PROCEEDINGS OF SCIENCE

The PicoCal of LHCb Upgrade 2

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The LHCb experiment aims to collect a dataset of 300 fb^{-1} in its high-luminosity phase. Such an objective calls for challenging upgrades of all the detector systems to successfully operate at a peak luminosity of $1.5 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$. The future electromagnetic calorimeter, named PicoCal, will have to face a high radiation dose and mitigate a harsh occupancy, keeping the current energy resolution. To meet these requirements, the calorimeter regions are redesigned with finer granularity, longitudinal segmentation, and a timing resolution of approximately 20 ps. The candidate technologies are Spaghetti calorimeter (SpaCal) with garnet scintillating crystals (GAGG) and tungsten absorber in the innermost region, SpaCal with scintillating plastic fibres and lead absorber in the intermediate area, and Shashlik with polystyrene tiles, lead absorber, and fast WLS fibres in the outer part. An additional timing layer based on microchannel-plate technology was investigated. This proceeding summarises the proposed new features and the status of the art of the R&D project, reporting results from test-beam activities.

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1. Introduction

The LHCb experiment is a single-arm forward spectrometer operating at the LHC [1]. Its physics program focuses on *CP* violation, rare decays, and heavy-flavour spectroscopy [2]. LHCb is carrying on its third data-taking period (Run3) in the so called *Upgrade 1* configuration [3]. An intense R&D effort is ongoing to make the detector able to profit from the much higher instantaneous luminosity deliverable by the LHC [4, 5]. The target peak luminosity for Run5 is $1.5 \times 10^{34}\text{cm}^2\text{s}^{-1}$, namely seven times more than the one in Run3 and Run4. The LHCb electromagnetic calorimeter (ECAL) is a $7.76 \times 6.30\,\text{m}^2$ wall, 12.6 m downstream of the interaction point [6]. As shown in Fig 1-left, it is expected to absorb up to 1 MGy in its lifetime, demanding high radiation tolerance in the inner region (the limit for the current Shashlik technology is 40 kGy). Furthermore, higher granularity will be mandatory to cope with the high occupancy regime. Simulation studies demonstrated that measuring the time of the energy deposits is a critical feature for the combinatorial background rejection in *Upgrade 2* conditions. Another *Upgrade2* feature will be the double-side readout with photomultiplier tubes (PMT) on the front and back faces of the calorimeter. The target energy and time resolution are: $\sigma_E/E = 10\%/\sqrt{E[\text{GeV}]} \oplus 1\%$ and $\sigma_t \approx O(10\,\text{ps})$. The name of the new calorimeter project is *PicoCal*. Its development plans foresees an *enhancement* phase between Run3 and Run4, and a generalized upgrade between Run4 and Run5 (*Upgrade 2*)[1]. The central and right plots of Fig. 1 illustrate the geometry of the PicoCal regions. The Shashlik technology will be exploited in the outer regions [7]. It is based on alternating lead and plastic-scintillator tiles as passive and active materials crossed by wave-length shifting fibres (WLS). It fulfils the energy resolution target, several spare modules are available and can be upgraded to implement the double-side readout. The ongoing R&D focuses on the WLS to improve radiation hardness and timing capabilities. The candidate technology for the central region is the Spaghetti Calorimeter (SpaCal). It involves lead or tungsten matrices as passive components and plastic (polystyrene) or crystal (GAGG) fibres as scintillating parts [8]. By design, this new technology has a small Moliere's radius and high radiation-hardness properties [9]. Section 2 summarises energy- and time-resolution results from test-beam campaigns. In parallel to the characterisation of the timing performance of SpaCal and Shashlik, the feasibility of an ancillary layer dedicated to the timing was investigated. Section 3 resumes laboratory and test-beam results about it.

2. Main Test Beam Results

Test-beam campaigns were conducted at DESY (1–5 GeV electrons) and CERN-SPS (20–100 GeV electrons). Fig. 2 illustrates the energy resolution results for the SpaCal prototypes. As shown in the right plot, a 3-degree tilt was enough to avoid channelling effects and was used in all the cases. The target energy resolution was verified. Fig. 3 displays the time resolution of SpaCal and Shashlik prototypes depending on the energy of the impinging electron. The time stamps were measured using the constant-fraction-discrimination algorithm. Depending on the technology, a time resolution better than 20 ps was achieved at different energies. In the SpaCal case, the double-sided readout was effective for good time resolution at low energy.

[1]The detailed schedule of the Runs is available at http://lhc-commissioning.web.cern.ch/schedule/LHC-long-term.htm

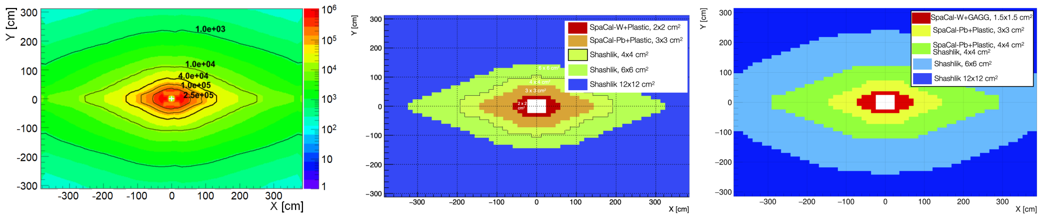

Figure 1: Left: Expected radiation dose (in Gray) absorbed by the ECAL at the end of LHCb operations depending on the position on its surface. Center and right: map of PicoCal regions in the *enhancement* [5] and *Upgrade2* [4] phases. Technology names and cell granularities are listed in the legend. Double-sided readout and timing features will be included only in the *Upgrade2* phase.

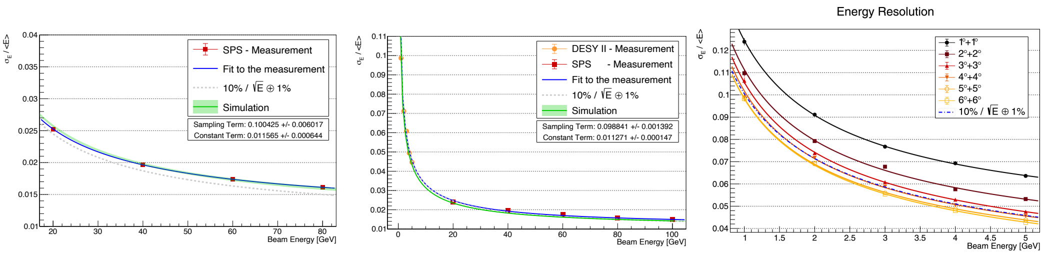

Figure 2: SpaCal energy resolution from test-beam campaigns. Left: Lead-polystirene, double-side readout; center: tungsten-polystirene, single-side readout; right: tungsten-GAGG, double-side readout. Details on prototypes and data-taking methods are documented in Ref. [4, 5, 9].

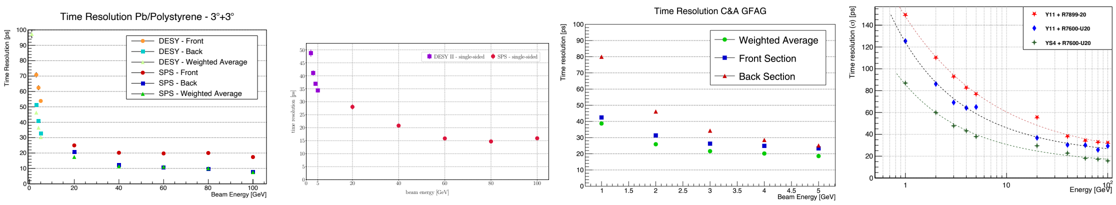

Figure 3: SpaCal energy resolution from test-beam campaigns. From left to right: Lead-polystirene with double-side readout, tungsten-polystirene with single-side readout,tungsten-GAGG with double-side readout, Shashlik with single-side readout with various PMT and WLS configurations. Details on prototypes and data-taking methods are documented in Ref. [4, 5, 9].

3. R&D on LAPPD timing layer

Having a surface of 20×20 cm^2, the LAPPD by Incom Inc. [10] is the largest microchannel-plate photomultiplier (MCP-PMT) ever built, all made of inexpensive materials [11]. The feasibility of a LAPPD timing layer located between the front and back sections of the PicoCal was investigated. The large number of charged particles moving at the shower maximum allows the detection of a sizable signal from primary ionisation within the MCP tiles. In turn, this allows operations without the photocathode -the less radiation-tolerant part of the LAPPD- with the advantage of further cost reduction. Ageing campaigns of Incom MCPs demonstrated a not problematic gain reduction up to an integrated charge of 300 C/cm^2, namely the target lifetime for a PicoCal application. Not relevant gain and dark-rate degradations were observed up the expected radiation dose. Test beams at DESY and SPS verified a time resolution better than 20 ps at low energy. Laboratory tests studied the time-resolution degradation depending on the rate of the impinging particles.The situation for rates up to a few MHz/ cm^2 is acceptable, but the expected particle flux in PicoCal innermost regions demands a vigorous R&D effort to improve the LAPPD capabilities in high-rate environments. Experimental methods and detailed results are documented in Ref. [12].

4. Conclusions

The LHCb PicoCal prototypes meet radiation hardness and energy resolution targets. The time-resolution requirements are met at high energy. The LHCC approved the upgrade programme documented in the Framework-TDR [4, 5]. The current R&D is focuses on the optimisation of the PMT coupling and response homogeneity with full-size prototypes. The timing-layer R&D improved the knowledge about the integration of the MCP technology in calorimeter detectors.

Acknowledgments

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References

[1] LHCb collaboration, *JINST* **3** (2008) S08005.

[2] LHCb collaboration, arXiv/1808.08865.

[3] LHCb collaboration, *JINST* **19** (2024) P05065 LHCb-DP-2022-002, [2305.10515].

[4] LHCb collaboration Tech. Rep. CERN-LHCC-2021-012, CERN, Geneva (2022).

[5] LHCb collaboration Tech. Rep. CERN-LHCC-2023-005, CERN, Geneva (2023).

[6] LHCb collaboration Tech. Rep. CERN-LHCC-2000-036, CERN, Geneva (2000).

[7] S. Barsuk et al., LHCb-2000-043, CERN-LHCb-2000-043.

[8] L. Martinazzoli, ph.d thesis, CERN, 4, 2023. CERN-THESIS-2023-045.

[9] L. An et al., *Nucl. Instrum. Meth. A* **1045** (2023) 167629 [2205.02500].

[10] Incom. 294 Southbridge Road, Charlton, MA 01507, available at: https://incomusa.com/.

[11] LAPPD Collaboration, arXiv/1603.01843.

[12] LHCb PicoCal Group, *JINST* **19** (2024) C02045.