The CMS Fast Beam Condition Monitor at the HL-LHC

Vahid Sedighzadeh (IUT) on behalf of the CMS collaboration

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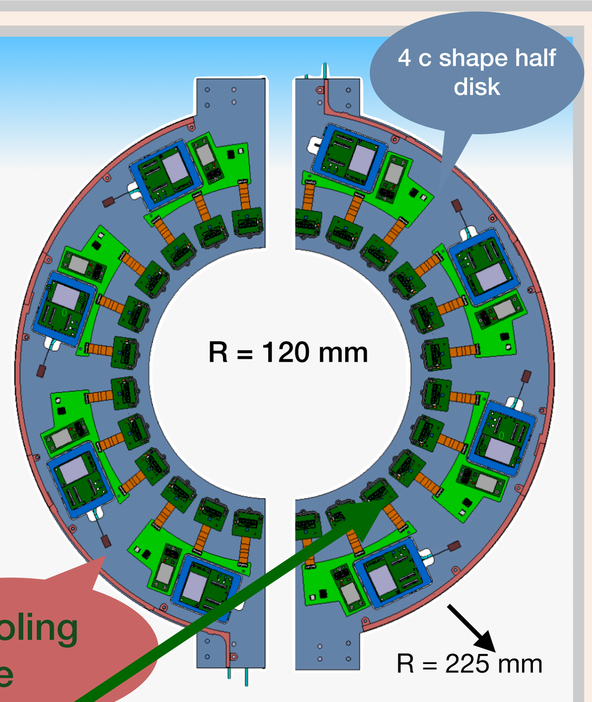
Abstract:To face the hightened requirements of real-time and precision bunch-by-bunch luminosity determination and beam-induced background monitoring at the High-Luminosity LHC, the CMS BRIL project constructs a stand-alone luminometer, the Fast Beam Condition Monitor (FBCM). It will be fully independent from the CMS central timing, trigger and data acquisition services and able to operate at all times with a fast triggerless readout. The CO2-cooled silicon-pad sensors will be connected to a dedicated front-end ASIC to amplify the signals and provide a few ns timing resolution. FBCM is based on a modular design, adapting several electronics components from the CMS Tracker for power, control and read-out functionalities. The 6-channel FBCM23 ASIC outputs a single binary high-speed asynchronous signal carrying the Time-of-Arrival and Time-over-Threshold information. The prototype chip is under extensive tests. The detector design and the results of the first validation tests are reported.

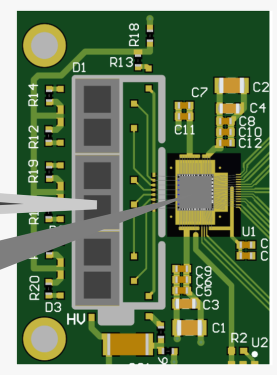
FBCM

The FBCM is a silicon pad sensor-based standalone luminometer capable of running independently from CMS data taking that will replace the current Fast Beam Condition Monitor (BCM1F) luminometer. It will use 288 sensors with an area of 1.7 x 1.7 cm². A dedicated application-specific integrated circuit (ASIC) has been designed for FBCM. The primary role of the FBCM luminometer is precise luminosity measurement (1% precision). Several nanoseconds time resolution of FBCM also allows for independent beam induced background measurement.



From the physics point of view, the FBCM sensors should have a particular area and distance to the beamline, balancing occupancy, and acceptance.

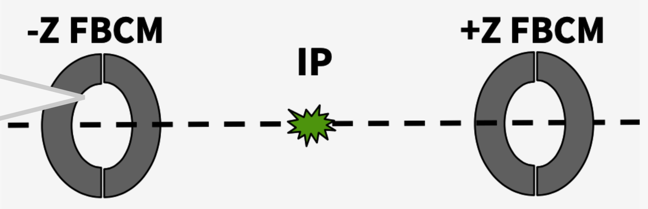
150 or 290 μm thickness sensors



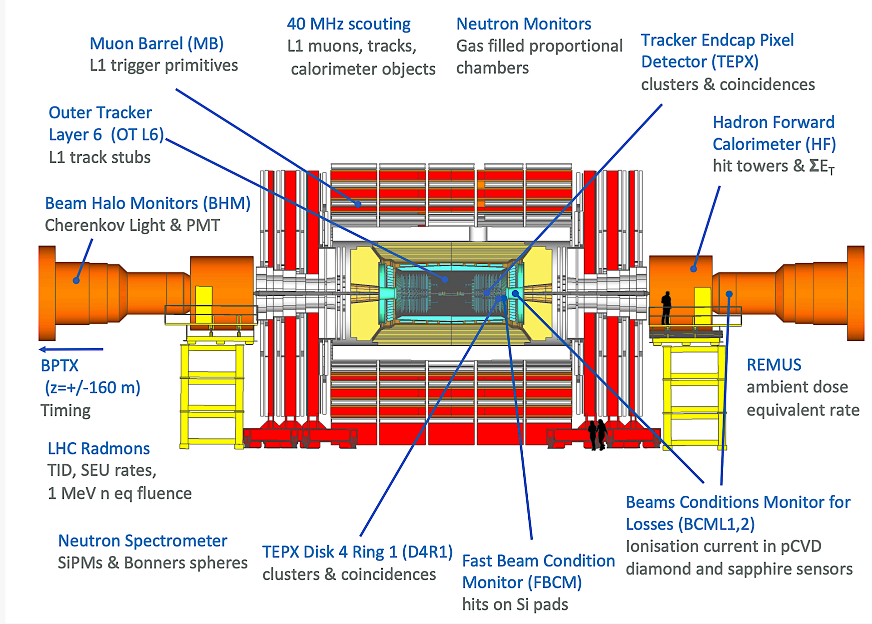
Effects the number of hits and linearity.
Effects the noise and signal separation.

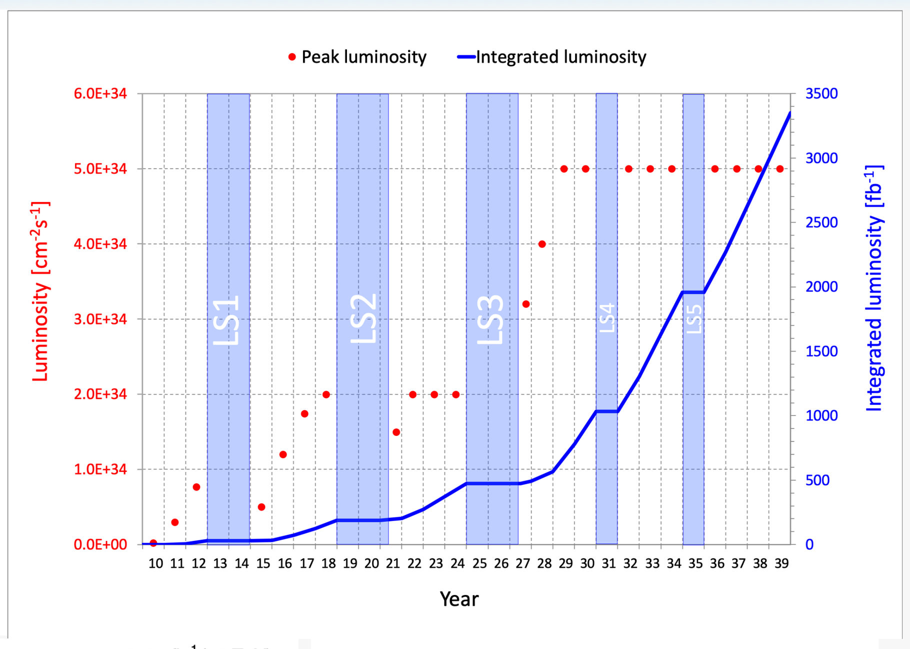
ASIC

Detector modules should stand up to 200 Mrad of total ionizing dose, and ASIC technology has been selected accordingly.

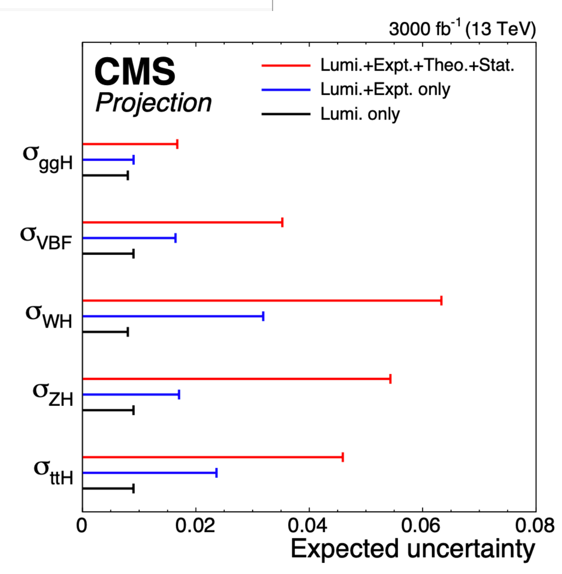


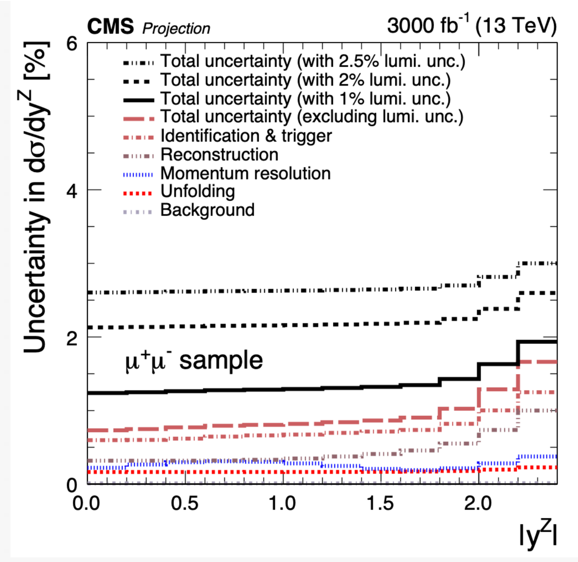
HL-LHC





The precision of the integrated luminosity associated with the data analyses in physics measurements typically directly impacts the final uncertainties.

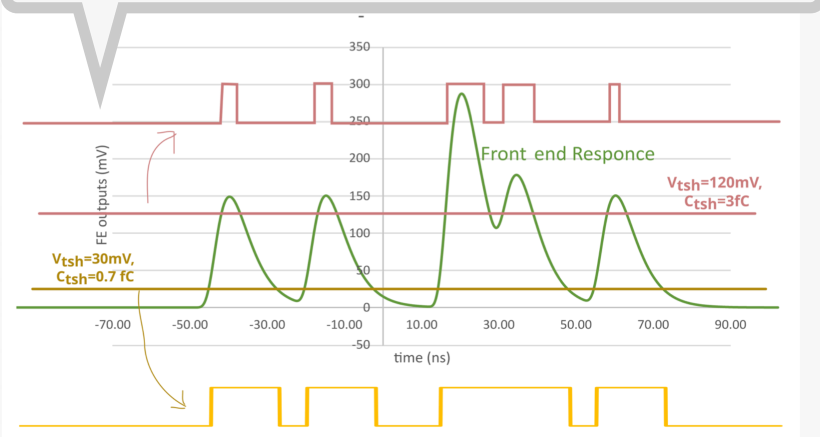


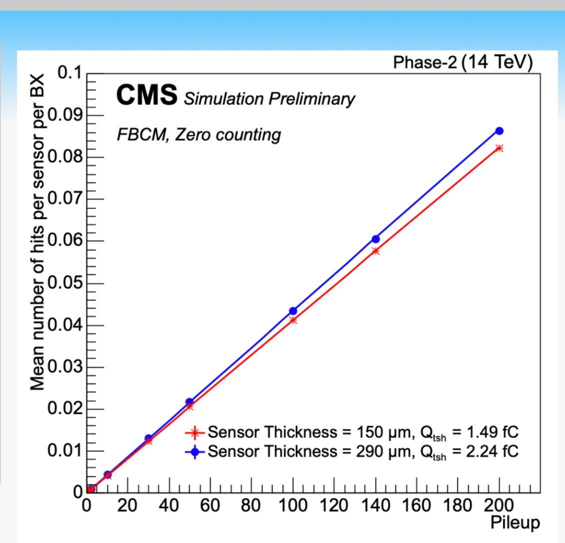


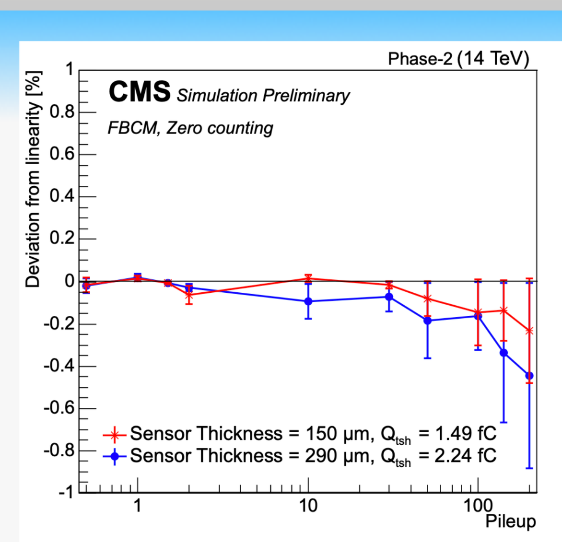
Calibration & Linearity

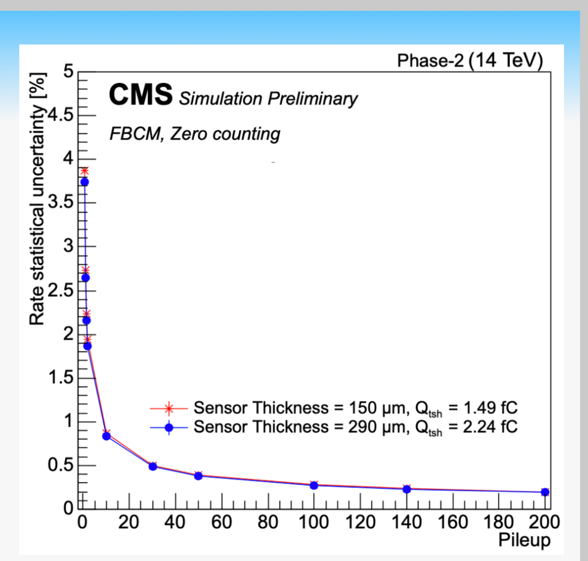
For the calibration of the luminometer, special beam scans known as van der Meer (VdM) scans are performed, during which the calibration constant is measured. VdM scans are conducted at low pileup values (below 1.5), whereas data collection occurs at high pileup values (up to 200 in HL-LHC). Therefore, it is necessary to extrapolate this calibration constant to high pileup conditions. This involves checking how collision rates deviate from linearity at high pileups, and incorporating these adjustments into our luminosity calculations.

Incoming particle signal from sensor converted into a digital signal by ASIC. Then sampled with inner tracker portcard lpGBT, converted into optical signal and packaged data is transmitted to the processing backend electronics.









Difference between the mean number of hits fitted at low pileup (close to the conditions where detector is calibrated) and extrapolated to higher pileup values (corresponding to conditions expected during physics data taking) and the observed number of the mean number of hits at that pileup in the simulation, divided by the mean number of hits.

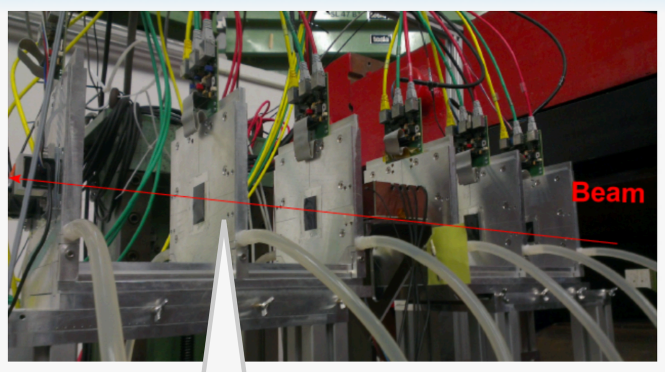
In this simulation study, four different thresholds on the deposited charge (Q_{tsh}) were studied for two types of sensors. Among all the combinations, the Si-pad sensor of 150 μm thickness with a threshold of Q_{tsh} = 1.49 fC, as well as the sensor of 290 μm thickness with Q_{tsh} = 2.24 fC demonstrated the best linearity.

Test beam

A new ASIC, irradiated to 200 MRad, was tested to prove its functionality. Data from this test is currently being analyzed. Only 2-pad sensors were tested in this initial phase. A second test beam is being prepared in July to evaluate the response of 6-pad sensors. The final sensor selection will be based on the results of these test beams.
One test board is equipped with one ASIC, which read out 6 silicon pad sensors.
Time over Threshold spectra for all six sensors on the test board was measured.

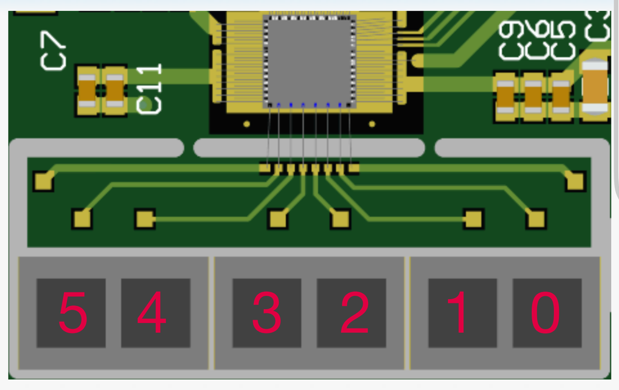
Most of the test beam has been conducted using a 15 GeV proton beam, along with other types of particles whose data has not yet been analyzed.

Inner tracker pixel module installed behind the FBCM was used to create the effective mask for telescope and FBCM data readout.



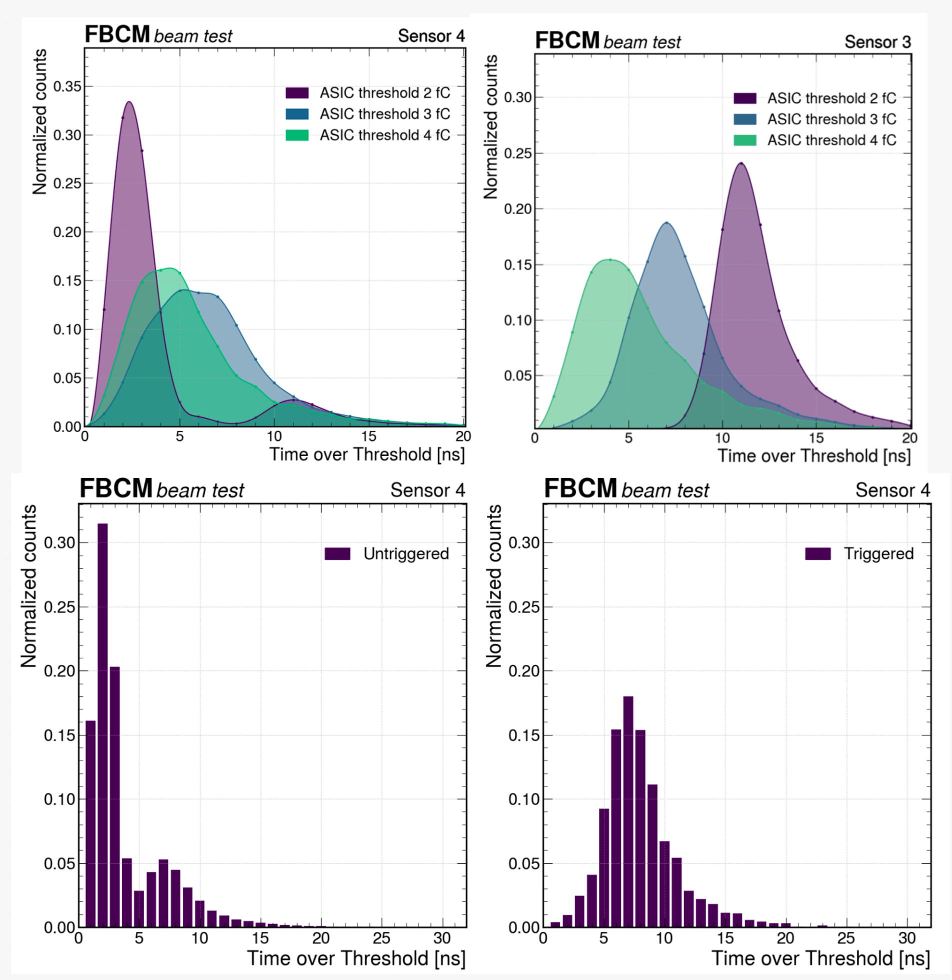
AIDA telescope with six pixel planes is used to reconstruct the trajectory of the particles. Using telescope track pointing information it is possible to study the response of the sensor as a function of the hit position. This analysis is ongoing.

Two data acquisition modes were used at the test beam: triggered and untriggered. Triggered readout is used to test the noise reduction via reduction of the integration window, however this mode is only used for validation tests and will be not available in operation of FBCM detector.



The difference between channel 3 and 4 is the length of the signal path between signal and ASIC input. It is visible on the figure, that channel 4 with longer signal path has higher noise. Therefore design of the test board is being modified for the next test beam to use direct bonding to the ASIC inputs and minimize the lenght of the signal path for all channels.

Normalized distribution of the Time over Threshold (ToT) in sensor 3 for an ASIC threshold of 2 fC (violet), 3 fC (blue) and 4 fC (green) respectively. Note that as the ASIC threshold increases, the distribution shifts to lower ToT values.



Summary:

The following steps are planned for the simulation to compare and verify the results with the test beam data:

- Simulation of the latest ASIC used in the test beam.
- Sensors responce change as a function of the radiation dose plan to be simulated and integrated into the CMS sofrware. This will allow for comparison with the test beam results for irradiated sensors.
- Time-over-threshold plots for different ASIC thresholds to be extracted from the simulation and compared with the corresponding plots from the test beam.

References

1. CERN-LHCC-2021-008 CMS-TDR-023. URL: https://cds.cern.ch/record/2759074/files/CMS-TDR-023.pdf
2. 2. G. Auzinger *et al* 2024 *JINST* 19 C03048, "The CMS Fast Beam Condition Monitor for HL-LHC" URL: https://iopscience.iop.org/article/10.1088/1748-0221/19/03/C03048
3. Jan Kaplon *et al* 2024 *JINST* 19 C02026, "The optimization, design and performance of the FBCM23 ASIC for the upgraded CMS beam monitoring system".