Virtex-6 Radiation Studies & SEU Mitigation Tests

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Considerations for SEUs in FPGAs

- Configuration memory SRAM is often corrupted by SEUs
  - This can be measured in a beam test…
    - ➢ Recovery from this is done with scrubbing tools or a Program cycle
      - E.g. subsystems have CMS issue a Program command every 20 minutes
      - This is suitable for preventing long-term accumulation of errors
  - But these SEUs do not necessarily cause a disruption in operations
    - ➢ A large fraction of the SRAM bits are not used in a given firmware project
    - ➢ SEUs in these unused bits have little or no impact on logic operations

  → It is more useful to determine the probability to have a real operational problem: we look for SEUs that cause a logic failure
- For the SEUs that cause operational disruptions
  - What is the SEU cross section for this to happen?
  - How does it depend on which FPGA elements are involved?
    - ➢ CLB logic, Block RAMs, GTX modules, etc.
  - Design firmware with tests that are sensitive to each specific element in the FPGA architecture, and measure the error rate
  - Results can be extrapolated to an arbitrary firmware design based the on fraction of each device element in used in the test

SEU Tests for CMS Muon Electronics

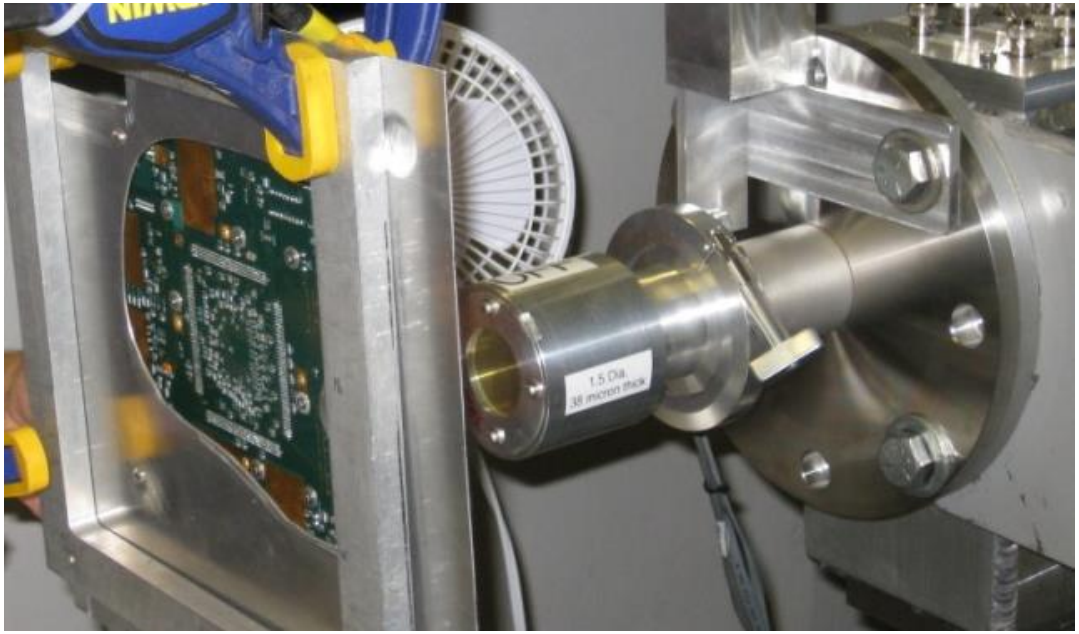
This work was done as R&D work for the Cathode Strip Chamber electronics in the CMS Endcap Muon system

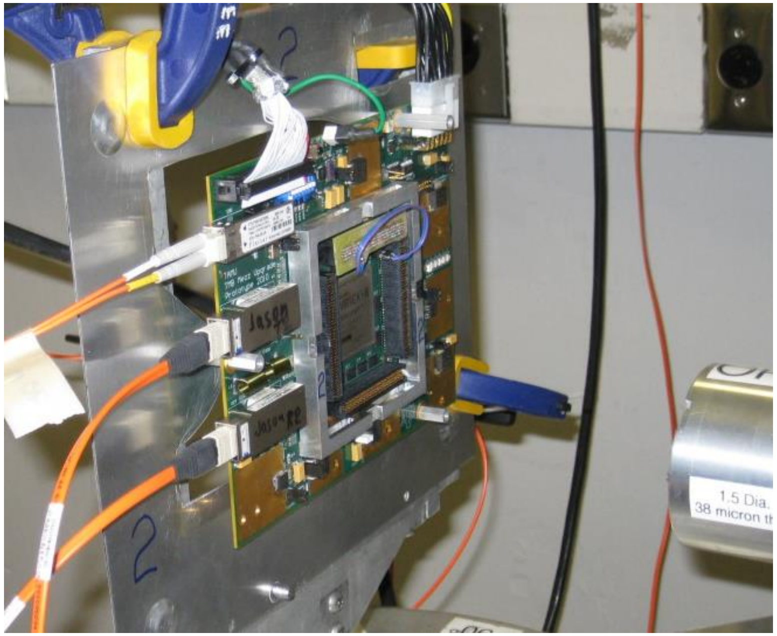
- Tests were performed at UC Davis and TAMU Cyclotron facilities using a collimated proton beam
  - The beam was collimated uniformly on one chip at a time with a precision flux measurement
  - We tested two identical FPGAs running the same firmware
  - All chips tested survived 30 kRad dose in the beam

- Firmware design for rad tests
  - Specific modules were instantiated in the code to test different FPGA elements
    - Block RAMs, CLBs and GTX
    - Used a large fraction of each in the FPGA
  - All of these modules were running simultaneously in firmware
  - Errors in each module were monitored & logged by software via gigabit Ethernet fiber connection to a PC

Test Beam Photos

The Texas A&M University cyclotron at the Radiation Effects Facility, and the UC Davis Crocker Laboratory cyclotron





FPGA SEU Results for CSCs

- Xilinx Virtex-6 FPGA, model xc6vlx195t-2ffg1156ces
  - Enabled native ECC feature in Block RAMs to protect data integrity
  - CLB tests based on a triple-voting system
    - ➢ Implemented with a custom designed TMR logic module
  - Results are summarized below
- GTX Transceiver (55% used in FPGA)
  - Random PRBS data patterns @3.2 Gbps on each of eight links
  - These SEUs only caused transient bit errors in the data
  - SEU cross section result: $\sigma = (10 \pm 0.8) * 10^{-10}$ cm^2
- Block RAM (74% used in FPGA)
  - Software controlled write and read for BRAM memory tests
  - No data corruption was detected in the BRAM contents
  - SEU cross section: $\sigma_{90\%} < 8.2 * 10^{-10}$ cm^2
- CLB (43% used in FPGA)
  - SEU cross section result: $\sigma = (6.0 \pm 0.5) * 10^{-9}$ cm^2
    - ➢ With this we expect ~1 CLB SEU per FPGA per day per CSC chamber in CMS
  - Our results here were less than ideal… to be repeated later this year

Xilinx Scrubbing Tool Experience at OSU

- SEM Controller for Xilinx Virtex-6
  - Xilinx LogiCORE IP Soft Error Mitigation Controller v3.6
- Xilinx built-in feature for Soft Error Mitigation
  - Continuously reads configuration memory and checks each frame for errors
  - If single bit errors exist, it corrects the error and re-writes the frame
- But the built in feature has known issues
  - A simple web search explains how to deal with them
  - Experts suggest using the SEM Controller IP core
- The SEM Controller:
  - Utilizes the built-in feature to do continuous readback and CRC checking
  - Handles correcting single bit errors
  - Has port for injecting errors for testing

SEM Controller

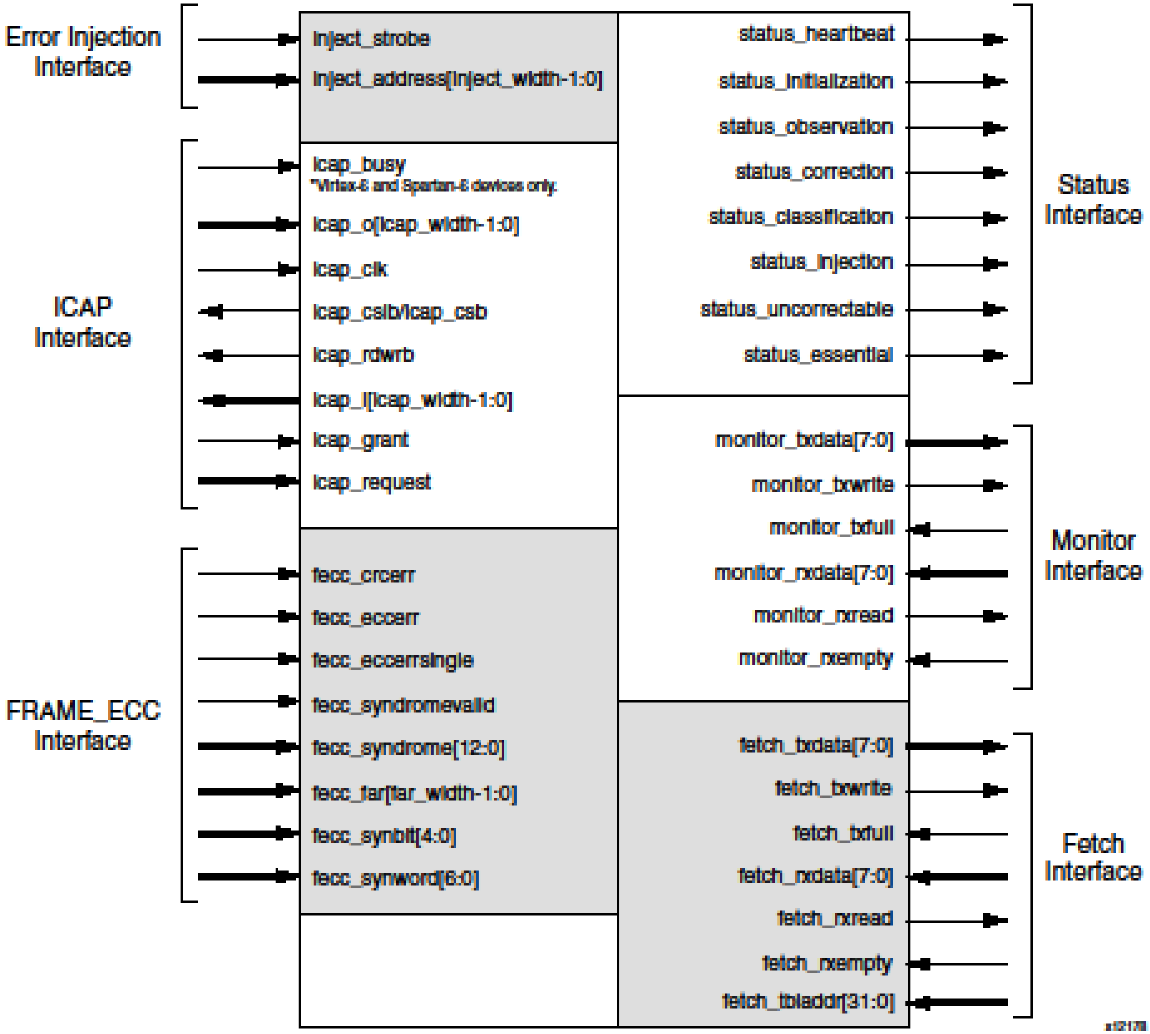
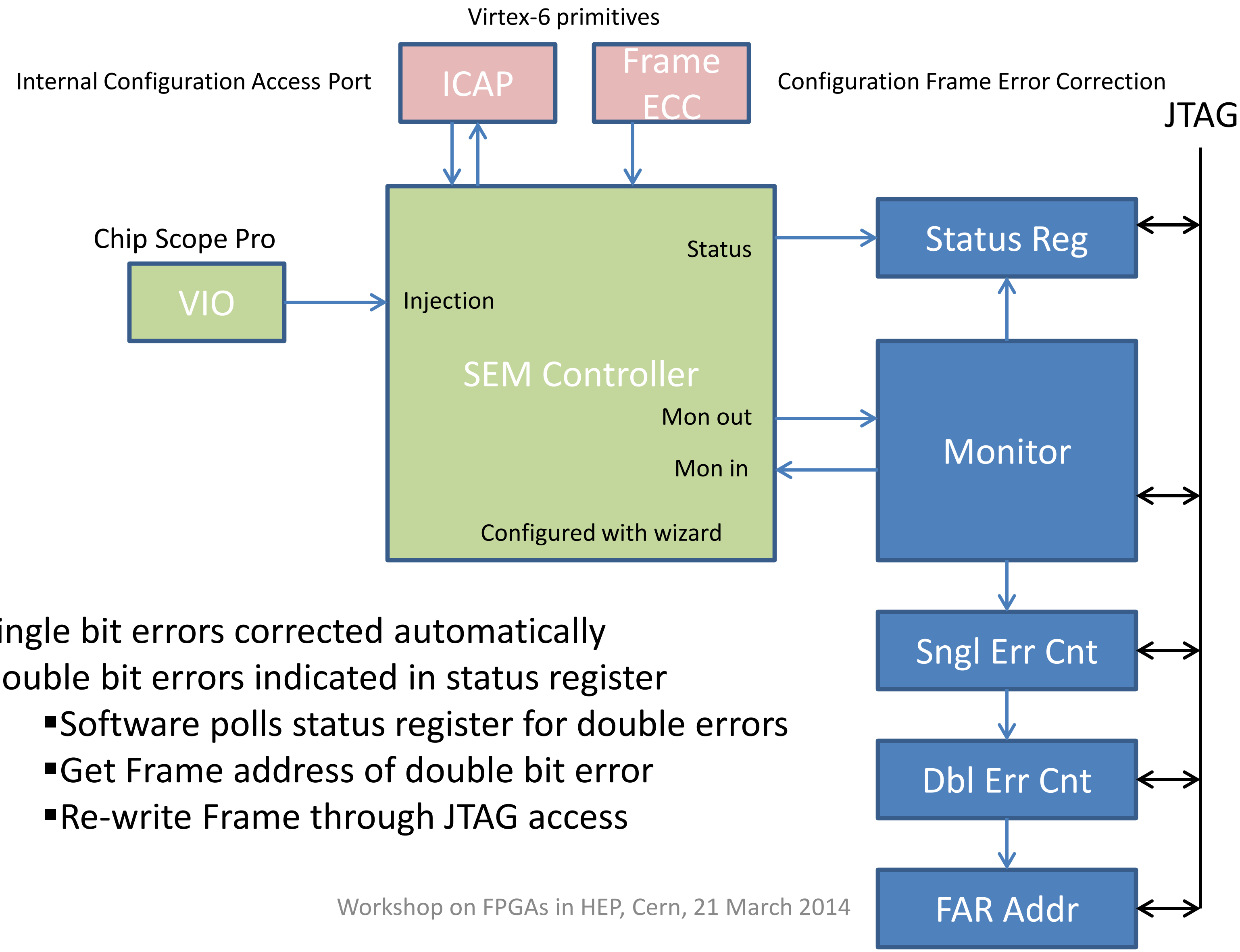


Figure 2-1: **SEM Controller Ports**

Taken from Xilinx document PG036

SEM Controller



- Single bit errors corrected automatically
- Double bit errors indicated in status register
  - Software polls status register for double errors
  - Get Frame address of double bit error
  - Re-write Frame through JTAG access

Extra Slides…

SEU Test Results for Other CSC Electronics

- Finisar Optical Transceiver ftlf8524e2gnl: Transmit side
  - Gigabit Ethernet packet transmission tests to PCI card, 4 kB @ 500 Hz
    - Bad or missing packets received at the PC are “transmit” SEUs
    - Note that the duty cycle here is significantly less than 100%
  - These SEUs caused lost GbE packets and rare “powerdown” events
  - SEU cross section result: $\sigma = (4.3 \pm 0.3) * 10^{-10}\ cm^2$
  - Correcting for real CSC transmitter duty cycle: $\sigma = 6.7 * 10^{-8}\ cm^2$ per link
    - We expect to see ~10 SEU per link per day during HL-LHC running
      - Very low rate of single bit errors: just 1 error per 20 trillion bits on each link

- Finisar Optical Transceiver ftlf8524e2gnl: Receive side
  - These SEUs only caused transient bit errors
  - SEU cross section: $\sigma = (7.5 \pm 0.1) * 10^{-9}\ cm^2$ per link
    - We expect to see ~1 SEUs per link per day
  - *Three Finisars tested: one died at 33 krad, another at 41 krad
    - The third chip survived with 30 krad and still working on the bench in 2014

Summary of All TAMU Reactor Tests (1)

Part/Chip Name	Chip Type	10 krad Exposure Pass/Fail	30 krad Exposure	Result Comments
Maxim 8557ETE	Voltage Regulator	Pass	Fail	5 out of 6 die at 30 krads
Micrel MIC69502WR	Voltage Regulator	Pass	Pass	
Micrel MIC49500WU	Voltage Regulator	Pass	Pass	
National Semi LP38501ATJ-ADJCT-ND	Voltage Regulator	Pass	Pass	
National Semi LP38853S-ADJ-ND	Voltage Regulator	Pass	Pass	
Sharp PQ05VY053ZZH	Voltage Regulator	Pass	Fail	Fails to regulate
Sharp PQ035ZN1HZPH	Voltage Regulator	50% Pass	Fail	Fails to regulate
Sharp PQ070XZ02ZPH	Voltage Regulator	Fail	Fail	Fails to regulate
TI TPS740901KTWR	Voltage Regulator	Pass	Pass	
TI TPS75601KTT	Voltage Regulator	Fail	Fail	Fails to regulate
TI TPS75901	Voltage Regulator	Fail	Fail	Fails to regulate
ST Micro 1N5819	diode	Pass	Pass	
ON Semi 1N5819	diode	Pass	Pass	
Fairchild 2N7000	N-channel FET transistor	N/A	Pass	
Analog Devices AD8028AR	High Speed, Rail-to-Rail Input/Output Amplifiers	N/A	Pass	
Analog Devices ADM812	Voltage Monitor	N/A	Pass	
National Semi LM41211M5-1.2	Precision Micropower Low Dropout Voltage Reference	N/A	Pass	
National Semi LM4121AIM5-ADJ	Precision Micropower Low Dropout Voltage Reference	N/A	Pass	

Summary of TAMU Reactor Tests (2)

Part/Chip Name	Chip Type	10 krad Exposure Pass/Fail	30 krad Exposure	Result Comments
National Semi LM19CIZ	TO-92 Temperature Sensor	N/A	Pass	
Maxim MAX680CSA	+5V to ±10V Voltage Converter	N/A	Pass	
Maxim MAX664CSA	Dual Mode 5V/Programmable Micropower Voltage Regulator	N/A	Fail	Dead
Maxim MAX4372	High-Side Current-Sense Amplifier	N/A	Pass	
Micrel MIC35302	High-Side Current-Sense Amplifier	N/A	Fail	Dead
Micrel MIC37302	High-Side Current-Sense Amplifier	N/A	Fail	Dead
Fairchild MM3Z4V7C	Zener Diode	N/A	Pass	
Fairchild MM3Z5V1B	Zener Diode	N/A	Pass	
Sharp PQ7DV10	Variable Output 10A Voltage Regulator	N/A	Pass	
TI TPS7A7001	Very Low Dropout, 2A Regulator	N/A	Fail	Fails to regulate

Summary of TAMU Reactor Tests (3)

Part/Chip Name	Chip Type	10 krad Exposure Pass/Fail	30 krad Exposure	Result Comments
TI SN74LVC2T45	Two-bit Dual-supply Tri-statable Bus Transceiver	N/A	Pass	
Analog Devices ADM660AR	CMOS Switched-Capacitor Voltage Converter	N/A	Pass	
Analog Devices ADM8828	Switched-Capacitor Voltage Inverter	N/A	Pass	
Intersil ICL7660S-BAZ	Switched-Capacitor Voltage Converter	N/A	Fail	Dead
Linear Technology LTC1044CS8	100mA CMOS Voltage Converter	N/A	Pass	
Maxim MAX1044CSA	Switched-Capacitor Voltage Converter	N/A	Fail	Dead
Maxim MAX860-UIA "uMAX"	Switched-Capacitor Voltage Converter	N/A	Pass	
Maxim MAX861-ISA	Switched-Capacitor Voltage Converter	N/A	Pass	
Microchip TC1044SCOA	Charge Pump DC-TO-DC Voltage Converter	N/A	Pass	
Microchip TC962COE	High Current Charge Pump DC-to-DC Converter	N/A	Pass	