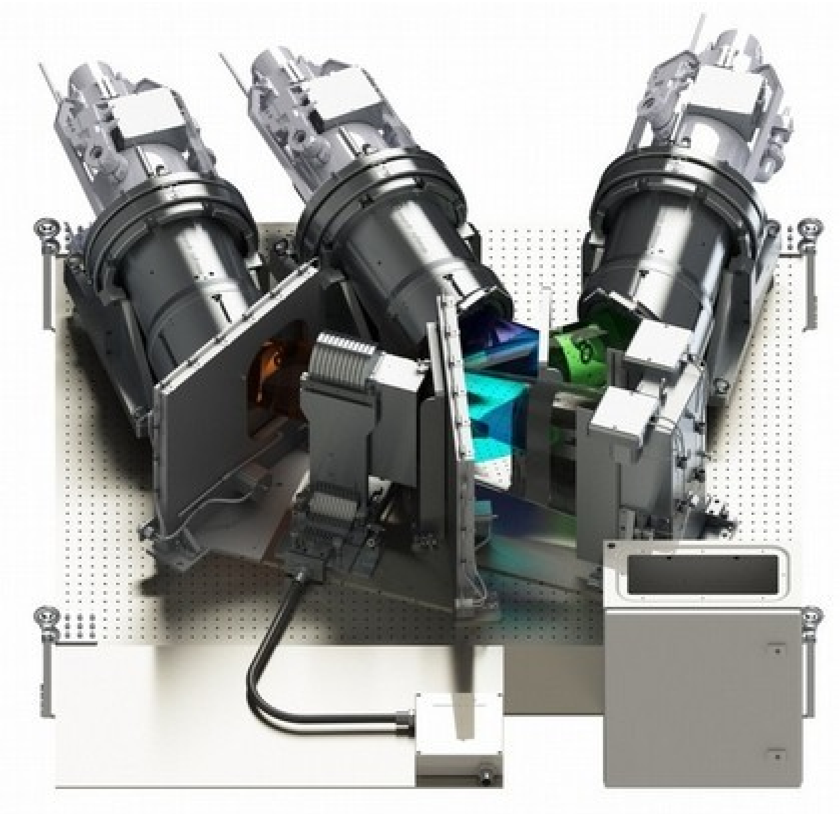


DESI SM#8 Throughput Measurement

Laurent Le Guillou
(Sorbonne Univ. / LPNHE)
Julien Guy
(LBL)

DESI Spectro Telecon
2019-08-27

LPNHE : Julien Coridian, Patrick Ghislain, Julien Guy, Sonia Karkar, Laurent Le Guillou, Yann Orain, Philippe Repain, Eduardo Sepulveda
AMU : Pierre-Eric Blanc, Sandrine Perruchot, Xavier Regal, Samuel Ronayette
CEA : C. Magneville

Meas. campaign: SM#8 (July-Aug. ‘19)

- **SM#8 campaign: July 30th- August 2nd (LLG, PEB)**
  - Everything went well
  - Some extra scans (full 10x10mm & 100 microns scans) for FRD

Exposure time : shutter time correction

- Series of exposures with **increasing exposure time** and **different neutral densities** filters have been taken and analysed.
- Assuming at least linearity for low fluxes, we were able to estimate an effective exposure time correction (**same result on the 3 arms**) :

$$\Delta t^{\mathrm{EM\#1}}_{\mathrm{effective}} = [\mathrm{EXPREQ}] + 0.36\,\mathrm{s} \pm 0.01\,\mathrm{s}$$

$$\Delta t^{\mathrm{SM\#1}}_{\mathrm{effective}} = [\mathrm{EXPREQ}] + 0.662\,\mathrm{s} \pm 0.003\,\mathrm{s}$$

$$\Delta t^{\mathrm{SM\#2}}_{\mathrm{effective}} = [\mathrm{EXPREQ}] + 0.660\,\mathrm{s} \pm 0.004\,\mathrm{s}$$

$$\Delta t^{\mathrm{SM\#3}}_{\mathrm{effective}} = [\mathrm{EXPREQ}] + 0.637\,\mathrm{s} + 0.004\,\mathrm{s}$$

$$\Delta t^{\mathrm{SM\#4}}_{\mathrm{effective}} = [\mathrm{EXPREQ}] + 0.660\,\mathrm{s} \pm 0.005\,\mathrm{s}$$

$$\Delta t^{\mathrm{SM\#5}}_{\mathrm{effective}} = [\mathrm{EXPREQ}] + 0.658\,\mathrm{s} \pm 0.004\,\mathrm{s}$$

$$\Delta t^{\mathrm{SM\#6}}_{\mathrm{effective}} = [\mathrm{EXPREQ}] + 0.681\,\mathrm{s} \pm 0.017\,\mathrm{s}$$

$$\Delta t^{\mathrm{SM\#7}}_{\mathrm{effective}} = [\mathrm{EXPREQ}] + 0.656\,\mathrm{s} \pm 0.021\,\mathrm{s}$$

$$\Delta t^{\mathrm{SM\#8}}_{\mathrm{effective}} = [\mathrm{EXPREQ}] + 0.648\,\mathrm{s} \pm 0.008\,\mathrm{s}$$

SM#8: Gains measured at CEA/Saclay (CMV)

- Much better CCDs than EM#1, readout system with identical setup at CEA & Winlight
- Gains obtained with a PTC with **true flats on the CEA / Saclay testbench** after CCD integration into the cryostats (Ch. Magneville (CMV) & colleagues).

Amplifier *(Blue CCD)*	gain
B1-A *(CEA top-left)*	1.31
B1-B *(CEA bottom-left)*	1.31
B1-C *(CEA top-right)*	1.31
B1-D *(CEA bottom-right)*	1.31

Amplifier *(Red CCD)*	gain
R1-A *(CEA top-right)*	1.70
R1-B *(CEA top-left)*	1.68
R1-C *(CEA bottom-right)*	1.45
R1-D *(CEA bottom-left)*	1.51

Amplifier *(NIR/Z CCD)*	gain
Z1-A *(CEA bottom-right)*	1.46
Z1-B *(CEA bottom-left)*	1.50
Z1-C *(CEA top-right)*	1.62
Z1-D *(CEA top-left)*	1.51

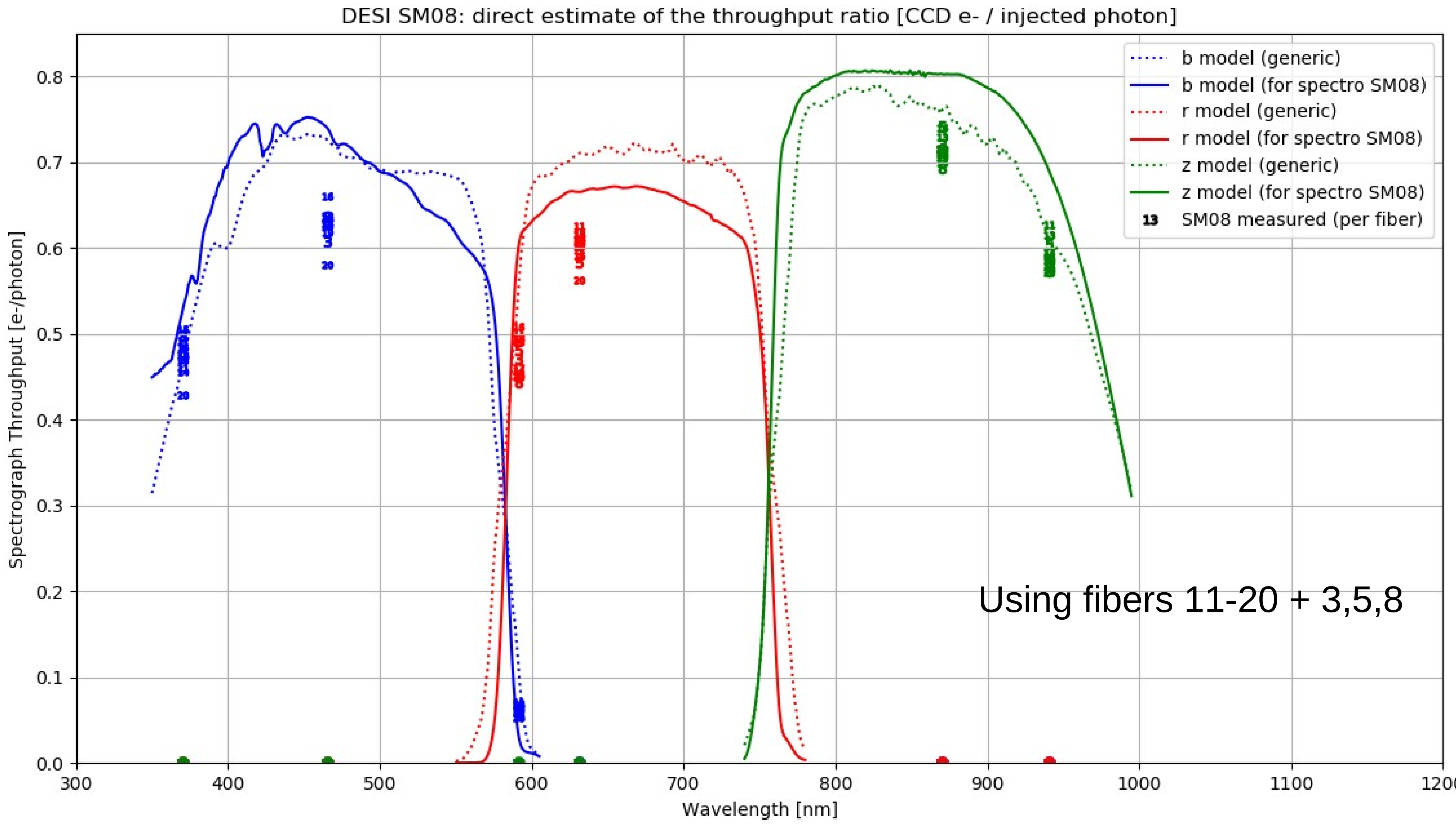
Direct throughput estimate (without a model)

- We first estimate the spectrograph throughput by **dividing** the **integrated flux in each CCD** (for each LED and each fiber 11-20) by the **injected flux (DKD)** :

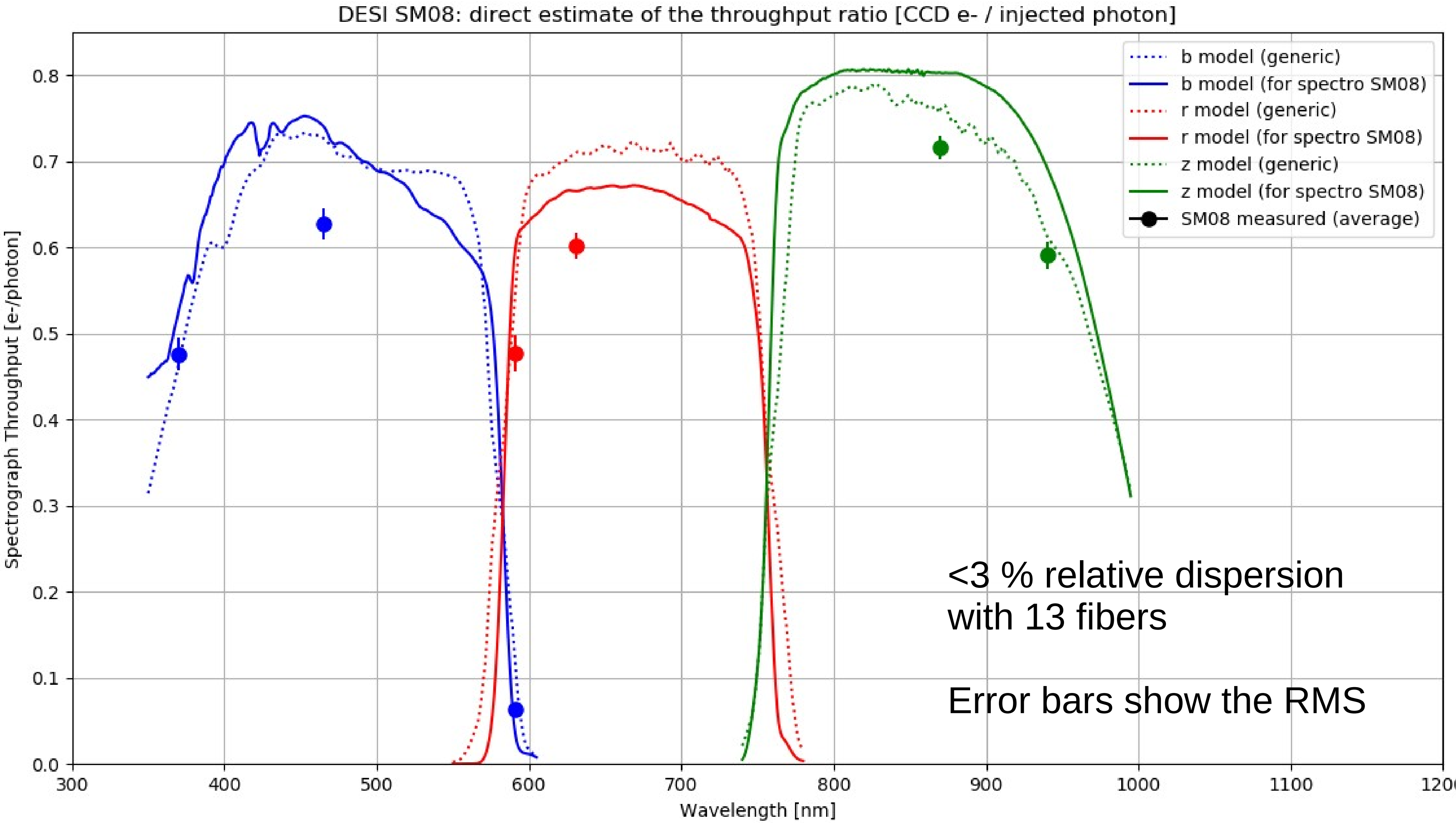
$$\eta_{[\text{e-}/\gamma]}(\lambda_{\text{LED}}) = (QE_{\text{CCD}} \times T_{\text{optics}}(\lambda_{\text{LED}})) = \frac{\phi^{\text{CCD}}_{[\text{e-}/\text{s}]}(\text{LED})}{\phi^{\text{injected}}_{[\gamma/\text{s}]}(\text{LED})}$$

- A this step, no FRD correction.
- What we got that way is an **estimate of the spectrograph throughput** at the LED wavelength (weighted by the LED spectrum)
- Comparison with the **DESI generic optical model** (**without fibers**)

SM#8 : direct throughput estimate



SM#8 : direct throughput estimate (no FRD corr.)



<3 % relative dispersion with 13 fibers

Error bars show the RMS

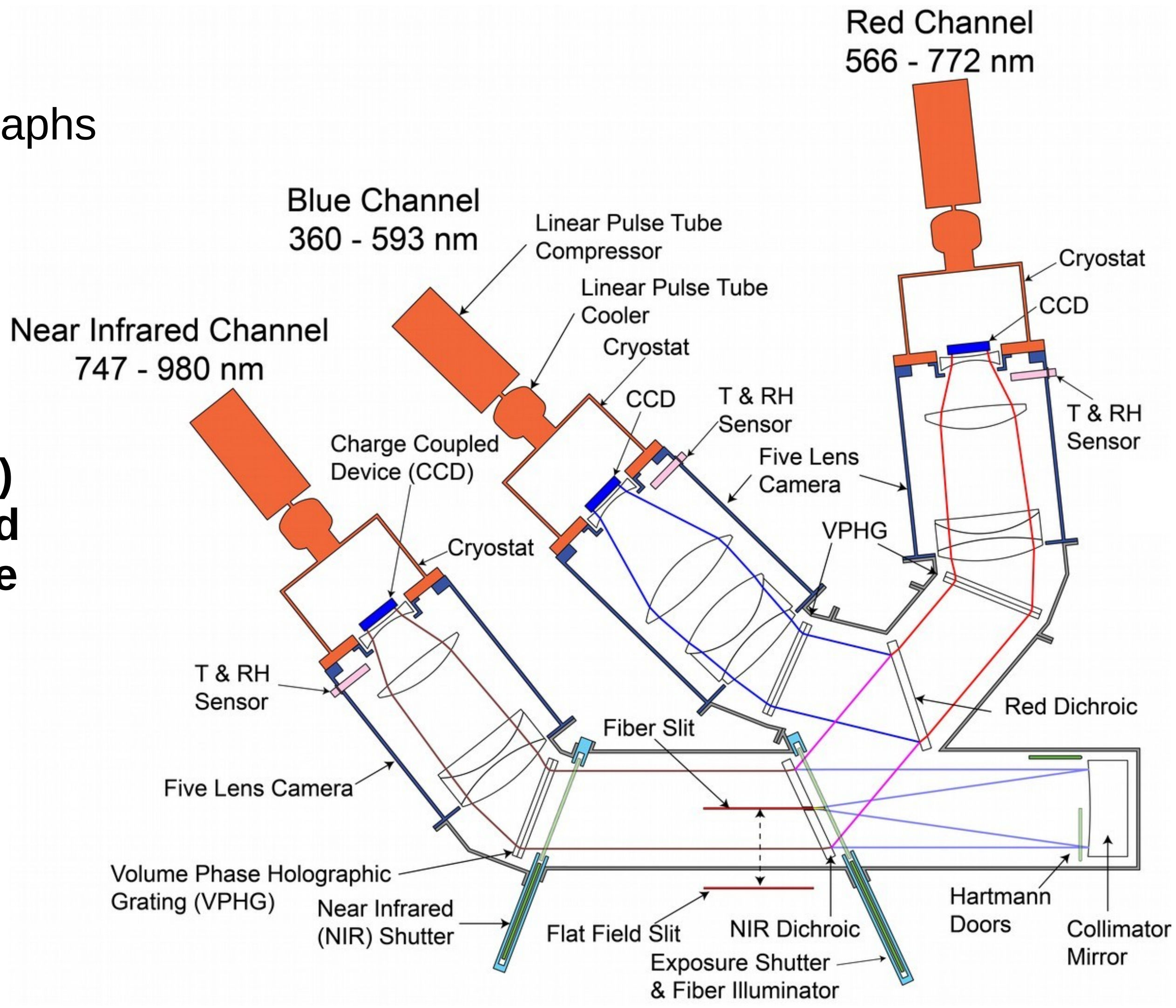
FRD note & DESI Throughput paper

- **Effect of the fiber focal ratio degradation (FRD) on the throughput estimate**
  - Underestimate the throughput, at max by around 10%
  - Analysis ongoing, note in prep.
- **Paper on the direct measurement of the throughput of all DESI spectrographs (Le Guillou L., Guy J., Karkar S., Blanc P.-E., Perruchot S., et al.)**
  - In prep., being created on DESI publication board.

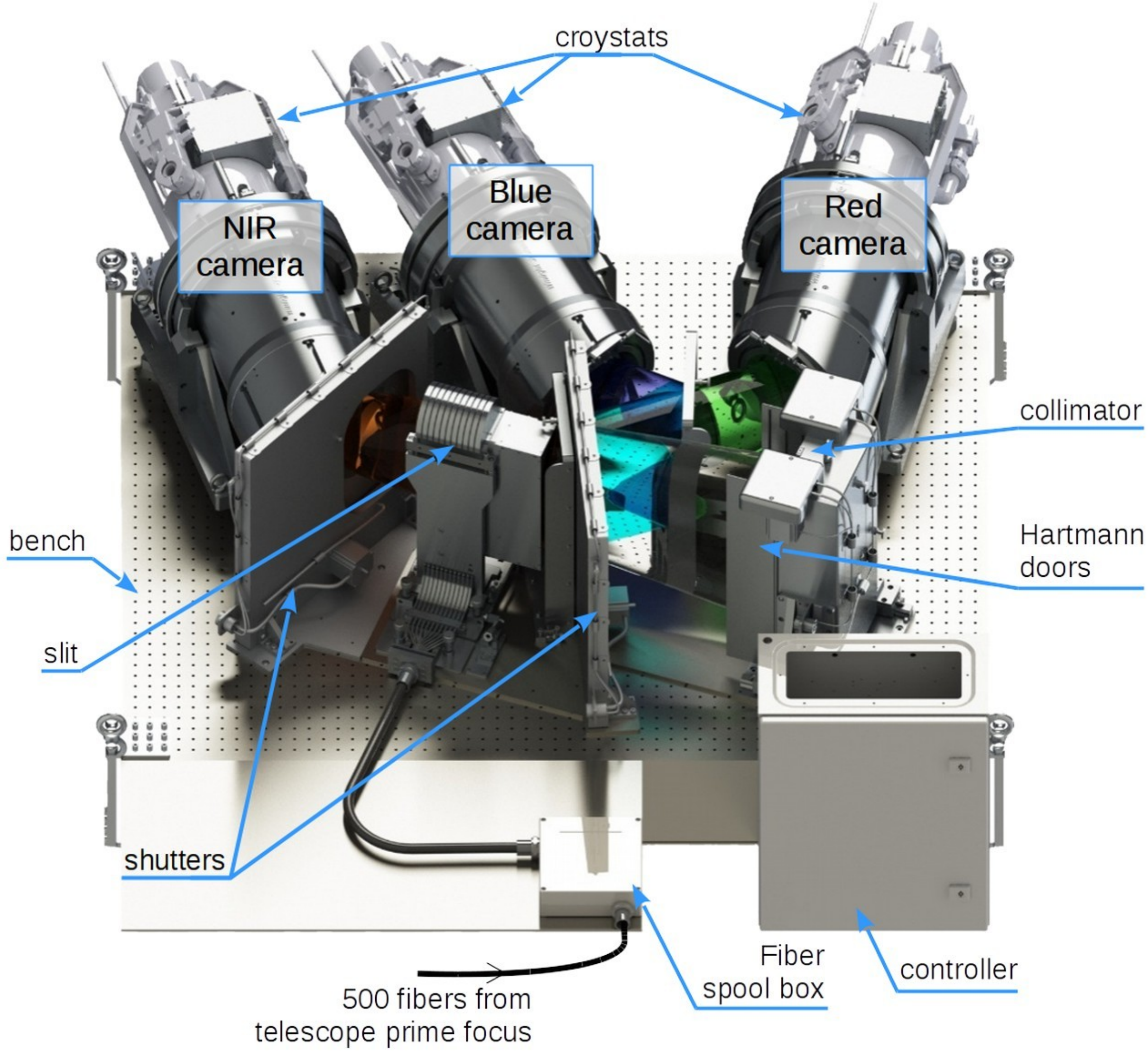
Suppl. Slides

The DESI spectrograph

- 10 identical spectrographs
- 10 x 500 fibers
- 3 arms :
  NIR, Red, Blue
- **Fiber slit (500 fibers) may be removed and replaced by a sparse fiber slit for tests.**

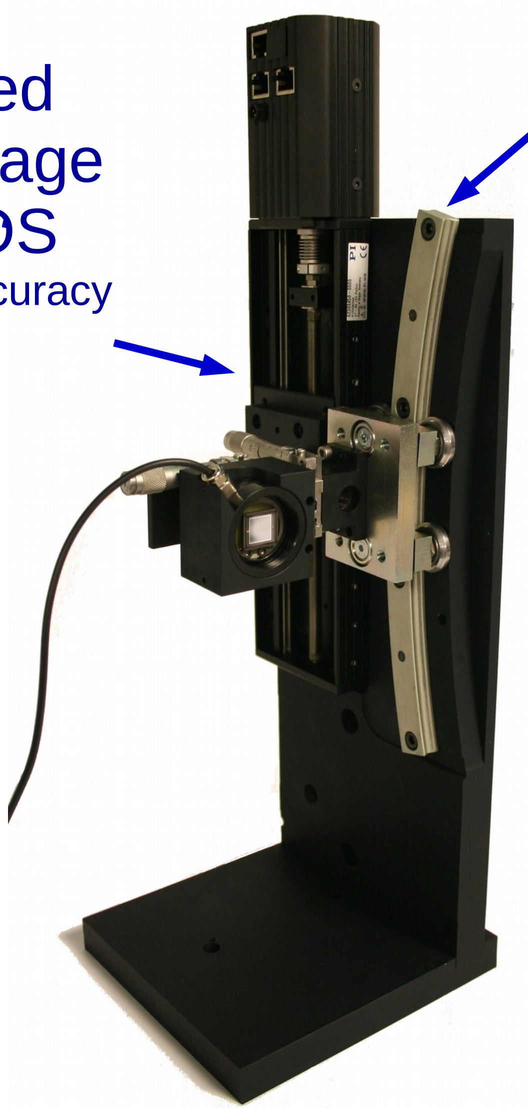


The DESI spectrograph



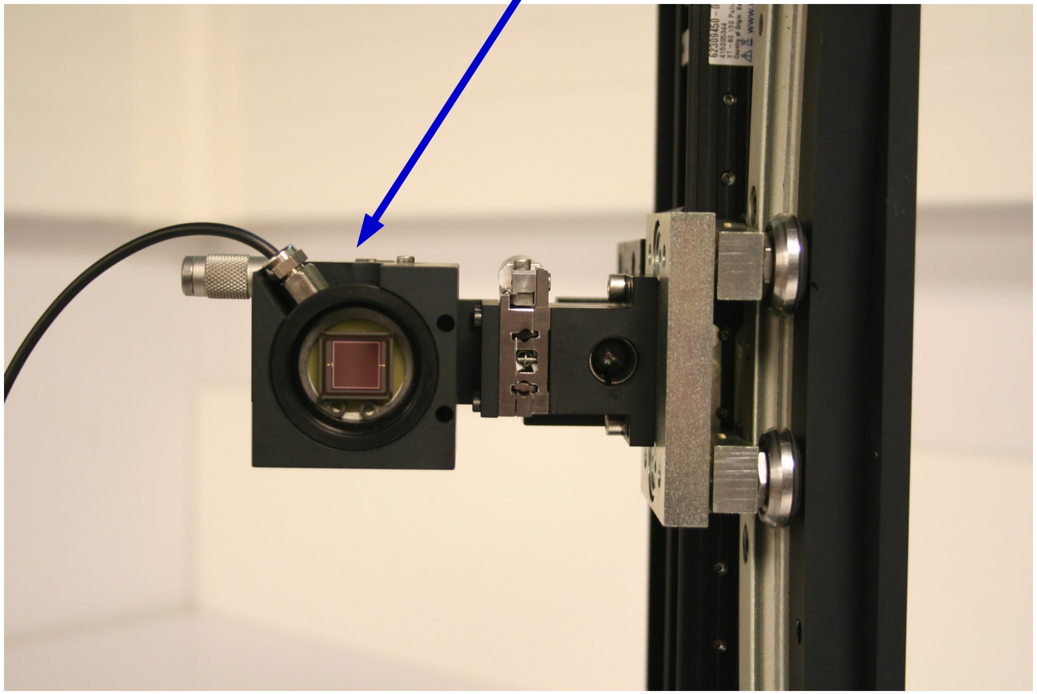
Throughput measurement device

Motorized
linear stage
Pi/MICOS
<0.4 µm accuracy

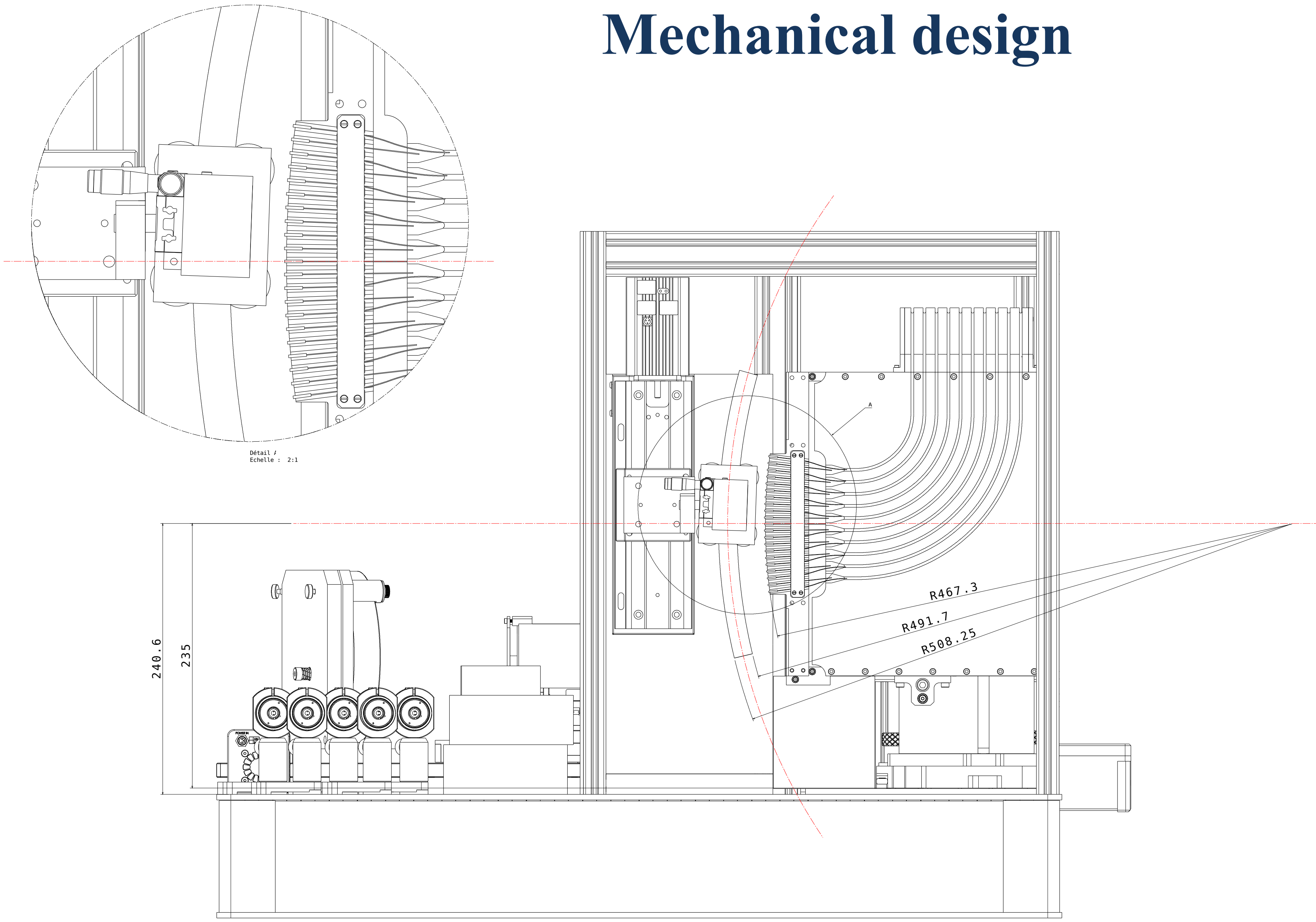


Curved rail
(radius 500 mm)

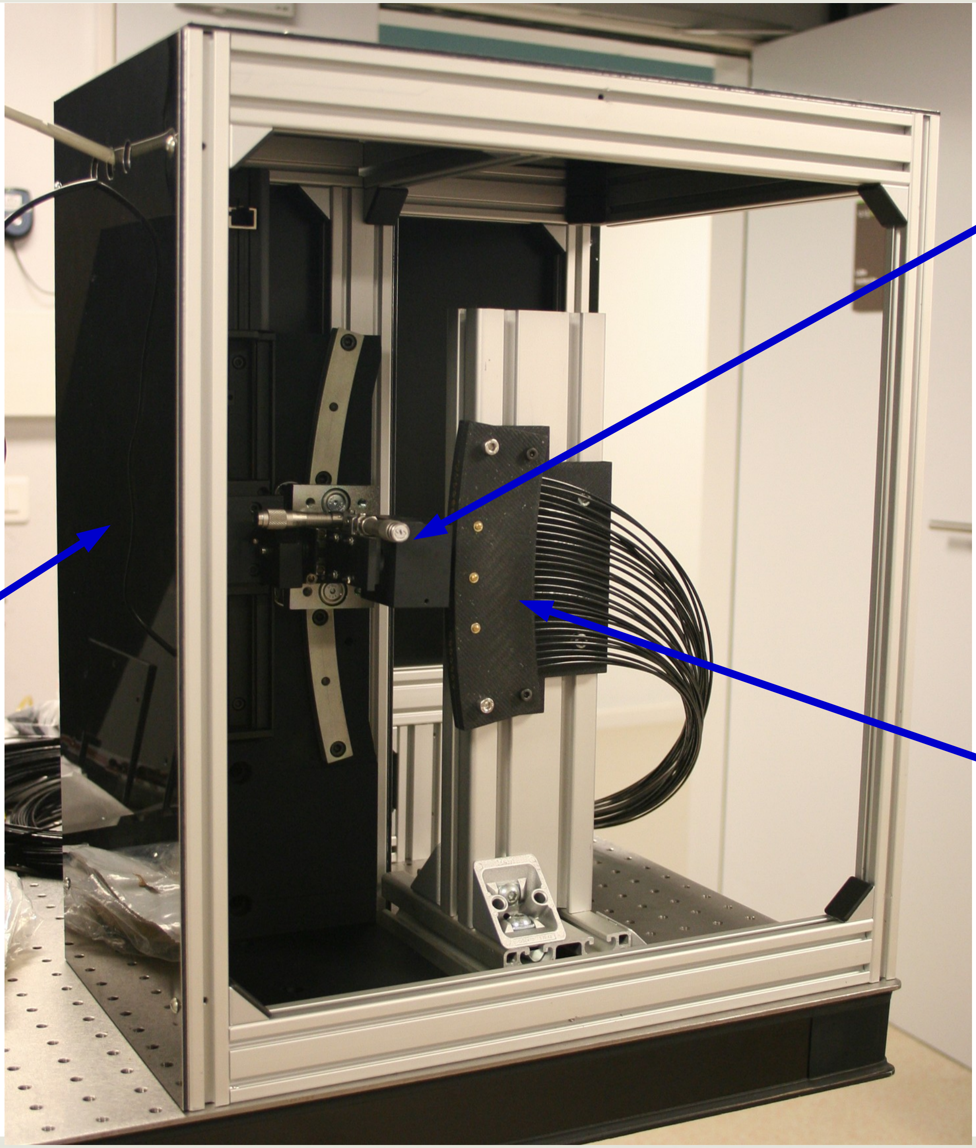
Calibrated
Photodiode
10x10 mm²



Mechanical design



Throughput measurement device

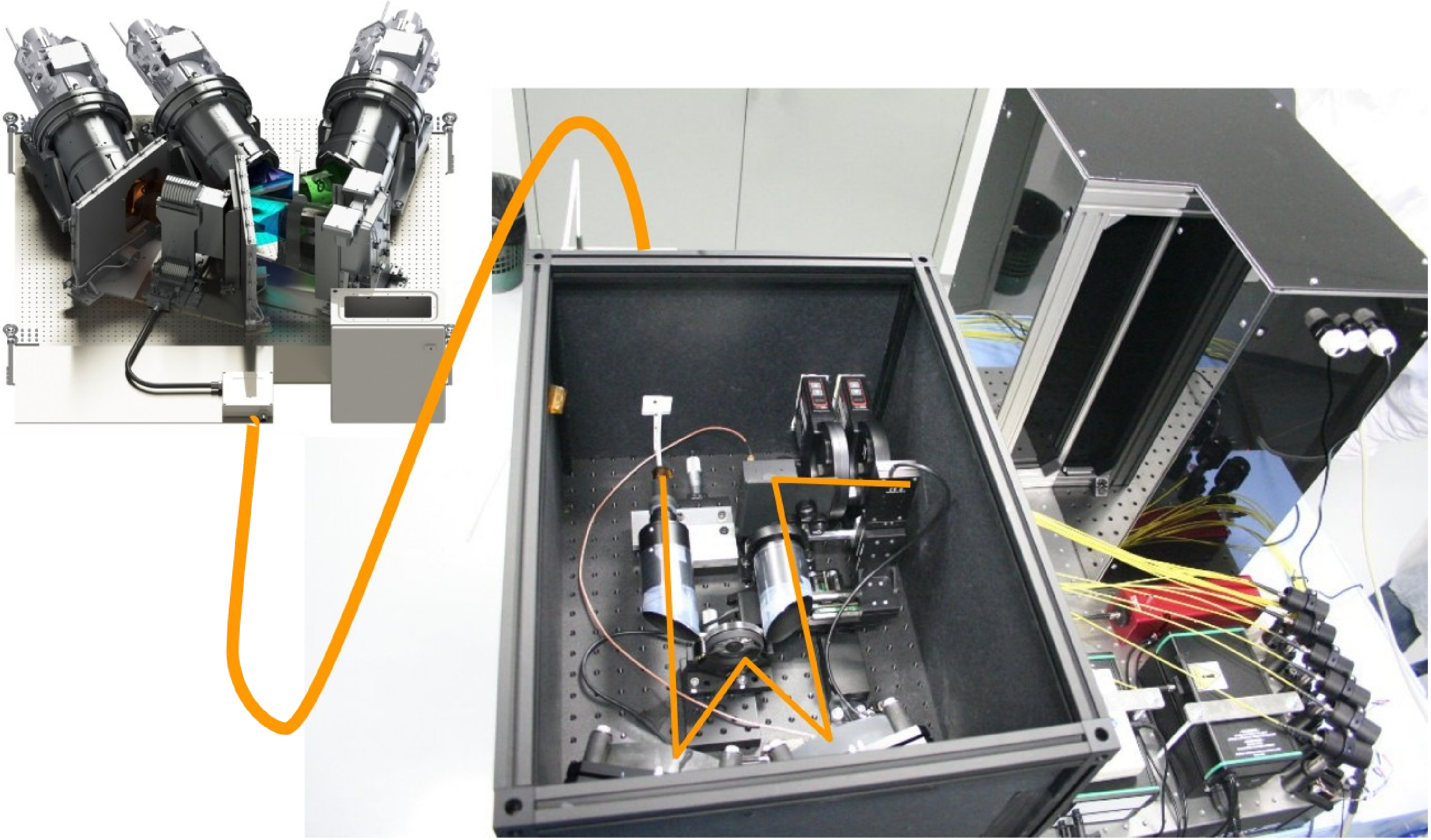


Calibrated
Photodiode

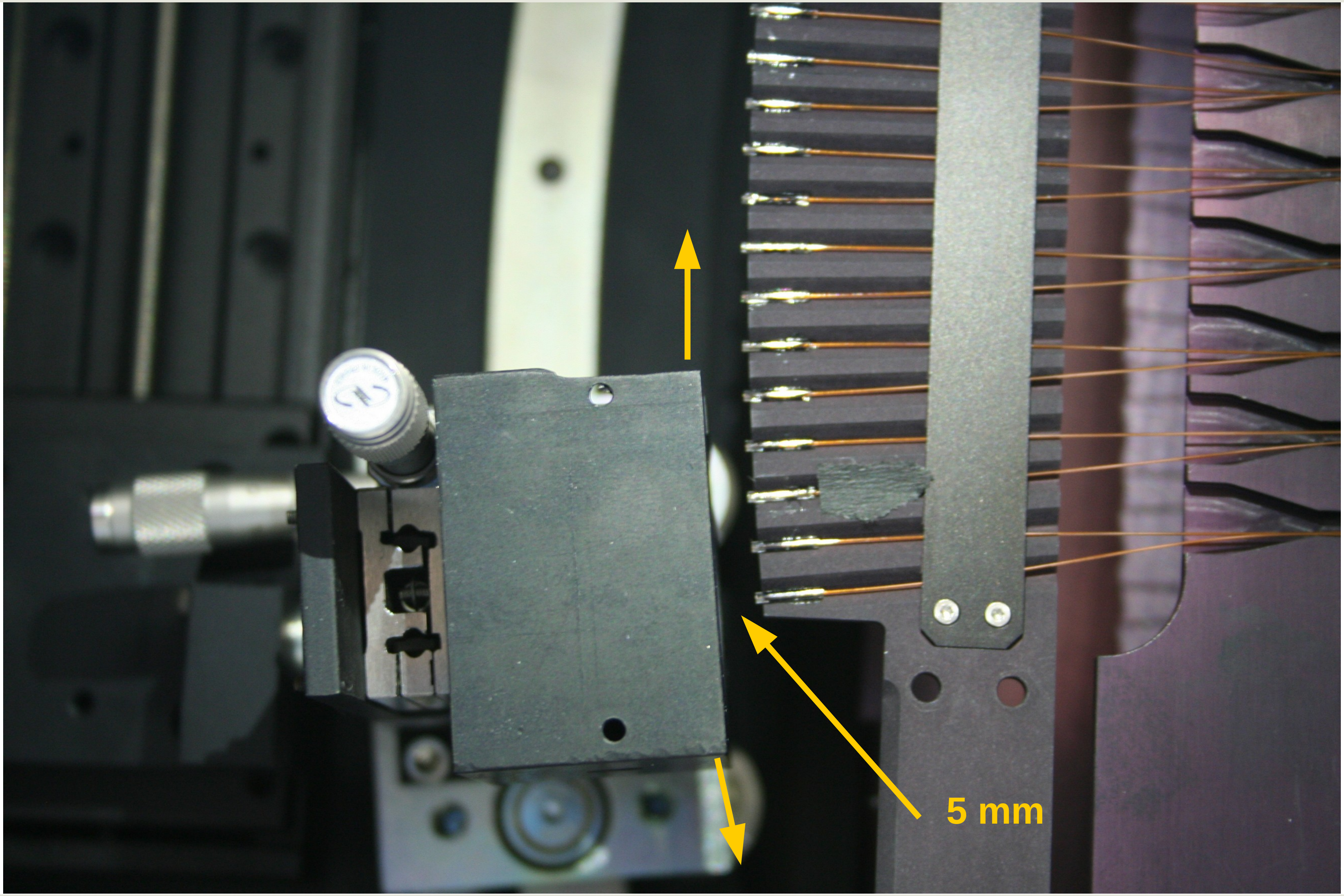
Dedicated
Dark Box

Mock test slit
3D printed
Old fiber bundle
(DESY, H1)

Illumination Testbench

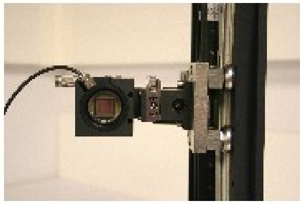


Installation of our device at Winlight

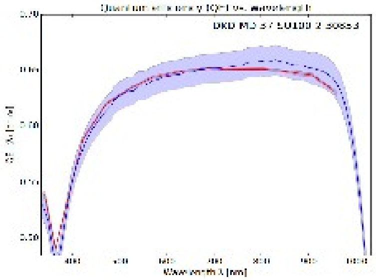


DKD photocurrents analysis

I(t) [pA] ; [e-/s]

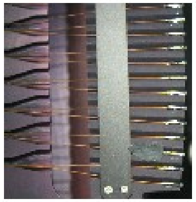


DKD Photodiode + Keithley 6514



/ QE [e-/photon]

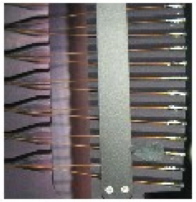
ϕ_{total} Total fiber flux [photon/s]



Total LED flux from 1 fiber

FRD correction

$\phi_{injected}$ Injected flux [photon/s]



Injected LED flux from 1 fiber

$$\phi_{\text{injected}} = \frac{I - I_{\text{dark}}}{QE_{\text{DKD, LED}}} \times \text{FRD}_{\text{fiber}}$$

$$QE_{\text{DKD, LED}} = \frac{\int \phi_{\text{LED}}(\lambda) QE_{\text{DKD}}(\lambda)\, d\lambda}{\int \phi_{\text{LED}}(\lambda)\, d\lambda}$$

Throughput measurement principles

- Measurement to be done during **slit removal/reinstall** repeatability test (limited overhead)
- **Calibration of the total flux** at the exit of each fiber of the sparse fiber slit
- **Proposed Procedure** : for the same illumination setups (LEDs)
  - **(1) Sparse Test Slit outside of the spectrograph, in front of our device** : flux (in the same illumination conditions) measured by our calibrated photodiode for each LED / fiber ;
  - **(2) Sparse Test Slit inside the spectrograph** : integrated flux measured on the CCD for the 3 arms of the spectrograph for each LED / fiber ;
  - **Ratio (1)/(2)** gives **throughput** (from fiber exit to the CCD included)

Integrated LED flux [e-/s] on the 3 CCDs

- For **each LED**, for **each fiber** 11 – 20, a **separate exposure**
- Frames are reduced (DESI pipeline), spectrum region is integrated
- CCD amplifier gains [ADU → e-] are applied
- Resulting CCD flux [e-] is then **divided by the effective exposure time**
- The resulting spectrum is **integrated on the whole arm wavelength range**

$$\phi^{\text{CCD}}_{[\text{e-/s}]} = \frac{\text{gain}^{\text{ampli}}_{[\text{e-/ADU}]} \times \sum_{\text{ill. pixels}}^{\text{spectrum}} \phi^{\text{CCD}}_{[\text{ADU}]}(\text{pixel})}{\Delta t^{\text{exposure}}_{[\text{s}]}}$$

- **We need to calibrate the exposure time and the CCDs amplifiers gains**