SciFi -
A Large Scintillating Fibre Tracker for LHCb

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Motivation for the LHCb Upgrade

Most physics result at LHCb are statistically limited:

→ after long shutdown 2 (2018-2020)
  • increase luminosity by a factor of 5, i.e. run at \( 2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \)
  • readout detector at 40MHz using a software trigger, i.e. replace current L0 hardware trigger

➢ consequences for the tracking system:
  • higher occuppancy
  • stringent requirements on radiation hardness

Drift tubes & silicon detectors will be replaced by single technology: Scintillating Fibre Detector with SiPM readout.
Requirements for SciFi Tracker

➢ SciFi Tracker has to cover 12 layers,
  area of each layer is 5 x 6m²
  ➢ 3 stations, each 4 layers in
    X-U-V-X geometry
➢ single hit efficiency close to 99%
➢ resolution better than 100µm
➢ low material budget: ~1% X0 per layer
➢ survive radiation level of
  ➢ 35kGy near beampipe
  ➢ ~10^{12} neutrons/cm² at readout

See talk by Matthias Karacson
(Session N43-7)
From single fibres to a tracking system:

1. Winding of fibre mats

Scintillating fibres (Kuraray SCSF-78MJ, Ø 250µm) are arranged in a matrix of
- 6 layers of fibres
- 275µm pitch

Fibre mat:
- 242.4 x 130.65 cm²
- 8km of fibres per mat
- covered by light tight polyimide foil
- mirror at far end to enhance light yield

Challenges:
- Over 10,000km of fibres to be tested and processed
- 1200 fibre mats have to be produced

Front view of scintillating fibres in fibre mat:
Fibre testing & bump removal

Fibre QA at CERN:
- bump detection & removal
- diameter, light yield and attenuation
- length measurement
- radiation hardness

Fibre mat winding

Fibre mat winding at winding centres
- winding & gluing of 6 layers of fibre
- finishing:
  - bond light tight foil and end-pieces
  - optical cut
- extensive QA:
  - geometry
  - light yield from β-source
From single fibres to a tracking system:
2. Building detector modules

- 8x Fibre mat
- 2x panels made Carbon fibre/Nomex core

Challenge:
Alignment of fibres & fibre mats to ~60µm

Total: 144 modules
Alignment of fibres & fibre mats in detector module

- Inherit precision of wheel by means of glue alignment pins

- Use pins for alignment using precisely machined (30µm) grooves in gluing jig

- Alignment of fibre mats and fibres of better than 60µm has been achieved.
Detecting the light with SiPM arrays:

Custom made SiPMs by Hamamatsu and Ketek are evaluated

- Optimization for high Photon Detection Efficiency (~45%) at low dark count rate & correlated noise (X-talk, after pulses)
- SiPMs will be operated at -40°C to limit radiation effects
Bringing all together:

Readout 2x 2048 SiPM channels

First full size module in cosmic test set-up
Light yield from cosmic test set-up
Light yield from cosmic test set-up

lower light yield caused by wrong SiPM calibration
Light yield along fibres measured with full size module in cosmic set-up

Mirrors enhances light yield for particles detected close to the mirror by ~65%.
Front-end electronics

➢ 560,000 SiPM channels readout @40MHz → data reduction at front end mandatory
➢ PACIFIC: Custom made ASIC
  - 64 channels, 3 threshold discriminator
  - noise suppression
➢ Cluster building and zero suppression by FPGA on clusterization board
➢ Transfer of data and signal distribution by master board

See talk by Jose Mazorra de Cos (Session N47-4)
Performance: Test beam results

➢ Test beams at CERN SPS (H8) with 180GeV/c protons.

➢ Special test beam modules with a single, full size fibre mat (2.42m x 0.13m) have been tested.

\[
\sigma = 75\mu m
\]

\[
\sigma = 80\mu m
\]
Challenge radiation hardness: Scintillating fibres

- Fibres suffer from irradiation:
  - production of scintillation light unaffected
  - attenuation length decreases

Before irradiation:
\[ I(x) = I_0 \cdot e^{-\alpha \cdot x} \]

After irradiation:
\[ I(x) = I_0 \cdot e^{-(\alpha + \alpha_{irr}) \cdot x} \]

- maximum expected rate close to beam pipe 35kGy
- down to 60Gy close to SiPM
  → expected loss of effective light yield 40% close to mirror after 10 years
Summary:

➢ The SciFi tracker is crucial to cope with the LHCb upgrade requirements
  - low mass (1% X0 per layer)
  - allows for fast tracking
  - good hit efficiency & resolution
➢ An efficient collaboration between 17 institutes in 8 countries
➢ Production of detector modules has started
➢ Installation in 2019
Backup
Challenge: radiation hardness: SiPM arrays

- SiPMs are sensitive to radiation damage, especially neutron irradiation
- expect $\sim 10^{12}$ n/cm² close to SiPMs for 50fb$^{-1}$
- neutron irradiation results in increase of dark count rate...
- ...but dark count rate decreases with T

Challenge:
Cooling of 150m of SiPM arrays to -40°C

dark count rate decreases by a factor of 2 every 10°
Light injection system for SiPM calibration

- Scratched fibre embedded in the module ends
- Shines evenly across the fibre and SiPMs
- Driver
  - Gigabit LASER Driver
    (GBLD, a radiation tolerant ASIC)
  - Vertical-cavity surface emitting laser (VCSEL) with wavelength of 670 nm
The Front-end ASIC PACIFIC

PACIFIC:
- TSMC 130nm
- 64 channel current mode input
- 2 bit/ch digital output
- High bandwidth (~300 MHz)
- Low power (6.5 mW/ch)
- Low input impedance (~50Ω)
- Fast shaping
- Dual gated integrators (zero deadtime)
- 25ns peak resolution