The CLIC Accelerator Project Status and Plans

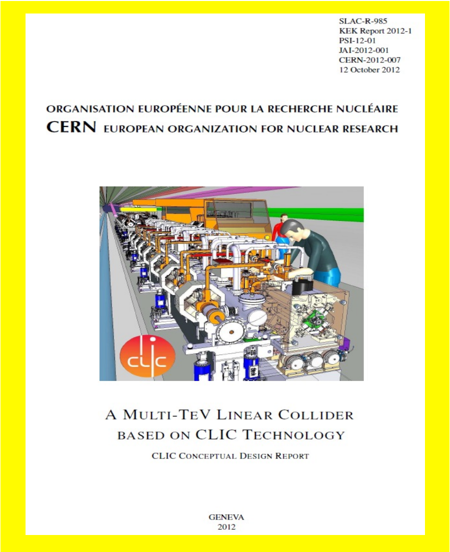
Higgs Hunting, Paris, July 2018

Daniel Schulte
For the CLIC collaboration

CLIC Introduction

CLIC: Compact LInear Collider

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

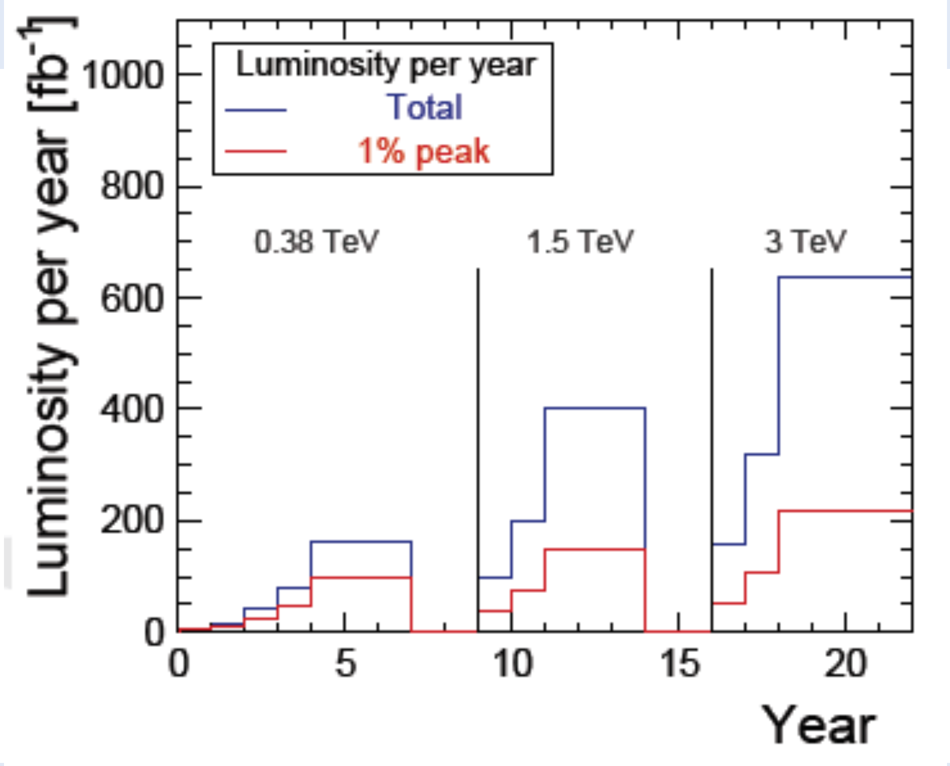
Getting ready for data taking by the time the LHC programme reaches completion

CLIC Collaboration

CLIC Staged Scenario

Plenty of physics at low centre-of-mass energies

Energy and luminosity targets from Physics Study Group



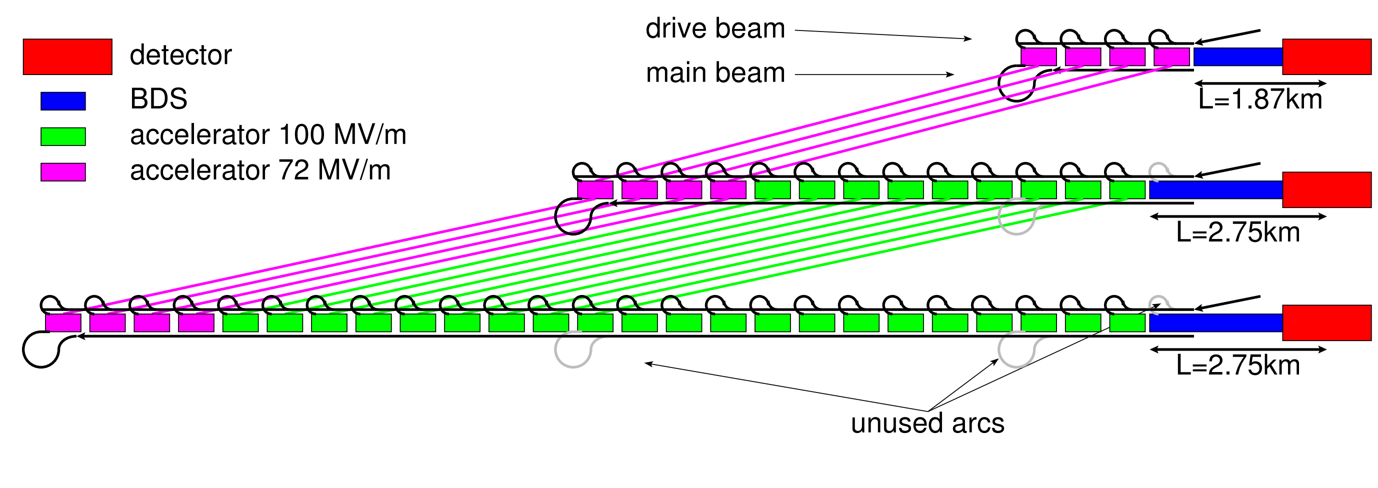
Stage	$\sqrt{s}$ (GeV)	$\mathscr{L}_{int}$ (fb^{-1})
1	380	500
	350	100
2	1500	1500
3	3000	3000

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



CLIC Staged Scenario

Plenty of physics at low centre-of-mass energies

Energy and luminosity target
Study Group

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

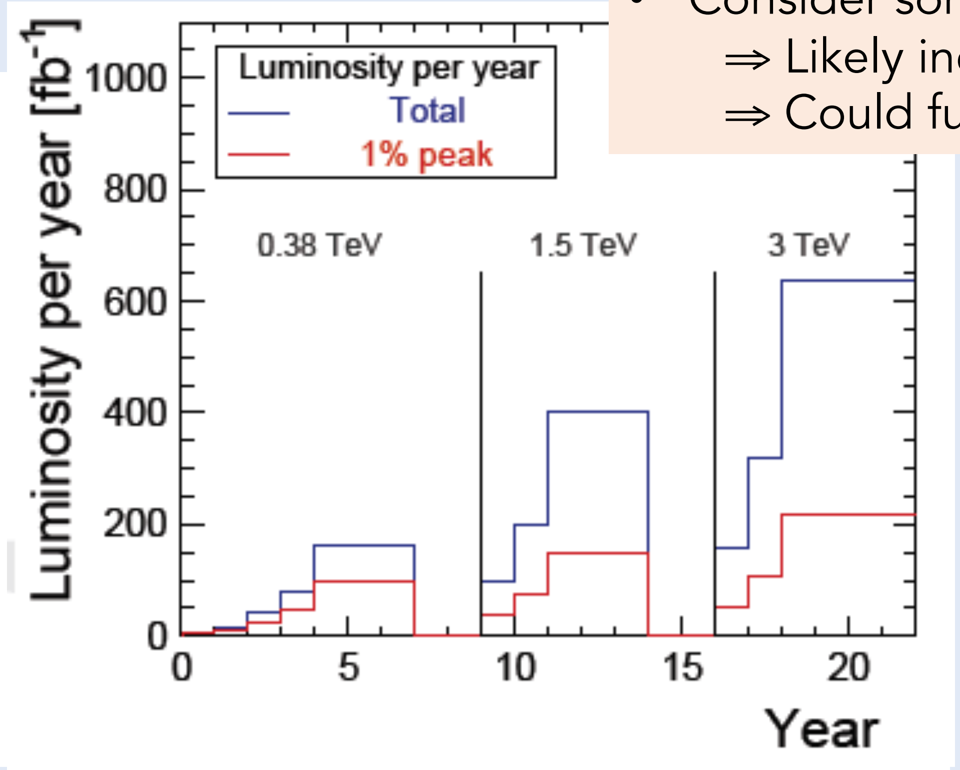
This is being reviewed

- Review of effective operation time for luminosity per year showed increase from 1.08 x 10^7 s to 1.2 x 10^7
- Consider some extra years at full luminosity
  - ⇒ Likely increases integrated luminosities
  - ⇒ Could further improve physics results

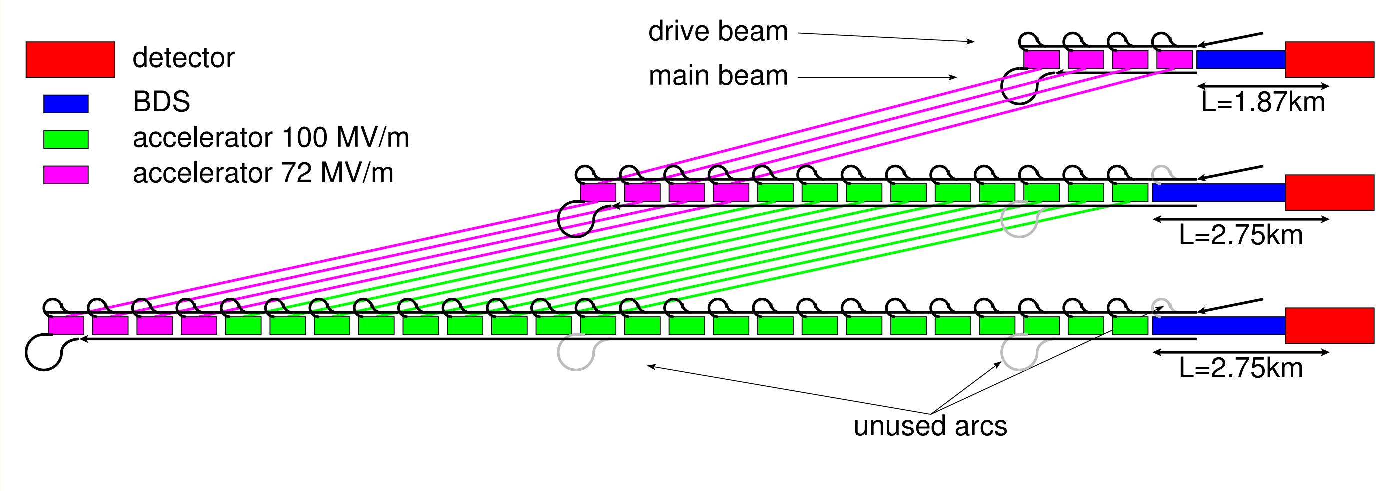
Top above threshold
Higgs via Zh and WW fusion

Study top at threshold

To be updated with more input from LHC and stage 1

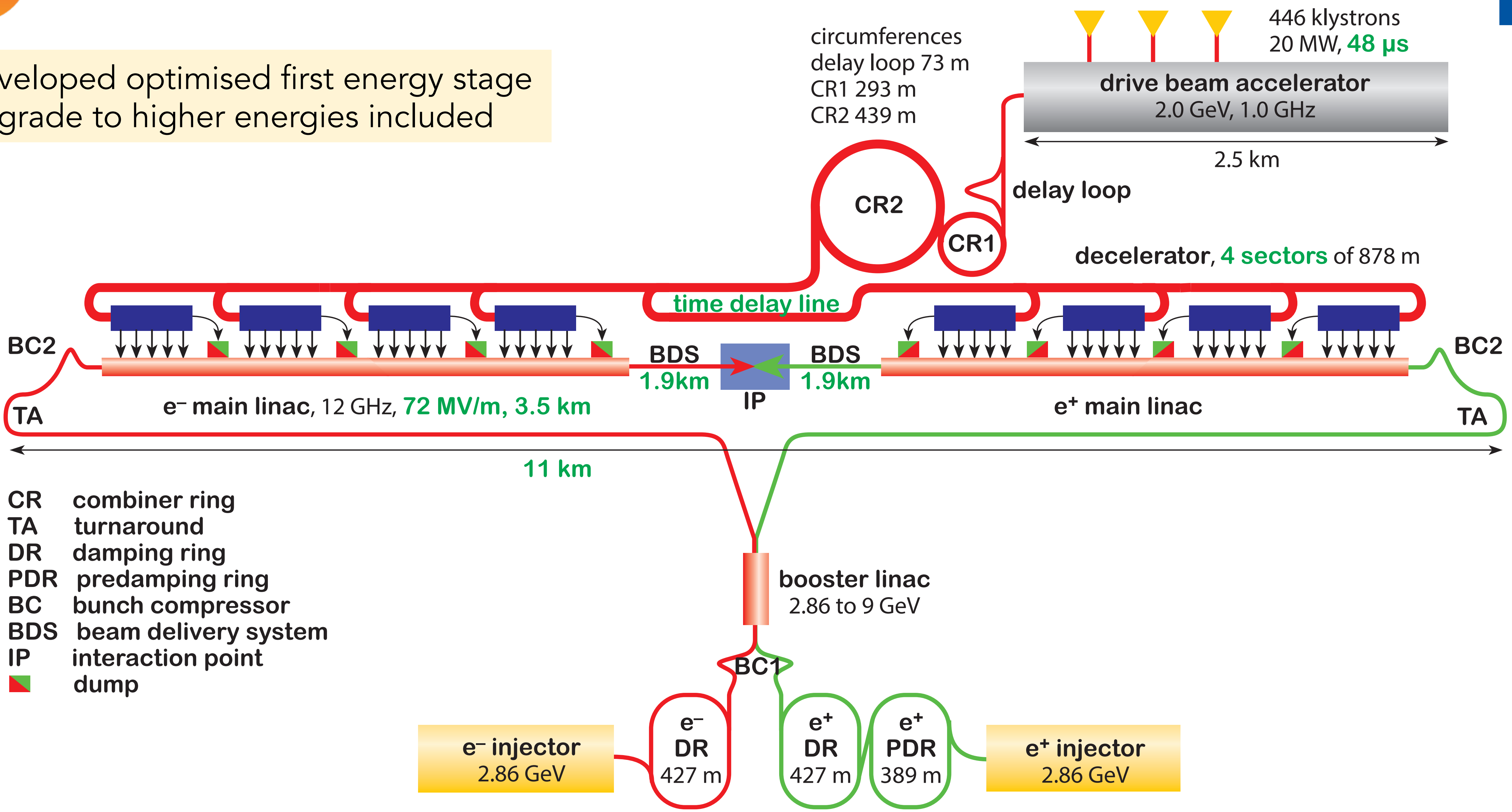


Implementation in stages



CLIC at 380 GeV

Developed optimised first energy stage
Upgrade to higher energies included

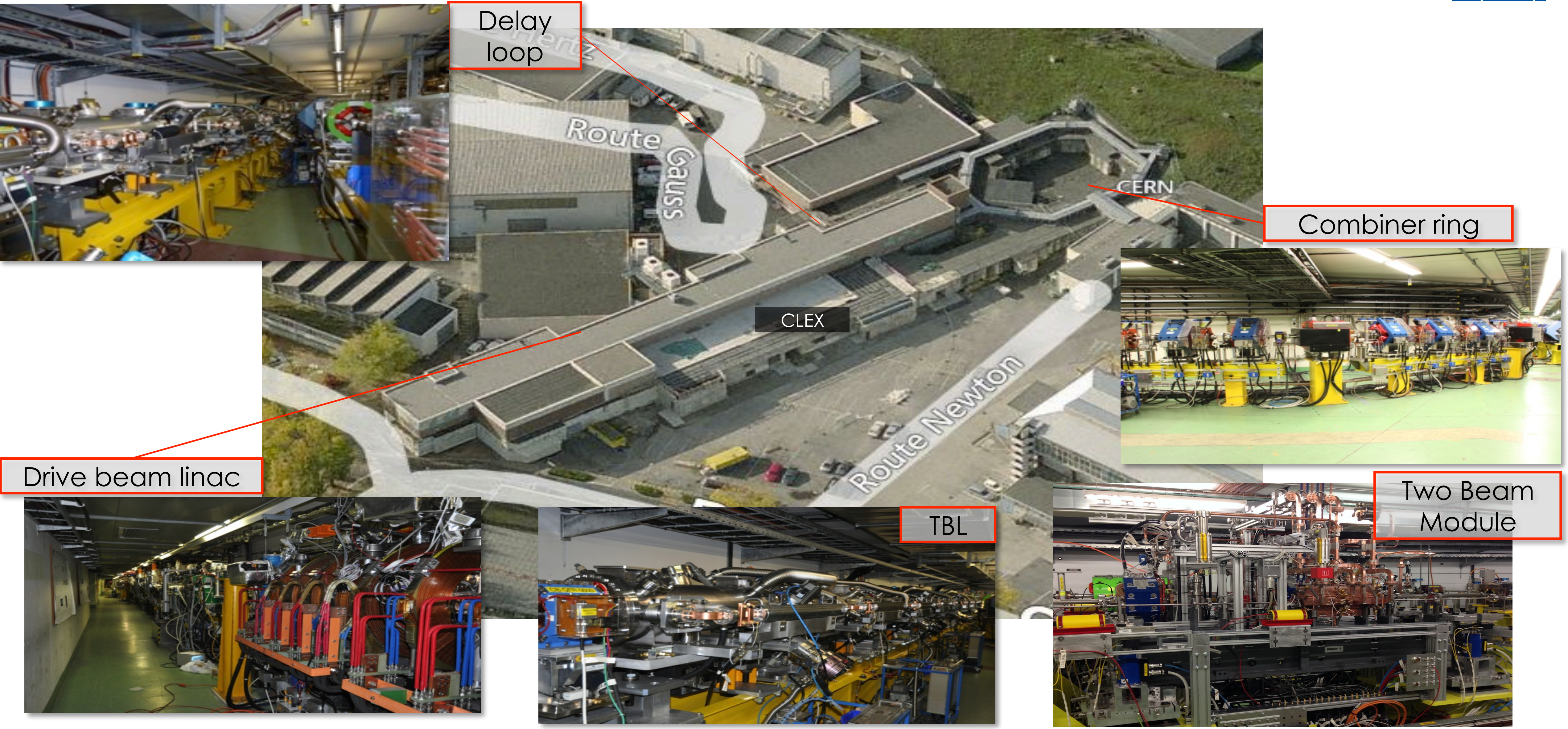


Key Parameters

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

Gradient is optimised for luminosity and cost
Installed modules can be reused at higher energies

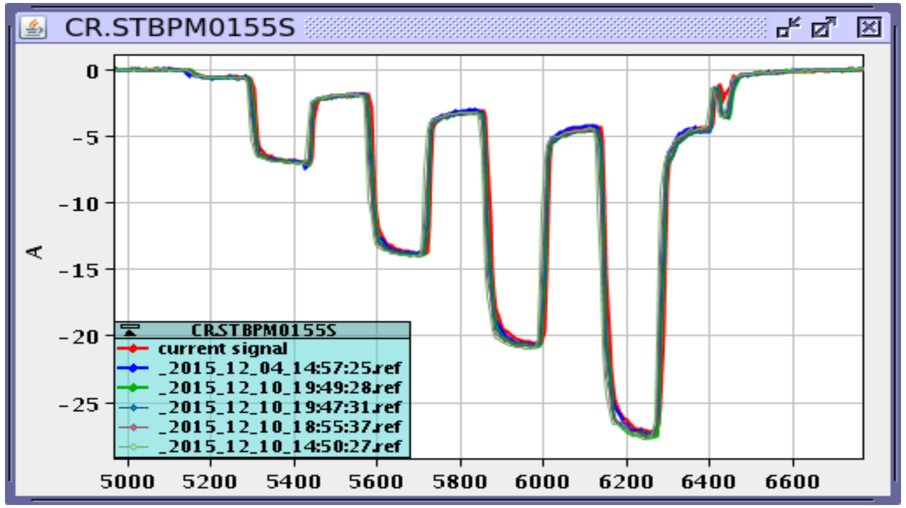
Reminder: CLIC Test Facility (CTF3)



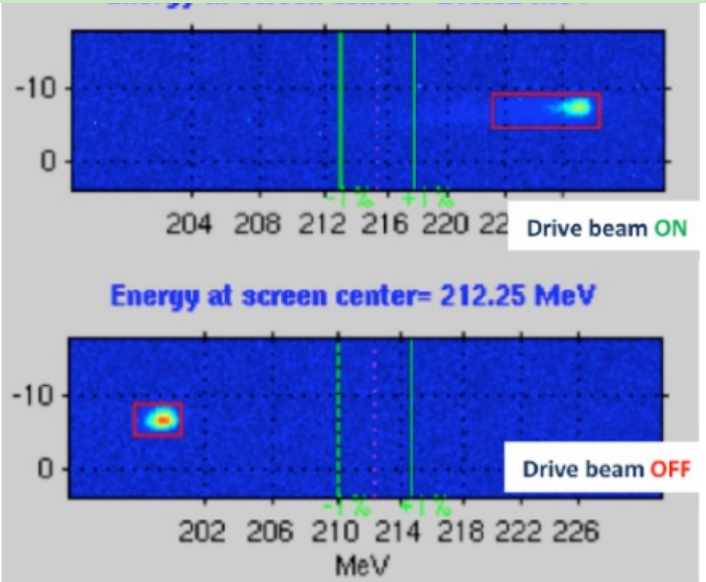
Reminder: Drive Beam Scheme Performance

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

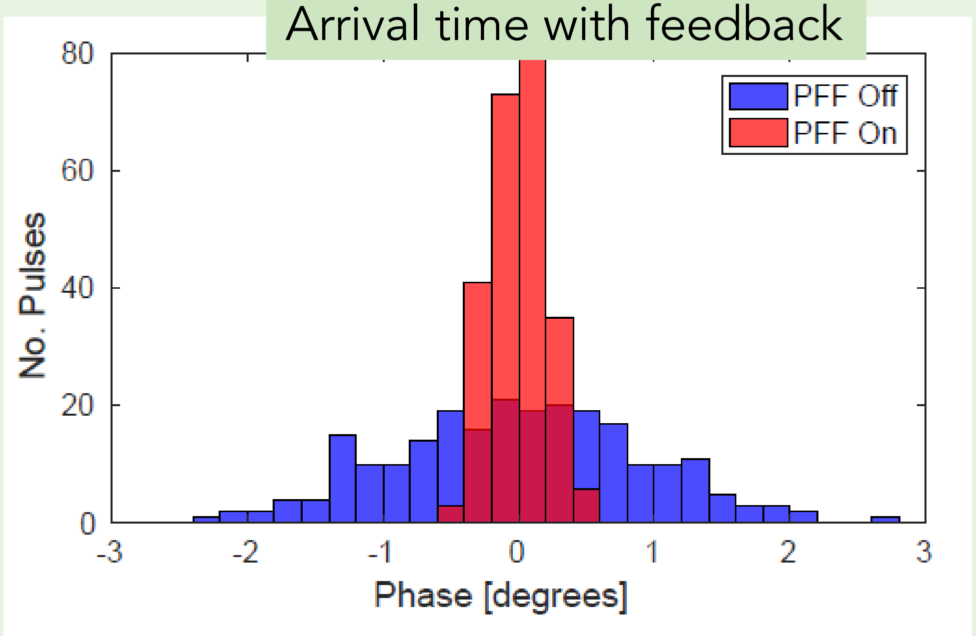
Detailed simulations of drive beam performance in CLIC



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

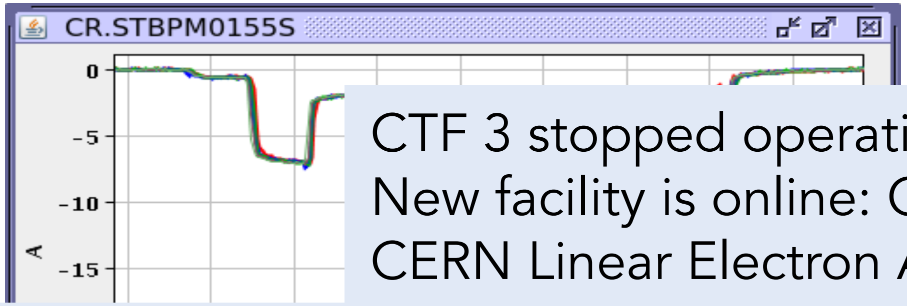
Parameter	CLIC goal	CTF3 measured
Arrival time	50 fs	50 fs
Current after linac	0.75×10^{-3}	$0.2\text{-}0.4 \times 10^{-3}$
Energy	1.0×10^{-3}	0.7×10^{-3}

Reminder: Drive Beam Scheme Performance

CTF3 measurements:
- RF to drive beam efficiency > 95%
- Current multiplication factor 8
- Most of beam quality
- 14

Deta
perfo

dient



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

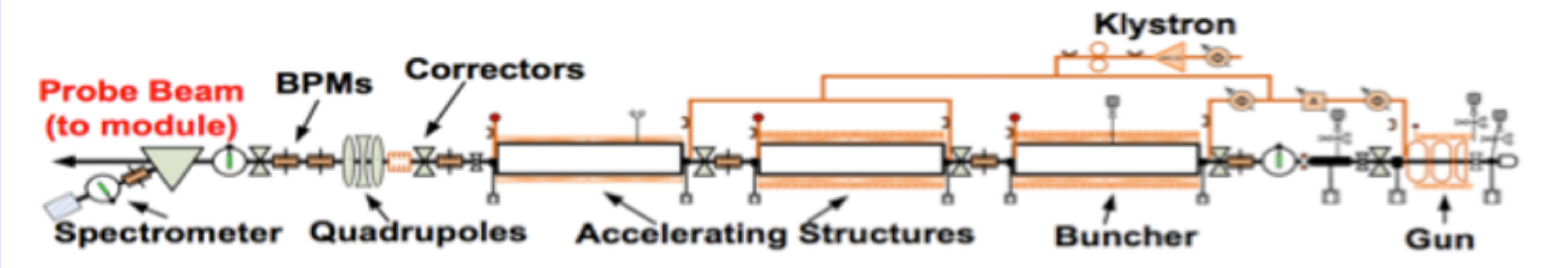
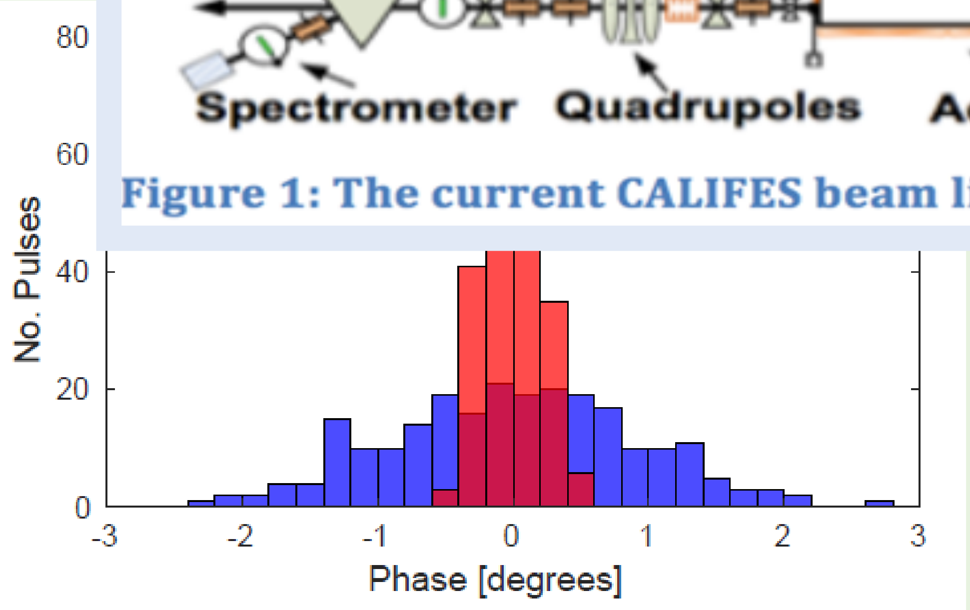
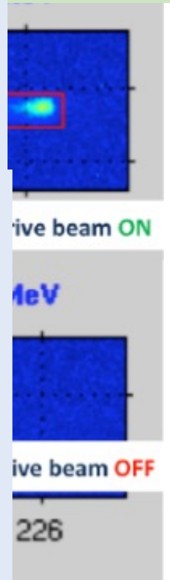


Figure 1: The current CALIFES beam line. The length of the facility (as shown) is ~20m.

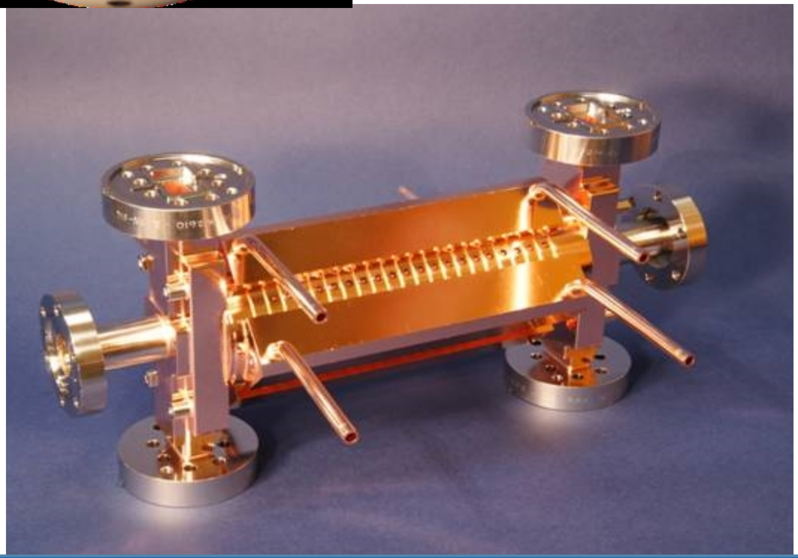


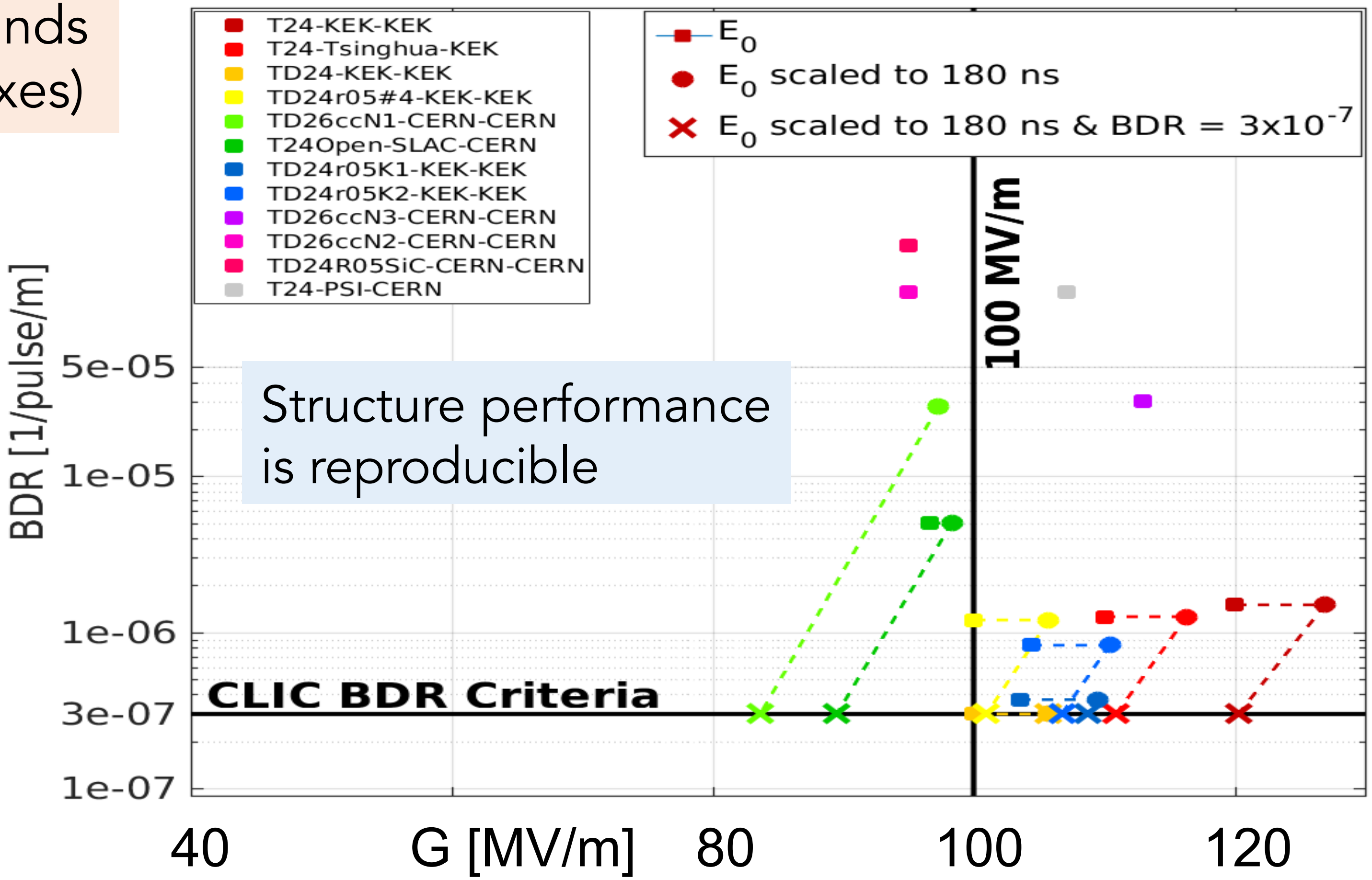


Parameter	CLIC goal	CTF3 measured
Arrival time	50 fs	50 fs
Current after linac	0.75×10^{-3}	$0.2\text{-}0.4 \times 10^{-3}$
Energy	1.0×10^{-3}	0.7×10^{-3}

CLIC Structure Development

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

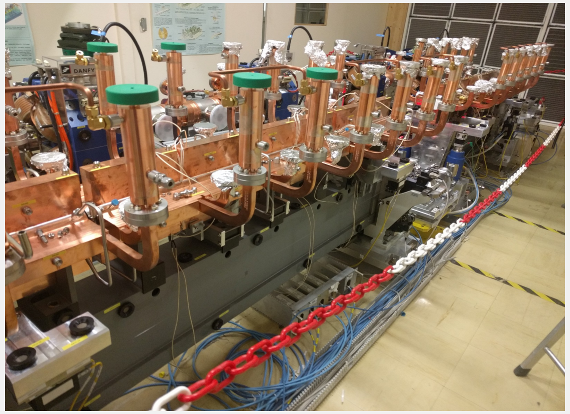




Structure performance is reproducible

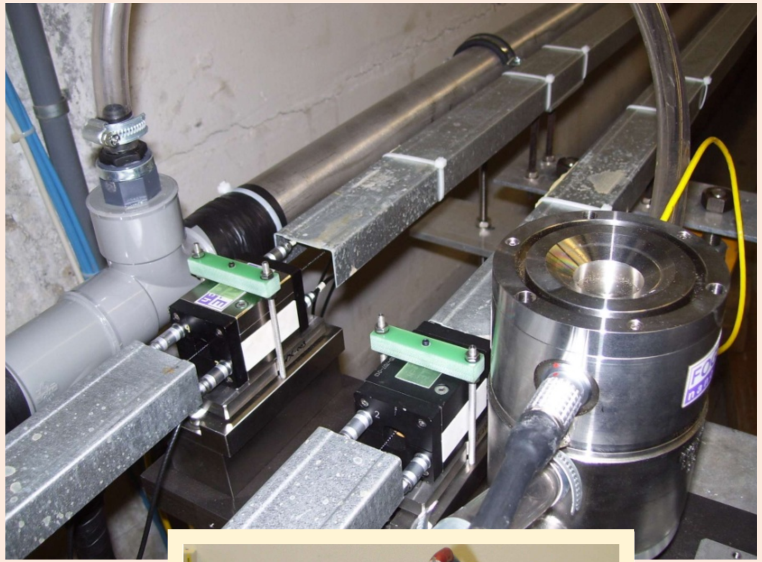
Further optimisation ongoing of structure production for industrialisation

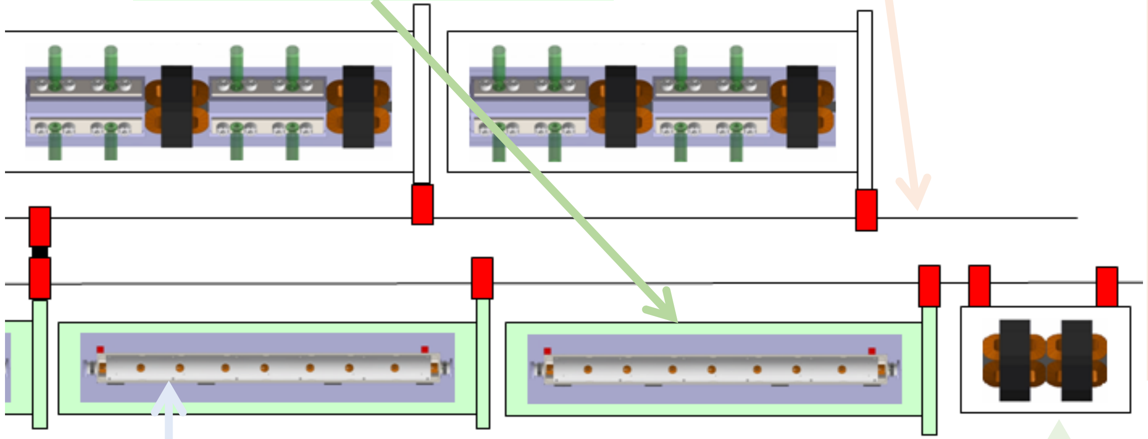
Main Linac Module and Imperfection Mitigation

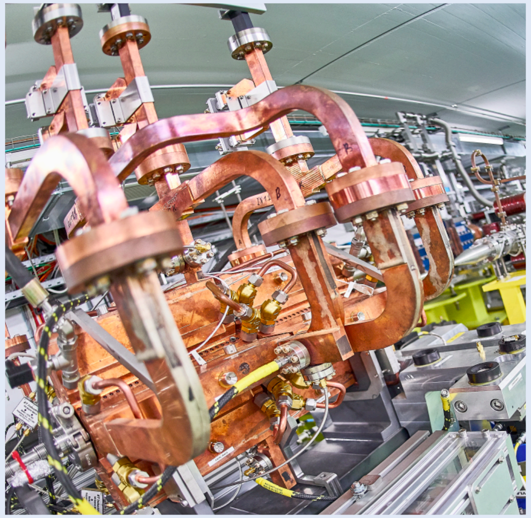


Components are mounted accurately on movable girders

Overlapping wires provide accurate position information

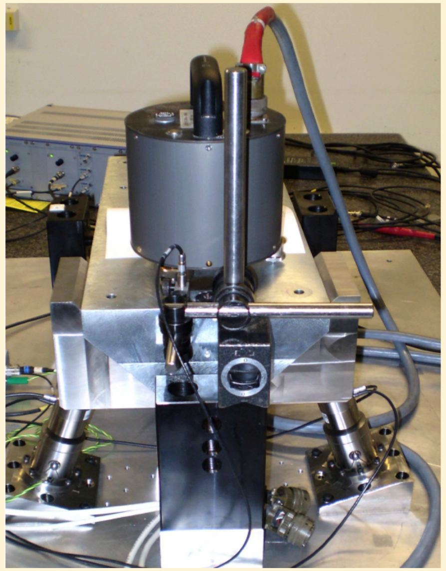






Wake monitors in each structure measure beam offset (3.5 μm)

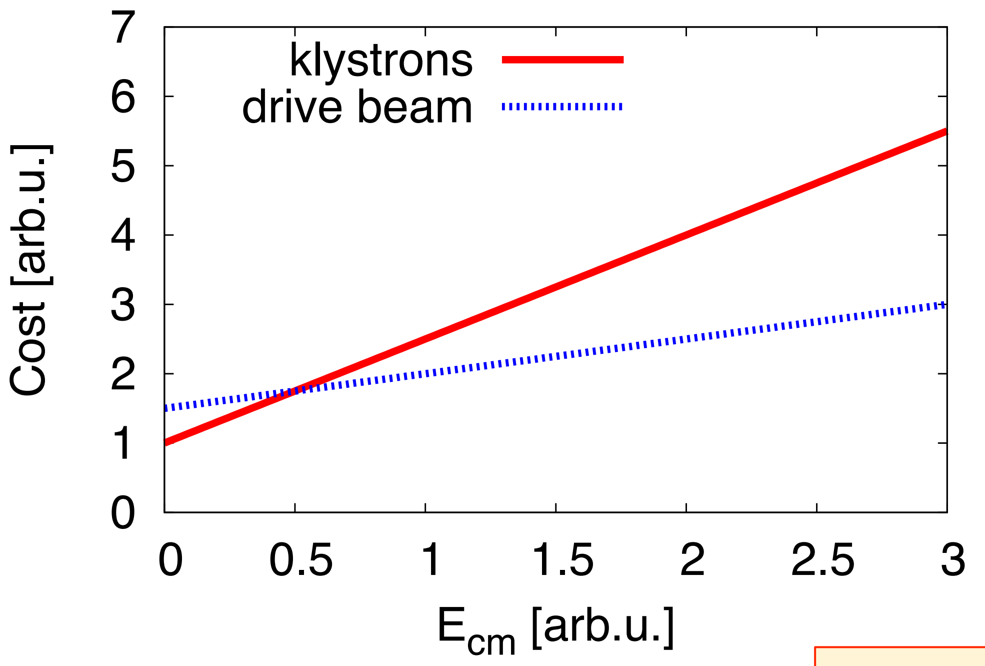
Magnets are stabilised mechanically to nm against ground motion and vibrations

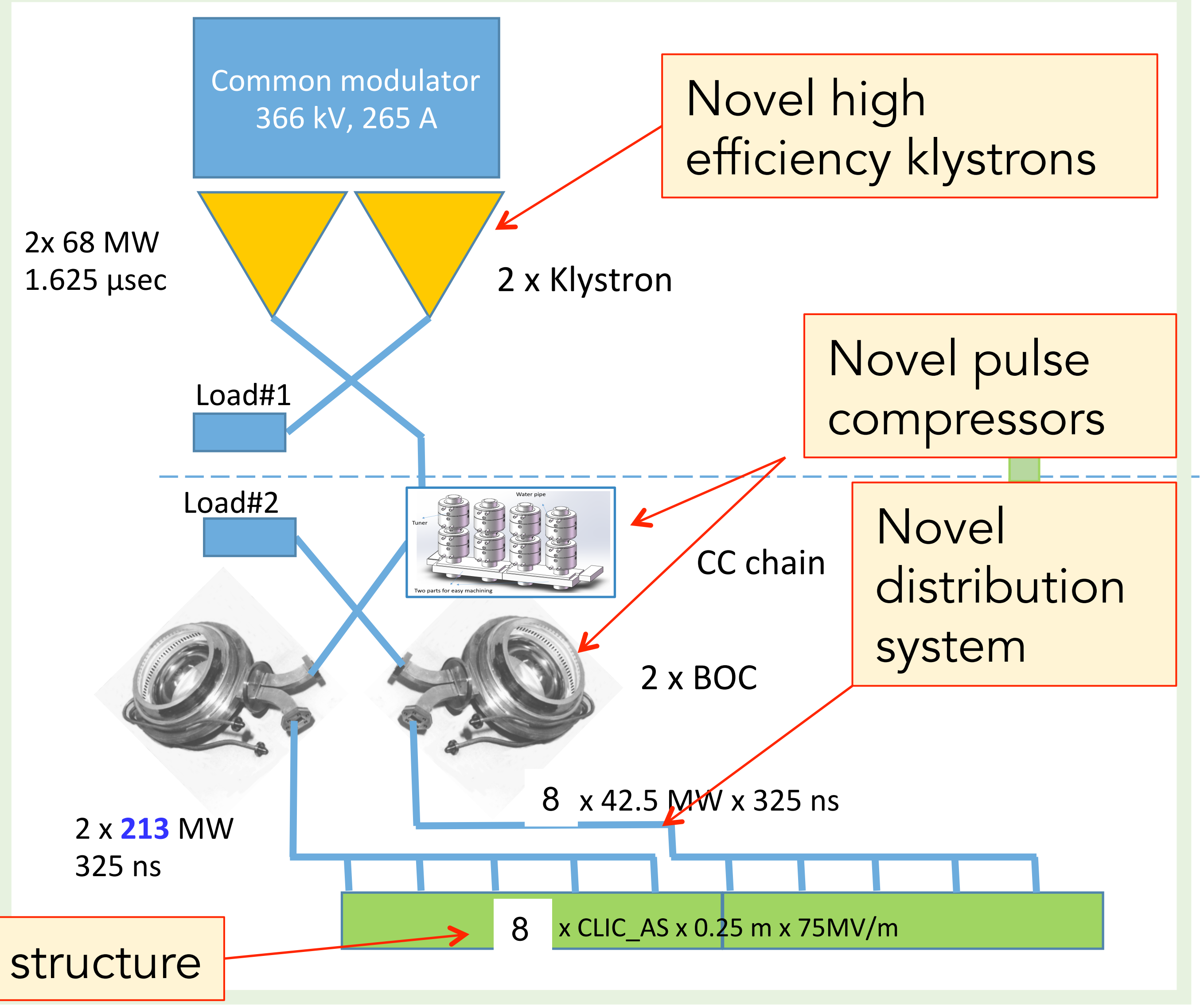


In addition to high accuracy optimisation for cost

Klystron-based Alternative

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



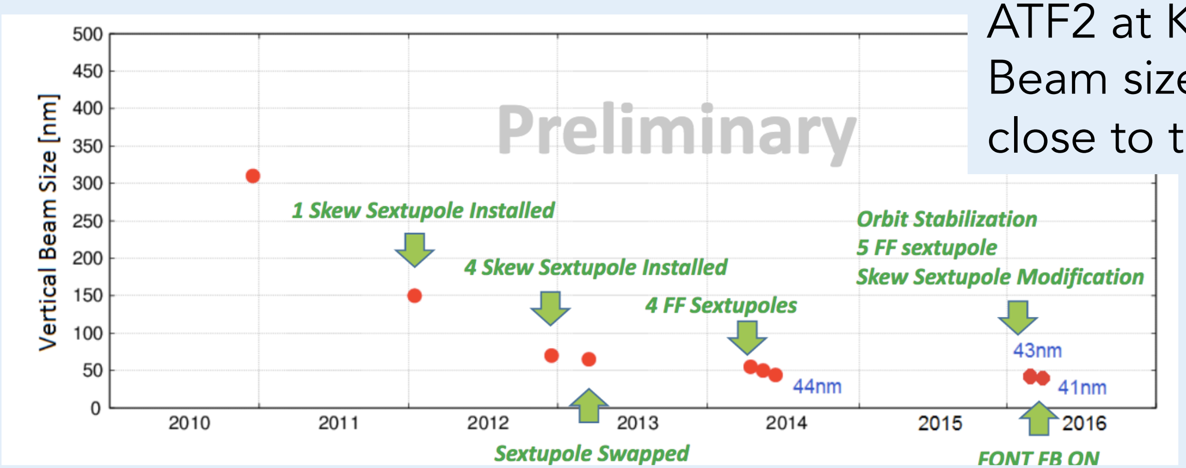


Beam Quality for Luminosity

- Production of low-emittance beams in damping ring
  - Similar to existing light sources

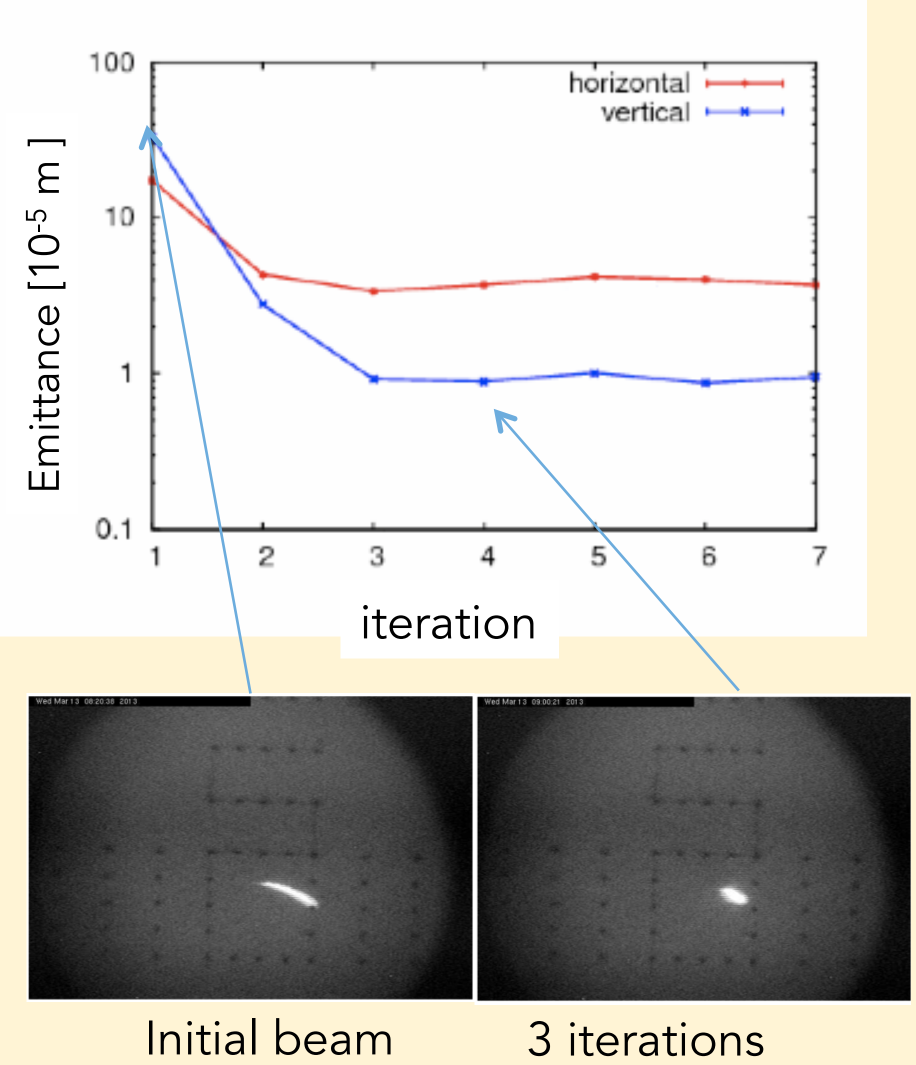
- Quality preservation in transport
  - Minimisation of imperfections
  - Optimised lattice design
  - Sophisticated beam-based tuning

- Focusing of beam in beam delivery system
  - Advanced lattice design
  - Advanced tuning
  - Test at FFTB and ATF2



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

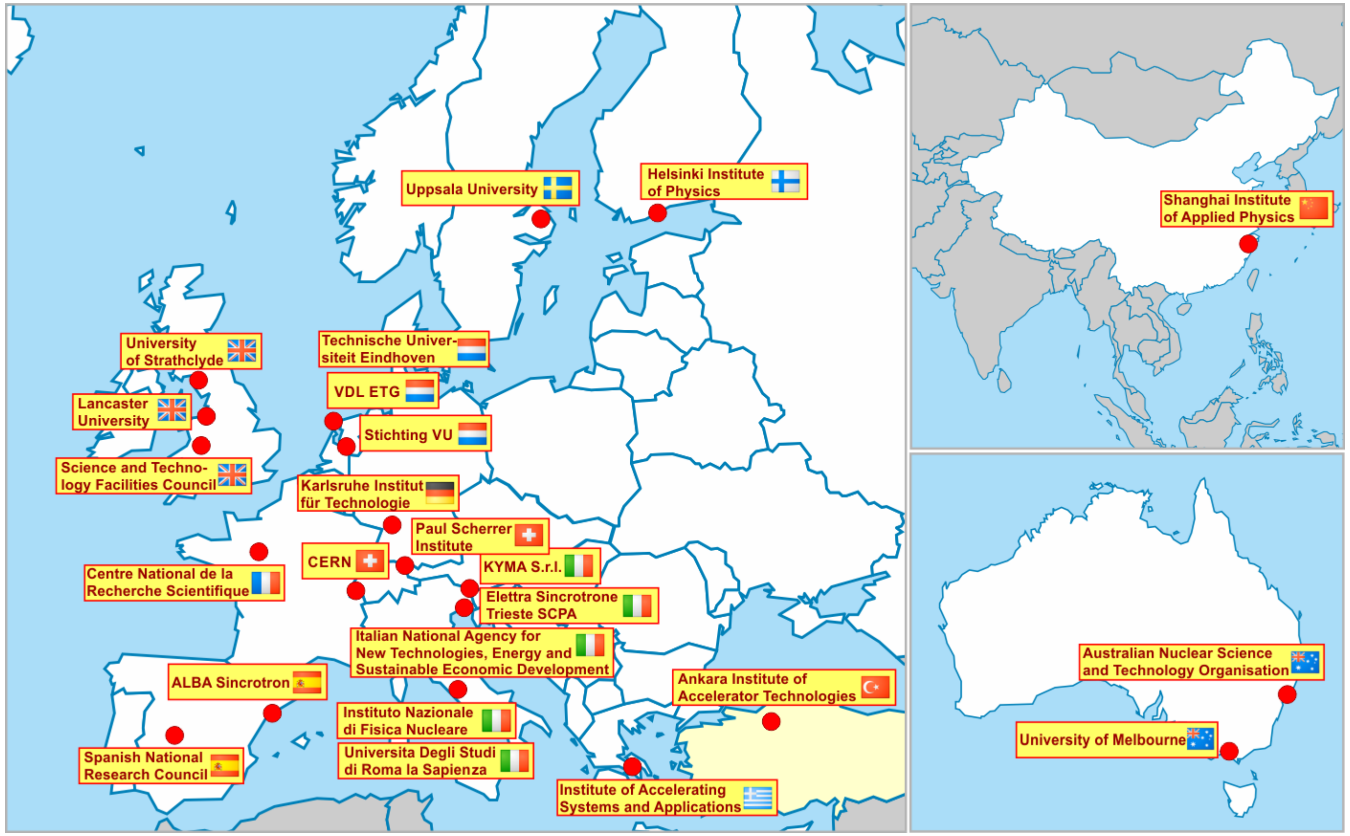
Dispersion Free Steering Test at FACET (SLAC)



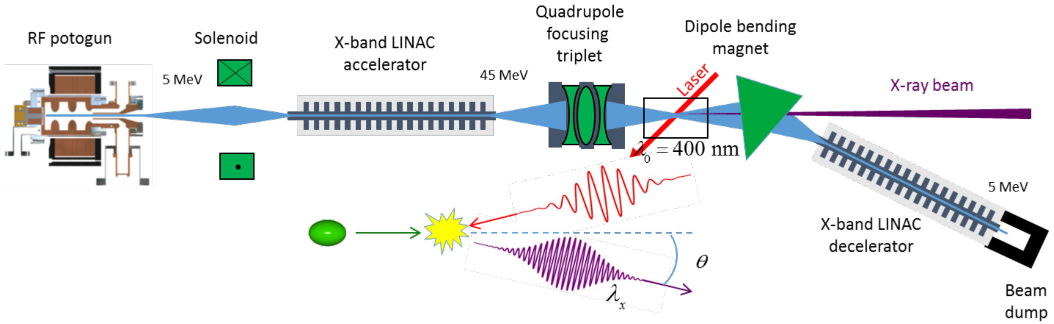
CLIC Technology Development and Applications

CLIC technology for CLIC and different applications

- Recent EU co-funded FEL design study
- SPARC at INFN-LF
- Electrons to SPS for dark matter searches?
- …

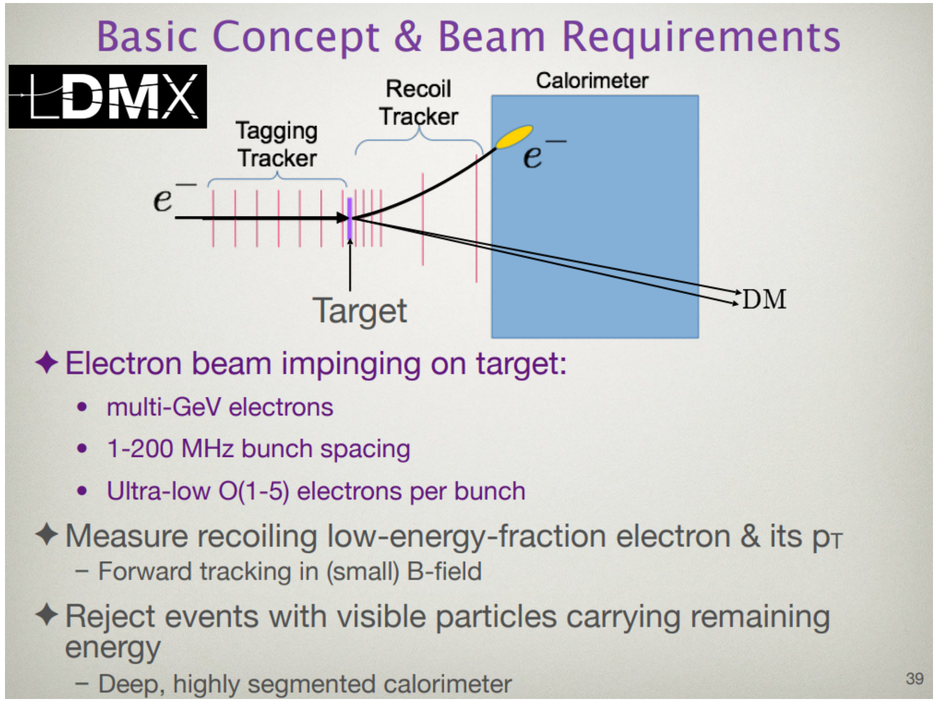


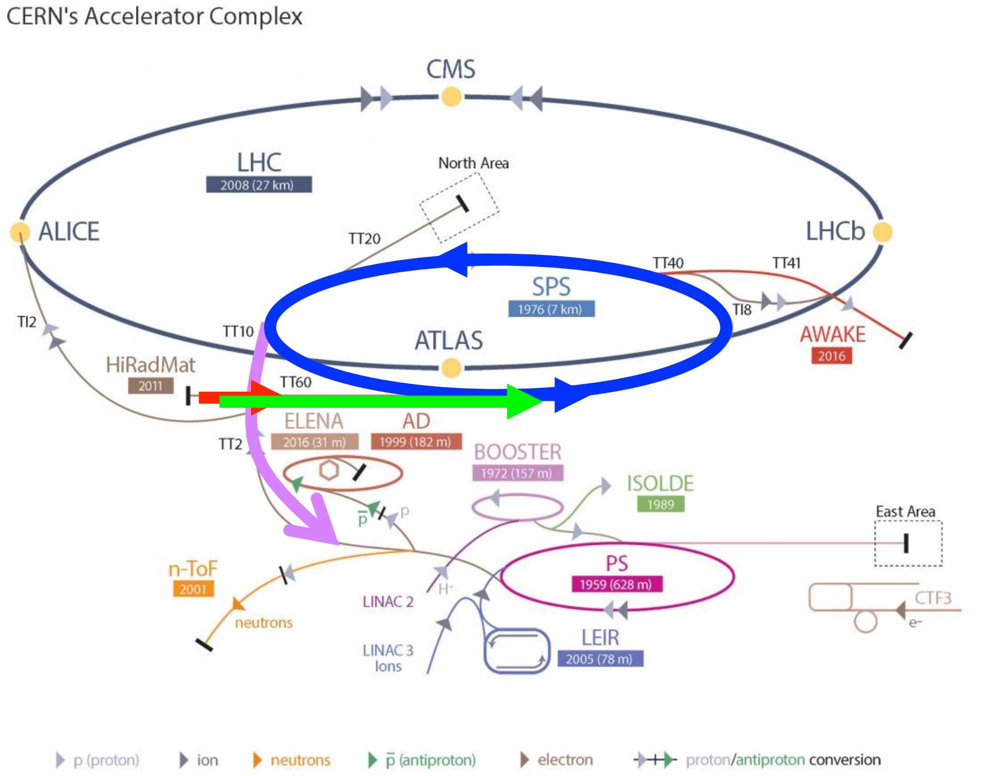
INFN Frascati advanced acceleration facility
EuPARXIA@SPARC_LAB



Eindhoven University led
SMART*LIGHT Compton Source

Note: Dark Matter Searches





3.5 GeV Linac
12 GHz CLIC
technology

Transfer to SPS

Acceleration to
about 16 GeV
in SPS

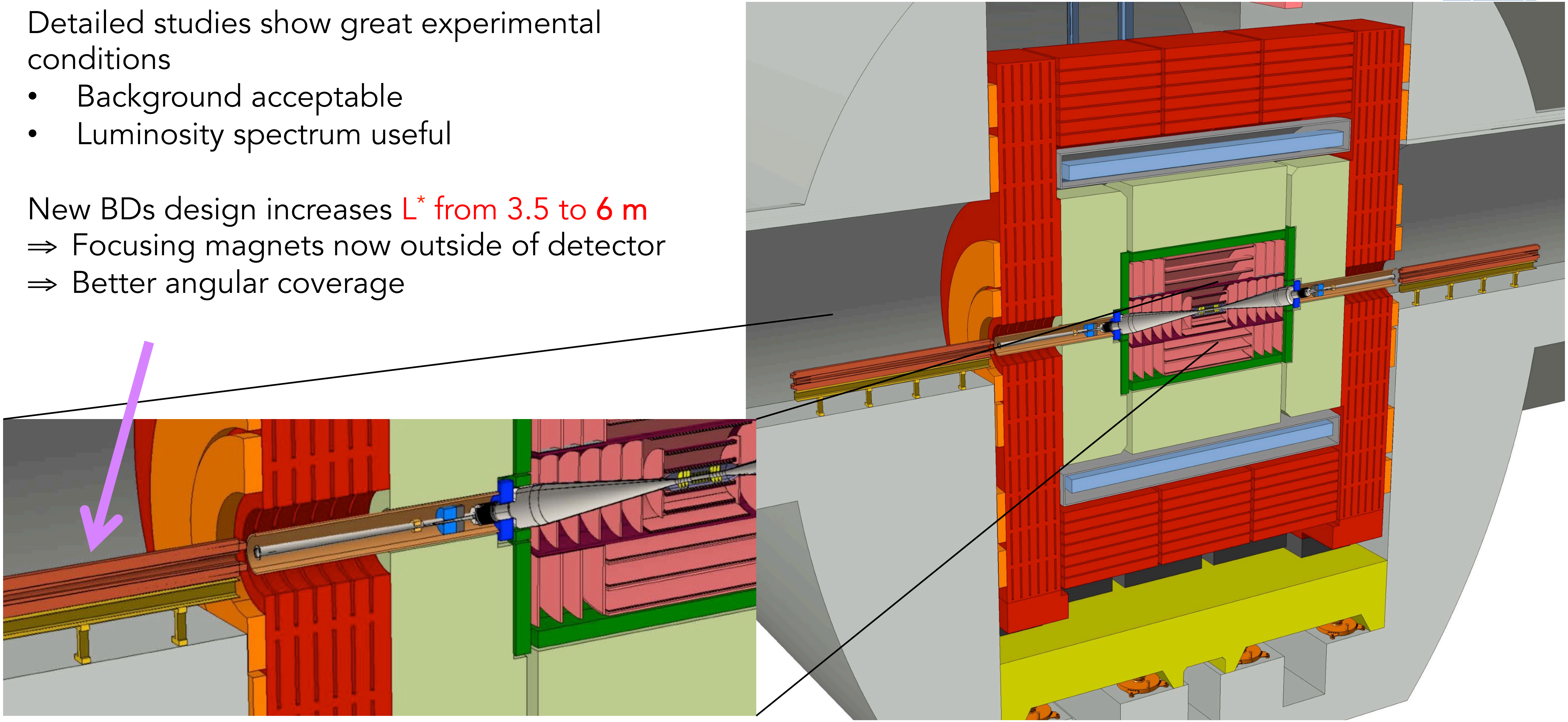
Extraction

Basically all tunnels and infrastructure exist
Need 3.5 GeV linac with CLIC technology

Comment: Increased L* for Detectors

Detailed studies show great experimental conditions
- Background acceptable
- Luminosity spectrum useful

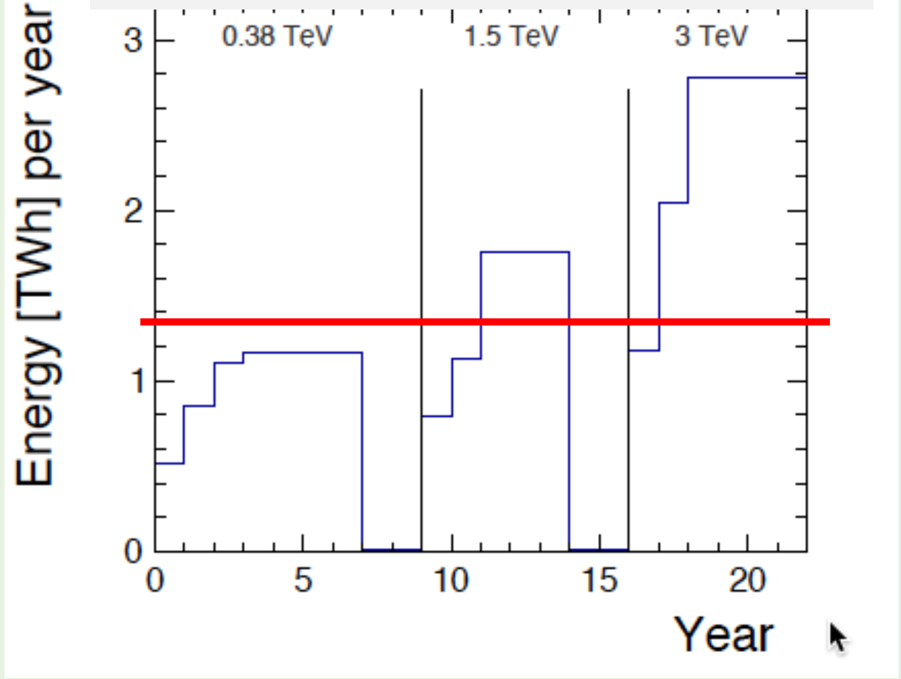
New BDs design increases L* from 3.5 to 6 m
⇒ Focusing magnets now outside of detector
⇒ Better angular coverage



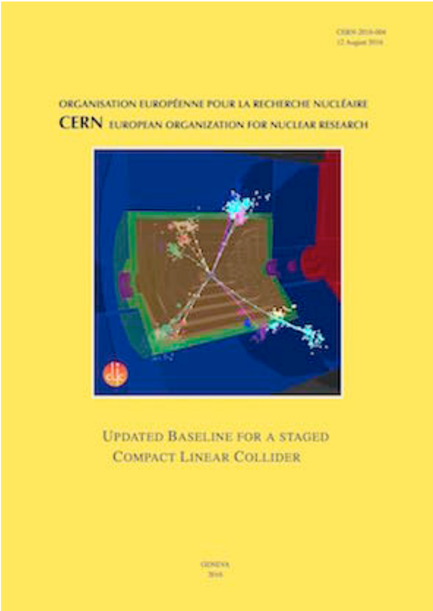
Cost and Power

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**

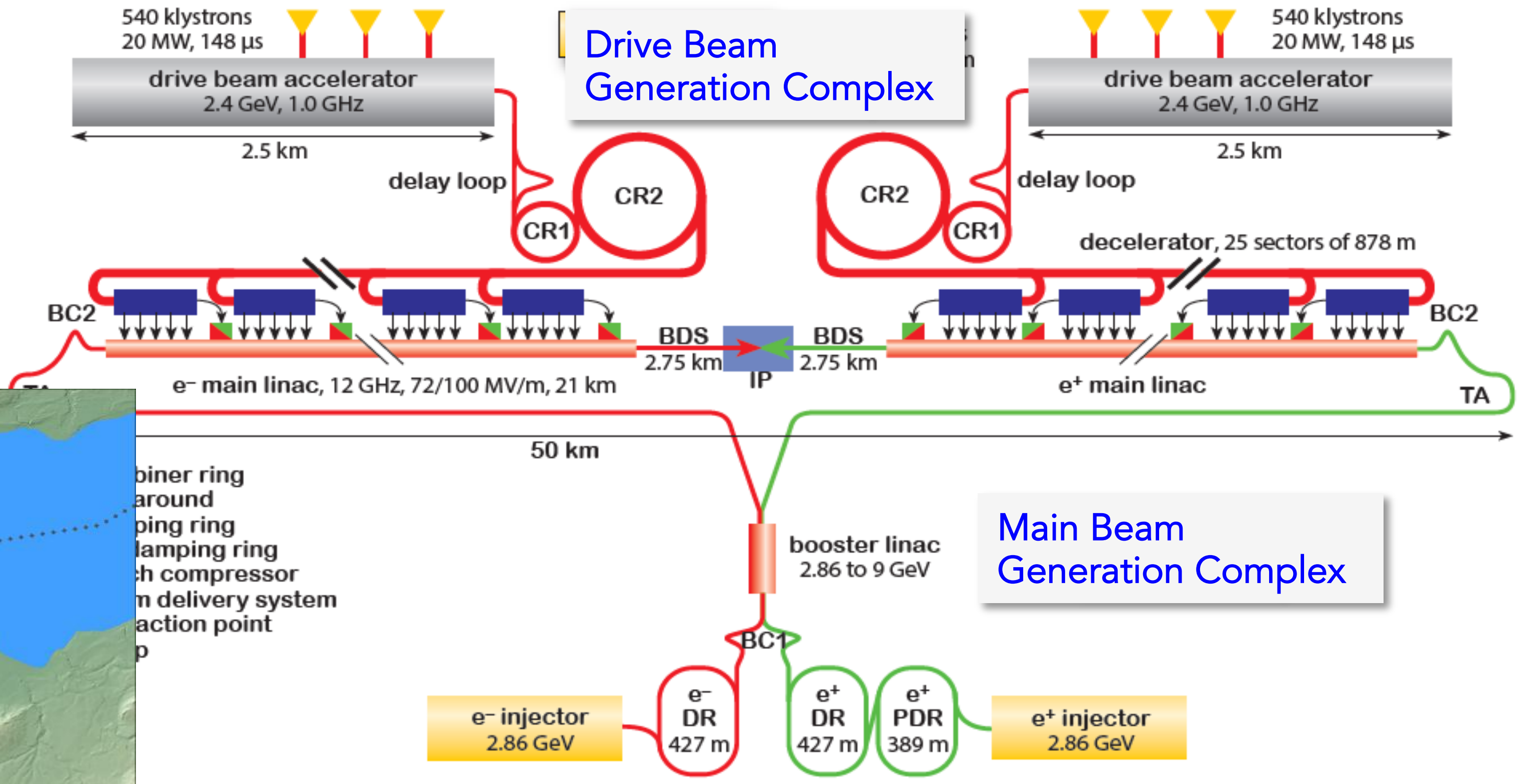
Improvement of cost and power is ongoing
Detailed bottom up estimate
Already savings, seems we meet goal

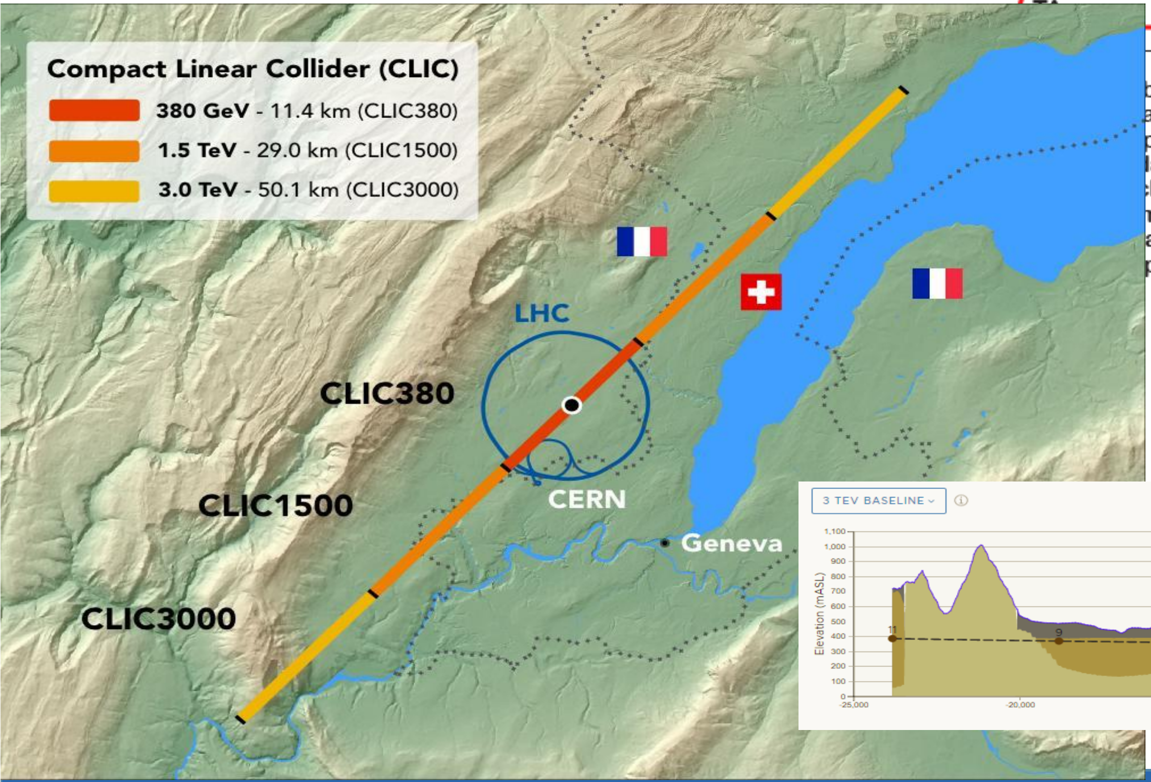
CLIC Site and Upgrade to 3 TeV

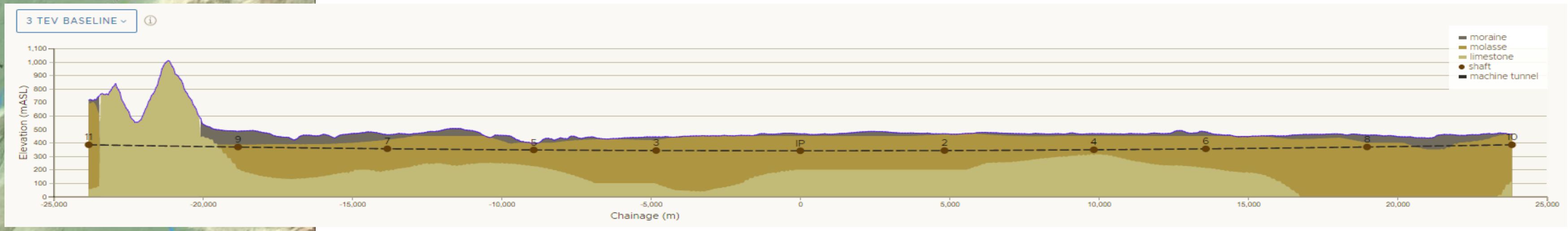
Can re-use previous systems and components

Just add more linac and drive beam pulse length

At 3 TeV add one drive beam







Conclusion

Important progress toward the EU strategy

- Much improved technical maturity
- Light sources are prototypes of damping rings
- 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
- Writing of Project Implementation Plan is well advancing, ready by end of 2018

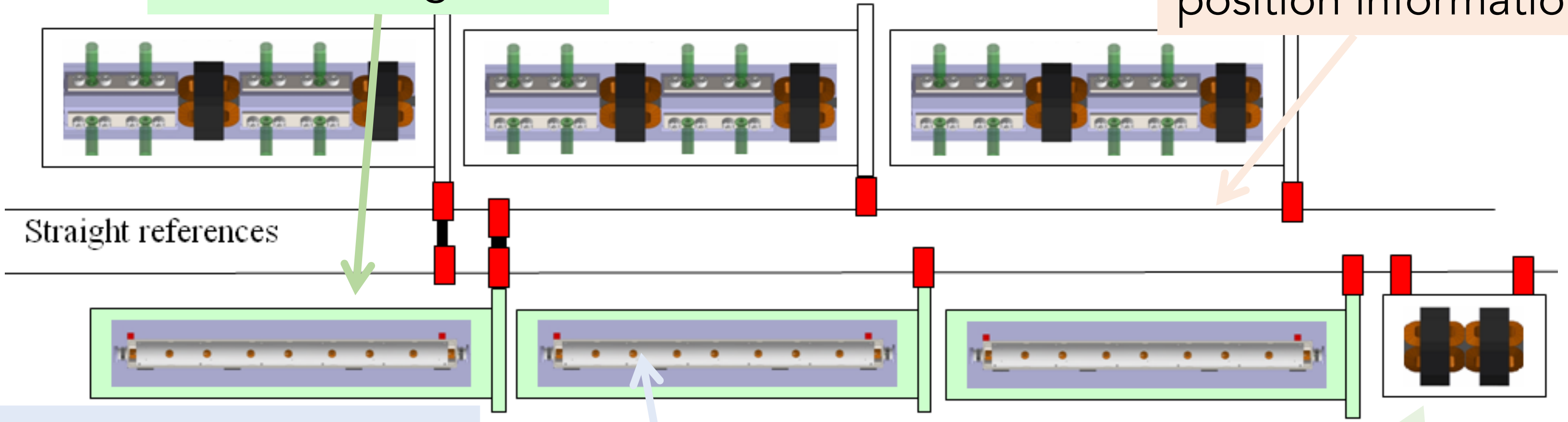
Many thanks to L. Evans, S. Stapnes, W. Wuensch, Ph. Burrows, I. Syratchev and the CLIC team

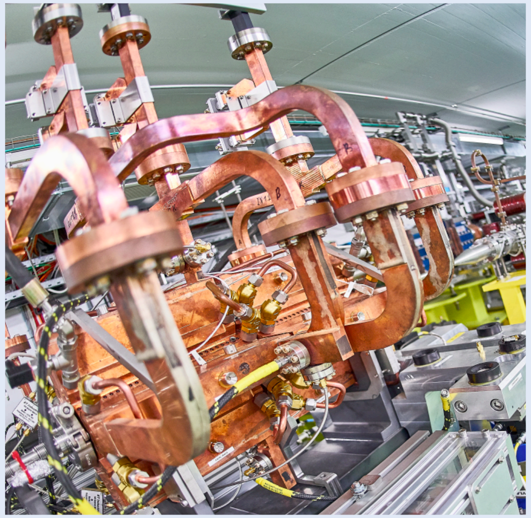
Reserve

Main Linac Imperfection Mitigation

Components are mounted accurately on movable girders

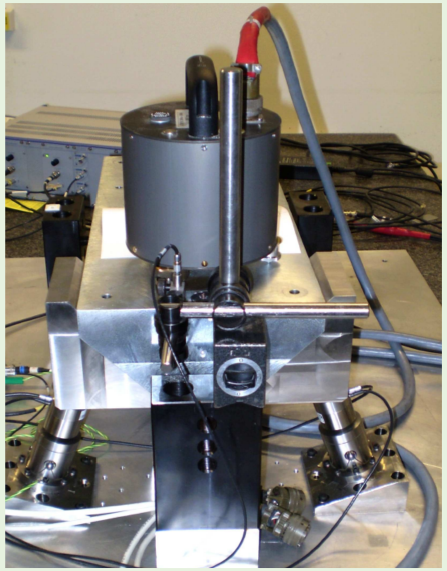
Overlapping wires provide accurate position information





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

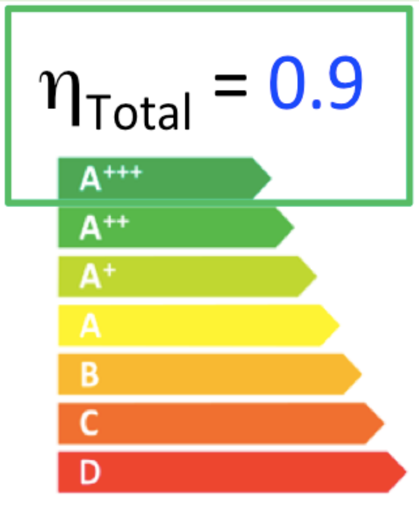
Magnets are stabilised mechnically to nm against ground motion and vibrations

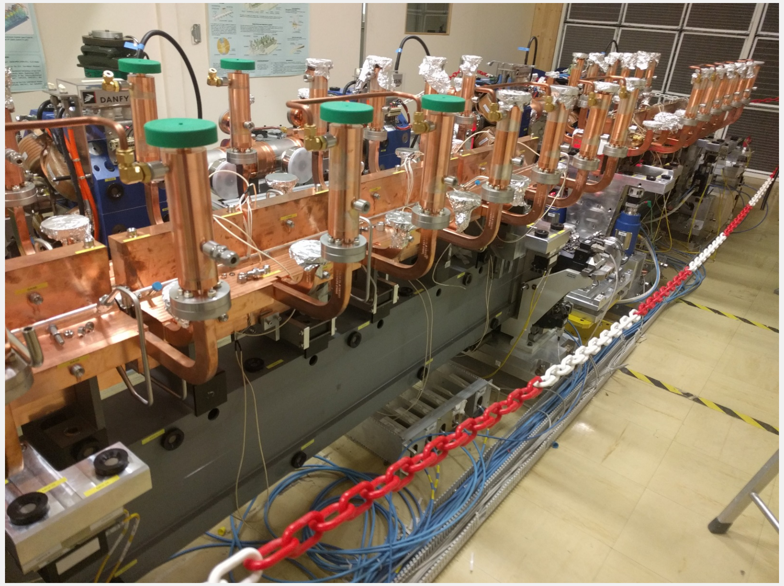


Optimised lattice design
Sophisticated beam-based alignment, e.g. dispersion free steering (i.e. different energy beams)

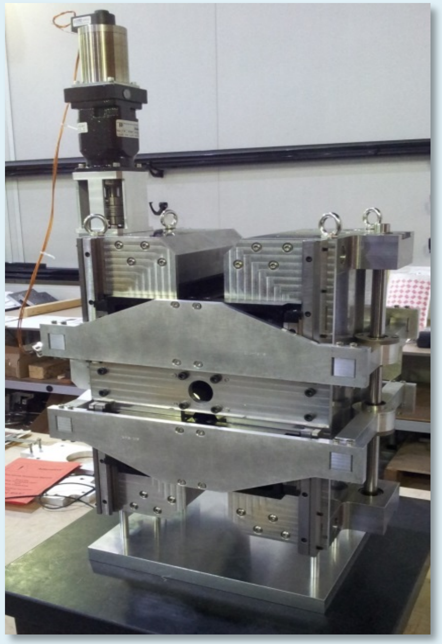
Other CLIC Technology Development

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

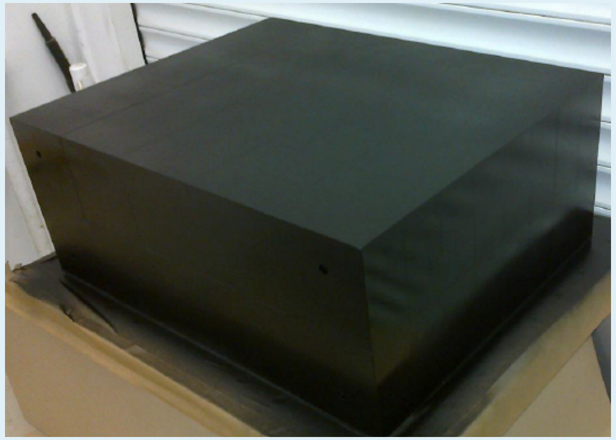




New module design
Reduce cost of mechanical system and control



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