LIGHT CALIBRATION SYSTEM
CIEMAT

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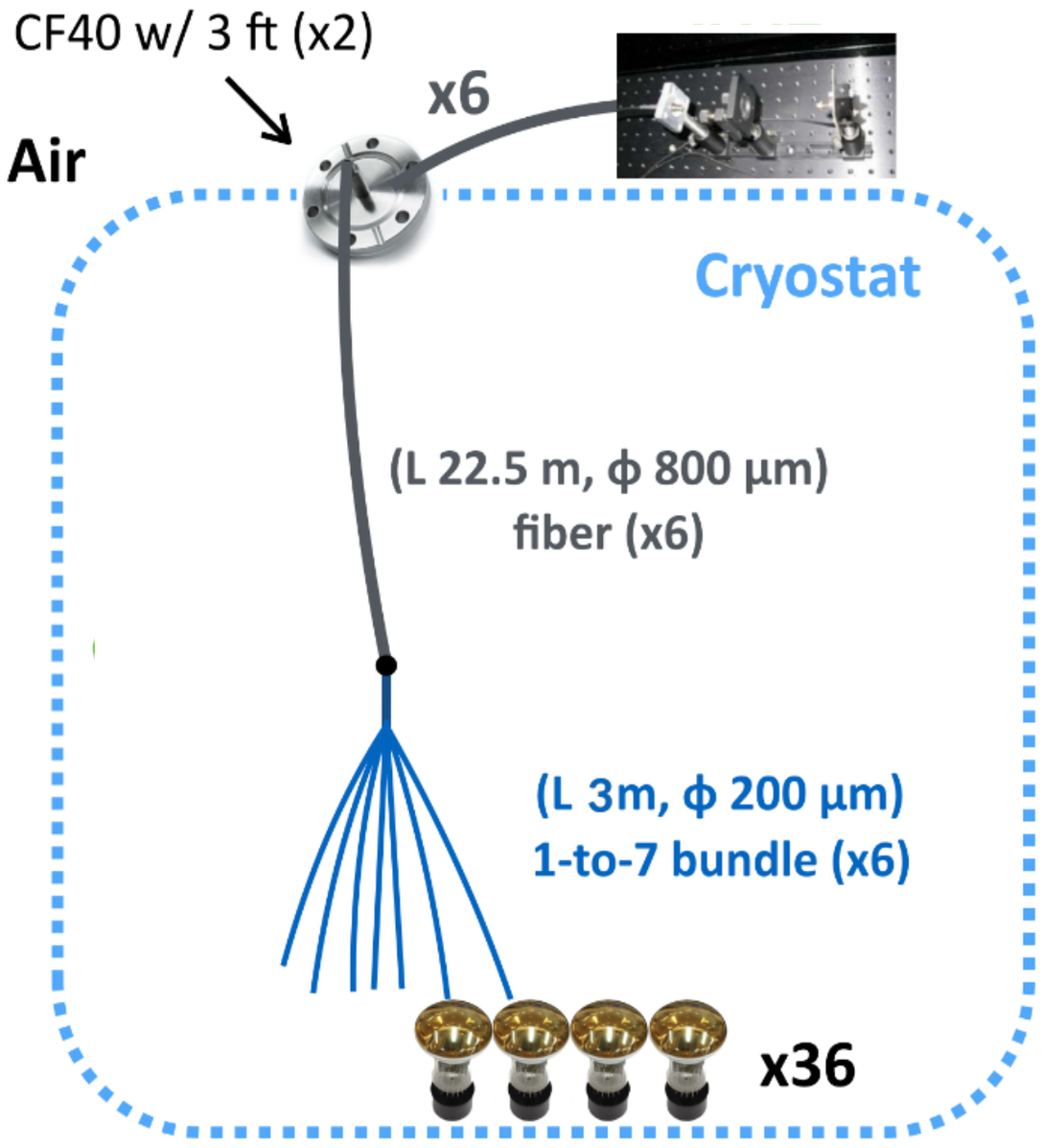
Light calibration system overview

Goal
- Determine PMT gain (SPE)
- Study PMT stability

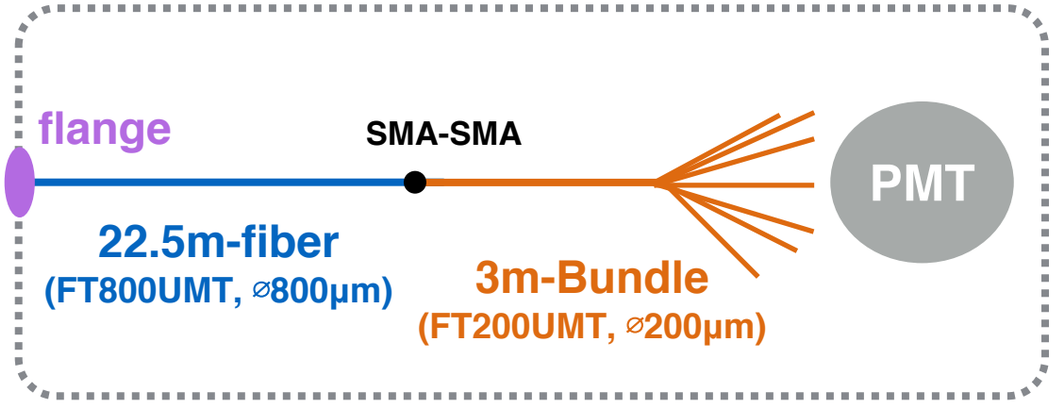


- **Black box** with light source (6 Kaputschinsky LEDs) and reference sensor out of cryostat [IFAE]
- **6 fibers** to cryostat [IFAE]
  Thorlabs, ϕ 1000 mm, M59L01
- 2 **CF40**, each with 3 optical FT [CIEMAT]
  Allectra
- Inside the cryostat (6x): [CIEMAT]
  - **22.5-m fiber** *Thorlabs ϕ 800 µm, FT800UMT, SS jacket*
  - **Matting sleeve** - vacuum compatible SMA to SMA
  - **3-m 1-to-7 bundle** → 1 fiber per PMT
    Thorlabs ϕ 200 µm, FT200UMT, SS jacket common end, black jacket at split ends

  All fibers with SMA connectors

Status of inner system

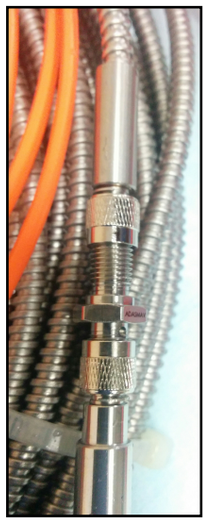
Configuration inside the dewar



All components available and tested at CIEMAT:

[x2] CR40 flanges with 3 SMA feedthroughs (Allectra) + O-rings

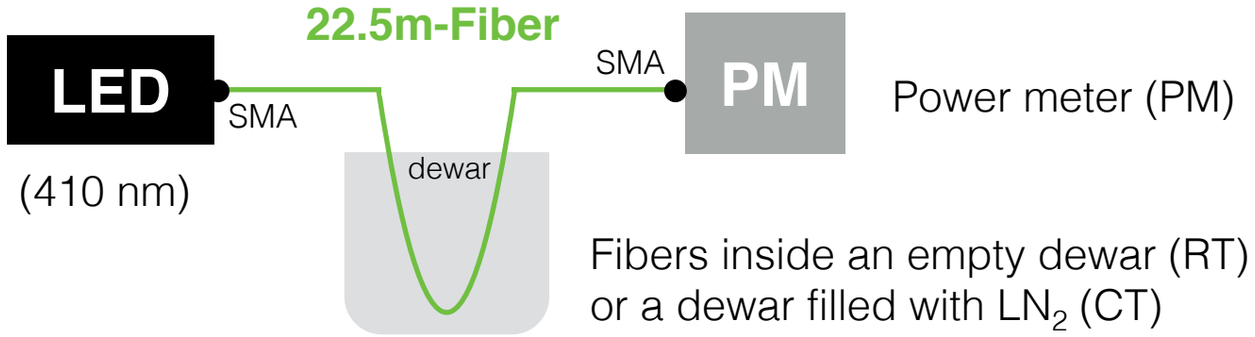
[x7] Fibers (Thorlabs): FT800UMT, ⌀ 800µm, L 22.5m, SMA connectors



[x8] Vacuum compatible matting sleeves

[x7] 1-to-7 fiber bundles (Thorlabs): FT200UMT, ⌀ 200µm, L 3m, SMA connectors

Fibers characterization



Power meter (PM)

Fibers inside an empty dewar (RT) or a dewar filled with LN_2 (CT)

P_{LED} = 36 µW	RT	CT
Fiber #	**P (µW)**	**P (µW)**
1	4,28	3.35
2	5,27	4.59
3	5,15	4.29
4	5,10	4.30
5	4,75	4.09
6	4,82	4.04
7	4,77	4.02
Mean	4,88	**4.10**
RMS	0,33	**0.38**

The power output @ RT is recovered once the LN2 has evaporated (next day)

P_{LED} = 36 µW	RT	CT
Fiber	**Power (µW)**	**Power (µW)**
1 m	6.12	5.91

$\langle P_{fiber} \rangle / P_{LED}$ = 17%

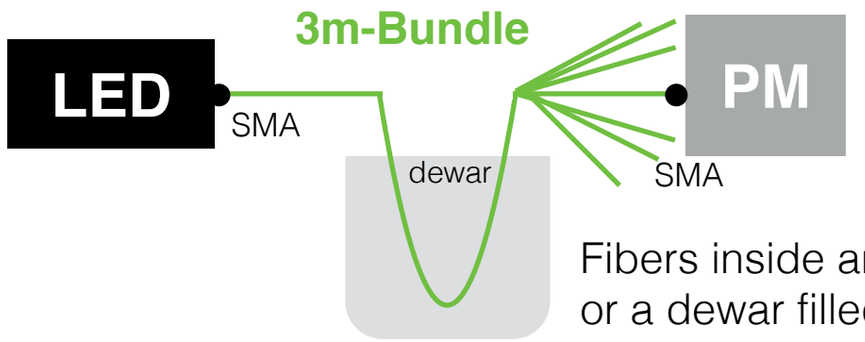
S_{fiber}/S_{SMA} = 6.05%

(0.39 NA → 23°)

All fibers tested 👍🏽

- **Light transmission loss from 1 m to 22.5 m @ RT: 20%** (0.97 dB)
  Expected at 410 nm 60 dB/km → 26% (from Thorlabs)
- **Light transmission loss from RT to CT: 16%** (0.76 dB)

Bundles characterization



Fibers inside an empty dewar (RT) or a dewar filled with LN_2 (CT)

P_{LED} = 36 µW	RT	CT
Bundle #	**P (nW)**	**P (nW)**
1	387	243
2	425	276
3	400	246
4	396	293
5	375	220
6	375	236
7	392	269
Mean	393	255
RMS	17	25

The power output @ RT is recovered once the LN2 has evaporated (next day)

P_{LED} = 41 µW	RT	CT
Bundle	**P (nW)**	**P (nW)**
1 m	375	345

$\langle P_{fiber} \rangle / P_{LED} = 0.91\%$

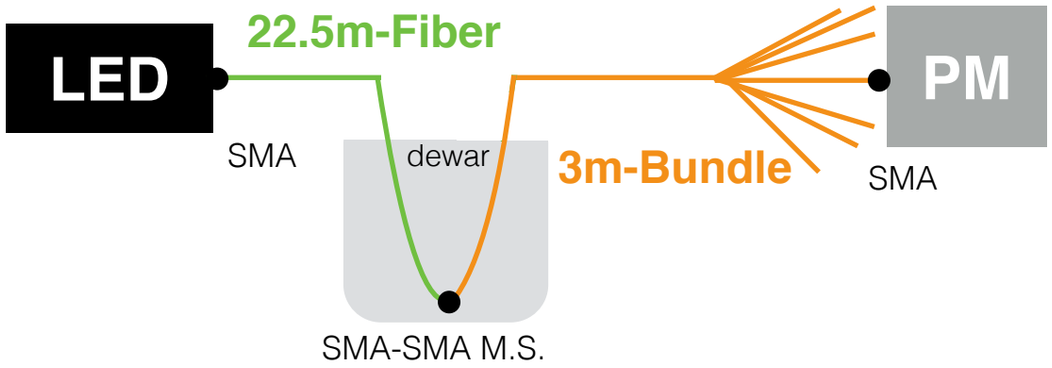
$S_{fiber}/S_{SMA} = 0.37\%$

All bundles tested 👍🏽

- **Light transmission loss from 1 m to 3 m @ RT: negligible (*)**
  Expected at 410 nm 60 dB/km → 3% (0.18 dB) from Thorlabs)
- **Light transmission loss from RT to CT: 35%** (1.87 dB)

(*) Measurements repeated 3 times, systematic error is 6%

[Fiber+bundle] characterization



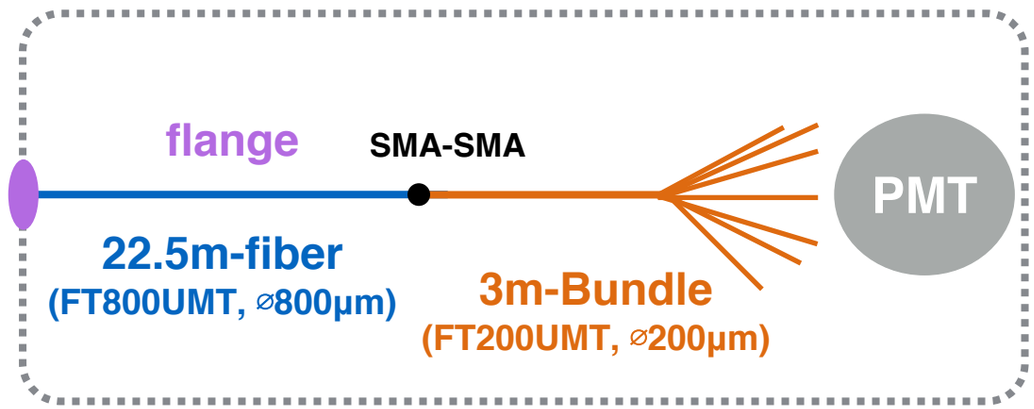
Fibers	Mating sleeve	Mean P/fiber (nW)	RMS (nW)
RT	RT	(P_{LED} = 39 μW) 286	16
CT	Outside the dewar @ RT	(P_{LED} = 37 μW) 150	12
CT	Inside the dewar @ CT	(P_{LED} = 39 μW) 139	8

22.5m-Fiber #3
3m-Bundle #2

- **Light transmission loss per matting sleeve with SMA connection:**
  20% (0.97 dB) measured with laser
  Expected <1.5 dB → <29% (from Thorlabs)
- **Matting sleeve light transmission loss from RT to CT: 12%** (0.56 dB)
- **Fiber + Matting sleeve + bundle light transmission loss from RT to CT:**
  51% (2.92 dB)

Inner fibers: expected light transmission at 410 nm

Configuration inside the dewar



$A\,(dB) = -10 \log (P_{in}/P_{out})$

$A_{geo} = -10 \log (S_{200}/S_{800}) = 12$ dB
$S_{800\ \mu m\text{-fiber}} = 0.503\ mm^2$
$S_{200\ \mu m\text{-fiber}} = 0.031\ mm^2$

- **Expected attenuation from Thorlabs at RT**

  $A_{RT} = A_{MS(Flange)} + A_{22.5m} + A_{MS} + A_{Geo} + A_{3m} =$
  $= 1.5$ dB $+1.35$ dB $+ 1.5$ dB $+ 12$ dB $+ 0.18$ dB $=$ **16.6 dB** (2.2% light transmission)

- **Estimated attenuation from measurements at RT**

  $A_{RT} = A_{MS(Flange)} + A_{22.5m} + A_{MS} + A_{Geo} + A_{3m} =$
  $= 0.97$ dB $+ 0.97$ dB $+ 0.97$ dB $+ 12$ dB $+ 0$ dB $=$ **14.91 dB** (3.2% light transmission)

Consistent as exp. A_{MS} is upper value

- **Estimated attenuation from RT to CT**

  $A_{CT} = A_{MS(Flange)} + A_{22.5m+MS+bundle} = 0.56$ dB $+ 2.92$ dB $=$ **3.48 dB** (45% light transmission)

Total estimated attenuation at CT

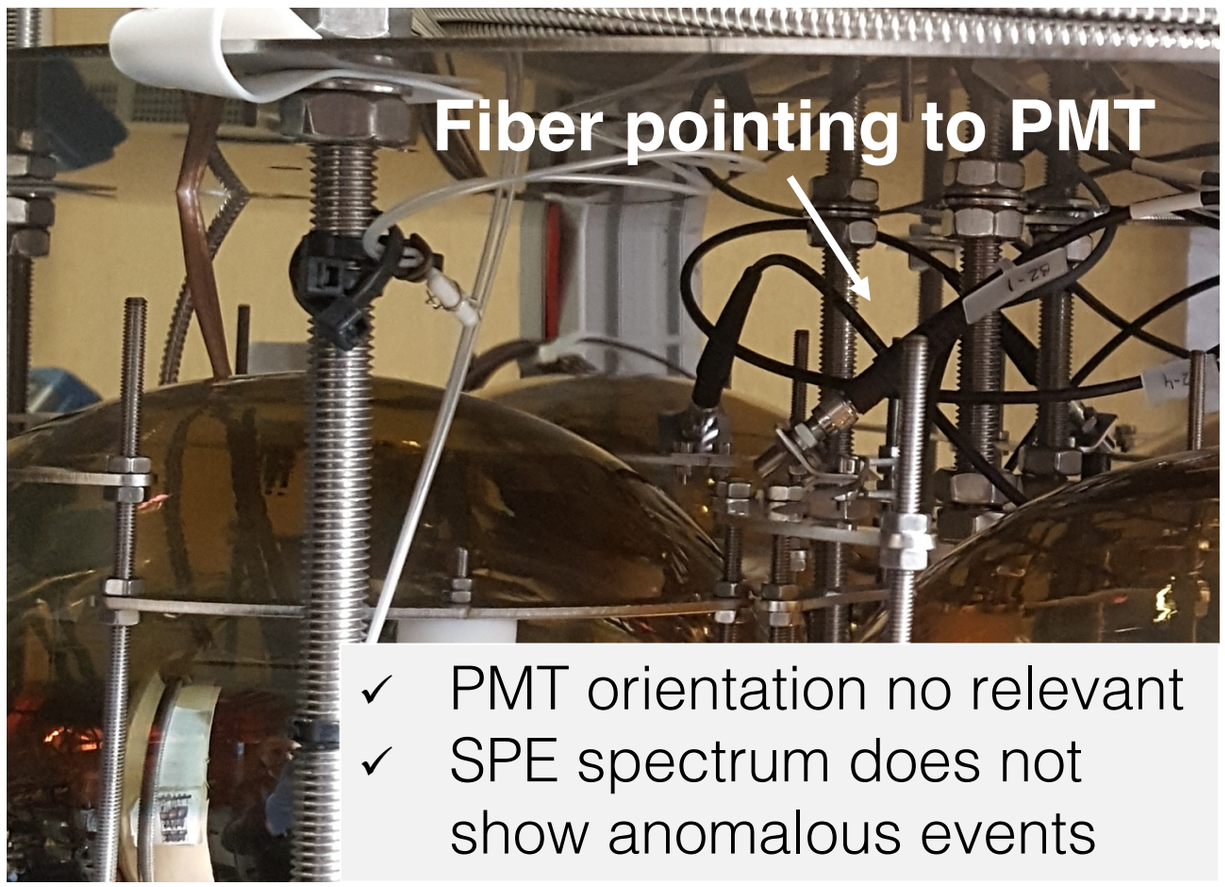
$A_T = A_{RT} + A_{CT} = 14.91$ dB $+ 3.48$ dB $=$ **18.39 dB (1.45% light transmission)**

Measurements with fibers and PMTs @ CT

Inner fibers (inside dewar at CT):

- Set 5 —> 1m-fiber + 1m-bundle
- Set R1 —> 22.5m-fiber + 1m-bundle
- Set R2 —> 22.5m-fiber + 3m-bundle

.....> **Different sets of PMTs and configurations of fibers!**



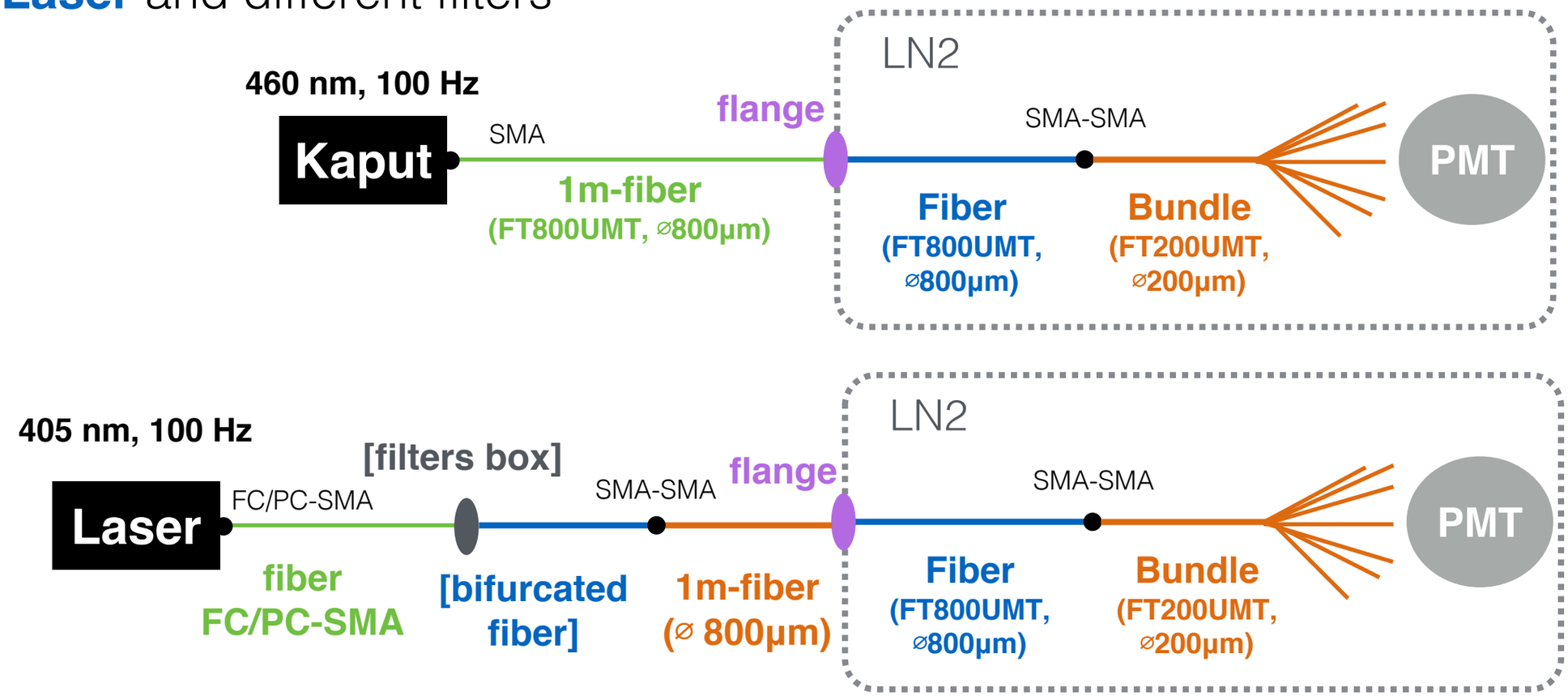
- ✓ PMT orientation no relevant
- ✓ SPE spectrum does not show anomalous events

Measurements with fibers and PMTs @ CT

Light source and external fibers (outside dewar at RT):

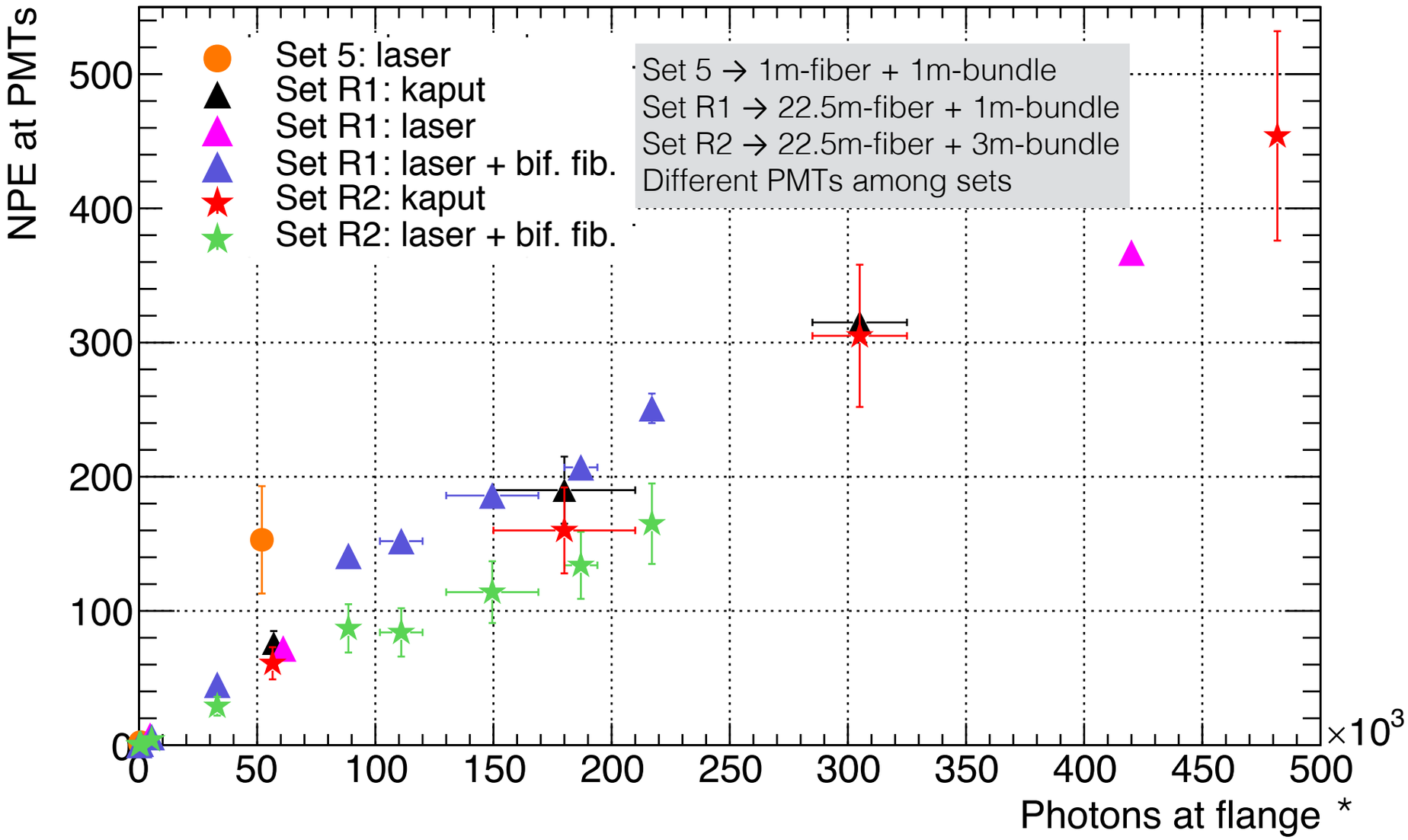
Designed to vary the amount of incident light form SPE to a higher amount avoiding PMT saturation.

- **Kaputschinsky LED** at different voltages
- **Laser** and different filters



Measurements → **Photons at flange measured with power meter** **vs.** **NPE at PMTs**

Results



* Calculated from power measured at flange with power meter

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

f_{kapu} = 10 MHz
f_{laser} = 80 MHz
h = 6.62x10^{-34}Js
c = 3x10^{8}m/s
λ_{kapu} = 460 nm
λ_{laser} = 405 nm

Results

Measured at CT

	NPE at PMTs / NPh at flange	**Light transmission** (*)	**Attenuation**
Kapu	0,10%	**1.42%**	**18.5 dB**
Laser	0.08%	**1.14%**	**19.4 dB**

(*) PMT quantum efficiency at CT: 7%
PoS(PhotoDet2015)019

Expected attenuation from Thorlabs at RT + from RT to CT

- $\mathbf{A_{Kapu}} = A_{MS(Flange)} + A_{22.5m(*)} + A_{MS} + A_{Geo} + A_{3m} + A_{CT(LED)} =$
  $= 1.5\ dB + 1.13\ dB + 1.5\ dB + 12\ dB + 0.15\ dB + 3.48\ dB =$ **19.8 dB (1.05% LT)**
- $\mathbf{A_{laser}} = A_{MS(Flange)} + A_{22.5m(*)} + A_{MS} + A_{Geo} + A_{3m} + A_{CT(LED)} =$
  $= 1.5\ dB + 1.58\ dB + 1.5\ dB + 12\ dB + 0.21\ dB + 3.48\ dB =$ **20.3 dB (0.93% LT)**

Measured attenuation by PMTs and PM is consistent with the expected attenuation (upper value) 👍🏼

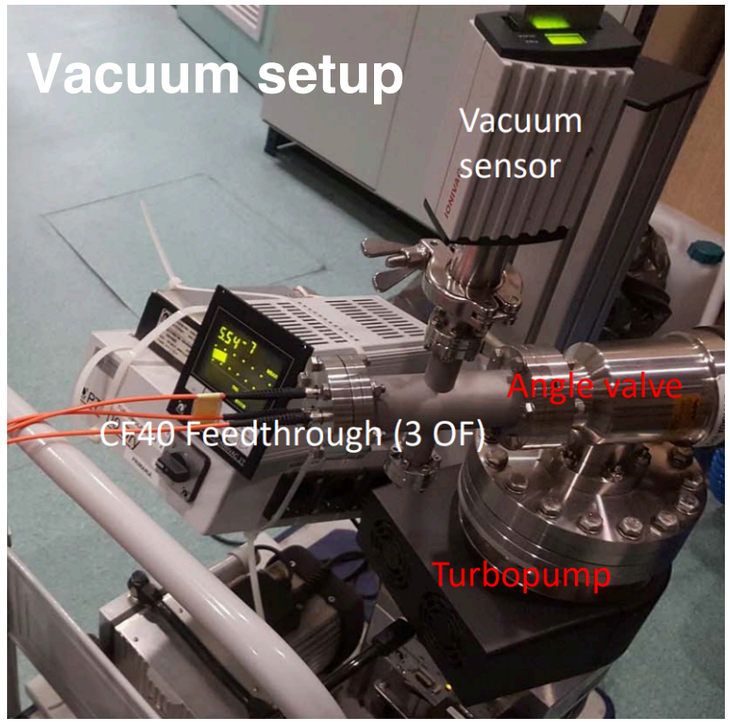
(*) $A_{405nm} = 70$ dB/km (laser)
$A_{460nm} = 50$ dB/km (kapu)

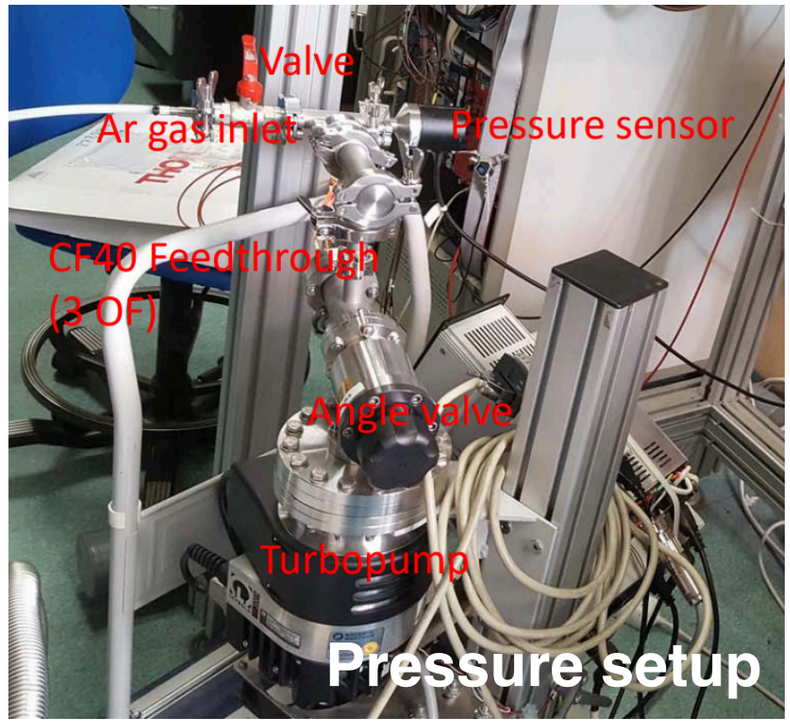
Flange tightness verification

Vacuum test

1. Vacuum of the system after 30 min pumping:
   - Blank flange: 4.3 x10^{-7} mbar
   - Feedthrough (3 OF): 5.5 x10^{-7} mbar
2. Close the valve and turn off the pump:
   - Blank flange: 1.5 mbar after 5 d
   - Feedthrough (3 OF): 1.12 mbar after 3 d
     2.09 mbar after 7 d

Allectra specification for the feedthrough:
HV: 1 x10^{-8} mbar to ambient pressure





Pressure test

1. Vacuum of the system with the FT (3 OF): 9 x10^{-6} mbar after 5 min pumping
2. Leak Detector: No leaks found on the feedthrough (~10^{-8} mbar x l / s)
3. Remove leak detector, vacuum of the system, close valve, and turn off pump.
4. Open the Ar injection valve up to 2 bar a and close valve → 2 bar after 7 days

- No appreciable vacuum differences between FT (3 OF) or blank flange
- No significant pressure leaks up to 2 bar

Feedthrough is sufficiently hermetic 👍

Conclusions

All components available and tested at CIEMAT 👍🏽

Expected and measured light attenuation of the inner system
~20 dB (~1% light transmission)

To discuss

Testing the full light calibration system with IFAE (February).

Paper about the LCS (report about CIEMAT work available)