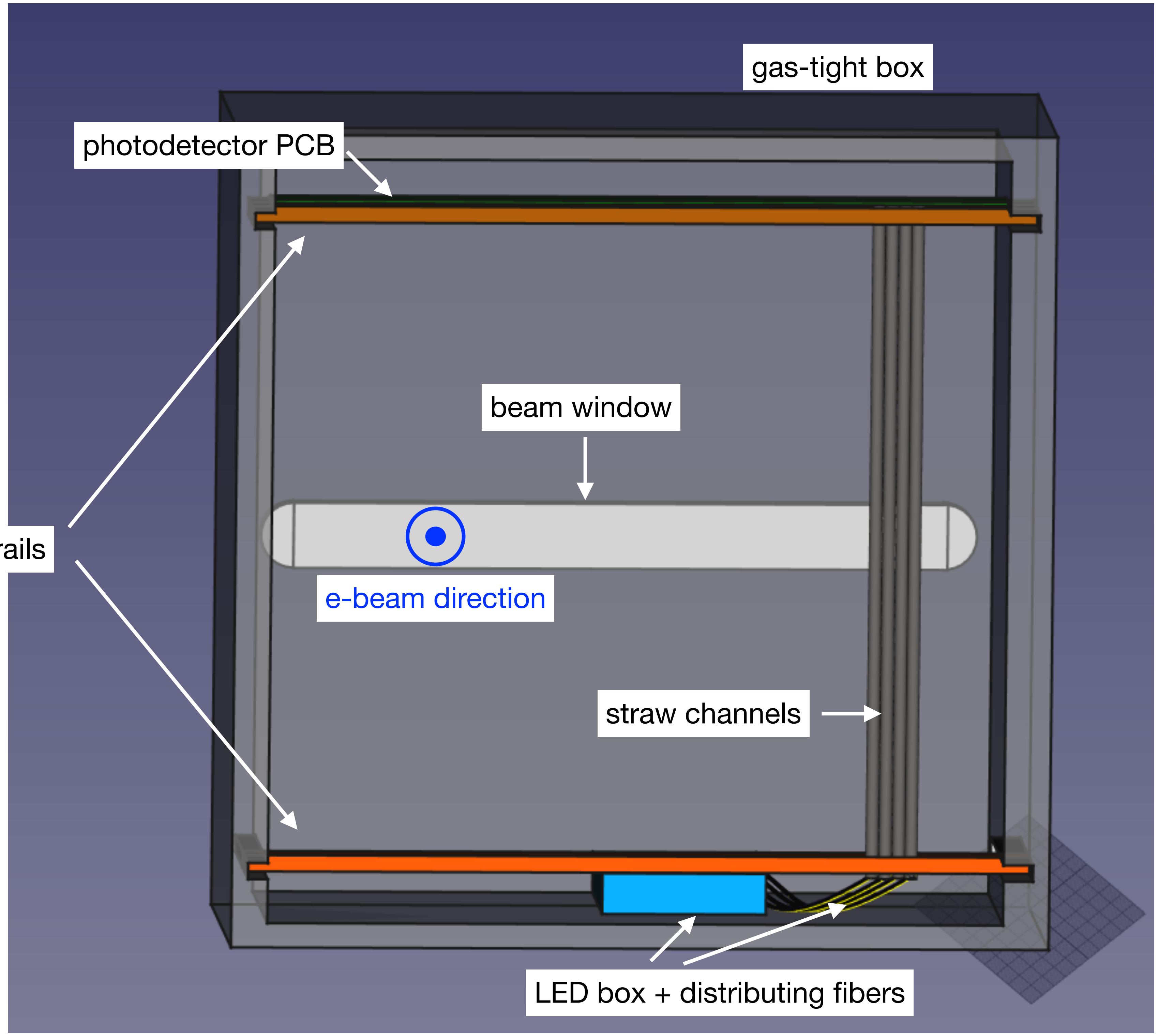
LUXE Cerenkov Detectors Update

Louis and Ruth

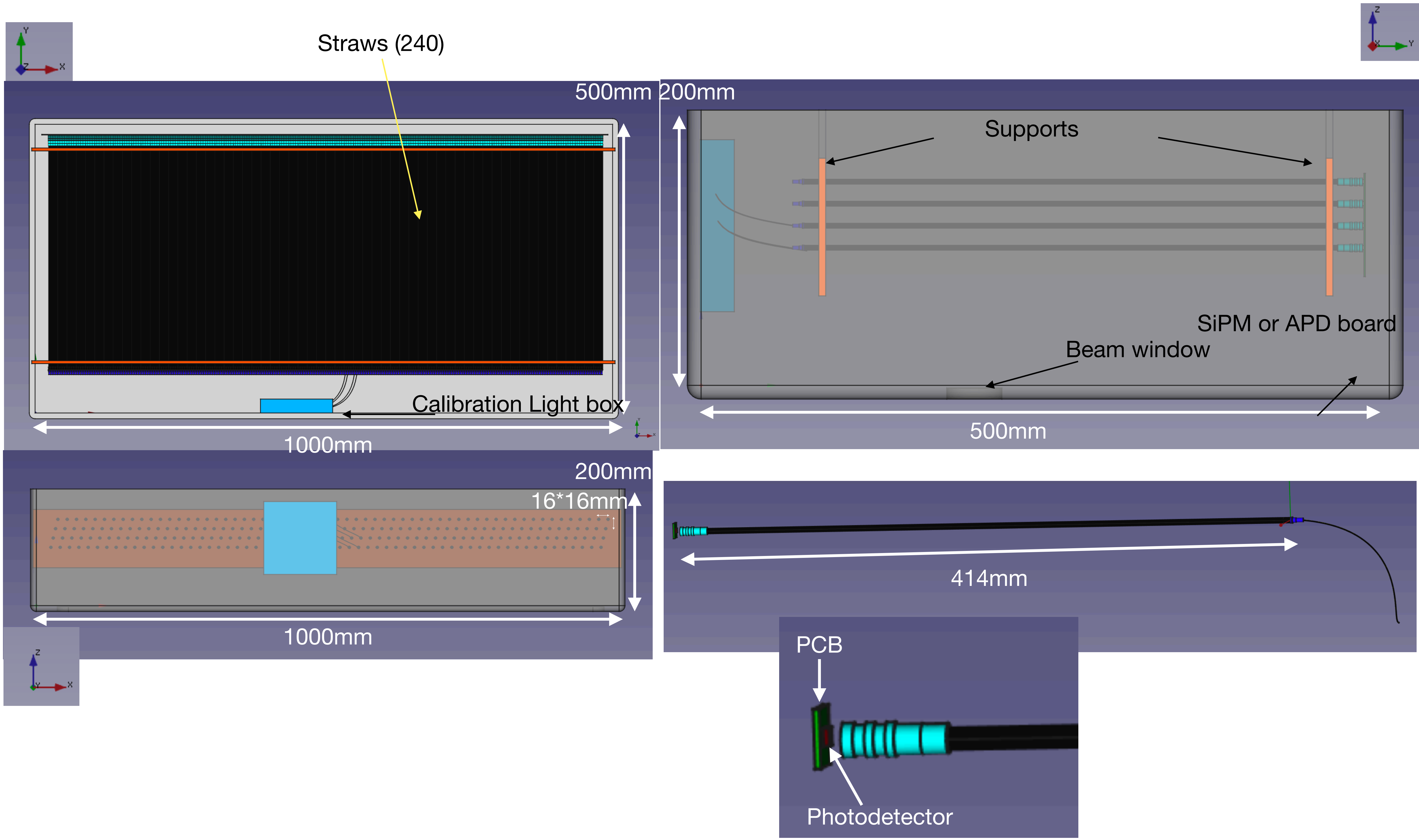
LUXE technical meeting

14th July 2021

Straw Cerenkov design: For orientation



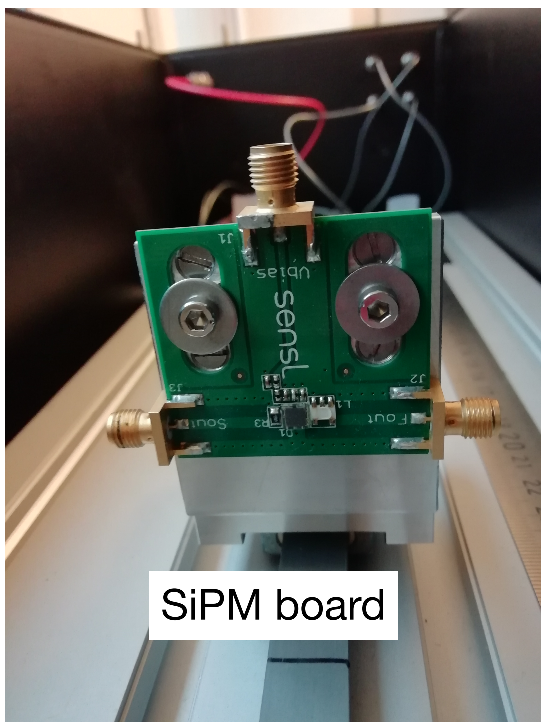
Most recent design

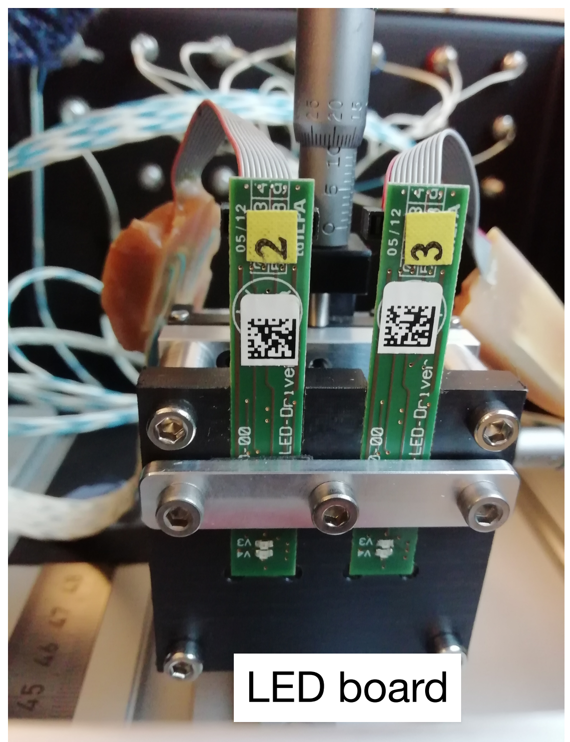


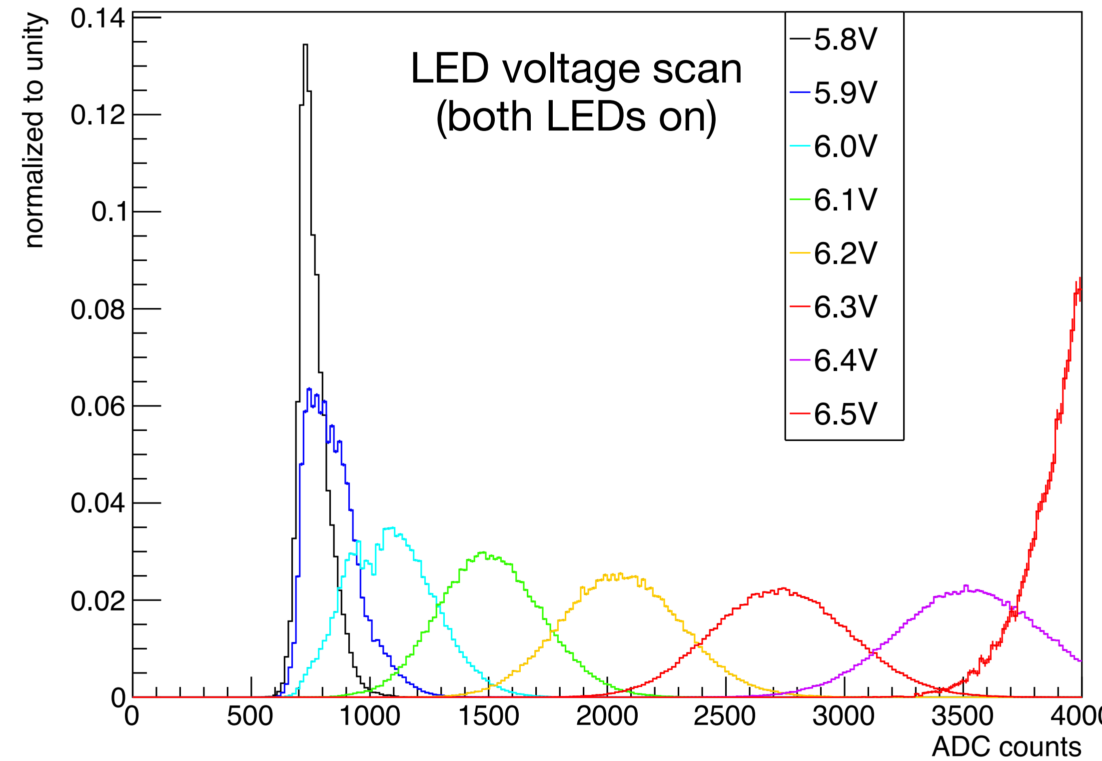
- New design idea: stagger 4 layers of straw channels spaced ~2cm apart, to have more distance between photodetectors on PCB, but still have full coverage

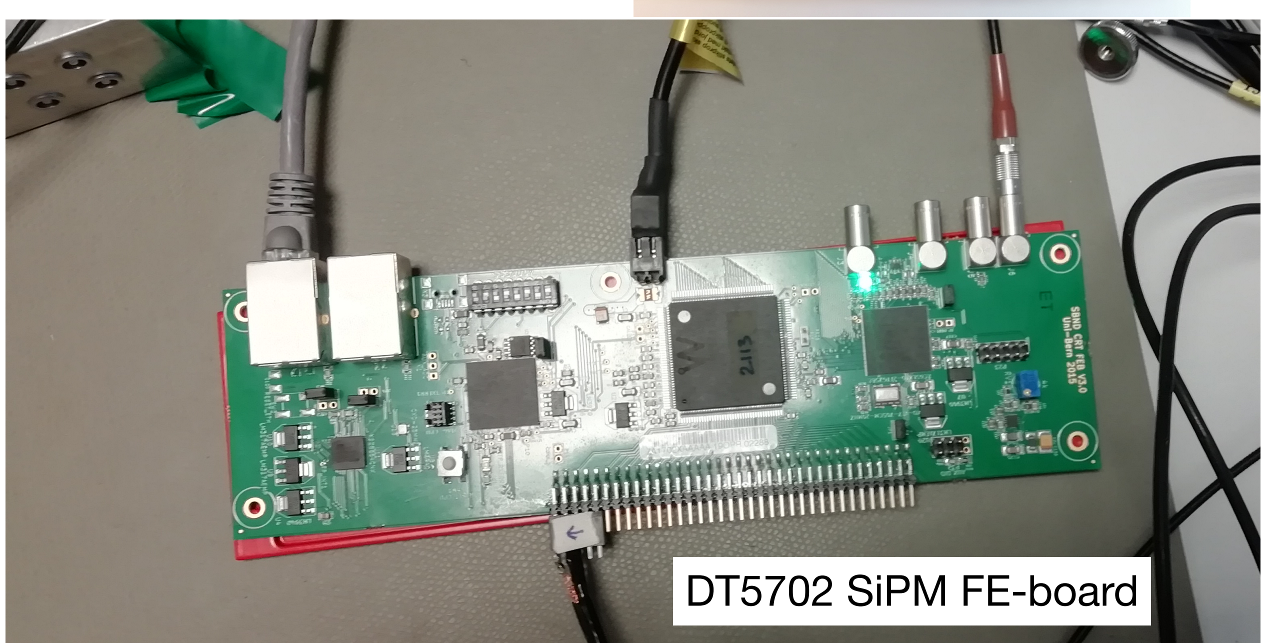
Lab Update

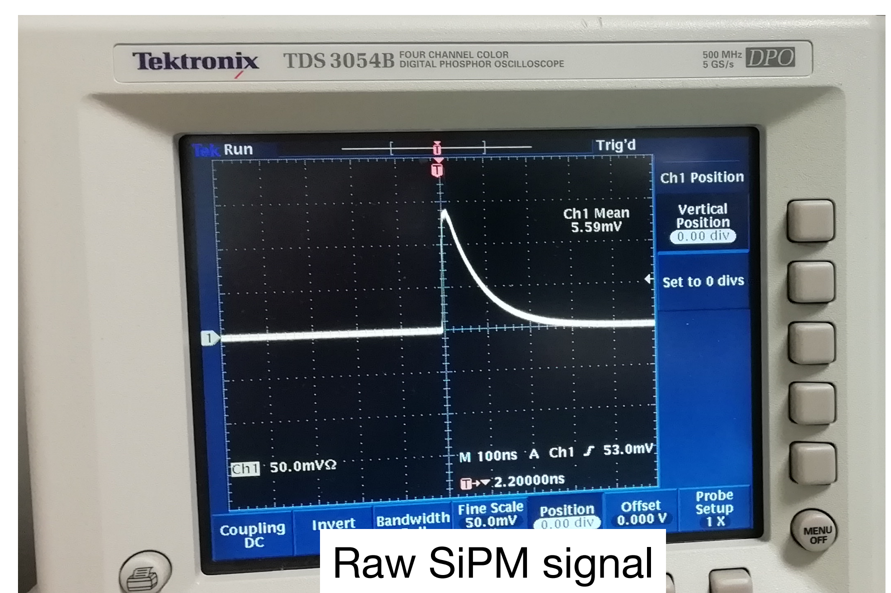
- CAEN DT5702 SiPM readout board working
- Example readout software is in principle “plug and play” — but not very flexible, so we will need to add some bits on top
  → will get modified version from Yan
- Took some first data with LED calibration board and SiPM in the light-tight box


SiPM board


LED board

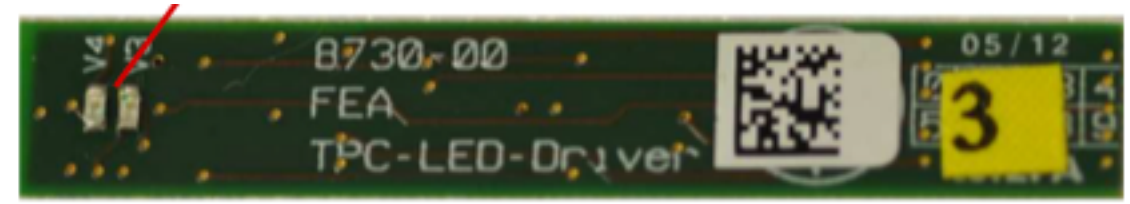



DT5702 SiPM FE-board

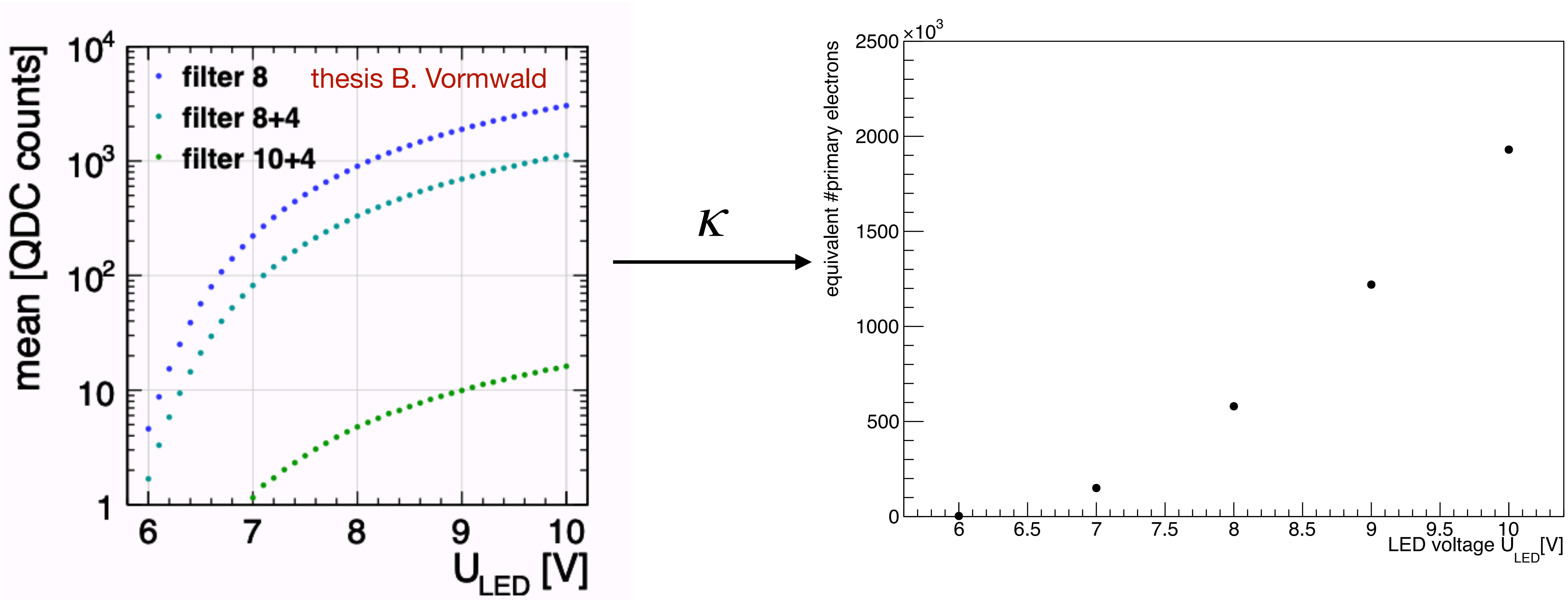


Raw SiPM signal

LED calibration



- we have the precision calibration board
- which "number of incoming Compton electrons" do the different LED voltages correspond to?



- knowledge of the photodetector, readout electronics, channel geometry, filte is encoded in κ:

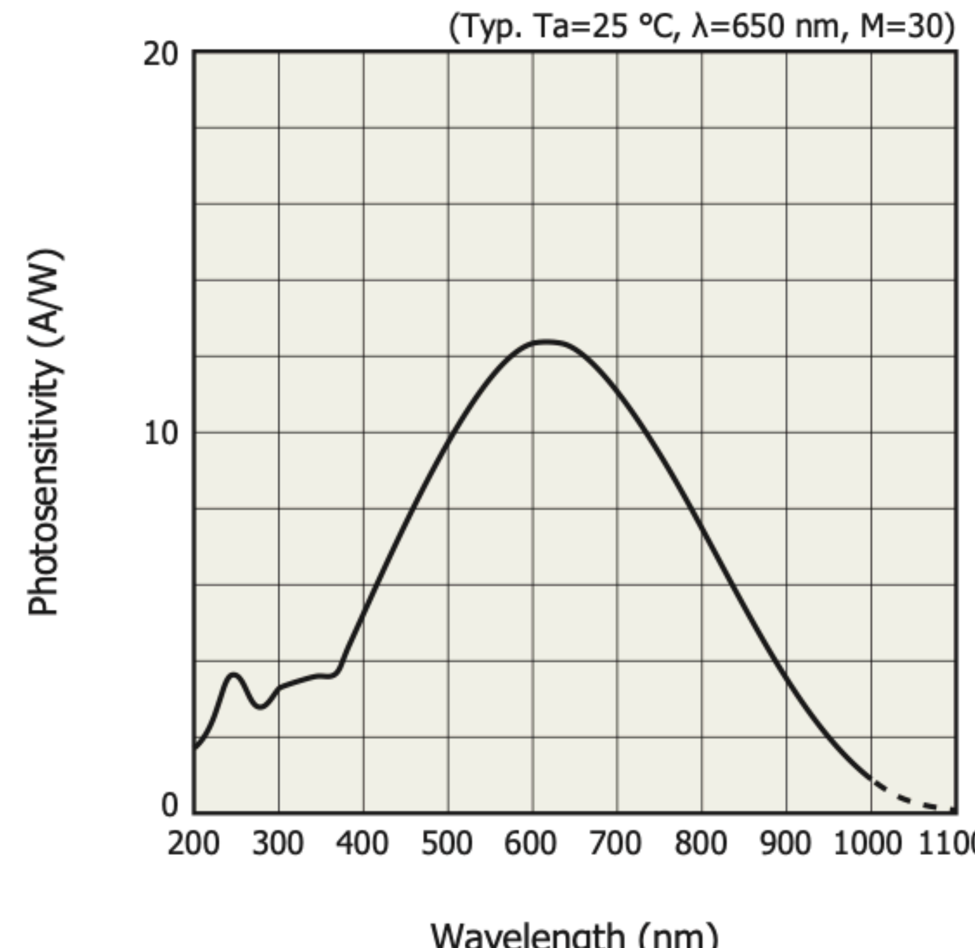
$$\kappa = \int_{\lambda_{min}}^{\lambda_{max}} PDE \cdot \epsilon_{refl} \cdot N_{\gamma}(\lambda) \cdot \epsilon_{filt}$$

- using info on setup used in thesis (κ≈6.5) and our setup (κ≈0.03,assuming ϵ_{filt}=0.5 for Straws), can calculate equivalent number of primary electrons for each LED operating voltage
- ϵ_{filt}=0.5 seems ok based on what we have seen, but would need to determine this more precisely in high-rate test with electrons

In LUXE conditions would have ~100x the amount of light than is created by our LED at U=10V.

APD vs. SiPM?

- SiPMs may have too much gain for us (gain ~1e6)
  → alternative could be Avalanche Photodiodes (gain 100-1000)
- we contacted Hamamatsu, they have an integrated option
  (S12702-12, 3mm diam APD + powering + preamp circuit, cost: ~500€)
- for readout would need a digitizer (e.g. CAEN-743 family) in addition

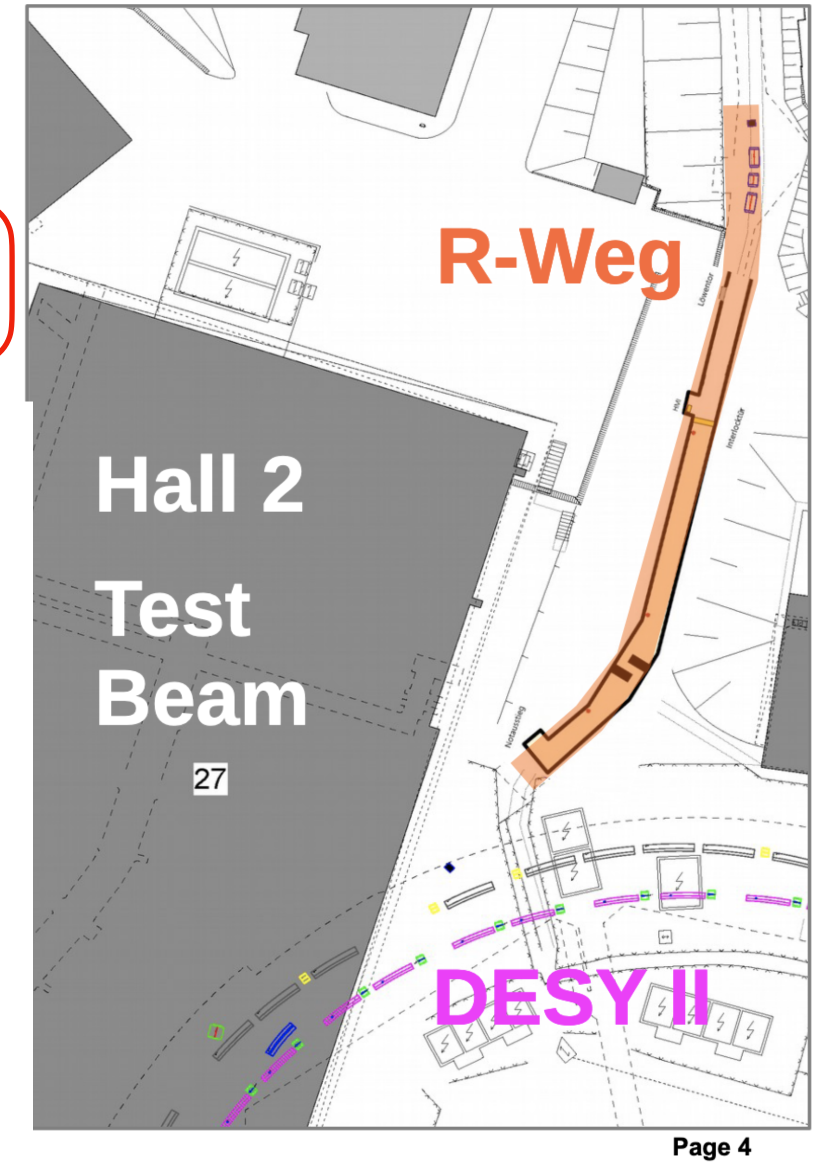


- APD has frequency range 4kHz to 40MHz, is it possible to detect short pulses (130fs XFEL beam bunch, 35fs LASER pulse)?
  → discussed this with Yan: should work (we only measure integrated signal and with 10Hz we have time in between pulses), following up with Hamamatsu to be sure
- alternative APD solution: CMS developed APD modules for their ECAL, Yan will contact responsible people

Possible Test @ R-Weg

Close to LUXE conditions

- Using the “dumped” beam
  - Repetition rate up to 12.5Hz intensity max/min $2 \times 10^{10} > 1 \times 10^{8}$ /bunch
  - Extraction energy 456 MeV - 6.3 GeV (7 GeV)

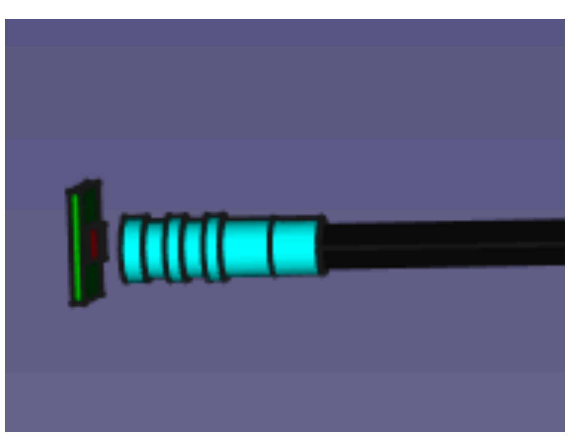


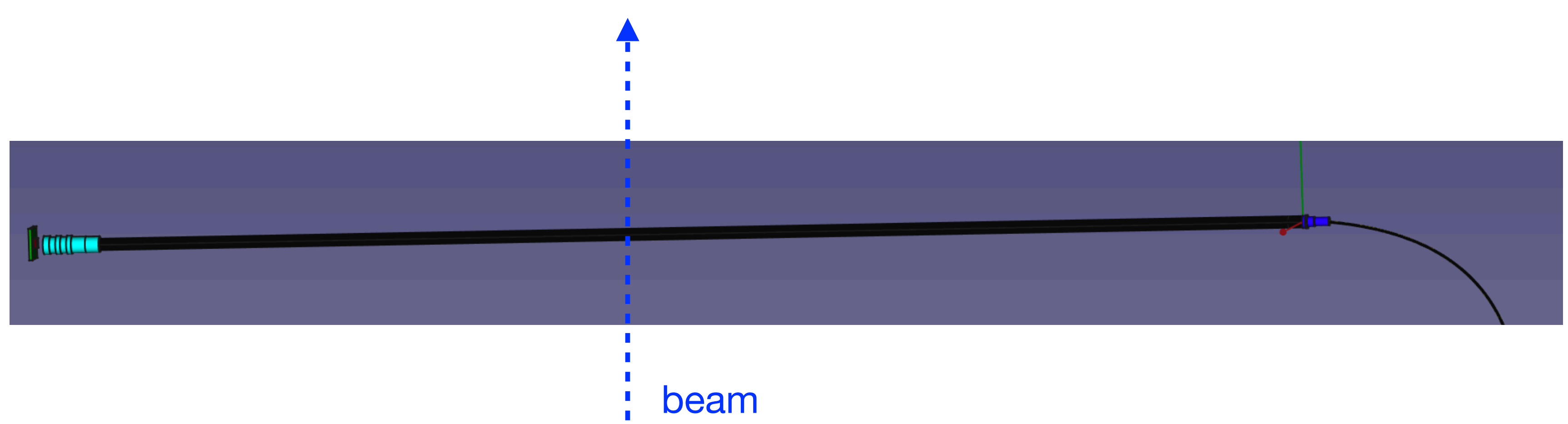
- R-weg facility got permission to operate beam (not for users yet though)

Proposal for a minimal test:

- Single air-filled straws glued to photodetector (+ possibly filters), other end of the straw sealed
- test SiPMs, APDs in LUXE-like conditions
- measure channel reflectivity for straws

Preparing for this test now: preparing a written proposal, getting a few photodetectors + readout





Summary

- Made progress in the lab with SiPMs
- working out which APDs and readout to get for testing
- Preparing for a minimal (but very useful!) test at the R-weg facility

Long-term (in view of end-of-year TB):

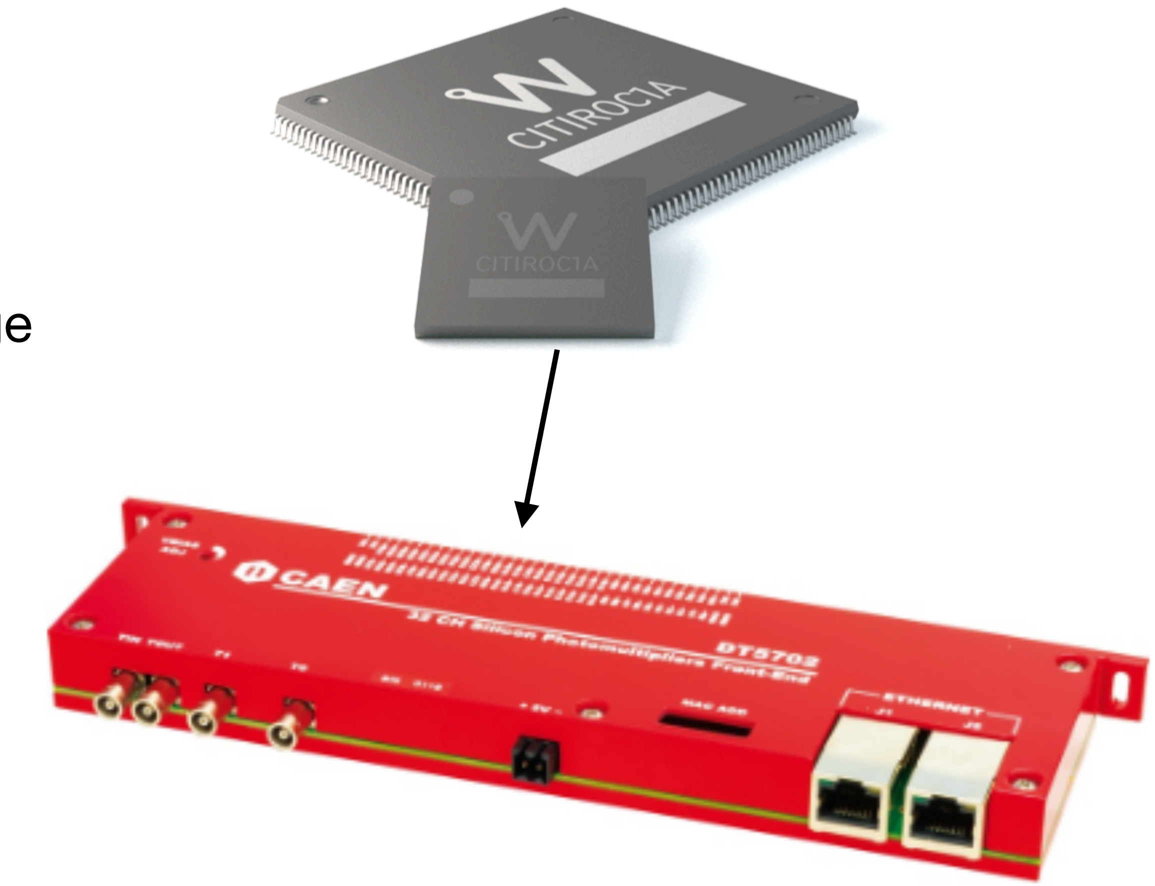
- make the existing prototype work with new generation of photodetectors
- how to integrate the straws? A straw Prototype?

BACKUP

https://www.weeroc.com/products/sipm-read-out/citiroc-1a

Cerenkov detectors: ADC

- CAEN DT 5702 contains WeeRoc Citiroc readout-chip
- Citiroc has provides two readout modes:
  - photon counting (low light environment)
  - analogue charge integration ← we want this!
- Citiroc uses built-in ADC to digitize the measured charge
- dynamic range of the ADC : 160 fC - 400 pC
  (2 preamplifiers with different gain)
- output: multiplexed signal (high-gain and low-gain) for each of 32 input channels



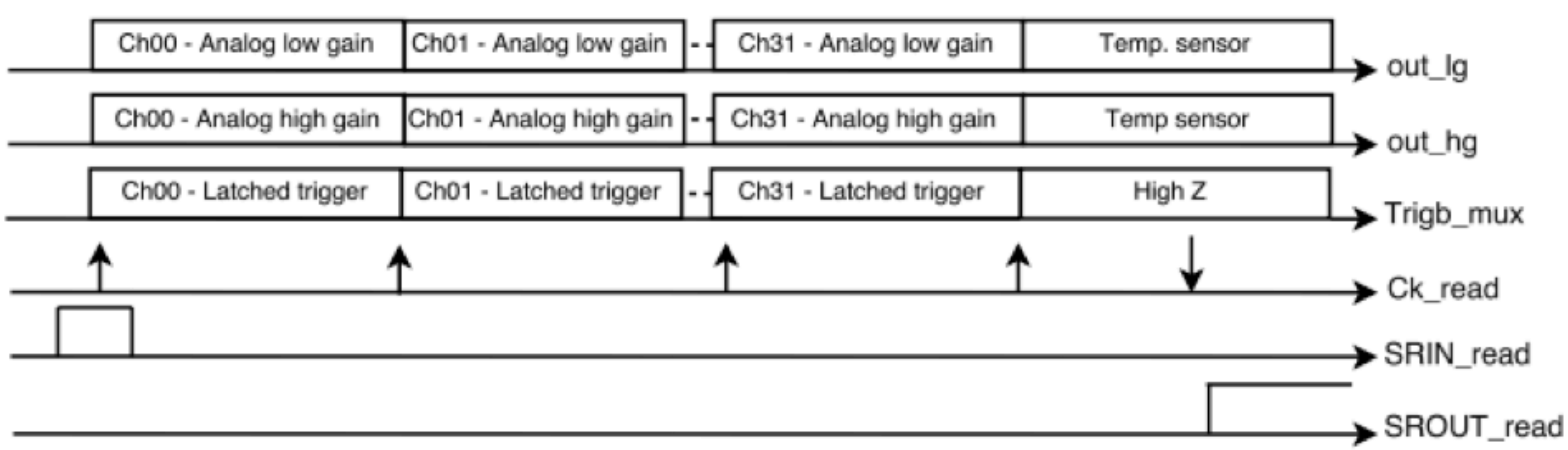
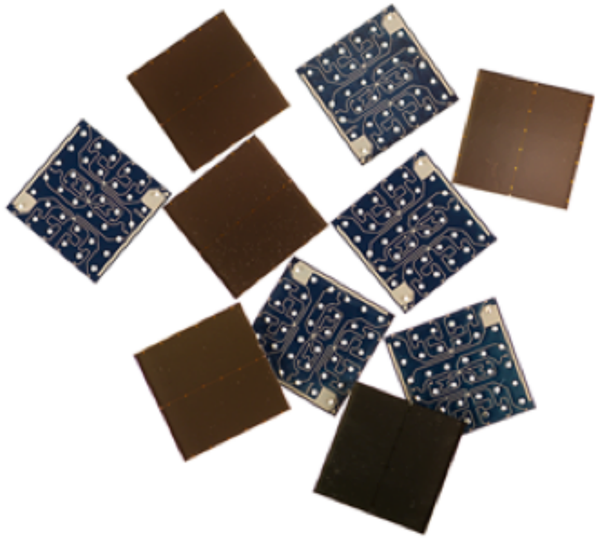


Figure 16 - Read register description scheme

https://www.onsemi.com/pdf/datasheet/microj-series-d.pdf

Cerenkov detectors: SiPM



J-Series SiPM Sensors

Silicon Photomultipliers (SiPM), High PDE and Timing Resolution Sensors in a TSV Package

ON Semiconductor®

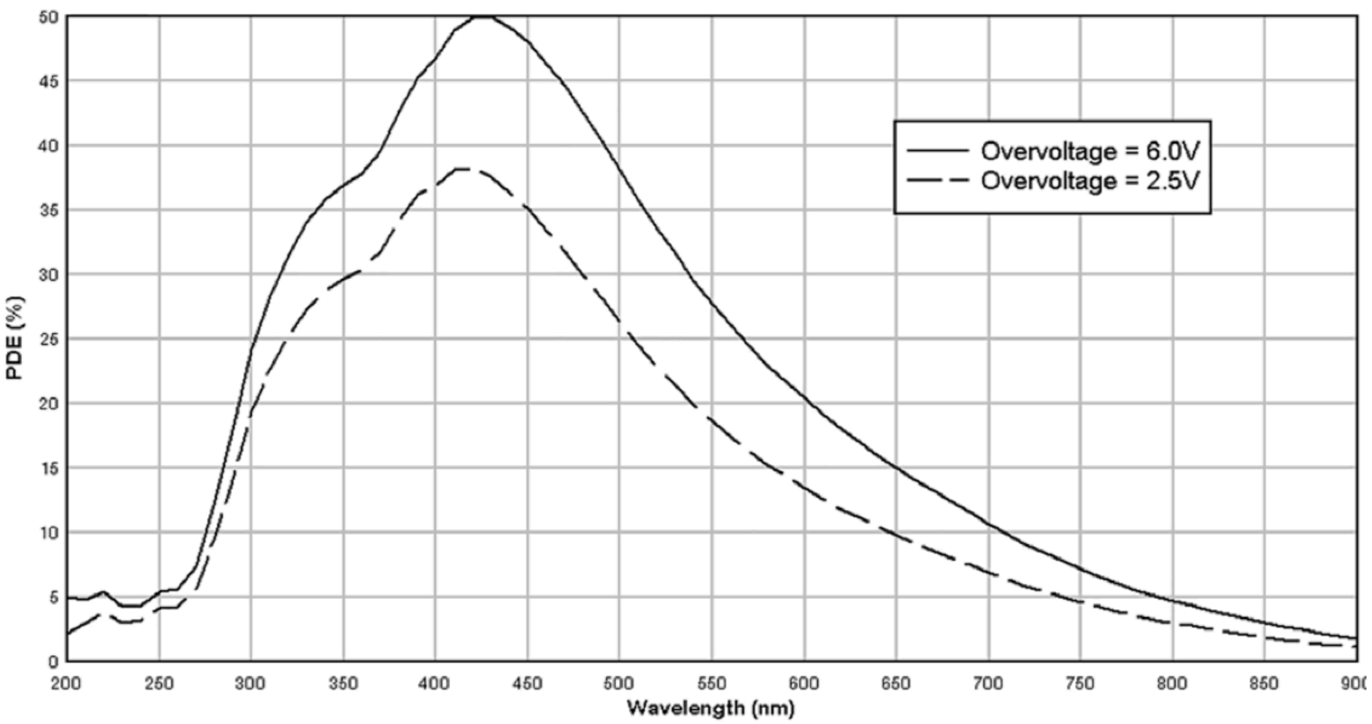
www.onsemi.com

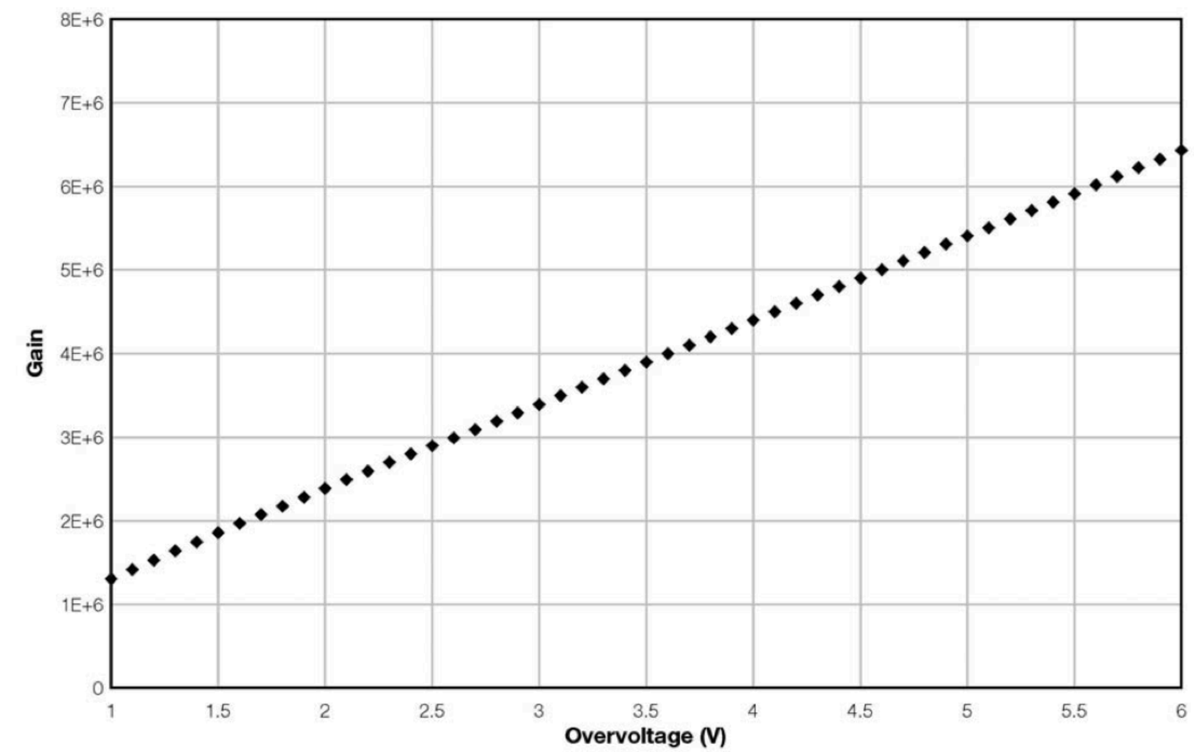
Parameter (Note 1)	**Minimum**	**Typical**	**Maximum**	**Unit**
Breakdown Voltage (Vbr) (Note 2)	24.2		24.7	V
Overvoltage (OV)	1		6	V
Operating Voltage (Vop = Vbr + OV))	25.2		30.7	V
Spectral Range (Note 3)	200		900	nm
Peak PDE Wavelength (λp)		420		nm
Temperature dependence of Vbr		21.5		mV/°C

	30035		**40035**		**60035**		**Unit**
	Overvoltage						
Parameter (Note 4)	**+2.5 V**	**+6 V**	**+2.5 V**	**+6 V**	**+2.5 V**	**+6 V**	**Unit**
Gain (anode-cathode)	2.9×10^6	6.3×10^6	2.9×10^6	6.3×10^6	2.9×10^6	6.3×10^6	

Cerenkov detectors: SiPM

https://www.onsemi.com/pdf/datasheet/microj-series-d.pdf





- gain reduction by lowering operating voltage is smaller than for gaseous PM
- photon detection efficiency, defined as:

$$PDE = \eta \cdot \epsilon_{Avalanche} \cdot F$$

where η: quantum efficiency, $\varepsilon_{\text{Avalanche}}$: probability to start avalanche, F: fill factor (ratio of SiPM active/inactive area

High Particle Rate Mitigation: Cerenkov Gas

- **Frank-Tamm** formula: - Number of Cerenkov Photos per charged primary

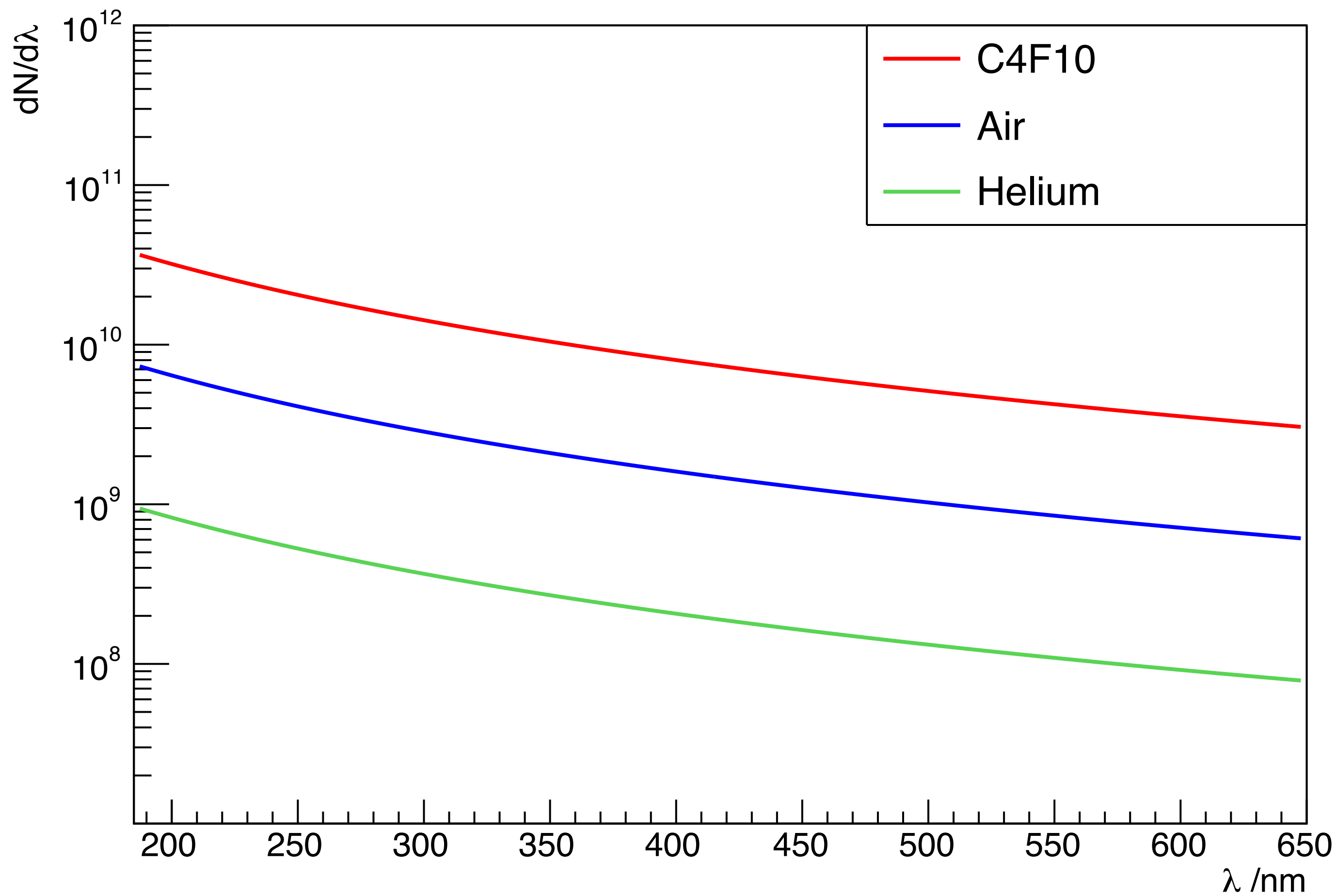
$$\frac{d^2N}{dxd\lambda} = \frac{2\pi\alpha}{\lambda^2}\sin^2\theta_c$$

$$\cos\theta_c = \frac{1}{\beta n}$$

Cerenkov angle
n: refractive index

$$\alpha = \frac{1}{137.036}$$

fine-structure constant



- Integrating over x (our z!) and λ and assuming β≈1:

$$N_\gamma = 2\pi\alpha l_z\left(1-\frac{1}{n^2}\right)\left(\frac{1}{\lambda_{\mathrm{min}}}-\frac{1}{\lambda_{\mathrm{max}}}\right)$$

$\lambda_{min/max}$: lower/upper wavelength sensitivity limit for PMT

l_z: length traversed in Cerenkov medium