Modular beam telescope based on scintillating fibres and silicon photomultipliers

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Scintillating fibres for tracking
The SciFi telescope
• Modular design
• Test beam at SPS

Future developments
• Timing and large area
A SciFi tracker for LHCb

Large-scale SciFi technology application
- Placed downstream the magnet
- Total area of 340 m²
- 11’000 km fibres (Ø250 μm, 2.8 ns decay time) arranged in mats
- 4000 Silicon Photomultipliers (SiPMs) 128-channel arrays for a total of 500k read-out channels

Some advantages of SciFi technology
- Cover large area at relatively low cost and with high granularity
- No electronics and services in acceptance

Related talk:
B. D. Leverington, *Test beam results of the LHCb Scintillating Fibre Tracker.*
Fibre-based telescope for beam test

Two independent tracking stations

2× X+Y fibre detection planes (10 cm mats)

128-channel SiPM arrays

VATA64 «asynchronous sample and hold»
Limited to ~1kHz

Integrated scintillator triggers

LEDs for response calibration and trigger delay fine tuning

DUT placed in the centre for optimal track resolution free to move in transverse direction for position scans

Upstream

Downstream

Particle beam:
180 GeV µ, π, p at CERN SPS
5 GeV electrons at DESY
Setup of the latest test beam (Oct. 2017)

Particle beam: 180 GeV $\mu$, $\pi$, $p$ at CERN SPS

DUT: X+Y fibre mat of the same type as the tracking stations placed inside one of the stations
Setup of the latest test beam (Oct. 2017)

The two tracking stations VATA64 read-out electronics

- Beam
- Upstream scintillator trigger
- DUT
- The two tracking stations
- VATA64 read-out electronics

- Flex cable
- SiPM array
- Y fibre mats
- X fibre mats
- VATA64 read-out board
Track resolution and efficiency

Hit resolution $\sigma_{\text{hit}}$
- At the DUT: $\sigma_{\text{Residual}}^2 = \sigma_{\text{hit}}^2 + \sigma_{\text{track}}^2$
- $\sigma_{\text{hit}}$ same for all layers:
  $$\sigma_{\text{hit}} = 32\,\mu\text{m} \Rightarrow \sigma_{\text{track}} = 16\,\mu\text{m}$$

Hit detection efficiency $\varepsilon_{\text{hit}}$
- At the best hit resolution: $\varepsilon_{\text{hit}} = 99.6\%$
- Track finding efficiency $\sim 98.6\%$
- Reduce the number of tracks with multiple scattering: cut on track $\chi^2$
- Reject events with high energy delta electrons
  - At SPS: $\varepsilon_{\text{track}} = 50\%$ used tracks
Setup long module testing (f.ex. DESY)

The two tracking stations

DUT: SciFi 2.5m long modules

Electron beam

XY table for DUT positioning

Front-view

Long module angular scan

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Future developments
Large area device and timing

SHiP charm cross section experiment at SPS

Measurement of charm hadrons production cross-section of 400 GeV/c protons on SHiP target

- Tracking systems including SciFi modules
- Fibres and SiPMs of the same type as LHCb SciFi
  - STiC front-ends synchronized with beam trigger (~10 kHz)
  - Hit time resolution expected <1 ns, ~300 ps for the track using all planes. Limitations: small number of photons (~20), scintillator decay time 2.8ns
  - Hit resolution <50 µm expected

Integrate timing in the telescope to measure timing resolution for (large area) DUTs, rate increased up to 1 MHz
Summary

- Development of a beam telescope base on the same technology as the LHCb SciFi tracker with sufficient track resolution to characterize SciFi modules.

- Used successfully at SPS & DESY test beams to test large area fibre modules.

- Next improvements/developments:
  - Integrate timing measurement with the replacement of read-out electronics with STiC.
  - Development of a 400×400 mm² SciFi tracking system with 8 planes and timing measurement.
Thank you for your attention!
Hit position measurement and track reconstruction

Hit position calculation
- Signal shared by several channels
- Clustering algorithm to calculate the barycentre and to suppress noise

Planes alignment
- Alignment in the transverse direction using *Millepede*
- Set-up allows very good preliminary alignment (order of 200 μm correction)
Telescope optimisation ($\Delta V$)

- **SiPM over-voltage optimised** for the best hit resolution

- Correlated and random noise from the SiPM (fluctuation in signal amplitude in the cluster)

- Loose information from neighbours (too few signal)
SiPMs

Customised SiPM array produced by Hamamatsu for the SciFi tracker optimised for the LHCb SciFi tracker

High photo-detection efficiency (necessary due to low amount of light from the fibres)

- Pixel \(~60 \times 60 \mu m^2\) with \(~70\%\) fill factor
- Sensitive area: \(32.54 \times 1.625 mm^2\)
- Non-sensitive area between dies on the same package
- Low correlated noise (essential with the expected high DCR) over a wide operation range

Low correlated noise (essential with the expected high DCR) over a wide operation range
Event display (SPS) – accepted event
Event display (SPS) – rejected event
Event display (SPS) – rejected event

X

Y
QA for Scintillating fibres

Fibres are produced by Kuraray (300 km every two weeks) and delivered at CERN where quality assurance tests are performed.

Goal of QA:

1. Acceptance test regarding optical and scintillation properties:
   - Attenuation length with UV LEDs
   - Scintillation yield with beta source
   - Irradiation tests with X-ray source

2. Removal of fibre sections out of mechanical specification ensuring high quality fibre mat production
   - Fibre defects (large diameter fluctuation) «bump» identified with laser micrometre scanner
   - Bump shrinking with heating element or cutting

Bump shrinking by heating

Bump shrinking is fully automatic and it preserves fibre strength, cladding and 85% light transmission.

Example:

Before 415 µm → After 337 µm

Fibber Bumps larger than 500 µm must be cut away and the fibre re-glued (~15 min, 1-2×/spool).
Fibre mat winding

- Four production centres: RWTH Aachen and TU Dortmund (DE), EPFL (CH) and Kurchatov Institute (RU)
- Custom winding machine produced by an industrial company (one per winding centre)
- Fibre mat of 2.5 m length × 13 cm width, 6 fibre layers with a total of 7 km of fibres
- Mat winding takes 4h (1 per day)

Visual monitoring to detect fibre jumps

Alignment pin groove in the wheel, filled with glue during winding, allows precision positioning at later production steps

~1200 mats required for the SciFi tracker
Aimed production rate: 4 mats/week/site
Mat production steps

1. **Winding**

2. **Glue curing** with wheel rotating for 12h in an area with controlled humidity and temperature

3. **Cutting and unforming**

4. **Foil lamination** with black 25 μm thick capton foil (both sides, ensures light tightness) and end piece gluing

5. **Optical cut** with a milling machine (polishing with a diamond head)

6. **Mirror gluing**

7. **QA tests** with optical scanner and β-source (light yield homogeneity)

8. **Delivery** to Heidelberg and Nikhef for module assembly + integration of SiPMs, cooling and FE electronics