Fast Beam Condition Monitor of the CMS experiment at the HL-LHC

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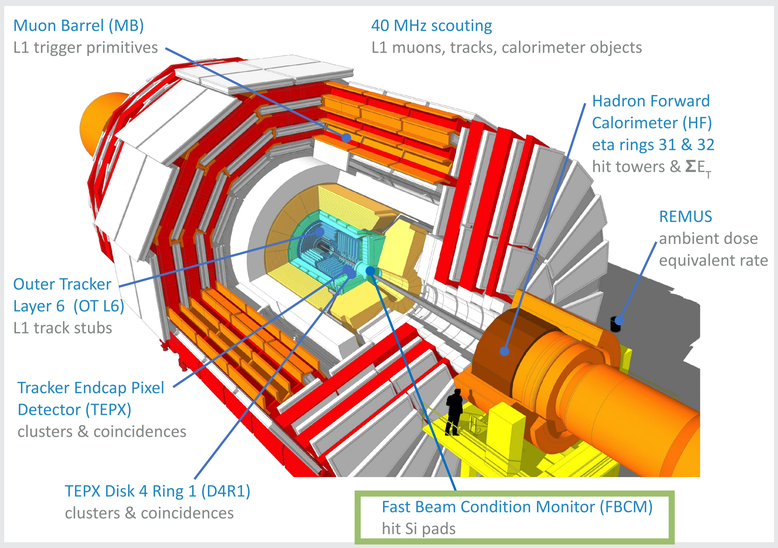
Goal

- A standalone luminometer capable of running independently from CMS data taking is essential for the BRIL luminosity measurement program for HL-LHC,
- Independent, stateless, asynchronous and fast online luminometer for high-precision, bunch-by-bunch luminosity (& BIB),
- **Fast Beam Condition Monitor** (FBCM) based on silicon-pad sensors with fast and asynchronous front-end chip is planned to be installed,
- Integration Study is ongoing to install the FBCM, behind the CMS Inner TEPX.

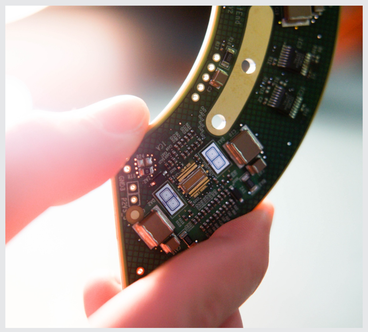
CMS Luminometers for HL-LHC

In Run 2+3 luminosity at CMS has been measured with two dedicated luminometers and by exploiting measurements of main CMS subsystems. **FBCM** is planned as a standalone luminometer and BIB monitor for the HL-LHC era. It will not only provide independent operation but also monitoring outside of stable beams and during central DAQ downtimes.



Run 3 BCM1F

- Successful in the previous operation periods – in use since Run 1, evolving naturally with the aim of an ideal luminometer,
- uses fast asynchronous FE ASIC providing narrow pulses and fast return to baseline,
- sub-bunch-crossing time resolution to measure bunch-by-bunch, lumi. and BIB
- luminosity obtained with "zero-counting": $\mu = -\ln[p(0)] = -\ln[1 - p(\neq 0)]$
- Phase II OT **Si** sensors, providing excellent **S/N** and improved radiation tolerance,
- 3D printed **Ti** cooling loop providing active cooling (-20°C) thus improved longevity,
- AC-coupling to prevent baseline drift due to leakage current,



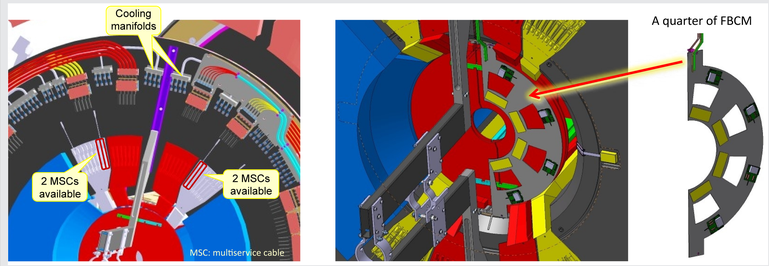
- 48 independent channels,
- μTCA backend system with an improved peak finder algorithm.

FBCM design

Front-end:

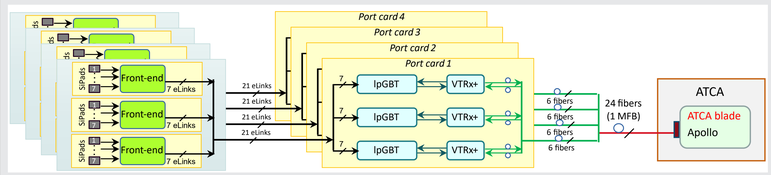
Four D-shaped quadrants form the full system - each of them will have $4+$ modules with 21 sensors $+$ 3 FE ASIC (need customized design) with Inner Tracker port cards for opto-transmission, control and monitoring (lpGBT & VTRX+)

$\Rightarrow$ **Total of 336 silicon-pad sensors.**



Backend:

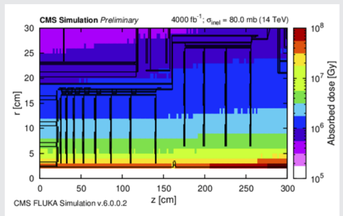
Advanced Telecommunications Computing Architecture (ATCA) blades - for signal processing and histogramming the number of hits per BX.

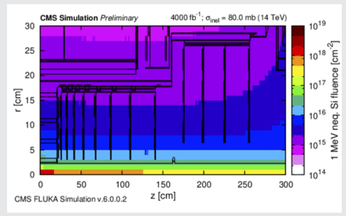


Location and Environment:

Very close to the beam-pipe $8.5\ \text{cm} < R < 21\ \text{cm}$, $\eta \sim 3.5$, just outside the last Tracker layer $z = 283.5\ \text{cm}$,

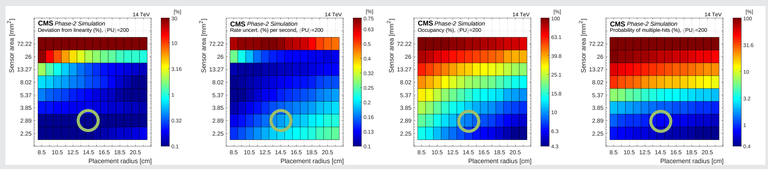
$\Rightarrow$ at $4000\ \text{fb}^{-1}$: TID < 200 Mrad, 1 MeV neq fluence $< 3.5 \times 10^{15}\ \text{cm}^{-2}$.





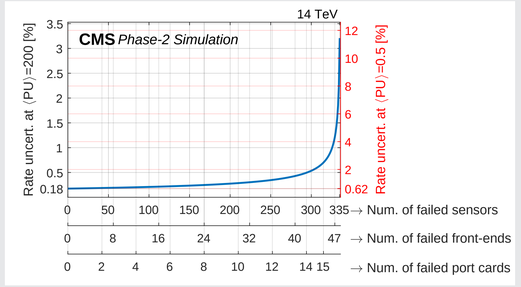
Sensor choice

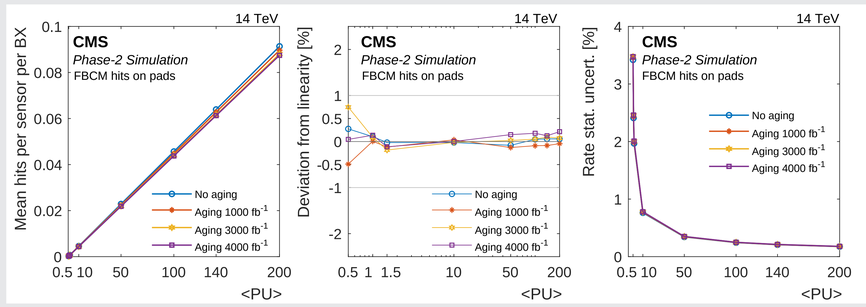
AC-coupled sensors developed for the Phase II CMS Upgrade, with optimized thickness of $300\ \mu\text{m}$ and small size of $2.89\ \text{mm}^2$ for a good compromise between statistics and linearity over wide pileup range. Good statistical precision for physics and VdM conditions as well as low risk of zero-starvation was found for $R = 14.5\ \text{cm}$.



FBCM performance

- Effects of loss of modules as well as aging on luminosity performance has been studied.
- The mean number of hits per BX per sensor (left), the deviation from linearity (center), and the statistical uncertainty in the rate (right) estimated as a function of pileup. The aging effects on the expected performance of FBCM are also shown for three values of integrated luminosity. No significant change to the performance is expected. However, degradation of the charge collection efficiency will affect the signal-to-noise ratio.

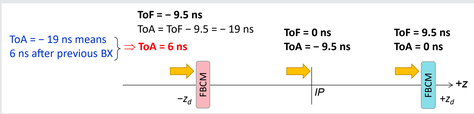




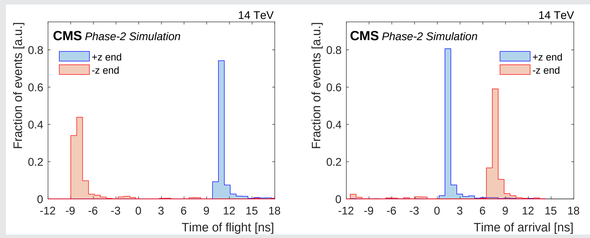
Beam Induced Background

BIB is measured either at the beginning of a bunch train or at non-colliding bunches, so that it can be separated from the albedo.

- **ToF**: time with respect to nominal collision time at IP
- **ToA**: delay with respect to the expected in-time collision products



BIB simulations using CMS reconstruction SW framework with input from FLUKA were carried out. Using time binning of 0.78 ns at 40 MHz rate will allow to identify incoming BIB @ $\text{ToA} = 6$ ns with a clear signature.



References

[1] The CMS Collaboration, *The Phase-2 Upgrade of the CMS Beam Radiation, Instrumentation, and Luminosity Detectors: Conceptual Design*. CERN-CMS-NOTE-2019-008.

[2] The CMS Collaboration, *The Phase-2 Upgrade of the CMS Beam Radiation Instrumentation and Luminosity Detectors - Technical Design Report*. CERN-LHCC-2021-008, CMS-TDR-023.

[3] BCM1F Picture: CERN Document Server - *BRIL LS2 Activity: PLT BCM1F Integration*

[4] FLUKA, `http://www.fluka.org`

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