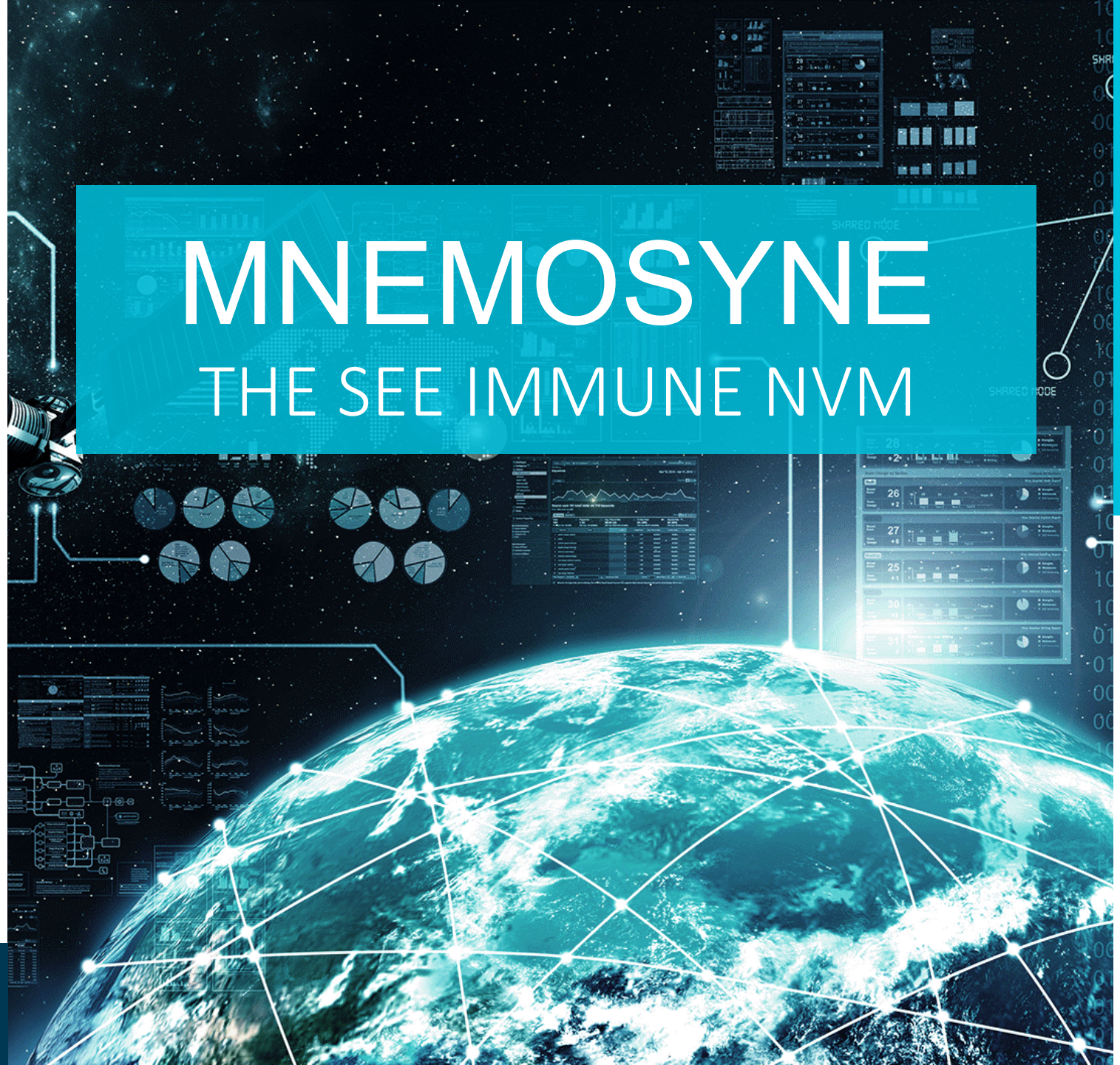


MNEMOSYNE

THE SEE IMMUNE NVM

Jérôme SALLES

ESTEC, Netherlands, 6th SEFUW

March, 25th, 2025

AGENDA

- Context
- Requirements
- Developments
- Tests
- Results

CONTEXT

1 CONTEXT

European program

European Commission

- EU Horizon 2020 program for research and innovation
- Developed by 3D PLUS in the frame of a research and innovation program
- Guaranteed supply chain - fully manufactured in Europe
- **Users' Cross validated** by a consortium of Radiation Effects and European Space Electronics experts

1 CONTEXT

1 Consortium, 6 partners

European Commission

3plusD a HEICO company

imec

TRAD Tests & radiations a HEICO company

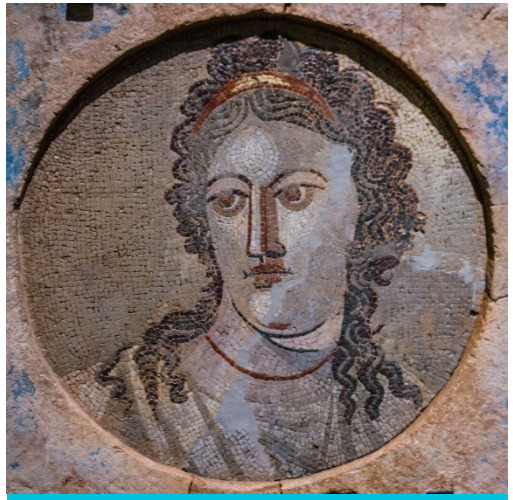
NanoXplore

beyond gravity

REQUIREMENTS

MNEMOSYNE

The Memory Goddess



Mosaïc from Tarragone national museum

- Mnemosyne, daughter of Ouranos and Gaia. She is the goddess of memory in Greek mythology. She embodies knowledge and the transmission of wisdom.

- Mother of the nine Muses, through them, she becomes the source of inspiration for the arts and sciences. Without her, all knowledge would be doomed to oblivion.

2 MNEMOSYNE REQUIREMENTS

More details

- **Non volatile memory ASIC with SPI and EEPROM interfaces**
- **High Density**
- **Radiation Immune**
- **Applications:**
  - FPGA configuration bitstream storage
  - Boot code storage for microcontrollers and micro processors
- Strengthen the reliability (temperature, data retention, life time) to reach space requirements.
- Identify and analyse the process & circuit radiation sensitivity and verify the memory cells SEU/SEL immunity on the STT-MRAM FDSOI process
- Mitigate the risks of TID which degrade the performance and lead to functional failure at component level
- Mitigate the risk of SET/SEFI leading to component level data loss or functional error
- Design the control logic and interface around the MRAM to adapt to space design requirements

DEVELOPMENTS

MNEMOSYNE DEVELOPMENT

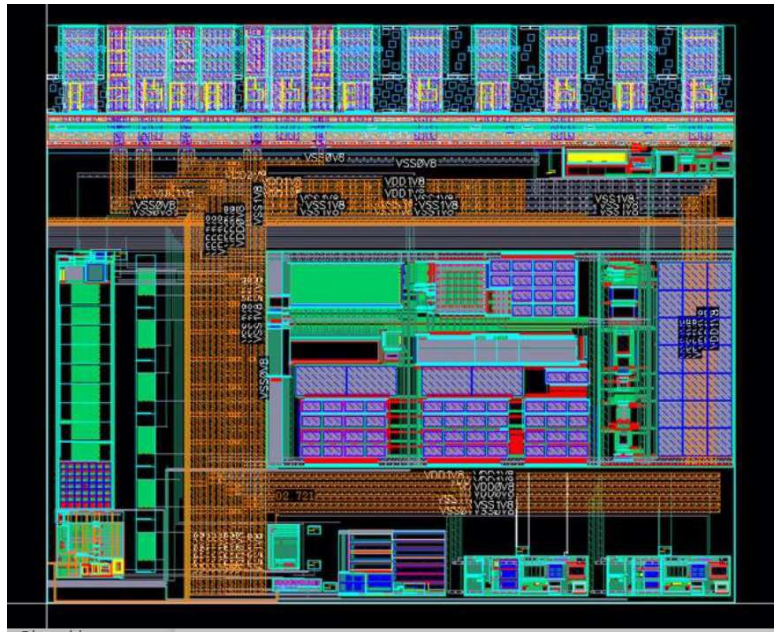
Technologies

- **22 nm FDSOI Technology**
  - **SEL immune chip**
  - Existing **Rad Hard Digital library**
  - **Mature, reliability proven** and commercially available in Europe process
  - **40% die scaling, and 70% power saving vs 28 nm**
- **STT-MRAM** process provides a **SEU immune Memory cell**
- **Rad Hard design techniques** on analog and power blocks, control logic and interfaces
- **Stacking of multiple** chips to achieve higher densities (**up 8 dies for 1Gbits**)

MNEMOSYNE DEVELOPMENT

Analog design

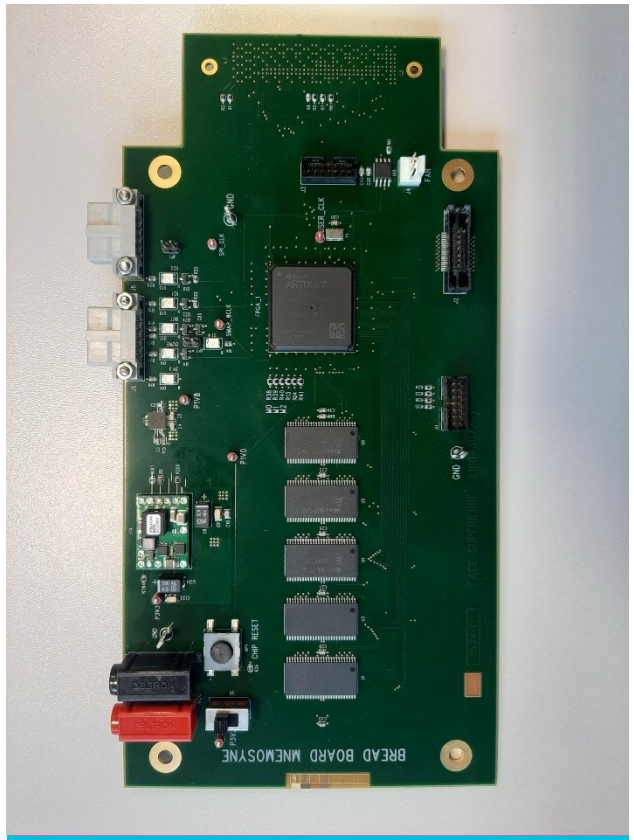
imec



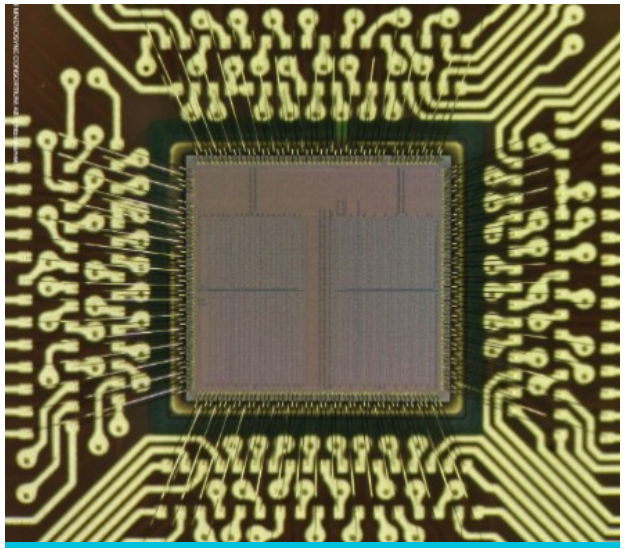
- Hard macro PMU
- 1.8V to 0.8V LDO
- 0.8V RC oscillator
- Power up/down sequence control
- Trimming of IVREF & RC osc

MNEMOSYNE DEVELOPMENT

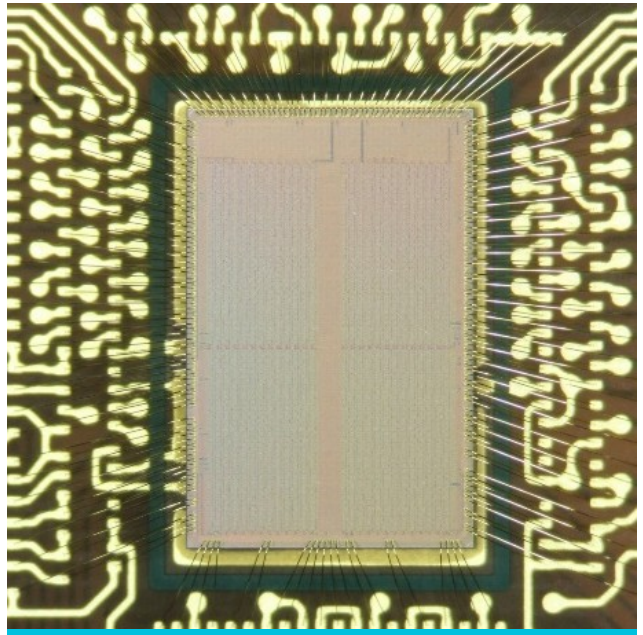
Three phases



Breadboard

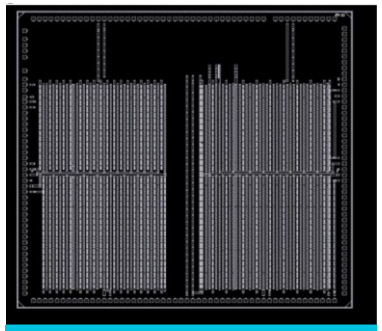


Test vehicle 64Mb

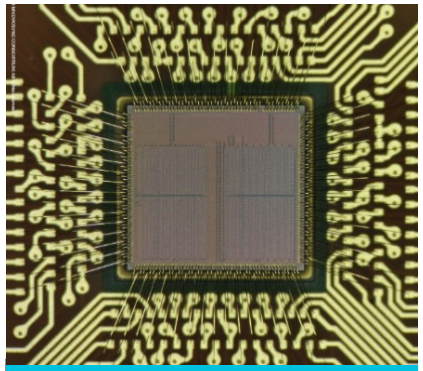


Prototype 128 Mb

TV AND PROTYPE DESIGN



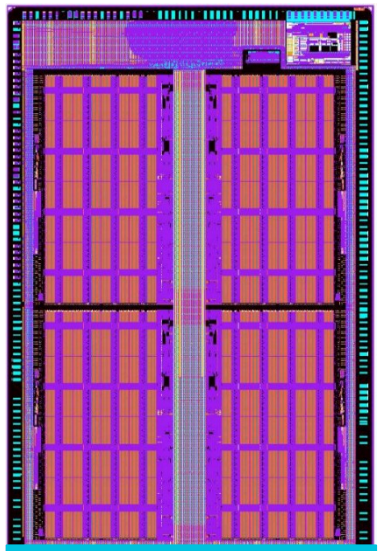
64 Mbit TV layout



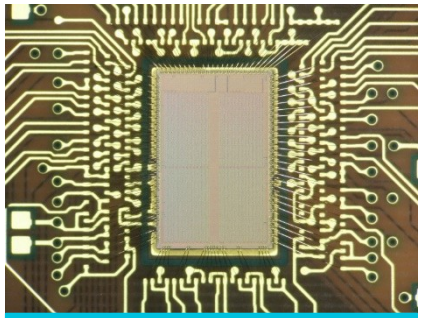
64 Mbit TV bonded

- **Test Vehicle**
- 186 pads
- All functionality can be bypassed
- Each module can be characterized individually
- SPI 1.8v & 3.3v

- **Prototype**
- 225 pads
- PMU can be bypassed
- SPI 1.8v & 3.3v interfaces
- EEPROM 3.3v interface added



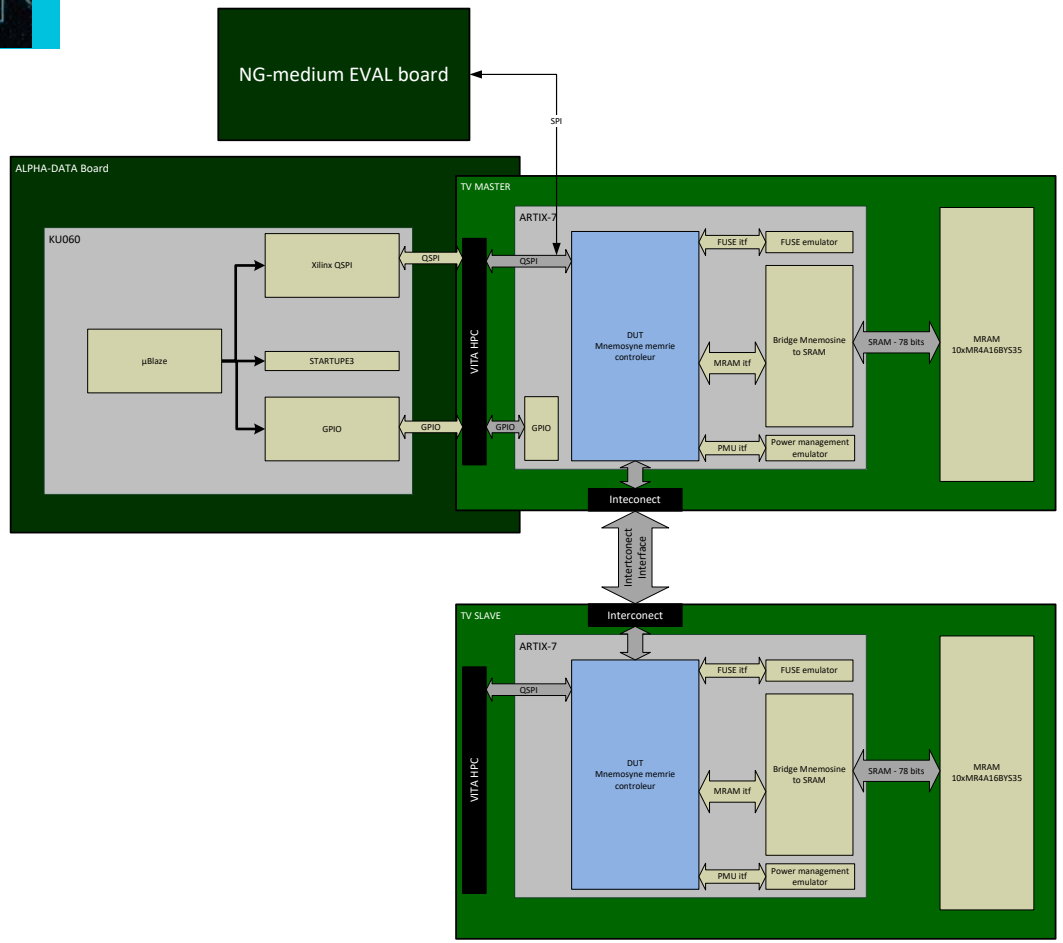
128 Mbit Proto layout

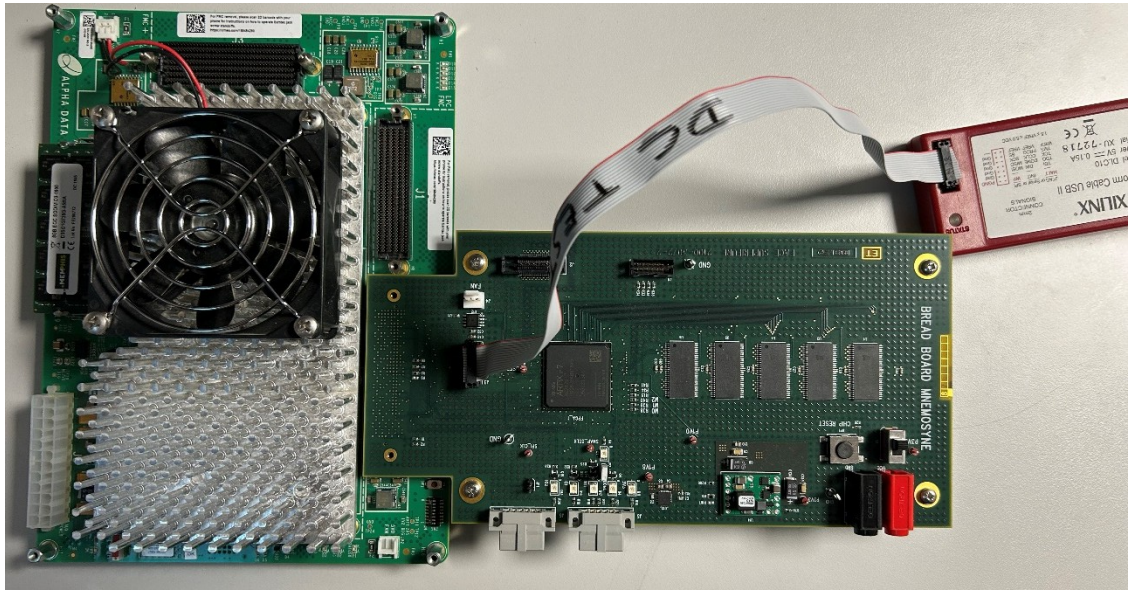


128 Mbit Proto bonded

MNEMOSYNE DEVELOPMENT

Braedboards





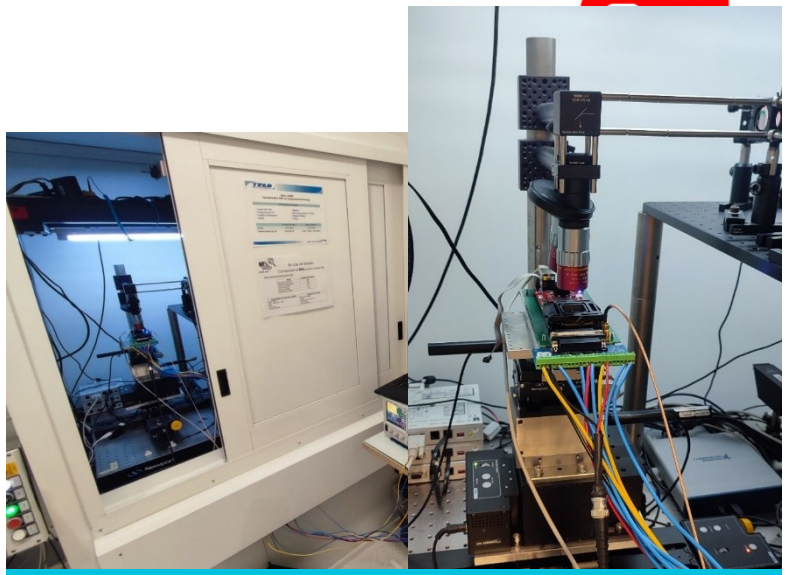
- Test boot of NG-MEDIUM
- Test boot of XQRKU060 FPGA
- Use XQRKU060 FPGA as hardware validation platform

TESTS

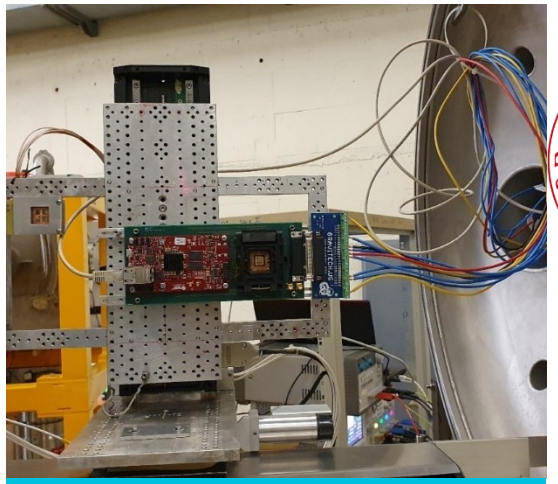
4 TESTS

Test Vehicle

- TID > 100 krad(Si)
- SEL/SEU LETh > 60 MeV.cm²/mg
- 1000h Life test passed with 3Θ measurements
- Overall Functional and Performance validated
- Laser tests to pinpoint the location of the SEE sensitivity source
- Functional issue found during campaign, corrected for prototype run
- **Radiation and reliability performances achieved**



MNEMOSYNE TV at TRAD laser facility

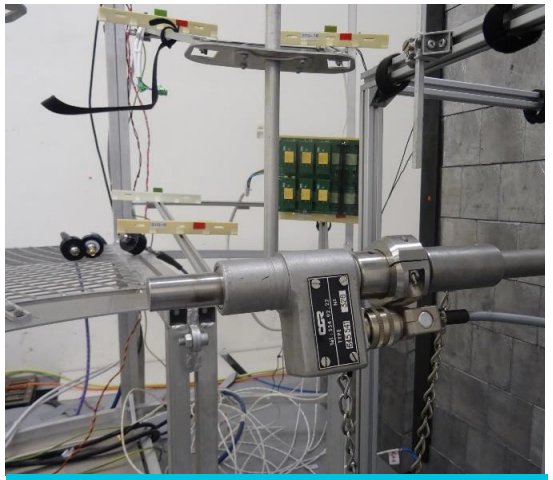


SIRAD test setup

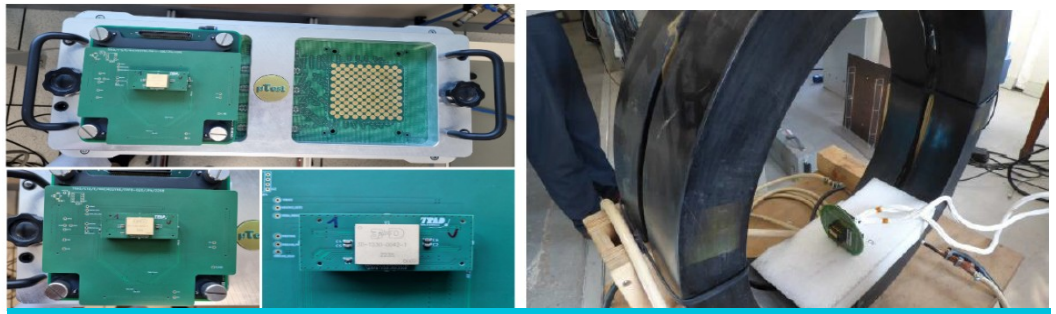
4 TESTS

TID and Magnetic tests

- **TID performed by TRAD using 60Co source at 310 rad/h (low dose rate)**
  - TID level > 100 krad(Si) has been validated
- **Magnetic Test**
  - Static Magnetic Field > 1000 Gauss
  - Power Frequency Magnetic Field > 1000A/m



TID test setup



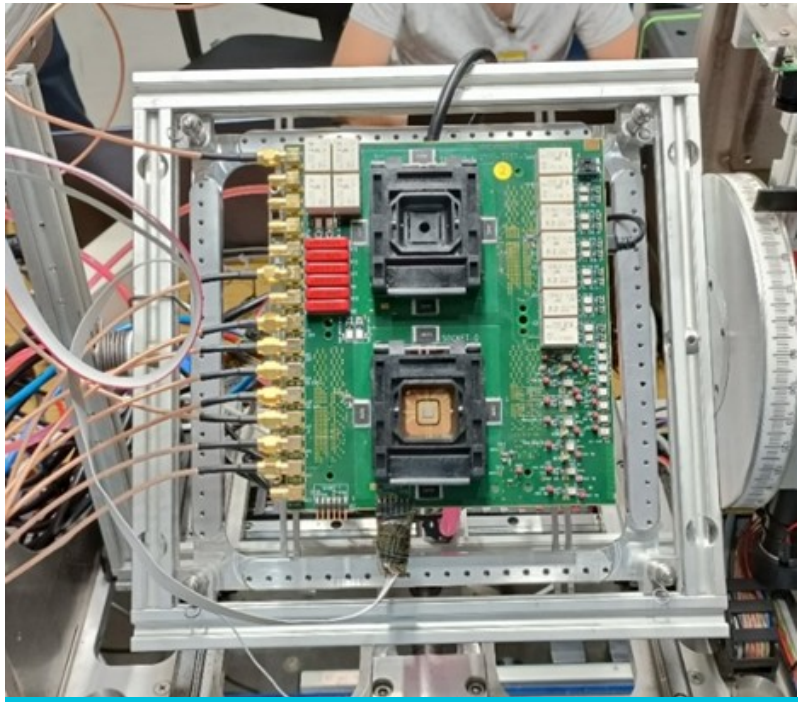
Magnetic test setup

TRAD Tests & radiations a HEICO company

TESTS

SEE tests

- Beam test to characterize the ASIC SEE response at LNL, Italy and UCL, Belgium
  - SEL LETth > 60 MeV.cm²/mg
  - SEU LETth > 60 MeV.cm²/mg
- Latest SEE campaign (June 2024) at RADED, Finland
  - SEL LETth > 85 MeV.cm²/mg
  - SEFI LETth > 85 MeV.cm²/mg
  - SEU LETth > 85 MeV.cm²/mg
  - SET LETth > 85 MeV.cm²/mg



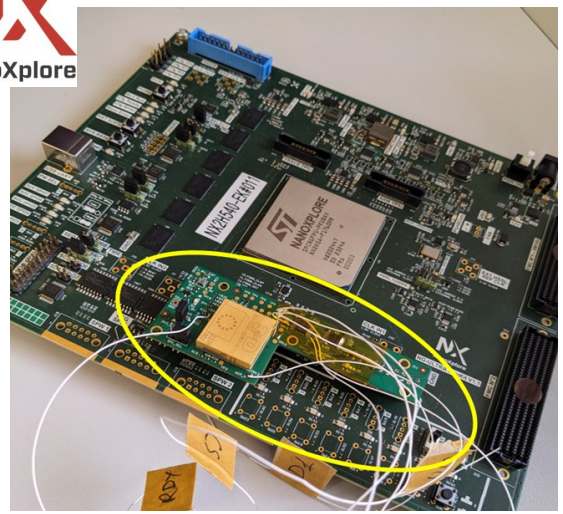
SEE test bench

4 TESTS

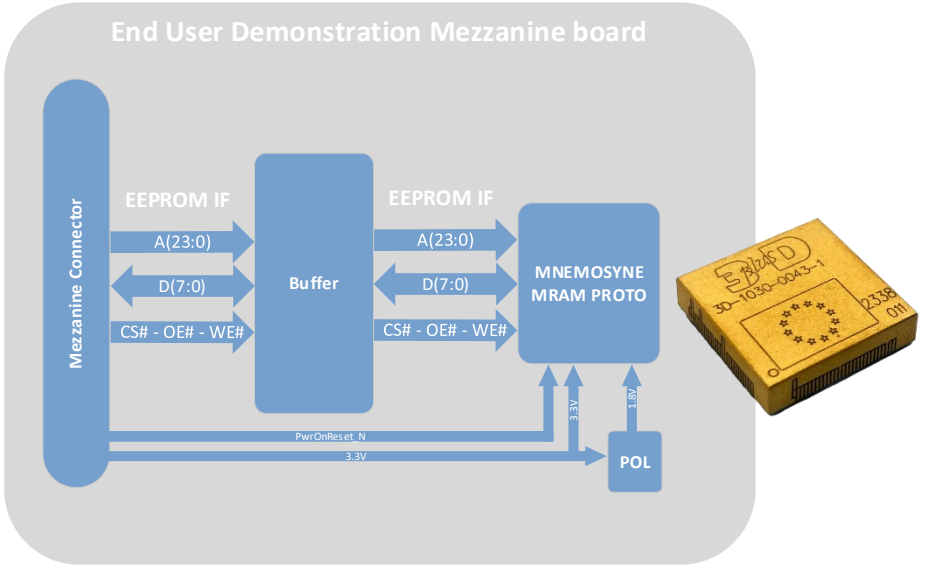
Functional tests

- **NG MEDIUM** : Successful operation
- **NG ULTRA 300** : in progress, first analysis shown positive feasibility
- **NG ULTRA** : Flash boot time: miss match boot time performances.

NanoXplore



beyond gravity



The functional tests performed by Beyond Gravity show that the MNEMOSYNE memory ASIC works as expected with a processor using the EEPROM interface

RESULTS

MNEMOSYNE ASIC

Radiation & Reliability Results

- SEL sensitivity:
  - Immune to SEL up to at least LETth > 85 MeV.cm²/mg
- SEFI sensitivity:
  - **Immune to SEFI** up to at least LETth > 85 MeV.cm²/mg
- SEU sensitivity:
  - **Immune to cell SEU** up to at least LETth ≥ 85 MeV.cm²/mg
- SET sensitivity:
  - **EEPROM interface: immune to SET** up to at least LET ≥ 85 MeV.cm^2.mg^{-1}
  - **1.8V SPI interface: immune to SET** up to at least LET ≥ 85 MeV.cm2.mg-1
  - **3.3V SPI interface:** sensitive to SET in read mode only (no write errors observed)
- TID sensitivity:
  - No performance degradation > 100 krad(Si)
- Magnetic sensitivity:
  - No functional degradation > 1000 Gauss*
- Life test:
  - No functional degradation after 1000 hrs at +125 °C

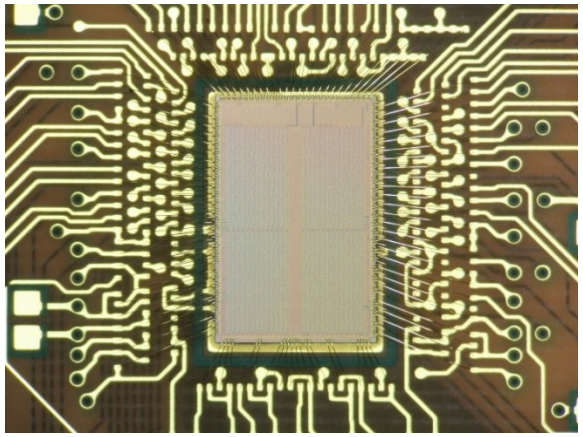
MNEMOSYNE ASIC

Functional Results

- SPI 1.8v interface
  - Quad SPI up to 100MHz fast read
  - Octal SPI up to 50MHz fast read
  - 512 Mbits or 1 Gbits density
- SPI 3.3v interface
  - Quad SPI up to 100MHz fast read
  - 512 Mbits or 1 Gbits density
- EEPROM 3.3v Interface
  - 128 Mbits density

- Boot LEON2 micro controleur
- Boot Xilinx FPGA
- Boot Nanoxplore FPGA
- Issue to boot Nanoxplore SOC

CONCLUSION



This memory ASIC is a beautiful tribute to Mnemosyne goddess.

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