Trigger-less Muon Data Acquisition (TM-DAQ) system for the GRAPES-3 muon telescope

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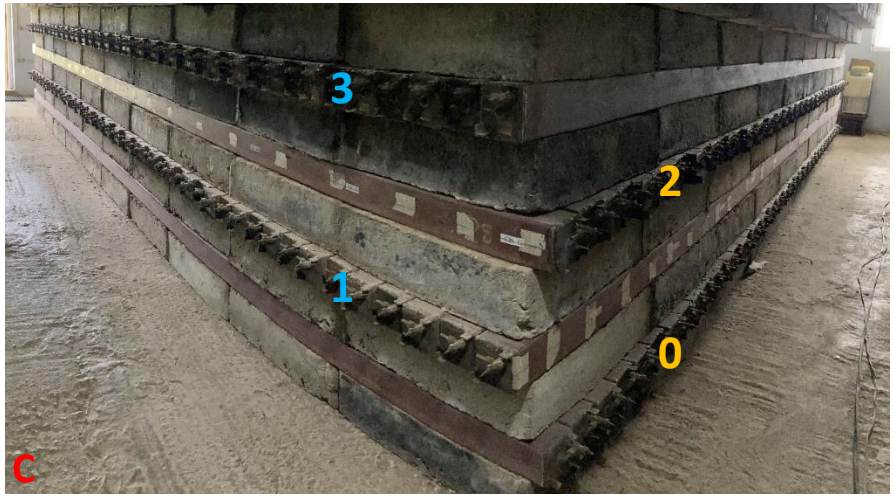
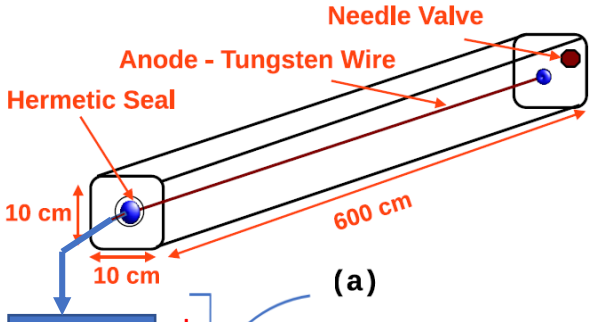
The GRAPES-3 EXPERIMENT



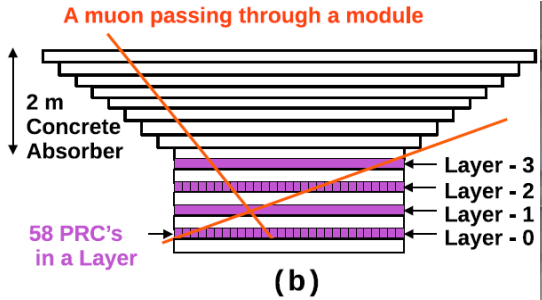
VIEW OF EXISTING MUON MODULE

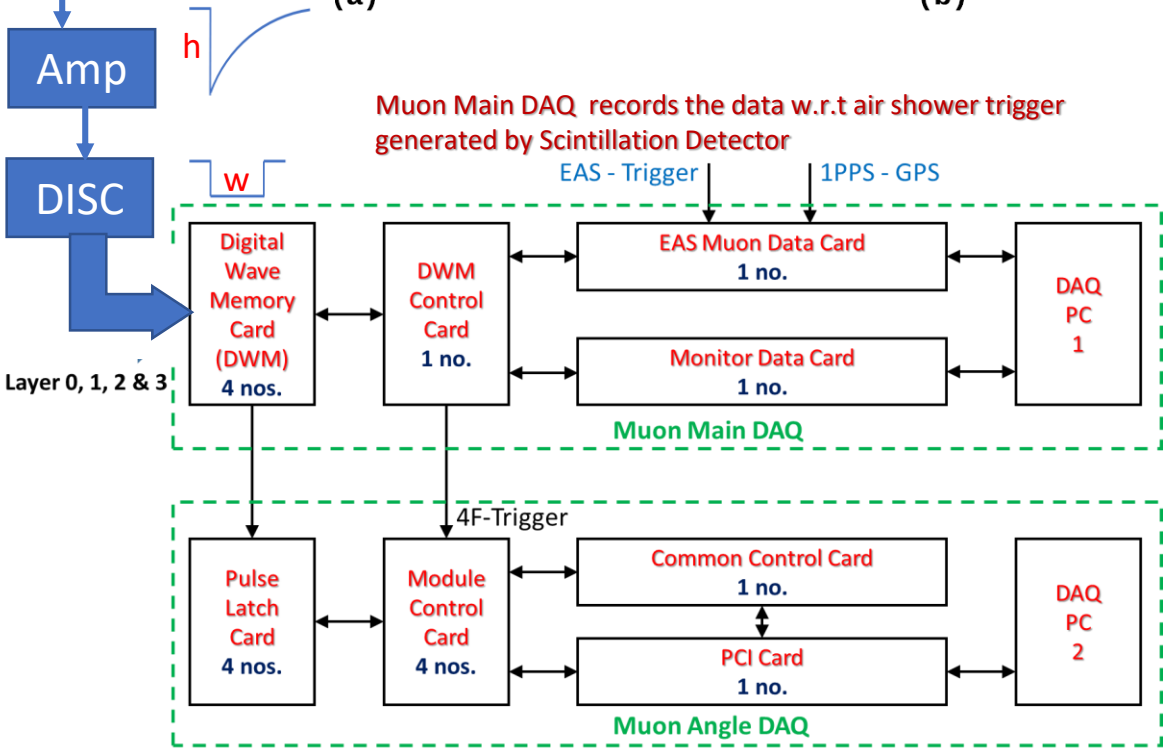
Existing Conventional DAQ for Muon Detector

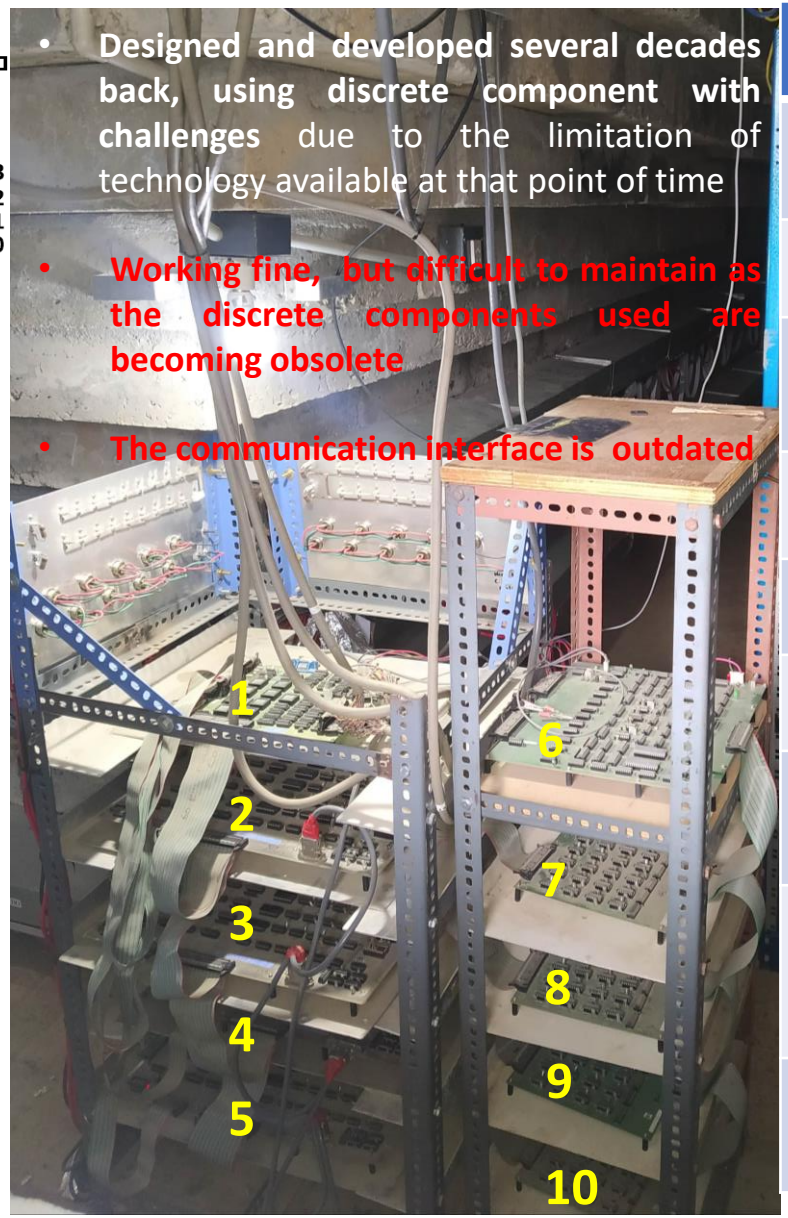
Proportional Counter (PRC)



Muon Module







- Designed and developed several decades back, using discrete component with challenges due to the limitation of technology available at that point of time
- Working fine, but difficult to maintain as the discrete components used are becoming obsolete
- The communication interface is outdated

Challenges in Existing DAQ

Two DAQ streams: Mu-Main and Mu-Angle
Mu-Main: Width and Time of each PRC w.r.t. Air shower trigger
Mu-Angle: 4- fold (whenever a Muon passes through all 4 layers of PRC's as show in picture b)
It uses 10+ large area PCB per modules
Large Dead time: 12 – 20 %
Pulse Arrival Time: Not measured
Pulse Width is measured for 1 channel (1000 sec) at a time in each layer time
No direct CRM for PRC's Only 4F and Any3F at every second Other folds – time multiplexed
Restricts the measurement of Muon angle up to Up to 45°

Triggerless Muon DAQ Concepts and Physics Horizon

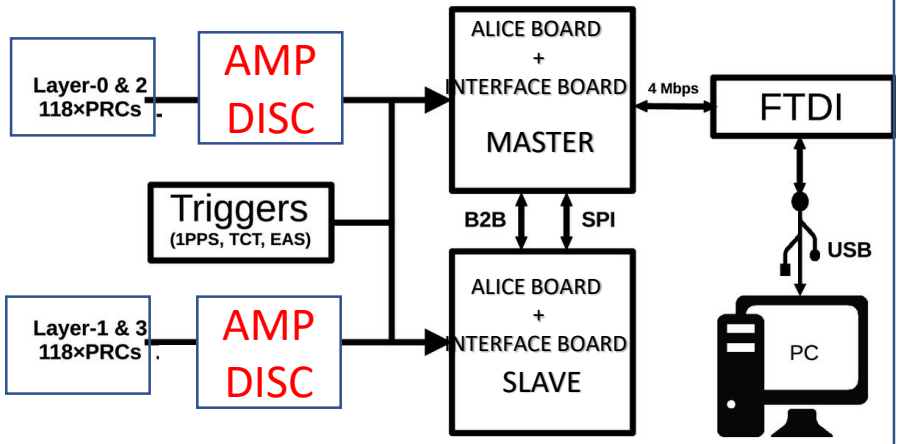
- **Trigger less Muon Data**
  - **Records the arrival time and the pulse width for each and every hit from the proportional counter**
  - **Record the hit rate of PRC, various triggers, temperature etc.**
    - **Pulse Width measurement is done with a resolution of 10 nano-second**
    - **Absolute pulse arrival time is measured with a resolution of 10 nano-second**

- **Physics dependent reconstruction of raw data can be done in offline mode**
  - **Rigidity dependent study of Moon Shadow**
  - **Transient Phenomenon**
    - **Thunderstorm Physics**
    - **Solar Physics**
  - **Air Shower Physics**
    - **Air showers at large zenith angles, muon rich showers**
  - **New Physics** (This enables users to do Physics beyond standard model)
    - **Search for tachyons, low beta particles (monopoles, WIMP etc.), serendipitous searches**

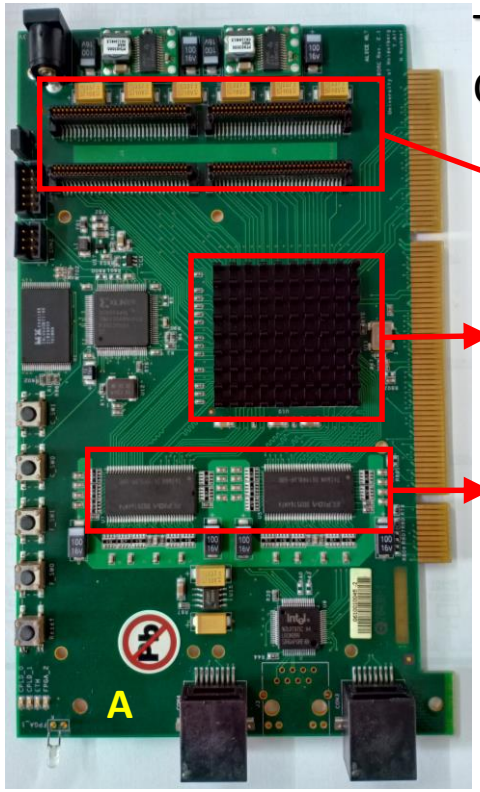
Architecture of TM-DAQ System

- **System requirement**
  - A device with adequate I/O's to process all the PRC channel in parallel, better timing resolution, excellent signal processing capability and memory
- **Solution: FPGA based embedded systems**
- **Received large number of ALICE Boards (~150 number) from ALCIE Collaboration as gratis**
- **Designed interface card to access the FPGA I/O's**

Due to the limitation of I/O's, 2 No's Alice Board + interface Board combination is used to process 1 module



ALICE Board



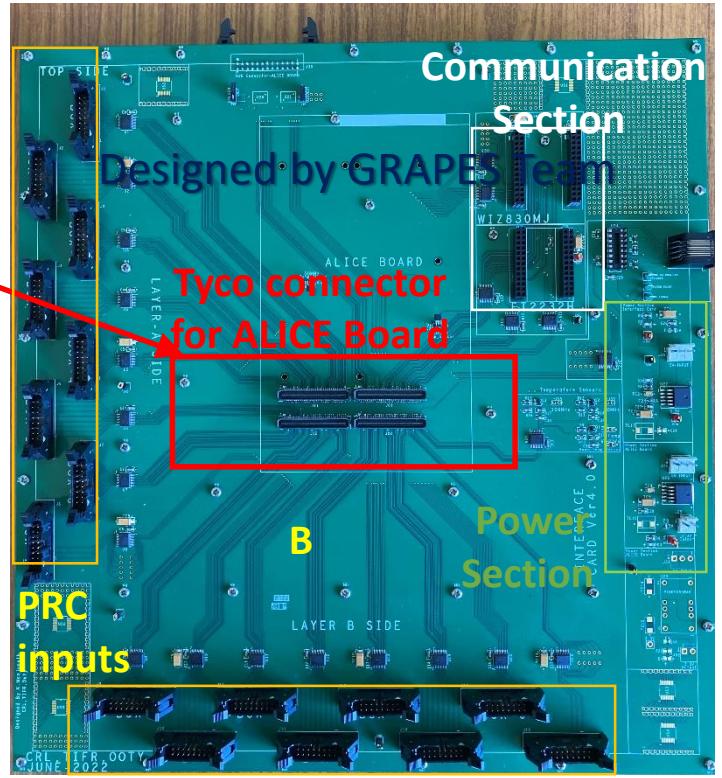
Tyco Connectors

FPGA Chip

DDR Memories

Xilinx Virtex-4 FPGA (XC4VLX40)
Clocks: 100 MHz & 50 MHz
DDR SDRAM (EDD2516A)- 4 Physical chips Each with 32MB
Tyco connector - 158 Usable I/O Pins
Board Size : 17.4 X 10.6 CM

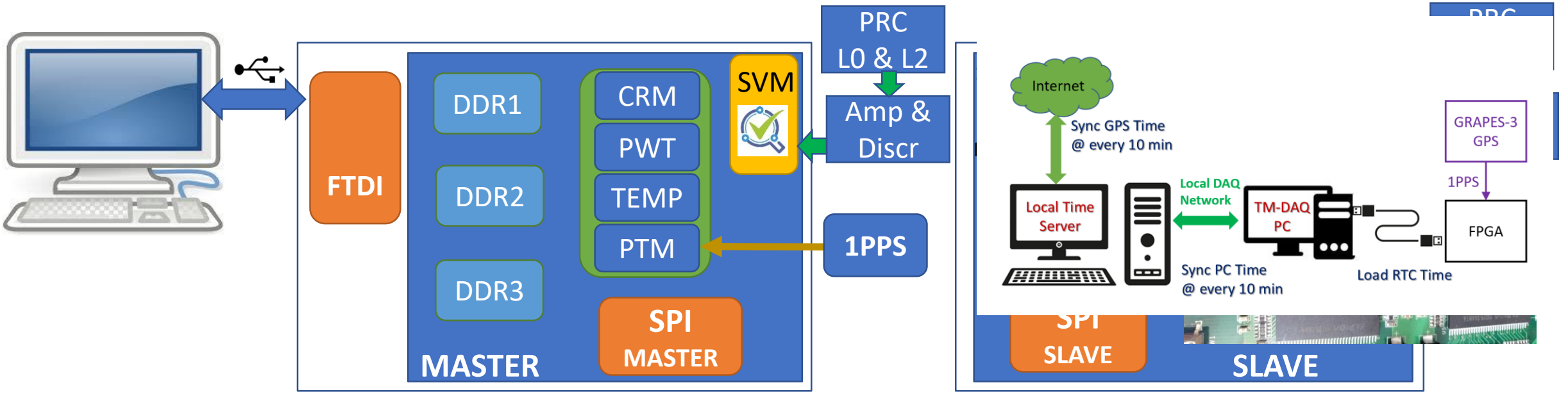
Interface Board



Designed interface card to access the FPGA I/O's

- Level translator section
- Power section (to the ALICE board)
- Communication section
- Size 36 X 34 Cm

FIRMWARE MODULES FOR TM-DAQ



Communication Module

Since the ALICE card has only 158 accessible I/O's, we need to have 2 Alice boards to process one module. So we should have proper inter board communication for which we have

1. SPI communication Module for Master and slave
2. DDR Controller for SPI DDR (DDR3) in Master

- Recording interval 250ms
  - Real Time Clock (RTC) /Time Synchronization/Clock Counter/Time Calibration Trigger (TCT)
    - ➢ Complete time information ranging from year to nanosecond is managed inside FPGA by using smart algorithms
    - ➢ GPS synchronization ensures the accuracy of time
    - ➢ All raw data is recorded and any correction (e.g. w.r.t. temperature) can be done offline during analysis
- The temperature and the Counting rates of crystals are recorded as part of data

TM-DAQ

	USB Protocol	SPI Protocol
Max Theoretical Speed	8 MBytes/Sec	~1 MBytes/sec
Speed in TM-DAQ	The data transfer speed using USB protocol is ~1.5 MBytes/Sec	The data transfer speed using SPI protocol is ~500 KBytes/Sec
	600 KBytes/Sec	300 KBytes/Sec
Data Volume in TM-DAQ	~60 GBytes/Day/Module	~30 GBytes/Day/Module

Hardware Monitoring and Auto reset option

- All the critical signals are continuously monitored in the Master board and Slave board
- Any abnormality for more than 2 sec will initiate the Auto reset feature
- Auto reset will reset the DAQ and re-initialize all the parameters
- This feature is very unique which reduces the down time drastically

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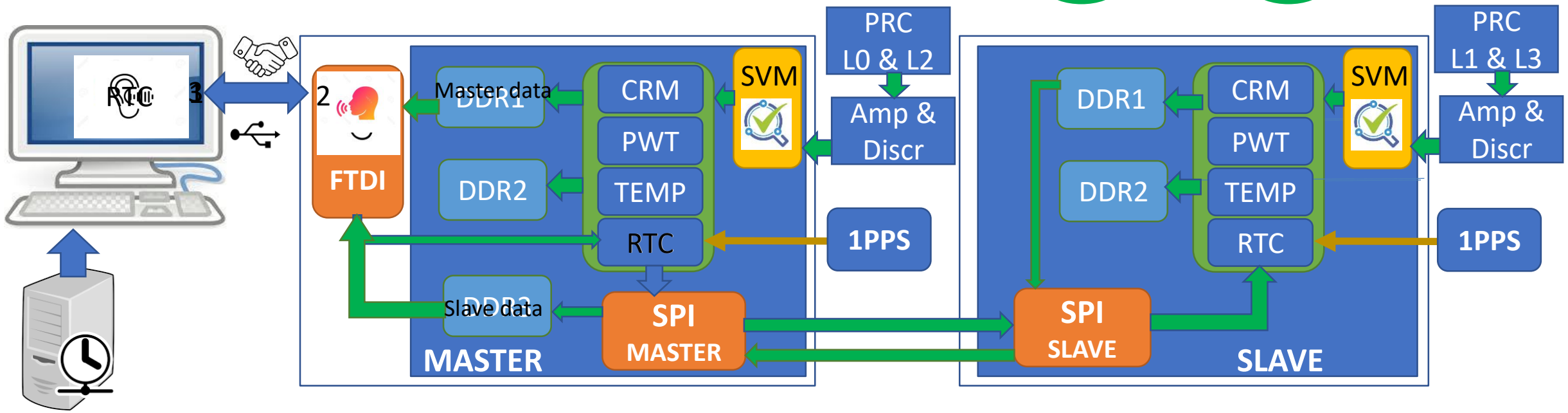
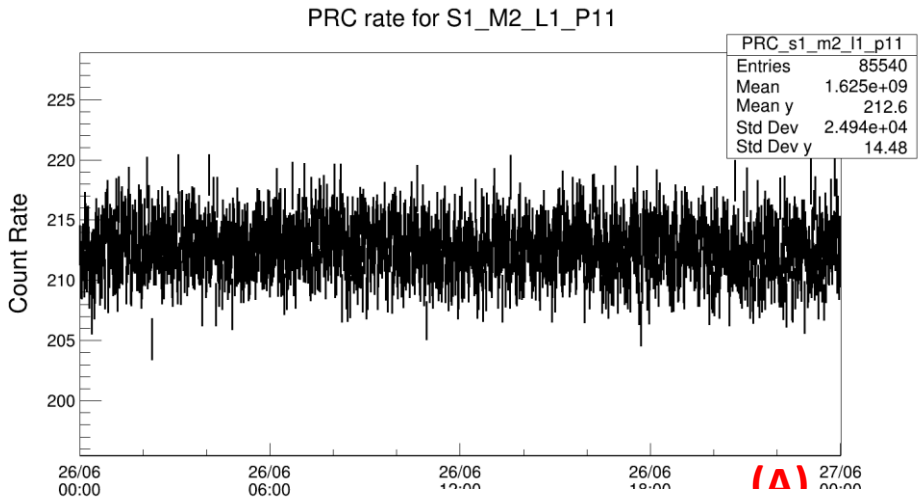
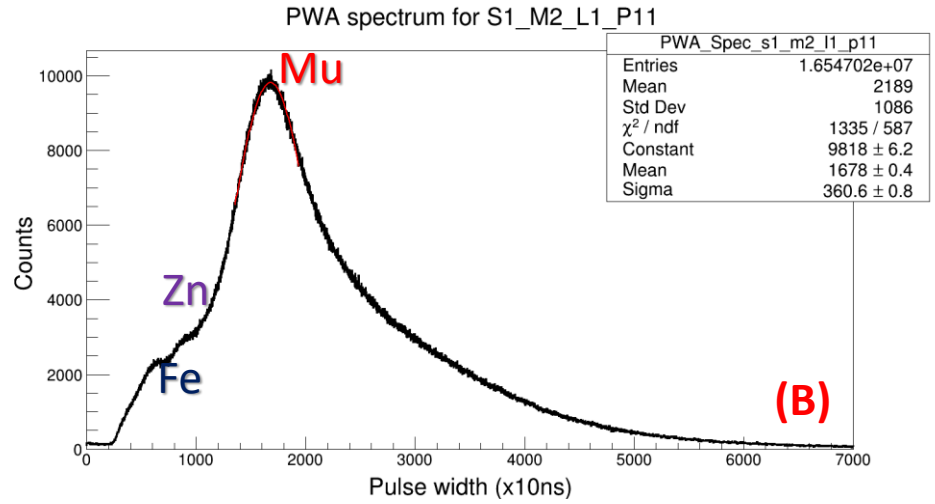
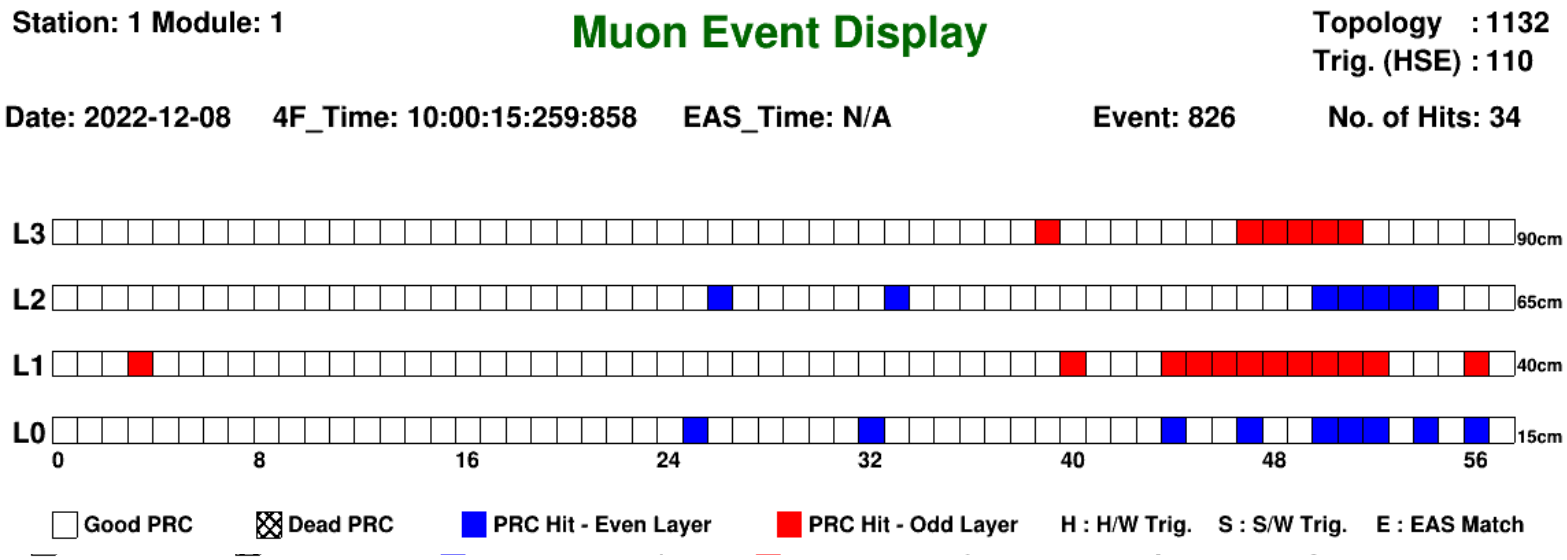


Observation

- The stability and data quality of TM-DAQ seems to be very good and last several months we have not seen any failures (one module is continuously since 02nd Jan 2022 (~350days) without any break)

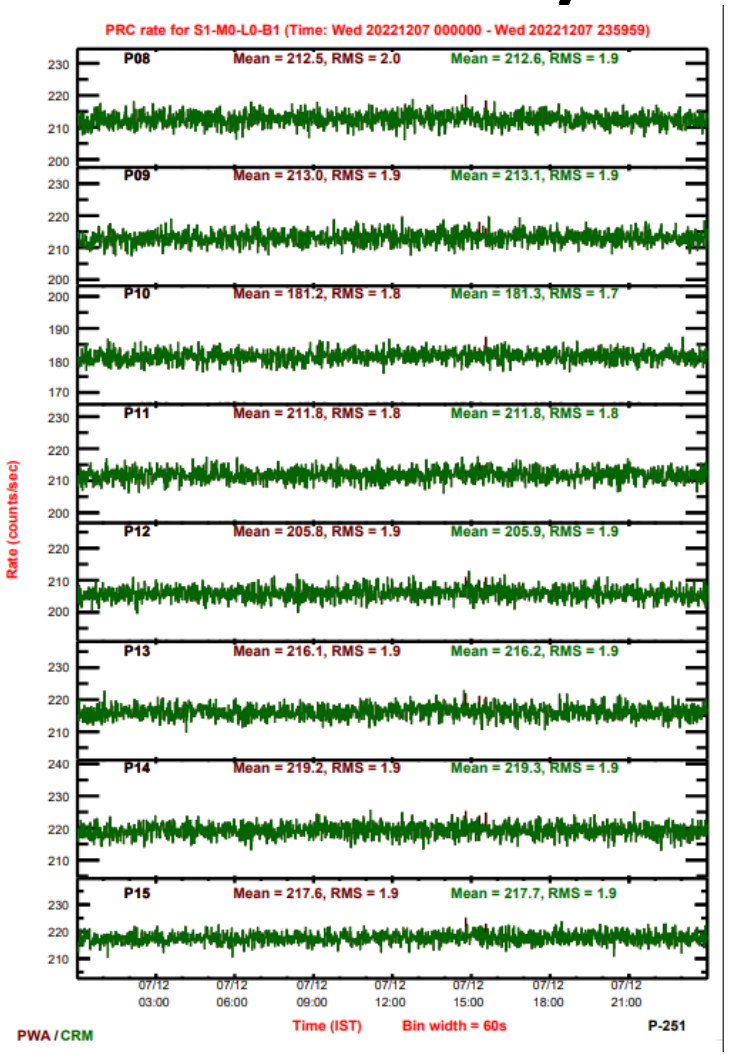


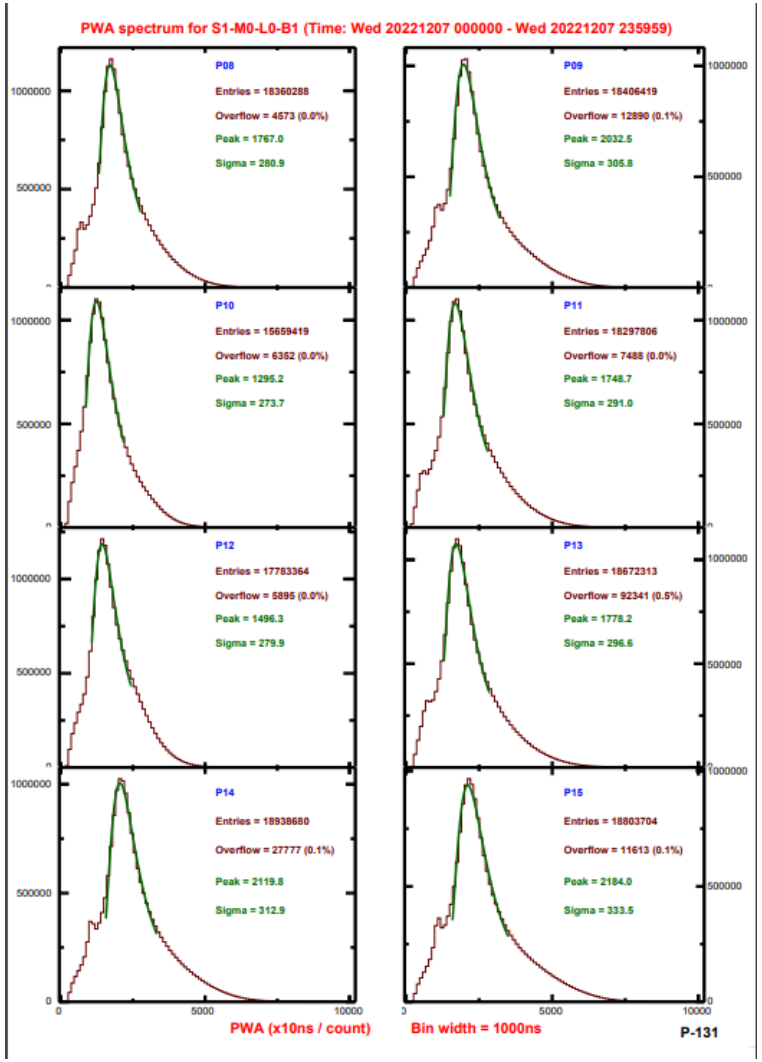




(C)

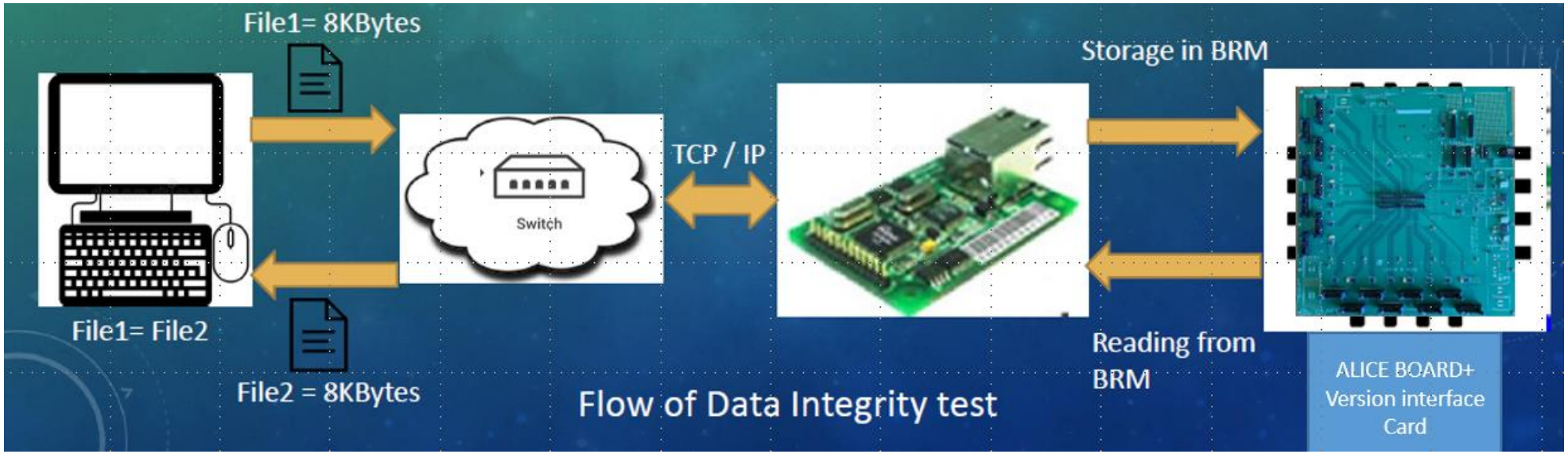
Daily Monitoring Plots





Ethernet Communication for TM-DAQ (Presently working on)

- The TM-DAQ in present version uses USB protocol for data recording ,Since we are using USB protocol for data recording, the Data taking PC has to be in close vicinity of the module thus we require one data taking PC per module.
- To avoid having one computer for each module, We are working on Ethernet protocol using WIZNET chip for transferring the data from the DAQ to the data taking computer.
  - ❖Data integrity test completed
  - ❖ Bandwidth test completed (Speed = ~ 5Mbytes/sec)



Summary

- Installation completed in 8 Muon modules with USB communication (50% of the existing Muon modules)
- Ethernet testing is in advanced stage and expected to complete in Jan 2023
- Daily data quality monitoring programs are developed and commissioned
- Muon reconstruction algorithm is developed
- For more details https://g3indico.tifr.res.in/event/858/contributions/2420/
  (Mini Workshop on Triggerless Muon DAQ System for GRAPES-3 Muon Detector-6 Dec 2021)

Thank You!!!