SciFi - The New Scintillating Fibre Tracker for LHCb

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Content

The LHCb detector will be upgraded during the Long Shutdown 2 (LS2) of the LHC in order to cope with higher instantaneous luminosities and to read out the data at 40MHz using a trigger-less read-out system. The current LHCb main tracking system, composed of an inner and outer tracking detector, will not be able to stand the increased particle multiplicities and will be replaced by a single homogenous detector based on scintillating fibres.

The new Scintillating Fibre (SciFi) Tracker covers a total detector area of 340 m2 and will provide a spatial resolution for charged particles better than 100 μm in the bending direction of the LHCb spectrometer. The detector will be built from individual modules (0.5 m × 4.8 m), each comprising 8 fibre mats with a length of 2.4 m as active detector material. The fibre mats consist of 6 layers of densely packed blue emitting scintillating fibres with a diameter of 250 μm. The scintillation light is recorded with arrays of state-of-the-art multi-channel silicon photomultipliers (SiPMs). A custom ASIC will be used to digitize the SiPM signals. Subsequent digital electronics performs clustering and data-compression before the data is sent via optical links to the DAQ system. To reduce the thermal noise of the SiPM in particular after being exposed to a neutron fluence of up to 10^{12} neq /cm^2, expected for the lifetime of the detector, the SiPMs arrays are mounted 3D-printed titanium cold-bars placed in so called cold-boxes and cooled down by to -40^{o}C.

The production of fibre mats and modules is in full swing: fibre mats are being produced in four production centers and assembled to 5 m long modules at two sites. In parallel the readout electronics is finalized and its series production is prepared. The detector installation is foreseen to start end of 2019.

The talk will give an overview of the detector concept and will present the experience from the series production complemented by most recent test-beam and laboratory results.

Keyword
Scintillating Fibre Tracker,SciFi,SiPM,Tracking

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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 340 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 will therefore operate at -40°C. The SiPM design has been optimised and a pre-series of 500 devices has been received.

The project has transited to series production mode and manufacturing of fibre mats and modules is in full swing. By the time of the conference, about half of the approx. 1000 fibre mats will have been produced and tested. A multitude of innovative technologies and tools had to be developed to ensure the required production yield and quality.

The fully customized PACIFIC ASIC has 64 channels, each comprising a fast pre-amplifier, shaper and dual gated integrators. The integrated signal is compared with 3 thresholds leading to 2 bit information. Test results of lab and beam tests will be presented.

The project is on track for installation during the LHC shutdown LS2.

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

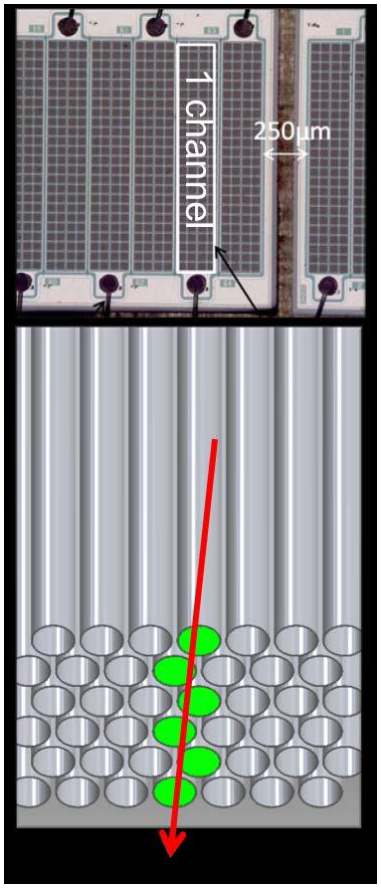

Figure 1: Principle of signal generation and detection in a close-packed 6-layer mat of scintillating fibres. The top part of the figure shows a close view of the SiPM array.