

# Two-beam Module: Engineering design, System integration and R&D program

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A. Samoshkin and A. Solodko

*Acknowledgements to all members of the CLIC Module WG*

3 February 2011

## OUTLINE

- Introduction: method and general layout
- CLIC two beam module design: status and main issues
- R&D program: status and future steps



# CLIC feasibility issues

| System  | Item                            | Feasibility Issue   | Unit       | Nominal    |
|---|---------------------------------|---|------------|------------|
| Two Beam Acceleration                         | Drive beam generation           | Fully loaded accel effic  | %          | 97         |
|   |                                 | Freq&Current multipl  | -          | 2*3*4      |
|   |                                 | 12 GHz beam current   | A          | 4.5*24=100 |
|   |                                 | 12 GHz pulse length   | nsec       | 240        |
|   |                                 | Intensity stability   | 1.E-03     | 0.75       |
|   |                                 | Drive beam linac RF phase stability                             | Deg (1GHZ) | 0.05       |
|   | Beam Driven RF power generation | PETS RF Power   | MW         | 130        |
|   |                                 | PETS Pulse length   | ns         | 170        |
|   |                                 | PETS Breakdown rate   | /m         | < 1·10-7   |
|   |                                 | PETS ON/OFF   | -          | @ 50Hz     |
|   |                                 | Drive beam to RF efficiency                                     | %          | 90%        |
|   |                                 | RF pulse shape control  | %          | < 0.1%     |
|   | Accelerating Structures (CAS)   | Structure Acc field   | MV/m       | 100        |
|   |                                 | Structure Pulse length  | ns         | 240        |
|   |                                 | Structure Breakdown rate  | /m MV/m.ns | < 3·10-7   |
|   | Two Beam Acceleration           | Power production and probe beam acceleration in Two beam module | MV/m - ns  | 100 - 240  |
|   |                                 | Drive to main beam timing stability                             | psec       | 0.05       |
|   |                                 | Main to main beam timing stability                              | psec       | 0.07       |
| Ultra low beam emittance & sizes              | Ultra low Emittances            | Emittance generation H/V  | nm         | 500/5      |
|   |                                 | Emittance preservation: Blow-up                                 | nm         | 160/15     |
|   | Alignment                       | Main Linac components   | microns    | 15         |
|   |                                 | Final-Doublet   | microns    | 2 to 8     |
|   | Vertical stabilisation          | Quad Main Linac   | nm>1 Hz    | 1.5        |
|   |                                 | Final Doublet (assuming feedbacks)                              | nm>4 Hz    | 0.2        |
| Operation and Machine Protection System (MPS) |                                 | 72MW@2.4GeV<br>main beam power of 13MW@1.5TeV                   |            |            |

Demonstration of novel scheme of two beam acceleration and extension of the basic tests to compact modules integrating all technical systems for RF production, beam measurement and acceleration including alignment, stabilisation and vacuum at their nominal parameters.  
 ➔ performance/cost driver

§ IPAC 10- JP. Delahaye invited paper

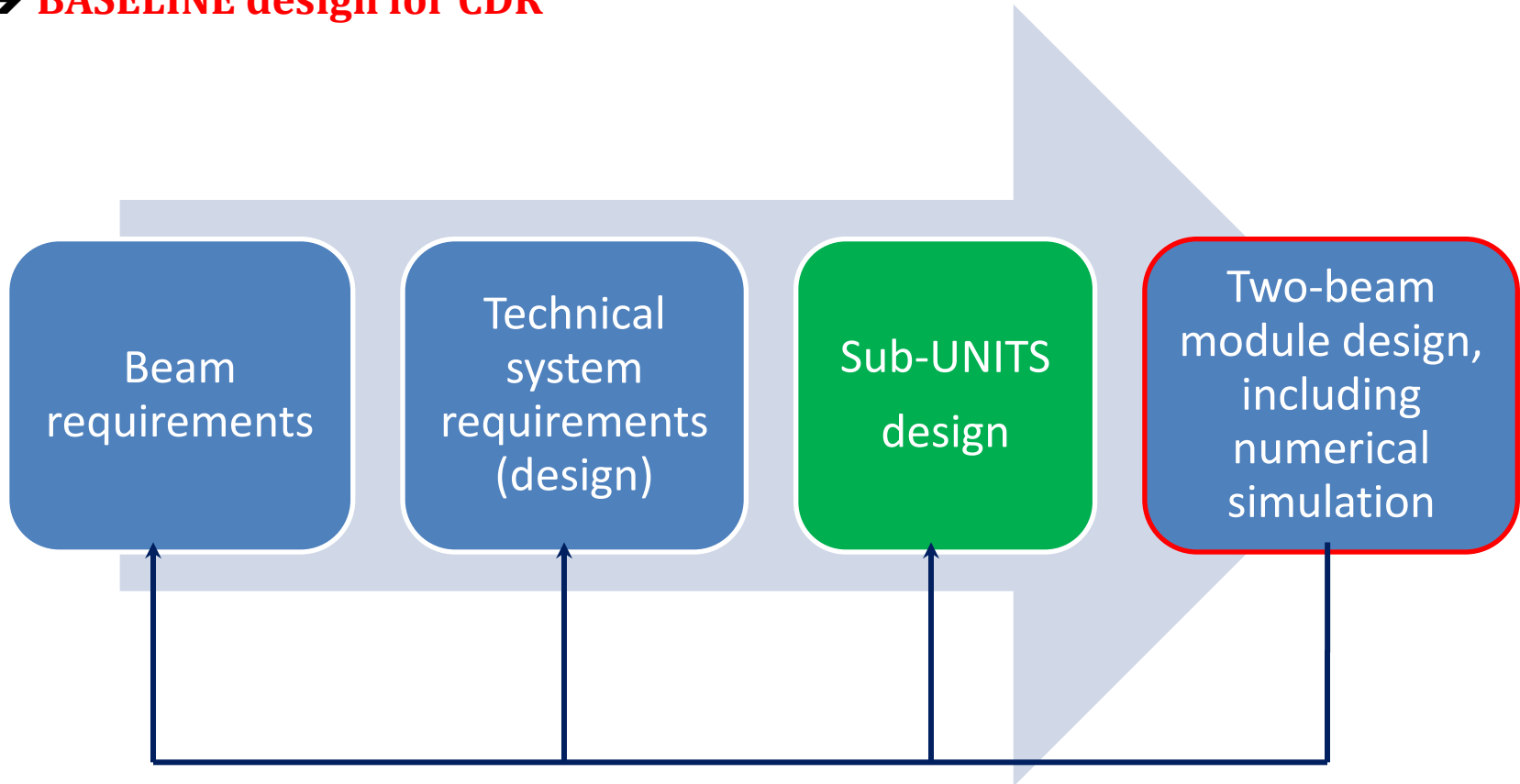
# Steps towards two-beam module design

Several interfaces and several issues have to be addressed

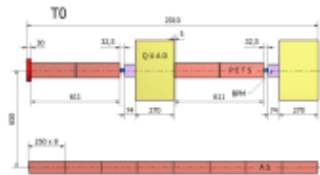
Filling factor should be as high as possible → very compact design

Design should also take into account assembly, transport and maintenance

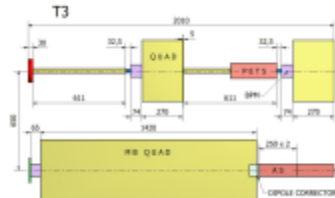
→ **BASELINE design for CDR**



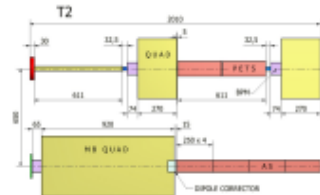
# Two-beam module types



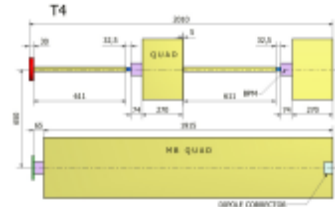
Standard Module  
8374 per Linac



Module Type 3  
477 per Linac

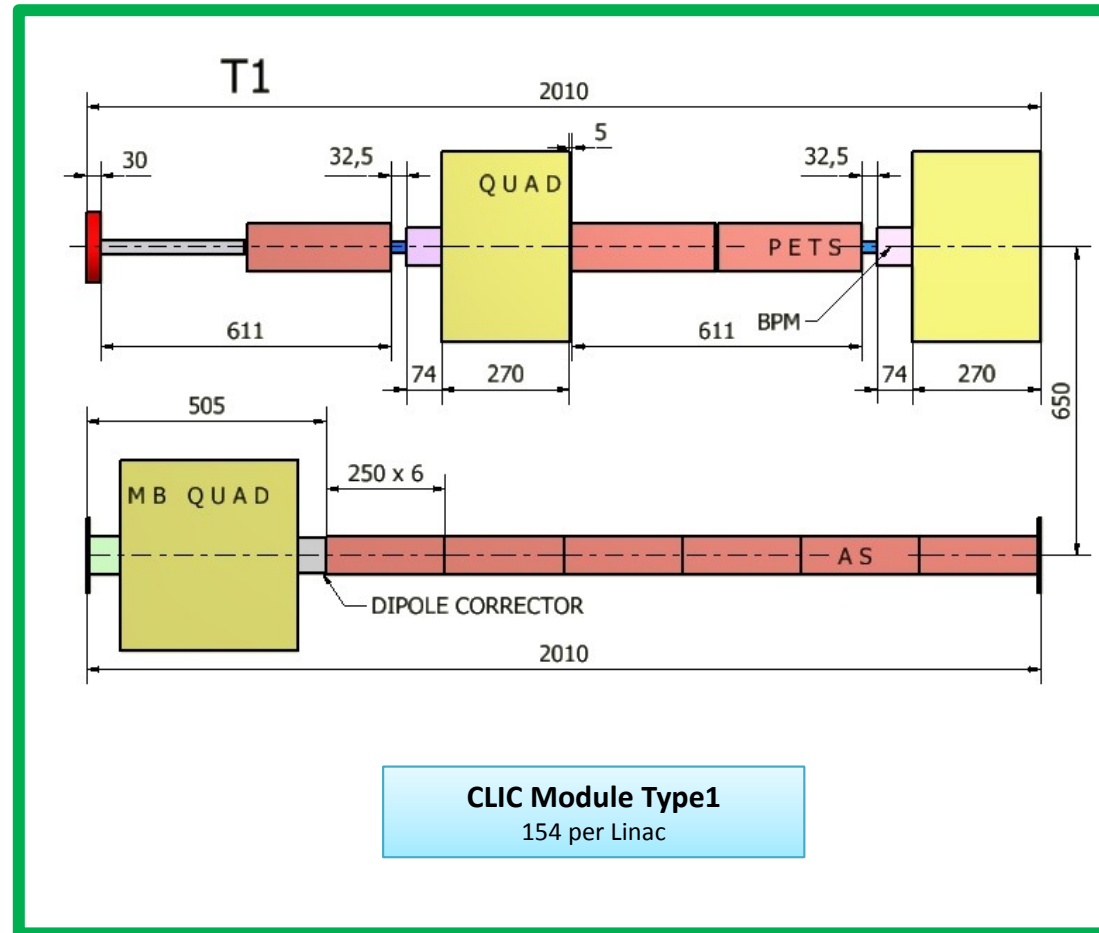


Module Type 2  
634 per Linac



Module Type 4  
731 per Linac

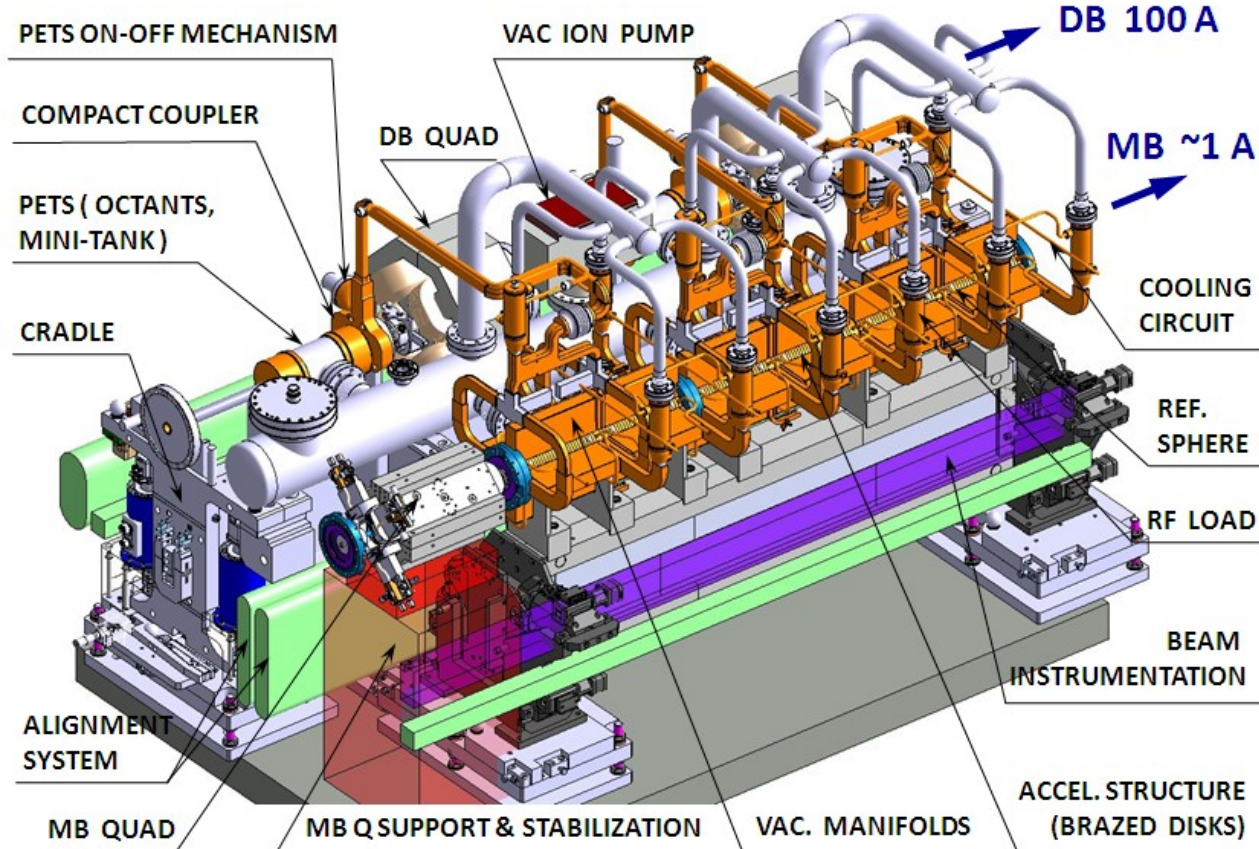
+ special modules (end-sector region, modules with instrumentation and/or vacuum equipment) to be studied in TDR phase



**CLIC Module Type1**  
154 per Linac

# CLIC two-beam module (T1)

A. Samoshkin



## CLIC at 500 GeV (4248 modules)

26312 Accelerating structures

13156 PETS

~ 70000 RF components

## CLIC at 3 TeV (20924 modules)

142812 Accelerating structures

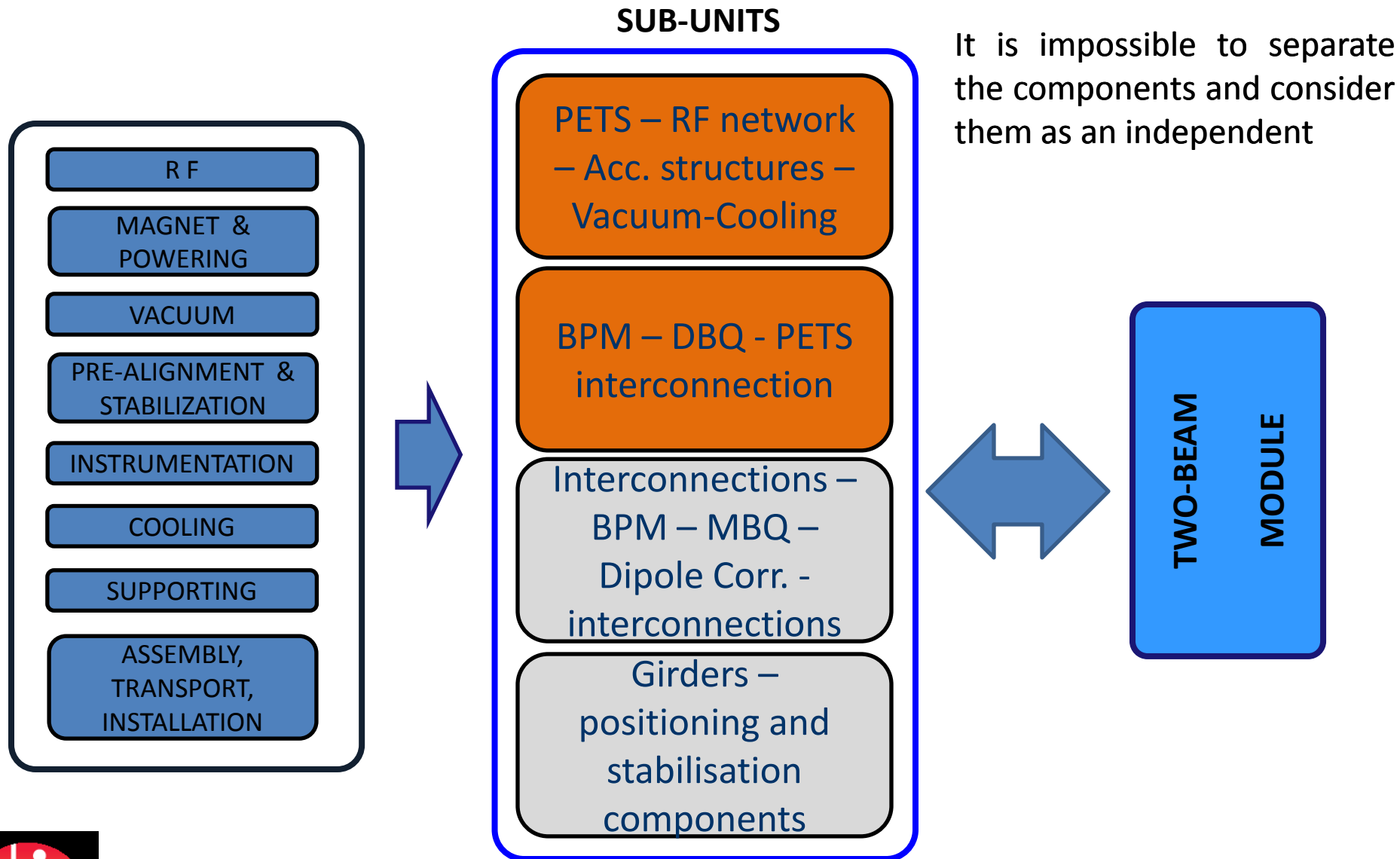
71406 PETS

~ 400000 RF components

Many issues appear  
during the  
integrated design



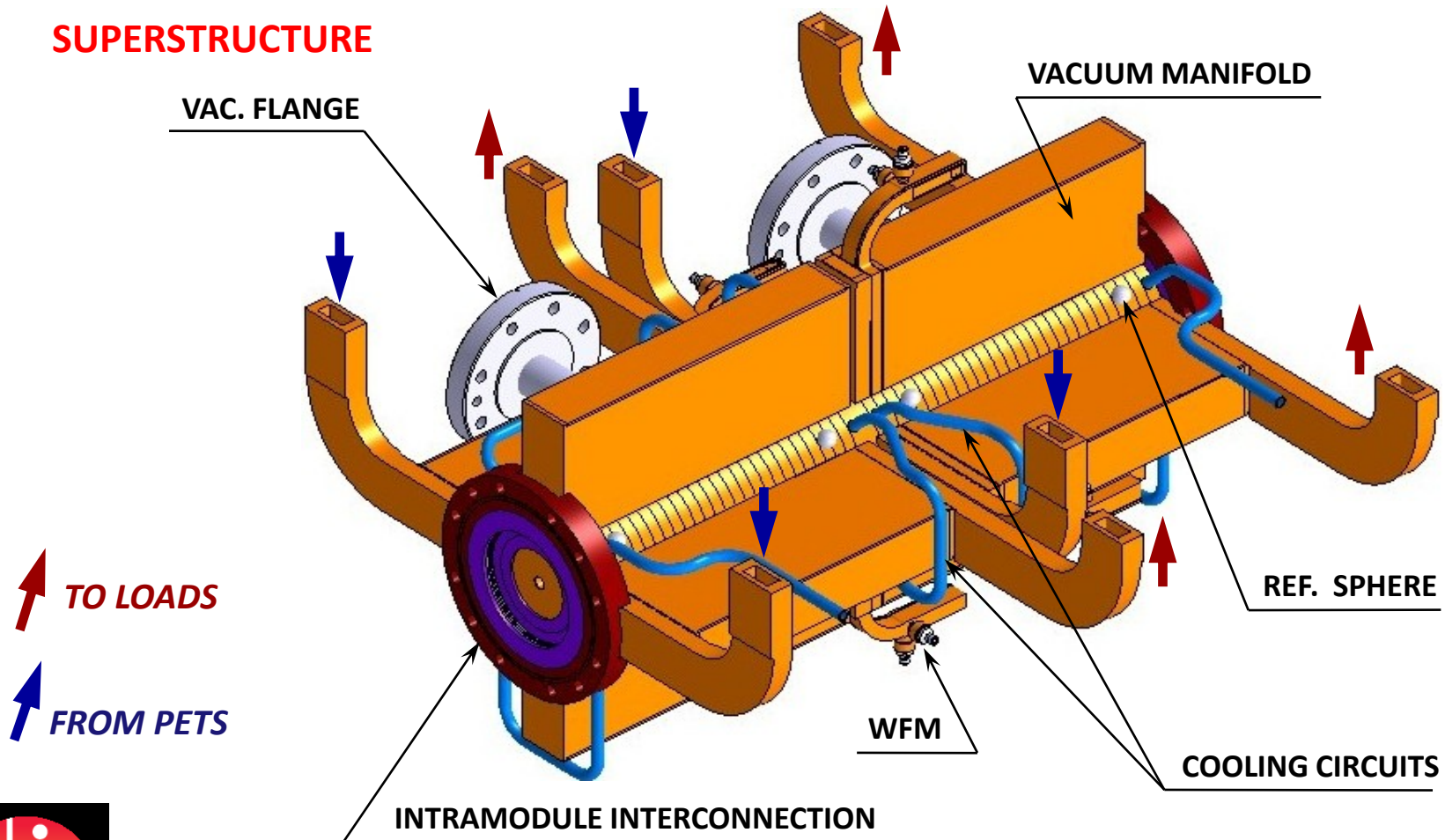
# CLIC two-beam module sub-units



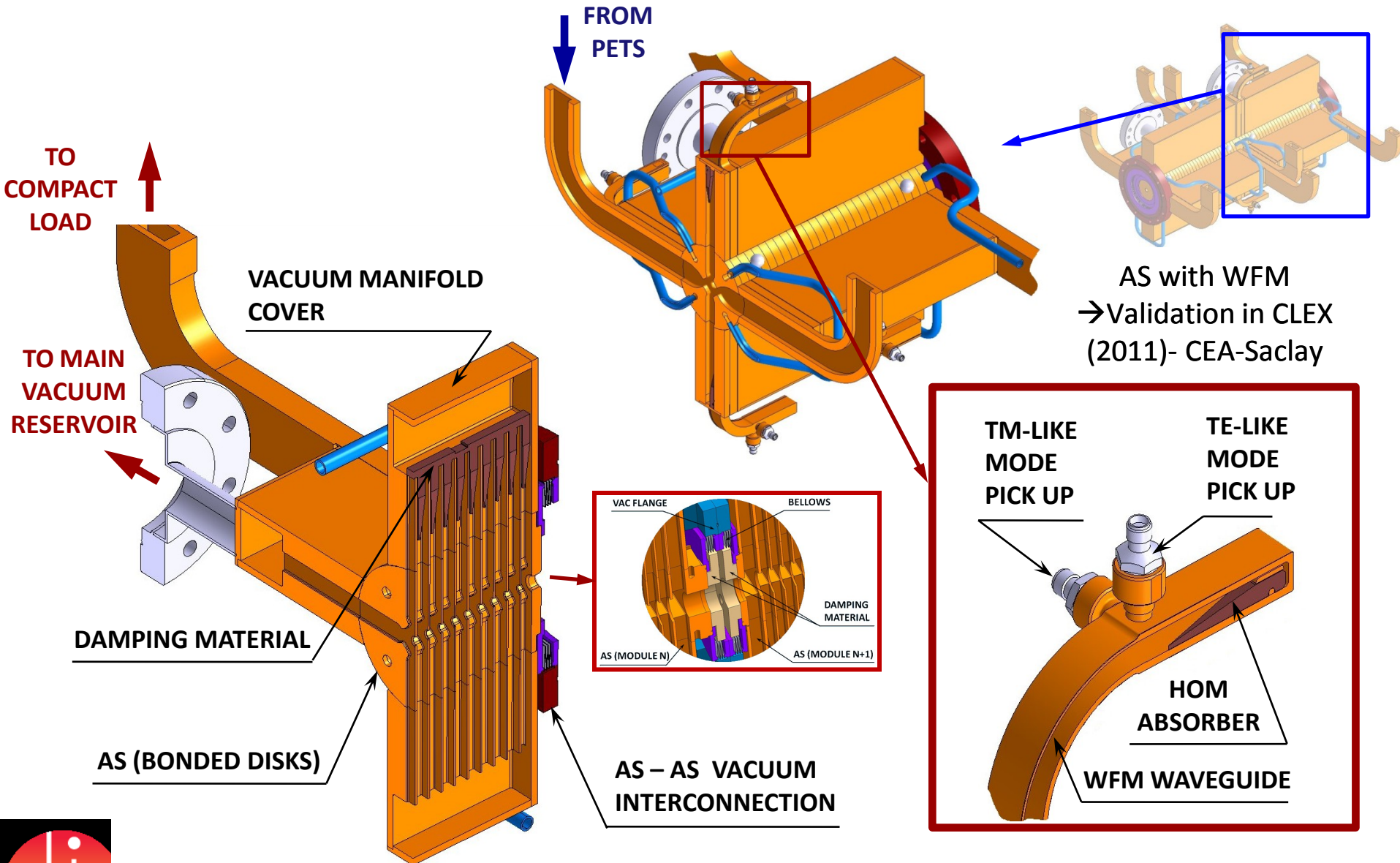
# Accelerating structures (1)

- Shape accuracy  $\pm 2.5 \mu\text{m}$  - assembly accuracy is  $\pm 5 \mu\text{m}$
- Integration of damping loads, WFM (1 per Super-AS), vacuum manifolds, cooling circuits, supports + interconnection to adjacent components and inter-beam waveguides

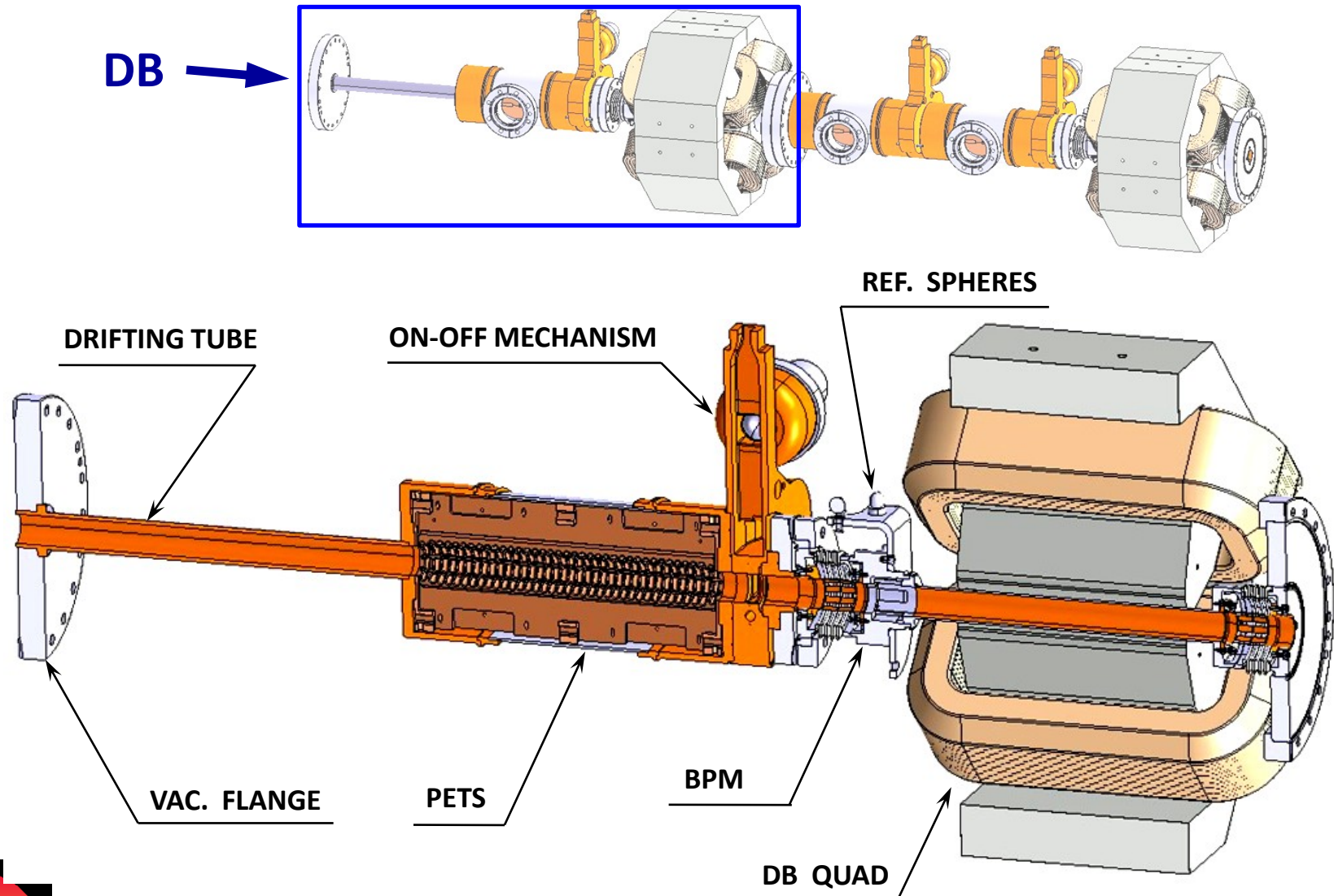
## SUPERSTRUCTURE



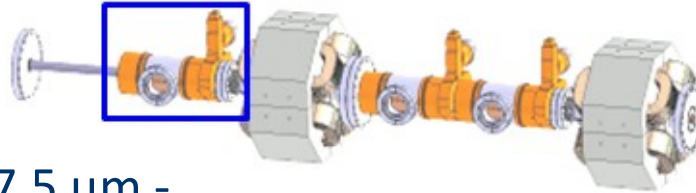
# Accelerating structures (2)



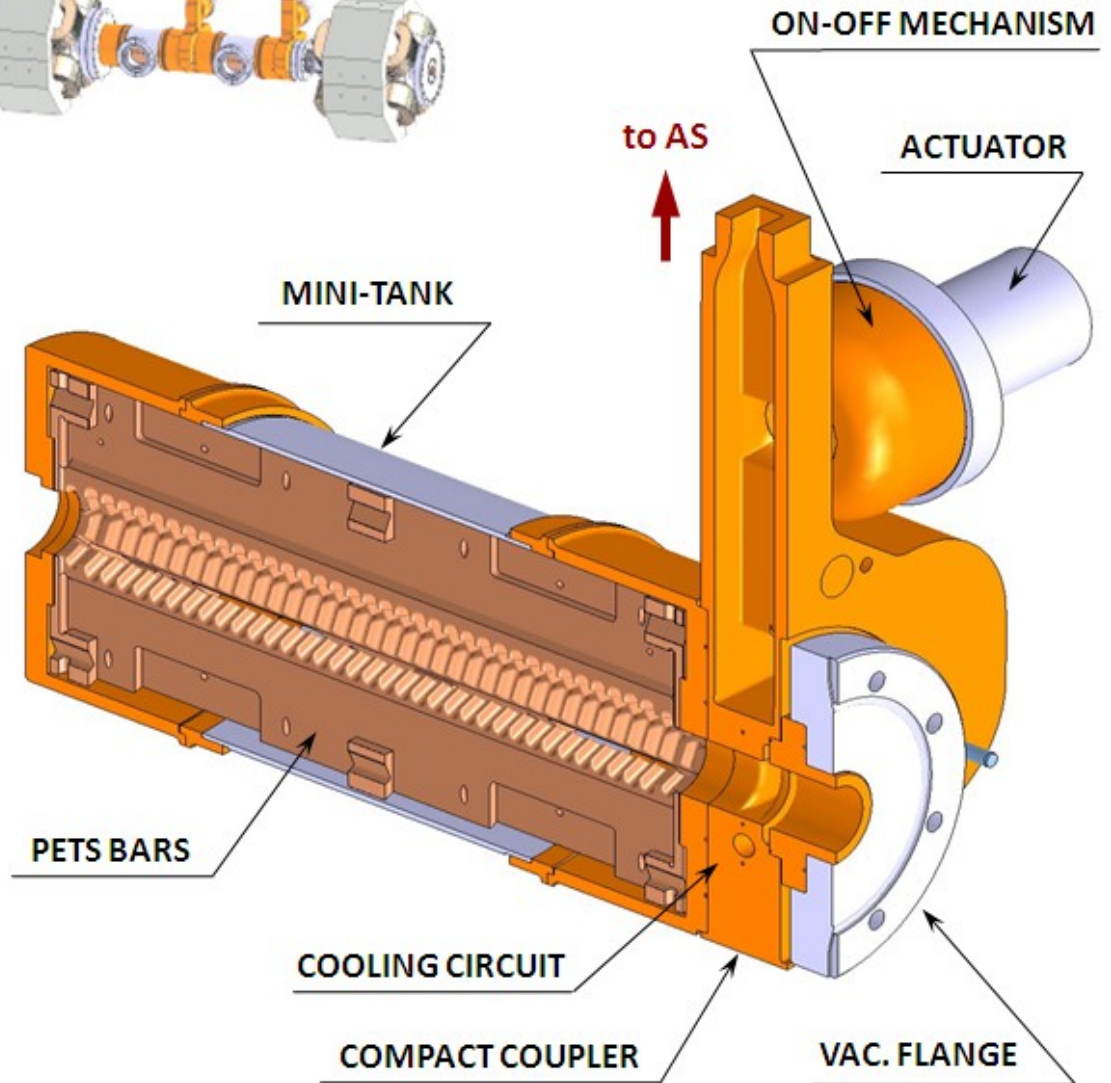
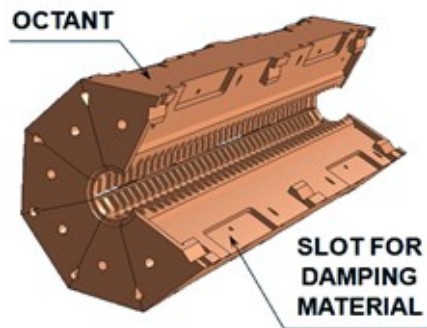
# Drive Beam Components (T1)



# PETS

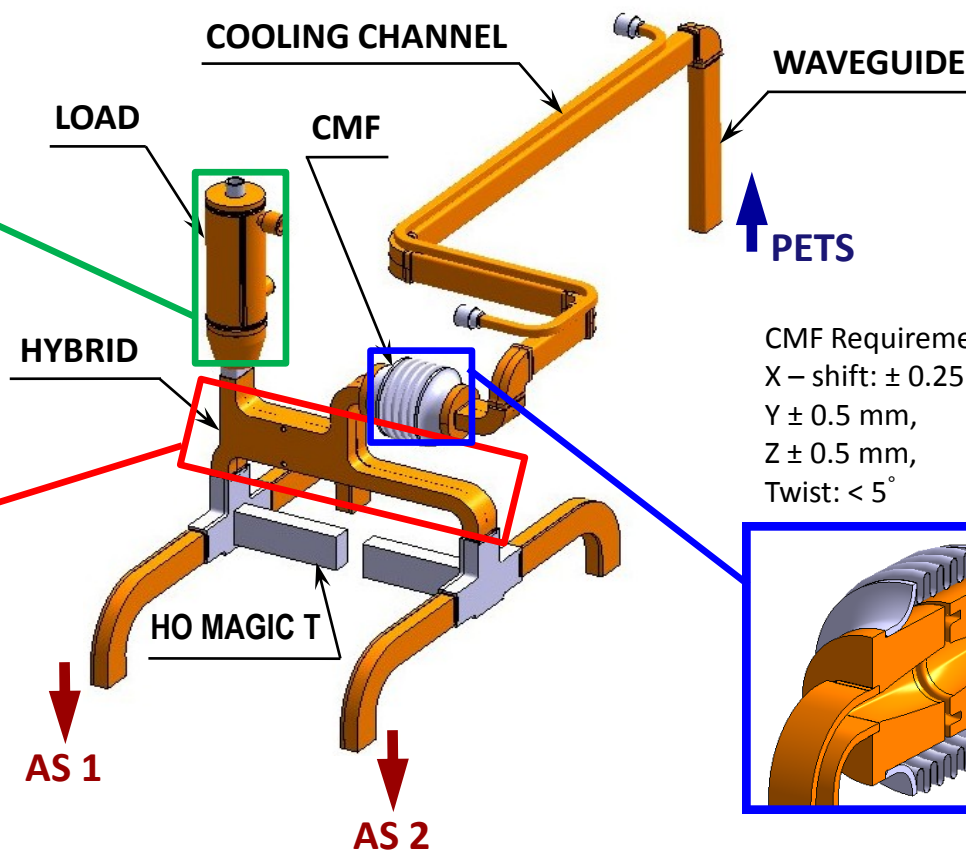
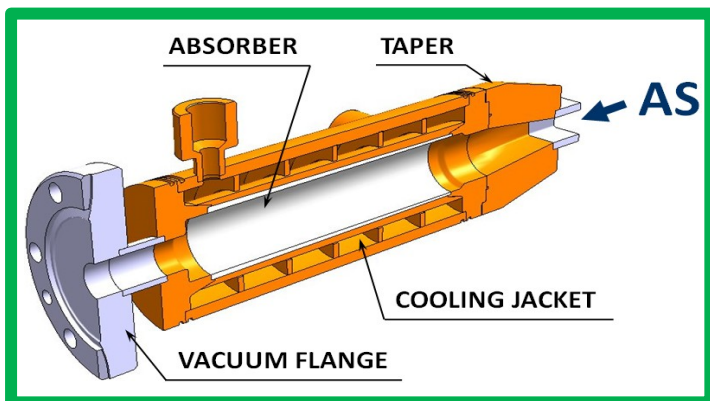
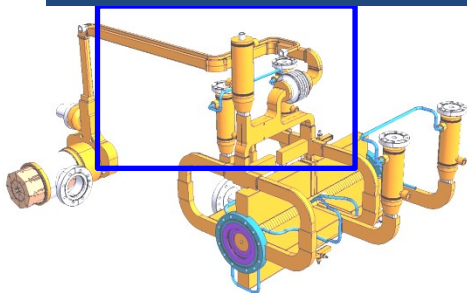


- Shape accuracy  $\pm 7.5 \mu\text{m}$  - **assembly accuracy** is  $\pm 7.5 \mu\text{m}$
- Integration of **on-off mechanism, damping loads, vacuum connections, cooling circuits, supports + interconnection** to adjacent components and inter-beam waveguides

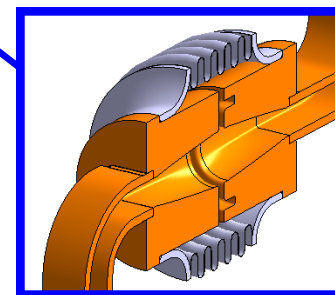
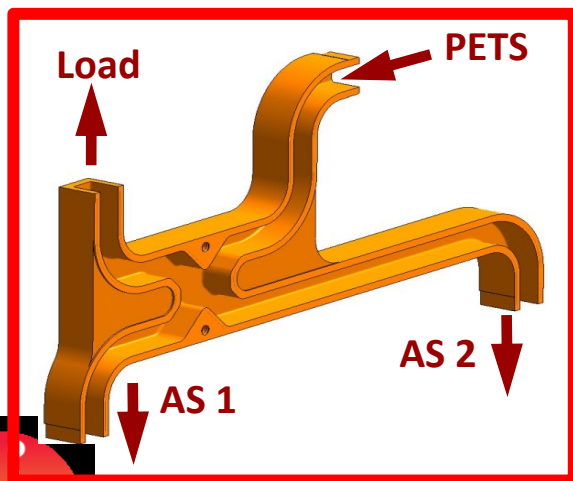


# RF Network layout

- X-band rectangular waveguides;
- the power transmission without electrical contact between two beams, and also MB and DB independent alignment is getting possible with CMF;
- Hybrid, RF loads, splitters

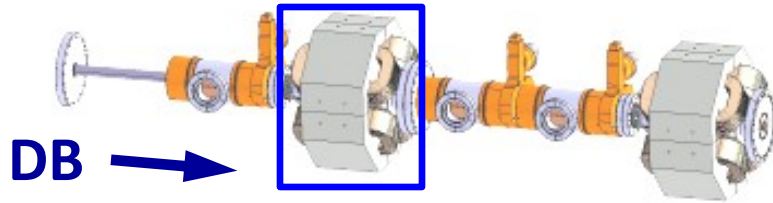


CMF Requirements:  
 X – shift:  $\pm 0.25$  mm,  
 Y  $\pm 0.5$  mm,  
 Z  $\pm 0.5$  mm,  
 Twist:  $< 5^\circ$



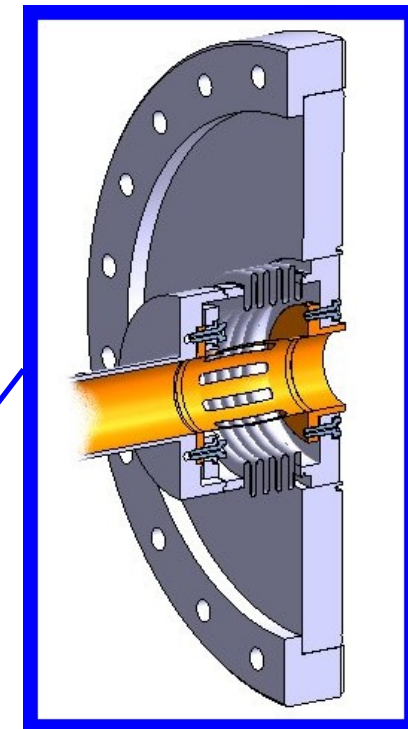
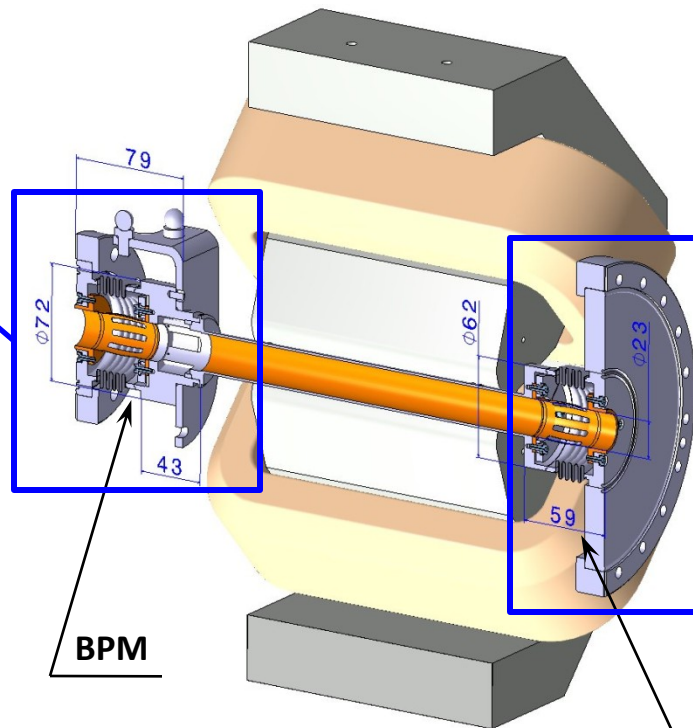
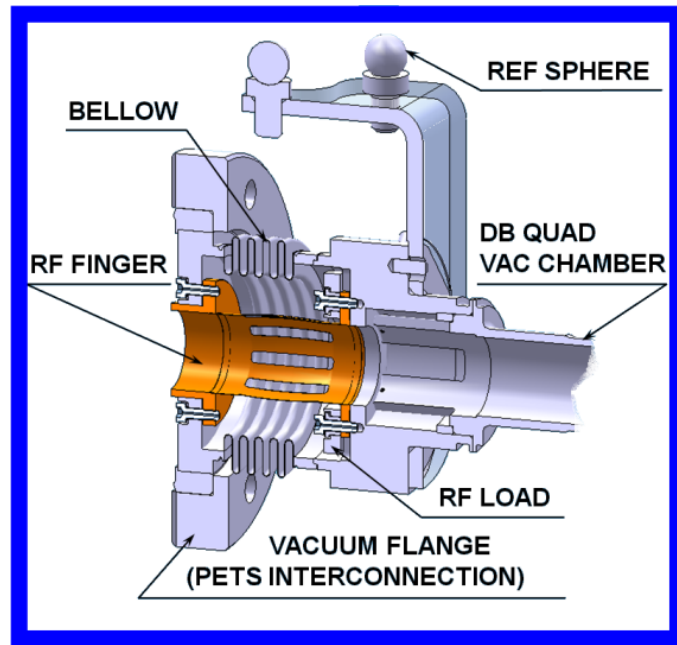
11

# Interconnection – BPM – Vacuum Chamber – Interconnection



DB: The active length specified is 150 mm. The total number of quads required for both linacs is ~42000. In current module design the DB Quad vertical size drives the beam height.

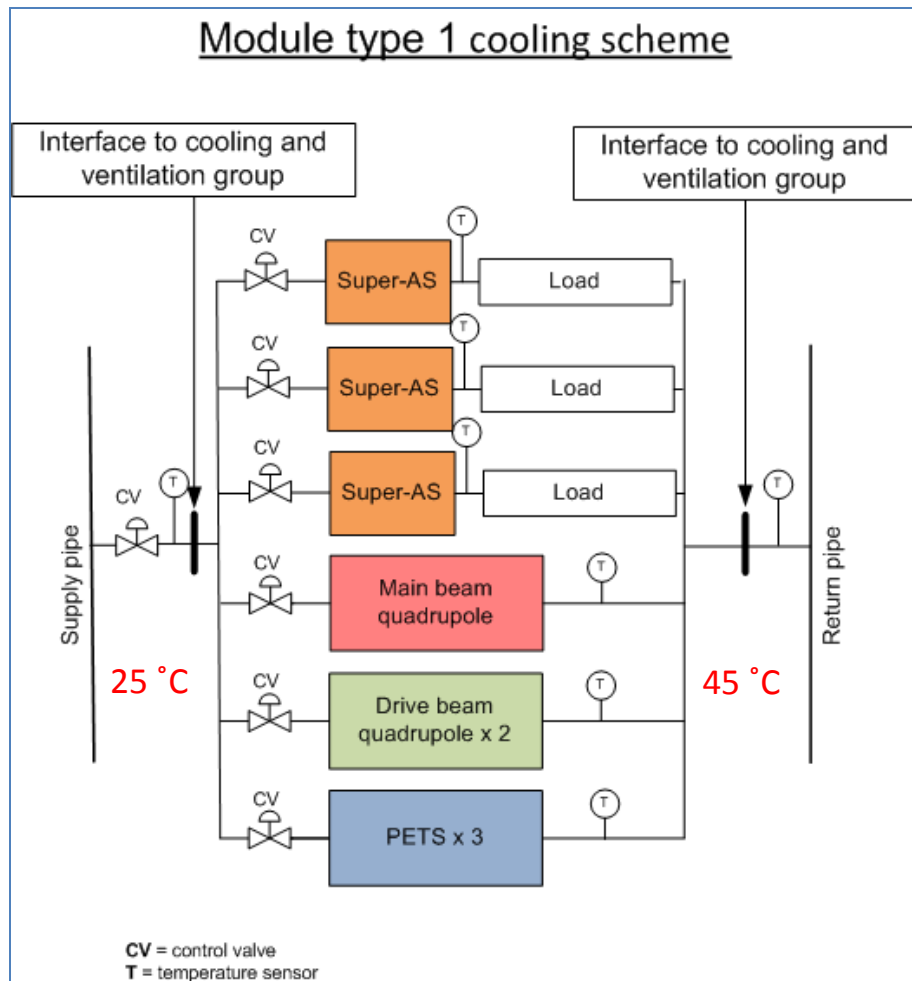
**DB Quadrupole** working gradient: 81.2-8.12 T/m, current density: 4.8 A/mm<sup>2</sup>, magnet aperture: Ø23mm



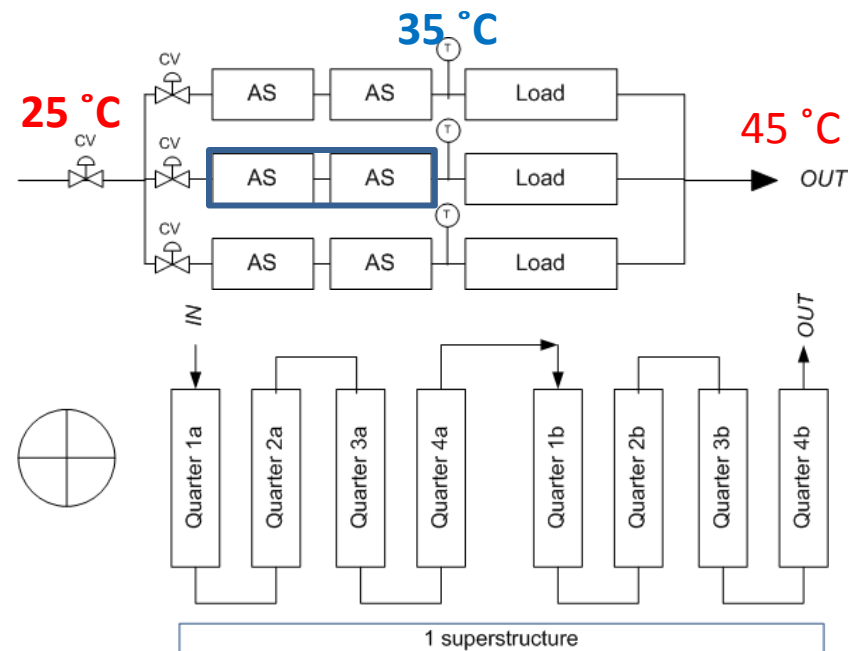
# Module cooling scheme

One inlet/outlet access point close to IP

Module type 1 cooling scheme



**6139 W per Type 1 module**



$T_{\text{water\_in}} = 25\text{ °C} [\pm 2\text{ °C}]$

$Re = 5800$  ( $d = 7\text{ mm}$ )

$h = 3750\text{ W/m}^2/\text{K}$

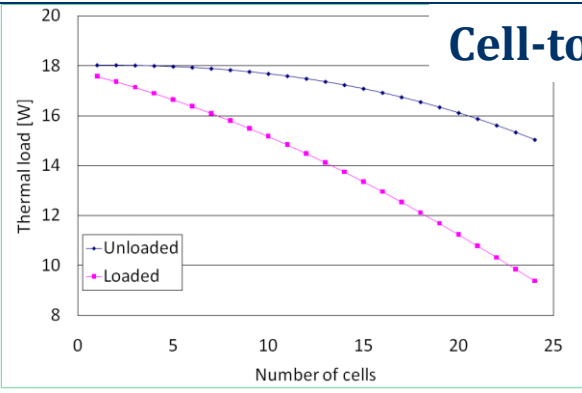
$V = 70\text{ l/h}$  [per AC. STR.]

$V = \sim 350\text{ l/h}$  [per MODULE]

$V = 3500\text{ m/h}$  [per LINAC]

# Thermal analysis

## Cell-to-cell heat dissipation



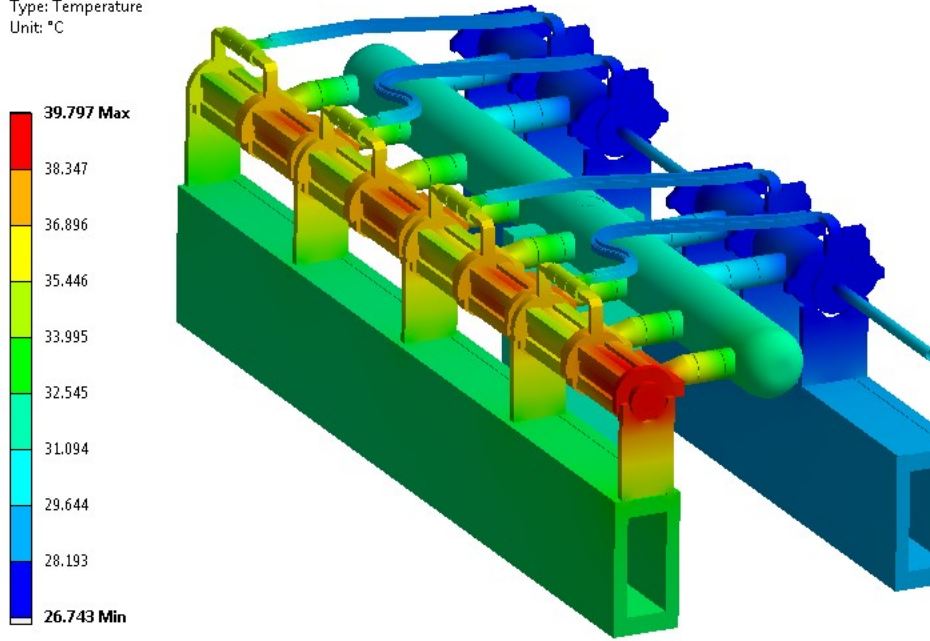
Unloaded 821W

Loaded 672 W

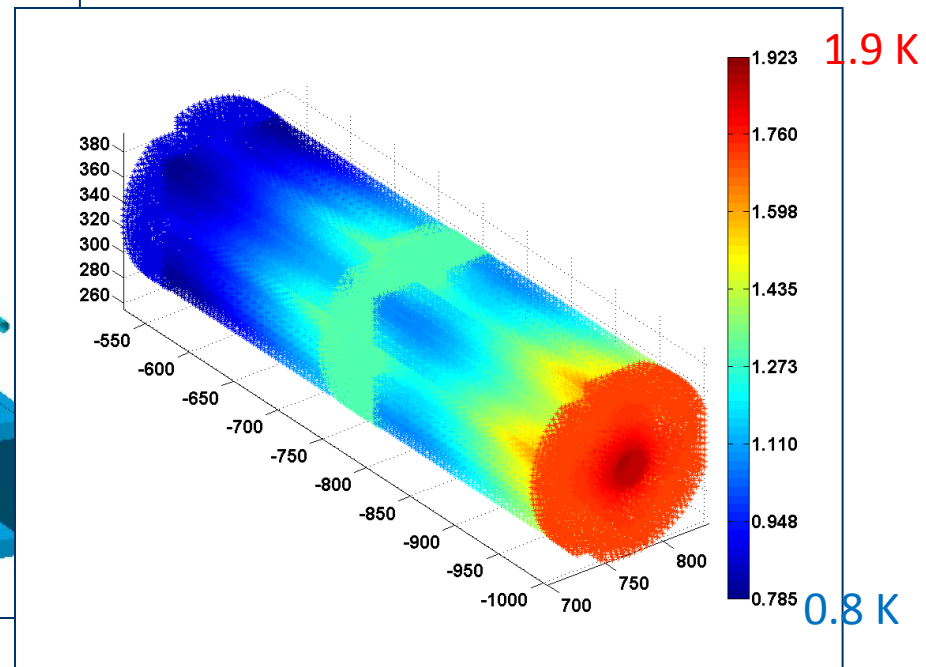
Average dissipated power for a super-structure

Unloaded AS-PETS-WG-Vacuum -Girder  
Temperature  
Type: Temperature  
Unit: °C

## Unloaded case



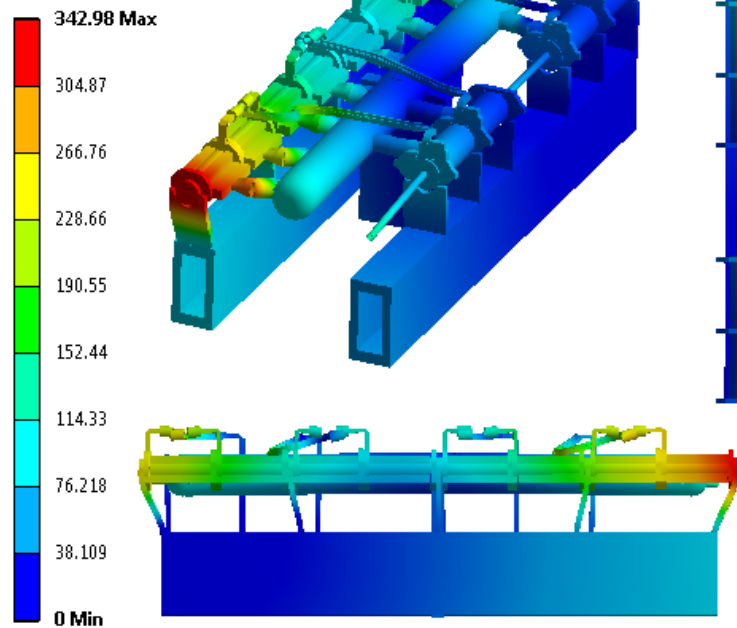
## Temperature difference Unloaded to Loaded



# Structural analysis

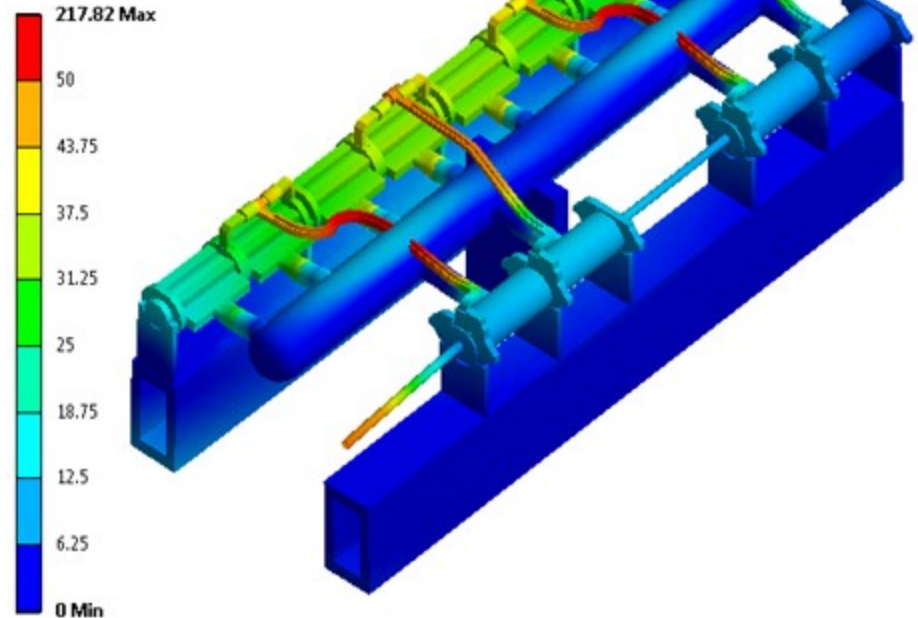
## Static Structural (ANSYS)

Module's Total Deformation under gravity with vacuum and RF applied  
Type: Total Deformation  
Unit:  $\mu\text{m}$



Gravity + Vacuum + RF (unloaded)

Module's Total Deformation under gravity and vacuum applied  
Type: Total Deformation  
Unit:  $\mu\text{m}$



Gravity + Vacuum

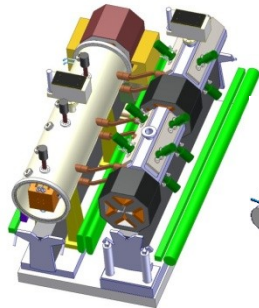
Based on previous module design → 8 accelerating structures as 1 UNIT

# Actions following thermo-structural analysis

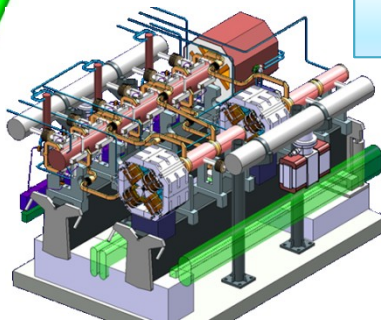
- To limit longitudinal deformation, for the CLIC two beam modules, decoupling of accelerating structure: from 8 as one unit to 2 as one unit (now  $< 80 \mu\text{m}$ )
  - Although for the first prototype modules the most critical configuration was chosen (8 as one unit)
- New RF network layout with additional RF components (new analysis under way)
  - To be validated with the prototype module program
  - *Impact on RF/beam to be determined*
  - *Fallback solution under study: mini-pumps fixed directly on each structure. No lateral stress on RF structures (study in 2011)*
- The module evolution justifies a new TMM from March (technical students from HIP, CEA and from ACAS):
  - New model with also magnets and RF components

# Two-beam module evolution

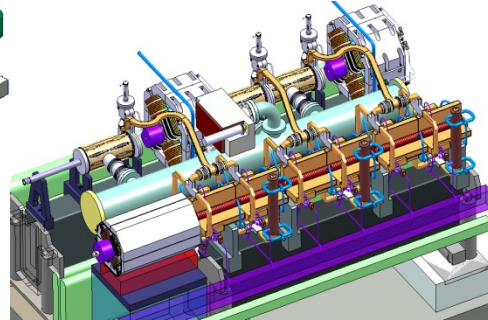
Integration steps and model design evolutions



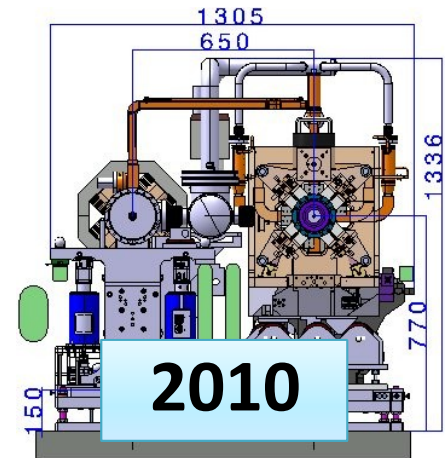
2007



2008



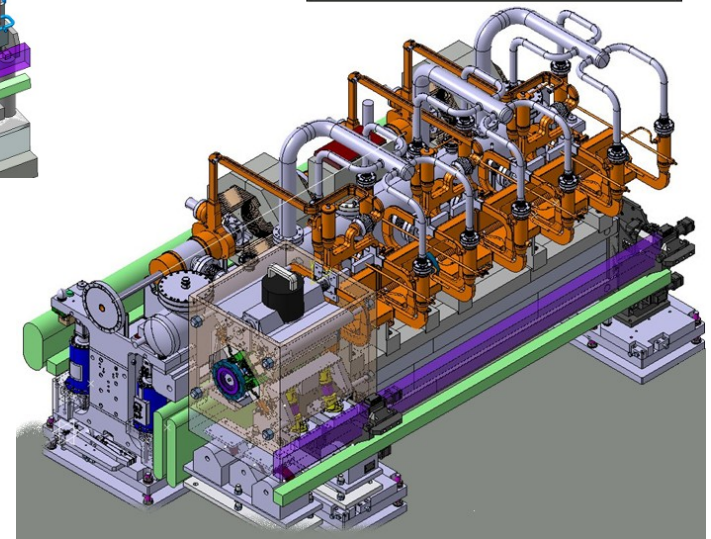
2009



2010

2011 – 2013 +

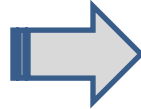
Prototype module  
program



# Steps towards two-beam acceleration modules

## 2009-2011

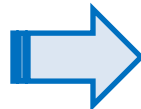
Two-beam test stand  
(PETS and ac.  
structures)



Demonstration of the two-beam acceleration with one PETS and one accelerating structure at nominal parameters in CLEX

## 2010-2013

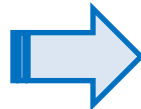
Prototype modules in  
LAB [x4]



### Demonstration of the two-beam module design

This implies the assembly and integration of all components and technical systems, such as RF, magnet, vacuum, alignment and stabilization, in the very compact 2-m long two-beam module

Prototype modules in  
CLEX [x3+1]



### Demonstration of the two-beam acceleration with two-beam modules in CLEX

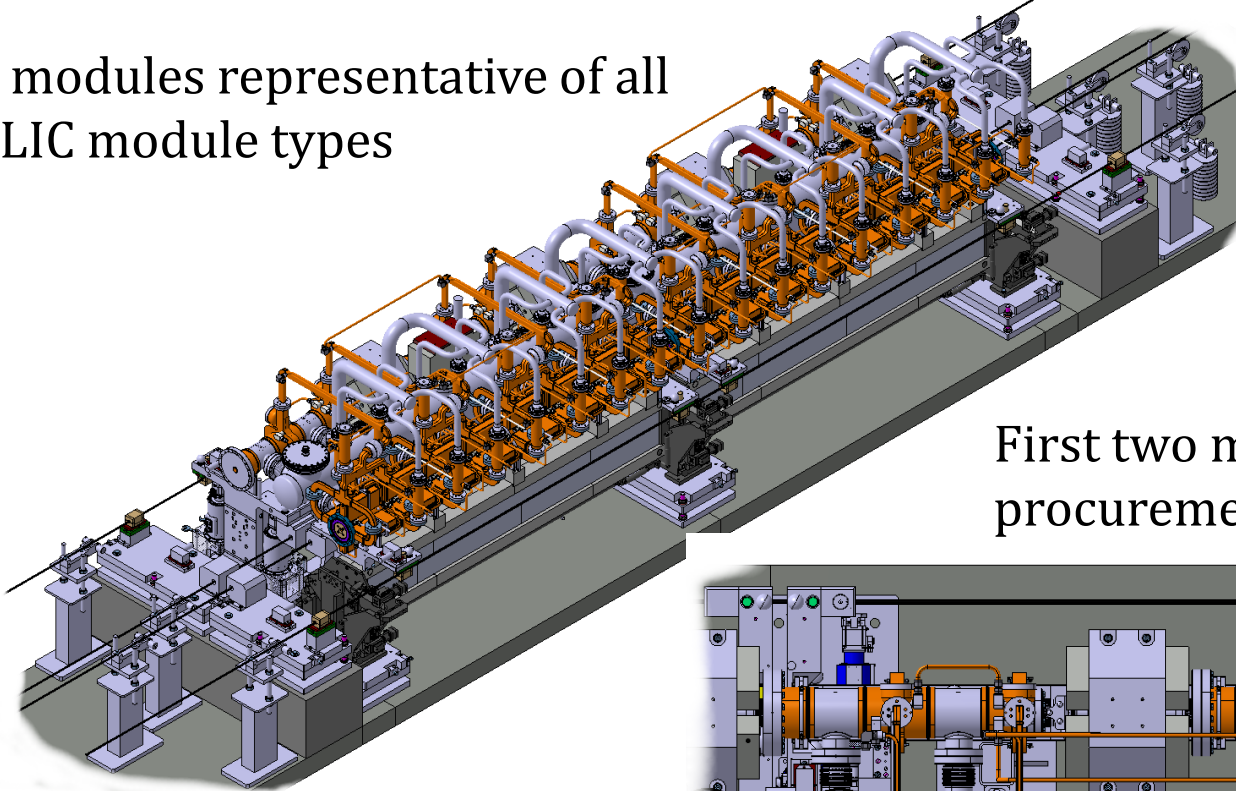
Address other feasibility issues in an integrated approach

Industrialization and mass production study

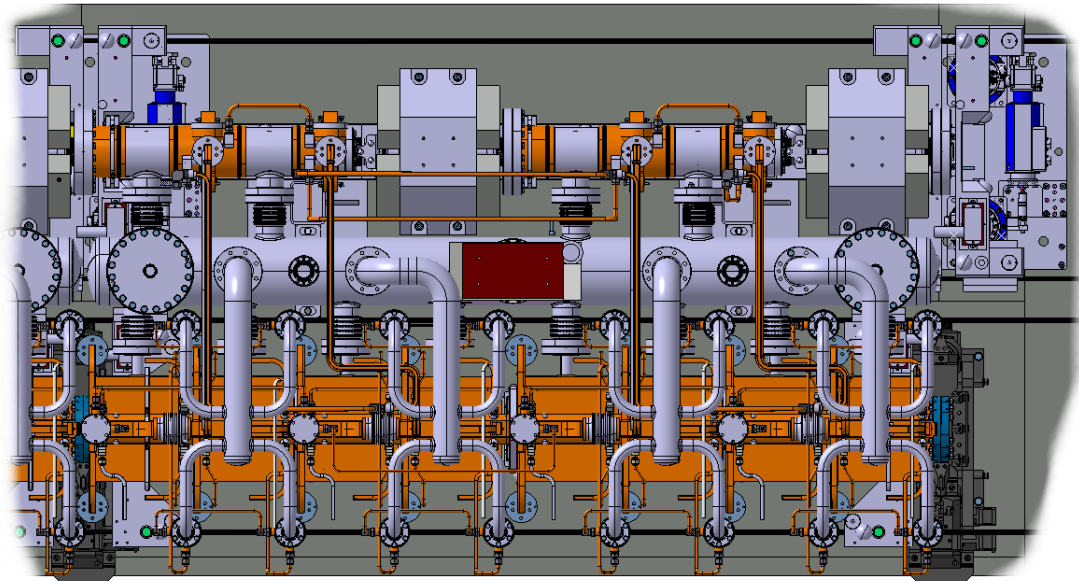
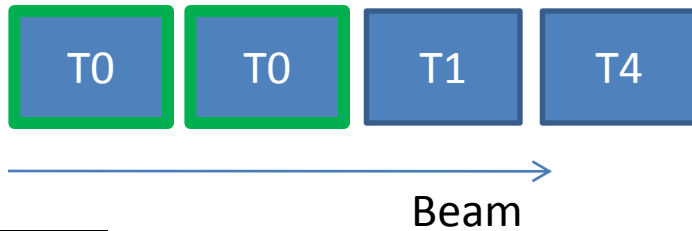
# Prototype modules in the lab

D. Gudkov

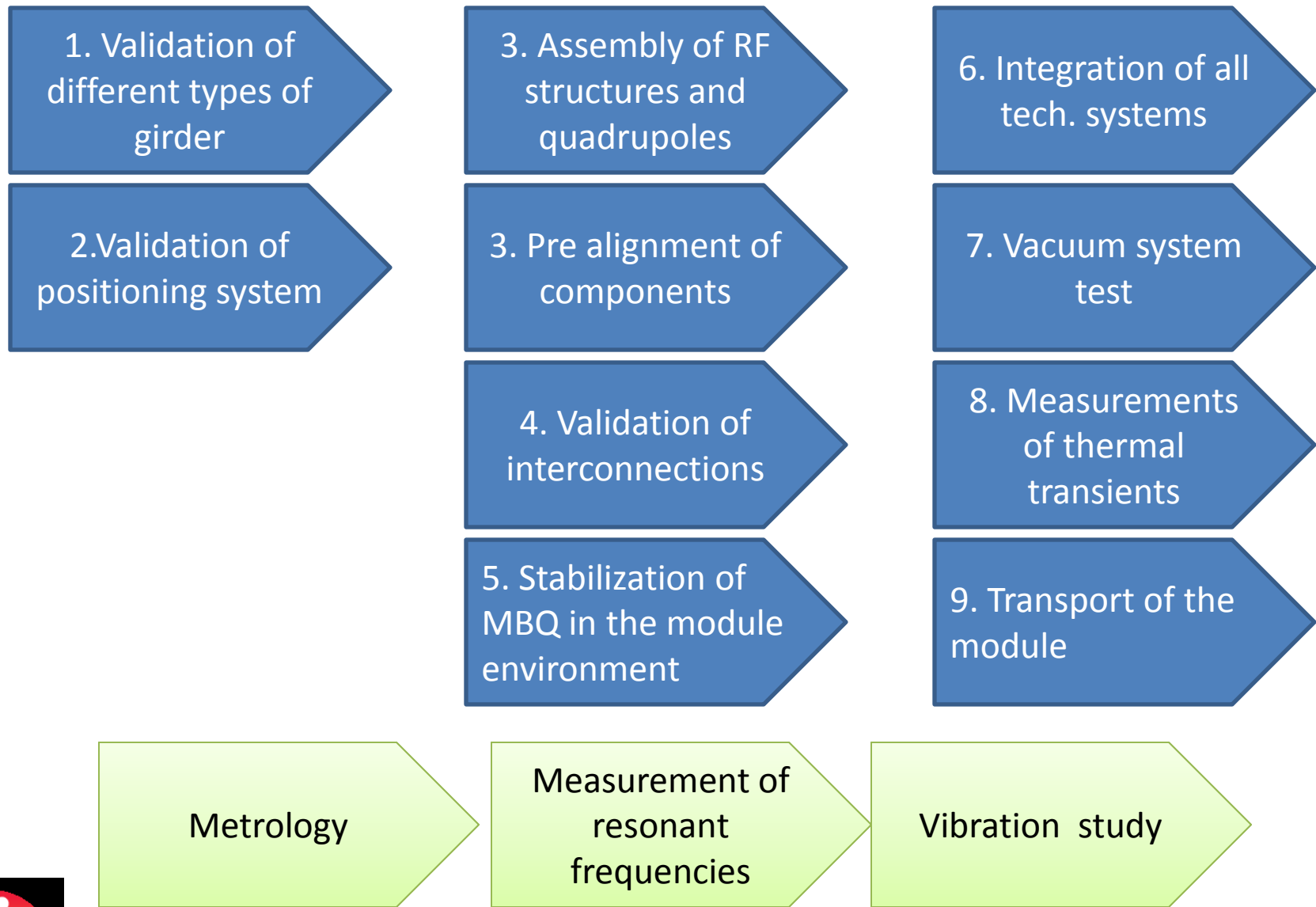
4 modules representative of all CLIC module types



First two modules under procurement/assembly/testing

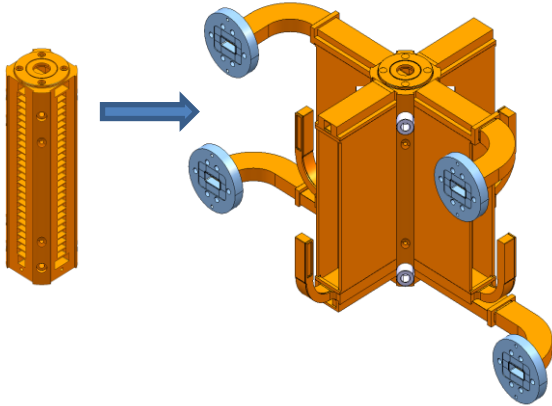


# Prototype modules in the lab - Purpose

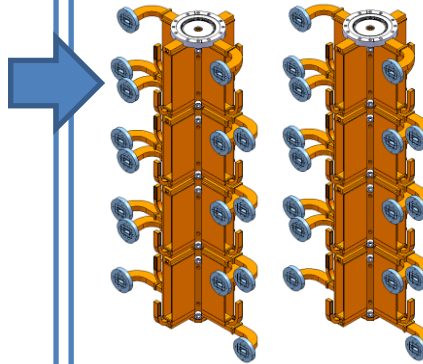


# Accelerating structure mock-ups

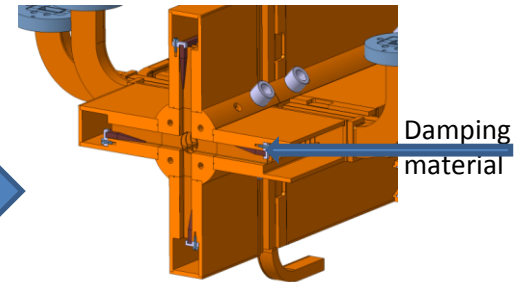
1. Brazing of manifolds; interface WGs; cooling adapters;



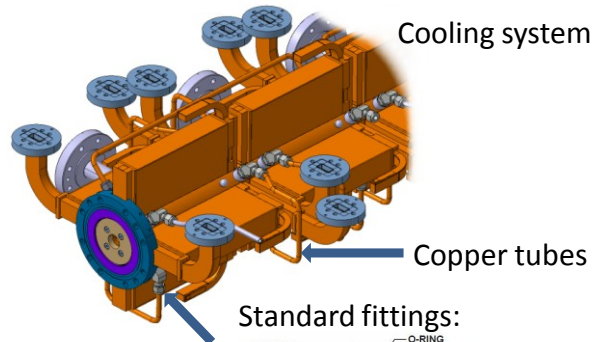
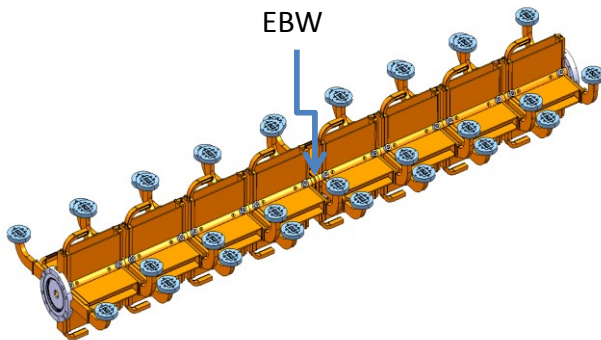
2. Brazing of 2 stacks 1005 mm long each:  
Includes:  
4 AS with manifolds;  
Interconnection MB-MB;



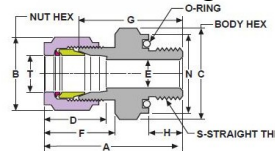
3. Installation of the damping material, welding of covers:



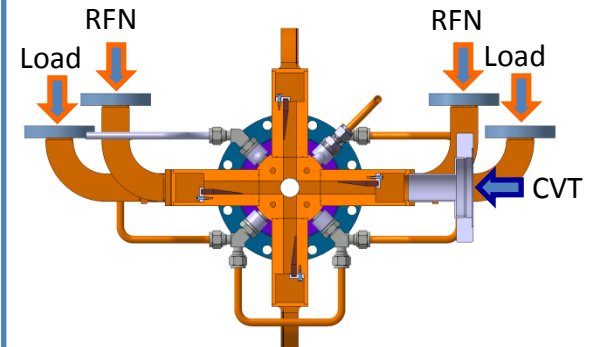
4. Welding (EBW) of two stacks together:



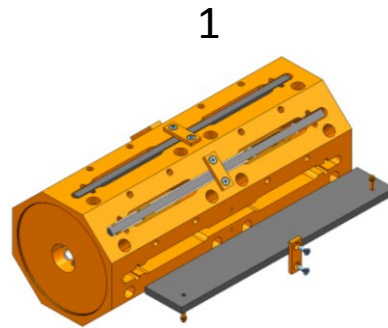
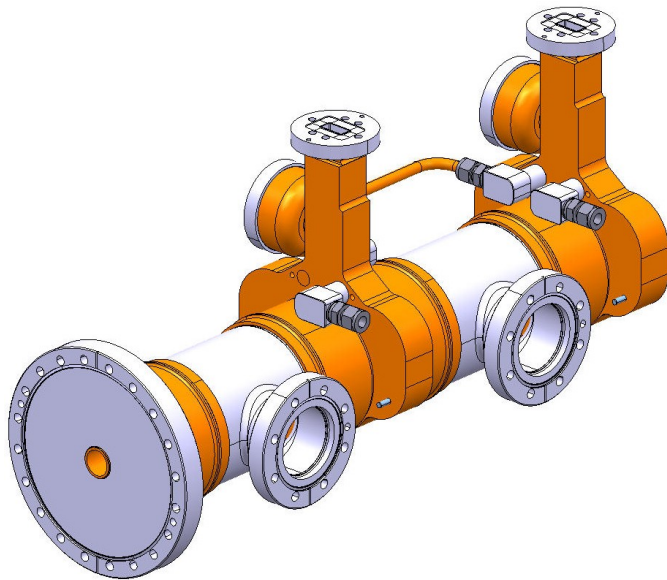
Standard fittings:



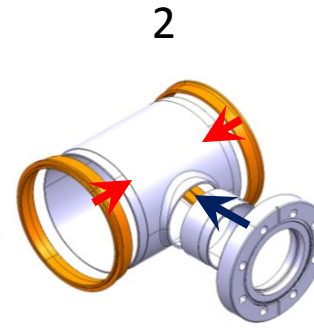
AS Interfaces



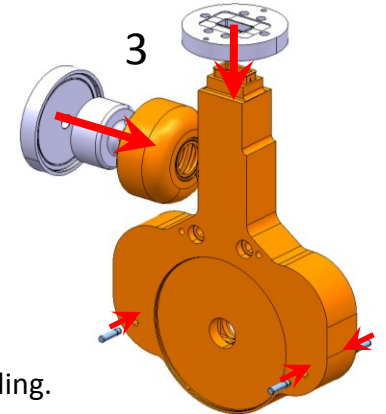
# PETS mock-ups



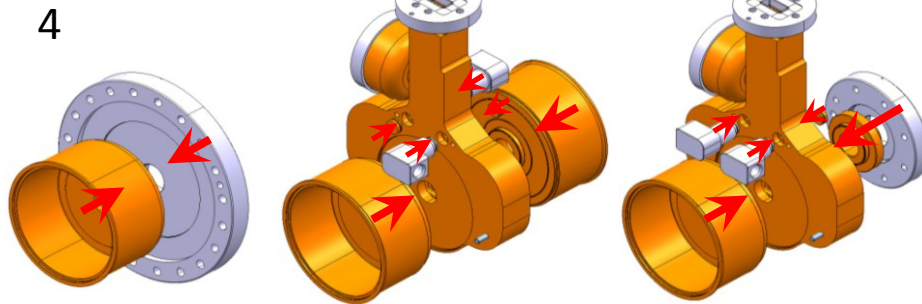
PETS mock-up. Screwing.



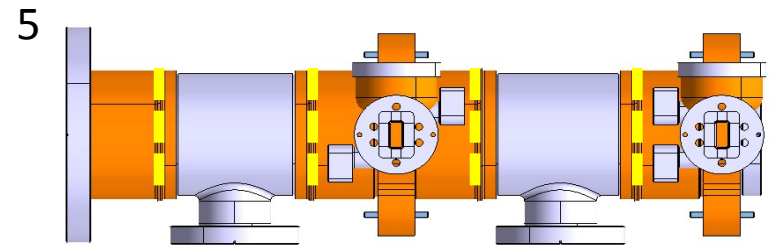
Minitank. Brazing & Welding.



Compact coupler. Brazing.



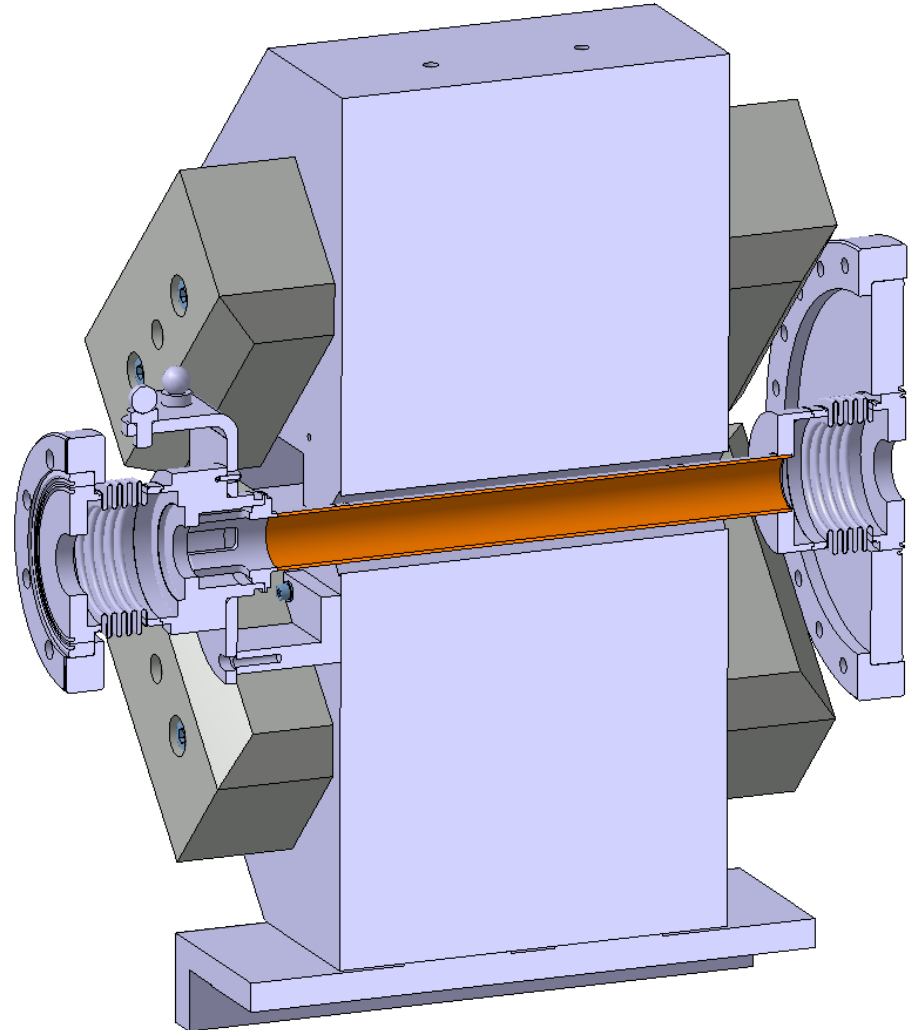
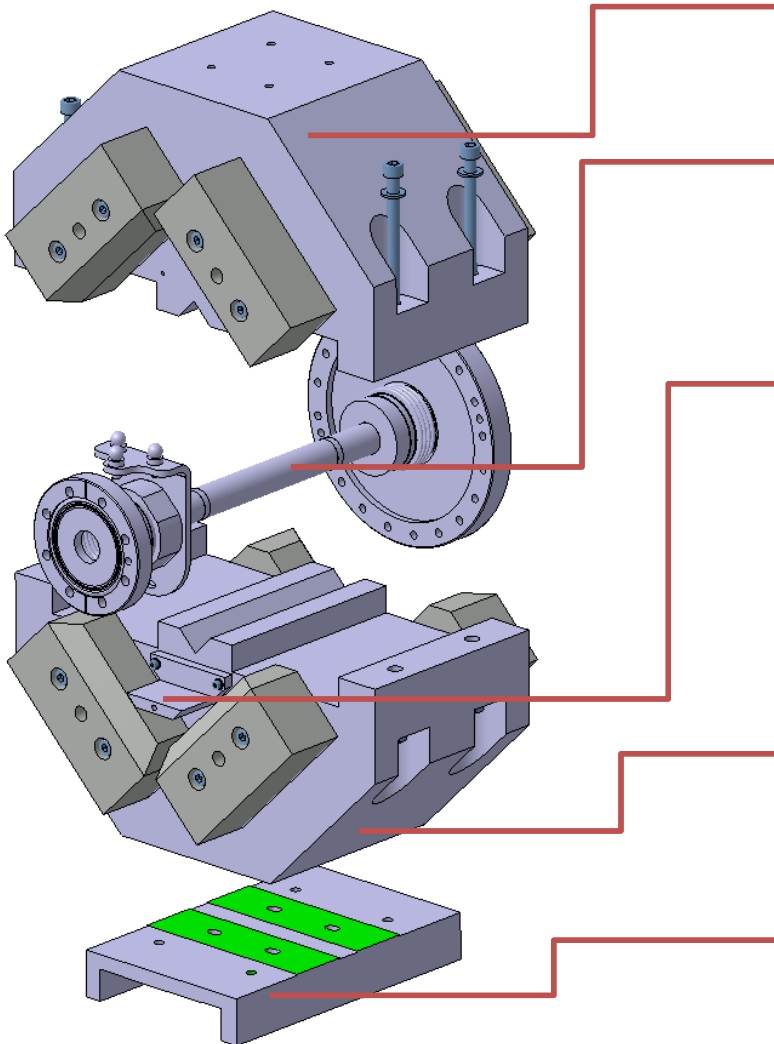
CC subassemblies. Brazing.



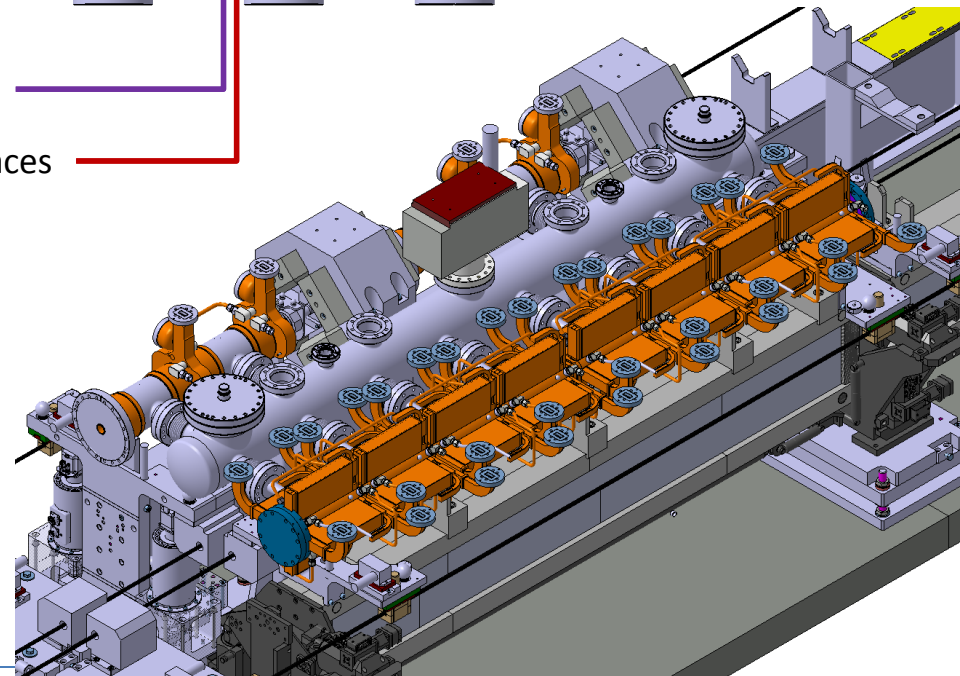
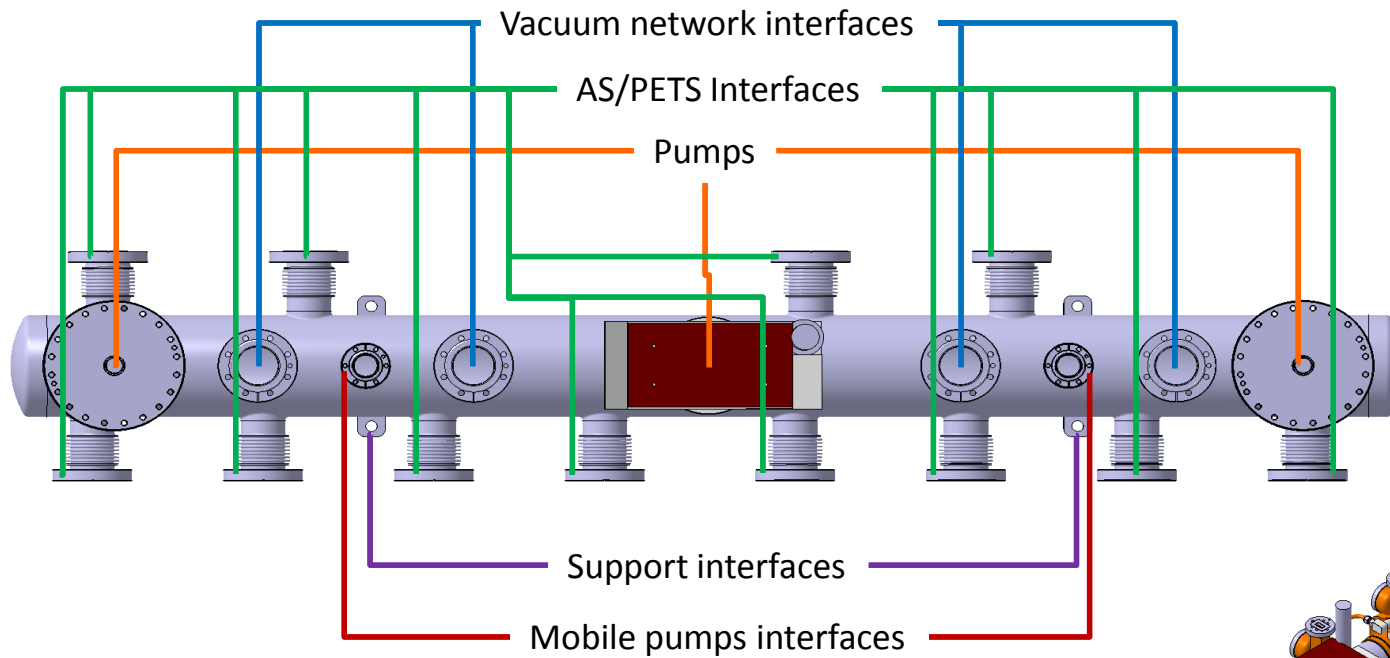
General assembly. EB welding.

# DB Quad + DB BPM + Vacuum chamber

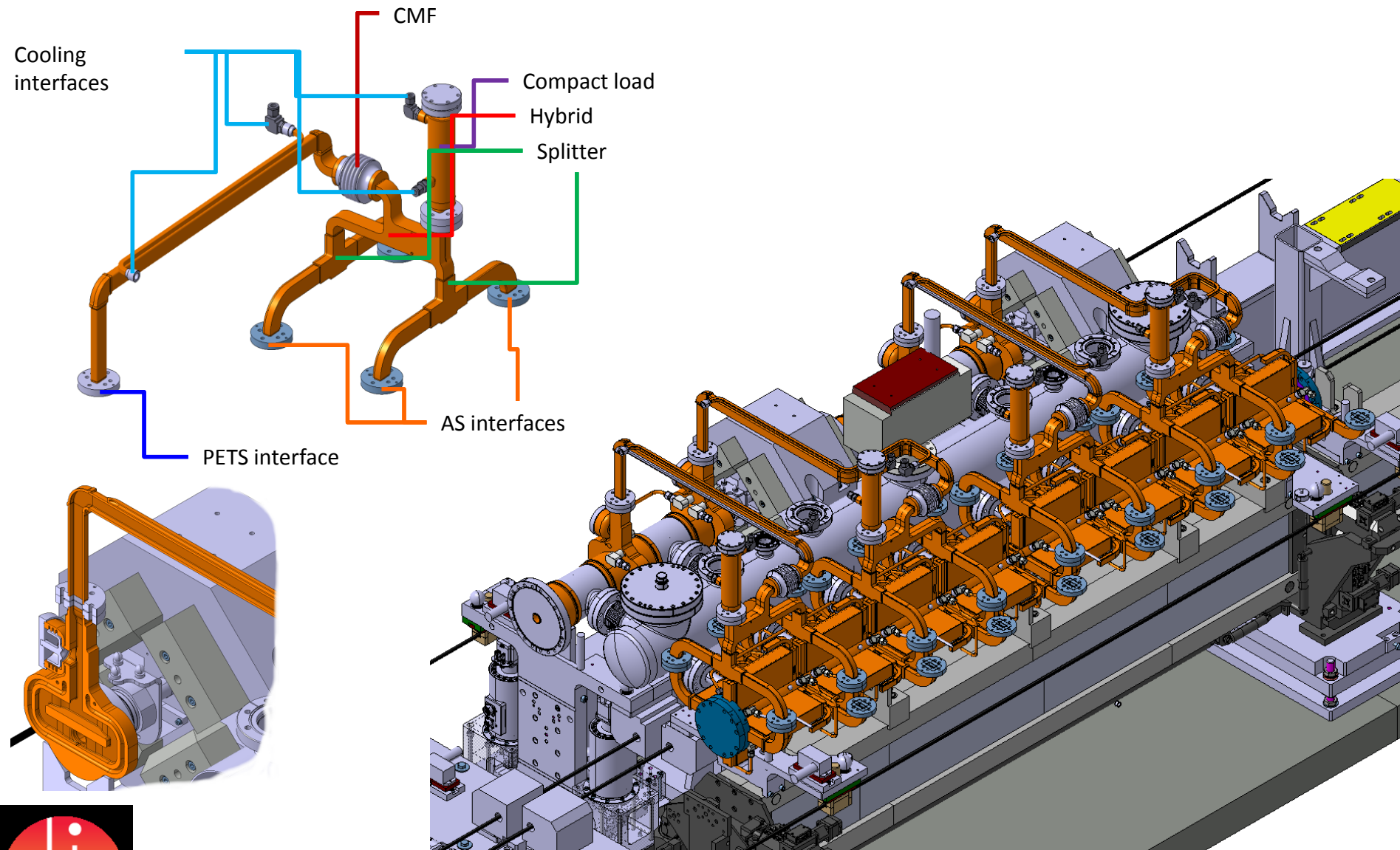
DBQ Mock-up Subassembly



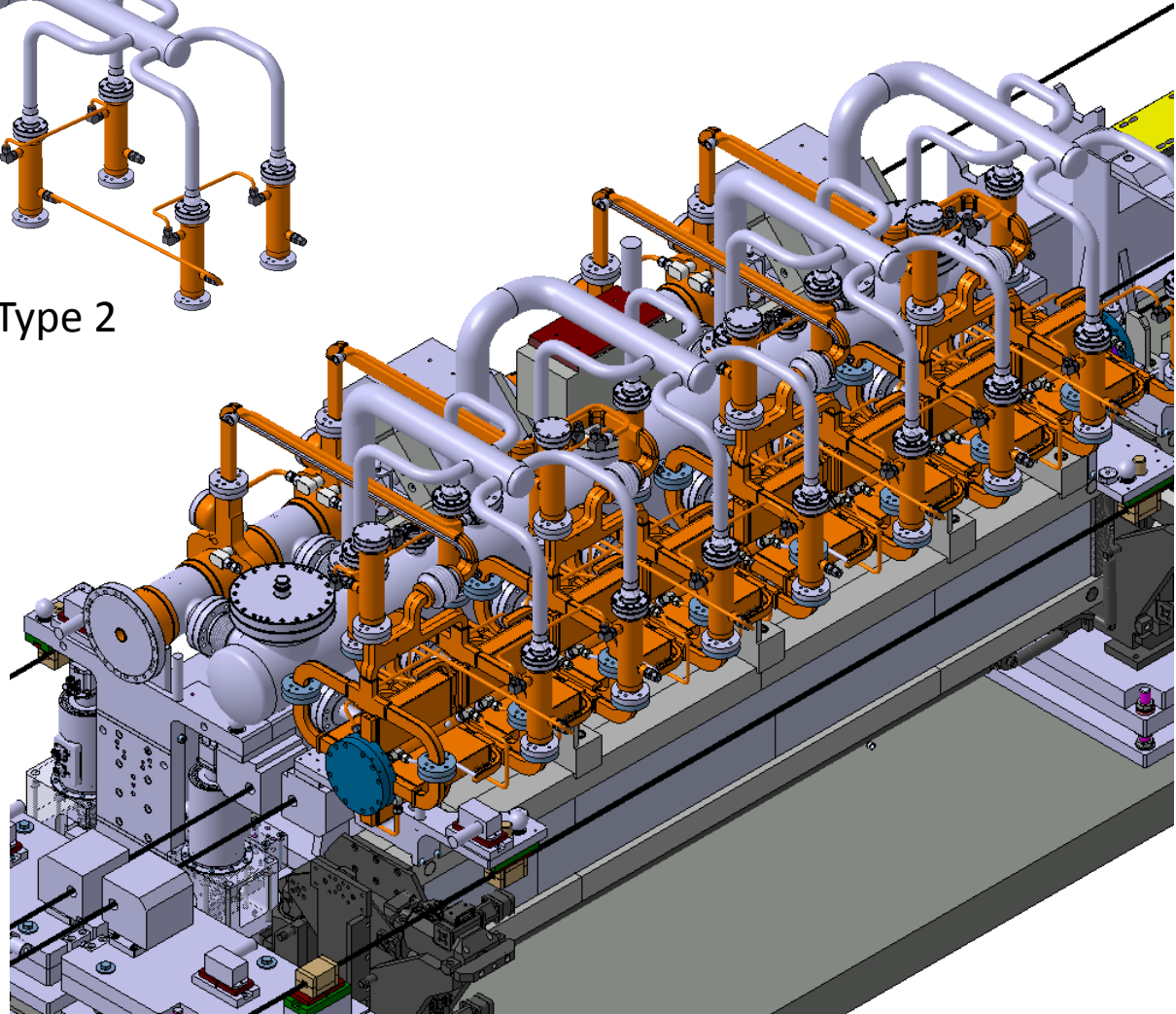
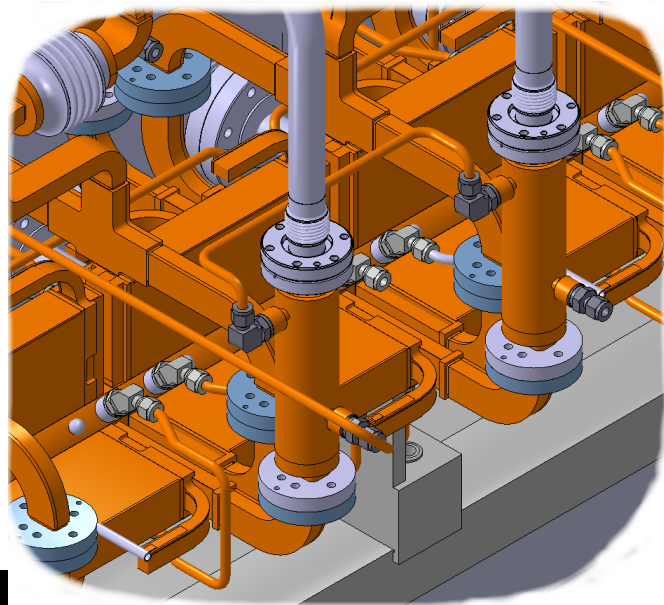
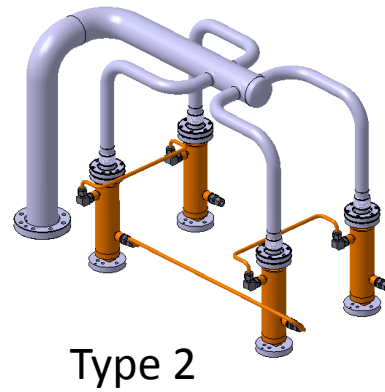
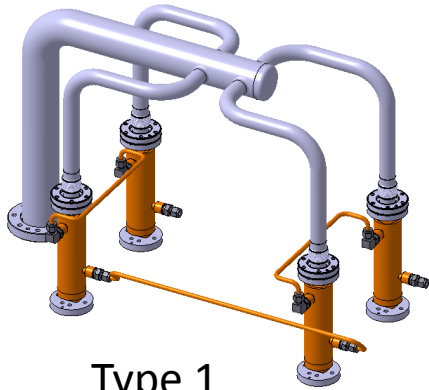
# Vacuum Tank Installation



# RF-Network Installation

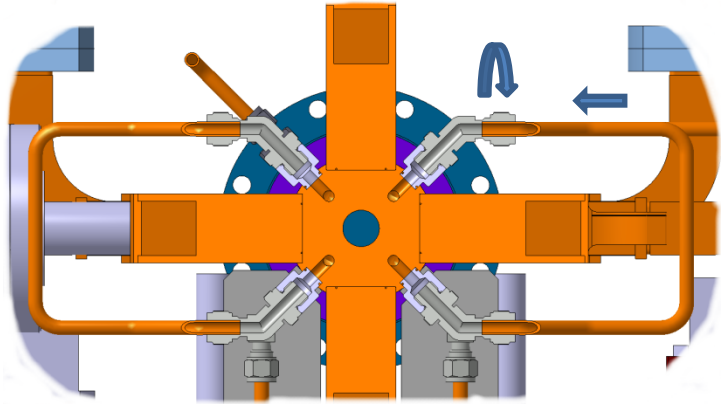


# Vacuum Network Installation

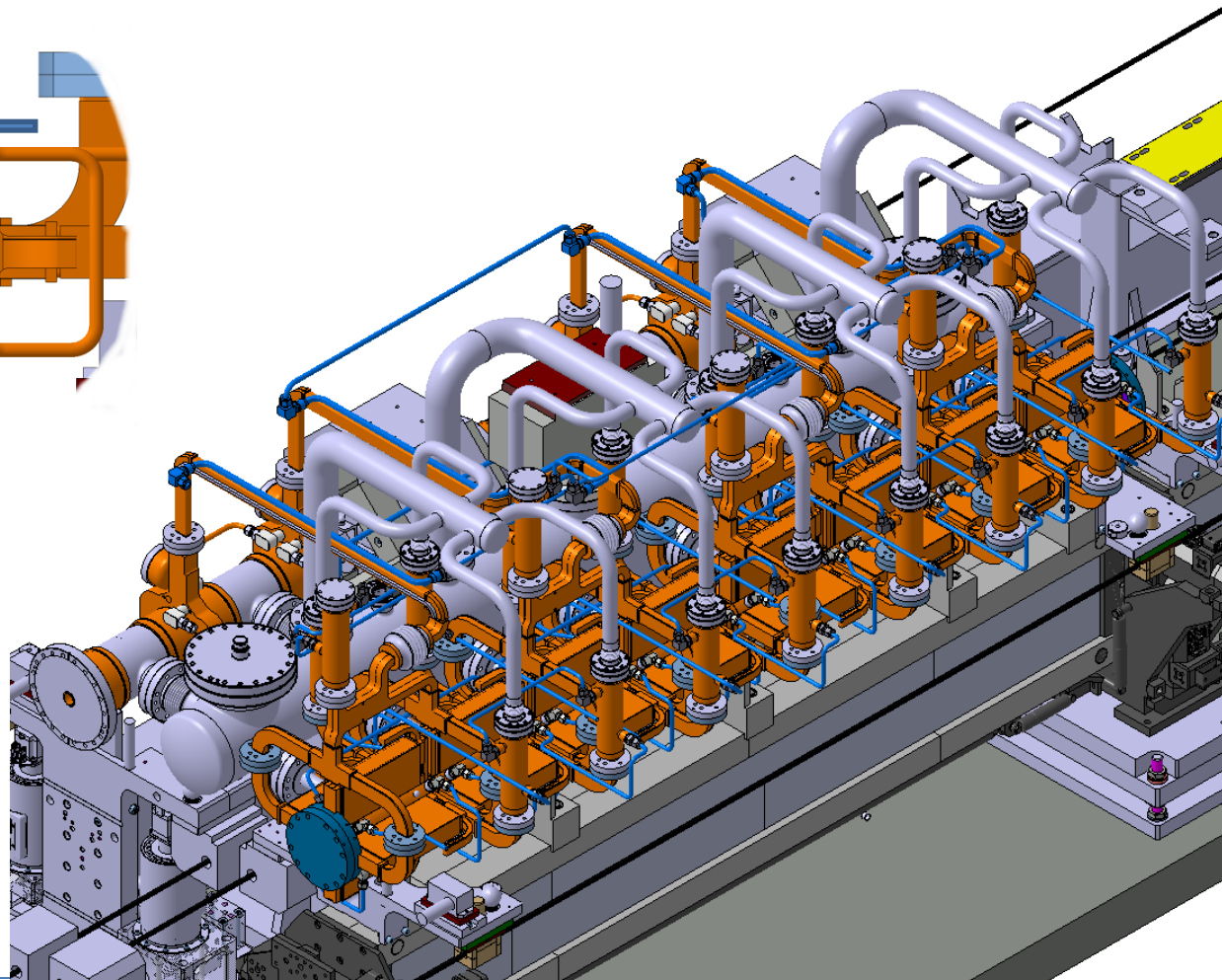


# Cooling System Installation

Standard fittings are used to avoid brazing or welding operations:



1. Insert tube
2. Tighten the nut



# Girders – Procurement strategy

N. Gazis

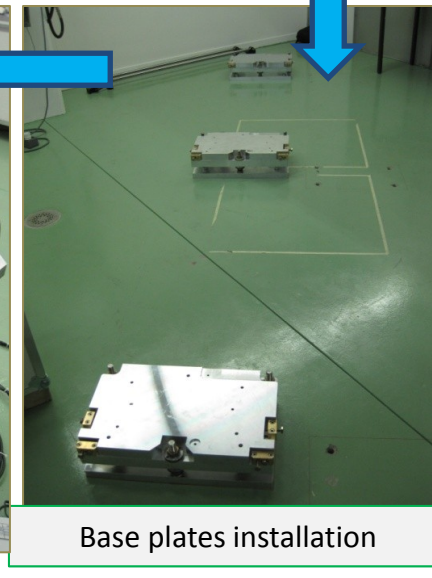
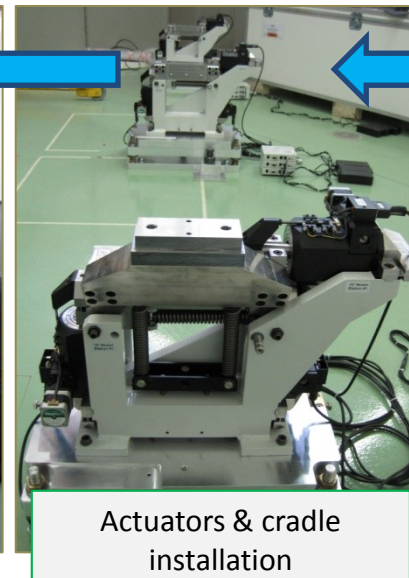
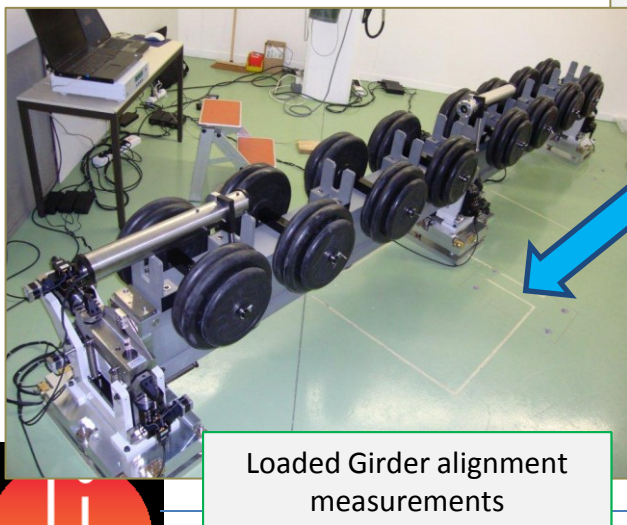
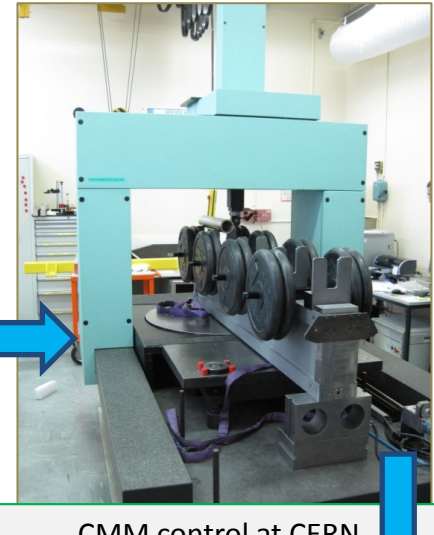
|                | Boostec  |        | Epucet   |        |
|----------------|--|--------|--|--------|
|                | Type 0   | Type 0 | Type 1   | Type 4 |
| DB             | Measured max. deformation<br>12-15 $\mu\text{m}$ |        | Measured max. deformation<br>19-20 $\mu\text{m}$ |        |
| MB             | Measured max. deformation<br>7-9 $\mu\text{m}$   |        |  |        |
| Micro-Controle |  |        |  |        |

3 companies with three different strategies:

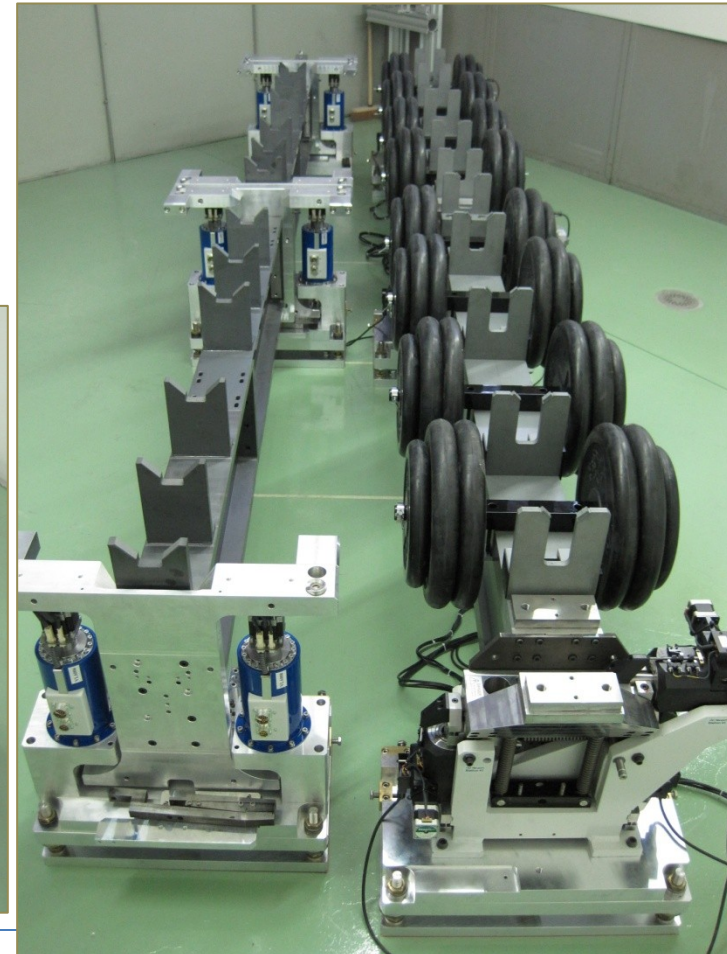
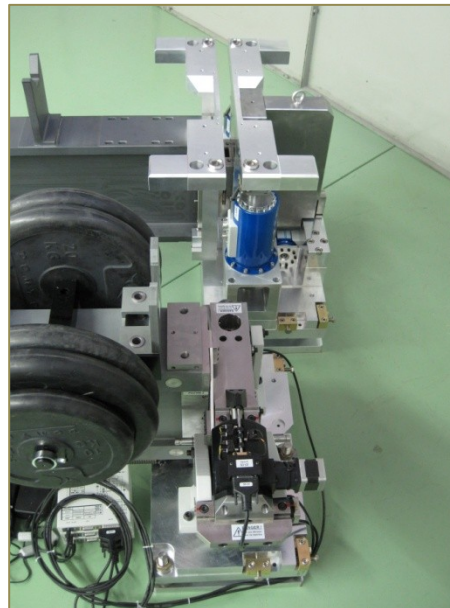
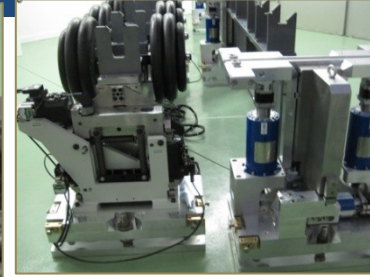
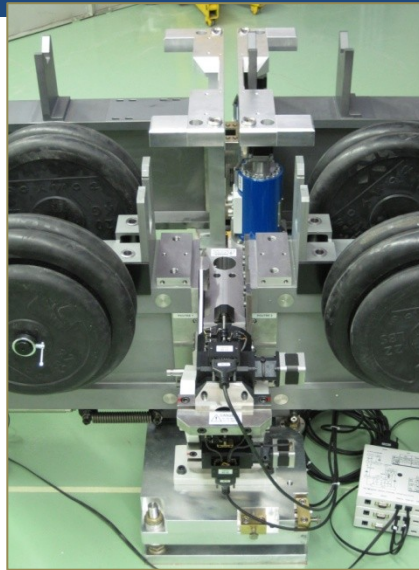
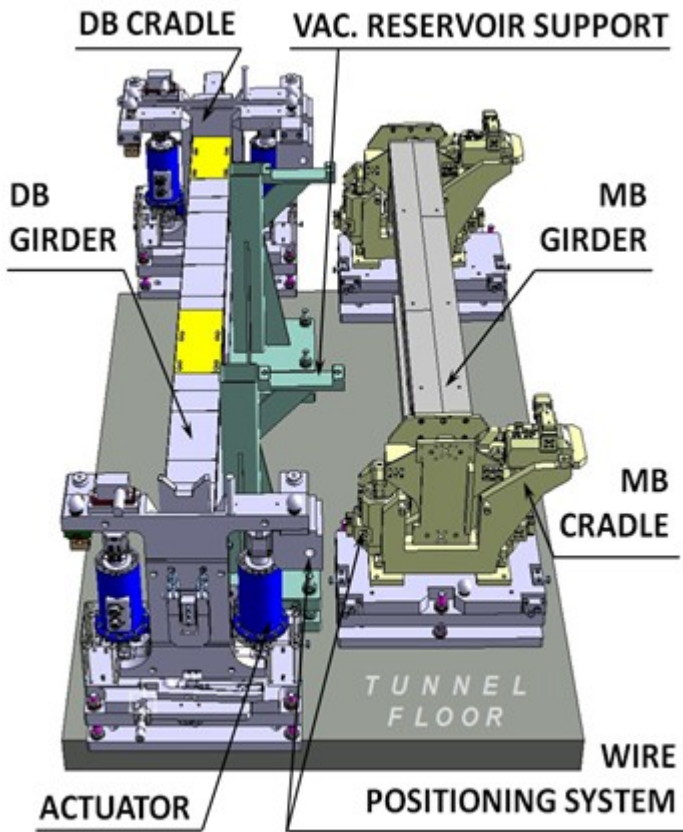
- **Boostec:** 2 SiC girders with V-shaped supports [Nov 2010]
- **Microcontrole:** 2 SiC girders with V-shapes supports, and positioning system [Dec 2010] [pre-stressed]
- **Epucet:** 2 Mineral cast girders [Nov 2010]

**Modal Analyses for all CLIC  
Two-Beam Module Girder  
prototype configurations:  
Eigenfrequencies (f)  $\geq 35$   
Hz**

# Micro-Controle Girders (Type 0)



# Girders - Final Assembly



Visit on Thu 3 February

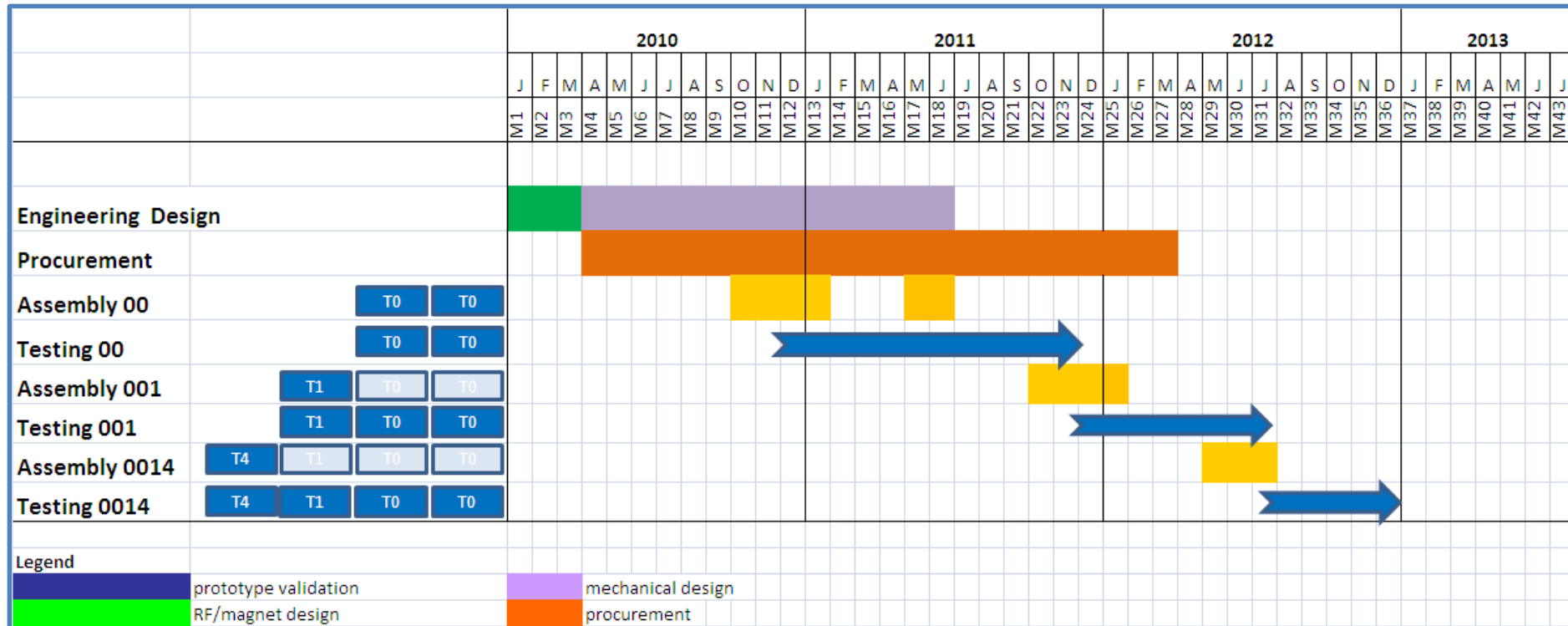


03 Feb 2011

ACE, G. Riddone

30

# Prototype modules in the lab - Schedule



- Under tendering: vacuum system, beam instrumentation and RF system for the first two T0 modules and supporting system for T1 module
- Most probably tests will continue in 2013

# Prototype modules to be tested in CLEX

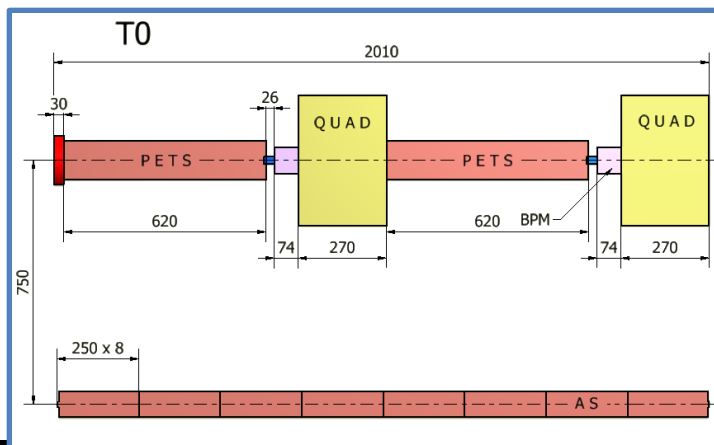
A. Solodko

3 modules to be tested with beam and RF



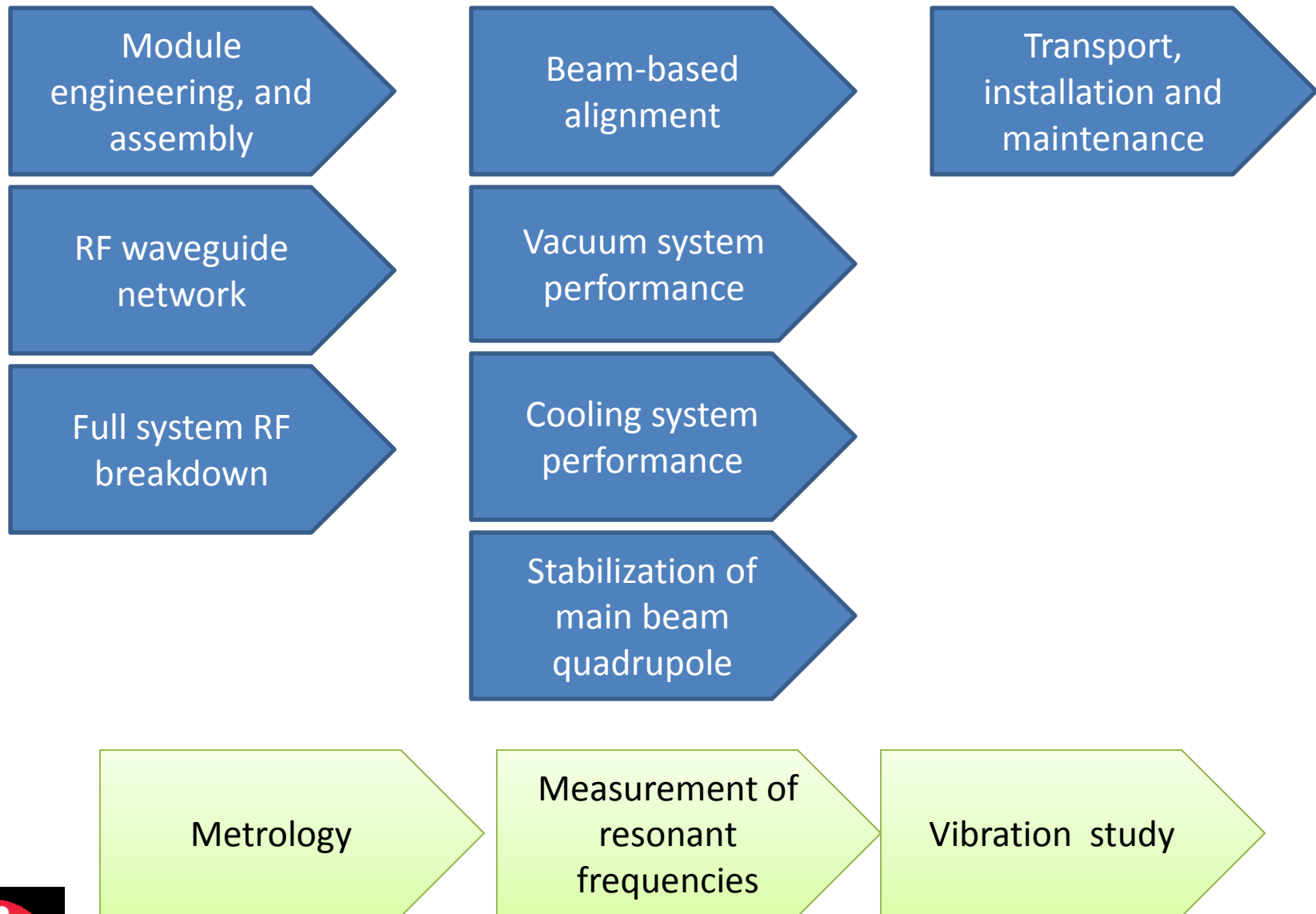
Double length PETS feeding two accelerating structures each

Fully equipped accelerating structures

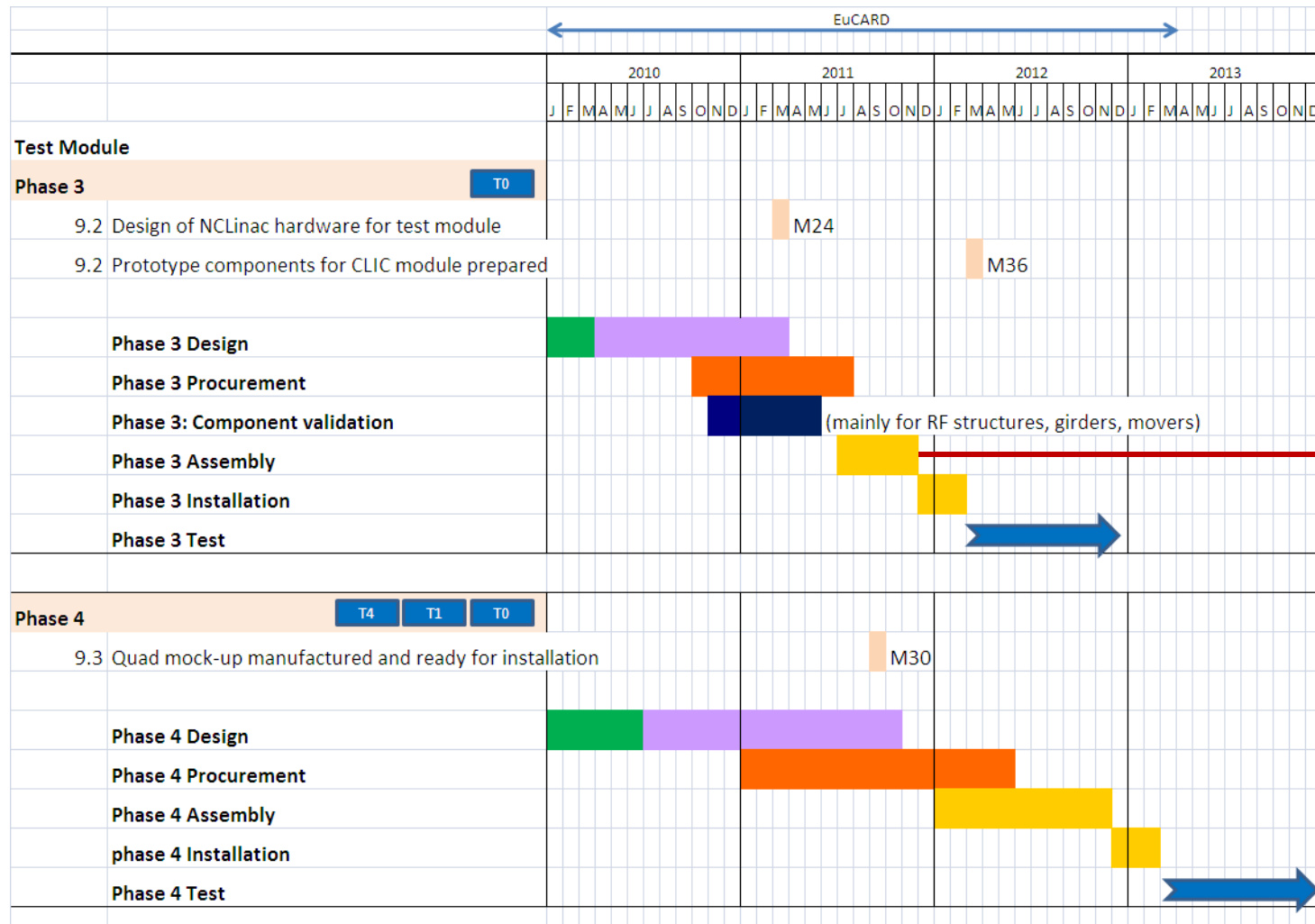


First module to be ready by 2012

# Prototype modules in CLEX- Purpose



# Prototype module in CLEX- Schedule



Availability of components depends on the feedback from the modules in the lab. and high power test of RF structures

# Main conclusions

- Two-beam module is an important part of the CLIC program. At present about 15 collaborators are actively involved
- CLIC module design is very challenging: many requirements, limited space (as compact as possible) → design is available for CDR
- At the end of 2009 the prototype module project has been approved: 7 modules → we will learn a lot about the module behavior under different load conditions → input for new design
- Comprehensive validation of type 0 girders under way
  - First measurements are very promising
- Next months will be very busy with the assembly of the components (mainly RF structures) – aim complete validation of type 0 modules by end of 2011
- Feed back from first modules in the lab is needed before launching the procurement for modules in CLEX (2<sup>nd</sup> half of 2011)



# EXTRA SLIDES



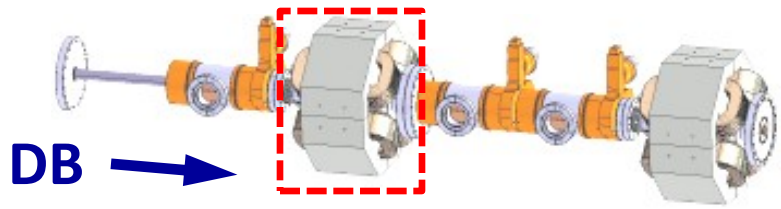
# Main requirements

The module design and integration has to cope with challenging requirements

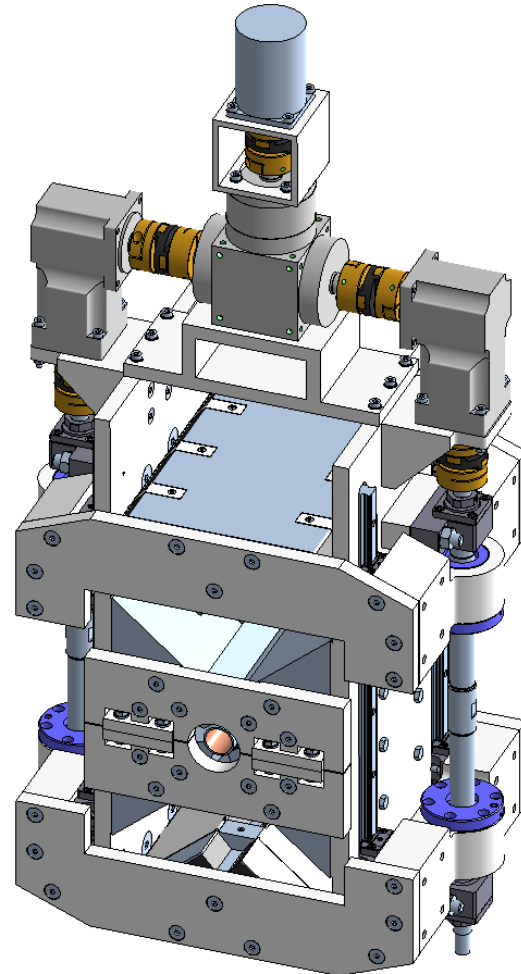
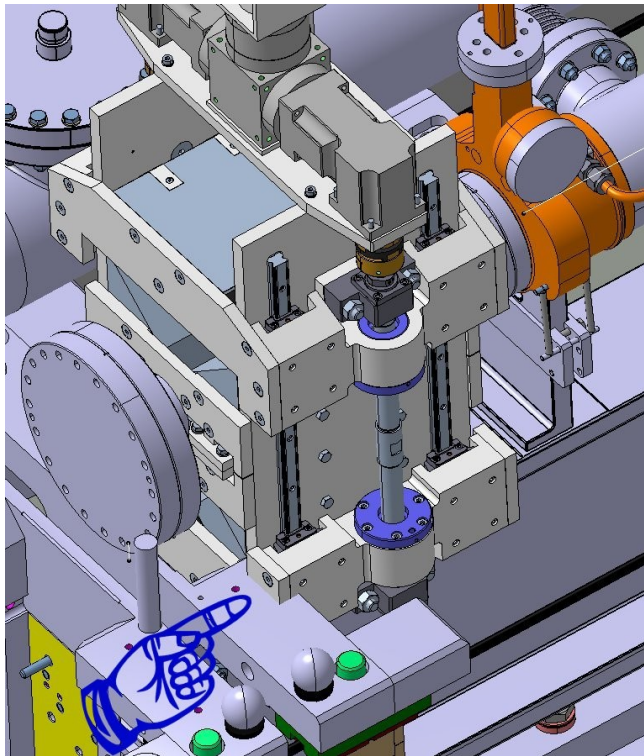
| SYSTEM                            | REQUIREMENT/S   |
|-----------------------------------|---|
| R F                               | AS shape tolerance $\pm 2.5 \mu\text{m}$  |
| INSTRUMENTATION                   | BPM resolution: MB - 50 nm, DB – 2 $\mu\text{m}$ , temporal - 10 ns (MB & DB),          |
| SUPPORTING                        | Max. vertical & lateral deformation of the girders in loaded condition 10 $\mu\text{m}$ |
| COOLING                           | ~400 W per AS, alignment preservation   |
| MAGNET & POWERING                 | DB 81.2-8.12 T/m, current density: 4.8 A/mm <sup>2</sup> , MB 200 T/m                   |
| PRE-ALIGNMENT & STABILIZATION     | active pre-alignment $\pm 10 \mu\text{m}$ at $1\sigma$ , MB Q stabilization 1 nm >1Hz   |
| VACUUM                            | 10 <sup>-9</sup> mbar   |
| ASSEMBLY, TRANSPORT, INSTALLATION | same transverse interconnection plane for DB & MB                                       |

A baseline solution for CDR was defined for each technical system

# Alternative DB magnet



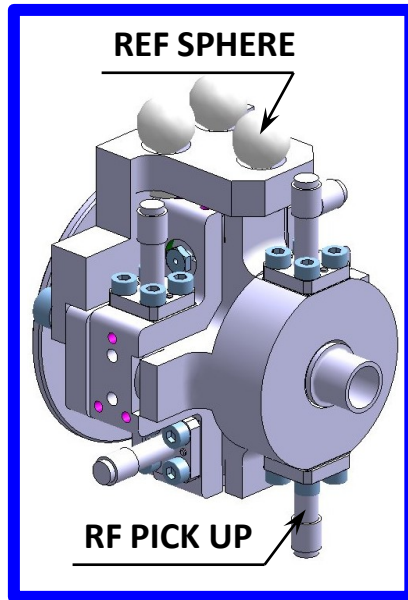
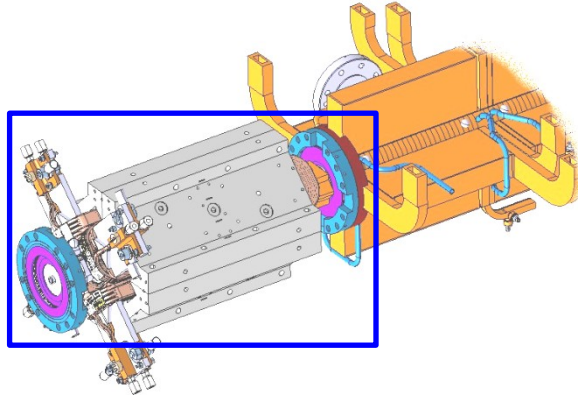
ALTERNATIVE:  
DB tuneable permanent magnet solution is under investigation (Cockcroft Institute)



# MB: BPM – Vac. Chamber – Dipole corr.

**MB**

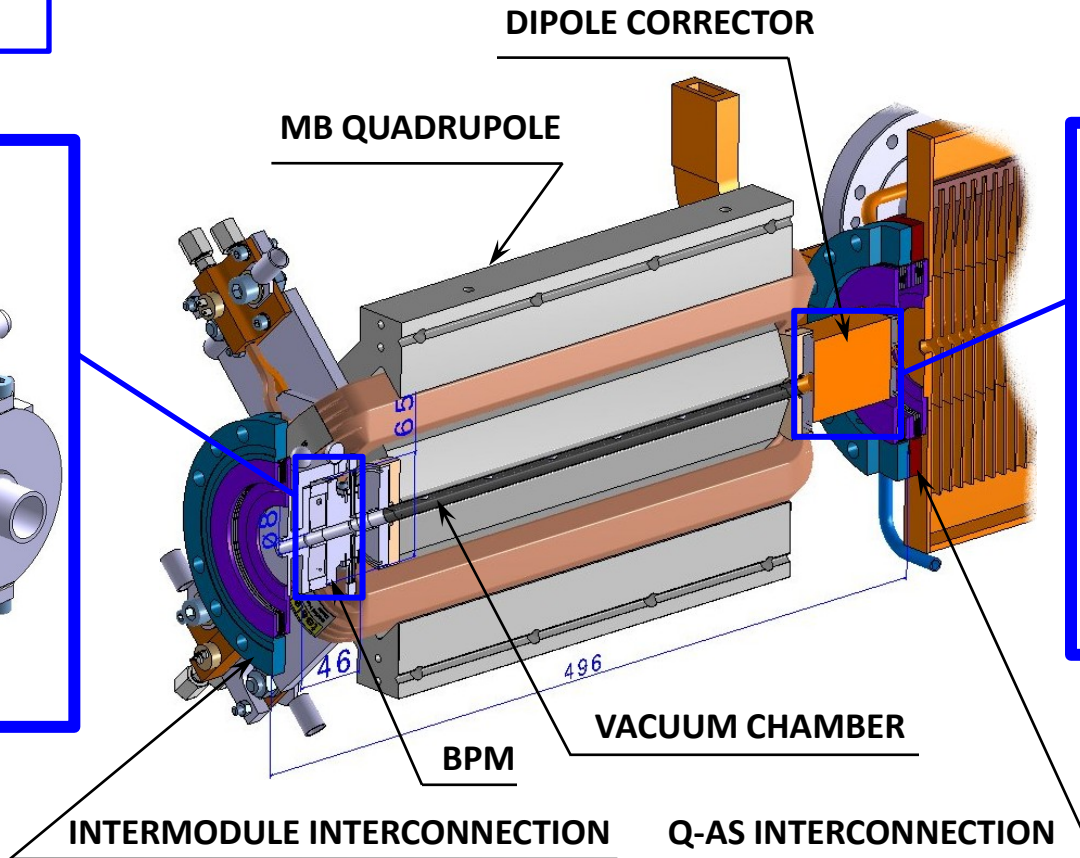
The beam pipe is attached to the magnet and must be aligned to the magnetic centre of the Quad with an accuracy better than  $30\text{ }\mu\text{m}$ ; transverse tolerance for pre-alignment  $17\text{ }\mu\text{m}$  at  $1\sigma$ ; stabilization:  $1\text{ nm} > 1\text{Hz}$  in vertical &  $5\text{ nm} > 1\text{Hz}$  in horizontal direction at  $1\sigma$ .



REF SPHERE

RF PICK UP

MB BPM



DIPOLE CORRECTOR

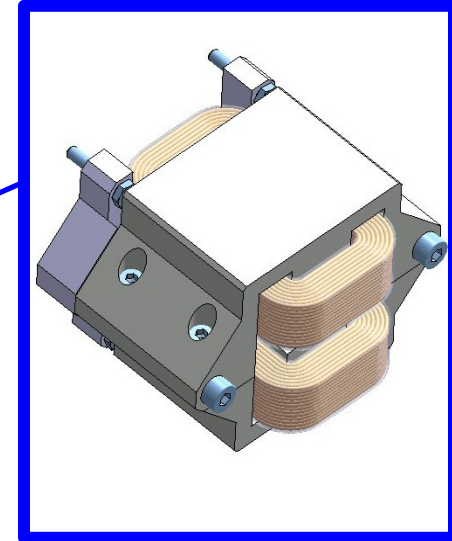
MB QUADRUPOLE

BPM

VACUUM CHAMBER

INTERMODULE INTERCONNECTION

Q-AS INTERCONNECTION



DIPOLE  
CORRECTOR

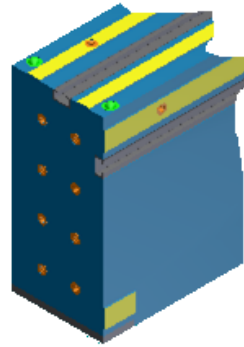
Longitudinal space constraints - Still an issue!

ACE, G. Riddone

# Girders and positioning system

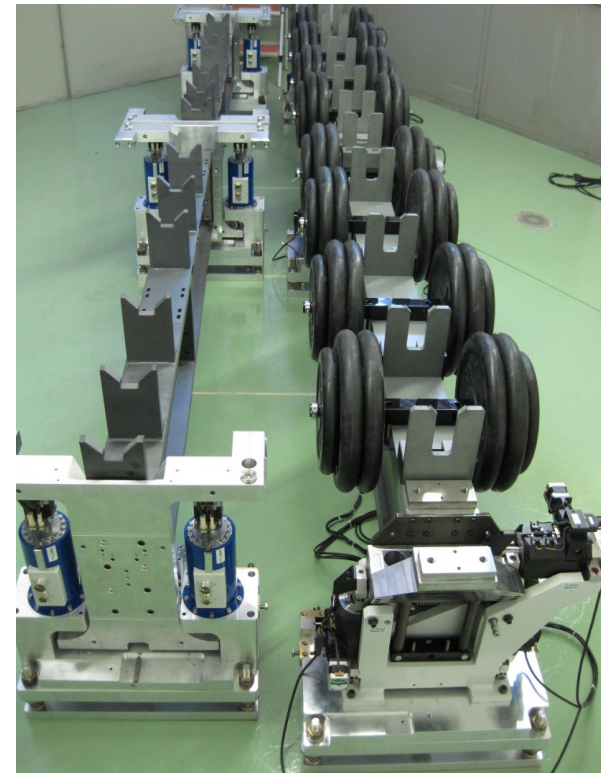
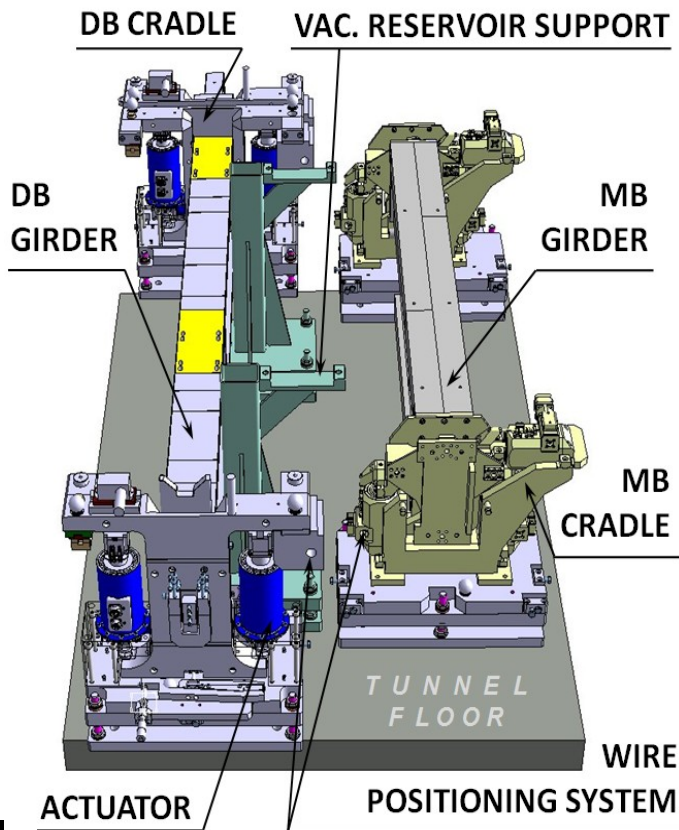
## **BASELINE:**

- interconnected girders form a “snake system”
- MB girders are not of the same length
- MB Q support interrupts the MB girder
- MB Q beam pipe and AS are connected by bellows



requirement :  
yellow ref. surfaces  
precision - 2  $\mu\text{m}$

Max. vertical & lateral  
deformation of the  
girders in loaded  
condition - 10  $\mu\text{m}$

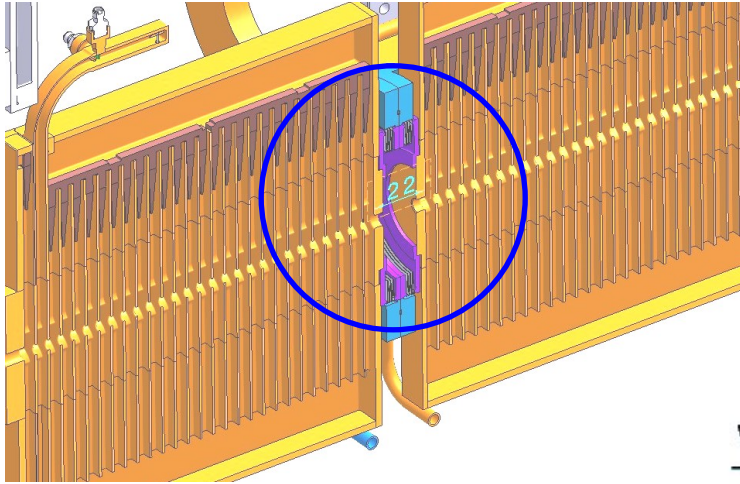


Lab test setup. B162/R-011

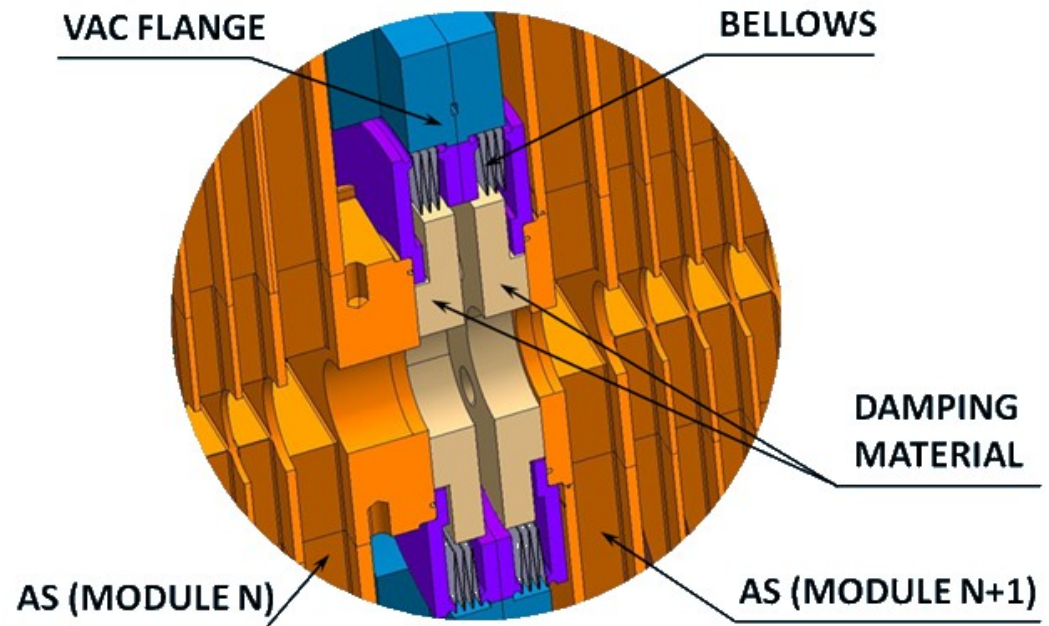
The main components of both beams are supported  
on girders linked to one chain all along the linac.

ACE, G. Riddone

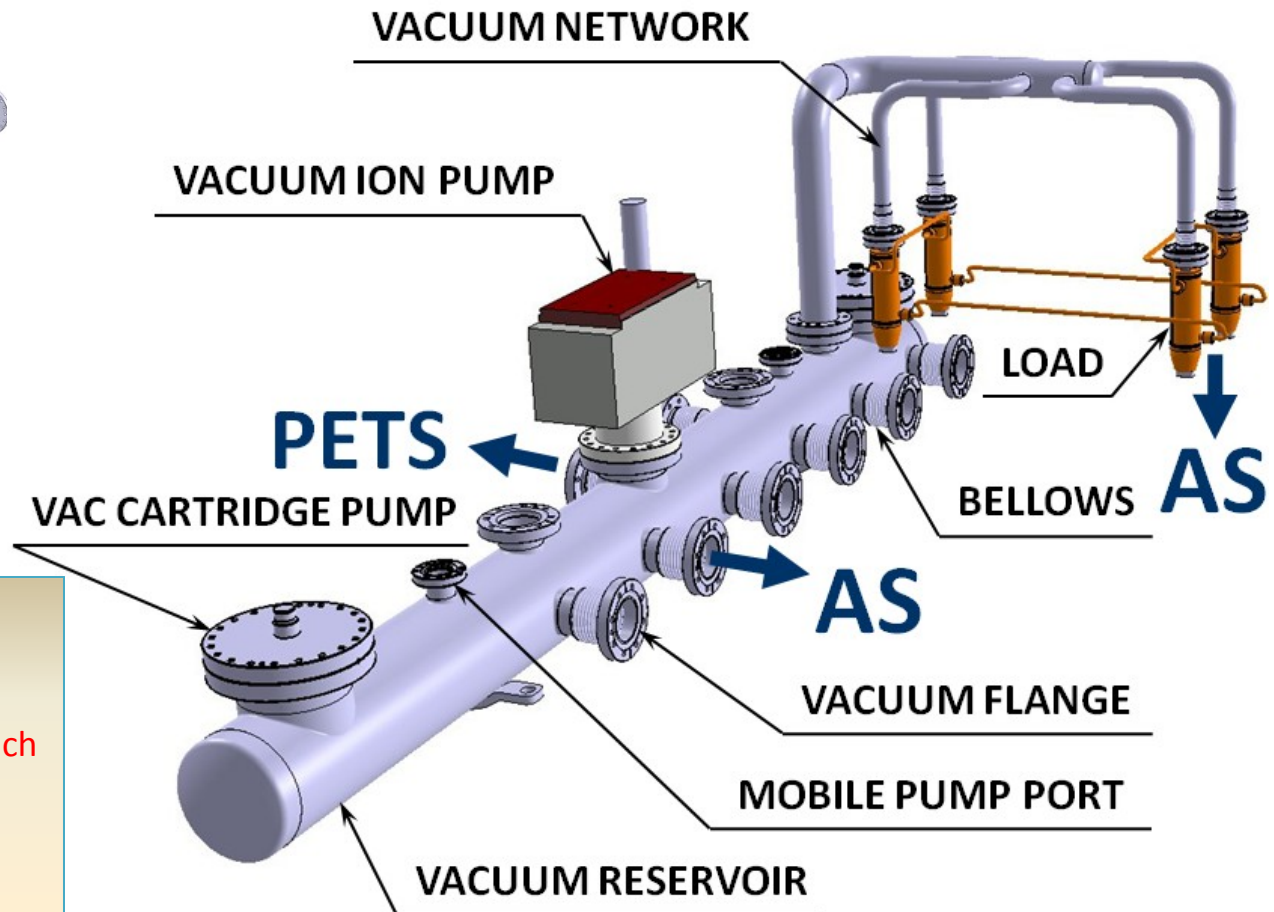
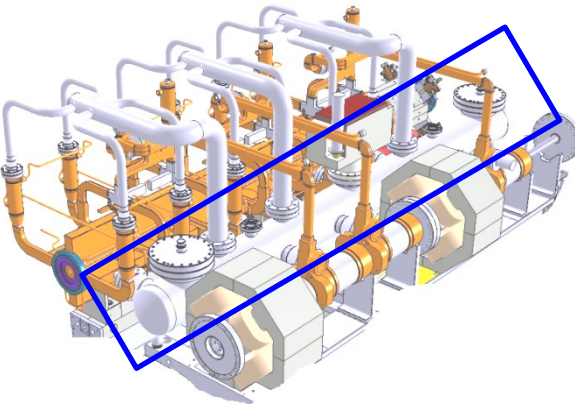
# AS – AS Vacuum Interconnection



A low pressure level ( $10^{-9}$  mbar) is needed for keeping the good beam quality. The interconnections between main components should sustain the vacuum forces, provide an adequate electrical continuity with low impedance and remain flexible not to restrict the alignment.



# Vacuum layout



## ALTERNATIVE SOLUTION

→ Mini-Pumps fixed directly on each structure. No lateral stress on RF structures. (study → 2011)

# Vacuum system in the module

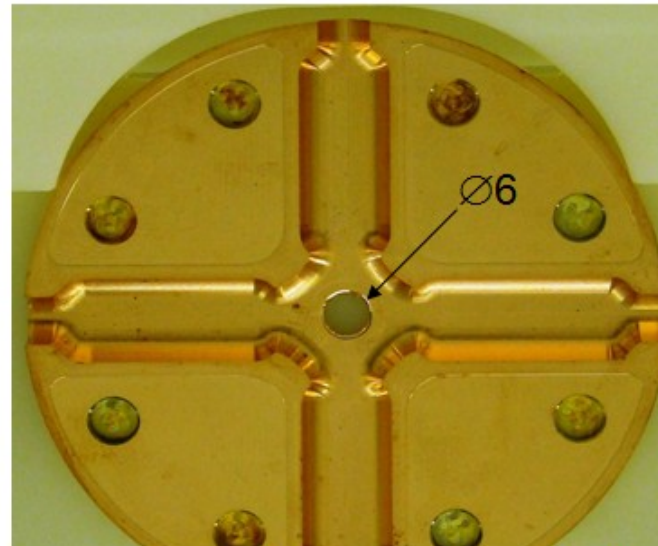
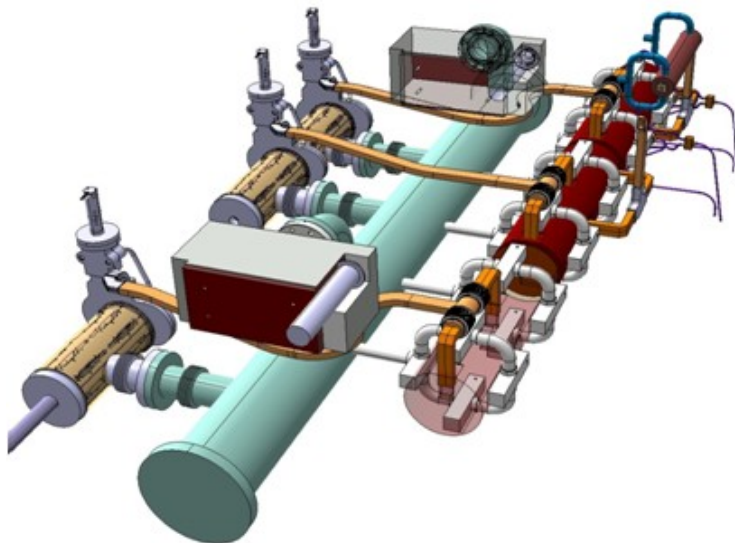
C. Garion, ILWS10

## Requirements

Field ionization studies resulted in a lowering of the vacuum threshold for fast ion beam instability to: pressure  $< 1$  nTorr [G. Rumulo]

## Specificities

1. Non-baked system  $\rightarrow$  vacuum is driven by water
2. Low conductance (beam pipe diameter  $\sim 10$  mm) and large areas ( $\sim 3000$  cm<sup>2</sup>/AS)



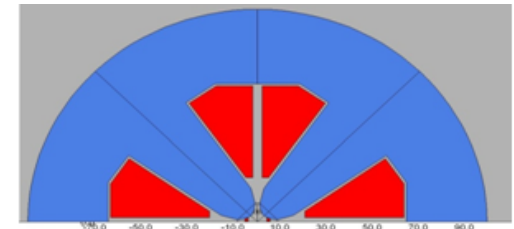
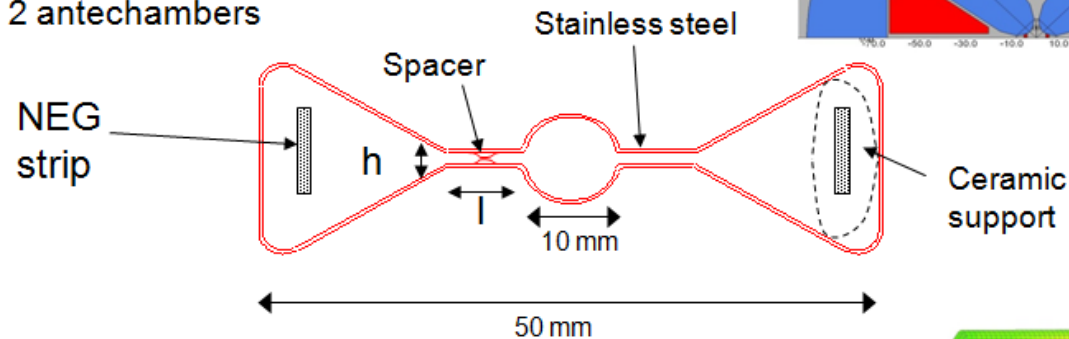
Typical shape and dimensions of an accelerating structure disk

# Vacuum chamber for the MB quadrupoles

C. Garion, ILWS10

Present design:

- Stainless steel vacuum chamber, squeezed in the magnet
- NEG strips sited in 2 antechambers
- Copper coated

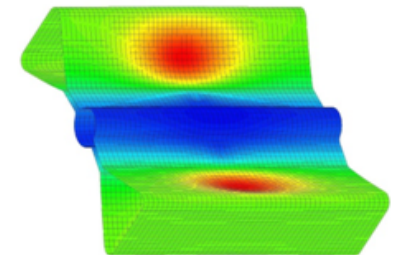


Effective pumping speed per unit length:  $S_{\text{eff}} Q h^2 / l$

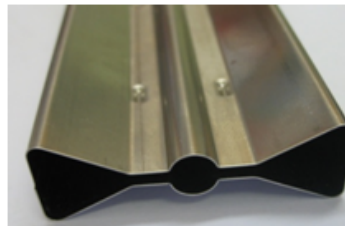
Pressure in the central part is determined by the gap  $\rightarrow$  reduce the sheet thickness  $\rightarrow$  stability becomes an issue (0.3 mm for the prototype)

$$q = 2 \cdot 10^{-11} \text{ mbar.l/s.cm}^2 \rightarrow P \sim 8 \cdot 10^{-10} \text{ mbar}$$

Prototype has been manufactured and is being tested.

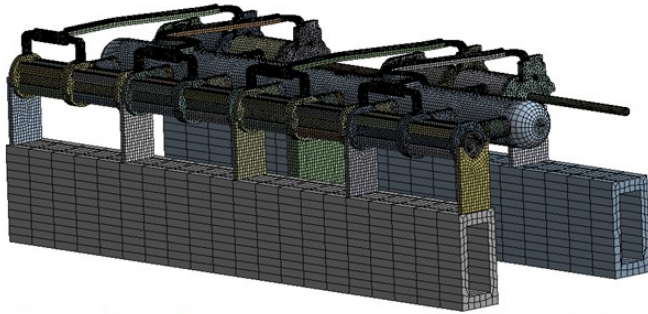


Buckling mode



## TMM AS Cooling 2K configuration

TMM model configuration with AS water temperature rise of 2 K through a module.



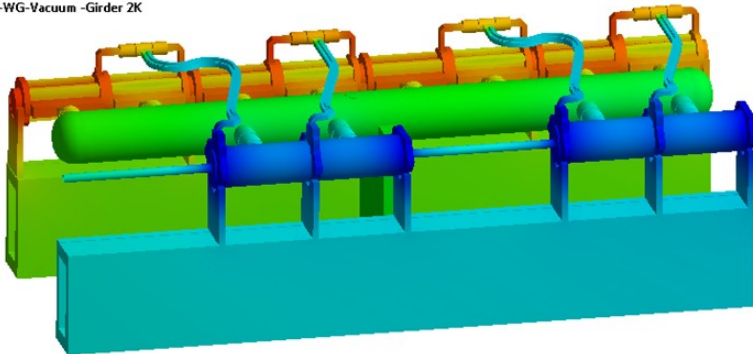
### Results

Lowering the water  $\Delta T$  to 2 K for AS, maximum temperature of a module becomes 34.5 C.

Unloaded AS-PETS-WG-Vacuum -Girder 2K

Temperature  
Type: Temperature  
Unit: °C

34.514 Max  
33.65  
32.786  
31.923  
31.059  
30.195  
29.331  
28.467  
27.604  
26.74 Min



### Structural

Lowering the water  $\Delta T$  for AS to 2 K, maximum deformation of a module yields 261  $\mu m$ .

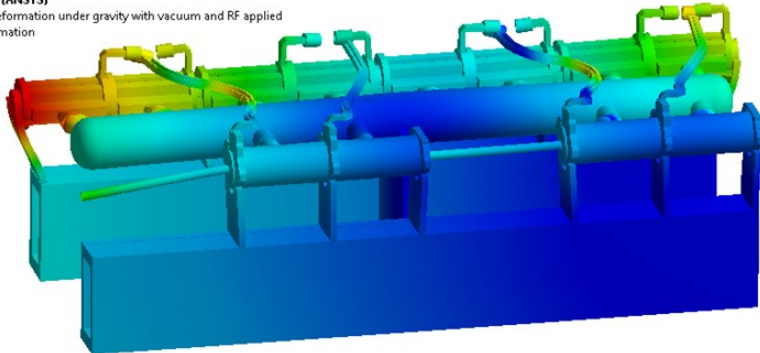
Static Structural (ANSYS)

Module's Total Deformation under gravity with vacuum and RF applied

Type: Total Deformation

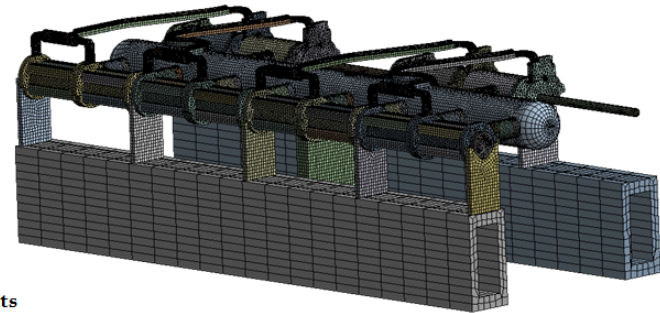
Unit:  $\mu m$

261.09 Max  
232.08  
203.07  
174.06  
145.05  
116.04  
87.031  
58.02  
29.01  
0 Min



## TMM AS Cooling 5K configuration

TMM model configuration with AS water temperature rise of 5 K through a module.



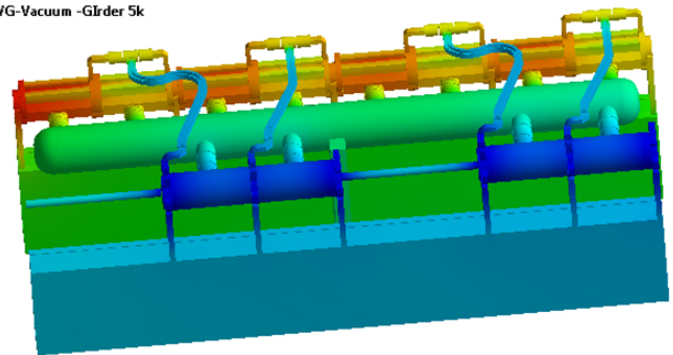
### Results

Lowering the water  $\Delta T$  to 5 K, maximum temperature of a module becomes 36.5 C.

Unloaded AS-PETS-WG-Vacuum -Girder 5k

Temperature  
Type: Temperature  
Unit: °C

36.482 Max  
35.4  
34.317  
33.235  
32.153  
31.07  
29.988  
28.906  
27.823  
26.741 Min



### Structural

Lowering the water  $\Delta T$  to 5 K, maximum deformation of a module yields 292  $\mu m$ .

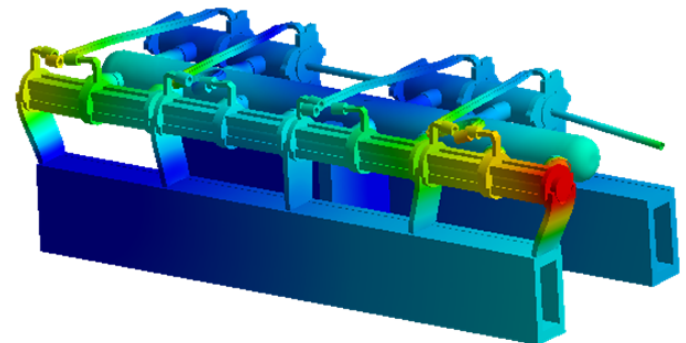
Static Structural (ANSYS)

Module's Total Deformation under gravity with vacuum and RF applied

Type: Total Deformation

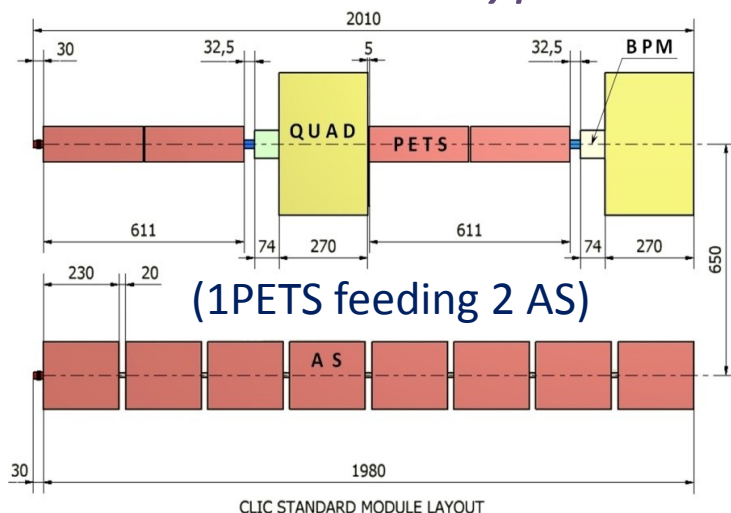
Unit:  $\mu m$

292.26 Max  
259.78  
227.31  
194.84  
162.36  
129.89  
97.419  
64.946  
32.473  
0 Min



# CLIC module vs CLEX module

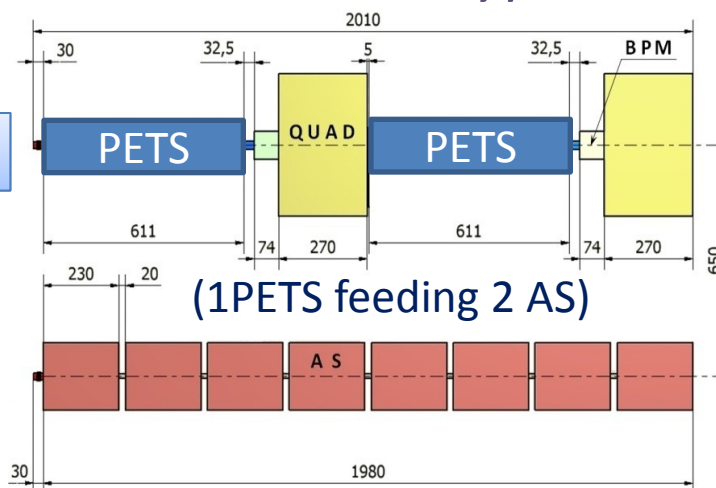
## CLIC module type 0



| Parameters            | CTF3             | CLIC                       |
|-----------------------|------------------|----------------------------|
| Energy                | 0.150 GeV        | 2.4 GeV                    |
| Pulse length          | 1.2 $\mu$ s      | 140 $\mu$ s                |
| Multiplication factor | $2 \times 4 = 8$ | $2 \times 3 \times 4 = 24$ |
| Linac current         | 3.75 A           | 4.2 A                      |
| DB final current      | 30 A             | 100 A                      |
| RF frequency          | 3 GHz            | 1 GHz                      |
| Repetition rate       | up to 5 Hz       | 50 Hz                      |
| Energy per beam pulse | 0.7 kJ           | 1400 kJ                    |
| Average DB power      | 3.4 kW           | 70 MW                      |

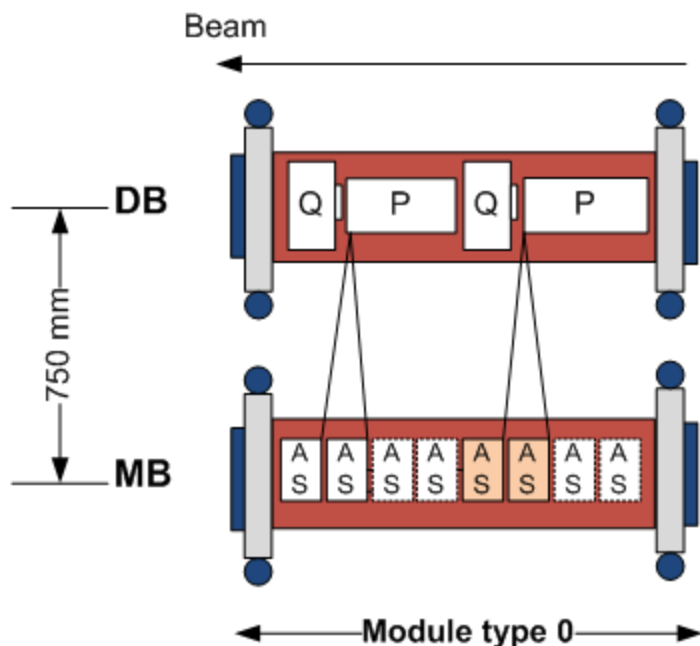
## CLEX module type 0

Double length PETS



# Prototype Module - CLEX: Phase 3

Phase 3 foresees the installation and testing of 1 module type 0: AS equipped with WFM (5  $\mu\text{m}$  accuracy / few WFM in the 1<sup>st</sup> powered AS)

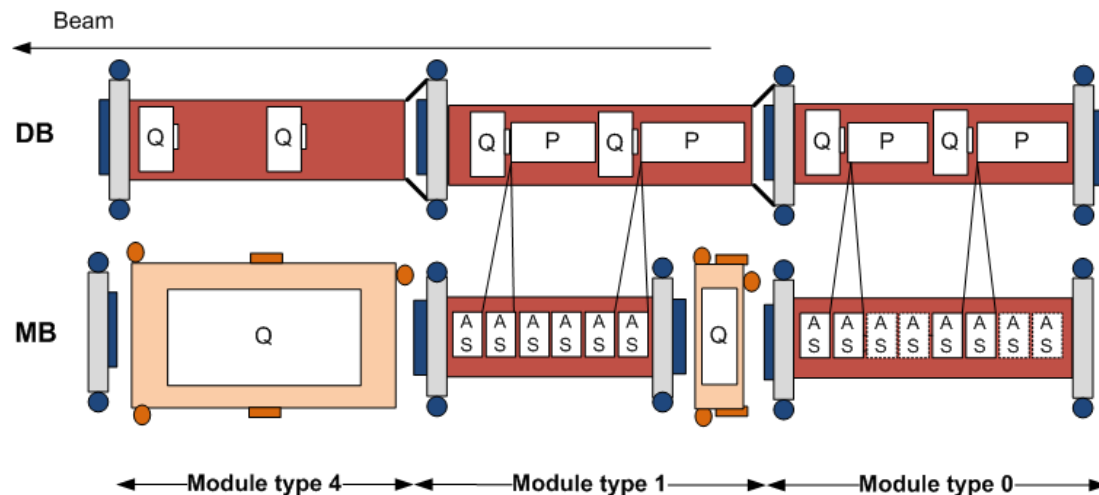


Existing PETS

3.1 / Nominal power and pulse length for 1 PETS and 2 AS  
Recirculation  
12 A and 240 ns

3.2 / No modifications on the module type 0 HW  
No Recirculation  
Current increase from 12 A to 19.2 A  
Pulse length reduced from 240 ns to 140 ns

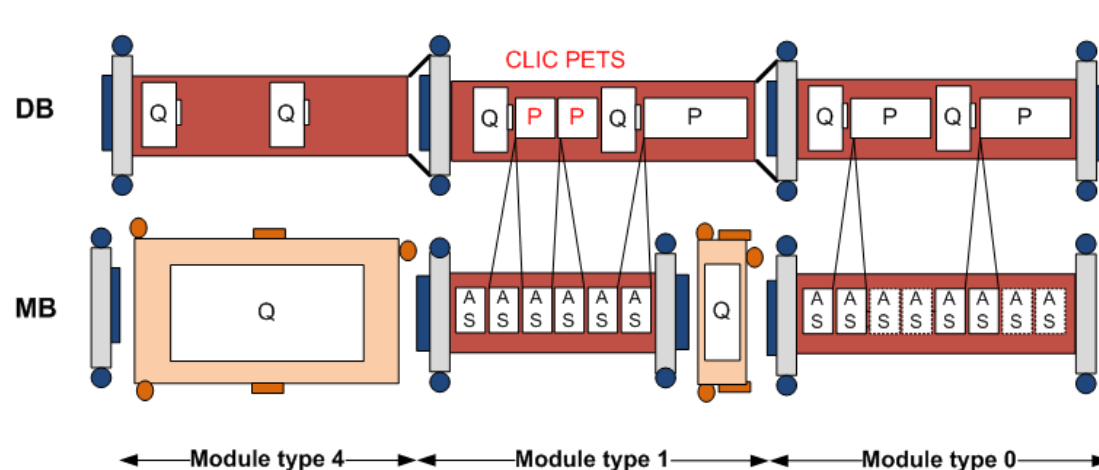
# Prototype Module - CLEX: Phase 4



PHASE 4.1

Existing PETS

No modifications on the module type 0  
**Addition of new modules - type 1 and 4**  
 Increase of current from 19.2 A to 22 A



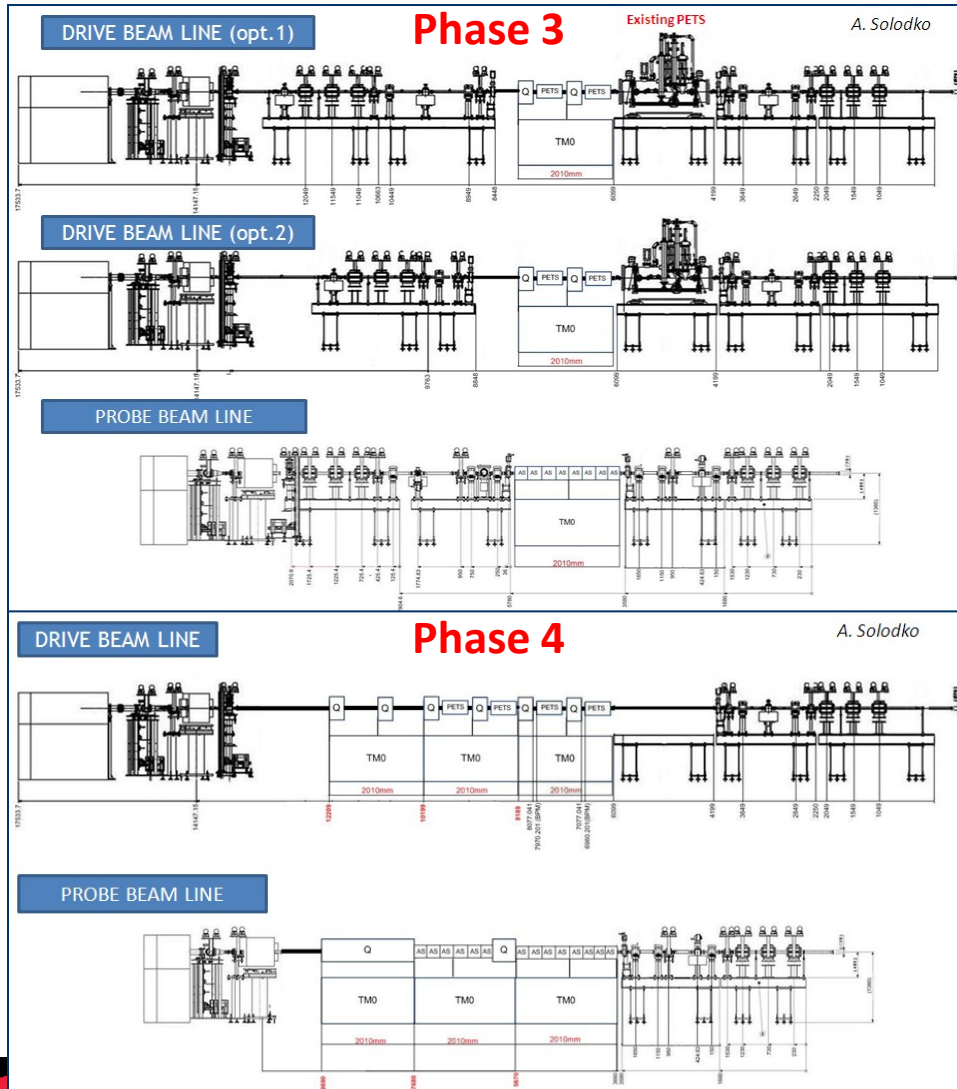
PHASE 4.2

Existing PETS

**Modification on the module type 1**  
 (2 CLIC PETS)  
 Needed klystrons and PC

All AS are with WFM

# Prototype Modules - installation in CLEX



## Phase 3:

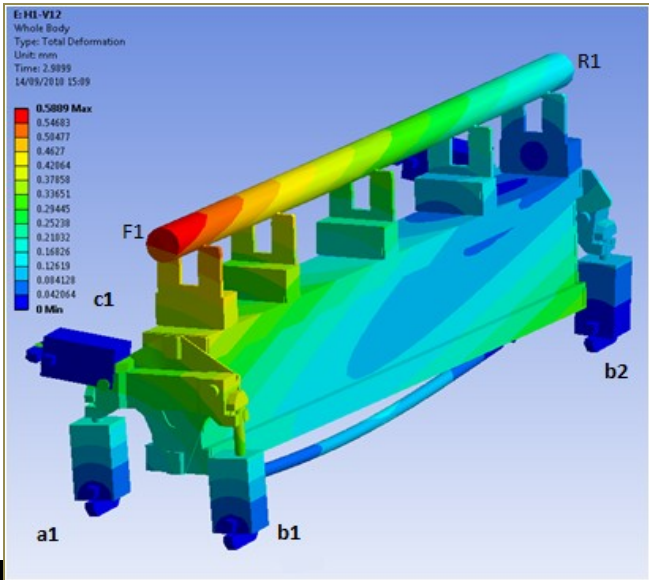
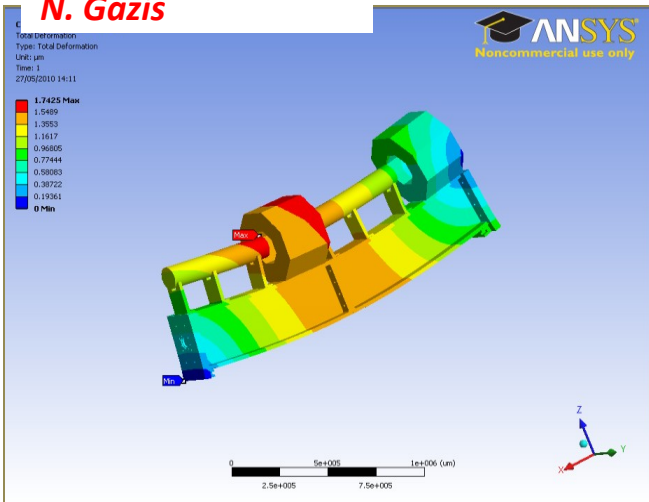
- Existing PETS (currently under test) will be reused
- It will be moved to allow for Type 0 module installation

## Phase 4:

- Instrumentation downstream the type 0 module will be removed
- Installation of type 1 and 4 without displacing type 0

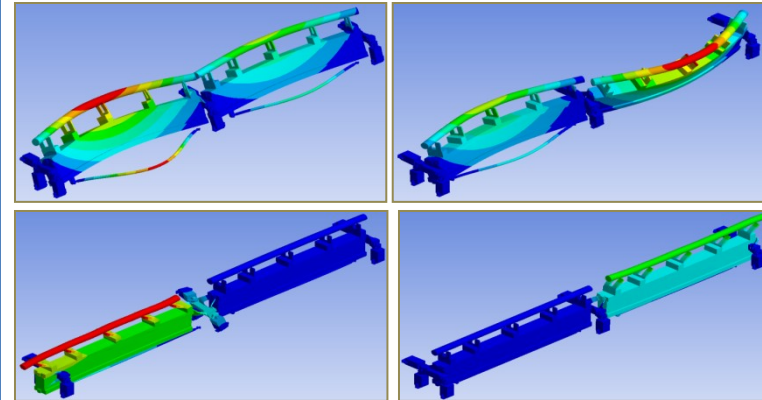
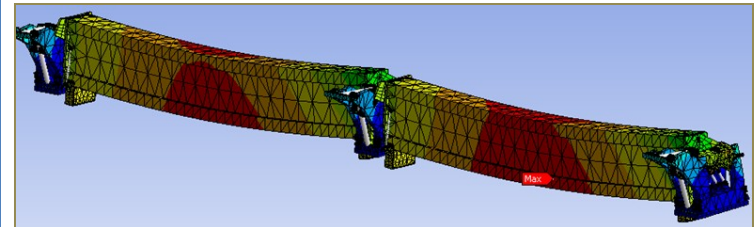
# Girders - structural and modal analysis

N. Gazis

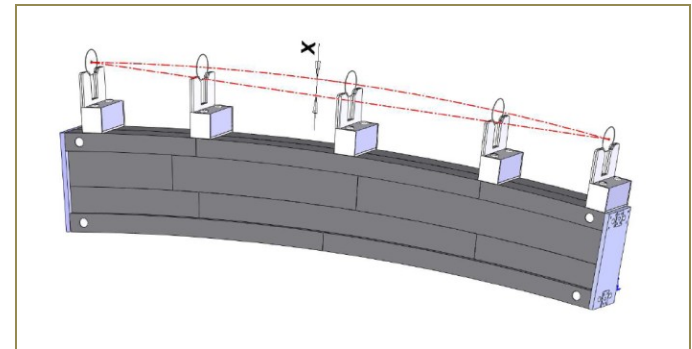


➤ Modal Analyses for all CLIC Two-Beam Module Girder prototype configurations:  
Eigenfrequencies ( $f$ )  $\geq$  35 Hz

➤ Static Analyses of loaded CLIC Two-Beam Module Girder prototype configurations: 80  $\mu\text{m}$   $\geq$  Deformations ( $\epsilon$ )  $\geq$  10  $\mu\text{m}$



Modal Analysis



Pre-stressed solution

Pre-stressed girders, according to the simulated RF component loads, with precision machining after the integration of the V-shaped supports.

# Girders

*Design*



**Firm**

**Boostec**

**Micro-Controle**

**Epucrer**

*Girder  
identification*

B3069

B3079

Poutre 1

Poutre 2

DB01E

DB02E

*Alignment  
Measurement*

V-supports axis  
alignment

V-supports axis alignment

Top Reference Surface  
planarity

*Value*

**15  $\mu$ m**

**12  $\mu$ m**

**7  $\mu$ m**

**9  $\mu$ m**

**19  $\mu$ m**

**20  $\mu$ m**

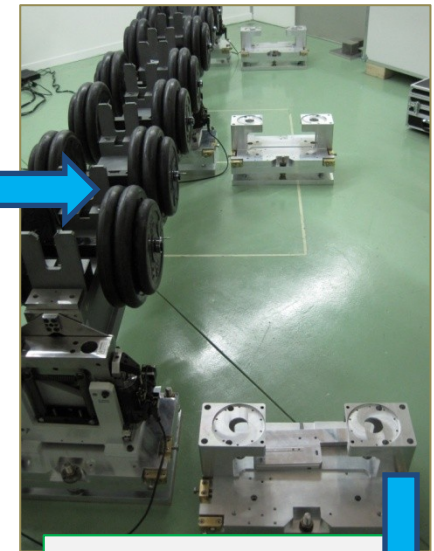
## Boostec Girders (Type 0)



Visit for on site inspection and preliminary dimensional control (Lazer Tracker)



Delivery and dimensional control (Lazer Tracker) at CERN



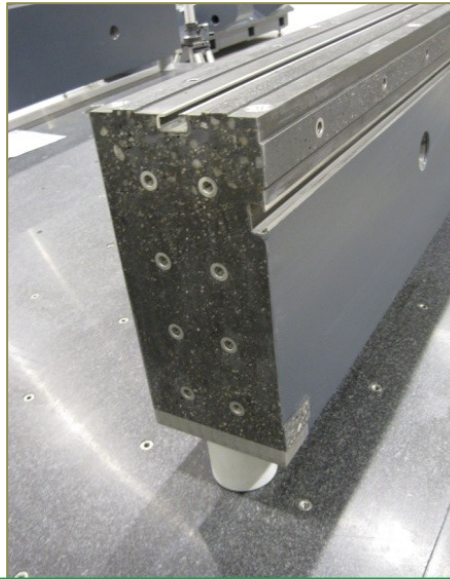
Base plates installation

CMM control at CERN  
(finished on 24 Jan 2011)



Girder installation

## Epucet Girders



Visit for on site inspection and preliminary dimensional control (Lazer Tracker)



Delivery and dimensional control (Lazer Tracker) at CERN

CMM control at CERN

Installation at CERN

# Type 0 girders



# Module power dissipation

| Components                   | Type 0 | Type 1 | Type 2 | Type 3 | Type 4 |       |
|------------------------------|--------|--------|--------|--------|--------|-------|
| Ac. structures [W]           | 3285   | 2464   | 1642   | 821    |        |       |
| PETS [W]                     | 352    | 264    | 176    | 88     |        |       |
| DB quadrupoles [W]           | 342    | 342    | 342    | 342    | 342    |       |
| MB quadrupole [W]            |        | 890    | 1780   | 2600   | 3831   |       |
| Loads [W]                    | 2861   | 2146   | 1430   | 715    |        |       |
| WGs [W]                      | 45     | 34     | 23     | 11     |        |       |
| <b>Total per module [W]</b>  | 6885   | 6139   | 5393   | 4578   | 4173   |       |
| <b>Number of modules</b>     | 8374   | 154    | 634    | 477    | 731    | 10370 |
| <b>Total per linac [kW]</b>  | 57655  | 945    | 3419   | 2184   | 3050   | 67254 |
|                              | 67254  |        |        |        |        |       |
| <b>Total per linac [W/m]</b> | 3203   |        |        |        |        |       |