Straw Cerenkovs: Dynamic range & TB plans

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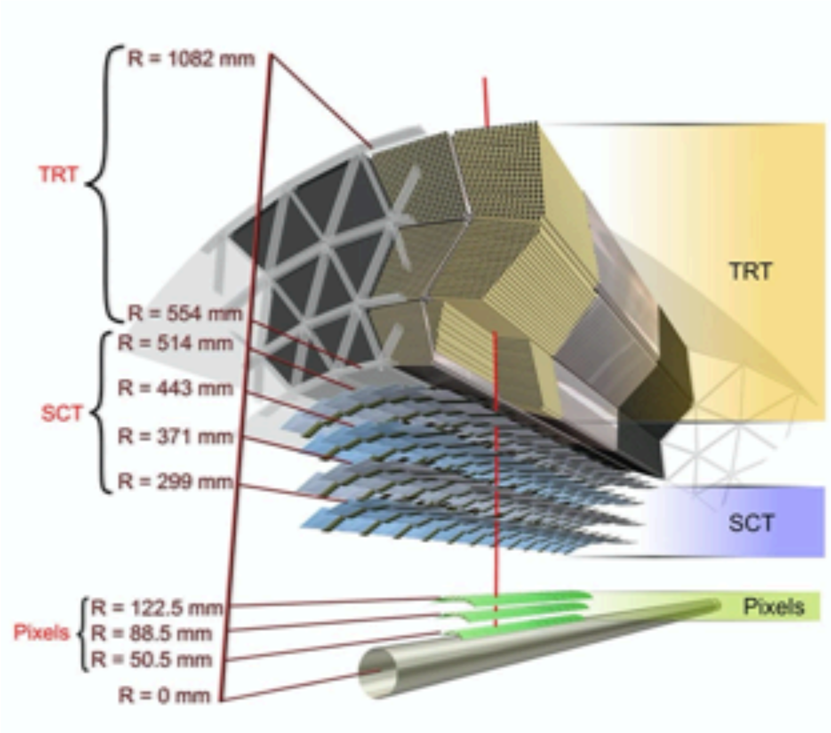
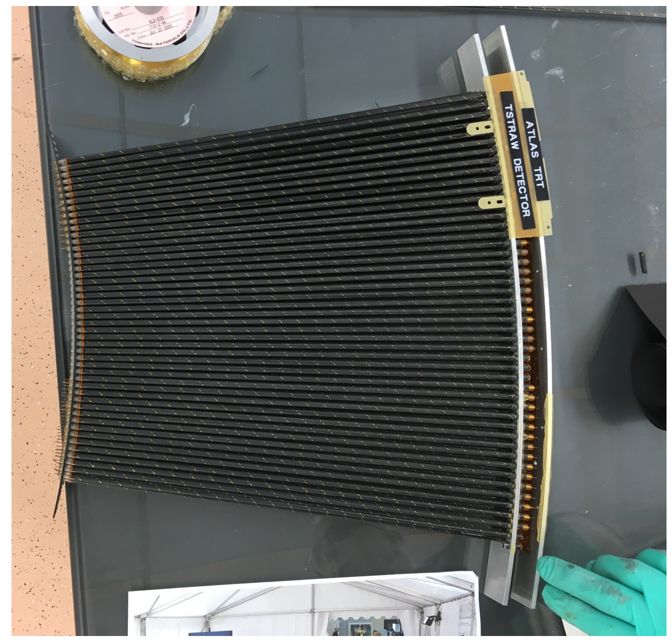
12th May 2021

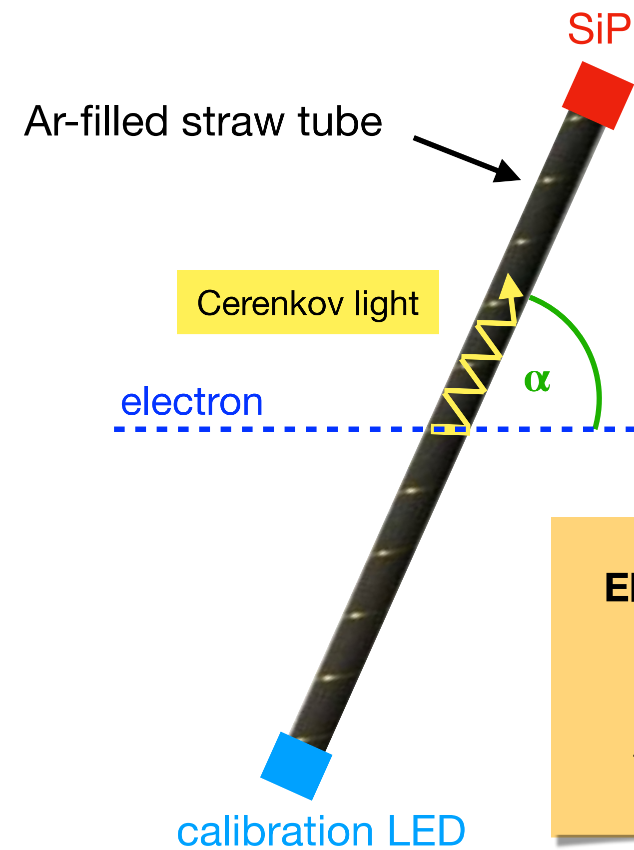
Cerenkov detectors: Straw tube design



ATLAS inner detector + TRT



ATLAS TRT Endcap module

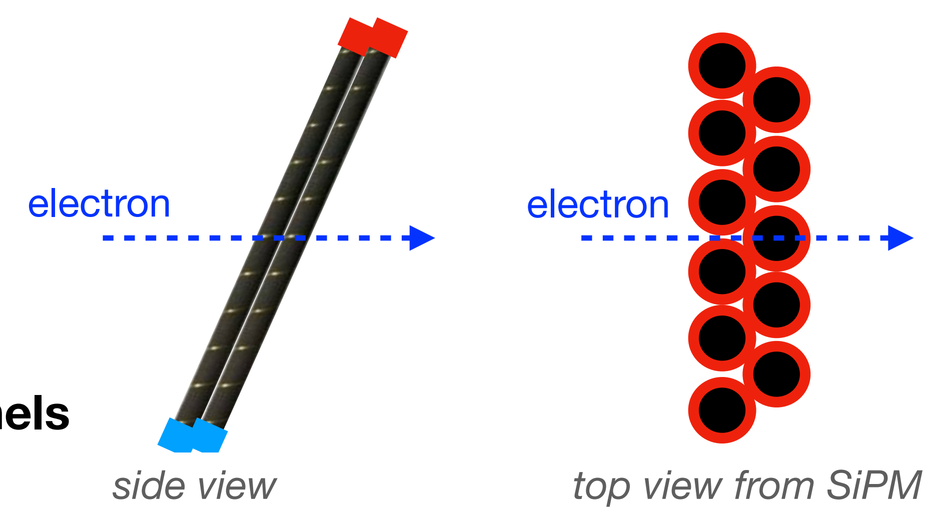


Electron path length in straw tube:

$$\Delta z_{electron} = \frac{d_{straw}}{\sin\alpha}$$

LUXE Cerenkovs: tilted straw channel design

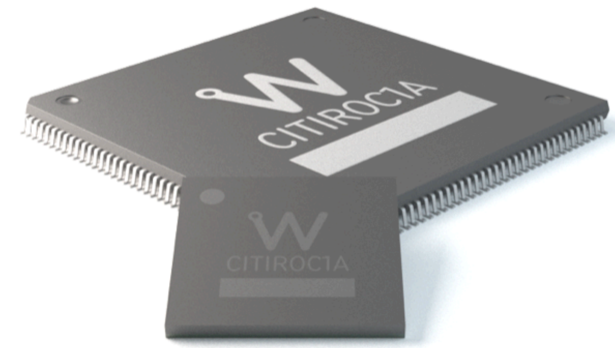
- small Cerenkov channel segmentation with metal channels is challenging (engineering, stability etc.)
- ATLAS transition radiation tracker (TRT) consists of thousands of straw (drift-) tubes
- straw tube: gas-filled aluminium-coated kapton foil tube (diameter d_{straw}=4mm) with anode wire inside
  → straw tube shells are reflective!
- **idea for LUXE Cerenkovs: use straw tube shells instead of metal channels**
- 3D-printed support structures and end connectors
- ATLAS TRT group provided us with straws for a prototype, more are available
  → prototype work starting soon (Covid-permitting)

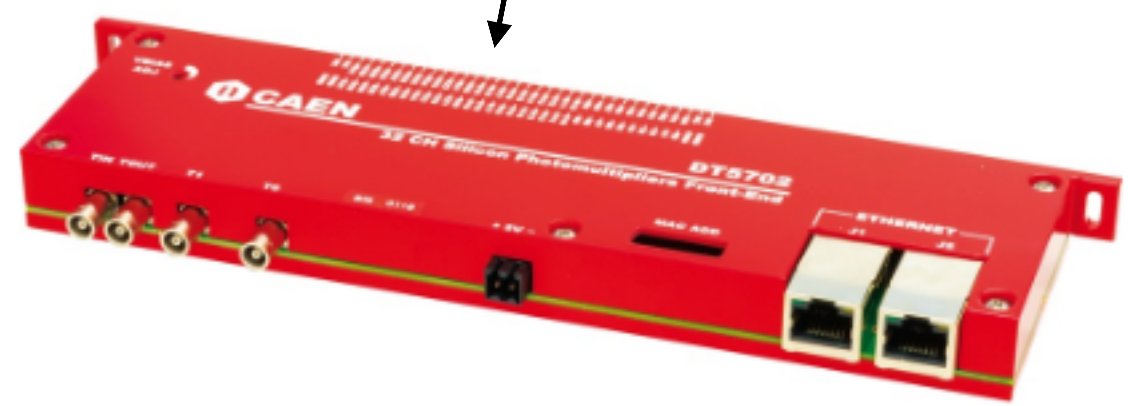


staggering of multiple channel layers for additional spatial resolution

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





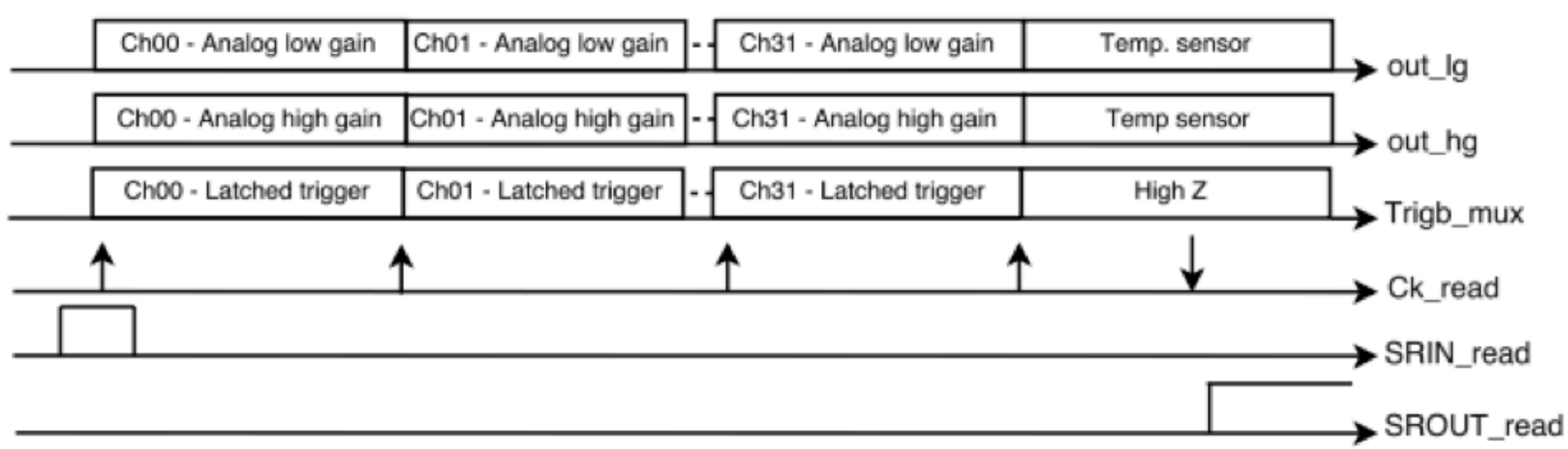
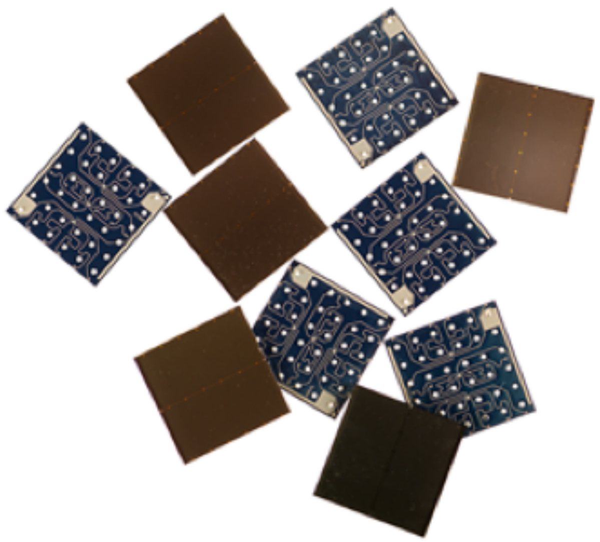


Figure 16 - Read register description scheme

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®

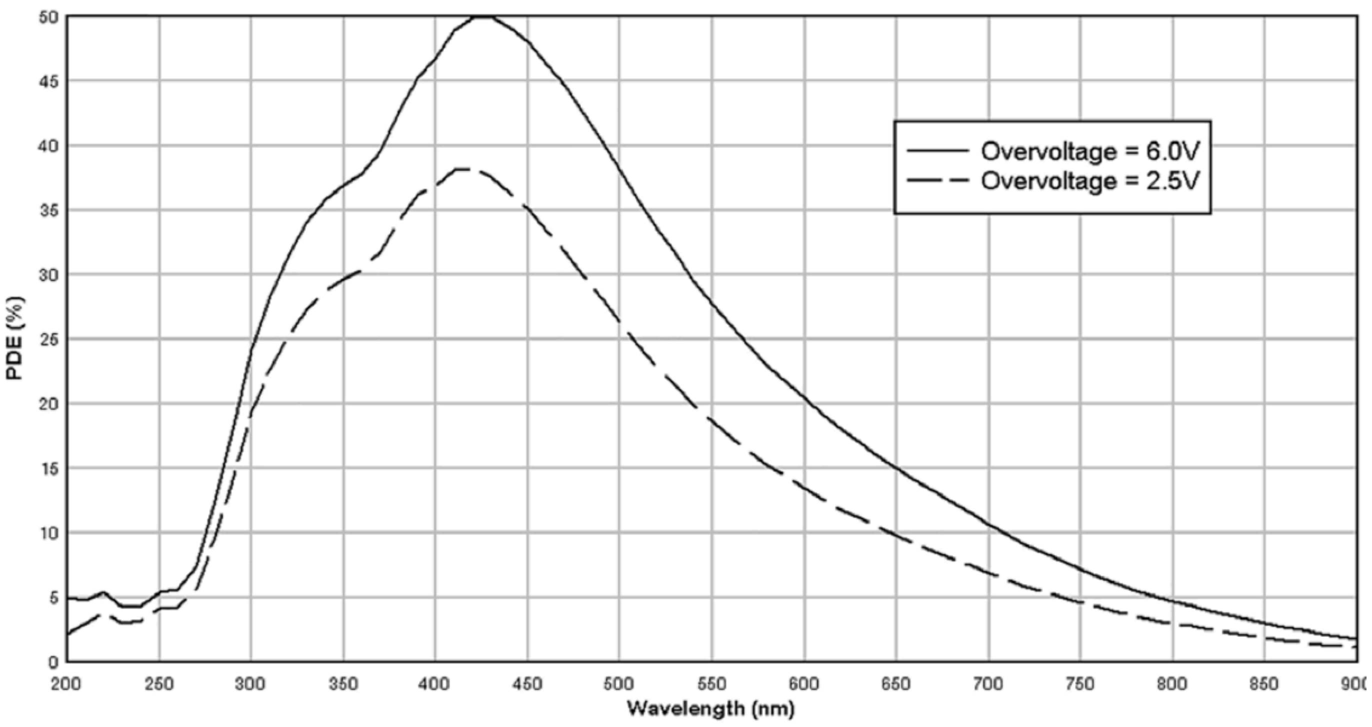
www.onsemi.com

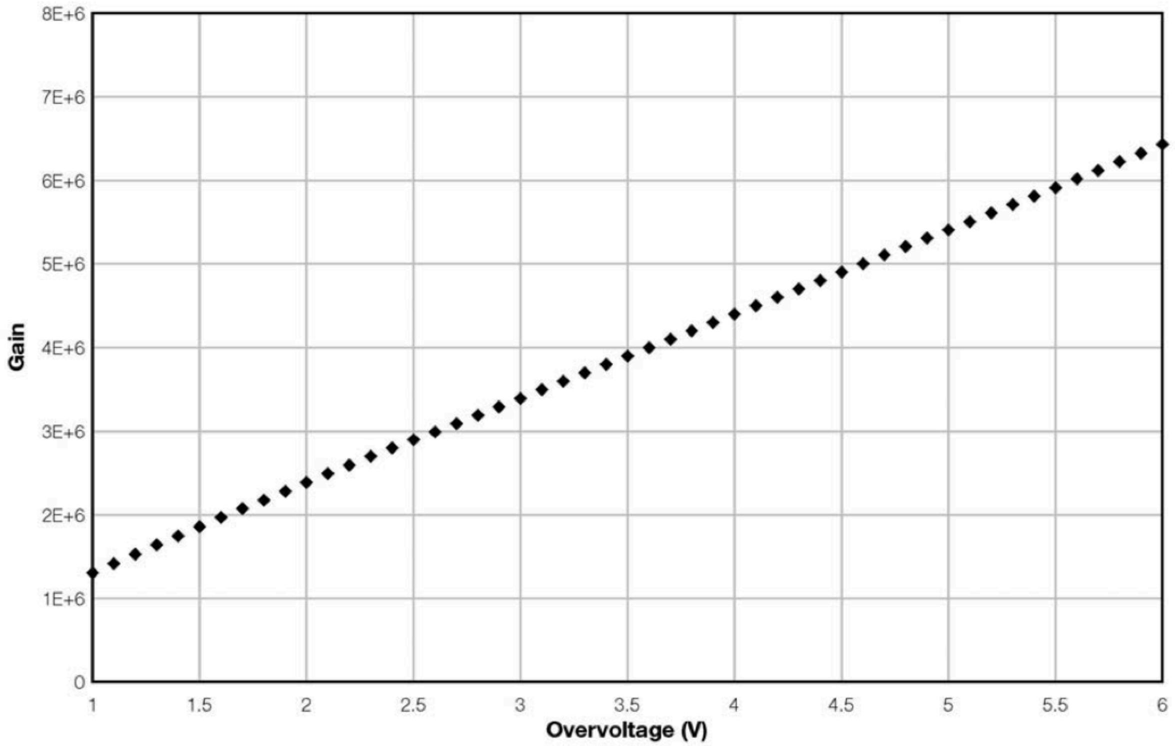
Parameter (Note 1)	**Minimum**	**Typical**	**Maximum**	**Unit**
Breakdown Voltage (Vbr) (Note 2)	24.2		24.7	V
Overvoltage (OV)	1		6	V
Operating Voltage (Vop = Vbr + OV))	25.2		30.7	V
Spectral Range (Note 3)	200		900	nm
Peak PDE Wavelength (λp)		420		nm
Temperature dependence of Vbr		21.5		mV/°C

Parameter (Note 4)	**30035**		**40035**		**60035**		**Unit**
	Overvoltage						
	+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

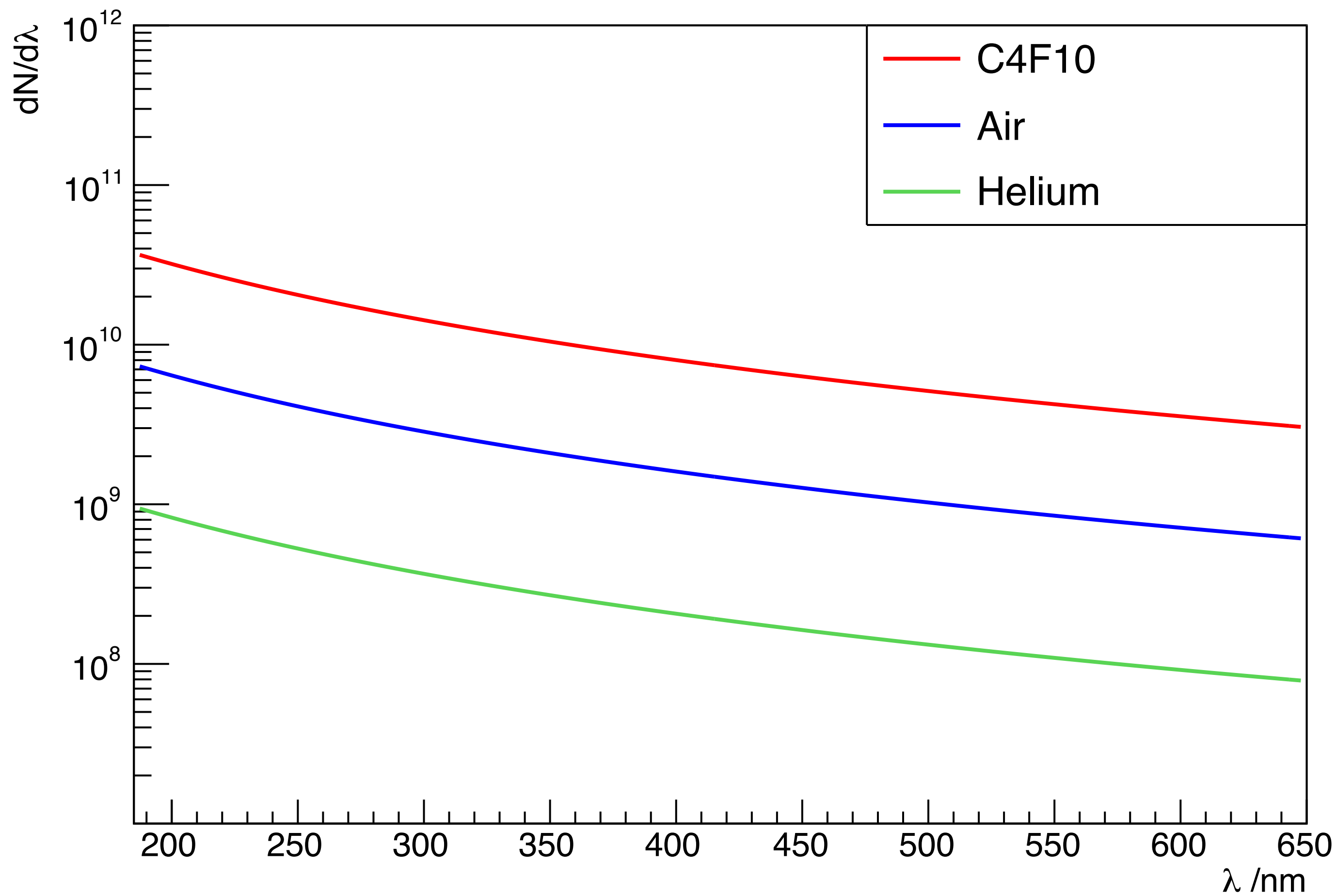
$$\frac{d^2N}{dxd\lambda} = \frac{2\pi\alpha}{\lambda^2}\sin^2\theta_c$$

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

Cerenkov angle
n: refractive index

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

fine-structure constant



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

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

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

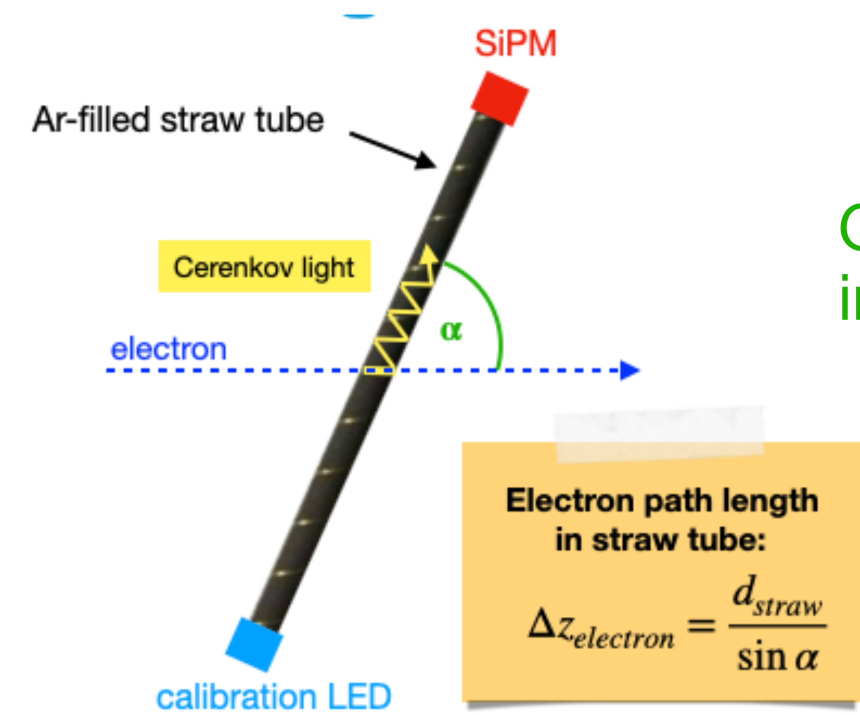
l_z: length traversed in Cerenkov medium

High Particle Rate Mitigation

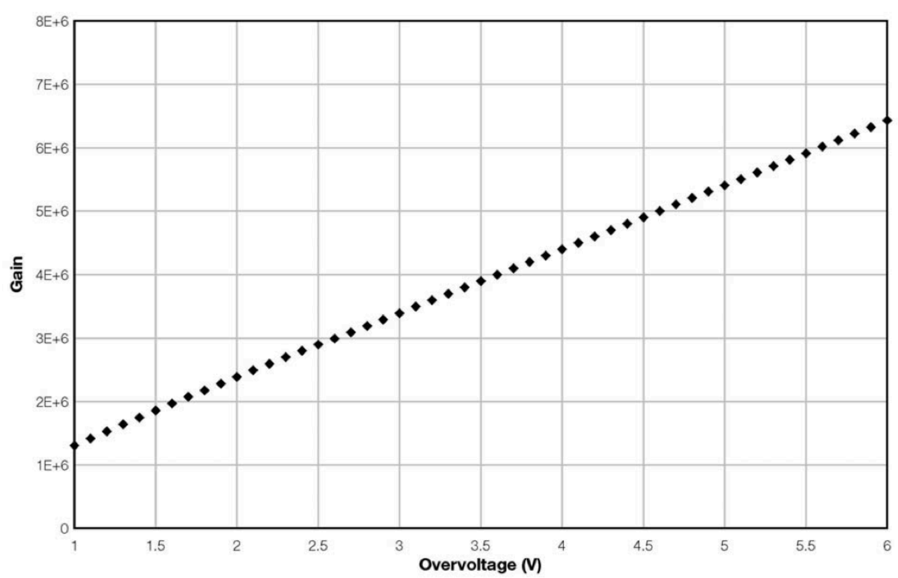
$$N_\gamma = 2\pi\alpha l_z \left(1 - \frac{1}{n^2}\right)\left(\frac{1}{\lambda_{\min}} - \frac{1}{\lambda_{\max}}\right)$$

Medium	Refractive Index n	N_γ per primary 300-650nm	N_γ per primary 185-650nm
C_4F_{10}	1.0014	230	495
Air (15°, 1atm)	1.00028	46	100
Helium (0°, 1atm)	1.000036	6	13

Gas refractive index



Geometry: incidence angle

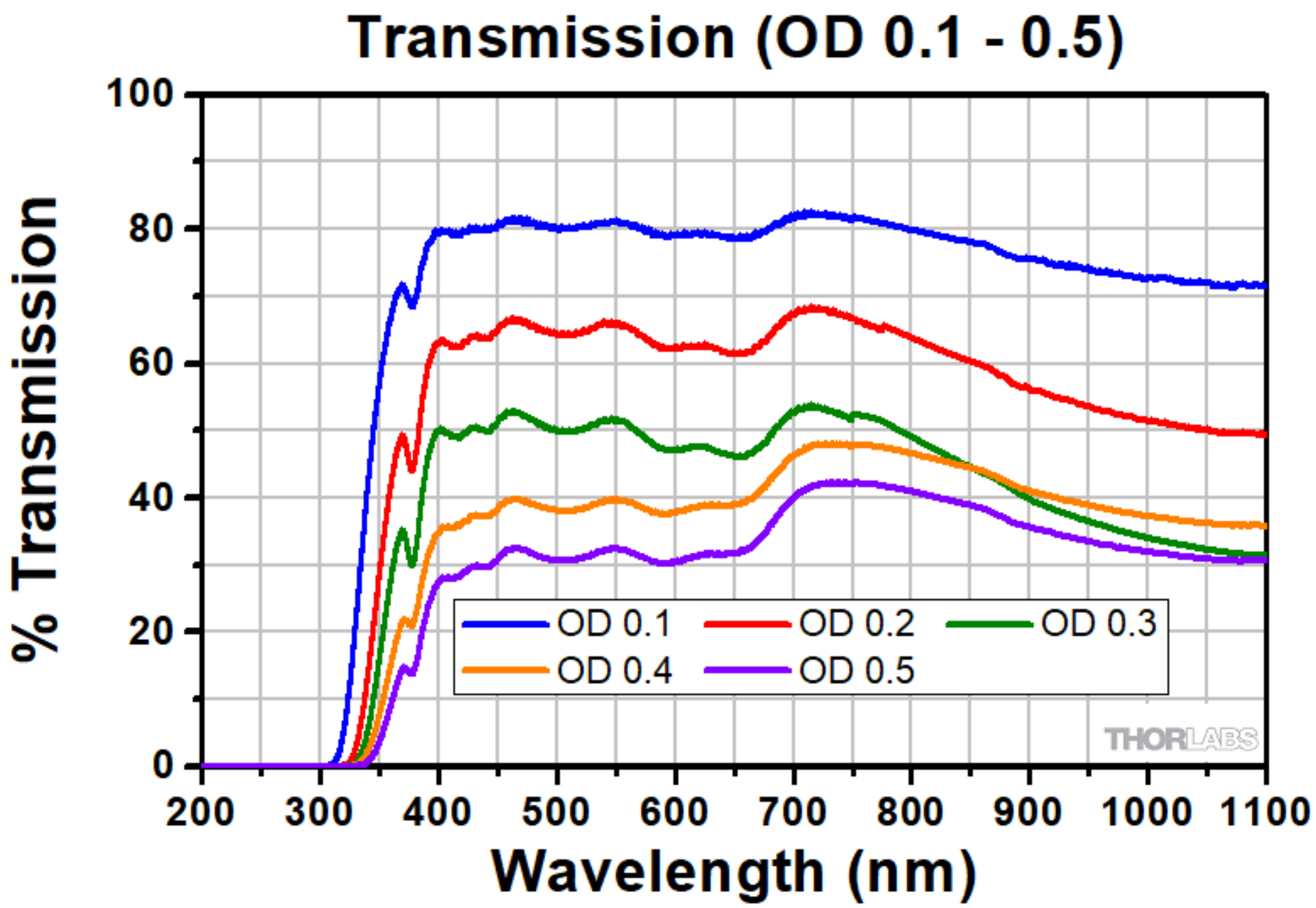


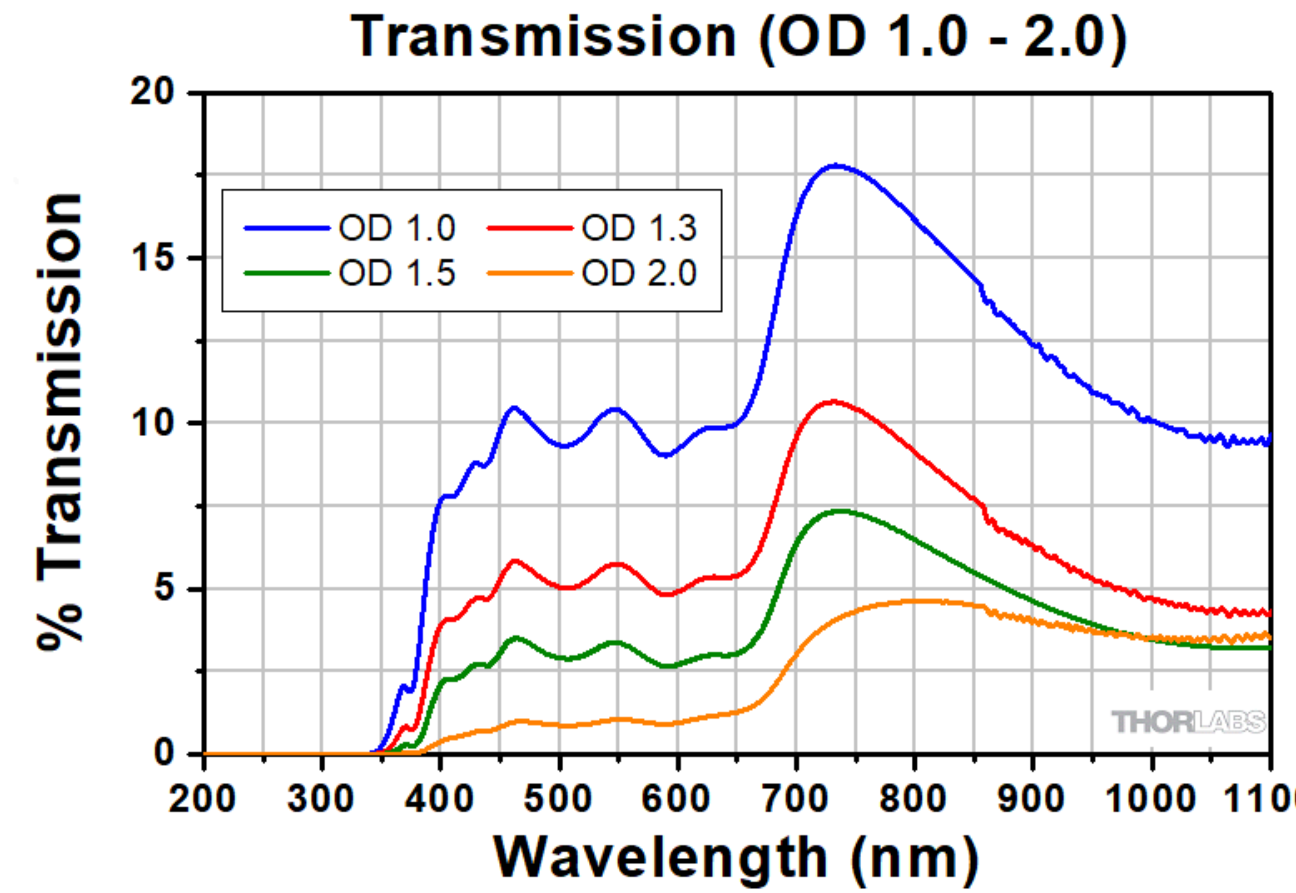
Gain: reducing PMT operating voltage
→ reduction factor ~100!

optical filters
→ transmissivity available down to 10^{-6}

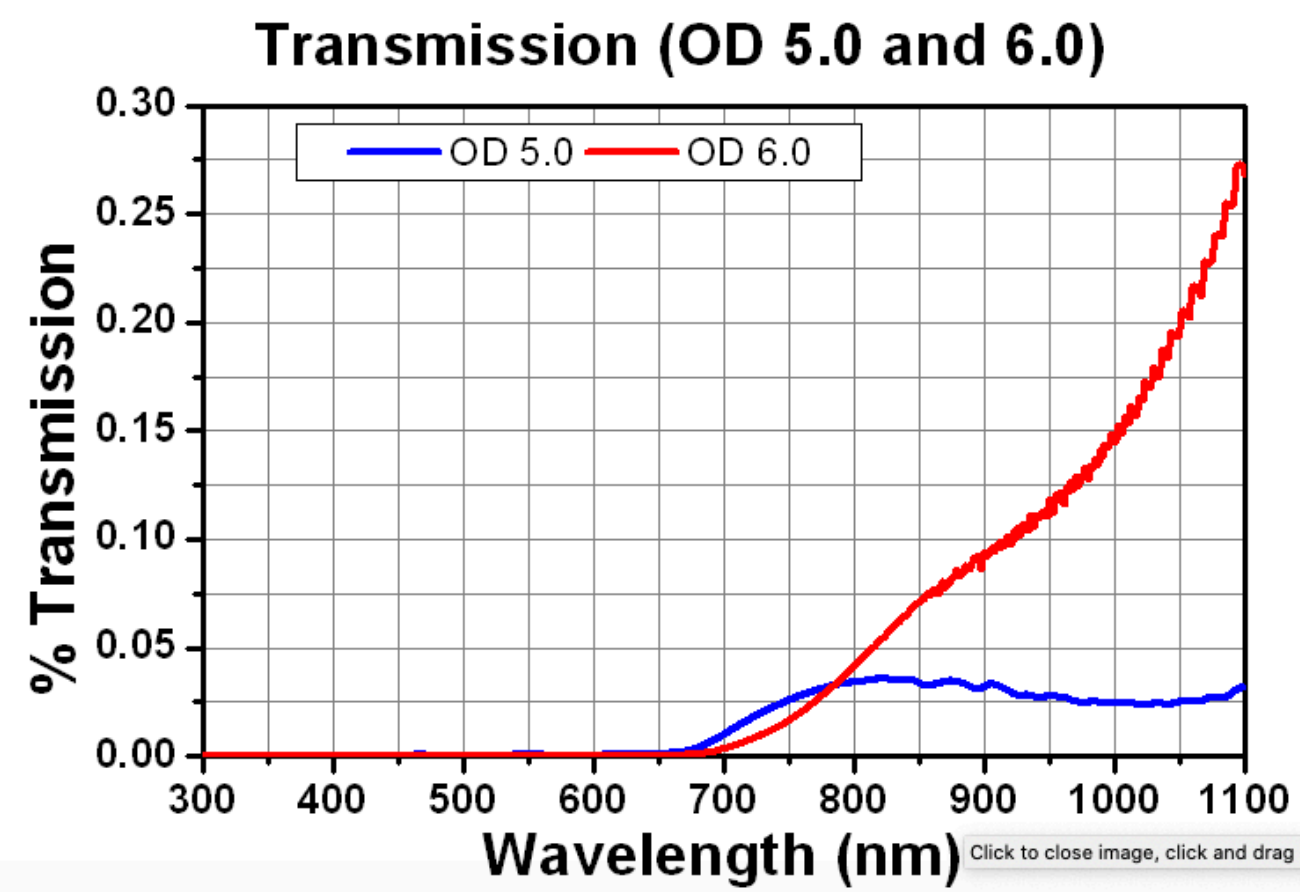
Optical filters

$$\mathrm{OD} = \log_{10}\left(\frac{1}{T}\right), \text{ or } \; T = 10^{-\mathrm{OD}}$$





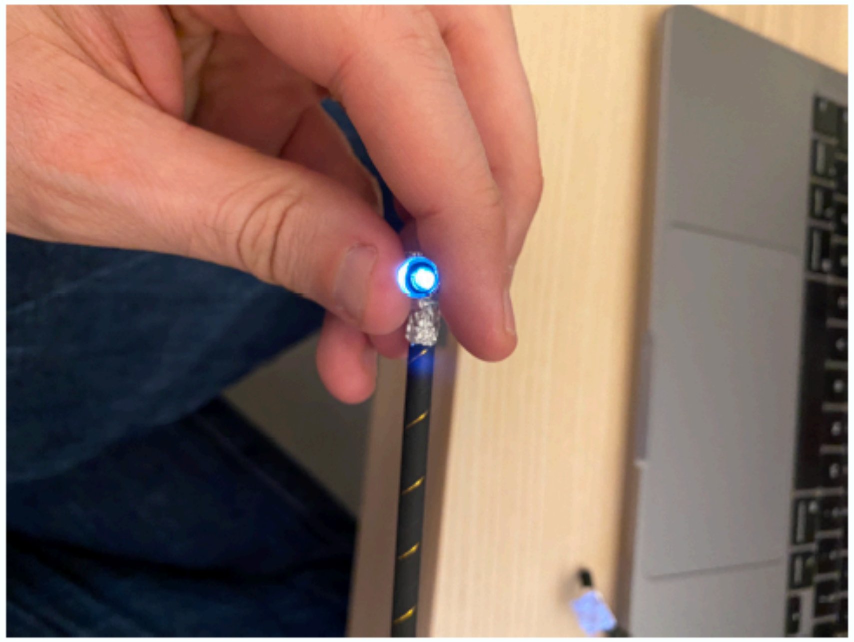
- filters help in two ways
- globally reducing light level
- cutting off the ($1/\lambda$ falling) Cerenkov spectrum at low energies
- must make sure not to over-kill



Channel reflectivity

LED

LED through the straw



LED through 2 straws with 1 reflection on aluminium foil

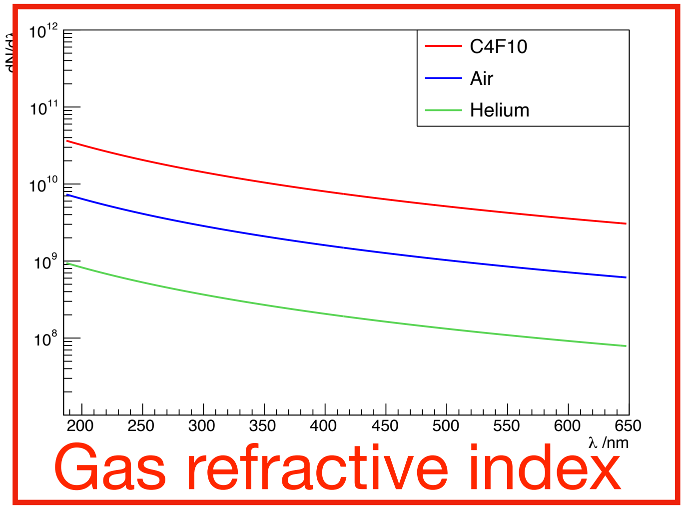
LED through the 3 straws with 2 reflection on aluminium foil

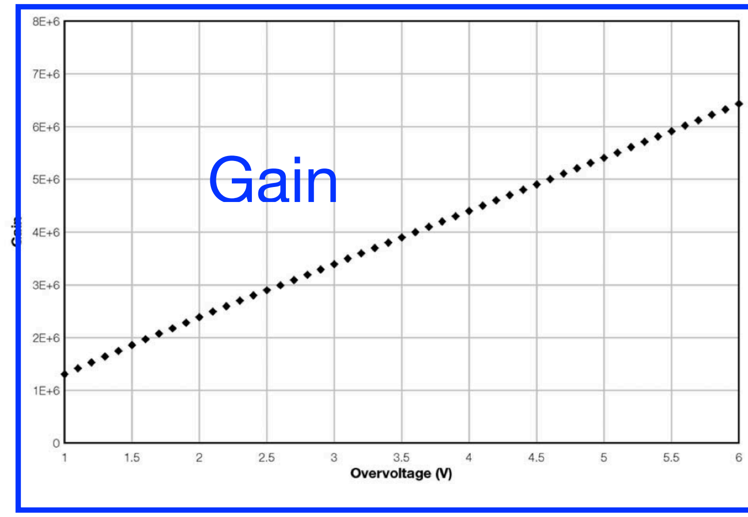
- channel reflectivity determines how much light reaches SiPM
- this depends on the angle of incidence (number of reflections)
- need to measure!

→ This would be best to do in a high-rate TB!

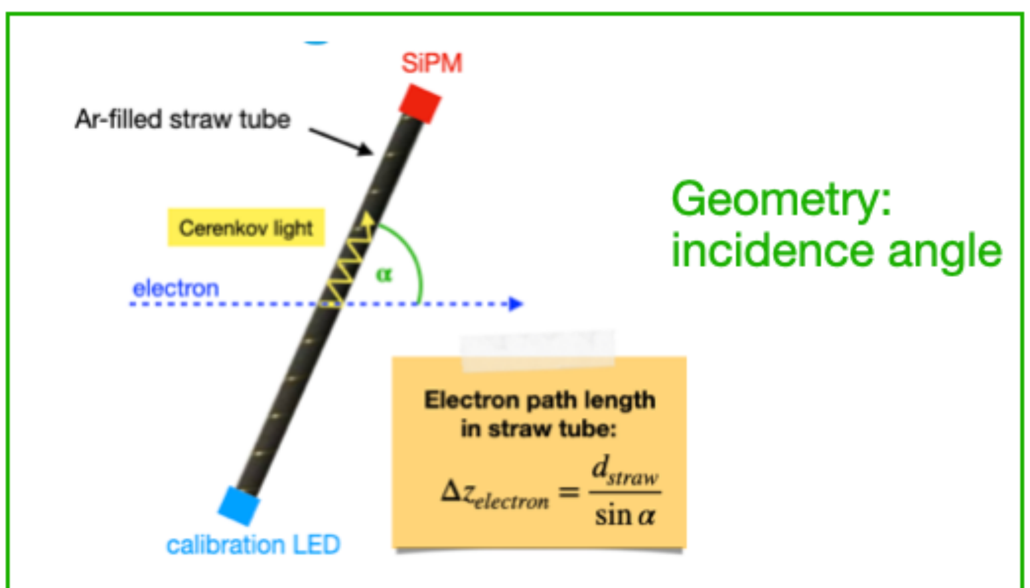
Would be sufficient to just hold Straw with air in it into the beam!

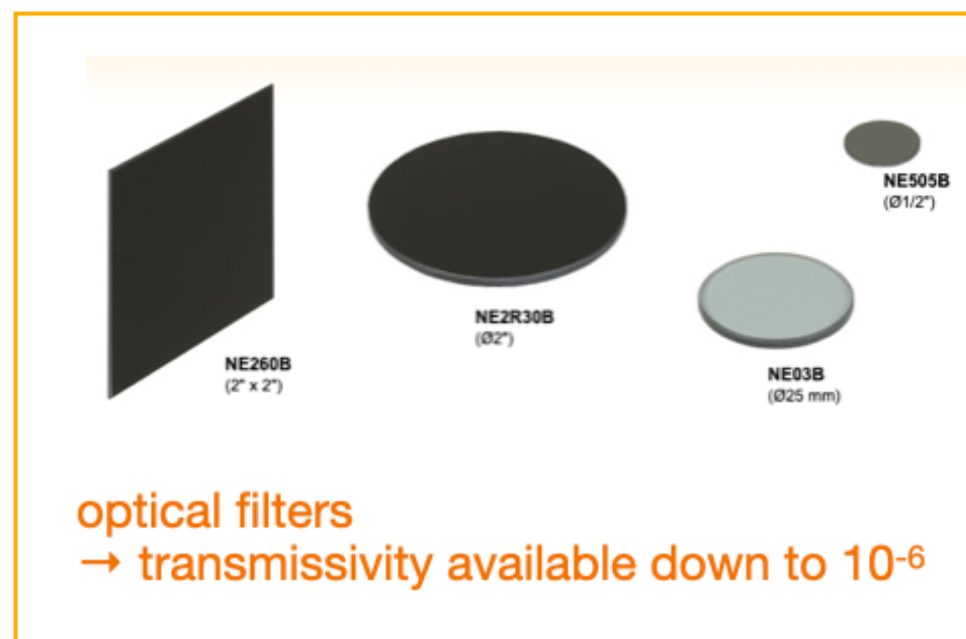
Putting it all together





$$Q_{ADC} = 2\pi N_e e \alpha_{QED} \underline{\frac{d_{straw}}{\sin\alpha}} \underline{\left(1 - \frac{1}{n^2}\right)} \underline{r_{chan}} \underline{T_{filter}} \underline{G_{SiPM}} \int_{\lambda_{min}}^{\lambda_{max}} \underline{\frac{1}{\lambda^2}} \underline{PDE(\lambda)}\, d\lambda$$



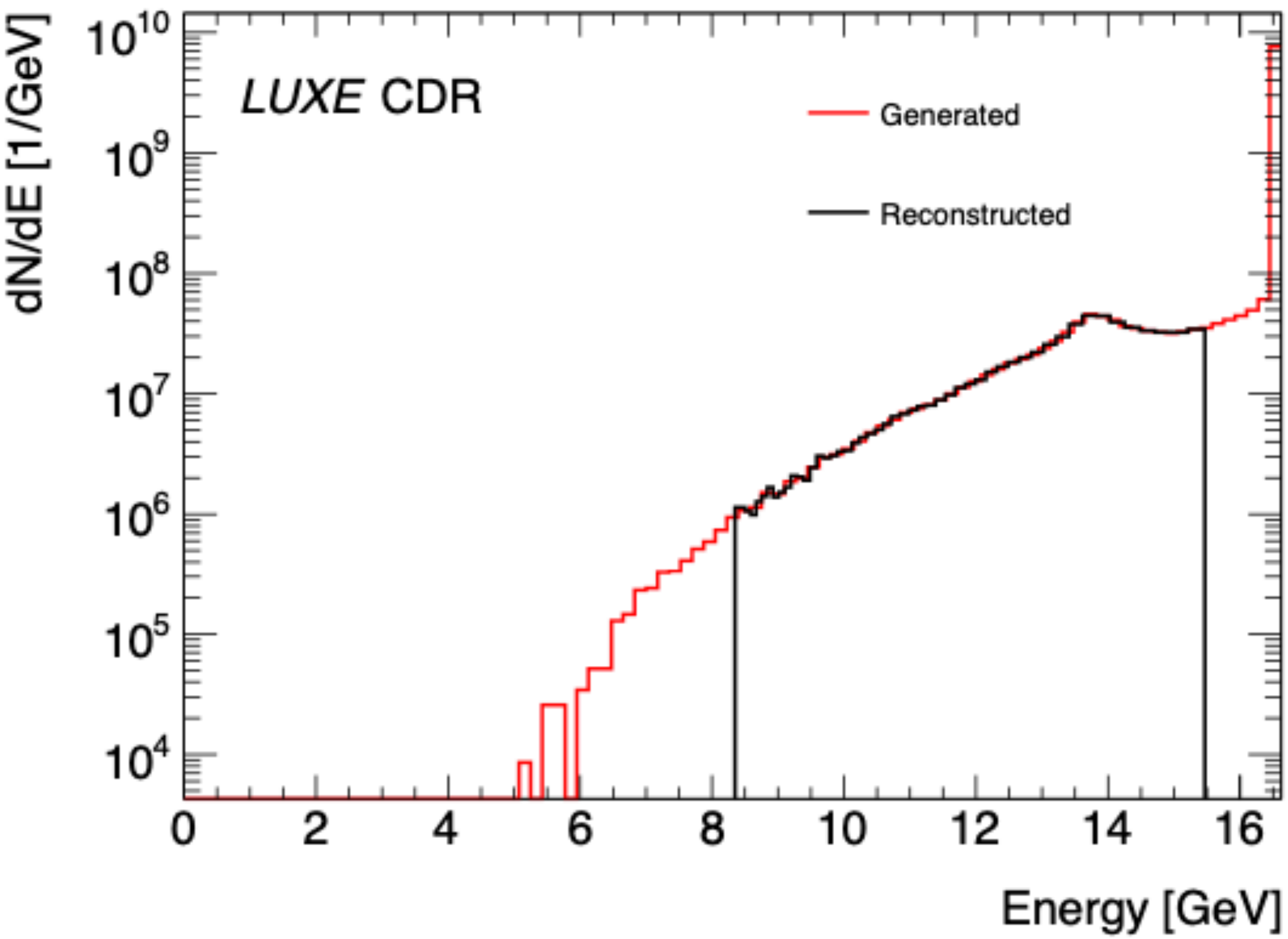


Putting it all together

$$Q_{ADC} = 2\pi N_e e \alpha_{QED} \frac{d_{straw}}{\sin\alpha}\left(1 - \frac{1}{n^2}\right) r_{chan} T_{filter} G_{SiPM} \int_{\lambda_{min}}^{\lambda_{max}} \frac{1}{\lambda^2} PDE(\lambda)\, d\lambda$$

- assuming: - d_{straw}=4mm, α=90°
  - Argon gas n=1.00028
  - channel reflectivity r_{chan}=0.5
  - G_{SiPM}=2.9 x 10^6
  - T_{filter}=1 (no filter)
  - N_e = 5x10^7 Compton electror

→ **charge at ADC input 7 x 10^5 pC !!**
→ **need filter with T_{filter}~5x10^{-4}**



We have more than enough light! Need to find a configuration that works!

Test beam proposal

Test beam at DESY (single electrons):

- possibly in earlier TB: gain experience with metal channel prototype, readout, synch with Telescope etc.?
- operation of new straw-channel prototype
- trigger strategies stand-alone and with telescope
- alignment of the straws
- alignment of straws/bowing of channels
- gas to use: C4F10 for higher light yields, possibly Ar/Air?
- for alignment measurements need to synchronize with the Telescope

<u>Needs:</u> - Ar, C4F10 gas bottle near TB area, or permit to transport filled prototype
- safe way to fill gases (especially C4F10) (ventilated area for flushing small prototype slowly for ~2h, Protective equipment for filling (gloves, goggles +?))
- safe way to operate C4F10-filled prototype in TB hall (tray+ventilation, sniffer needed?)
- telescope for alignment measurement
- metal channel prototype: High voltage (~1kV), 1 crate, 1 computer
- straw prototype: 1 computer, DT 5702 board

High-Rate test beam (R-Weg?):

- channel reflectivity measurement (requires just a single straw with a SiPM on it!)
- different gas mixtures, gas pressures, temperature variations
- channel tilt angle
- different ND filters
- staggered layer readout
- high-rate linearity tests of SiPM and readout