Development of the fibres of MOONS

Isabelle Guinouard*[a], David Lee [b], Hermine Schnetler [b], William Taylor [b], Jean-Philippe Amans [a], David Montgomery [b], Ernesto Oliva [c]

[a] GEPI, Observatoire de Paris-CNRS-Université Paris Diderot-Paris Sciences et Lettres, 5 Pl. Janssen, 92195 Meudon, France;
[b]ATC, Royal Observatory, Blackford Hill, Edinburgh, EH9 3HJ, UK;
[c] INAF, Osservatorio Astrofisico di Arcetri 50125 Firenze, IT;

ABSTRACT

MOONS will exploit the full 500 square arcmin field of view offered by the Nasmyth focus of the Very Large Telescope and will be equipped with two identical triple arm cryogenic spectrographs covering the wavelength range 0.8 - 1.8 µm, with a multiplex capability of approximately 1000 fibres. Each triple arm spectrograph will produce spectra for half of the targets simultaneously. The system will have both a medium resolution (R~4000-6000) mode and a high resolution (R~20000) mode.
The fibres are used to pick off each sub field of 1.05 arcseconds and are used to transport the light from the instrument focal plane to the two spectrographs. Each fibre has a microlens to focus the beam into the fibre at a relative fast focal ratio of F/3.65 to reduce the Focal Ratio Degradation (FRD).

This paper presents the overall design of the fibre system and describes the specific developments required to optimise its performance. The design of the fibre input optics, the choice of the fibre connector, and the layout of the slit end are described. The results of preliminary tests to measure the effect of twisting on the FRD performance of prototype fibres are also discussed.

Keywords: MOONS, VLT, Optical fibres, Multi Object Spectroscopy

1 INTRODUCTION

MOONS is described in several papers of which "MOONS: an optical and near-IR multi-object spectrograph for the Very Large Telescope" (Cirasuolo & al.) [1] is the most important. Fibres are used to pick off each sub field and are used to transport the light from the instrument focal plane to the two spectrographs. The distance between the two determined the length of the fibre assemblies which in the current design is in the order of 10m.
The fibre light path consists of three fibre assemblies, namely the Fibre Front-End Assembly (FFA) and two Fibre Slit-End Assemblies (FSS) for each spectrograph. A schematic view of this system is shown in Figure 1.

Firstly the front-end fibre sub-assembly consists of the micro-lens, the micro-lens holder and one single 7 m fibre. On the fibre connector side of this assembly, the fibre end will be prepared to match the Multi-fibre Termination Push-on (MTP) male connector. Sixteen fibre front-end fibres will be combined into a fibre front-end sub-assembly by bringing the bundle together using a fork and insert the fibres into one 24 fibre MTP male fibre connector. Thirty two Fibre Front-End Sub-assemblies will be combined into a Fibre Front-End Assembly (FFA). Two FFAs will be required, one for each of the spectrographs. Each front-end fibre sub-assembly male fibre connector will be mated with its female counterpart, which is part of the Fibre Slit-End Sub-Assemblies (FSS). The two fibre slit-end assemblies are identical and consist of 32 fibre slit-end sub-assemblies. Each fibre slit-end sub-assembly consists of 16 slit-end fibres consisting of a fibre female connector, single fibre (approximately 3 metres in length) and terminates in a sub-slit.

* Contact: Isabelle.Guinouard@obspm.fr; phone +33-1-45077983; fax +33-1-45077709. GEPI, Observatoire de Paris

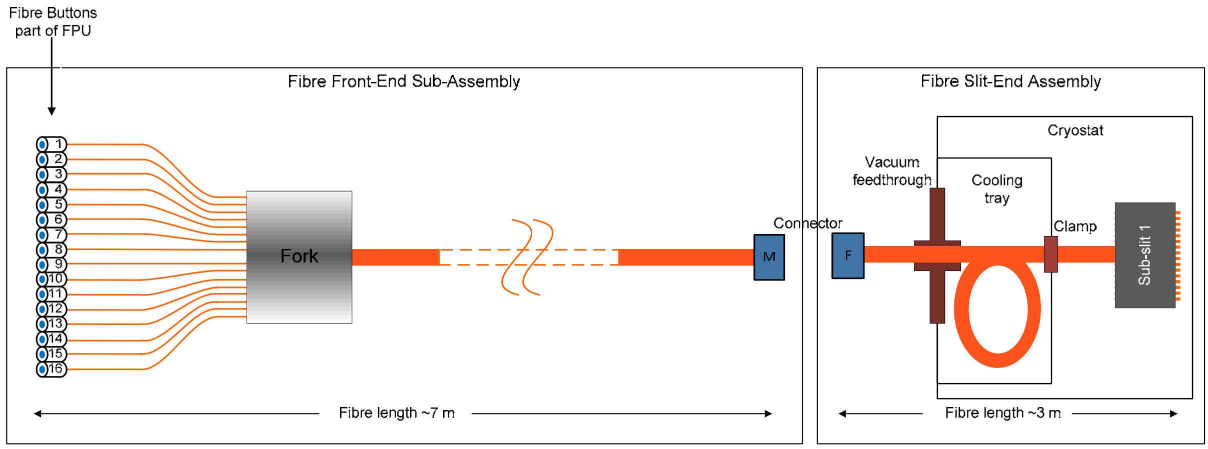

Figure 1 Bundle design

2 PRELIMINARY DESIGN

2.1 Fibre button optical design description

To comply with the science requirements, each fibre shall have an on-sky aperture ≥ 1 arcsec. The aperture is adapted by a single microlens glued onto a fibre with a core diameter of 150 µm. This lens will also help to limit the loss of light and is also required to speed up to focal ratio such that the output of the fibres will match the spectrograph's input focal ratio of F/3.5. The optical aperture conversion at the input of each fibre is shown in Figure 2. Thus in MOONS, we inject at a fast F ratio of F/3.65, which limits the FRD. At the output, the F ratio is slightly degraded and is at F/3.5.

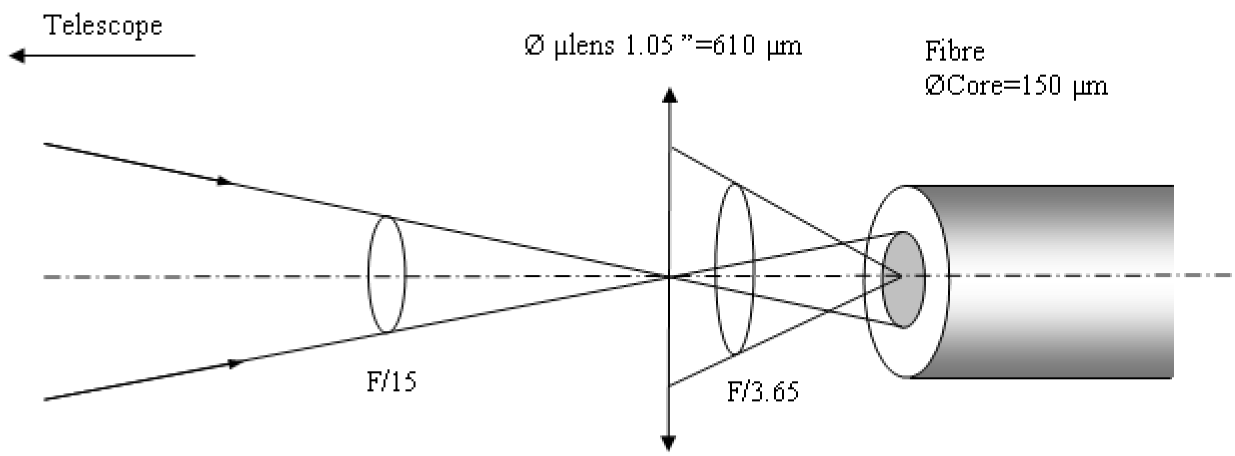

Figure 2 Fibre injection principle (pupil image on fibre core)

The size of the fibre button is minimised to allow close positioning of fibres. Due to the large number of fibres, the manufacturing and assembling process of the front-end fibres has to be simplified and needs to be robust.

As such the micro-lens preliminary design is done in collaboration with AMS. In order to simplify the design of the spectrograph and save costs, the micro-lens should simply consist of using a standard coloured glass (e.g. RG-630 or RG-695, data sheet in Figure 3).

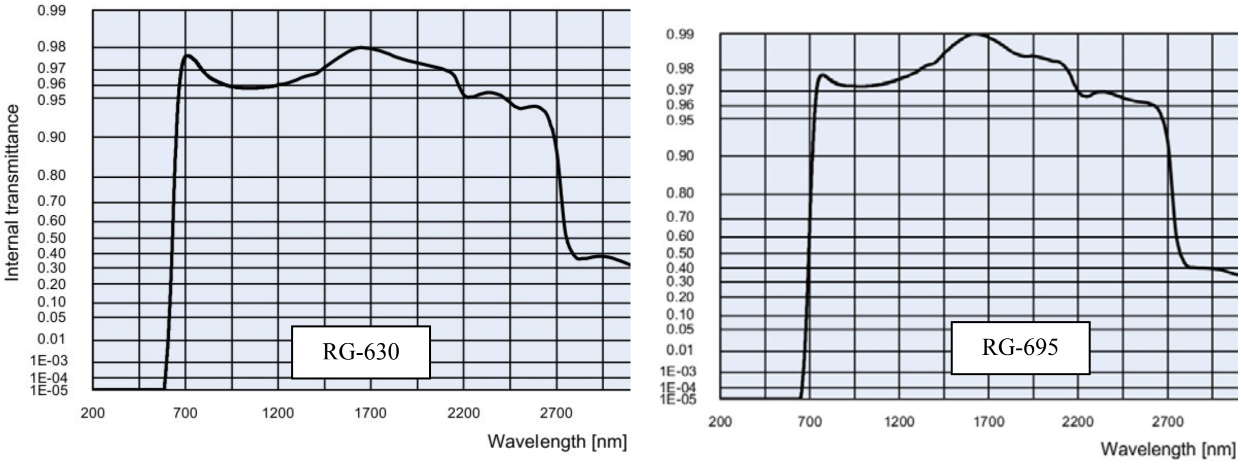

Figure 3 RG-630 & RG-695 Data Sheet from Schott

The micro-lens plays the role of the filter in order to block the second and higher orders. The micro-lens is a circular lens on a square base as shown in Figure 4. Around the lens, a field stop is needed to block the parasite light. (Oliva & al.,[2])

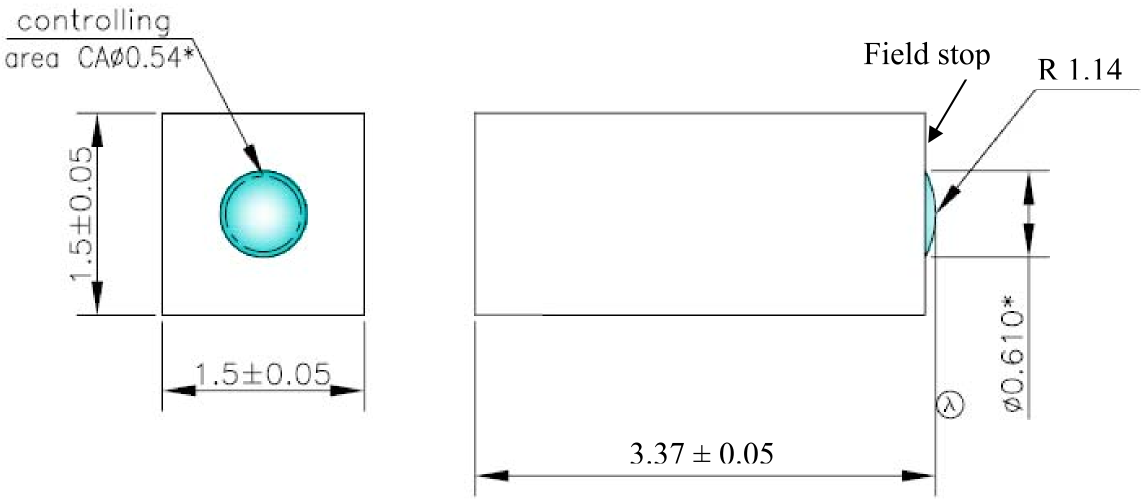

Figure 4 Preliminary design of the microlens (AMS)

2.2 Fibre selection

At this stage, only Polymicro were investigated. Polymicro fibres are well known and are used in various astronomical instruments.

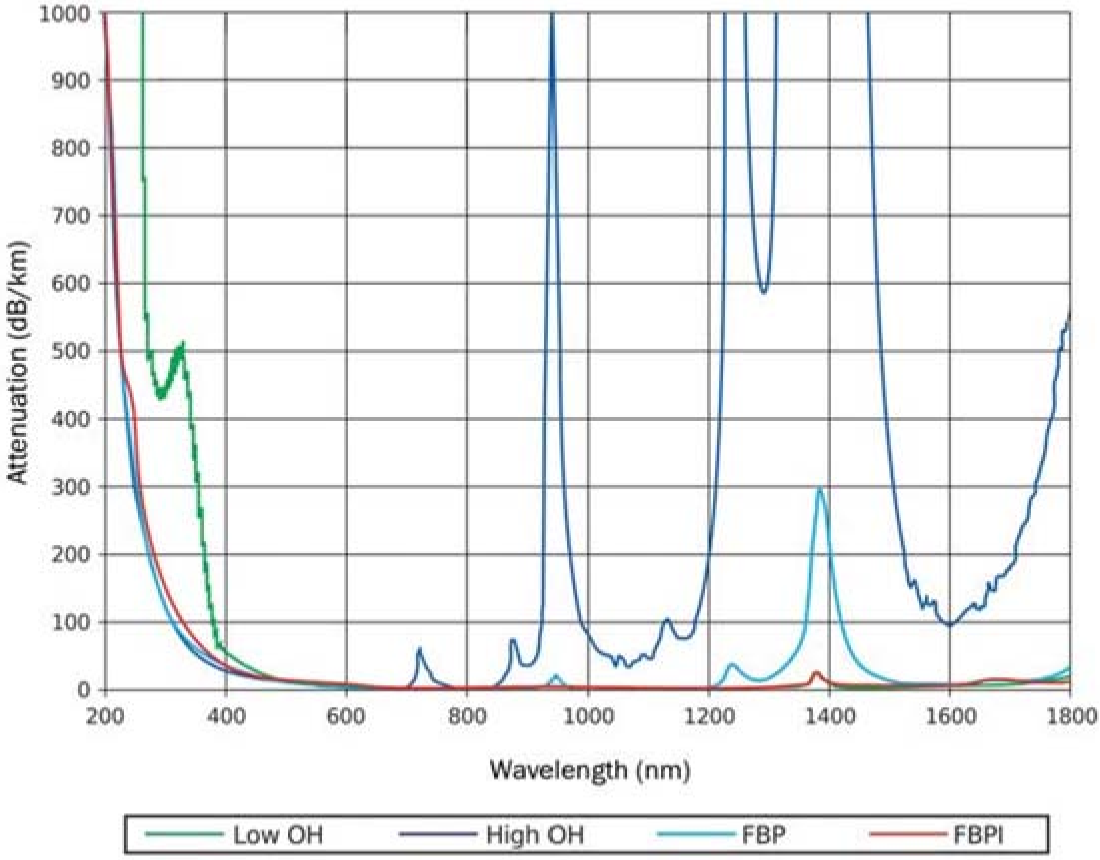

Figure 5 Spectral attenuation performance comparisons between FBPI fibre and three other Polymicro fibres (data from Polymicro)

The wavelength coverage for MOONS is from 0.8 µm to 1.8 µm. The new fibre FBPI and the low OH FI could be selected (see Figure 5).
In order to optimize the performance of the fibre and so to decrease the Focal Ratio Degradation (FRD), the ratio between the core and the cladding is 1.2.

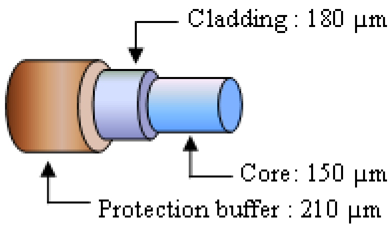

Figure 6 Structure of the fibre

The FRD is the decrease in focal ratio (decrease in effective F-number) in an optical fibre. The ability of a fibre to preserve the angular distribution of the input beam from the telescope to the spectrograph is very important.
The major causes of FRD are mechanical variations in the fibre dimensions with length (under the manufacturer's control) and the mechanical set-up of the instrumentation (under the control of the user). Small variations in the fibre core diameter or core-clad interface can cause mode stripping, resulting in FRD. Both macro bending and micro bending will cause FRD.

2.3 FRD tests

The optical fibres are positioned within the MOONS input focal plane using an array of 1000 fibre positioning units with one fibre attached to each positioning unit. The fibre positioning unit is a small robotic arm driven by two motors with the central motor driving an inner arm and the second outer motor driving the outer arm. The patrol field of each positioner is an annulus and the fibre is moved into position by an appropriate rotation of the inner and outer motors. As a consequence of the rotating nature of the positioner unit each fibre will be subjected to a degree of twisting as it is moved into place. The fibre positioner unit is approximately 200 mm in height with the optical fibre clamped at one end onto the outer positioning arm and at the other end to the positioner base plate. During positioning the combination of inner and outer arm rotations will cause the fibre to be subjected to approximately one-and a half (1½) twists over the 200 mm fibre length corresponding to a twist specification of approximately 7 twists per metre.

It is well known that placing an optical fibre under mechanical stress, e.g. by clamping the fibre with excessive force, causes the fibre's output focal ratio to change – an effect commonly known as Focal Ratio Degradation (FRD). However it was not clear how the fibre's FRD performance would be affected by twisting so it was decided to conduct optical tests on a prototype MOONS fibre to determine the effect of twist on FRD. (Lee & al. [3])

The prototype MOONS optical fibre consisted of a 1 m length of Polymicro FIP150165195 fibre, with a 900 μm PEEK protective outer tube, terminated at one end with an SMA connector and at the other end with a 2.5 mm diameter ferrule. To test the FRD the fibre was illuminated with an F/3.3 input beam and an image of the output beam was captured for a range of twist angles. The FRD set up is similar to that described in Lee, Haynes and Skeen, MNRAS, 326 (2001). The light source consists of an intensity stabilised tungsten halogen lamp illuminating an integrating sphere. Light from the output port of the integrating sphere is coupled into the optical fibre using an SMA fibre collimation lens. The lens illuminates the fibre at a numerical aperture of 0.15. The fibre collimator lens is mounted in the central bore of a computer controlled rotation stage and both the lens and fibre are rotated at the input end during testing. The output beam of the fibre is measured using a camera system consisting of a collimator lens, a Schott RG780 bandpass filter, a camera lens, and a CMOS detector. The camera system is mounted onto a computer controlled translation stage which provides focus adjustment. Once the test fibre has been fixed in place by the operator the FRD measurement is performed under computer control by a National Instruments Labview script which controls focus adjustment, fibre twist, image capture, and data storage. The FRD test is performed at a wavelength of 800 – 1000 nm with a maximum of ±7 twists applied to the fibre achieved by driving the rotation stage through to ±7 full revolutions. A picture of the FRD test set up is shown in the following figure and the effect of applying 7 twists can be seen to cause deformation of the PEEK tubing.

The images generated by the FRD tests were analysed using an IDL script to determine the flux contained within a focal ratio of F/3.16 and check the radial profile of the output beam. The measured flux within an F/3.16 output beam as a function of fibre twist is shown in the graph at the left of figure 8. The red, green, and blue plots are for three different fibres, with each fibre tested twice. The plot shows a small reduction in the fibre throughput as the amount of twist increases with the red fibre showing the largest variation. The focal ratio of F/3.16 was chosen for the analysis aperture as it represents an aperture which is approximately 4% larger than the input aperture (F/3.3) and this is the amount of oversizing available in the instrument.

The radial profile of the fibre output beam is plotted in the graph on the right of figure 8. This is shown for the same three fibres as in the left-hand plot. The profiles for -7, 0, and +7 twists are over plotted showing that the broadening of the fibre output beam as the fibre is twisted is extremely small.

The result of the FRD twist test is that the output beam of the fibre is only slightly affected by applying 7 twists per metre with the measured flux within an F/3.16 output beam reducing by less than 1%. The fibre to fibre throughput variation was measured to be 4% for the 10 fibres tested. The conclusion of these preliminary tests is that twist induced FRD has a small effect on fibre throughput but it is significantly less than the fibre to fibre throughput variation.

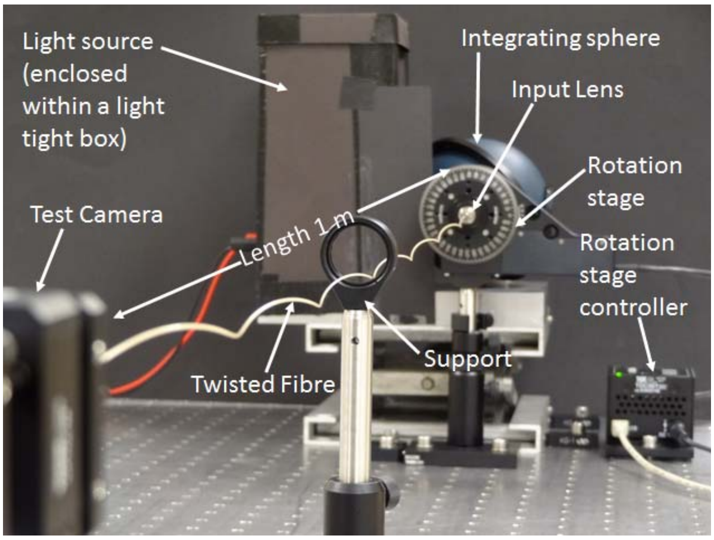

Figure 7 Picture of the MOONS prototype fibre FRD test set up.

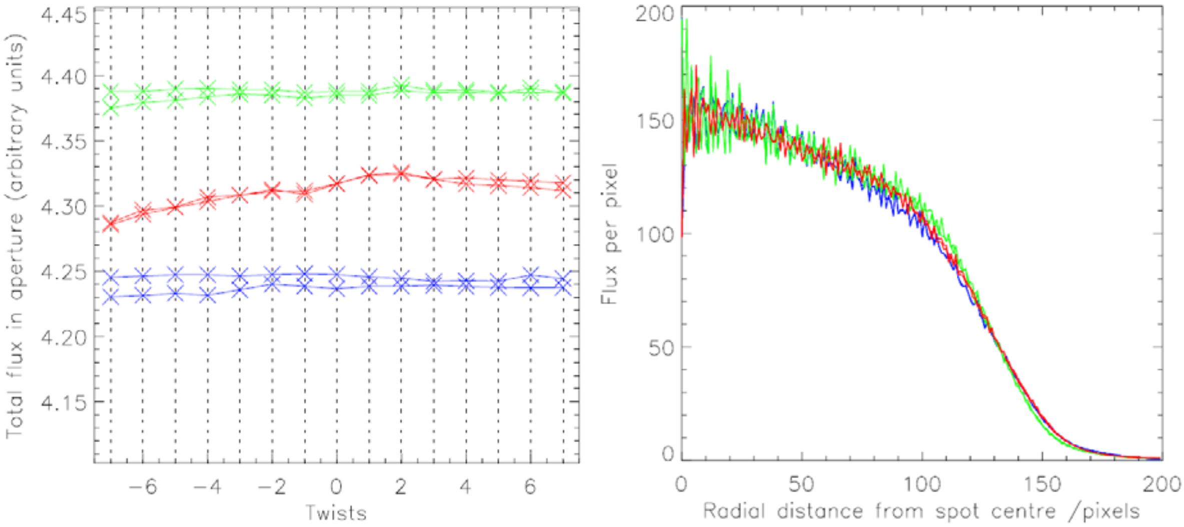

Figure 8 The plot on the left shows the measured fibre output flux within an F/3.16 aperture as a function of fibre twist and the plot on the right shows the measured radial profile of the fibre output beam.

2.4 Front-end assembly

The fibre button needs to be attached to the fibre positioning arm (see Figures 9 & 10). The arm holds the cylindrical (button) 2.5 mm in diameter and 6.0 long. The fibre fits in a slot at the bottom 1.0 mm wide. A countersink screw (not shown) clamps the cylinder in place.

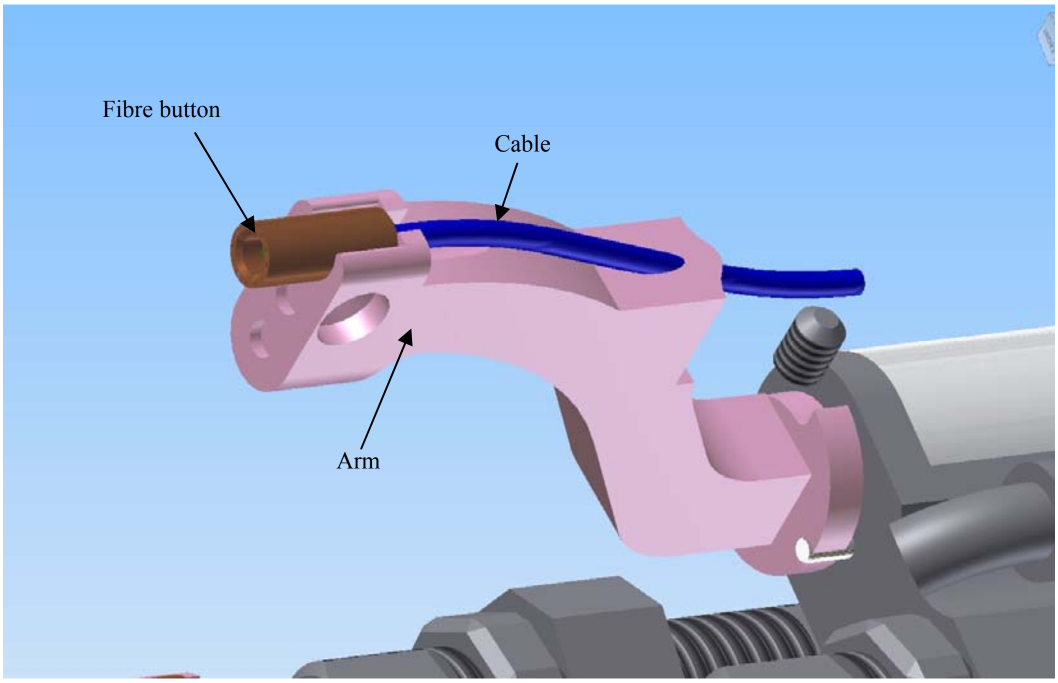

Figure 9 Preliminary design of the arm

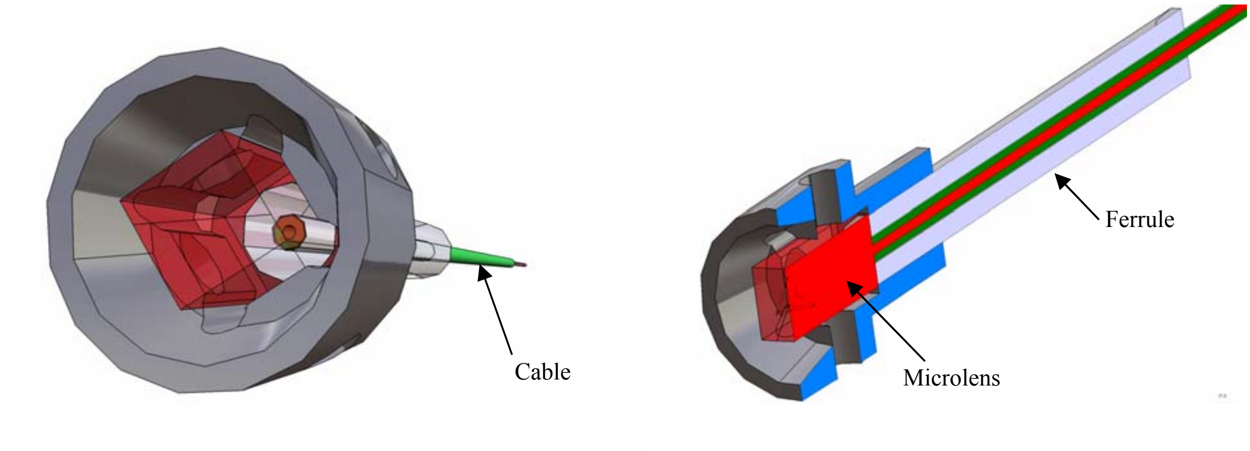

Figure 10 Preliminary design of the fibre button

2.5 Fibre connector

In order to facilitate the integration of the instrument, a connector will be placed about 3 metres from the slit. A sample from USConec, from the APOGEE (32 MTP connector), was sent (Figure 11). An MTP connector (mechanical transfer push-on) is a high performance MPO connector (multi-fibre push-on) with enhancements to improve both the optical and mechanical performance (Brunner & al., [4]).

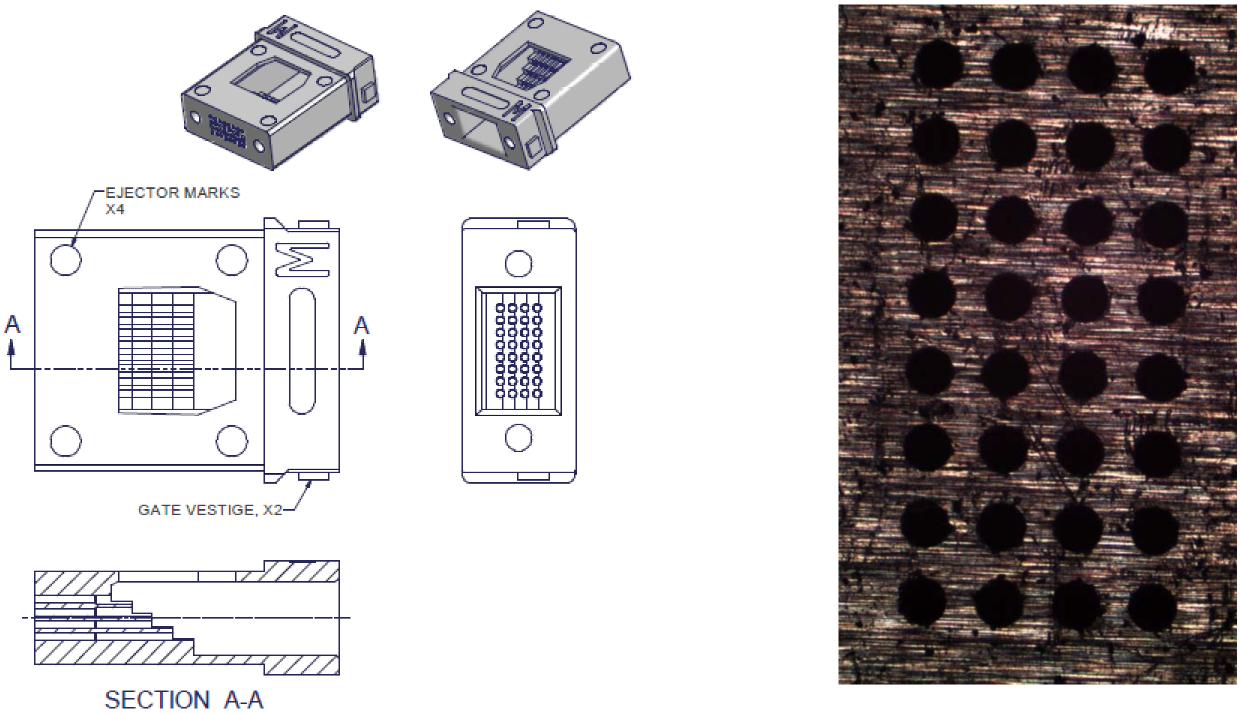

Figure 11 Data sheet from US Conec and picture of a MTP connector

The insertion losses are typical in the order of 0.1 dB for all the fibres and less than 0.35 dB maximum for any single fibre.

2.6 Slit-end assembly

For the cross-talk considerations, the fibres need a relative spacing (spacing/size of the fibre core). The minimum spacing between 2 fibres is 5 dark pixels, i.e. 2.66 x Ø fibre core diameter, as shown in Figure 12 below.

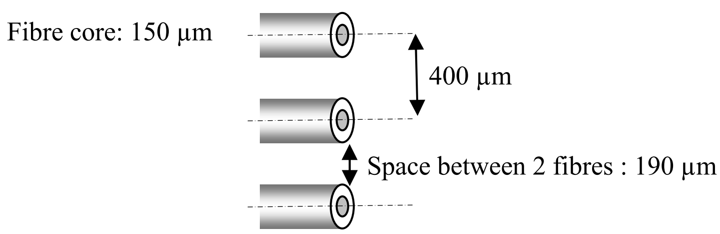

Figure 12 Distance between fibres at the slit

These extremities have to guarantee a good parallelism and a good alignement of the fibres to optimimise the coupling with the spectrograph. In order to comply with these specifications, each fibre will be aligned in a ve groove. The fibres are placed in the mechanical sub-slit (cemented in the ve grooves) and polished (flat polishing). Each sub-slit consists of 16 fibres (see Figure 13).

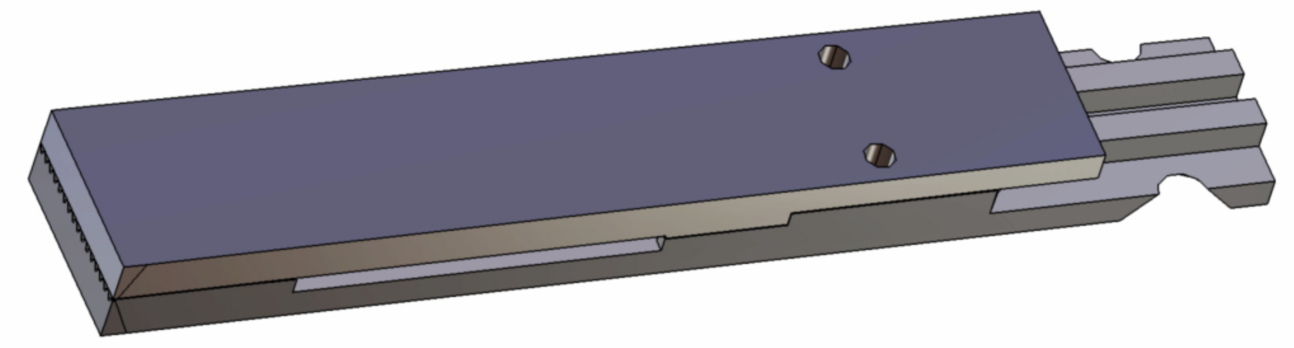

Figure 13 Preliminary design of the sub-slit

Each slit module (see Figure 14) is fed by 32 fibre sub-assemblies which terminate in a sub-slit.
The slit support has to be designed in order to fit the optical constraints of the spectrograph as the slit curvature. The sub-slits are adjusted in position without resorting to any complicated adjustement, since it is ensured by the mechanical precision of the mount. The slit is placed in cryogenic environment.

Figure 14 Preliminary design of the slit

3 CONCLUSION

In this paper we have described here the preliminary design of the MOONS fibre designs developed during Phase A. The table below summarizes the principal technical requirements for the fibre assemblies:

Number of fibres	1024
Number of bundles	64 bundles of 16 fibres
Fibre length	10 m
Sky aperture	1.05 arcsec
Fibre diameter	150/180/210 μm
Wavelength range	0.8 – 1.8 μm
Input numerical aperture (conversion realized with coupling microlens)	Nasmyth: F/15 to F/3.65 into the fibres
Output numerical aperture	F/3.5
Interobject	5 dark pixels (2.66 x Ø fibre core)

Table 1 Summury matrix

The phase B of the project will start in July and the team will commence with the preliminary design phase. The design and the throughput estimation have to be consolidated by analysis and prototyping. Table 2 below lists all the loss terms associated with the fibre system which reduces the overall throughput of the instrument.

Contributors	**Mean throughput (%)**
Decentration (misalignment) and/or tilt of telescope pupil/fibre	93
Microlens surface transmission	99
Fresnel losses	95
Transmission of the fibre	96
Connector	99
Parallelism of fibre optical axis	99
FRD effect	97
TOTAL	**80**

Table 2 Fibre assembly throughput estimation

The study of the fibre system is based on a close collaboration with the overall project team and also with industry in order to avoid delays, and to reduce costs and eliminate risks during the manufacturing and integration phase.

REFERENCES

[1] Cirasuolo M., et al. "MOONS: an optical and near-IR multi-object spectrograph for the very Large telescope" Proc. SPIE 9147-22 (2014)
[2] Oliva E., Tozzi A., Ferruzzi D., et al. "Updated optical design and trade-off study for the MOONS-VLT multi-object spectrometer", Proc. SPIE 9147-84 (2014)
[3] Lee D., Haynes R., Skeen D.J. "Properties of optical fibres at cryogenic temperatures", Mon. Not. R. Astron. Soc. Vol. 326, pp. 774-780 (2001)
[4] Brunner S., et al. "APOGEE fiber development and FRD testing", Proc. SPIE Vol. 7735 (2010)
[5] Schnetler H., Cirasuolo M., Lunney D.W., et al." An illustrative example using model based systems engineering to design and plan the construction of the next generation multi-object optical and near-infrared spectrograph (MOONS) for the European Southern Observatory (ESO)" Proc.SPIE 9150-23 (2014)
[6] Li Causa G., Pedichini F., Vitali F., et al. " Virtual MOONS: a focal plane simulator for the MOONS thousand-fiber NIR spectrograph" Proc SPIE 9147-229 (2014)