Measuring Luminosity and Beam-Induced Backgrounds with the CMS Fast Beam Conditions Monitor

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On behalf of the CMS collaboration

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Outline

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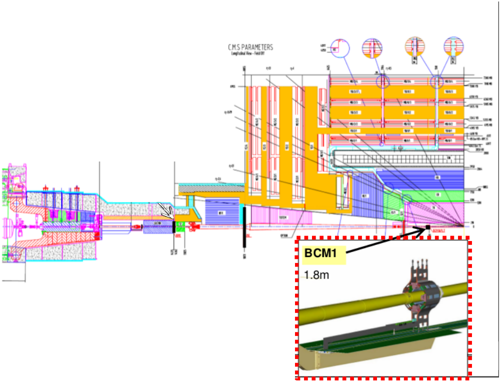
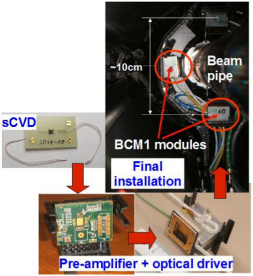
  - detector geometry
  - sensor material
  - electronics
  - signal characterstics
- beam gas measurement
  - measurement strategy
  - performance/cross-checks
- luminosity measurement
  - measurement strategy
  - calibration
  - systematics
  - performance/cross-check with other CMS luminometers
- conclusions and outlook

Fast Beam Conditions Monitor (BCM1F)

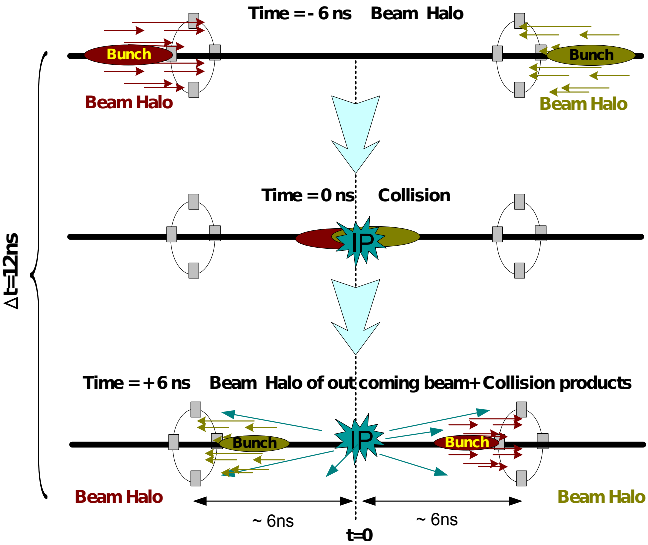
Measure single particle rates in the inner part of CMS with nanosecond time resolution.



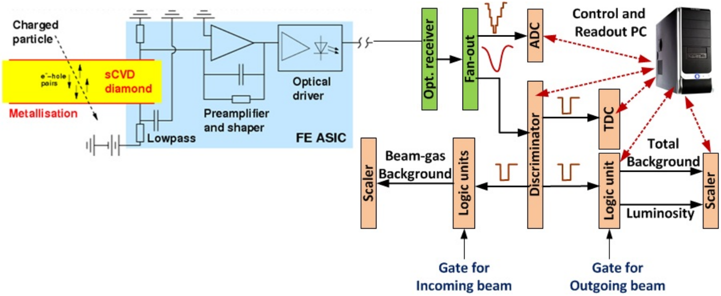


Design spcifications:

- 2×4 single crystal chemical vapor deposition (sCVD) diamonds ($5 \times 5 \times 0.5\text{mm}^3$)
- $z = \pm 1.8$m
- $r = 5$cm


Time = - 6 ns Beam Halo
Bunch
Bunch
Beam Halo
Beam Halo
Time = 0 ns Collision
IP
Δt=12ns
Time = + 6 ns Beam Halo of outcoming beam+Collision products
IP
Bunch
Bunch
Beam Halo
Beam Halo
~ 6ns
~ 6ns
t=0

Front-end/Back-end Electronics



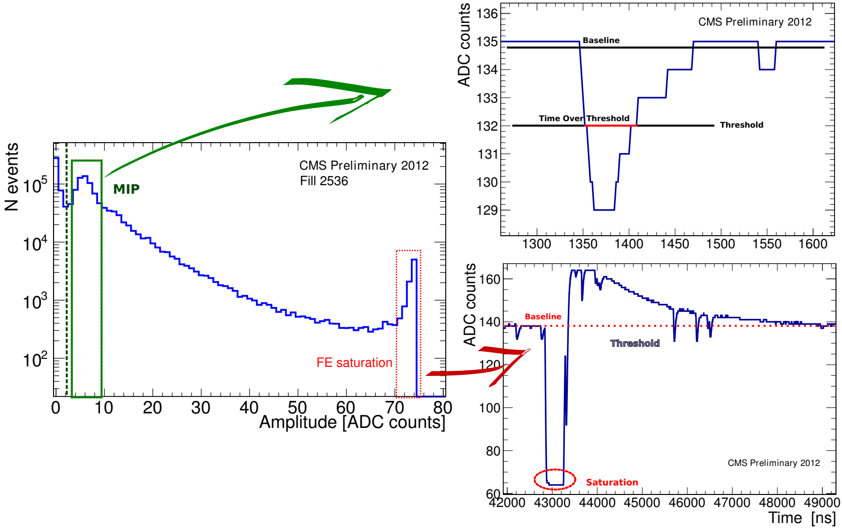
Front-end

- radiation hard pre-amplifier developed for readout of silicon strip detectors.
- 25 ns peaking time.

Back-end

- fixed-threshold discriminator
- bunch-by-bunch rates at 40.08 MHz
- ADC for offline signal analysis

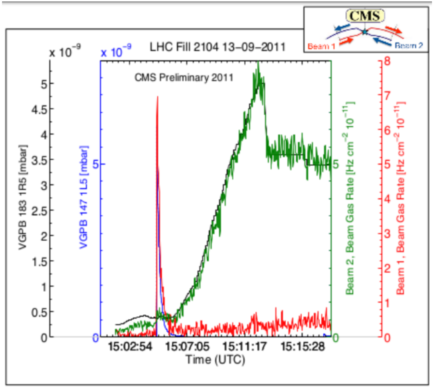
Signal Characteristics



Beam Gas Monitoring

Interactions of the primary beam protons, with rest gas in the beam pipe (beam-gas interaction)

- Dominated by inelastic collisions small angles "parallel" to the inner pixel detector at low radius
- Flux relative to collisions $\sim 10^{-5}$ (pressure dependent)
- BCM1F measurement based on rate counting beam halo products from non-colliding bunches.



Luminosity Basics

For a *pp* collider, the luminosity can be defined as,

$$L = \frac{\mu_{vis} \cdot n_b \cdot f_{orbit}}{\sigma_{vis}} \qquad (1)$$

- $\mu \equiv$ average number of inelastic collisions
- $f_{orbit} \equiv$ orbit frequency ($= 11246$ Hz)
- $n_b \equiv$ number of colliding bunches ($\lesssim 1380$)
- $\sigma_{inel} \equiv$ inelastic *pp* cross-section

Where we account for the detection efficiency by considering $\sigma_{vis} = \varepsilon\sigma_{inel}$. σ_{vis} is measured using a Van der Meer scan (see back-up for details).

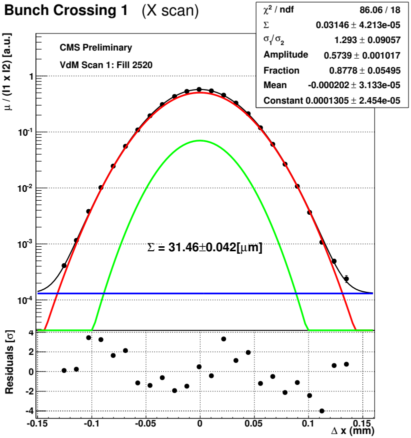
Zero Counting

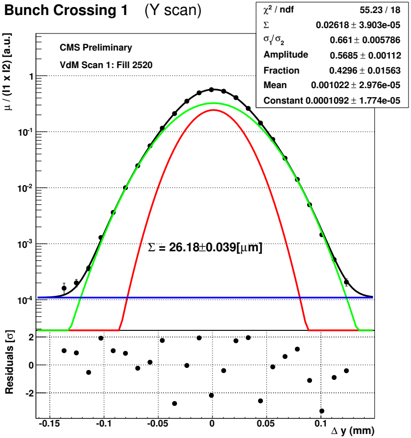
Assuming that the number of observed interactions is Poisson distributed with and MPV of μ, we can determine μ by measuring the number of colliding bunch crossings with no observed interaction,

$$P_n = \frac{\mu^n e^{-\mu}}{n!} \rightarrow \mu = -\ln[P_0] \quad \text{where} \quad P_0 = 1 - P_{OR} = 1 - \frac{N_{OR}}{N_{BX}} \qquad (2)$$

Van der Meer Calibration Results

Overlap region is measured for scans in the x (left) and y (right) directions

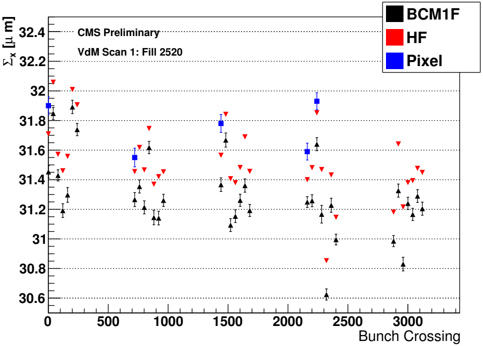




Results of Van der Meer scan are fit to a double gaussian plus a constant component. The two gaussian components are in red and green, the constant component is in blue, and the combined result is in black.

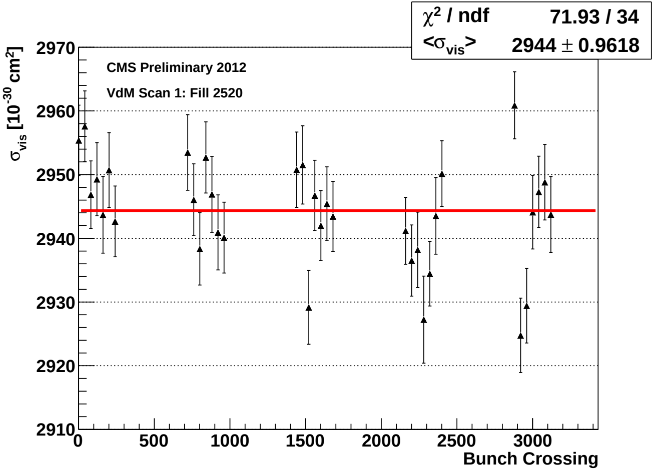
Calibration Cross-checks

Luminosity at CMS is provided online by the Forward Hadronic Calorimeter (HF) and offline by pixel cluster counting. The one common quantity that can be compared between the two detectors and the BCM1F is the measured effective beam width.



We find an agreement within 1% on average with both detectors.

Bunch-by-bunch Results for σ_{vis}



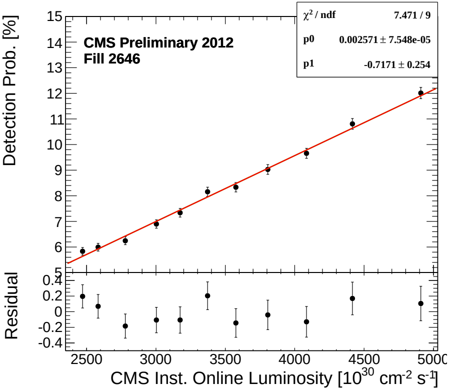
$$\sigma_{vis} = \pi \Sigma_Y \Sigma_X \frac{(\mu_{X,peak} + \mu_{Y,peak})}{N_1 N_2} \Rightarrow \sigma_{vis} \approx 2.94\text{mb} \quad (3)$$

Linearity of Hit Probability

The single hit probability per bunch crossing for BCM1F as a function of the instantaneous online luminosity measured by HF was determined for each diamond. Only bunch crossings following the abort gap (i.e., the first in the orbit) is considered.

From the linearity, it can be inferred that:

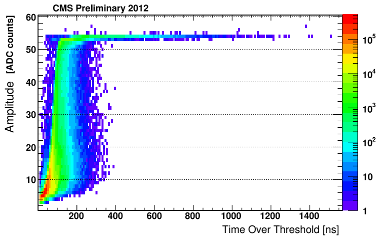
- counting rate is reasonably insensitive to pile-up
- calibration can be extrapolated to higher luminosities

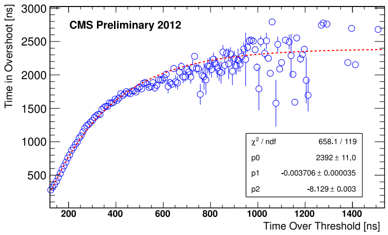


Simulating Detector Effects

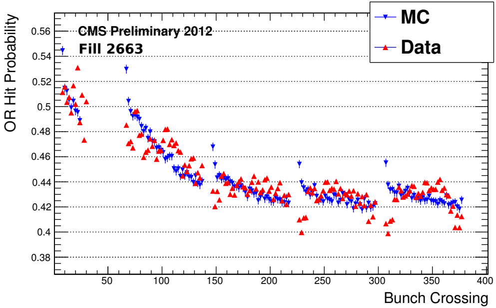
To model and correct for inefficiencies (mainly from saturating events) in hit counting, a MC simulation was developed taking into account the following characteristics:

- diamond-by-diamond single bunch hit probability
- time over threshold
- correlation between time over threshold/pulse amplitude and time in overshoot
- evolution of overshoot amplitude





MC Results



Apart from expected bunch-by-bunch variations that are not modelled, the main sources of inefficiency are accounted for.

- baseline overshoots account for the exponential drop off in efficiency over lager time scales.
- From the MC model, a set of bunch-by-bunch corrections for a given luminosity condition can be derived.

Conclusions

- The BCM1F sCVD-based detector has proven effective for measuring:
  - Beam-induced backgrounds
  - Online luminosity (within 1% of established luminometers)
- Source of inefficiencies in particle counting have been identified and reproduced with a Monte-Carlo simulation.

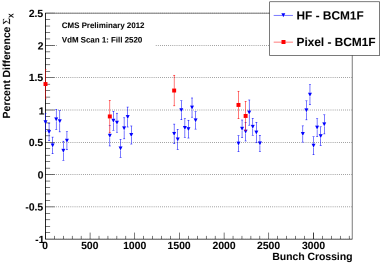
Outlook for BCM1F during the long shut-down

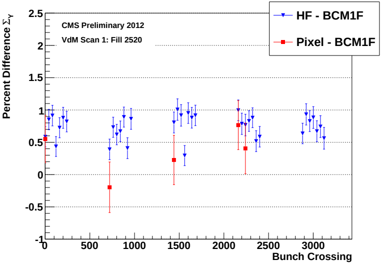
A design of a new radiation hard, front-end ASIC is being developed. New features include,

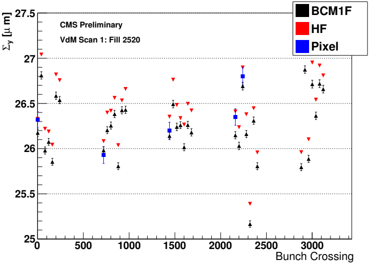
- Peaking time $\leq$ 10 ns
- FWHM $\leq$ 10 ns
- Baseline recovery $\leq$ 30 ns

Back-up

Calibration Cross-checks



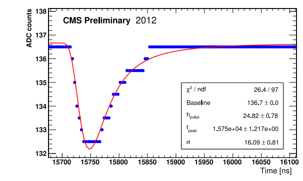




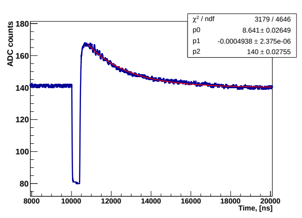
Systematic shift of BCM1F w.r.t. HF possibly due

- afterglow corrections
- HF higher sensitivity in tails
- length-scale corrections

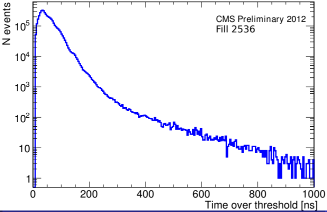
Signal Characteristics



Signal pulse fit to a Landau distribution.



Decay of overshoot in test pulse fit with function of the form $p_0 - e^{p_1(x - p_2)}$



Using the Van der Meer scan to calibrate BCM1F luminosity

By measuring beam parameters, an absolute measuremnt of the luminosity can be made using the relation,

$$L = \frac{f_{rev} N_1 N_2}{2\pi \Sigma_x \Sigma_y} \tag{4}$$

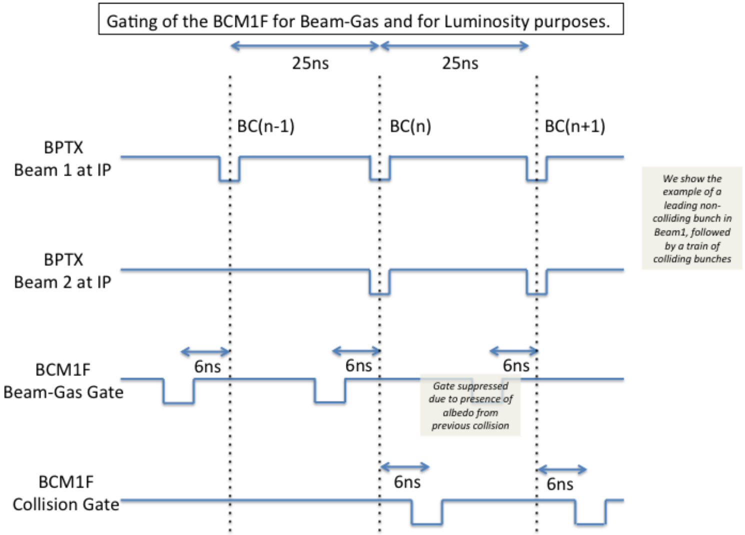
The calibration factor is extracted by measuring our counting rate versus beam separation independently in the X and Y directions, and fitting the result to a double Gaussian plus a constant,

$$\mu_X(x) = \mu_{X,peak}\left(\frac{f_1 \Sigma_X}{\sigma_1} e^{\frac{(x-X_0)^2}{2\sigma_1^2}} + (1 - \frac{f_1 \Sigma_X}{\sigma_1}) e^{\frac{(x-X_0)^2}{2\Sigma_X^2}(1-f_1)^2(1-\frac{f_1 \Sigma_X}{\sigma_1})^2}\right) + \mu_0 \tag{5}$$

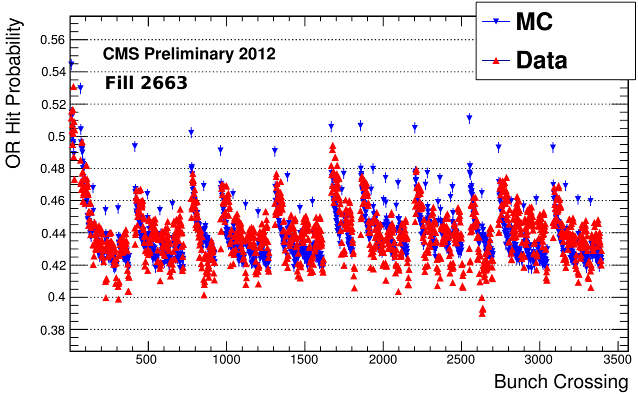
Equating the the VdM and standard lumi equations,

$$\sigma_{vis} = \pi \Sigma_Y \Sigma_X \frac{(\mu_{X,peak} + \mu_{Y,peak})}{N_1 N_2} \Rightarrow \sigma_{vis} = 2.9\text{mb} \tag{6}$$

Gating Logic



MC Results



Result for full orbit