ALCOR Irradiation test

Results from SEU and TID tests

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INFN Torino

dRICH Meeting
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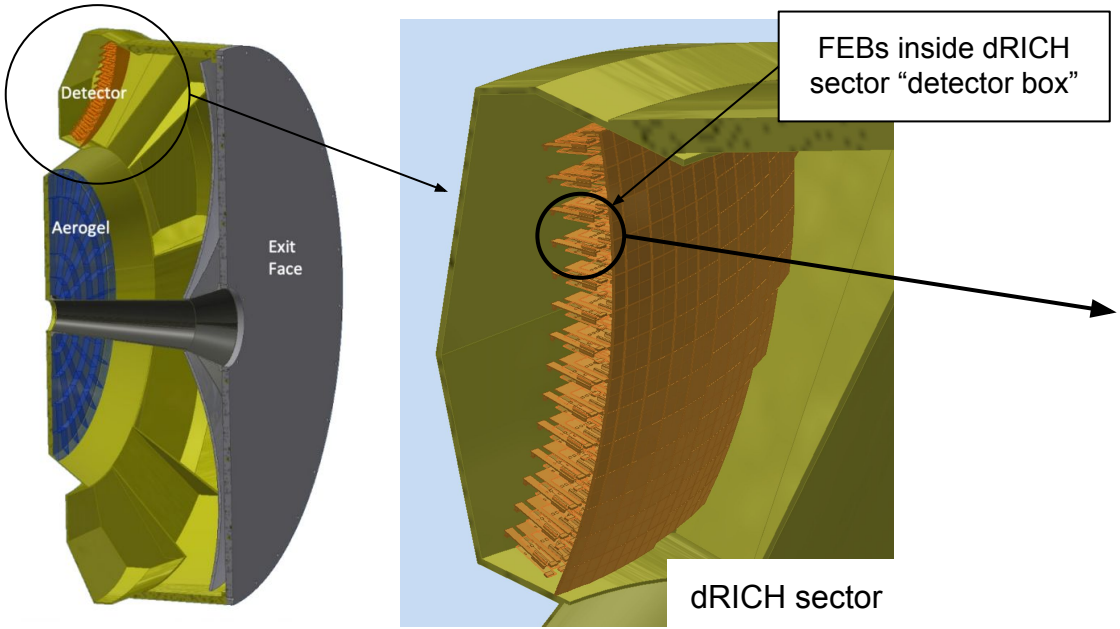
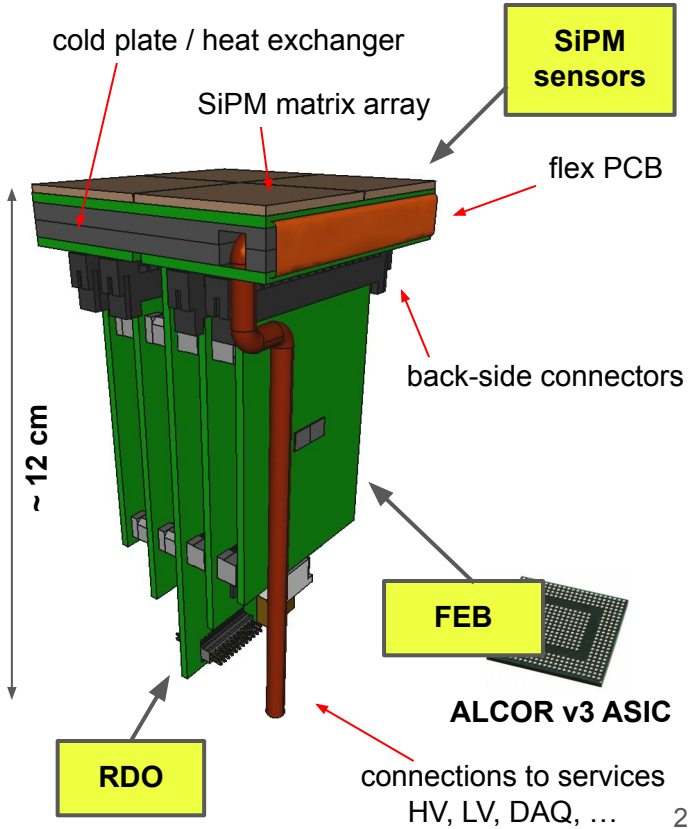
ePIC dRICH electronics





- **1 PDU**: 4x64 SiPM array device (256 channels), **4 FEBs, 1 RDO**
- **1 ALCOR** (64 channels) per **FEB:** 8x8 SiPM matrix readout
- 1248 PDUs for full dRICH readout
- **4992 FEBs → 4992 ALCOR v3**
- **319488 readout channels**

The dRICH PDU radiation environment

The dRICH-PDUs are in a moderately hostile radiation environment

- Φ (p+n > 20 MeV) = 700 Hz/cm^2
- TID ≅ 2.3 krad (for 1000 fb^{-1})

} note these values include a **safety factor of 5**

ref data: https://wiki.bnl.gov/EPIC/index.php?title=Radiation_Doses

Single Event Effects (SEE): localized event induced by one single ionizing particle → **SEU, SEL**

- **Pixel** configuration registers and FSMs **already protected against SEU** in ALCOR v2 (but with a bug in autocorrection)
- Periphery registers not protected, TMR will be added in ALCOR new version
- On board prevention of SEL: **current monitor** on FEB regulators

Total Ionizing Dose (TID) effects: electronic devices suffer long-term radiation damage

- Same technology already verified for TID up to a **few hundreds of krad**
- Also other FEB components need to be tested and validated

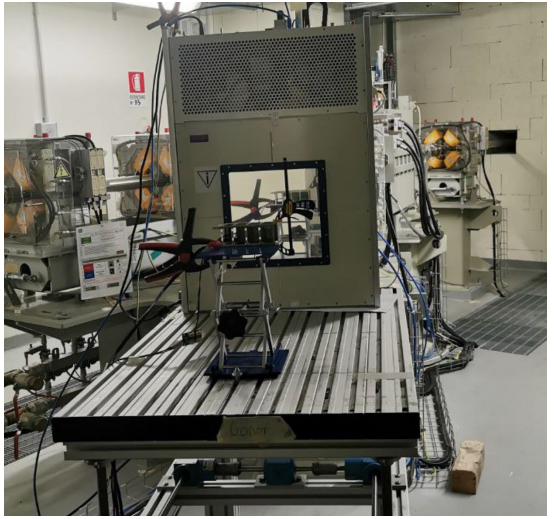
ALCOR irradiation tests

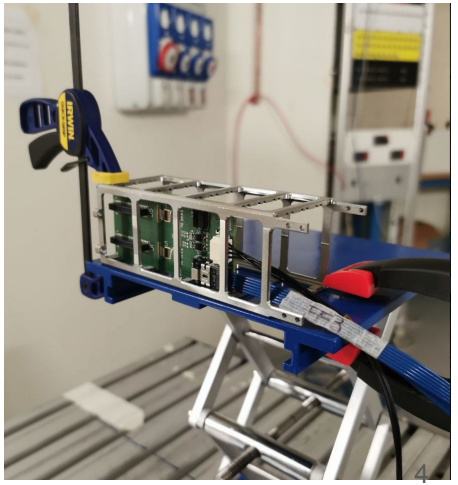
SEU/SEL and TID tests at Centro of Proton-Therapy in Trento (TIFPA) with ALCOR v2.1 (July 2024 and December 2024)

- Beam: 100 MeV proton
- Intensity: 10 - 100 nA
- Runs: typically 600 s
- Fluence collected per run: 10^{11} - 10^{12} p/cm^2

➢ **Total TID: 436 krad**

➢ **Total fluence: 4.64 · 10^{12} p/cm^2** (July 2024) and **3.2 · 10^{12} p/cm^2** (December 2024)





SEU and TID setup and measurements

FE ALCOR DUAL: Board n. 15, Chip 1

1. **SEU-SEL monitoring** → Bologna DAQ: Kintex7 FPGA KC705 Evaluation Kit + python DAQ software
   - ➢ Read ALCOR registers every second, monitor currents from power supply, monitor data stream
2. **TID measurements** → Torino DAQ: Kintex7 FPGA KC705 Evaluation Kit + LabView DAQ software
   - ➢ Perform **TDC** and **VTH scans** at following TID steps: 0, 47, 163, 328, 436 krad

TDC: *Scan phase delay* of FPGA digital test-pulse to assess TDCs response

Front-End: *Threshold scan* using on-chip test-pulse injection to test analogue Front-End response (amplifier + discriminator)

SEU/SEL results (July 2024)

ECCR/BCR/PCR registers checked against SEU (every second)

- ECCR $\sigma = (9.4 \pm 1.8) \cdot 10^{-14}$ cm^2/bit — periphery register → no TMR in ALCOR v2.1
- BCR $\sigma = (7.6 \pm 1.1) \cdot 10^{-14}$ cm^2/bit — periphery register → no TMR in ALCOR v2.1
- PCR $\sigma = (3.3 \pm 0.5) \cdot 10^{-15}$ cm^2/bit — pixel register → TMR (with auto-correction bug)

SEU rate in ePIC:

- dRICH Flux = 140 (h > 20 MeV) / (cm^2 s)
- ALCOR bits: (2048 + 192) = 2240 → ALCOR-64 bits will be 4480
- Total ALCOR: 4992
- Total bits: $4992 \cdot 4480 = 2.2 \cdot 10^7$ bits

➢ $\sigma = 3.3 \cdot 10^{-15}$ cm^2/bit → **MTBF** = $9.8 \cdot 10^4$ seconds → **every 27 hours**

➢ No latchup events (from power supply currents monitoring)

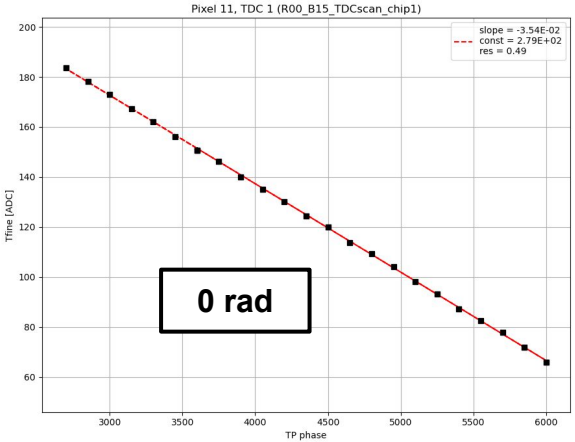
SEU/SEL results (December 2024)

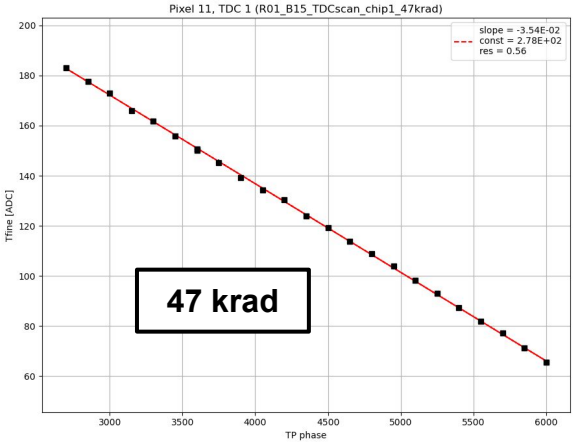
ECCR/BCR/PCR registers checked against SEU (every second), **PCR re-written every 10 seconds to "mask" TMR auto-correction bug**

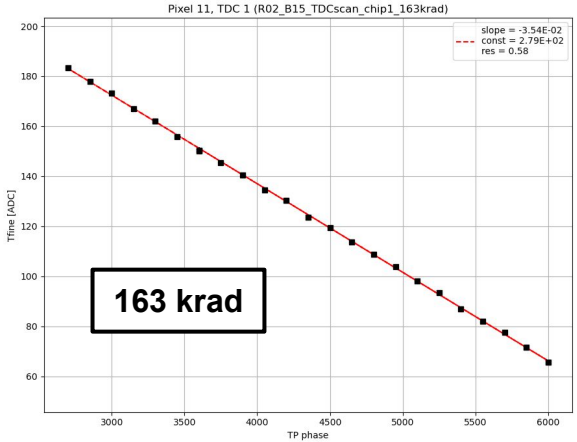
- ECCR $\sigma = 9.8 \cdot 10^{-14}$ cm^2/bit — periphery register → no TMR in ALCOR v2.1
- BCR $\sigma = 6.1 \cdot 10^{-14}$ cm^2/bit — periphery register → no TMR in ALCOR v2.1
- PCR **no SEU detected** — re-written every 10 seconds to avoid TMR auto-correction bug

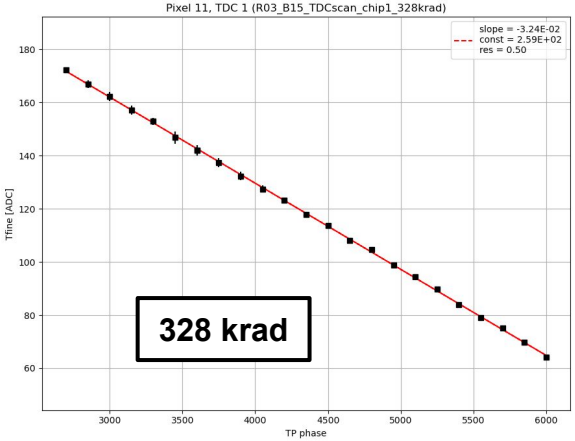
ALCOR v3: TMR SEU protection added also for periphery registers (used *CERN TMRG tool* for all registers), Hamming code SEU protection for FSMs

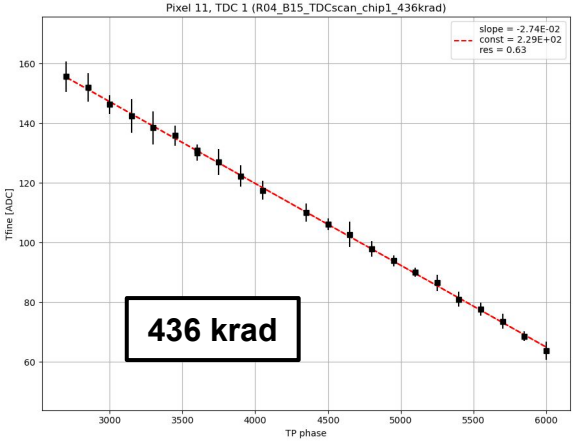
ALCOR TID - TDC response

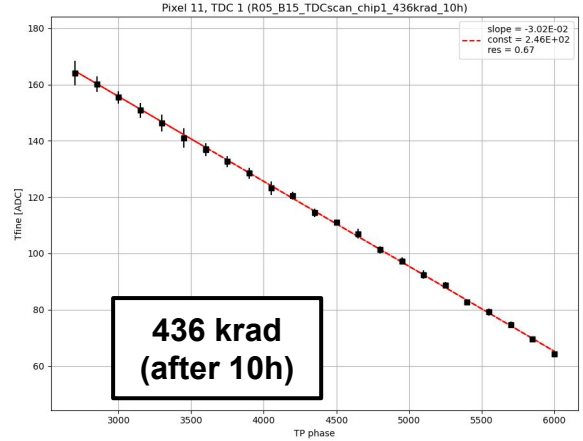








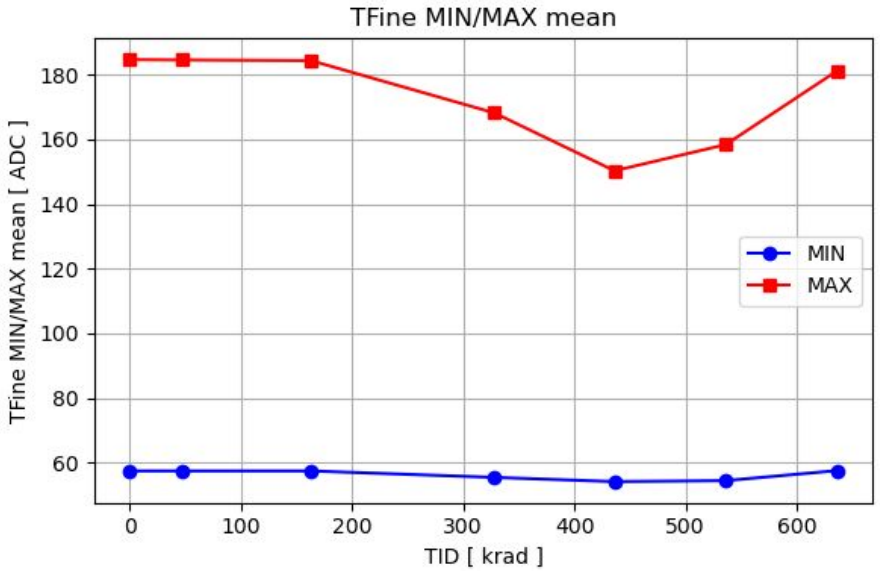


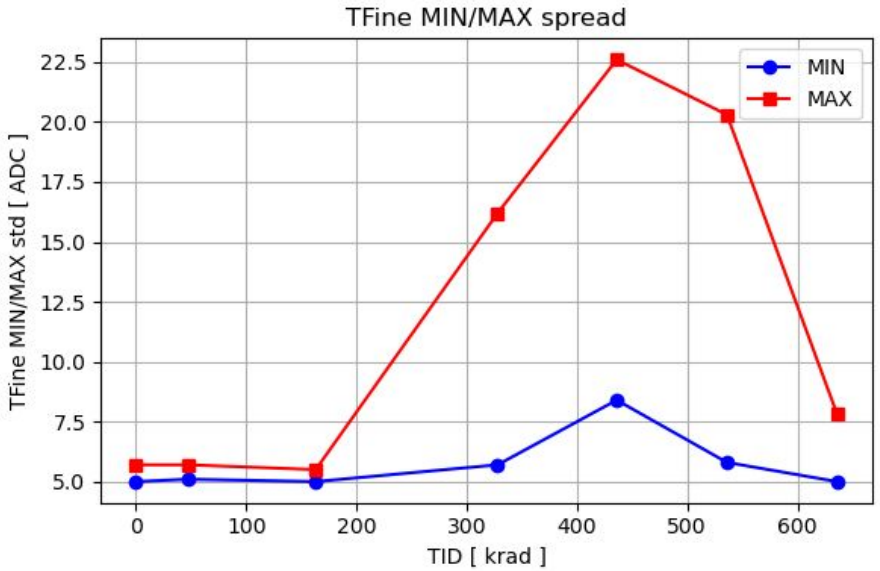


TP phase scan (3600 → 1 clk cycle) at different TID → extract TFine MIN, MAX, sigma, slope, IF, LSB

*last two points = 436 krad after 10 hours and 5 months

TDC results - TFine MIN & MAX



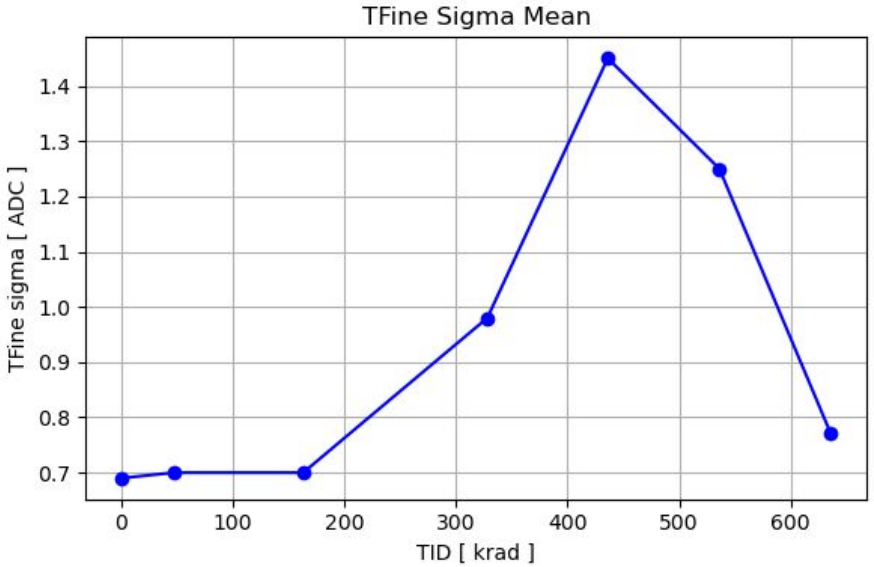


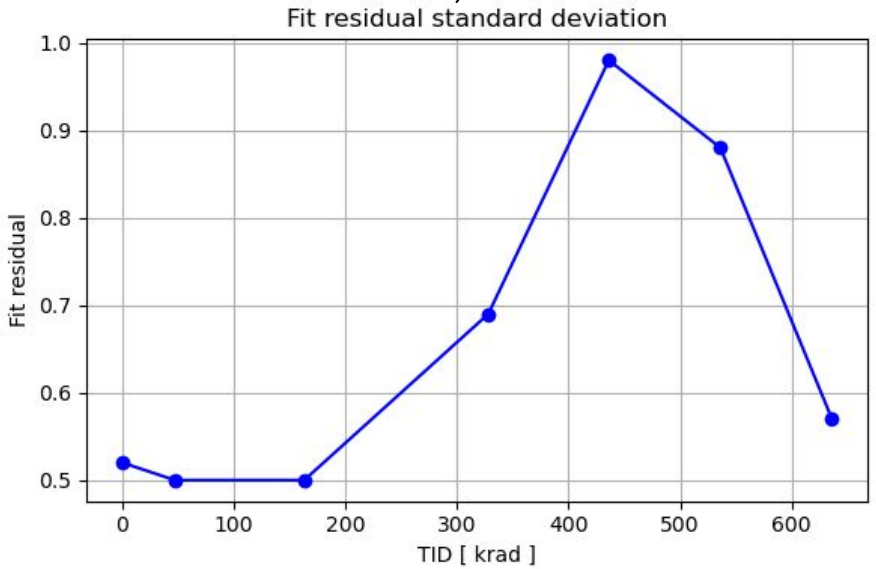
- **TFine MIN** distribution not affected too much
- **TFine MAX** distribution degraded after 328 krad
- Recovered by annealing almost completely

*last two points = 436 krad after 10 hours and 5 months

TDC results - TFine sigma & Fit residual

$$S_{res} = \sqrt{\frac{\sum (Y - Y_{est})^2}{n-2}}$$

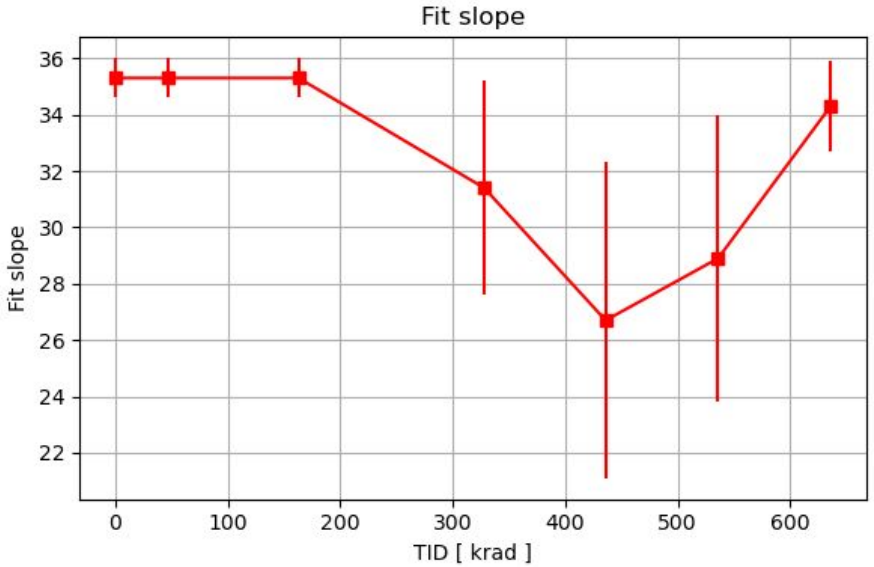


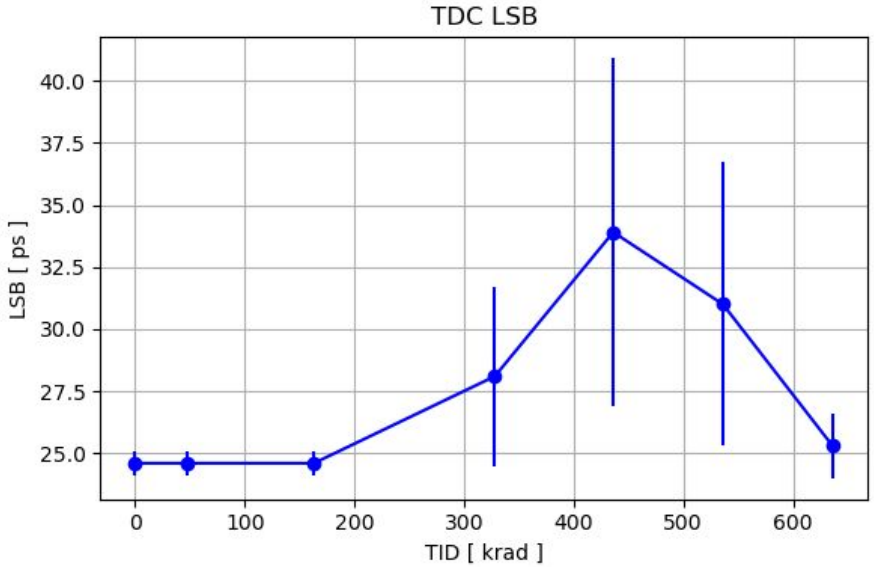


- **TFine sigma** starts to increase after 328 krad, >2 ADC after 436 krad on several pixels/TDCs
- **Fit residual** shows linearity degrading after 328 krad, much worse after 436 krad
- Recovered by annealing almost completely

*last two points = 436 krad after 10 hours and 5 months

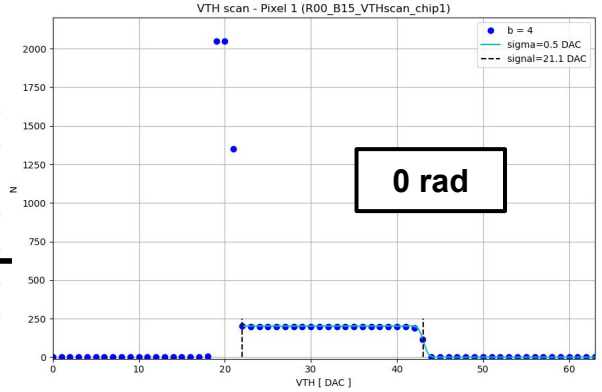
TDC results - Fit slope and TDC LSB

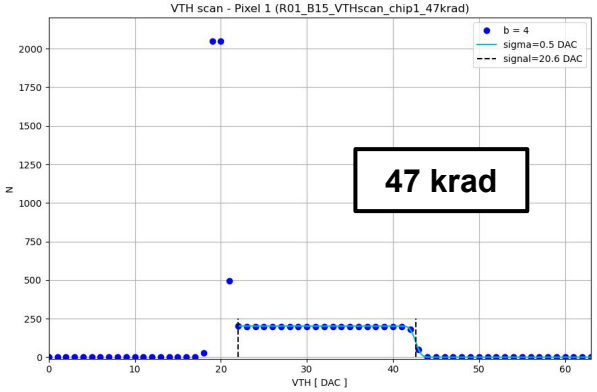


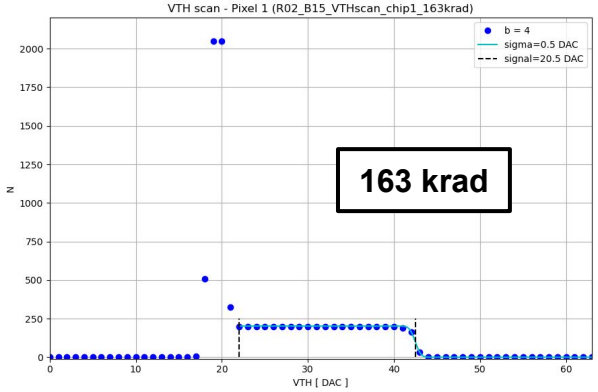


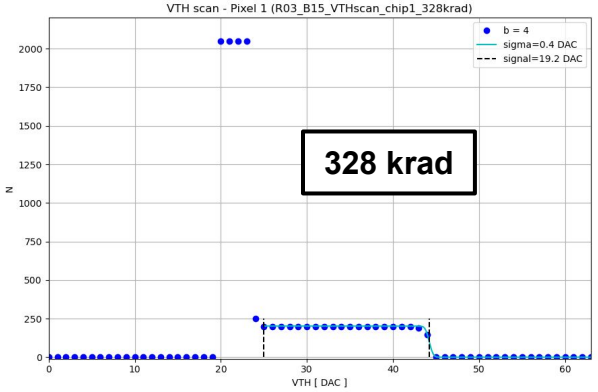
- Fit slope degraded after 328 krad → worse **linearity** and very broad **LSB** distribution
- Recovered by annealing almost completely

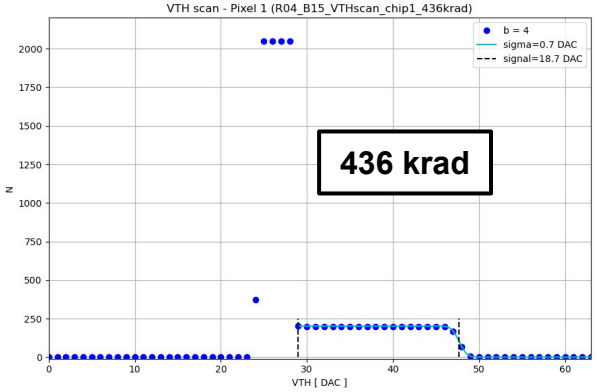
ALCOR TID - FE response

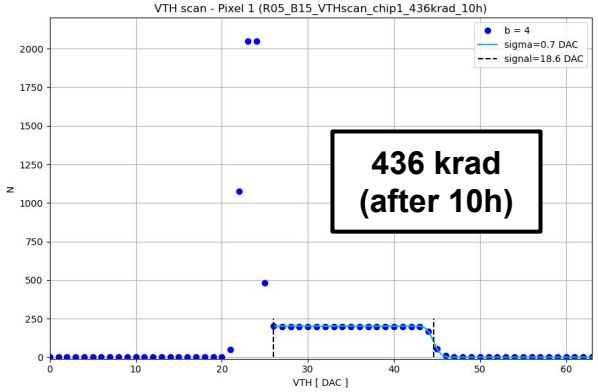






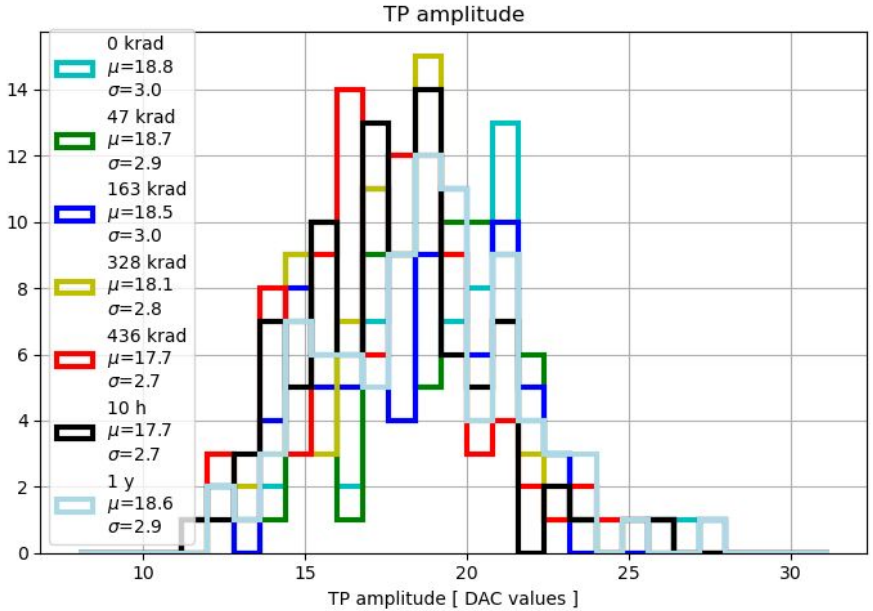


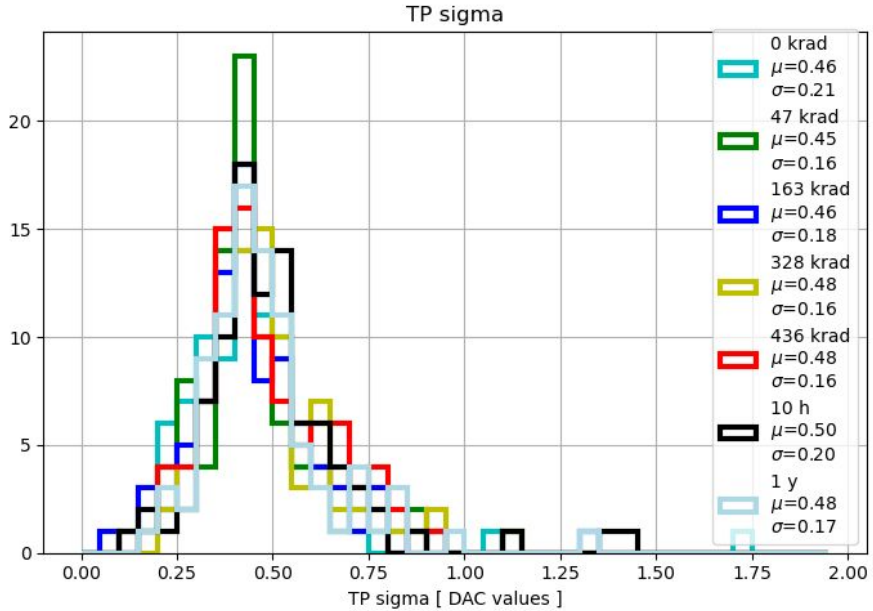




VTH scan (6-bit DAC) with internal TP at different TID → extract baseline level, signal amplitude and sigma

Front-End results - Signal

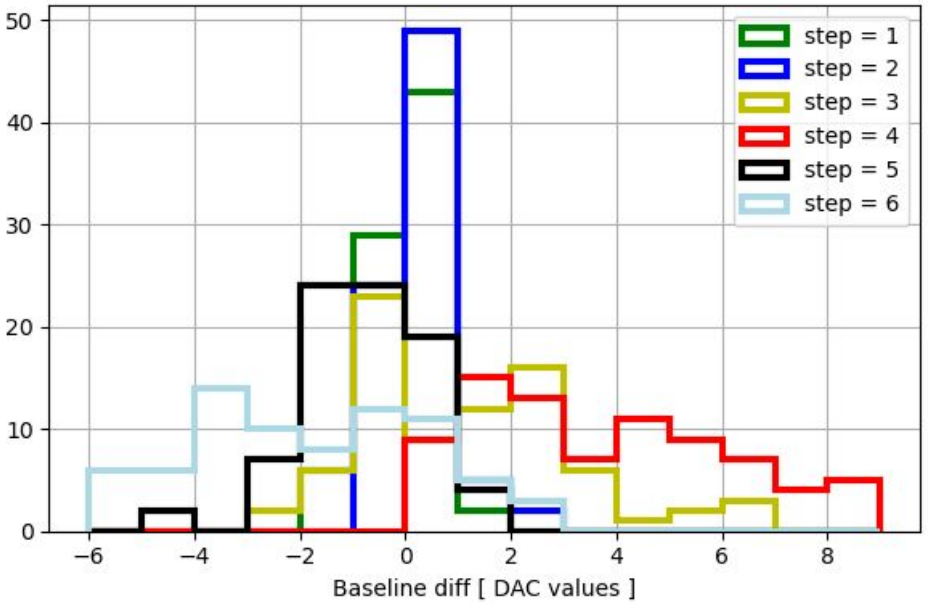


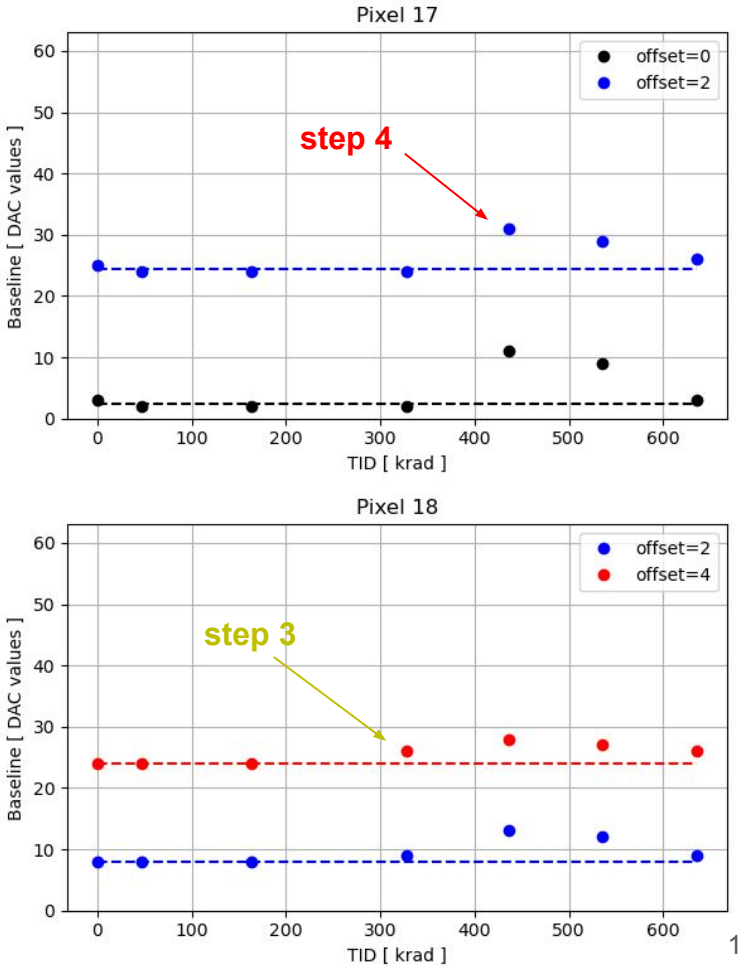


- Very small decrease in **signal amplitude** (almost completely recovered by annealing)
- Very small increase in **signal sigma** (almost completely recovered by annealing)

*last two points = 436 krad after 10 hours and 5 months

Front-End results - Baseline





Signal baseline moving up after **step 3** (328 krad) and/or **step 4** (436 krad), returning down after **step 5** (10h annealing) and **step 6** (5m annealing)

Summary

- ALCOR tolerance for total ionizing dose (TID) effects has been tested up to 436 krad
  - No significant effects on Front-End response for TID up to 436 krad
  - Some decrease on TDC performance only after TID of 328 krad
- These results match well with [1] and show that the **technology is sufficiently radiation tolerant to be used in the ePIC dRICH environment**
  - No special design techniques were adopted to increase the TID tolerance of ALCOR
  - TDC performance worsening likely due to some radiation induced leakage current in one of the switches controlling the dual-ramp operations, where very small currents are employed
- **MTBF due to SEU more than adequate for dRICH operations**
  - Design improvements already implemented in ALCOR v3
- Repeat irradiation tests with ALCOR new version (when available) and other FEB components

[1] F. Lenta *et al* 2024 *JINST* **19** C04047, DOI 10.1088/1748-0221/19/04/C04047