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A Scintillating Fibre Tracker for the LHCb Upgrade

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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 $2 \times 10^{32}$ cm$^{-2}$ s$^{-1}$
    (design specification)

- upgrade of whole detector is planned for LS2 in 2018/19
  - increase instant luminosity up to $2 \times 10^{33}$ to record a total integrated luminosity of $50$ fb$^{-1}$
  - 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

- 250µm diameter scintillating fibres (pitch 280µm)
- read out by multi-channel Silicon-Photomultipliers (SiPM) (pitch 250µm)
- 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 60-100µm
  - low material budget
Radiation Environment

- detector components have to withstand the harsh LHC environment

- SiPMs
  - 1MeV neutron equivalent of 6E11 / cm²
  - dose <100Gy
  - may be lowered with shielding

- fibres
  - dose up to 30kGy 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 (≈0.1kGy)
  - 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 dependent
- 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

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°, -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 280µm thread
- glue is placed on the fibre right before it touches the wheel
- the 1\textsuperscript{st} layer of fibres is used as thread for the 2\textsuperscript{nd} 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.