Crab Cavity Alignment and Monitoring System
Inner triplets cold mass monitoring System

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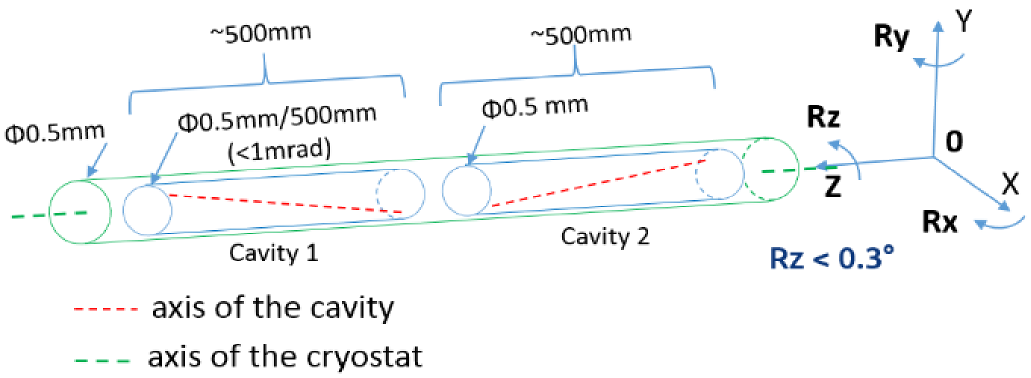
Projet HL-LHC: mini revue sur les activités SU CERN – 2017.06.29

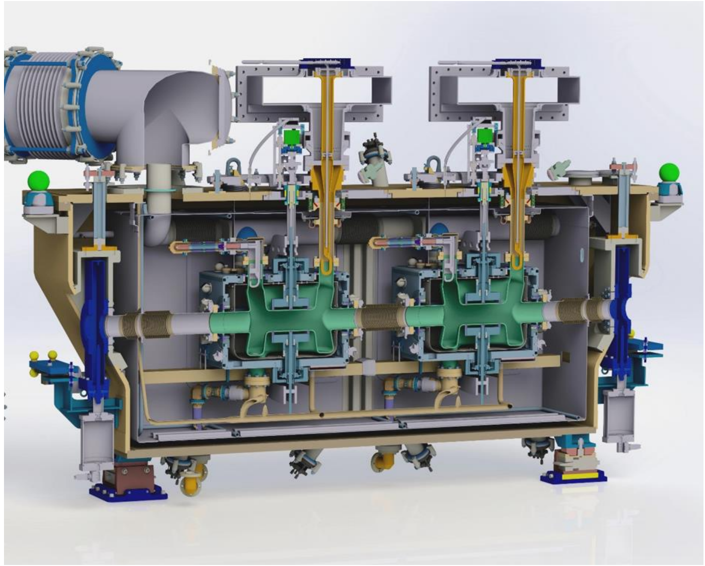
Crab cavities position monitoring system

- Introduction to crab cavities position monitoring
- Position monitoring and adjustment issues
- Position monitoring systems - status

Crab cavities alignment tolerances

- X-Y: **0.5mm (3σ) for mechanical alignment**
  + 0.5mm for operation errors
- Rz < 0.3°
- Rx, Ry (mean axis of CC inside Φ0.5mm)

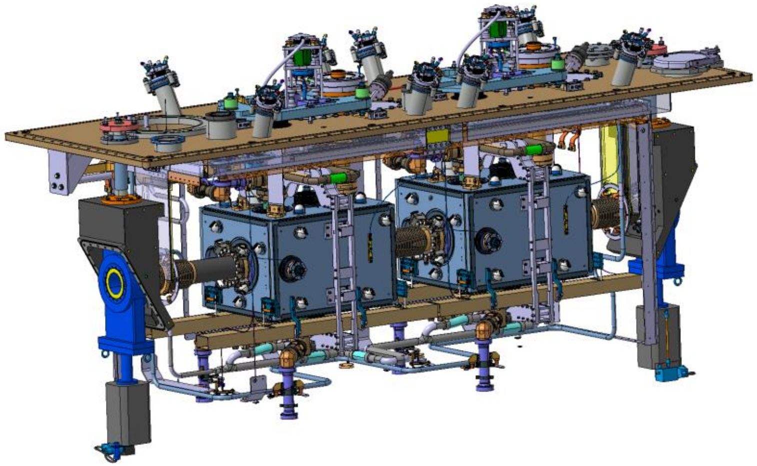




Adjustment and position monitoring issues

Mean axis of the cavities within Φ0.5mm

- Complex structure of cryomodule → unknown impact of RF, vacuum, cryogenics interfaces on cavity alignment
- Required information about cavities alignment under cooling down, operation conditions
- Monitoring system accuracy ~50-100µm needed



Main issues

- Monitoring of cold objects (<3K) from the level of room temperature cryostat
- Contraction of the cavities (helium tank) – impossible to fiducialise the components at operating temperature. Use of thermal contraction models needed (verification and correction of the models during in-situ measurements SM18, SPS)
- Stability of the cryostat shape during operation

- HL-LHC environmental conditions:
  - Radiation → 10MGy (beam pipe), 1MGy (cryostat surface)
  - All position monitoring system components installed on cavity (helium tank) should work well after cool-down and withstand cooling-warming cycles
  - Vacuum compatible

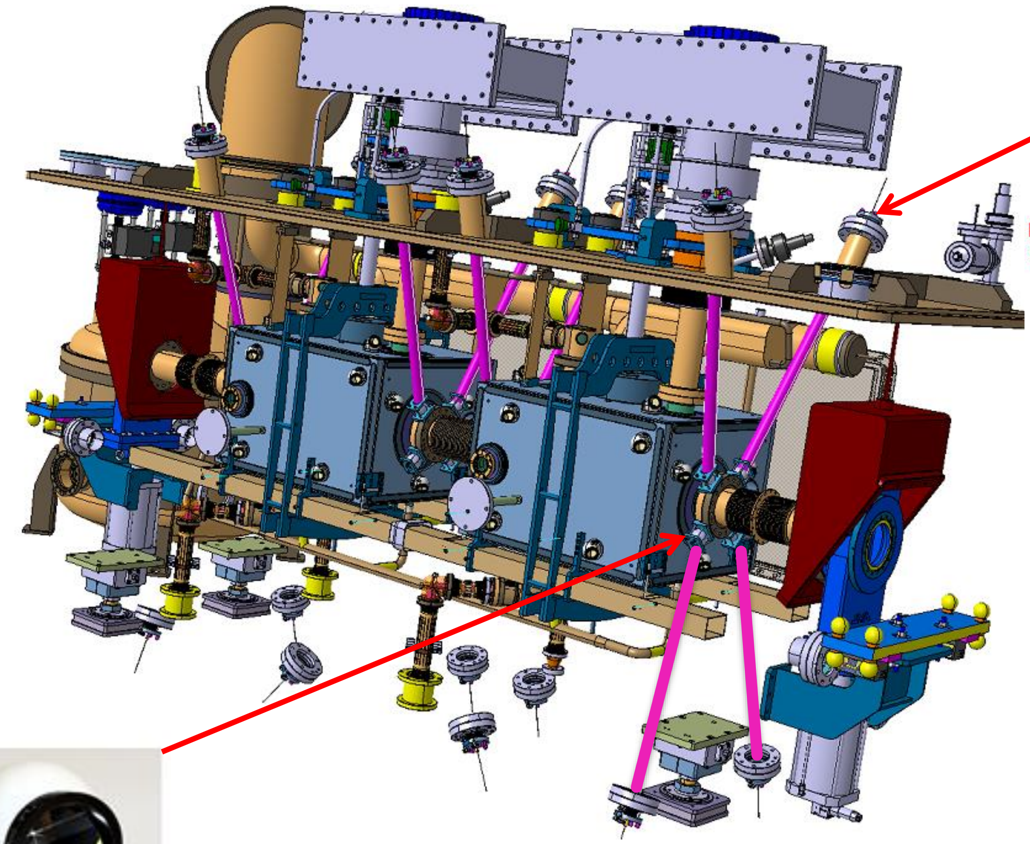
Position monitoring systems

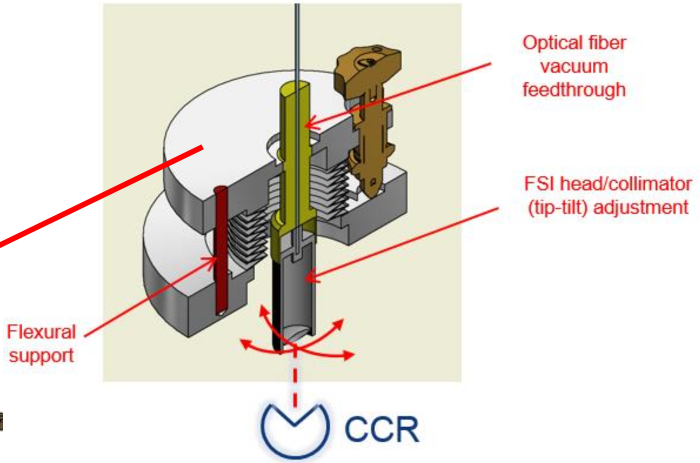
SPS Cryo-module monitoring systems

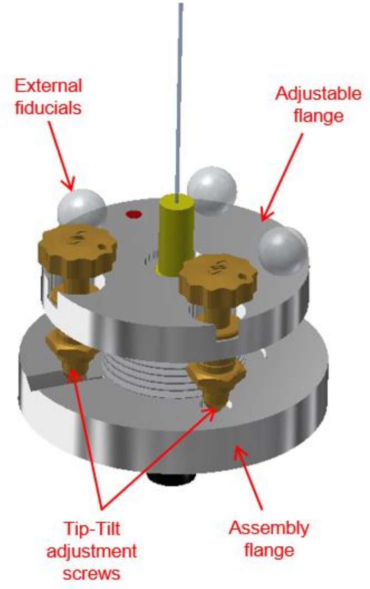
- Two systems selected – one as primary - for future HL-LHC use, second one for cross-check purposes:
  - Frequency Scanning Interferometry (FSI) based – future LHC solution
  - „Brandeis" Camera Angle Monitoring (BCAM) – only for SPS test
- Both systems provide non contact measurements

- FSI system selected as baseline solution for future HL-LHC use
  - Monitor of the SPS prototype through different phases (vacuum, cold, etc.) will allow for final decision on extrapolation of monitoring solution to HL-LHC crab-cavity cryomodules

Position monitoring systems - FSI

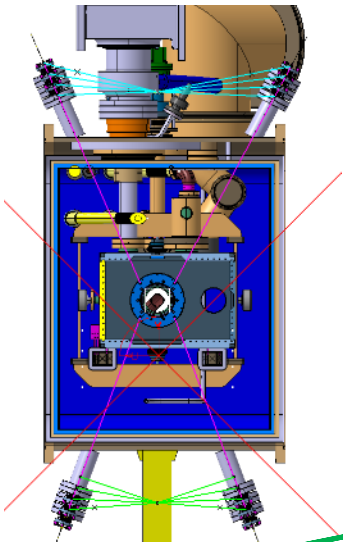


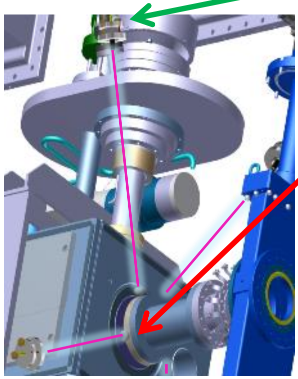




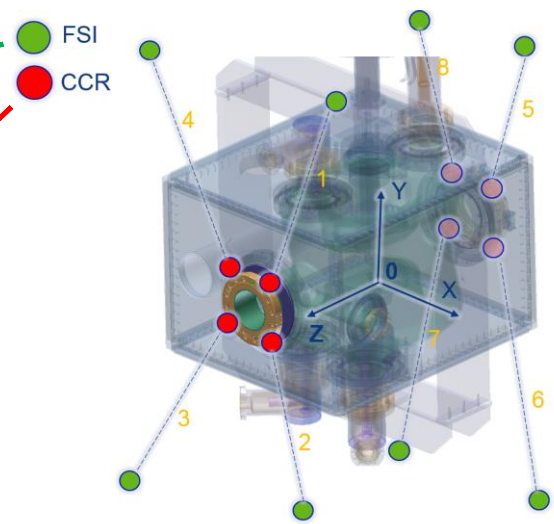
Position monitoring systems - FSI

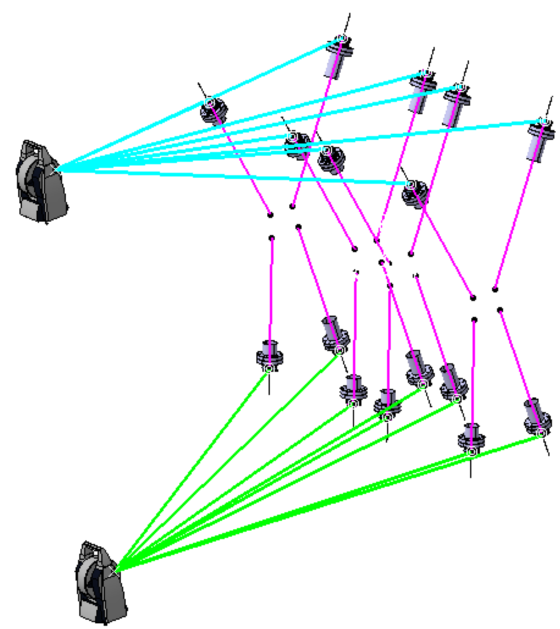
Frequency Scanning Interferometry (FSI)





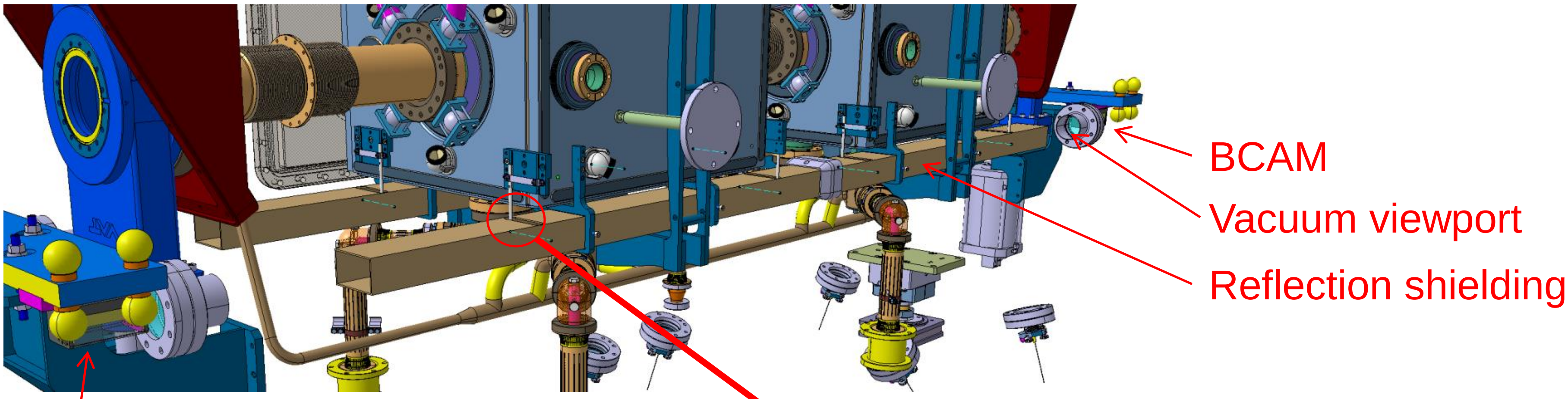
- 6 targets per cavity are required to calculate cavity position and orientation (least mean square method).
- Cavity fiducialisation data and measured distances between FSI heads and centres of CCR targets used
- Current design assumes 4 targets per flange (8 Corner Cube Retroreflectors [CCR] per cavity)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

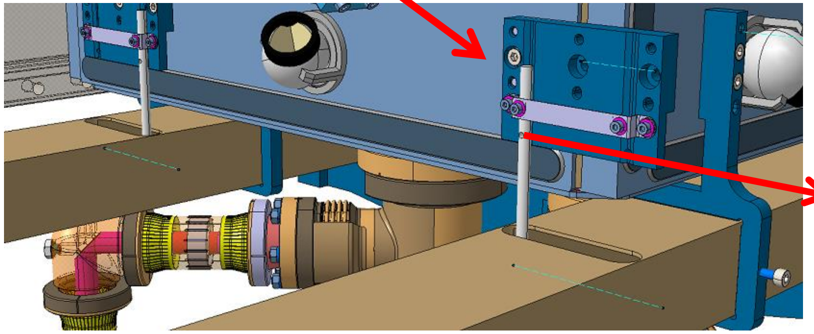


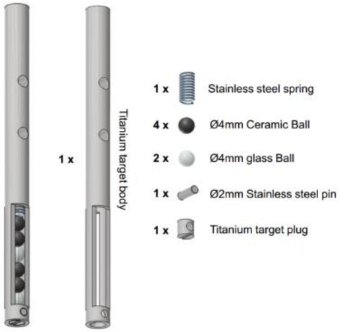


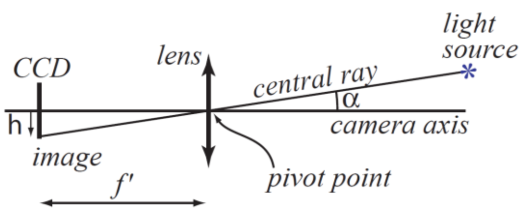
Position monitoring systems - BCAM

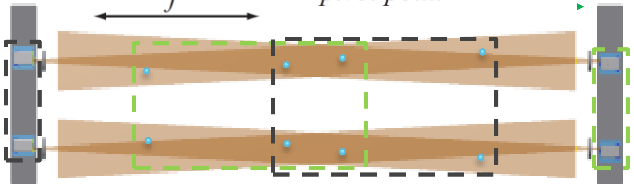
BCAM solution – cryo-module implementation (DQW)







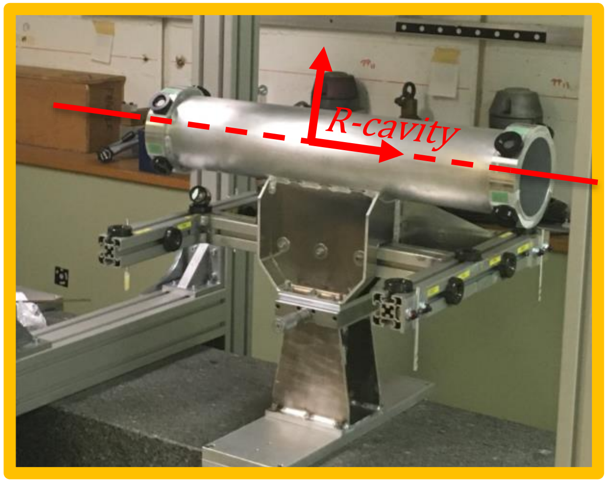




Position monitoring systems - solution validation

Test setup

R-general



Helium tank mock up (CMM measurement : micrometric uncertainty)

Strategy verified in geodesy base on the 1:1 alignment monitoring system mock-up

- Tests at room temperature (~20°C)
- Atmospheric pressure, stable bench frame shape
- **Accuracy of both systems better than 50µm (1σ)**

Parameters FSI	Accuracy
Tx : radial (mm)	0.021
Ty : vertical (mm)	0.009
Tz : longitudinal (mm)	0.028
Rx : pitch (mrad)	0.030
Ry : yaw (mrad)	0.072
Rz : roll (mrad)	0.187

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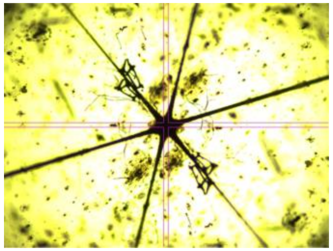
Position monitoring systems - components validation

10MGy

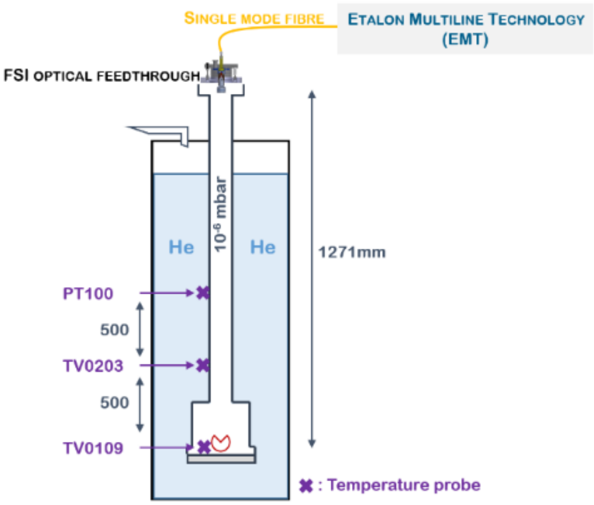


Radiation tests of BMRs and optical components finished in December 2016

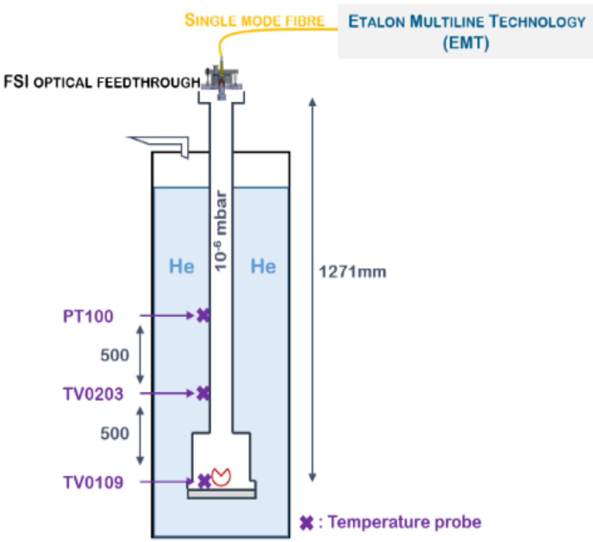
- Ceramic BMRs and collimators validated with TID of 10MGy
- BMR mirror centricity lost ~20µm

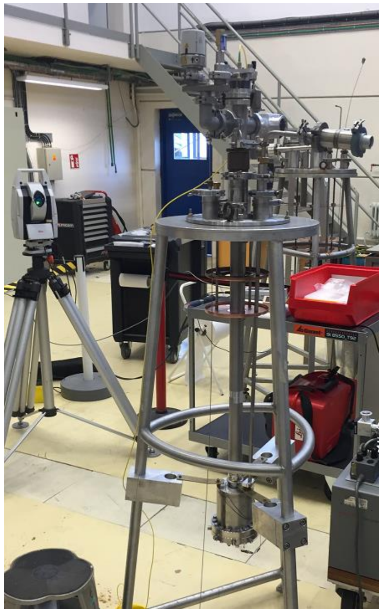
Irradiated and new reflectors tested under cryogenic conditions in CERN Cryo-Lab

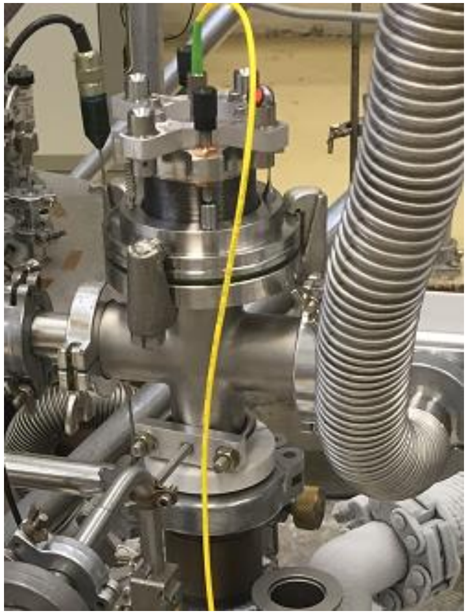
- Liquid nitrogen test
- Test of whole measurement setup under operation conditions – helium cooling setup
- No damage of targets or FSI reading performance lost observed



Position monitoring systems - components validation







Test of FSI measurement chain in operation conditions

- BMR + flange support cooled down to 4K, setup under vacuum
- FSI head prototype at room temperature
- 3 cooling-warming cycles per target. The FSI measurement crosschecked with AT401 measurements between the cycles
  - No visible deformation of FSI head under vacuum, measurements stable in time
  - AT401 measurements between cooling cycles confirmed FSI reading within 20µm accuracy
  - Intensity of BMR reflected signal lower when reflector cooled, but no impact on measurements

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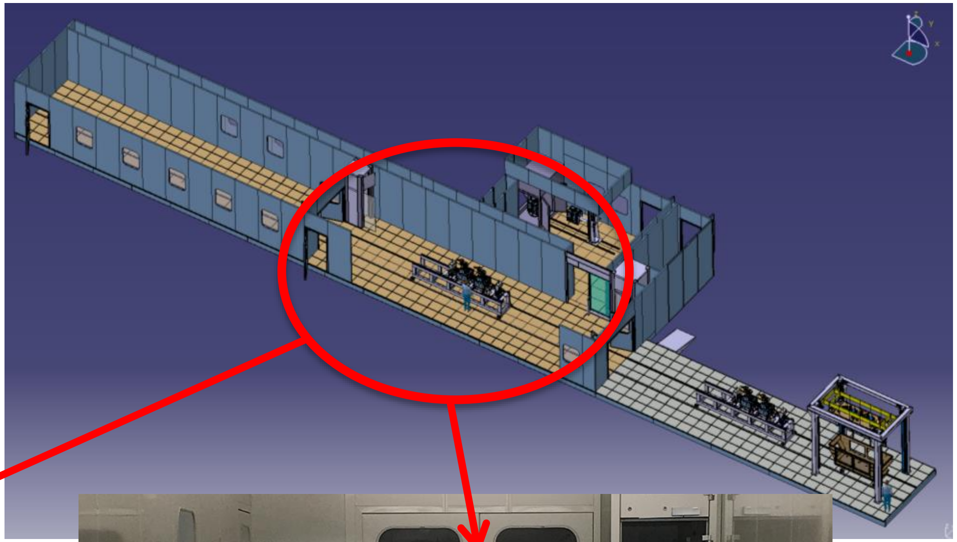
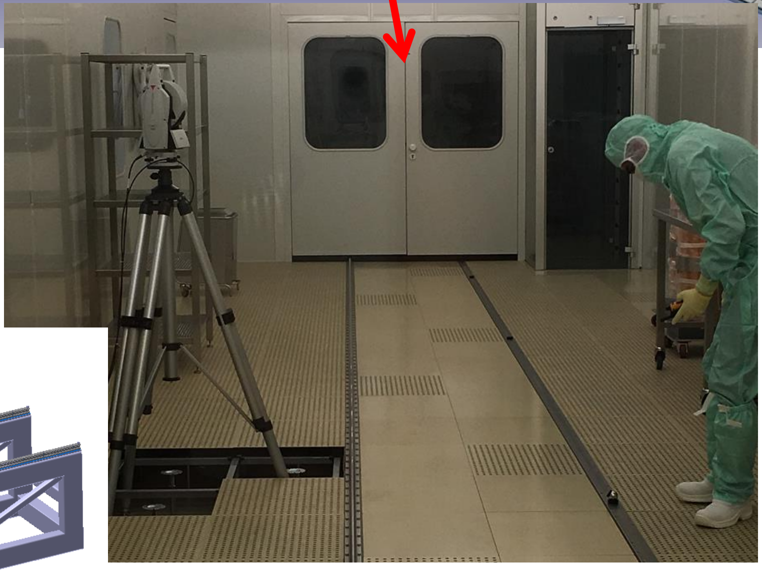
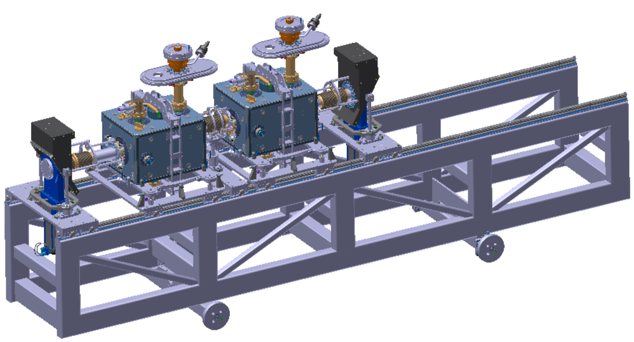
Position monitoring systems – cavities string assembly

- Validation of survey equipment use in ISO5 clean room
  - Laser tracker stability and placement
  - Verification of available space and optimal measurements position
  - CC alignment chariot tests next week

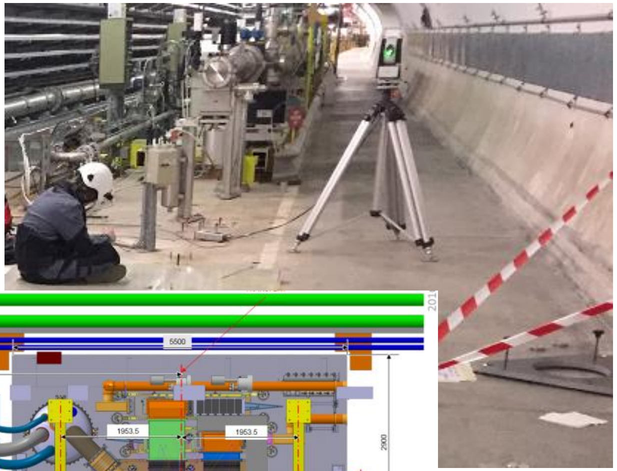


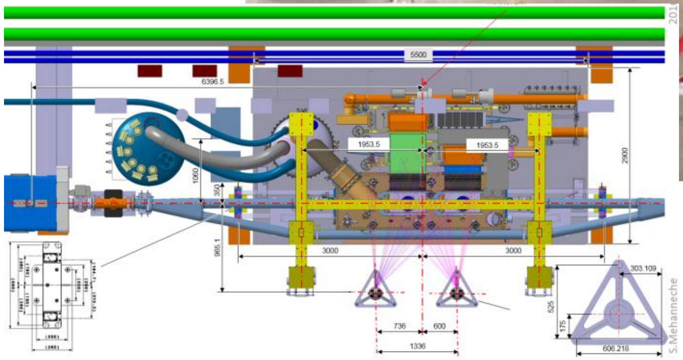


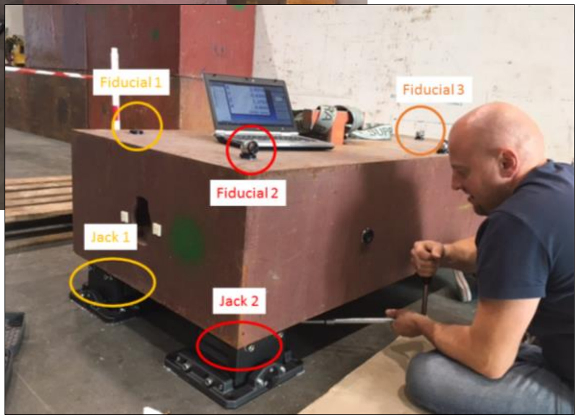


Position monitoring systems – SPS test

- SPS-LSS6 crab-cavity cryomodule installation zone equipped with network of fiducials and re-measured
- Coordinates of all important (requested) components marked
- Special supports for laser tracker pillars installed in transport zone
- Cables installation pending







Cryomodule supporting jacks tested with the 3. 7T nominal load

- OK for the manual pre-adjustment of cryo-module
- Adjustment resolution at the level ~10um
- The jack adjustment precision at the level ~50um (fixing of blocking screws)

Crab cavities position monitoring systems – status

- BCAM and FSI strategy for crab-cavity position monitoring validated in laboratory conditions. Waiting for SM18 test to confirm real system accuracy under cold
- FSI head prototypes and reflectors validated under nominal cavity operation conditions without performance lost
- Alignment steps / acceptance criteria (+ methods and tools) in the assembly process have been defined
- Components for BCAM and FSI system (especially series of 18 FSI heads) received and under validation
- Preparations of string assembly and cryomodule assembly ongoing
  - Tests of alignment activities with ‚string-chariot' and cavity mock-up out of clean room to elaborate best practices in ISO5

Further works

- Measurements in SM18 – validation of the final system
- Finalize SPS test preparation
  - Validation of SPS movable table at supplier premises
  - Implementation of movable table stability monitoring
  - SPS test stand components alignment
  - Monitoring system software integration

Inner triplet cold mass monitoring system

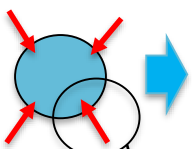
- Introduction to triplet cold mass position monitoring
- FSI integration layout
- Dipole test preparation
- Cold mass monitoring system - status

Introduction

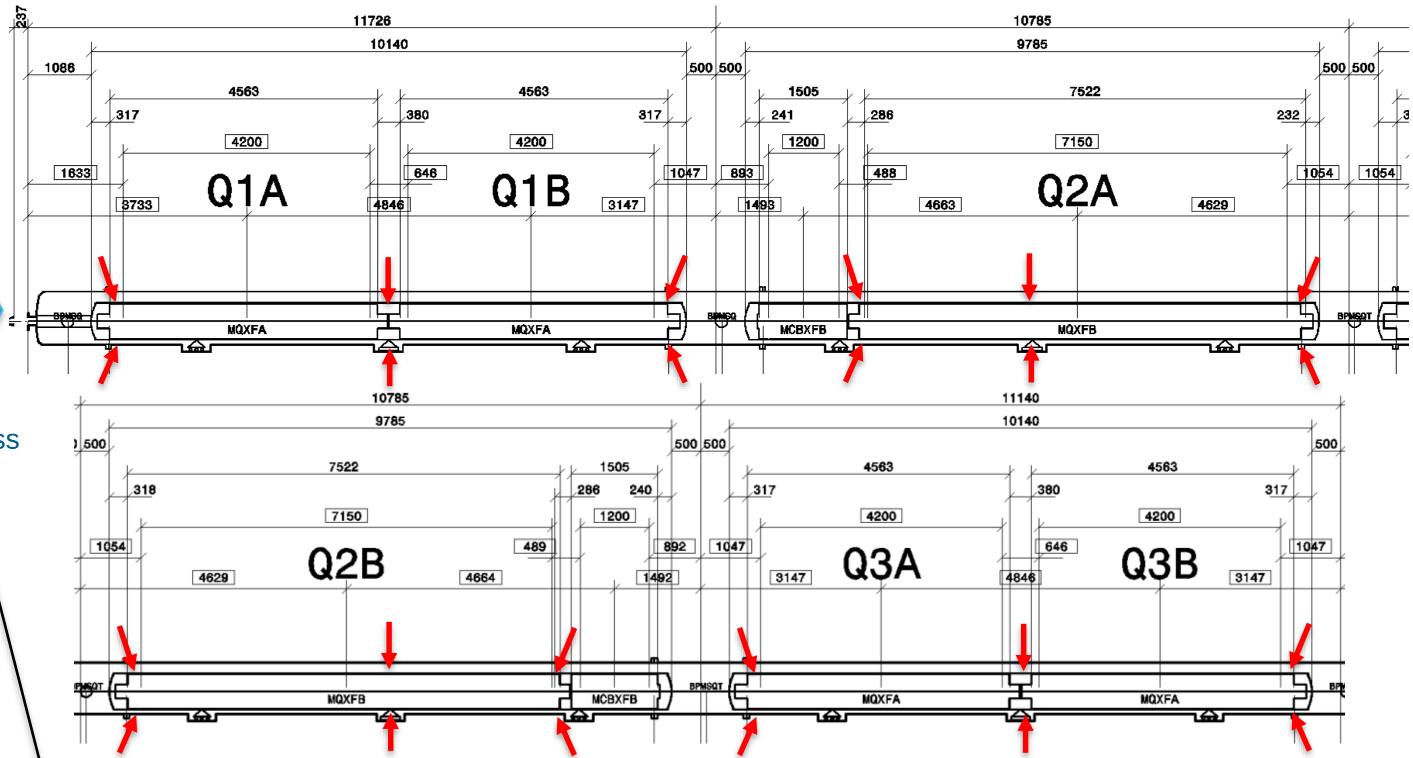
- Reason to monitor triplets cold masses position
  - Unknown position of cold mass w.r.t. warm, fiducialised cryostat
  - Impact of very small triplets moves for beam orbit
  - Variable conditions of cryogenic, vacuum system impact on cold mass position

Inner triplet – proposed FSI integration layout

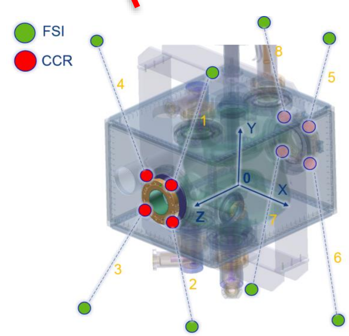
IR5 right example:
LHCLSXH_0010



3 x 4 FSI heads
for each cold mass



48 FSI heads per triplet needed

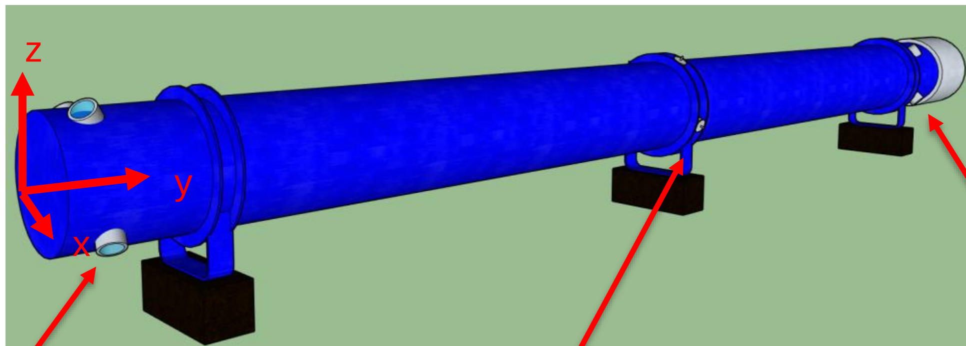


- Integration of optical heads interfaces on the cryostat: CF/DN63 flanges for FSI heads installation
- Holes for laser pass through the thermal shield
- Include the case of contraction of cold masses

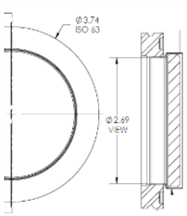
Dipole test

Dipole test objective:

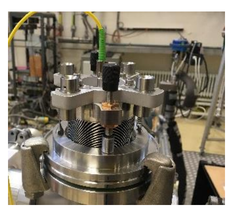
- Check real performance of cold mass monitoring system with triplet similar object (dipole 4001)
- Verify stability of 3 foot support of cold mass (planned for future triplet design)
- Verify real impact of cryogenic and vacuum on cold mass position



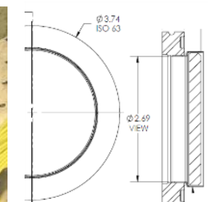
4 FSI mount + collimator
+ 4 Viewport ISOK DN63
+ 4 PLX NMBR 1.5" targets

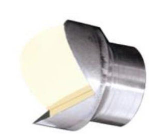


4 Feedthrough
+ 4 CCR targets

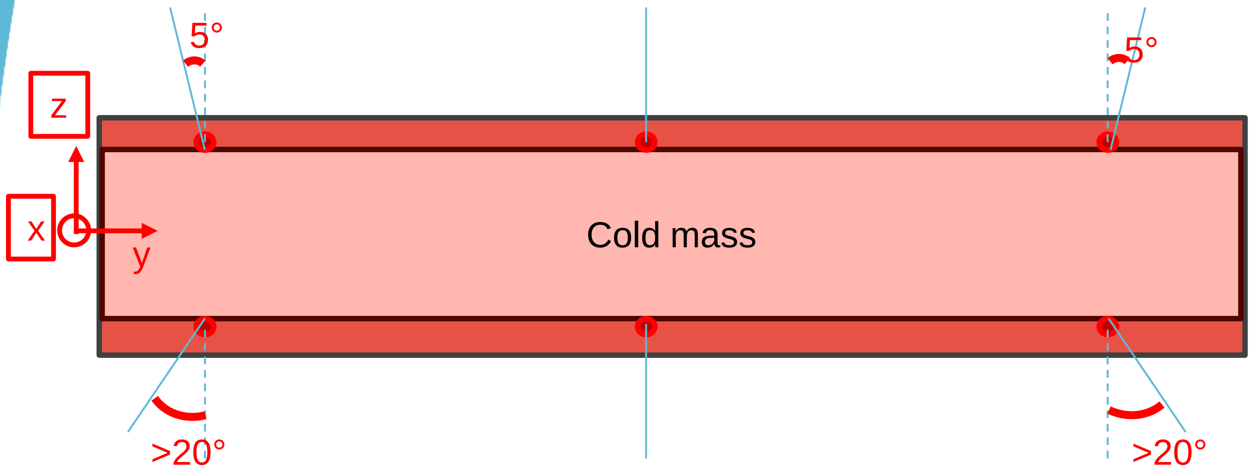


4 FSI mount + collimator
+ 4 Viewport ISOK DN63
+ 4 Low-cost Alu reflector





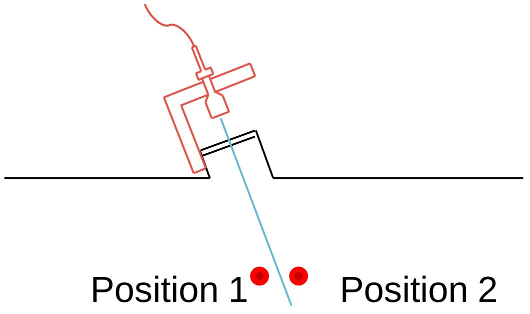
Dipole test - FSI instrumentation layout



Inclination of FSI mounts at the cryomodule extremity will provide information about longitudinal variation of cold mass position

Cold mass thermal contraction at FSI extremity locations :

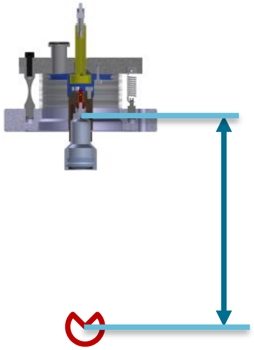
- FSI viewport flange tube positioned in the middle between room temp (Position 1) and cold (Position 2) of reflecting target
- tilt-tip adjustment system will provide collimator position variation in case of measurement before cooling down and after cooling down



Mechanical integration of FSI instrumentation

FSI head (feedtrough):

- ISOK DN63 flange needed
- Minimum distance between collimator ferrule tip and target centre: 200mm



FSI collimator tip-tilt adjusters:

- Fixation to the flange-tube (or vacuum vessel) by special clamp

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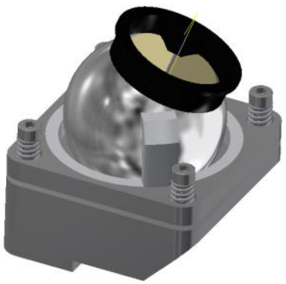
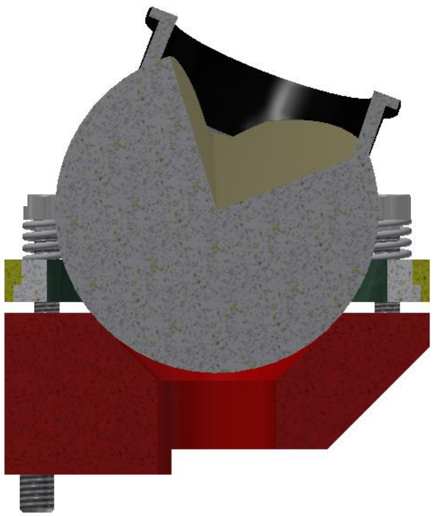
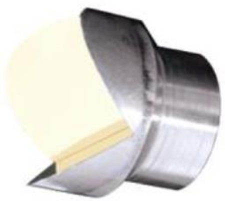
Mechanical integration of FSI instrumentation

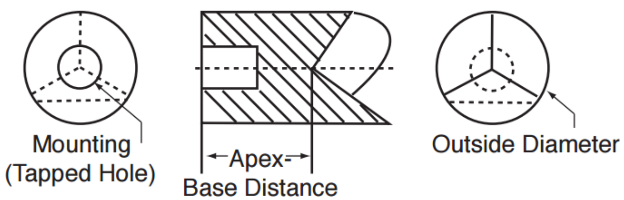
Reflector assembly on the cold mass;

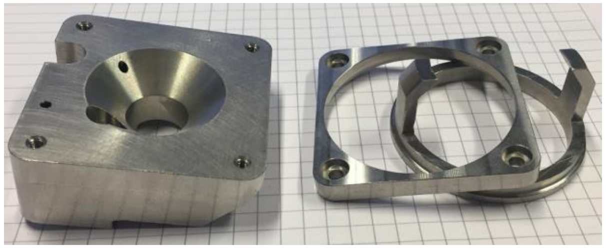
- Spherical reflector needs a conical prism
- To avoid components contraction effects (damage of prism, sustain repeatability) – prism should be pre-stressed with springs
- Conical cup might be re-designed to be welded to cold mass surface
- Low-cost Alu reflector mounted using threaded hole (intermediate plate to be welded needed







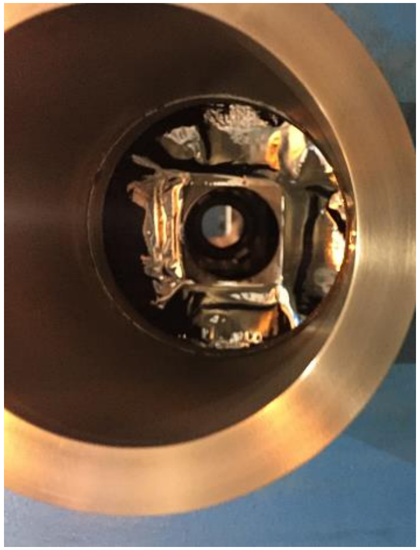


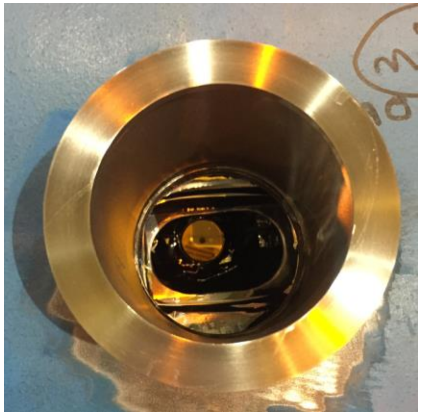


Current status of preparations

- 4 FSI heads & 8 External collimator structures ready to test with dipole
- All targets installed on the dipole cold mass
- Dipole cold mass cryostated and ready for fiducialisation in SM18
- First cool down mid July-Mid August

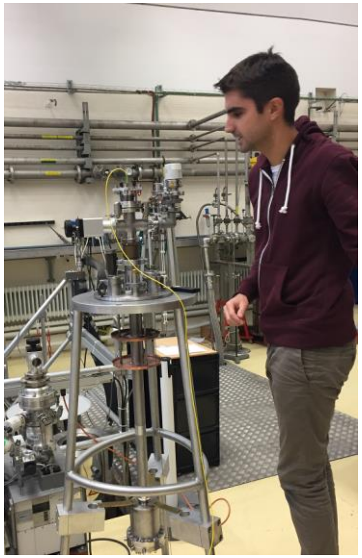
- More robust optics, 20-30mm transversal range optics under development



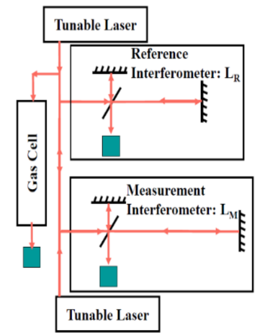


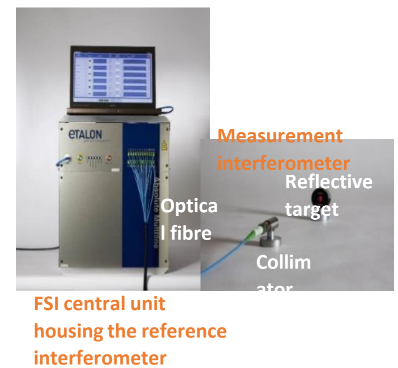
Thank you for your attention

Lessons learnt



- Experience in precision measurements of cold objects
- Know-how about behaviour of precise survey equipment under cryogenic and radiation





- Design of µm-precision measurement equipment for vacuum and radiation
- FSI became a reliable and economic solution for high precision measurements in harsh accelerator environment
    - Interest of developments carried out by ITER, ESO,
    - Industrila manufacturing of FSI heads requested by commercial partners