Status of the LANTERN project

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Optical Calibration

- Based on **photon counting statistics**
- **Low energy calibration** (from ~10 eV)
- 400 nm photons (~3 eV)

Based on Poisson Distribution

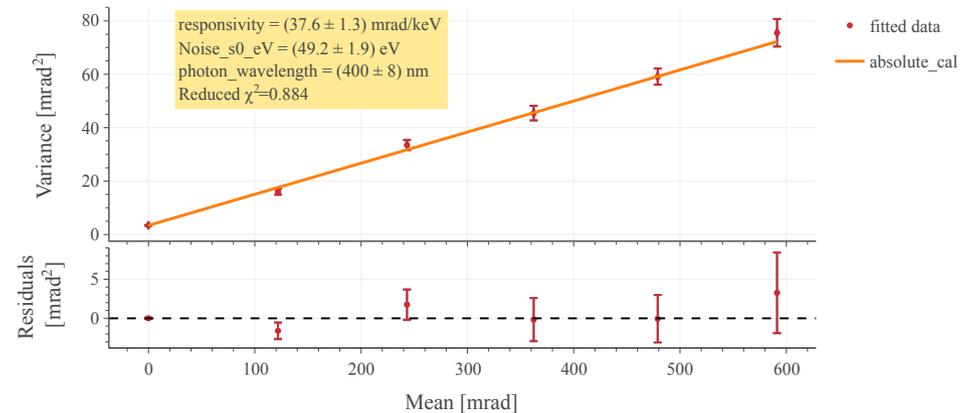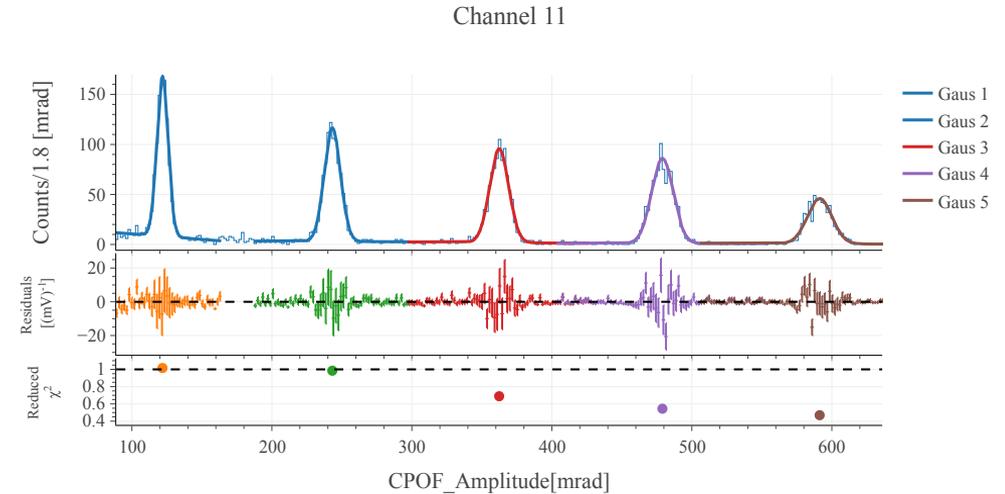$$\mu_\gamma = r \cdot N_\gamma$$

$$\sigma_\gamma = \sqrt{N_\gamma} \cdot r = \sqrt{\mu_\gamma \cdot r}$$

Fitting Function:
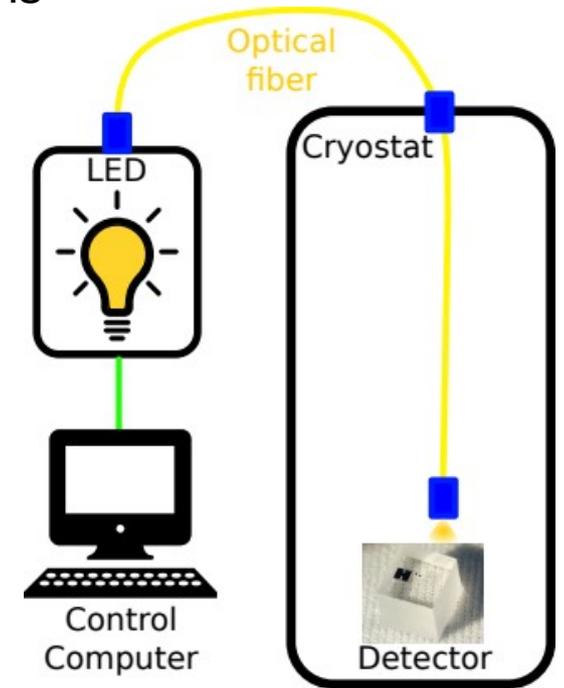
$$\sigma^2 = \sigma_0^2 + r \cdot \mu_\gamma$$
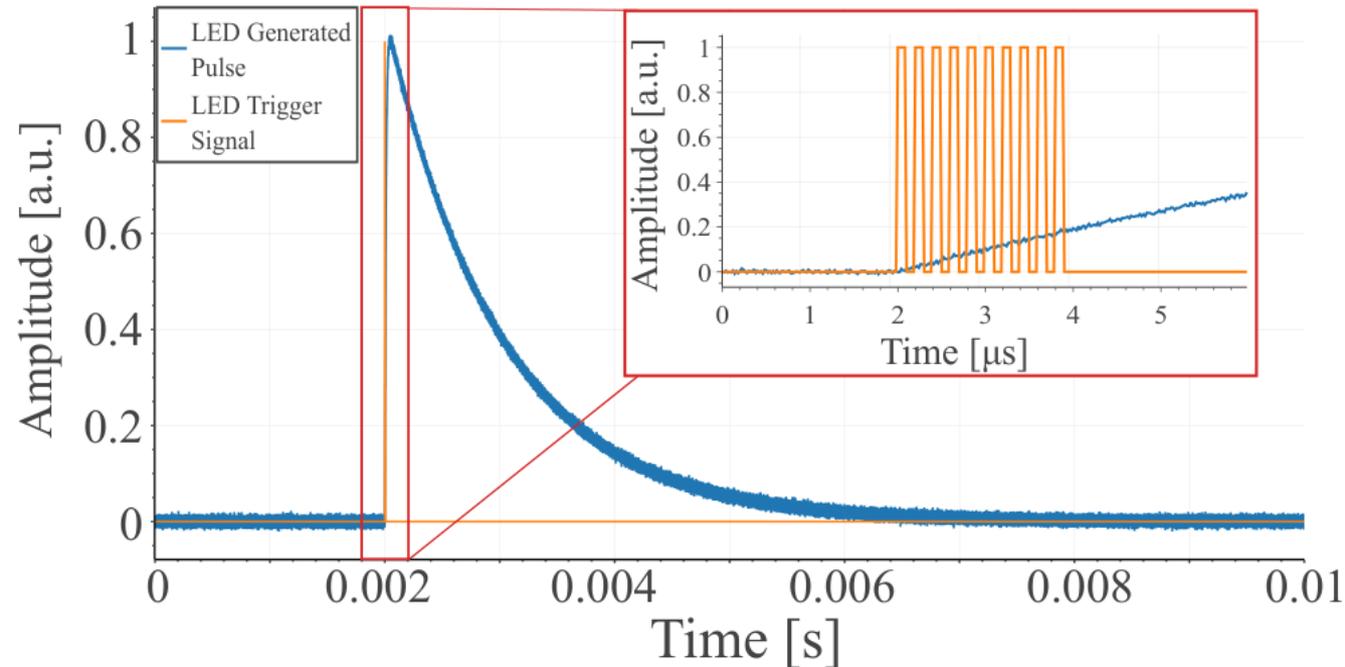
$\sigma_0 = \text{Detector Resolution}$

$$r : \frac{\text{mrad}}{\text{photon}} \longrightarrow k = \frac{\text{photon energy}}{r} \left[\frac{\text{eV}}{\text{mrad}} \right]$$

Channel 11

responsivity = (37.6 ± 1.3) mrad/keV
Noise_s0_eV = (49.2 ± 1.9) eV
photon_wavelength = (400 ± 8) nm
Reduced χ^2=0.884

Setup Concept

- **Fast light flashes (cycles)** for linear scaling of deposited energy

- Use monochromatic **LED** (**UV-Vis** wavelength, photon energy of O(5 eV))

- **Room temperature electronics**

- **No increase in particle background** → usable during physics runs

Non-Linearity Corrections

Linearize mean:

Number of cycles

Non-linearity Parameter

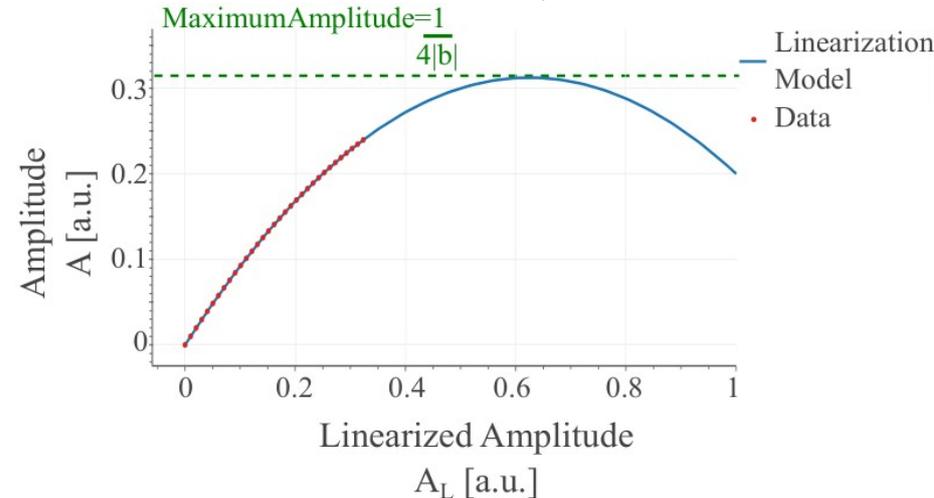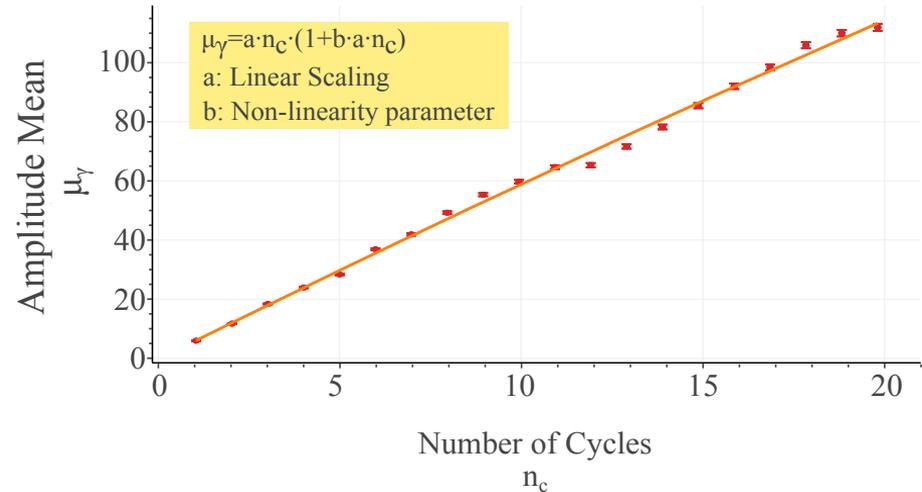$$\mu_\gamma = a \cdot n_c (1 + b \cdot a \cdot n_c)$$

Average Linear Response

$$\mu_\gamma^L := \frac{\mu_\gamma}{1 + b \cdot a \cdot n_c} = \boxed{a \cdot n_c}$$

How to convert event amplitude to energy

$$A_L(A) = \frac{-1 + \sqrt{1 + 4bA}}{2b}$$

$$E = k_L \cdot A_L \qquad k_L = \frac{\text{photon energy}}{r_L} \left[\frac{\text{eV}}{\text{mrad}} \right]$$
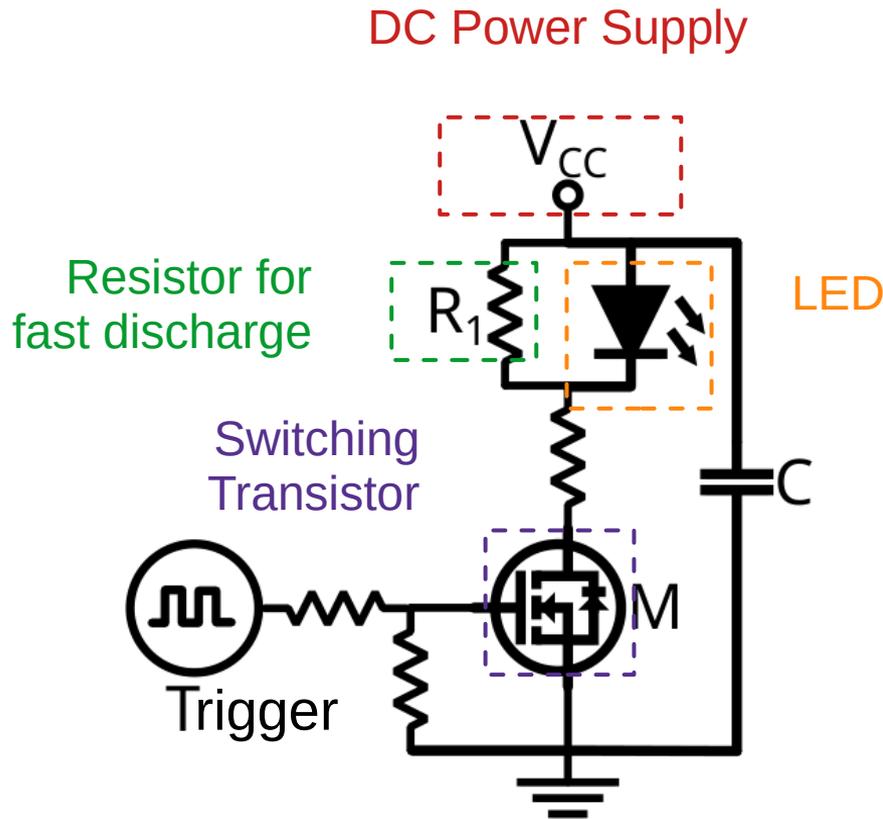
Attention: Valid only in LED range

$\mu_\gamma = a \cdot n_c \cdot (1 + b \cdot a \cdot n_c)$
a: Linear Scaling
b: Non-linearity parameter

Amplitude Mean μ_γ vs Number of Cycles n_c

MaximumAmplitude $= \frac{1}{4|b|}$

Linearization Model
• Data

Amplitude A [a.u.] vs Linearized Amplitude A_L [a.u.]

LANTERN: Concept and Tests

LANTERN: **L**ED **A**rray for **N**on-intrusive **T**uning of the **E**nergy **R**ange with **N**imbleness

* funded from Sapienza University PhD research-starting projects

DC Power Supply

Resistor for
fast discharge

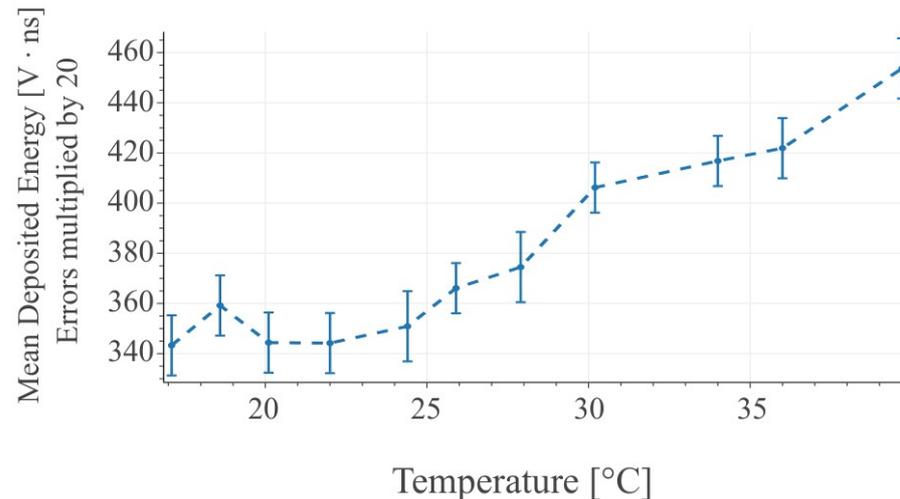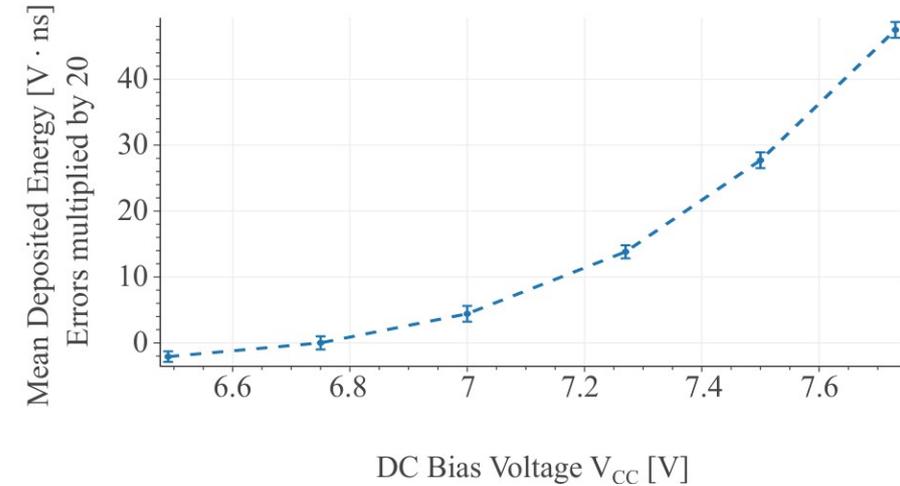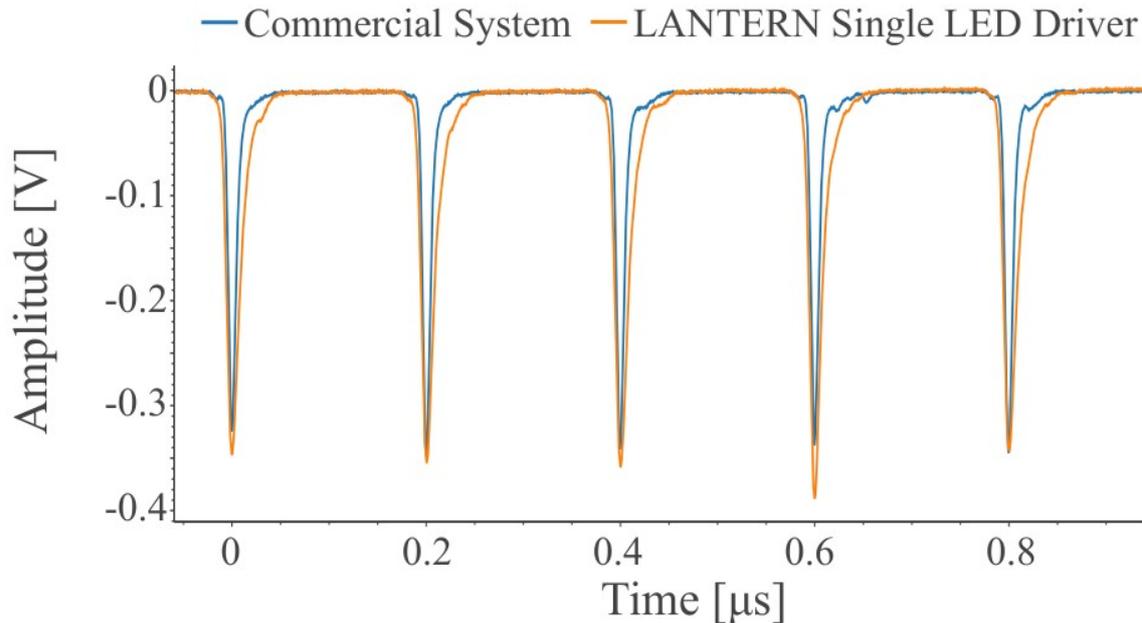LED

Switching
Transistor

Trigger

System Goals
- Scalability
- Wide dynamic range
- Reliability
- Stability

A

B

PMT Tests

- **Matched light emission** as commercial system

- Studied scaling with **DC bias voltage V_{cc}**

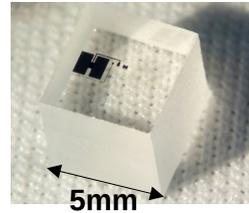- Studied scaling with operation **temperature**
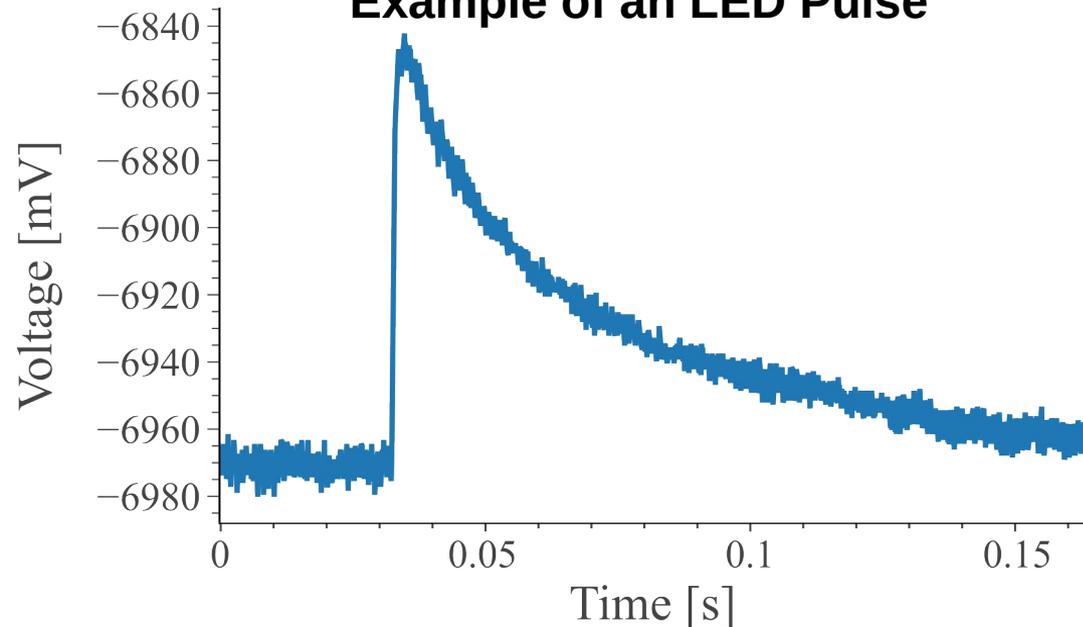
Validation of LANTERN on Cryodetectors

- **No pulse shape deformation** at high energies **observed**

- **Compatible calibration constant** between all tests

nucleus
EXPERIMENT

$CaWO_4$ and Al_2O_3 crystals
+
Transition Edge Sensors
(TES)

5mm

Example of an LED Pulse

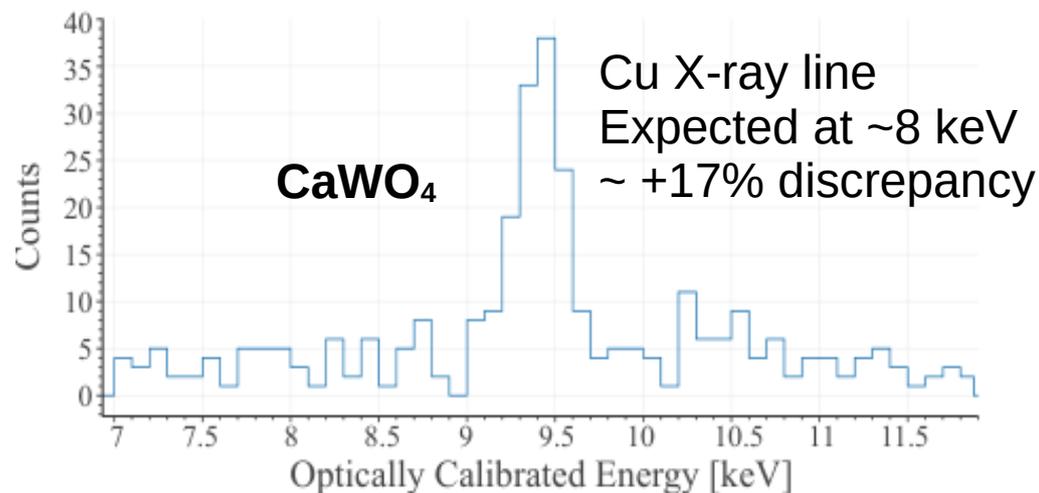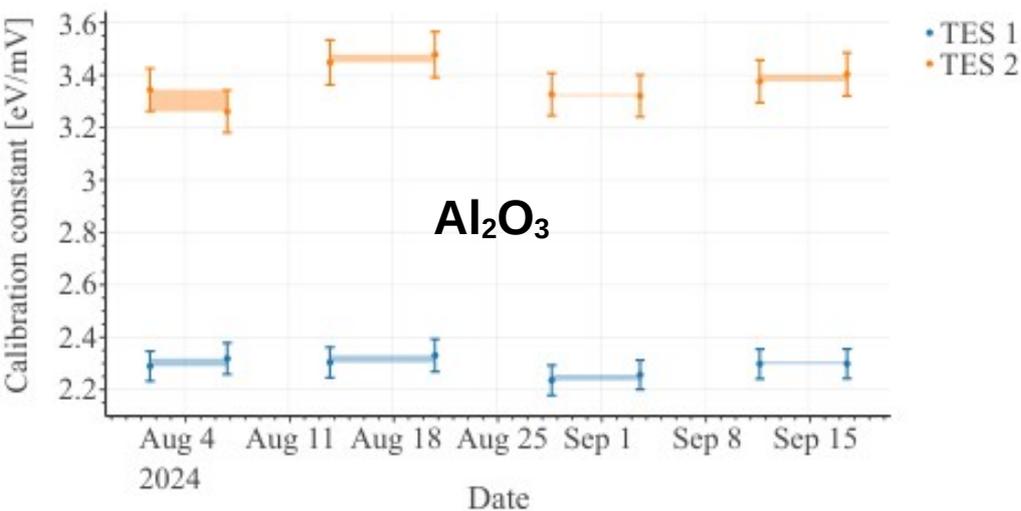|	Calibration Constant [eV/mV]	Mean Rise Time [ms]
Commercial	16.9 ± 0.6	0.94 ± 0.09
LANTERN	17.5 ± 0.7	0.92 ± 0.14

Cryodetector Tests on NUCLEUS detectors

- Performed with **LANTERN single LED using 250 nm**

- **Stable calibration** on Al_2O_3 and $CaWO_4$

- **Al_2O_3 dynamic range: 30 eV – 4 keV**
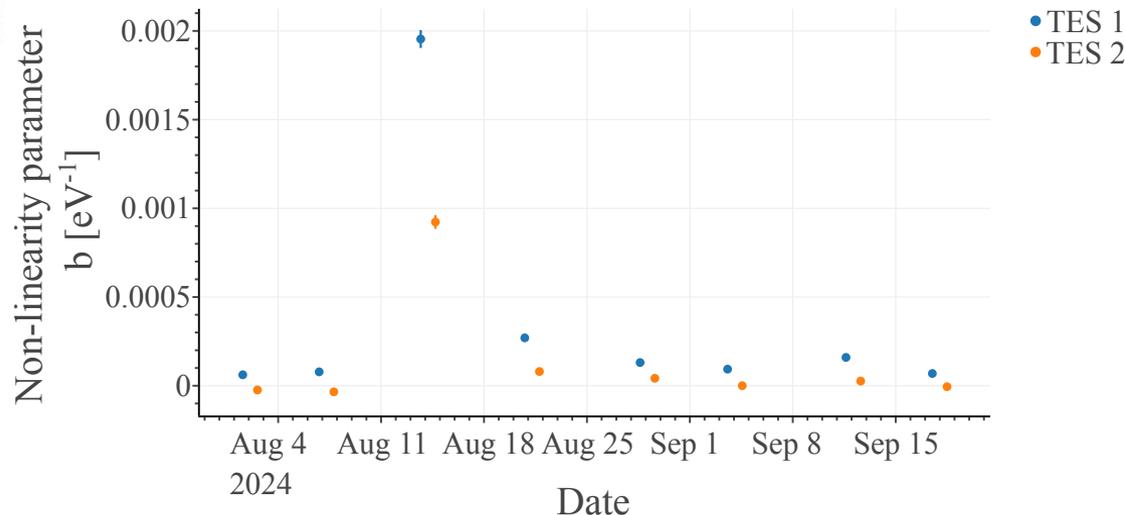
- **$CaWO_4$ dynamic range: 45 eV – 12 keV**

$CaWO_4$ and Al_2O_3 crystals
+
Transition Edge Sensors
(TES)

5mm

Cu X-ray line
Expected at ~8 keV
~ +17% discrepancy

Linearization Issue

- **Damage on LANTERN made it non-linear** (does not affect calibration)

- Damage due to **over biasing**

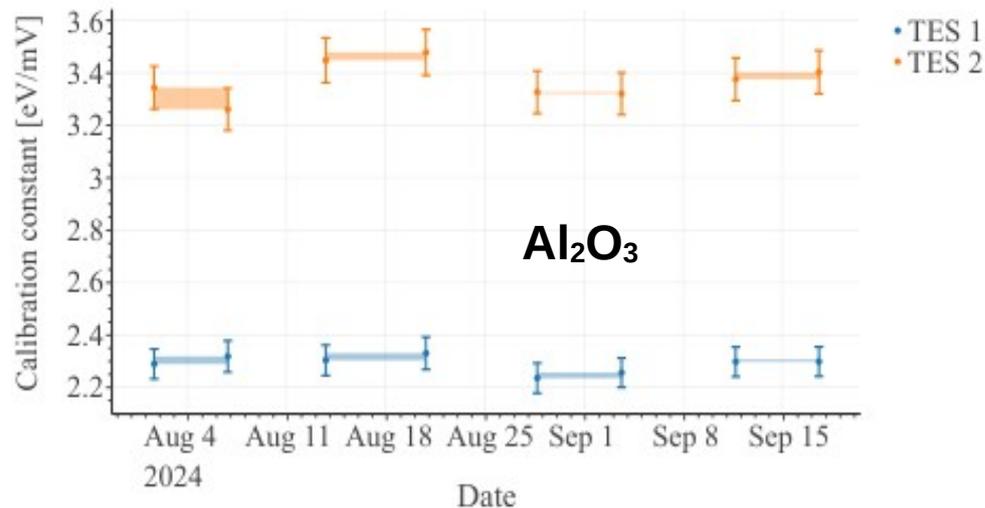- **Back to nominal values after fixing**

- **Calibration not affected!**

$CaWO_4$ and Al_2O_3 crystals
+
Transition Edge Sensors
(TES)

5mm

Al_2O_3

Multi-pixel LANTERN Electronics

- **Scaling concept:** Multplexed LED drivers

- Targeted **64 LEDs**

- **On-chip voltage regulation**

- **Designed for in vacuum operation** → mounting inside cryostat at 300K stage.

Mounting Concept

LED

LED coupler

Fiber Aligner

Fiber Bundle

Detector

Trigger Signal

Serial Connection

Serial Connection

Room Temperature

LANTERN

Fiber Thermalizations

Detector

External electronics with a software control:
- LANTERN
- Signal Generator Control
- x64 Optical Channels

Where we left off: PMT Tests

- Higher Luminosity
- **Dark Counting tests** (20 min duration): **No increase** observed
- **Matched light emission** as commercial system
- Studied scaling with **DC bias voltage V_{cc}**
- Studied scaling with operation **temperature**
- Tested in **vacuum operation**

Configuration	Counts
Dark	734
With Trigger - Enable False	731
Nearby LED shining	715
Far away LED shining	702

- **5mm of Si are semitransparent to IR**

- Use them to penetrate the stack and perform **pixel ID**

- **Worked with 2 wafers** (needs further tests)

1200 nm

RefractiveIndex.INFO

Pixel identification using IR light

Pixels under optical fiber

- LED 1
- LED 2
- LED 3

Current Status

We have all the ingredients…
but we need to start cooking!!

Conclusion

The Road so Far ...

- **Promising tests** on both PMT and Cryodetectors
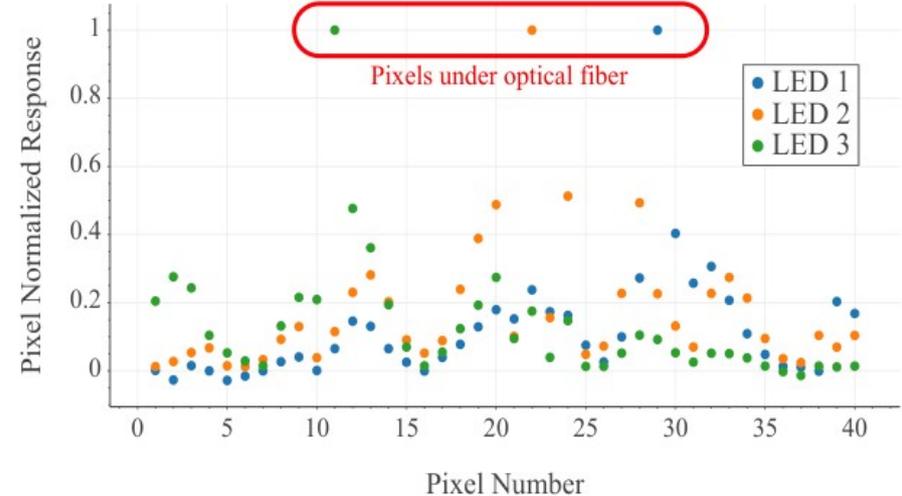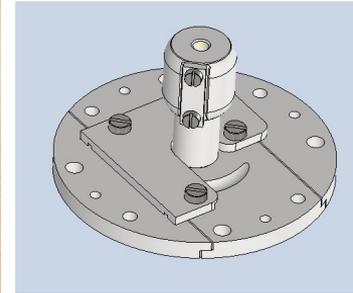- LANTERN used **successfully in NUCLEUS** for physics run
- In NUCLEUS ~ **17% calibration discrepancy** X-rays
  (-10% on BULLKID see @Matteo Folcarelli Tomorrow)
- Produced **5 PCBs**, bought **fibers** and optical mountings, fiber
  thermalization elements are under production, **LEDs** are available

The Road Ahead ...

- **Mount LEDs on PCBs**
- Test the electrical and optical behavior of PCBs
- **Test thermalization of optical fibers !**
- Test in vacuum operation of PCBs (again)
- Develop control software (preliminary version already available)
- Deploy full system in Rome's cryostat

Thank you for your attention!!!

Variance Scaling with Energy

Optical Calibration

- Detector effects (position effects or others) can produce a quadratic scaling between variance and mean

- Fitting ω allows to take them into account in the calibration. The "r" parameter remains the one used for the calibration constant

- Saturation competes with this effect, so it is advised to perform the linearization first

Based on Poisson Distribution

$$\mu_\gamma = r \cdot N_\gamma$$

$$\sigma_\gamma = \sqrt{N_\gamma} \cdot r = \sqrt{\mu_\gamma \cdot r}$$

Fitting Function:

$$\sigma^2 = \sigma_0^2 + r \cdot \mu_\gamma + \omega \mu_\gamma^2$$

$\sigma_0 = \text{Detector Resolution}$

$r : \dfrac{\text{mV}}{\text{photon}} \longrightarrow k = \dfrac{\text{photon energy}}{r} \left[\dfrac{\text{eV}}{\text{mV}}\right]$

$$\sigma_{LED}^2 = \sigma_{N_{ph}}^2 \langle \epsilon_{ph} \rangle^2 + \sigma_{\langle \epsilon_{ph} \rangle}^2 \langle N_{ph} \rangle^2 = \langle N_{ph} \rangle \langle \epsilon_{ph} \rangle^2 + \frac{\sigma_{\epsilon_{ph}}^2}{\langle N_{ph} \rangle} \langle N_{ph} \rangle^2 =$$

$$= \langle N_{ph} \rangle \langle \epsilon_{ph} \rangle^2 \left(1 + \frac{\sigma_{\epsilon_{ph}}^2}{\langle \epsilon_{ph} \rangle^2}\right) = E_{dep} \langle \epsilon_{ph} \rangle \left(1 + \frac{\sigma_{\epsilon_{ph}}^2}{\langle \epsilon_{ph} \rangle^2}\right) \approx E_{dep} \langle \epsilon_{ph} \rangle \left(1 + 10^{-4}\right)$$