LHCb SciFi – The New Fibre Tracker for LHCb

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Scintillating plastic fibres as active elements in tracking detectors are being exploited since more than 30 years [1]. They allow building intrinsically fast and particularly low mass detectors with a high degree of geometrical adaptability. On the other hand, the achievable spatial resolution is correlated with the fibre diameter and hence with the light yield, unless one conceives staggered multi-layer fibre arrangements which come at a cost in terms of number of readout channel and material budget. A further limitation is the moderate radiation hardness of plastic scintillators which prevent its use in very harsh environments.

It's in particular the dramatic evolution of the photodetection technology, currently culminating in the so-called SiPM, which revived the interest in the SciFi technology and opens up new fields of application. The intrinsic properties of the SiPM, in particular the combination of high sensitivity, high gain and fast pulse shape, implemented in a solid-state sensor of sub-mm^2 size, allow designing large-scale high-resolution SciFi detectors read out at LHC speed.

LHCb is developing a large planar SciFi tracker which will, from LHC Run 3 onwards, replace the currently installed Outer Tracker (based on gas straw tubes) and Inner Tracker (Silicon microstrips) by a single detector technology [2]. The detector 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 5 m in height. Blue emitting scintillating plastic fibres of 250 μm diameter are arranged in a staggered close-packed geometry to 5 or 6-layer fibre mats. The mats are 2.5 m long and mirror coated at one 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). The height of a SiPM channel (1.6 mm) extends over all 5 (or 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. Provided the signals can be read out with an analog or a multi-threshold electronics, the spatial resolution can be pushed well beyond the digital resolution $D_{fibre}/\sqrt{12} = 72\ \mu m$.

Apart from the spatial resolution, two more performance figures characterise a tracking detector: the hit efficiency and the ghost rate. The hit efficiency is directly linked to the amplitude of the signals (measured in photoelectrons) and the minimum threshold at which the photodetector can be operated. The ghost rate is related to the noise cluster rate, which depends again (but not only) on the threshold applied to the photodetector. In a harsh radiation environment, as expected at LHCb, the operation and the achievable performance of the detector are fully governed by radiation related effects. The ionising dose (up to 35 kGy in the inner region close to the LHCb beampipe) degrades the transparency of the scintillating fibre and hence the amplitude of the detectable signal. The SiPMs, located more than 2.5 m above and below the beampipe, are exposed only to small ionizing doses, however they suffer from a neutron fluence 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. There is unfortunately no equivalent remedy which would neutralise the radiation damage to the scintillating fibres. 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.

Since the introduction of the double cladding structure (CERN RD7 and Kuraray, 1990), the technology and performance of scintillating fibres have not seen major advances. In many tracker designs, the performance is still limited by moderate scintillation yield, optical attenuation length and radiation hardness. Moreover, the traditional technology of building fibre mats by winding fibres on a wheel which carries a fine-pitch thread lacks the precision and repeatability of a silicon device produced by wafer-level microfabrication incl. photo-lithographic patterning. This makes the construction of a fibre large-scale tracker a labour-intense endeavour of which only a small part can be outsourced to industry.

Recently a Russian group developed a novel type of plastic scintillator, in which so-called Nanostructured Organosilicon Luminophores (NOL) are admixed to the polystyrene (PS) matrix [3]. Unlike in traditional plastic scintillators, where the activator and wavelength shifting dyes are independently and randomly distributed in the PS matrix, the NOL approach couples activator and wavelength shifters via bridges of Silicon nanoparticles to dendritic antenna structures. The close geometric correlation of activator and wavelength shifting complexes is expected to reduce losses of UV photons and to increase the overall efficiency of the conversion process by profiting from non-radiative energy transfer (Förster transfer). This was demonstrated by comparing the light yield of disk-shaped scintillator samples (Ø25 mm × 0.2 mm), exposed to 5.49 MeV a-particles with that of standard scintillators (UPS89 from Amcrys-H, Ukraine) of the same geometry. The authors of reference [3] report for different NOL formulations up to 49% higher light yield and at the same time reduced decay time constants. Measurements need to be performed with minimum ionising particles, the tolerance of the material to ionising dose needs to be established and the results need to be confirmed by other groups. If NOL material is found to maintain its appealing properties also in fibre form, NOL fibres would be an attractive option for the LHCb SciFi tracker, particularly for the inner region where the signal degradation due to ionising dose is most expressed.

References

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