CLIC Status and Outlook

May 2012

Covering:

- The CLIC accelerator studies
  - Feasibility studies
  - Performance studies
  - Implementation studies
  - Conceptual Design Reports in preparation
- Briefly on the detectors at CLIC, the physics goals
- Timelines and programme for the coming years
- Summary

Current CLIC&CTF3 Collaboration

CLIC multi-lateral collaboration - 44 Institutes from 22 countries

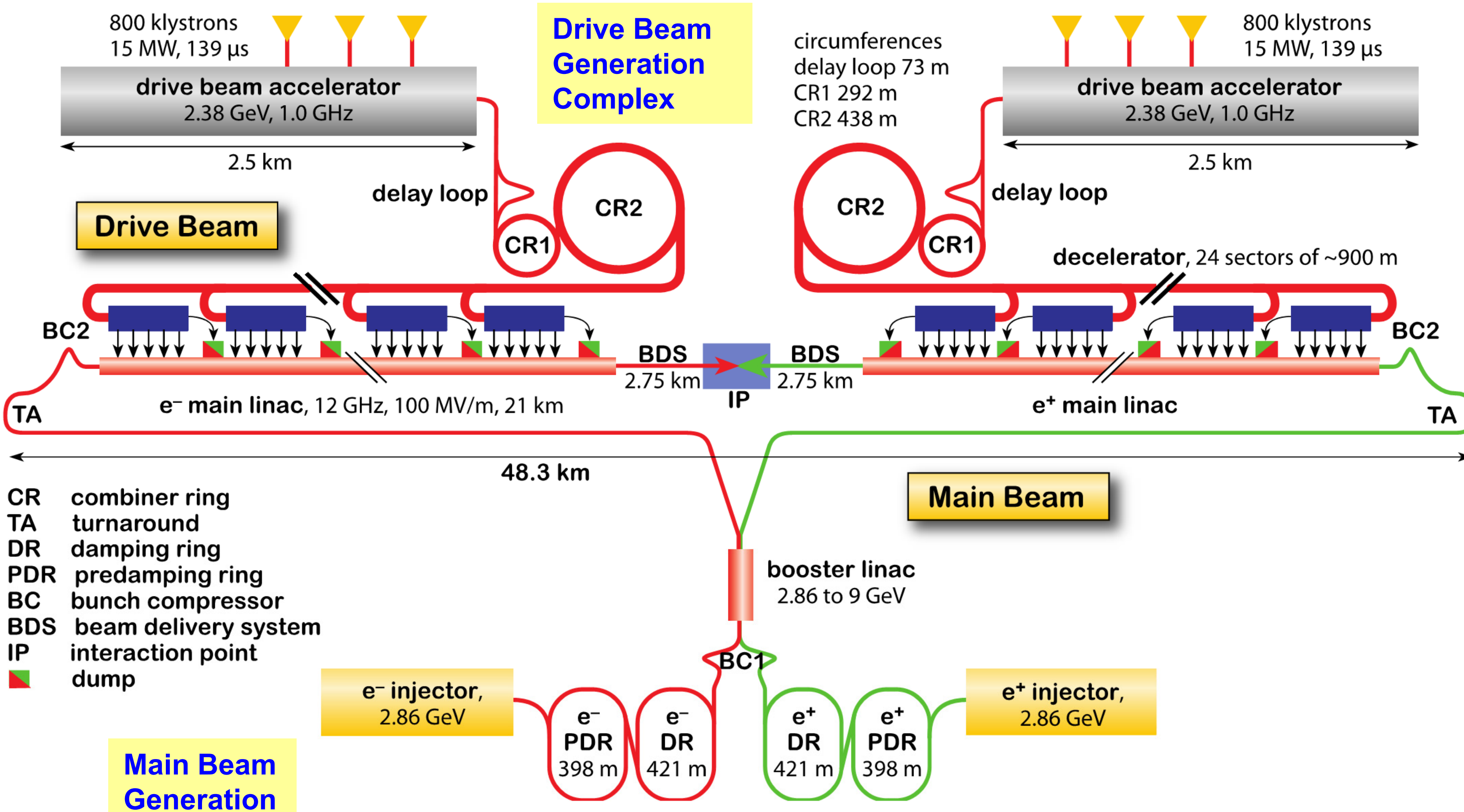
ACAS (Australia)
Aarhus University (Denmark)
Ankara University (Turkey)
Argonne National Laboratory (USA)
Athens University (Greece)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
ETH Zurich (Switzerland)
FNAL (USA)

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 (Russia)
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)

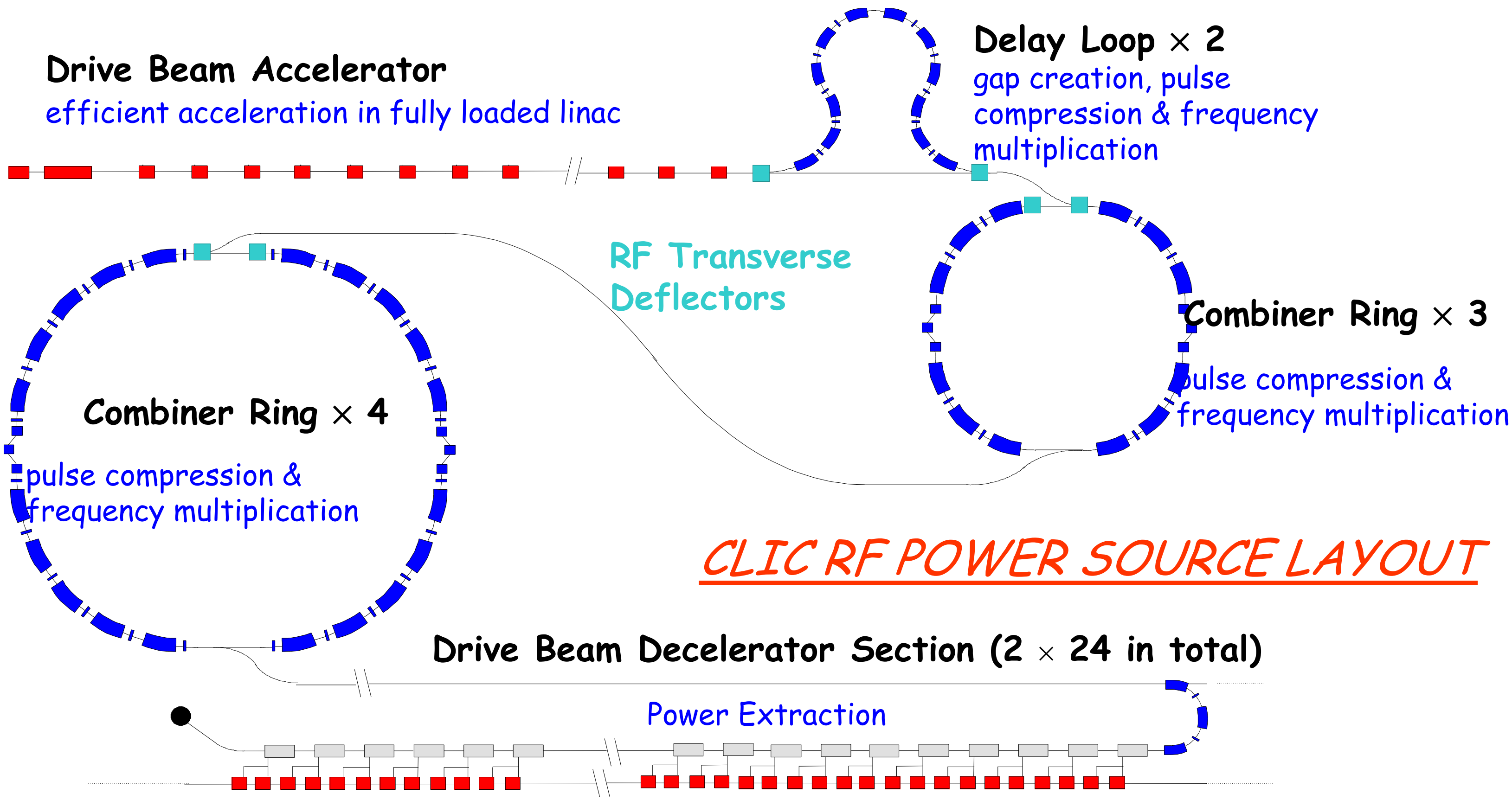
CLIC Layout at 3 TeV



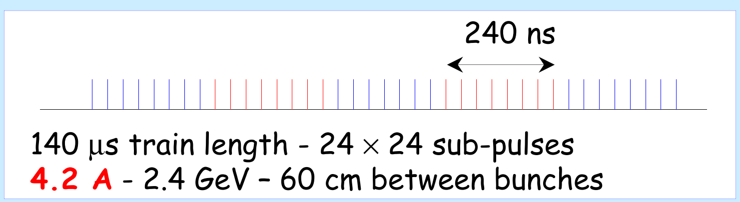
CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump

Main Beam Generation Complex

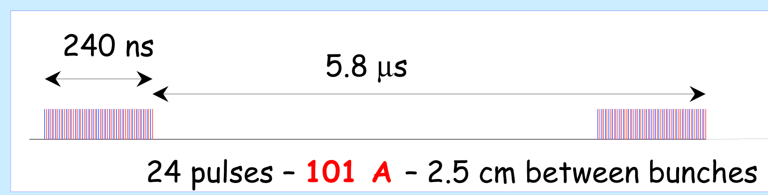
CLIC Power Source Concept



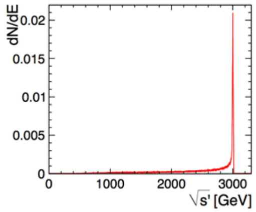
Drive beam time structure - initial



Drive beam time structure - final

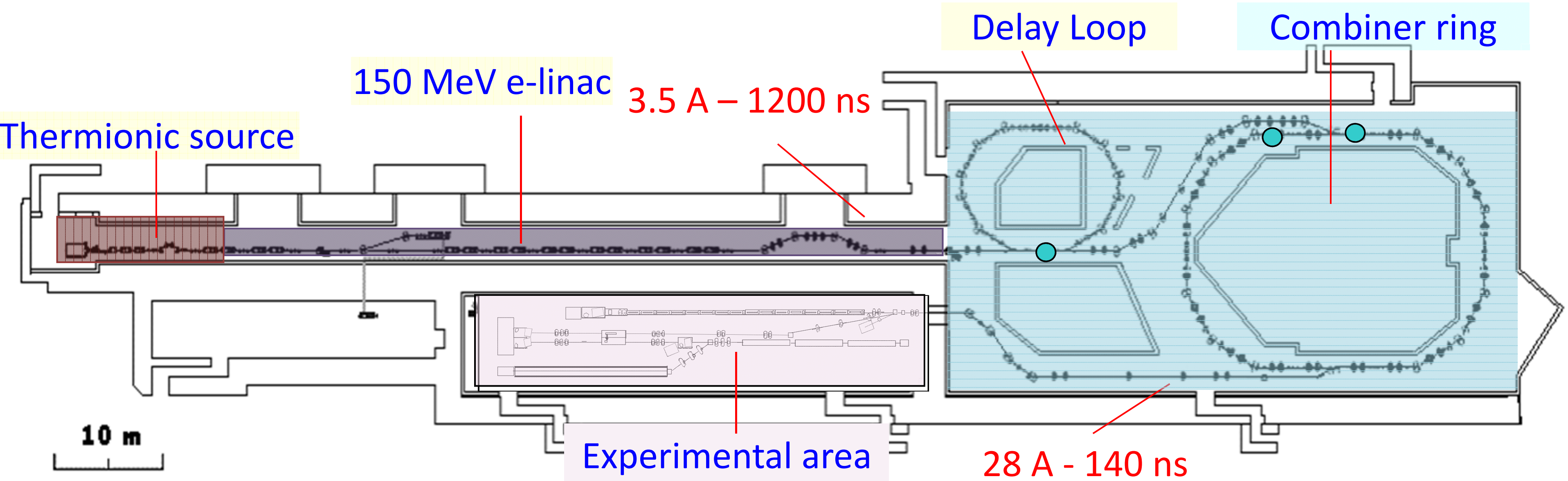


CLIC Main Parameters



parameter	symbol		
centre of mass energy	E_{cm} [GeV]	500	3000
luminosity	$\mathcal{L}$ $[10^{34}\ cm^{-2}s^{-1}]$	2.3	5.9
luminosity in peak	$\mathcal{L}_{0.01}$ $[10^{34}\ cm^{-2}s^{-1}]$	1.4	2
gradient	G [MV/m]	80	100
site length	[km]	13	48.3
charge per bunch	N $[10^9]$	6.8	3.72
bunch length	σ_z [μm]	72	44
IP beam size	σ_x/σ_y [nm]	200/2.26	40/1
norm. emittance	ϵ_x/ϵ_y [nm]	2400/25	660/20
bunches per pulse	n_b	354	312
distance between bunches	Δ_b [ns]	0.5	0.5
repetition rate	f_r [Hz]	50	50
est. power cons.	P_{wall} [MW]	271	582

CLIC Test Facility (CTF3)



parameter	unit	CLIC	CTF3
accelerated current	A	4.2	3.5
combined current	A	101	28
final energy	MeV	2400	≈ 120
accelerated pulse length	μs	140	1.2
final pulse length	ns	240	140
acceleration frequency	GHz	1	3
final bunch frequency	GHz	12	12

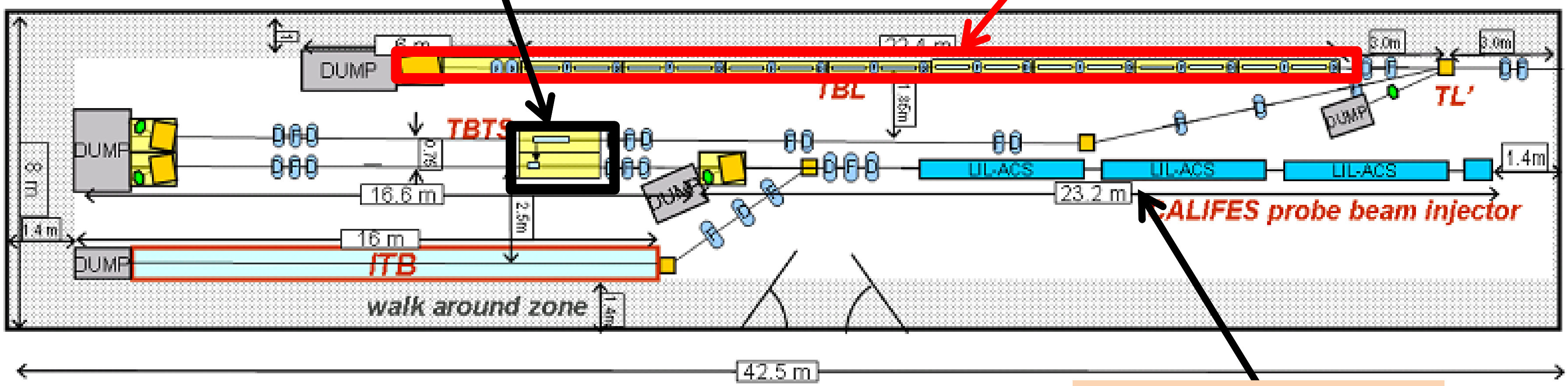
Recycled infrastructure
- made it affordable
- causes lots of headache

For detailed results see talk of R.Corsini yesterday: TUOBC01

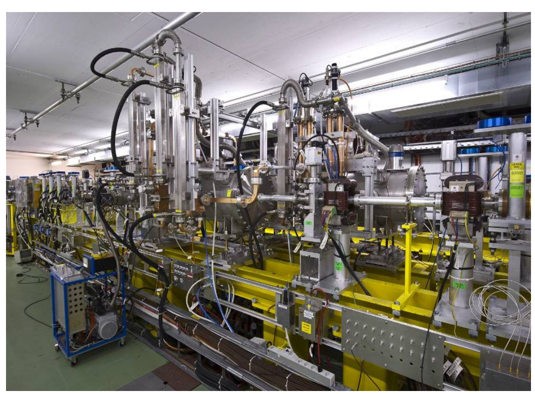
Drive Beam Deceleration and Module: CLEX

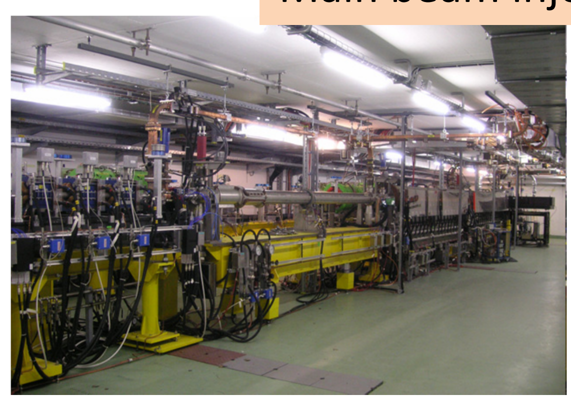
TBTS (two-beam test stand)
- power transfer to main beam
- module design

TBL (test beam line)
- drive beam stability during deceleration



Main beam injector



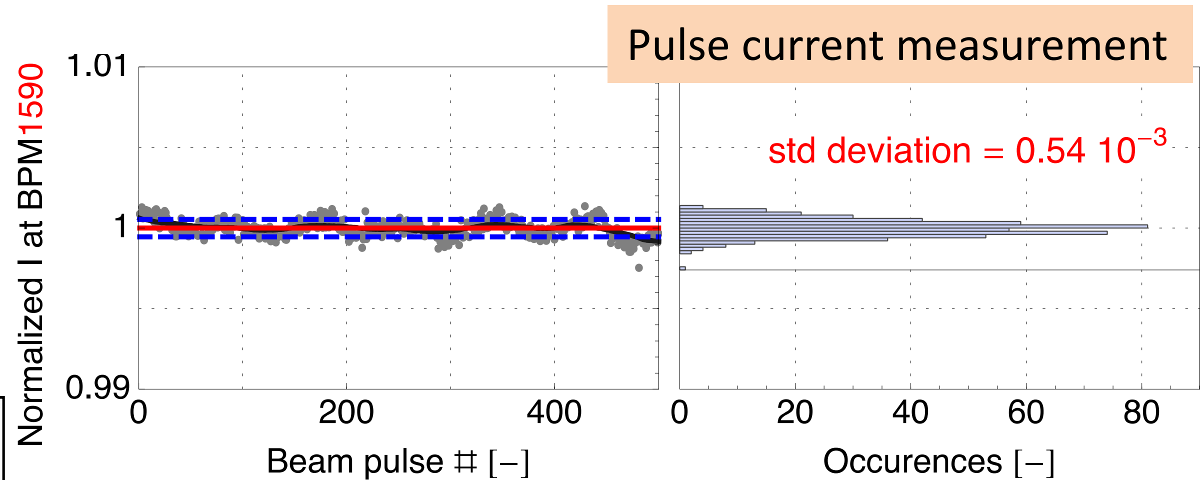


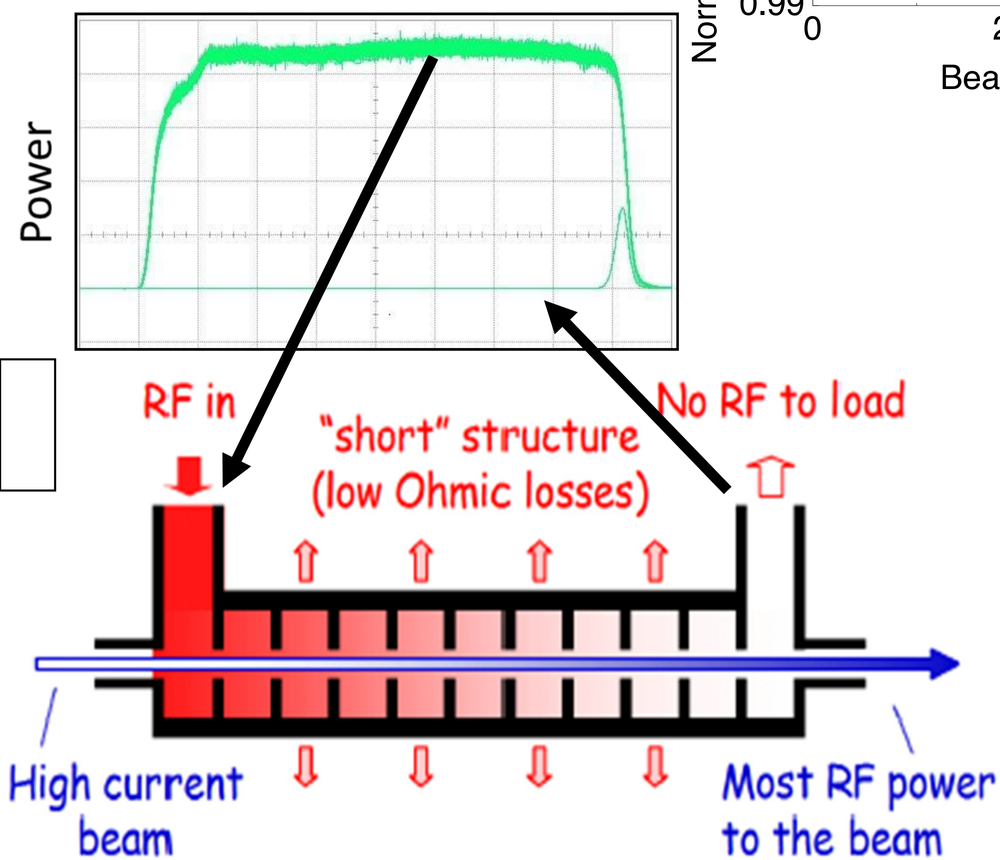
Drive Beam Linac

95.3% RF to beam efficiency

No instabilities

Phase switch works OK





Parameter	CLIC goal	CTF3 measured at end of linac
Transverse emittance	100µm	50-60µm
Pulse current	7.5e-4	5.4e-4

Drive Beam Combination

29 A reached, routinely 25A

Significant increase of transverse emittance

Current jitter increases to O(0.1%-1%)

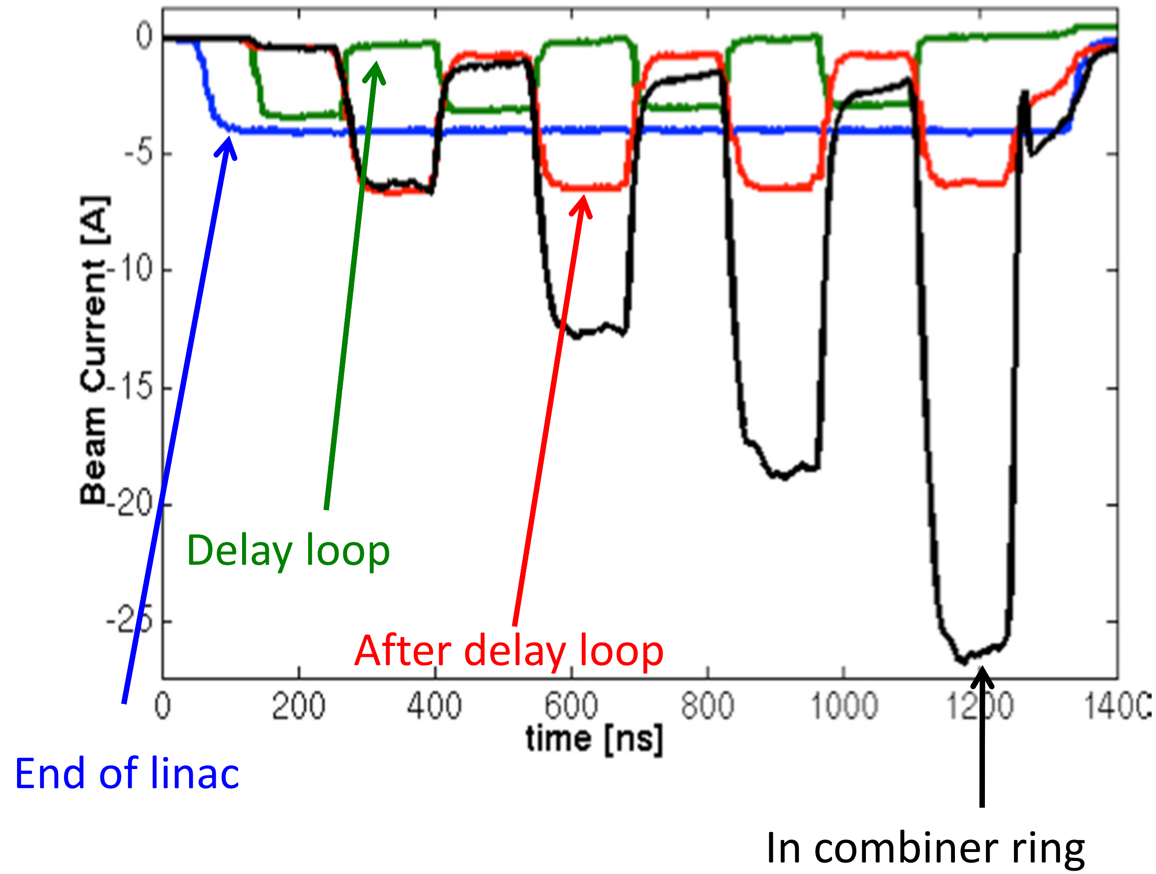
Focus has been on current:

- will now further improve beam quality

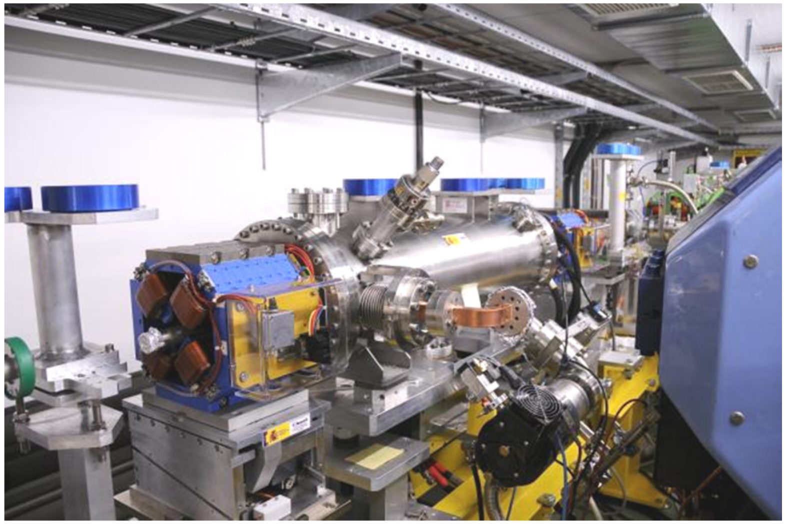
CTF3 specific issues need to be addressed and limits identified

- RF pulse compression
- Beam energy in combiner ring is 5% of that in CLIC
- Geometric emittance 20 times larger
- …

Current measurement in CTF3



TBL: Drive Beam Deceleration



9 out of 16 PETS installed

Rest will come this year

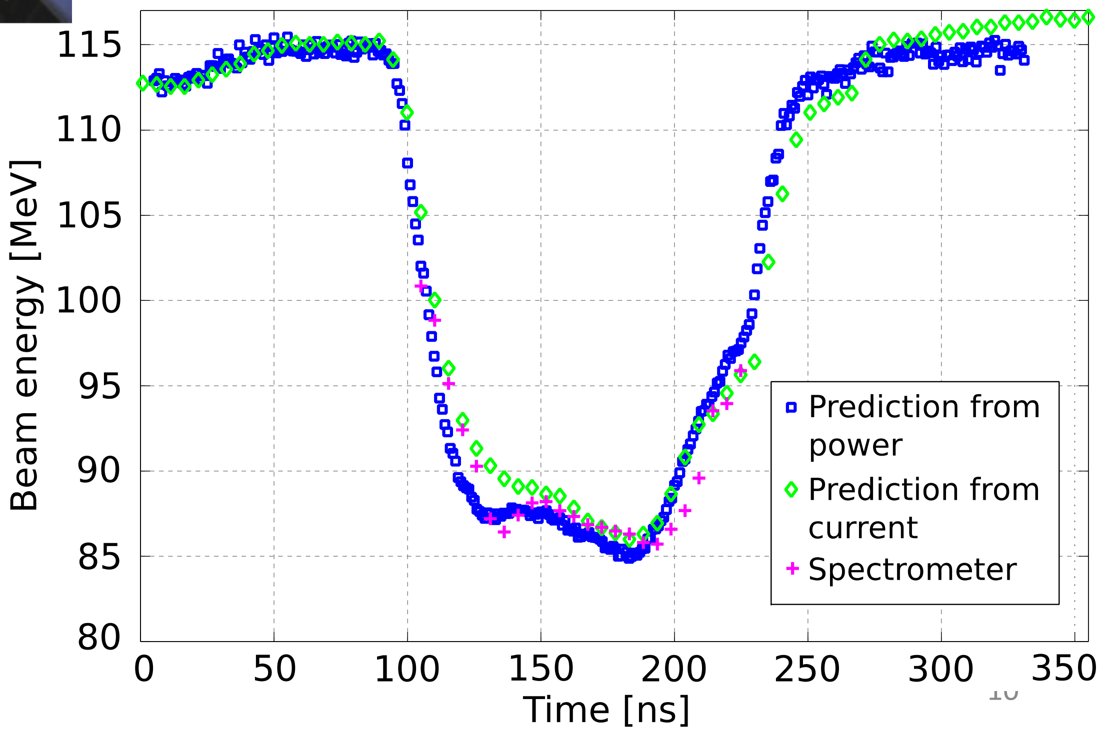
~26% deceleration

Final goal is 50% deceleration

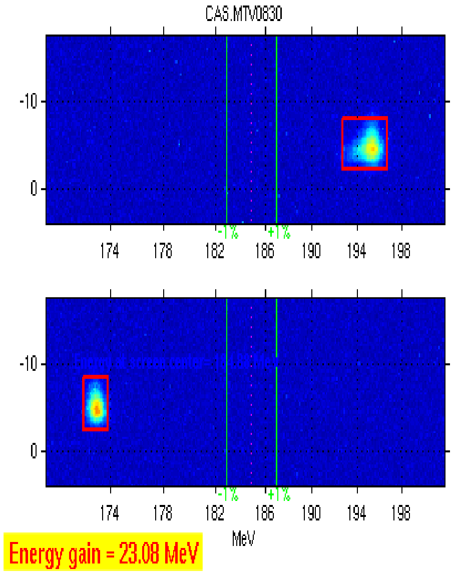
Measured in TBL:
Up to 21A current
- optics understood
- no losses in TBL

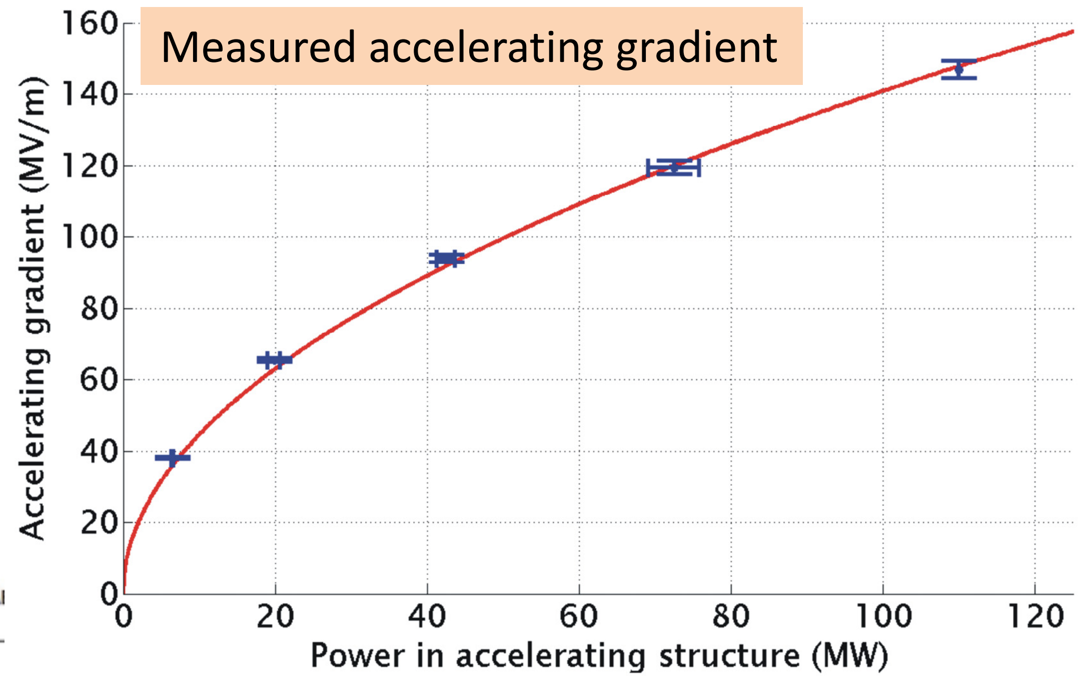
On-off mechanism verified

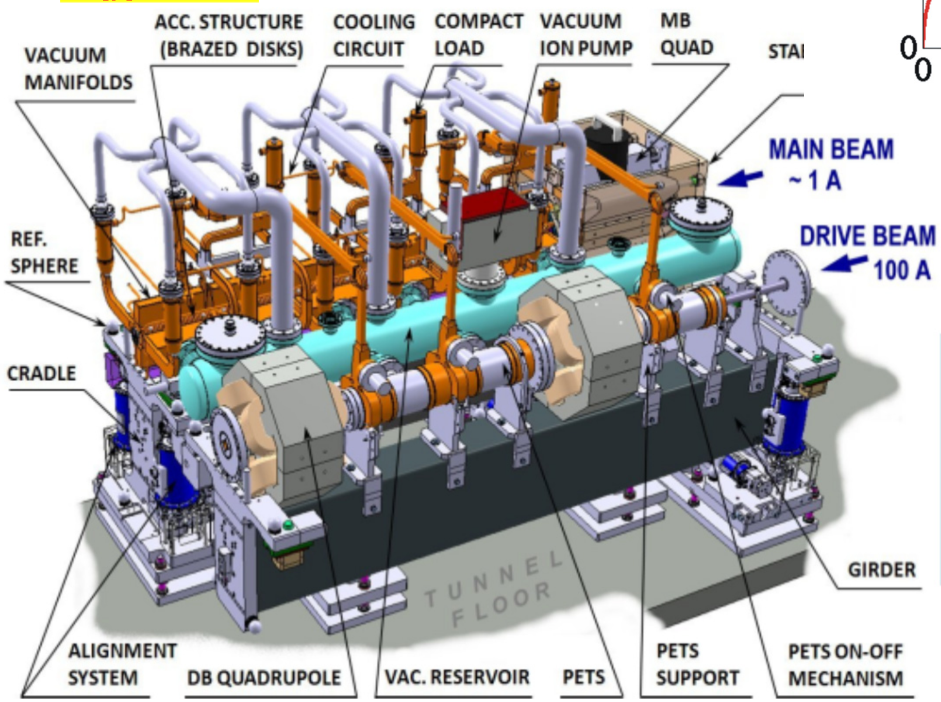
Good agreement
- power production in PETS
- beam current
- beam deceleratio



TBTS: Two Beam Acceleration



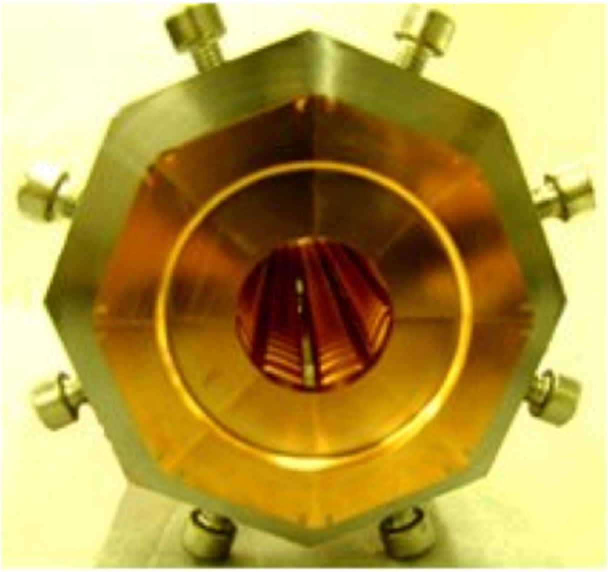


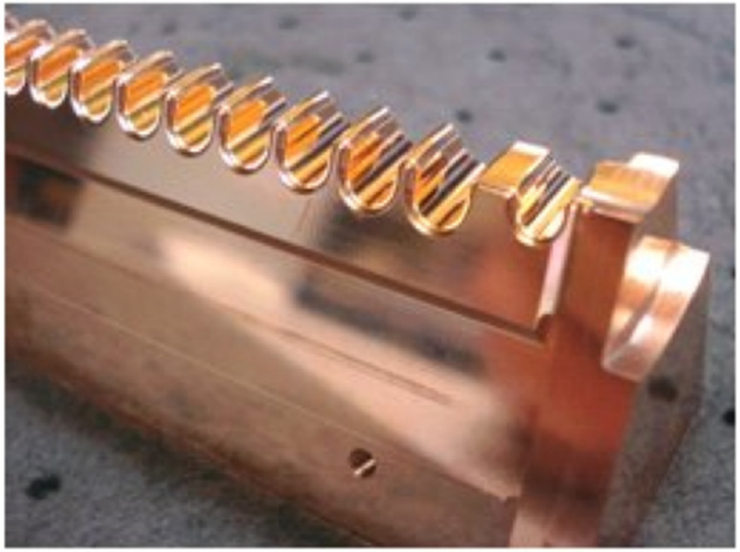


Maximum gradient
145 MV/m

Consistency between
- produced power
- drive beam current
- test beam acceleration

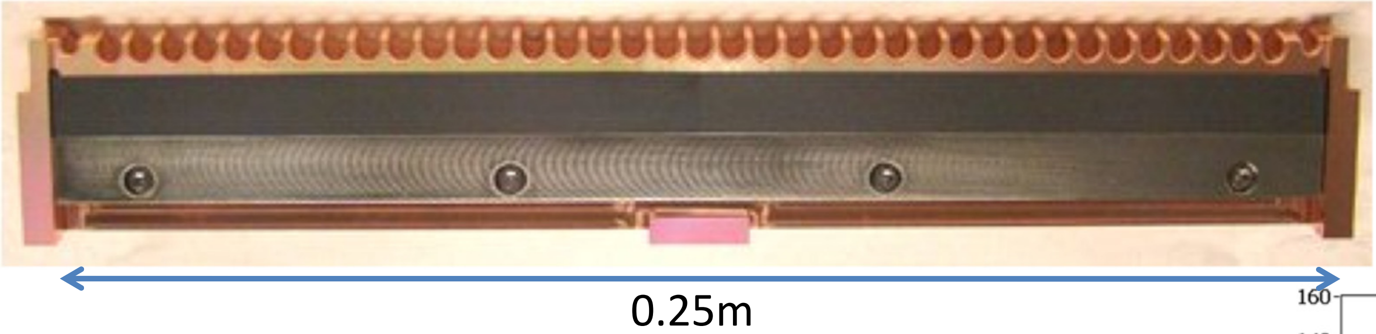
PETS





Designed with more margin than accelerating structures

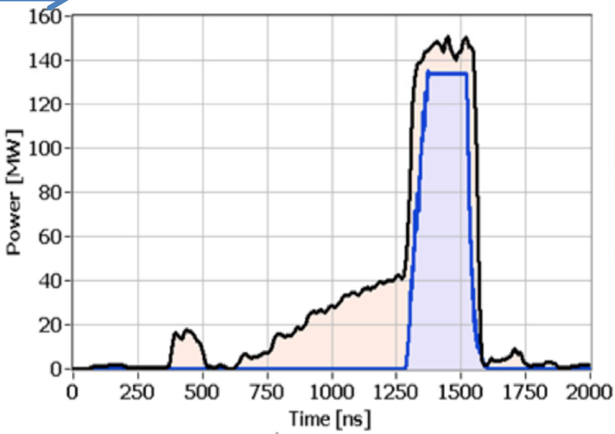
$P_{out} \approx 130MW$



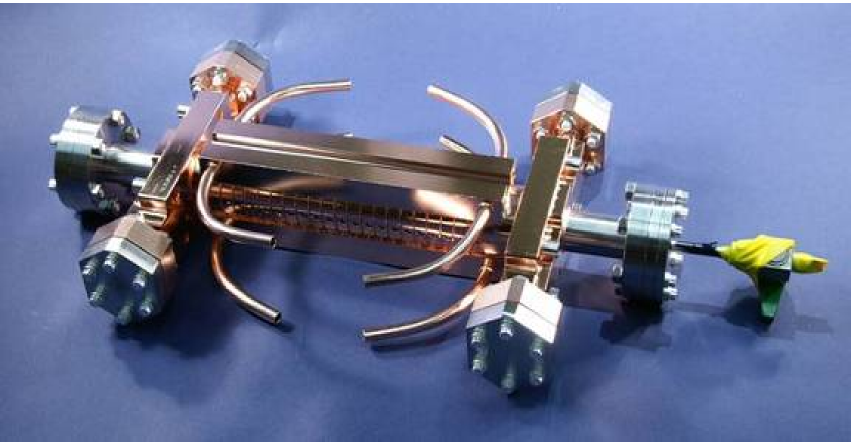
Measurements at SLAC:
No breakdown last O(8 10^6 pulses)
-> P consistent with p≤10^{-7}/m/pulse

On-off mechanism also successfully tested

Pulse used for measurement and nominal pulse (blue)

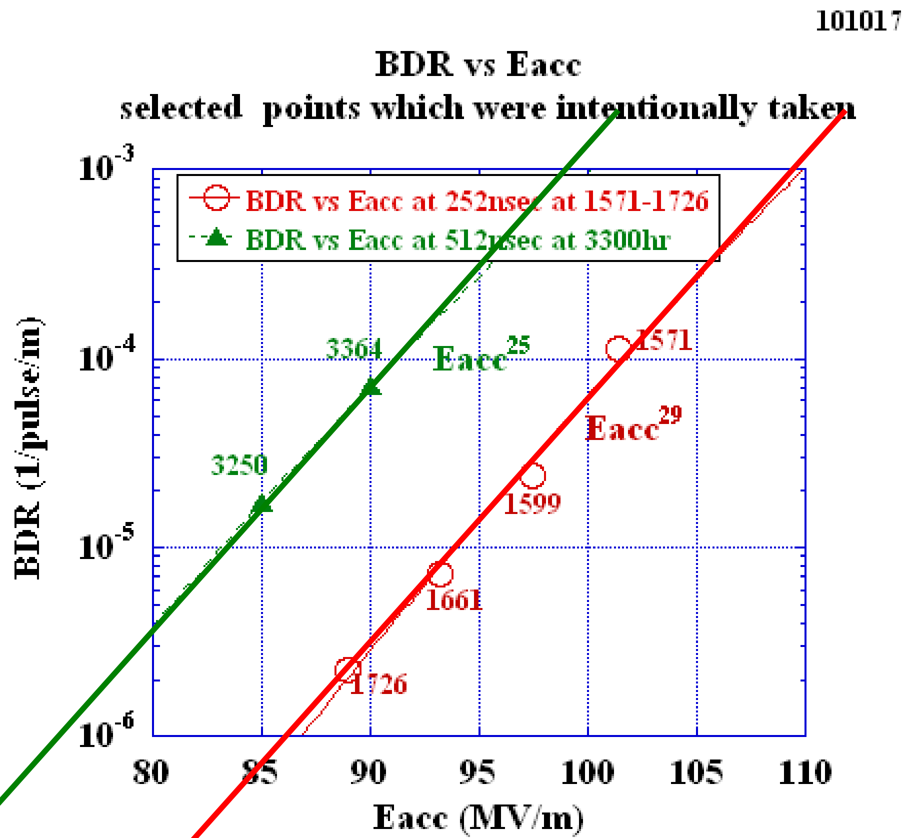


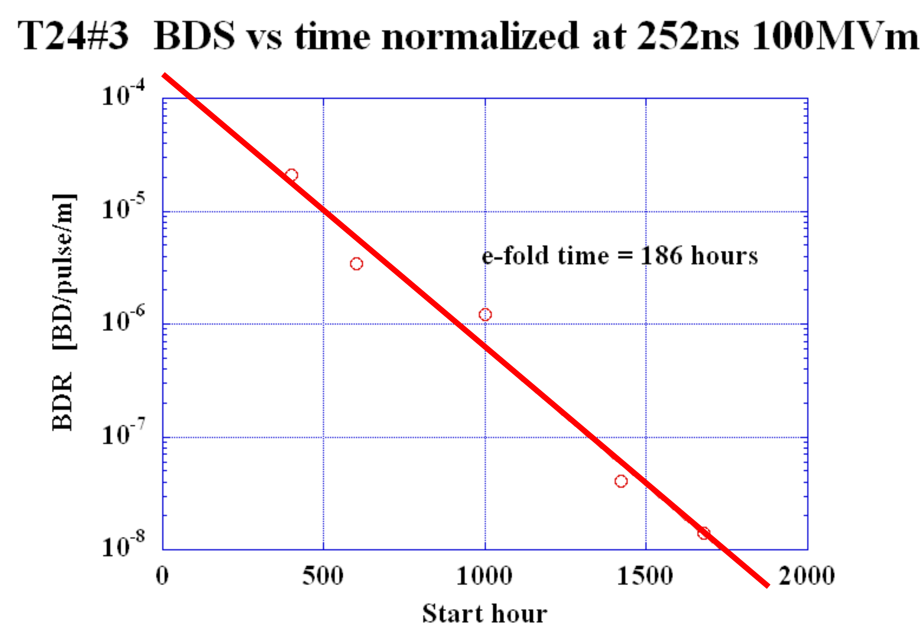
Accelerating Structure



- Require <1% probability of even a single break down in any structure
  - $p \leq 3\times10^{-7} m^{-1} pulse^{-1}$

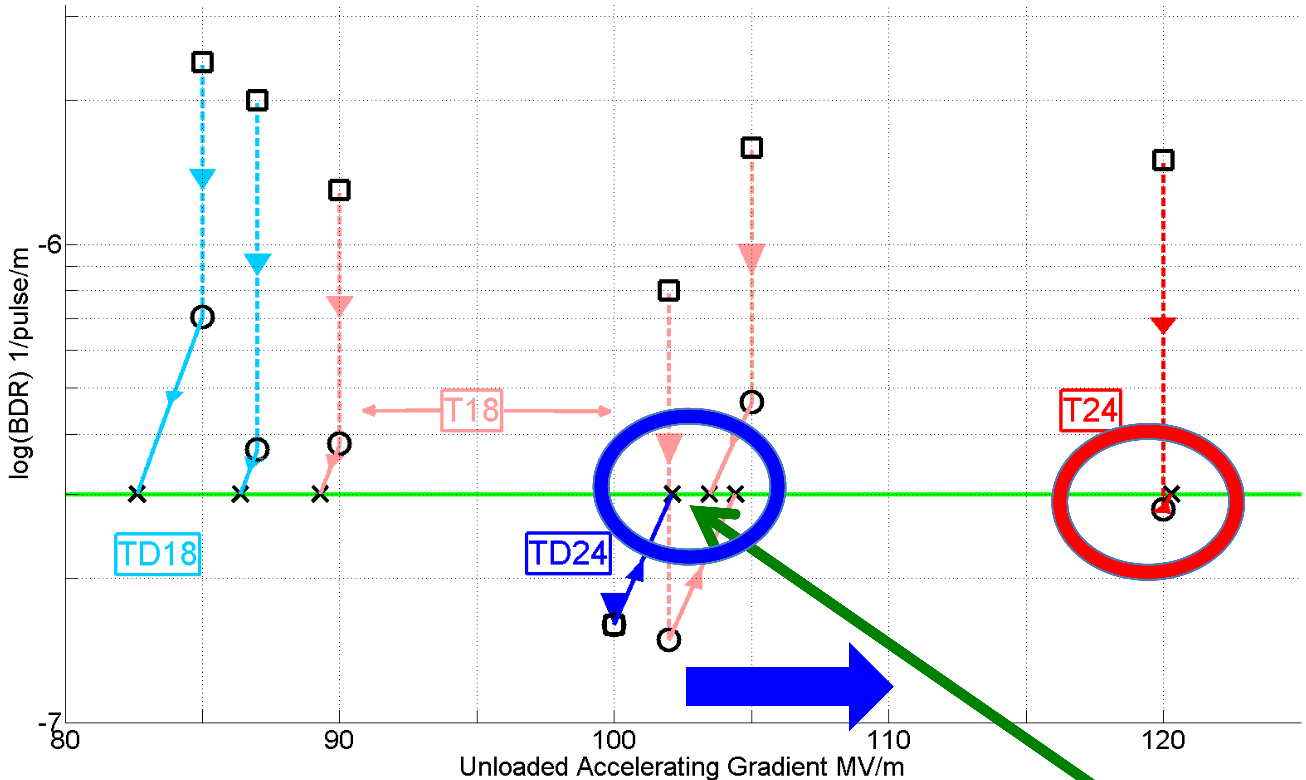
- Design based on empirical constraints





Achieved Gradient

Tests at KEK and SLAC



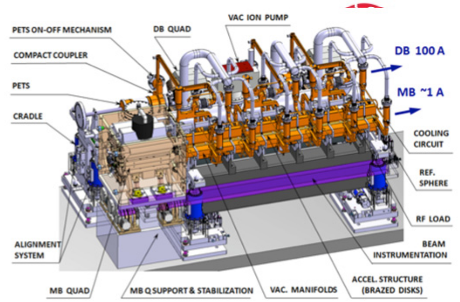
Measurements scaled according to

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

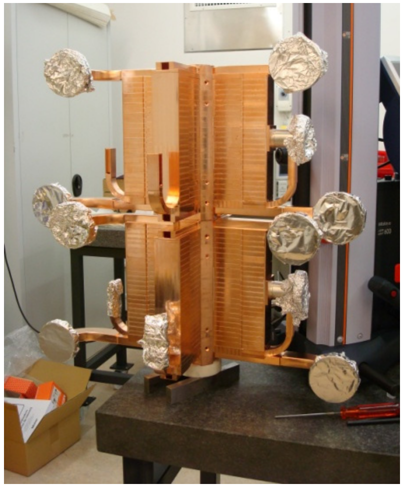
Unloaded 103MV/m
Expected with beam loading 86-103 MV/m

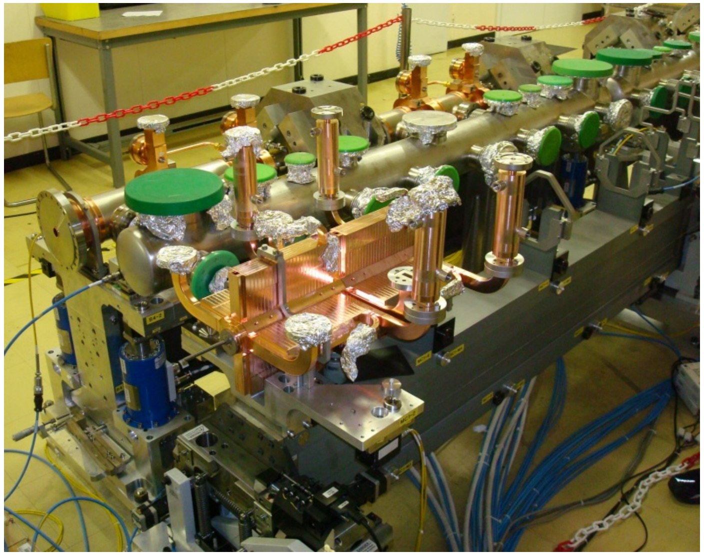
	Simple early design to get started	More efficient fully optimised structure
No damping waveguides	T18	T24
Damping waveguides	TD18	TD24 = CLIC goal

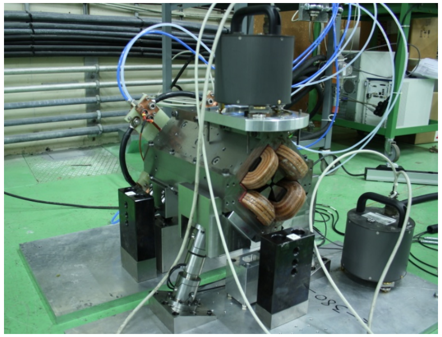
Prototype two-beam module

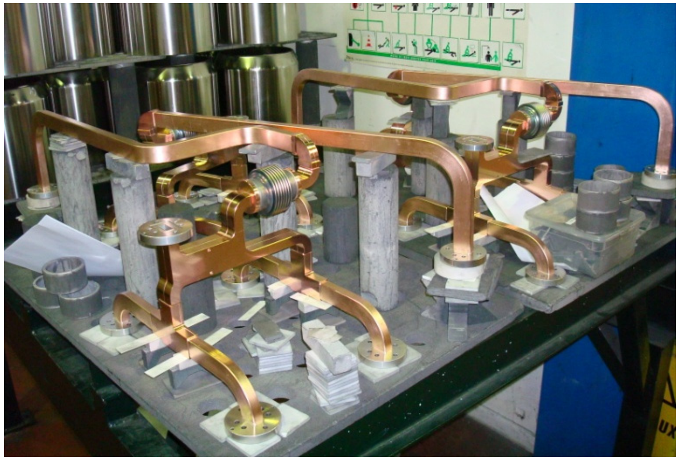


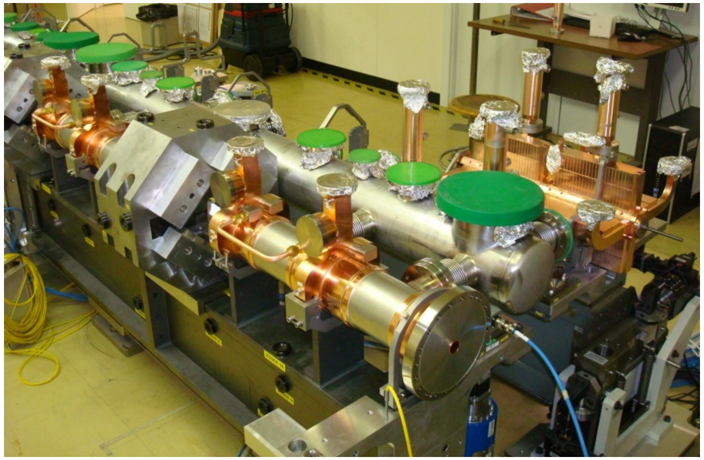
- 4 accelerating structures as one stack: 2-m long
- 2 PETS units completed
- RF and vacuum networks completed







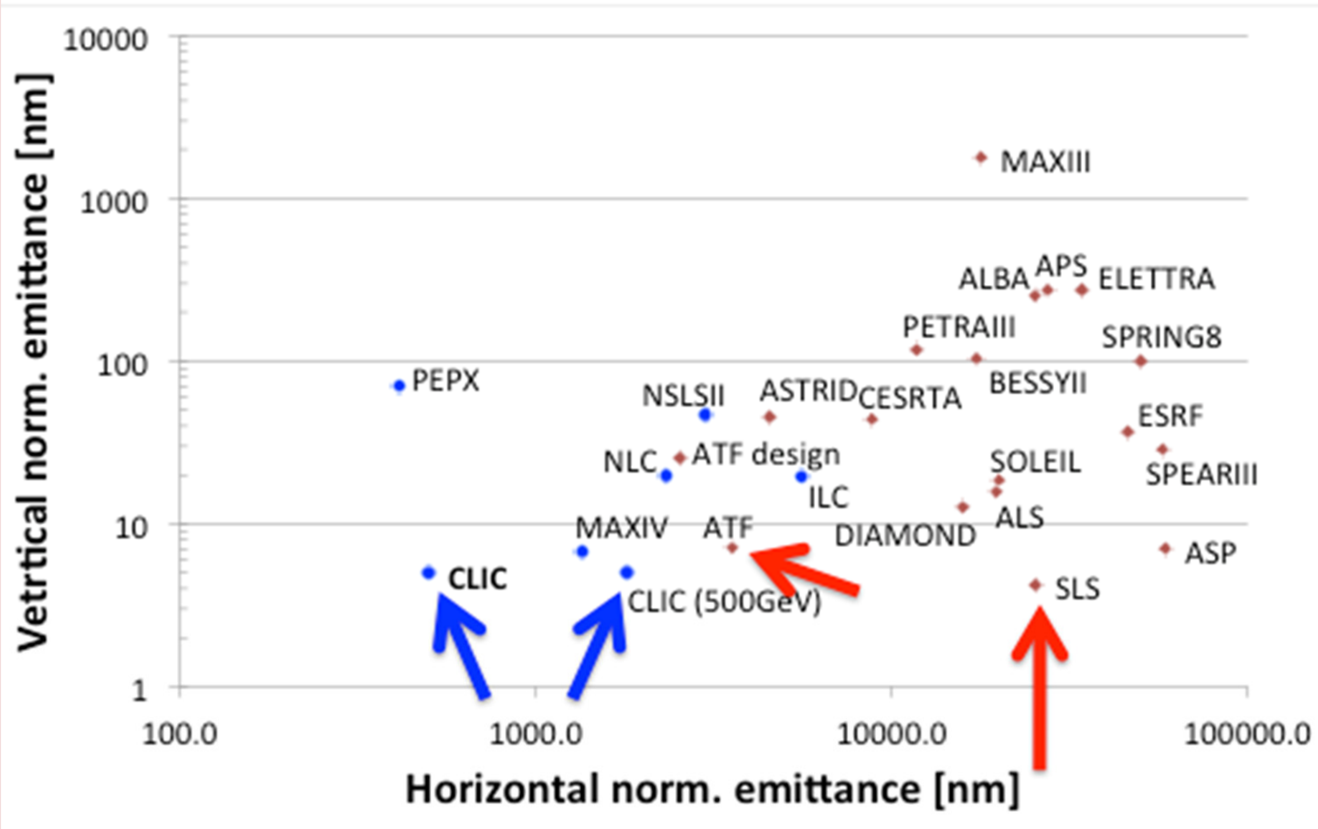




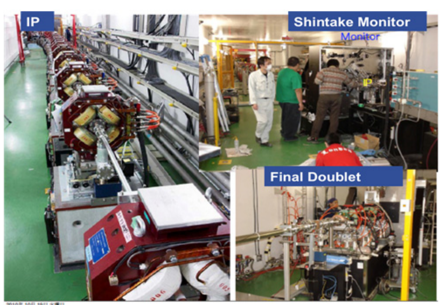
Emittance Generation

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



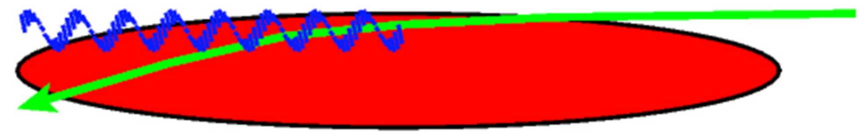
CLIC @3 TeV would achieve 1/3 of luminosity with ATF performance (3800nm/15nm@4e9)



Damping ring design is consistent with target performance

Main Beam Emittances

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



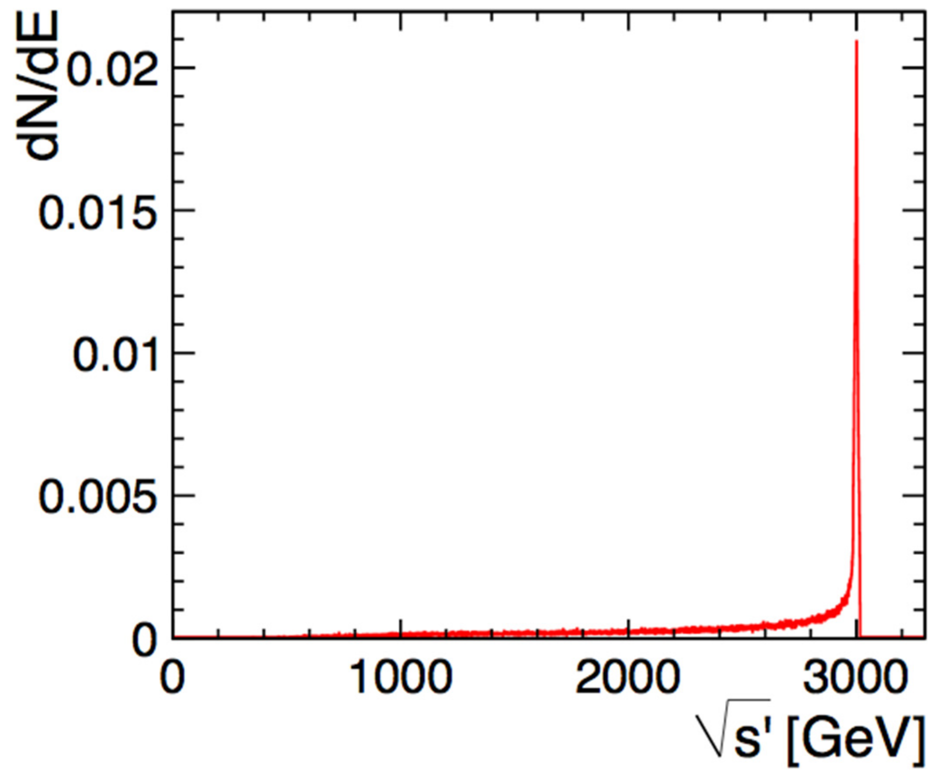
$$\mathcal{L} = H_D \frac{N^2}{4\pi\sigma_x\sigma_y} n_b f_r$$

$$\mathcal{L} \propto H_D \; \frac{N}{\sigma_x} \; N n_b f_r \; \frac{1}{\sigma_y}$$

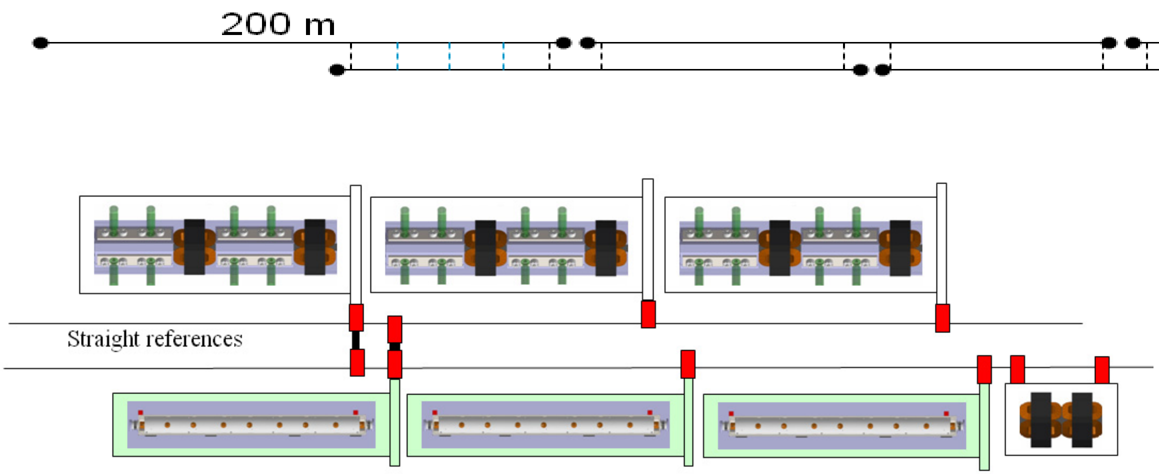
Beam power

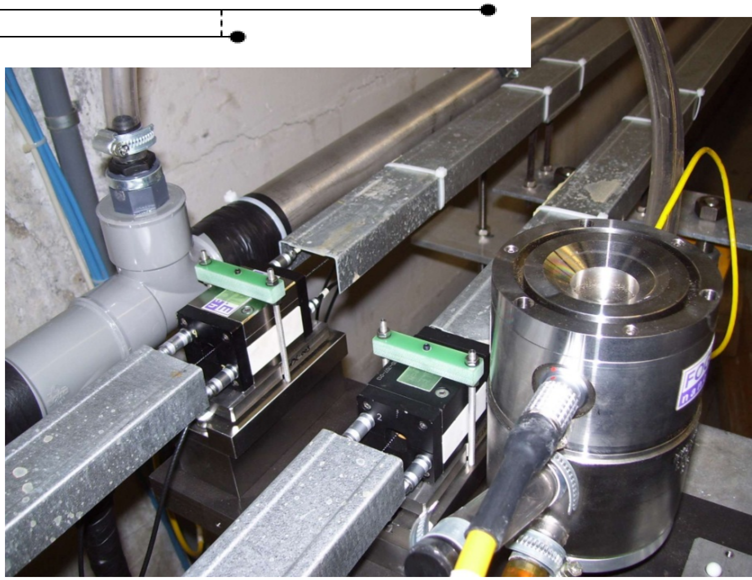
Luminosity spectrum

Beam Quality (+bunch length)

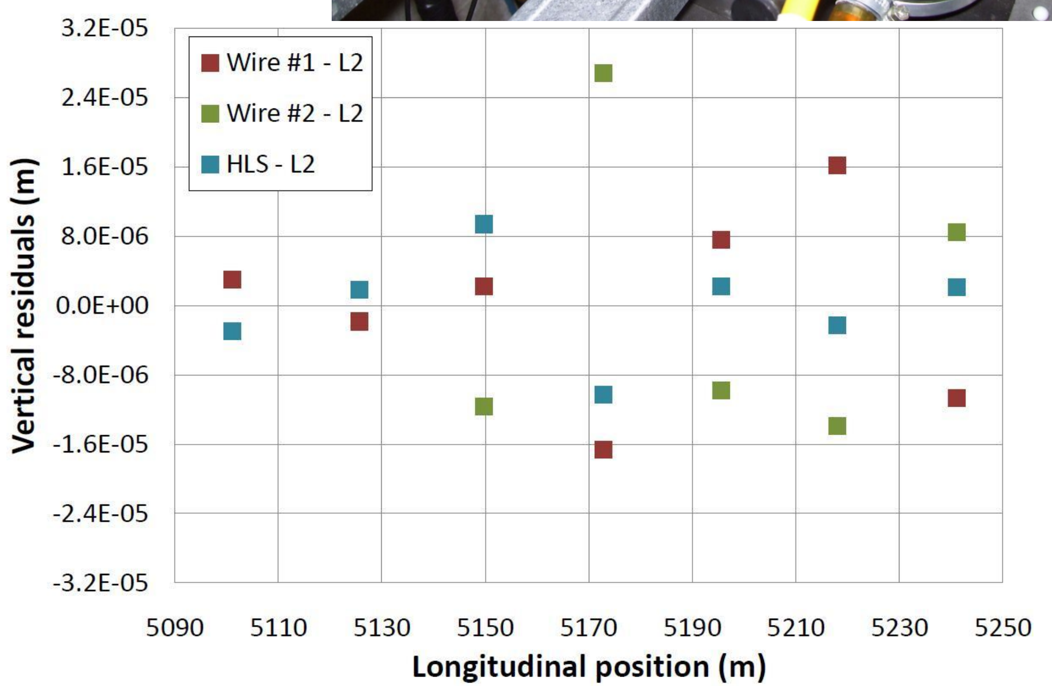


Pre-alignment System





- Required accuracy of reference point is 10 µm

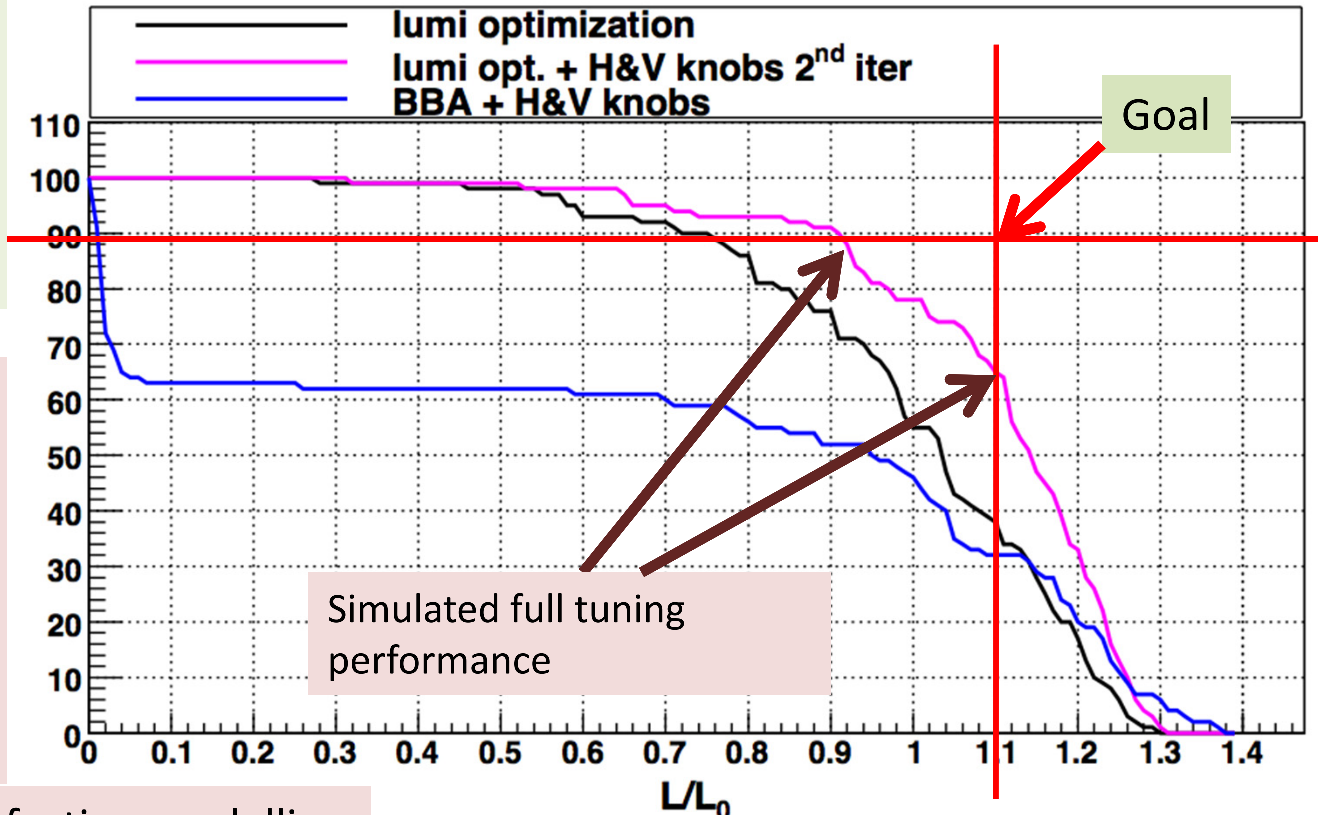


- Test of prototype shows
    - vertical RMS error of 11µm
    - i.e. accuracy is approx. 13.5µm
- Improvement path identified
- Several other technical developments linked to alignments issues -> see CDR

BDS Design and Alignment

Main design issues
- chromaticity
- non-linear effects
- synchrotron radiation
- tuning
- stability

Probability to achieve more than L/L_0 [%]



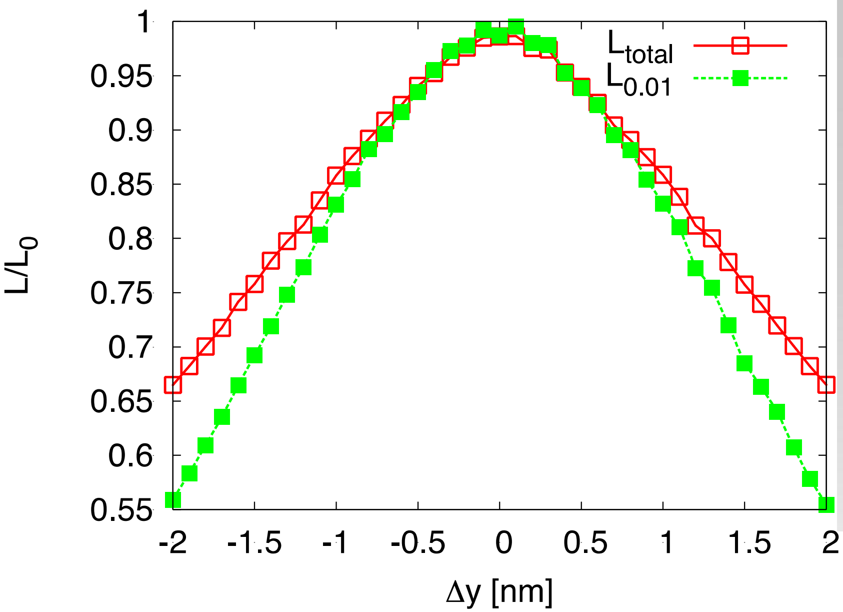
Static imperfections:
- Goal is $L \geq 110\%\ L_0$, with probability of 90%

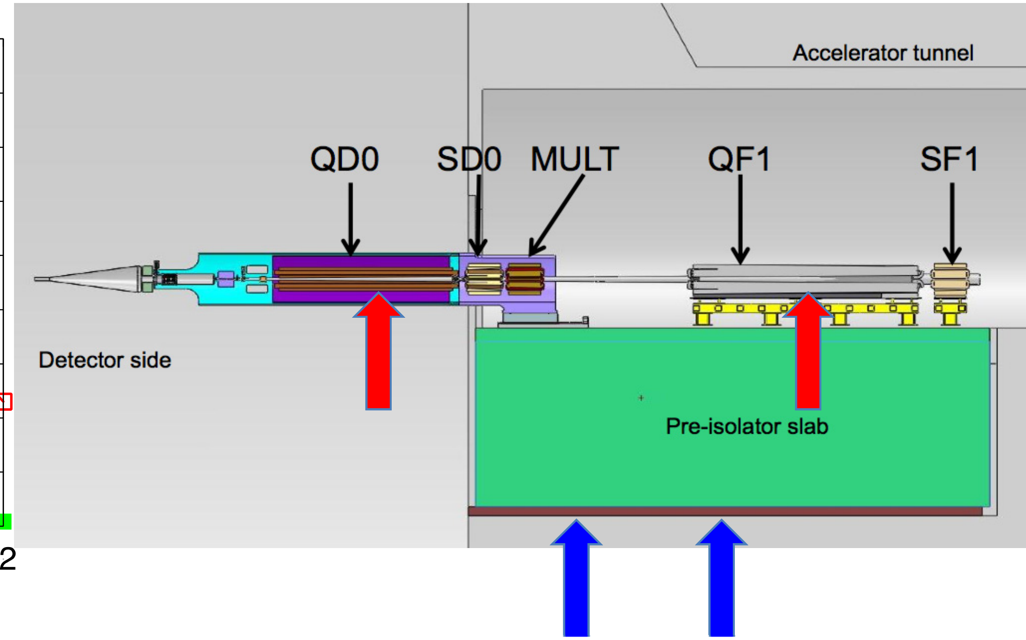
Convergence is slow
- faster method is being developed

Need more complete imperfection modelling
- independent sides
- field errors
- dynamic imperfections during tuning
- realistic signals

Design is OK
Imperfection mitigation comes close to target
Test programme at ATF2 at KEK

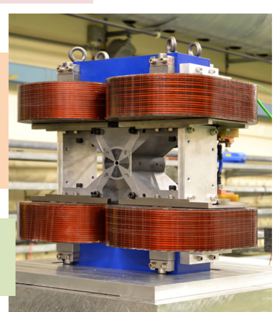
Ground Motion and Its Mitigation



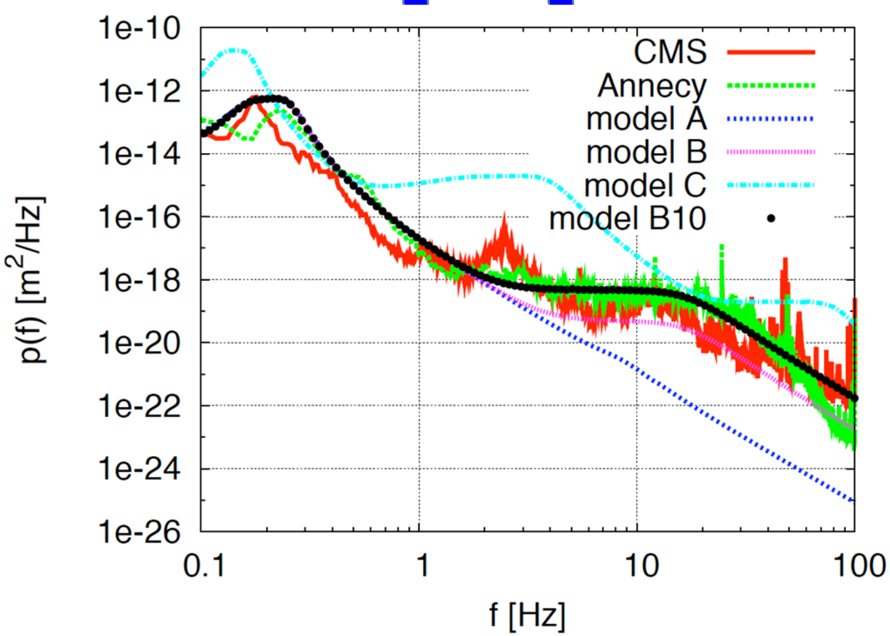


Natural ground motion can impact the luminosity
• typical quadrupole jitter tolerance O(1nm) in main linac and O(0.1nm) in final doublet

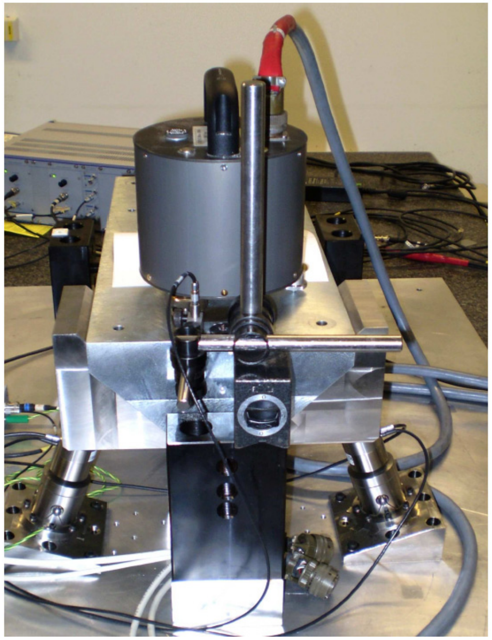
-> develop stabilisation for beam guiding magnets

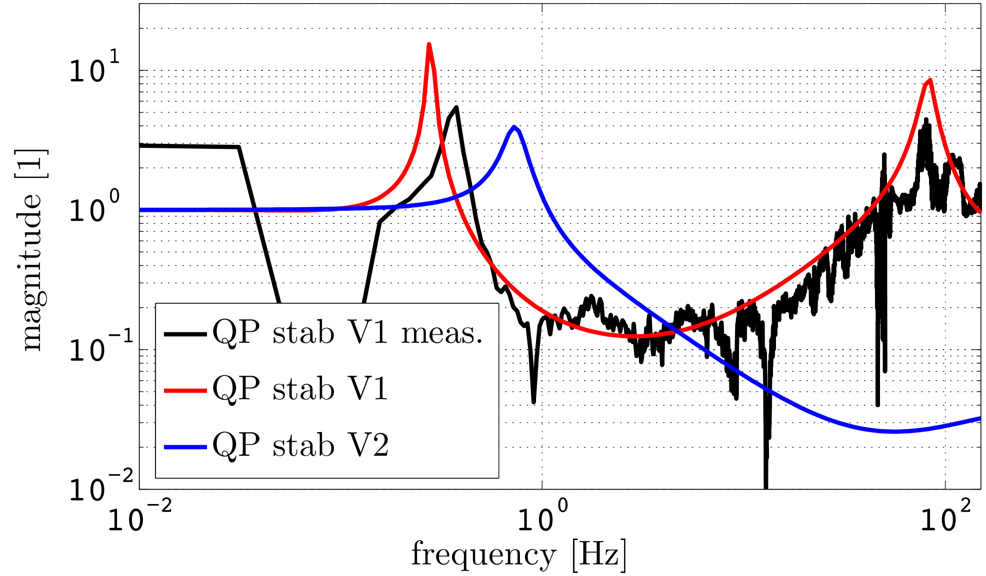


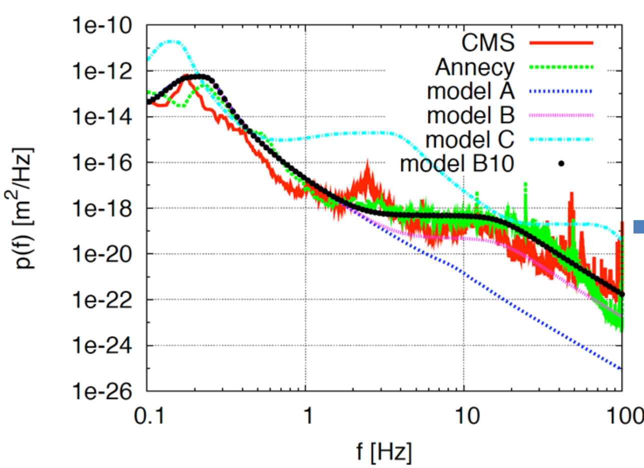
Final Focus QD0 Prototype



Active Stabilisation Results







Code

Machine model
Beam-based feedback

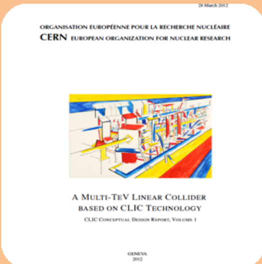
Luminosity achieved/lost [%]	B10
No stab.	53%/68%
Current stab.	108%/13%
Future stab.	118%/3%

Close to/better than target

Conclusion of our 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 – Improvements on operation, reliability, losses, more deceleration (more PETS) to come
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 CDRs



Vol 1: The CLIC accelerator and site facilities (H.Schmickler)

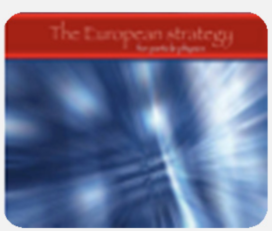
- CLIC concept with exploration over multi-TeV energy range up to 3 TeV
- Feasibility study of CLIC parameters optimized at 3 TeV (most demanding)
- Consider also 500 GeV, and intermediate energy range
- Complete, final editing ongoing, presented in the SPC In March 2012 (Daniel Schulte)

http://project-clic-cdr.web.cern.ch/project-CLIC-CDR/

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 ready for print end 2011, presented in SPC in December 2011 (Lucie Linssen)

http://lcd.web.cern.ch/LCD/CDR/CDR.html#Overview



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)
- Summer 2012: Ready for the European Strategy Open Meeting

- Main information page:http://clic-study.org/accelerator/CLIC-ConceptDesignRep.php
- Now a few words about the physics and detector studies

CLIC machine environment

	CLIC at 500 GeV	CLIC at 3 TeV
L ($cm^{-2}s^{-1}$)	2.3×10^{34}	5.9×10^{34}
BX separation	0.5 ns	0.5 ns
#BX / train	354	312
Train duration (ns)	177	156
Rep. rate	50 Hz	50 Hz
σ_x / σ_y (nm)	≈ 200 / 2.3	≈ 45 / 1
σ_z (µm)	72	44

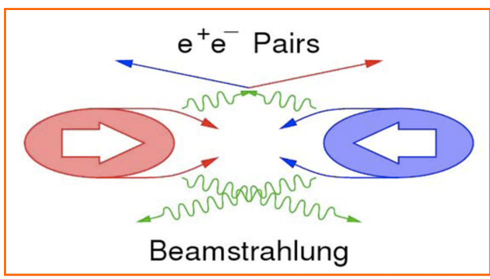
Drives timing requirements for CLIC detector

Simplified view:

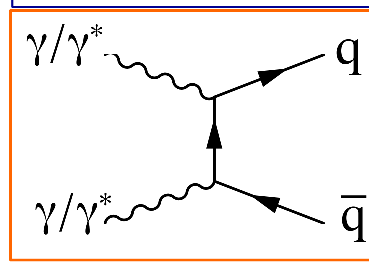
Pair background
- Design issue

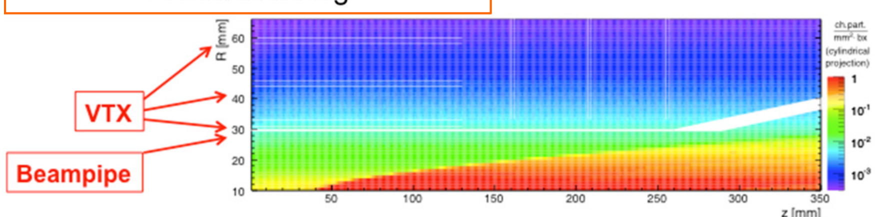
γγ → hadrons
- Impacts on the physics
- Needs suppression in data

Beam related background:
- Small beam profile at IP leads to very high E-field



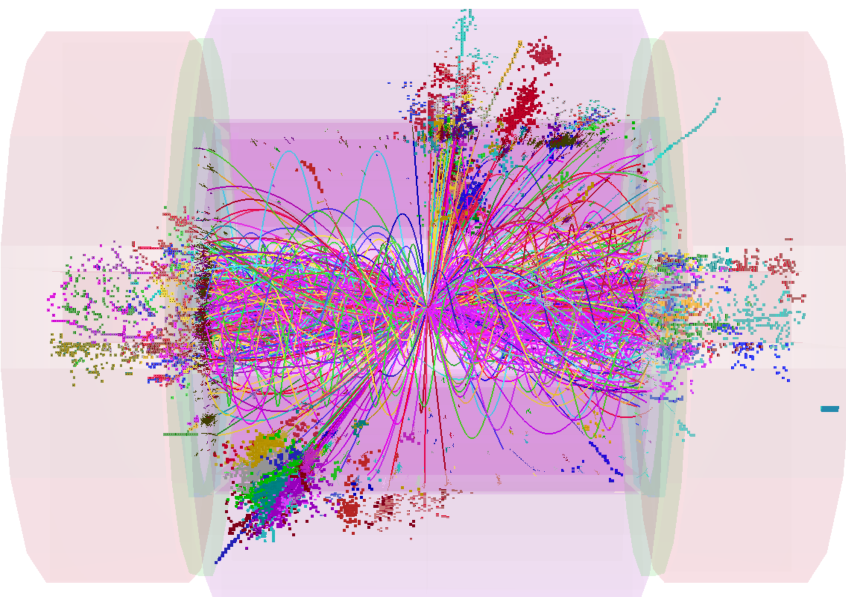
- **Beamsstrahlung**
  - Pair-background
  - γγ to hadrons



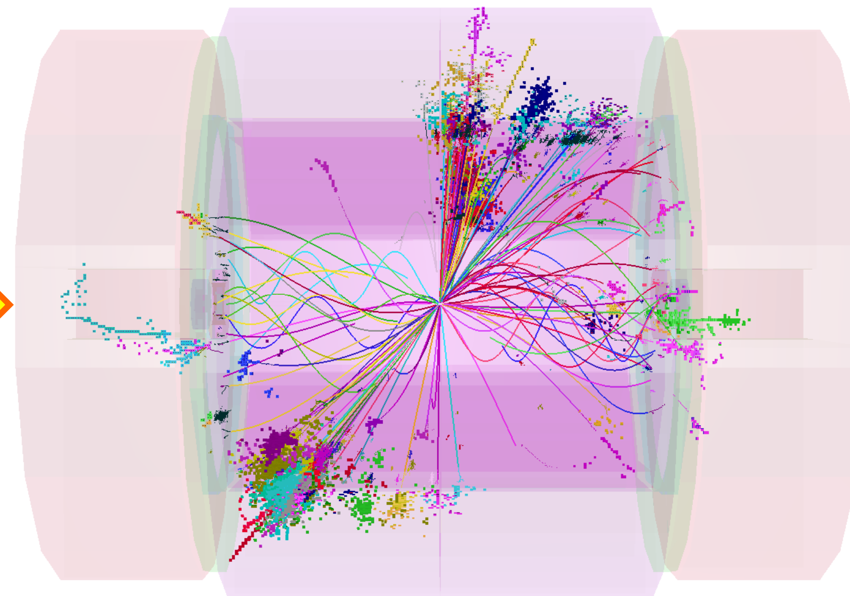


combined p_T and timing cuts

1.2 TeV



100 GeV



$$e^+e^- \to H^+H^- \to t\bar{b}b\bar{t} \to 8 \text{ jets}$$

1.2 TeV background in reconstruction time window

100 GeV background after tight cuts

The CLIC CDRs

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, final editing ongoing, presented in the SPC In March 2012

http://project-clic-cdr.web.cern.ch/project-CLIC-CDR/

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 ready for print end 2011, presented in SPC in December 2011 (Lucie Linssen)

http://lcd.web.cern.ch/LCD/CDR/CDR.html#Overview

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)
- Summer 2012: Ready for the European Strategy Open Meeting

CLIC physics potential

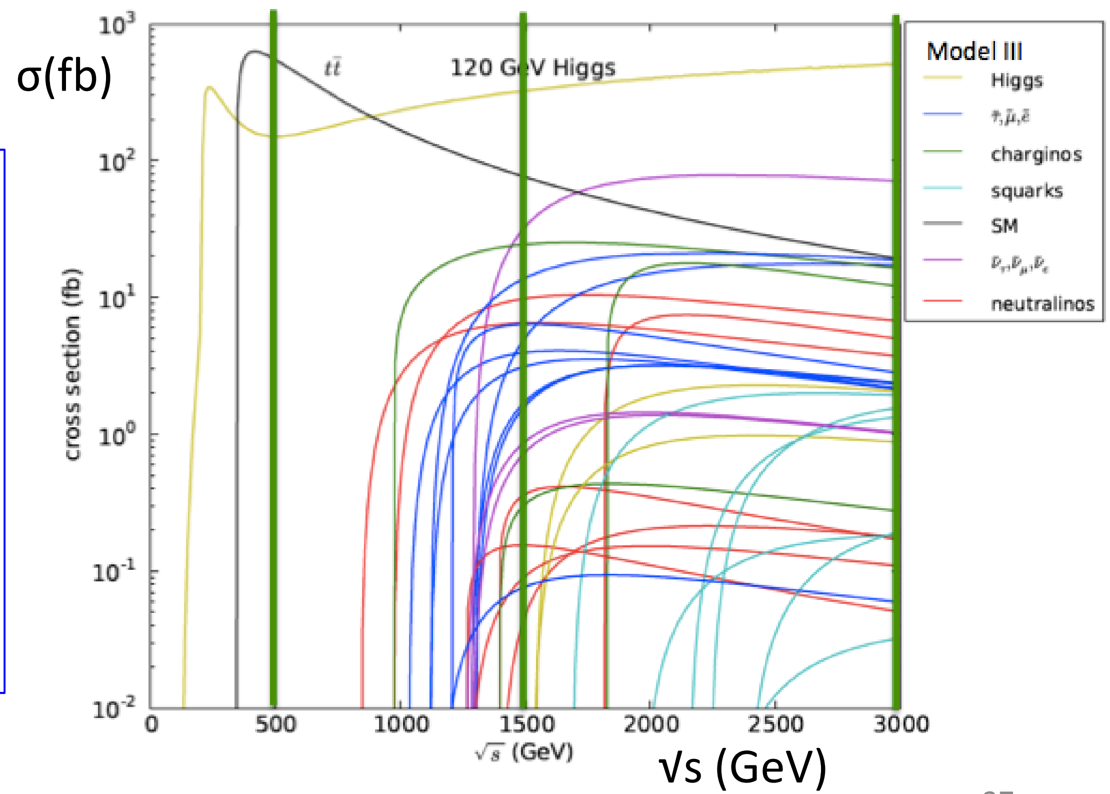
CLIC physics potential is complementary to LHC

Beyond LHC discovery reach:

- e+e- collisions give access to additional physics processes
  - weakly interacting states (e.g. slepton, chargino, neutralino searches)
  - more clean conditions than in LHC
- Defined initial state + more precise measurements

Examples highlighted in the CDR

- Higgs physics (SM and non-SM)
- Top
- SUSY
- Higgs strong interactions
- New Z' sector
- Contact interactions
- Extra dimensions
- ….

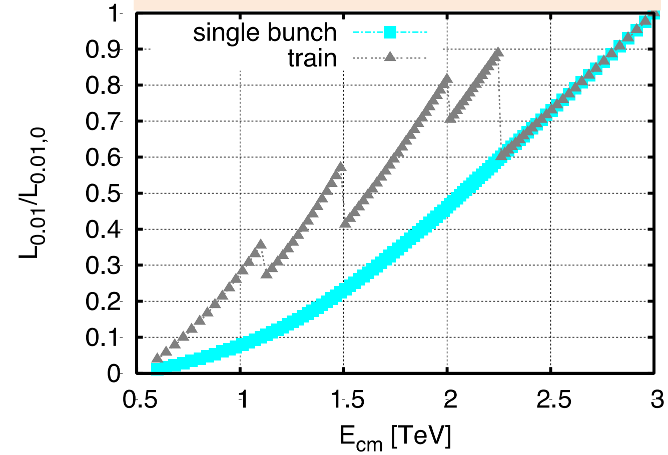


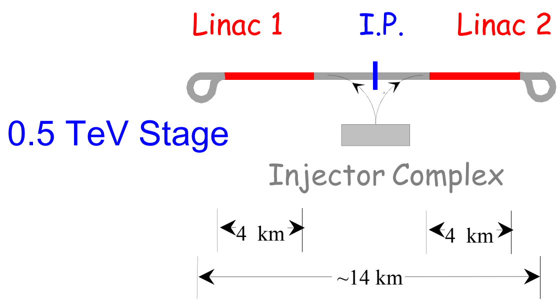
CLIC Implementation – in stages?

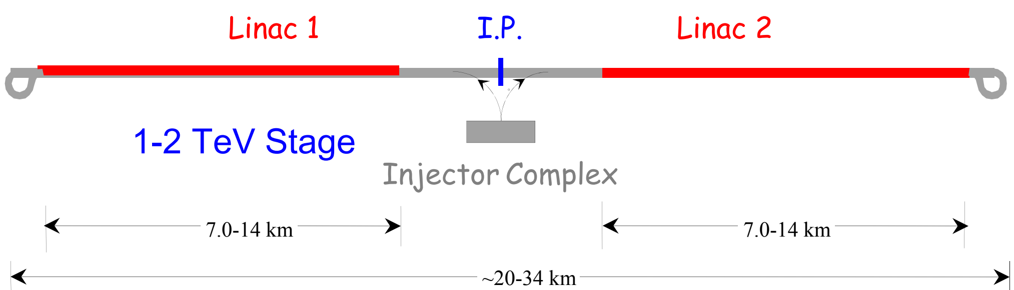
CLIC two-beam scheme compatible with energy staging to provide the optimal machine for a large energy range

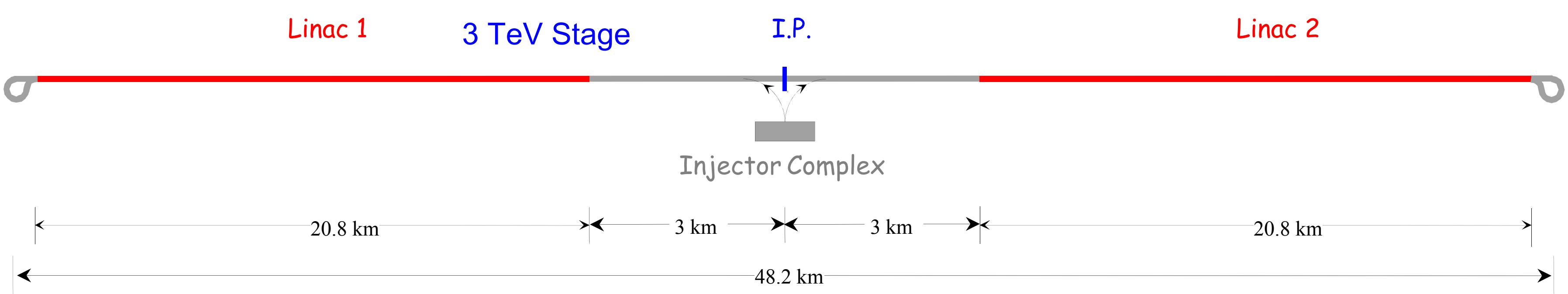
Lower energy machine can run most of the time during the construction of the next stage. Physics results will determine the energies of the stages

Need to operate at lower than nominal energy

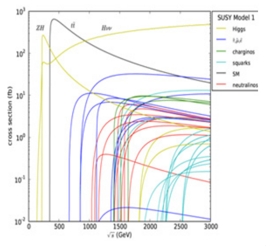






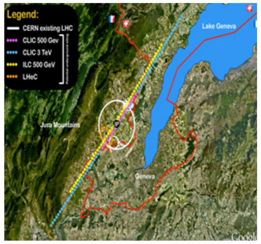


Implementation issues



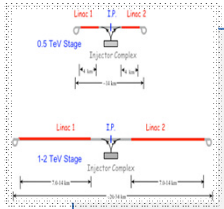
Physics - how do we build the optimal machine given a physics scenario (partly seen at LHC ?):

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

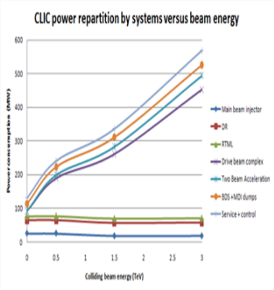


Construction scenario (and approval scenario):

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

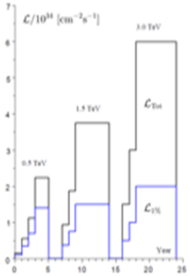
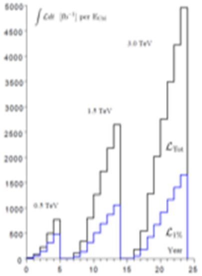


Costs - Initial machine plus energy upgrade: External cost review 21-22.2.2012, costs will be discussed in volume 3 of the CDR



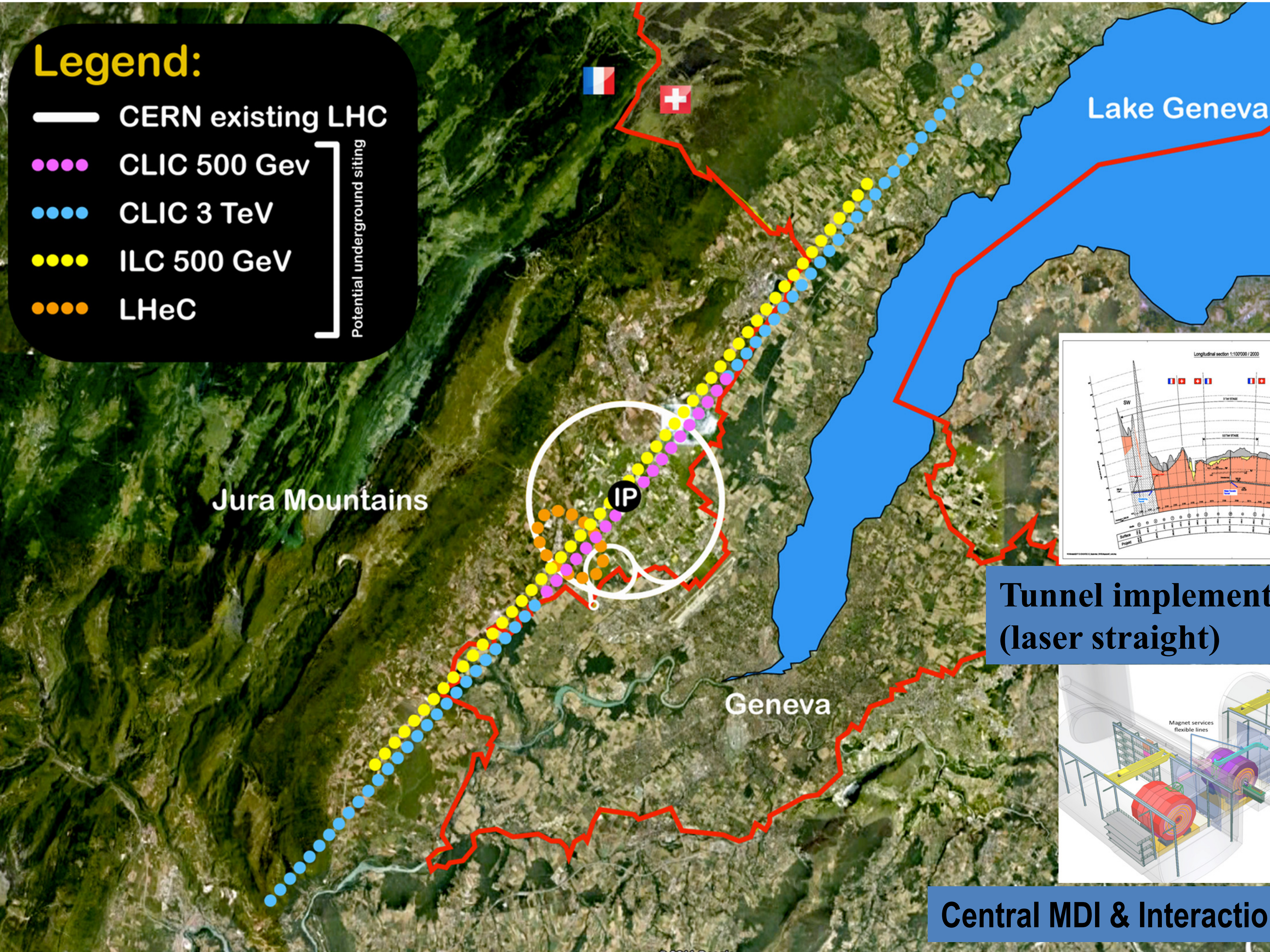
Power and energy development.

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

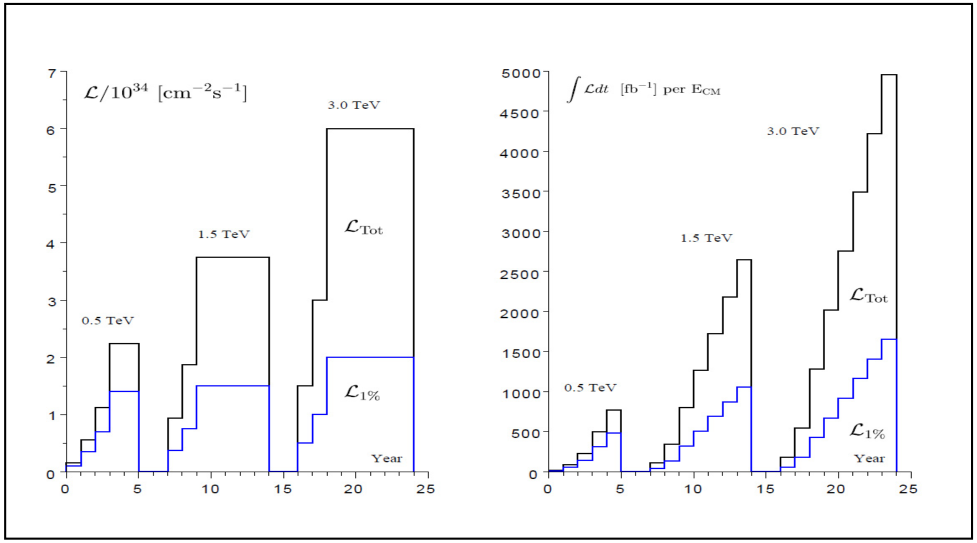
Timescale/lifecycle for project re-defined: Buildup of drive beam (CLIC zero), stage one – physics, more stages/extensions

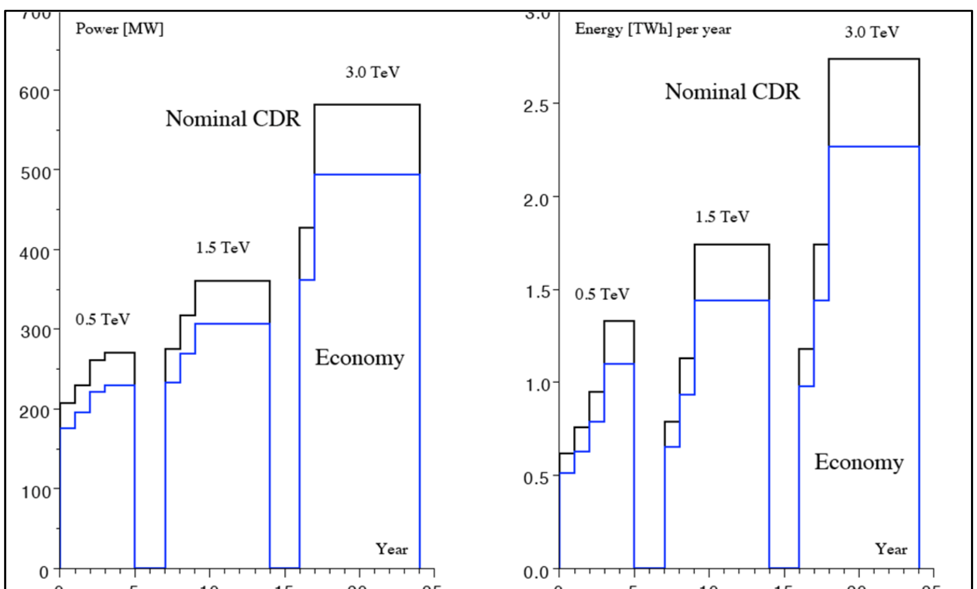
Parameters: energy steps and scans, inst. and int. luminosities, commissioning and lum. ramp up times.



Legend:
CERN existing LHC
CLIC 500 Gev
CLIC 3 TeV
ILC 500 GeV
LHeC
Potential underground siting
Lake Geneva
Jura Mountains
IP
Geneva
Tunnel implement
(laser straight)
Magnet services flexible lines
Central MDI & Interactio

A possible energy/luminosity example





With a model (see figure for one preliminary example) for energies and luminosities, and assumptions about running scenarios (see below), one can extract power and energy estimates as function of time.

Step 1: Make "reasonable" assumptions about luminosity ramp up times, i.e. commissioning time, efficiencies, up/down times year by year and look at the running time needed to reach certain integrated luminosity targets

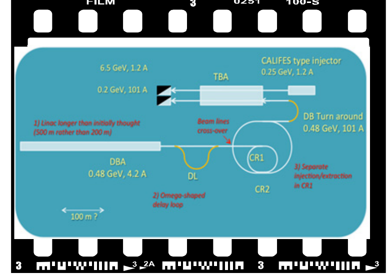
Top figure:
Black curves: Instantaneous and integrated luminosity (full spectrum)
Blue curves: Instantaneous and integrated luminosity (within 1% of peak)

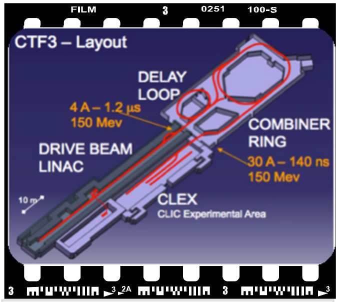
Step 2: Make assumptions about power during stops (scheduled, fault, downtime) : (40 MW, 45 MW, 60 MW) at (0.5, 1.5, 3) TeV, respectively

Lower figures
Black curves: Power and energy consumption as function of time
Blue curves: The same after reductions – that we will need to study in the next phase of the project

Further reductions:
Scale with inst. luminosity – i.e. running at the very end of the project lifetime might be power limited and require more time, and look at power management/scheduling of running (use cheap periods)

CLIC project time-line





Final CLIC CDR and feasibility established, also input for the Eur. Strategy Update

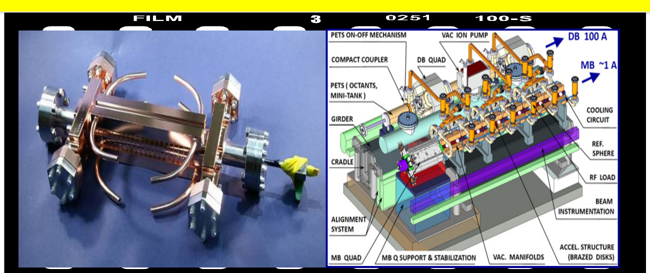
From 2016 – Project Implementation phase, including an initial project to lay the grounds for full construction:

- CLIC 0 – a significant part of the drive beam facility: prototypes of hardware components at real frequency, final validation of drive beam quality/main beam emittance preservation, facility for reception tests – and part of the final project)
- Finalization of the CLIC technical design, taking into account the results of technical studies done in the previous phase, and final energy staging scenario based on the LHC Physics results, which should be fully available by the time
- Further industrialization and pre-series production of large series components for validation facilities
- Other system studies addressing luminosity issues (emittance conservation) …
- Environmental Impact Study

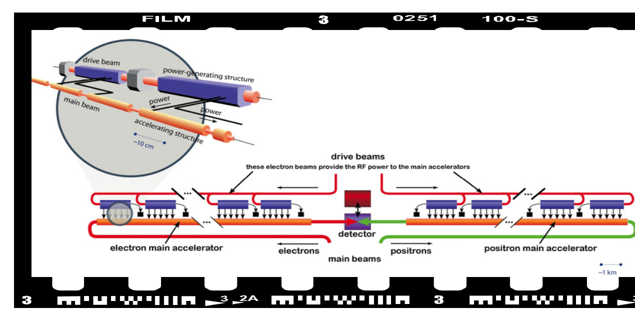
2004 - 2012	2012 - 2016	2016 – 2022	~ 2020 onwards

2011-2016 – Goal: Develop a project implementation plan for a Linear Collider:

- Addressing the key physics goals as emerging from the LHC data
- With a well-defined scope (i.e. technical implementation and operation model, energy and luminosity), cost and schedule
- With a solid technical basis for the key elements of the machine and detector
- Including the necessary preparation for siting the machine
- Within a project governance structure as defined with international partners



CLIC project construction – in stages, making use of CLIC 0



The objectives and plans for 2012-16

In order to achieve the overall goal for 2016 the follow four primary objectives for 2011—16 can defined, to be addressed by activities (studies, working groups, task forces) or work-packages (technical developments, prototyping and tests of single components or larger systems at various places):

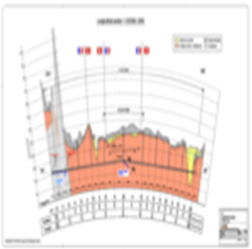
1) Define the scope, strategy and cost of the project implementation.

Main input:

The evolution of the physics findings at LHC and other relevant data

Findings from the CDR and further studies, in particular concerning minimization of the technical risks, cost, power as well as the site implementation.

A Governance Model as developed with partners.



2) Define and keep an up-to-date optimized overall baseline design that can achieve the scope within a reasonable schedule, budget and risk.

Beyond beam line design, the energy and luminosity of the machine, key studies will address stability and alignment, timing and phasing, stray fields and dynamic vacuum including collective effects.

Other studies will address failure modes and operation issues.

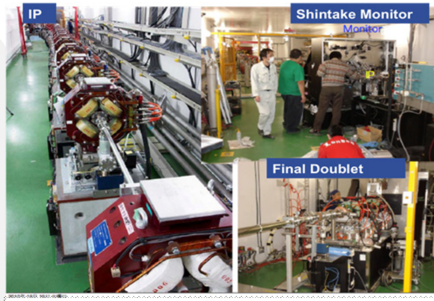
parameter	symbol		
centre of mass energy	E_{cm} [GeV]	500	3000
luminosity	$\mathcal{L}$ [10^{34} cm^{-2}s^{-1}]	2.3	5.9
luminosity in peak	$\mathcal{L}_{0.01}$ [10^{34} cm^{-2}s^{-1}]	1.4	2
gradient	G [MV/m]	80	100
site length	[km]	13	48.3
charge per bunch	N [10^9]	6.8	3.72
bunch length	σ_z [μm]	70	44
IP beam size	σ_x/σ_y [nm]	200/2.26	40/1
norm. emittance	ϵ_x/ϵ_y [nm]	2400/25	660/20
bunches per pulse	n_b	354	312
distance between bunches	Δ_b [ns]	0.5	0.5
repetition rate	f_r [Hz]	50	50
est. power cons.	P_{wall} [MW]	240	560

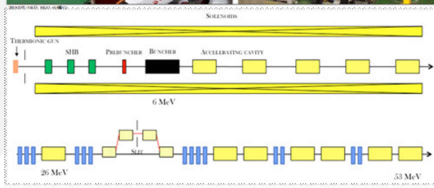
The objectives and plans for 2012-16

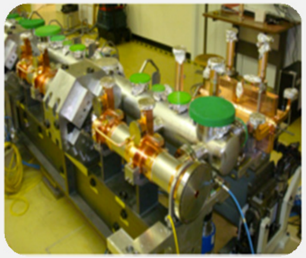
3) Identify and carry out system tests and programs to address the key performance and operation goals and mitigate risks associated to the project implementation.

The priorities are the measurements in: CTF3+, ATF and related to the CLIC Zero Injector addressing the issues of drive-beam stability, RF power generation and two beam acceleration, as well as the beam delivery system.

Technical work-packages and studies addressing system performance parameters



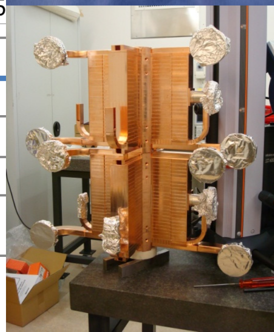


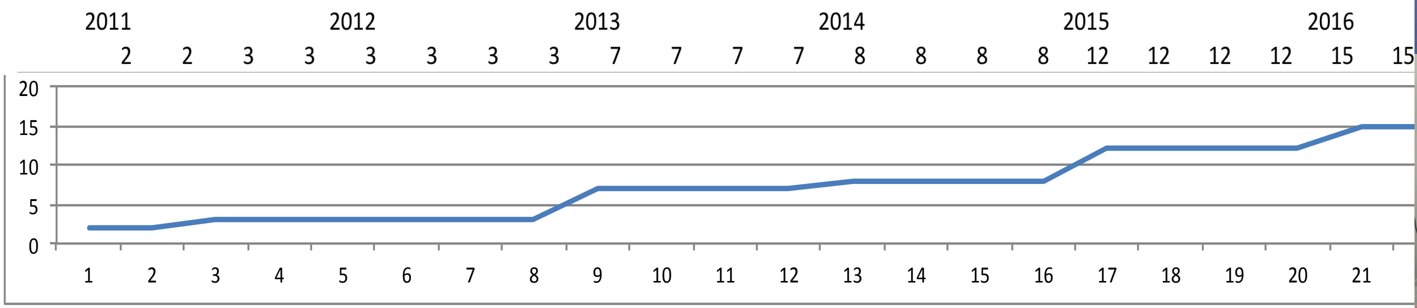


Develop the technical design basis. i.e. move toward a technical design for crucial items of the machine and detectors, the MD interface, and the site.

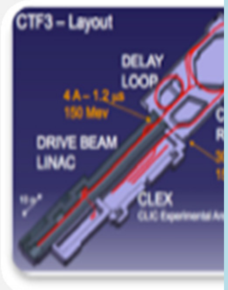
Priorities are the modulators/klystrons, module/structure development including testing facilities, alignment/stability and site studies.

Technical work-packages providing input and interacting with all points above



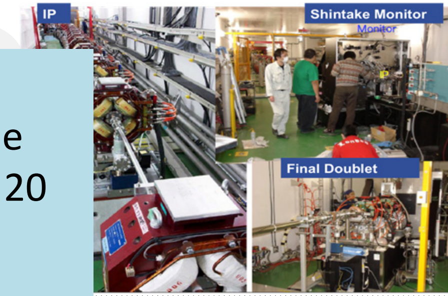


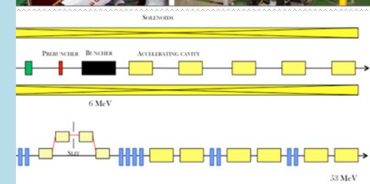
The objectives and plans for 2012-16

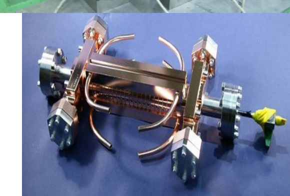


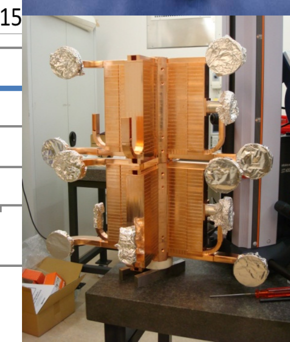
The programme combines the resources of collaborators inside the current collaboration, plus several new ones – and involves around 20 CERN groups.

Have ~75 submitted descriptions of ongoing or planned efforts linked to these work-packages 2012-16 from groups outside CERN (result of CLIC working meeting 3-4.11: https://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=156004
(still open for more interests)

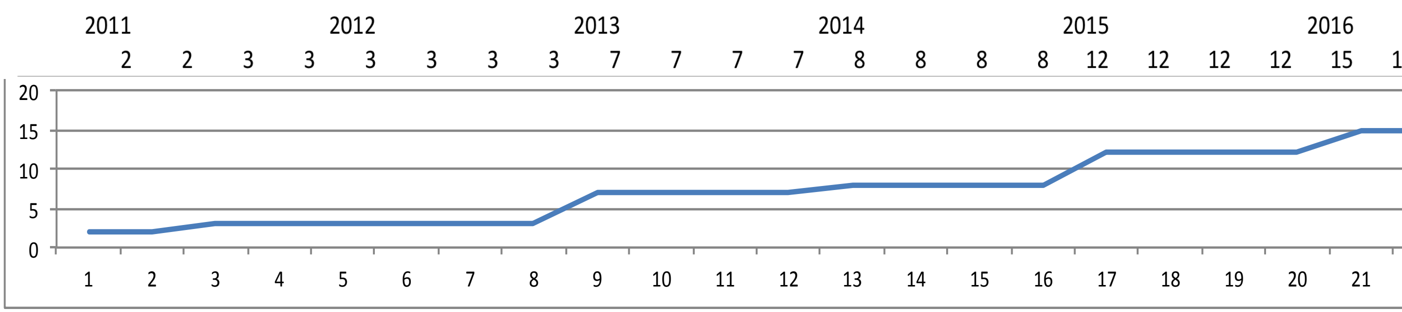








number of rf ports



Summary

- Technical status of accelerator and detectors very good concerning potential and feasibility being documented in the CDR volumes – being completed this year
- 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
- Beyond this phase (i.e. 2016-2022) the CLIC project moved towards larger systems overlapping with project implementation preparation; key issues remain the drive beam, luminosity performance and robustness, structures and module development plus power/cost

- Thanks to the CLIC collaboration for the slides and work presented – for and from the CDR and also presentations and many posters in this conference
- In particular Daniel Schulte and Lucie Linssen's slides from recent CERN presentations