CLIC RF structure precise assembly and thermo-mechanical modeling in CLIC

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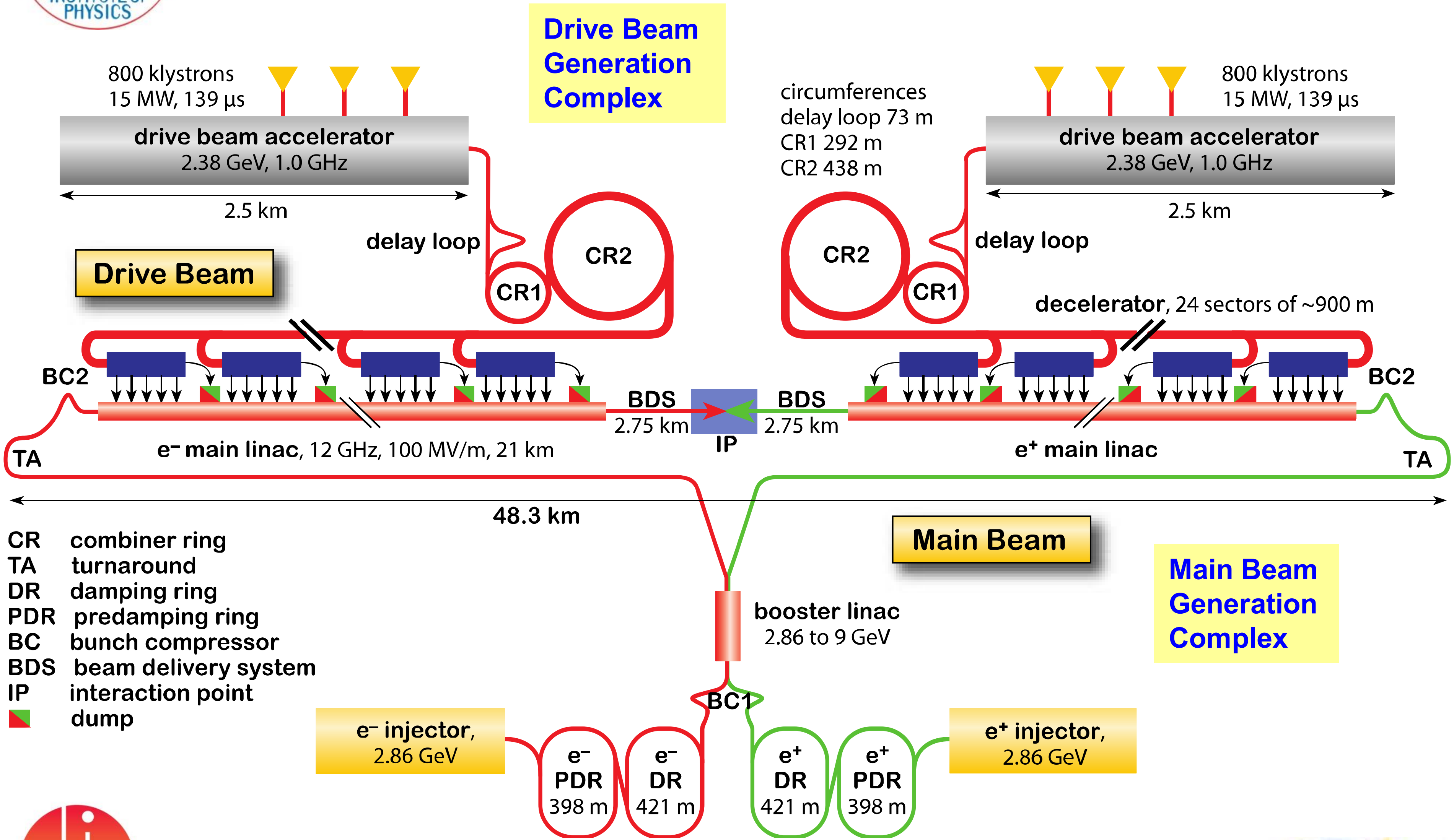
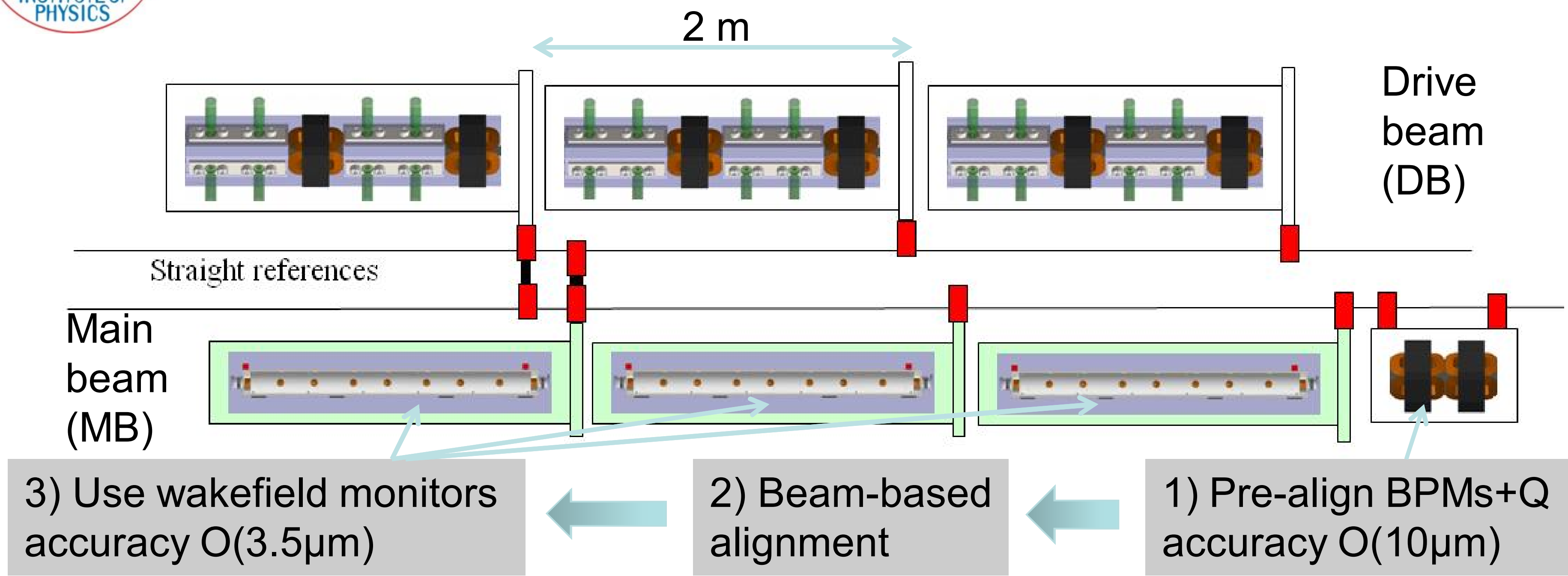
Outline:

- CLIC & its requirements
- RF structure manufacturing & assembly
- RF structures in operation: thermo-mechanical modeling of CLIC module

CLIC at 3 TeV


Drive Beam Generation Complex
800 klystrons
15 MW, 139 μs
drive beam accelerator
2.38 GeV, 1.0 GHz
2.5 km
circumferences
delay loop 73 m
CR1 292 m
CR2 438 m
delay loop
CR2
CR1
Drive Beam
decelerator, 24 sectors of ~900 m
BC2
BDS
2.75 km
IP
TA
e⁻ main linac, 12 GHz, 100 MV/m, 21 km
e⁺ main linac
48.3 km
Main Beam
Main Beam Generation Complex
booster linac
2.86 to 9 GeV
BC1
e⁻ injector,
2.86 GeV
e⁺ injector,
2.86 GeV
e⁻ PDR 398 m
e⁻ DR 421 m
e⁺ DR 421 m
e⁺ PDR 398 m
CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump

Tolerances of main linacs



Starting point pre-alignment must be μm precise:
- precise manifacturing & assembly of RF structures
- precise alignment of RF structures & CLIC modules
- stability of RF structure during operation

courtesy of D. Schulte

CLIC RF structures

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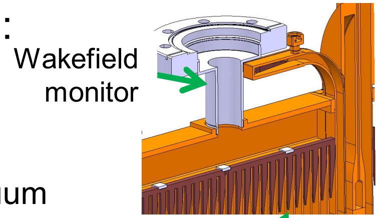
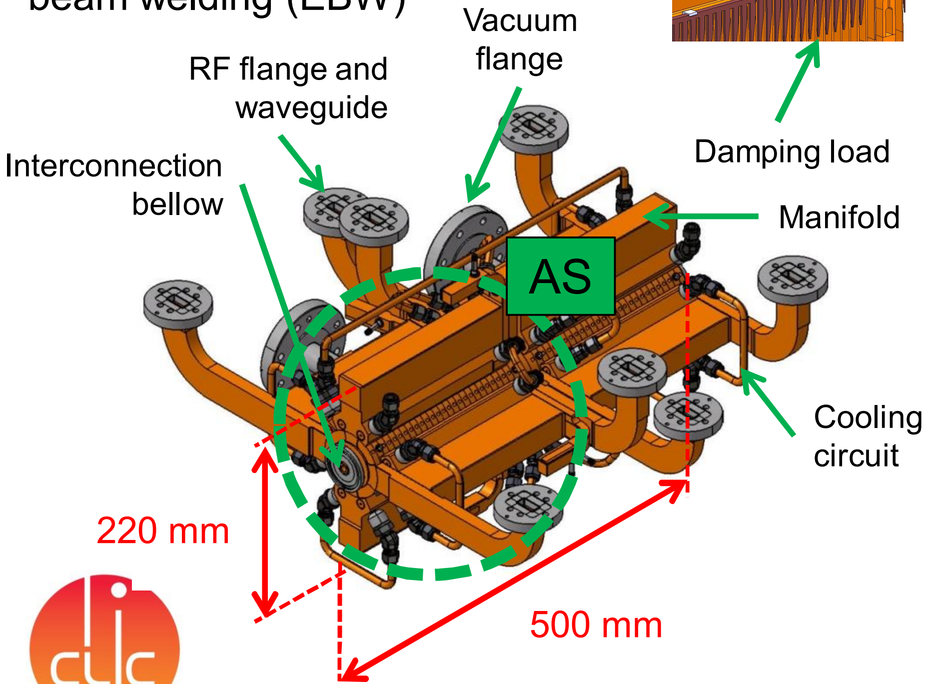
ACCELERATING STRUCTURES (AS)

REQUIREMENTS

- COAXILITY ERROR: < 10 μm
- ALIGNMENT ERROR BTWN MANIFOLDS & DISKS STACK: ±10 μm

main assembly technologies: diffusion bonding (H_2), brazing (H_2) & electron beam welding (EBW)

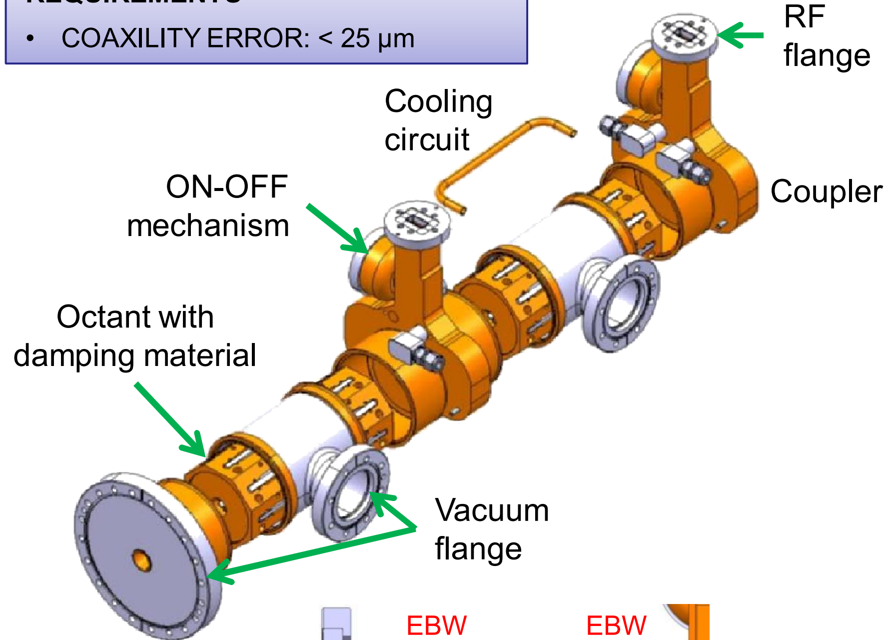


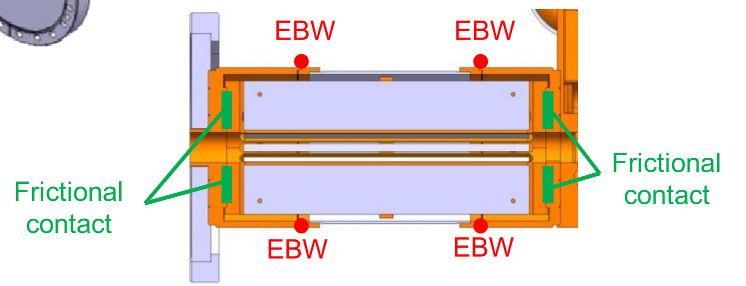


POWER EXTRACTION AND TRANSFER STRUCTURES (PETS)

REQUIREMENTS

- COAXILITY ERROR: < 25 μm





courtesy of CLIC RF structure production team

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1st step: machining

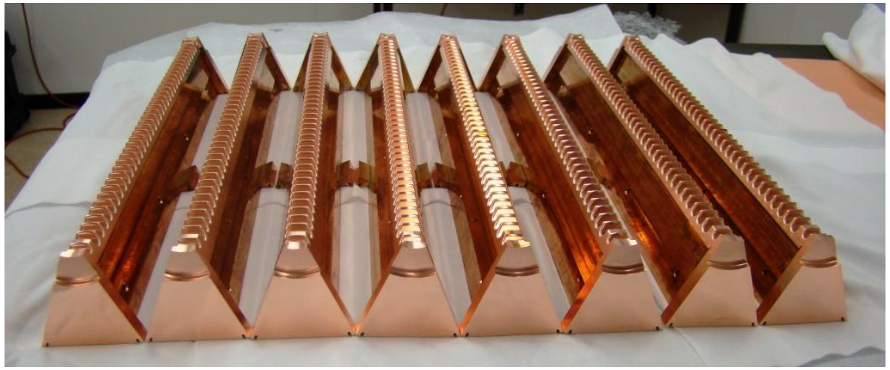
AS disks

- *Cu OFE UNS C10100*
- *Shape accuracy ± 2.5 µm (iris)*
- *Flatness accuracy ± 10 µm*
- *Roughness Ra 0.025 µm (iris)*
- *Ø 80 mm*
- *30 disks diffusion bonded*
- *Length 250 mm*

Diamond turning & milling

PETS quadrants

- *Cu OFE UNS C10100*
- *Shape accuracy ± 7.5 µm*
- *Roughness Ra 0.1 µm*
- *8 octants diffusion bonded*
- *Length 300-1000 mm*



Milling

courtesy of S. Atieh & G. Riddone

2nd step: assembly

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AS example: TD26_CC_SiC

courtesy of F. Rossi

(1) MACHINING

(2) QUALITY CONTROL

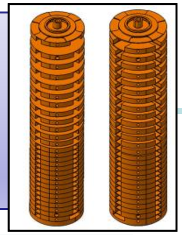
1. Inlet inspection
2. Dimensional control
3. SEM
4. Preliminary RF tests

(3) CLEANING

1. Etching with SLAC solution
2. Degreasing + deoxidation + passivation

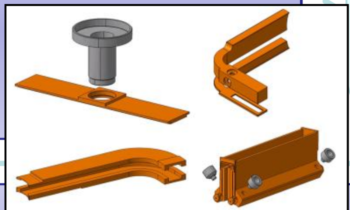
(4) H_2 DIFFUSION BONDING (1040 °C)

1. Disks stack (x2)



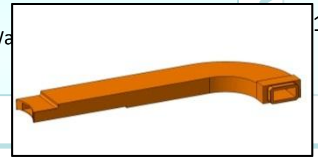
(5) H_2 BRAZING (Au/Cu 25/75, 1040 °C)

1.
2.
3.
4.



(6) MACHINING

1. Wa

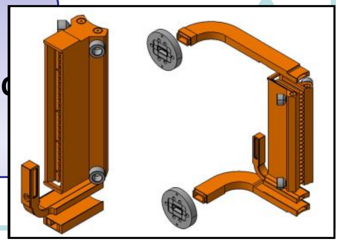


(7) CLEANING

1. Degreasing + deoxidation + passivation

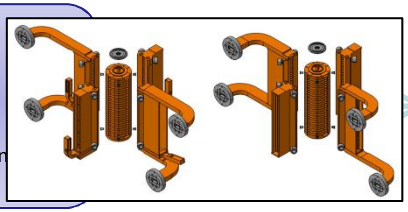
(8) H_2 BRAZING (Au/Cu 25/75, 1040 °C)

1. Vacuum manifolds (x6)



(9) H_2 BRAZING (Au/Cu 35/65, 1020 °C)

1. 4 vacuum manifolds + 1 disks stack + 1 intercon flange + 8 steel inserts + tuning studs (x2)

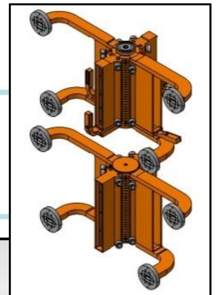


(10) QUALITY CONTROL

1. Vacuum test
2. Cooling circuit test

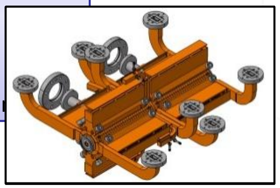
(11) H_2 BRAZING (Au/Cu 50/50, 980 °C)

1. 2 accelerating structures



(12) EBW

1. Covers and vacuum fla



(13) QUALITY CONTROL

1. Vacuum test

(14) RF CHECK AND TUNING

(15) VACUUM BAKING (650 °C, 10 days)

(16) CONDITIONING

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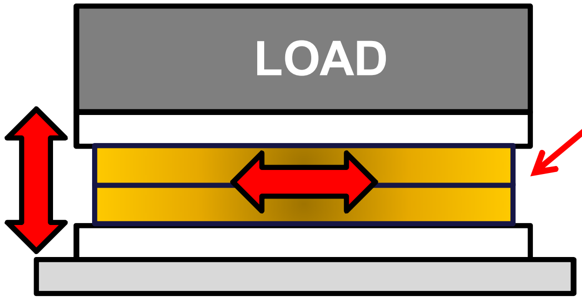
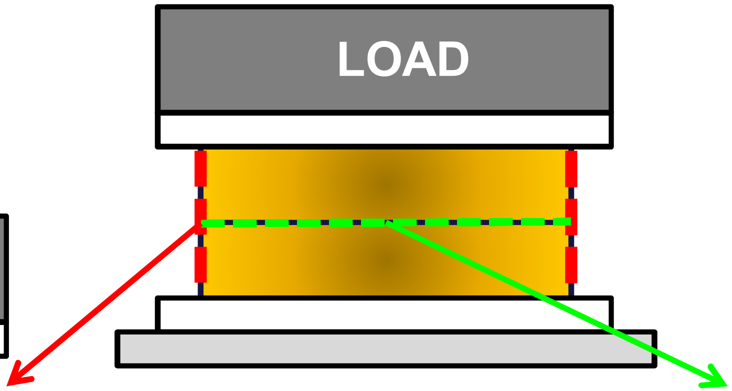
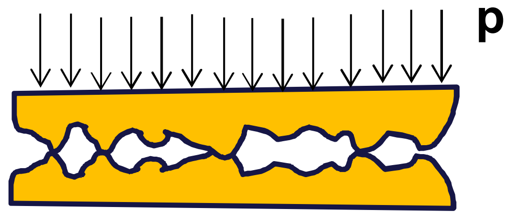
Deformation during diffusion bonding

MACROSCOPIC DEFORMATIONS





MICROSCOPIC DEFORMATIONS



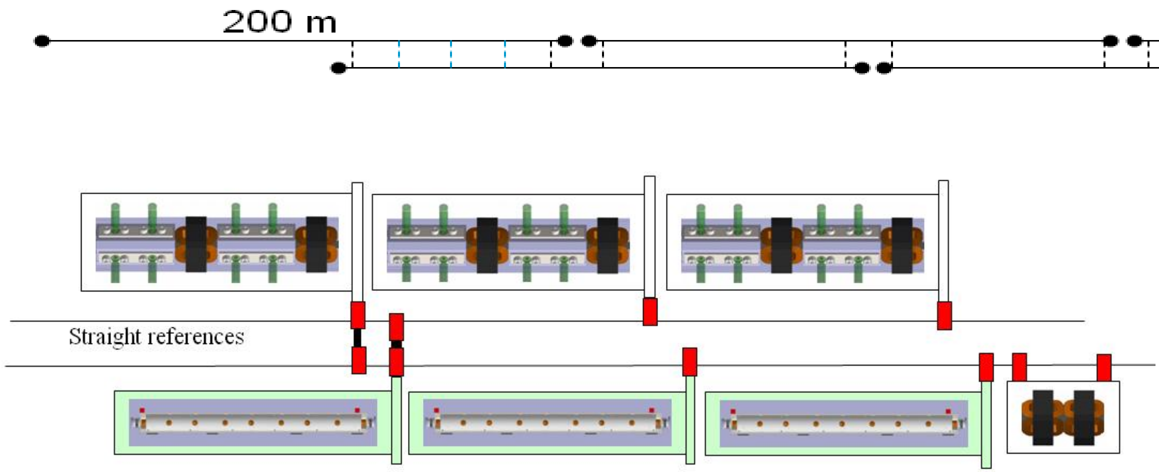
VARIABLES
- Load, time, temperature

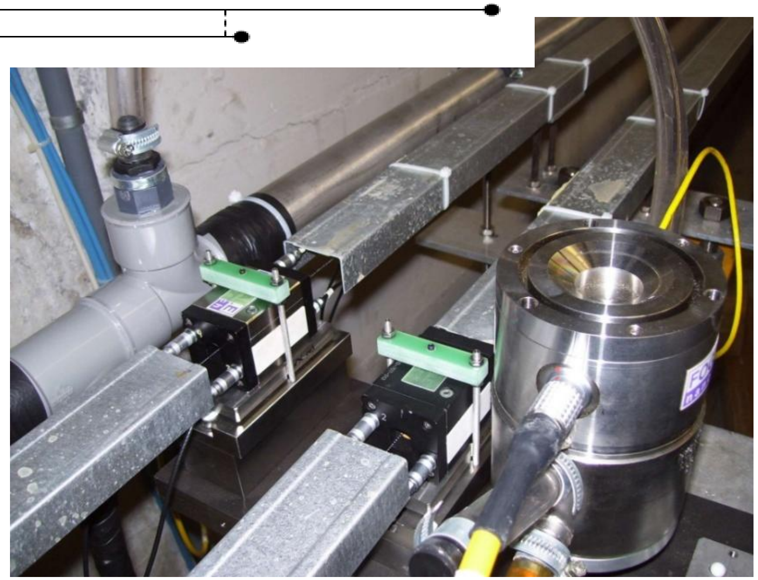
VARIABLES
- Pressure, temperature, time geometry (roughness & flatness), cleaning

- experimental tests indicate visco-plastic behaviour, creep ($T/T_{melt} = 0.96$)
- on flat geometries experimental tests, analytic calculations & transient finite element with creep included seems to agree
- next: transient simulation of more complex geometries ⇒ AS disk stack
- *future: characterisation of creep behaviour of Cu near melting point*

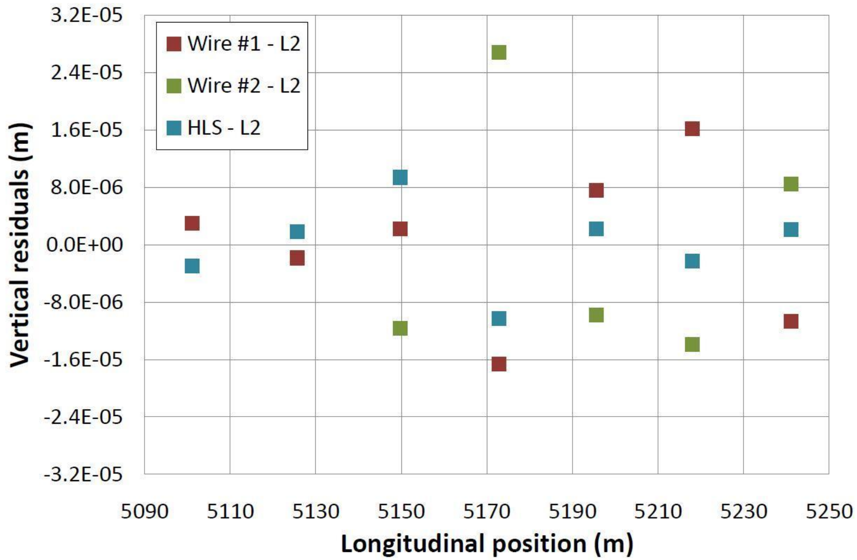
courtesy of F. Rossi

3rd step: alignment





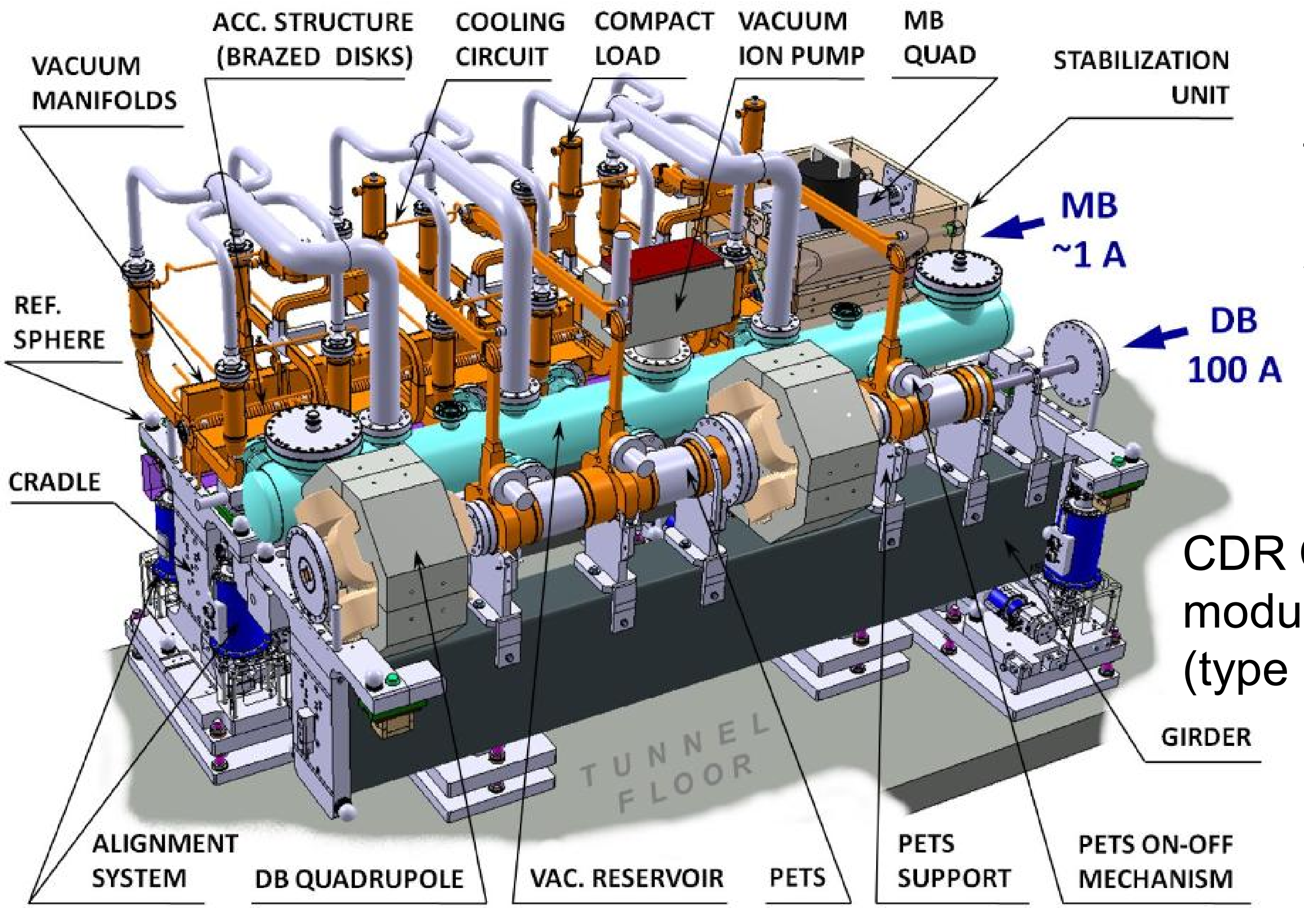
Test results with vertical RMS ~11μm



- Required accuracy of reference point: 10 μm

courtesy of CERN survey team

Last step: stability in operation



thermal power during operation ~7 kW/module

CDR CLIC two-beam module configuration (type 1)

courtesy of A. Samoshkin

Thermo-mechanical modelling

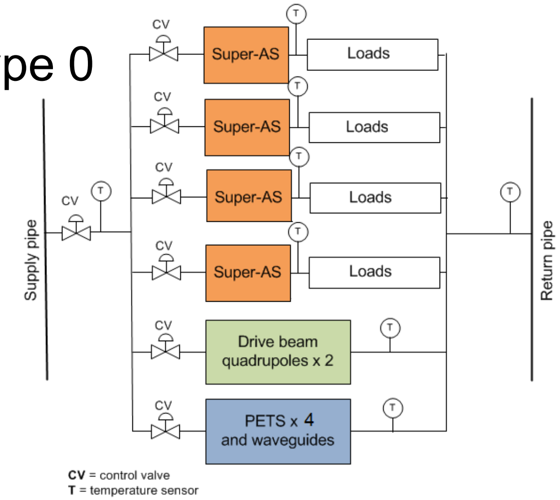
3 module types simulated:
- CLIC module type 0 (4 AS, no MB Q),
- CLIC module type 1 (3 AS, 1 AS replaced by a MB Q)
- prototype module type 0 (tested in lab without beam in 2012)

⇒ used in near future for validating thermo-mechanical model

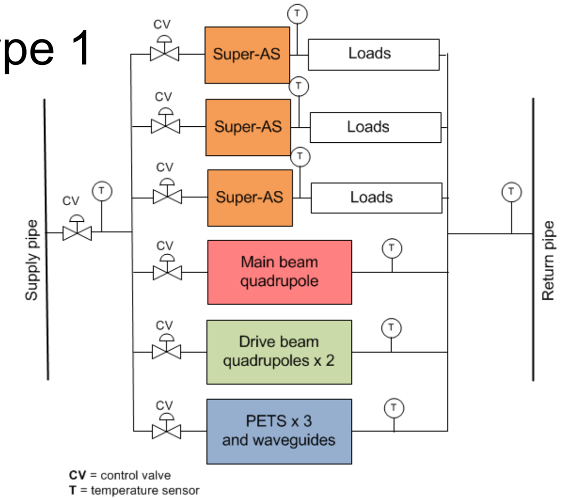
- geometry of main components simplified & implemented in ANSYS
- shell (solid) elements for modelling thin-walled structures (other structures)
- a 3D thermo-fluid dynamics analysis simulating integrated cooling system ⇒ derive temperature distribution ⇒ input for simulation of structural response

CLIC module cooling scheme

type 0

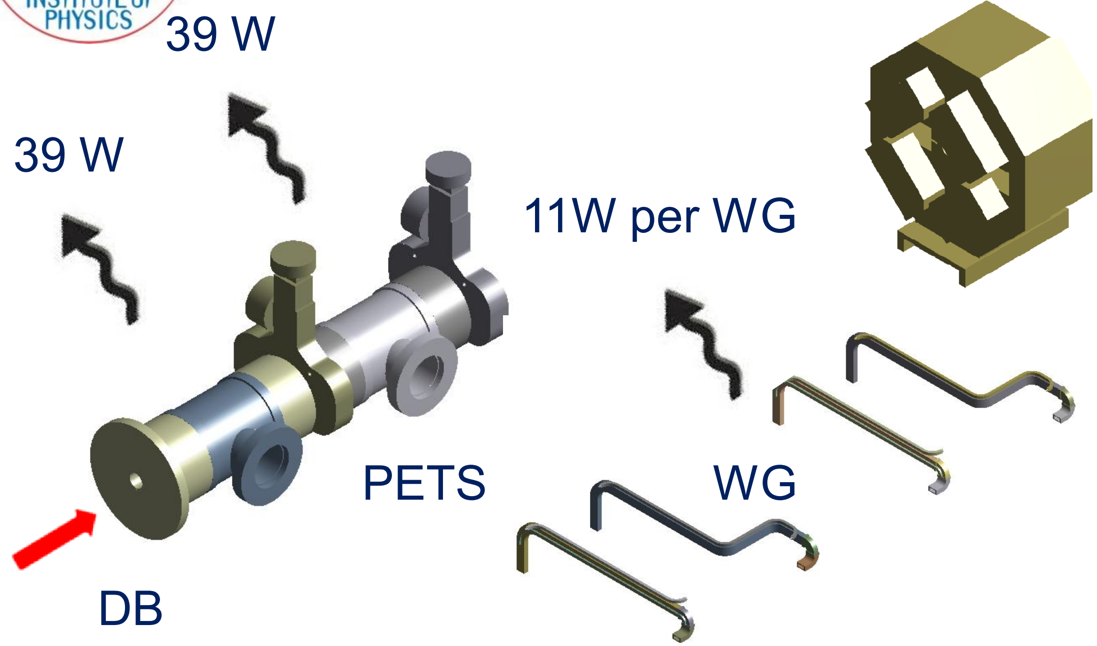


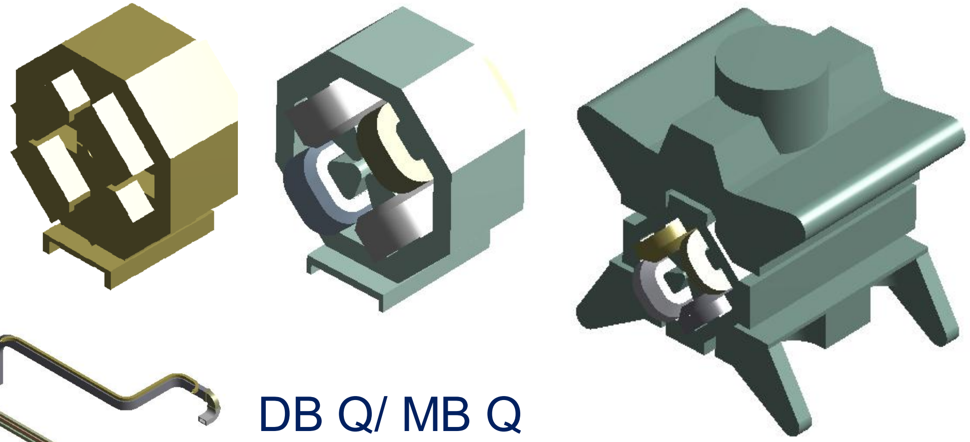
type 1



- linear actuators & bellows simulated using equivalent stiffness elements
- linear elastic behaviour of material assumed

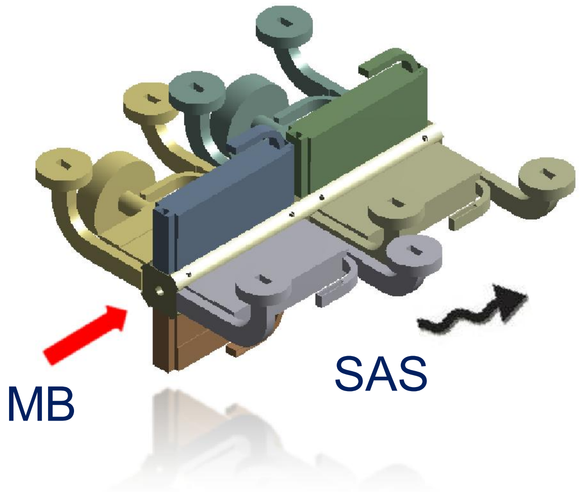
Thermal and mechanical loads



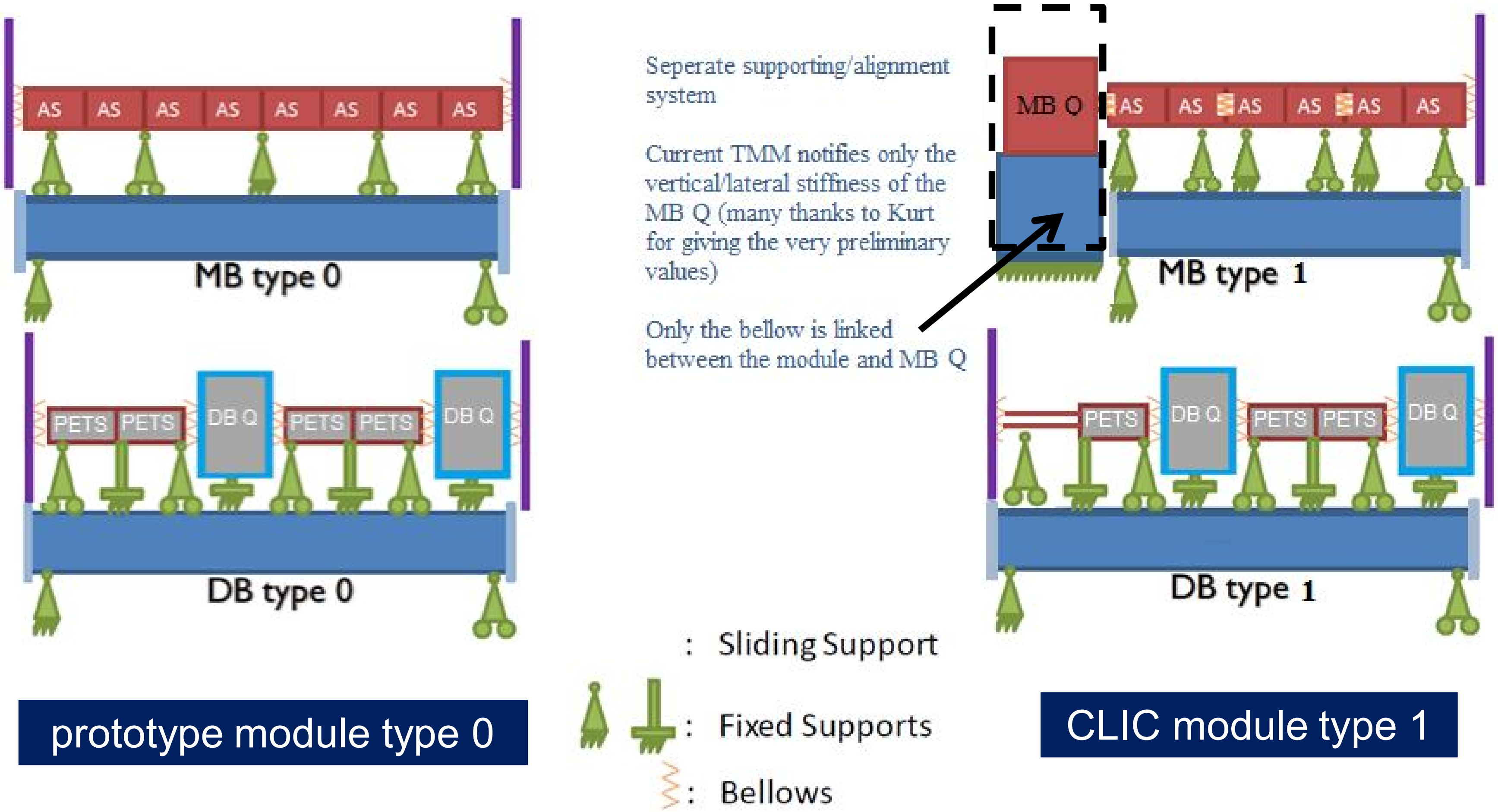


- Maximum temperature variation of 5°C for mock-up magnet considered (current reference value) – Courtesy of A. Bartalesi

Item	Description	Value
Input flow MB	mass flow Unloaded	68.6 kg/h
Input flow MB	mass flow Loaded	56.2 kg/h
Input flow DB	mass flow	37.4 kg/h
Water input	temperature	25 °C
HTC MB	convection to water	5079 $W/(m^2 \cdot K)$
HTC DB	convection to water	1407 $W/(m^2 \cdot K)$
HTC Air	convection air	4 $W/(m^2 \cdot K)$



Boundary conditions



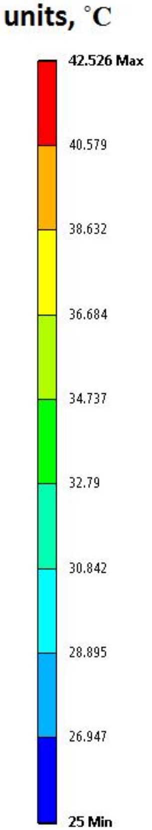
prototype module type 0

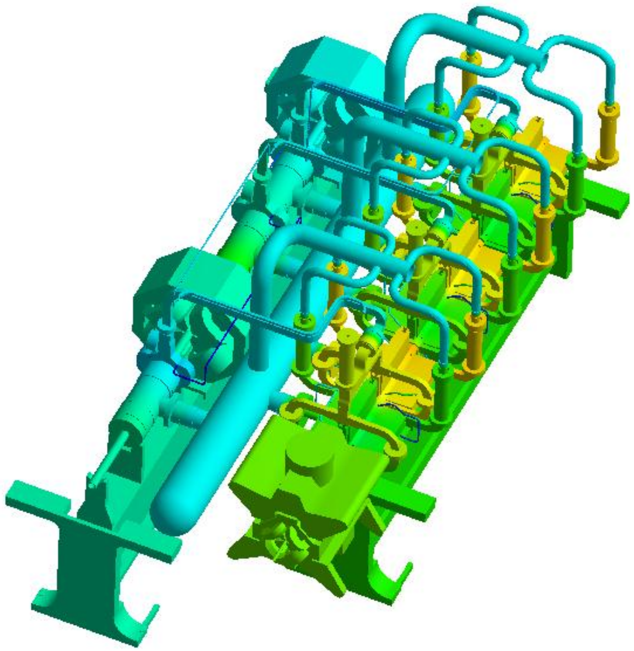
CLIC module type 1

courtesy of N. Gazis

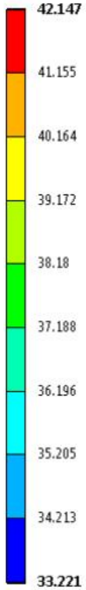
Thermal results

CLIC module type 1

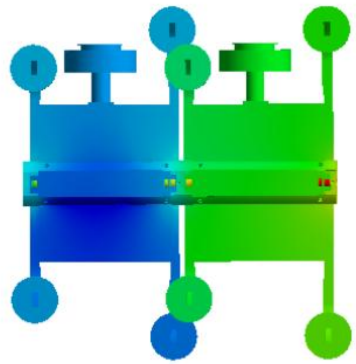


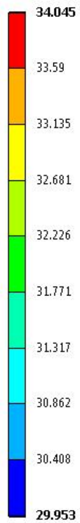


Item	Unloaded	Loaded
Max temp. of AS	42.5 ˚C	40.7 ˚C
Max temp. of PETS	34˚C	34˚C
Water output temp MB	35.0 ˚C	34.9 ˚C
Water output temp DB	28.2 ˚C	28.2 ˚C

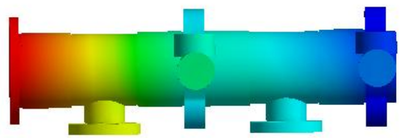


AS





PETS



Deformation results: RF for AS

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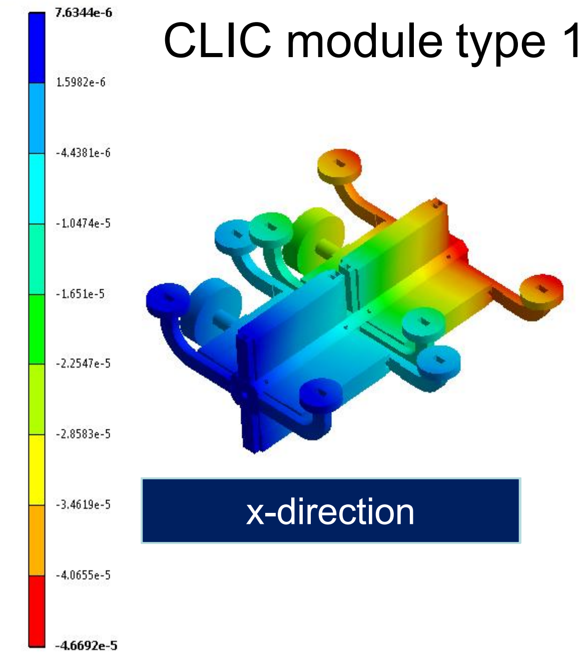
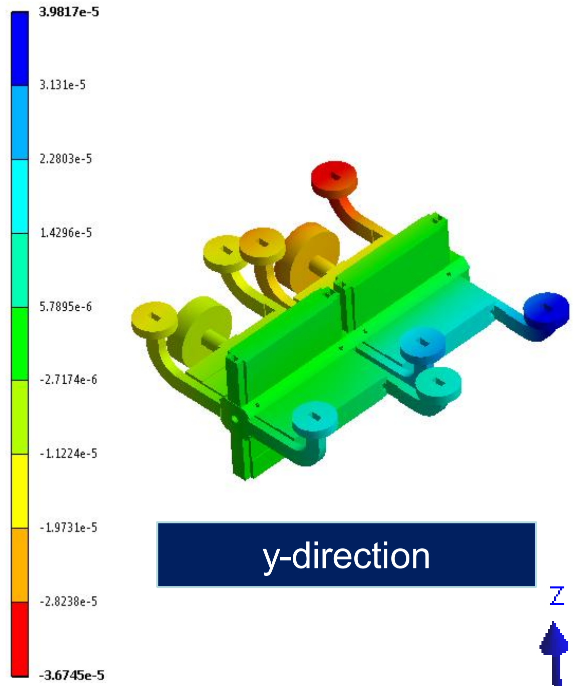
CLIC module type 1

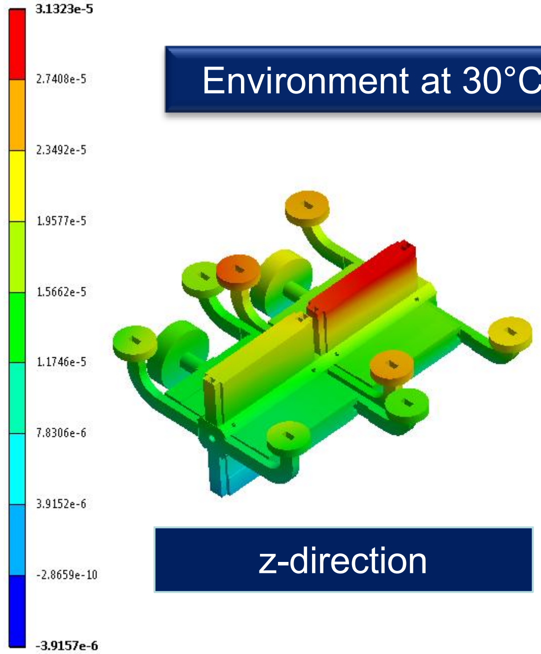
Environment at 30°C



x-direction

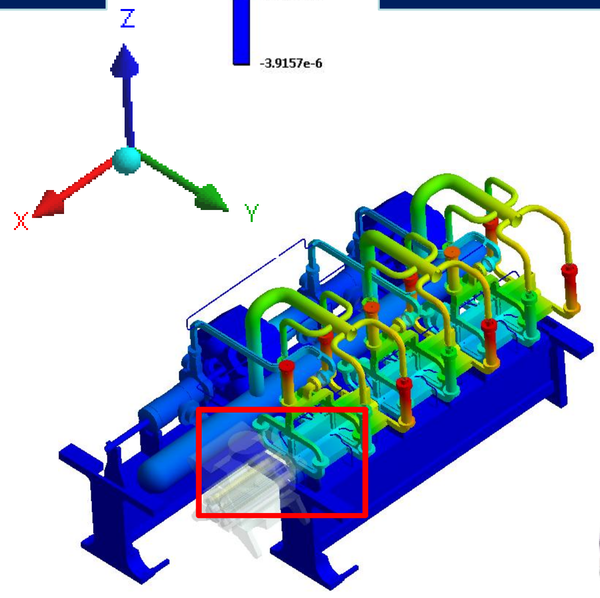


y-direction



z-direction

Item	x	y	z
Max. def. AS (RF unloaded)	45 µm	1.6 µm	15 µm
Max. def. AS (RF loaded)	40 µm	1.4 µm	12 µm



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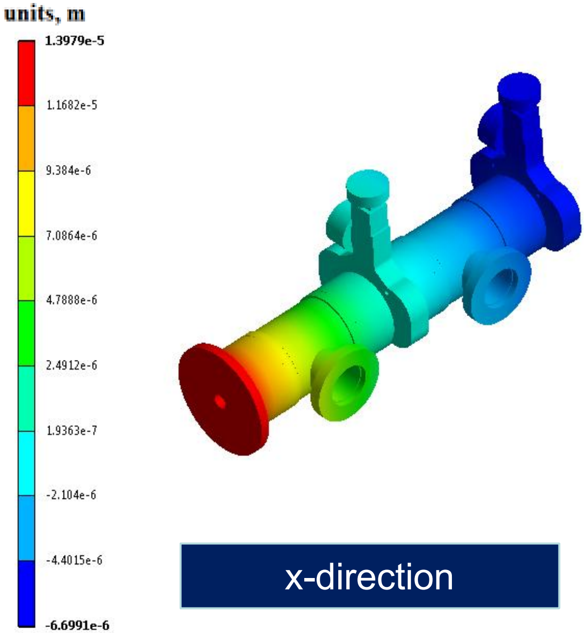
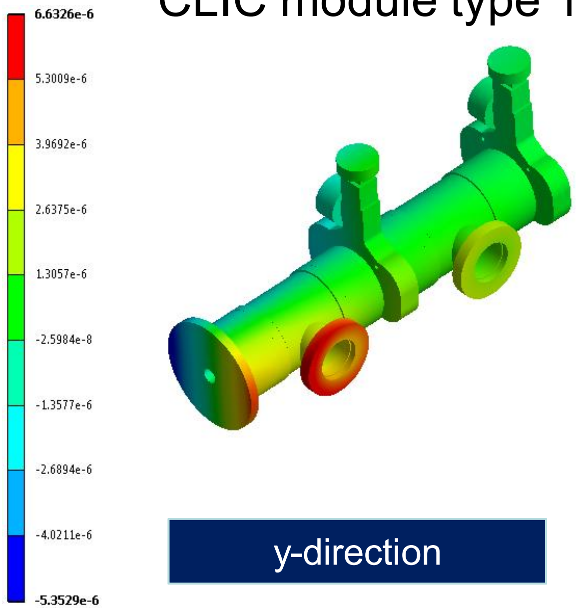
Deformation results: RF for PETS

CLIC module type 1

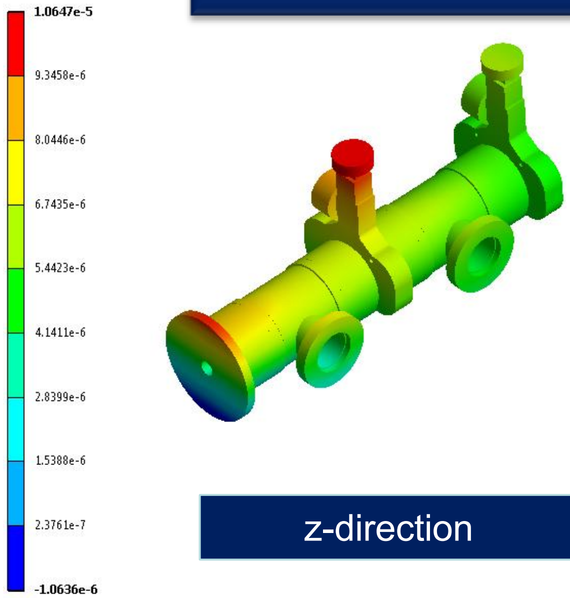
Environment at 30°C



x-direction

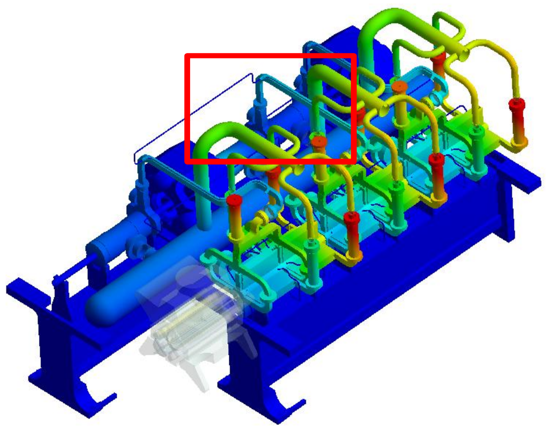


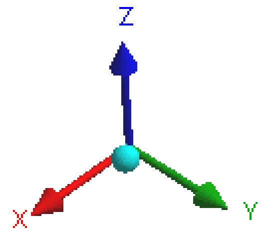
y-direction



z-direction

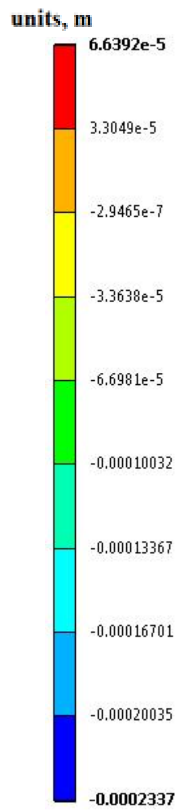
Item	x	y	z
Max. def. PETS, RF	15 µm	0 µm	6 µm

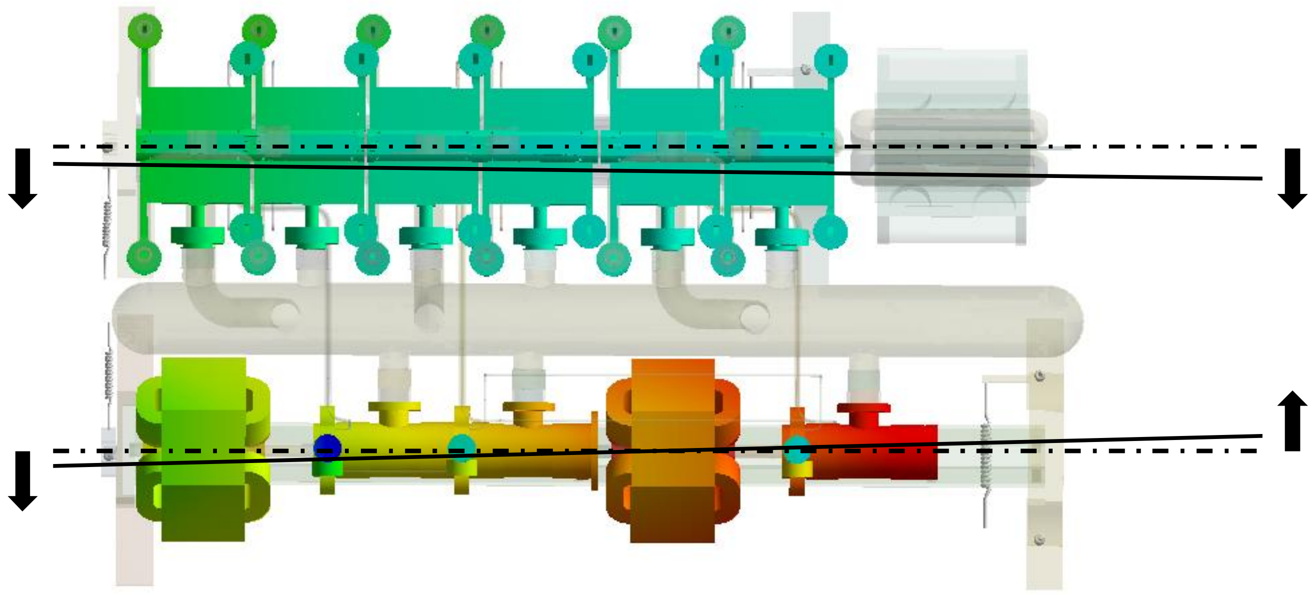




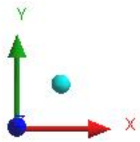
Deformation results: vacuum

CLIC module type 1





Item	x	y	z
Max. def. AS, vacuum	0 µm	130µm	4µm
Max. def. PETS, vacuum	3 µm	54 µm	10 µm



CLIC module simulation: summary

Resulting temperatures inside CLIC module:

Temperature	CLIC type 1	CLIC type 0	prototype type 0
Max temp. of module [°C]	40.7	40.2	43
Water output temp MB [°C]	34.9	34.9	34.8
Water output temp DB [°C]	28.2	29.8	29.8

Resulting displacements due to different loads:

Load type	CLIC type 1	CLIC type 0	prototype type 0
AS (RF) [µm]	40	50	183
PETS (RF) [µm]	16	15	47
AS (vacuum) [µm]	130	49	30
PETS (vacuum) [µm]	54	10	131
AS (gravity) [µm]	23	31	27
PETS (gravity) [µm]	36	36	40

Temperature change of ~10 °C (MB) & ~5 °C (DB)

Larger deformation (~180 µm vs ~45 µm) in prototype than CLIC module due to different interconnections

Small displacements (few µm) between RF loaded & unloaded operation

Vacuum displaces AS & PETS towards each other

Conclusions

- Precise starting point for CLIC beam-based alignment requires:
• precise machining & assembly of RF structures
• precise alignment of RF structures & CLIC modules
• stability during CLIC operation

- three first point validated experimentally & last using FEM

- model for deformation during bonding process under work

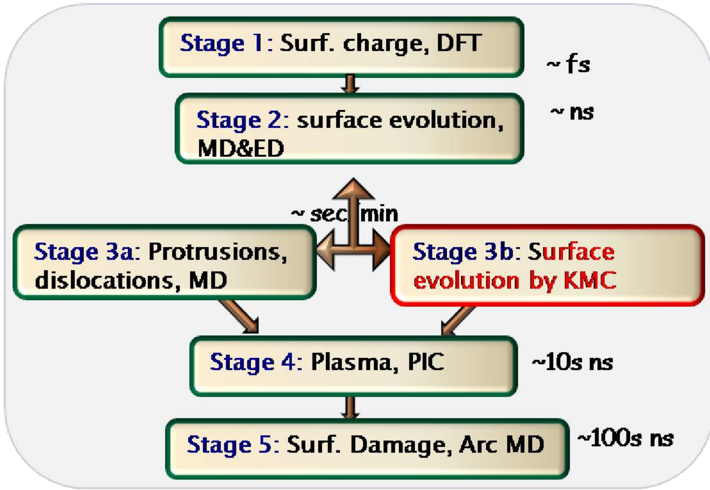
- thermo-mechanical model for CLIC module (including RF structures) for CLIC operation developed

- to be validated with experimental data from mock-up module during 2012-13

Aim: able to predict deformations during assembly & operation precisely $\Rightarrow$ effect included in assembly & alignment

CLIC activities @ Helsinki

Multiscale modeling of breakdown in CLIC RF structures



F. Djurabekova, A. Pohjonen, S. Parviainen, A. Ruzibaev and K. Nordlund, HIP and Department of Physics, UH
(in collaboration with W. Wuensch and S. Calatroni)

CLIC RF structure R&D

A. Meriläinen, L. Kortelainen, T. Niinikoski, A. Nummela, K. Österberg, J. Väinölä and W. Zhou, HIP & Department of Physics, UH

- high-precision assembly & machining R&D for CLIC RF structures
  (in collaboration with VTT & Finnish companies…)
- modeling & study of thermo-mechanical behavior of CLIC module
- industrialisation & cost study for CLIC RF structures
- development of technique for dynamic vacuum measurement (DVM) & hardness depth profiling of Cu surface using laser-ultrasound
  (in collaboration with prof. E. Haeggström et al.)

within CLIC RF structure development group (*W. Wuensch & G. Riddone*)

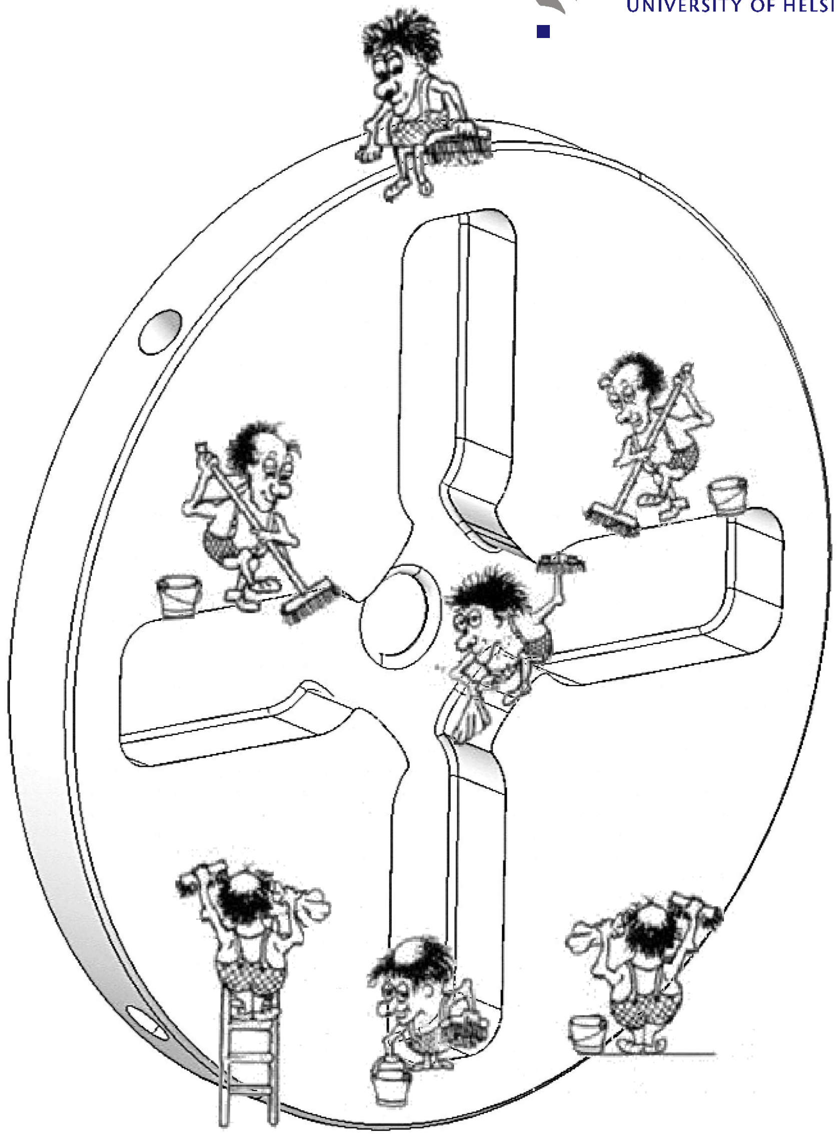
Thanks & references

Acknowledgements:

- R. Raatikainen, R. Nousiainen (HIP/UH)
- F. Rossi, G. Riddone (CERN)
- A. Samoshkin (JINR)
- CLIC RF structure production team
- CLIC RF structure R&D team
- CERN survey team

References:

- R. Raatikainen, “Modelling of the thermo-mechanical behavior of the two-beam module for the Compact Linear Collider”, CERN-THESIS-2011-178
- R. Raatikainen et al., “Improved modelling of the thermo-mechanical behaviour of the CLIC two-beam module”, to be present at IPAC’12 in May 2012.



courtesy of F. Rossi

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Open position

Marie Curie Linking Industry to CERN

MeChanICs SEEKS

ACCELERATOR PHYSICIST OR ENGINEER FOR Postdoctoral 2-year Fellowship

From 1.9.2012 onwards

Technical Coordination of RF structure Manufacturing & Assembly
Placed at CERN working for Helsinki Institute of Physics

If interested please contact Kenneth.Osterberg@Helsinki.Fi