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Swiss contributions to CLIC accelerator R&D

Terence Garvey

CHIPP meeting, Sursee, 25th June, 2013.

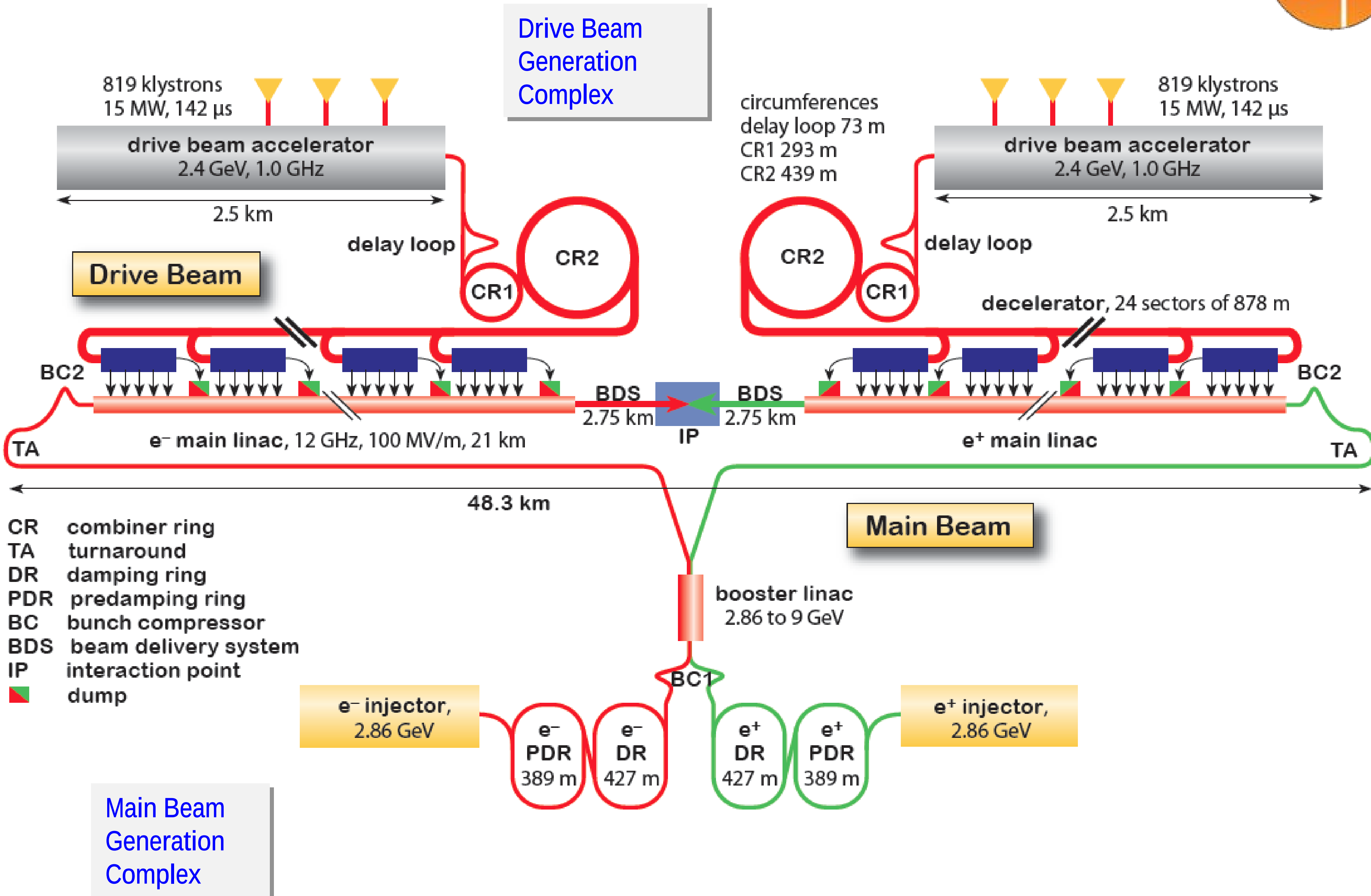
Characteristics of CLIC

Obtain the required energy using normal conducting, high accelerating gradient, 100 MV/m, structures with pulse lengths of the order of 200 ns.

Meet the necessary high peak power requirements by employing high frequency (X-band, 12 GHz) structures powered by the so-called drive beam scheme (i.e. not klystrons). Structure peak input powers are ~ 250MW/m.

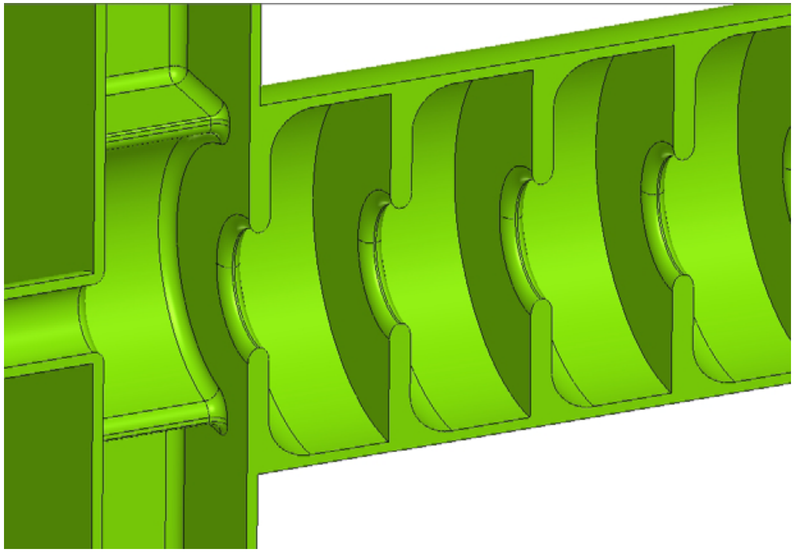
Meet the luminosity needs with acceptable *high average power* consumption by producing, transporting and colliding low-emittance, multi-bunch beam trains. This requires high performance damping rings, micron-level precision and alignment of the main linacs, higher-order-mode free accelerating structures, nano-meter quadrupole stabilisation and sub-nm final focus stabilisation.

CLIC Layout at 3 TeV



Requirements of the accelerating structures

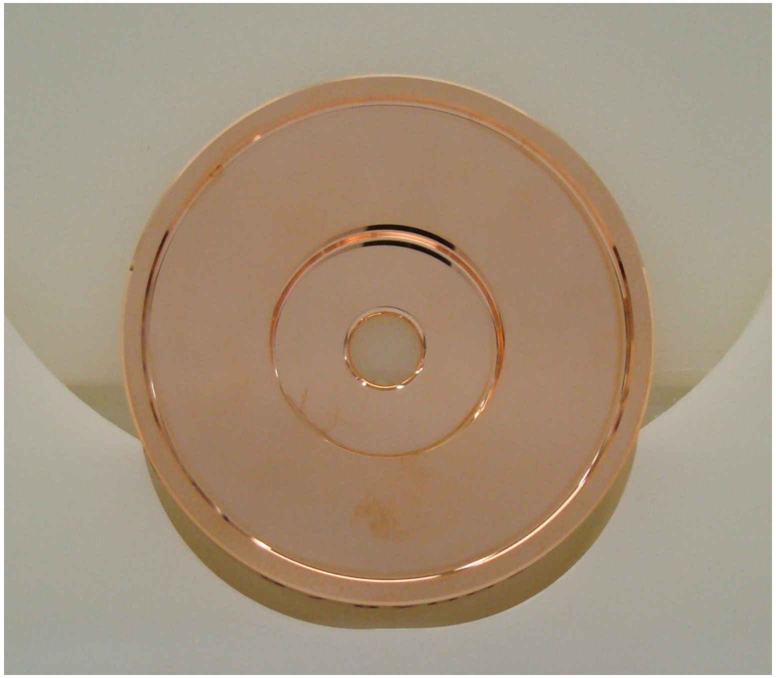
- Should reach 100 MV/m under beam loading conditions
  - keep facility length to a ‘reasonable’ value (~ 30 km of active acceleration).
- Should have higher-order-mode Q’s below ~ 10
  - reduced wake-field effects →use HOM ‘dampers’
- Should exhibit a breakdown rate (BDR) < 3×10^{-7} per pulse per meter
  - requirement to limit luminosity loss < 1%



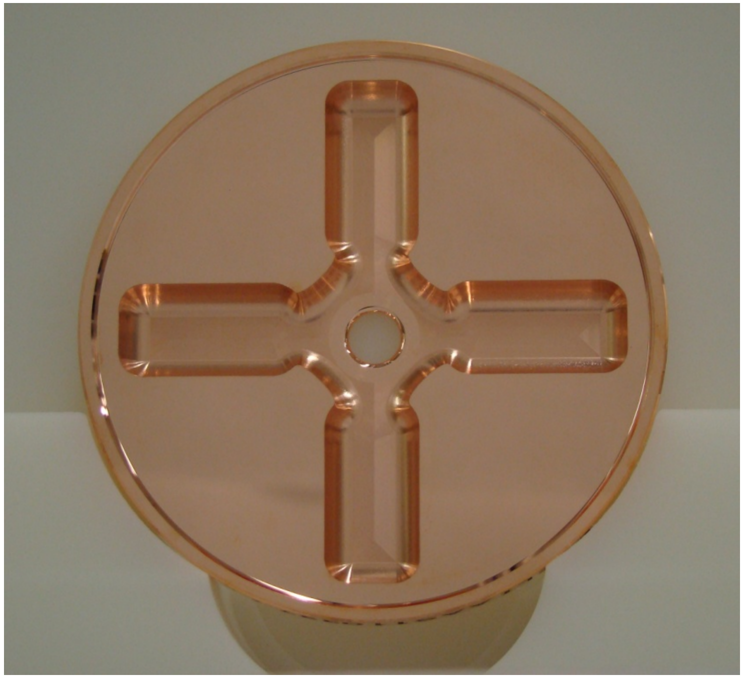
Schematic of typical multi-cell Traveling Wave structure

Damped and un-damped disk geometries.

Damping is achieved by coupling the higher-order-modes out into wave-guide runs perpendicular to the beam axis. The modes are then dissipated in “lossy” ceramics inserted into the WG.
The acceleration mode is “cut-off” by suitable choice of the WG width.



Un-damped

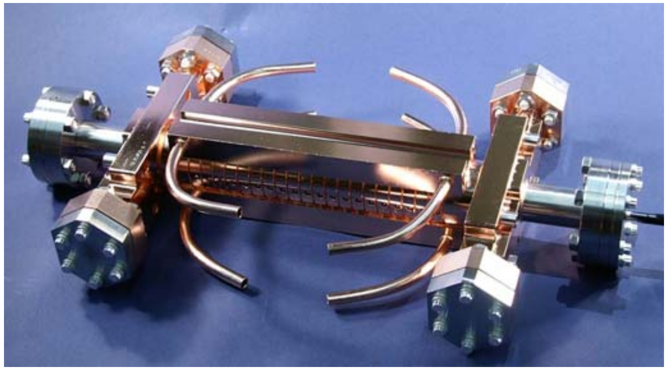


Damped

Machining is much more complicated.

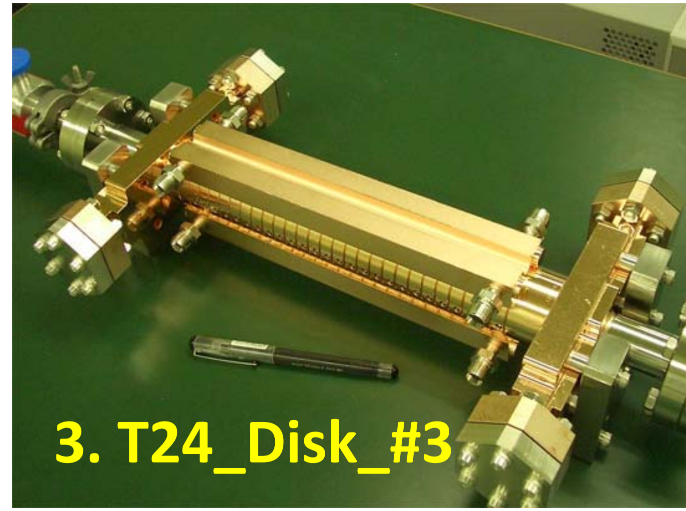
CLIC structures: Fabrication and test

T18 →TD18→T24→TD24→TD24R05



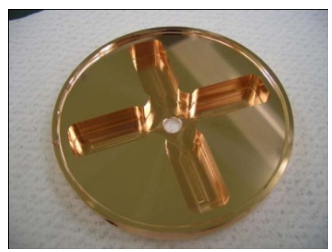
1. T18_Disk_#2

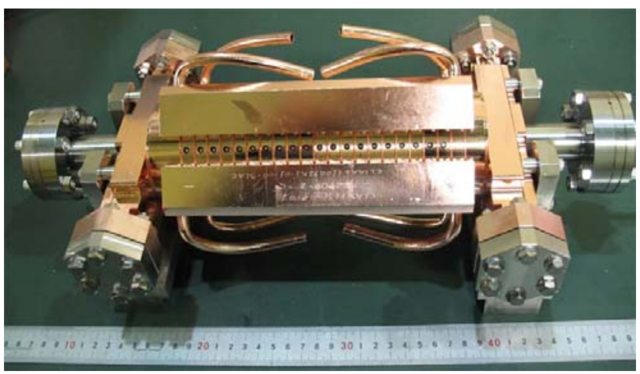
Un-damped



3. T24_Disk_#3

damped

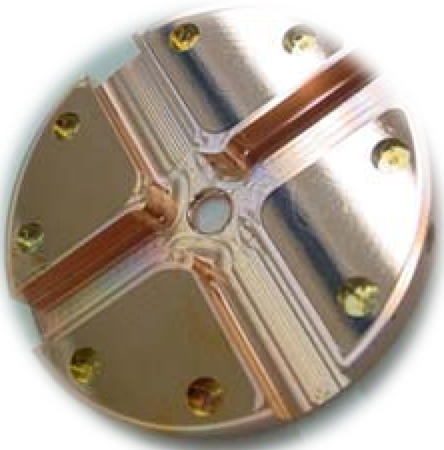


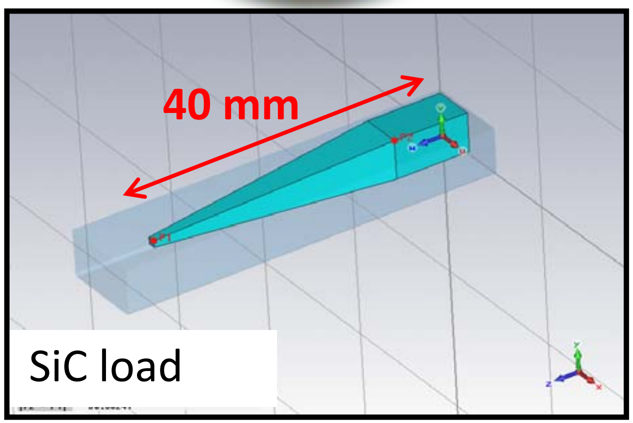


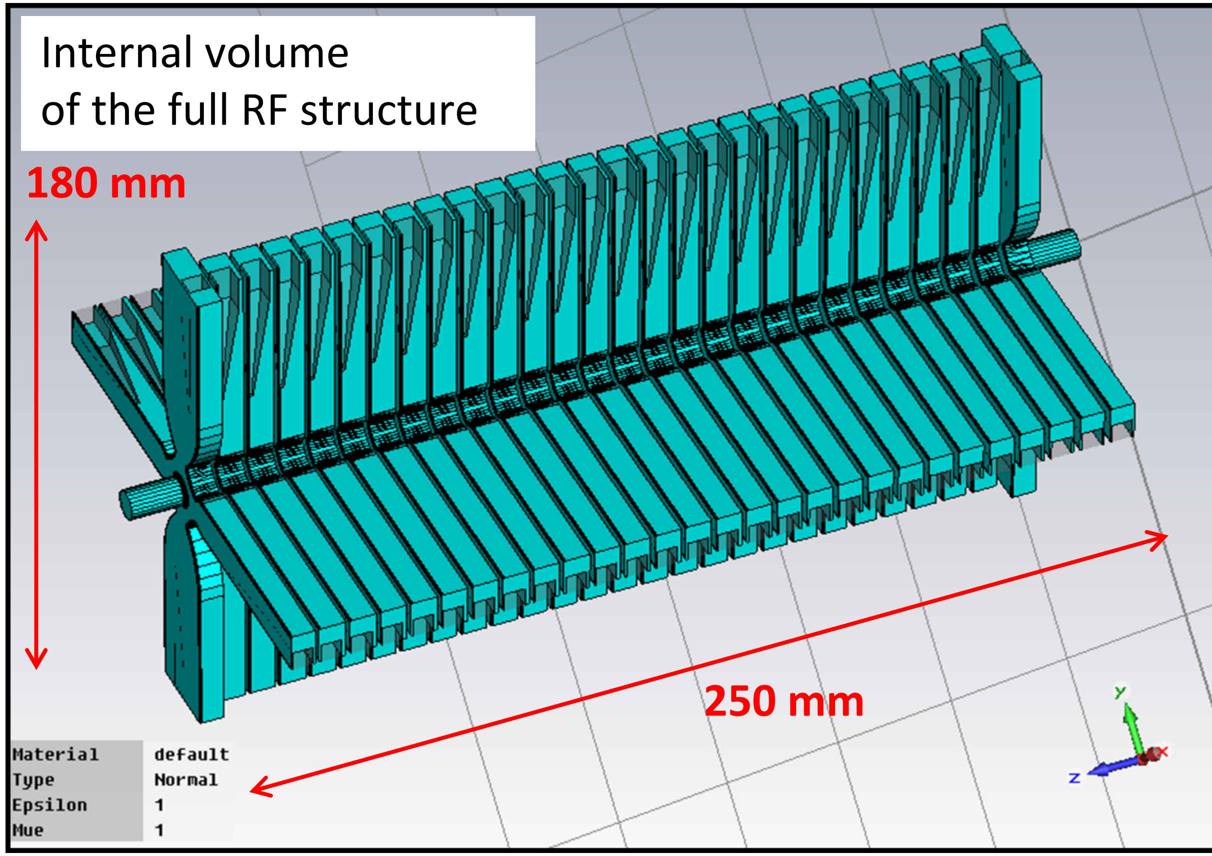
2. TD18_Disk_#2

4. TD24_Disk_#4

The CLIC accelerating structure







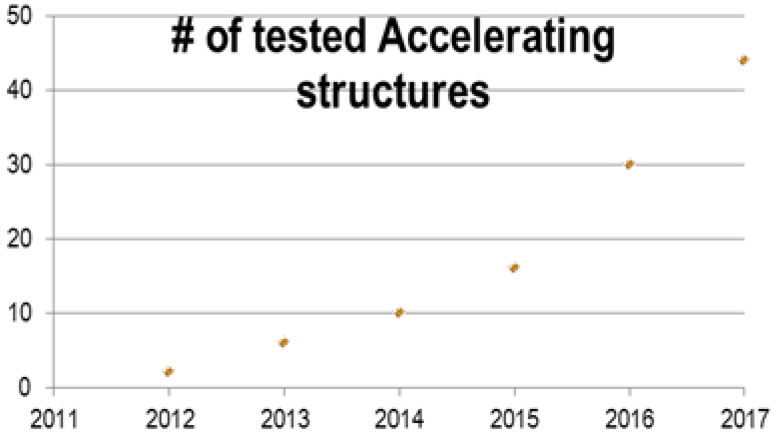
The dielectric properties of the load material (ε_r, tan δ) were first determined experimentally over a large range of frequencies (De Michele, Pieloni)
« EM characterization of damping materials for CLIC RF accelerating structures »,
De Michele and Grudiev, paper in preparation.

Testing structures at high power

Testing of an adequate number of structures at full power, to establish confidence in the design, is a critical part of the CLIC R&D program.

3 TeV c.m. version of CLIC would need ~ 140'000 structures

Problem – no available commercial high power 12 GHz klystrons.



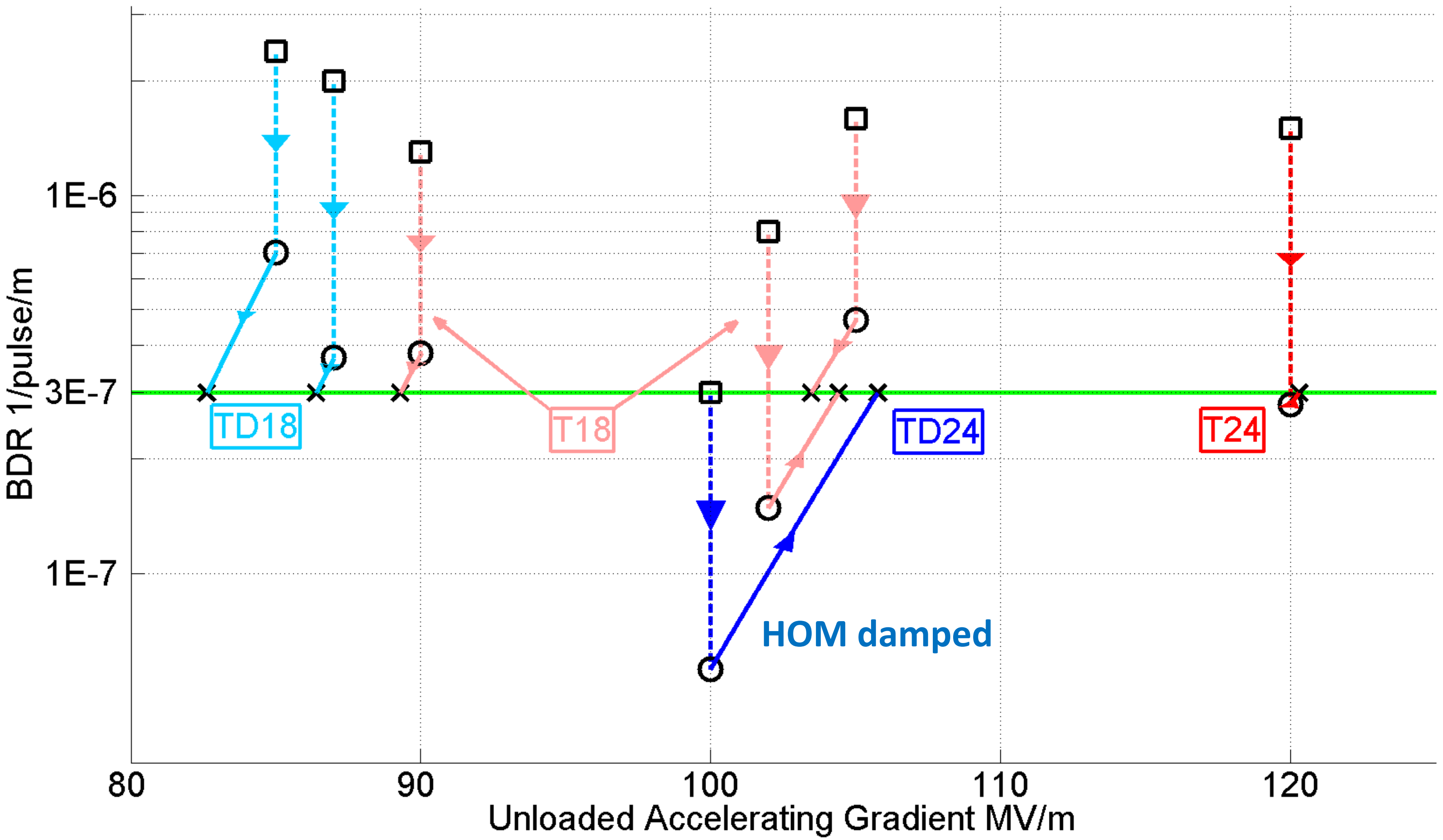
<u>Tests foreseen to be performed with</u>

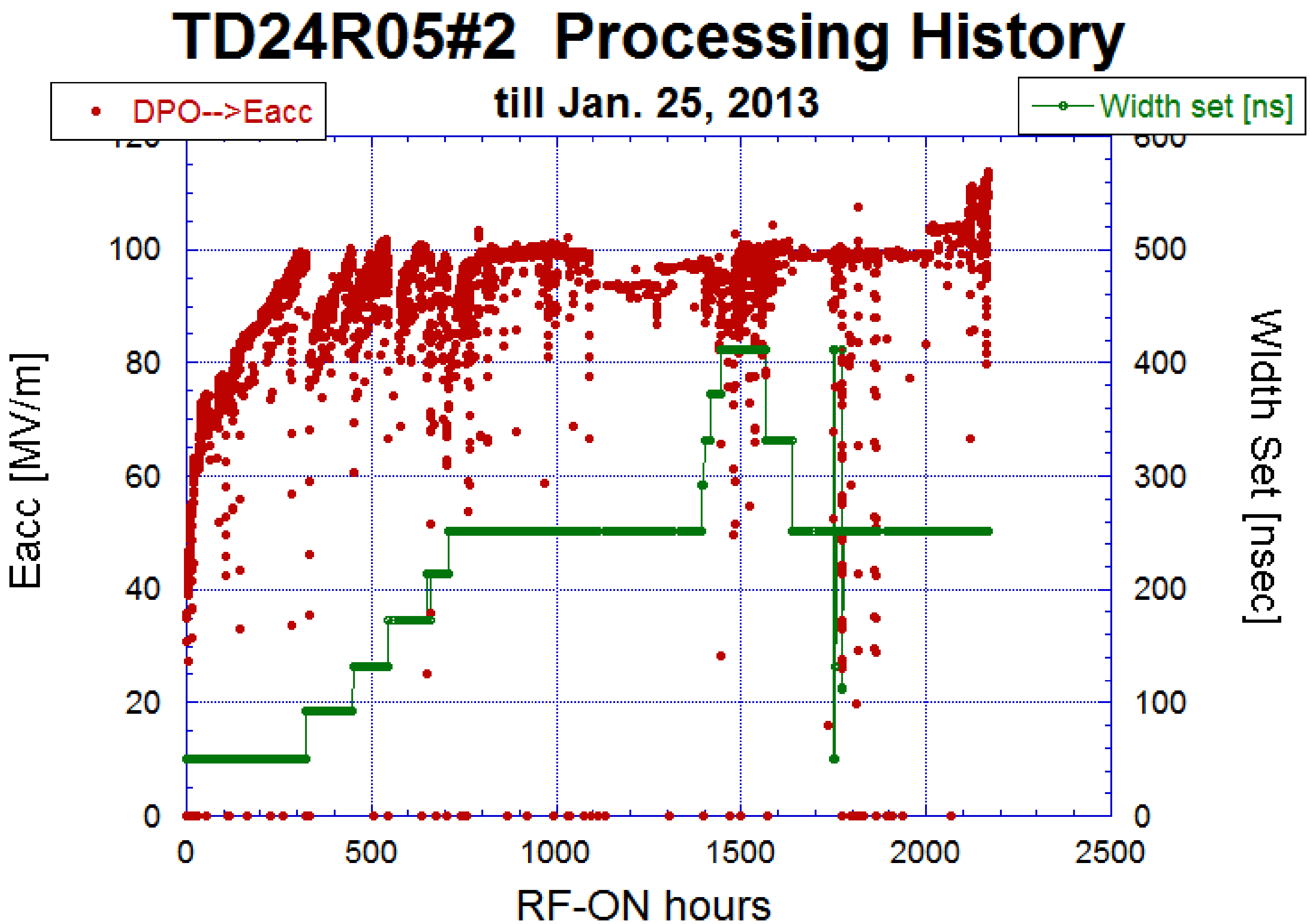
1. Klystrons at SLAC and KEK (but at 11,4 GHz)
2. Stand alone test stands to be built at CERN (Xbox1, Xbox2)*
3. Tests with beam on CLIC Test Facility CTF3 (Two Beam Test Stand).
4. Full beam-loading tests
5. Wake-field experiments (FACET, SLAC)

In 2006 the project changed RF frequency from 30 GHz to 12 GHz (cost optimisation found in 12 ~ 14 GHz range).

*12 GHz chosen in order to benefit from existing infra-structure from CTF3 and LEP Injector Linac (3 GHz)

Accelerating gradients achieved in tests.
Status: 4-9-2012




TD24R05#2 Processing History
till Jan. 25, 2013
DPO-->Eacc
Width set [ns]
Eacc [MV/m]
Width Set [nsec]
RF-ON hours
0
20
40
60
80
100
0
100
200
300
400
500
600
0
500
1000
1500
2000
2500

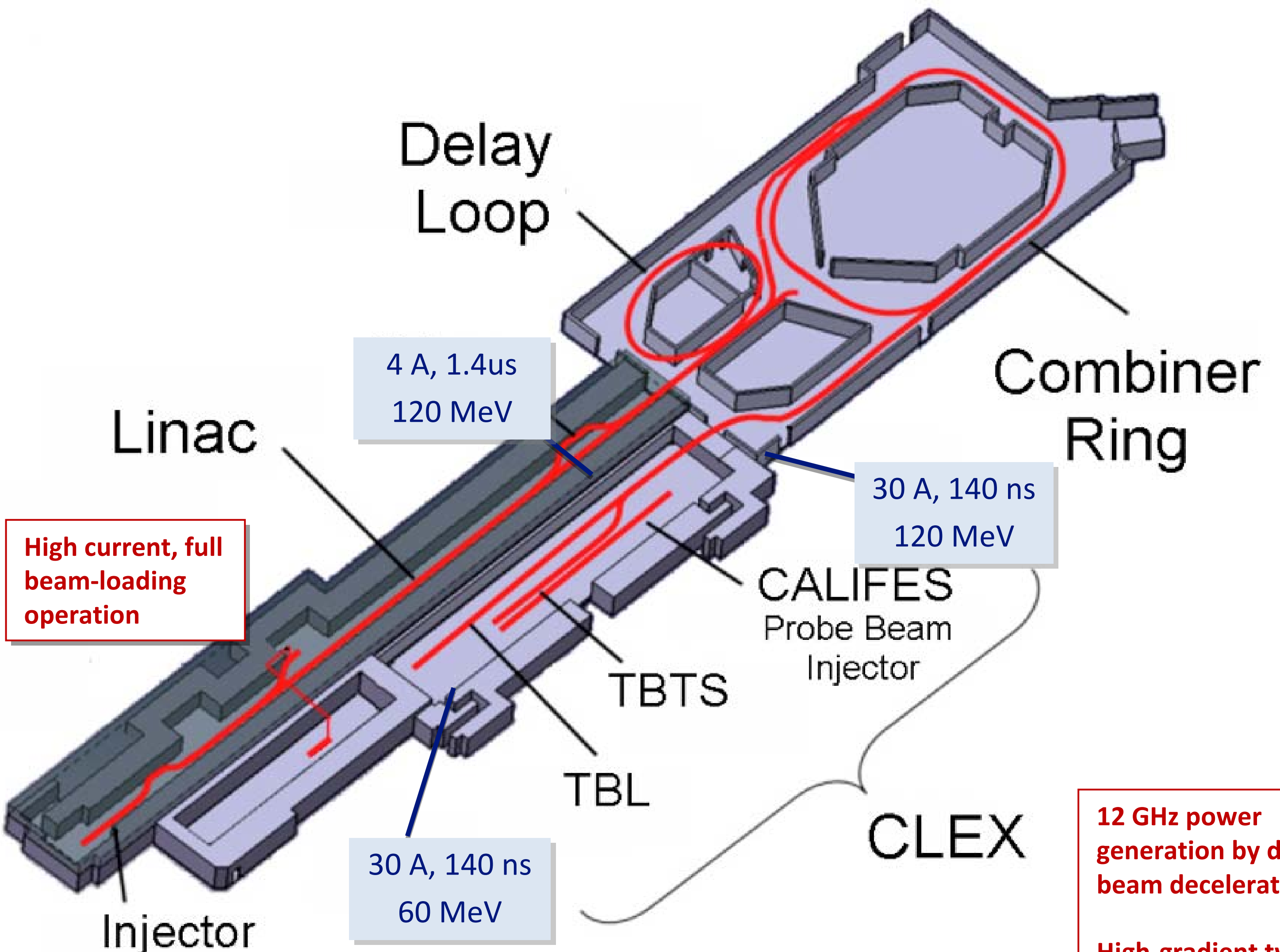
Layout of the CERN X-band test stand (X-box 1)

Clockwise from top-left:

- Modulator
- XL5 klystron (SLAC)
- RF Pulse compressor
- DUT + connections
- Accelerating structure

Gallery
Bunker

CLIC Test Facility (CTF3)



High current, full beam-loading operation

12 GHz power generation by drive beam deceleration

High-gradient two-beam acceleration

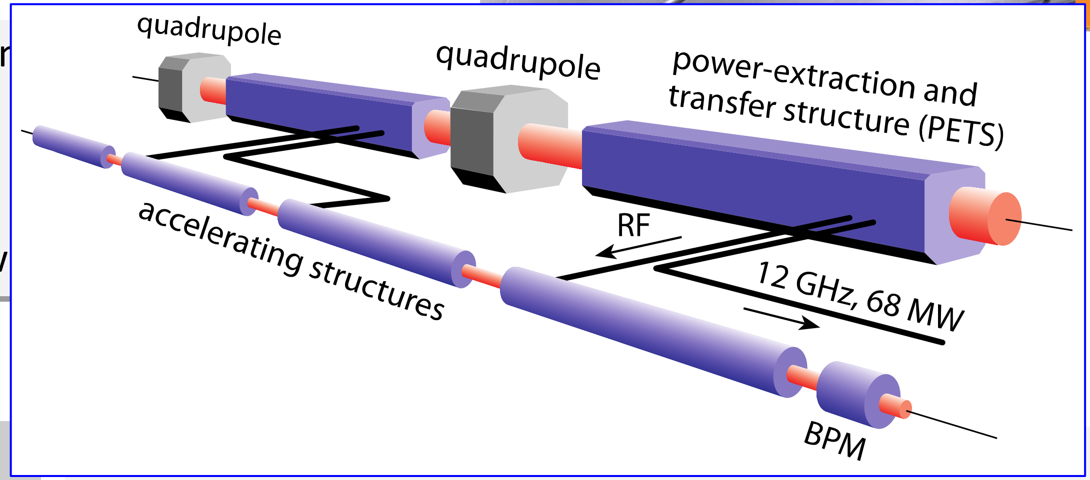
Bunch phase coding

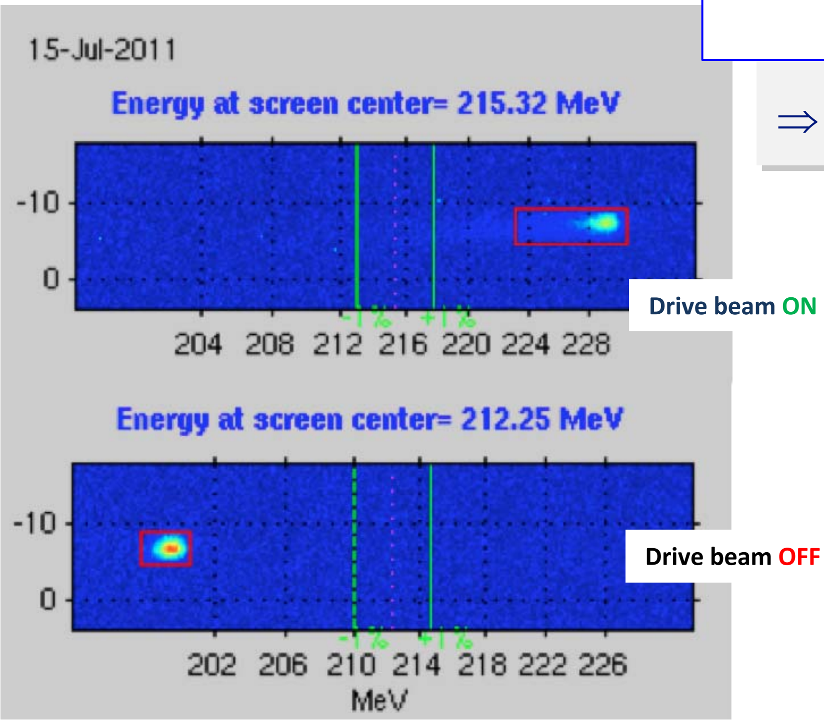
Two-Beam Acceleration

Two-Beam Acceleration demonstration in

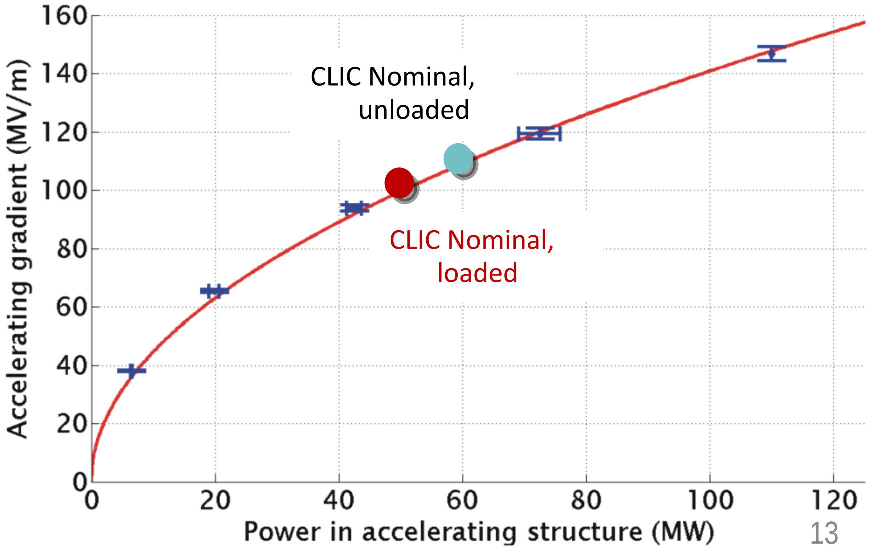
Up to 145 MV/m measured gradient

Good agreement with expectations (pow

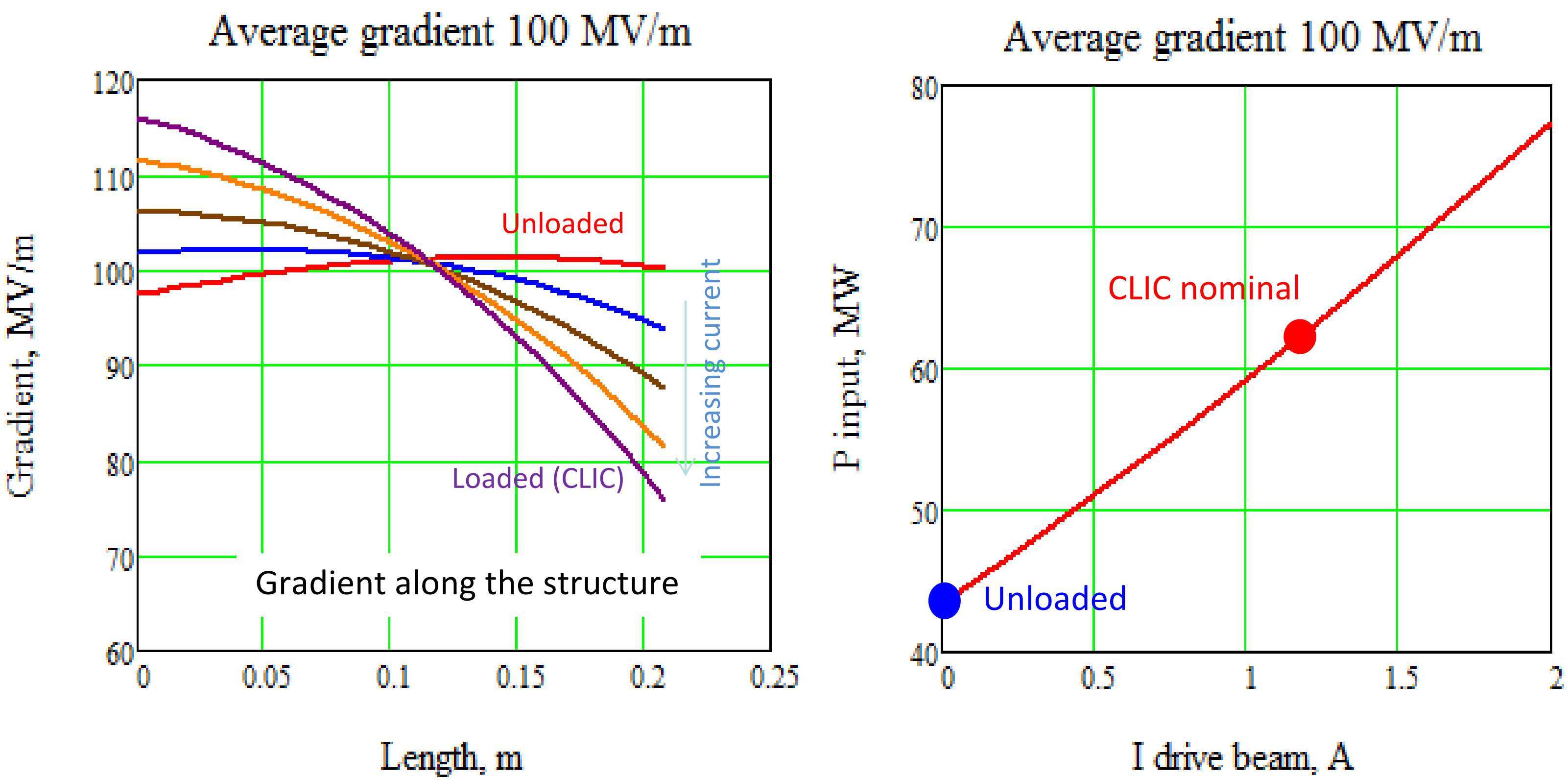




⇒ Corresponding to a gradient of 145 MV/m



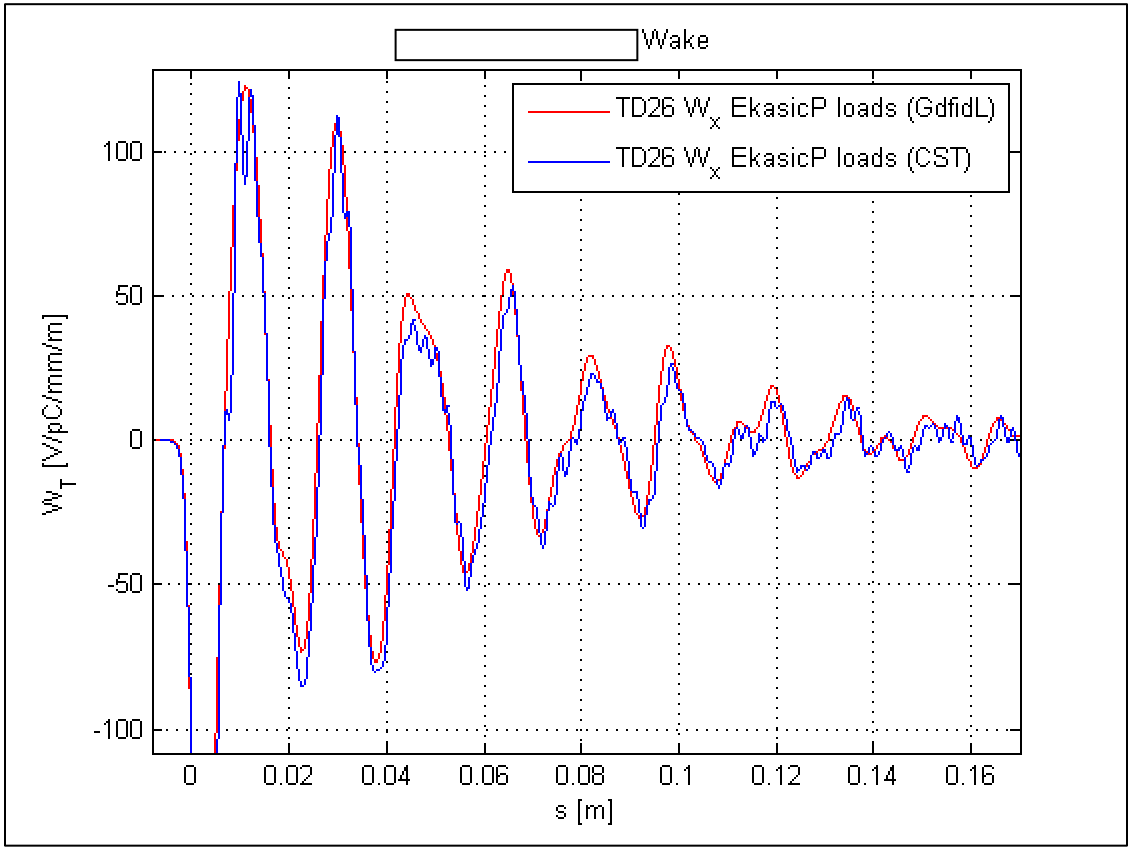
Full beam loading test



Testing of accelerating structure with nominal beam loading was a missing block in the CLIC test program. Such a test will be done using the CTF3 (1.2 A) drive beam and RF power delivered from X-box1.

The main target of this experiment is to compare loaded and unloaded accelerating structure breakdown trip rate.

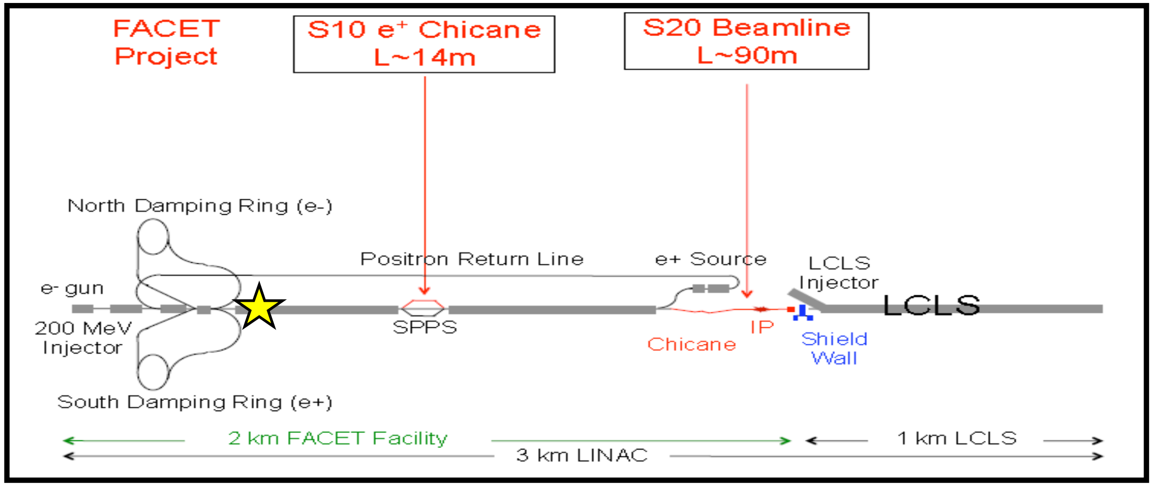
Simulations of the wake-field with damping

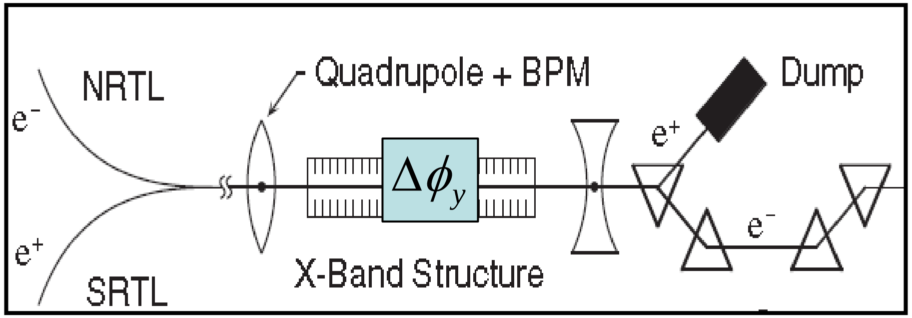


Experimental confirmation would be desirable (before building 30 km of them!)

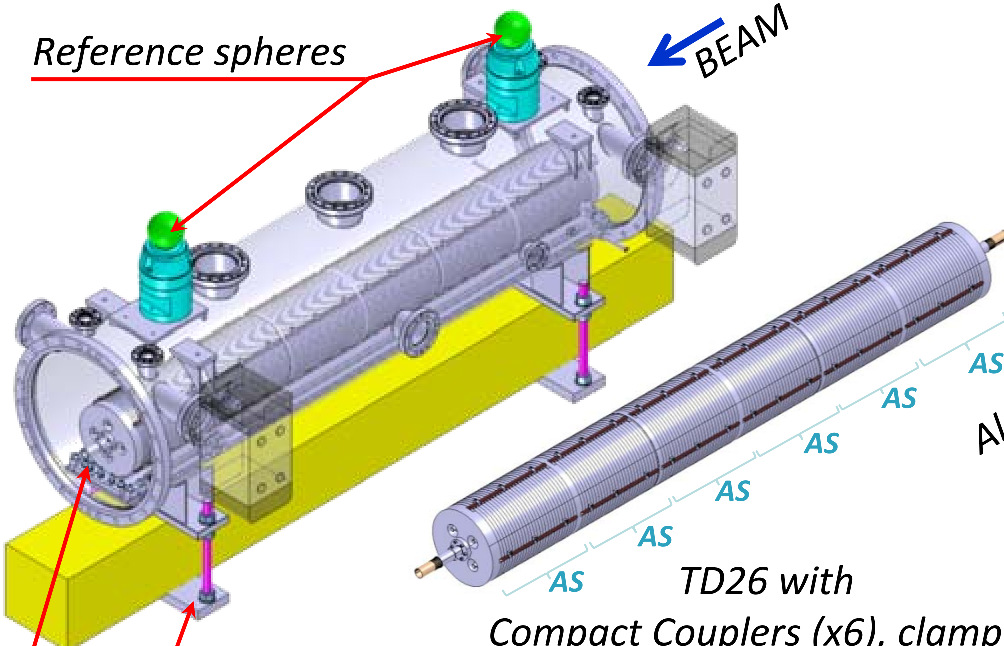
Experiment at FACET (SLAC)

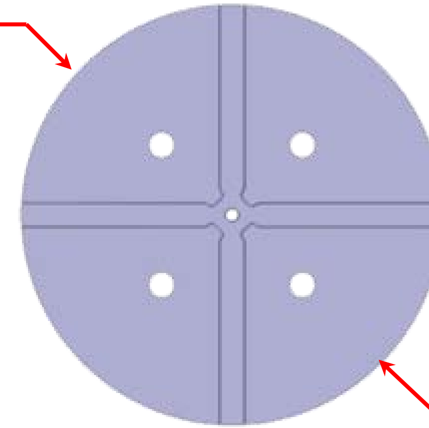
Aim: Measure the wake-fields using positron (drive) and electron (witness) bunches.
Wake-fields are excited by **driving positron bunch** passing through the structure with an offset from the linac axis.
The **electron witness bunch** gets a kick from the excited wake-fields.
The **transverse wakefield** can be calculated from the measurements of the deflecting angle of the witness bunch with respect to a reference trajectory.

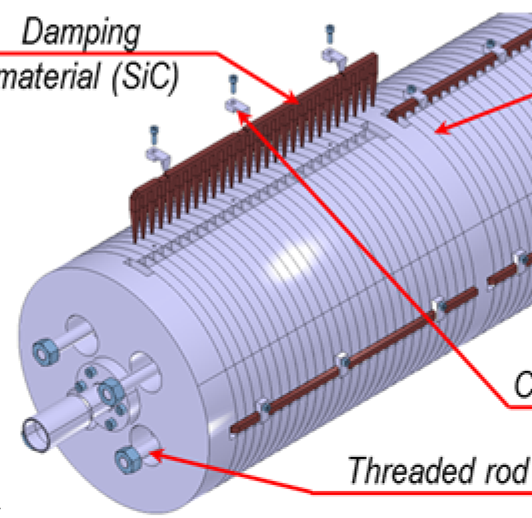




CLASSE Experiment at SLAC – mapping out the wake-fields



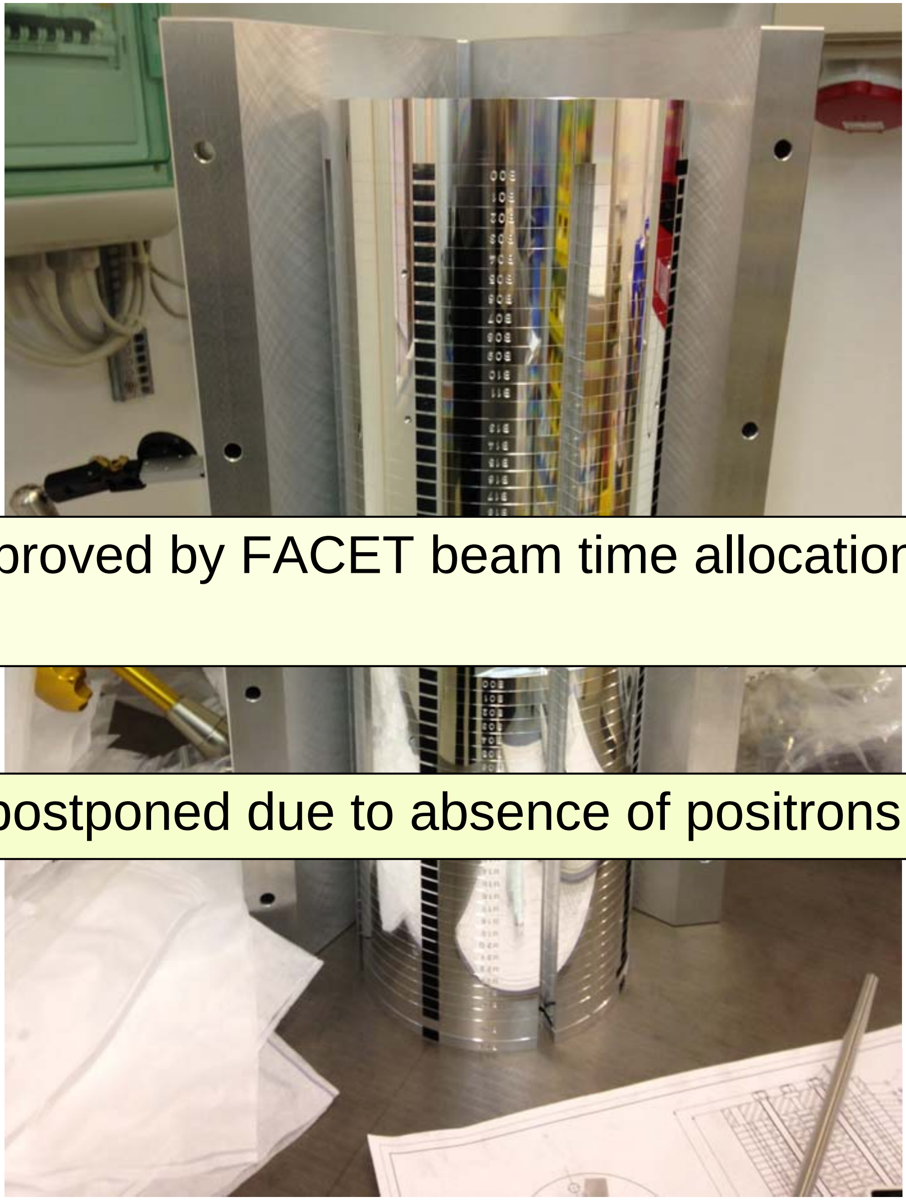




6 sections, 26 cells each, compact coupler design

Clamped aluminum disks

Multi-Purpose Test (CLASSE) Structure

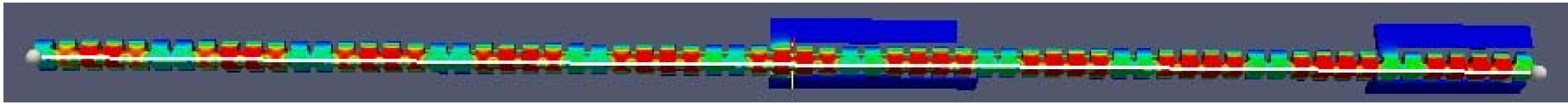


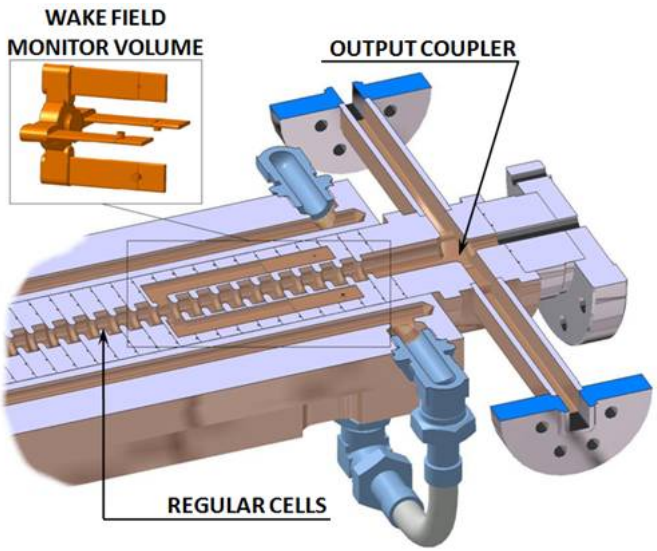
Experiment approved by FACET beam time allocation committee!

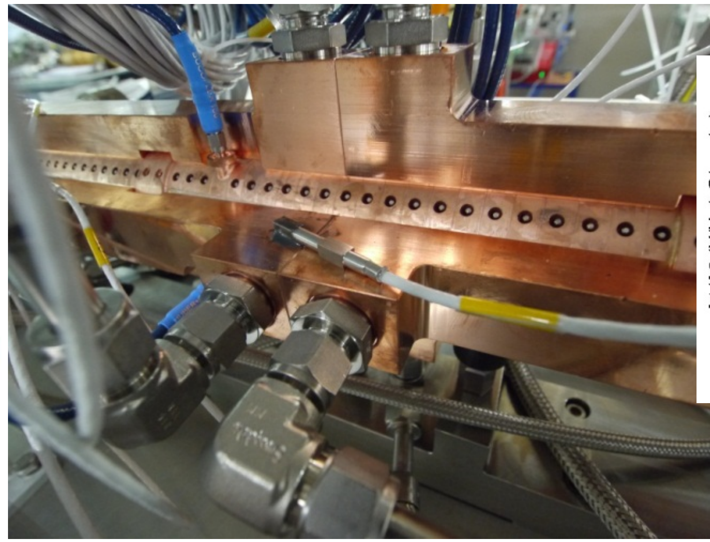
But – postponed due to absence of positrons in 2013

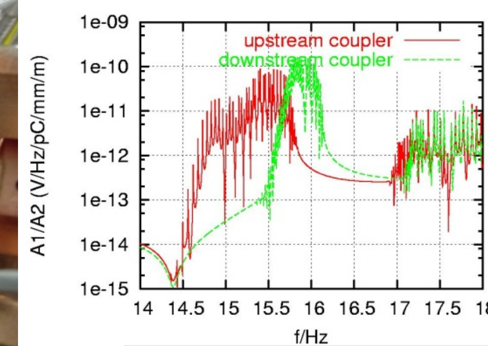
Wake-Field Monitors

X Band structure CLIAPSI with integrated wake-field monitors showing accelerating mode





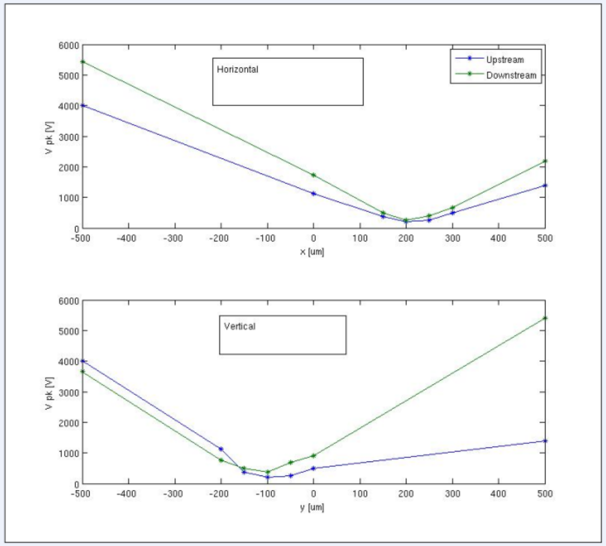




WFM output spectra

Wake field monitors as integrated devices are excellent tools

- Ensuring optimum structure alignment as opposed to indirect methods as e.g. measuring the beam emittance
- Showing not only offsets but also errors in roll and pitch of the structure
- Giving information about internal alignment errors due to random offsets or bends

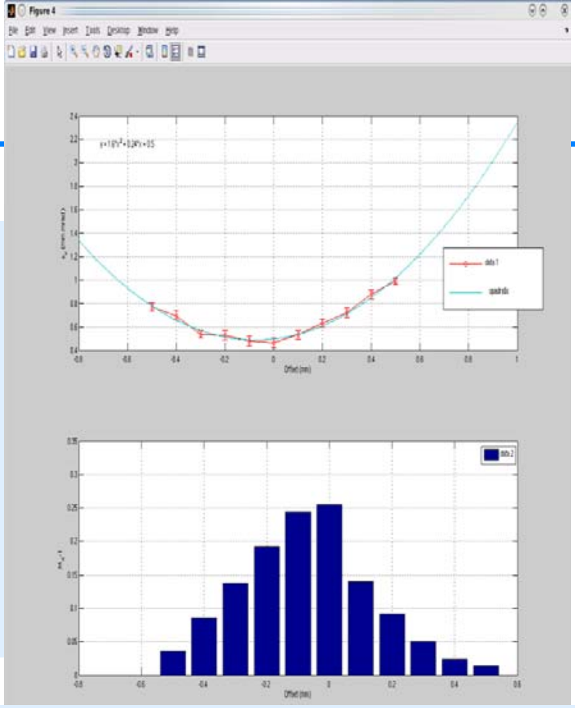


WFM signal level vs. structure offset as measured in SITF

Beam emittance versus vertical offset:

Optimum alignment corresponds to position with minimum WFM signal levels.

'Proof of Usefulness'



Task within EuCARD2: Develop front end for existing monitors

- Wide band signals – 2 GHz band width at 15 GHz center frequency
- Optimize signal/noise to reach theoretical micron scale resolution
- Allow for spectral analysis to extract information about higher order misalignments (pitch, roll, bend), while also giving simple 'operator' signal
- Evaluating Electro-Optical approach with promising properties with respect to radiation damage, electromagnetic interference and bandwidth.
  - Technology already used in space communications
  - Optical fibers vs. hollow wave guides in classical RF
  - 'Passive' front end (essentially only optical modulator) near structure: robust to radiation damage)
  - Off the shelf components available up to 40 GHz: possible secondary applications for break down monitors, wide band wall current pickups etc.)

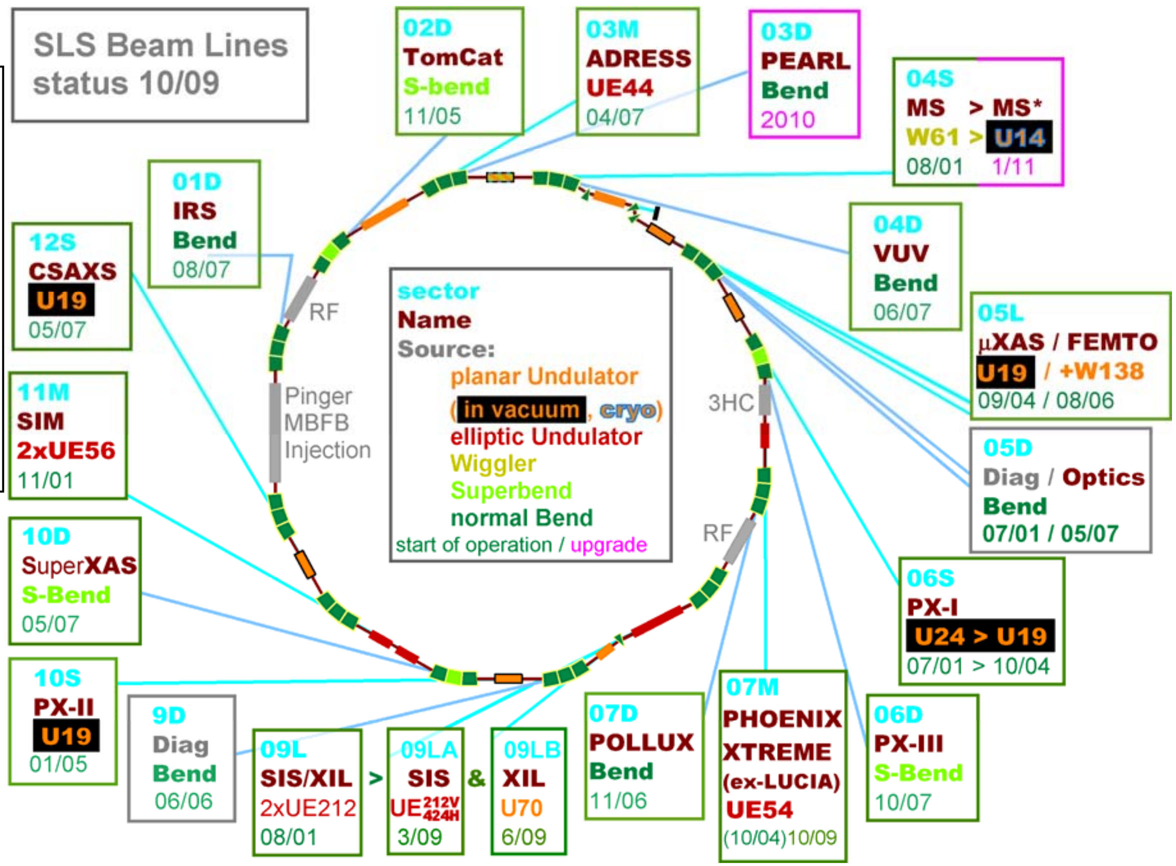
Damping ring developments

Test **I**nfrastructure and **A**ccelerator **R**esearch **A**rea
www.eu-tiara.eu
Work package 6 “SVET”

Partially funded by the European Commission under the FP7-INFRASTRUCTURES-2010-1/INFRA-2010-2.2.11 project TIARA (CNI-PP). Grant agreement no 261905

Swiss Light Source
-2.4 GeV electron storage ring for synchrotron radiation.

Used for vertical emittance tuning and studies of transverse coupling control.



Damping ring developments

CLIC DR specification for the vertical emittance is 0.9 pm (geometrical) @ 2.86 GeV.

So-called “quantum emittance” limit, given by photon-emission recoil into
1/γ radiation cone , $\varepsilon_v \sim 0.09 \langle\beta_y\rangle/\rho$ pm (0.2 pm, SLS).

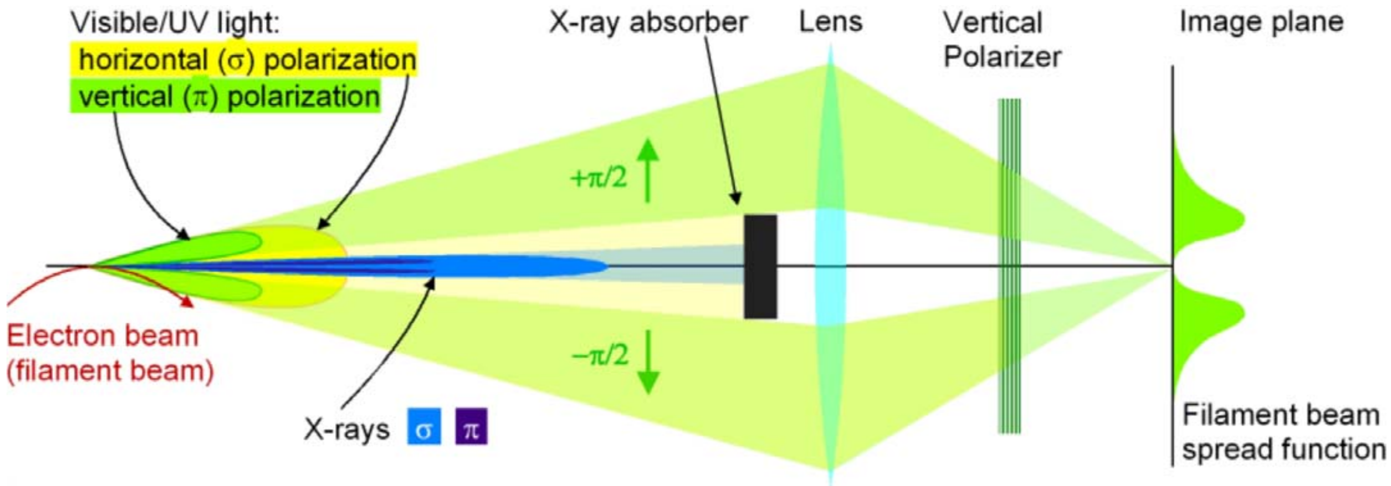
In practice vertical emittance is usually much larger than this (~ few pm @ SLS) due to lattice imperfections → vertical displacements in sextupoles leading to transverse
spurious vertical dispersion, betatron coupling HOR ↔ VER.

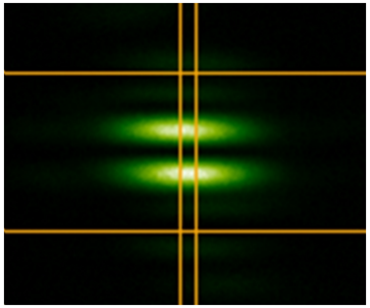
<u>Coupling correction schemes</u>
Skew-quadrupoles (12) in dispersive sections added to reduce vertical dispersion
Skew-quadrupoles (24) in non-dispersive sections to reduce transverse coupling
obtained $\varepsilon_V/\varepsilon_H$ = 0.05% (CLIC aims for 1%).

Emittance measurement based on transverse profile monitor.

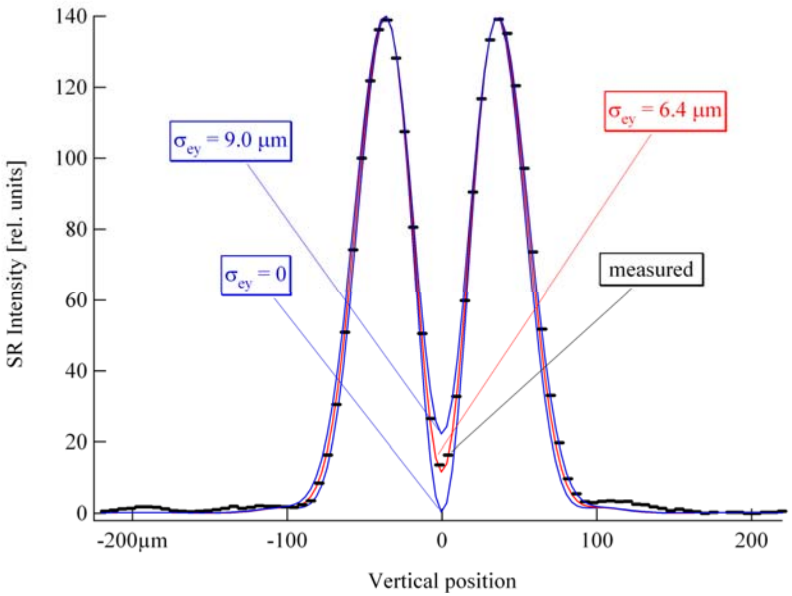
Principle of the Beam Size Monitor – the π-polarization method

Å. Andersson, et al., *Determination of Small Vertical Electron Beam Profile and Emittance at the Swiss Light Source*, NIM-A 592 (2008) 437-446





- imaging of vertically polarized SR in the visible/UV
- phase shift of π between two radiation lobes
  - → destructive interference in the mid plane
  - → $I_{y=0} = 0$ for point-like beam
  - → $I_{y=0} > 0$ for beam with finite vertical beam size



Procedure for SLS Vertical Emittance Tuning

1. re-alignment of magnet girder to remove main sources of vertical dispersion

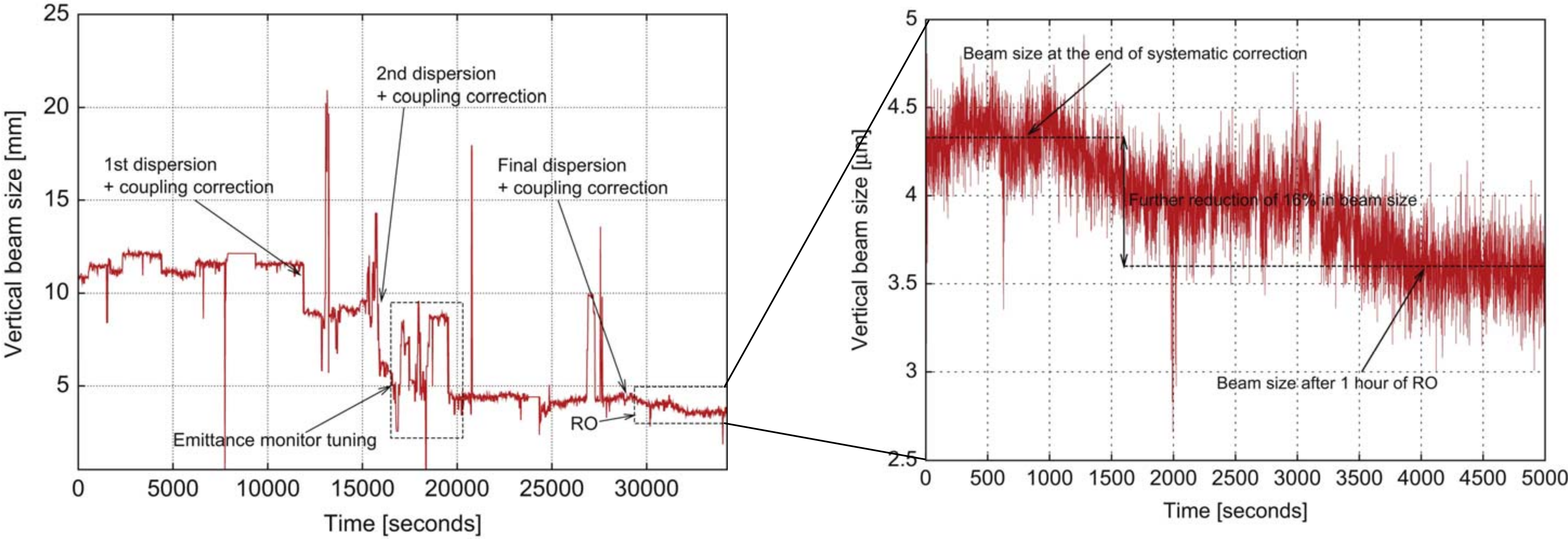
   → reduction of rms vertical correction kick from ~ 130 μrad to ~ 50 μrad

2. measurement & correction of vertical dispersion and betatron coupling

   → model-based skew quadrupole corrections (12 dispersive and 24 non-dispersive skew quads)

3. "random walk" optimization of vertical beam size

   → skew quadrupole corrections using beam size measurements from profile monitor

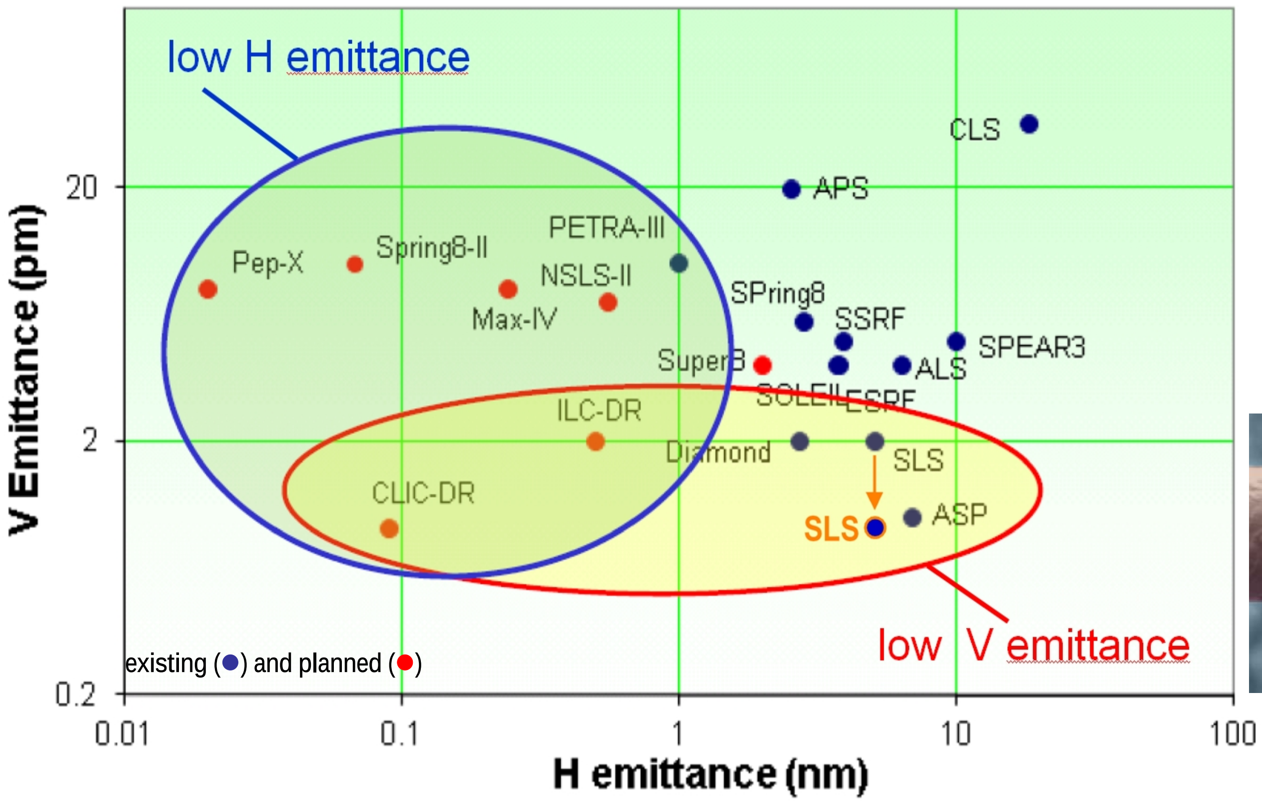


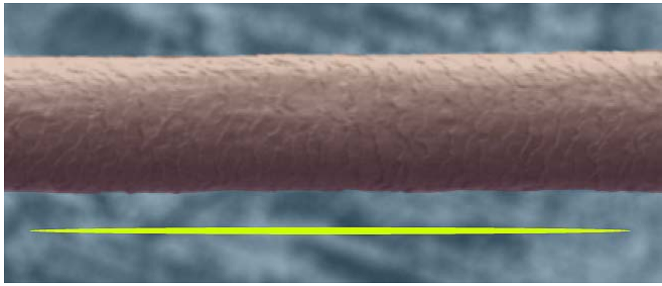
M. Aiba, et al., *Ultra Low Vertical Emittance at SLS Through Systematic and Random Optimization*, NIM-A 694 (2012) 133-139

SLS Vertical Emittance Optimization – Results

- vertical beam size: **3.6 ± 0.6 μm**
- vertical emittance: **0.9 ± 0.4 pm**
- error estimate from beam size and β-function at monitor

Limited by monitor resolution!



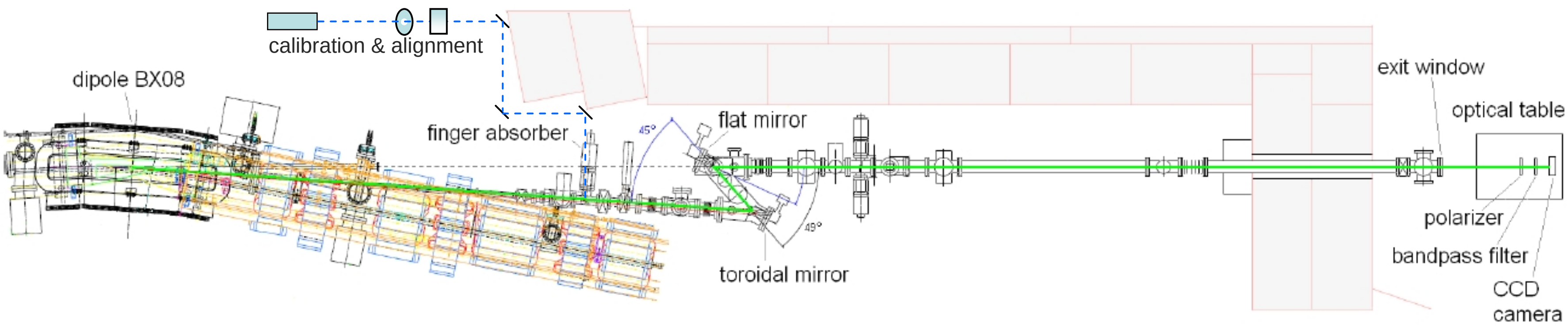


Horizontal and Vertical Emittances of Storage Rings

Figure based on:

R. Bartolini, Low Emittance *Ring Design,* ICFA Beam Dynamics Newsletter, No. 57, Chapter 3.1, 2012.

The New SLS Beam Size Monitor



Main Features of the New SLS Beam Size Monitor

- longer beamline (X08DA) → optics table fully accessible outside of accelerator tunnel
- higher magnification ratio (M = -1.45) → increase of measurement precision
- toroidal mirror as focusing element → free selection of SR wavelength without shift of image plane
  → shorter wavelength increases resolution
- π-polarization & interferometric method → matched operating ranges (nominal and high resolution)
  → cross-checking of results
- alignment & calibration set-up → online inspection of monitor at 266 nm and 532 nm

Summary

EPFL / PSI contributions to CLIC accelerating structures

- Characterisation of HOM damping materials
- Wake-field simulations
- Engineering design effort
- Conception of SLAC experiment - CLASSE structure
- Wake-field monitors

Actors: L. Rivkin (P.I.), G. De Michele (graduate student), T. Pieloni (former post-doc).

PSI contributions to CLIC damping ring study

- Emittance tuning procedures
- Construction and operation of the beam profile monitor
- Studies of intra-beam scattering (not discussed here)

Actors: M. Aiba, M. Boege, A. Saa Hernandez, N. Milas, M. Rohrer, V. Schlott, A. Streun.

Principal CERN collaborators: W. Wuensch, A. Grudiev, G. Riddone, Y. Papaphilippou

I thank W. Wuensch, G. De Michele, M. Dehler and A. Saa Hernandez for slides.

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Thank you for your attention!