High Luminosity LHC

Crab Cavity Alignment and Positioning System

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EN/MEF-SU Micro-Technology & Instrumentation Team

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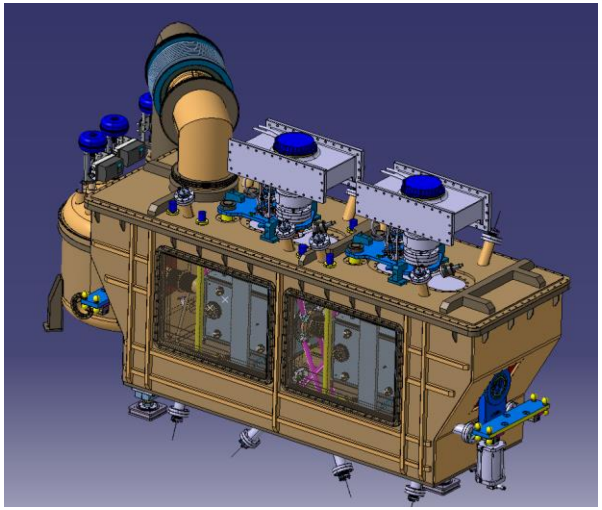
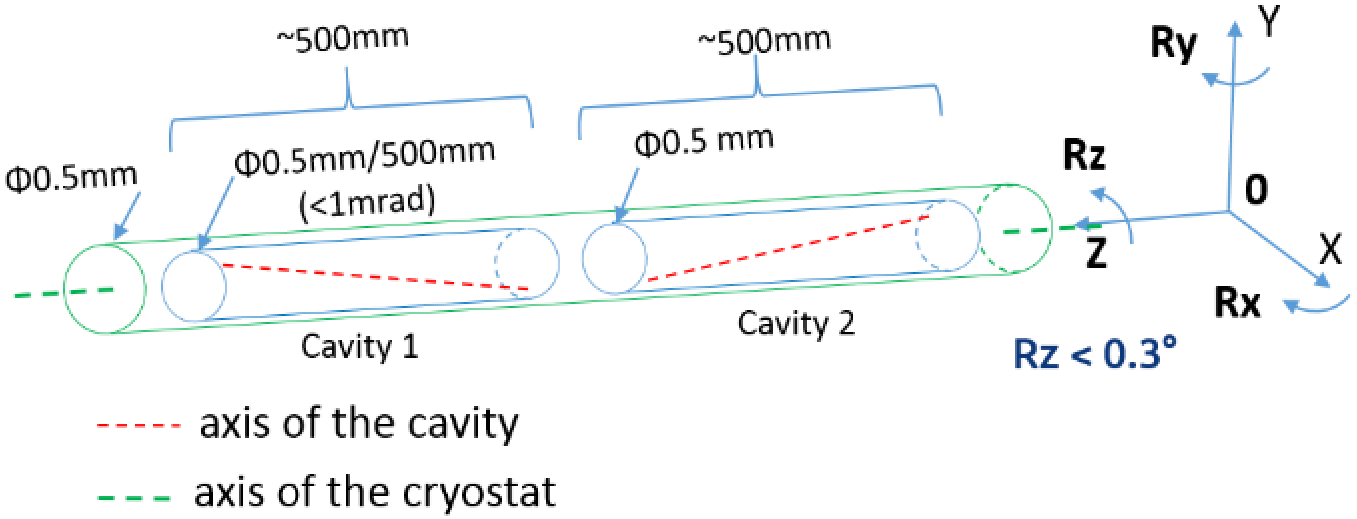
Outline

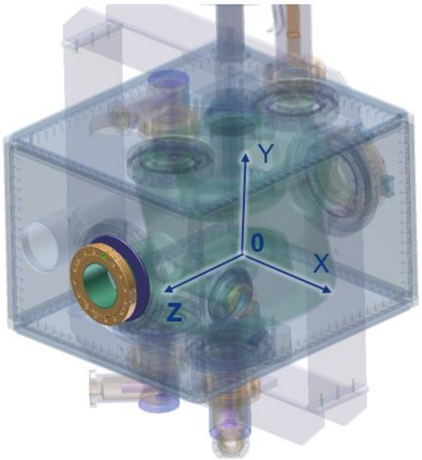
- Alignment tolerances
- Position monitoring and adjustment issues
- Adjustment of dressed crab cavity position
- Position monitoring systems
- Summary

Alignment tolerances

- X-Y: **0.5mm (3σ) for mechanical alignment**
  + 0.5mm (3σ) for operation errors
- Rz < 0.3°
- Rx, Ry (mean axis of CC inside ϕ0.5mm)





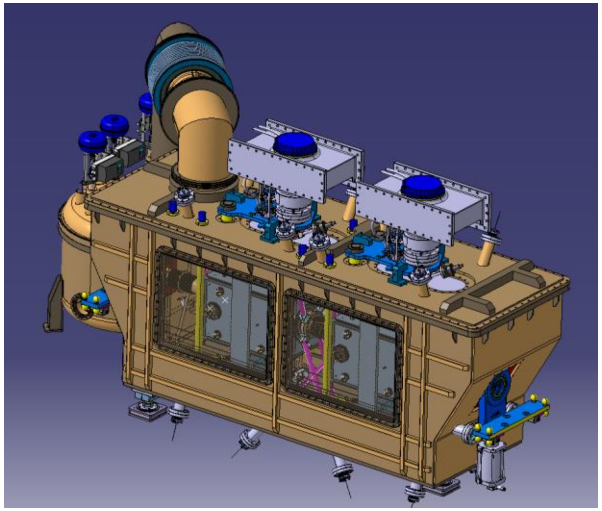


Position monitoring and adjustment issues

To monitor position of mean axis of the cavities within Φ0.5mm →
Accuracy of the monitoring system should be at the level of ~50-100μm

Main issues

- Need to monitor the cryogenic components (<3K) from the level of room temperature cryostat
- Contraction of the cavity (helium tank) – impossible to fiducialise the components at operating temperature. Needed use of thermal contraction models (verification and correction of the models data after in-situ measurements)
- Stability of the cryostat shape under vacuum forces
- Safety reasons - adjustment of the cavity (helium tank) position inside the cryostat only when helium pumped out
- Adjustment system should provide micrometric resolution



Position monitoring and adjustment issues

SPS Cryomodule is the prototype unit to confirm it future HL-LHC use →
Monitoring system should withstand HL-LHC environmental conditions

Radiation

- All monitoring system components should withstand:
  - TID of 10MGy (beam pipe),
  - TID of 1 MGy (cryostat surface)

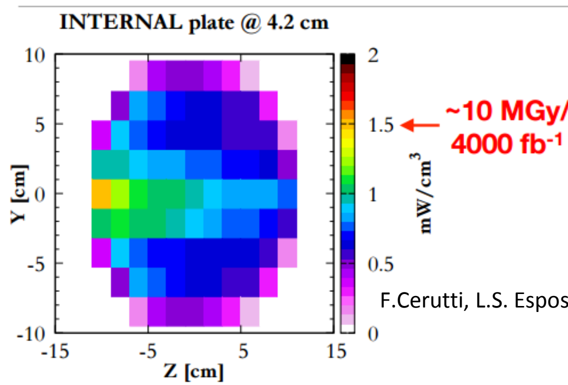
without performance lost

Temperature

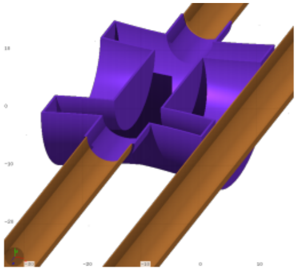
- All position monitoring system components installed on cavity (helium tank) should work well after cool-down and withstand cooling-warming cycles

Vacuum compatibility

Crab cavities @ 7.5 × 10^{34} cm^{-2} s^{-1}



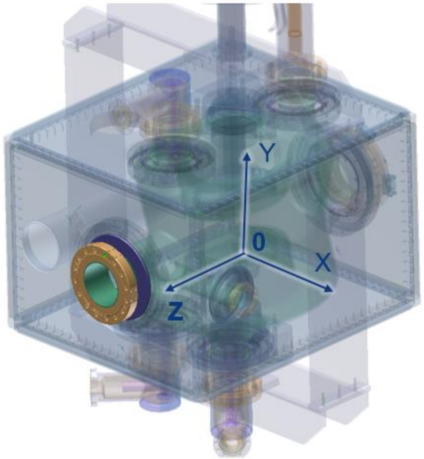
F.Cerutti, L.S. Esposito: *Energy deposition for HL-LHC v1.1: TAN/D2/Q4*



Adjustment of dressed crab cavity position

To ensure proper position tuning within requested tolerances

- Suspension system of the cavity should allow easy adjustment in 5DOF:
  - X, Y shifts
  - Rotation around axes X, Y, Z
- Resolution of adjustment should be at the µm level
- Adjustment system should allow for easy intuitive and ergonomic operation



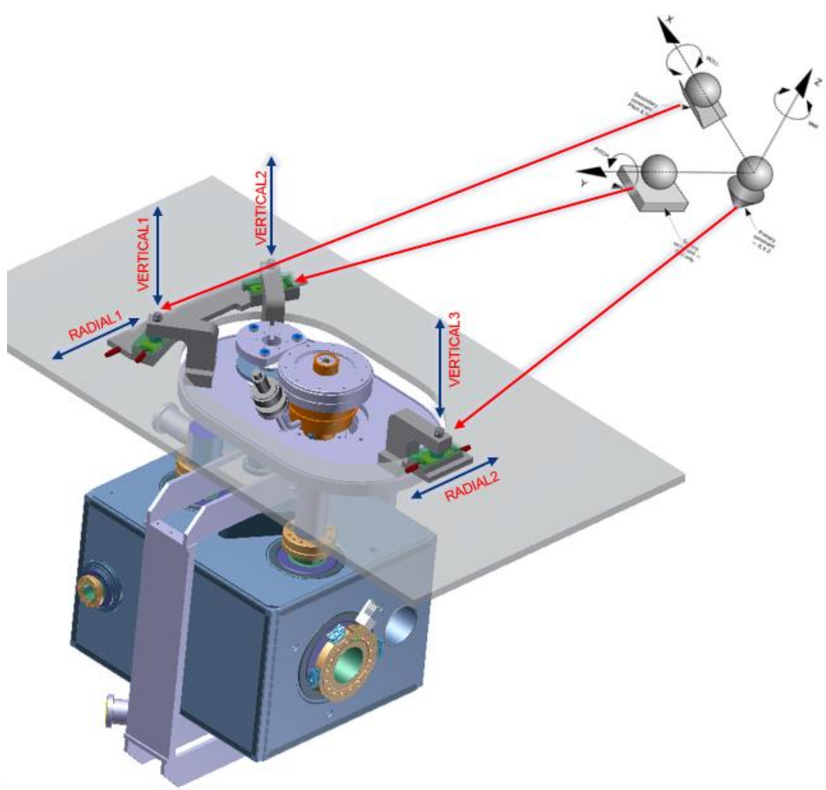
Constraints

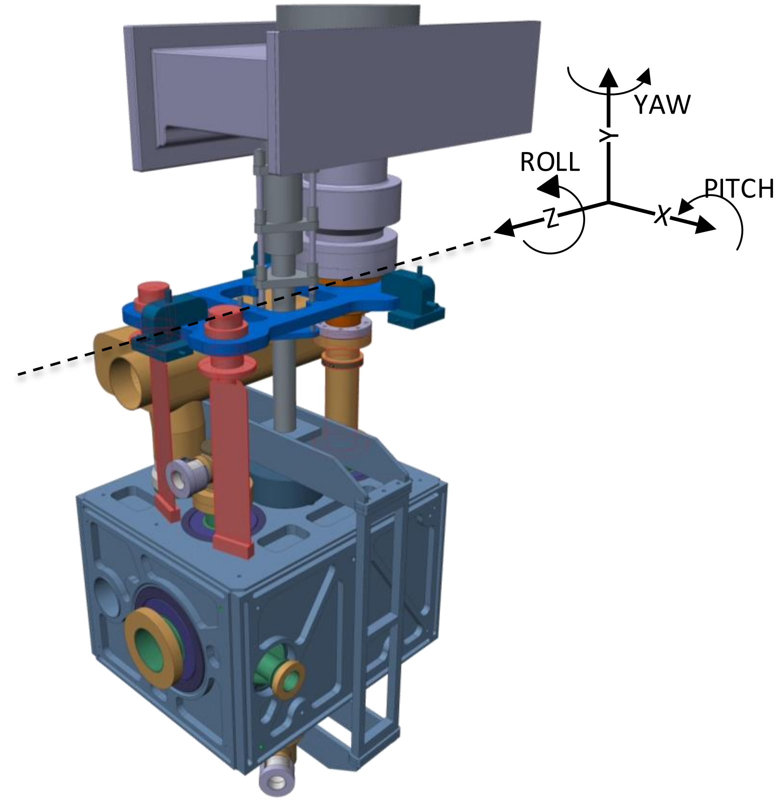
- Space inside/outside cryostat limits side walls displacement of regulation mechanisms
- Tuner mechanism position should be constant w.r.t. FPC/helium tank
- Thermal loses through suspension links should be as low as possible
- Due to high load force on the FPC, created by RF waveguide – the position setting should be insensitive to forces variations on the waveguide

Adjustment of dressed crab cavity position

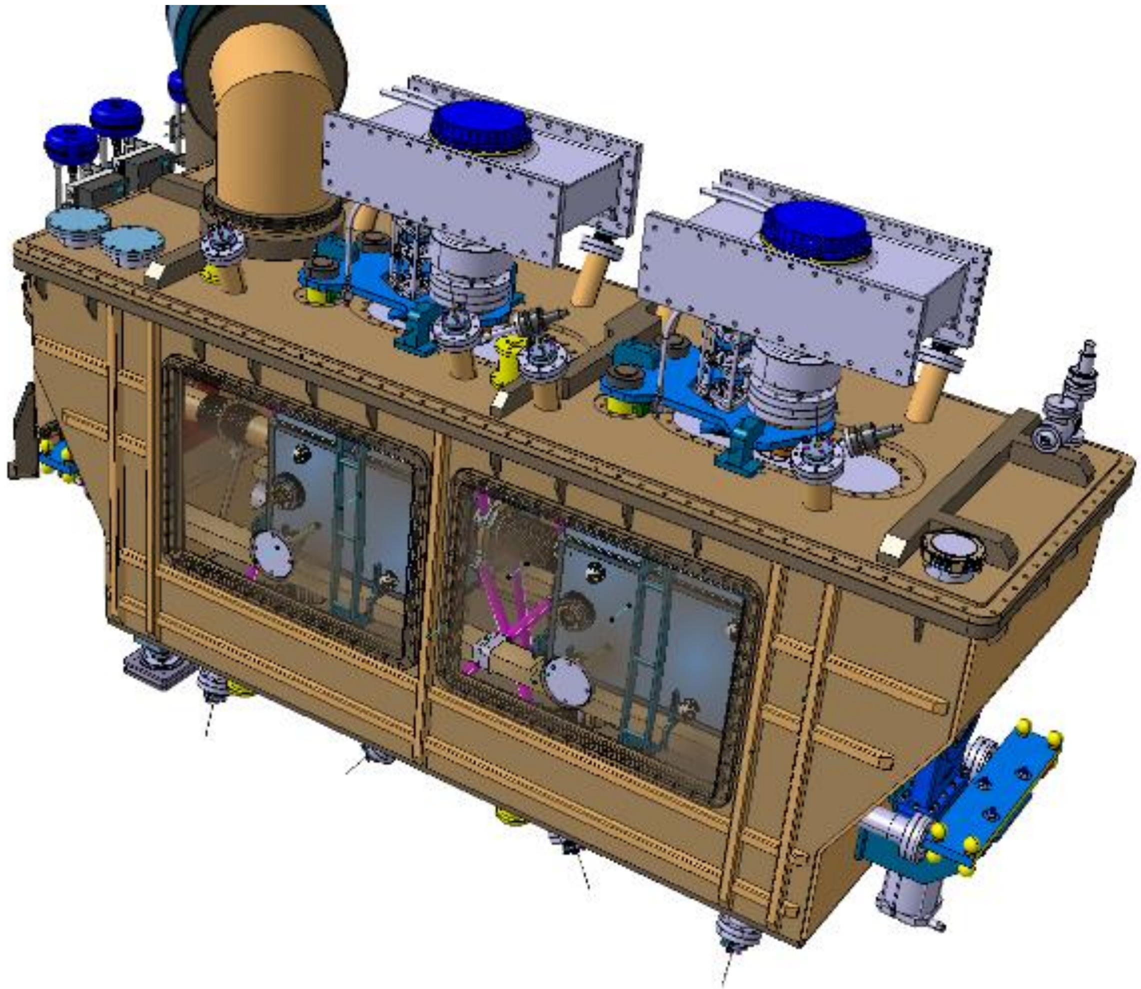
Solution selected

- Top supporting plate 3-point kinematic mount, with 2 radial and 3 vertical adjusters
- Dressed cavity rigidly suspended on the supporting plate by FPC and blades. Blade suspension compensates thermal contraction effect (blades as flexural joints)





Adjustment of dressed crab cavity position



Position monitoring systems

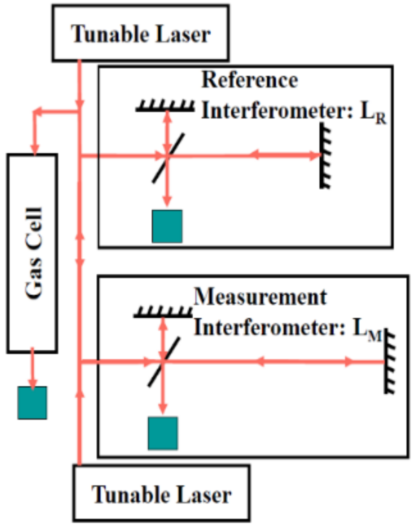
SPS Cryo-module monitoring systems

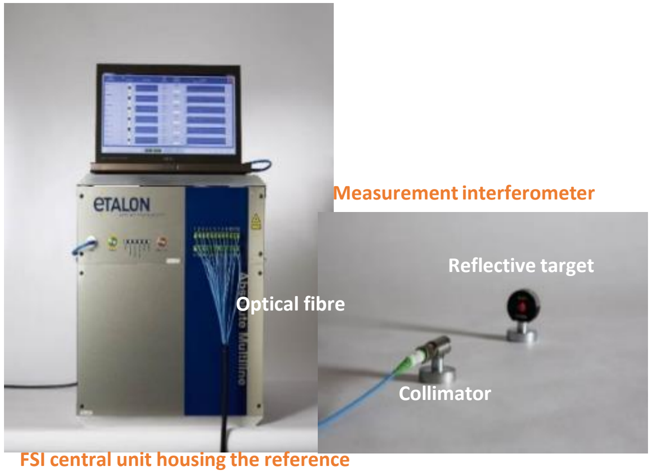
- Two systems selected – one as primary - for future HL-LHC use, second one for cross-check purposes:
  - Frequency Scanning Interferometry (FSI) based – future LHC solution
  - „Brandeis" Camera Angle Monitoring (BCAM) – only for SPS test
- Both systems provide non contact measurements

- FSI system selected as promising for future HL-LHC use

Position monitoring systems - FSI

FSI solution – absolute interferometric distance measurement



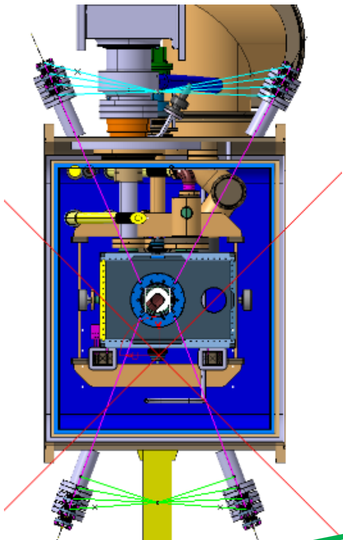


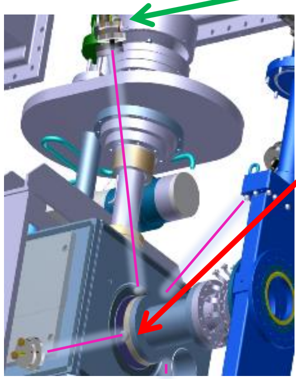
- Absolute distance measurement
- 8 channels expandable to 100
- Uncertainty (95%) = 0.5 µm/m
- Traceable
- Measurement distance: 0.2 – 20 m
- Fibre length – up to several hundreds meters

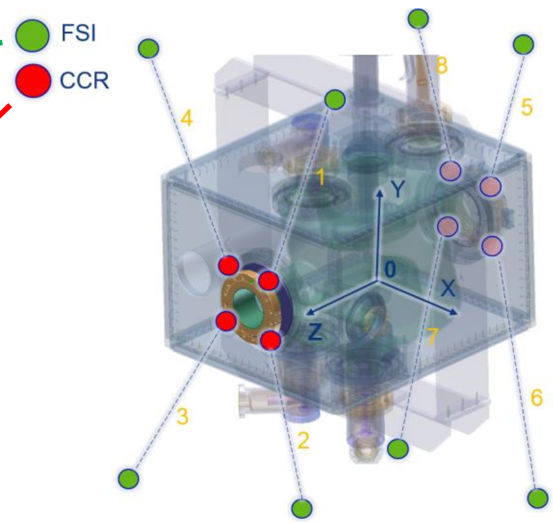
Position monitoring systems - FSI

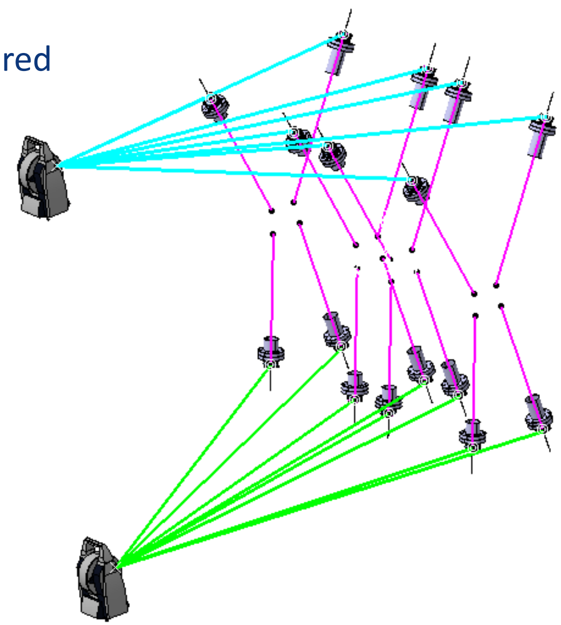
FSI solution – system configuration

- 6 targets per cavity is required to calculate cavity position and orientation (least mean square method).
  Cavity fiducialisation data and measured distances between all FSI heads and centres of CCR targets are used
- Current design assumes 4 targets per flange
  (8 Corner Cube Retroreflectors [CCR] per cavity) to provide measurements redundancy
- Dressed cavity have to be fiducialized (known cavity geometry w.r.t. refernece targets)
- Positions of the FSI heads have to be measured



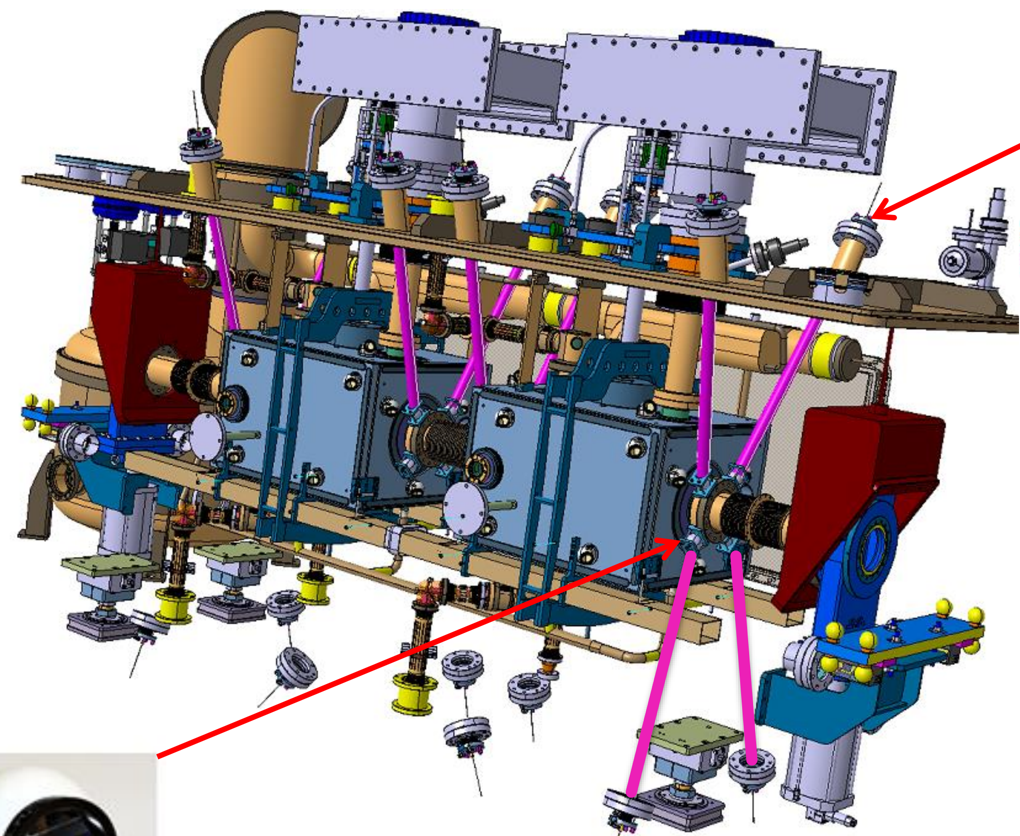


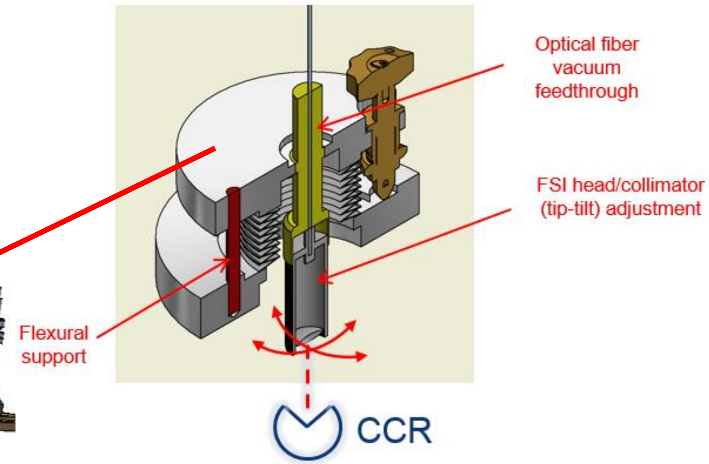


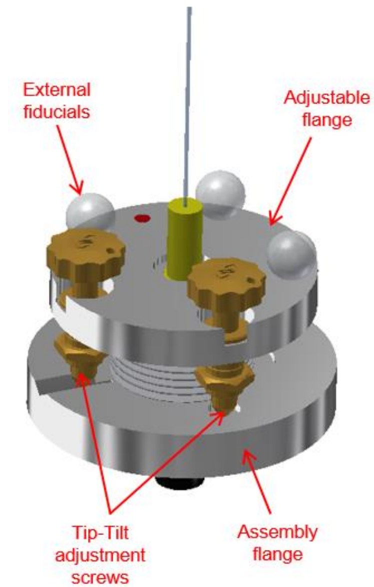


Position monitoring systems - FSI

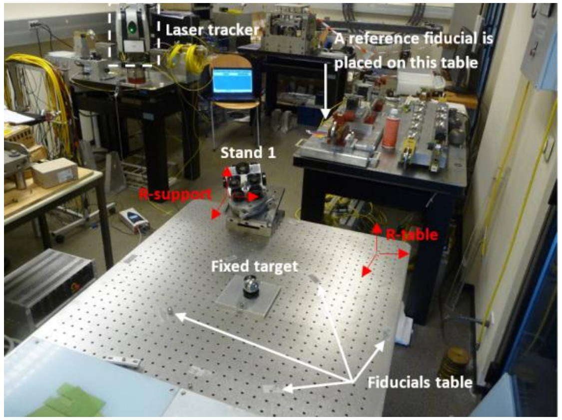
FSI solution – cryo-module implementation (DQW)







Position monitoring systems - FSI



Project status

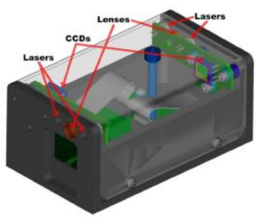
- Algorithms for cavity position/orientation calculations ready. Currently used for simulations of impact of different measurement conditions and system configuration on calculation results
- FSI head calibration approach verified. Accuracy of distance measurement ~10µm
- Design of FSI head prototype under finalization
- Irradiation campaign for optical components pending at Fraunhofer institute in Germany (CCR: TID 10MGy, collimators: TID 1MGy). End of tests – December 2016

Further work

- Test of targets (CCR) in cryogenic conditions
- Irradiation of FSI head (feedtrough + head fibre connection), test of prototype FSI head
- Construction of single crab-cavity FSI system test bench. Validation of system performance in laboratory conditions
- SM18, SPS DAQ and data processing software development
- Measurements in SM18 – validation of the final system

Position monitoring systems - BCAM

BCAM solution – operation principle

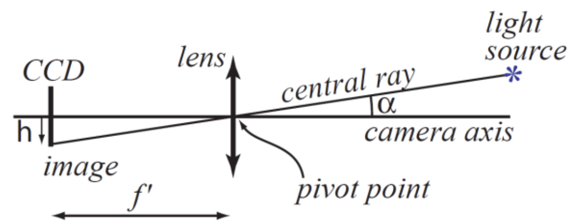


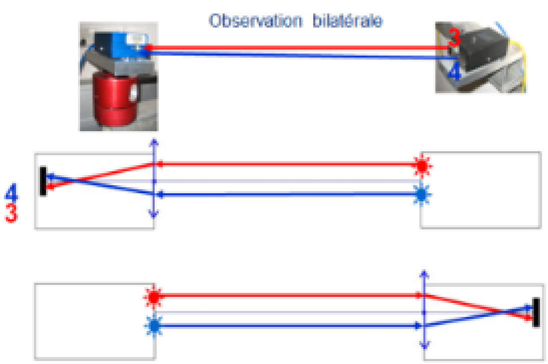
The system consists of:

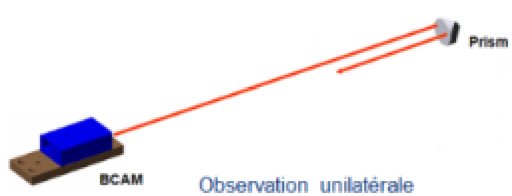
- CCD 7.4 µm pixels, 659x494 pixels
- 1 lens (field of view 100 mrad x 70 mrad)
- Laser diodes

Resolution : 5 µrad

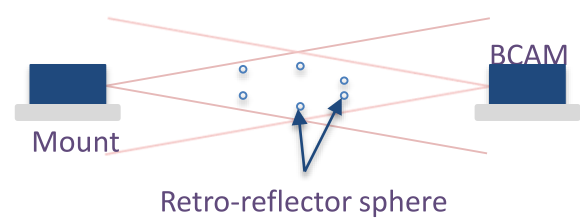
Accuracy of 50 µrad (absolute measurements)





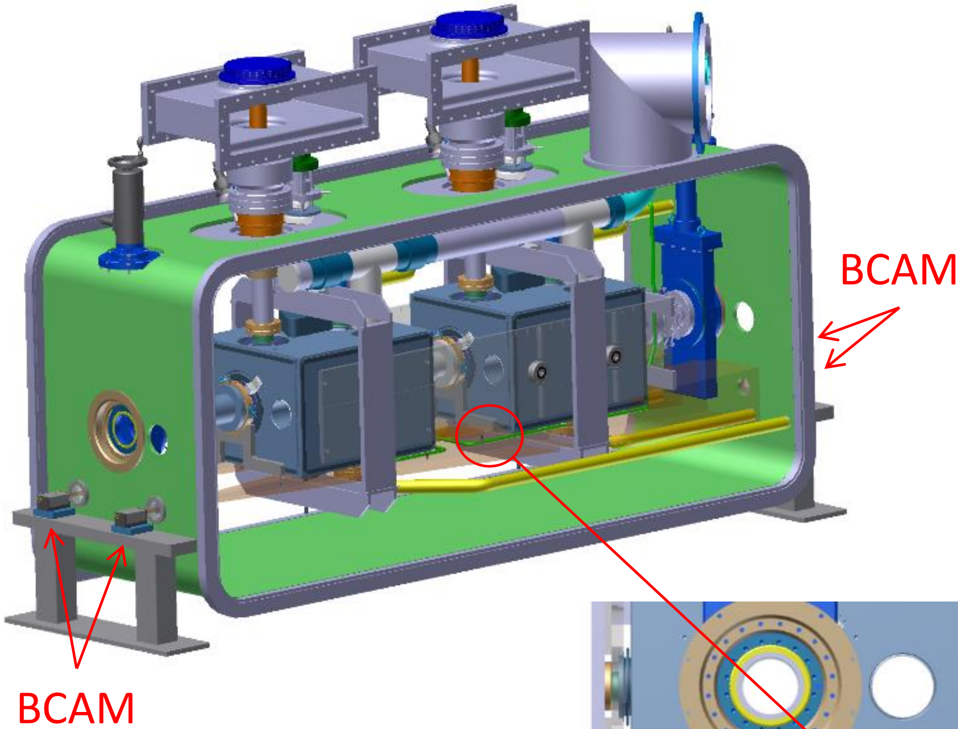


Creation of a closed geometrical network

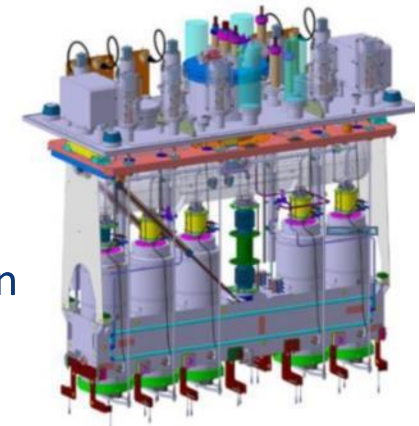


Position monitoring systems - BCAM

BCAM solution – system configuration



Based on HIE-Isolde installation



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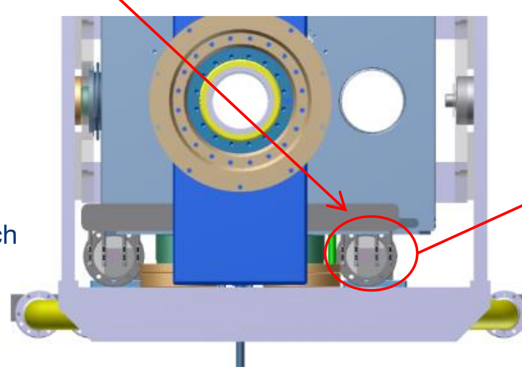
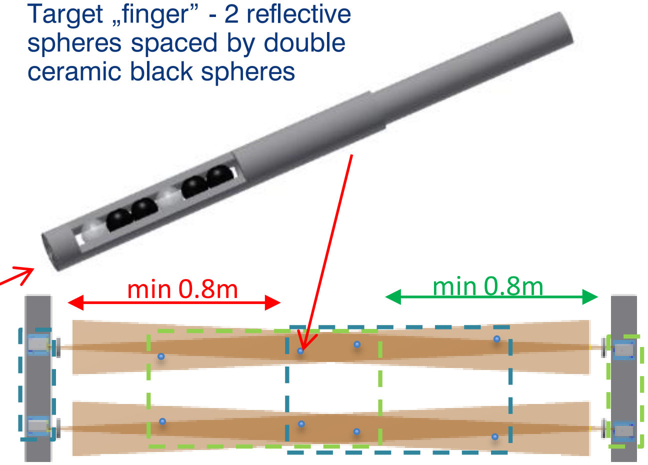


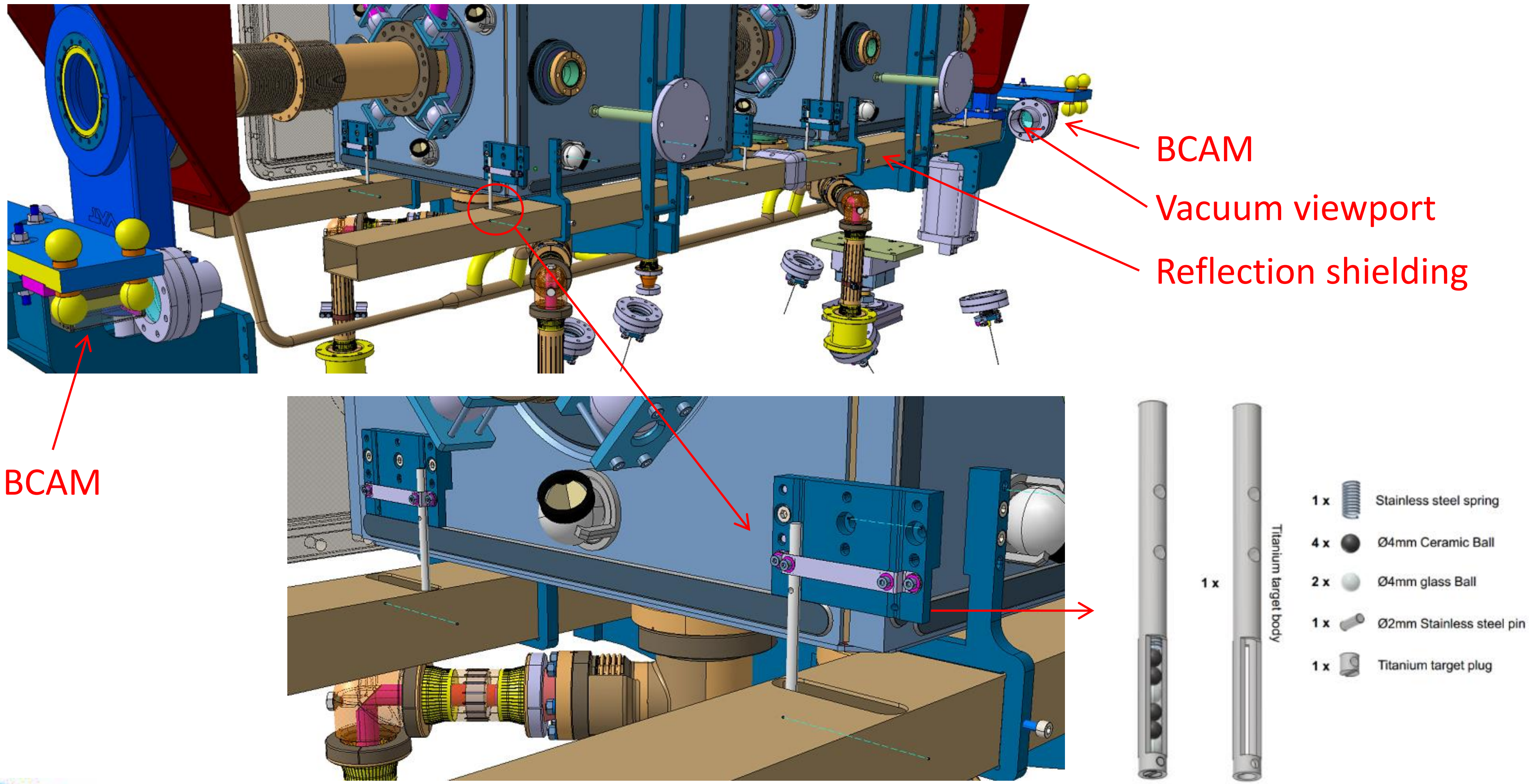
4 target „fingers" on each side of cavity

Target „finger" - 2 reflective spheres spaced by double ceramic black spheres



Position monitoring systems - BCAM

BCAM solution – cryo-module implementation (DQW)



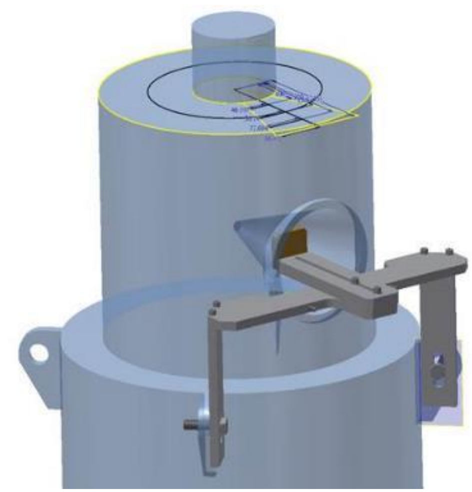
Position monitoring systems – BCAM

Project status

- Initial algorithms for cavity position/orientation calculations ready and preliminarily validated on the simplified test bench
- Irradiation campaign of the retroreflective balls finished (Atomki institute – Hungary). As the system will be used only for the SPS - tested for TID 300kGy. No impact on balls reflection performance observed
- Tests of reflection shielding have shown problems with reflectivity of anodized surfaces

Further work

- Fiducialisation of the helium tank mock-up on CMM and laboratory verification of system performance
- Tests and calibration of vacuum viewports
- Update of reflective shielding design to minimize internal reflections
- SM18, SPS - DAQ and data processing software development
- Measurements in SM18 – validation of the final system



Summary

- The most challenging aspect of crab-cavity monitoring system design is need of absolute measurement of cold object position from the room temperature cryostat level
- Possible imperfections (nonlinearities in thermal contraction model, non repeatable deformation of cryostat, e.t.c.) influencing the position calculation makes the required alignment tolerances tight
- Very high radiation levels results in difficult selection and validation of equipment (considering parameters stability of precise µm-components)
- Initial results of FSI system tests an simulations looks promising for future HL-LHC use
- Parallel BCAM system used in SPS test will allow for crosscheck of FSI installation performance

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