The ATLAS Beam Condition Monitor Commissioning

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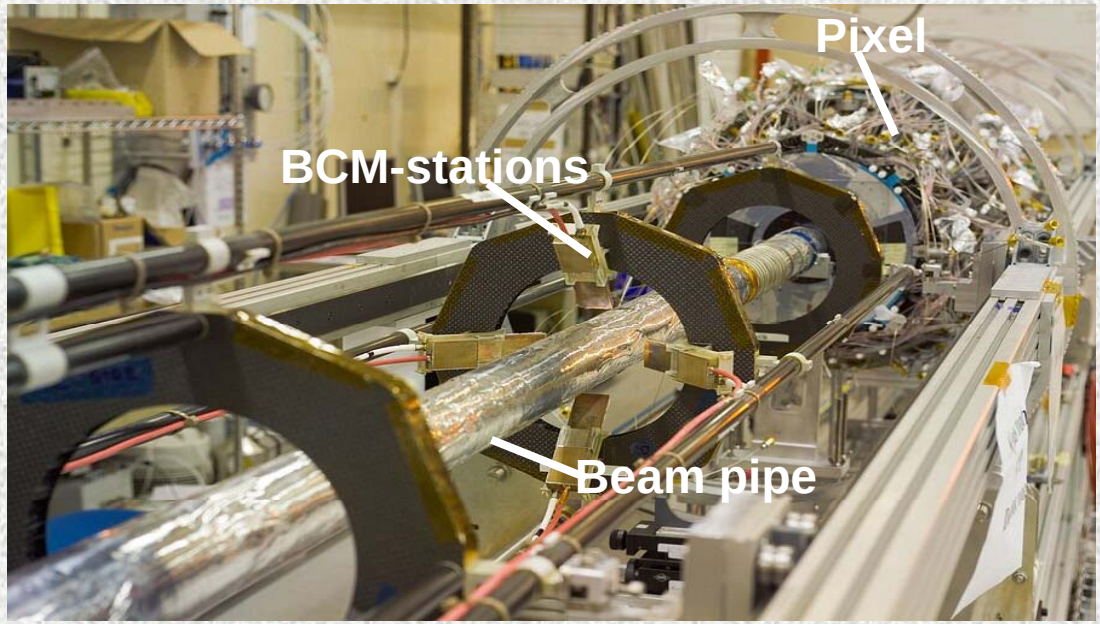
TWEPP

Naxos, Greece
15-19 September 2008



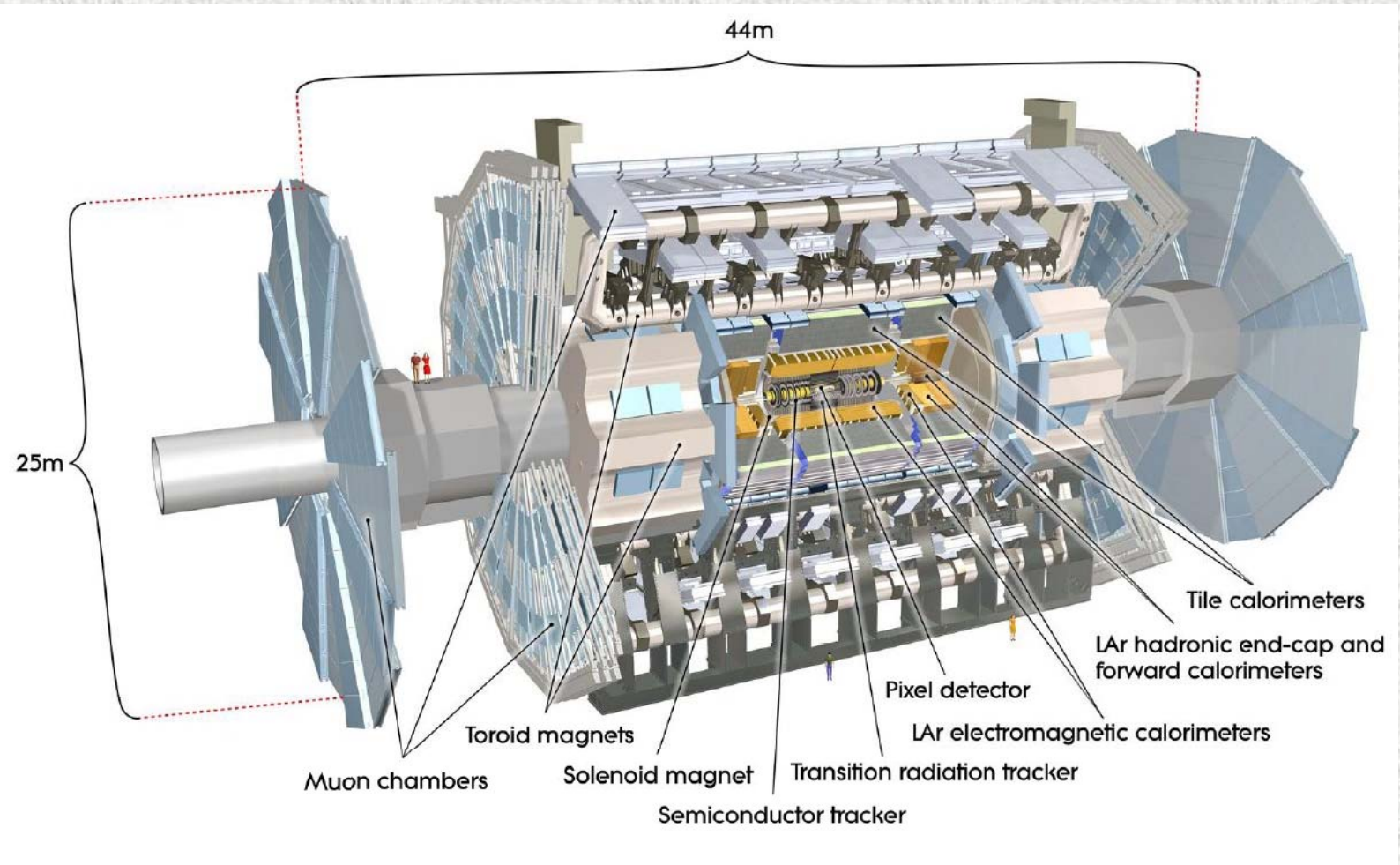
The ATLAS BCM collaboration

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

All you ever wanted to know about BCM:
https://twiki.cern.ch/twiki/bin/view/Atlas/BcmWiki

The ATLAS Spectrometer

A Toroidal **L**hc **A**pparatu**S**



The Inner Detector (ID):

- closest to the interaction
- efficient tracking of charged particles in a homogeneous axial magnetic field of 2 T
- vertex reconstruction
- electron identification capabilities in Transition Radiation Tracker (TRT)
- consists of: Pixel Detector, SemiConductor Tracker (SCT) and TRT

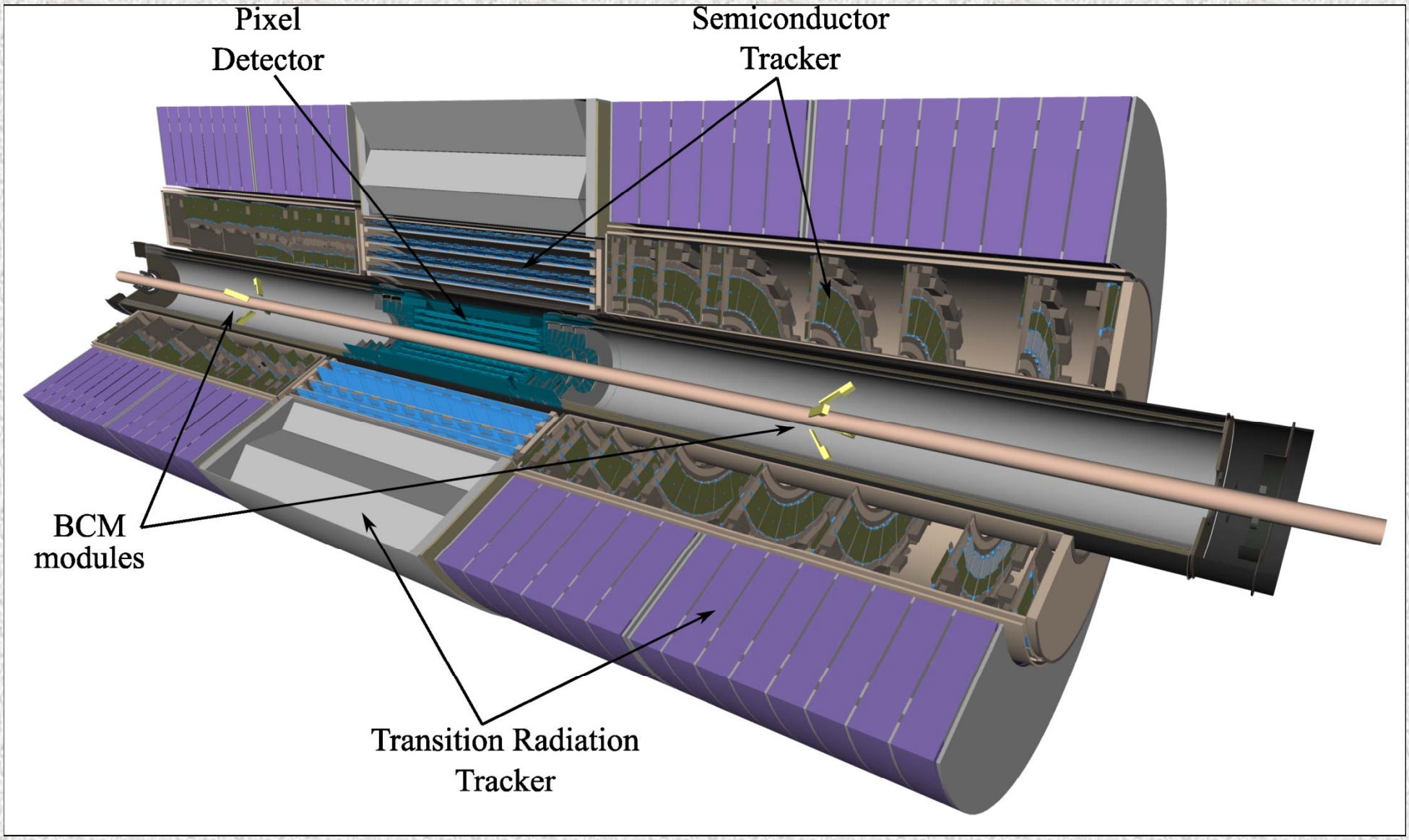
Calorimeter system:

- stop and measure energy of particles and distinguish between photons, electrons and hadronic jets
- consists of: an electromagnetic (EM) calorimeter in the inner part, hadronic barrel calorimeter (Tile Calorimeter), hadronic end cap (HEC) and forward calorimeters (FCAL).

Muon Spectrometer:

- independent tracking and momentum measurement of muons over large area
- high p_T muon trigger
- strong toroidal magnetic field of up to 4 T, generated by super-conducting air-core toroids,

ATLAS Inner Detector



Beam Accidents - Protection

- ATLAS is furthest from injection – safest (?)
- Passive protection:
  - ATLAS and CMS have Target Absorber Secondaries (TAS) collimators @ z=±18m: protecting inner triplet of quadrupols from secondaries produced in p-p collisions and Inner Detector from beam failures
- Active protection:
  - Beam Interlock System (BIS): two redundant optical loops transporting **`BeamPermit`** signals – a logical AND of **`UserPermit`** signals provided by user systems (machine beam loss or beam position monitors, experiment BCMs, etc.)
  - Beam Condition Monitors (BCMs): contribute **`UserPermit`** signals to the BIS
  - If **`UserPermit`** is set to **`False`** optical loop is interupted ⇒ **`BeamPermit`** removed, beam dump procedure initiated (beam is dumped within 3 turns ~270 μs) + no injection from SPS

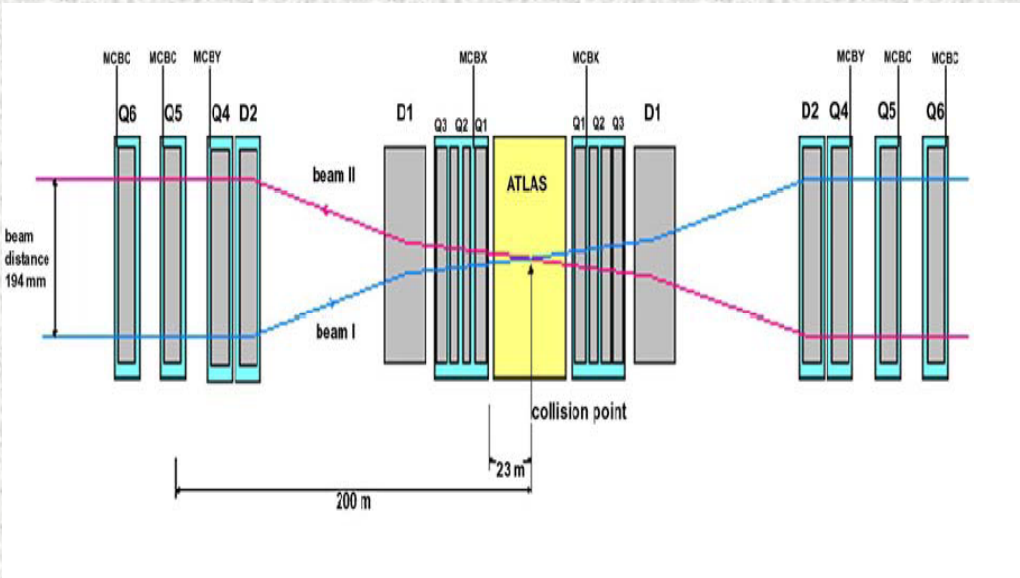
Beam Accidents

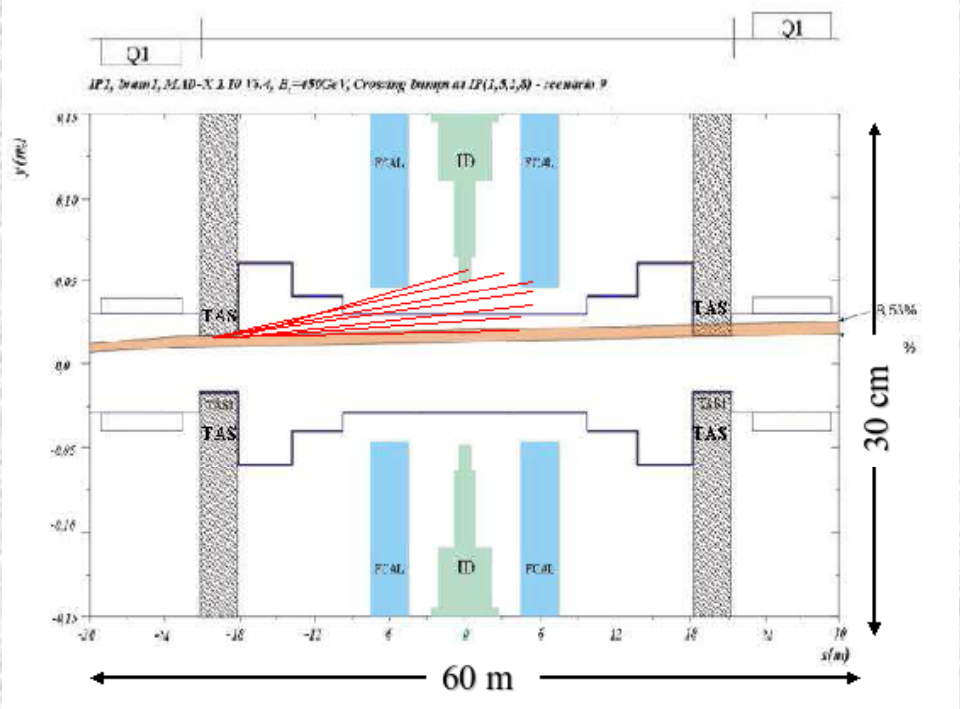
- Most likely due to wrong magnet settings:
  ~8000 magnets powered by ~1700 different electronic circuits
- Single turn losses
  - @ injection from SPS
  - 450GeV + pilot bunch only (5 10^9 protons) – no danger to detectors
  - BCM will diagnose the loses and eventually prevent further false injections
- Multi-turn losses
  - RF, magnet or collimator failure
  - TAS limits the damage to the innermost spectrometer
  - different time scales ranging from few turns (100's of μs) to seconds
    the most rapid due to warm dipole magnet (D1) failure closest to ATLAS interaction point τ = ~5 turns

⇒ BCM has **~2 turns** (~150 μs) to act

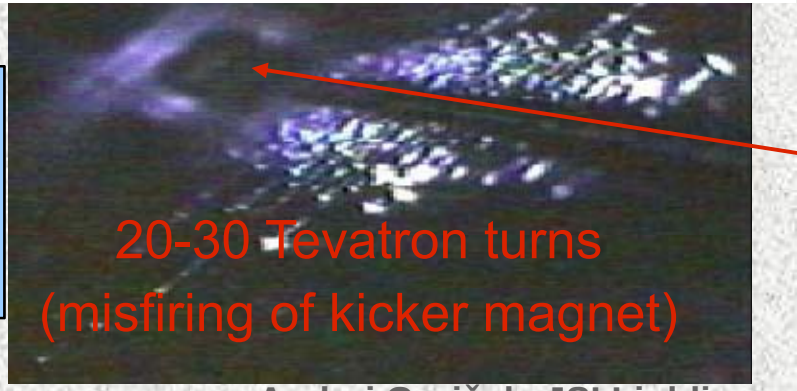
Simulation + past experience

Simulations of beam orbits with wrong magnet settings (D. Bocian) exhibit scenarios with beam scrapping TAS collimators



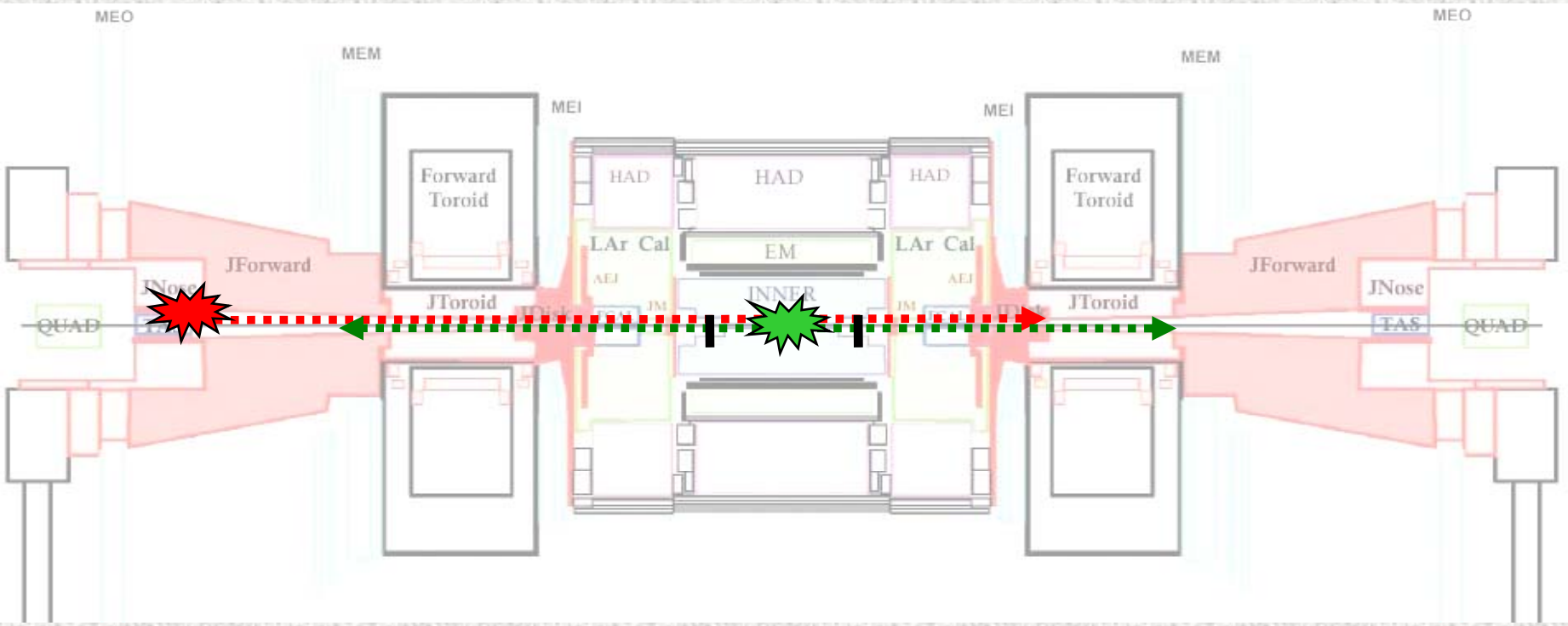


LHC will circulate 2808 bunches per colliding beam, each bunch consisting of 1.1×10^{11} protons at energy of 7 TeV – about 200-times more energy stored in beams compared to maximum value in previous accelerators like HERA or Tevatron.

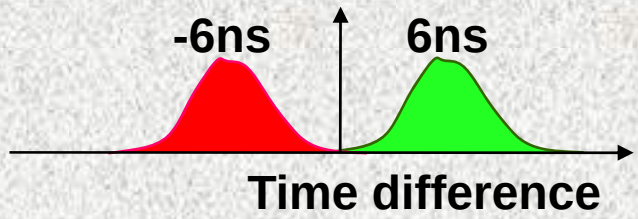


BCM background vs. Interaction Events

Measurement every proton bunch crossing (every 25ns)
Distinguish between interactions and background (scraping of collimators, beam gas,...)
→ ***requirement: better than 12.5 ns width+baseline restoration***



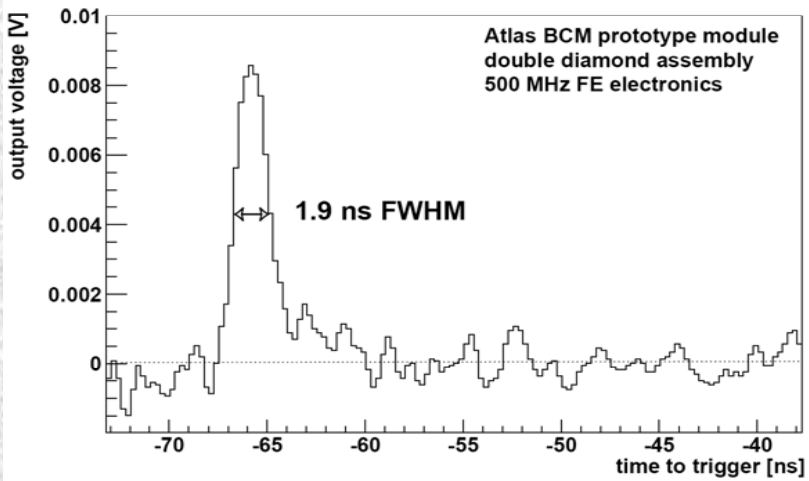
❙ ❙ 2 detector stations, symmetric in z
TAS (collimator) event: Δt=2z/c=12.5ns (ideally)
Interaction: Δt = 0, 25, … ns

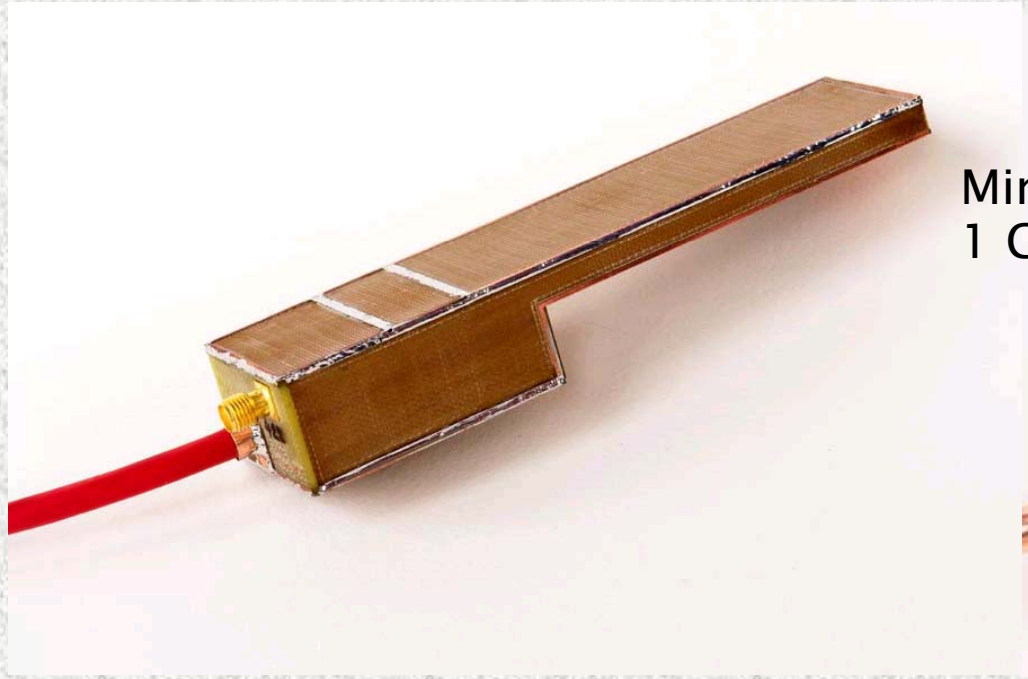


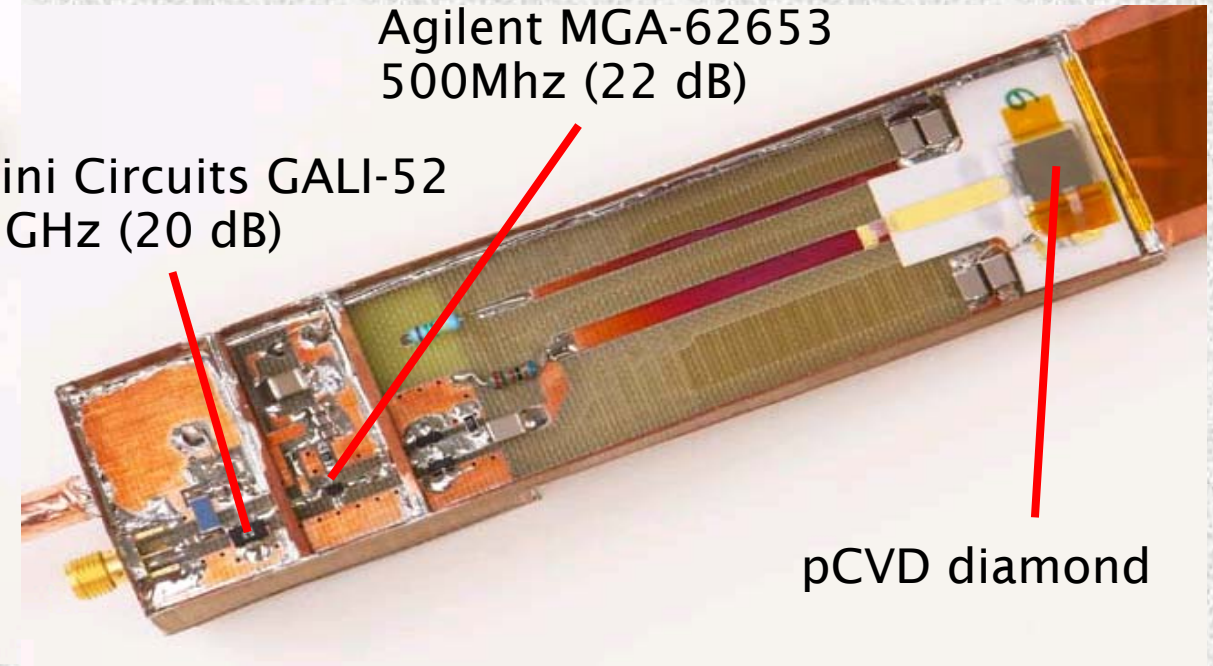
Detector module

- pCVD diamond sensors (*10x10 mm²*, contact 8x8mm², 500μm thick)
  - Shown to withstand > 10^{15} p/cm²
- Fast & short signal (FWHM~2ns, rise time<1ns)
  - Large charge carrier drift velocity (10^7 cm/s) (operates with high drift field - 2 V/ μm)
  - Short charge lifetime (trapping)
- Very Low leakage current after irradiation
  - Does not require detector cooling

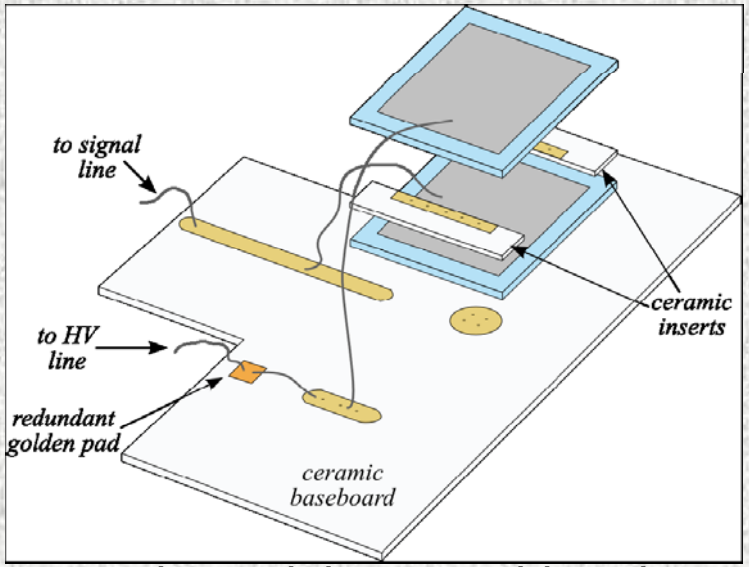
typical event





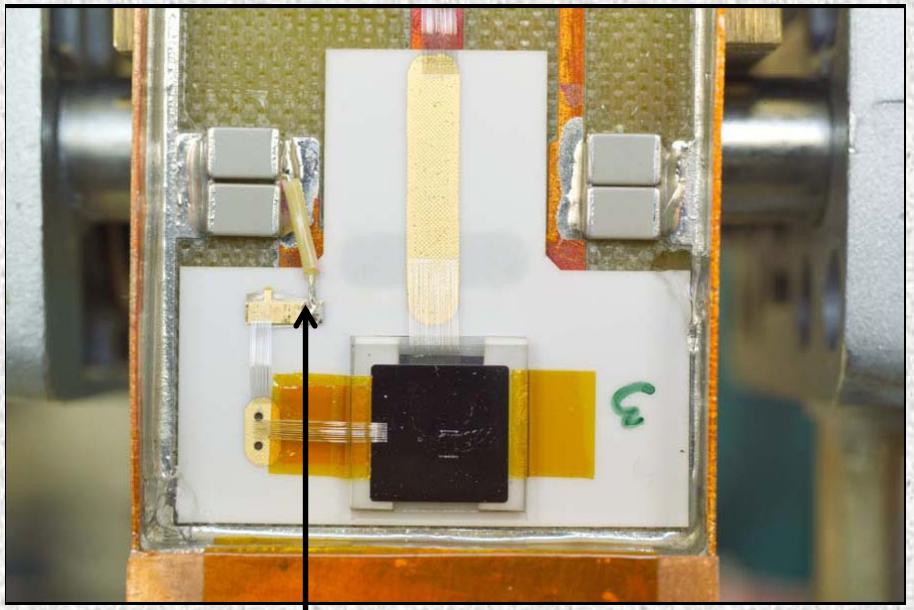


Detector module assembly

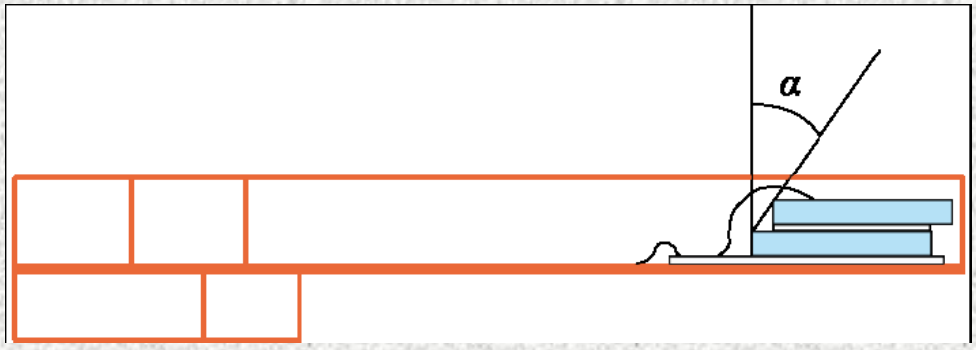


ceramic module assembly scheme

- increase modularity of BCM detector modules

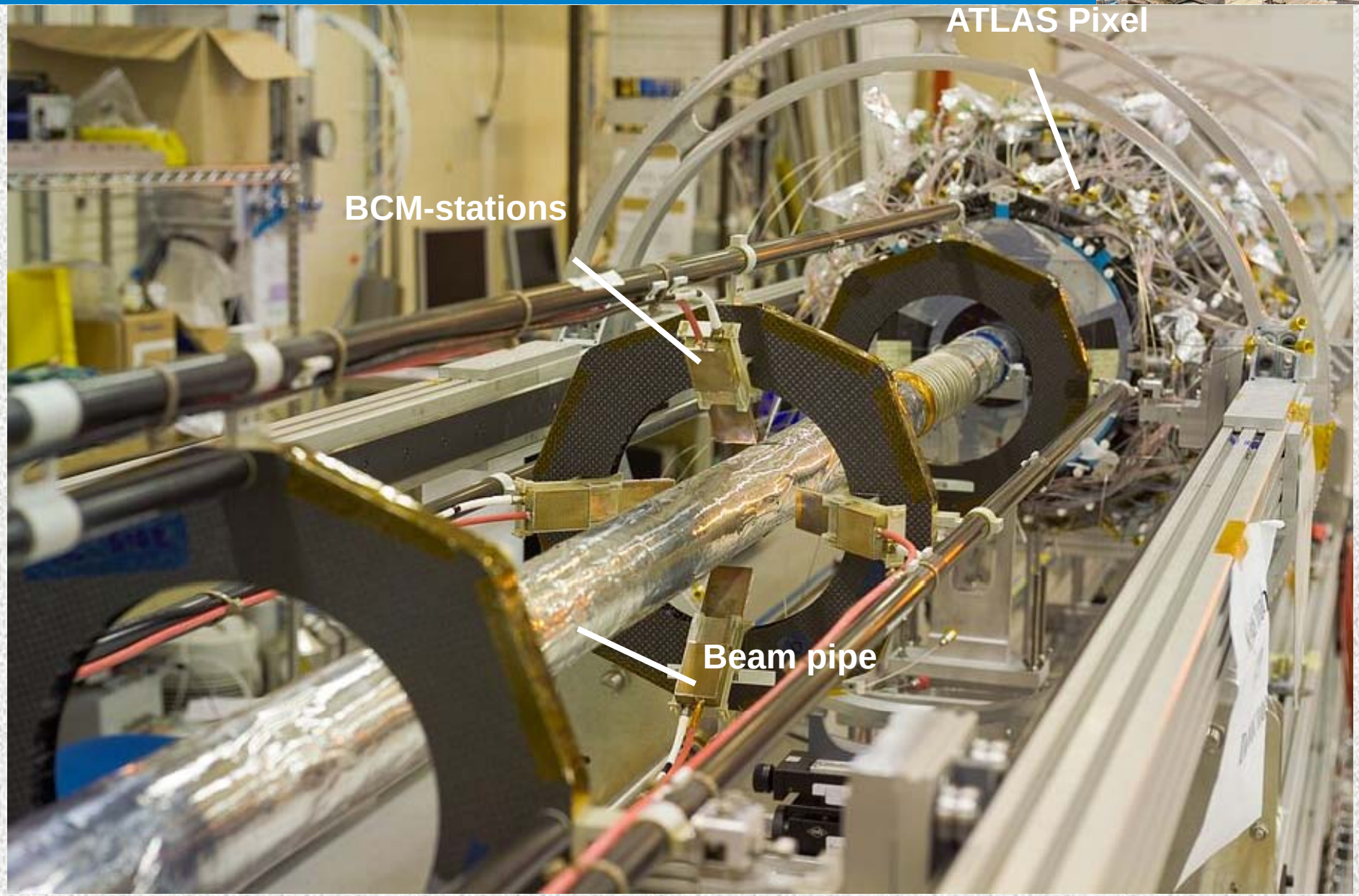


redundant HV connection



alignment of diamond sensors in BCM detector module
(at 45° = along beam direction)

BCM installed on Pixel detector

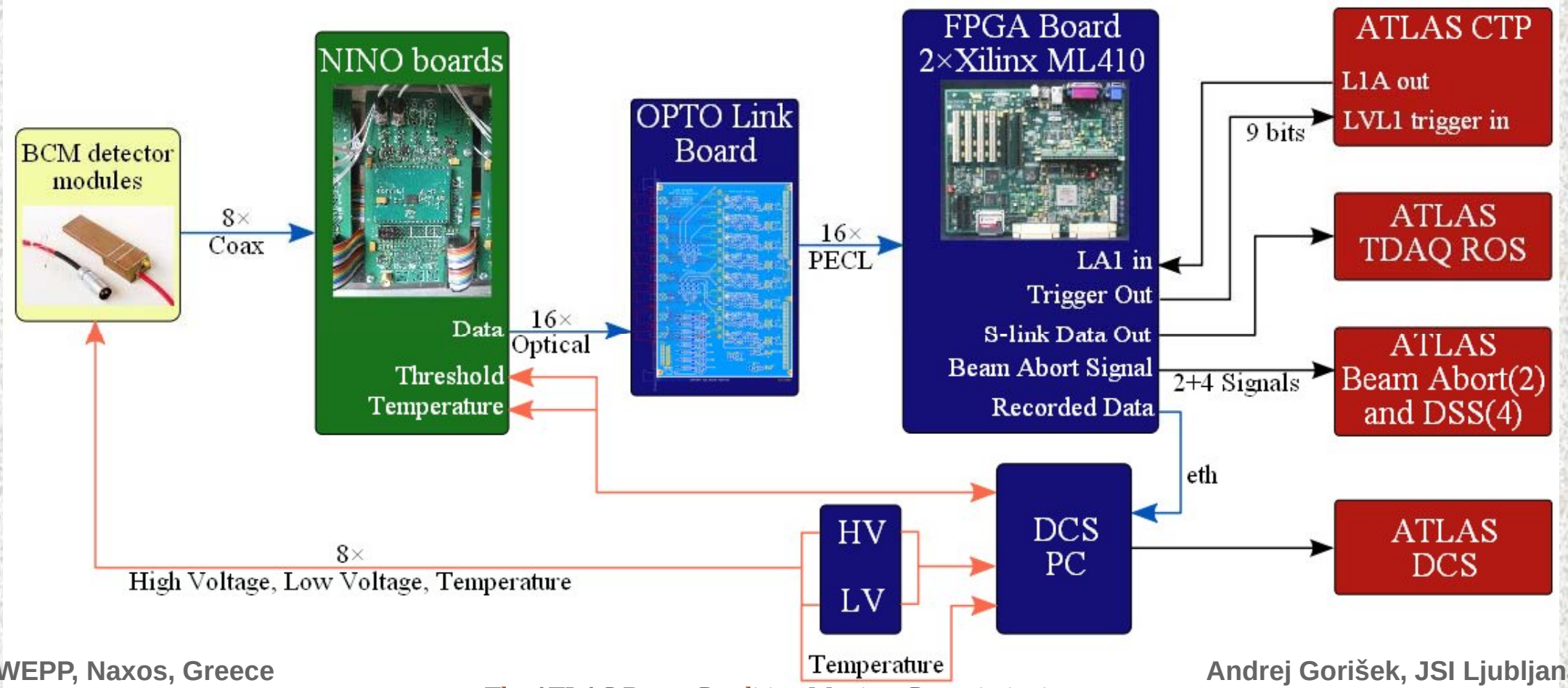


The 8 installed modules

MODULE	410	413	420	422	404	405	408	424
preferred polarity	+1000V	+1000V	-1000V	-1000V	+1000V	+1000V	-1000V	-1000V
MPV [mV]	2.77	2.15	2.67	2.40	2.43	2.30	2.21	2.70
SNR	**7.8**	**7.0**	**7.8**	**7.3**	**6.5**	**7.0**	**7.0**	**8.2**

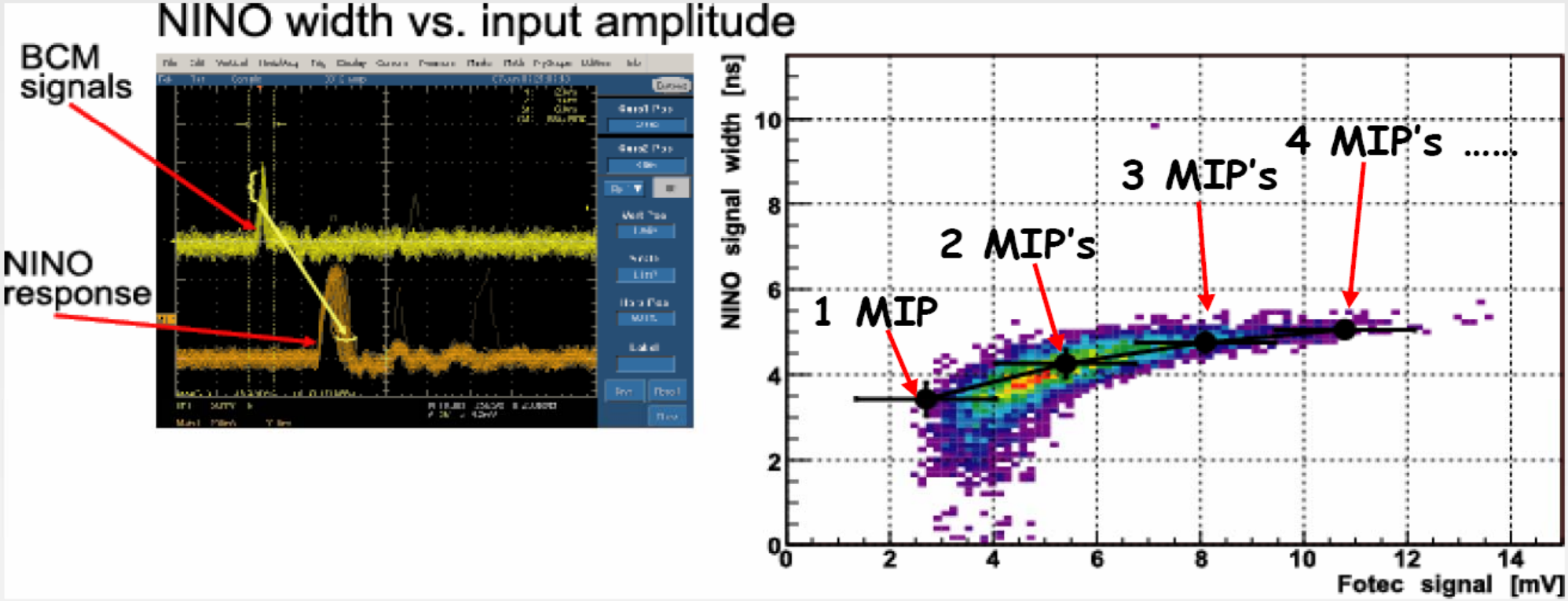
BCM readout chain

- analogue signals from BCM detector modules routed to region behind calorimeter (lower radiation levels – 10Gy in 10 years) where they are digitized by custom board based on NINO chip
- signals from separate BCM detector modules are connected to separate NINO boards for electrical ground separation – minimize interference (grounds connected together close to detector modules)
- optical signals are taken to electronics room (USA15) for processing by Vitrex-4 based FPGA board



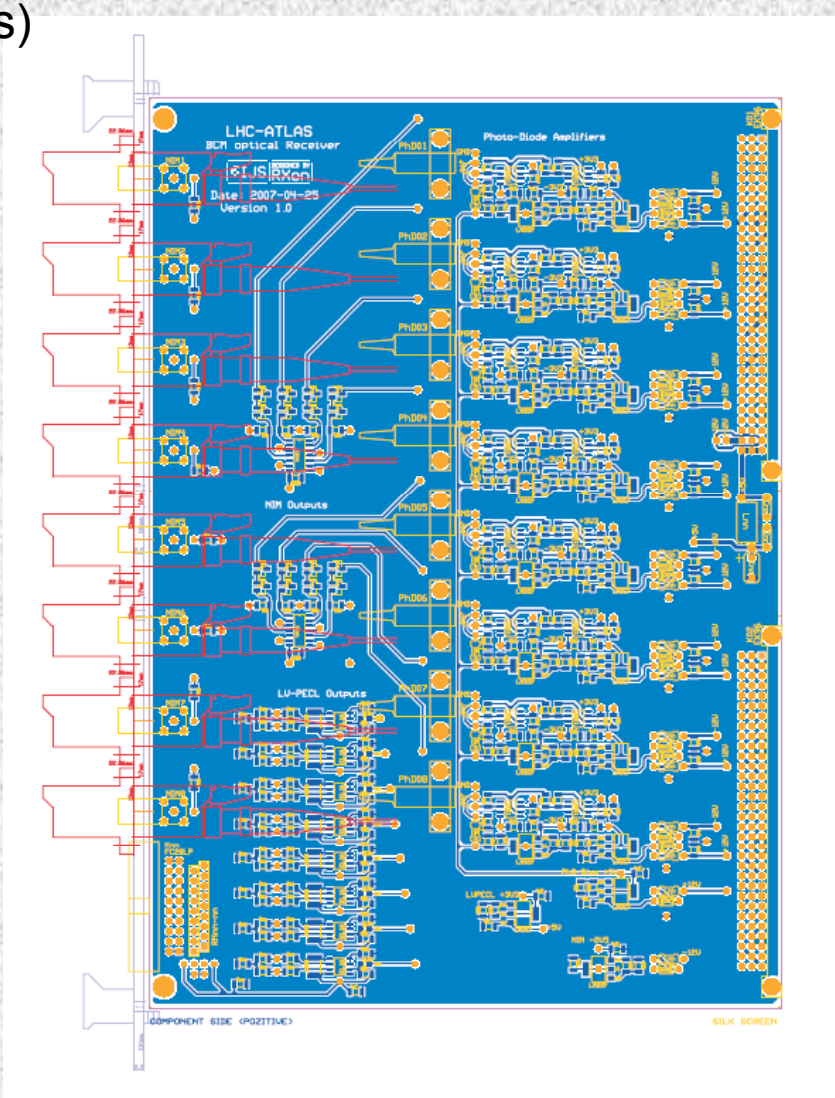
NINO board

- amplifier-discriminator-TOT chip
- developed for ALICE RPC ToF (CERN-MIC – F. Anghinolfi et al.)
- radiation tolerant; IBM 0.25μm technology
- LVDS output signal with rise time <1ns & jitter <25ps
- 8 differential inputs (2 used on each board)
- output signal width correlated to the input charge (min. detection threshold 10fC)
- each BCM module connected to two NINO inputs in 1:11 ratio to increase NINO dynamic range
- resulting two TOT digital signals from the NINO chip are further converted into optical signal with radiation tolerant laser diodes (Mitsubishi FU-427SLD-FV1).



OPTO link board

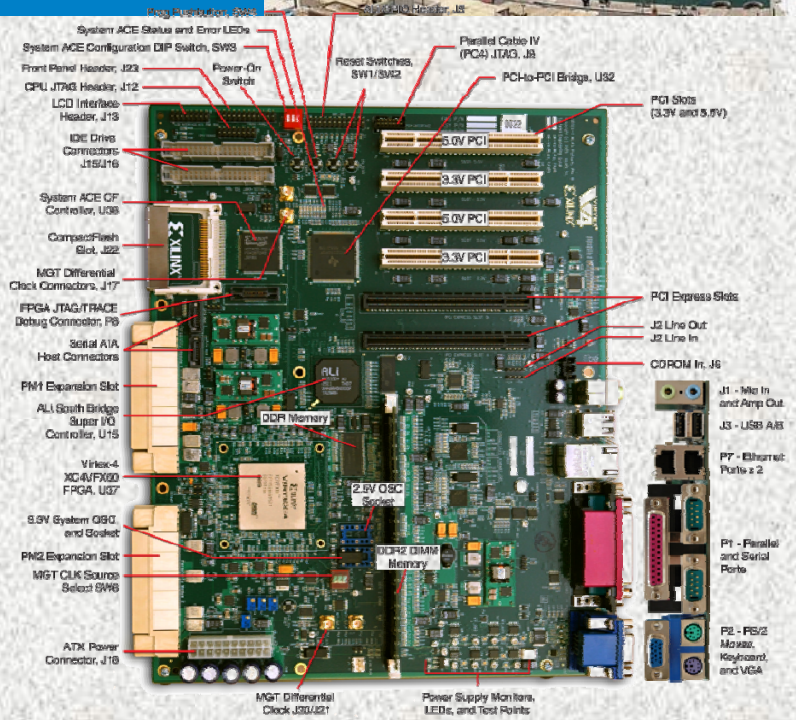
- 70m optical fibres from NINO boards
  (single mode fibers equipped with E2000 APC connectors)
- **receives** 8 optical signals from 4 NINO boards
  (photo diode – Lightron LP3A4-SNC1)
- PECL output to FPGA
- NIM level monitor output

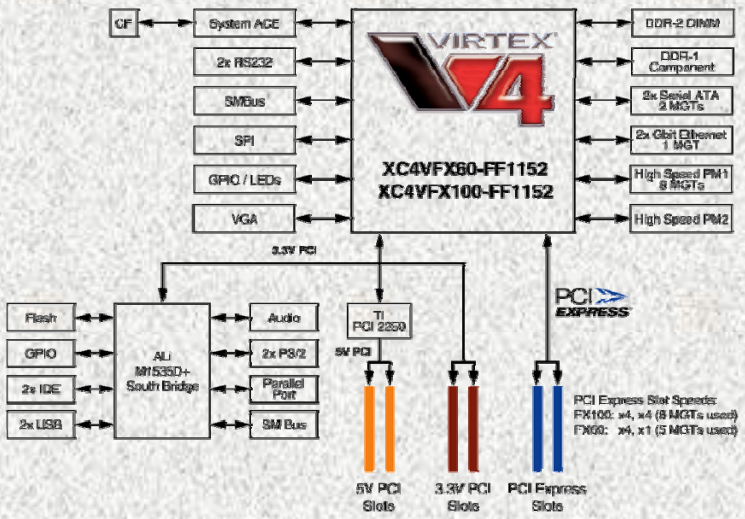


Backend - FPGA

ML410 development board based on Virtex-4

- 8 RocketIO serial input/output channels sampling the received signals with frequency of 2.56 GHz
- real-time signal processing: signal arrival time, pulse width calculation
- RAM (circular buffer) stores 3×10^6 last LHC bunch crossings (for “post mortem”)
- additional analysis:
  - in-time and out-off time hits
  - rates and trends of rates of each module
  - coincidences for different combination of modules
- Use 2 boards and have them communicate
  - channels arranged in redundant fashion (vertical modules to one and horizontal modules to another FPGA board for high gain channels and the opposite for low gain channels)



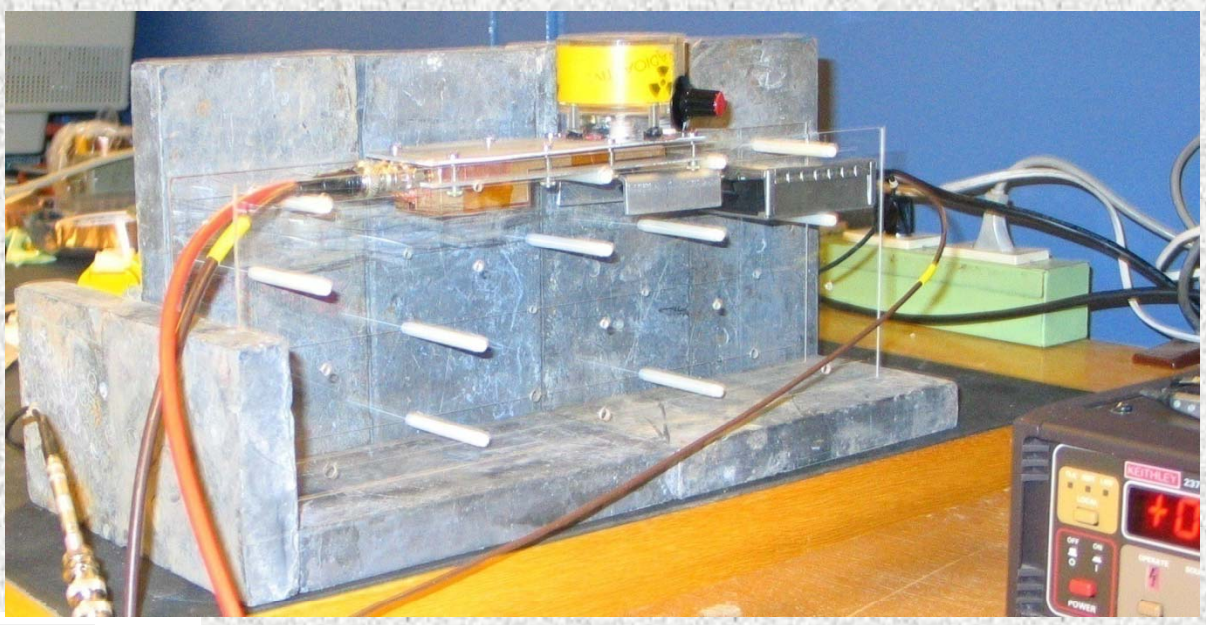


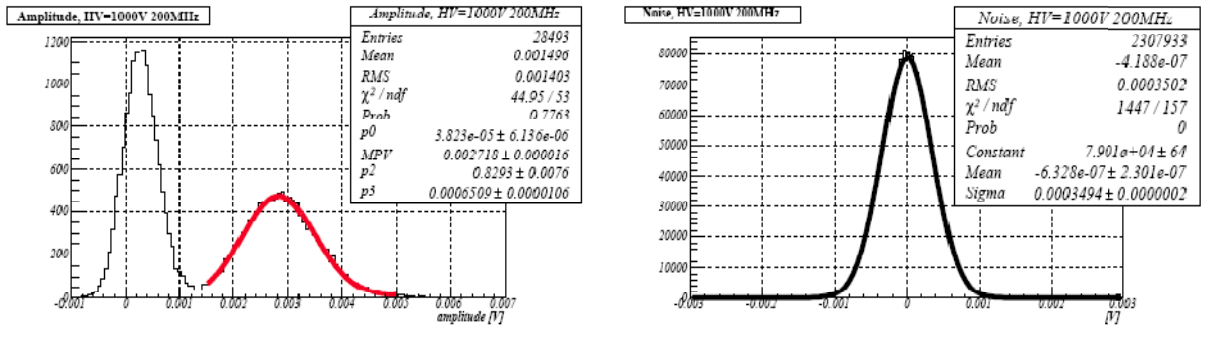
FPGA outputs

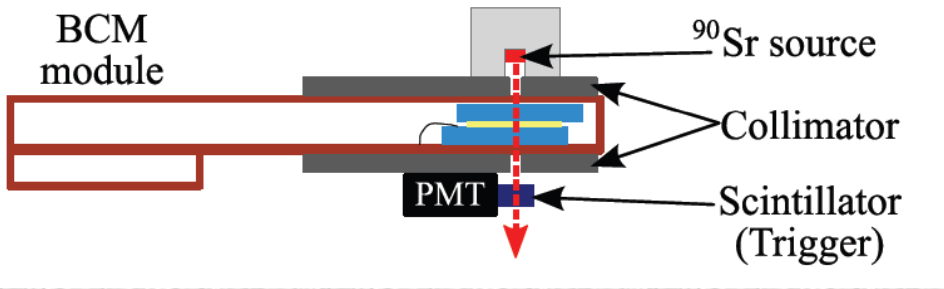
- LHC Beam Abort:
  In case of beam failures, two redundant signals, indicating that beam conditions in the ATLAS Inner detector have reached the unacceptable levels, will be sent to the BIS resulting in beam abort.
- ATLAS Detector Safety System (DSS)
  This hardware interlock system guards the experimental equipment and acts to prevent damages from any detected faulty situation. The BCM system has 4 electrical connection to DSS in order to send warnings or alarm signals.
- ATLAS Detector Control System (DCS)
  - a PC, integrated into the ATLAS DCS system
  - monitor the temperature of detector modules and NINO electronics boards
  - control the high and low voltages
  - more sophisticated information (average rates, histograms, etc.), obtained from processed signals, available to ATLAS and LHC control through DCS PC connected via Ethernet to FPGA.
  - In case of a beam abort, all recent information from BCM, currently stored in ring buffer of FPGA, is transfered through DCS for post mortem analysis.
- ATLAS Data Acquisition (DAQ)
  - FPGA also acts as a ROD. L1A signal will cause FPGA to send data to the ATLAS DAQ system through standard optical S-link.
- ATLAS LVL1 trigger
  - information to the ATLAS LVL1 trigger in a form of 9 (temporarily 6) bits for topologically interesting events

BCM QA

- QA of all modules through production cycle
  - Raw sensor characterization / ceramic module
    - I/V, CCD
  - Module performance
    - Noise
    - Signal from ^{90}Sr
  - Thermal cycling:
    10 cycles from -25°C to 45°C
  - Infant mortality – 12h @ 80°C
- Resulting S/N from 6.5 to 8.2 for perpendicular incidence



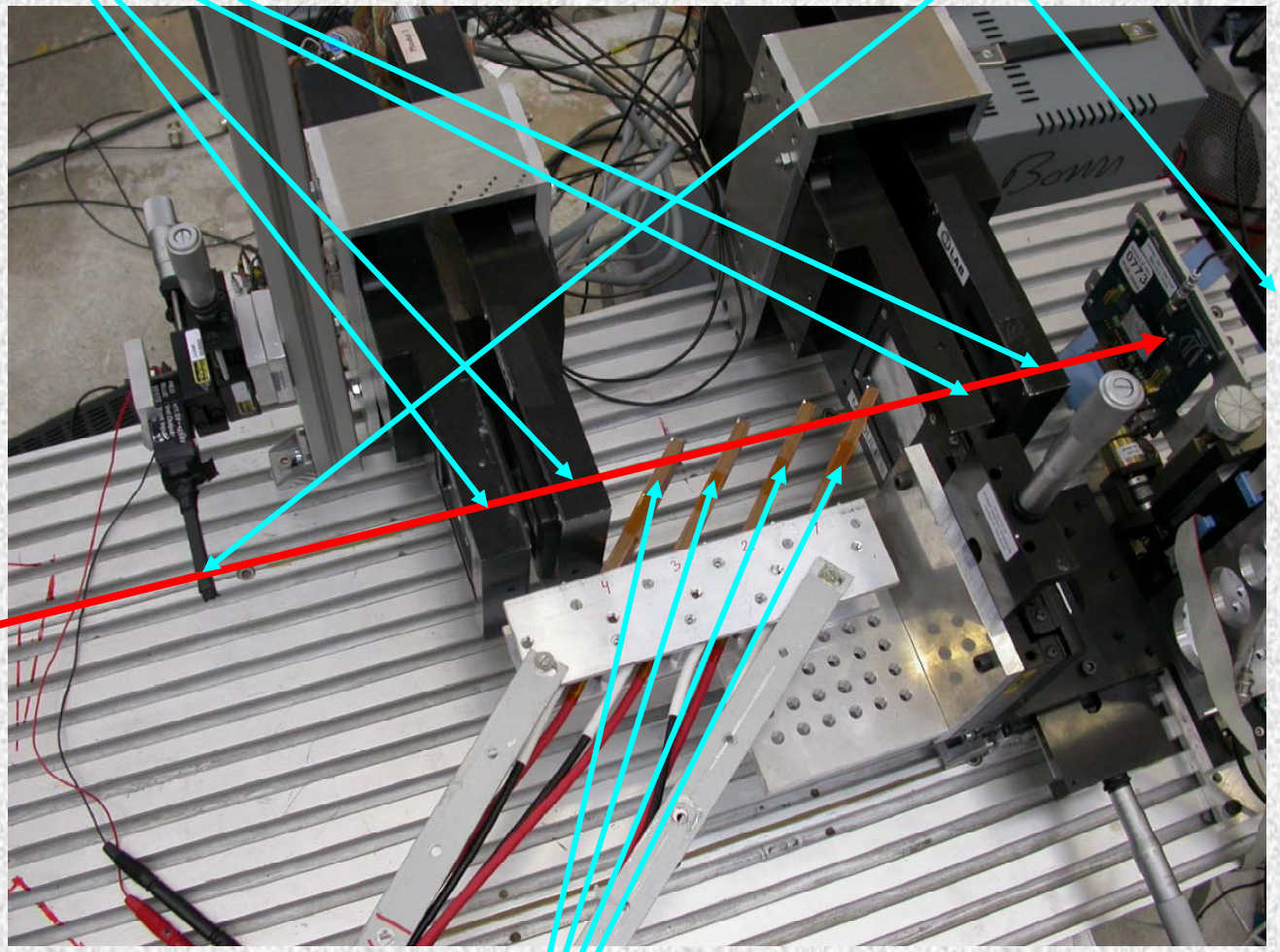




SPS beam test setup

4 tracking modules – Si-strip
(4 XY point along particle trajectory)

trigger scintillators

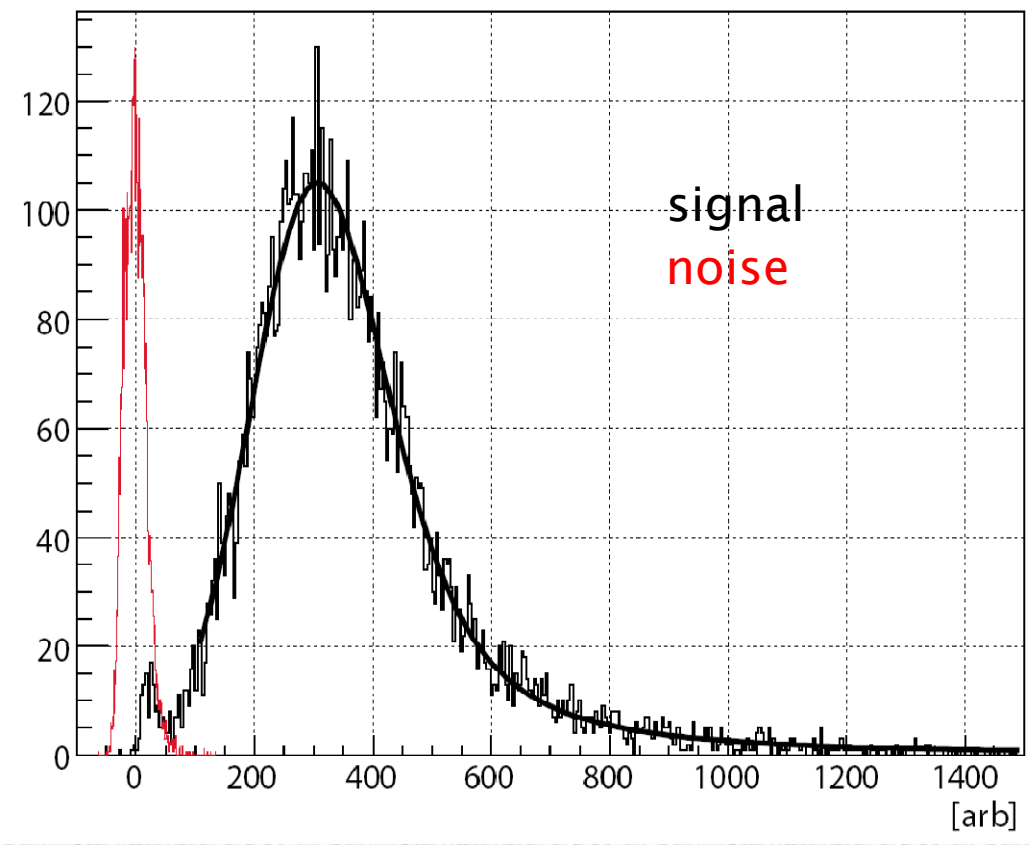


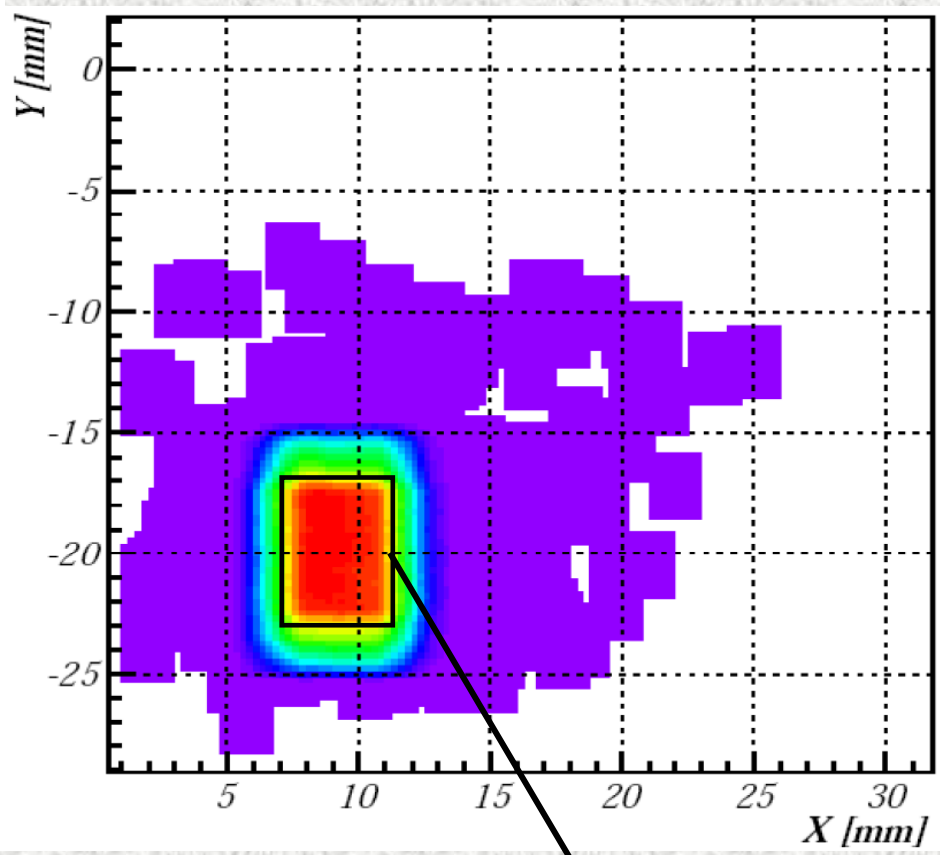
180GeV/c
π beam

BCM modules

Analog signals – surface uniformity

- all modules tested in beam-test setup:
  - signal & noise performance
- surface uniformity

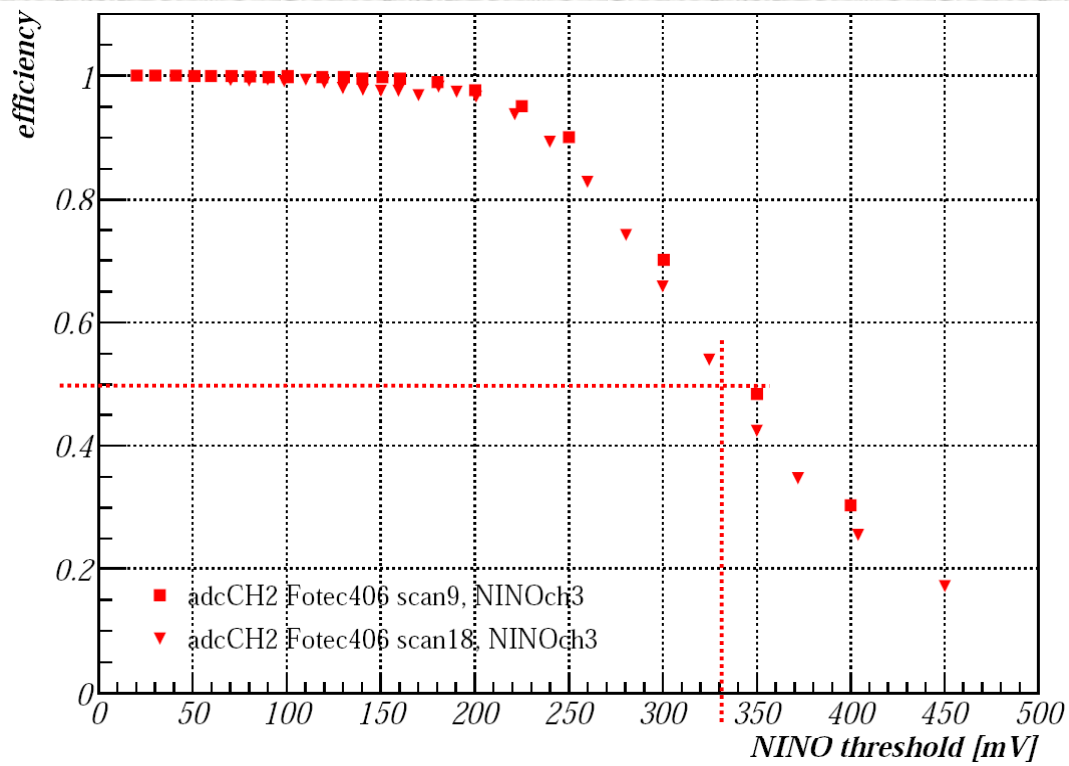


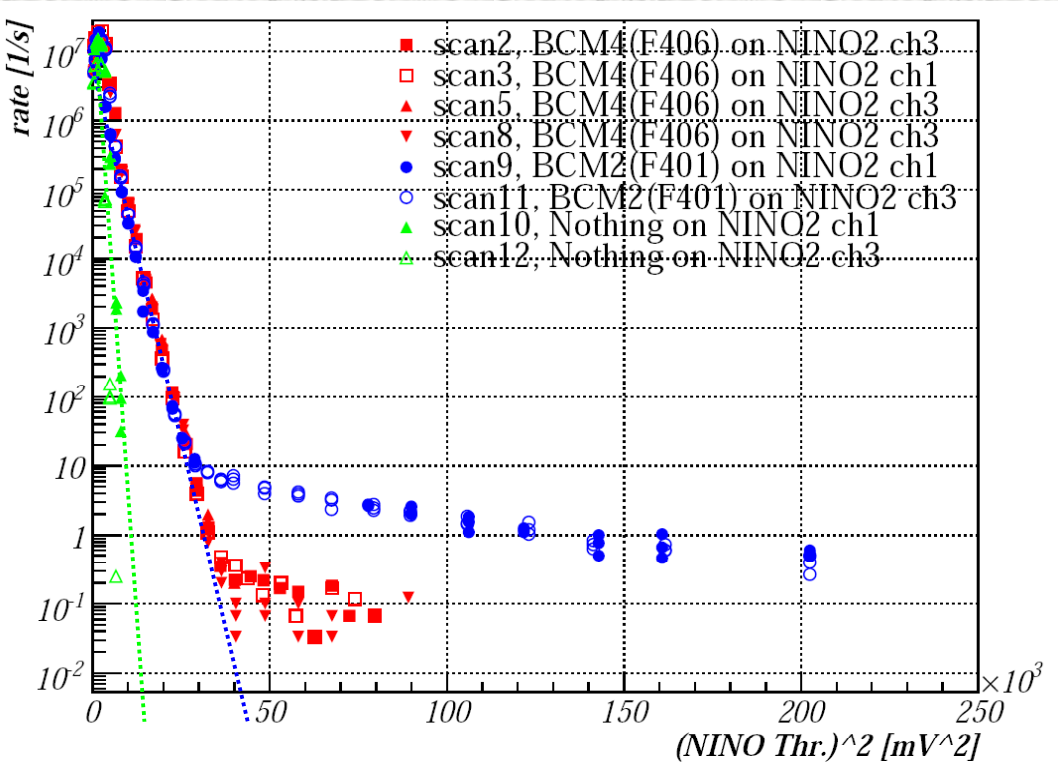


size of diamond sensor (tilted 45°)
signal uniform over surface

Efficiency and noise rate

- SNR after NINO digitization ~7.2
- contribution of NINO (no input) to σ ~29mV compatible with decrease in SNR (compatible with SNR before NINO normalized to 45º ~10)

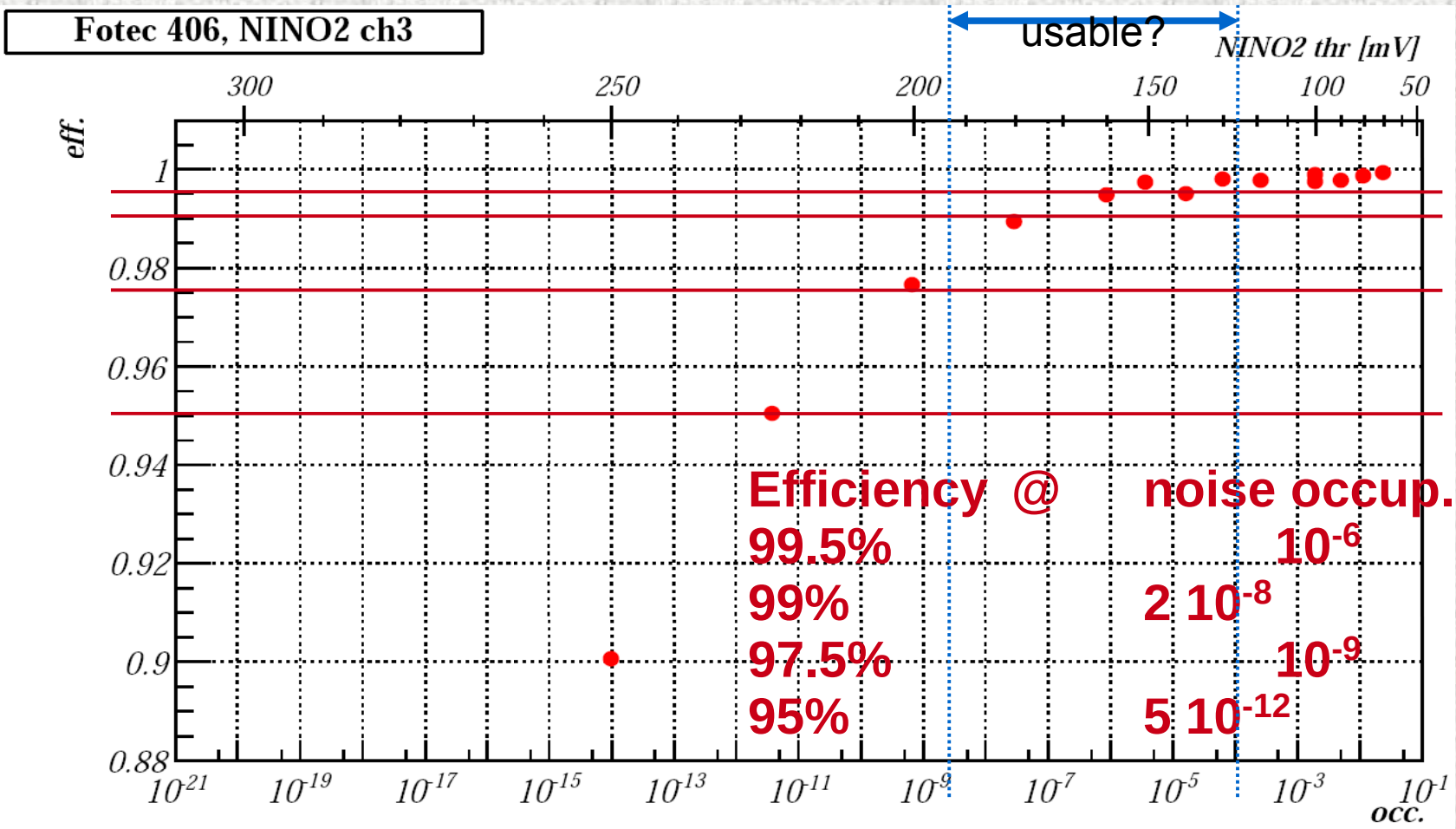




Efficiency vs. noise occupancy

NINO digital circuit features amplifier discriminator and TOT measurement

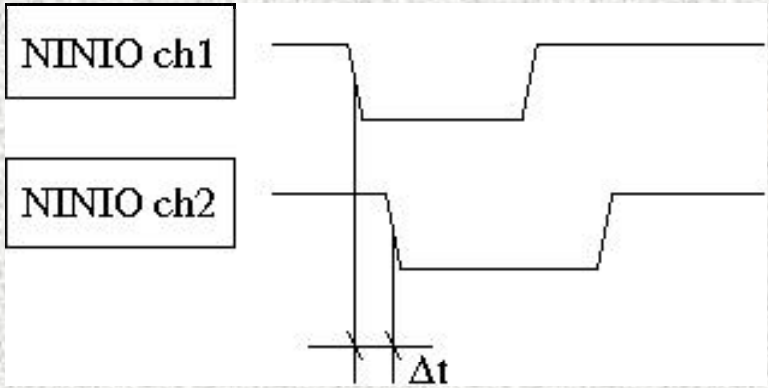
- by changing the discriminator threshold efficiency and noise rate (occupancy) changes
- noise occupancy is scaled noise rate to 25 ns interval
- efficiency of system up to digital circuit (NINO) triggering on an incident MIP (in scintillators)

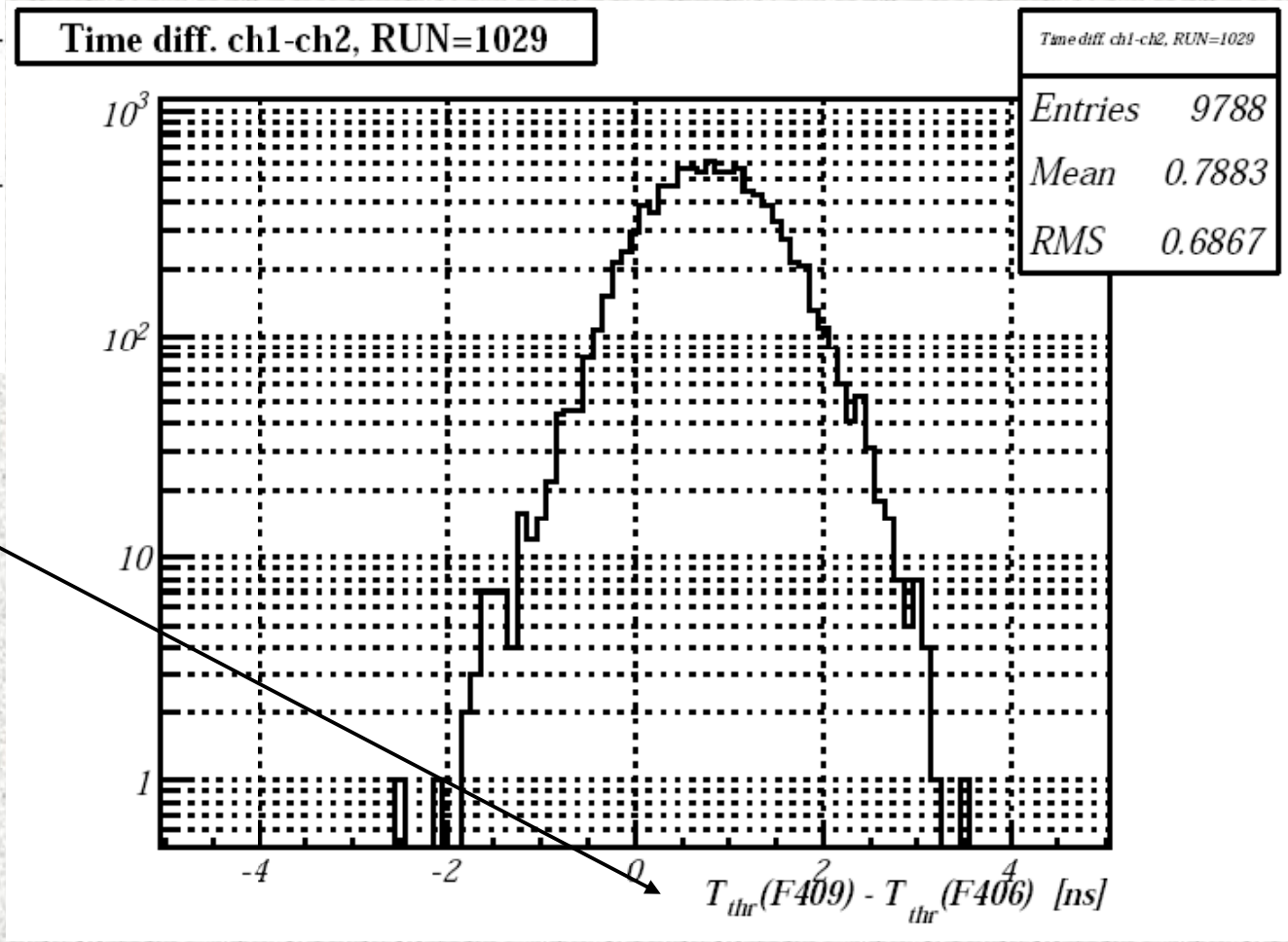


Timing resolution

Time difference between two detectors:

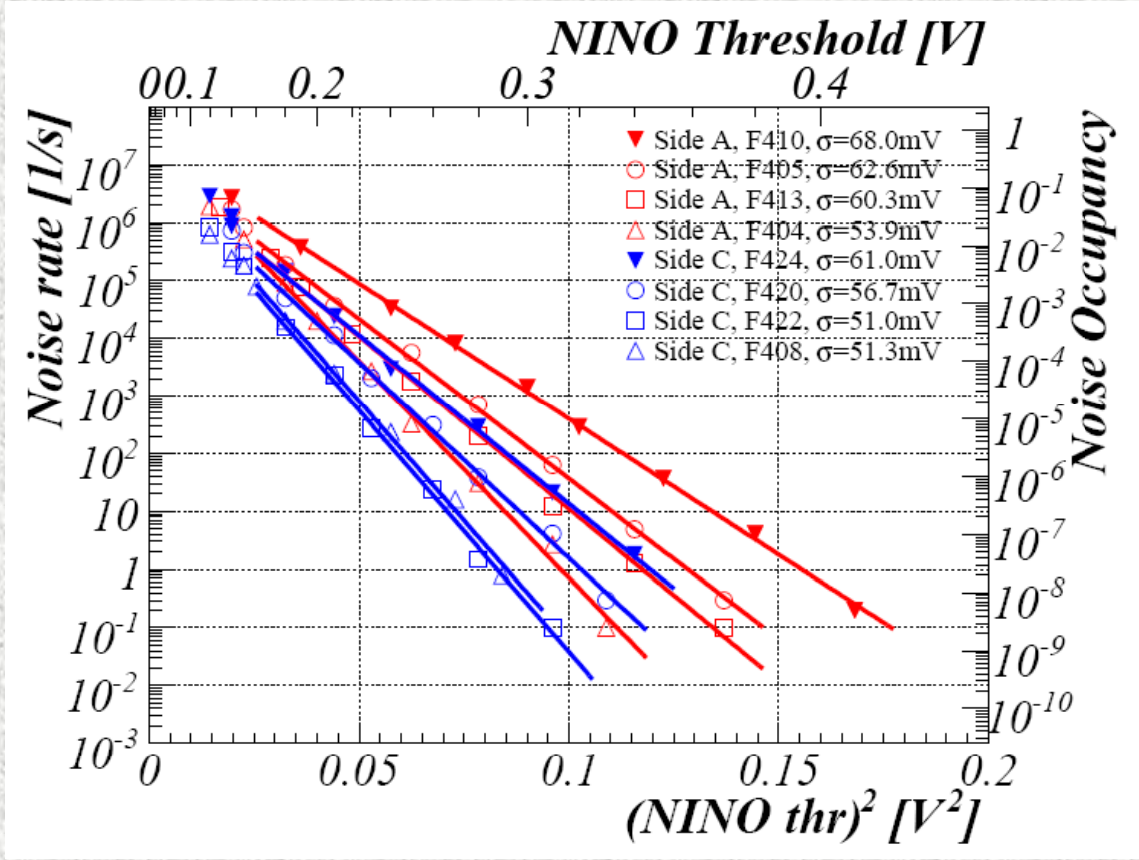
- RMS~500 ps per detector (end of read out chain)
- practically all events inside [-2ns,2ns]





Noise performance of installed modules

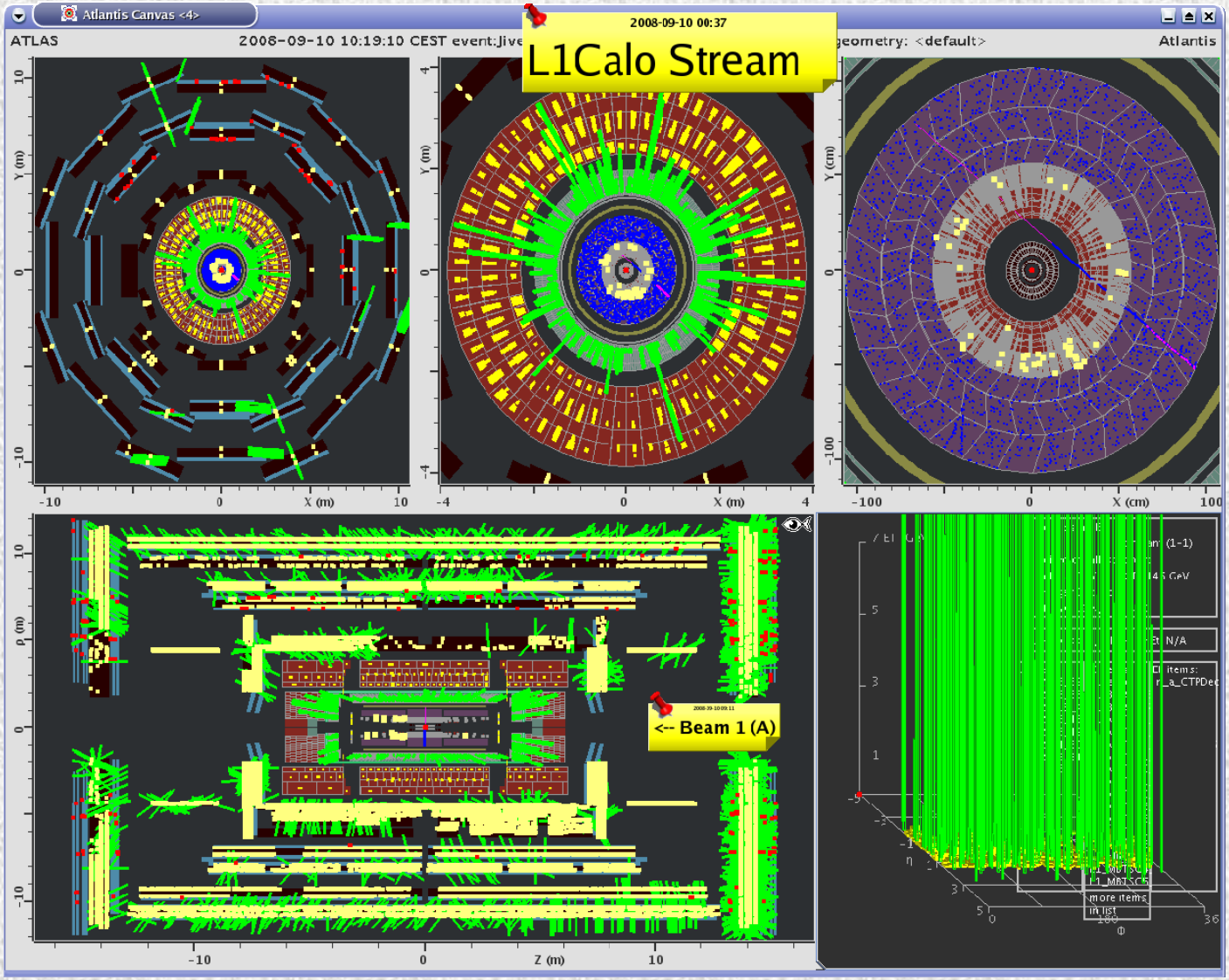
Gaussian noise observed on all channels
All modules in range between 50mV and 70mV



Module	Position [Side, (x,y)]	Noise σ [mV]
F410	A, (+x,0)	68.0
F405	A, (0,+y)	62.6
F413	A, (-x,0)	60.3
F404	A, (0,-y)	53.9
F424	C, (+x,0)	61.0
F420	C, (0,+y)	56.7
F422	C, (-x,0)	51.0
F408	C, (0,-y)	51.3

ATLAS – “First Event”

2 10^9 protons in one beam on colimator



Summary

- The ATLAS BCM was constructed using radiation hard pCVD diamonds
  - back to back ”double decker” configuration at 45° towards the beam
- Test beam and on-the-bench result indicate operable system
  - S/N, risetime, pulse-width,... meet the design criteria
  - efficiency/noise occupancy reasonable
- ATLAS BCM status (commissioned!):
  - FE installed in January 2007
  - NINO TOT electronics installed in spring 2008 – noise performance adequate
  - FPGA Xilinx Vitrex-4 based back-end – running in common ATLAS framework