Design and Performance of a Cryogenic System for Liquid-Argon detectors R&D

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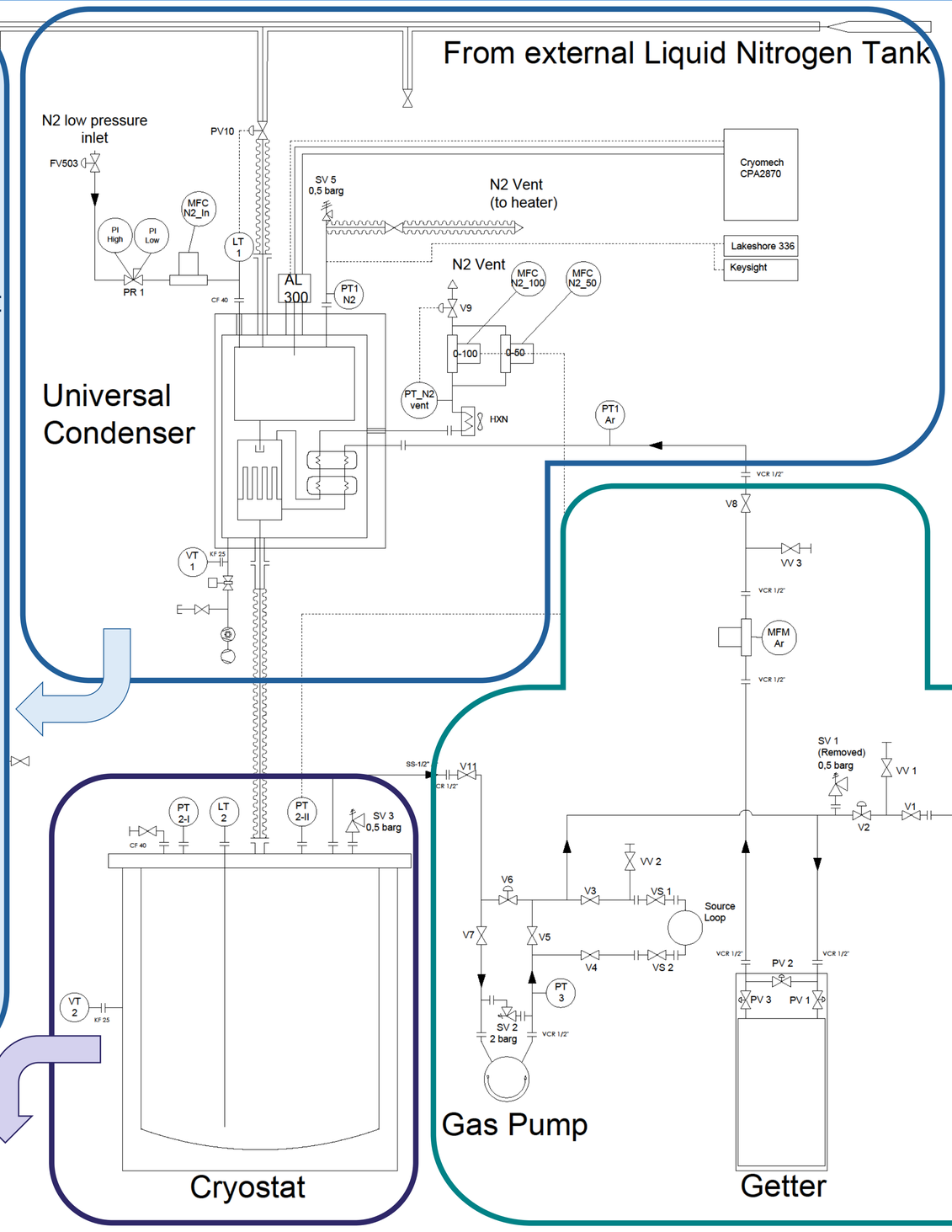
Detectors for direct dark matter searches based on noble liquids require cryogenic systems capable of maintaining highly stable thermodynamic conditions while liquefying, purifying, and continuously recirculating the argon target. A TPC Characterization Facility has been established at INFN Napoli Cryogenic Laboratory as a flexible test-bed for R&D on noble-liquid detectors, which recently was included as an infrastructure in DRD2. The facility currently hosts the DarkSide-Proto-0 experiment, a dual-phase liquid-argon TPC prototype. The cryogenic system serving the facility is engineered to deliver efficient argon liquefaction, stable long-term recirculation, and impurity concentrations in the ppb range. Its architecture includes a vacuum-insulated double-walled cryostat, a compact condenser thermally coupled to a nitrogen cooling loop, a purification stage based on a high-temperature getter, and a custom gas-handling panel equipped with a variable-speed recirculation pump. Since its commissioning, the system has demonstrated excellent thermal stability and reliable operation during extended runs, with precise control of pressure, temperature, and flow conditions. This contribution presents the design and operational performance of the cryogenic system, highlighting its long-term stability, thermodynamic control, and suitability as a platform for high-sensitivity liquid-argon detector development.

UNIVERSAL CONDENSER

Custom dual-loop device (Ar and LN), 2x brazed-plate heat exchangers (pre-cooling) and a shell-and-tube exchanger for liquefaction of GAr.

Alternative operation modes: direct LN supply / AL300 cryocooler for GN_2 liquefaction/reintegration.

Precise cooling power control via GN_2 flow regulation.

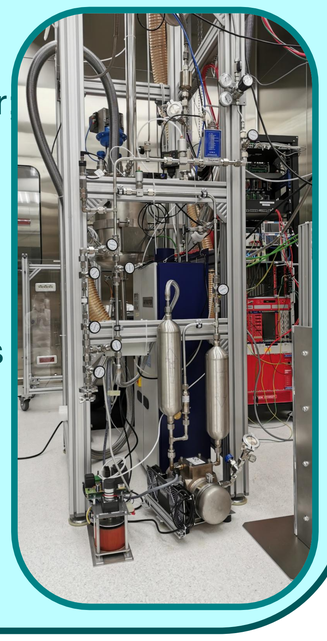


GAS PANEL

- Tunable-speed metal bellow recirculation pump;
- Expansion tanks to dampen vibrations.
- PS4-MT50-R SAES getter
- Pressure sensor (MKS), mass flow meter (Sierra) and controller (MKS) for Ar;

GAr (6.0) flow from cylinders to condenser.

Purifies recirculated gas to <1 ppb impurities (e.g., O_2, H_2O, CO_2).



SLOW CONTROL

Hardware: NI cRIO-9039 real-time controller;
24 Pt100 RTD inputs, 13 analog inputs/outputs, 8 digital I/O; Lakeshore336 + ps for cryocooler control;

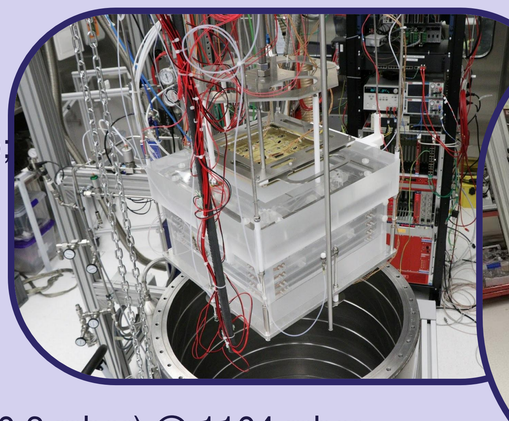
Software: LabVIEW-based user interface; EPICS-MIDAS cloud integration.

Continuous pressures, flows, temperatures and levels monitoring; Real-time trends, alarms systems;

CRYOSTAT

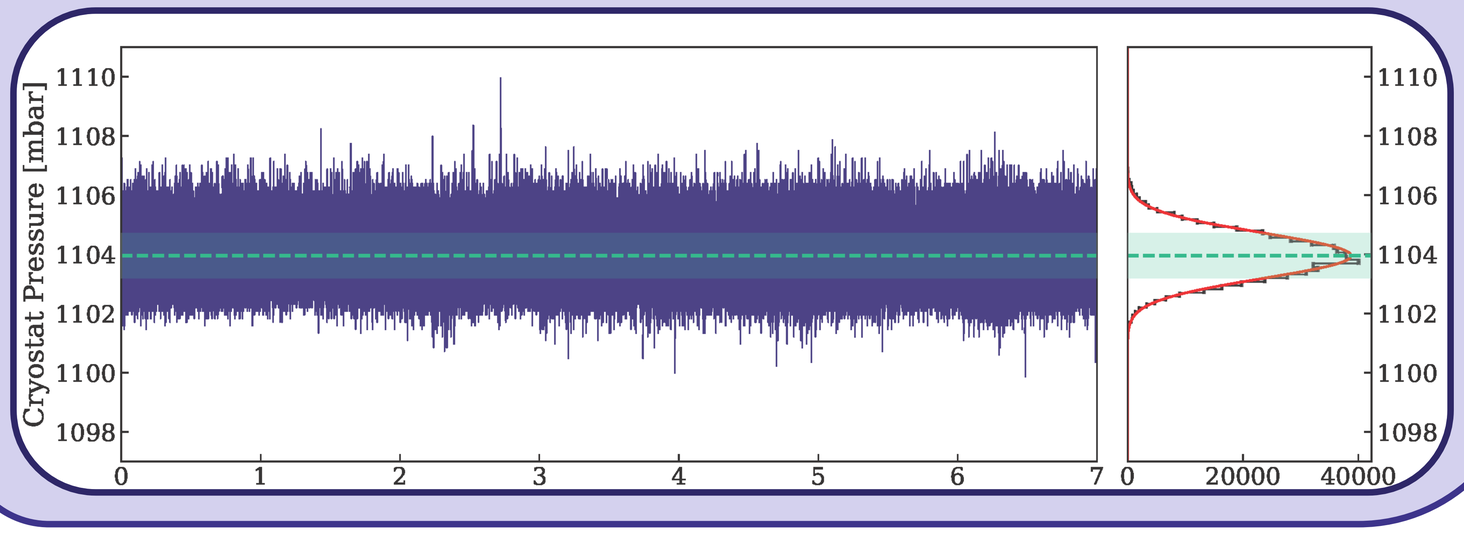
- Double-wall stainless-steel vessel with vacuum insulation, 300 L capacity;
- 2x pressure gauges for redundancy;
- 0.5 barg set relief valve;

Ar filling speed up to 65 slpm (5 L/h of LAr).



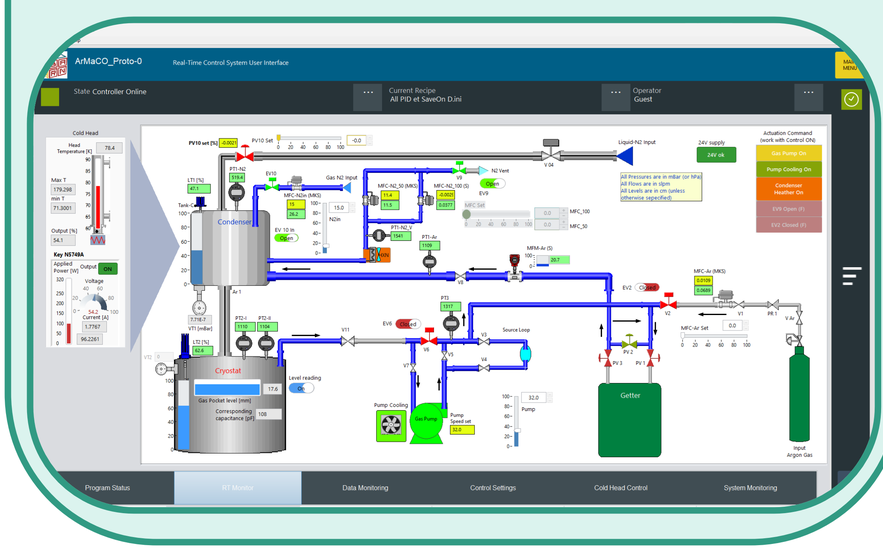
Requirements

- ΔP<10 mbar (std. dev. 0.8 mbar) @ 1104 mbar setpoint via PID-controlled cooling from condenser;



PID automatic controls:

- **PID1** regulates condenser LN level (LT1) or pressure (PT1-N2) via proportional valve PV10;
- **PID2** controls cryostat pressure (PT2-II) by venting GN_2 through MFC-N2;
- **PID 3** controls the GN_2 flow into the LN buffer, keeping the level constant by condensing the injected GN_2 via the cryocooler;
- **Lakeshore PID** controls the cold head temperature via heater power (Keysight 300W ps).



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