1st LHC Beams and Collision Preparations with the Diamond ATLAS Beam Conditions Monitor

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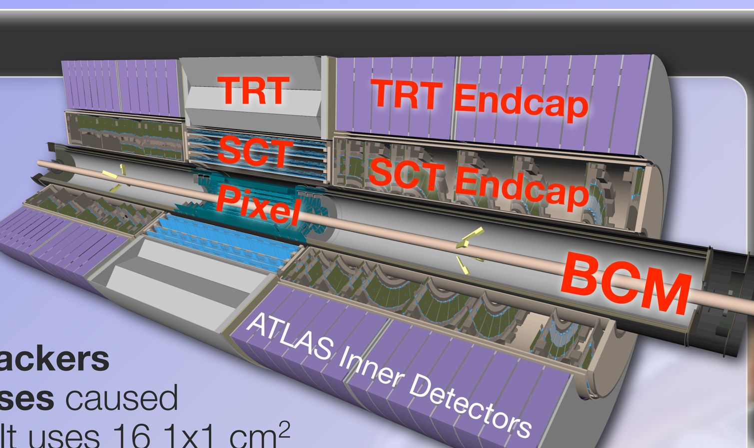
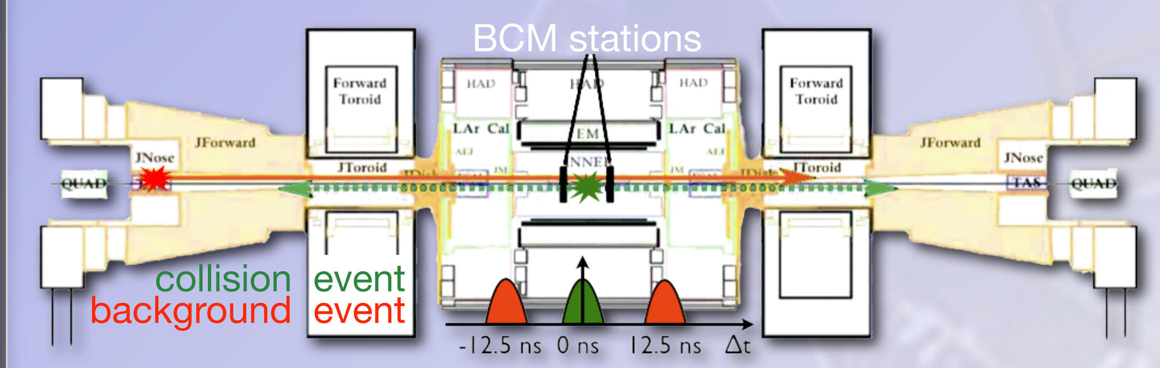
Introduction:



The **Beam Conditions Monitor** (BCM)[1] of the ATLAS experiment **protects** the Inner Detector **silicon trackers from high radiation doses** caused by LHC beam incidents. It uses 16 1x1 cm² 500 µm thick polycrystalline chemical vapor deposition (pCVD) **diamond sensors** arranged in 8 positions around the interaction point. **Time difference measurements** with **2.56 GHz sampling** are performed to **distinguish** between **collision and background**. In case of excessive beam background due to beam incidents, the **BCM can trigger** a **beam abort**. A **FPGA based readout system** performs the **online data analysis** and interfaces results to ATLAS and the beam abort system. The **diamond sensors**, **detector modules** and their **readout system** are described. Results of **operation** with **1st LHC beams** are reported. Results of commissioning and **timing** measurements with **cosmic muons** in preparation **for 1st LHC collisions** are summarized.

Beam Conditions Measurements:

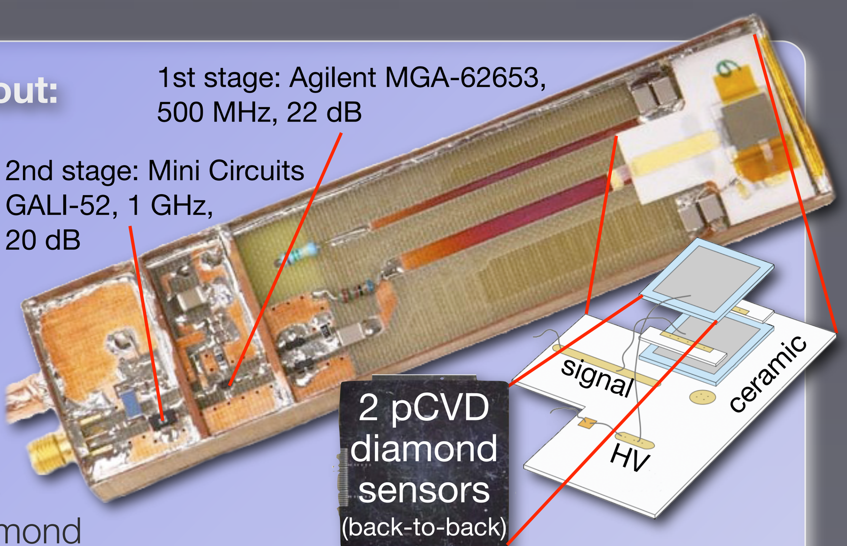
Experiences at Sp$\bar{p}$S, LEP, RHIC, HERA and Tevatron show that **beam incidents can lead to detector damage**. Instantaneous beam conditions measurement with the **ATLAS BCM** can **distinguish** for each bunch crossing: **normal collisions**, **beam gas**, **beam halo**, **pilot beam loss** (5 x 10^9 protons at 450 GeV) and **beam loss** (2808 x 1.15 x 10^{11} protons at 7 TeV).
Between **two detector stations** located at positions ±z along the beampipe the **Time Of Flight (TOF) is measured** in order to distinguish **background** from **collision events**. **Collision events** in the middle between the two stations result in **Δt = 0**, whereas **background** events outside the two stations result in Δt measurements of **±2z/c**. Since the **LHC revolution** time of 86 µs is **short compared** to the timescale of **magnet failures** (order of 1 ms) this distinction can be used to **generate alarm and abort signals**. Beams get aborted **before tracker detectors are harmed by high instantaneous radiation doses.**



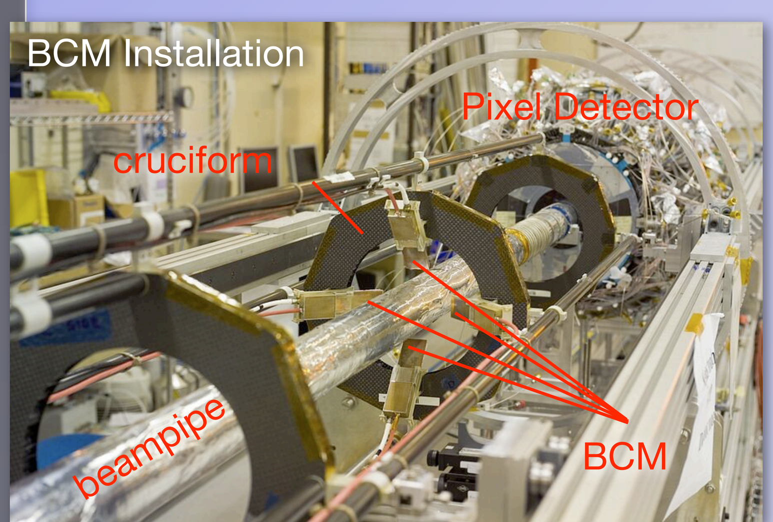
BCM detectors need to be **fast** with **signal rise times** of about 1 ns, **pulse widths** around 3 ns and **baseline restoration** times in the order of 10 ns. Close to the beampipe they have to withstand radiation doses up to **50 MRad** during the 10 years of expected operation.

PROPERTY	ADVANTAGE
high resistivity	large active area
low dielectr. const.	low capacitance
low leakage current	low noise
high mobility	fast signals
room temperature	no cooling
radiation hard	no replacement

Detectors & Readout:



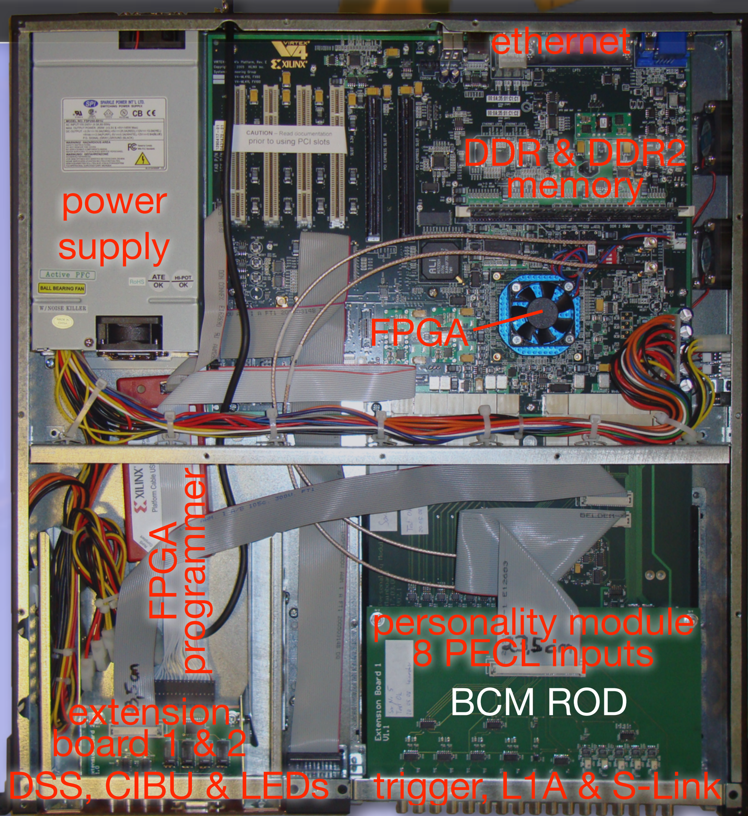
Each BCM detector contains **two pCVD diamond sensors** glued **back-to-back** to an alumina ceramic board. The **sensor material** was developed by the CERN RD42 Collaboration[2] and Diamond Detectors Ltd.[3]. Sensors of **1 x 1 cm²** and **500 µm** thickness have **Ti-Pt-Au 8 x 8 mm²** contacts on both sides. With **1 kV bias voltage** typical sensors have a **charge collection distance of 220 µm** and a **leakage current below 100 pA**.
The **double sensor** layout **doubles the charge signal** with a **noise increase of only 30%**. With respect to the beam axis the sensors are **mounted tilted at 45°**. With a most probable **MIP energy loss of 9.0 ke⁻** (mean: 11.3 ke⁻) **signal/noise ratios of ~10** are achieved.



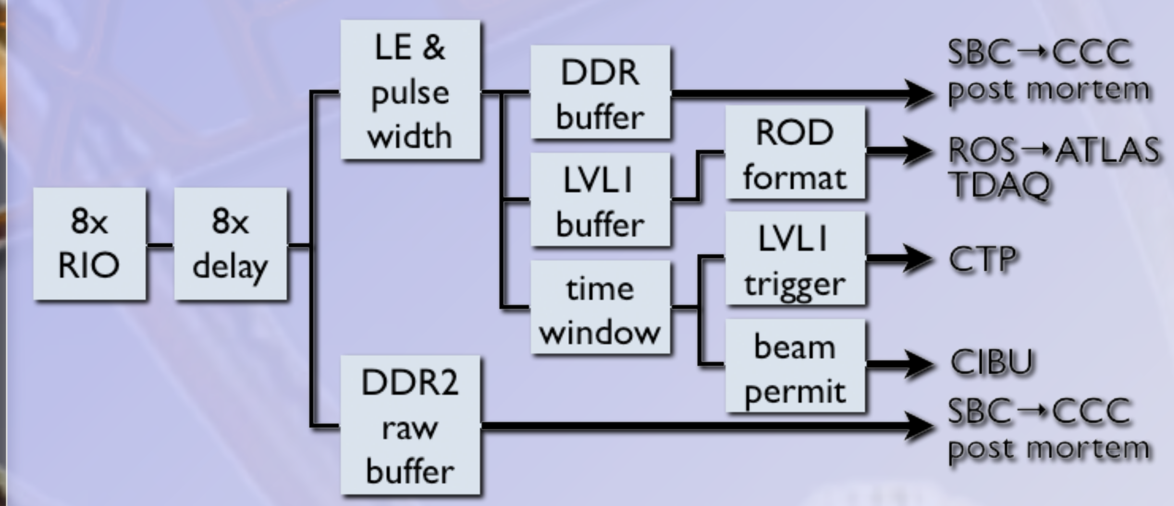
The copper plated module boxes also contain **two RF current amplifiers** (a 500 MHz low noise and a 2 GHz broadband microwave amplifier **with ~20 dB amplification each**) in separate shielded compartments. The **amplifier radiation hardness** was qualified with **reactor neutrons** and **protons** up to **fluences of 10^{15}/cm²**.
Four detector boxes are installed inside the ATLAS Pixel volume **at each detector side**. It results in sensor positions of **±1.84 m** from the interaction point at a radius of **5.5 cm**. ...

... The signals are routed via **14 m long coaxial cables** to **readout electronics outside the Hadronic Calorimeter**, where radiation tolerant readout electronics (10 Gy in 10 years expected) can be used.
The signal is split with a ratio of 1:11 to increase the dynamic range of the measurement. Both signals are **amplified** in a **NINO** [4] chip. **Discriminators with adjustable thresholds** in the NINO **digitize** the signals in order to **encode** the **charge** seen at the input to a **Time-Over-Threshold** (TOT) **length** of a LVDS digital pulse with **rise times** of about **1 ns** and **25 ps jitter**. **Radiation tolerant laser diodes** convert them into **optical signals**, transmitted via **70 m long optical fibers** to the off-detector electronics in the counting room.

Data Acquisition:

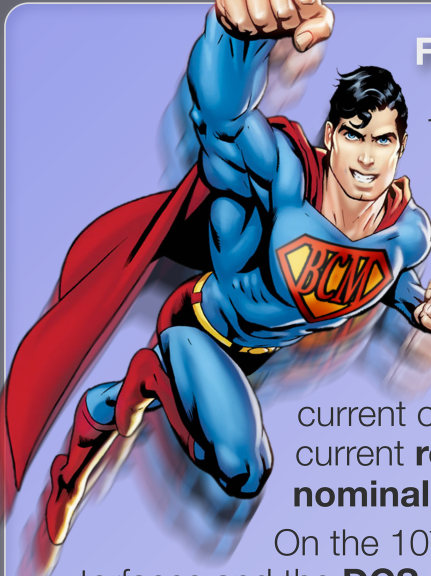


Optical signals are **converted to PECL electrical signals** on two 8 channel opto receiver boards. Read Out Drivers (**ROD**) with a Virtex-4 Field Programmable Gate Array (**FPGA**) **sample** the signals **with 2.56 GHz**, resulting in 64 samples of 390 ps length for each bunch crossing. The **ROD outputs the results of its signal processing** to the **ATLAS Central Trigger Processor** (CTP), **DAQ** (TDAQ), **Detector Control System** (DCS), **Detector Safety System** (DSS) and the **Controls Interlocks Beam User** (CIBU) system.
Input channels can be **delayed** in steps of 390 ps to compensate cable length differences. DDR2 memory is used as a **cyclic buffer** to store the **raw data of the last 1123 LHC revolutions**. **Pattern matching** is used for **edge detection** and a **binary search-tree** to find **rising and falling edges** and to calculate pulse widths. The **processed data** is stored in a DDR cyclic buffer **for the last 816 LHC revolutions**. Both cyclic buffers can be read out **in the case of a beam abort via ethernet to the LHC post mortem system.**

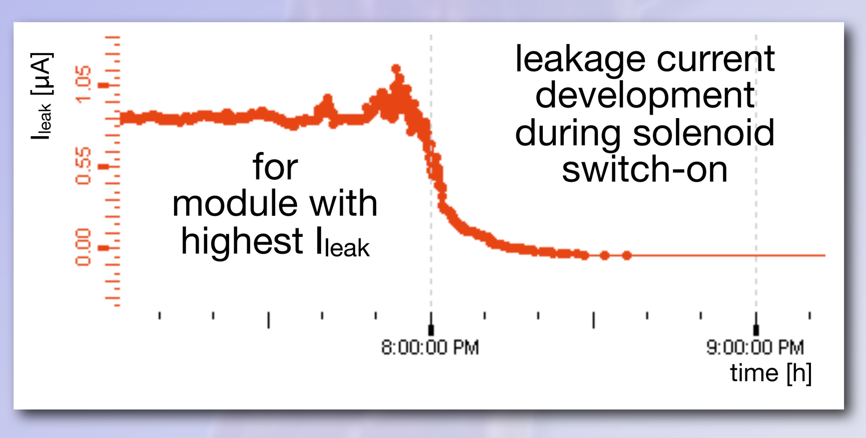


A **Level1 buffer** stores the **processed data together with a bunch crossing identifier**. Input **Trigger signals** are used to **select data** which are **fed via a optical gigabit link to the** Read Out Subsystem (**ROS**) and the subsequent standard **ATLAS DAQ readout chain**.
In a third data path the **leading edge and pulse width information** is analyzed by a time window module. **Configurable time windows** are used to **detect on-time (collision)** and **out-of-time (background)** hits. A Level1 trigger module searches for **coincidences**, e.g. between on- and out-of-time hits, and provides **9 trigger signals to the CTP**. They are used to trigger **minimum bias events**, trigger on **beam background** and **events with high multiplicity** or **with high amplitude hits**. A **beam permit module** searches for **coincidences between on- and out-of-time hits**, as well as for **high multiplicities in coincidence with high gain hits** in order **to trigger a LHC beam abort**. Beam warning and beam abort signals are provided to the DSS and injection permit and beam permit signals to the CIBU.
The 16 detector channels are **connected** to the optical receivers and RODs in the **most possible redundant way**. If one of the receivers or RODs stops working **still information from all eight detectors are available** (4 high gain and 4 low gain channels).

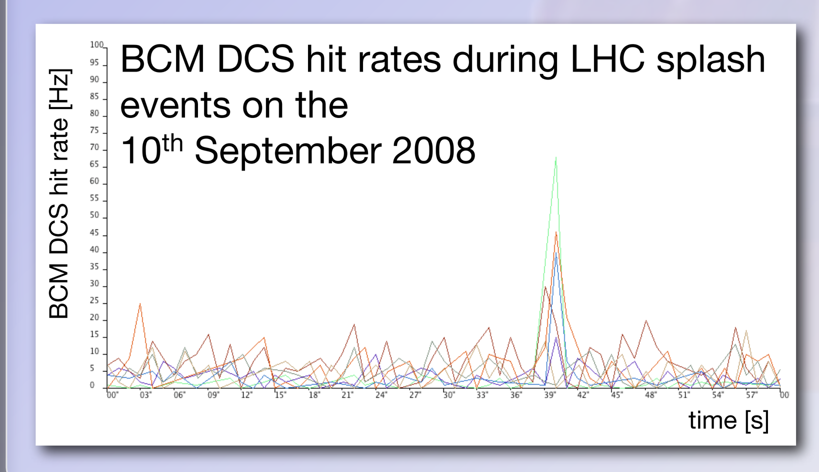
First LHC beams:



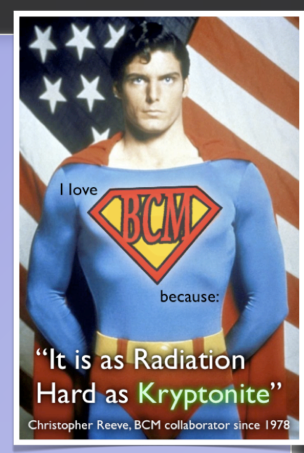
The BCM detectors are **operated since the beginning of Aug. 2008** with a nominal **bias voltage of 1000 V** when the ATLAS solenoid **magnet is on**. If the **magnet is off** the bias voltage is **reduced to 800 V** in order to **reduce** the effect of **erratic dark currents**.
For the detector with the highest leakage current of **0.8 µA without magnetic filed** the leakage current **reduces to 0.025 µA** with the solenoid at its **nominal magnetic field** of 2 T.
On the 10th of Sept. 2008 the **beam abort** and **DSS** interfaces and the **DCS readout** were **activated for the first LHC beams**. The BCM **DCS** measures **hit rates** with an **integration time** of **one second**.
Rates are transmitted via ethernet to a DCS PC and provided to the global ATLAS DCS.



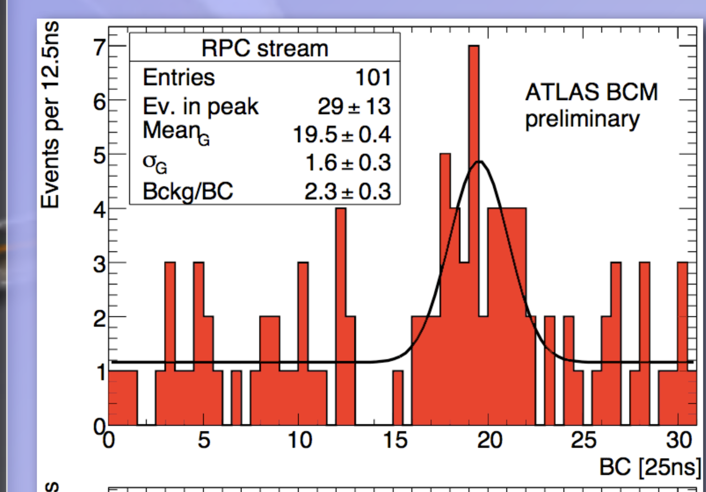
One of the beams was initially **directed at beam collimators** just outside ATLAS which **created a particle shower through the detector**.
For **five detectors peaks in the hit rates were observed** for splash events.

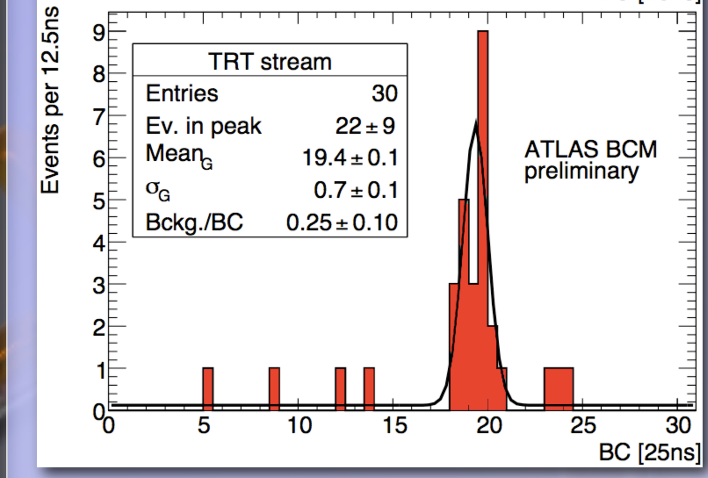


Commissioning with Cosmic Muons:

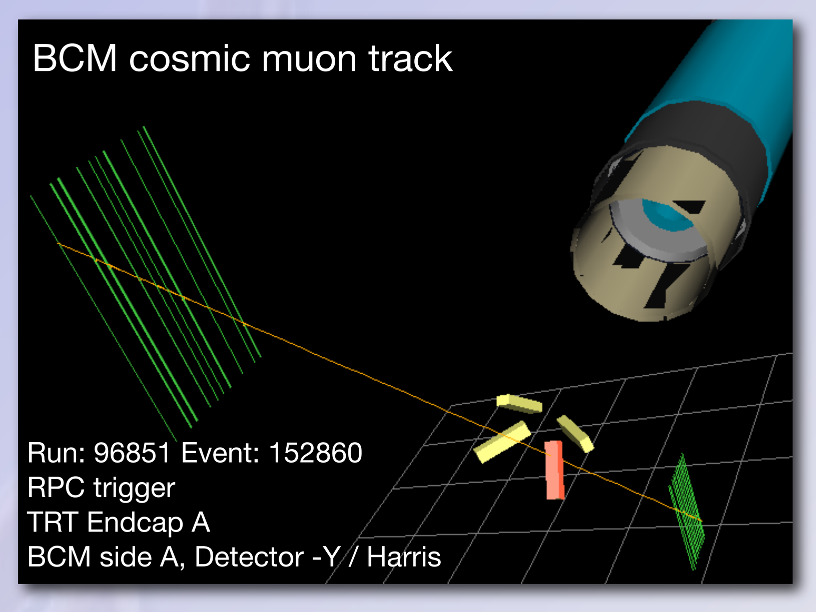


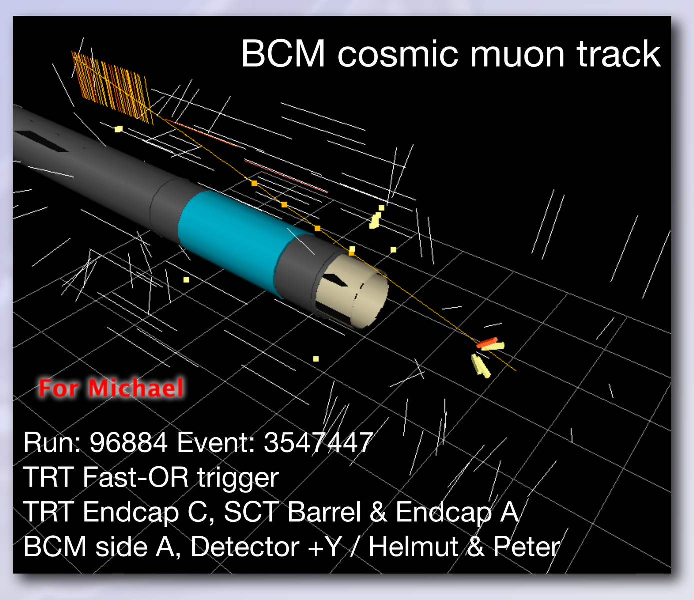
In the Nov. 2008 ATLAS Inner Detector combined **cosmic data taking period** 51 million events were recorded. **Two cosmic triggers** with a **total trigger rate of 150 Hz** were used. One trigger uses the **Resistive Plate Chamber (RPC)** muon detector and the other one the **Transition Radiation Tracker (TRT)**. In the BCM **online monitoring 25 events** with in total 81 hits were found and a sampling ratio of ~40% was measured for the used trigger frequency.





For each trigger from the CTP the BCM **reads out 31 consecutive bunch crossings** (LVL1As). Most hits showed up in LVL1A bin 19 **as expected from an initial timing calibration** on the basis of cable and fiber length measurements.
Analysis of the data shows for **both triggers in total 131 events** with a peak at LVL1A 19.5 (RPC) and 19.4 (TRT), respectively. The lower peak width of the TRT Fast-OR triggered hits can be explained by a **lower jitter of this trigger**. For the RPC triggered data stream all but one **high gain channels show at least one hit close to the expected LVL1A** bin.
Since no threshold tuning (only a **noise rate equalization**) was performed, the **track occupancies for the channels are different**. The higher track probability for the vertical modules (odd channel numbers) is due to the angular distribution of the cosmic muons. Known **unequal trigger efficiencies** between the two TRT endcaps contribute to the asymmetry observed between the A and C side in the TRT triggered data stream. Examples for **cosmic muon tracks through BCM detectors** are shown for each of the triggers with **hits in the TRT and SCT barrels and endcaps**.





Conclusions & Outlook:

Eight **pCVD diamond detector modules** are operated as **ATLAS BCM**. **TOT encoded charge information** is **sampled with 2.56 GHz** by a FPGA based ROD. **Beam abort and trigger signals** are generated by searching **in-time and out-of-time coincidences**. Post mortem **history** for about **1000 LHC revolutions** is provided and information is interfaced to ATLAS TDAQ, DCS and DSS. Increases of the hit rates were observed during the **LHC startup "beam-splash" events**. BCM **cosmic muon tracks** were found in the RPC and TRT triggered data streams. With higher statistics in future cosmic data taking periods the **timing configuration can be optimized** in preparation **for the first LHC collisions**. Even with limited statistics it can serve as a **high precision time reference** for TRT and SCT.

References:

[1] **The ATLAS Beam Conditions Monitor**, *ATLAS BCM Collaboration*, 2008 JINST 3 P02004.
[2] CERN RD42 collaboration: "CVD Diamond Radiation Detector Development". - **RD42 Status Report: Development of Diamond Tracking Detectors for High Luminosity Experiments at the LHC**, *RD42 Collaboration*, LHCC-RD-016, CERN-LHCC-2008-005.
[3] Element Six Ltd., King's Ride Park, Ascot, Berkshire SL5 9BP UK.
[4] **NINO: an ultra-fast and low–power front–end amplifier and discriminator ASIC for the multi-gap resistive plate chambers**, F. Anghinolfi et al., Nucl. Instr. Methods A, 533:183–187, 2004.
[5] **Development of Beam Conditions Monitor for the ATLAS Experiment**, Irena Dolenc, Doctoral Thesis, University of Ljubljana, 2008.

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www.cern.ch/bcm