Characterisation of Silicon Photomultipliers for LHCb Upgrade 2 RICH

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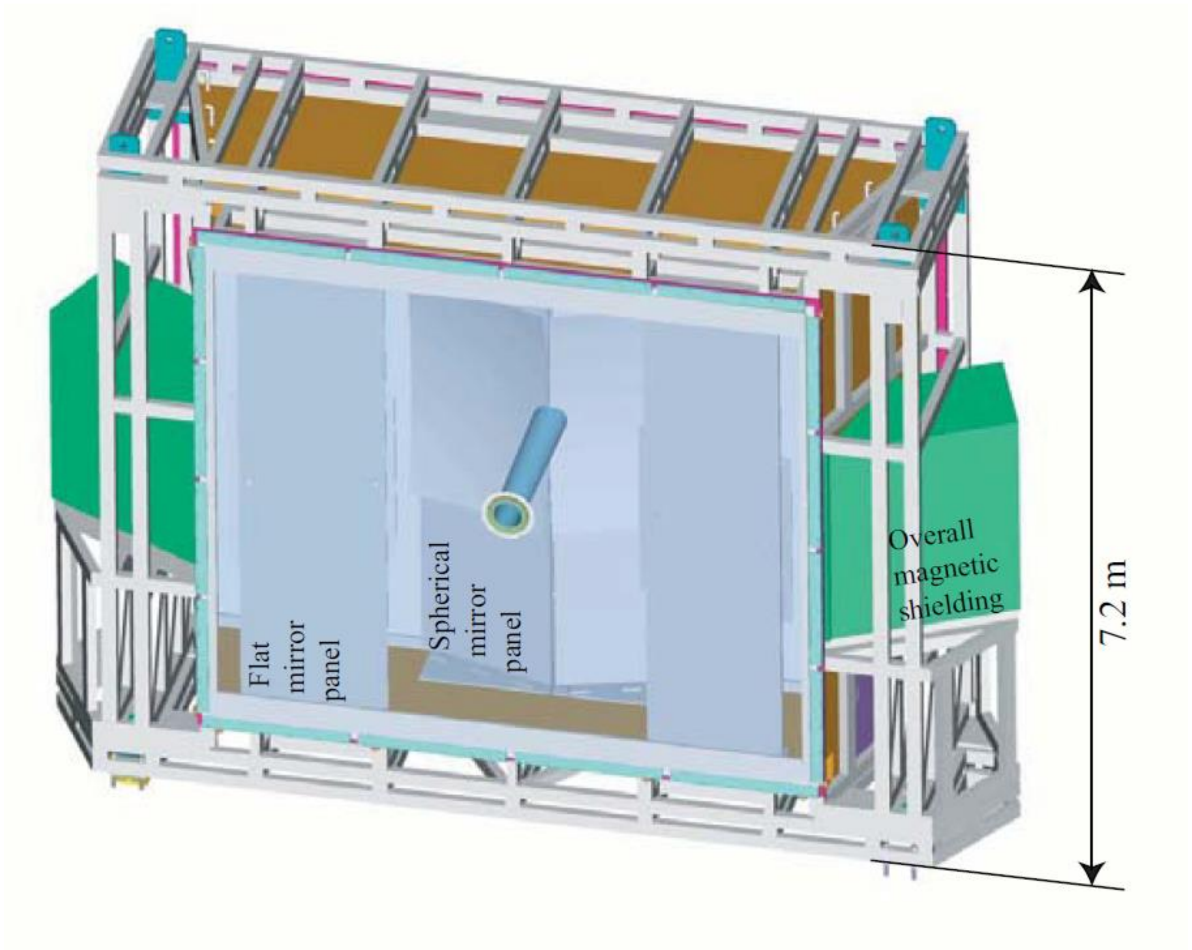
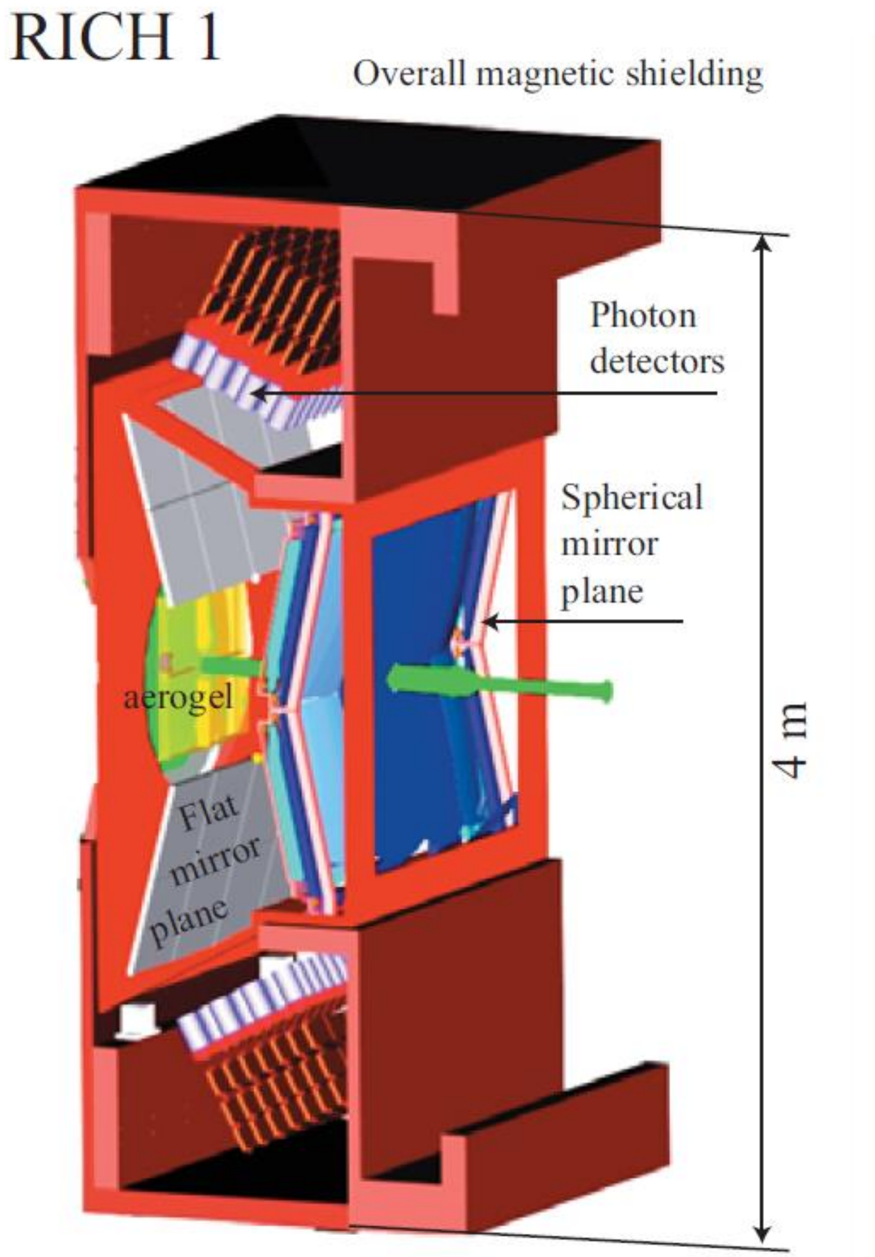




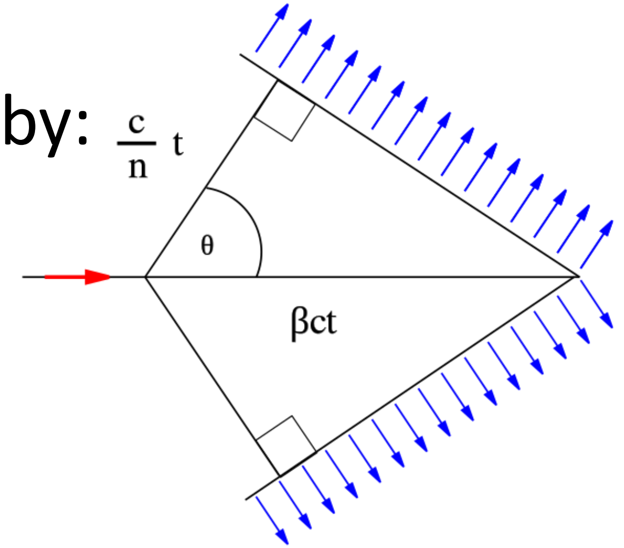
A little background

What is RICH?

- RICH stands for Ring imaging Cherenkov detector.
- Cherenkov radiation: charged particles passing through a medium emit light if their speed is higher than the speed of light in the medium.
- The light is emitted in a cone with opening angle given by:

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

- By measuring the cone's opening angle, you can obtain particle's velocity. Then, if you know particle's momentum, measured in the tracker, you can identify it by calculating its mass.



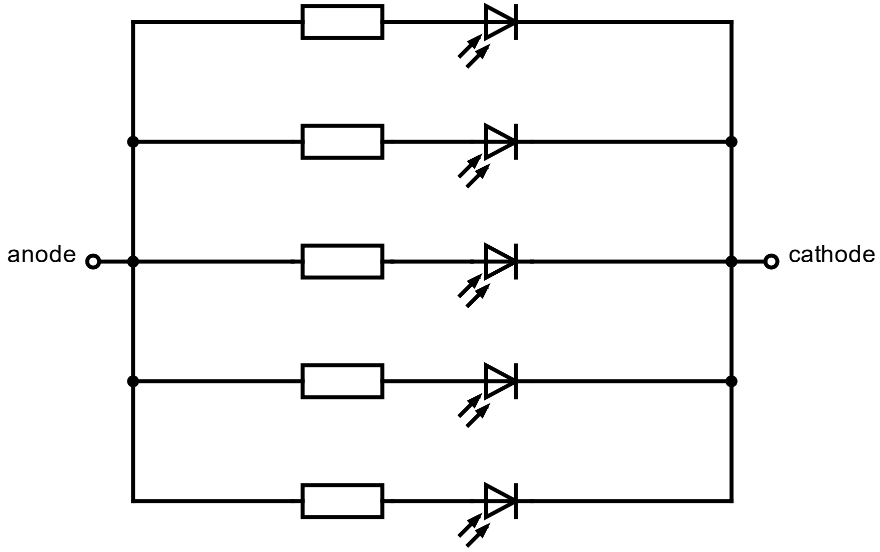
Source: https://commons.wikimedia.org/wiki/File:Cherenkov.svg

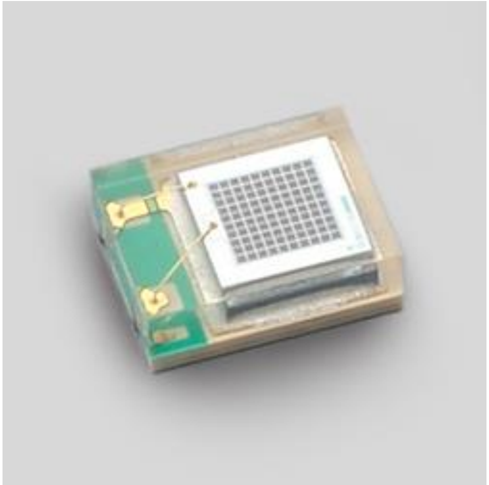
Why do we need to upgrade them?

- Current maximum instantaneous luminosity: $2 \cdot 10^{33}\ cm^{-2}s^{-1}$
- Projected maximum instantaneous luminosity after the LHCb upgrade 2 (planned for 2032): $1.5 \cdot 10^{34}\ cm^{-2}s^{-1}$
- Current photodetectors (multi-anode photomultiplier tubes) do not have required spatial and temporal resolution to handle this increase.

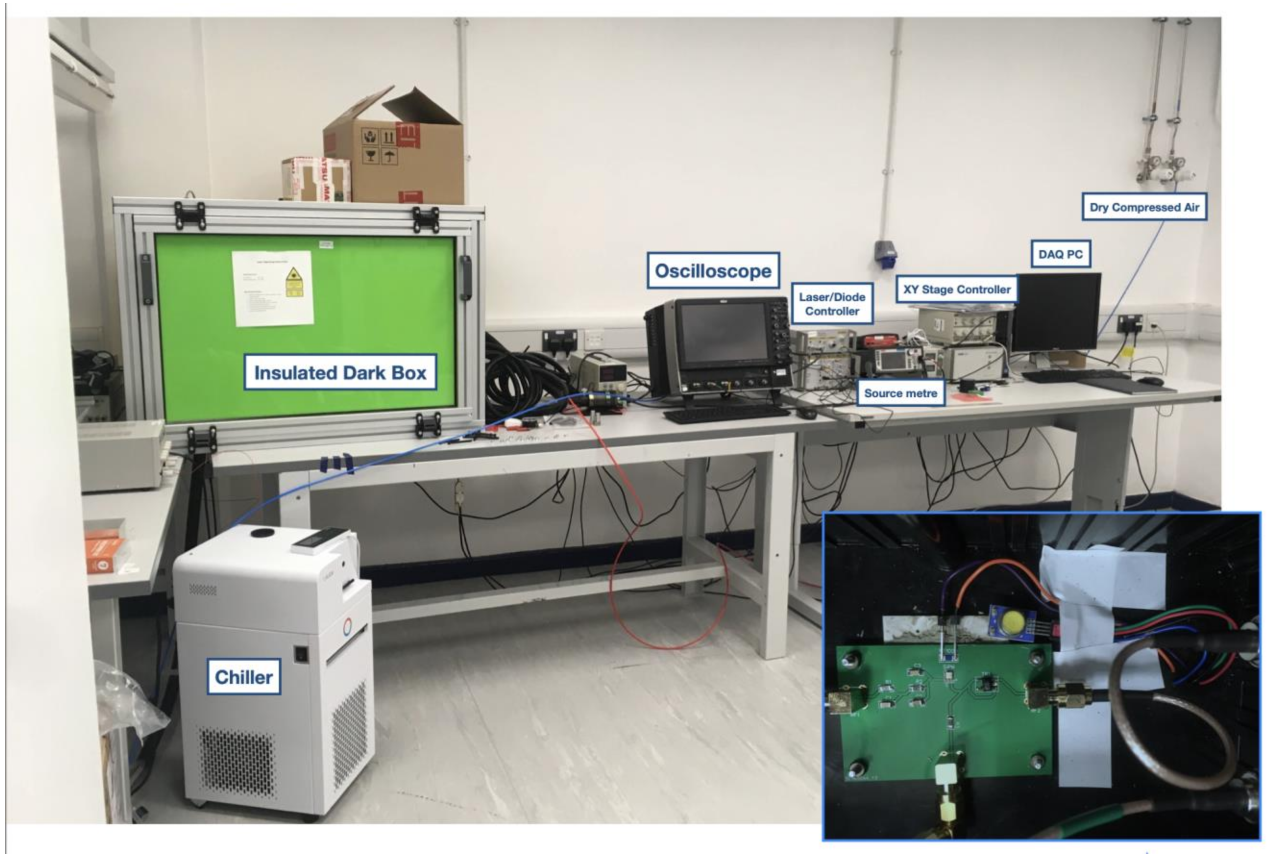
What is a silicon photomultiplier (SiPM)

- A single-photon sensitive light detector consisting of an array of single photon avalanche diodes.
- Operated at a reverse bias above its breakdown voltage.
- Single photon gets absorbed and creates an electron-hole pair by exciting an electron above the band gap. The charge carriers get accelerated by the voltage and produce more charge carriers by ionisation of Si lattice – avalanche.
- The signal gets quenched by the quenching resistor.





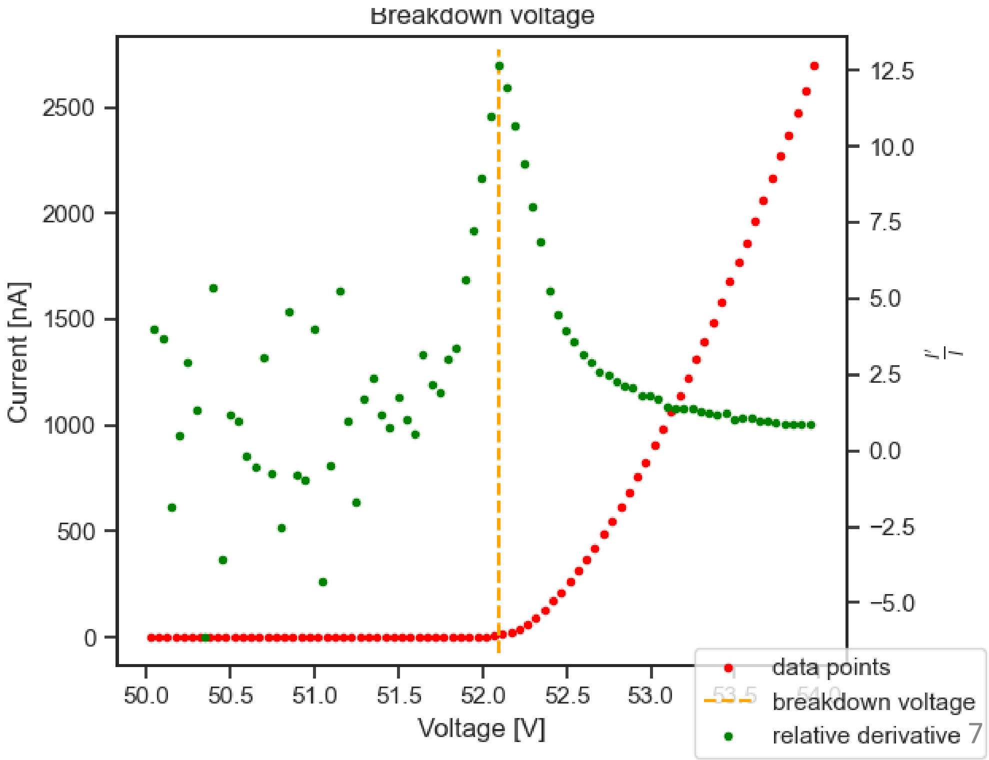
Source: https://hep.hamamatsu.com/eu/en/products/S13360-1350PE.html



My work – measurement of SiPM parameters

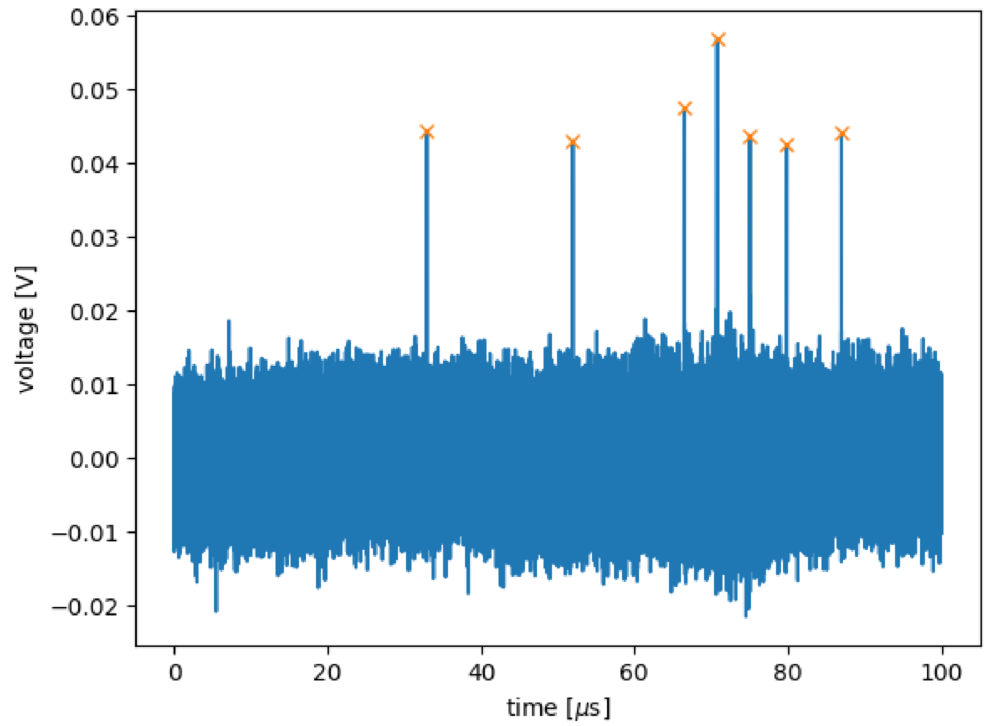
Breakdown voltage

- SiPMs start detecting single photons when biased at the breakdown voltage of its constituent diodes.
- Experimental truth: the breakdown voltage corresponds to the local maximum of a $\frac{\frac{dI}{dV}}{I}$ curve.
- Typical operating point: V_{BR} + 3-4 V.
- Increasing voltage increases the probability of photon detection, but also increases noise in the system.
- Typically, breakdown voltage decreases linearly with temperature.



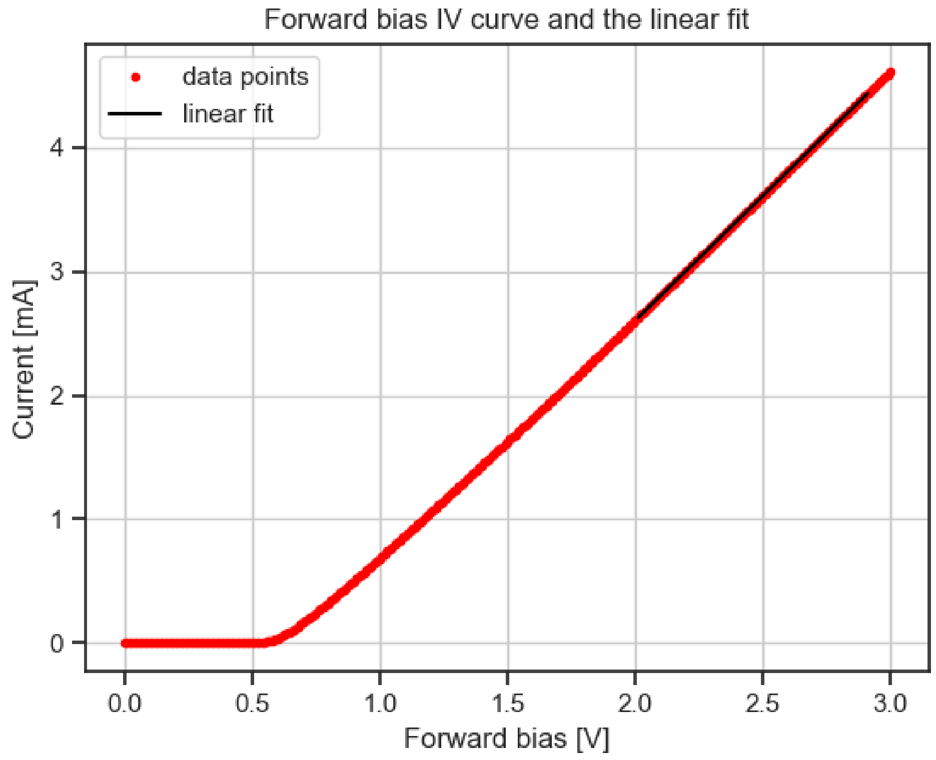
Main source of noise – dark counts

- Thermal excitation of electrons can also cause avalanche in a diode – a dark count.
- Dark current (current due to dark counts) increases with overvoltage and depends exponentially on temperature.
- Cooling the system down is the principal way of dealing with it.



Forward bias – quenching resistance

- As forward bias increases, voltage drop across the diode becomes negligible compared to the resistor.
- Slope of the linear part of a forward IV curve is given by $\frac{1}{R_{||}}$, where $R_{||}$ is the total parallel resistance.
- Knowing the total no. of cells, individual quenching resistance can be calculated.



Outlook: neutron irradiation

- SiPMs are expected to receive $10^{14}\ cm^{-2}$1-MeV-equivalent neutron fluence during the operation of RICH after upgrade 2.
- Main problem: collisions between neutrons and Si atoms create vacancies and interstitial defects.
- The defects give rise to energy levels inside the band gap.
- These energy levels facilitate thermal excitation of electrons, increasing drastically the dark current.
- How much do you need to cool the device to counter this?

Thanks for listening!