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ICECUBE
UPGRADE

POCAM

in the IceCube Upgrade

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ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International
Cosmic Ray Conference
12–23 July 2021

POCAM Concept and Design

The Precision Optical Calibration Module (POCAM) [1] [2] is designed to be a high precision, self-monitoring, isotropic, nanosecond, multi-wavelength calibration light source for a precise measurement of the energy scale and resolution within the IceCube Upgrade. The pulsing mimics high-energetic neutrino events and, in combination with the self-calibration, can be used to reduce systematic uncertainties [3] within the illuminated detector volume.

The goals of these in-situ calibrated flashes are, in addition to the calibration of optical detector properties, the verification of its energy scale. Additionally, the POCAM poses a way to further improve the calibration of individual DOMs and the understanding of the refrozen drill hole ice and the Antarctic anisotropy in the IceCube detector volume. Over 20 such POCAMs will be calibrated and deployed in the IceCube Upgrade.

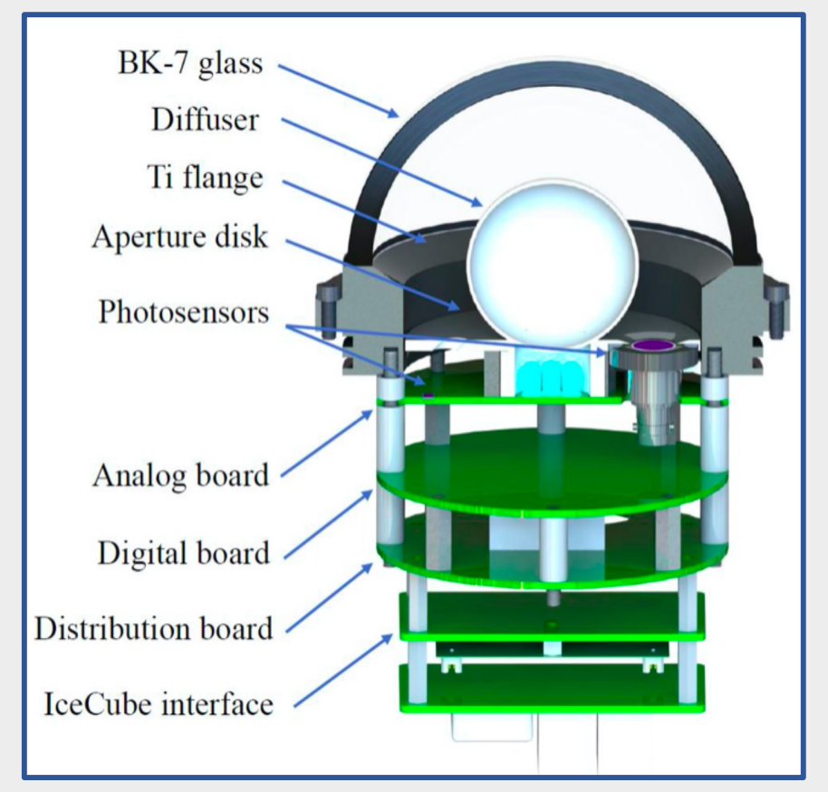


Fig.1 POCAM hemisphere assembly

Light Emitters

6 emitters (3 LEDs (365, 405, 465 nm), 3 LDs (405, 455, 520 nm)) and 4 driver circuits

- ➢ #1&2 Kapustinsky [4] type drivers:
  - ‣ Simple and proven design
  - ‣ Pulse properties pre-selectable by capacitance *C* and inductance *L*
- ➢ #3 &4 redundant LD type drivers:
  - ‣ Fast high-current switching GaN-FET
  - ‣ Adjustable pulse width
  - ‣ Significantly more light output
  - ‣ Laser diodes and UV LEDs
  - ‣ Longer minimal pulse width

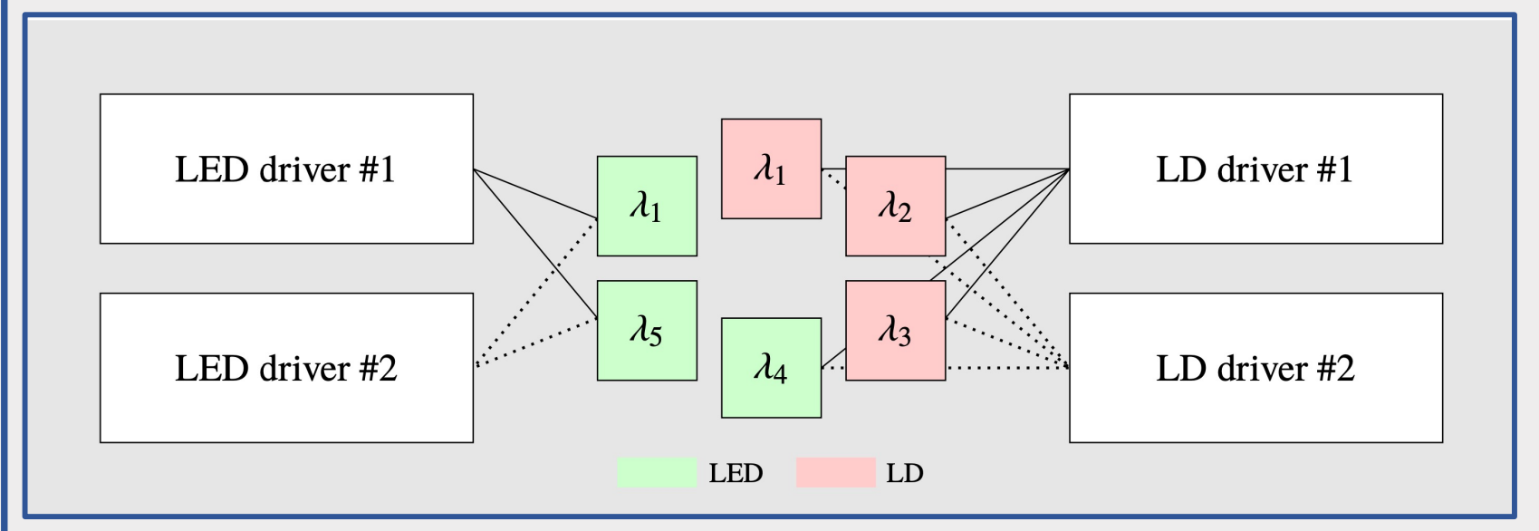


Fig.2 Layout of LEDs, LDs and pulse drivers in the POCAM

Test with 405 nm LED

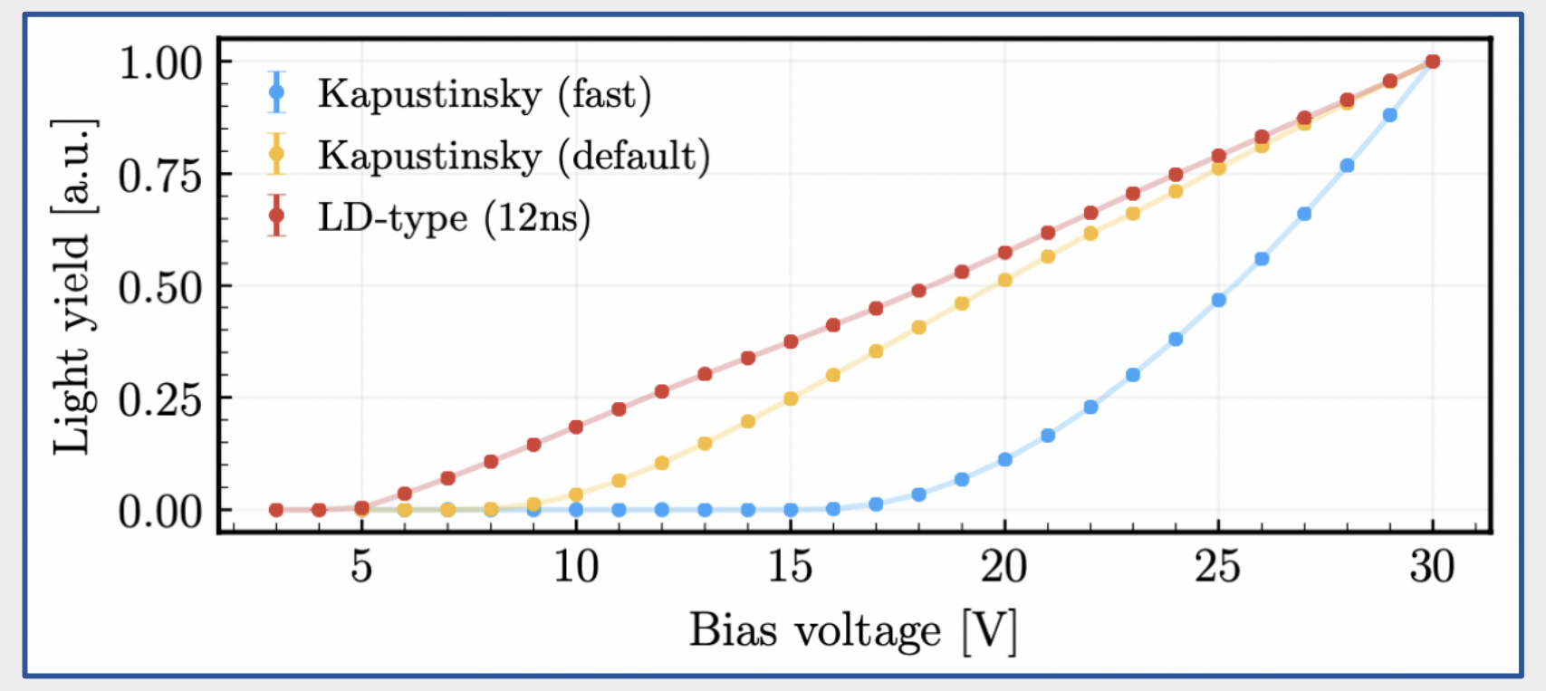


Fig. 3 Intensity yield as a function of voltage

Blue curves: Fast Kapustinsky (C =100pF, L=22nH) with significantly later light onset (left) and 1 – 3 ns FWHM pulse width (right)
Yellow curves: Default Kapustinsky (C=1.2nF, L=22nH), sooner light onset (left) and 4 – 8 ns FWHM pulse width (right)
Red curves: LD-type driver, showing linear intensity behaviour (left), adjusted between 1.5 – 35 ns in FWHM input pulse widths

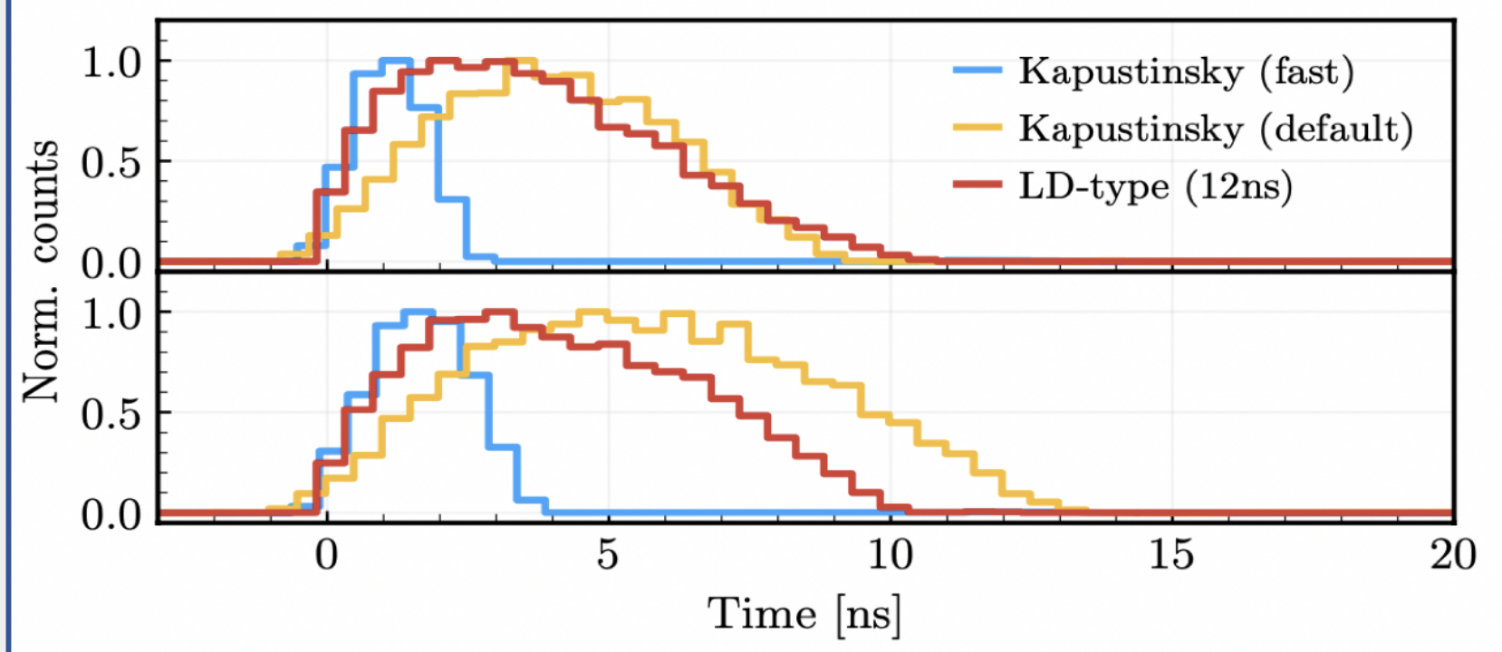


Fig. 4 Time profiles at minimal-working (top) and maximal (bottom) applied bias voltage

Calibration Setups

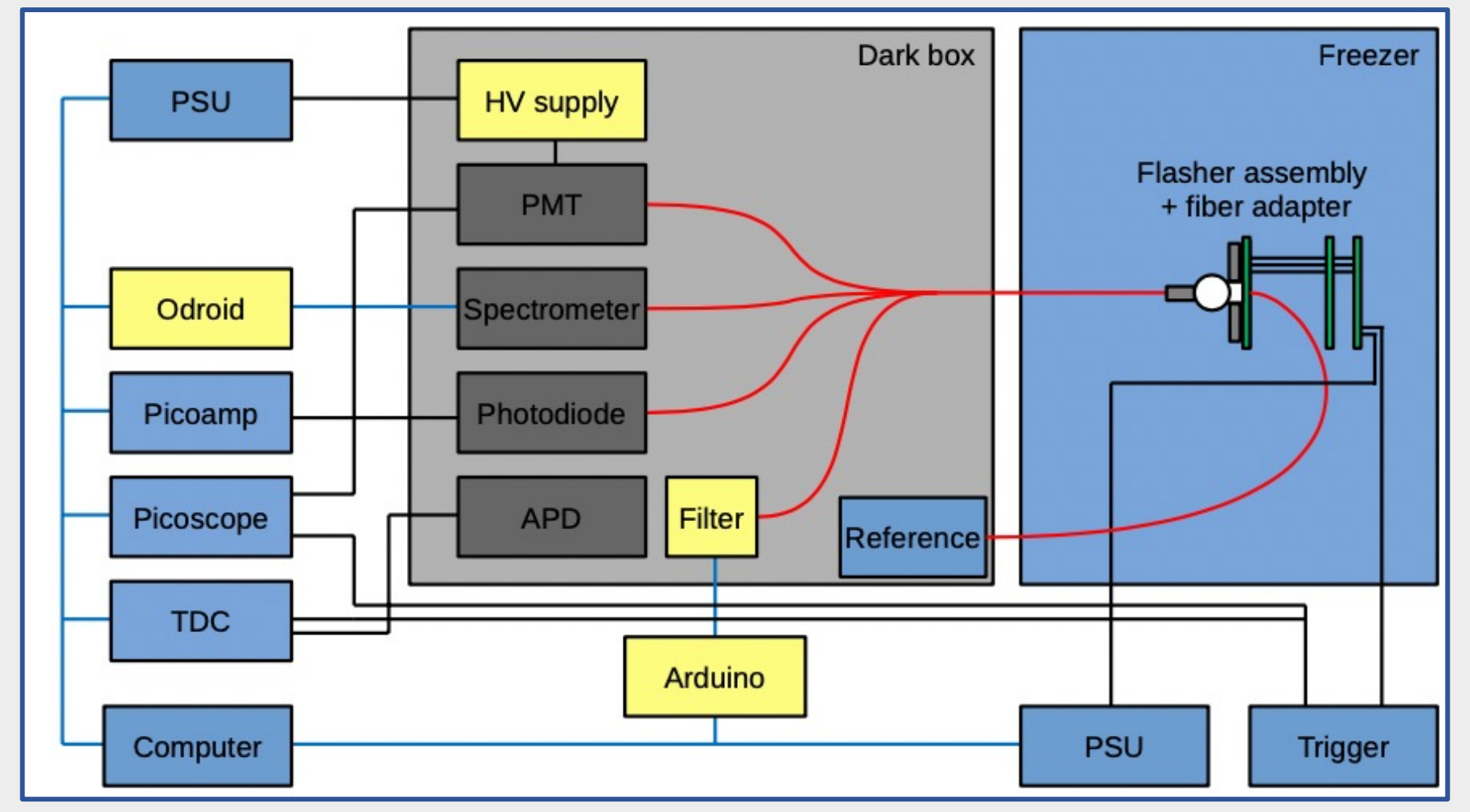


Fig. 5 Schematical workflow diagram of the light pulser calibration station:
To calibrate the flashers, we have a dark box to measure the POCAM light characteristics. This dark box houses four sensors. A *photodiode*, which records the light intensity and is read out by a pico-ammeter. A *PMT*, which also records light intensity and the PMT pulses are further recorded with the help of a digital oscilloscope. An *APD*, which uses time-correlated single photon counting to measure the pulse time profile. Finally, a *spectrometer* is also installed, which directly records and outputs the spectrum via serial command.

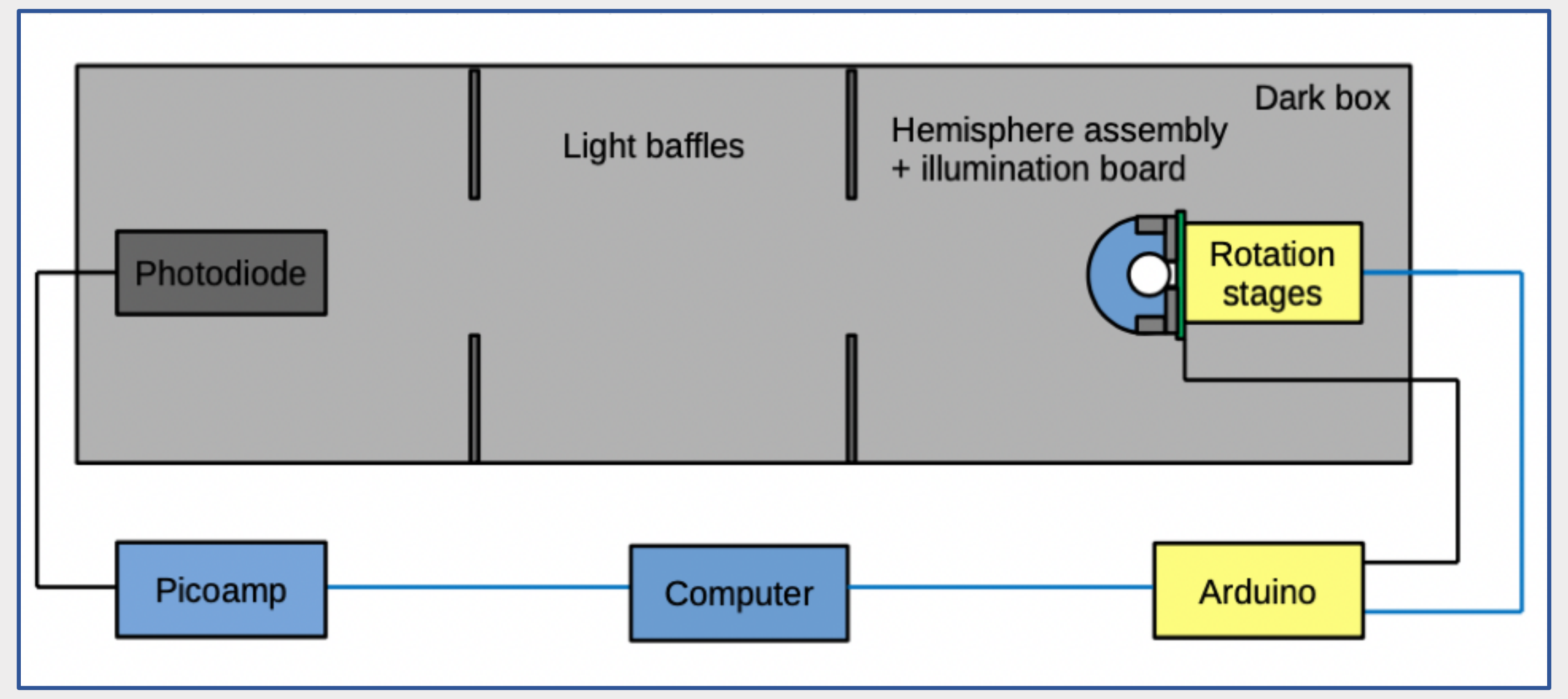


Fig. 6 Schematical workflow diagram of the emission profile calibration station:
The emission profile setup consists of a dark box with a two-axis rotation stage assembly on which the POCAM hemisphere is mounted, with a dedicated illumination board. On the opposite side, a photodiode is mounted. Light baffles in between further reduce stray light from reflections off of inner surfaces.. A dedicated measurement PC then controls the characterization scan for a set of azimuth and zenith angles as well as LEDs and measures the intensity data of the PD. The PD is monitored by a pico-ammeter. This data is then eventually written to file. The relative emission profile provided can further be used to calculate the total hemispherical light yield.

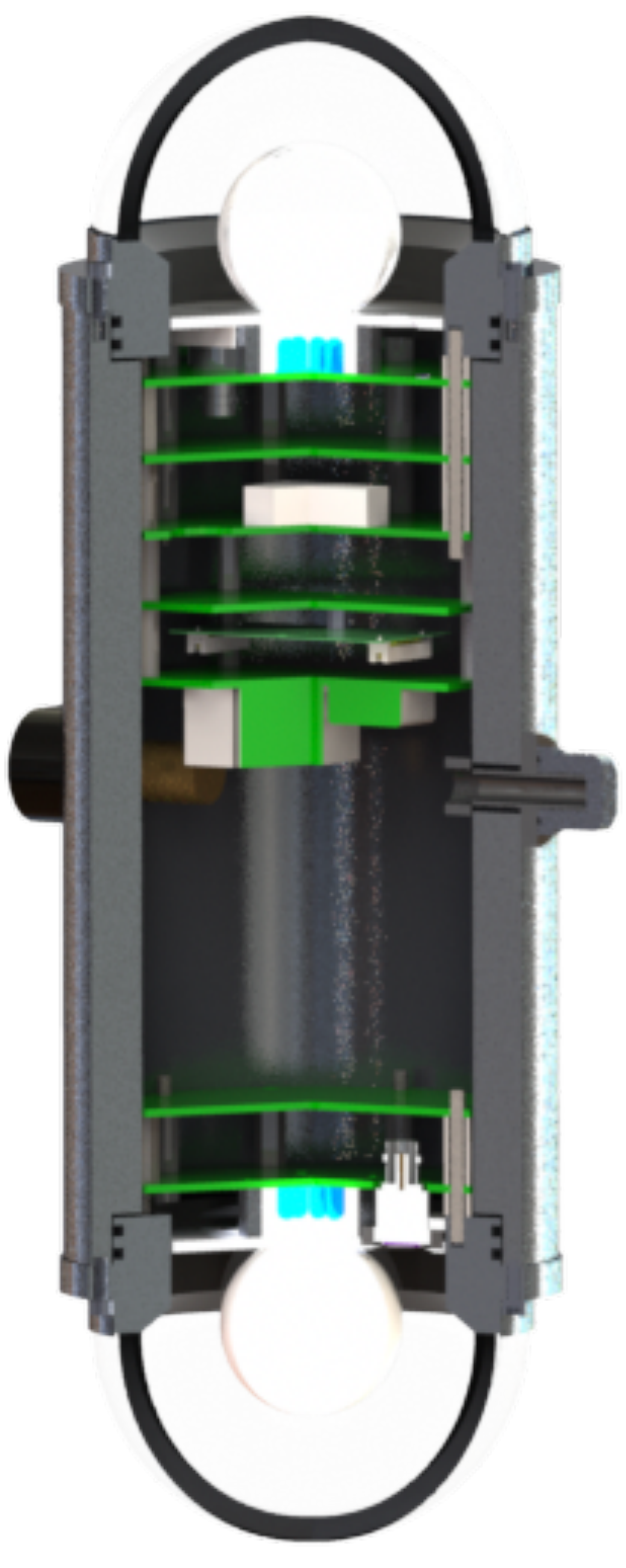
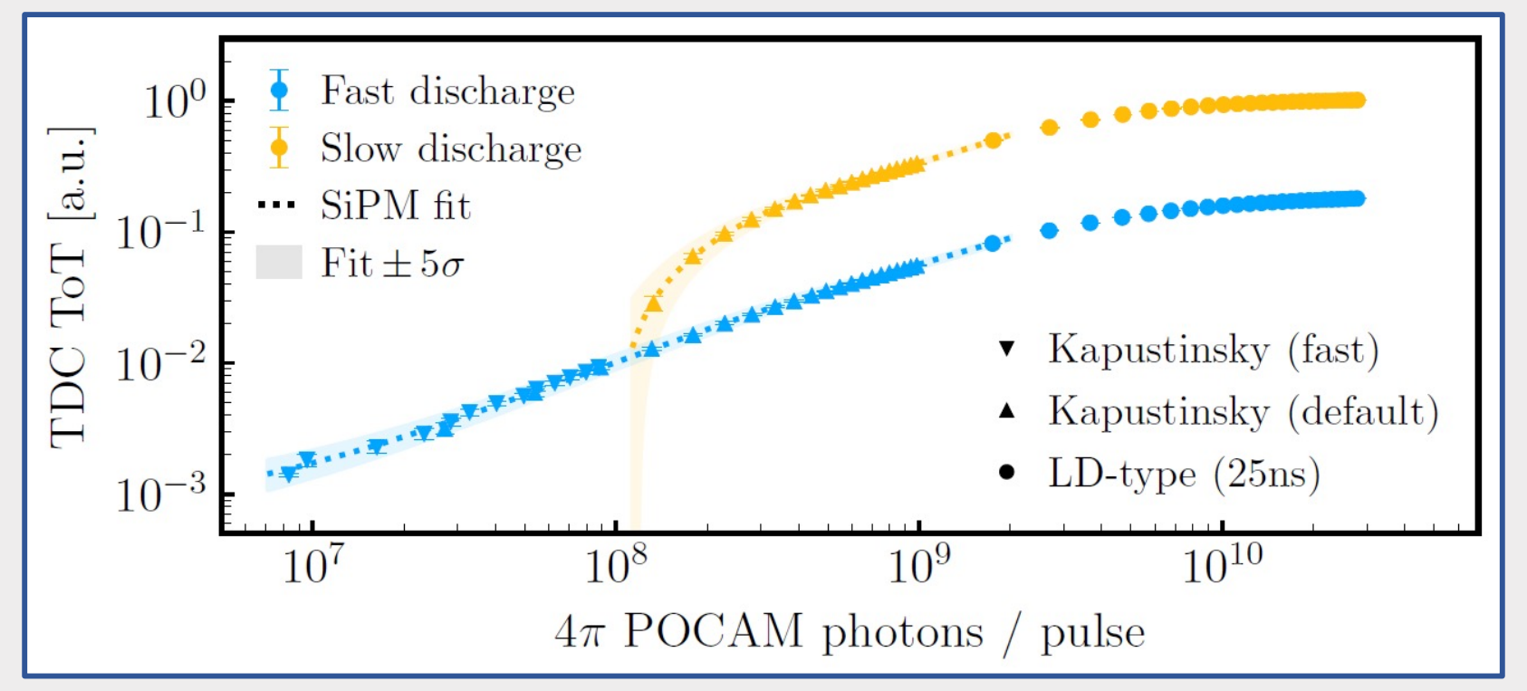


Fig.7 Readout response of the SiPM for all the drivers at 405 nm.(SiPM over-voltage 5V)
The SiPM intends to work in the low intensity regime and makes use of an FPGA discriminator, the signal from which is then fed into a time-digital-converter (TDC) to determine the time-over-threshold (ToT)



Self-monitoring sensors:

For the POCAM to self monitor the light output per pulse and correct for any intensity fluctuations, two sensors- a SiPM and a photodiode (PD) - are embedded into the aperture disk of the POCAM.

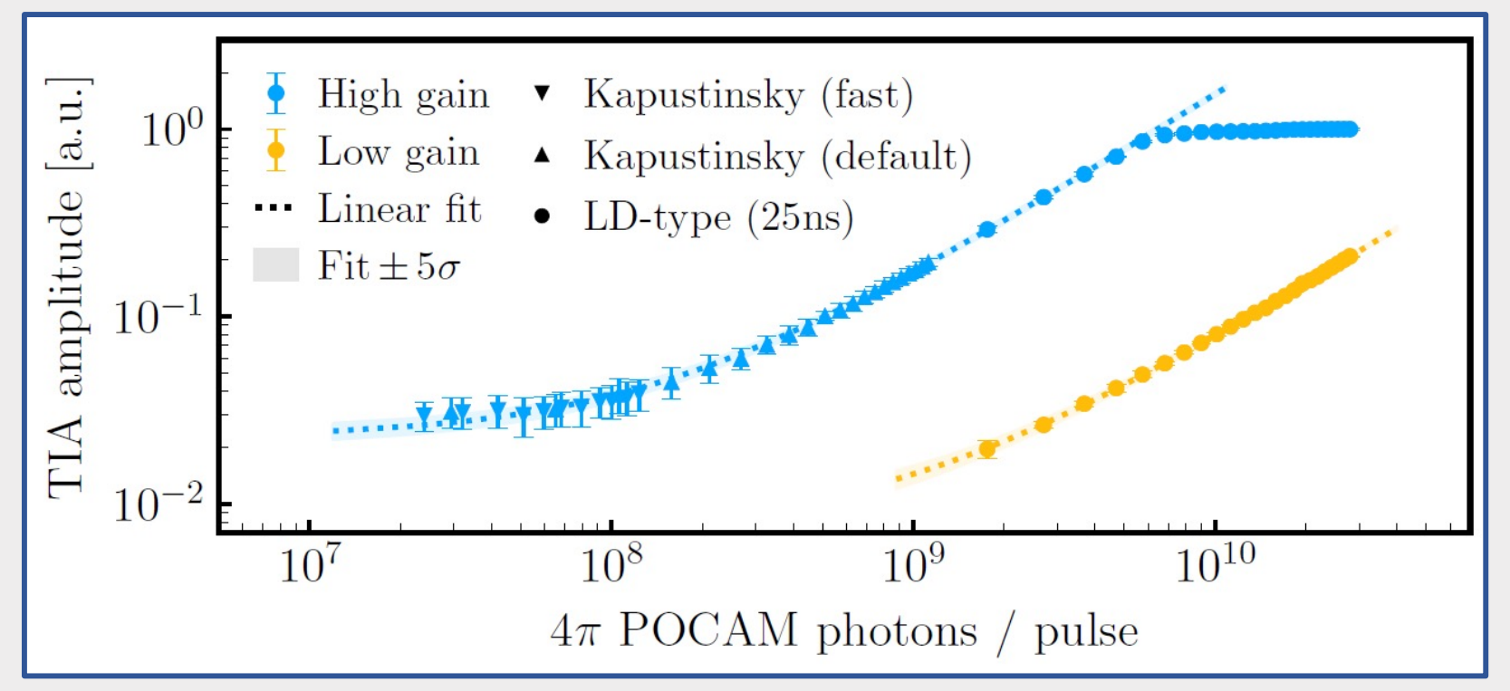


Fig.8 Readout response of the photodiode for all the drivers at 405 nm. The photodiode is responsible for high intensity light measurements and makes use of a transimpedence amplifier (TIA), followed by secondary high gain and low gain amplifiers, which provides a voltage amplitude proportional to the measured charge of the PD.

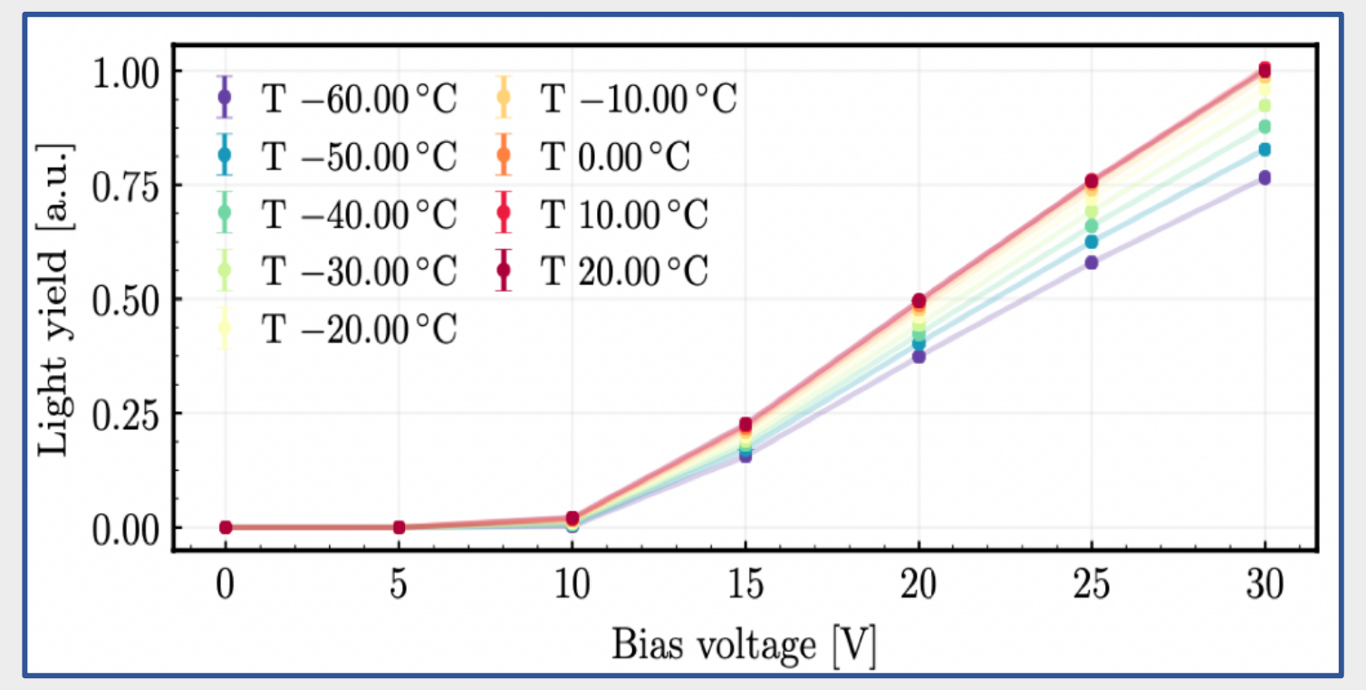
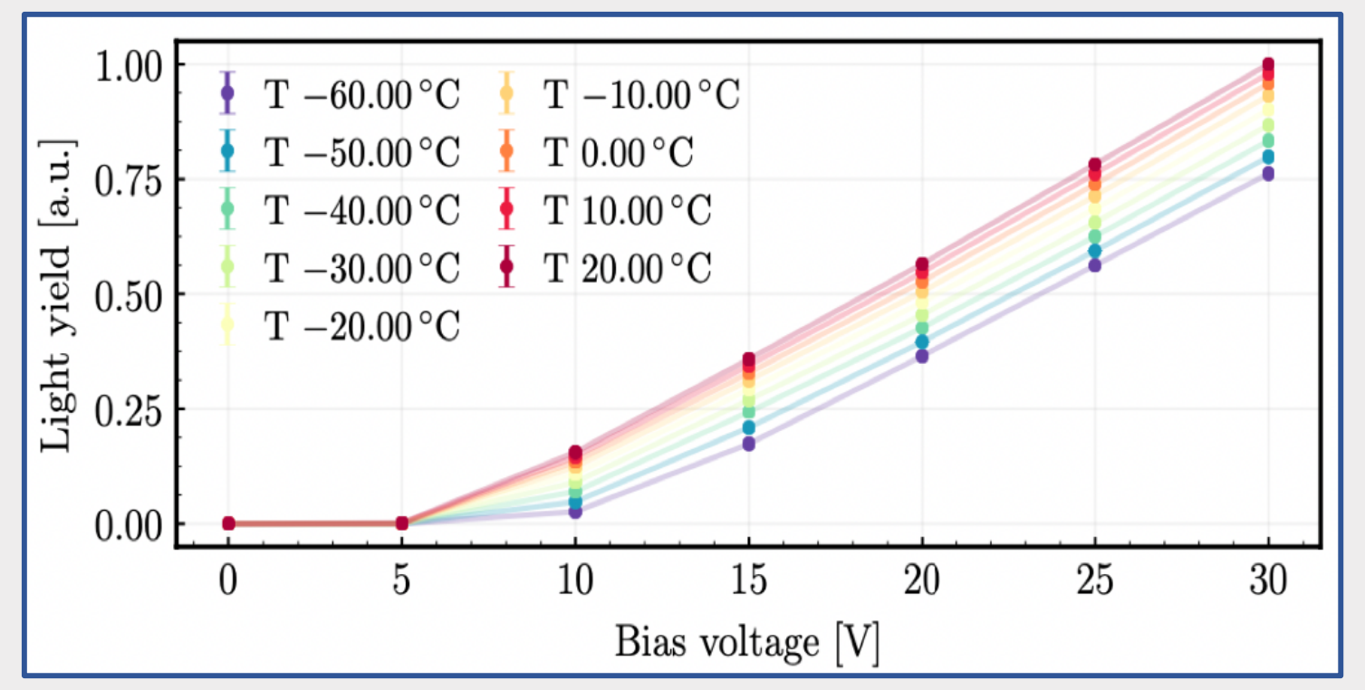


Fig. 9 Temperature dependence of the pulser intensity as a function of bias voltage measured for both the default Kapustinsky (left) and LD-type (right) driver at 25 ns, using respective 405 nm emitters. The fast Kapustinsky shows a similar behaviour to the default driver and thus has been omitted in this figure. The pulsers show decreasing intensities for decreasing temperatures due to most likely increased series resistance



Prototype Calibration:

- Relative flasher characterization performed. Intensity output shown in Fig.9.
- No significant temperature dependence on time profile observed. Emission spectrum showed only small temperature dependence.
- Emission profile of a POCAM hemisphere also measured Fig. 10.
- Absolute light yield uncertainty is 4.1%
- For isotropy measured: 1σ-error of 1.5% over entire zenith range , only 0.4% between 0 – 60°
- Estimated total 4π light yield with 405nm LED: Kapustinsky fast: $(5.1 \pm 0.4)\cdot 10^7$ photons/pulse
  Kapustinsky default:$(7.5 \pm 0.6)\cdot 10^8$ photons/pulse
  LD-type at 25ns: $(2.4 \pm 0.2)\cdot 10^{10}$ photons/pulse

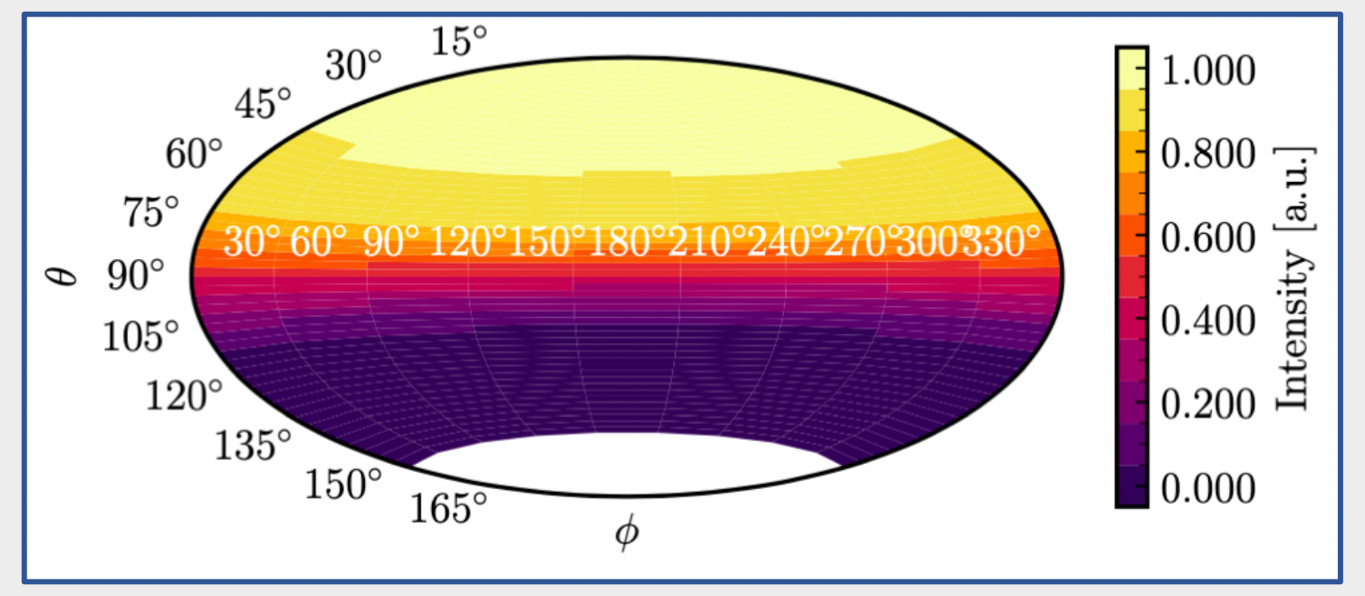
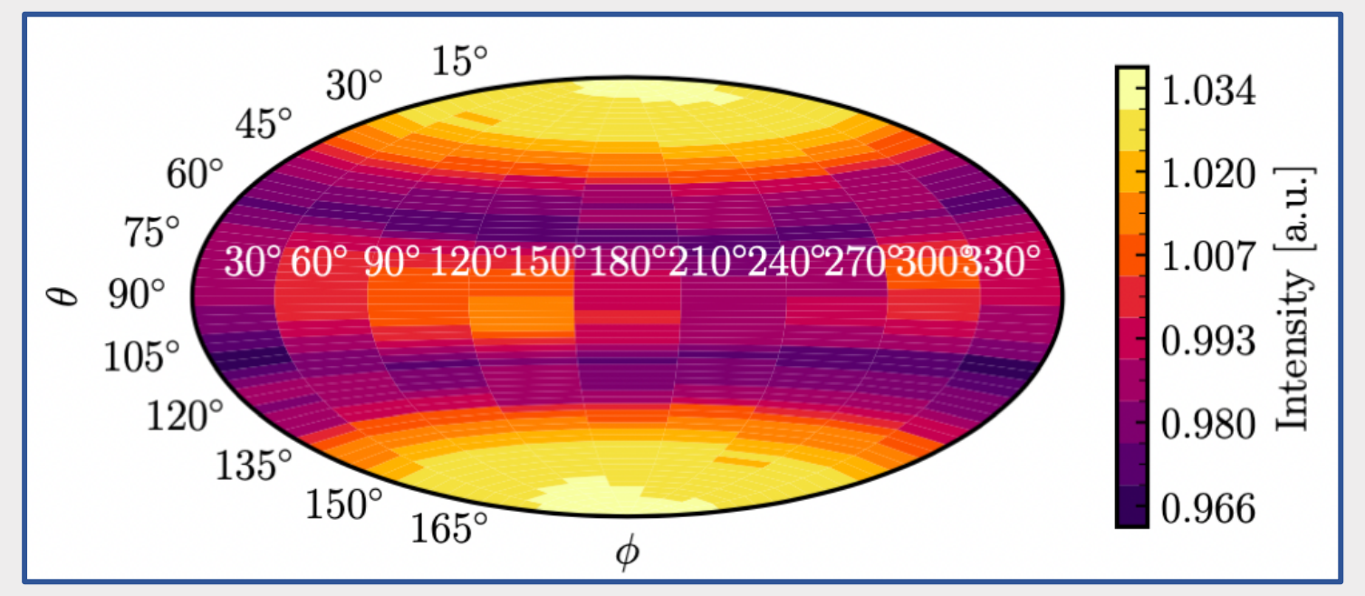


Fig. 10 POCAM hemisphere prototype emission profile in Mollweide projection for a single hemisphere (left) and a virtual complete POCAM (right) in air, where we mirrored and randomly rotated the emission of the hemisphere to create a virtual complete POCAM emission pattern. The pixels represent all measured angular steps with color normalized to maximum (top) and average (bottom) intensity.



Summary:

This work summarizes the developments of the third and final POCAM iteration in the scope of the IceCube Upgrade. In comparison to previous deployments in GVD [5] and STRAW [6], we have optimized several features of the POCAM including total light yield and subsequent dynamic range, spectral composition of emitters, self-monitoring precision, isotropy and internal structure. Additionally we have developed two dedicated experimental setups which allow a streamlined fingerprint-characterization of individual POCAMs versus temperature, light pulser configuration and orientation.

References:

1. F. Henningsen et al. *A self-monitoring precision calibration light source for large-volume neutrino telescopes* JINST 15 (2020) no.07, P07031 [arXiv:2005.00778 [astro-ph.IM]]
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