Future LC objectives

- Strongly support the Japanese initiative to construct a linear collider as a staged project in Japan.
- Prepare CLIC machine and detectors as an option for a future high-energy linear collider at CERN.
- Further improve collaboration between CLIC and ILC machine experts.
- Move towards a “more normal” structure of collaboration in the detector community to prepare for the construction of two high-performance detectors.

ILC TDR “almost ready” and Japanese initiative progresses, see talk of Brian Foster

CLIC CDR completed, see talk of Steinar Stapnes (detector & physics issues in talk of Juan Fuster)

Single slide in talk of Steinar Stapnes

See talk of Juan Fuster concerning LC detector and physics studies – ILC DBD and CLIC CDR

CLIC Status and Outlook

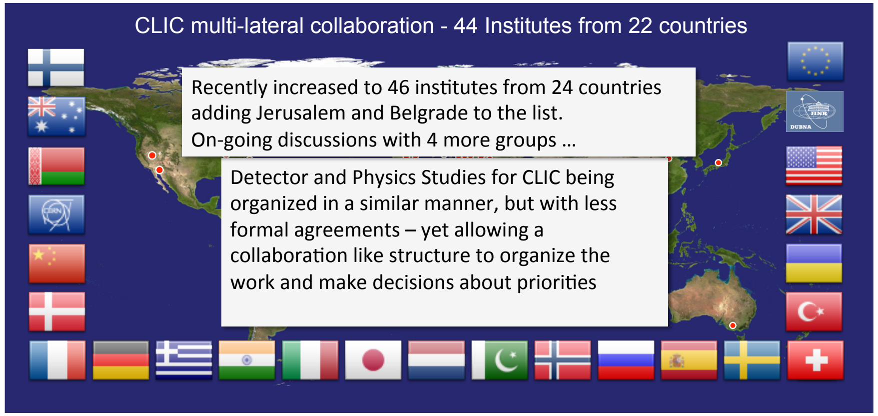
ECFA - November 2012

Steinar Stapnes

Covering:
- The CLIC accelerator studies
  - Feasibility studies and Performance studies
  - Documented in volume 1 of the CDR
- CLIC detector and physics studies (see talk of Juan Fuster)
  - Documented in volume 2 and 3 of the CDR
- Project implementation studies
  - Including timelines and programme for the coming years
  - Mainly documented in volume 3
- Summary

- Material: The Conceptual Design Report (volume 1-3) just completed – see later for references

Current CLIC Collaboration



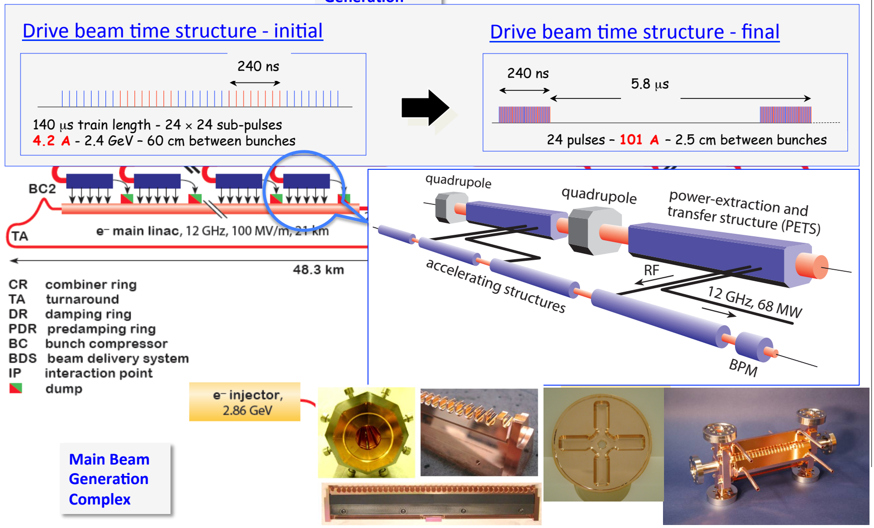
Recently increased to 46 institutes from 24 countries adding Jerusalem and Belgrade to the list.
On-going discussions with 4 more groups …

Detector and Physics Studies for CLIC being organized in a similar manner, but with less formal agreements – yet allowing a collaboration like structure to organize the work and make decisions about priorities

ACAS (Australia)
Aarhus University (Denmark)
Ankara University (Turkey)
Argonne National Laboratory (USA)
Athens University (Greece)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
ETH Zurich (Switzerland)
FNAL (USA)
Gazi Universities (Turkey)
Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
IHEP (China)
INFN / LNF (Italy)
Instituto de Fisica Corpuscular (Spain)
IRFU / Saclay (France)
Jefferson Lab (USA)
John Adams Institute/Oxford (UK)
Joint Institute for Power and Nuclear Research SOSNY /Minsk (Belarus)
John Adams Institute/RHUL (UK)
JINR
Karlsruhe University (Germany)
KEK (Japan)
LAL / Orsay (France)
LAPP / ESIA (France)
NIKHEF/Amsterdam (Netherland)
NCP (Pakistan)
North-West. Univ. Illinois (USA)
Patras University (Greece)
Polytech. Univ. of Catalonia (Spain)
PSI (Switzerland)
RAL (UK)
RRCAT / Indore (India)
SLAC (USA)
Sincrotrone Trieste/ELETTRA (Italy)
Thrace University (Greece)
Tsinghua University (China)
University of Oslo (Norway)
University of Vigo (Spain)
Uppsala University (Sweden)
UCSC SCIPP (USA)

CLIC Layout at 3 TeV

Drive Beam Generation

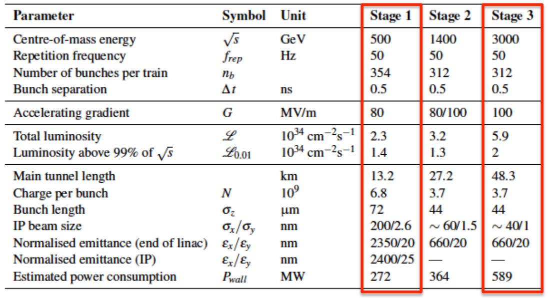


CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
🟥 dump

Main Beam Generation Complex

Possible CLIC stages studied

Table 1: Parameters for the CLIC energy stages of scenario A.



Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1400	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		354	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	80	80/100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	2.3	3.2	5.9
Luminosity above 99% of $\sqrt{s}$	$\mathscr{L}_{0.01}$	10^{34} cm^{-2}s^{-1}	1.4	1.3	2
Main tunnel length		km	13.2	27.2	48.3
Charge per bunch	N	10^9	6.8	3.7	3.7
Bunch length	σ_z	µm	72	44	44
IP beam size	σ_x/σ_y	nm	200/2.6	∼ 60/1.5	∼ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	2350/20	660/20	660/20
Normalised emittance (IP)	$\varepsilon_x/\varepsilon_y$	nm	2400/25	—	—
Estimated power consumption	P_{wall}	MW	272	364	589

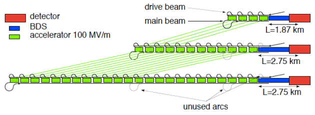
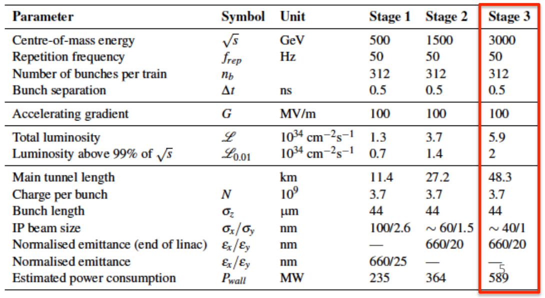


Fig. 3.6: Simplified upgrade scheme for CLIC staging scenario B.

Table 2: Parameters for the CLIC energy stages of scenario B.

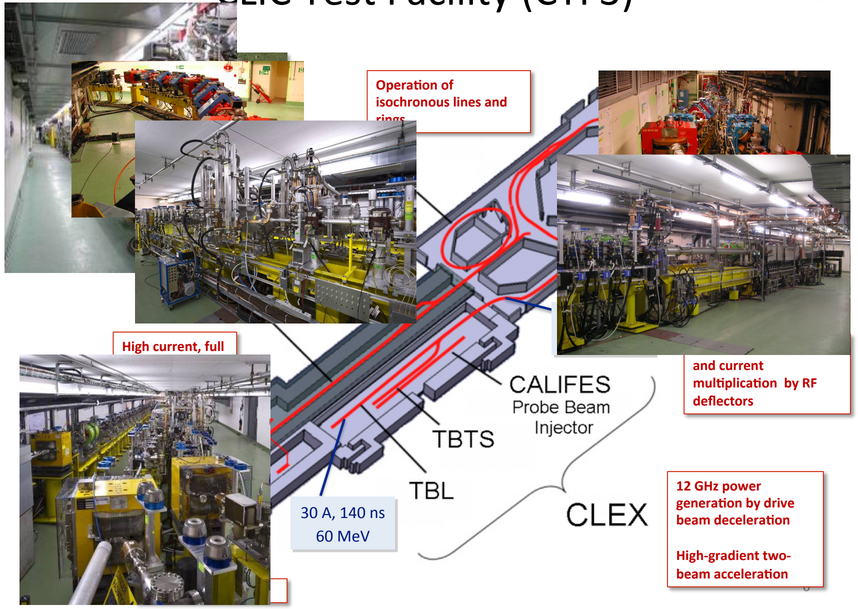


Parameter	Symbol	Unit	Stage 1	Stage 2	Stage 3
Centre-of-mass energy	$\sqrt{s}$	GeV	500	1500	3000
Repetition frequency	f_{rep}	Hz	50	50	50
Number of bunches per train	n_b		312	312	312
Bunch separation	Δt	ns	0.5	0.5	0.5
Accelerating gradient	G	MV/m	100	100	100
Total luminosity	$\mathscr{L}$	10^{34} cm^{-2}s^{-1}	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	∼ 60/1.5	∼ 40/1
Normalised emittance (end of linac)	$\varepsilon_x/\varepsilon_y$	nm	—	660/20	660/20
Normalised emittance	$\varepsilon_x/\varepsilon_y$	nm	660/25	—	—
Estimated power consumption	P_{wall}	MW	235	364	589

Key features:

- High gradient (energy/length)
- Small beams (luminosity)
- Repetition rates and bunch spacing (experimental conditions)

CLIC Test Facility (CTF3)



Operation of isochronous lines and rings

High current, full

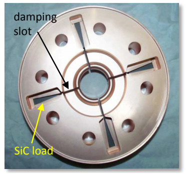
and current multiplication by RF deflectors

30 A, 140 ns
60 MeV

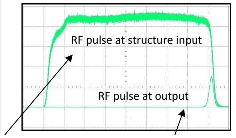
12 GHz power generation by drive beam deceleration

High-gradient two-beam acceleration

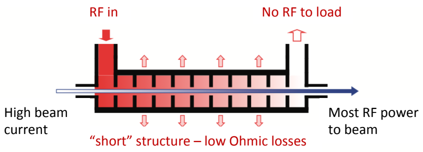
Drive Beam Generation



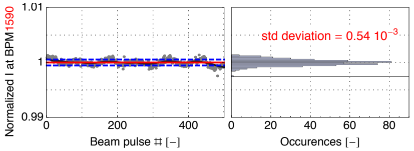
Full beam loading acceleration

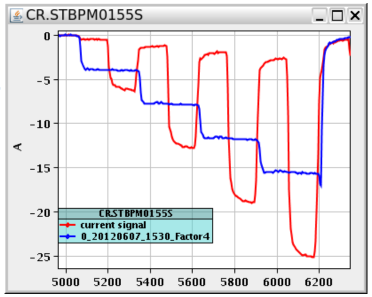


95.3% RF to beam efficiency
Stable high current acceleration
Current stability
Isochronicity, phase coding
Factor 8 current & frequency multiplication



Pulse charge measurement





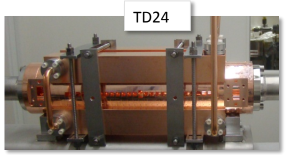
Factor 8 combination

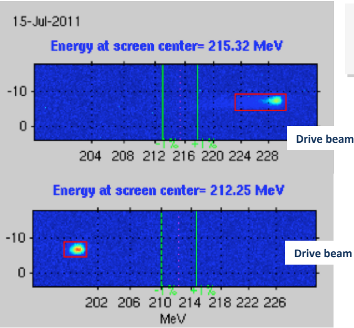
Two-Beam Acceleration

Two-Beam Acceleration demonstration in TBTS

Up to 145 MV/m measured gradient

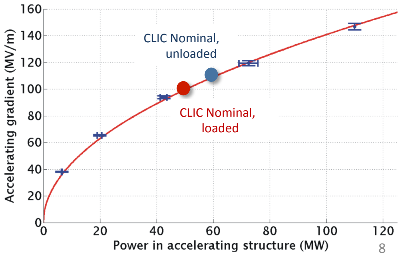
Good agreement with expectations (power vs. gradient)



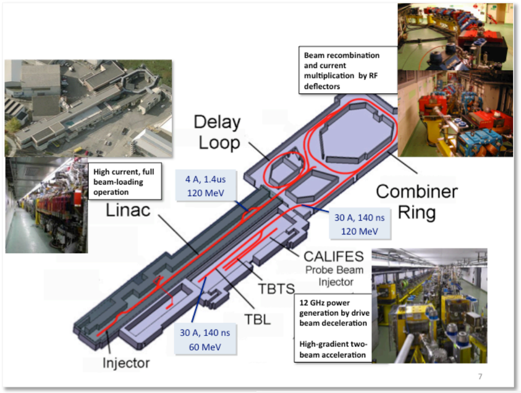


Maximum stable probe beam acceleration measured: 31 MeV

⇒ Corresponding to a gradient of **145 MV/m**



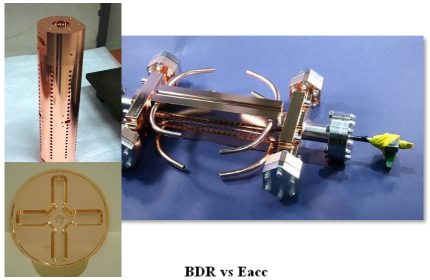
Other test-facilities



Several other test-facilities are important:
- ATF at KEK
- FACET at SLAC
- X-band test facilities at KEK and SLAC (more in progress)
- CesrTA for electron cloud studies

.... and several more for specific technical developments

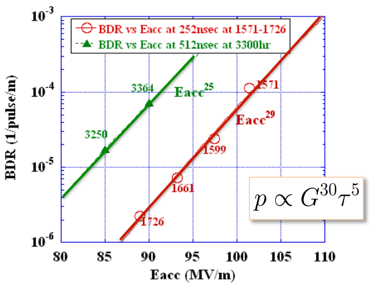
Accelerating Structures



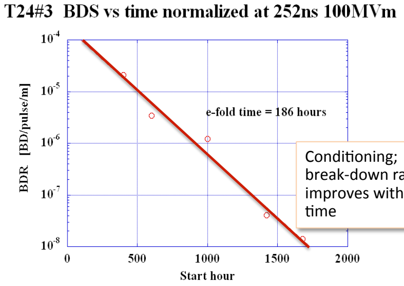
- Gradient limited by break-down, must include HOM damping

- Require <1% probability of even a single break-down in any structure
  - $p \leq 3 \times 10^{-7} m^{-1} pulse^{-1}$

- Design based on empirical constraints



$$p \propto G^{30} \tau^{5}$$



Conditioning; break-down rate improves with time

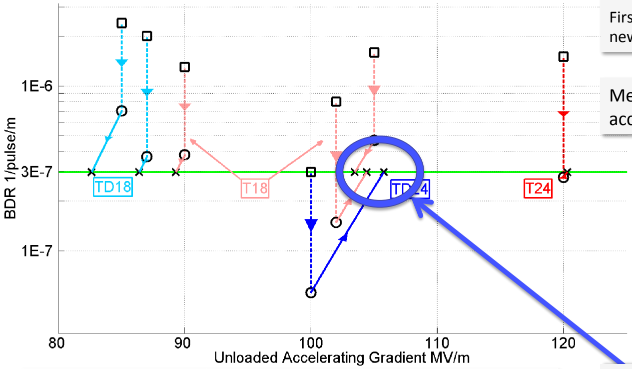
Achieved Gradient

Tests at KEK and SLAC

First cavity test ongoing at new CERN test station

Measurements scaled according to:

$$p \propto G^{30} \tau^{5}$$

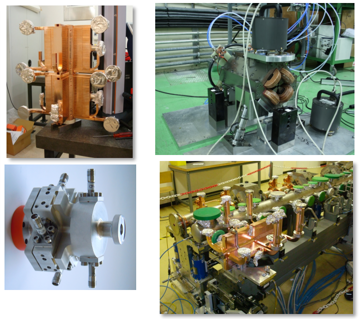


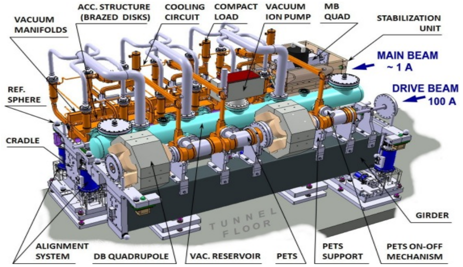
Unloaded 106 MV/m
Expected with beam loading 0-16% less

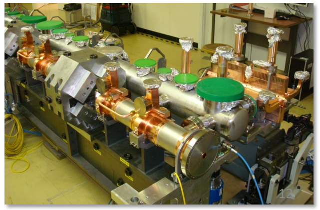
	Simple early design to get started	More efficient fully optimized structure
No damping waveguides	T18	T24
Damping waveguides	TD18	TD24 = CLIC goal

Two-Beam Modules

Next Steps:
- Complete modules being assembled in lab and for beam-tests
- Installation and test of full-fledged Two-Beam Modules in CLEX
- First module in development, installation end 2013
- Three modules in 2014-2016



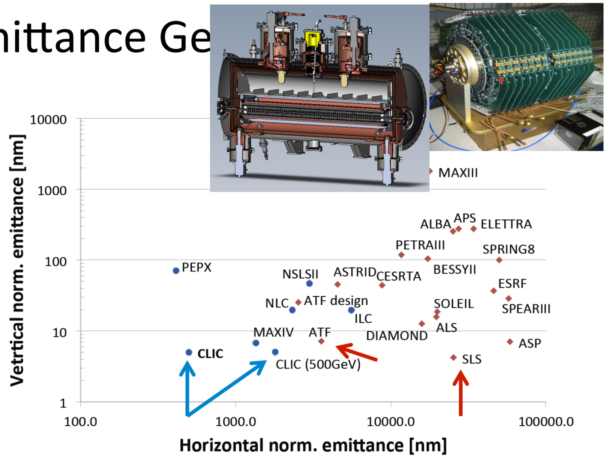




Emittance Ge

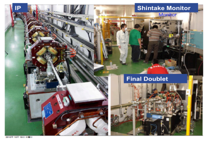
Many design issues addressed:
- lattice design
- dynamic aperture
- tolerances
- intra-beam scattering
- space charge
- wigglers
- RF system
- vacuum
- electron cloud
- kickers

In addition: wiggler and kicker developments



	ϵ_x [nm]	ϵ_y [nm]
Damping ring exit	500	5
RTML exit	600	10
main linac exit	660	20

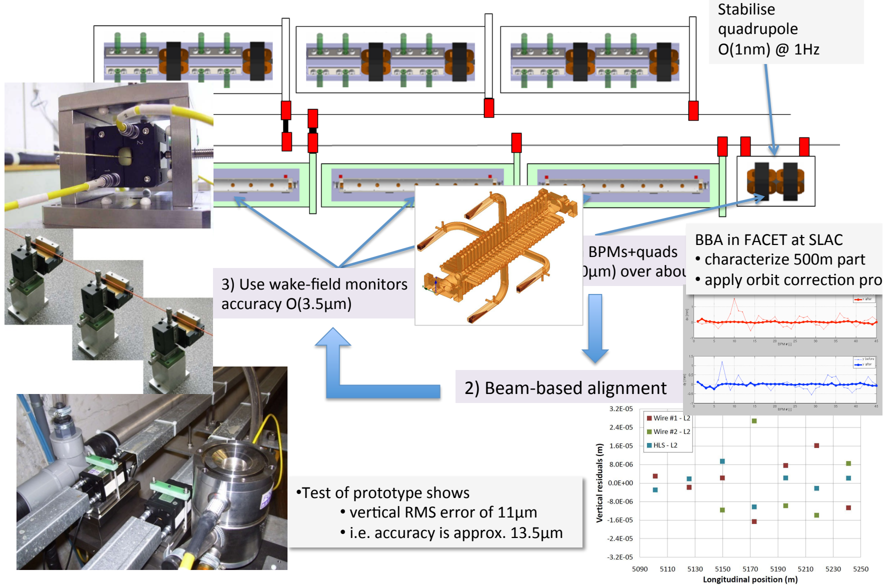
Damping ring design is consistent with target performance



CLIC @3 TeV would achieve 1/3 of nominal luminosity with ATF performance

(3800nm/15nm@4e9)

Main Linac Tolerances



Stabilise quadrupole O(1nm) @ 1Hz

3) Use wake-field monitors accuracy O(3.5μm)

BPMs+quads
)μm) over abou

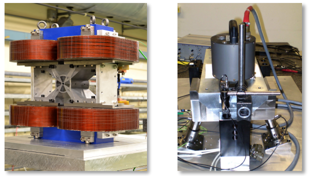
BBA in FACET at SLAC
- characterize 500m part
- apply orbit correction pro

2) Beam-based alignment

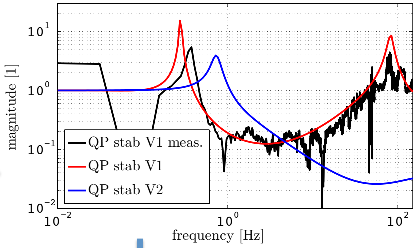
- Test of prototype shows
  - vertical RMS error of 11μm
  - i.e. accuracy is approx. 13.5μm

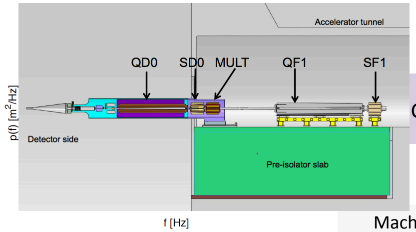
Active Stabilization

Typical quadrupole jitter tolerance O (1nm) in main linac and O(0.1nm) in final doublet



Final Focus QD0 Prototype





Code

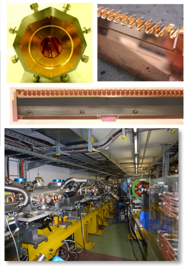
Machine model
Beam-based feedback

Luminosity achieved/lost [%]	B10
No stab.	53%/68%
Current stab.	108%/13%
Future stab.	118%/3%

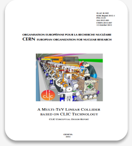
Close to/better than target

Conclusion of the CDR studies

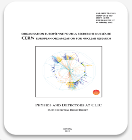
Main linac gradient	– Ongoing test close to or on target – Uncertainty from beam loading
Drive beam scheme	– Generation tested, used to accelerate test beam, deceleration as expected (13 PETs in CTF3 - figure) – Continued work on operation, reliability, losses, deceleration 2012-13
Luminosity	– Damping ring like an ambitious light source, no show stopper – Alignment system principle demonstrated – Stabilisation system developed, benchmarked, better system in pipeline – Simulations seem on or close to the target
Operation Machine Protection	– Start-up sequence defined – Most critical failure studied – First reliability studies – Low energy operation developed



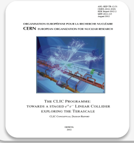
The CLIC CDR documents



Vol 1: The CLIC accelerator and site facilities (H.Schmickler)
- CLIC concept with exploration over multi-TeV energy range up to 3 TeV
- Feasibility study of CLIC parameters optimized at 3 TeV (most demanding)
- Consider also 500 GeV, and intermediate energy range
- Complete, presented in SPC in March 2012 https://edms.cern.ch/document/1234244/



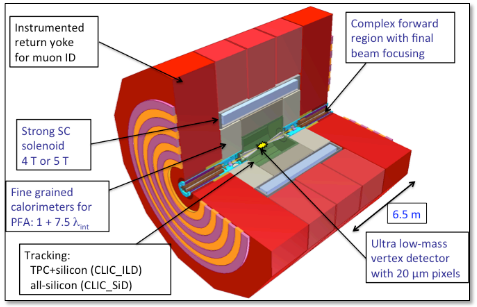
Vol 2: Physics and detectors at CLIC (L.Linssen)
- Physics at a multi-TeV CLIC machine can be measured with high precision, despite challenging background conditions
- External review procedure in October 2011
- Completed and printed, presented in SPC in December 2011 http://arxiv.org/pdf/1202.5940v1

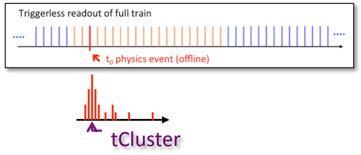


Vol 3: "CLIC study summary" (S.Stapnes)
- Summary and available for the European Strategy process, including possible implementation stages for a CLIC machine as well as costing and cost-drives
- Proposing objectives and work plan of post CDR phase (2012-16)
- Completed and printed, submitted for the European Strategy Open Meeting in September http://arxiv.org/pdf/1209.2543v1

In addition a shorter overview document was submitted as input to the European Strategy update, available at: http://arxiv.org/pdf/1208.1402v1

CLIC Physics and Detector studies





See talk of Juan Fuster later

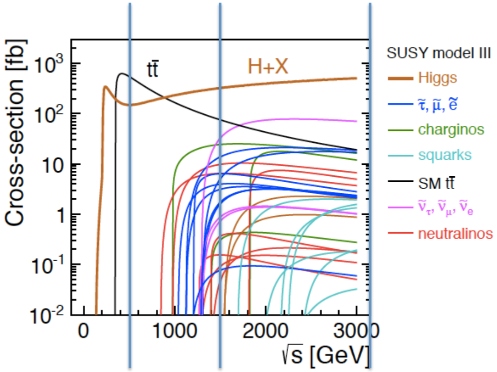
- Detailed GEANT 4 simulation
  - Consider in particular pair background and γγ-processes
- Studied using full reconstruction with background
  - Make full use of timing and fine granularity to reconstruct the physics objects with very high precision
- Have verified that the CLIC bunch and timing structures are fully compatible with high precession e+e- physics
- Studies at a range of CM energies from 350 to 3000 GeV (SM, Higgs, BSM)

CLIC physics potential

LHC complementarity at the energy frontier:
- How do we build the optimal machine given a physics scenario (partly seen at LHC ?)

Examples highlighted in the CDR:
- Higgs physics (SM and non-SM)
- Top
- SUSY
- Higgs strong interactions
- New Z' sector
- Contact interactions
- Extra dimensions

Detailed studies at 350, 500, 1400, 1500 and 3000 GeV for these processes



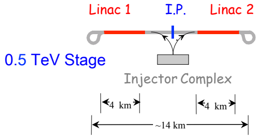
Stage 1: ~500 (350) GeV => Higgs and top physics
Stage 2: ~1.5 TeV => ttH, ννHH + New Physics (lower mass scale)
Stage 3: ~3 TeV => New Physics (higher mass scale)

CLIC Implementation – in stages?

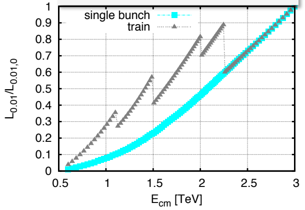
CLIC two-beam scheme compatible with energy staging to provide the optimal machine for a large energy range

Lower energy machine can run most of the time during the construction of the next stage.

Physics results will determine the energies of the stages



Need to operate at lower than nominal energy



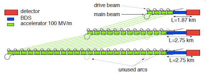
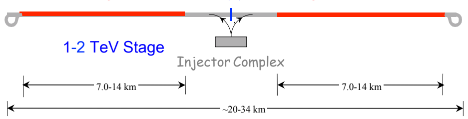
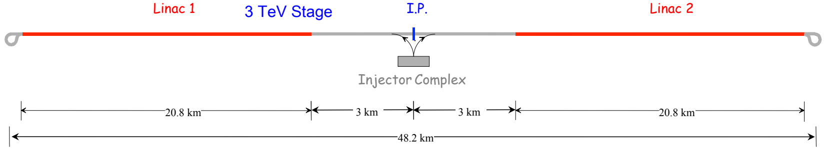
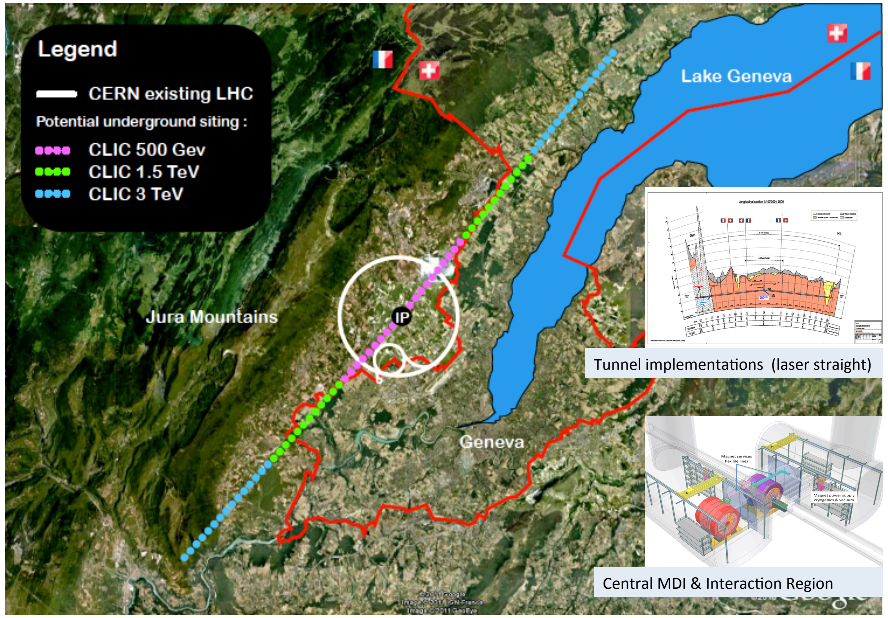


Fig. 3.6: Simplified upgrade scheme for CLIC staging scenario B.





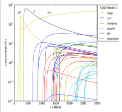
CLIC near CERN



Tunnel implementations (laser straight)

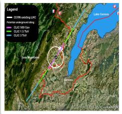
Central MDI & Interaction Region

Implementation issues



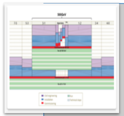
Physics - how do we build the optimal machine given a physics scenario (partly seen at LHC ?):

Understand the benefits of running close to thresholds versus at highest energy, and distribution of luminosities as function of energy



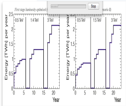
Construction scenario (and approval scenario):

Explore how we in practice will do the tunneling and productions/ installation/movement of parts in a multistage approach ?
Environmental impact study



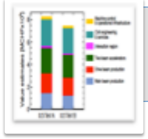
Timescale/lifecycle for project re-defined: Buildup of drive beam (CLIC zero), stage one – physics, more stages/extensions

Parameters: energy steps and scans, inst. and int. luminosities, commissioning and lum. ramp up times.



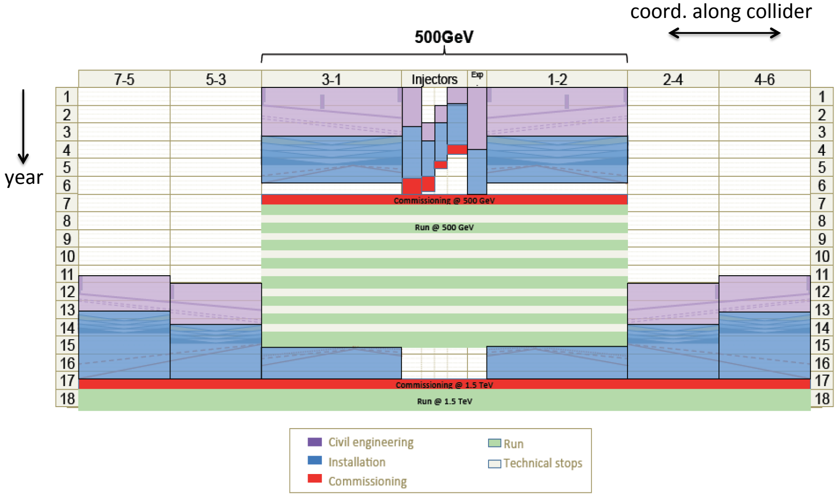
Power and energy development.

Have started to work on energy estimates (not only max power at max luminosity and the highest energy) based on running scenarios and power on/off/standby estimates



Costs - Initial machine plus energy upgrade: External cost review 21-22.2.2012, costs discussed in volume 3 of the CDR

Schedule first two stages



Possible luminosity examples

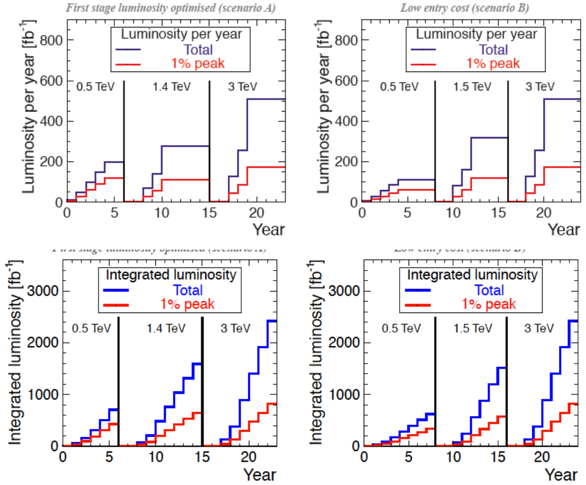


Fig. 5.2: Integrated luminosity in the scenarios optimised for luminosity in the first energy stage (left) and optimised for entry costs (right). Years are counted from the start of beam commissioning. These figures include luminosity ramp-up of four years (5%, 25%, 50%, 75%) in the first stage and two years (25%, 50%) in subsequent stages.

Based on 200 days/year at 50% efficiency (accelerator + data taking combined)

Target figures: >600 fb^{-1} at first stage, 1.5 ab^{-1} at second stage, 2 ab^{-1} at third stage

Power/energy consumption

Considering 150 days per year of normal operation at nominal power and a luminosity ramp-up in the early years at each stage of collision energy, the development of yearly energy consumption can be sketched.

Re-optimize parts
    Reduced current density in normal-conducting magnets
    Reduction of heat loads to HVAC
    Re-optimization of accelerating gradient with different objective function
Efficiency
    Grid-to-RF power conversion
    Permanent or super-ferric superconducting magnets
Energy management
    Low-power configurations in case of beam interruption
    Modulation of scheduled operation to match electricity demand: Seasonal and Daily
    Power quality specifications
Waste heat recovery
    Possibilities of heat rejection at higher temperature
    Waste heat valorization by concomitant needs, e.g. residential heating, absorption cooling

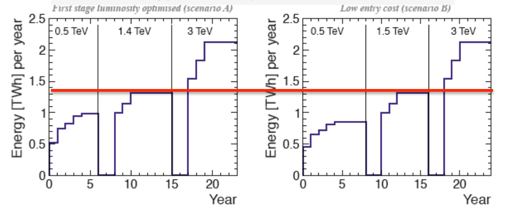
Beyond:
Scale with inst. luminosity – i.e. running at the very end of the project lifetime might be power limited and require more time.

Staging scenario	$\sqrt{s}$ (TeV)	$\mathcal{L}_{1\%}$ (cm^{-2}s^{-1})	$W_{main\ beam}$ (MW)	$P_{electric}$ (MW)
A	0.5	$1.4 \cdot 10^{34}$	9.6	272
	1.4	$1.3 \cdot 10^{34}$	12.9	364
	3.0	$2.0 \cdot 10^{34}$	27.7	589
B	0.5	$7.0 \cdot 10^{33}$	4.6	235
	1.5	$1.4 \cdot 10^{34}$	13.9	364
	3.0	$2.0 \cdot 10^{34}$	27.7	589

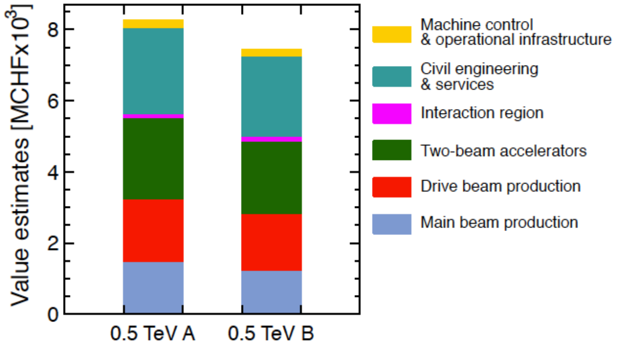
Table 5.2: Residual power without beams for staging scenarios A and B.

Staging scenario	$\sqrt{s}$ (TeV)	$P_{waiting\ for\ beam}$ (MW)	$P_{shutdown}$ (MW)
A	0.5	168	37
	1.4	190	42
	3.0	268	58
B	0.5	167	35
	1.5	190	42
	3.0	268	58

CERN energy consumption 2012: 1.35 TWh



Costs



First to second stage: 4 MCHF/GeV (i.e. initial costs are very significant)

Caveats:
    Uncertainties 20-25%
    Possible savings around 10%
    However – first stage not optimised (work for next phase), parameters largely defined for 3 TeV final stage

---

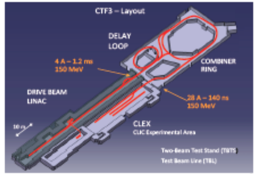
The CLIC concept have been developed over many years. During the last 4-5 years there has been a concerted effort to prepare a **Conceptual Design Report**, to be ready when LHC data-taking was expected to be well underway (part of the European Strategy as formulated in 2006)

Focus has been on addressing all key critical issues for the concept, as well developing a coherent implementation model, and associated detector and physics studies to illustrate the physics performance

CLIC project time-line

2012-16 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.



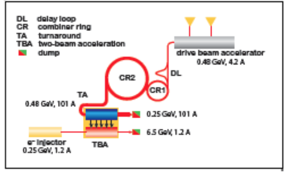
2016-17 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects), take decisions about next project(s) at the Energy Frontier.

2017-22 Preparation Phase

Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

Prepare detailed Technical Proposals for the detector-systems.



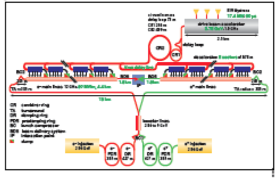
2022-23 Construction Start

Ready for full construction and main tunnel excavation.

2023-2030 Construction Phase

Stage 1 construction of a 500 GeV CLIC, in parallel with detector construction.

Preparation for implementation of further stages.



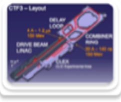
2030 Commissioning

From 2030, becoming ready for data-taking as the LHC programme reaches completion.

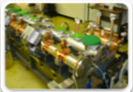
Project Implementation Plan 2012-16

Define the scope, strategy and cost of the project implementation
LHC data crucial – also at nominal energy
Costs, power, scheduling, site, etc

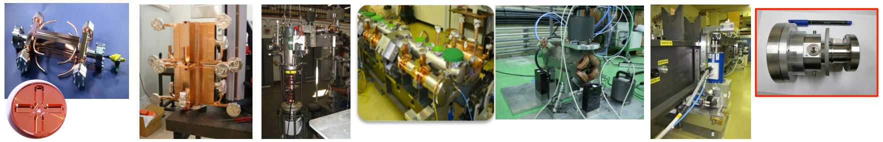
Define and keep an up-to-date optimized overall baseline design that can achieve the scope within a reasonable schedule, budget and risk.
Overall design and system optimisation, activities across all parts of the machine from sources to beam-dump, links to technical developments and system verification activities



Identify and carry out system tests and programs to address the key performance and operation goals and mitigate risks associated to the project implementation.
Priorities are the measurements in: CTF3+, ATF, FACET and related to the CLIC Drive Beam Injector studies, addressing the issues of drive-beam stability, RF power generation and two beam acceleration, as well as beam delivery system studies.

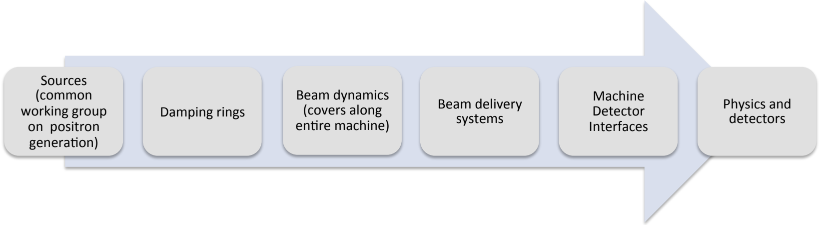


Develop the technical design basis. i.e. move toward a technical design for crucial items of the machine – X-band as well as all other parts.
Priorities are the modulators/klystrons, module/structure development including significantly more testing facilities and alignment/stability



LC common studies

Many common problems and solutions even though the basic core acceleration methods differ, and the parameters to be achieved by the systems below differ – in some cases leading to different solutions



Sources (common working group on positron generation)

Damping rings

Beam dynamics (covers along entire machine)

Beam delivery systems

Machine Detector Interfaces

Physics and detectors

In addition common working groups on: Cost and Schedule, Civil Engineering and Conventional Facilities – and a General Issues Working Group

Three general actions:

- Move (for some of these groups) towards more genuine combined working group in order to optimize resources and maximize exchange of experiences
- Further development of common work in the area of Detector and Physics
- Increased help across the borders of ILC/CLIC wrt implementation planning for the two projects – inside a common overall organization

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Summary

- Technical progress within the CLIC accelerator and detector studies very significant and results have now been documented in the CDR volumes:
  - Substantial work on a staged implementation also documented
  - CDR process finished and focus is now on next phase(s)
- Plans for 2012-16 well defined for CLIC – with key challenges related to system specifications and performance, system tests to verify performances, technical developments of key elements, implementation studies including power and costs
  - A rebaselining of the machine stages with particular emphasis on the lower energy stages in progress, including an option of an initial klystron based stage
  - The programme combines the resources of collaborators inside the current collaboration, plus several new ones now joining. Wherever possible common work with ILC is implemented and being strengthened.
  - The work needed also in the area of Physics and Detectors being defined, many studies made in common with ILC
  - CLIC workhop planned for last week of January – more help warmly welcome: https://indico.cern.ch/conferenceDisplay.py?confId=204269
- Thanks to the CLIC collaboration for the slides and work presented – for and from the CDR and also recent presentations

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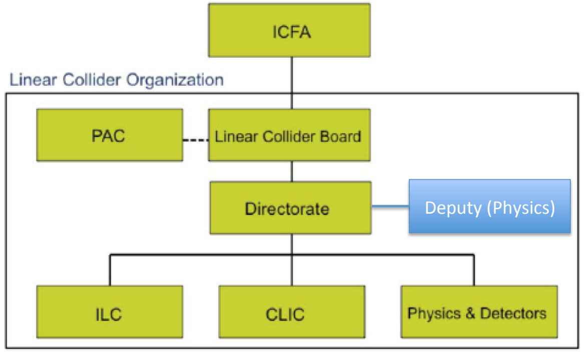
LC organisation



ICFA

Linear Collider Organization

PAC

Linear Collider Board

Directorate

Deputy (Physics)

ILC

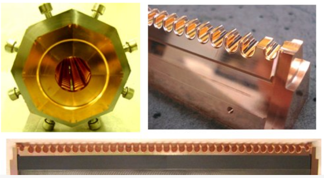
CLIC

Physics & Detectors

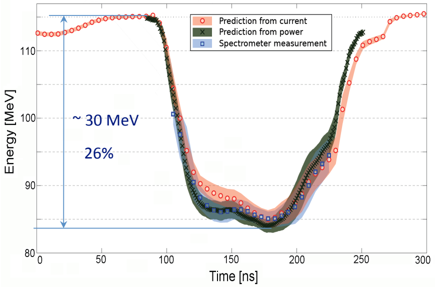
Power Production & Drive Beam Deceleration

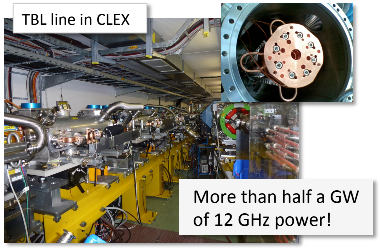
TBTS:
Power production in PETS ($P_{out} \approx$ 200MW)
Breakdown rates checked
On-off mechanism tested successfully

TBL:
13 PETS installed
Up to 21 A current transported
optics understood - no losses
Good agreement current/RF/deceleration
~ 26% deceleration
(Final goal is 40% deceleration)



Measurements at SLAC:
No breakdown last O(8 10^6 pulses)
-> P consistent with p≤10^{-7}/m/pulse





TBL line in CLEX

More than half a GW of 12 GHz power!

BDS Design and Alignment

Main design issues

- chromaticity
- non-linear effects
- synchrotron radiation
- tuning
- stability

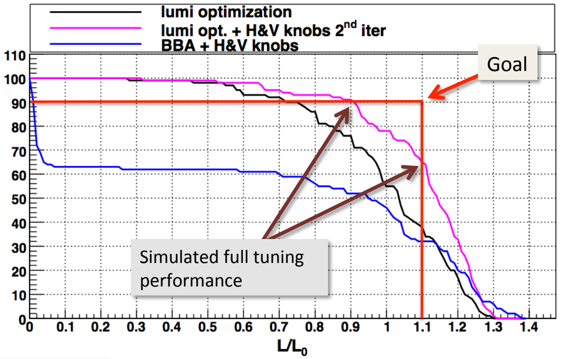
Static imperfections:

- Goal is L ≥ 110% L_0, with probability of 90%

Convergence is slow

- faster method is being developed

Probability to achieve more than L/L_0 [%]



Goal

Simulated full tuning performance

Need more complete imperfection modeling

- independent sides
- field errors
- dynamic imperfections during tuning
- realistic signals

Design is OK

Imperfection mitigation comes close to target

Test program at ATF2 at KEK

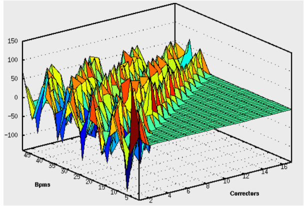
T501: BBA studies at SLAC

T501: FACET test-beam proposal to study advanced global correction schemes for future linear colliders.

CERN-SLAC collaboration where algorithms developed at CERN are tested on the SLAC linac.

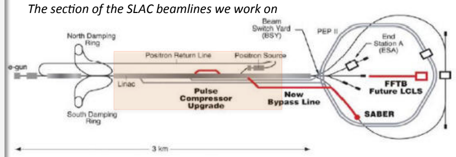
The study includes linac system identification, global orbit correction and global dispersion correction.

Successful system identification and global orbit correction has been demonstrated on a test-section of 500 m of the linac.

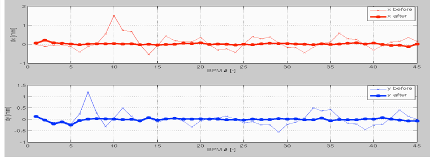


(Above) Measured Rx response matrix for the test-section of the linac (17 correctors, 48 BPMs)

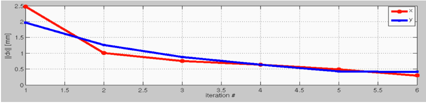
The section of the SLAC beamlines we work on



RESULT: Example of global orbit correction of a test-section of the SLC linac:



(above) Horizontal and Vertical trajectories before and after orbit correction



(above) Iterations of orbit correction: convergence of the algorithm