LHCb Upgrade: Scintillating Fibre Tracker

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The LHCb SciFi Tracker [1] is part of a major upgrade campaign of the LHCb detector to allow operation during the LHC Run 3, i.e. from 2019 onwards, at a levelled luminosity of 2×10^{33} $cm^{-2}s^{-1}$ and at a readout rate of 40 MHz (bunch crossings every 25 ns). The SciFi tracker is designed to replace the current Outer Tracker (based on gas drift tubes) and the Inner Tracker (silicon microstrips). It consists of 3 tracking stations with 4 independent planes each (X-U-V-X, stereo angle ±5°) and extends over 6 m in width and 4.8 m in height (see Fig. 1). Blue emitting scintillating plastic fibres of type SCSF-78MJ from Kuraray with 250 µm diameter are arranged in a staggered close-packed geometry to 6-layer fibre mats. The mats are 2.4 m long and mirror coated at the non-read end. The scintillation light exiting at the other end is detected by linear arrays of SiPM detectors (128 channels of 0.25 x 1.6 mm2 size). As shown in Fig.2, the height of a SiPM channel (1.6 mm) extends over all 6 layers of the fibre mat. The pitch (0.25 mm) allows resolving the clusters of hit fibres of typically 2 or 3 channels width. The signals are therefore read out with fully customised 3-threshold electronics which shall push the spatial resolution beyond the digital resolution $D_{fibre}/ \sqrt{12} = 72\mu m$. Reading and processing the signals from 600’000 SiPM channels at a rate of 40 MHz is a major challenge requiring massive use of FPGAs and state-of-the-art optical links.

While the chosen technology - staggered fibre mats with SiPM array readout - has been previously demonstrated in the PerdAIX balloon experiment [2], the LHCb requirements and the environment push it to the limits in several respects.

The scintillation light has to travel up to 2.4 m, the reflected light even up to 4.8 m, before it can be detected by the SiPM. This requires 250µm fibres of particularly long attenuation length (>3m) which is a challenge for the fibre producers. With a propagation delay of 6 ns/m there may be spill-over effects into the next bunch crossing.

The ionising dose in the inner region close to the LHCb beampipe is expected to reach 35 kGy, fortunately falling off to values of about 50 Gy close to the SiPMs. This means however that radiation damage affects mainly the light which is anyway already the most attenuated on its way to the SiPM.

The SiPMs, located more than 2.4 m above and below the beampipe, are exposed only to small ionizing doses, however they suffer from a neutron fluence (without dedicated shielding) of up to $1.2 \cdot 10^{12}\,cm^{-2}$ (1 MeV equivalent). Proportional to the neutron fluence, the leakage current (or, equivalently, the dark noise rate) of the SiPMs rises to values which de facto makes them unusable. *Normal* operation can be restored by cooling the SiPMs, which suppresses the noise rate by a factor of about $2^{\Delta T/10}$. The SiPMs in the LHCb SciFi Tracker are therefore foreseen to operate at -40°C.

The detector design has to foresee sufficiently thick scintillating fibre layers, such that the signal after radiation damage still guarantees the high hit efficiency required for the tracking. The detector will therefore be built from fibre mats made out of 6 layers of fibres. Each mat has a widths of 130 mm and a length of 2.4 m. Modules (52cm × 4.8 m) are built from 8 single fibre mats embedded between two supporting light-weighted carbon fibre / honeycomb panels. The module ends are foreseen to carry the readout boxes containing the cooled SiPM arrays (at -40°C) and the readout electronics. A total of 144 modules are necessary to cover the active surface of the tracker of 360 m^2.

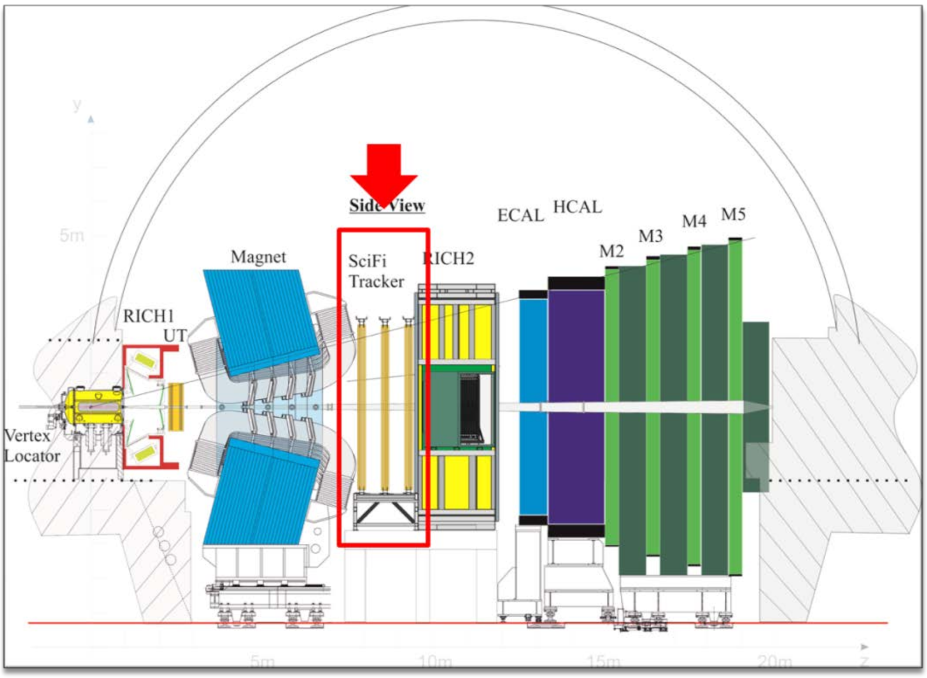

Figure 1: Overview: The SciFi tracker in the upgraded LHCb experiment.

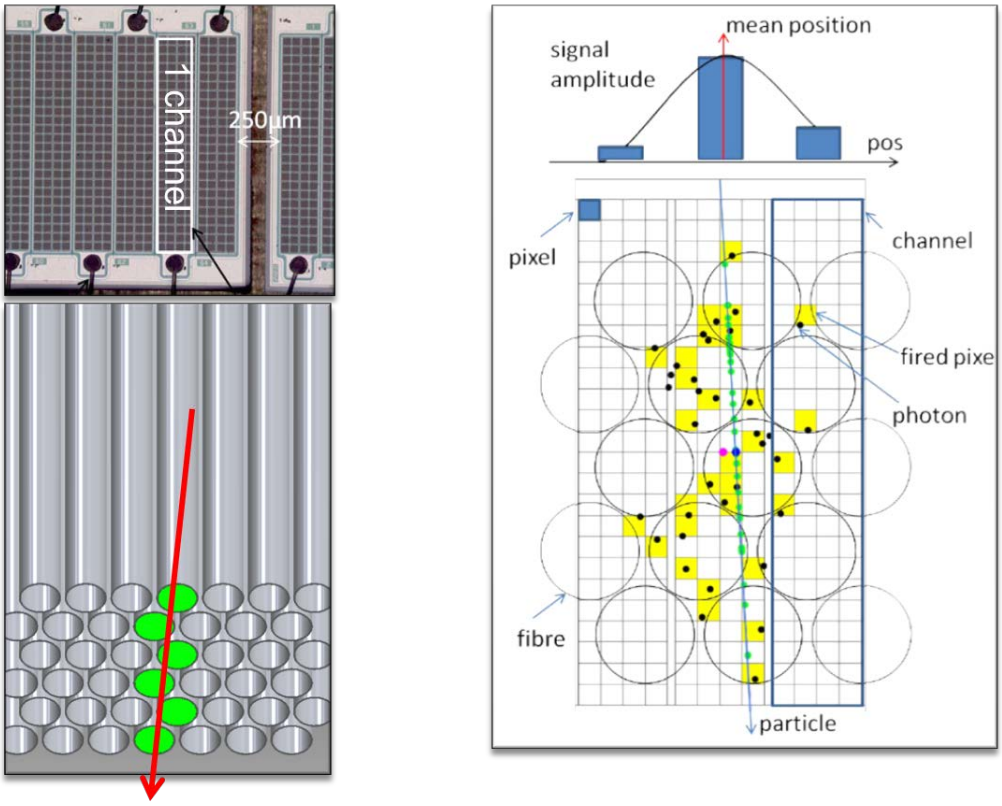

Figure 2: Principle of signal generation and detection.

References:

[1] LHCb Upgrade Technical Design Report, LHCb Tracker. CERN/LHCC 2014-001

[2] B. Beischer et al., Nucl. Meth. Instr. A 622 (2010) 542-544