Measuring the radiation hardness of the ATLAS ITkPixV1 chip

LHCC Poster Session – 17-18 November 2021

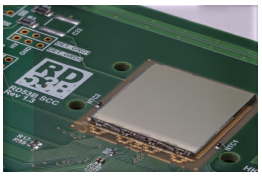
Motivation

- Pixel detector upgrade for ITk requires a new readout chip to deal with increased radiation and data rates
- Study the ATLAS/CMS readout chip prototype for the HL-LHC upgrades
- Understand impact of TID damage at the doses expected in the lifetime of HL-LHC (approximately 1 Grad)
- Deliver radiation in a controlled way using X-ray systems

ITkPixV1

- Latest prototype of ATLAS readout chip
- Designed by the RD53 collaboration in 65 nm technology

→ Used in pre-production and close to final ITk chip

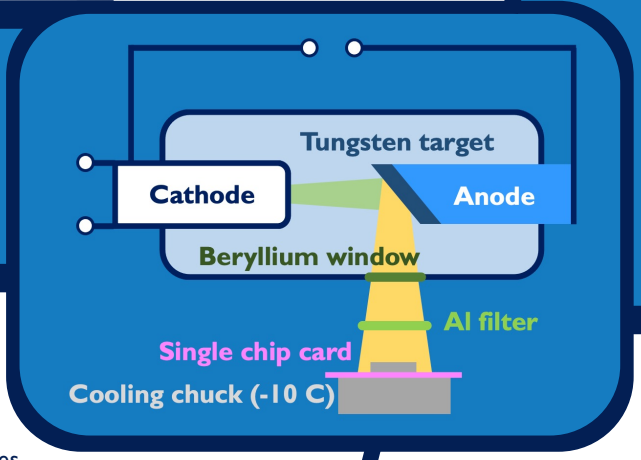


Irradiation setup

X-ray setup at Oxford:

- Comet MXR-160/22 tube
- Tungsten target
- Calibrated using cross-calibrated diode

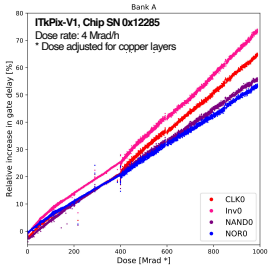
→ Up to 4 Mrad/h dose rate

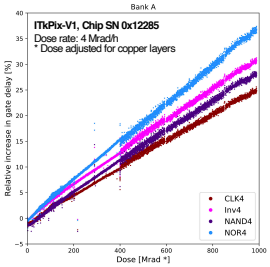


High dose rate

- Irradiation to 1 Grad at a dose rate of 4Mrad/h
- Delay degradation:
  - 70% for strength 0 gates
  - 40% for strength 4 gates

→ Strength 4 gates representative of gates used in the chip logic

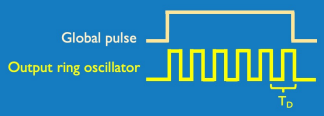




Ring oscillators

- 42 ring oscillators in ITkPixV1, made with different logic cells and different transistor sizes (strength 0 or 4)
- Oscillator drives a 12-bit counter, enabled for a given time

→ Calculate frequency f or delay $T_D = 1/(N \cdot f)$



- During irradiation oscillation frequency decreases

→ Characterise damage to different kinds of logic cells

→ Proxy to understand gate delay

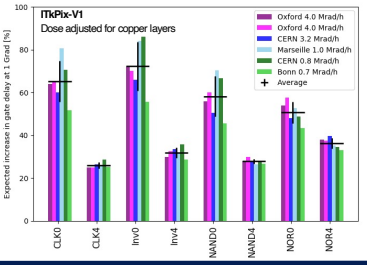
→ Expected issues for > 200% increase

- Frequency depends on voltage and temperature

→ Measured during irradiation and accounted for

X-ray irradiation results

Gate delays measured at different sites:



- Many high dose rate irradiation campaigns of ITkPixV1 performed at different sites

→ Good agreement between results

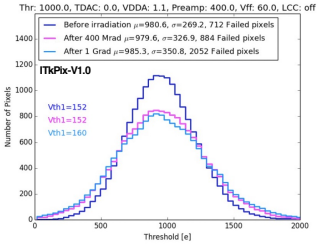
Low dose rate effects

- In ITk the total dose will be delivered over a much longer period of time
- Increased damage to small transistors at lower dose rate and non-linear behaviour at high total doses → but expected gate delay in the chip still within specifications

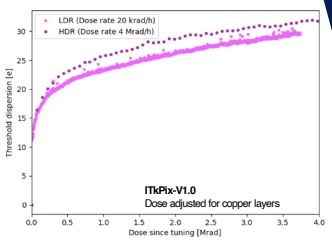
Analog Front-End (AFE)

- ITkPixV1 uses a differential analog front-end
- Study impact of radiation damage on the AFE
- Figure of merit: tuned and untuned threshold distribution

- Increase in threshold dispersion with irradiation, but threshold tuneable for most chip settings after 1 Grad
- No significant difference in threshold dispersion for low and high dose rates



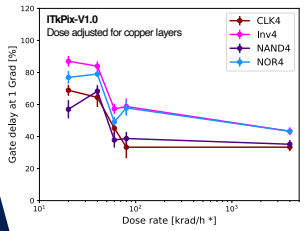
Untuned threshold distributions before and after irradiation



Threshold dispersion at low and high dose rates

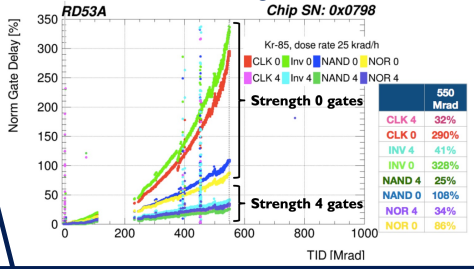
Low dose rate results with X-rays

→ Factor 2 larger damage at low dose rate



Low dose rate irradiation of RD53A using Kr-85 source

→ Non-linear behaviour at high total doses



Conclusions

- Tested radiation tolerance of ITkPixV1 chips up to total doses of 1 Grad
- Ring oscillator measurement show delay degradation of up to 40 % for strength 4 gates (corresponding to gates used in chip)
  - Low dose rate increases damage by approximately a factor of 2
  - AFE of ITkPixV1 experiences no significant issues up to total doses of 1 Grad & no dose rate effect on AFE

Maria Mironova *(University of Oxford)*, **for the ATLAS collaboration**
maria.mironova@physics.ox.ac.uk

ATLAS EXPERIMENT