RD09 – 9th International Conference on Large Scale Applications and Radiation Hardness of Semiconductor Detectors

The ATLAS Beam Conditions and Beam Loss Monitors

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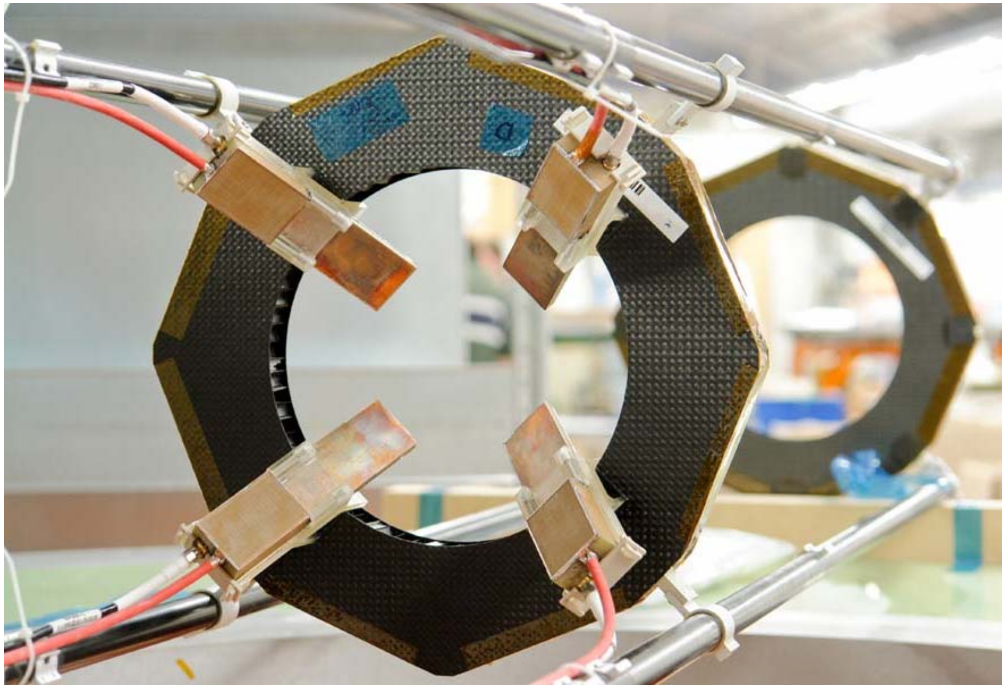


30 September - 2 October 2009, Florence, Italy

The ATLAS BCM collaboration members

- ***CERN***
  - D. Dobos, J .Hartert, H. Pernegger, E. Stanecka, P. Weilhammer
- ***JSI, Ljubljana***
  - V. Cindro, I. Dolenc, A. Gorišek, G.Kramberger, B. Maček, I. Mandić, E. Margan, M. Zavrtanik, M. Mikuž
- ***OSU, Columbus***
  - H. Kagan, J. Moss, S. Smith
- ***Univ. of Applied Science, Wiener Neustadt***
  - E. Griesmayer, H. Frais-Kölbl, M. Niegl†
- ***Univ. Toronto***
  - M. Cadabeschi, E. Jankowski, D. Tardif, W. Trischuk

BCM web page: *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)

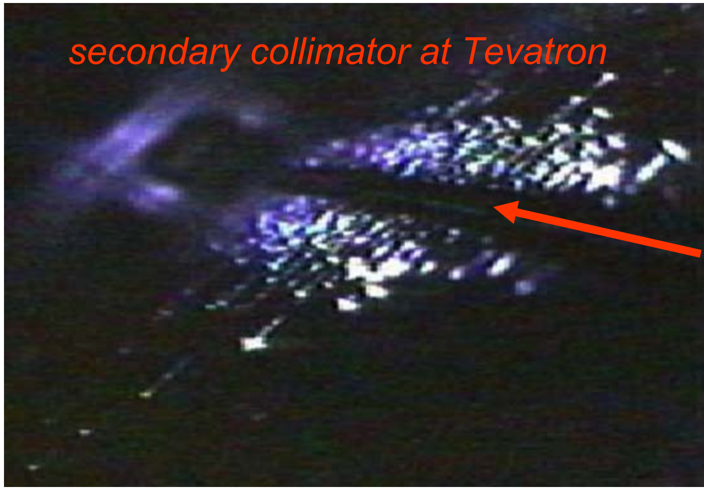
Motivation

❖ 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

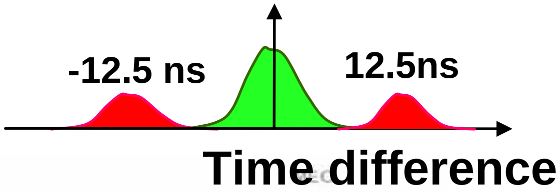
Protection from beam accidents

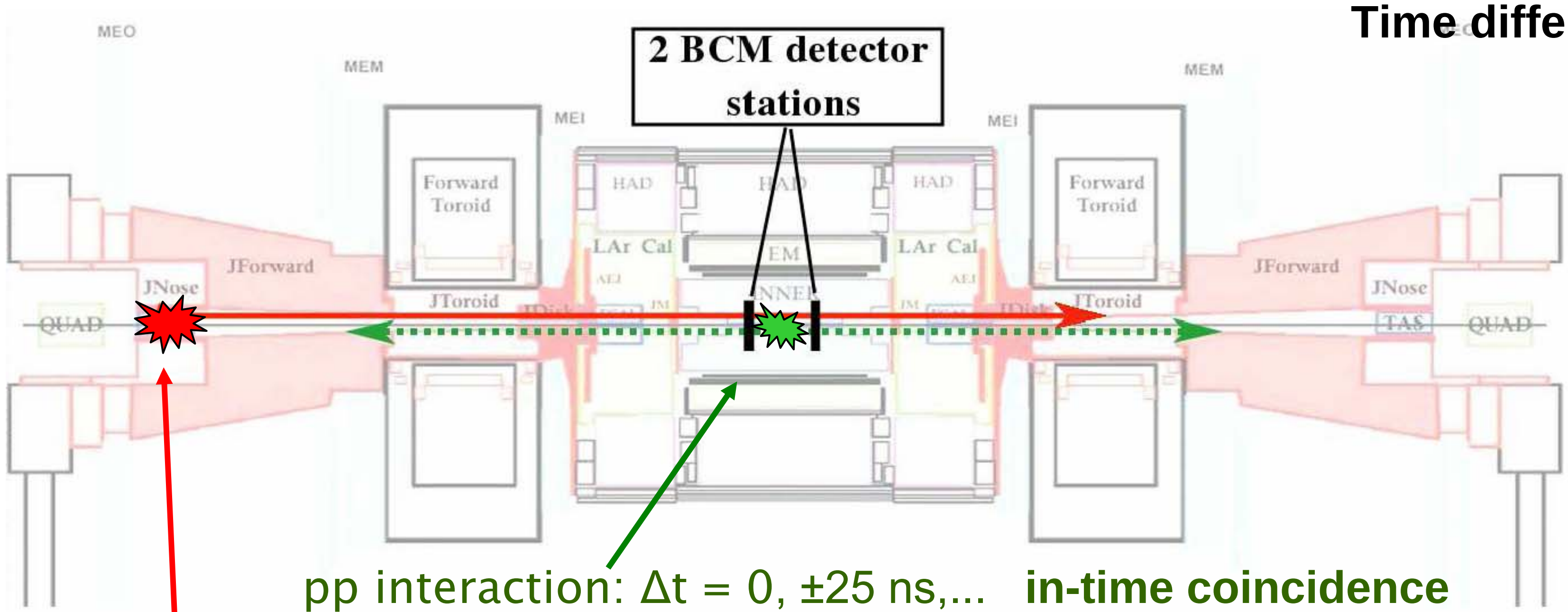
- ATLAS and CMS have Target Absorber Secondaries collimator (TAS) @ Z=±18 m for **passive protection**:
  - protects inner triplet magnets from secondaries produced in *pp* collisions
  - protect Inner Detector from beam failures

- **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 → optical loop interrupted → *BeamPermit* drops
    - beam dumped within 3 turns ~ 270 μs
  - 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)



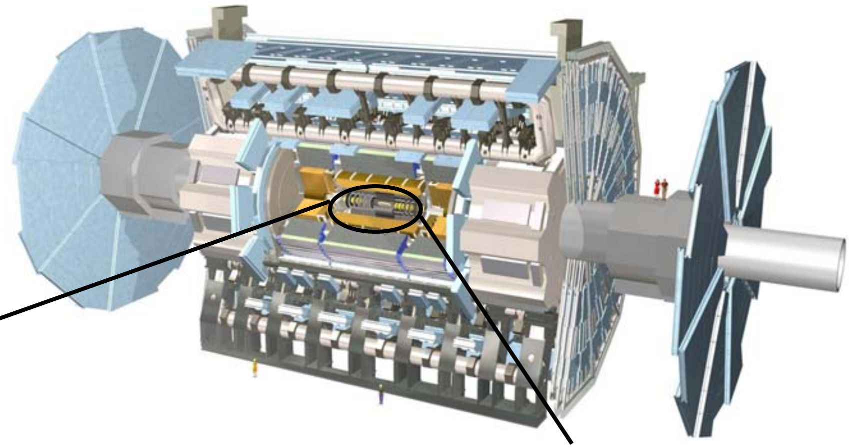


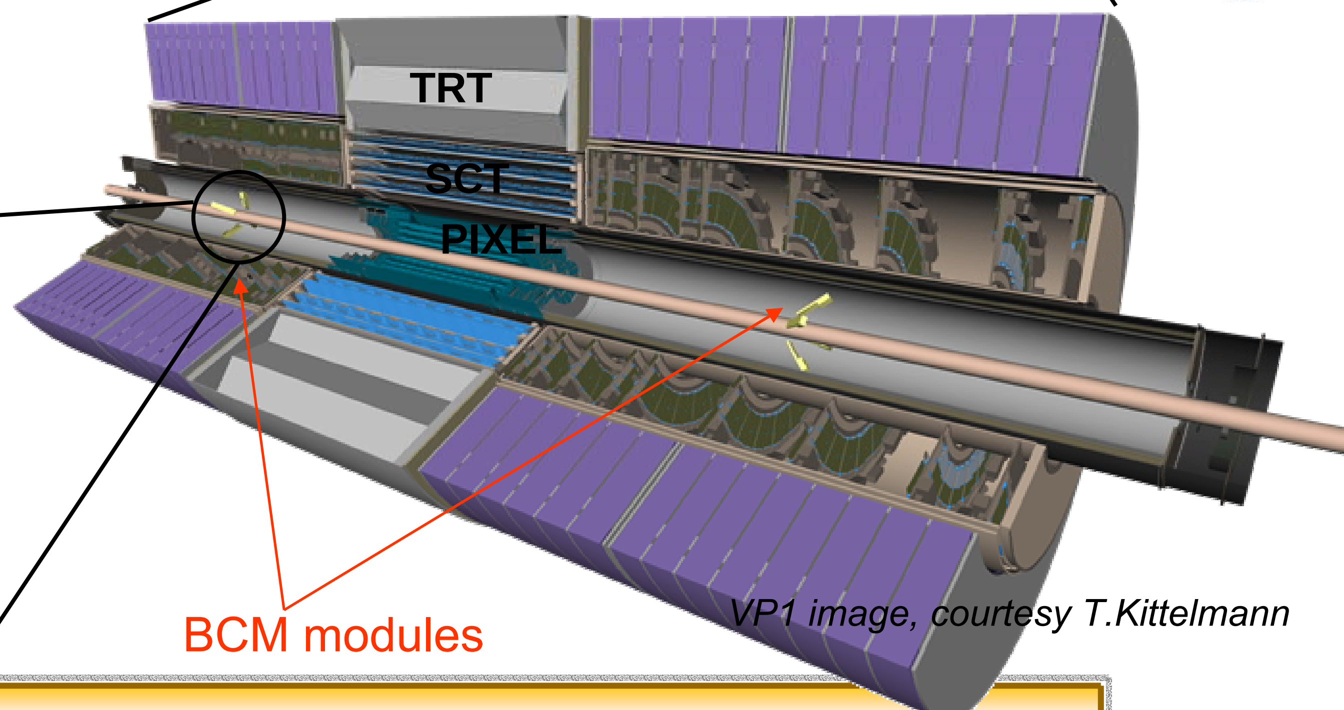
pp interaction: Δt = 0, ±25 ns,... **in-time coincidence**

TAS (collimator) event: Δt=2z/c=±12.5 ns, ... – **out-of-time coincidence**

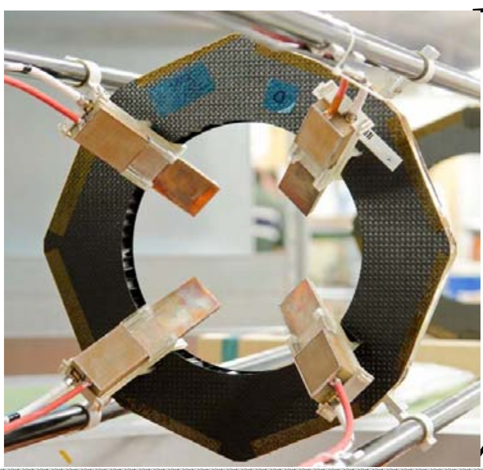
Realization

- 4 detector modules on each side of the detector (within PIXEL volume)
- mounted on PIXEL support structure
  - modules at $z=\pm 183.8$ cm
  - $r=5.5$ cm ($\eta \approx 4.2$)
  - 45° angle with respect to the beam pipe



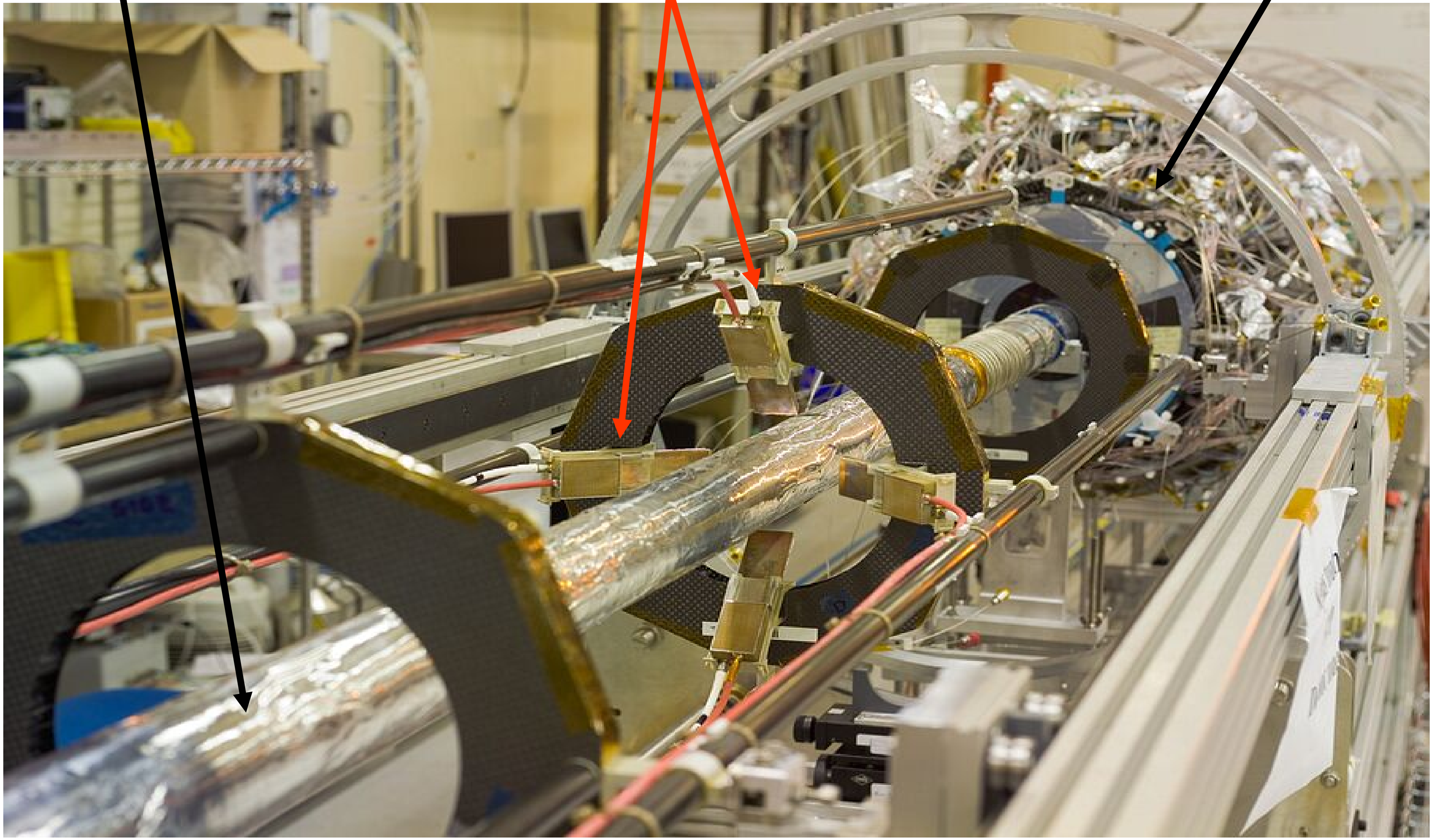


VP1 image, courtesy T.Kittelmann



Installation

beam pipe **BCM modules** **PIXEL**



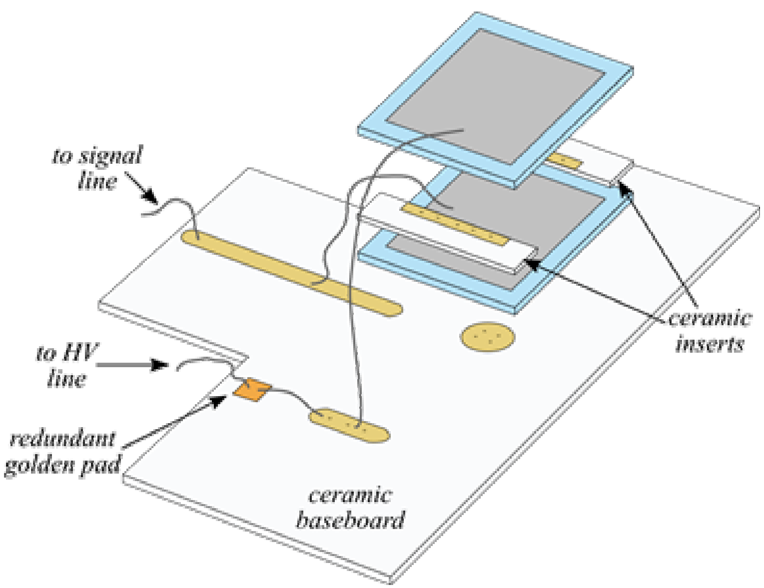
BCM diamond sensor

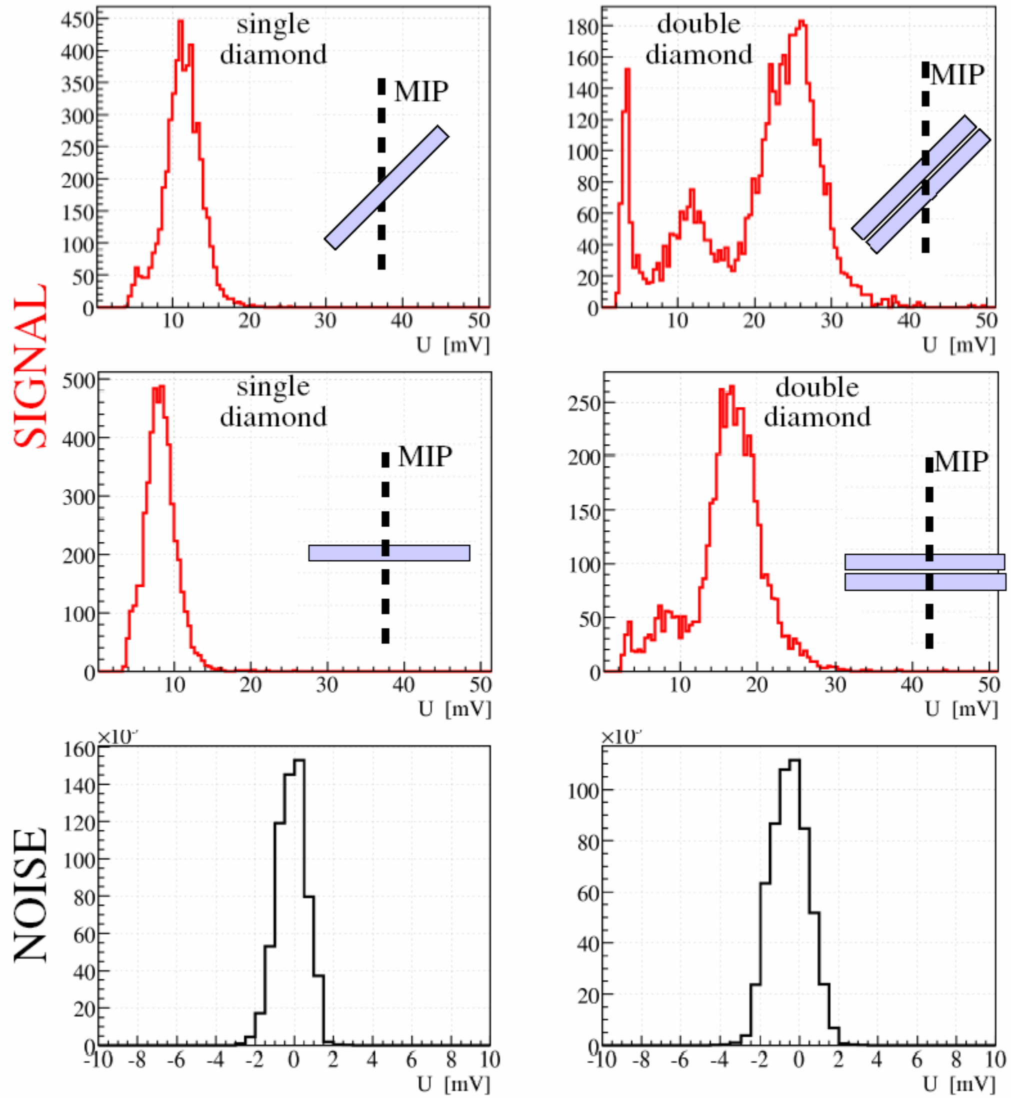
- requirements
  - bunch-by-bunch measurement
    - fast signal (1ns)
    - narrow width (2 ns)
    - fast baseline restoration (10 ns)
  - radiation hard
    - close to interaction point & beam pipe
    - estimated to 0.5 MGy & 10^{15} pions/cm^2 in 10 years

- 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 >200μm

Signal optimization

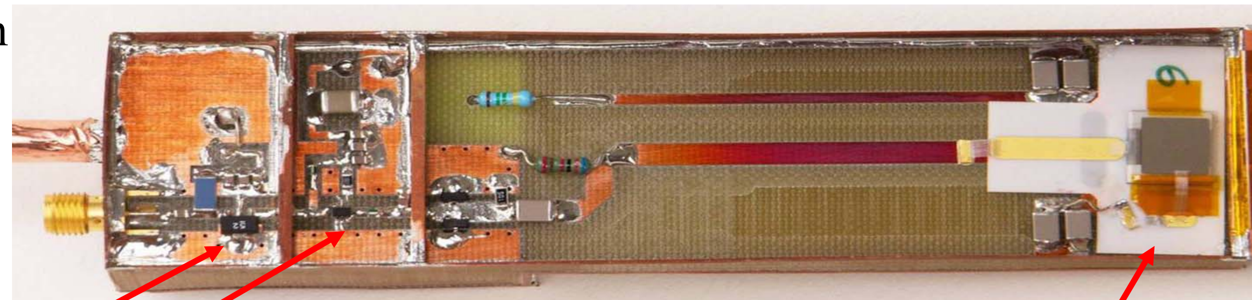
- ❖ diamonds 10×10 mm & 500μm thick
- ❖ two diamonds per module
  - double the signal
  - only 30% more noise
- ❖ diamonds at 45° w.r.t. the beam pipe
  - $\sqrt{2}$ of the signal





BCM module

- two stage amplification

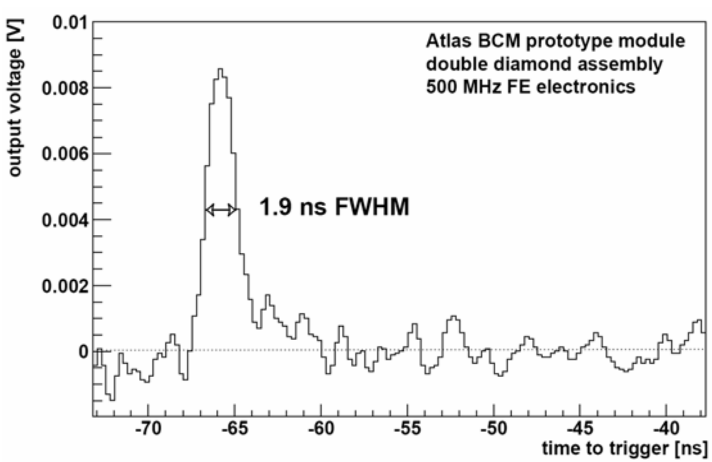


1st st stage: *Agilent MGA62653, 500MHz (22db)*

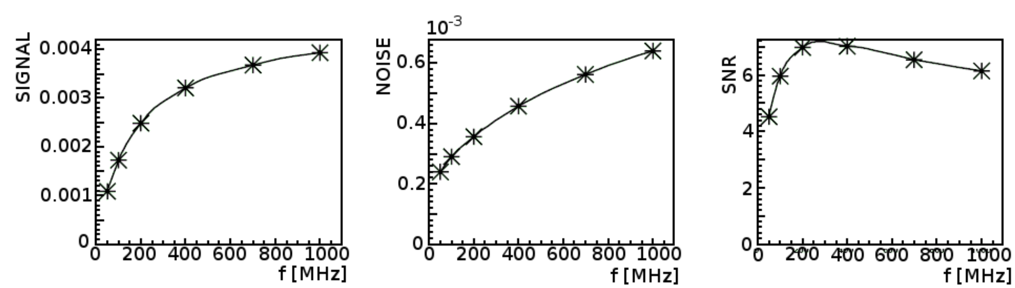
2st st stage: *Mini Circuit GALI52,1GHz (20dB)*

diamond configuration

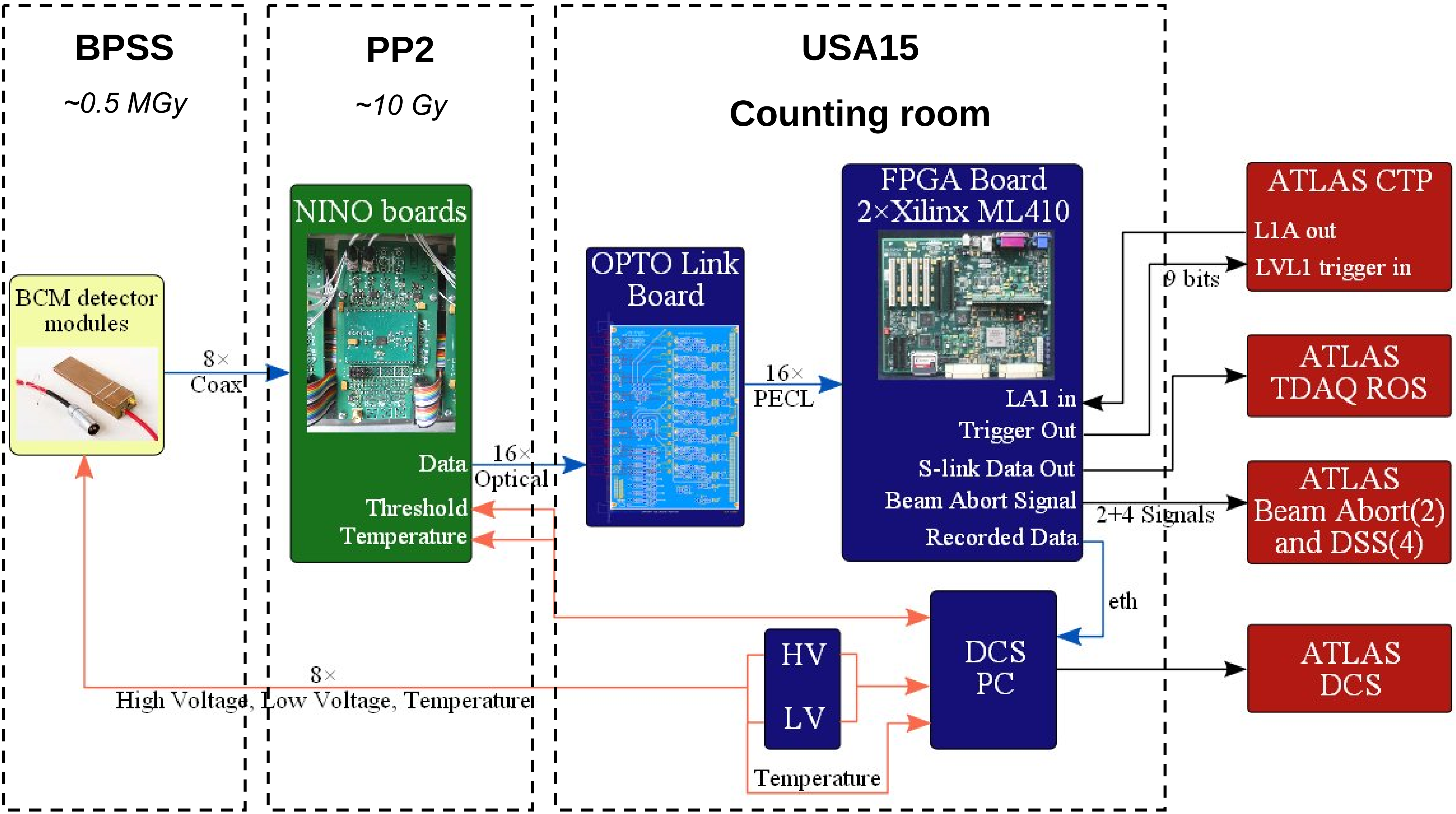
- typical signal before band-width filter



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



BCM connectivity



Cosmic run

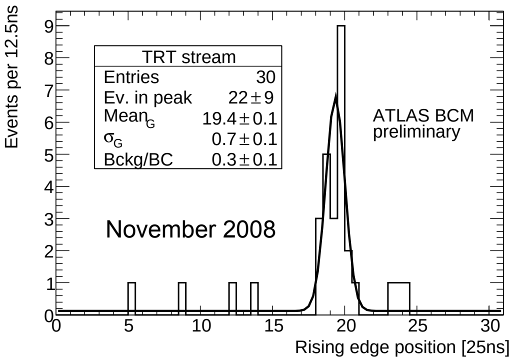
- BCM data recorded in two ATLAS cosmic runs
  - November 2008:
    - Transition Radiation Tracker (TRT) stream ~2.5 M triggers
    - Resistive Plate Chamber (RPC) stream ~34 M triggers

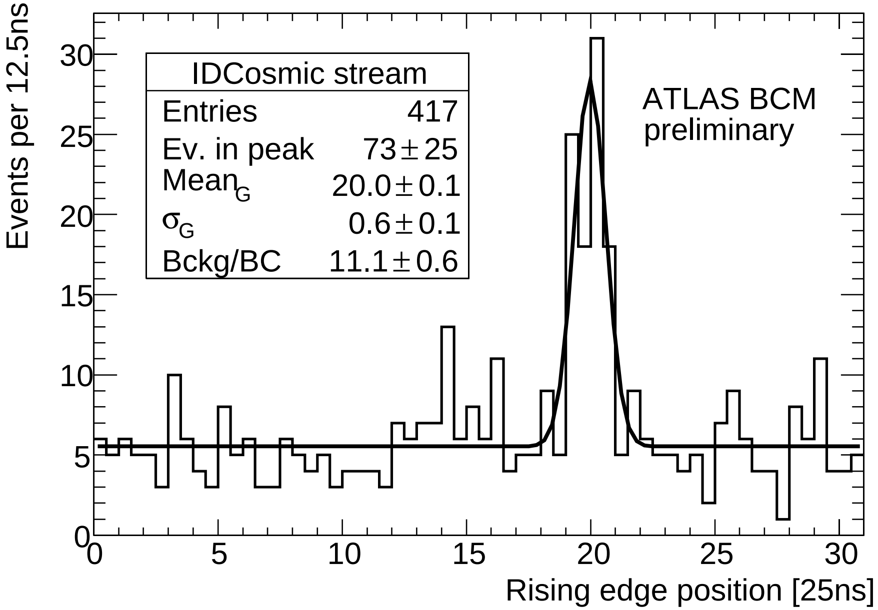
    131 events with BCM info
  - June 2009:
    - RND stream (~2.6 M triggers)
    - IDCosmic stream (~34 M triggers)

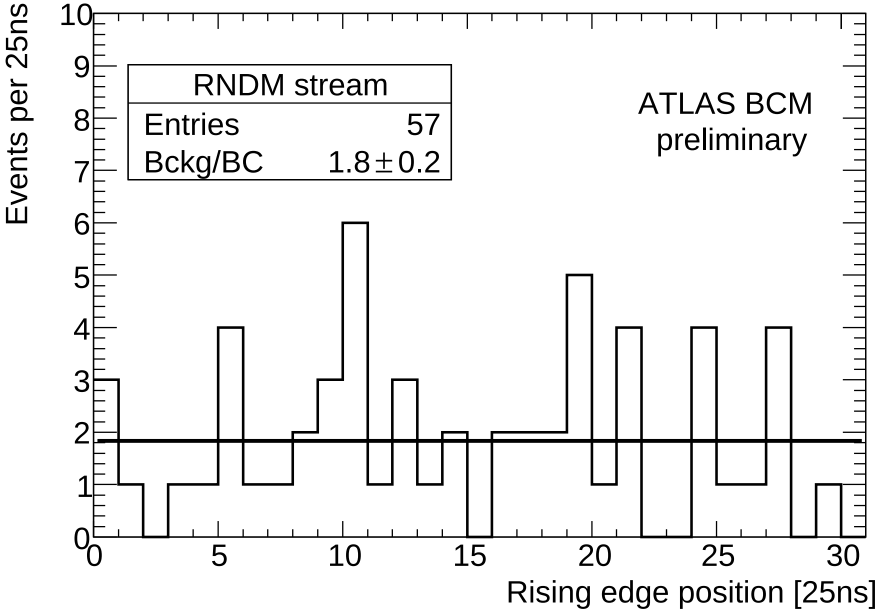
    474 events with BCM info
  - different threshold settings
  - for each trigger 32 consecutive BCs were read-out
    - 18 BCs before trigger
    - 13 BCs after trigger

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







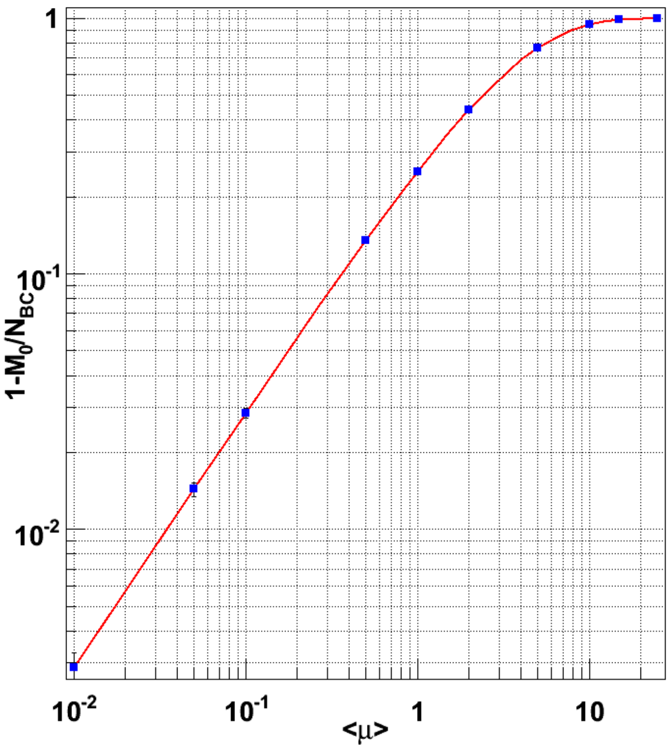
Luminosity monitoring

- 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

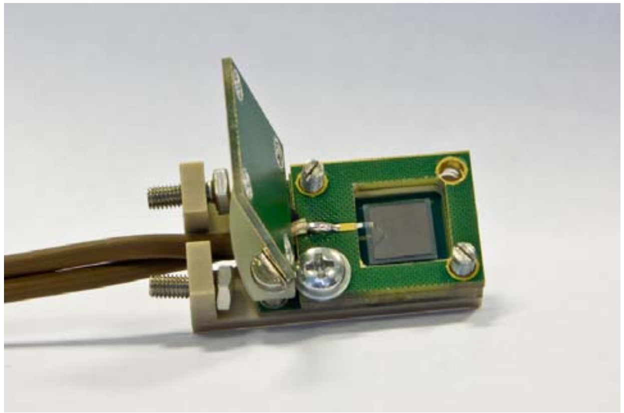
- Monte-Carlo simulations under-way to provide initial calibration used before first beam-separation scans, and understanding systematic

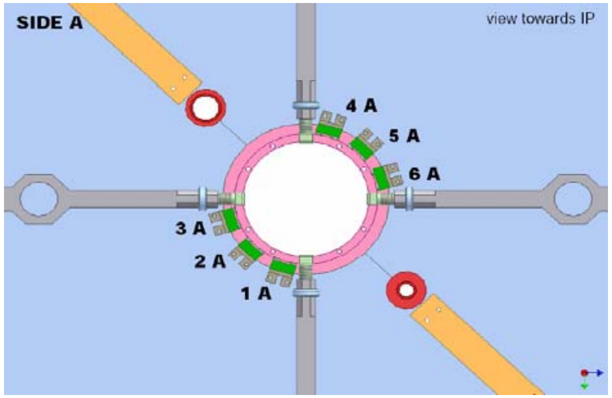
non-empty event probability simulation



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 45º 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

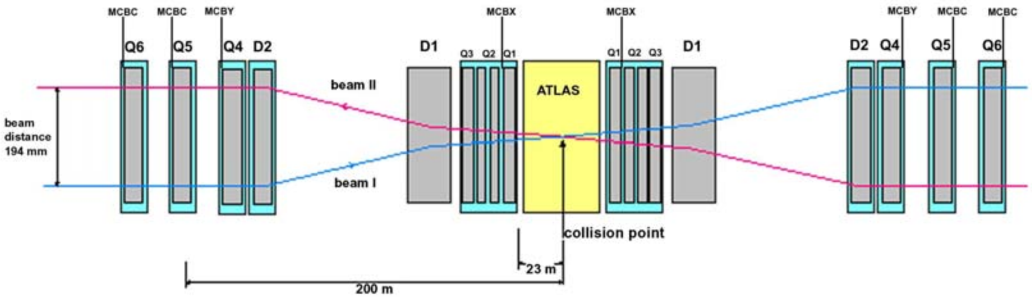
Backup slides

Beam-loss scenarios

More types of beam losses:

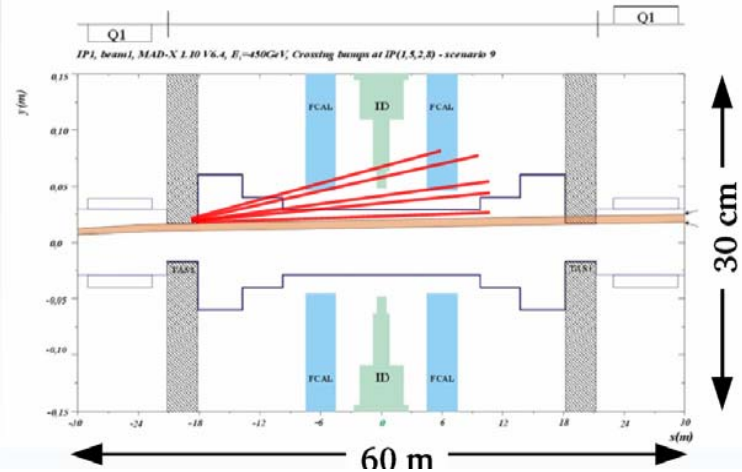
❖ **multi turn losses *(intervention)***

- beam degradation (equipment failure, wrong magnet settings, ...)



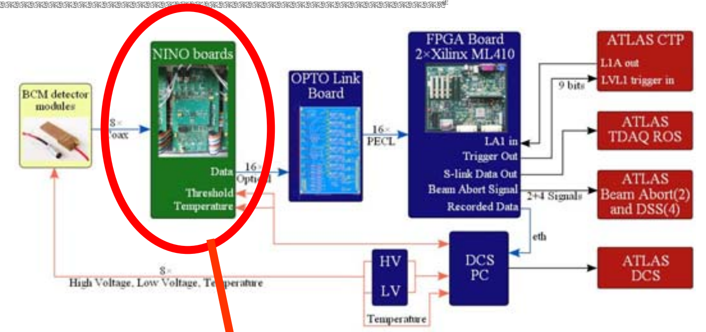
❖ **single turn losses *(diagnostics)***

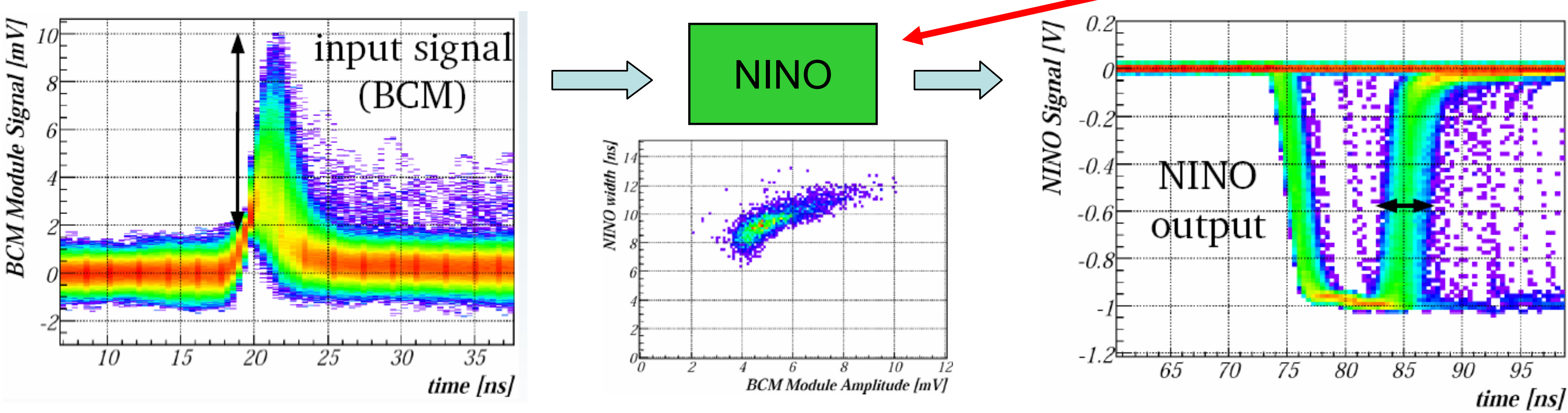
- likely during injection due to wrong magnet settings
- IR1 (ATLAS) furthest from injection
- pilot bunch will be used to test the magnet settings (5×10^9 p @ 450GeV)
- simulation of beam orbits with wrong magnet setting (D. Bocian) exhibit scenarios with pilot beam scrapping TAS collimator



Signal processing - *NINO*

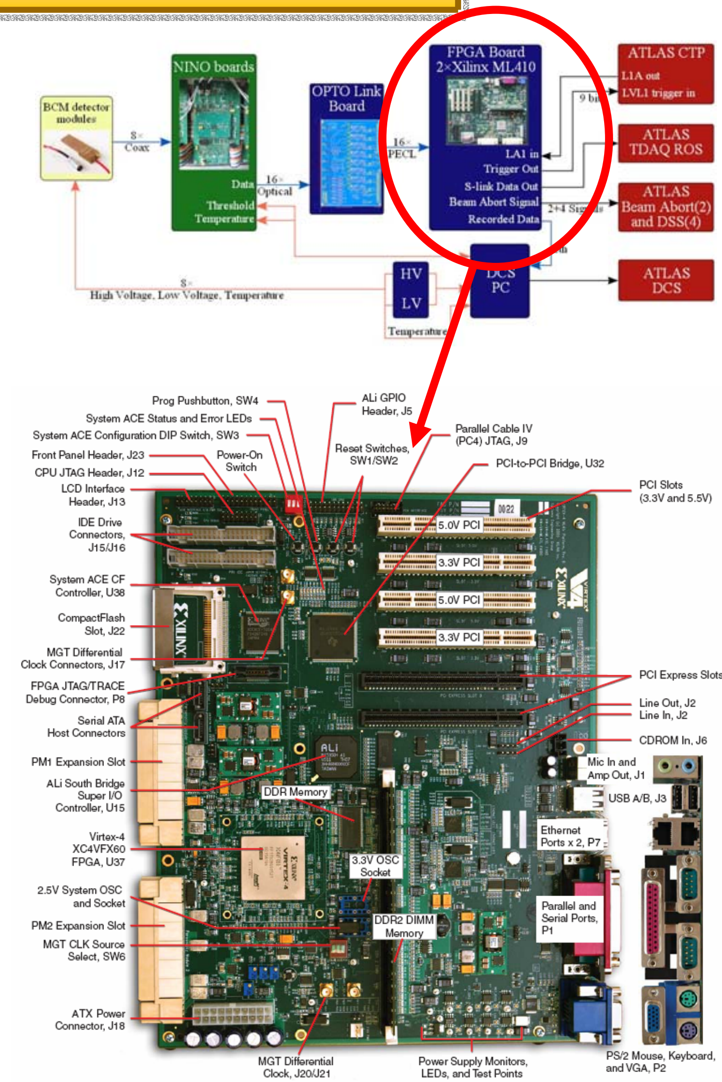
- developed for ALICE ToF (F. Anghinolfi et al.)
- radiation tolerant
- fabricated in 0.25 µm IBM process
- peaking time< 1 ns, jitter <25 ps
- time-over-threshold amplifier discriminator chip
- width of LVDS output signal depends on input charge
- rad-tolerant laser diodes transmit fibers to USA15 counting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



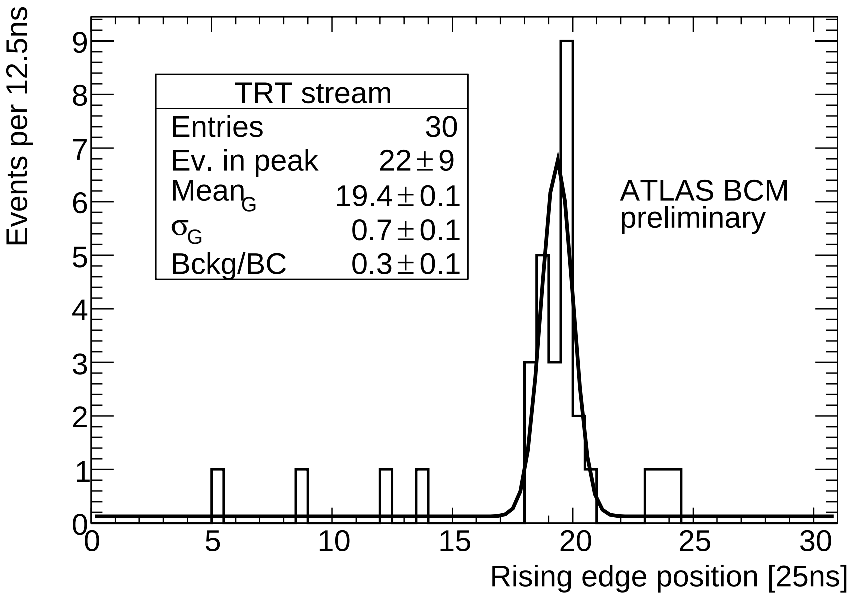


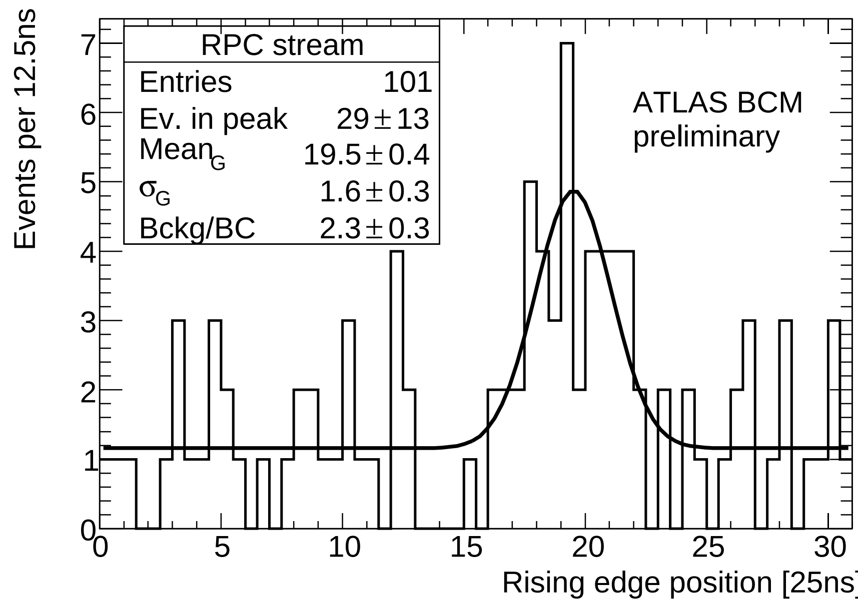
Signal processing - *ROD*

- 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 lever due to different trigger & threshold settings
- timing remains the same
- TRT stream exhibits approx. same distribution width as IDCosmic stream of 2009
- RPC stream distribution broader because of RPC geometry

Channel occupancy November 2008

- 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