SciFi
the new tracker of the LHCb experiment

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on behalf of the LHCb SciFi Tracker Collaboration

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LHCb experiment

Forward experiment dedicated to CP violation and rare decays studies: Large heavy flavour sample requiring excellent vertexing and tracking capabilities

LHCb: previous design

Main Tracker: Si-strip in inner region and straw-tube in outer region
LHCb Upgrade

**LS2 LHCb:** \( \mathcal{L} = 2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1} \) \( 5x \) the current, 50 fb\(^{-1}@10 \text{ years} \)

**Issues**

**Bandwidth:** Saturation of L0 hadron trigger @1MHz

40 MHz (25 ns spacing) trigger-less readout electronic
Full event-selection in CPU farm

**Multiplicity:** High Occupancy (>20%) affects Pattern Recognition Algo

**Unique technology:** Increase segmentation in outer tracker region, preserving spatial resolution of <100 µm in inner tracker
LHCb Upgrade

**LS2 LHCb:** \[ \mathcal{L} = 2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1} \] *5x* the current, 50 fb\(^{-1}@10\) years

**Requirements**

New Main Tracker of LHCb experiment

- **Readout at 40 MHz**
- Spatial resolution in bending plane <100 \(\mu\)m
- X/X0 <1.5% per detection layer
- Hit efficiency \(\sim 99\%\)
  
  *many implications*

- Resist to 35 kGy dose (hottest region) and
  
  \[ 6 \times 10^{11} \text{ 1 MeV n_{equivalent}/cm}^2 \text{ (outside sensitive area)} \]
SciFi Tracker

**General Idea**

- 6 layers of scintillating fibers $\varnothing 250\mu\text{m}$ readout by SiPM array

**Cluster**: Grouping adjacent SiPM channels to improve spatial resolution, mitigate noise and optimize data throughput

**Light Detector**

Photon collection outside sensitive area also improves uniformity
SciFi Tracker

* 3 tracking stations with 4 planes each \((0, +5^0, -5^0, 0)\)
* 10.000 km fibers in 128 modules
* 4096 SiPM arrays @128 channels = 524k channels

12 layers covering a sensitive area of \(6 \times 4.8 \text{ m}^2\) result to the largest high-precision scintillating fiber tracker
Components

Fibres to Module

Silicon PhotoMultiplier
Front-End Electronics
**Scintillating fibers**

**specs:** double cladded round fibres *Kuraray SCSF-78MJ*

- solvent Polystyrene, activator PTP and WLS

**Inner Cladding:** PMMA, $n=1.49$

**Outer Cladding:** FP, $n=1.42$

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\[
\mathcal{N}_{\text{obs}} = \frac{dE}{dx} \frac{N}{dE} \Delta x \quad \text{Eff}_{\text{trap}} \quad \left( e^{-\frac{l}{\Lambda}} + \eta_{\text{mirror}} e^{-\frac{2L-l}{\Lambda}} \right) \quad \text{PDE}_{\text{SiPM}}
\]

- \(~250\) photons \quad \sim 5.4\%
- \(~50\%\) \quad (\Lambda=3.5m, L=2.4m) \quad 45\%

\(~18\) photo-electrons for 6 fibres

\(~35\%\) drop due Radiation \@10 years in beam pipe region
MAT Production

After a very stringent fiber quality-control...

- Winding @ 80 cm custom-made wheel
  - 1st Lamination
  - Curing
  - Tempering
  - 2nd Lamination
  - Shrinking
- End-piece gluing
- Optical cut
- Mirror gluing

Diamond milling of optical surface

275 µm pitch

Inspection

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**2x4 MATS** aligned in precision vacuum table with grooves sandwiched by carbon fibre (rigidity) and honeycomb (planarity, lightness)

**endplug** housing laser driver for calibration

Light and stiff detector

4M fibers aligned within 50 µm precision
Components

Fibre to Modules

Silicon Photomultiplier

Front-End Electronics
Silicon Photo-Multiplier

Avalanche photodiode operating in geiger mode (high gain and QE)

MultiPixel Photo-Counter

Charge proportional to the amount of pixels fired

10-12 photo-electrons foreseen after many years
**Silicon Photo-Multiplier**

**Hamamatsu MPPC S13552 - H2017**

- 64x2 channels array with 250 μm pitch
- Sensors are glued in 3D printed Ti bar
- Small distances between fibre and pixels
- After-pulse <0.1%

setting over-voltage of 3.5V

peak PDE = 45%

7% correlated noise
Silicon Photo-Multiplier

Irradiation with $6 \times 10^{11}$ $1\text{MeV}_{\text{eq}}/\text{cm}^2$

Dark Current Rate (DCR) rises exponentially due neutron radiation

Need to cool down to $-40^0\text{C}$ → $\text{DCR} = 14 \text{ MHz per channel}$
Cold-box

- Each Cold-box houses 16 SiPMs cooled at -40°C by Novec 649 circulating in vacuum insulated lines
- Provides precise SiPM alignment
- Dry air flushing prevents ice formation (-70°C dew point)
- 3D print Ti bar design copes termal expansion
Components

Fibre to Modules
Silicon Photomultiplier

Front-End Electronics
Front-End Electronics

Challenges and Requirements

- 2048 channels @40 MHz per module
- 288 units needed
- power consumption, high throughput
- large $\delta_{\text{shape}}$ SiPM signals (~18 p.e)
- signal exceeds 25 ns
- fast shaping and integrators
- 14 MHz DCR/channel (-40°C & radiation)
- efficient noise reduction
- Clusterization Algorithm
  “smart ADC” in digitization (optimizing bandwidth)
Front-End Electronics

1 SciFi Module ➔ 2 RoB ➔ 2 FEEs

**PACIFIC board**

Analog and Digital

- 4 PACIFIC ASICs CMOS 130 nm technology
- 64 channel current mode input (10 mW/channel)
- Fast shaping to reduce spill over
- Double gated integrators to avoid dead time
- 2-bit/channel from 3 hysteresis comparators
Front-End Electronics

Cluster board

Clusterization Algorithm & Zero-Suppression

* 2 FPGAs Microsemi Igloo 64x

* Algorithm:

Cluster criteria

Position from cluster baricenter

\[ Q_{\text{seed}} > Q_1 \text{ & } Q_{\text{neig}} > Q_0 \]

or

\[ Q > Q_2 \]

example: 3 clusters

SiPM channel

- \( Q_0 \): 1.5 p.e
- \( Q_1 \): 2.5 p.e
- \( Q_2 \): 4.5 p.e

1 SciFi Module → 2 RoB → 2 FEEs

1 Master Board

4 Cluster Boards

4 Pacific Boards
Front-End Electronics

**Master board**

Data transmission & Slow/Fast control

- 8+1 GBT chipset (data+control)

**Bandwidth**

- 128x SiPM sensor
- 2 PACIFIC ASICs
  - 2 x 2b x 64 @40MHz
- 1 Cluster FPGA zero-suppression
- GBT chipset
  - 112b @40MHz
- VTTX link
  - x8
- FEE
  - x4
- 1 Module
  - x144

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1 SciFi Module ➔ 2 RoB ➔ 2 FEEs ➔ 4 Pacific Boards ➔ 4 Cluster Boards ➔ 1 Master Board ➔ SciFi

SiPM

1 SciFi Module      2 RoB

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10.24 Gb/s

4.48 Gb/s

20.64 Tb/s
**Front-End Electronics:**

Test-system: 2048 independent pulse-injector channels to fully characterizes the RoB prior to the installation.

**Full Module:** light pulse injection by laser driver triggered from FEE

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[Graph Image]

- **Ratio:**
  - 0pe
  - 1pe
  - 2pe
  - 3pe
  - 4pe
  - 5pe

- **Threshold DAC:**
  - 100
  - 150

- **Data:**
  - Fit
  - Spectrum $\times 10$
Performance

Cluster efficiency = 99.47%

Resolution ~ 65 µm

resolution without clusterization: \(\frac{250 \mu m}{\sqrt{12}}\) + manufacturing tolerances

2 final Modules + FEE tested successfully with 450 GeV protons at SPS CERN in July 2018

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Installation

**CFrames & Services**

12 CFrames in total

Prototype in Spring 2019

- **SiPM bias**
- **FEE power**
- **dry gas**
- **SiPM cooling**
- **FEE water cooling**
- **vacuum Novec**

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Installation is ongoing well, to be completed in 2020
... half of CFrames before beam-pipe installation

@13 feb 2020

serial production of CFrames

SciFi
The LHCb SciFi team is finalizing the construction of the largest Scintillating Fiber tracker ever build, able to run at 40 MHz.

Detector installation scheduled for this summer and start of data-taking for next year.

Collaboration composed by many people from 17 institutions.

We have satisfied all Tracker requirements, as cluster efficiency and spatial resolutions, and overcome many challenges, mostly related to radiation environment we will face.
Conclusion

Sci-fi & Fantasy

Reality
Backup slides
Scintillating fibers: Quality Assurance

- Diameter monitoring & cladding integrity & bump shrinking > 350 µm

Spool from Kuraray

~ 2 mm

Laser micrometer

Target spool

Tension control

LN detector

Bump shrinking

Cladding test

Attenuation length

Resistance to X-rays

Minimum bending radius, decay time, natural aging for a fraction of fibres

Ionization light-yield

1 MeV e⁻

270 µm

10 p.e visible

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