Verification of Co-60 TID testing representativeness for EEE components flown in the Jupiter environment

Project Name: ECo-60
ESA Contract No: RFQ/3-13975/13/NL/PA
Company Details: LIP

M. Pinto, P. Assis, M. Ferreira and P. Gonçalves

ESA-CNES Final Presentation Days:
Space Environments and Radiation Effects on EEE components

8 March 2017

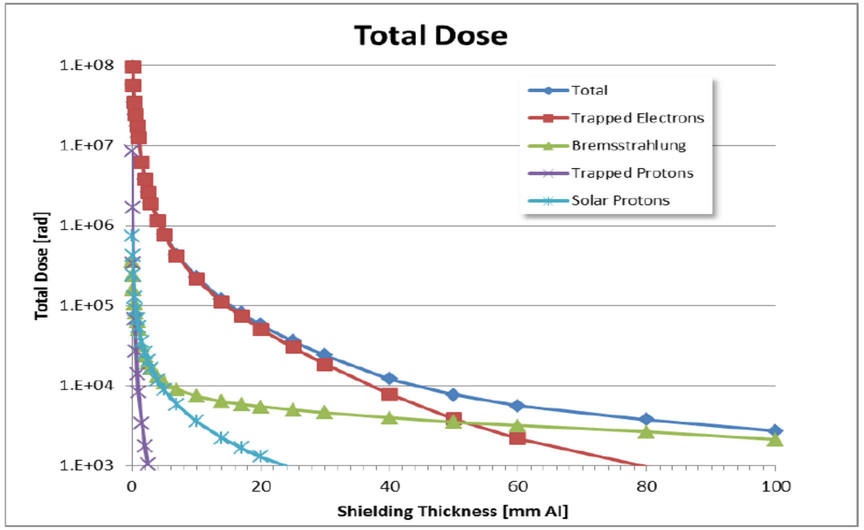
Outline

- Motivation
- General Procedures
  - Components
  - Irradiation Campaigns
  - Test Setup
- Radiation Test Plan
- Irradiation Results
- Conclusions

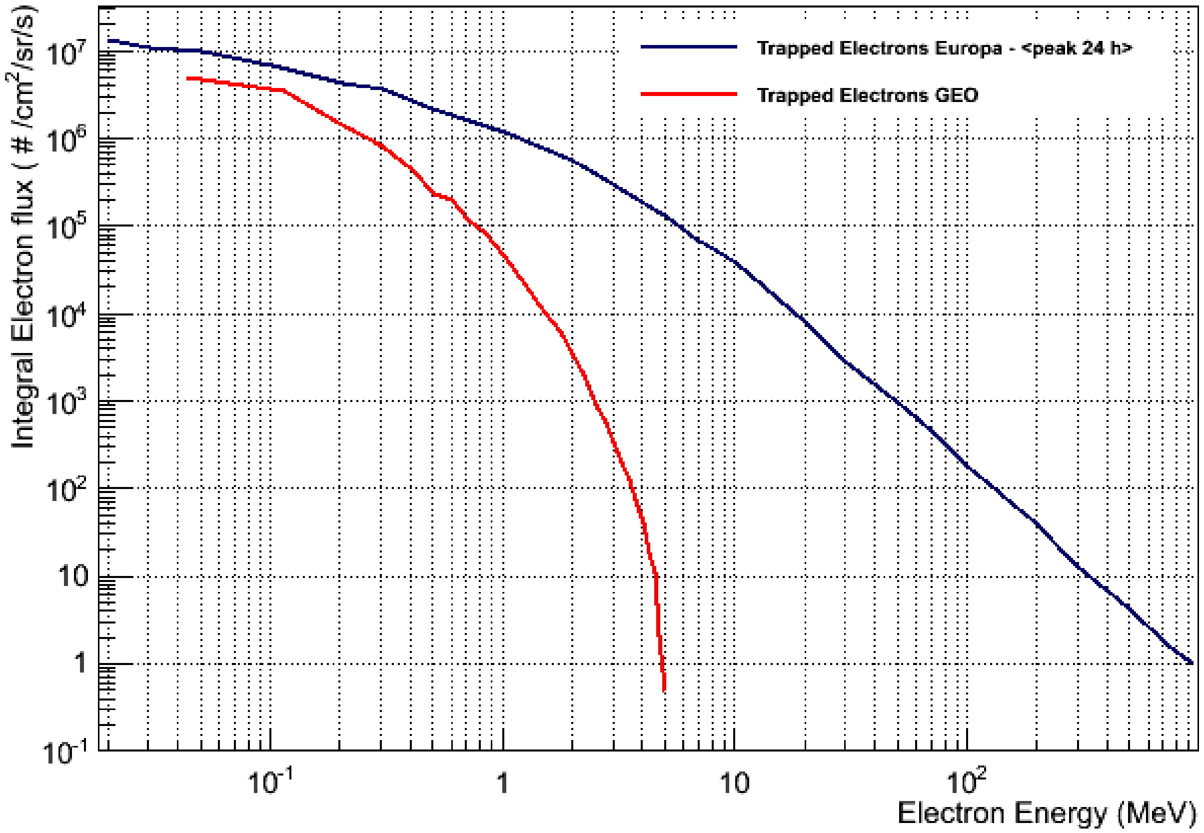
Motivation (1)

- ESA Next Class-L mission (JUICE) is to be flown to Jupiter in 2022.

- Unlike in Earth GEO, the Jovian system radiation environment is dominated by high energy electrons.

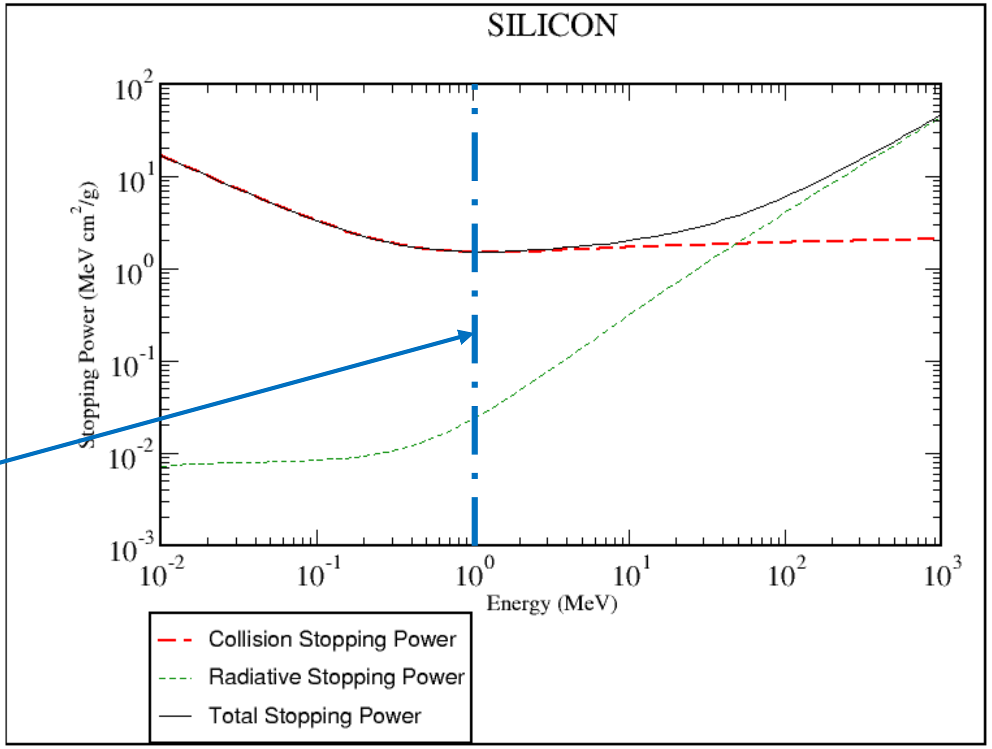


Dose in Si as a function of spherical Al shielding as calculated by SHIELDOSE-2Q for the entire JUICE mission.



Motivation (2)

- ❑ The current standard TID testing utilizes Co-60 sources
(Total Dose Steady-State Irradiation Test Method" (ESCC Detail Specification No. 22900, Issue 2, August 2003))



- ❑ For higher energies radiative energy loss increases

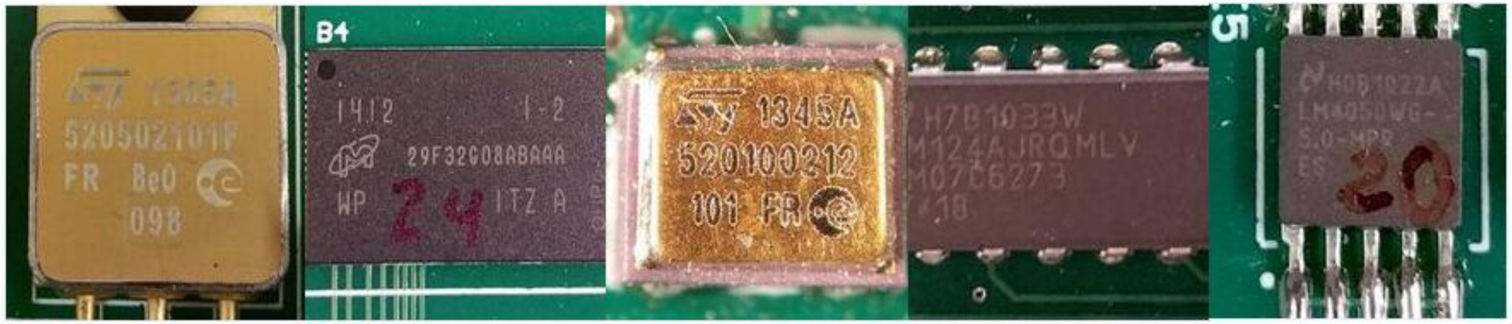
Electron Energy (MeV)	Stopping Power (MeV/g/cm²)		
	Collision	Radiation	Total
1	1,51	2.4×10^{-2}	1,53
5	1,62	1.4×10^{-1}	1,76
10	1,70	0,31	2,01
30	1,81	1,11	2.92
50	1,86	1,94	3.80

Objective: Verification of Co-60 TID testing representativeness for EEE components flown in the Jupiter environment

General Procedures – Components (1)

- 5 Components

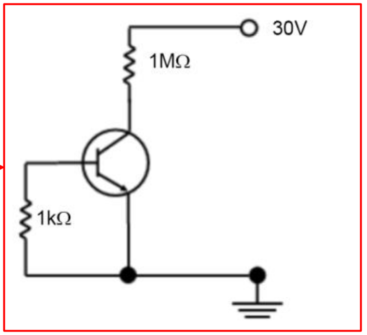
<table>
<tr><th rowspan="2">Component Type</th><th colspan="3">Component</th></tr>
<tr><th>Reference</th><th>Manufacturer</th><th># of Parameters</th></tr>
<tr><td>Transistor (discrete MOS/CMOS)</td><td>STRH100N10</td><td>STMicroelectronics</td><td>6</td></tr>
<tr><td>FLASH-NAND Memory (MOS/CMOS IC)</td><td>MT29F32G08ABAAA WP-ITZ</td><td>Micron</td><td>8+2</td></tr>
<tr><td>Transistor (Bipolar)</td><td>2N2222</td><td>STMicroelectronics</td><td>4+4</td></tr>
<tr><td>OPAMP (Analog ICs non ELDRS)</td><td>LM124</td><td>Texas Instruments</td><td>11</td></tr>
<tr><td>Voltage Reference (Analog ICs displaying ELDRS)</td><td>LM4050WG5.0-MPR</td><td>Texas Instruments</td><td>5</td></tr>
</table>



- Different biasing conditions

Unbiased

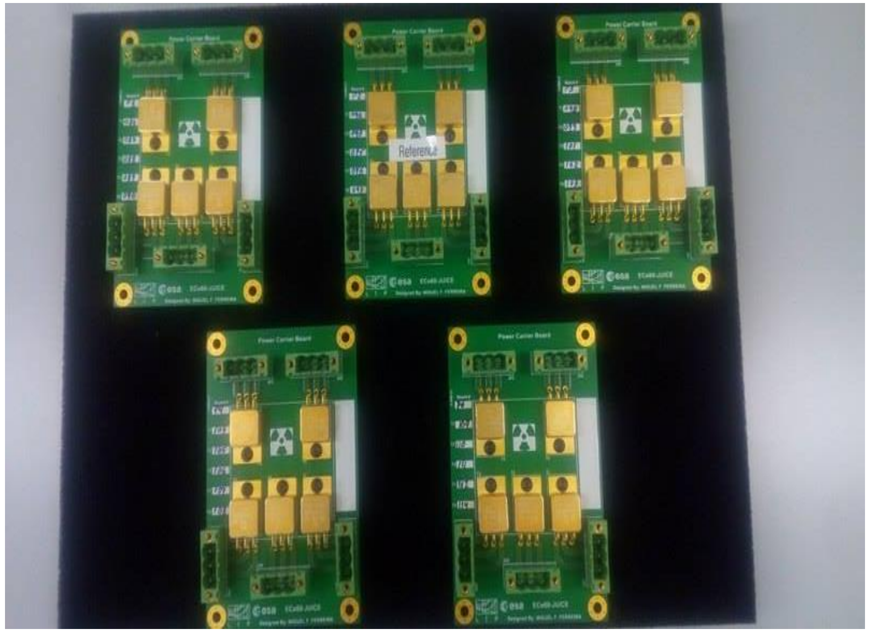
Static bias with V=3.3V



Unbiased

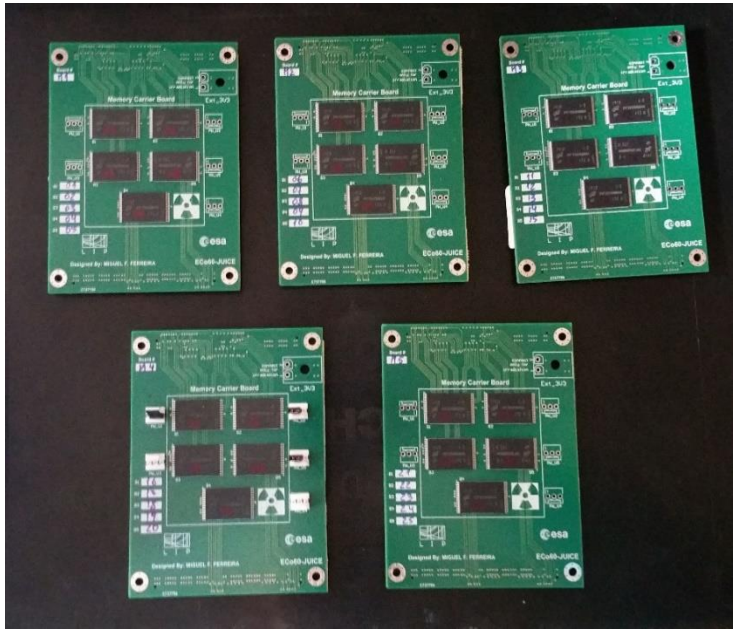
General Procedures – Components (2)

Power Carrier Boards



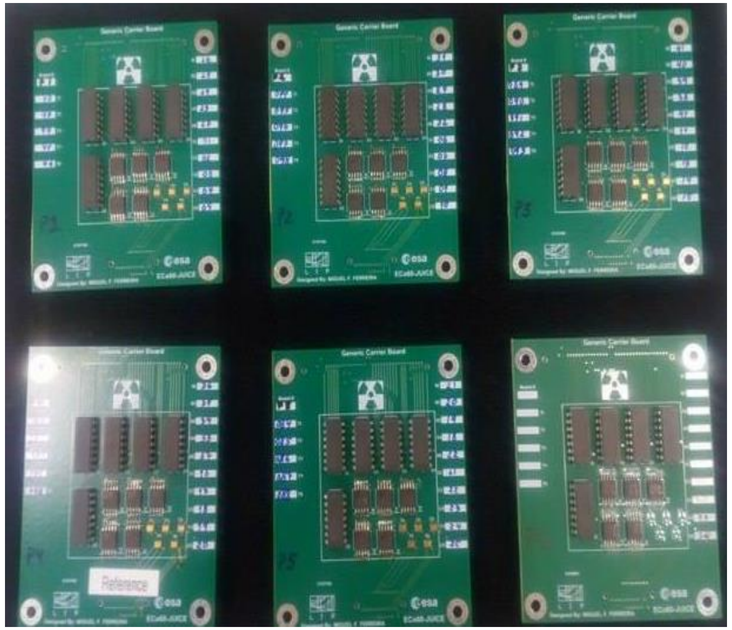
Transistor (discrete MOS/CMOS)
STRH100N10

Memory Carrier Boards



FLASH-NAND Memory (MOS/CMOS IC)
MT29F32G08ABAAAWP-ITZ

Generic Carrier Boards



Transistor (Bipolar) 2N2222
OPAMP Analog ICs non ELDRS LM124
Voltage Reference Analog ICs displaying ELDRSLM4050

1 board type irradiated per campaign
1 reference across campaigns (always the same)

General Procedures – Radiation Test Facilities

Facility	Irradiation type	Irradiation Code	Dose Rate (krad/h)	
ESA-ESTEC	Co60	Co1	0.28 krad/h	
Campus Tecnológico e Nuclear (CTN-Lisbon)	Co60	Co2	24 krad/h	
			Nominal	Corrected
Hospital Santa Maria (HSM-Lisbon)	12 MeV e^-	Eb1	24 krad/h	21.6 krad/h
RADEF	12 MeV e^-	Eb2	24 krad/h	21.6 krad/h
RADEF	20 MeV e^-	Eb3	24 krad/h	22.8 krad/h

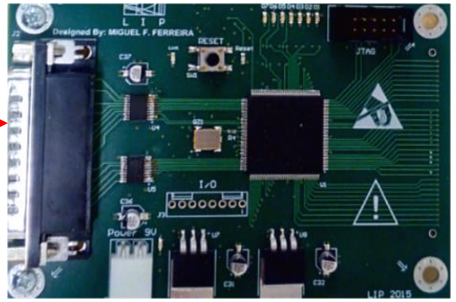
All doses were calculated in water with a resolution better than 10%. In the case of electrons the dose had to be converted from dose at maximum peak to dose at surface.

General Procedures – Test Setup (1)

Measuring Units

Control Board

Digio

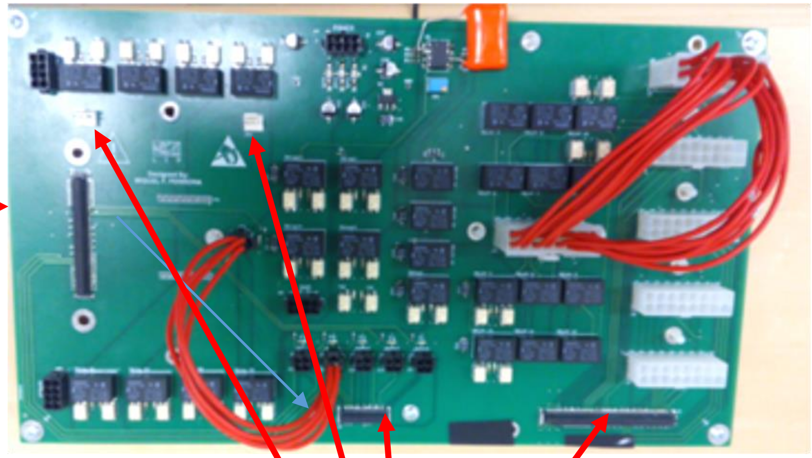


Relay control

SMU

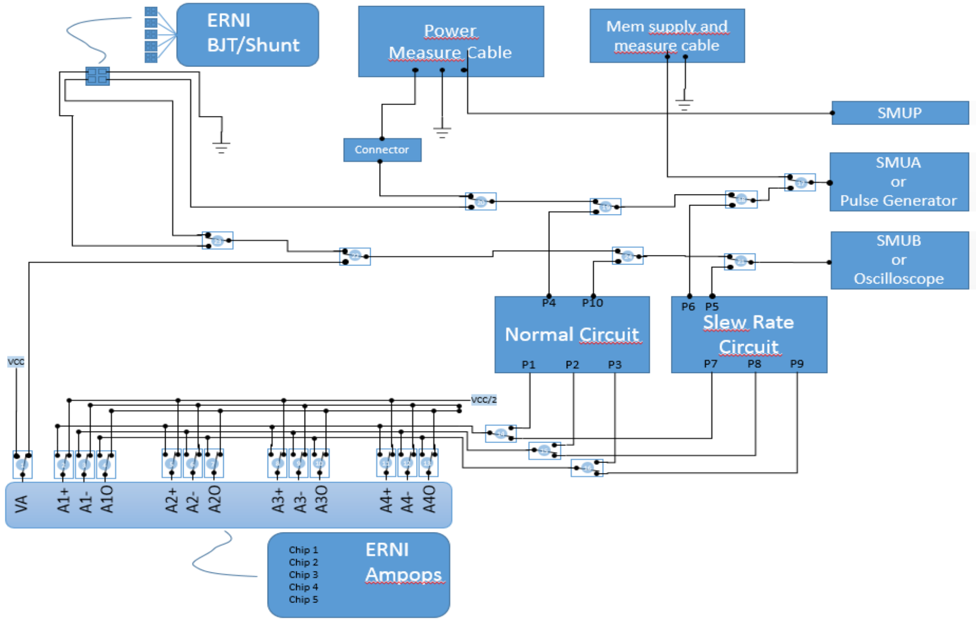
SMU

Test Board



Carrier boards

Python scrypt controls Keythley units including digio.



General Procedures – Test Setup (2)

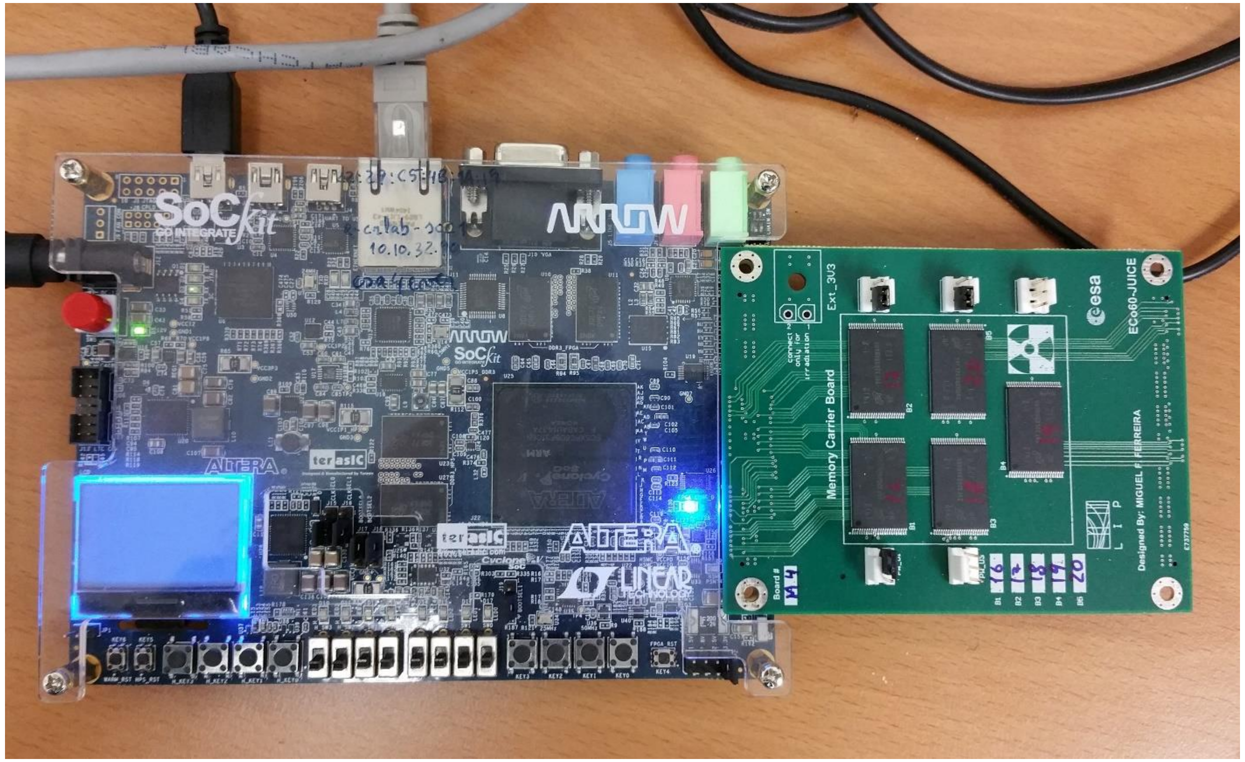
Test system developed @ LIP
Based on SOC development board from ARROW/ALTERA

FPGA + microprocessor in one chip.

FPGA firmware writes, reads and tests the memory;

Microprocessor runs Linux. Controls the system and stores the data for offline processing.

Data: number, location and content of cells with errors



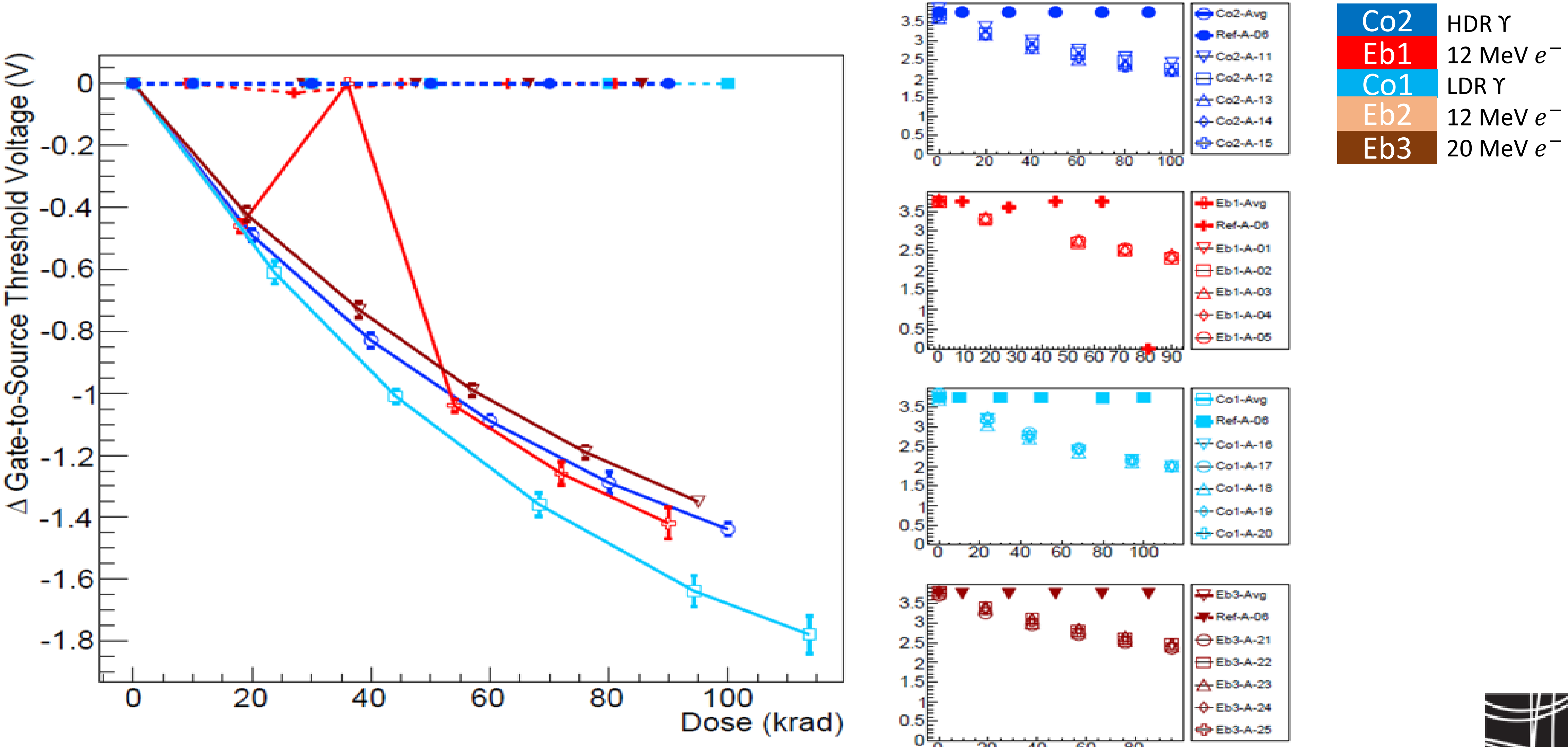
Radiation Test Plan (1)

- 3 Phases
  - Pre-Irradiation
    - Measuring Setup Development
    - Pre-Measurement of key parameters of the components
  - Irradiation
    - 20 krad steps irradiations up to 100 krad
    - Components measured before and between irradiation steps
    - Reference measured at several points for comparison
  - Annealing (on-going)
    - Every week during the first month
    - Every month during the last 8 months (ends in July)

# of irradiated components

Component	Co1	Co2	Eb1	Eb2	Eb3
Transistor (discrete MOS/CMOS)- STRH100	5	5	5	0	5
FLASH-NAND Memory (MOS/CMOS IC) - MT29	5	5	5	0	0
Transistor (Bipolar) - 2N2222	5	5	5	2	0
Analog ICs non ELDRS – LM124	5	5	5	5	5
Analog ICs displaying ELDRS – LM4050	5	5	5	5	5

Results – Transistor (discrete MOS/CMOS) STRH100 (1)



Similar degradation for electrons and gammas

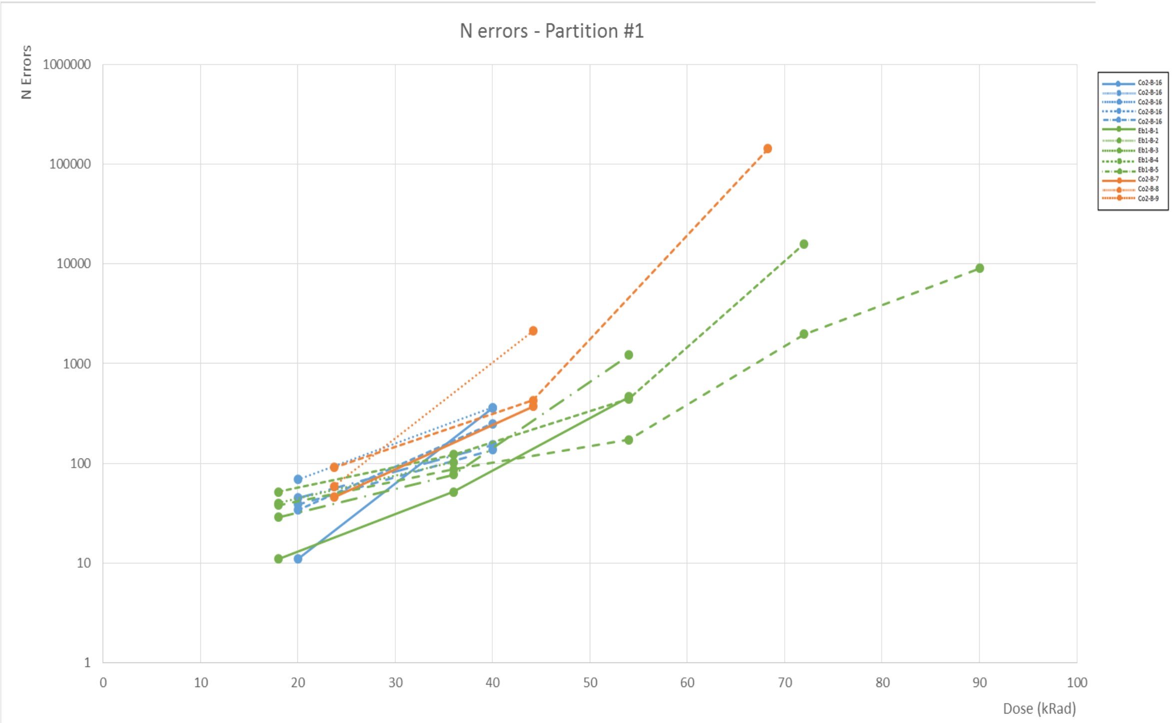
Results – Transistor (discrete MOS/CMOS) STRH100 (2)

Characteristics	Test Conditions	Status
Gate-to-Source Leakage Current 1	VGS=20V, VDS=0V	No apparent degradation
Gate-to-Source Leakage Current 2	VGS=-20V, VDS=0V	No apparent degradation
Drain Current	VDS=40V, VGS=0V	Radiation degradation Similar for electrons and gammas
Gate-to-Source Threshold Voltage	VDS≥VGS ID=1mA	Radiation degradation Similar for electrons and gammas
Static Drain-to-Source On Resistance	VGS=12V, ID=24A	No apparent degradation
Source-to-Drain Diode Forward Voltage	VGS=0V, ISD=48A	No apparent degradation

Results – FLASH-NAND Memory (MOS/CMOS IC) MT29 (1)

(black)	Unresponsive after irradiation step
XYZ (green)	Responsive after irradiation step
(yellow)	Data not read
(grey)	Not Available

	UUID	Irradiation Code	Dose (krad)				
			20	40	60	80	100
Sample	Co2-B-16	Y HDR					
	Co2-B-17						
	Co2-B-18						
	Co2-B-19						
	Co2-B-20						
			18	36	54	72	90
	Eb1-B-1	12 MeV e^- HDR					
	Eb1-B-2						
	Eb1-B-3						
	Eb1-B-4						
	Eb1-B-5						
			23.04	42.87	66.27	91.60	110.3
	Co1-B-6	Y LDR					
	Co1-B-7						
	Co1-B-8						
	Co1-B-9						
	Co1-B-10						

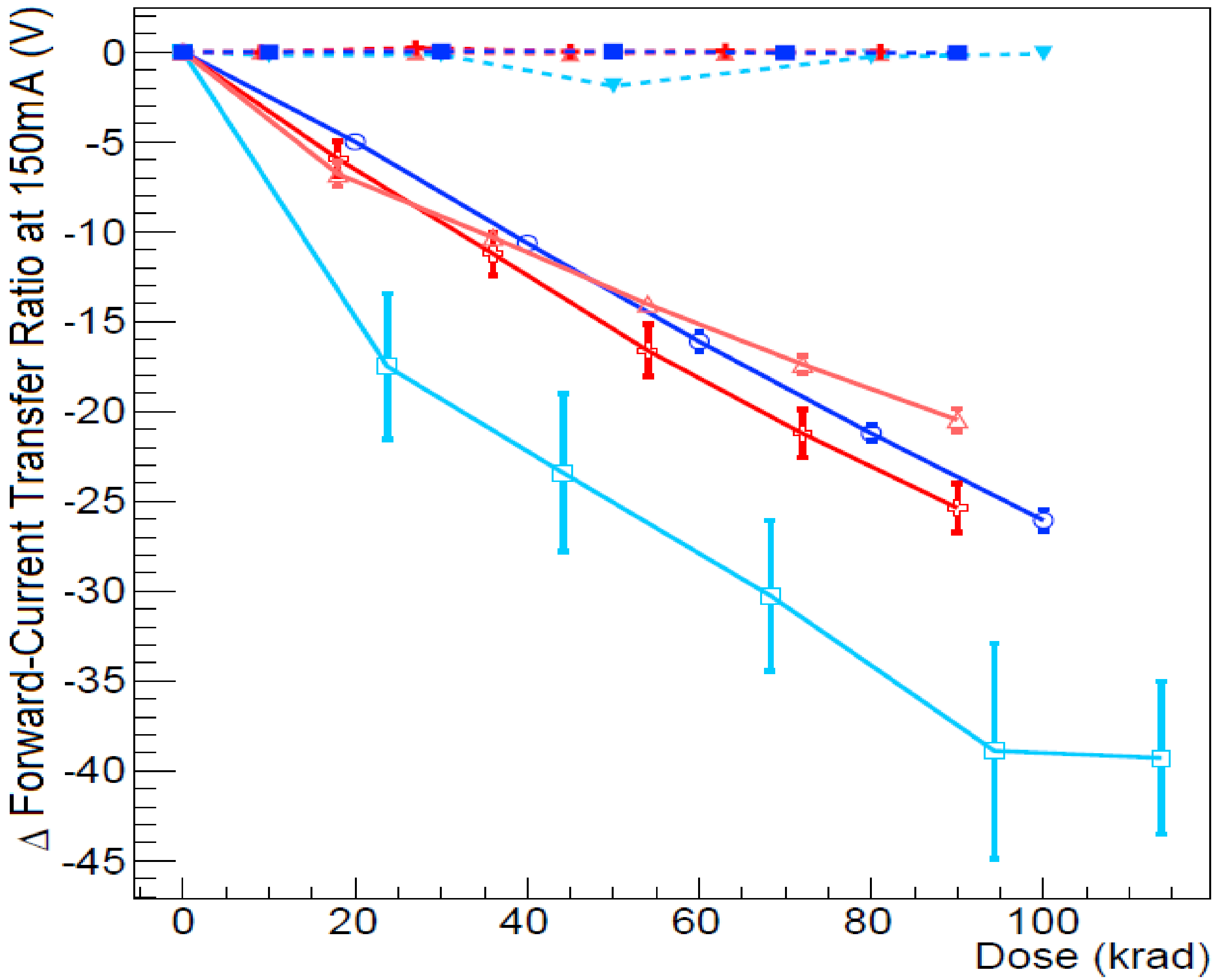


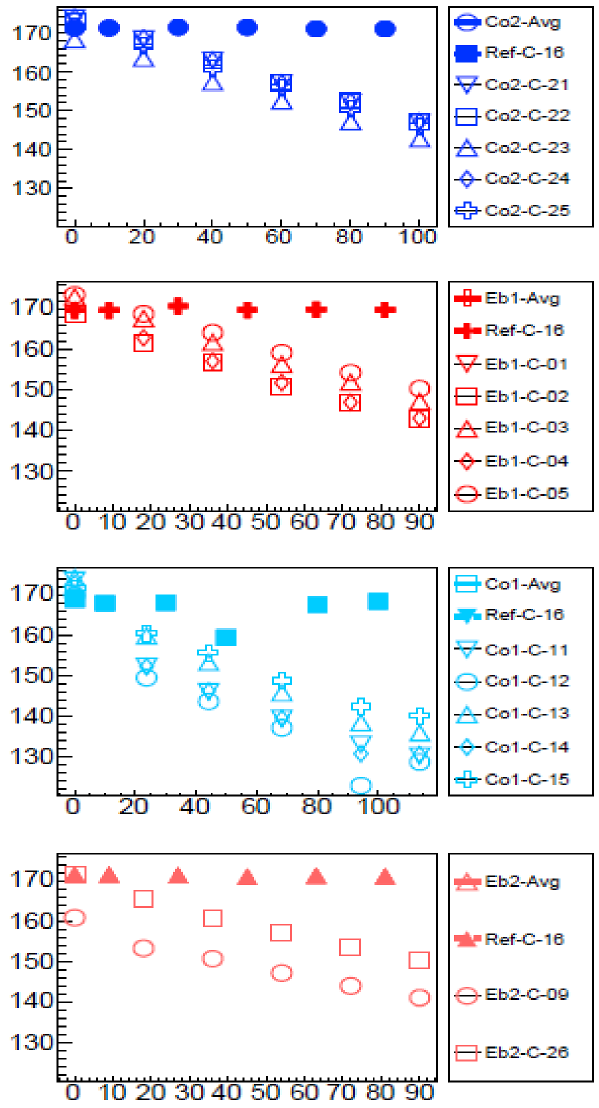
Memories show less sensitivity to the electron beam

Results – FLASH-NAND Memory (MOS/CMOS IC) MT29 (2)

Functional Tests			
Partition #	Pattern	Type of test	Status
1	All ‘0’	Static	Radiation degradation Less sensitive to electrons.
2	All ‘1’	Static	No apparent degradation
3	Checkerboard	Static	Radiation degradation Less sensitive to electrons.
Power Supply tests			
Current			Status
Idle			No apparent degradation
Active			No apparent degradation

Results – Transistor (Bipolar) 2N2222 (1)





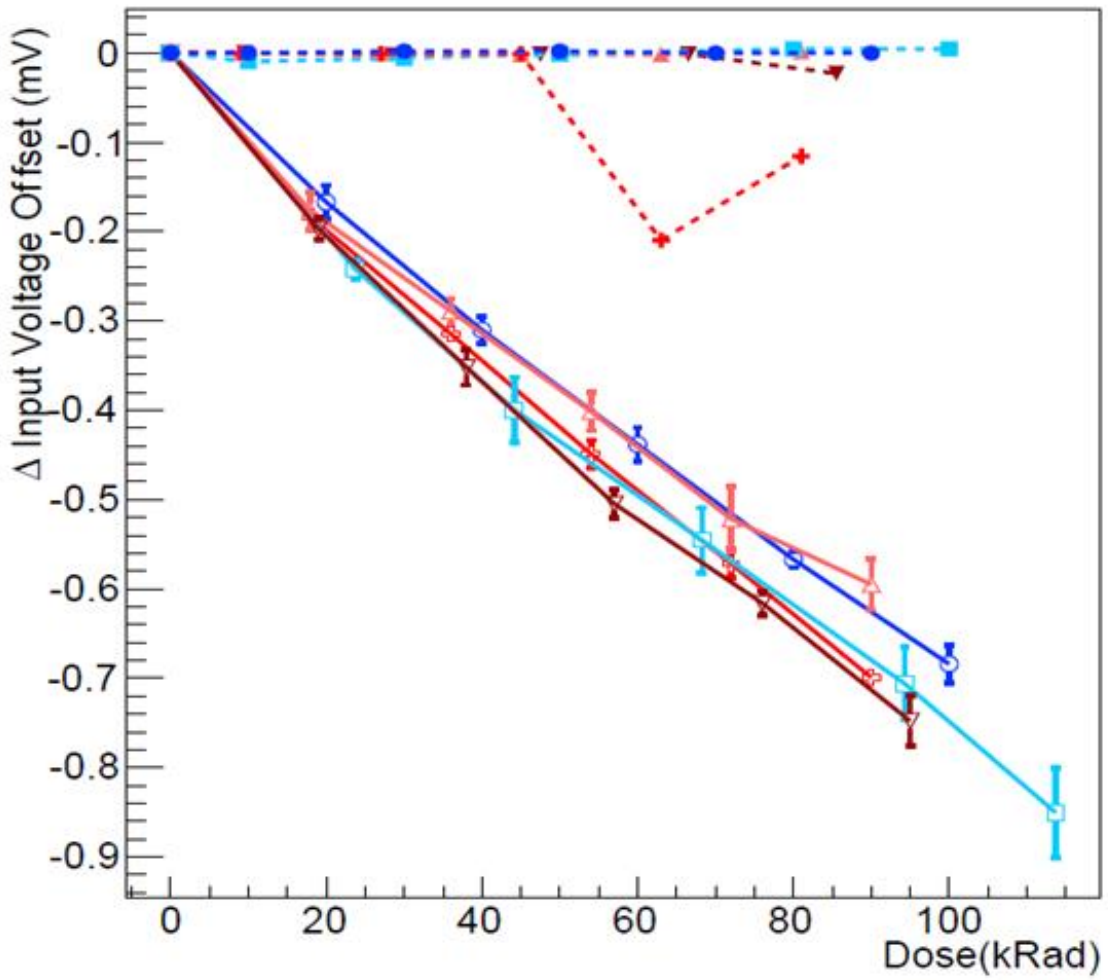
Co2	HDR ϒ
Eb1	12 MeV e^-
Co1	LDR ϒ
Eb2	12 MeV e^-
Eb3	20 MeV e^-

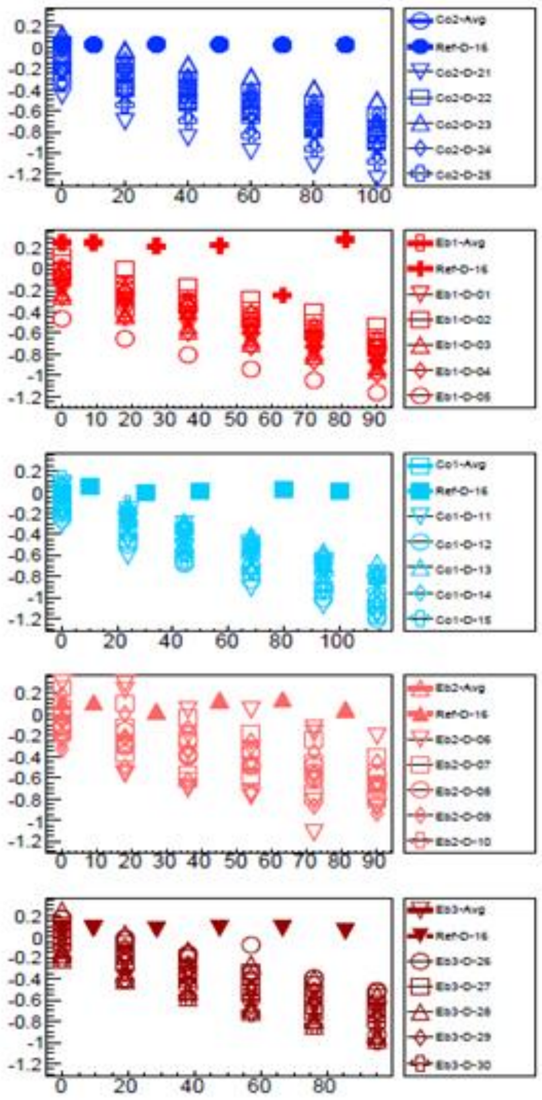
Similar degradation for electrons and gammas - ELDRS

Results – Transistor (Bipolar) 2N2222 (2)

Characteristics	Test Conditions	Status
Collector-Base Cut-off Current	V_{CB} = 60V	No apparent degradation
Emitter-Base Cutoff Current	V_{EB} = 3V	No apparent degradation
Collector-Emitter Saturation Voltage	I_C = 150mA, I_B = 15mA	No apparent degradation
Base-Emitter Saturation Voltage	I_C = 150mA, I_B = 15mA	No apparent degradation
Forward-Current Transfer Ratio	V_{CE} = 10V, I_C = 100µA	Radiation degradation Similar for electrons and Co60 ELDRS
	V_{CE} = 10V, I_C = 10mA	Radiation degradation Similar for electrons and Co60 ELDRS
	V_{CE} = 10V, I_C = 150mA	Radiation degradation Similar for electrons and Co60 ELDRS
	V_{CE} = 10V, I_C = 500mA	Radiation degradation Similar for electrons and Co60 ELDRS

Results – OPAMP Analog ICs non ELDRS LM124 (1)

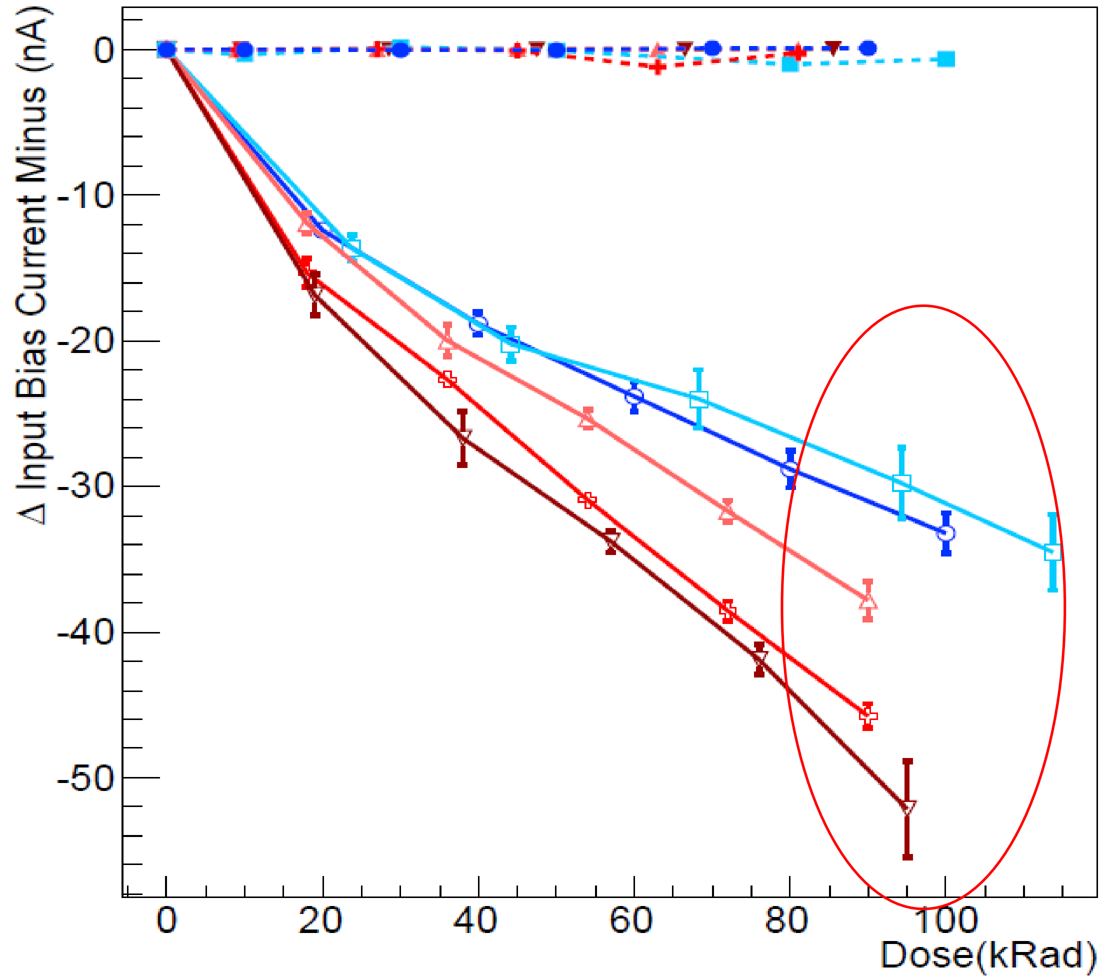


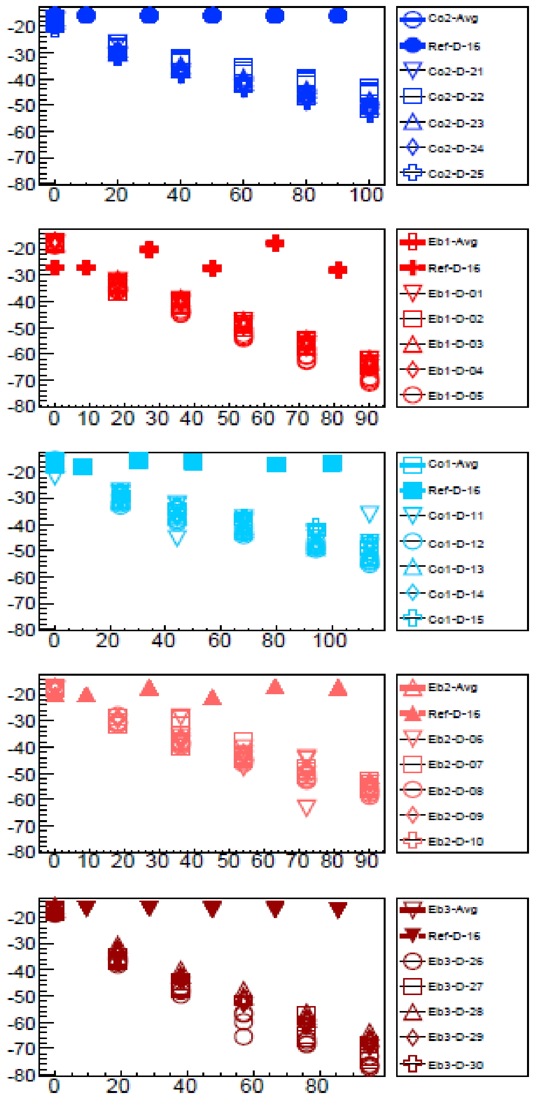


Co2	HDR ϒ
Eb1	12 MeV e^-
Co1	LDR ϒ
Eb2	12 MeV e^-
Eb3	20 MeV e^-

Similar degradation for electrons and gammas – no ELDRS

Results – OPAMP Analog ICs non ELDRS LM124 (2)





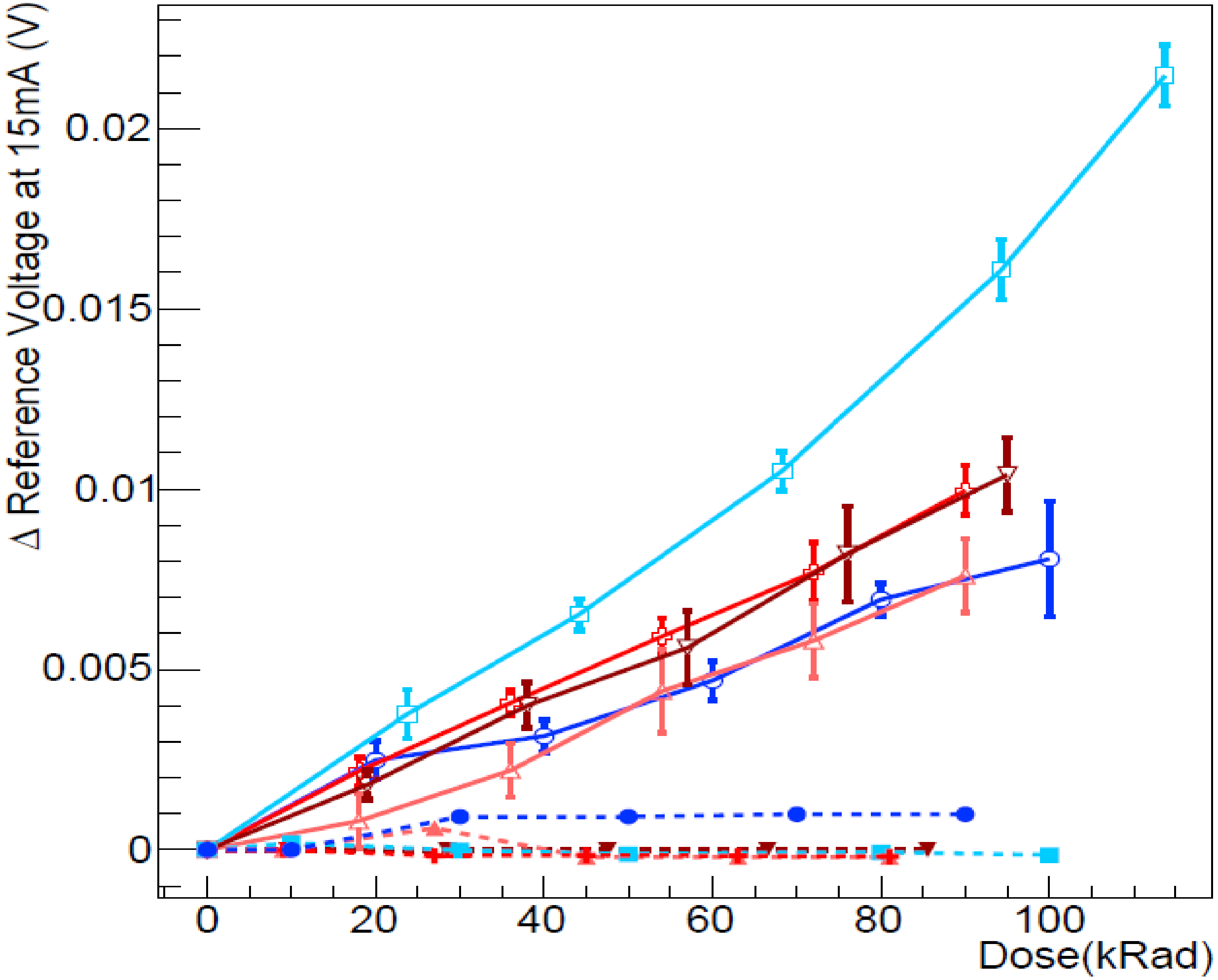
Co2	HDR γ
Eb1	12 MeV e^-
Co1	LDR γ
Eb2	12 MeV e^-
Eb3	20 MeV e^-

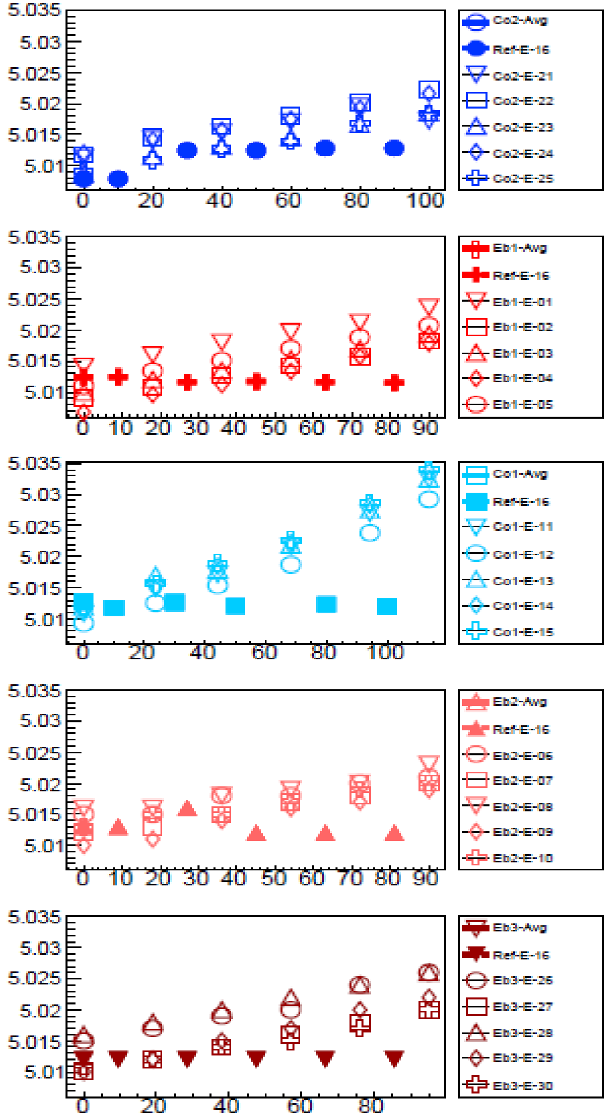
Higher sensitivity for electrons – no ELDRS

Results – OPAMP Analog ICs non ELDRS LM124 (3)

Characteristics	Test Conditions	Status
Power Supply Current	Vcc+ = 30V, Vcc- = Gnd	No apparent degradation
Input Bias Current	Vcc+ = 30V, Vcc- = Gnd, Vcm = +15V	Radiation degradation Higher degradation for electrons
Input Offset Current	Vcc+ = 30V, Vcc- = Gnd, Vcm = +15V	No apparent degradation
Input Offset Voltage	Vcc+ = 30V, Vcc- = Gnd, Vcm = 15V	Radiation degradation Similar for electrons and Co60
Common Mode Rejection Ratio	Vcc+=30V, Vcc- = Gnd, Vcm=-15V Vcc+=2V, Vcc- =-28, Vcm=-13V	Radiation degradation Higher degradation for electrons
Power Supply Rejection Ratio	Vcc- = Gnd, Vcm = +1.4V, 5V ≤ Vcc ≤ 30V	Radiation degradation Similar for electrons and Co60
Voltage Gain	Vcc+ = 30V, Vcc- = Gnd, 1V ≤ Vo ≤ 26V, Rl = 10K Ohms	No apparent degradation
Slew Rate: Rise	VCC+ = 30V, VCC- = Gnd	No apparent degradation
Slew Rate: Fall	VCC+ = 30V, VCC- = Gnd	No apparent degradation
Maximum Output Voltage Swing	VCC+ = 30V, VCC- = Gnd, VO = +30V, RL = 10KΩ	Radiation degradation Similar for electrons and Co60

Results – Reference Voltage Analog ICs displaying ELDRS LM4050 (1)





Co2	HDR ϒ
Eb1	12 MeV e^-
Co1	LDR ϒ
Eb2	12 MeV e^-
Eb3	20 MeV e^-

Similar degradation for electrons and gammas – ELDRS

Results – Reference Voltage Analog ICs displaying ELDRS LM4050 (1)

Characteristics	Test Conditions	Status
Reference Voltage	I_R=74 µA	Radiation degradation Similar for electrons and Co60 ELDRS
	I_R=100 µA	Radiation degradation Similar for electrons and Co60 ELDRS
	I_R=1 mA	Radiation degradation Similar for electrons and Co60 ELDRS
	I_R=10 mA	Radiation degradation Similar for electrons and Co60 ELDRS
	I_R=15 mA	Radiation degradation Similar for electrons and Co60 ELDRS

Conclusions

- 5 component types were selected for irradiation:
  - Power MOSFET
  - Flash-NAND Memory
  - Bipolar Transistor
  - OPAMP
  - Reference Voltage

- Components were irradiated in 5 conditions different conditions:
  - Co60 LDR (ESTEC)
  - Co60 HDR (CTN-Lisbon)
  - 12 MeV HDR (HSM-Lisbon)
  - 12 MeV HDR (RADEF)
  - 20 MeV HDR (RADEF)

- Most component parameters showed similar response to electron and ϒ TID

- FLASH-NAND Memories showed less sensitivity to electron TID

- Some of OPAMP LM124's parameters showed enchanced sensitivity to electrons

Components showed more sensitivity to Co60 than to 12 MeV and 20 MeV electron beams, except for three measured OPAMP parameters: Input Bias Current (+) and (-) and CMRR for which higher sensitivity to electrons was observed. This can be due to TNID effects.

ACKNOWLEDGMENTS

The work of P. Assis, P. was partly supported by Portuguese national funds and FEDER funds within COMPETE-Programa Operacional Factores de Competitividade through Fundação para a Ciência e a Tecnologia, Portugal.

We would like to thank Geraldine Chaumont from ST Microelectronics and Kirby Kruckmeyer from TEXAS Instruments for providing the components for the tests.

We would also like to thank Paula Campos from CTN-IST and Esmeralda Poli and Luis Prudêncio from Hospital de Santa Maria radiotherapy unit in for all their support in the irradiation campaigns.