

MUSE Optical Alignment Procedure

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ABSTRACT

MUSE (Multi Unit Spectroscopic Explorer) is a second generation VLT integral field spectrograph (1x1arcmin² Field of View) developed for the European Southern Observatory (ESO), operating in the visible wavelength range (0.465-0.93 μ m). A consortium of seven institutes is currently assembling and testing MUSE in the Integration Hall of the Observatoire de Lyon for the Preliminary Acceptance in Europe, scheduled for 2013.

MUSE is composed of several subsystems which are under the responsibility of each institute. The Fore Optics derotates and anamorphoses the image at the focal plane. A Splitting and Relay Optics feed the 24 identical Integral Field Units (IFU), that are mounted within a large monolithic instrument mechanical structure. Each IFU incorporates an image slicer, a fully refractive spectrograph with VPH-grating and a detector system connected to a global vacuum and cryogenic system. During 2011, all MUSE subsystems were integrated, aligned and tested independently in each institute. After validations, the systems were shipped to the P.I. institute at Lyon and were assembled in the Integration Hall

This paper describes the end-to-end optical alignment procedure of the MUSE instrument. The design strategy, mixing an optical alignment by manufacturing (plug and play approach) and few adjustments on key components, is presented. We depict the alignment method for identifying the optical axis using several references located in pupil and image planes. All tools required to perform the global alignment between each subsystem are described. The success of this alignment approach is demonstrated by the good results for the MUSE image quality.

MUSE commissioning at the VLT (Very Large Telescope) is planned for 2013.

Keywords: Optical alignment, Integration, Procedures, Tools, Results, MUSE instrument

1. INTRODUCTION

Built for the European Southern Observatory (ESO) for the second generation VLT instrumentation, MUSE (Multi Unit Spectrograph Explorer) will be installed on the Very Large Telescope (VLT) Nasmyth platform B for a first light in 2013. MUSE is an innovative IFS, named Integral Field Unit (IFU) in MUSE instrument, which combines a 1'x1' Field of View (FoV), with a spectral resolution reaching 3000 and a spatial sampling of 0.2'' matching the spatial resolution provided by a ground layer adaptive optics system named GALACSI. MUSE operates in a large visible and near IR spectral range (0.465 – 0.93 μ m) with 2 functional modes a Wide Field Mode (WFM) and a Narrow Field Mode (NFM) where the latter has an eight times higher spatial resolution - [1] and [2].

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The MUSE instrument is composed of a Calibration Unit, a Fore-Optic which includes an optical derotator and an anamorphoser by 2, a splitting optics cutting the FoV in 24 parts and 24 relay optics which feed 24 identical IFU. Each IFU is composed of an original advanced image slicer associated with a high-throughput spectrograph with a Volume Phase Holographic Grating (VPHG) and a 4k×4k CCD detector. The Figure 1 gives a mechanical overview of MUSE with all subsystems.

This paper describes the Optical Alignment Procedure of the Multi Unit Spectroscopic Explorer (MUSE) instrument performed in Lyon Integration Hall. The aims are to:

- Propose a sequence and a process of the global alignment procedure between each subsystem,
- To check the different interfaces with their available references,
- To give alignment accuracy requirements, foreseen adjustments with their range and sensitivity and alignment errors due to the use of AIT Tools,
- Define and describe all AIT Tools required to perform the alignment.

2. MUSE DESCRIPTION

To achieve the system performances, MUSE optomechanical design is divided into 5 main subsystems as shown in Figure 1 - [12].

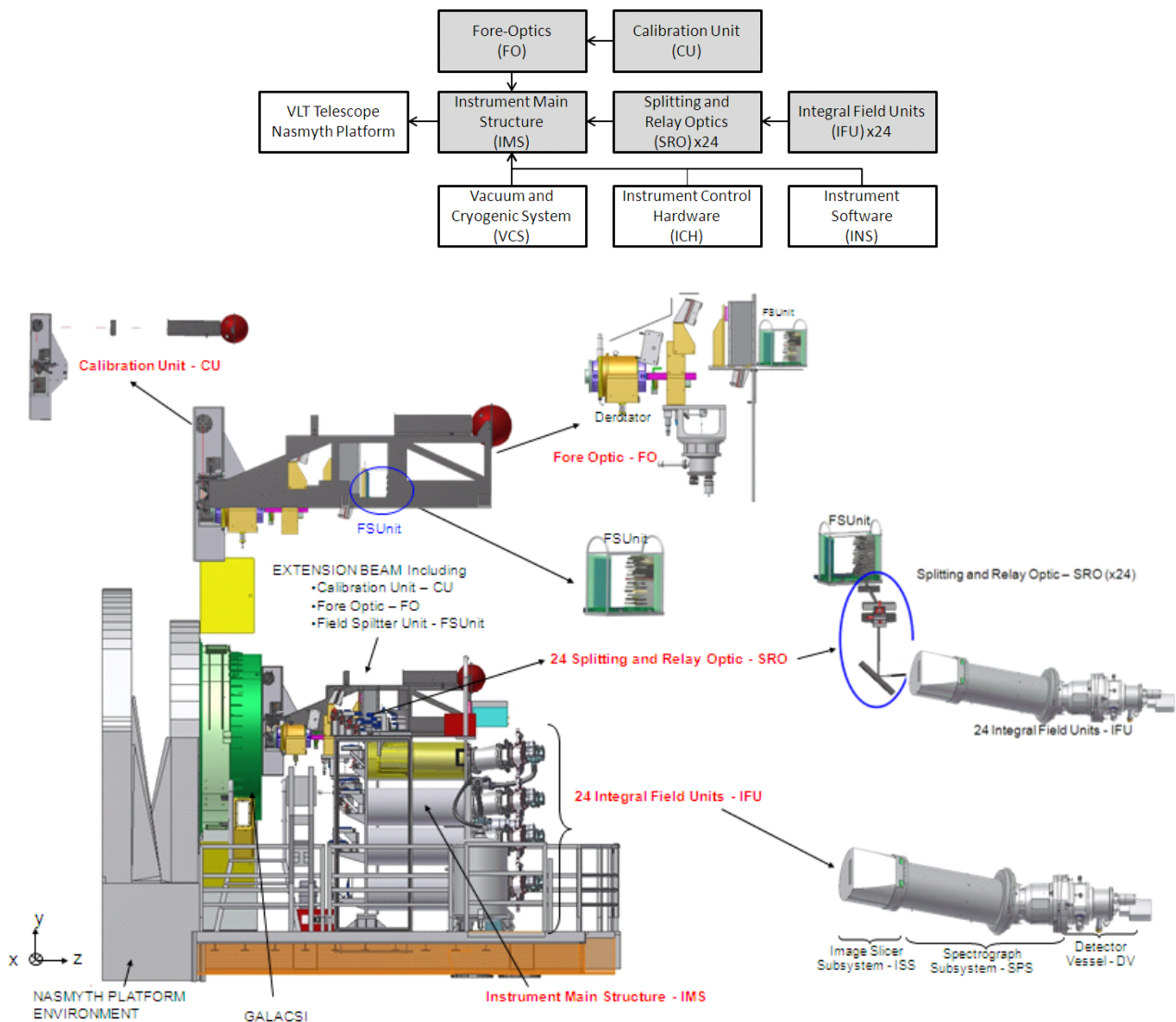


Figure 1: MUSE Mechanical Overview

2.1 The Instrument Main Structure (IMS) - [7]

That is the central mechanical part which supports the Splitting and Relay Optics, the 24 IFUs and the Extension Beam where the Fore-Optics and the Calibration Unit are set.

2.2 The Calibration Unit (CU)

The Calibration Unit (CU) [3] simulates the VLT beam f-number and mimics the telescope pupil. Moreover, it provides a Flat Field, all the light sources for flatfield illumination and spectral calibration of the WFM and NFM, several field masks.

2.3 The Fore-Optics (FO)

The Fore-Optics (FO) [8] performs the following functions:

- To transform a rotating square Field of View (FoV), from the telescope, into a static FoV at the entrance of the Splitter and Relay Optics sub-system,
- To anamorphose by a factor by 2 the FoV,
- To compensate for the atmospheric dispersion in NFM,
- To filter the undesirable wavelengths to avoid second order pollution and /or Laser Guide Star pollution,
- To switch between WFM and NFM,
- To start/end the exposure (Instrument Main Shutter).

2.4 The Splitting and Relay Optics (SRO)

The goal of the Splitting and Relay Optics (SRO) - [7] -is:

- To split the output Fore Optics FoV in 24 subFoVs,
- To magnify each subFoV from the FO output to each IFU,
- To image the VLT pupil at the entrance of the Integral Field Unit.

This system is replicated 24 times except for splitting part.

2.5 The Integral Field Units (IFU)

The Integral Field Units (IFU), which is replicated 24 times, is composed of 3 main subsystems:

- Image Slicer Sub-system (ISS) which has 2 functions :
 - To transform a rectangular FoV into a serie of 48 mini “slits” that are re-arranged along a pseudo-slit, which will be located at the entrance of a spectrograph,
 - To image the input pupil (itself being an image of the VLT pupil) at the entrance pupil of the spectrograph.
- Spectrograph (SPS)
 - To disperse the pseudo slit over the MUSE wavelength bandwidth and with the specified resolution,
 - To image the FoV onto CCD chip.
- Instrument Detector System (IDS) – ([4], [9])
 - To acquire and record 4kx4k CCD chip of 15 μ m pixel square in a raw exposure.

3. ALIGNMENT STRATEGY AND PREPARATION

3.1 Alignment Strategy

The MAIT sequence starts with the manufacturing of the subsystems which are then assembled, aligned and tested independently at the premises of the consortium institutes. An internal MUSE review is performed at the institute location before shipment to Lyon. In Lyon, the principle idea of the MUSE instrument alignment is to align the optical train to maximize the Encircled Energy (EE) and to avoid any vignetting. Best EE performance is verified by optical performance measurements after each subsystem integration at interface plane.

The MAIT activities have been organized in order to fulfil the following requirements:

- If possible, perform subsystems full tests before shipment to Lyon in order to limit the debugging activities in the integration hall.

- Decouple as much as possible the AIT of long lead item from the general sequence in order to prevent catastrophic schedule delays. This is achieved by requiring the spectrograph alignment to be independent from the detector head.

3.2 Alignment Sequence Overview

First, the Instrument Main Structure (IMS) is assembled in the integration hall. It is prepositioned on the replica of Nasmyth Platform. Then the structure is aligned wrt a VLT Simulator which mimics VLT focal plane. The integration is followed by the Electronics Cabinets (ICE) and the Vacuum and Cryogenic System (VCS) - [5] - which are integrated in parallel. The Fore Optics (FO), the Field Splitter and Separator (FSUnit) and the Calibration Unit (CU) are mounted onto Extension Beam which is put on a special support near to IMS. After individual alignment and tests of Extension Beam, this is mounted onto IMS. The Instrument Control Software is also delivered. The Relay Optics are then mounted on the IMS and aligned with respect to the Field Separator on one side and to the IFU on the other side. Alignment to the IFU flange is performed with an IFU Simulator. Each IFU is independently mounted, aligned and validated in CRAL optical laboratory. As soon as each IFU is validated, the corresponding IFU is mounted onto IMS with the IFU positioning tool. After each insertion of IFU, MUSE end to end tests can start. The Preliminary Acceptance in Europe (PAE) milestone should conclude this MAIT sequence.

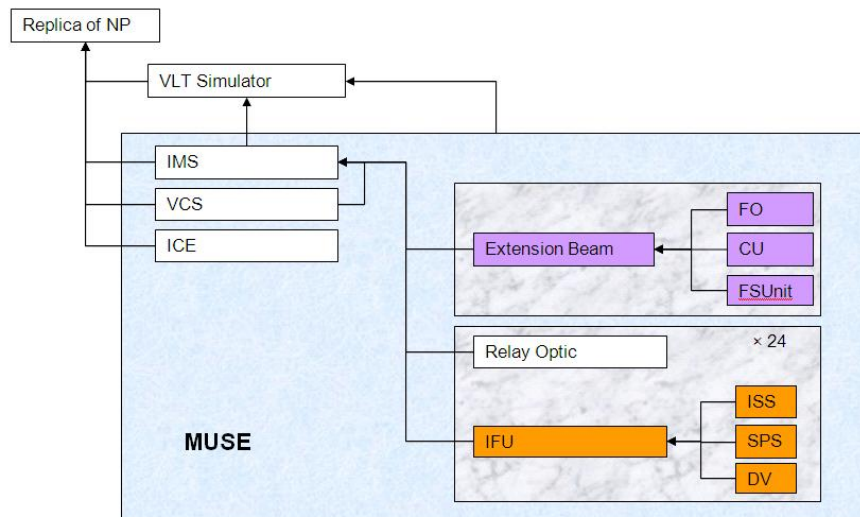


Figure 2: Global flow Chart for MUSE alignment in Lyon

4. MUSE OPTICAL ALIGNMENT PROCEDURE

4.1 Preparation of the Nasmyth Platform environment

The goal of this step is to preposition the MUSE Instrument Main Structure in its adjustment range with regard to (wrt) the telescope focal plane position. For that, Paranal environment constraints are replicated using a Nasmyth Platform Replica and a VLT Simulator.

Firstly, a Nasmyth Platform Replica, composed of 3 rails with the same interface as Paranal, is installed in Lyon integration hall. Each rail has 3 reference holes for laser tracker measurement (x , y , z , θ_z) and a reference plane for orientation (θ_x , θ_y) - Figure 3. The rails of the Nasmyth Platform replica are adjusted together with spirit level in order to reach a planarity between each rail lower than $10''$. The positioning and orientation is reached thanks to laser tracker in using the reference holes located onto rails. The final positioning between each rail is better than $100\mu\text{m}$ and the orientation lower than $30''$.

Secondly, a VLT Simulator which simulates the focal and pupil plane of VLT is aligned wrt Nasmyth platform replica. It is composed of (Figure 5):

- A plate which is representative of NAR Interface in terms of orientation (θ_x , θ_y , θ_z),
- A Nasmyth Focus materialized with a target which can be measured with the laser tracker. It gives the positioning,

- A focusable autocollimator which allows the beam orientation and pupil centre.

The Nasmyth Focus is mounted onto the focusable autocollimator to reach the coaxiality by mechanical design. The NAR interface and the Nasmyth Focus are aligned wrt Nasmyth platform replica with laser tracker (accuracy <1 arcmin and $100\mu\text{m}$). The focusable autocollimator is adjusted in tilt wrt NAR Interface in using a flat mirror set directly onto NAR Interface (accuracy $<10''$). Finally, the MUSE Gravity Stable (GS) is given by the VLT Simulator.

Thirdly, the MUSE Instrument Main Structure (IMS) is mounted onto the Nasmyth platform replica and pre-aligned wrt the VLT Simulator. The goal is to set MUSE in its adjustment range ($<500\mu\text{m}$ and <1 arcmin). The final adjustment will be done at the end with optical tool (§4.4). The VLT Simulator is the reference for the laser tracker measurement because it represents the MUSE gravity stable. The MUSE front plate (orientation) and the central hole (positioning) onto IMS are measured with the laser tracker and compared to the VLT Simulator (Figure 4). Three air locks allow to unload MUSE in order to insert and move MUSE into six degrees of freedom (Figure 6): (x, z, θ_y) performed between IMS and its supports and (y, θ_x, θ_z) between IMS supports and the Replica of Nasmyth Platform.

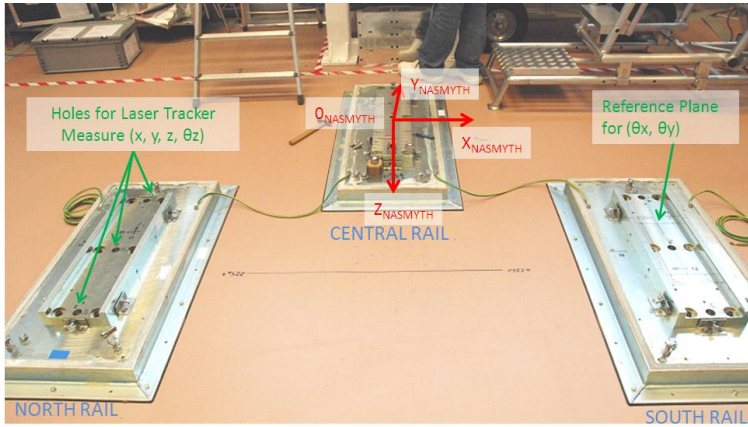


Figure 3: Nasmyth Platform Replica

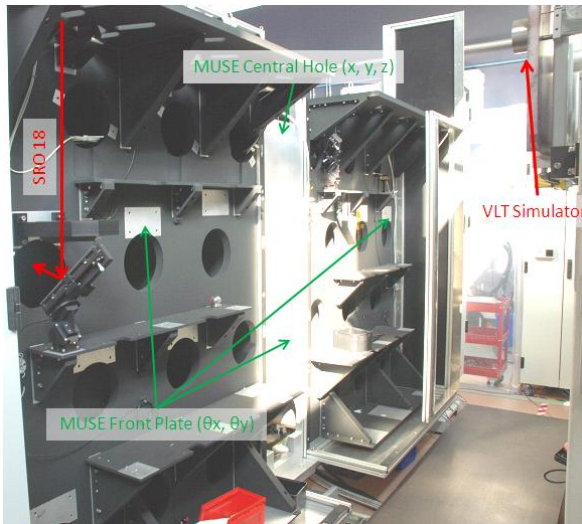


Figure 4: MUSE IMS references (MUSE central hole and MUSE Front Plate)

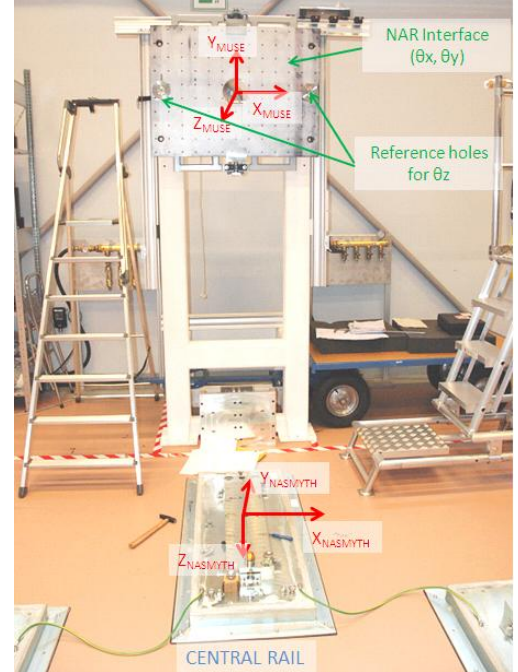


Figure 5: VLT Simulator



Figure 6: Feet tuning of Main Structure

4.2 Alignment of Extension Beam (EB) alone (include CU+FO+FSUnit)

The Extension Beam is integrated alone onto its support. It includes the integration of Calibration Unit, Fore Optics and Field Splitter Unit.

4.2.1 References and optical axis definition

The MUSE mechanical reference is the plane composed of the 4 FO feet and 2 holes available into 2 Fore Optics feet. The reference system is measured with the Romer arm measuring device and takes as reference (accuracy < 25 μm) - Figure 7.

Four optical Reference Targets are located onto Extension Beam (Figure 7). These targets are references for Internal MUSE alignment.

- Ref EB1 is located in the CU Pupil Plane. It is a perforated mirror with a target centred on it.
- Ref EB2 is located in the CU Focal Plane. It is a perforated mirror with a target centred on it
- Ref EB4 is located below the junction plate. Same design as Ref EB1&2
- Mirror M3: This is a 310 x 60 x 50 mm thick mirror. One large target on a mechanical plate is composed of 4 hollow sub targets which is glued on its reflective surface. For that, the edges of mirror are the reference and the target is glued on the mirror wrt these edges under 3D measuring machine. These sub targets are located at different locations along y axis:
 - M3Target1. It defines the VLT entrance optical axis which is the same as FO entrance optical axis.
 - M3Target2. It defines the positioning of FO exit optical axis.
 - M3Target3. It is located in the same location (x, y) as the 25th mirror of the Field Separator.
 - M3Target4. It is located at the top of FSUnit.

These 4 optical Reference Targets are positioned wrt the MUSE mechanical references with the Romer arm measuring device. The positioning errors are lower than 100 μm and 2 arcmins.

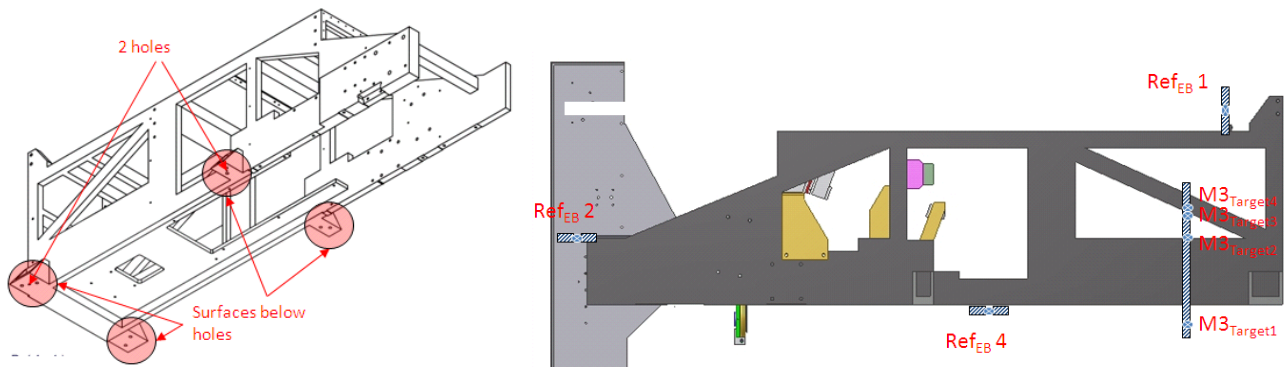


Figure 7: Left: MUSE mechanical references. Right: MUSE optical references

4.2.2 Fore Optics Wide Field Mode alignment

The first step of the FO alignment is to align the Optical Derotator (OD) on its mechanical rotation axis.

On an optical bench, a Sighting Telescope (ST) defines an optical axis; one reticle is put on the front of the optical derotator mechanic (ODM) (Figure 8, Left) and one flat mirror on its back (Figure 8, Middle). The ST is adjusted in X, Y and Tip/Tilt as well as the flat mirror, until the reticle and the autocollimation on the flat mirror remain stable through the ST when the ODM is rotating around Z. The ODM axis of rotation is on the ST axis.



Figure 8: Left: Alignment mirror of ODM. Middle: Alignment target of ODM. Right: Alignment target of OD

Then the reticle and the flat mirror are removed, the OD is mounted in its mechanic. A target located at the objet plane of the OD positioned using the ST, and a tool called Pupil/Image Check (PIC) tool is inserted. This tool allows to measure both image and pupil wobbles when the OD rotates. In MUSE, it is located between NFM switching unit and the first anamorphic mirror (FOaM1) on IRLOS interface. It is placed onto a translation stage in order to translate it onto MUSE optical beam whenever that will be necessary. It stays in the MUSE instrument during its lifetime to periodically check the positioning of MUSE at Nasmyth focus or after an earthquake. The OD is aligned by minimizing both wobbles. It is a sensitivity task as both wobble are coupled at the level of the OD. We obtain an image wobble of 0.62mm in diameter and a pupil wobble of 0.080mm for a specification of 1.6mm and 0.320mm respectively.

The final step for the OD setup is to create a reference target in front of the OD that will be used for the alignment of the OD on the Extension Beam. This target consists in a reticle and a flat mirror attached to the ODM (Figure 8, Right).

The second step of the FO alignment process is to create one Optical Axis (OA) that will be the reference for the OD alignment on the EB. The ST and 2 adjustable Pentaprisms (PP1 and2) are used to create this OA (Figure 9, Left). RefEB1, RefEB2 and M3 are used to align the Pentaprisms, nevertheless as each reference target is not perfect; It is not possible to create an OA that is centered and perpendicular onto each target. RefEB1 and M3 are the most important references so RefEB2 has been partially used.

Then, the 2 Anamorphic Mirrors have been inserted in the optical path and aligned in order that M3 is centered (Figure 9, Right). Because of the anamorphose, it is not possible to see the autoreflexion of RefEB1 onto M3 with the ST. To cope with this, the FO Field Lens was inserted in the optical path, if M3 stays centered, it means the optical axis is orthogonal to the FO Field Lens and thus to M3. We obtain then an OA with a decenter below 0.3mm and with a tilt below 1arcmin wrt M3.

Finally, the OD is inserted and aligned in X, Y and Tip/tilt using its reference target, with the already know criteria: reticle and autocollimation seen stable with the ST when the OD rotates. The alignment target is then removed and final check is performed looking at M3 wobble and the autocollimation cross wobble with the PIC tool. The pupil wobble has increased to 0.120 μ m and M3 reaches now 1.4mm which is compatible to 0.62mm of residual wobble and the decenter of 0.3mm of the OA wrt M3.

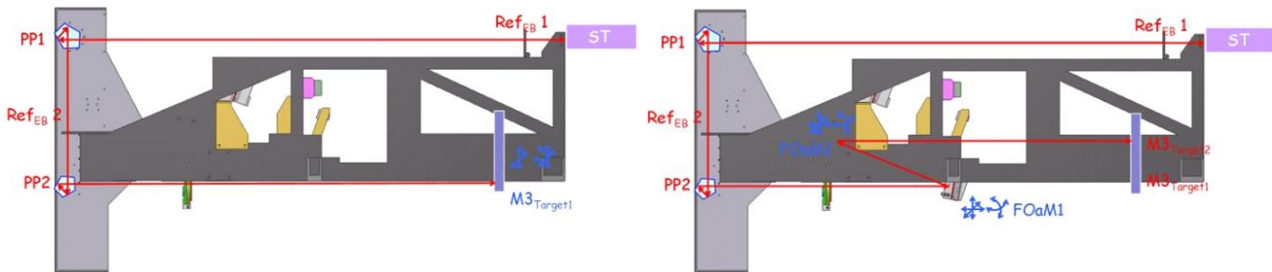


Figure 9: Left: Definition of optical axis. Right: Alignment of 2 anamorphic mirrors

4.2.3 Calibration Unit alignment

Once the FO Anamorphic Mirrors and the OD are aligned, the ST, RefEB1 and 2 and the Pentaprisms mount are removed so that the CU Integrating Sphere, the 2 CU Folding Mirrors, the CU Relay Lens and the CU stages with its set of Calibration Masks can be mounted (Figure 10). The alignment process is simple and consists to align the CU optical beam onto the OD optical axis by minimizing both image and pupil wobbles seen by the PIC. Here wobbles are decoupled: the folding mirror before the CU mask along the optical path only affects the pupil, The CU mask decenters in X and Y helps to align the FoV without affecting the pupil. The 2nd FM stays in a fixed position.

Finally, the focus is done thanks to the Z translation stage of the CU Mask using a camera at the FO exit (with the FO Field Lens included). This adjustment takes into account the missing glass thickness of 20mm of SILICA that exists in the FSU assembly.

A wobble image of 1.1mm and pupil wobble of 0.201mm are measured which is compliant with requirements (1.6mm in Fov and 0.320mm in pupil). The FSUnit can be inserted and aligned and after the Extension Beam can be move on the Instrument Main Structure (Figure 10, Right).

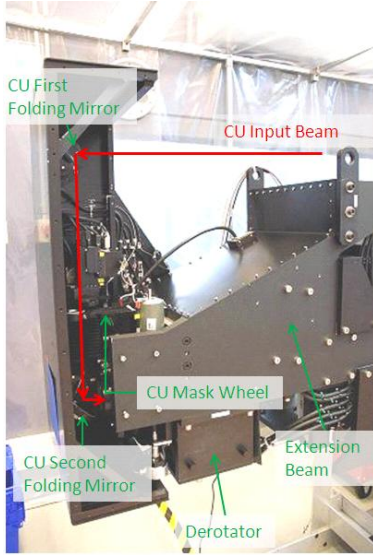


Figure 10: Left: Calibration Unit Front Plate. Right: Integration of Extension Beam onto MUSE structure

4.2.4 Field Splitter Unit (FSU) alignment

To align the FSUnit wrt FO, a FO Simulator is used. It is composed of a ST focusing from a finite to infinite planes, a folding mirror at 45° mounting onto vertical translation stage deflecting the vertical beam into a horizontal beam for feeding the field separator, a mechanical mount keeping all optics in position and switching them in and out the MUSE beam and a target for aligning the vertical motion.

First, the ST is aligned wrt RefEB4 in position and orientation (Figure 11, Left – Step1). The FSUnit is installed and aligned in (x, z, θ_y) until the target located onto the FSUnit baseplate remains centred onto the ST (Figure 11, Left – Step1). Second, folding mirror translation along y-axis is adjusted with the target onto Folding Mirror (telescope mode). Third, Folding Mirror (θ_x, θ_y) is adjusted until M3 remains centred in (x, y) into ST (autocollimation mode) (Figure 11, Left – Step2). The contingency in position are checked between RefEB4 and M3 mirror. The folding mirror is set onto $M3_{\text{Target}}$ corresponding to the theoretical position of the 25th mirror of the field separator (Figure 11, Left – Step3). The contingency between M3 mirror and 25th mirror of FSep is noted. For the first alignment, they are consistent in θ_x within $15''$ accuracy and in θ_y within $30''$. The FSUnit is readjusted in θ_y until 25th mirror remains centred into ST (autocollimation mode). Now, the FSUnit is fixed into its position.

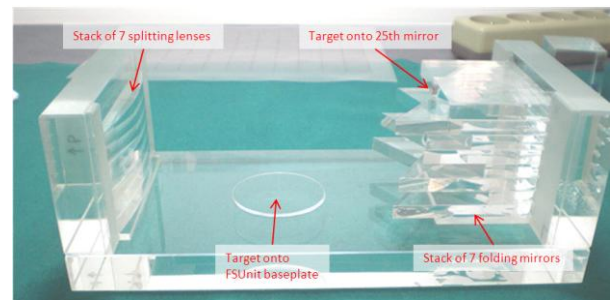
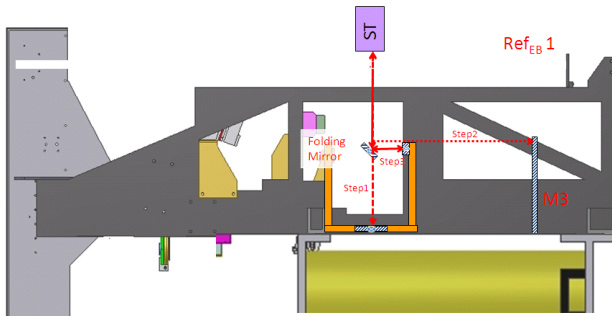


Figure 11: Left: Field Splitter Unit (FSU) alignment. Right: Field Splitter Unit prototype with stacks of 7 lenses and 5 active mirrors.

4.3 Alignment of 24 channels

The alignment of 24 channels consists of the alignment of the Extension Beam wrt IMS, Relay Optics (RO) and IFUs into IMS. This sequence is repeated 24 times expect for the alignment of the EB onto IMS which is done only once.

4.3.1 Integration of Extension Beam wrt IMS

The Extension Beam is installed thanks to pins precisely to $\pm 50\mu\text{m}$ in x, z and θ_y onto IMS with the crane (Figure 10). The FM1 mapping consists of a process to optimize the FSUnit position and orientation wrt 24 channels. For that, five reference spherical mounted reflectors (SMR) are located onto corresponding FM1 mirrors of channels n°18, 19, 21, 22, 23 (Figure 12). They are located within mechanical tolerances wrt IMS positioning and checked with laser tracker. They have to be placed at different distance from the FSep to allow reasonable angular resolution. Thanks to the FO-Simulator, which has been aligned with mechanical references of the Extension Beam (§4.2.4), the offset in x and y axes is measured with SMR and compared with their respective decenters (Figure 12). If the optical check is out of specification for the SRO acceptance range ($\pm 1\text{mm}$, $\pm 0.5^\circ$), there are 2 options for last adjustments. First, FSUnit is readjusted in x, z and θ_y wrt FM1 mapping until it stays inside FO tolerances. Second, the EB is adjusted wrt IMS in y, θ_x and θ_z by shimming. The FSUnit is aligned with respect to the M3 mirror in theta X. Then X, thetaY and Z degrees of freedom have been tuned to reach the best compromise on the 5 paths available of the FSO prototype. The Figure 12 shows the results of FM1 mapping of the autoreflection on the FO simulator of the laser tracker ball positioned at each FM1 mirror. The alignment in X and Y is inferior 0.5mm except for Y of path 18 and 22 where a shimming of the mirror has to be anticipated.

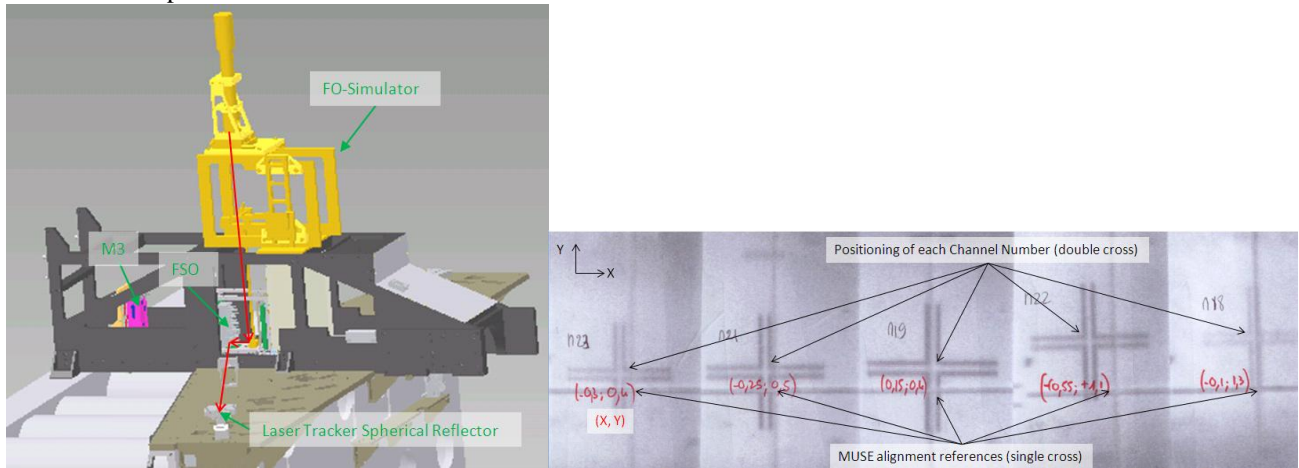


Figure 12: Left: SRO Pre-alignment with FO-Simulator. Right: Results of FM1 mapping onto channels n°18, 19, 21, 22, 23

4.3.2 Alignment of Relay Optics

The main tool to align the Relay Optics is the IFU Simulator. It allows to:

- Pre-align the SRO with FO-Simulator ($\pm 1\text{mm}$; $\pm 0.5^\circ$),
- Align the FoV and Pupil coming from {CU+FO+SRO} ($\pm 0.1\text{mm}$; $\pm 0.02^\circ$),
- Perform image quality of {CU+FO+SRO},
- See any vignetting into all SRO optical components planes.

The IFU Simulator is composed of (Figure 13):

- Same interface as IFU called IFU Flange which is the reference for SRO/IFU interface,
- A detection module with a camera objective, a teleconverter x2 and Apogee CCD to record the FoV and pupil. This detection could sight from IFU input plane to infinity,
- A target located into the IFU entrance plane. The central part (target and mirror) is only dedicated to the SRO pre-alignment alone with the FO-Simulator. The extremity part is dedicated to {CU+FO+SRO} alignment, image quality and vignetting tests.

The IFU Simulator is aligned and characterized independently using Romer arm measuring device for positioning and autocollimator for orientation. The IFU Simulator is inserted into the IMS at the respective channel position. The mirror of the FO-Simulator is slid vertically to sub field slice of the field separator according to position of the IFU Simulator. FM1 and a calibrated target mounted onto FM2 position are installed. The ST is focused onto this target. FM1

is aligned in (z, θ_x, θ_y) until the target is centred onto ST. FM2 is installed onto IMS. FM2 is aligned in (z, θ_x, θ_y) in using an iterative process with the ST focused either onto IFU Simulator target or at the infinity.

The imaging optics (singlets and doublets) of the corresponding relay path are inserted into the beam before the last alignment step takes place. In order to mimic the original light path, the calibration unit CU and the FO is used for illumination. Illuminating by this way will take into account residual errors of the Fore Optics in telecentricity that is compensated out by the SRO optics. Observing is done with the IFU-Simulator. The fine adjustment does concentrate on the folding mirrors FM1&2 of SRO that will feed the image slicer of each IFU. The tolerances of the imaging lenses are not very tight, therefore mechanical tolerances are sufficient and do not need extra alignment. Fine-adjustment is performed into the relay path by squaring up and centering the beam on the IFU-simulator with FM1/FM2 (z, θ_x, θ_y) in few iterative processes.

For the first channel alignment, the position of pupil and field is within specification ($<0.1\text{mm}$; <1 arcmin) except for the θ_z position of the field (Figure 13, Right): 18 arcmin remain instead of the ± 1.5 arcmin specified. It should mainly come from the FSep mirror angle, could also get a combined impact from the FM1 and FM2 misalignment. It is a complex procedure to identify. At the present time, it is still investigated. The Figure 13 shows that there is no vignetting onto SRO channel and measured PSF is 95% of ensquared energy into one MUSE spaxel which is compliant with requirement of 90%.

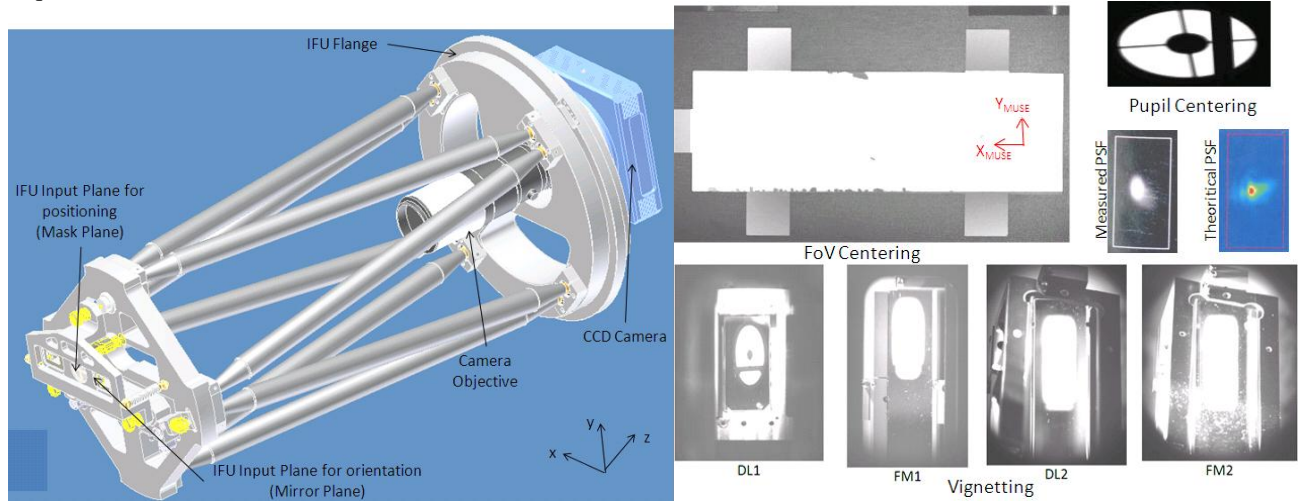


Figure 13 : Left: General View of IFU Simulator. Right: Results of SRO Alignment with IFU Simulator: FoV and Pupil Centering, PSF and vignetting

4.3.3 Integration of IFU into IMS

No alignment is done when the IFU is inserted into structure due to functionality of the IFU Simulator because the same reference IFU Flange is used. All IFUs are composed of one Image Slicer Subsystem (ISS), one Spectrograph (SPS), and one Detector Vessel (DV). Each of these subsystems is assembled and tested before to be integrated into the IFU ([10] and [11]). To validate independently each IFU, the same tools that were mounted onto IMS are used (replica of IMS mechanical interface and alignment of Illumination Unit with the IFU Simulator). Thanks to this philosophy, no further alignment needs to be done after the IFU is inserted. Nevertheless a dedicated tool, named IFU Positioning (Figure 14), is needed. This tool allows to insert each IFU at its corresponding z-angle and to insure a perfect positioning ($<30\mu\text{m}$) and orientation ($<30''$). This step is duplicated 24 times.



Figure 14: IFU Insertion onto IMS with IFU Positioning Tool

4.4 Alignment of MUSE wrt VLT Simulator or Telescope

That is the last step of the MUSE alignment corresponding to the alignment of MUSE wrt VLT Simulator. The FO Pupil&Image Check (§ 4.2.2) is set in position in order to see the pupil and field coming from the CU. MUSE is tilted and translated until there is the superimposition of pupils and fields coming from CU and VLT Simulator. The adjustments available for MUSE are the same as for the IMS before (§4.1).

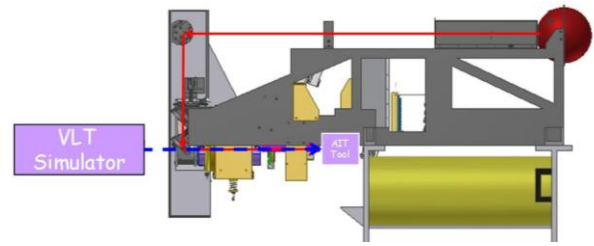


Figure 15: Alignment of MUSE wrt VLT Simulator

5. FIRST RESULTS OF END TO END TESTS

The success of this alignment approach is demonstrated by the correct results for the MUSE positioning and image quality. A MUSE detailed results of the end-to-end tests are presented by Loupias et al. during this conference [6]. Only positioning and image quality results are summarized hereafter. The Figure 16 presents a raw CCD image of MUSE channel 18 at the best focus. The CU continuum lamp illuminates across the entire FoV. Forty eight spectra corresponding to 48 mini slits are represented onto the Figure 16. Due to θz defects within SRO channel 18 (§ 4.3.2), four slits are lower illuminated. That shows the coherence between IFU Simulator and its corresponding IFU (Figure 13).

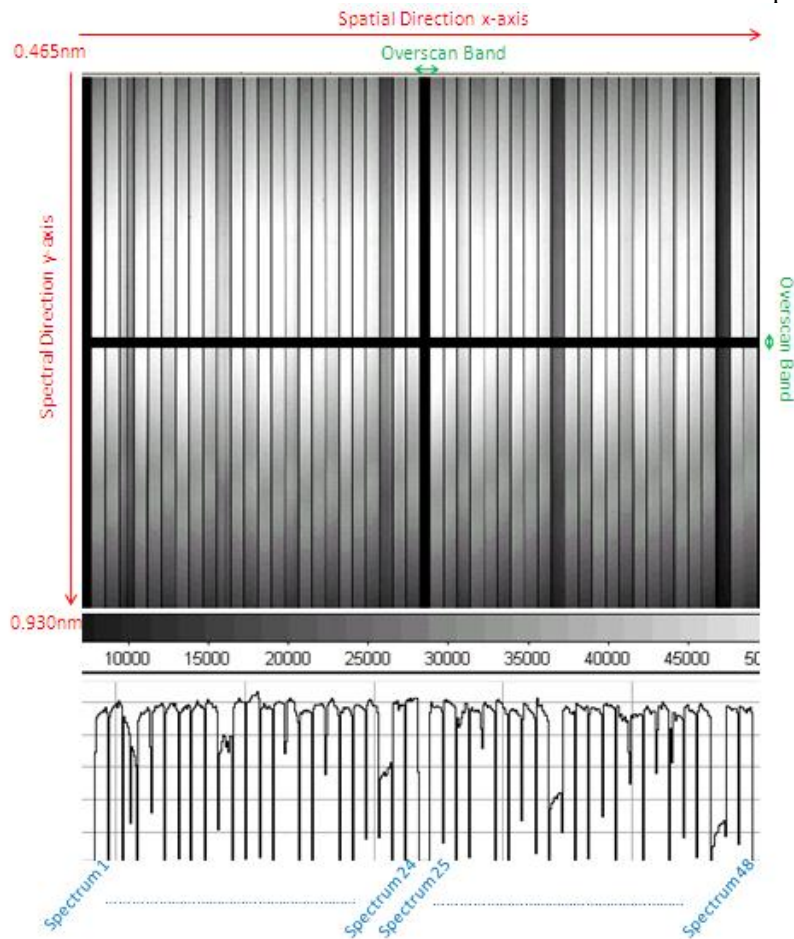


Figure 16: MUSE Continuum flat field exposure of one single channel (out of a total of 24)

For the WFM, the image quality has been measured using the Calibration Unit [3] that illuminates a grid of pinholes with spectral lamps (HgCd, Ne and Xe). These spots are re-images through the entire optical path of channel 18 and the resulting PSF is measured at the final detector plane. The MUSE Image Quality is within the requirements (Figure 17) but it needs to be determined for all other channels and re-measured after the retrofits are done.

CCD area	EE of IFU itself	EE of Channel_18	EE Spec
465 nm < λ < 600 nm	1.30 pixel	1.85 pixel	2.20 pixel
600 nm < λ < 800 nm	1.18 pixel	1.48 pixel	1.90 pixel
800 nm < λ < 930 nm	1.37 pixel	1.73 pixel	1.78 pixel

Figure 17: MUSE Image Quality onto Channel 18

6. CONCLUSIONS AND FUTURE DEVELOPMENTS

The first integration and alignment of MUSE main opto-mechanical subsystems validates global optical design, MAIT process and few top level performances. In the present case, this first MUSE alignment reveals a certain number of validations which are very encouraging on the road towards the official Preliminary Acceptance in Europe through ESO. Nevertheless, some non compliances mostly linked to FSO defects have been identified and should be solved for the next steps.

The MAIT process has been demonstrated to be feasible. No major alignment showstoppers have been identified and it can be concluded that the MUSE alignment process works well. A huge experience has been collected from this MUSE first channel alignment and tests. Some modifications on alignment tools and on the process have been identified in order to optimize the final alignment onto the telescope. The integration of the 23 remaining channels needs to be done following the now established procedure.

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