The CLIC project

Status and prospect

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Overview

CLIC status

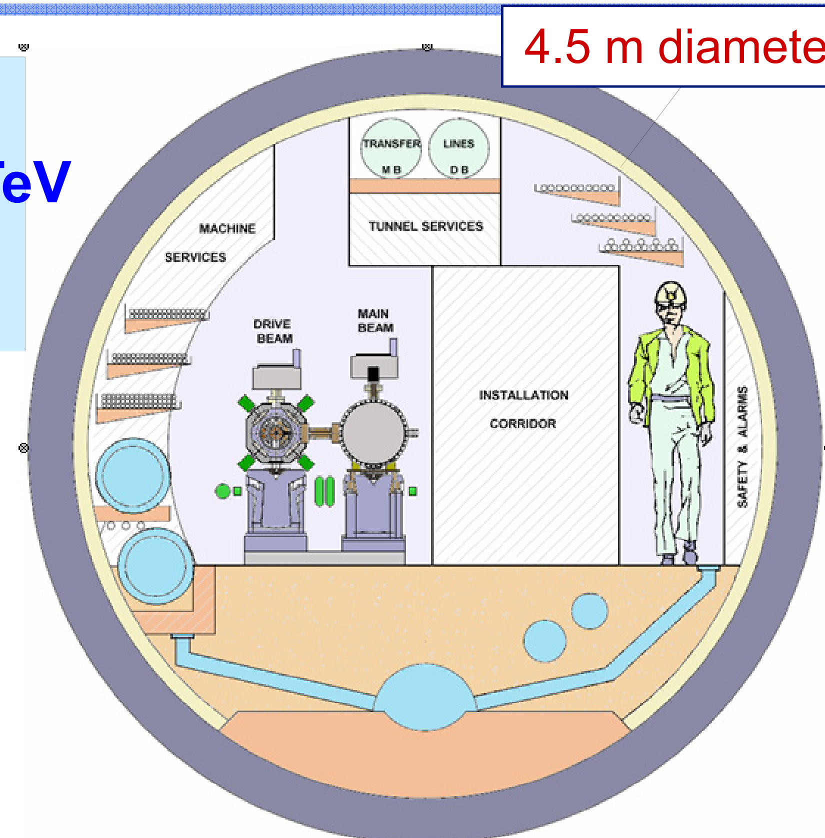
The period 2012-2018

X-band activites

Compact Linear Collider - CLIC

- **High acceleration gradient: > 100 MV/m**
  - **"Compact" collider: total length < 50 km at 3 TeV**
  - **Normal conducting acceleration structures at high RF frequency (12 GHz)**

- **Novel Two-Beam Acceleration Scheme**
  - **Cost effective, reliable, efficient**
  - **Single tunnel, no active power components**
  - **Modular, staged energy upgrade**

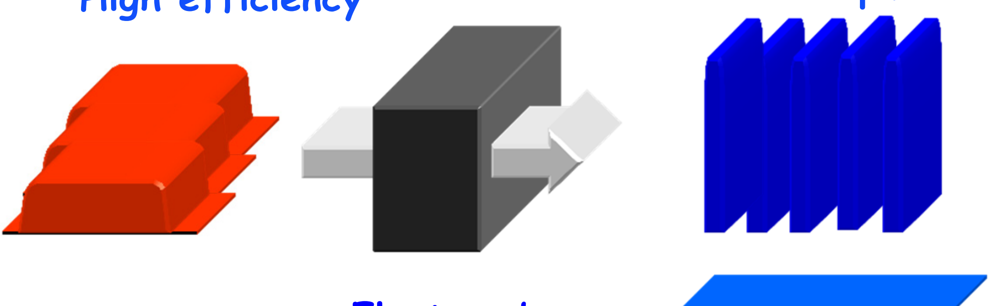


CLIC TUNNEL CROSS-SECTION

Compact rf pulses: by e- compression

'few' Klystrons
Low frequency
High efficiency

Accelerating Structures
High Frequency - High field
-> short pulses

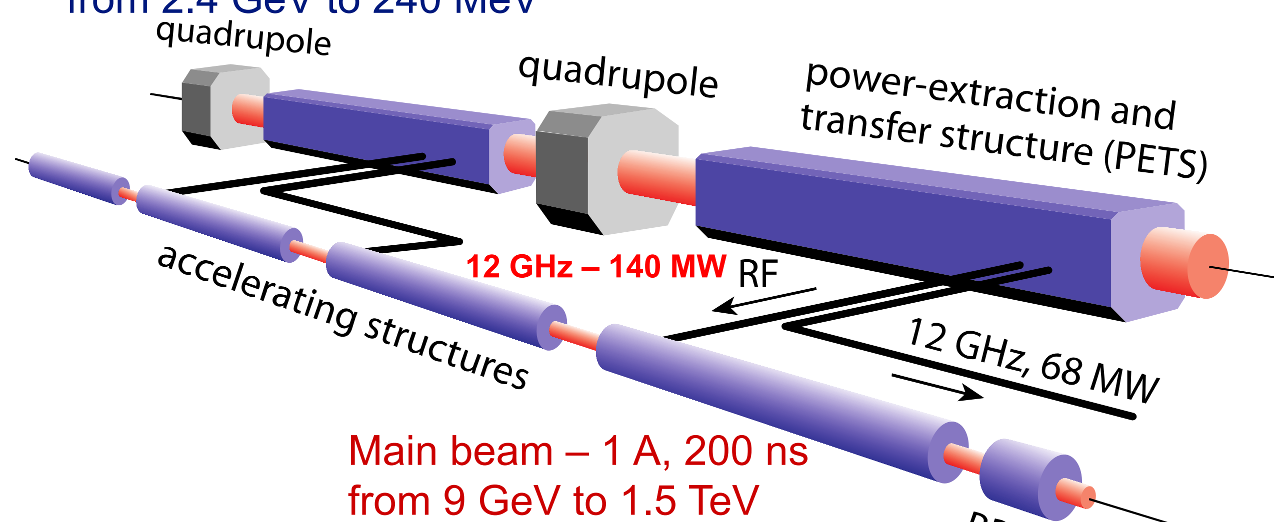


Long RF Pulses
P_0 , τ_0

Electron beam manipulation : Power compression, Frequency multiplication

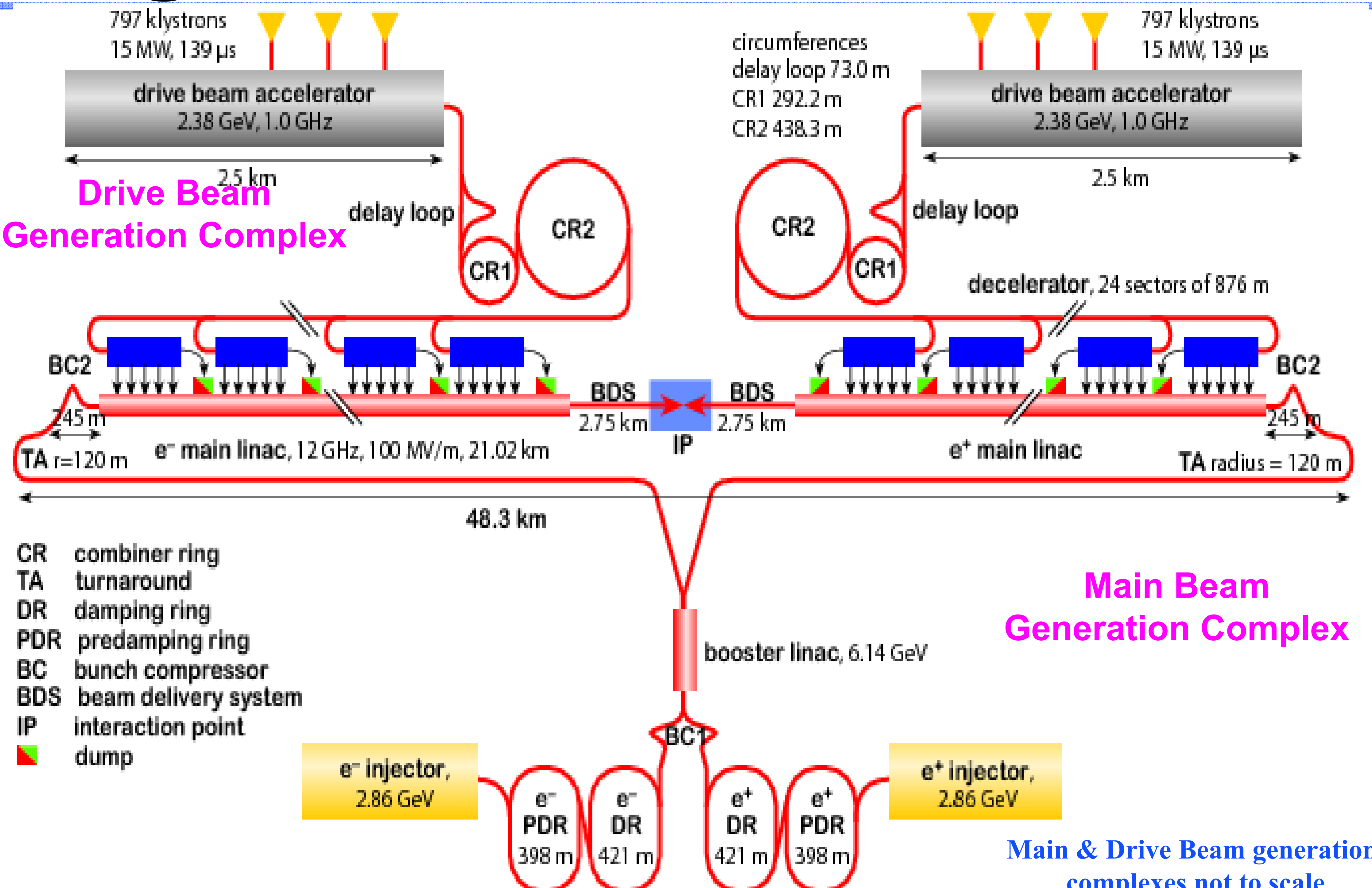
Short RF Pulses
$P_A = P_0 \times N$
$\tau_A = \tau_0 / N$

Drive beam - 100 A, 240 ns
from 2.4 GeV to 240 MeV



Main beam – 1 A, 200 ns
from 9 GeV to 1.5 TeV

CLIC layout 3 TeV



Main & Drive Beam generation complexes not to scale

CLIC: Linear Collider collaboration

European Strategy priorities related to the Energy Frontier:

•LHC and LHC luminosity upgrades (until ~2030)

- Higgs and Beyond the Standard Model physics in long term programme

•BSM – does it show up at LHC at 14 TeV, 2015 onwards ?

- What are the best machines to access such physics directly post-LHC …. we don't know but we can prepare main options the next years towards next strategy update (~2018)
- Two alternatives considered; higher energy hadrons (HE LHC or VHE LHC), **or highest possible energy e+e- with CLIC**

•**ILC in Japan**, a possibility for exploring the Higgs in detail, starting at 250 GeV

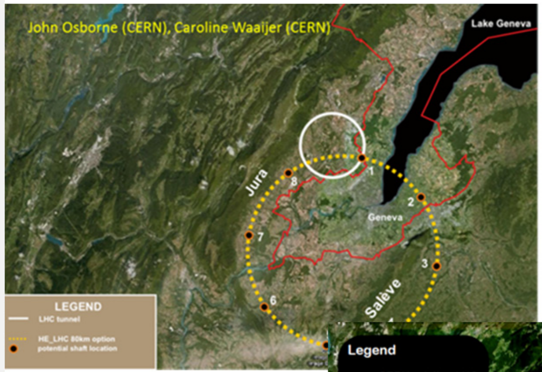
- If implemented a comprehensive programme that can map out the Higgs sector in particular

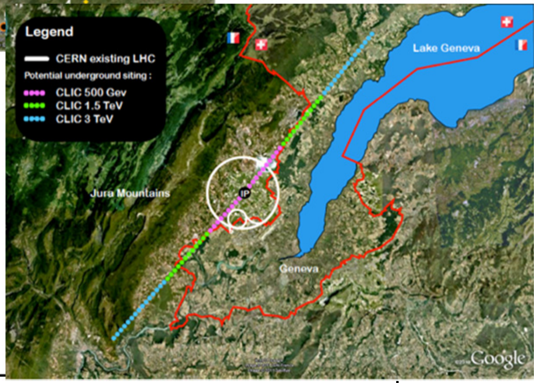
In accordance with this, pursue three connected activities in the period towards 2017-18 (when LHC results at nominal energy are becoming mature):

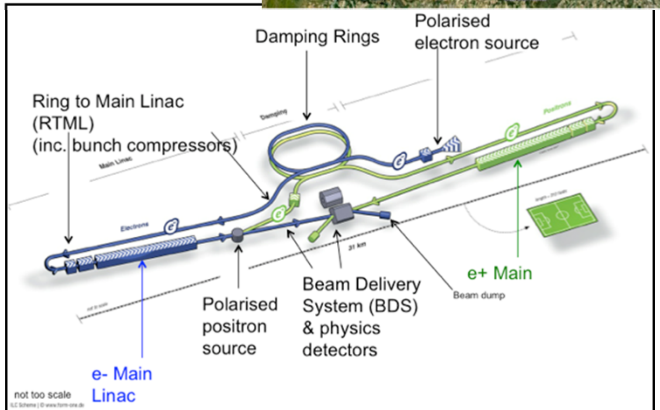
•**CLIC as option for the energy frontier (accelerator, det&phys studies)**

•ILC project development - towards a construction project

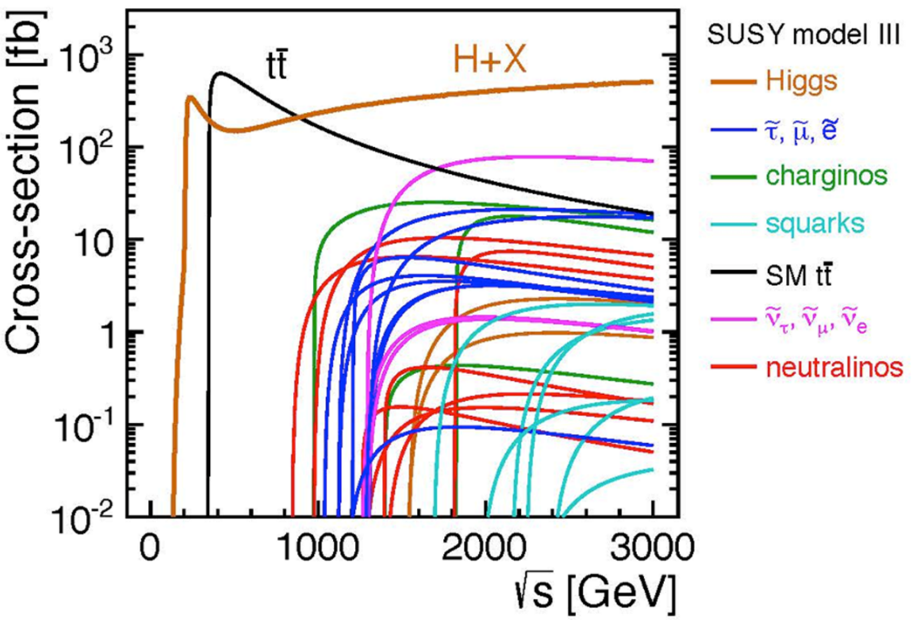
•Common activities wherever possible







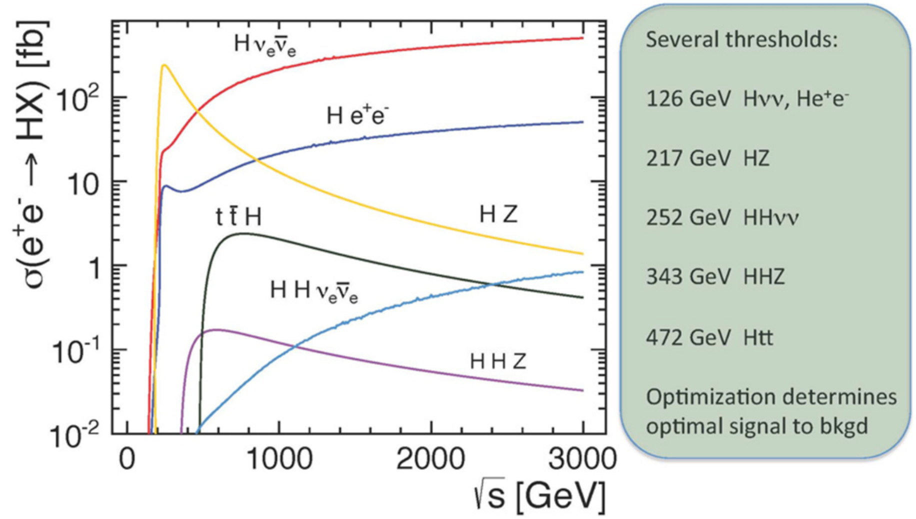
- **Physics case for the Linear Collider:**
  - **Higgs physics (SM and non-SM)**
  - **Top**
  - **SUSY**
  - **Higgs strong interactions**
  - **New Z' sector**
  - **Contact interactions**
  - **Extra dimensions**
  - **….**



Recently: Further work on completing picture of Higgs prospects at ~350 GeV, ~1.4 TeV, ~3 TeV, example for CLIC:

collision energy Polarization e⁻/e⁺	√s = 1.4 TeV unpolarized	√s = 1.4 TeV -80% / +30%	√s = 3.0 TeV unpolarized	√s = 3.0 TeV -80% / +30%
Δ σ(HHνν)	≈ 22%	≈ 18%	≈ 10%	≈ 7%
Δ λ_{HHH}	≈ 28%	≈ 22%	≈ 16%	≈ 11%
Numbers with polarized beams obtained by scaling signal and background cross sections, ignoring polarization-dependent changes to kinematic properties.				all cross section values: mH = 120 GeV

Higgs boson Production Cross-Sections



Lebrun et al., arXiv:1209.2543

The CLIC CDR documents

Vol 1: The CLIC accelerator and site facilities

- 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
- https://edms.cern.ch/document/1234244/

Vol 2: Physics and detectors at CLIC

- Physics at a multi-TeV CLIC machine can be measured with high precision, despite challenging background conditions
- External review procedure in October 2011
- http://arxiv.org/pdf/1202.5940v1

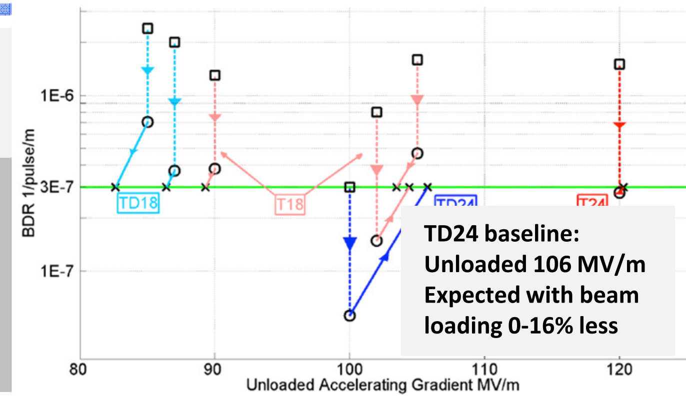
Vol 3: "CLIC study summary"

- 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)
- 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

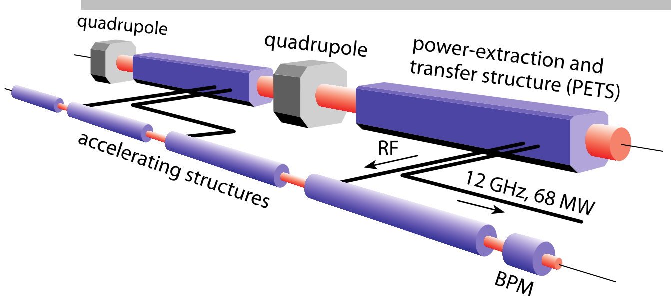
An input document to Snowmass 2013 has also been submitted: http://arxiv.org/abs/1305.5766

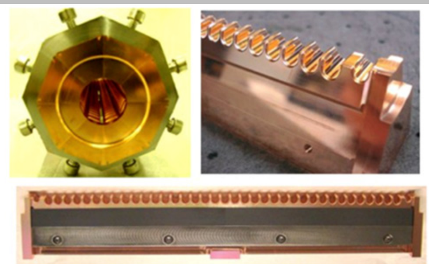
Conclusion of the accelerator CDR studies

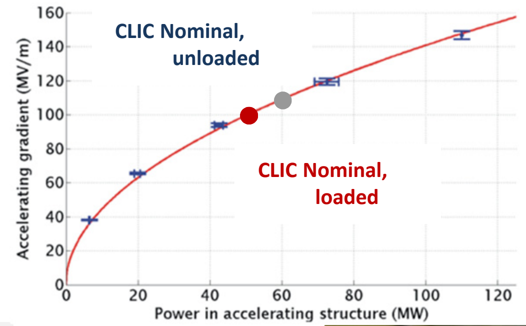


Main linac gradient
- Ongoing test close to or on target
- Uncertainty from beam loading being tested

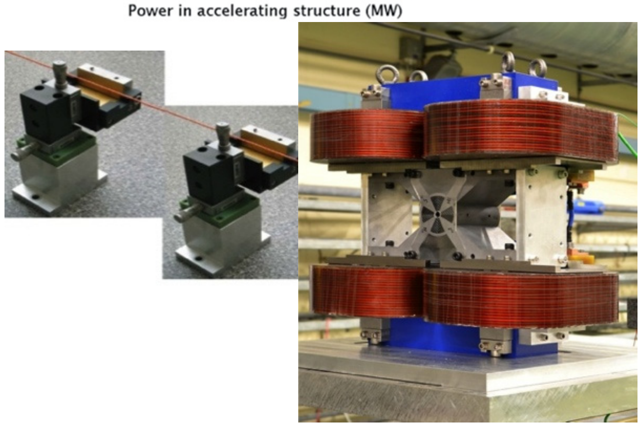
Drive beam scheme
- Generation tested, used to accelerate test beam above specifications, deceleration as expected
- Improvements on operation, reliability, losses, more deceleration studies underway







Luminosity
- Damping ring like an ambitious light source, no show stopper
- Alignment system principle demonstrated
- Stabilisation system developed, benchmarked, better system in pipeline
- Simulations on or close to the target



Operation & Machine Protection
- Start-up sequence and low energy operation defined
- Most critical failure studied and first reliability studies

Implementation
- Consistent three stage implementation scenario defined
- Schedules, cost and power developed and presented
- Site and CE studies documented

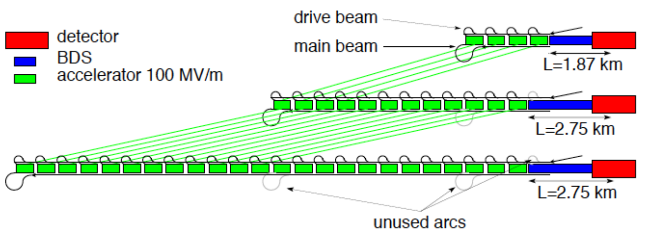
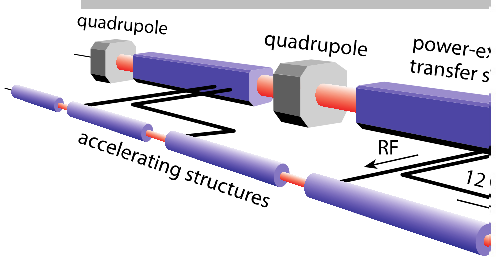


Fig. 3.6: Simplified upgrade scheme for CLIC staging scenario B.

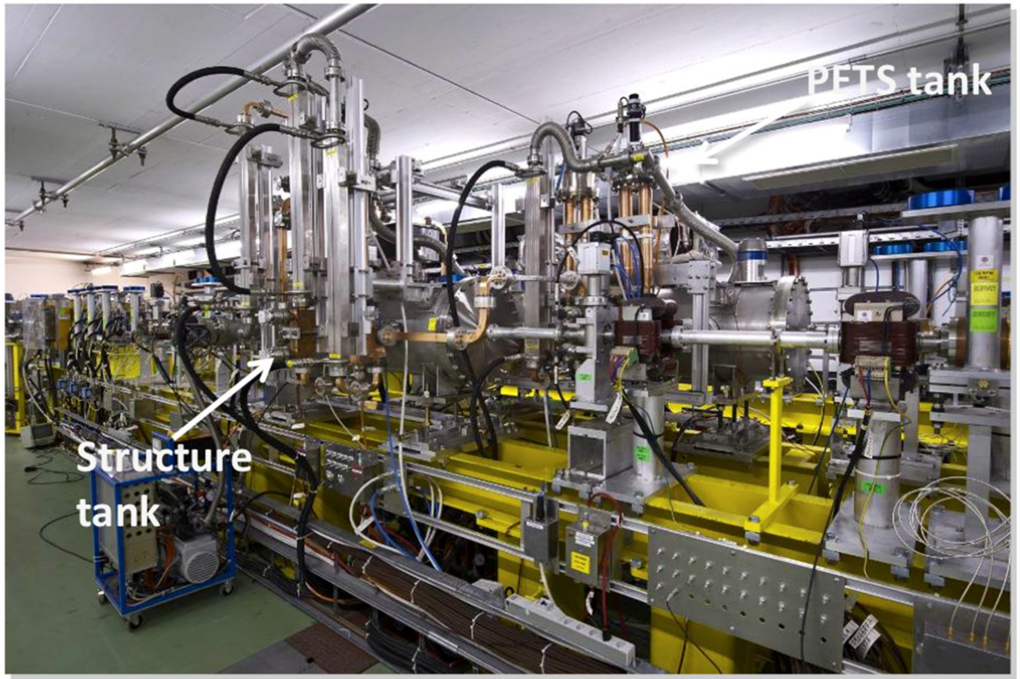
Conclusion of the accelerator CDR studies

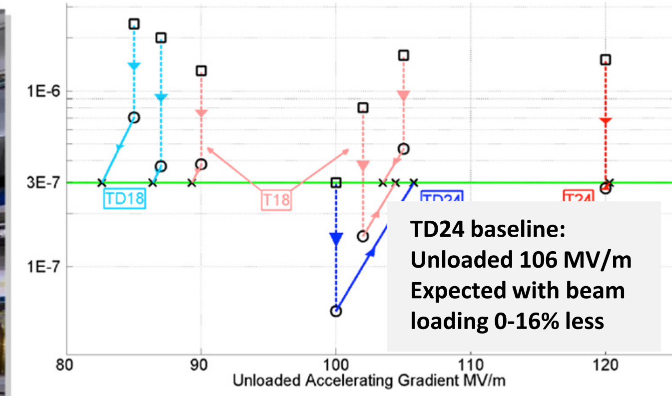
Main linac gradient

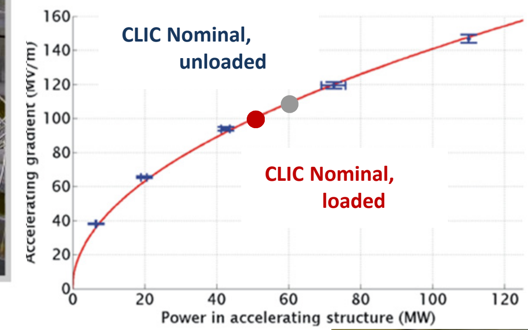
Drive beam scheme



a)

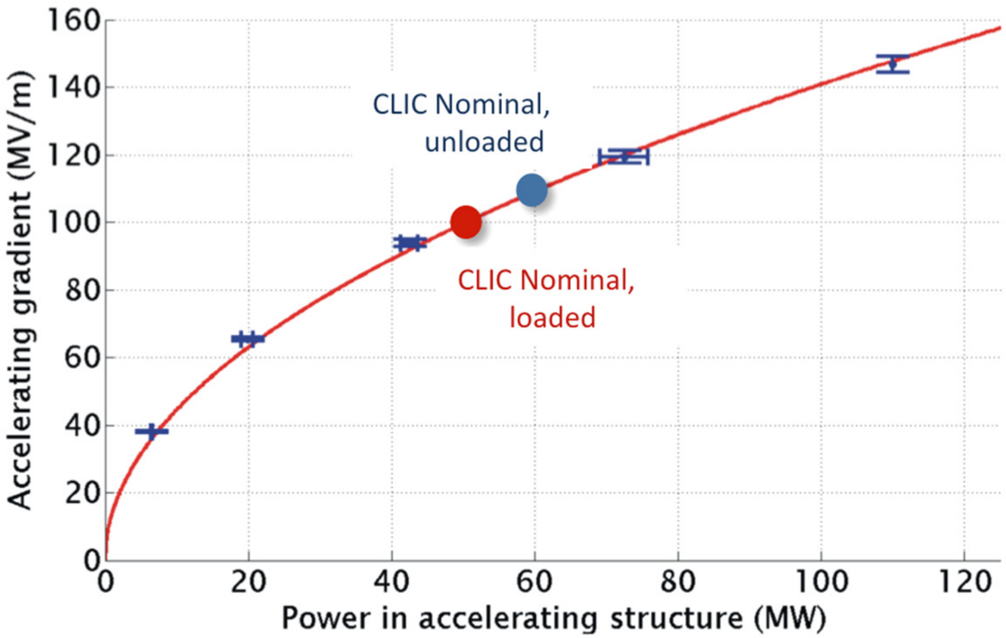


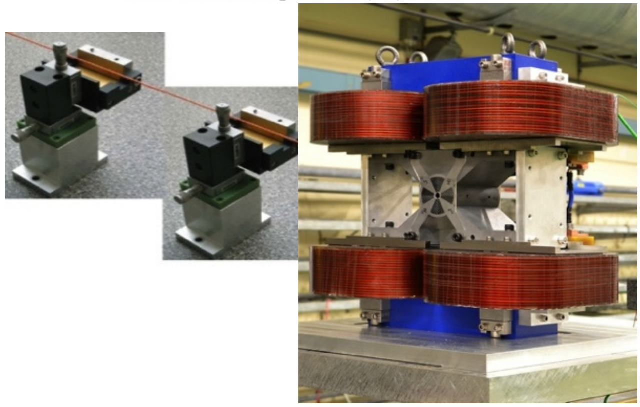




Luminosity

b)





Operation & Machine Protection

Implementation

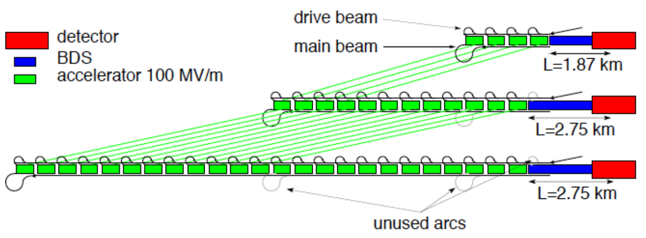
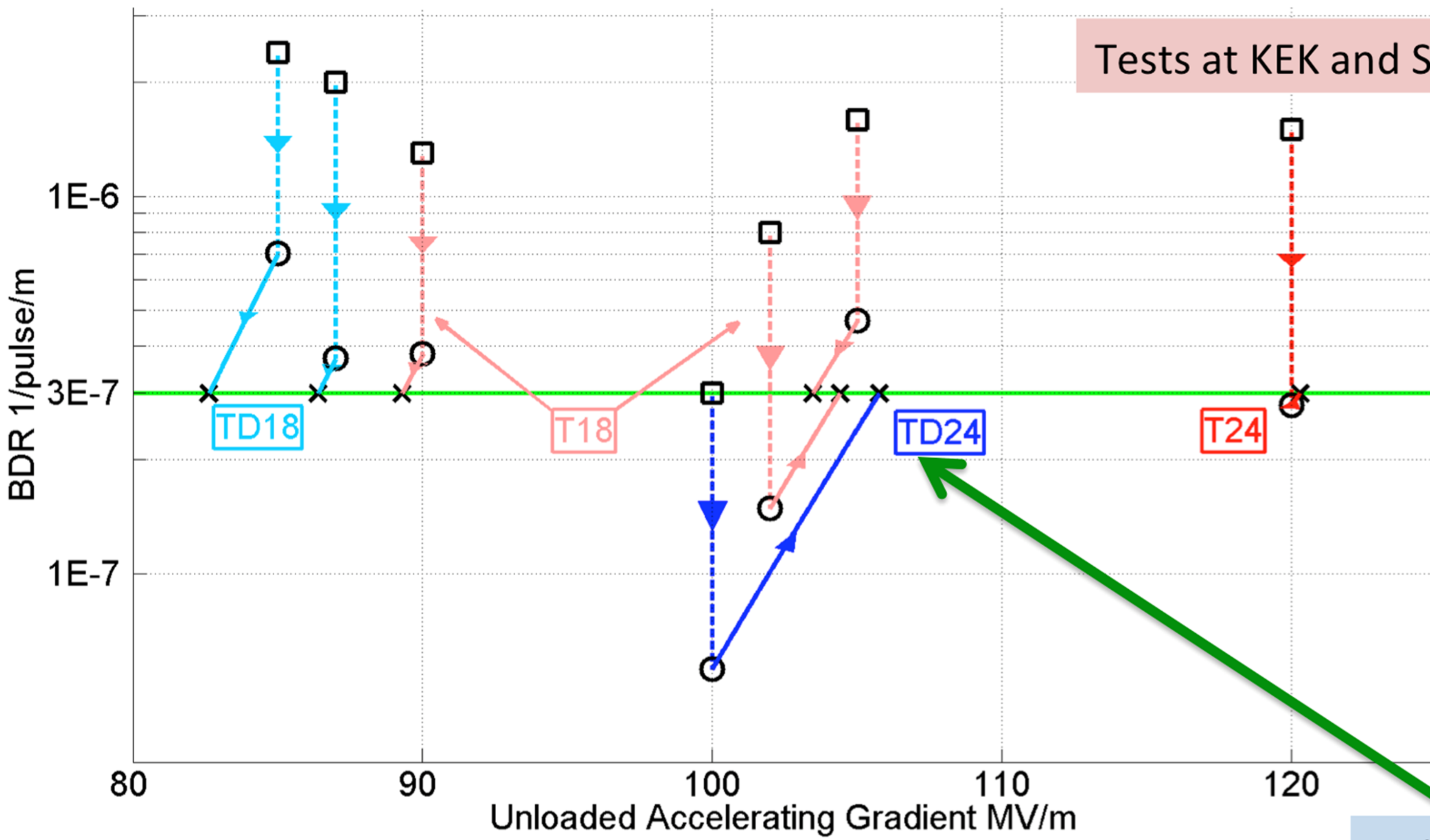


Fig. 3.6: Simplified upgrade scheme for CLIC staging scenario B.

Conclusion of the accelerator CDR studies



Measurements scaled according to

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

Unloaded 106MV/m
With loading 0-16% less

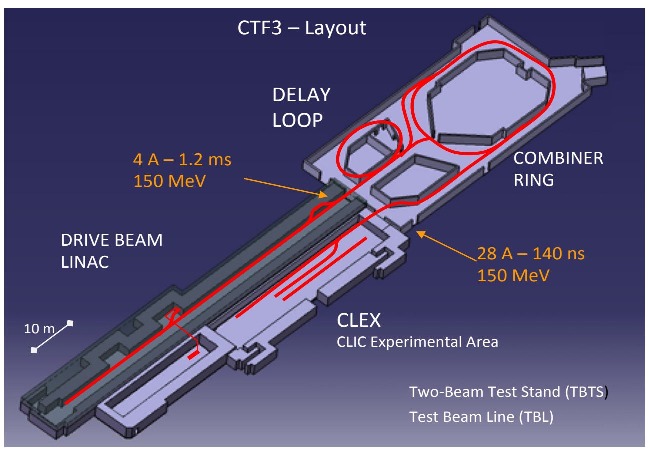
	Simple early design to get started	More efficient fully optimised structure
No damping waveguides	T18	T24
Damping waveguides	TD18	TD24 = CLIC goal

RF Team

Possible CLIC Timeline

2012-18 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.



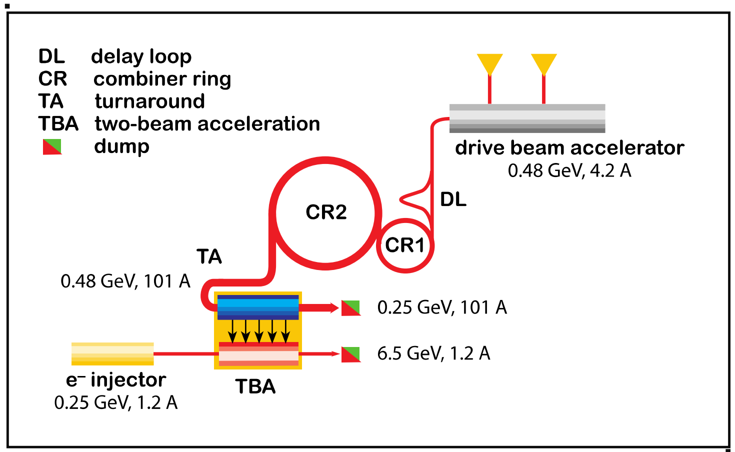
2018 Decisions

On the basis of LHC data and Project Plans (for CLIC and HiE LHC variants in particular), take decisions about next project(s) at the Energy Frontier.

2019-23 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.



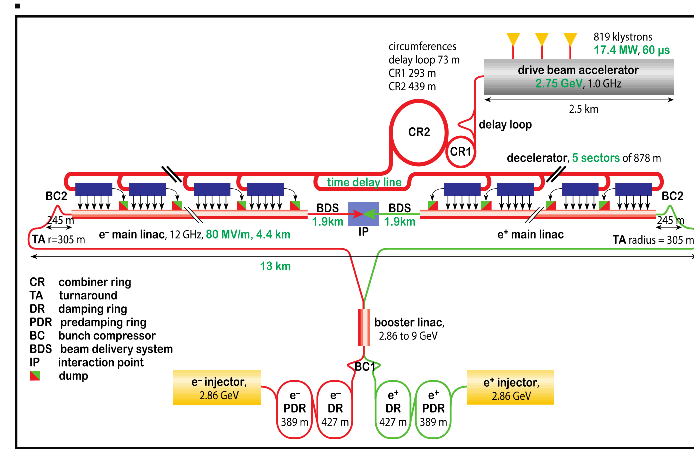
2023-24 Construction Start

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.

The CLIC Collaboration

CLIC multi-lateral collaboration - 48 Institutes from 25 countries

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CERN
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IAP (Russia)
IAP NASU (Ukraine)
IHEP (China)
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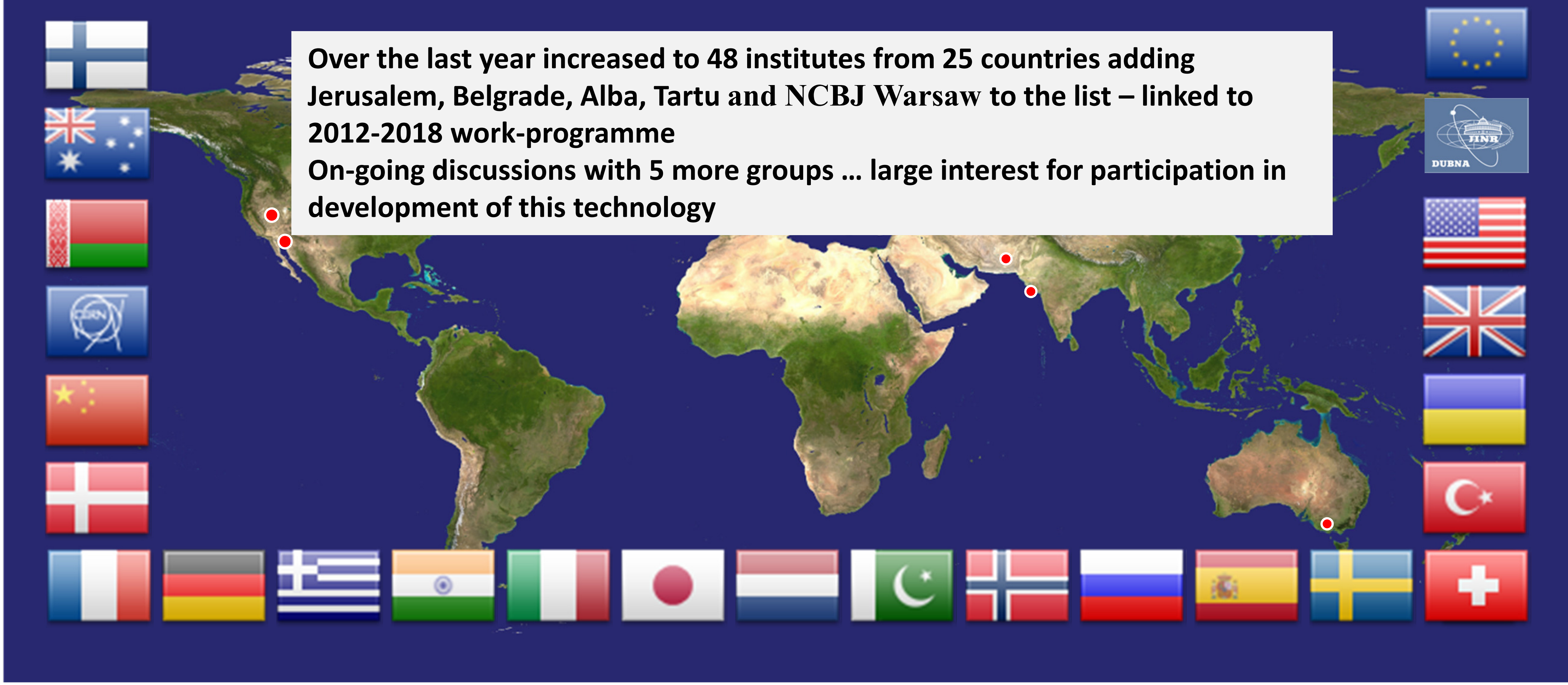
The CLIC Collaboration

CLIC multi-lateral collaboration - 48 Institutes from 25 countries



Over the last year increased to 48 institutes from 25 countries adding Jerusalem, Belgrade, Alba, Tartu and NCBJ Warsaw to the list – linked to 2012-2018 work-programme
On-going discussions with 5 more groups … large interest for participation in development of this technology

ACAS (Australia)
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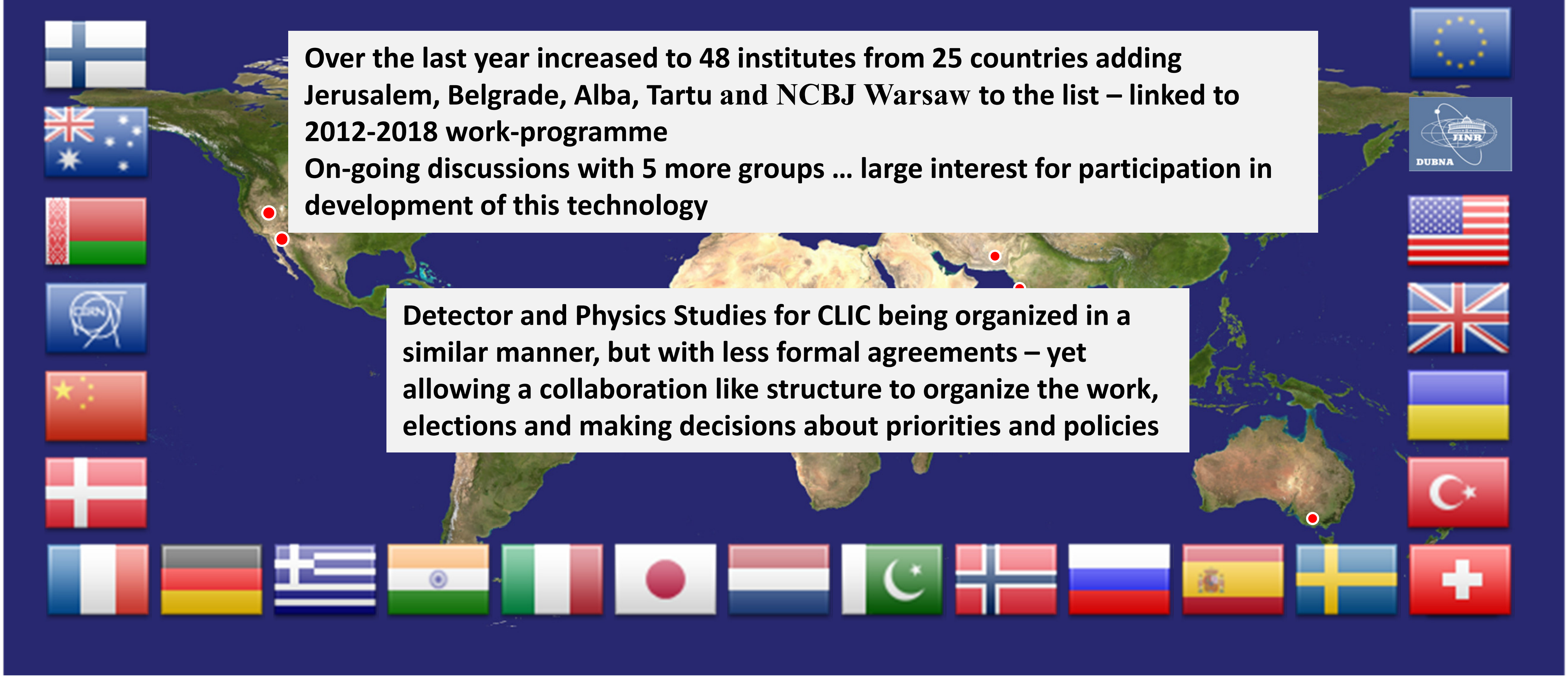

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Detector and Physics Studies for CLIC being organized in a similar manner, but with less formal agreements – yet allowing a collaboration like structure to organize the work, elections and making decisions about priorities and policies

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CLIC status

The period 2012-2018

X-band activites

CLIC Accelerator Activities 2012-18

An optimised machine:

- Higgs mass scale known and much improved cost and power models allow significant optimization
- Re-baselining studies ongoing (~375 GeV, ~1.5 TeV, 3 TeV) – including klystron based part, to be prepared for the optimal implementation strategy
- Overall design and system optimisation, technical parameters for all systems
- Cost, power/energy optimisation, scheduling, site including specific developments/studies

System tests:

- Studies of drive-beam stability and RF units, beam-loading experiments, deceleration, RF power generation and two beam acceleration with complete modules, as well as beam based alignment/beam delivery system/final focus studies
- CTF3+ programme
- ATF, FACET for luminosity performance and various other smaller programmes for specific technology developments
- Continuing/increasing links to light source community related to low emittance rings and X-band based FELs design studies

Energy reach:

- Linked to X-band technology development and industrialisation
- Increase test-capacity (several sites)
- Detailed studies and optimisation of all the critical RF elements (main structures the most central) as well as further industrialisation

Luminosity performance:

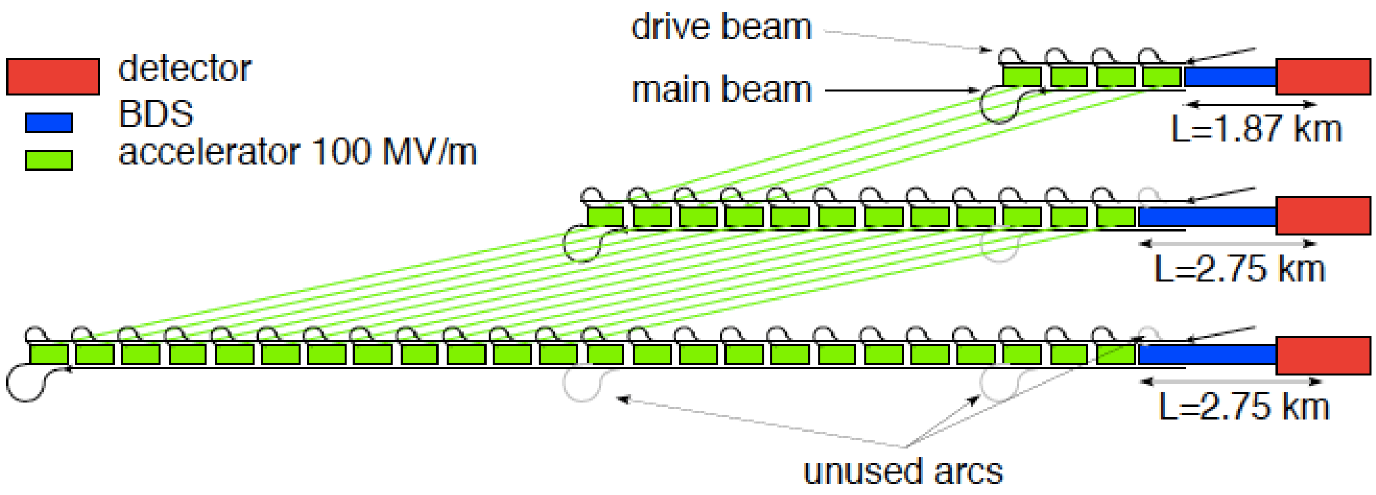
- Overall performance simulation and optimisation of each system – in some case linked to experimental benchmarking and/or tests (some examples below)
- Damping ring designs including experimental development and studies
- Main linac alignment and stability, wakefield studies, BBA alignment
- Final focus optimisation and studies
- Overall performance, reliability, robustness and risk studies

Technical developments:

- Critical elements, for performance, costs or power consumption, industrial developments or as needed for systemtest (some examples below)
- Module development including complete modules (RF, alignment/stability, magnets, instrumentation, vacuum, cooling, controls) for lab and CTF3
- RF power systems development (1 GHz)
- Alignment and stability methods and hardware

Rebaselining: Goals for Next Phase

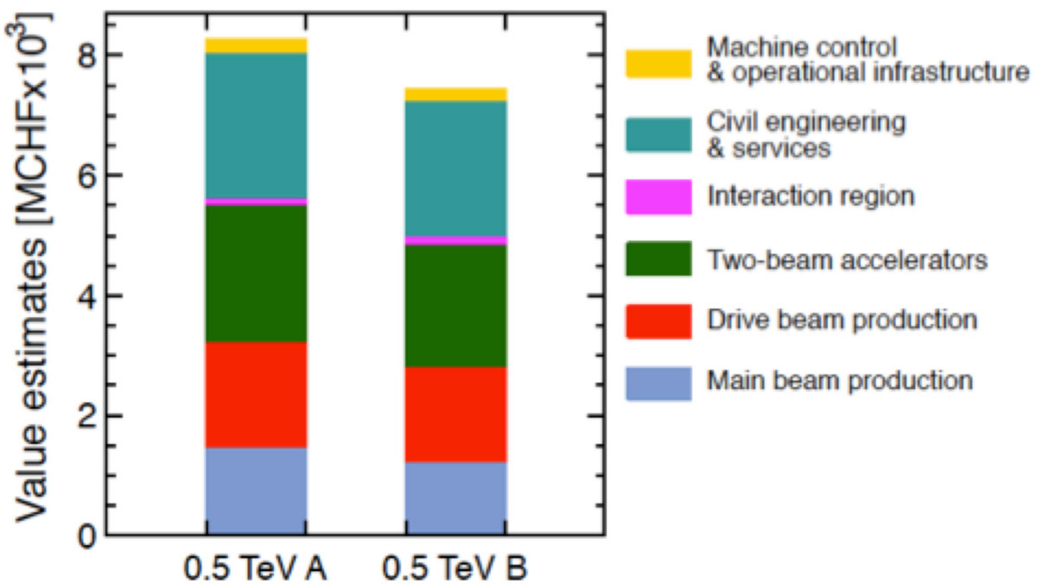
- Iterate on energy choices
  - Stage optimised for 375GeV for Higgs and top
  - 1-2TeV depending on physics findings, will still also do Higgs
  - 3TeV as current ultimate energy, includes more Higgs
- Focus on optimisation of first energy stage
  - But consider upgrades



- Identify, review and implement cost and power/energy saving options
  - Identify and carry out required R&D
- Re-optimise parameters (global design)
  - Develop an improved cost and power/energy consumption model
  - Iterations needed with saving options
- Study alternatives
  - E.g. first stage with klystrons

- Need to remain flexible, since we are waiting for LHC findings
  - But have some robustness of specific solutions and can anticipate this to some extent

Cost/power reductions : some identified savings



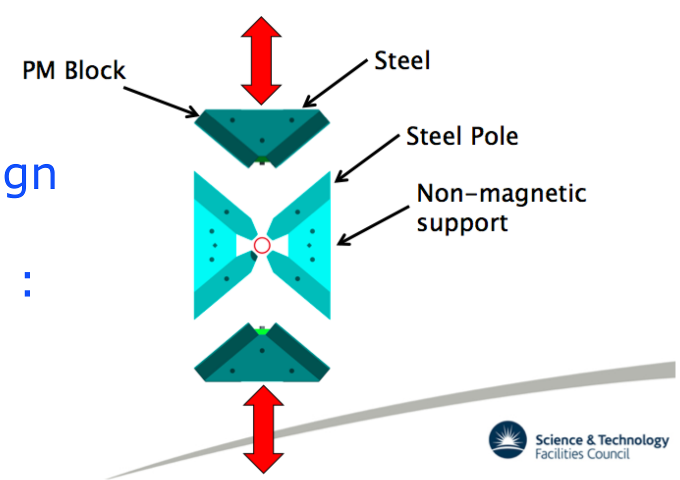
First to second stage: 4 MCHF/GeV (i.e. initial costs are very significant)

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

- Use of **permanent or hybrid magnets** for the drive beam (order of 50'000 magnets)
- Increase **drive beam accelerator** peak klystron power (has been underestimated) and increase L-band tube efficiency > 70%
- Electron **pre-damping ring** can be removed with good electron injector
- Dimension drive beam accelerator building and infrastructure are for 3TeV, **dimension to 1.5TeV results in large saving**
- Potential to use **cheaper material** for the drive beam accelerator structures
- Systematic **optimization** of injector complex linacs in preparation
- Power consumption:
  - Optimize and reduce overhead estimates

Permanent magnet design for the decelerators :



L-band klystron optimization studies :

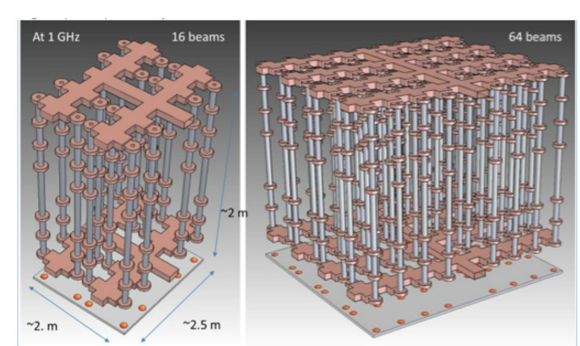


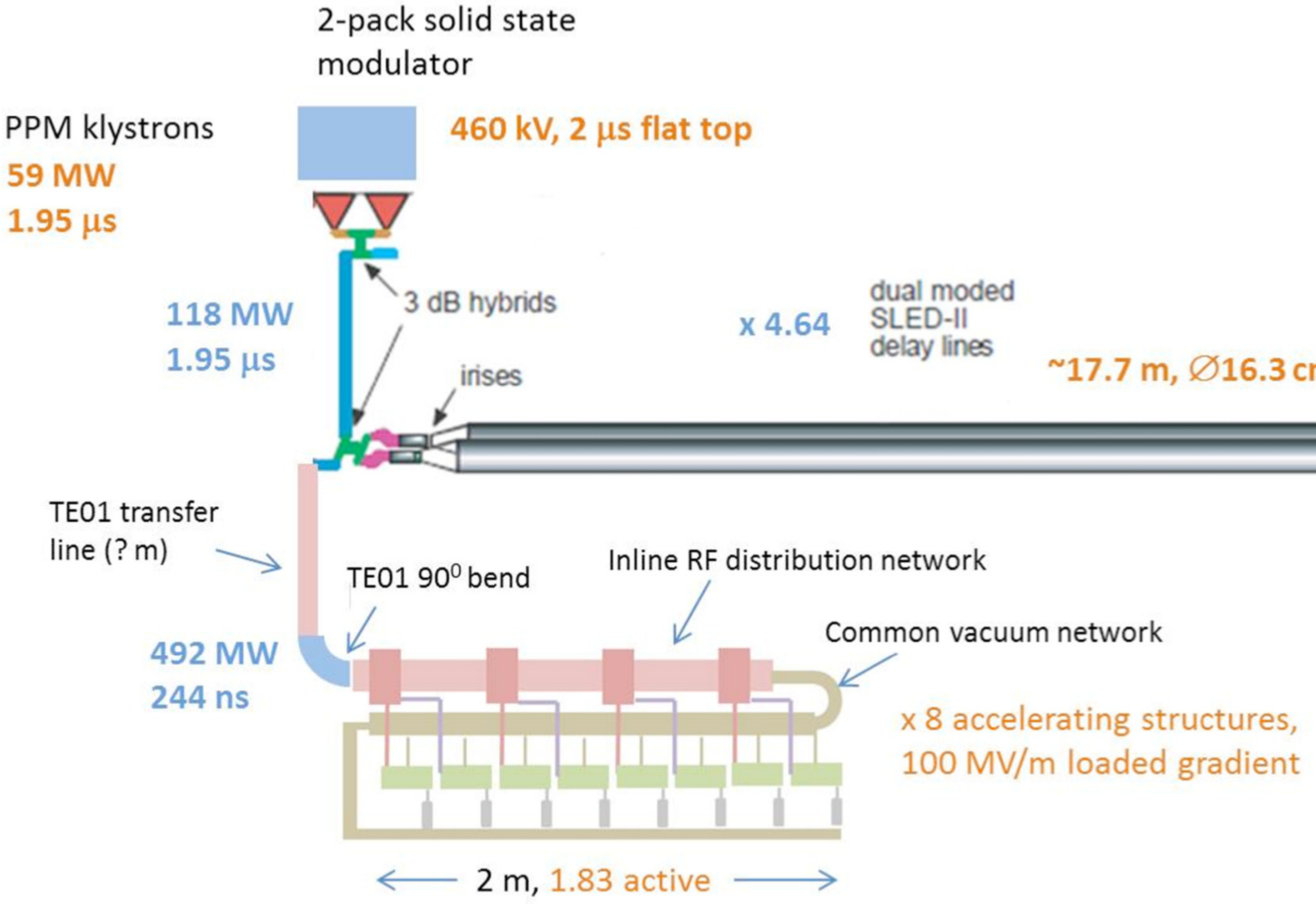
Figure 18: The clustered klystrons with 'most compact' RF distribution network [13].

Study of Klystron-based CLIC

Linac energy overhead	10%
Linac filling factor	≈ 0.75
Number of klystrons	4484
Number of structures	17936
Active length/single linac	2.242 km
Length/single linac:	3 km
bunches/pulse	312
particles/bunch	$3.72 \cdot 10^9$
repetition rate	50 Hz
Luminosity	$10^{34}\text{cm}^{-2}\text{s}^{-1}$

Only interesting for first energy stage
Would need ~30,000 klystrons at 3TeV

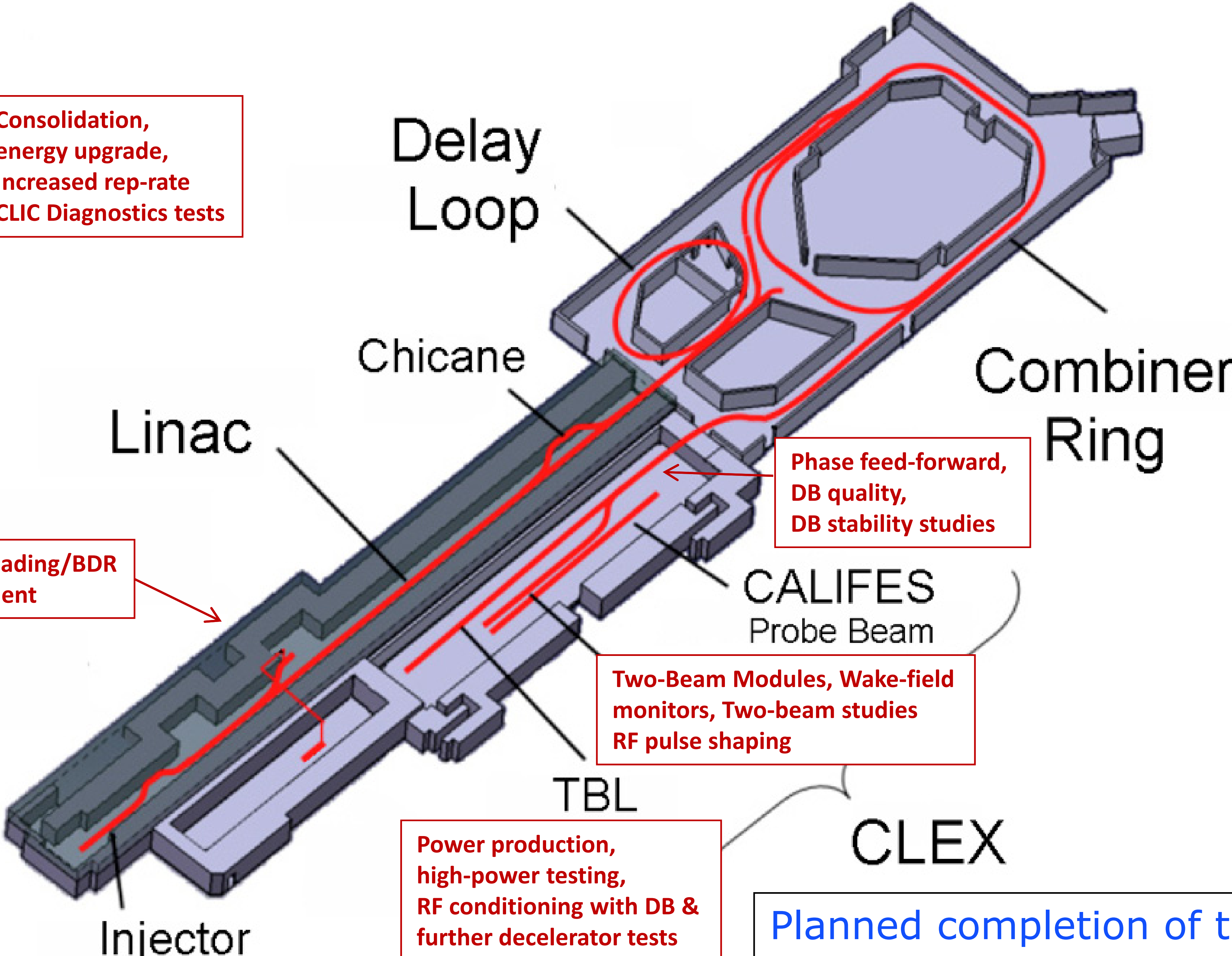
Simple parametric cost study has shown that nominal structure CLIC_G is very good for klystron-based approach
Can use the same structure for drive beam and klystron-based



Defined RF unit based on this structure and achieved klystron performances

A simplified-model cost comparison shows similar cost for 500 GeV klystron-based CLIC as 500 GeV drive beam CLIC.

CLIC Test Facility (CTF3)



Consolidation,
energy upgrade,
Increased rep-rate
CLIC Diagnostics tests

Phase feed-forward,
DB quality,
DB stability studies

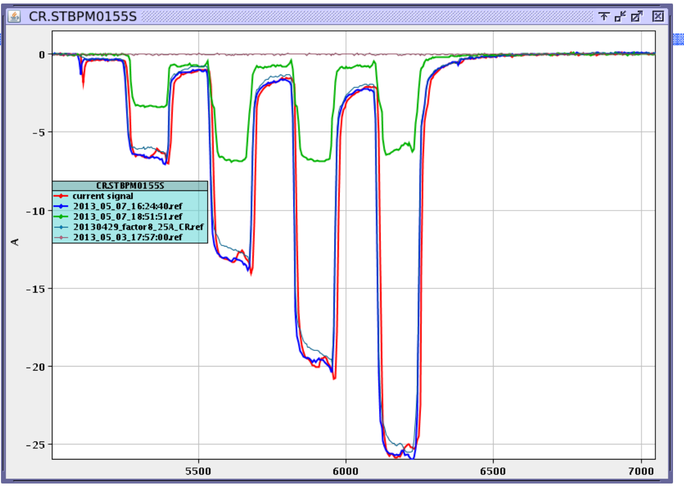
Beam loading/BDR experiment

Two-Beam Modules, Wake-field monitors, Two-beam studies
RF pulse shaping

Power production,
high-power testing,
RF conditioning with DB &
further decelerator tests

Planned completion of the CTF3 program: end 2016

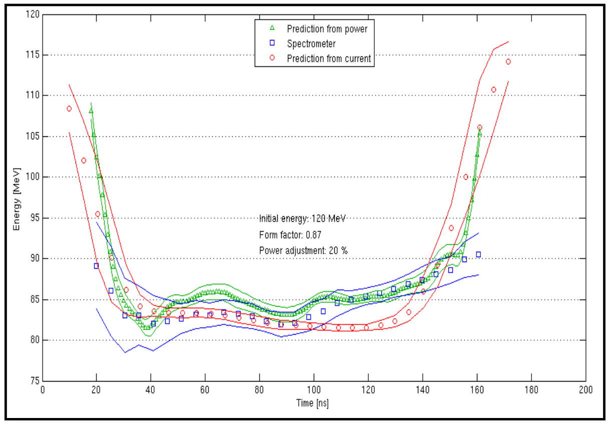
CTF3: recent results and plans



- Operation with **8 times combination** now routine
- New feedbacks added to improve phase stability

Goal is to achieve

- $\varepsilon_x = \varepsilon_y \cong 150\ \mu m$ also for factor 8, currently $\varepsilon_x = 550 \mu m$ due to orbit error
- Charge stability $\sigma_Q \approx 10^{-3}$ for factor 8



- **Deceleration increased from 30% to 35%**
- Decelerator BPM prototype tested (stripline, LAPP)
- Good understanding of the optics

Goal is to reach 40% deceleration

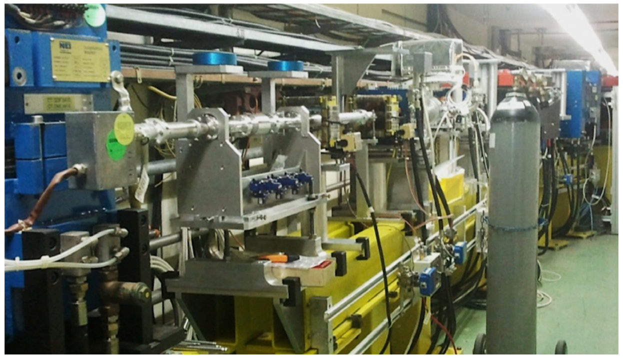
Feed-forward to correct drive beam phase

Phase monitors successfully tested

Goal:

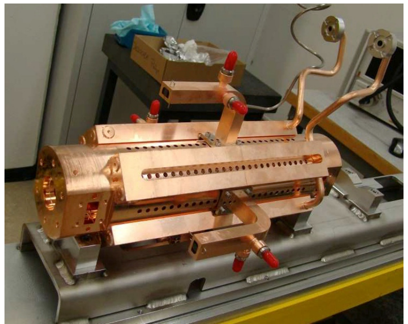
- Install kickers and amplifiers (FONT5) in 2013
- First tests in autumn

INFN Frascati
JAI/Oxford



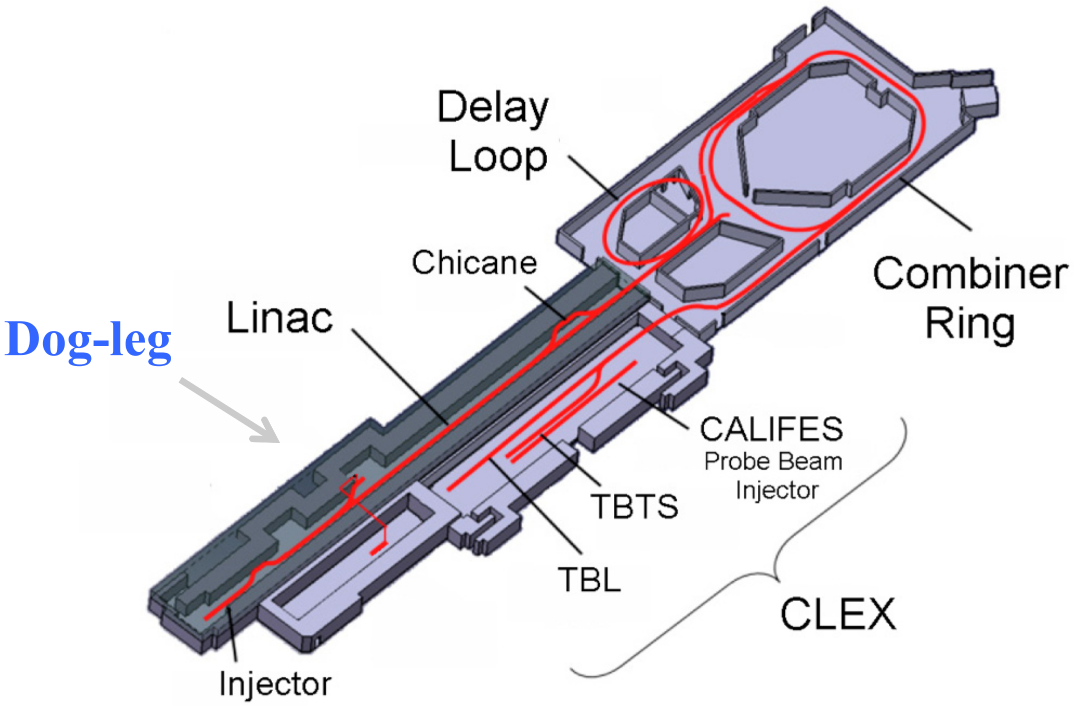
CEA IRFU - Saclay

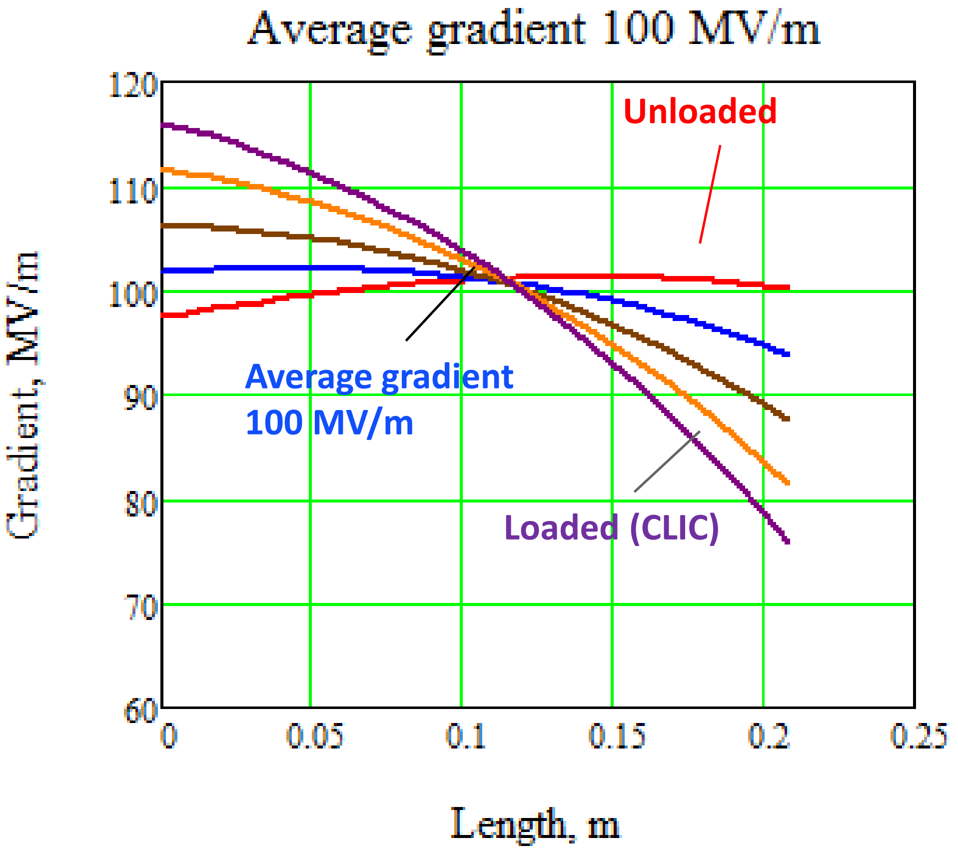
- Structure with **wakemonitor** installed in TBTS
- Resolution (required: 3.5 um) is being tested

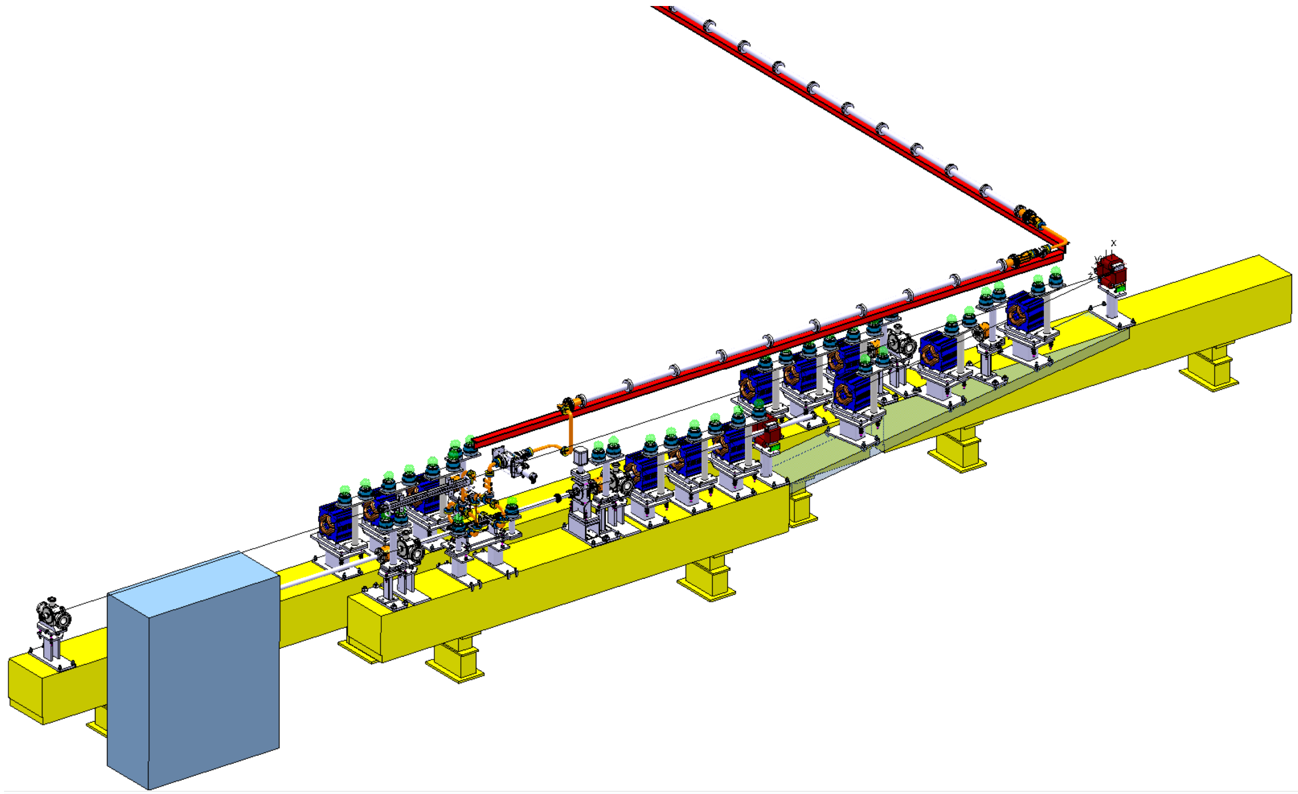


- **1 GHz klystron test stand**, with gun and sub-harmonic buncher planned

Beam Loading Test Facility



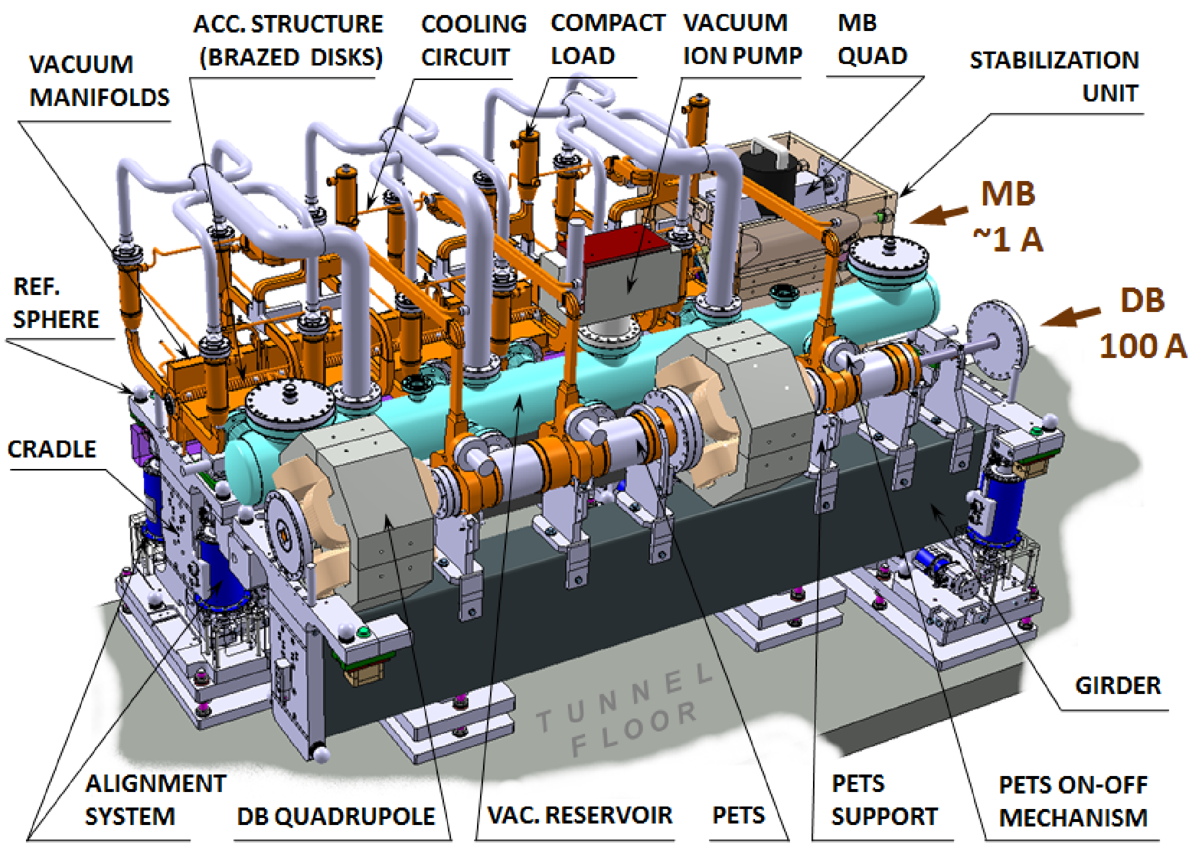


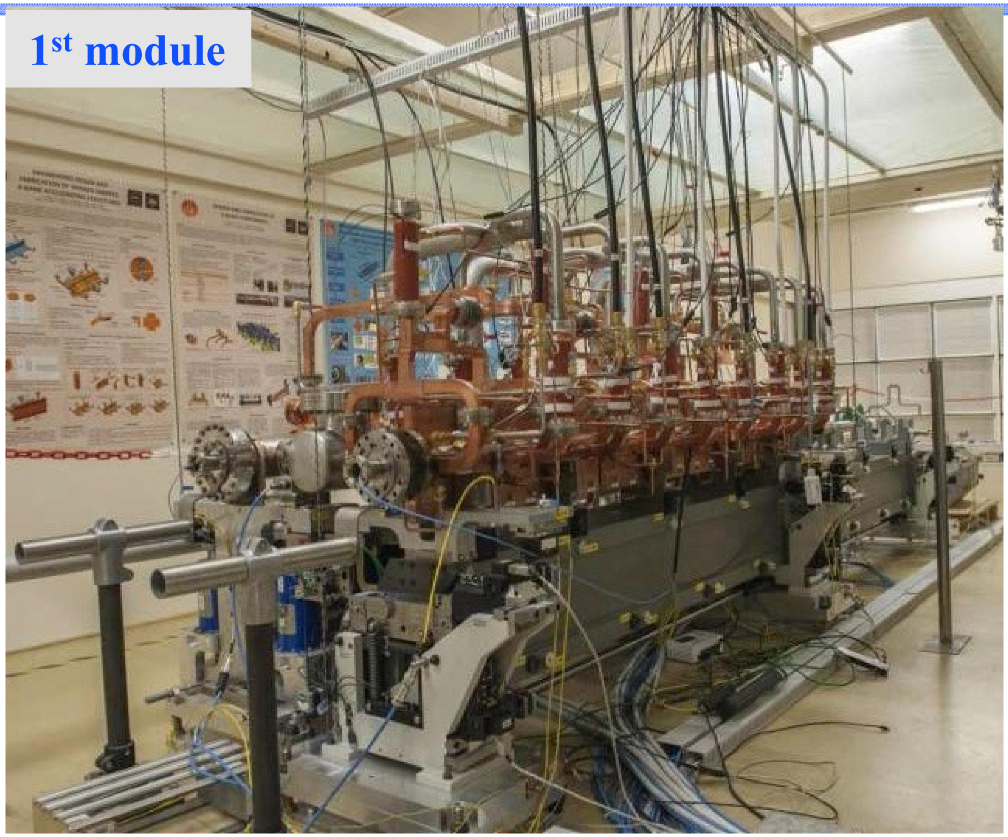


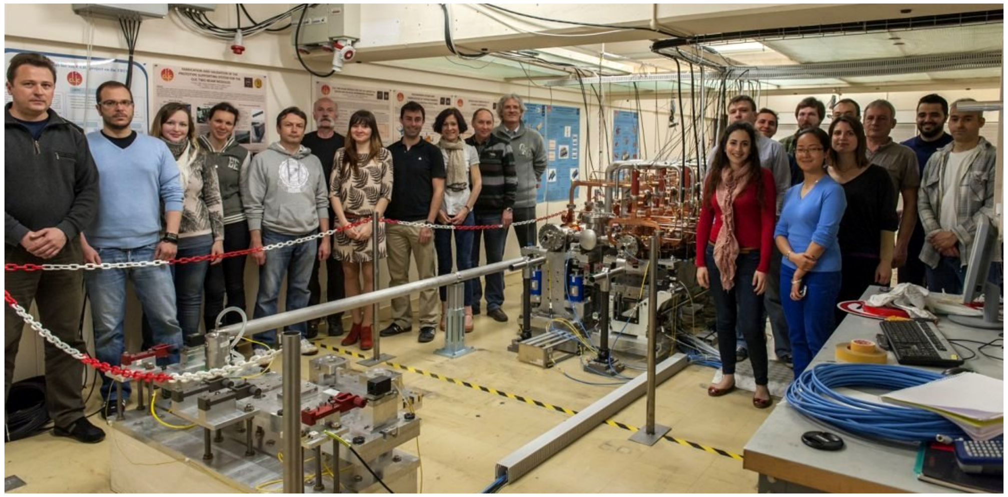
Test stand in CTF3 dog-leg to test gradient with **beam loading**

- Structure powered at full power with 12 GHz klystron
- 1 A drive beam sent through structure
- System begin commissioned
- Conditioned structure to come this year

CLIC Two-beam Module







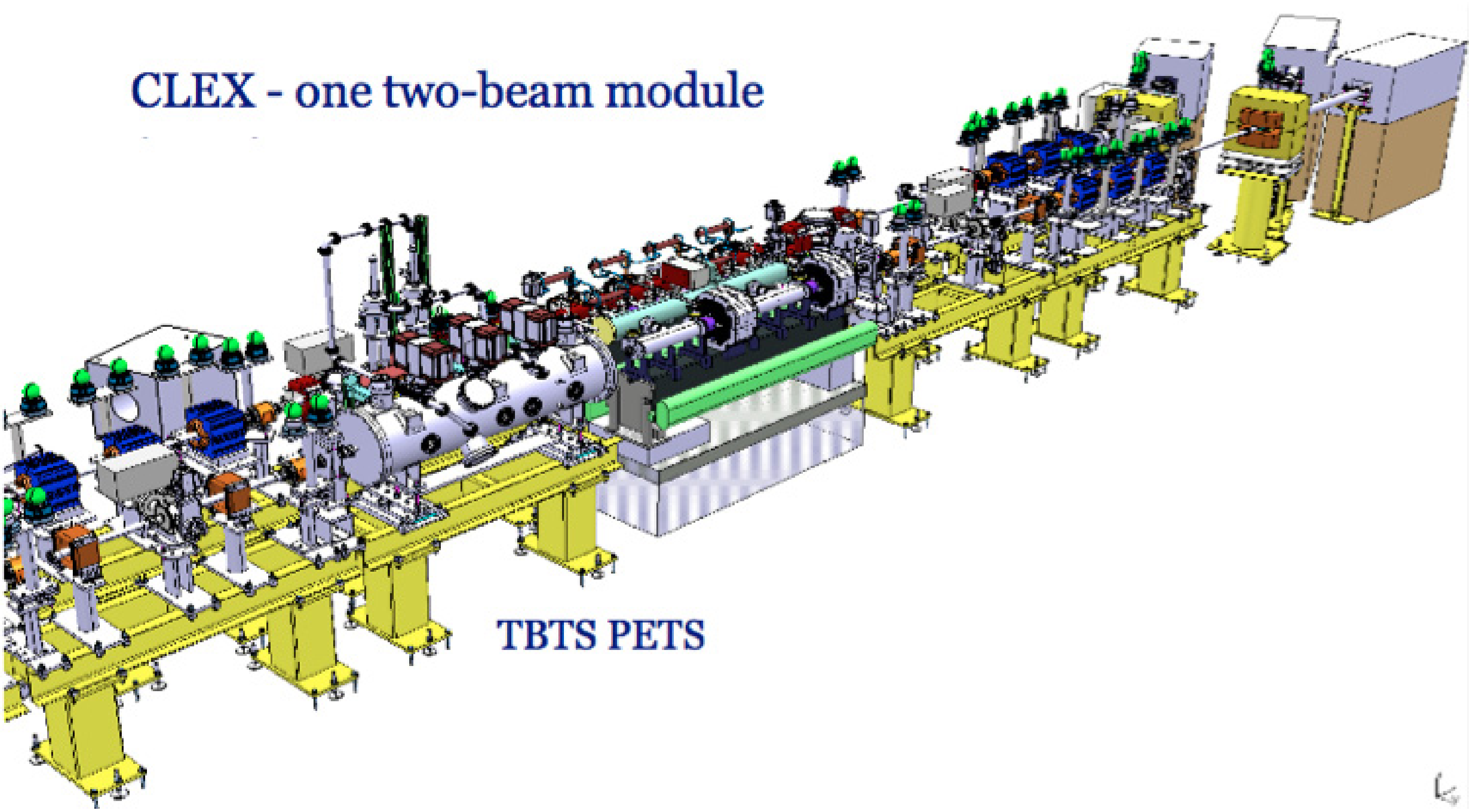
G. Riddone, Module Team

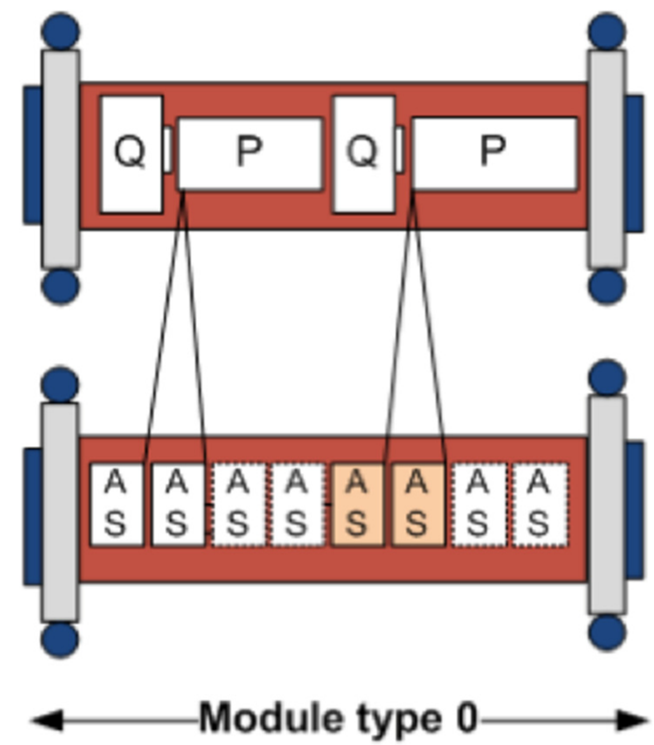
Complete test modules:

- **First laboratory CLIC module completed**
- All safety measures implemented (power dissipation ~7 kW per module)
- DAQ and control system
- (Labview based) tested and validated
- First tests promising and in line with FEA simulations

CTF3 Two-beam Module

A Two-Beam Module with full rf functionality planned to be installed in CTF3

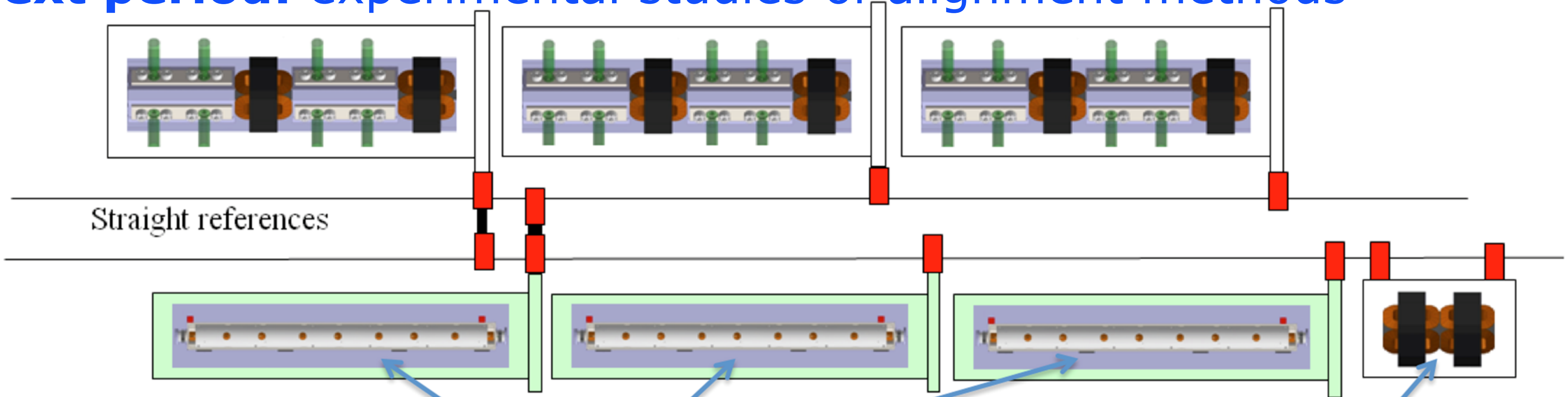




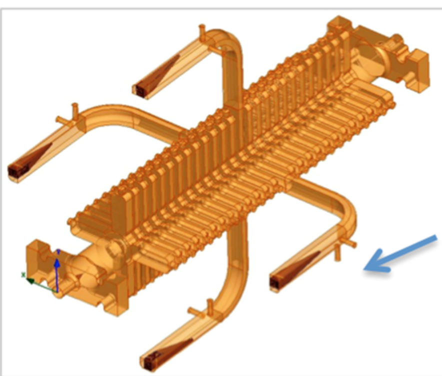
Will provide validation of the CLIC module functionality with rf and beams

Main Linac Alignment

Emittance preservation feasibility for LC: mainly simulation studies.
Next period: experimental studies of alignment methods

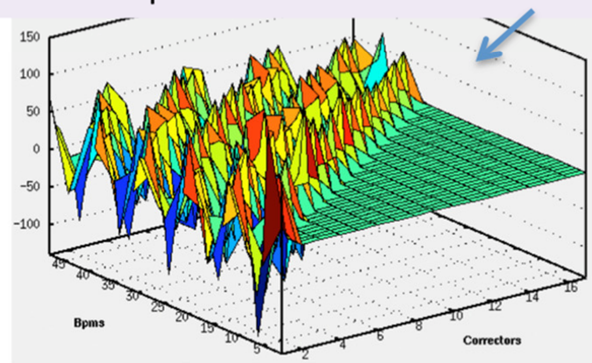


1) Pre-align BPMs+quads accuracy O(10µm) over about 200m and Stabilize quadrupole O(1nm) @ 1Hz
Next period: dedicated research test stand



3) Use wake-field monitors accuracy O(3.5µm).
Next period: improved design and testing in the CLIC Test Facility.

2) Beam-based alignment
Next period: experimental tests at FACET



CLIC Beam-Based Alignment tests at FACET

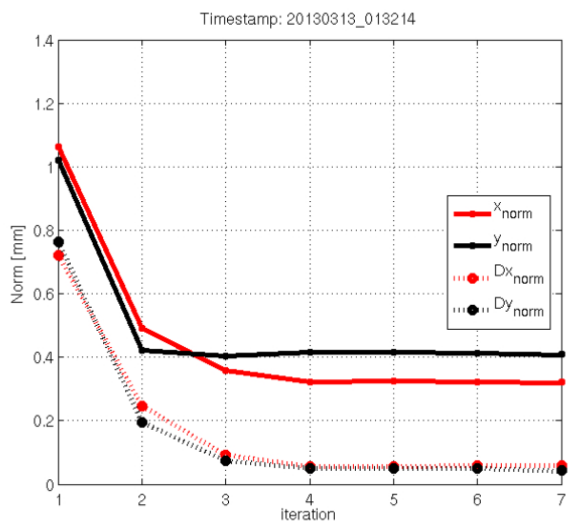
A. Latina,
J. Pfingstner,
E. Adli,
D. Schulte

Dispersion-free Steering (DFS) proof of principle – March 2013

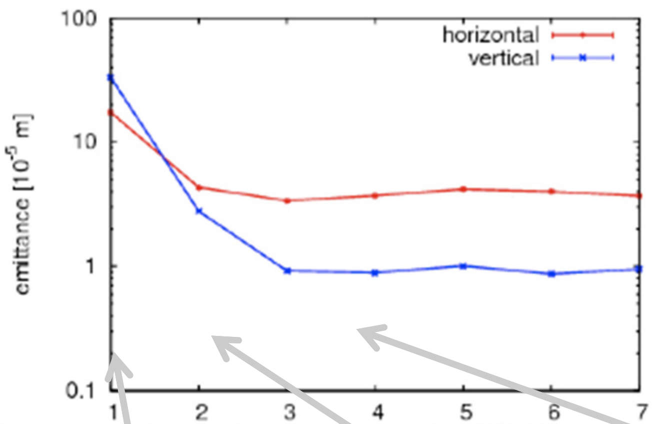
DFS correction applied to 500 meters of the FACET linac

- SysID algorithms for model reconstruction
- DFS correction with GUI
- Emittance growth is measured

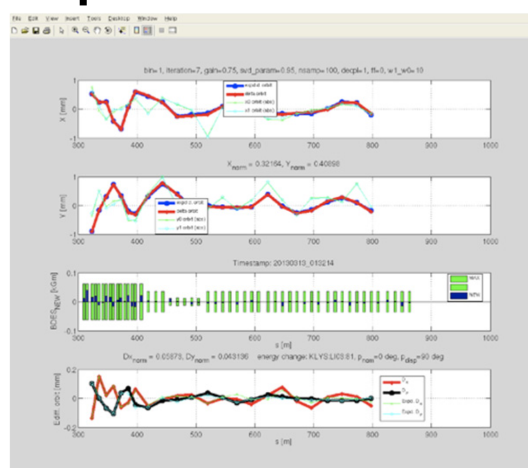
Orbit/Dispersion

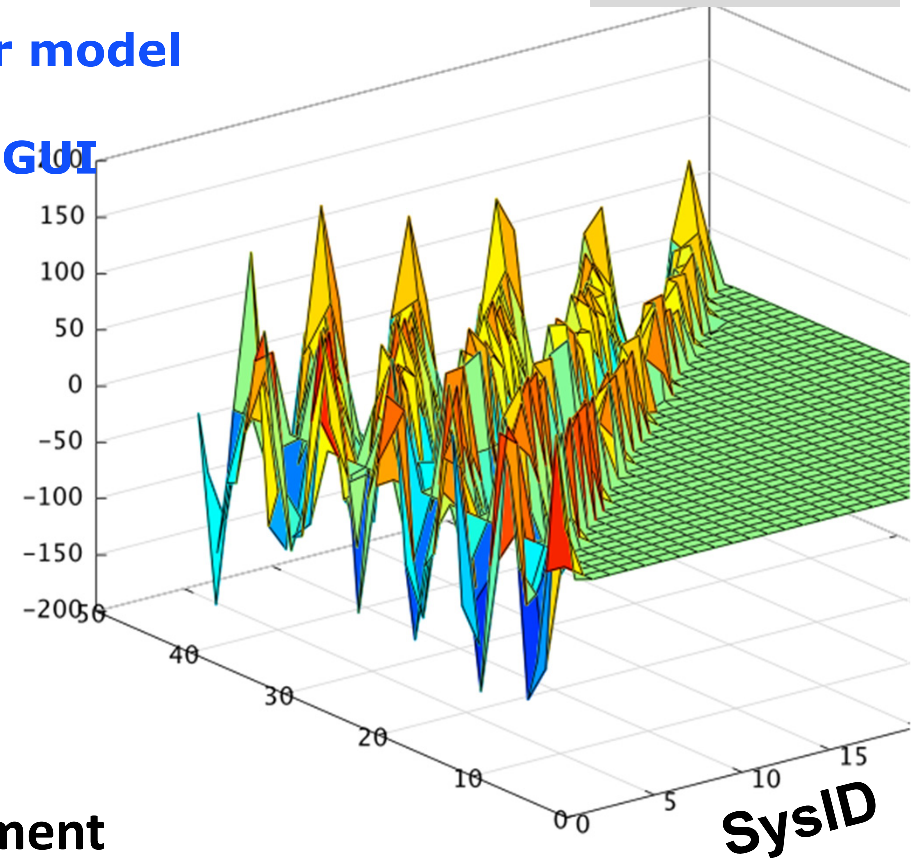


Emittance

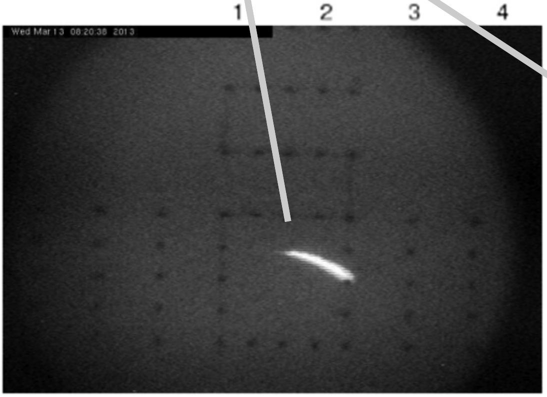


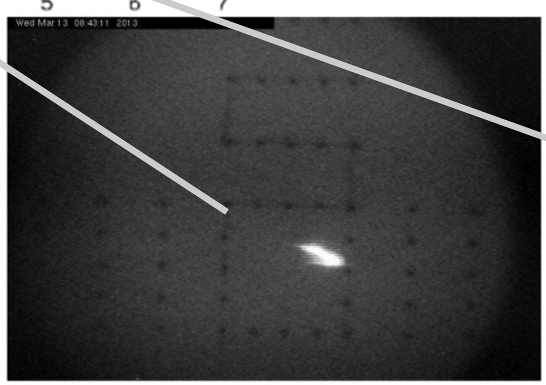
Graphic User Interface:

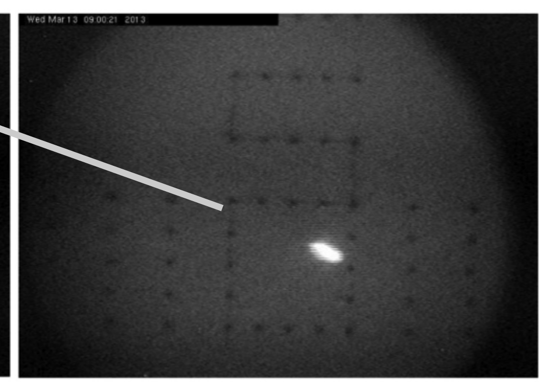




Beam profile measurement





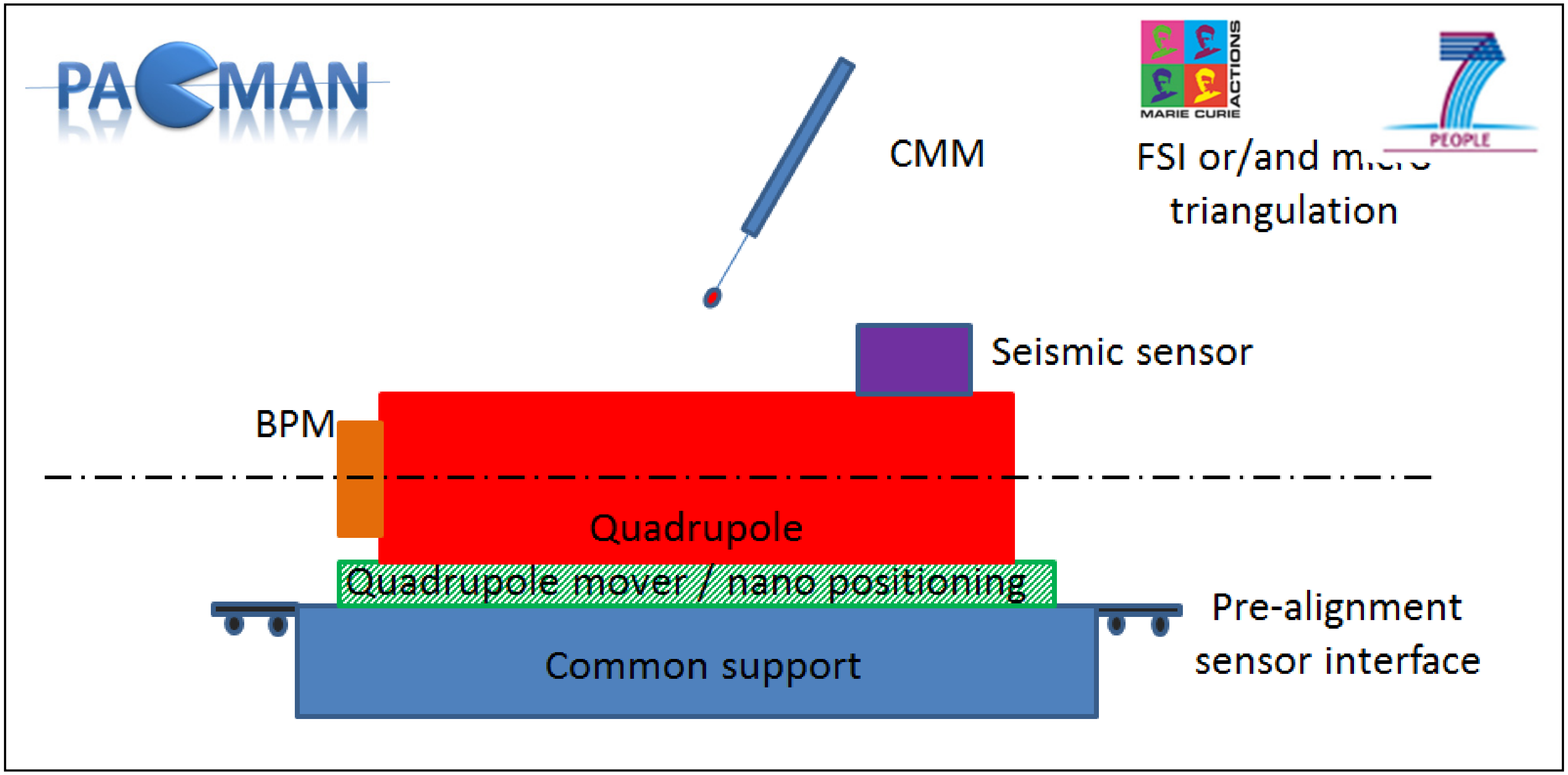


Before correction | After 1 iteration | After 3 iterations

Incoming oscillation/dispersion is taken out and flattened; emittance in LI11 and emittance growth significantly reduced.

"PACMAN" test-bench

Particle Accelerator Components Metrology and Alignment to the Nanometre scale



- Develop an alternative solution integrating all the alignment steps and technologies integrated at the same time and location (CMM machine)
- Build **a full prototype** at CERN
- 15 academic and industrial partners, EC funds **10 PhD students** (Marie Curie) : applications process just finished

CLIC status

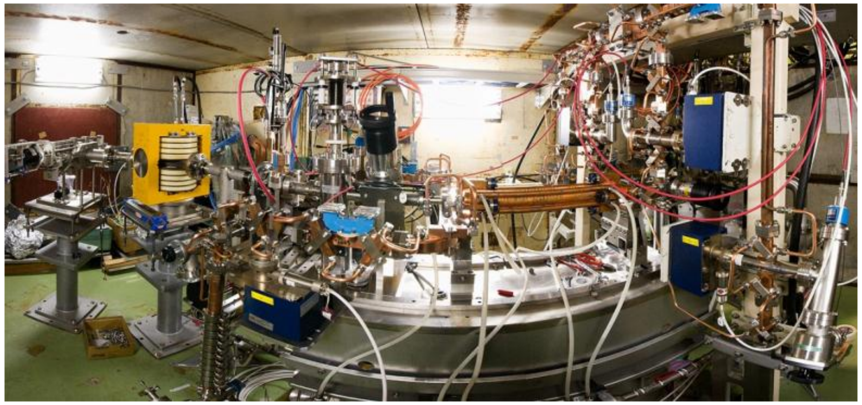
The period 2012-2018

X-band activites

12 GHz Test Stands for CLIC

Previous:
Scaled 11.4 GHz tests at SLAC and KEK.

NEXTEF at KEK

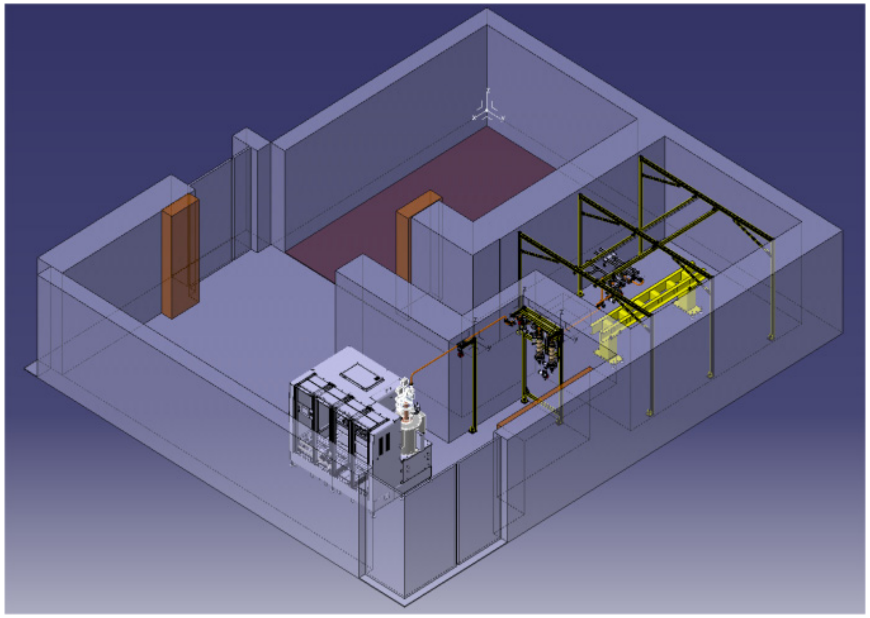


ASTA at SLAC

XBOX1 at CERN operational with SLAC klystron

100 MW can be provided in pulses of 250 ns, 50 Hz.
Can power two CLIC accelerating structures.

XBOX2 at CERN, industrial klystron should be ready this year



Planned capacity : power six CLIC accelerating structures

Next period: greatly increased X-band rf test capability, at 12 GHz, at CERN

Collaboration: CLIC X-band to FELs

New initiative**: CLIC X-band technology to FELs**

CERN does not do light sources

- It is not part of CERN's mandate

But use of X-band in FELs in other labs would help CLIC for a number of tasks

- Further technical developments with industry
  - Will create the industrial basis
- Performance studies of accelerator parts and systems
  - From components up to large scale main linac system test

We think that FELs can profit from X-band technology

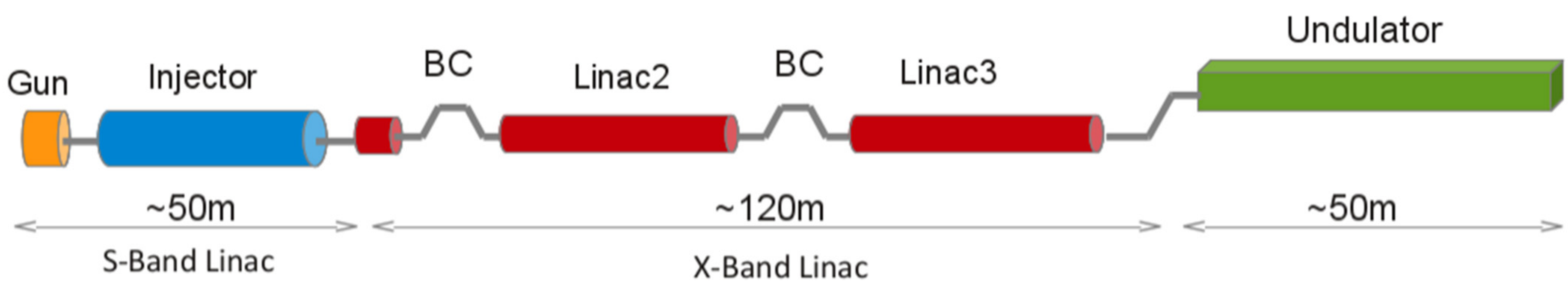
- For collaborators to judge based on further studies

CLIC will work with laboratories to build an FEL and help them as needed (including RF, instrumentation, alignment, beam dynamics, test stands, industrial contacts …)

Compact FEL : details

Collaboration **kick-off meeting**: D. Schulte, CERN, September 2013. Institutes from 5 countries present.

Looked a bit into a linac design for a typical Angstrøm FEL :



Proposal of Ch. Adolphsen et al. shows concept for X-band

E=6GeV Q=250pC σ_z=8µm ε≈400nm-500nm

Swiss FEL (C-band, approved):

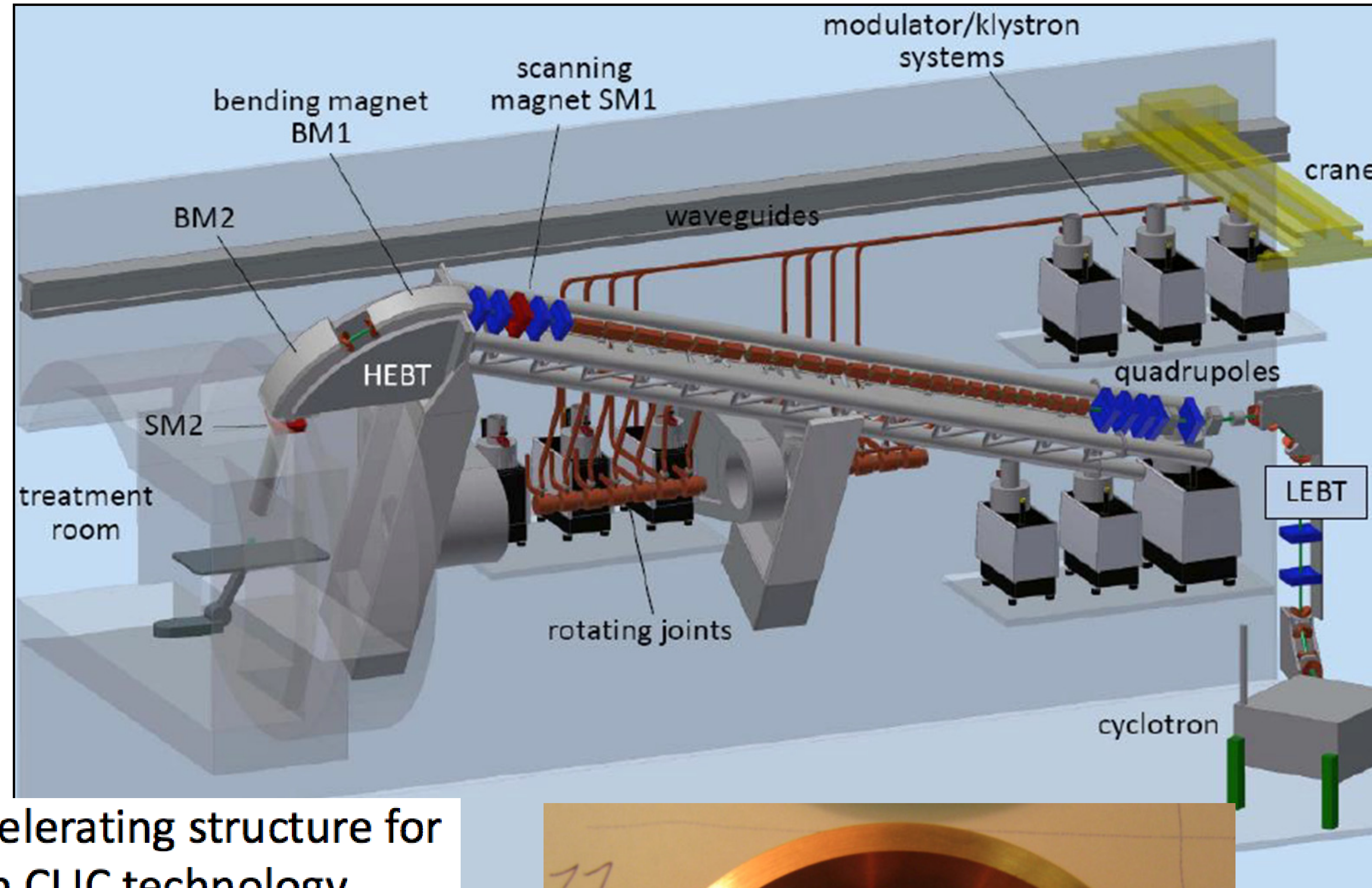
E=5.8GeV Q=200pC σ_z=7µm ε≈200nm-500nm

As example we did chose Q=250pC, E=6GeV and will go for similar bunch lengths
Do not study injector (use the one from PSI for now) or undulator

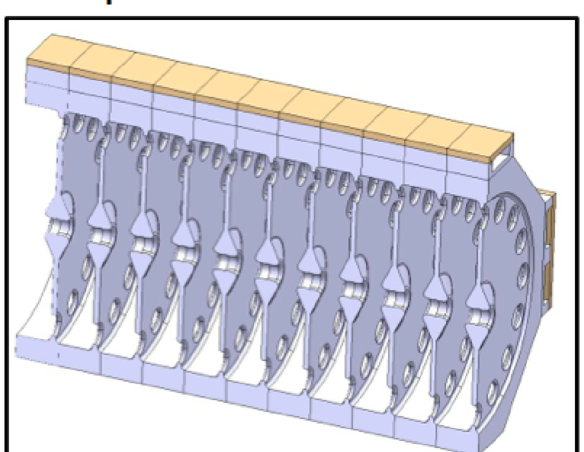
High-gradient hadron therapy structures

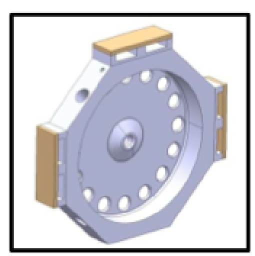
Technology transfer of CLIC high-gradient research to 3 GHz high gradient structures for **proton therapy** (TERA Tulip project).

Increase the effective gradient in proton therapy linac structures (cyclinacs) to about **50 MV/m** (factor two).



Backward wave high-gradient accelerating structure for proton acceleration based on CLIC technology





Conclusions

- The CDR volumes document :
  - The feasibility studies for CLIC
  - A staged approach to implement the project

- Active and varied program for the next period :
  - **Rebaselining** is on the way with focus also on low energy
  - System tests (**modules**, test stands)
  - Stabilization and alignment demonstrations -> **luminosity reach**
  - Focus on **cost** and industrialization

- Collaborations are formed to promote the use of CLIC technology for other applications; **FELs and medical**

- Thanks to the CLIC collaboration for the slides and work presented