CLICpix Radiation Testing and Validation

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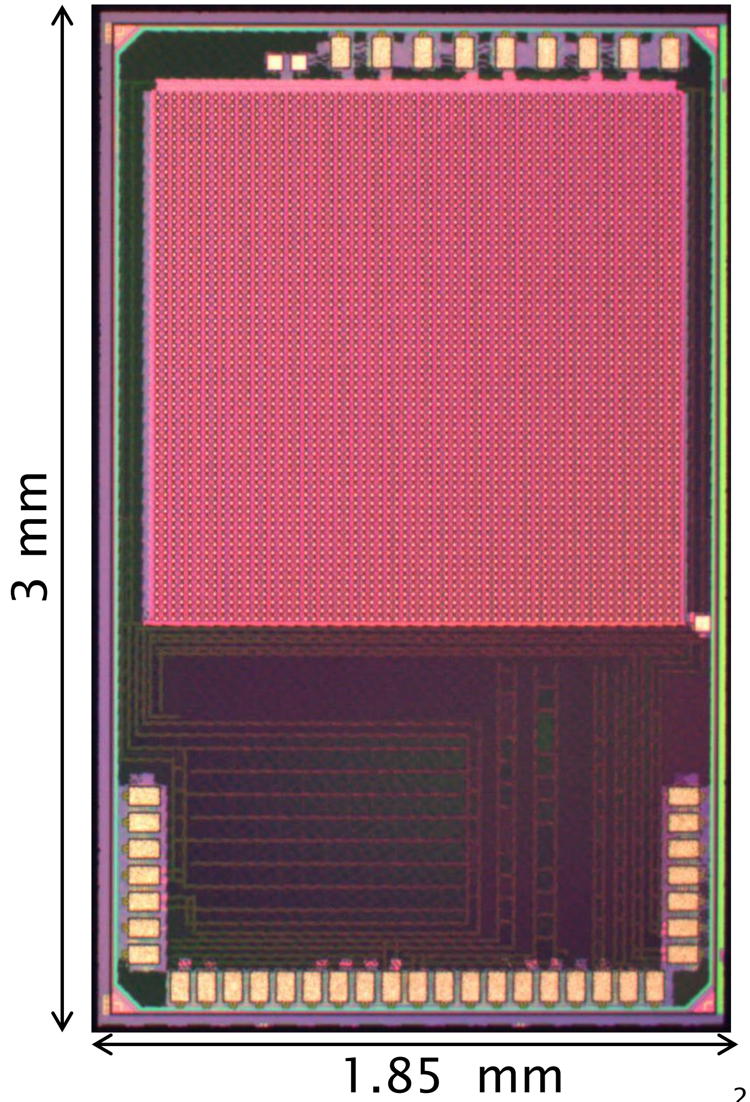
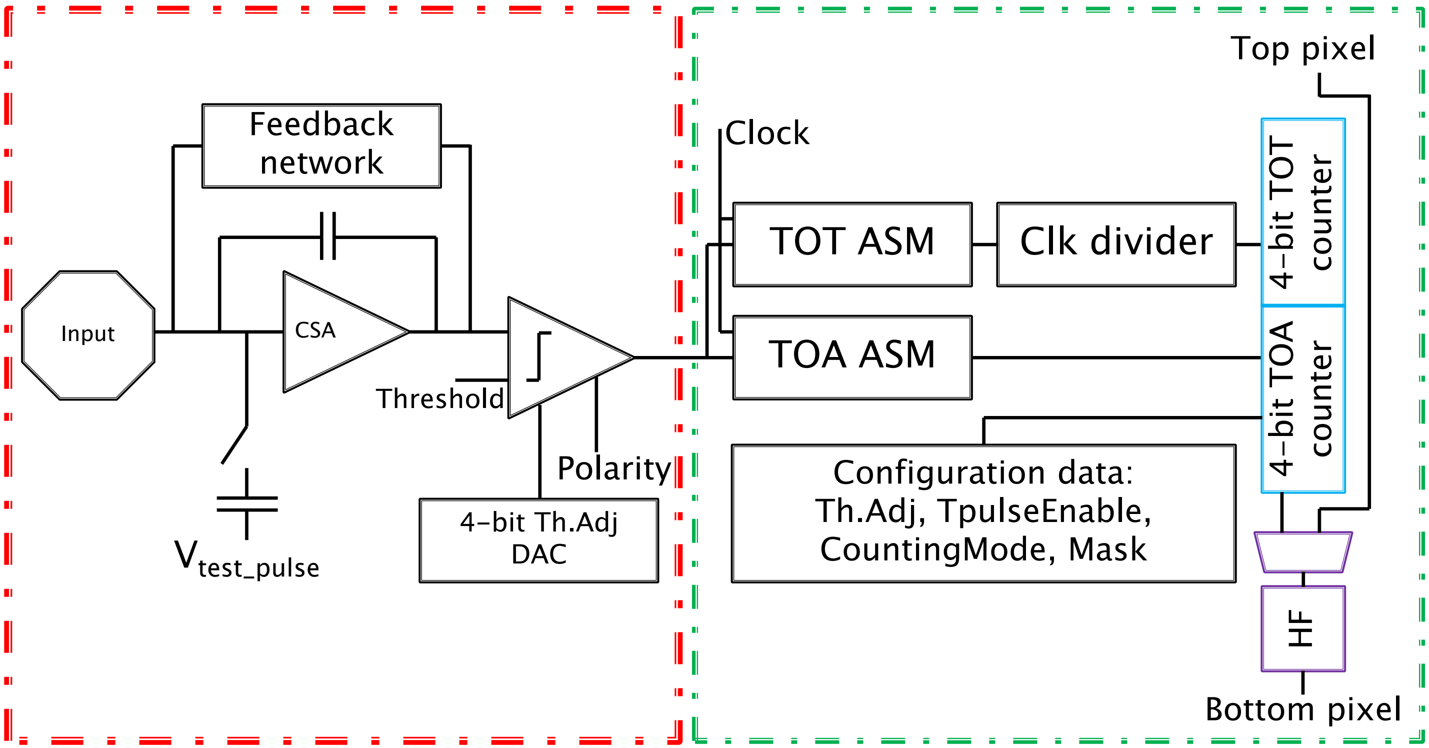
CLICpix

- CLICpix is a hybrid pixel detector to be used as the CLIC vertex detector
- Main features:
  - small pixel pitch (25 μm),
  - Simultaneous TOA and TOT measurements
  - Power pulsing
  - Data compression

- A demonstrator of the CLICpix architecture with an array of 64x64 pixels has been submitted using a commercial 65 nm technology and tested
- The technology used for the prototype has been previously characterized and is being validated for HEP use and radiation hard design up to very high doses



Pixel architecture



- The analog front-end shapes photocurrent pulses and compares them to a fixed (configurable) threshold
- Digital circuits simultaneously measure Time-over-Threshold and Time-of-Arrival of events and allow zero-compressed readout

Tests performed so far

	Simulations	Measurement
TOA Accuracy	< 10 ns	< 10 ns
Gain	44 mV/ke$^-$	40 mV/ke$^-$
Dynamic Range	up to 40 ke$^-$ (configurable)	up to 40 ke$^-$ (configurable)
Non-Linearity (TOT)	< 8% at 40 ke$^-$	< 4% at 40 ke$^-$
Equivalent Noise	~60 e$^-$ (without sensor capacitance)	~51 e$^-$ (with a 6% variation r.m.s.)
DC Spread (uncalibrated)	σ = 160 e$^-$	σ = 128 e$^-$
DC Spread (calibrated)	σ = 24 e$^-$	σ = 22 e$^-$
Power consumption	6.5 μW	7 μW

Measurements expressed in electrons depend on the test capacitance. A nominal value of 10 fF was assumed here

Why radiation testing?

- CLIC radiation hardness requirement: <1Mrad
- LHC upgrade: 1Grad! But…

- Knowing how blocks react to radiation can be useful to better understand how they work
- Test results can be very useful for people using 65 nm technology for LHC applications
- … such as the RD53 collaboration

The RD53 collaboration

- Collaboration on future pixel chips for ATLAS/CMS/LCD
- Development and characterization of circuits and building blocks needed for pixel chips
- Share circuit blocks
- Some blocks which will be useful for CLIC are already being designed (bandgap, I/O cells…)

- Work is ongoing using the same technology used for CLICpix

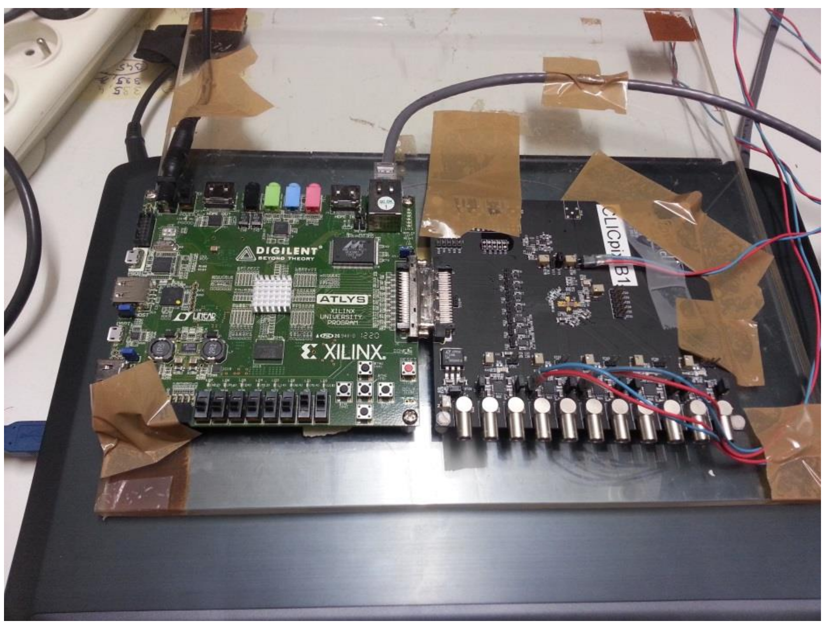
Total Dose Effects

- Threshold voltage shift in both NMOS and PMOS devices
- Leakage current increase in NMOS transistors
- Very large decrease in PMOS transconductance for high radiation doses (>200 Mrads), dependent on the device size
- Reduced speed of digital circuits

- Testing on single transistors have been carried out by researchers at CERN and CPPM

Test setup

- A in-house calibrated X-ray test setup was used to evaluate Total Dose effects
- Tests were automated using a linux PC and the already tested CLICpix board and Spartan-6 FPGA
- Two different chips were tested and they showed similar results



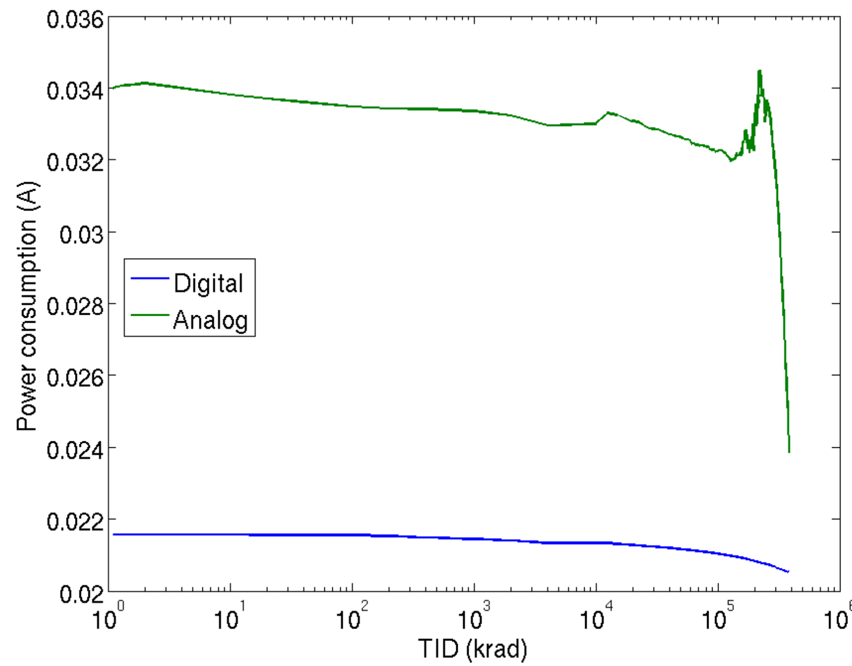
Test routines

- Small radiation steps in the dose range interesting to the CLIC project (< 10 Mrad)
- Larger steps for higher doses (until the chip stopped working)

- The main analog performances of the chip were monitored throughout the test

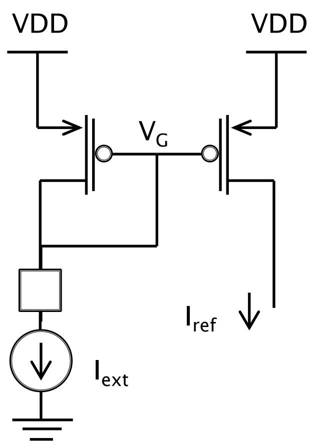
Power consumption

- Digital power consumption had a very limited variation up to very high dose rates
- The digital features of the chip kept working normally for the whole test
- The analog power consumption plummeted after ~250 Mrads (after which the chip was not functional anymore)



- The PMOS current mirror used to bias the chip “switched off” at high doses, making it impossible to power the chip

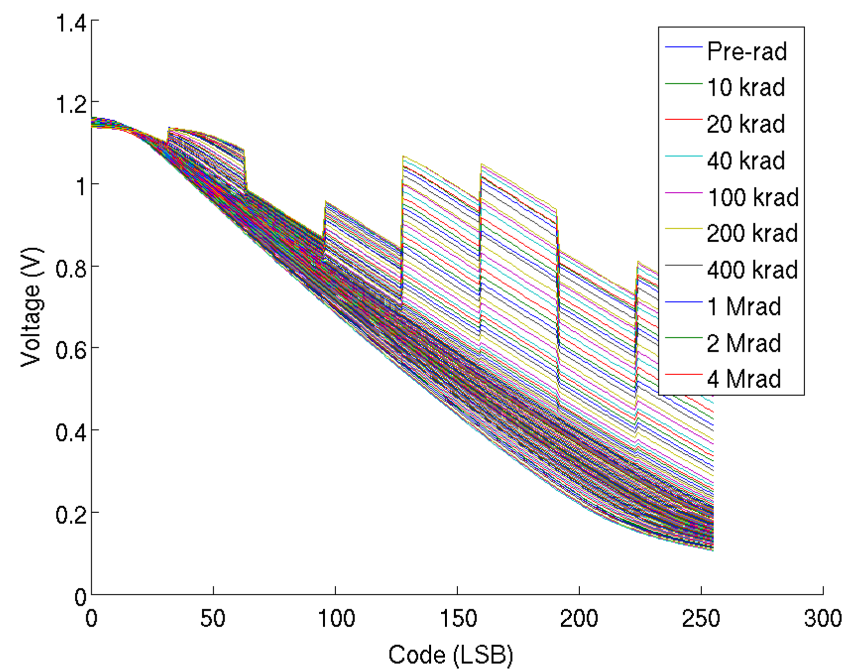
Reference Current Input



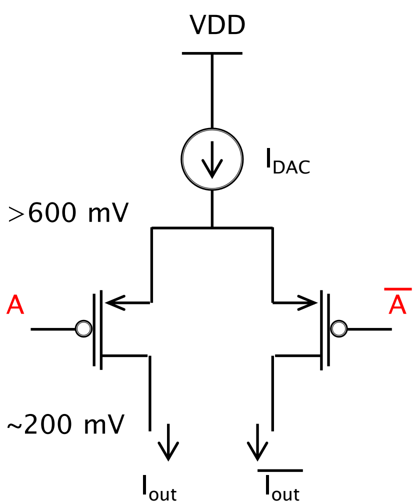
- The chip uses a PMOS current mirror to copy an external reference current
- At high doses, the PMOS devices in the mirror are unable to provide enough current
- A final version of CLICpix would use a bandgap to generate a reference voltage inside the chip, making it more robust

Digital to Analog Converters

- DACs used for biasing kept their linearity for low rates, with a minimal variation of their characteristics
- At high rates (>300Mrads) a large non-linearity appears



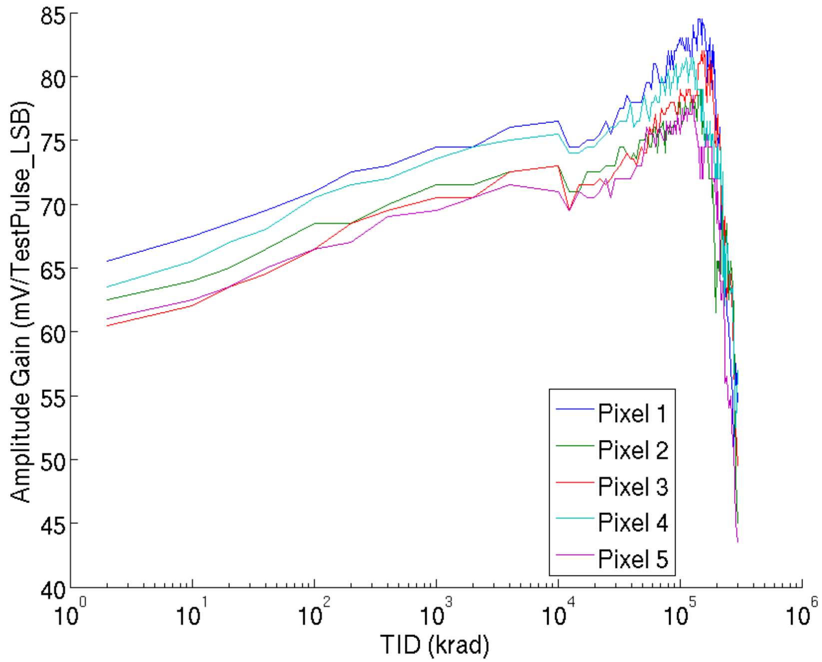
TID effect on PMOS transistors



- DACs use PMOS switches to control a current mirror for each bit
- At high rates switches irradiated while they are ON (their control voltage is GND) degrade more quickly than the one irradiated while they are OFF
- Damaged switches are unable to let the nominal current pass (they are permanently OFF)

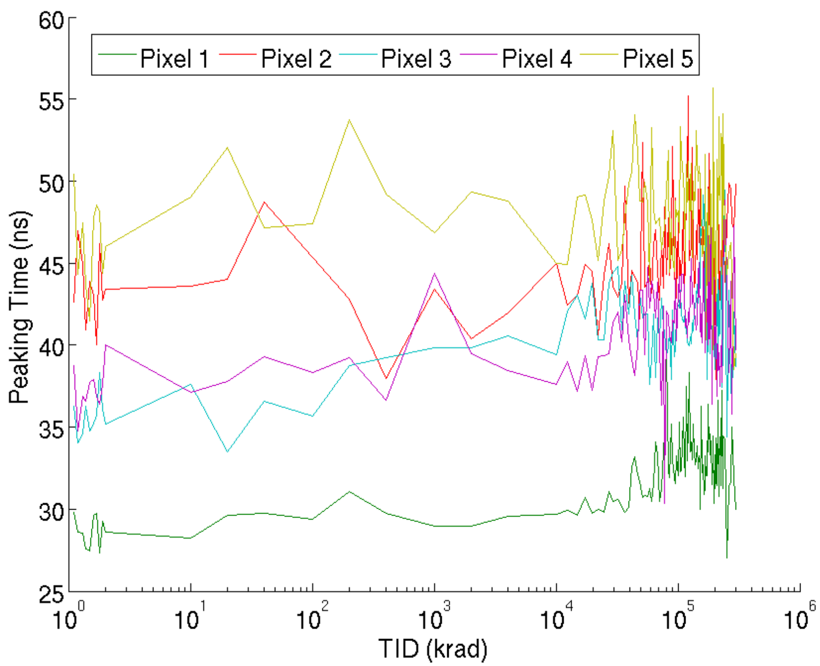
Front-end gain

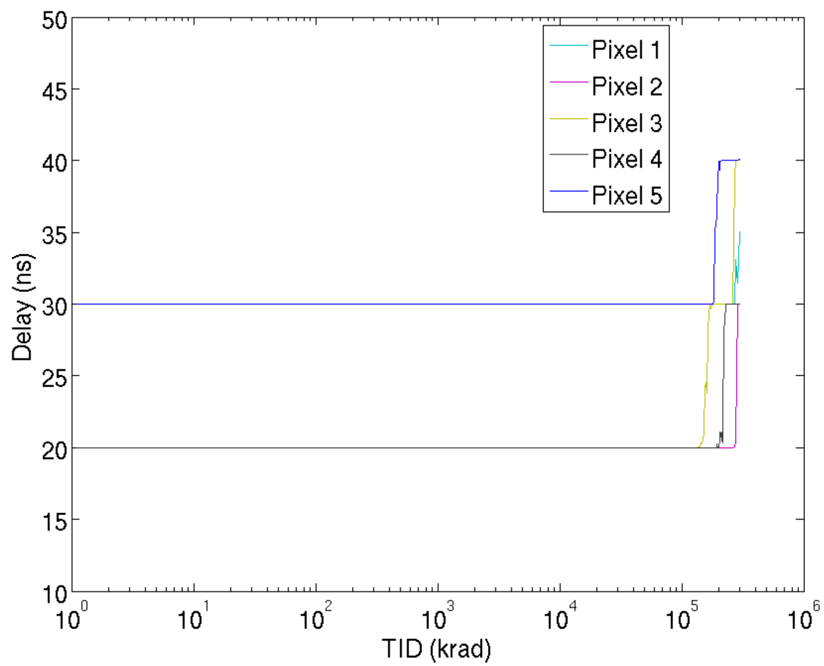
- The voltage gain of the analog front-end shows some variation for low rates, due to a reduction of the gain of the preamplifier or a decrease in the feedback current
- A higher variation can be noted for higher doses



Front-end timing

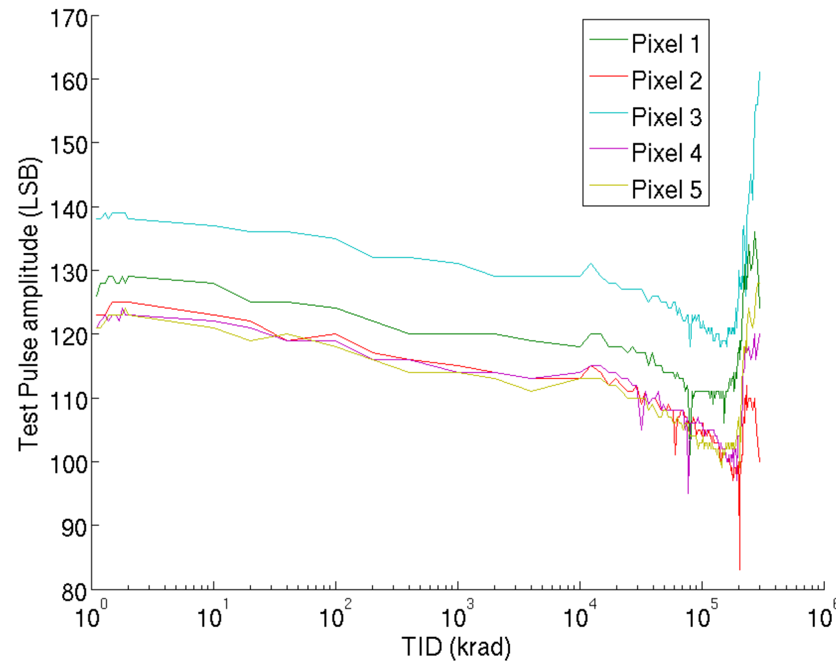
- Peaking time of the front-end is almost constant up to high rates
- The delay due to the logic and the discriminator is constant
- The measurement uses the internal clock for a 10 ns accurcay. The peaking time measurement is not “clean” because of low statistics





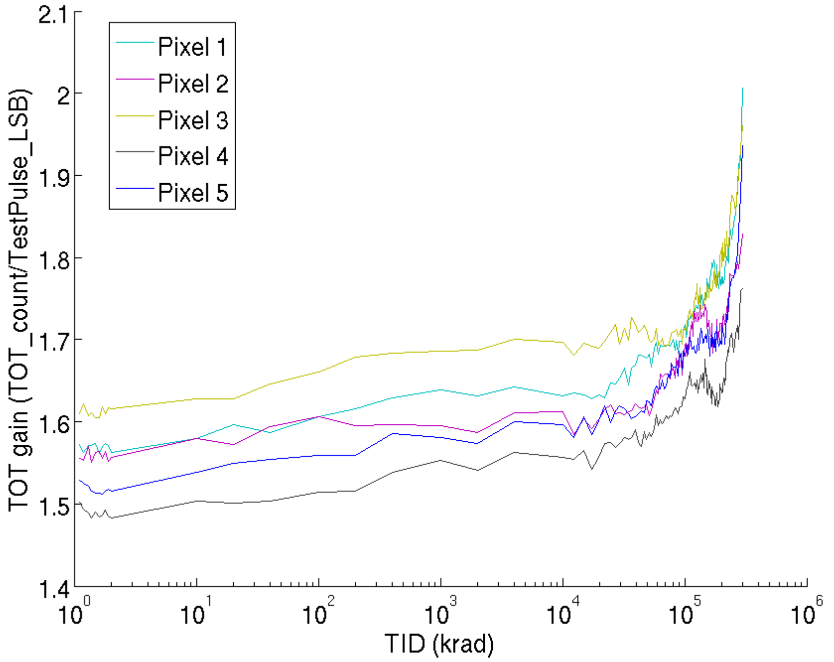
Threshold voltage variation

- Variation of threshold voltage is limited for low rates and it is compatible with the drift in the DAC characteristic
- Different pixels show the same behavior



TOT measurements

- TOT gain increases with radiation dose, especially at high doses
- This effect is probably caused by a decrease in the front-end feedback current



Other comments

- All I/O interfaces and digital structures did not show any significant degradation during irradiation, even after the analog front-end stopped working
- The chips regained some functionality after a week of annealing at room temperature (the total power consuption could be set back to pre-rad value). After annealing measurement will be analyzed soon
- The measurement was performed at a doserate of ~150 krad/minute (~75 krad/minute for the first 10 Mrads). The high doserate could have an effect on the radiation damage and needs to be explored

Conclusions and future work

- The performances of CLICpix with respect to radiation damage were studied
- In the sub-Mrad range, where CLIC will operate, the chip did not show any significant change, even in a high doserate test. Periodic re-calibration can anyway be performed to correct any DAC characteristics and threshold drift
- At very high doses (>200 Mrads), even basic blocks fail (switches, current mirrors). Further investigation on simpler structures is needed to develop circuits robust to such doses
- Data on annealing and noise measurements are still being acquired and analyzed

Thanks for your attention