Towards the Final Telescope Sensor

Status Report

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on behalf of IPHC and IRFU/Saclay

▷ **More info. on IPHC Web site : http://wwwires.in2p3.fr/ires/web2/rubrique.php3?id_rubrique=63**

OUTLINE

- **Strategy of the chip development (reminder)**
- **Col. // sensor prototyping:** *description of architecture, IDC prototype lab and beam test results*
- **Zero supp. and output memory μ-circuits :** *SDC-2 prototype short description and test results*
- **The question of radiation tolerance**
- **Final chip : status of design and plans**
- **Summary - Outlook**

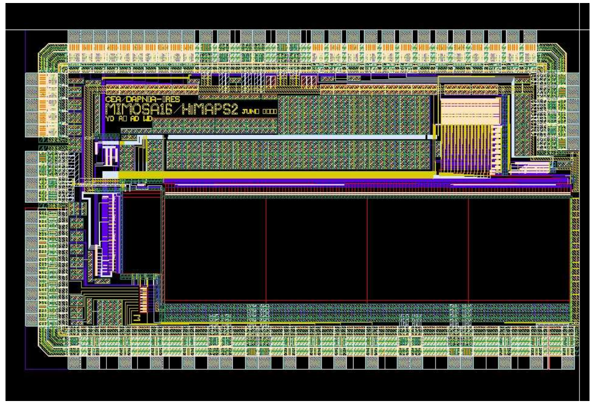
- **Motivation for a dedicated beam telescope architecture:**
  - ≏ *beam intensity : read-out* $\lesssim 10^4$ *frames / second*
  - ≏ *DUT surface & resolution requirements : active surface of 1x2 cm*^{2} *with* $\gtrsim$ *0.5 million pixels*
  - ⇛ *sensor should incorporate zero suppression* ⇛ **+** *integrated signal discrimination*

- **Development strategy:** *two prototyping lines pursued in parallel*
  - ≏ *column // architecture adapted to the required speed* ▷ *MIMOSA-16* ▷ **IDC/**MIMOSA-22
  - ≏ *integrated* $\emptyset$ *and output memories adapted to the corresponding occupancy (e.g. SDC-2 / SUZE-01)*

- **Specific goals of IDC/MIMOSA-22 :**
  - *validate the fast read-out architecture developed in MIMOSA-16 (next slide) at* **Real Scale**
  - *extract an optimal pixel design (sensing diode characteristics)*
  - *improve the chip testability (JTAG, analog outputs, pads, ...)*

- **Objective beyond IDC/MIMOSA-22 :**
  - *once validated, the IDC/MIMOSA-22 architecture will be merged with SDC-2/SUZE-01*
    - ⇛ *Final Sensor (TC/MIMOSA-26), to be sent for fabrication in Autumn*

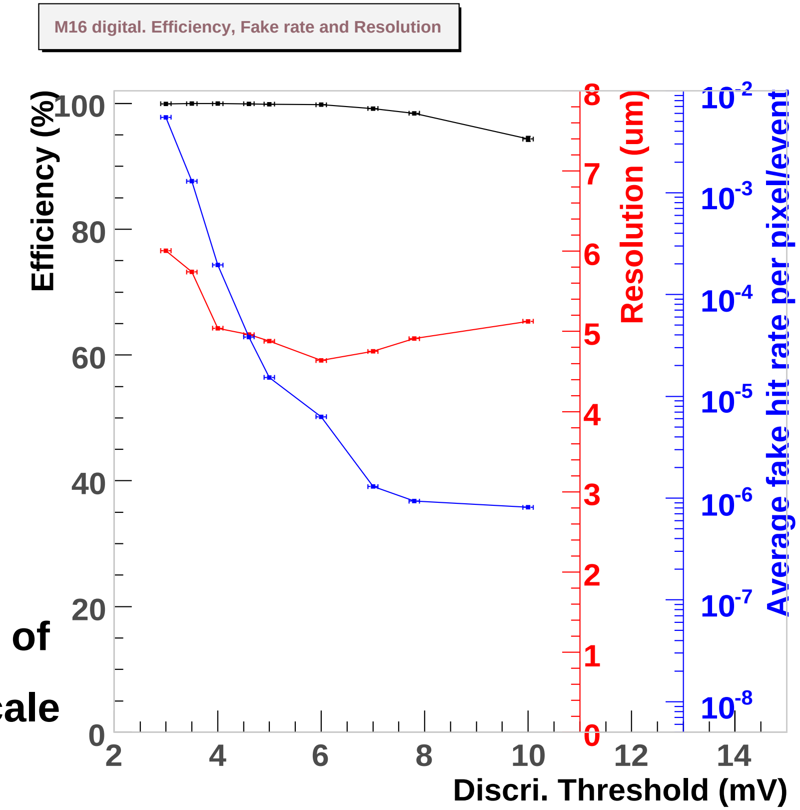
- MIMOSA-16 : ◇ *fabricated in 2006 (coll. with IRFU/Saclay)*
  - ◇ *32 col. of 128 pixels (25 μm pitch, integrated CDS)*
  - ◇ *24 col. ended with an integrated discriminator*
  - ◇ *4 different pixels (i.e. 4 sub-arrays)*



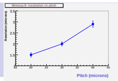
- *Tests at CERN-SPS ($\sim$ 180 GeV π^-) in Summer 2007*

  $\rightarrowtail$ *results of one sub-array (S4)*

Discri. threshold	*Detection eff.*	*Fake rate*	*Resolution*
4 m V	*99.96 $\pm$ 0.03 (stat) %*	$\sim$ *2·10^{-4}*	$\sim$ *4.8 – 5.0 μm*
6 m V	*99.88 $\pm$ 0.05 (stat) %*	$<$*10^{-5}*	$\sim$ *4.6 μm*



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



Main Characteristics of the IDC/MIMOSA-22 Sensor

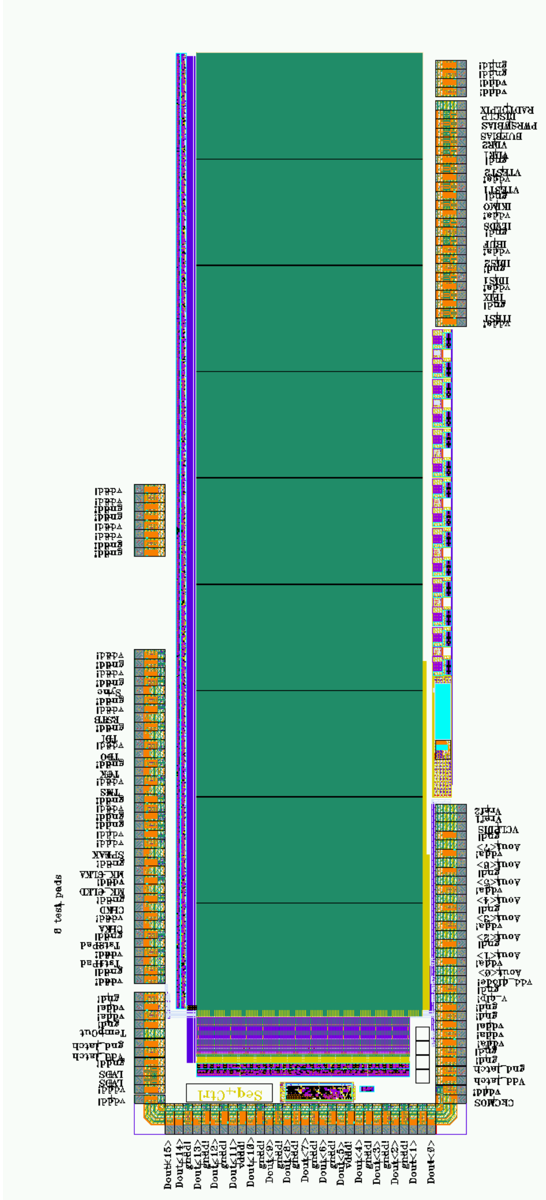
♣ **Extension of MIMOSA-16 $\longrightarrow$ larger surface, smaller pitch, optimised pixel, JTAG, more testability**

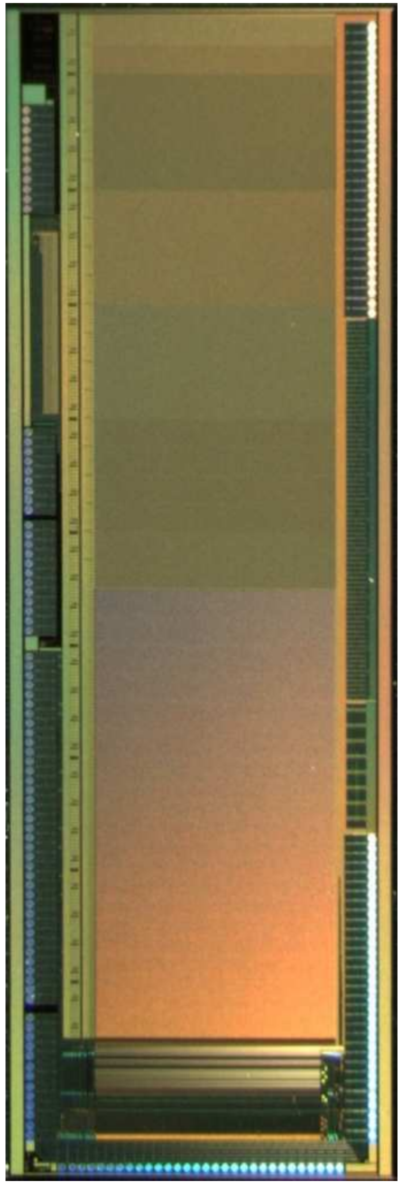
Pixel characteristics (*optimal charge coll. diode size ?*) :

- ⋇ pitch : 18.4 μm (compromise resolution/pixel layout)
- ⋇ diode surface : $\sim$ 10 – 20 μm^2 to optimise charge coll. & gain
- ⋇ 128 columns ended with discriminator
- ⋇ 576 pixels per column ($\equiv$ final column length)
- ⋇ 8 columns with analog output for test purposes
- ⋇ 9 sub-matrices of 64 rows :

  17 pixel designs w/o ionising rad. tol. diode

  $\Rrightarrow$ active digital area $\sim$ 25 mm^2 (128 x 576 pixels)
- ⋇ read-out time $\sim$ 100 μs ($\sim$ 10^4 frames/s)

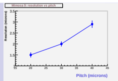




Testability :

- ⋇ JTAG + bias DAC $\longrightarrow$ programmable chip steering
- ⋇ 2 additionnal DC voltages to emulate pixel's output

  for independent discriminator performance assessment
- ⋇ output frequency $\leq$ 40 MHz



IDC/MIMOSA-22: Pixel Designs Investigated

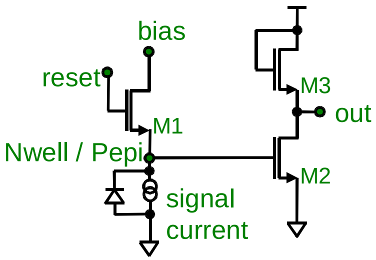
- **Topics investigated :**
  - ⋇ *optimum between CCE (⇛ large diode) and capacitive noise (⇛ small diode)*
  - ⋇ *effective and robust pre-amplification scheme*
  - ⋇ *low noise (ionising) radiation tolerant design*
  - ⋇ *temperature dependence of performances*
  - ⋇ *performance uniformity over full active surface*
  - ⋇ *comparison with MIMOSA-16 performances (24 columns of 128 pixels)*

- **5 pixel designs implemented, combining 2 reset & 2 ampli. variants (w/o rad. tol. diode, diff. diode sizes):**
  - ⋇ *reset diode with (standard) common source amplifier : w/o improved gain*
  - ⋇ *self-biased feedback diode with common source amplifier with improved gain*
  - ⋇ *feedback reset diode with common source amplifier : w/o improved gain*

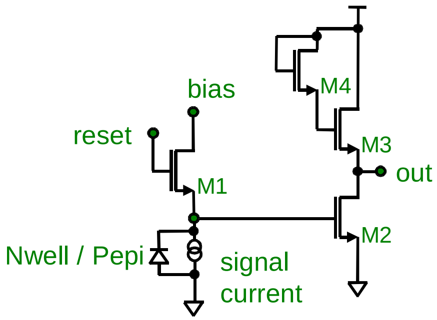
- **Status :**
  - ⋇ *back from foundry since Feb.'08*
  - ▷ *lab tests of analog and digital (discri.) outputs with ^{55}Fe source completed*
  - ▷ *first beam tests (CERN-SPS / August '08) partially analysed*

Various pixel designs (rad. tol. and standard) :

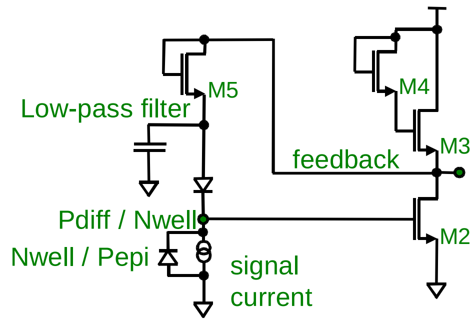
- *reset diode (improved gain)*
- *self-biased diode with feedback (improved gain)*



(S13)



(S10)



(S6)

Main results obtained with exposure to ^{55}Fe source (t$_{r.o.}$ = 92.5 μs) :

- *Noise :*
  - *Temporal (pixel) Noise $\sim$ 0.5 – 0.7 mV (10 $<$ N $<$ 14 e$^-$ ENC)*
  - *FPN $\sim$ 0.25 mV*
  - *N (rad. tol. pixels) $\sim$ N (standard pixels) + 1 e$^-$ ENC*
- *Cluster CCE :*
  - *3x3 pixels : 70 – 80 %*
  - *5x5 pixels : 80 – 90 %*
- *modest T dependence between $\sim$ 10°C and 35°C : $\lesssim$ 10 % noise variation*
- *5 different chips characterised : identical performances within $\pm$ 5 %*

IDC/M22 Lab Tests : Analog Output Results

	S6		S7		S8		S9		S10	
	mV	e-	mV	e-	mV	e-	mV	e-	mV	e-
TN	0.612	11.5	0.601	10.7	0.615	11.3	0.595	10.0	0.639	11.6
FPN	0.250	4.7	0.263	4.6	0.254	4.4	0.273	4.6	0.222	4.0

	S12		S13		S15		S16		S17	
	mV	e-	mV	e-	mV	e-	mV	e-	mV	e-
TN	0.636	11.2	0.692	13.4	0.682	12.8	0.536	12.4	0.527	11.4
FPN	0.225	4.0	0.269	5.2	0.277	5.2	0.218	5.1	0.217	4.7

- Pixel Noise ~ 0.6mV
- FPN ~ 0.25 mV

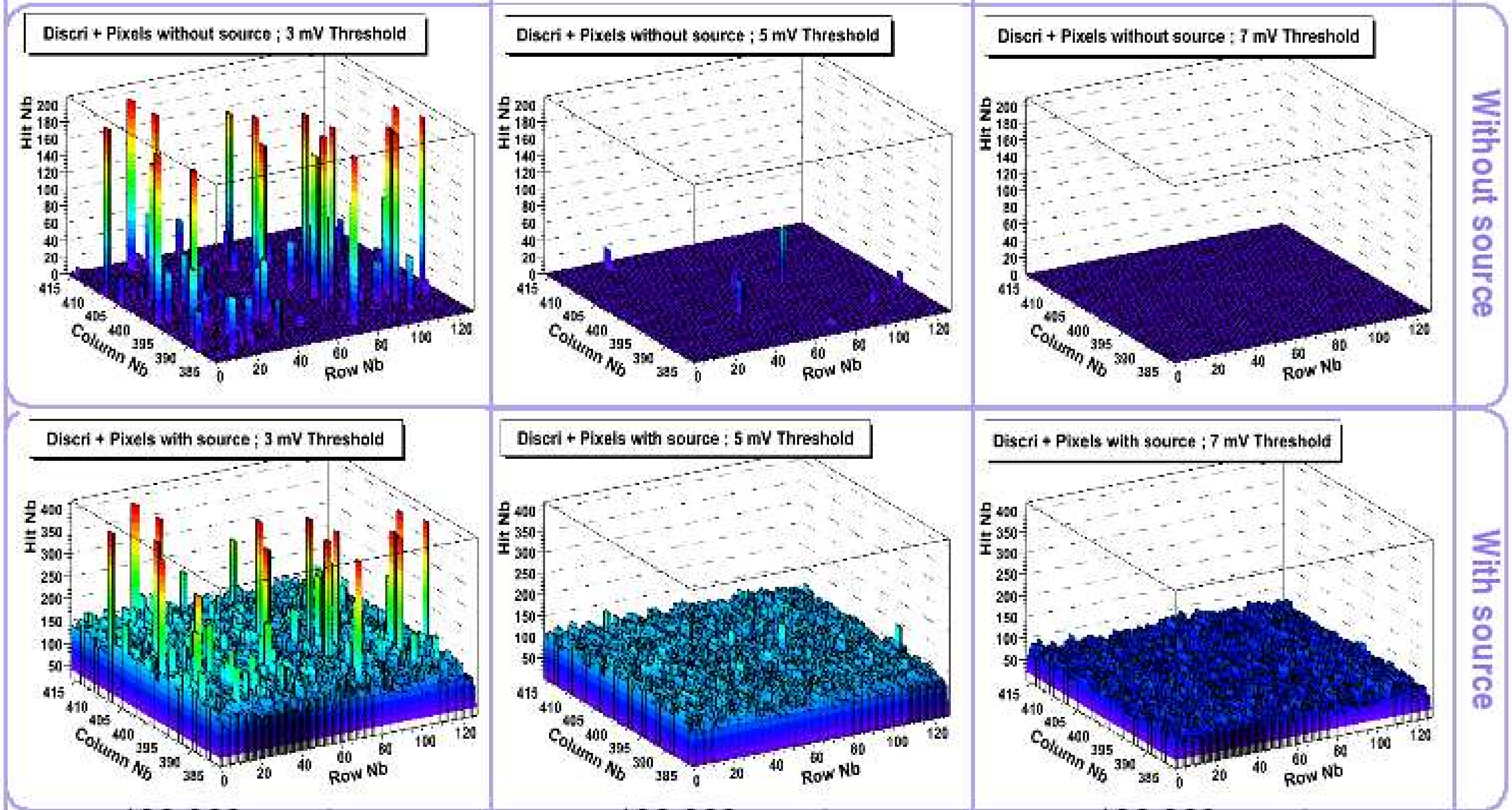
$\Rightarrow$ Similar results than smaller prototype MIMOSA16 ones

- RadTol pixels (S6, S10, S13) Noise slightly higher than for standard pixels

IDC/M22 Lab Tests : Digital Output Results (1/2)

S12 response for 3, 5 and 7 mV threshold without and with ^{55}Fe source

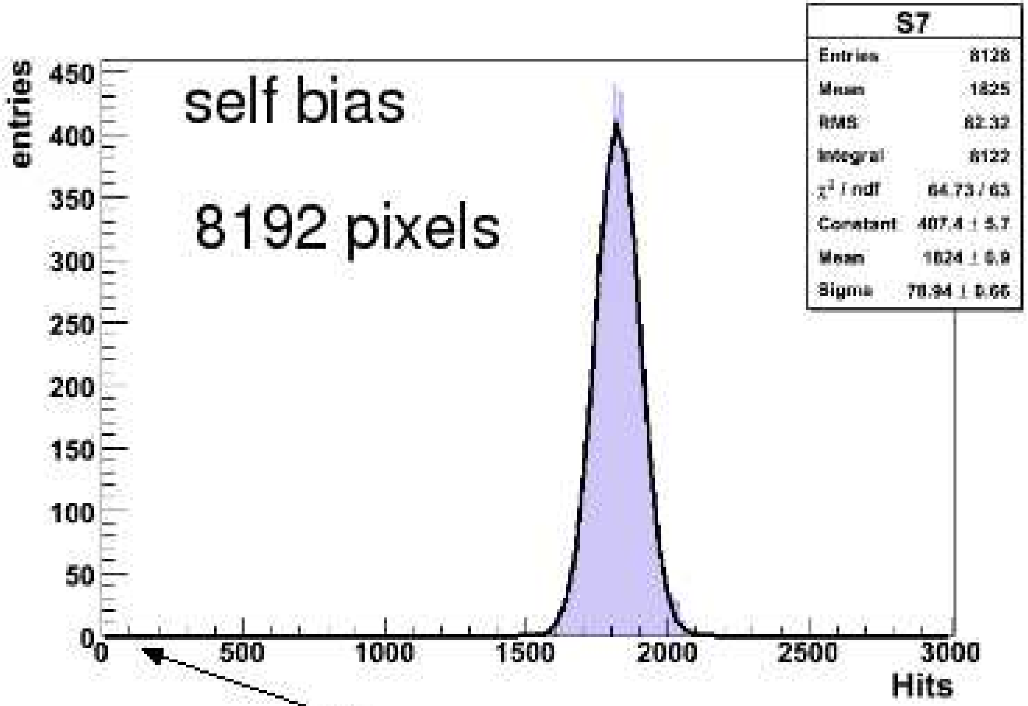
3 mV threshold | 5 mV threshold | 7 mV threshold

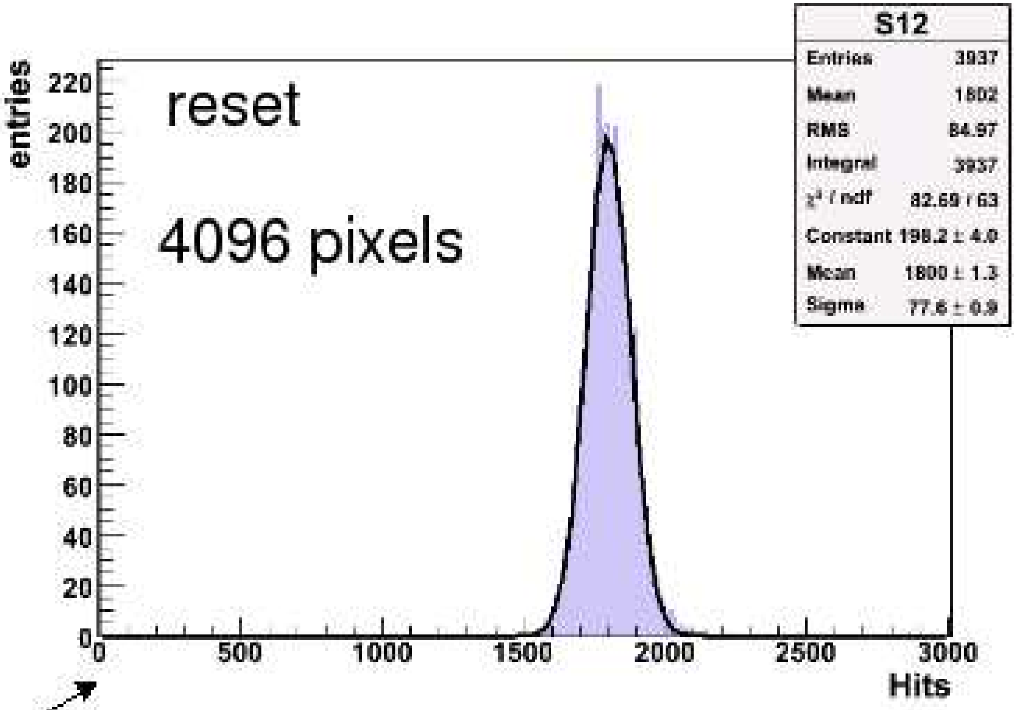


100.000 events | 100.000 events | 100.000 events

IDC/M22 Lab Tests : Digital Output Results (2/2)

5 mV threshold with ^{55}Fe source



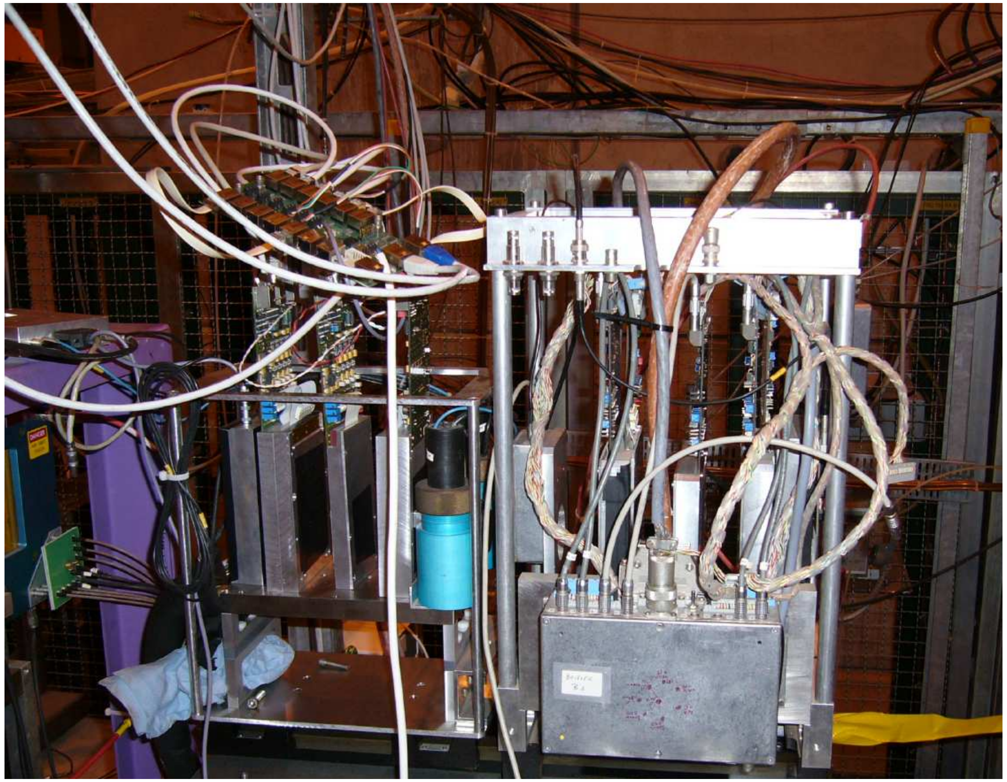


No dead pixel number

Good uniformity of discriminator response, within 4%

IDC/M-22 Beam Tests : Data Taking Conditions

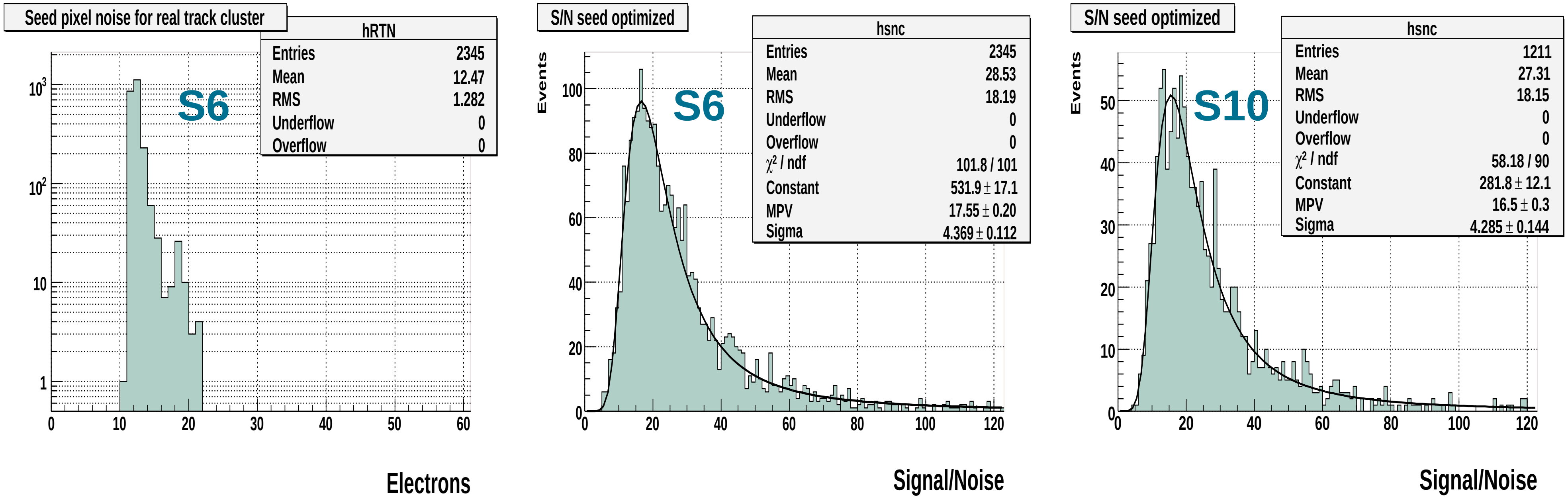
- about 2 weeks of beam time in August at CERN-SPS
- T4-H6 beam line : $\sim$ 100 GeV π^- beam
- MIMOSA-22 chip mounted on Si-strip telescope
- poor beam conditions $\Rightarrow$ only 2 chips tested
- most data collected with 1 (non-irradiated) chip :
  6 different discriminator threshold values (2.1 – 6.6 mV)



- irradiated chip (150 kRad) only tested with 2 threshold values (3.1 & 4.2 mV)

$\Rightarrow$ **Results of data analysis still very preliminary !!!!**

- Noise and S/N (seed pixel) distributions delivered by the 8 columns without discriminator



- **Detection performances (det. eff. , N and S/N for hits where the seed pixel exhibits S/N $>$ 4) :**

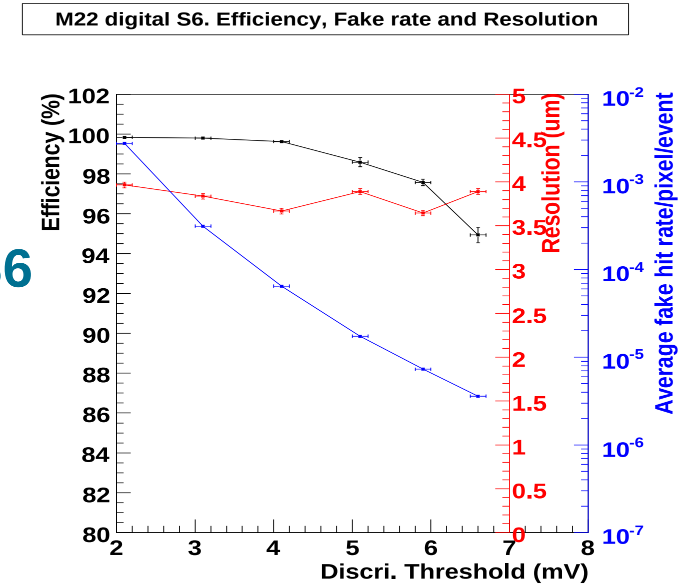
Sub-array	*S6*	*S7*	*S8*	*S9*	*S10*	*S12*	*S13*
Det. eff.	*99.93 % $\pm$ 0.05 %*	*99.95 % $\pm$ 0.04 %*	*100.00 % +0/-0.30 %*	*100.00 % +0/-0.14 %*	*99.87 % $\pm$ 0.09 %*	*100.00 % +0/-0.08 %*	*100.00 % +0/-0.07 %*
N (e^- ENC)	*12.5 $\pm$ 0.1*	*11.6 $\pm$ 0.1*	*12.3 $\pm$ 0.1*	*10.6 $\pm$ 0.1*	*13.6 $\pm$ 0.1*	*12.1 $\pm$ 0.1*	*14.0 $\pm$ 0.1*
S/N (seed, MPV)	*17.6 $\pm$ 0.2*	*18.5 $\pm$ 0.2*	*20.9 $\pm$ 1.1*	*19.5 $\pm$ 0.5*	*16.5 $\pm$ 0.3*	*18.2 $\pm$ 0.3*	*16.0 $\pm$ 0.3*

⋇ *very satisfactory performances (det. eff. $\sim$ 99.9 % and single pt resolution $\lesssim$ 1.5 μm)*

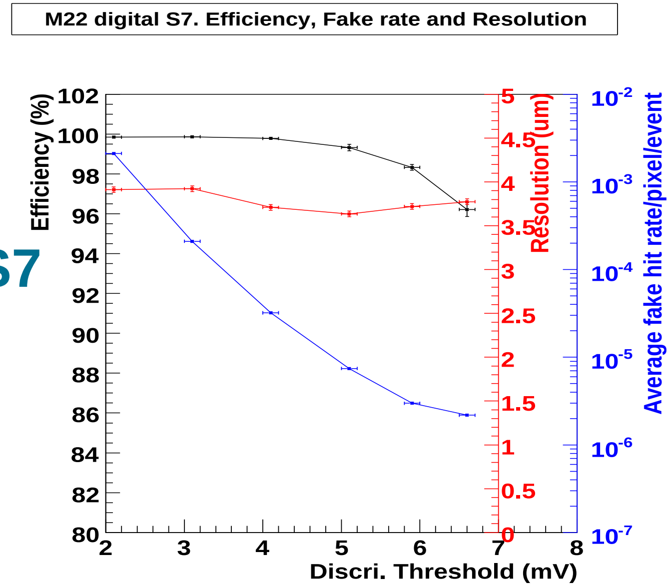
$\Rrightarrow$ **pixel architecture (diode size, rad. tol. diode design, amplification scheme) validated**

- **Det. efficiency, fake hit rate & single pt resolution for S6, S7, S12, S13 vs discri. threshold (prelim.) :**

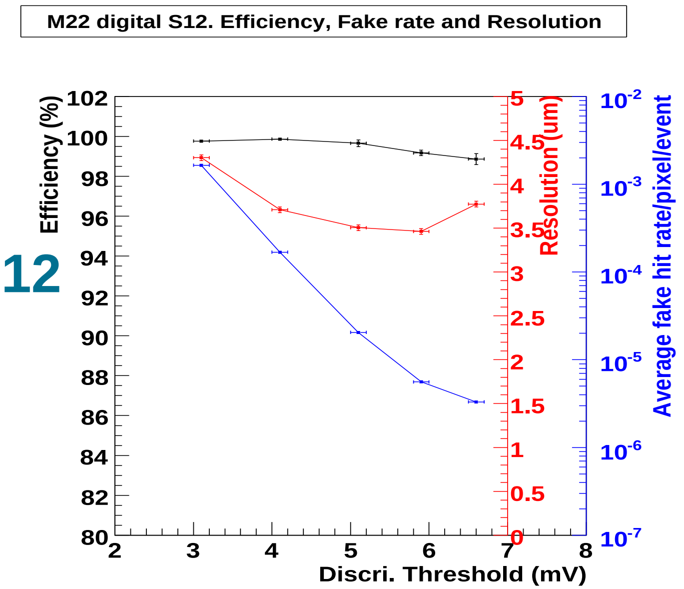
S6



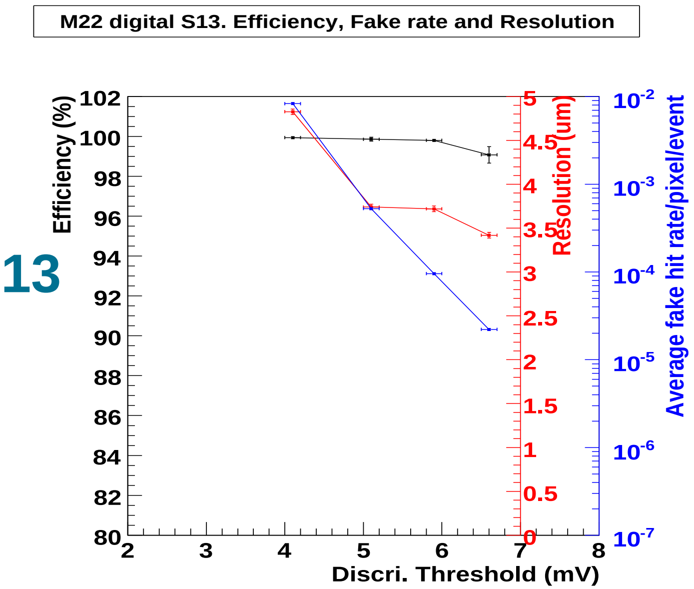
S7



S12

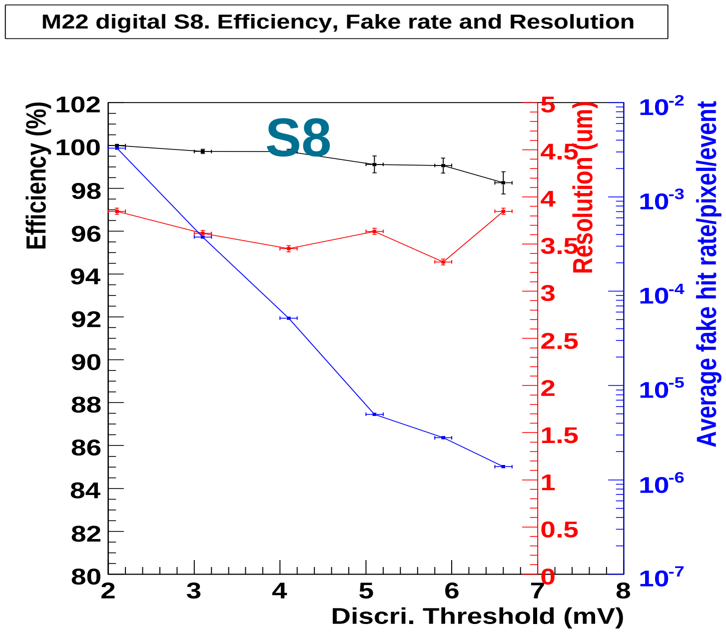


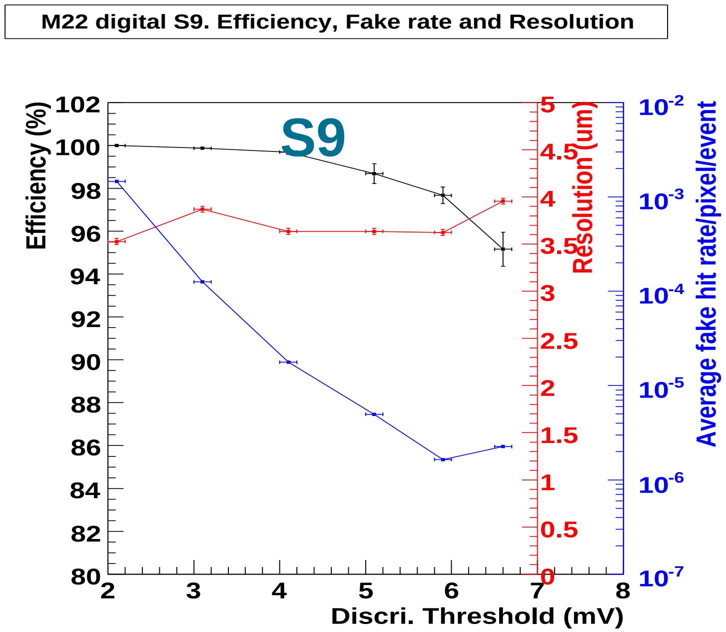
S13

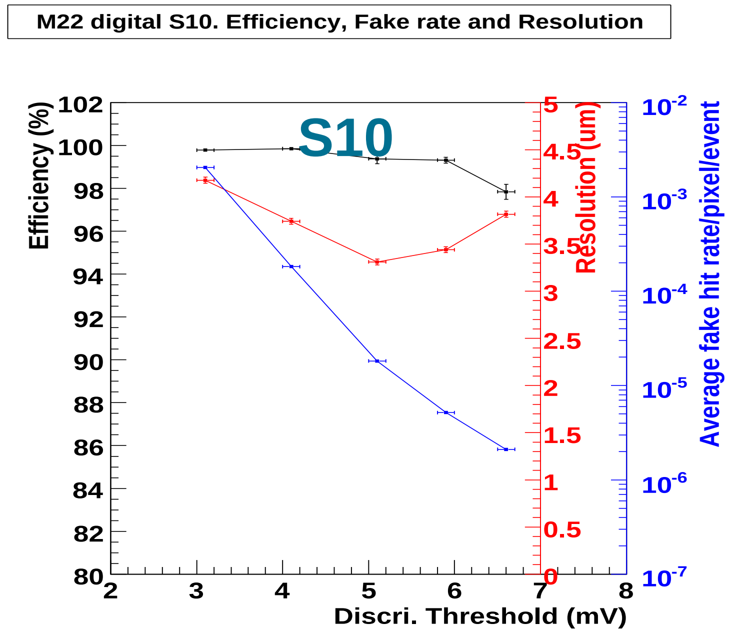


▷ ▷ ▷ **Detection efficiency $\gtrsim$ 99.8 % for all (rad. tol. and standard) pixel architectures !!!**

Detection efficiency, fake hit rate & single pt resolution for S8, S9, S10 vs discri. threshold (prelim.) :







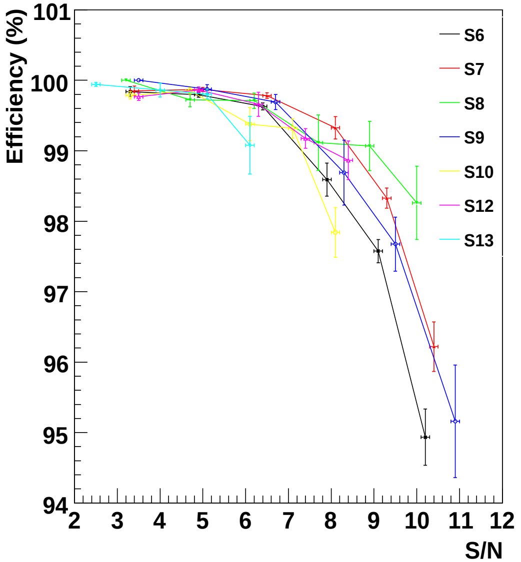
Main (still preliminary) results:

- *rather marginal performance differences between the 7 sub-arrays (e.g. rad. tol. vs standard)*
- *det. eff. of analog output $\sim$ 99.9 % for all sub-arrays $\Rrightarrow$ pixel architecture validated*
- *det. eff. of digital output $\gtrsim$ 99.8 % for all 7 sub-arrays (agrees with MIMOSA-16)*
- *fake hit rate seems larger than for MIMOSA-16 but acceptable : O(10^{-4} – 10^{-5})*
- *single point resolution $\gtrsim$ 3.5 μm (as expected)*
- *no performance non-uniformity observed over the chip surface $\Rrightarrow$ real scale check validated*

IDC/M-22 Beam Tests : Pixel Performance Comparison

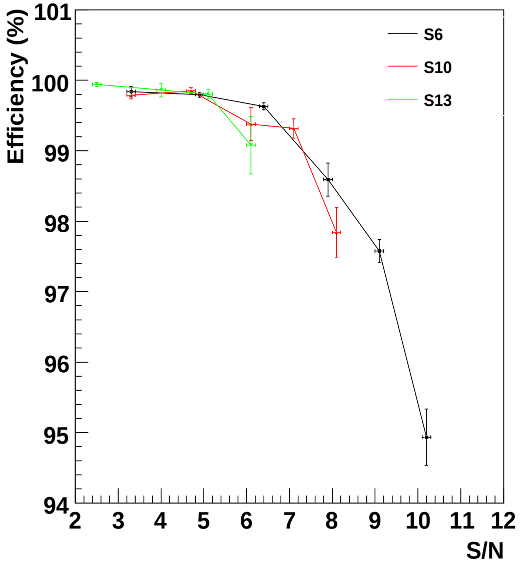
- **Comparison of det. efficiency & fake hit rate vs S/N for all sub-arrays (prelim.)** :

M22 digital



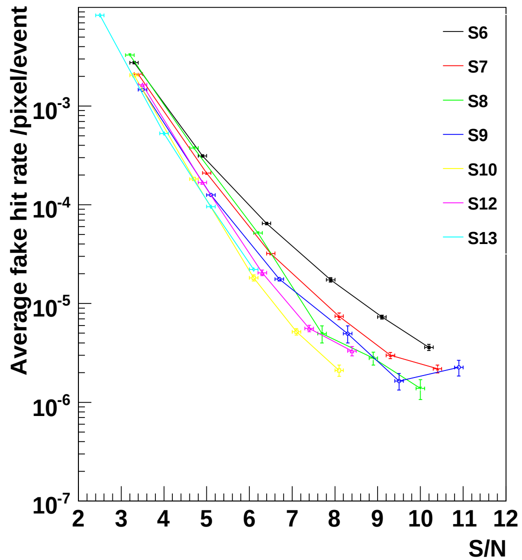
Det. eff. for all pixels

M22 digital



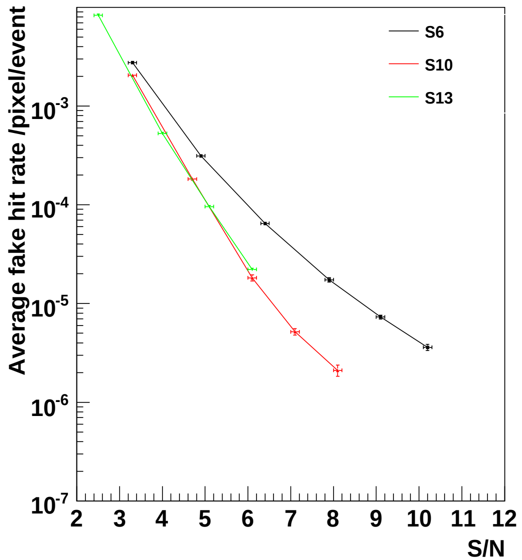
for rad. tol. pixels

M22 digital



Fake rate for all pixels

M22 digital



for rad. tol. pixels

▷ **Observed performance differences (& analysis maturity) don't allow yet deciding for a given pixel archi.**

⇛ **Wait for :** ⁂ *more sensors tested* ⁂ *more beam tests*

⁂ *MIMOSA-22bis performances* ⁂ *radiation tolerance studies*

- **1st chip (SDC-2/SUZE-01) with integrated $\emptyset$ and output memories (no pixels) :**

  ⋇ *2 step, raw by raw, logic :*

  ◇ *step-1 (inside blocks of 64 columns) :*

  identify up to 6 series of $\leq$ 4 neighbour pixels per raw

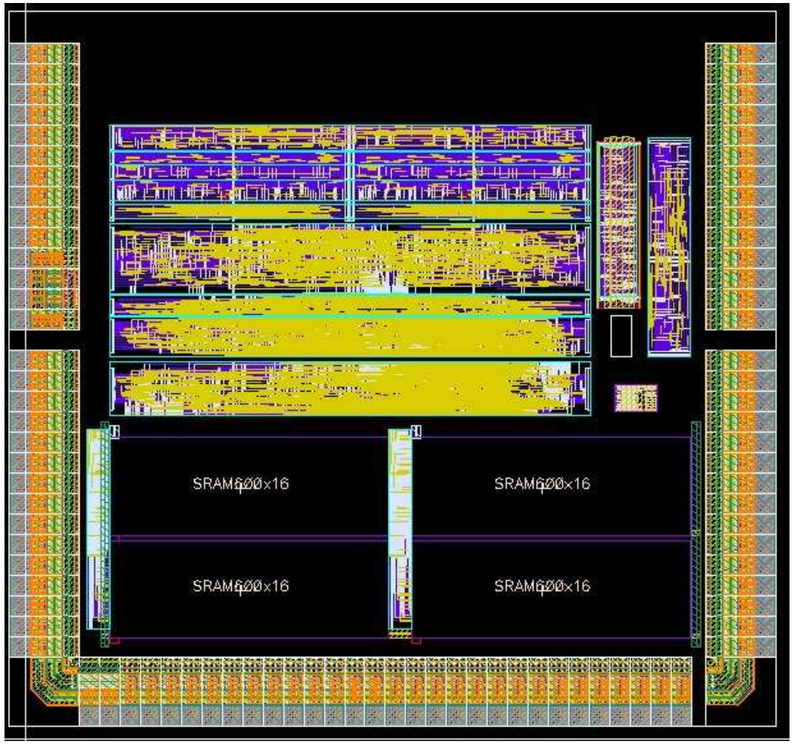
  delivering signal $>$ discriminator threshold

  ◇ *step-2 : read-out outcome of step-1 in all blocks*

  and keep up to 9 series of $\leq$ 4 neighbour pixels

  ⋇ *4 output memories (512x16 bits) taken from AMS I.P. lib.*

  ⋇ *surface $\sim$ 3.9 $\times$ 3.6 mm^2*



- **Test results summary :**

  ⋇ *back from foundry end of Sept. '07 $\rightarrowtail$ (lab) tests completed*

  ⋇ *design performances reproduced up to 1.15 $\times$ design read-out frequency (T_{room}) :*

  noise values as predicted, no pattern encoding error, can handle $>$ 100 hits/frame at rate $>$ 10^4 frames/s

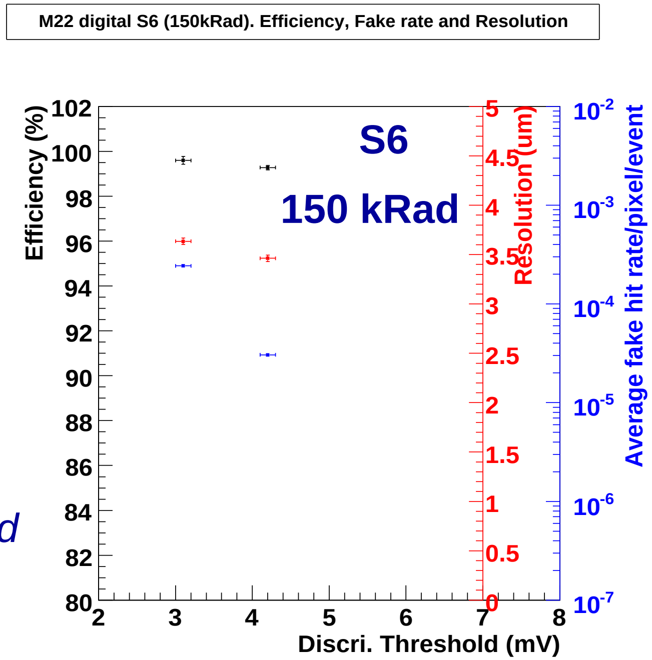
- **Still to do :** *evaluate radiation tolerance (latch-up) of ouput memories*

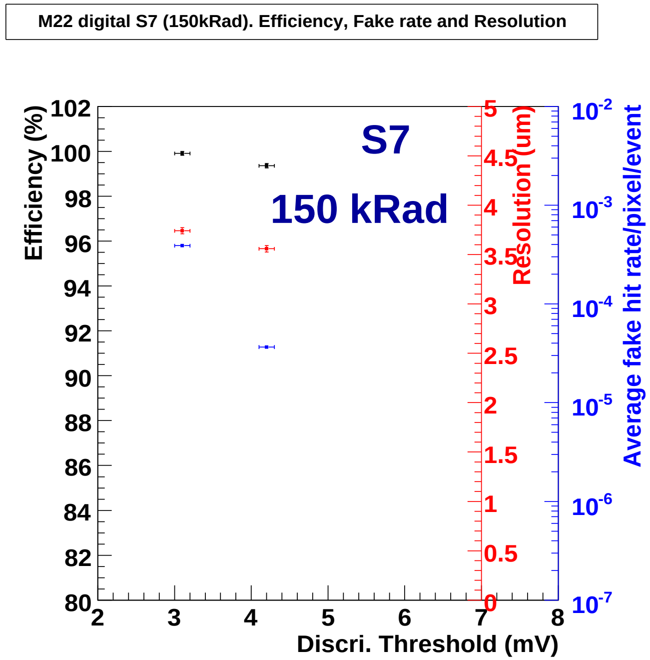
Why may radiation tolerance be a conCERN ?

- max. annual doses at DESY $\lesssim 10^{11}$ e^- (few GeV)/yr $\Rrightarrow$ $\lesssim$ 3.5 kRad & 10^{10} n_{eq}/cm^2
- max. annual doses at CERN $\lesssim$ several 10^{12} π^- (10^2 GeV)/yr $\Rrightarrow$ $\lesssim$ O(10^2) kRad & O(10^{12}) n_{eq}/cm^2

Assessing radiation tolerance (10 keV X-Rays):

- Noise of IDC/M-22 (S6) :
  - $\sim$ 12.5 e^- ENC before irradiation
  - $\sim$ 16–17 e^- ENC after 150 kRad $\rightarrowtail$
  - $\sim$ 22 e^- ENC after 300 kRad



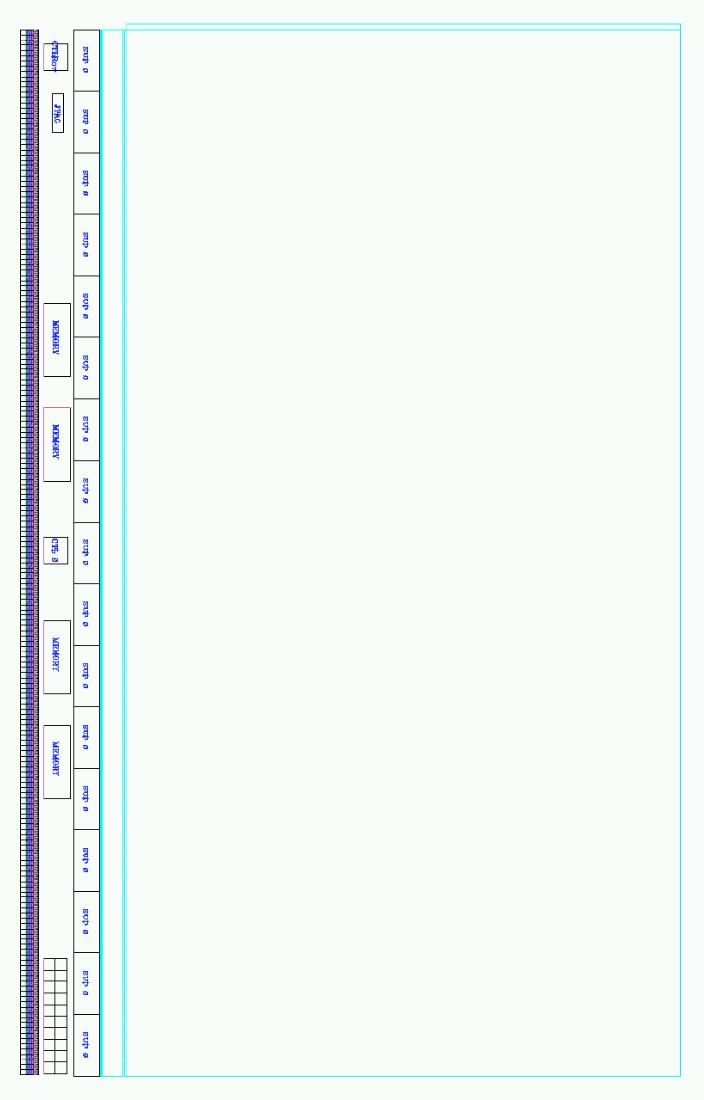


- New design (MIMOSA-22bis) fabricated
  - $\triangleright$ tests in Septembre (lab, SPS)
- MIMOSA-22 non-ionising radiation tolerance assessment under way with fluences of 3 & $6{\cdot}10^{12}$ n_{eq}/cm^2
- Latch-up tests of SDC-2/SUZE-01 foreseen in Septembre

Main Parameters of the Final Sensor : TC/MIMOSA-26

Autumn 2008 : fabrication of MIMOSA-26 = Final Sensor (TC)

- IDC/M-22 (binary outputs) complemented with $\emptyset$ (SDC-2/SUZE-01)
- best performing (rad. tol.) pixel architecture of IDC/MIMOSA-22
  $\hookrightarrow$ wait for Octobre beam tests at CERN-SPS
- Active surface : 1152 columns of 576 pixels (21.2 x 10.6 mm^2)
  $\hookrightarrow$ extension of IDC & SDC-2 from 128 col. to 9 x 128 col.
- Pixel pitch : 18.4 $\mu m \rightarrowtail \sim$ 0.7 million pixels
  $\hookrightarrow \sigma_{sp} \gtrsim$ 3.5 $\mu m \Rrightarrow$ pointing resolution $\sim$ 2 μm on DUT surface
- Integration time $\sim$ 110 $\mu s \rightarrowtail \sim 10^4$ frames / second
- $\emptyset$ based on 18 groups of 64 columns and assuming $\leq$ 9 "clusters" per row
- Chip dimensions : $\sim$ 21 x 12 mm^2
- Data throughput: 1 output at $\geq$ 80 Mbits/s or 2 outputs at $\geq$ 40 Mbits/s
- Engineering run : 2 (+ $\leq$ 4) wafers of $\gtrsim$ 30 chips expected (if yield $\sim$ 50 %)



- **Design under way $\Rrightarrow$ planned submission date $\geq$ mid-November '08**

- **Col. // architecture with discri. outputs validated for m.i.p. detection on real scale (***128 col. of final length* **) :**
  - *read-out frequency* $\sim 10^4$ *frames/s* ✓
  - *pixel noise* $\sim$ *11–13 e*$^-$ *ENC* ⇛ *S/N* $\sim$ *17–19 (MPV)* ✓
  - $\epsilon_{det} >$ *99.5 % (prelim. !!!) with fake rate* $\sim$ *O(*10^{-4} *-* 10^{-5}*), like MIMOSA-16* ✓
  - $\sigma_{sp} \gtrsim$ *3.5* μm ⇛ *resolution on impact position on DUT surface* $\lesssim$ *2* μm ✓

- $\emptyset$ μ**-circuit with output buffers validated for 128 col. at read-out frequency** $>$ **nominal value** ✓

- **Radiation tolerance :**
  - *still a concern for use of telescope (copies ?) at CERN, FermiLab, ...*
  - *improved pixels under development*
  - *latch-up tests of output memories in preparation (to be done in Septembre)*

⇛ **TC** $\equiv$ **final sensor (combining col. // architecture with** $\emptyset$ μ**-circuit) :**
  - *design under way (crucial issue : extension from 128 to 1152 col. of IDC combined with SDC-2)*
  - *in absence of unexpected pb, submission should take place* $\gtrsim$ *mid-Novembre '08*

    ↪ **TC sensor tests expected to start in January 2009**