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EM Spectrograph Tests

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Throughput Measurement Device

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1 Introduction - Motivation

In this document we describe the opto-mechanical device we designed and built to calibrate the light flux injected by the DESI fiber sparse slit into the DESI spectrograph, in order to measure the spectrograph throughput by comparing the injected light flux to the integrated flux measured in the CCD cameras of the 3 spectrograph arms (B,R,Z aka NIR).

The acceptance tests of the DESI spectrographs are performed at Winlight (Pertuis, France), under the responsabiliy of the AMU team (Aix-Marseille Université). The throughput measurement is part of the acceptance tests of the engineering model of the DESI spectrograph module (EM#1) and will also be performed for the ten DESI spectrographs (SM#1 to SM#10).

The results of the throughput measurements are described in a separated document [DESI-3181].

2 Context and design principles

2.1 Spectrograph modules

The DESI spectrograph modules are fully described in [Jelinsky et al., 2016]. A CAD rendering and a schematic view are shown on figure 1.

A DESI spectrograph module is designed to receive the light from 500 fibers, such that the ten spectrographs will accomodate the 5000 fibers coming from the Mayall focal plane.

In each spectrograph, the 500 fiber ends are arranged on a curved slit (curvature radius 486.3 mm, see fig. 3). The light from the fibers is collimated by a spherical mirror, then separated by two dichroics into three channels: blue (B), red (R) and near-infrared (NIR/Z), covering together a spectral range from 360 to 980 nm. In each channel, a volume phase holographic grating (VPHG) provides the light dispersion. The resulting spectra are then focused using a 5-lens camera on a 4k$\times$4k, $15\,\mu$m pixels CCD detector, cooled down to 140 K (R and NIR) or 170 K (B). The exposure time is controlled through a mechanical shutter in front of the fiber slit (fig. 1).

2.2 AMU Test bench

A dedicated optical testbench has been developed, built, tested by the AMU team and installed at Winlight to perform various tests on the spectrograph modules [Perruchot et al., 2016]. The testbench is automated and remotely controlled, fully integrated with the spectrograph constrol software (ICS). It is mounted on a 600×900 mm^2 optical table, and sits in the clean room next to the spectrograph.

During the tests at Winlight, the 500-fiber injection slit is replaced by a sparse fiber slit, equiped with 21 well separated fibers (fig 3). The AMU optical testbench feeds the entrance of the fiber bundle (fig 4) with a Mayall-like optical beam by using an appropriate Offner relay. Several light sources are available: spectral lamps (Kr, HgAr, Cd, Ne), a tungstene lamp that provides a continuous spectrum, and 6 bright LEDs at 370 nm, 465 nm, 591 nm, 631 nm, 870 nm and 940 nm from Thorlabs with a $\approx$20 nm wide spectrum. All the sources may be switched on/off independently, and the current in the LEDs may be adjusted between 0 and 20 mA.

A fiber bundle is used to inject the light from the various sources into an integrating sphere; the beam pass through two filter wheels populated with interference filters and neutral densities, and an integrating sphere to mix and homogenize fluxes. The resulting beam at the exit port of the sphere is then sent into an optical relay (Offner relay) to inject the light into the fiber slit bundle with the appropriate F-ratio; the optical relay is equiped with a mask installed in the pupil plane, which contains a large aperture to illuminate all the fibers at once, and a small pinhole to illuminate only a single fiber (fig. 3). The testbench thus offers the capability to inject light into any single fiber of the sparse fiber slit at once, with a well controlled flux and spectral distribution (fig. 4).

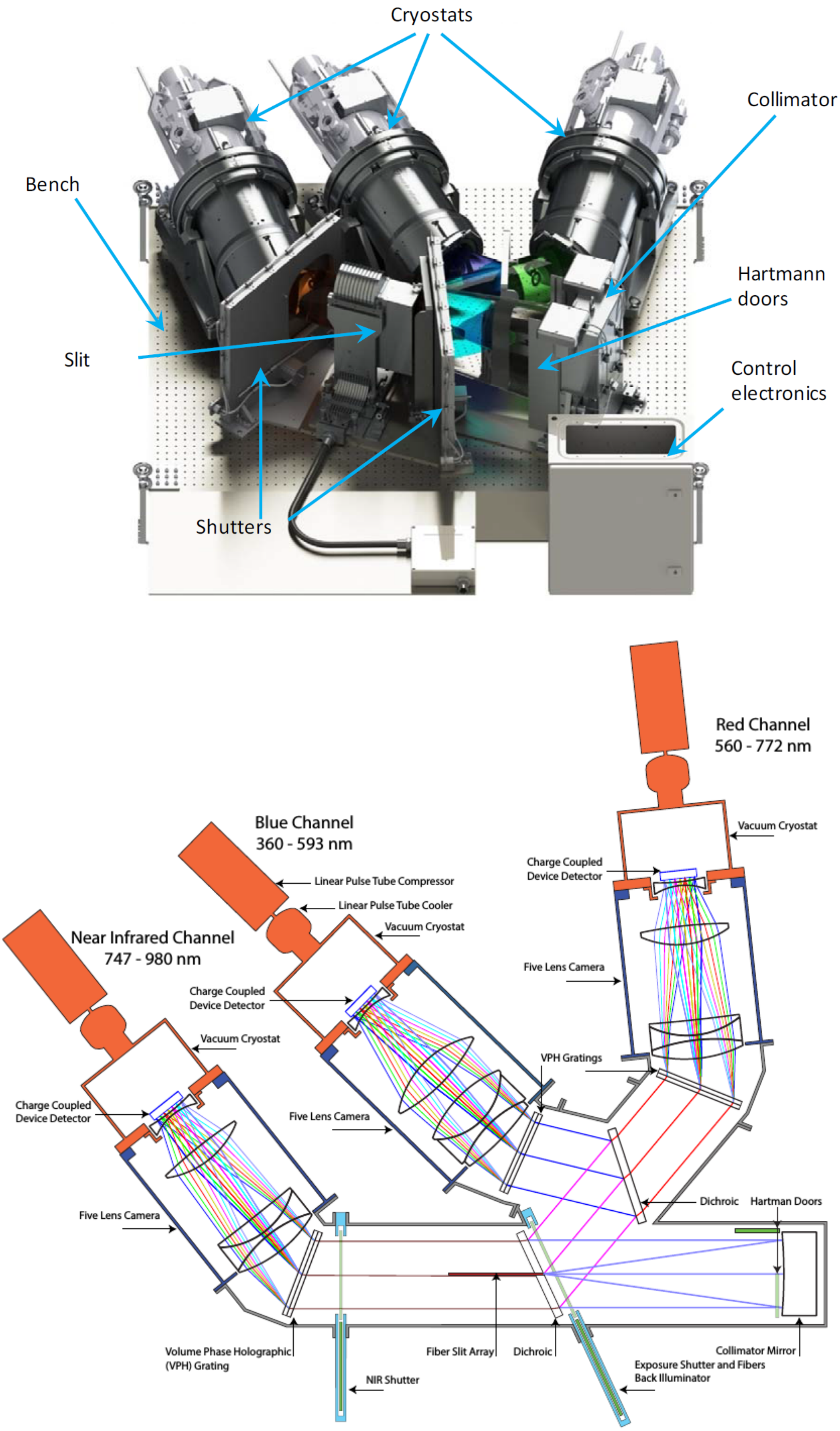


Figure 1: Top: CAD rendering view of one full DESI spectrograph module (without baffling). The spectrograph dimensions are $1.8\,\mathrm{m}$ *(wide)* $\times$ $1.4\,\mathrm{m}$ *(deep)* $\times$ $0.6\,\mathrm{m}$ *(high). The 500-fiber injection slit can be extracted, and is replaced by a sparse fiber slit during the acceptance tests. Bottom: optical layout of the spectrograph, showing the optical path for the three channels, from the fiber slit to the CCDs.*

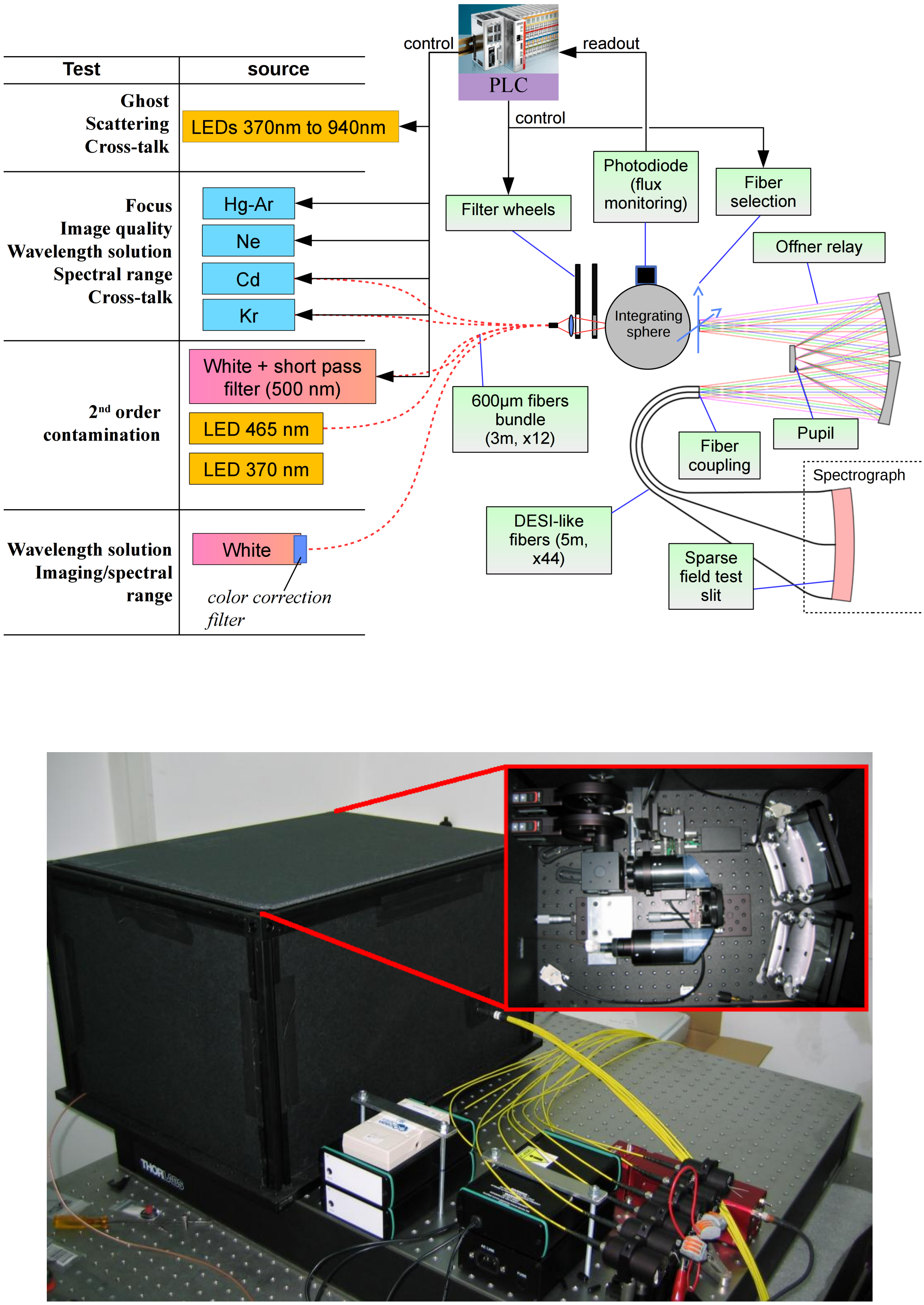


Figure 2: Top: synoptic description of the AMU optical testbench. The available light sources are listed on the left; the light beam goes through two filter wheels (one for filters and the other for neutral densities) into a integrating sphere, then through the Offner relay, and is injected into the 5-m fiber bundle of the sparse fiber slit. Bottom: picture of the AMU testbench. The offner relay is inside the black box on the left, and all the light sources are on the right. This photo has been taken before the installation of our throughput measurement device.

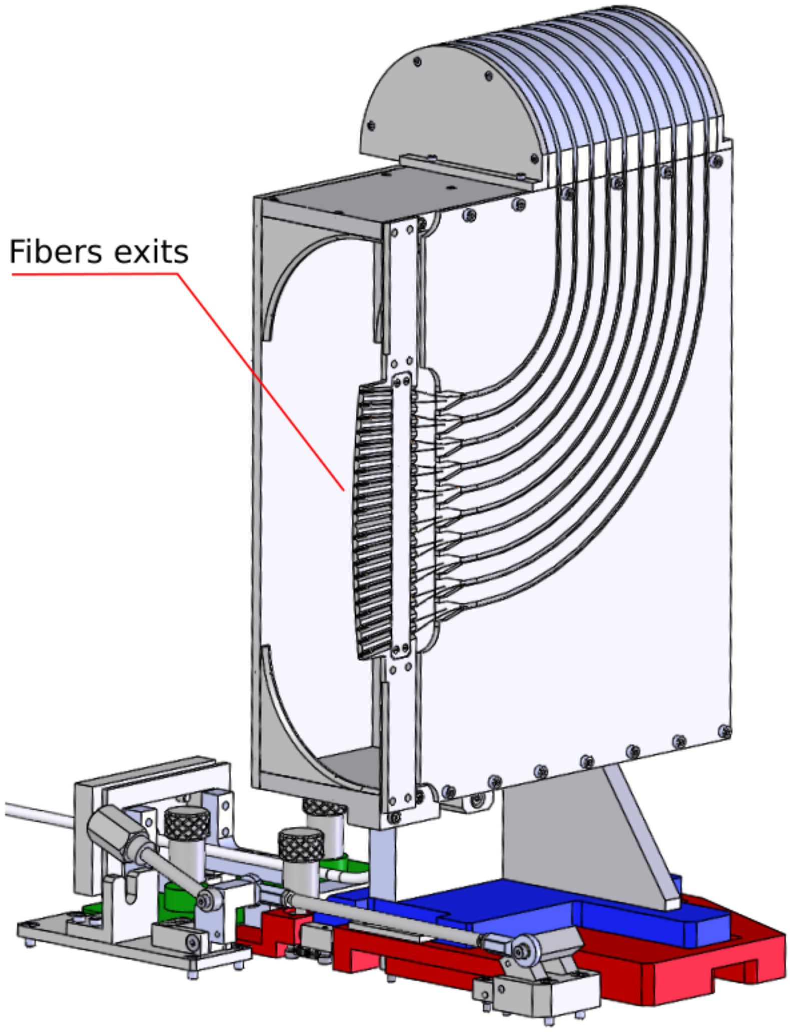


Figure 3: Sparse fiber slit used for the optical tests. In fact the fixation system on the bottom is simpler than the one shown on this drawing (from [DESI-1953]).

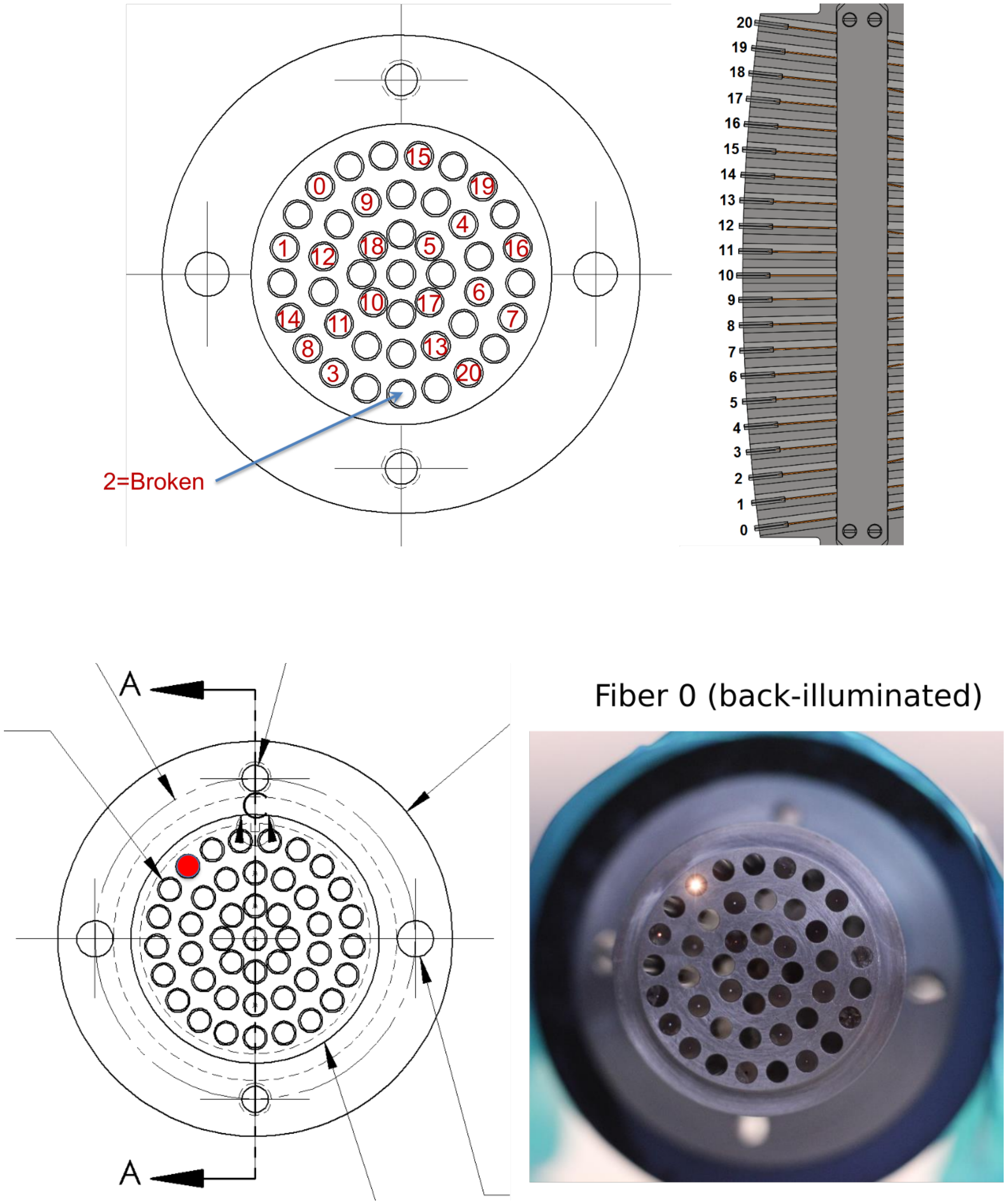


Figure 4: Top: numbering scheme of the fibers of the sparse fiber slit, on the bundle end (left) and on the fiber slit (right). Bottom: fiber bundle back illuminated (fiber #0 on the picture) to check the fiber numbering (from [DESI-1953]).

2.3 Proposed throughput measurement procedure

As the fiber slit used for the tests can be extracted from the spectrograph, while still attached to the AMU testbench, we proposed to build an additional device to measure the light flux coming from all the fibers of the sparse fiber slit, using a calibrated photodiode moving in front of the sparse fiber slit.

We proposed to do this for different illumination setups, when the sparse fiber slit is outside the spectrograph; and then to repeat the same illumination setup sequences when the sparse slit is installed in the spectrograph, and measure the resulting spectra on the 3 CCDs. The ratio will provide an estimate of the instrument throughput, from the exit of the fiber to the CCD sensors.

To do this measurement, we proposed to use the 6 powerful LEDs of the test bench, as they were bright enough, and the LEDs spectra are narrow (a few tens nm) and compact (so the total integrated flux can be measured in the spectrograph). They also cover reasonably the spectral range of the 3 arms of the spectrograph (2 LEDs per arm).

The throughput measurement is planed to be done in two steps, during the repeatability tests to limit the overhead:

1. When the sparse test slit has been removed from the spectrograph, it is installed in front of the throughput measurement device; for each fiber, the photodiode is centered to catch the whole beam. The absolute flux is measured by the calibrated photodiode, for each LED and each test slit fiber, separately;

2. When the sparse test slit is back in place inside the spectrograph, frames are taken on the three spectrograph arms, for each LED and for each test slit fiber, in the same illumination configurations as in step 1. The CCD flux is integrated for each arm, separately for each LED/fiber configuration. The illumination level is monitored using the second photodiode fixed on the integrating sphere, to ensure the injected illumination is the same in both configurations (outside/inside the spectrograph).

The ratio (2)/(1) of the integrated fluxes measured in both configurations provides an estimate of the spectrograph throughput, from the fiber exit to the CCD, including the CCD quantum efficiency:

$$\eta_{[\text{e-}/\gamma]}(\lambda_{\text{LED}}) = (QE_{\text{CCD}} \times T_{\text{optics}}(\lambda_{\text{LED}})) = \frac{\phi^{\text{CCD}}_{[\text{e-/s}]}(\text{LED})}{\phi^{\text{injected}}_{[\gamma/\text{s}]}(\text{LED})} \tag{1}$$

3 Mechanical design

We designed and built a specific device to measure the light flux coming from each fiber of the sparse test slit, when the test slit is moved outside of the spectrograph (fig 5). It consists of a calibrated photodiode, moving on a 500 mm radius curved rail, to keep the photodiode at a constant (adjustable) distance from the sparse slit fiber ends (curvature radius $R = 468.3$ mm).

The linear stage vertical support is made of black anodized aluminium, as well as the photodiode support. We also added an extra aluminium plate and two aluminium blocks to precisely constrain the sparse fiber slit position, in such a way that the curvature centers of the photodiode trajectory matches the curvature center of the sparse slit (see fig. 6).

The precise positioning is done through a RS-232 controlled motorized linear stage from PI/Micos (Pollux VT80, range 150 mm, unidirectional positioning accuracy better than $0.4\,\mu$m) coupled with the photodiode moving support by a rotula (see fig. 6). The linear movement along the linear stage is thus transmitted to the photodiode support attached on the 500 mm radius curved rail. The resulting position accuracy is around $1\,\mu$m.

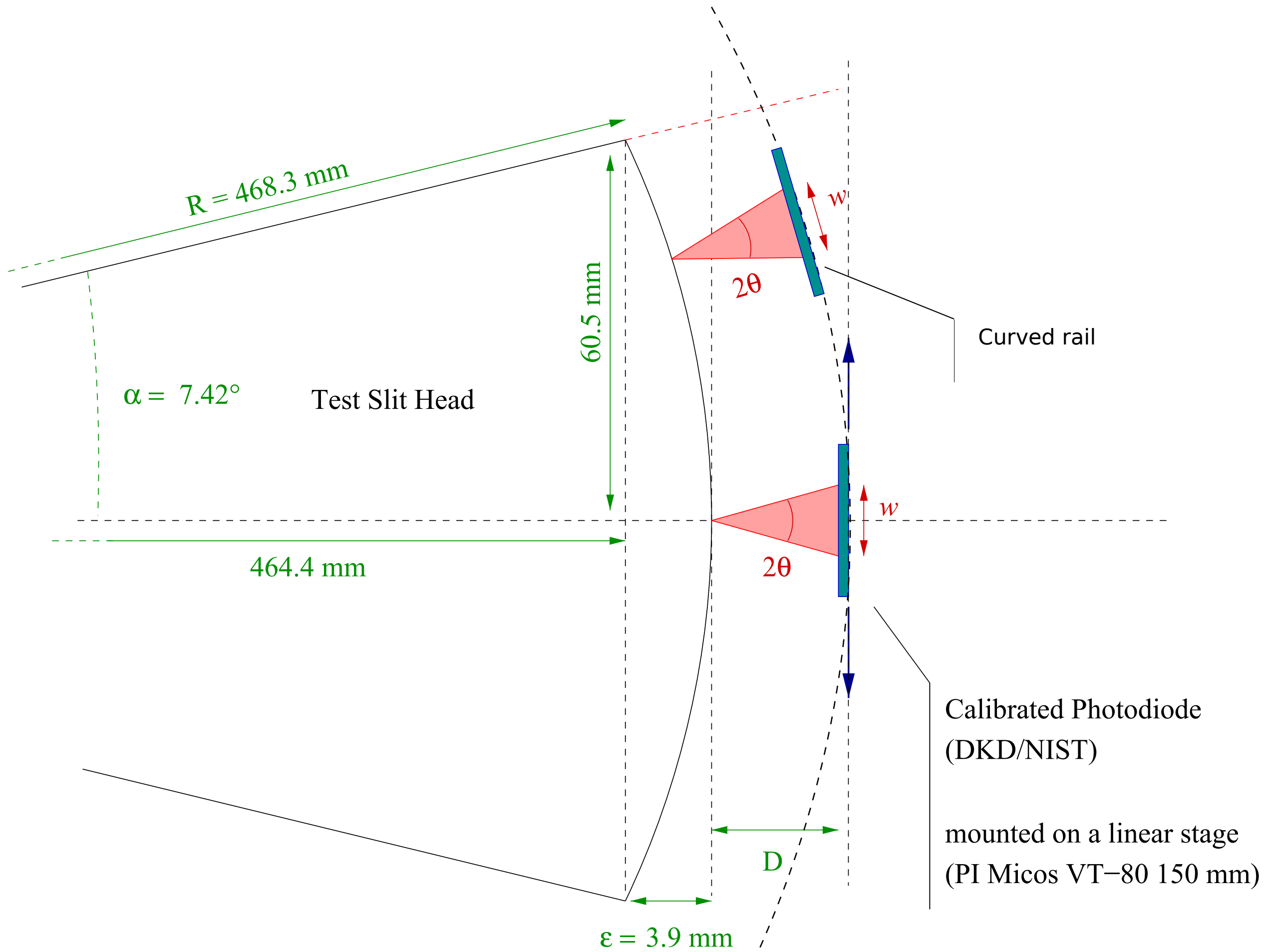


Figure 5: Mechanical design: As the end of the fiber slit is a 468.3 mm circle, the photodiode moves along a concentric circle, at a short distance (of the order of 10 mm) to catch the whole light beam. The 10 mm × 10 mm *DKD photodiode is large enough to catch the whole beam.*

The photodiode is 10 mm × 10 mm wide, and typically placed at 10 mm from the test slit fiber end; it is large enough to catch the whole light beam coming from a test slit fiber: the injected beam (by the Offner relay) is f/3.57, and with 99% enclosed energy within f/2.5.

The photodiode centering, and the distance between the photodiode and the fiber ends can be manually adjusted using two micrometric stages (see fig. 6 and 7).

We also used this device to scann the fiber output beam with a 100 μm slit placed in front of the photodiode, to model the beam and estimate the focal ratio degradation of the sparse slit fibers (FRD).

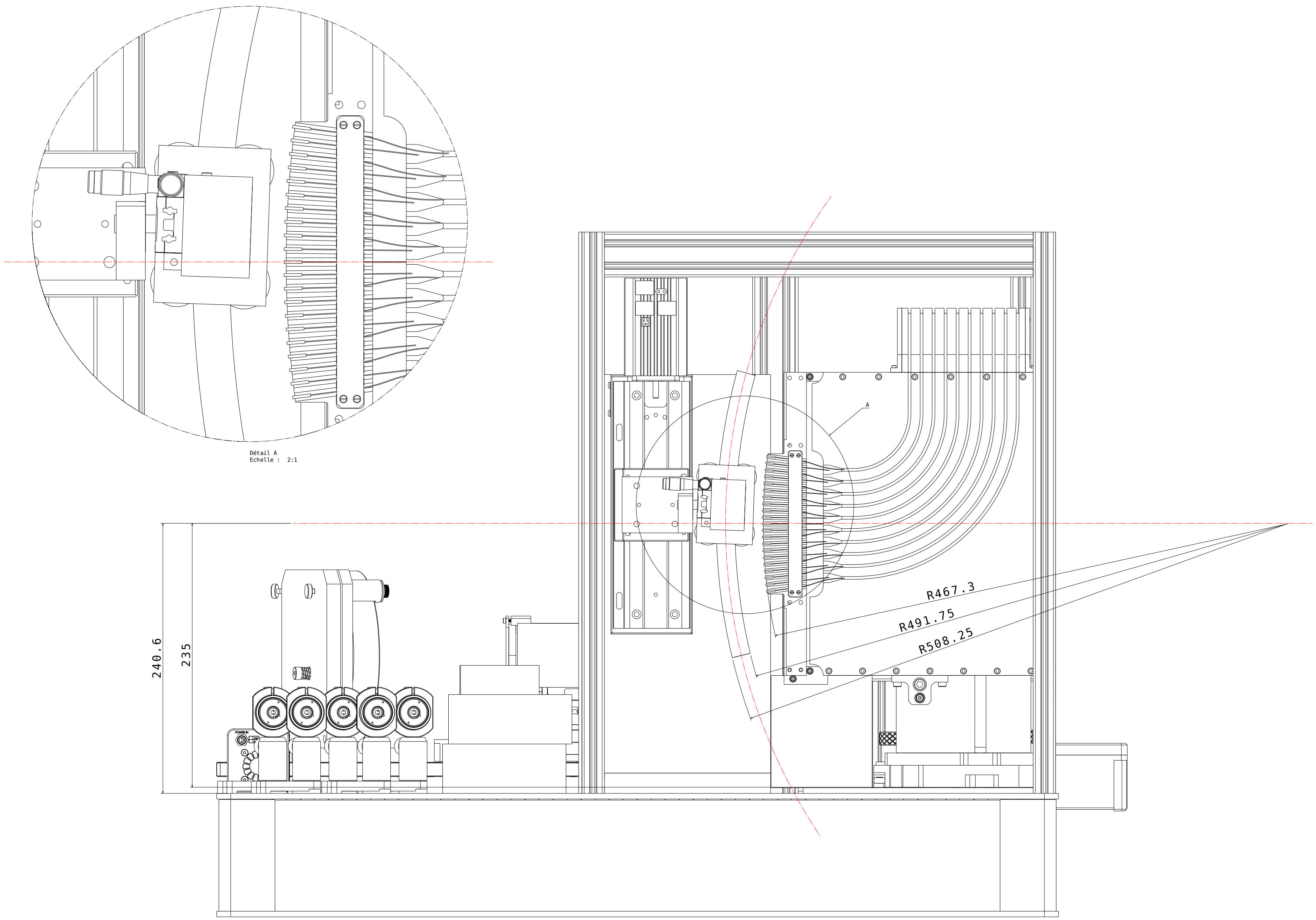


Figure 6: Drawing of the throughput measurement device on the AMU testbench, with the sparse fiber slit in place.

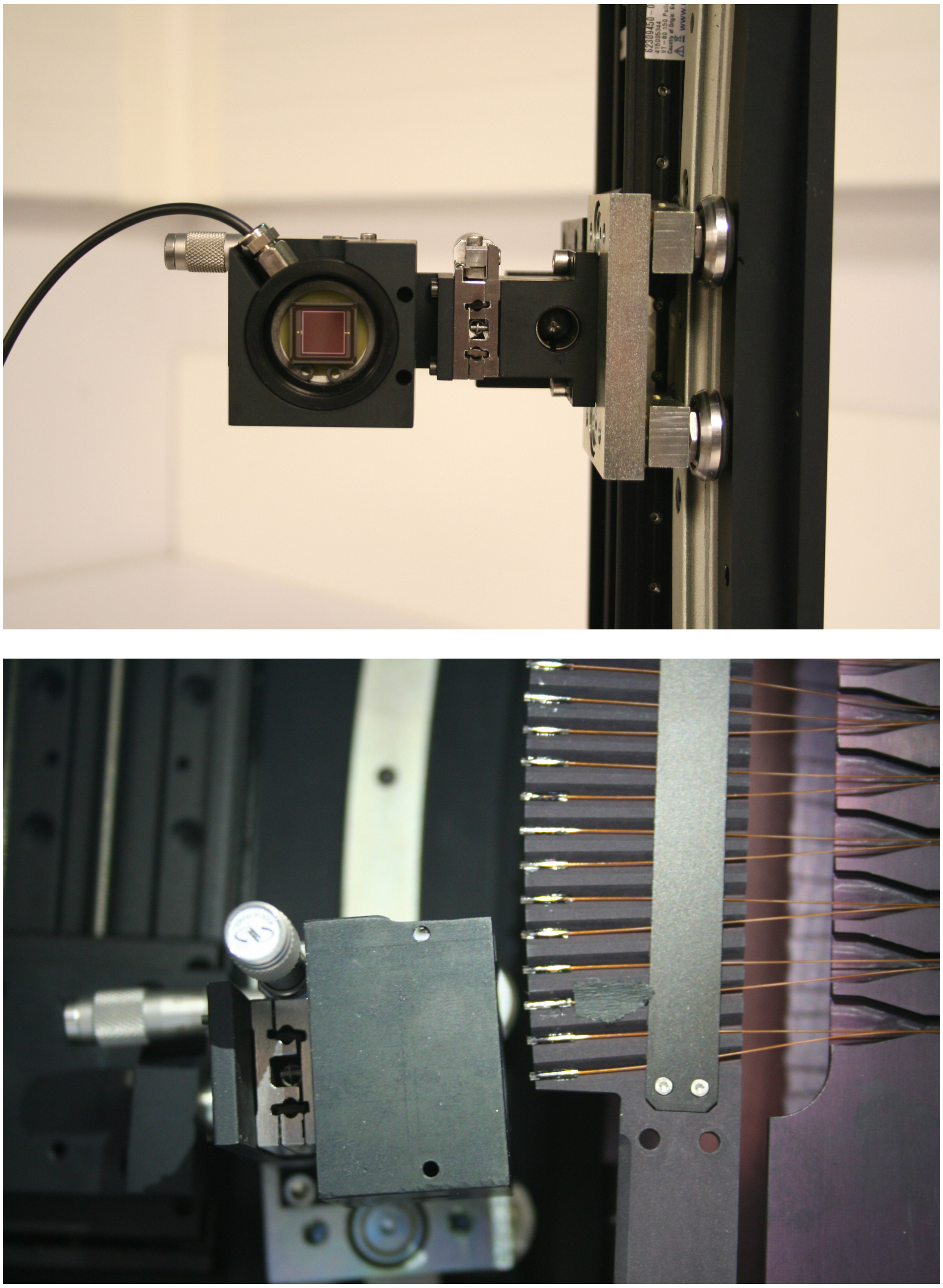


Figure 7: Top: throughput measurement device, with the 10×10 mm^2 calibrated photodiode used to measure the total light flux getting out of the test slit fibers. Bottom: throughput measurement device, with the photodiode moving in front of the sparse test slit. The two micrometric linear stages used to adjust the photodiode centering and the distance between the photodiode and the fibers are visible.

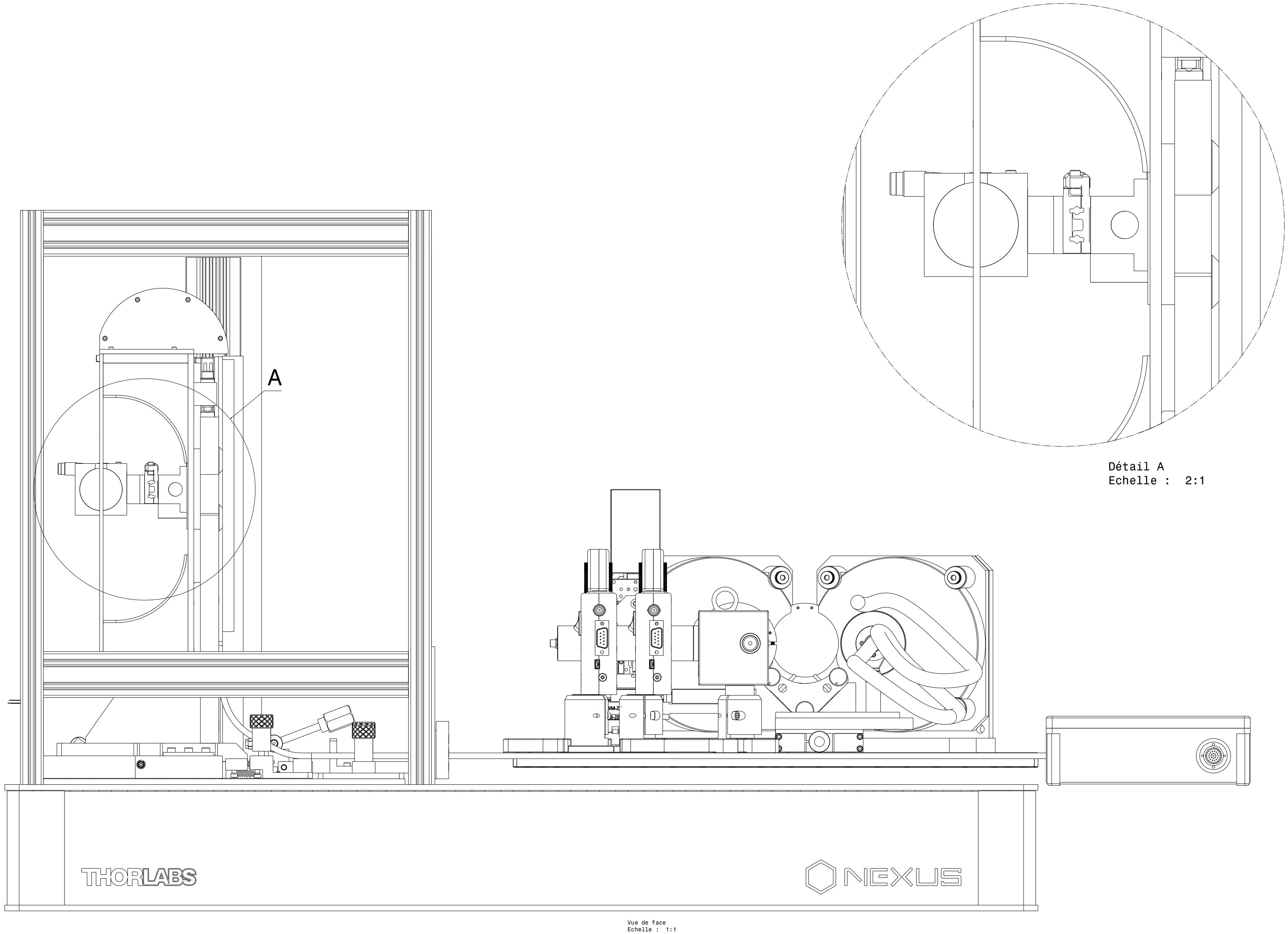


Figure 8: Side view of the AMU test bench, with the throughput device and the sparse fiber slit in place in the dedicated dark box. The centering of the photodiode support relatively to the sparse fiber slit is shown. The precise centering can be adjusted with a small micrometric linear stage.

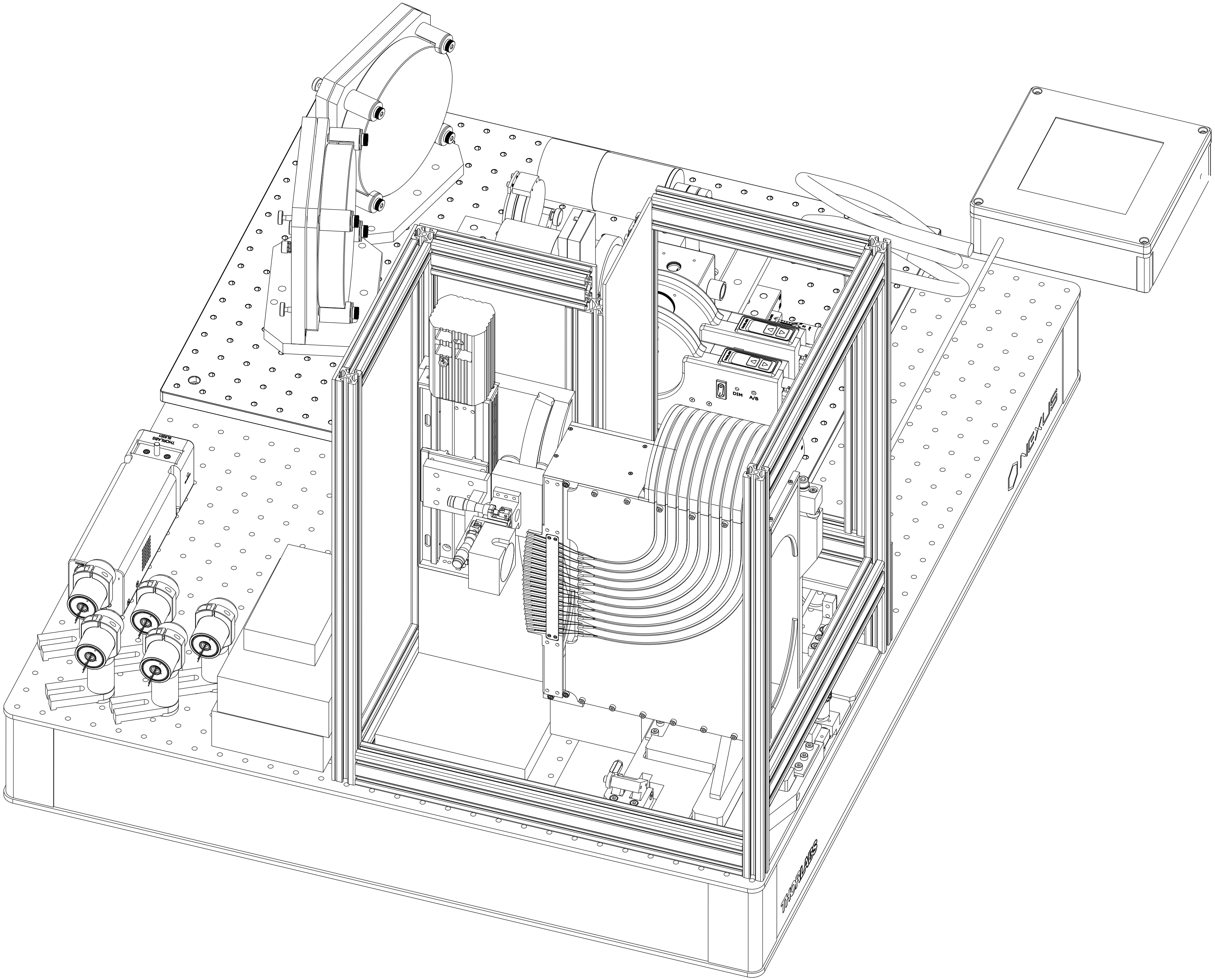


Figure 9: Another view from the AMU testbench with the throughput measurement device in place, and its dedicated dark box.

4 Absolute flux measurements

4.1 Calibrated silicon photodiode

The light flux coming from each sparse slit fiber is measured using a $10\,\mathrm{mm} \times 10\,\mathrm{mm} = 100\,\mathrm{mm}^2$ calibrated photodiode from Gigahertz-Optik (fig. 10). The model is MD-37-SU100 (S/N 30853), and its spectral responsivity $s(\lambda)$ is provided, certified by Gigahertz-Optik under the control of the DKD (the German institute for standards) with a 2% relative uncertainty on the 250–1100 nm spectral range (fig. 11). Using a NIST calibrated photodiode (0.2% accuracy), we checked on the LPNHE spectrophotometric test bench the accuracy of the provided spectral responsivity [DESI-2635].

Figure 10: Calibrated photodiode model MD-37-SU100 (10 mm × 10 mm) from Gigahertz-Optik.

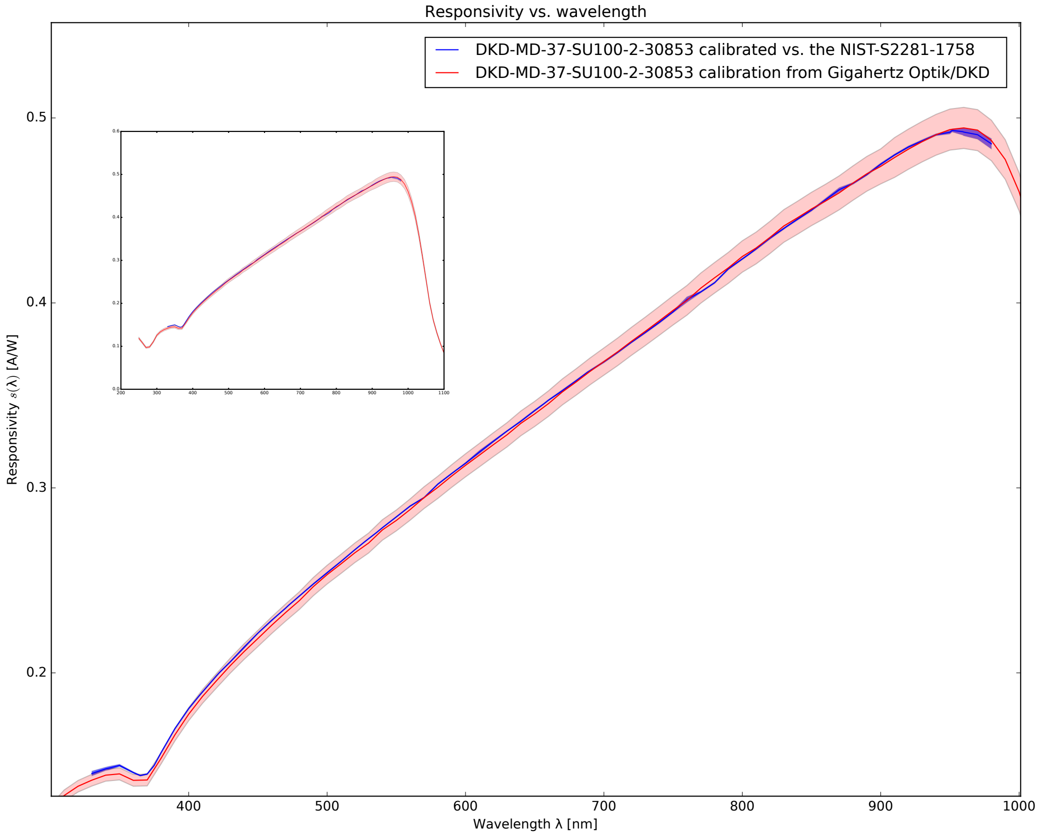


Figure 11: Responsivity [A/W] for the DKD-MD-37-SU100-2-30853 photodiode: provided by Gigahertz Optik/DKD (in red, 1-sigma contour), and measured on the LPNHE spectrophotometric testbench using a NIST calibrated photodiode as reference (in blue, 1-sigma contour). See [DESI-2635].

4.2 Picoammeter

The photocurrent from the photodiode is measured with a picoammeter from Keithley, model 6514 (fig. 12), properly calibrated by Tektronics/Keithley and with an accuracy in the fA range. We also used a second picoammeter from Keithley (Keithley 6482) to monitor the light flux level in the integrating sphere with a second photodiode, to control the stability of the illumination. The measured photocurrents vary between $0.1\,\mathrm{pA}$ to a $10\,\mathrm{pA}$, which correspond to illumination powers from approx. 0.1 pW to 1 nW.

Figure 12: Electrometer/picoammeter model 6514 from Tektronics/Keithley (photo from Tektronics).

#id	ammeter model	provider	resolution	serial	calibration date
#1	Keithley 6514	Tektronix	1 fA	1118345	2008-XX-XX
#2	Keithley 6514	Tektronix	1 fA	4036939	2015-05-05
#3	Keithley 6514	Tektronix	1 fA	4131086	20XX-XX-XX
#4	Keithley 6482 (2-channel)	Tektronix	1 fA	1410711	2016-01-29

Table 1: Picoammeters used to measure the photodiode photocurrent.

5 Dedicated dark box

As the expected light fluxes are very low, we built a dedicated dark box to limit the contamination from external light sources (fig. 13). The dark box consists of a structure of anodized aluminium modular elements from ELCOM, with black DIBON panels attached on it. The convoluted shape of the box is a compromise, resulting of two constraints:

- the box had to fit on the available space on optical table of the AMU testbench;
- the bundle of the sparse fiber slit cannot be detached, so the box has several removable panels to be able to insert the sparse slit with the bundle attached, without any risk of damaging the fragile bundle.

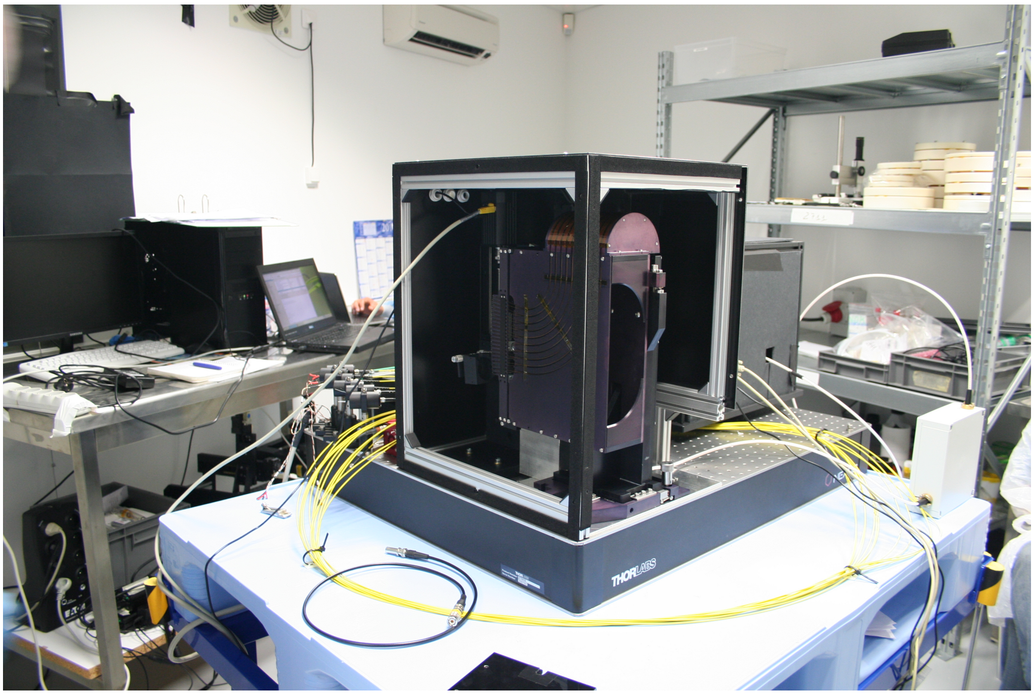


Figure 13: Throughput measurement device installed on the AMU test bench, in its (open) dedicated dark box. The sparse test slit has been put in place in front of it.

6 Conclusions

We designed and built a specific opto-mechanical device to calibrate the light flux injected by the DESI fiber sparse slit into the DESI spectrograph, in order to measure the spectrograph throughput. This device has been tested, and is now installed at Winlight on the AMU testbench. It is used for the throughput measurements of the DESI spectrographs modules.

The results of the throughput measurements are described in a separated document [DESI-3181].

References

[Jelinsky et al., 2016] Jelinsky, P., Edelstein, J., et al. (2016). The dark energy spectroscopic instrument (DESI) spectrographs. In *Proc. SPIE*, volume 9908.

[Perruchot et al., 2016] Perruchot, S., Secroun, A., Blanc, P.-E., Ronayette, S., Régal, X., Castagnoli, G., Le Van Suu, A., Ealet, A., Cuby, J.-G., Elliot, A., et al. (2016). Integration and testing of the DESI spectrograph prototype. In *Ground-based and Airborne Instrumentation for Astronomy VI*, volume 9908, page 99087W. International Society for Optics and Photonics.

[DESI-0957] Perruchot, S., Secroun, A. and Blanc, P.-E. (2014). Spectrograph Acceptance Test Plan, Aix Marseille Université

[DESI-1953] Jelinsky, P. (2016). Ferrule test slit measurements. DESI Project.

[DESI-2080] Ronayette, S (2017). Spectrograph AIT Acceptance Test Procedures (2017). Aix Marseille Université

[DESI-2635] Le Guillou, L., Schahmanèche, K., Karkar, S., Repain, Ph. (2017). Intercalibration of Silicon Photodiodes Laboratoire de Physique Nucléaire et de Hautes Energies (LPNHE).

[DESI-3181] Le Guillou, L., Guy, J., Karkar, S., Ghislain, P., Repain, Ph., Coridian, J., Blanc, P.-E., Perruchot, S., Ronayette, S., and Regal, X. (2017). Throughput measurement of the DESI EM/SM#1 spectrograph. Laboratoire de Physique Nucléaire et de Hautes Energies (LPNHE) and Aix Marseille Université (AMU).

A Photodiodes calibrated by DKD/Gigahertz Optik

In this section, we include the official calibration documents for the DKD-MD-37-SU100-2-30853 and DKD-MD-37-SU100-2-30854 photodiodes, calibrated by the Gigahertz-Optik (certified by the German standards service, the *Deutscher Kalibrerdienst* aka "DKD"), that we bought for the DESI project.

The throughput measurements for the EM#1 and SM#1 spectrographs have been performed using the DKD-MD-37-SU100-2-30853 photodiode.

Si photodiode reference	**provider**	**calibration**	**date**	**geometry**	**area**
DKD-MD-37-SU100-2-30853	Gigahertz-Optik	DKD	2015-11-30	$10 \times 10\,\mathrm{mm}$	$100\,\mathrm{mm}^2$
DKD-MD-37-SU100-2-30854	Gigahertz-Optik	DKD	2015-11-30	$10 \times 10\,\mathrm{mm}$	$100\,\mathrm{mm}^2$

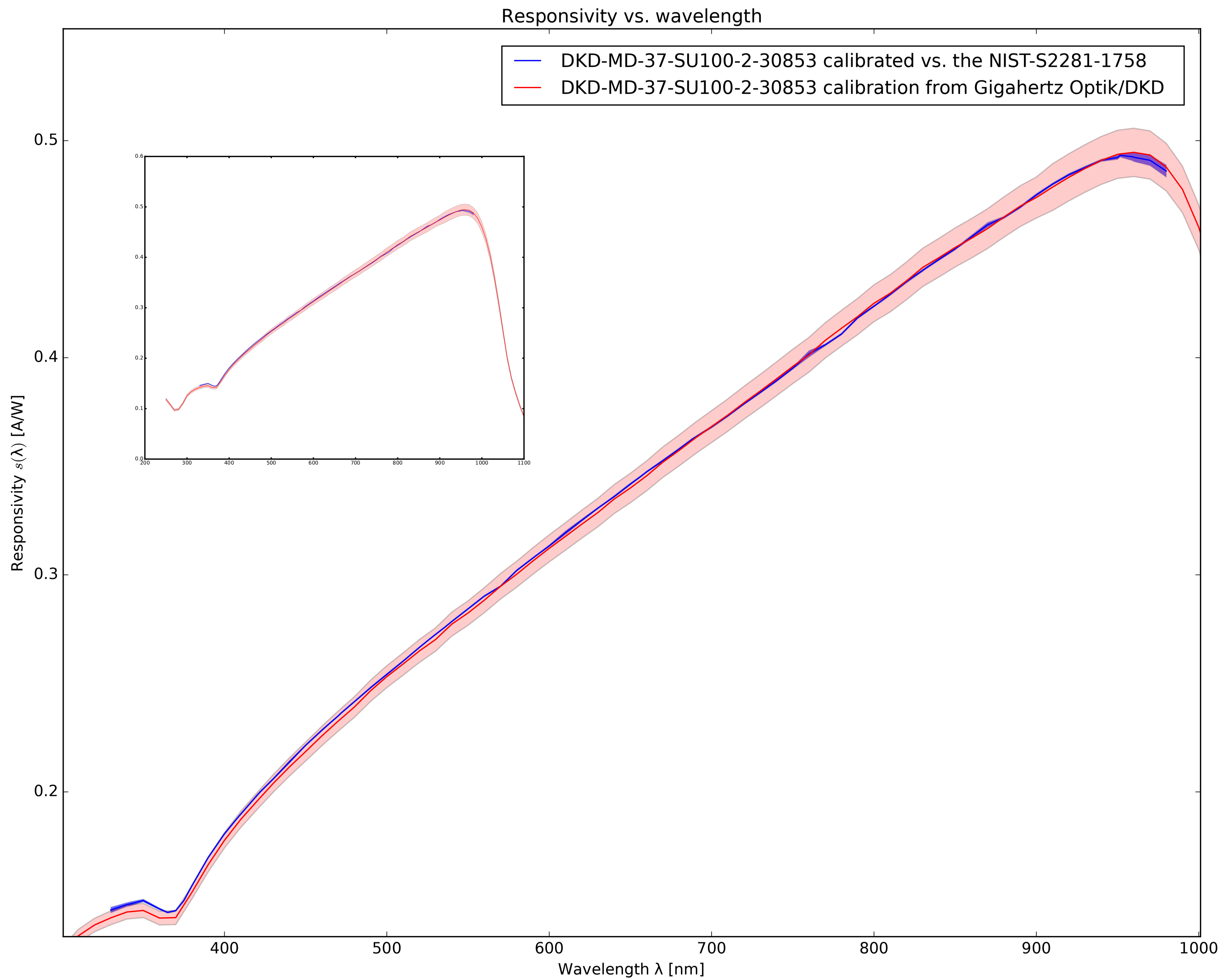


Figure 14: Responsivity [A/W] for the DKD-MD-37-SU100-2-30853 photodiode: provided by Gigahertz Optik/DKD (in red, 1-sigma contour), and measured on the LPNHE spectrophotometric testbench using a NIST calibrated photodiode as reference (in blue, 1-sigma contour). See [DESI-2635].

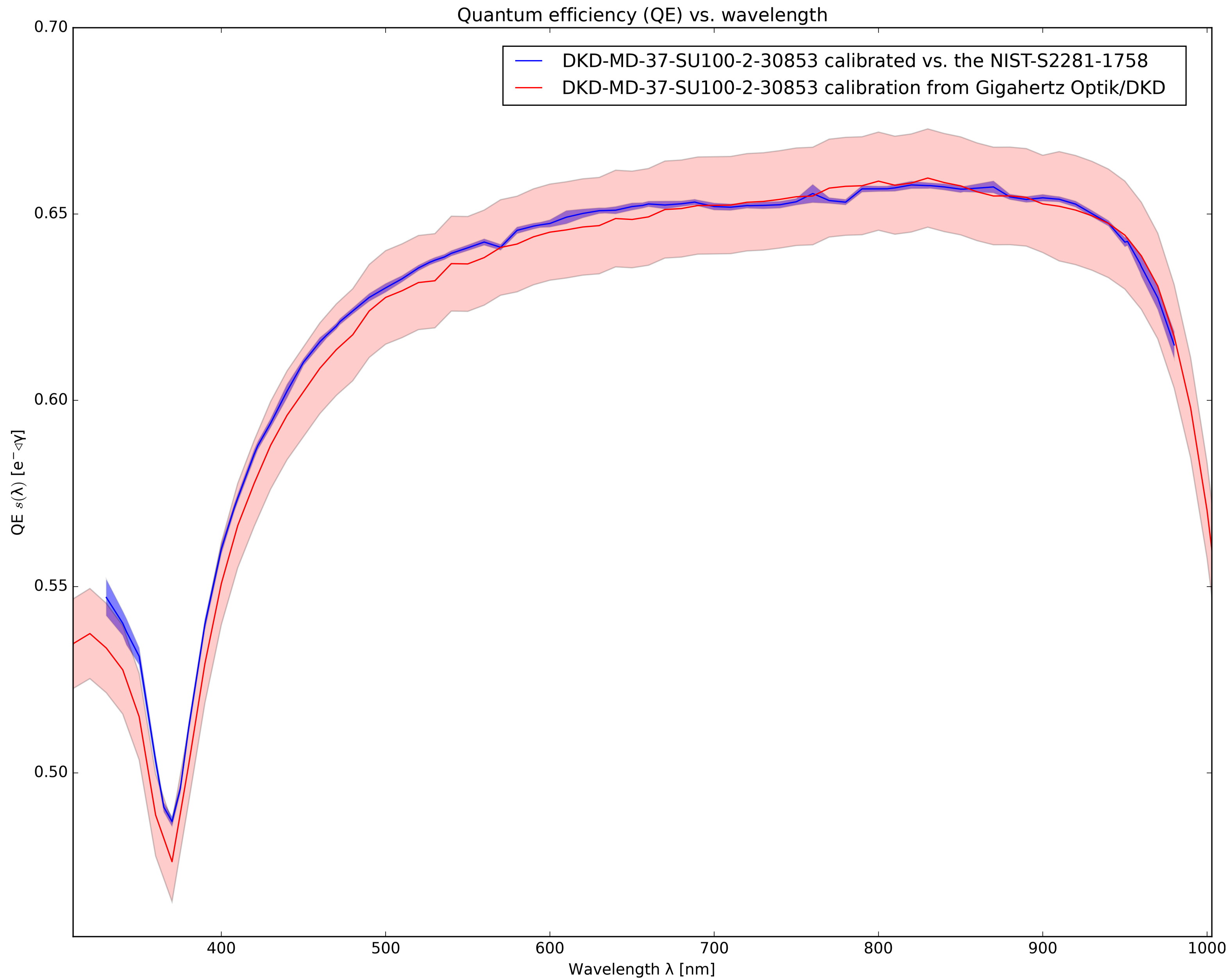


Figure 15: quantum efficiency (QE) [e^-/photon] for the DKD-MD-37-SU100-2-30853 photodiode: provided by Gigahertz Optik/DKD (in red, 1-sigma contour), and measured on the LPNHE spectrophotometric testbench using a NIST calibrated photodiode as reference (in blue, 1-sigma contour). See [DESI-2635].

Kalibrierlaboratorium für optische Strahlungsmessgrößen
Calibration laboratory for optical radiometry

GIGAHERTZ-OPTIK GMBH

26231-01
WERK
2015-11

Werkskalibrierschein
Calibration Certificate

Kalibrierzeichen
Calibration mark

Gegenstand *Object*	**Silizium Photodiode im Gehäuse mit Datenstecker Anschluss** *Silicon detector with data connector*
Hersteller *Manufacturer*	**Gigahertz-Optik GmbH**
Typ *Type*	**MD-37-SU100-2**
Fabrikate/Serien-Nr. *Serial number*	**30853**
Auftraggeber *Customer*	**Acal BFi France S.A.S** **ZI La Petite Montagne Sud, CE1834 Lisses** **4, Allee du Cantal** **F-91018 EVRY Cedex**
Auftragsnummer *Order No.*	**319467 / OP / 000 / 21000 / (26231)**
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	**5**

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).

Methoden und Verfahren der Kalibrierung entsprechen den Anforderungen der ISO17025. Die internen Transfernormale werden regelmäßig gegen Normale kalibriert, welche einen DKD/DAkkS-Kalibrierschein haben oder rückführbar auf ein Normal mit DKD/DAkkS-Kalibrierschein kalibriert sind oder gegen Normale eines nationalen Metrologieinstituts kalibriert sind.

Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

This calibration certificate documents the traceability to national standards, which realise the units of measurement according to the International System of Units (SI).

Methods and procedures of calibration meet the requirements of ISO17025. The intern used transfer standards were regular calibrated against standards, which have DKD/DAkkS certificates or are traceable to a standard with DKD/DAkkS or National Metrology Institute certificate.

The user is obliged to have the object recalibrated at appropriate intervals.

Stempel *Seal*	Datum *Date*	Stellv. Leiter des Kalibrierlaboratoriums *Deputy Head of the calibration laboratory*
Kalibrierlaboratorium Optische Strahlungs-messgrößen Gigahertz-Optik GmbH	30. November 2015	Dipl.-Ing. (FH) Stephan Fenk

• Gigahertz-Optik GmbH • An der Kälberweide 12 • 82299 Türkenfeld • Tel. +49 (0)8193-93700-0 • Fax +49 (0)8193-93700-50 •

1. Beschreibung des Kalibriergegenstandes:
Es handelt sich um einen Silizium Messkopf, Typ MD-37-SU100-2, Seriennummer 30853. Der Signalabgriff erfolgt mittels Datenstecker Anschluss..

1. Description of the calibration object:
The calibration object is a Silicon detector head, type MD-37-SU100-2, serial number 30853. The current will be taken by data connection.

2. Messverfahren:
Die spektrale Empfindlichkeit $s(\lambda)_\Phi$ wurde durch Vergleich mit einem Bezugsnormal BN-9102-111, (73345 PTB 13, 10.2013, due to 10.2016), IET 1004 bestimmt, dessen spektrale Empfindlichkeit auf die nationalen Normale der Physikalisch-Technische Bundesanstalt (PTB) zurückgeführt wird. Bestrahlt wurde mit der durch einen Gitterdoppel-monochromator zerlegten Strahlung einer Halogenglühlampe. Die spektrale Empfindlichkeit der Photodiode ergibt sich aus dem gemessenen Ausgangsstrom I zu $s(\lambda)_\Phi = I/\Phi(\lambda)$.

2. Measurement:
The spectral responsivity $s(\lambda)_\Phi$ was measured by comparison with a transfer standard BN-9102-111, (73345 PTB 13, 10.2013, due to 10.2016), IET 1004, which was calibrated in reference to the PTB. The measurements were made using a double monochromator. The radiation was made from a Halogen lamp. The spectral responsivity of the photodiode is given by the ratio of the output current I to $s(\lambda)\Phi = I/\Phi(\lambda)$.

3. Messbedingungen:
Art der Bestrahlung: $s(\lambda)_\Phi$
Der Empfänger befand sich im konvergenten Strahlungsbündel, das von einem etwa auf dem Empfängerfenster liegenden Bild des Monochromatoraustrittsspaltes ausging. Die Bündelachse stand senkrecht und zentrisch zur Frontfläche des Empfängerfensters.
Die Messung des Ausgangsstromes erfolgte mittels Optometer P-9201-4-TF, SN 6075/2, IET1589 bei einer Raumtemperatur von (24 ± 2) °C.

3. Conditions during the calibration:
The photodiode was set in a convergent beam. The beam axis has been almost perpendicular and centric to the entrance of the monochromator output. The output current of the photodiode was measured by using an Optometer P-9201-4-TF, SN 6075/2, IET1589. The temperature of the room was (24 ± 2) °C.

4. Messergebnisse:
Spektrale Empfindlichkeit $s(\lambda)_\Phi$ in Abhängigkeit von der Wellenlänge λ
Siehe hierzu die Seiten 4 - 5 mit graphischer und numerischer Darstellung. Die numerischen Werte der spektralen Empfindlichkeit $s(\lambda)_\Phi$ sind in A/W gegenüber der Wellenlänge λ in nm aufgeführt. Die graphische Darstellung dient nur der Veranschaulichung. Verbindlich sind nur die numerischen Werte der Tabelle.

4. Result of the measurement:
Spectral responsivity $s(\lambda)_\Phi$ versus wavelength
Page 4 - 5 shows the graphic and numerical data. The numerical data of the spectral responsivity $s(\lambda)_\Phi$ are shown versus the wavelength (λ), unit (A/W). Only the numerical data are guaranteed.

Die spektrale Bandbreite $\Delta\lambda$ des Monochromators betrug:
The spectral bandwidth $\Delta\lambda$ of the monochromator was:
250 nm – 1100 nm: 10 nm

Für die relative Messunsicherheit gilt folgende Aufspaltung:
For the relative uncertainty is following table responsible:

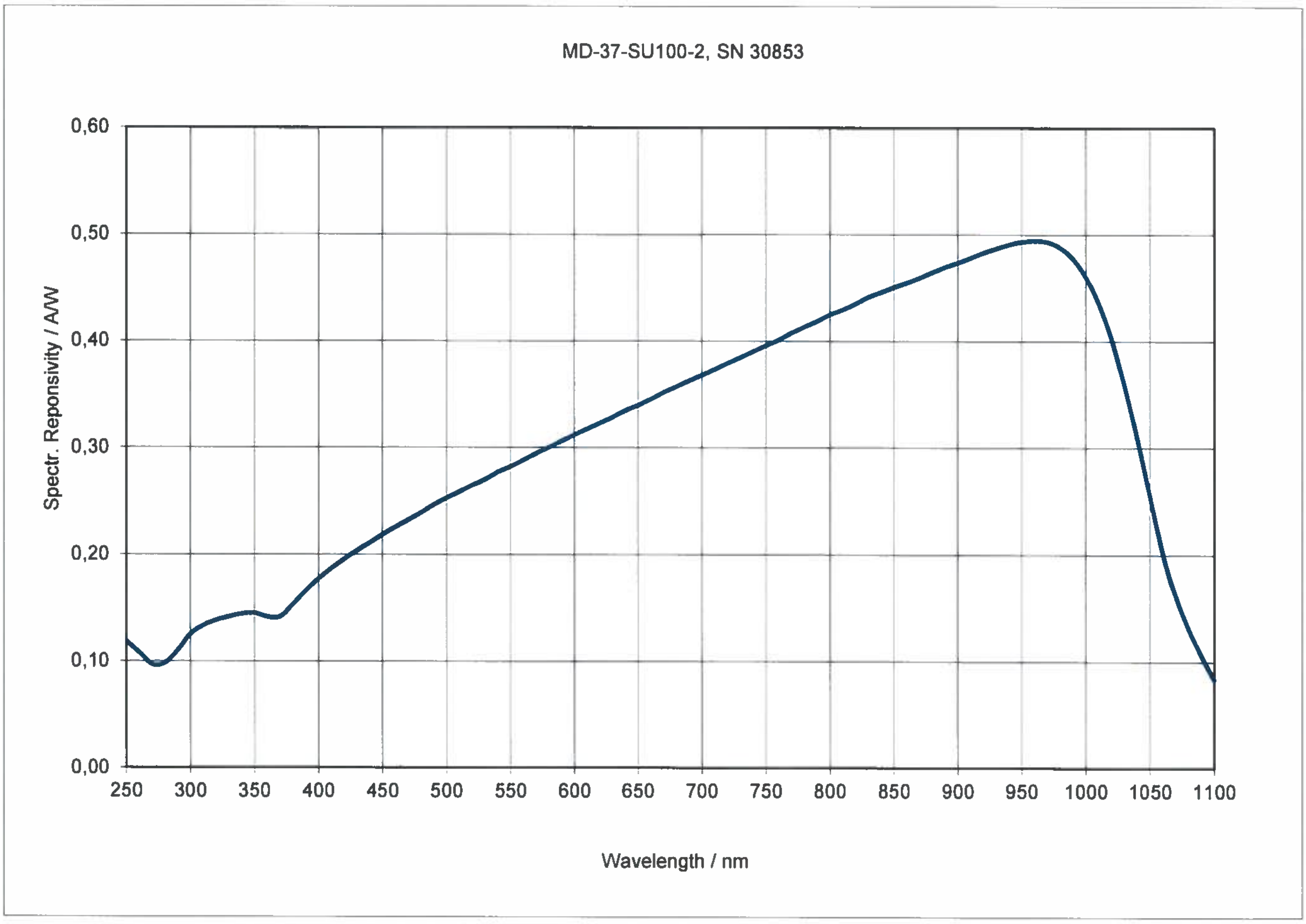
Wellenlänge in nm *Wavelength*	Relative Messunsicherheit in % *Relative uncertainty*
250 - 370	± 4,5
380 - 900	± 4
910 - 1070	± 4,5
1080 - 1100	± 5

Die angegebene Messunsicherheit (k = 2) setzt sich zusammen aus den Unsicherheiten des Kalibrierverfahrens und des Kalibriergegenstandes während der Kalibrierung. Ein Anteil für die Langzeitstabilität des Kalibriergegenstandes ist nicht enthalten.
The measuring insecurity (k = 2) stated is composed of the insecurities of the calibration method and of the calibrating object during the calibration. A share for the long term stability of the calibrated item is not included.

5. Bemerkungen:
Die oben angegebene Kalibriernummer 26231-01-WERK-2015-11 ist am Messkopf MD-37-SU100-2, Seriennummer 30853 angebracht. Der Kalibrierwert ist im Datenstecker des Messkopfes eingespeichert und kann mittels Menü aufgerufen werden.
Eine Abhängigkeit der spektralen Empfindlichkeit von anderen als den angegebenen Betriebsbedingungen oder Einflußgrößen ist nicht untersucht worden. Es ist mit einer wellenlängenabhängigen Alterung der spektralen Empfindlichkeit zu rechnen.
Eine Rekalibrierung innerhalb eines Jahres ist zu empfehlen.

5. Remarks:
The calibration report number 26231-01-WERK-2015-11 is marked on the detector head, type MD-37-SU100-2, serial number 30853. The calibration factor is stored into the data plug in of the detector head. It can be chosen by menu.
Dependence of the spectral responsivity from other as the given conditions is not examined. It is reckon in a wavelength dependence spectral responsivity during the life of the detector head.
Yearly recalibration is recommended.

Grafische Darstellung der Messwerte:
Graphic of the measured data:



Numerische Darstellung der Messwerte:
Numerical value of the measured data:

Wavelength / nm	Spectral responsivity / A/W	Wavelength / nm	Spectral responsivity / A/W	Wavelength / nm	Spectral responsivity / A/W
250,0	0,1186	540,0	0,2773	830,0	0,4416
260,0	0,1081	550,0	0,2824	840,0	0,4461
270,0	0,0970	560,0	0,2883	850,0	0,4508
280,0	0,0986	570,0	0,2947	860,0	0,4550
290,0	0,1102	580,0	0,3003	870,0	0,4595
300,0	0,1256	590,0	0,3064	880,0	0,4648
310,0	0,1337	600,0	0,3122	890,0	0,4698
320,0	0,1387	610,0	0,3177	900,0	0,4738
330,0	0,1420	620,0	0,3233	910,0	0,4786
340,0	0,1447	630,0	0,3287	920,0	0,4831
350,0	0,1454	640,0	0,3349	930,0	0,4872
360,0	0,1419	650,0	0,3400	940,0	0,4909
370,0	0,1421	660,0	0,3456	950,0	0,4937
380,0	0,1538	670,0	0,3519	960,0	0,4946
390,0	0,1665	680,0	0,3573	970,0	0,4934
400,0	0,1777	690,0	0,3630	980,0	0,4878
410,0	0,1873	700,0	0,3683	990,0	0,4775
420,0	0,1957	710,0	0,3736	1000,0	0,4601
430,0	0,2039	720,0	0,3793	1010,0	0,4354
440,0	0,2115	730,0	0,3847	1020,0	0,4023
450,0	0,2186	740,0	0,3903	1030,0	0,3588
460,0	0,2258	750,0	0,3960	1040,0	0,3087
470,0	0,2326	760,0	0,4014	1050,0	0,2549
480,0	0,2391	770,0	0,4080	1060,0	0,2011
490,0	0,2466	780,0	0,4136	1070,0	0,1611
500,0	0,2531	790,0	0,4190	1080,0	0,1315
510,0	0,2589	800,0	0,4251	1090,0	0,1062
520,0	0,2649	810,0	0,4297	1100,0	0,0840
530,0	0,2702	820,0	0,4354		

GIGAHERTZ-OPTIK GMBH

Werkskalibrierschein
Calibration Certificate

Kalibrierzeichen
Calibration mark

26231-02
WERK
2015-11

Gegenstand *Object*	**Silizium Photodiode im Gehäuse mit Datenstecker Anschluss** *Silicon detector with data connector*
Hersteller *Manufacturer*	**Gigahertz-Optik GmbH**
Typ *Type*	**MD-37-SU100-2**
Fabrikate/Serien-Nr. *Serial number*	**30854**
Auftraggeber *Customer*	**Acal BFi France S.A.S** **ZI La Petite Montagne Sud, CE1834 Lisses** **4, Allee du Cantal** **F-91018 EVRY Cedex**
Auftragsnummer *Order No.*	**319467 / OP / 000 / 21000 / (26231)**
Anzahl der Seiten des Kalibrierscheines *Number of pages of the certificate*	**5**

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).

Methoden und Verfahren der Kalibrierung entsprechen den Anforderungen der ISO17025. Die internen Transfernormale werden regelmäßig gegen Normale kalibriert, welche einen DKD/DAkkS-Kalibrierschein haben oder rückführbar auf ein Normal mit DKD/DAkkS-Kalibrierschein kalibriert sind oder gegen Normale eines nationalen Metrologieinstituts kalibriert sind.

Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

This calibration certificate documents the traceability to national standards, which realise the units of measurement according to the International System of Units (SI).

Methods and procedures of calibration meet the requirements of ISO17025. The intern used transfer standards were regular calibrated against standards, which have DKD/DAkkS certificates or are traceable to a standard with DKD/DAkkS or National Metrology Institute certificate.

The user is obliged to have the object recalibrated at appropriate intervals.

Stempel *Seal*	Datum *Date*	Stellv. Leiter des Kalibrierlaboratoriums *Deputy Head of the calibration laboratory*
Kalibrierlaboratorium • Optische Strahlungs-messgrößen • Gigahertz-Optik GmbH	30. November 2015	Dipl.-Ing. (FH) Stephan Fenk

1. Beschreibung des Kalibriergegenstandes:
Es handelt sich um einen Silizium Messkopf, Typ MD-37-SU100-2, Seriennummer 30854. Der Signalabgriff erfolgt mittels Datenstecker Anschluss..

1. Description of the calibration object:
The calibration object is a Silicon detector head, type MD-37-SU100-2, serial number 30854. The current will be taken by data connection.

2. Messverfahren:
Die spektrale Empfindlichkeit $s(\lambda)_\Phi$ wurde durch Vergleich mit einem Bezugsnormal BN-9102-111, (73345 PTB 13, 10.2013, due to 10.2016), IET 1004 bestimmt, dessen spektrale Empfindlichkeit auf die nationalen Normale der Physikalisch-Technische Bundesanstalt (PTB) zurückgeführt wird. Bestrahlt wurde mit der durch einen Gitterdoppel-monochromator zerlegten Strahlung einer Halogenglühlampe. Die spektrale Empfindlichkeit der Photodiode ergibt sich aus dem gemessenen Ausgangsstrom I zu $s(\lambda)_\Phi = I/\Phi(\lambda)$.

2. Measurement:
The spectral responsivity $s(\lambda)_\Phi$ was measured by comparison with a transfer standard BN-9102-111, (73345 PTB 13, 10.2013, due to 10.2016), IET 1004, which was calibrated in reference to the PTB. The measurements were made using a double monochromator. The radiation was made from a Halogen lamp. The spectral responsivity of the photodiode is given by the ratio of the output current I to $s(\lambda)\Phi = I/\Phi(\lambda)$.

3. Messbedingungen:
Art der Bestrahlung: $s(\lambda)_\Phi$
Der Empfänger befand sich im konvergenten Strahlungsbündel, das von einem etwa auf dem Empfängerfenster liegenden Bild des Monochromatoraustrittsspaltes ausging. Die Bündelachse stand senkrecht und zentrisch zur Frontfläche des Empfängerfensters.
Die Messung des Ausgangsstromes erfolgte mittels Optometer P-9201-4-TF, SN 6075/2, IET1589 bei einer Raumtemperatur von (24 ± 2) °C.

3. Conditions during the calibration:
The photodiode was set in a convergent beam. The beam axis has been almost perpendicular and centric to the entrance of the monochromator output. The output current of the photodiode was measured by using an Optometer P-9201-4-TF, SN 6075/2, IET1589. The temperature of the room was (24 ± 2) °C.

4. Messergebnisse:
Spektrale Empfindlichkeit $s(\lambda)_\Phi$ in Abhängigkeit von der Wellenlänge λ
Siehe hierzu die Seiten 4 - 5 mit graphischer und numerischer Darstellung. Die numerischen Werte der spektralen Empfindlichkeit $s(\lambda)_\Phi$ sind in A/W gegenüber der Wellenlänge λ in nm aufgeführt. Die graphische Darstellung dient nur der Veranschaulichung. Verbindlich sind nur die numerischen Werte der Tabelle.

4. Result of the measurement:
Spectral responsivity $s(\lambda)_\Phi$ versus wavelength
Page 4 - 5 shows the graphic and numerical data. The numerical data of the spectral responsivity $s(\lambda)_\Phi$ are shown versus the wavelength (λ), unit (A/W). Only the numerical data are guaranteed.

Die spektrale Bandbreite $\Delta\lambda$ des Monochromators betrug:
The spectral bandwidth $\Delta\lambda$ of the monochromator was:
250 nm – 1100 nm: 10 nm

Für die relative Messunsicherheit gilt folgende Aufspaltung:
For the relative uncertainty is following table responsible:

Wellenlänge in nm *Wavelength*	Relative Messunsicherheit in % *Relative uncertainty*
250 - 370	± 4,5
380 - 900	± 4
910 - 1070	± 4,5
1080 - 1100	± 5

Die angegebene Messunsicherheit (k = 2) setzt sich zusammen aus den Unsicherheiten des Kalibrierverfahrens und des Kalibriergegenstandes während der Kalibrierung. Ein Anteil für die Langzeitstabilität des Kalibriergegenstandes ist nicht enthalten.
The measuring insecurity (k = 2) stated is composed of the insecurities of the calibration method and of the calibrating object during the calibration. A share for the long term stability of the calibrated item is not included.

5. Bemerkungen:
Die oben angegebene Kalibriernummer 26231-02-WERK-2015-11 ist am Messkopf MD-37-SU100-2, Seriennummer 30854 angebracht. Der Kalibrierwert ist im Datenstecker des Messkopfes eingespeichert und kann mittels Menü aufgerufen werden.
Eine Abhängigkeit der spektralen Empfindlichkeit von anderen als den angegebenen Betriebsbedingungen oder Einflußgrößen ist nicht untersucht worden. Es ist mit einer wellenlängenabhängigen Alterung der spektralen Empfindlichkeit zu rechnen.
Eine Rekalibrierung innerhalb eines Jahres ist zu empfehlen.

5. Remarks:
The calibration report number 26231-02-WERK-2015-11 is marked on the detector head, type MD-37-SU100-2, serial number 30854. The calibration factor is stored into the data plug in of the detector head. It can be chosen by menu.
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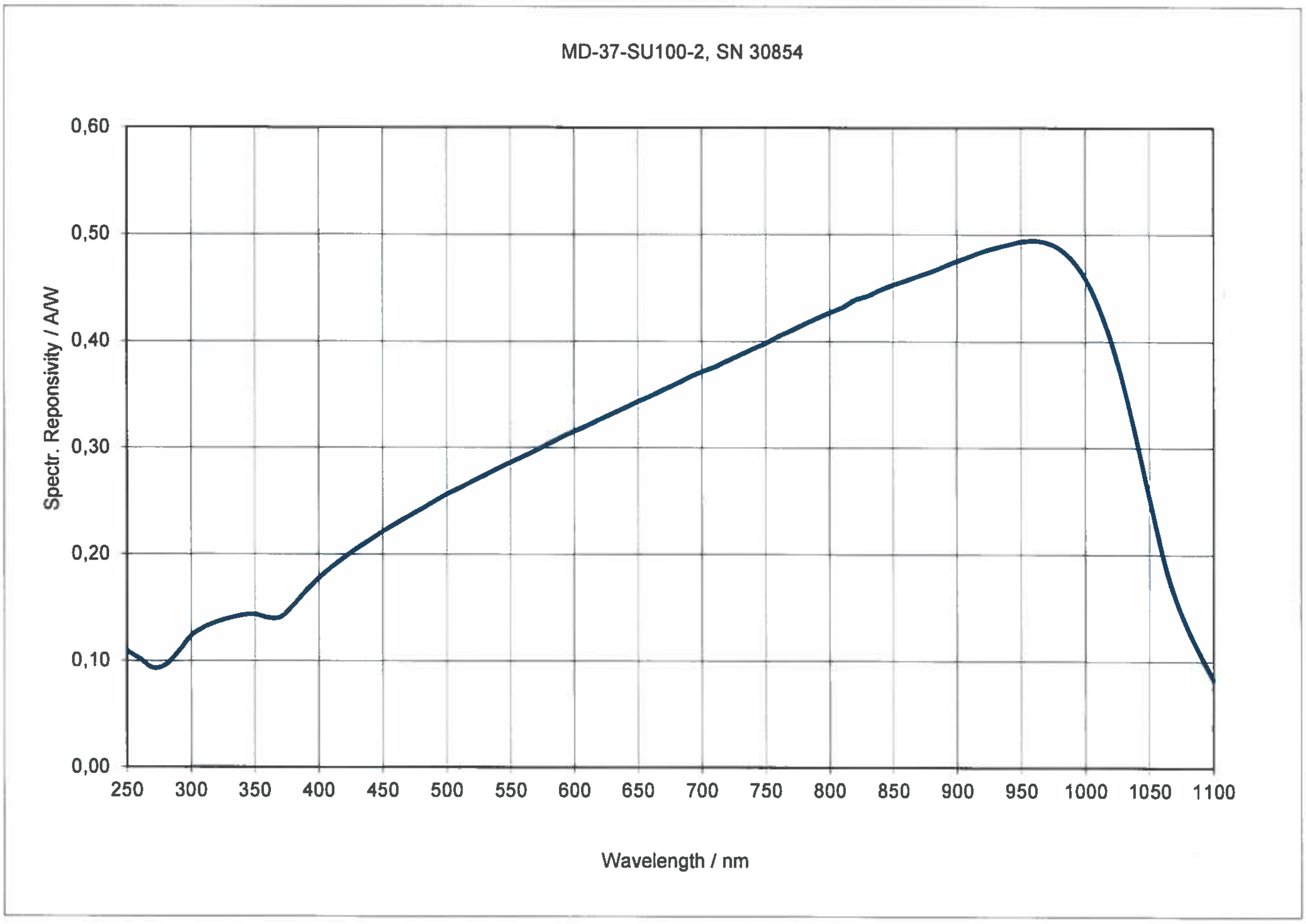
Graphic of the measured data:



Numerische Darstellung der Messwerte:
Numerical value of the measured data:

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270,0	0,0935	560,0	0,2921	850,0	0,4534
280,0	0,0966	570,0	0,2979	860,0	0,4573
290,0	0,1088	580,0	0,3040	870,0	0,4617
300,0	0,1238	590,0	0,3101	880,0	0,4658
310,0	0,1317	600,0	0,3159	890,0	0,4707
320,0	0,1367	610,0	0,3209	900,0	0,4754
330,0	0,1403	620,0	0,3270	910,0	0,4801
340,0	0,1431	630,0	0,3325	920,0	0,4845
350,0	0,1439	640,0	0,3382	930,0	0,4879
360,0	0,1408	650,0	0,3439	940,0	0,4909
370,0	0,1413	660,0	0,3490	950,0	0,4937
380,0	0,1526	670,0	0,3548	960,0	0,4945
390,0	0,1661	680,0	0,3604	970,0	0,4925
400,0	0,1779	690,0	0,3666	980,0	0,4868
410,0	0,1881	700,0	0,3718	990,0	0,4760
420,0	0,1973	710,0	0,3763	1000,0	0,4587
430,0	0,2058	720,0	0,3822	1010,0	0,4336
440,0	0,2138	730,0	0,3877	1020,0	0,3999
450,0	0,2214	740,0	0,3932	1030,0	0,3574
460,0	0,2287	750,0	0,3987	1040,0	0,3073
470,0	0,2356	760,0	0,4051	1050,0	0,2539
480,0	0,2424	770,0	0,4104	1060,0	0,2002
490,0	0,2495	780,0	0,4164	1070,0	0,1597
500,0	0,2564	790,0	0,4221	1080,0	0,1305
510,0	0,2624	800,0	0,4274	1090,0	0,1055
520,0	0,2686	810,0	0,4322	1100,0	0,0835
530,0	0,2744	820,0	0,4393		