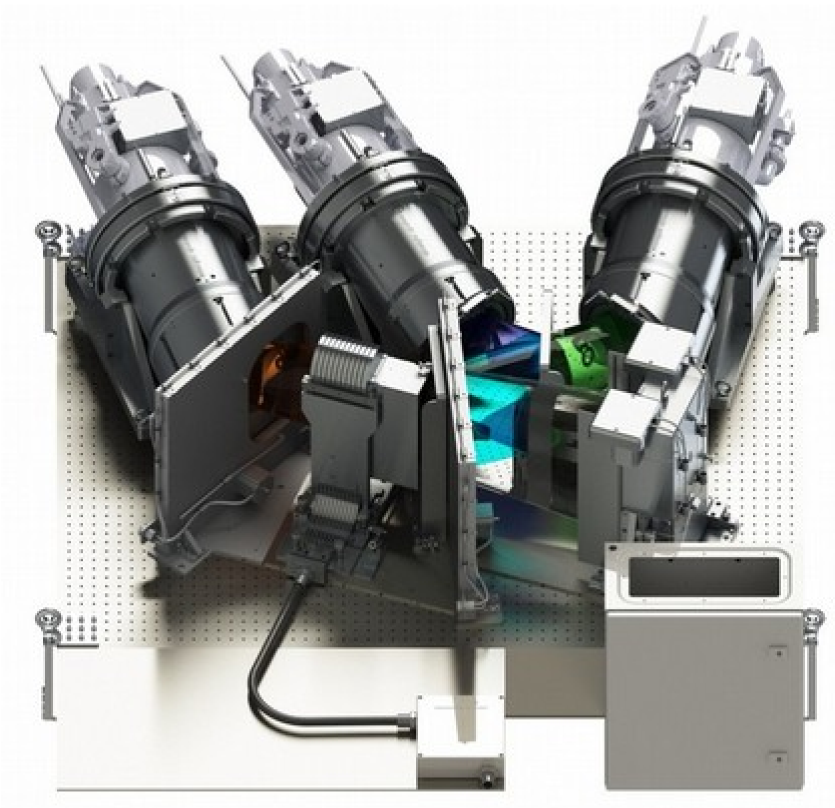

DESI SM#2 & SM#3 Throughput Measurement

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DESI Spectro Telecon
2018-12-18

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AMU : Pierre-Eric Blanc, Sandrine Perruchot, Xavier Regal, Samuel Ronayette
CEA : C. Magneville

Meas. campaigns: SM#3 (oct. 18) SM#2 (dec. 18)

- **SM#3 campaign: October 28th-31st (LLG, PEB)**

  We moved something (probably the masks in the Offner):

  → “before” spectro dataset not usable (and less flux injected in fibers)

- **SM#2 campaign: December 9th-12th (LLG, PEB)**
  - Everything went well
  - Some extra scans (full 10x10mm photodiode scans) for FRD

Exposure time : shutter time correction

- Series of exposures with **increasing exposure time** and **different neutral densities** filters have been taken.
- Shutter control system had been changed due to shutter problems in July 2017. Shutter is opening & closing at a lower speed now.
- Assuming at least linearity for low fluxes, we were able to estimate an effective exposure time correction (**same result on the 3 arms**) :

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

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

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

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

SM#2: Gains measured at CEA/Saclay (CMV)

- Much better CCDs, readout system with identical setup at CEA & Winlight
- **Cryos & CCD of SM#3 were mounted on SM#2** (and vice-versa)
- Gains obtained with a PTC with **true flats on the CEA / Saclay testbench** after CCD integration into the cryostats (Ch. Magneville (CMV) & colleagues).
- Gains were **double checked with data taken at Winlight** (JG).

Amplifier *(Blue CCD)*	gain
B1-A *(CEA top-left)*	1.28
B1-B *(CEA bottom-left)*	1.29
B1-C *(CEA top-right)*	1.32
B1-D *(CEA bottom-right)*	1.31

Amplifier *(Red CCD)*	gain
R1-A *(CEA top-right)*	1.66
R1-B *(CEA top-left)*	1.50
R1-C *(CEA bottom-right)*	1.60
R1-D *(CEA bottom-left)*	1.60

Amplifier *(NIR/Z CCD)*	gain
Z1-A *(CEA bottom-right)*	1.48
Z1-B *(CEA bottom-left)*	1.49
Z1-C *(CEA top-right)*	1.67
Z1-D *(CEA top-left)*	1.67

SM#3: Gains measured at CEA/Saclay (CMV)

- Much better CCDs, readout system with identical setup at CEA & Winlight
- **Cryos & CCD of SM#2 were mounted on SM#3** (and vice-versa)
- Gains obtained with a PTC with **true flats on the CEA / Saclay testbench** after CCD integration into the cryostats (Ch. Magneville (CMV) & colleagues).
- Gains were **double checked with data taken at Winlight** (JG).

Amplifier *(Blue CCD)*	gain
B2-A *(CEA top-left)*	1.28
B2-B *(CEA bottom-left)*	1.27
B2-C *(CEA top-right)*	1.27
B2-D *(CEA bottom-right)*	1.29

Amplifier *(Red CCD)*	gain
R2-A *(CEA top-right)*	1.77
R2-B *(CEA top-left)*	1.67
R2-C *(CEA bottom-right)*	1.50
R2-D *(CEA bottom-left)*	1.53

Amplifier *(NIR/Z CCD)*	gain
Z2-A *(CEA bottom-right)*	1.45
Z2-B *(CEA bottom-left)*	1.50
Z2-C *(CEA top-right)*	1.62
Z2-D *(CEA top-left)*	1.52

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)** :

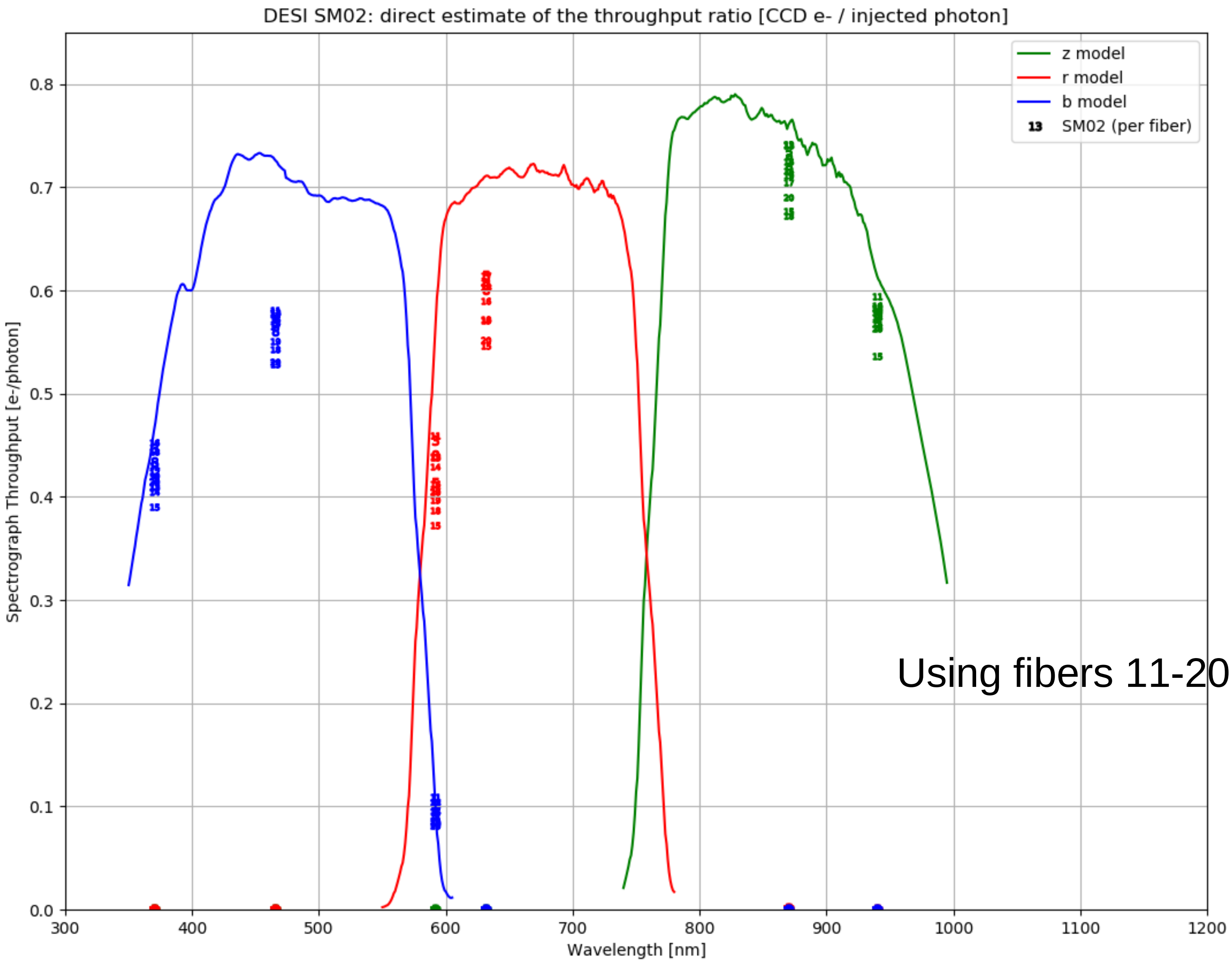
$$\eta_{[\text{e-}/\gamma]}(\lambda_{\text{LED}}) = (QE_{\text{CCD}} \times T_{\text{optics}}(\lambda_{\text{LED}})) = \frac{\phi^{\text{CCD}}_{[\text{e-}/\text{s}]}(\text{LED})}{\phi^{\text{injected}}_{[\gamma/\text{s}]}(\text{LED})}$$

- 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)

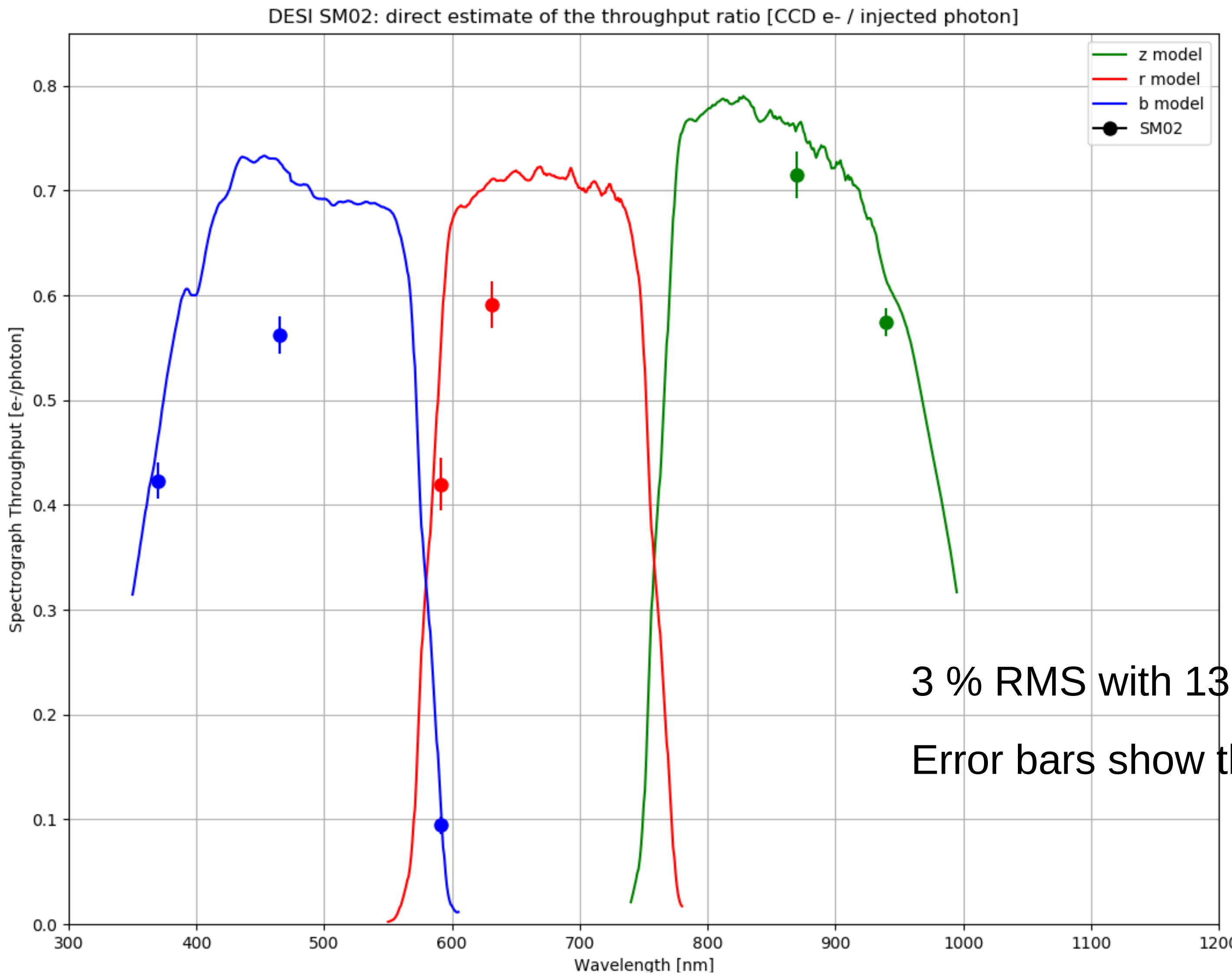
- Comparison with the **DESI generic optical model** (**without fibers**)

SM#2 : direct throughput estimate



Using fibers 11-20 + 3,5,8

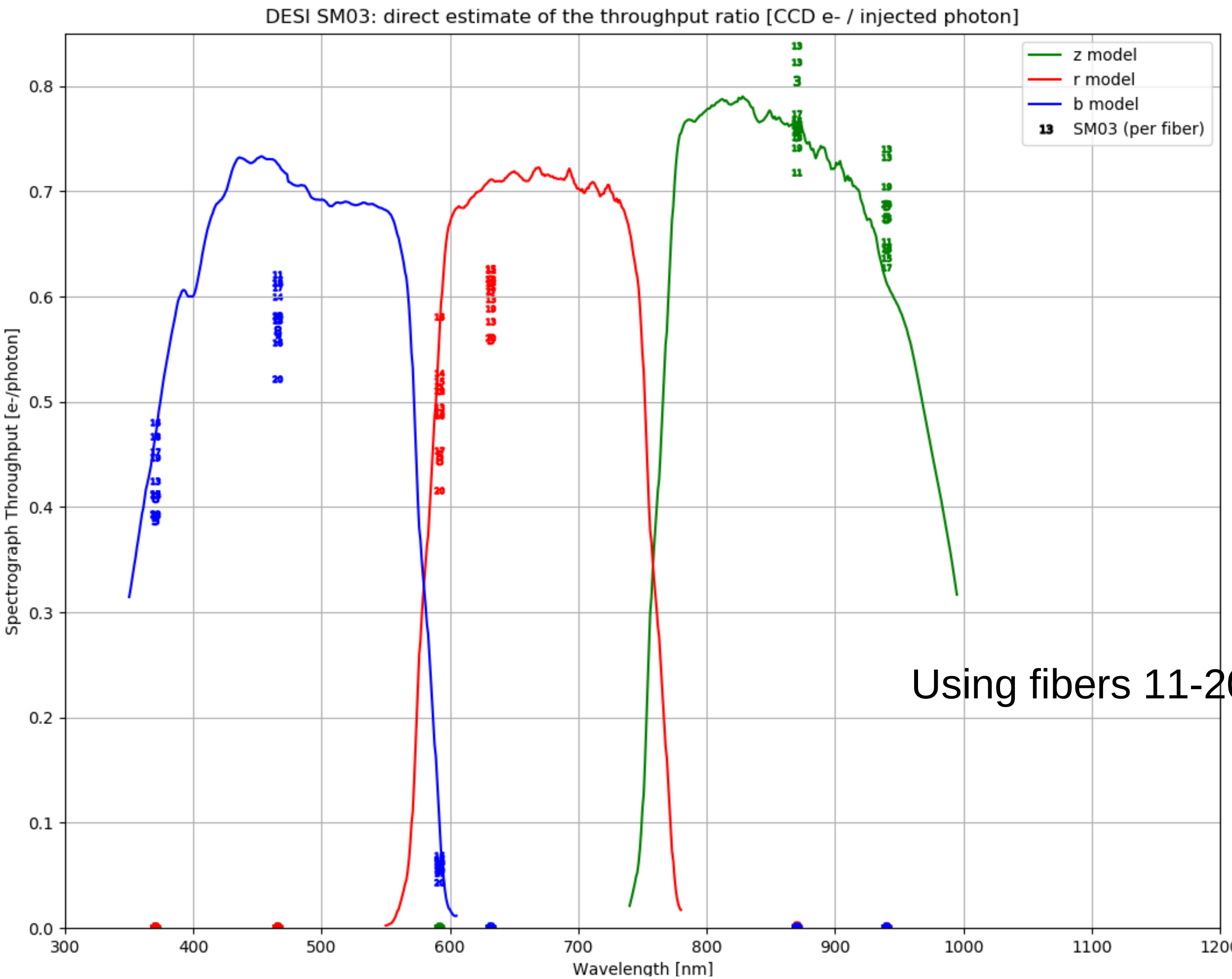
SM#2 : direct throughput estimate



3 % RMS with 13 fibers

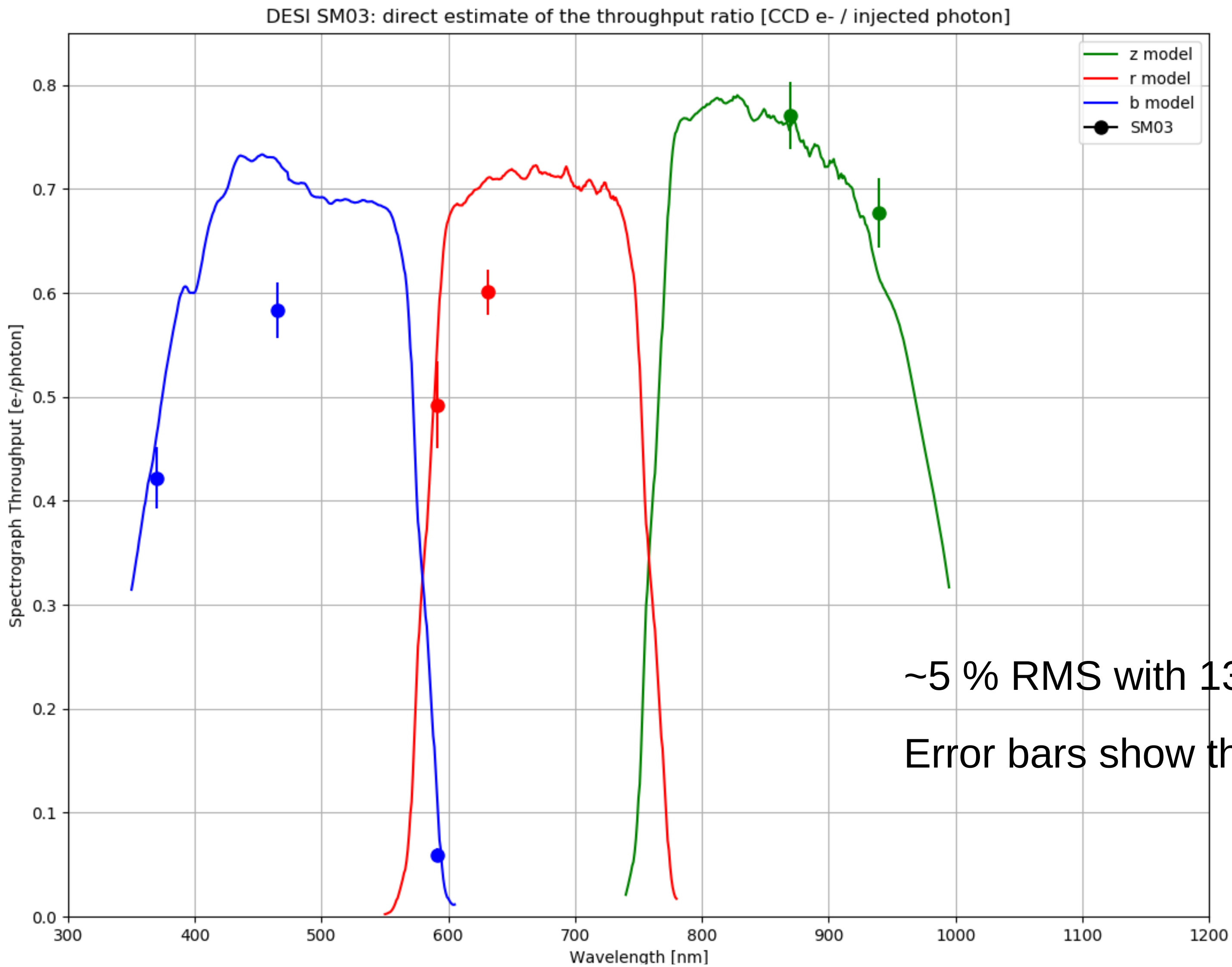
Error bars show the RMS

SM#3 : direct throughput estimate



Using fibers 11-20 + 3,5,8

SM#3 : direct throughput estimate



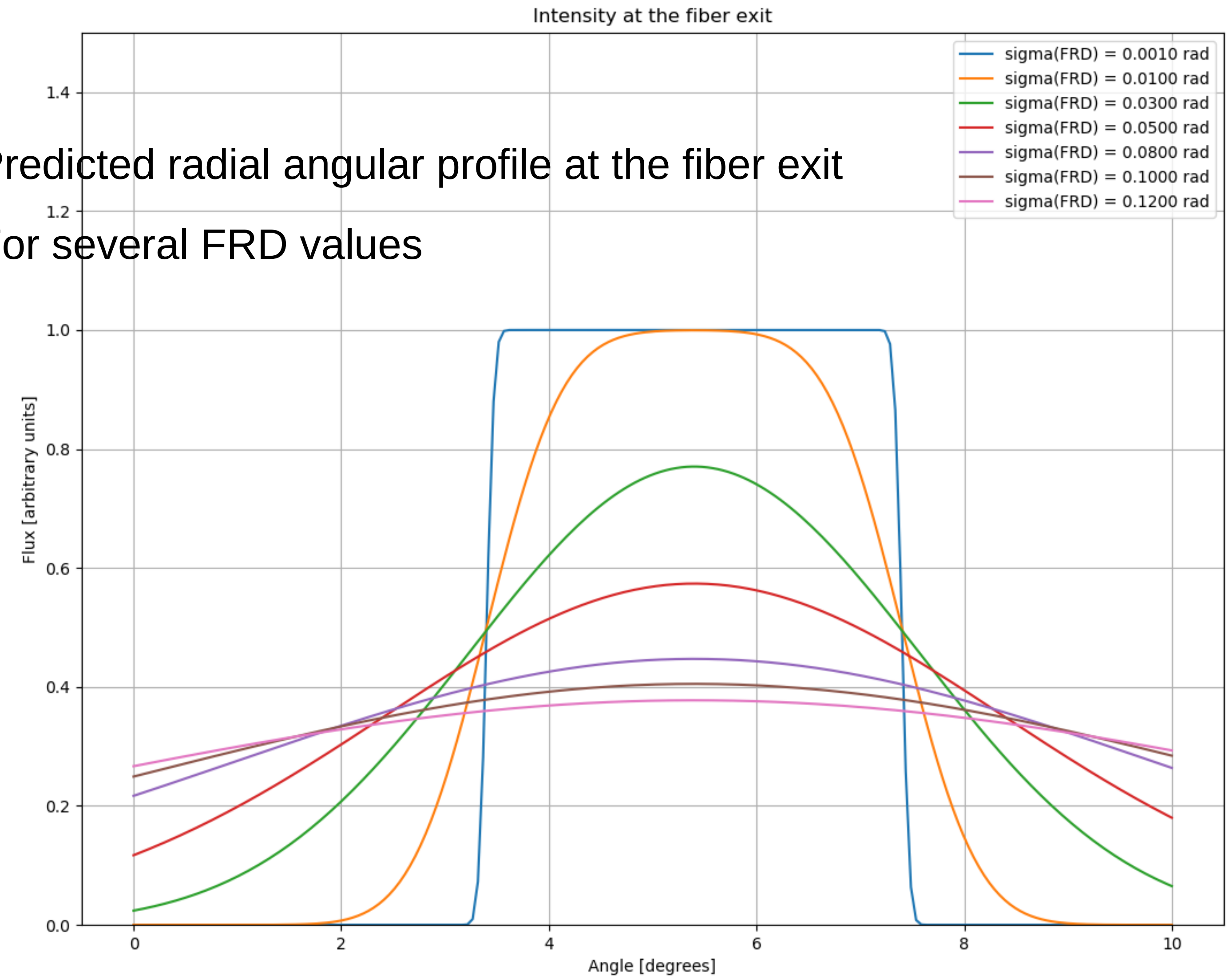
~5 % RMS with 13 fibers

Error bars show the RMS

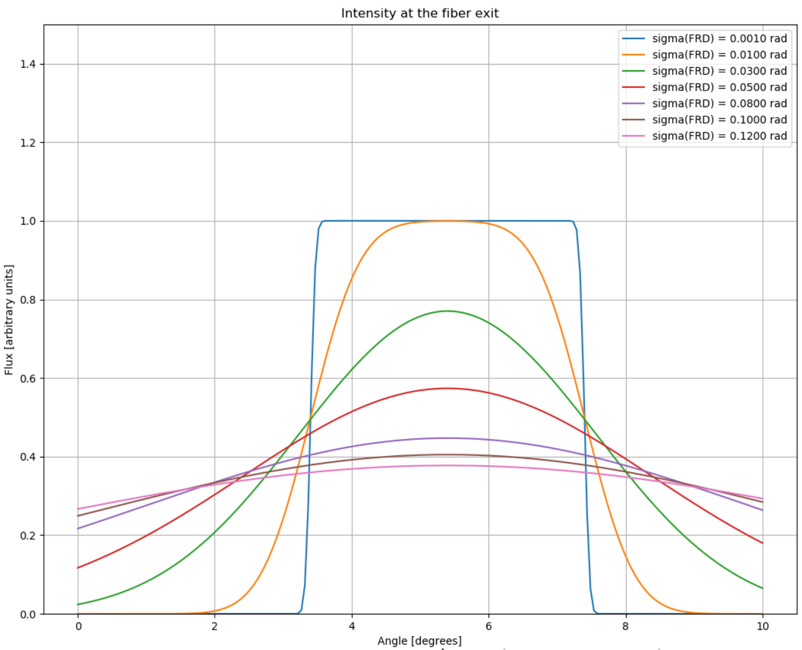
Focal Ratio Degradation (FRD) Systematics

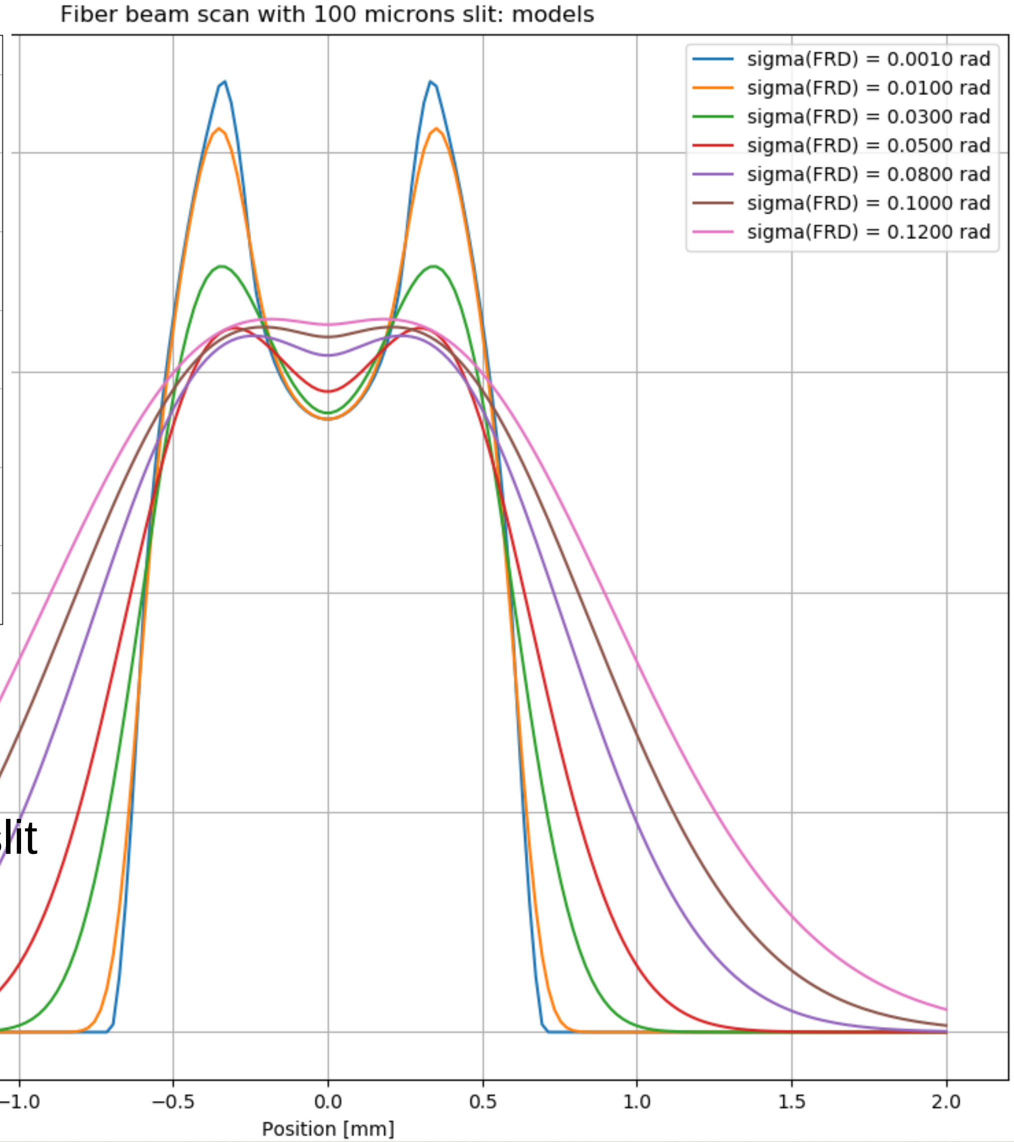
Predicted radial angular profile at the fiber exit

For several FRD values



Expected 100 microns scan profiles

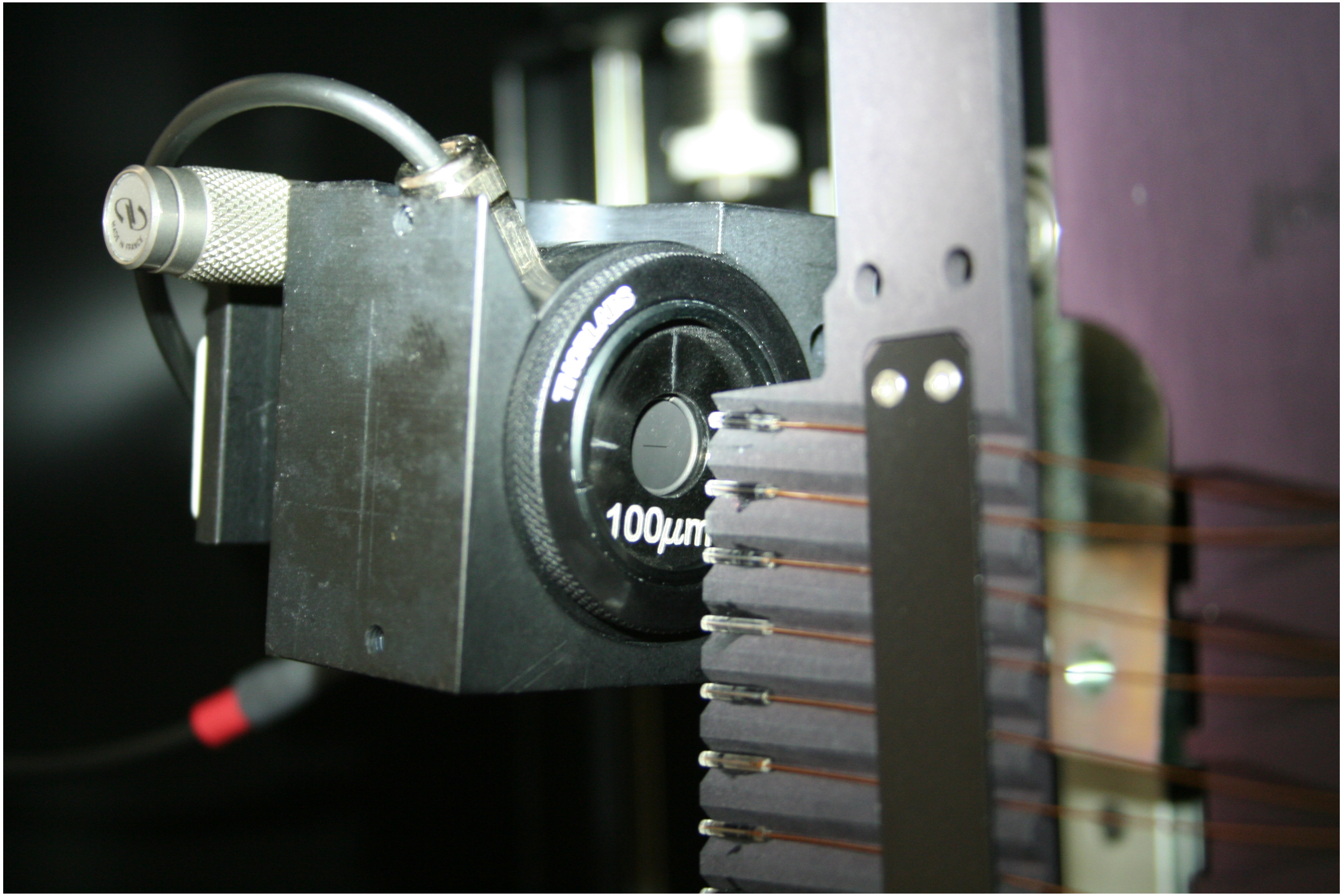




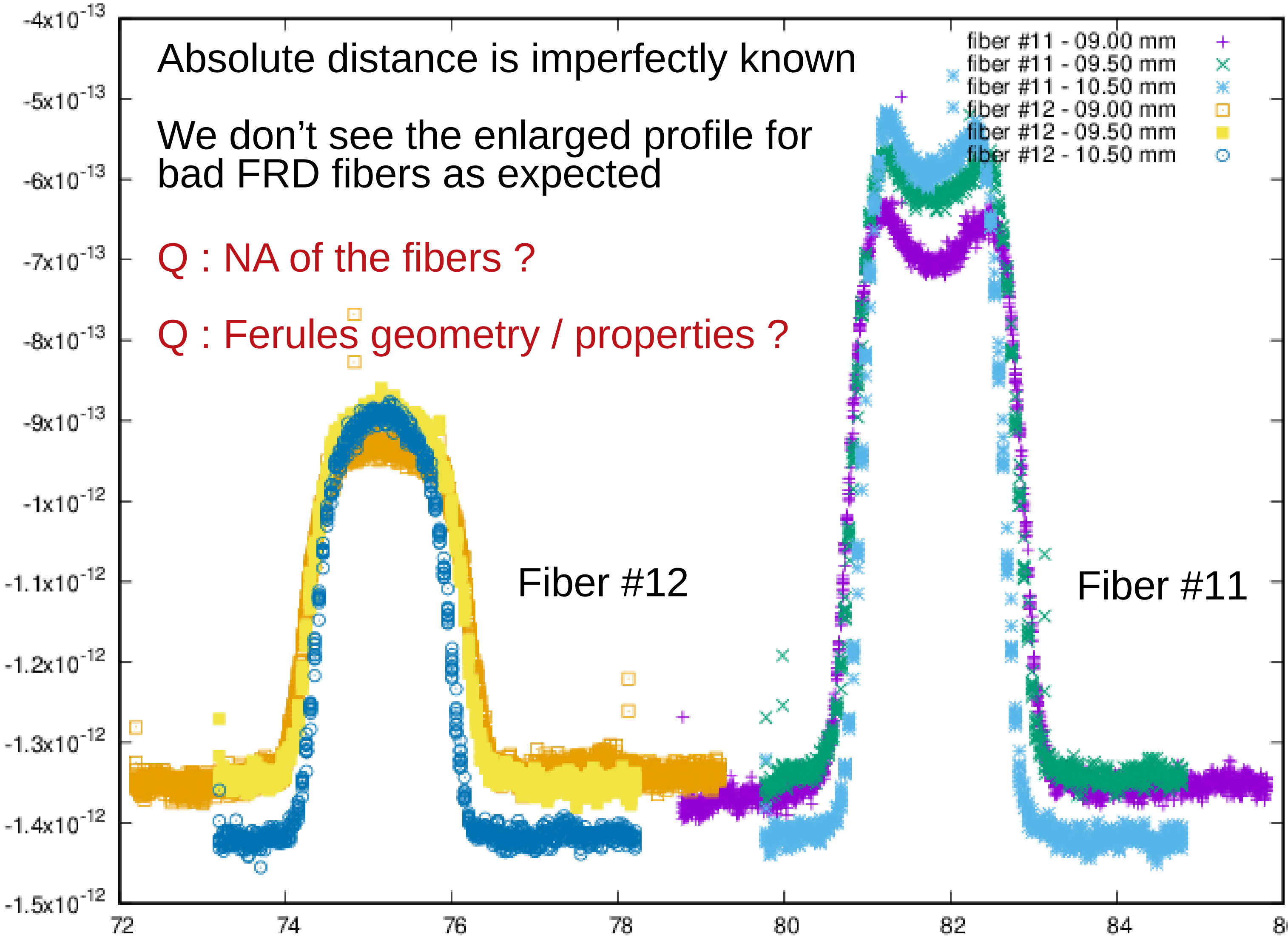
Corresponding predicted

scan profiles with the 100 microns slit

Scanning the beam at the fiber exit (100 microns)



Measured scan profiles



FRD Correction & Systematics (preliminary)

- Preliminary **estimate of the FRD correction** :

Our interpretation :

Numerical Aperture of the fiber : $\mathrm{NA} = n_{\mathrm{silica}} \sin(\theta_{\mathrm{max}})$

NA fibers → 0.22 ± 0.02 (Taken from DESI-2472)

Fuse silica optical index : from 1.45 to 1.48 (wavelength)

Corresponding angle→ **8.72° to 8.54°** (consistent with scans half-width)

Spectro acceptance → **8.0°** (f / 3.56) (central fiber #11)

Rough estimate of maximum light loss : **14-12 % at max.**

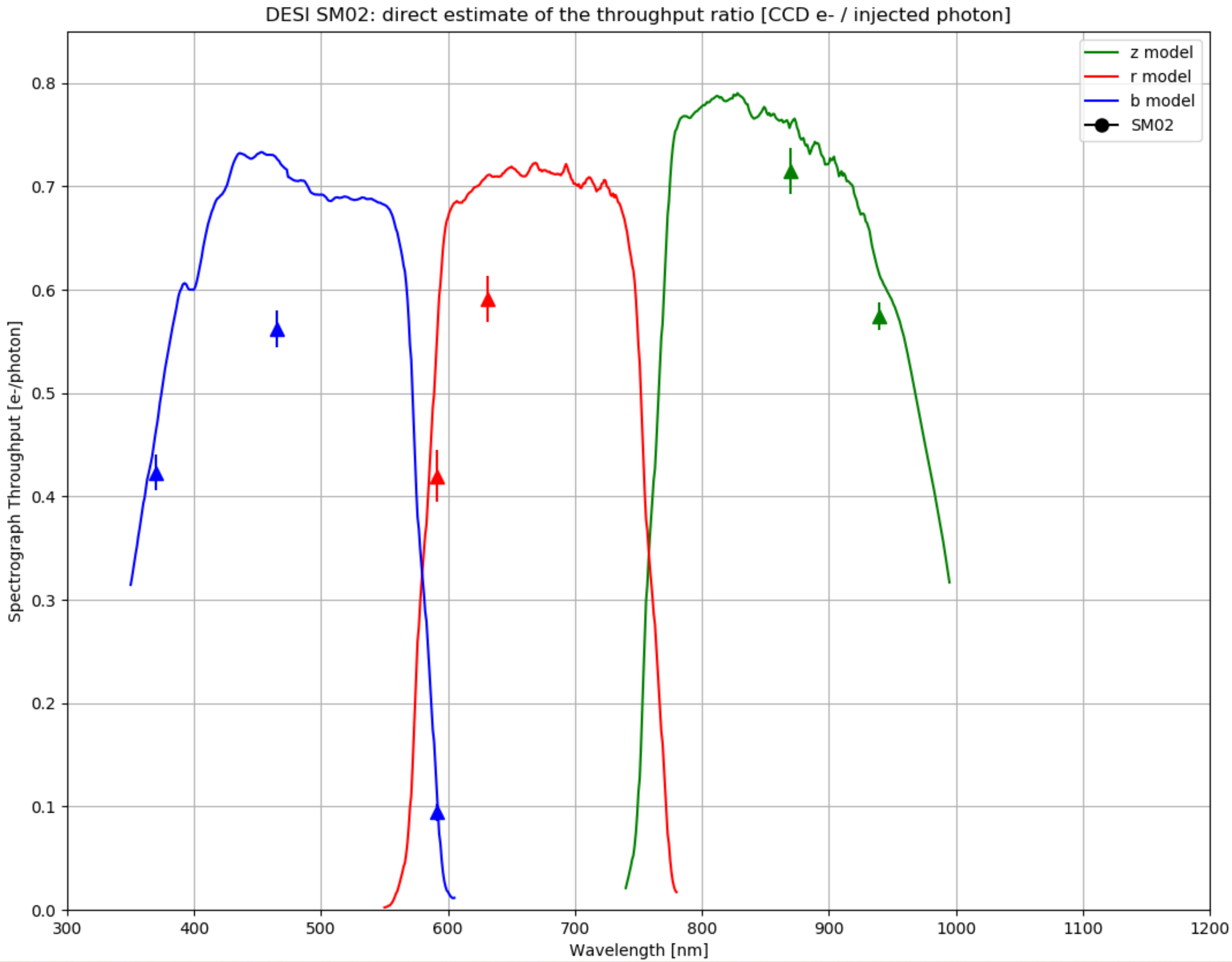
(depends in fact of the profile at the fiber exit, so probably less)

→ ***The throughput is probably a bit higher****… (on going work)*

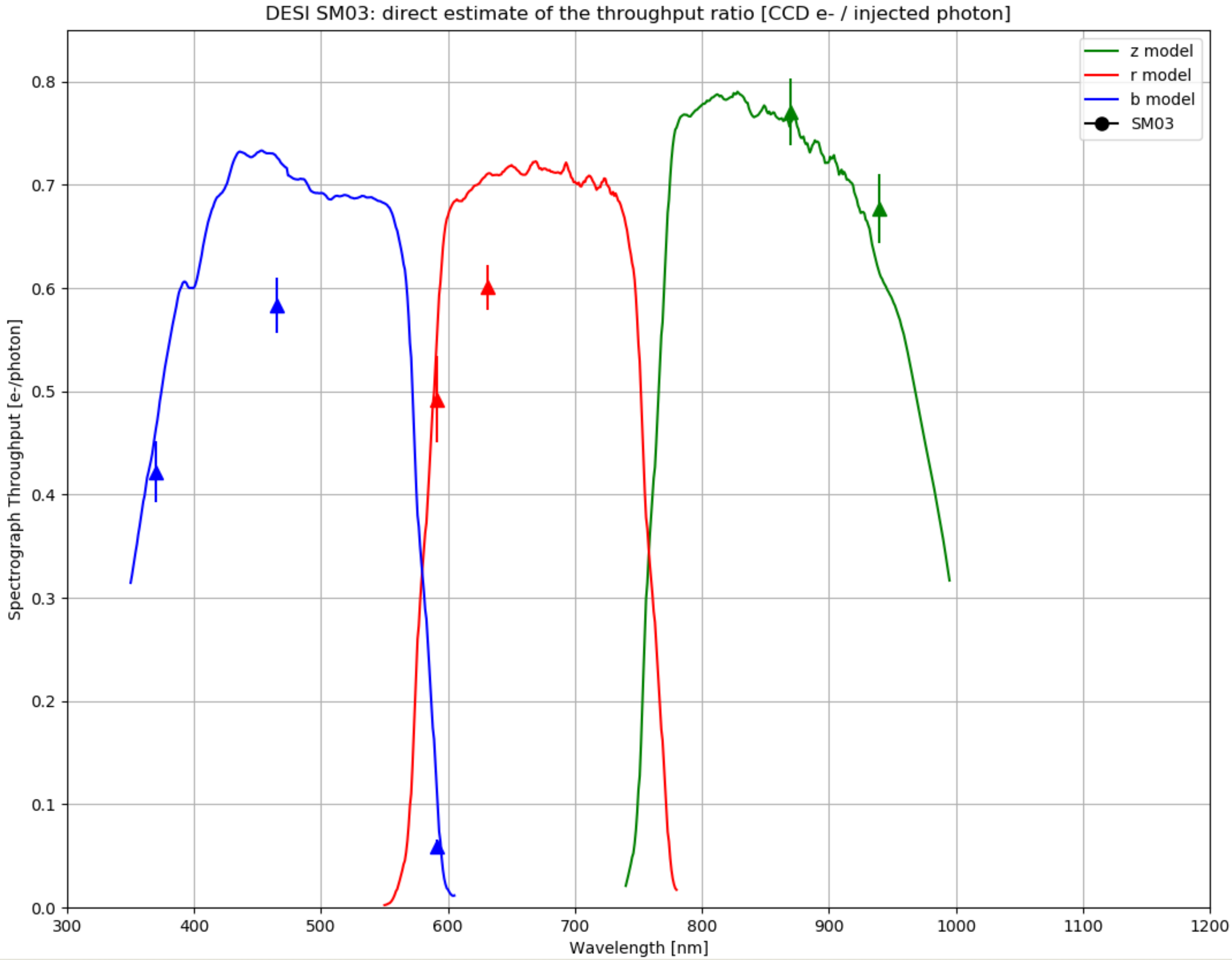
Systematics / Error budget (tentative)

Systematics	*Value*
Photodiode calibration	~2 %
Dispersion amongst fibers (3-5% rms)	~1 % on average
Amplifier gains	~3 %
Effective exposure correction	< 1 %
Focal Ratio Degradation Correction	Still to be determined

SM#2 : direct throughput estimate



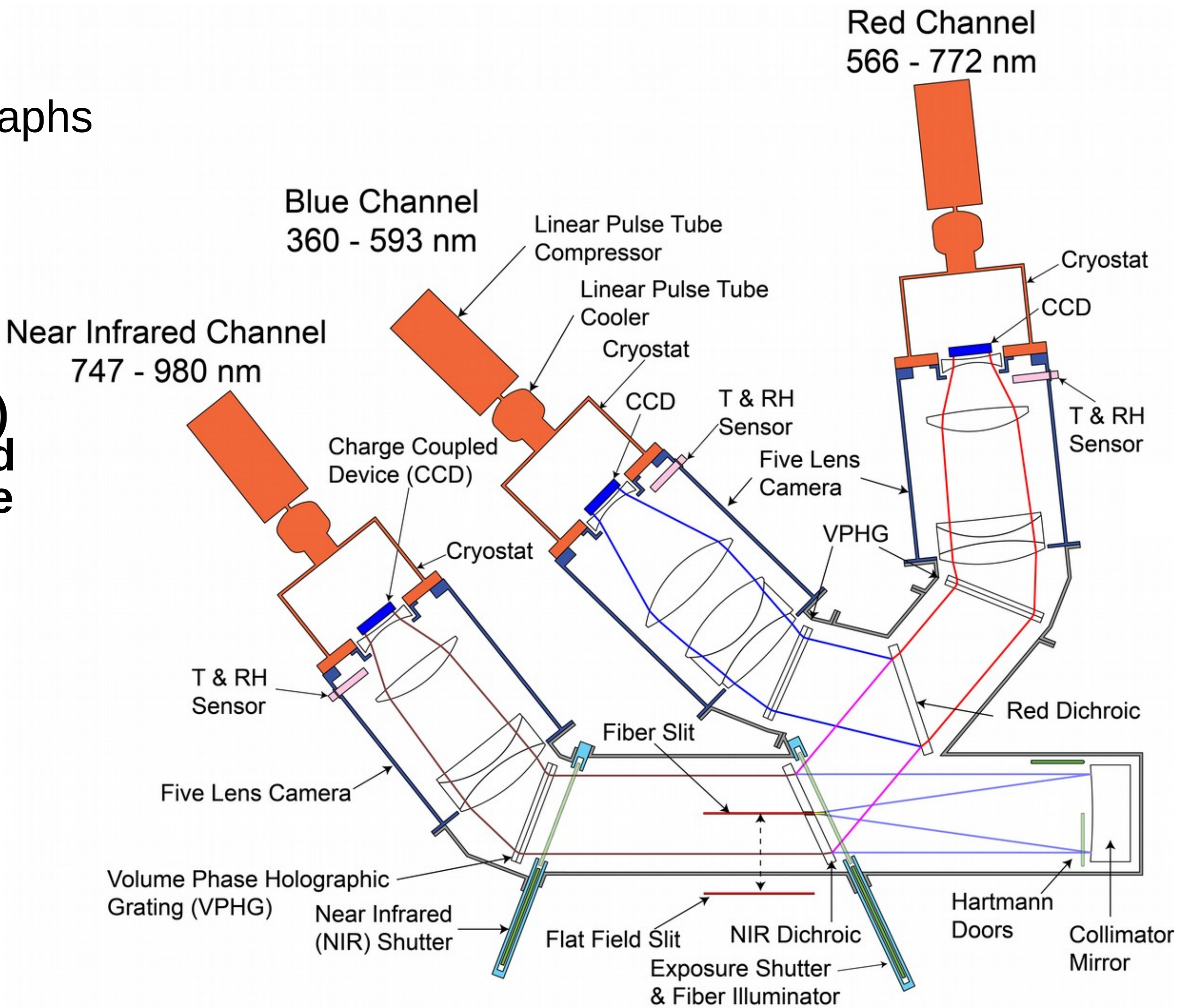
SM#3 : direct throughput estimate



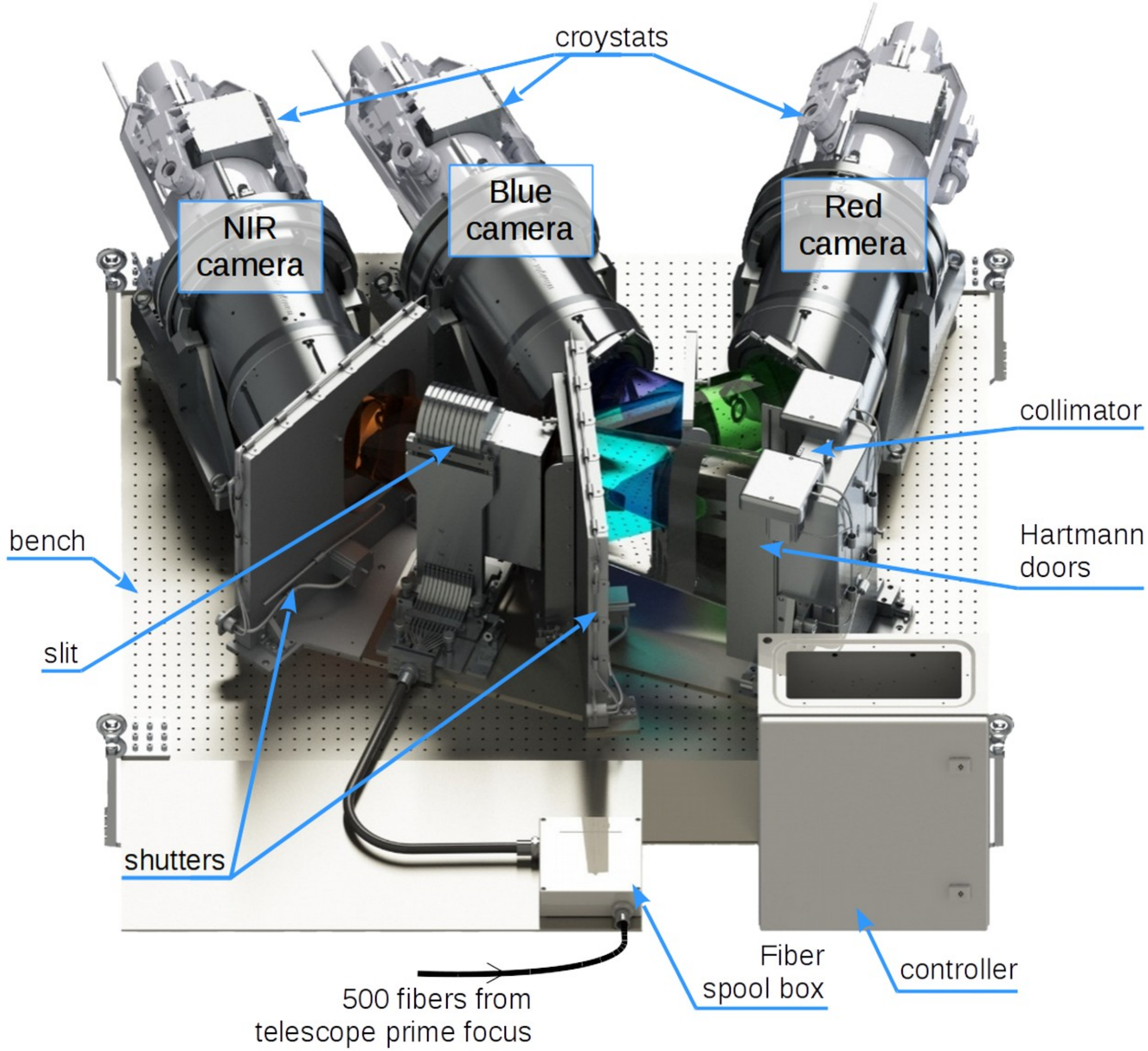
Suppl. Slides

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.**

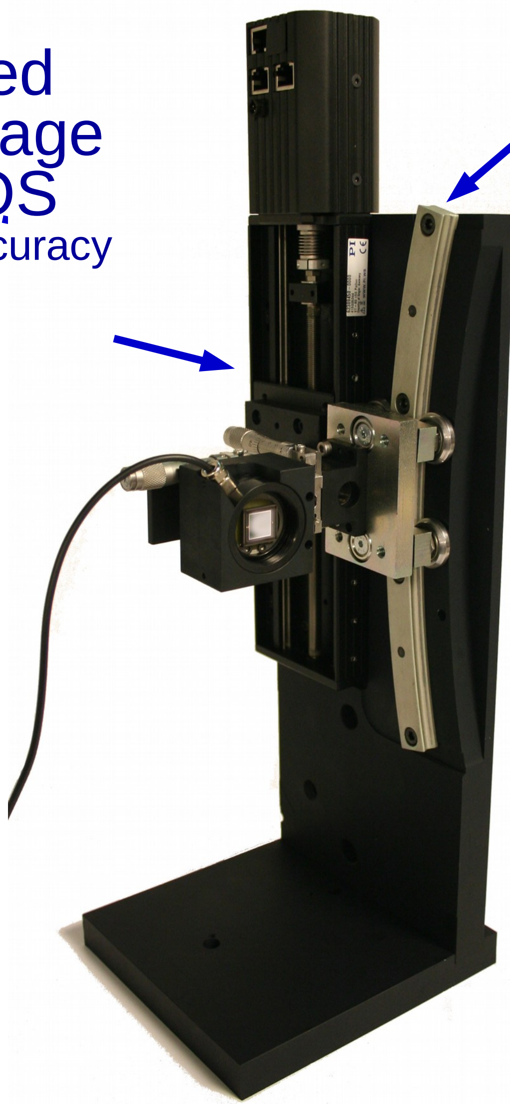


The DESI spectrograph



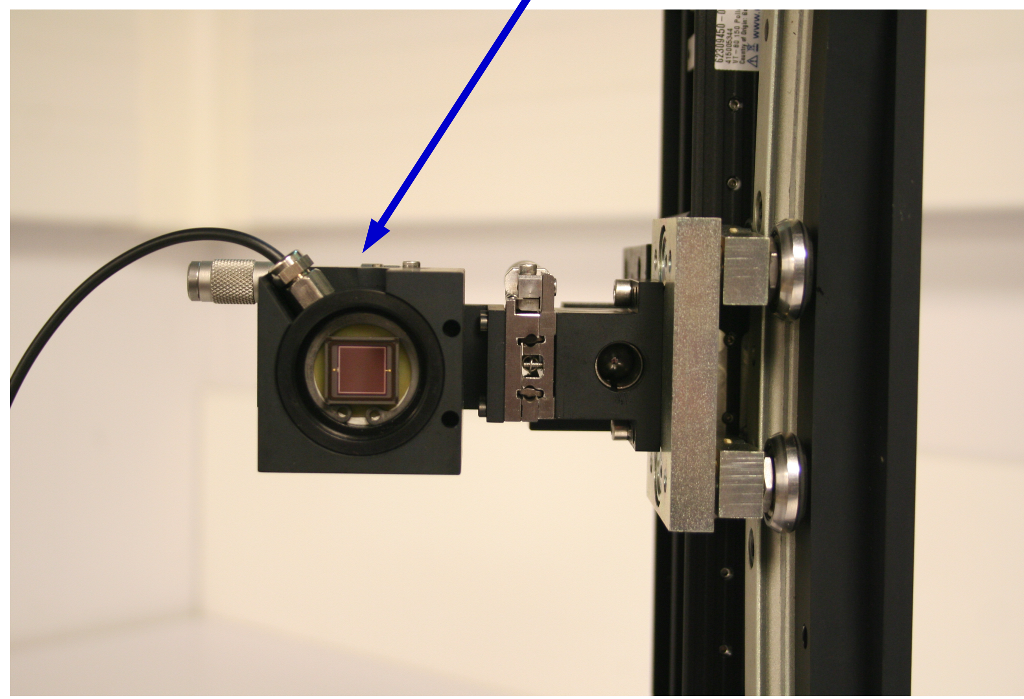
Throughput measurement device

Motorized
linear stage
Pi/MICOS
<0.4 µm accuracy

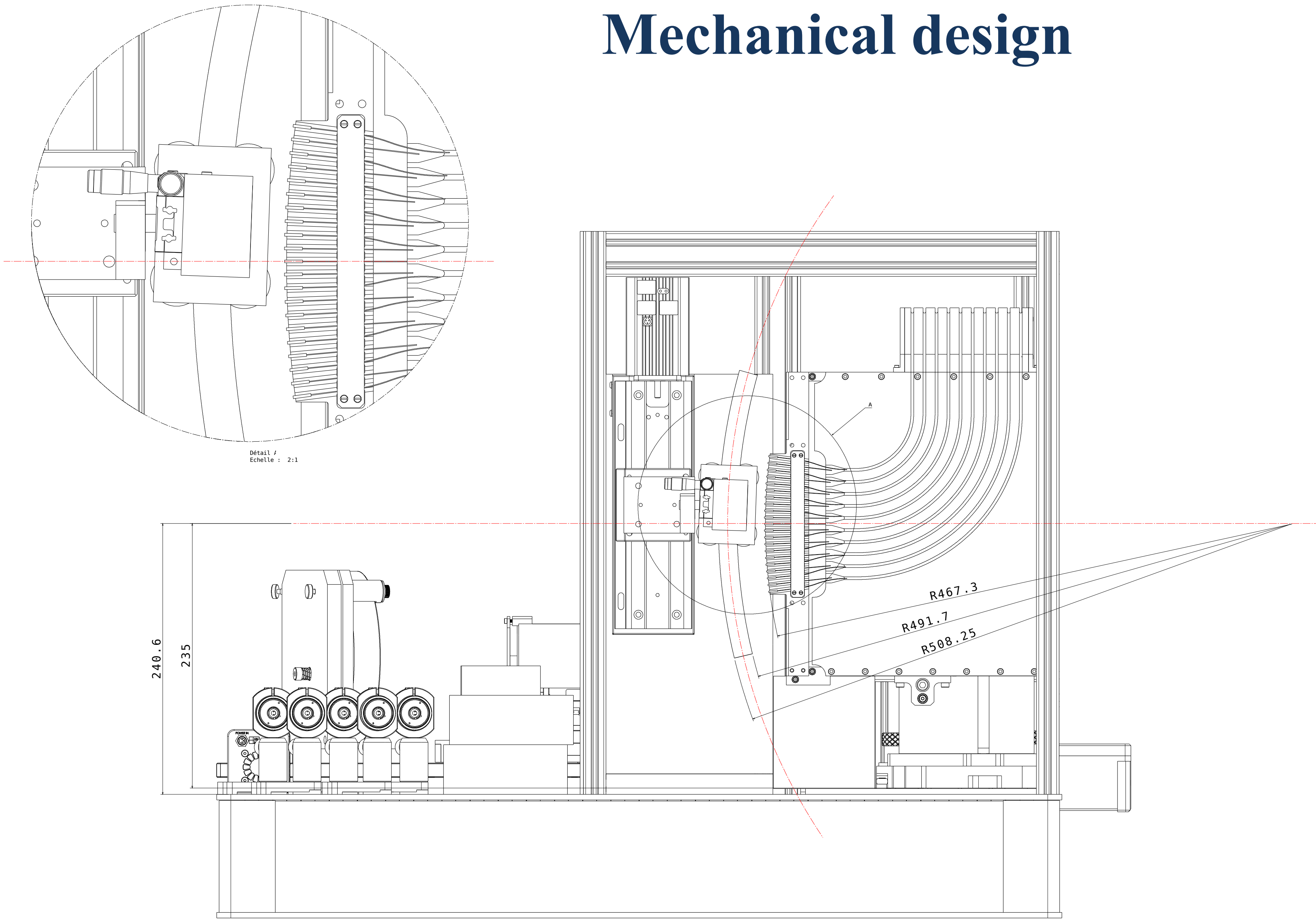


Curved rail
(radius 500 mm)

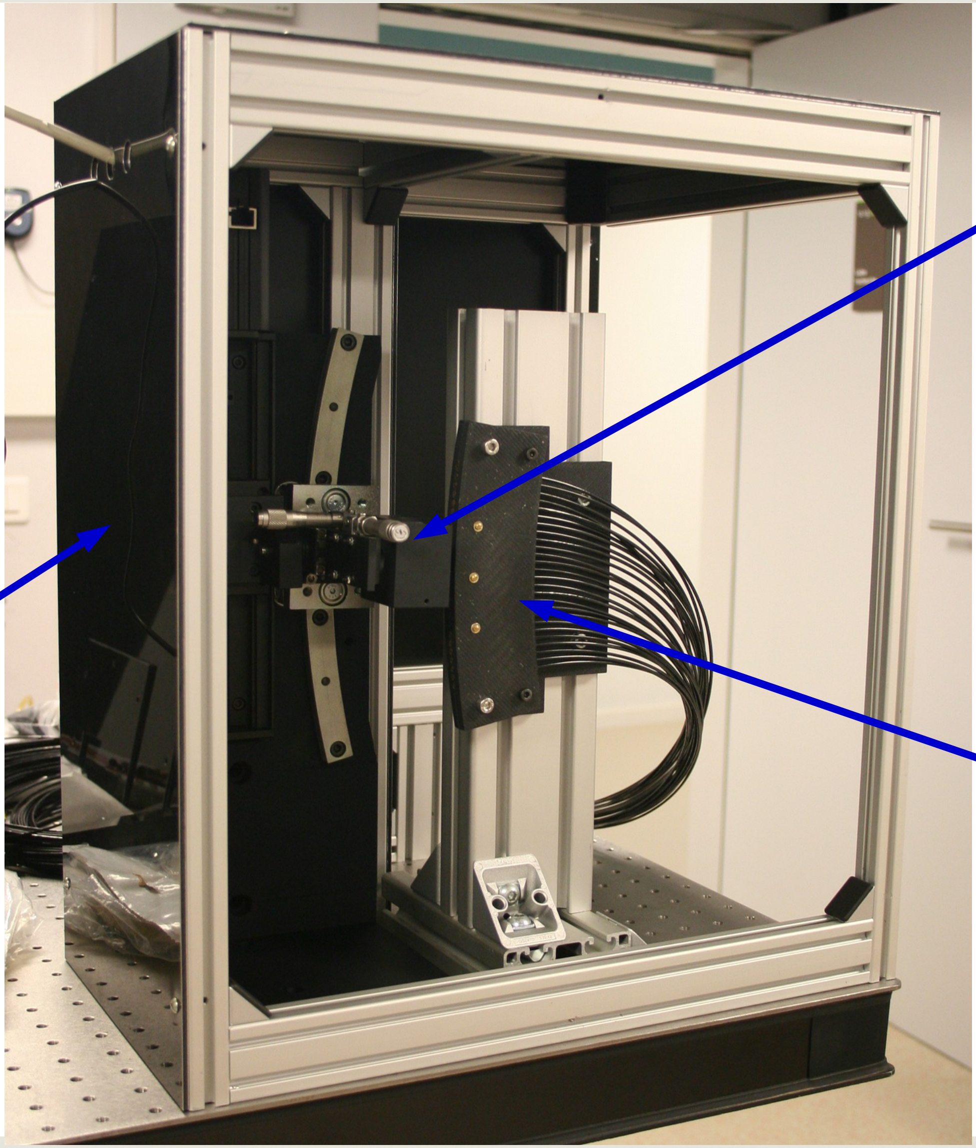
Calibrated
Photodiode
10x10 mm²



Mechanical design



Throughput measurement device

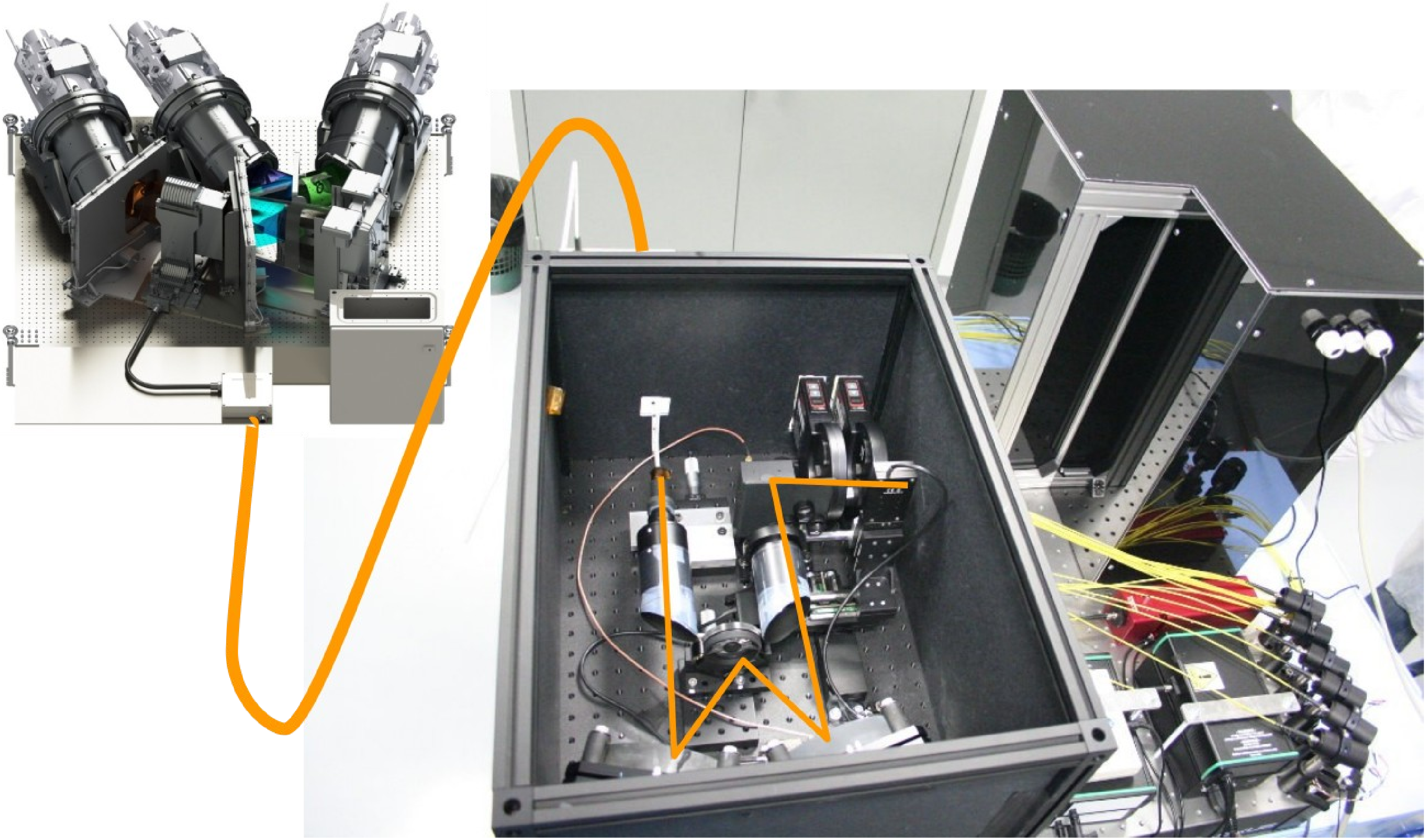


Calibrated Photodiode

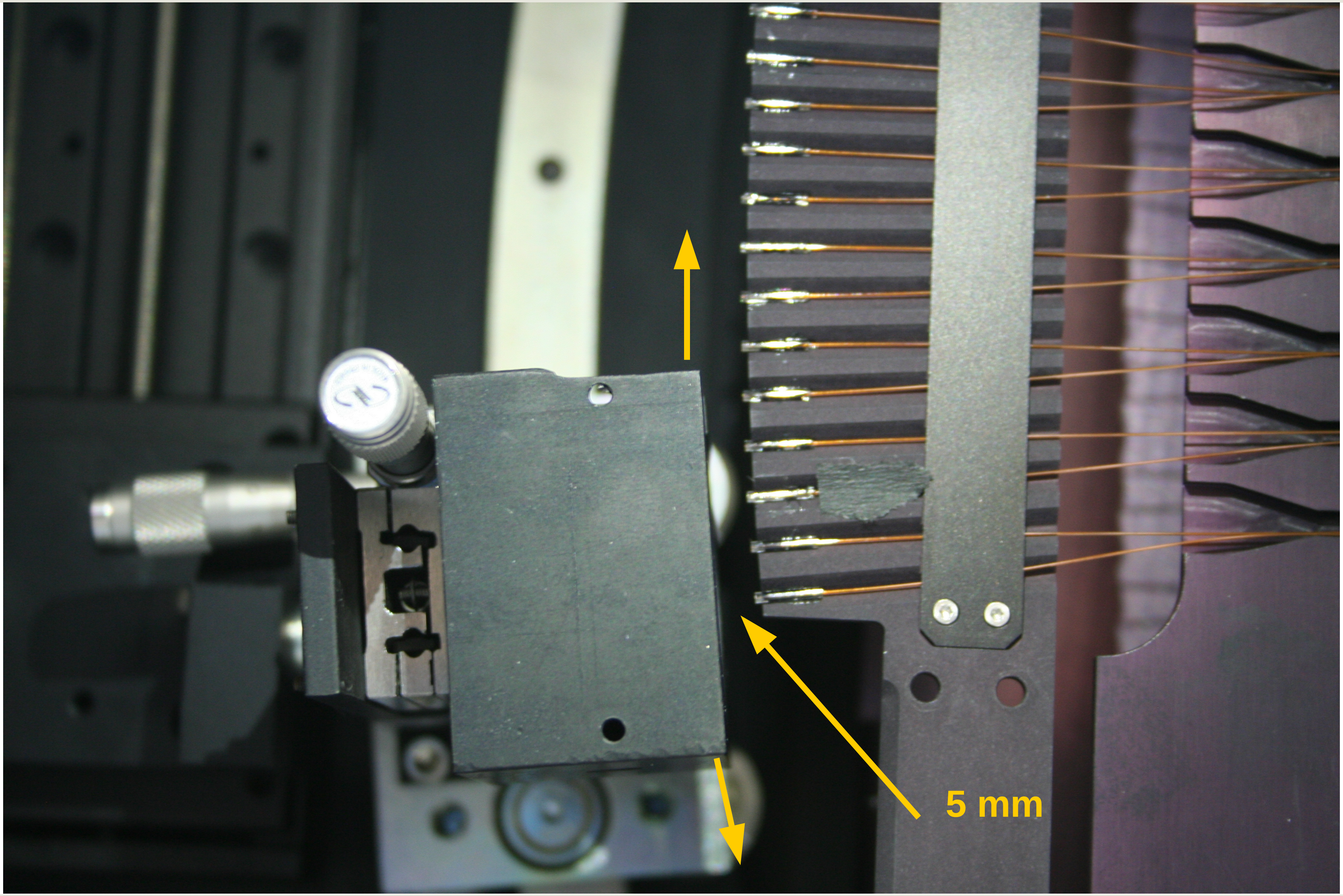
Dedicated Dark Box

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

Illumination Testbench

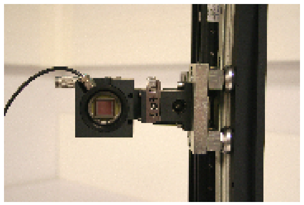


Installation of our device at Winlight

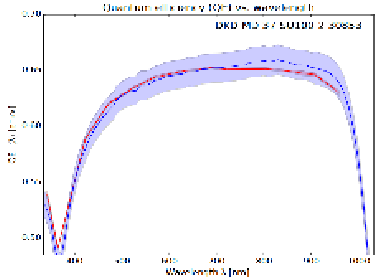


DKD photocurrents analysis

$I(t)$ [pA] ; [e−/s]

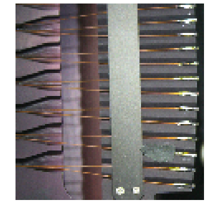


DKD Photodiode + Keithley 6514



$/ \, QE$ [e−/photon]

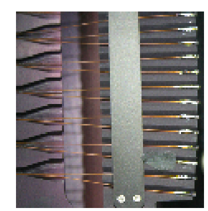
ϕ_{total} Total fiber flux [photon/s]



Total LED flux from 1 fiber

FRD correction

ϕ_{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**

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

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