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A Scintillating Fibre Tracker for the LHCb Upgrade

Robert Ekelhof, TU Dortmund
on behalf of the
LHCb Collaboration

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Related Talks of Interest

- Wednesday plenary
 - "The LHCb upgrade "
 - Eric Van Herwijnen (CERN)
 - "Recent advances in the development and applications of scintillating fibres in HEP and astroparticle physics experiments"
 - Frédéric Blanc (EPFL, Switzerland)
- Monday, Tracker and Applications I
 - "The Performance and Radiation Hardness of the Outer Tracker Detector for LHCb"
 - Evelina Gersabeck (Universität Heidelberg)
 - "Tracking and Alignment of the LHCb detector"
 - Maurizio Martinelli (Nikhef, Amsterdam)

LHCb & SciFi Upgrade

LHCb

- single-arm spectrometer (10-300mrad)
- dedicated to heavy flavour physics at the LHC, looks for
 - indirect evidence of new physics in CP violation
 - rare decays of beauty and charm hadrons

LHCb Upgrade

- current detector optimised for lower luminosity than LHC could deliver
 - one interaction per bunch crossing
 - instant luminosity $2\text{E}32 \text{ cm}^{-2} \text{ s}^{-1}$
(design specification)
- upgrade of whole detector is planned for LS2 in 2018/19
 - increase instant luminosity up to $2\text{E}33$ to record a total integrated luminosity of 50fb^{-1}
 - great change in Trigger, change to full software trigger
 - this requires 40MHz readout of FE electronics
 - several subdetectors will be replaced

SciFi @ LHCb

- upgrade of downstream tracking stations T1-T3, since the occupancy in the current Outer Tracker would be too high
- two alternatives:
 - enlarged silicon IT + drifttube OT
 - SciFi CT (or full area FT without OT)

SciFi @ LHCb

- 250 μ m diameter scintillating fibres (pitch 280 μ m)
- read out by multi-channel Silicon-Photomultipliers (SiPM) (pitch 250 μ m)
- 5 layers for sufficient light output
- 5m acceptance is split in two halves of 2.5m fibres
 - SiPM readout on the outer edge
 - mirrored ends at the inner edge

SciFi @ LHCb

- how does it work?
 - hits in neighbouring channels form cluster
 - hit position calculated by weighted sum
 - different thresholds can be set for best SNR
- requirements
 - high hit detection efficiency (98-99%)
 - spatial hit resolution of 60-100 μ m
 - low material budget

Radiation Environment

- detector components have to withstand the harsh LHC environment
- SiPMs
 - 1MeV neutron equivalent of $6 \times 10^{11} / \text{cm}^2$
 - dose $< 100 \text{ Gy}$
 - may be lowered with shielding
- fibres
 - dose up to 30 kGy near beam pipe
 - falls rapidly to outer edges

Fibre R&D

Scintillating Fibres

- baseline fibre Kuraray SCSF-78MJ
- scintillating core & two claddings
- "scintillation" known to be radiation hard
- attenuation length effected by irradiation
- 3HF (green) fibres more radiation hard, but lower light yield and longer decay time
- existing literature inconsistent concerning quantative results

Irradiation Campaigns

- different irradiations where performed
 - in situ LHCb ($\approx 0.1\text{kGy}$)
 - CERN PS (3kGy, 22kGy)
 - Karlsruhe (10kGy, 40kGy)
 - Munich (100kGy)
- attenuation of light measured with excitation by UV-LED or radioactive sources

Irradiation Results

- the data of the different campaigns where analysed wavelength dependend
- the attenuation length as function of the dose is fitted with the empirical model developed by Hara et al.*
- although the damage occurs quickly (in dose), it mainly affects the center
- new physically motivated models are tested to fit the data and are used for simulation of light transport

- K. Hara, K. Hata, S. Kim, M. Mishina, M. Sano, Y. Seiya, K. Takikawa, M. Tanaka, and K. Yasuoka. „Radiation hardness and mechanical durability of kuraray optical fibers.“ Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 411(1):31 – 40, 1998.

SiPM R&D

Characterisation

- SiPM = array of Geiger mode avalanche photodiodes ("pixels")
- number of fired pixels gives the number of photons
- multichannel SiPMs by Hamamatsu and KETEK
- noise simulation to test the effect of different parameters
 - primary noise
 - temperature
 - neutron dose
 - crosstalk
 - after-pulse
 - shaping time
 - thresholds

Irradiation

- several irradiation campaigns (accelerators, in situ, radioactive sources)
- noise increases linearly with dose
- noise reduced by factor 2 every 10°C
- cool SiPMs to -40°C (maybe -50°C)
- heated during Technical Stop for annealing
- annealing at ambient T too slow for TS
- at 40°C -> few days
- at 60°C -> few hours

Crosstalk & Improvements

- pixel-pixel x-talk
- fine for signal
- brings dark noise above 1 p.e.
- lowering crosstalk with trenches
- additional improvements:
 - higher PDE
 - green shifted sensitivity
 - optimised pulse shape

Viability Assessment

- Technical Board of LHCb asked for a viability assessment of the SciFi Tracker technology for LHCb
- main goal was to judge the radiation hardness of the fibres and SiPMs
- it was concluded that it's a viable technology option for the LHCb upgrade tracker system (March 2013)

next step is to build demonstrator modules to prove

- precise fibre layers
- building of large size modules
- coupling to SiPMs
- Cooling
- technology choice (silicon strips + drift tubes vs SciFi) in November

Modules

Overview

- LHCb downstream tracking: 3 stations with 4 layers of 6x5m
 - 4 layers: 0° , $+5^\circ$, -5° , 0° stereo angle
- one SciFi module:
 - 53cm wide, 5m long (high)
 - 2x4 fibre mats
 - 2x16 SiPMs (with 128ch each)
 - 2x one cooling bar
- 10k km of scintillating fibre
- 600k channels

Fibre Mats

- production method for a fibre mat inspired by production of fibre modules by RWTH Aachen for the PEBS experiment
- fibres are wound on a wheel (1m diameter) with a 280 μ m thread
- glue is placed on the fibre right before it touches the wheel
- the 1st layer of fibres is used as thread for the 2nd layer and so forth
- after glue has cured "enough", the mat is cut and taken off to be flattened
- the sides along the fibres are cut to achieve a good edge

fibre mats

Fibre Mats

- alternative to threads on the wheel is investigated
- Kapton substrate with groove structure which is positioned on the wheel
- photoimageable coverlay (epoxy-like, DuPont)
- the Kapton stays attached to the fibre mat and can provide alignment marks

Support Structure

- fibre mats are positioned in the middle of a sandwich structure
- support panel is not divided, 5m long
- honeycomb with carbon fibre skins (+light tight foil)
- radiation length $\approx 0.6\%$ (+ $\approx 0.3\%$ for fibres)
- SiPMs mounted to "end piece"
- alignment pins on the fibre mats ensure the straightness

Support Structure

- "End Cap"
 - top/bottom end of module with connection to FE board
 - enclosure for cold volume
 - connection from fibres to SiPMs to cooling pipe
 - mounting point of module

SiPM Cooling

- cool down to -40°C
- cooling power dominated by heat leaks
- different technologies under investigation
 - liquid cooling (2-phase, single-phase)
 - air cooling
 - peltier cooling
- simulations performed to estimate heat load and evaluate the influence of different module geometries
- tests with mockups performed and ongoing
- in parallel: tests of thermally cycled fibres

Electronics

- many of the existing integrated front-end electronics chips for SiPMs optimized for calorimeter readout
- instead of large dynamic range, good linearity, fast sampling and readout are needed
- it was decided to develop an optimized ASIC to read out the SiPMs with 40MHz

Simulation

- simulate all steps from light attenuation to tracking
- possible to test the influence of different parameters on tracking performance, e.g.
 - detector layouts (distances between layers, mono-layer vs bi-layer)
 - dead regions
 - stereo angles
 - radiation damage
 - misalignment
 - timing of signal (fibres, SiPMs, electronics)

Summary

- radiation environment is an important issue for a scintillating fibre tracker with SiPM readout at LHCb, but damage is understood and can be coped with
- R&D towards the demonstrator modules is on the home stretch
- after the technology choice the work will continue towards the TDR in March 2014