# Status of ATLAS diamond Beam Condition Monitor


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**Vertex 2007**

*16th International Workshop on Vertex detectors*
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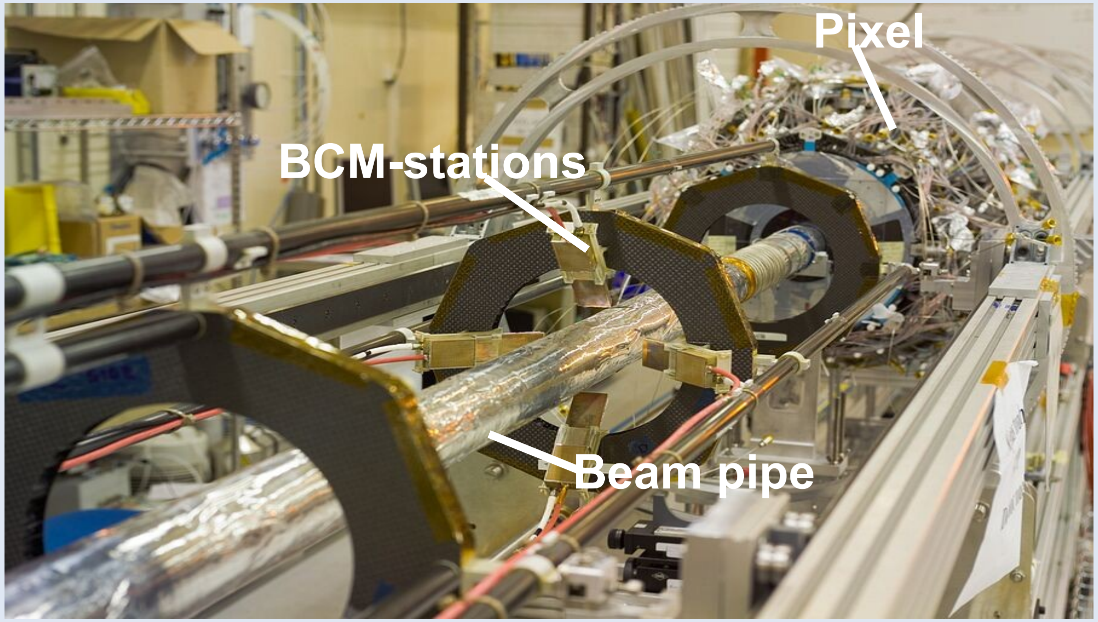


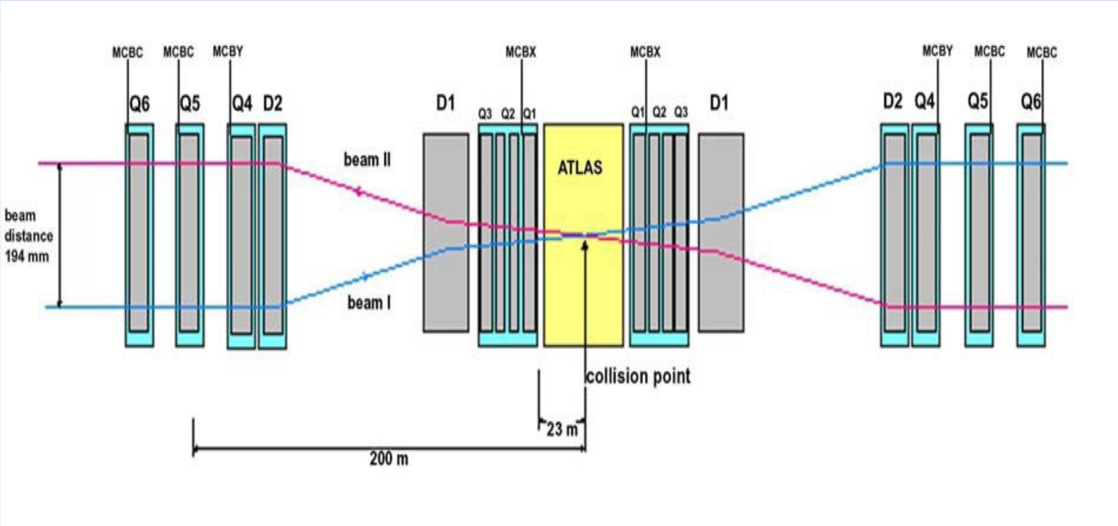
# The ATLAS BCM collaboration

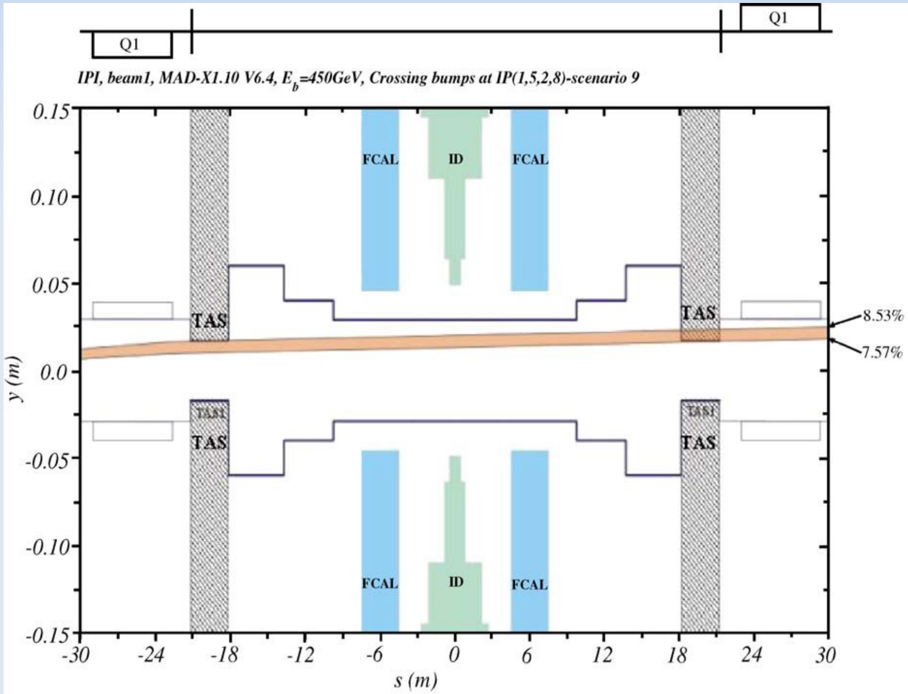
- ***JSI, Ljubljana***
  - V. Cindro, I. Dolenc, A. Gorišek, G.Kramberger, B. Maček, I. Mandić, E. Margan, M. Zavrtanik, M. Mikuž
- ***CERN***
  - D. Dobos, H. Pernegger, P. Weilhammer
- ***Univ. of Applied Science, Wiener Neustadt***
  - E. Griesmayer, H. Frais-Kölbl, M. Niegl
- ***OSU, Columbus***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

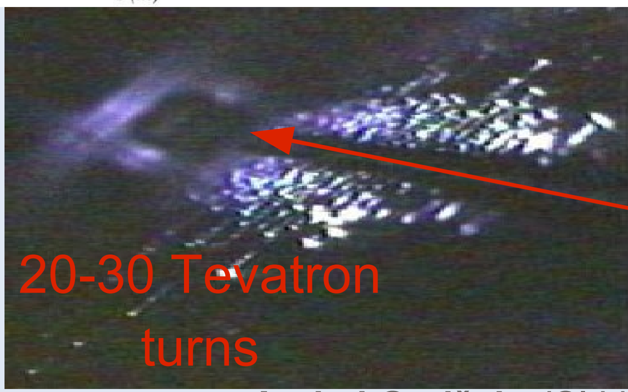
All you ever wanted to know about BCM:
https://twiki.cern.ch/twiki/bin/view/Atlas/BcmWiki

# BCM - motivation

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



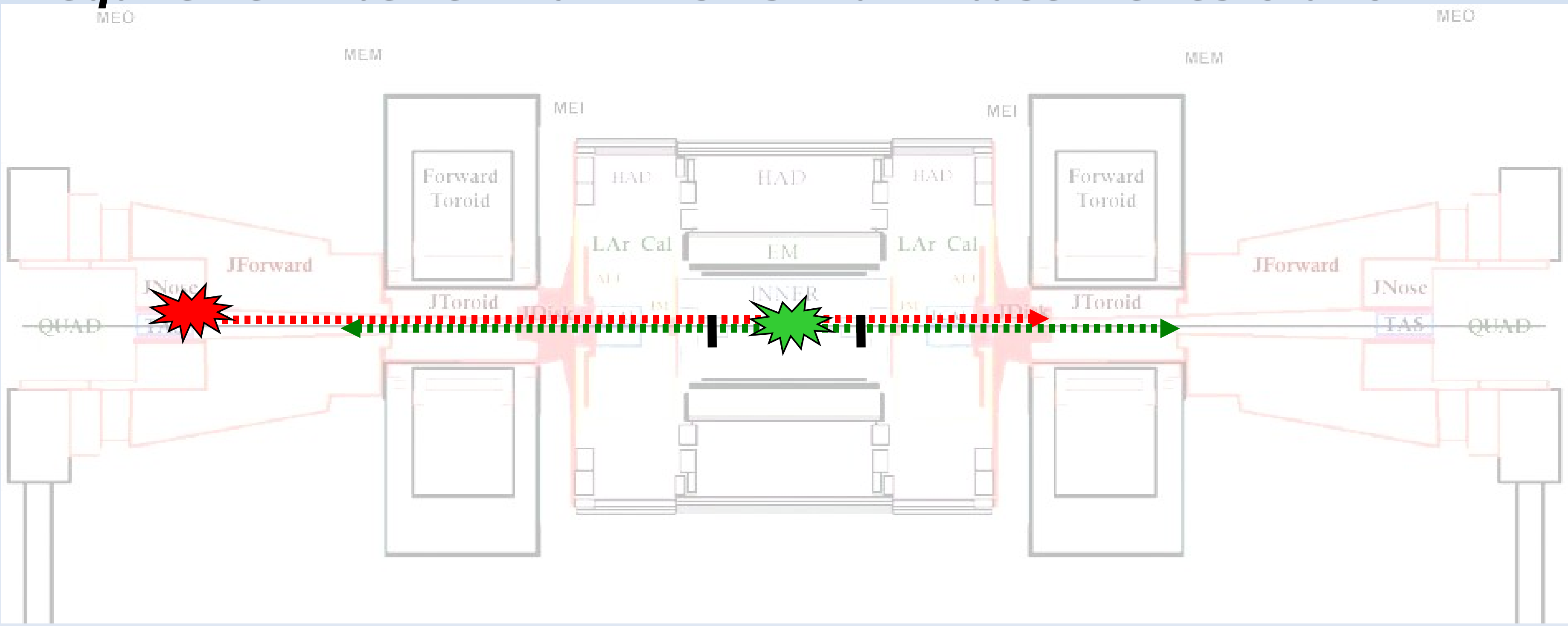

- ✦ Time constants of magnets large (~ms)
- ✪ Can abort beam if detected early

# BCM background vs. Interaction Events

Instantaneous measurement of beam conditions warning/alarm/abort signals in ATLAS @ LHC: 7 TeV/c protons (pp collision → several 100 tracks)

- 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: t = 0, 2z/c; Δt=2z/c

Interaction: Δt = 0, 25, ... ns

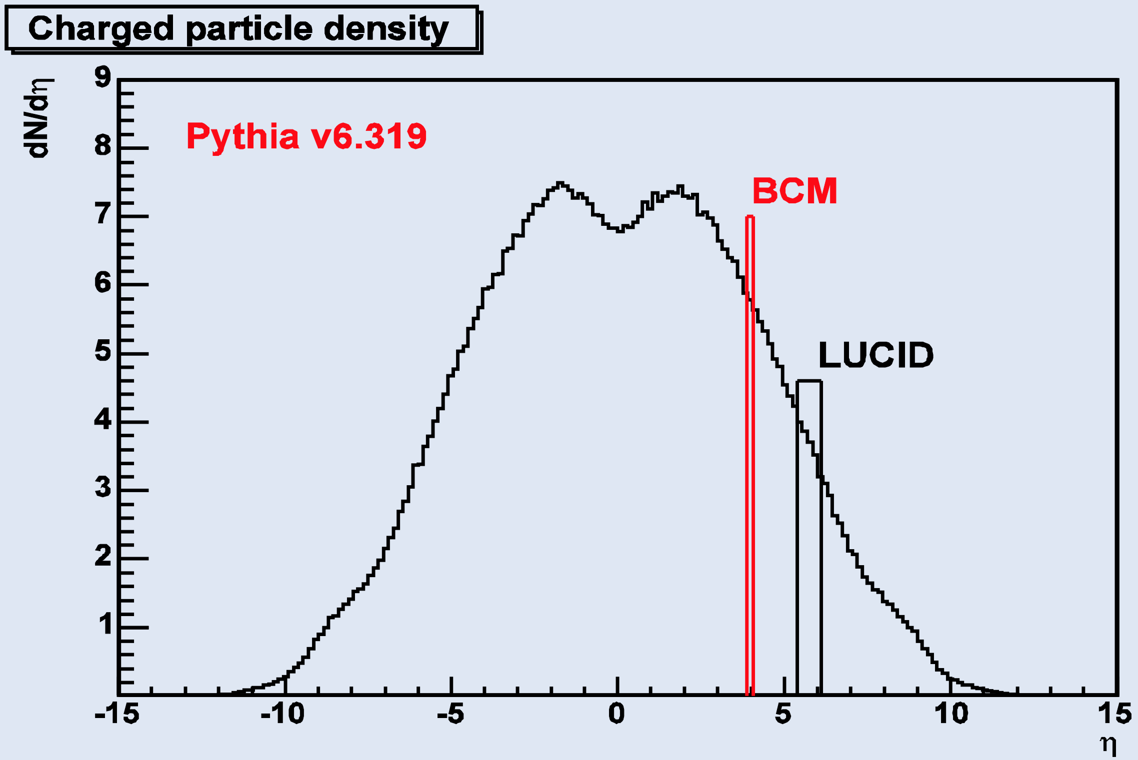
# Luminosity monitoring

Additional to ATLAS main luminosity monitor LUCID

Requirement: Single MIP sensitivity

- Poisson with average of < 1 MIP per diamond detector
- S/N for MIP's ~10:1 before irradiation
- 4 detectors per station (coincidence)

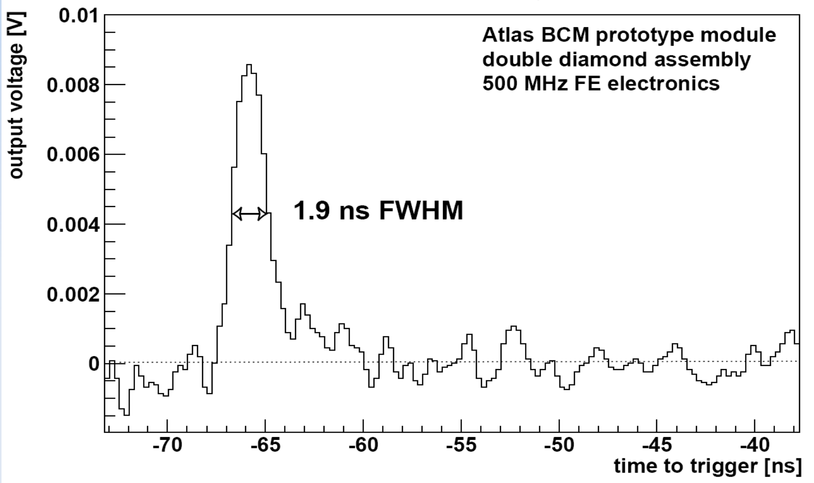
Provides instantaneous monitoring of BX rates and luminosity (at $\eta$~4).

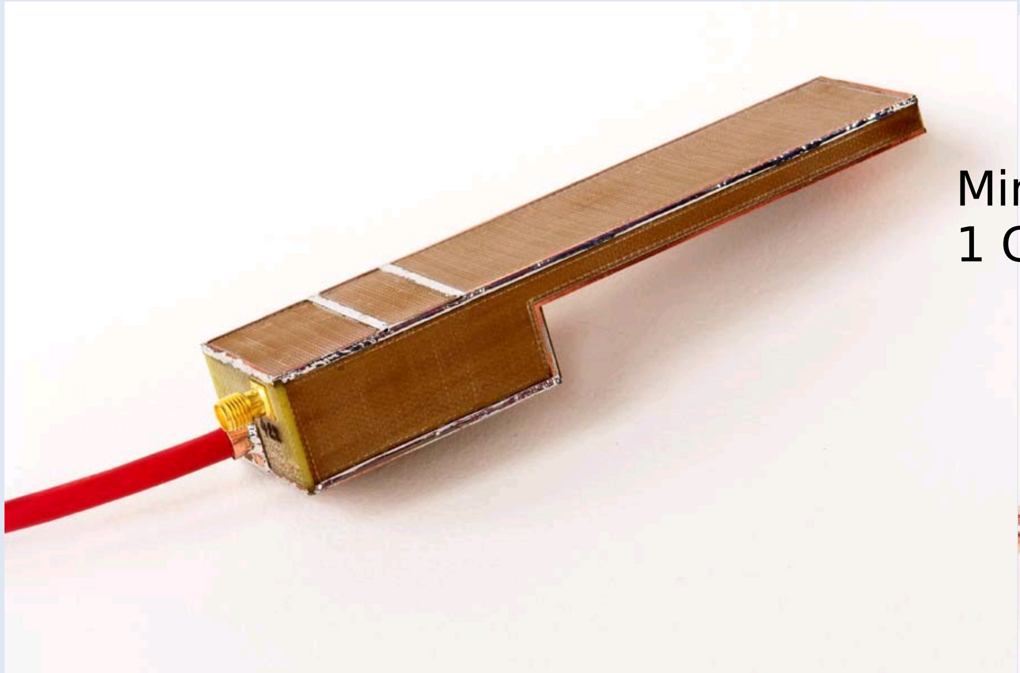


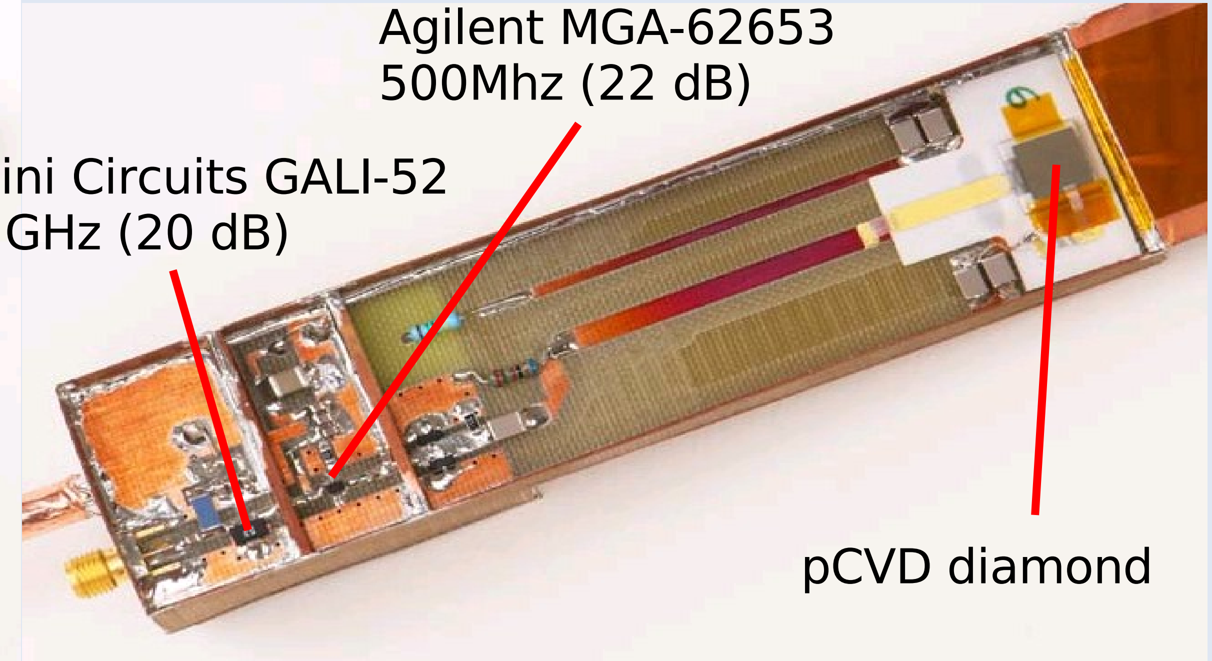
# Detector module

- pCVD diamond sensors (10x10 mm$^2$, contact 8x8mm$^2$, 500µm thick)
  - Shown to withstand > $10^{15}$ p/cm$^2$
- 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***

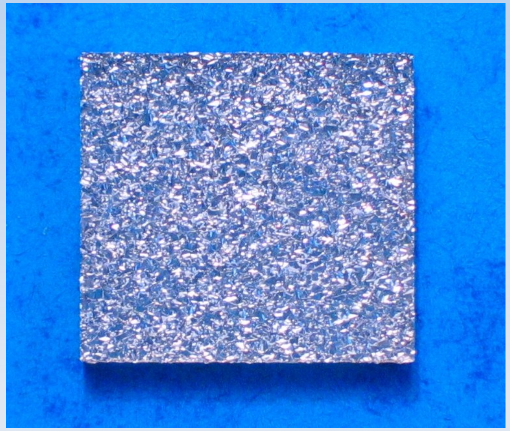


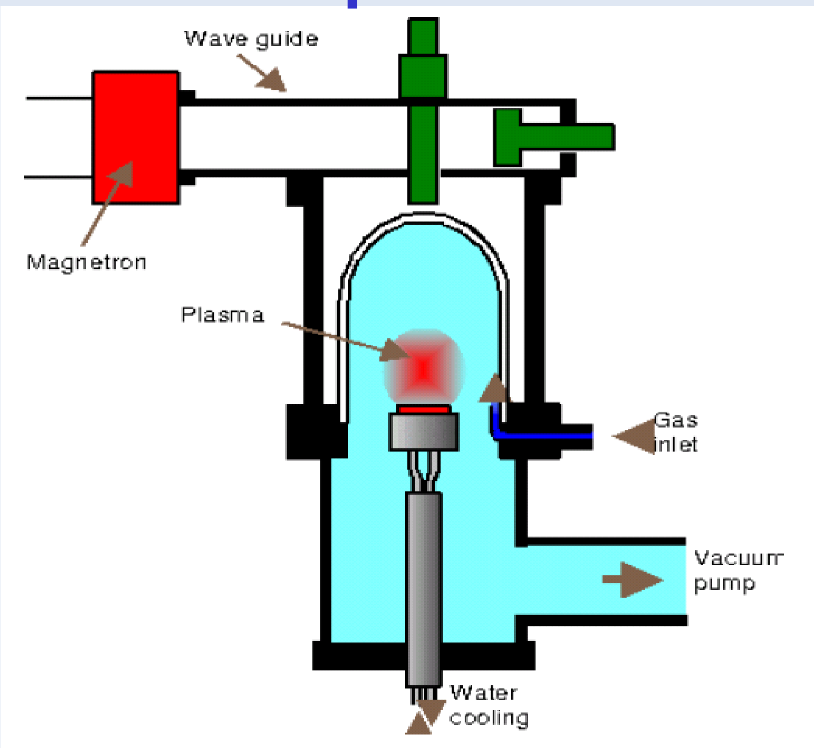


# Diamond sensors

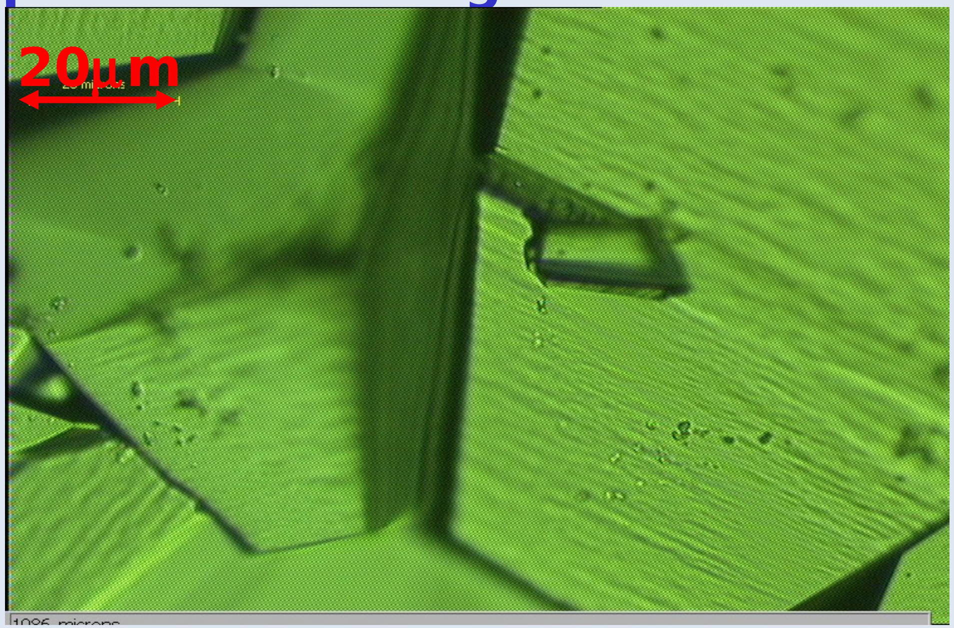
- developed in collaboration RD42 and Diamond detectors Ltd.
- synthesized in microwave plasma reactor
- substrate determines the diamond growth (Si → polycrystalline diamond or diamond substrate → single crystal diamond)
- growth speed ~1μm/h



**microwave plasma reactor**



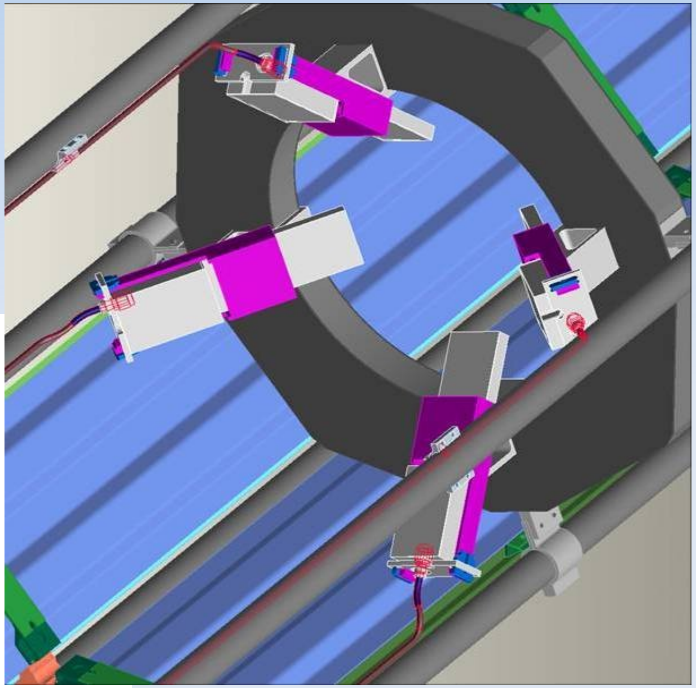

**pCVD diamond growth surface**

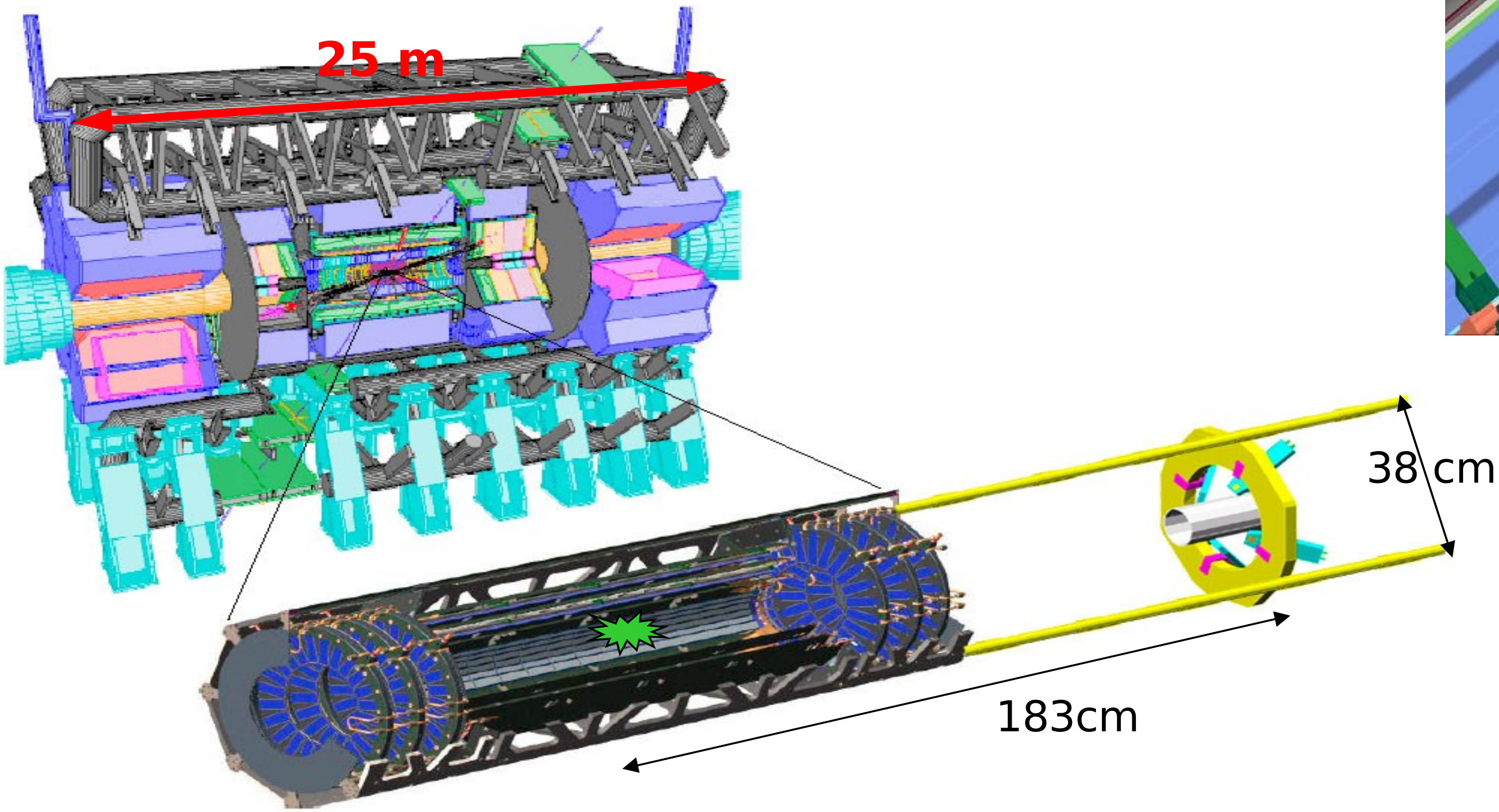



→ see later talks by W. Trischuk and K. Oliver

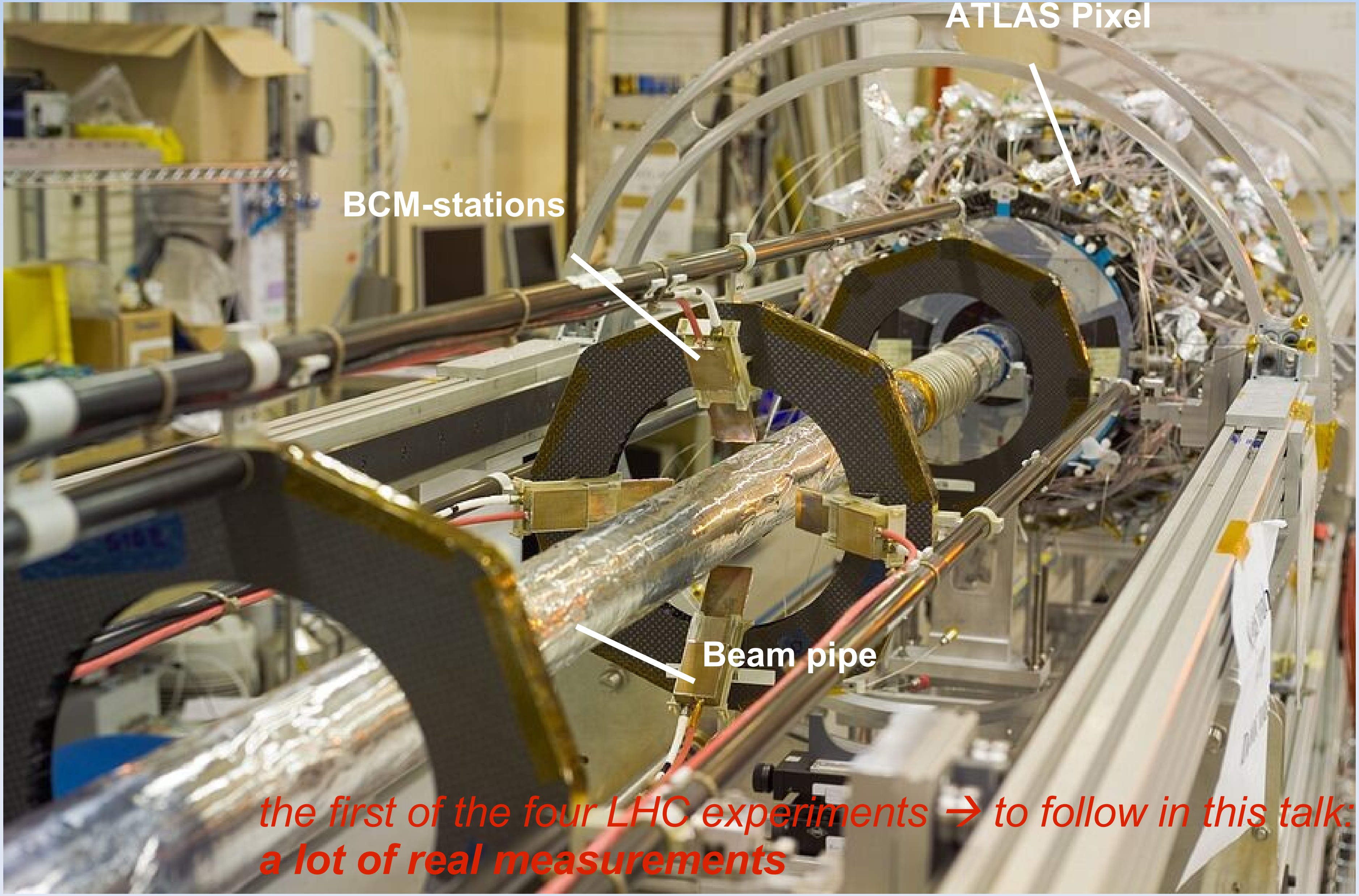
# Implementation

- 4 BCM stations on each side of the ATLAS Pixel detector
- Mounted on Beam pipe support structure at
  z = ±183.8 cm (~12.5ns) and r ~ 5 cm (diamond sensor)



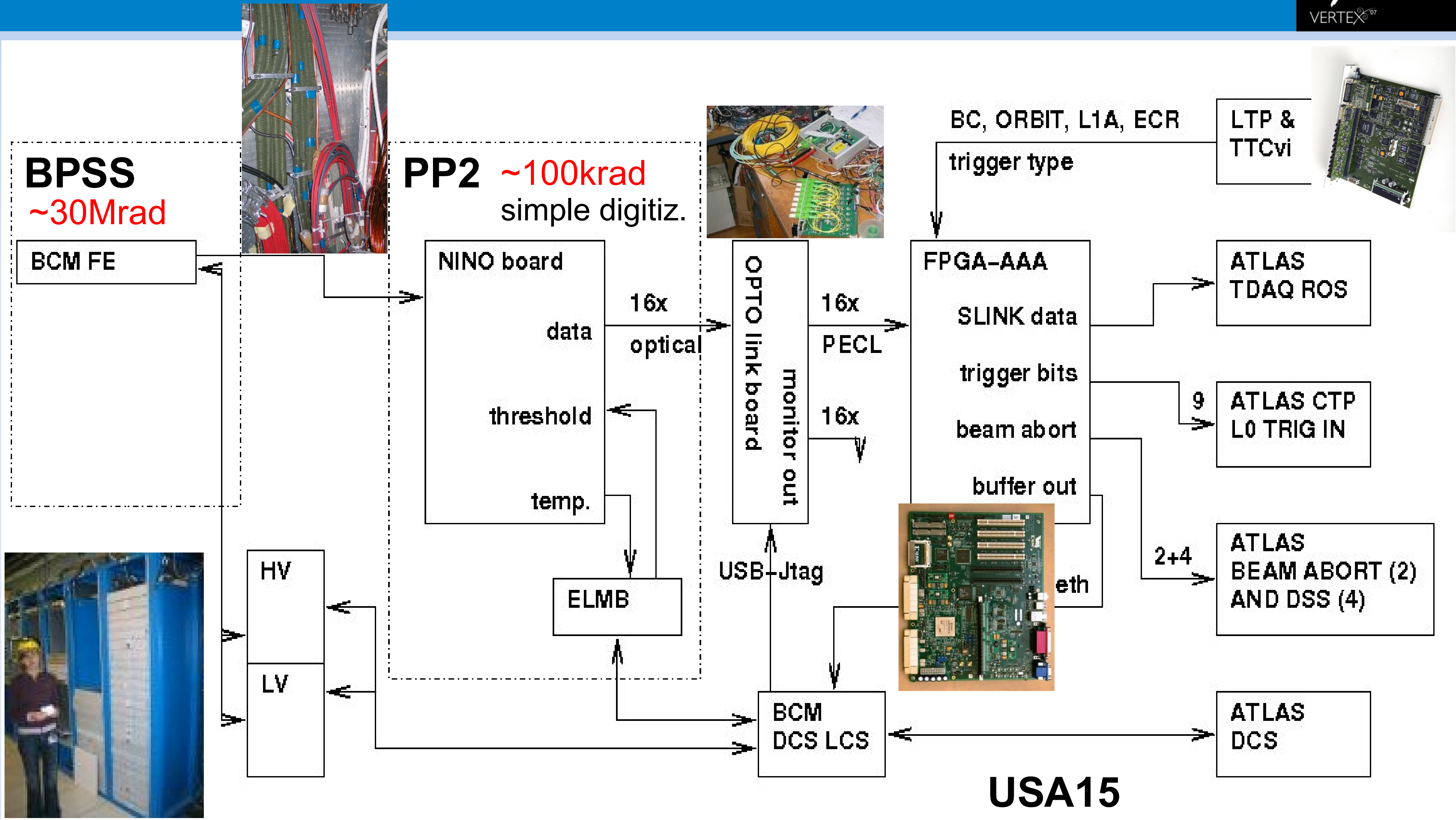



# BCM installed



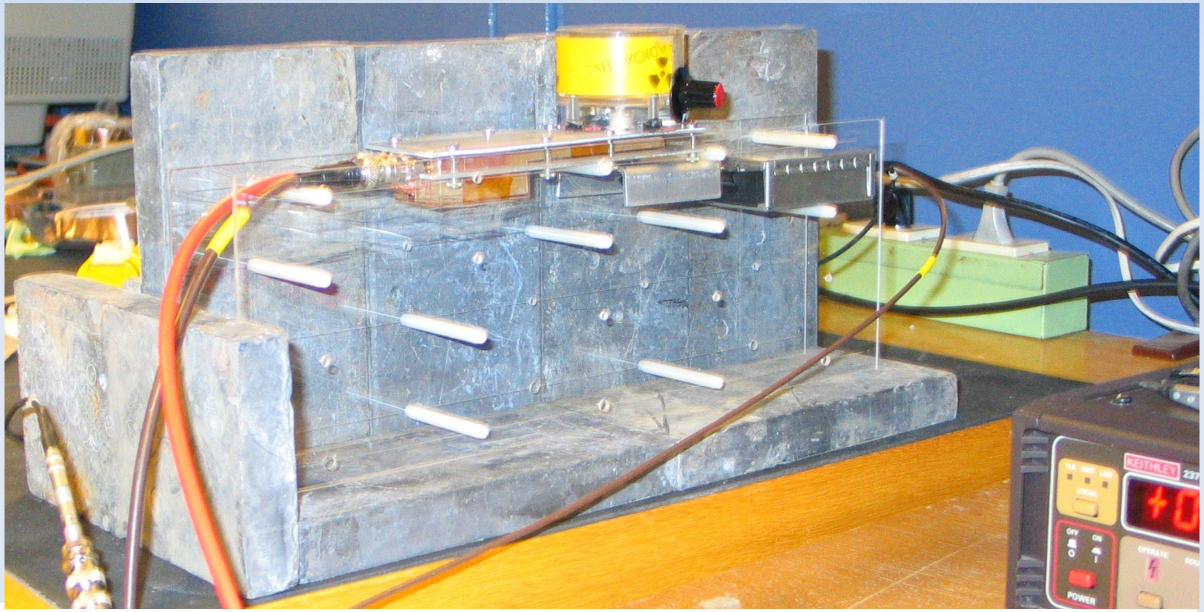

*the first of the four LHC experiments → to follow in this talk:*
***a lot of real measurements***

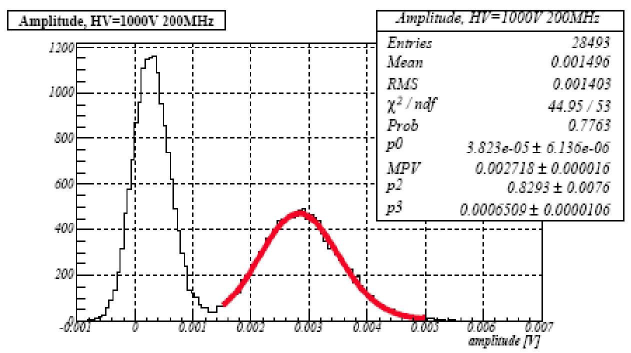
# BCM connectivity

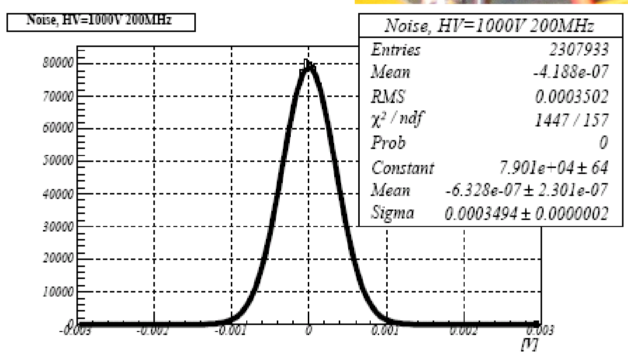


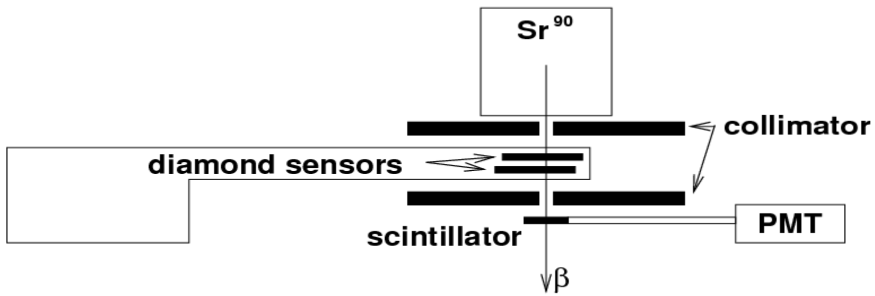
# BCM QA

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





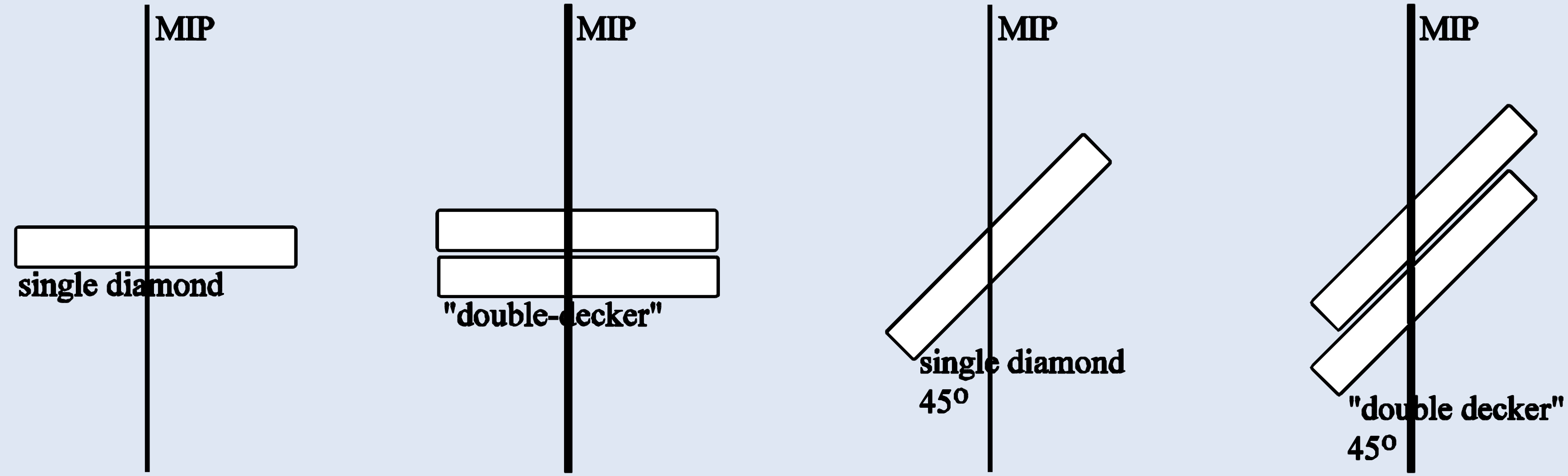



# Design consideration
# ”double decker”, 45°

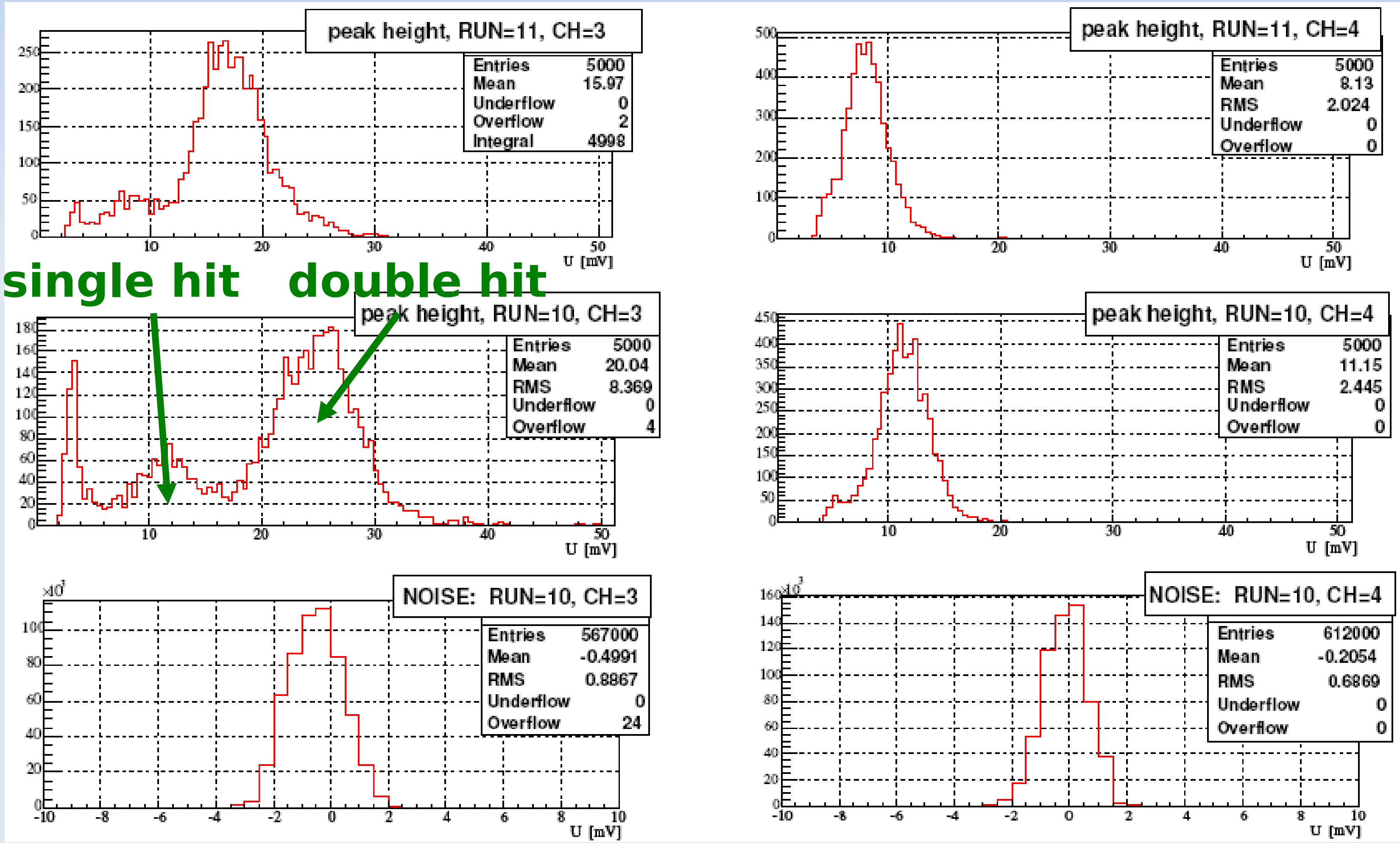
Comprehensive R&D program in last 2 years

- two diamonds: signal x2, noise increase for ~30%
- 45 : signal increases for ~41% noise doesn't change
- thick (500μm) diamond give larger pulses than thin (350μm) at field of 2V/μm
- Optimization of the band width of the FE electronics (optimal BW around 200-300 MHz)



# Design consideration beam test

**”Double-decker”** | **Single diamond**




**0°**

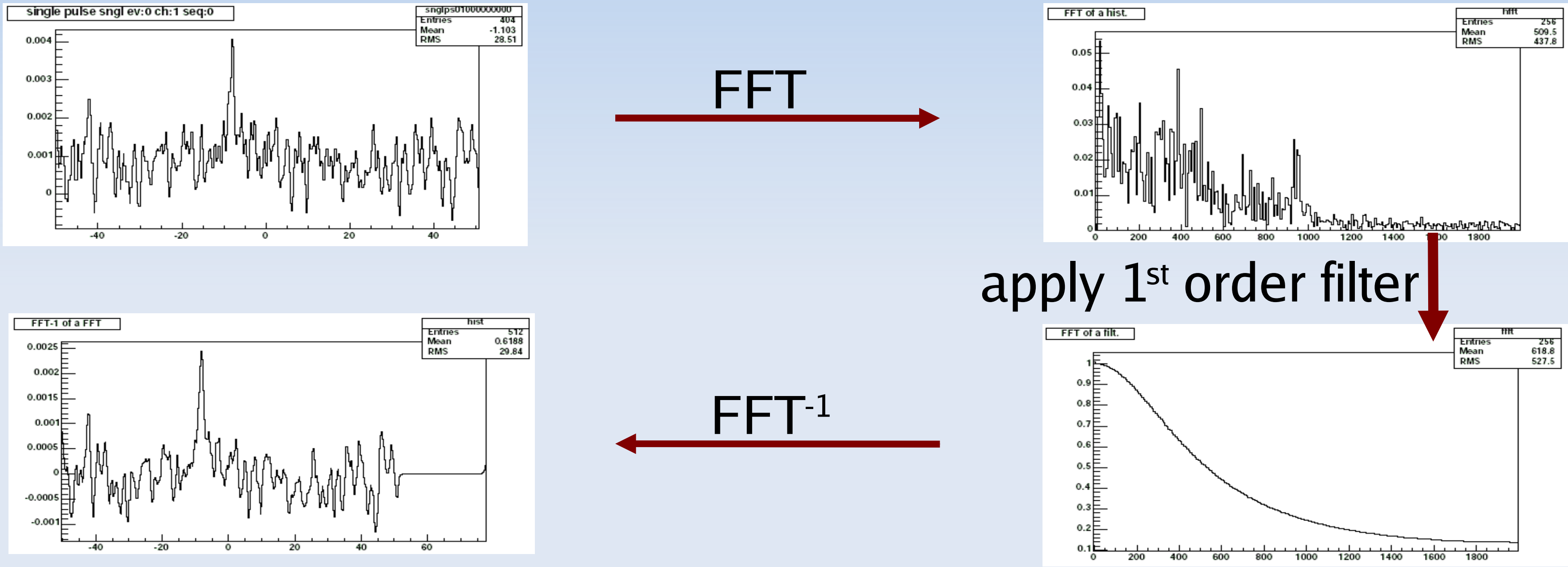
**45°**

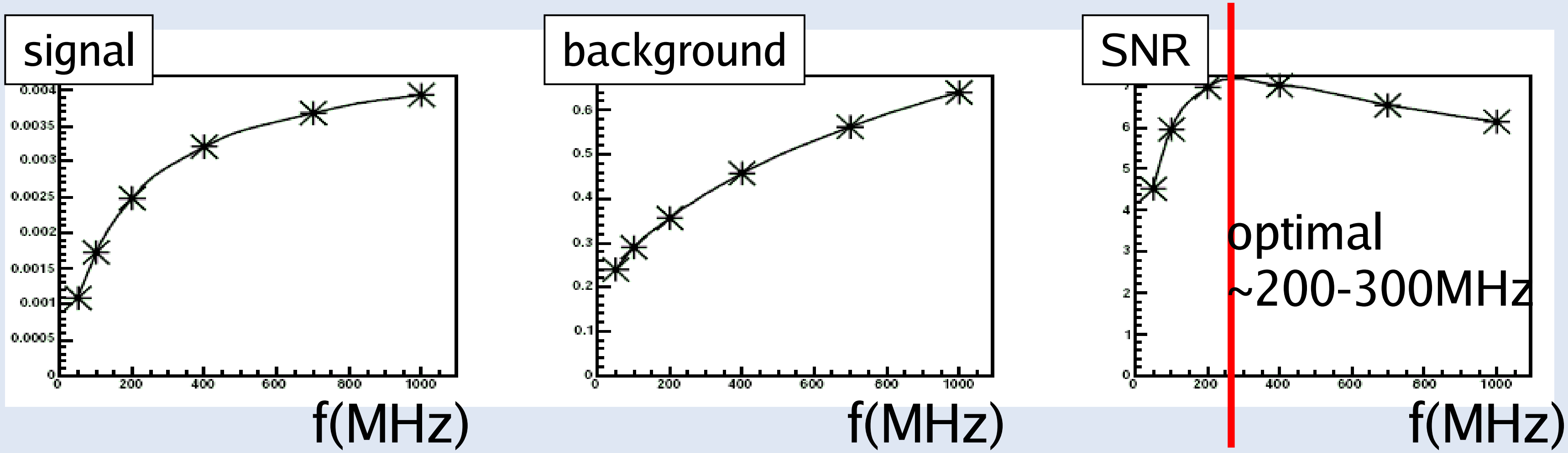
Signal increase 0→45° by ~ √2

Signal increase in ”double-decker” by 2, noise by 15-30%

# Design consideration - BWL

**BWL effect confirmed by FFT analysis**

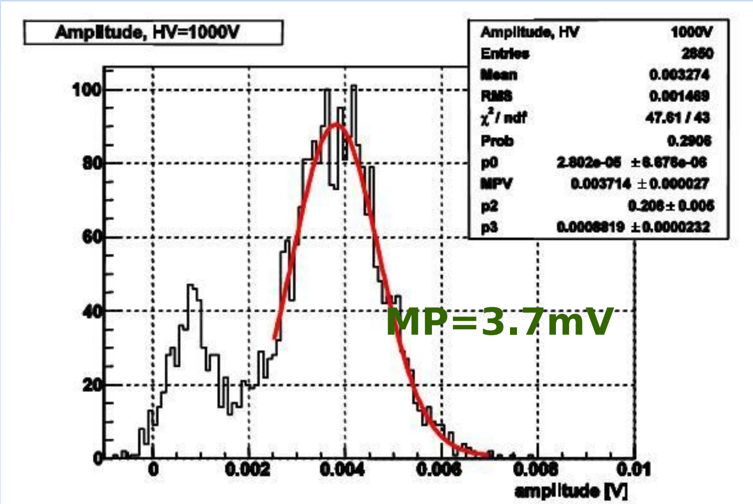


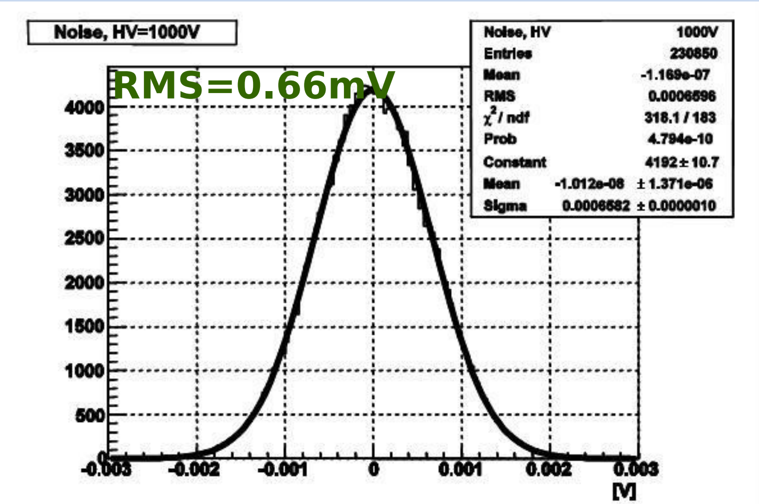



# Design considerations – BWL on the bench measurements

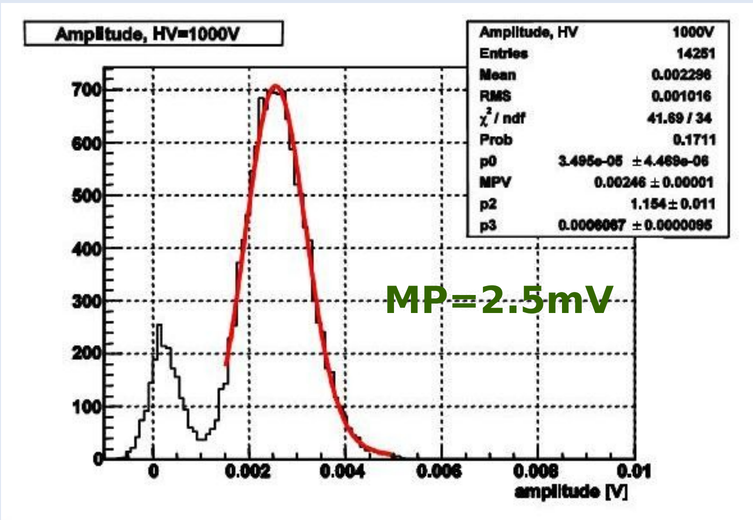
**amplitude** | **noise**

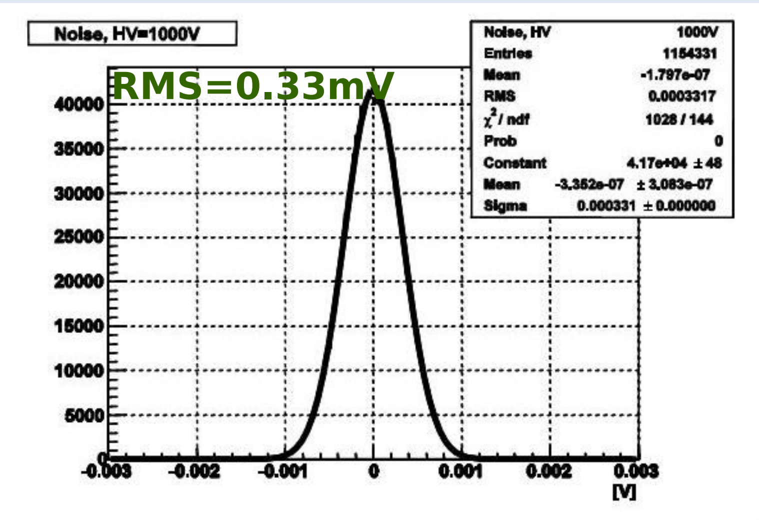
**no BWL**




**BWL**

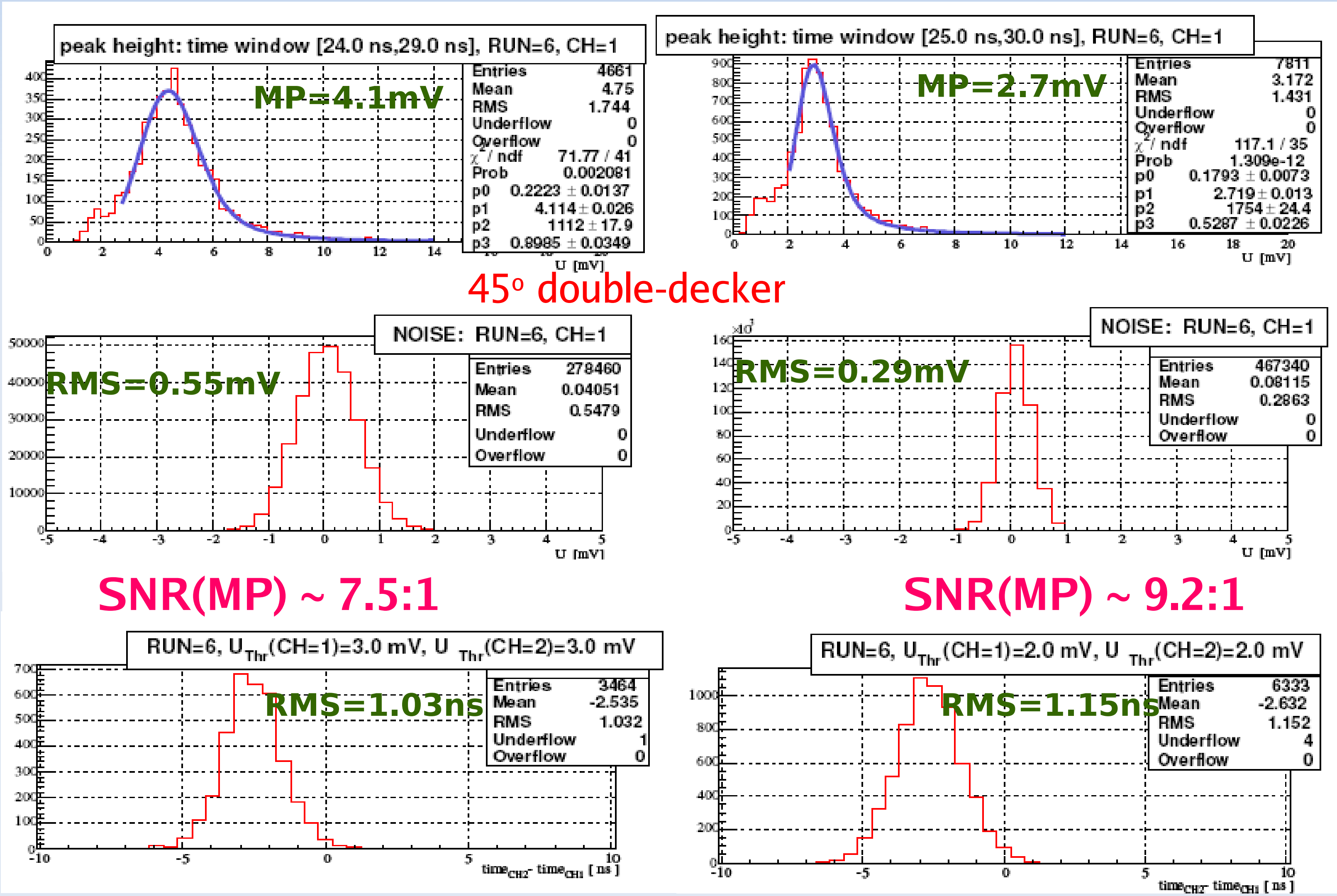


# Design consideration - BWL beam test

Limiting bandwidth on scope to 200 MHz improves S/N

**No bandwidth limit** | **200 MHz bandwidth limit**




***BUT***
10 % worse timing

# QA – HV scan, sensor thickness, type of contacts

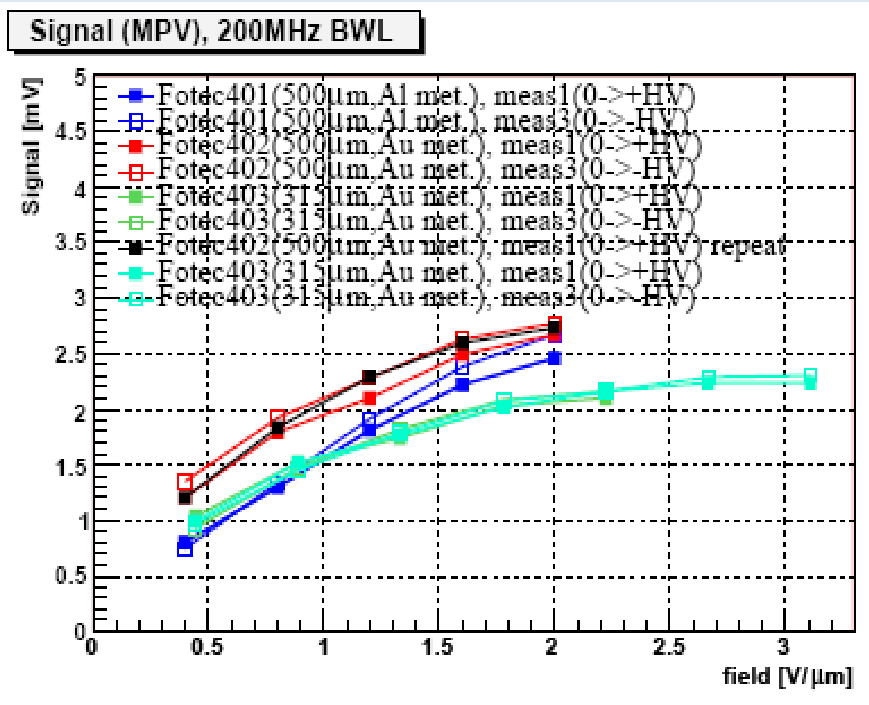
**Thick diamond with 2 different contacts**

- no significant difference between Al and Au

**Thinner diamond:**

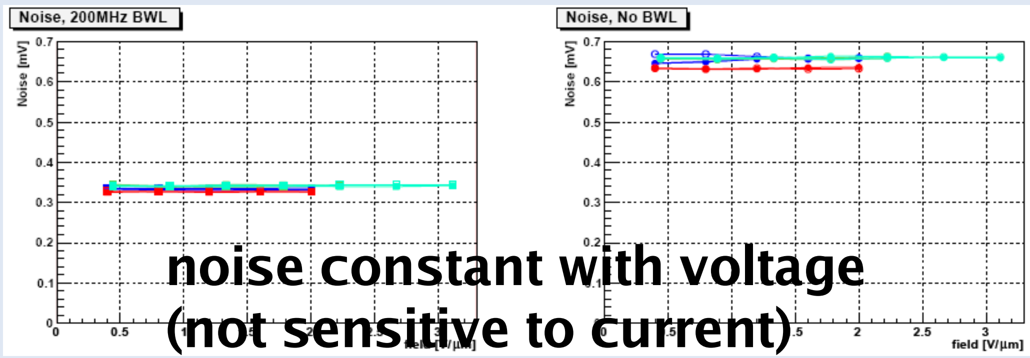
- smaller signal even at higher fields than thick diamonds

**200MHz BWL**




**Thick diamond:**

- SNR(MP) at 2V/µm **no BWL**: 4.7-6.3
- SNR(MP) at 2V/µm **with BWL**: 6.5-8.2




**noise constant with voltage (not sensitive to current)**

# QA results summary

| MODULE | | 410 | 413 | 420 | 422 | 404 | 405 | 408 | 409 | 424 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Test @+1000V, box opened** | MPV [mV] | **2.46** | **2.12** | **2.08** | **2.35<br>2.31** | **2.47** | **2.28** | **2.10** | **2.32** | **1.97** |
| | noise [mV] | 0.369 | 0.312 | 0.347 | 0.344<br>0.343 | 0.371 | 0.335 | 0.335 | 0.333 | 0.338 |
| | SNR | 6.67 | 6.79 | 5.99 | 6.83<br>6.73 | 6.66 | 6.81 | 6.27 | 6.97 | 5.83 |
| **Test @+1000V, box closed** | MPV [mV] | **2.35<br>2.42** | **2.17** | **2.00** | **2.39** | **2.38** | **2.38** | **2.14** | **1.73** | **2.02** |
| | noise [mV] | 0.352<br>0.352 | 0.308 | 0.342 | 0.330 | 0.356 | 0.333 | 0.330 | 0.298 | 0.331 |
| | SNR | 6.69<br>6.68 | 7.05 | 5.85 | 7.24 | 6.69 | 7.15 | 6.48 | 5.81 | 6.10 |
| **Final Test for +polarity, After 14.5h@140C (only F410) or 12h@80C and Thermal Cycling** | MPV [mV] | **2.77<br>2.33** | **2.15** | **2.08** | **2.33** | **2.43** | **2.30** | **2.21** | **?** | **2.01** |
| | noise [mV] | 0.355<br>0.337 | 0.309 | 0.344 | 0.330 | 0.372 | 0.328 | 0.332 | ? | 0.328 |
| | SNR | 7.80<br>6.91 | 6.96 | 6.05 | 7.06 | 6.53 | 7.01 | 6.66 | ? | 6.13 |

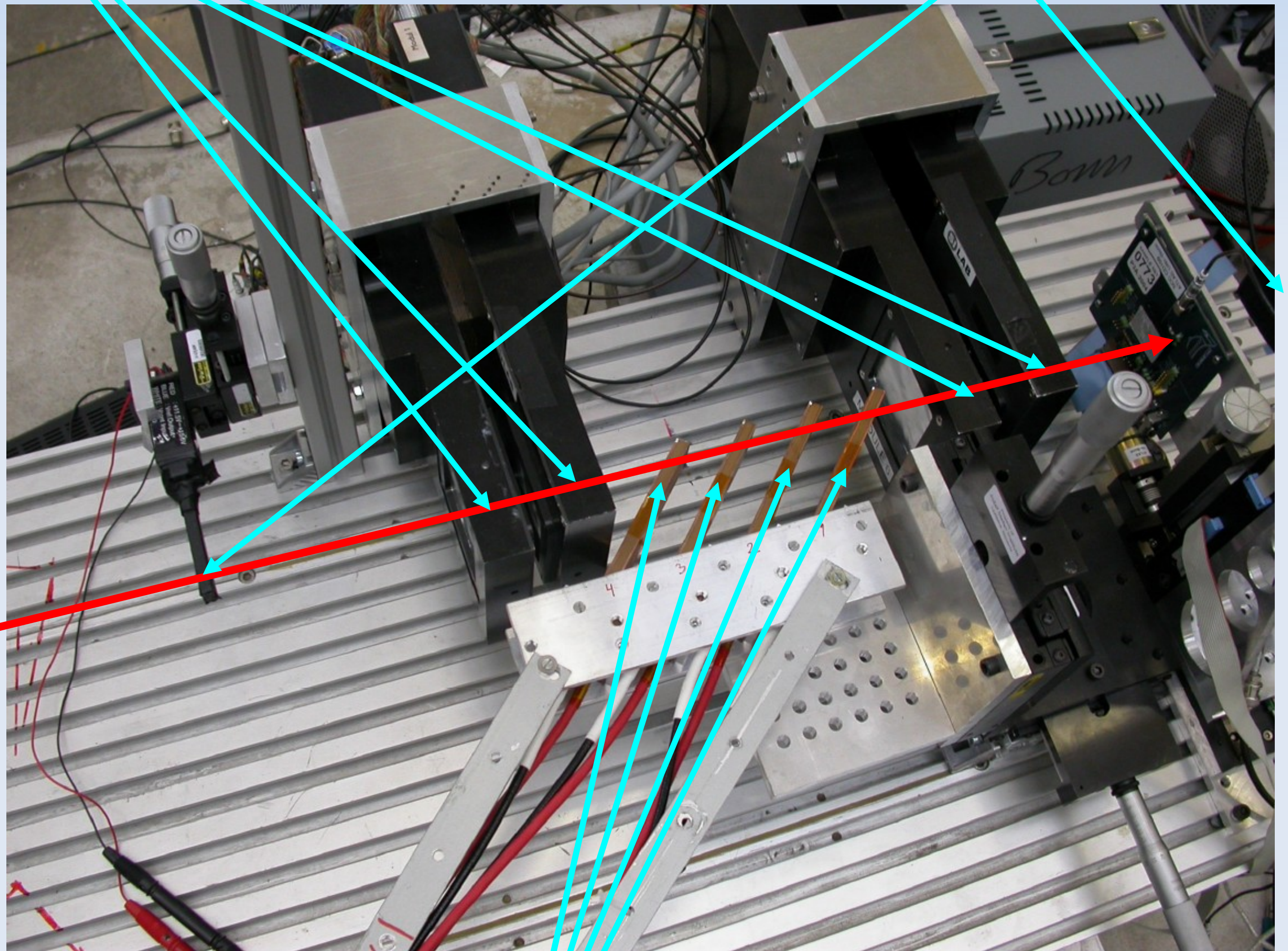
# Installed modules

| 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** |

# SPS beam test setup

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

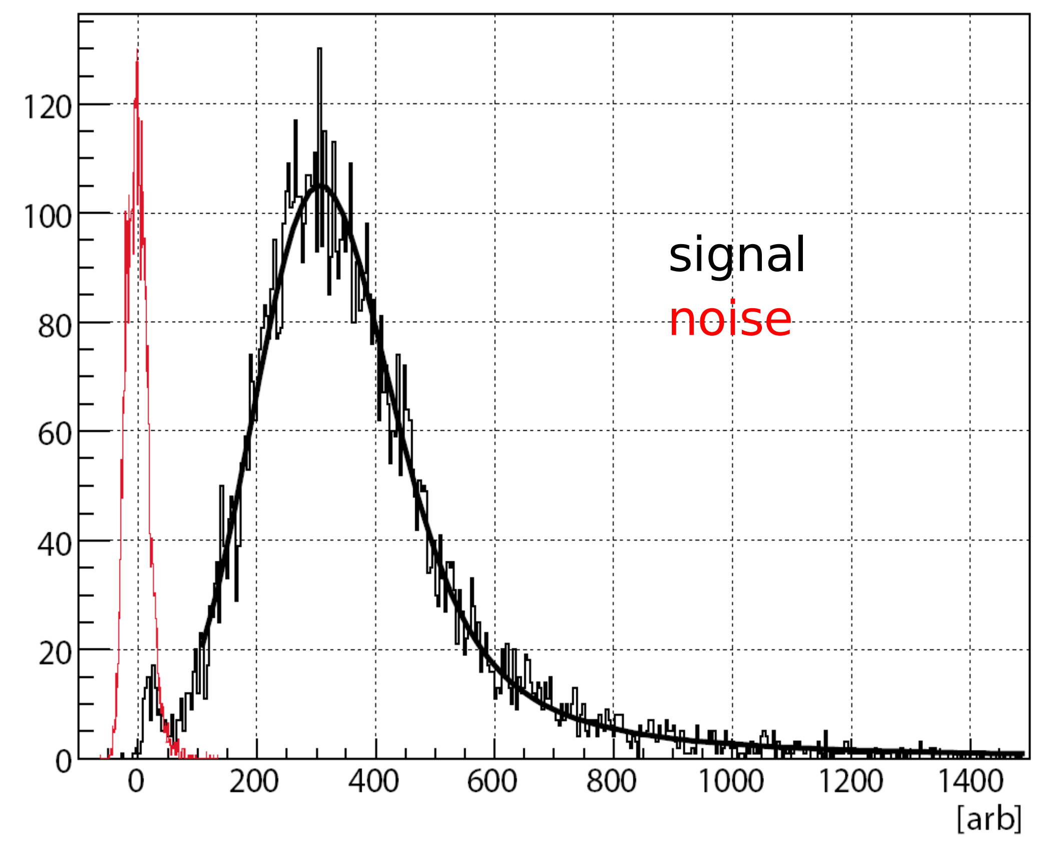
trigger scintillators

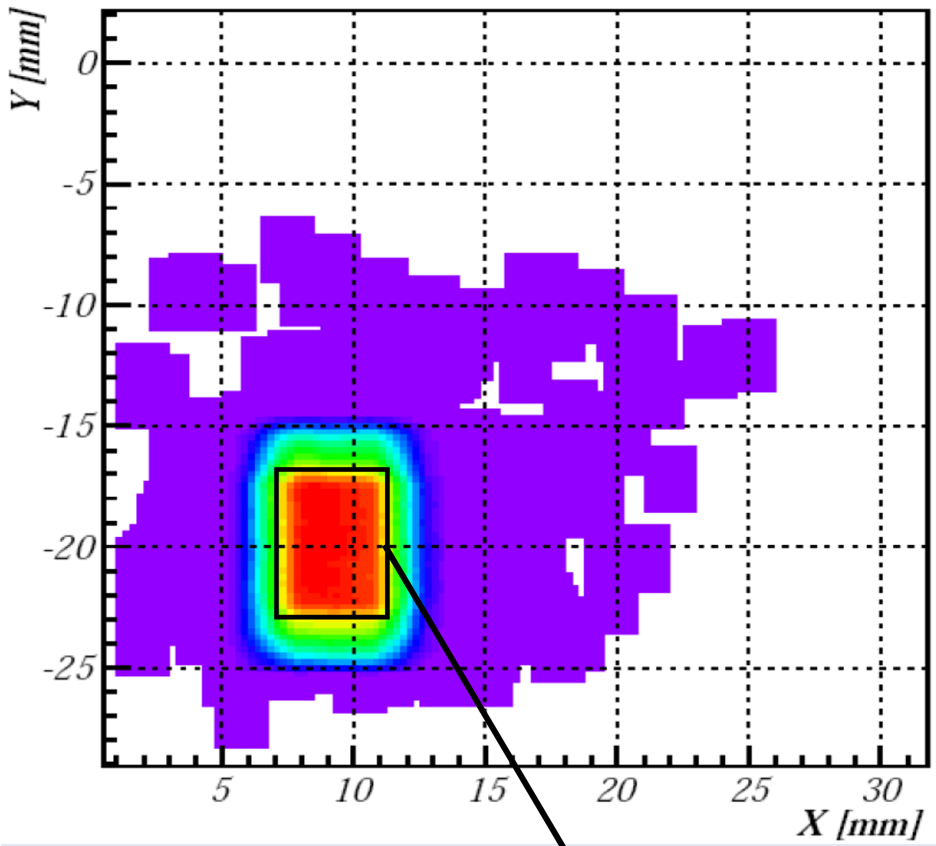


**180GeV/c**
**π beam**

BCM modules

# Analog signals – surface uniformity



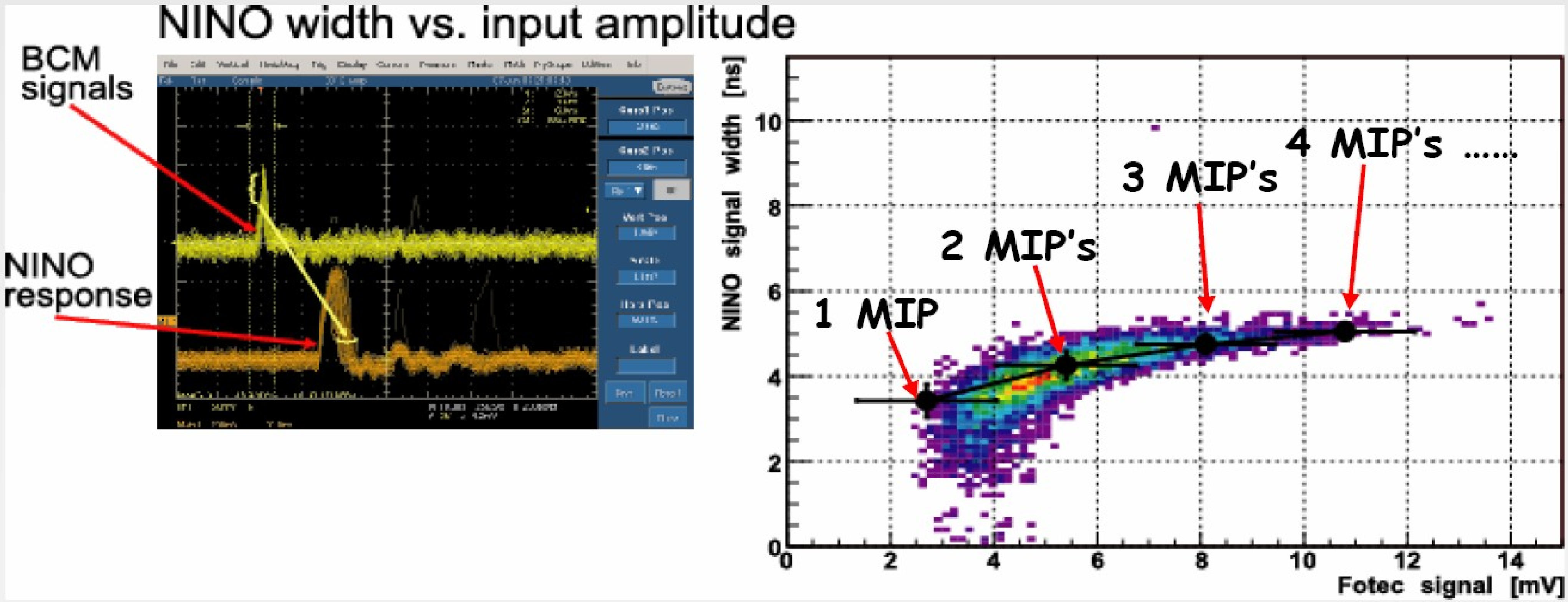




size of diamond sensor (tilted 45°)
signal uniform over surface

# NINO board

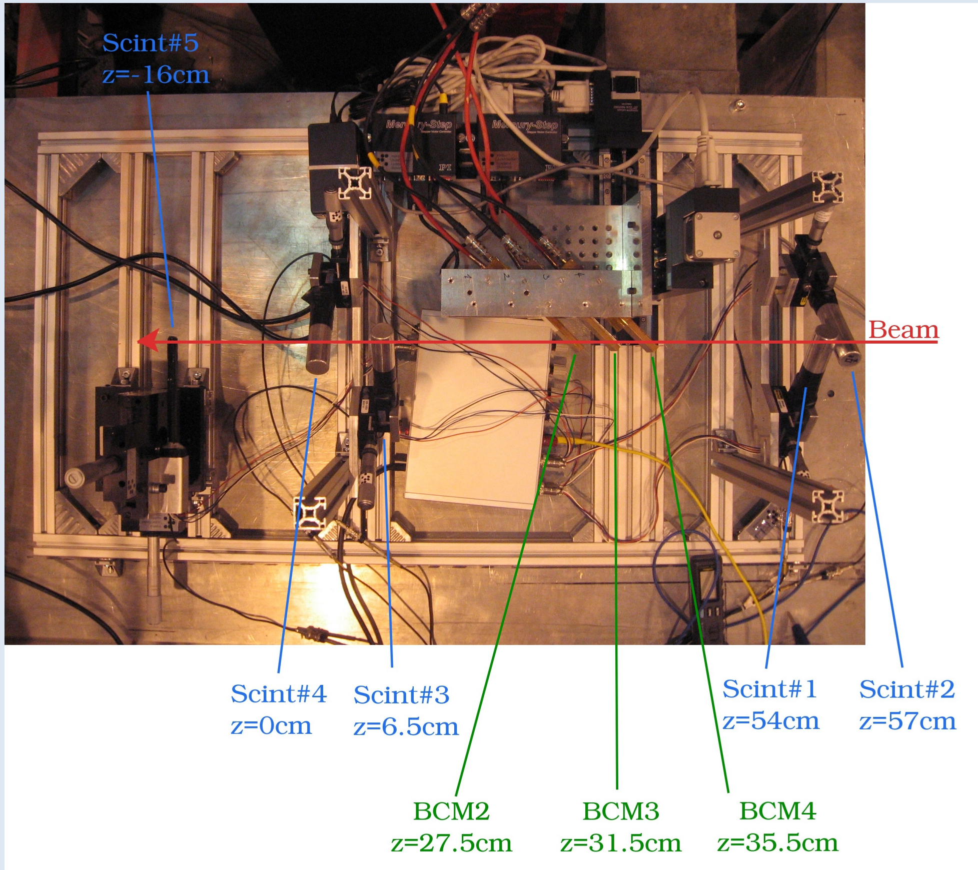
NINO amplifier-discriminator-TOT chip:

- radiation tolerant
- IBM 0.25µm technology
- developed for ALICE ToF (F. Anghinolfi et al.)
- <1ns peaking time & <25ps jitter
- min. detection threshold 10fC
- pulse width depends on input charge



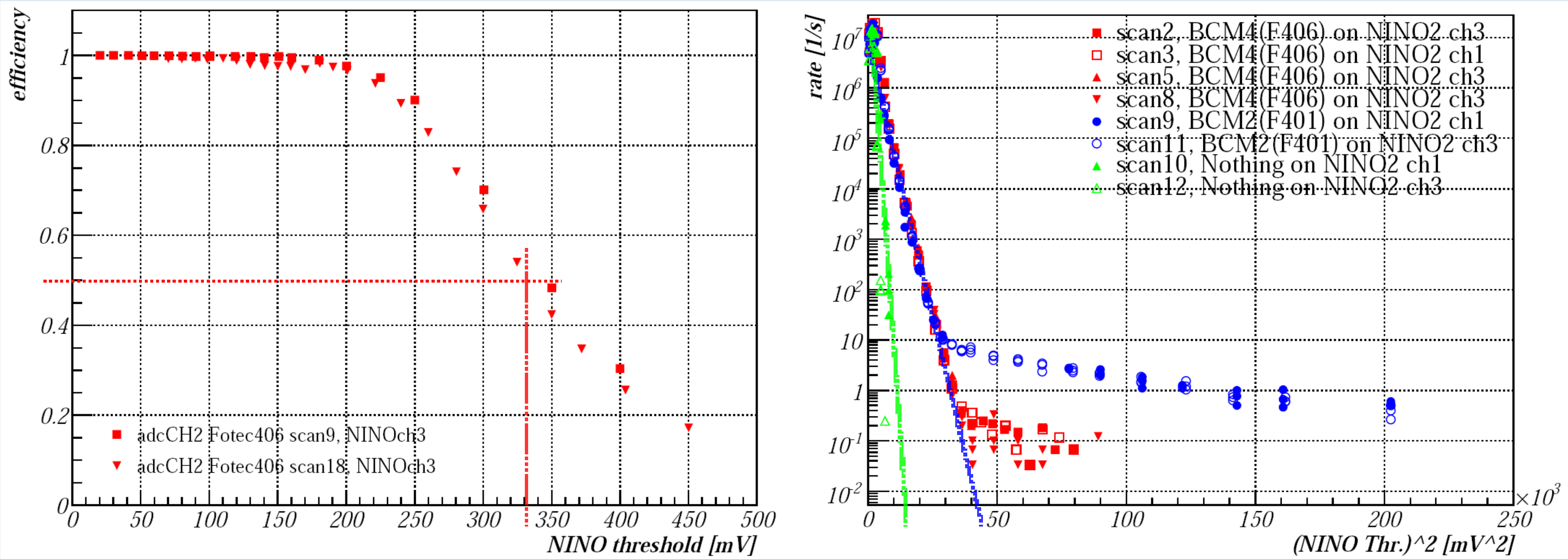
# SPS beam test 2007

- Four SPS test-beam periods (some shared with RD42)
  - End June ✔
  - Mid July ✔
  - End August ✔
  - End October
- No telescope
  - Finger scintillators (2x2 mm$^2$), motorized moving
- Tests with 3 spare BCM modules
- Aims for 2007
  - Establish digital performance of NINO board
    - Amplitude encoding (TOT)
    - Noise
    - Time resolution
  - Test of FPGA code



# Efficiency and noise rate

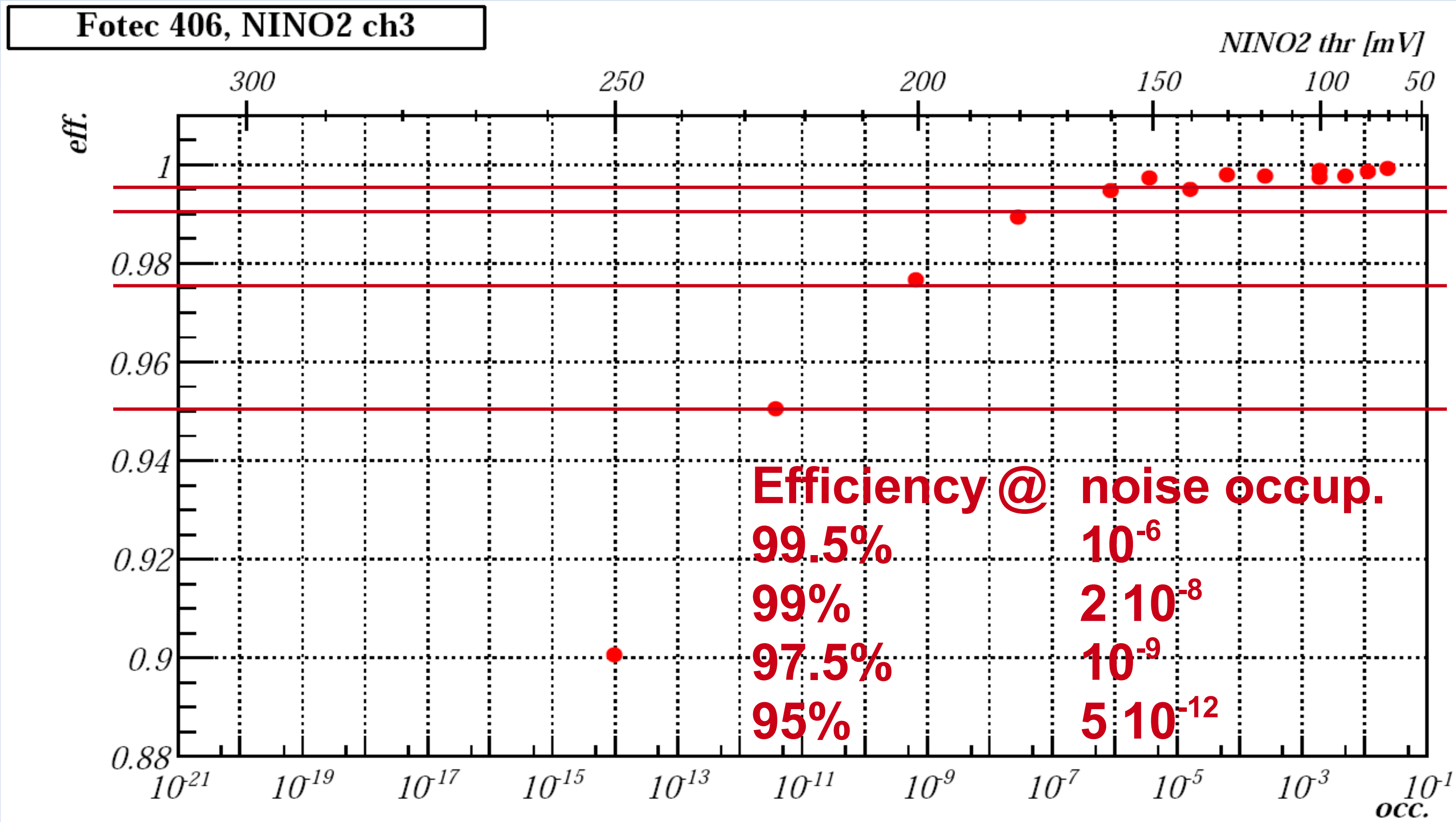
- ✗ SNR after NINO digitization ~7.2 (σ~45mV)
- ✗ contribution of NINO (no input) to σ ~29mV compatible with decrease in SNR (compatible with SNR before NINO normalized to 45° ~10)



# Efficiency vs. noise occupancy

*NINO digital circuit features amplifier discriminator and TOT measurement*

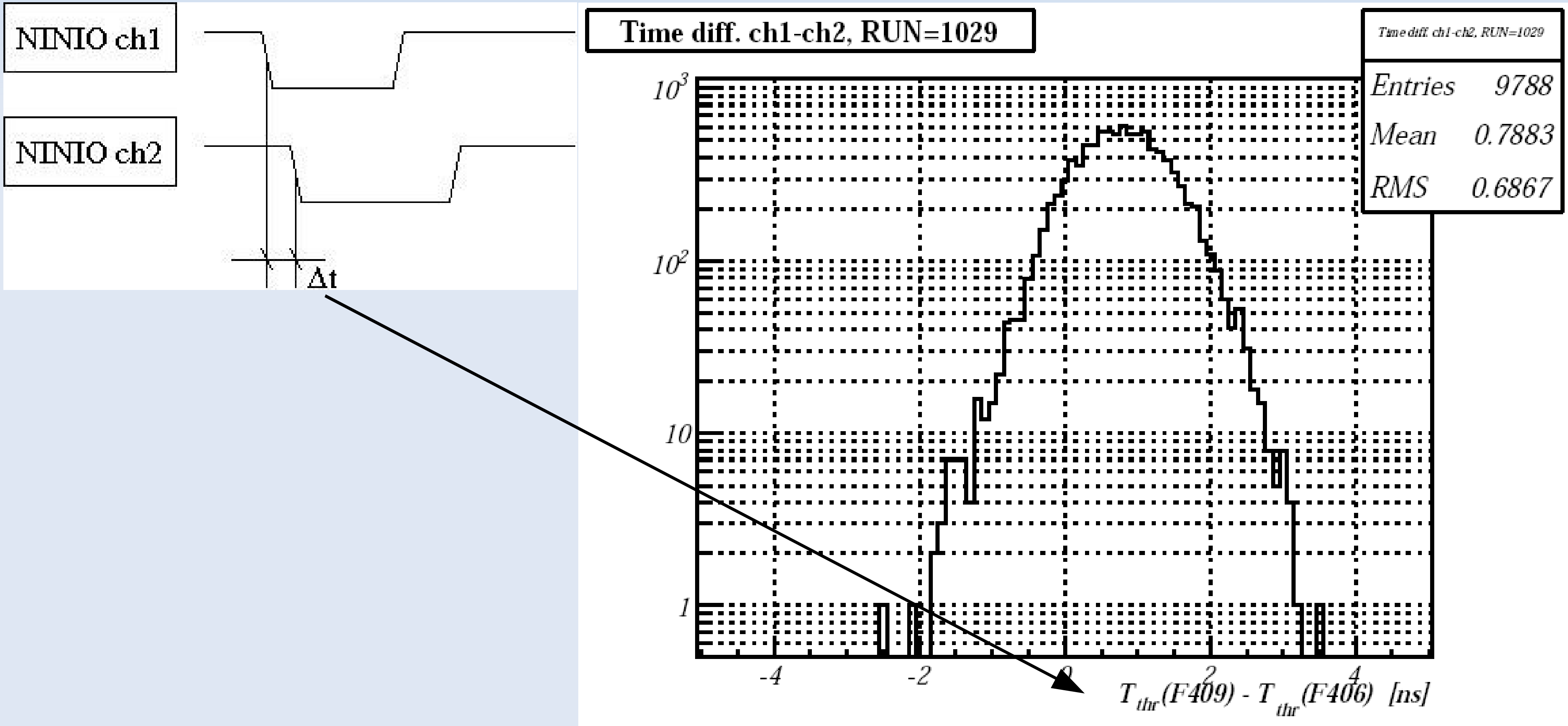
- ✗ by changing the discriminator threshold efficiency and noise rate (occupancy) changes
- ✗ noise occupancy is scaled noise rate to 25 ns interval
- ✗ efficiency of system up to digital circuit (NINO) triggering on an incident MIP (in scintillators)



# Timing resolution

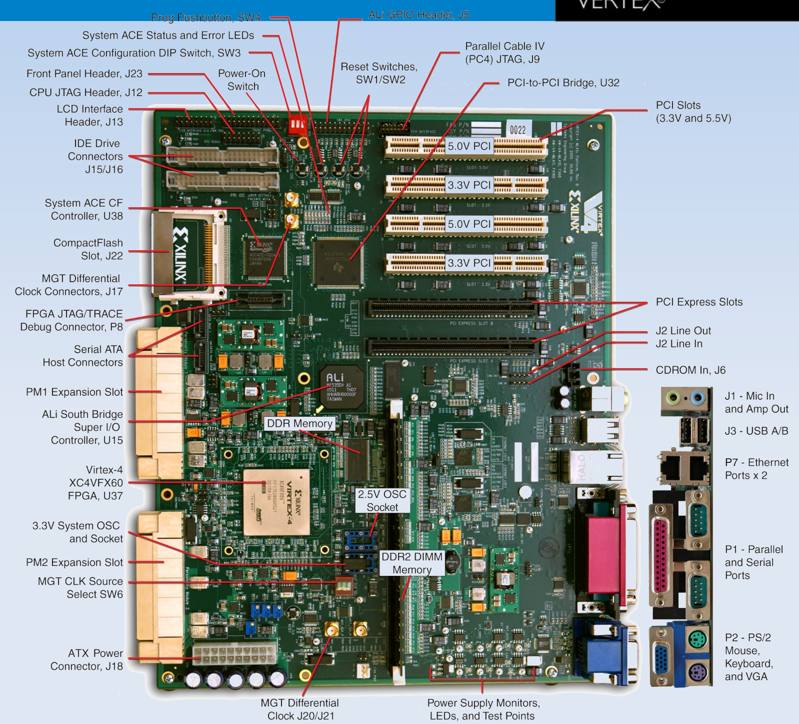
Time difference between two detectors:

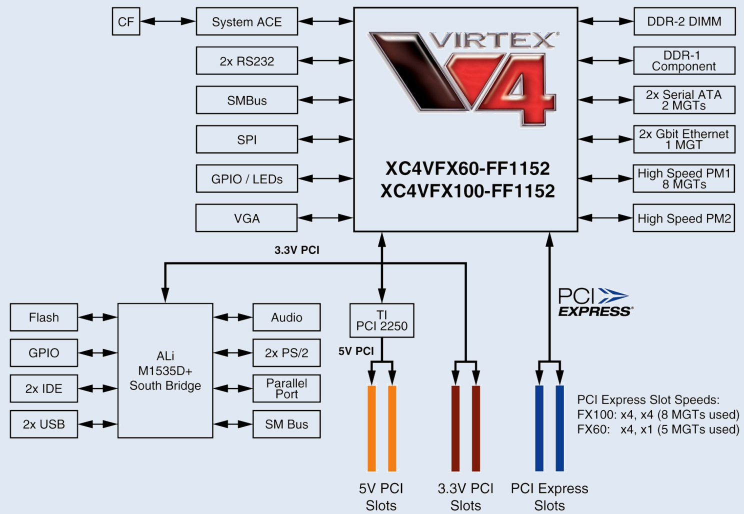
- RMS~500 ps per detector (end of read out chain)
- practically all events inside [-2ns,2ns]



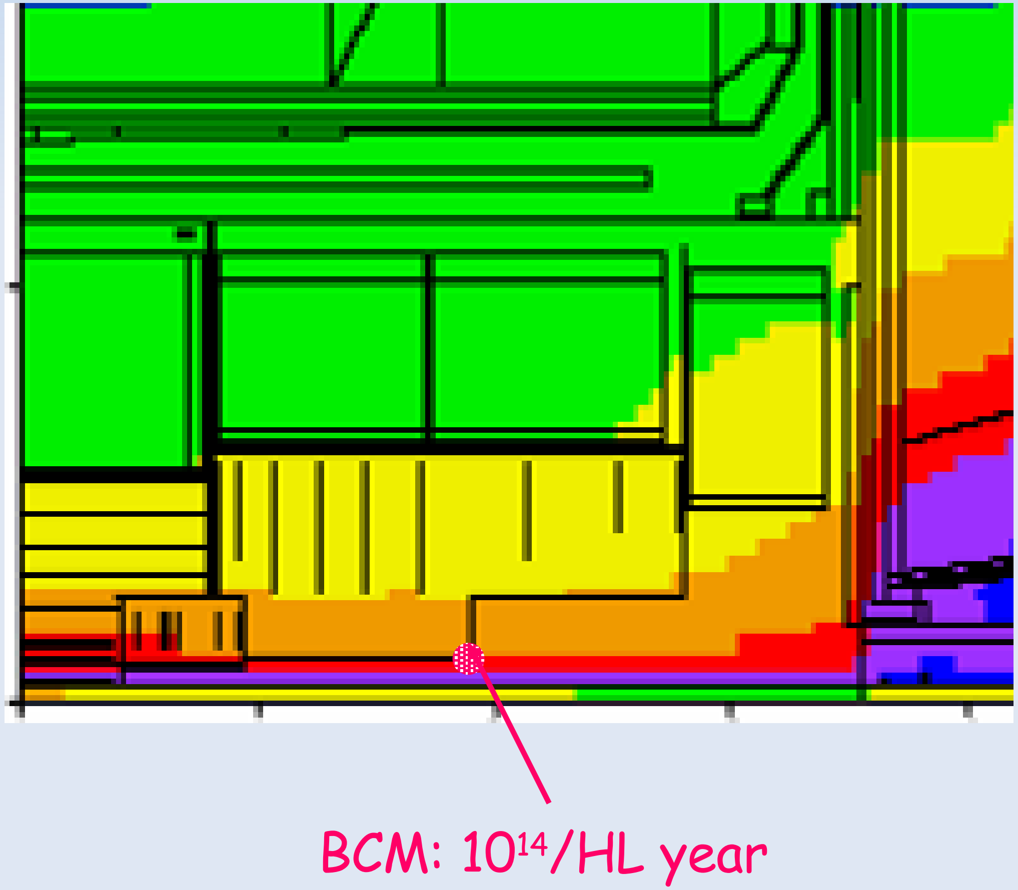
# Backend - FPGA

- Includes
  - Rocket I/O acquisition of BCM signals from optical board (2 GHz sampling)
  - Edge detection, pulse width calculation
  - DDR2 circular buffers
  - Ethernet + Client Software on PC
  - In-time/out-of-time coincidences
  - Ready now
- Still to be done
  - On-line histogramming of coincidences
  - Include S-Link, counters for event ID, insert event ID into data stream
  - Use 2 boards and have them communicate
  - v2.0 (for OctoberTB) should be as close to the final ATLAS version as possible



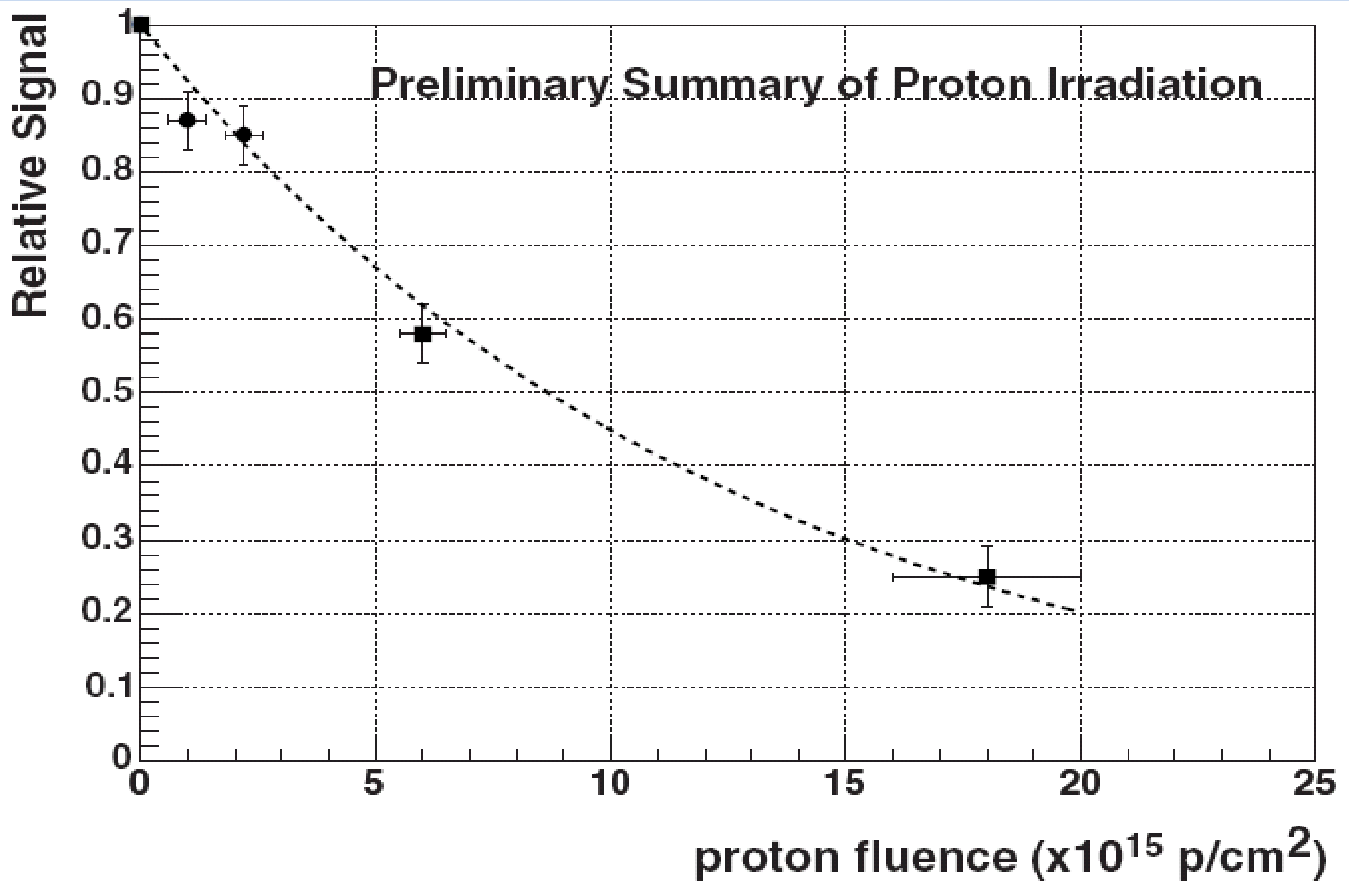
# Radiation hardness




- Individual components tested for radiation hardness
- Want to assess performance of complete module
- Irradiation/test of one module
  - Test in beam
  - Irradiate to $10^{14}$ p/cm$^2$
  - Test in beam
  - Irradiate to $3\times10^{14}$ p/cm$^2$
  - Test in beam
  - Irradiate to $10^{15}$ p/cm$^2$
  - Test in beam
- First → second step this year
- Activation analysis @$10^{14}$ done, handling OK for 2nd step

# Sensor irradiations

Preliminary results of sensor irradiation up to 1.8 $10^{16}$ p/cm$^2$



# Radiation hardness – amplifiers

**Devices**

- 1st stage: Agilent MGA-62563 GaAs MMIC Low noise amplifier
- 2nd stage: Mini Circuits Gali 52 InGaP HBT broad band microwave amplifier

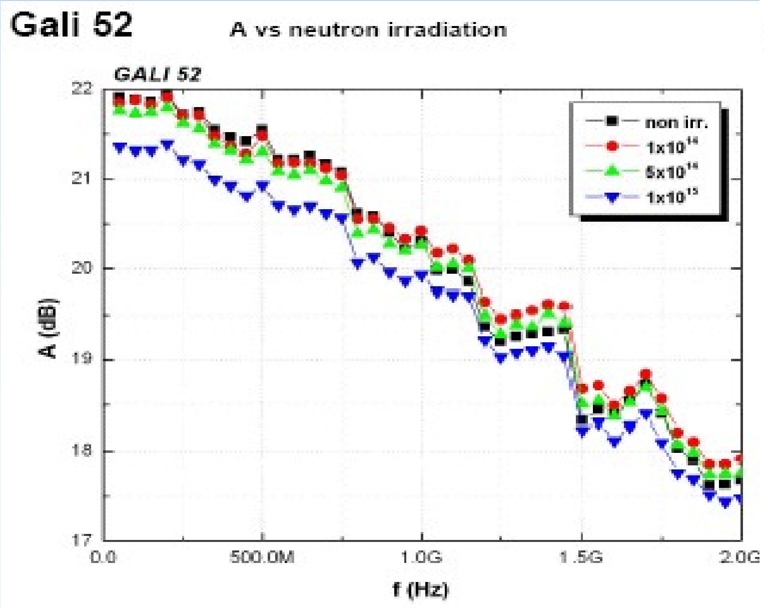
**Irradiations**

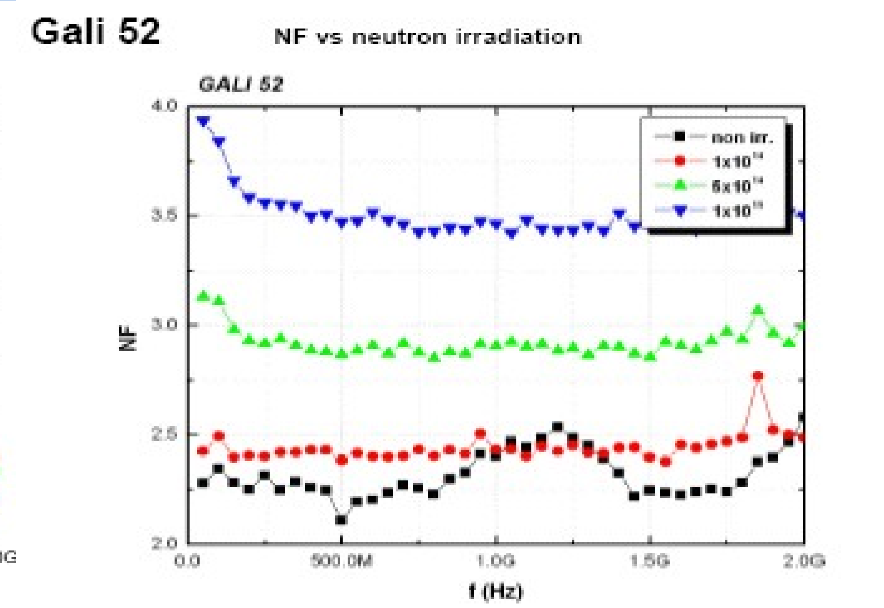
- **n:** TRIGA nuclear reactor at J. Stefan Institute in Ljubljana
- **p:** CERN PS 24 GeV/c
- **γ:** TRIGA nuclear reactor at J. Stefan Institute in Ljubljana

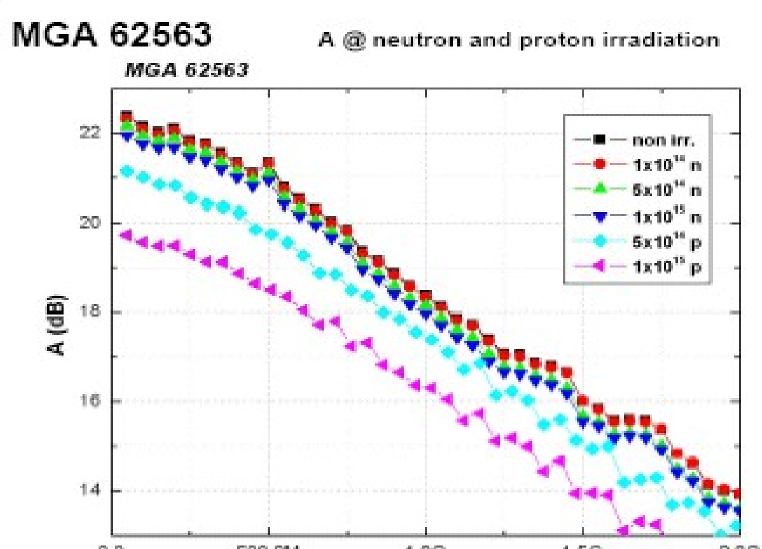
**Measurements:**

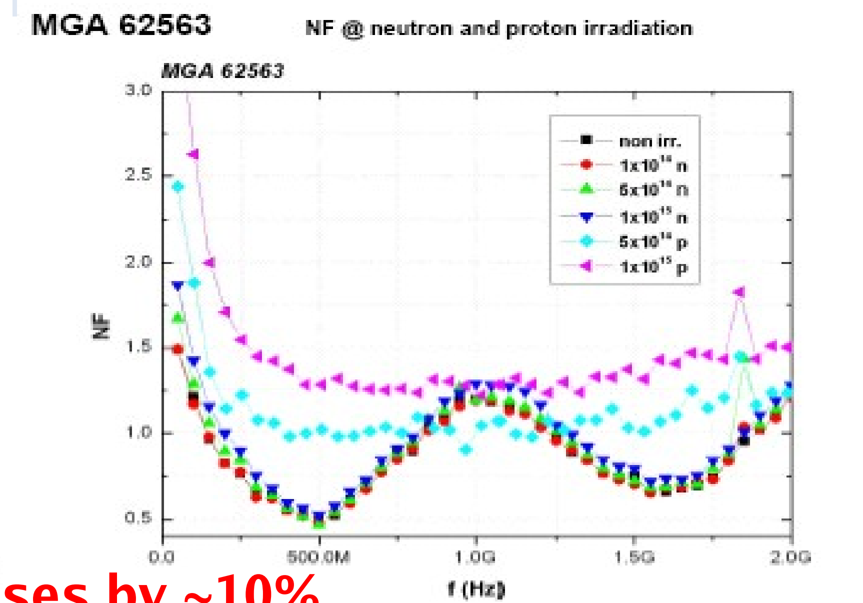
- S parameter set and/or NF-Gain measurements:
  - Anritsu 37369C Vector Network Analyzer
  - Agilent N8973A Noise figure Analyzer

# Radiation hardness



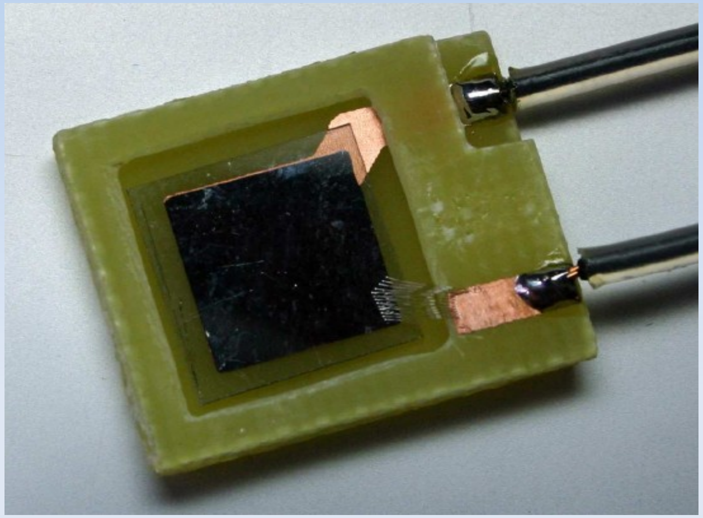




**Amplifier still usable after $10^{15}$ $n_{eq}/cm^2$**

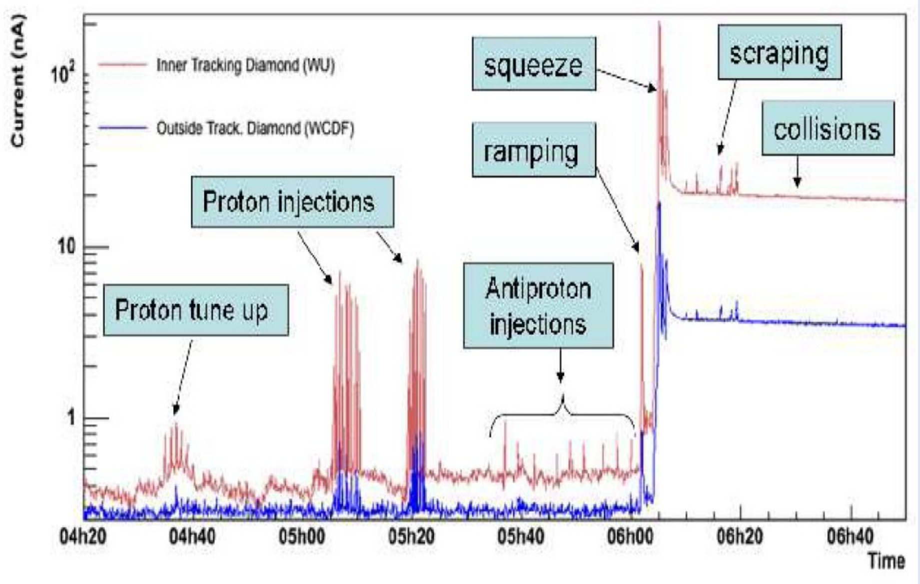
**gain decreases by ~10%**

# Redundant system BLM

- BLM – Beam Loss Monitor installed in CDF
  - Averaging of ionization current in pCVD diamond on 20 μs scale
  - Custom VME electronics, triax cables
  - Good experience, just got included in Tevatron abort system
- ATLAS BLM plans
  - Copy as much LHC machine system
  - 8 diamonds (4+4) on IDEP at pixel PP1
  - 12 m coax to PP2 (BLM cards rad-tolerant)
  - BLM digitizes current integrated over 40 μs
  - Optical transmission (GOH) to USA15
  - Changes at level of abort logic
- standalone in case of BCM trouble, otherwise complementary info



- performance of CDF BLM system

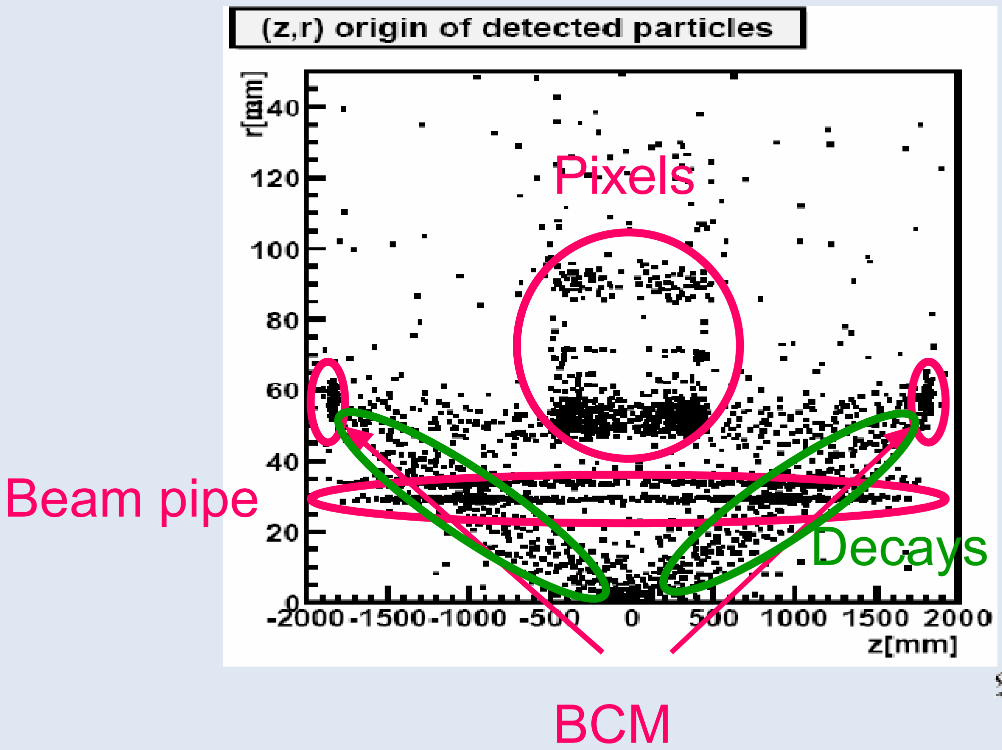


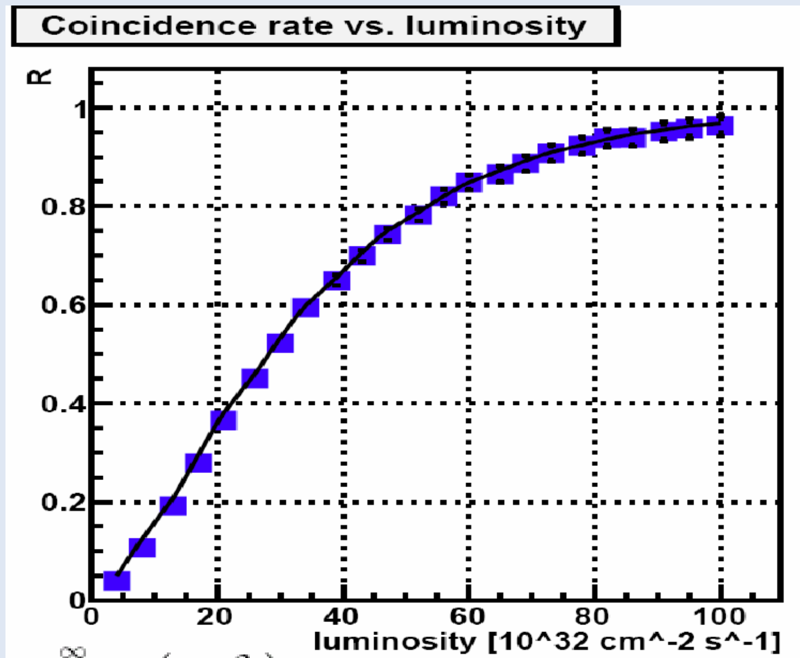
# Summary

- The ATLAS BCM was constructed using 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 resonable
- ATLAS BCM status:
  - FE installed in January 2007
  - secondary redundant system (BLM) is being designed (similar to CDF)

# BACKUP: simulations

- Simulations in full ATHENA framework
- Average number of tracks in BCM diamonds per p-p collision: 0.375
- Surprise: half of events from decays and scattering in material
- Studies of coincidences to establish FPGA algorithms ongoing




$$\mathfrak{R}(\mathfrak{L}) = \sum_{N=0}^{\infty} \mathfrak{P}\left(N, \frac{\mathfrak{L}}{\mathfrak{L}_o}\right) \left[\left(1 - e^{-P_A N r_{TR}}\right)\left(1 - e^{-(1-P_A) N r_{TR}}\right)\right]$$