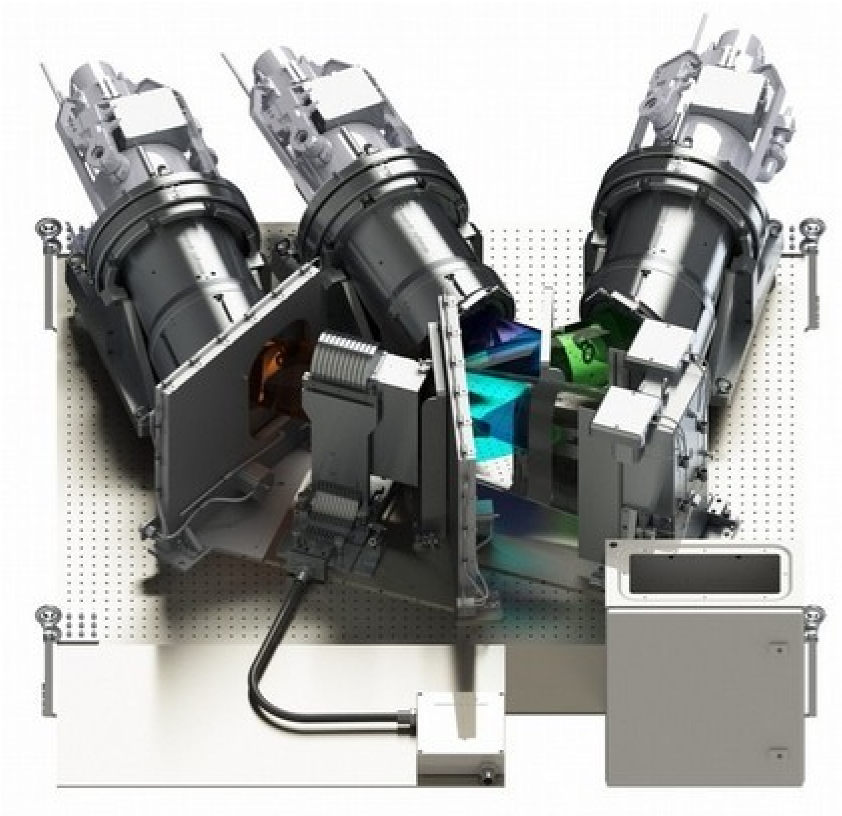

DESI Spectro. EM#1 Throughput Measurement

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DESI France, LPNHE
2018-02-02

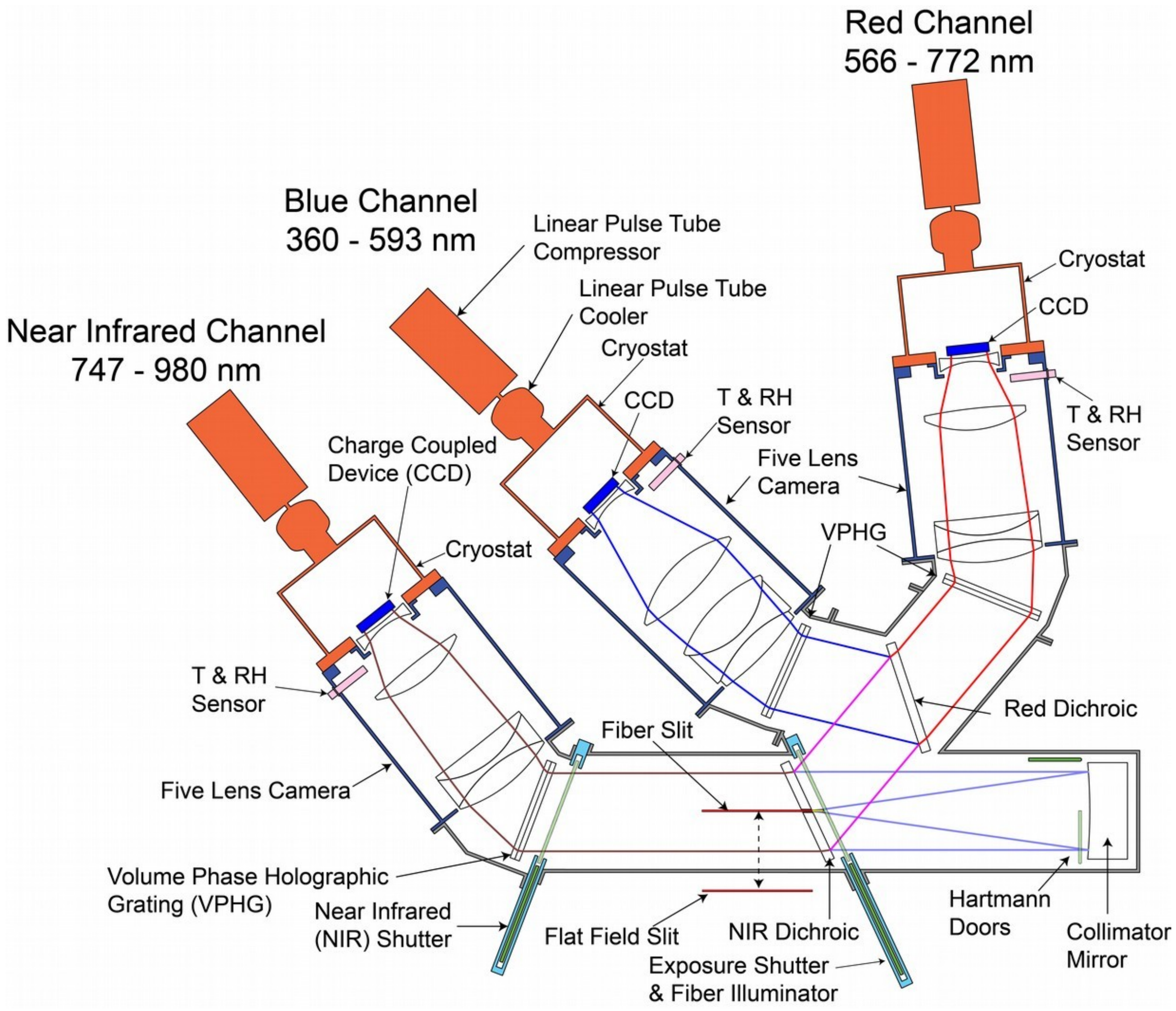
LPNHE : Julien Coridian, Patrick Ghislain, Julien Guy, Sonia Karkar, Laurent Le Guillou, Yann Orain, Philippe Repain, Eduardo Sepulveda
AMU : Pierre-Eric Blanc, Sandrine Perruchot, Xavier Regal, Samuel Ronayette

Talk outline

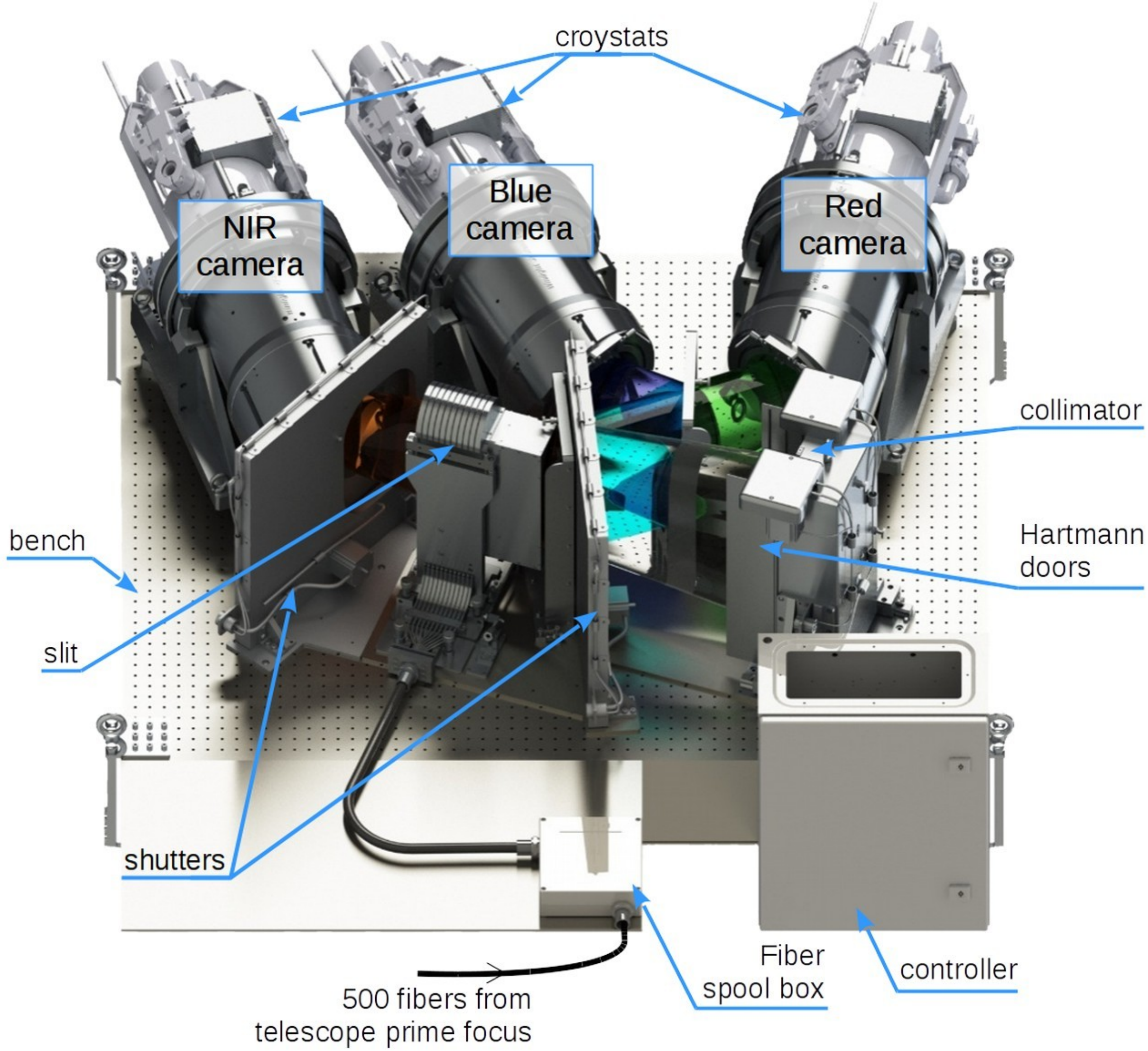
- **Throughput Measurement: Principles**
- **Flux Calibration Device for the Test Fiber Slit**
- **Measurement Campaigns**
- **Data analysis (Preliminary)**
  - Flux measurements with the calibrated photodiode (DKD)
  - LED spectra with DESI spectrograph: reduction, extraction
  - Exposure time: shutter time correction
  - Gain correction: Gain of the CCD amplifiers
  - First direct throughput estimate (without a throughput model)
  - Combining with a model derived from Tungstene lamp exposures
- **Focal Ratio Degradation (FRD) estimate**

The DESI spectrograph

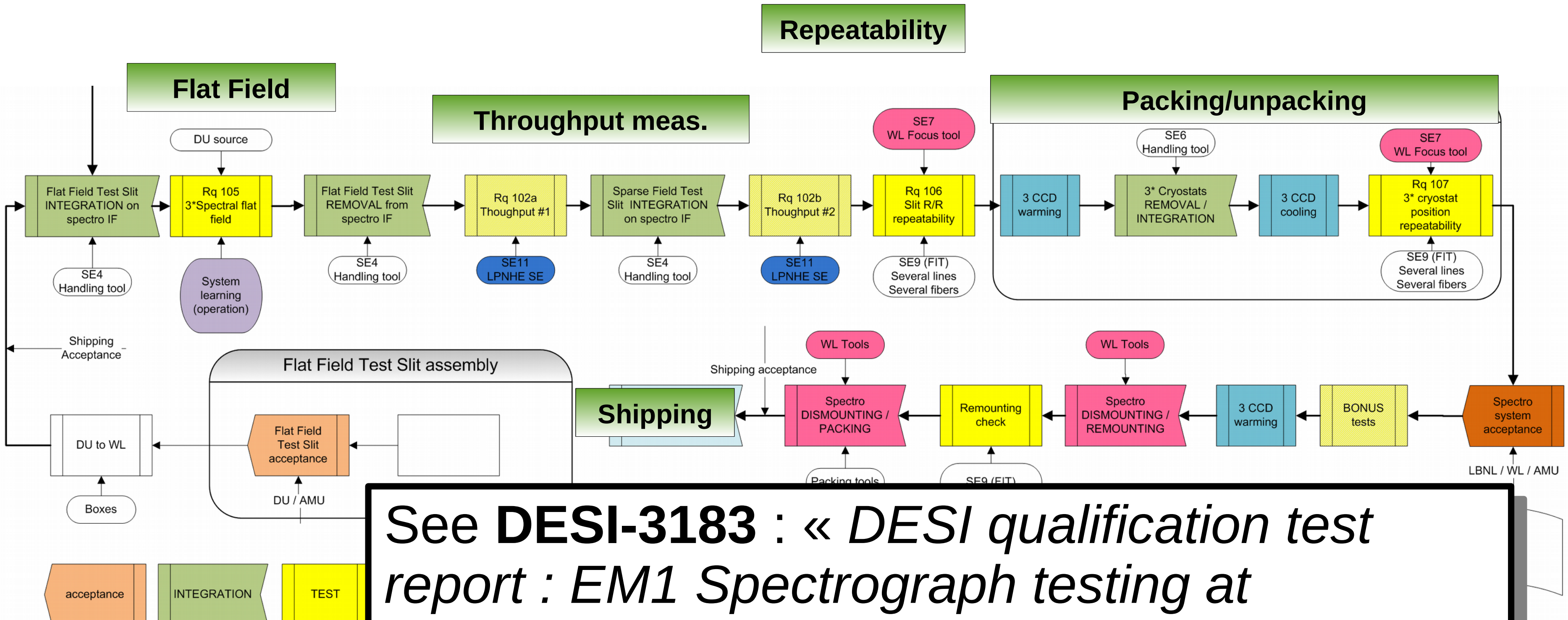
- 10 identical spectrographs
- 10 x 500 fibers
- 3 arms : NIR, Red, Blue



The DESI spectrograph

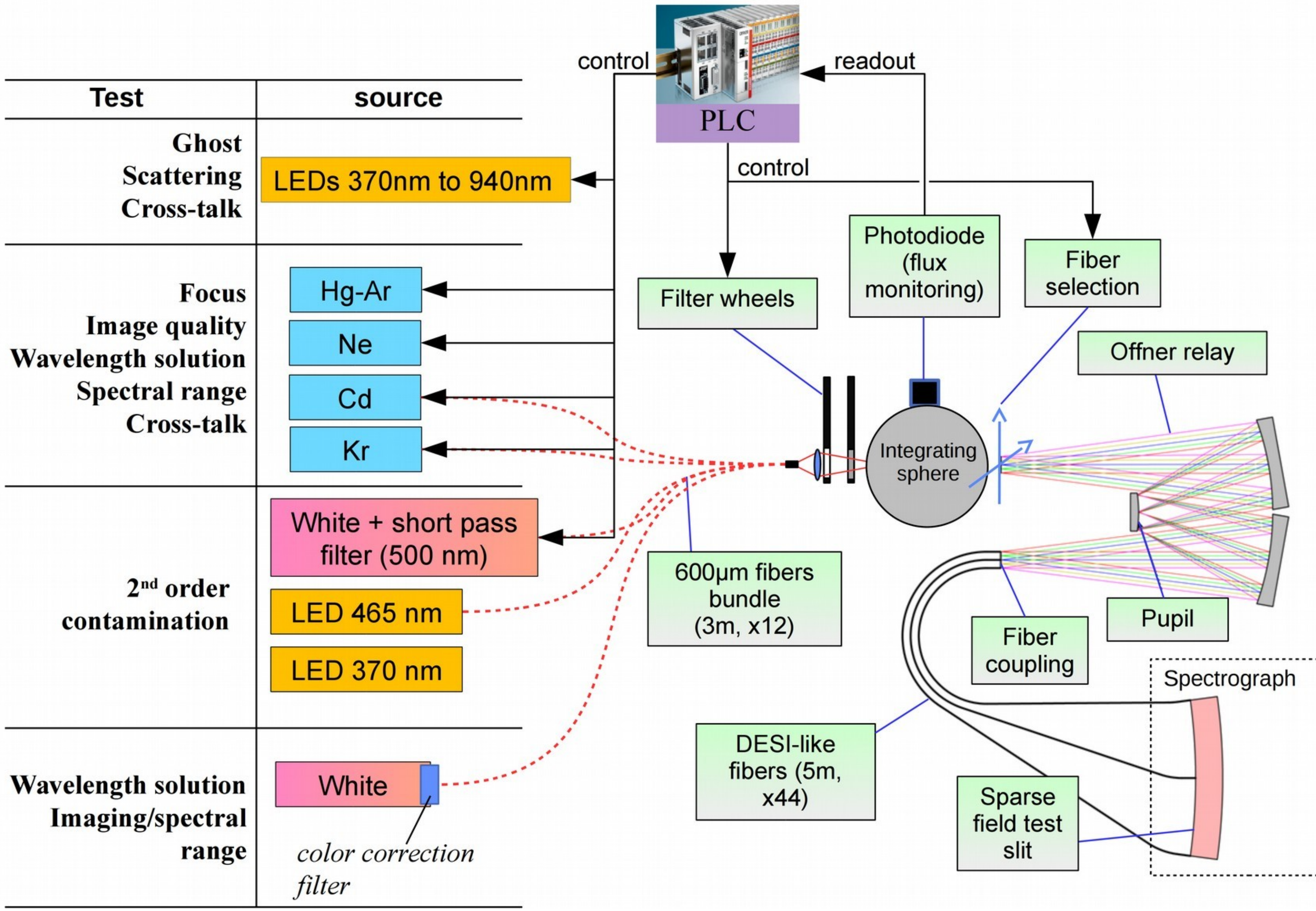


Incl. in Spectro. Qualification Tests (AMU)

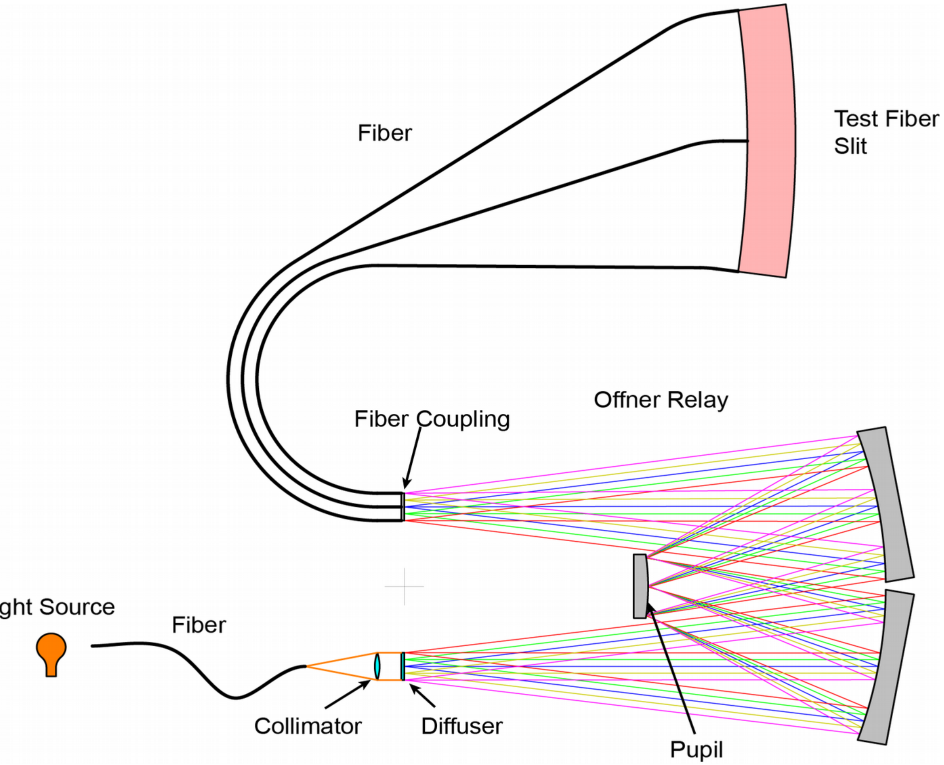


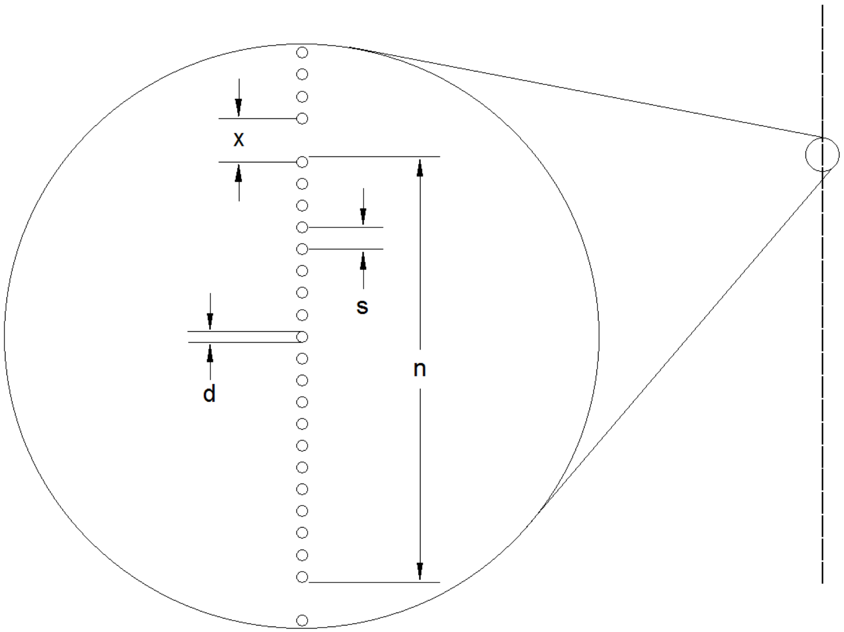
See **DESI-3183** : « *DESI qualification test report : EM1 Spectrograph testing at Winlight* », S. Ronayette, J. Guy, L. Le Guillou, Sept. 2017.

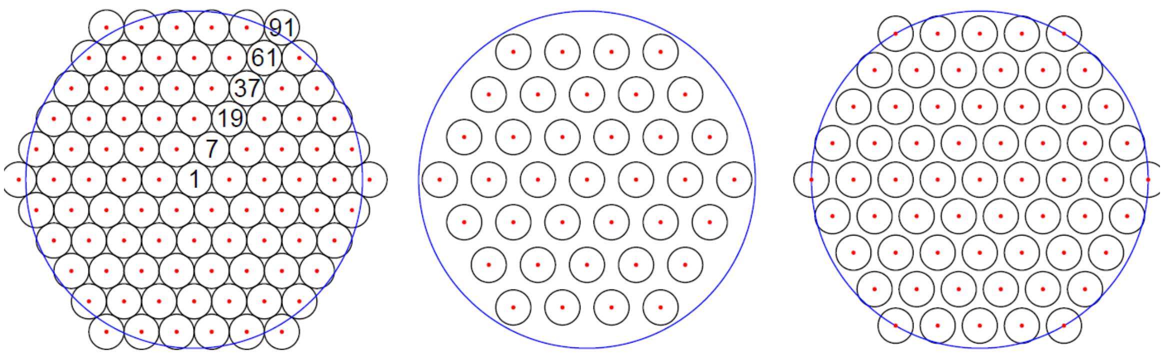
Illumination Testbench (AMU@Winlight)



Sparse fiber slit(s): allows single fiber illumination



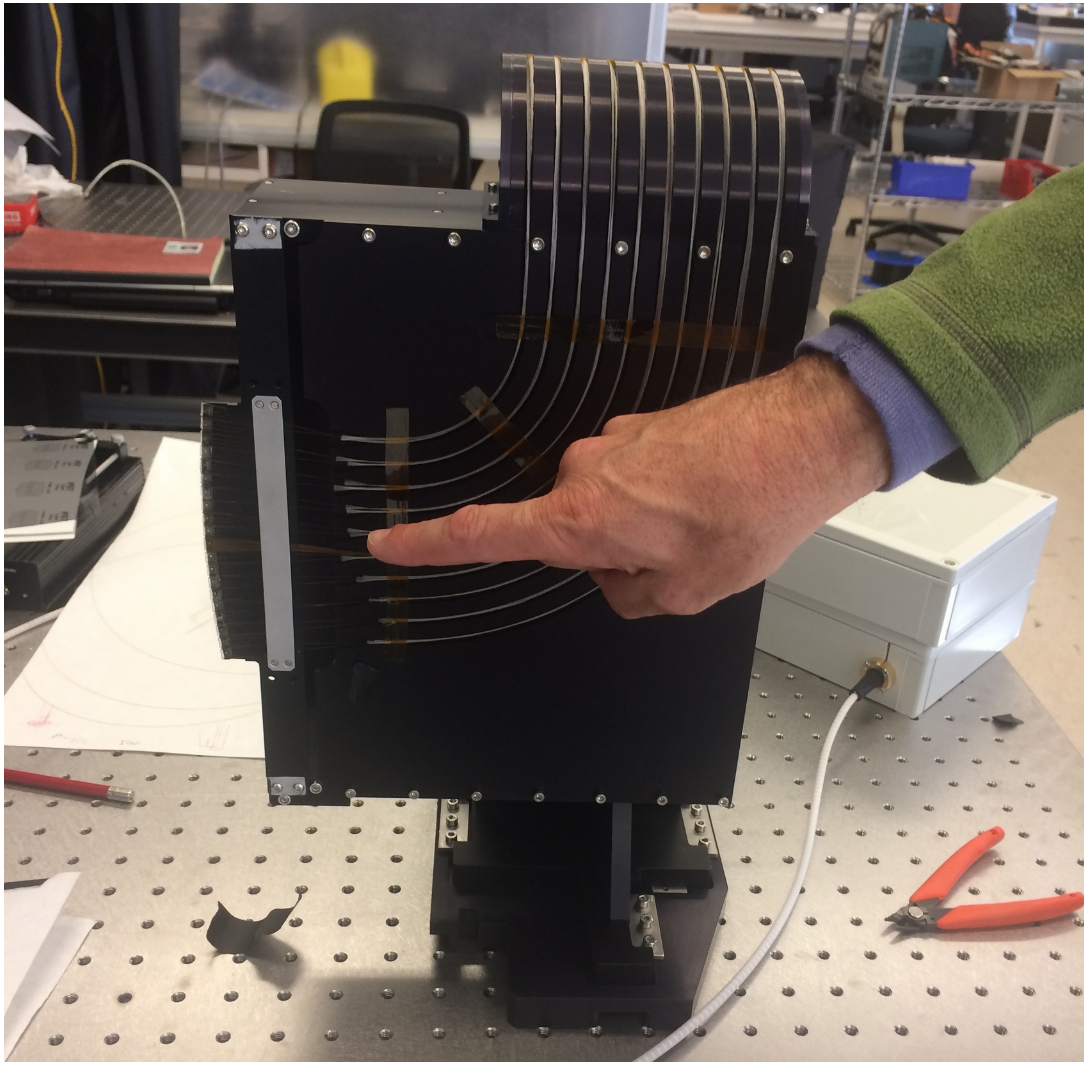


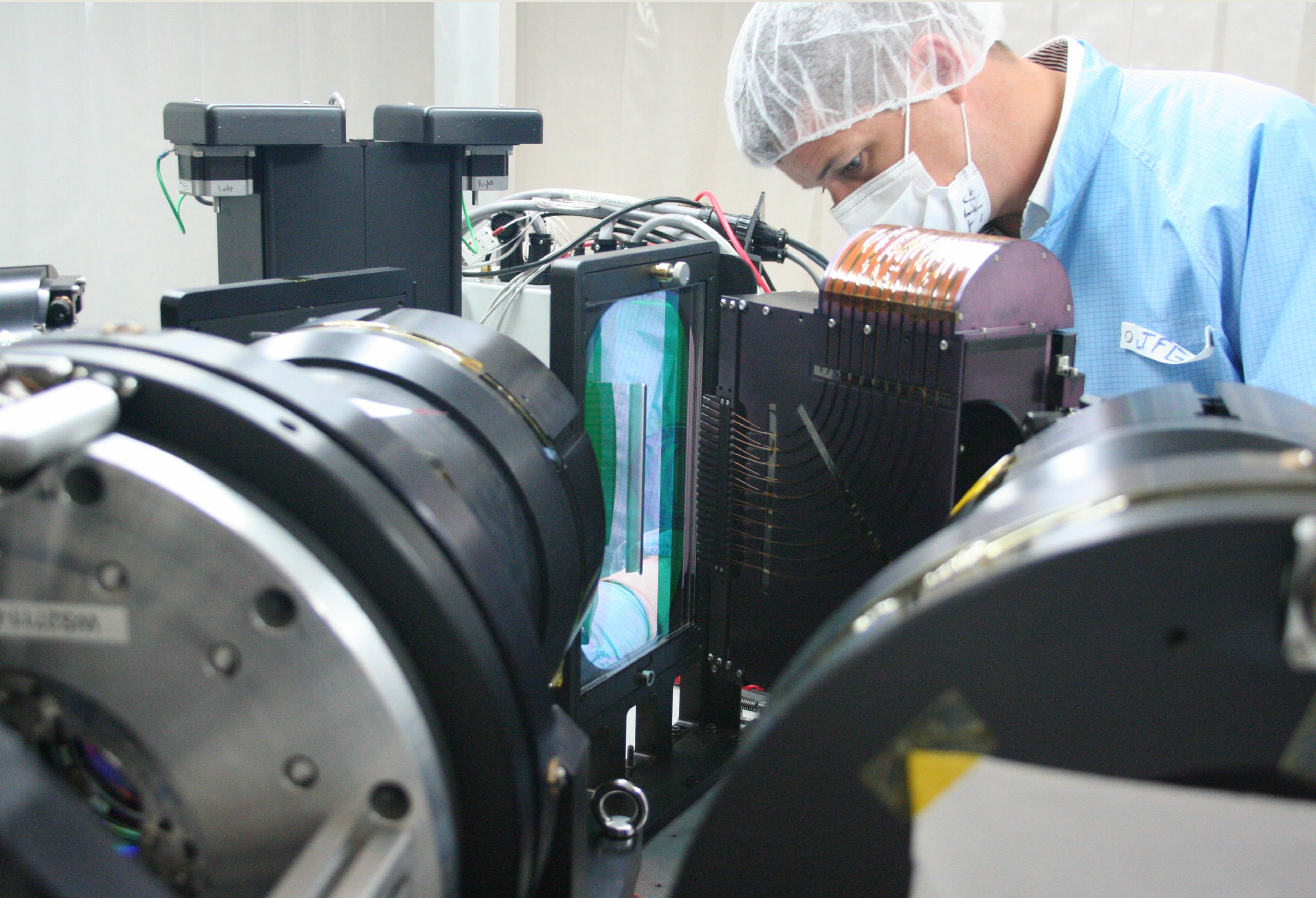


Fiber slit(s): "sparse fiber slit"

- 21 well separated fibers
- May be illuminated individually (AMU bench)

Fiber : f/3.57
Angle θ ~ 8°

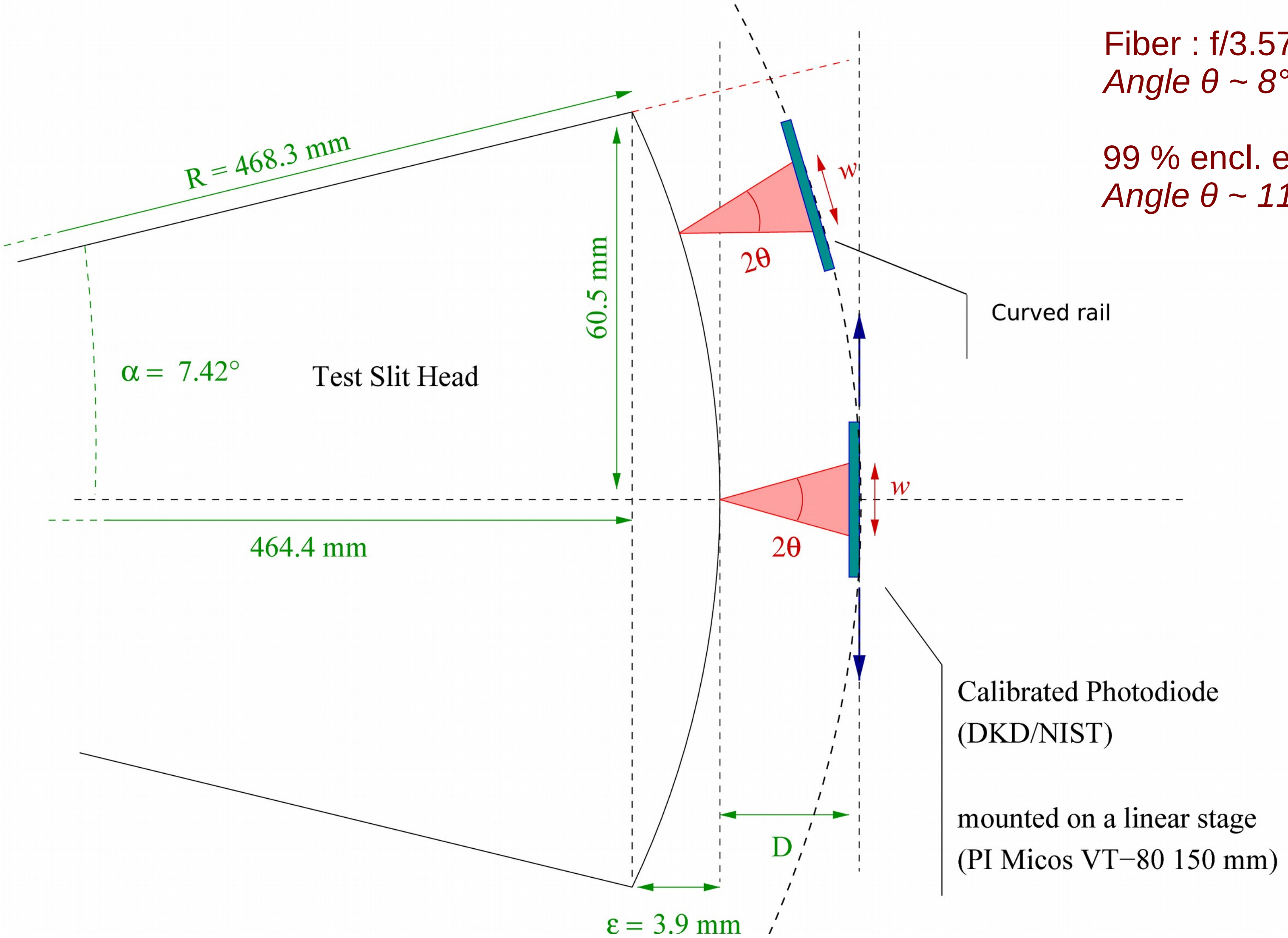



Left
Right

Throughput measurement principles

- **Motivation** : for many previous spectrograph projects, effective transmission **much lower than predicted** from optical models. **Huge risk**, may **endanger the DESI science**.
- 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)

Mechanical design



Fiber : f/3.57
Angle θ ~ 8°

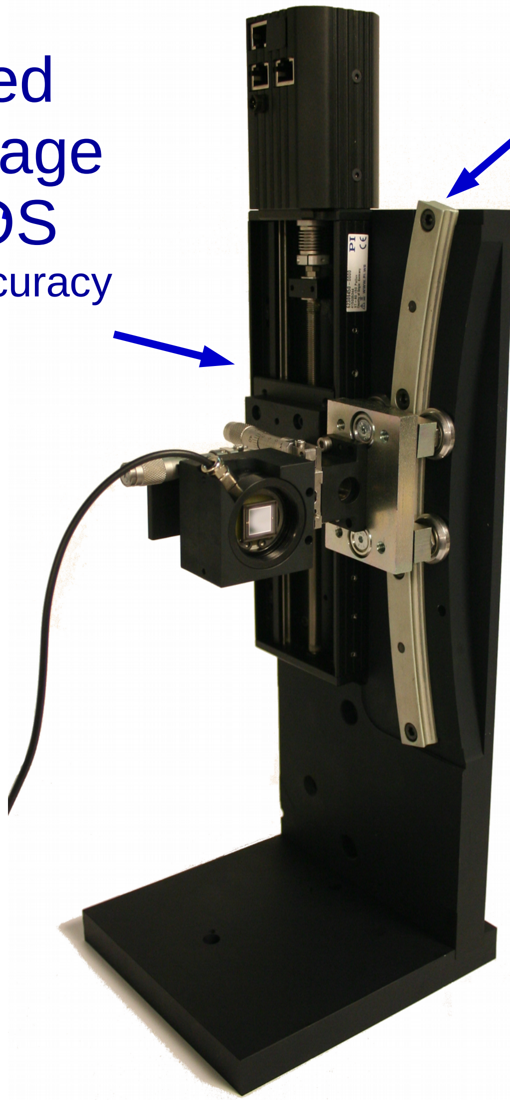
99 % encl. energy : f/2.5
Angle θ ~ 11.3°

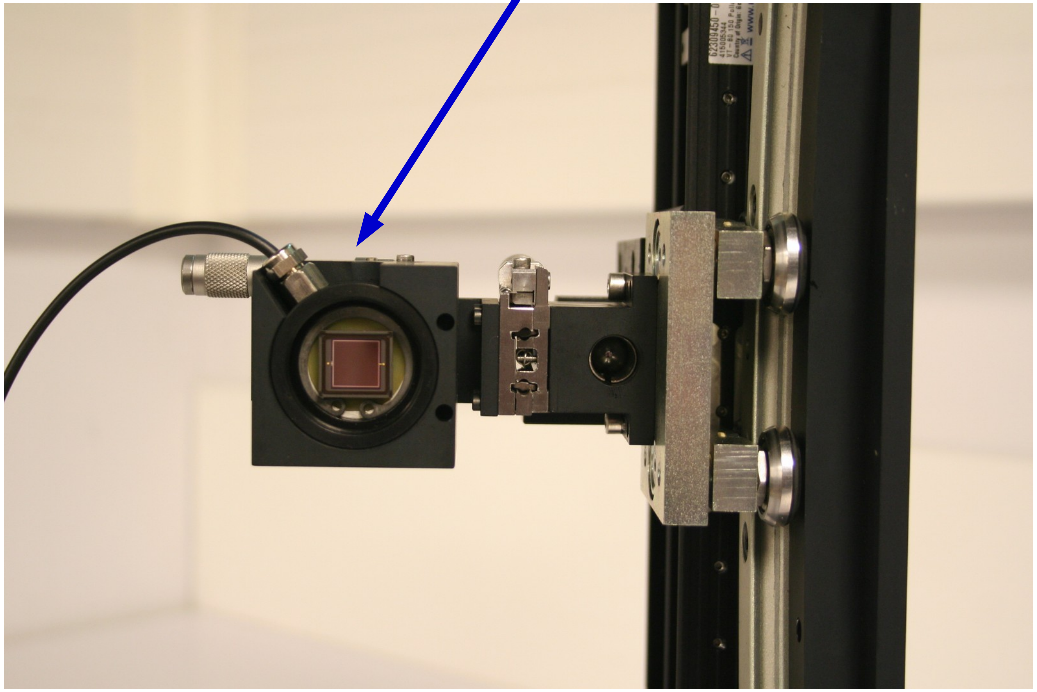
Throughput measurement device

Motorized linear stage Pi/MICOS
<0.4 µm accuracy

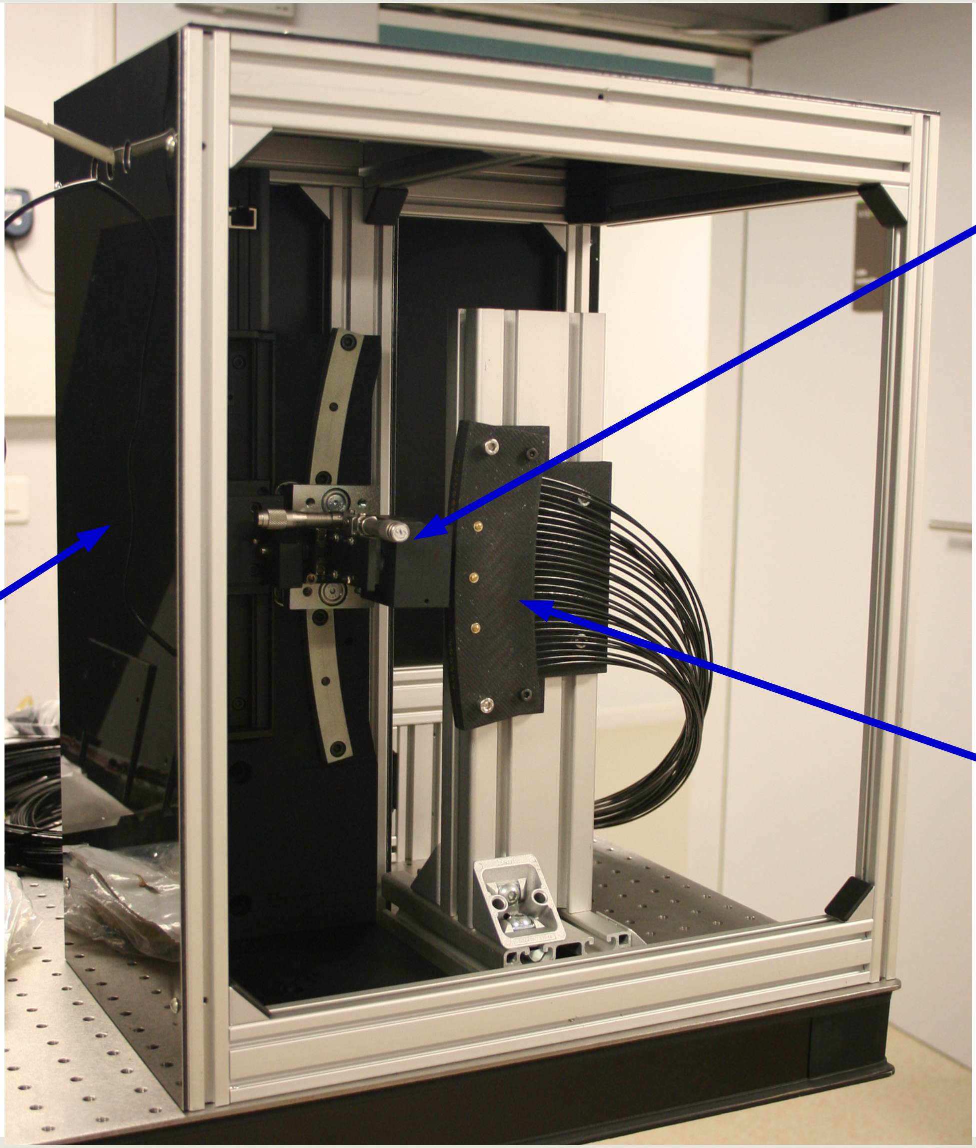
Curved rail
(radius 500 mm)

Calibrated Photodiode
10x10 mm²





Throughput measurement device



Calibrated Photodiode

Dedicated Dark Box

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

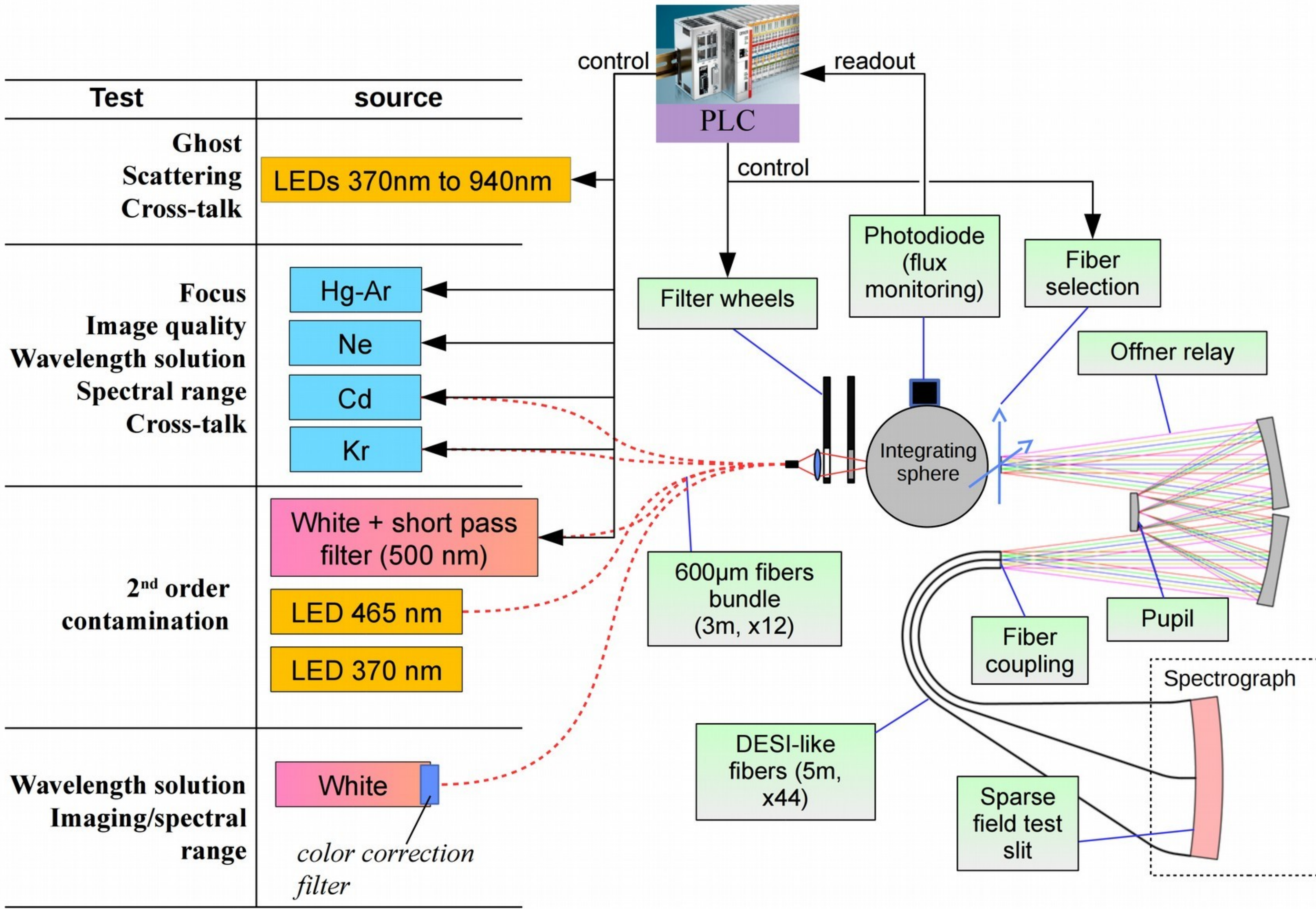
Calibrated Photodiode

- MD-37-SU100 **calibrated** (**spectral responsivity** [A/W])
  - **DKD** (DE) **certified absolute calibration**
  - 2 % on 250 – 1100 nm.
- Size : 10x10 = 100 mm²
- Photodiode current readout : picoammeter

  Keithley 6514, or better **6482** (2 channels), (fA)
- **Simultaneous monitoring** of :
  - Light flux in the integrating sphere
  - Light flux exiting the fiber

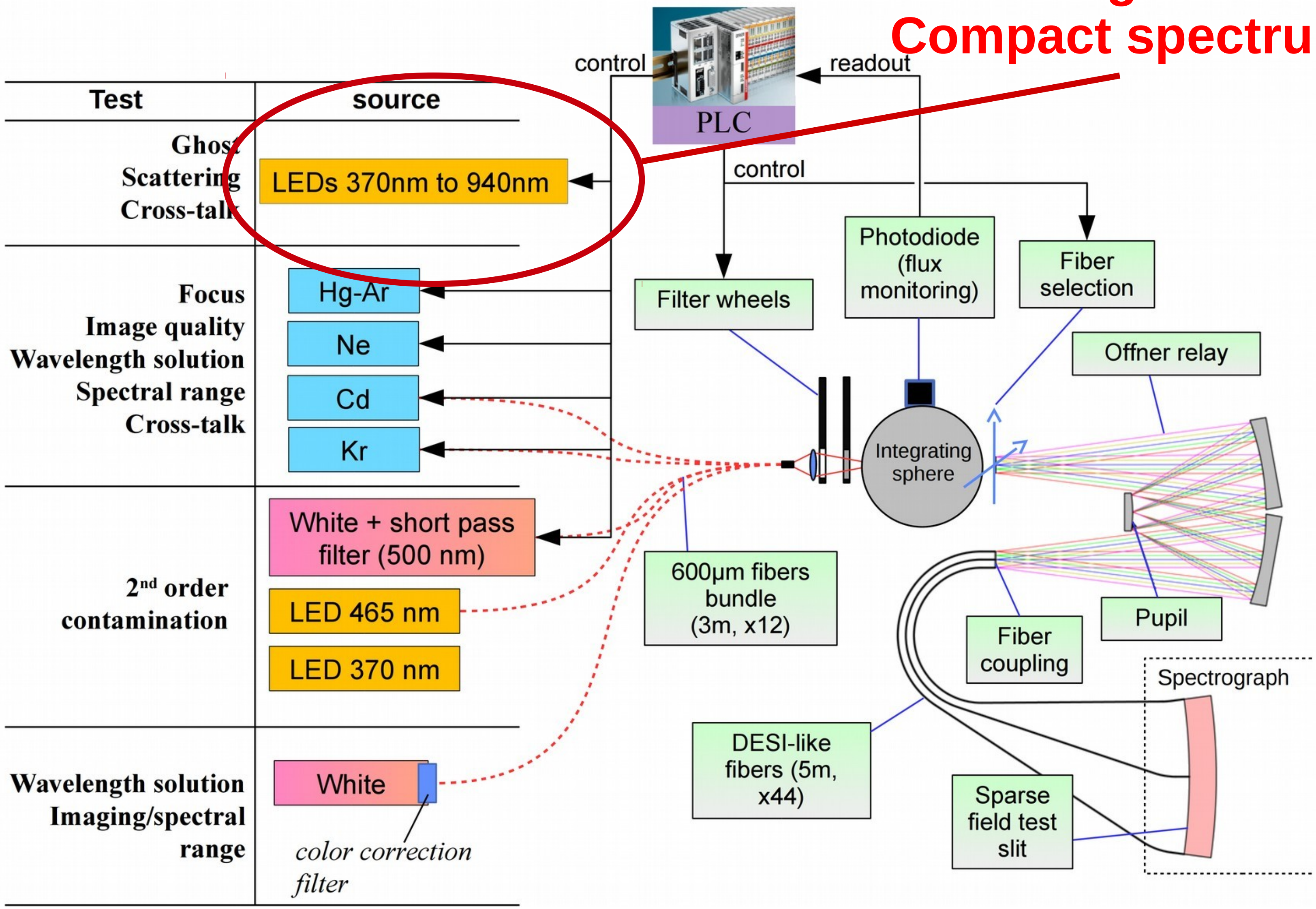
  → Control of the **illumination stability**

Illumination Testbench (AMU)

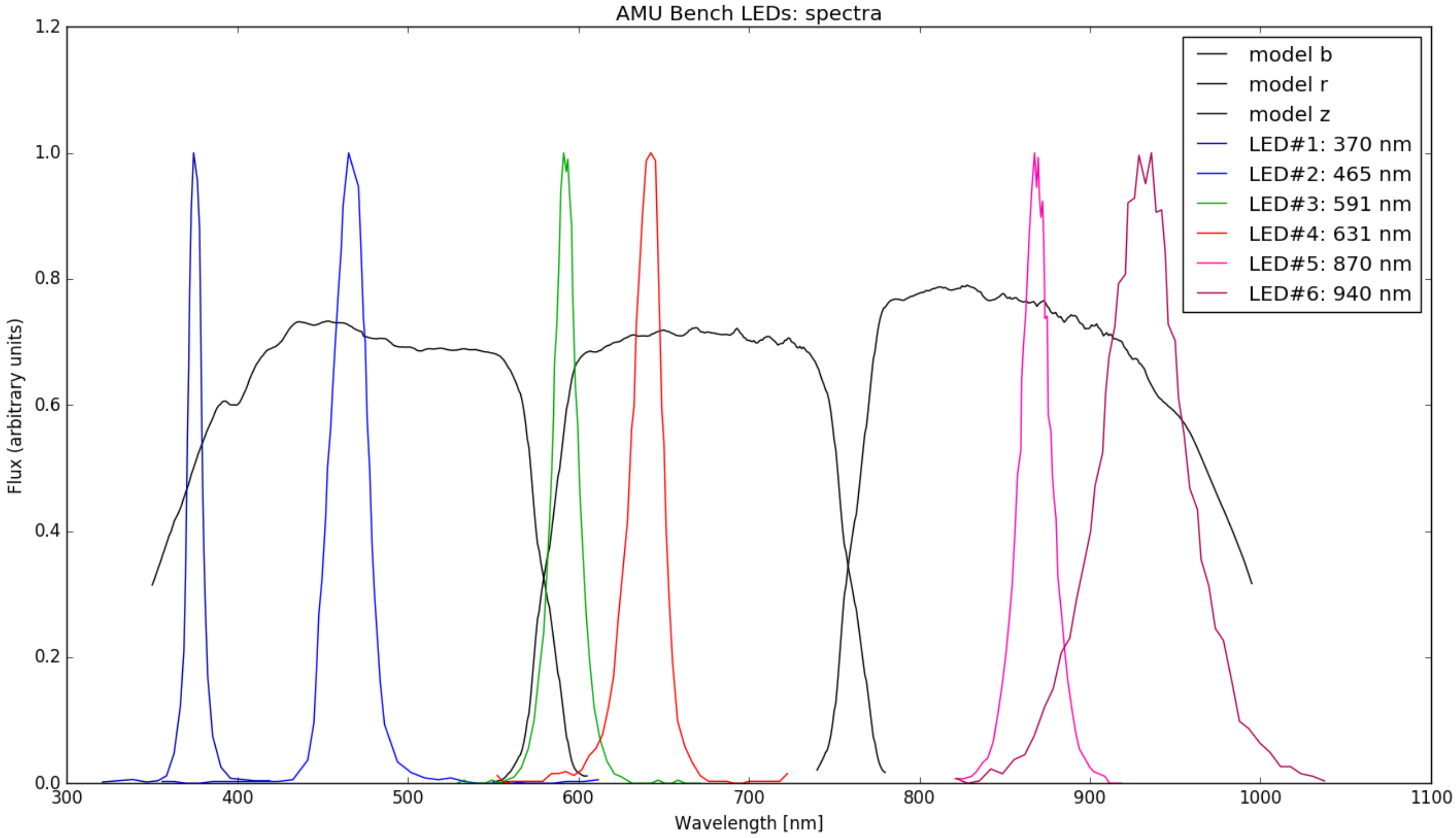


Illumination Testbench (AMU)

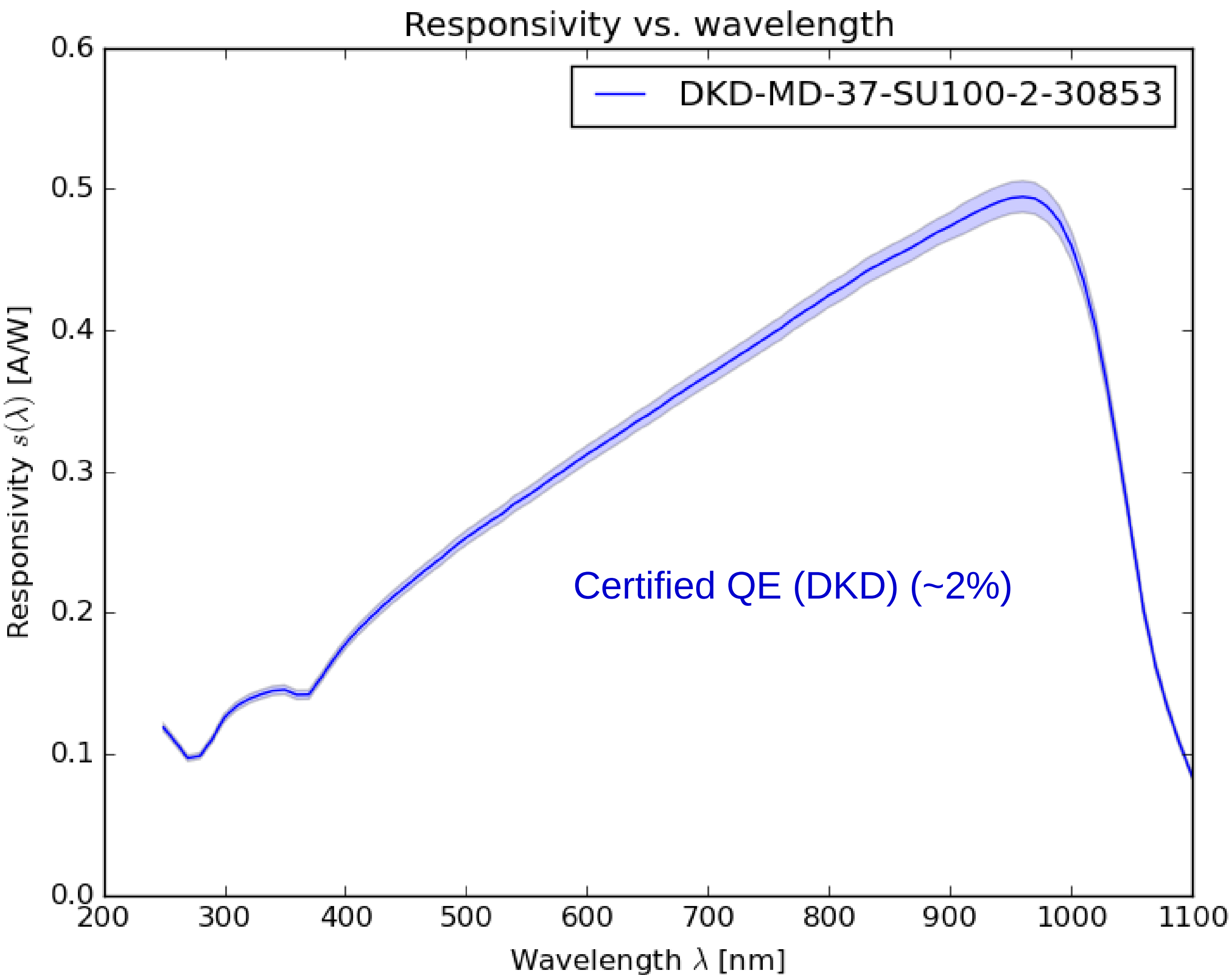
LED : bright enough
Compact spectrum !



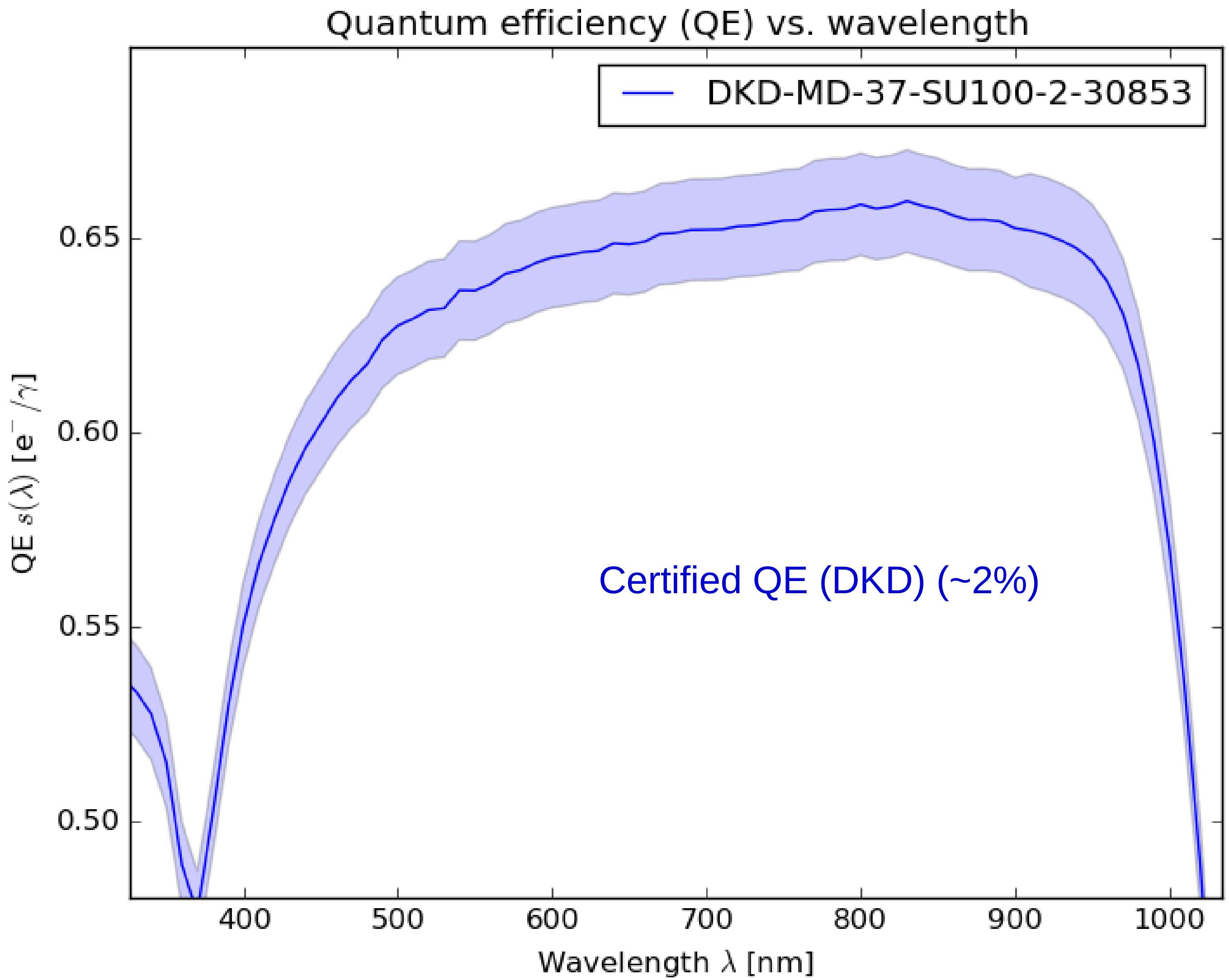
LED spectra: compact spectra



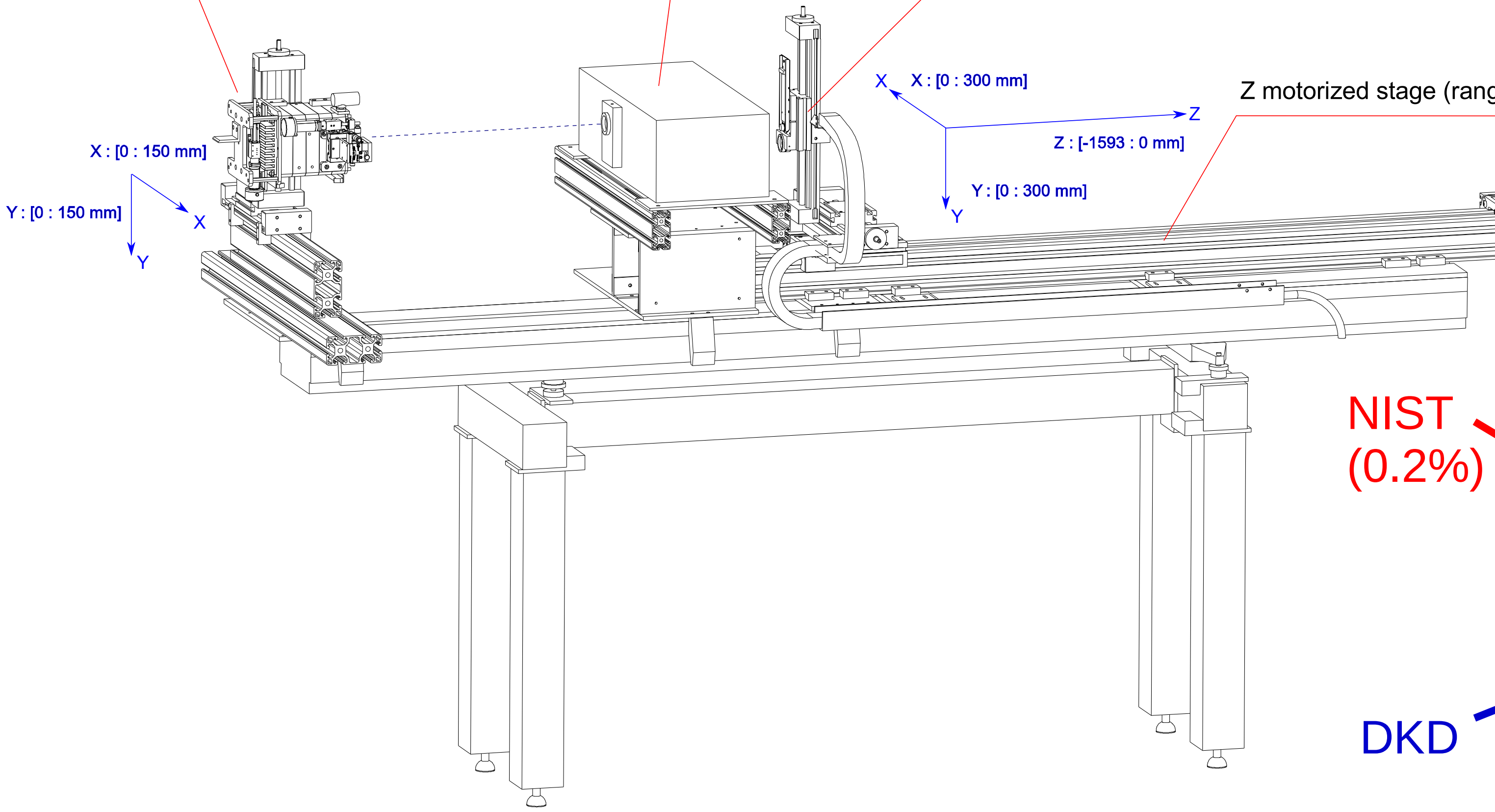
Photodiode Calibration (DKD certified)

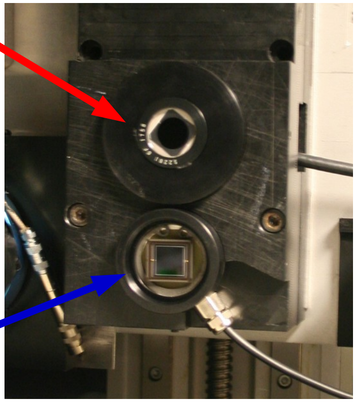


Photodiode Calibration (DKD certified)

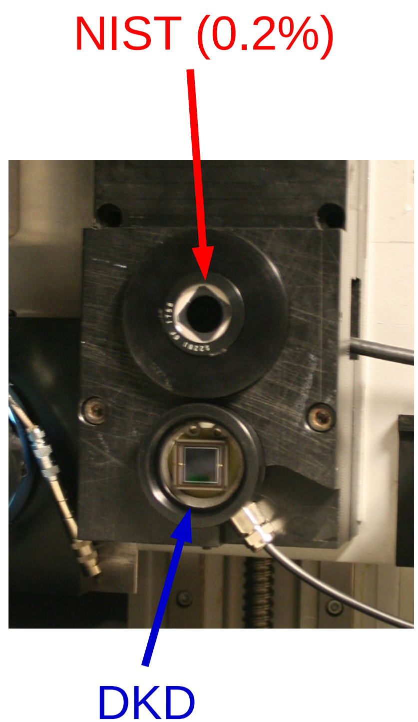


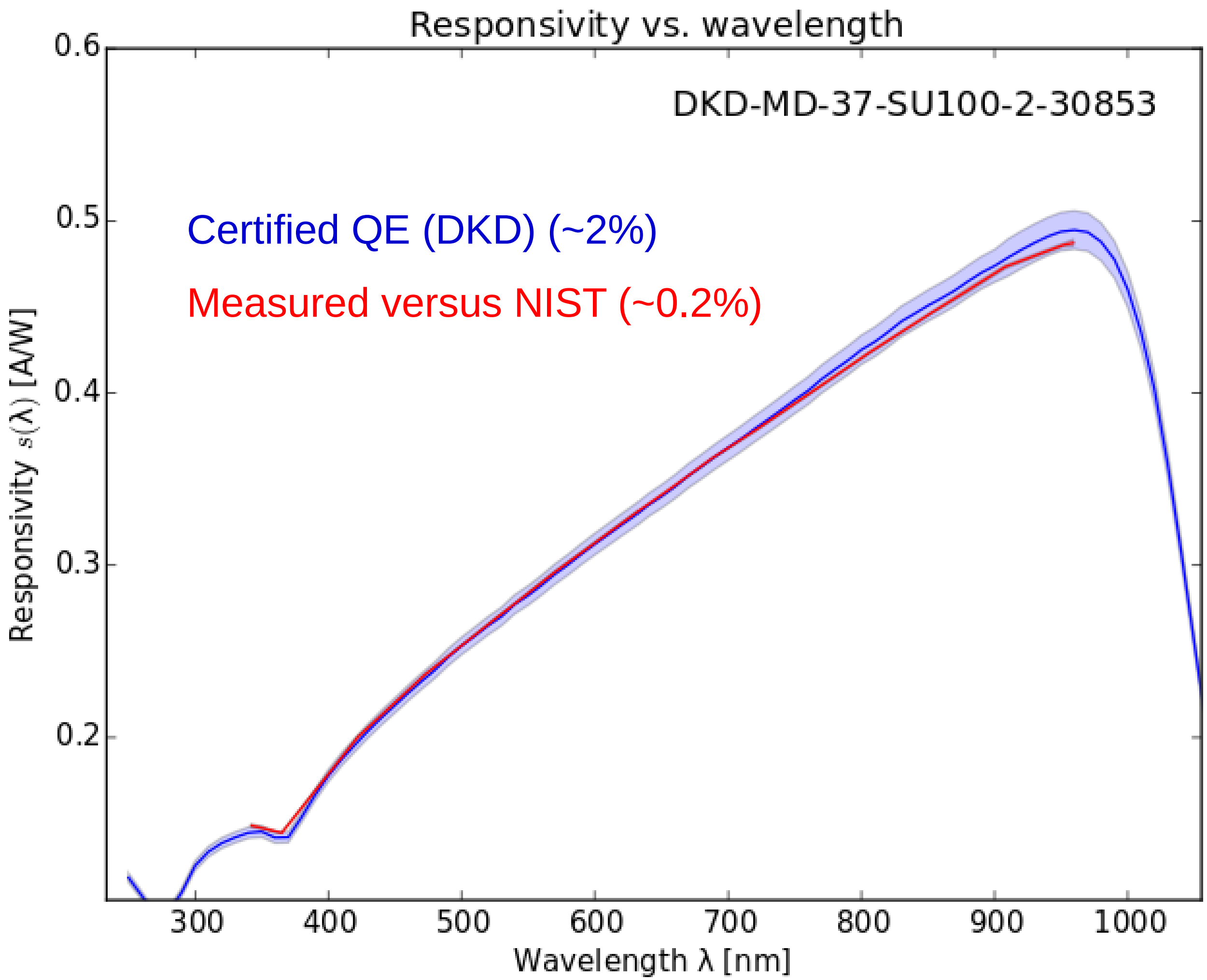
Intercalib. : DICE spectrophotometric bench





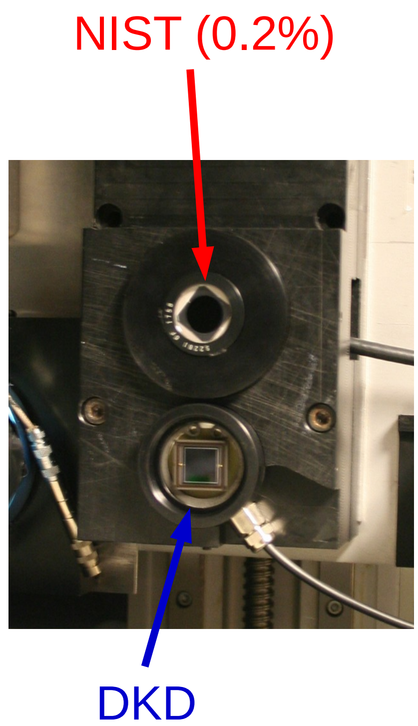
Photodiode Calibration & checks at LPNHE

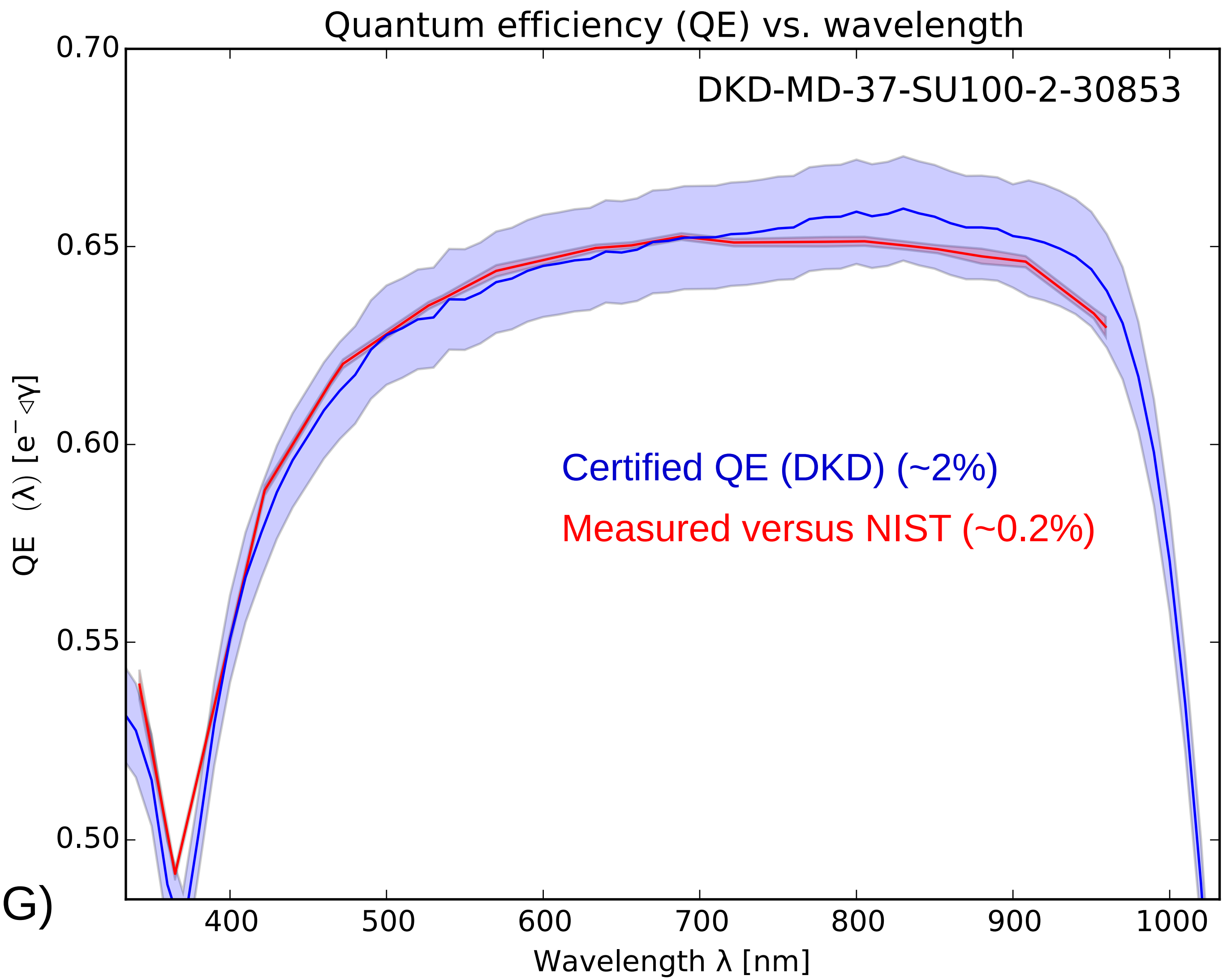




See DESI-2635 (LLG)

Photodiode Calibration & checks at LPNHE



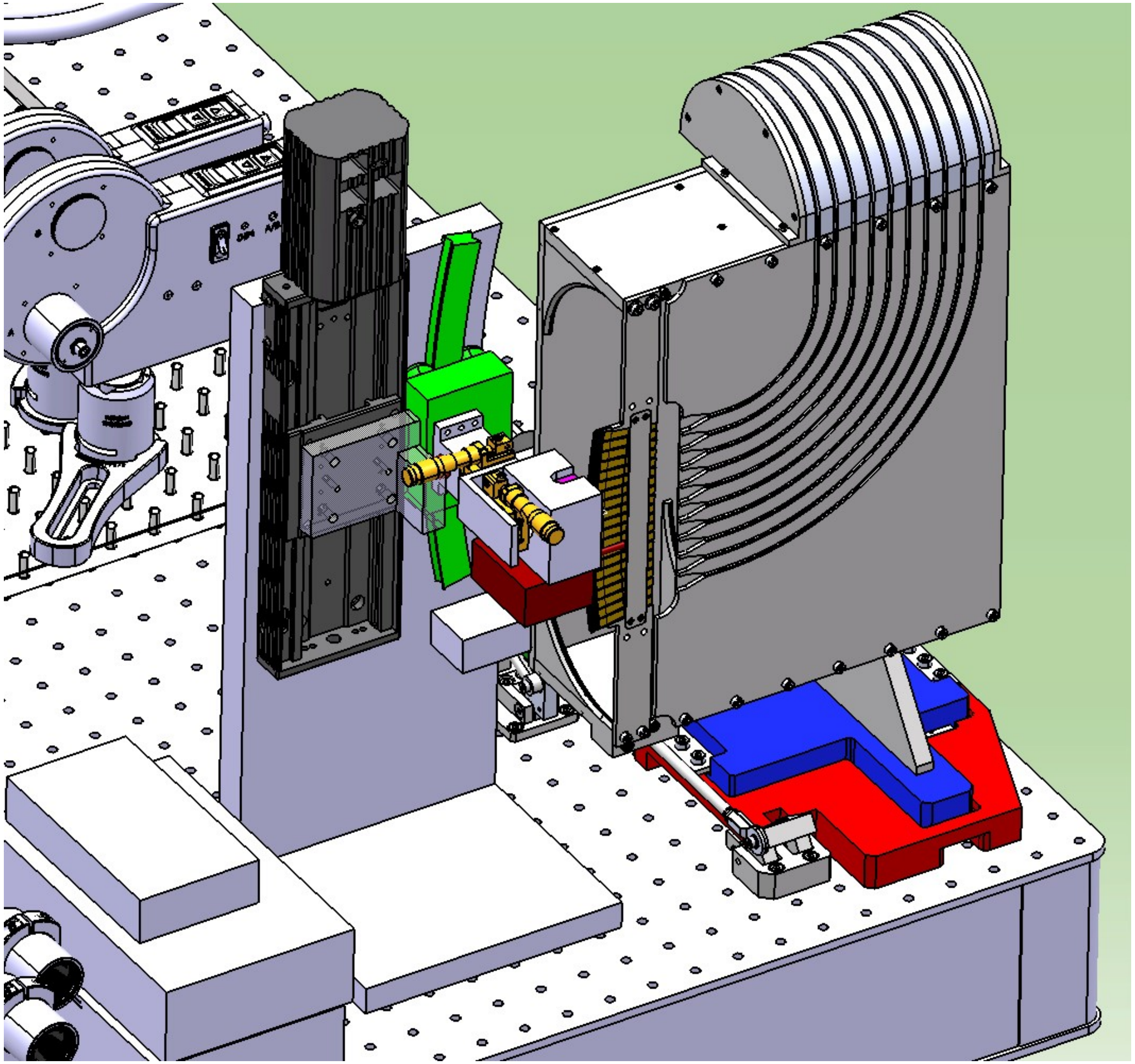


See DESI-2635 (LLG)

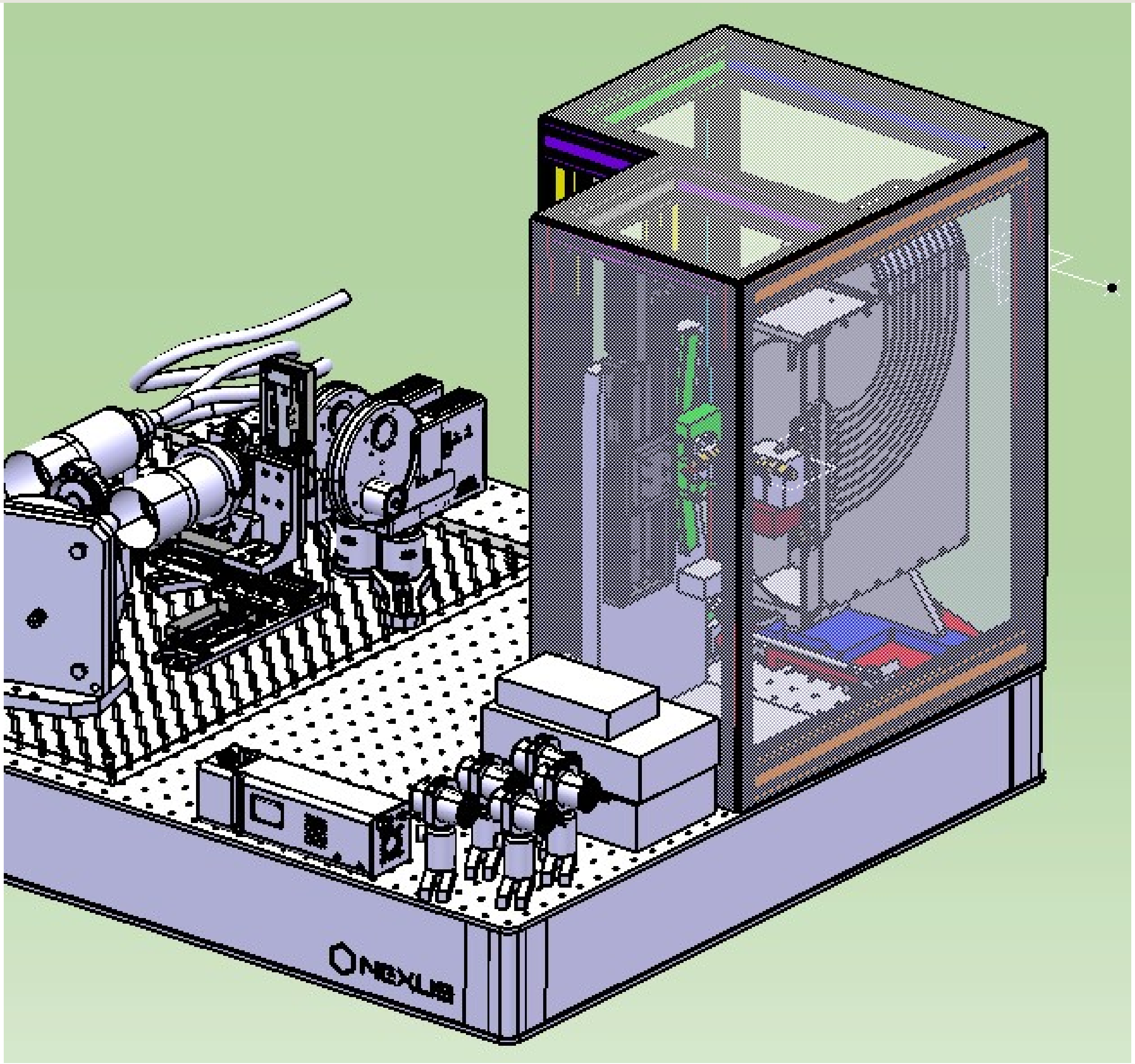
Integration on the AMU Testbench

- **Challenging mechanical interface** between the fiber slit and our device (collision with fiber ends should be avoided at all cost!!)

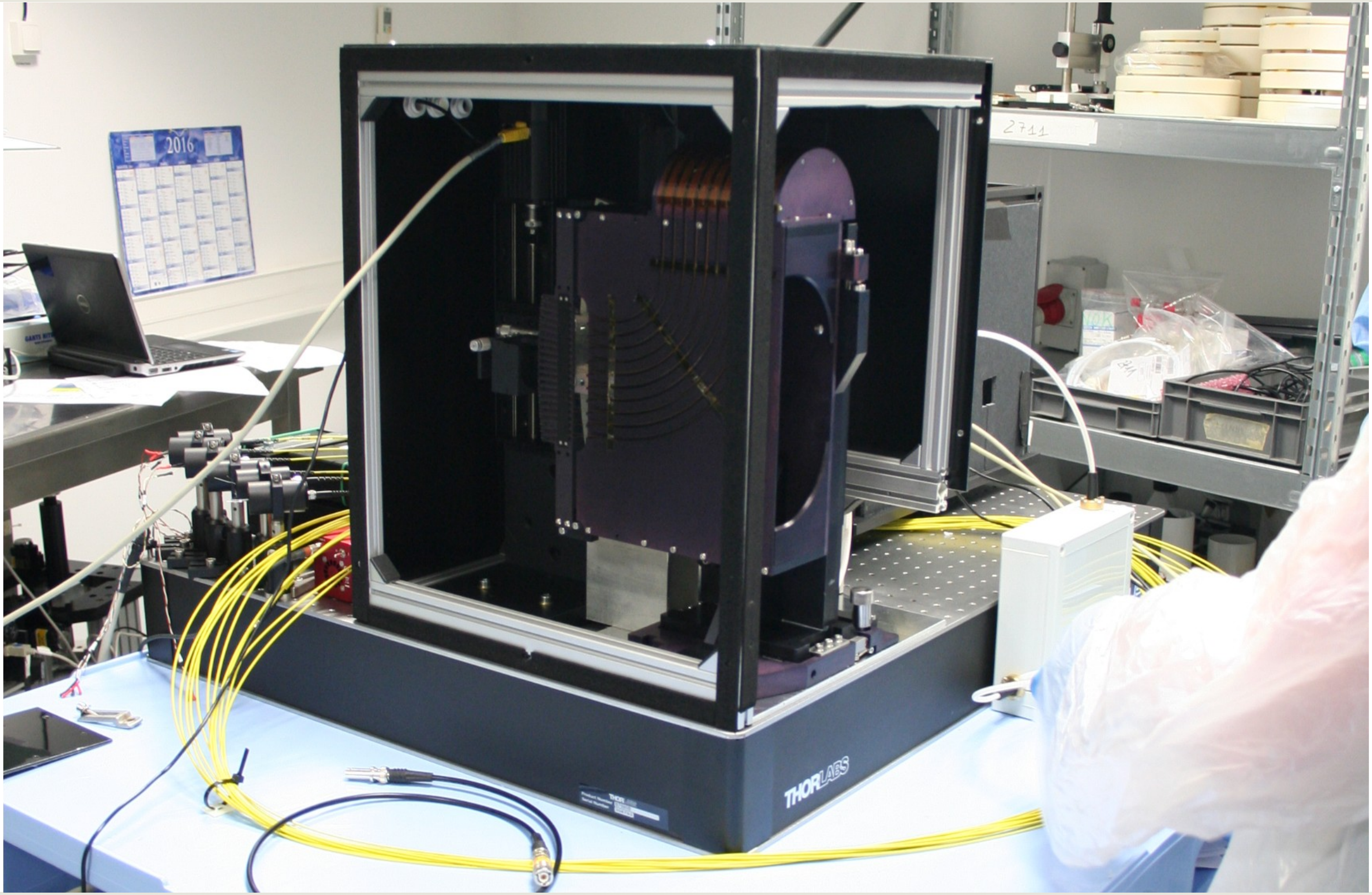
- **Integration within the AMU testbench software** and the **ICS** (Xavier Regal, AMU)



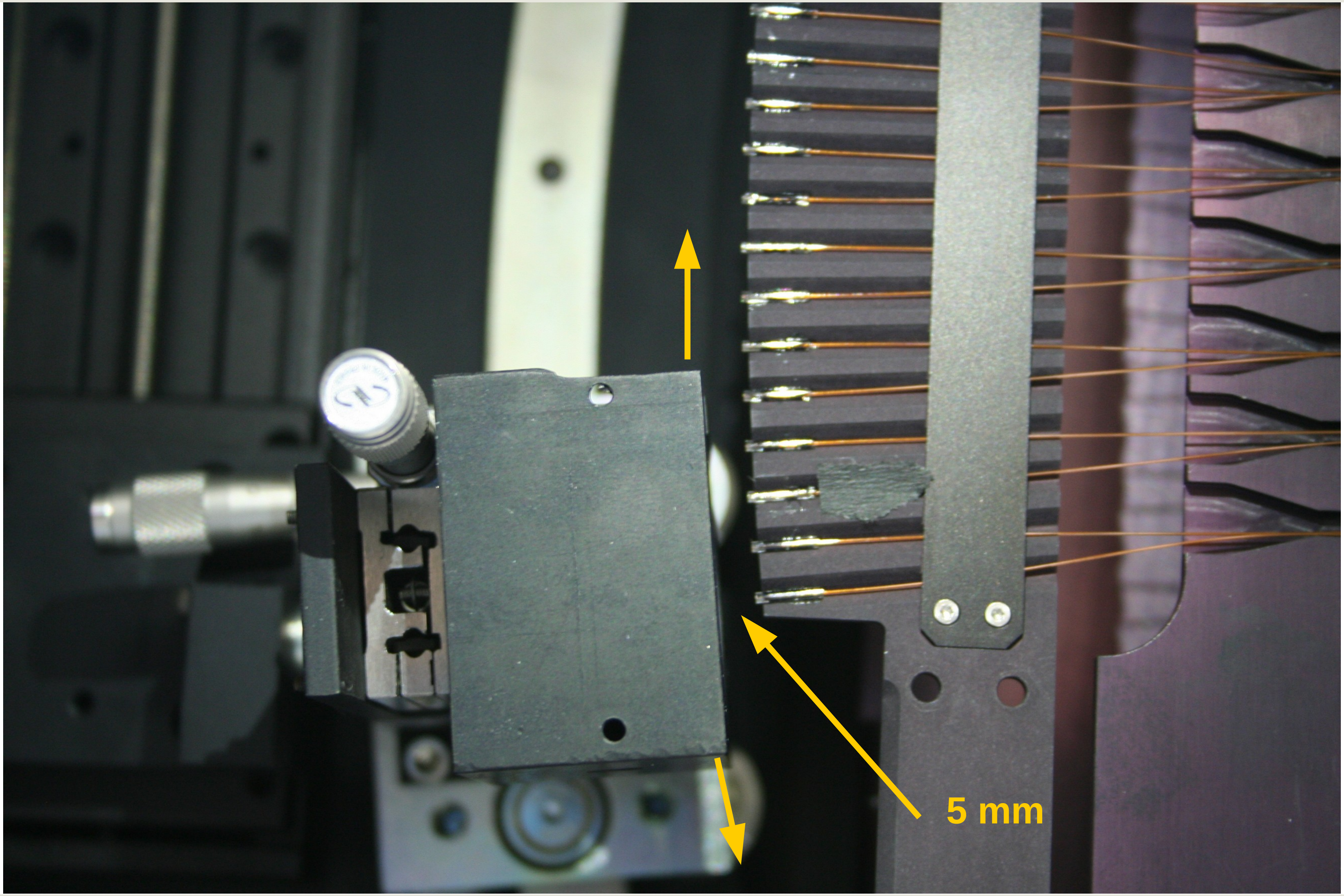
Integration on the AMU Testbench (dark box)



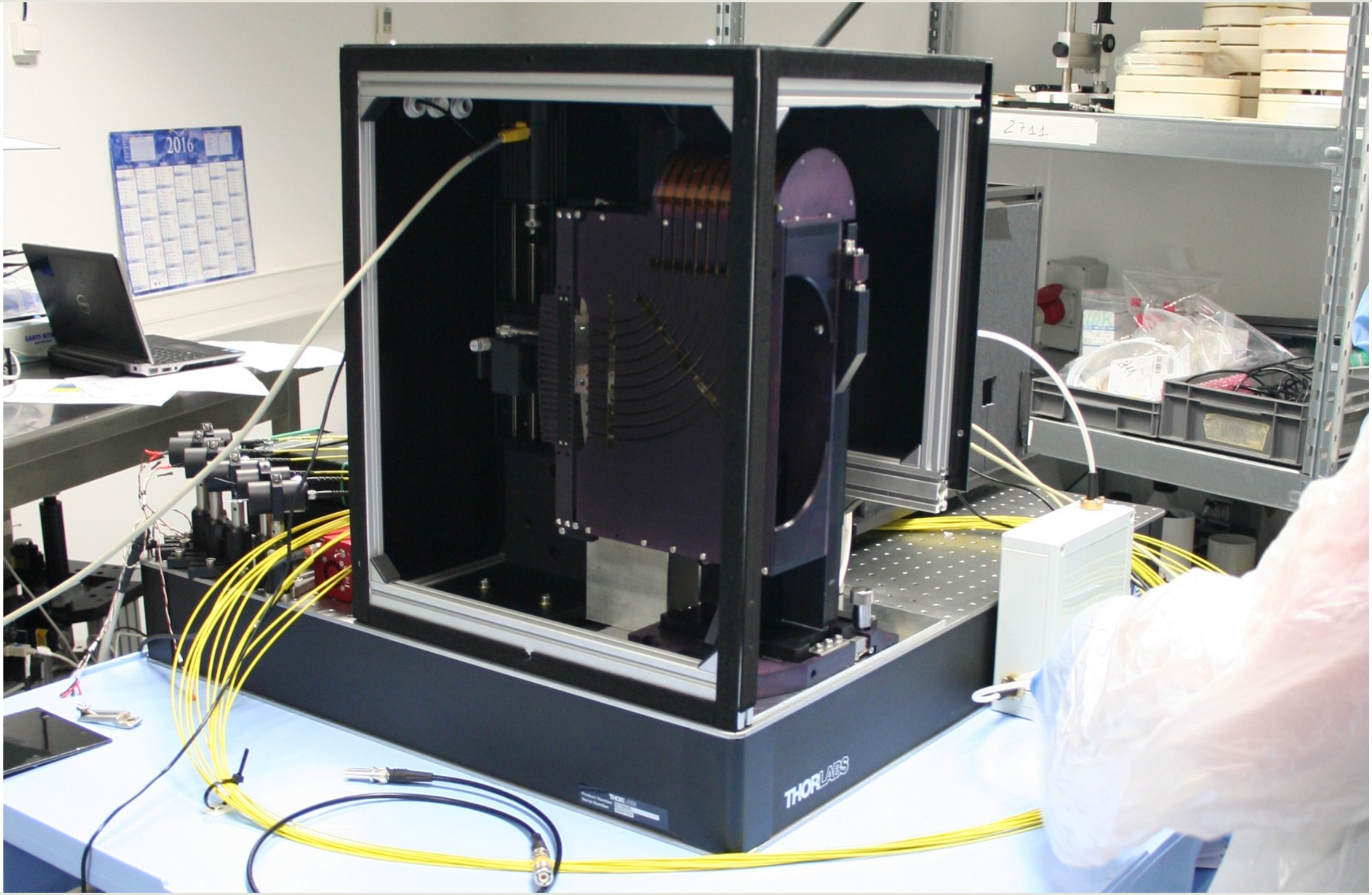
Installation at Winlight (sept. 2016)



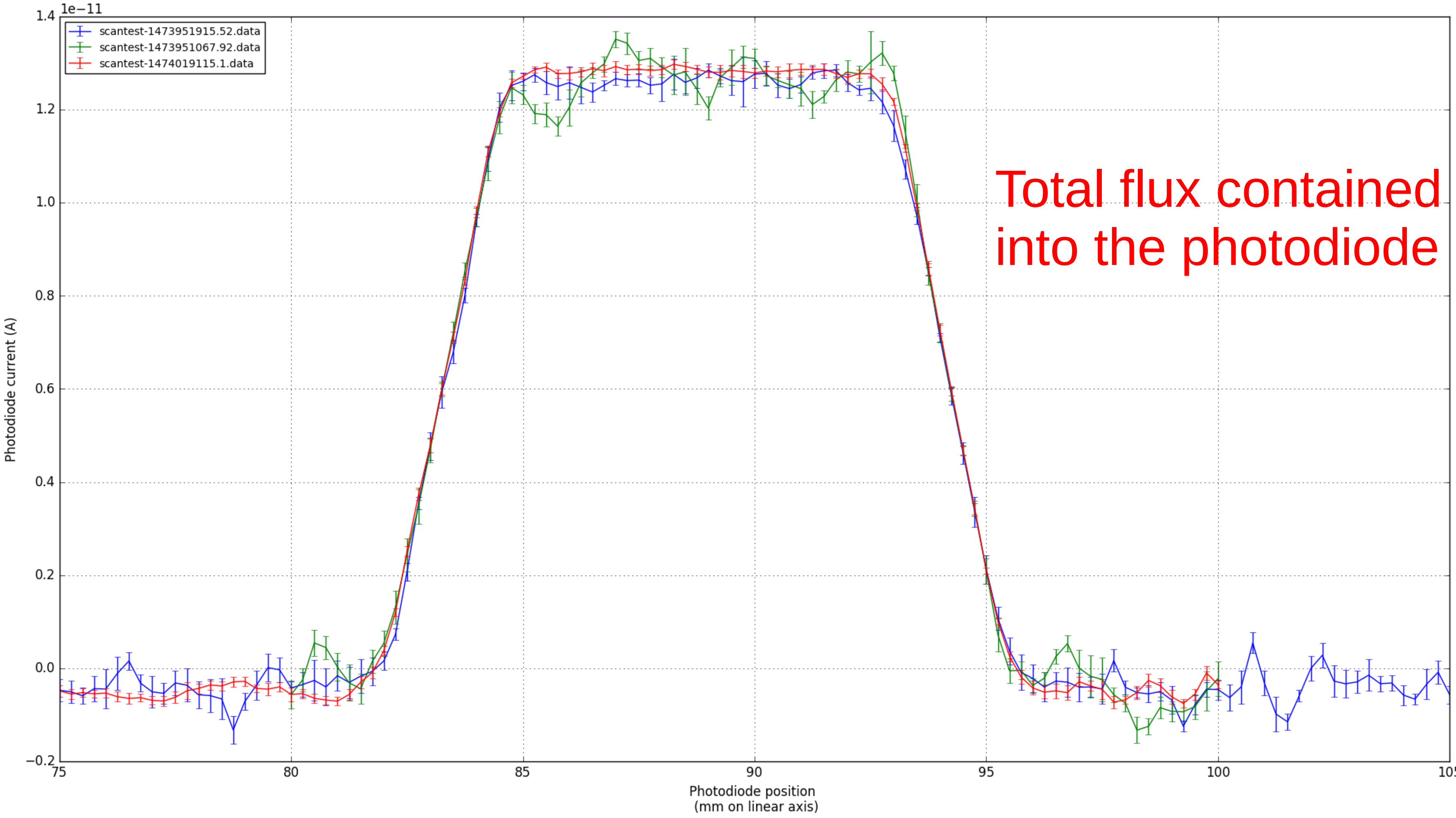
Installation at Winlight (sept. 2016)



Installation at Winlight (sept. 2016)



Scan of the fiber beam by moving the photodiode



Total flux contained into the photodiode !

Measurements campaigns (2017)

- **1st campaign: Jan 31 to Feb 2, 2017 (LLG, JG, PEB, SR)**
  - **Absolute flux measurements** (slit in the box)
  - **Separate spectra of all LEDs / individual fibers** (slit in spectro)
  - Scanning the fiber beam with the entire 10x10 photodiode
  - CCD frames to estimate **true shutter time** (W)
  - CCD frames to estimate **the amplifier gains** (W)

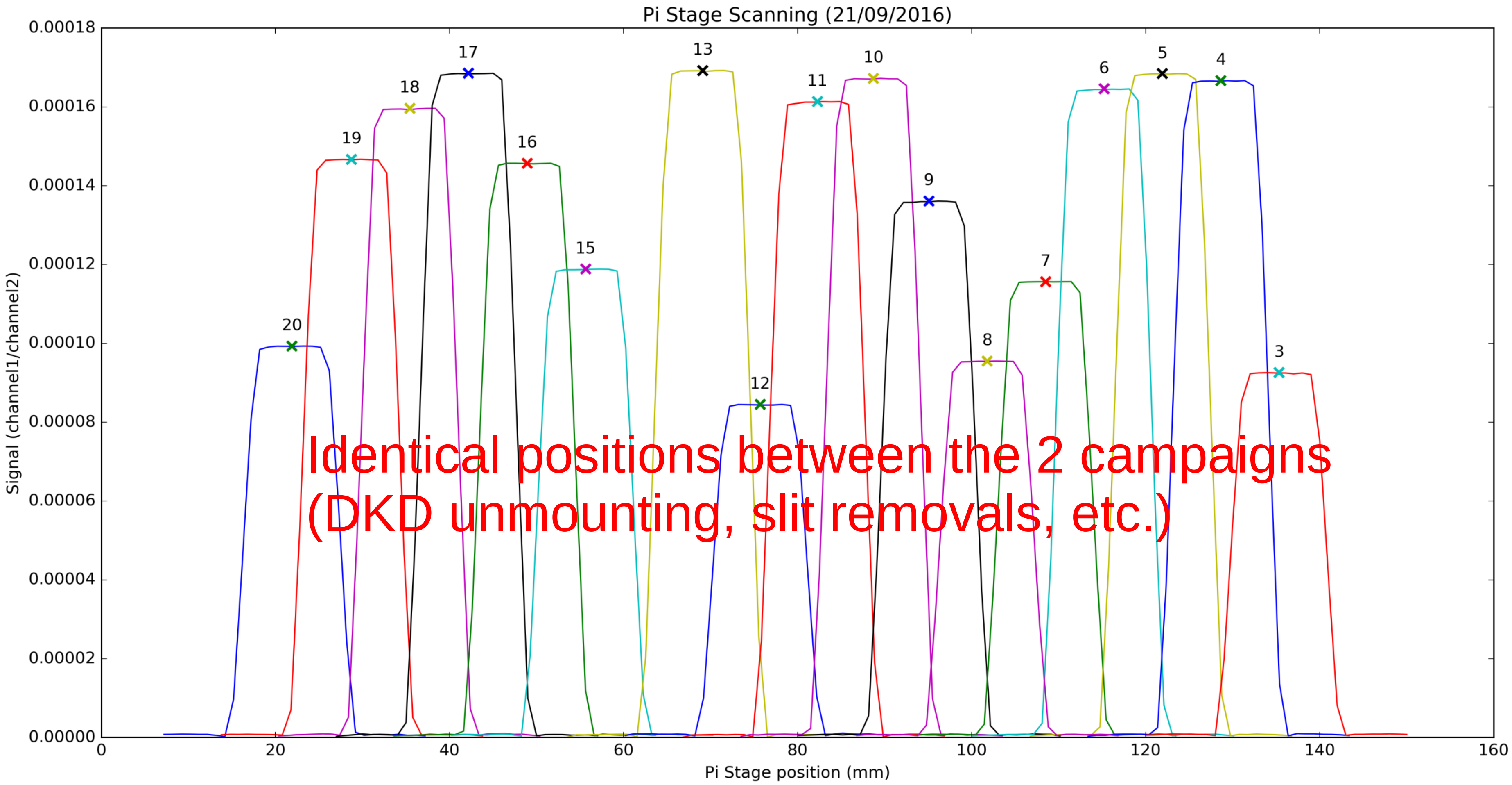
Measurements campaigns (2017)

- **2nd campaign: March 14 – 17, 2017 (LLG, PEB, SR)**
  - **Absolute flux measurements** (slit in the box)
  - **Separate spectra of all LEDs / individual fibers** (slit in spectro)
  - Scanning the fiber output beam with the entire photodiode
  - **Scanning the fiber output beam with a 100 µm slit** in front of the photodiode (to model the beam and estimate the FRD)
  - CCD frames to estimate **true shutter time** (W)
  - CCD frames to estimate **the amplifier gains** (W)
  - **Flat slit** available: **flats, for better ampli. gain measurements**
- **3rd campaign: July 3 – 5, 2017 (LLG, PEB)**
  (cancelled due to shutter problems)

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)

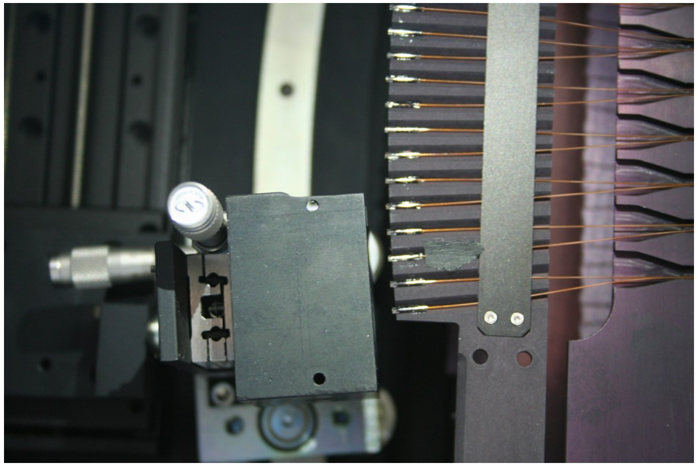
Scan of all the sparse slit fibers (centering)

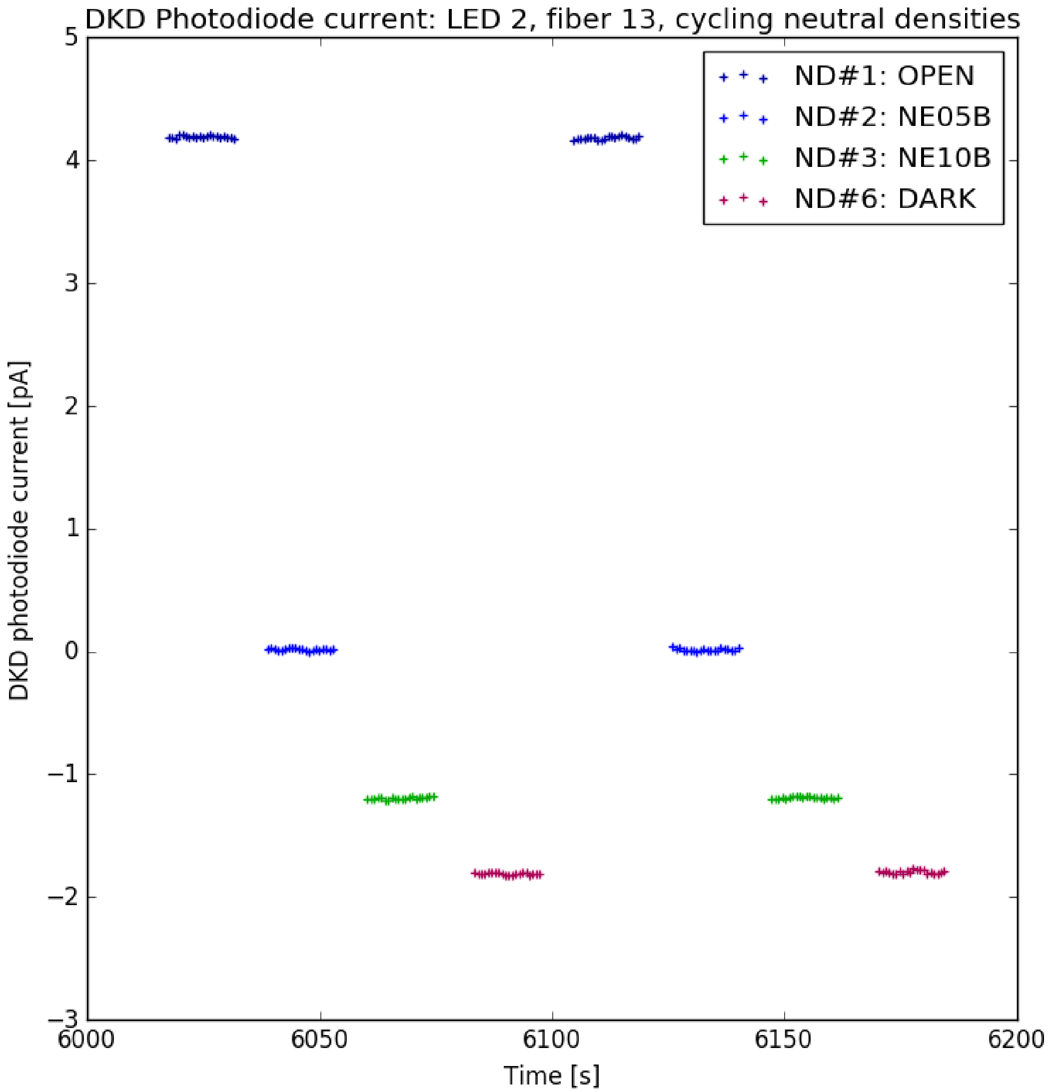


1 broken fiber; last one unreachable (mechanical limit)

Absolute flux measurements (DKD photocurrent)

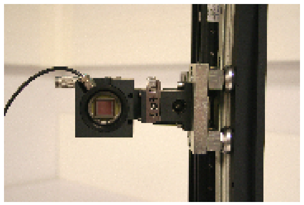
- **For each fiber, for each LED :**
  - centering the DK photodiode to catch the whole beam
  - measuring the photocurrent
- **Cycling over OPEN, DARK, and other neutral densities filters**
- **Subtracting dark current**
- **Photocurrents RMS < 0.01 pA**



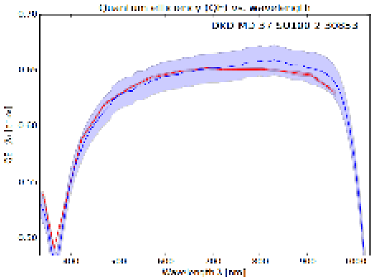


DKD photocurrents analysis

I(t) [pA] ; [e−/s]

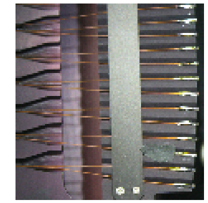


DKD Photodiode + Keithley 6514



/ QE [e−/photon]

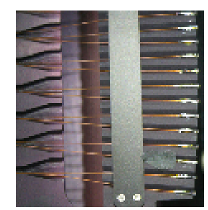
ϕ_{total} Total fiber flux [photon/s]



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)

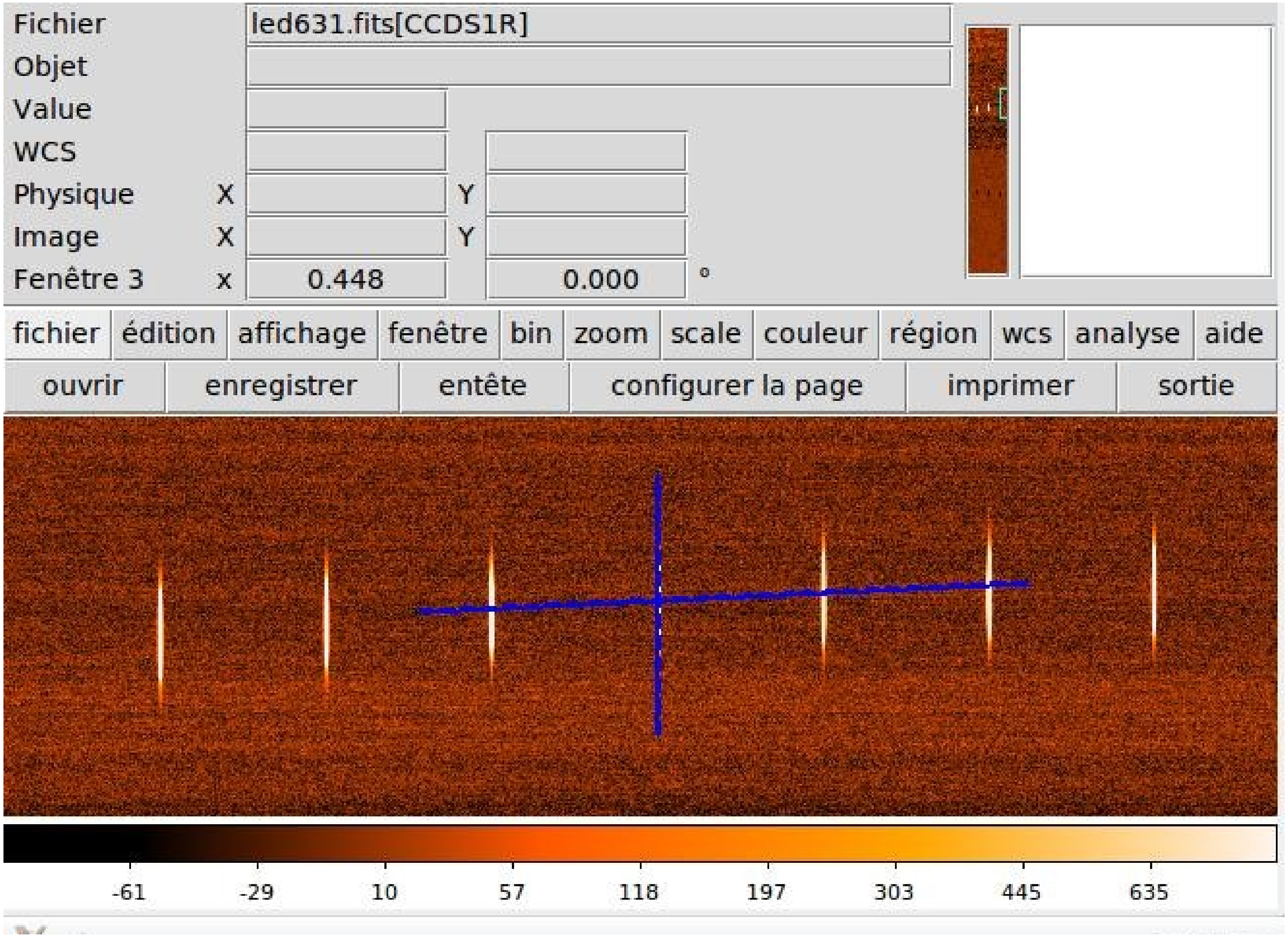
Integrated LED flux [e-/s] on the 3 CCDs

- 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**

LED spectra

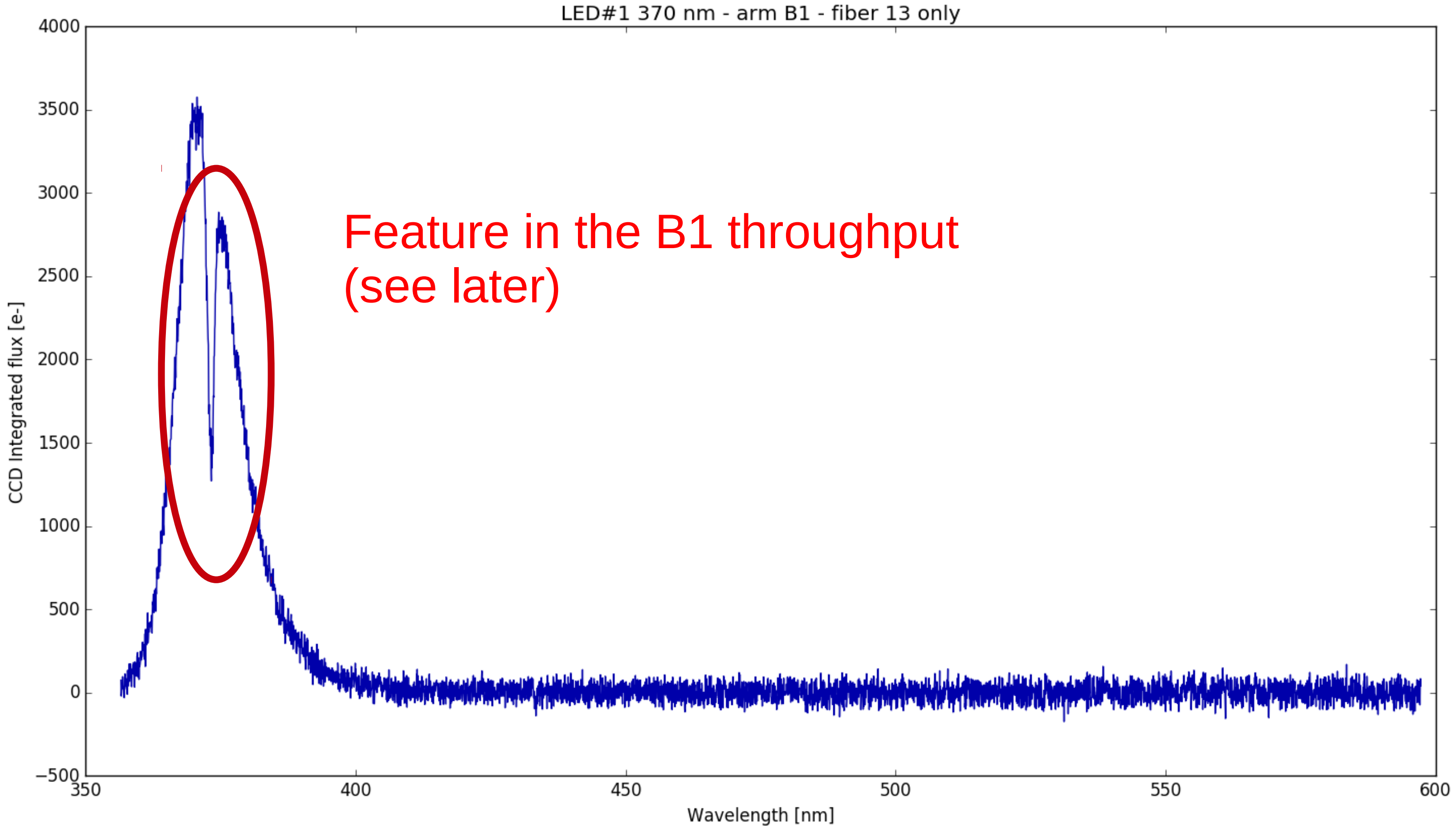

Fichier
led631.fits[CCDS1R]
Objet
Value
WCS
Physique X Y
Image X Y
Fenêtre 3 x 0.448 0.000 °
fichier édition affichage fenêtre bin zoom scale couleur région wcs analyse aide
ouvrir enregistrer entête configurer la page imprimer sortie
-61 -29 10 57 118 197 303 445 635

LED spectrum extraction (pipeline JG)

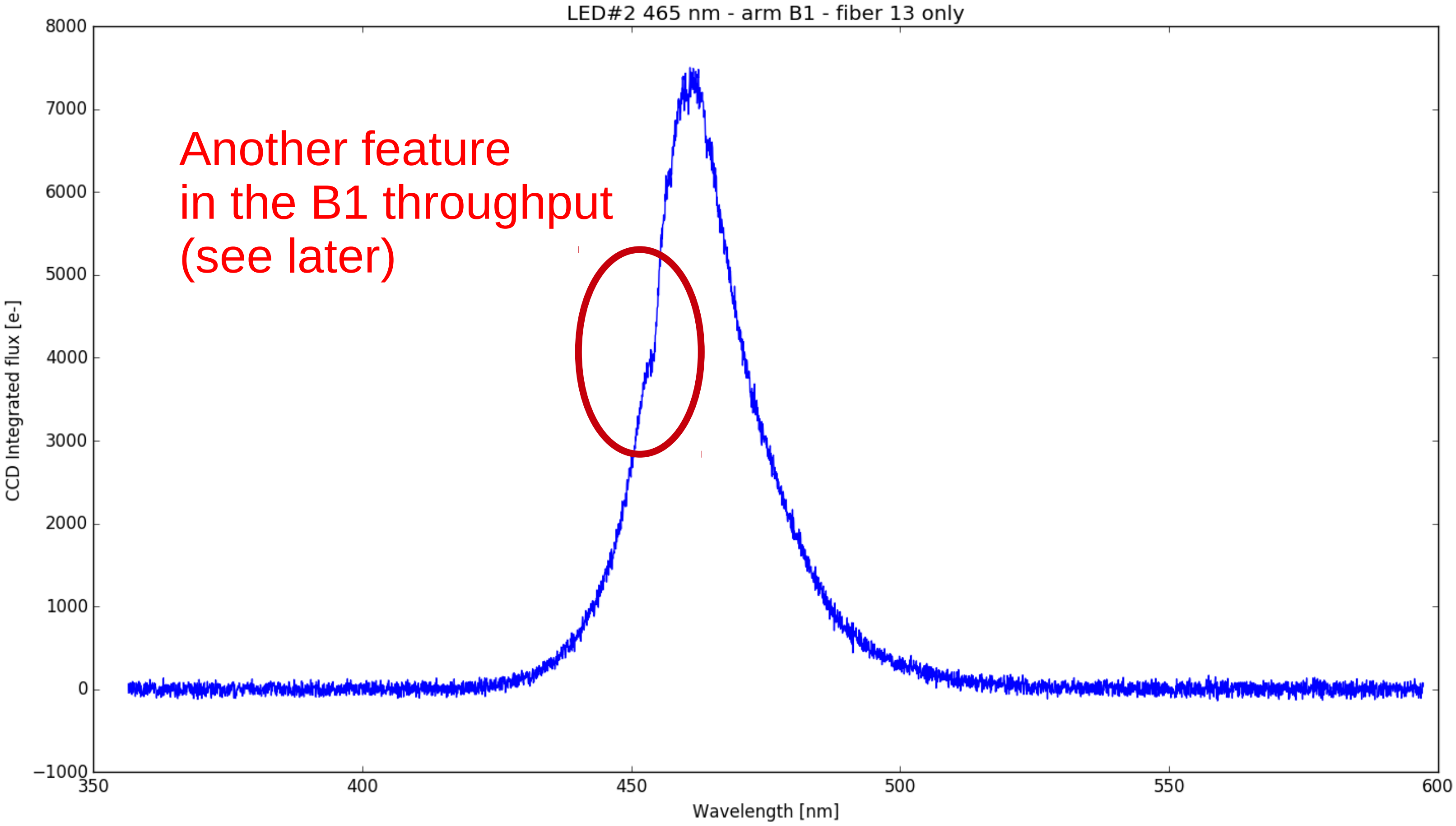
- **Removing Bias / Dark current** (dark model)
- **Automatic extraction of all fiber spectra**
- **« Boxcar » : sum on 9 CCD pixel wide**
- Wavelength calibration from lamps and PSF model
  - Wavelength calibration better than 0.1 nm

    (no temperature correction)
- We verify that the **background is consistent with zero**
- We assume gain = 1 and the **gain correction is applied later**

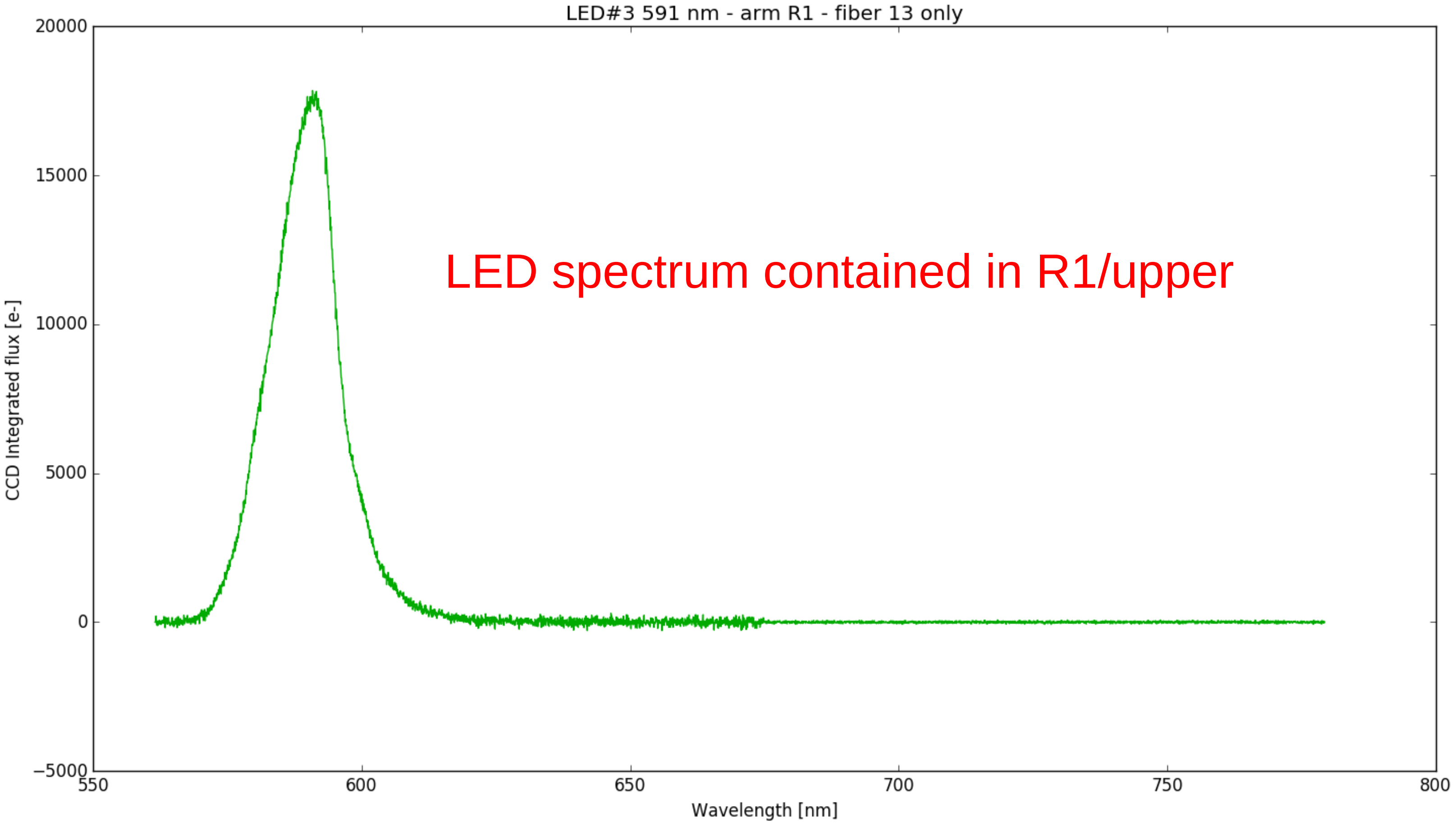
Spectrum in DESI arm B1: LED#1: 370 nm



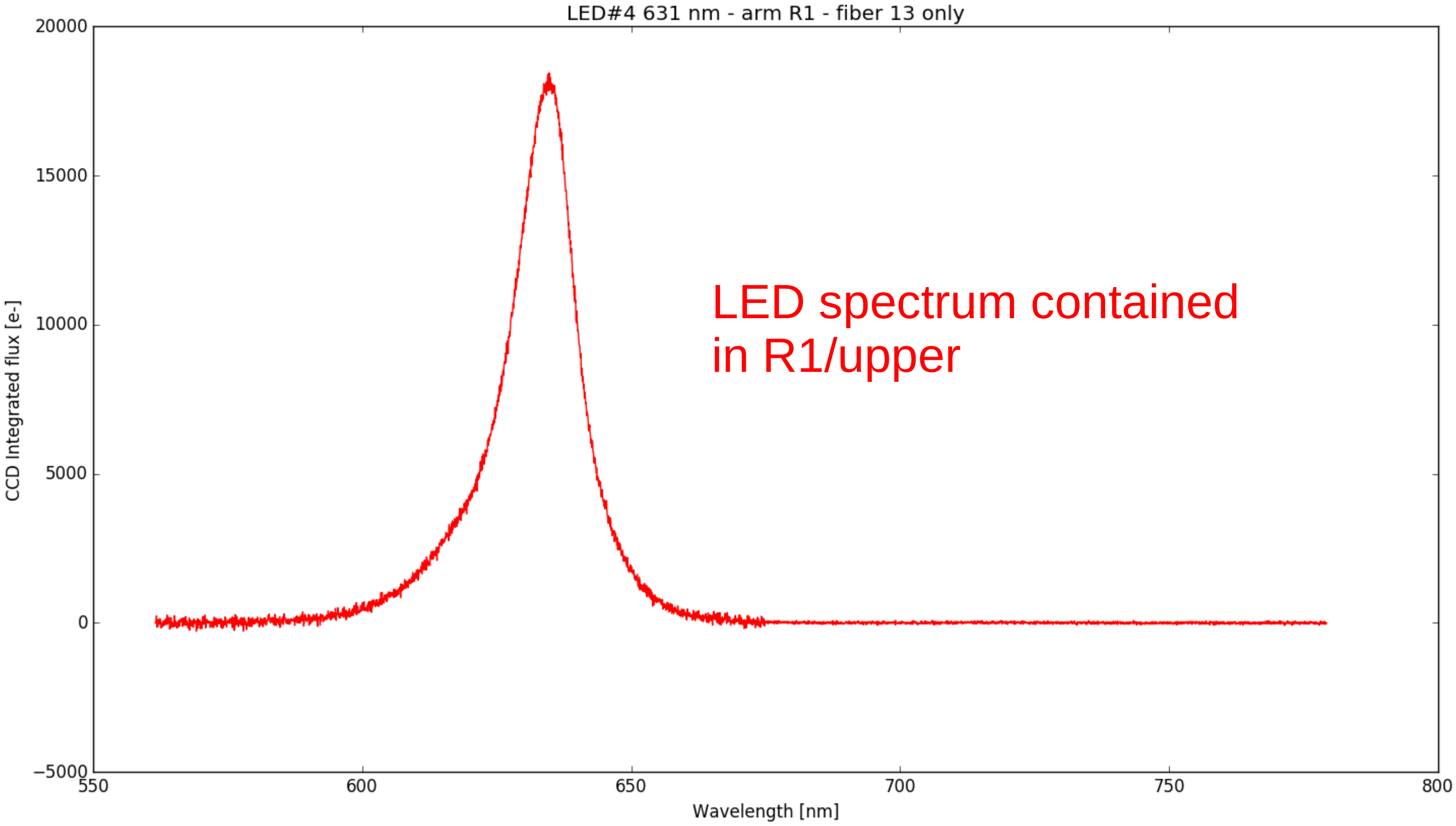
Spectrum in DESI arm B1: LED#2: 465 nm



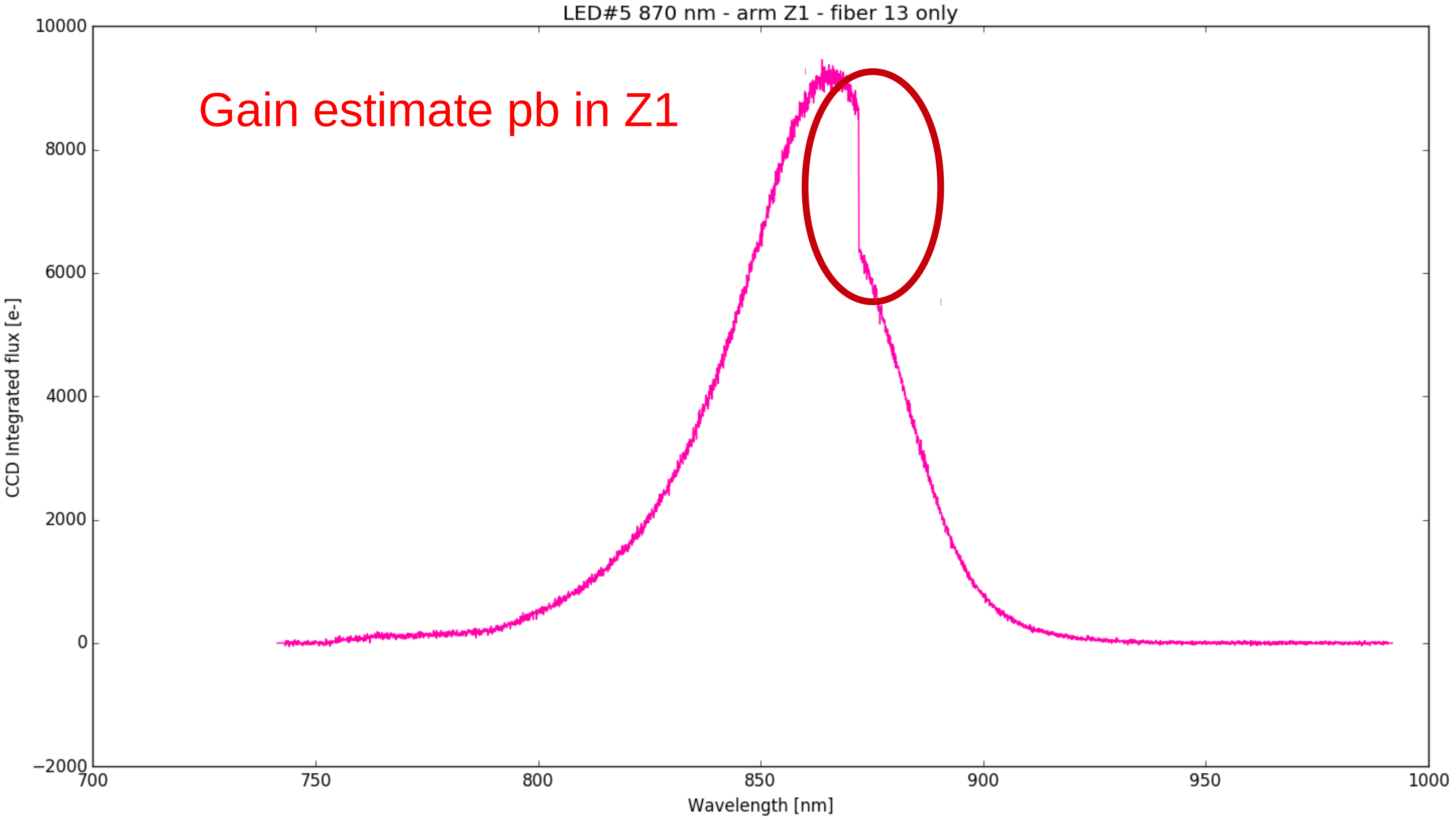
Spectrum in DESI arm R1: LED#3: 591 nm



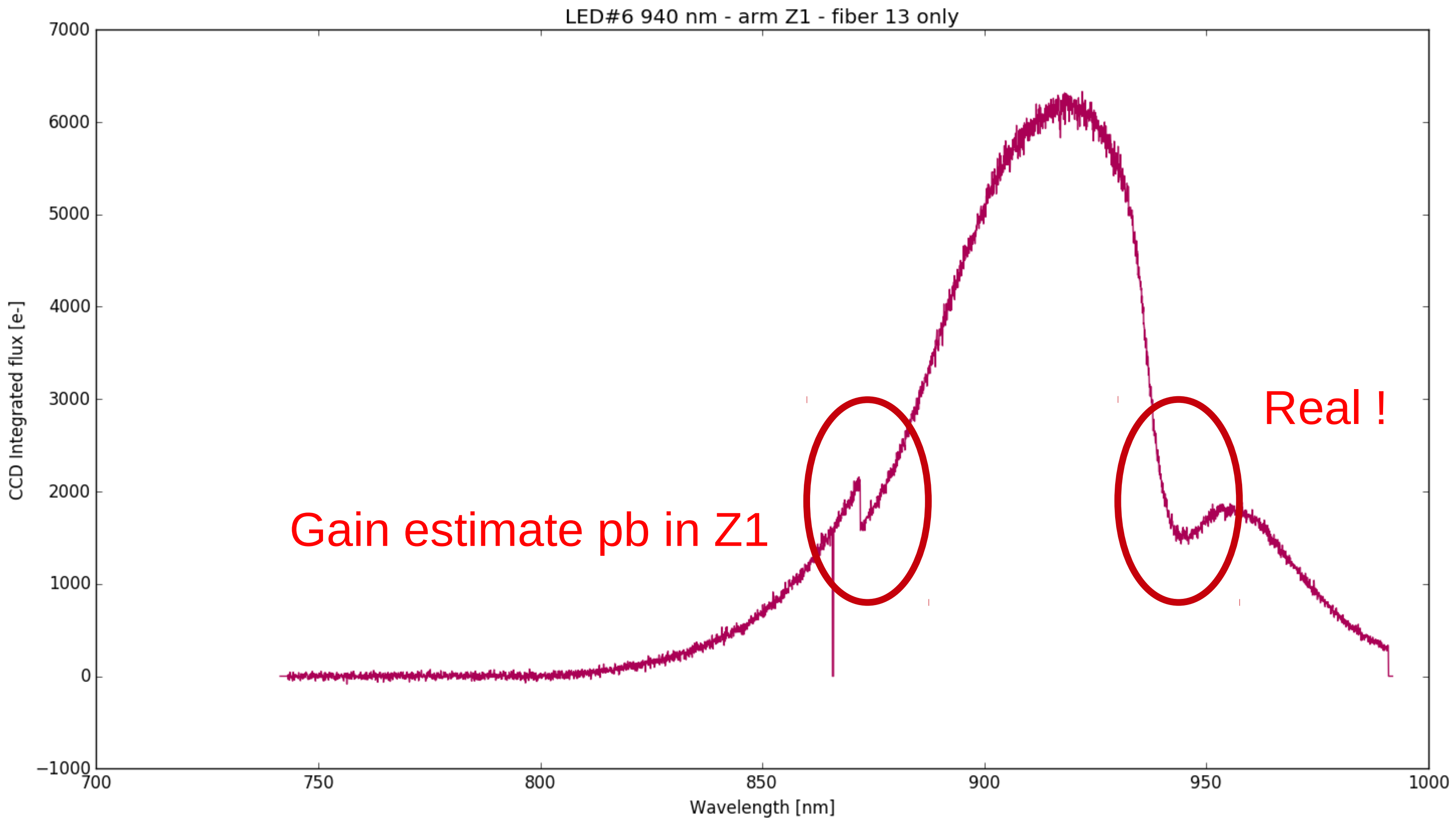
Spectrum in DESI arm R1: LED#4: 631 nm



Spectrum in DESI arm Z1: LED#5: 870 nm



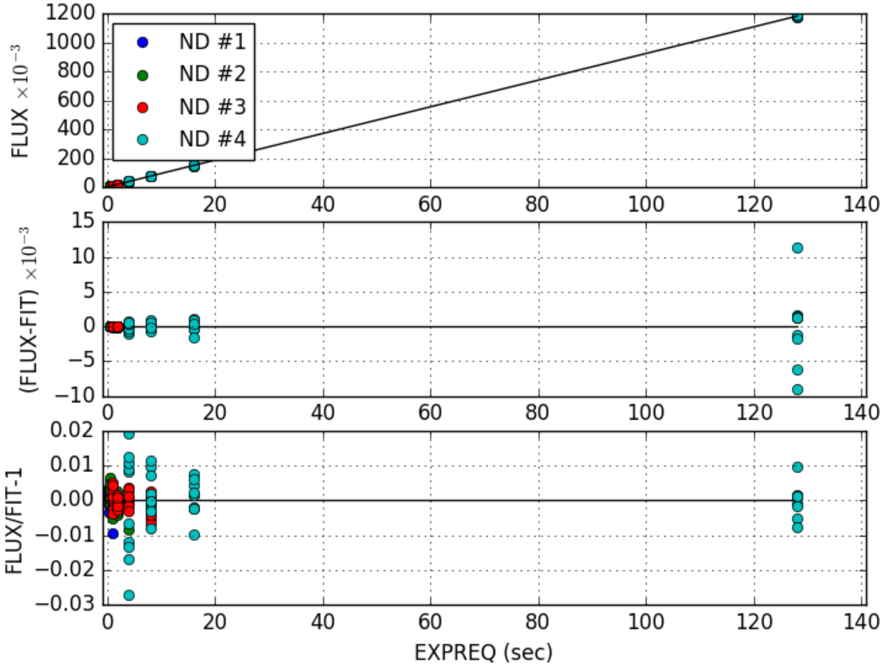
Spectrum in DESI arm Z1: LED#6: 940 nm



Exposure time : shutter time correction

- Series of exposures with **increasing exposure time** and **different neutral densities** filters have been taken (first and second campaigns).

- Non-linearity corrections were needed.



- Assuming at least linearity for low fluxes, we were able to estimate an effective exposure time correction (**same result on the 3 arms**) :

$$\Delta t_{\text{effective}} = [\text{EXPREQ}] + 0.36\,\text{s} \pm 0.01\,\text{s}$$

- **Q : What is EXPTIME** (in FITS headers) **?**

Amplifier gain determination (DESI-2657, JG)

- We measured the amplifier gains **with a PTC (Pixel Transfer Curve)** (variance versus mean flux curve)

- Amplifier gains were estimated in two ways :

  - **Tungsten lamp spectra** (DESI-2657),
    → ramp of exposure time, exposure pairs

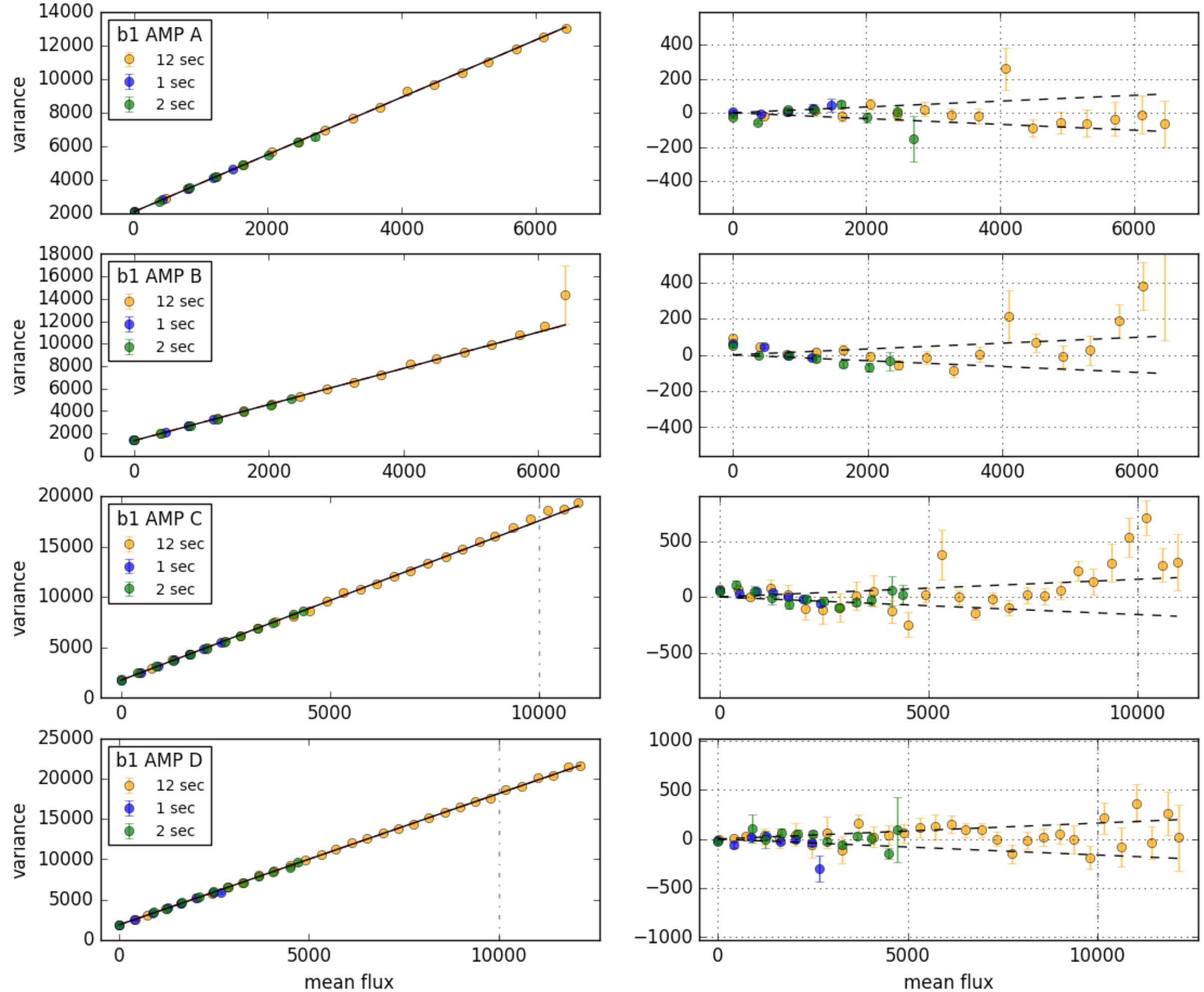
  - **Flat with flat slit**, **tungsten**, (2017-03-29),
    → ramp of exposure time, exposure pairs

Amplifier gain determination : PTC (arm B)

- **Building PTC** (photon transfer curve) **for each CCD amplifier**
- **b amplifiers** are reasonably **linear**
- **Using tungsten spectra**

Amplifier	gain
B1-A	0.587
B1-B	0.614
B1-C	0.630
B1-D	0.615

- **See DESI-2657 (JG)**

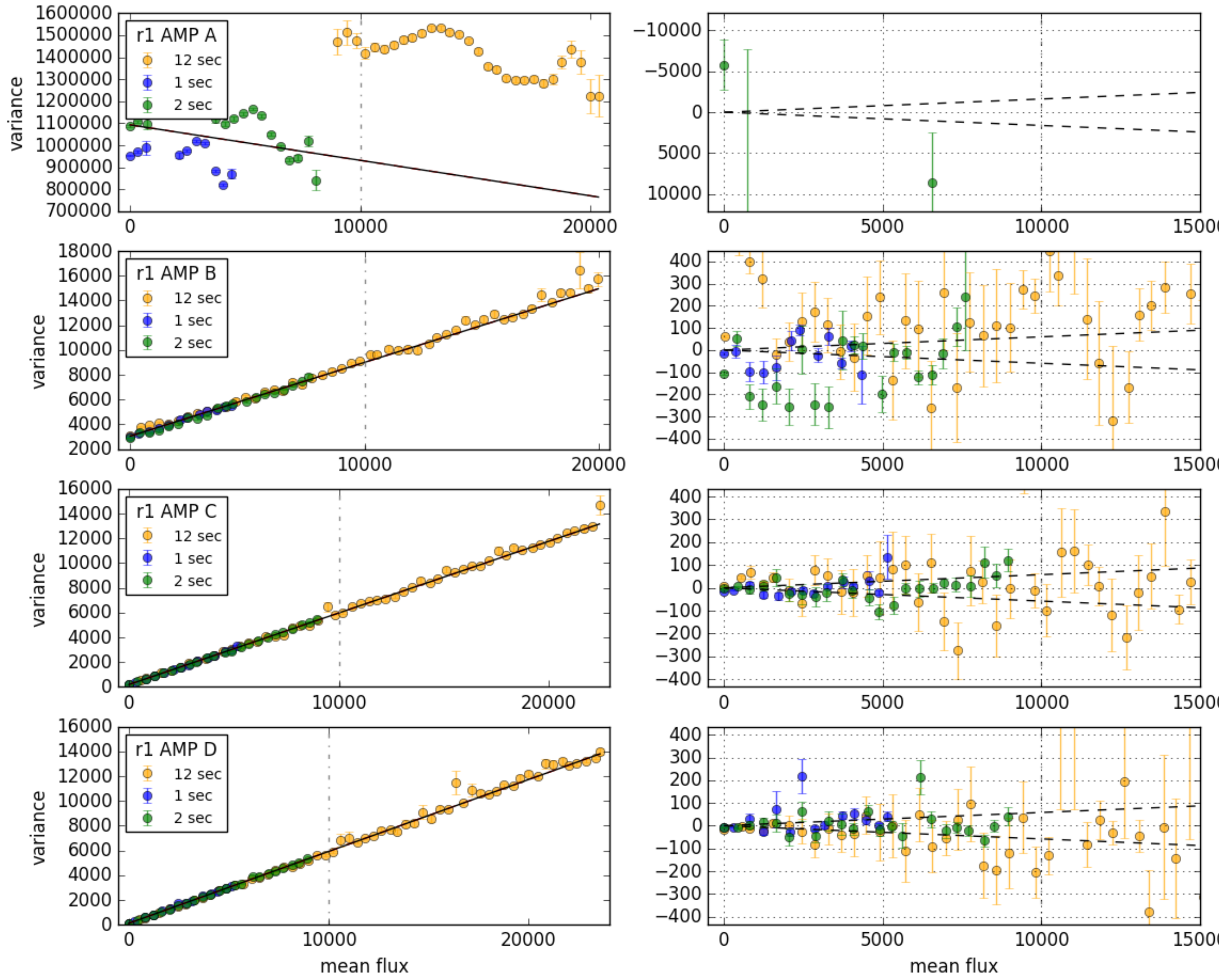


Amplifier gain determination : PTC (arm R)

- Amplifier r1-A **unusable**
- **Other r amplifiers** are reasonably **linear**
- **Using tungsten spectra**

Amplifier	gain
R1-A	unusable
R1-B	1.658
R1-C	1.726
R1-D	1.723

- **See DESI-2657 (JG)**

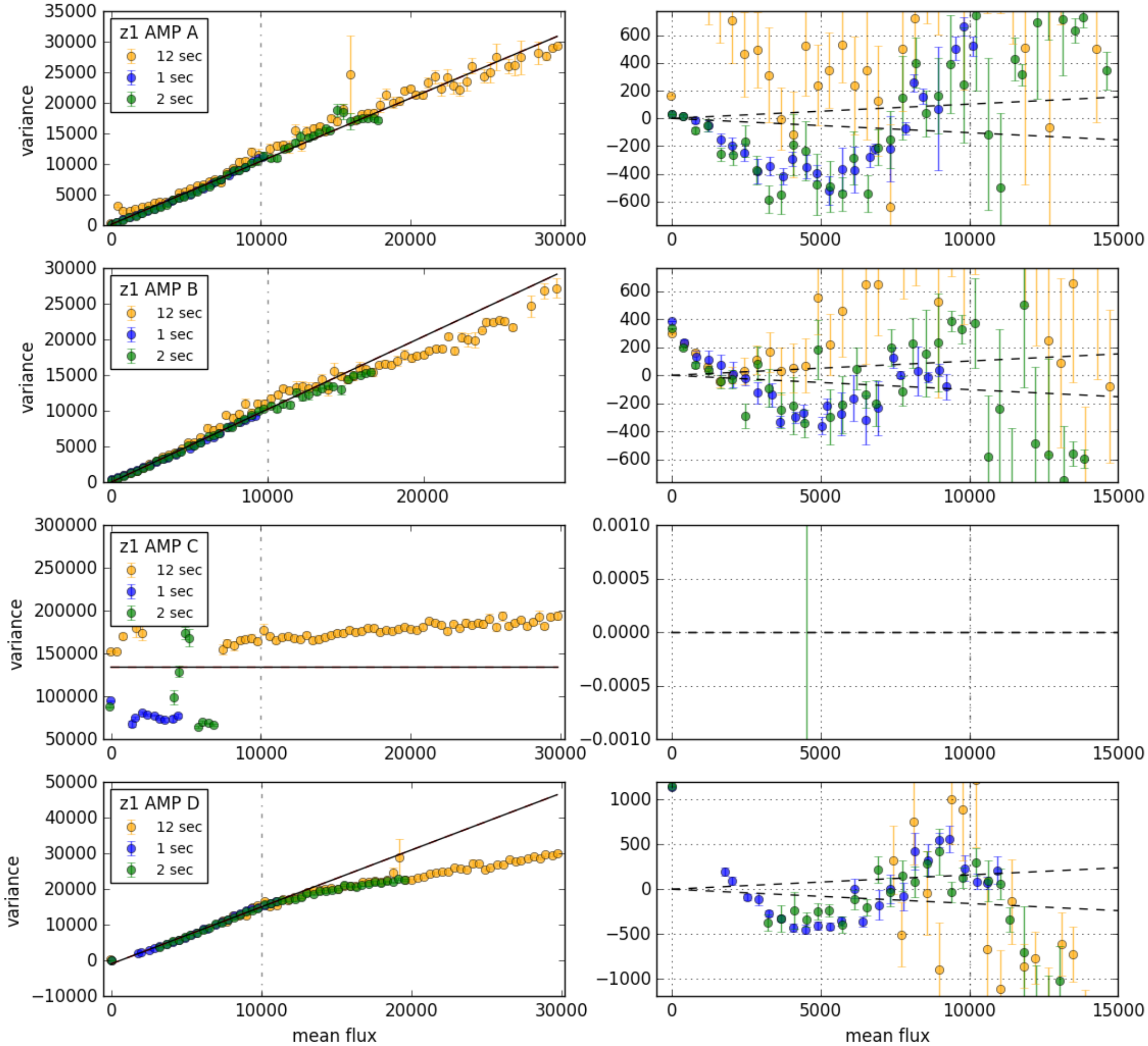


Amplifier gain determination : PTC (arm Z)

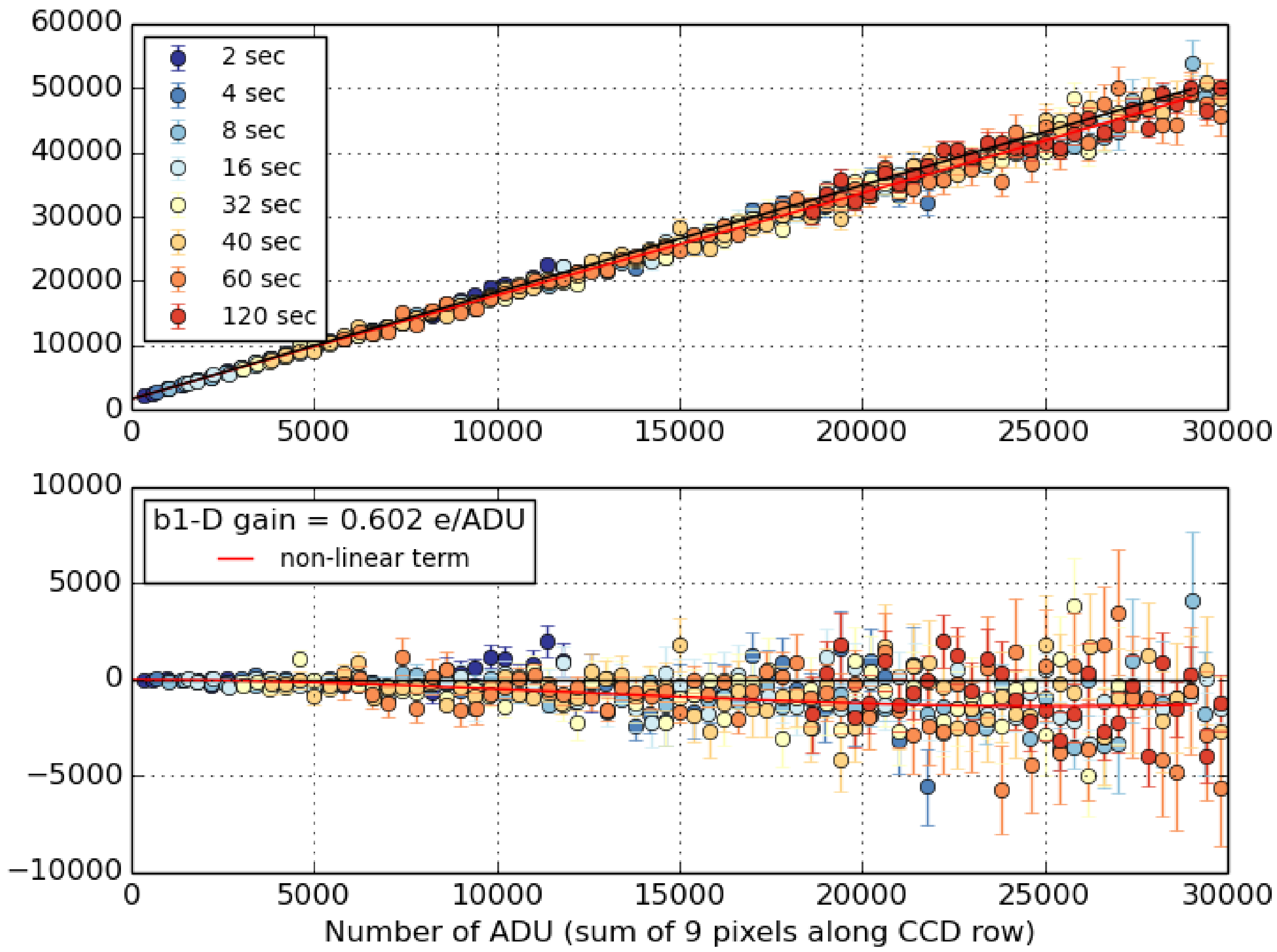
- Highly **non-linear** amplis
- Z1-C **unusable**
- **Using tungsten spectra**

Amplifier	Gain (< 5000)
Z1-A	1.072
Z1-B	1.135
Z1-C	Unusable
Z1-D	0.774

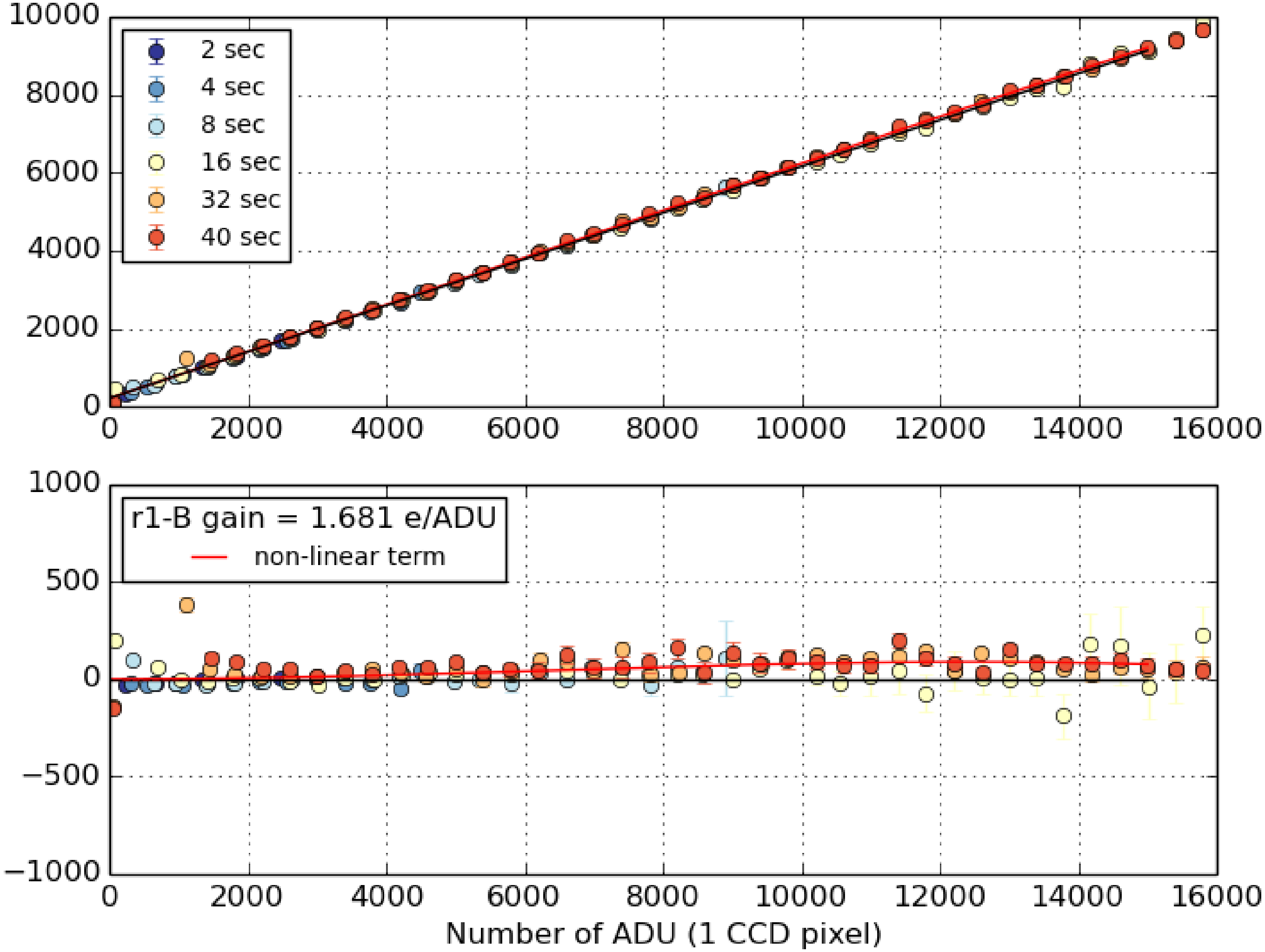
- **See DESI-2657 (JG)**



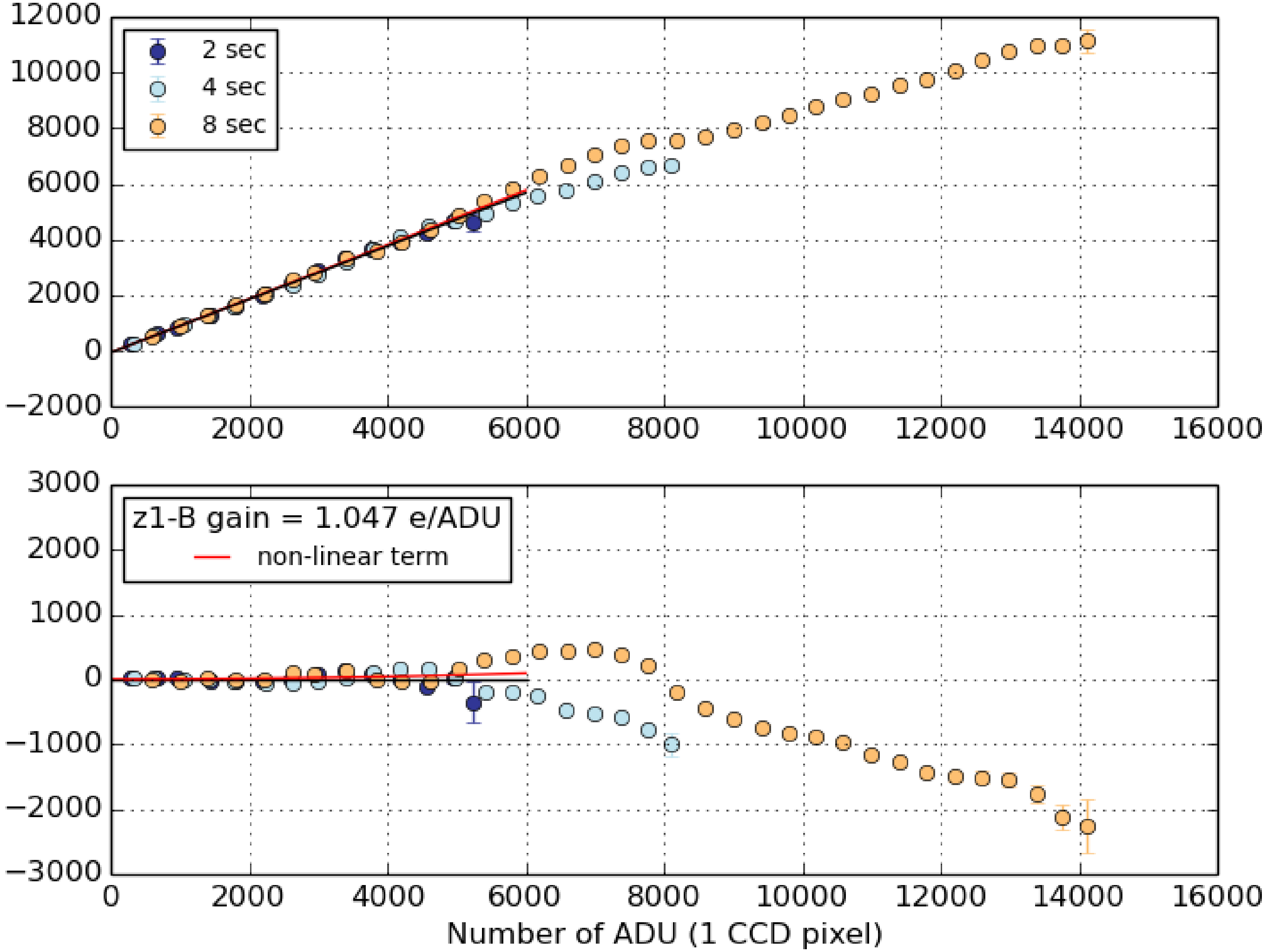
Amplifier gain (flat slit, tungsten): b1-D



Amplifier gain (flat slit, tungsten): r1-B



Amplifier gain (flat slit, tungsten): z1-B



Amplifier gain determination (flat slit, tungsten)

- Gains obtained with a PTC with **flat slit exposure, tungsten lamp** :

Amplifier	gain
B1-A	0.546
B1-B	0.619
B1-C	0.624
B1-D	0.602

Amplifier	gain
R1-A	unusable
R1-B	1.681
R1-C	1.666
R1-D	1.677

Amplifier	Gain (< 5000)
Z1-A	–
Z1-B	1.047
Z1-C	???
Z1-D	0.687

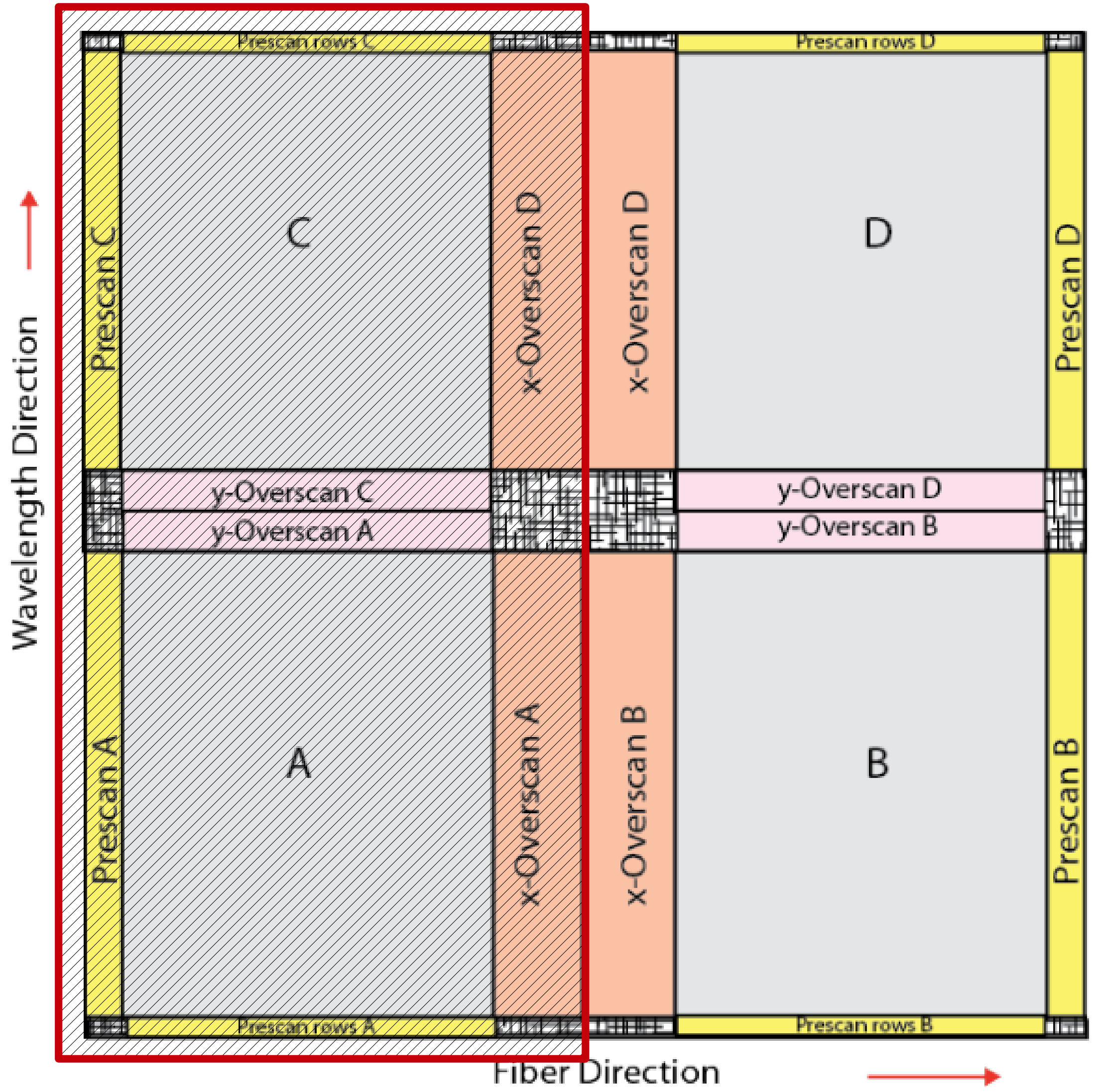
- For this analysis, we used the gains **obtained from the flat slit exposures** (seem more reliable)

- **For b1 & r1, gain systematics around 3 %**

- **For z1, huge uncertainties due to the important non-linearity**

Measurement strategy: using fibers 11 – 20

- r1-A **unusable**
- z1-C **unusable**
- **We choose to take LED spectra only with amplifiers B and D → fibers 11 to 20**
- **Limiting the flux in all spectra (< 5000 ADU in all pixels) to avoid amplifiers non-linearity**



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)** :

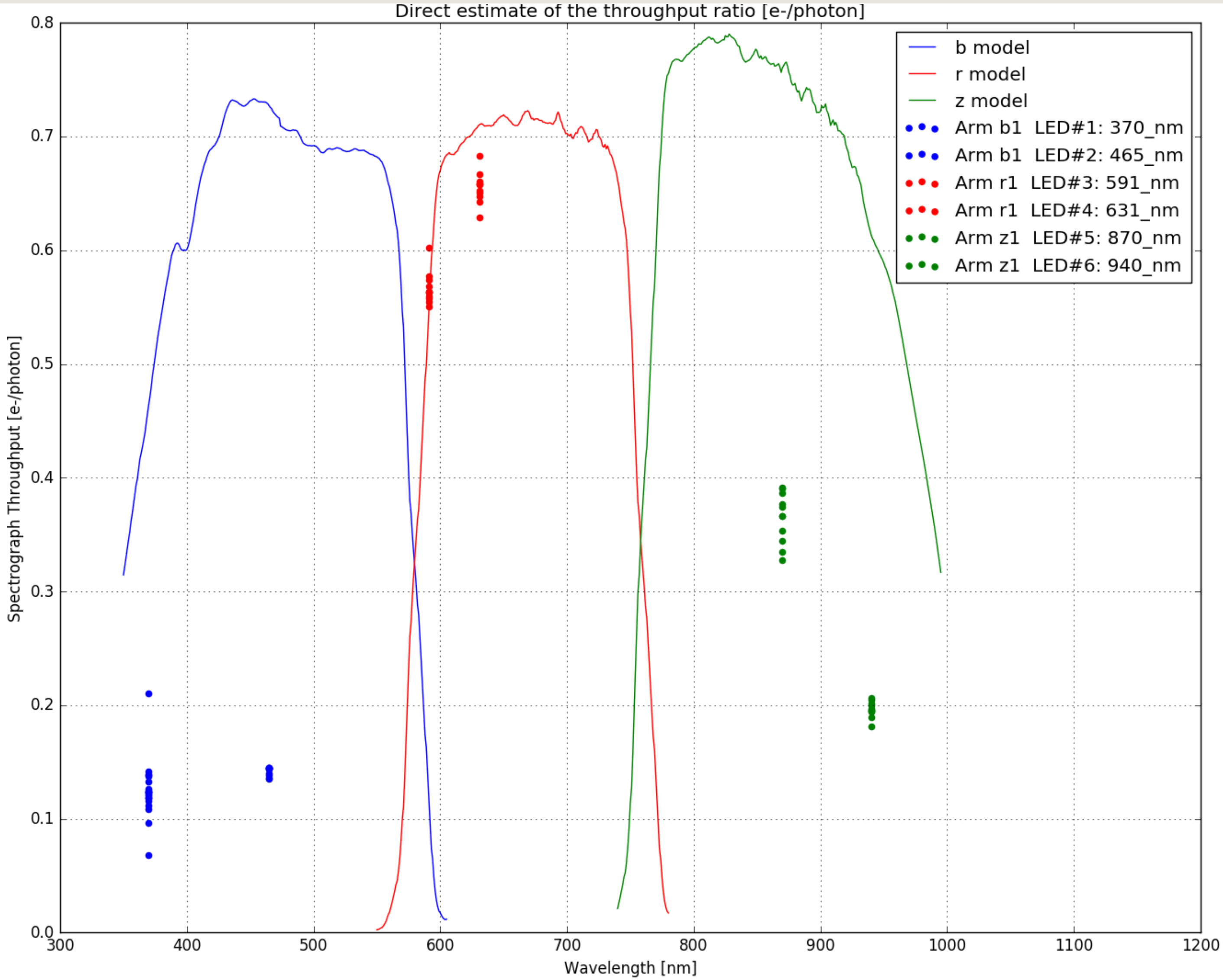
$$\eta_{[\text{e-}/\gamma]}(\lambda_{\text{LED}}) = (QE_{\text{CCD}} \times T_{\text{optics}}(\lambda_{\text{LED}})) = \frac{\phi^{\text{CCD}}_{[\text{e-}/\text{s}]}(\text{LED})}{\phi^{\text{injected}}_{[\gamma/\text{s}]}(\text{LED})}$$

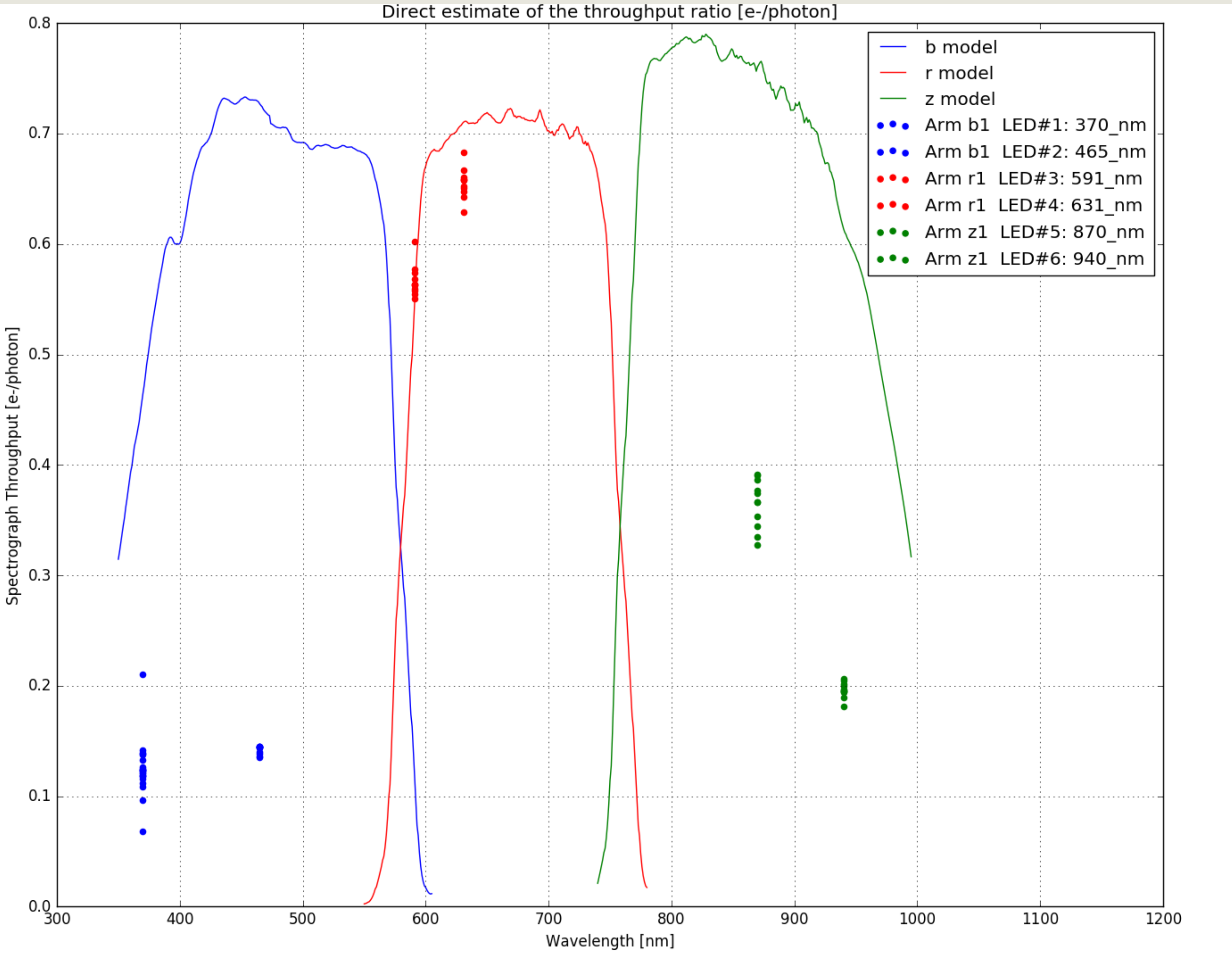
- For the moment, no FRD correction (see below).

- What we got that way is an **estimate of the spectrograph throughput** at the LED wavelength (weighted by the LED spectrum)

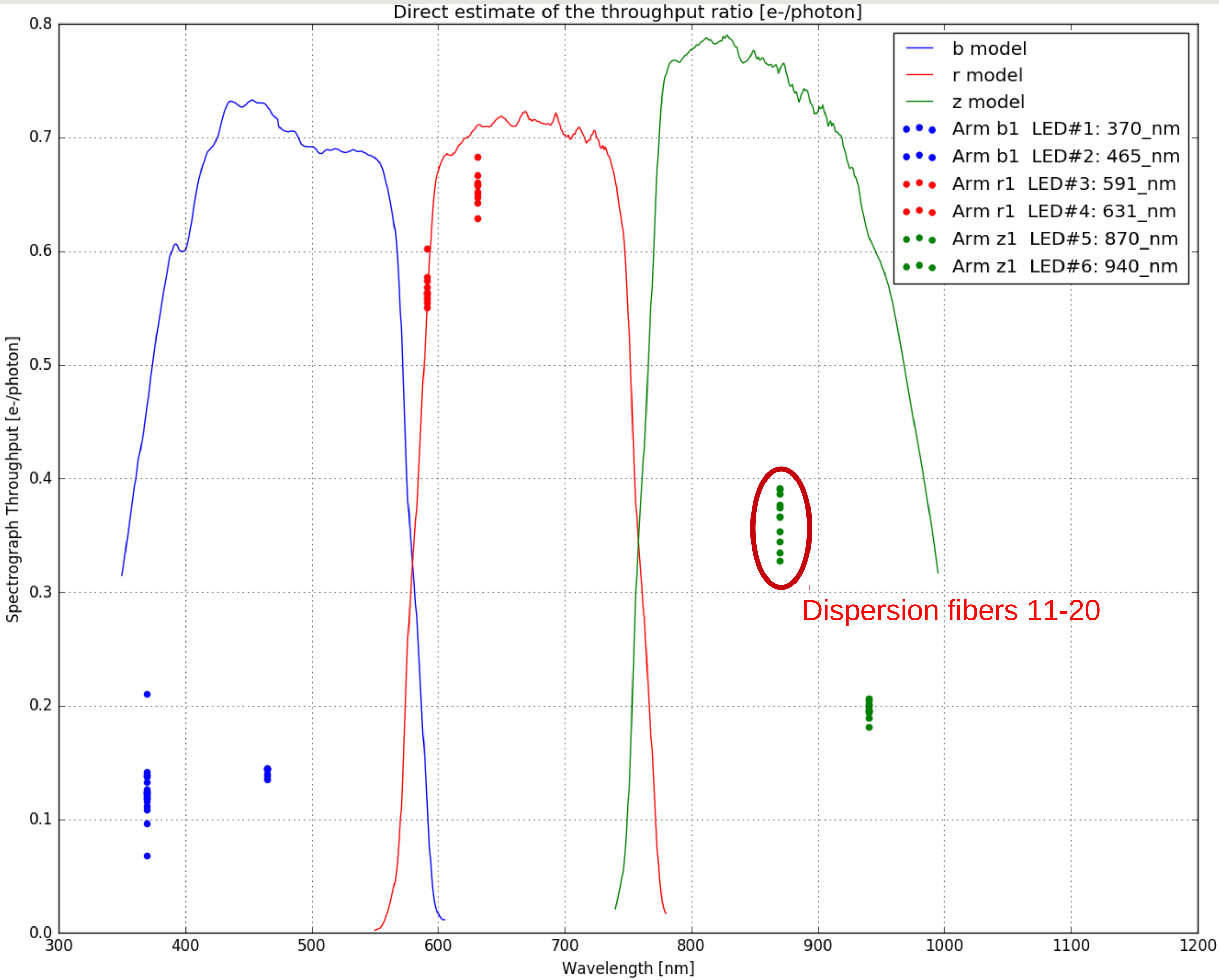
- Comparison with the **DESI optical model** (**without fibers**)

Direct throughput estimate (without a model)



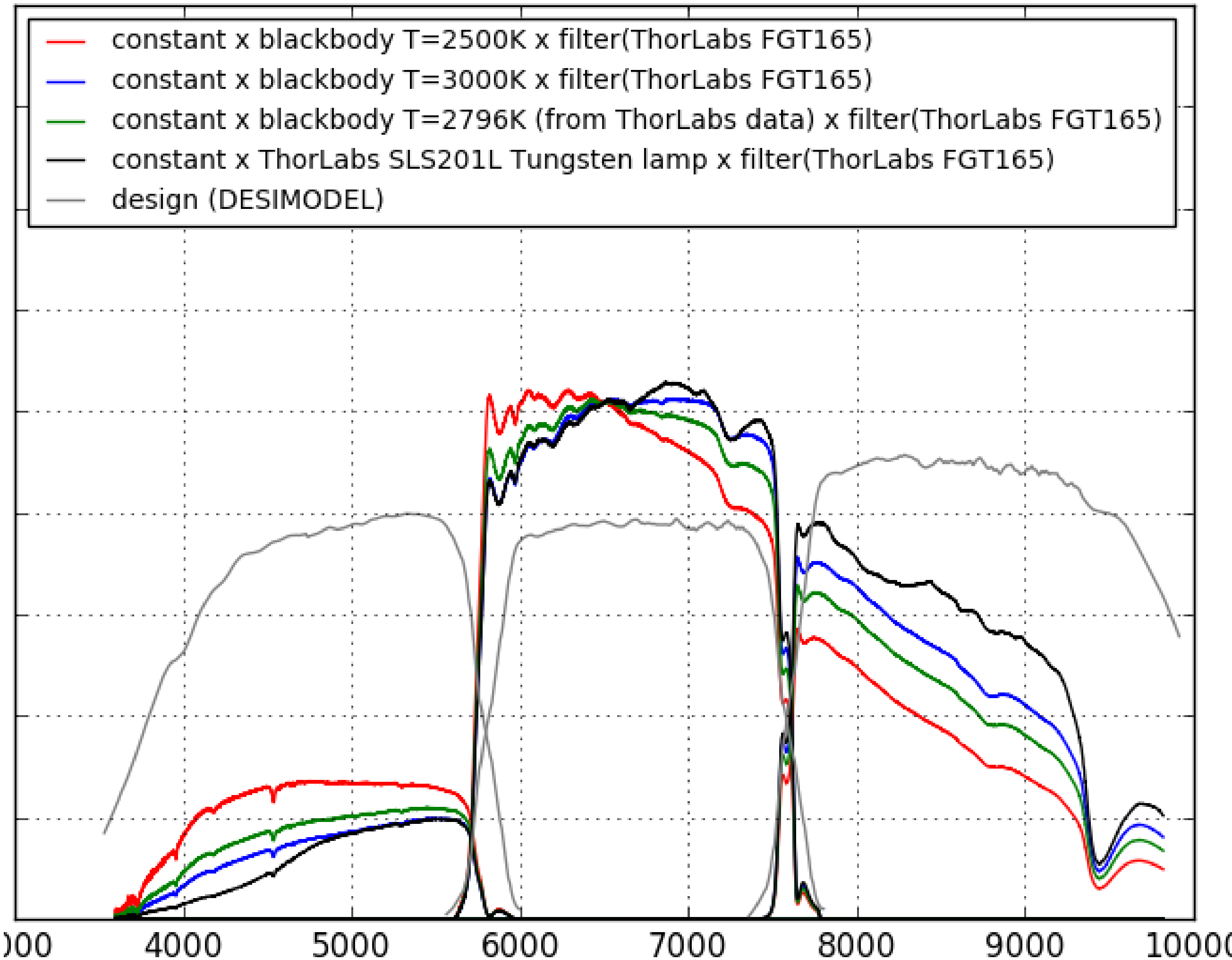


Direct estimate of the throughput ratio [e-/photon]
Spectrograph Throughput [e-/photon]
Wavelength [nm]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
300
400
500
600
700
800
900
1000
1100
1200
b model
r model
z model
Arm b1 LED#1: 370_nm
Arm b1 LED#2: 465_nm
Arm r1 LED#3: 591_nm
Arm r1 LED#4: 631_nm
Arm z1 LED#5: 870_nm
Arm z1 LED#6: 940_nm

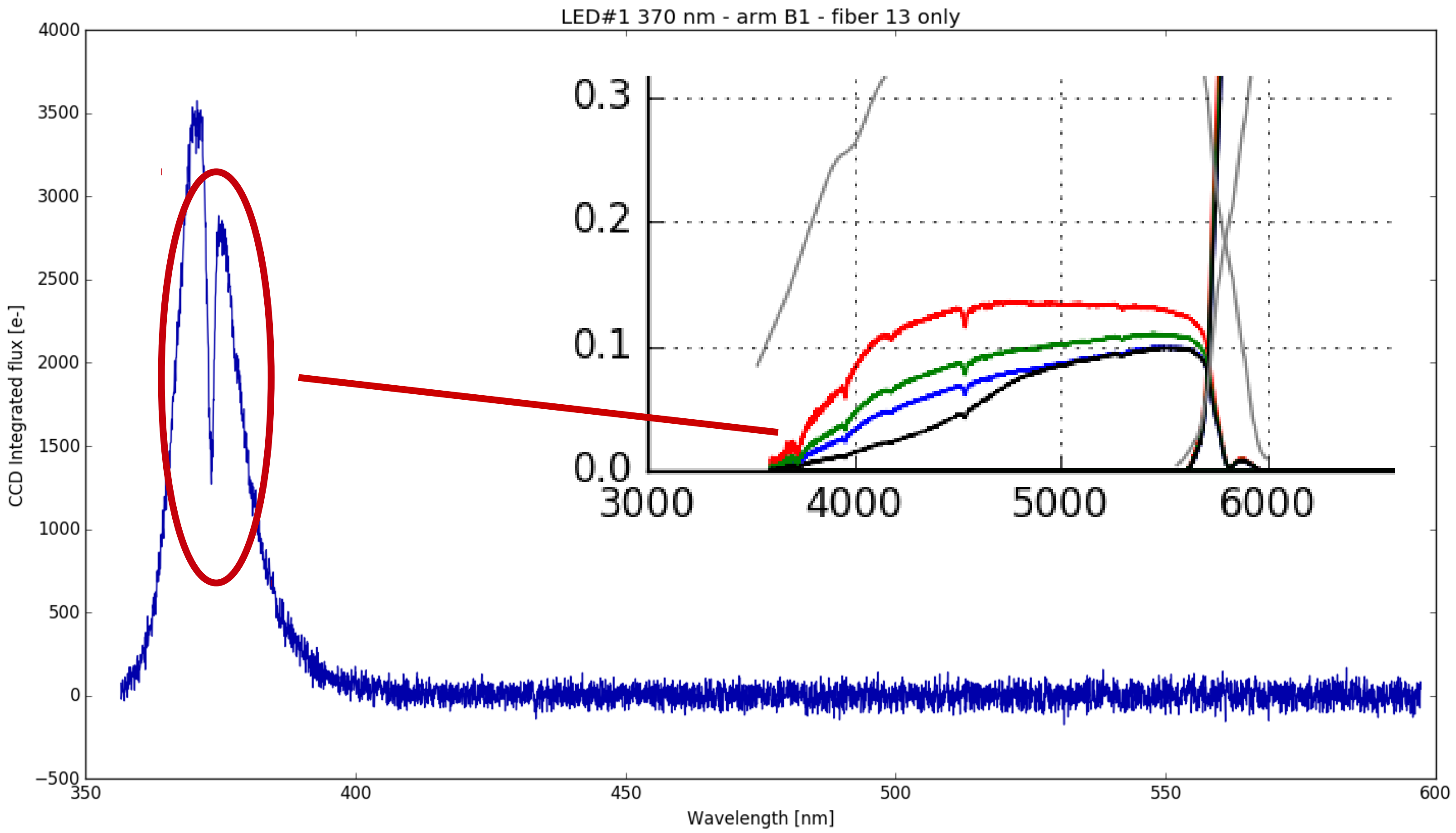

Direct estimate of the throughput ratio [e-/photon]
Spectrograph Throughput [e-/photon]
Wavelength [nm]
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
300
400
500
600
700
800
900
1000
1100
1200
b model
r model
z model
Arm b1 LED#1: 370_nm
Arm b1 LED#2: 465_nm
Arm r1 LED#3: 591_nm
Arm r1 LED#4: 631_nm
Arm z1 LED#5: 870_nm
Arm z1 LED#6: 940_nm
Dispersion fibers 11-20

Throughput shape from Tungsten lamp exposures

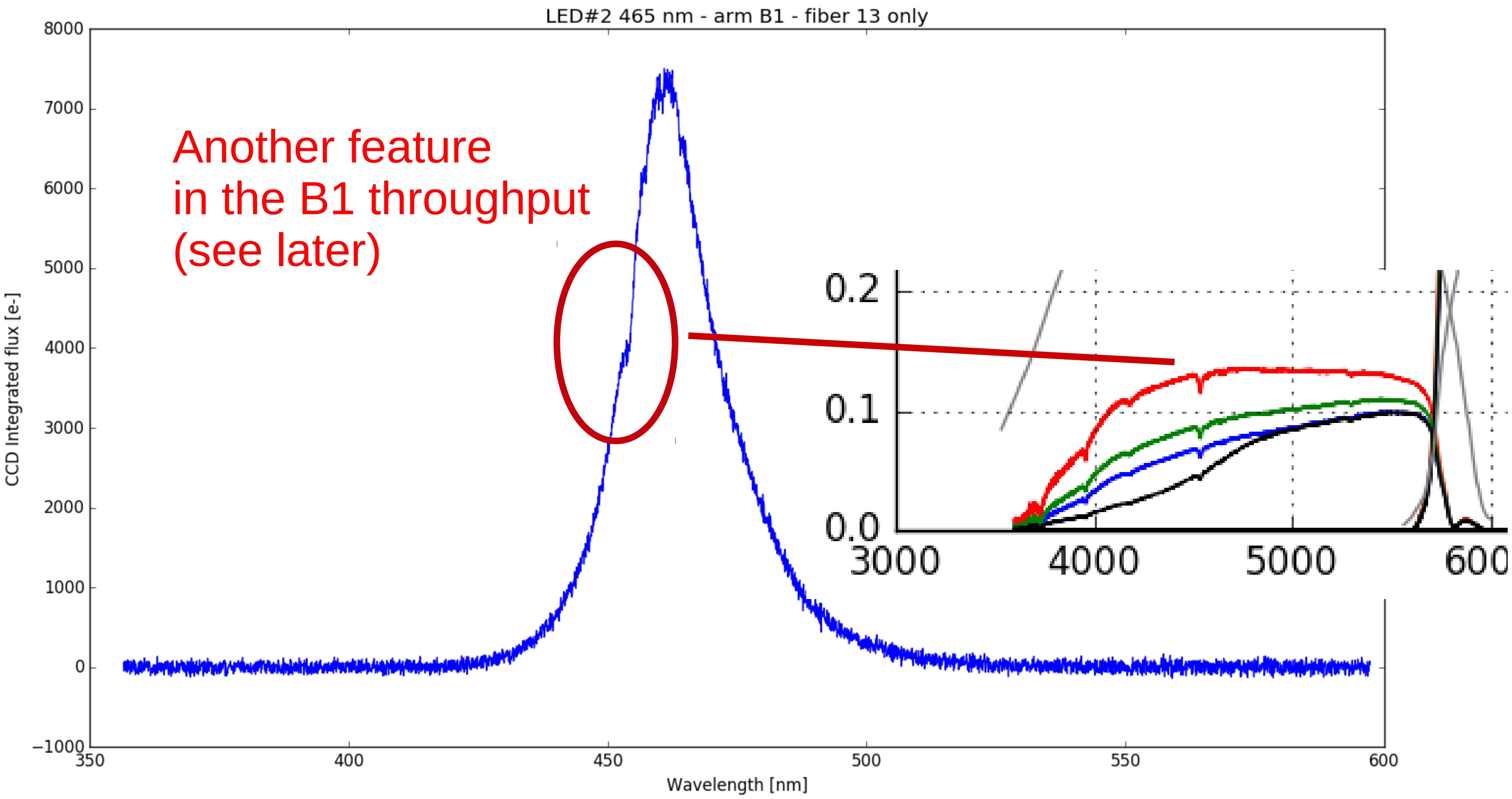
- **Derived from Tungsten lamp exposures**
- **Hypotheses on Tungsten spectrum** (blackbody, Thorlabs specs)
- **Normalisation to be determined ! Gives the shape of the throughput function**
- **« Absorption » features : some are real** and also seen in **LED spectra** (see below)



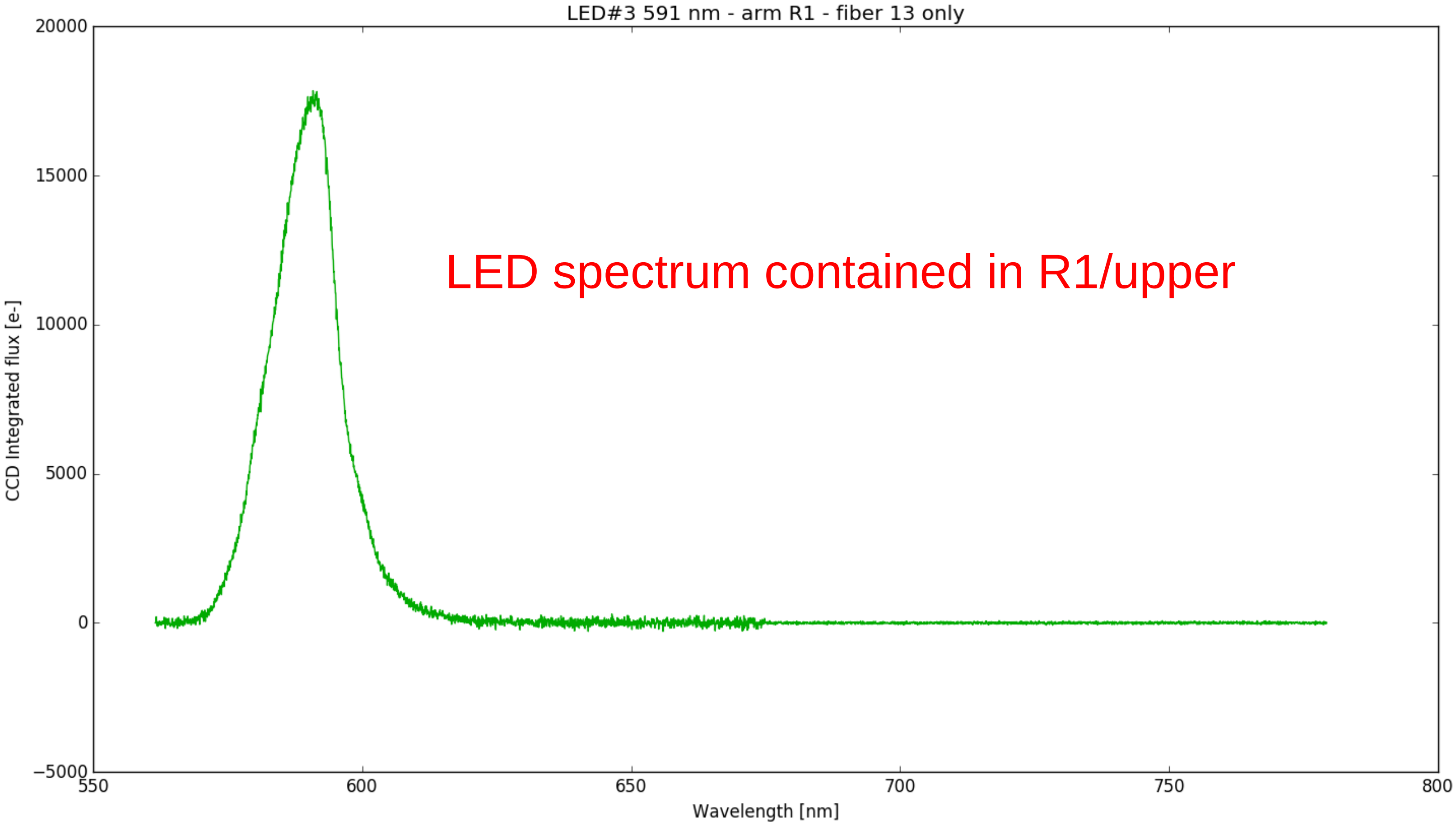
Spectrum in DESI arm B1: LED#1: 370 nm



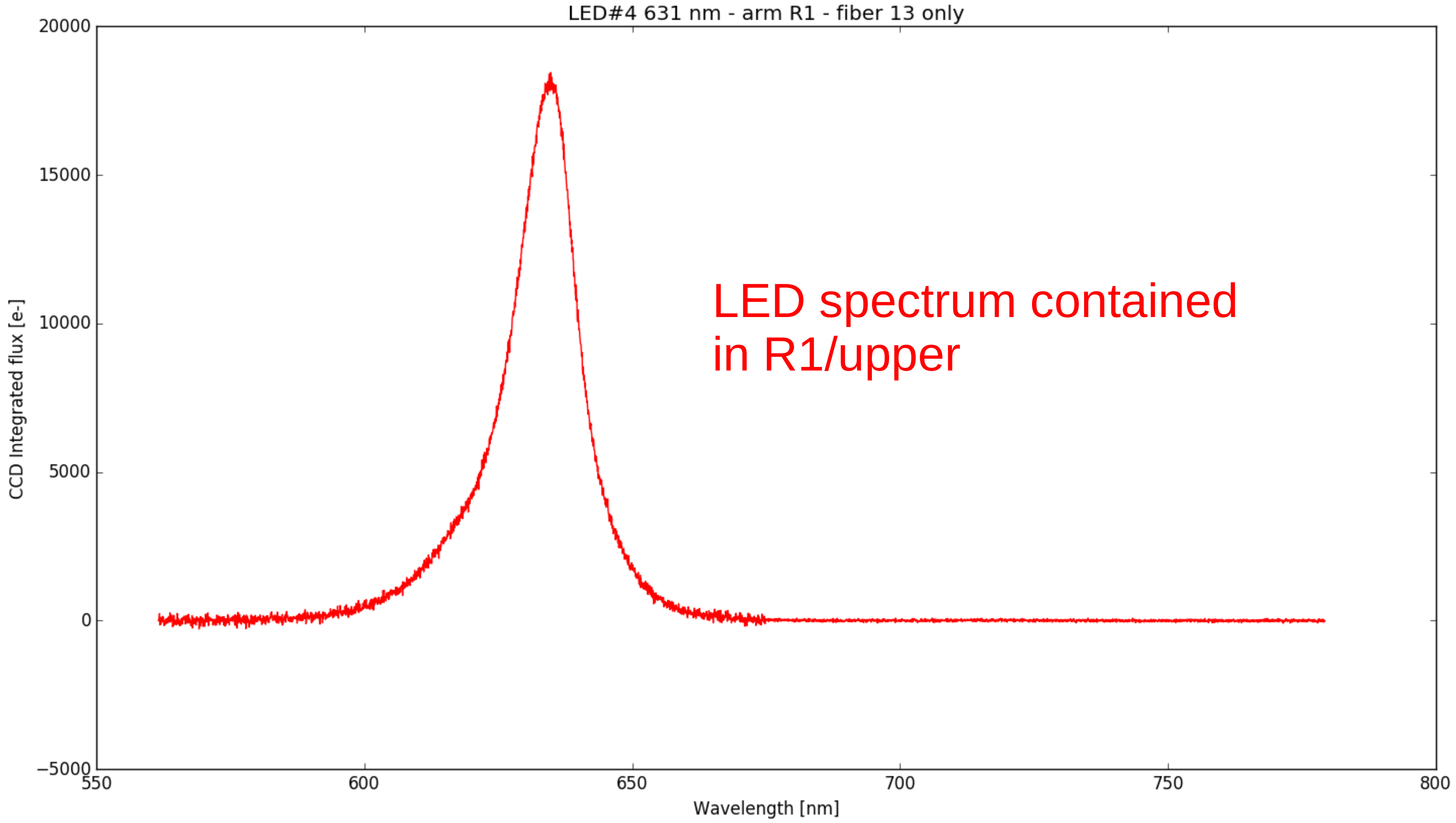
Spectrum in DESI arm B1: LED#2: 465 nm



Spectrum in DESI arm R1: LED#3: 591 nm

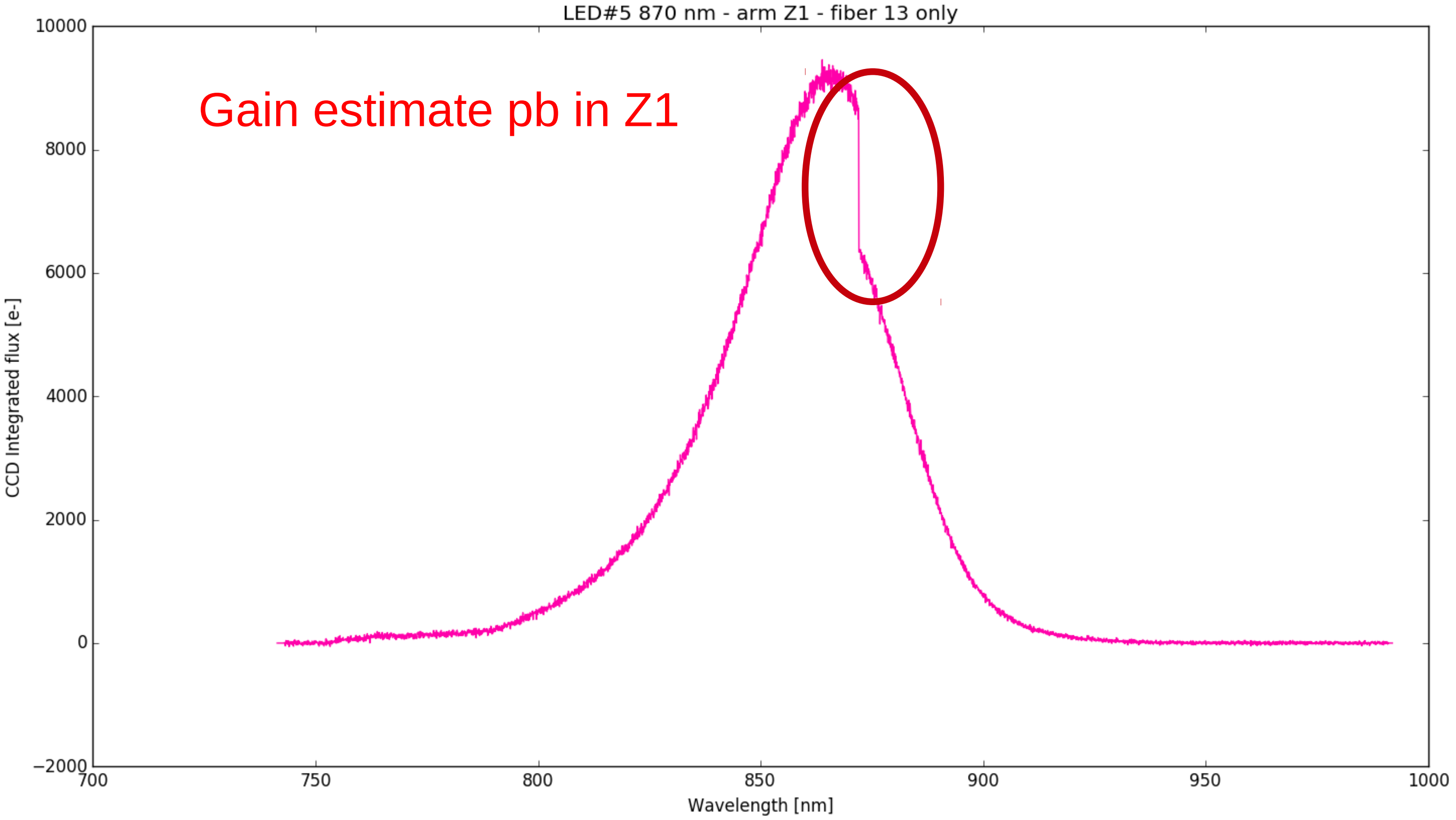


Spectrum in DESI arm R1: LED#4: 631 nm

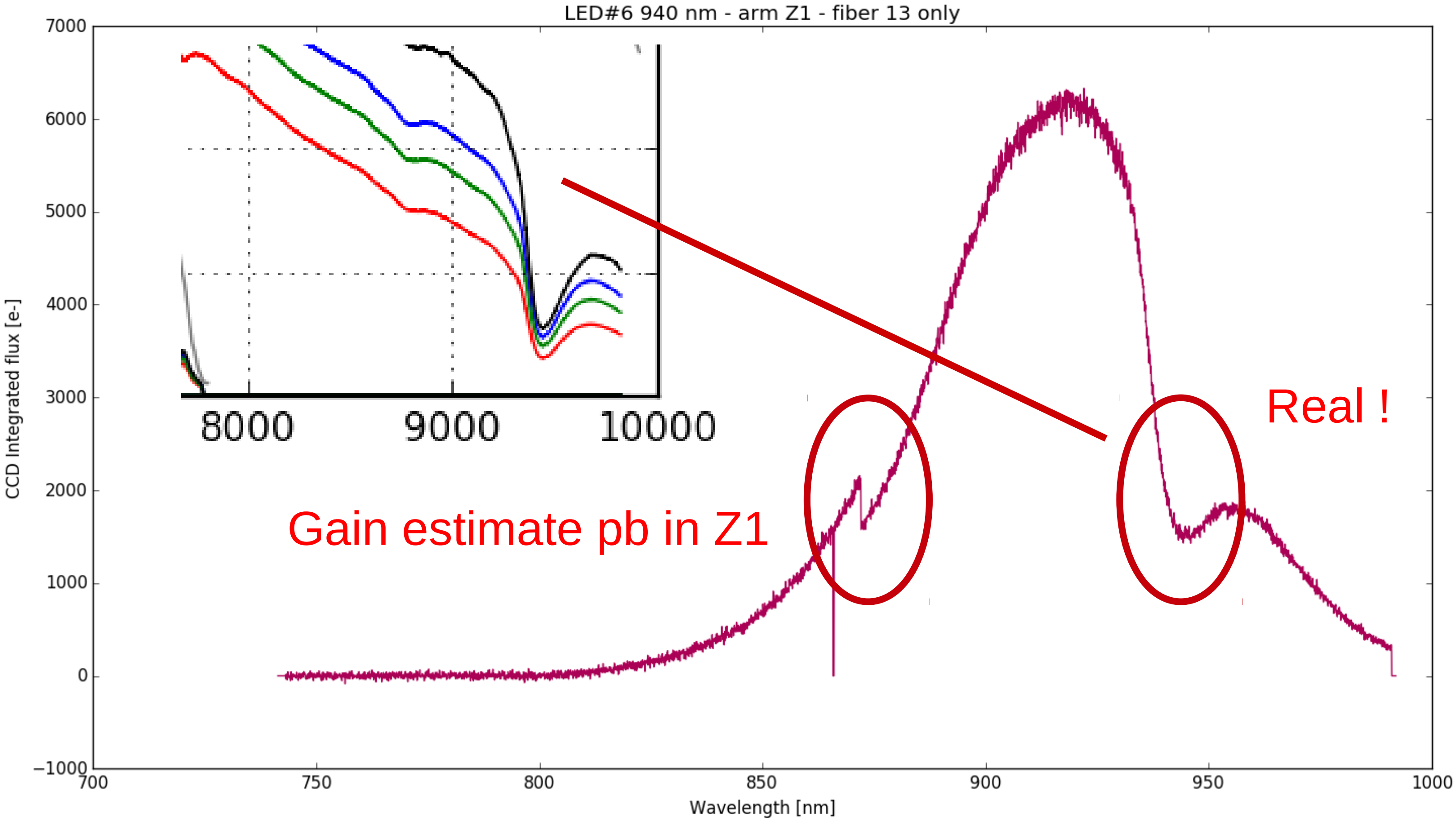


LED spectrum contained in R1/upper

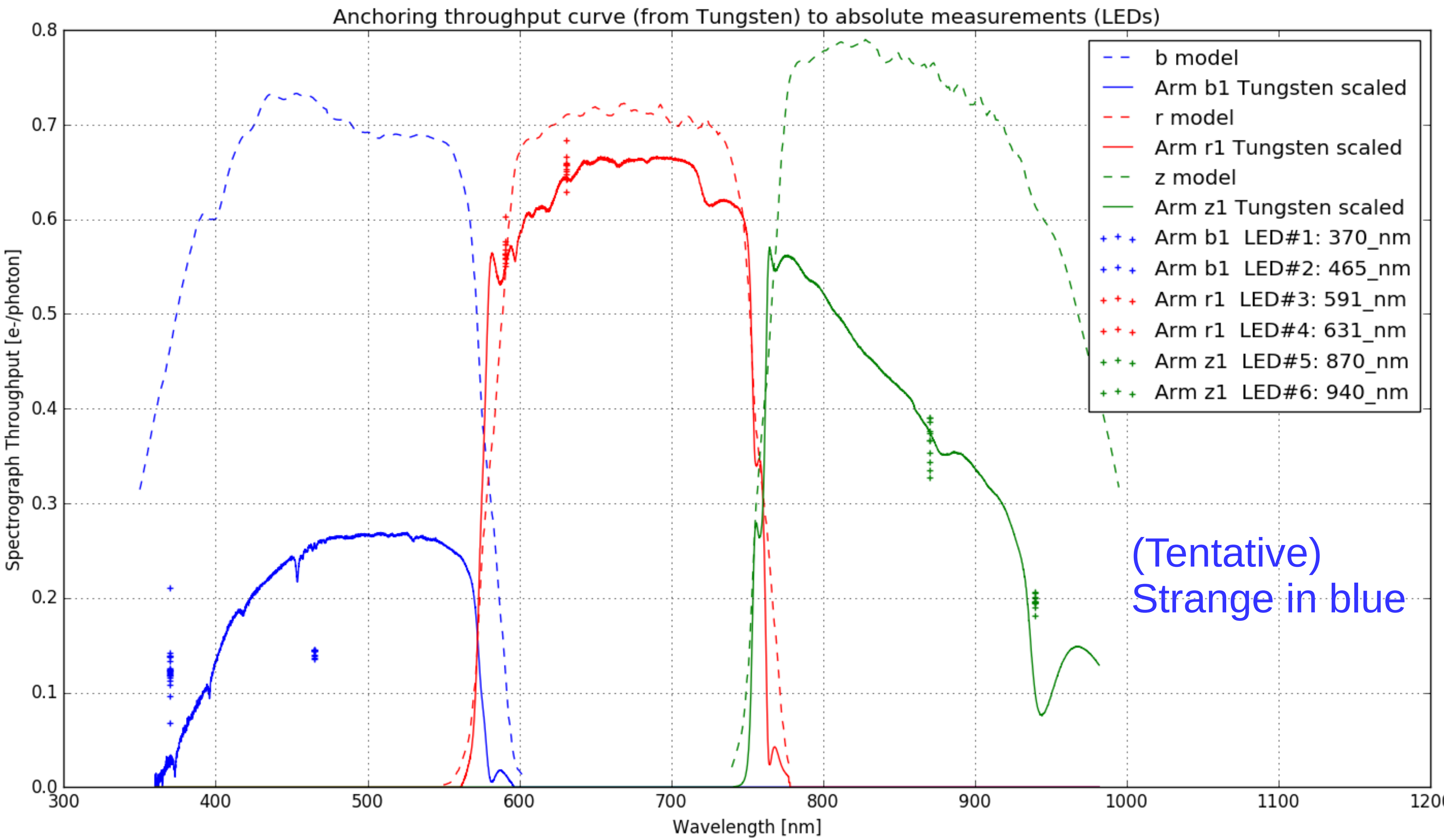
Spectrum in DESI arm Z1: LED#5: 870 nm



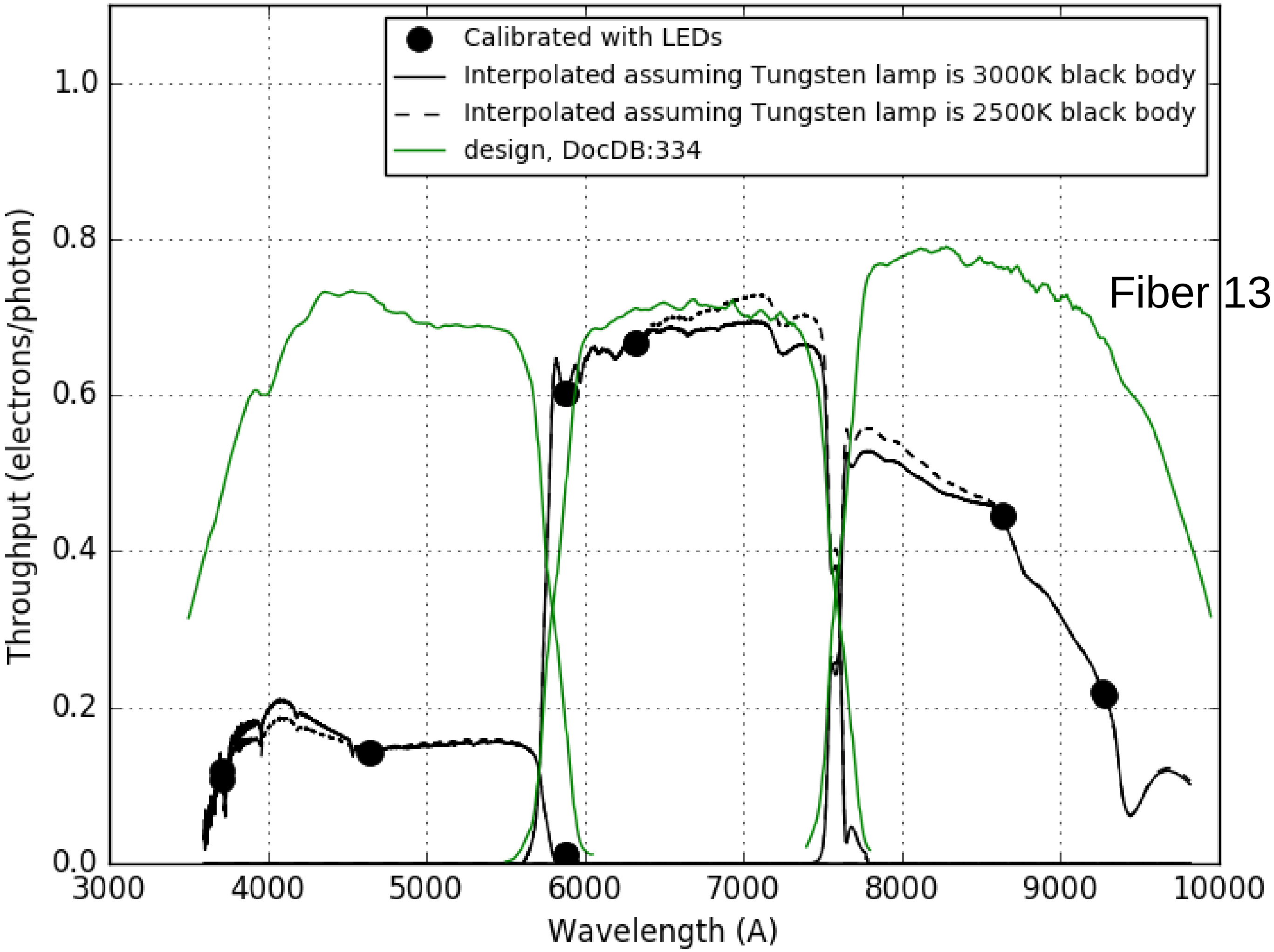
Spectrum in DESI arm Z1: LED#6: 940 nm



Anchoring Tungsten to LED measurements

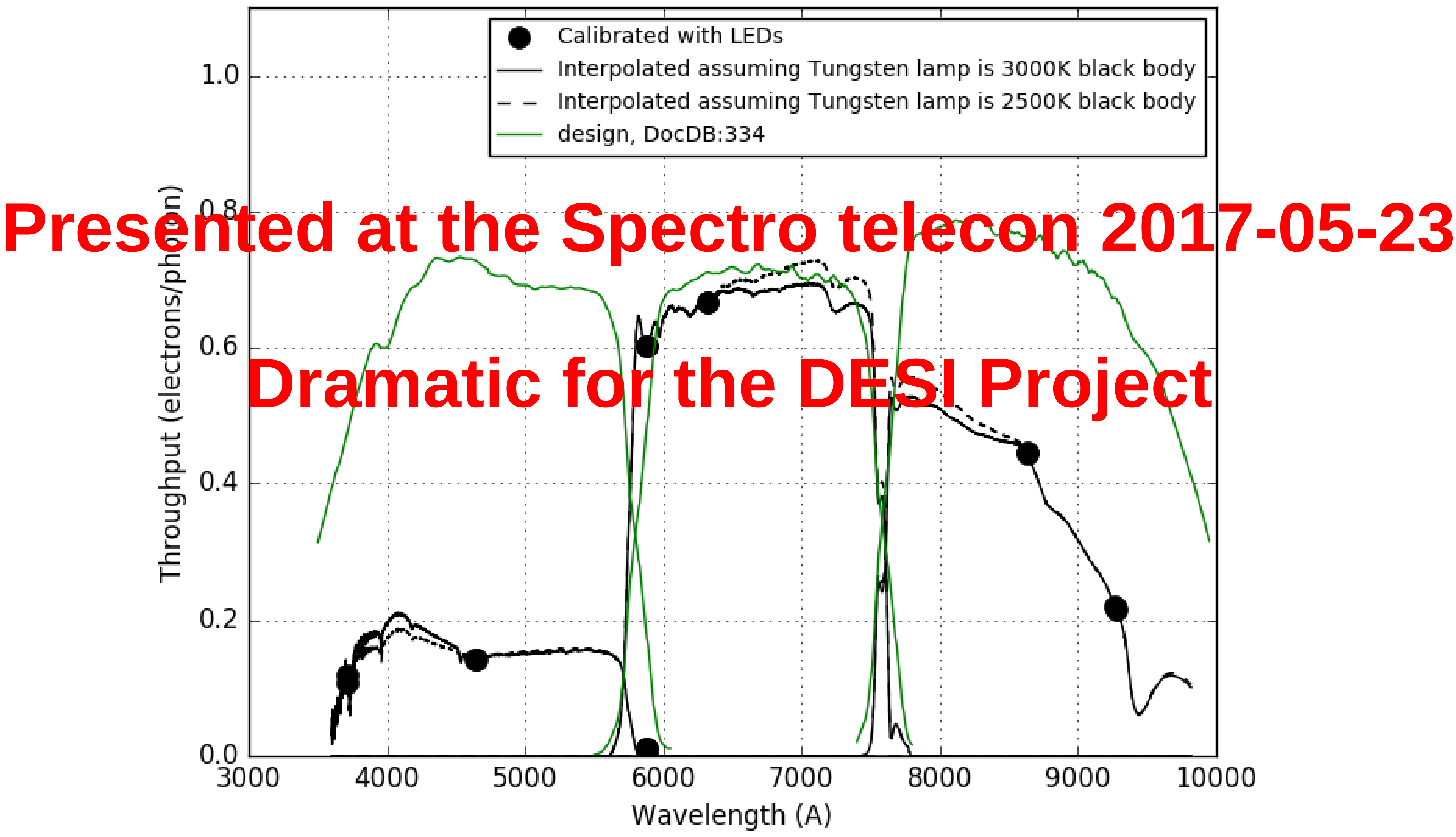


With a model of the tungsten lamp spectrum



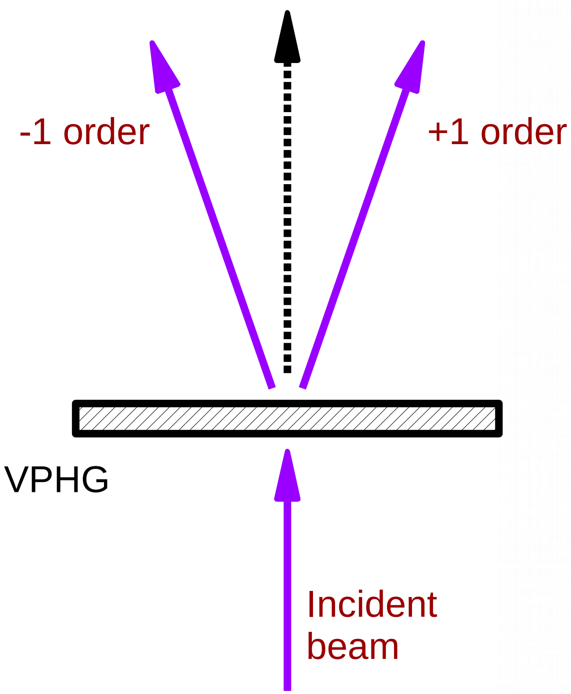
Fiber 13 only

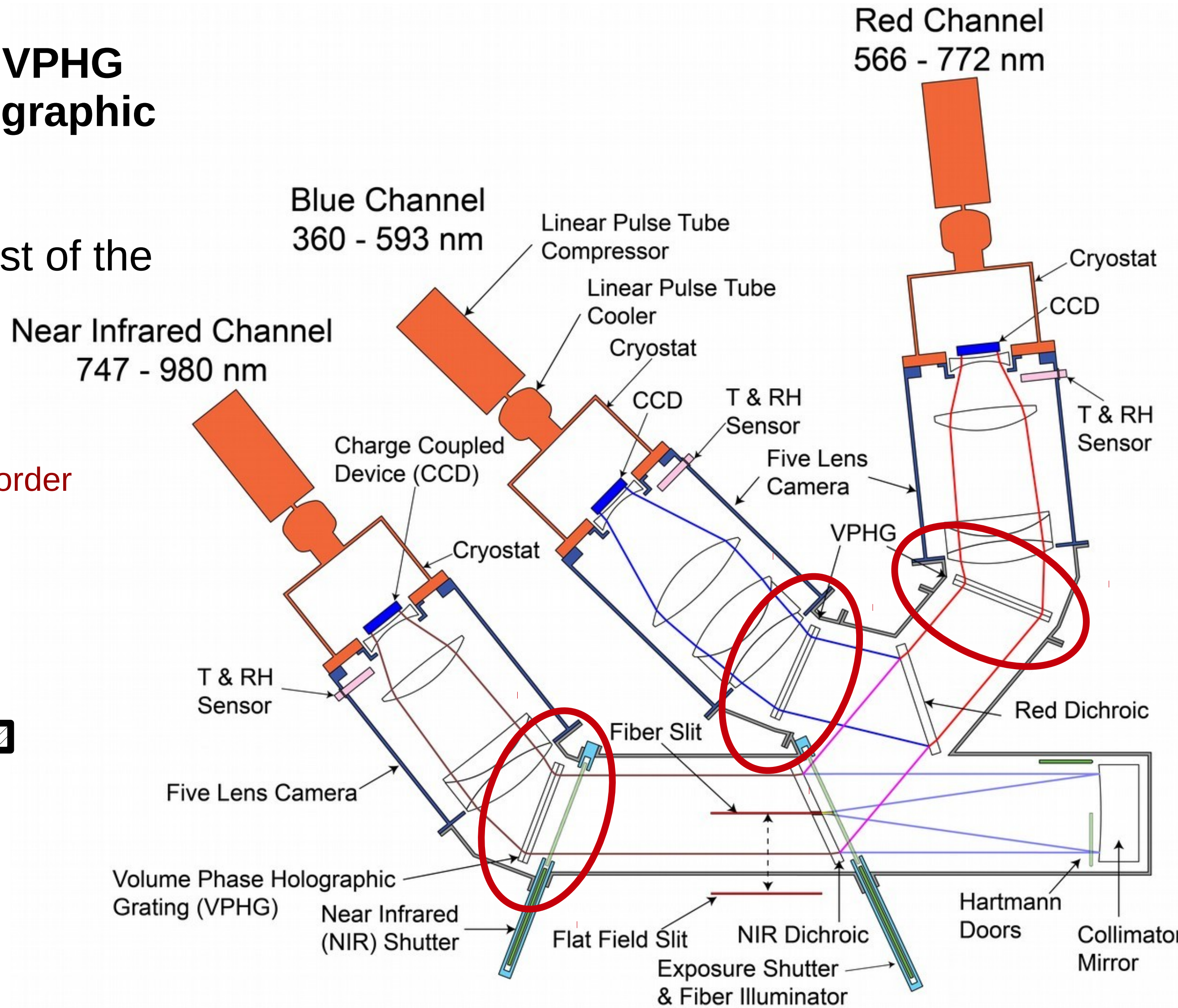
Result: Very Low Throughput in B & Z(NIR) arms



Very Low Throughput in B and Z arms: why ?

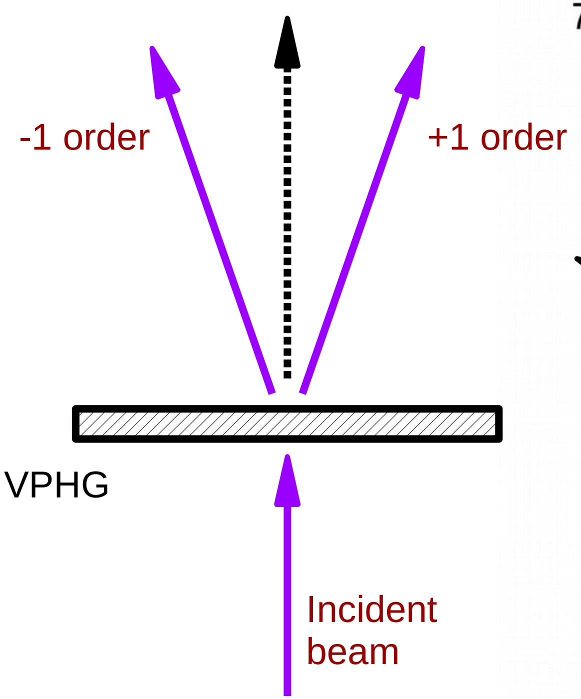
- **Possible culprit : the VPHG « Volume Phase Holographic gratings »**
- **Optimized** to send most of the flux **in order +1**

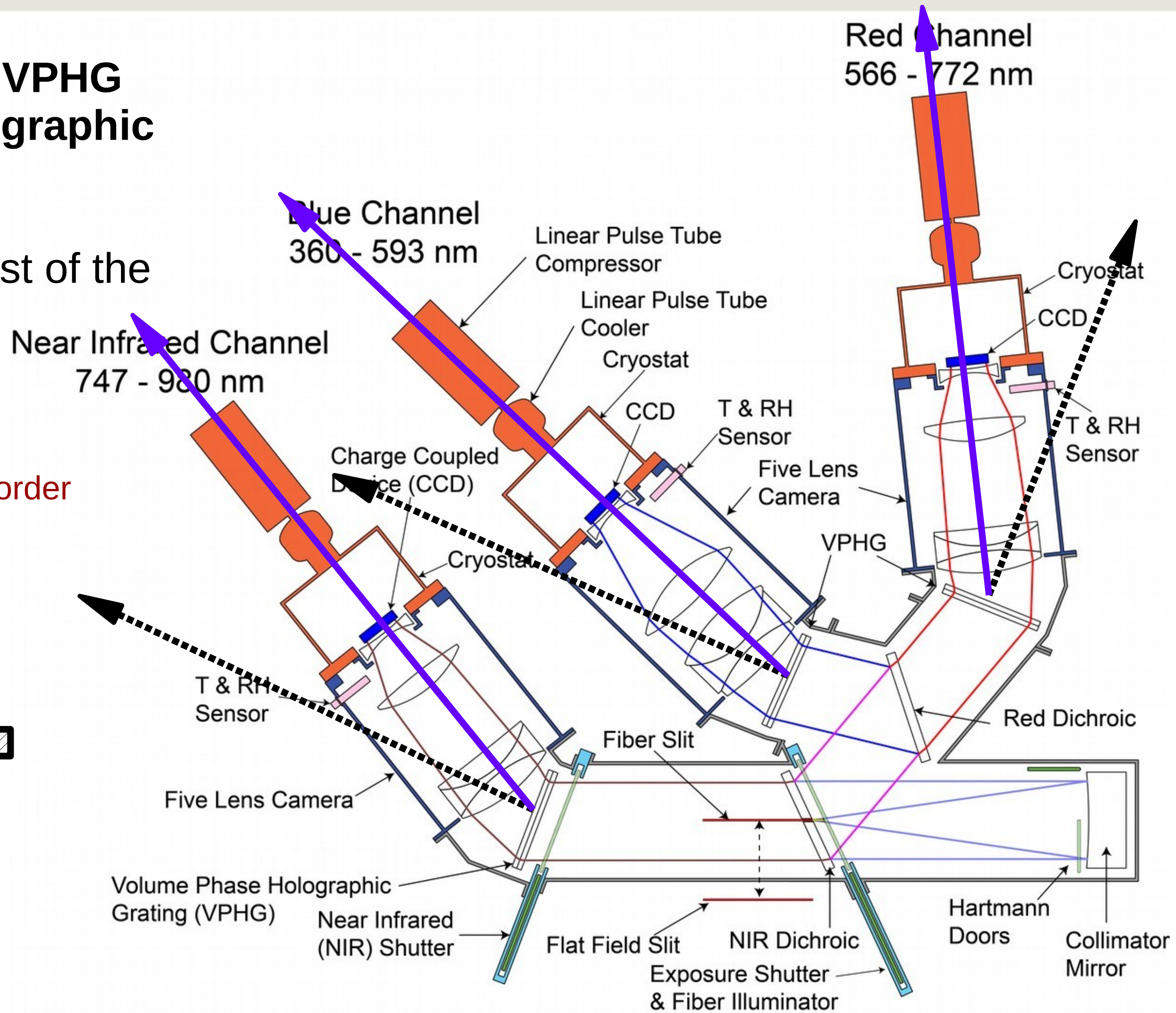




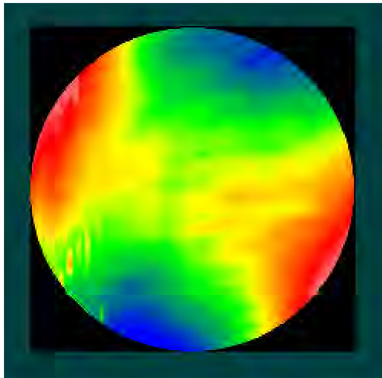
Hypothesis: are some VPHG upside-down ?

- **Possible culprit : the VPHG « Volume Phase Holographic gratings »**
- **Optimized** to send most of the flux **in order +1**

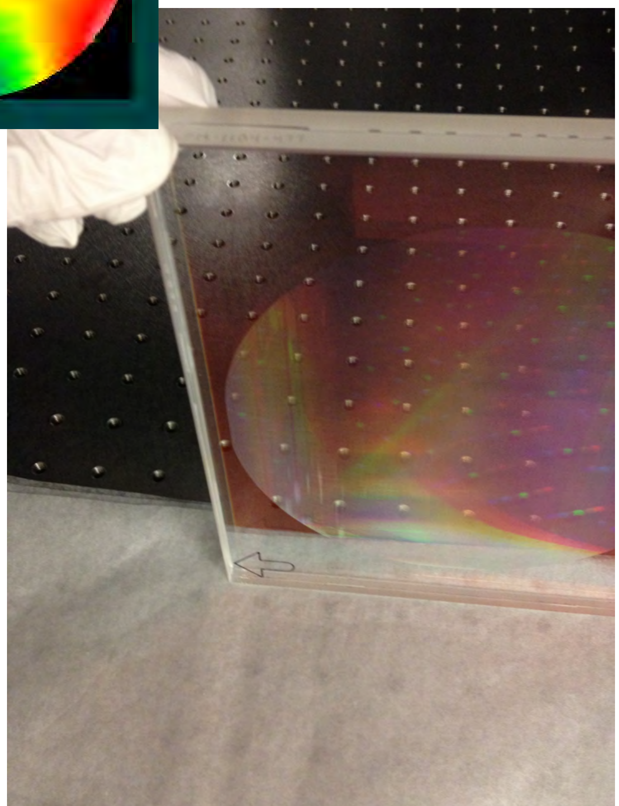


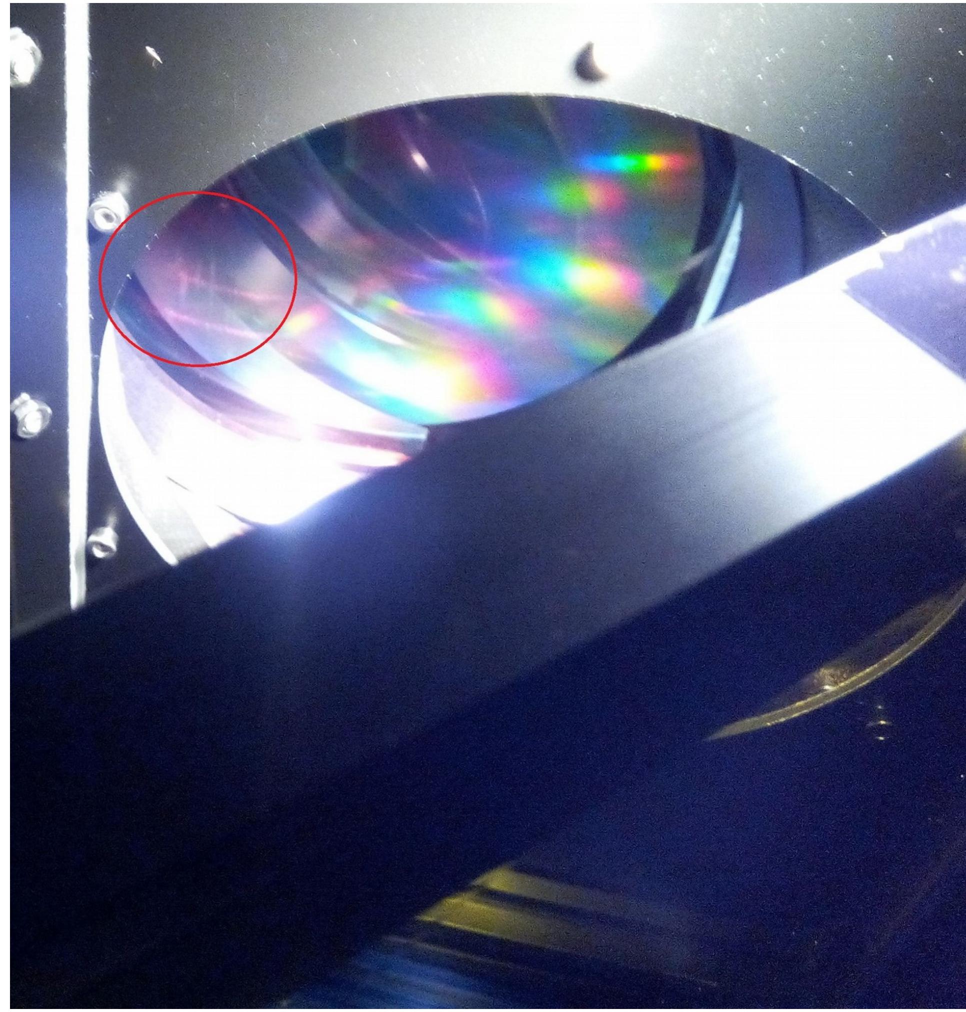


VPHG were mounted upside-down in B & Z arms

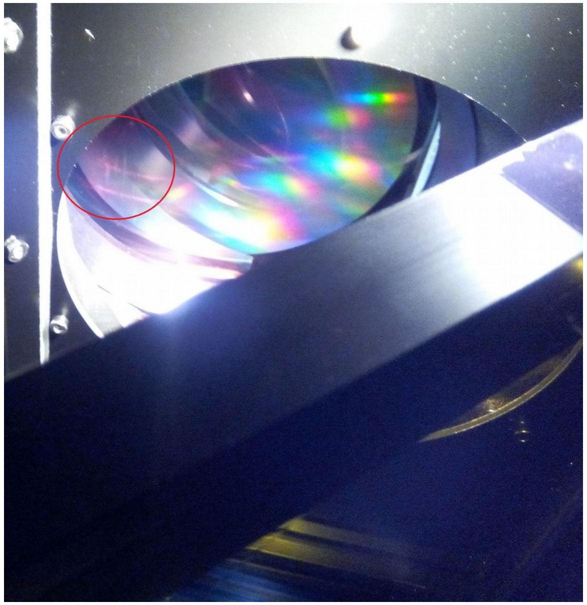


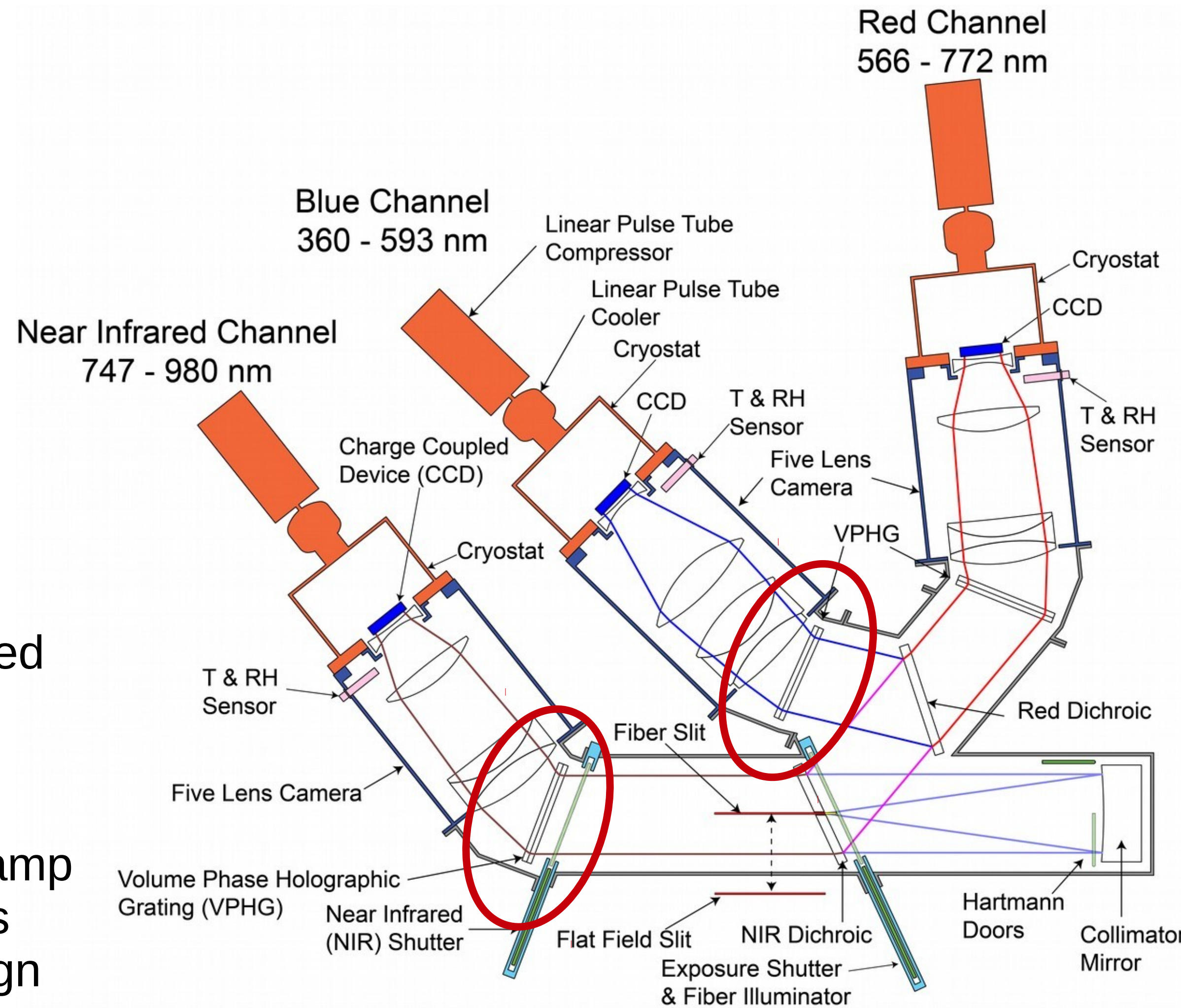
Blue arm VPHG
(photos Eric T.)





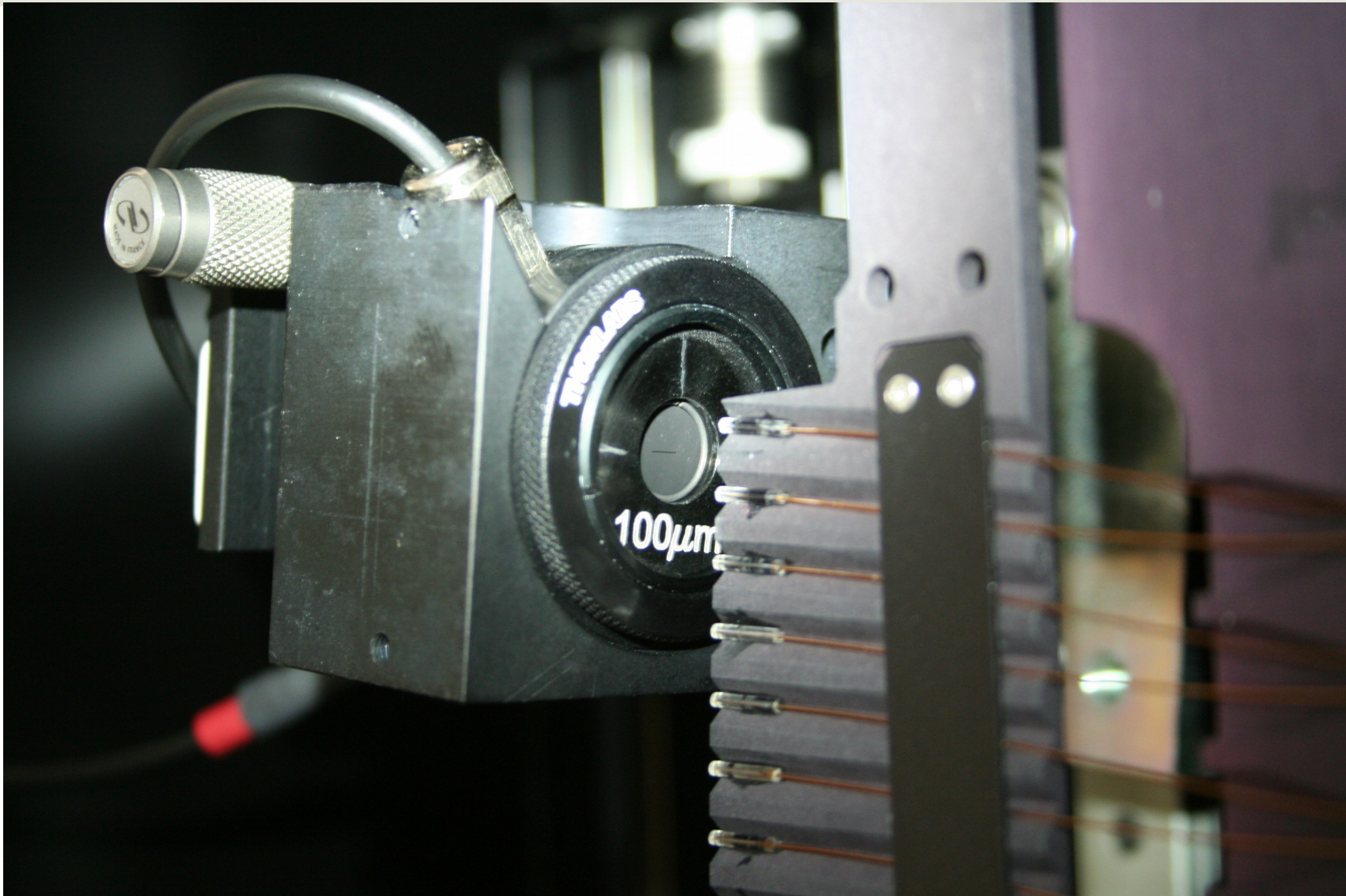
VPHG were mounted upside-down in B & Z arms





- **B & Z VPHG** were dismounted and **remounted in the right orientation** (June 2017).
- First checks with Tungsten lamp show that the throughput has been improved. July campaign cancelled (shutter problems)

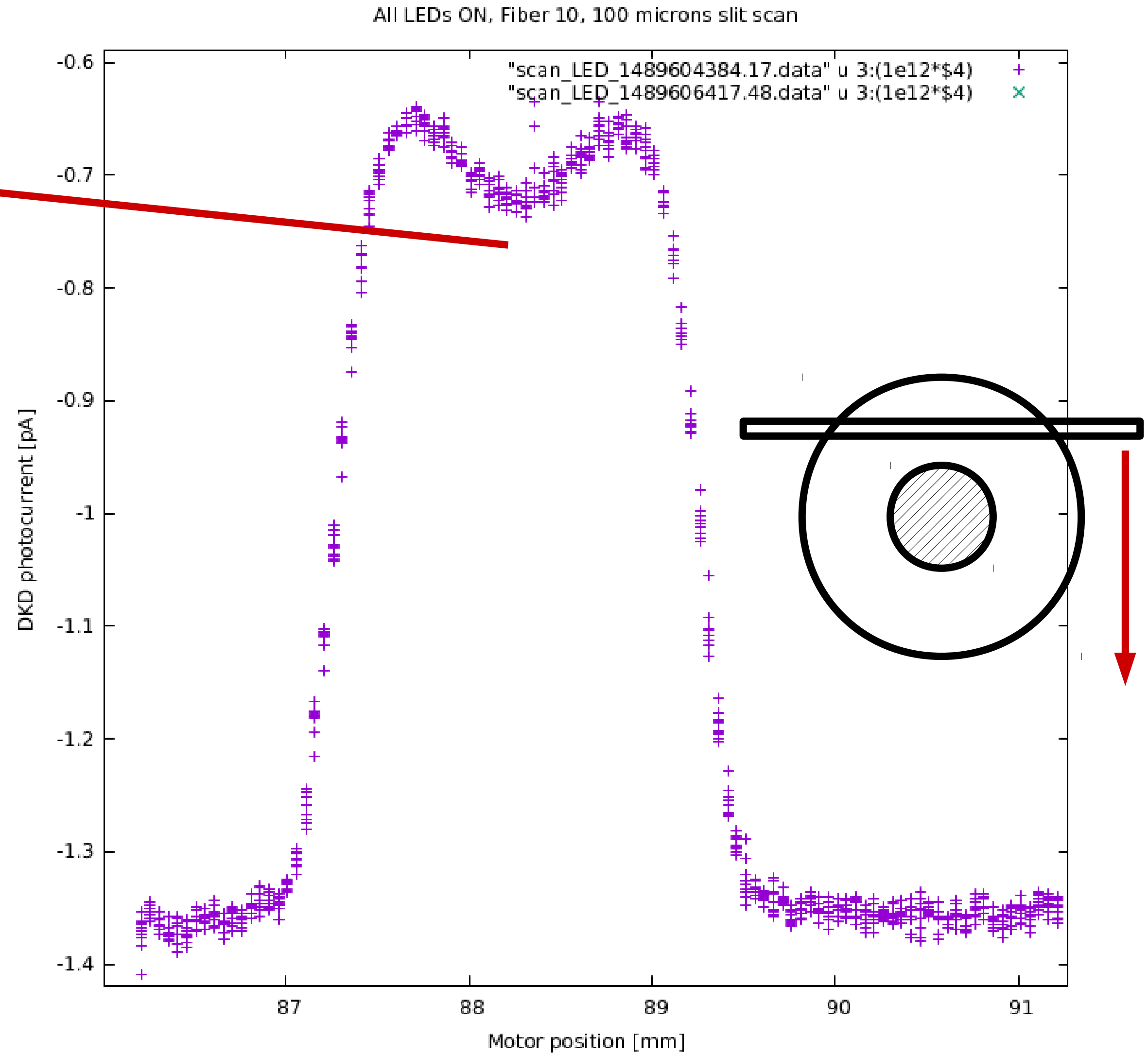
Next: estimating the FRD from fiber beam scans



Systematics: FRD, estim. from fiber beam scans

Beam central occultation (convolved by the 100 microns slit)

- Using the 100 microns slit scans **to model the fiber exit beam**
- Estimating the Focal Ratio Degradation from this dataset
- **Scan shapes vary from fiber to fiber**
- **On-going analysis**



Conclusions et perspectives

- We **designed, built, tested at LPNHE, installed at Winlight and used a device** to **measure the throughput** of the DESI spectrographs.

- Measurements for **spectro EM#1 : very low throughput in B1 and Z1.**

- Allowed to **fix the wrong mounting of 2 VPHG in B and Z arms, for EM#1 and the 9 next ones.** Fixed the mounting procedure and validated the usefulness of this measurement.

- Next campaign: **late Feb / early March 2018** on Spectrograph SM#1 (EM#1 *refurbished*).

- Two DESI notes (*in prep.*), maybe a paper (measurement method).