Radiation Validation of the CMS HCAL Front-End Electronics

CMS HCAL ESR

December 5-6, 2002

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Fermilab

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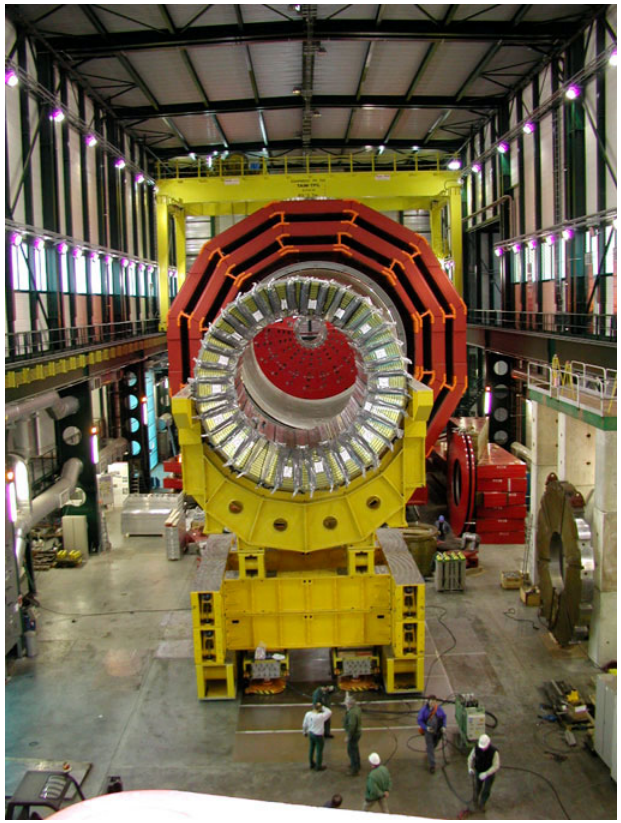
Radiation Effects

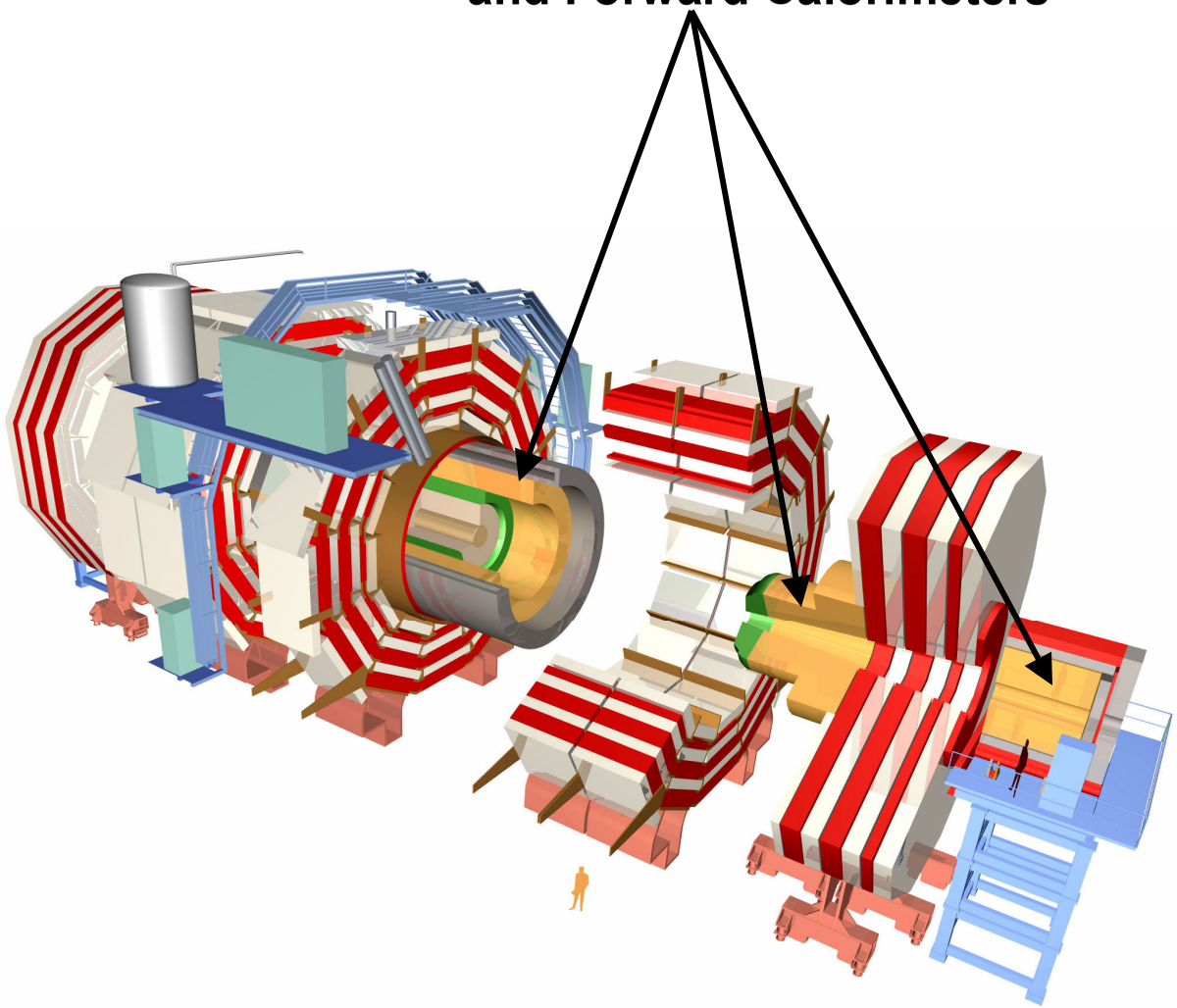
Radiation Damage

- **Cumulative Effects**
  - Gradual performance degradation
    - Displacement Damage
    - Total Ionizing Damage (TID)

- **Single Event Effects**
    - Single Event Upset (SEU)
    - Catastrophic Single Event Effects such as Single Event Latch-Up (SEL) or Burn-Out (SEB)

CMS Hadron Calorimeter





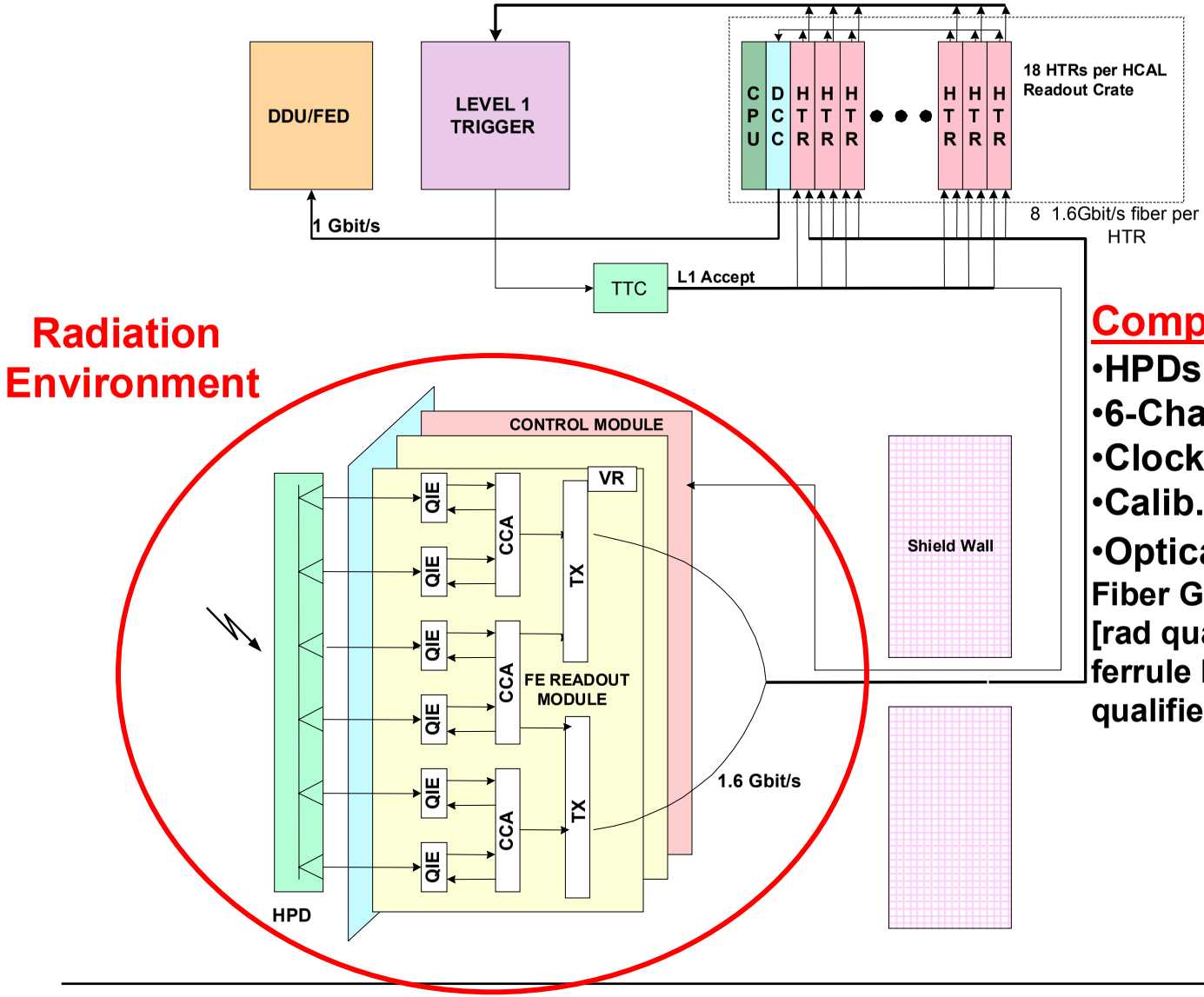
HCAL Radiation Environment

Radiation Dose over 10 LHC yrs (known to within a factor of 3)

	Neutron F				Ch. Had. F	Max. TID
HCAL	Total	E>100keV	2-20MeV	E>20MeV	E>5MeV	Rads/10y
Barrel FEE box	3.1E11	1.3E11	4.3E10	2.4E10	2.7E8	190
Endcap FEE box	6.5E10	2.8E10	5.2E9	2.8E9	1.6E8	71
Exp. Hall						
HF Shield	2.0E11	1.0E11	5.6E10	3.5E10	1.5E9	330

Relevant radiation testing level for SEE

FE/DAQ Readout



Components to Qualify

- HPDs
- 6-Channel FE Boards
- Clock Control Monitoring
- Calib. Modules (LEDs)
- Optical Links (Plasma Optics Fiber Graded-Index Multimode [rad qualified by Atlas], MT ferrule based connectors [rad qualified by CMS Tracker Group])

6 Channel FE Board

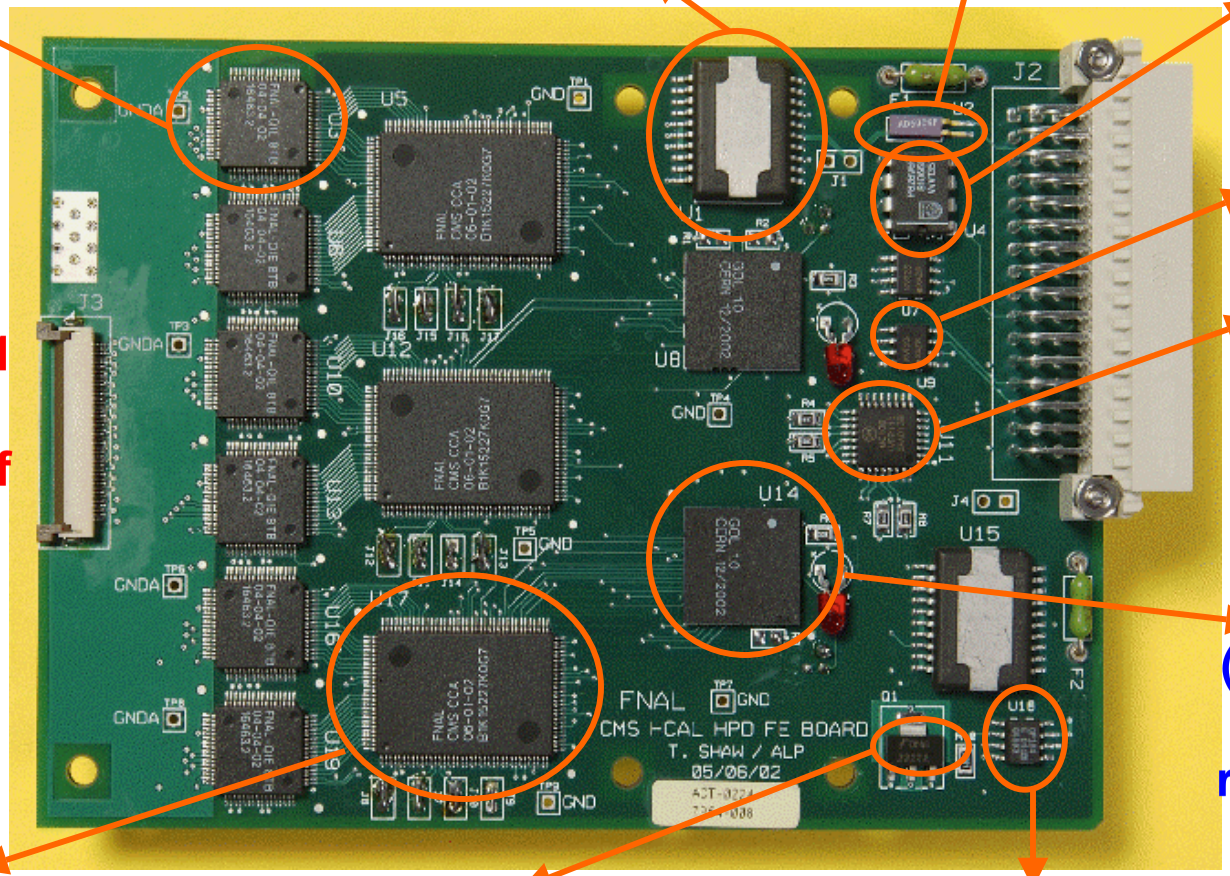
Custom ASICs

QIE (6 / board)
Fermilab

Low Voltage Regulator
(2 / board) CERN
Developed in rad hard process

AD590
Temp Sensor

P82B96
I2C Transceiver
(change to P82B715



MC100LVELT23
LVPECL-LVTTL

Honeywell
VCSEL
HFE419x-521
(2/board)
[back side of board]

MC100LVEP111
LVPECL clock
fanout chip

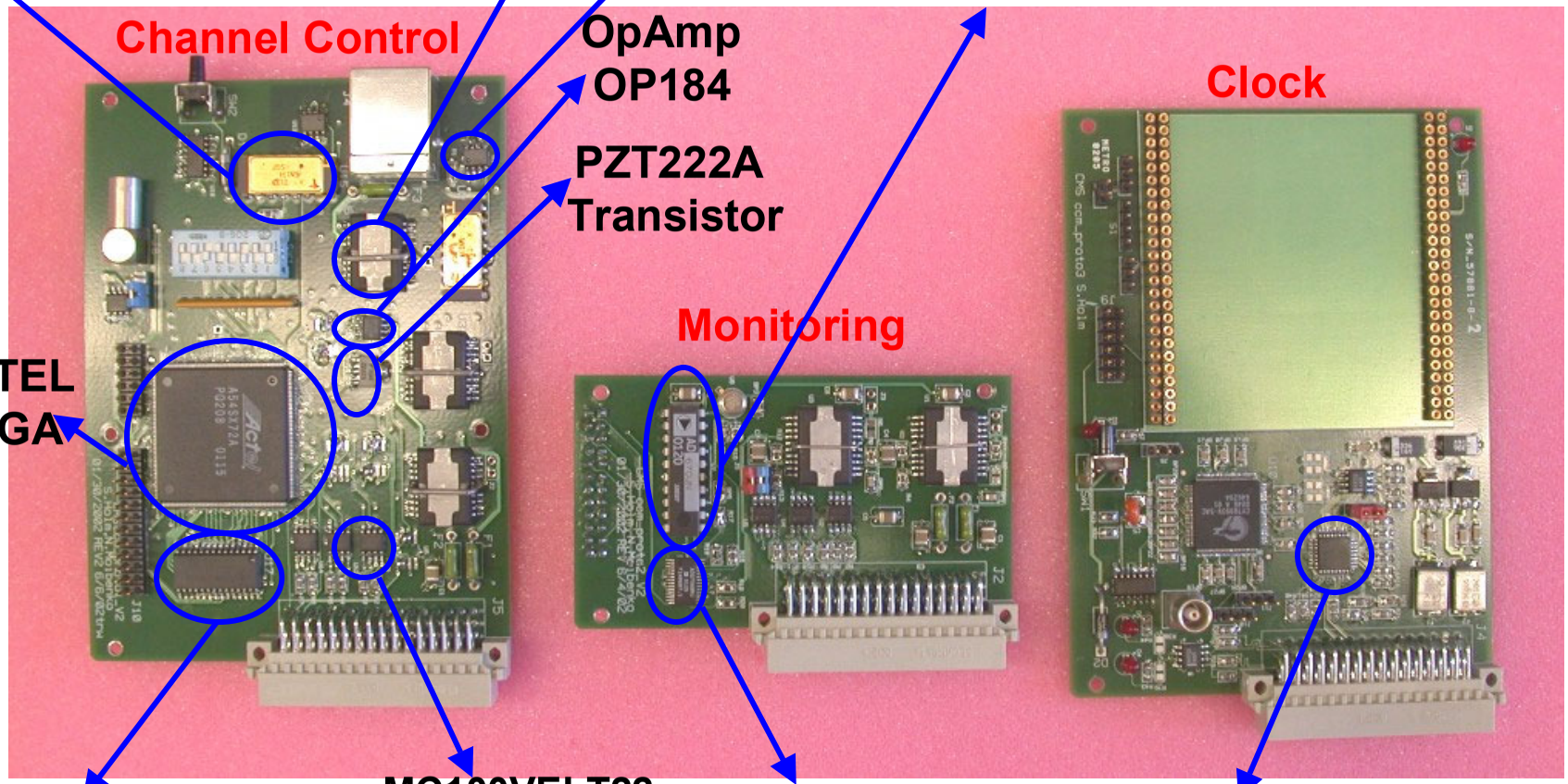
Gigabit Optical Link [GOL]
(2 / board) CERN
Developed in rad hard process

CCA
(3 / board)
Fermilab

PZT222A transistor

OP184 bi-polar OpAmp

Clock Control Monitoring



Testing Strategy

Plan

- **Test all electronic devices up to the expected 10yr radiation levels of 1 kRad and 4E11 n/cm^2 (1E11 n/cm^2 testing for SEE studies [based on E>20 MeV fluence])**
  - Test individual components

    # SEE/device/fluence x (1E11 n/cm^2/10yr) x # devices
  - Full System Test (scheduled for Oct `02)
- **Spec parts**
  - SEU requirement is device specific
    - **QIE reset every orbit**
  - Require < 1 SEL/10yr* or SEL sensing circuit
  - Require HPD susceptibility of << 1 SEB/10yr
  - Require bi-polars operate after 10 yr TID level

*** SEL can lead to severe failure**

- **Set spec based on board failures**

 # SEL/device/fluence x (1E11 n/cm^2/10yr) x # devices

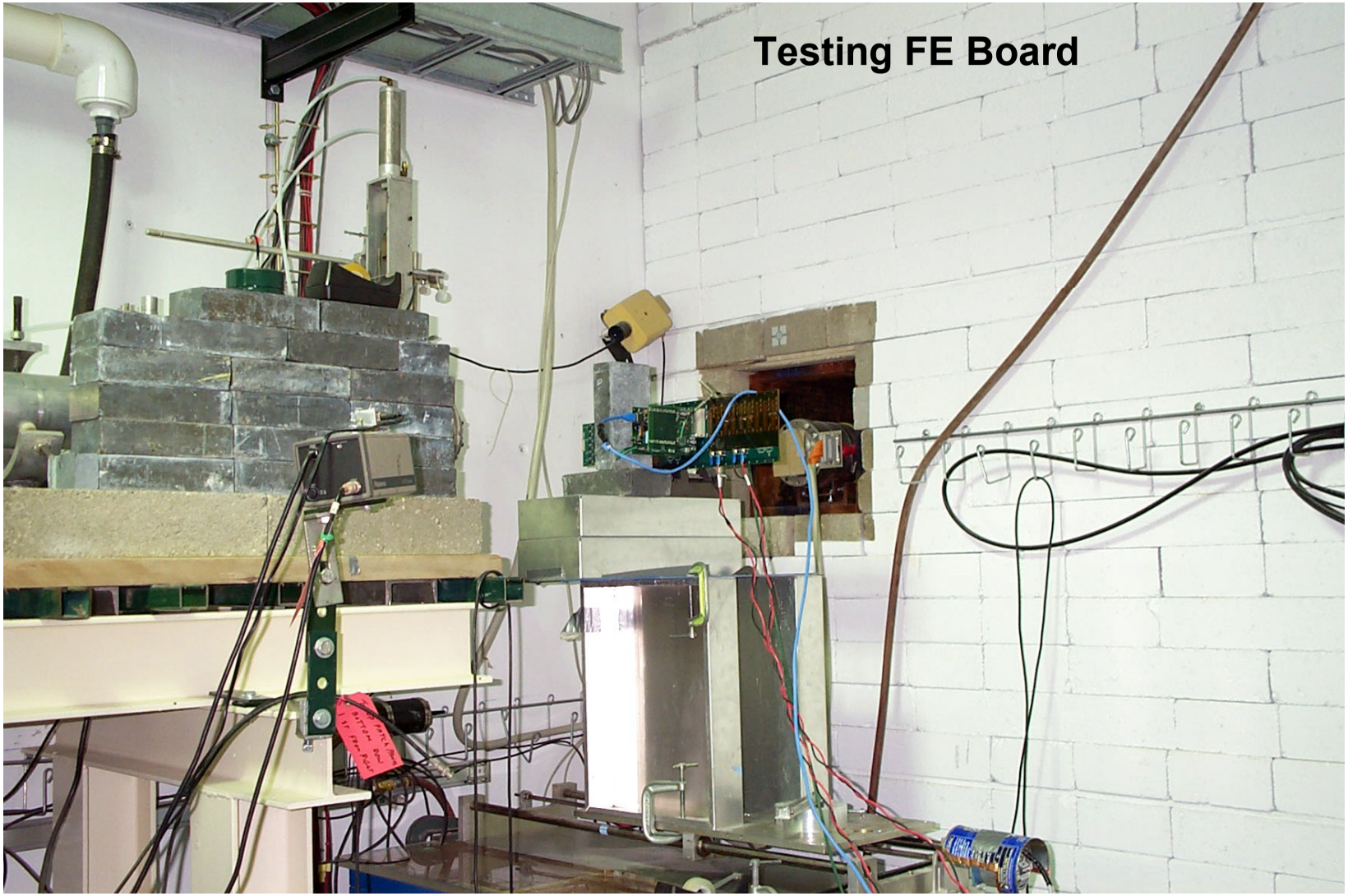
  - Try to achieve <<1 CCM failure/10yr and << 1 FE board failure/10yr
    - **Problem: limited by available beam time and component activation**
  - # Diff chip types - CCM (10 chips); FE (11 chips)

    <1/100 of a failure/yr for CCM chip

    <1/110 of a failure/yr for FE board chip
  - **Set spec: < 1 SEL/10yr for full FE system or CCM system**
- **Irradiate multiple devices + give high dose**
- **Full board tests of final FE boards and CCM boards**

All tests performed at Indiana U Cyclotron Facility (200 MeV beam) unless otherwise noted

Experimental Area at IUCF



QIE and CCA ASICs

QIE and CCA

- QIE – AMS 0.8 μm bi-CMOS process
  - Bi-polars (TID + bulk damage)
  - MOS circuits (SEU)
    - Reset every orbit so SEU in "static" registers are not an issue
- CCA – HP 0.5 μm bulk-CMOS process
  - MOS circuits (SEU)

Study processes with AMS and HP test registers

- Min + guard ring
- 2 X min + guard ring
- SEU tolerant

SEU Xsec results

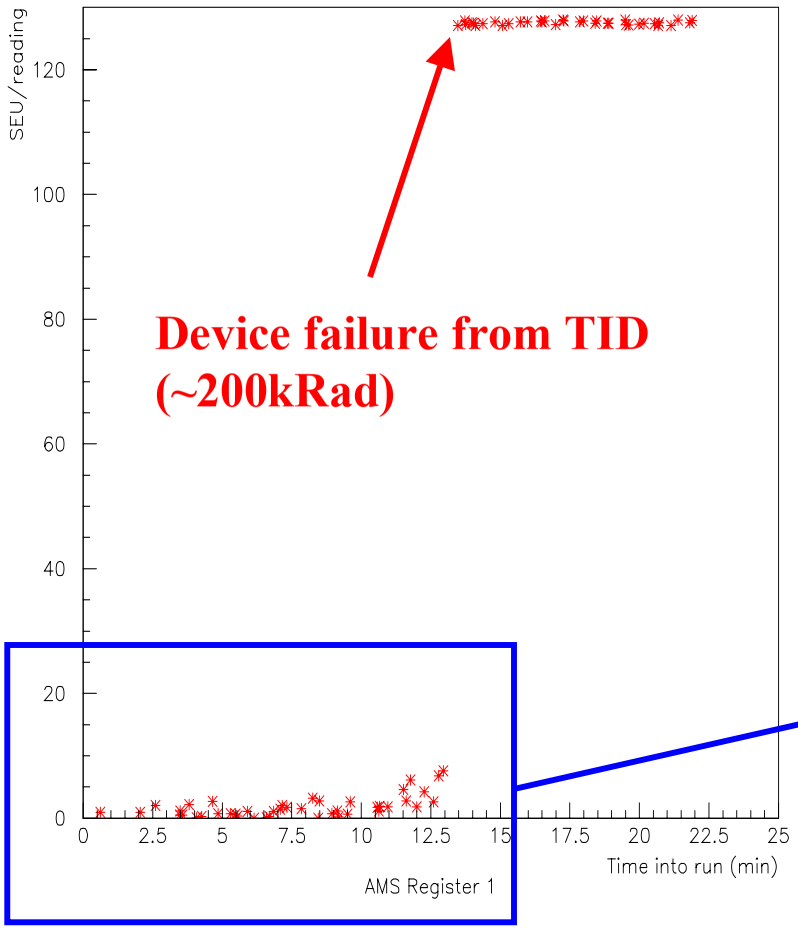
- (1-10)E-15 SEU per n/cm^2 per cell (depending on angle) for conservative design using 2Xmin feature size + guard ring *
- For a complex ASIC with 1000 cells and an E>20MeV neutron fluence of 1E11 n/cm^2 over a 10 yr operating period

  →Expect 0.01-0.1 of an upset per ASIC per year

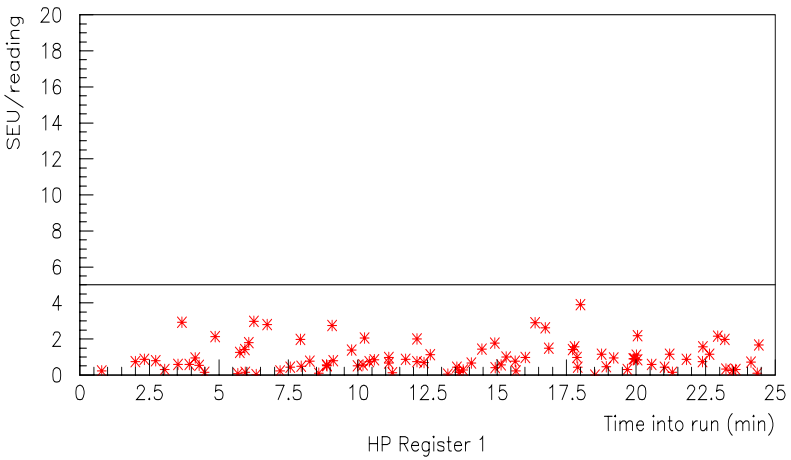
* Using modified Liu-Cell to reduce power dissipation. Liu-Cell has been tested: " Low Power SEU Immune CMOS Memory Circuits," Norley, Liu, Whitaker, Trans. Nucl. Sci 39, No. 6, 1992, p. 1679

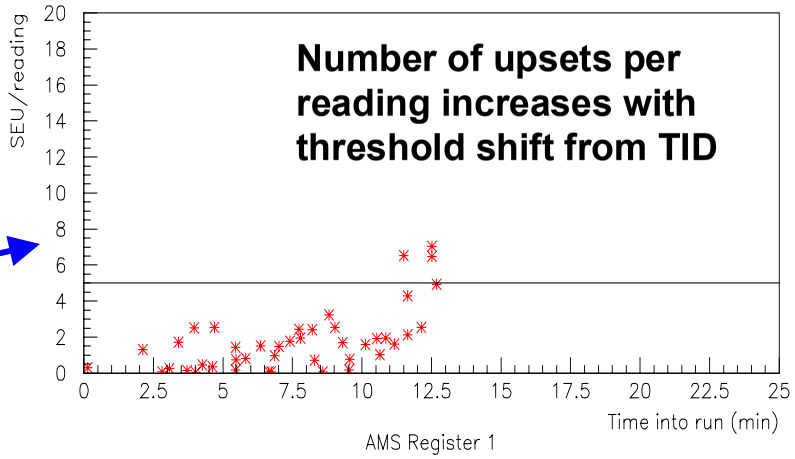
SEU ASIC studies

AMS – Most sensitive register (Minimum size + guard ring)



HP and AMS registers (Minimum + guard ring)



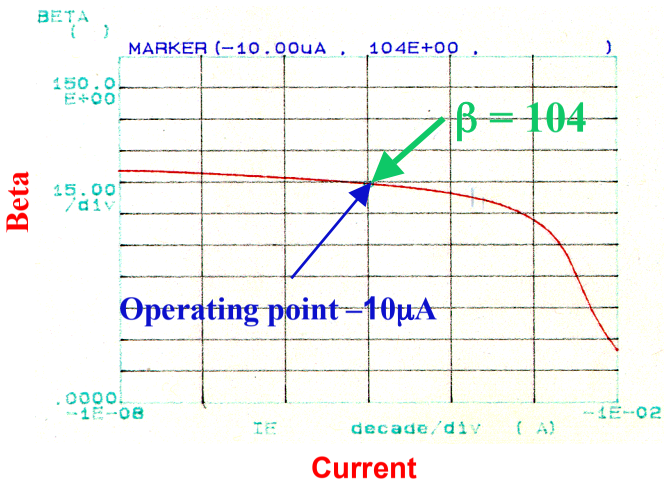


Bi-polar Radiation Studies for QIE

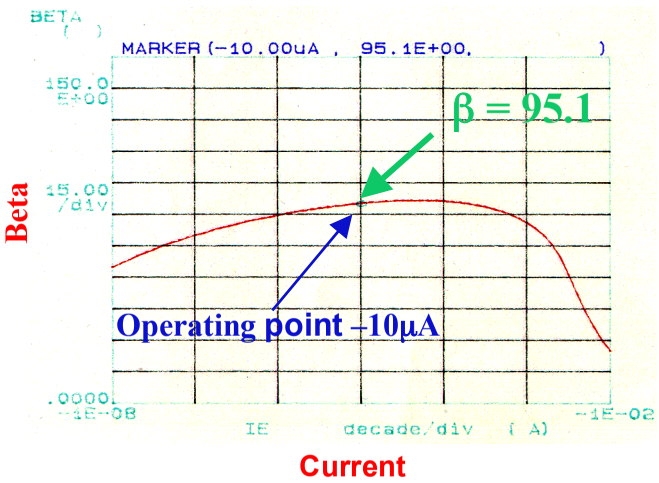
Bi-polars from AMS 0.8 μm bi-CMOS process

- Beta for npn-transistors dropped by 5-10% after equivalent of 5E11 n/cm^2

Pre-irradiation



Post-irradiation (6 weeks)



SEB HPD Studies

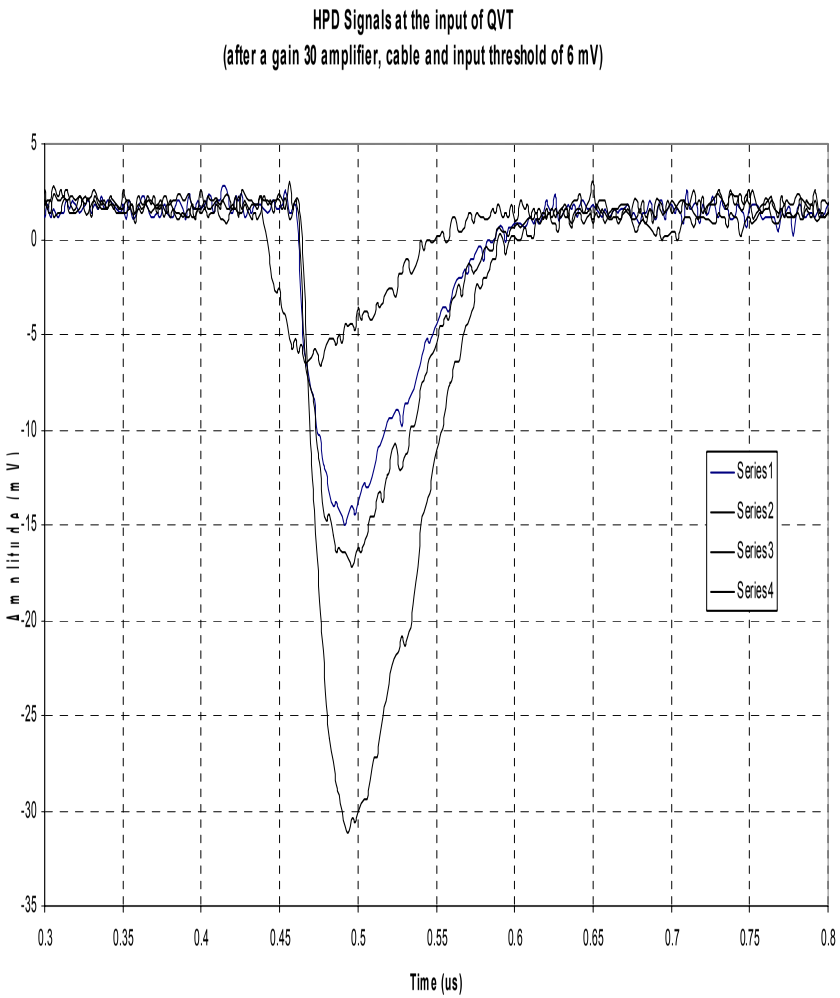
Two candidate mechanisms

- **Spallation events**
  - No problem for HPD lifetime
  - May need QIE input protection
- **Avalanches**
  - Potential for SEB (could limit max. bias)
  - May need QIE input protection

Distinguish between mechanisms

- **Pulse height**
  - Spallation independent of bias
  - Avalanche exponential with bias
- **Rate**

Signals from HPD in proton beam



HPD Results

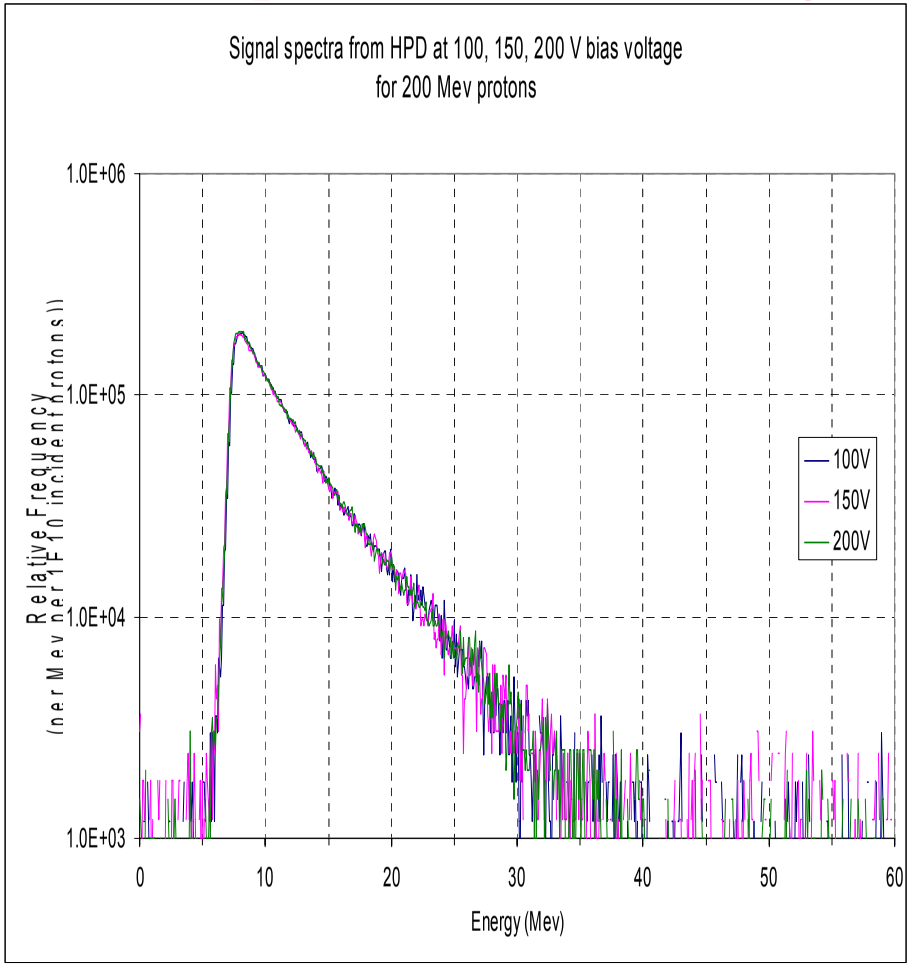
Low-energy neutrons

- Small dark current increase
- No degradation in performance

Protons–Dose HPD to 10yr equiv (~2E11p/cm^2)

- No SEB events observed
- HPD signal independent of bias
  - **No indication of avalanche events**
- HPD signal independent of HV
- Spectrum fits model of 200MeV protons in Si
  - **MIP + nuclear interaction**
  - **Fits model to within a factor of two**
- Small increase in leakage current consistent with previous neutron study

Signal spectra vs. bias voltage



"Results of hybrid photodiode irradiation by 200-MeV protons," A. Baumbaugh, et al., FERMILAB-TM-2162 (Dec 2001).

ACTEL FPGA

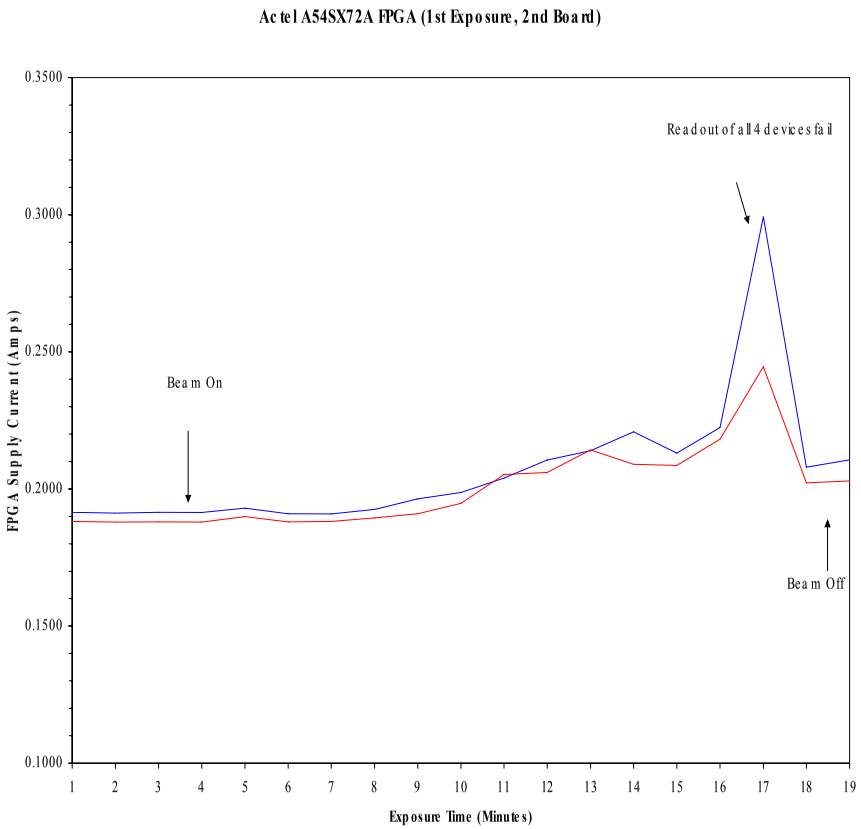
Actel Anti-fuse FPGA

- Bi-polar parts sensitive to large TID
  - Transistors stop working but still OK for SEL testing

Actel FPGA A54SX72A

- Set up as ~2000 bit shift register – no triple vote
- Transistors stop working at ~150kRad
- Set limit of <1 SEL (CCM) /10yrs
- SEUs seen at an acceptable level (1 SEU per week).

Actel FPGA Current (up to 2E11 p/cm^2)



Actel FPGA

Triple vote logic test

- Set up as three 670 bit shift register
- No SEU or SEL seen
- Current increases during irradiation
- Set limit of < 1 SEU/28.5 years for CCM system
  - Final FPGA configuration will not have triple vote for all logic, just for critical elements
- Set limit of < 1 SEL/28.5 years of operation for full CCM system

Clock Chip Results

Clock Chips Studies

- Previous rad test shows PECL is more robust
- Chips studied (operated at 40 MHz)
  - MC100LVEP111 (diff. PECL clock driver)
  - MC100LVELT23 (Dual Diff. LVPECL-LVTTL)
  - MC100LVELT22 (Dual Diff. LVTTL-LVPECL)
    - No latchups seen
      - Set limits of <1 SEL /10yrs for FE boards and <1 SEL /10yrs for CCM system for each chip
    - No clock glitches seen
    - Current draw is very steady

PECL chips run like champs!

I2C Buffer

Two types of I2C buffers tested (1/FE card & 4/CCM)

- **P82B96**
  - No SEL, no readback after 120 kRads
  - parts die due to ionizing radiation (120 kRads)
- **P82B715**
  - Parts survive – no SEL seen, no readback errors
  - Set limit for FE of < 1 SEL/system/12 yrs
  - Set limit for CCM of < 1SEL/system/40yrs

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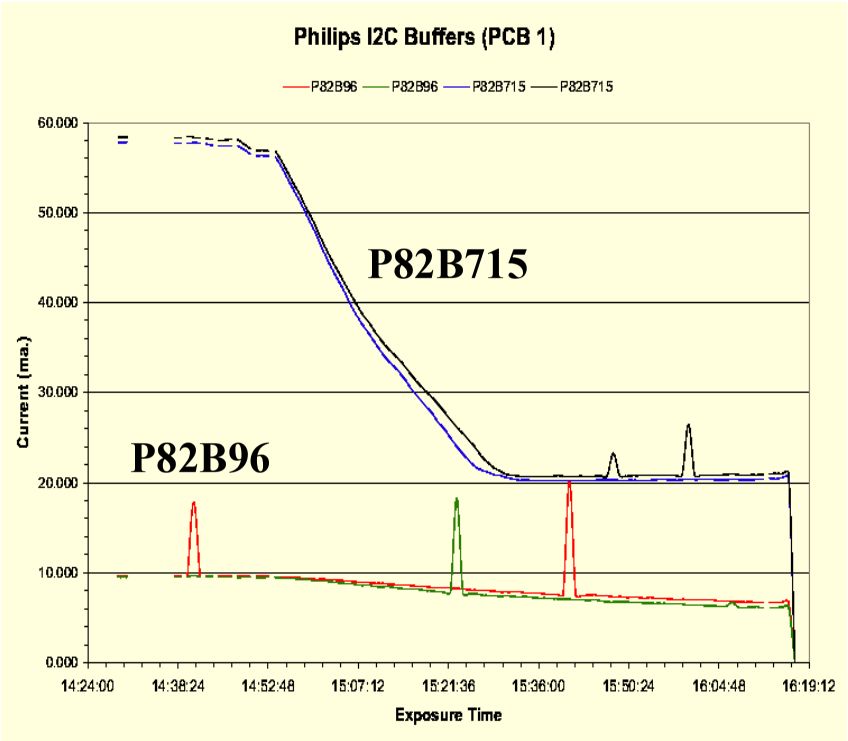
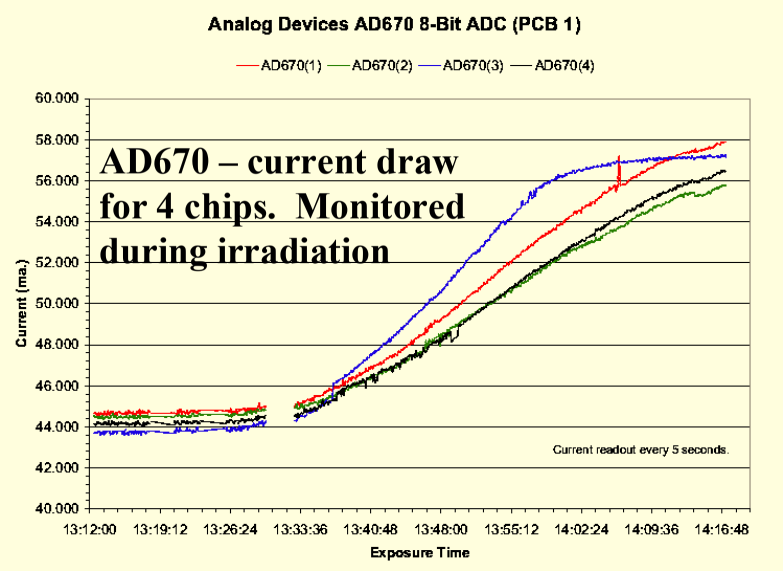


AD670 & RS485

AD670 – A/D converter (1/CCM)

- Bipolar ADC
- Readback of part fails due to Xilinx chip failure – A/D not converting
  - Set limit of < 1 SEL in system/11yrs
  - Set limit of < 1 SEU in system/11yrs



RS485 transceiver (2/CCM)

- No SEU or SEL seen
  - Set limit of < 1 SEL in the system/20yrs
  - Set limit of < 1 SEU in system/20yrs

Other Components

VCSEL radiation testing

- **HFE419x-521: LC connectorized VCSEL**
  - Pillpack: Honeywell rad tested > 100MRad with less than 14% degradation in light output
  - Plastic window in connectorized version not tested
    - **Irradiated LC connectorized VCSEL to 5E11 n/cm^2 – no effect on data transmission**

FE module breakout fiber

- **Measure transmission through fiber pre-irradiation**
- **Dose fiber to 10yr equivalent of 5E11 p/cm^2 (~30 kRad)**
- **No measurable difference seen in transmission (12hrs after irradiation – some annealing)**

Analog MUX–ADG706

- **No latch-ups: Set limit < 1 SEL /yr in full CCM system**
- **SEUs seen (some noise events) – not an issue given its function in the system**

LEDs (Toshiba blue, Nichia green)

- **No change in light level**

FE Board

Test FE boards for latchup (1644 boards in system)

- **Write/Read CCA registers continuously during irradiation**
- **2 boards tested – Total fluence=129x10yr dose for 1 board**
  - No CCA errors & No latch-ups seen
    Overcurrent circuit trips at ~6E12 p/cm^2 (~380kRads)
    - **6.5V supply draws lots of current due to CMOS section of QIE failing from TID. Seen in previous shift register test.**
  - Set limit of < 1 SEL/9.5 months for FE boards in system
    - **Need ~15 boards to study SEU/SEL in FE boards for 10yr operation**

CCM

Test CCM for latch-up (132 boards in system)

- **Write/read registers continuously during irradiation**
- **1 board – Fluence = 25 x 10yr dose for 1 board**
  - No read errors & no latch-ups seen Overcurrent circuit trips at ~2.5E12 p/cm^2 (~150 kRad)
  - A/D stops working → Actel part stops working
    - **No triple vote logic in Actel part**
  - Set limit of < 1 SEL /2yrs operation
    - **Need ~5 boards to study SEU/SEL in CCM system for full 10yr operation**

Low Voltage

VICOR DC-DC converter

- Irradiate w/ protons to 2E11 p/cm^2 (12 kRad TID)
- Developed methodology for de-rating of input voltage, output voltage and output current
- No SEBs seen when operated in appropriate de-rated conditions

Converter model	Proton Energy	Vin [V]	Vout [V]	Iout [A]	Max. fluence [p/cm^2]	Test result and Vds conditions
V375B5C200A	60MeV	260	5	1	1.0x10^{11}	No failure (Vds = 275V)
	300MeV	260	5	1	1.0x10^{11}	No failure (Vds = 275V)
	300MeV	260	5	5	0.5x10^{11}	No failure (Vds = 290V)
	300MeV	260	5	10	0.5x10^{11}	No failure (Vds = 310V)
	300MeV	260	5	15	0.45x10^{11}	Fail SEB (Vds = 330V)
V375B12C250A	60MeV	260	12	5	1.59x10^{11}	No failure (Vds = 310V)
V300B12C250AL	60MeV	207	12	1	1.0x10^{11}	No failure (Vds = 210V)
	200MeV	200	7.5	20	2.0x10^{11}	No failure (Vds = 255V)
	300MeV	200	7.7	19.77	3.0x10^{11}	No failure (Vds = 255V)
	300MeV	200	12	19.77	1.6x10^{10}	Fail SEB (Vds = 310V)
V300B5C200A	200MeV	200	5.2	25	2.0x10^{11}	No failure (Vds = 290V)

"Single event burnout in DC-DC converters for the LHC experiments," C. Rivetta, et al., Fermilab-CONF-01-250-E (Sept 2001).

Studies performed at PSI (200 MeV), Indiana Cyclotron (200 MeV), and Louvain-la-Neuve (60 MeV)

Summary & Plans

Radiation validation status

- **All components tested and validated** **(FERMILAB-CONF-02-224-E)**
  - All components operate well beyond 10yr dose levels
  - Acceptable SEU levels expected
  - SEL limit of < 1 SEL / 10yr for FE system and < 1 SEL / 10yr for CCM system achieved for each component
    - **Spec of <<1 FE board SEL / 10yr and <<1 CCM SEL / 10yr for each system (all chips combined) difficult to achieve due to limited beam time and activation of components**
    - **Study by dosing FE boards and CCMs to 10yr fluence x number of boards in system**
  - Set limit of <<1 SEB / 10yr for HPDs
- **Full system SEU/SEL test schedule for Feb '03**
  - Purchase final components (require each component comes from a single fabrication lot). Validate components with board tests.
- **HCAL FE electronics production begins Summer `03**
  - Test beam boards needed beginning March '03