Development of Fast and Radiation Tolerant Monolithic Active Pixel Sensors With Column Parallel Readout.

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On behalf of the IPHC-Strasbourg team:

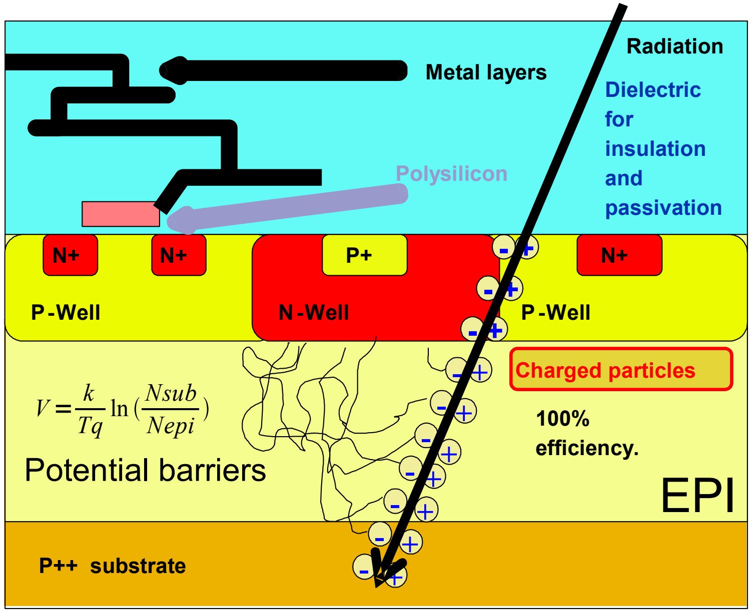
http://www.iphc.cnrs.fr/-CMOS-ILC-.html

In collaboration with IRFU-Saclay and IKF-Frankfurt

- **Monolithic Active Pixel Sensors (MAPS) – reminder**
- **The need for sensor with column parallel architecture**
- **Development of fast and radiation tolerant MAPS with column parallel architecture**
  - In-pixel amplifier development → Mimosa 22/22bis
    - implemented structures
    - improvement of radiation tolerance
    - extended laboratory test results
    - conclusions
- **Talk summary**

OUTLOOK

Monolithic Active Pixel Sensors (MAPS) - reminder



- Introduced in 1999 as devices made in standard CMOS technology, MAPS integrate the **sensing elements and the processing electronics on the same substrate.**

- Signal created in low resistivity p-type silicon layer (epitaxial layer)
  - EPI thickness ~10-15 µm
  - Charge ~80 e- h /µm
  - Signal ~ 800 - 1200 e- …but only ~20% available on the single collection diode.

  - Charge propagation – EPI layer not depleted - thermal diffusion in EPI (+reflection on highly dopped boundaries with PWELL and substrate)
  - Collection – by NWELL/p-EPI reverse biased diodes < 100 ns
  - Charge to voltage conversion on the sensing diode capacitance (several fF)
  - Fill factor – 100% - active volume located underneath the read-out electronics
  - **Possible to thin down to ~50µm**

<u>MAPS sensors are developed to equip EUDET, STAR, CBM, ILC, ...</u>

Requirements vs. MAPS performance

Achievements of MAPS (Mimosa) with analog output:
- single point resolution ~1-3µm (10-40µm pitch)
- detection efficiency > 99.5% @ fake hit rate < 10^{-4}
- radiation tolerance – 1MRad (no in-pixel ampli.) & 10^{13} n_{eq}/cm^2 (pixel pitch of 10µm)
- thicknes of ~50µm

Applications of MIMOSA sensors:

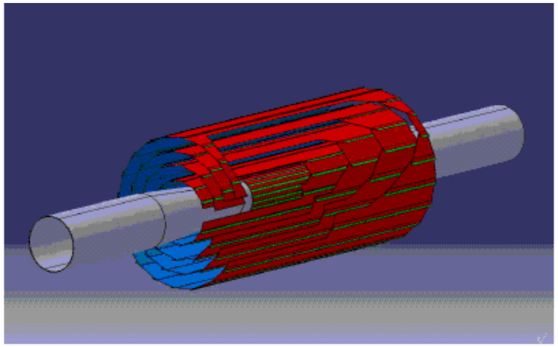
EUDET JRA1 → high resolution beam telescope

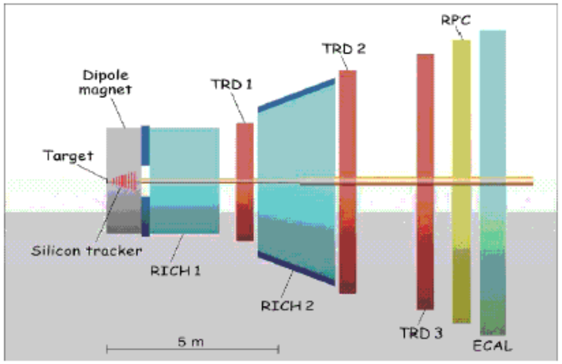
STAR exp. at RHIC → Vertex Detector upgrade

ILC → Vertex Detector (option)

CBM → Vertex Detector at FAIR/GSI

…





Requirements vs. MAPS performance

High granularity, fast read-out and radiation tolerance - required simultaneously for many applications
e.g. CBM at FAIR

<u>R&D on radiation tolerant chip with integrated signal processing:</u>

Column (N) parallel architecture → reduction of read-out time by factor of N

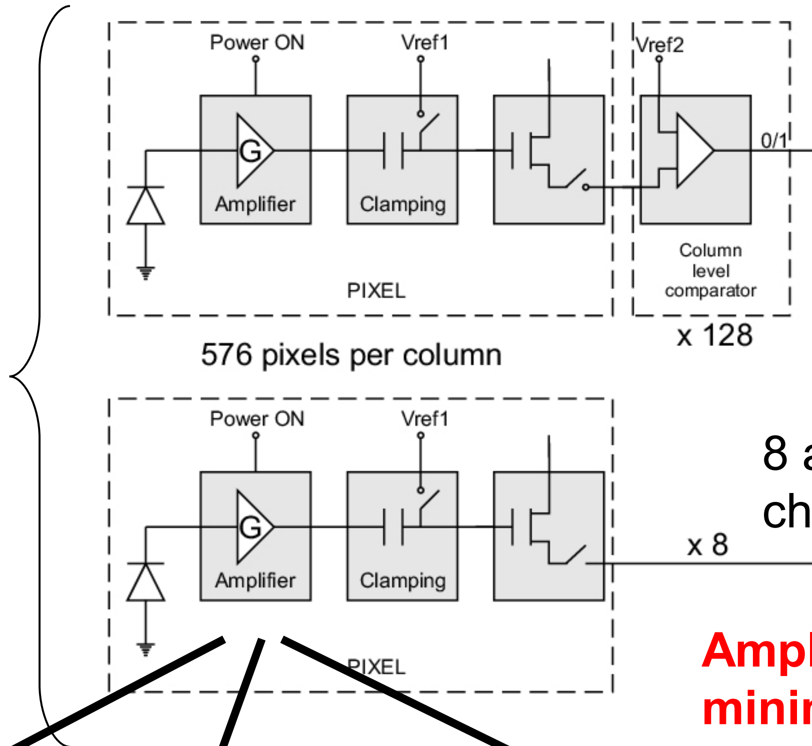
In chip data sparsification → selects and sends information about addresses of pixels delivering S>threshold... **<u>but this needs:</u>**

column level analog to digital conversion → simplest is a comparator
… but.... signal in range of fixed pattern noise (FPN) at the ADC input
→ reduction of FPN, in pixel Correlated Double Sampling (CDS) and signal amplification needed

Column parallel architecture development – Mimosa 22

AMPLIFIERS

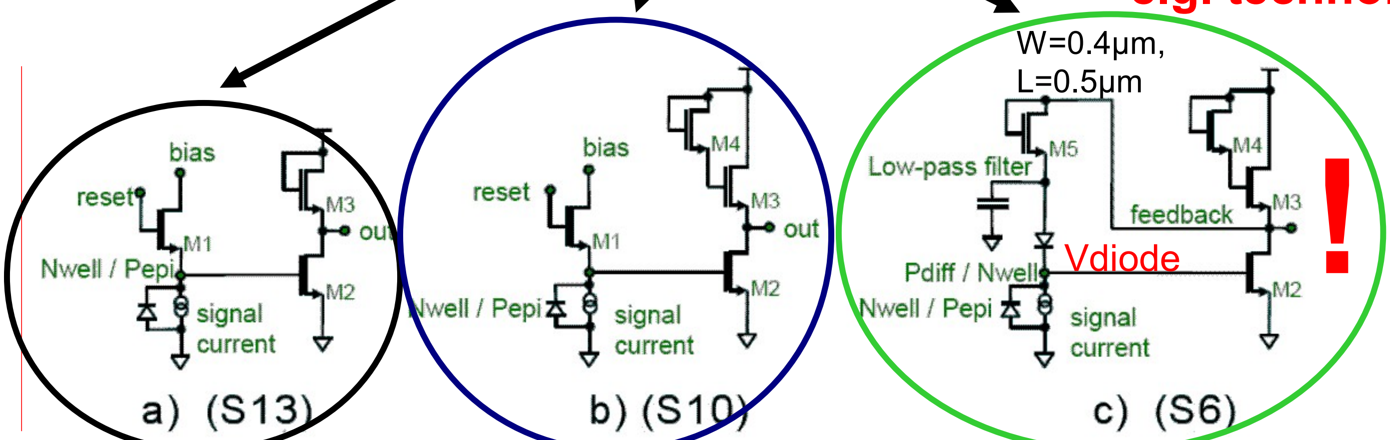
Mimosa 22/22bis



Digital outputs

8 analog outputs for chip characterization (noise, CCE, ...)

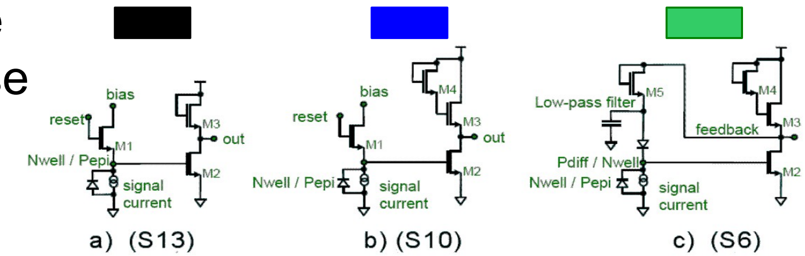
Amplifier with feedback allows to minimize the FPN noise related to e.g. technology non-uniformities.

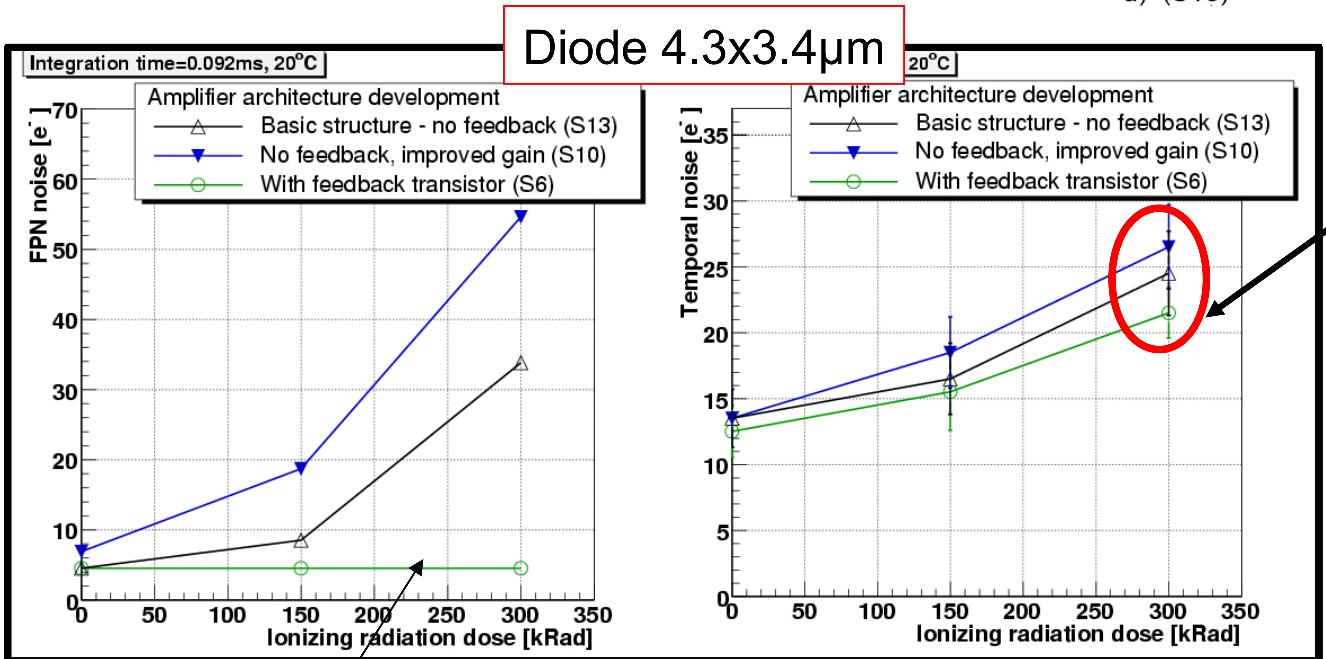


If Vdiode ↗ then Vout ↘ then Vdiode ↘

Performance of pixel equipped with feedback amplifier

- sensors were irradiated up to 300kRad with XRAY source at CERN
- using 8 analog outputs FPN and temporal noise were estimated for not irradiated sensor and those irradiated to 150kRad & 300kRad
- conditions: +20C, integration time ~92μs





Residual rise of temporal noise noticed...

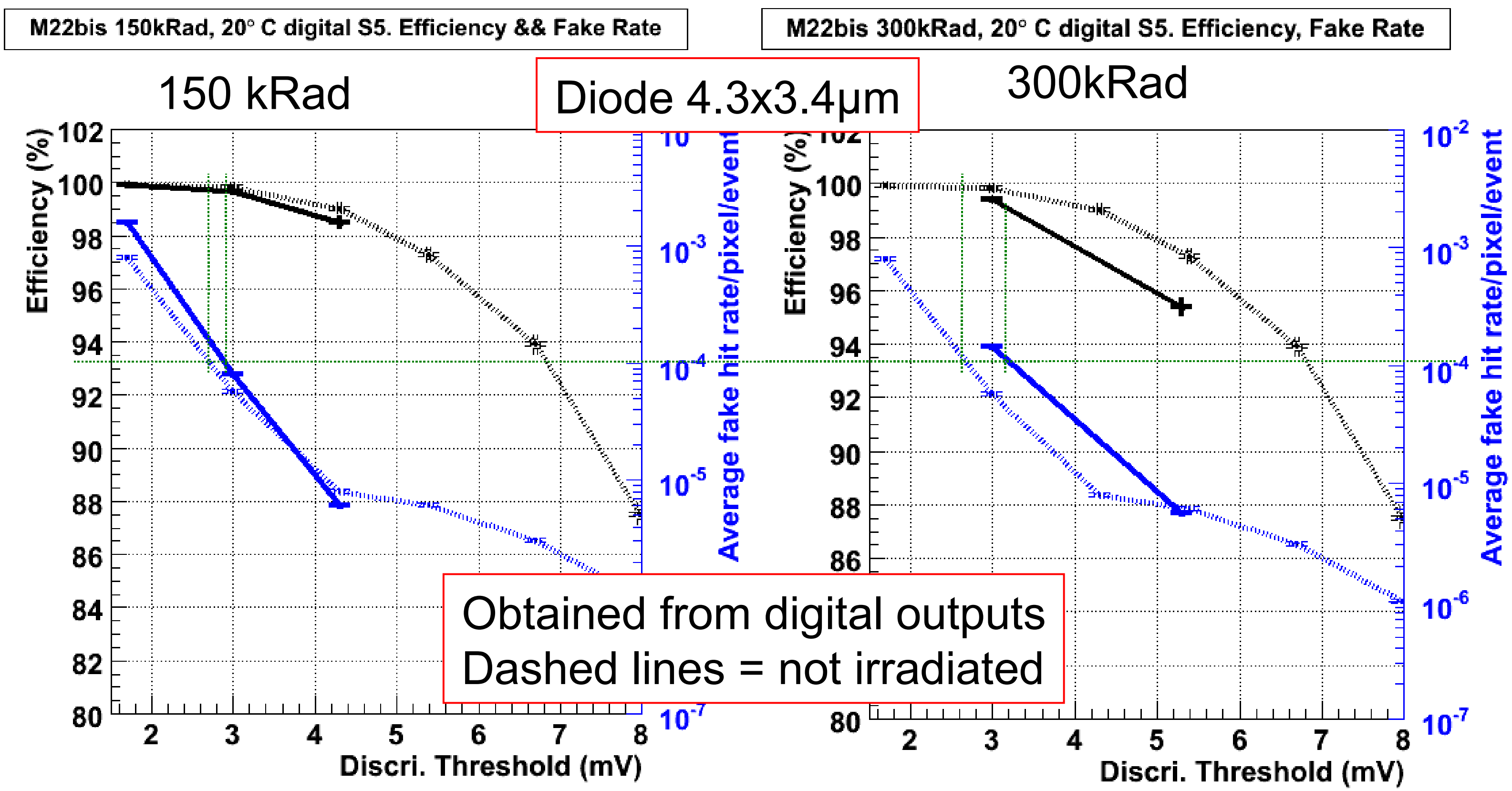
...but from previous studies on chips without in-pixel signal processing the noise was in order of ~15e after dose of 1MRad

After ionizing irradiation FPN noise for structures with feedback remains stable.

Performance of pixel equipped with feedback amplifier

<u>Beam test :</u>

- performed for not irradiated and gamma irradiated sensors (150kRad & 300kRad)
- conditions: + 20C, integration time ~92μs, ionizing dose ~ 300kRad
- after 300kRad detection efficiency starts to degrade ~99% (assumed average fake hit rate 10^{-4})



Amplifier radiation tolerance improvement

Increase of noise at amplifier output after ionizing radiation dose can be associated to:
1) increase of diode leakage current
2) decrease of low pass filter time constant
3) not optimal biasing point

Can be optimized

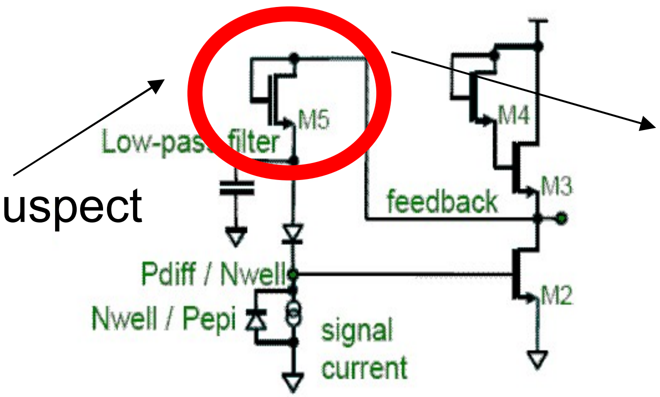
Convert all transistors to ELT ?

Advantages: - good radiation tolerance

Disadvantages:

- lager size → increase pitch → decrease granularity → drop in non-ionizing radiation tolerance
- no SPICE models for ELT transistors → hard to design analog circuits with good performance

The suspect



c) (S6)

Feedback ELT = less Source to Drain leak:
- biasing point more stable after irradiation
- filter time constant remains stable
- ..but with feedback, DC points depends also on previous circuit states ~„memory"
- implement 2 other structures where feedback transistors differ in gm

Diode design already radiation tolerant

Structures with modified feedback transistors – Mimosa 22bis

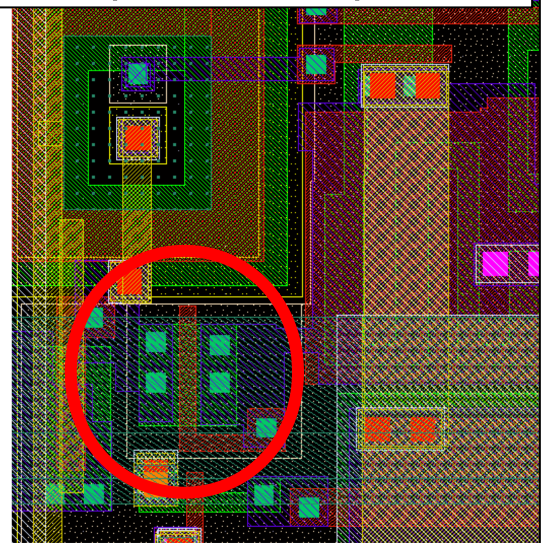
Diodes:

4.3x3.4µm :
- feedback ELT
- “standard” feedback (Mimosa 22 like W=0.4µm, L=0.5µm)

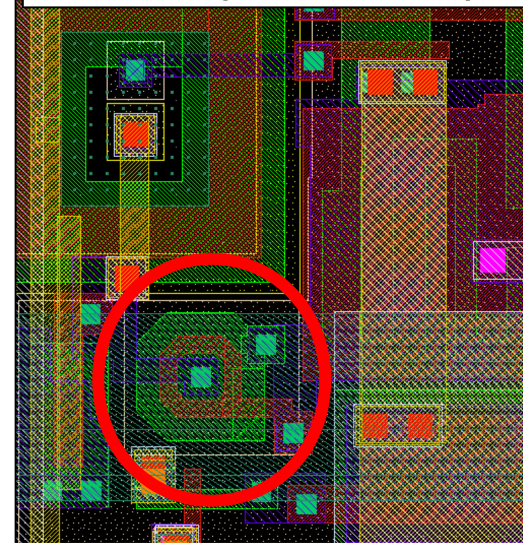
3.1x3.65µm :
- feedback ELT
- feedback “strong”
- feedback “weak”

...to study influence of feedback transistor on amplifier performance after irradiation

Structure with „STRONG” feedback transistor:
W=2,1µm L=0,35µm



Structure with feedback ELT:
W~4,4µm L~0,35µm



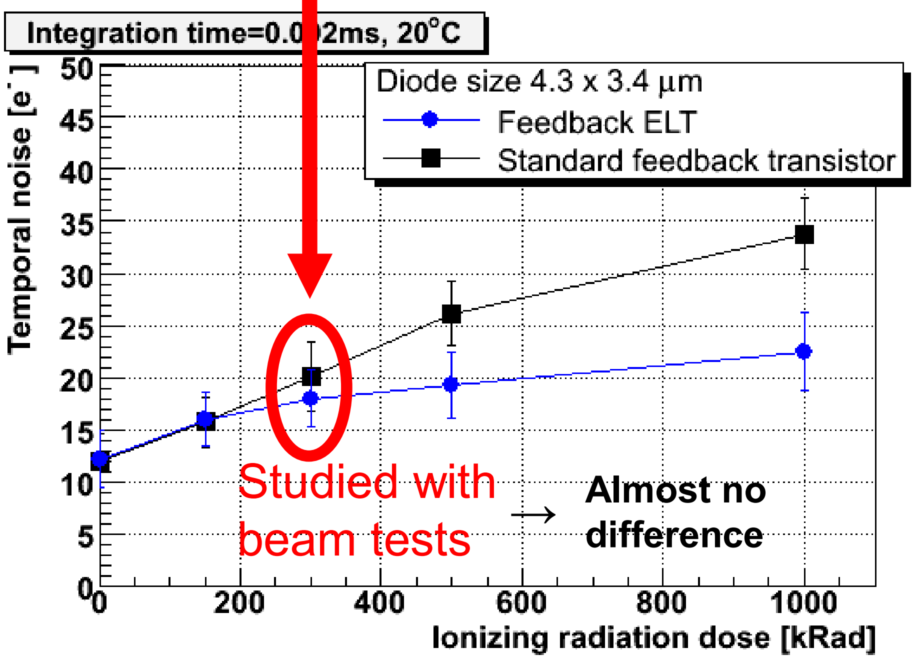
+ Structure with “WEAK” feedback transistor (not shown here)
W=0,35µm L=1,05µm

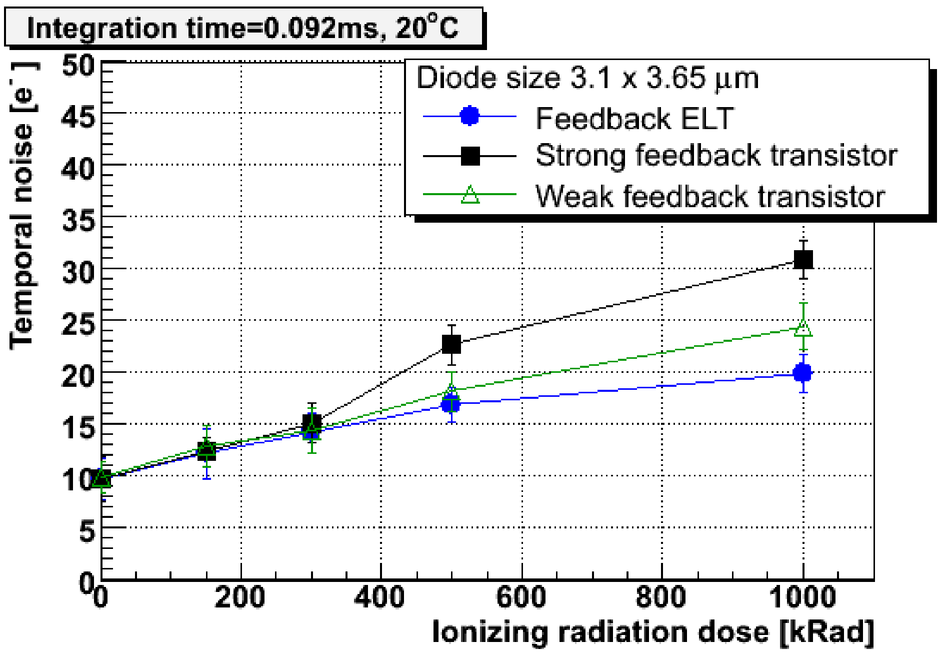
Motivation for extended tests

During BEAM TESTS: + 20C, integration time ~92μs, ionizing dose ~ 300kRad

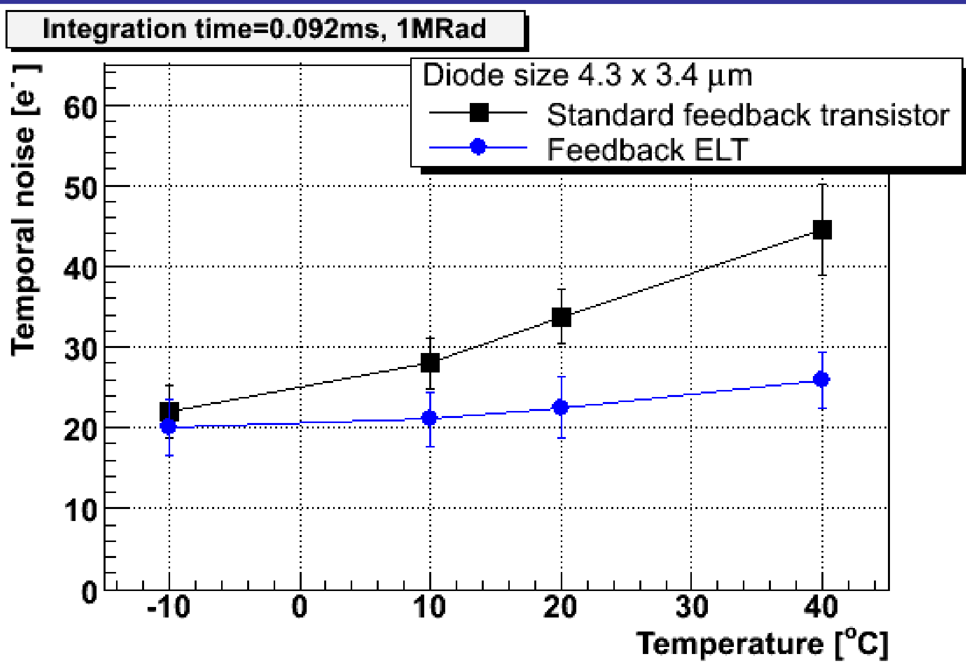
Observation: Both structures have similar performances

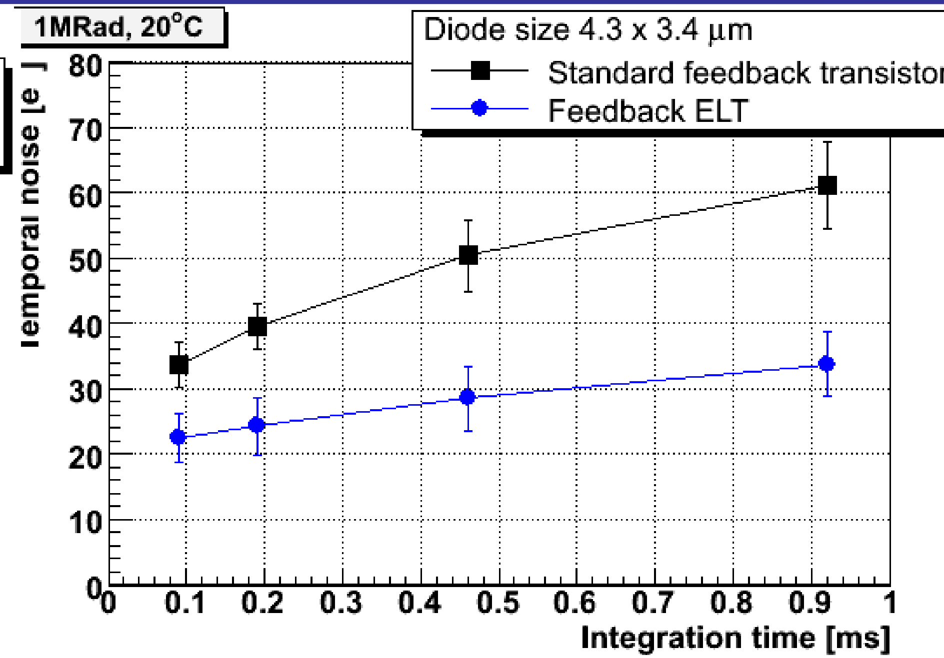
Extended tests needed to cover working conditions for ultimate chip:
- different integration time
- wider temperature range
- ionizing dose up to 1MRad (150kRad-ILC, 300kRad-STAR, 1MRad-CBM)





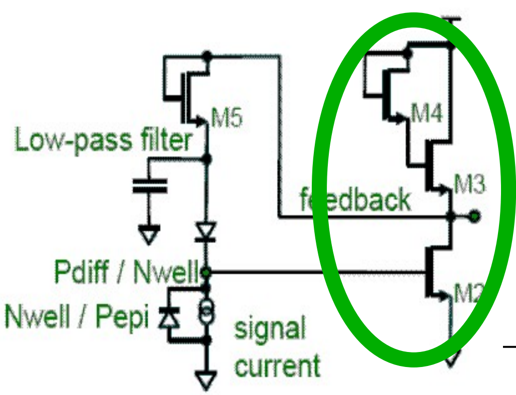
Temporal noise vs. temperature & integration time





Cooling and decreasing integration time are beneficial.

Architectures equipped with ELT in feedback exhibit the best radiation tolerance.



Influence of input and load transistor parameters (W,L) on output noise after irradiation was studied.

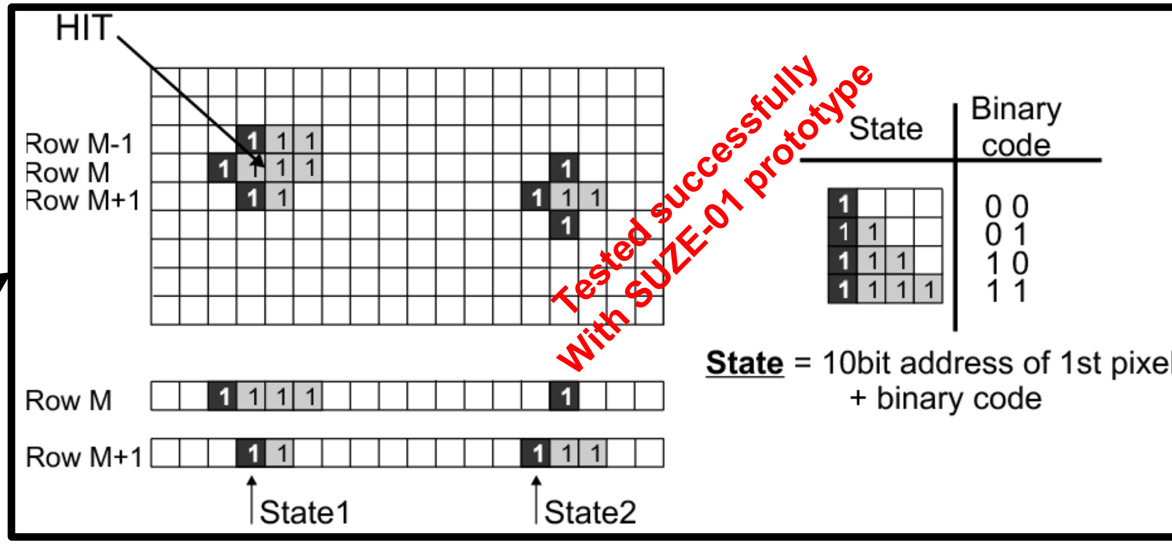
Observation: Feedback ELT structures with input and load transistor with larger transconductance exhibit only slightly better performance after irradiation.

Mimosa 26- Reticule size chip with data sparsification

Mimosa 22 column parallel architecture (analog part)

+

Zero suppression SUZE 01 (digital part)



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1st

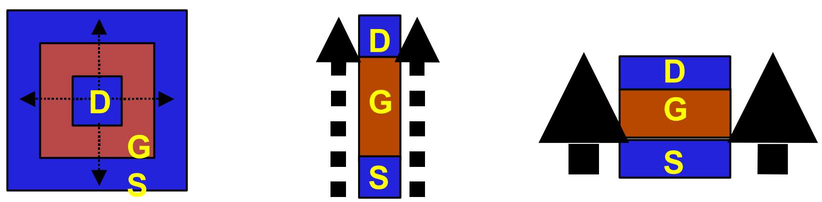
full scale chip with data sparsification (Mimosa 26)

- 1152x576 pixels
- read-out time 100us
- programmable bias and mode settings
- temporal noise of 0.64 mV ~12e and a FPN of 0.29 mV
- characterisation on-going in Strasbourg
- analog part has the same performance as in previous designs
- beam tests expected in Autumn

Summary

Radiation tolerance:

- important reduction of FPN noise after irradiation obtained with structures equipped with feedback transistor
- above 300kRad detection efficiency starts to degrade (~99%)
- implementation of enclosed layout transistor in the feedback is beneficial. 25-50% less noise after 1MRad compared to structures equipped with standard transistor (at room temperature & nominal frequency) ...but there is still excessive noise from in-pixel electronics as compared to sensors without in-pixel signal processing
- new test structures submitted – (feedback capacitance, diode → ELT(diode), cascode amplifier)
- influence of feedback transistor type and geometry on amplifier performance verified →



Feedback LP filter resistance ~1/leakage current

Sensor architecture:

1st full sale sensor with integrated sparsification (r.o. In 100µs, ~660000 pixels with 18.4µm pitch) for EUDET telescope currently under test (satisfactory preliminary results) - 1st beam test characterisation at CERN in September 2009