The ATLAS Beam Conditions and Beam Loss Monitors

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**BCM web page:** [https://twiki.cern.ch/twiki/bin/view/Atlas/BcmWiki](https://twiki.cern.ch/twiki/bin/view/Atlas/BcmWiki)
Overview

- why Beam Conditions Monitor (BCM)
- basic operating principle
- design of the BCM
- commissioning with cosmics
- Beam Loss Monitor (BLM)
Motivation

- LHC will store more than two orders of magnitude more energy than any previous accelerator (~2800 bunches with $10^{11}$ protons @ 7 TeV => 360 MJ per beam)

- beam losses could be dangerous to ATLAS Inner Detector

- experience shows that beam accidents can happen
  - Tevatron device misinterprets a command to retract and instead moves into the beam
  - 10 ms were needed until beam was dumped

- time constants of magnets are in the order of few LHC turns (~ms) → fast action can dump the beam in time & prevent beam accidents
Protection from beam accidents

- ATLAS and CMS have Target Absorber Secondaries collimator (TAS) $Z=\pm18$ m for **passive protection**:
  - protects inner triplet magnets from secondaries produced in $pp$ collisions
  - protect Inner Detector from beam failures

- **active protection** - Beam Interlock System (BIS):
  - two redundant optical loops for $BeamPermit$ signals
  - user systems provide $UserPermit$ signals
    - machine beam loss monitors
    - machine beam position monitors
    - experiment Beam Conditions Monitor
    - ...
  - if any of $UserPermit$ signals drops $\Rightarrow$ optical loop interrupted $\Rightarrow$ $BeamPermit$ drops
    - beam dumped within 3 turns $\sim 270\,\mu s$
  - additional $InjectionPermit$ signal for preventing injection until experiments ready
    - prevents injection, but does not effect circulating beams
BCM protection

- time of flight measurement to distinguish between interactions and downstream background (beam gas, halo, TAS scrapping)
  - measurement each proton bunch crossing .... every 25 ns
  - two detector stations @ z=±1.9 m (±6.25 ns)

pp interaction: $\Delta t = 0, \pm 25$ ns, ... in-time coincidence

TAS (collimator) event: $\Delta t=2z/c=\pm12.5$ ns, ... – out-of-time coincidence
Realization

- 4 detector modules on each side of the detector (within PIXEL volume)
- mounted on PIXEL support structure
  - modules at $z=\pm183.8$ cm
  - $r=5.5$ cm ($\eta\approx4.2$)
  - 45° angle with respect to the beam pipe
Installation

beam pipe  BCM modules  PIXEL
BCM diamond sensor

- requirements
  - bunch-by-bunch measurement
    - fast signal (1 ns)
    - narrow width (2 ns)
    - fast baseline restoration (10 ns)
  - radiation hard
    - close to interaction point & beam pipe
    - estimated to 0.5 MGy & $10^{15}$ pions/cm$^2$ in 10 years

- Poly-crystalline CVD diamond chosen as sensor material
  - Developed by CERN RD42/Element Six Ltd., metallized with radiation hard process at Ohio State University
  - radiation hardness – shown to withstand fluences up to $10^{15}$ p/cm$^2$
  - Fast signal – operate at high drift field 2 V/µm
  - Low leakage current – no cooling required
  - high charge mobility and ccd of >200 µm
Signal optimization

- diamonds 10×10 mm & 500μm thick
- two diamonds per module
  - double the signal
  - only 30% more noise
- diamonds at 45° w.r.t. the beam pipe
  - $\sqrt{2}$ of the signal
BCM module

- two stage amplification

1st stage: Agilent MGA62653, 500MHz (22db)
2nd stage: Mini Circuit GALI52, 1GHz (20dB)

- typical signal before bandwidth filter

- bandwidth limit
  - 4th order 200 MHz filter used
  - increases S/N by 50%
  - 10% worse timing resolution
BCM Connectivity

**BPSS**
- ~0.5 MGy

**PP2**
- ~10 Gy

**USA15**
- Counting room

**BCM Detector Modules**
- 8× Coax

**NINO Boards**
- Data
- Threshold
- Temperature

**OPTO Link Board**
- 16× Optical

**FPGA Board**
- 2× Xilinx ML410
- LA1 in
- Trigger Out
- S-link Data Out
- Beam Abort Signal
- Recorded Data

**High Voltage, Low Voltage, Temperature**

**DCS**

**PC**

**ATLAS CTP**
- L1A out
- LVL1 trigger in

**ATLAS TDAQ ROS**

**ATLAS Beam Abort(2) and DSS(4)**

**ATLAS DCS**
BCM data recorded in two ATLAS cosmic runs

- November 2008:
  - Transition Radiation Tracker (TRT) stream ~2.5 M triggers
  - Resistive Plate Chamber (RPC) stream ~34 M triggers
- June 2009:
  - RND stream (~2.6 M triggers)
  - IDCosmic stream (~34 M triggers)

- different threshold settings

- for each trigger 32 consecutive BCs were read-out
  - 18 BCs before trigger
  - 13 BCs after trigger

131 events with BCM info

474 events with BCM info
Timing histograms for cosmic data

- histogram the BC number of reconstructed BCM hits
- random uniform background as expected
- Gaussian peak
  - at BC=20
  - 6 out of 1 M IDCosmic triggers gives true BCM hits
- width of distribution is dominated by trigger timing
Luminosity monitoring

- BCM will contribute to luminosity monitoring with
  - Monitor instantaneous luminosity
  - vertex position monitoring
  - determine dead time
  - beam separation scans

- first algorithms will be based on non-empty event counting
  - monitoring of luminosity per BCID
  - providing instantaneous luminosity at Hz rate

- Monte-Carlo simulations under-way to provide initial calibration used before first beam-separation scans, and understanding systematic
ATLAS BLM system

- **BLM – beam loss monitor**
  - implemented as a back-up system to BCM
  - majority of the system copied from LHC beam loss monitors

- **sensors**
  - one 8×8mm diamond, 500 μm thick
  - operated at 500 V
  - current @ 500 V is typically less than 1-2 pA

- 12 sensors installed on Inner Detector End Plate (6 on each side)
  - z~3450 mm, r~65 mm
  - coaxial cable to PP2

- **BLM cards at PP2 digitize integrated current**
  - over range of time periods 40 μs – 80s
  - converted to frequency (LHC CFC cards, radiation tolerant)
  - optical fiber to USA15 counting room
  - data recorded by FPGA

- information complementary to BCM, but can be used standalone in case of BCM problems
  - each time period can have independent threshold
  - upon exceeding the threshold a beam-dump signal is issued
Summary

- ATLAS BCM will monitor the beam conditions
  - using TOF measurements
  - diamond as sensitive material
  - "double decker" configuration at 45° towards the beam
  - additional goals to safety
    - triggering
    - beam-separation scans
    - luminosity
    - ....

- First experience with the system obtained in last eighteen months

- BLM implemented as a redundant system for safety purposes

- Looking forward to using it in the real LHC environment
Beam-loss scenarios

More types of beam losses:

- **multi turn losses (intervention)**
  - beam degradation (equipment failure, wrong magnet settings, ...)

- **single turn losses (diagnostics)**
  - likely during injection due to wrong magnet settings
  - IR1 (ATLAS) furthest from injection
  - pilot bunch will be used to test the magnet settings ($5 \times 10^9$ p @ 450GeV)
  - simulation of beam orbits with wrong magnet setting (D. Bocian) exhibit scenarios with pilot beam scrapping TAS collimator
Signal processing - NINO

- developed for ALICE ToF (F. Anghinolfi et al.)
- radiation tolerant
- fabricated in 0.25 µm IBM process
- peaking time < 1 ns, jitter < 25 ps
- time-over-threshold amplifier discriminator chip
- width of LVDS output signal depends on input charge
- rad-tolerant laser diodes transmit fibers to USA15 counting room
Signal processing - ROD

- Optical signals received and transformed into PECL on two 8 channel optical receiver boards
- PECL signal from individual receiver board connected to Read Out Driver (ROD) based on Xilinx Virtex-4 based FPGA board
- ROD samples input signals with 2.56 GHz -> 64 samples of 390 ps for each BC (25 ns)
- Raw data stored in DDR2 memory module for more than the last 1000 LHC turns
- Real-time signal processing: rising edges and pulse widths are reconstructed in signals (at most the first 2 for each BC):
  - LHC post mortem analysis
  - On trigger (L1A) signal data is formatted and sent over optical link to Read Out Subsystem (ROS)
  - In-time and out-of-time coincidences: 9 trigger signals to CTP
  - High multiplicity  → LHC beam abort system and ATLAS DSS
- Personality modules developed for interfacing input and output signals to RODs
- Provides connections to:
  - ATLAS Central Trigger Processor (CTP)
  - Triggered data acquisition (TDAQ)
  - Detector Control System (DCS)
  - Detector Safety System (DSS)
  - Controls Interlocks Beam User (CIBU)
Timing histograms for cosmic data (2008)

- lower noise level due to different trigger & threshold settings
- timing remains the same
- TRT stream exhibits approx. same distribution width as ID Cosmic stream of 2009
- RPC stream distribution broader because of RPC geometry
channels 0-7 are low gain channels (expect to show signal for ~5 or more MIPs traversing the sensor simultaneously)

NINO thresholds not calibrated - different noise occupancies of readout channels

no hits on C side with TRT Fast OR