Upgrades to the Beam Condition Monitors at CMS

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Overview

• Introduction to currently used diamond based beam monitoring systems.
  – System overview of BCMF and BCML
  – Problems related to diamond detectors

• CMS phase 2 upgrade (HL-LHC)
  – Requirements for beam monitoring detector
  – Possible detector technologies
  – Radiation environment
CMS diamond beam monitoring systems

Upgrades to BCM detectors at CMS

3rd Dec 2015

M. Guthoff - Upgrades to BCM detectors at CMS
Detector system features

**BCMF**

- **Concept:** Fast particle counter
- **Application:**
  - Machine induced background measurement
  - Luminosity measurement
- **Detector:**
  - 5x5mm$^2$ sCVD
  - Two pad metallization to reduce pile up.
- **Electronics:**
  - Fast preamp
  - Optical transmission
  - Discrimination + time histogramming; ADC; FPGA signal processing.

**BCML**

- **Concept:** Detector current measurement
- **Application:**
  - Beam loss monitoring (fast & intense events)
  - Active protection
- **Detector:**
  - 1x1cm$^2$ pCVD
  - Replaces LHC BLM ionization chamber
- **Electronics:**
  - LHC BLM readout electronics (40us integration)
  - Will follow changes made by LHC.
BCMF: Backend signal processing

- VME based (used in production):
  - Realtime Histogramming Unit
  - ADC data acquisition
- uTCA based (under development):
  - FMC125 ADC signal processing in FPGA.
    - Amplitude histogram, timing histogram, RAW ADC acquisition
    - In the future signal de-convolution to mitigate pileup

A. Zagozdzinska:
IEEE NSS 2015
Note in preparation
**BCMF: features and problems**

- **Detector & front end system:**
    - 24 sCVD diamonds with 48 channels
    - Design specification for HV rating: 1000V
  - Problems:
    - Noisy channels, HV trips (I > 3uA).
      - Expected current per diamond $O(100\text{nA})$
    - Reduction of HV necessary: 50-250V “left”
    - Will do test beam with spare detector on hadron beam line to investigate further.
**BCML: features and problems**

- **Measurement of detector current**
  - Sensitive to erratic current behavior
  - Magnetic field at BCML1 helps, at BCML2 not strong enough.

- **BCML1 survivability good**
  - Has to rely on magnetic field
  - Durability to be studied next year
  - But:
    - ~100m front end cable: More noise, flattening of fast pulses
    - BCMF problems reflect also on BCML 1
      - Only 6 out of 8 channels working

- **BCML2**:
  - Operational HV limited to about 200V with pCVD diamonds.
    - Radiation hardness depends on applied HV.
    - Estimations predict failure after 100 fb⁻¹
CMS phase 2 Upgrade

• Upgrade of the CMS detector in the scope of the HL-LHC project.
  – Goal: deliver $3000 \text{ fb}^{-1}$ (Run 1: $30 \text{ fb}^{-1}$, LHC lifetime $300 \text{ fb}^{-1}$)
  – Instantaneous luminosity: $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ -> 4 billion collisions per second (LHC design $1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$)
  – Up to 140 collisions per bunch crossing (at the same time) (currently ~20)

• Continued need for two beam monitoring systems
  – Fast particle counter
    • Precision luminosity measurement
    • Machine induced background measurement
  – Detector current measurement
    • Active protection
    • Monitoring of fast & intense loss events
Radiation tolerance needed

Target 3000 fb\(^{-1}\):

- **Dose:** \(O(10 \text{ MGy})\)
- **24 GeV-p-eq fluence:**
  - At pixel: \(~10^{16} \text{ cm}^{-2}\)
  - Forward region: \(~3\times10^{16} \text{ cm}^{-2}\)
BCMF upgrade

- **Expected rates:**
  - Luminosity: 100 - 200 MHz/cm²
  - Machine induced background: \(~100\) kHz/cm²

- **Detector size:**
  - Low rates require sufficient total detector area
    - Commissioning, Heavy Ion, Van der Meer scans
    - Beam background measurements
    - At least same total detector area: Currently \(~12\)cm²

- **Detector granularity**
  - Minimize pile up at high rates with granularity
    - Decrease detector size by factor 3 (currently 0.125 cm²)

  ➢ Need > 150 channels
  ➢ Could use pixelated or strip detector.

- **Sensor technology:**
  - **Diamond:** no cooling required, R&D necessary
  - **Silicon:** Cooling available at Central Tracker, unlikely for potential detector at forward location
BCML upgrade

- Detector requirements:
  - High dynamic range
    - Low dark current while high saturation
    - Nominal beam background rates: \( \sim 10^5 \text{ Hz/cm}^2 \)
    - Collision products: \( \sim 10^8 \text{ Hz/cm}^2 \)
    - Beam abort threshold: \( \sim 10^6 \text{ Particles per event (}\sim 10^{10}\text{Hz/cm}^2\)\n  - Size & Material budget
    - Has to be optimized for detectors at Pixel location.

- Detector location:
  - More flexibility since it does not require timing
  - Sensitive to beam background
  - Accessibility (especially if replacements needed)
    - Residual dose environment make access undesirable
Possible detector technologies:

• **Diamond detectors:**
  - Radiation hardness only achievable with sufficient HV
  • Need magnetic field to suppress erratic currents.

• **Sapphire detectors:**
  - Compensate very low signal with increased detector area
  - Prototype campaign ongoing

• **Ionization chambers:**
  - Impossible to place inside CMS
  - Potentially for BCML2 location.
Timeline phase 2 upgrade

- Technical design report in 2020
- Detector R&D in the next 2-3 years!
Summary

• Continued needs for beam monitoring and detectors suitable for luminosity measurement.

• Currently installed diamond detector based system with various problems.
  – HV stability / noise. -> No possibility to overcome radiation damage
  – Granularity not suitable for Luminosity upgrade

• Detector R&D ongoing
  – New detector designs necessary to fulfill the requirements in HL-LHC
THANK YOU
BACKUP
• sCVD in BCML (500V)
• random current bursts occurring at high rates
• Similar symptom to pCVD erratic currents but less pronounced
24 GeV proton equivalent in Diamond

- Similar defined to 1 MeV neutron equivalent in silicon.
- Relative damage potential of each particle is weighted with the damage potential of the reference particle.

\[
\text{Flux}_{24 \text{GeV} - p-eq} \left[ \frac{24 \text{GeV protons}}{cm^2 \times s} \right] = \frac{DPA_{\text{simulation}} \left[ \frac{1}{s} \right]}{DPA_{\text{norm}} \left[ \frac{cm^2}{24 \text{GeV protons}} \right]}.
\]
Monitoring with BCML

- BCML data includes different integration times to allow an analysis of fast beam loss events.
- Fast events are not significant in BCMF and
Electronics

- New front end electronics has to be identified:
  - Fast good timing
  - Trigger less readout
  - Dead time free
  - Digital readout

- Optical path
  - Currently no rad-hard solution for analogue transmission.
  - Digital optical data transmission used by CMS tracker

- Back end electronics:
  - Fast time histogramming
  - Signal amplitude measurement
  - Pileup mitigation.
  - Advanced FPGA based signal processing being developed already for current system.