SEMESTER REPORTS

1. semester

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PhD Programme: Particle and Nuclear Physics
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PhD Thesis: High precision luminosity measurement for tests of the Standard Model at the LHC CMS experiment

Introduction

The Large Hadron Collider (LHC) at CERN stands at the forefront of experimental particle physics, providing the highest-energy hadron collisions with exceptional statistical precision. The scientific impact of LHC experiments depends on the accuracy of the measurements using the high statistics collision data. Among the key parameters governing collider experiments, luminosity plays a central role, as it directly determines the rate of observable events and thus the precision of cross-section measurements. Accurate luminosity determination is essential for testing the Standard Model and for investigating rare processes and potential signals of new physics. Uncertainties in luminosity determination can become the most important limitation for the high precision results on W, Z and Higgs boson or top quark production.

My research within the Compact Muon Solenoid (CMS) Collaboration focuses on precision instrumentation, data analysis, and the development of advanced luminosity measurement techniques. This work includes operating and calibrating existing luminometers during LHC Run 3, utilising Run 3 data for high-precision luminosity determination, and contributing to the design and validation of next-generation detector technologies for the High-Luminosity LHC (HL-LHC). I am particularly involved in the CMS BRIL (Beam Radiation, Instrumentation and Luminosity) project, focusing on the Beam Condition Monitor with Fast readout (BCM1F), a dedicated bunch-by-bunch real-time luminometer using Silicon-pad sensors and featuring two different back-end systems, a legacy VME-based and a novel μTCA-based. Maintaining high data quality and operational stability of BCM1F is essential for achieving the sub-percent precision required for Run 3 luminosity measurements.

The anticipated increase in beam intensity and radiation levels during the HL-LHC era presents significant challenges for existing luminosity measurement systems, such as detector ageing, saturation effects, and non-linear responses. Addressing these issues motivates my work on the Fast Beam Condition Monitor (FBCM), a next-generation luminometer that builds on the BCM1F concept with improved radiation hardness, increased channel count, and advanced readout capabilities. Through direct involvement in detector operation, data analysis, and test-beam studies, my research supports both the current precision physics program of CMS and the long-term development of robust luminosity instrumentation for the HL-LHC.

Description of research work carried out in current semester

I contributed to the Run 3 BCM1F publication (currently under internal review) primarily on the performance achieved using the μTCA back-end the system. Figure 1 (left) demonstrates the derivative-based peak-finding algorithm using a dedicated Python implementation of the SNRD filtering used in the detector firmware. Monitoring plots provide clear examples of well-performing and problematic channels (see Figure 1 (right)) and support channel selection in day-to-day detector operations. In addition, I quantified the relative changes in the most probable value (MPV) of the signal amplitude spectra and for the test pulse for μTCA channels during the 2023-2025 data-taking period, as well as correlation plots between the signal amplitude spectra (which is sensitive to both sensor and electronics aging) and test pulse MPV (which is independent from the sensor performance), as shown in figure 2). The monitoring of these quantities, together with the calibration constant that turns BCM1F rate to luminosity allows to keep the operational parameters close to optimal.

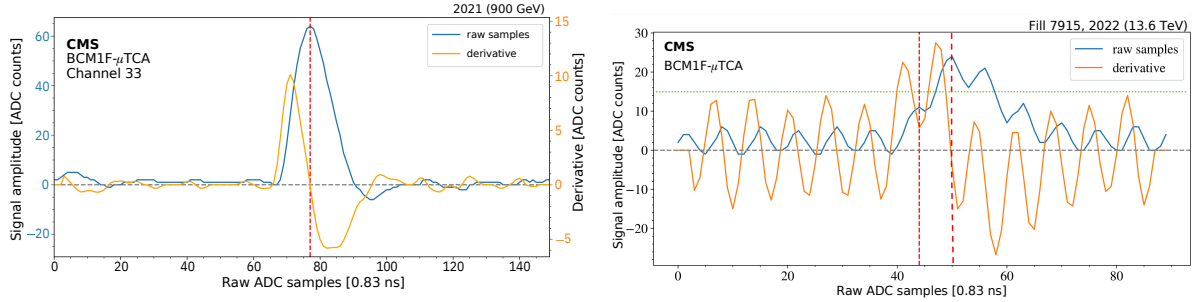

Figure 1: μTCA hit signal with the corresponding derivative for (left) a good and (right) a noisy channel

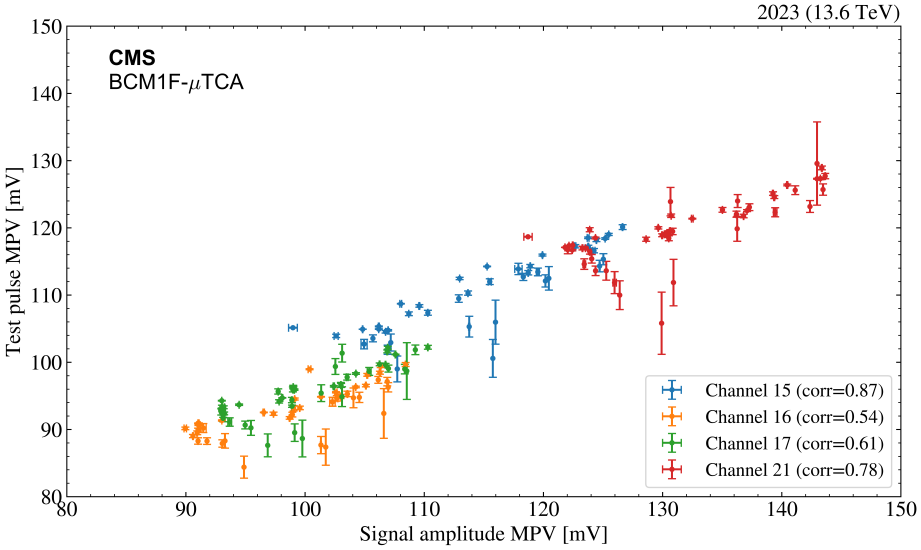

Figure 2: Correlation of the signal MPV vs. test pulse MPV for selected μTCA channels

Furthermore, I extracted the afterglow model which describes the observed rate in the detector after a collision due to late signal due to imperfect detector timing, late particles

or detector activation. I used single or few (¡10) colliding-bunch data for different LHC fills between 2022 and 2025 and performed a comparative evaluation of the results (figure 3). The percent-level out-of-time contribution need to be subtracted in physics fills to get an accurate luminosity.

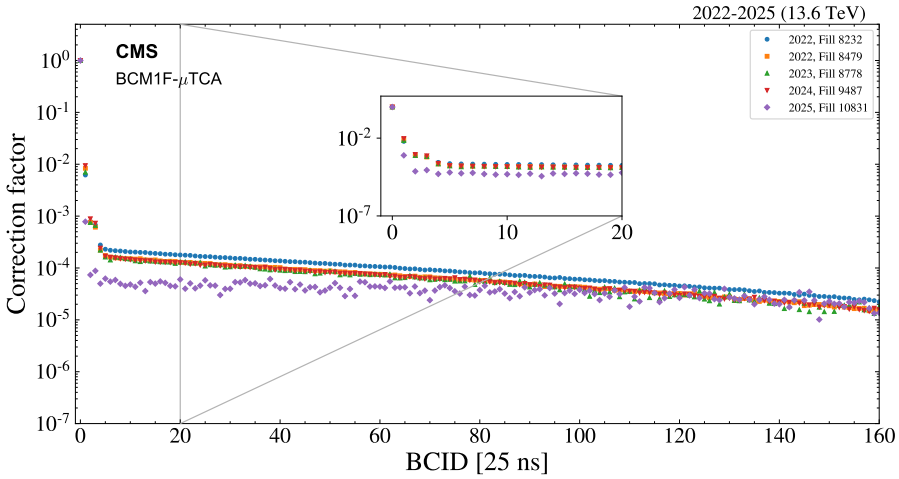

Figure 3: Run 3 afterglow models for BCM1F using the μTCA backend

I was involved in the day-to-day operation of the BCM1F detector, including calibration and performance monitoring. In addition to regularly checking the online monitoring system to evaluate detector performance, I recorded raw data on a weekly basis and produced diagnostic plots for all μTCA channels, focusing on the minimum derivative (DdT) and minimum amplitude (DaT) thresholds as well as timing characteristics. The detector performance was discussed in regular meetings with other detector experts, during which I presented the findings and the modifications applied.

After returning from the CMS BRIL 2025 Testbeam at the CERN T9 beamline where I participated in the data taking in August 2025, I began analysing the recorded data of the FBCM prototype detector modules. This includes the Time-over-Threshold (ToT) analysis for different sensors, including both fresh and irradiated ones, to investigate radiation-induced ageing effects. In addition, efficiency plots were produced using existing analysis frameworks. I participate in the regular FBCM technical meetings focused on the test beam data processing and analysis. The testbeam results are planned to be published later in 2026.

In preparation for the 2026 testbeam, I attended dedicated FBCM engineering meetings to acquire the necessary expertise to perform FBCM ASIC characterisation.

Studies in current semester

During the current semester, I successfully completed two courses:

- Experimental methods of particle physics II. (FIZ/2/004E) (grade: 5)
- Data Mining and Machine Learning (FIZ/3/084) (grade: 4)

Publications

I am one of the authors of the paper "Detector design and luminosity measurement performance of the Beam Condition Monitor with fast readout (BCM1F) at the CMS experiment in Run 3", which is under internal review and will be submitted to Eur. Phys. J. C by the CMS BRIL Collaboration.

Selected presentations

- Weekly BRIL Operations and DPG (19 Sept 2025): BCM1FUTCA Optimization
- BCM1F meeting (24 Sept 2025): uTCA system updates, timing adjustment
- Weekly BRIL Operations and DPG (17 Oct 2025): uTCA status Report
- BCM1F meeting (22 Oct 2025): uTCA status update