The Scintillating Fibre Tracker for the LHCb Upgrade

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on behalf of the LHCb SciFi Tracker group
Outline

- LHCb and the Upgrade overview
- The SciFi Tracker
  - Detector basics
  - Challenges
The LHCb detector

- Built for indirect searches for new physics via precision measurements of quantum loop induced processes in the b- and c-quark systems
  - Rare decays
  - Particle/anti-particle asymmetry

Theoretical predictions

Deviations from predictions
b-mesons are produced in the forward direction at the LHC
Current LHCb

Proton beam

Proton beam

B-meson decay time

few mm

PV

τ

ś

D

K

K

K

π

sv

few

metres

Vertex Locator

Magnet

RICH1

RICH2

T1

T2

T3

M1

M2

M3

M4

M5

ECAL

SPD/PS

HCAL

5m

10m

15m

20m

z
- LHCb is running at twice its design value (~$2 \times 10^{12}$ fb/year), 180+ papers published

- Almost every physics measurement in LHCb is limited by statistical uncertainties, not systematic

We need more data!!
Limitations

- LHCb collision rate is tuned to manage data rate (can be increased), but...

- Statistics are limited by the 1MHz hardware trigger rate and then detector occupancy

![Graph showing saturation of hadronic modes with L0-hardware trigger]
Detector Occupancy and Efficiency

Outer Tracker = 5 mm straw gas drift tubes (2.5m long)
- Detector is insensitive to multiple tracks per tube (35ns drift time)

Good!!

BAD!!

Outer Tracker tracking efficiency decreases above 25% occupancy → 40% expected in the upgrade

Beam bunch spacing will be 25ns in 2015+
Current visible pp interactions/event:

- Poisson distribution with $\mu \approx 2$
- Upgrade is at $\mu \approx 5$

- 72 tracks, on average for a B-Bbar event;
- 180 in upgrade

→ We need a high hit detection efficiency (98+%)
LHCb Detector Upgrade

- Replace 1 MHz hardware trigger → 40MHz software trigger, all front-end electronics to 40 MHz

- Visible interactions per bunch crossing increase to $\mu = 2.5 - 5$ (from 1.8)

- Expected **annual** physics yields increase (with respect to 2011)
  - 14 Tev cross section ($\times 2$), trigger rate ($\geq \times 4$), luminosity ($\geq \times 2.5$)
    - $\times 10$ in muonic channels
    - more than $\times 20$ in hadronic channels

- 10 times smaller uncertainties after 10 years
LHCb Upgraded Spectrometer
The SciFi Tracker

Scintillating fibres
- fast scintillation decay time (2.8ns)
- good light yield and attenuation length

An array of pixelated silicon photomultipliers
- fast signals
- high photon detection efficiency (40+%)  
- compact channel size
52 cm fibres

mirror

SiPM

fibres

SiPM

X U V X

3 x

U & V at 5°

6 metres

5 metres
Scintillating Fibres

Polystyrene core with 2 dyes

300 photons per MIP produced (only 5% captured)

Only a few photons after 2.5m

SCSF-78MJ

3.5m avg att. length
Fibre Mats

Fibre mats are produced from winding a single fibre onto a threaded wheel.

- Need about 8km of fibre for one mat of 6 layers 2.5 metres long
- 10,000 km of fibre in total ...
Fibre Mats

Epoxy is injected in the mold from the bottom up.

Cutting will create dead fibres on the edges.
13.5 cm (500 fibres wide) mats are now being produced as well
SiPMs

- The SiPM pixel is a photo-diode (reverse-biased, above breakdown)
- a single free electron/hole-pair can trigger an avalanche of electrons
- $10^6$—$10^7$ gain
- 40-50% photon detection efficiency

![SiPM diagram]

Sketches from Wei Shen, PhD Thesis Uni Heidelberg
Basic principle

Typically one observe 15-20 photoelectrons for 5 layers of fibre
SiPM Ch.

5mm straws
pitch 5.25 mm

Track
Challenges

Previous Presentations at TIPP 2014:

- **Scintillating Fibre and Radiation Damage Studies for the LHCb Upgrade**
  - Mirco Deckenhoff on June 4th, 2014
- **Silicon Photomultipliers for the LHCb Upgrade Scintillating Fibre Tracker**
  - Zhirui Xu on June 4th, 2014
- **Cooling for the LHCb Upgrade Scintillating Fibre Tracker**
  - Petr Gorbounov on June 2nd, 2014

Posters at TIPP 2014:

- **Detector Module Design, Construction and Performance for the LHCb SciFi Tracker**
  - Robert Ekelhof
- **Front-End Electronics for the LHCb Upgrade Scintillating Fibre Tracker**
  - Herve Chanal

Technical Design Report:

- **LHCb Tracker Upgrade Technical Design Report,**
Challenges: Fibre irradiation

- The scintillating fibres darken with radiation (up to 35 kGy expected near the beam pipe over the upgrade lifetime)
Challenges: Fibre bumps

- Defects of the fibre can be created during the extrusion process making “blobs”

For a good mat:
- $\text{rms}(dx) = 8\text{–}15\,\mu m$
- $dx = 275\,\mu m$

Fibre diameter over one spool

[Histogram showing fibre diameter distribution with mean and RMS values: $\text{Mean} = 247.4$, $\text{RMS} = 2.919$.]

Dimensions:
- 250 $\mu m$
- 380 $\mu m$
Challenges: Neutrons and Cooling

- SiPMs create **single photo-electron signals from thermal electrons**, cross-talk between pixels makes 1 photo-electron look like 2+
- Neutron damage to silicon worsens thermal problem, expect $10^{12}$ neutrons/cm$^2$
- Acceptable cluster rates require -40C cooling and +40C annealing

$$dark\ noise \propto T^2 \exp\left(\frac{-E_g}{2k_B T}\right)$$

![Graph showing dark currents and temperatures](image)
Challenges: Electronics

- Digitizes the 560,000 SiPM signals and forms the clusters and hit positions
- ASIC (PACIFIC) and front-end board development
Challenges: Detector design

- Stability and alignment of the detector must be ~100μm
- Must be <1% of a radiation length per detector layer (4mm equiv. of plastic)

Summary

• The order of magnitude increases in precision will allow new physics searches down to Standard Model theoretical uncertainties

• The SciFi tracker is crucial to scope with the upgrade requirements

• SciFi collaboration with 10 countries in 20 institutions

• Begin construction in end of 2015; Ready for installation in 2018