Current Status of the Fast Beam Condition Monitor Upgrade at CMS

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Beam Condition Monitor

Context

- LHC running at unprecedented beam energies and intensities
- Even small beam losses may cause damage to CMS detector components

Purpose of Beam Condition Monitor

- Monitor particle fluxes near the beam pipe
- Ensure sufficiently low inner detector occupancy for data-taking
- Detect beam loss conditions
- Initiate reactions when necessary (beam abort)
Fast Beam Condition Monitor BCM1F (up to 2012)

8 5mm x 5mm single-crystal CVD diamonds (Element 6) positioned around the beam-pipe, radial distance 4.5 cm, 1.8 m from interaction point

- Diamond → no cooling, robust, radiation-hard
- Sensor module: diamond, radiation-hard preamplifier, optical driver

Bunch-by-bunch information on flux of beam halo and collision products

- Monitor condition of beam: ensure low radiation for silicon tracker
- Calculate luminosity

Readout independent of CMS DAQ
BCM1F Electronics

Output: hit rates
Small geometric acceptance: only “see” small fraction of bunches
BCM1F Upgrade

Implications of LHC upgrade for BCM1F

- Radiation: Luminosity $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ → BCM1F charged particle flux $\sim 3 \times 10^{7}$ cm$^{-2}$s$^{-1}$
- 25 ns bunch spacing
- High hit rate

24 diamonds x 2 metallization pads per diamond = 48 channels for higher dynamic range

Minimize and deal with radiation damage

Scale up full system from 8 channels

Faster electronics

Integrate readout with other luminosity subsystems

Upgrade sensor layout
Upgrade Carriage Design

One piece semi-rigid PCB

Old carriage

Rigid

Flex
BCM1F Diamonds for Upgrade

Significant issue in Run I: radiation damage

- Effect: diamond polarization decreases efficiency

Primary line of defense: higher HV

Other possibilities

- Red light illumination
- Alternating voltage polarity

Old and new diamonds recently characterized with split metallization (talk from Maria Hempel)
Several sources of inefficiency in front-end electronics, especially for (rare) high-amplitude signals

- Overshoot (few μs)
- Long rise time (~25 ns)
- Time-over-threshold (~100 ns)
New Fast Front End ASIC

Developed by AGH - Krakow

IBM CMOS8RF 130nm technology

~50 mV/fC charge gain, < 1ke- ENC

Rise time ~ 7 ns

Time-over-threshold < ~30 ns
Overshoot time very small

Large improvement in behavior: addresses previous problems

D. Przyborowski
Fast ASIC with Full Chain

Read out test pulses to ASIC with optical transmission board

3 fC
Radiation damage of laser driver visible in decreasing signal amplitude

- 25% gain lost in BCM1F optical transmission after 30 fb$^{-1}$, fluence $8.78 \times 10^{13}$ cm$^{-2}$ (24 GeV protons)
Improving Optical Chain

Improvements

- Multi-amplitude test pulse to monitor linearity of response
- Laser diodes on carriage arm (lower radiation)
- Temperature sensor to account for optical response to temperature
  - Bragg grating: wavelength of transmitted light sensitive to temperature changes
- Temperature stabilization (other subsystems)
Use “tried and true” discriminator path for initial running while commissioning digitizer path

LUT: create coincidences between all 48 channels

RHU for readout (later slide)
Upgrading Back End Electronics

Two parallel tracks:

**Discriminator path**

**Fixed-threshold vs. constant-fraction**

- **Fixed-threshold**: lower deadtime
- **Constant-fraction**: better time resolution

Preliminary conclusion: deadtime outweighs resolution -> use FTD (CAEN V895) for primary path but install CFD to run and test in parallel

**Digitizer with fast peak-finding algorithms**

Identify pulse arrival time and peak height, distinguish signals close in time (overlapping)

Development of algorithms ongoing

Current hardware choice: uTCA ADC FMC mezzanine system. Multiple FMC candidates, to be tested
Upgrading Data Acquisition: RHU

Recording Histogram Unit (RHU): Readout of full-orbit histograms

- No deadtime
- 8 histogramming input channels
- Bins of 6.25 ns = 4/bunch bucket (14k bins/orbit)
- Bunch clock, orbit clock, beam abort
- Configurable sampling period
- Ethernet readout

Developed at DESY-Zeuthen

Prototype installed Sept. 2012, validated during 2012-2013 run

Next revision: Optical fiber input (timing signal), ECL input mezzanine connection

Rev. 2 prototype produced by end of January
Upgrading Data Acquisition: LumiDAQ

BCM1F output hit rates acquired via LumiDAQ system

- Expansion of already-existing structure
- Combines data from all CMS luminosity detectors

Common timing signal distributed via optical fiber

- Hit count integration interval
- Synchronization important

Common data format: 3564 bins
Luminosity Algorithms for Upgrade

Simple combinations of sensors used to measure luminosity in Run I

- Saturation at high pileup levels foreseen post-upgrade

New algorithms needed, development via simulation

W. Warzycha
Conclusions

Many improvements in the works to increase effectiveness

- Carriage: 48 channels, single PCB
- Diamond sensors: minimize effects of radiation damage using higher voltage
- New fast front end ASIC to reduce inefficiencies
- Optical chain: lower radiation for laser driver, multi-amplitude test pulses
- Back end: Discriminator path in parallel with digitizer peak-finding
- RHU, LumiDAQ for collection of hit rates
- Algorithms for luminosity measurement

Future plans

- Full sensor chain to be tested in January at test beam
- Synchronization of readout electronics within timing/LumiDAQ framework
IBM CMOS8RF 130nm technology
2.5 V power supply (high voltage enabled design)
Power consumption $\sim 11$ mW/ch (10mW of output buffer)
FE ASIC Fast MIPs

Distinguishability of MIPs with 12.5 ns interval

Output voltage (mV) vs. Time (ns)

- $V_{fed} = 300$ (mV)
- $V_{fed} = 350$ (mV)
- $V_{fed} = 400$ (mV)
- $V_{fed} = 450$ (mV)
- $V_{fed} = 500$ (mV)
- $V_{fed} = 550$ (mV)
- $V_{fed} = 600$ (mV)
- $V_{fed} = 650$ (mV)
- $V_{fed} = 700$ (mV)
- $V_{fed} = 750$ (mV)
Effects of Radiation: Diamond Sensors

Polarization → Inefficiency, changes with time
Change in response depends on HV, luminosity
Ongoing investigation
  - Recent study: thinning diamond appeared to improve polarization, more study needed

Important to characterize systematic error on luminosity calibration (TIE IN SLIDE WITH DIAMOND STUFF)
Improving Timing Performance: Discrimination

Current discriminator: CAEN v258B fixed-threshold discriminator

- Does not discriminate pulses closer than ~12 ns: deadtime causes loss of consecutive signals
- Triggers pulses of different amplitudes at different times: “time walk” ΔT ~12 ns

CFDs significantly improve on FTD time walk

- v812: better time resolution for trigger of single pulse
- CFD950: better resolution between consecutive pulses

(TIE IN WITH UPGRADED BACKEND SLIDE)
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Tested two constant-fraction discriminators: CAEN v812, PSI CFD950

Both CFDs significantly improve on FTD time walk

- v812: better time resolution for trigger of single pulse
- CFD950: better resolution between consecutive pulses