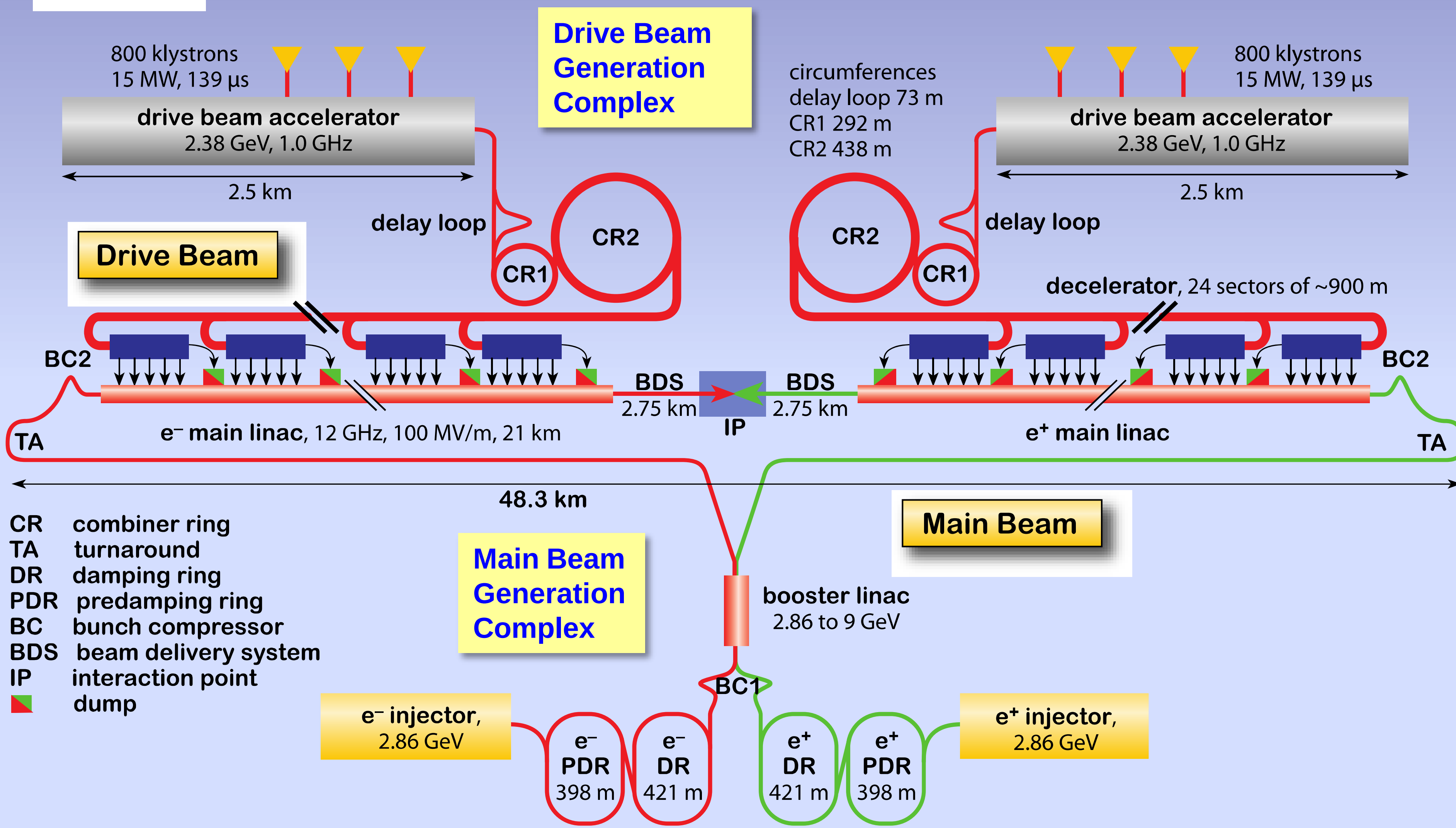
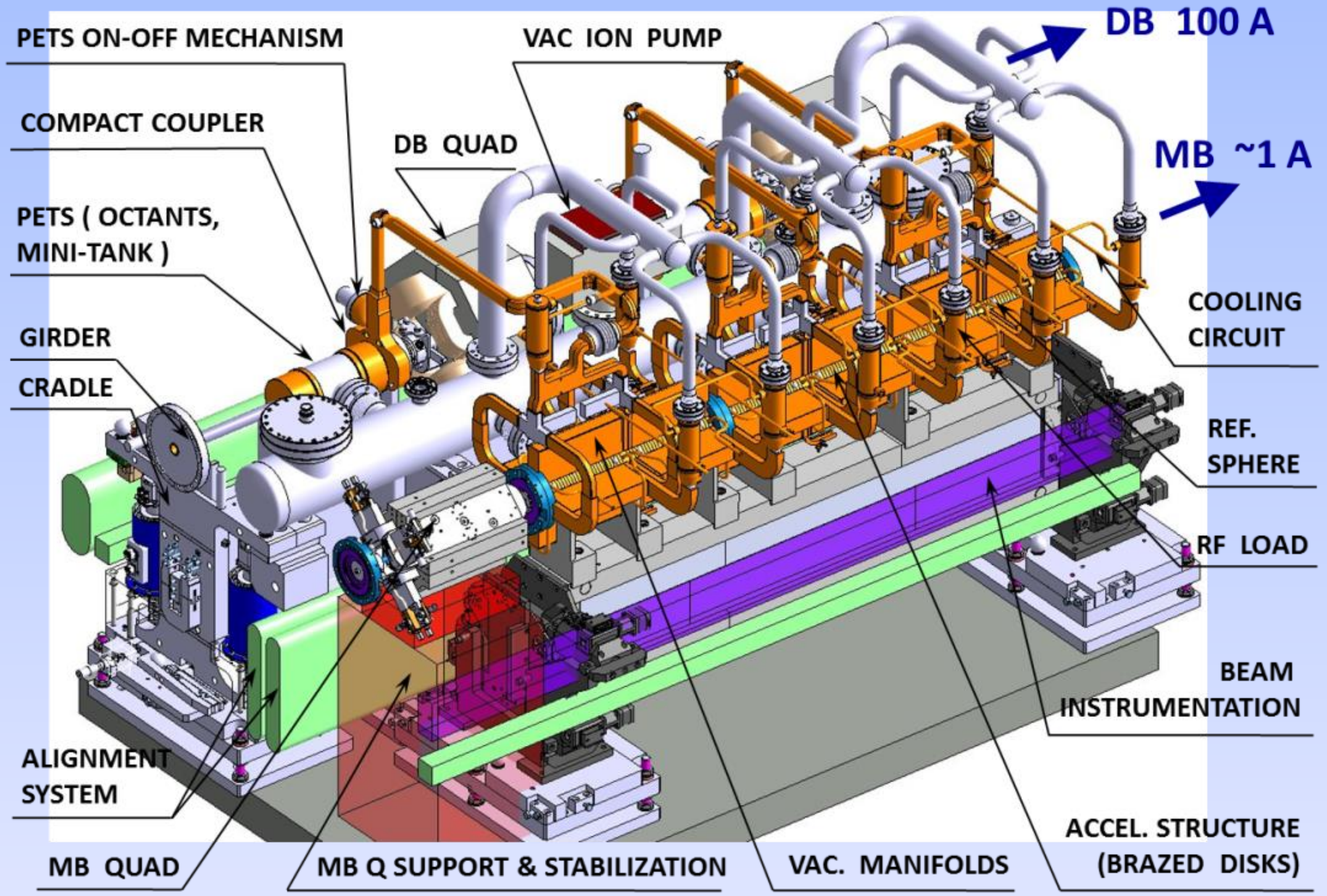
CLIC Module & IMPACT of PACMAN on its alignment

- CLIC module introduction
- Status and results
- Possible PACMAN impact

CLIC Layout at 3 TeV



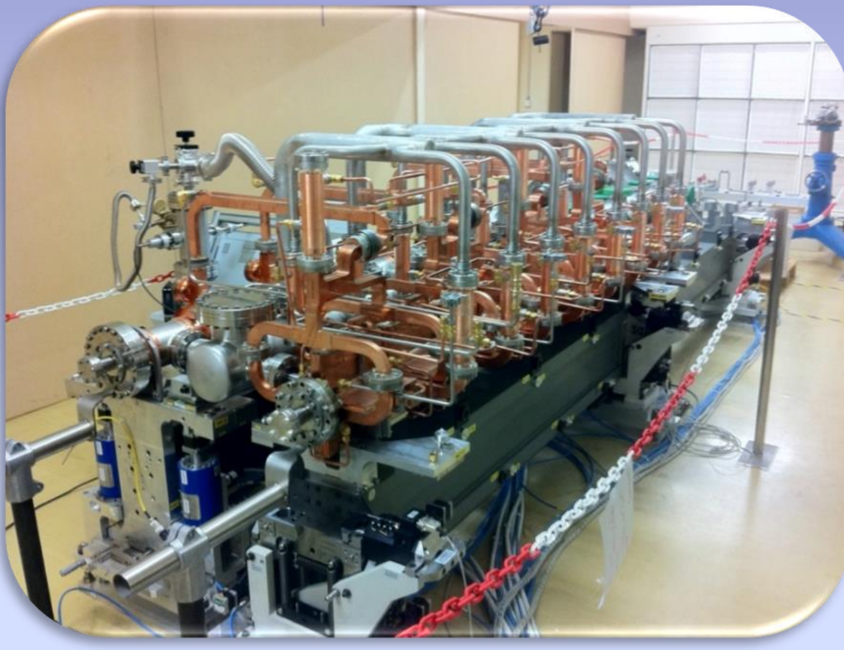
Two-beam module layout

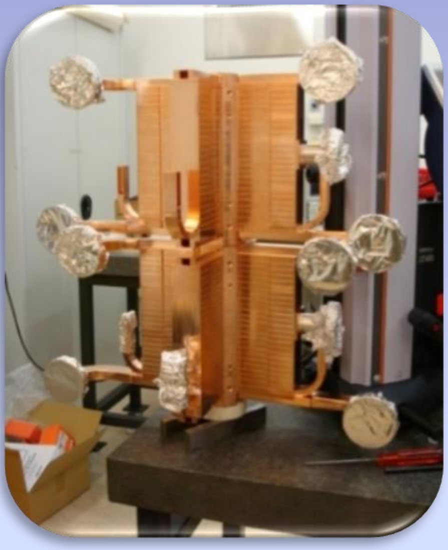


CLIC at 500 GeV (4232 modules)
26920 Accelerating structures
13460 PETS
~ 70000 RF components

CLIC at 3 TeV (21460 modules)
142760 Accelerating structures
71380 PETS
~ 400000 RF components

Two-Beam Modules





Main Module Requirements

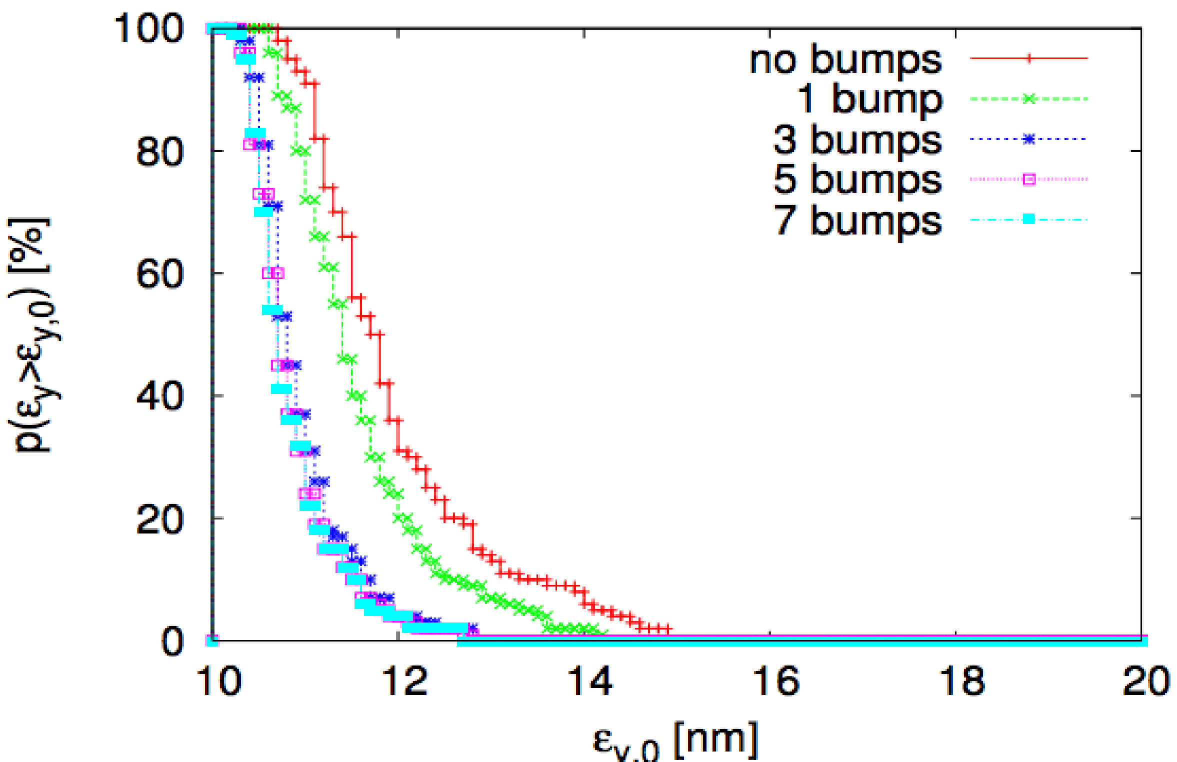
SYSTEM	REQUIREMENTS
RF	AS/PETS shape tolerance ± 2.5/ ±7.5 μm AS/PETS Assembly ± 15/ ± 25 μm RF phase stability, HOM damping, Wakefield monitors
INSTRUMENTATION	BPM resolution: MB - 50 nm, DB – 2 μm
SUPPORTING	Max. vertical & lateral deformation of the girders is ~ 10 μm Capability for beam based alignment corrections
COOLING	~400 W per AS, ~ 7.5 kW per modules, max ΔT= 10 deg per SAS
MAGNET & POWERING	DB: 81.2-8.12 T/m, current density: 4.8 A/mm2, MB: 200 T/m
PRE-ALIGNMENT & STABILIZATION	active pre-alignment ± 14 μm at 1σ, beam axis included in a cylinder of radius 10 μm MB Q stabilization 1 nm > 1 Hz (vertical)
VACUUM	10^{-9} mbar to avoid stabilities
ASSEMBLY, TRANSPORT, INSTALLATION	Preserve alignment and tolerances

Module design and integration coping with challenging requirements from different technical systems.

Final Emittance Growth (CLIC)

imperfection	with respect to	symbol	value	emitt. growth
BPM offset	wire reference	σ_{BPM}	14 μm	$0.367\,nm$
BPM resolution		σ_{res}	0.1 μm	$0.04\,nm$
accelerating structure offset	girder axis	σ_4	10 μm	$0.03\,nm$
accelerating structure tilt	girder axis	σ_t	200 $\mu radian$	$0.38\,nm$
articulation point offset	wire reference	σ_5	12 μm	$0.1\,nm$
girder end point	articulation point	σ_6	5 μm	$0.02\,nm$
wake monitor	structure centre	σ_7	5 μm	$0.54\,nm$
quadrupole roll	longitudinal axis	σ_r	100 $\mu radian$	$\approx 0.12\,nm$

- Selected a good DFS implementation
  - trade-offs are possible
- Multi-bunch wakefield misalignments of $10\,\mu m$ lead to $\Delta\epsilon_y \approx 0.13\,nm$
- Performance of local pre-alignment is acceptable



A. Latina

CLIC Module R&D

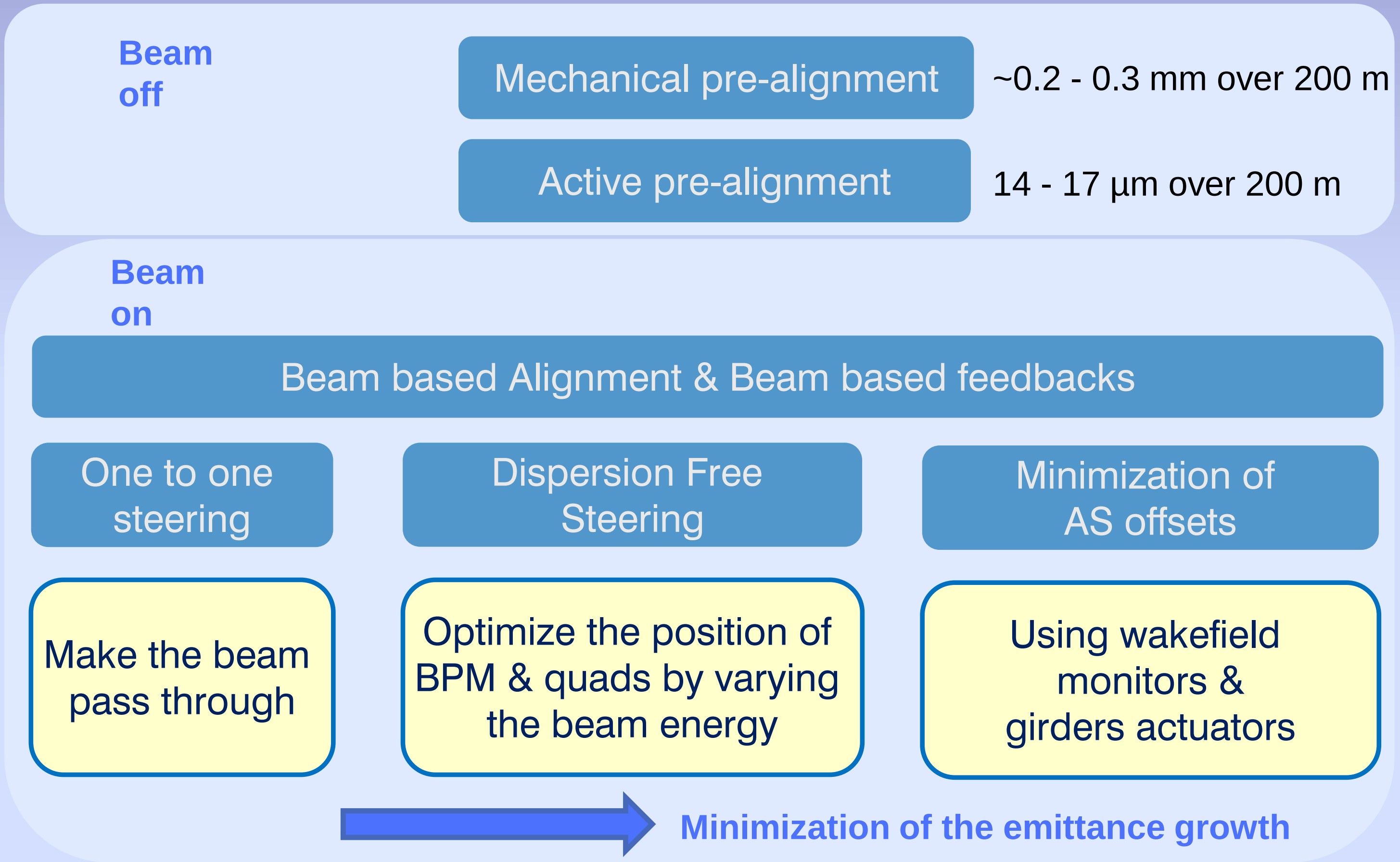
CLIC prototype Module with real RF components installed in CTF3 and tested with drive and probe beam

CLIC mechanical test modules with mock up components in a dedicated Lab for thermo-mechanical, alignment and integration testing.

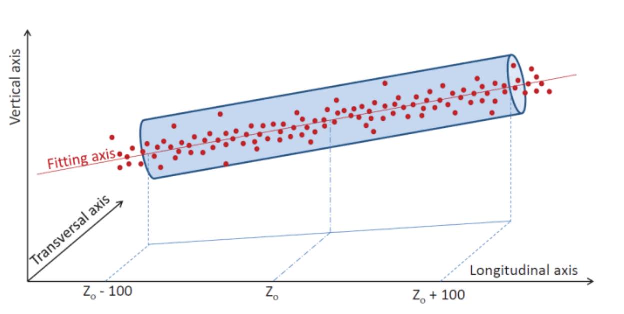
A

B

CLIC project: alignment strategy



Pre-alignment strategy



The zero of each component will be included in a cylinder with a radius of a few microns:

➔ 14 µm (RF structures & MB quad BPM)

➔ 17 µm (MB quad)

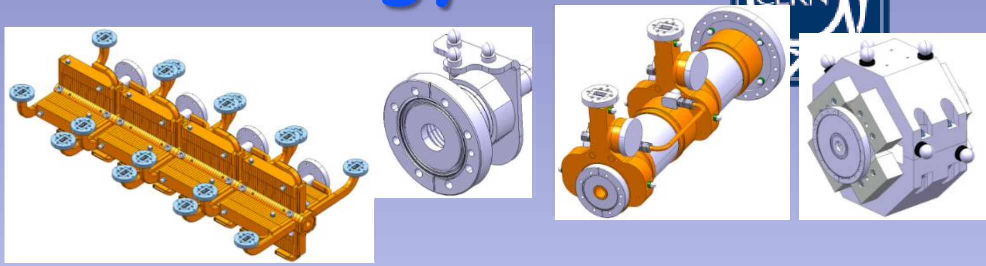
➔ 20 µm (DB quad)

Budget of alignment errors

Steps	AS	MB quad	Achieved
Zero of components to fiducials	5 µm	10 µm	**????**
Fiducials to sensor interface on support	5 µm	5 µm	Yes
Sensor interface on support	5 µm	5 µm	Yes
Sensor measurement w.r.t straight reference	5 µm	5 µm	Yes
Stability knowledge of the straight reference	10 µm	10 µm	Yes, on short range
Total error budget	**14 µm**	**17 µm**	

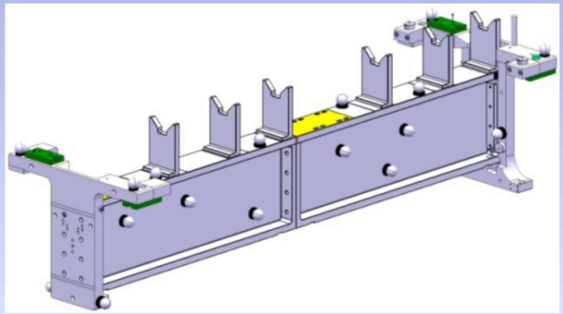
The combination of the 3 first steps is the object of PACMAN

Pre-alignment strategy



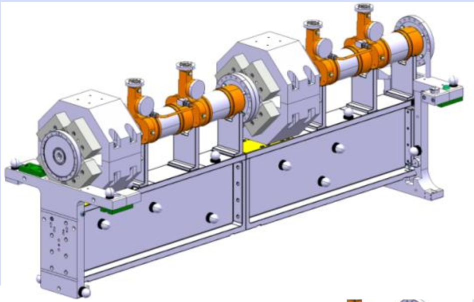
Fiducialisation of components

⇓



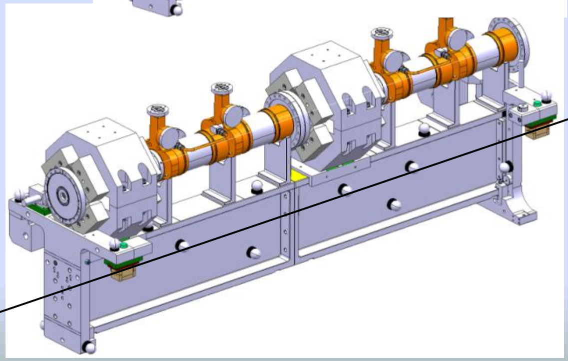
Fiducialisation of their common support

⇓



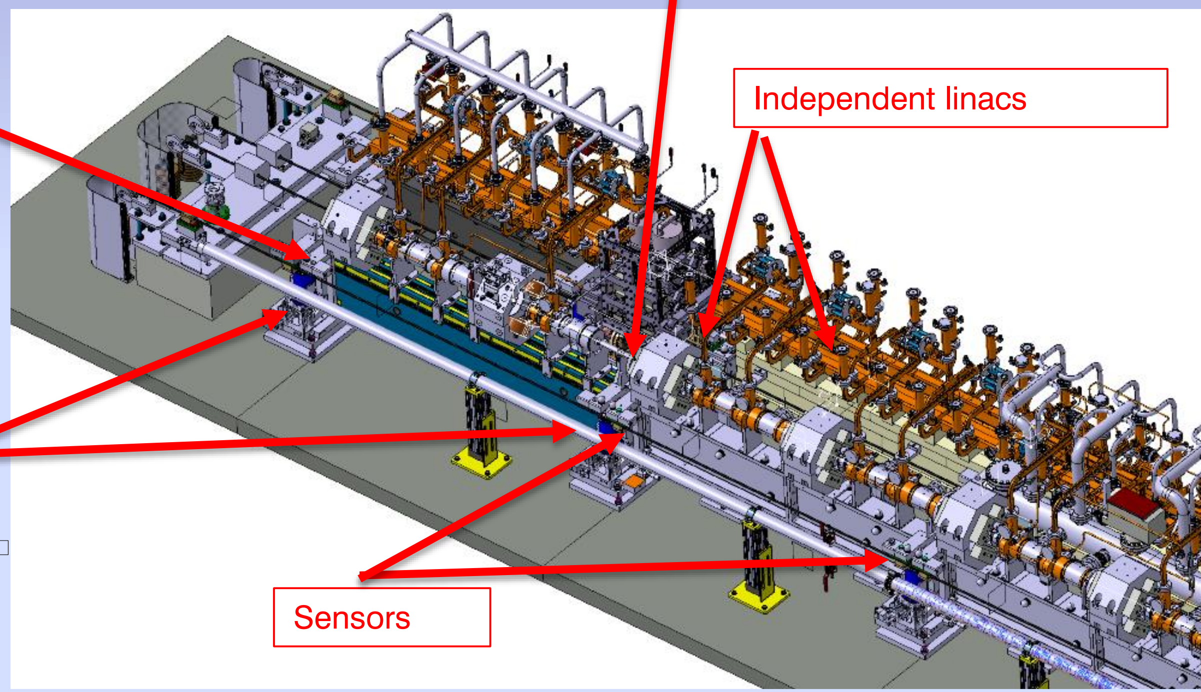
Alignment on a common support

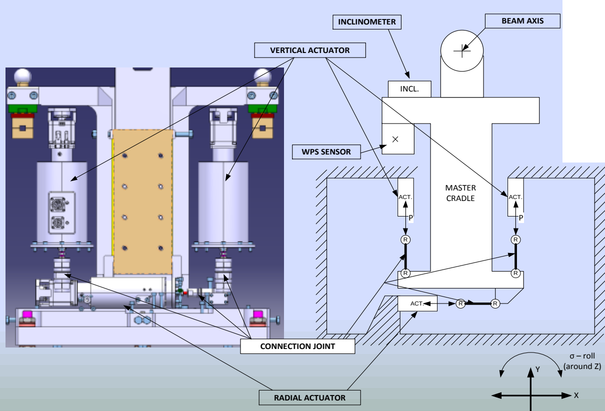
⇓

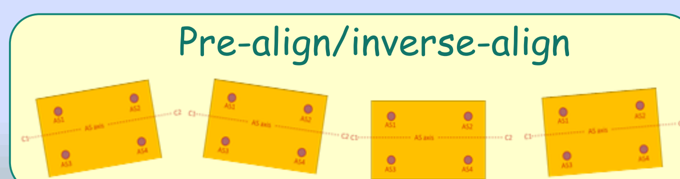


Whole assembly ready to be aligned

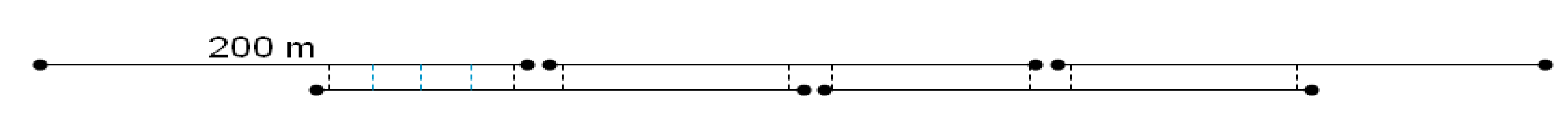
Pre-alignment in the tunnel

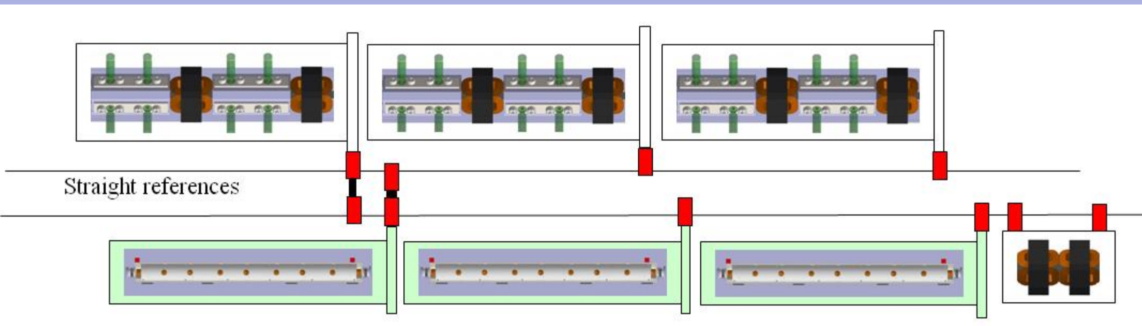


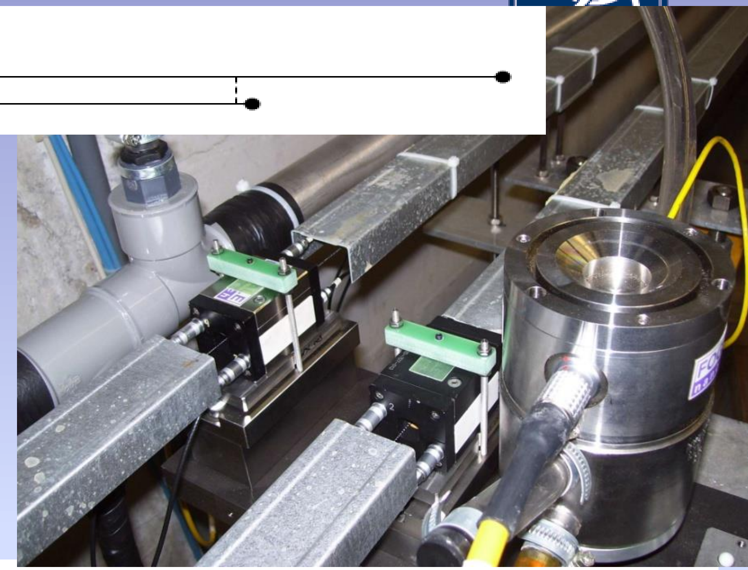




CLIC Pre-alignment System



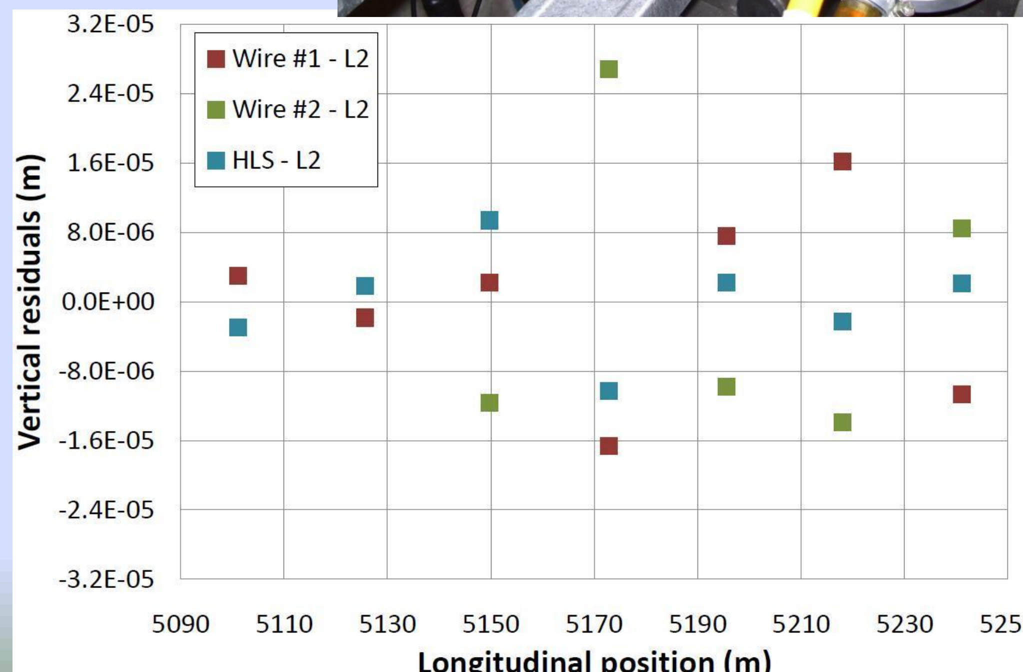




- Required accuracy of reference points is 10µm

- Test of prototype shows
  - vertical RMS error of 11µm
  - i.e. accuracy is approx.13.5µm

- Improvement path identified

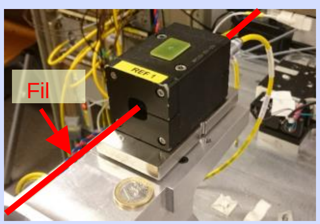


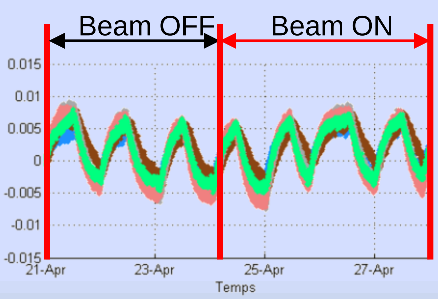
Pre-alignment in the tunnel

Sensors → Study of different configurations
→ Inter-comparison between sensors
→ Study of the supporting solutions

cWPS (capacitve Wire Positioning System)

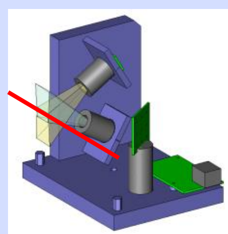
- Range : +/- 5 mm
- Repeatability: +/- 1 µm
- Linearity : ~ 2 µm/mm
- Accuracy : 5 µm
- Resolution : < 1 µm
- RAD-HARD

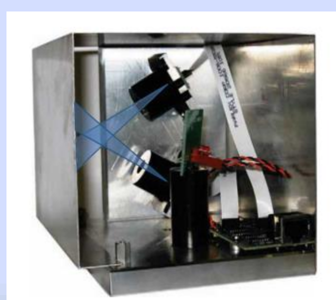




oWPS (optical Wire Positioning System)

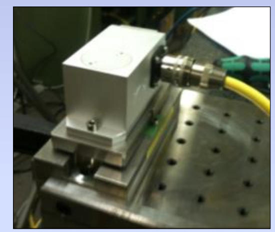
- Range : +/- 15 mm
- Repeatability: +/- 1 µm
- Linearity : ~ 3 µm/mm
- Accuracy : ~ 10 µm
- Resolution : < 1 µm



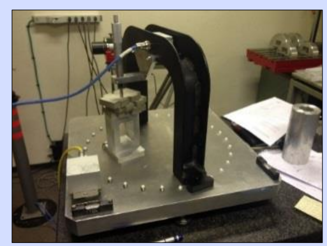


Tilt-meter

- Range : +/- 15 mrad
- Repeatability system: +/- 5 µrad
- Linearity : ~ 2 µrad / mrad
- Resolution : < 1 µrad

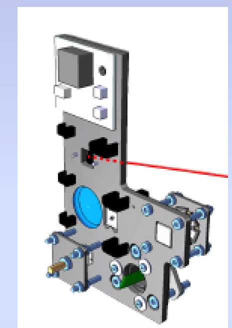


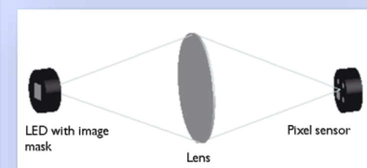
Absolute Tilt-meter



RasChain

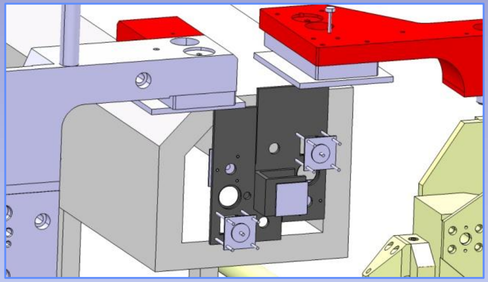
- System 3 points
- Range : +/- 10 mm
- Repeatability: under tests
- Resolution : under tests





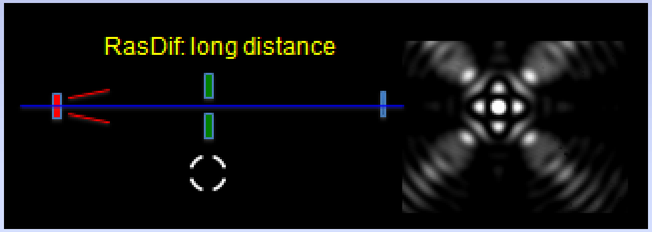
- *LAB (2011 – 2013) : 2 cWPS + 2oWPS + 1 Relative Tilt meter (without beam)*
- *LAB (2013 – 2014) : 2 cWPS + 2 Nikhef sensors + 1 Relative Tilt meter (without beam)*
- *CLEX (2014-2015) : 4 cWPS (With Beam)*
- *LAB (2015) : 2 cWPS + 2oWPS + 1 Absolute Tilt meter (without beam) FUTURE*

Alternative alignment sensor development

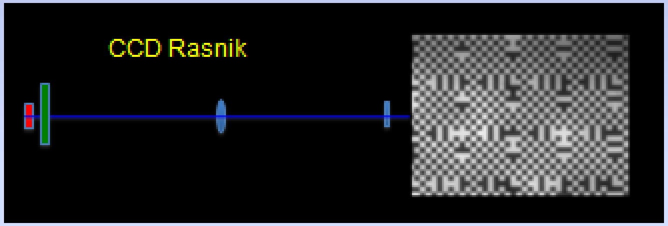


2 main systems developed by NIKHEF

RasDif



RasNik



Development of sensors

- Length between girders not the same
- Use of oWPS interface
- Choice of the components
- Software, preparation of database

Qualification (@ NIKHEF)

- Influence of T°
- Necessity of thermal shielding

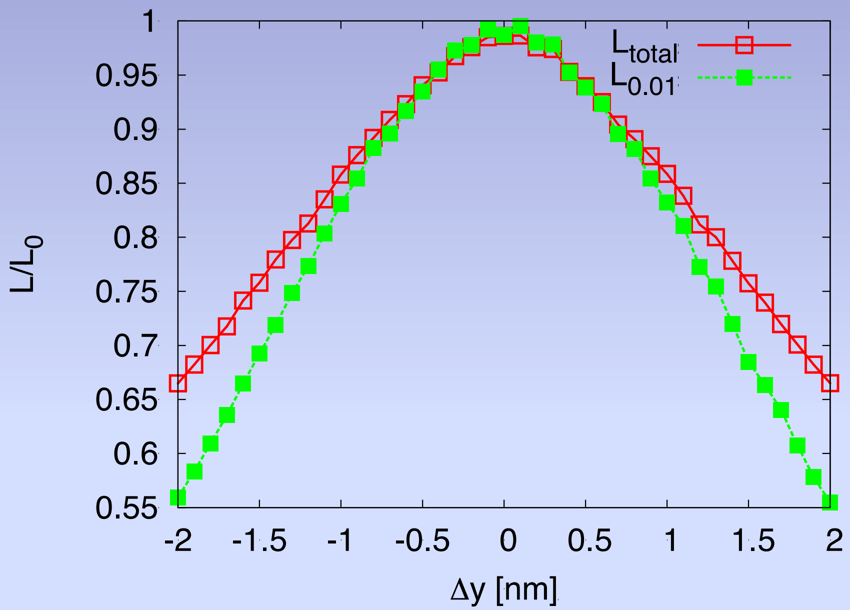
Integration in 3D models

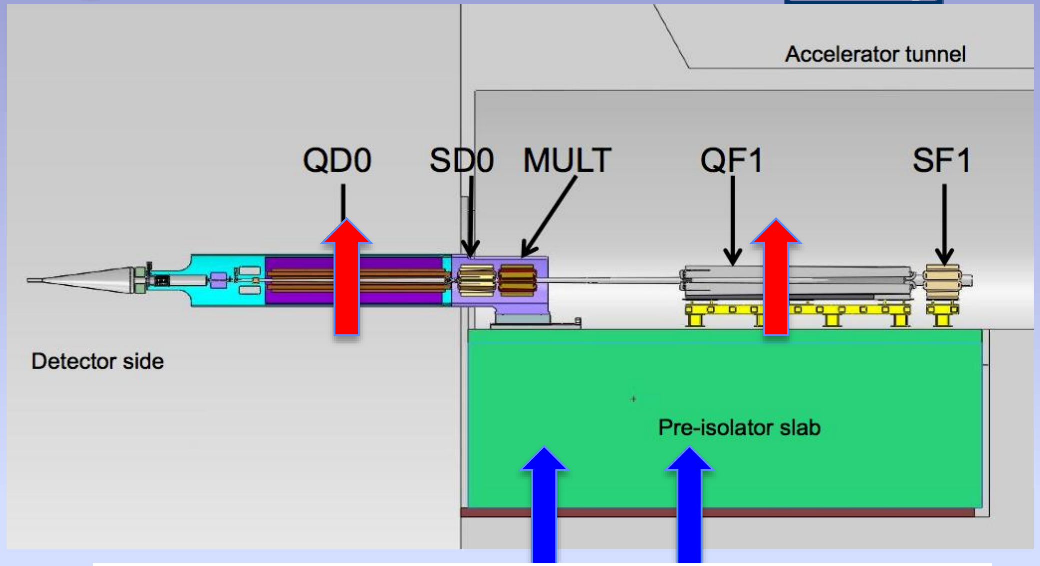
- Exchange of 3D models

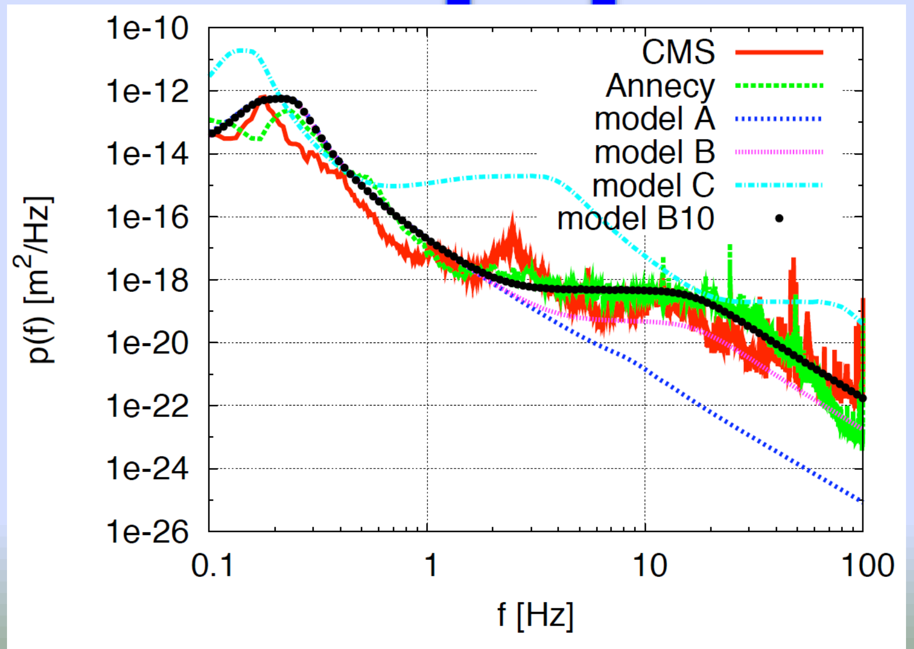
Installation & analysis of data

- Longitudinal position of cradles not good
- Interferences with other systems
- One cradle with problem

Ground Motion and its Mitigation



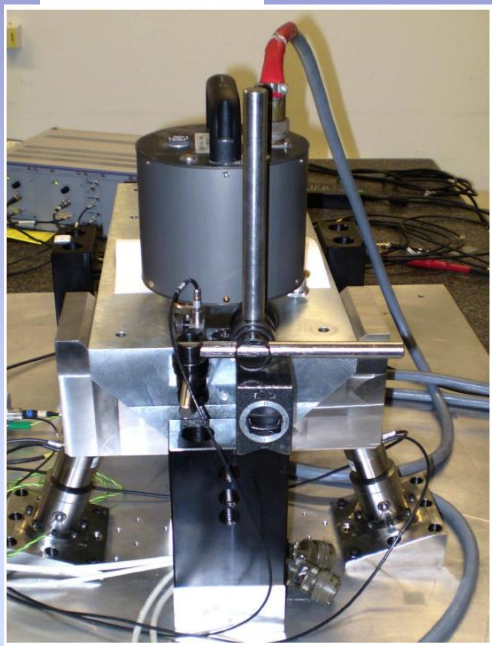


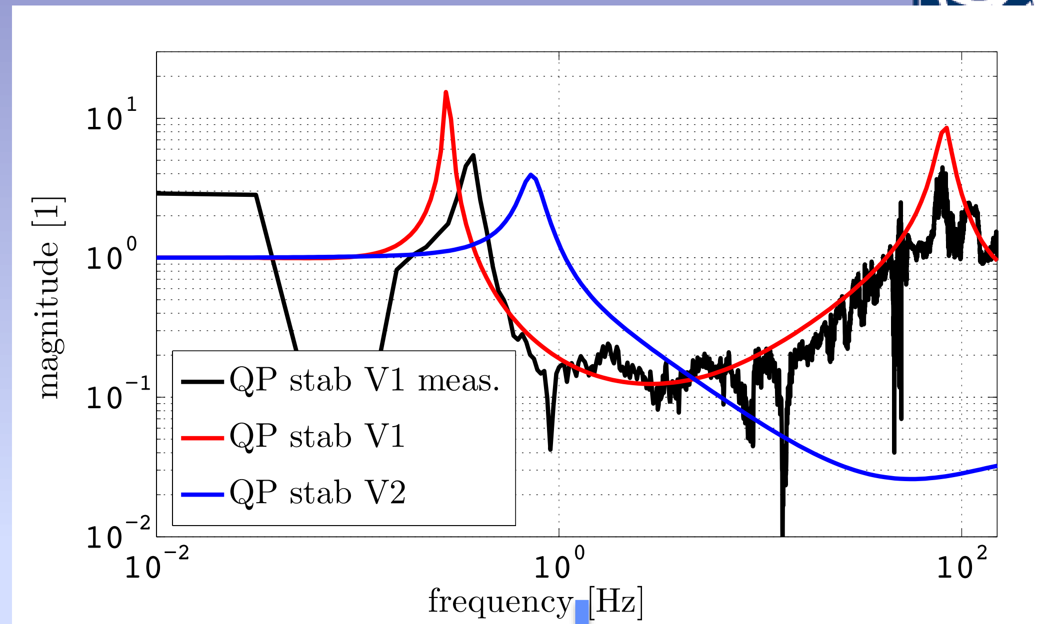


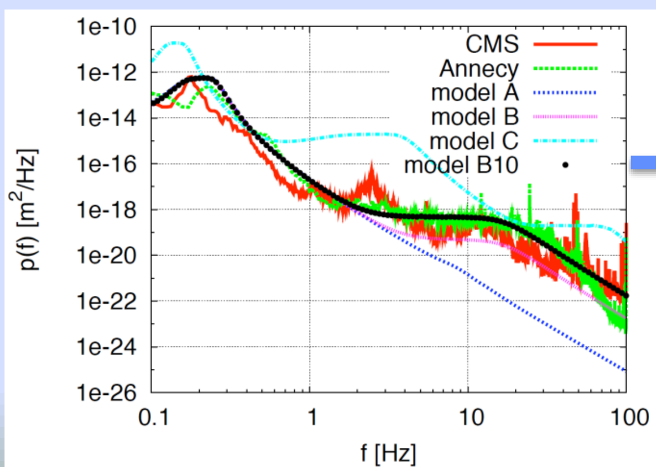
Natural ground motion can impact the luminosity

• typical quadrupole jitter tolerance O(1nm) in main linac and O(0.1nm) in final doublet

Active Stabilization Results







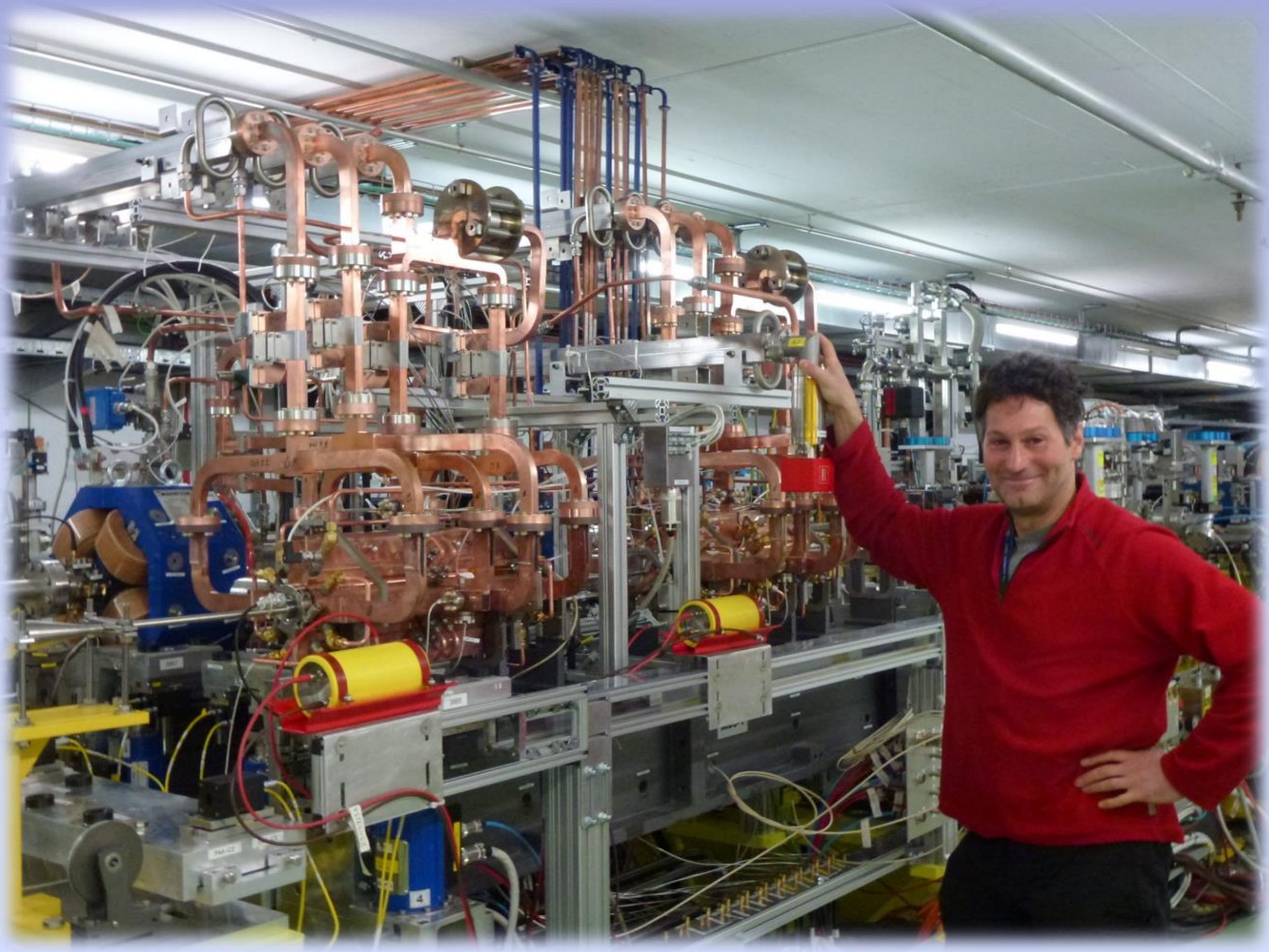
Code

Machine model
Beam-based feedback

Luminosity achieved/lost [%]

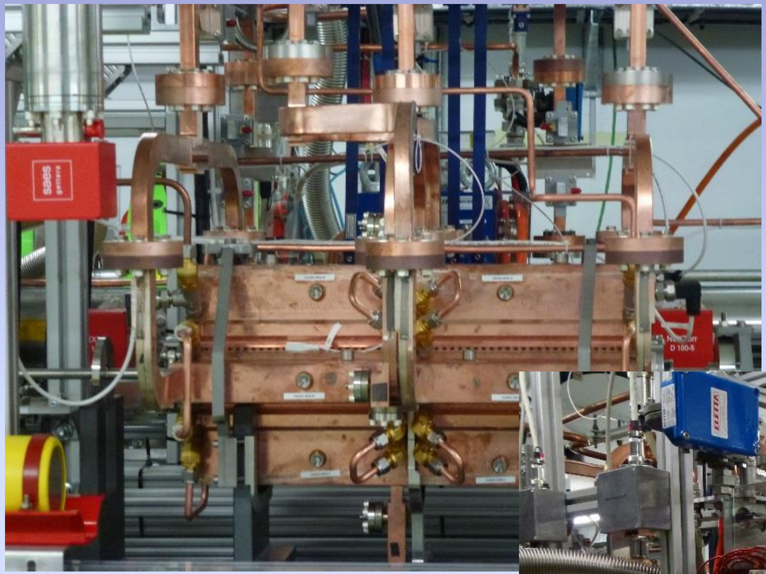
	B10
No stab.	53%/68%
Current stab.	108%/13%
Future stab.	118%/3%

First CLIC prototype module completely installed in CLEX

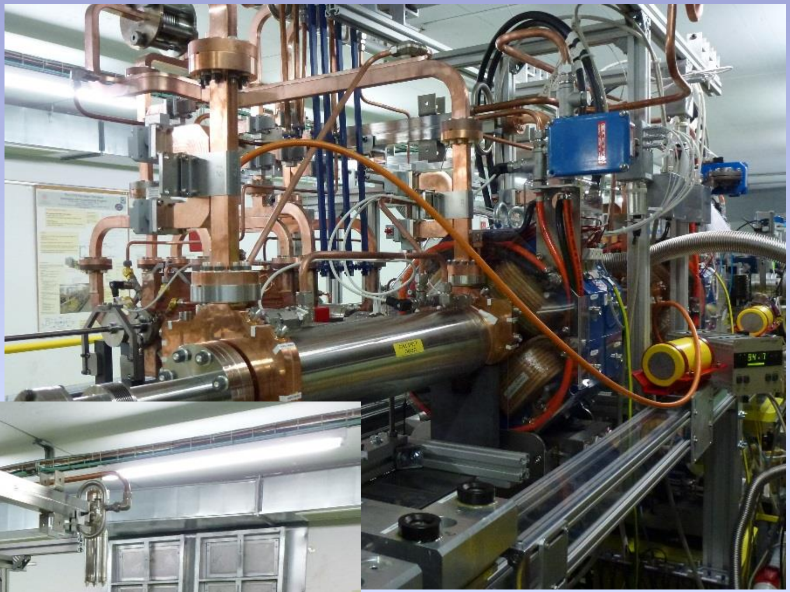


Fully equipped module including superstructures with SiC damping, rf distribution, active alignment system, BPM's and Quads

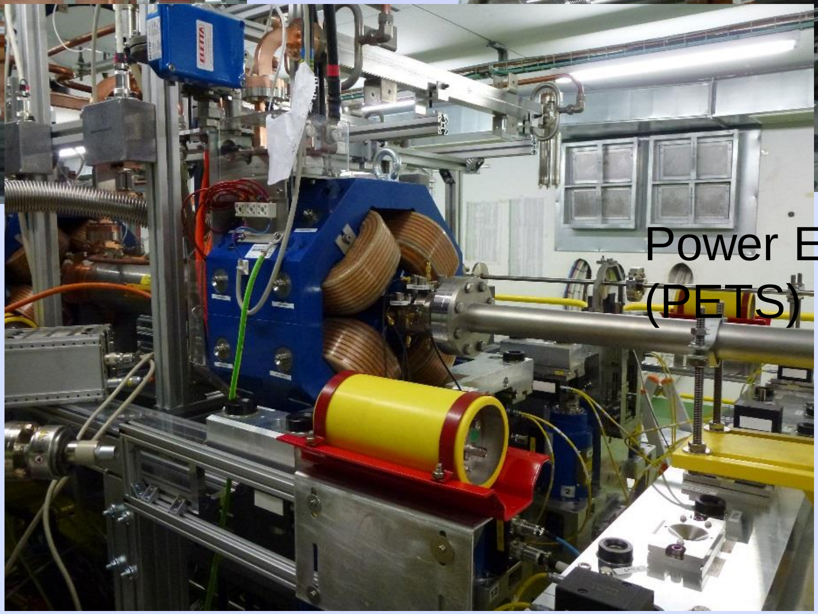
First CLIC prototype module completely installed in CLEX



CLIC superstructure

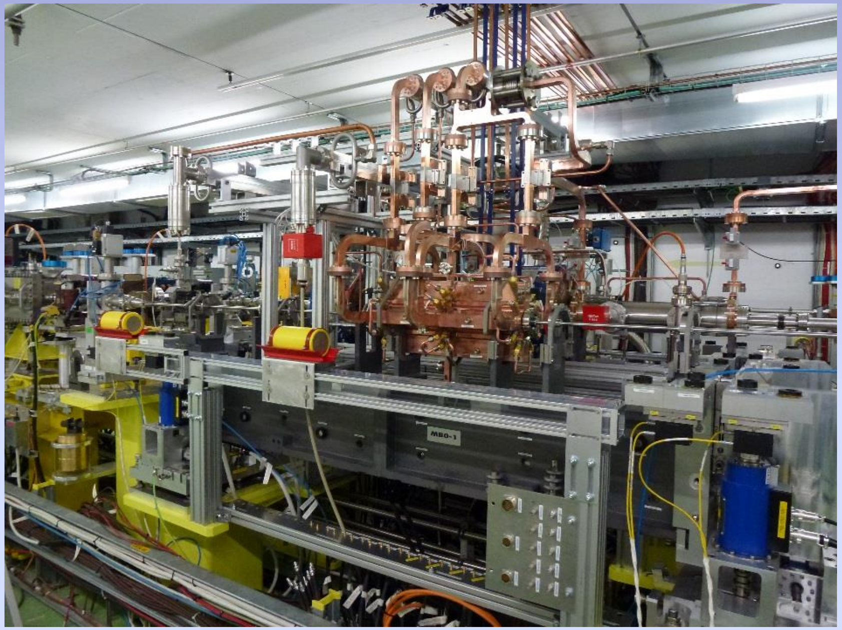


Power Extraction Structure (PETS)

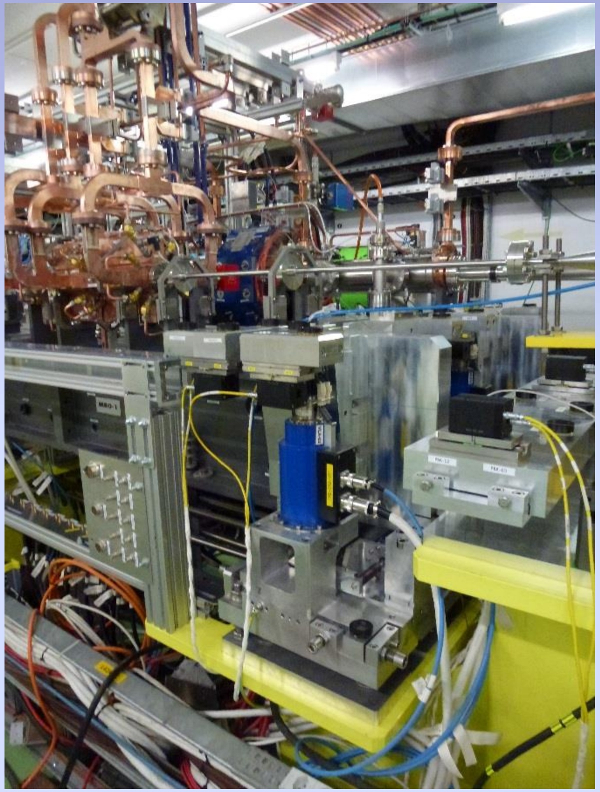


Dive Beam Quad + BPM

First CLIC prototype module completely installed in CLEX

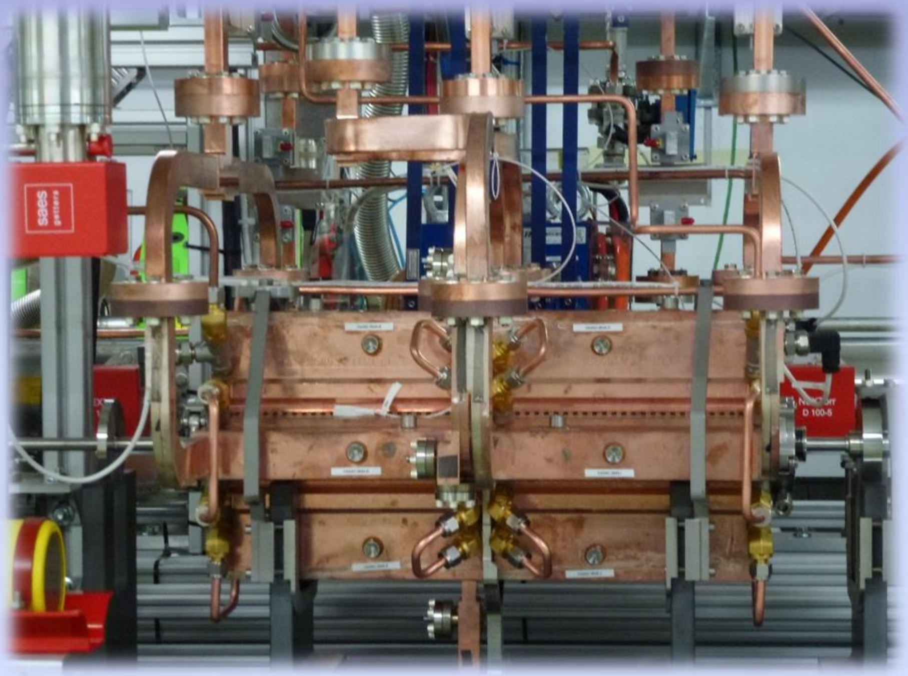


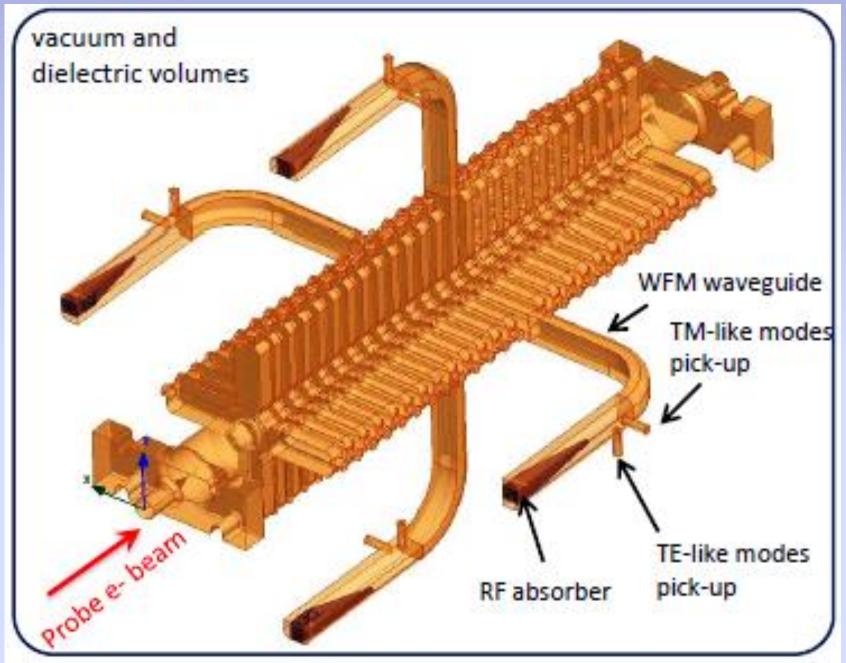
Module support out of SiC



Actuators of the alignment system

Wakefield monitors

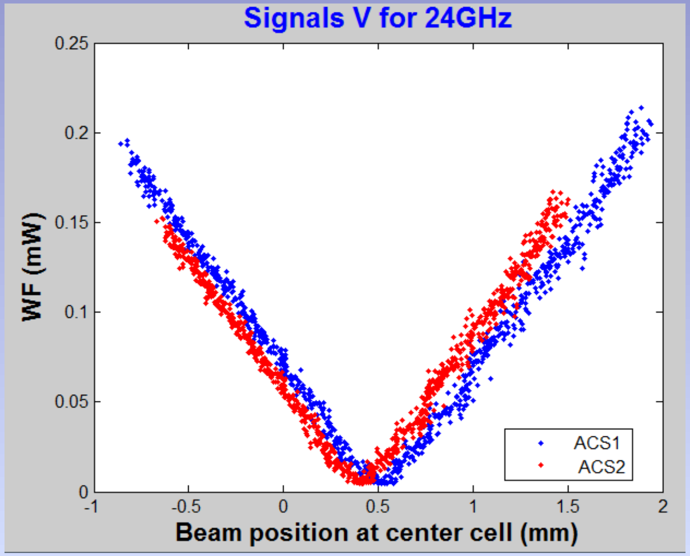


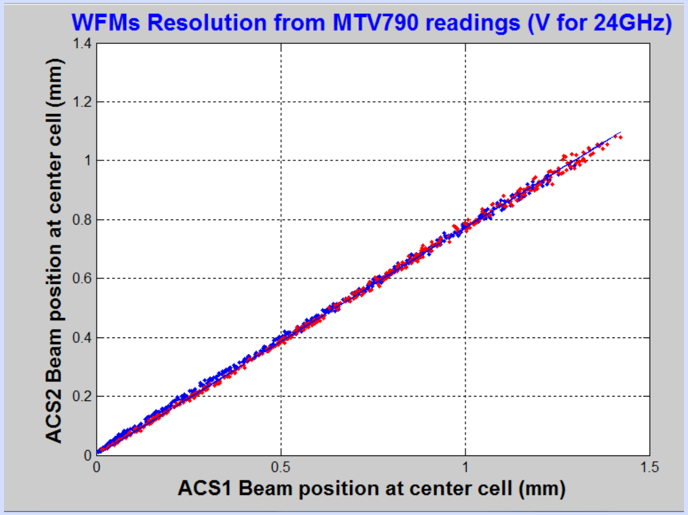


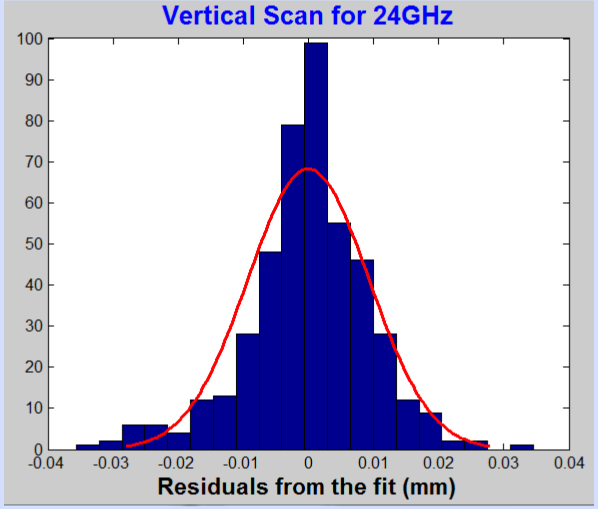
TM-like at 18 GHz and TE-like at 24 GHz HOM pick-ups

5 um resolution required for CLIC Beam Based Alignment scheme

Wakefield monitors





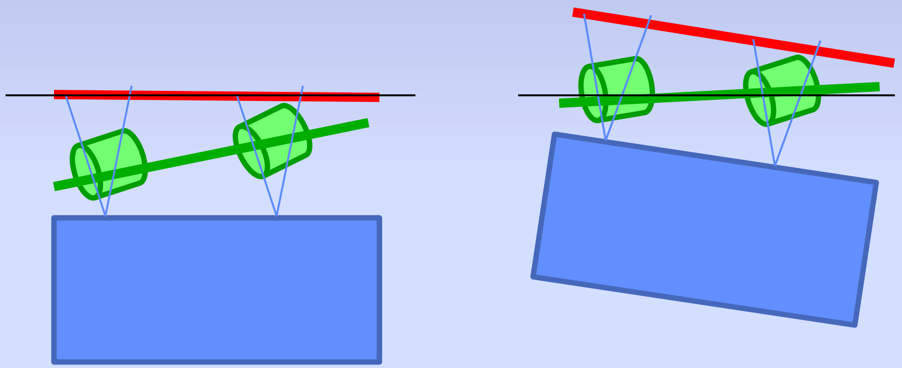


Required 5 um resolution demonstrated in the two beam test stand, ongoing with the prototype module

CLEX Alignement

Component Drive Beam		Radial (µm)	Vertical (µm)	Error budget (µm)
PETS1	Enter	65	37	100
	Exit	-27	15	100
DBQ1	Enter	-9	-4	20
	Exit	-2	19	20
PETS2	Enter	28	78	100
	Exit	-51	58	100
DBQ2	Enter	8	11	20
	Exit	-3	-14	20

Component Main Beam		Radial (µm)	Vertical (µm)	Error budget (µm)
AS1	Enter	-51	-59	10
	Exit	-161	-16	10
AS2	Enter	-68	-85	10
	Exit	-139	-103	10

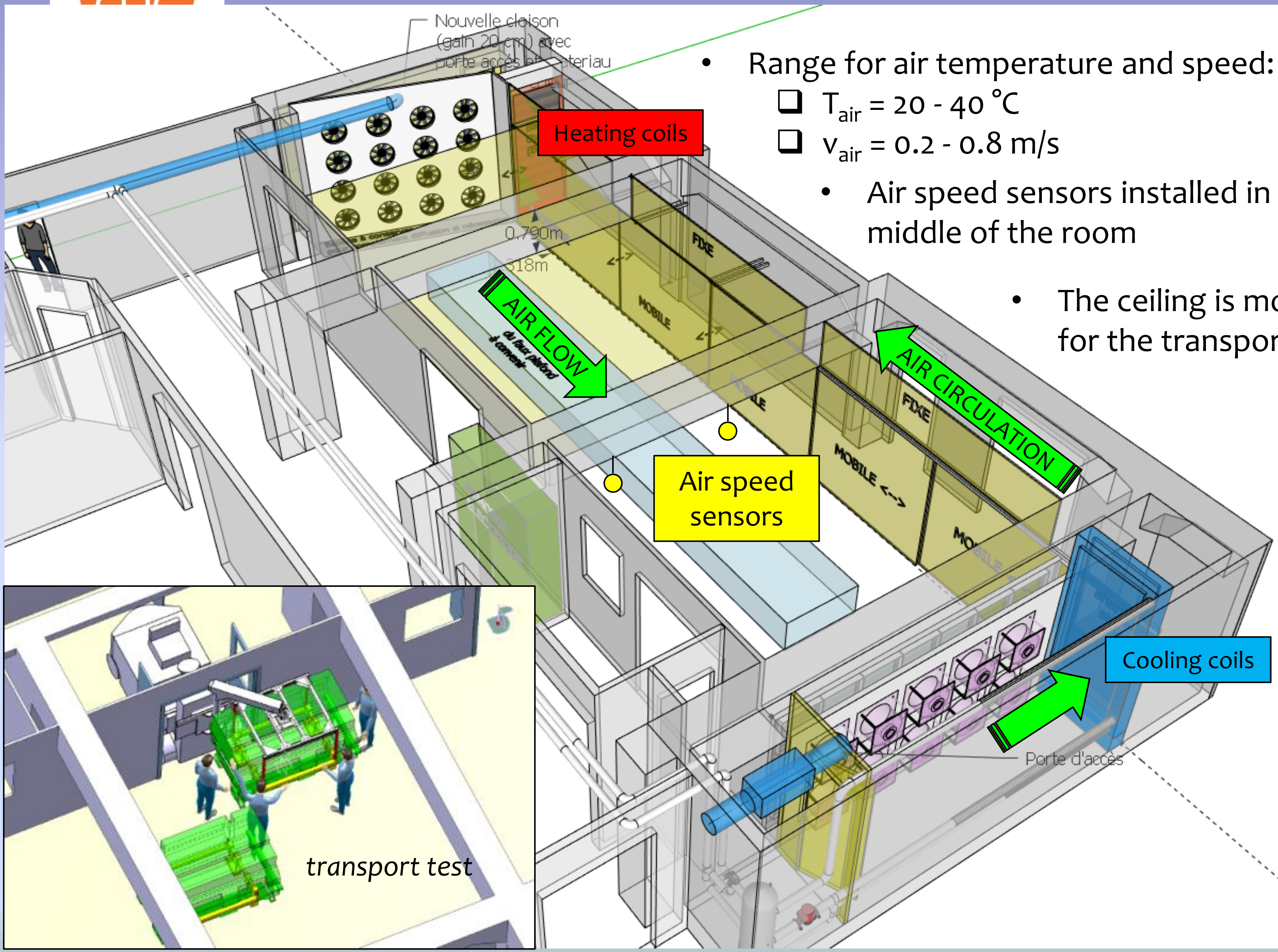


Component Main Beam		Radial (µm)	Vertical (µm)	Error budget (µm)
AS1	Enter	29	-24	10
	Exit	-65	39	10
AS2	Enter	46	-8	10
	Exit	-10	-7	10

Vivien Rude

Lab-Module test stand

- Range for air temperature and speed:
  - ❑ T_{air} = 20 - 40 °C
  - ❑ v_{air} = 0.2 - 0.8 m/s
    - Air speed sensors installed in the middle of the room
    - The ceiling is movable for the transport test



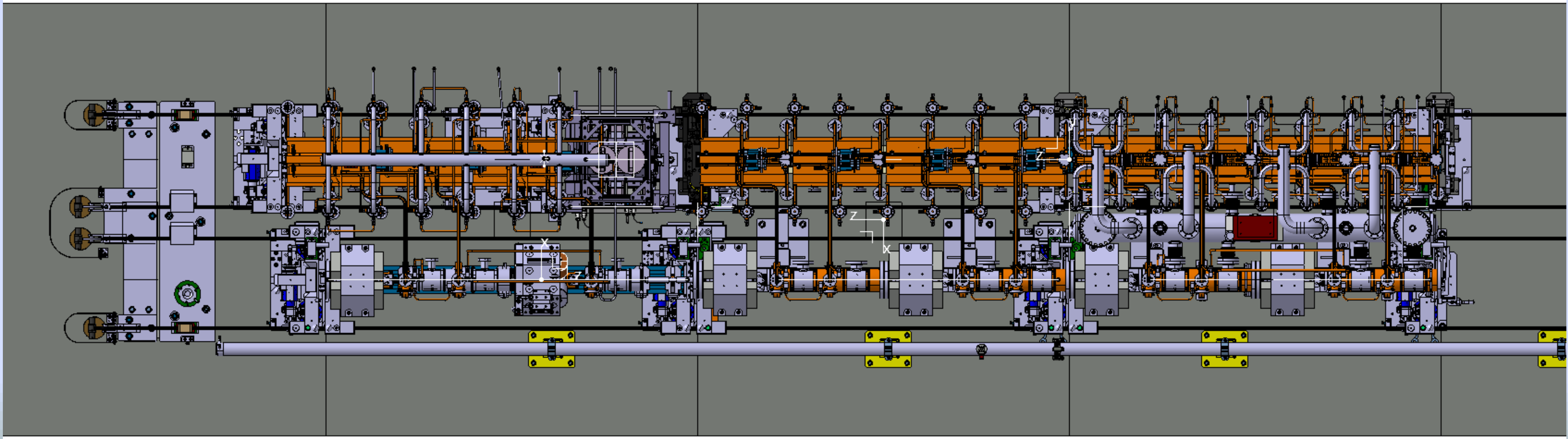
Module configuration in the Lab
T1-T0-T0

- Thermo-mechanical measurements under vacuum
  Alignment and temperature response measurements
  Thermal and mechanical coupling between girders and modules
  Thermo-mechanical comparison of T0 and T1
  Failure modes: Control of time constants through water flow

- Outgassing of structures with SiC

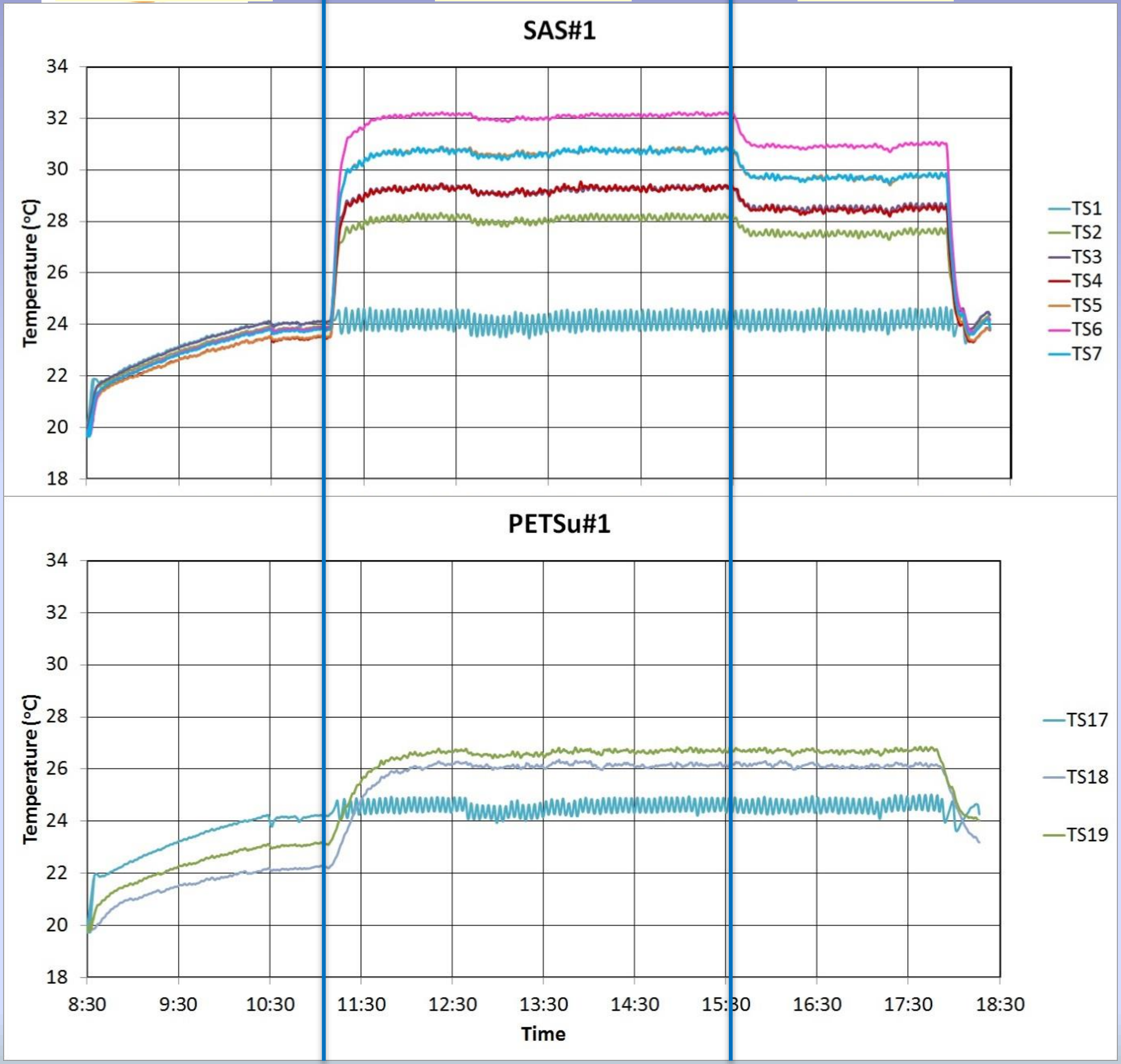
- Module interconnects T0-T0-T1 (snake system)

- Alignment of mini module string

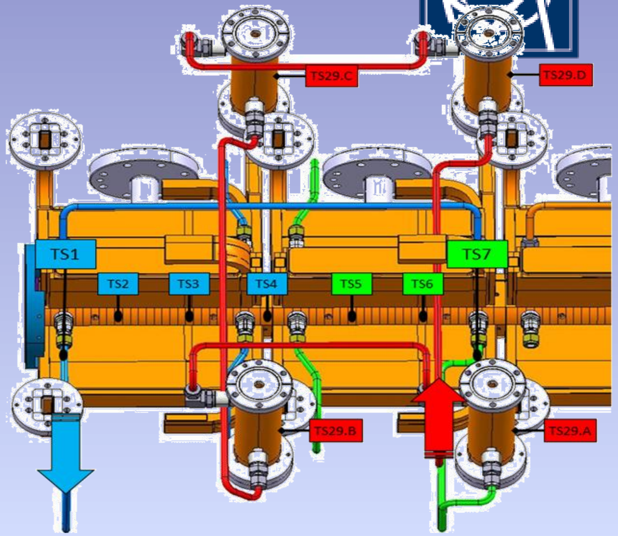


Thermal test data example

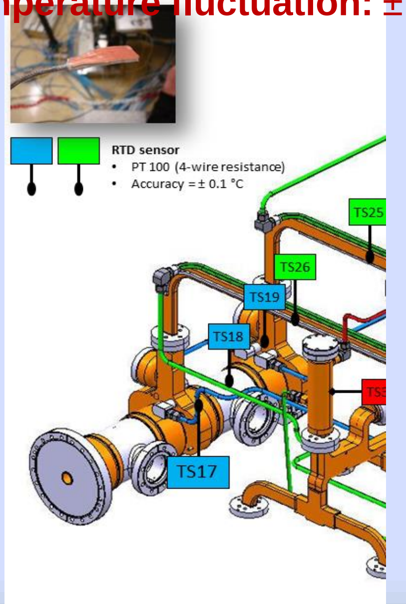
Water only | Unloaded | Loaded



Temperature evolution (Zero - Unloaded - Loaded conditions)

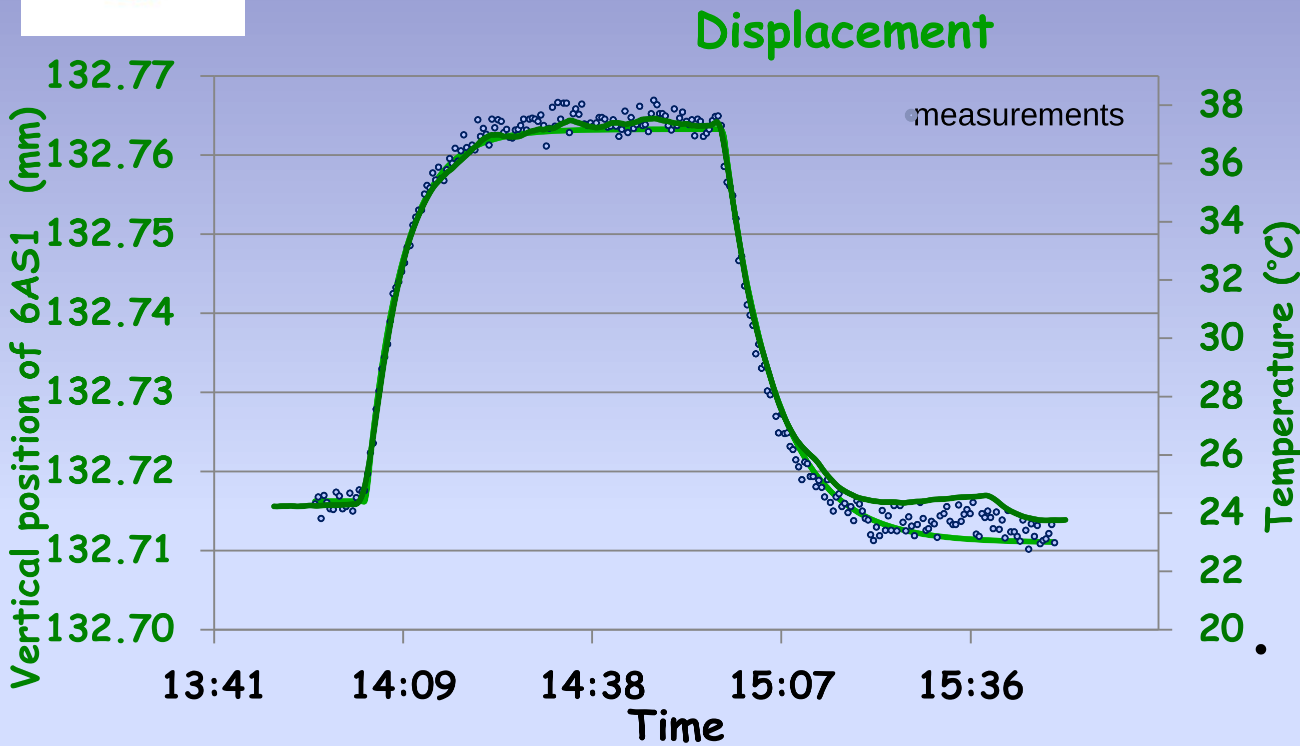


Temperature fluctuation: ± 0.2 ^{o}C



Elena Daskalaki, Alex Vamvakas, Anastasia Xydou

Results: One point of AS



Time constants (min)

	Δx	ΔT
Rise	7.28	7.52
Fall	7.87	7.33

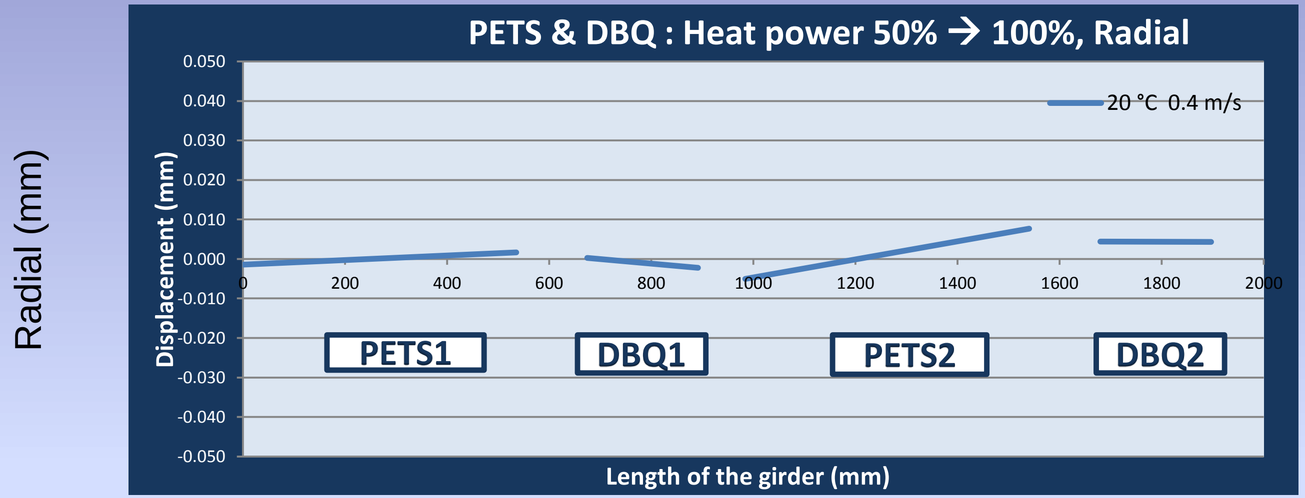
- *Vertical displacement of AS axis*
- *No radial displacement was detected*

- Movement and temperature dynamics are the same
- Time constants can be calculated as in the case of temperature

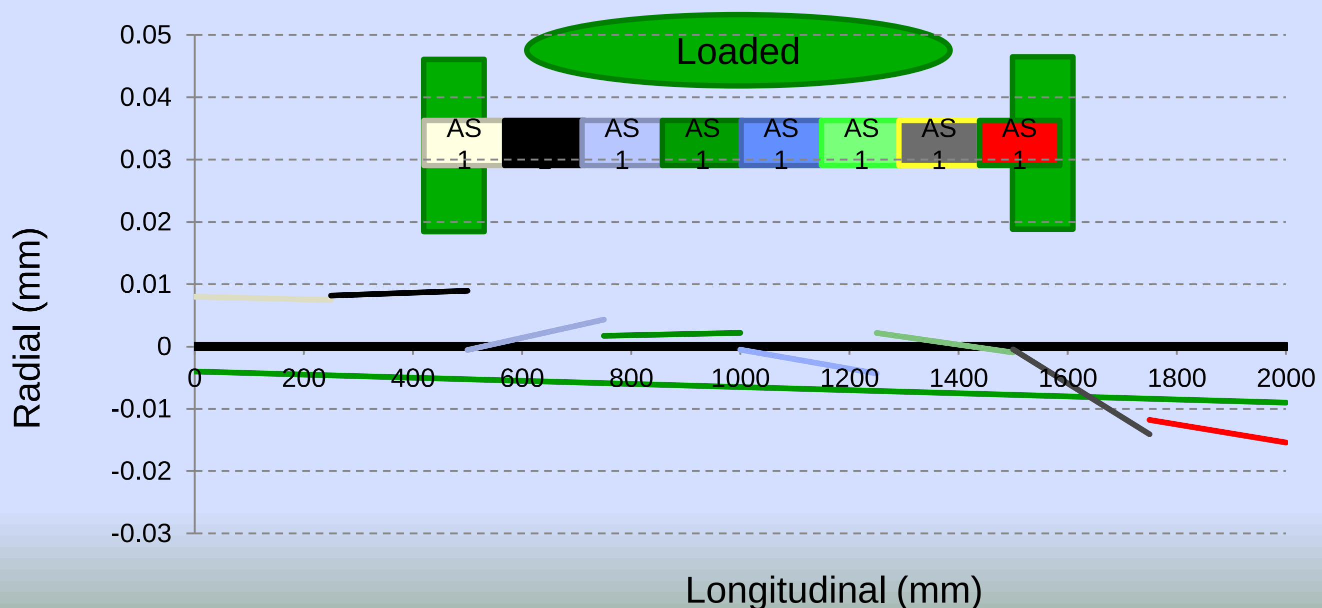
Mathieu Duquenne , Eleni Daskalaki

Experimental result: displacements, example

DRIVE BEAM



MAIN BEAM

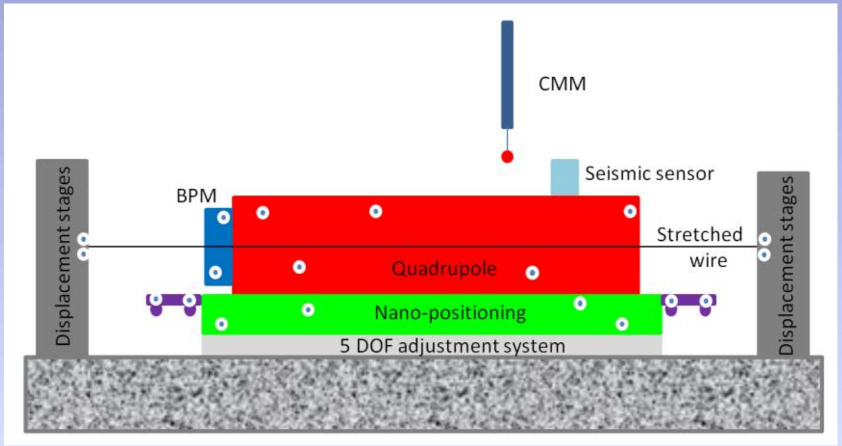


Production flow
when to we do the alignment

Production of components | Assembly on girder | Fiducialisation Pre-alignment | Transport | Final position Commissioning

- Many permutation possible
- PACMAN suggest to do the assembly, fiducialisation and pre-alignment in one step (at CERN ?)
- Can industry do that at a reasonable cost
- Can this be automatized ?
- Cost model for alignment needed
- Will the alignment survive the transport ?
- Can it be done in the final location in the tunnel ?

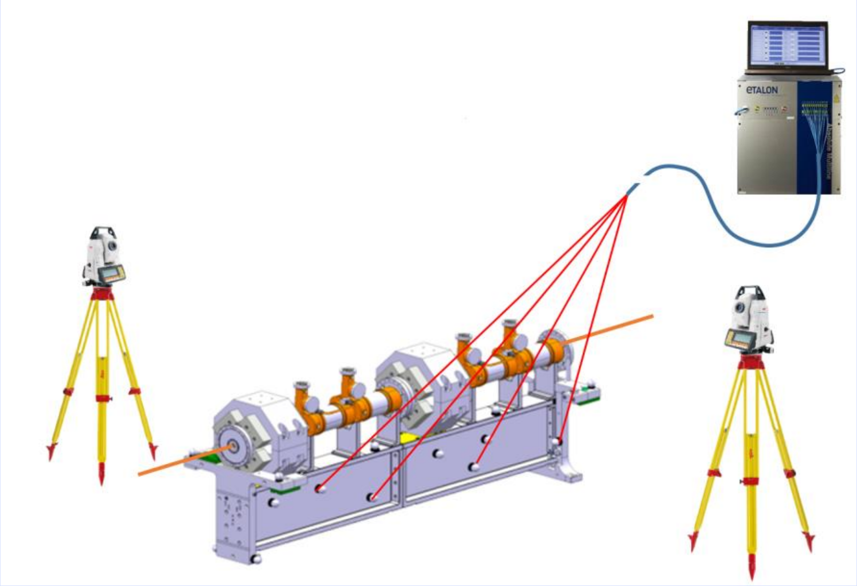
PACMAN and its possible impact on the CLIC modules



Combine references & methods of measurements in the same place to gain time and accuracy

Prove their feasibility on a final bench

Extrapolate the tools & methods developed to other projects



Development of a high accuracy portable solution (micro-triangulation + FSI), replacing CMM measurements:

- Check in-situ fiducialisation + initial alignment of components (with stretched wire or using external alignment targets
- Do in-situ fiducialisation + initial alignment in the tunnel, after transport

PACMAN and its possible impact on the CLIC modules

- Nano-positioning needed for CLIC components like MBQ, any progress in devices, controls or cost will be directly beneficial

- Development of a mobile alignment system based on laser trackers or similar technologies would be very convenient and would add flexibility to the production scenario.
  Possibility to align or realign in the tunnel might be even essential !

- Better knowledge of components functional centre of course great but does not solve the whole problem
  Referencing the MB-BPM better with respect to the wire would have the biggest impact on emittance budget. Additional margins welcome.
  Which level of alignment would be a game changer ?

- Reduction of cost for alignment and fiducialisation of course very welcome

Further discussion

- Can we integrate fiducials / position sensors into the components ?
- Wake-field monitor with respect to structure centre using the wire
  Can we gain on fabrication tolerances ?
- Can we improve the reference line ? Currently one of the biggest errors
- Can PACMAN improve the cost of the CLIC modules and assembly ?

Conclusions

- CLIC two beam module R&D well advanced with very promising results and lots of lessons learned
- Need to develop credible fabrication, alignment and installations scenarios (risk sharing between industry and CLIC)
  Alignment is a critical step in this work flow
- PACMAN clearly can have a big impact on the alignment scenario and its success. This would improve the performance of CLIC

END

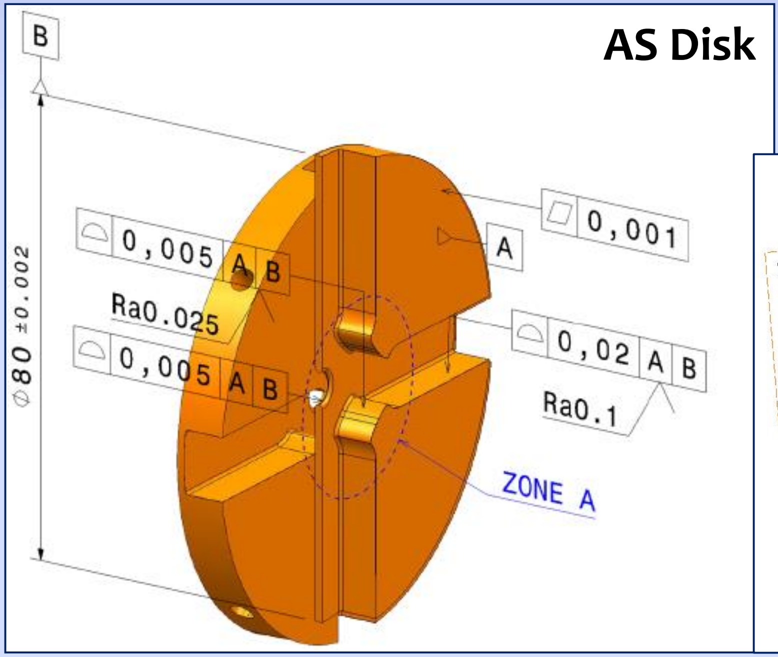
Fabrication and Alignment Tolerances

- Pre-alignment tolerances MB: 14 μm rms for rf structures, 17 μm rms for quads, BPMs 10 μm ,10 μm rms in BDS over 200 m with respect to the reference wire
- Pre-alignment tolerances DB: Quads 20 μm, PETS 100 μm/ 1 mrad, BPMs 20 μm ?
- Vibration tolerances MB: Quads 10 nm horizontal, 1.6 nm vertical; ACC 8 μm, 6 μrad horizontal, 1.4 μm, 1.1 μrad vertical
- Structure straightness 5 μm, wake field monitor 3.5 μm ?
- Delta T for one structure 5 deg, 10 deg for one superstructure ? Each SAS is individually regulated, one valve for PETS, MB Quad and DB quads per module
- Girder deformation loaded 10 μm
- Pre-alignment at 20 deg, calculate displacement with temperature
- Installation sequence: Install support with wire system, align, install modules (girders with equipment)
  Install components on girder with cradle, determine position, align (one girder/ full module on which reference ?), transfer to tunnel, link to wire already installed and aligned ?

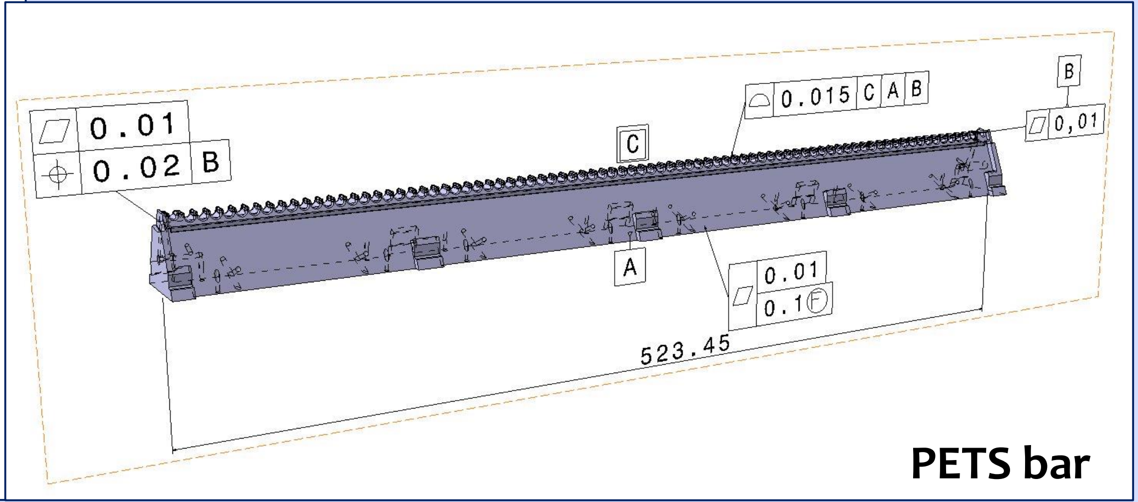
Shape tolerances for AS and PETS

Dictated by beam physics and RF
➔ ultra high precision machining

Turning – milling
Several annealing steps
(no burrs, no scratches)

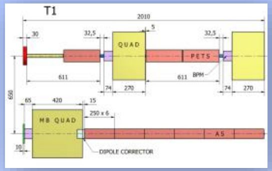


AS Disk

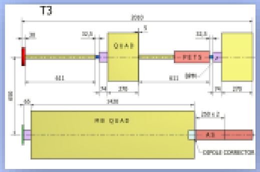


PETS bar

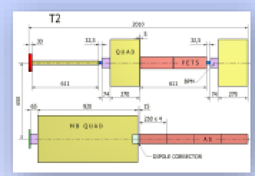
TBM main types



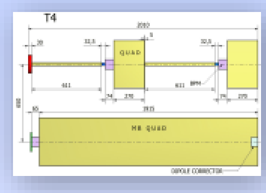
Module Type 1
3 %



Module Type 3
9 %



Module Type 2
12 %



Module Type 4
3 %

1 to 4 pairs of AS
replaced by
MB Quadrupoles

CLIC Module Type 0
73 %

Standard Module
(L = 2010 mm)
DB (100 A)
4 PETS, 2 Quads with BPM
Each PETS feeds 2 AS

MB (1 A)
8 acc. structures
MB filling factor: 91%