RHBD for WFEE of X-IFU/ATHENA Space Observatory

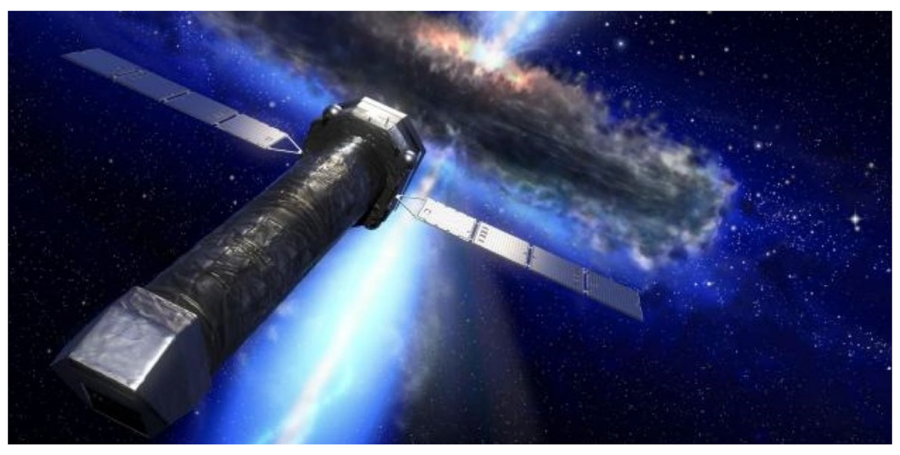
SERESSA 2018

Si CHEN, Damien PRÊLE, Fabrice VOISIN, Philippe LAURENT, Andrea GOLDWURM

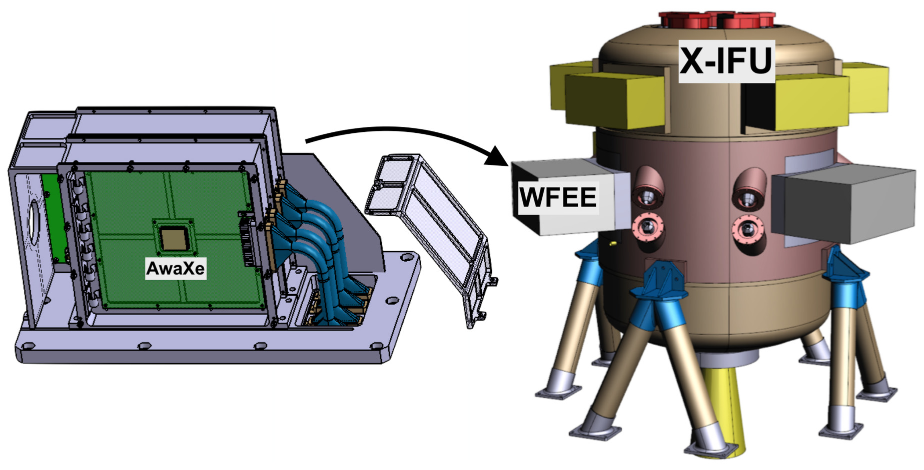
APC, Univ Paris Diderot, CNRS/IN2P3, CEA/Irfu, Obs de Paris, Sorbonne Paris Cite, France

ATHENA Space Observatory

- **ATHENA** (Advanced Telescope for High-ENergy Astrophysics) telescope of ESA
- "Hot and Energetic Universe" science theme
- Two X-Ray instruments: **X-IFU** (X-ray Integral Field Unit) and WFI (Wide Field Imager)
- Launching: 2030, 5 year lifetime, Sun-Earth L2

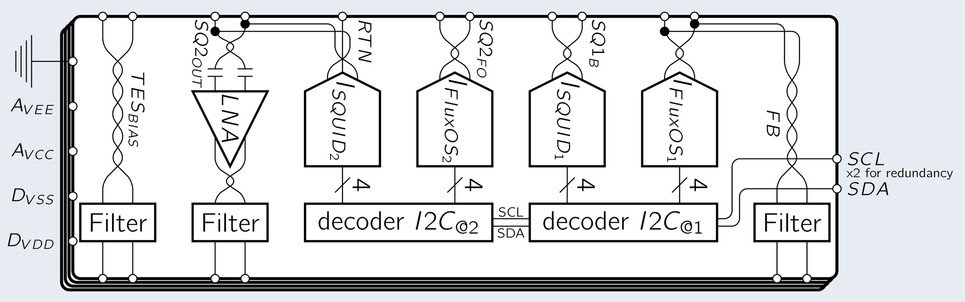


X-ray Integral Field Unit (X-IFU)



- 3840 pixels microcalorimeters (TES), 50 mK
- FDM 1:40 by LC filters, 96 channels
- 2 SQUID stages are biased and low-noise amplified by the following warm stage **WFEE**

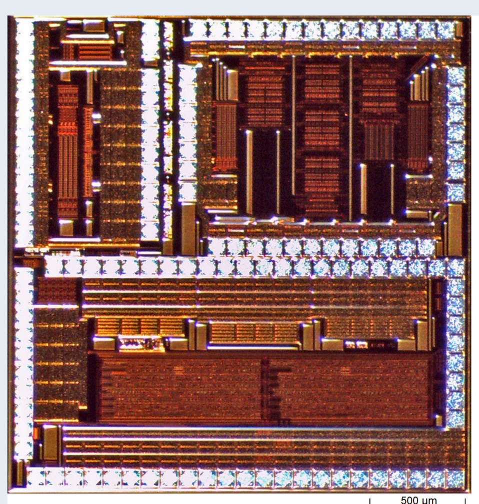
Warm Front-End Electronics (WFEE)

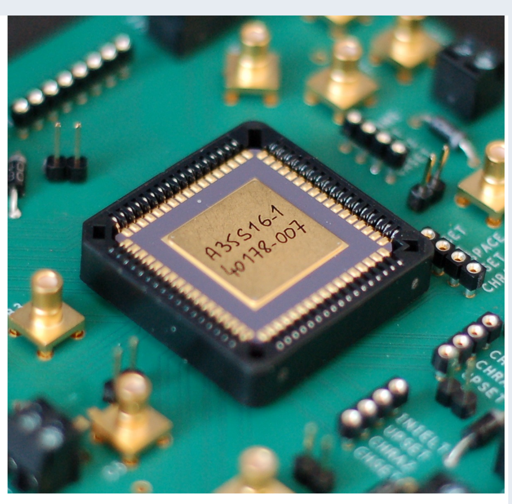


Simplified block diagram of one of the 96 WFEE channels

- 3 WFEE boxes -> 12 ASIC -> 8 channels/ASIC
- Power consumption: 24 W total, 0.25 W/channel
- AMS 350 nm SiGe BiCMOS technology
- LNA, configurable SQUID biasing, Series decoders $RS485/I^2C$, Housekeeping, etc
- 1^{st} ASIC (2016), **AwaXe_v1** (Athena Warm Asic for X-ifu Electronics, Version 1), functional and radiation tests

ASIC AwaXe_v1



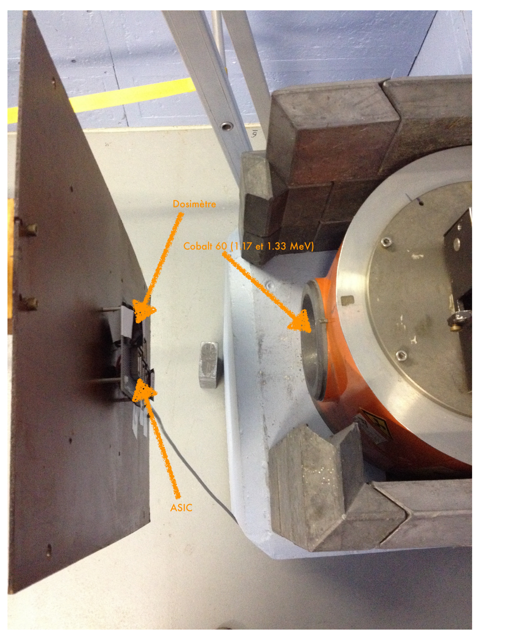


- 3 LNA with gain 3 V/V, 8 V/V and 10 V/V
- Configurable current sources with 16 levels output, $40\ \mu A$ range, configured by 4 bits
- 2 I^2C decoders (master/slave distance up to 10 m)
- 4 registers of 8 bits (for SEL radiation test)
- 5 MOS & 2 NPN HBT (different topologies)

Total Ionizing Dose (TID) effect Verification

- CoCase, CEA Saclay, γ source of ^{60}Co
- 1.25 MeV energy
- Low dose rate: 0.01 rad/s (Si)
- Total dose up to 100 krad
- TID estimation for WFEE behind a 2 mm Al shield during 5 years of ATHENA:

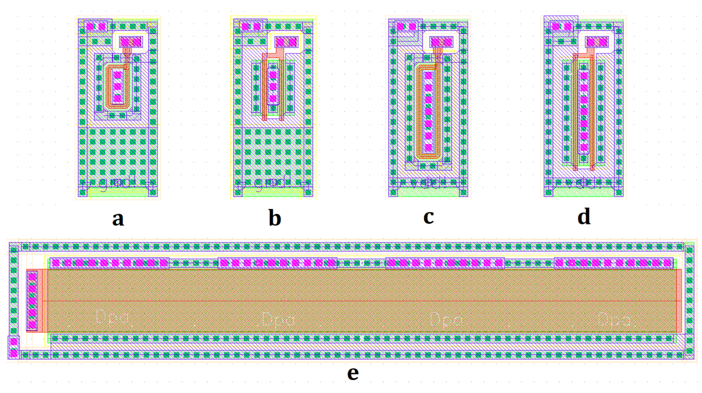
Launch Year	TID	TID worst case
2028	1.7 krad	6 krad
2029	2.7 krad	7 krad
2030	5 krad	10 krad
2031	7.4 krad	12 krad
2032	10 krad	14 krad

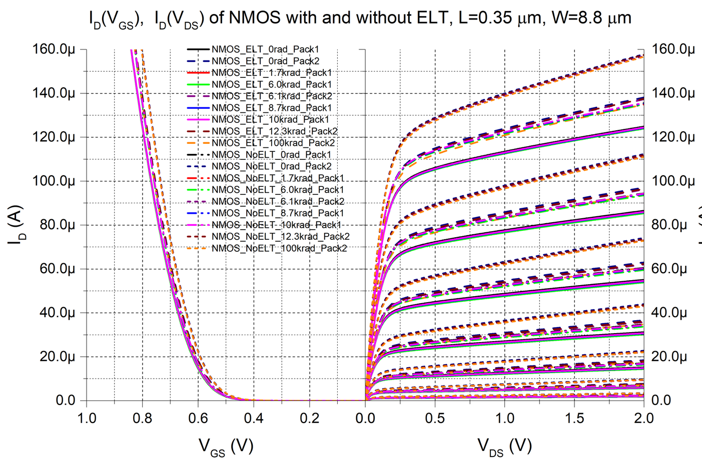


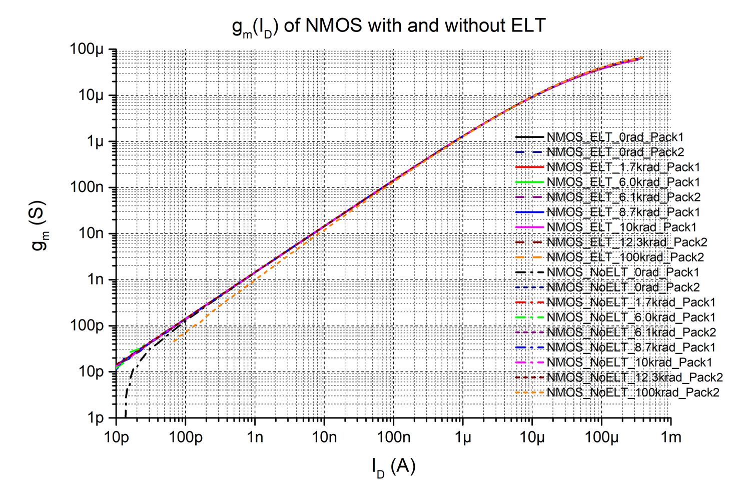
Pack1	0 rad	1.7 krad	6.0 krad	8.7 krad	10.0 krad
Pack2	0 rad	–	6.1 krad	12.3 krad	100 krad

TID effects on MOS

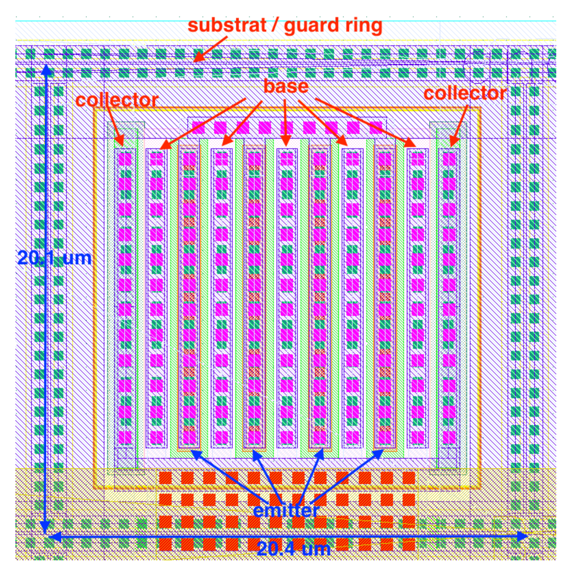
- a) NMOS with ELT gate
- b) NMOS without ELT gate
- c) PMOS with ELT gate
- d) PMOS without ELT gate
- e) PMOS without ELT gate with larger size

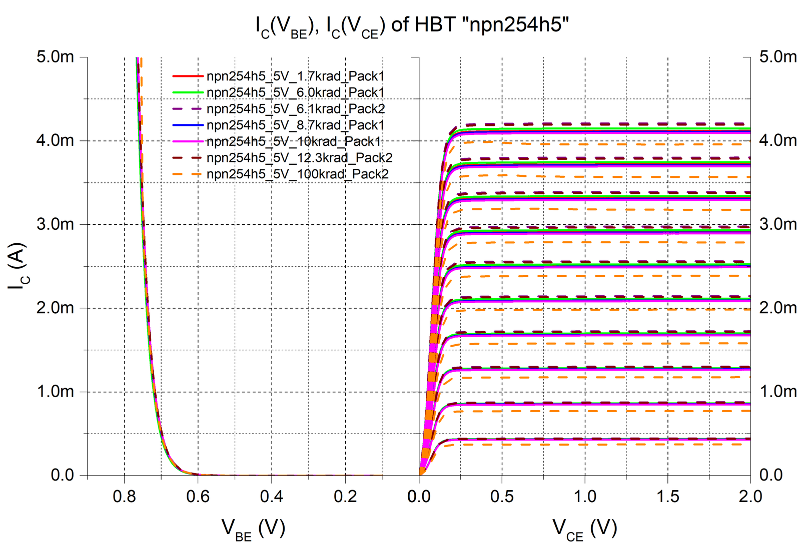


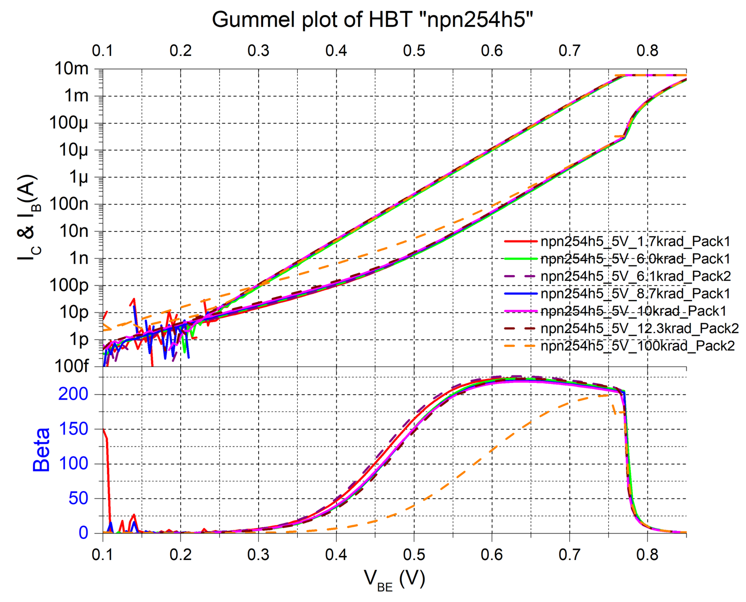




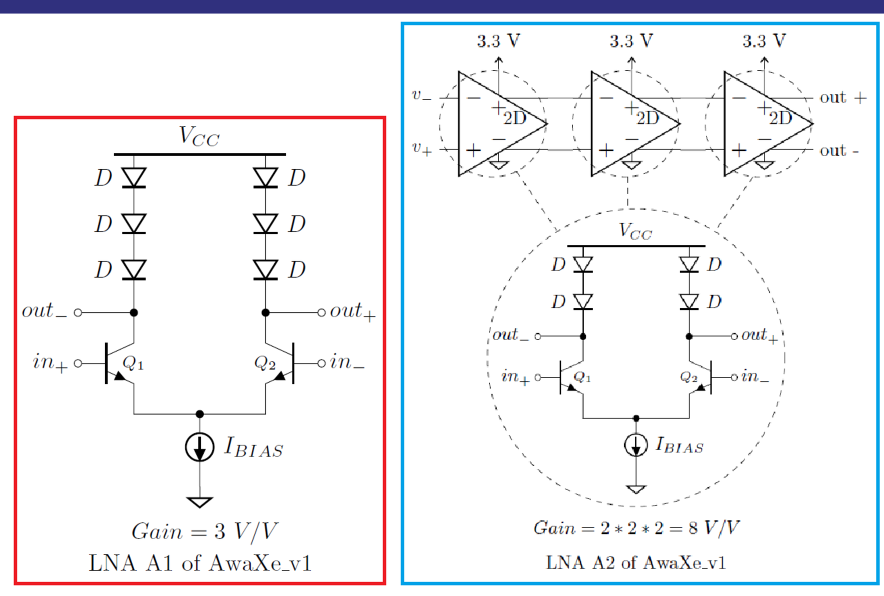
TID effects on HBT "npn254h5"





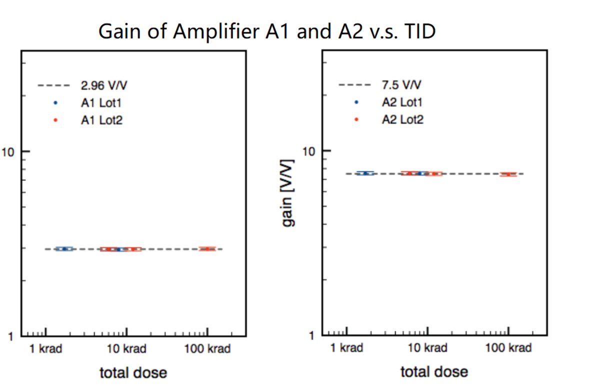


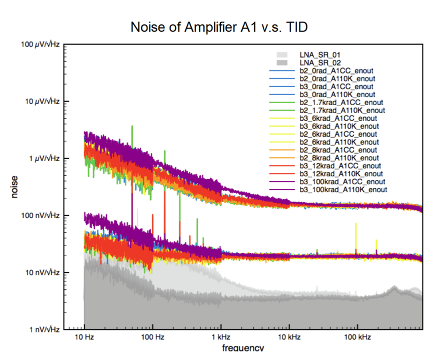
TID effects on Amplifier



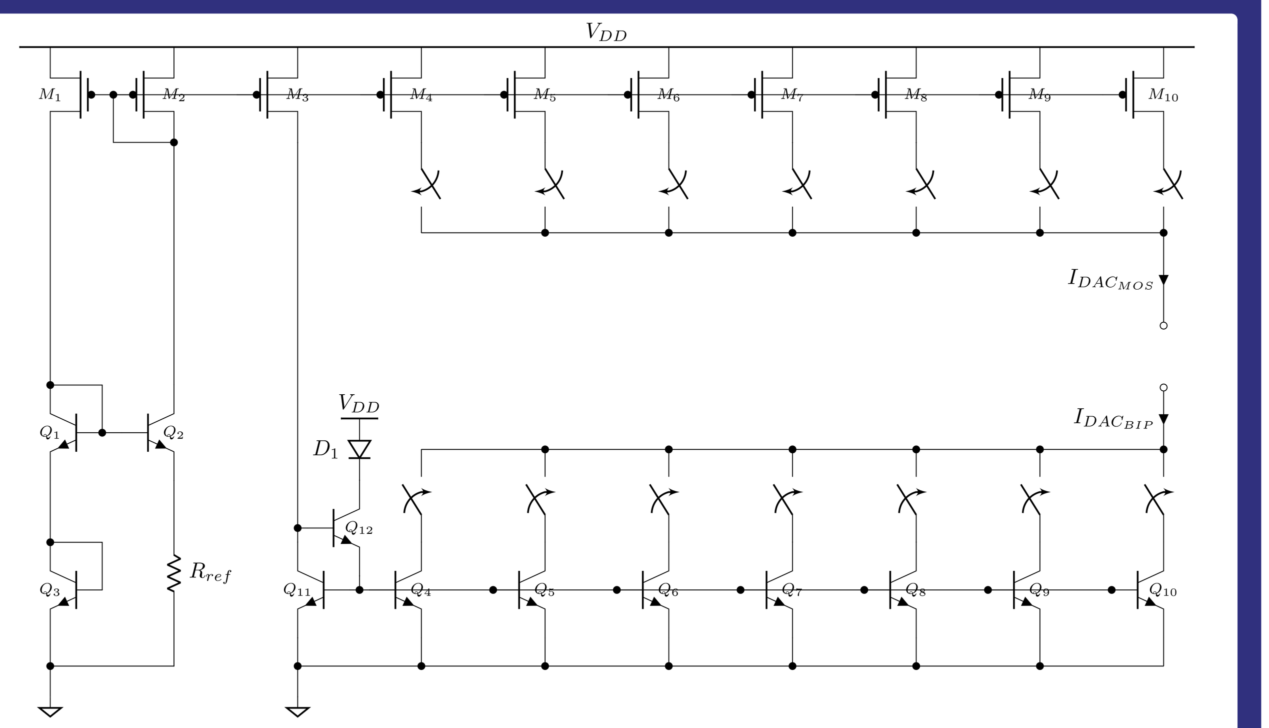
$$|Gain| = g_m \times Z_D \times n_D \approx \frac{qI_C}{k_BT} \times \frac{k_BT}{qI_D} \times n_D = n_D \tag{1}$$

$$S_{v(in)} \approx 2 \times \Big(\underbrace{4k_BTR_{BB'}}_{\text{parasite thermal noise}} + \overbrace{2qI_B}^{i_n^2} R_s^2 \Big) + \underbrace{\frac{2qI_C}{g_m^2}}_{e_n^2} + \frac{\overbrace{2qI_D \times Z_D^2 \times n_D}^{\text{due to diodes}}}{gain^2} \tag{2}$$

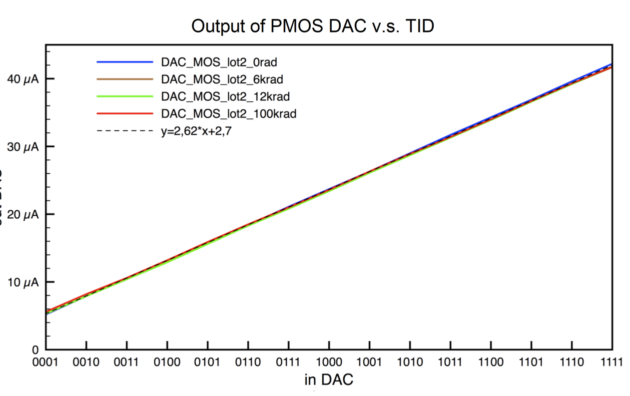


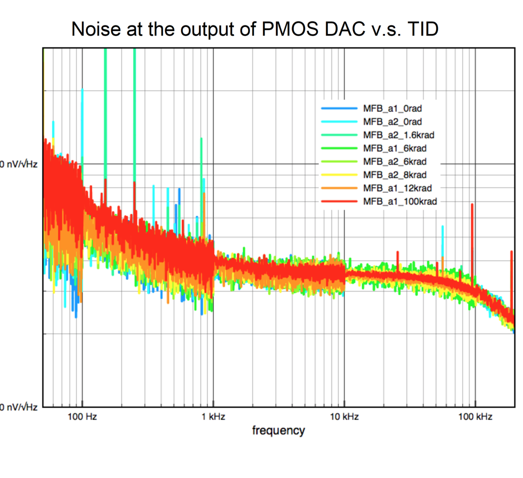


TID effects on DAC

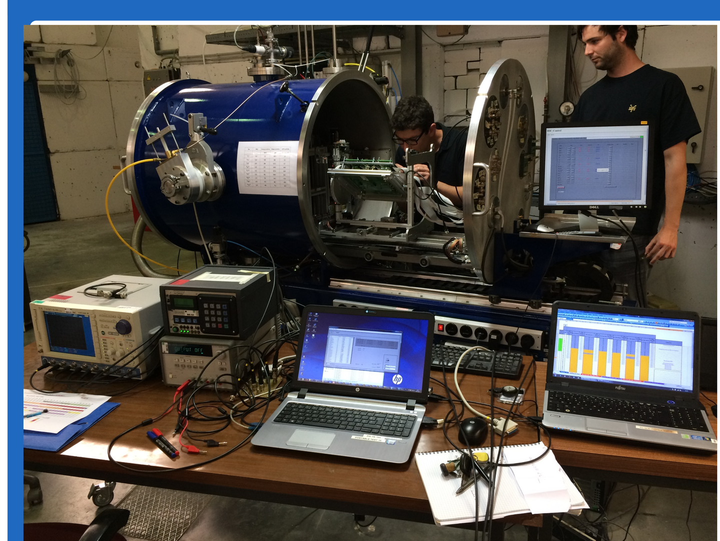


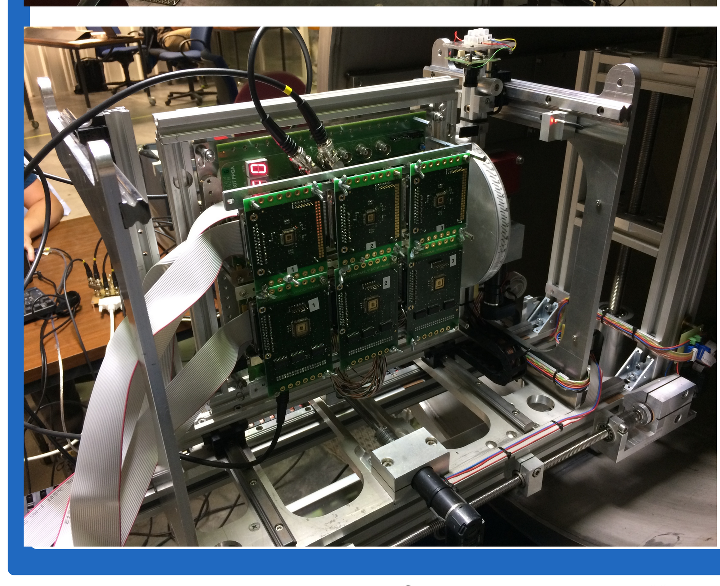
- Reference V_{BE} of Q_3, $R_{ref} = 7\ k\Omega$
- Switches: Transmission gates, controlled by 4 bits
- 16 levels output, 6-40 μA, each step $\approx 2.5\ \mu A$





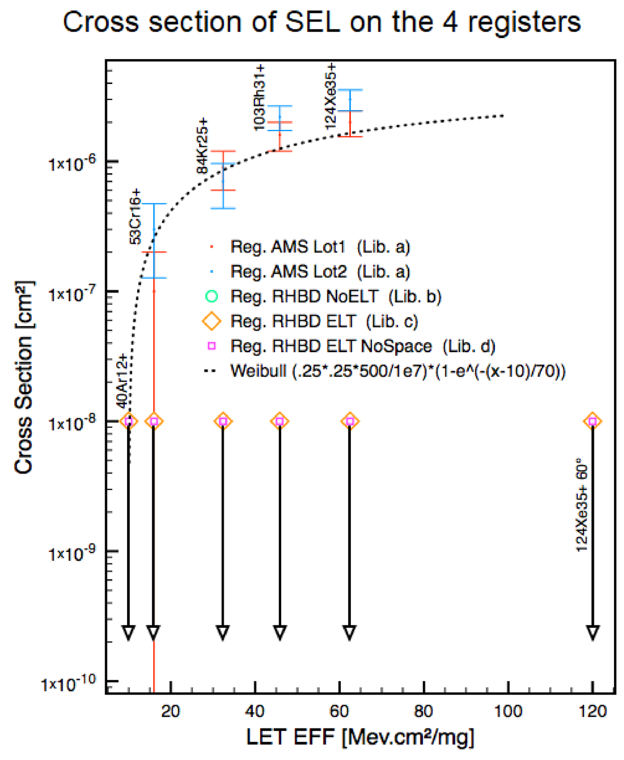
Single Event Latch-up (SEL) effect Verification



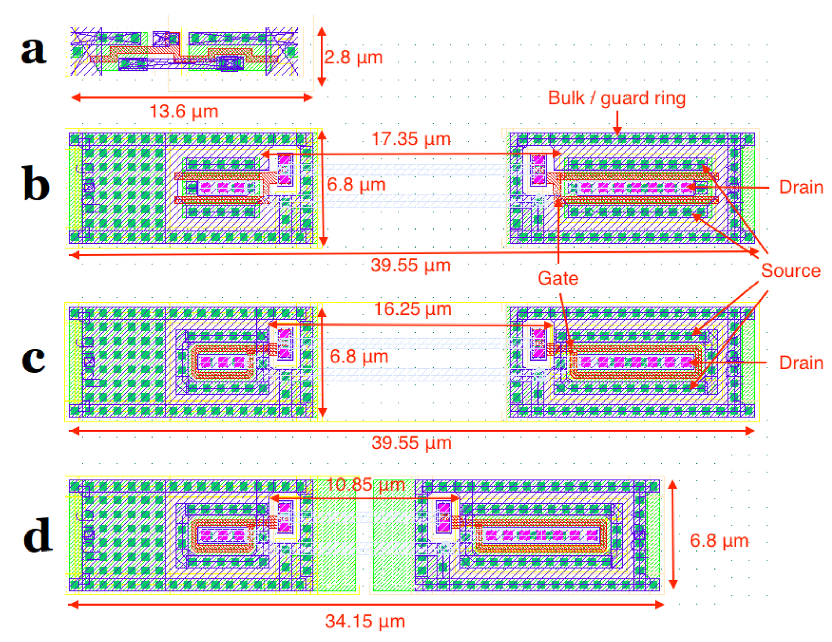


- Cyclotron at UCL, Belgium
- Heavy ions, fluence $10^7/cm^2$
- LET available: 1.3 - 62.5 $MeV \cdot cm^2/mg$
- LET doubled to 125 $MeV \cdot cm^2/mg$ by increasing the incident angle 0° -> 60°

Cross section of SEL on the 4 registers



- 4 Registers, with different RHBD design:



Conclusion

- No significant TID effect at 100 krad on the MOS and HBT used for WFEE
- No SEL effect on registers with RHBD design for WFEE up to 125 $MeV \cdot cm^2/mg$

References

[1] D. Prêle et al. *"Gain drift compensation with no feedback-loop developed for the X-Ray Integral Field Unit/ATHENA readout chain"*, JATIS (2016).

[2] S. Chen et al. *"Development of the WFEE Subsystem for the X-IFU Instrument of the ATHENA Space Observatory"*, SPIE (2018).

[3] J.D.Cressler et al., *"Radiation effects in SiGe technology"*, IEEE tran. on Nuclear Sci.(2013).

Acknowledgement

Supported by CNRS (Centre National de la Recherche Scientique) and CNES (Centre National d'Etudes Spatiales) under the WFEE project. The support of CEA Saclay (Commissariat à l'énergie atomique et aux énergies alternatives), TRAD (Tests & Radiation Company) and UCL (Université Catholique de Louvain) was also greatly appreciated for the radiation tests.

Damien PRÊLE: prele@apc.in2p3.fr
Fabrice VOISIN: voisin@apc.in2p3.fr
Si CHEN: sichen@apc.in2p3.fr