LIGHT CALIBRATION SYSTEM @ CIEMAT

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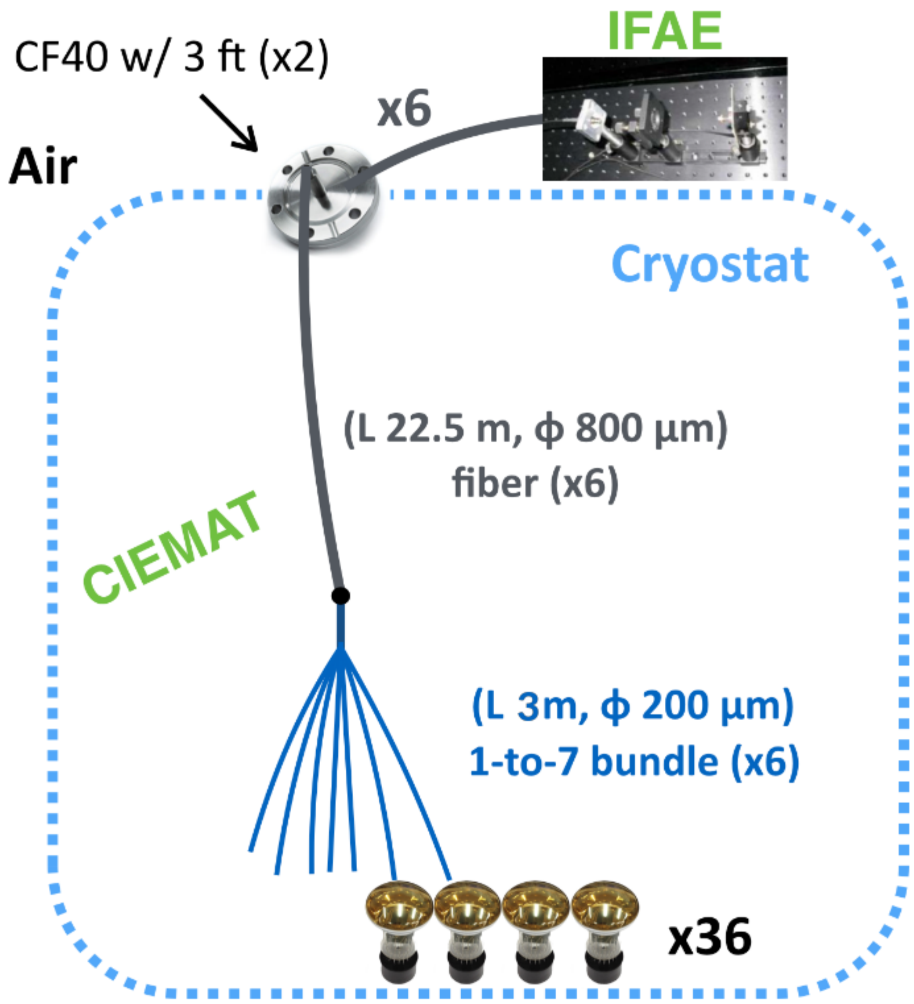
Design



- Black box with **light source** (Kaputschinsky LEDs) outside of cryostat
- **6 fibers** going to cryostat - *ϕ 1000 mm, M59L01*
- **2 CF40**, each with 3 optical feedthroughs
- Inside the cryostat (**6x**):
  0.39 NA TECS™ Hard Clad, Step-Index, Multimode Fiber from Thorlabs
  - 22.5 m **fiber -** *ϕ 800 mm, FT800UMT, SS jacket*
  - 3 m **1-to-7 bundle –** *ϕ 200 mm, FT200UMT SS jacket common end, black jacket at split ends*
  - Vacuum compatible SMA to SMA matting sleeve
- All fibers with **SMA** connectors

All fibers provided by Thorlabs

Inner Fibers attenuation

Almost complete setup under testing in LN_2:

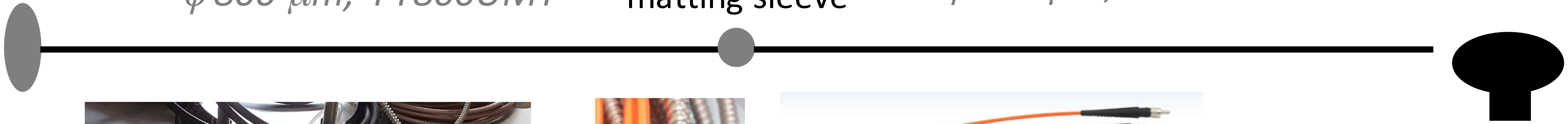
optical feedthrough*

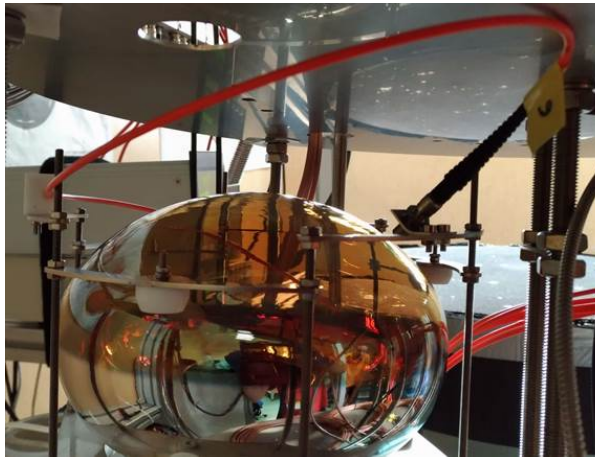
22.5 m **fiber**
ϕ 800 μm, FT800UMT

Vacuum compatible SMA to SMA matting sleeve

1 m** **1-to-7 bundle**
ϕ 200 μm, FT200UMT

8” PMT



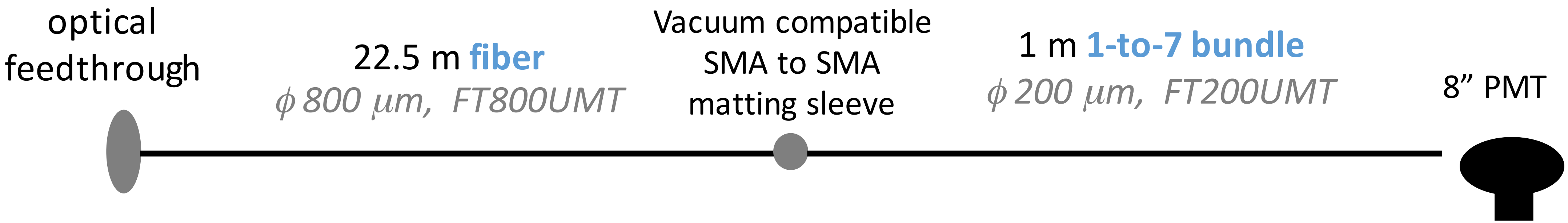


*Final design 3 feedthroughs per flange

**Final design 3 m

Inner Fibers attenuation

Light transmission has been measured:



Light transmission:

RT:	0.7	x	0.117	x	0.7	x	0.06	=	0.003 total
CT:	0.7	x	0.08	x	0.6	x	0.05	=	0.002 total

Assuming homogeneous light at SMA flange feedthrough
Measured in different steps, need to measure everything together

Determination of light required at flange

- Input power at flange determined with a power meter
- Fiber system described in slide 3 in LN_2
- Study of PMT response to see:
    - Single photoelectron
    - Maximum light before PMT saturation
- Comparison of PMT response (number of photoelectrons) to input power measured with the power meter (pW at a determined frequency)
- Light sources:
    - Kaput + 1m fiber (ϕ *800* μm*, FT800UMT)*
    - Laser + fiber + filter box + fiber

Results Kaput

PMT Measurements taken on 29/8 at 1300 V and on 31/8 at 1200 V
PM taken on 23/8

Number of PE:

V_{Kapu} (V)	P (pW) @ flange	PMT #1 (V_{PMT} = 1300 V)		PMT #1 (V_{PMT} = 1200 V)		PMT #2 (V_{PMT} = 1300 V)		PMT #2 (V_{PMT} = 1200 V)		PMT #3 (V_{PMT} = 1300 V)		PMT #3 (V_{PMT} = 1200 V)		Average
	f_{Kapu} = 1 kHz*	f_{Kapu} = 200 Hz	f_{Kapu} = 1 kHz	f_{Kapu} = 100 Hz	f_{Kapu} = 200 Hz	f_{Kapu} = 200 Hz	f_{Kapu} = 1 kHz	f_{Kapu} = 100 Hz	f_{Kapu} = 200 Hz	f_{Kapu} = 200 Hz	f_{Kapu} = 1 kHz	f_{Kapu} = 100 Hz	f_{Kapu} = 200 Hz	
5	8	0.32	0.31	0.23	0.39	0.3		0.19	0.19	0.32		0.25	0.25	**0.3 ± 0.1**
6	12	17	17	14	14	15	15	12	12	15	14	13	13	**14 ± 2**
7	39	86	79	87	84			66	66	71	58	74	72	**76 ± 9**
8	84			216	211					154	133	191	180	**190 ± 25**
9	137											315	303	**315**

Gain monitored between measurements.
Results in red indicate that NPHE is underestimated due to PMT saturation.
PMTs 4 and 5 not considered as they have less gain.
* Power for 100 Hz and 200 Hz can be extrapolated.

Recommendation: Do not calibrate with 1 kHz, rather use **100 Hz** (200 Hz also saturates the PMT earlier)

Results Laser (Set 5)

PMT measurements taken on 6/7
PM on 28/7

Filter	Laser Power	P (pW) @ flange	PMT #1 (V_{PMT} = 1400 V)	PMT #2 (V_{PMT} = 1400 V)	PMT #3 (V_{PMT} = 1400 V)	PMT #4 (V_{PMT} = 1400 V)	PMT #5 (V_{PMT} = 1400 V)	
		f_{Laser} = 200 Hz*	f_{Laser} = 200 Hz	f_{Laser} = 200 Hz	f_{Laser} = 200 Hz	f_{Laser} = 200 Hz	f_{Laser} = 200 Hz	Average
40	50%	0.035	1.4	0.6	1.5	1.4	1.3	**1.2 ± 0.4**
40	100%	0.061	2.5	1.1	2.7	2.2	2.3	**2.2 ± 0.6**
20	100%	5.1	188	91	167	146	172	**153 ± 40**

* Measured at 80 MHz and extrapolated
Note that PMTs 1-5 at Set 5 were different that at R1

PMT measurements taken on 30/8
PM on 23/8

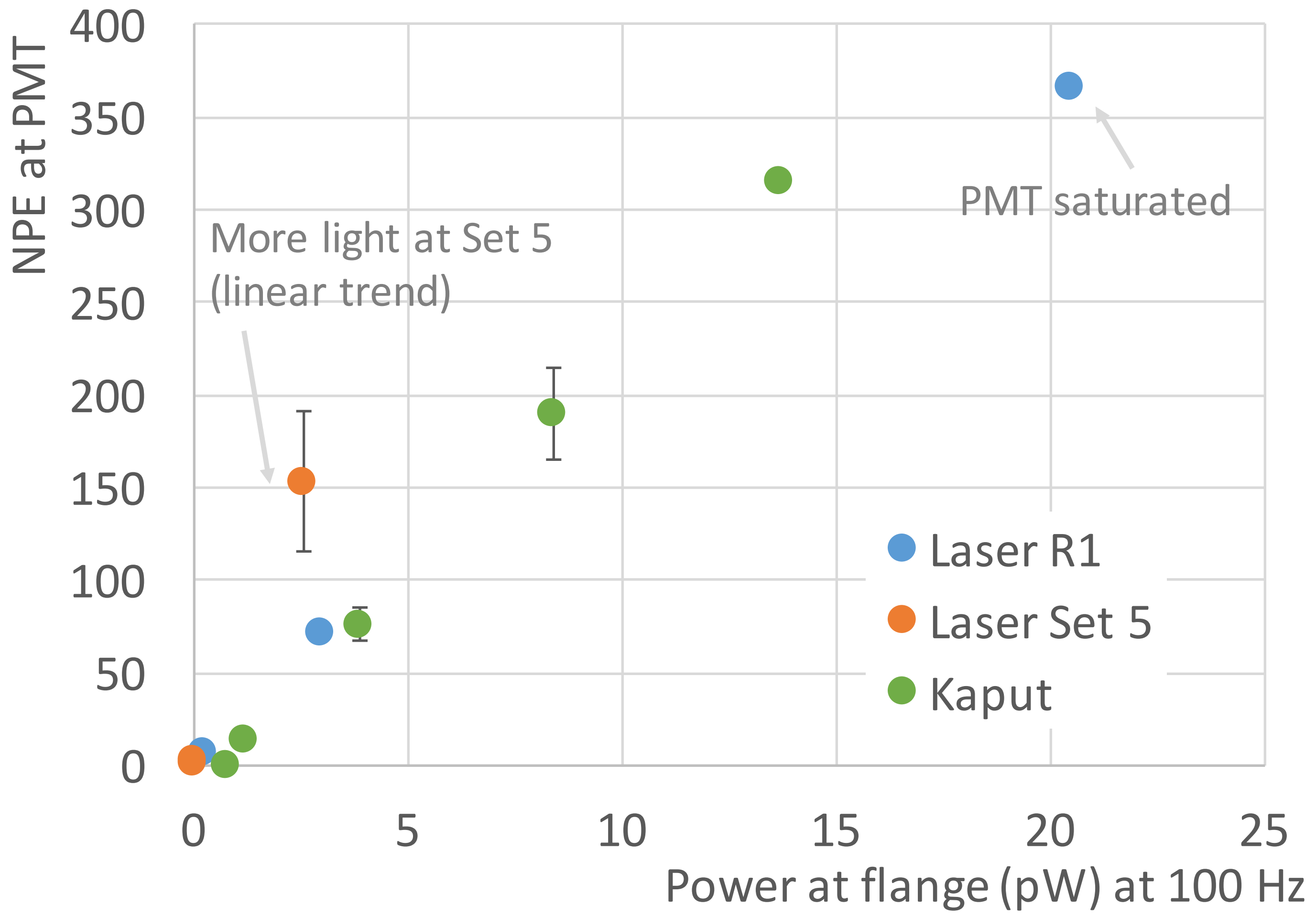
Results Laser (R1)

Filter	Laser Power	P (pW) @ flange	PMT #1 (V_{PMT} = 1200 V)	PMT #2 (V_{PMT} = 1200 V)	PMT #3 (V_{PMT} = 1200 V)	
		f_{Laser} = 100 Hz*	f_{Laser} = 100 Hz	f_{Laser} = 100 Hz	f_{Laser} = 100 Hz	**Average**
40	100%	0.23	7 / 5.3	8 / 6	8 / 5.7	**7 ± 1**
30	100%	2,99	72	75	68	**72 ± 3**
20	100%	20,5			367	**367**

* Measured at 10 MHz and extrapolated.
Measurements with filter 40 repeated twice.
Gain monitored between measurements.
Results in red indicate that NPHE is underestimated due to PMT saturation.

There are more measurements taken with the laser available (the ones with the "bifurcated fiber"), but since we do not have the PM value yet they cannot be used for comparison.

NPE at PMT vs Power at flange



	P (pW) @ flange	Average (NPE)
Kapu	0.8	0.3 ± 0.1
	1.2	14 ± 2
	3.9	76 ± 9
	8.4	190 ± 25
	14	315
Laser Set5	0.02	1.2 ± 0.4
	0.03	2.2 ± 0.6
	2.6	153 ±40
Laser R1	0.2	7 ± 1
	3.0	72 ± 3
	21	367

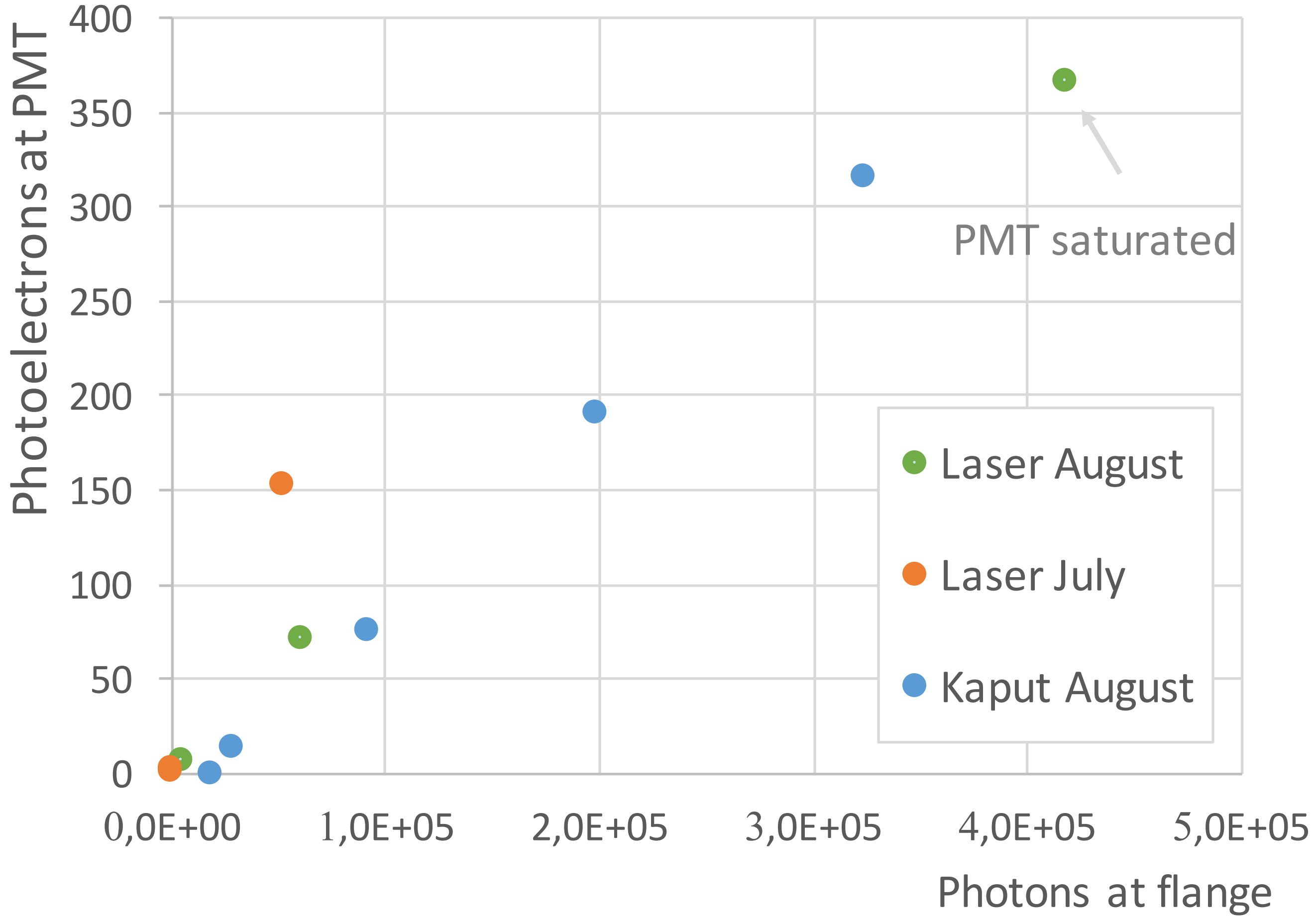
Results in purple limited by power meter resolution, real value could be smaller

Recommendation:
Range required at flange: 0.02 – 20 pW

NPE at PMT vs NP at flange

$$\text{NPh} = \frac{P \cdot t}{E} = \frac{P/f}{(h \cdot c)/\lambda}$$

F = 100 Hz
h = 6.62×10^{-34} Js
c = 3×10^{8} m/s
λ_{kapu} = 470 nm
λ_{laser} = 405 nm

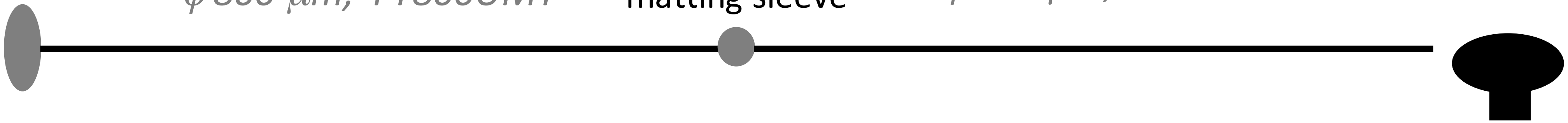


	P (pW) @ flange	P (NPh) @ flange	Average (NPE)	Light trans (%)
Kapu	0.8	$1.9 \cdot 10^4$	0.3 ± 0.1	0.001
	1.2	$2.8 \cdot 10^4$	14 ± 2	0.050
	3.9	$9.2 \cdot 10^4$	76 ± 9	0.082
	8.4	$2 \cdot 10^5$	190 ± 25	0.096
	14	$3.2 \cdot 10^5$	315	0.097
Laser Set 5	0.02	$3.6 \cdot 10^2$	1.2 ± 0.4	0.347
	0.03		2.2 ± 0.6	0.347
	2.6	$5.2 \cdot 10^4$	130 ±40	0.294
Laser R1	0.2	$4.7 \cdot 10^3$	7 ± 1	0.141
	3.0	$6.1 \cdot 10^4$	72 ± 3	0.117
	21	$4.2 \cdot 10^5$	367	0.088

Recommendation:
Range required at flange: 300 – 400 000 photons

Inner Fibers – expected light transmission

optical feedthrough	22.5 m **fiber** *ϕ 800 μm, FT800UMT*	Vacuum compatible SMA to SMA matting sleeve	1 m **1-to-7 bundle** *ϕ 200 μm, FT200UMT*	8" PMT



Light transmission:

RT:	0.7	x	~~0.117~~	x	0.7	x	0.06	=	~~0.0034~~ 0.030 total
CT:	0.7	x	~~0.08~~ 0.9	x	0.6	x	0.05	=	~~0.0017~~ 0.019 total
			~~0.09~~ (Set 5)						~~0.0019~~ 0.021 total (R0)

We expect ~~0.17% (0.19% for Set 5)~~ light transmission
1.9% (2.1% for Set 5)

However, in our case, we are not illuminating the optical feedthrough homogeneously, we are using a 800 μm diameter fiber. The exact light transmission will have to be evaluated, but as an approximation, we can omit the second factor (only consider a 0.9 l.t. for the 22.5 m one)

Conclusions

- Do not calibrate with 1 kHz, rather use **100 Hz** (200 Hz also saturates the PMT earlier)
- Range required at flange: **0.02 – 20 pW** at 100 Hz (300 – 400 000 photons)
- Light transmission:
  - Expected (inner fibers): 1.9% (R1 & Kaput), 2.1% (Set 5)
  - Measured:
    - Kaput: 0.10%
    - Laser Set 5: 0.33%
    - Laser R1: 0.11%

  Conclusion: QE could explain the difference (one order of magnitude). However no such a big **difference (x3)** is expected **between Set 5 and R1**. R1 and Kaput are consistent 🤔
- Actions:
  - Measure light input with PM after opening and analyze data with “bifurcated fiber”
  - Order x7 bundles, x6 fibers, x2 flanges (CF40, x3 ft)
  - Test a 3m bundle + 22.5 m fiber with PMT upon arrival