MUSE instrument global performance analysis

M. Loupias*[a], R. Bacon[a], P. Caillier[a], A. Fleischmann[c], A. Jarno[a], A. Kelz[b], J. Kosmalski[a], F. Laurent[a], M. LeFloch[d], JL. Lizon[f], A. Manescau[f], H. Nicklas[c], L. Parès[d], A. Pécontal[a], R. Reiss[f], A. Remillieux[a], E. Renault[a], M.M. Roth[b], G. Rupprecht[f], R. Stuik[e]

[a]Université de Lyon, Lyon, F-69003, France; Université Lyon 1, Observatoire de Lyon, 9 avenue Charles André, Saint-Genis Laval, F-69230, France; CNRS, UMR 5574, Centre de Recherche Astrophysique de Lyon; Ecole Normale Supérieure de Lyon, Lyon, F-69007, France;

[b]Astrophysikalisches Institut Potsdam, An der Sternwarte 16, 14482 Potsdam, Germany;

[c]Institut für Astrophysik, Georg-August-Universität, 37077 Göttingen, Germany;

[d]Laboratoire Astrophysique Toulouse Tarbes, Université de Toulouse, CNRS, 14 av. E. Belin, 31400 Toulouse, France;

[e]Universiteit Leiden, P.O. Box 9513 NL-2300RA Leiden, The Netherlands;

[f]ESO, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München, Germany

ABSTRACT

MUSE (Multi Unit Spectroscopic Explorer) is a second generation instrument developed for ESO (European Southern Observatory) and will be assembled to the VLT (Very Large Telescope) in 2012. The MUSE instrument can simultaneously record 90.000 spectra in the visible wavelength range (465-930nm), across a 1*1arcmin² field of view, thanks to 24 identical Integral Field Units (IFU). A collaboration of 7 institutes has successfully passed the Final Design Review and is currently working on the first sub-assemblies. The sharing of performances has been based on 5 main functional sub-systems. The Fore Optics sub-system derotates and anamorphoses the VLT Nasmyth focal plane image, the Splitting and Relay Optics associated with the Main Structure are feeding each IFU with 1/24th of the field of view. Each IFU is composed of a 3D function insured by an image slicer system and a spectrograph, and a detection function by a 4k*4k CCD cooled down to 163°K. The 5th function is the calibration and data reduction of the instrument. This article depicts the breakdown of performances between these sub-systems (throughput, image quality…), and underlines the constraining parameters of the interfaces either internal or with the VLT. The validation of all these requirements is a critical task started a few months ago which requires a clear traceability and performances analysis.

Keywords: 3D spectroscopy, MUSE instrument, system analysis, performance validation

1. INTRODUCTION

MUSE project has passed the Final Design Review in March 2009. The next steps are the acceptance in Europe in 2011-2012 and the delivery to the VLT, in Paranal Chile in 2012. There MUSE will meet GALACSI[10] (Ground Atmospheric Layer Atmospheric Corrector for Spectral Imaging) the adaptive optics system conceived and realized by ESO. MUSE main modes Wide Field and Narrow Field modes will benefit from the Adaptive Optics correction of GALACSI. This AO system will enable MUSE to cover a broad range of astrophysical applications, ranging from monitoring of the Solar System outer planets to spectroscopy of very high redshift galaxies. The most challenging scientific and technical application[1], and the most important driver for the instrument design, is the study of the progenitors of normal nearby galaxies out to redshifts z>6. This main scientific goal will make use of ~80 hour exposure in Wide Field Mode, which images a 1*1 arcmin² field of view with a resolution of 0,2 arcsec, and a spectral resolution of ranging from 1750 at 465nm to 3750 at 930nm. This imposes very high constrains in instrumental throughput and image quality including its stability. That is why MUSE design has been pushed to minimize the number optical elements, and the number of movements to operate the instrument. The section 2 describes the various MUSE sub-systems. Section 3 gives a detailed overview of the different design criteria, like the image quality, throughput trade-off... Section 4 deals with the interfaces between sub-systems, and section 5 presents the MUSE performance validation, followed by the conclusion.

*send correspondence to loupias@obs.univ-lyon1.fr; fax +33 478868386

Modeling, Systems Engineering, and Project Management for Astronomy IV,
edited by George Z. Angeli, Philippe Dierickx, Proc. of SPIE Vol. 7738, 773804
© 2010 SPIE · CCC code: 0277-786X/10/$18 · doi: 10.1117/12.857212

2. MUSE DESIGN AND FUNCTIONAL ANALYSIS

2.1 Fore Optics sub-system

The Fore Optics (FO) function is to adapt and reshape the telescope image through a derotation, an anamorphose and a stabilization step. The Very Large Telescope is an alt-azimuthal mount. Its Nasmyth focus rotates with the parallactic and altitude angle. The first function of the FO is to derotate the field of view through a derotator. The anamorphose of the field, done just after the derotation, insures the Nyquist criteria for the spectral sampling. MUSE has two functional modes a Wide Field Mode (WFM) and a Narrow Field Mode (NFM). A mode switching unit can be included in the beam path. It contains a magnification by 8 which increases the spatial resolution of the instrument in NFM to 0.025arcsec. For both narrow and wide field modes the stabilization of the field with respect to the telescope is mandatory. MUSE sits on the Nasmyth Platform which rotates and wobbles up to 100microns corresponding to ~0.2arcsec in the vertical direction. For NFM, the field stabilization uses the tip tilt star of the Adaptive Optics system located inside the FO sub-system. For WFM, a slow guiding system uses the remaining field between the square scientific field and the circular field supplied by the telescope to guide on a few natural stars. In NFM the interface stability between MUSE and GALACSI is maintained to better than 5mas RMS, while in WFM, the Slow Guiding System reduces the error in image quality due to shifts in the interface between MUSE and GALACSI to less than 35 mas RMS.

2.2 Splitting and Relay sub-system

The Splitting and Relay Optics associated with the Main Structure[3] insure the splitting of the field in 24 sub-fields. The Field Splitting Optics, see Figure4, is a complex optical assembly composed of 24 lenses stripes stacked in front of 24 reflective mirrors which spread the different paths from 16 to 36° on each side of the incident beam. The relay of the beam to the entrance of each Integral Field Unit is done by 2 mirrors combined with 2 to 3 lenses for each path. All these optics are mounted on the main mechanical structure. The critical performance for the Splitting and Relay system is its stability overtime.

2.3 The 3D sub-system

The 3D function is realized by the slicer[8] and spectrograph. The slicer cuts and rearranges the 2D sub field of view in a 1D pseudo slit of 0,2arcsec resolution. The spectrograph including a Volume Phase Holographic Grating disperses the slit in the perpendicular second direction and achieves a spectral resolution of 1750 at 465nm to 3750 at 930nm. The most constraining design parameter comes from the length and volume of the spectrograph to arrange 24 of them in a compact structure, the feasible height of the slice to reach the spatial resolution. The height of the slice in MUSE is set to 950microns, which induces a challenging manufacturing process[11]

2.4 The detector sub-system

The detection is performed by 24 CCDs cooled down to 163°K by liquid nitrogen flow. The vacuum and cryogenic system[9] insuring the optimum operating conditions of these CCDs is a complex design at the backside of the instrument. The very low read out noise, the high quantum efficiency increased by a graded anti reflective coating are key features of these CCDs. The chip has a format of 4k by 4k pixels of 15microns size.

The assembly of the 2 fore mentioned sub-systems, the 3D function and the detector, is called the Integral Field Unit (IFU) within the MUSE consortium.

2.5 The calibration sub-system

The main function of the Calibration Unit[2] is to mimic the beam of the VLT as closely as possible, to create a homogeneous focal plane, and feed it with different light sources. This illumination allows qualifying the response of the instrument, in terms of flatfield, wavelength calibration, image quality, geometry and optical aberrations. A MUSE efficiency monitoring system, thanks to calibrated photodiodes is also implemented. The data reduction software uses the calibration data to remove the instrumental signature and produce science ready data cubes.

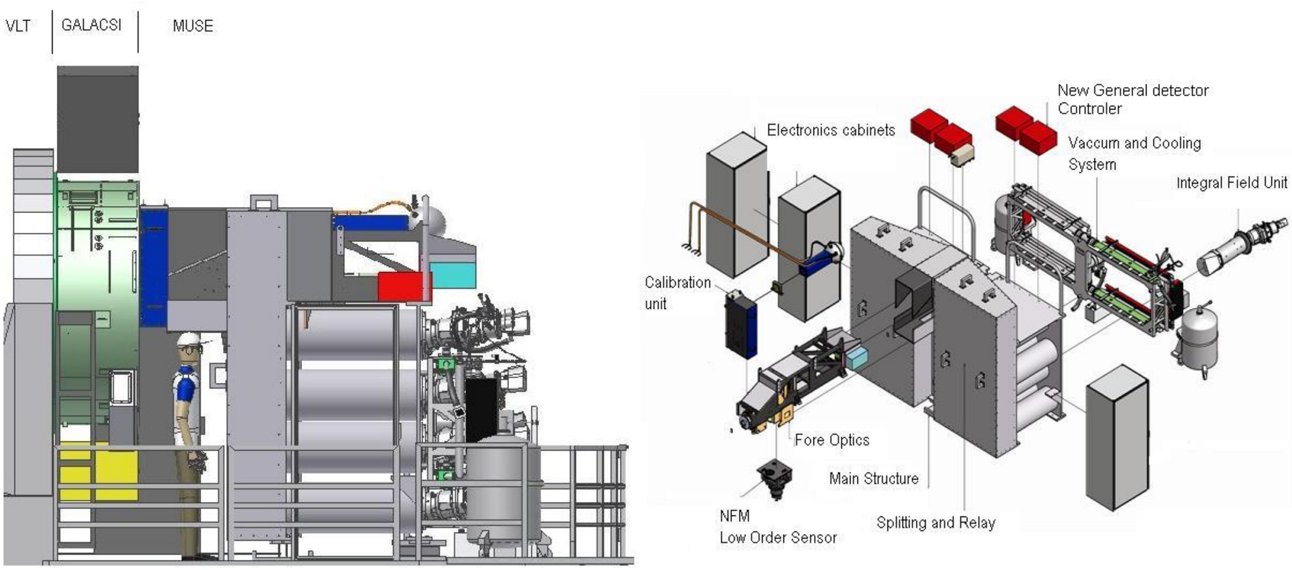

Figure 1: MUSE and GALACSI installed on the VLT Nasmyth Platform on the left, exploded view of MUSE sub-systems on the right

3. SYSTEM BUDGETS AND TRADE-OFFS

The conception, realization and test of the different functions of the instrument have been shared between the institutes of the consortium. The management[7] of different institutes work load and planning is a fundamental task to insure the final delivery. The project management team is located in Centre de Recherche Astrophysique de Lyon (France). The Calibration Unit is developed by AIP in Potsdam (Germany), the Fore Optics is built by LATT in Toulouse (France), the Splitting and Relay System is realized by IAG in Göttingen (Germany), the slicer and spectrograph are conceived by CRAL in Lyon (France), and the Detection system is the responsibility of ESO in Garching (near Munich, Germany). Each institute has its own design team and needs a set of requirements specific to its own sub-system only. For that reason, several budgets derive the top level instrumental requirements into sub-systems requirements guiding the different phases of the instrument development. In addition global designers in each field of expertise like, optics, mechanics and electronics, are in charge of assembling, and checking the homogeneity of sub-systems designs. Hereafter are described the current budgets used to validate the instrument. The most constraining ones are the Image Quality and Throughput budgets which are developed for the 4 first sub-systems: Fore Optics, Splitting and Relay, Slicer and Spectrograph, and Detector. The budgets regarding VLT platform, like mass or power consumption will also include the Calibration Unit. During the Preliminary Design Phase, some budgets had less than 10% margin. The design of MUSE has improved to gain some contingencies for throughput, mass, etc…The current budgets exhibit some savings, which are giving some margins for a successful conclusion at the end of the the realization phase.

3.1 Image Quality

This is obviously the most complex budget. The top level performance is given in terms of Full Width Half Maximum of the Point Spread Function during 1 hour exposure averaged over 3 different spectral bandwidths, called blue from 465 to 600nm, red from 600 to 800nm, and near infrared from 800 to 930nm. These 3 spectral bandwidths were selected to correspond to the increasing spatial resolution provided by the companion Adaptive Optics project GALACSI, which corrects better in the near infrared wavelengths. It is to note that the interfaces between the 4 main MUSE sub-systems are image planes. The easiest approach was to consider a Gaussian PSF. This assumption presents several advantages. It allows to quadratically sum the performance, to easily translate in percent of Ensquared Energy on one spatial pixel and distribute to the different sub-systems. This assumption considers independent sub-systems, this is a conservative approach since the global performance will be better than the sum of sub-system performances. This rule of thumb approach drove the first phases of Zemax design and tolerance analysis. The global image quality performance is divided in two sources: The designed image quality associated with manufacturing and alignment margins expressed in percent of Ensquared Energy in one spatial pixel, and the stability which includes thermal and mechanical drift in microns rms during one hour observation. An advantage to express the image quality in ensquared energy instead of PSF FWHM, is to constrain the energy in the core of the PSF.

From the preliminary optical design phase came the confirmation that most of the Image Quality budget was driven by the spectrograph. A lot of efforts have been spent to design an athermal spectrograph over the operational range 0 to 15°C, without any too fragile substrate, with the best performance for this very fast optical system (F/1.96). In order to reduce the number of optical surfaces for the throughput performance two sub-systems have been coupled: Fore Optics and Splitting and Relay achieve together 90% ensquared energy over one spatial pixel. The global optical design has assembled all sub-systems together, and has checked that the assembly is well within the quadratic sum of all the sub-systems, and allows a 15% margin for the alignment. The Narrow Field Mode image quality of the instrument is diffraction limited. The CCD is a peculiar optical system. Its image quality budget is estimated including the flatness of the chip, and the diffusion of charges in the chip substrate. The last step is then the pixelisation effect which is simulated by the convolution of the PSF by a Gaussian with a FWHM equal to the pixel size of 0,2arcsec.

The second part of the image quality budget is the stability. MUSE sits on a Nasmyth platform which turns with the azimuth angle of observation. The differential dilation of the steel structure of the telescope compared to the MUSE aluminum structure, and the relative motion of MUSE on its platform brings 0,18arcsec rms motion. Adding to this the tracking accuracy of the telescope 0,2arcsec rms, or the MUSE derotator wobble 0,12arcsec rms, it was necessary to implement a Slow Guiding System (SGS) to correct for differential motions between the telescope and MUSE. The goal of the SGS is to stabilize the field up to 0,03 arcsec rms. This system is embedded in the Fore Optics sub-system, so that the stability requirement of the FO is restricted to the stability between the SGS detector and the FO output image plane. The main contribution to this budget comes from the Splitting and Relay system. A wide Finite Element Analysis has been performed to estimate the impact of the wobble of the platform and the thermal deformation under operational conditions. This analysis drove many designs tuning of the Main Structure and of the optics mounts for the Relay optics to stay within the requirement of 28microns rms during 1 hour observation. In smaller proportion the IFU design was also oriented by stability considerations. For example the cooling system with continuous flow of nitrogen was preferred to the compressor solution to avoid vibrations for the VLT Interferometry among others arguments.

The following table summarizes the current image quality budget of the MUSE instrument.

REQUIREMENT		**VALUES**					
		Fore Optics	Splitting & Relay	Slicer	Spectrograph	Detector	MUSE
Image quality in WFM in % of Ensquared Energy in 1 spatial pixel	465<λ<600nm	>90%		>92%	>82% EE in 2 spatial pixels	>54%	>29%
	600<λ<800nm			>90%	>80%	>74%	>40%
	800<λ<930nm			>88%	>80%	>85%	>44%
Stability at the sub system output plane in 1 hour in microns rms		Slow guiding system~7	28	2	2		

Table 1: MUSE image quality budget.

3.2 Throughput

Instrument throughput has a direct impact on science. This led us to a major effort to optimize this budget. During the design phase, each sub-system had the strong constrain to minimize the number of optical surfaces. For example the first design of the Fore Optics sub-system was using 2 plane mirrors to redirect the beam and 2 lenses to magnify it, a main design evolution has been to put radius of curvature onto the mirrors to remove the lenses. These optical surfaces were gained at a cost of loss of independence in image quality specification between 2 sub-systems. We have experienced number of durability problems on different kind of coatings, in nominal or abnormal conditions. That is why the qualification of all coating designs under representative environmental conditions (assembly and integration, transport, operation) is mandatory. A study has been launched to assess the feasibility of dielectric coating for MUSE mirrors. This technology exhibits better performance and durability than protected silver enhanced coating. Nevertheless each mirror case needs a dedicated analysis, since the planarity of these multi-layers coatings is worse than the metallic ones, and the sensitivity to incidence variation is higher. The Volume Phase Holographic Gratings are also key elements for the throughput performance. They have required of a long iterative process with the supplier to define final performance. A test bench has been set up[7] on purpose, in Lyon, to test the efficiency of these critical gratings. It has revealed a non uniformity on the first grating over its surface which is used on 70*110mm. The process has been improved by the supplier for the series production. Another critical element is the detector quantum efficiency. The performances of the MUSE detectors are exceptional. A graded anti reflective coating is deposited on the chip. Its thickness varies along the spectral direction. This optimizes the quantum efficiency as a function of the wavelength detected since a given position on the chip detects only one wavelength. The extensive tests done with the chip to qualify the quantum efficiency are a major step in the validation of the instrument.

The budget and the estimation of the final throughput performance have evolved significantly over the design phases as a function of technological improvements. The budget is now stable and the current estimation exhibits a comfortable margin as shown in the table below. Nevertheless the cleanliness of the integration phase and the conservation of the performance until the acceptance in Chile remains a difficult parameter to assess, and will induce particular care in the integration and test sequence. To be noticed that the nominal Wide Field Mode of MUSE uses a blue cut off filter to remove the second order pollution by the grating. This high-pass filter at 465nm removes the second order contamination which can rise up to 8% in the redder part of the spectrum. The * in the table means that the blue filter is taken into account, so that the average over the bandwidth ranges from 480 to 600nm only.

REQUIREMENT		**VALUES**					
		Fore Optics	Splitting & Relay	Slicer	Spectrograph	Detector	MUSE
Average optical efficiency WFM	465<λ<600nm	>0.895	>0.83	>0.90	>0.53	QE >0.85	>0.277*
	600<λ<800nm	>0.91	>0.87	>0.925	>0.69	QE >0.85	>0.395
	800<λ<930nm	>0.905	>0.84	>0.91	>0.57	QE> 0.6	>0.217
ESTIMATION		**VALUES**					
Average optical efficiency WFM	465<λ<600nm	>0.90	>0.83	>0.92	>0.63	QE >0.94	>0.40*
	600<λ<800nm	>0.91	>0.87	>0.94	>0.71	QE >0.94	>0.49
	800<λ<930nm	>0.89	>0.84	>0.95	>0.67	QE> 0.71	>0.33

Table 2. MUSE throughput budget and estimation.

3.3 Mass and power consumption

The VLT Nasmyth platform accepts up to 8 tons. This limit has to be shared between the sub-systems of MUSE and some electronics of GALACSI, since this fore mentioned instrument is attached to the rotating adaptor of the Nasmyth focus. At the time of the preliminary design phase, the mass estimation was very close to the limit. The power consumption of MUSE and GALACSI electronics was too demanding for the 2 Nasmyth platform service connection points which deliver 2kW Unaltered Power Supply (UPS) and 6kW normal power each. It was decided to deport electronics from the Nasmyth Platform to the Azimuth Platform below. Then some more savings in mass were realized on the Main structure and on the IFU which is multiplied by 24. Here is the current mass budget and estimation which exhibits safe margin of 13% at this phase of the project. Concerning the power consumption, today the estimation is 3.5kW of unaltered power and 7.1KW of normal power are necessary on the Nasmyth platform which correspond to 10% and 40% margins respectively.

Subsystems	Specification	Current Estimation
	Kg	Kg
GALACSI	650	524
Calibration Unit	80	80
Fore Optics	280	270
Splitting and Relay	150	140
3D function	1920	1736
Detector	2200	2008
Electronics	500	445
Main Structure	1850	1765
Total	7630	6968
Margin (Kg)	370	1032
Margin (%)	5%	13%

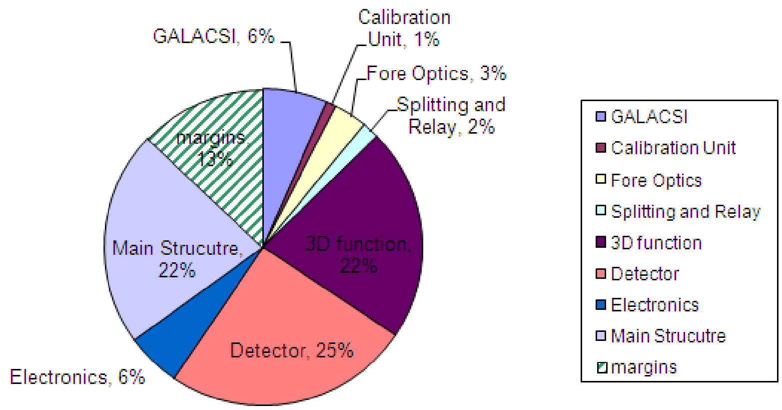

Table 3. MUSE mass budget and estimation

4. INTERFACES BETWEEN SUB-SYSTEMS

The early design of the interface is a critical task. Sub-systems designers are often concentrated on their internal design and hardly realize the need of a clear interface definition between sub-systems at an early stage. For MUSE we have tried to reduce to its minimum the number of interface documents. In total 6 Interface Control Documents (ICD) have been defined, 2 of which are external, the others being internal to the instrument, as depicted in the following scheme.

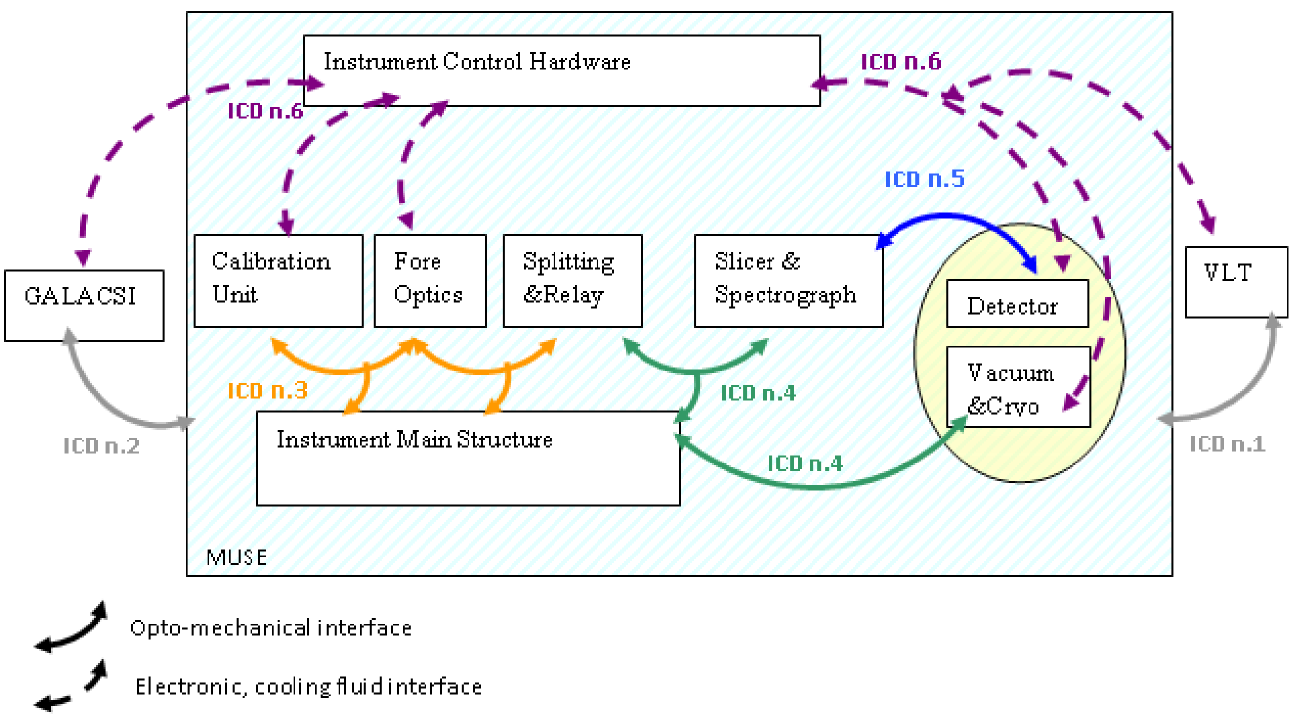

Figure 2: MUSE interfaces documentation architecture

Each Interface Control Document (ICD) contains the coordinates of the sub-system. Reference frames for optical object and image planes, mechanical references frames are defined. They are positioned with respect to the MUSE global coordinate system. Another section defines the tolerances in positioning of the different elements of the interface on the 6 degrees of freedom. Most of the sub-systems have their optical interfaces on image planes, the tolerances for field size and aperture are defined. One single ICD is dedicated to electronics for the complete instrument, where 3 out of 5 sub-systems are concerned. The interfaces make the difficult trade-off between minimizing the number of alignment degrees of freedom, and on the other hand insuring the proper alignment and reducing the risk of re-machining. At this phase of the MUSE project all the interfaces documents are in a released version, which means that any request for modification has to go through a defined quality cycle of change request. Details of some interfaces are presented in the next chapters.

4.1 Splitting structure interface

Here is the example of the ICDn°4 in Figure 2. It insures the proper feeding of the IFU. On one side is the splitting and Relay system and on the other the IFU. The optical interface between these sub-systems is positioned onto the first optical element of the IFU the Image Dissector Array[8] (IDA). The global budget for this interface takes into account the oversizing of IDA with respect to the input image field and the tolerance to its pupil position. This budget is then shared in 3 parts: the purely mechanical interface, and the optical plane position with respect to their mechanical reference for IFU and Splitting system respectively. The mechanical interface is only defined by the tolerance of the interface drawing between the flange of the IFU and the back side surface of the Main Structure. Each of the 2 opto-mechanical tolerances is the responsibility of one sub-system. The Splitting and Relay sub-system is in charge of aligning the input beam with respect to the back flange of the structure within the defined tolerance while the alignment of the IDA image plane with respect to the IFU flange is the responsibility the other sub-system.

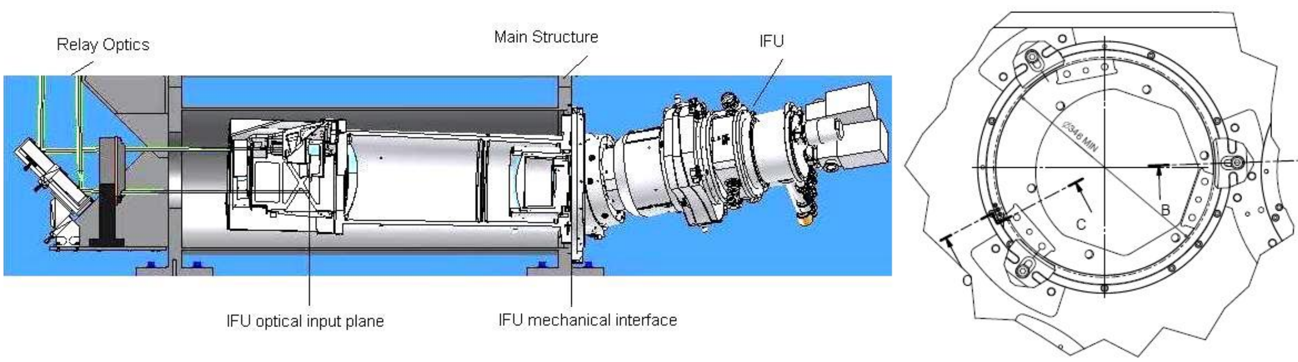

Figure 3: Side view of the interface between IFU, Main Structure and Relay Optics on the right, detail of the mechanical interface drawing of the IFU flange on the left.

4.2 Front extension interface

Part of this ICD (n°3 in the Figure2), details the connection between the Fore Optics and the Splitting and Relay System. In this case, it was not possible to fully disentangle the different contributions to this interface. Firstly the optical interface image plane is located inside the Field Splitting Optics (FSO). Two different optical designers have worked on two parts of the same piece of optics that will be glued together. Secondly the mechanics is also interconnected. The Field Splitting Optics sits on the mechanical structure of the Fore Optics called the extension beam. Here the number of interface drawings to be controlled is more numerous. The alignment process is also more deeply analyzed. Three degrees of freedom can be tuned on one side of the mechanical interface between FSO and the extension beam. On the other side, three plates of 5mm thickness are inserted in the design between the Extension beam and the Main Structure. They will be used a fuses to compensate for the three other degrees of freedom in case of mistake, or slight tolerance overpass. This removes the risk of re-machining the big structural mechanical parts.

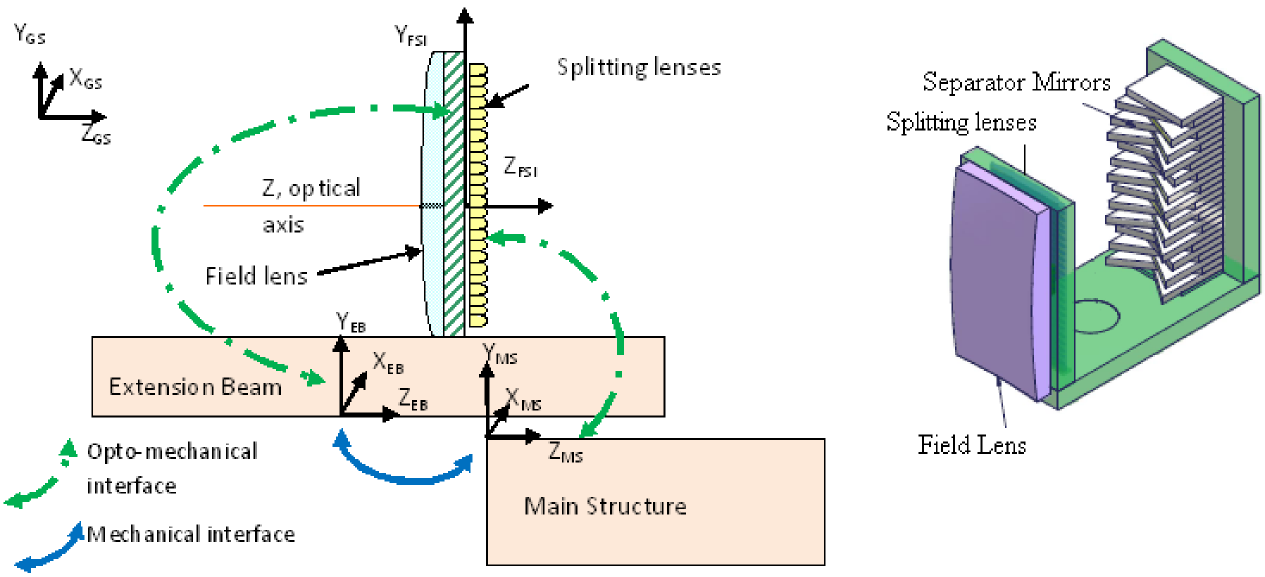

Figure 4: Schematic of the different actors of the front extension interface and their connections, on the left the Field Splitting Optics

5. INSTRUMENT PERFORMANCE VALIDATION

The verification matrix is the key component for the validation of the instrument. The specifications and interfaces requirements come from a top down process, whereas the verification follows the bottom up direction. The tests have started on the first manufactured items. One IFU has been fully assembled and tested[4]. Some elementary tests are critical and should not be neglected. For one of the main instrument performances, the throughput, it is mandatory to proceed to a detailed validation of the detectors. Monochromatic flatfield exposures can only be taken on the detector alone without the spectrograph. This test is necessary to be able to diagnose any second order pollution of the spectra caused by the grating. The Volume Phase Holographic Grating efficiency is a critical parameter, which follows a complex process for its manufacturing. A dedicated bench has been developed to early diagnose any discrepancy[5]. Another bench to measure the full spectrograph throughput performance is also being qualified. It aims at detecting any faulty coating or its degradation in time.

Aside from the throughput performance, the number of low response or lost pixels is also a system budget. The detector contributes to it, through the cosmetic of the chip: dark, bright pixels or columns, but also with traps pixels. This kind of pixel captures electrons, and releases them only after several readings of the chip. A dedicated test called "pocked pumping" uses a flatfield exposure and clocks the chip several times in both directions to reveal the trap pixel. This procedure can only be done in the laboratory and determines the position of these pixels necessary for a good data reduction of the images. Afterglow, linearity or fringing are other features of the chip which will be extensively tested at sub-system level to insure a proper analysis of the global instrument image.

The same importance of individual tests applies to the Image Quality validation. The estimation of an image quality defect on the assembled Integral Field Unit is difficult due to the pixelization effect of the detector. The elementary tests are hence crucial. Let's take the example of the first IFU tests. The wavefront error measurement of the slicer sub-system mirrors, or the oversampled measurement of the spectrograph PSF at supplier premise have proven their conformity in Image Quality. The detector flatness, or diffusion measurement were compliant to their requirements. The mechanical interfaces between these 3 sub-systems were checked. A dedicated bench in ESO could check the position of the chip with respect to its mechanical interface. A dedicated piece of software has been developed in Lyon to estimate the best focus position of the assembled IFU. The criterion of ensquared energy in one spatial pixel could not be used because the size of the pixel does not sample enough the PSF. That is why the software oversamples the image and calculates the side of the square which contains 80% of the PSF energy using a spline interpolation. This is our new test criterion. With all these tools developed and checks performed, it has been possible to detect a discrepancy in the whole IFU assembly test. We could then correct the faulty measurement bench. Along with the successive integration of MUSE elements, we will pile up the requirements to reach the high level instrument requirement which emphasizes again the care to take for the validation of the unitary tests. Any incoherence in the sum of performances will have to be investigated.

6. CONCLUSION

The MUSE consortium is well on tracks for the Preliminary Acceptance phase. The different budgets have been worked out to exhibit enough margins to resist to the current phase. This was achieved at the cost of more complex interfaces. The set of specifications and interfaces requirements are now stabilized and in released version since Final Design Review. Any change request has to be clearly notified to all concerned partners. A quality process has been set up to insure such an information flow and validation process. The elementary tests are the basis of the verification matrix, or of the pyramid of requirements. They have started on sub-systems and even on the first assembled Integral Field Unit. This first out of 24 has been retrofitted because of major non-compliances, but much was learnt from the testing process and we have upgraded most of our testing tools to reach the final performance. This exciting assembly phase has just started. This is the truth time, where we will discover unexpected feature (hopefully not too much!) interpret them, and validate the full instrument performance step by step until the ultimate test on the sky during the commissioning in Paranal…

ACKNOWLEDGEMENTS

We thank CNRS/INSU and University Claude-Bernard Lyon I for their strong support to the MUSE project.

REFERENCES

[1] Bacon, R., and al., “The second-generation VLT instrument: MUSE**”,** Proc. SPIE, 7735-7, (2010) in prep.
[2] Kelz, A., and al., “The calibration unit and detector system tests for MUSE”, SPIE, 7735-186, (2010) in prep.
[3] Kölher, C., and al., “Analyzing the MUSE opto-mechanics serving as an optical bench in 3D space”, SPIE, 7735-169, (2010) in prep.
[4] Laurent, F., and al., “MUSE Integral Field Unit: Test results on the first out of 24”, SPIE, 7739-9, (2010) in prep.
[5] Renault, E., and al., “Efficiency measurements performed on the MUSE VPHG”, Proc. SPIE, 7739-100, (2010) in prep.
[6] Renault, E., and al., “Optomechanical system of AIT tools to perform tests and integrations of 24 IFU”, (2010) in prep.
[7] Caillier, P., and al., “The MUSE project from the dream toward reality”, SPIE, 7738-29, (2010) in prep.
[8] Laurent, F., and al., “MUSE image slicer: test results on largest slicer ever manufactured”, Proc. SPIE, 7018-71, (2008).
[9] Lizon, JL., and al., "LN2 continuous flow cryostats, compact vibration free cooling system”, SPIE, 7739-154, (2010) in prep.
[10] Arsenault, R., and al., “ESO Adaptive Optics Facility », Proc. SPIE, 7015-75, (2008)
[11] Vives, S., et al., “New technological developments in Integral Field Spectroscopy”, Proc. SPIE, 7018-86, (2008)