TOAD slow control and PVT measurements

TOAD update for ND-GAr Meeting

Hank Hua

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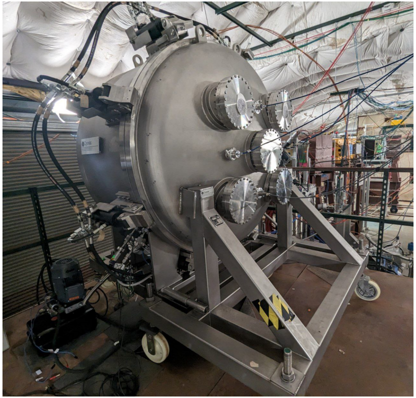
Outline

- Introduction to TOAD and TOAD electronics
- TOAD slow control
- PVT measurements
- Quick TOAD update
- Summary and outlook

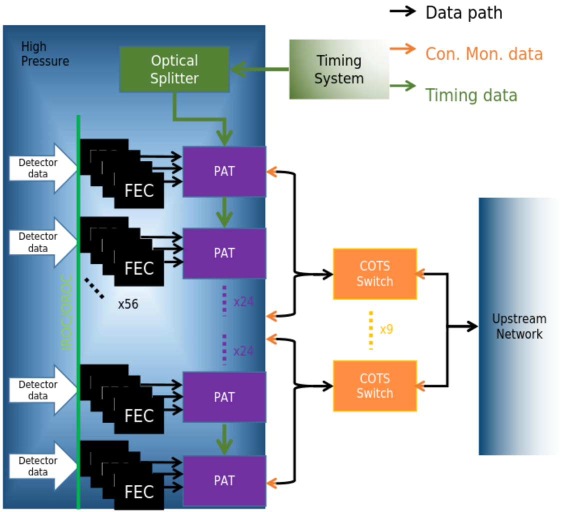
What is TOAD?

- Teststand for Overpressurised Argon Detector
- Located at Fermilab for low energy hadron beam
- Design
  - High pressure gas TPC (1 m^3) – 5 Bar
  - Ar-CH_4 – ratio 96:4
  - Charge based readout using ALICE outer read out chamber (OROC)
  - Testing readout electronics for ND-GAr

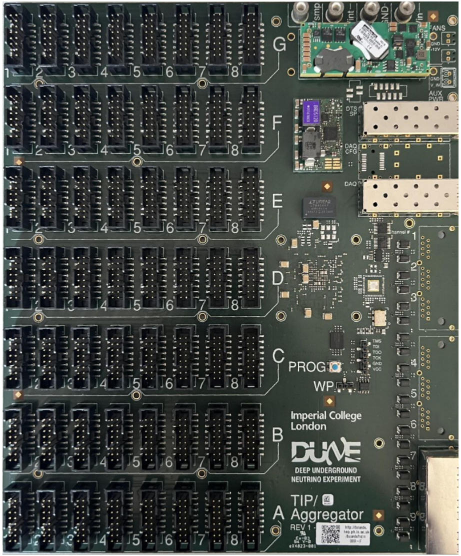


TOAD electronics

- 156 Front End Cards (FEC) perform digitisation and zero-suppression, $\mathcal{O}$(10k) channels
- 3 Power, Aggregation and Timing (PAT) board aggregates data received, synchronises with timing system, and sends to DAQ



PAT components



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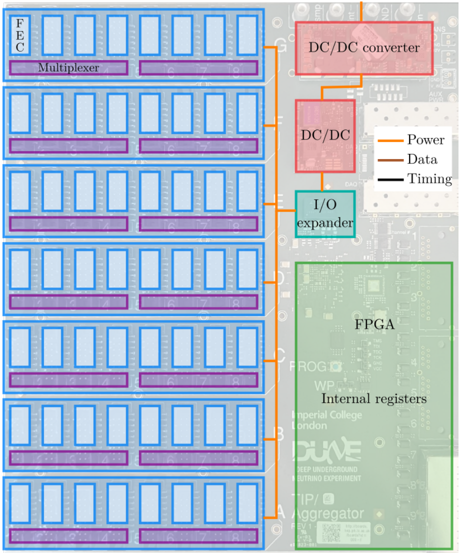
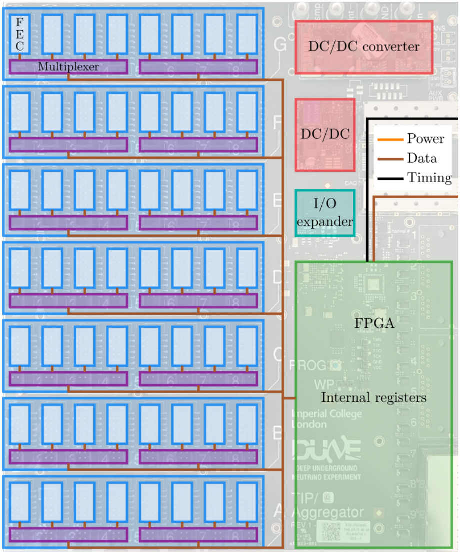
PAT components

- Field programmable gate array (FPGA) and various external components to control power, aggregation, and timing
- Power
  - DC/DC converter converts voltage from power supply to those usable by the FPGA and FECs
  - I/O expander controls power delivery to each FEC



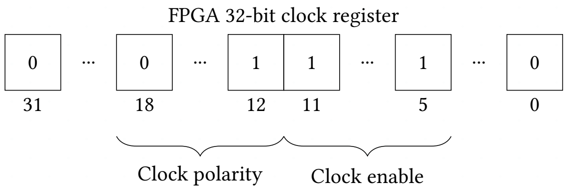
PAT components

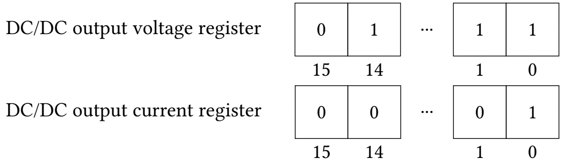
- Field programmable gate array (FPGA) and various external components to control power, aggregation, and timing
- Aggregation
  - 7 FEC groups, 8 FECs per group
  - Multiplexer controls the communication with FECs, 2 multiplexers per group
  - Data stored in buffers within FPGA
- Timing
  - DUNE Timing System (DTS) can be integrated



Communication protocols

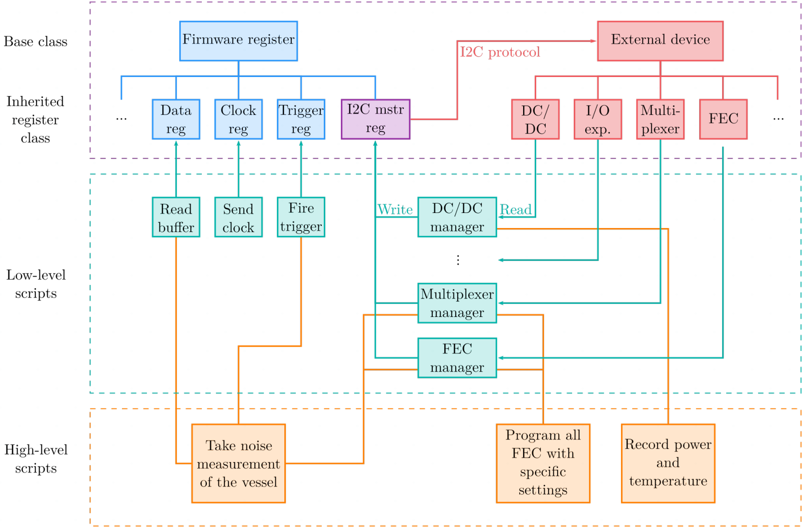
- How to talk to different components and devices?
- Read and write to registers
- Within FPGA
  - 32 bit registers inside FPGA firmware
  - Communication via IPBus
- External devices
  - We can only communicate with FPGA
  - Commercial slow control interfaces, e.g. I2C, through FPGA
  - Multiple registers per device, size not fixed





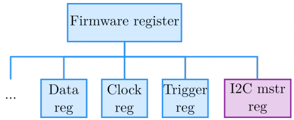
Design

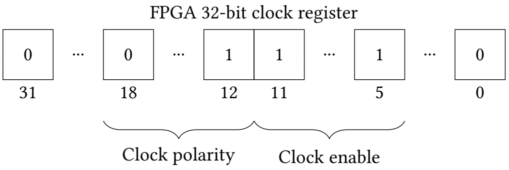
- Modular, scalable approach
- Not specific to our setup



Firmware registers

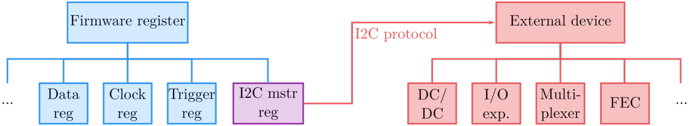
- Registers implemented by firmware, within FPGA
- A base firmware register class, contains general methods
- Inherited by physical registers
  - Register-specific bits map
  - Accessible methods to read/write register
- I2C master register controls I2C communication with external devices





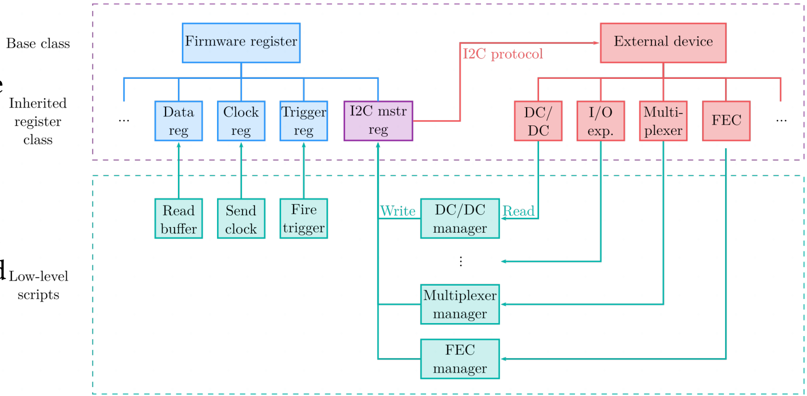
External devices

- We are only connected to FPGA, have to talk to I2C master register to access external devices
- I2C register base class
  - I2C commands for I2C master register to read/write external registers
- Inherited by external devices
  - Device-specific register map
  - Accessible methods



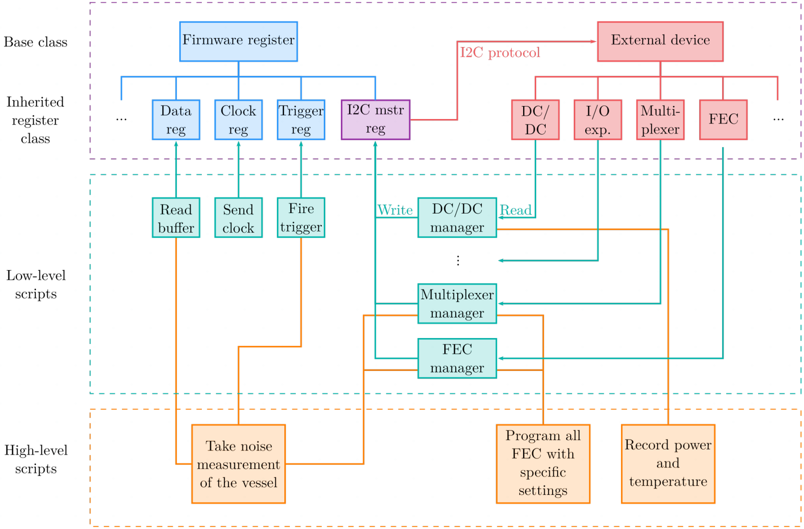
Low-level scripts

- More user-friendly command line interface
- Typically instantiates specific register class
- I2C-related scripts read device register map and write on I2C master register



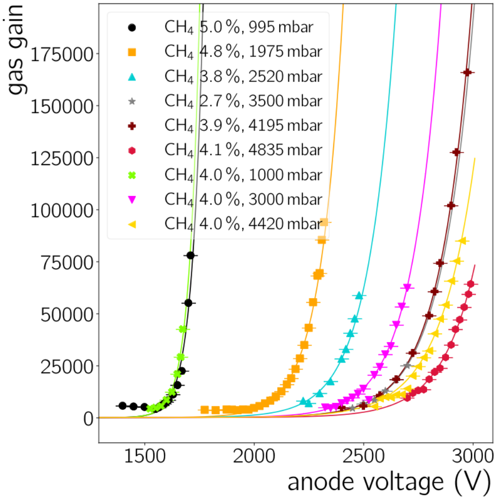
High-level scripts

- Combines various low-level scripts to perform more actions
- Examples:
  - Perform noise measurement across all FECs
  - Program all FECs with specific configurations
  - Periodically record power output and temperature from DC/DC



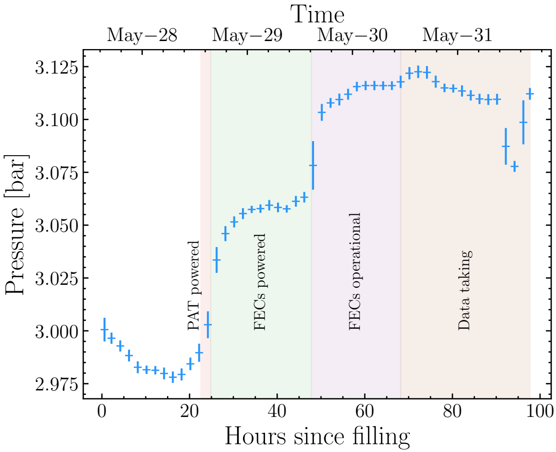
Motivation

- A functional slow control system gave us an opportunity for PVT studies
- Why do we care about pressure, volume, temperature (PVT) measurements?
  1. Previous test at RHUL – maximum gain achieved at 4.835 bar pressure and 4.1% CH_4
  2. Pressure increase due to heat – could exceed the maximum pressure if not careful
  3. Rate of leakage, rate of stabilisation
- No specific gas temperature monitor – have to infer from pressure measurement



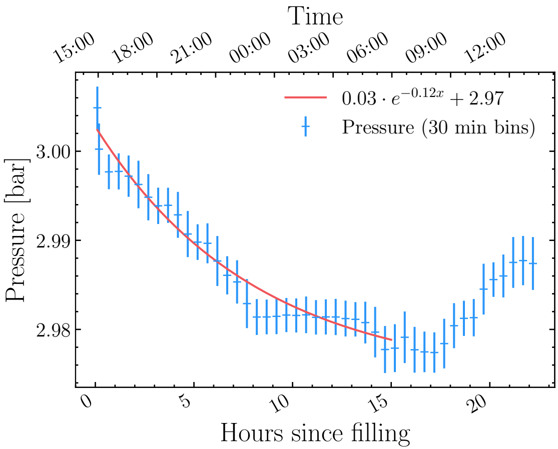
Pressure measurements

- Pressure is measured by a manometer inside the vessel
- A separate slow control system provides continuous monitoring



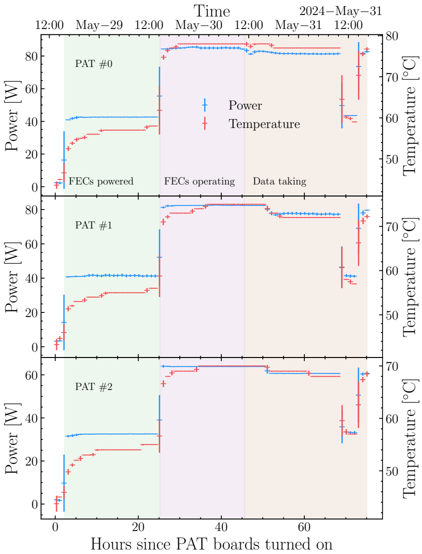
Overnight pressure change

- Pressure decreases overnight
- Fitting exponential function $f = Ae^{bt} + c$ gives a time constant $1/b \sim 9$ hours
- Future measurement considerations:
  - Longer duration
  - Thermometer on the vessel to correlate with temperature change



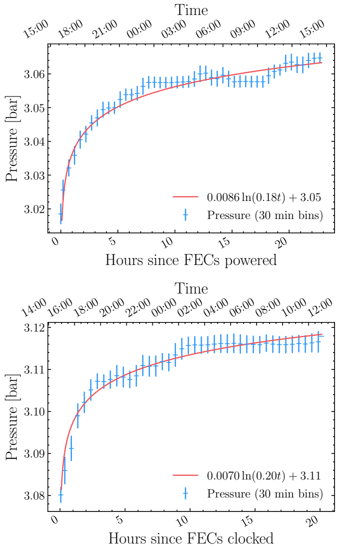
DC/DC measurements

- DC/DC components on each PAT board can measure voltage and current delivered to the FECs, and temperature
- Slow control system provides continuous monitoring of these parameters



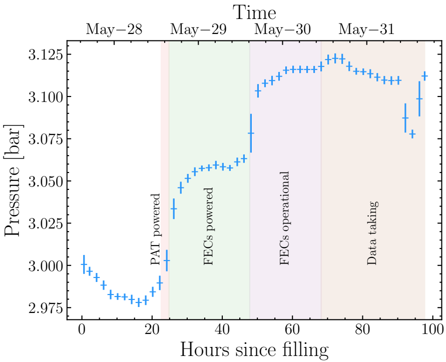
Pressure equilibrium

- How long does it take for the pressure to stabilise given a change in temperature?
- Estimate when $\dot{P} < 1\,\mathrm{mbar/hr}$ from fit
  - FEC powered: $t = 8.6\,\mathrm{hours}$
  - FEC powered and clocked: $t = 7.0\,\mathrm{hours}$



Gas temperature

- Assumption: gas at room temperature when filling
- Measured a $\Delta P = 0.156$ bar, $PV = nRT$ gives $\Delta T \sim 15\,°\mathrm{C}$
- But DC/DC temperature increased by $\sim 35\,°\mathrm{C}$ $\Longrightarrow$ vessel is dissipating $\sim 20\,°\mathrm{C}$ worth of heat
- Future studies: correlate power dissipated by DC/DC with temperature change

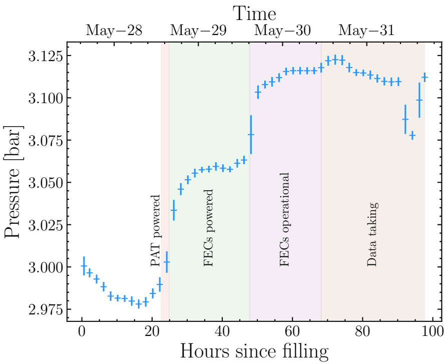


What pressure should we fill to?

- Burst disk of 5 bar installed to the vessel
- From ideal gas law,

$$\frac{P_{\text{final}} - P_{\text{fill}}}{P_{\text{fill}}} = \frac{\Delta T}{T_0} \implies P_{\text{fill}} = \frac{P_{\text{final}}}{1 + \Delta T / T_0}$$

- For a 15 °C rise in gas temperature from room temperature, maximum fill pressure $P_{\text{fill, max}} = 4.76$ bar
- To reproduce maximum gain measured at RHUL (at 4.84 bar), $P_{\text{fill}} = 4.60$ bar



TOAD update

- Operation firmware ready – can now perform continuous readout from FECs instead of having to trigger
  - DC/DC on PAT boards can reach 90 °C in this mode at 1.3 bar
- Pump-and-purged several cycles to remove dust / moisture in the vessel
- Sparking at OROC anode – could be due to expansion of OROC stretching the wires
- Performed noise measurement at 4.5 bar Ar-CH_4 (96:4) – demonstrated that electronics function under 4.5 bar

Summary and outlook

- Scalable and modular slow control system for TOAD
- Preliminary PVT analysis with slow control system
- Upcoming: migrate slow control code to C++ and integrate with DUNE-DAQ

Overnight leakage

- Pressure decreases overnight
- Leakage + temperature change (minor)
- Fitting an exponential function $f = Ae^{bt} + 1$ gives a time constant $1/b \sim 1321$ hours