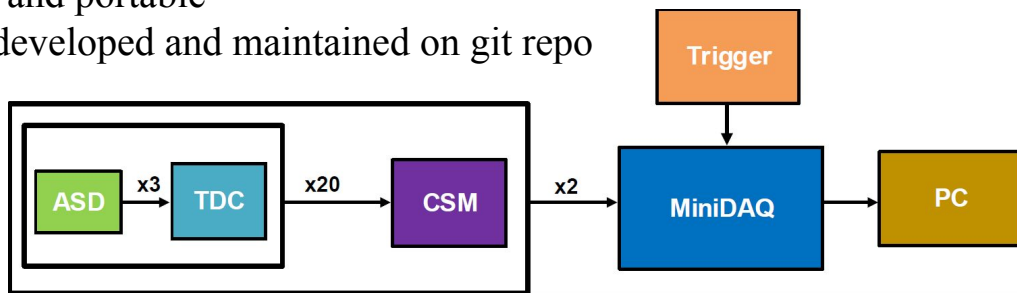


SiPM and drift tube readout and DAQ

Yuxiang Guo
US Higgs Factory Planning, SLAC
Dec 19, 2024

A portable MiniDAQ system with MDT front-end electronics

- New front-end electronics and DAQ developed for ATLAS MDT phase-2 upgrade to cope with HL-LHC requirements
- This MiniDAQ system is also used for FCC-ee R&D for straw tracker and drift chamber tests with cosmic rays and test beams
- System is lightweight and portable
- User friendly GUI is developed and maintained on git repo



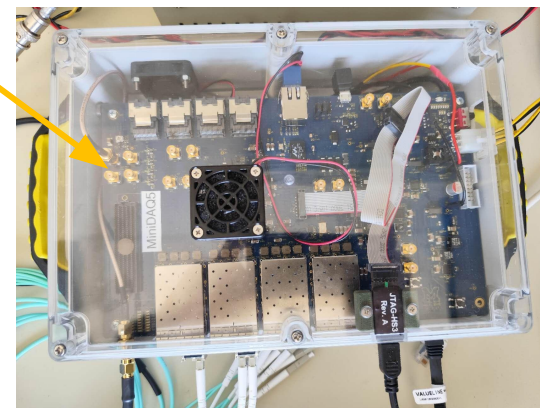
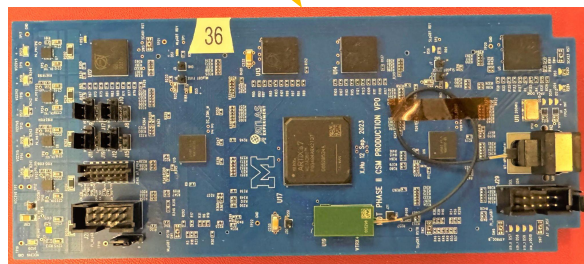
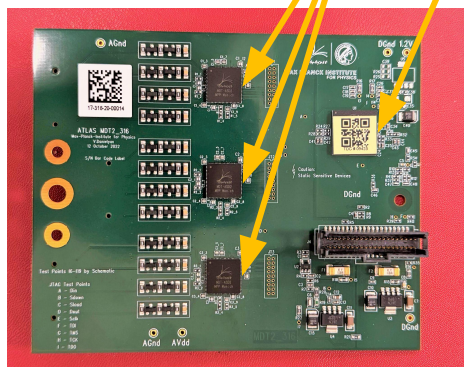
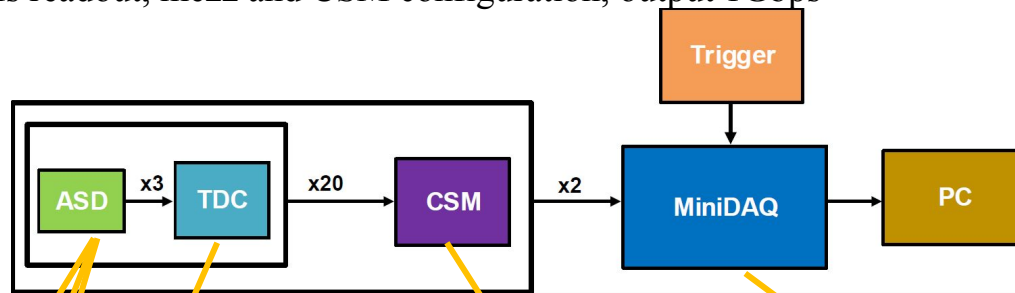
The MiniDAQ readout system used to read out data from 2 CSMs

- Basic readout channels = 960, data rate to DAQ = 40.96 Gbps, DAQ offline dump rate = 1 Gbps
- Readout channels and data rate can be doubled by adding one SFP+ FMC module
- Front-end voltage and temperature are monitored

A portable MiniDAQ system with MDT front-end electronics

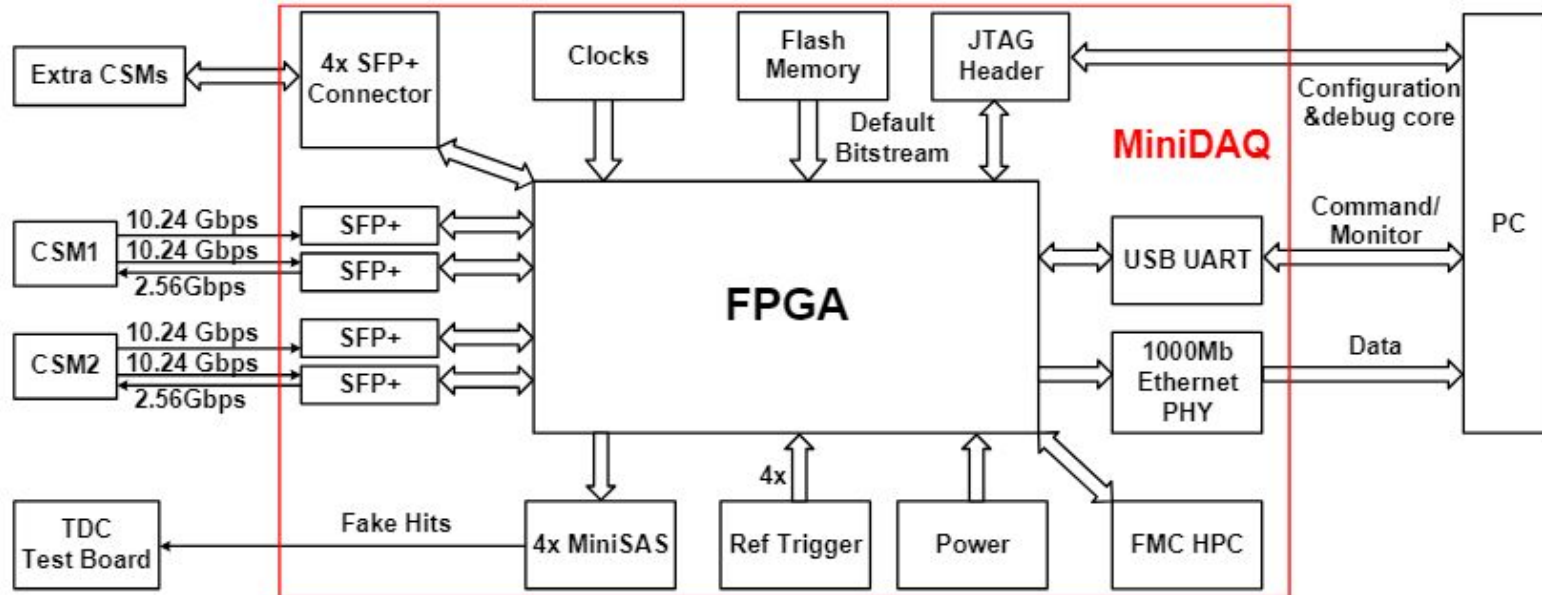
ASICs, front-end PCBs and MiniDAQ boards produced by various institutions

- ASD: Amplifier-shaper-discriminator circuit, 8 channels, peaking time 12 ns, small signal gain 18 mV/fC
- TDC: Time to digital converter, 24 channels, bin size 0.78 ns, 100 us dynamic range, output 2*320Mbps
- CSM: Chamber service module, 20 mezzanine readout and monitor, output 2*10.24Gbps
- MiniDAQ: 2 CSMs readout, mezz and CSM configuration, output 1Gbps



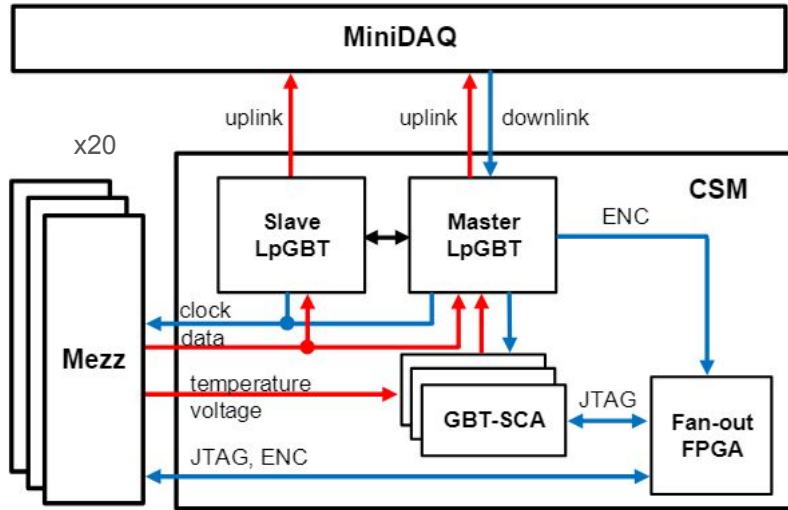
MiniDAQ board hardware

- FPGA: Xilinx Ultrascale KU035-1FBVA676C
- SFP+: 4 on board, 4 can be expanded through FMC connector
- On board oscillators for GTH reference clock and logic clock
- 4 High-speed comparators as external trigger
- Gigabit Ethernet for data dumping, USB UART for GUI communication

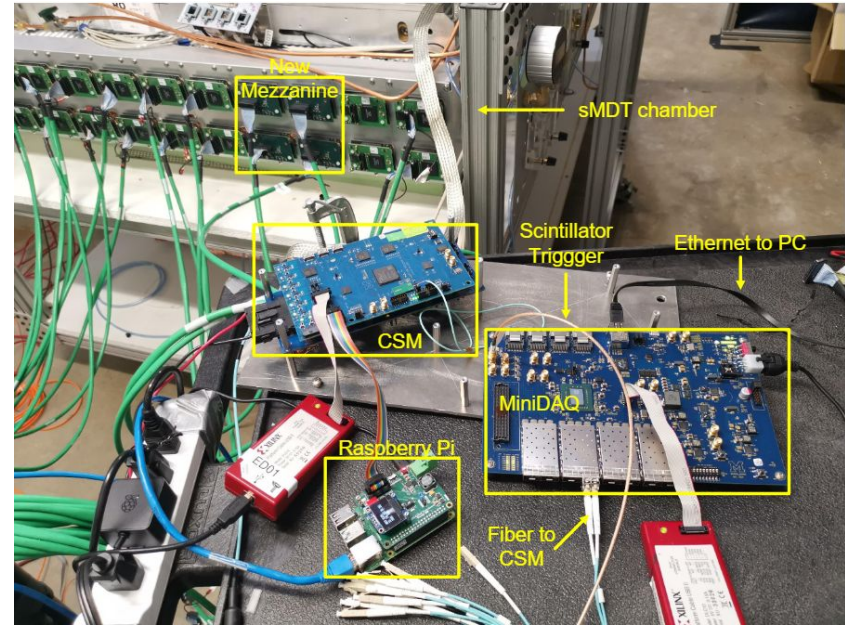


MiniDAQ data flow

- Data mode default: front-end triggerless, trigger matching in MiniDAQ for offline data storage
- Data mode optional: front-end triggered, all triggered data sent out for storage
- Each CSM contains 2 uplink fibers and 1 downlink fibers. **Configurations, clocks** and monitoring requests are distributed through downlink (2.56 Gbps), **detector data and monitoring info** are read back via uplinks



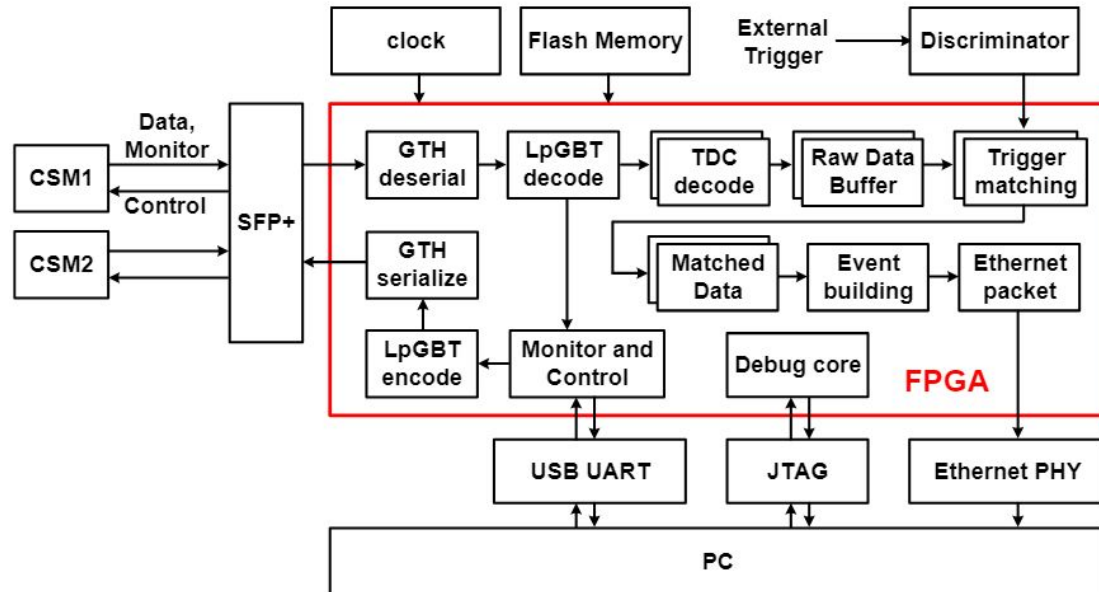
uplink (red) and downlink (blue) data flow



Hardware connection

MiniDAQ firmware logic

- **Multi-stage decoding:** GTH deserial->LpGBT decode->TDC and monitoring data decode
- **Idle word filtering:** select valid hit data into RAMs
- **Trigger matching and event assembly:** External triggers are digitized by an FPGA-TDC. Timing info is compared with front-end TDC timing stored in the RAMs. Matched data are assembled with trigger and sent out as one event.



Functional block diagram of the miniDAQ system

MiniDAQ configuration GUI

- Configuration GUI Based on PyQt5
- Multi tabs for different hardware (LpGBT, SCA, Mezz)
- Multi-level popup windows for detailed configuration

The screenshot displays the 'Mezz Config' tab of the MiniDAQ configuration GUI. It features a 'SCA start' button and a table of sensor data for Mezz0 to Mezz39. The table includes columns for 'check all', 'AVDD(V)', 'DVDD(V)', and 'Temp(C)'. Below the table is a 'clear info' button and an 'Output Log' section displaying system logs.

	Mezz0	Mezz1	Mezz2	Mezz3	Mezz4	Mezz5	Mezz6	Mezz7	Mezz8	Mezz9	Mezz10	Mezz11	Mezz12	Mezz13	Mezz14	Mezz15	Mezz16	Mezz17	Mezz18	Mezz19
<input type="checkbox"/> check all	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
AVDD(V)	0	2.9863	0	2.9769	0	2.9989	0	0	0	2.9993	0	0	0	0	0	0	0	0	0	0
DVDD(V)	0	1.1931	0	1.1937	0	1.2039	0	0	0	1.2015	0	0	0	0	0	0	0	0	0	0
Temp(C)	0	42.89	0	43.26	0	42.99	0	0	0	42.99	0	0	0	0	0	0	0	0	0	0

	Mezz20	Mezz21	Mezz22	Mezz23	Mezz24	Mezz25	Mezz26	Mezz27	Mezz28	Mezz29	Mezz30	Mezz31	Mezz32	Mezz33	Mezz34	Mezz35	Mezz36	Mezz37	Mezz38	Mezz39
<input type="checkbox"/> check all	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
AVDD(V)	0	0	0	0	3.0033	2.9979	0	0	0	0	0	0	0	0	0	0	3.0011	2.9998	0	0
DVDD(V)	0	0	0	0	1.2037	1.2031	0	0	0	0	0	0	0	0	0	0	1.2046	1.2047	0	0
Temp(C)	0	0	0	0	42.28	42.87	0	0	0	0	0	0	0	0	0	0	41.69	43.94	0	0

clear info

Output Log

```
2024-12-18 15:59:08>>TDC16 DVDD= 0.1824
2024-12-18 15:59:08>>TDC16 DVDD_GND= 0.0173
2024-12-18 15:59:08>>TDC16 TEMP= 0.3091
2024-12-18 15:59:09>>TDC16 TEMP_GND= 0.0103
2024-12-18 15:59:09>>TDC17 AVDD= 0.4492
2024-12-18 15:59:09>>TDC17 AVDD_GND= 0.0100
2024-12-18 15:59:09>>TDC17 DVDD= 0.1829
2024-12-18 15:59:09>>TDC17 DVDD_GND= 0.0205
2024-12-18 15:59:09>>TDC17 TEMP= 0.3167
2024-12-18 15:59:09>>TDC17 TEMP_GND= 0.0105
```


MiniDAQ configuration GUI

- Auto scan all connected mezzanine (blue=connected, gray=unconnected)
- JTAG configuration verification for TDC and ASD (green=success, red=failure)

The screenshot displays the MiniDAQ configuration GUI with three levels of interaction:

- Main Tab:** The primary interface for configuring mezzanines. It features a grid of mezzanine slots (Mezz 0 to Mezz 39) with checkboxes for connection status and buttons for scanning and writing configurations. A "Main Tab" label points to this area.
- 2nd level popup:** A "Single Mezz Config" dialog box that allows for detailed configuration of a selected mezzanine, including TDC and ASD settings. A "2nd level popup" label points to this dialog.
- 3rd level popup:** A "TDC Setup0" dialog box that provides fine-grained control over TDC parameters, such as enabling various triggers and setting widths. A "3rd level popup" label points to this dialog.

Below the main tab, an "Output Log" window shows system messages, and a "Mezz Config" window at the bottom provides additional configuration options and buttons like "Save_setup" and "Load_setup".

Main Tab

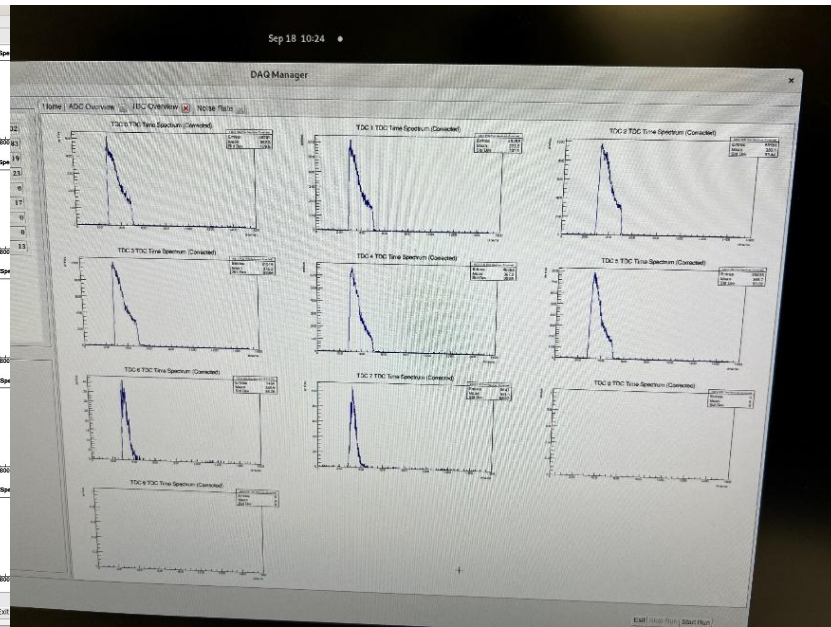
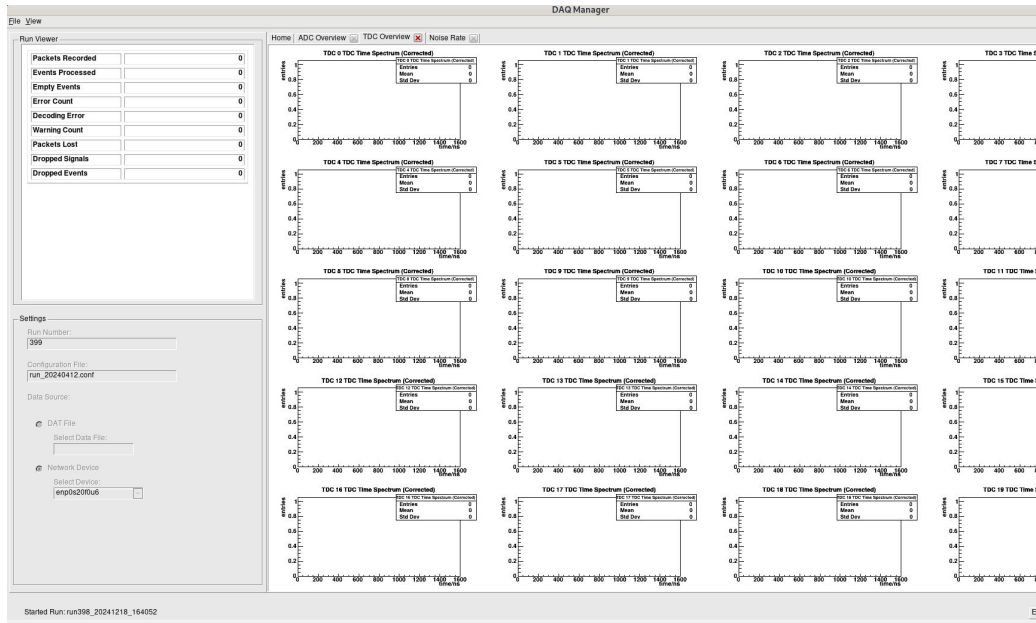
2nd level popup

1st level popup

3rd level popup

MiniDAQ online monitor GUI

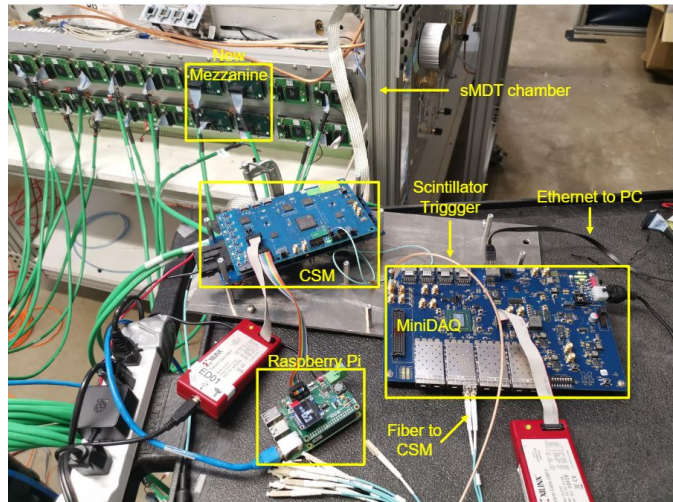
- Online monitor GUI Based on ROOT
- Real time spectra and hit rate display
- Warning/error info display (from decoded data)
- Examples shown below are the online display in the straw test beam experiment in Sept. 2024



MiniDAQ implementation

The system has been successfully used in:

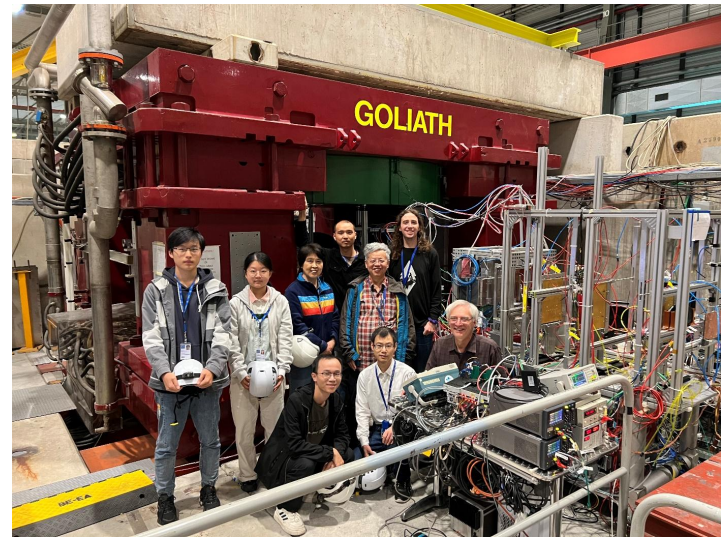
- Michigan sMDT construction commissioning for 50 chambers
- MDT chamber cosmic test with new mezzanine, CSM, CSM-MB for Phase 2 upgrade
- CERN GIF++ test beam study for sMDT under high gamma rate (July 2021)
- CERN DRD1/WP3 test beam study for straw chamber (September-October, 2024)



sMDT construction commissioning



Testing at CERN GIF++



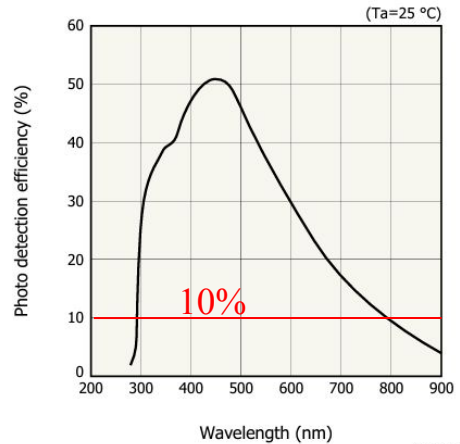
Testing at CERN H4 and T9

SiPM vs PMT

Why using SiPM?

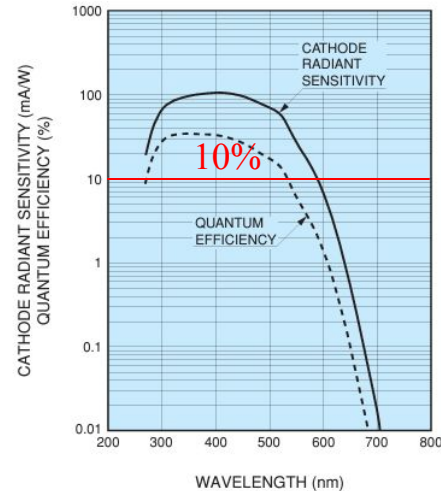
- Broader photo detection efficiency in wavelength (covers Cherenkov light)
- Not sensitive to magnetic field
- Small unit size (usually 1mm*1mm), not easy to break

Photon detection efficiency vs. wavelength (typi

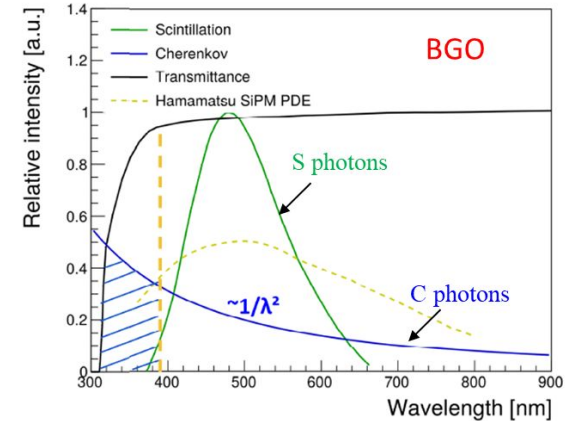


Hamamatsu SiPM S14160

Figure 1: Typical spectral response



Hamamatsu PMT R1924



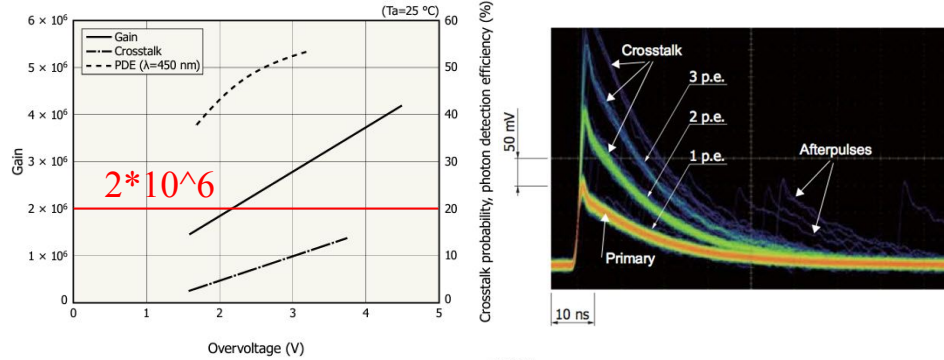
BGO scin. vs Cherenkov photon intensity

SiPM vs PMT

Why using SiPM?

- Comparable gain (10^6)
- Significant lower bias voltage (usually <70 V)
- Comparable rise time (slow fall time though)

Overvoltage vs. gain, crosstalk probability, photon detection efficiency



Hamamatsu SiPM S14160

Figure 2: Typical gain and dark current charact

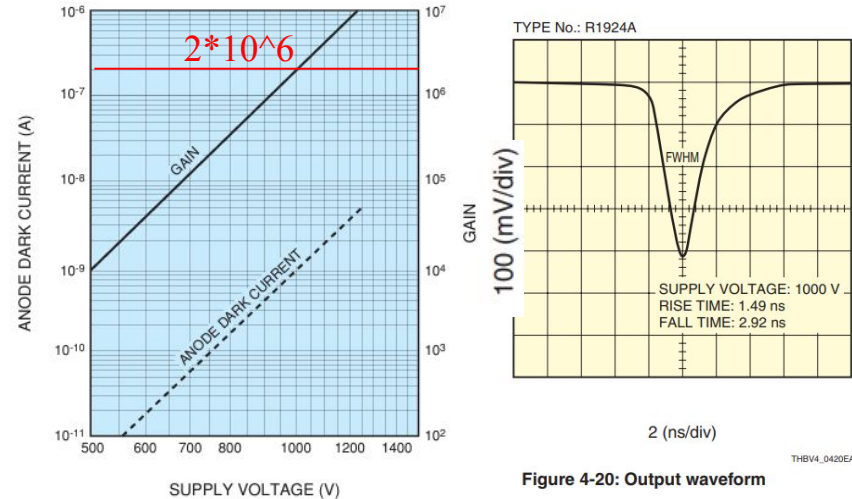
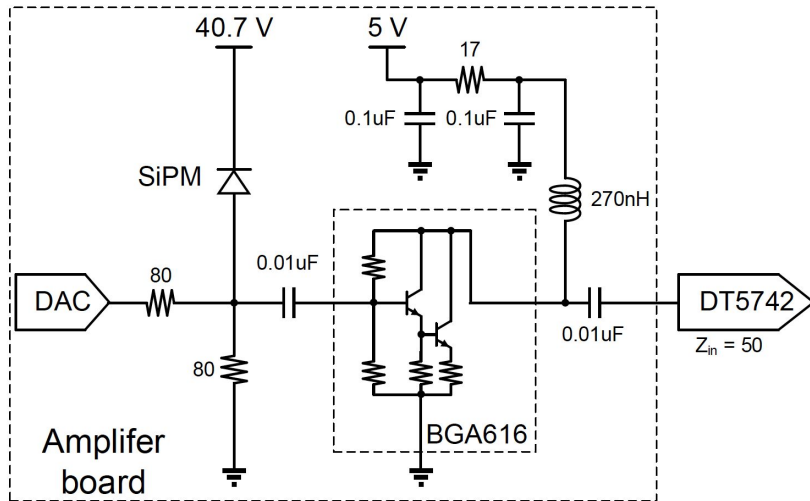


Figure 4-20: Output waveform

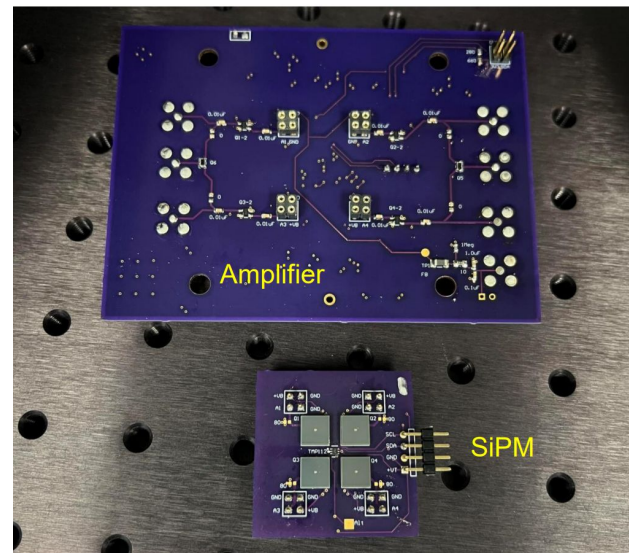
Hamamatsu PMT R1924

SiPM readout in FCC-ee R&D CalVision dual readout project

- Boards designed by the University of Virginia group
- Four S14160-6050HS (6 x 6 mm²) SiPMs on board, micro-cell pitch 50 μm
- Single-stage RF amplifier for each channel (gain ~ 10)
- Domino-ring sampler⁴ (DRS4) digitizer, 5 Gsps, 200 ns window, 16+1 channel maximum



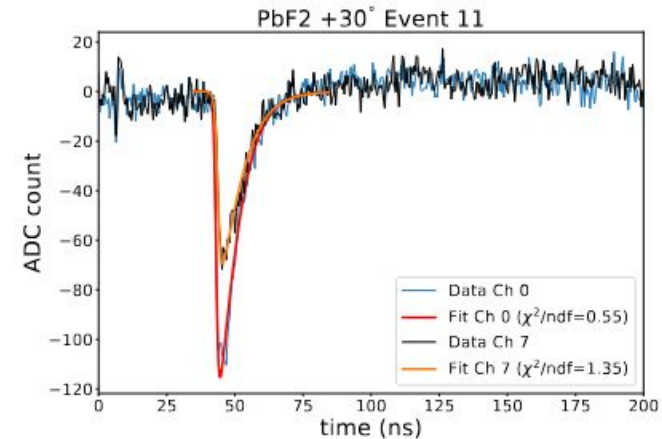
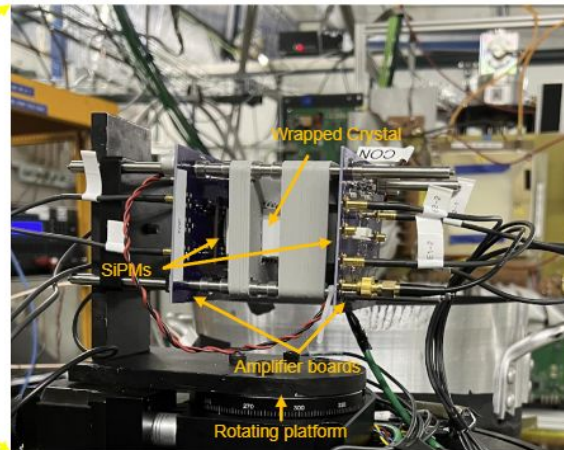
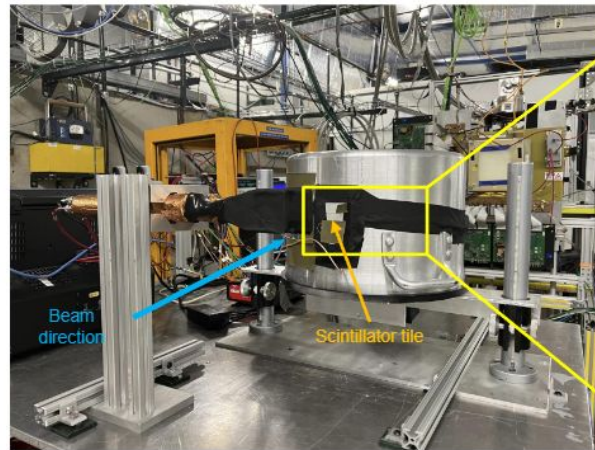
Single-channel schematic



4-channel amplifier board and SiPM board

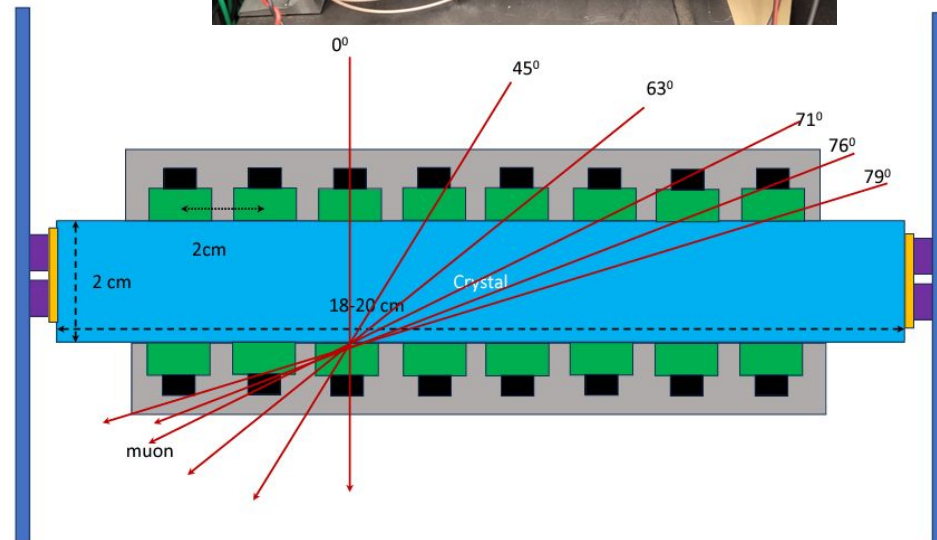
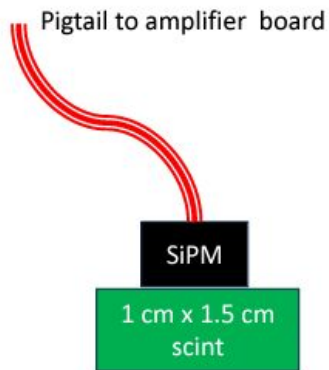
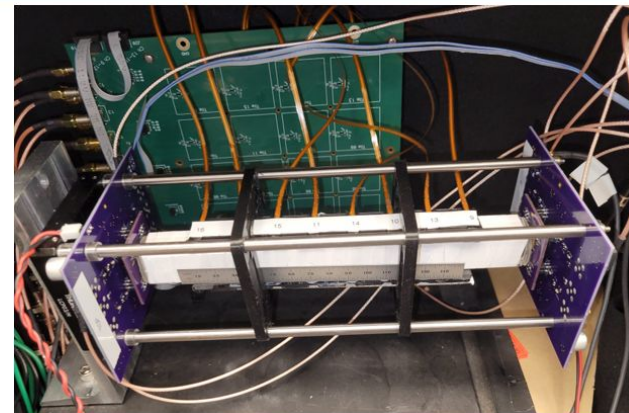
Test beam study for PbF_2 at Fermilab

- PbF_2 crystal sits on a rotating platform
- Angular dependence studied for Cherenkov light with SiPM waveform
- If only leading edge info is needed (waveform digitization not required), can use MiniDAQ system as readout (such as scintillator strips with SiPM)



Angular study with cosmic ray

- 1 cm * 1.5 cm scintillator tile coupled with SiPM, spaced 2 cm apart along the crystal long surface as trigger
- Incident angle can be defined when choosing desired SiPM pair as coincidence trigger
- SiPM signal and bias routed out to amplifier board by pigtail cable
- Amplifier board designed by Fermilab



Summary

- MiniDAQ is a lightweight readout system, currently used for ATLAS MDT phase 2 upgrade chamber commissioning
- 960 channel basic, 1920 channel with expandable port, MiniDAQ can easily handle one or more drift chamber
- SiPM readout has been studied for CalVision dual readout
- Same scheme can be adopted for scintillator tiles coupled with SiPM and readout by MiniDAQ