Prog. Report & Plans on Demonstrator & Ultimate Sensors

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OUTLINE

- **MIMOSA-14 (alias MIMO★-2) beam test results**
- **Plans for MIMO★-3 $\longmapsto$ demonstrator**
- **Progress and Plans for the final sensors: 1) fast col.. // with ADC, 2) high precision array**
- **Summary**

MIMO★-2 Characteristics

- **AMS 0.35 μm OPTO techno. (... may still be available for 10 yrs ...):**
  - ◇ **2 matrices of 64 x 128 pixels (30 μm pitch) $\mapsto$ active area of 4 x 4 mm^2**
    - $\hookrightarrow$ **1 matrix with rad. hard pixels (already tested with MIMO-11)**
  - ◇ **JTAG architecture for steering**
  - ◇ **frame r.o. time: 0.8, 1.6, 4.0 ms (pixel r.o. frequency: 10, 4, 2 MHz)**

- **Developed for STAR vertex detector upgrade:**
  - ◇ **operated at T $\lesssim$ 40°C**
  - ◇ **required rad. tolerance: $\lesssim$ 3·10^{11} n$_{eq}$/cm^2 – O(10) kRad/yr**
    - $\hookrightarrow$ **installation of Large version inside apparatus in 2007/2008**

MIMO★-2 beam test results

DESY: 5 GeV/c Electrons in November 2005

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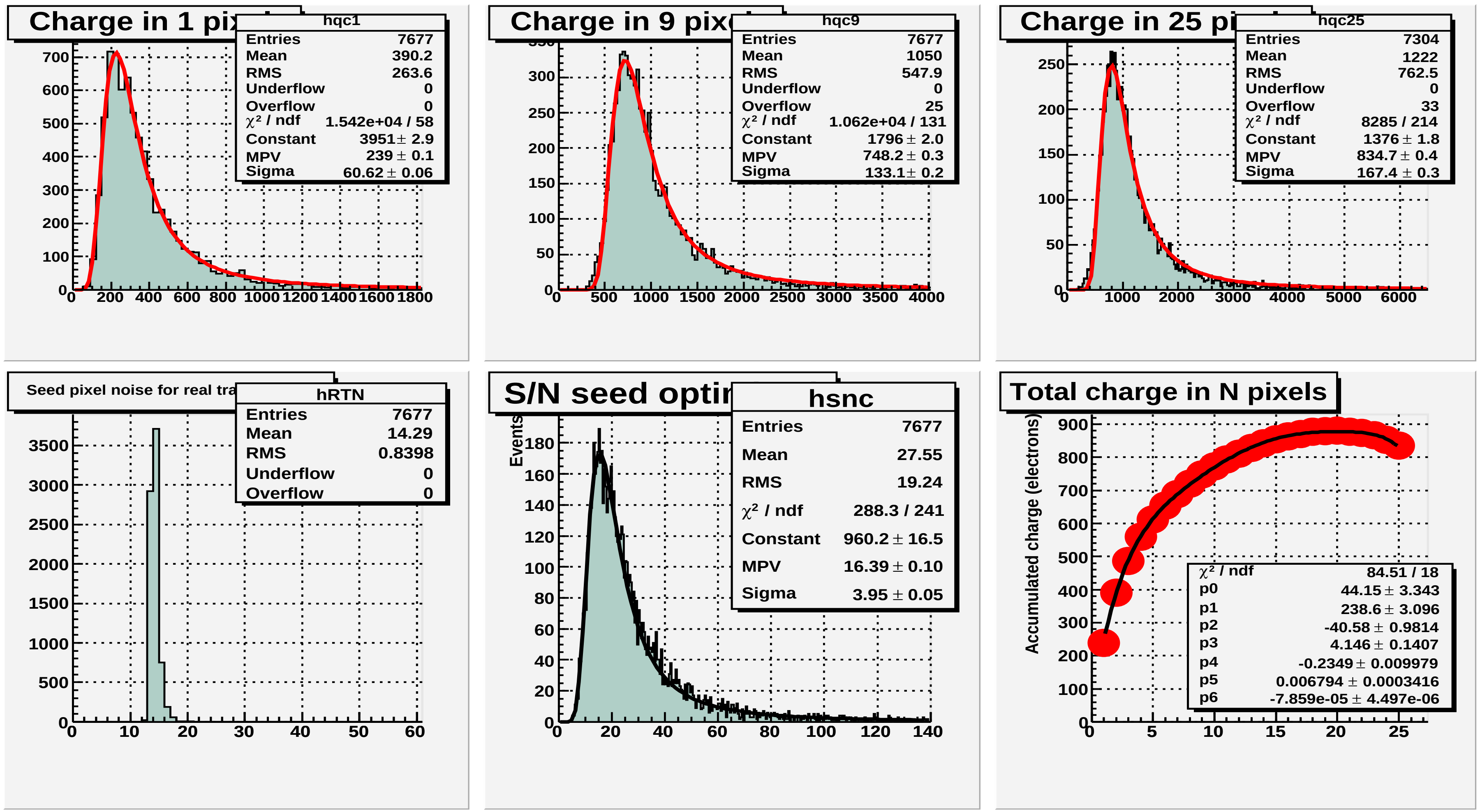
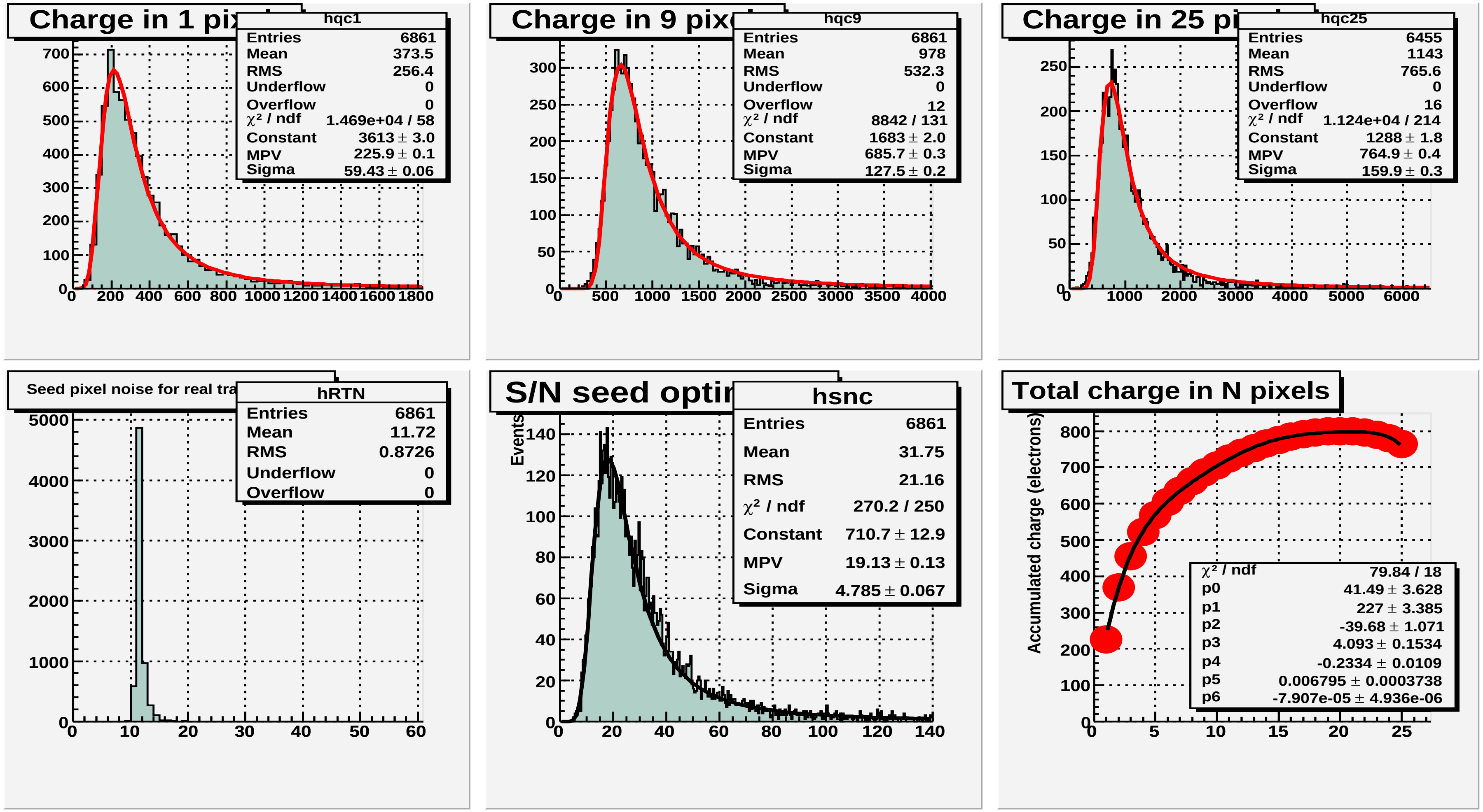
MIMO★-2 Beam Test Results: 10 MHz and 40°C

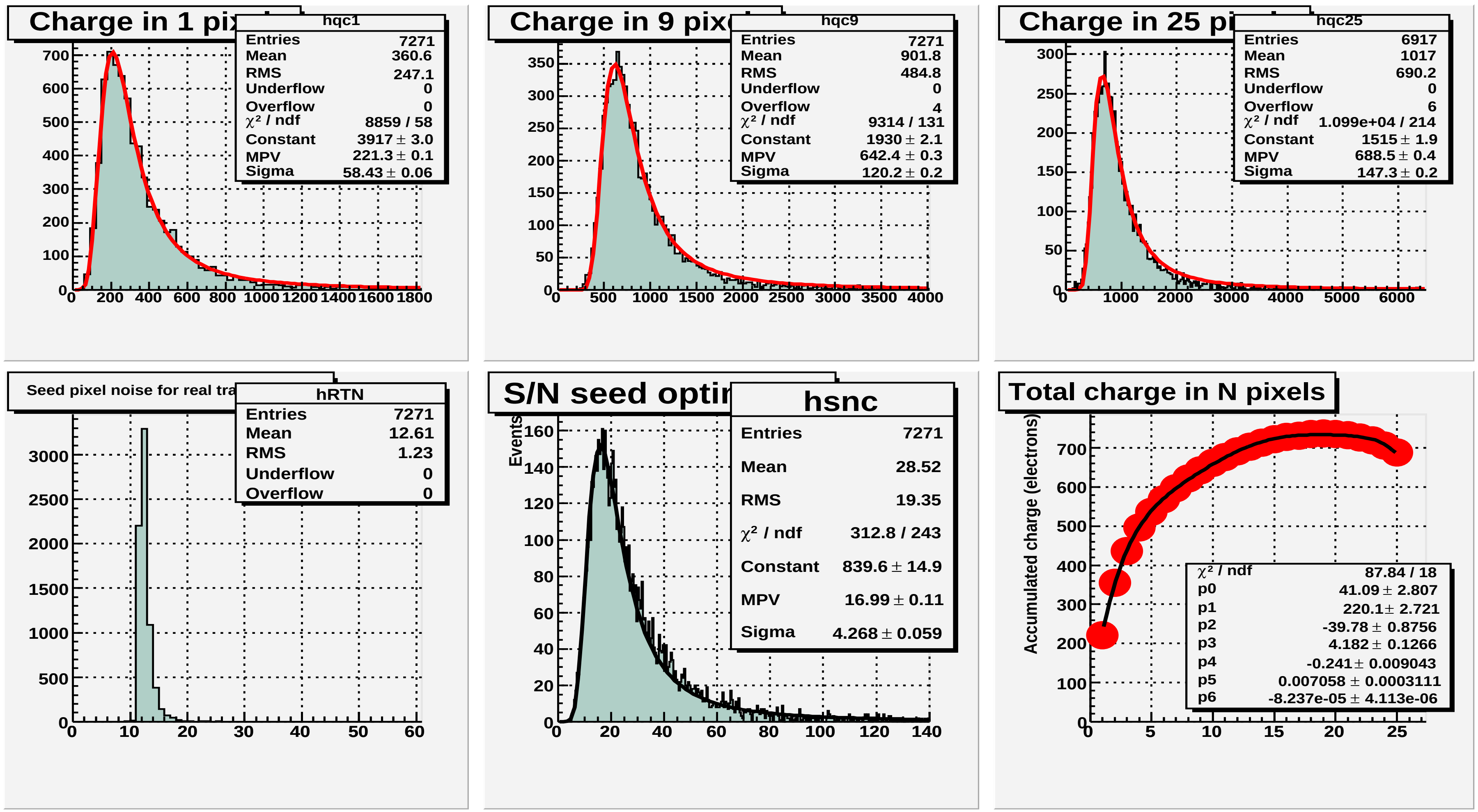
M14 ; run 14508; Pl 9, sub 1, dist 150; Gain 8.24; eff 99.974 +- 0.018; Seed 5.0; Neigh 2.0



M14 ; run 14512; Pl 9, sub 1, dist 150; Gain 8.00; eff 99.985 +- 0.015; Seed 5.0; Neigh 2.0

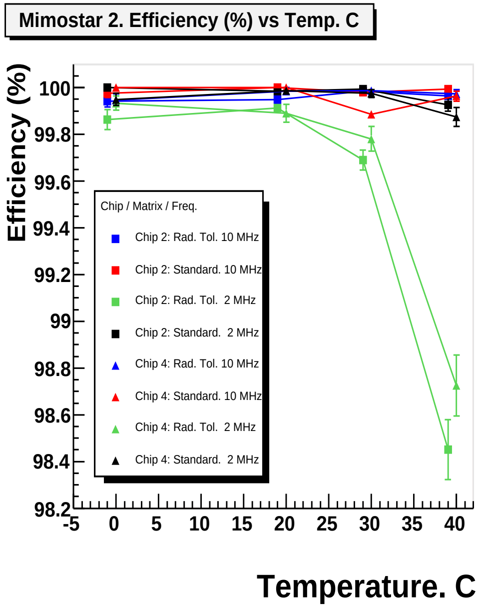


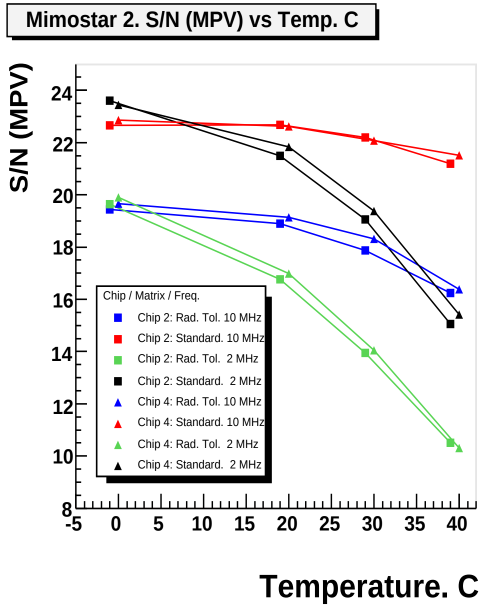
M14 ; run 14513; Pl 9, sub 1, dist 150; Gain 6.92; eff 99.890 +- 0.039; Seed 5.0; Neigh 2.0



Summary of MIMO★-2 Beam Test Results

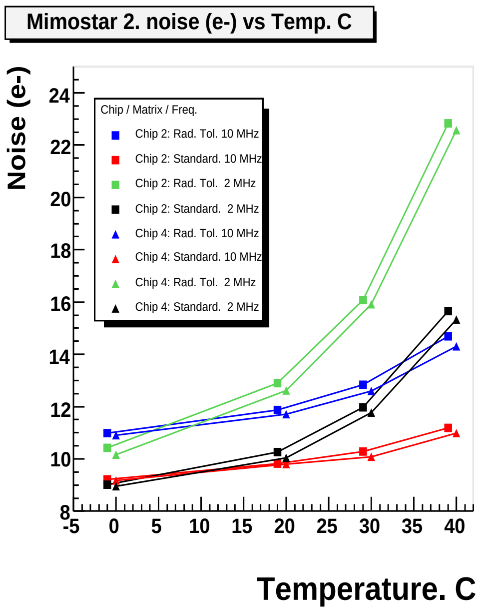
- ▶ **JTAG design fully proved**
- ▶ **Main results at T = 25° and $t_{r.o.}$ = 0.8 & 4 ms:**
  - ∴ N ∼ 11 - 14 e^- ENC
  - ∴ S/N ∼ 15 - 21 (MPV)
  - ∴ $\epsilon_{det} \gtrsim$ 99.8 %
  - ∴ $\sigma_{sp} \sim 3\ \mu m$ (MIMOSA-9)

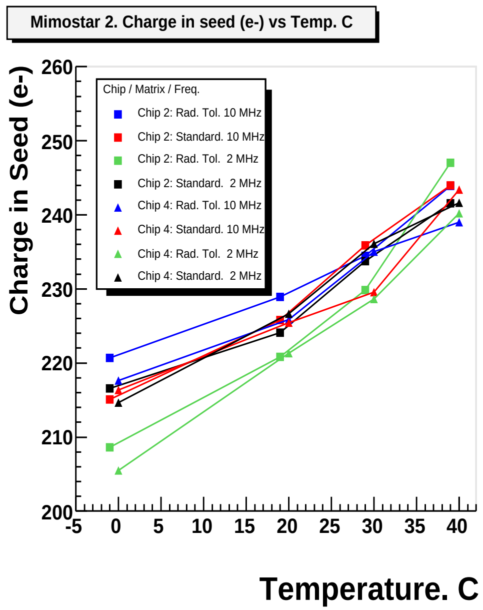




▶ **CONCLUSION:**

- ◇ **Architecture of sensor for telescope demonstrator running at room temperature validated**
  - ↪ **few sensors available early ’06 for EUDET**
- ◇ **Design of final sensor for demonstrator can start**
  - ↪ ∴ **fabrication $\gtrsim$ Summer ’06**
  - ∴ **chips available for mounting ∼ end ’06**





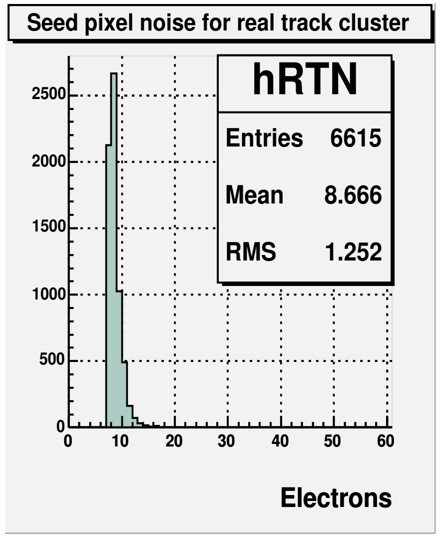
Reminder: M.I.P. Detection Perfo. of the Technology

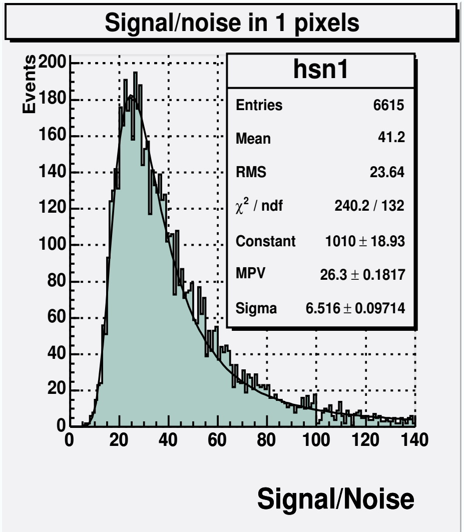
▶ **Fabrication process explored with MIMOSA-9, -11, -14, -15**

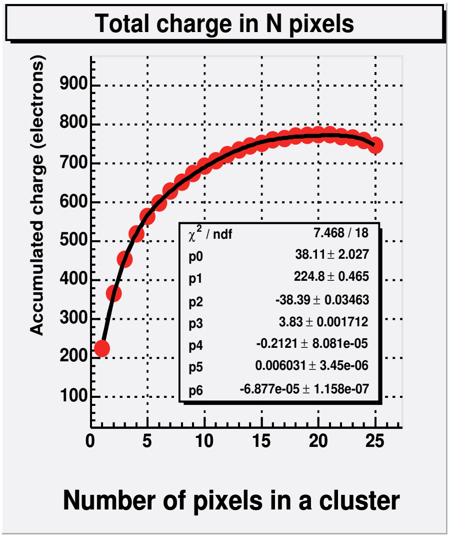
↪ **assessed in terms of epi. thickness, noise & S/N (T), rad. tolerance, ...**

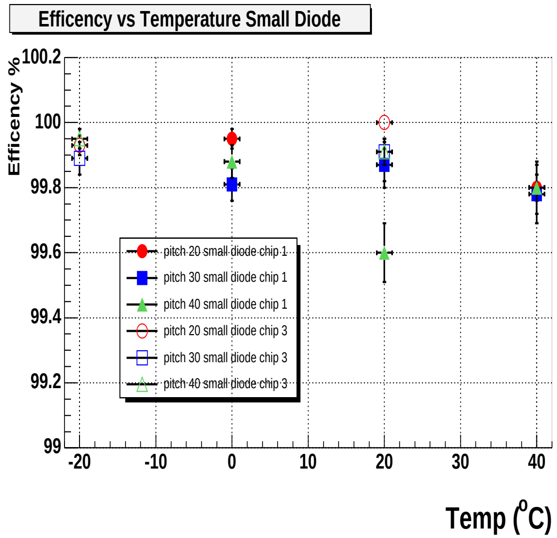
▶ **Excellent m.i.p. detection performances (observed with 120 GeV/c π^- at CERN-SPS):**

◇ **S/N $\sim$ 20-30 (MPV) $\longrightarrow \epsilon_{\mathbf{det}} \sim$ 99–99.9 %** ◇ **σ_{sp}= 1.5 μm (20μm pitch) – 3 μm (30μm pitch)**









■ **AMS-0.35μm OPTO: most attractive process tested up to now ↦ baseline for further sensor R&D**

(seems available for long ...)

NEXT STEPS

SENSORS EQUIPPING THE TELESCOPE DEMONSTRATOR

Next Step: MIMO★-3 (1/2)

MIMO★-3L (for Large) :

- ○ Technology: AMS 0.35 OPTO
- ◇ STAR upgrade for physiscs run $\leq$ 2009 (AuAu coll.)
- ○ 640 x 256 pixels (30 μm p;itch) = 10 sub-arrays of 64 x 256 pixels
- ◇ Active surface $\sim$ 19.2 x 7.7 mm^2 (10 x MIMO★-2)
- ○ 2 // outputs (50 MHz) $\longmapsto$ t$_{r.o.}$ = 1.6 ms
- ◇ Same JTAG design as MIMO★-2
- ○ Fabrication planned for late Summer 2006 via engineering run
  $\hookrightarrow$ to be mounted on 20 cm ladders at LBNL in 2007 $\longmapsto$ physics $\geq$ 2008
- ◇ Reticle (engineering run) will host several other chips

Next Step: MIMO★-3 (2/2)

- **MIMO★-3M (for Medium) = 40 % of MIMO★-3L surface**
  - ○ **256 x 256 pixels (30 μm p;itch) = 4 sub-arrays of 64 x 256 pixels**
  - ◇ **Active surface $\sim$ 7.7 x 7.7 mm^2 (4 x MIMO★-2)**
  - ○ **4 // outputs (10 MHz) $\mapsto$ t$_{r.o.}$ = 1.6 ms (baseline)**
  - ◇ **Same JTAG design as MIMO★-2**
  - ○ **To be fabricated planned in same engineering run as MIMO★-3L**
  - ◇ **Some (rather minor) details may still vary w.r.t. the above (e.g. sub-arrays of 64 x 320 pixels)**

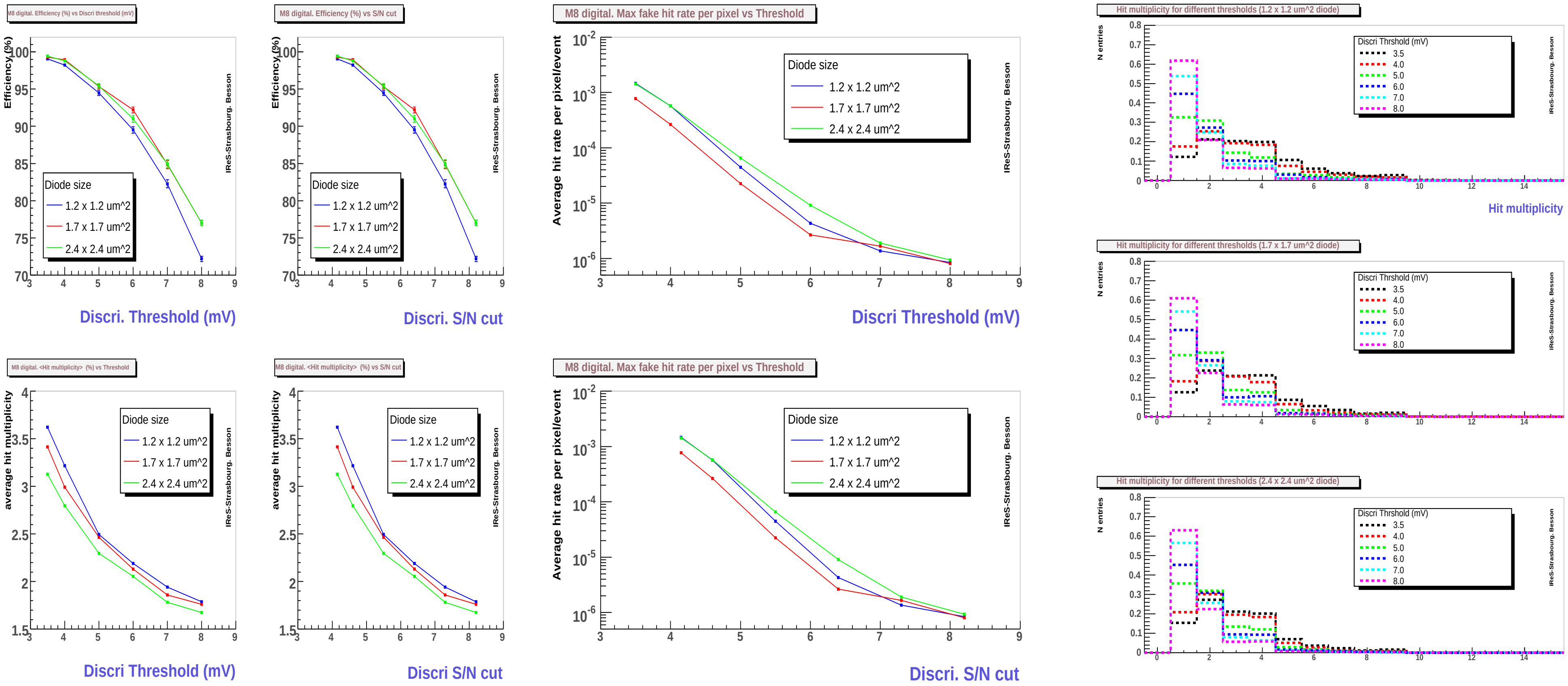
- **Time -Line: chip fabricated and tested $\leq$ end 2006**

PROGRESS AND PLANS FOR

FINAL SENSORS EQUIPPING THE TELESCOPE

Fast Col. // Chip with Discri Output: Beam Test Results

- MIMOSA-8 tests with 5 GeV/c e^- beam at DESY in September 2005
- Excellent m.i.p. detection performances despite modest thickness of epitaxial layer
  - ◇ det. eff. ∼ 99.3 % for fake rate of ∼ 0.1 %
  - ◇ discriminated cluster multiplicity ∼ 3–4



- Archi. validated for next steps: techno., rad. tol. pixel at T_{room}, ADC, zero supp., etc. ↦ EUDET (2008)

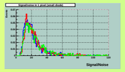
- MIMO★-3L and MIMO★-3M manufactured via engineering run hosting several other devices:
  ILC VD, CBM VD, other GSI expts, generic functionnalities, ...

- Several devices are relevant for EUDET:
  - new version of MIMOSA-8 (rad. tol. pixe, col. // r.o., digital output with 2xCDS & discri.)
  - various 4-5 bits ADC architectures to (ultimately) replace discri. of MIMOSA-8
  - imager prototype (512 x 512 pixels ?) for high precision hit position det. (13-15 μm pitch)
  - several other test structures ....

- First studies of zero suppression architecture behind ADC have started

- High precision sensor design implemented in MIMOSA-15 will be tested early 2006

- Thinning investigations $\lesssim$ 50 μm continue



SUMMARY

- **Chip architecture for telescope demonstrator works very well**
  $\hookrightarrow$ **few sensors will be available early 2006 for EUDET**

- **Design of final sensor for demonstrator can start:**
  $\hookrightarrow$ $\therefore$ **fabrication $\lesssim$ end Summer 2006 $\mapsto$ chips available for mounting $\sim$ end 2006**
  $\therefore$ **more details on output signals and chip steering in Wojciech's talk**

- **Engineering run will also include:**
  - ○ **prototype (extension of MIMOSA-8) for final chip**
  - ◇ **various ADC alternatives for final chip**
  - ○ **imager prototype for high precision hit position determination**

- **Zero suppression study for final sensor has started**

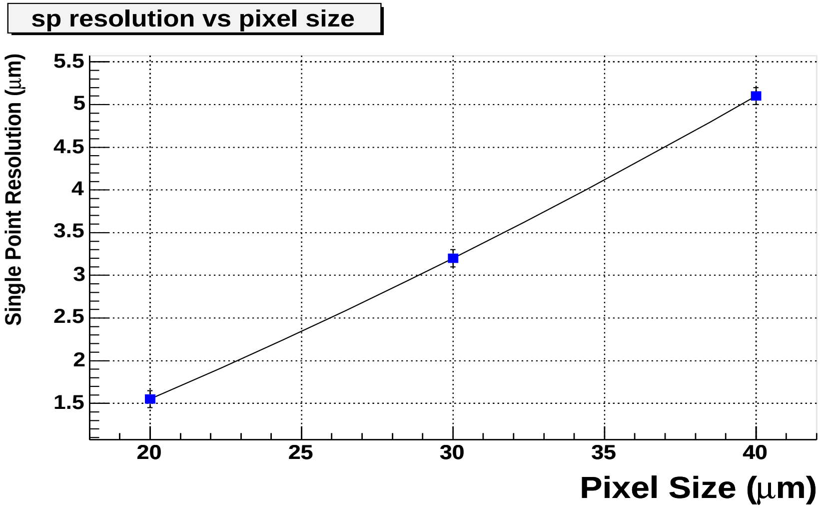
BACKUP SLIDES

SPATIAL RESOLUTION, RAD. TOLERANCE,

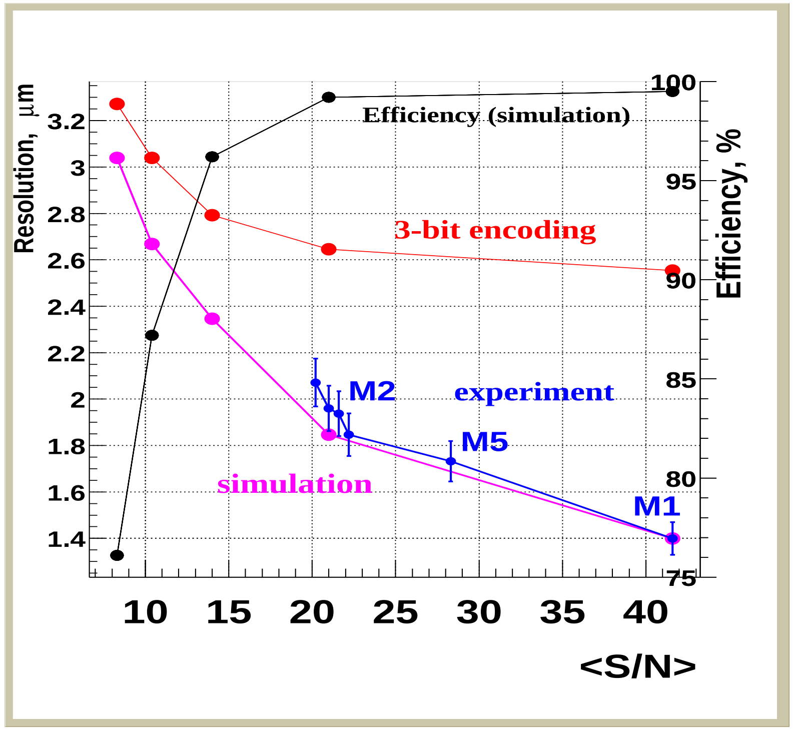
MIMOSA-8

Observed Spatial Resolution

- **Single point resolution versus pixel pitch:**
  - ◇ chips mounted on Si-strip telescope (8 planes) installed on a 120 GeV/c π^- beam at CERN-SPS
  - ◇ clusters reconstructed with eta-function, exploiting charge shared between pixels
  - ◇ $\sigma_{\mathrm{sp}} \sim 1.5\ \mu\mathrm{m}$ (20 μm pitch) $\mapsto \sigma_{\mathrm{sp}} \sim 5\ \mu\mathrm{m}$ (40 μm pitch)



- **σ_{sp} dependence on S/N and on ADC granularity:**
  - ◇ results found with "simple" pixels are excellent (but no integrated signal processing ...)
  - ◇ noise of FAST pixels will be $\sim$ twice higher ($\sim$ 20 e^- ENC)
  - ◇ effect simulated on real MIMOSA data (120 GeV/c π^-) (simulation consistency cross-checked with data)

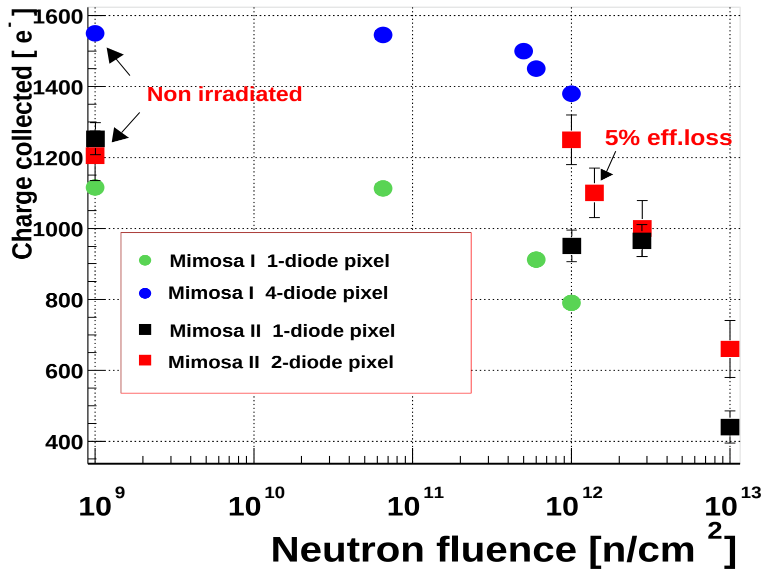


- $\epsilon_{\mathrm{det}} \gtrsim$ 96 % if $<$S/N$>$ $\gtrsim$ 14

  $\sigma_{\mathrm{sp}} \lesssim 3\ \mu\mathrm{m}$ even if $<$S/N$>$ $\sim$ 10 and only 3-bit encoding

RADIATION TOLERANCE

- Neutrons of O(1 MeV) at JINR (Dubna):
  irradiation of up to 10^{13} n_{eq}/cm^2
- Tests with 2 sensors from diff. fabrication processes:
  - ◇ AMS-0.6 ($\lesssim$ 14 μm epitaxy)
  - ◇ AMI-0.35 ($\sim$ 4 μm epitaxy)
    $\hookrightarrow$ charge loss for $\lesssim 10^{12}$ n_{eq}/cm^2
    modest increase of I_{leak} & noise ($\lesssim$ 10 %)



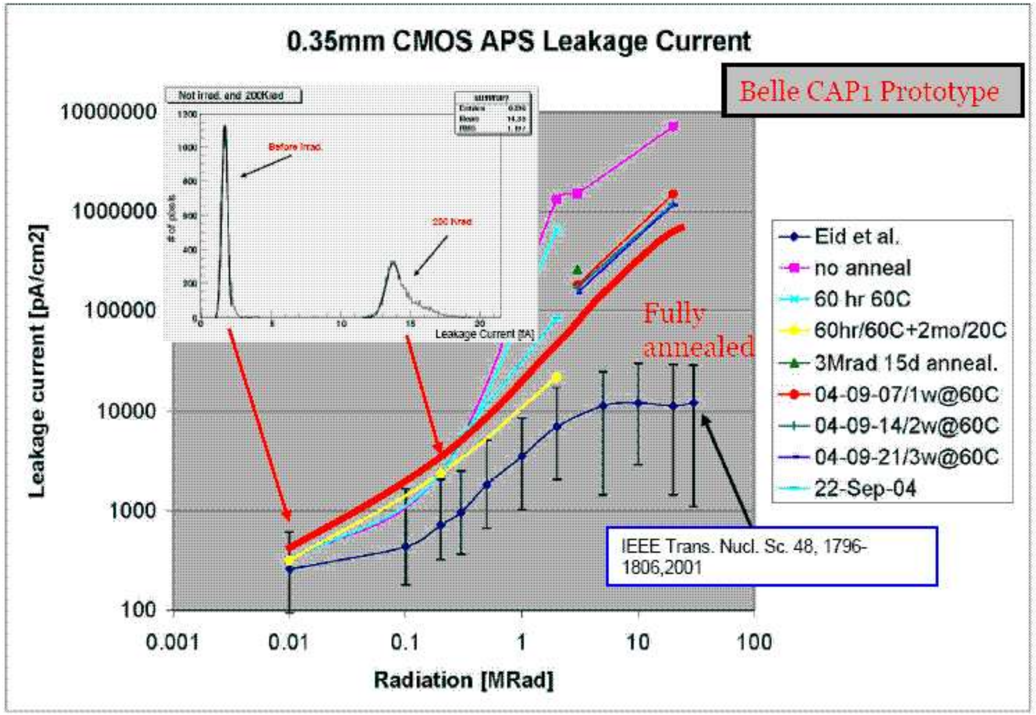
- AMS-0.35 OPTO ($\gtrsim$ 10 μm epitaxy)
  $\hookrightarrow$ S/N(MPV) vs fluence and T:

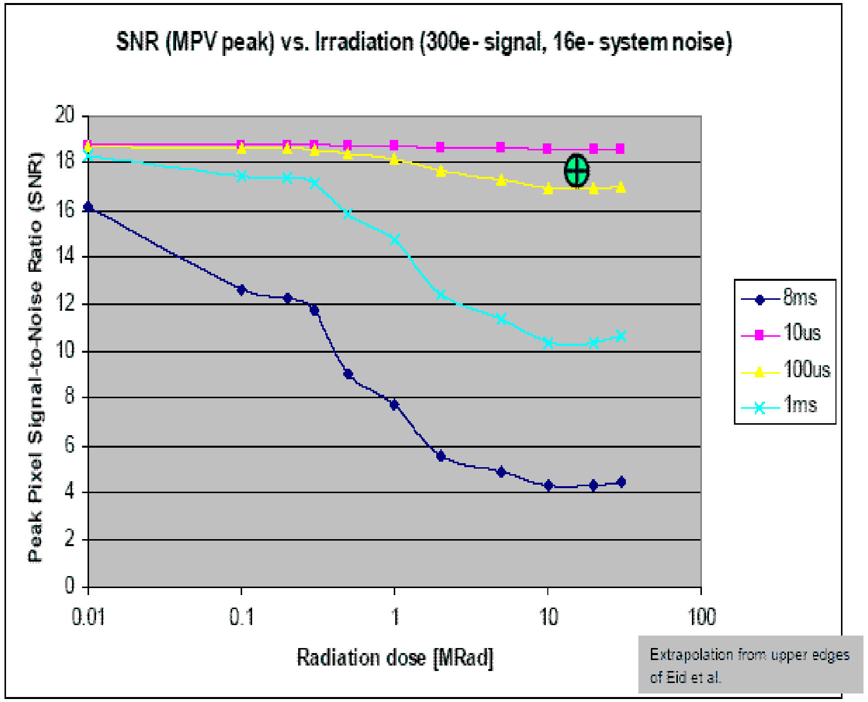
$\mapsto$ fluences of $\lesssim 10^{12}$ n_{eq}/cm^2 acceptable,
better performances with T $< 0^\circ$C
(ϵ_{det} $\gtrsim$ 99.5 $\pm$ 0.1 %)

Fluence	T = -20°C	T = 0°C
0	28.4 $\pm$ 0.2	26.3 $\pm$ 0.2
10^{11} n_{eq}/cm^2	25.3 $\pm$ 0.2	24.5 $\pm$ 0.4
10^{12} n_{eq}/cm^2	18.7 $\pm$ 0.2	–

- Rad. tolerance is fabrication process dependent $\mapsto$ need more measurements
- Room for improvement ? $\longrightarrow$ explore recovering procedures (vs t, T)

- **3 major effects expected from ionising radiation:**
  - ◇ **Shift of threshold voltages: $\propto$ Nb(holes) created & trapped in gate oxide $\propto$ oxide thickness**
    - $\hookrightarrow$ **aim for $\lesssim$ 10 nm thick oxide ($\sim$ the case for $\leq$ 0.35 μm technologies)**
  - ◇ **Leakage current in NMOS transistors**
  - ◇ **Leakage current in N-channel intertransistors**

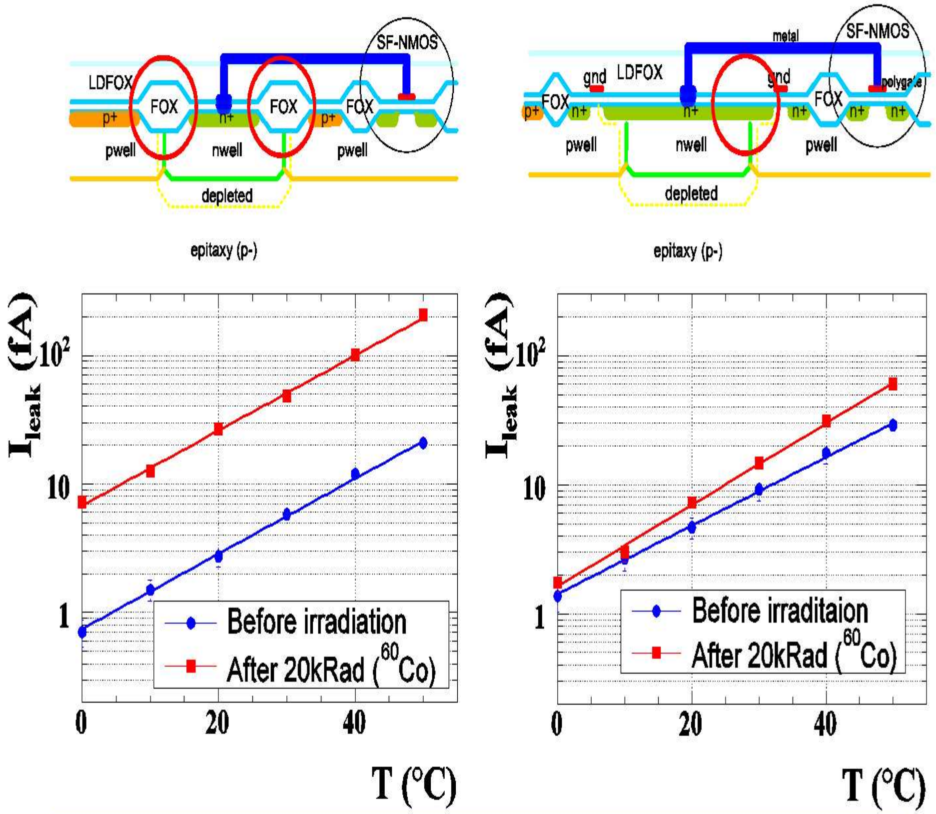




- **Aim for short integration time and for T $\lesssim 0^{\circ}$C**

■ **Pixel designs avoiding thick oxide around N-well and including guard-ring**

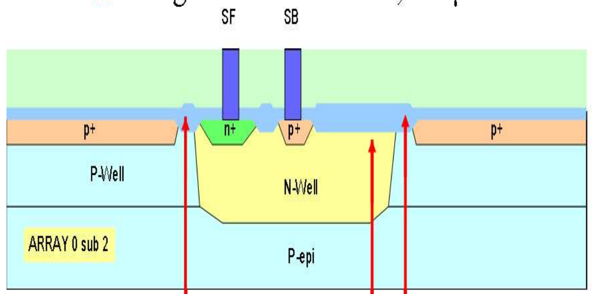
Studies on radiation hardness (ionising): MIMOSA9

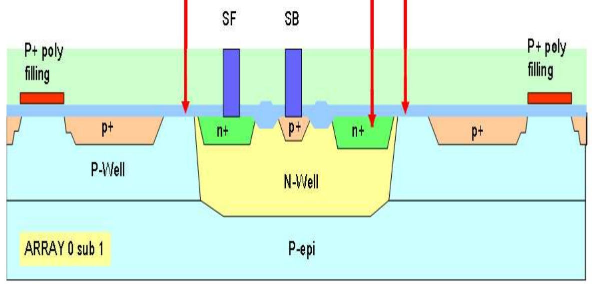


Increase of leakage current depends on the diode layout.
Probable reason: Presence of thick oxide (FOX) near the diode.

Beamtest on MIMOSA11

Running conditions: +40°C, 700µs readout time



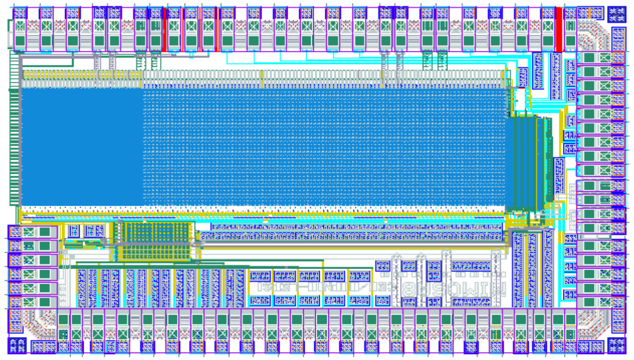


	New	After 20kRad
Standard pixel (A0 Sub 2)		
S/N (MPV):	23.9	10.3
Det Eff [%]:	99.9	97.7
Noise [e-]:	10.7	23.5
Hardened pixel (A0 Sub 1)		
S/N (MPV):	14.9	15.1
Det Eff [%]:	99.5	99.6
Noise [e-]:	16.1	16.1

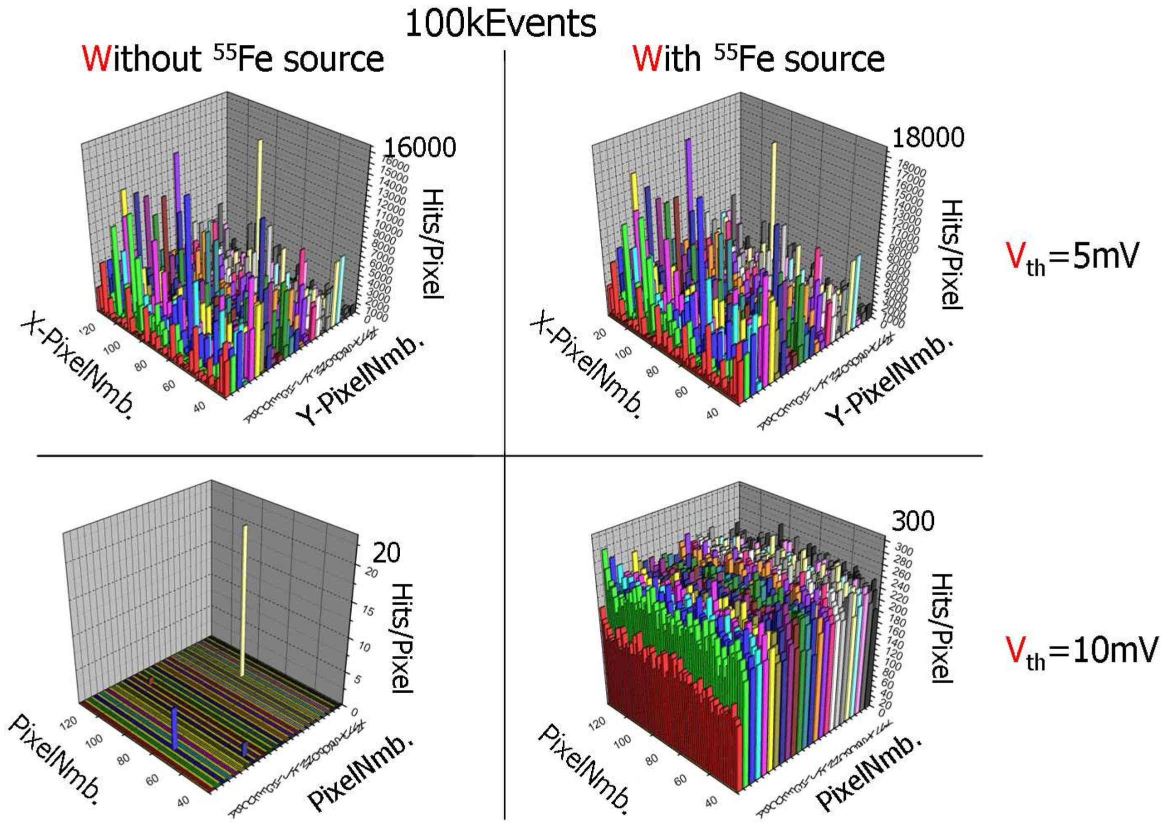
Radiation hardened pixel remains stable after irradiation.
Obvious reason: Leakage current increases after irradiation slower than for the standard pixel.
S/N of the radiation hard pixel is not yet optimized (See MIMOSA15).

MIMOSA-8 (FAST COL. // WITH DISCRIMINATED OUTPUT)

CHARACTERISTICS AND LAB TEST RESULTS



- **MIMOSA-8:**
  - **TSMC 0.25 μm digital fab. process (8 μm epitaxy)**
  - **32 // columns of 128 pixels (pitch: 25 μm)**
  - **4 sub-arrays featuring AC and DC coupled on-pixel voltage amplif.**
  - **on-pixel CDS**
  - **discriminator at end of each column**



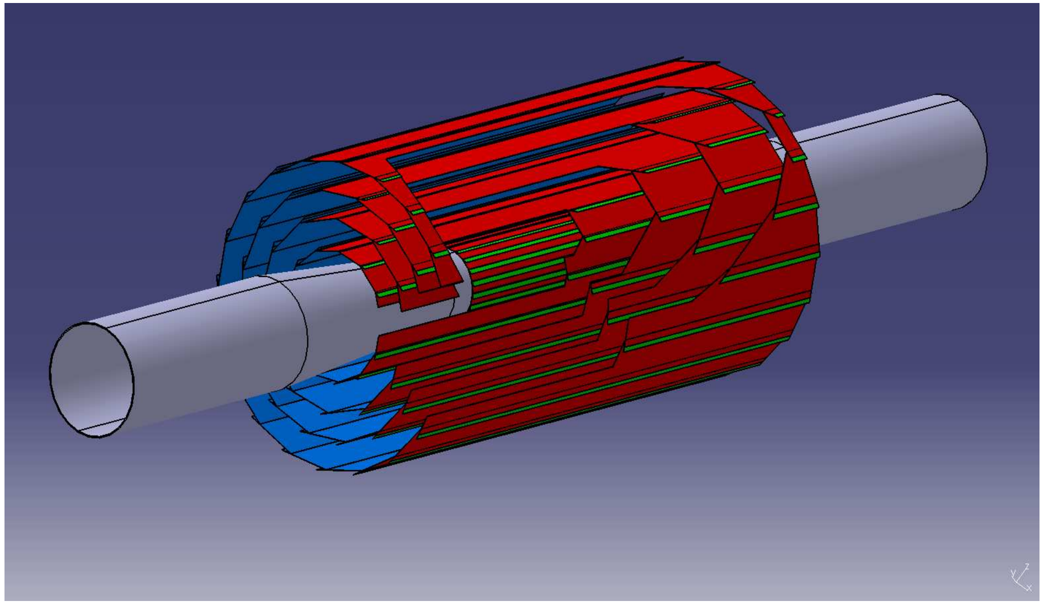
- **tests with ^{55}Fe source:**
  - ◇ **conversion factor: 50 – 110 μV/e$^-$,**
  - ◇ **pixel noise (including CDS): $\sim$ 13 – 18 e$^-$ENC !**
  - ◇ **little pixel-to-pixel dispersion ($<$ 10 e$^-$ENC)!**
  - ◇ **discriminator operational:**
  - $\hookrightarrow$ **discriminated ^{55}Fe X-Ray clusters observed !**

■ **Architecture seems worth extending with integ. ADC $\mapsto$ EUDET E.U. project**

Application to the ILC Vertex Detector

- Geometry: 5 cylindrical layers (R=15 – 60 mm), $||cos\theta|| \leq$ 0.90 – 0.96
- $\sigma_{\mathbf{IP}} = \mathbf{a} \oplus \mathbf{b/p} \cdot \mathbf{sin^{3/2}}\theta$, with a $<$ 5 μm and b $<$ 10 μm
- Read-out time: ¶ 25 μs in L0 ¶ 50 μs in L1 $\therefore$ $\lesssim$ 200 μs in L2, L3, L4

Layer	Radius (mm)	Pitch (μm)	$t_{r.o.}$ (μs)	N_{lad}	N_{pix} (10^6)	P^{inst}_{diss} (W)	P^{mean}_{diss} (W)
L0	15	20	25	20	25	$<$100	$<$5
L1	25	25	50	26	65	$<$130	$<$7
L2	37	30	$<$200	24	75	$<$100	$<$5
L3	48	35	$<$200	32	70	$<$110	$<$6
L4	60	40	$<$200	40	70	$<$125	$<$6
Total				142	305	$<$565	$<$29



- Ultra thin layers: $\sim$ 0.1 % X_0/layer (?)
- Very low P^{mean}_{diss}: $<<$ 100 W ($\mapsto$ minimise cooling)
- Rad. tolerance (3 yrs): $\lesssim 3 \cdot 10^{10} n_{eq}/cm^2$ – $\lesssim 6 \cdot 10^{12} e_{10MeV}/cm^2$ (150 kRad, $2 \cdot 10^{11} n_{eq}/cm^2$)

Application to ILC: Various FE Architectures

▷ **Fast col. // architecture (like MIMOSA-8), allowing to process signal (CDS, ADC, sparsification) during BX:**

↪ **complex, close to technology limits ↦ much design & test effort needed (but quite universal output)**

▶ **Alternative ↦ 2 phase μcircuit architecture exploiting beam time structure, reducing data flux:**

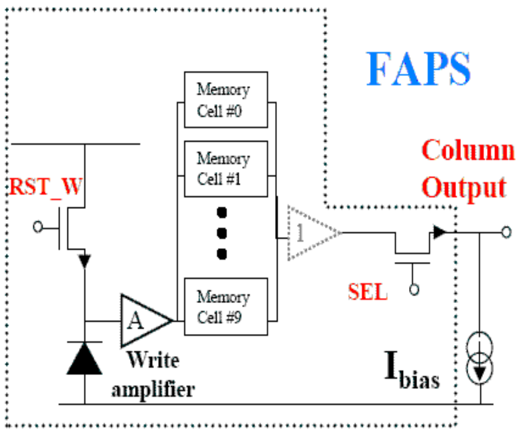
1) charge stored (eventually sampled) inside pixel during train crossing: O(1) ms

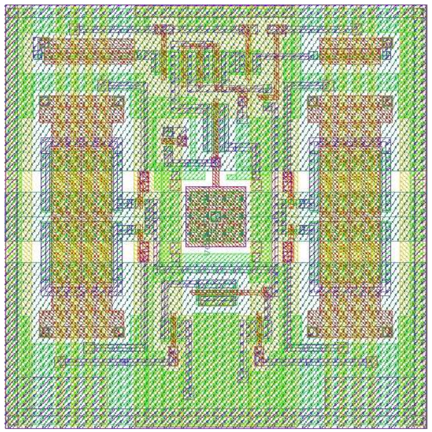
2) signal transfered and processed inbetween trains: O(100) ms

▶ **Different strategies of storage during train crossings:**

∴ **20 – 25 μm large pixels with $\gtrsim$ 20 capacitors**

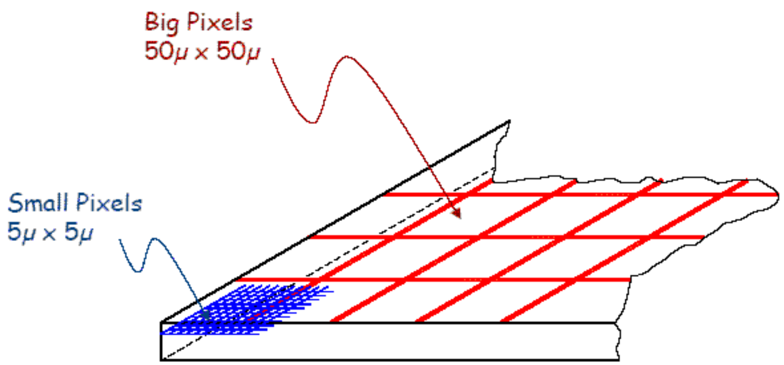
↪ $\lesssim$ **50 μs long snapshots/capacitor**





▷ **Difficulty: are small capacitors precise enough ?**

∴ $\lesssim$ **5 μm large pixels with 1 capa.(hit position) and 50 μm large pixels for hit zone selection**



▷ **Difficulty: can cluster size be $\lesssim$ 3 pixels ?**