Beam Conditions Monitor in ATLAS

I. Dolenc[1], V. Cindro[1], H. Frais-Kölbl[6], A. Gorišek[1], E. Griesmayer[6], H. Kagan[4], G. Kramberger[1], I. Mandić[1], M. Mikuž[1,2], H. Pernegger[3], W. Trischuk[5], P. Weilhammer[3], M. Zavrtanik[1]

[1]Jožef Stefan Institute, Ljubljana Slovenia; [2]University of Ljubljana, Slovenia; [3]CERN, Geneva, Switzerland; [4]Ohio State University, Columbus, USA; [5]University of Toronto, Toronto, Canada, [6]Fotec, Wiener Neustadt, Austria

Mail to: irena.dolenc@ijs.si

ABSTRACT

In order to monitor beam conditions and detect signs of beam instabilities which could cause damage to their detectors, LHC experiments have decided to develop their own system in addition to those provided by accelerator. ATLAS Beam Conditions Monitor (BCM) is the first monitoring system that is based on single beam bunch crossing measurement rather than integrating the accumulated particle flux. It consists of eight detector modules with polycrystalline CVD diamond pad sensors, placed symmetrically around the interaction point along the beam axis. By use of fast electronics, time-of-flight measurement will provide unique distinction between normal beam events of colliding protons and anomalous events which induce background and could in worst case damage the ATLAS detector. Additionally BCM modules will be used to measure interaction rate providing an estimation of LHC luminosity.

In January 2007 eight final modules were installed onto ATLAS Beam Pipe Support Structure.

PURPOSE

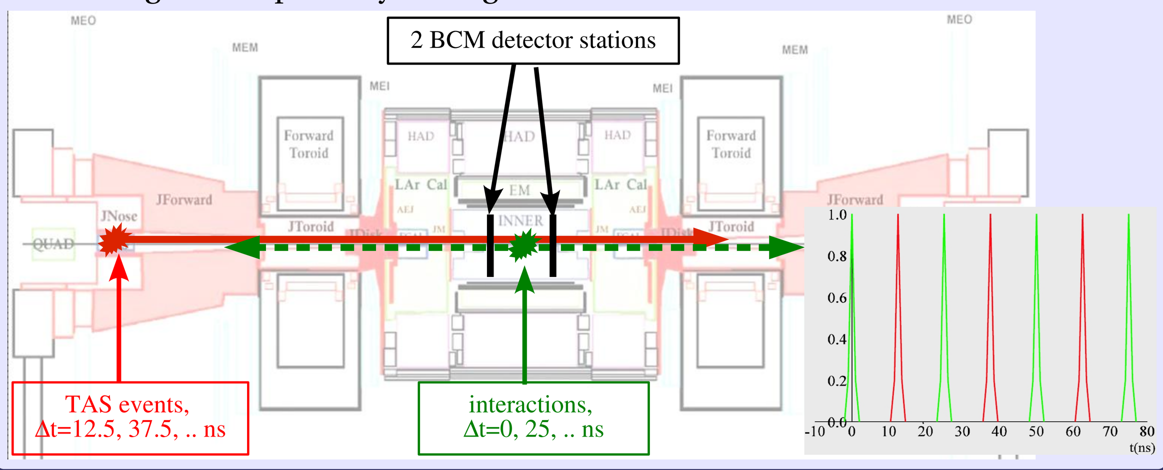
- To detect signs of beam anomalies in ATLAS such as
  - Beam scraping the TAS collimator
  - Beam gas interactions
- Provide information about p-p interactions
  - Luminosity monitor

REQUIREMENTS

- Multiple interactions every 25ns → fast signal
  - Rise time <1ns
  - Width <3ns
  - Baseline restoration in <10ns
- One 7TeV proton hitting TAS collimator gives ~1MIP/cm² → single MIP sensitivity
- Installation close to the beam pipe at large η
  - Radiation hardness of sensors up to 30MRad and 10^{15} particles/cm²
  - No maintenance

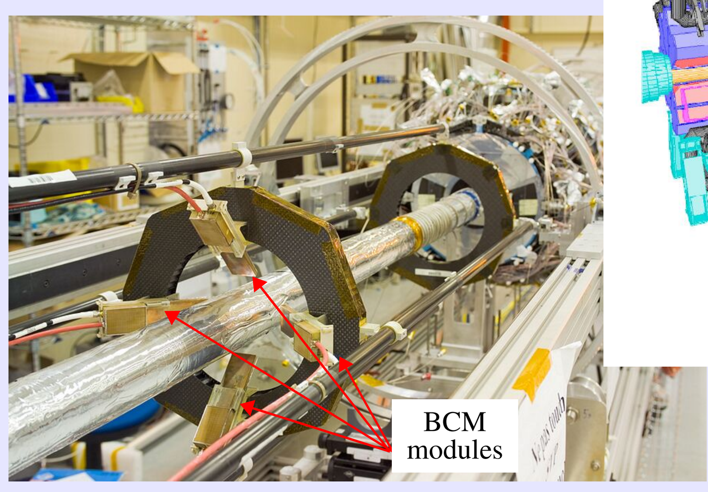
WORKING PRINCIPLE

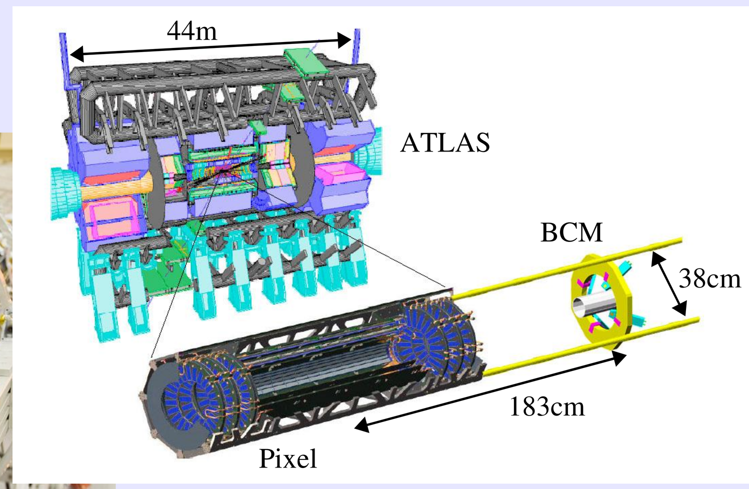
- Distinguish background events (TAS, beam-gas interactions) from interaction events by the time difference between two successive signals
- Two detector stations placed symmetrically around IP at $\mp z$:
  - Interactions - signals every 25ns
  - Background - signals at $\Delta t = 2\Delta z/c$ on one side
- Background optimally distinguished with Δt=12.5ns ⇒ Δz=1.9m



REALIZATION

- Two stations, each with eight detector modules at ϕ=0°, 90°, 180°, 270°
  - Mounted on Beam Pipe Support Structure at z=183.3cm
  - Sensors at r~55mm

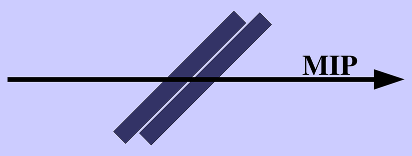


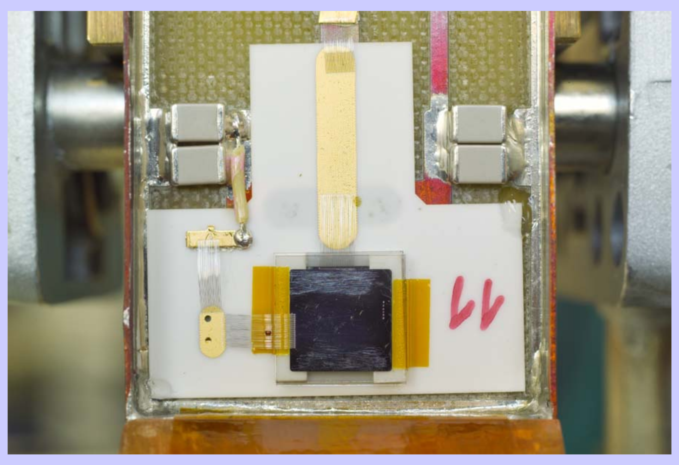


Polycrystalline CVD diamond SENSORS

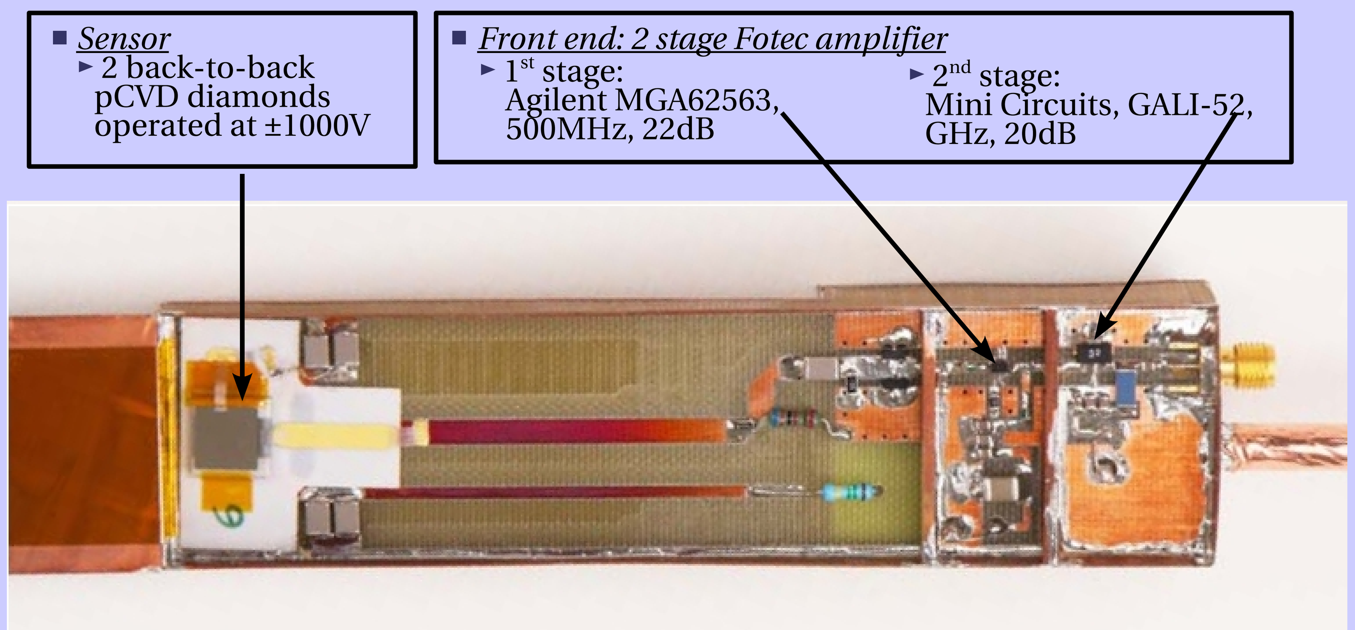
- Fast and short signal
  - High charge carrier velocity – sensors will be operated at 2V/µm, close to velocity saturation
  - Short trapping times even before irradiation
- Low leakage current – no cooling required
- Irradiation hard - shown to withstand fluences up to 2.2×10^{15}p/cm²
- Characteristics of BCM diamonds
  - Developed by CERN RD42/Element Six Ltd., metalized with radiation hard process at Ohio State University
  - Size 10×10cm², thickness ~500 µm
  - Charge collection distance ~220 µm
- Sensor assembly:

  two diamonds back-to-back at 45° to increase the signal

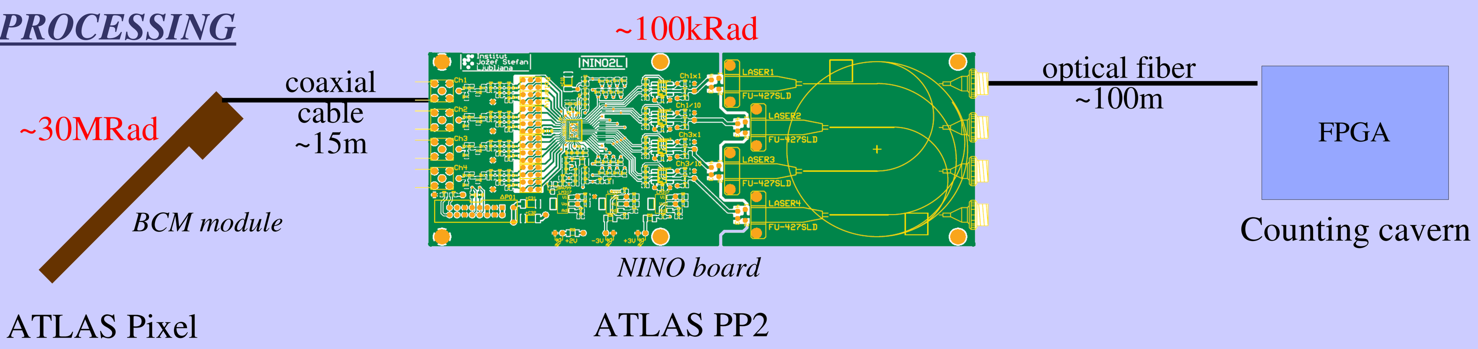




DETECTOR MODULE



SIGNAL PROCESSING

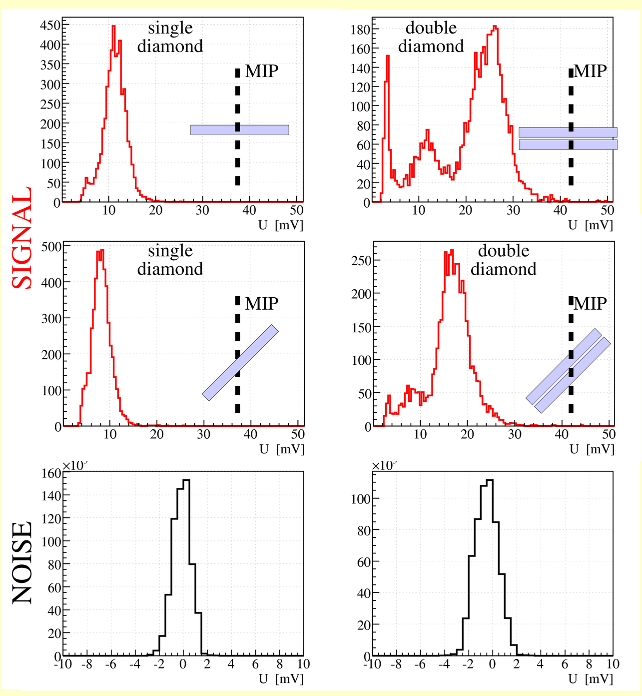


BACK – END: NINO chip

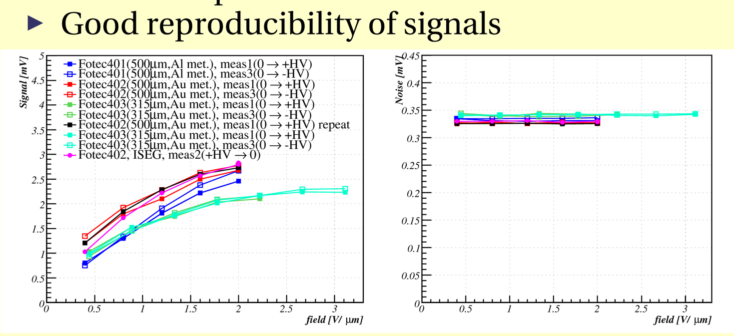
- Timing amplifier-discriminator
- 1ns peaking time, 25ps jitter
- Designed at CERN for ALICE ToF
- Pulse width depends on input charge (time-over-threshold LVDS output)
- Radiation tolerant
- Signal split in to 2 inputs (1:12) to increase dynamic range

BCM MODULE TESTS

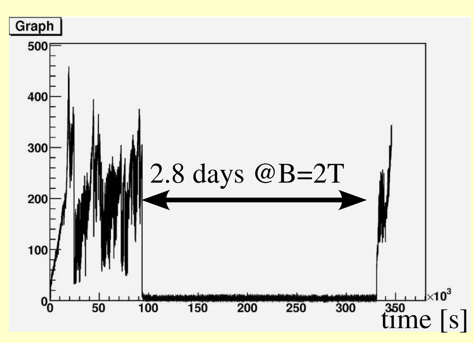
- **Beam test at MGH Boston in October 2004**
  - Proton beam 200MeV and 125MeV (signal ≥2.3MIPs)
  - Single and two back-to-back sensors at 90° and 45° to the beam
  - 90°→ 45°: signal increase by ~√2
  - single diamond → double diamond: signal increase by factor 2, noise by ~30%, SNR improved by ~50%



- **Bench tests**
  - 30MBq ^{90}Sr source (~ MIP signal), signals recored with LeCroy LC564A oscilloscope
  - Module stability tests (signal stable to few % during 24h)
  - Noise independent of HV
  - Good reproducibility of signals



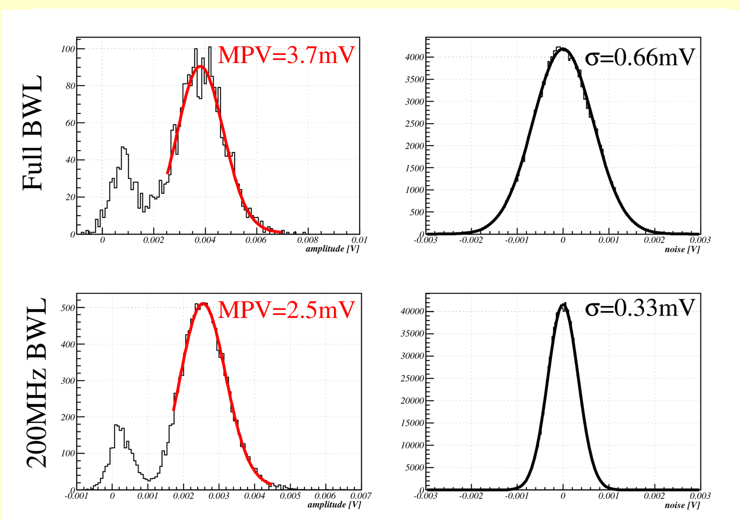
- **Leakage currents in pCVD diamond**
  - Leakage current increases by factor >100 on timescale of days; erratic behaviour on time scale of minutes; also observed in BaBar at lower fields 1V/µm
  - Module (inclined by 45°) placed in strong magnetic field Current stays <10nA



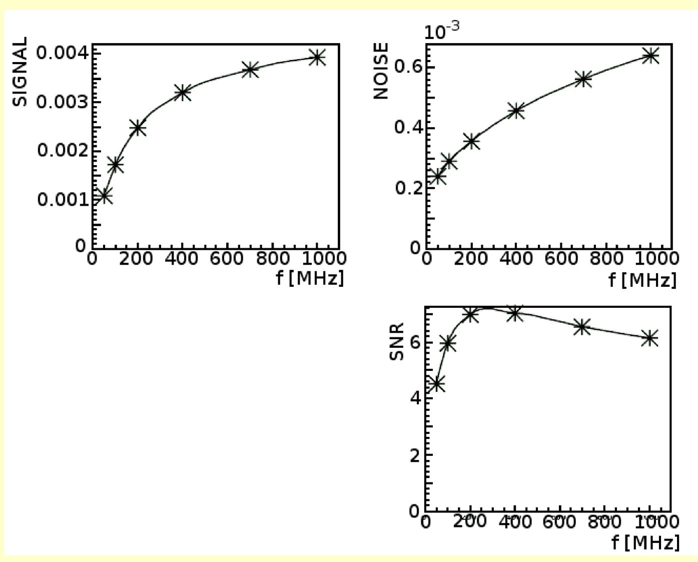
- **Bandwidth optimization**
  - Bench test with ^{90}Sr as MIP:

    Full bandwidth (500MHz) → 200MHz BW;

    SNR improved by factor ~1.3

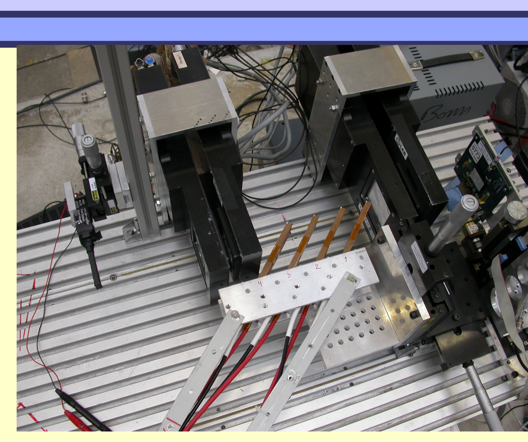


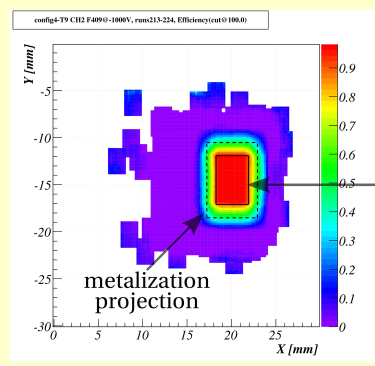
- Offline FFT analysis of BCM MIP signal (applying 1st order filter):

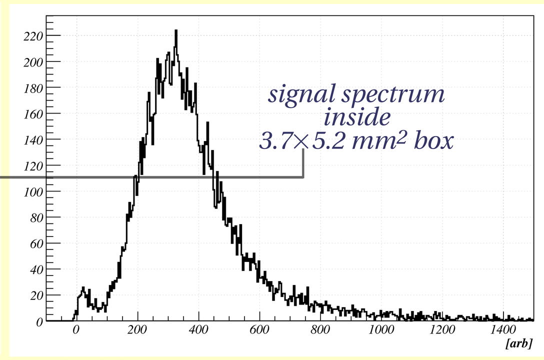


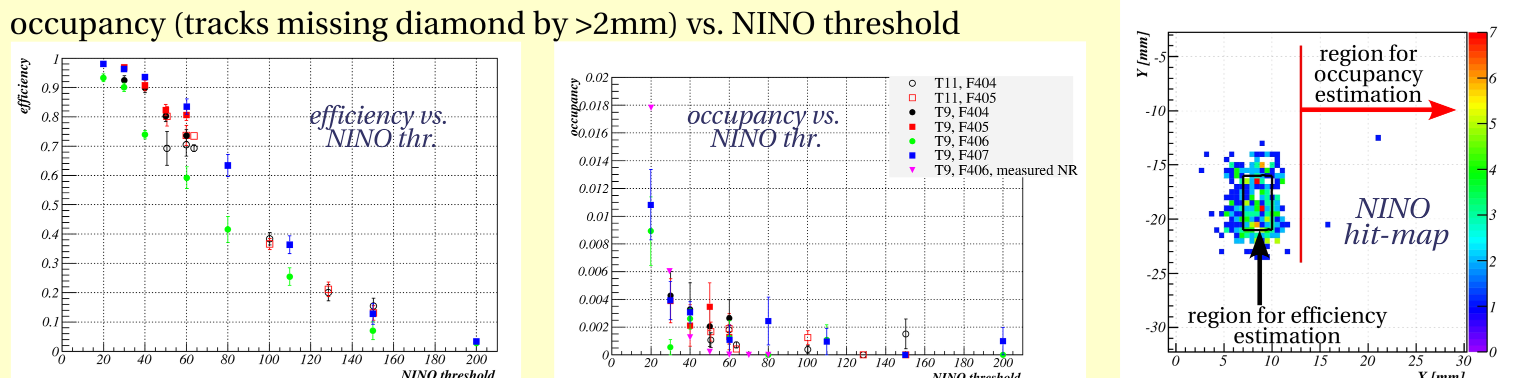
BCM MODULE TESTS

- **Beam test in CERN PS in summer 2006**
  - CERN PS T11 and T9 pion beam (3.5 and 12GeV/c) – ~MIP signal
  - Setup:
    - Analogue readout (BCM → ORTEC ampl. → CAEN ADC)
    - Time-over Threshold readout (BCM → NINO → CAEN ADC)
    - Final high and low voltage power supplies, cables, connectors
    - Tracking: Bonn Si telescope (4 horizontal, 4 vertical planes; resolution ~6µm)
  - Analogue data:
    - sensor uniformity (fraction of tracks with sig.>100 in 2×2.8mm² box, box moved in steps of 0.2mm over the sensor plane):
  - Time-over-Threshold data:
    - efficiency (tracks inside central diamond region 3×5mm²) vs. NINO threshold
    - occupancy (tracks missing diamond by >2mm) vs. NINO threshold









QUALIFICATION TEST of FINAL BCM MODULES

- Procedure:
  - Module PCBs properly cleaned (Vigon EMF solution)
  - Accelerated aging for one module (14h @ 140°C → >10years @20°C), infant mortality test for other modules (12h @ 80°C)
  - Thermal cycling (10 temperature cycles between -25°C and 40°C)
  - No change in SNR observed
- Bench tests with ^{90}Sr as source of MIP signal
  - Signals recoreded with LeCroy LC564A oscilloscope, 200MHz BWL applied
  - Signal: maximum value in 2ns interval
  - Noise: baseline fluctuations in 20ns interval before signal
  - No change in SNR observed after thermo-mechanical tests
  - Summary table for qualification tests of eight final modules:

Module	F410	F413	F420	F422	F404	F405	F408	F424
Bias [V]	+1000	+1000	-1000	-1000	+1000	+1000	-1000	-1000
Current	20	200	200	40	80	40	20	10
SNR	7.8	7.0	7.8	7.3	6.5	7.0	7.0	8.0