Radiation Tolerance of CMOS Sensors for the HFT :

Which Pixel Pitch for ULTIMATE ?

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OUTLINE

- **Which ULTIMATE pitch is best suited to HFT non-ionising radiation ?**
  - **what is the radiation dose ?**
  - **safety margins ?**
- **What consequences on other critical parameters ?**
  - **power dissipation**
  - **pixel matrix read-out speed**
  - **data throughput of output memories**
- **Where is the optimum ?**
- **Summary**

- **High density of sampling nodes** *allows faster collection of signal charge*

  $\hookrightarrow$ *prevents thermal diffusion of minority carriers* $\Rrightarrow$ *alleviates recombination probability (interstitial traps)*

- **Benefits from pitch reduction :**

  ⁕ *improved granularity* $\Rrightarrow$ *improved* σ_{sp} $\Rrightarrow$ *target value may be reached with less bits ...* $\rightarrowtail$ *binary read-out*

  $\hookrightarrow$ *digital-to-analog conversion becomes less power consuming*

- **Draw-backs from pitch reduction :**

  ⁕ *nb of pixels / column* $\nearrow$ $\Rrightarrow$ $t_{int.}$ $\nearrow$ $\sim$ *pitch*$^{-1}$

  ⁕ *nb of columns / chip* $\nearrow$ $\Rrightarrow$ P_{diss} $\nearrow$ $\sim$ *pitch*$^{-0.8}$

  ⁕ *total nb of pixels* $\nearrow$ $\Rrightarrow$ *raw nb of noisy pixels* $\nearrow$ $\Rrightarrow$ *data throughput capabilities may saturate*

$\Rrightarrow$ **Optimal pixel pitch of ULTIMATE should account simultaneously for all these parameters**

Non-Ionising Radiation Tolerance: Pitch Dependence

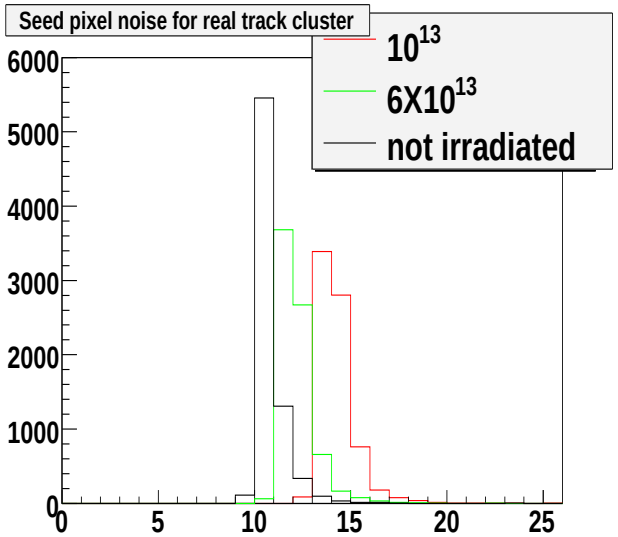
- MIMOSA-15 (20 μm pitch, analog output) irradiated with O(1 MeV) neutrons $\longmapsto$ tests at DESY (few GeV e^-)
  - T = - 20°C, $t_{r.o.} \sim 700\ \mu s$
  - ○ $5.8 \cdot 10^{12}$ n_{eq}/cm^2 values derived with **standard** and with **soft** cuts

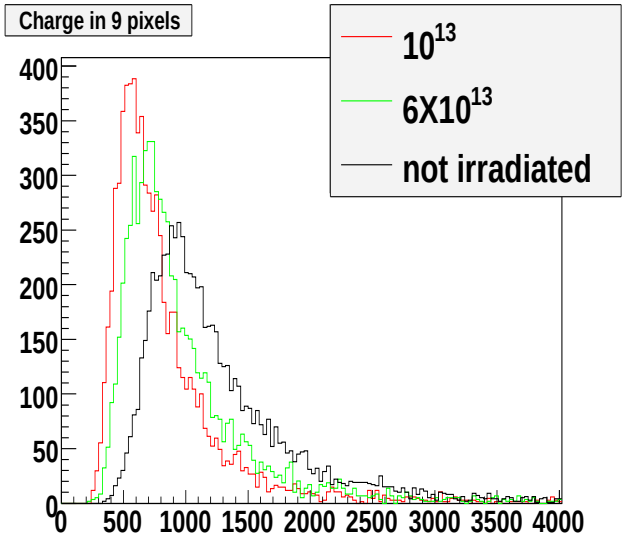
Fluence	0	0.47	2.1	5.8 (5/2)	5.8 (4/2)
S/N (MPV)	27.8 $\pm$ 0.5	21.8 $\pm$ 0.5	14.7 $\pm$ 0.3	8.7 $\pm$ 2.	7.5 $\pm$ 2.
Det. Eff. (%)	100.	99.9 $\pm$ 0.1	99.3 $\pm$ 0.2	77. $\pm$ 2	84. $\pm$ 2.

- MIMOSA-18 (10 μm pitch, analog output) irradiated with $\lesssim 10^{13}$ O(1 MeV) n/cm^2 (+ 100–200 kRad γ gas)

  $\longmapsto$ tested with $\sim$ 120 GeV π^- beam (CERN-SPS) in Summer-Autumn 2007

  ▷ Results obtained with : • T = -20°C • $t_{r.o.} \sim 3$ ms • cuts at 5N (seed) & 2N (crown)





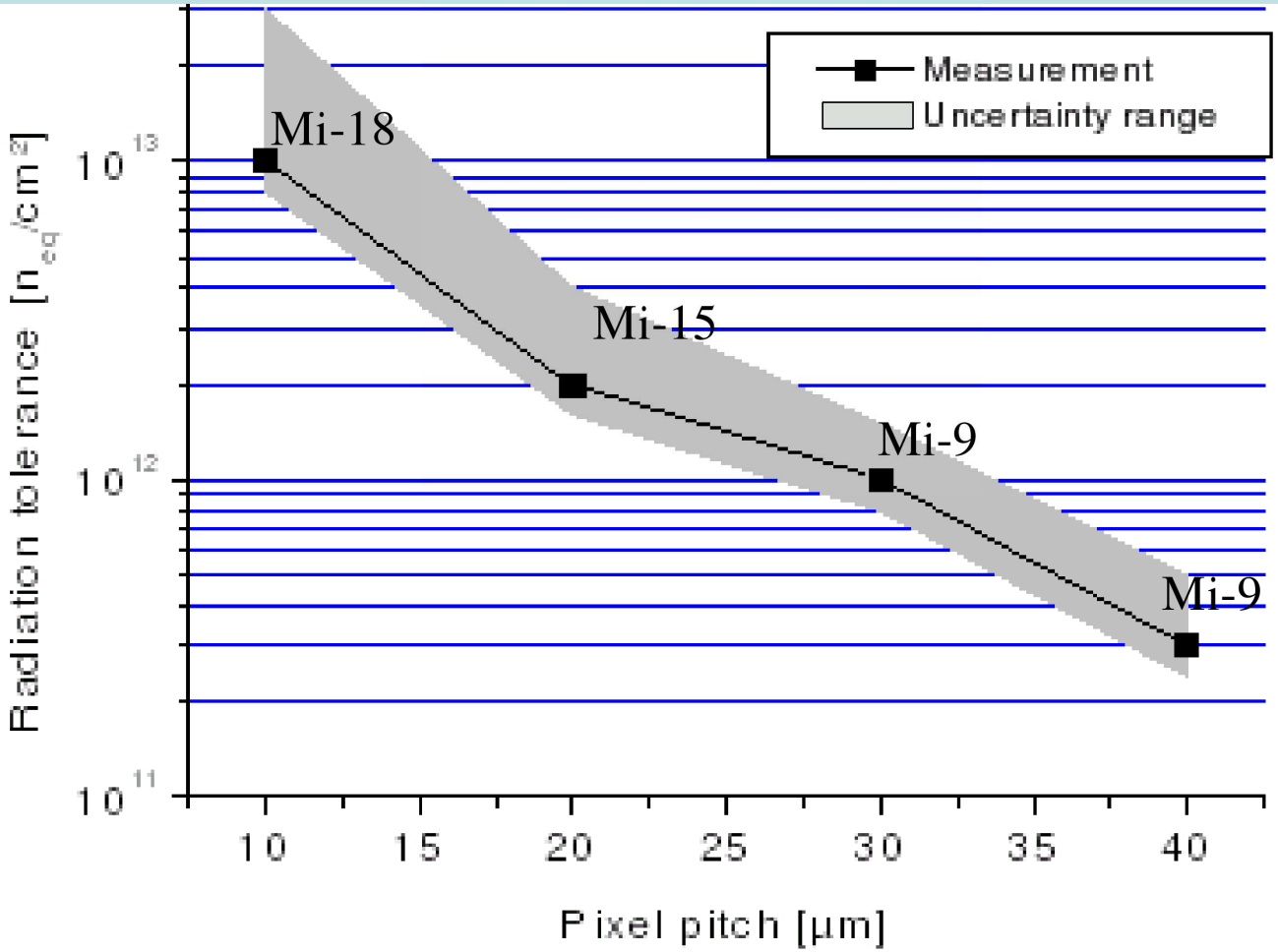
Fluence (n_{eq}/cm^2)	0	$6 \cdot 10^{12}$	$1 \cdot 10^{13}$
Noise ($e^- ENC$) (-20°C, 3 ms, 5N/2N)	10.8 $\pm$ 0.3	12.2 $\pm$ 0.3	14.3 $\pm$ 0.3
Q_{clust} (e^-)	1026	680	560
S/N (MPV)	28.5 $\pm$ 0.2	20.4 $\pm$ 0.2	14.7 $\pm$ 0.2
Det. Eff. (%)	99.93 $\pm$ 0.03	99.85 $\pm$ 0.05	99.5 $\pm$ 0.1

- *$\sim 10^{12}$ to 10^{13} $n_{eq}/cm^2/s$ affordable at $T < 0°C$ & $t_{r.o.} \sim$ O(1) ms & adapted pitch*

  $\hookrightarrow$ study tolerance for digital output (larger pixel noise), $T > 0°C$, ... , annealing ?????

Radiation Tolerance vs Pitch for AMS-0.35 OPTO

Tolerance against non-ionising radiation



Main conclusion:
Small pixels seem mandatory to improve radiation hardness

- **"Optimum" preserving radiation tolerance, power dissipation, read-out speed, data flow (noise) ?**

- **Assumed fluences to accommodate :**
  - *Inner layer :* $\gtrsim 10^{12} n_{eq}/cm^2$ $\Rrightarrow$ **critical**
  - *Outer layer :* $\gtrsim 10^{11} n_{eq}/cm^2$ $\Rrightarrow$ **not critical**

- **Typical pitch values adapted to these very different fluences:**
  - *Inner layer :* $\lesssim 20\ \mu m$
  - *Outer layer :* $\gtrsim 30\ \mu m$

- **Consequences :**
  - *Power dissipation :* $\sim$ *115 mW/cm*^{2} *(outer layer) &* $\sim$ *170 mW/cm*^{2} *(inner layer)* $\Rrightarrow$ *average* $\sim$ *130 mW/cm*^{2}
    $\hookrightarrow$ *equivalent to 25* μm *pitch everywhere)*
  - *Read-out (integration) time :* $\sim$ *130* μs *(outer layer) &* $\sim$ *200* μs *(inner layer)*
  - *Data flow : see talk of Christine*

- **Questions :**
  - *Are different integration times for both layers acceptable ?*
  - *Is a total 130 mW/cm*^{2} *power dissipation (i.e. 10 % increase w.r.t. previous value) OK ?*
  - **Less conventional approach : rectangular pixels in outer layer**
    Example : 18.4 x 36.8 μm^2 **(outer) & 18.4 x 18.4** μm^2 **(inner)** $\Rrightarrow$ **average P**$_{diss}$ $\sim$ **110 mW/cm**^{2}