Radiation Tolerance of the MUX64 for the HGTD of ATLAS

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Outline:

- ☐ **Introduction**
- ☐ **NIEL test**
- ☐ **TID test**
- ☐ **Conclusion**

Introduction

■ MUX64

- The MUX64 ASIC is a 64-to-1 analog multiplexer developed to expand the ADC input channels in the peripheral electronics of HGTD for the ATLAS Phase-II upgrade.
- Up to 10 detector modules (60 signals in total) can be monitored in an ADC channel. The one output is addressed by a 6-bit decoder presented inside the MUX64.

- The MUX64 will be used in the radiation field of high-luminosity pp collisions at LHC to an integrated luminosity of 4000 fb^{-1}.
- To verify the radiation tolerance of the MUX64, Non Ionizing Energy Loss (NIEL) and Total Ionizing Dose (TID) tests were performed.

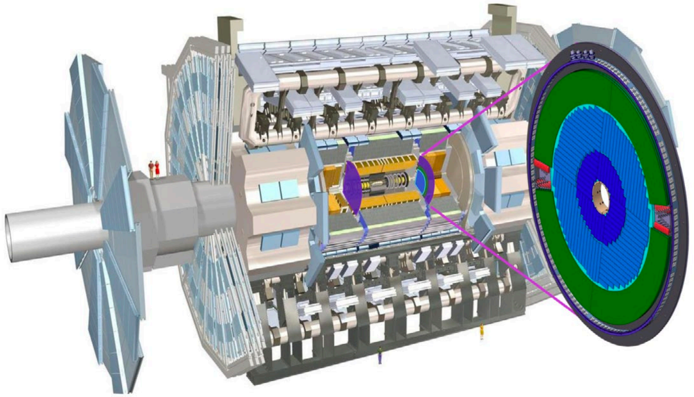


Fig1. Schematic of the ATLAS detector and the HGTD vessel

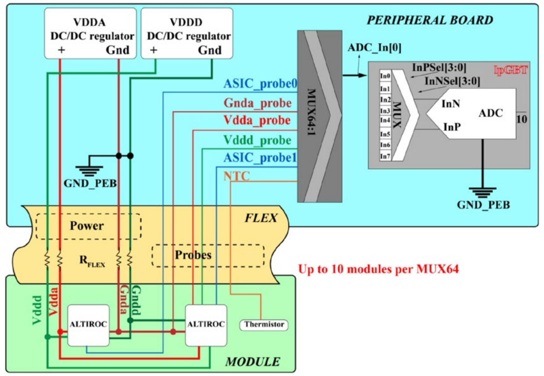


Fig2. Schematic view of the voltage monitoring of a module of HGTD

Fig3. A MUX64 chip in QFN88 packaged

Introduction

■ Radiation tolerance requirement

- ➢ The MUX64 on the PEB are distributed around 0.8 m from the beam pipe center in the HGTD vessels in the end-cap regions 3.5 m away from the interaction point.
- ➢ The radiation field is simulated with the Genta and Fluka listed in Table 1.(Link)

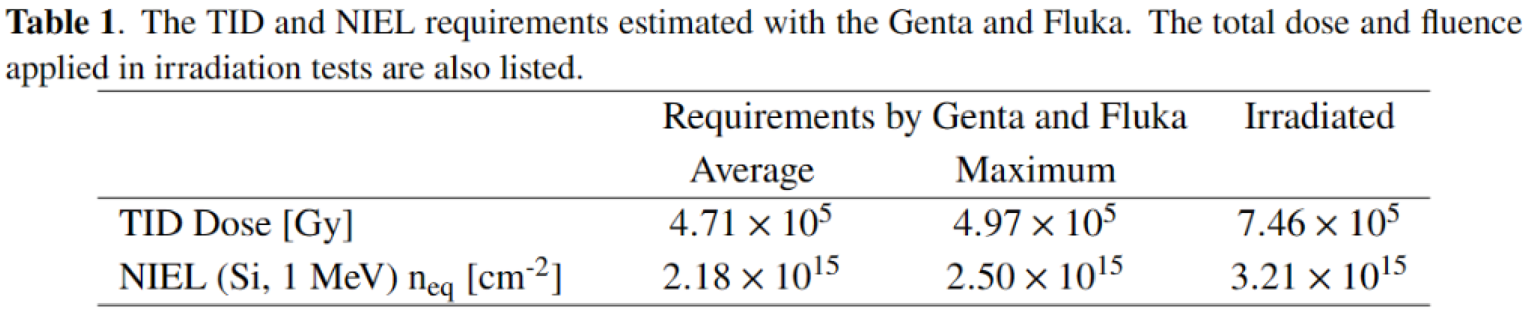


Table 1. The TID and NIEL requirements estimated with the Genta and Fluka. The total dose and fluence applied in irradiation tests are also listed.

	Requirements by Genta and Fluka		Irradiated
	Average	Maximum	
TID Dose [Gy]	4.71×10^5	4.97×10^5	7.46×10^5
NIEL (Si, 1 MeV) n_{eq} [cm^{-2}]	2.18×10^{15}	2.50×10^{15}	3.21×10^{15}

- ➢ The on-resistance (R_{on}) between the selected input channel and the output must be less than 900 Ω (after NIEL test and TID test) to achieve the required resolution and radiation tolerance.

Introduction

■ NIEL test of MUX64

- ➢ The NIEL test was conducted with 80 MeV protons beam at the Associated Proton Experimental Platform (APEP) of the China Spallation Neutron Source (CSNS) facility.
- ➢ Two MUX64 chips were irradiated to a fluence of 3.21×10^{15} (Si 1 MeV neq)/cm^2 simultaneously.

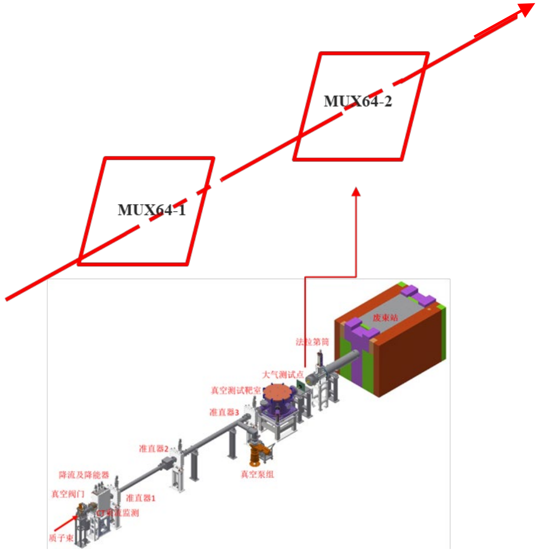


Fig4. Schematic view of two MUX64 at APEP of CSNS

■ TID test of MUX64

- ➢ The TID test was carried out in a MultiRad160 X-ray machine.
- ➢ Five MUX64 chips were irradiated to 0.746 MGy (Si) one by one at a dose rate of 5.98 Gy/s (Si).

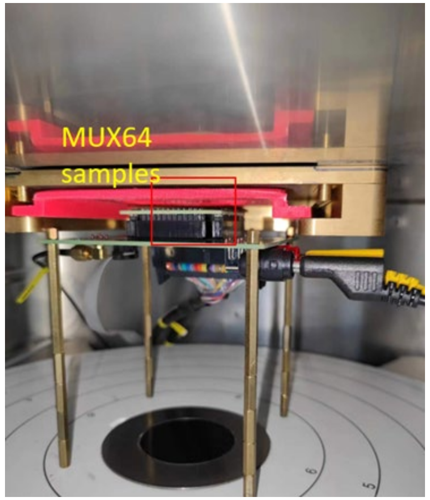


Fig5. A MUX64 chip in X-ray machine before irradiation

NIEL test

■ Parameters of the APEP:

- Energy: 10-80 MeV (proton); Beam Injection rate: $10^5 - 10^{10}\ pps/\mathrm{cm}^2$.
- Beam spot size: $10 \times 10\ mm^2 - 50 \times 50\ mm^2$.

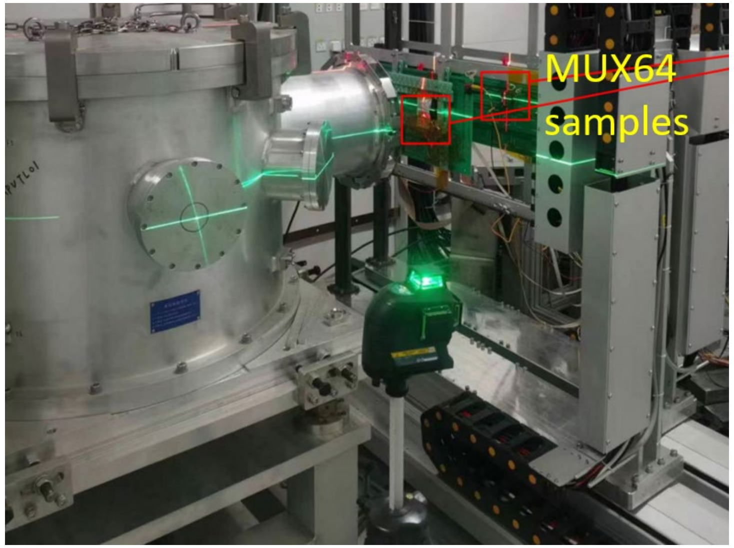


Figure 6. Photo of the two MUX64 at APEP

■ NIEL test conditions

- The two MUX64 chips were positioned **in sequence** to the proton beam.
- **A thin aluminum foil** (0.002cm) was affixed to the front of the first MUX64 chip in order to measure the proton flux. (Active Al measurement was applied. The monitoring channel is ^{27}Al(p, x) ^{22}Na.)
- The proton beam test was conducted with an average flux rate of $(2.55 \pm 0.19) \times 10^9\ \mathrm{cm^{-2}s^{-1}}$ for the first 5.13 days.
- The second period followed with $(1.50 \pm 0.11) \times 10^9\ \mathrm{cm^{-2}s^{-1}}$ for 9.35 days.
- **The accumulated equivalent fluence** is 3.21×10^{15} (Si, 1 MeV $\mathrm{n_{eq}}$)/cm^2 with **the scale factor** of 80 MeV protons to 1 MeV neutrons (1.378) being considered.

NIEL test

Before NIEL test

- The 64 inputs (V_{in}) of the chip were provided with varying voltages ranging from 0.05 V to 1.00 V during the NIEL test. (Fig7.a)
- The R_{on} of each channel was measured and sorted by input voltage (R_{on}-V_{in} curve plotted as Fig7.b).

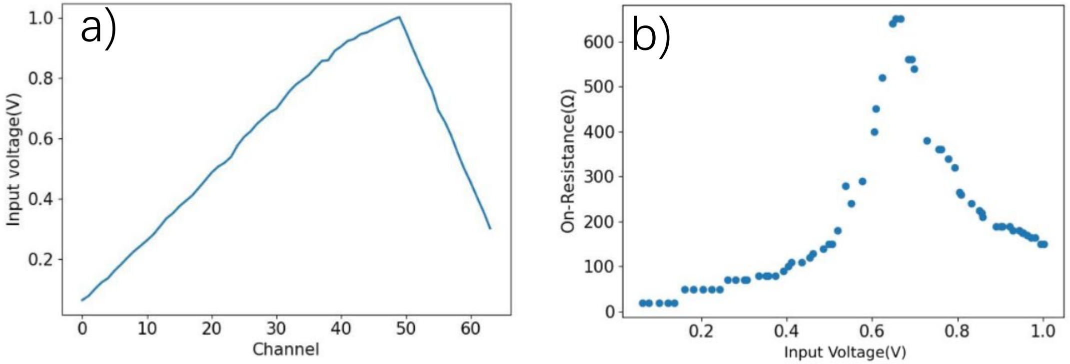


Fig7. a: The voltages (V_{in}) applied to the MUX64 inputs during proton beam test are plotted; b: The R_{on} versus V_{in} prior to the proton beam fluence.

After NIEL test

- The R_{on} and the output voltages (V_{out}) were recorded during the NIEL test.
- The smooth surface of Fig8.a indicates no obvious functional abnormality. (No channel miss-selection)
- The observed changes on ΔR_{on} is mild, which demonstrates the excellent tolerance of the MUX64 to the NIEL fluence.

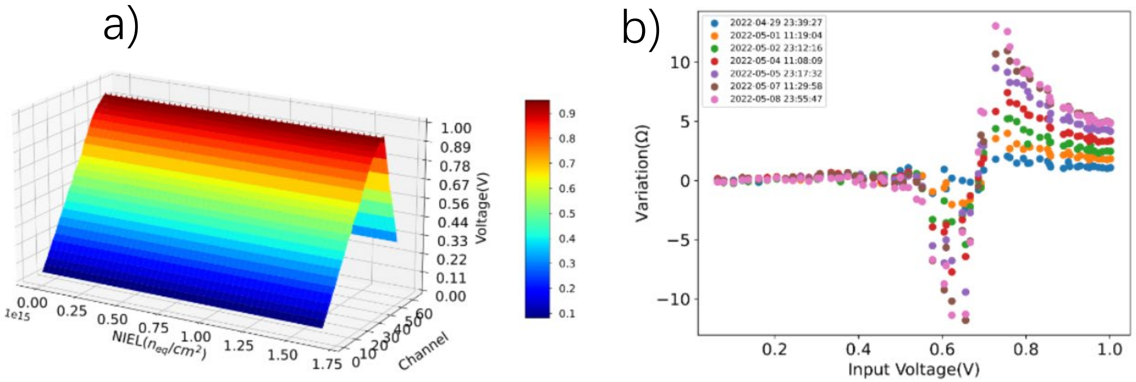


Fig8.a: The V_{out} during proton beam test versus the accumulated fluence; b: The ΔR_{on} versus V_{in} after the first period of 1.54×10^{15} (1 MeV n_{eq}) /cm^2, with additional accumulated fluence of the second period of up to 1.67×10^{15} (1 MeV n_{eq}) /cm^2.

TID test

■ Parameters of the MultiRad160 X-ray machine:

- Max voltage: 160 kV, Max current: 25 mA , max dose rate = 5 Gy/s (positioned in air, 14.5 cm from the source).
- The MultiRad160 used in this test has been calibrated (in Si) by the ATLAS ITK strip group at 40 kV, 20 mA.

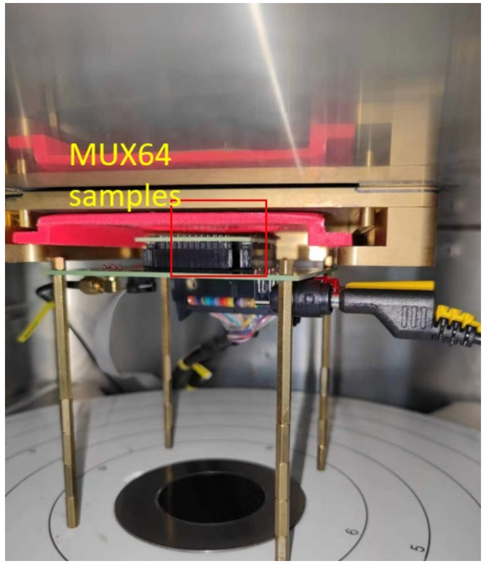


Figure 9. Photo of the MUX64 in the X-ray machine cavity

■ TID test conditions

- The MUX64 sample in X-ray cavity was supported 10 cm from the source.
- A 0.15 mm Al foil was applied to absorb low energy photons. (Dose rate calibration had included the Al filter.)
- Dose rate: 5.98 Gy/s (in Si, 10 cm from source, 40 kV, 20 mA).
- Total irradiation dose: (35 h per chip) 7.46×10^5 Gy. Five chips were tested in total.
- The temperature in the X-ray cavity was not controlled but recorded. The ambient temperature fluctuated between 20 °C and 27 °C.
- The R_{on} of the MUX64 has a temperature dependence, which decreases by 3 Ω / °C with rising temperature.

TID test

Before TID test

- The R_{on} of MUX64 samples were measured for the inputs of each channel in a range of 0.05 V to 1.20 V in steps of 0.05 V.
- The R_{on}-V_{in} curves of all the 64 channels were measured before irradiation at 28 °C (Fig10) and recorded during irradiation.

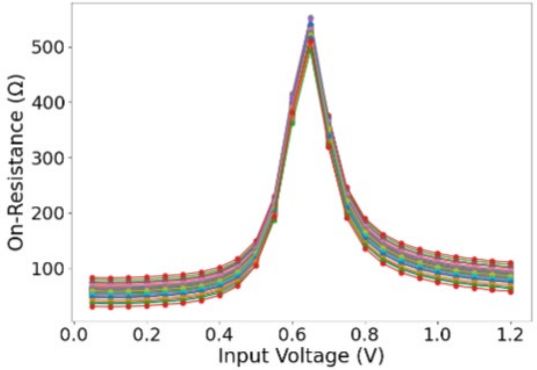


Fig10. The scan on R_{on} versus V_{in} of a MUX64 sample prior to TID irradiation conducted at temperature of 28 °C.

After TID test

- The R_{on} of irradiated chip was measured at 27 °C.
- The irradiated chip was bias for 8 days for potential annealing effect and measured again at 25 °C.
- The ΔR_{on} after irradiation observed is below 35 Ω (Fig11.a). And the annealing recovery is not significant (Fig11.b).
- The result of all five irradiated MUX64 samples are compatible. The magnitude is mild.

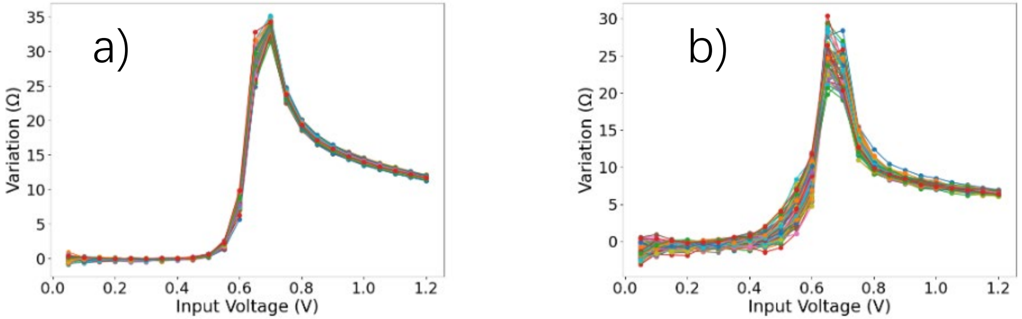


Fig11. a: The ΔR_{on} of a irradiated MUX64 in V_{in} scan after 7.46×10^5 Gy, measured at 27 °C. After 192 hours bias for potential annealing effect, the ΔR_{on} versus V_{in} is shown in b at 25 °C.

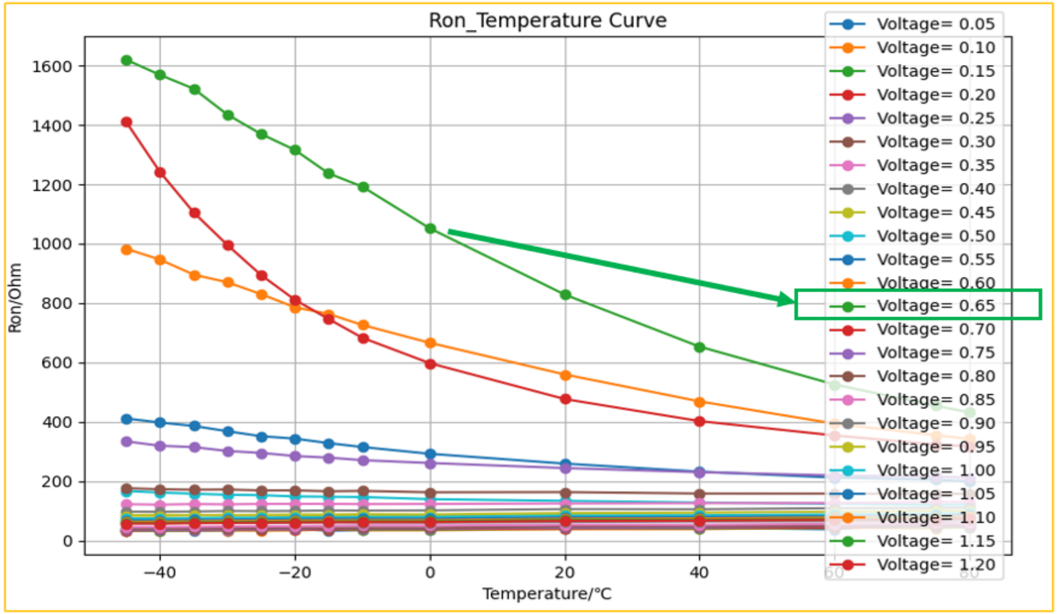
Conclusion

- The MUX64 chips underwent NIEL and TID tests were evaluated for radiation tolerance. The NIEL test had the fluence accumulated to 3.21 × 10^{15} (Si, 1 MeV n_{eq}) /cm^2. In the TID test had the MUX64 samples exposed to 7.46 × 10^5 Gy.
- The variation observed are rather mild, with the NIEL introducing ΔR_{on} below 25 Ω, and the TID below 35 Ω.
- The specification for MUX64 requires the R_{on} smaller than 900 Ω. And the radiation induced variations are negligible.
- The MUX64 has good radiation tolerance performance for the HGTD application.

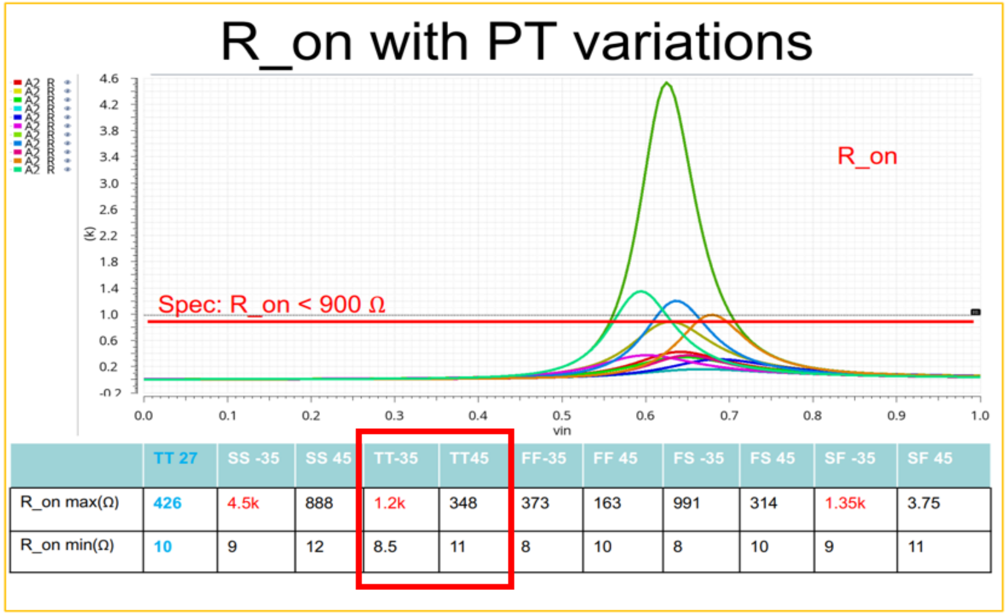
Thank you!

Ron-Temperature Curve

- When the input voltage is in the range of 0.55V to 0.75V, the on-resistance decreases as the temperature increases, in the lower and higher voltage range, increases, but not significant.
- This trend is consistent with simulation results.



Test curve of channel0 of chip0

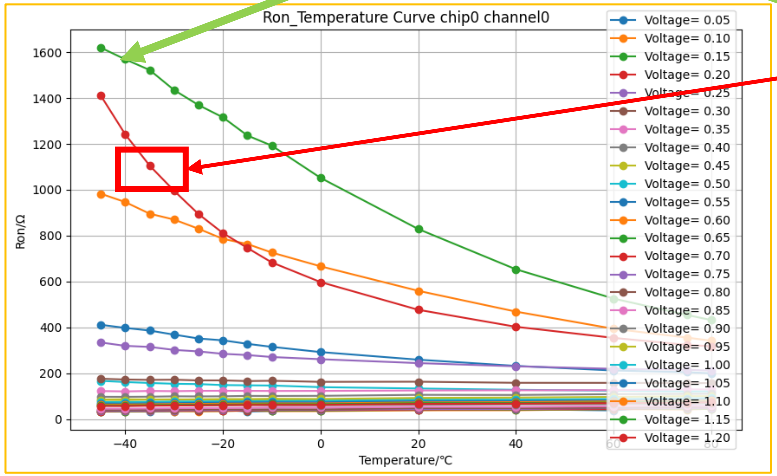


	TT 27	SS -35	SS 45	TT-35	TT45	FF-35	FF 45	FS -35	FS 45	SF -35	SF 45
R_on max(Ω)	426	4.5k	888	1.2k	348	373	163	991	314	1.35k	3.75
R_on min(Ω)	10	9	12	8.5	11	8	10	8	10	9	11

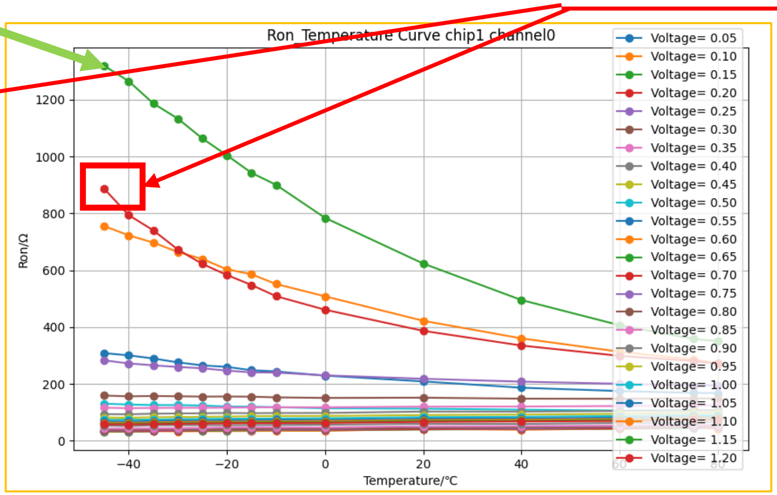
Simulation curve

Ron-Temperature Curve

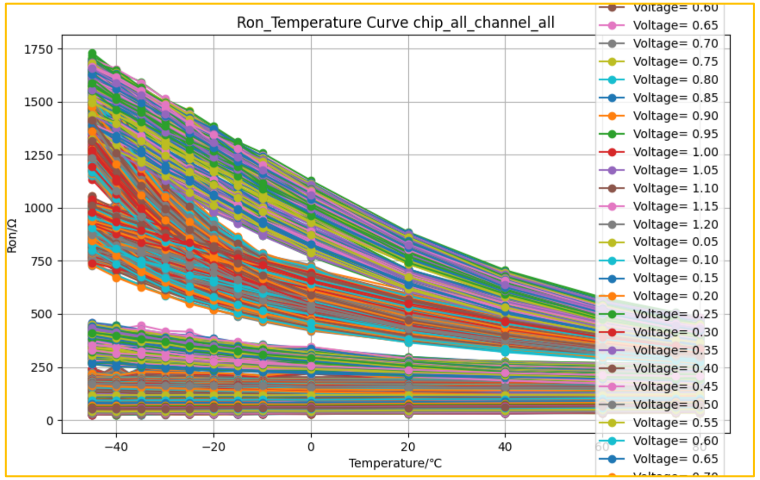
- The maximum on-resistance (-45°C) varies significantly between different chips,
- The shape of the curve is not similar at the input voltage of 0.7V.



Ron-Temperature curves of chip0 channel0 at different input voltages



Ron-Temperature curves of chip1 channel0 at different input voltages



Ron-Temperature curves of all channels of all chips at different input voltages

- Under -35°C conditions, the difference in on-resistance between channels is about 400Ω, making it impossible to use an average curve as the characteristic Ron-Temperature curve.

Ron-Temperature Curve at 0.7V

- The curves at 0.7V are clearly divided into two types
- The two types of curves intersect under near room temperature.