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Title: CMS Forward calorimeter Run 3 data analysis

Abstract: The Beam Radiation Instrumentation and Luminosity (BRIL) project focuses on precision luminosity measurements and beam-induced background studies. One of the primary systems used for precise luminosity measurement is the Forward Hadron (HF) Calorimeter. While HF provides excellent stability and linearity, the detector is susceptible to significant radiation activation. This activation, involving multiple short-lived isotopes with typical lifetimes of hundreds of nanoseconds, can introduce biases in measurements taken every 25 ns . Another potential source of systematic uncertainty arises from imperfections in the timing alignment of the detector, leading to signal spillover into neighboring measurement slices or bunch-crossings. To correct these effects, a multi-parameter fit should be derived and applied to the full year of data, significantly impacting the final luminosity measurement. Students participating in this project will gain insights into data analyses, work with Python-based data processing tools, including pandas and numpy.

Project description and deliverables:
With the upcoming high-luminosity upgrade, the increased number of interactions per bunch crossing and higher collision energy will place unprecedented demands on luminosity and beam-induced background measurements. Target luminosity uncertainty requested by CMS for Phase 2 is less than 2% for the real-time values and better than 1% for final offline recorded luminosity. The way to approach this is based on the use of data coming from various CMS subsystems for luminosity and beam-induced background measurements.
The focus of this project would be on the Forward Hadron (HF) Calorimeter, which has two counting algorithms. The “HF occupancy” (HFOC) method is based on “zero counting”, which tracks the fraction of bunch crossings with no energy depositions above a threshold.

The “HF transverse energy” method (HFET) is based on the assumption that the measured transverse energy sum is proportional to the luminosity, where the transverse energy is defined as E*sin θ. HFOC and HFET require corrections to account for out-of-time (OOT) signals, also known as "afterglow" effects. There are two types of such effects. Type 1 effects result from the spillover of the signal recorded by the electronics into the next 25 ns bunch slot. In contrast, Type 2 effects result from the activation of the material surrounding the detector, which produces an exponentially decaying tail after a colliding bunch. Both types of OOT response can be measured and corrected using data from isolated bunch running.
In the result, using the Toy MC method to simulate different filling scheme patterns with pre-known luminosity and Type 2 tails, try to explore the influence of Type 1 and the possible effect of their drift during the year. The ultimate goal is to improve the physics corrections that will be applied to the full year of data as part of the project.
Final product of the project will be the framework which allows offline application of the corrections and data reprocessing.

Detailed plan:
Week 1 onboarding, reading literature and papers regardless CMS inner structure and signal processing pipeline. Computer CERN account, get access to the data and run the codes to open and plot the data.

Week 2-5 HF afterglow model, check single bunch fills and fills with isolated and train configuration. Improve the correction of HFET model on the single bunch using data and Toy MC, extrapolate this model on the train bunches. Check HFOC as the second step.

Week 6-8 Develop the framework for data analyses and reprocessing.

Week 9-12 Data reprocessing recorded in Run 3 (2022-2025)