X-Ray source for irradiation tests @Marseille

J.-L. Autran[2], M. Barbero[1], P. Barrillon[1], D. Fougeron[1], E. Joly [1], M. Menouni [1], S. Moindjie[2], T. Strebler [1]

[1]: CPPM

[2]: IM2NP

Outline

- Context
- Irradiation system
  - Calibration
  - Beam profil
- Main results
  - TSMC resistances
  - SLDO
  - ITKPixV1 (RD53B)
- Conclusion

Context

- CPPM has a partnership with IM2NP another laboratory based in Marseille. We share the use of an Xray machine with them.
- Main motivation: assume the specifications of RD53B chip (1 Grad then 500 Mrad @ -15 °C).
- Since 2018 we have started working with this machine.
- Firstly we irradiated, at room temperature, 65 nm transistors chip to check the TID effect and compare with previous results obtained at CERN. This step allowed us to cross-check the calibration of our X-ray tube.
- Irradiation of PCM in TSMC 65nm.
- 2019: characterization of SLDO , irradiation of several RD53A chips at high and low dose rate, still at room temperature.
- In parallel, we were developing a cooling system based on Peltier.
- 2021: ready for our first irradiations at low temperature in collaboration with IJC Lab group.
    - Concern the ITKPixV1 chip

Irradiation system

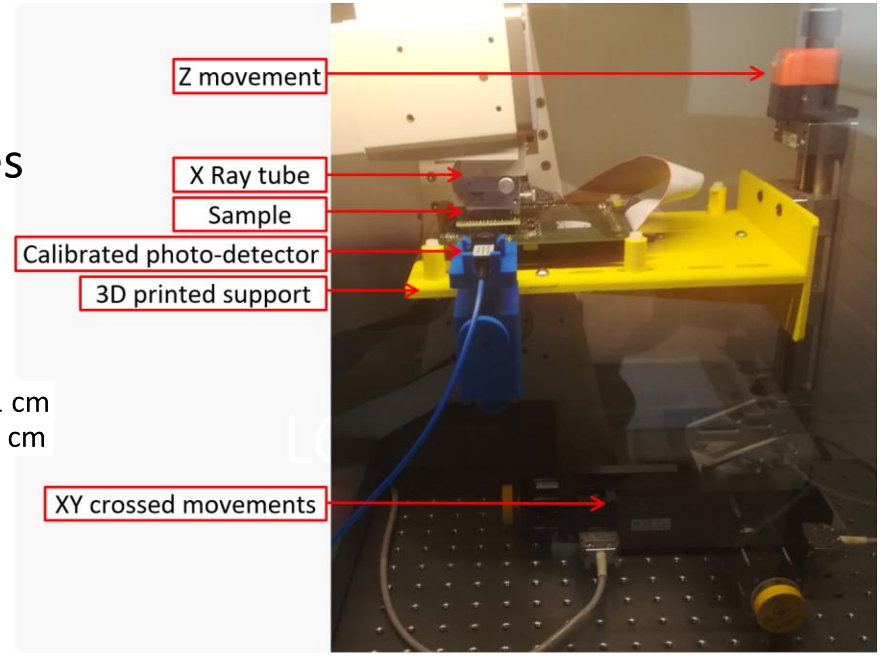
- X-ray machine (Thermofisher (ex Inel)
  - Generator Model Equinox3000 (400 W limited)
- Crossed movements table (PI Model VT-80).
  - Manual Z movement
    - Accuracy around ± 1mm
- Printed 3D support for X-Ray detector and samples

X-Ray generator (Equinox3000)

X-Ray generator	
Target material	Tungsten (peak@10 keV)
Dose rate	Up to 1,3Mrad(SIO_2)/hour max.
Supply voltage	20 kV max.
Tube current	20 mA max.
Al filter	120 µm
Temperature	Troom and LowT ***
Linear stage	
Travel range	150 mm max.
Velocity	20 mm/s max.
Repeatability	± 10 µm

Tube current:
- 20 mA : HDR * 20 krad/mn @1 cm
- 2,5 mA: LDR ** ~1 krad/mn @4 cm

Main features of our system



Example of an irradiation test setup (Transistors test @ Troom)

* : HDR=High Dose Rate
** : LDR = Low Dose Rate
***: LowT = -15°C @Load 0.5W/cm²

X-Ray sensors/calibration

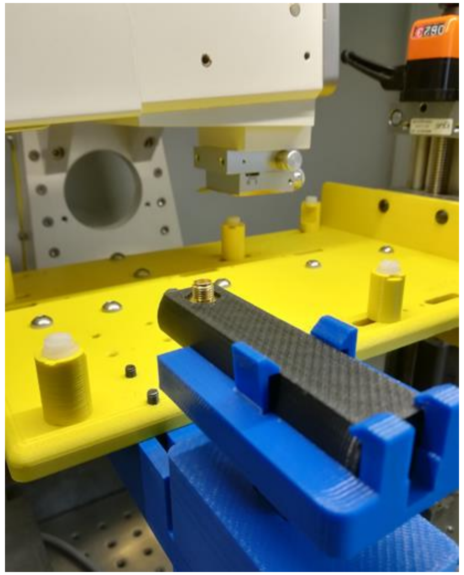
- Beam characteristics can be done with an ionization chamber (Type 23342)
  - Coupled with an « universal » dosemeter (UNIDOS E type 10008)
  - Give a direct reading of the dose rate
  - Afraid to overvalued it…
- Comparison with PIN diode (calibrated @CERN (EP/ESE group))

X-Ray Chamber (Type 23342)

X-Ray Chamber (Model TM23342)		AXUVHS5 (PIN diode)	
Sensitive volume	0.02 cm^3	Sensitive area	1 mm^2
Detection range	8 - 35 keV	Dark current	2 nA
Leakage current	±10fA	Reverse Voltage	50 V
Nominal response	1nC/Gy	Packaging	SMA

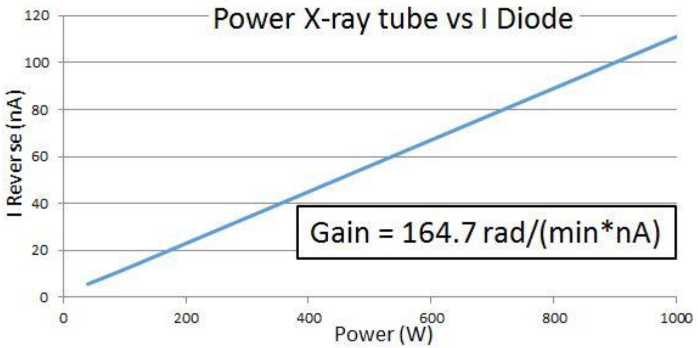
Main features of X-Ray Sensors

PIN diode (AXUVHS5)



PIN diode on its mechanical support

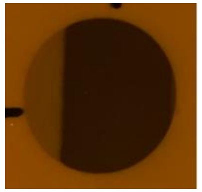
- ARACOR commercial irradiation system
- 3000 W (60 kV - 50 mA max.)
- 120 µm Al filter (to keep the deposited dose uniform)
- Pre-calibrated Quantrad sensor
- Extraction of the PIN diode real gain
  - Dose rate conversion



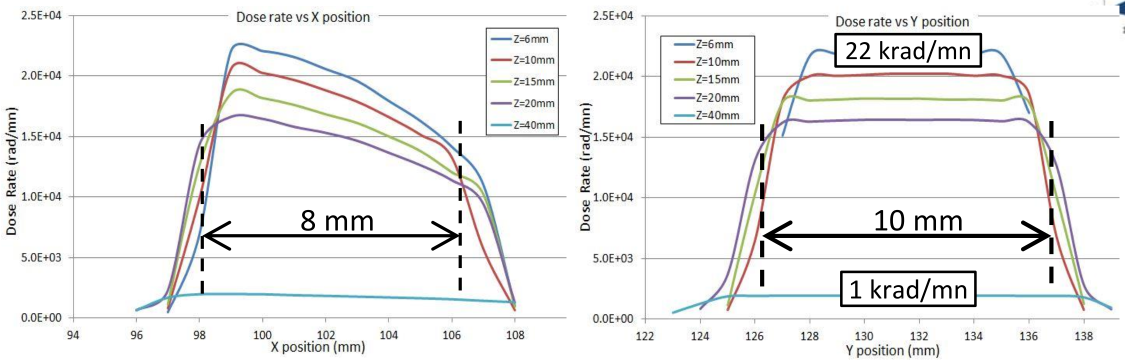
Extracted gain of AXUVHS5 (@20 kV)

Beam profile / 1st irradiations

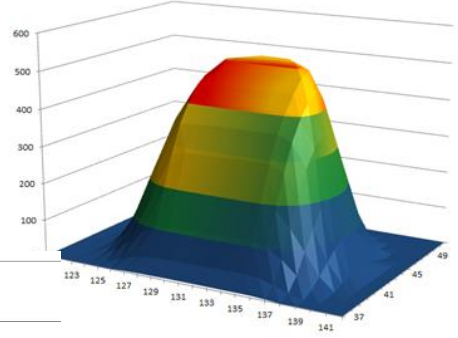
- Extraction of the beam profile
  - Characterization at different Z positions
  - Non uniformity in X position (~30%)



Beam spot photography



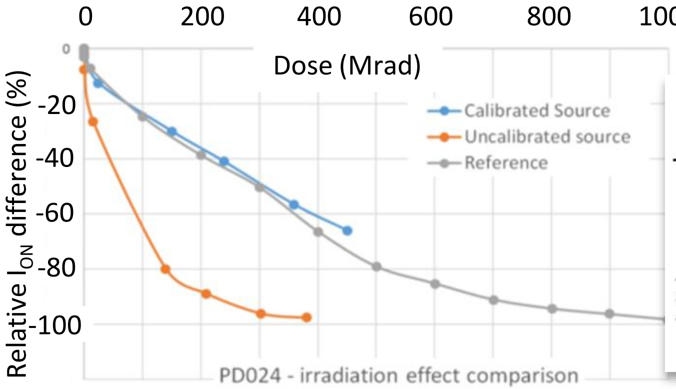
X Y beam profile versus distance of the tube



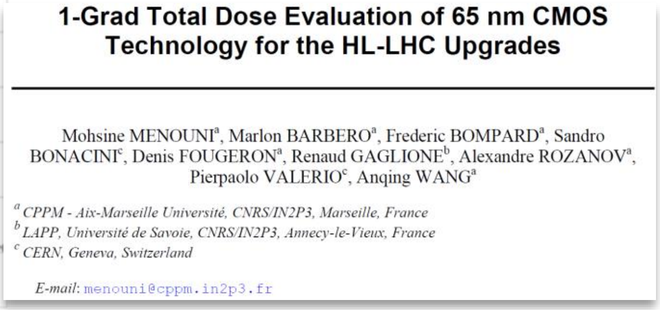
3D beam profile

Transistors test bench

- Irradiation campaign of TSMC65nm transistors chips
  - Comparison with a previous campaign carried out @CERN
  - Cross-check the calibration of our system



≠ TID effects on PMOS 240/60nm (@Troom)



1-Grad Total Dose Evaluation of 65 nm CMOS Technology for the HL-LHC Upgrades

Mohsine MENOUNI[a], Marlon BARBERO[a], Frederic BOMPARD[a], Sandro BONACINI[c], Denis FOUGERON[a], Renaud GAGLIONE[b], Alexandre ROZANOV[a], Pierpaolo VALERIO[c], Anqing WANG[a]

[a] CPPM - Aix-Marseille Université, CNRS/IN2P3, Marseille, France
[b] LAPP, Université de Savoie, CNRS/IN2P3, Annecy-le-Vieux, France
[c] CERN, Geneva, Switzerland

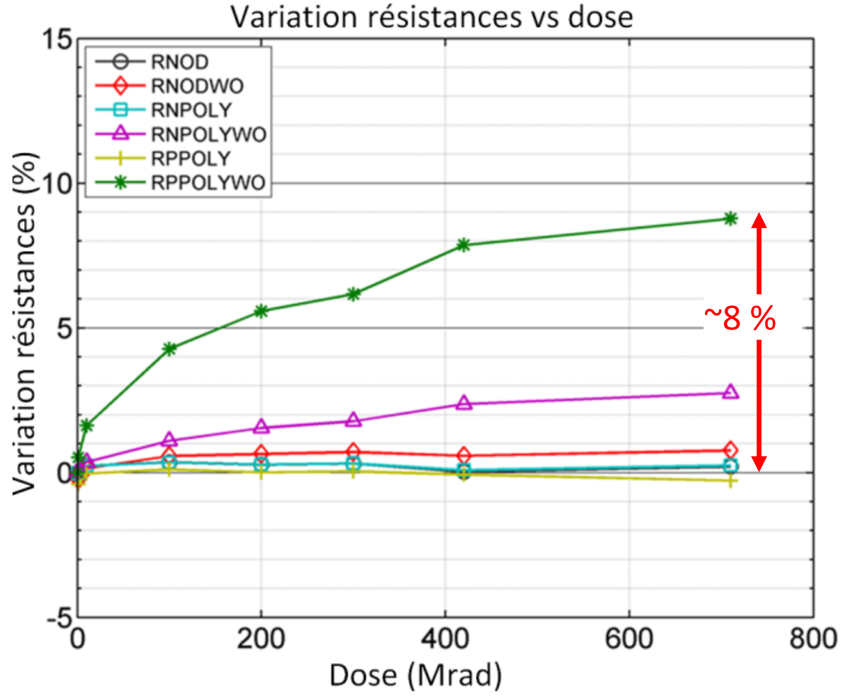
E-mail: menouni@cppm.in2p3.fr

Resistances irradiation test results

- 6 types of resistors available in TSMC65nm technology have been irradiated (@Troom)

Name	Material	Well type
RNOD	Oxide	N
RNODWO	Oxide without silicide	N
RNPOLY	Polysilicon	N
RNPOLYWO	Polysilicon without silicide	N
RPPOLY	Polysilicon	P
RPPOLYWO	Polysilicon without silicide	P

Resistors list for TSMC65 technology

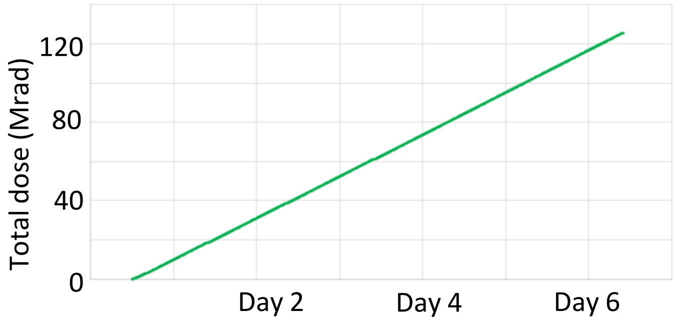


TID results

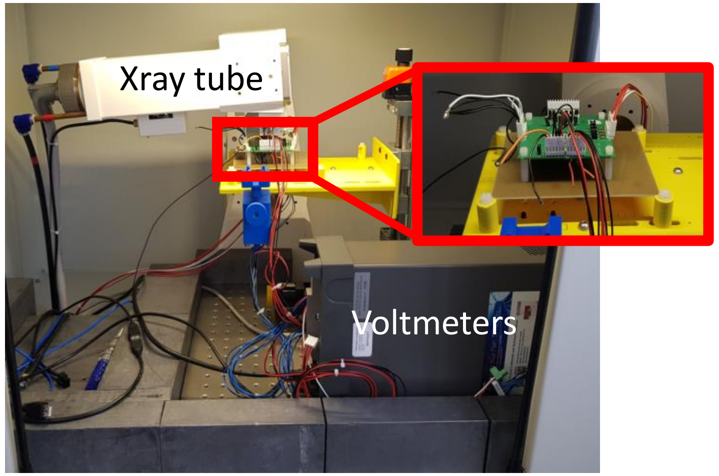
- Dose rate ~1 Mrad/hour
- TID: 700 Mrad
- RPPOLYWO
  - Advantages:
    - High resistivity
    - Low temperature variation
  - Drawback:
    - 8% total variation @700 Mrad
    - 3 % for RNPOLYWO (not recommended)
- Results presented in collaboration to avoid the use of RxPOLYWO resistances in analog designs

shunt-LDO irradiation test results

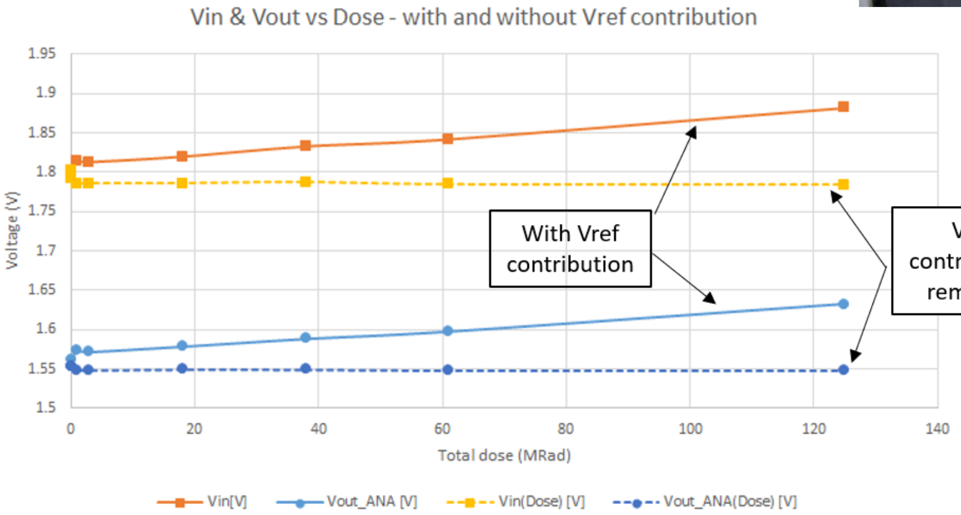
- A TowerJazz shunt-LDO (TJ180nm) has been designed @CPPM for depleted CMOS pixel developments
  - 1,8 V-2 A max, ~50 W/cm² (chip size: 7 mm²)
  - Need dedicated PCB for power dissipation
    - Chip on board on thermal planes
  - T_{CHIP} < 70 °C during irradiations
  - TID: 125 Mrad
  - Dose rate: ~1Mrad/hour
  - Analog Voltages monitoring
    - V_{IN}, V_{REF}, V_{OUT}
- Results:
  - V_{OUT} variation: 3 % @ 125 Mrad
  - Δ V_{OUT} < 1 % (consider V_{REF} contribution)

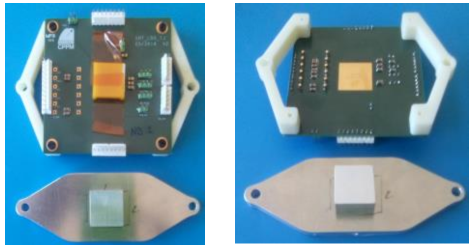


TID vs time



(a)



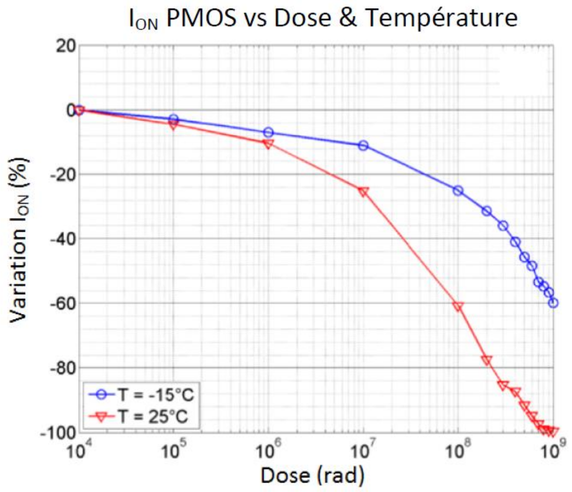


(b)

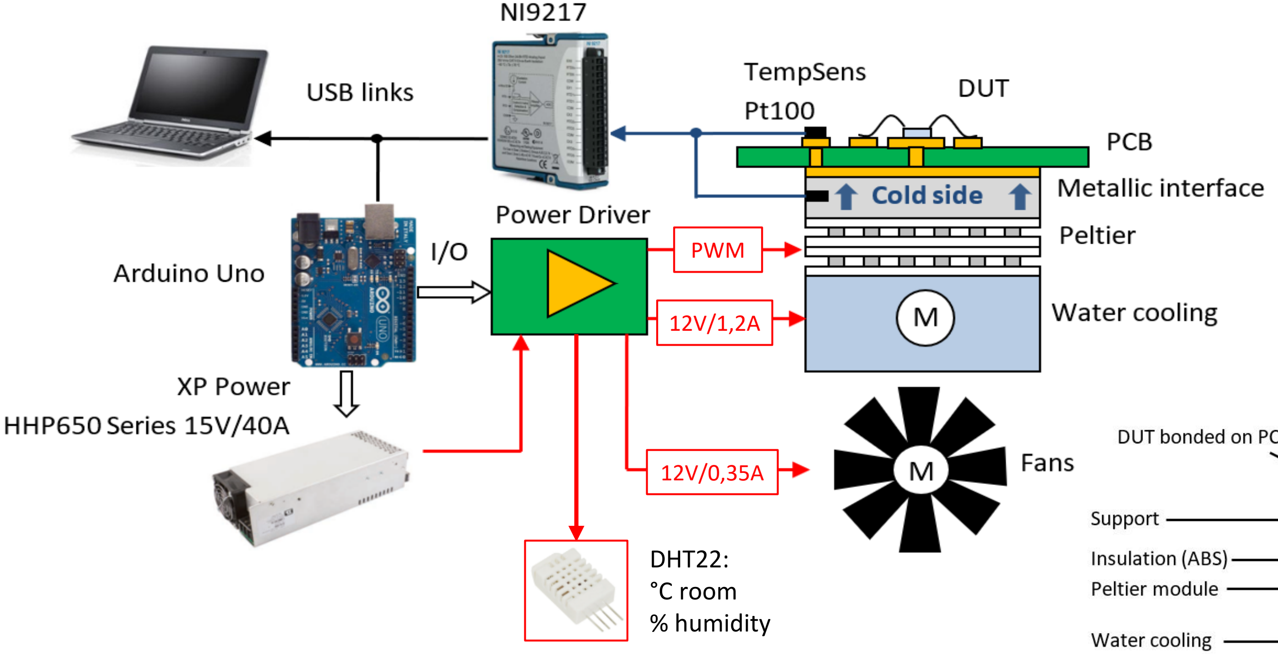
(a): SLDO irradiation test bench
(b): dedicated PCB

Low °C option

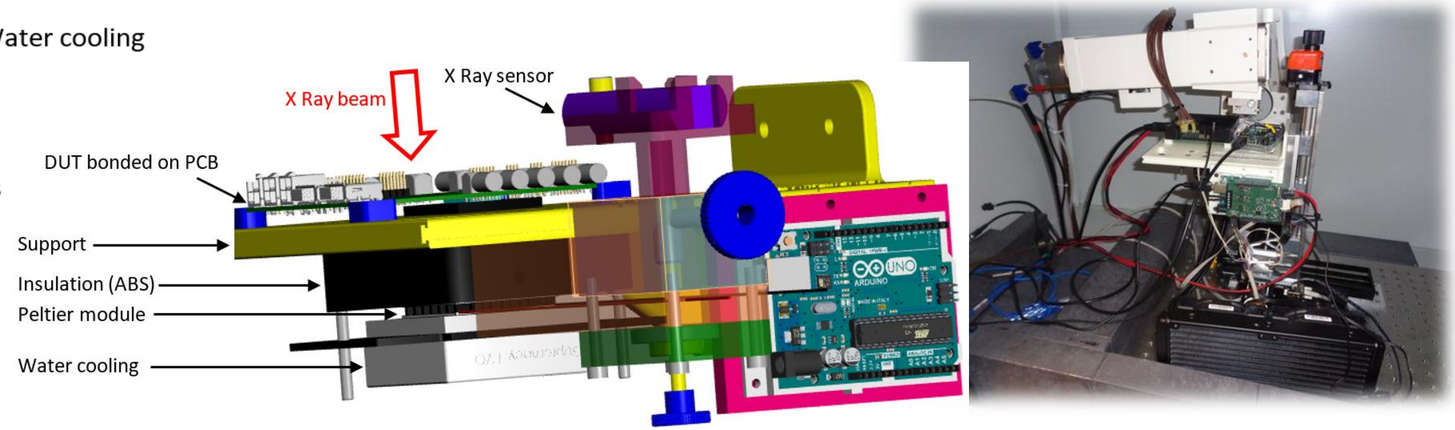
- Test system requires a Low °C option during irradiation
  - Technologies can show an other behavior
  - Power components (SLDO) need a constant °C
- Development of a cooling system (based on a Peltier module)
  - Irradiation with a minus regulated temperature (~-15 °C)



I_{ON} TID degradation vs °C (PMOS-TSMC65nm)



Peltier system synoptic

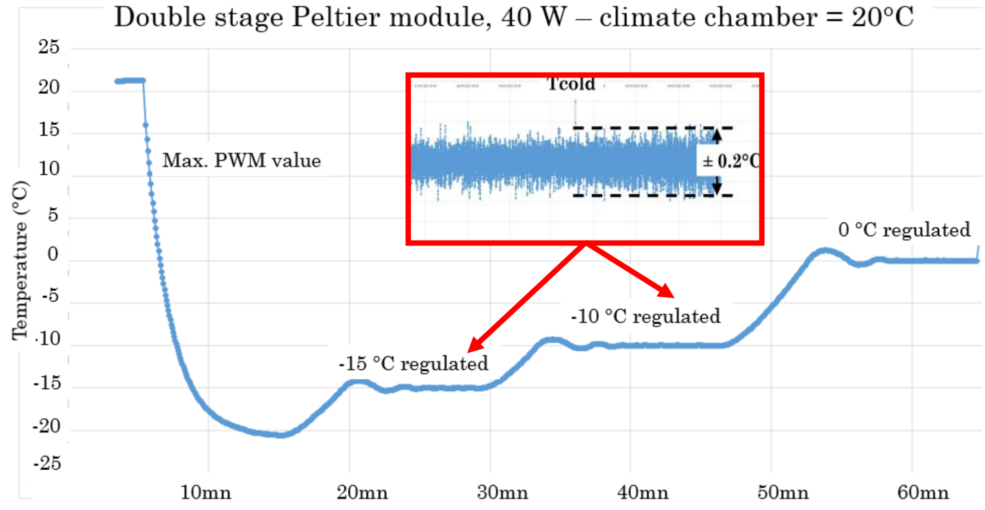


Mechanical integration under the X-Ray tube

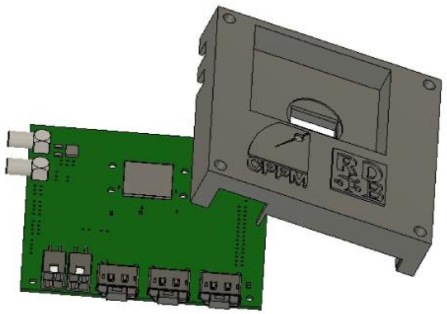
Low °C performances

- Cooling system features
  - Double stage Peltier module
    - 15 V / 7 A
    - Qmax = 40 W
  - Water cooling + fans:
    - 12V / 1,5 A - 12V / 0,3 A (currents monitoring)
  - Driven by Arduino Mega2560 (for final system)
  - Power driver board
  - Labview Software
    - LINX vi
    - Temperature, dew point monitoring
    - Temperature regulation
  - Requirements:
    - a constant Troom, dry air for low T°C
    - Good insulation for irradiated sample
- 2 items have been produced
  - 1 demonstrator (to control samples °C during tests)
  - 1 irradiation support (to irradiate @LowT)

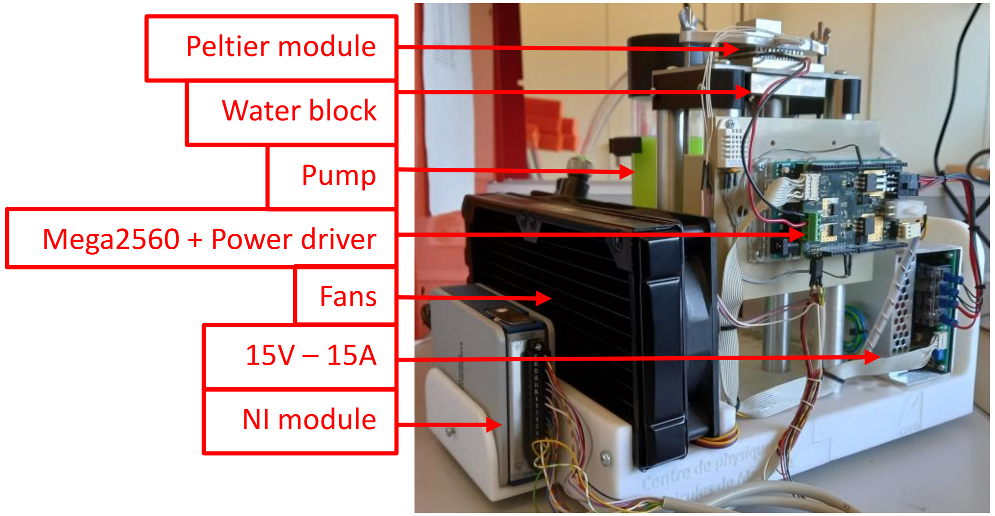
Peltier module (ref.: S2-192-14-20-11-18)



1st results of Peltier system in a climate chamber



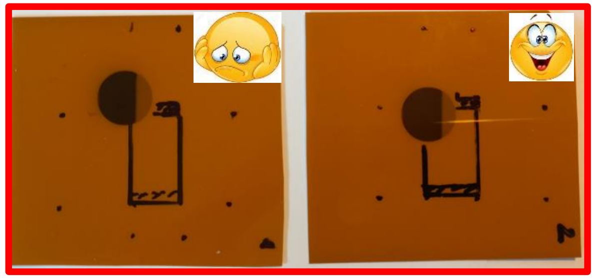
ITKPixV1 plastic insulation



Demonstrator bench with Peltier elements

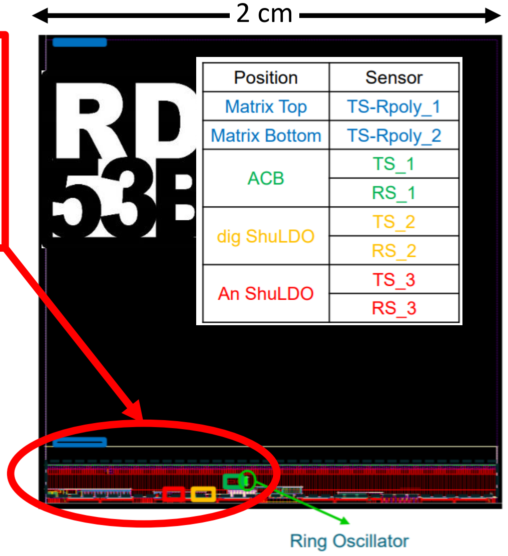
ITKPixV1 irradiation test preparation

- In collaboration with IJCLab (Jimmy Jeglot, Maurice Cohen-Solal, Yahya Khwaira, Abdenour Lounis, Slimani Cherif)
- Requirements from RD53 collaboration
- Calibration (cf.: slide 5)
- Pre-irradiation :
  - LDO mode
  - Check analog scans (Threshold, noise,…)
  - Temp. sensors calibration
  - Ring Oscillators calibration (vs T°C, V_{DDD})
  - °C @ -10°C on NTC
    - Reach ~-6 °C
- During irradiation :
  - RO measurements each 100 krad
  - Temperatures monitoring
  - Sensors measurements (dose, °C)
  - V_{DDD}, V_{DDA}, V_{REF}'s monitoring
- Post-irradiation (annealing) :
  - Turn OFF X-Ray tube, monitoring voltages, RO during 6 hours
  - Check analog scans (Threshold, noise,…)
  - Maintain @-15 °C, keep supplies ON and launch a periodic Voltages, RO monitoring

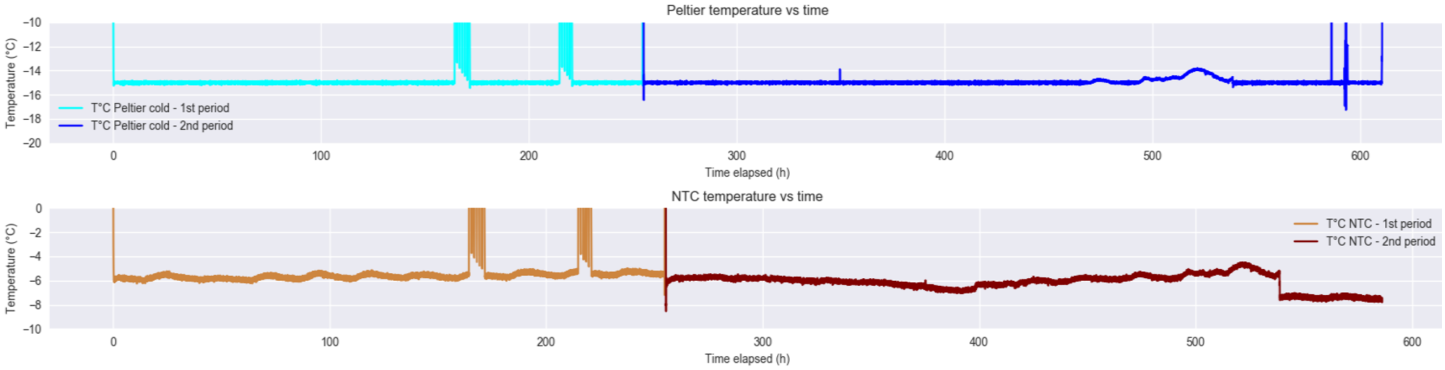


Checking beam position

- 3 rad sensors
- 3 temp sensors
- Ring Osc
- ADC monitoring
- LDO regulator



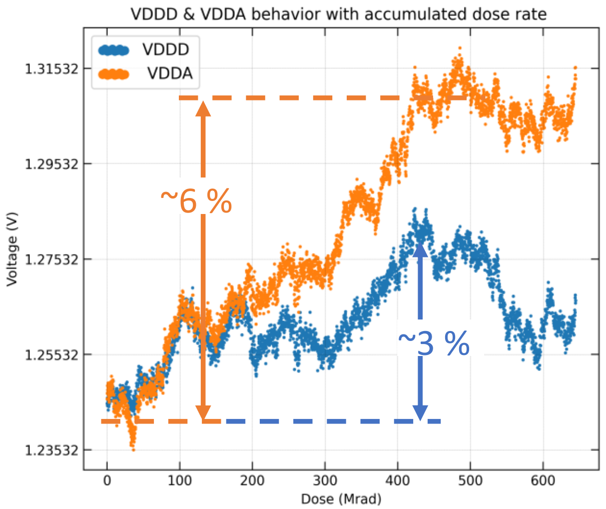
Zone of interest irradiation ITKPixV1



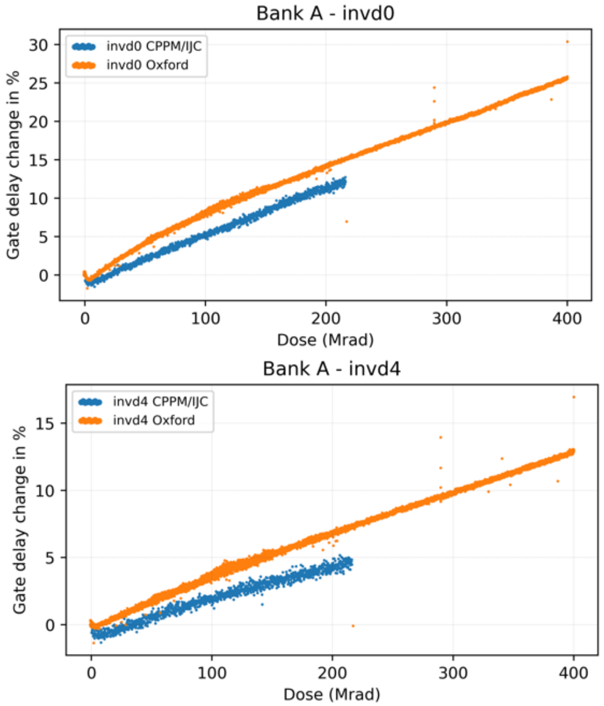
Temperature monitoring during irradiation

ITKPixV1 irradiation test results

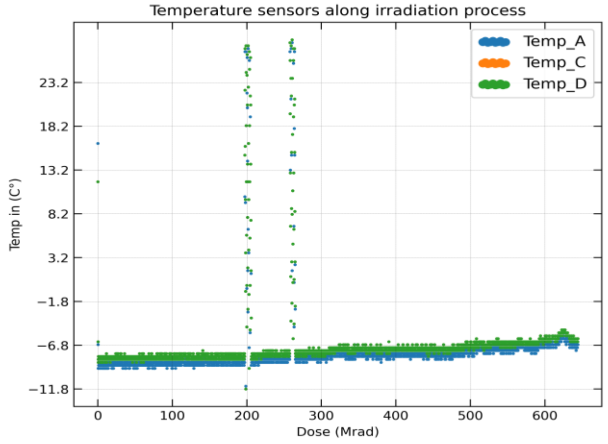
- 2 ITKPixV1 chips have been irradiated up to 650 Mrad
  - 20% TID correction (corresponds to real TID of 500 Mrad)
  - dose rate ~1,2 Mrad/hour
- Tests were conducted in strong collaboration between CPPM and IJCLab
- The temperature is well controlled and stable around -8 °C
  - Slight variation during irradiation
- The chip is in LDO mode
  - V_{DDD} and V_{DDA} are generated inside the chip by the regulator
- Drift of V_{DDD}/V_{DDA} due to the reference voltages V_{REFA}/V_{REFD} shift
  - Up to 6 % for V_{DDD}
- On chip Ring Oscillators
  - Designed by IJCLab and used intensively for dose monitoring
  - V_{REF} dependence for Ring Oscillators
    - results need to be normalized with other parameters:
      - VDDD, T °C
  - Increase for strength 0 gates up to 45%
    - Not used in the chip
  - Increase for strength 4 up to 28%
- The results we obtained are compatible with those obtained by other institutes (CERN, Oxford, Bonn, Berkeley)



V_{DD}'s variation RO versus dose



Comparison RO with results from Oxford



Temperature evolution versus dose

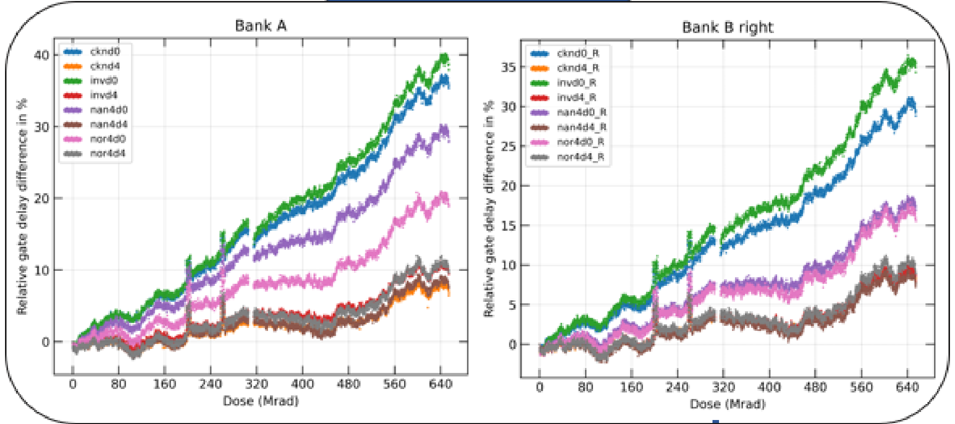
Ring Oscillators results

Ring Oscillator delays

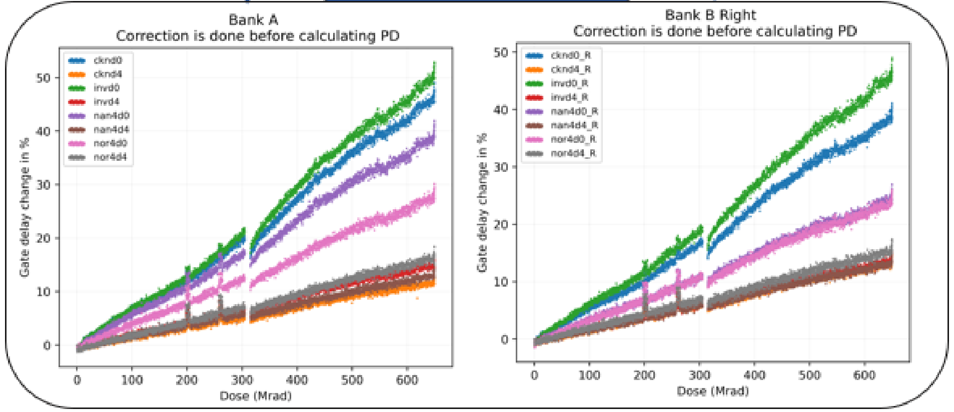
IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

CPPM ATLAS EXPERIMENT

No VDDD correction applied



VDDD correction applied



- Propagation delay is calculated using the following equation:

$$t_{pd} = \frac{1}{2N_g f} \qquad (1)$$

  - In which (Ng) is the number of gates for each ring oscillator and (f) is the extracted frequency.

- Moreover, digital voltage correction will be applied on the raw frequency data to eliminate the VDDD oscillations. Using the equation:

$$(Freq)_{after\ Vddd\ cor} = Freq_{before\ Vdd\ cor\ (1)} + (slope_{Freq/VDDD})(1.24 - VDDD)$$

- Then, relative gate delay change in % is calculated with equation 1. With respect to a reference value at 0 rad, using the following equation:

$$\text{Gate delay change in \% (GDC)} = \frac{(Pd - Pd\,ref)}{Pd\,ref} \text{ x } 100$$

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Conclusion

- Successful mutualization with IM2NP to have performed an irradiation system using a calibrated X-ray source
- Associated instrumentation offers an accurate system and a possibility to irradiate @Low Temperature
  - Dependent of environment
  - Ideal for prototypes
  - Limited with a big chip (0,5W/cm² - 4 cm² is critical)
- Still few modifications for an ultimate version
- 2 ITKPixV1 irradiation campaigns show some interesting results
  - Conform and comparable with other institutes
  - Data's from ring oscillators, sensors, V/Imux, etc have to be confirmed
  - Extraction of annealing data's are in progress
- Plan to irradiate ITKPixV1 @ Low Dose Rate (~60 krad/hour)