Study of SiPM performance for the upgrade of the LHCb main tracker

David Gerick, Physikalisches Institut, Heidelberg University

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

The LHCb experiment

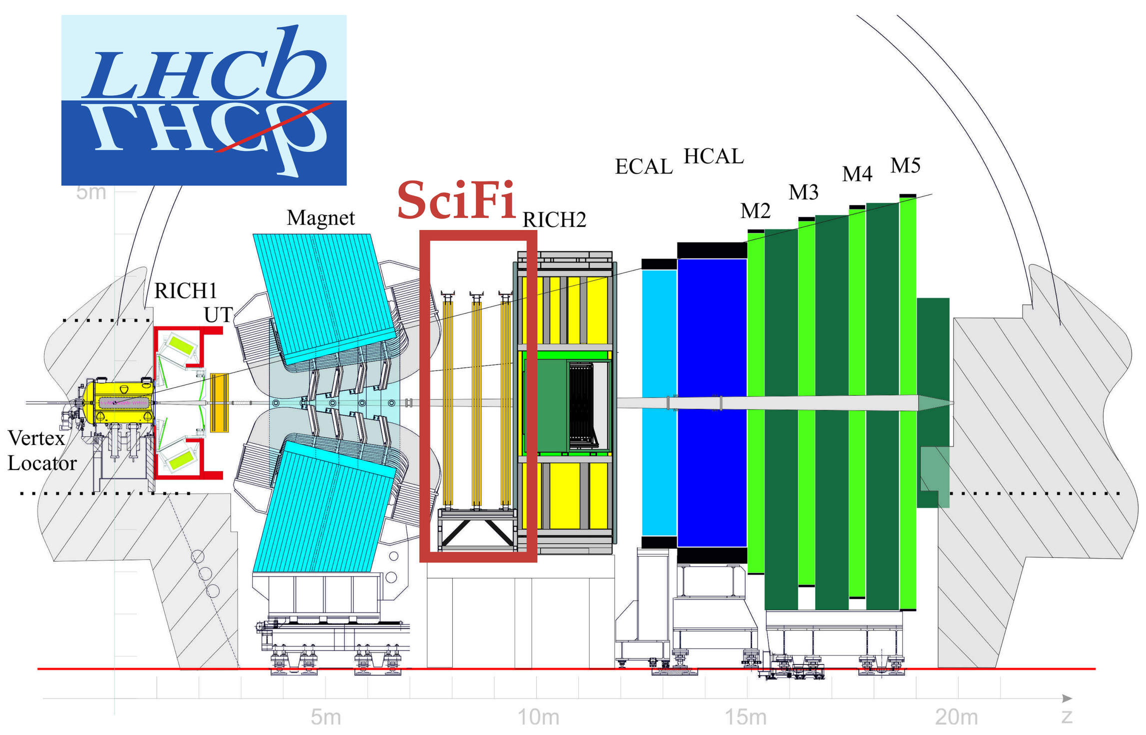

Figure 1: The upgraded LHCb detector

The LHCb experiment is a single arm forward spectrometer at the Large Hadron Collider (LHC). The main research topics cover the **indirect search for new physics** beyond the Standard Model (SM) in decays of hadrons containing charm and beauty quarks.

Scintillating Fibres

Scintillating fibres with a diameter of 250 µm emit a light spectrum in the range of 400-600 nm. Six layers of fibres are aligned and glued into mats of size 13.1 cm × 242.5 cm.

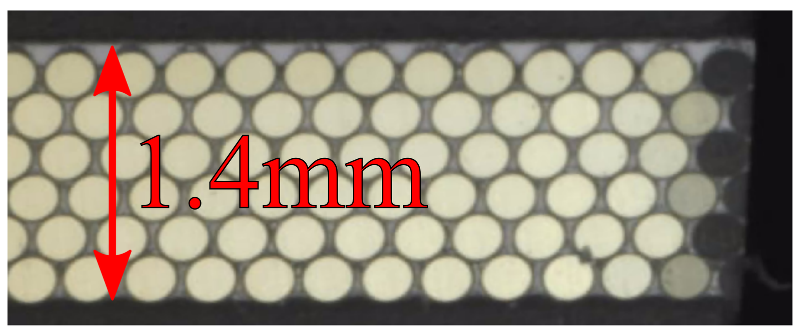

Figure 3: detail of a fibre mat cross-section

Dark Count Rate in SiPM

Non-ionizing neutron radiation damages the silicon crystal structure and enhances the rate of thermally triggered pixels, so-called dark count rate (DCR). DCR increases linearly with neutron fluence, as shown in Fig. 6.

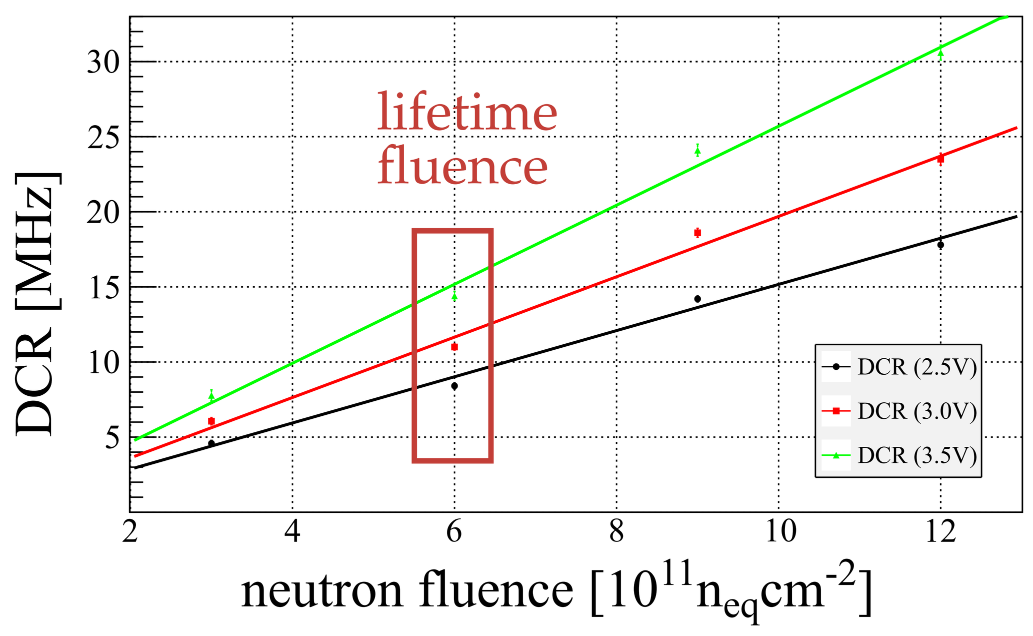

Figure 6: DCR of one SiPM channel after irradiation

Conducted radiation campaigns at neutron research reactors in Mainz and Ljubljana to beyond expected lifetime fluence.

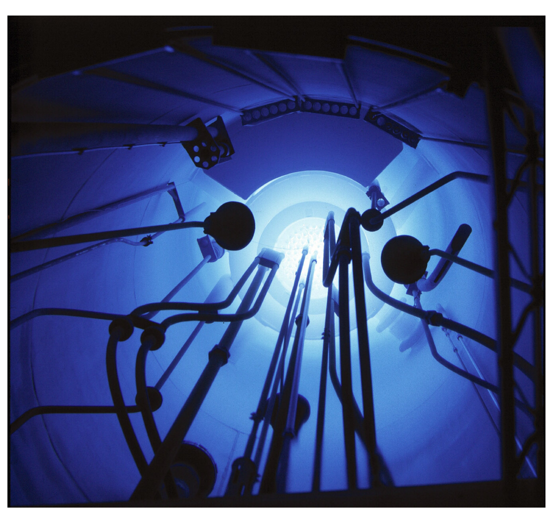

Figure 7: neutron research reactor in Mainz

References

[1] LHCb collaboration. *The LHCb Detector at the LHC*, JINST 3 (2008) S08005

[2] LHCb collaboration. *LHCb Tracker Upgrade TDR*, CERN-LHCC 2014-001, LHCb TDR 15

[3] LHCb collaboration. *LHCb Scintillating Fibre Tracker: Test Beam Report 2015*, LHCb-PUB-2015-025

The LHCb Scintillating Fibre Tracker

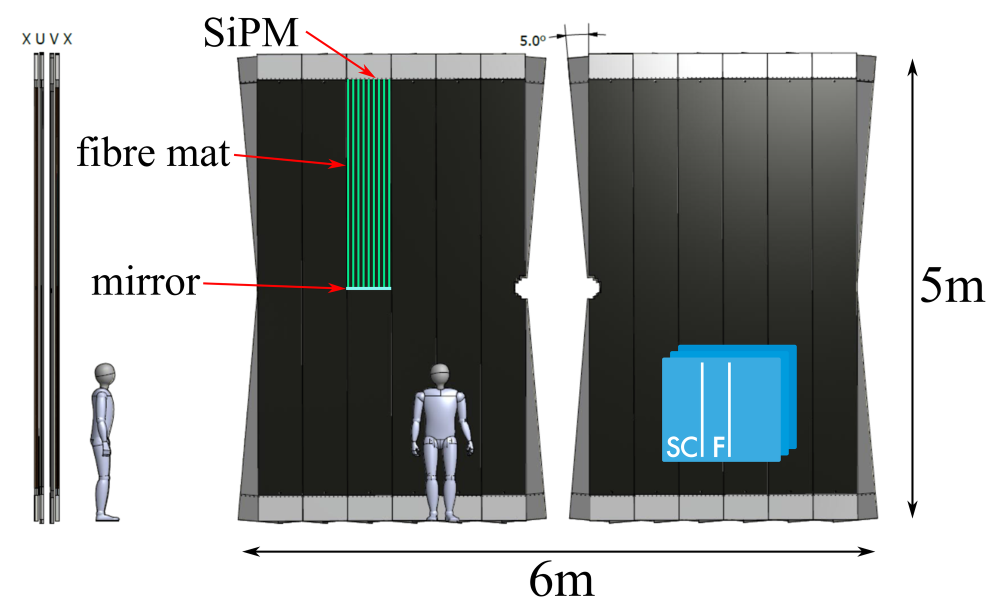

Figure 2: Side and front view of the SciFi Tracker

A total area of 340 m^2 will be covered in twelve layers, making it **world's largest fibre tracker**.

Main detector specifications:

- spatial resolution < 100 µm
- dead-time free read-out at 40 MHz
- single hit efficiency ~99%
- radiation hard to record 50 fb^{-1}

The SciFi Tracker will replace the gaseous straw-tube tracking stations. The new detector consists of two components:

1) **scintillating fibres**
2) **silicon photomultiplier (SiPM)**

Silicon Photomultiplier

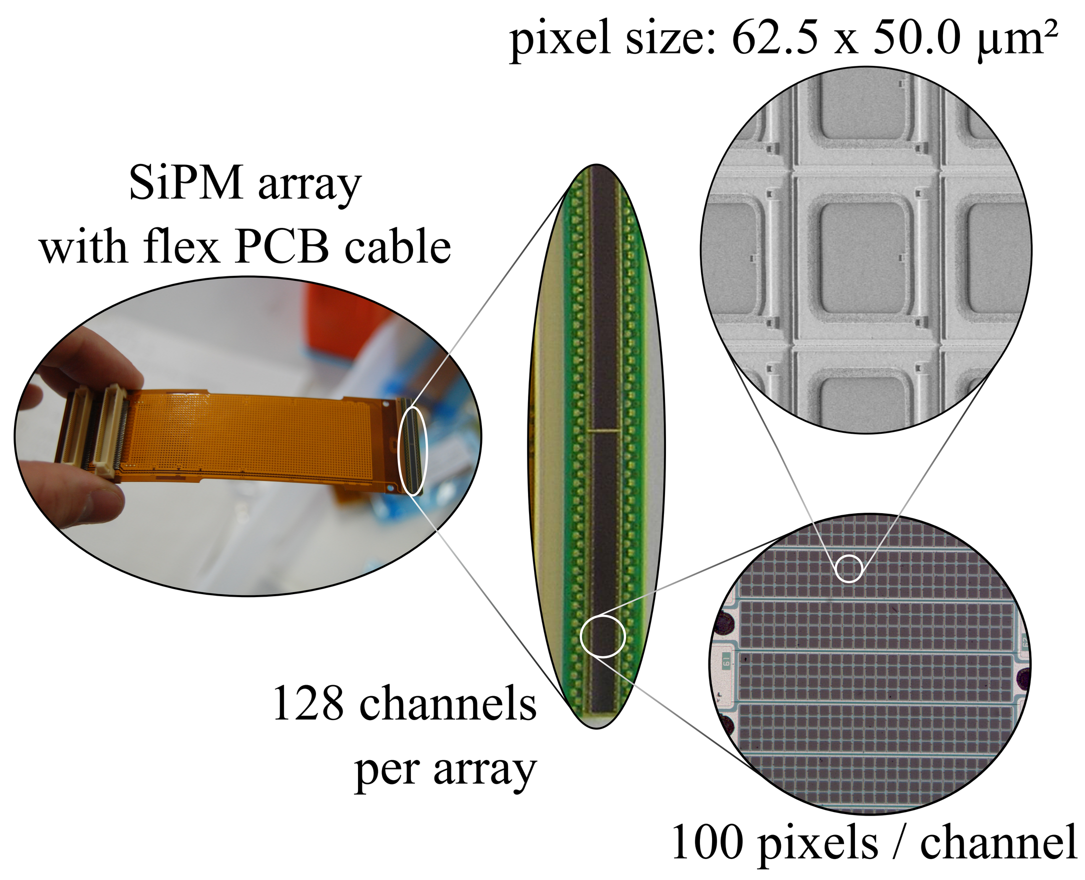

Figure 4: Zoom into a SiPM array

SiPM are pixelated single photon counters operated in Geiger mode, with gain of $10^6 - 10^7$ and photon detection efficiency of up to 50%. They are powered by $\mathcal{O}(50\,\text{V})$ and insensitive to B-fields. In the SciFi Tracker, 40 MHz read-out rate and resolution below 100 µm are achieved.

SiPM threshold calibration

The custom designed read-out chip for LHCb only returns 2-bit amplitude information.
A full-ADC readout would create the well-known photopeak spectrum, but with the limited amplitude information, the threshold values have to be scanned. The discrete photo peak spectrum appears as a step-like function:

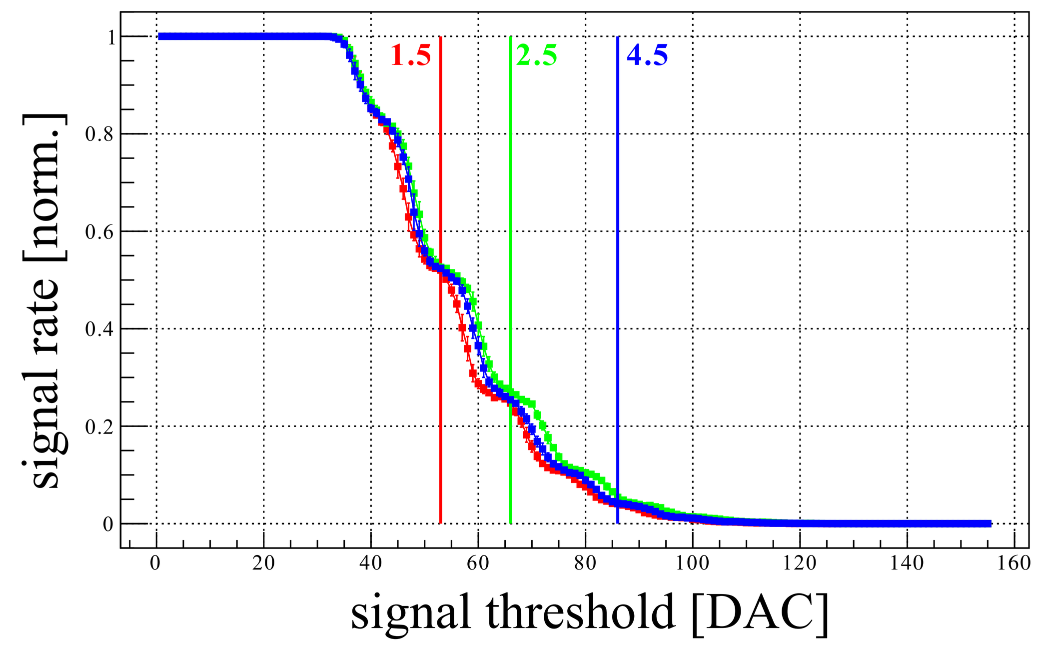

Figure 5: Threshold scan for SiPM calibration

The corresponding [DAC] values for the calibration of three thresholds are extracted by fits.

Clustering of SiPM channels and Noise Cluster Rates (NCR)

Neighbouring channels above threshold are clustered for hit position determination and efficient DCR suppression. The cluster algorithm with three thresholds is illustrated in Fig. 8.

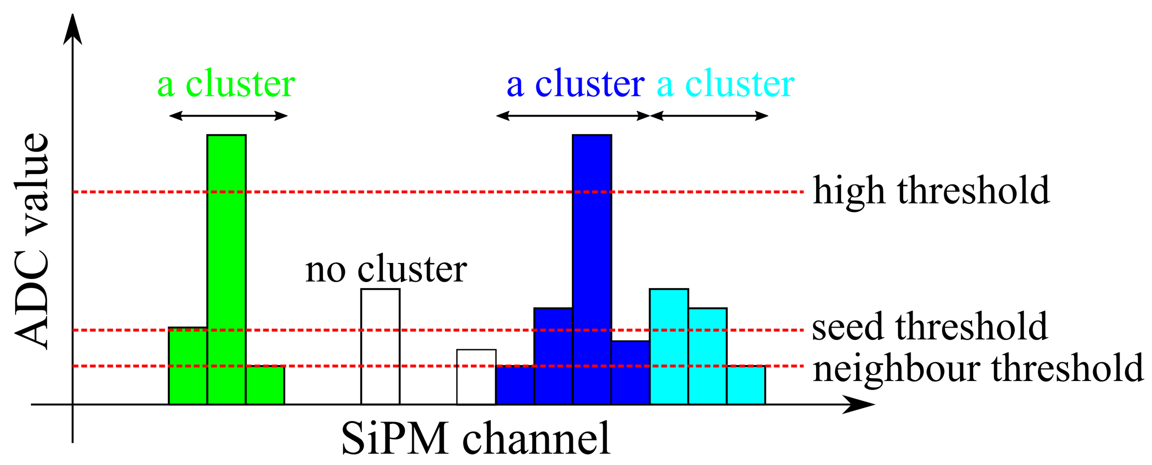

Figure 8: Cluster algorithm for the SciFi Tracker

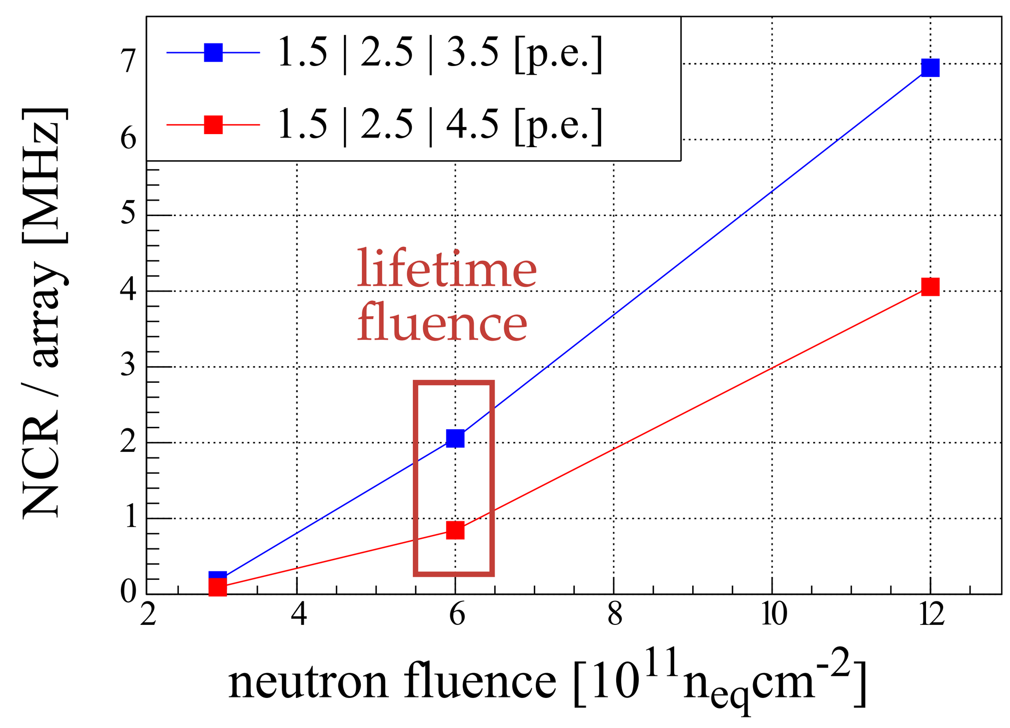

Figure 10: NCR in 128 channels at different neutron fluences and for two threshold configurations

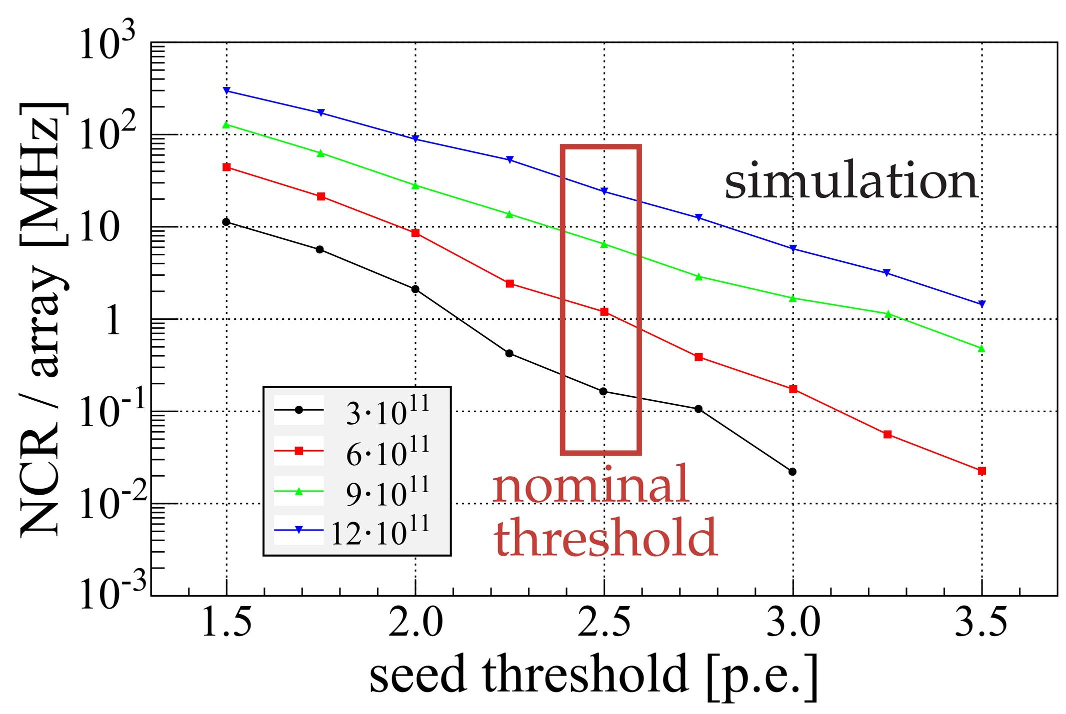

Figure 9: NCR in 128 channels simulated from a single channel DCR spectrum

Stand-alone MonteCarlo simulations using a measured DCR spectrum show the exponential increase of NCR with delivered neutron fluence in Fig. 9.
Direct measurements of the NCR in Fig. 10 agree with these previous simulations.

Conclusion:

The measured NCR per 128 SiPM channel (at lifetime neutron fluence) undercuts critical rates. **NCR = 1-2 MHz** can safely be handled by FEE, bandwidth and track reconstruction algorithms.