ALCOR - dRICH Readout

Fabio Cossio on behalf of the ALCOR group
INFN Torino

EPIC Electronics & DAQ WG meeting
eRD109 Monthly Progress Reports

03.10.2024

ALCOR irradiation tests

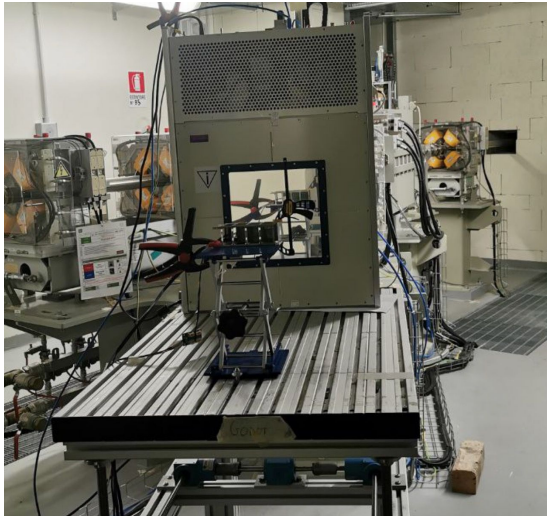
SEU/SEL and TID tests at Centro of Proton-Therapy in Trento with ALCOR v2.1 (July 2024)

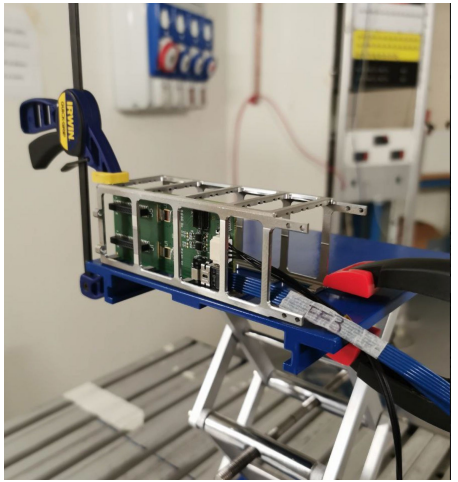
- Beam: 100 MeV proton
- Intensity: 10 - 100 nA
- Runs: typically 600 s
- Fluence collected per run: 10^{11} - 10^{12} p/cm^2

TID steps: 0, 47, 163, 328, 436 krad → Perform **TDC** and **VTH scans**

➢ **Total TID: 436 krad**

➢ **Total fluence: 4.64 · 10^{12} p/cm^2**





Other requirements: radiation tolerance

The dRICH-PDUs are in a moderately hostile radiation environment

- Φ (p+n > 20 MeV) = 200 Hz/cm^2
- TID ≅ 650 rad (for 1000 fb^{-1}) < 1 krad

} note these values include a safety factor 5

SEU-SEL

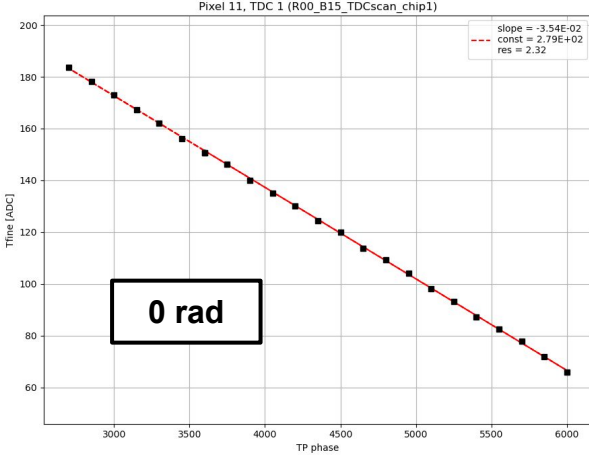
- **Pixel** configuration registers and FSMs **already protected against SEU** in ALCOR v2
- TMR SEU **protection added also for periphery** configuration registers, Hamming code SEU protection for FSMs: Single Error Correction, Double Error Detection codes (SECDED)
- On board prevention of SEL: **current monitor** on FEB regulators

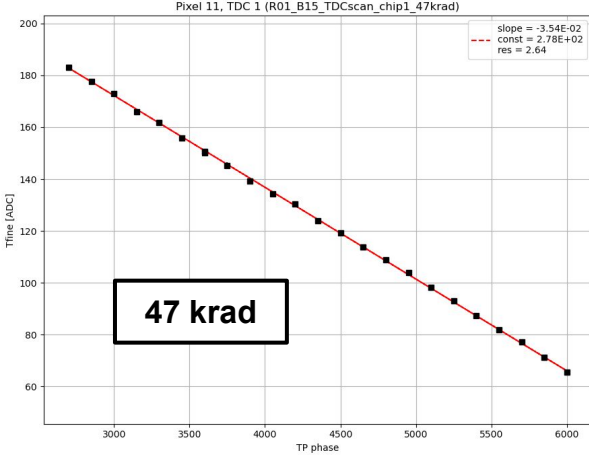
TID

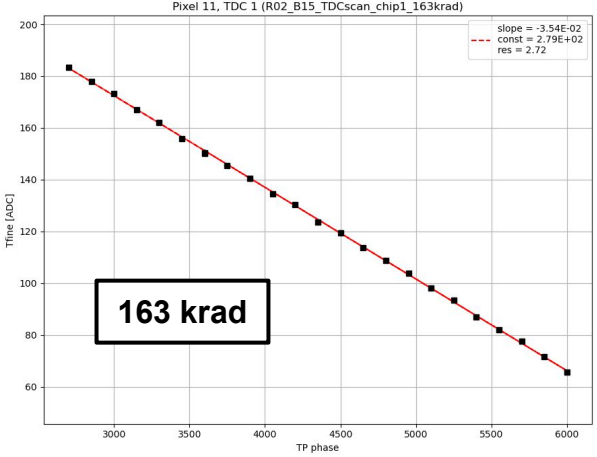
- Same technology already verified for TID up to a **few hundreds of krad**
- Also other FEB components will be tested and validated

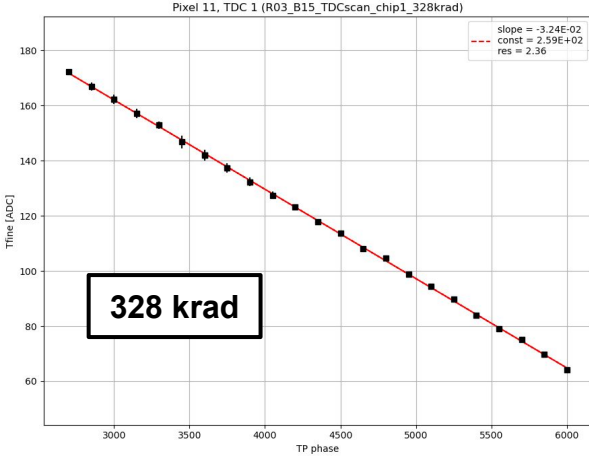
➢ Irradiation tests campaign: SEU/SEL and TID tests at Centro of Proton-Therapy in Trento with ALCOR current version foreseen in July 2024

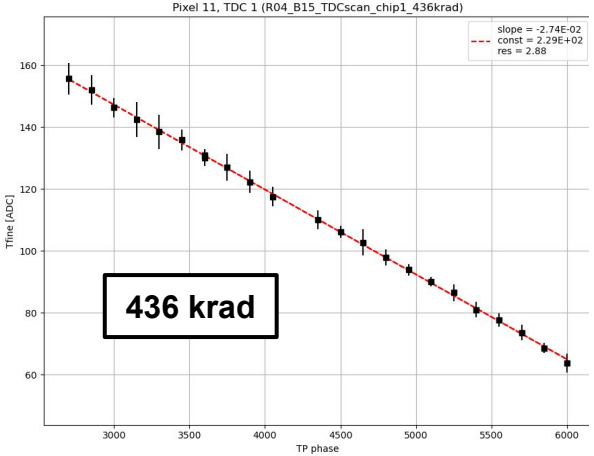
ALCOR TID - TDC response

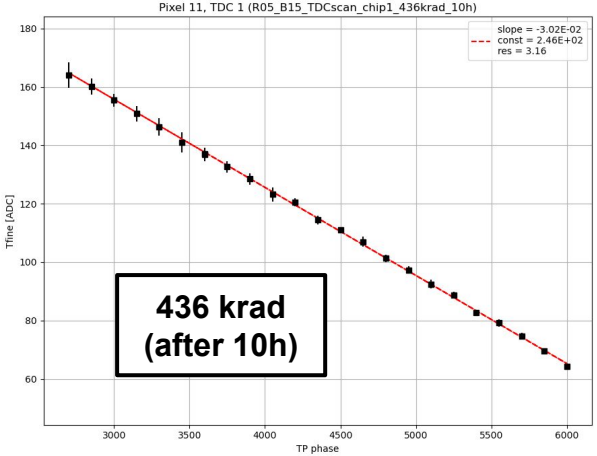








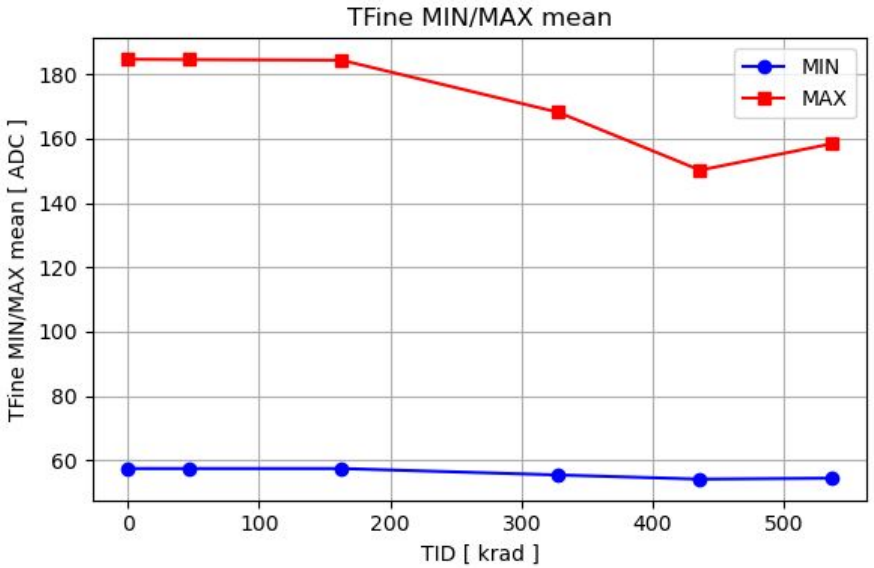


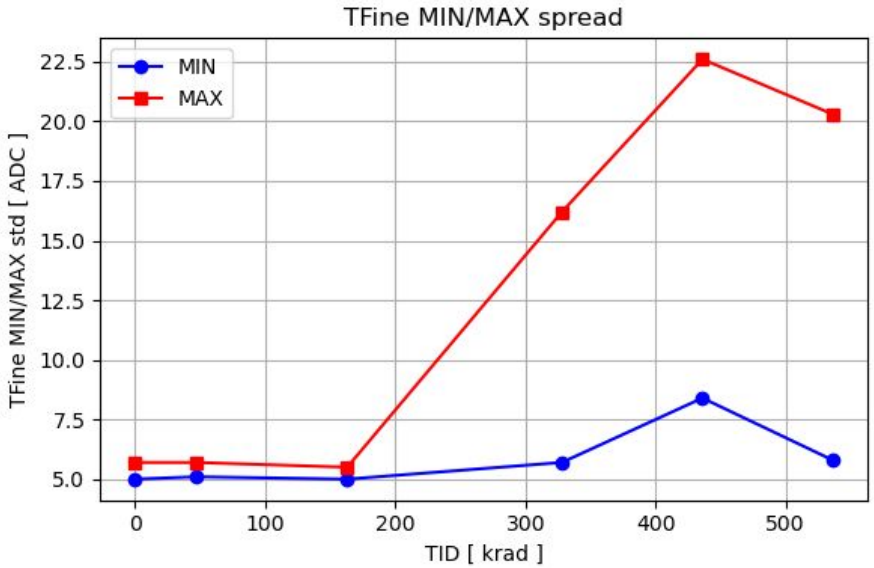


TP phase scan (3600 → 1 clk cycle) at different TID → check TFine MIN, MAX, sigma, slope, IF, LSB

*last point = 436 krad after 10 hours

TDC results - TFine MIN & MAX (32 channels - 128 TDCs)



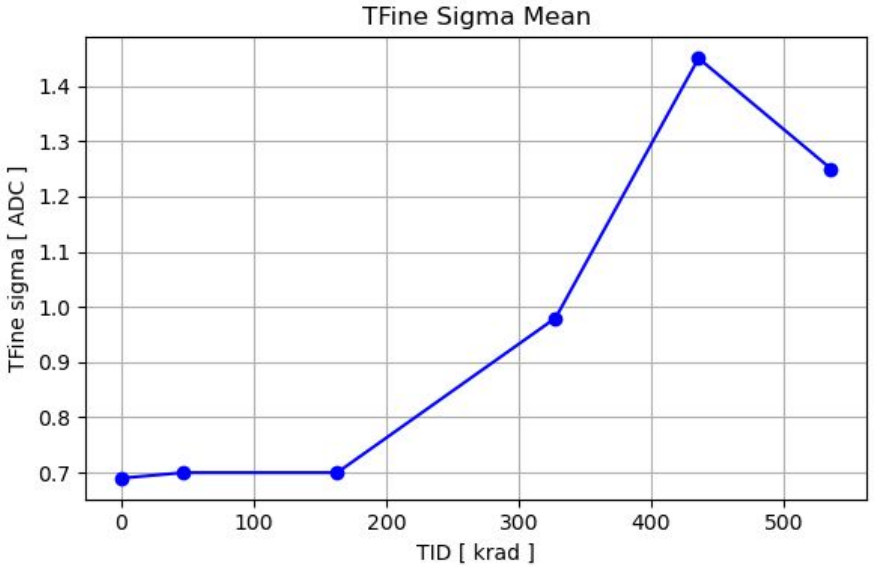


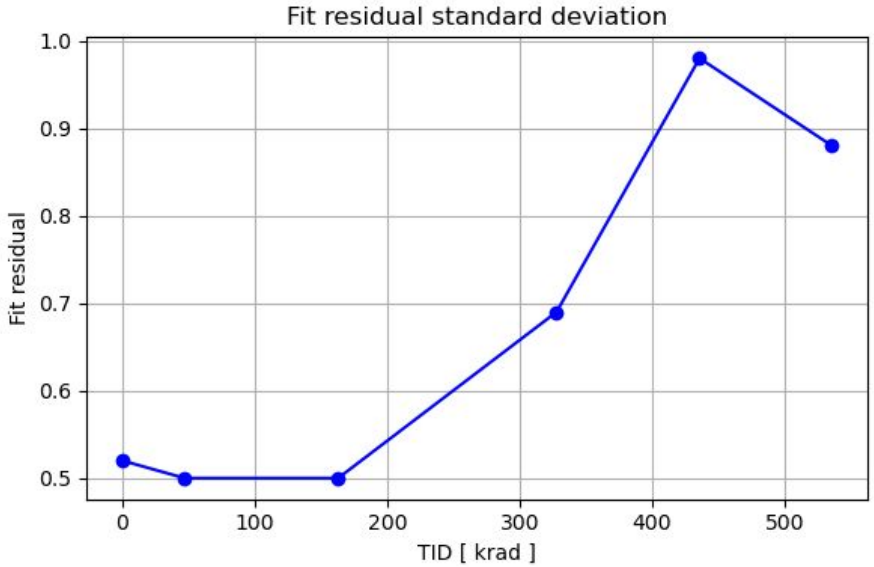
- **TFine MIN** distribution not affected too much
- **TFine MAX** distribution degraded after 328 krad
- *last point seems to show some annealing

***last point = 436 krad after 10 hours**

TDC results - TFine sigma & Fit residual

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

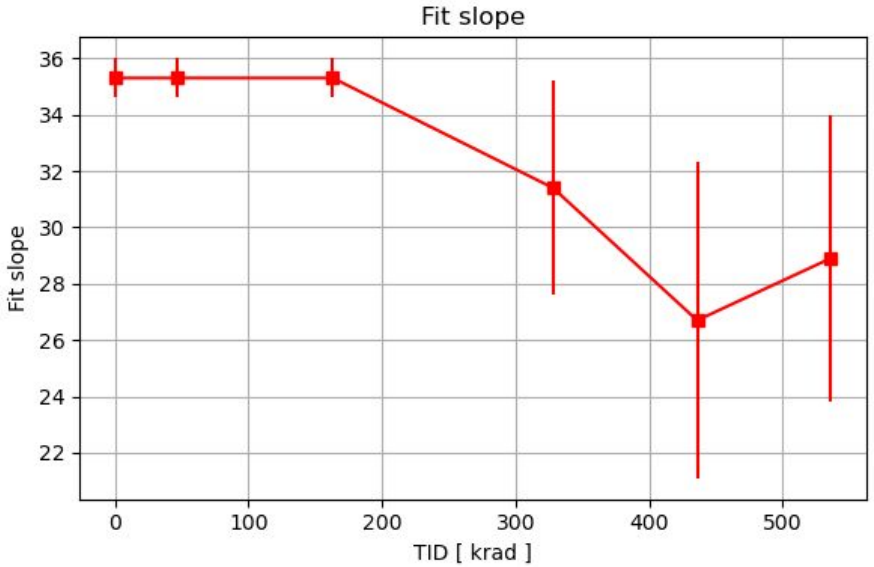


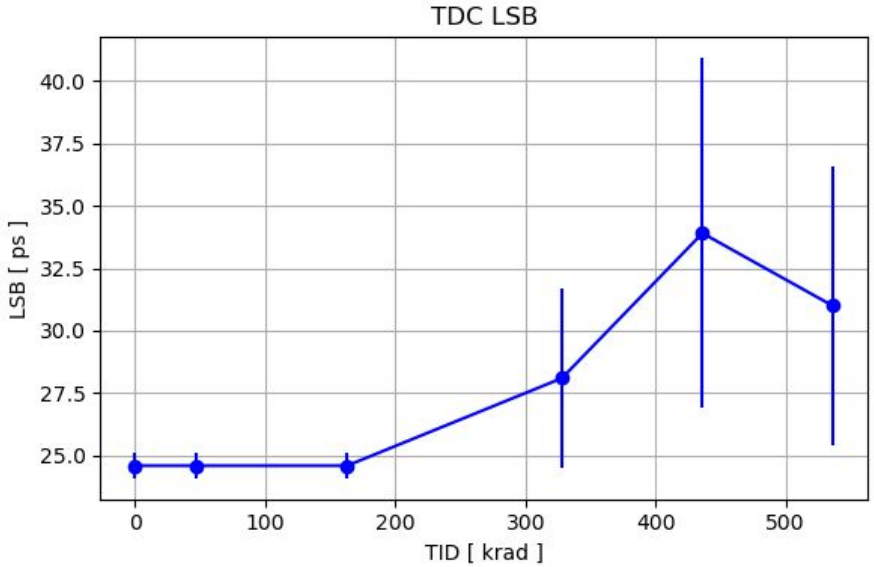


- **TFine sigma** starts to increase after 328 krad, >2 ADC after 436 krad on several pixels/TDCs
- **Fit residual** shows linearity degrading after 328 krad, much worse after 436 krad
- *last point seems to show some annealing

***last point = 436 krad after 10 hours**

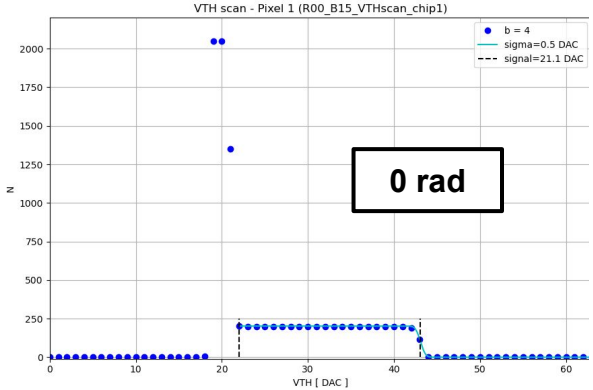
TDC results - Fit slope and TDC LSB

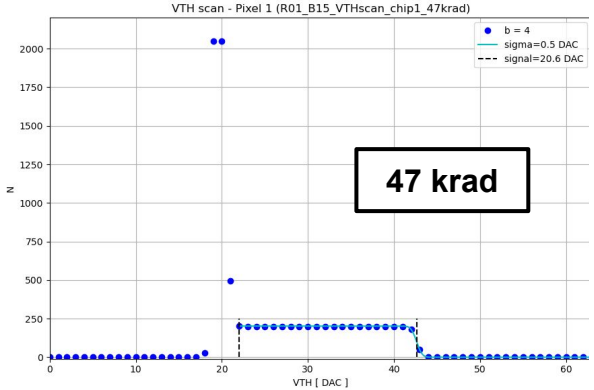


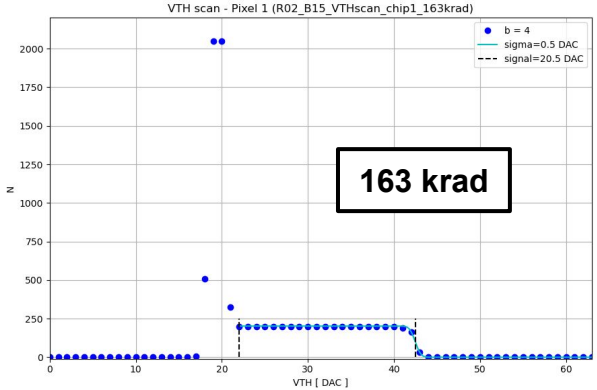


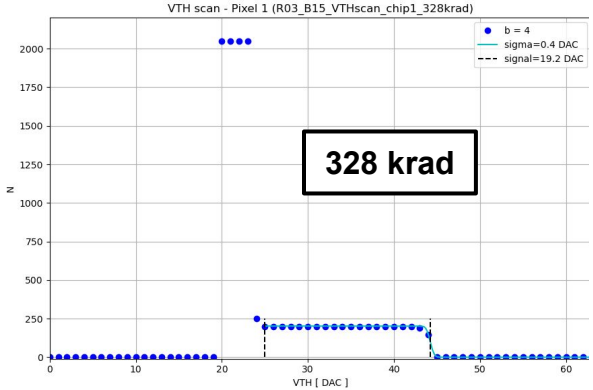
- Fit slope degraded after 328 krad → worse **linearity** and very broad **LSB** distribution
- *last point seems to show some annealing

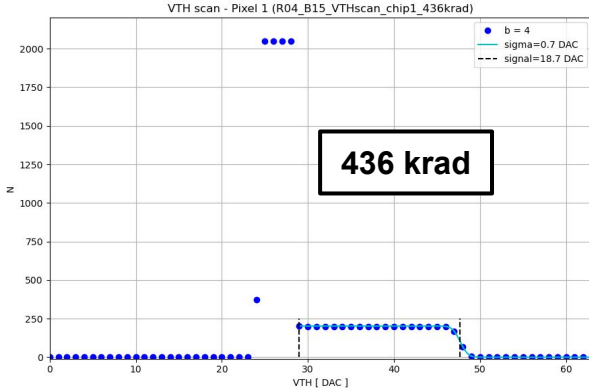
ALCOR TID - FE response

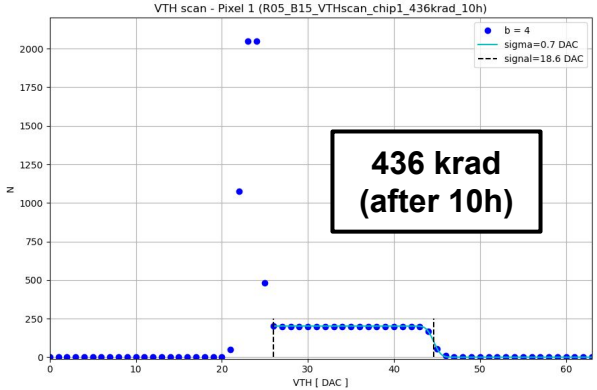






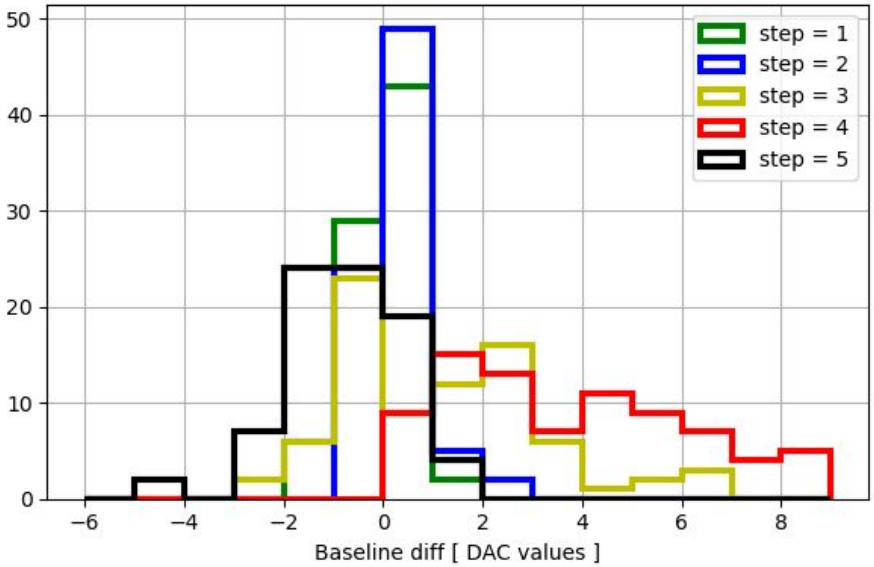




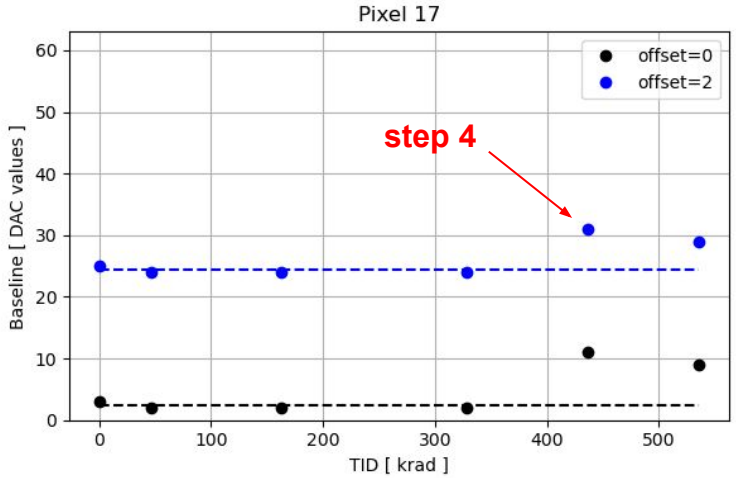


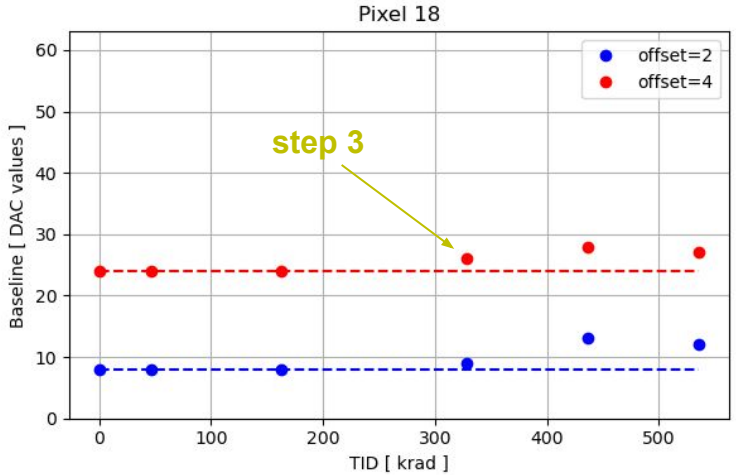
VTH scan (6-bit DAC) with internal TP at different TID → check baseline level, signal amplitude and sigma

Front-End results - Baseline

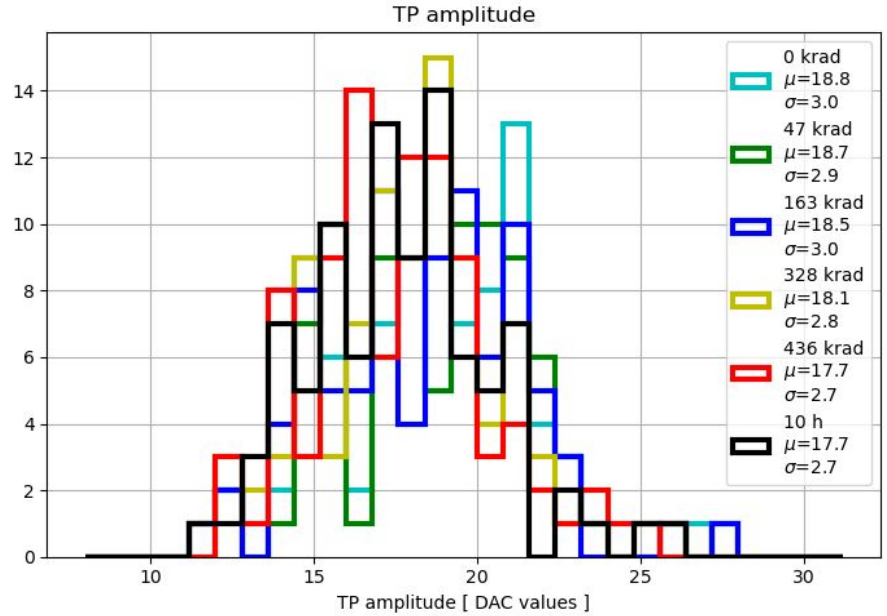


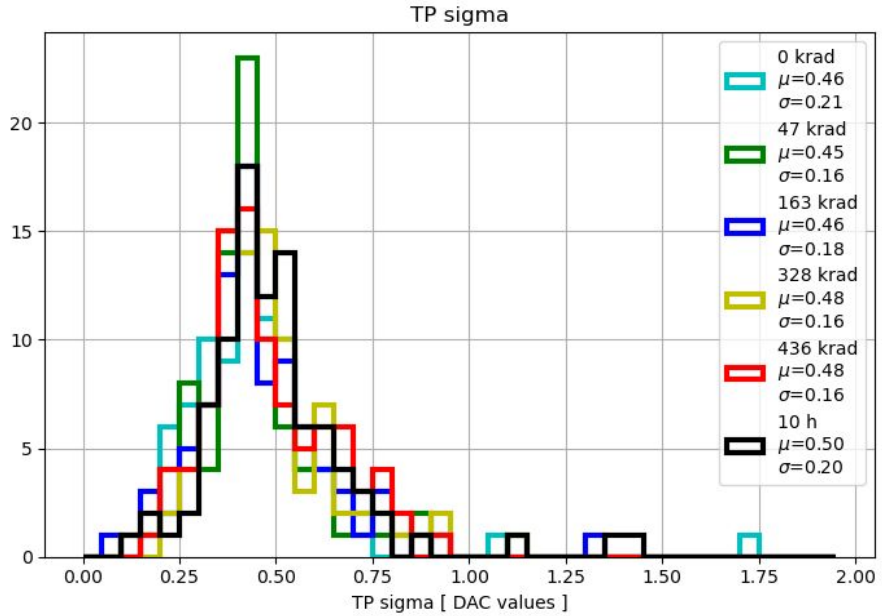
Signal baseline slightly moving up after **step 3** (328 krad) and/or **step 4** (436 krad), but it can also be VTH moving down





Front-End results - Signal





- Very small decrease in **signal amplitude**
- Very small increase in **signal sigma**

ALCOR SEU/SEL

ALCORv3: TMR SEU protection added also for periphery registers, Hamming code SEU protection for FSMs

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

Found minor bug in pixel TMR
MTBF expected to improve with ALCORv3

SEU rate in ePIC:

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

➢ $\sigma = 3.3 \cdot 10^{-15}$ cm^2/bit → **MTBF** = 6.9 · 10^5 seconds → **every 191 hours**

➢ No latchup events (from currents monitoring)

TID-SEU tests 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
- Repeat TID-SEU tests, together with RDO irradiation tests, to have more TID points and SEU statistics

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

ALCOR submissions plan

ALCOR is designed in UMC 110 nm CMOS technology (submission to IMEC)
ALCOR is part of INFN in-kind contribution

- ALCORv3 MPW was planned for 25th Nov 2024: run canceled by UMC
  - We have to go to the first MPW shuttle of next year, waiting for 2025 schedule
  - Quotation for BGA packaging available
  - Purchase orders for MPW and packaging already started

- ALCOR mass production in 2026
  - Preliminary quotations for ALCOR **engineering run** and **packaging assembly** already available

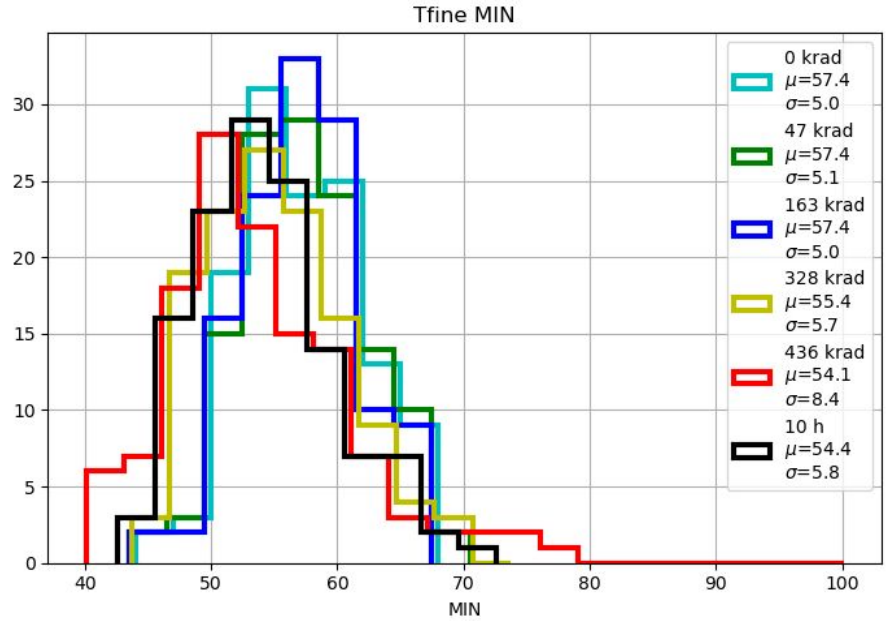
Milestones

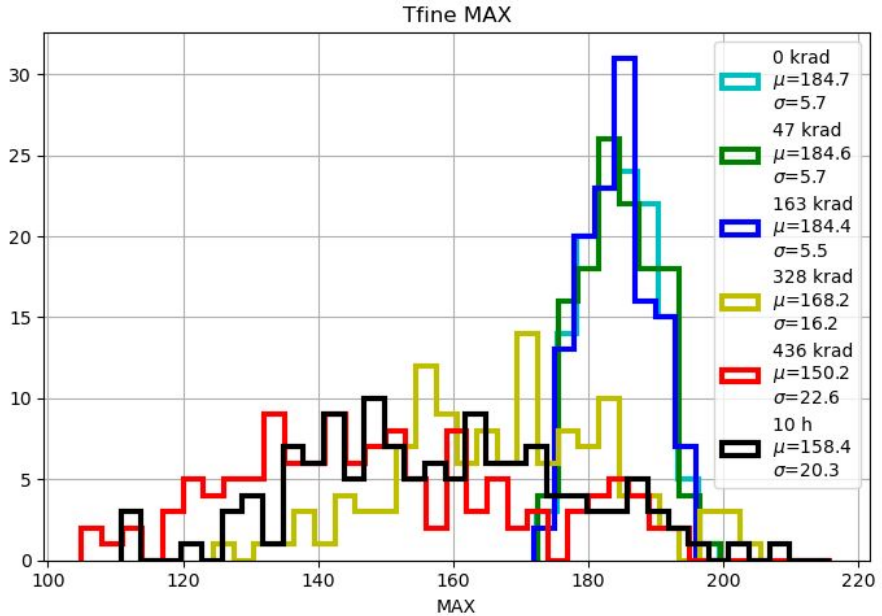
- Readiness at 75% of the final design of ALCOR v3 by September 2024
  - MPW run canceled by UMC, waiting for 2025 MPWs schedule from UMC and IMEC
  - Top level integration and verification ongoing
  - Optimization of ALCOR data frames structure to match EIC orbit period
  - ALCOR v3 will be ready for tapeout by the end of 2024

- Completion of irradiation tests on ALCOR v2 and evaluation of SEU cross-section by July 2024
  - Results show good radiation tolerance for dRICH requirements
  - No effects from TID up to 200-300 krad
  - MTBF due to SEU more than adequate for dRICH operations

Backup Slides

TDC results - TFine MIN & MAX (32 channels - 128 TDCs)





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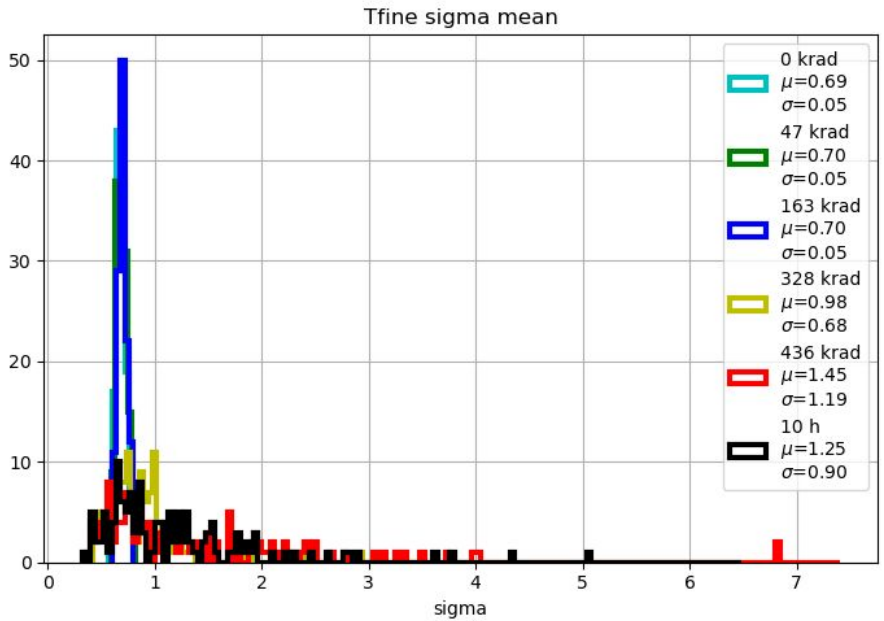

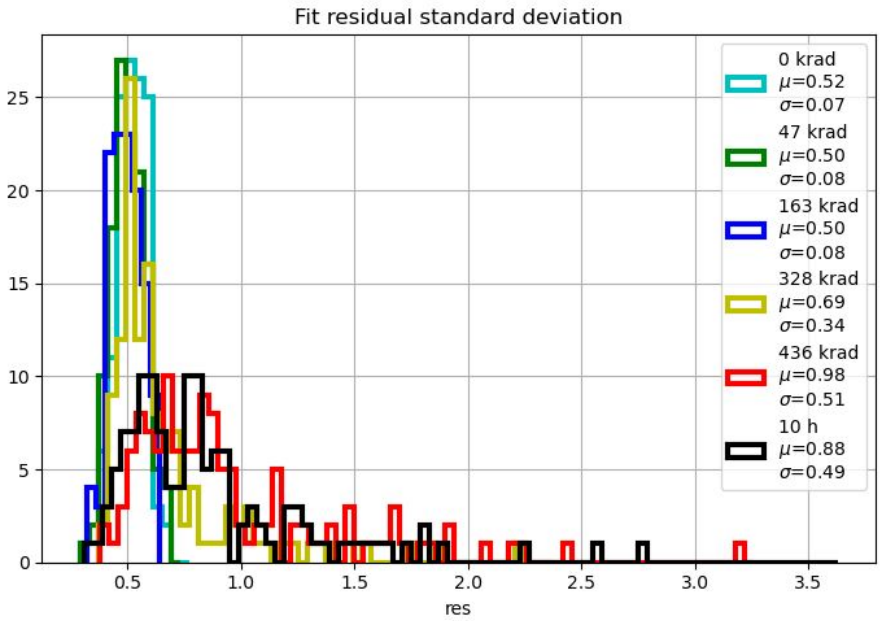

- **TFine sigma** starts to increase after 328 krad, >2 ADC after 436 krad on several pixels/TDCs
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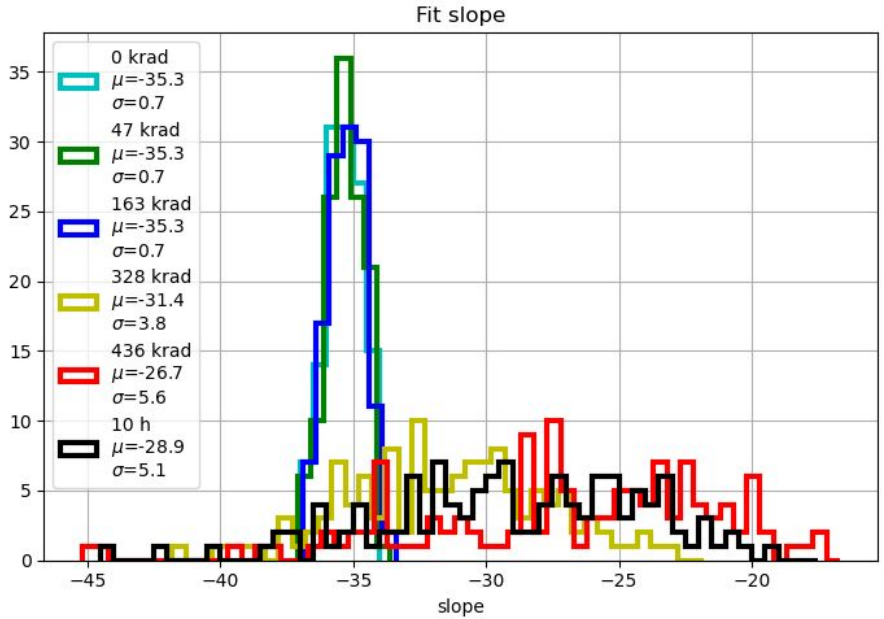
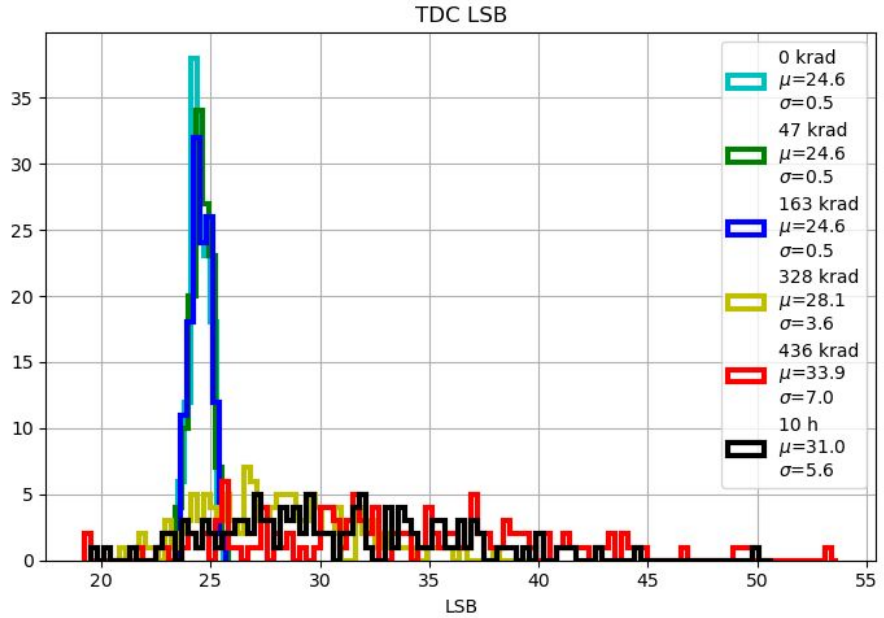
TDC results - Fit slope and TDC LSB



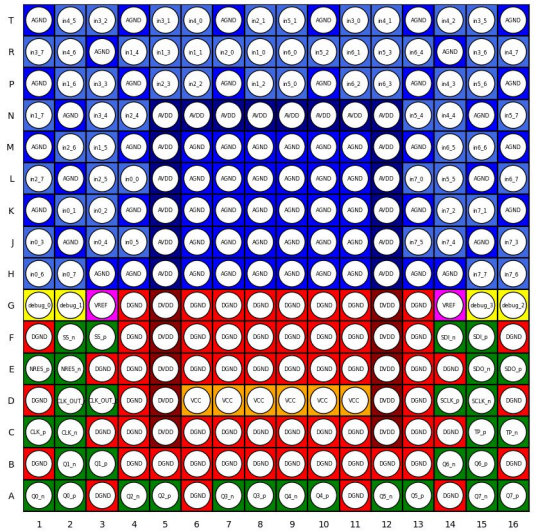


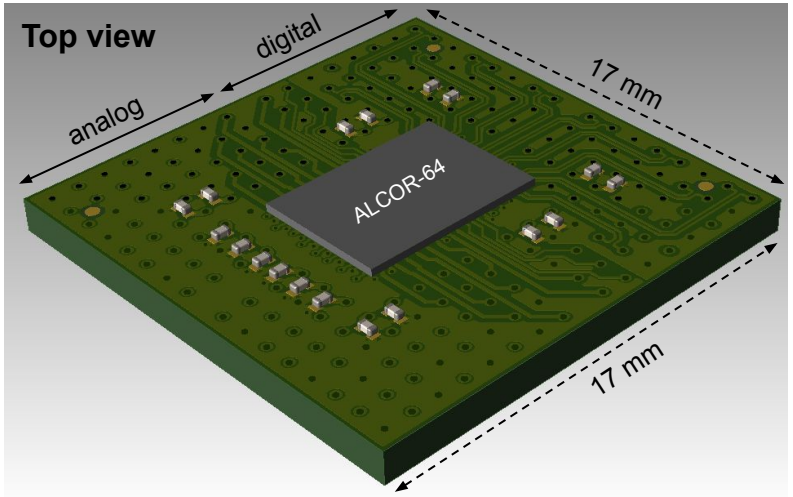
- Fit slope degraded after 328 krad → worse **linearity** and very broad **LSB** distribution

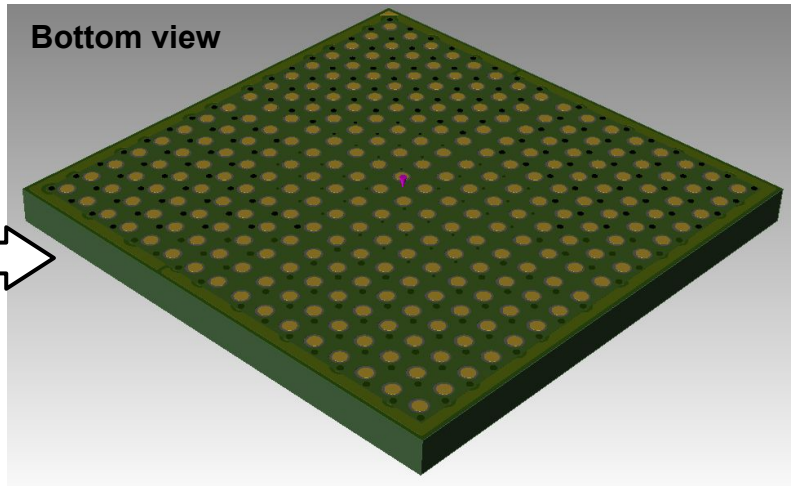
ALCOR BGA package

BGA substrate designed by INFN Torino, package assembly done by external company

- Size: 17 x 17 mm^2
- Balls number: 256 (16x16)
- Pitch: 1 mm



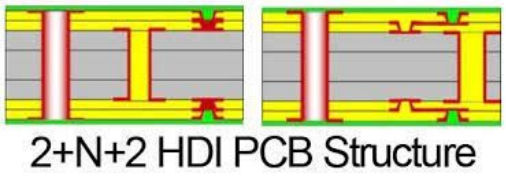


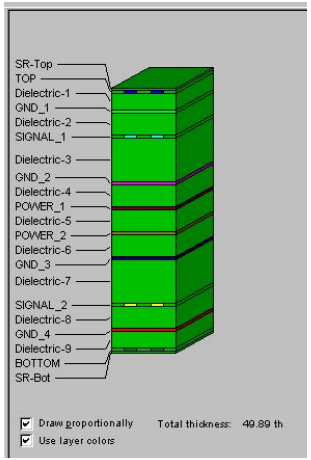


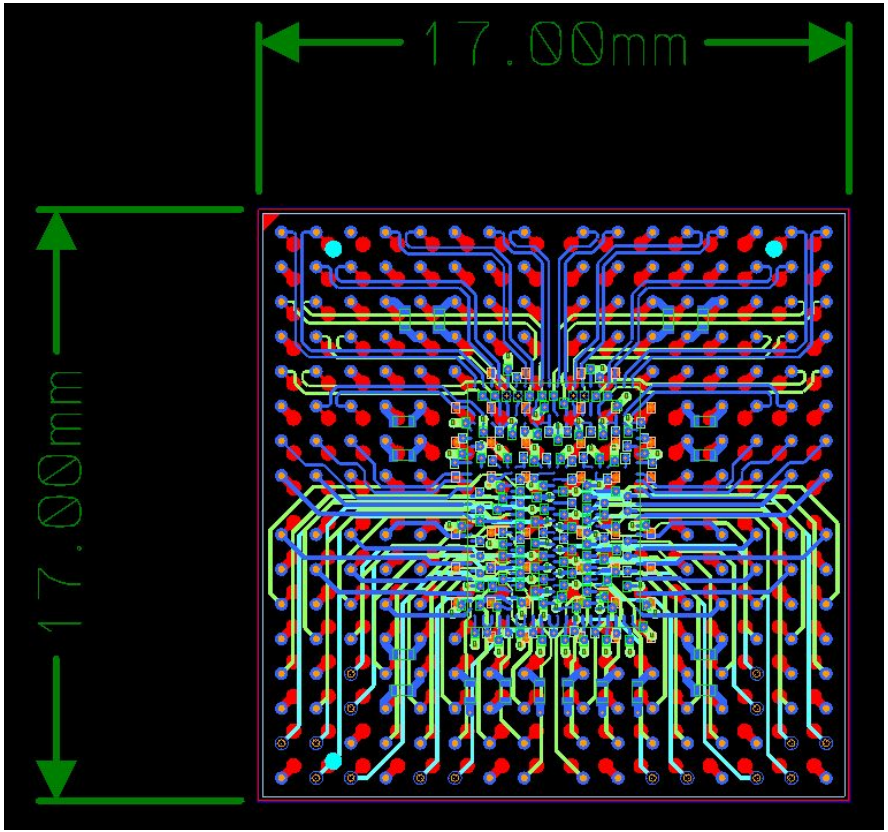
ALCOR BGA package

BGA substrate designed by INFN Torino, package assembly done by external company

- Size: 17 x 17 mm^2
- Balls number: 256 (16x16)
- Pitch: 1 mm
- Material: BT-Epoxy
- 10 layers (2+N+2)
- Total thickness = 1.27 mm





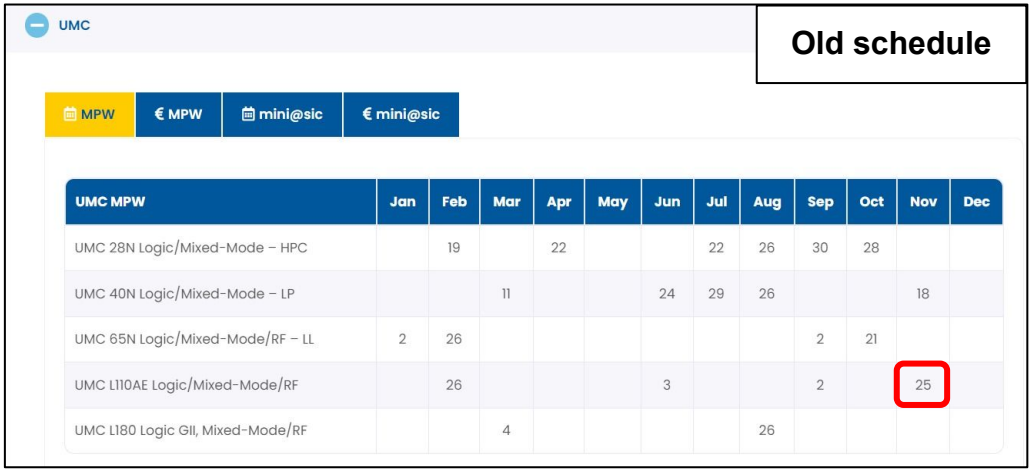


ALCOR v3 MPW run

25th Nov MPW run canceled by UMC

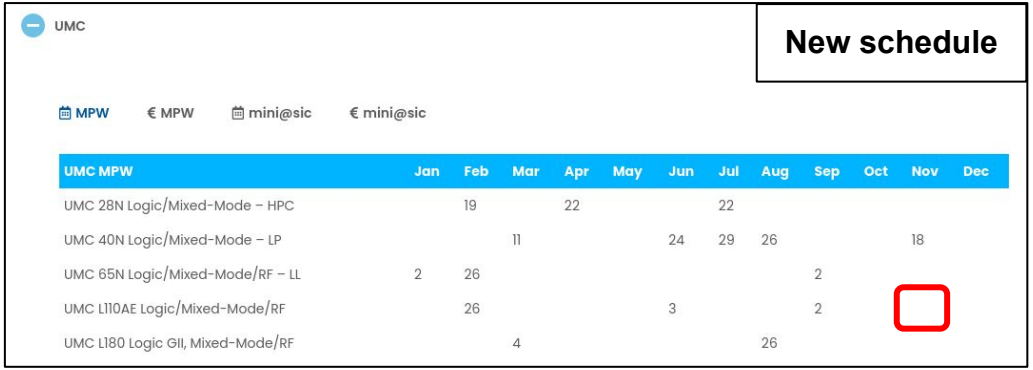
- We have to go to the first MPW shuttle of next year, waiting for 2025 schedule

Old schedule



UMC MPW	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UMC 28N Logic/Mixed-Mode – HPC		19		22			22	26	30	28		
UMC 40N Logic/Mixed-Mode – LP			11			24	29	26			18	
UMC 65N Logic/Mixed-Mode/RF – LL	2	26							2	21		
UMC L110AE Logic/Mixed-Mode/RF		26				3			2		25	
UMC L180 Logic GII, Mixed-Mode/RF			4					26				

New schedule



UMC MPW	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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UMC 40N Logic/Mixed-Mode – LP			11			24	29	26			18	
UMC 65N Logic/Mixed-Mode/RF – LL	2	26							2			
UMC L110AE Logic/Mixed-Mode/RF		26				3			2			
UMC L180 Logic GII, Mixed-Mode/RF			4					26				