



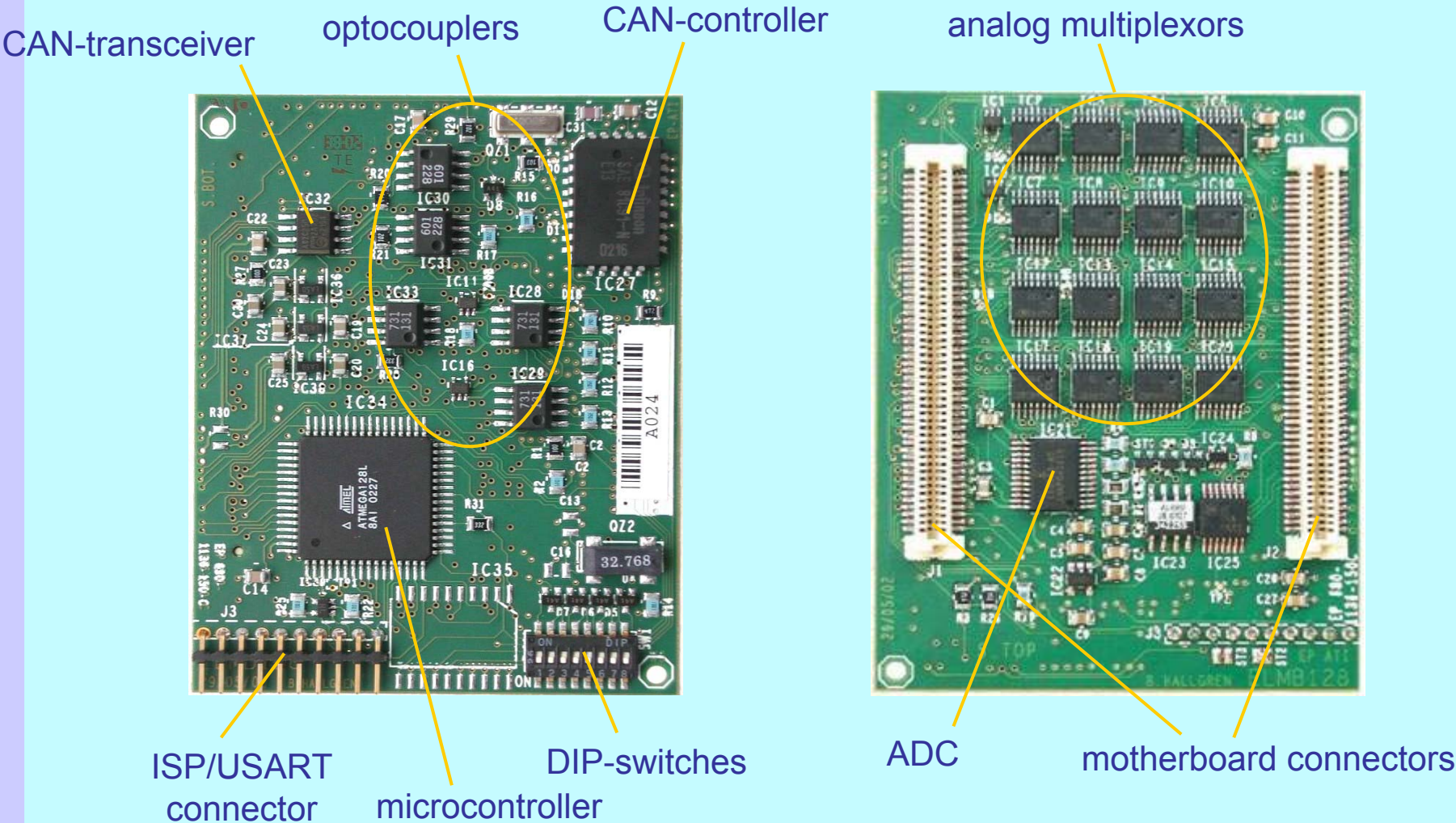
Radiation Tolerance of Series Produced ELMBs

Bjorn Hallgren (CERN-EP/ATE) and Henk Boterenbrood (NIKHEF)

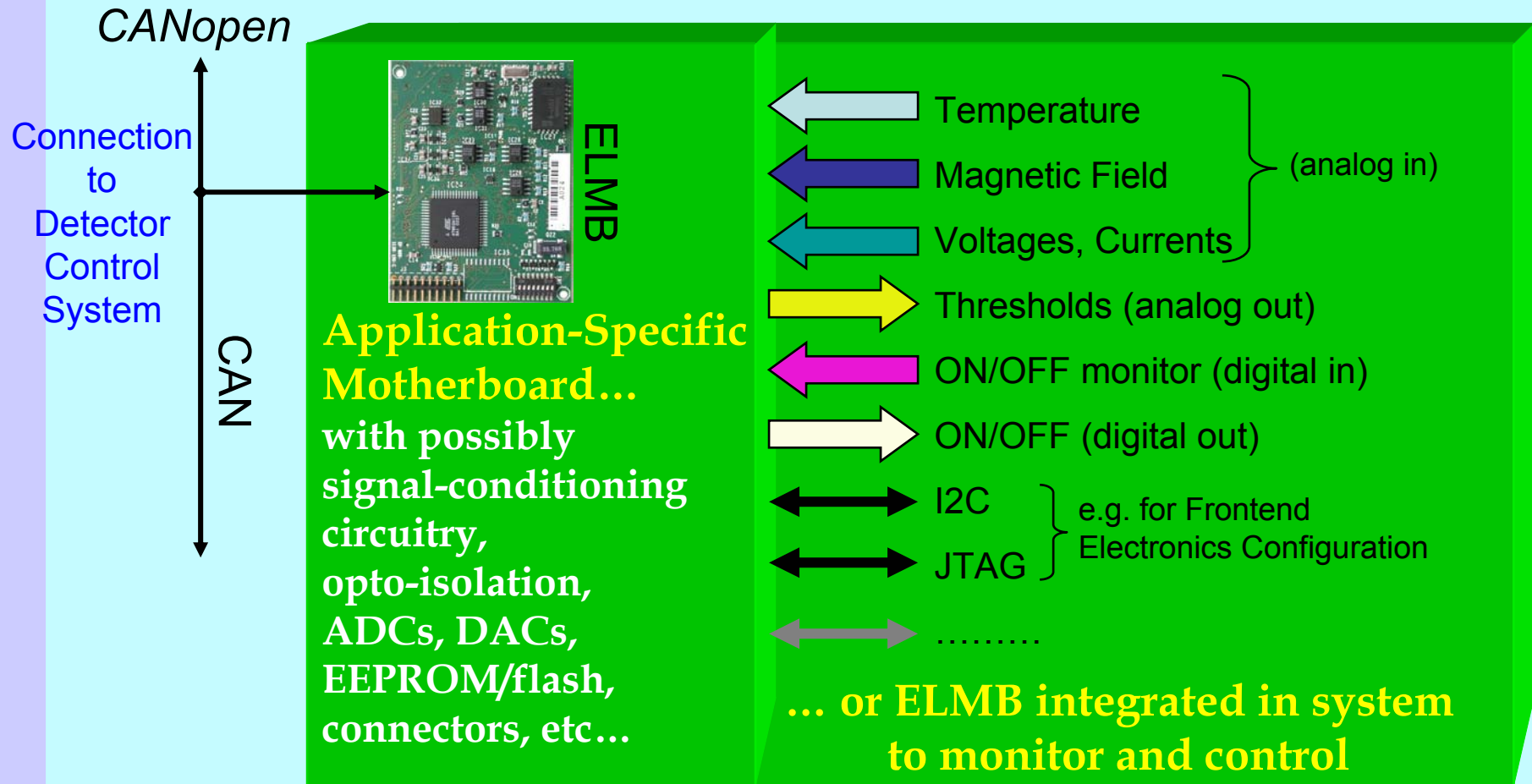
ELMB: Embedded Local Monitor Board

- Credit-card sized plug-on board
 - Microcontroller: user programmable with C-language
 - Communication: CAN-interface 125 kbits/s @ 300m
 - Low power: Can be remotely powered
 - 64-channel 16-bit ADC (optional), max 30 samples/s
 - Firmware remotely upgradeable
- General-purpose CAN-bus based standard building block for various control and monitoring tasks in the LHC experiments (initially for ATLAS),
- CERN LHC Experiments, Gas systems, Rack monitoring ...
- 1000 pieces have been produced 2001 (ELMB103) and 2002 (ELMB128)
- **CERN and NIKHEF development**
- Low Cost = ~80 CHF for Jan 2004 series production of 10000 pieces

ELMB128: the board



ELMB: Embedded...

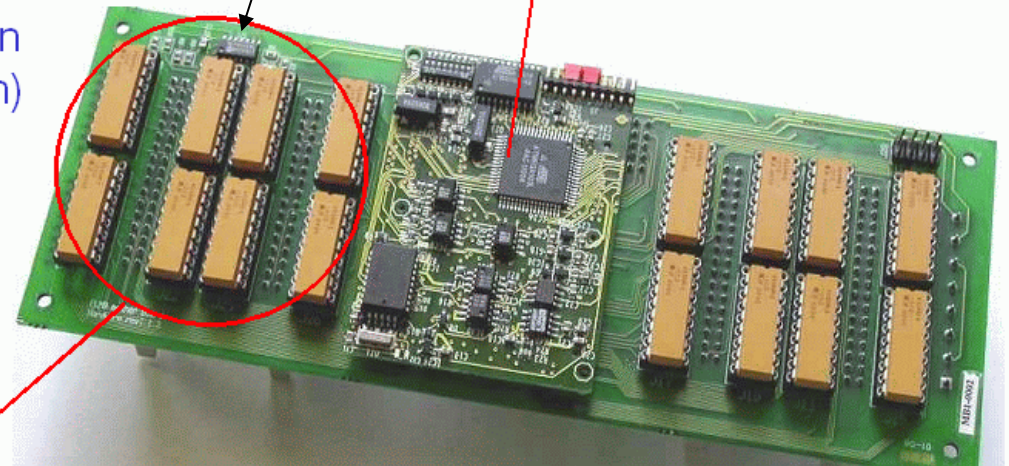
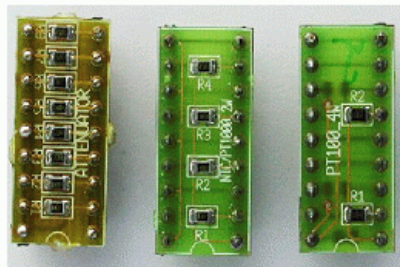
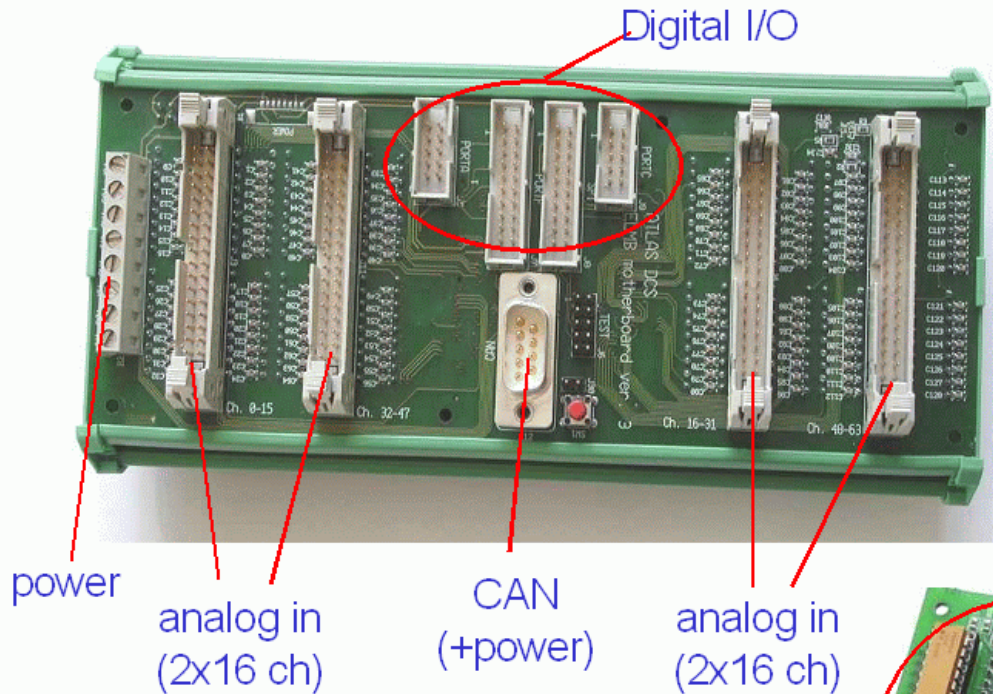


ELMB: general-purpose Motherboard

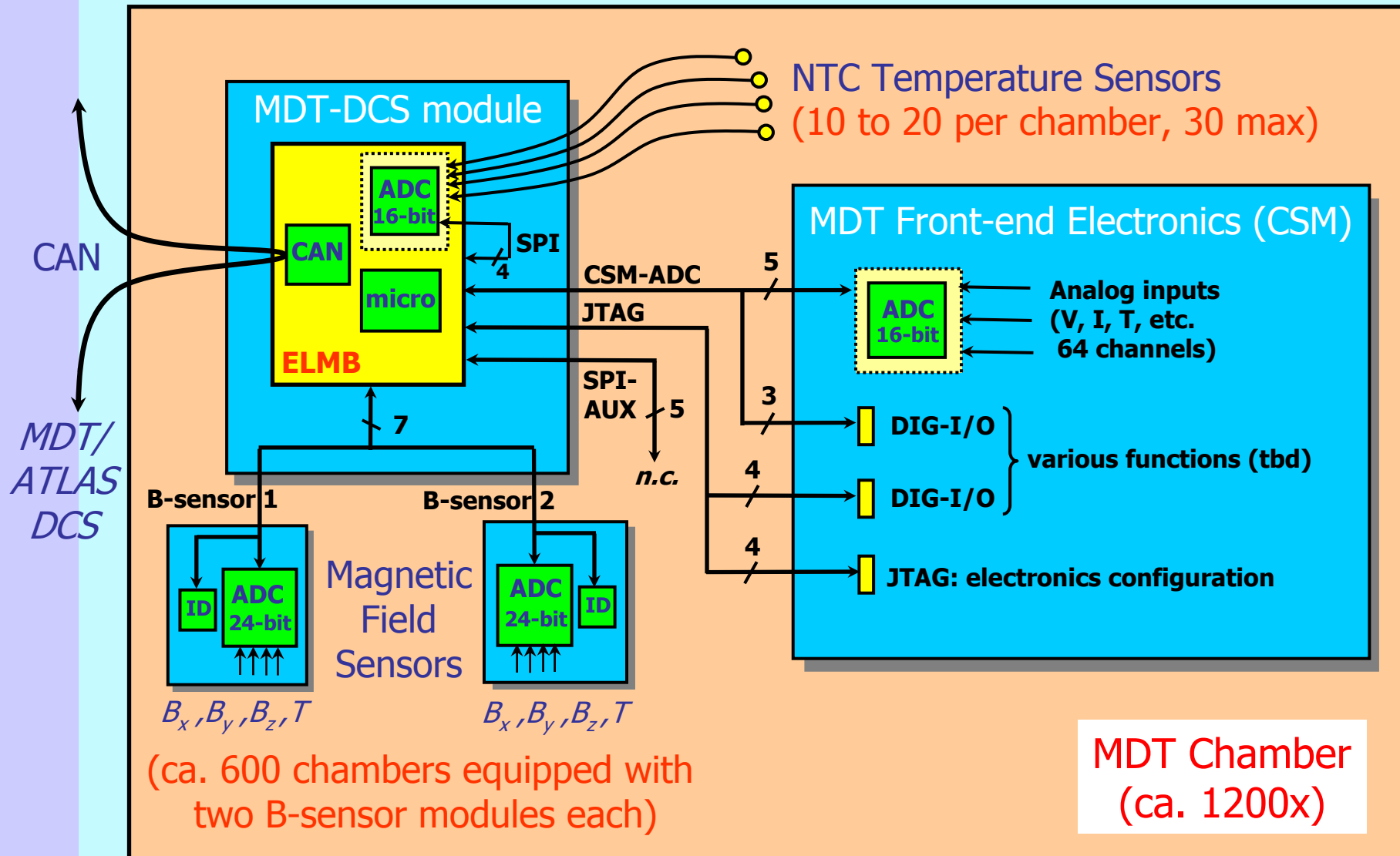
(ca. 300 produced)

Not radiation qualified yet

ELMB with general-purpose
CANopen application firmware
and Bootloader (off production)



ELMB Application Example: Muon MDT



ELMB Application Example: Muon MDT



ELMB Application Example: Muon RPC



ELMB controls:

- Temp sensors
- TTC
- Delay chips
- FPGA
- Flash prom FPGA
- Flash prom SPI
- I²C I/O registers
- Coincidence matrix ASIC (about 200 I²C registers)
- Optical link controls using JTAG and I²C protocols and Dig I/O

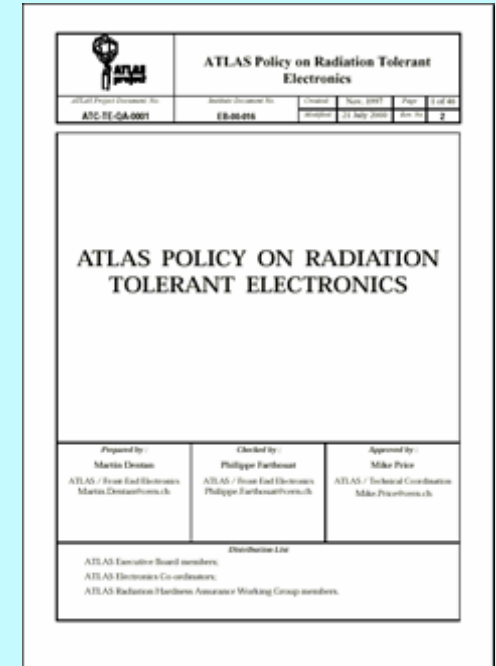
(courtesy of S.Veneziano)

PAD board with TTCrx, ELMB, XCV200 and Optical Link

ELMB

Radiation Tolerance Criteria

according to
the **ATLAS POLICY ON RADIATION TOLERANT
ELECTRONICS**



ELMB:

- Contains CMOS SRAM, EEPROM, flash, bipolar devices, and optocouplers.
- Therefore sensitive to all types of radiation
 - TID = Total Ionizing Dose (Ex: Gammas, ...)
 - NIEL = Non Ionizing Energy Loss (Ex Neutrons,...)
 - SEE = Single Event Effect (Ex: Protons etc)

ELMB Radiation Tests

– Simulated Radiation Values Jan03 (calculated for ATLAS Muon Barrel 1)

- TID: 1 Gy x 3.5 x 1 x 4 = 14 Gy in 10 years
- NIEL: $4.6 \cdot 10^{10}$ n/cm² x 5 x 1 x 4 = $9 \cdot 10^{11}$ n/cm² (1 MeV eq.) in 10 years
- SEE: $5.1 \cdot 10^9$ h/cm² x 5 x 1 x 4 = $1 \cdot 10^{11}$ h/cm² (>20 MeV) in 10 years

Safety factor
for simulated
radiation
levels

Low Dose Rate effect,
5 or 1
ELMB = 1

COTS mixed: factor 4,
COTS homogeneous in preselection: factor 2
COTS homogeneous in production: factor 1
ELMB either 2 or 4

ELMB Radiation Tests

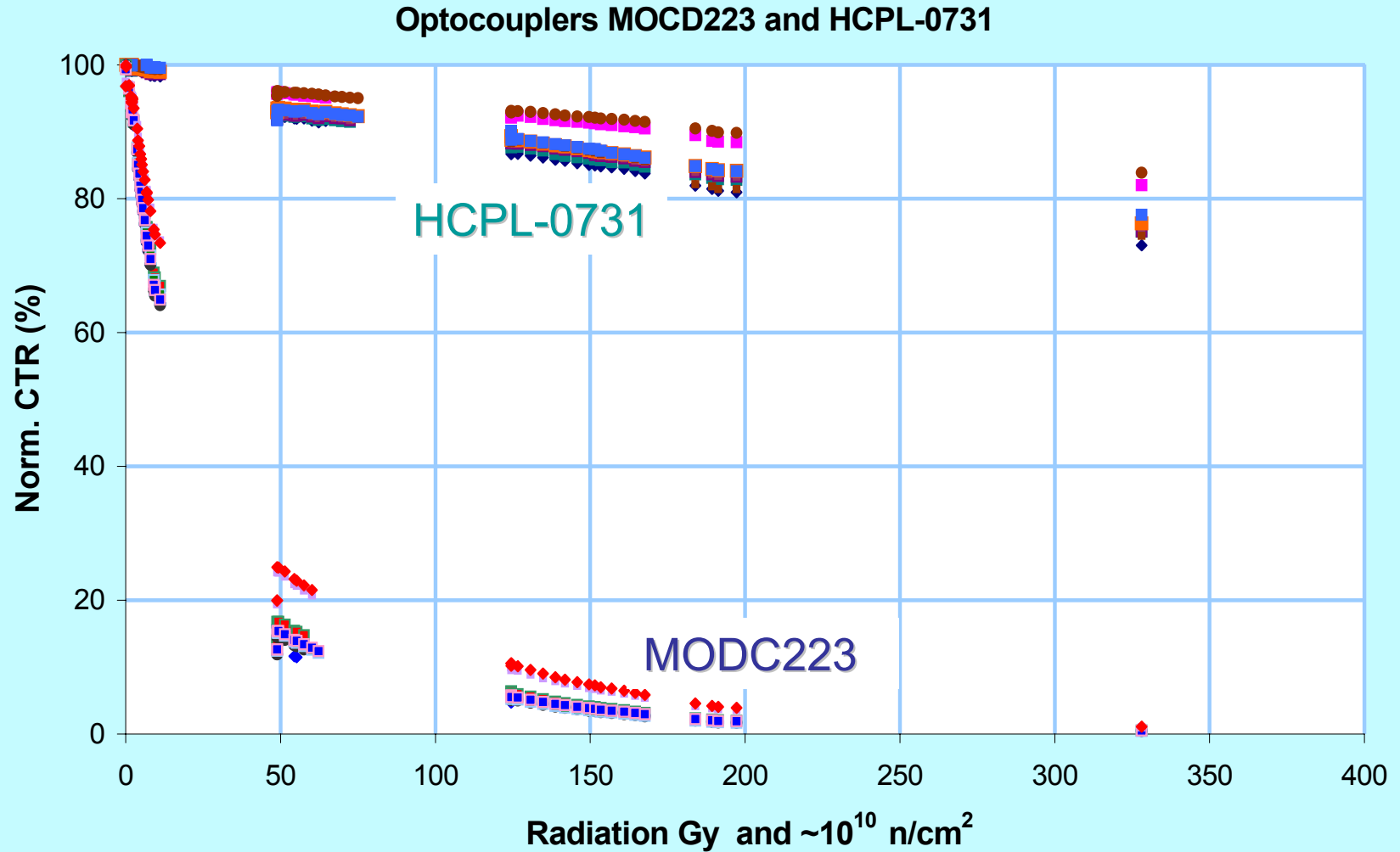
- Components 1998 to 2003
- Preseries (1000 pieces) 2001 - 2003
- Production Nov 2003

Radiation test 1998 and 1999

Radiation tests of critical components

- Optocouplers x 4 types
- Analog CMOS multiplexors
- Flash microcontrollers
- SEU in CAN controller

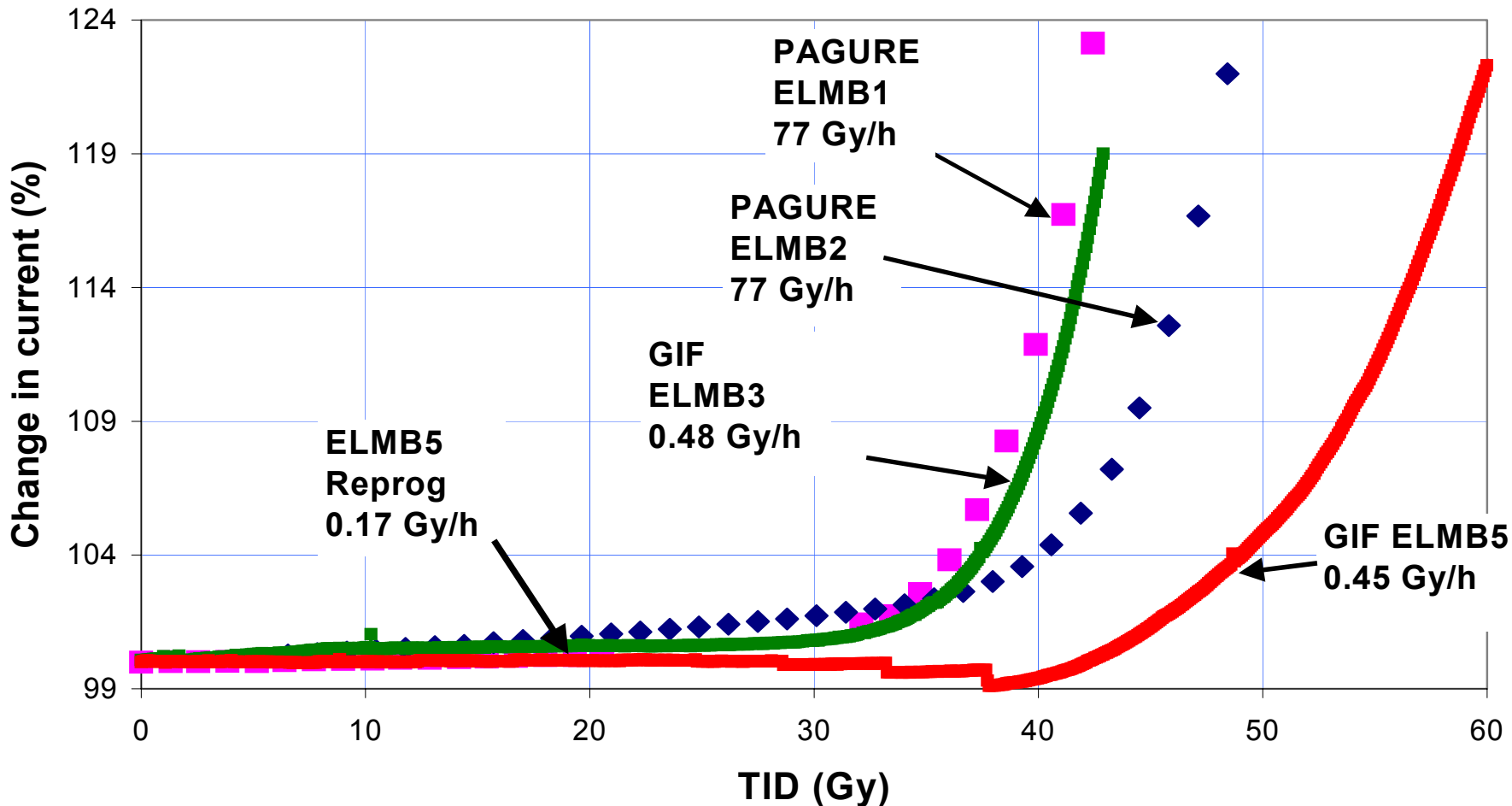
Online test of optocouplers at TCC2



TID tests at Pagure and CERN GIF

Comparison GIF versus PAGURE

- ELMB1
- ELMB2
- ELMB3
- ELMB5



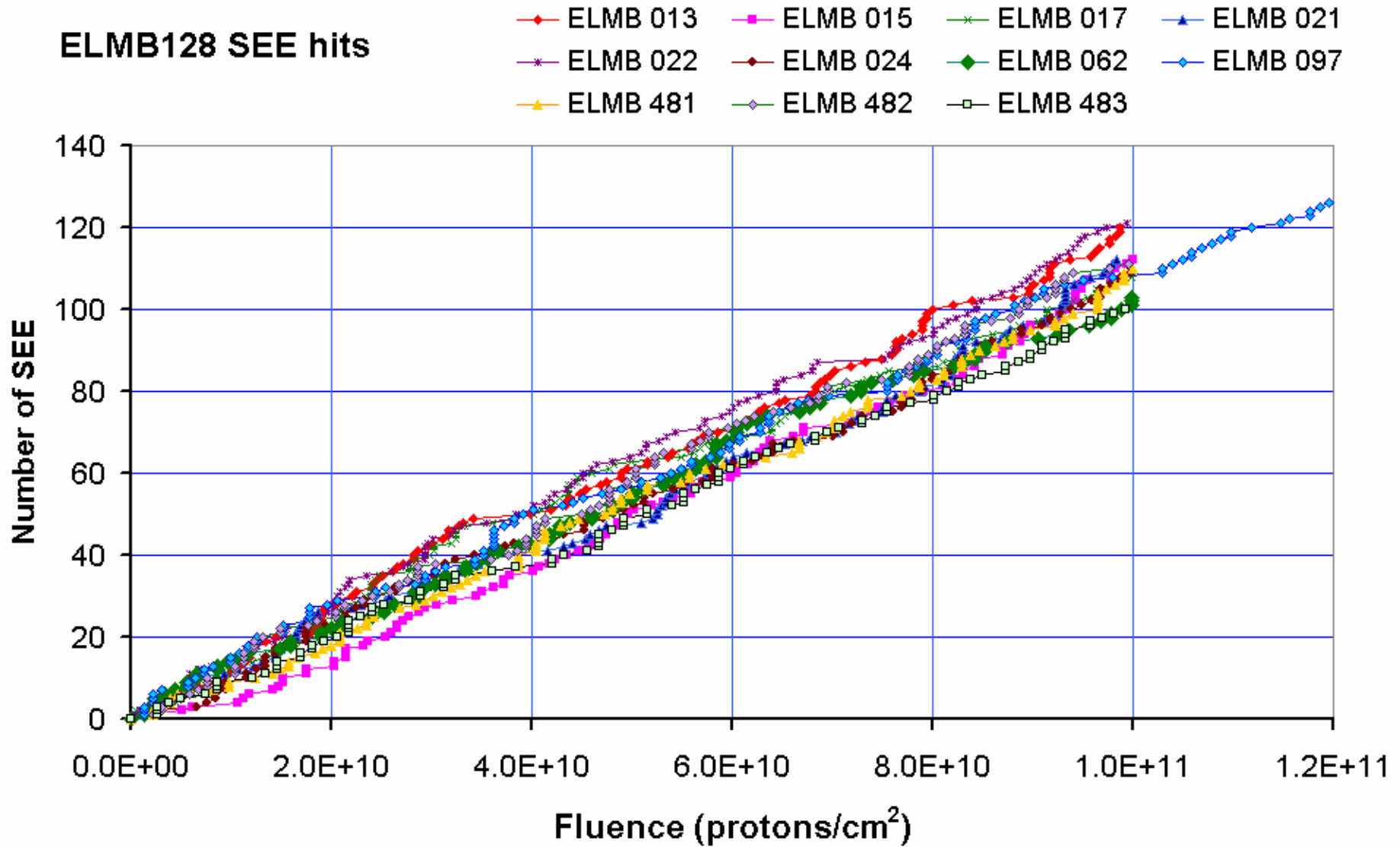
ELMB Radiation Test: SEE / TID (March 2003)

- CRC cyclotron, Louvain-la-Neuve (B) 3 tests,
- Nov 2003, March 2003 and June 2001
 - 12 ELMB128s, each irradiated to at least $1.0 \cdot 10^{11}$ p/cm² corresponding to TID = **140 Gy**
 - Total fluence: $1.2 \cdot 10^{12}$ p/cm²
(2001: fluence: $0.33 \cdot 10^{12}$ p/cm²)
 - ELMBs powered, running
 - 'standard' firmware (doing ADC and digital I/O, CAN-bus message handling)
 - additional periodic (every 5 s) checking of unused parts of memory and device registers, filled with bit patterns

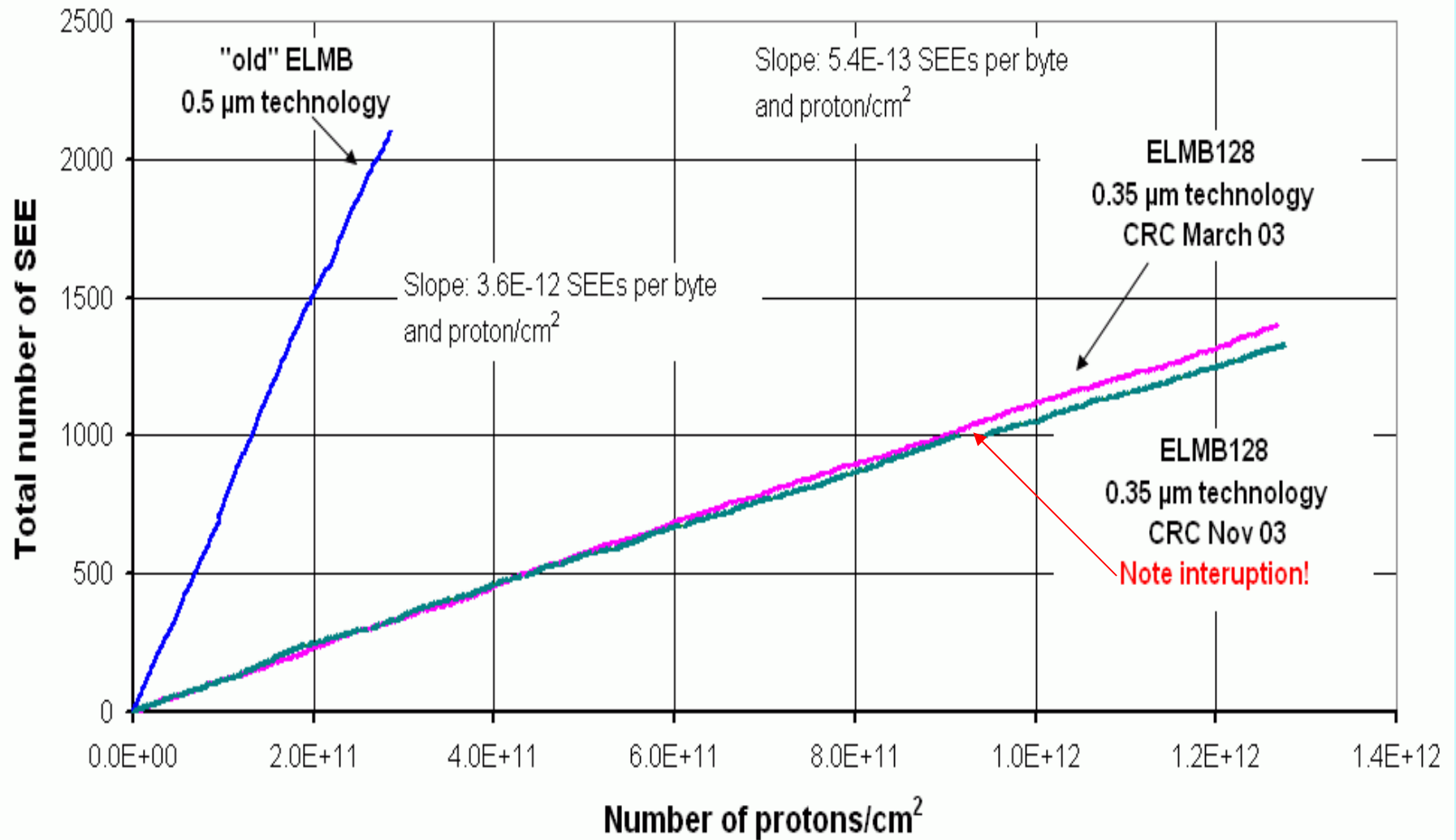
Systematic SEE test

- Standard *ELMBio* application
 - rad-tolerance increasing (software) features enabled
 - timer-triggered read-out of 4 ADC channels and Dig-In (every 5 s)
 - by host-PC: periodic SDO-read (every 5 s)
 - by host-PC: periodic SYNC (readout of 64 ADC chans, every 100 s)
- Code extensions: memory checks (every 5 s)
 - Flash (pattern in unused space, program code CRC)
 - EEPROM (pattern in unused space)
 - SRAM (pattern in unused space)
 - CAN (pattern in unused registers)
 - ADC (registers with known preset values)
 - Microcontroller Registers (pattern in unused registers)

SEE in the ELMB SRAM 2kbytes



SEE in the ELMB SRAM 2 kbytes



RadTest: SEE results

- **Functional SEEs**

- count 'abnormal' behaviour, and categorize according to necessary action to fix it

	ELMB103 June 2001	ELMB128 March 2003	ELMB128 Nov 2003 ¹⁾
Power cycling	4	0	1
Software reset	5	1	1
Automatic recovery	20	13	tbd
Fluence	$3.3 \cdot 10^{11}$ p/cm²	$1.3 \cdot 10^{12}$ p/cm²	$1.2 \cdot 10^{12}$ p/cm²

¹⁾ Very preliminary

ELMB128 Radiation Test: NIEL

- CEA Valduc, Prospero 1998-2001

Tests both with and without power to find sensitive components = opto's and bipolar components.

ITN, Portugal, Reactor, Feb 2003

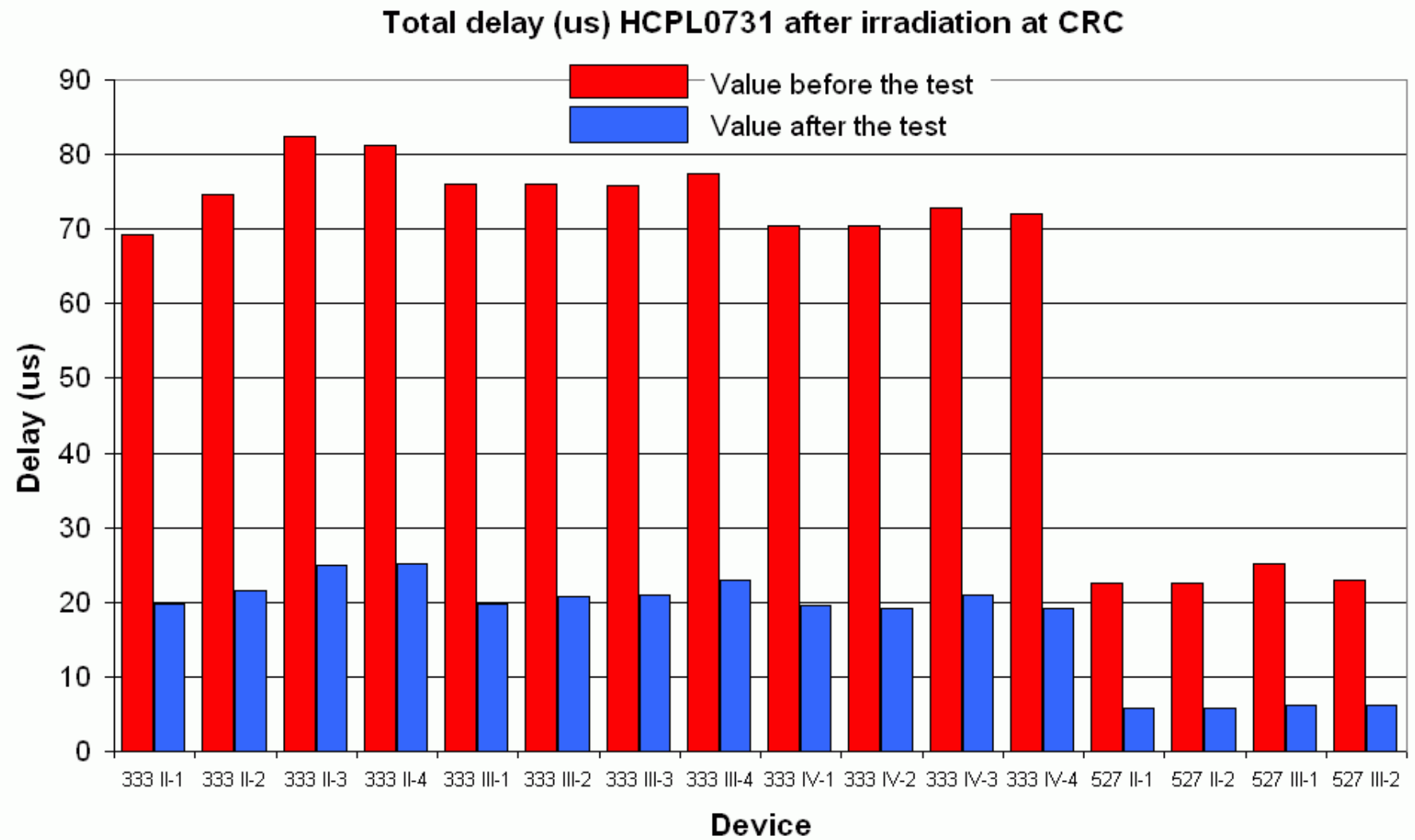
3 ELMB128s unpowered, $2 \cdot 10^{12} \text{ n/cm}^2$: **OK**

3 ELMB128s unpowered, $8 \cdot 10^{12} \text{ n/cm}^2$: **NO** - Voltage regulators and Opto-couplers

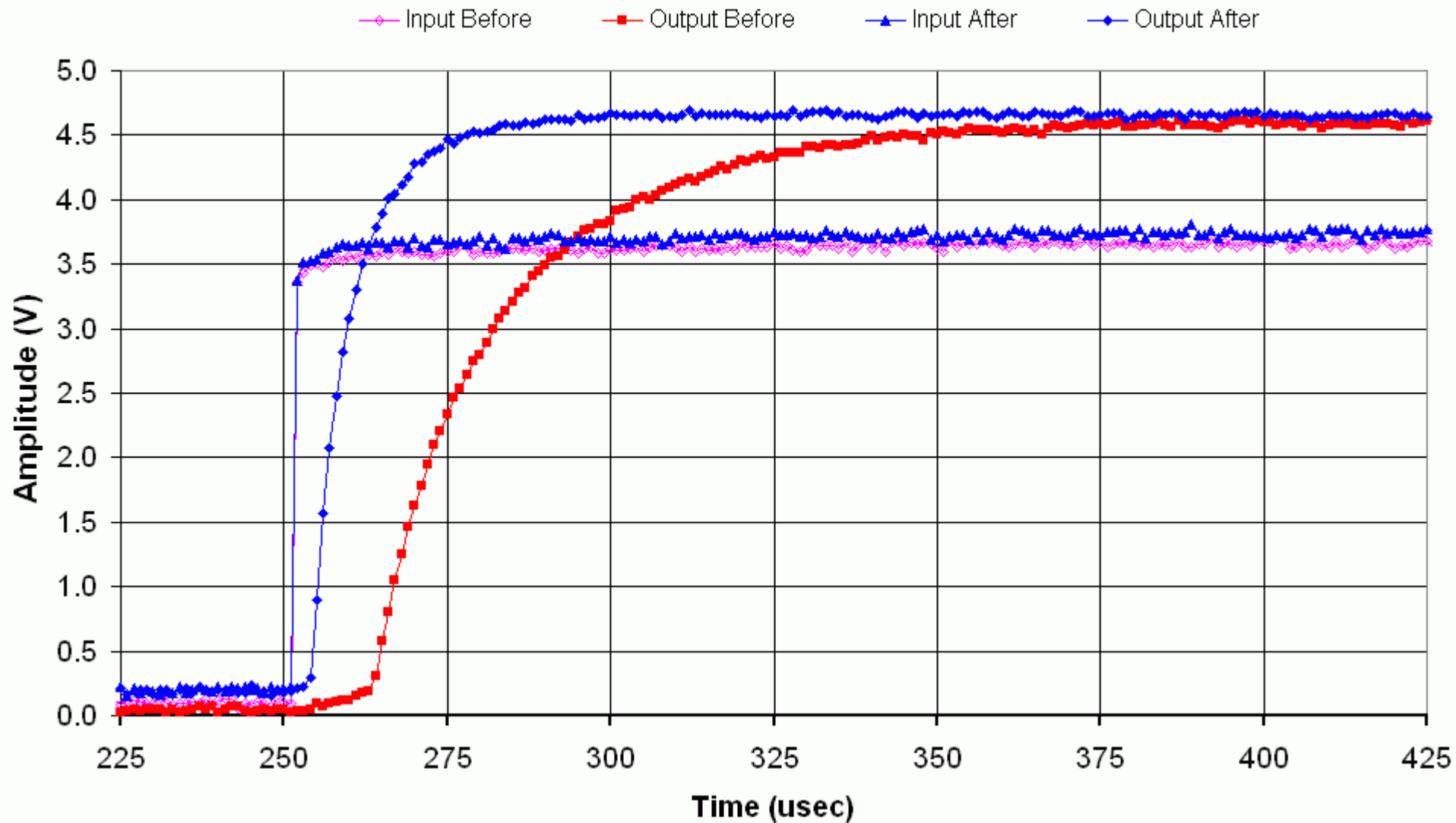
- CEA Valuc, Prospero Nov 2003, $6 \cdot 10^{12} \text{ n/cm}^2$: **OK**

Online measurements of 10 x ELMB128 plus optocoupler measurements

Optocoupler delay improves with radiation!

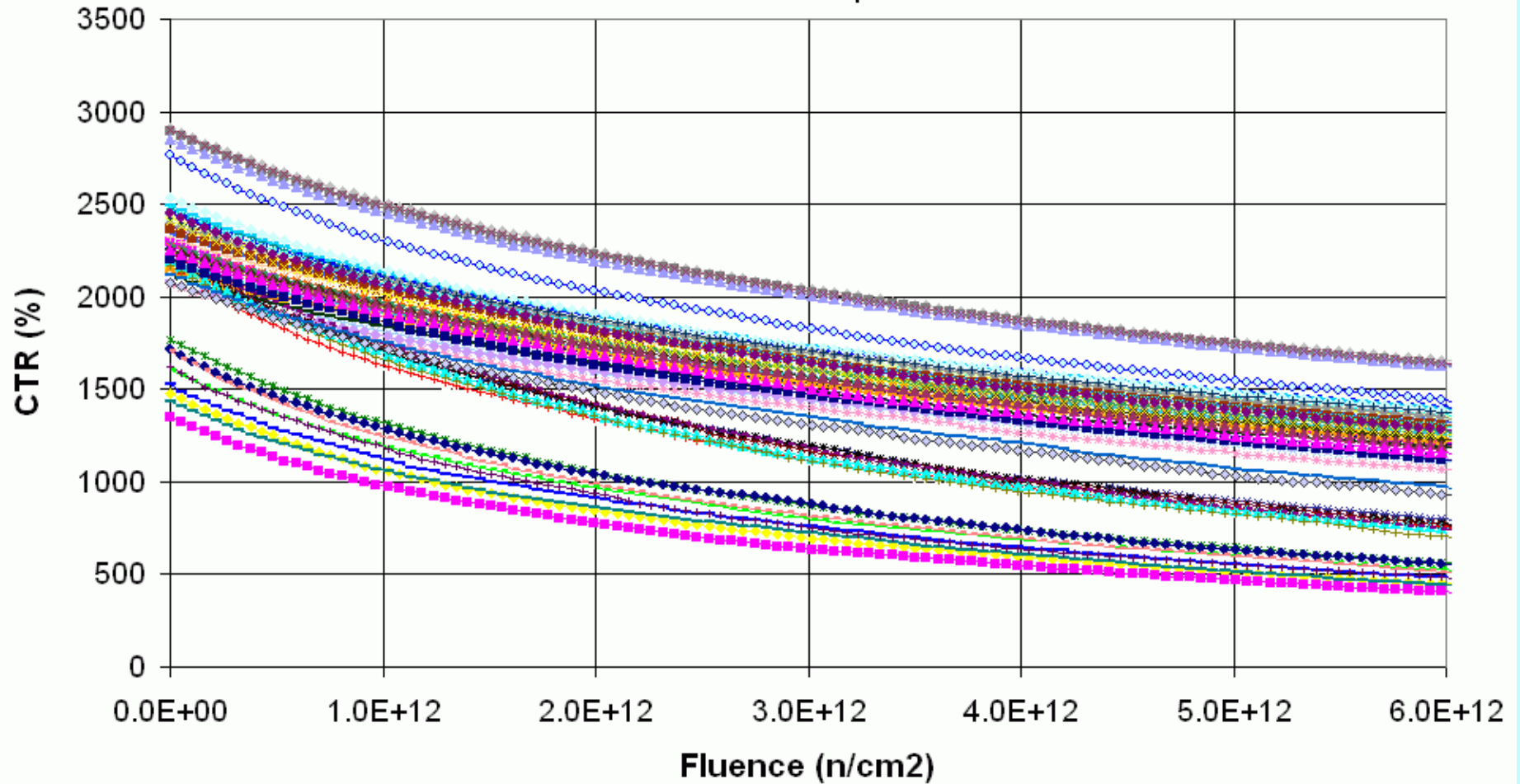


HCPL0731 II-1 before and after 1E12 protons/cm2

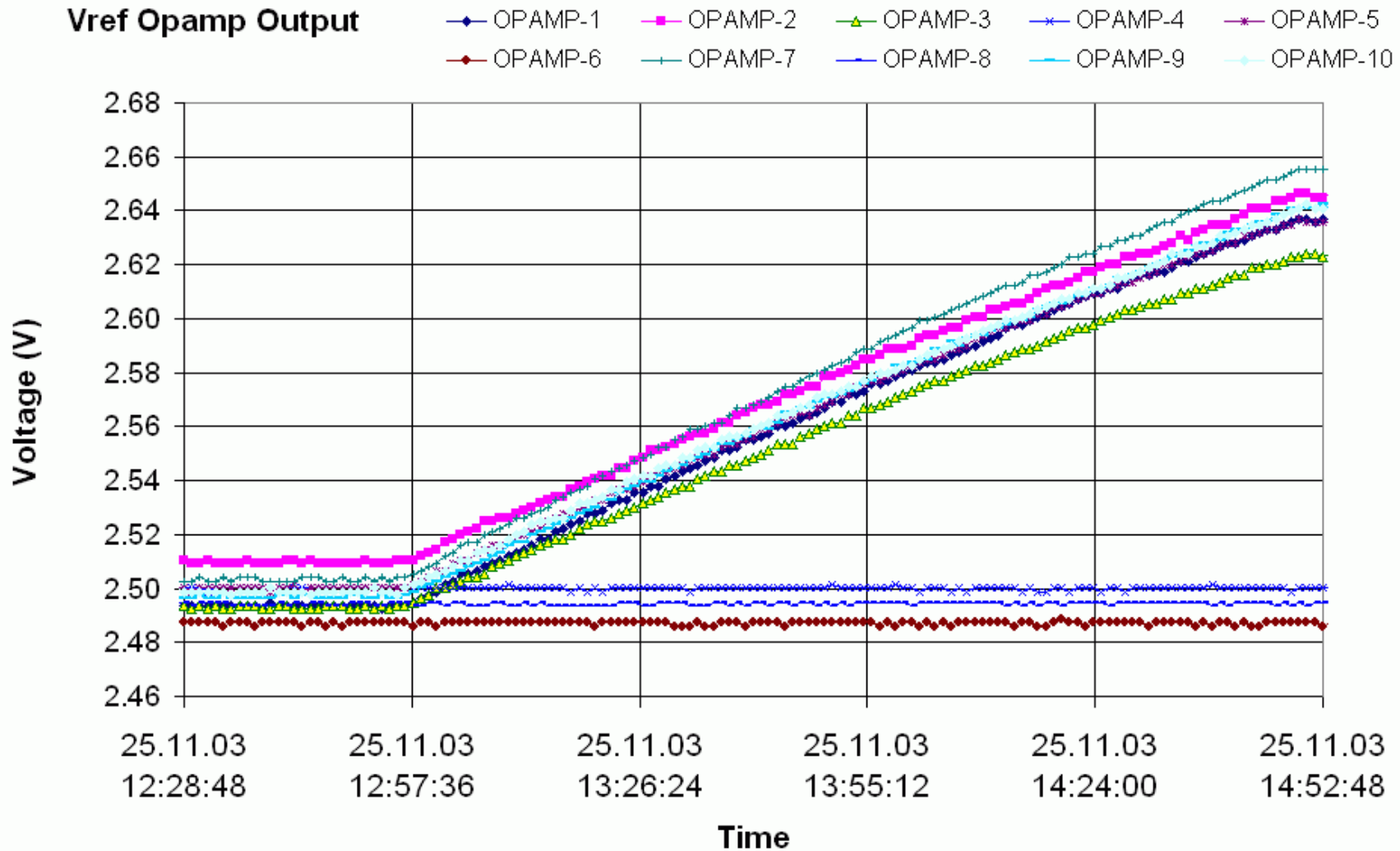


Optocoupler CTR

60 x HCPL0731 Current Transfer Change at the
Neutron irradiation at Prospero 25/11 2003



Some of the Motherboard Opamps are sensitive to neutrons



Summary

The ELMB128 series production is tested according to the ATLAS POLICY ON RADIATION TOLERANT ELECTRONICS to the following levels:

- **TID = 140 Gy**
- **NIEL = $6 \cdot 10^{12}$ neutrons/cm² (1MeV equiv.)**
- **SEE = $5 \cdot 10^{11}$ h/cm² (>20MeV)**