Status of the CSM FPGA Irradiation Test for the HL-LHC ATLAS Muon Spectrometer Upgrade

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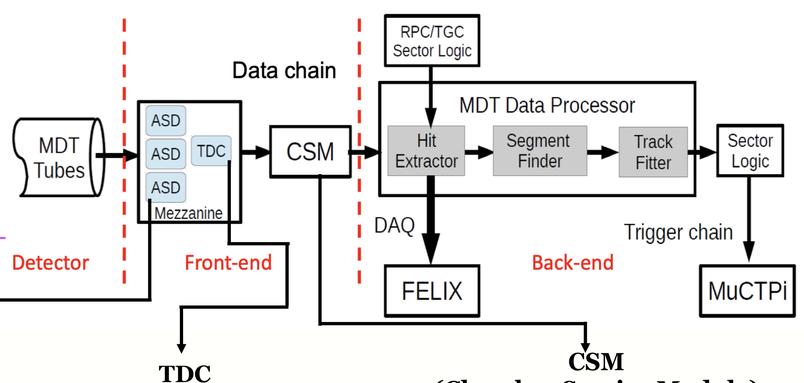
MDT FRONT END ELECTRONICS

- The upgrade requires **higher trigger rate (1 MHz)** and **longer latency (10 μs)**
- **New feature:** MDT hits will be included in the level-0 trigger
- Description of custom-built front-end electronics below

Block Diagram of MDT Trigger and readout electronics for Phase-II Upgrade



- 3 8-channel, Analog ASIC
- Processes signals from the MDT and sends 8-outputs to TDC
- ASIC designed in MPI-Munich

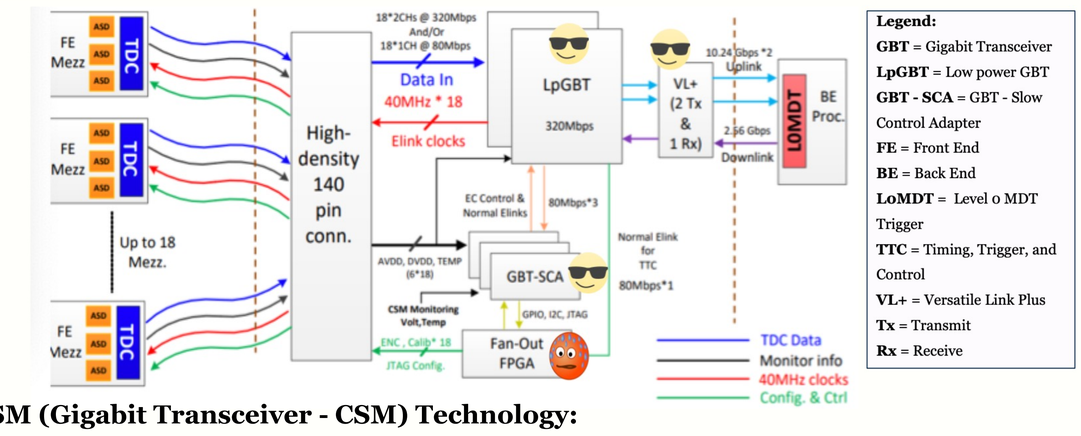
- Digital ASIC
- Performs a time measurement
- 80 Mbps → 320 Mbps x 2
- ASIC designed at the University of Michigan

- 20 -Mezzanine Multiplexer board
- LpGBT-based CSM
- 2 Gbps → 10.24 Gbps x 2
- CSM designed at the University of Michigan

Talk focuses on testing radiation hardness of a custom-built front-end electronics (mezzanine card + CSM module) for the HL-LHC

arXiv:2011.11699

Chamber Service Module Logic Flow



Legend:
GBT = Gigabit Transceiver
LpGBT = Low power GBT
GBT - SCA = GBT - Slow Control Adapter
FE = Front End
BE = Back End
LoMDT = Level 0 MDT Trigger
TTC = Timing, Trigger, and Control
VL+ = Versatile Link Plus
Tx = Transmit
Rx = Receive

GBT-CSM (Gigabit Transceiver - CSM) Technology:

- **Two-fold Function**: a **multiplexing center** between FE Mezzanines and BE LoMDT and handles **TTC and Monitoring information**
- LpGBT, GBT-SCA, and VL+ have built-in radiation hardness tested at CERN

Fanout FPGA is the most sensitive component to radiation inside the CSM

PHASE-II MDT CSM RADIATION REQUIREMENTS

	MDT FE			MDT CSM		
	TID	NIEL	Hadrons>20	TID	NIEL	Hadrons>20
SRL (1000	15.70	3.57	0.685	5.32	2.91	0.528
4000 fb-1	62.80	14.28	2.74	21.28	11.64	2.11
x(SF sim)	94.20	21.42	4.11	31.92	17.46	3.17
RTC (ASIC)	94.20	27.85	8.22	31.92	22.70	6.34
RTC (COTS)	282.6	83.5	24.7	95.8	68.1	19.0
Max at	BIS8 sMDT	BEE	BEE	EIL	EIL	EIL

Figure 1: MDT and RPC Radiation Requirements Radiation based on standard ATLAS simulation

→ **SEE Radiation Requirement**

Average Flux in ATLAS per 10 years: **1.9E12 n/cm^2/10y**

Average Flux in ATLAS per seconds: **6.0E3 n/cm^2/s**

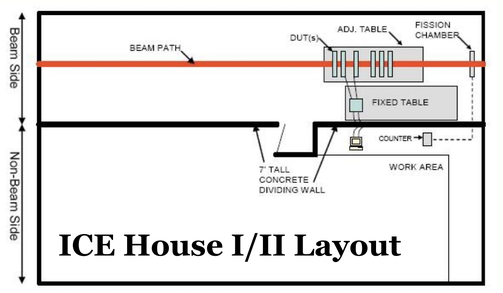
COTS qualification requires no significant performance drop and negligible no. of SEE after an average flux 1.9E12 n/cm^2/10y

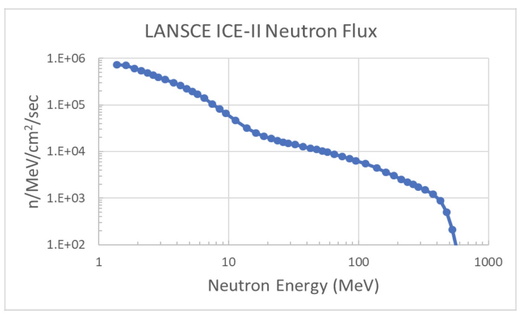
LANSCE IRRADIATION TEST

	LANSCE Beam Facility
Neutron Production	Tungsten neutron production targe
Beam Energy	Up to 800 MeV
Beam Spectrum	Similar to ATLAS energy spectrum
Beam Size	Collimated 2”
Flight Paths	+/- 30-degrees (ICE-I/ICE-II)
Flux[$\frac{n}{cm^2*s}$]	1.54E+06 * Degradation Factors
Total Fluence[$\frac{n}{cm^2}$]	4.72E+11 * Degradation Factors

*** > 3 orders of magnitude compared to ATLAS**

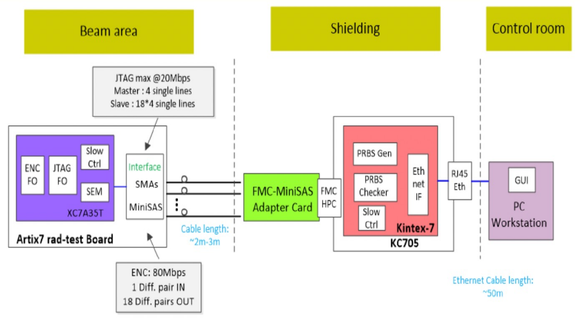
BEAM Degradation Factor:
CSM Board 1: 0.8970
CSM Board 2: 0.9080



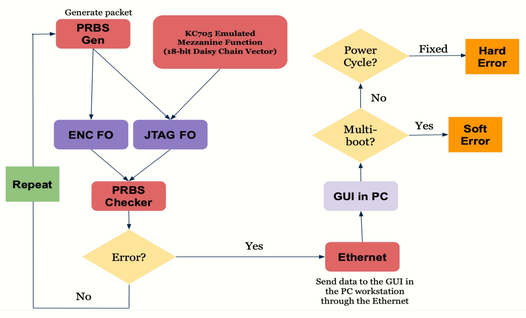


Hardware Setup

- KC705 Board + Bridge Board + miniSAS cable + Artix-7 rad-test Board
- 2 setups/run with the same hardware, firmware, software

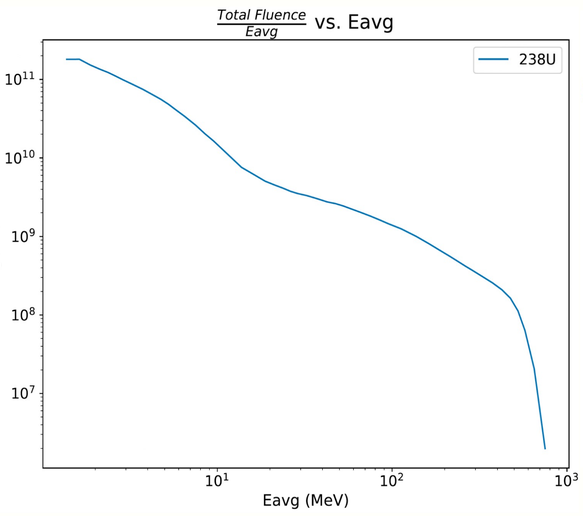


The beam area is the DUT (Artix-7) with a test firmware connected through FMC-miniSAS cables to the DAQ Firmware (KC705) shielded from the beam.

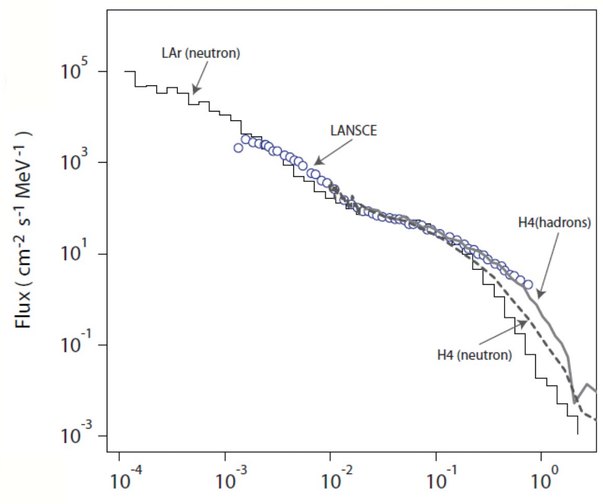


Data flow: the PRBS Gen generates random packets, then goes to Fanout. Packets are re-transmitted and the PRBS Checker checks for bit flips.

IRRADIATION TEST RESULTS

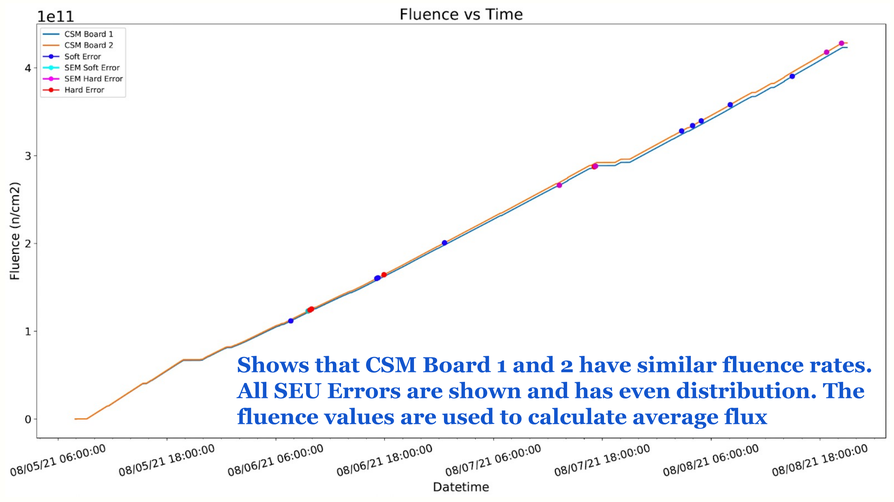


Total Fluence vs Eavg :
Energy spectrum at LANSCE during Beam run



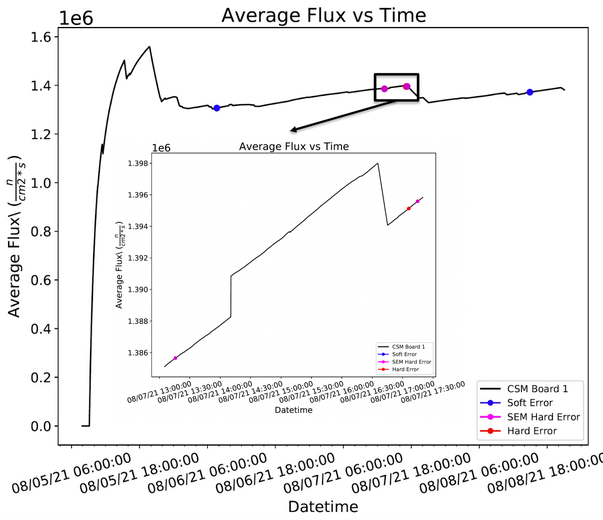
ATLAS LAr Detector Sample Energy Spectrum Plot

Energy Spectrum of neutrons emitted in fission. A good confirmation that LANSCE Energy Spectrum similar to ATLAS energy spectrum.

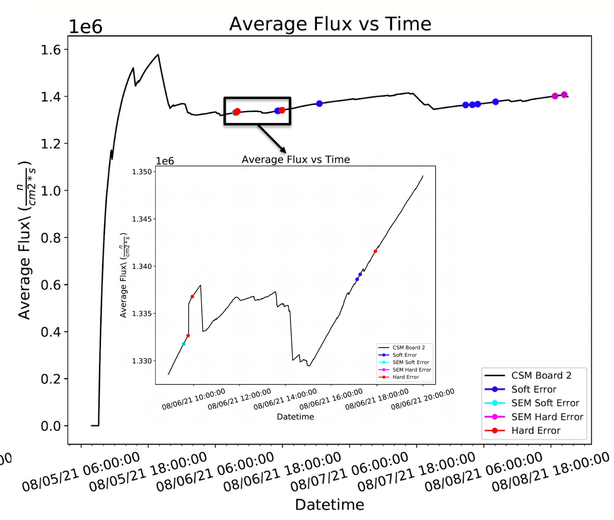


Shows that CSM Board 1 and 2 have similar fluence rates. All SEU Errors are shown and has even distribution. The fluence values are used to calculate average flux

Fluence vs Time: Used to calculate Average Flux (n/cm^2/s)



Average Flux vs. Time: CSM 1 with 5 SEU Errors - 2 Soft Errors, 1 Hard Errors, and 2 SEM Hard Errors (categorized in the end as Hard Errors)



Average Flux vs. Time: CSM 2 with 13 SEU Errors - 7 Soft Errors, 1 SEM Soft Error, 3 Hars Errors, 2 SEM Hard Errors (SEM errors categorized later as either Soft or Hard Error)

CSM Board 1 and 2 also have similar average flux rates. Plots summarize the different SEU errors that occurred during the beam test, and they show optimistic results.

SUMMARY

		Board #1 Soft Error = 2	Board #1 Hard Error = 3	Board #2 Soft Error = 8	Board #2 Hard Error = 5
> 10 MeV	Fluence (n/cm^2)	4.23E+11		4.28E+11	
	Ave. Flux (n/cm^2/s)	1.33E+06		1.34E+06	
	Cross-Section (cm^2)	4.73E-12 ± 3.34E-12	7.09E-12±4.09E-12	1.87E-11 ±6.61E-12	1.17E-11 ± 5.22E-12
> 20 MeV	Fluence (n/cm^2)	3.55E+11		3.59E+11	
	Ave. Flux (n/cm^2/s)	1.11E+06 (n/cm^2/s)		1.12E+06	
	Cross-Section (cm^2)	5.63E-12 ± 3.98E-12	8.45E-12 ± 4.88E-12	2.23E-11 ± 7.88E-12	1.39E-11 ± 6.23E-12

Table summarizes SEU results. The degradation factors for each board are applied to the fluence, average flux and cross section for soft and hard errors

Good results for custom-built electronics for MDT Phase-II upgrade and pass CSM Radiation Reqs.

- ~ 1.9E+11 $n/cm^2/10y$ (MDT CSM Requirement)
- LANSCE 3 days fluence ≈ **2-3 years** of ATLAS fluence
- 1 CSM board on average has ~9 errors in 3 years of ATLAS Run
- Average flux of LANSCE is **1000 higher** than ATLAS

(6.02E+3 $n/cm^2/s$ vs ~1.3E+6 $n/cm^2/s$) – Testing for worst case scenario

FUTURE WORK

- Successfully conducted SEU Irradiation test at LANSCE using custom-built front-end electronics for the MDT Phase-II upgrade
- Calculate Data Loss %
- Paper in the works to discuss custom-built front-end electronics, Irradiation test, and results
- Total Ionization Dose (TID) Test at BNL concluded and annealing test is ongoing

LANSCE radiation test results are promising, and analysis of SEU Test will continue this year. TID Results to be reported soon.