The LHCb upgrade and the Scintillating Fibre Tracker

PRESENTED BY BLAKE D. LEVERINGTON

PHYSIKALISCHES INSTITUT HEIDELBERG UNIVERSITÄT



ON BEHALF OF THE LHCB COLLABORATION



Presented at:



- LHCb and the Upgrade (briefly)
- ► The Scintillating Fibre Tracker (SciFi)
 - Detector Basics
 - Challenges







- Two other LHCb Upgrade talks at EPS-HEP:
 - Upgrade of the LHCb VELO detector by Mark Williams (Friday @ 15:30)
 - The LHCb Upgrade: Plans and Potential by Franz Muheim (Saturday at 9:45)
- Main points:
- 1. We want to **collect up 50 fb⁻¹** of integrated luminosity in 10 years to reduce statistical uncertainties to near theory levels
- 2. The current 1MHz readout is a bottle neck to collect more data at higher luminosity
 - Remove the LO hardware trigger and read out everything at 40 MHz; software trigger
- The granularity of the gas straw tube tracker is too low and must be replaced to handle the occupancy at higher luminosity; the silicon tracker was only designed for 10 fb⁻¹
 - Replace the central tracking stations with the Scintillating Fibre tracker

The LHCb Upgrade



OT tracking efficiency degrades above 25% occupancy

- Without a detector upgrade:
 - OT occupancy would grow to 40% at the higher luminosity
- Replace Inner and Outer tracker with a single technology
 - Higher granularity and resolution to handle occupancy
 - ► Light and uniform weight
 - ► High rate capability



In the LHCb luminosity upgrade

(not tied to LHC luminosity upgrade)

5

6

The Scintillating Fibre Tracker...





Scintillating Fibre Tracker

SiPM array

Scintillating Fibres (0.250mm diameter)



BASIC PRINCIPLE

Signal cluster



Typically, one observes 3-4 photoelectrons per layer of fibre

Position resolution: $\sigma(x) = 65 \ \mu m - 85 \ \mu m$









(b) side view

(a) end view





(scintillator) Polystyrene core with 2 dyes, PTP + TPB

Only a few photons after 2.5m

12

300 photons per MIP produced (only 5% of those are captured)

Also investigating nanostructured NOLfibres. Promises better light yield, but still in development.

S. A. Ponomarenko et al., Nature Scientific Reports 4, Article number: 6549.

SCINTILLATING FIBRES

Light transmission of scintillating fibre decreases under irradiation

up to 35 kGy expected near the beam pipe over the upgrade lifetime



Transmission losses from radiation

13

EPS-HEP VIENNA 2015

Light transmission of scintillating fibre decreases under irradiation

up to **35 kGy expected** near the beam pipe over the upgrade lifetime



Transmission losses from radiation

EPS-HEP VIENNA 2015

- Many technology improvements in the last two years related to LHCb
 - Pixel crosstalk reduced to <11% via trenching, <5% for next generation</p>
 - Photon detection improvements (PDE > 40%) by increased fill factor
 - More stable vs temperature changes (operate at 3.5V overvoltage)
 - Lower dark noise (improved silicon)
- Large area (2 x 64 channel)



Figure 15: *Cross-talk for the 128 channels at five different* ΔV .

Figures from LCHb-INT-2015-004 A. Kuonen Hamamatsu Breakdown voltage

Figure 8: V_{bd} over the 128 channels. Green points correspond to Hamamatsu measurements. Typical pattern repeat itself after 64 channels. 15



0.6 ΔV = 2.5V (Ref.) $\Delta V = 3.5V$ 0.5 0.45 $\Delta V = 4.5V$ Intenisty (a.u.) 0.4 0.35 0.3 0.25 0.2 0.15 0.1L 350 650 700 Wavelength [nm] 550 400 450 wavel 5001 (nm) 600 A. Kuonen et al,. LHCb-Int-2015-00

SCSF-78MJ (0.25 mmØ) un-irradiated (excitation with UV LED)

Fibre wavelength spectra overlaid with Hamamatsu SiPM photon detection efficiency



- cross-talk between pixels makes 1 pixel avalanche into 2+
- For the second sector $a_{10}^{11} n_{1MeV}^{10} cm^{-2}$
- A few MHz of 1pe signals from radiation damage after 50 fb⁻¹@ -40°C



Neutron eq. Damage





Top: plot from Frank Hönniger, DESY-THESIS-2008-002; reproduced from J. Stahl, DESY-THESIS-2004-028 (unavailable)

17

Bottom: plots from D. Gerick, Uni. Heidelberg (PhD student)

- A manageable dark count rate requires <u>cooling to -40°C</u>
 - 150m of silicon arrays, without vacuum





3D printed cooling bar



Image from D. Gerick, presented at DPG Wuppertal, 11.03.2015

Neutron Eq. Damage and Cooling

19

► PACIFIC

- ► TSMC 130nm
- ► 64 channels
- 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
- Front-end board development underway



The PACIFIC (Front-end ASIC)

- Successful test-beams of single mat fibre modules in November 2014 and May 2015
- @250cm from the photodetector
 - 16 photoelectrons (6 layers, with mirror)
 - ▶ 99% hit efficiency
 - ▶ σ_x=75µm
 - Signal loss from fibre radiation damage will reduce hit efficiency
 - But the good performance of the SiPMs and PACIFIC will allow us to keep the noise suppression thresholds low

Performance



Plans:

efficient

Maximize the mirror reflectivity co-

 Study fibre recovery effects and radiation damage in a more LHCblike like scenario

Investigate tracking performance from additional layers/modules

Optimize some neutron shielding



- Low mass (1% X0 per layer)
- Allows for fast tracking
- Good hit efficiency

Technology can cope with the higer radiation environment

- An extensive collaboration between 17 institutes* in 8 countries
- Production begins in 2016
- Installation in 2019

Summary

* 17 institutions: Kurchatov , ITEP, INR (RUS), Aachen, Dortmund, Heidelberg, Rostock (GER), EPFL (SUI), Clermont-Ferrand, LAL, LPNHE (FRA), Nikhef (NL), Barcelona, Valencia (SPA), CBPF (BRA), Tsinghua (CN), CERN 21

Scintillating Fibres : The gory details

Back-up



- Apply clustering and threshold cuts to reject dark noise clusters due to irradiation in the front-end electronics
- a balance between thresholds, hit efficiency and allowable noise clusters (ghost tracks and bandwidth)
- Clustering done on an FPGA after the PACIFIC; hit position output to data acquisition

Clustering





Letter of Intent CERN-LHCC-2011-001



Upgrade Framework TDR CERN-LHCC-2012-007



UPGRADE LHCo Trigger and Online

Trigger and Online CERN-LHCC-2014-016



UPGRADE

VELO CERN-LHCC-2013-021



24

PID CERN-LHCC-2012-007

The LHCb upgrade

$$I(x) = I_0 \left(A e^{-x/\Lambda_{short}} + (1-A) e^{-x/\Lambda_{long}} \right)$$

 $\Lambda_{short} \sim fewcm \\ \Lambda_{long} \sim 350cm$

 Data is typically fit to a single or double exponential; integrated over multiple effects





Fibres and Radiation Damage

- Different radicals are produced in the polystyrene matrix under ionizing radiation (few eV)
- Radicals are absorption centers which reduce the transmission of scintillation light
- Some radicals are unstable $(R+R\rightarrow X)$, some react with oxygen $(R+O_2 \rightarrow RO_2)$, some are permanent damage
- Diffusion of oxygen plays an important roll in formation and annealing (dose rate and diffusion effects)
- Half lives of hours and weeks depending on temp and O₂



Fig. 2. The additional absorption $\Delta \mu$ induced in the scintillator BCF-12 during irradiation in argon atmosphere. The stable absorption centers P are responsible for the permanent damage $\Delta \mu_{\rm P}$, while the annealable damage $(\Delta \mu_1 + \Delta \mu_2)$ is caused by R₁· and R₂. Rapid annealing occurs after inlet of oxygen.