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ATLAS Diamond Beam Conditions Monitor

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Presented in Irena's absence by Harris Kagan

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ATLAS BCM web page: https://twiki/cern.ch/twiki/bin/view/Atlas/BcmWiki

Motivation

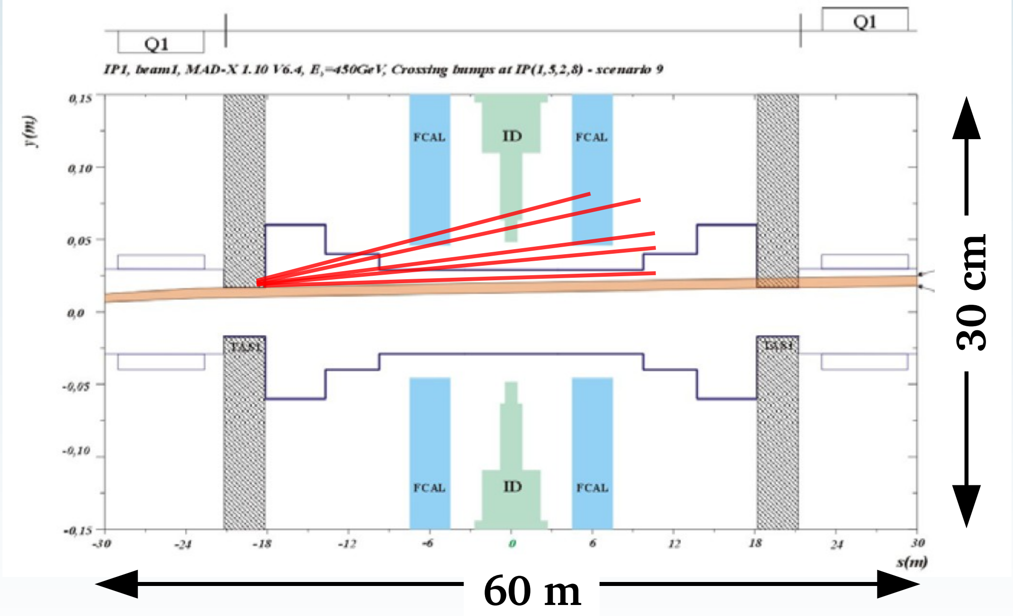
The goal of BCM system inside the ATLAS Inner Detector:

- Monitor beam conditions and distinguish each bunch crossing between **normal collisions** and **background events** during normal running
  - measure background rate (beam halo, beam gas) close to the vertex
  - measure collision rate and provide (bunch by bunch) relative luminosity information (additional measurement to LUCID, ATLAS main luminosity monitor)

- Primary goal: **protection** in case of larger beam losses
  - fast detection of early signs of beam instabilities (due to incorrect magnet settings, trips, …)
  - Issue warning and alarm signals for equipment protection
  - Input to ATLAS Detector Safety System and LHC Beam Abort

Beam Loss Scenarios

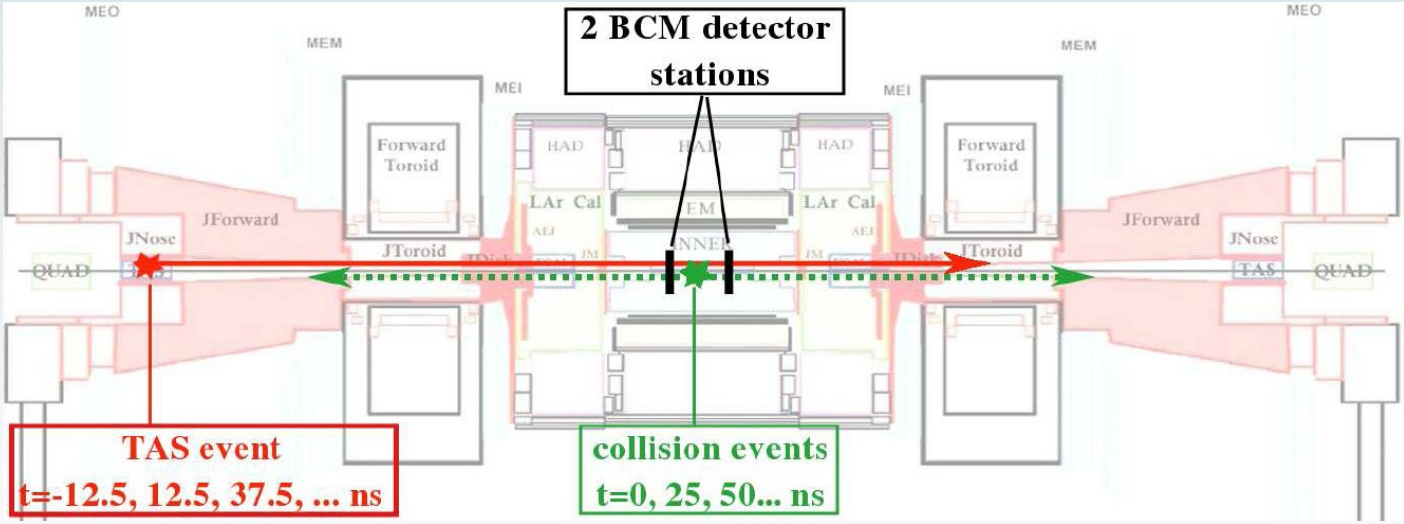
- **Multi-turn losses**
  - beam degradation (equipment failure, wrong magnet settings...)
  - time constants of magnets ~ms → can abort the beam if detected early
- **Single-turn losses of 360MJ/beam**
  - likely to occur during injection or beam dump processes
  - IR1 (ATLAS) can be rated the 'safest' of all interaction points (far away from injection, dump)
  - pilot bunch (single bunch of low intensity, 5×10^9p@450GeV; 360J) will be used to check the magnet settings
  - simulations of beam orbits with wrong magnet settings (D. Bocian) exhibit scenarios with beam scrapping TAS Cu collimator



ATLAS BCM principle of operation

Time of flight measurement to distinguish between collisions and downstream background events (beam gas, halo, TAS scraping…)

- measurement every proton bunch crossing (25 ns)
- place 2 detector stations at $z=\pm1.9$m:
  - secondary particles from **collisions** reach both stations at the same time (6 ns after collisions)
  - secondary particles from upstream **background** interactions reach nearest station 12.5ns before secondary particles from collisions (6 ns before collisions)
  - use “**out of time**” hits to identify the background events
  - use “**in time**” hits to monitor luminosity

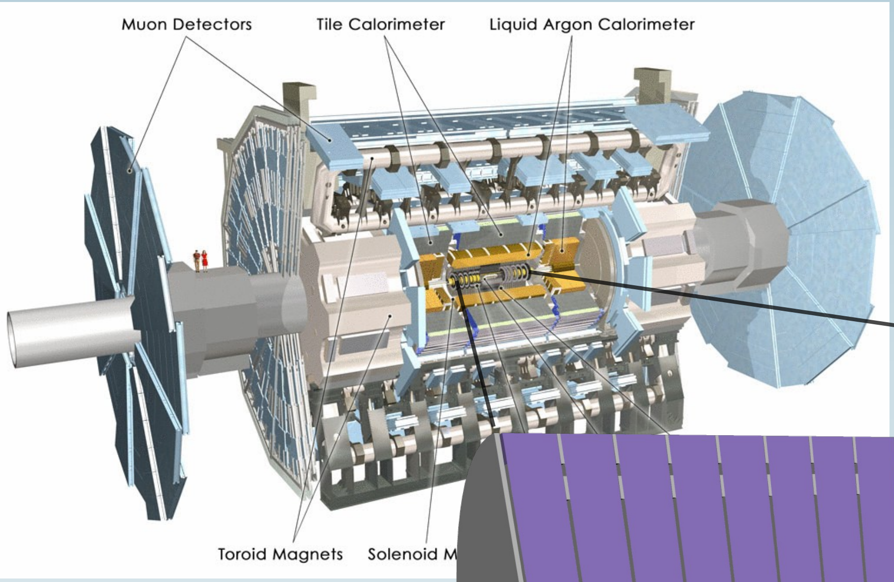


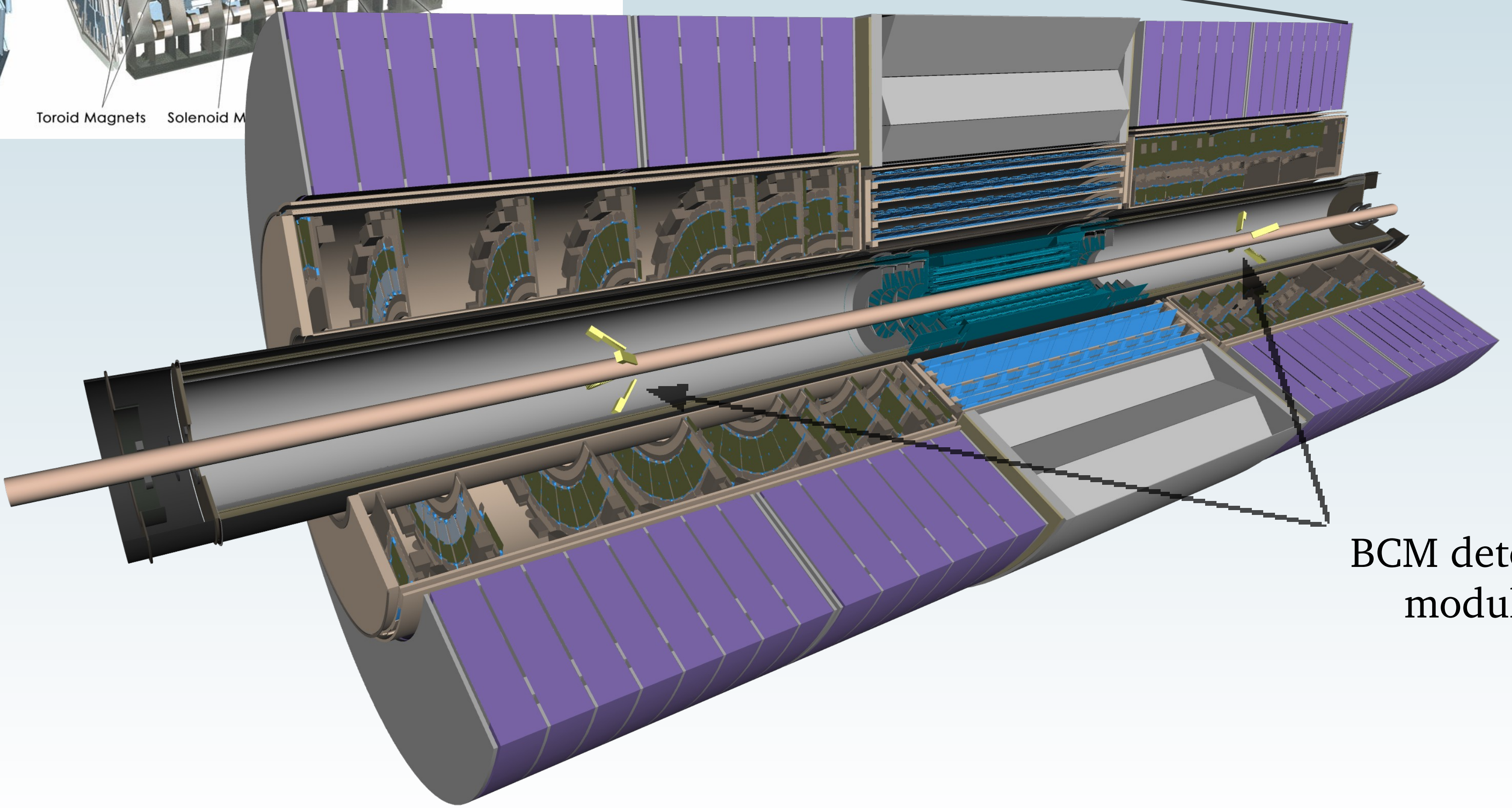
Requirements:

- fast and radiation hard detector & electronics:
  - rise time ~1ns
  - pulse width ~3ns
  - baseline restoration ~10ns
  - ionization dose ~0.5 MGy, 10^{15}particles/cm^2 in 10 years
- MIP sensitivity

Realization

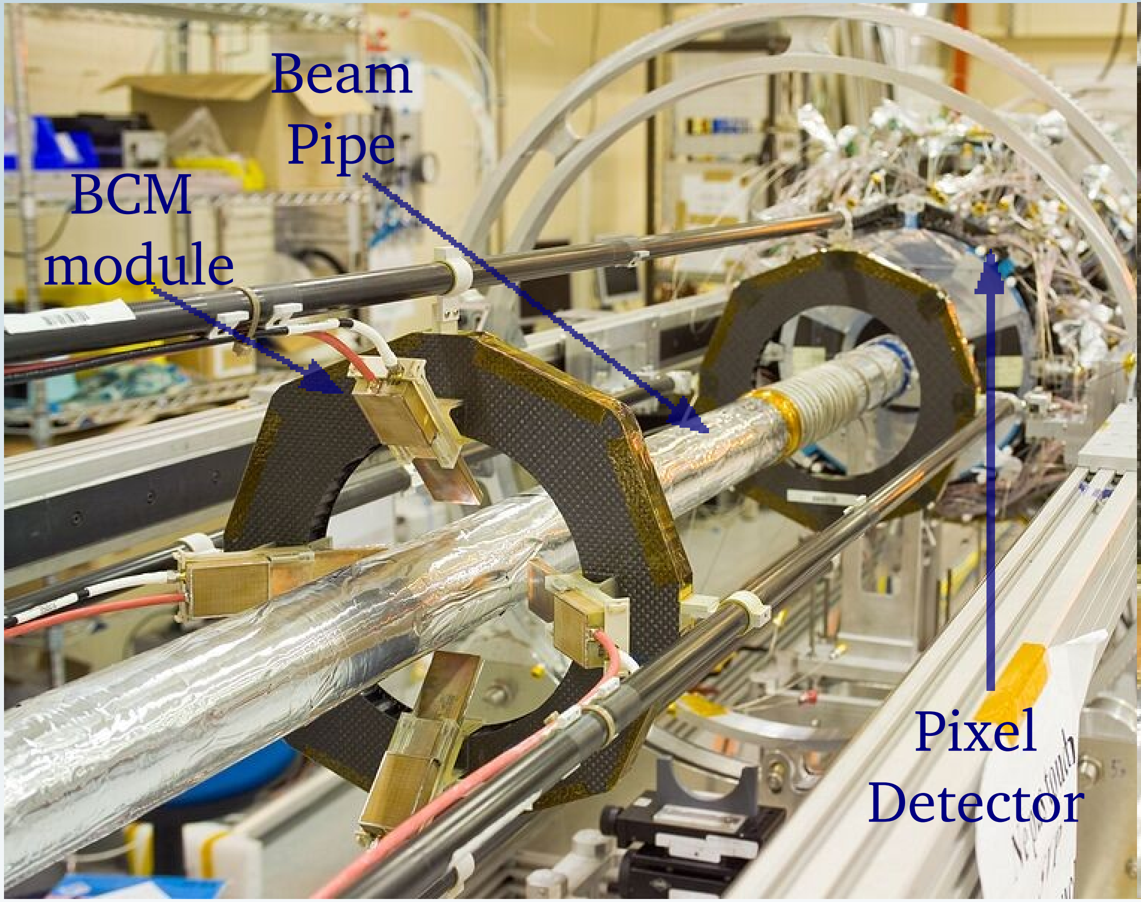
- 4 BCM detector modules on each side of the Pixel detector
- Mounted on Beam Pipe Support Structure at $z=\pm183.8$cm, sensors at $r=5.5$cm ($\eta\approx4.2$)

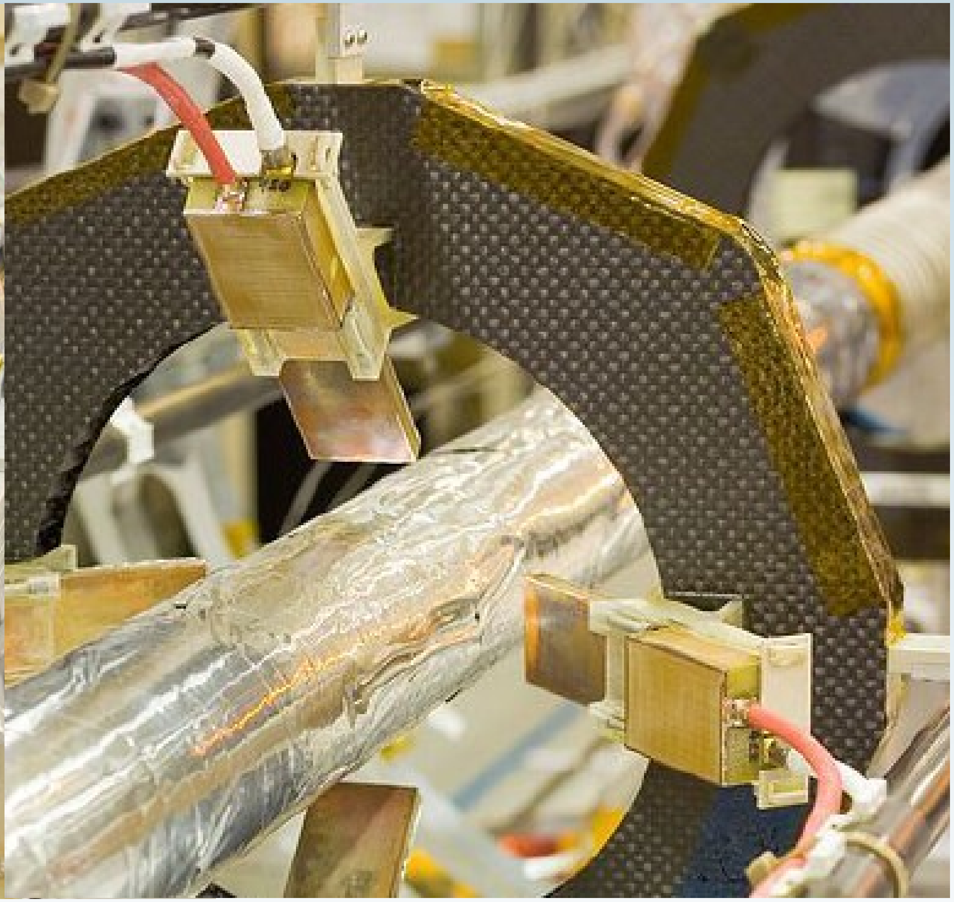




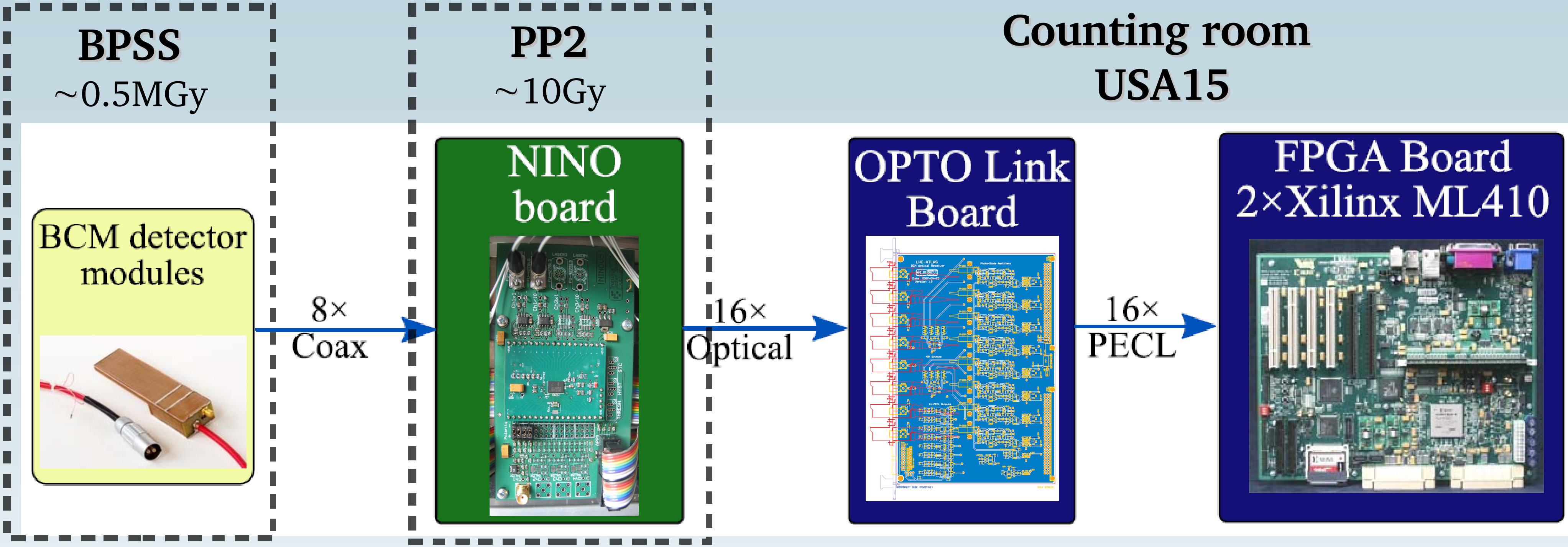
BCM Detector Modules Installed

BCM modules were installed on Beam Pipe Support Structure in November 2006 and lowered into ATLAS pit in June 2007





BCM System - Schematics



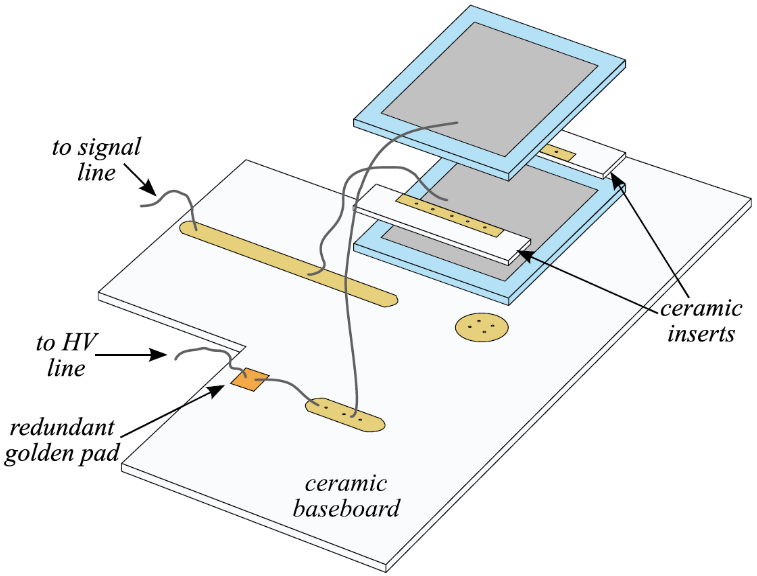
BCM Detector modules

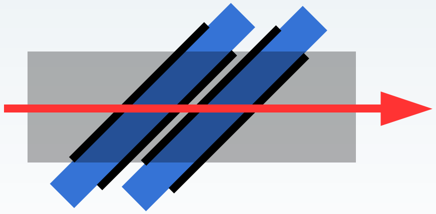
Poly-crystalline CVD diamond sensors

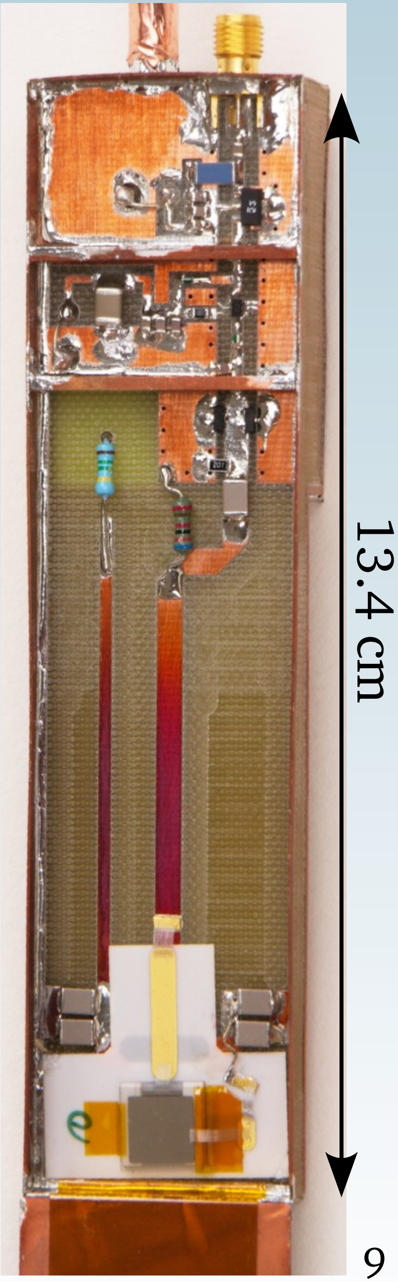
- developed by RD42 and Element Six Ltd.
- radiation hard: shown to withstand 10^{15}p/cm^2
- low leakage current → no cooling required
- fast & short signals – operate at high drift field 2V/µm

Double – decker assembly

- 2 back-to-back sensors each with
  - thickness 500µm,
  - CCD @1V/cm ~220µm
  - Size: 10×10 mm^2
  - Contact size: 8×8 mm^2
  - Operated at 2V/µm (1000V)
- Double signal compared to assembly with one sensor, but noise not measured to be two times higher
- For 45^o particle incidence signal increase by factor √2 → modules installed at 45^o to the beam pipe







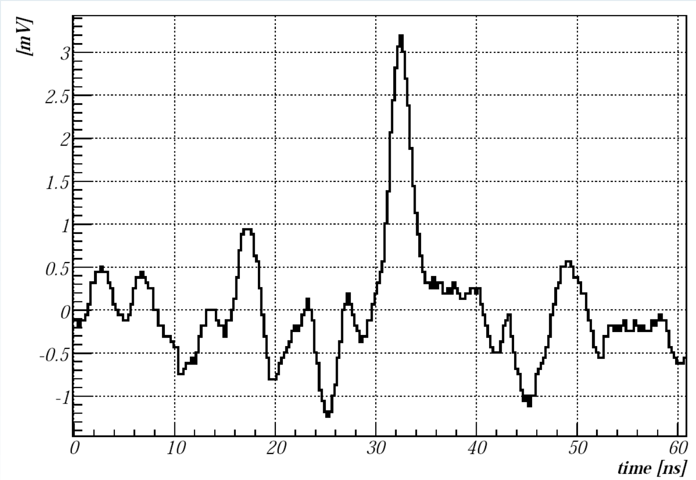
BCM Detector modules

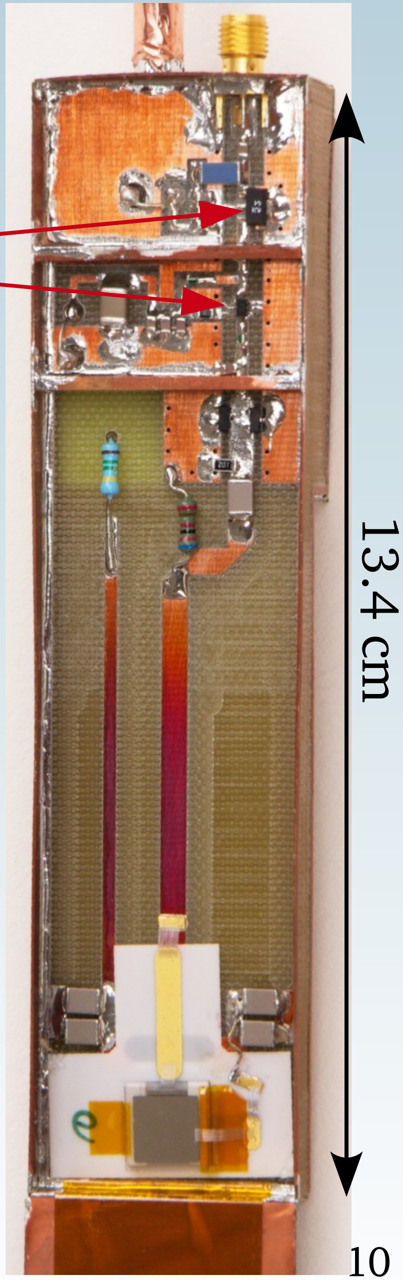
Front end electronics

- **2 stage amplifier:**
  - 1st stage: Agilent MGA-62653, 1GHz (20dB)
  - 2st stage: Mini Circuit GALI-52 500MHz (22dB)

- Limiting BWL to 200MHz improved S/N by 50% (but 10% worse timing resolution)
  → 4th order 200MHz filter integrated on NINO board before digitization

- Signals recorded with LeCroy LC564A digital oscilloscope with 200MHz BWL:
  - mean rise time 1.4ns
  - mean FWHM 2.9ns

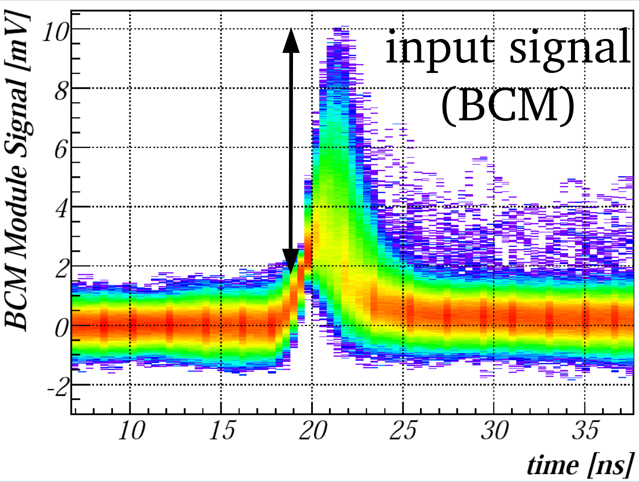


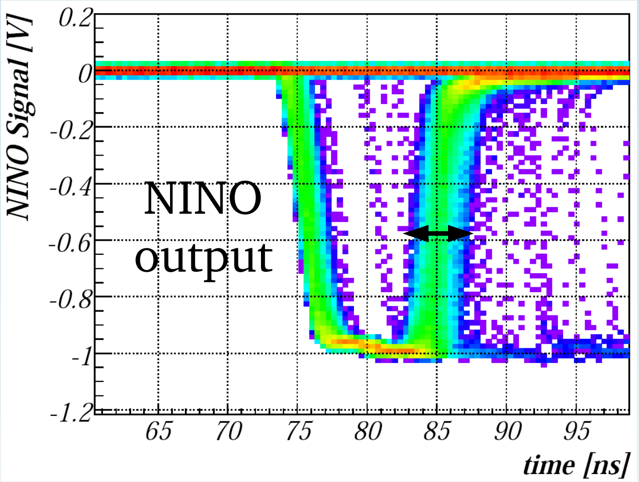


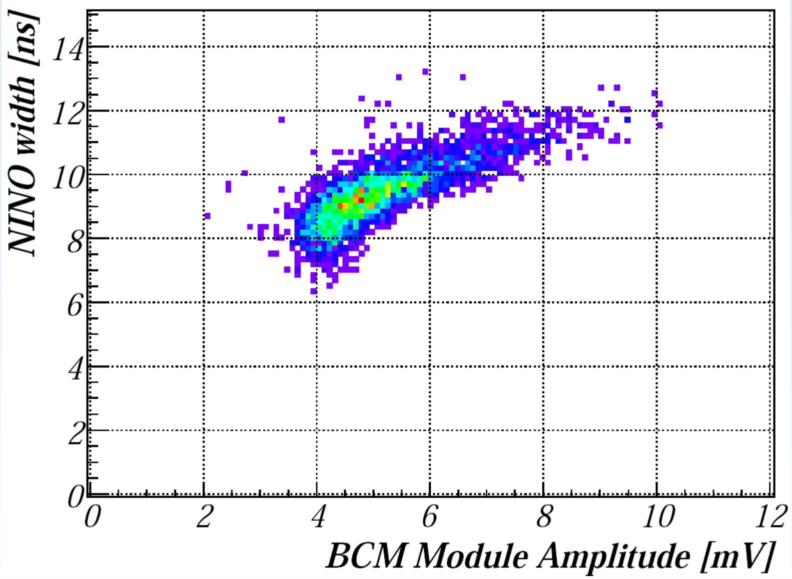
NINO board

NINO chip

- Developed for ALICE ToF (F. Anghinolfi et al.)
- Radiation tolerant
- Fabricated in 0.25µm IBM process
- Peaking time< 1ns, jitter <25ps
- Min. detection threshold 10fC
- Time-over-threshold amplifier-discriminator chip
- width of LVDS output signal depends on input charge



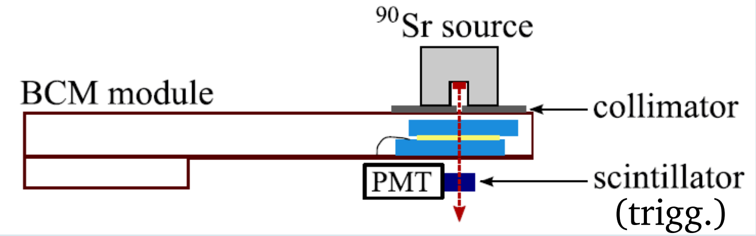


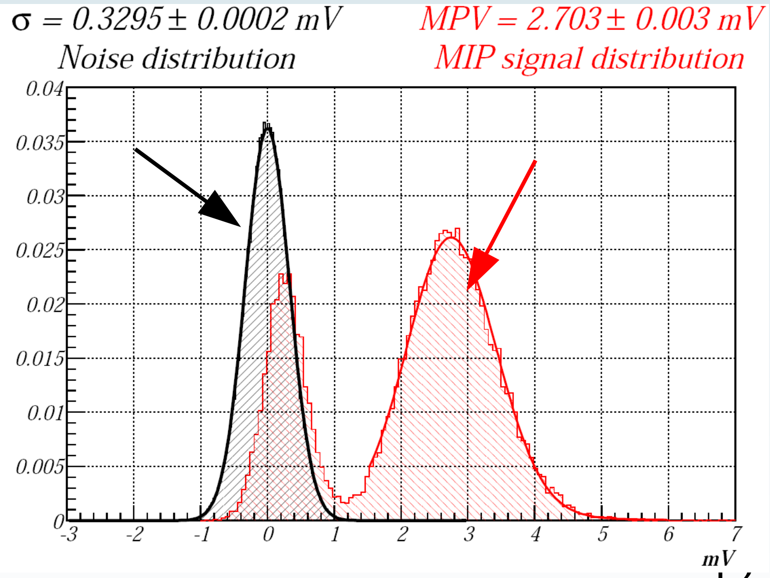


QA of BCM Modules

Qualification tests with final modules to select 8 for installation

- **Raw sensor characterization**:
  - I/V, CCD
- **Module performance**
  - All modules subjected to **thermo-mechanical test**
    - infant mortality test (12h @80^o)
    - accelerated ageing for one of the module (14h @120^o 10 years at 20^o)
    - thermal cycling (10 cycles from -25^o to 45^o)
  - **Module performance checked** before and after these tests with ^{90}Sr setup
    - no change in S/N observed
    - for normal particle incidence: typical S/N≈7–7.5



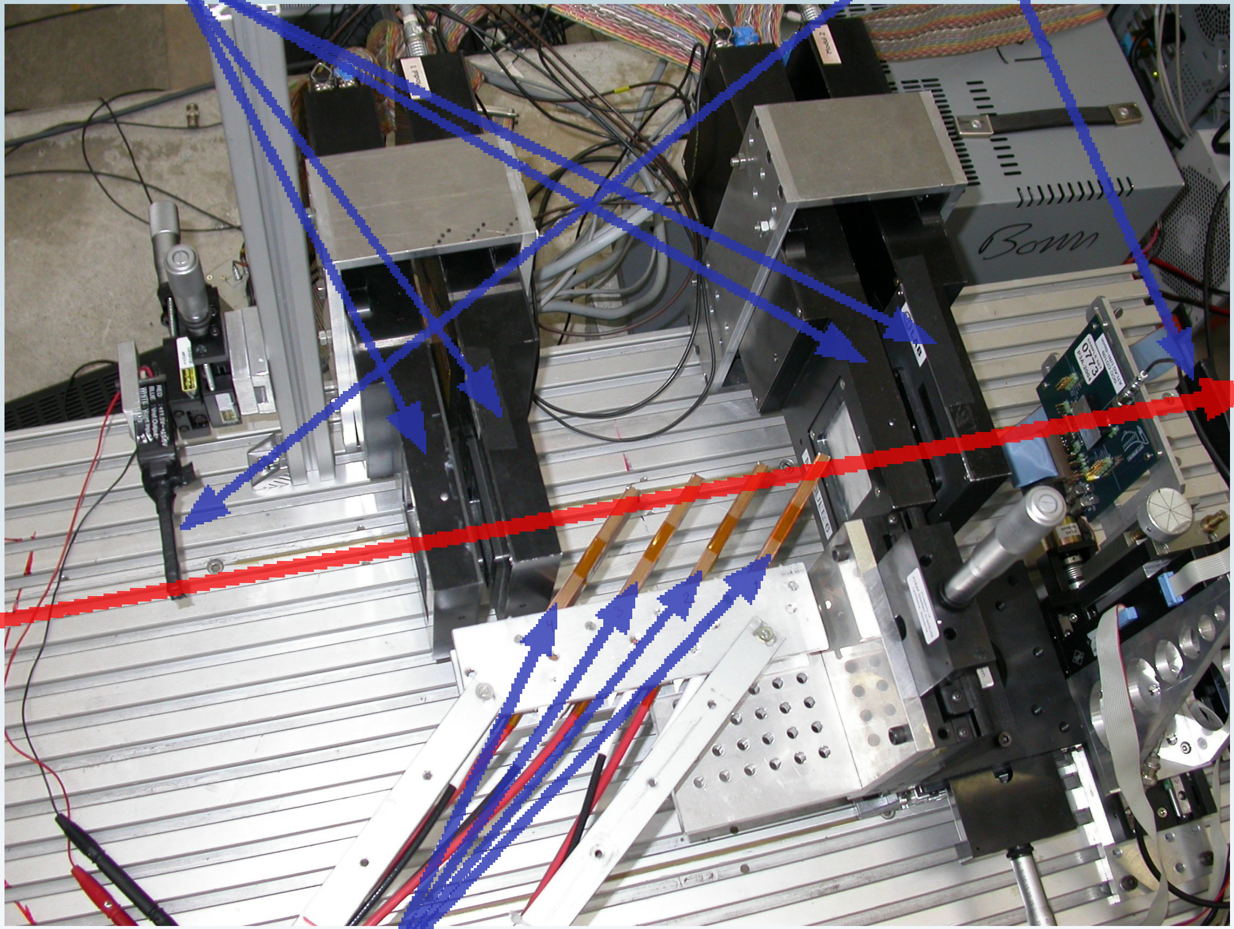


MODULE	404	405	408	410	413	420	422	424
Polarity	+	+	-	+	+	-	-	-
MPV [mV]	2.4	2.3	2.3	2.7	2.2	2.7	2.4	2.7
S/N	6.6	6.9	7.0	7.8	7.0	7.9	7.4	8.2
Current [nA]	70	35	20	25	250	200	40	10

Test Beam at CERN SPS/PS in 2006: Setup

Bonn Telescope:
4 Si-strip tracking modules
(4 XY points along pion path)

Trigger scintillators



Pion Beam

T9: p=3.5G eV/c
T11: p=12 GeV/c
H8: p=20,100 GeV/c

BCM detector modules

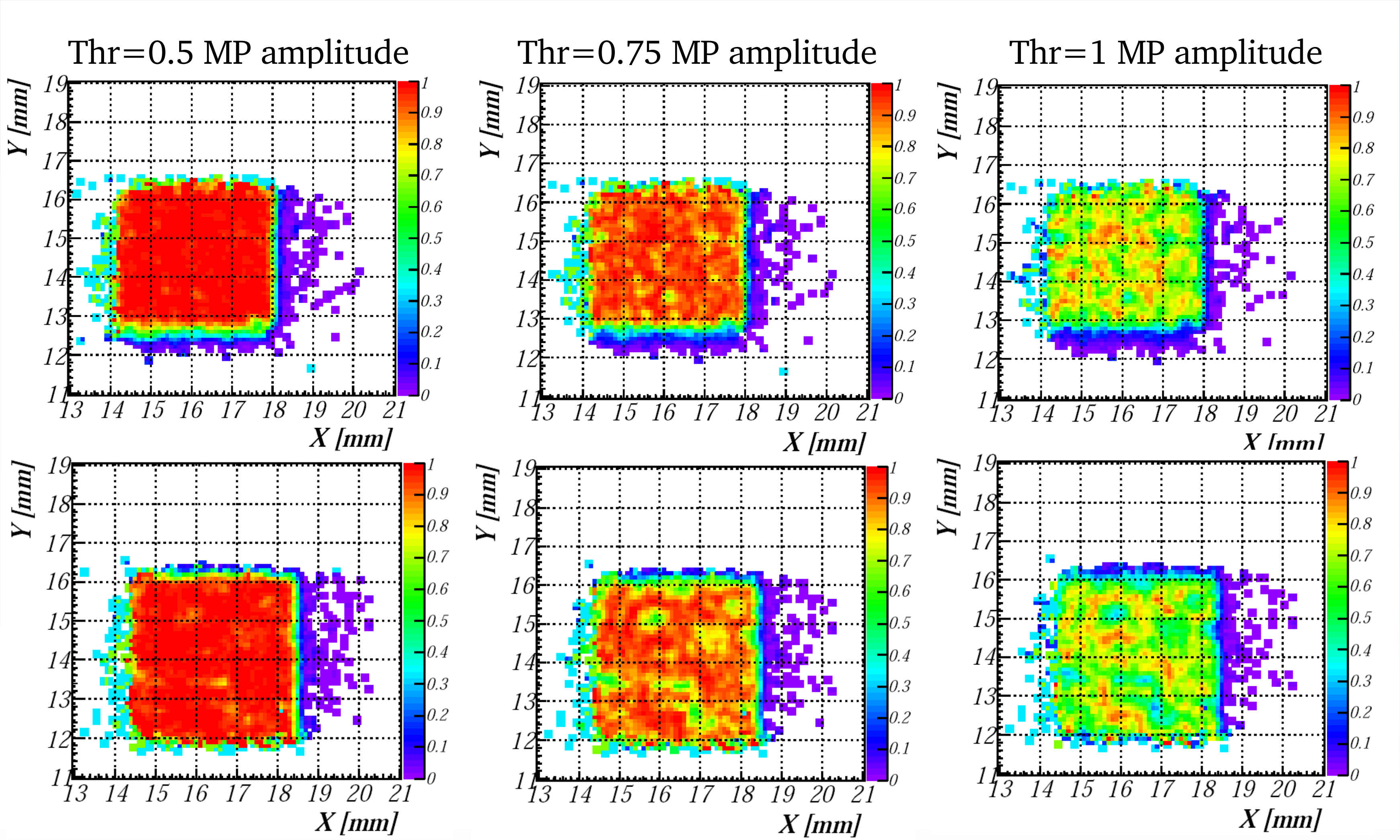
Test Beam at CERN SPS/PS in 2006: *xy* efficiency scan with analogue signals

Moving in **steps of 0.1mm** across the *xy* surface, calculating the fraction of tracks with analogue signal above chosen threshold in **0.2×0.2 mm^2 square** at each step:

- non-uniformity due to the grain structure of the diamonds in assembly

Module F408

Module F403

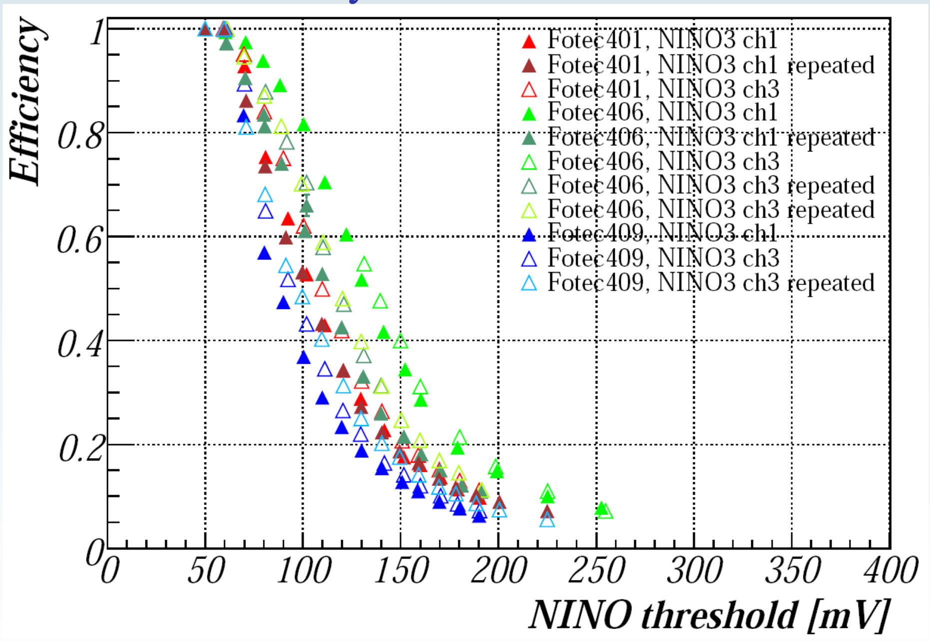


Test Beam at CERN SPS in 2007

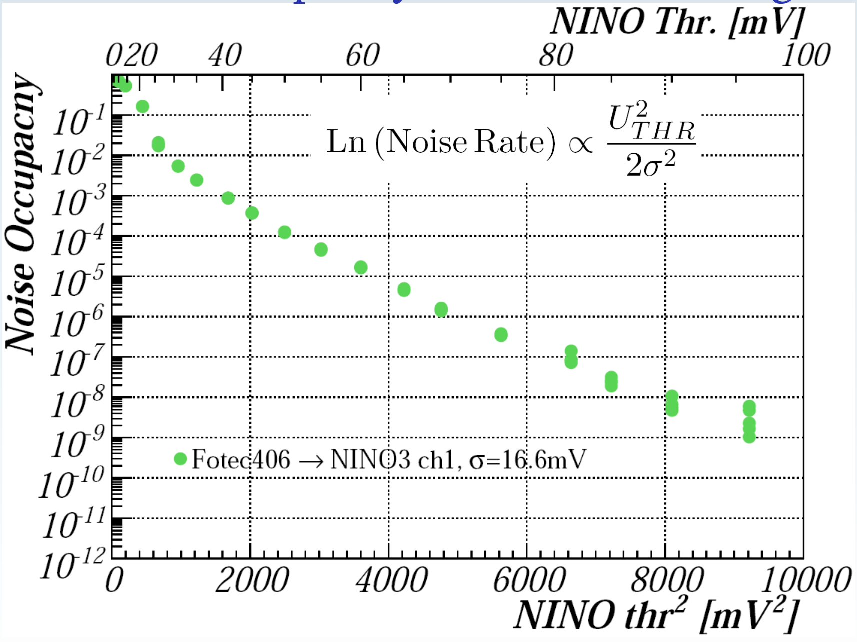
NINO board performance

- **Efficiency** curve with triggering on an incident MIP measured by varying the discriminator threshold on NINO board
  - median signal at 100-130mV with different modules
  - **final boards**: new amplification added (Mini Circuit GALI-52) to make system more manageable
- **Noise rate** measured in the lab:
  with spare detector module (F406, typical of those installed in ATLAS)
  → RMS noise σ=17mV, median signal ≈125mV → median S/N≈7.3

1MIP Efficiency

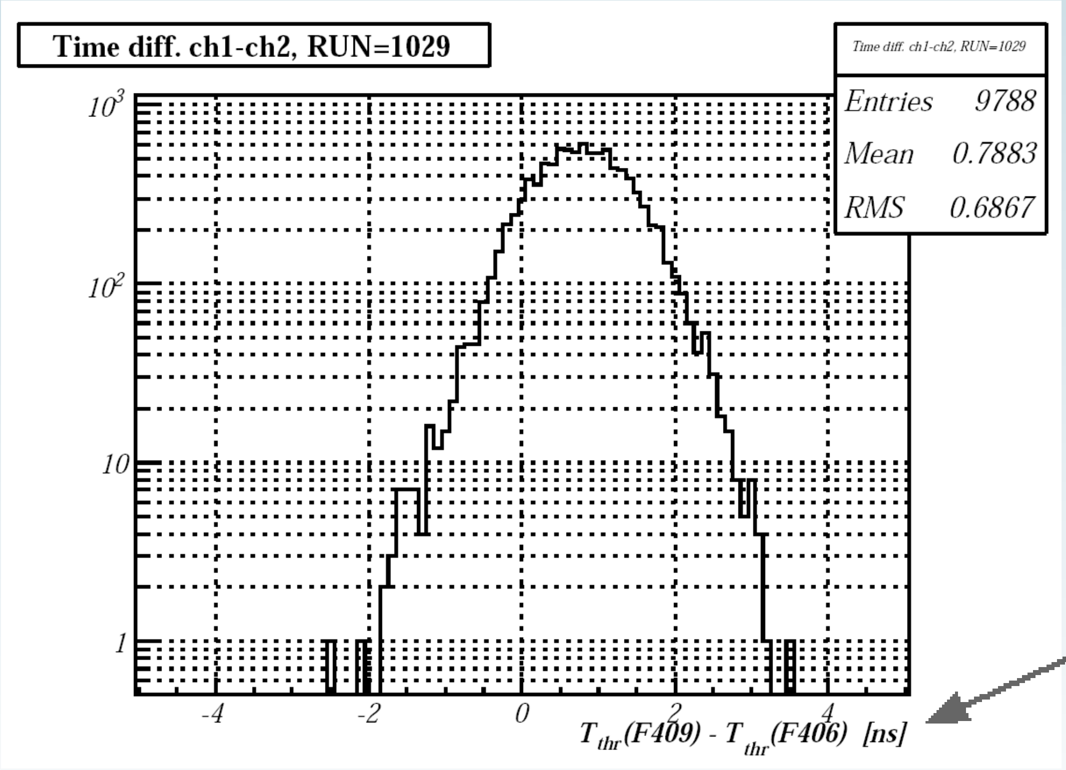


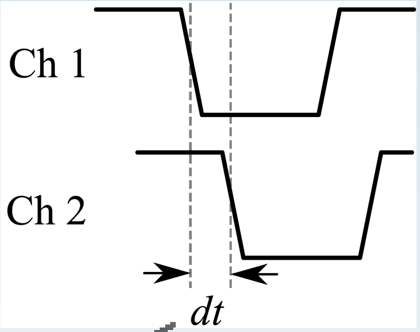
Noise Occupancy in bunch crossing



Timing resolution after TOT

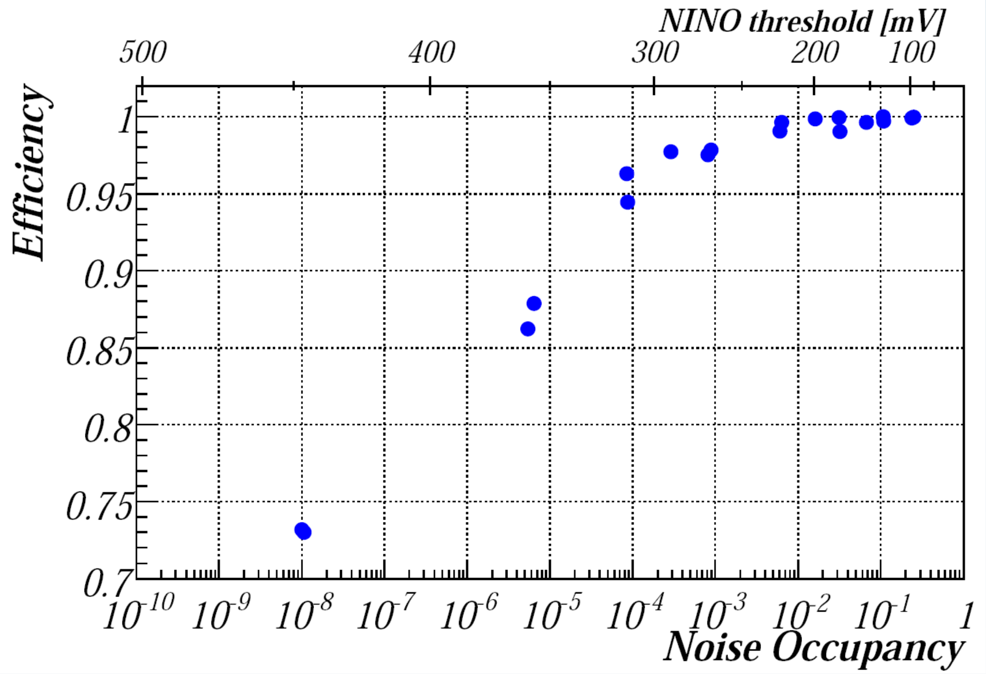
- Calculated time difference between NINO pulses
- RMS of time difference distributions bellow 1.1ns for scanned threshold range
  → time resolution for one module < 780ps





Performance of final NINO boards: Efficiency, Noise Rate

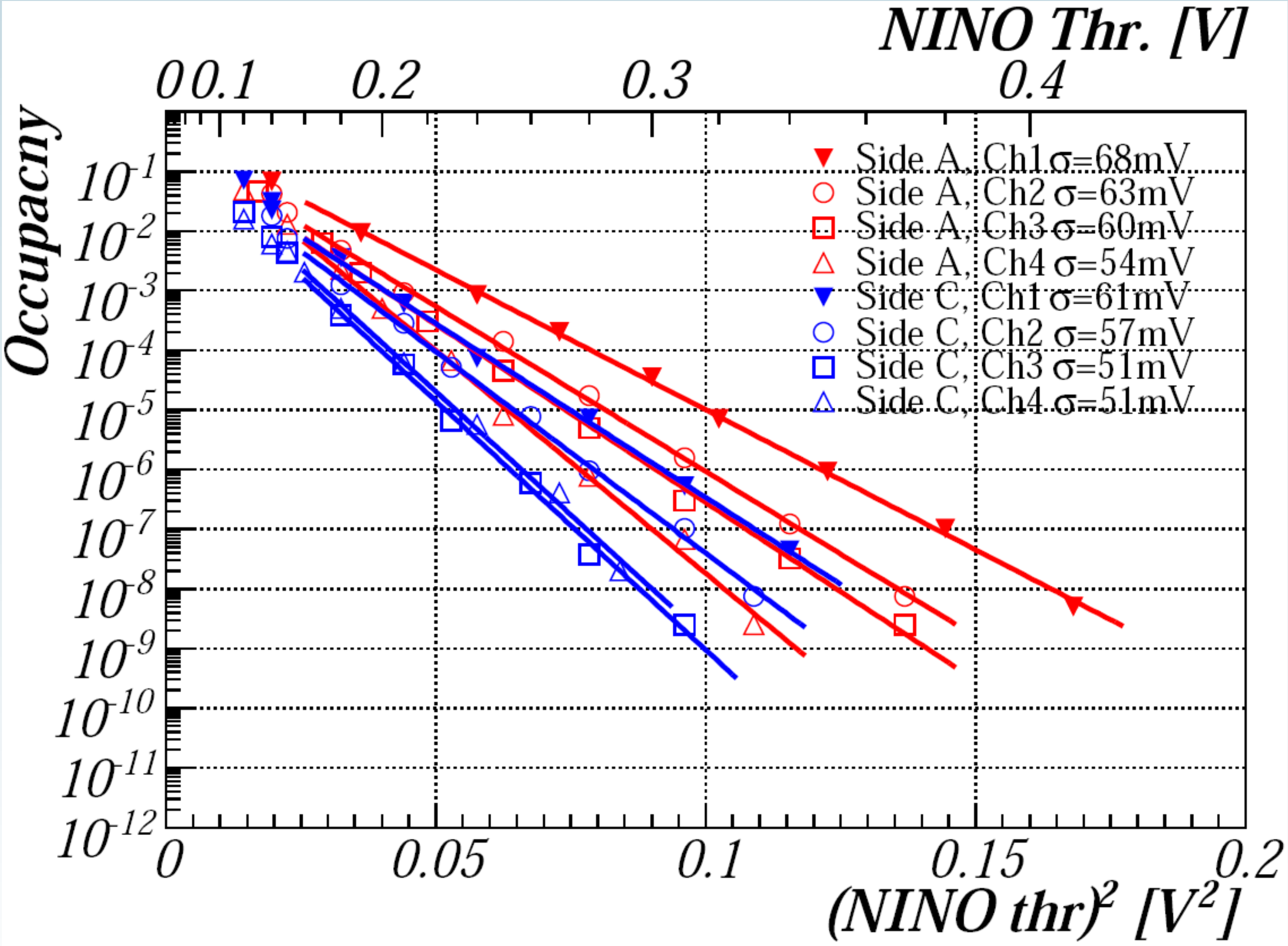
- Final NINO boards: with additional **amplification**
- **Noise RMS** estimated from noise rate measurement in lab with spare final NINO board and module F406 σ=75mV
- **Efficiency** curve measured with spare NINO board and module F406
  - ^{90}Sr source, trigger on BCM detector module signal (**non MIP** efficiency curve)
  - measured curve for final board **scaled to curve for 1MIP** (scaling factor calculated by comparing test beam and ^{90}Sr measurements obtained for the board tested in test beam):
    median efficiency ≈ 590mV, median S/N≈7.9



- 1MIP efficiency versus noise occupancy (noise rate scaled to 25ns interval – bunch crossing in ATLAS)
  - efficiency 0.95 – 0.99 for occupancies 10^{-3}–10^{-4}
- The exact level of fake rate depends on what kind of logical combination of signals will be used in ATLAS

Performance of installed NINO boards

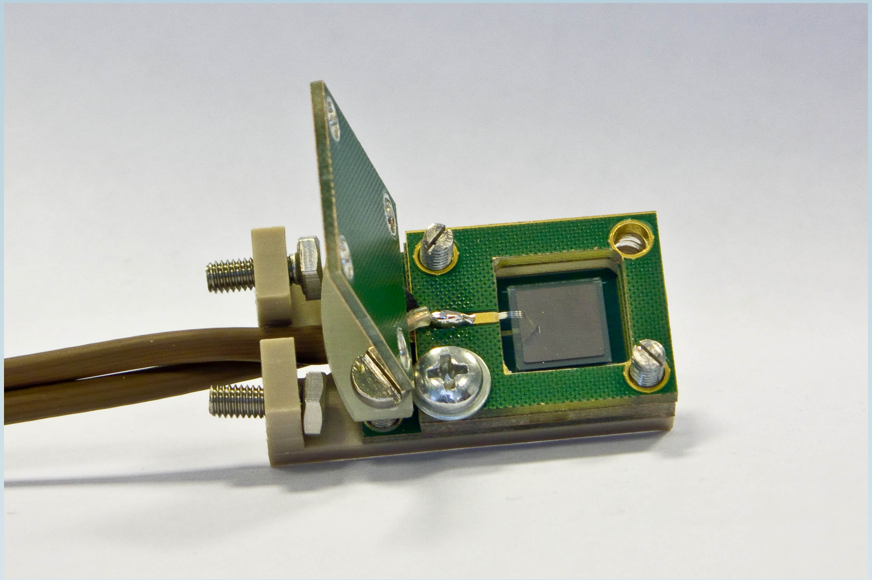
Noise rate measured in ATLAS pit (after installation of NINO boards in ATLAS)

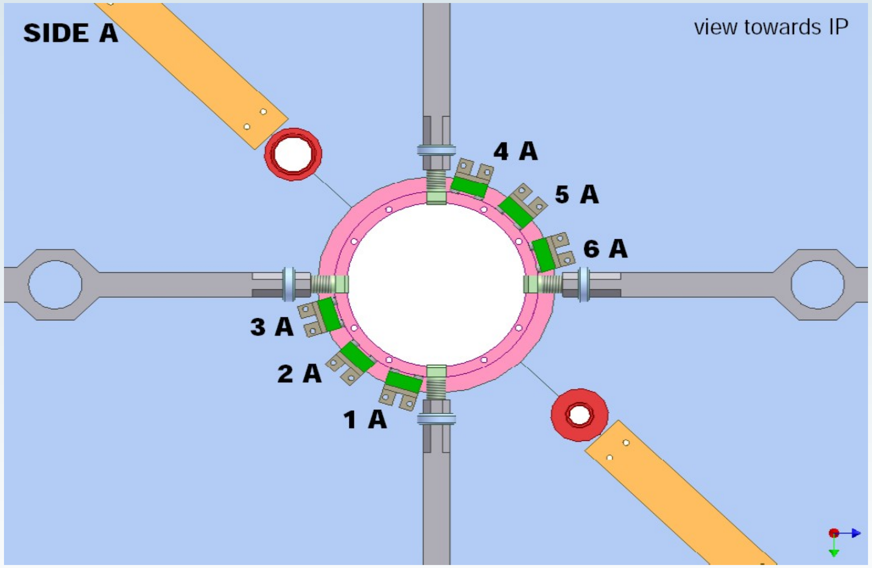


BLM - Redundant System

- **BLM – Beam Loss Monitor**
  - Mostly copied from BLM system installed in BaBar
  - **Sensors:**
    - one pCVD 8×8mm^2 diamond, 500µm thick. metallization 7×7mm^2
    - operated at +500V
    - current @500V typically <1-2pA
  - **12 diamonds** (6+6) installed on Inner Detector End Plate at pixel PP1 in May 2008
  - 12m coax to PP2 (radiation tolerant BLM cards)
  - **Digitization of ionization current** in diamond over 40µs, converted to frequency at PP2 (LHC CFC cards, radiation tolerant)
  - **Optical transmission** to USA15 counting room, recorded by Xilinx FPGA

- Use standalone in case of BCM troubles, otherwise complementary information





Summary

- ATLAS BCM will monitor beam conditions close to IP using **TOF measurement**
- **pCVD diamonds** as sensor material
  - 2 diamonds in a back-to-back configuration
  - at 45^{o} towards the beam
- Test beam and lab results indicated **operable system**
  - rise time, pulse width, S/N meet criteria
  - efficiency, noise occupancy acceptable
- **Status:**
  - BCM and BLM (redundant system) installed
  - focus shifted towards development of FPGA algorithms