University of Huddersfield
Centre for Precision Technologies
HI-LHC-UK, WP1, Task 2
STFC/CERN/UoH

ACS progress review and UoH contribution to HRMT 36

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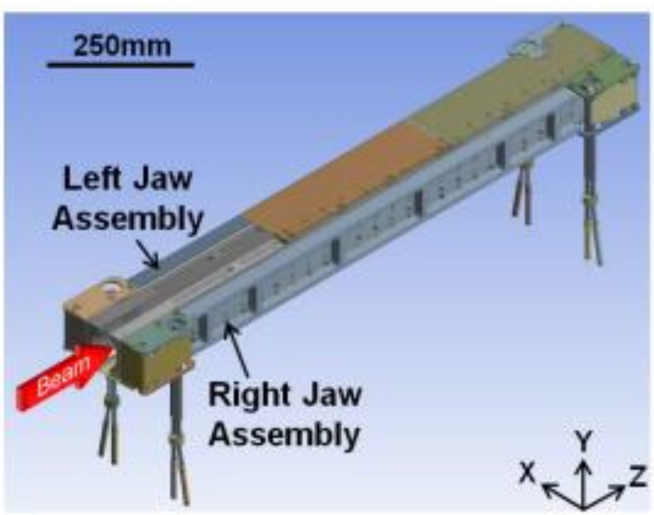
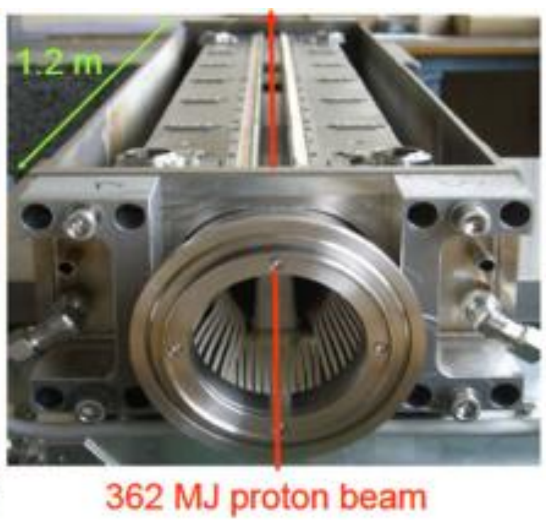
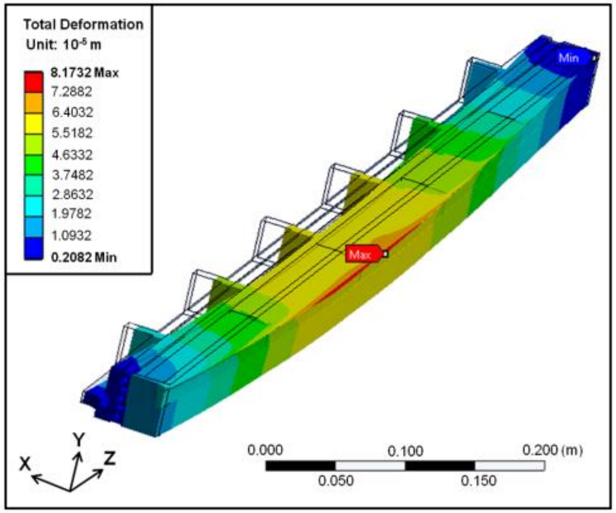
Contents:

1.1 Collimator straightness

- Straightness of collimator jaws affects performance. Specification of 100 µm includes production and assembly tolerances and deflection under operation.
- Ok for nominal conditions. Over time, deviation will occur for the following possible reasons:
  - Plastic deformation from beam impacts. Simulations show 82 µm under some conditions.
  - Irradiation effects on the material properties of the jaw components e.g. local variation in Young's modulus and thermal conductivity
  - Higher beam intensities and small gaps may cause localised heating that the cooling system cannot compensate.
- It is also being investigated whether control of the collimator shape i.e. deliberately adding a convex shape, could have additional HL advantages.







1.2 Task overview

- WP1, Task 2 – Design and production of an active collimator prototype
  - Perform thermal modelling of existing collimators using current and anticipated beam operating condition
  - Design a modified TCS collimator with integrated novel sensors and actuators. Establish radiation tolerance.
  - A prototype will be constructed and jaw straightness and position validated under varying conditions.
  - The prototype will also provide accurate jaw positioning relative to a wire used to represent the beam

1.3 Project change request

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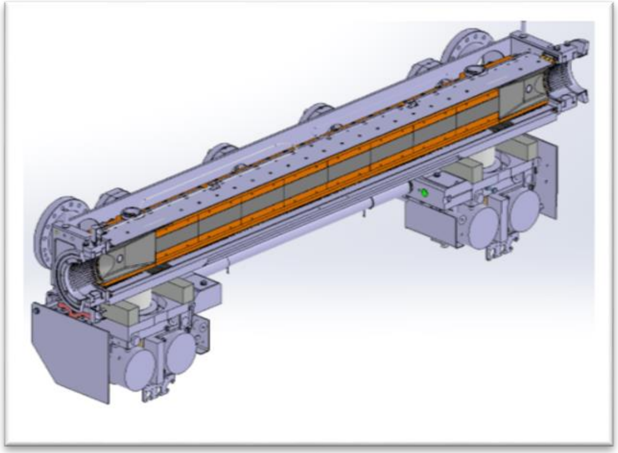
- Following discussions with CERN during the LTA, the scope has changed to include
  - measurement and correction of dynamic changes in jaw straightness.
  - impact events that could induce larger deformation of up to +/0.5mm
- ACS specification, Project plan, and Risks updated

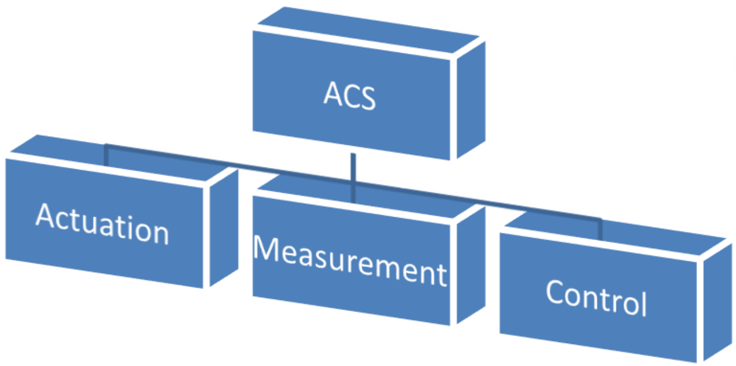
Identified risk	Consequence	Likelihood (L) #/10	Impact (I) #/10	Risk value (LxI)	Contingency
Piezo actuators unstable for adaptive collimator	System unable to respond to quick events	5	8	40	System uses originally envisaged thermal compensation for slow responses
Piezos and amplifiers expense	Insufficient funds for capital equipment	3	8	24	Request more funds or in-kind contribution from CERN
Increased difficulty incorporating actuation into jaw design	Piezo actuation cannot be used in jaw design	2	8	16	System uses originally envisaged thermal compensation for slow responses
Piezo dynamics effected by high bake-out temperatures	Loss of piezo static state/ compromised assembly of actuator	6	8	48	Use base ceramic material to make our own actuators

2. Adaptive Collimation System (ACS)

- Aim: to correct distortions in the collimator jaws, caused by in-operation events such as
  - Normal operation 1h BLT ≈ 75µm
  - Accidental slow losses 0.2 BLT ≈ 500µm
  - SPS injection error (288 Bunches)
  - Asynchronous beam dump (8 full LHC Bunches)
    - Beam dump and injection error results in high frequency displacements with amplitude in the mm range
- Travel: ±500 µm in first order shapes, ±75 µm in second order (highest)
- ACS to be incorporated upon TCSPM Prototype collimator currently being tested here at CERN.



- ACS consists of three areas of interest:

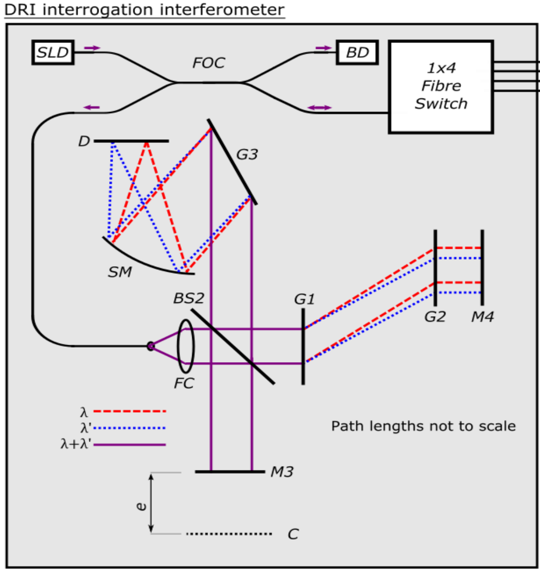


- Detailed final ACS specification for system capability submitted to CERN for sign off

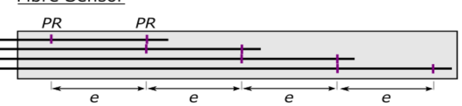
2.1 ACS Measurement – DRI

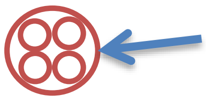
- Current Measurement Solutions being researched. Validation completed on test bench.
  - DRI (Dispersed Reference Interferometry) for fibre strain measurement.
  - Phase-resolved optical coherence tomography for fibre strain measurement.
- Expect 1kHz bandwidth using simple instantabneous phase unwrapping to get absolute distance at a resolution between 30 and 50nm. Second post processing method (variation in pixel phase from mean slope) for 5nm resolution also being investigated.
- Option for multiple cavities using either single or multiple fibres (YTBD)
  - Single: Requires mechanical (fusion) splice of multiple fibre sections to generate multiple cavities. Also requires spatial frequency division multiplexing and possibly lower visibility which could therefore affect speed if significant fibre darkening occurs.
  - Multiple: Easier to configure in terms of making cavities. Options for either Spatial frequency division multiplexing or time division multiplexing. This requires additional high speed fibre switch.

DRI interrogation interferometer



Fibre Sensor





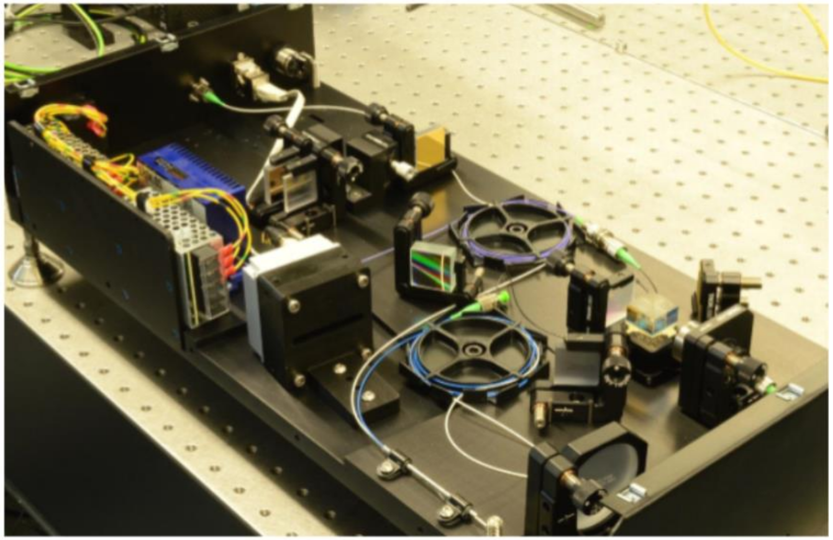
Fibre bunch
∅ <0.5 mm

Key:

BD	Beam Dump
BS	Beam Splitter
FOC	Fibre Optic Coupler
D	Detector
FC	Focusing Collimator
G	Grating
GC	Graded Index Collimator
L	Lens
M	Mirror
PR	Partial Reflector
PZT	Piezoelectric Translater
SLED	Superluminescent Light Emitting Diode
SM	Spherical Mirror

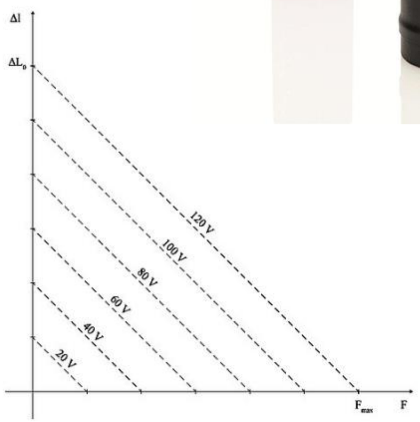
2.2. ACS Measurement - DRI

- Current Measurement Solution: DRI Strain measurement
- Bulk optic unit built for MultiMat and first dynamic tests
- Attributes:
  - Easy to install
  - Fibre design to withstand high temperatures.
  - Common mode system so bulk optics and other major components located away from vacuum tank
  - Absolute measurement system
  - High resolution. 8nm without image processing intensive pattern matching.
  - High bandwidth. Up to 2kHz without highly parallel GPU image processing.
- Disadvantages:
  - Fibres susceptible to spectral absorption (darkening). Currently operating with just 4% reflection (≈92% reduction from design maximum of 50%)
  - Bonding Issues. Requirement for fibre contact along the jaw, while avoiding the use of glue.
  - Higher hardware cost (Current estimate is €12k per jaw but this depends on speed of fibre multiplexors)



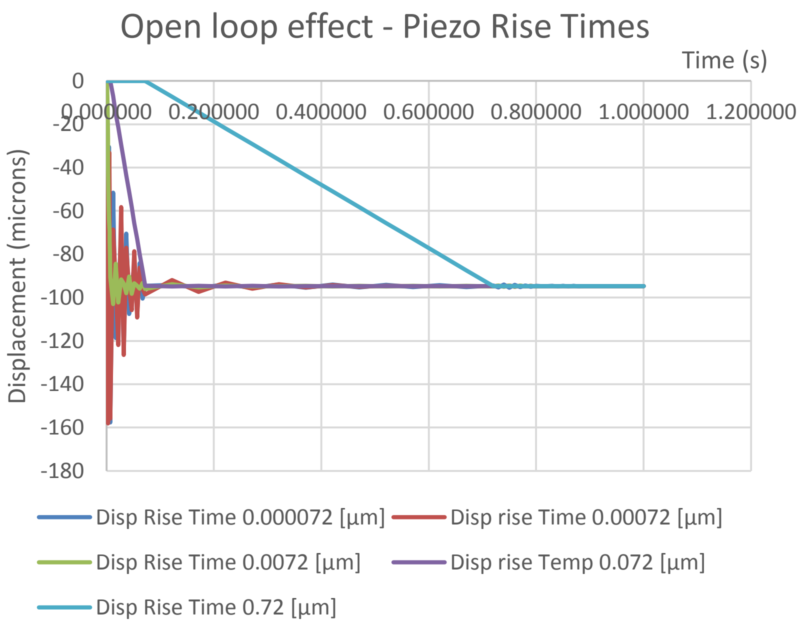
2.3. ACS Actuation

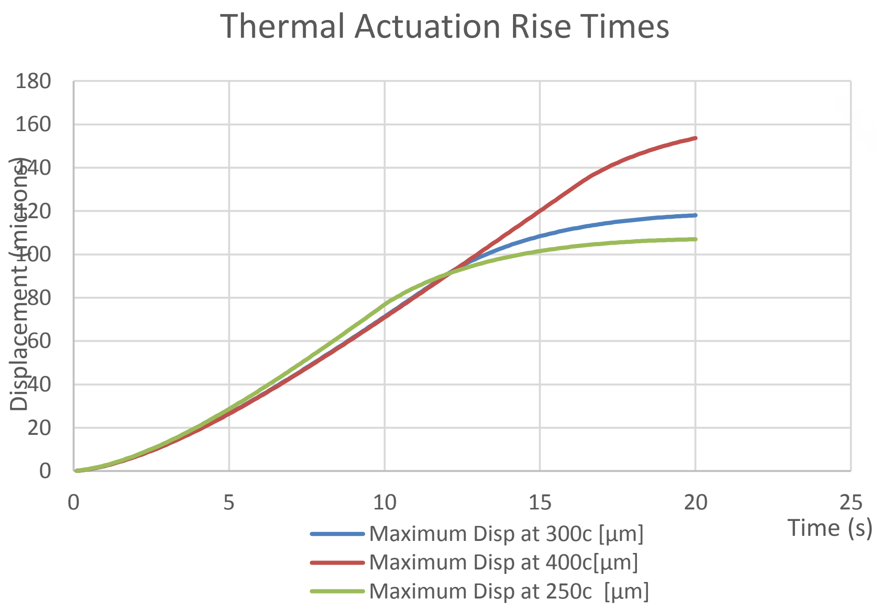
- Actuation solutions:
  - Originals thermal ‘heat pad’ type solutions were the focus. Not suitable for dynamic correction recently incorporated into the project.
  - Various actuators considered but current focus on Piezo actuators.
    - High force generation
    - Multiple options in the market.
    - Extremely fast rise times.
    - Displacement is inversely correlated to force generation.
    - Critical damage induced though high temps, over preloading, excess voltage, shock loading.
    - Require high voltages



2.4. ACS Actuation

- Open loop effect on rise times with Piezo and ceramic heater actuators





3. Multimat and HRMT 36

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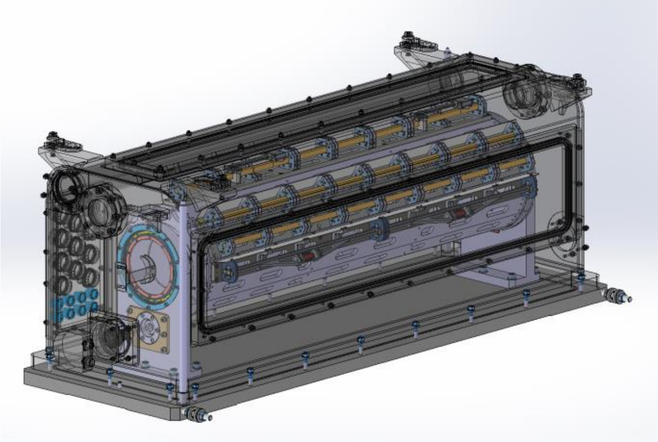
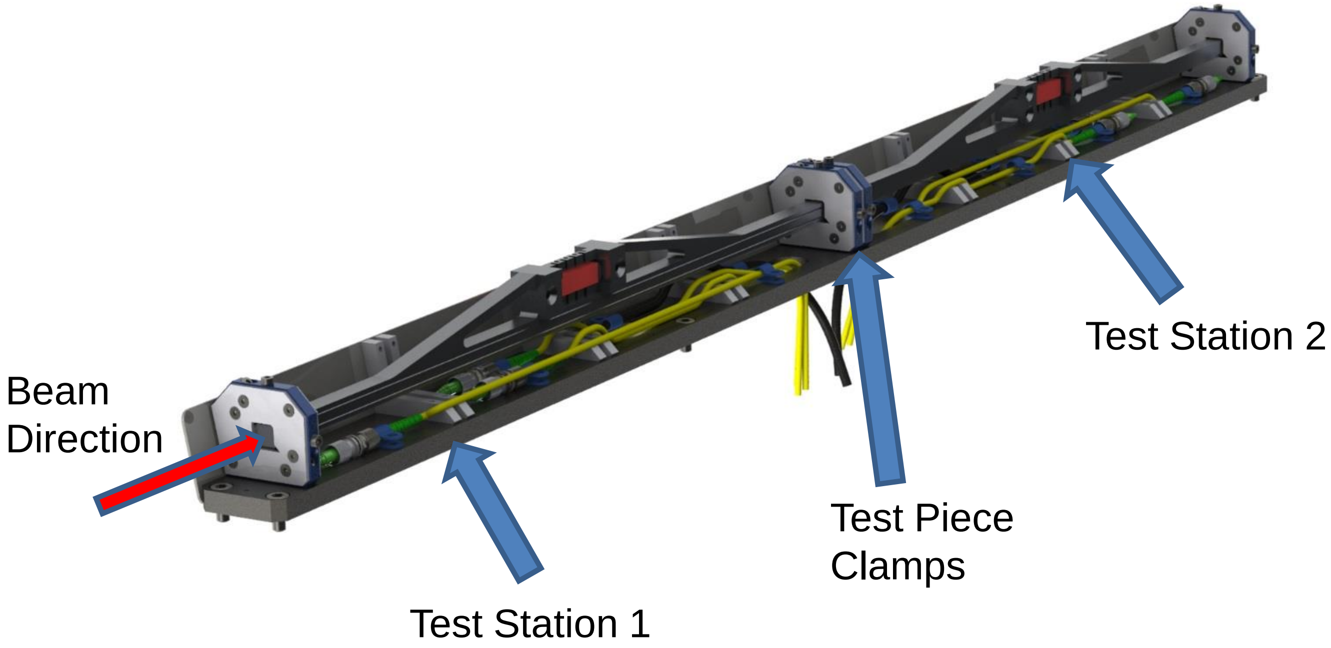
HiRadMat
High-Radiation to Materials

- What is Multi-Mat (HRMT 36) ?
  - Material testing experiment
  - 16 Stations for material samples
  - To be assembled summer 2017
  - Installed into HiRadMat In SPS At CERN
  - Testing Oct 2017
  - UoH have been given 1 dedicated station for equipment testing

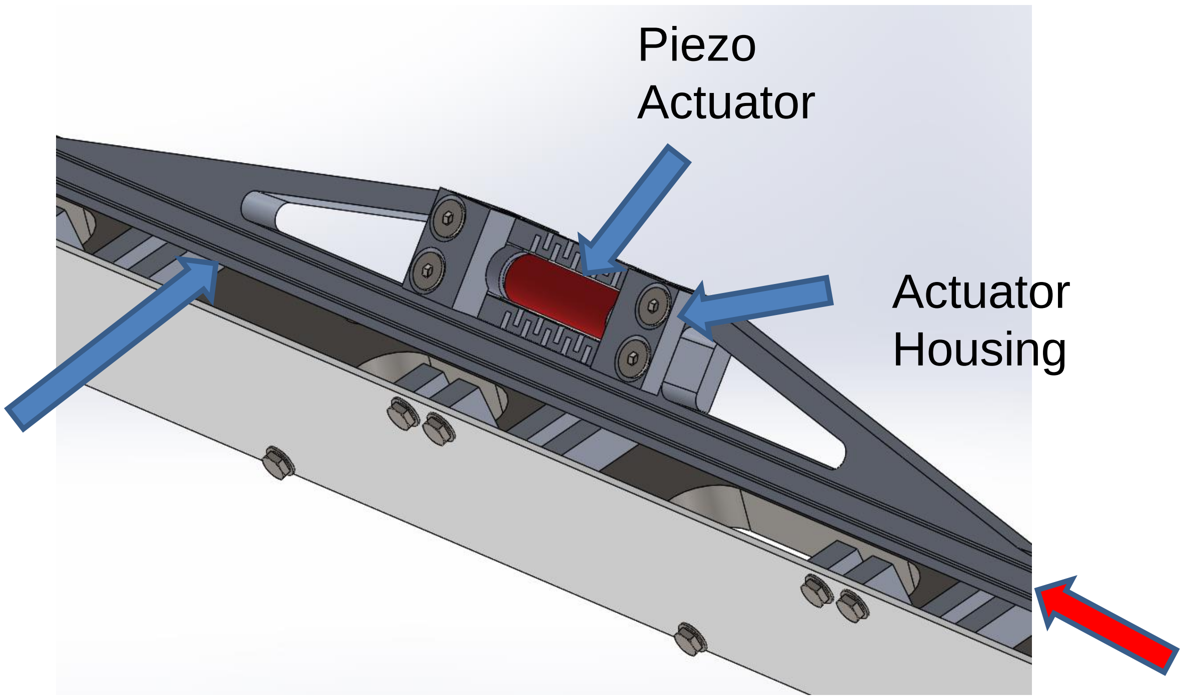


3.1. Multi-Mat Adaptive Collimation System V3 (MMACS)

- MMACS will allow us to test the measurement/ actuation when in close proximity to the beam.
- An apparatus has been has designed to test the proposed actuator and strain measurement systems

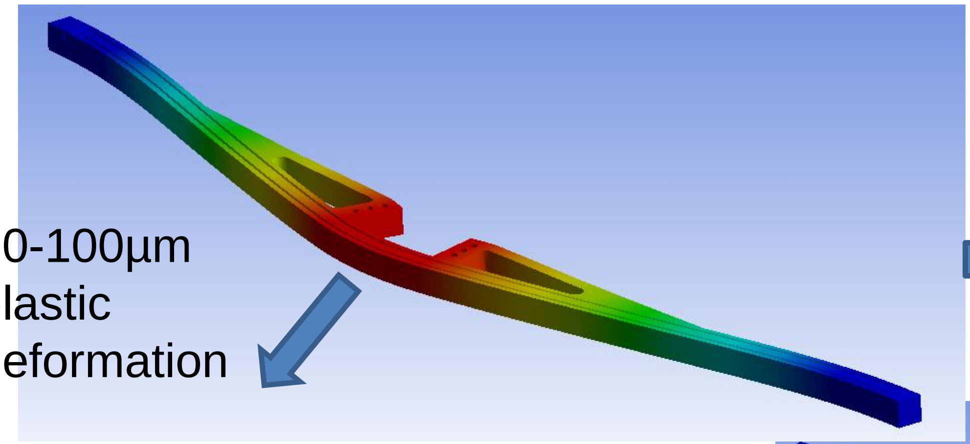


3.2. Multi-Mat Adaptive Collimation System (MMACS)



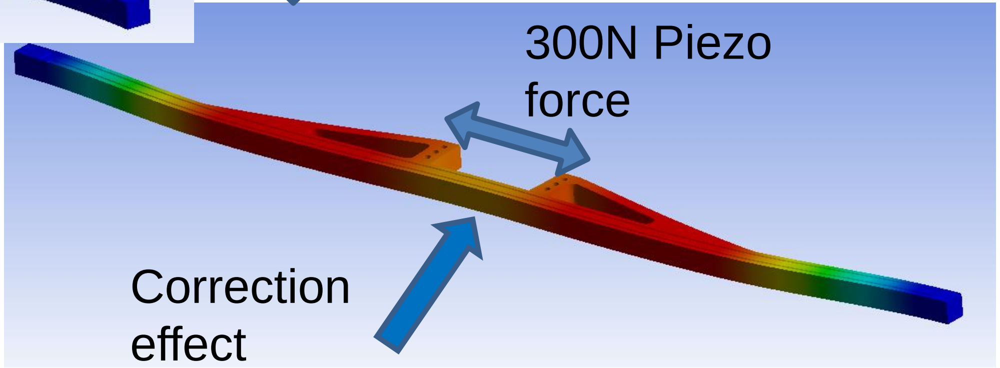
3.3. Multi-Mat Adaptive Collimation System (MMACS)

70-100µm elastic deformation



Offset beam to induce thermal distortion

Piezo to induce reversing force

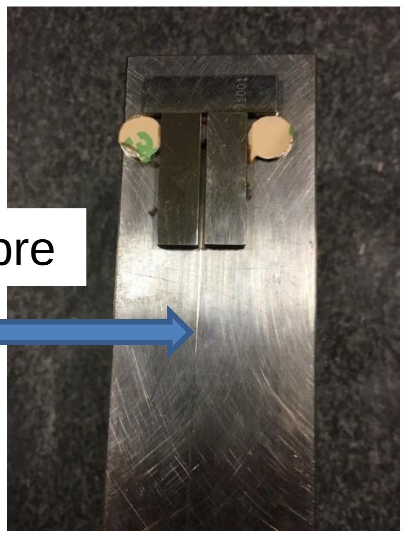


Beam impact will induce oscillatory response of 100-120µm in amplitude at 200Hz

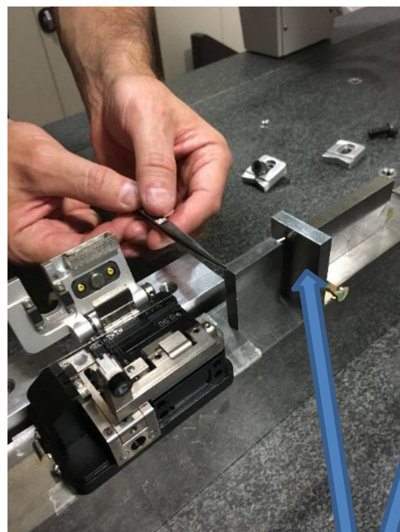
3.4. MMACS Fibre Cleaving

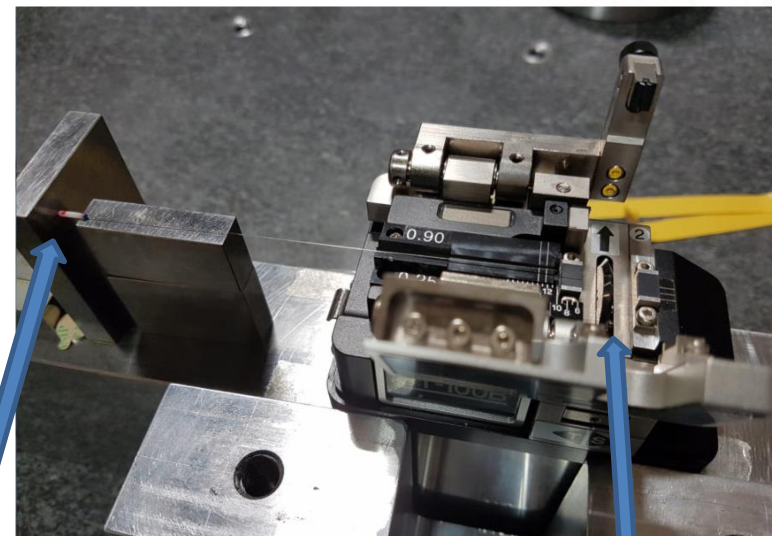
- DRI for MMACS requires four fibre cavities cleaved to the same length as the master fibre: 120mm ±20µm
- Original fibre length and cleave setup measured using CMM

Bare Fibre



Placement of the master fibre for CMM measurement





Datum edge

Cutting Face

Fibre cleaving

3.5. MMACS Sample Assembly

Current MMACS Test Sample

- Two Al 6082 samples 10x10x490mm
- Carbon fingers in the mounts to absorb external shocks
- 2x PICMA P888.91 actuators in stainless steel mounts

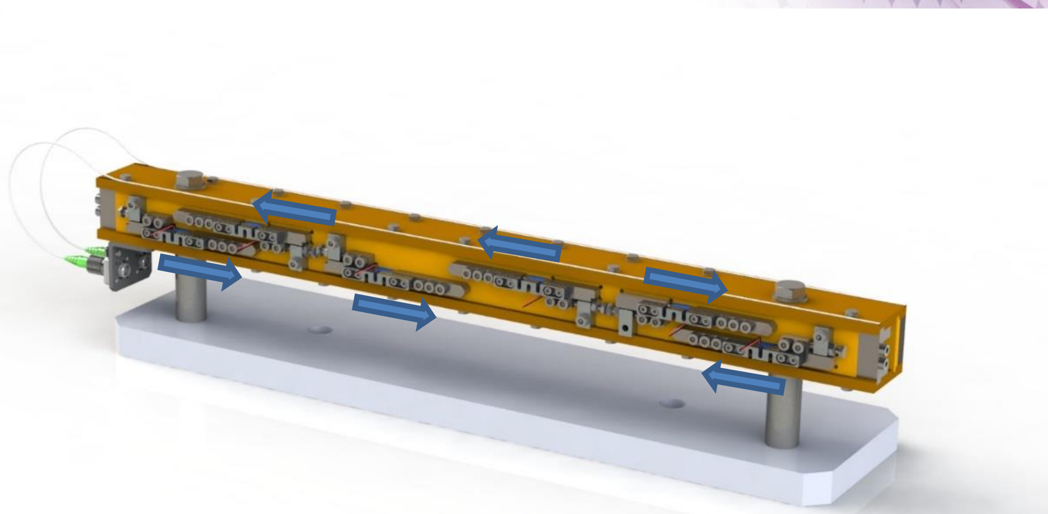
Piezo: PICMA P 888.91

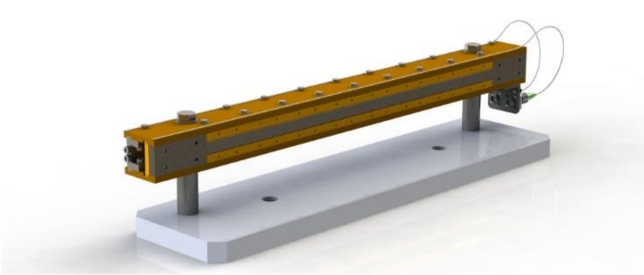
- Nominal displacement 32µm @100V
- Actual displacement 28µm due to external stiffness of sample
- Blocking force 3800N
- Transverse displacement of sample 180µm

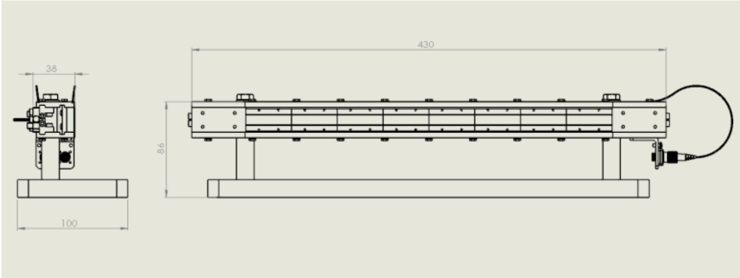
4. ACS 1/3 Scale collimator jaw

Design features:

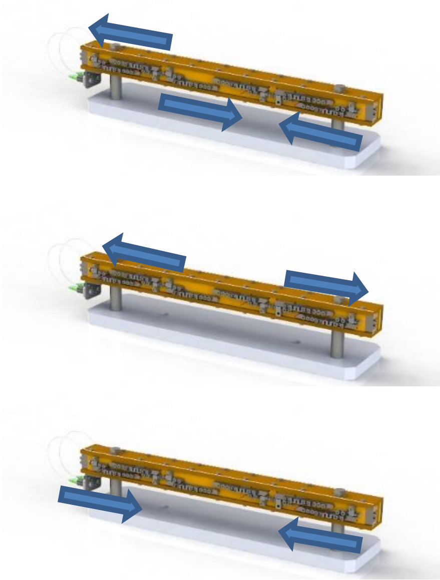
- 6 piezos in titanium mounts
- 5 cavities per track (10 total)
- Graphite jaw blocks
- Copper structure.
- Mounting holes for CMM bed for shape validation



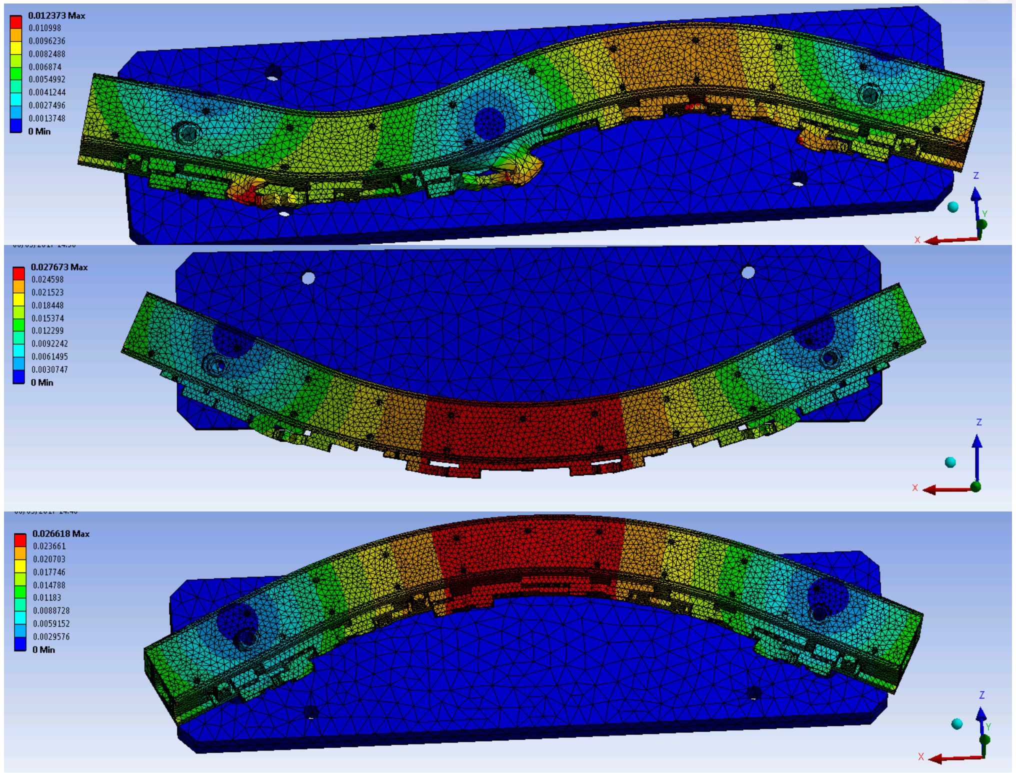




4.1. ACS 1/3 scale model simulation

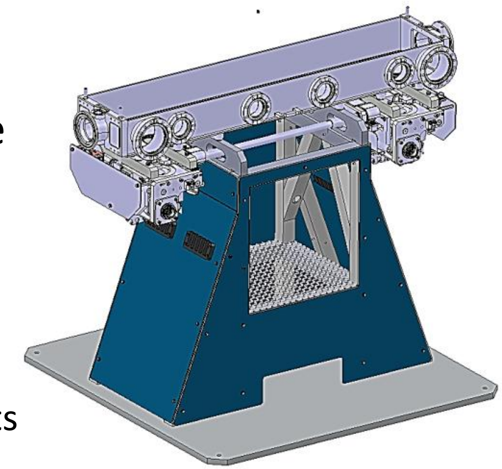


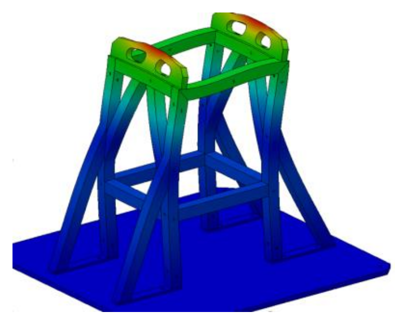
10µm of displacement at 400N of force required

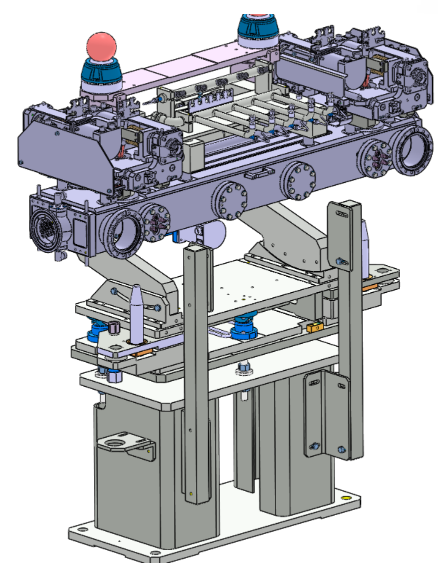


5. Other work

- CPT has been given a dedicated cleanroom/workshop for the ACS assembly.
- Design of new collimator test base has been devised, and is ready to issue.
  - Increases ease of use
  - Decreases H&S risks
  - Decreases associated costs.
  - High rigidity (±9µm) for dynamic tests
- Change parts will be designed (if needed) for the CERN base assembly.
- All drawings for the drive system have been marked with correct QTY and have been issued to manufacture.







Multi-Mat Adaptive Collimation System (MMACS)

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What Next?

- MMACS for Multimat will be delivered to CERN by end of next week.
- Installation and commissioning will take place in August
- HRMT 36 takes place in October
- 1/3 scale model to be ready for testing November this year.
- Vacuum testing for ACS parts TBC
- Overall project plan on target.

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Thank you

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Collimator straightness

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- Ok for nominal conditions. Over time, deviation will occur for the following possible reasons:
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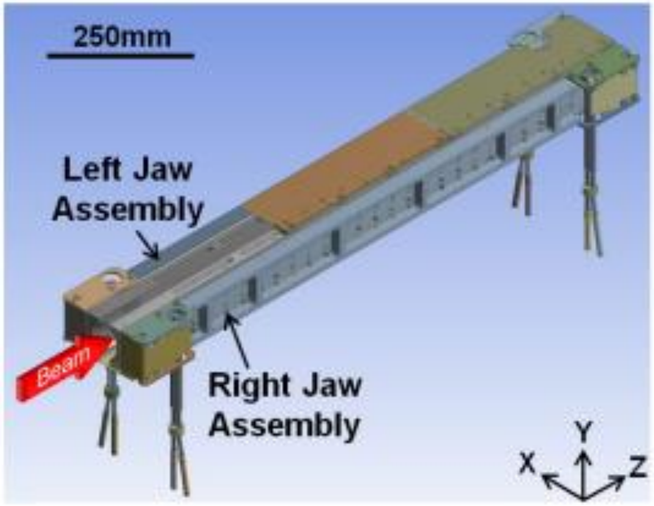
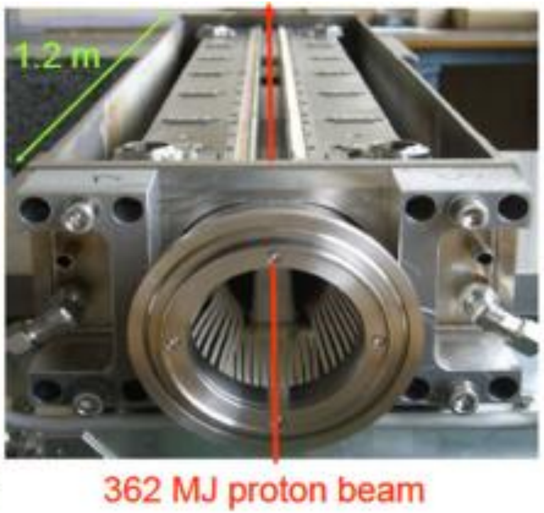
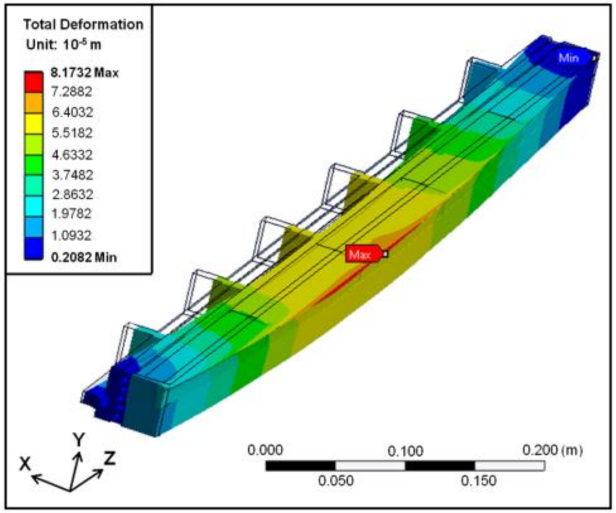
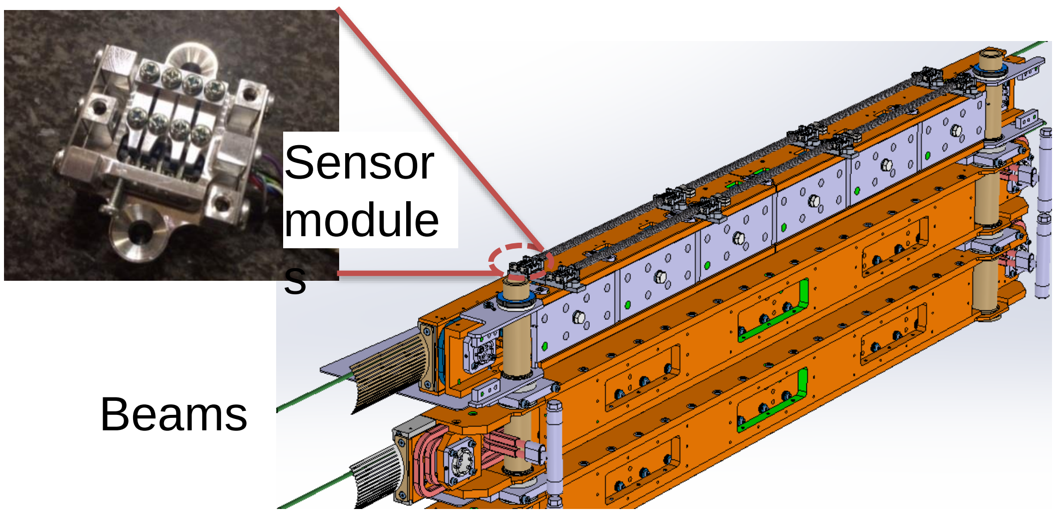




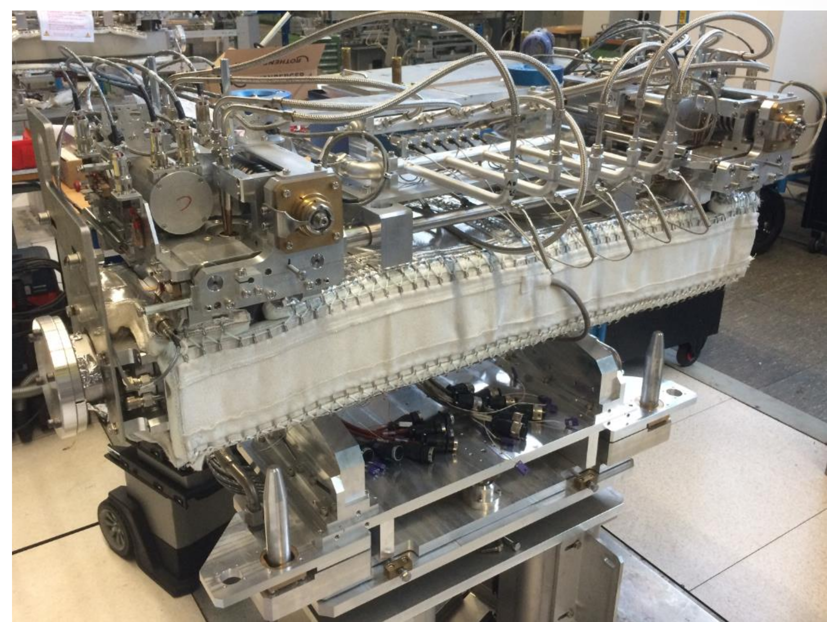


WP1 Task 2 - Aims

1. Deliver metrology enabled active collimator prototype
2. Improve and maintain jaw straightness to within 20µ under adverse operating conditions

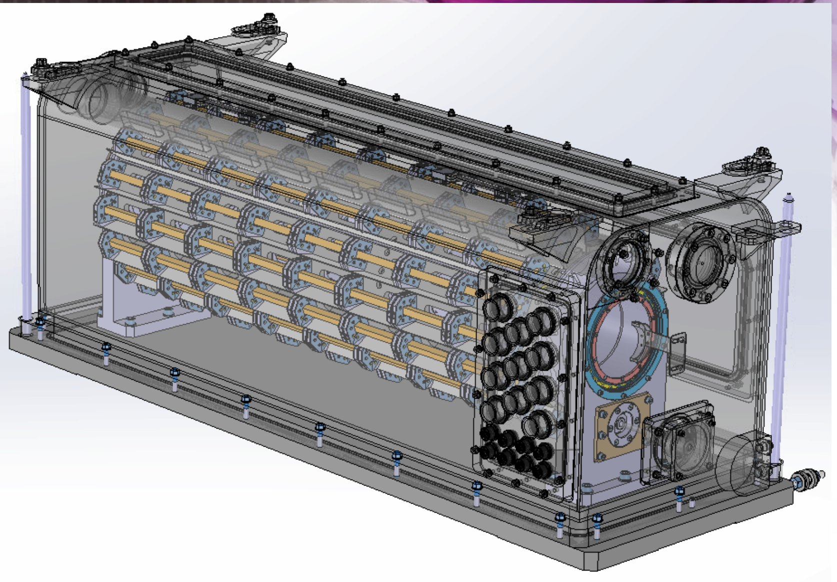


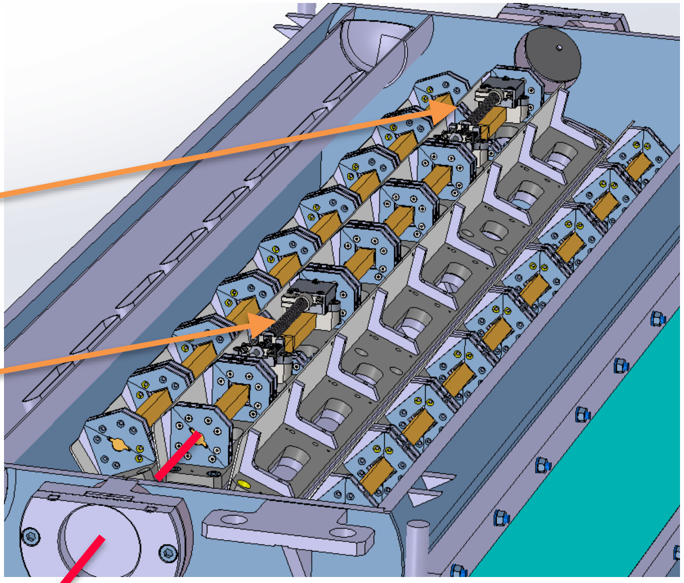
Example set-up on HiRadMat jaw



Sensor testing

- Preliminary NDT at local LINAC facility. Low dose, long exposure for existing sensor radiation hardness.
- New designs for integration into CERN MultiMat facility (Est. late 2017 for tests)
- Drum contains 16 lines for materials experiments. CERN allocating one to HL-LHC-UK sensor testing





Rear system: high dose from scattered particles

Front system: high shock from beam interaction with samples

Short term plan

- Tom Furness, a member of CPT, will begin an 18 month LTA at CERN working closely with the collimation team
- Initial tasks:
  - Design of MultiMat sensor tests and data analysis
  - Detailed review of existing relevant literature and collimator production specifications
  - Modelling and preliminary simulation of jaw deflection under various operating conditions
  - Design of distortion detection and actuation systems
- New adaptive collimator design signed off at end of LTA. Production, assembly and testing at UoH for remainder of project

Prototype manufacture and build

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A collaborative effort

Work item	UoH	CERN	Cost (£k) UoH	Cost (£k) CERN support
Detailed design work	Producing detailed models and assemblies based on Phase I simulations and designs. Detailed manufacturing drawings. Ongoing development updates and support to PDRF based on CAM requirements	Provide CAD models of all components that may require design modification, either major or minor, to enable integration of the sensor/actuator designs. Assistance with tolerancing and BOM	10	5
Materials for preliminary design and final prototype	Specialist materials such as Dispersion Strengthened Copper (Glidcop®) and other specialist or general materials for the collimator jaw assembly components (probably excluding the CC jaws) being re-designed and machined/produced by UoH	Specialist materials such as Dispersion Strengthened Copper (Glidcop®). Low-Z materials for jaws (CC, Copper diamond, Molybdimum Graphite). General materials for collimator assembly standard parts.	15	100
Drive and feedback system	Control system hardware and software for offline preliminary testing of jaw adaptive functionality using a wire electron-delivery system (bead pulling tests)	Supply of drive system components including specialist drive motors with radiation resistant wiring, feedback transducers and hardware required for control hardware and software that is very remote to the motors.	15	20
Manufacture of collimator prototype components	In-house machining of small to medium sized components based on design updates. Outsourcing of manufacture of large and specialist machining. Fixturing design and build. High precision coordinate and surface metrology for inspection and testing.	Specialist manufacture/subcontracting of jaw components such as CC jaw sections. Specialist process support such as brazing of cooling piping	55	30
Assembly fixturing and test platform	Create representative platform onto which the collimator can be mounted for in-house testing such as wire electron-delivery system (bead pulling tests) and integration into facilities for beam testing.	Support to the design of the fixturing to minimise effort in transition to HiRadMat and/or LHC testing facilities.	20	5
New sensor framework for adaptive jaws and condition monitoring	Integration of sensors, signal conditioning and processing for the real time condition monitoring framework. Signal conditioning systems. Radiation hardness testing/conversion of sensor systems	Installation and monitoring of sensors and actuators designed by PDRF in HiRadMat or similar facilities.	20	5
Cooling system	Design of cooling system suitable for stand alone testing and evacuation of very high heat loads (in the order of 30 kW) and which is compatible with LHC cooling supplies for final testing.	Support to the design and build of cooling system. Supply of some standard components such as heat exchangers, high flow rate pumps, piping, chiller control system suitable for evacuation of very high heat loads (in the order of 30 kW)	15	10
Vacuum system	Hardware for generating vacuum for design testing		10	
Cleaning		Temporary heat resistance components and cleaning processes required prior to LHC tests. Thermal treatment for preparing the components to UHV installation		5
		Totals (£k):	160	180

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