Monitoring the Performance of Silicon Detectors with Binary Readout

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Binary readout records the address of strips with pulse height exceeding a fixed threshold value .
The pulse height is not be known during data taking and the noise correlation is lost.
But:

the primary parameters of interest for a tracking device are not the signal and noise, but the single channel efficiency and the noise occupancy.
We propose to monitor both directly on-line during data taking.

Experience with the LPS at HERA
Experience with KEK beam tests
Experience with on-line monitoring at the ATLAS beam test 1995
Outline of a system to monitor the performance
of the silicon tracker with binary read-out.

ATLAS BEAM TEST IN H8 AT CERN IN SUMMER 1995:

Binary r-ϕ Modules in the H8 Beam Test

Tested Module	Hybrid	Detector [side,type,AC]			Pitch [micron]	Length [cm]	# of strips	Amp Chip	Pipe Line
UCSC	Kapton	n	n	AC	50	6,12	384	LBIC	CDP128
DDR2	Kapton	p	n	AC	50	6	384	LBIC	DDR2
LBIC1,LBIC2	Ceramic	p	n	DC	75	12	1536	LBIC	CDP128
ATT1,ATT2	Ceramic	p	n	DC	75	12	256,128	CAFE	CDP128
ATT	Ceramic	n	p	DC	75	12	180	CAFE	CDP128

The detector strips are directly bonded to the FEE.
The hybrid, which carries the FEE and the data and control signals, is mounted across the detector strips in the approximate center of the 12cm silicon detector module.

Objectives of the Binary H8 Beam Test

Test of ATLAS style front-end chips & detectors
Determination of signal/noise for 6cm and 12cm strip length
Determination of signal/noise for inclined tracks in 75m pitch detectors
On-chip data sparsification (ATLAS style data transmission protocol)
Test of clock pick-up for hybrids mounted across detectors
Module fabrication techniques
High speed DAQ (40MHz) based on DSP modules
On-line monitoring

MONITORING THE FRONT-END ELECTRONICS: CALIBRATIONS

The role of the calibration in a binary system differs from that in an analog read-out system:
It only has to monitor the performance of the FEE, but has no function in the data correction/analysis.
Thus the requirements on the accuracy and frequency of calibration runs are very relaxed.
A "bad channel" list is generated containing dead or hot channels.

Experience with a binary system in the LPS of ZEUS at HERA, consisting of about 35k channels:
every few month, a calibration is done, ascertaining that the system is stable.
The single hreshold in the experiment was held fixed in over a year of operation at HERA to 0.78 fC.

The architecture, chip design and fabrication technology of the LPS FEE system resembles closely
the proposed binary system for the silicon tracker of ATLAS.

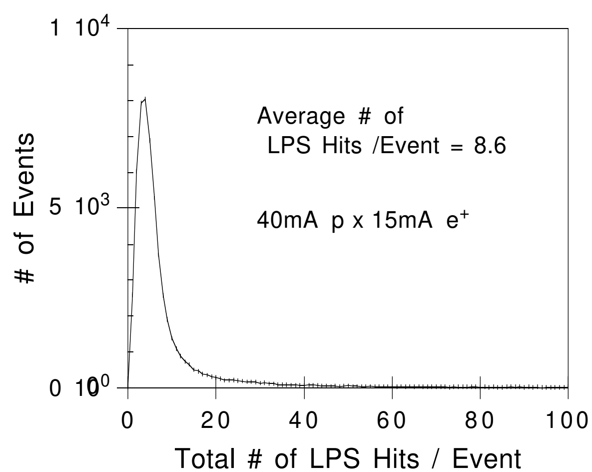
During H8, a total of four calibrations were taken, one before and one after each of the two running periods.

MONITORING OPERATIONAL CONDITIONS: OCCUPANCY PLOTS

During beam-on and beam-off operations, occupancy plots ("channel maps") are an important diagnostic tool. Hot or dead channels are flagged, and abnormal conditions of the beams or the operations are recognized.

In the LPS at HERA, the silicon detectors are as close as 2mm from the center of the 820GeV proton line. The strip occupancy during normal operations at HERA, is of the order $< 10^{-3}$ at a threshold of 0.78fC; this includes both electronics noise and beam related contributions.

The event multiplicity is low with no long tails, indicating that common noise is no problem.



26k channels in 32 planes

Both the channel occupancy and the event multiplicity are useful to identify noisy beam conditions on-line. From the occupancy, the charged particle dose is calculated directly.

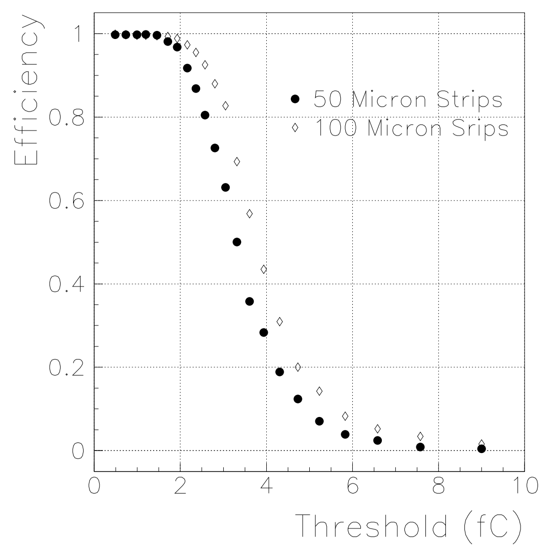
In H8, due to the low occupancy of the system, we were able to align the detectors relative to the beam by just looking at the profile of the beams in channel maps of all recorded events.

MONITORING SIGNAL-TO-NOISE: THRESHOLD SCANS

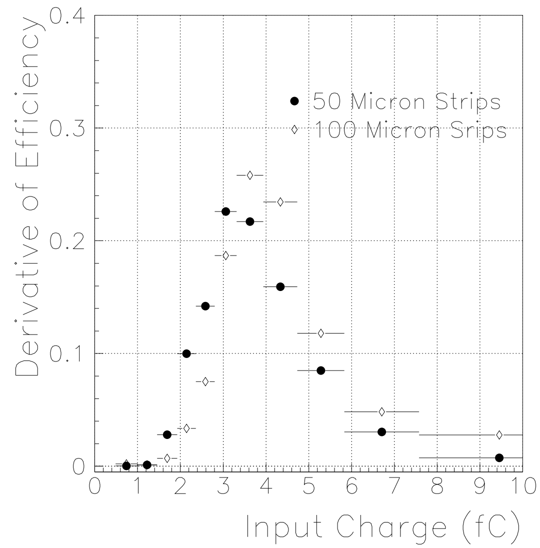
KEK beam test: tracking program determined the efficiency of each of the planes, off-line after alignment.
Inefficiencies less than 0.1% at 1fC threshold for the n-side operated at bias far above depletion.
Pulse height spectrum peaks close to the expected value of 4fC.

Counting rate as a function of varying threshold = Efficiency = Integral of pulse height spectrum.

Efficiency (Integral of Pulse height spectrum) =>



Pulse height spectrum



Performing these threshold scans interferes with data taking
Question: how often and how long to interrupt data acquisition for threshold scans?
With the anticipated high rate of charged particles at the LHC, scans will take only a few minutes.

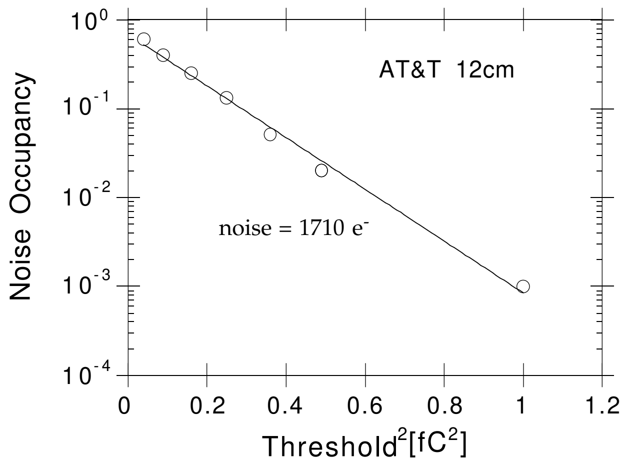
Degradation of the system due to radiation is a slow; only occasional threshold scans with beams needed.
Threshold scans will be needed after major intervention into the system, like after warming up for repairs.
Important to determine the operating conditions, i.e. threshold and bias voltage.

NOISE:

The noise charge can be extracted, from a threshold scan without beams, which takes only a few minutes.

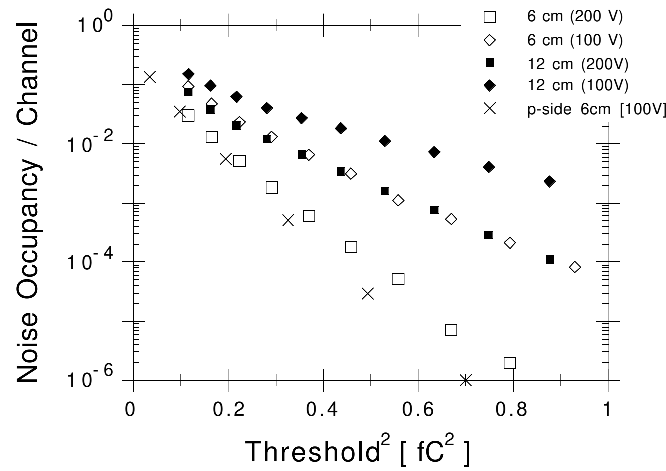
Noise Occupancy as a Function of Theshold

On-line for the ATT module in H8 n-side, p-bulk)



non-optimized capacitance ("narrow p-blocks")

Off-line for the UCSC module (n-side, n-bulk)



minimized capacitance

Noise Charge from Erf Fit to Noise Occupancy

Side: n/p	Length [cm]	Bias [V]	σ_n [e-]
n	6	100	1370
n	6	200	1180
n	12	100	1860
n	12	200	1550
p	6	100	1060

12cm long n-side detectors with binary readout reach noise occupancy of close to 10^{-4}
(corresponding to noise charges of 1500 electrons)

MONITORING EFFICIENCY & NOISE OCCUPANCY: TRACKING

The efficiency and noise occupancy are the parameters of immediate interest in tracking programs.
The efficiency has to be determined with an on-line tracking program..

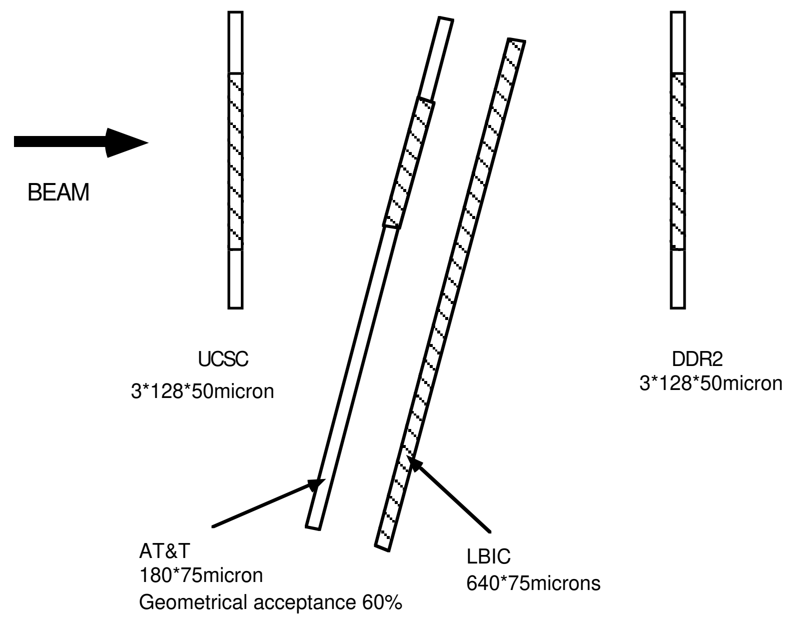
The binary system does not rely on determining the charge sharing between adjacent strips,
(e,g, position resolution ≈ pitch/√(12)).
The resolution is automatically ok if the efficiency is high and the noise is low (KEK beam tests).
No need to monitor the position resolution on-line in addition to efficiency and noise occupancy.

The binary data lends itself ideally to the task of <u>on-line</u> monitoring,
because no data corrections are needed (and are even possible!).

The requirements for the tracking programs are modest due to the low occupancy of the system.
Simple ratio's of 2-out-of-3 or 3-out-of-4 hits with modest p_t cut are sufficient.

Set-up during a particular run period in September 1995:
two stationary detectors ("anchors") and two devices (ATT & LBIC) under test on a rotary stage.
Shaded areas are the extend of read out channels.

BINARY H8 Beam Test CERN 1995



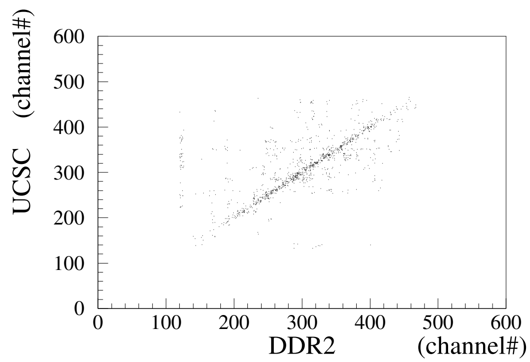
On-line monitoring during the beam test
during a threshold scan at a fixed bias voltage and a rotation angle of 14^{o} .
The rotation simulates worse case pulse height during ATLAS operations (pulse sharing among adjacent strips).

Efficiency determined from correlation plots.

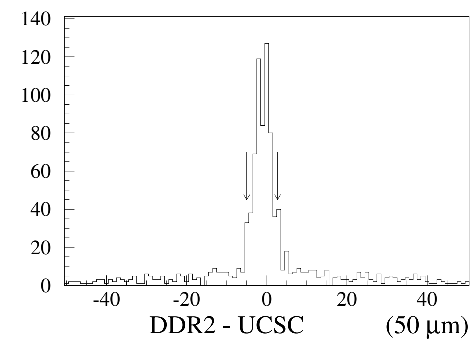
Beam particles were identified by hits in two anchor planes (UCSC, DDR2) with fixed threshold of 1fC.

Search for corresponding hits in the third plane (ATT).

Finding the Beam in Anchors:

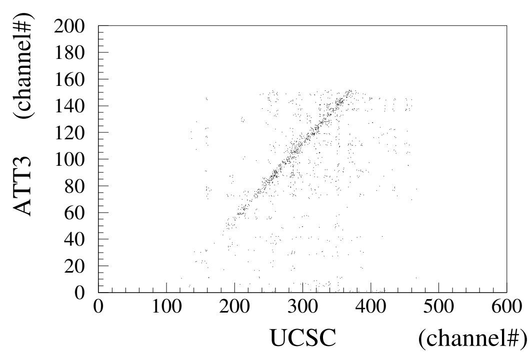


Correlation UCSC vs. DDR2 plane (threshold 1fC);

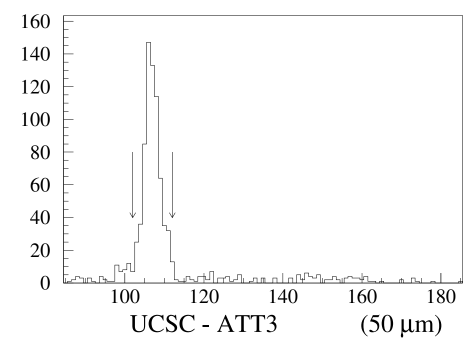


Projection onto the line Δ = DDR2-UCS C

Finding the Beam in DUT:



Correlation of hits in the ATT and UCSC planes.



Projection for beam particles

Efficiency = beam hits in ATT / beam hits in Anchors

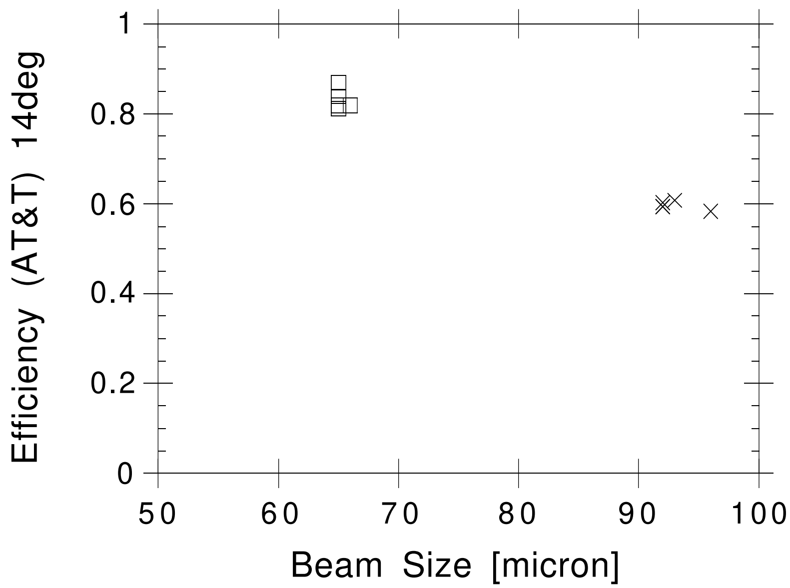
Acceptance of the anchor planes > Acceptance in ATT plane => relative Efficiencies.

(A cut on the beam position in the anchor planes would have given absolute efficiencies).

Monitor changing beam conditions

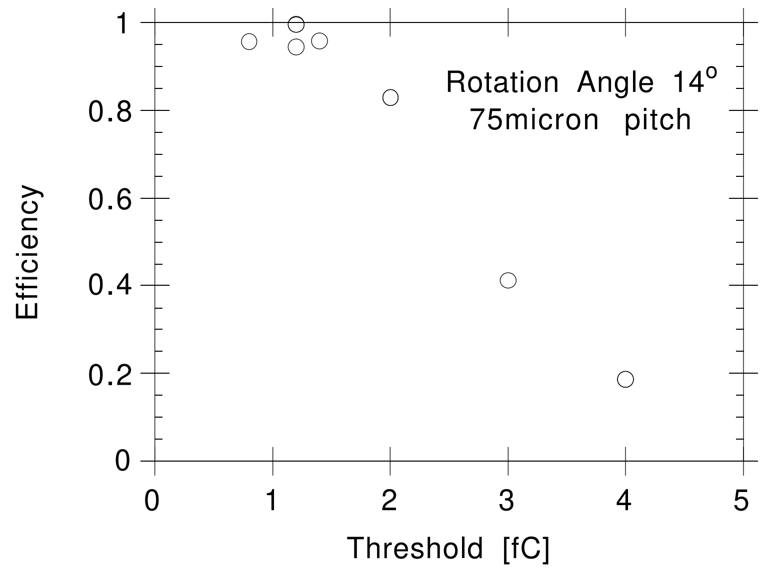
Beam not fully contained in the ATT detector => different relative efficiency for different beam sizes

On-line Efficiency at Thresholds of 0.8, 1.0 & 1.2 vs. Beam Size as determined in the UCSC Plane.



On-line Threshold Scan (small beam size)

(normalize efficiencies at low threshold to unity)



Efficiency has the same form as the one determined from off-line analysis in previous beam test.
The observed median is, as expected, lower than at normal incidence
because of the finite crossing angle of the beam.
Efficiency is still very high even at a threshold of 1.4fC.

PROPOSED SILICON SYSTEM MONITORING PROGRAM FOR ATLAS:

Outline of a monitoring program for the binary silicon detector system:

a) calibration of the FEE	every few days.
b) threshold curves:	every week.
c) occupancy:	continuously, with/without beams
d) efficiency and noise occupancy:	on-line during runs

On-line determination of the efficiency might be done best in the LEVEL 2 trigger, which performs tracking with cuts on high p_t patterns and stores this information for further trigger decisions . The selection is on three hits out of four in closely spaced layers with a cut of about 5GeV/c and up.

The output of the trigger program can determine the fraction of misses = inefficiency monitor.

Determine the efficiency per module and use the channel maps to monitor the channel to channel variations?

High statistics because all LEVEL 1 triggers will participate, as long as there is a track present.

CONCLUSIONS

The H8 beam test shows that binary modules have performance approaching the ATLAS requirements.

We were able to monitor the performance of the binary system on several levels:

Electronics calibration are needed to monitor the integrity of the system, not for data reduction and analysis.

The low noise in the binary system makes occupancy plots an important tool to monitor operational conditions.

Threshold scans allow to determine the pulse height and noise sigma's, but at not too frequent intervals.

Determination of efficiency and noise occupancy have been shown to be possible on-line during data taking.

For the ATLAS operation, we propose to investigate the use of the tracking algorithms of the LEVEL 2 trigger to select tracks for the on-line efficiency determination.