SiPM and drift tube readout and DAQ

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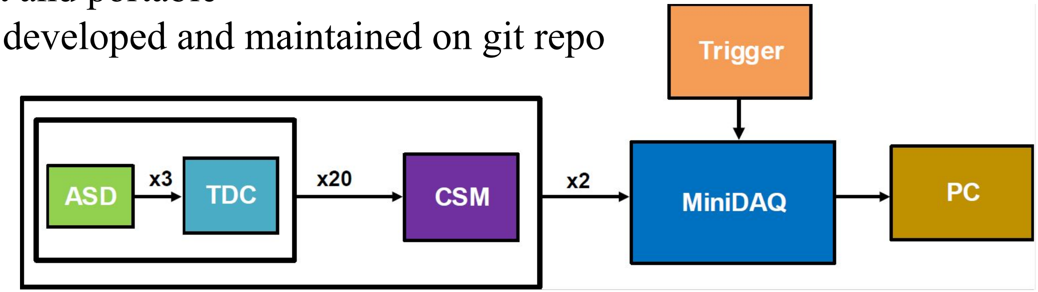
A portable MiniDAQ system with MDT front-end electronics

- 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



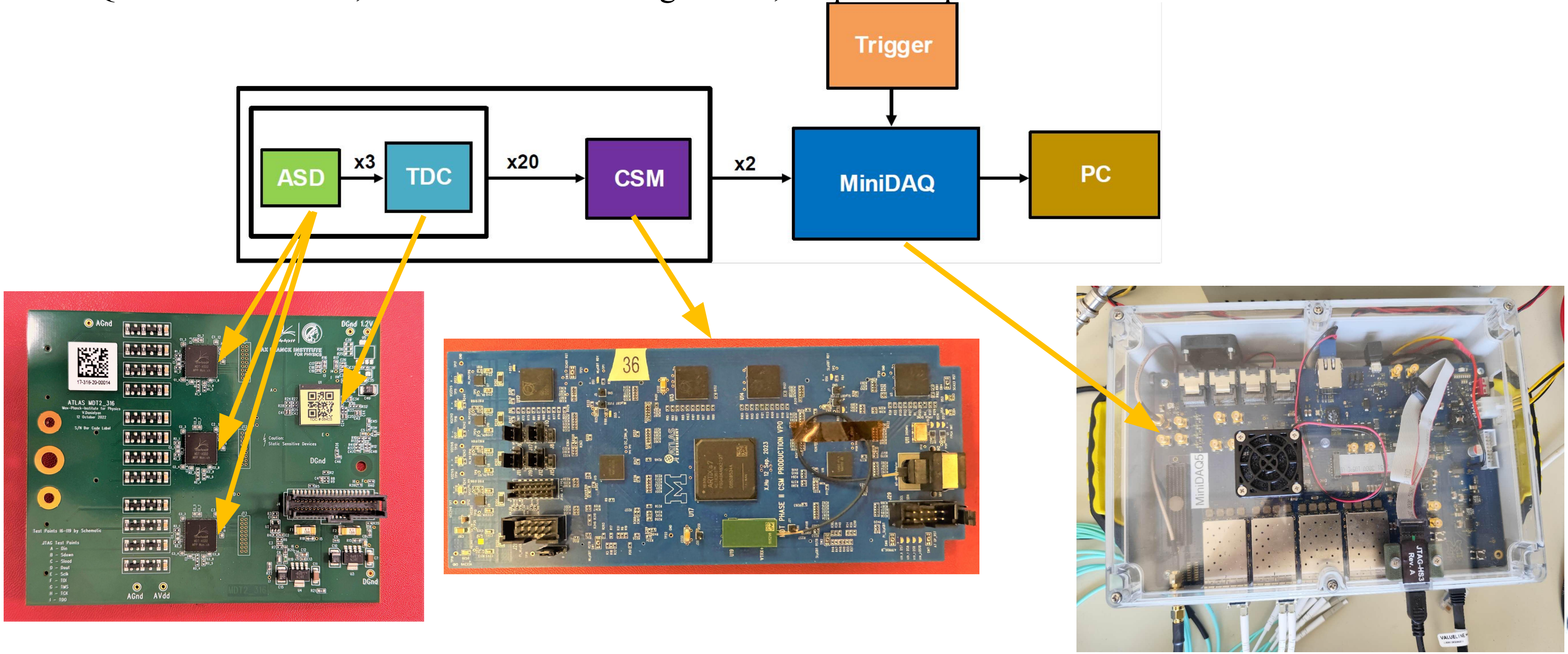
The MiniDAQ readout system used to read out data from 2 CSMs

- 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

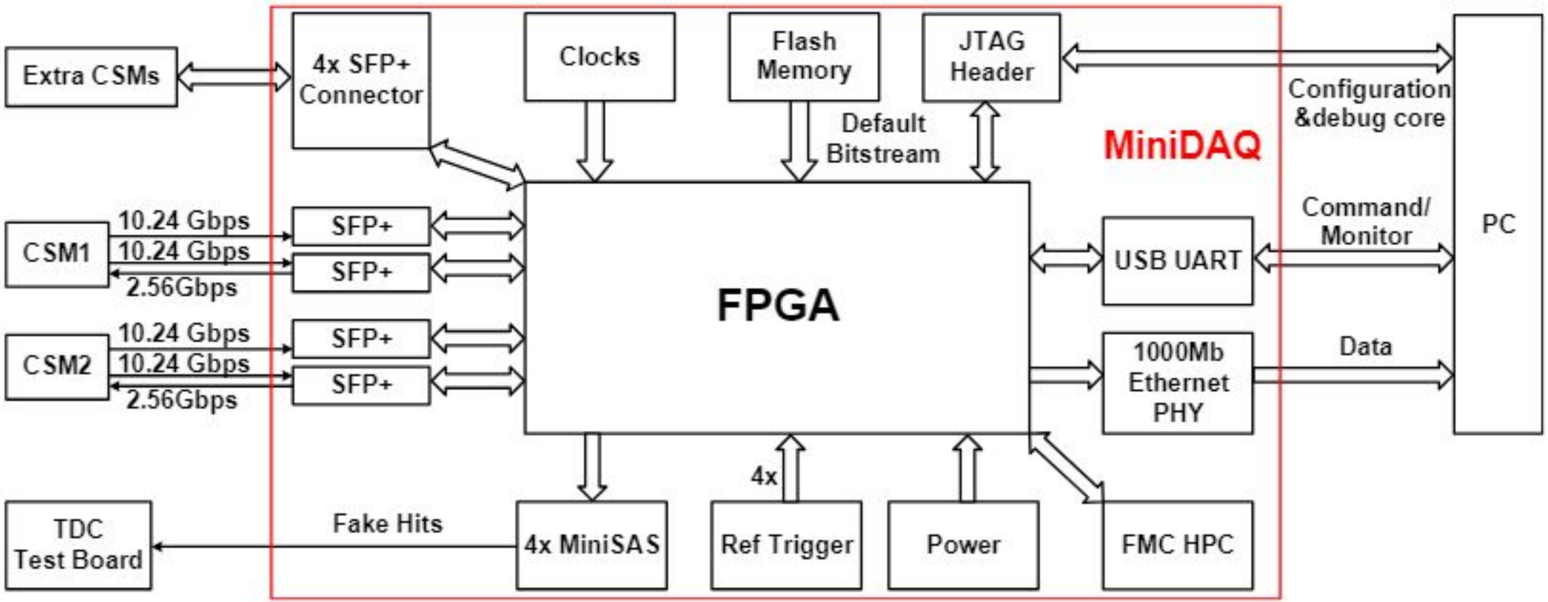
ASICs, front-end PCBs and MiniDAQ boards produced by various institutions

- 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



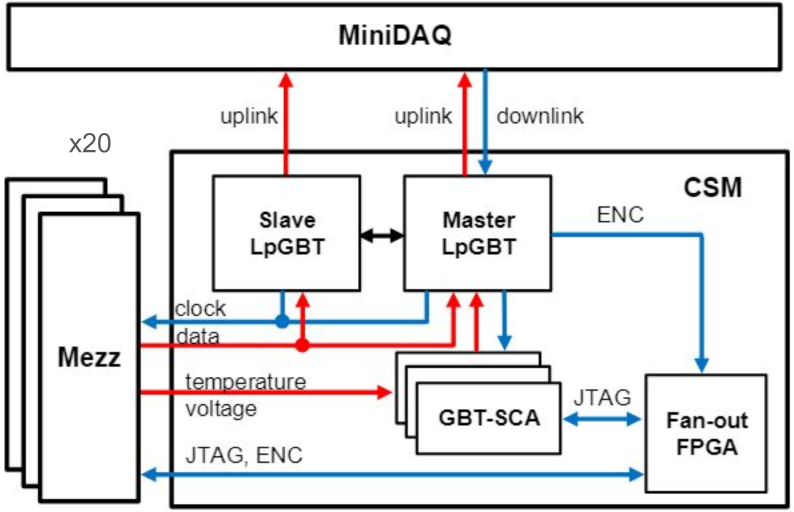
MiniDAQ board hardware

- 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

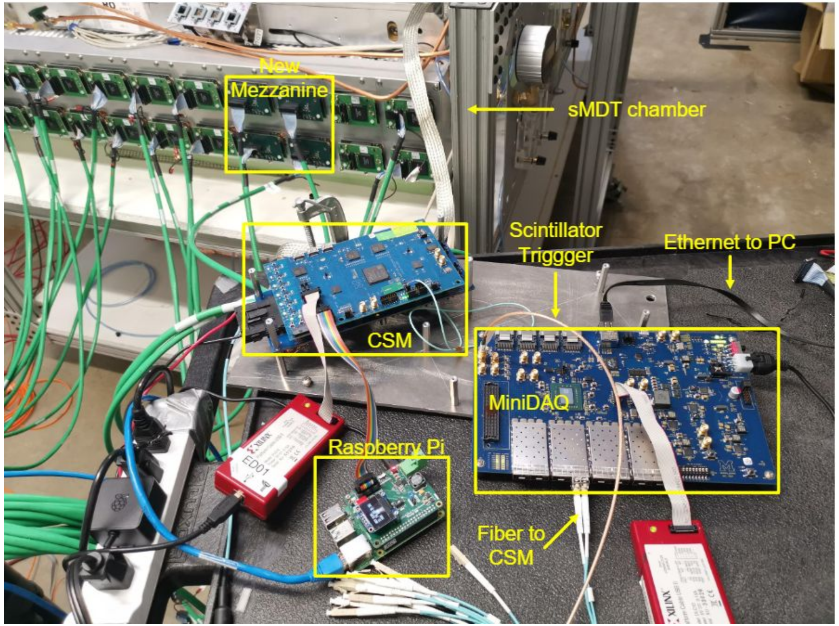


MiniDAQ data flow

- 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



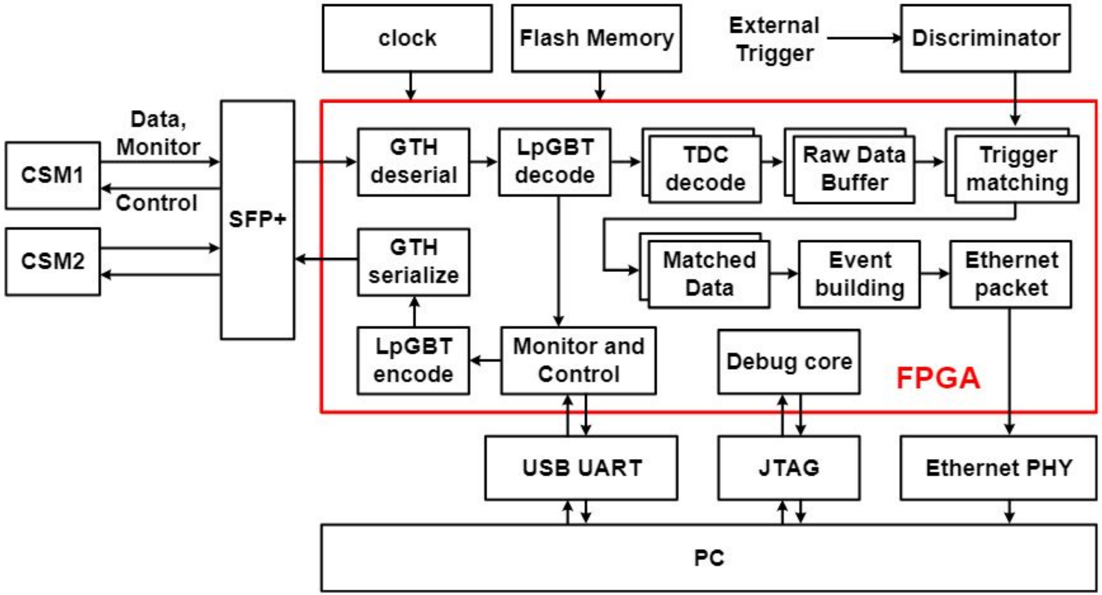
uplink (red) and downlink (blue) data flow



Hardware connection

MiniDAQ firmware logic

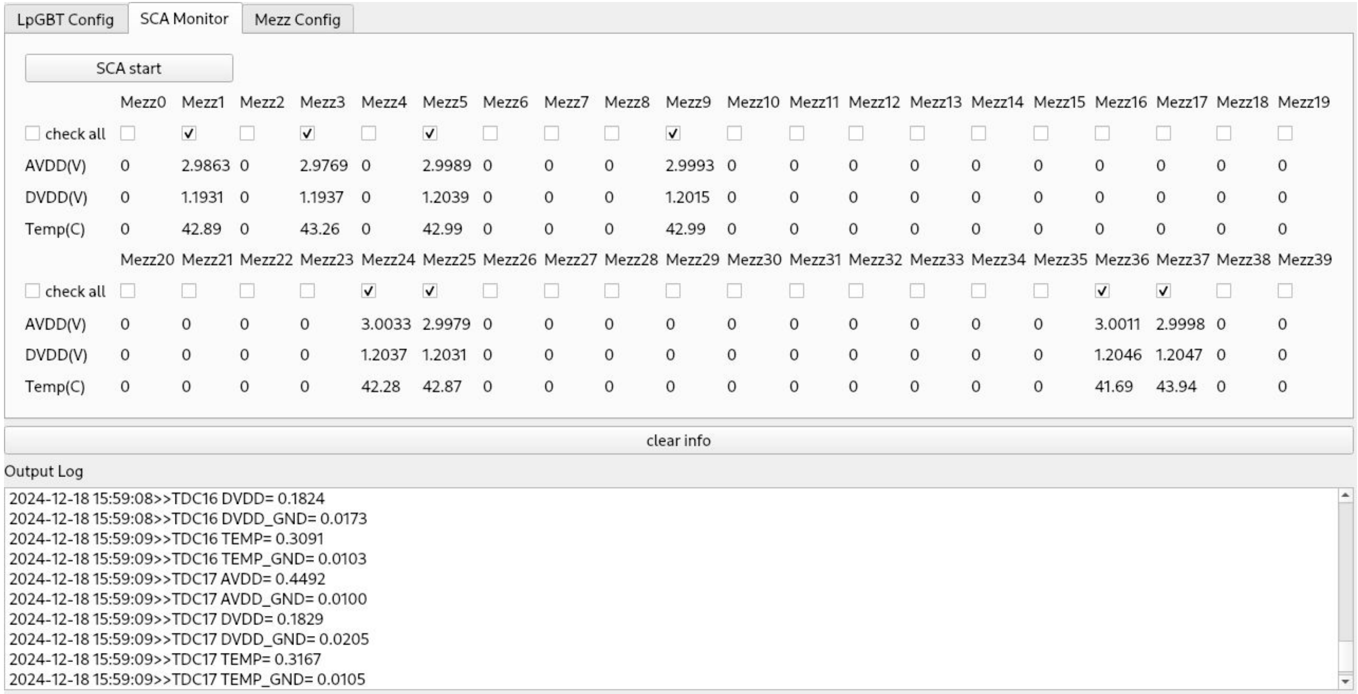
- Multi-stage decoding: GTH deserial->LpGBT decode->TDC and monitoring data decode
- Idle word filtering: select valid hit data into RAMs
- Trigger matching and event assembly: External triggers are digitized by an FPGA-TDC. Timing info is compared with front-end TDC timing stored in the RAMs. Matched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



Functional block diagram of the miniDAQ system

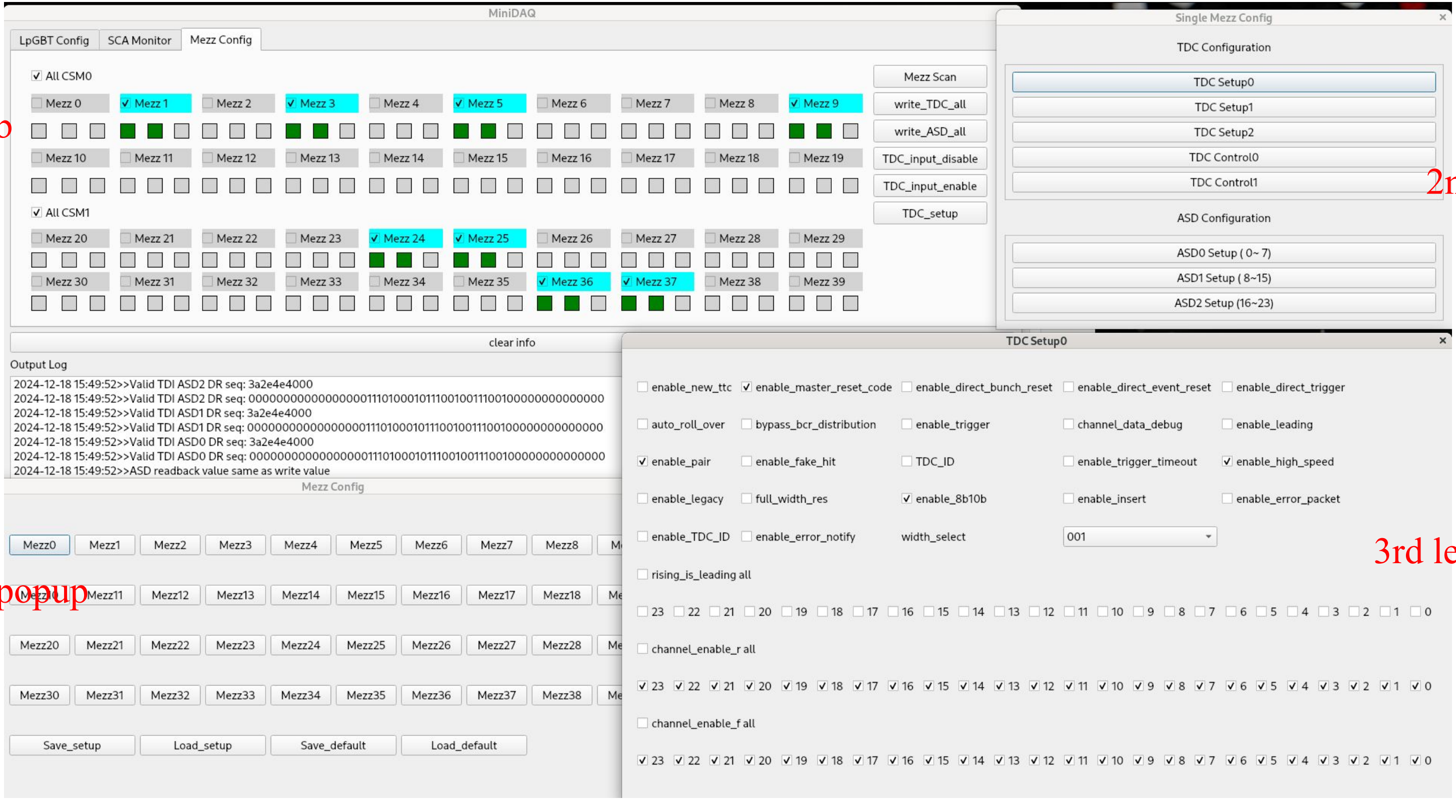
MiniDAQ configuration GUI

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



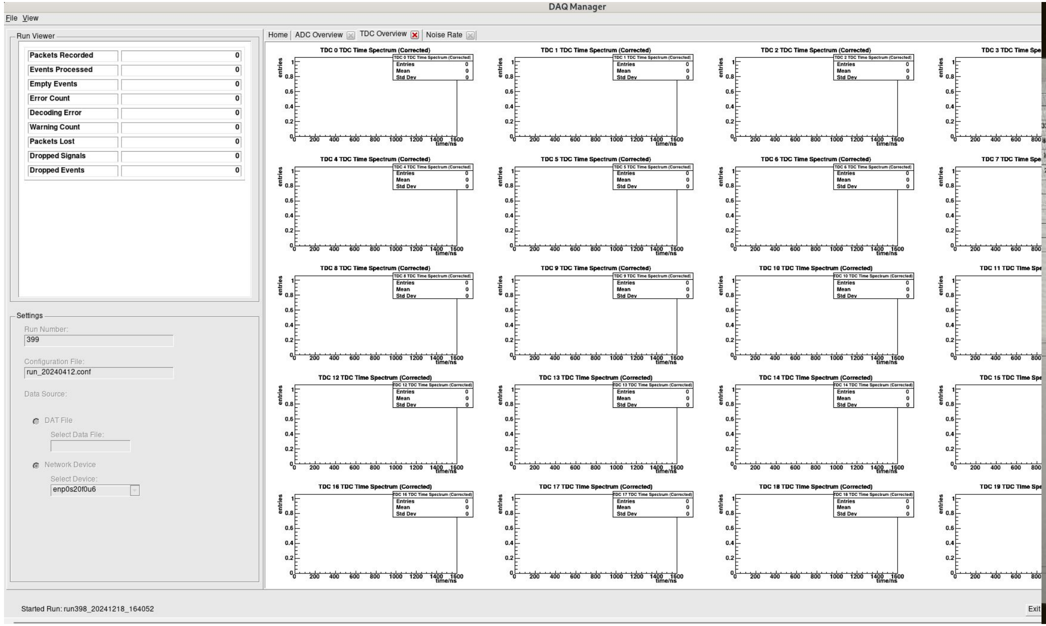
MiniDAQ configuration GUI

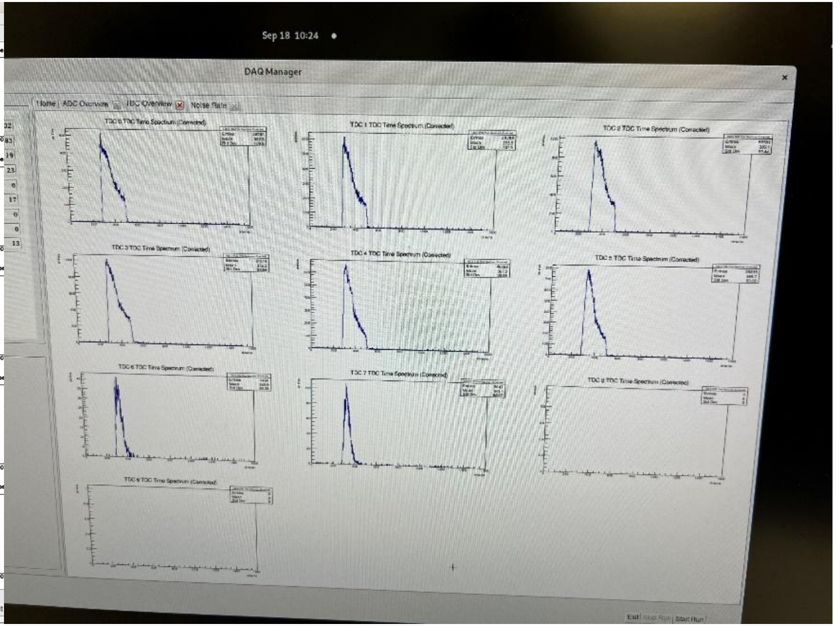
- Auto scan all connected mezzanine (blue=connected, gray=unconnected)
- JTAG configuration verification for TDC and ASD (green=success, red=failure)



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 dispay in the straw test beam experiment in Sept. 2024

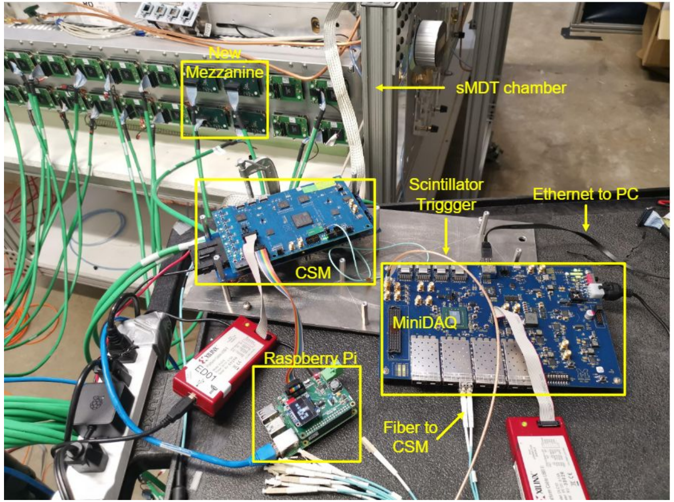




MiniDAQ implementation

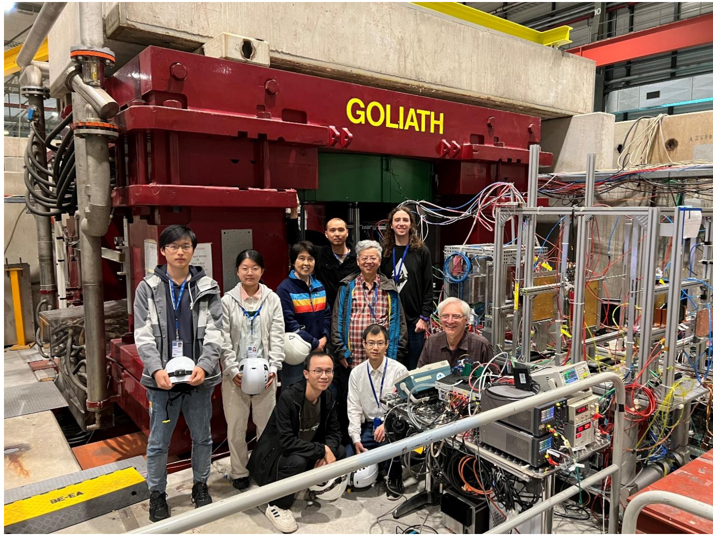
The system has been successfully used in:

- 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++

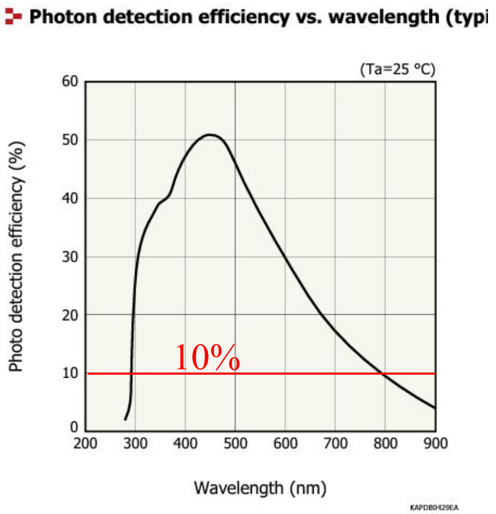


Testing at CERN H4 and T9

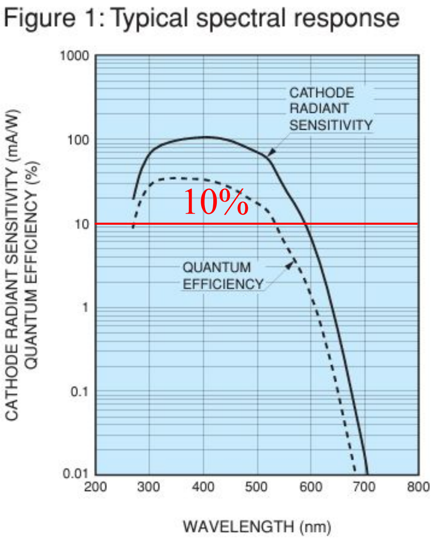
SiPM vs PMT

Why using SiPM?

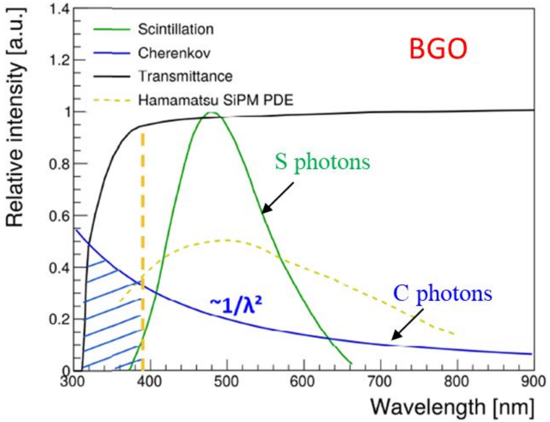
- Broader photo detection efficiency in wavelength (covers Cherenkov light)
- Not sensitive to magnetic field
- Small unit size (usually 1mm*1mm), not easy to break



Hamamatsu SiPM S14160



Hamamatsu PMT R1924



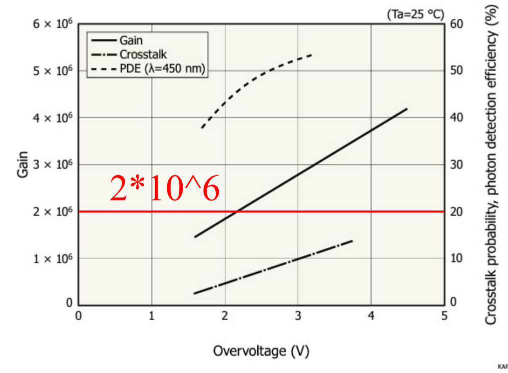
BGO scin. vs Cherenkov photon intensity

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



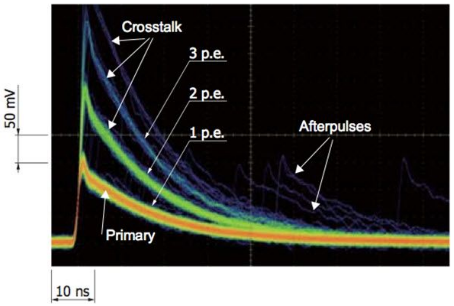
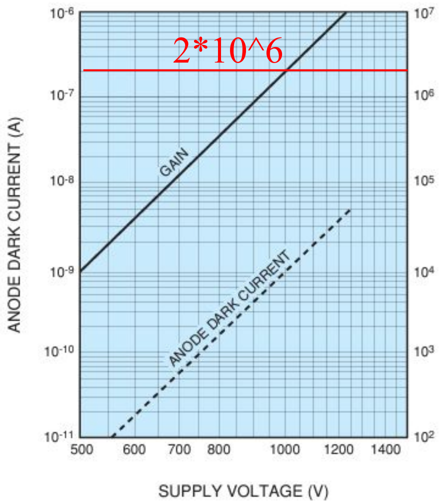


Figure 2: Typical gain and dark current charact



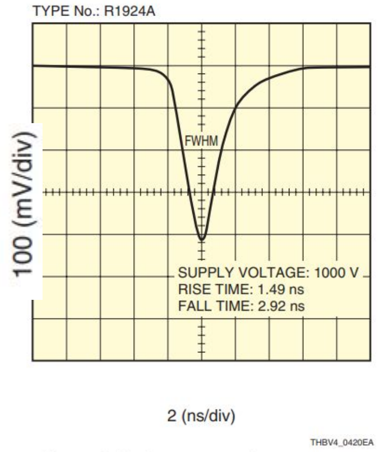


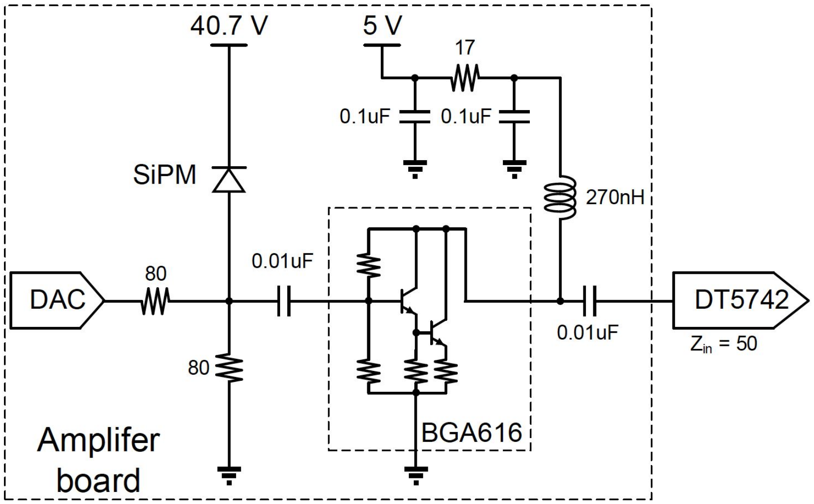
Figure 4-20: Output waveform

Hamamatsu SiPM S14160

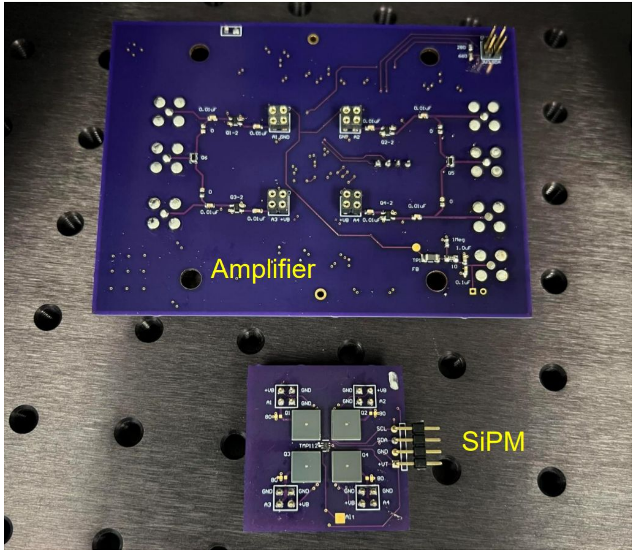
Hamamatsu PMT R1924

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 um
- Single-stage RF amplifier for each channel (gain ~10)
- Domino-ring sampler4 (DRS4) digitizer, 5 Gsps, 200 ns window, 16+1 channel maximum



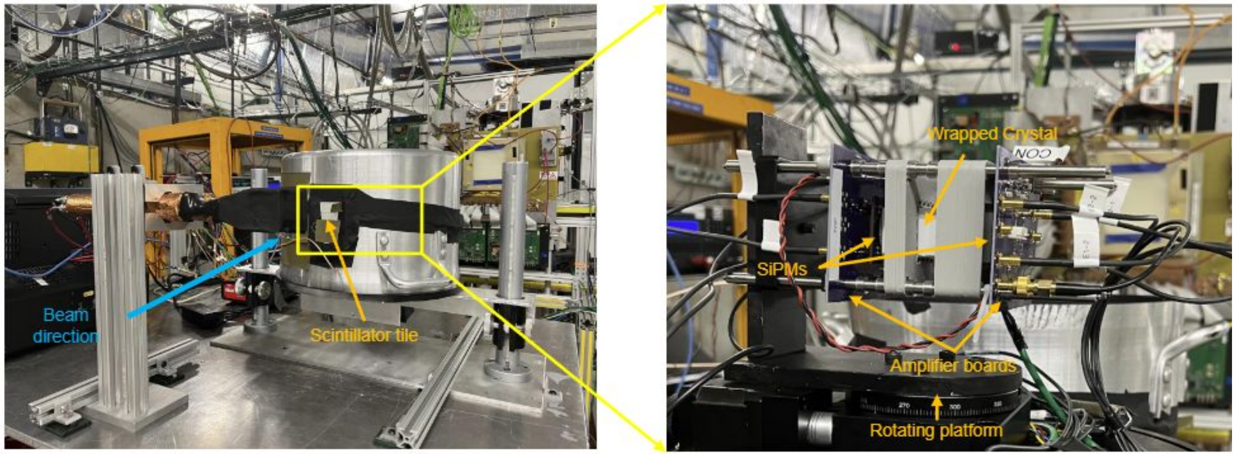
Single-channel schematic

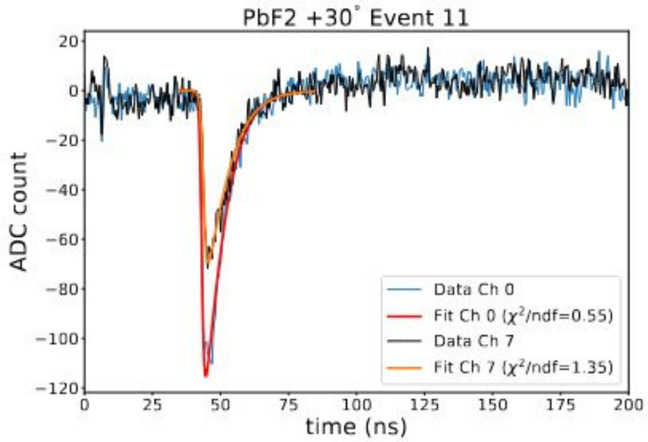


4-channel amplifier board and SiPM board

Test beam study for PbF_2 at Fermilab

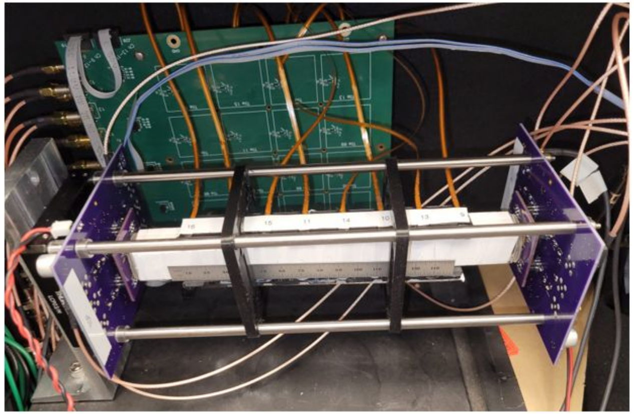
- PbF_2 crystal sits on a rotating platform
- Angular dependence studied for Cherenkov light with SiPM waveform
- If only leading edge info is needed (waveform digitization not required), can use MiniDAQ system as readout (such as scintillator strips with SiPM)

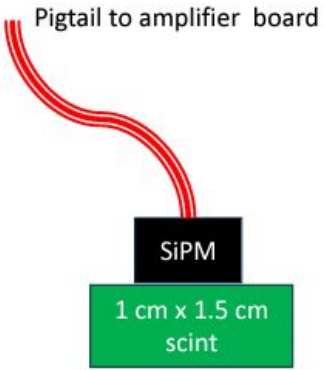


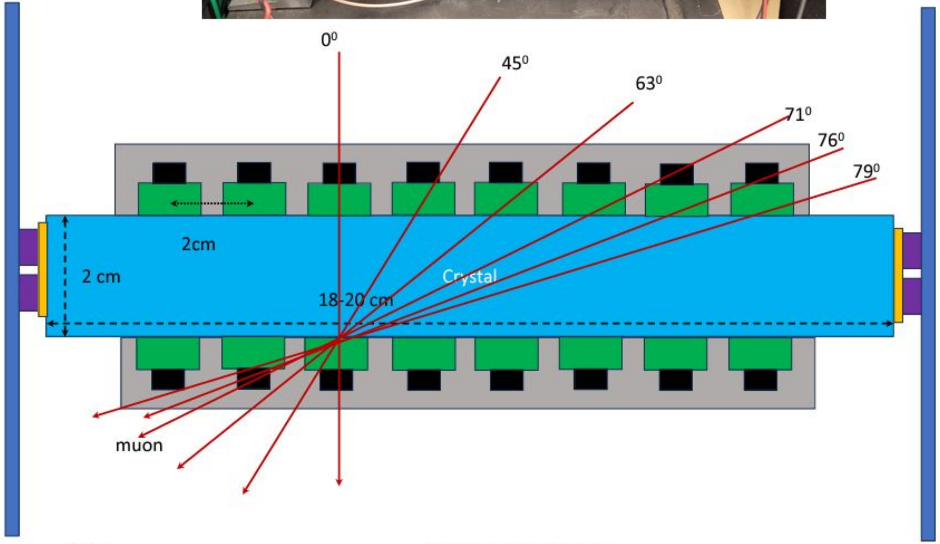


Angular study with cosmic ray

- 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