Trigger development for HGCAL's cassette testing system for CMS experiment

Tinfena Mattia

Final presentation – Summer Italian internship

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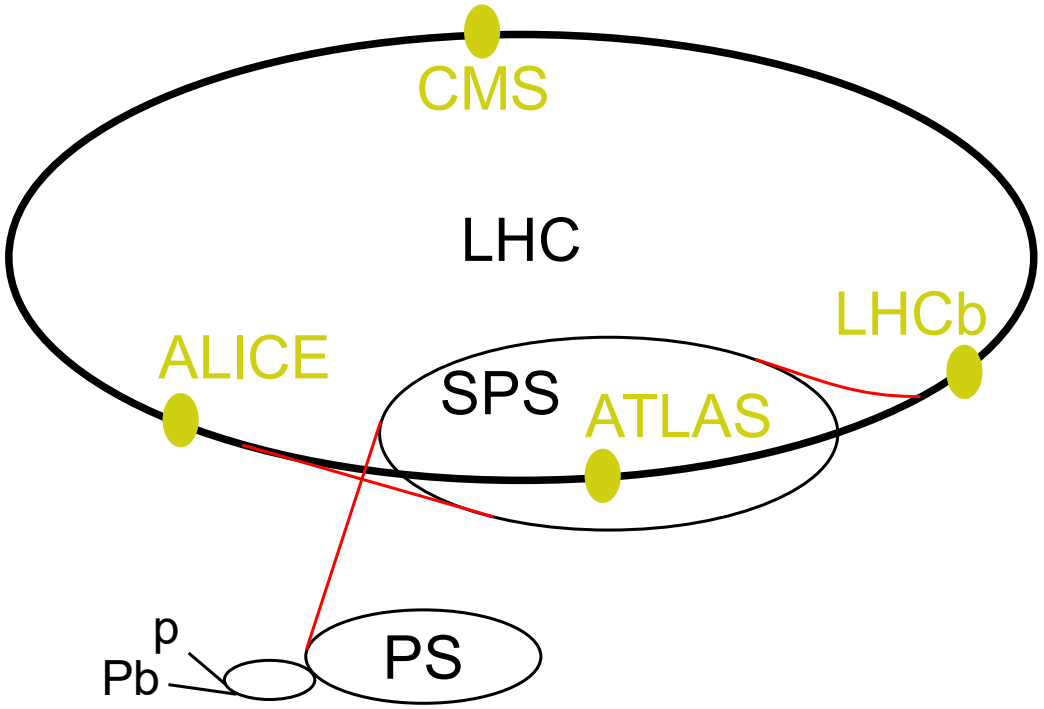
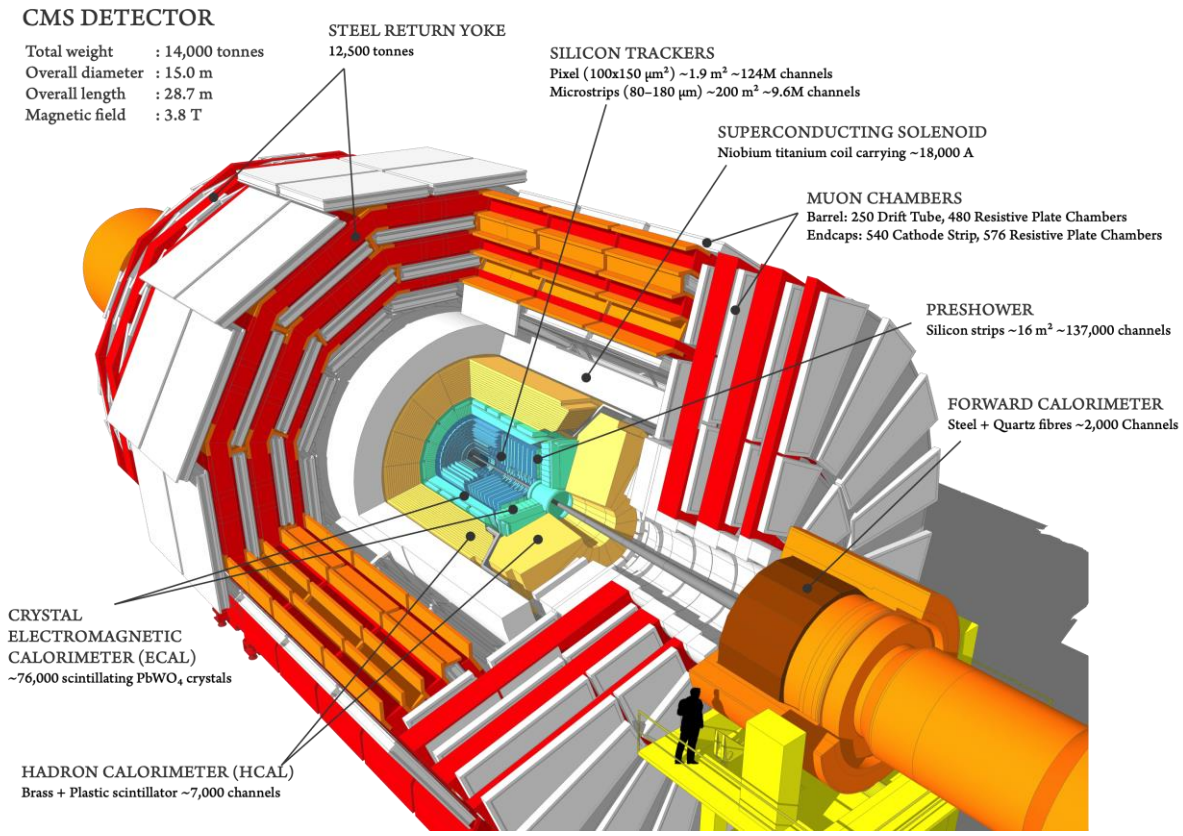
LHC – Large Hadron Collider

- The world's largest and highest-energy particle collider.
  - 17 mi in circumference
  - Deep 574 ft
- Four crossing points where the accelerated particles collide.
- Four detectors each designed to detect different phenomena:
  1. ALICE
  2. LHCb
  3. ATLAS
  4. CMS



CMS experiment

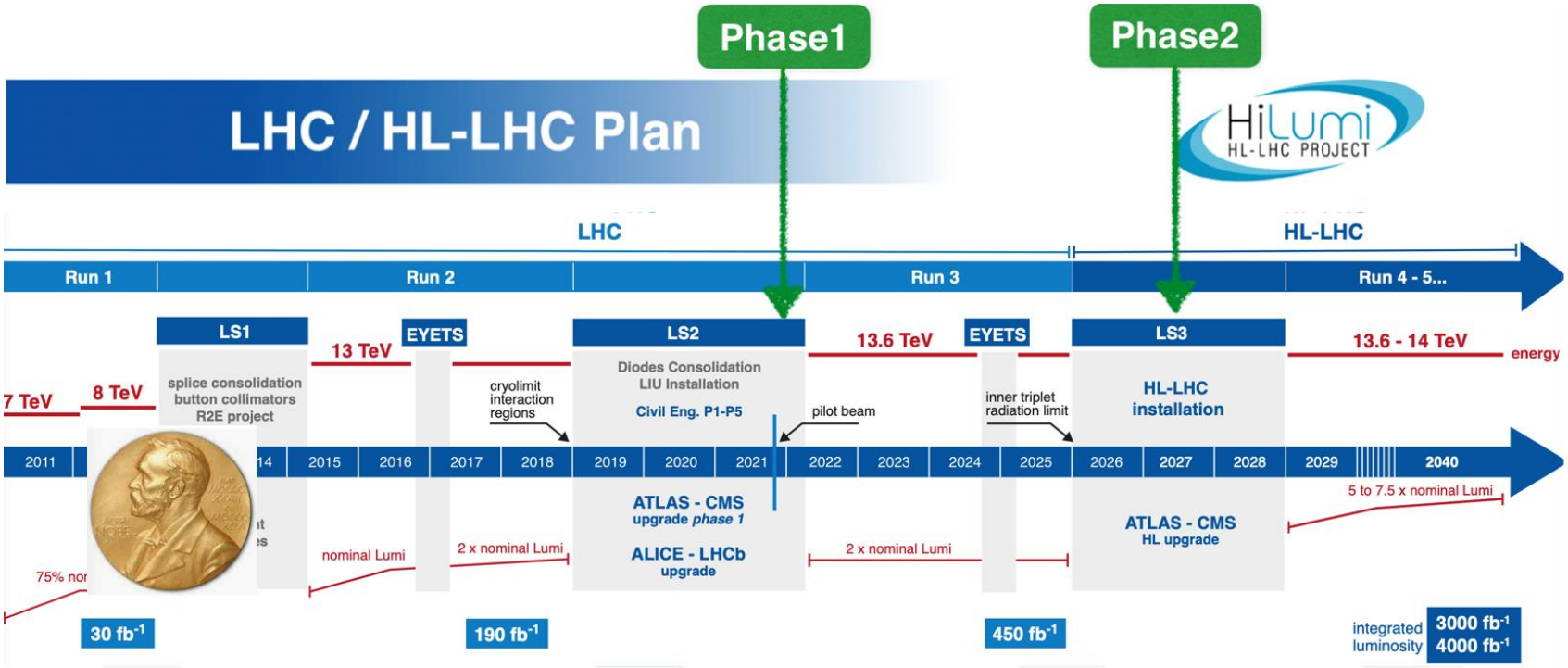
The Compact Muon Solenoid (CMS) experiment is one of the two large general-purpose particle physics detectors.

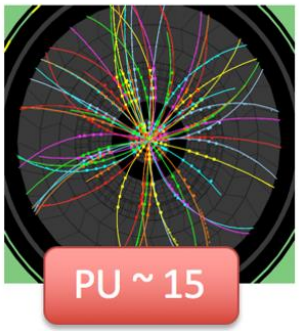


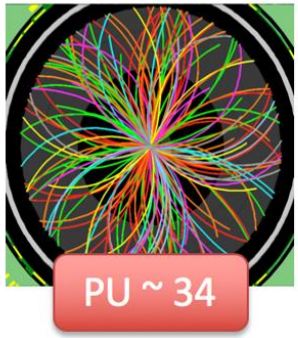
The principal sensors that there are in the CMS are in the barrel and in the endcaps:

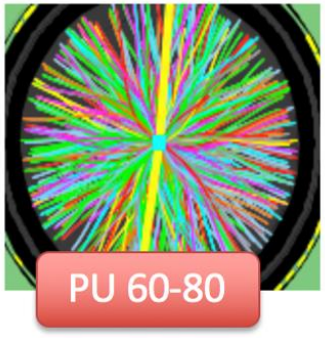
1. The tracker
2. The electromagnetical calorimeters
3. The hadronic calorimeters
4. The magnet
5. The muon detectors

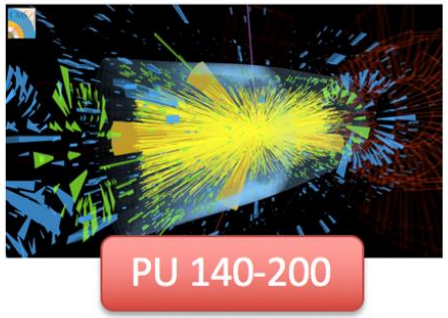
HL-LHC


Phase1
Phase2
LHC / HL-LHC Plan
HiLumi
HL-LHC PROJECT
LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
EYETS
LS3
13 TeV
13.6 TeV
13.6 - 14 TeV
energy
7 TeV
8 TeV
splice consolidation
button collimators
R2E project
cryolimit
interaction
regions
Diodes Consolidation
LIU Installation
Civil Eng. P1-P5
pilot beam
inner triplet
radiation limit
HL-LHC
installation
2011
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2040
ATLAS - CMS
upgrade phase 1
ALICE - LHCb
upgrade
ATLAS - CMS
HL upgrade
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
5 to 7.5 x nominal Lumi
30 fb-1
190 fb-1
450 fb-1
integrated
luminosity
3000 fb-1
4000 fb-1

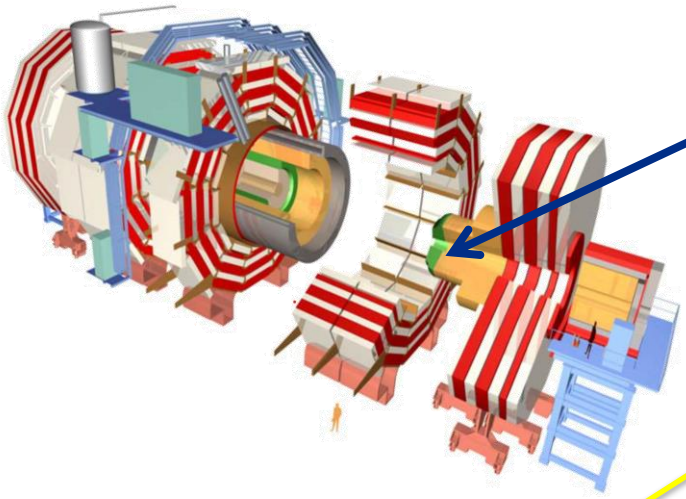

PU ~ 15


PU ~ 34

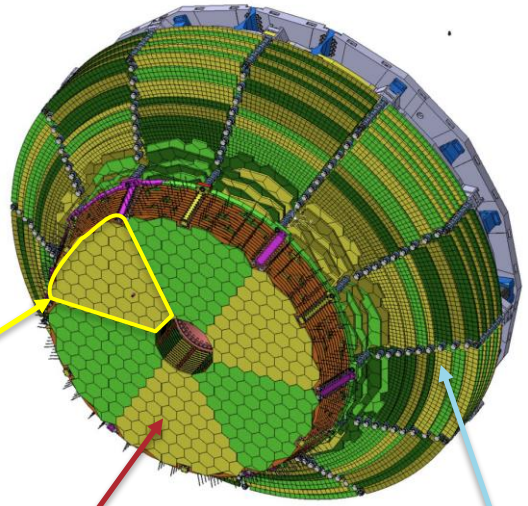

PU 60-80


PU 140-200

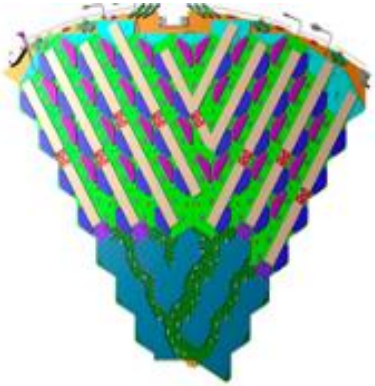
HGCAL - High Granularity CALorimeters

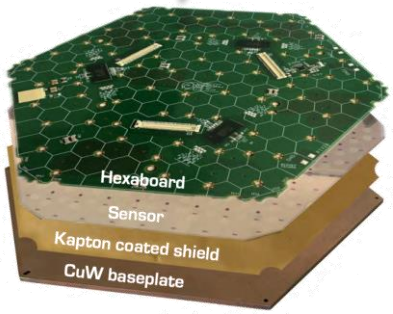


HGCAL

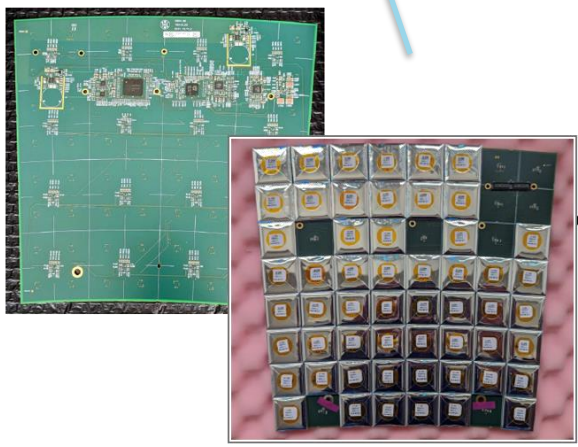


Cassette





Silicon sensors in the high radiation area

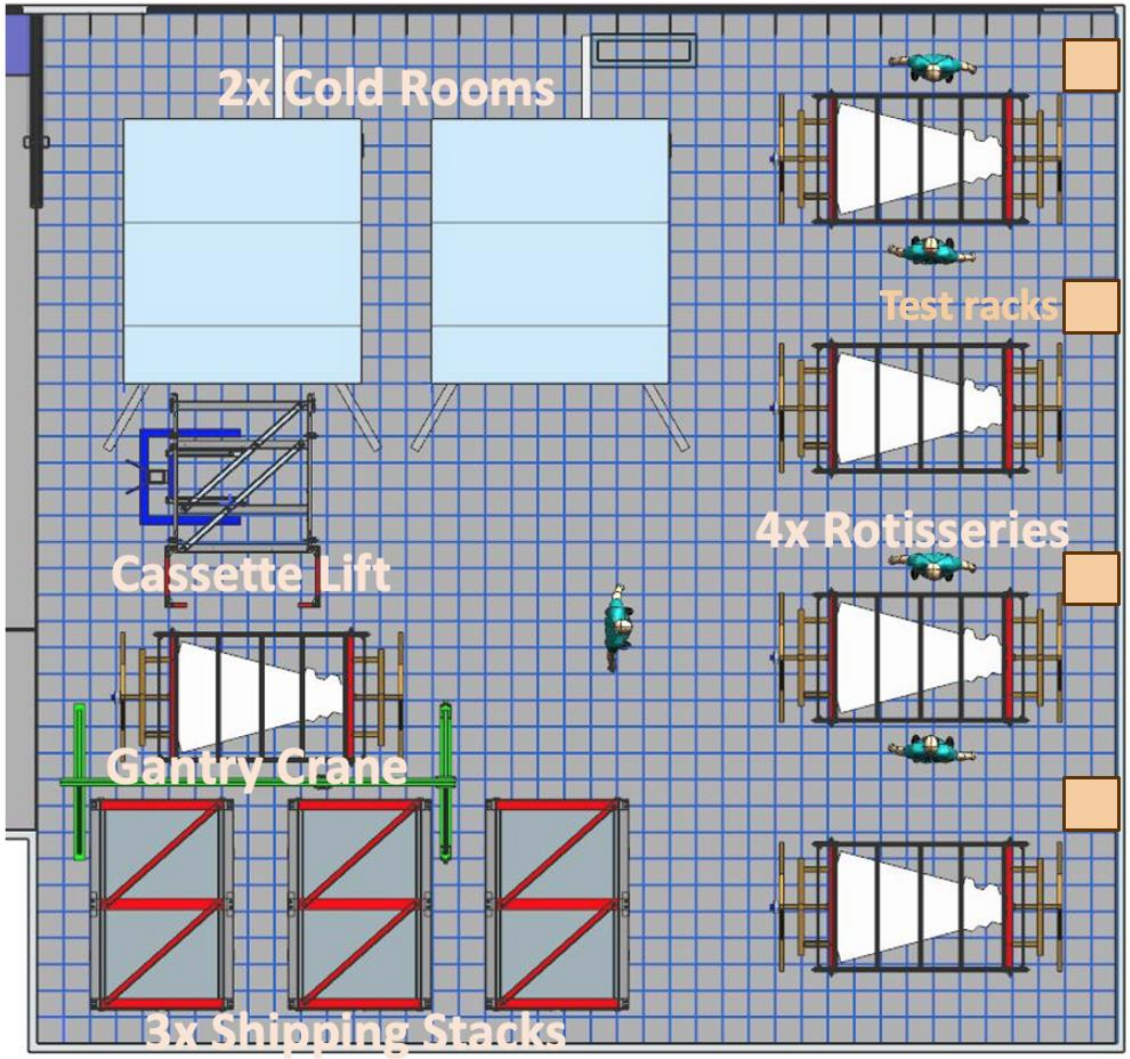


Plastic scintillators in the low radiation area

Fermilab

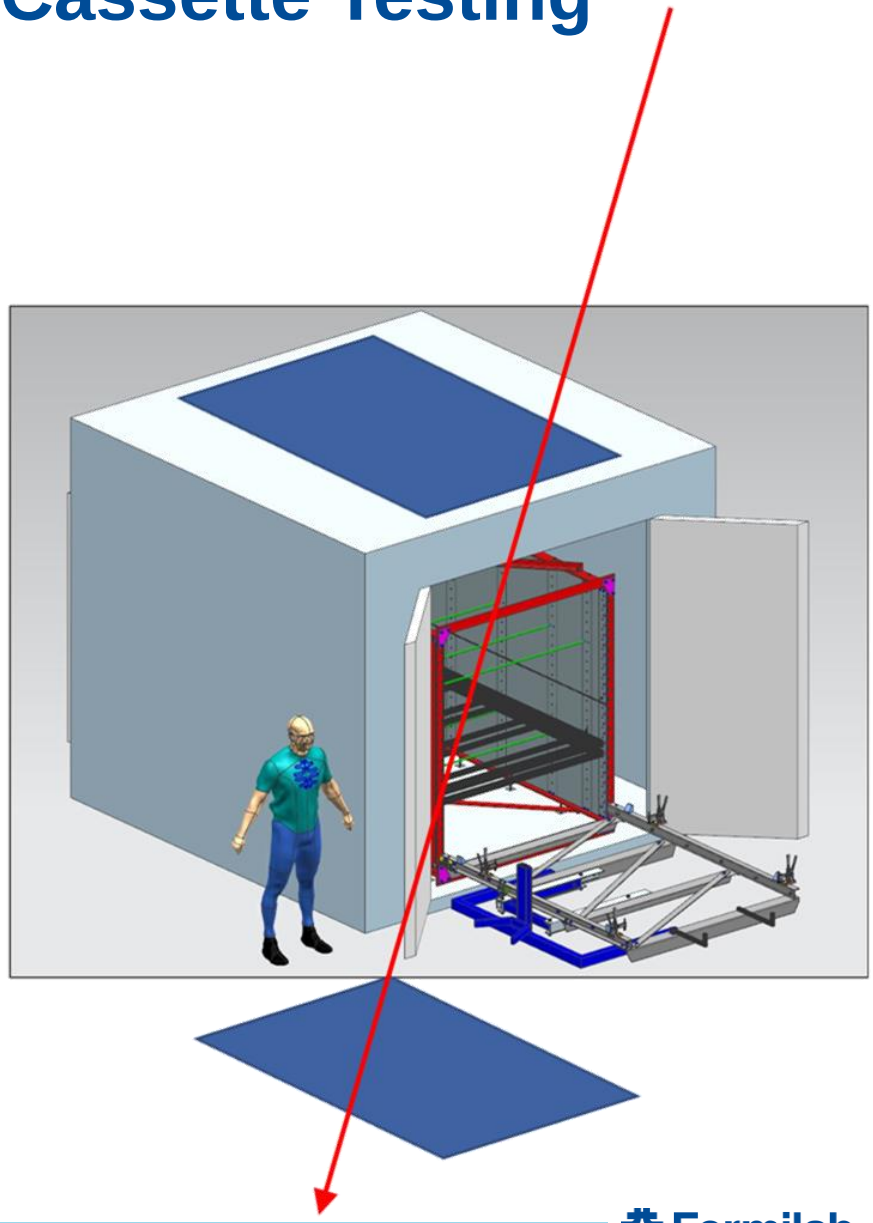
Cassettes production

- All the 525 cassettes for the hadronic portion of the HGCAL are produced at the Fermilab and assembled in the SiDet facility.
- The cassettes will be assembled in the Lab C where there are 4 assembling station and 2 cold rooms for long term testing.



Cosmic Trigger System for Cassette Testing

- The cassette burn-in test stand will have ~20 cassettes stacked and taking cosmic data for ~2 weeks
- We plan to install 2 planes of scintillators, above and below the cassettes to detect cosmic events and trigger the recording of the corresponding Trigger and DAQ events



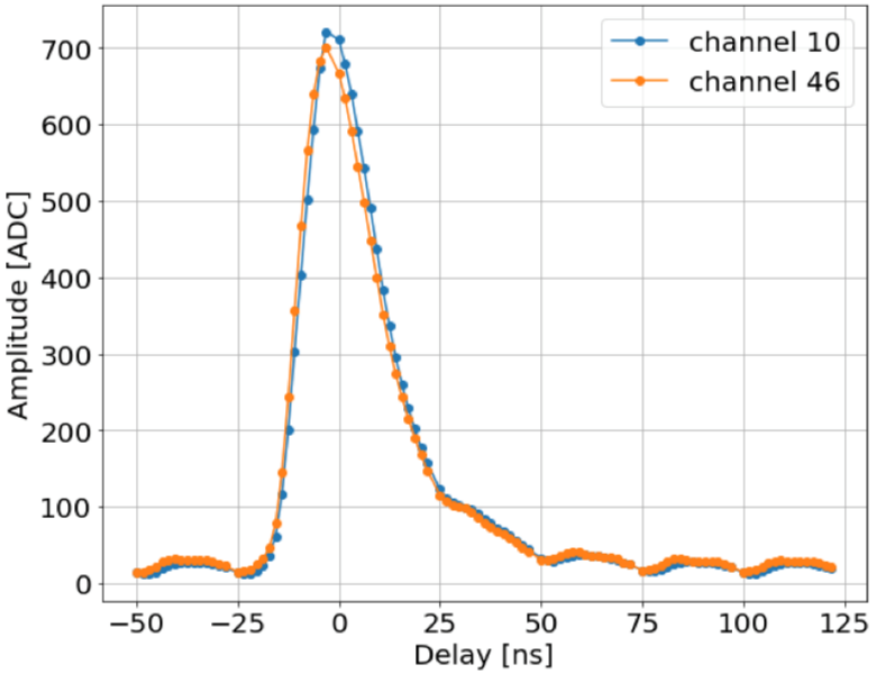
Trigger features

Time resolution:

- The time resolution requirement is driven by the need to trigger the right edge of the 40MHz clock (~25ns)
- But we could try to resolve the pulse shape of the HGCROC, so 1--5ns

Spatial resolution:

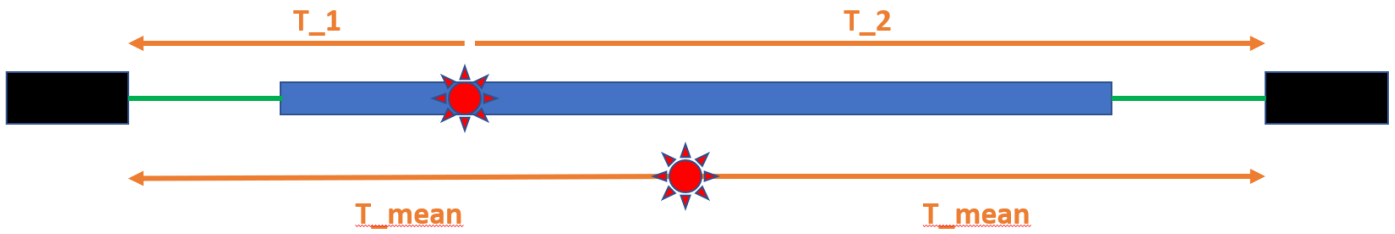
- Knowledge of the exact muon path is not needed for triggering
- The system upgrade to allows the offline analysis using the x-y location of the scintillator trigger hit should be too expensive
- So, we do not need spatial resolution in the scintillator trigger, 1 channel per layer is enough



Fermilab

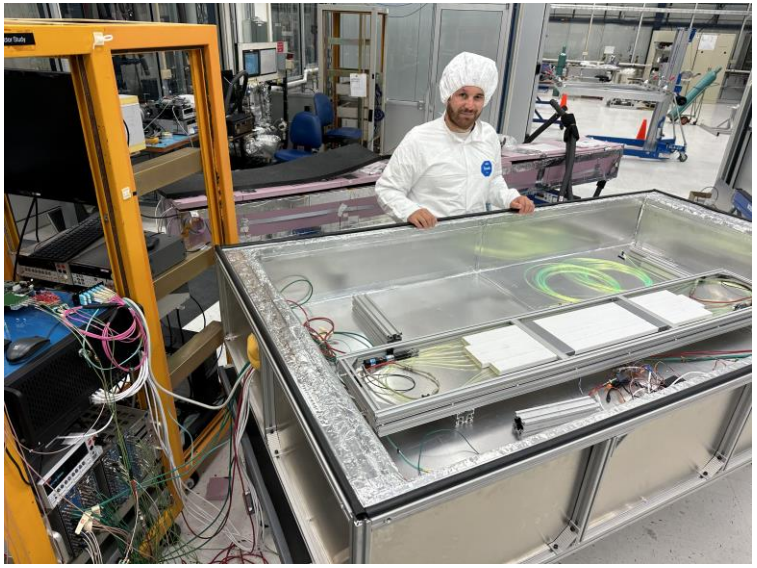
Technology adopted

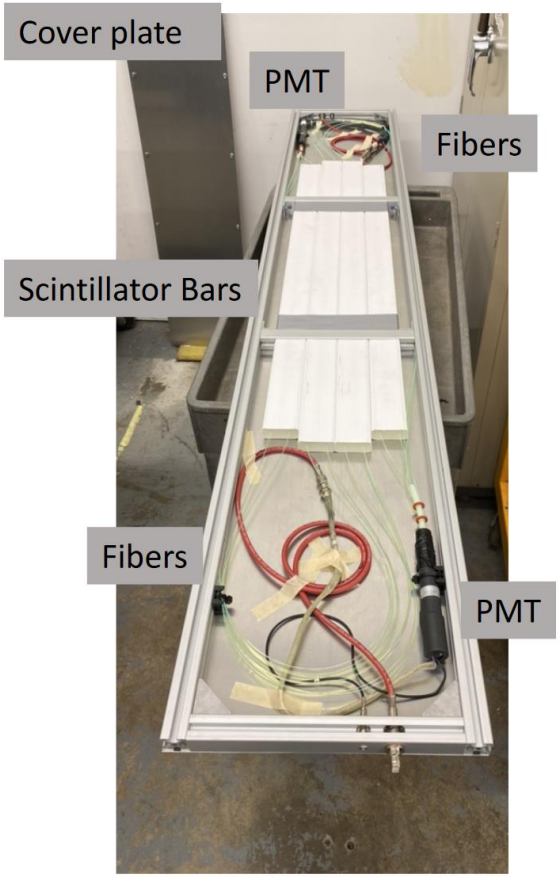
- The single channel requirement allows using a single slab of scintillator or an array of extruded scintillators with WLS fibers merged on one PMT
- The 1-5ns timing requirement must be compared to the size of the plane 5m/(0.2m*ns)= 25ns

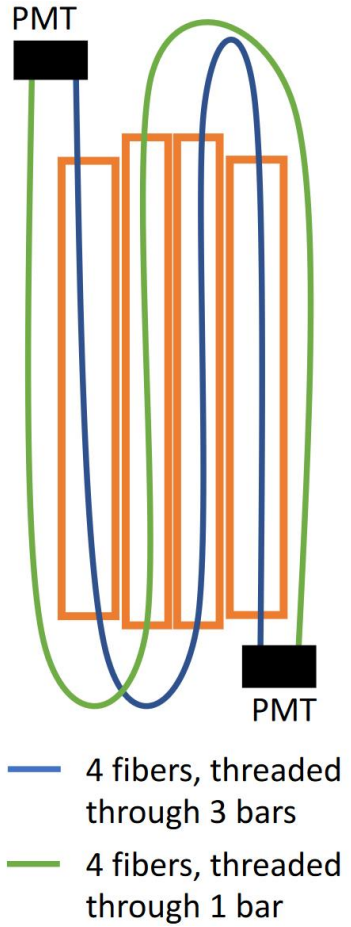


- Using 2 PMTs allows to calculate the mean time of arrival
- The mean time of arrival is independent of the location of the hit along the WLS fiber
- It appears the hit is always in the middle of the fiber, regardless of the true origin
- This eliminates the 10ns uncertainty

Testing system for the HGCAL's cassette







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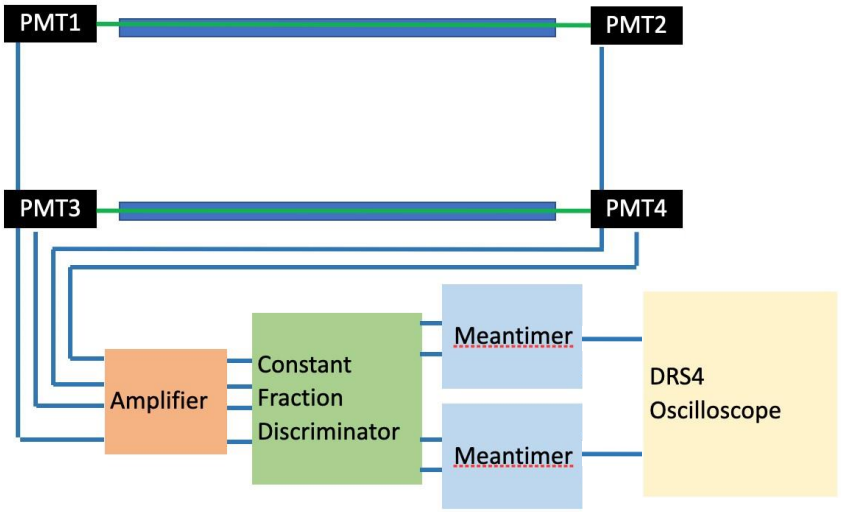
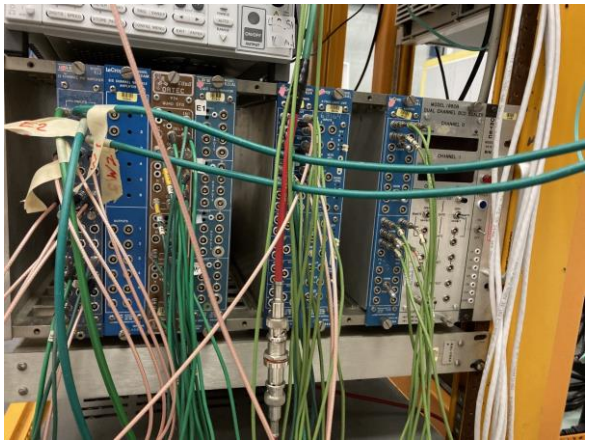
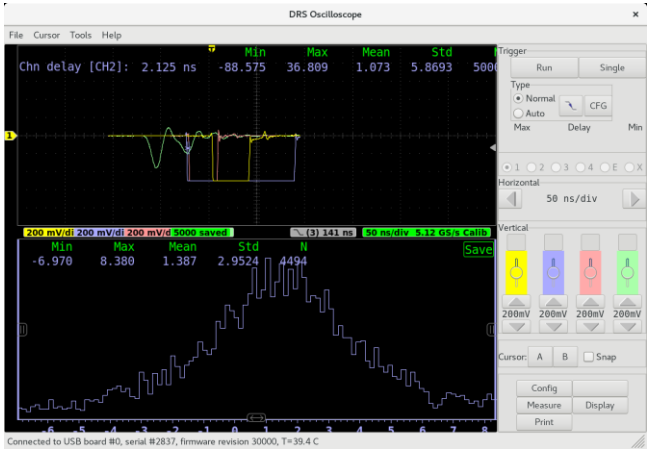
Testing system for the Fibers





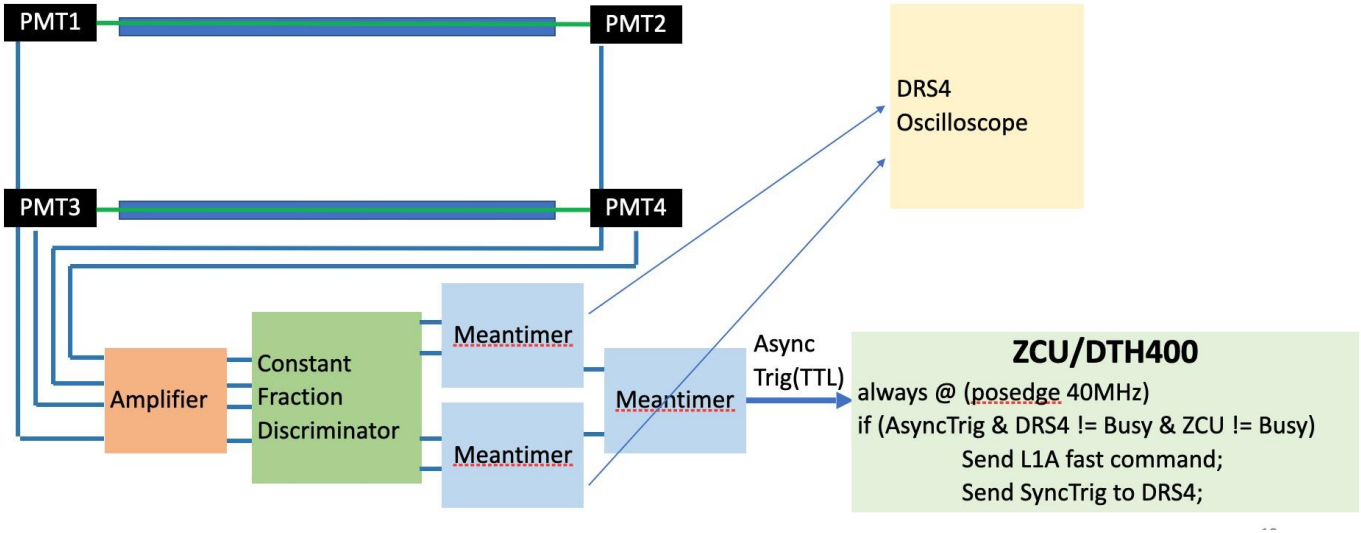
Old fibers

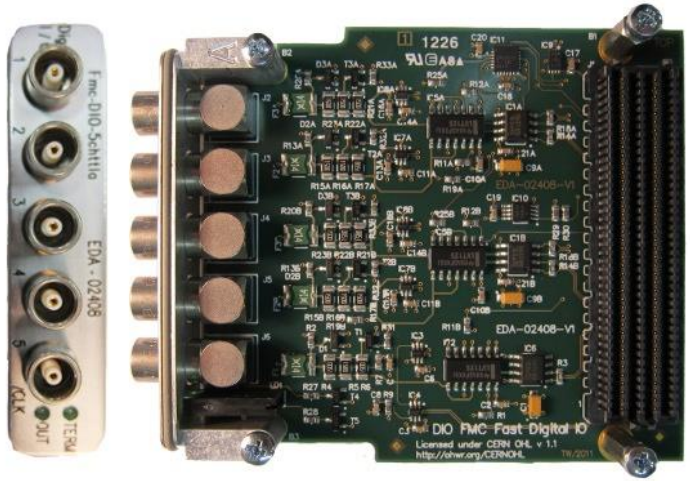


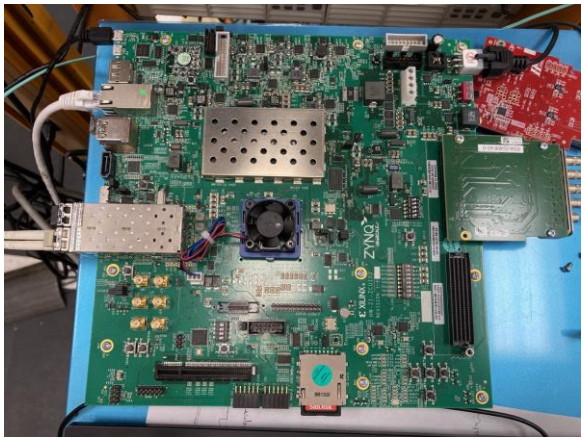
New fibers

Fermilab

Actual testing system for the HGCAL's cassette



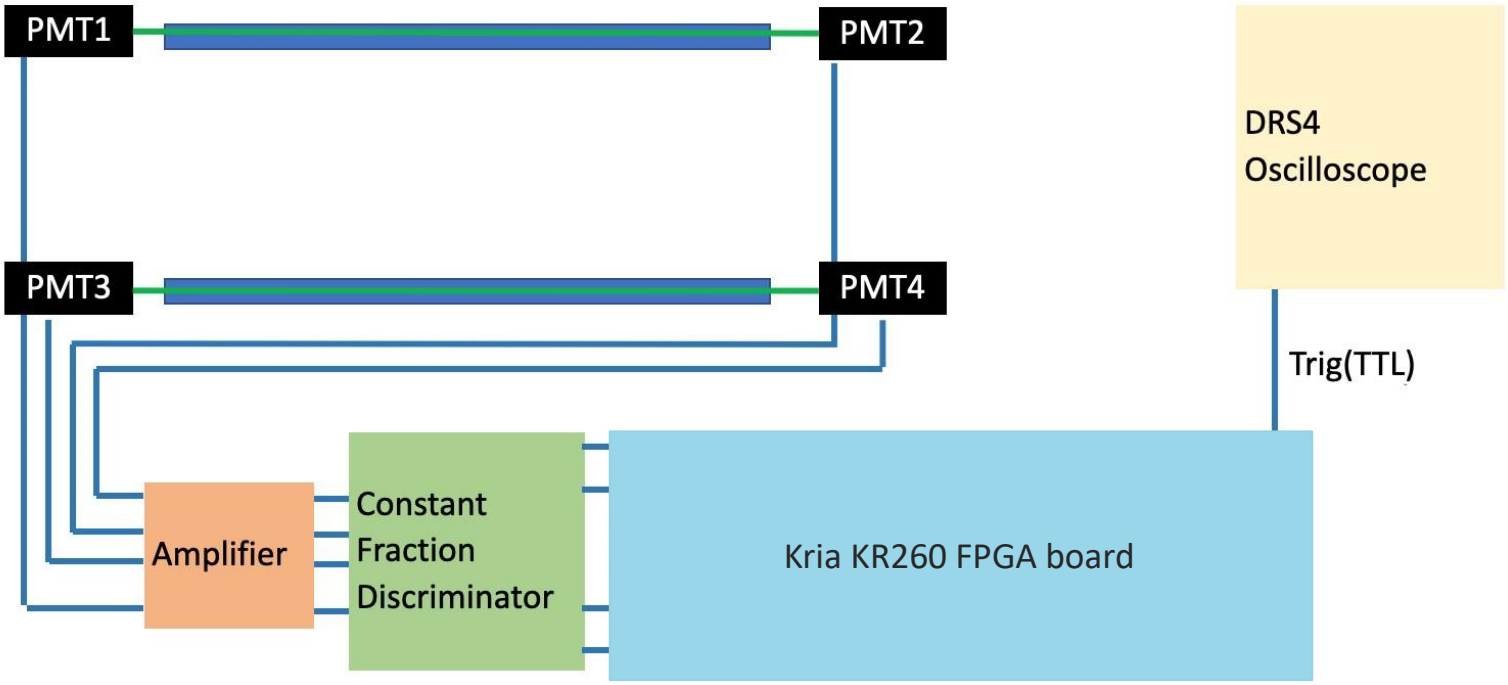




Fermilab

My Project Goal

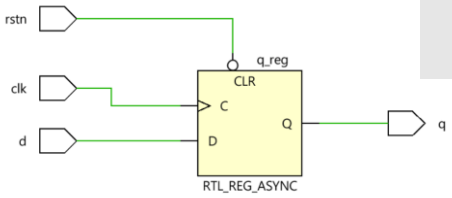
Using an FPGA we can compute the meantime directly from the CFD, in this way we have 4 slower inputs instead of 1 faster and we can use the PMOD interface



Xilinx FPGAs and Vivado suite

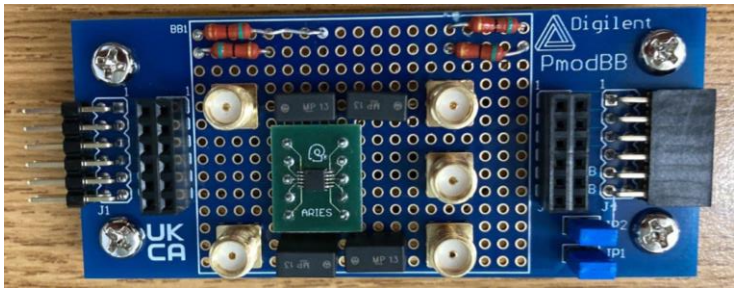
- The FPGAs – Field Programmable Gate Array are electronics devices that contain configurable logic blocks and a set of programmable interconnects that allow the designer to connect blocks and configure them to perform everything from simple logic gates to complex functions.
- FPGAs are programmed in Verilog that is an Hardware Description Language, a textual format for describing electronic circuits and systems
- FPGAs are generally used for:
  - Hardware prototyping
  - Hardware acceleration
  - Space avionics
  - Neural networks
  - Data acquisition

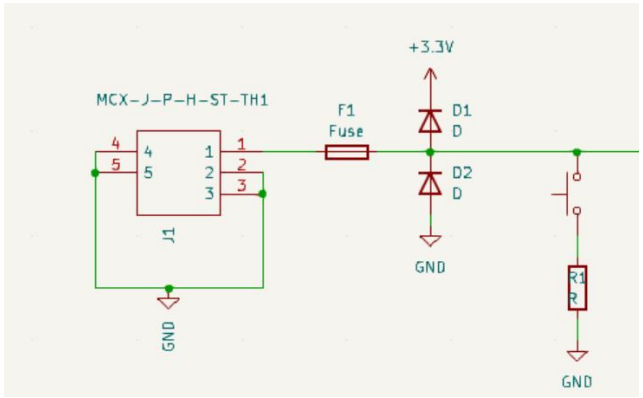

```
1  module dff  ( input d,
2                input rstn,
3                input clk,
4                output reg q);
5
6     always @ (posedge clk or negedge rstn)
7        if (!rstn)
8           q <= 0;
9        else
10          q <= d;
11 endmodule
```

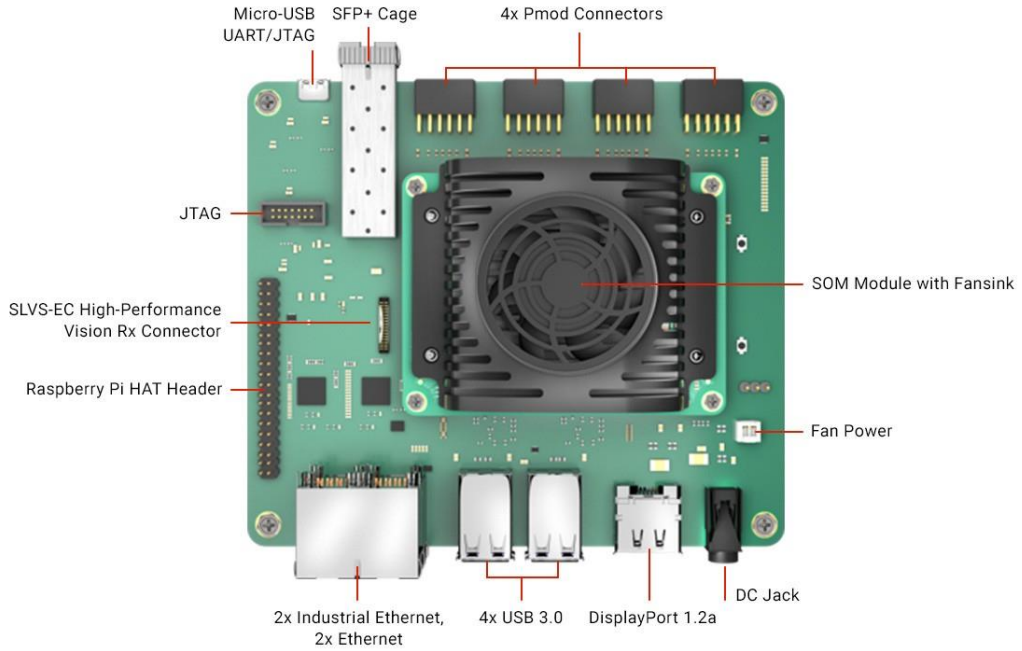


The Kria KR260 board

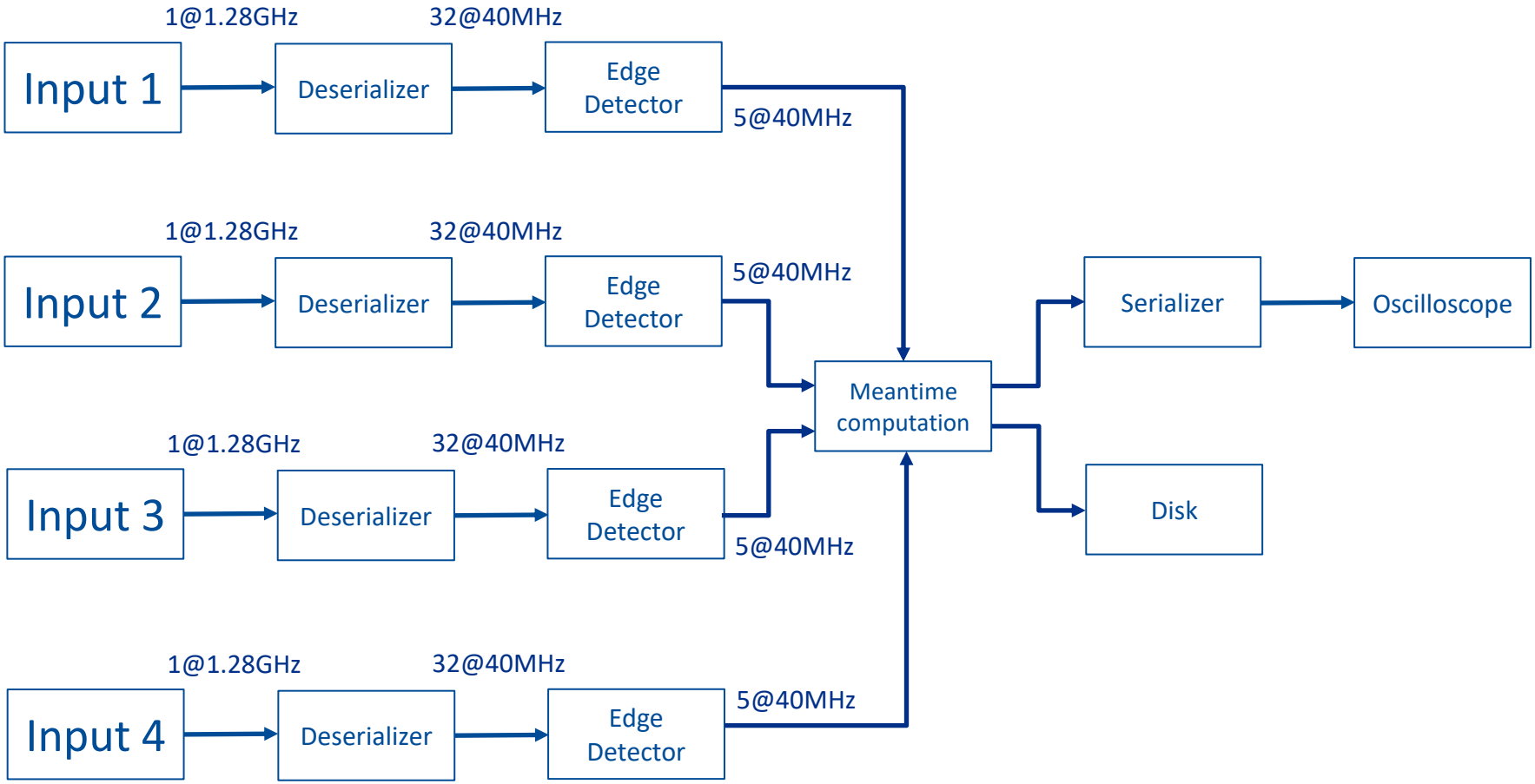
- First, we built an input board to test the system using a breadboard





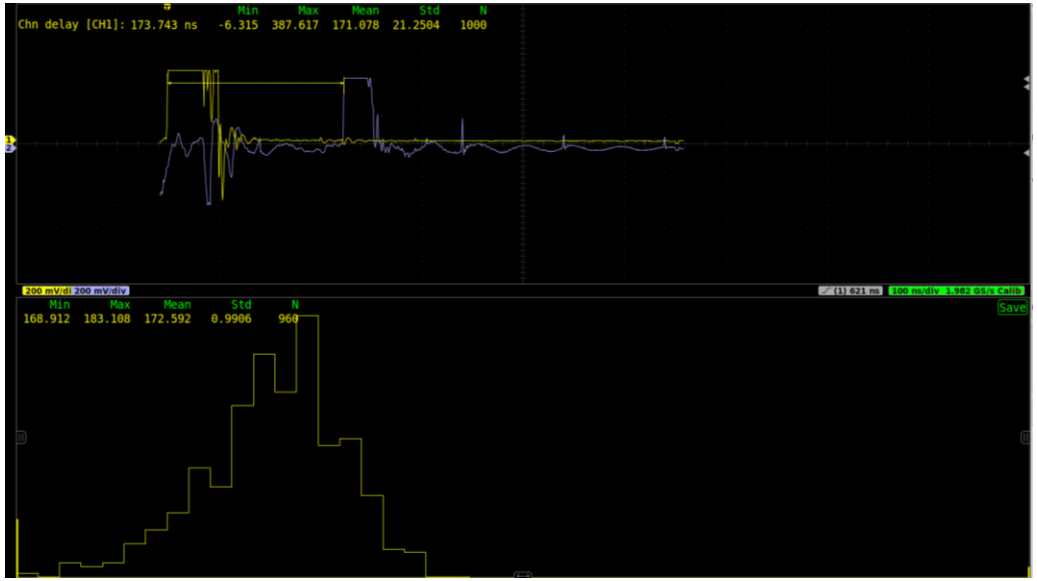


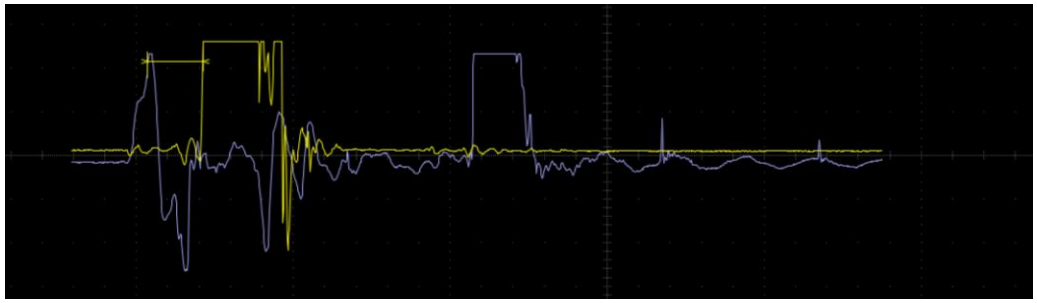
Firmware


1@1.28GHz
32@40MHz
Input 1
Deserializer
Edge Detector
5@40MHz
1@1.28GHz
32@40MHz
Input 2
Deserializer
Edge Detector
5@40MHz
1@1.28GHz
32@40MHz
Input 3
Deserializer
Edge Detector
5@40MHz
1@1.28GHz
32@40MHz
Input 4
Deserializer
Edge Detector
5@40MHz
Meantime computation
Serializer
Oscilloscope
Disk

First tests

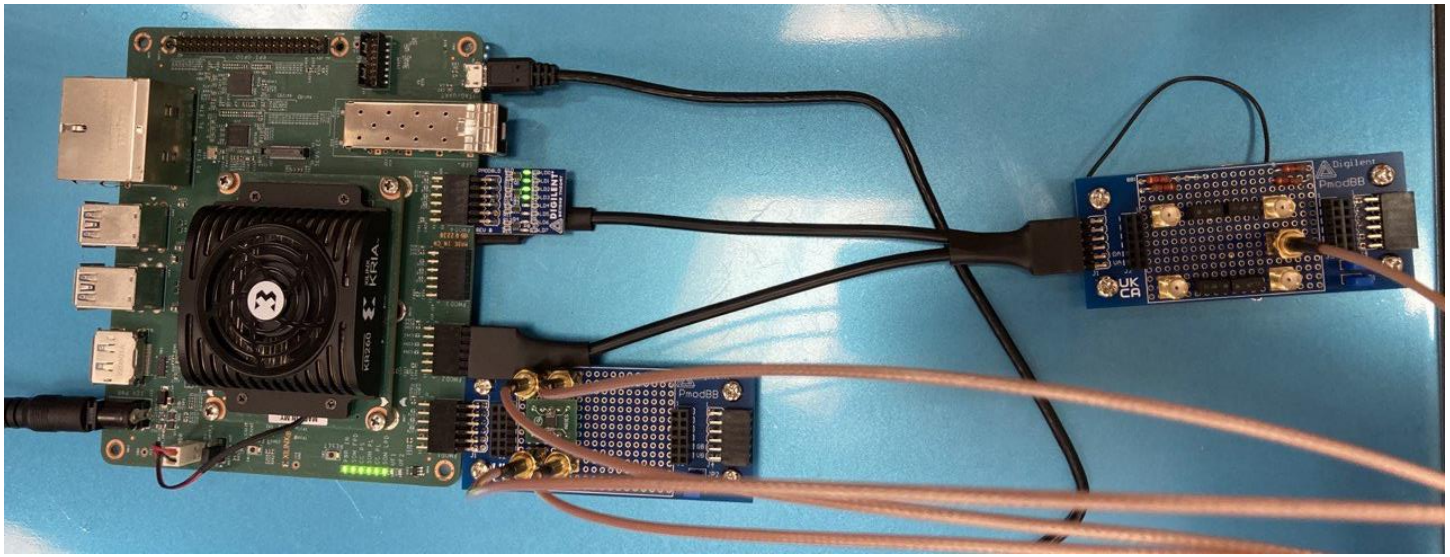
- The first tests were encouraging because we had a standard deviation less than 1ns but we had a lot of noise on the output caused by the crosstalk

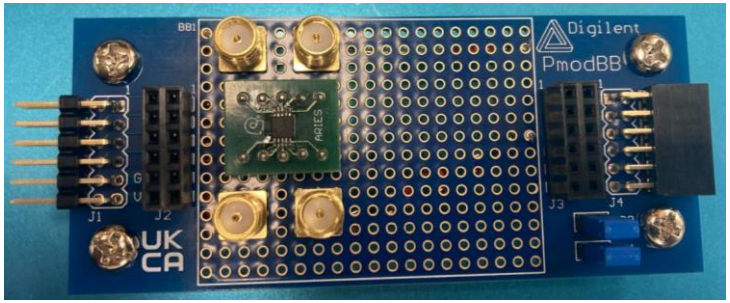




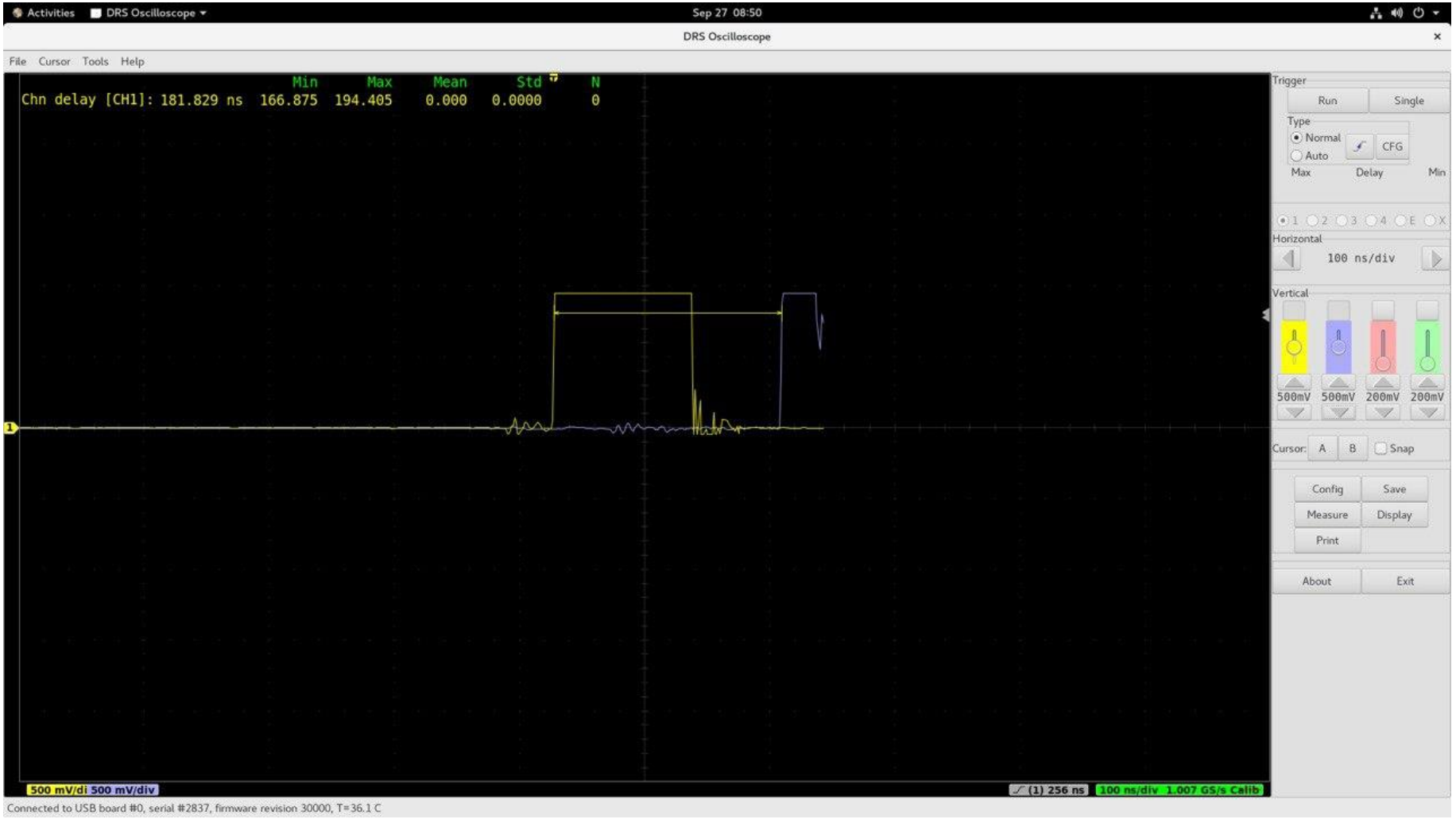
Solving the crosstalk problem

- To solve the crosstalk, we improved the board design with only the 4 inputs, and we used the old board in one separate PMOD connector for the output





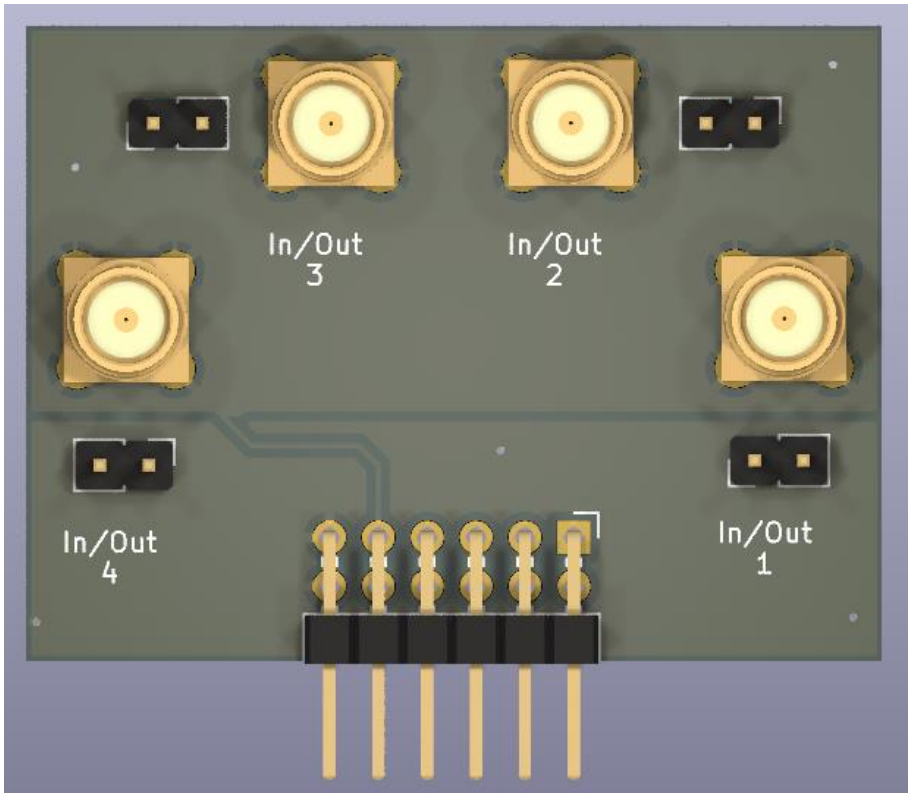
Solving the crosstalk problem

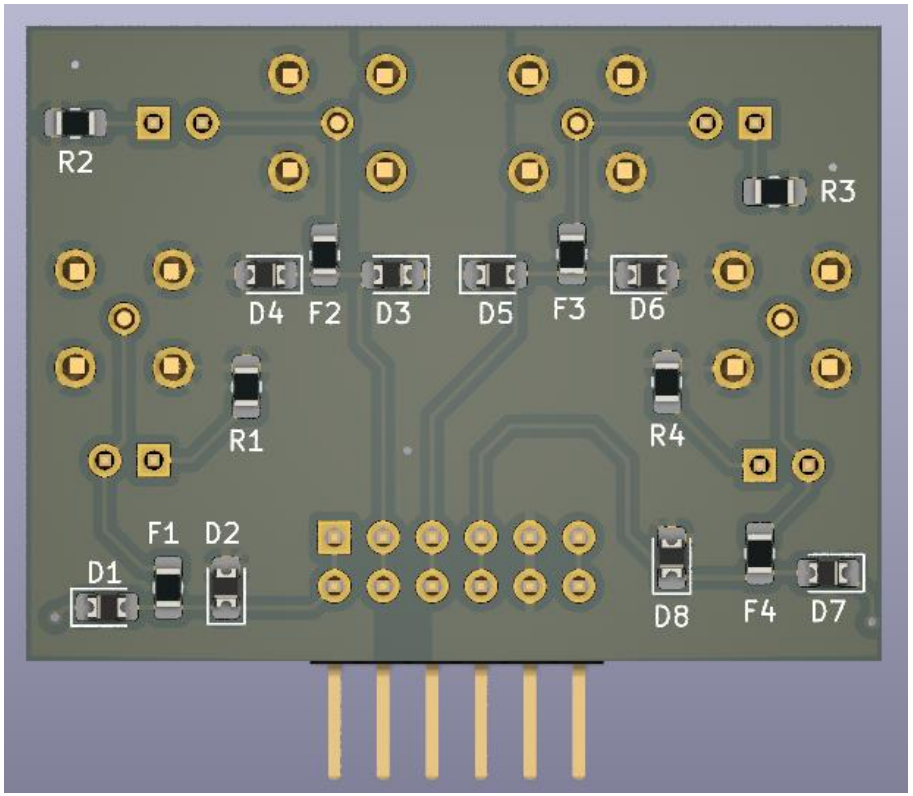


Fermilab

PCB development

- I designed a PCB for the final project that will be produced and tested, and I'll include the results in the final report





Summary

I really enjoyed this internship for the following reasons:

- I had hands-on experience with all aspects of developing a trigger system
- I assembled the scintillator trigger planes with WLS (wave length shifting) fibers and connected to PMTs
- I connected the trigger planes to the NIM logic system
- I developed a PMOD interface card to bring the signals to an FPGA board
- I learned how to program FPGA with the Vivado suite and the SystemVerilog language
- I developed the firmware to compute the meantime of the input signals
- Tested the system and obtained good results


Thank you for your attention
Any question?
Tyvek

Bibiography

- [1] “HGCROC3-Si Datasheet”
- [2] “Cosmic Trigger System for Cassette Testing”, Zoltan Gecse
- [3] “Status and Overview of the CMS HGCAL”, Zoltan Gecse