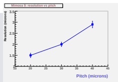


Status Report of the Validation of TC

(alias MIMOSA-26)

Marc Winter (IPHC/Strasbourg)

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

OUTLINE

- General features
- Type of tests performed
- Laboratory test results :
  - ▷ *Analog output*
  - ▷ *Discriminated output*
  - ▷ *Zero-suppression logic*
  - ▷ *Full chain output*
- Next steps & 2010 Perspectives
- Summary

General Features

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

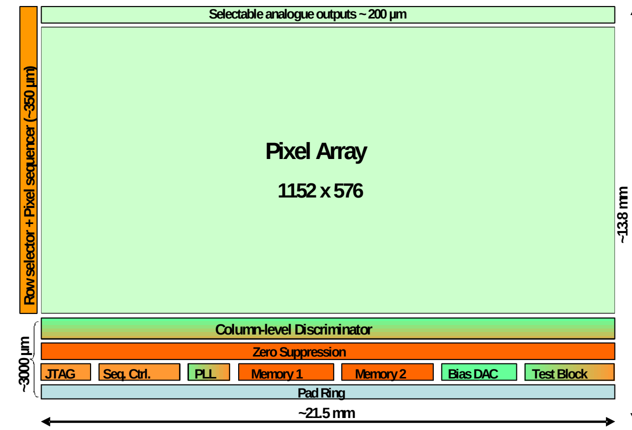
- **Status of sensor delivery :**
  - 3 wafers back from foundry at CMP since first half of February 2009
  - 1/2 wafer (41 sensors) diced and sent to IPHC $\rightarrowtail$ received $\gtrsim$ Feb. 17th
  - functionnality tests started in last decade of February 2009

    $\hookrightarrow$ most results shown last JRA-1 meeting (early June)
  - more recently: 1 wafer thinned to $\sim$ 120 μm and diced

    $\rightarrowtail$ 77 sensors received June 15th (1 broken)

Prominent Test Features

- **Functionnality tests** (level 0) **:**
  - JTAG ⟼ chip alive ? ⟼ 1 faulty chip out of 21+6 bonded
    - ▷ 1 chip with 1 raw & 1 col. dead – 3 chips with 1 raw or 1 col. dead
  - 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) ⟼
  - 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.

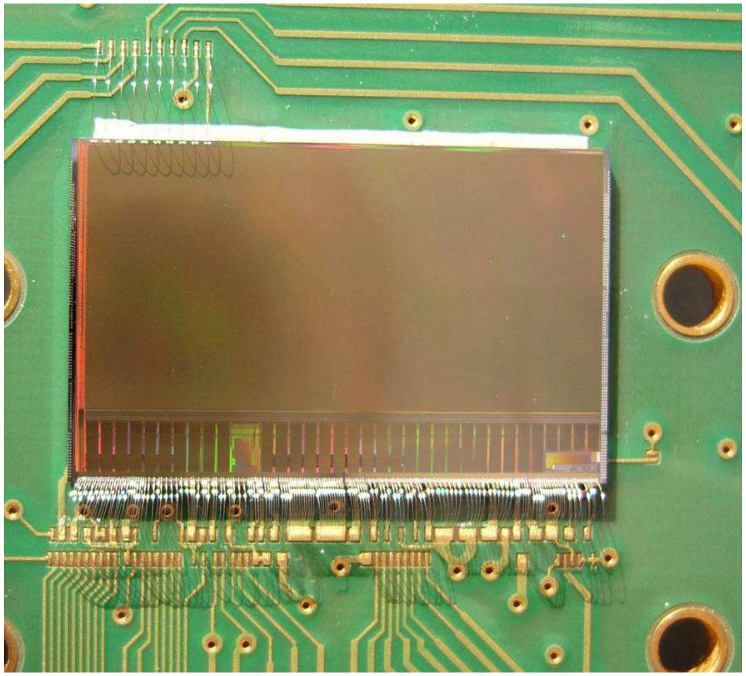
- **Digital output characterisation** (4 configurations) :
  - discriminators alone, i.e. isolated from pixel array (internal voltage injection)
    - ↪ scan threshold uniformity (offset dispersion & temporal noise)
    - (also: check possibility to disconnect individual discriminators ≡ disconnect pbtic columns)
  - discriminators connected to pixel array ⇛ 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 ⊕ discriminators ⊕ zero-suppresion ⊕ output memories

Reminder: Prominent TC Characteristics

- **TC $\equiv$ full scale sensor with integrated suppression**
  - **MIMOSA-22 (binary outputs) complemented with $\emptyset$ (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**

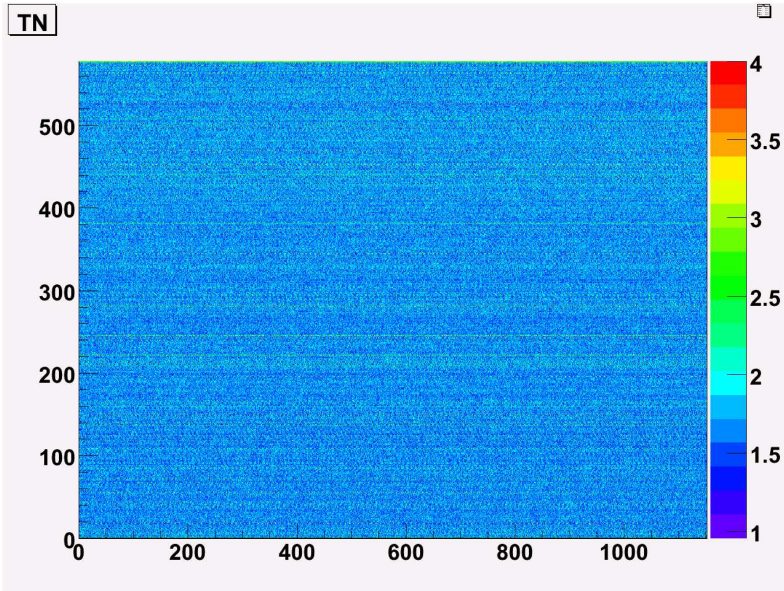
    $\Rrightarrow$ *suited to $> 10^6$ particles/cm^2/s*
  - *$\emptyset$ in 18 groups of 64 col. allowing $\leq$ 9 "pixel strings" / raw*
  - *Sensor full dimensions : $\sim$ 21.5 x 13.8 mm^2*
  - *Data throughput: 1 output at $\geq$ 80 Mbits/s*

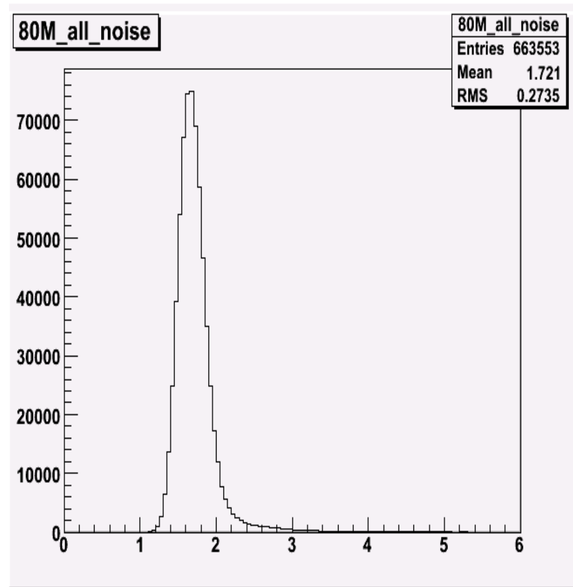
    or 2 outputs at 40/80 Mbits/s (all tests performed with 2 $\times$ 80 Mbits/s)

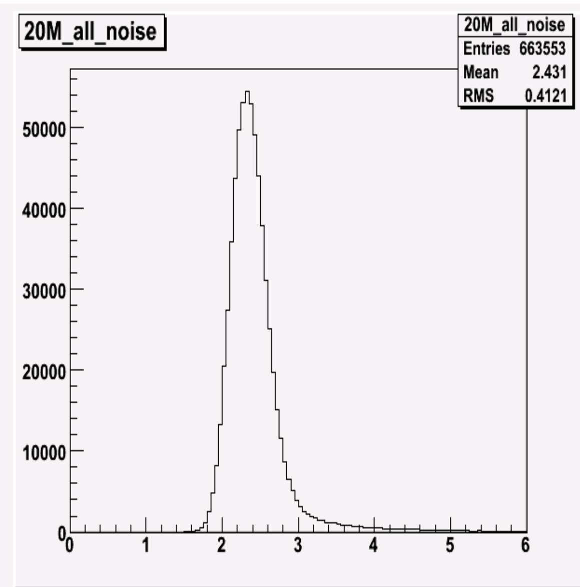


- **Fabricated in AMS-0.35 technology:**
  - Sensor expected to equip several EUDET BT copies ($\Rrightarrow$ I.P. handling ?)
  - Architecture $\equiv$ baseline for designing sensors adapted to STAR, CBM and ILC vertex detectors

- 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 %

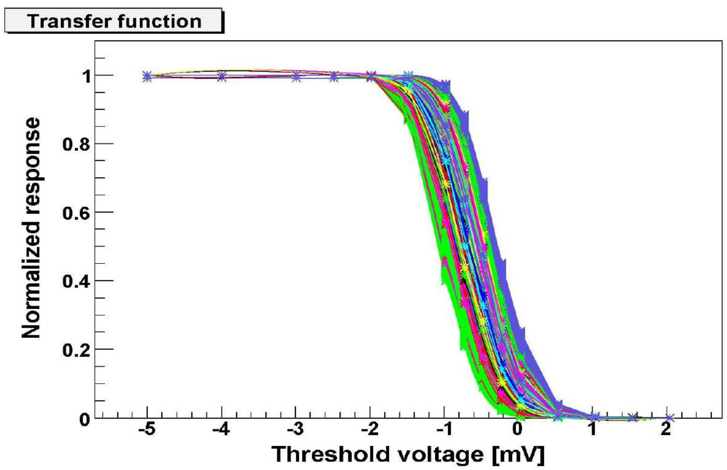
Analog Output Test Results: Summary

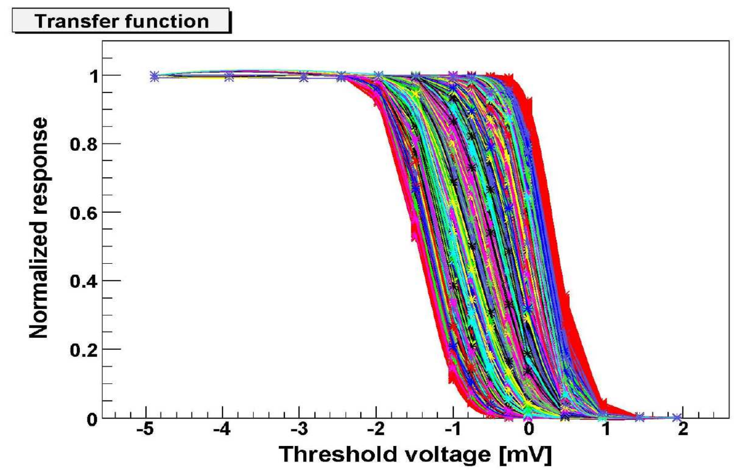
- All pixels are alive (none is dead !)
- Noise is uniform accross the 2 cm^2 sensitive area
- Satisfactory operation from 80 MHz (nominal) down to 20 MHz (and below)
- Noise and CCE performances are $\sim$ identical to those of MIMOSA-22
- All 8 sensors exhibit similar behaviours

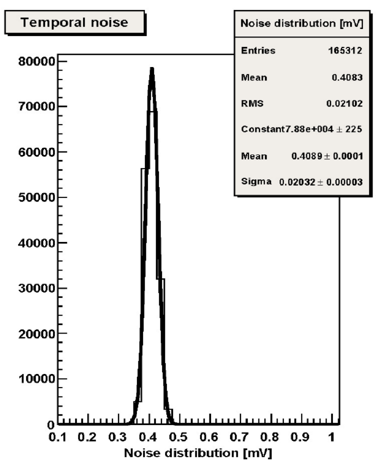
Isolated Discriminator Output Test Results

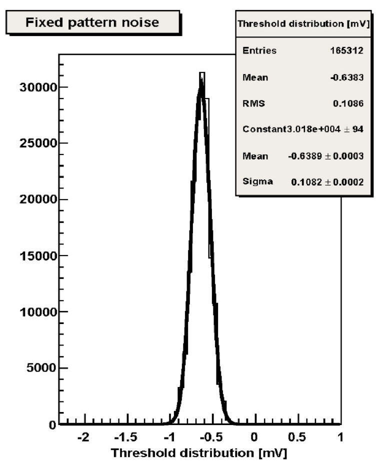
Digital output studied on 15+6 different sensors :

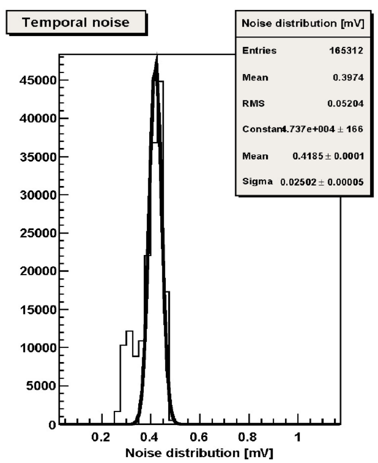
- ⁜ Noise performance assessed separately for each of the 4 groups of 288 columns (nominal r.o. speed)
- ⁜ Example of sub-array A and C (chip Nr.6)

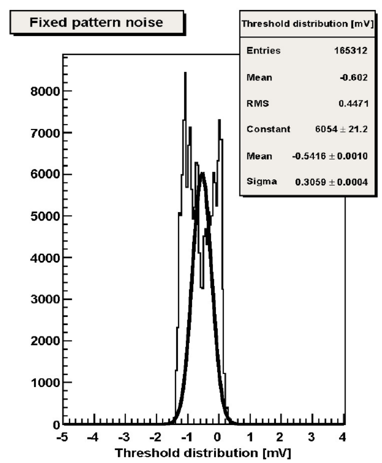




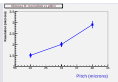








RMS ~ 0.02 mV RMS ~ 0.11 mV RMS ~ 0.05 mV RMS ~ 0.45 mV



- 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)

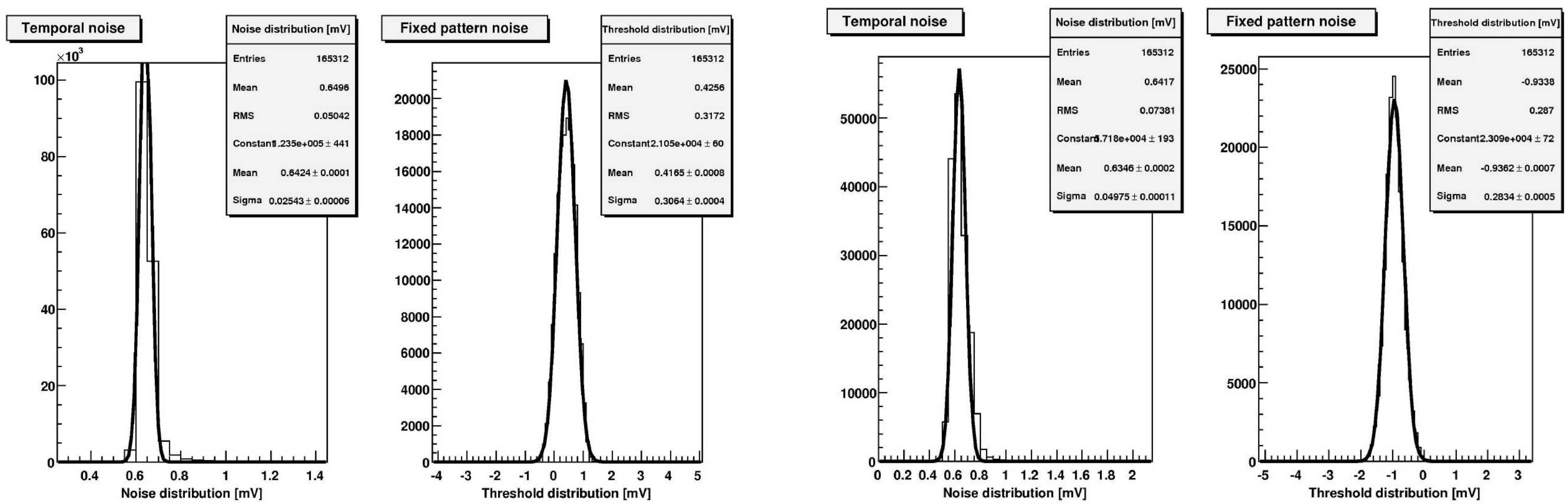
$\Rrightarrow$ **All discriminators are operational at nominal speed** (and below)

Analog $\oplus$ Discriminated Output Test Results

- Digital output studied on 15+6 (resp. 4) different sensors at 80 (resp. 20) MHz :

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

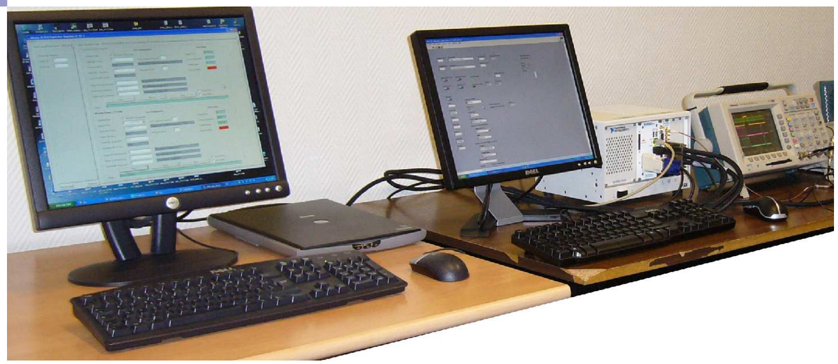
    $\hookrightarrow$ example of sub-array A and C of chip-6 :

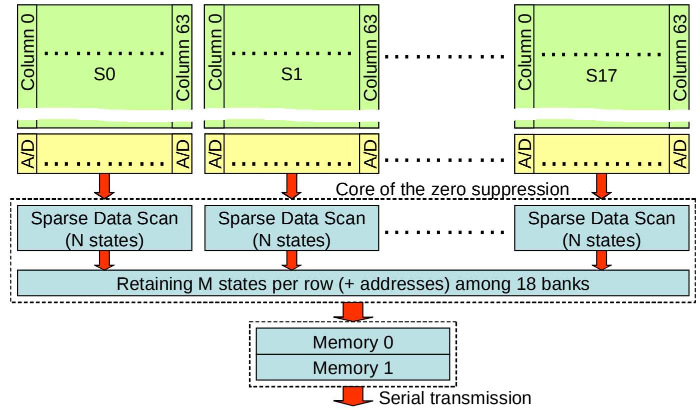


  - Typical value of total temporal noise $\sim$ 0.6–0.7 mV
  - Typical value of total FPN noise $\sim$ 0.3–0.4 mV
  - Results are $\sim$ identical to MIMOSA-22 values (N $\lesssim$ 12–13 e^- ENC)
  - 80 $\longrightarrow$ 20 MHz: pixel noise $\nearrow$ & discri. noise $\searrow$ $\Rrightarrow$ mild overall change

$\Rrightarrow$ **Array of 660,000 pixels coupled to 1152 discriminators works $\sim$ as expected**

Conclusion of the Mimosa 26 Ø Core test result





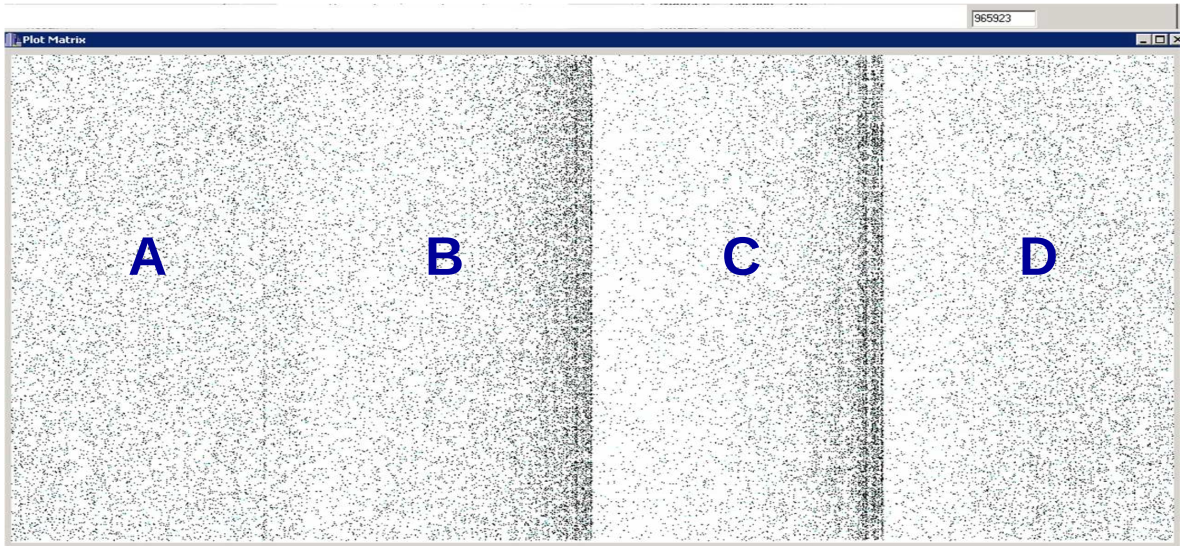
- The pixel array has 575 rows x 1152 columns.
- Zero suppression is based on row by row sparse data scan readout
- Functionality tests:
  - Encoding addresses (line, column) of the hit function (systematic and randomly),
  - Encoding of the states (0 to 9 STATES) in all column positions of the 18 banks (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)

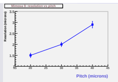


⋇ Fake hit rate due to pixel noise fluctuations at 80 MHz

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

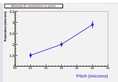
⋇ Varying operating T from +20°C to +40°C $\longrightarrow$ essentially no change (fake rate is $\sim$ stable)

⋇ Multi-hit emulation of pixel array checked to generate the right memory output pattern



Full Chain Multi Chip Test Results

- **Running 3 or 6 sensors simultaneously :**
  - Test with 6 sensors on frame header and trailer during 14 hours ($\sim 10^8$ frames without error)
  - Test with 3 sensors on zero-supp. data (1 emulated hit/line) running during 14 hours ($2.3 \cdot 10^6$ frames without error)
- **Running telescope of 2 sensors exposed to beta source:**
  - correlation between impacts in both layers clearly observed
  - system ready for beam tests at CERN
- **Running 3 sensors in EUDET BT demonstrator :**
  - telescope of 3 TC chips mounted as DUT in BT demonstrator in July (see talk by Ingrid)
  - BT tracks reconstructed in the 3 planes $\Rightarrow$ residues compatible with $\sigma_{sp} \gtrsim 3.5\ \mu m$



Summary of Imperfections Observed

Observed anomalies :

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

Next Steps

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

- **Beam tests:**
  - Period: 1st half of Septembre 2009 at CERN-SPS (T4-H6)
  - Objectives:
    - synchronous running of 6 (120 μm thin) sensors, ...
    - $\epsilon_{eff.}$ vs fake rate for various discriminator thresholds
    - σ_{SP}, cluster characteristics for various discriminator thresholds

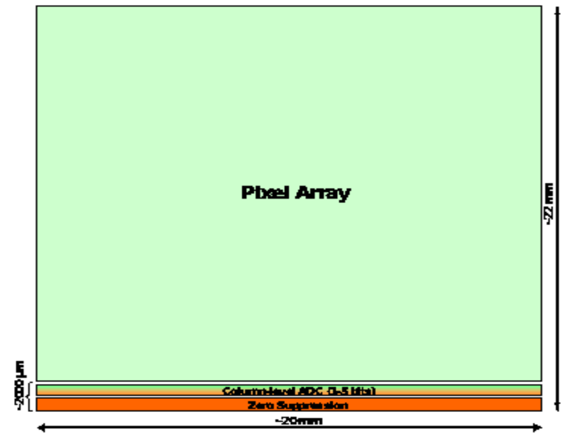
Ultimate Sensors

- **Use 2010 to upgrade the telescope with new sensors :**
  - $\sim$ double sensitive area
  - correct or mitigate MIMOSA-26 design weaknesses (discri. ramps, row 575 feature, a.s.o.)
  - improve ionising radiation tolerance (based on MIMOSA-22bis & MIMOSA-22ter tests)

$\Rrightarrow$ **Replace MIMOSA-26 with** ULTIMATE **sensor developed for STAR HFT :**

- 1152 columns of 1024 pixels

  $\Rrightarrow$ 21 $\times$ 19 mm^2 sensitive area & $\sim$ 200 μs integration time
- output memories about 2.5 times larger
- steering and read-out fully compatible with MIMOSA-26 r.o. chain
- fabrication in 1st semestre of 2010 $\Rrightarrow$ telescope running by end of 2010
- sensor fabrication and thinning costs covered via IPHC-Strasbourg



- **TC (alias MIMOSA-26) qualification:**
  - sensor has been quite extensively studied in lab (including synchronous operation of 6 chips)
  - MIMOSA-22 performances reproduced on complete sensitive surface
  - fabrication plus (120 μm) thinning yield $\sim$ 90 %
  - all imperfections found are affordable (will be corrected in sensors derived from MIMOSA-26)
  - running 3 sensors mounted on BT demonstrator successful

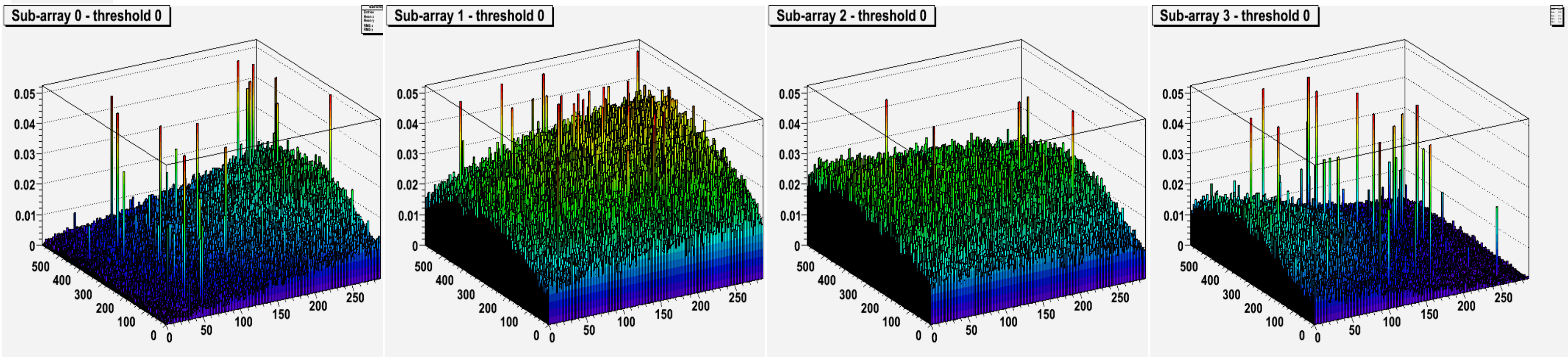
$\Rrightarrow$ **Overall performances within specifications $\Rrightarrow$ sensor validated for BT commissionning**

- **What remains to be done**
  - complementary lab tests : yield for 50 μm thin sensors, rad. tol. x-check, etc.
  - beam tests (Sept.) : 6 sensors (120 μm thin) $\rightarrowtail$ ϵ_{eff}, fake rate & σ_{SP} vs discri. threshold

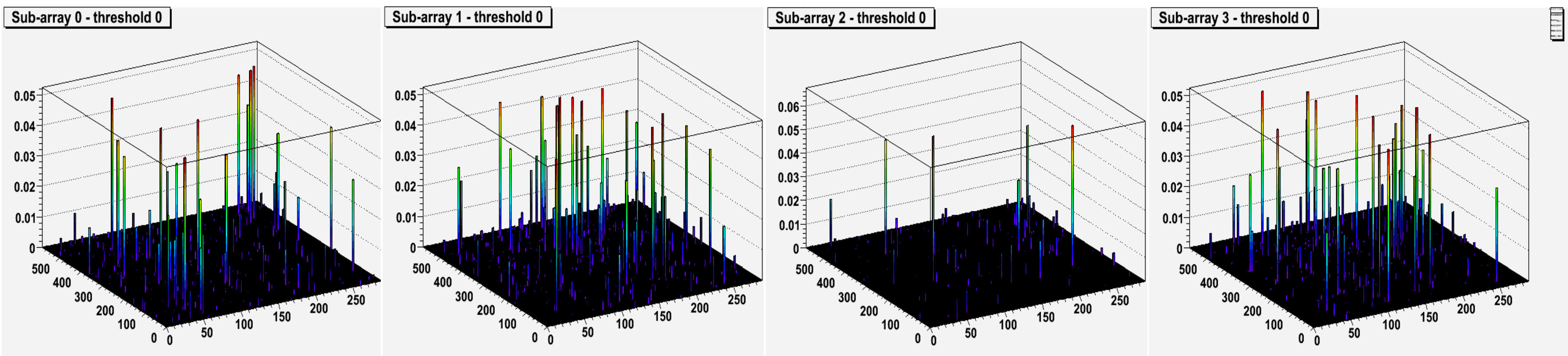
- **Motivation for an upgrade:**
  - steady increasing number of users $\Rrightarrow$ call for best possible final EUDET deliverable
  - use 2010, exploiting evolution of MIMOSA-26 architecture towards STAR-HFT sensor
  - added value : twice sensitive area, correction of imperfections, better ionising rad. tol., ...
  - effort is affordable ....

- Illumination with ^{55}Fe source
- MIMOSA-26 multi-sensor test
- Reminder : MIMOSA-22 test results

Illumination with ^{55}Fe Source

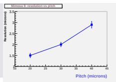


Avec source



sans source

Chip 8
Frequence 80 MHz
coupure sur bruit = 10



Integration Tests : Steering & Readout of N x Mimosa 26

Pattern generator

(Tektro DG2020A)

DAQ NI

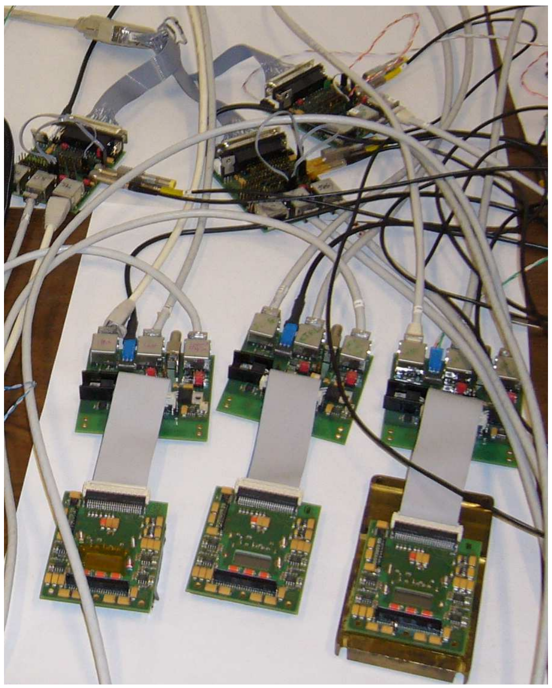
PXI 6562 Board

•Clock X 3

•Start X 3

•Clock & Sync X 1

•Data (D0,D1) X 3



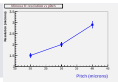
3 x Mimosa 26
Readout D0, D1 @ 80 MHz

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)

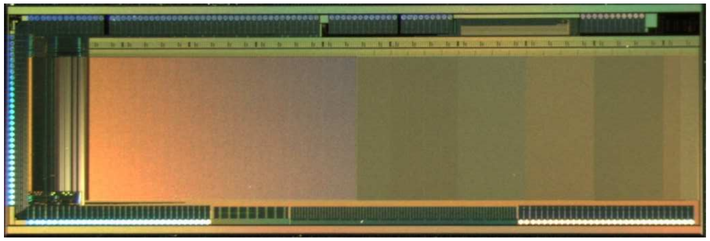
Tests Done / Results

- 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



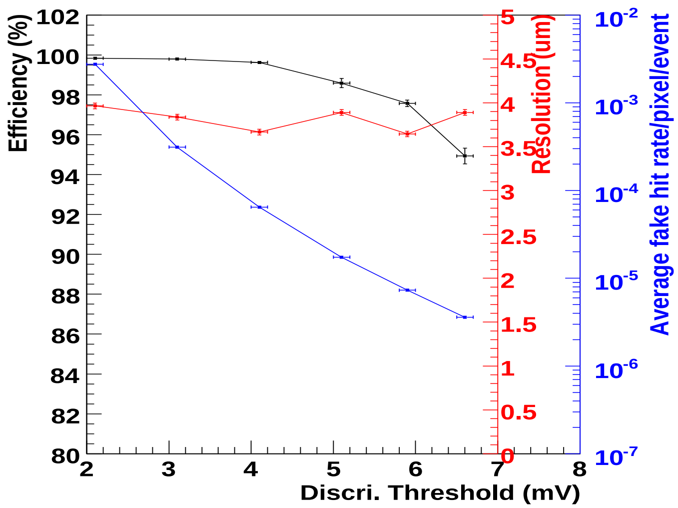
Performances of MIMOSA-22

- **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*

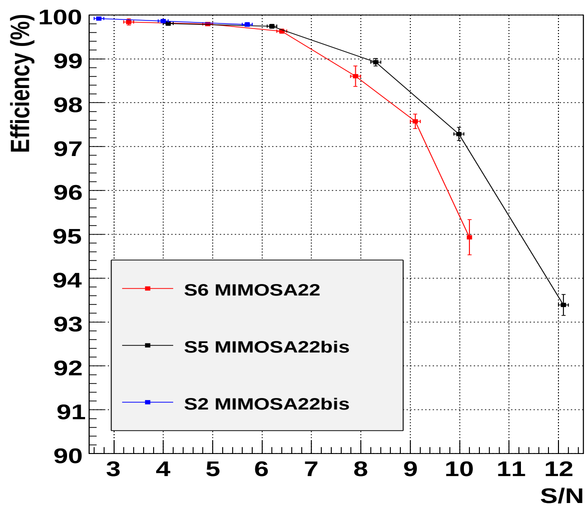


- **Tests at CERN-SPS ($\sim$ 120 GeV π^-) in 2008** $\rightarrowtail$ *results of different sub-arrays*

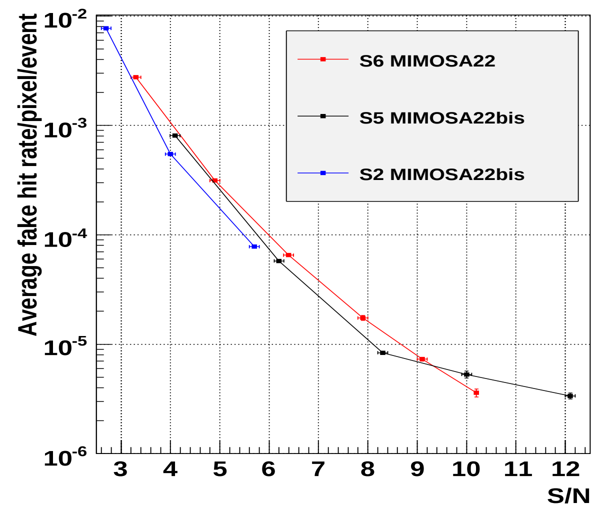
M22 digital S6. Efficiency, Fake rate and Resolution



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**