Status Report of the Laboratory Tests of MIMOSA-26

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on behalf of the IPHC/Strasbourg – IRFU/Saclay collaboration

▷ **Work of G.Claus, M.Goffe, G.Dozière, M.Gélin, K.Jaaskelainen and M.Specht**

OUTLINE

- General features
- Type of tests performed
- Laboratory test results :
  - ▷ *Analog output*
  - ▷ *Discriminated output*
  - ▷ *Zero-suppression logic*
  - ▷ *Full chain output*
- Next steps
- Summary

General Features

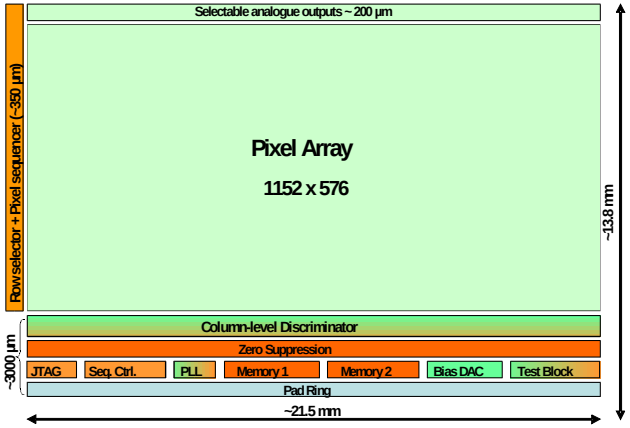
- **Sensor manufacturing :**
  - AMS-0.35 fabrication process : $\sim$ 15 μm thin(ck) epitaxial layer
  - 3 wafers fabricated (up to 3 additional wafers still available)
  - 82 chips per wafer

- **Status of sensor delivery :**
  - 3 wafers back from foundry at CMP in first half of February 2009
  - 1/2 wafer (41 sensors) diced and sent to IPHC $\rightarrowtail$ received $\gtrsim$ Feb. 17th
  - functionnality tests started in last decade of February 2009
    $\hookrightarrow$ 1st results shown last JRA-1 meeting (early March)
  - more recently: 1 wafer sent for thinning to $\sim$ 120 μm and dicing

Prominent Test Features

- **Functionnality tests** (level 0) **:**
  - ※ JTAG $\longmapsto$ chip alive ? $\longmapsto$ 1 faulty chip out of 21 bonded
  - ※ pattern of sensor output (frame header & trailer)

- **Analog output characterisation :**
  - ※ allows characterising pixel matrix and investigating (directly) pixel pbs
  - ※ activated from sensor side (top) opposite to digital r.o. side (bottom) $\longmapsto$
  - ※ 2 r.o. possibilities : 8 columns at right or sweeping through pixel array
  - ※ provides pixel noise and uniformity over sensitive area, spots dead or hot pixels, etc.

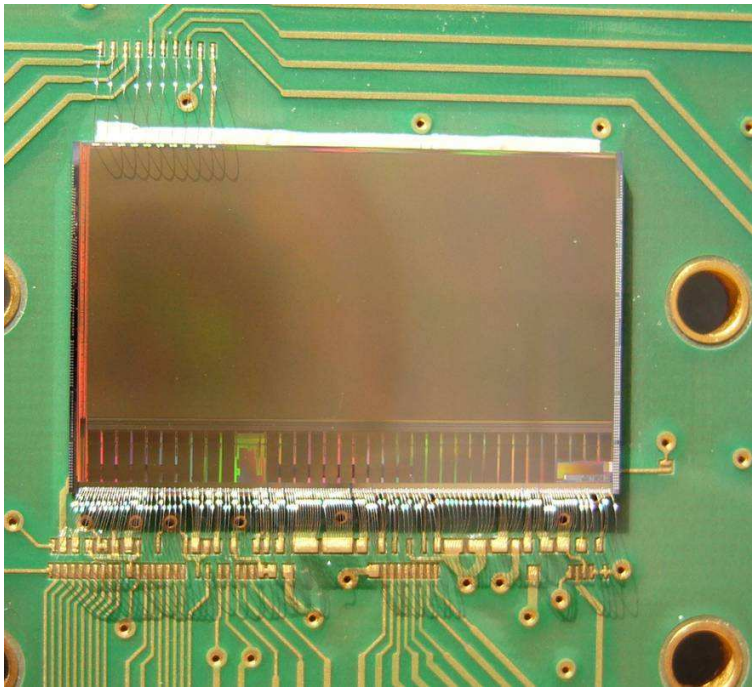


- **Digital output characterisation** (4 configurations) :
  - ※ discriminators alone, i.e. isolated from pixel array (internal voltage injection)
    $\hookrightarrow$ scan threshold uniformity (offset dispersion & temporal noise)
    (also: check possibility to disconnect individual discriminators $\equiv$ disconnect pbtic columns)
  - ※ discriminators connected to pixel array $\Rightarrow$ overall FPN and thermal noise
  - ※ zero-suppression logic and output memories (SUZE-01) alone (JTAG or fired pixel cheater)
  - ※ test of complete chain : pixel array $\oplus$ discriminators $\oplus$ zero-suppresion $\oplus$ output memories

- **Test structure of PLL, 8b/10b :** data transfer option

Reminder: Prominent MIMOSA-26 Features

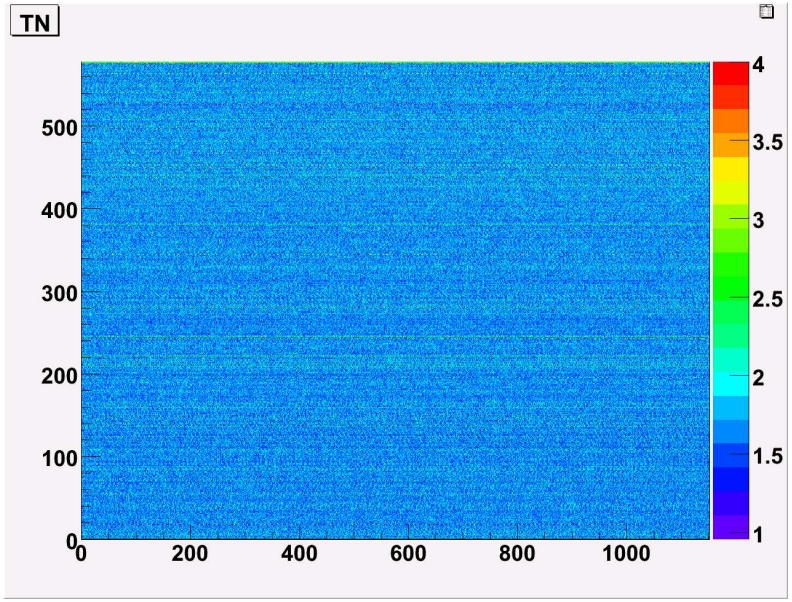
- **MIMOSA-26 $\equiv$ final sensor for EUDET telescope**
  - **MIMOSA-22 (binary outputs) complemented with $\varnothing$ (SUZE-01)**
  - **Active surface : 1152 columns of 576 pixels (21.2 x 10.6 mm^2)**
  - **Pitch : 18.4 $\mu m \rightarrowtail \sim$ 0.7 million of pixels $\rightarrowtail \sigma_{sp} \gtrsim$ 3.5 μm**
  - **Integration time $\lesssim$ 110 $\mu s \rightarrowtail \sim 10^4$ frames / second**
    $\Rightarrow$ *suited to $> 10^6$ particles/cm^2/s*
  - *$\varnothing$ in 18 groups of 64 col. allowing $\leq$ 9 "pixel strings" / raw*
  - *Sensor full dimensions : $\sim$ 21 x 12 mm^2*
  - *Data throughput: 1 output at $\geq$ 80 Mbits/s*
    or 2 outputs at 40/80 Mbits/s

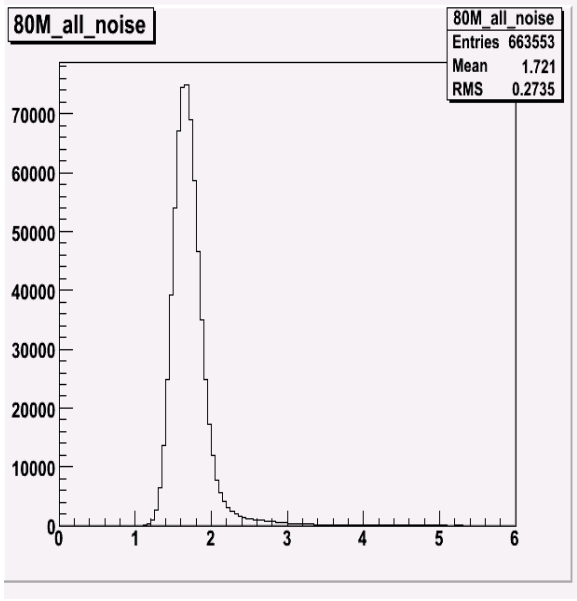


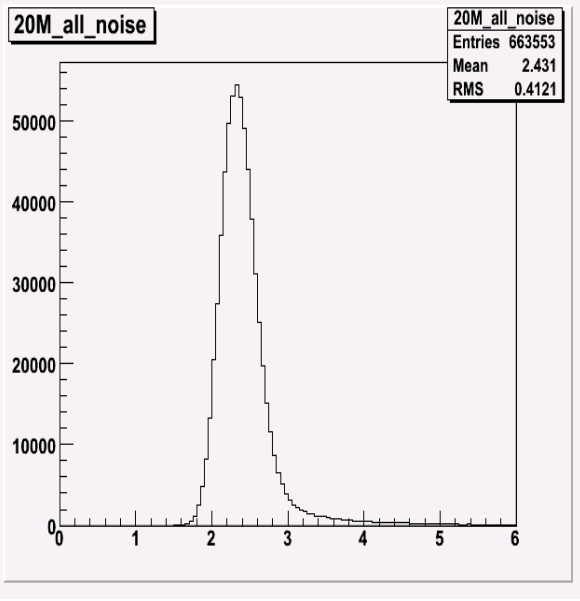
- **Fabricated in AMS-0.35 technology:**
  - Sensor expected to equip several EUDET BT copies
  - Architecture is baseline for STAR, CBM and ILC vertex detectors

Analog Output Test Results

- Analog response studied for 8 different sensors :

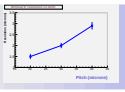






- CCE with ^{55}Fe source : comparison with MIMOSA-22

Cluster size	seed	2x2	3x3	5x5
MIMOSA-26	22 %	55 %	73 %	83 %
MIMOSA-22	22 %	58 %	75 %	86 %



Analog Output Test Results: Summary

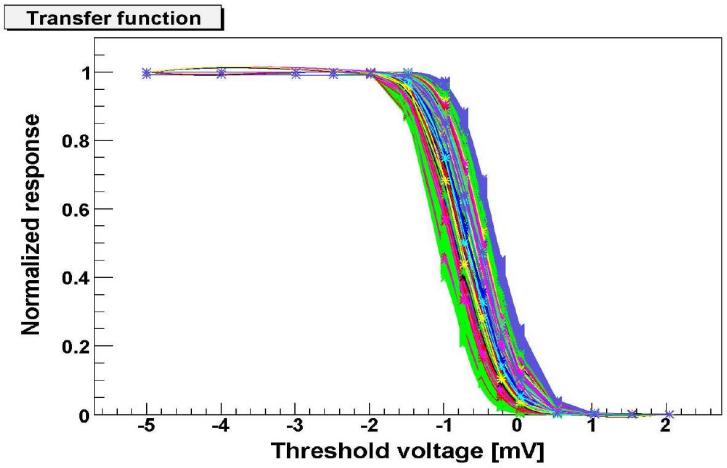
- All pixels are alive (none is dead !)
- Noise is uniform accross the 2 cm^2 sensitive area
- Satisfactory operation from 80 MHz (nominal) down to 20 MHz (and below)
- Noise and CCE performances are $\sim$ identical to those of MIMOSA-22
- All 8 sensors exhibit similar behaviours

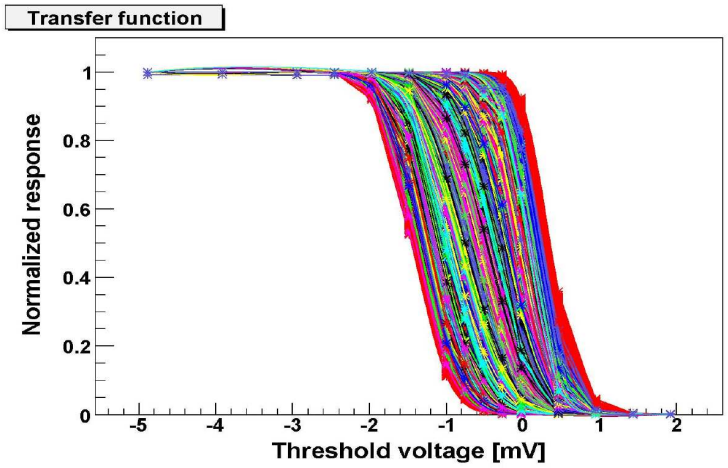
Isolated Discriminator Output Test Results

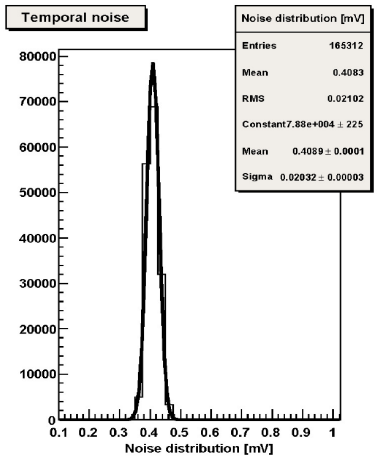
- **Digital output studied on 9 different sensors :**

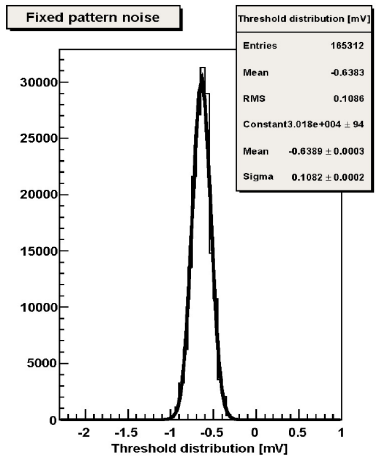
  - ⁂ Noise performance assessed separately for each of the 4 groups of 288 columns (nominal r.o. speed)

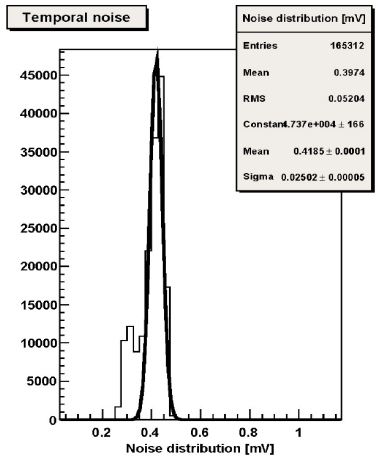
  - ⁂ Example of sub-array A and C (chip Nr.6)

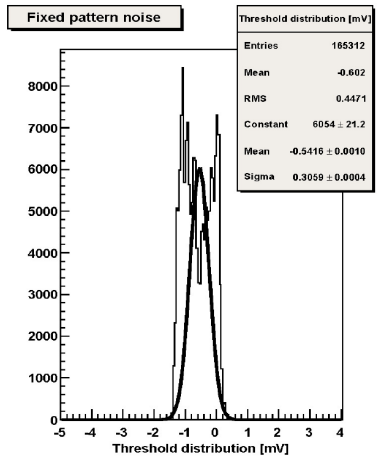


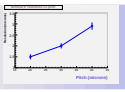












Summary of Isolated Discriminator Output Test Results

- Typical value of discriminator thermal noise $\lesssim$ 0.3–0.4 mV
- Discriminator FPN $\lesssim$ 3 e^- ENC (i.e. 0.15 mV)
- Results are $\sim$ identical to MIMOSA-22 values in sub-array A,
  and slightly worse in sub-array B, C, (D)

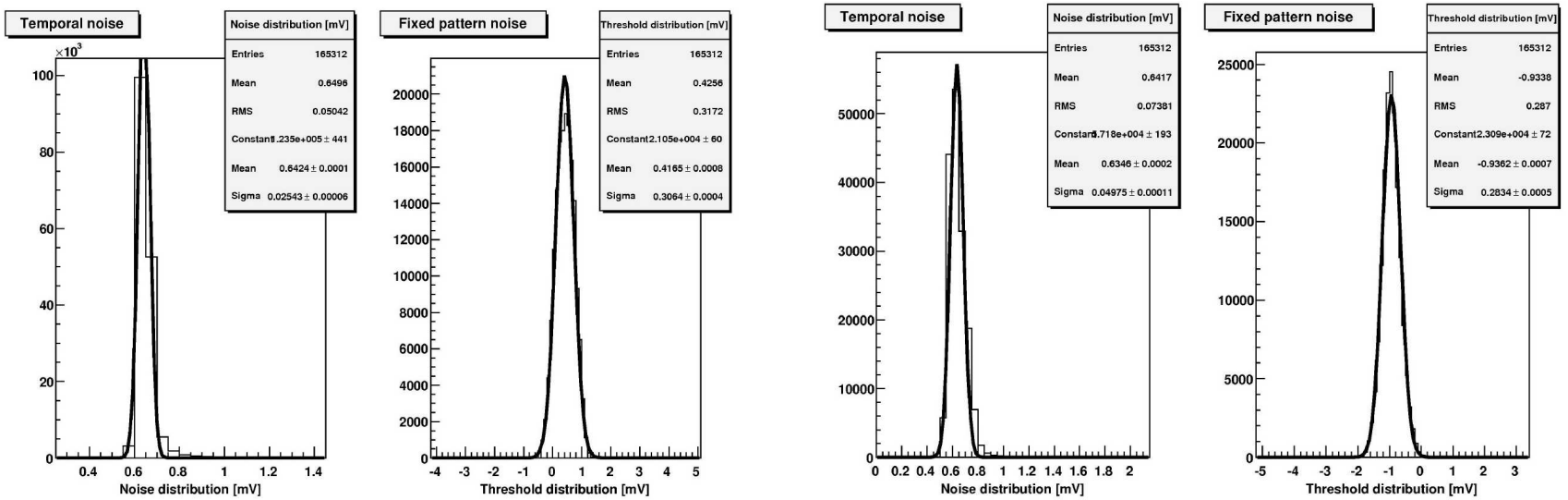
$\Rightarrow$ **All discriminators are operational at nominal speed** (and below)

Analog ⊕ Discriminated Output Test Results

- **Digital output studied on 9 (resp. 4) different sensors at 80 (resp. 20) MHz :**

※ Noise assessed separately for each group of 288 columns, at nominal r.o. speed & below

↪ example of sub-array A and C of chip-6 :



※ Typical value of total temporal noise ∼ 0.6–0.7 mV

※ Typical value of total FPN noise ∼ 0.3–0.4 mV

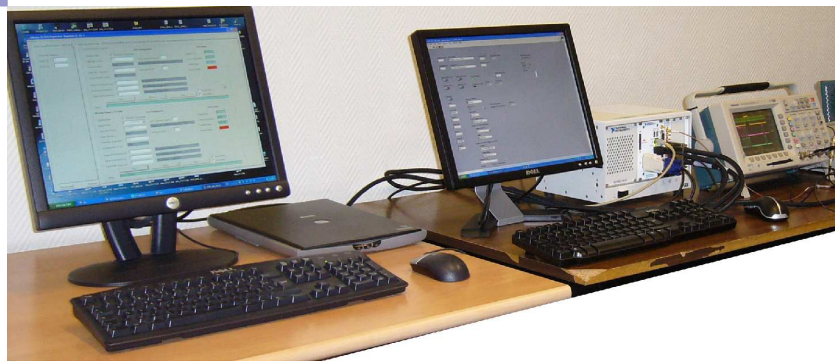
※ Results are ∼ identical to MIMOSA-22 values (N $\lesssim$ 12–13 e^- ENC)

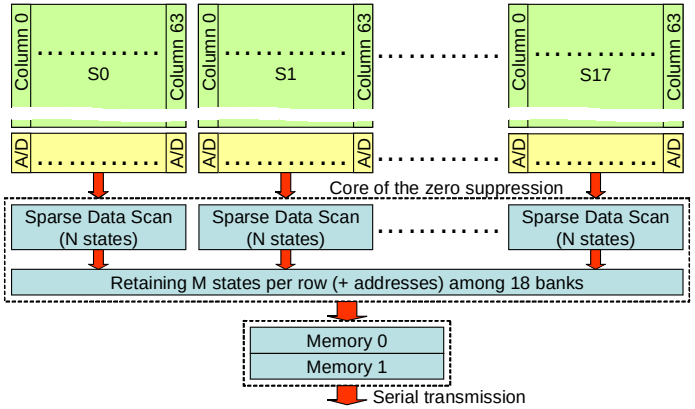
※ 80 ⟼ 20 MHz: pixel noise ↗ & discri. noise ↘ ⇛ mild overall change

⇛ **Array of 660,000 pixels coupled to 1152 discriminators works ∼ as expected**

Zero-Suppression and Output Memories Test Results

Conclusion of the Mimosa 26 Ø Core test result





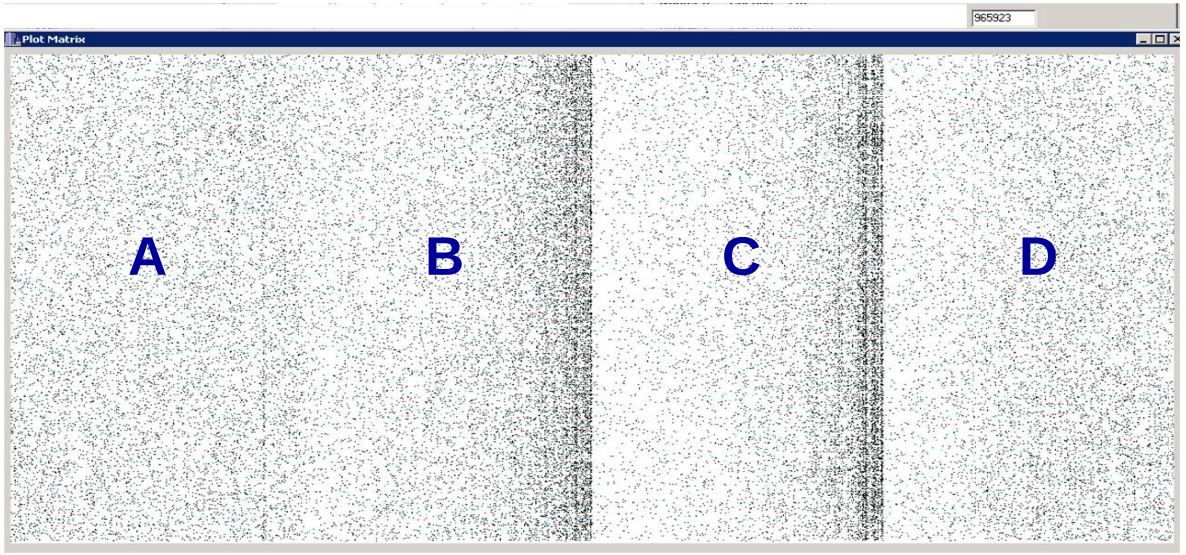
- The pixel array has 575 rows x 1152 columns.
- Zero suppression is based on row by row sparse data scan readout
- Functionality tests:
  - Encoding addresses (line, column) of the hit function (systematic and randomly),
  - Encoding of the states (0 to 9 STATES) in all column positions of the 18 banks (systematic and randomly),
  - Encoding of the shape of the state: 1 to 4 consecutive pixels (systematic and randomly),
  - Checking of the continuity between blocks,
  - Encoding patterns with more than 9 states detected (overflow)
  - Working Frequency range: 10 MHz to 115 MHz.
  - Output modes: 2 outputs 80 MHz, 1 Output 80 MHz, 2 outputs 40 MHz.

- 3 patterns tested 7 millions times without errors
- Robustness test: 199 frames x 10 000 random patterns test at 80 MHz without errors.

Full Chain Test Results

- **Full chain signal delivery studied on several different sensors :**

Ex: Chip-6 output
for 5 N threshold
(10,000 frames)



- Fake hit rate due to pixel noise fluctuations at 80 MHz

Discri. threshold	4 N	5 N	5.5 N	6 N	8 N	10 N
N_{pix} > threshold (10^{-4})	$\lesssim 8$	~ 1.5	~ 1	0.5	0.1	0.03

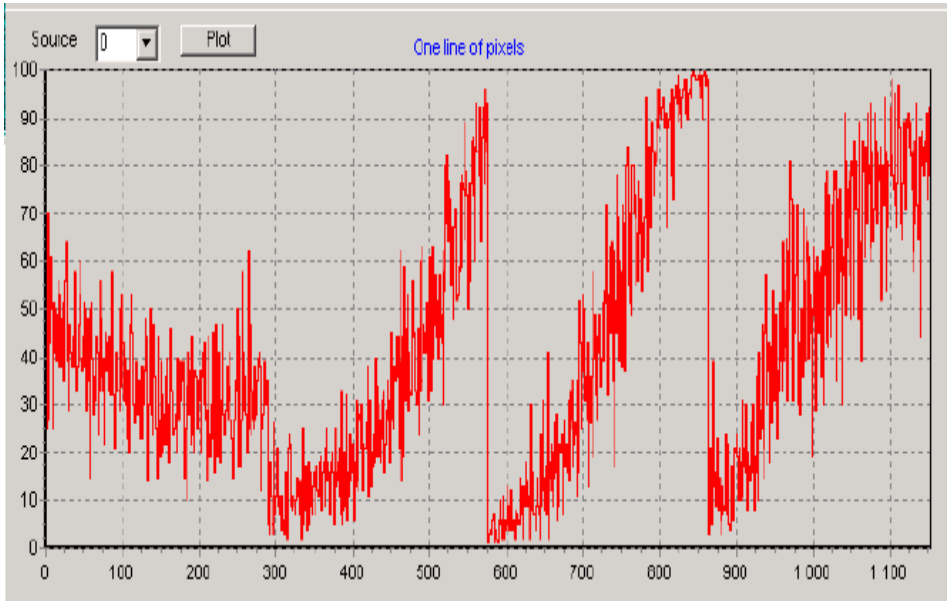
- Varying the operation T from +20°C to +40°C $\longmapsto$ essentially no change
- Multi-hit emulation of pixel array checked to generate the right memory output pattern

- **Running 3 sensors simultaneously :**
  - Test on frame header and trailer during 14 hours ($40 \cdot 10^6$ frames without error)
  - Test on zero-supp. data (1 emulated hit/line) running during 14 hours ($2.3 \cdot 10^6$ frames without error)

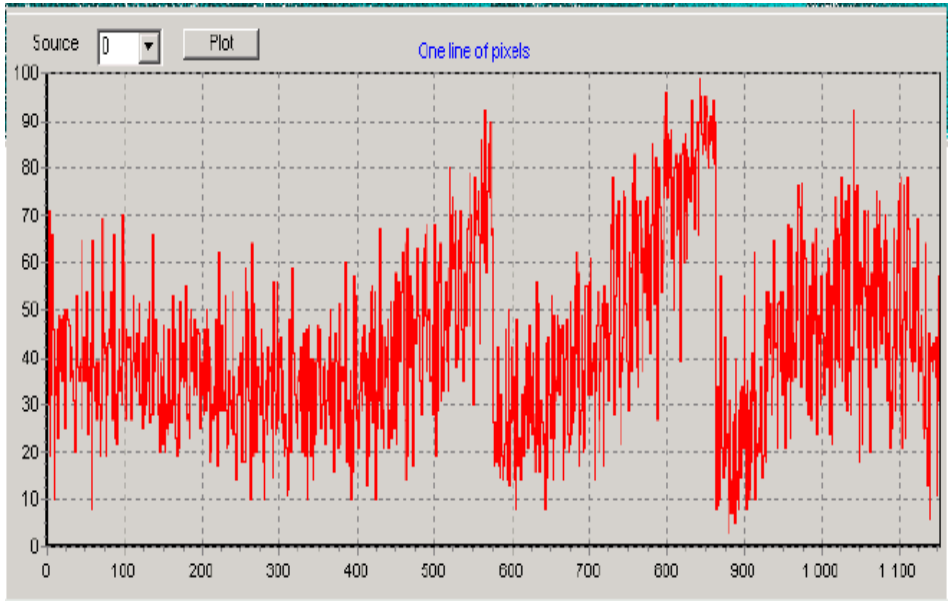
- Dispersion of Discriminator Thresholds

Threshold scan of discriminators :

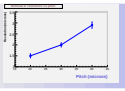
◇ Disconnected from pixel array



◇ Connected to pixel array



⇛ **Dispersion seems mitigated when connecting the discriminators to pixel array**



Summary of Imperfections Observed

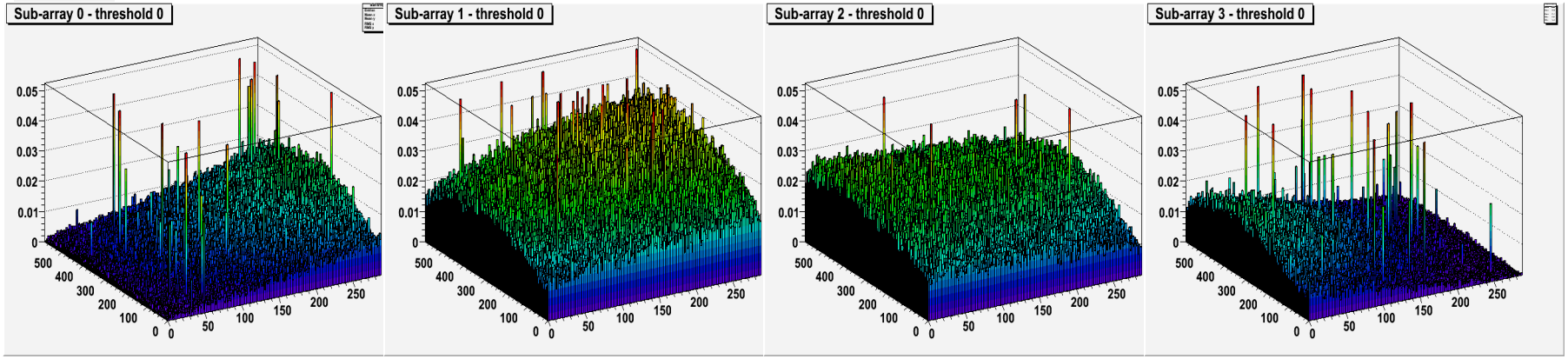
Observed anomalies :

- discriminator threshold non-uniformity $\Rightarrow$ understood: put threshold $\gtrsim$ 5.5 N in group B, C, (D)
- incomplete cluster encoding in raw 576 $\Rightarrow$ understood
- structures (”crocodile skin” - G.C.) in discri. threshold scan $\Rightarrow$ under study
  $\hookrightarrow$ discri. steering feature ?
- r.o. frequency dependence of pixel temporal N (calib. peak) $\Rightarrow$ due to integrated test μcircuitry ?
- etc.

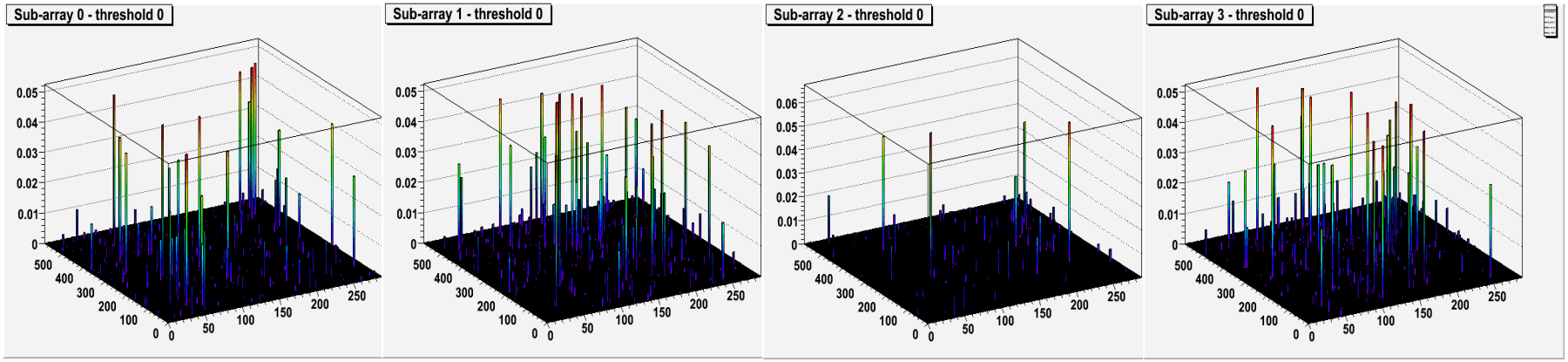
Comments :

- only modest disturbance expected on beam telescope operation
- part of anomalies suspected to come from too weakly optimised measurement procedures
- their study is essentialy motivated by the design plans of coming sensors which are derived from MIMOSA-26 : STAR, CBM, ILC

Illumination with ^{55}Fe Source

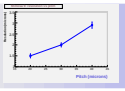


Avec source



sans source

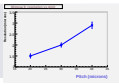
Chip 8
Frequence 80 MHz
coupure sur bruit = 10



Next Steps

- **Complement laboratory tests :**
  - Performances of 50 μm thin sensors
  - Improve understanding of anomalies (for MIMOSA-26 extensions)
  - Operate 6 sensors synchronously
  - Radiation tolerance ?

- **Beam tests:**
  - Period: Septembre 2009 at CERN-SPS (T4-H6)
  - Objectives:
    - N, $\epsilon_{eff.}$ vs fake rate for various discriminator thresholds
    - σ_{SP}, cluster characteristics for various discriminator thresholds
    - synchronous running of 6 sensors, ...



SUMMARY

- **MIMOSA-26** qualification:
  - ≙ sensor has been quite extensively studied in lab (including synchronous operation of 3 chips)
  - ≙ MIMOSA-22 performances reproduced on complete sensitive surface
  - ≙ fabrication yield $\gtrsim$ 90 %
  - ≙ all imperfections found are affordable (will be corrected in sensors derived from MIMOSA-26)

    ⇛ **Overall performances satisfy specifications ⇛ sensor validated for beam tests**

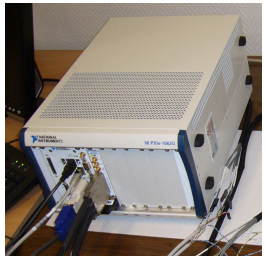
- **What remains to be done**
  - ≙ complementary lab tests: yield estimate for thinned sensors, operation of 6 sensors, etc.
  - ≙ beam tests in Septembre : ϵ_{eff}, fake rate and σ_{SP} vs discri. threshold

Integration Tests : Steering & Readout of N x Mimosa 26

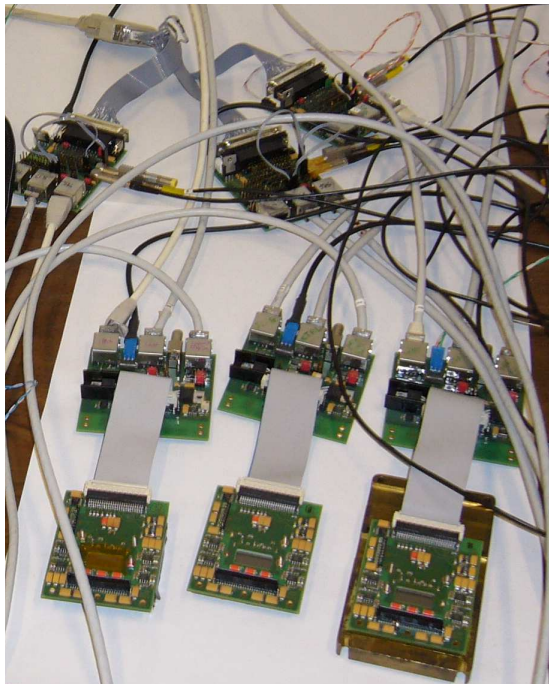
Pattern generator
(Tektro DG2020A)

•Clock X 3
•Start X 3

DAQ NI
PXI 6562 Board



•Clock & Sync X 1
•Data (D0,D1) X 3



3 x Mimosa 26
Readout D0, D1 @ 80 MHz

Goal / Method

- How to run more than one Mimosa 26 on a Telescope like DAQ system ?
  - How to start all Mimosa 26 at the same time ?
  - Will they keep synchronization over a long run ?
  - Trigger handling
- How to perform this test ?
  - Star distribution of clock and external Start to all Mimosa 26
  - External Start source synchronized / CLK falling edge
  - Acquisition of all Mimosa 26 by the same DAQ board (NI PXI 6562)

Tests Done / Results

- Test on Header & Trailer with 3 Mimosa 26
  - 40 10^6 frames without error → Test stopped after ~ 14H00
- Test on ZS data (one emulated hit / line) with 3 Mimosa 26
  - 2,3 10^6 frames without error → Test stopped after ~ 14H00
- Next steps …
  - Test with six Mimosa 26
  - Trigger handling

Commercial DAQ board : NI Flex RIO ?

NI FlexRIO – Custom I/O for LabVIEW FPGA and PXI

NI PXI-795xR *NEW!*

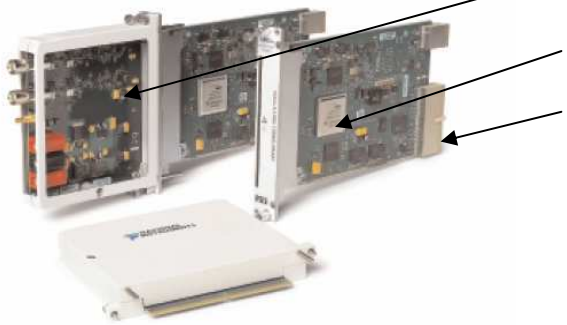
- Virtex-5 FPGA-programmable with the LabVIEW FPGA Module
- Up to 128 MB onboard DDR2 DRAM
- Access to 132 single-ended I/O lines, configurable as 66 differential pairs
- Customizable I/O with the NI FlexRIO Adapter Module Development Kit (MDK)
- 100 MHz digital I/O with the NI 6581 adapter module
- 3 DMA channels for high-speed data streaming

Operating Systems
- Windows Vista/XP/2000
- LabVIEW Real-Time

Required Software
- LabVIEW
- LabVIEW FPGA Module
  - LabVIEW code compiler for FPGAs
  - Emulated debugging mode

Recommended Software
- LabVIEW Real-Time Module

Driver Software (included)
- NI-RIO



Model	Bus/Form Factor	FPGA	FPGA I/O	Onboard Memory (DRAM)
PXI-7951R	PXI	Virtex-5 LX30	66 differential or 132 single-ended	0 MB
PXI-7952R	PXI	Virtex-5 LX50	66 differential or 132 single-ended	128 MB
PXI-7953R	PXI	Virtex-5 LX85	66 differential or 132 single-ended	128 MB
PXI-7954R	PXI	Virtex-5 LX110	66 differential or 132 single-ended	128 MB

Table 1. NI FlexRIO FPGA Modules

Future ?

- PXIe ? 250 MB/s / lane … X 1, 2, 4, 8, 12, 16, 32 → 6 GB/s …
  - Can't be handled by software …
  - Writing to disk + % of monitoring by software
- Fast serial links Gb/s
  - Direct handling on FPGA ?
  - User HW on Adaptater Module

Current Status

- 66 Differential inputs
- User defined Adaptator Module
- User defined on-board fw (deserialisation)
- PXI bus → Average ~ 60 MB/s

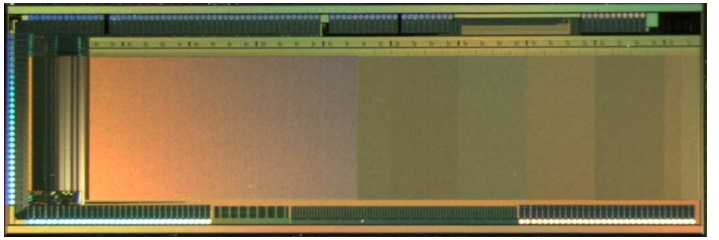
- 1 Mi26 plane @ 10 kframe/s → ~ 25 MB/s
  - 4 Planes ~ 100 MB/s → 60 % of full speed
  - 6 Planes ~ 150 MB/s → 40 % of full speed

Cost ?

- PXI-7951R (No RAM) ~ 2,8 K€
- PXI-7952R (128 MB RAM) ~ 3,7 K €
- Adaptator module SE 100 MHz ~ 1 K€
  - LVDS foreseen for end of summer
- PXIe Crate + CPU ~ 8 K €
- Adaptater Module Development Kit ~ 4,6 K€
  - Overhead of 4,6 K € (CAD files etc …)
  - ~ 60 € / enclosure

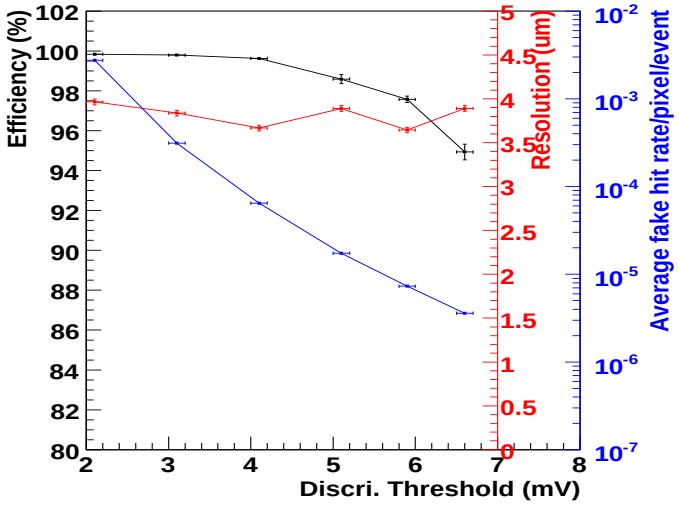
Performances of MIMOSA-22

- **MIMOSA-22** *:*
  - ◇ *fabricated in 2007/08 (coll. with IRFU/Saclay)*
  - ◇ *136 col. of 576 pixels (18.4 μm pitch, integrated CDS)*
  - ◇ *128 col. ended with an integrated discriminator*
  - ◇ *integrated JTAG controller*

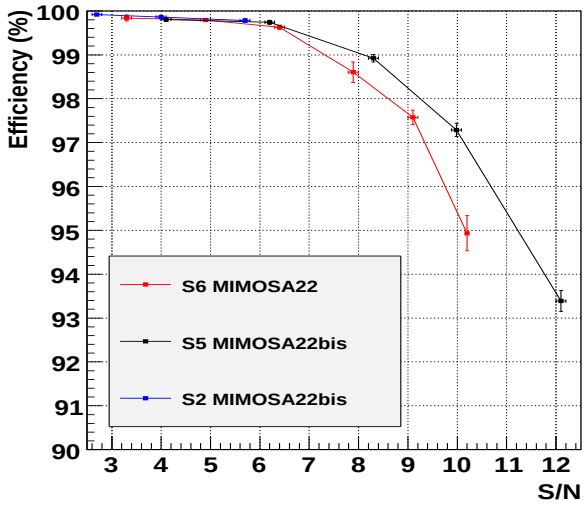


- **Tests at CERN-SPS ($\sim$ 120 GeV π^-) in 2008** $\longmapsto$ *results of different sub-arrays*

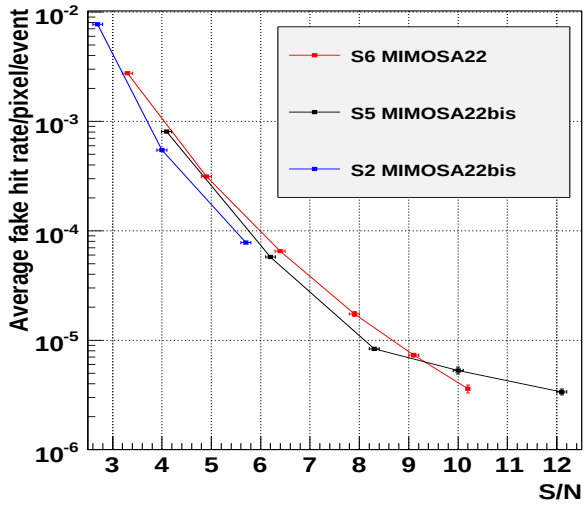
M22 digital S6. Efficiency, Fake rate and Resolution



S6 M22, S5 M22bis & S2 M22bis digital Efficiency



M22bis digital fake hit rate



▷▷▷ **Architectures of pixel (integrated CDS) and of full chain made of ”columns ended with integrated discri. ” validated at real scale**