The CMS Beam Halo Monitor detector system

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Machine-induced background
CMS BHM Group

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4. INFN Bologna, Italy
5. University of Minnesota, USA
Outline

1. Machine-induced background
2. Beam Halo Monitor detector
3. Detector system
   - Detector units
   - Electronics
4. First results
   - Splashes
   - Correlation to collimator movement
   - Commissioning data
Machine-induced background (MIB)

- Interactions with collimators
- Beam gas
- UFOs
Beam Halo Monitor

- **Purpose**: Provide an online, bunch-by-bunch, per beam MIB rate arriving at CMS at high radius
Problem

• Many more collision products (~$10^4$Hz/cm$^2$) than MIB particles (~1Hz/cm$^2$)

• Must find MIB signal amidst collision products $\Rightarrow$ factor of $\geq 10^4$ suppression required

• Solutions: DIRECTION-SENSITIVITY and PRECISION TIMING
Direction sensitivity

**MIB muon:** Arrives with incoming beam. Cherenkov radiation is seen by PMT.

**Collision product:** Arrives in opposite direction. Cherenkov radiation is absorbed by black paint.

**Cherenkov radiation:**
- Insensitive to neutron and gamma backgrounds
- Prompt signal in time with incoming particle
- Use quartz, radiation hard & UV transmissive
- Large signals – ~60 p.e./cm for forward particle

**2014 DESY test beam:**
- Background rejection of >99.99%
- With forward acceptance of >98%
Timing

- Golden locations allow for maximum separation in timing

\[ GL_{k+1} = \left( \frac{1}{4} + \frac{1}{2} k \right) \cdot (BX \, spacing) \approx 1.875m + 3.75m \cdot k \]
Detector placement

- Golden location 6 – 20.6m from IP
- 40 detectors, 20 at each end
- Acceptance of 21.2 cm\(^2\)/unit, 424 cm\(^2\)/beam
- Installed at radius of 1.8m from beam
- Placed in \(\phi\)-region of highest flux
Detector units

- SQ0 synthetic fused silica: 10 cm long, 5.2 cm diameter, UV transmissive, radiation hard
- Optically coupled to UV sensitive Hamamatsu R2059 PMT
- 3 layers of magnetic shielding: Permalloy, mumetal, iron
Detector units

• SQ0 synthetic fused silica: 10 cm long, 5.2 cm diameter, UV transmissive, radiation hard
• Optically coupled to UV sensitive Hamamatsu R2059 PMT
• 3 layers of magnetic shielding: Permalloy, mumetal, iron
• Every BX, every detector ➔ get 8-bit charge and 6-bit timing information
  – Histogram (μHTR)
• Calculate flux
  – Published to CMS and LHC operations every ~23s
Splashes

- **Indication of directionality**: a unit measuring beam 2 sees only beam 2 splashes, no beam 1 splashes.
Correlation to collimator movement

(Fill 3679, Circulating Beams, 5 May 2015)
Detector commissioning

- Commissioned with low detector thresholds
- Detailed bunch structure seen
- Tail consistent with albedo from cavern

(Fill 3858, Colliding beams, 14 June 2015)

Work in progress
Detector commissioning

- Three bunches of pure background

(Fill 3858, Colliding beams, 14 June 2015)
Summary

• New Beam Halo Monitor (BHM) will provide an online, bunch-by-bunch, per beam MIB rate arriving at CMS at high radius

• Takes advantage of directional nature of Cherenkov radiation and golden location timing to separate MIB from collisions product signals
Acknowledgements

- University of Minnesota: R. Rusack, J. Mans
- BRIL: A. Dabrowski
- BHM: N. Tosi, S. Orfanelli
- Other UMN, CERN, and Bologna students and technicians
ADDITIONAL SLIDES
The CMS detector

**CMS DETECTOR**
- Total weight: 14,000 tonnes
- Overall diameter: 15.0 m
- Overall length: 28.7 m
- Magnetic field: 3.8 T

**STEEL RETURN YOKE**
- 12,500 tonnes

**SILICON TRACKERS**
- Pixel (100x150 μm) ~16m² ~66M channels
- Microstrips (80x180 μm) ~200m² ~9.6M channels

**SUPERCONDUCTING SOLENOID**
- Niobium titanium coil carrying ~18,000A

**MUON CHAMBERS**
- Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
- Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

**PRESHOWER**
- Silicon strips ~16m² ~137,000 channels

**FORWARD CALORIMETER**
- Steel + Quartz fibres ~2,000 Channels

**CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)**
- ~76,000 scintillating PbWO₄ crystals

**HADRON CALORIMETER (HCAL)**
- Brass + Plastic scintillator ~7,000 channels
Beam, Radiation, Instrumentation, and Luminosity

Z = +/- 11.2 m
HF Luminosity:
- Quartz fiber calorimeter
- Photodetectors
- uTCA backend

Z = +/- 1.8 m, R = 5 cm
PLT:
- 48 si-pixel sensors
- Special 40 MHz readout

BCM1F:
- 24 scVD diamond sensors, 48 channels
- Fast MIP counter, triggerless readout

BCM1L:
- 8 pCVD diamond sensors
- Beam background monitoring
- Protection of CMS pixel detector

Z = +/- 20.625 m, R = 180 cm
BHM:
- Fast PMTs, directionality
- Backend electronics

Z = +/- 14.4 m
BCM2L:
- Inner ring: 4 sensors, R = 5 cm
- Outer ring: 8 sensors, R = 28 cm
MIB vs. PP

Flux (cm²/sec)

Radial distance [cm]

10^{-1} 10 10^{2} 10^{3} 10^{4}

MIB

PP
Beam halo contributions

All particles IR1 B1

All particles IR1 B2

Muons IR1 B1

Muons IR1 B2
MIB muons

Mean x 17.88
Mean y 2.571
Integral 0.2393

Polar angle wrt incoming beam [deg]

Flux [cm$^2$/sec]

Energy [GeV]
PP muons

Mean x: 1.586
Mean y: 175.7
Integral: 189.4
PP electrons
Cherenkov angle

\[ \cos \theta_c = \frac{1}{\beta n} \]

\[ E_{th} = \frac{nmc^2}{\sqrt{n^2 - 1}} \]

\( \approx 142 \text{ MeV for muons} \)
Cherenkov radiation

\[ \frac{\partial^2 N}{\partial x \partial \lambda} = \frac{2\pi \alpha}{\lambda^2} \left(1 - \frac{1}{\beta^2 n(\lambda)^2}\right) \]

**Figure 9** The wavelength of the Cherenkov light produced (left) and detected by the photocathode (right) as simulated when a muon of 4 GeV crosses 10 cm long quartz radiator, entering from the centre of the front face of the bar.
• Golden locations allow for maximum separation in timing

\[ GL_{k+1} = \left( \frac{1}{4} + \frac{1}{2}k \right) \cdot (BX \text{ spacing}) \approx 1.875m + 3.75m \cdot k \]
Test beam results

- Test beam studies performed at CERN in 2012

![Graphs showing forward and backward beam results](image-url)
Test beam results

- Test beam studies performed at DESY in 2014

Amplitude cut: Backward suppression to 0.01%, forward acceptance 100%
Test beam timing

R2059 +quartz bar

Number of Events

0 1 1.5 2 2.5 3 3.5 4 4.5 5

FWHM [ns]

Mean 3.09
RMS 0.2034
Hamamatsu R2059

**Graphs:**
- **Graph 1:**
  - **Title:** Gain vs. Supply Voltage (V)
  - **X-axis:** Supply Voltage (V)
  - **Y-axis:** Gain
  - Data points showing exponential growth of gain with supply voltage.

- **Graph 2:**
  - **Title:** Cathode Radiant Sensitivity and Quantum Efficiency vs. Wavelength (nm)
  - **X-axis:** Wavelength (nm)
  - **Y-axis:** Cathode Radiant Sensitivity (mA/W) and Quantum Efficiency (%)
  - Plotting showing peak sensitivity and efficiency at specific wavelengths.

**Legend:**
- **TPMHB0809EA**
- **TPMHB0286EA**

**Notes:**
- Data and analysis relevant to the performance of the Hamamatsu R2059 under different conditions.

**References:**
- 08/04/15
- 2015 APS DPF Meeting

**Institution:** University of Minnesota
Radiation studies

- Unit irradiated with 3000 fb\(^{-1}\) of \(\gamma\) rays
Detector units

- Permally layer
Detector units

- Mumetal layer
Magnetic shielding efficiency

- Gain decreases as field increases
- Largest decrease ~10%
- % decrease at 3.8T
Patch panel

- Acts as passive splitter and attenuator
Read-out electronics

- QIE10: digitizer
- uHTR: histogramming unit
- Other units: power, clocks, slow control, data read-out
Electronics Overview

**Front End Crate**
- **2* QIE10**
  - Integrates charge over 25 ns
  - Finds rising edge (0.5 ns)
  - Sends the digitized info to the backend

**Back End (BE) uTCA Crate**
- **2* uHTR**
  - Produces occupancy histograms by binning hits above threshold into four sub-bins in each bunch crossing based on the rising edge TDC value
  - Each channel is readout individually every $2^{14}$ LHC orbits (4 lumi-nibbles)

**Digitized Data**
- **ngCCM**
  - Distributes clock in the crate
  - Manages slow control of crate cards

- **GLIB**
  - Communicates and sends clock to the front-end

- **AMC13**
  - Receives, decodes, distributes clock (TTC) information

- **MCH**
  - Controls power and house-keeping
  - Sends out histograms via IPbus

**Histograms**

**TCDS CMS clock info + Slow control**

**BRIL DAQ**

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QIE10

- Reads analog PMT signal

24 QIE10 ASICs:
- Integrates charge over 25ns, produces 8-bit ADC value (0-340pC)
- Produces 6-bit TDC value based on fixed-threshold leading edge measurement (.5ns resolution)

Igloo2 FPGAs:
- Collect and format data
- Data sent to back-end via 5Gbps asynchronous optical link
QIE10 Range

Fraction of Range 0 Scale

ADC Code

Section 1
Section 2
Section 3
Section 4
QIE10 input
QIE10 block diagram
uHTR block diagram
Setting thresholds

- Cut out majority of PP events, in addition to cosmics

h12

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Setting thresholds

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Read-out electronics: VME

- Background rate:
  - Fan out
  - Discriminator
  - Scaler

- Amplitude measurement:
  - Fan out
  - QDC
Calibration system

- Measures health of system over time
- UV LED pulses of known timing and amplitude distributed to all PMTs, plus reference
Temporary calibration system

• Measures health of system over time
• UV LED pulses of known timing and amplitude distributed to all PMTs, plus reference
Calibration system

- Delivers pulses of expected signal size, ~600 photoelectrons

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Amplitude [pC]
BHM in BrilDAQ

• BrilDAQ: based on xDAQ publisher/subscriber framework

• bhmsource – reads out histograms from uHTRs

• bhmprocessor – calculates background rate for each beam, publishes every lumi section (\(2^{18}\) orbits = ~23s)
System overview

Experimental Cavern

40 units

CKC50, high bandwidth, double braided coaxial

Service Cavern

HV patch panels

Readout patch panels

DC

AC

VME scalers

Digitizers

Histogramming Units

Bril DAQ

HV patch panels

HV power supply
Splash events

- Send a bunch directly into the TCTs – creates a ‘splash’ of particles in one direction
Splashes

Beam 1 splashes, PF10 and MN07

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Beam losses
VME results

Rate [Hz] vs UNIX Time

- VME B1
- VME B2
- Lumi

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