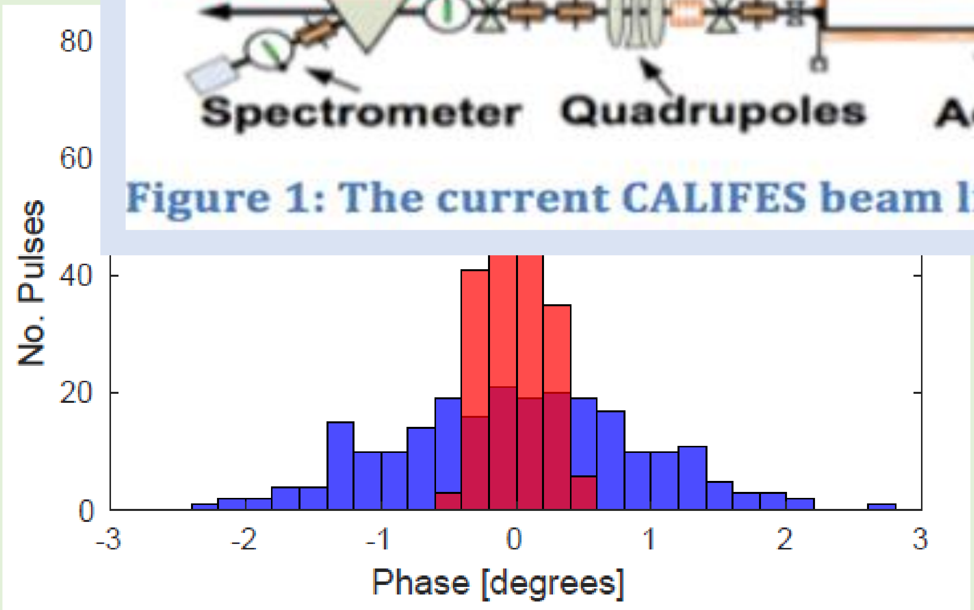


Figure 1: The current CALIFES beam line. The length of the facility (as shown) is ~20m.



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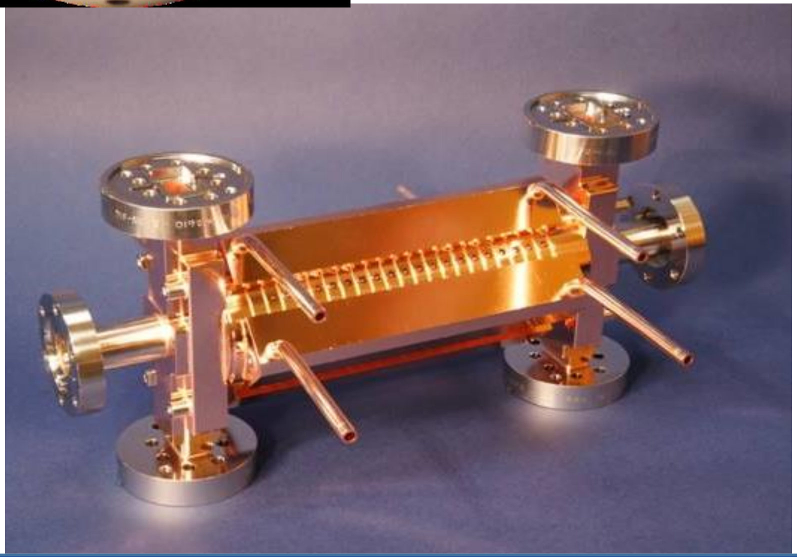
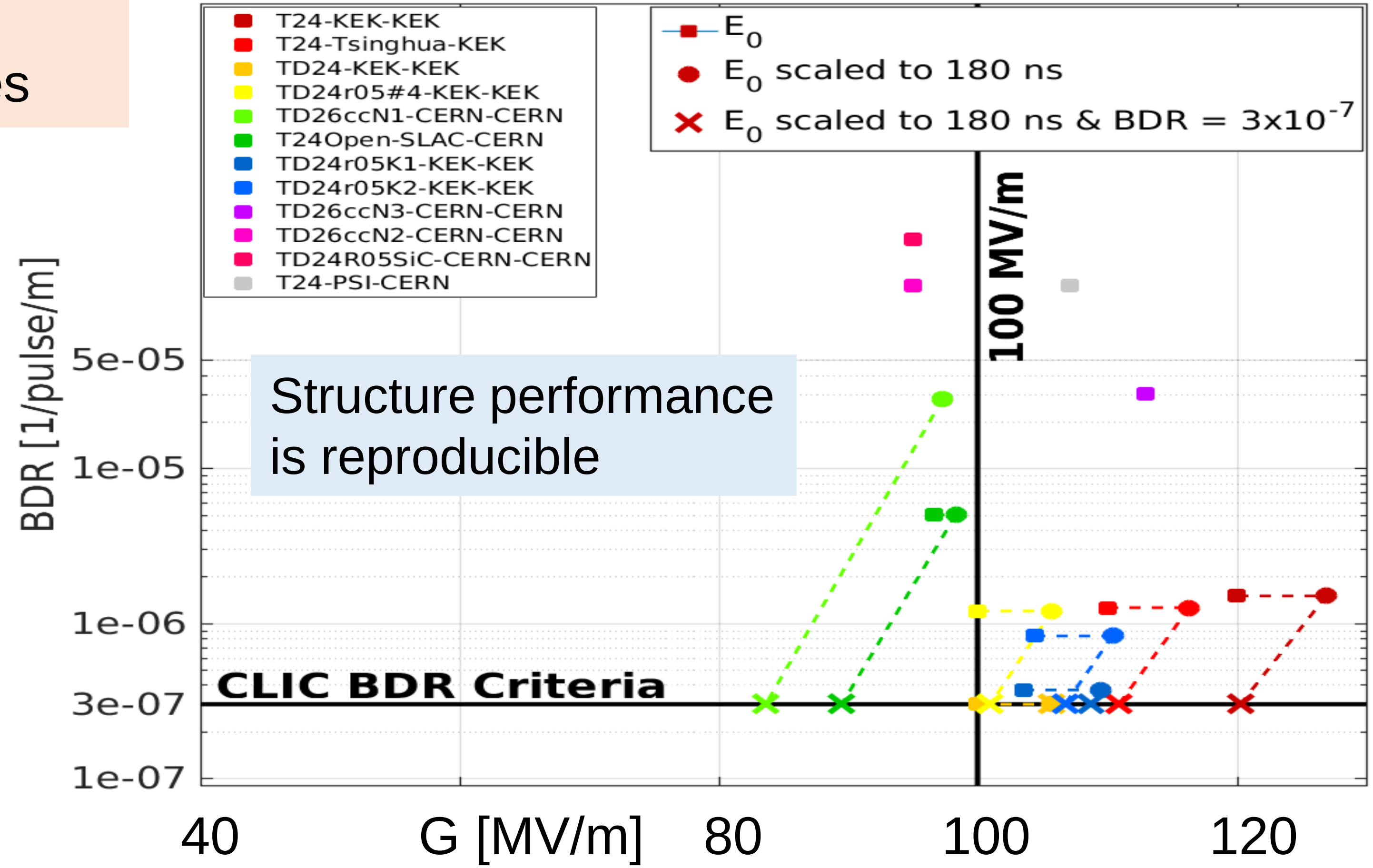
CLIC Structure Development

Several klystron-based test stands exist that test structures (X-boxes)

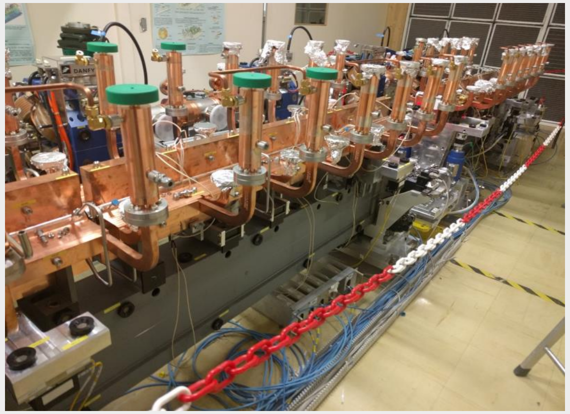




Structure performance is reproducible

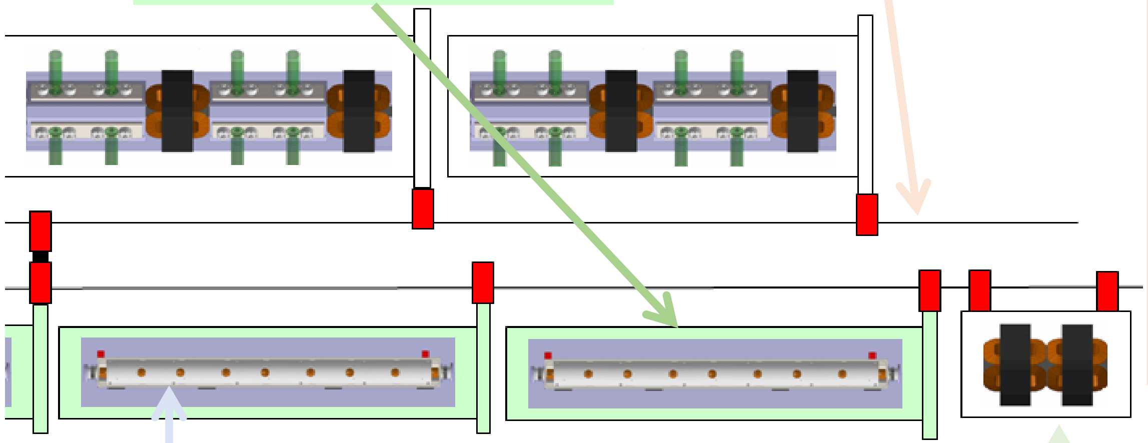
Further optimisation ongoing of structure production for industrialisation

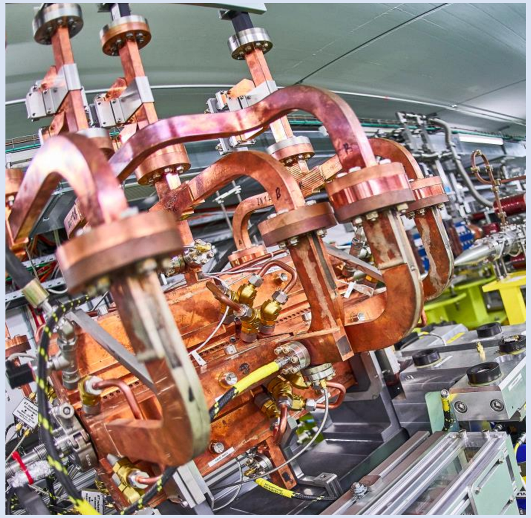
Main Linac Module and Imperfection Mitigation



Components are mounted accurately on movable girders

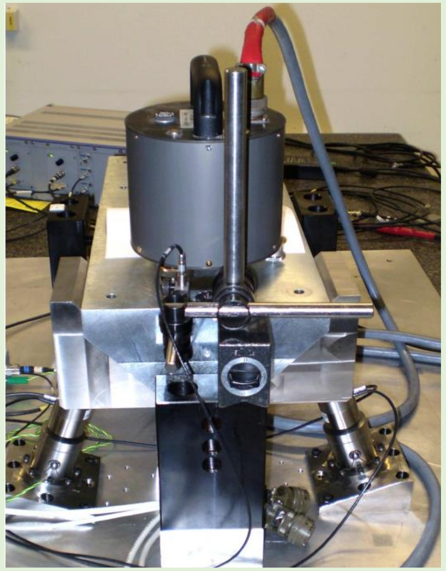
Overlapping wires provide accurate position information





Wake monitors in each structure measure beam offset (3.5 μm)

Magnets are stabilised mechnically to nm against ground motion and vibrations

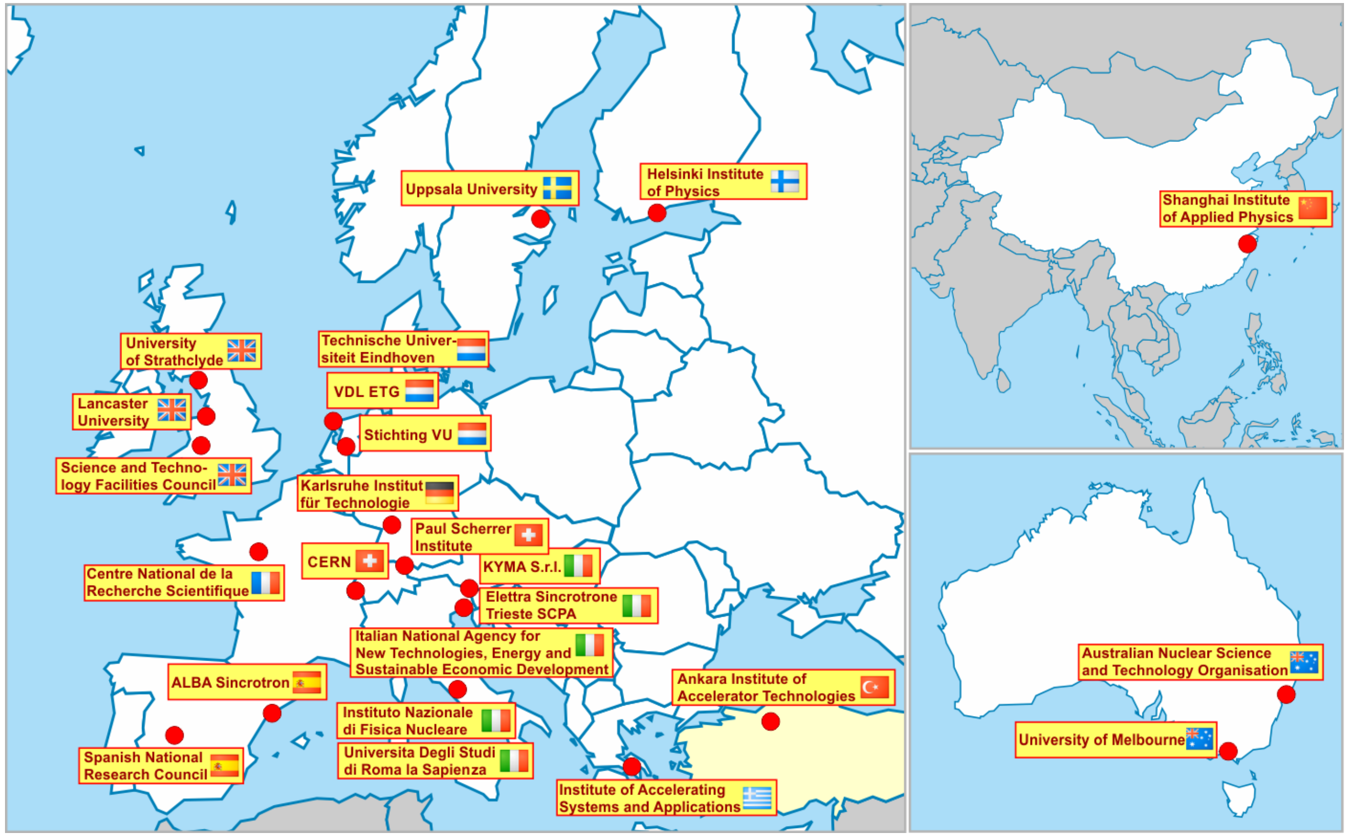


In addition to high accuracy optimisation for cost

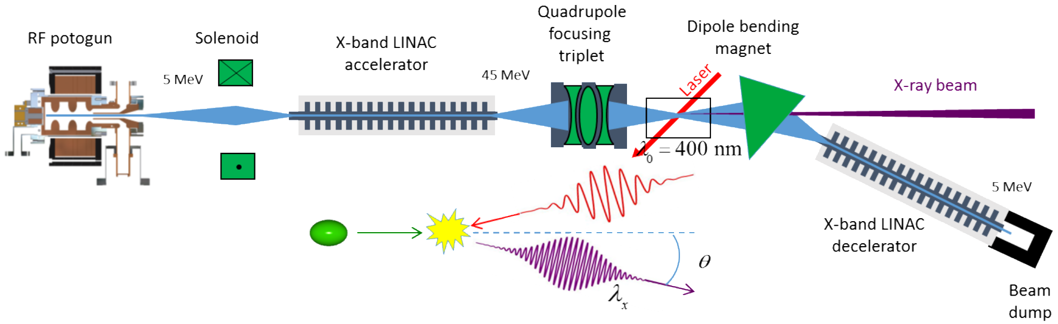
CLIC Technology Development and Applications

CLIC technology for CLIC and different applications

- EU co-funded FEL design study
- SPARC at INFN-LF
- …



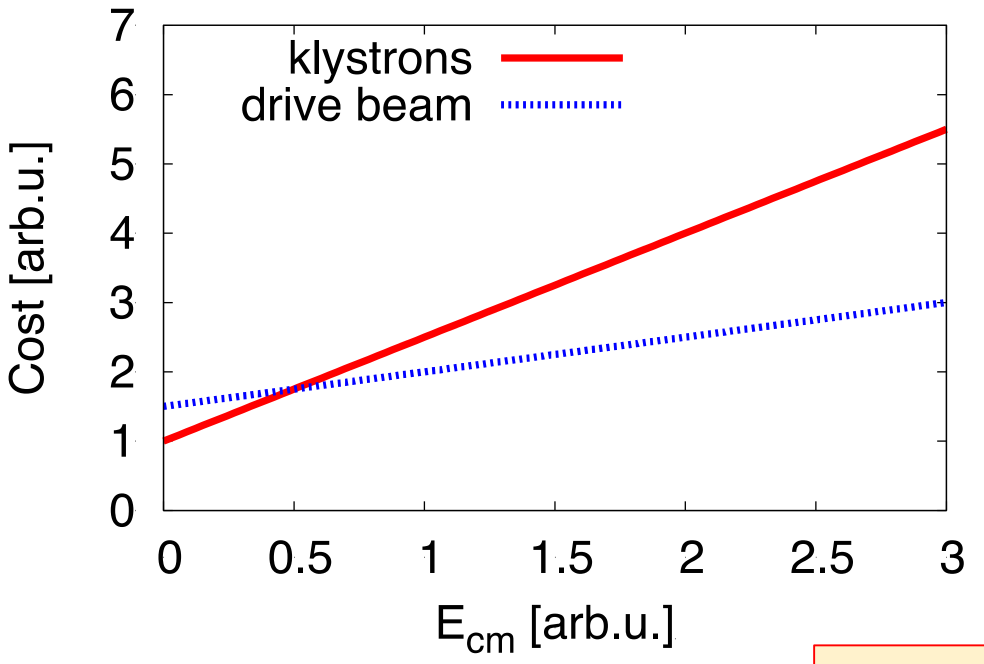
INFN Frascati advanced acceleration facility
EuPARXIA@SPARC_LAB

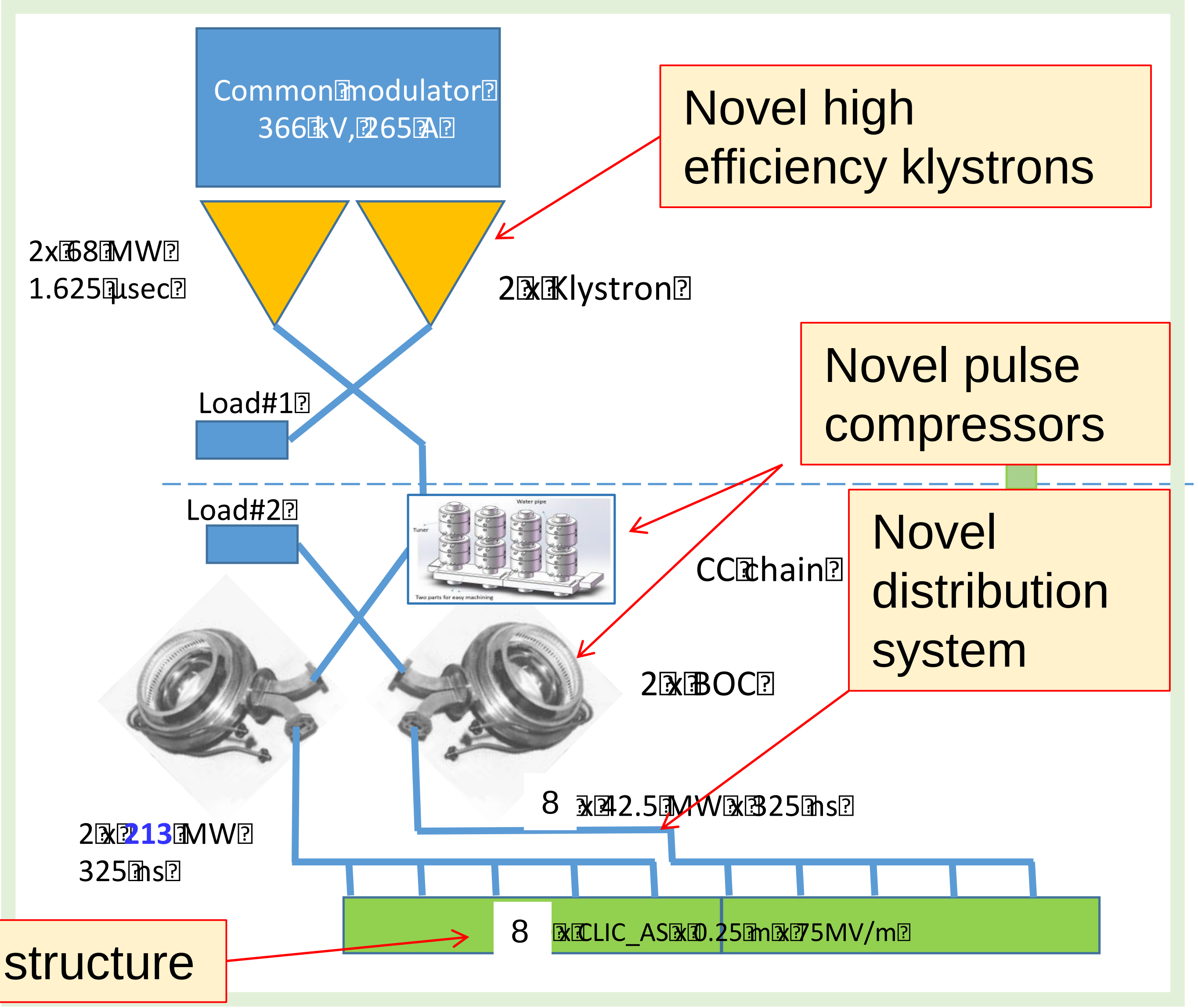


Eindhoven University led
SMART*LIGHT Compton Source

Klystron-based Alternative

Develop klystron-based alternative
Expect comparable cost for first energy stage
But increases faster for high energies

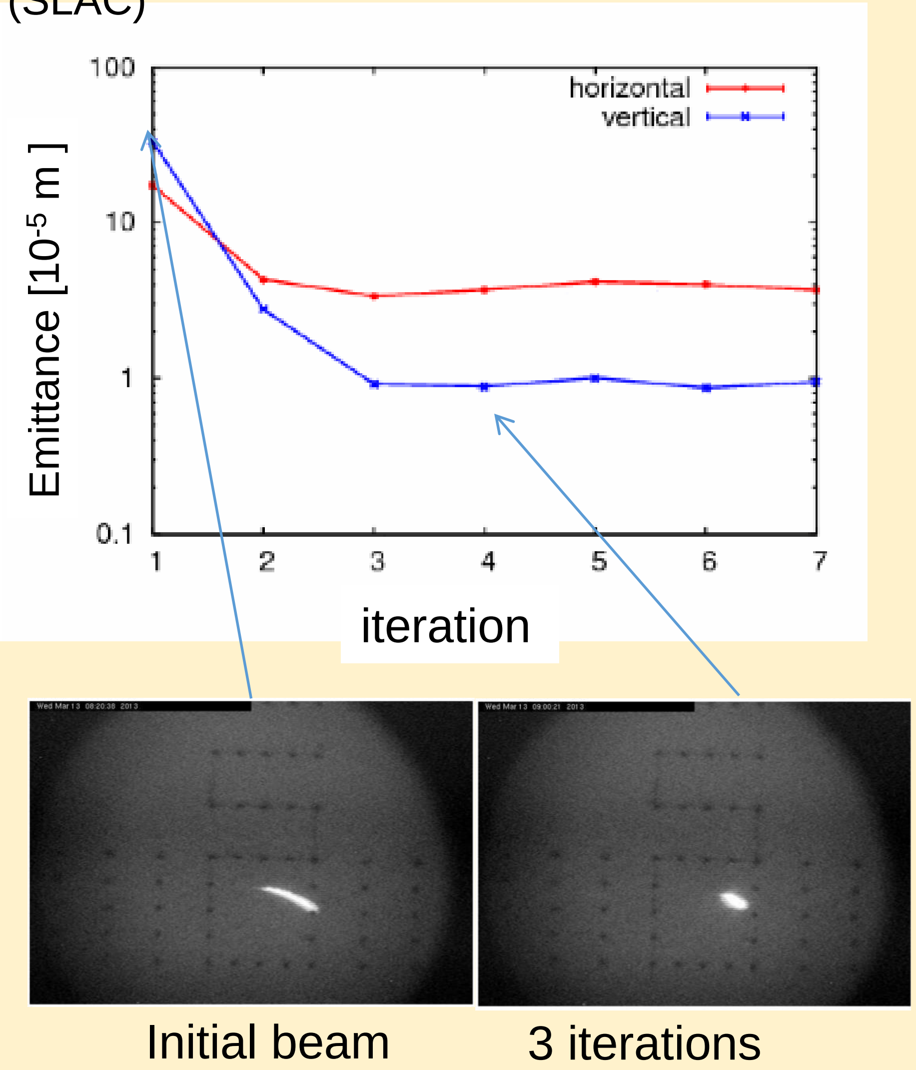


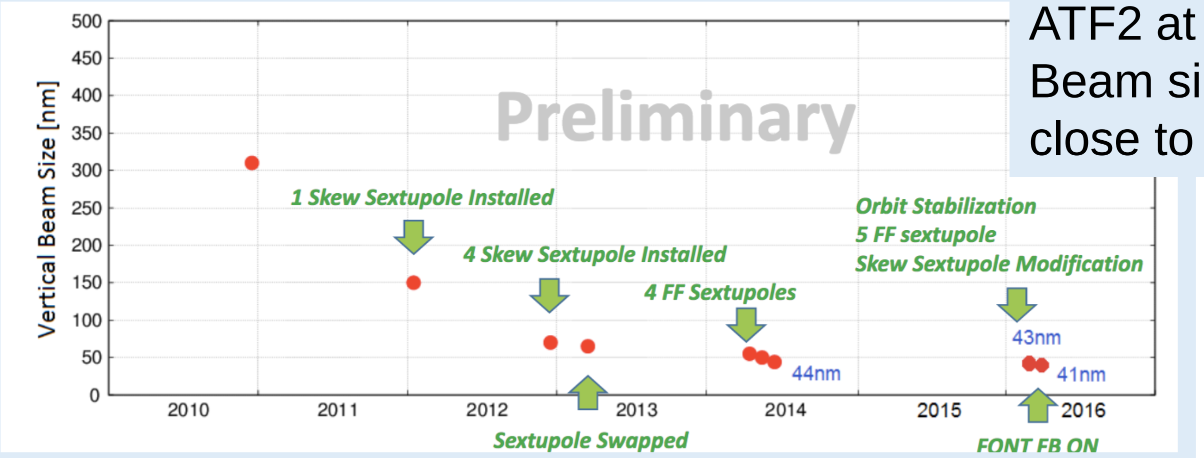


Beam Quality for Luminosity

- Production of low-emittance beams in damping ring
  - Similar to existing light sources
- Quality preservation in transport
  - Minimisation of imperfections
  - Optimised lattice design
  - Sophisticated beam-based tuning
- Focusing of beam in beam delivery system
  - Advanced lattice design
  - Advanced tuning
  - Test at FFTB and ATF2

Dispersion Free Steering Test at FACET (SLAC)



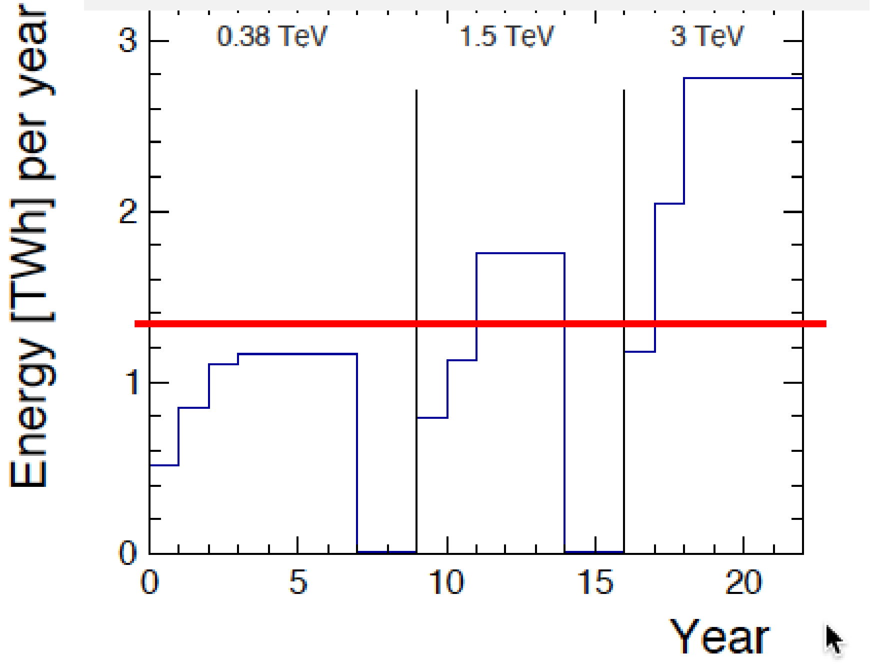


ATF2 at KEK
Beam size (41 nm) is close to target (37nm)

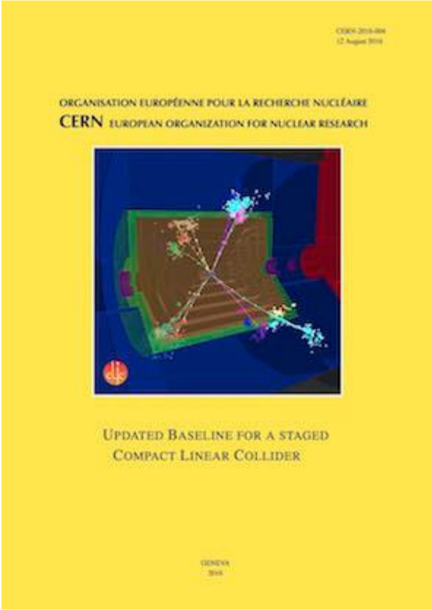
Cost and Power

Goals bring cost and power consumption down:
“reasonable cost”: O(6 GCHF)
Reasonable power < O(200 MW)

CERN energy consumption 2012: 1.35 TWh



Intial Estimate 252 MW



Initial value for 380 GeV (MCHF of Dec 2010)	
Main beam production	1245
Drive beam production	974
Two-beam accelerator	2038
Interaction region	132
Civil engineering etc.	2112
Control & operation	216
TOTAL	**6690**

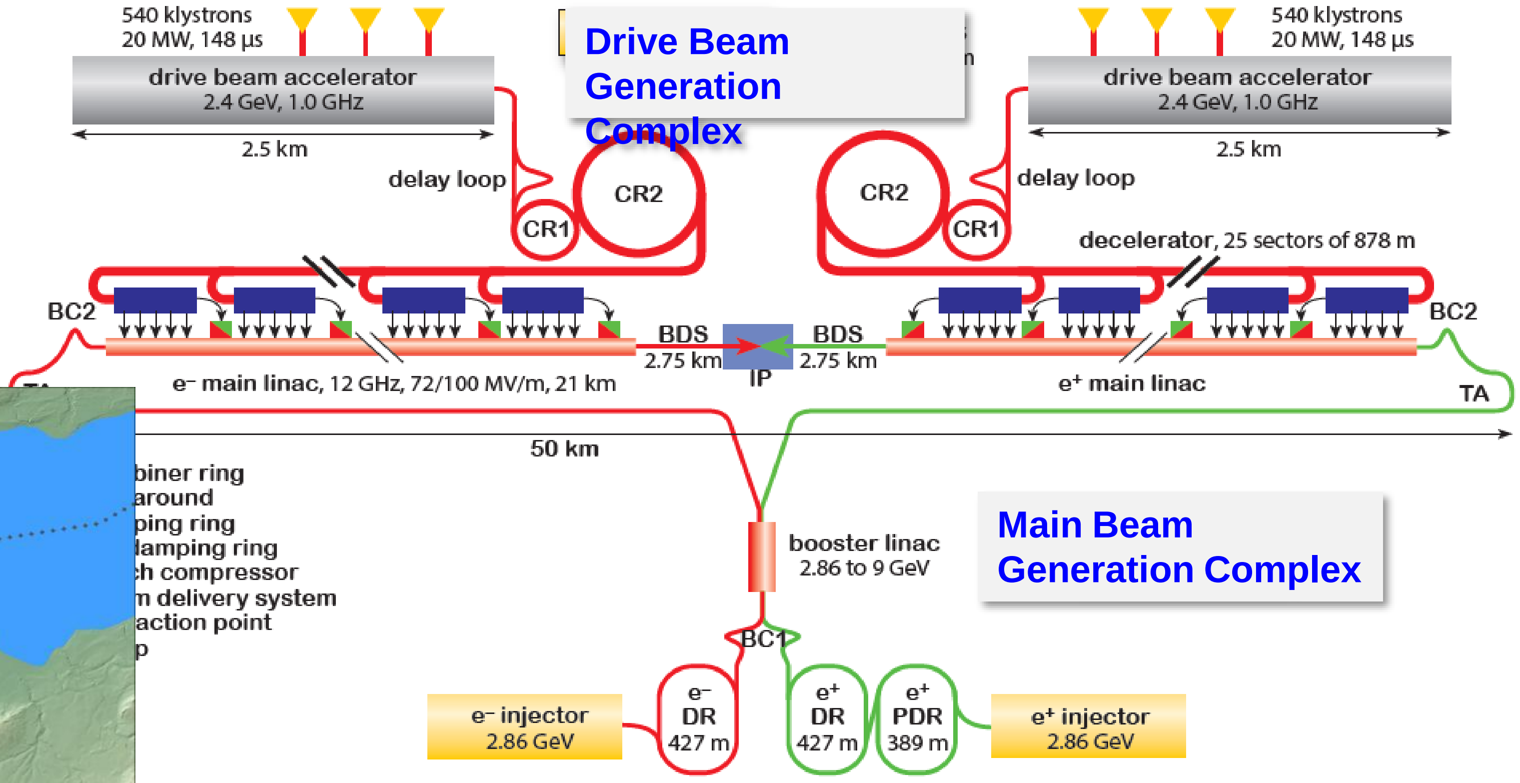
Improvement of cost and power is ongoing
Detailed bottom up estimate
Already savings, seems we meet goal

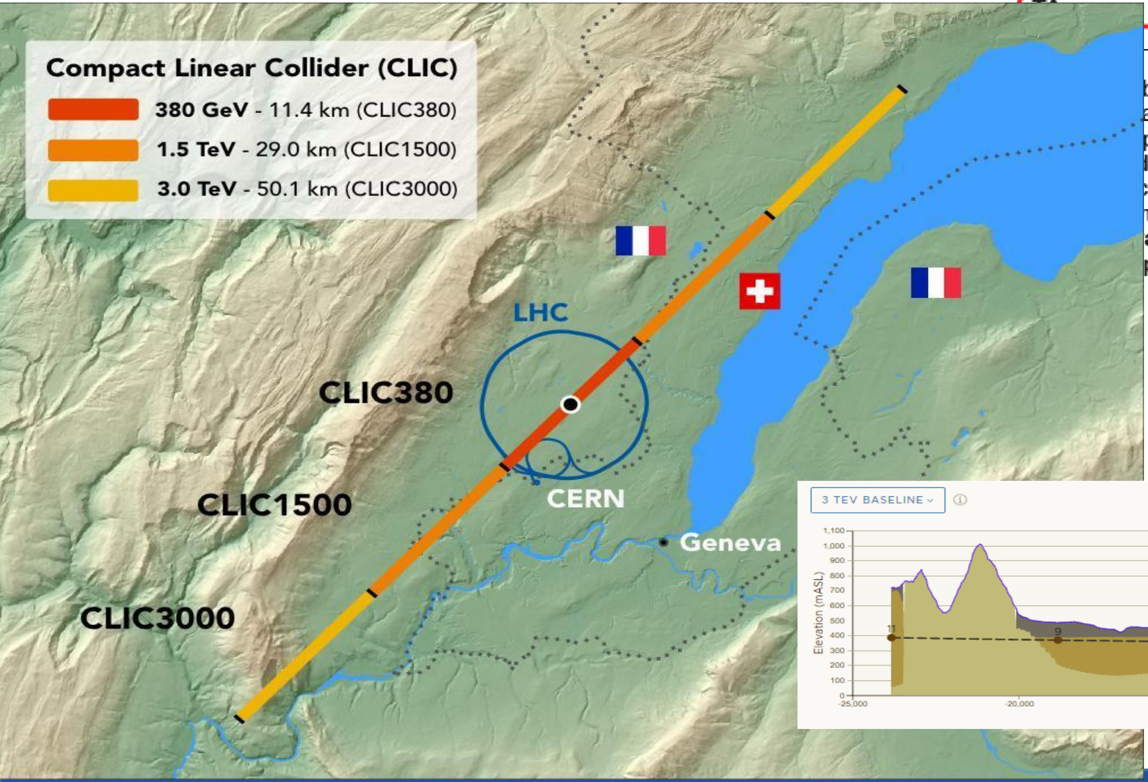
CLIC Site and Upgrade to 3 TeV

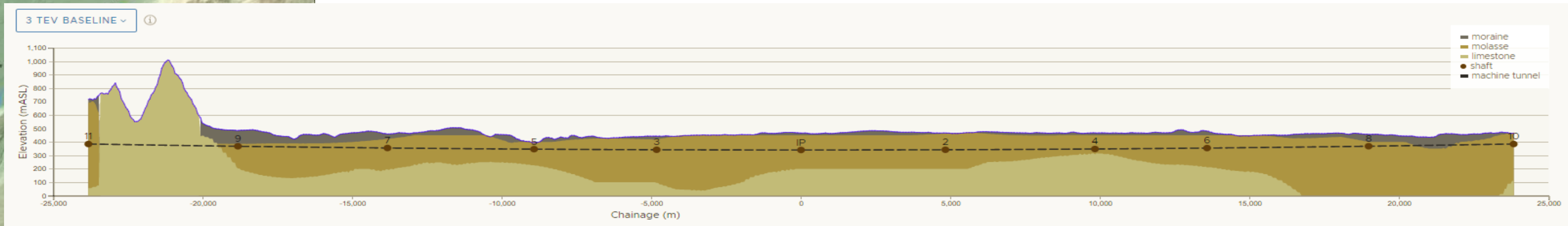
Can re-use previous systems and components

Just add more linac and drive beam pulse length

At 3 TeV add one drive beam



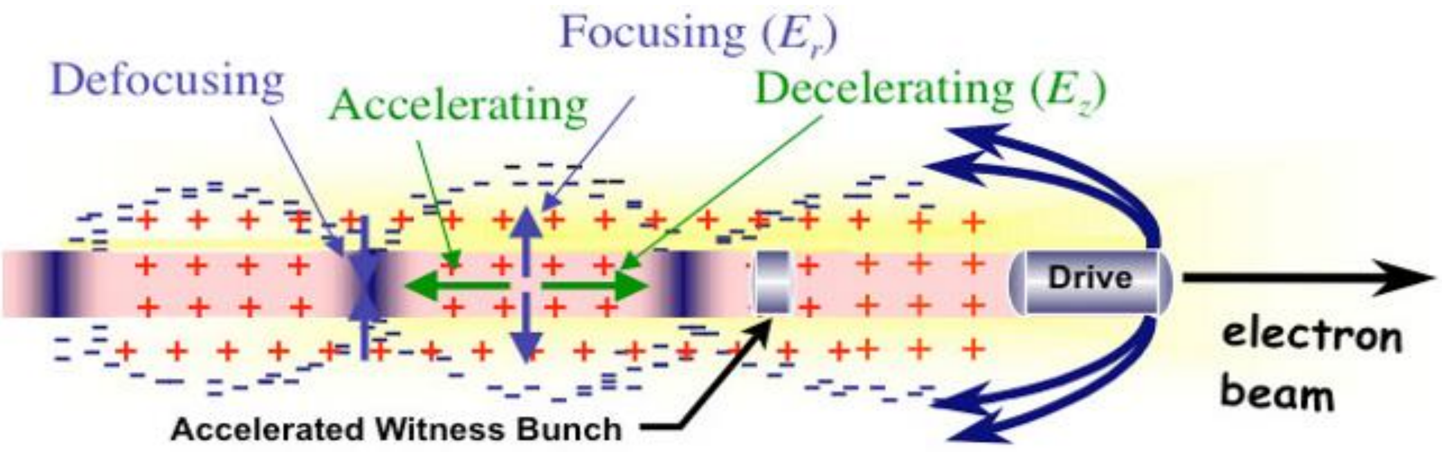




Exploration of Future Upgrades

Started exploration of novel acceleration methods for high-energy upgrades

- Make sure CLIC is consistent with this



Plasma-based acceleration demonstrated gradients of 50 GV/m
Dielectric structures could lead to reduced cost

Main challenges

- Preservation of beam quality has to be explored theoretically and experimentally
- Efficiency and beam stability
- Many technical challenges

Might be possible to reuse drive beam

Conclusion

Important progress toward the EU strategy

- Much improved technical maturity
- Normal conducting FELs are prototypes, e.g. Swiss FEL
- Further optimising 380 GeV first energy stage
- Work on further stages, including considerations of novel technologies
- Project Implementation Plan by end of 2018

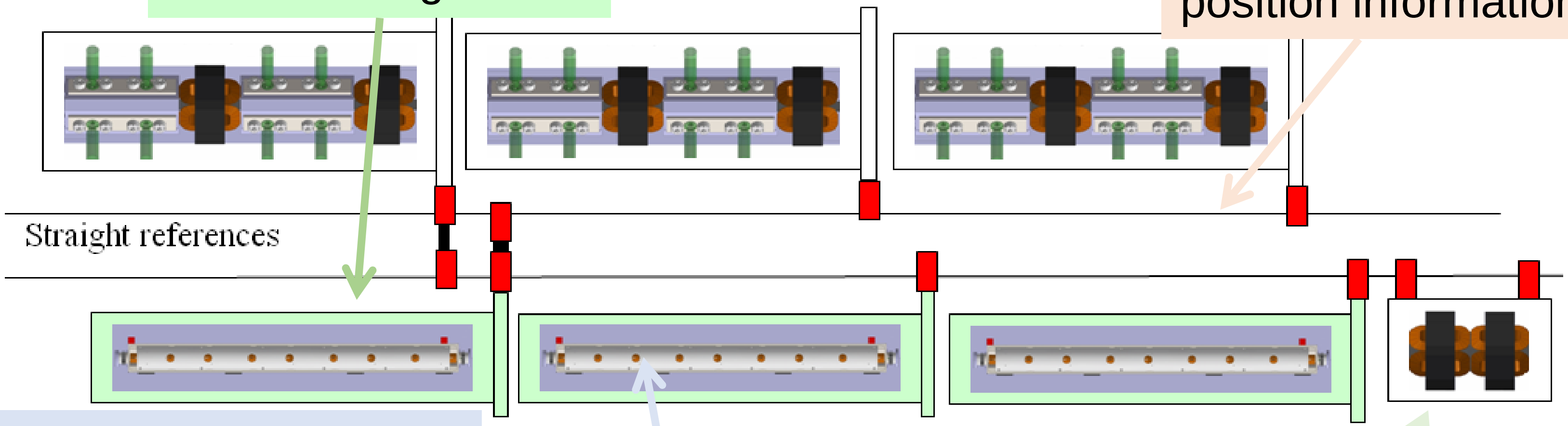
Many thanks to L. Evans, S. Stapnes, W. Wuensch, Ph. Burrows, I. Syratchev and the CLIC team

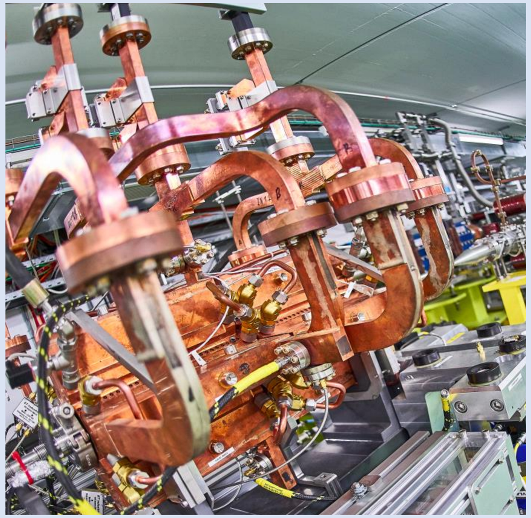
Reserve

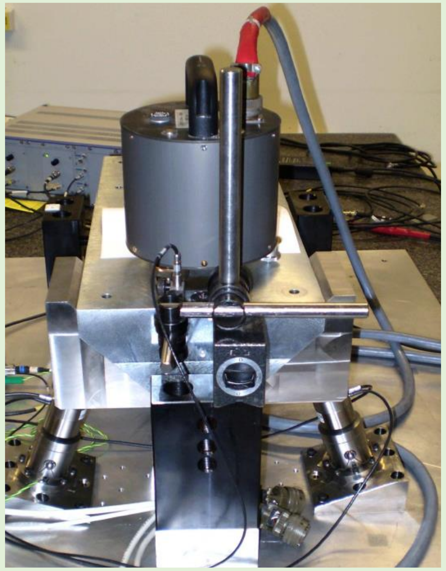
Main Linac Imperfection Mitigation

Components are mounted accurately on movable girders

Overlapping wires provide accurate position information







Wake monitors in each structure measure beam offset (3.5 μm)

Magnets are stabilised mechnically to nm against ground motion and vibrations

Optimised lattice design
Sophisticated beam-based alignment, e.g. dispersion free steering (i.e. different energy beams)

Other CLIC Technology Development

Redesign CLIC modulators and klystrons

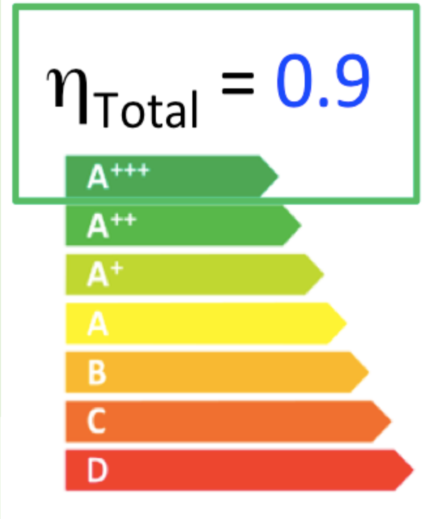
Aim: increase efficiency from 62% to 90%

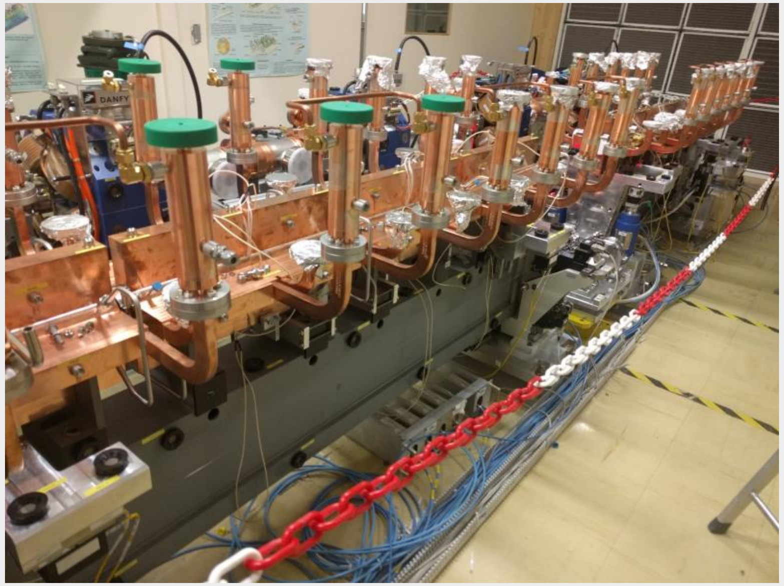
⇒ Less power consumption

⇒ Also important cost saving

Shorter tubes, no oil in modulator, …

⇒ Important cost saving





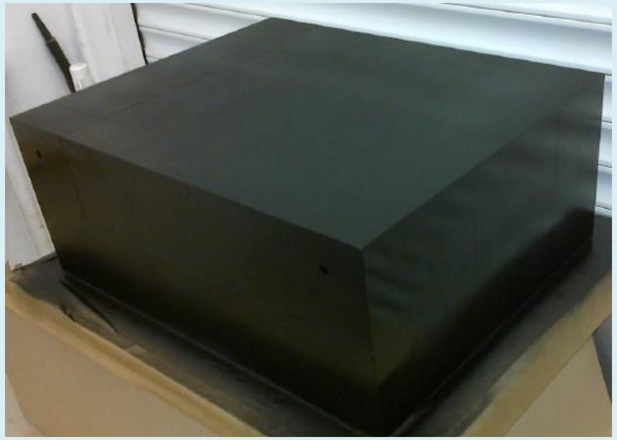
New module design

Reduce cost of mechanical system and control

Permanent magnets

Use tunable permanent magnets where possible

- Drive beam quadruoles
- Strongest permanent magnet developed in UK



Main beam injector

e.g. halved power for positron production