SciFi - A large Scintillating Fibre Tracker for LHCb

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The LHCb SciFi tracker [1] 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). With a total active surface of about 360 m^2 it is by far the largest high resolution fibre tracker ever built.

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 mirrors applied to 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 mm^2 size). As shown in Fig.1, 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 $D_{fibre}/\sqrt{12}$ = 72µm. Reading and processing the signals from 600'000 SiPM channels at a rate of 40 MHz is a major challenge requiring a dedicated FE chip as well as 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 from the inner part which has anyway already the longest path 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 1 MeV equivalent neutron fluence of up to $1.2 \cdot 10^{12}\,cm^{-2}$ (without dedicated shielding) . 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. Close-to-final versions of the SiPM arrays and the readout electronics are available.

Full-size fibre module have been prototyped and were tested in particle beams. We will report about photoelectric yields, detection efficiency and spatial resolution and the results of extensive radiation campaigns.

The project is now at the transition to series production and on track for installation during the LHC shutdown LS2. A multitude of innovative technologies and tools had to be developed to ensure the required production yield and quality. By the time of the conference, about 10% of the fibre mats will have been produced and tested.

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

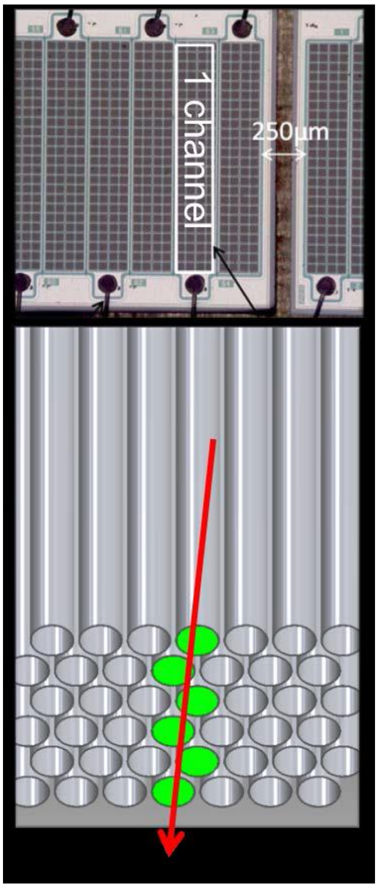

Figure 1: Principle of signal generation and detection in a close-packed 6-layer mat of scintillating fibres. The top part of the figure shows a close view of the SiPM array.