DarkSide-20k: The Next Stage in the Direct Dark Matter Search Using Liquid Argon

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For the Global Argon Dark Matter Collaboration (GADMC)

[1] Now at Los Alamos National Laboratory (LA-UR-23-23057)

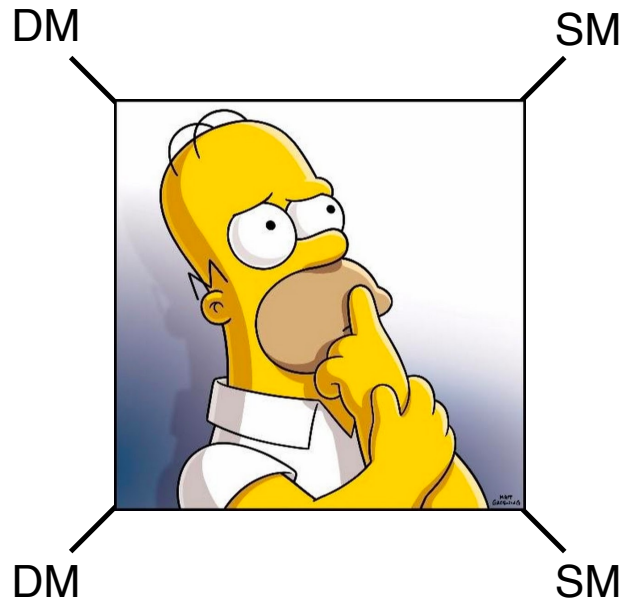
UCLA Dark Matter Conference – March 31, 2023

Outline

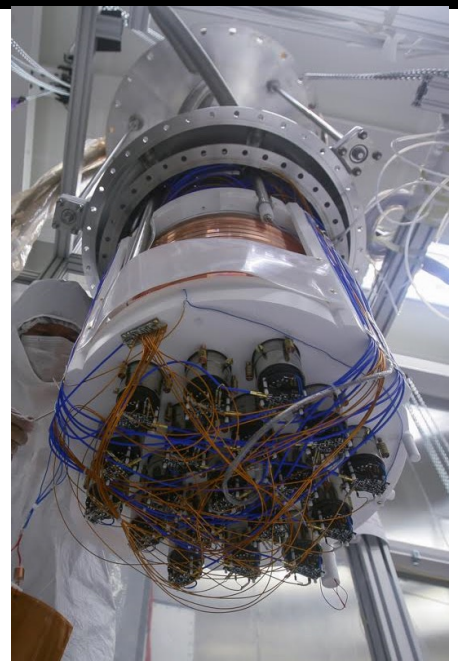
- DS-20k experimental design overview
  - Infrastructures
  - TPC and inner (neutron) veto design
- Underground argon (UAr) cryogenic system
  - Design and status overview

Other GADMC talks at UCLA-DM 2023

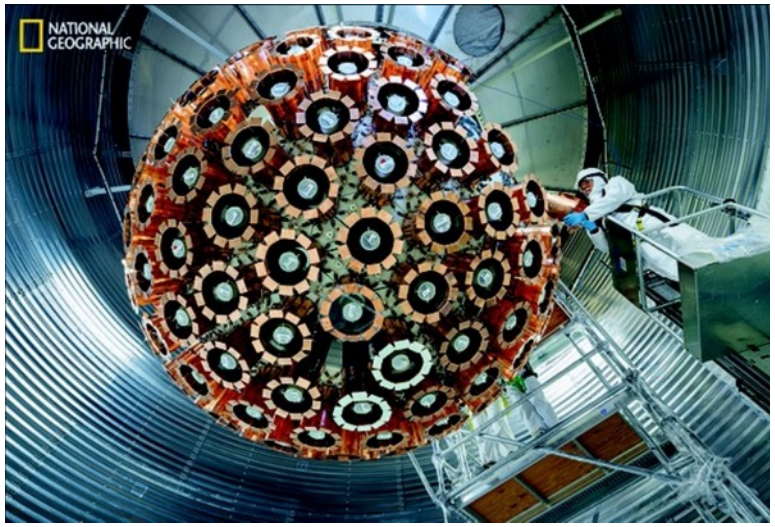
- Direct Detection with Argon – C. Galbiati – March 29 at 17:00
- Dark matter search in DEAP-3600: results and prospects – M. Lai – March 31 at 8:30
- From Photoelectrons to Bytes in DarkSide-20k – A. Capra – March 31 at 15:45
- The innovative Underground Argon Project: the path from procurement to purification for search of Dark Matter – F. Gabriele – March 31 at 18:00
- The NOA Facility @ LNGS – R. Tartaglia – April 1 at 8:00



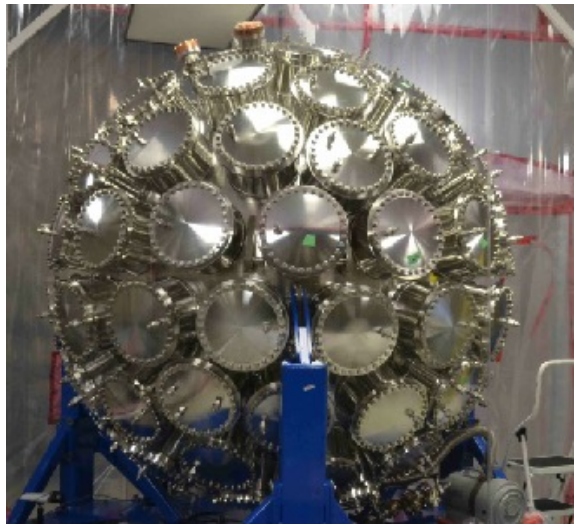
Global Argon Dark Matter Collaboration (GADMC)



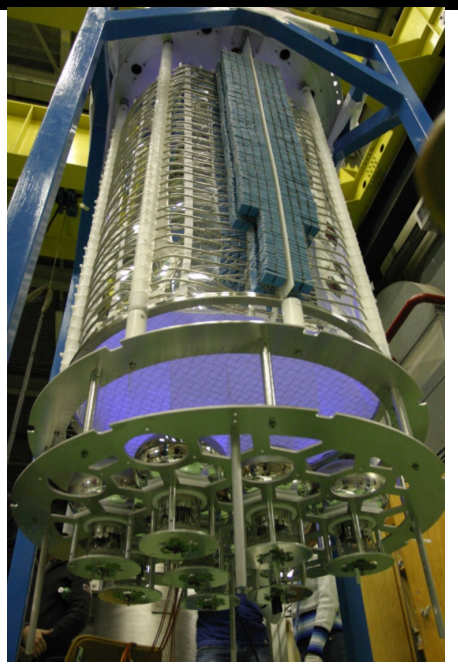
DarkSide-50
@ LNGS



DEAP-3600
@ Snolab



MiniCLEAN
@ Snolab



ArDM
@ Canfranc

GADMC

- ≈ 100 institutions w/ ≈ 500 members
- Exploiting LAr knowledge from multiple experiments to maximize exposure and WIMP sensitivity

DarkSide-20k @ LNGS

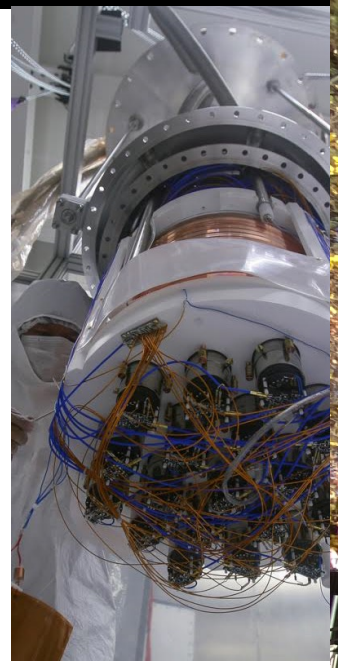
- Under construction
- Start of operations in 2026
- 20 t fiducial volume

ARGO

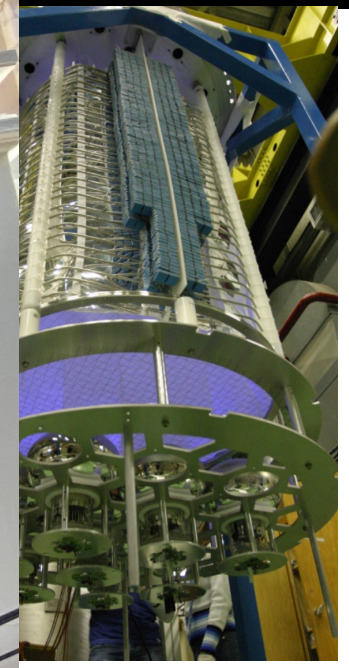
- Future LAr DM detector – 2030 and beyond
- 300 t fiducial volume

Glo … MC)

Collaboration meeting @ GSSI – L'Aquila, IT
Nov. 16, 2022



DarkSide-5
@ LNGS



ArDM
Canfranc

- ≈ 100 ins
- Exploitin
  multiple
  exposure

n 2026

030 and beyond

Sensitivity

Exposure: 200 t-y

- 20 t fiducial volume with nominal 10 year run time
- 5 σ discovery: 2.1 x 10^{-47} cm^2 @1 TeV/c^2
- 90% C.L. exclusion: 6.3 x 10^{-48} cm^2 @1 TeV/c^2
- Sensitivity to neutrino induced coherent scattering (CEvNS): 3.2 events

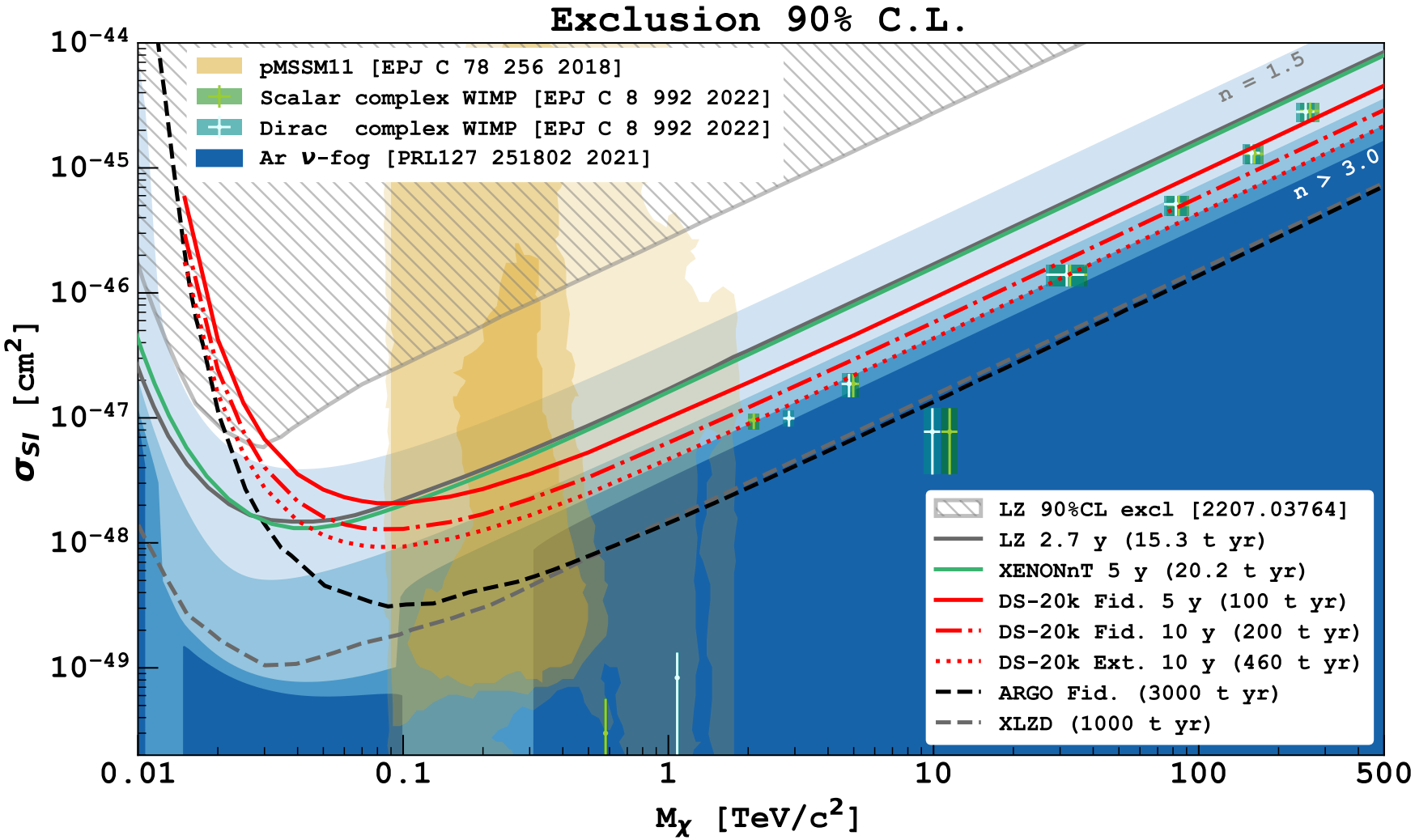
Instrumental Background

- 0.1 background events over 200 t-y in the ROI (30-200 keV_{nr})

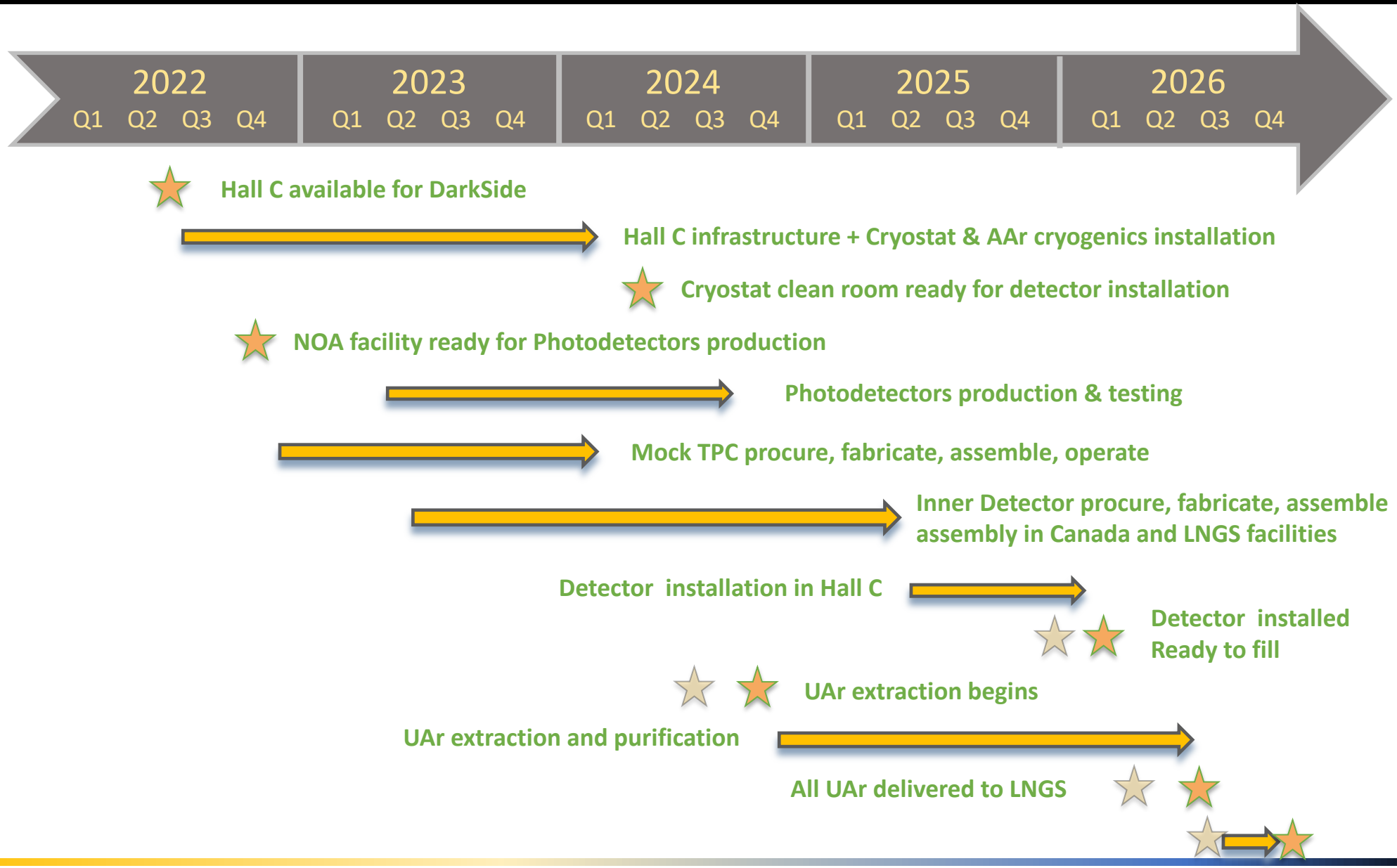
Electron Recoil Rejection

- Expect > 10^8 discrimination using PSD with argon

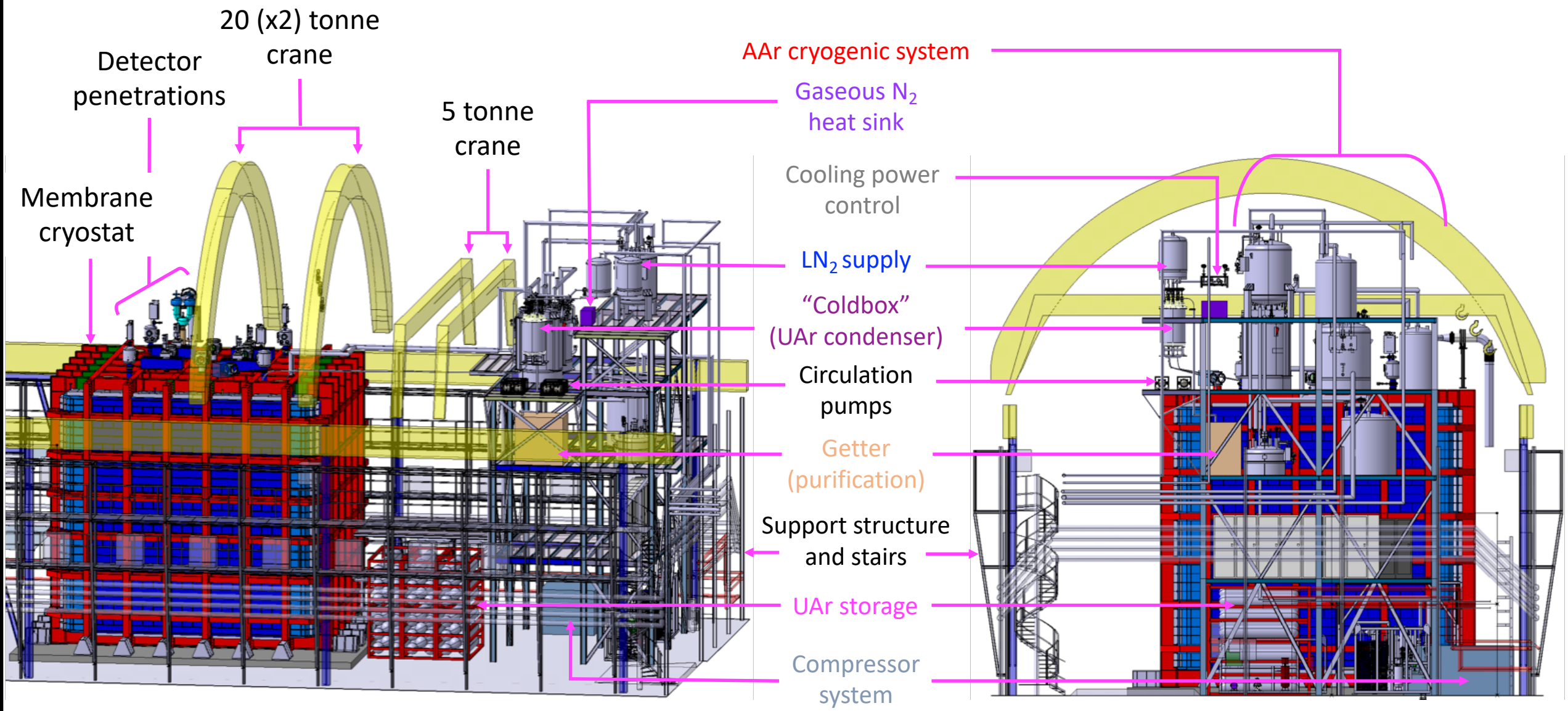
Spin Independent (SI) scattering



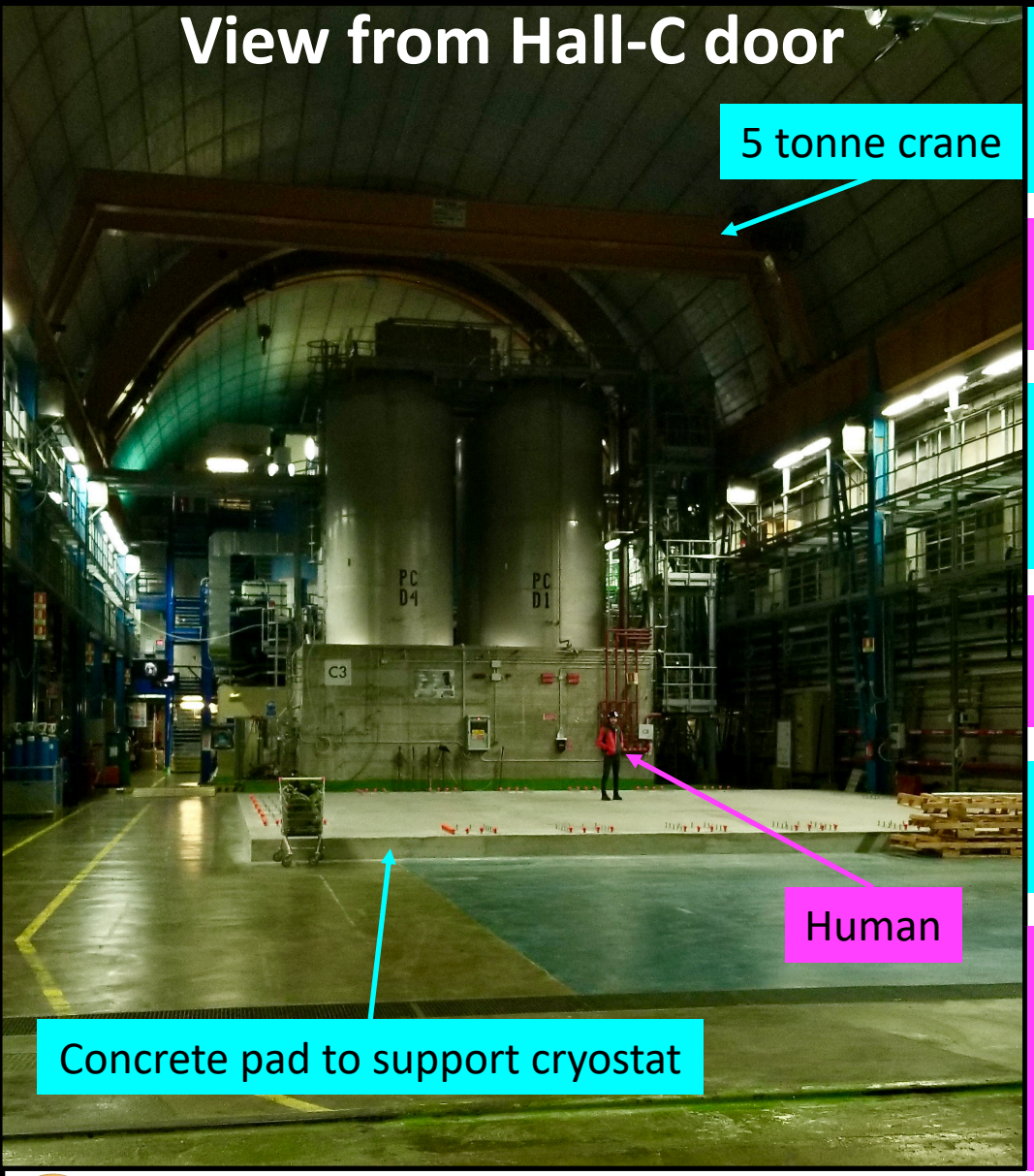
DS-20k Experimental Project Summary Timeline



DarkSide-20k in Hall-C at LNGS



DS-20k Cross Section Within Membrane Cryostat



Membrane "ProtoDUNE-like" cryostat

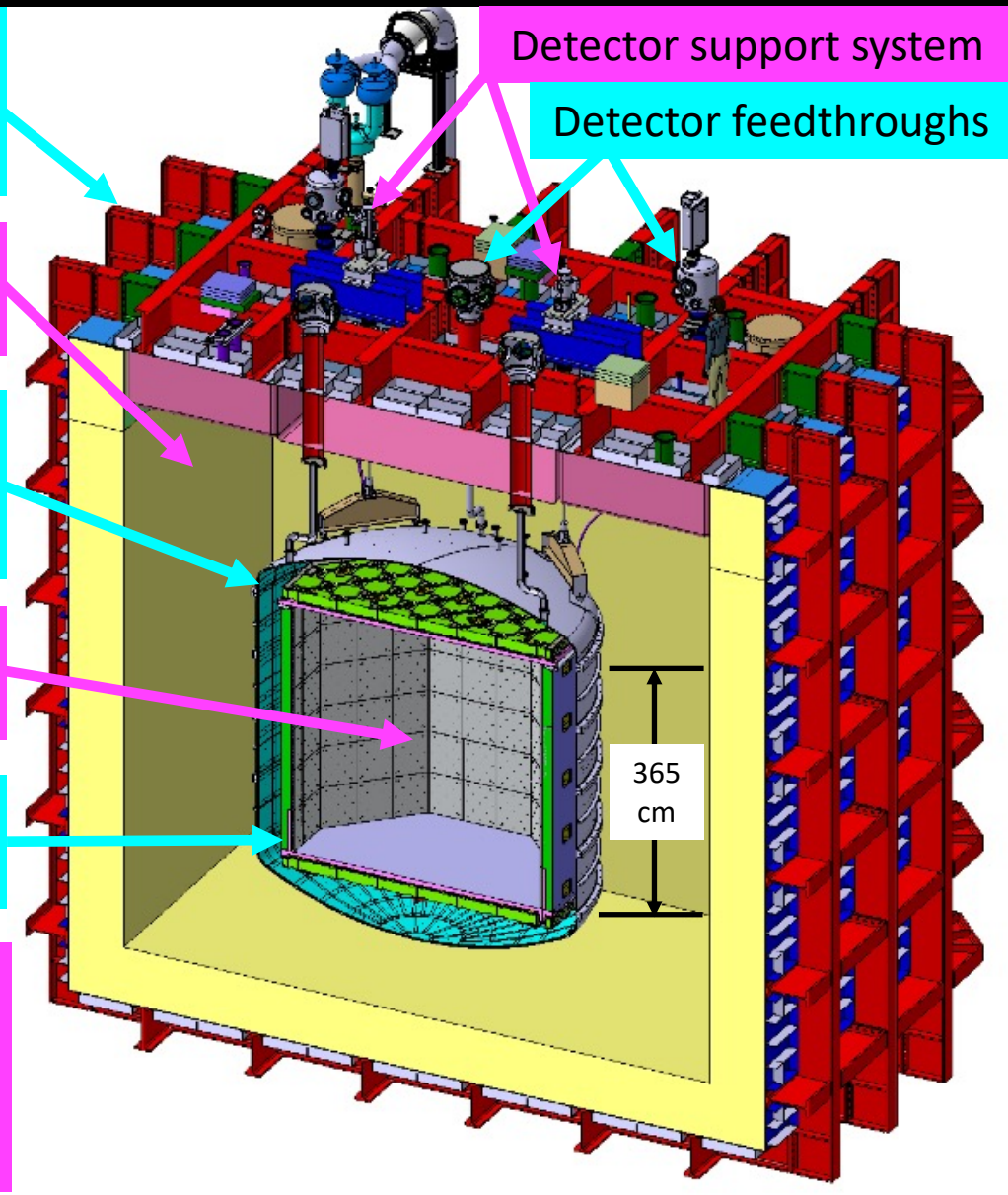
Atmospheric argon (AAr) volume (≈700 t)

Vacuum vessel containing UAr and TPC/veto

Underground argon (UAr) volume (≈100 t)

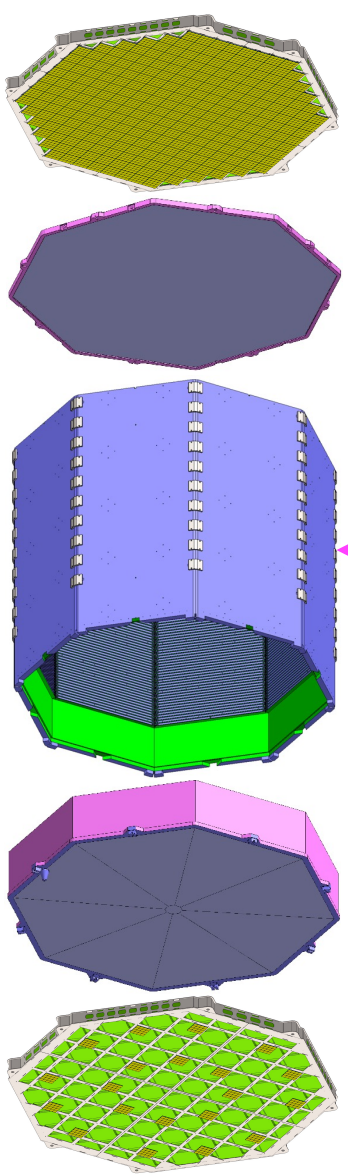
"Inner detectors", TPC and neutron veto

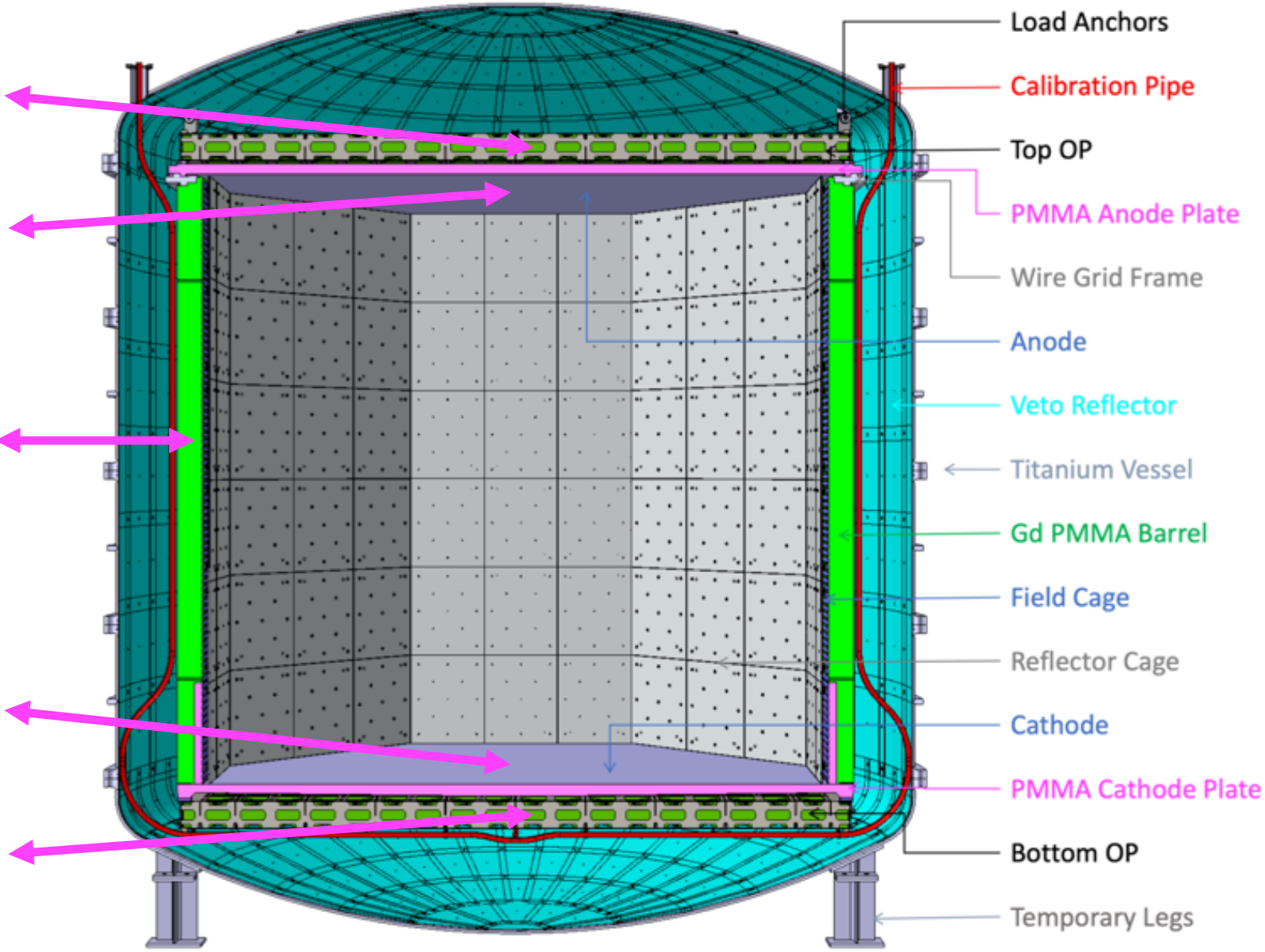
Outer veto will consist of SiPM arrays near the cryostat walls looking inward



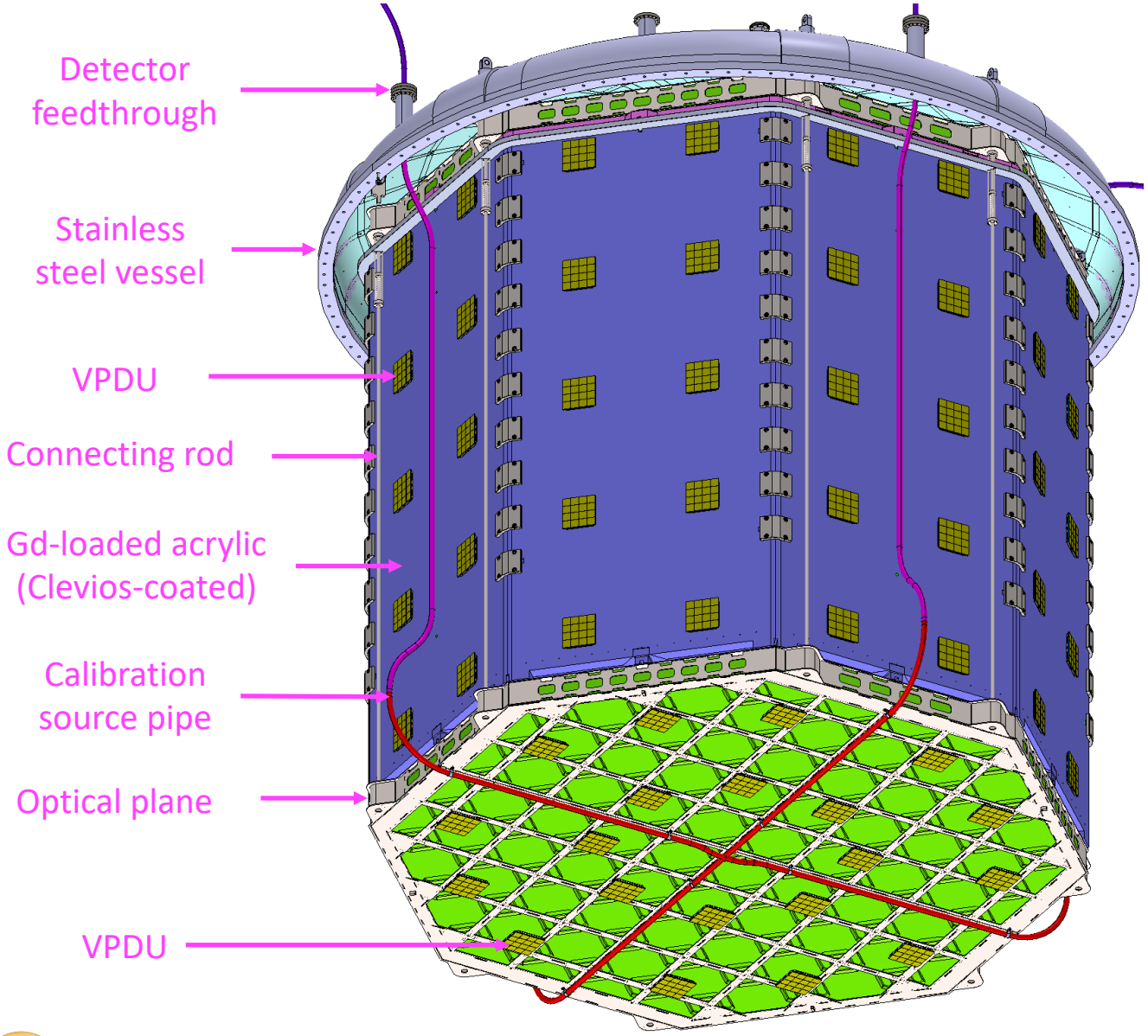
Inner Detectors (TPC and Neutron Veto)

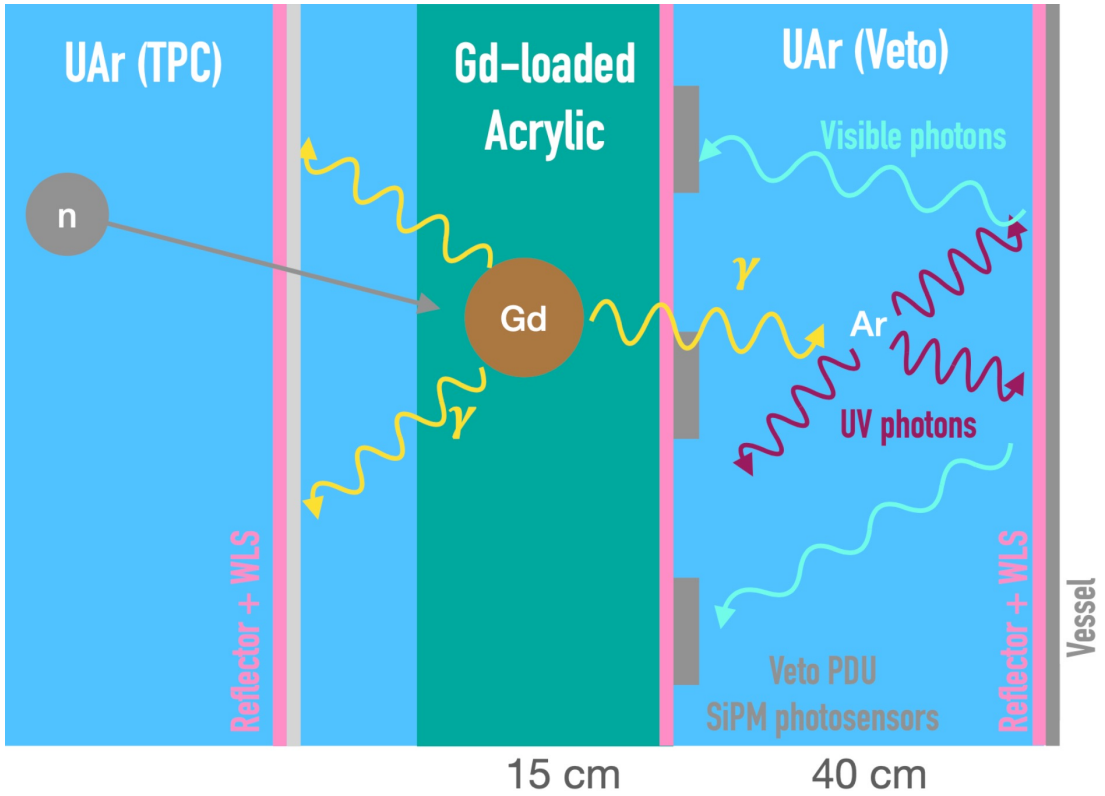
- DS-20k ⇔ **Dual-phase** argon **TPC** for DM search
- Fiducial volume ≈ 20 t **underground argon** (UAr), depleted in ^{39}Ar
- Active neutron veto integrated into the TPC structure via **gadolinium-loaded** (1% wt) PMMA (acrylic)
- "Reflector cage" covering inner TPC surface using **TPB-coated ESR** foils
- Sophisticated **silicon photomultiplier (SiPM)** based photo detection (total TPC area ≈ 21 m^2)





Neutron Veto

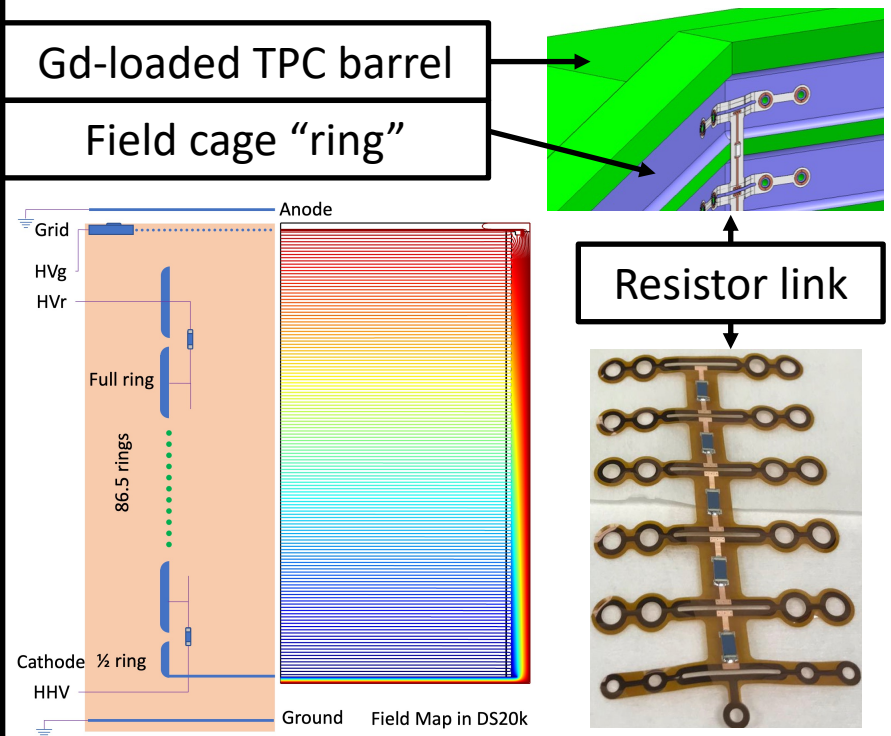


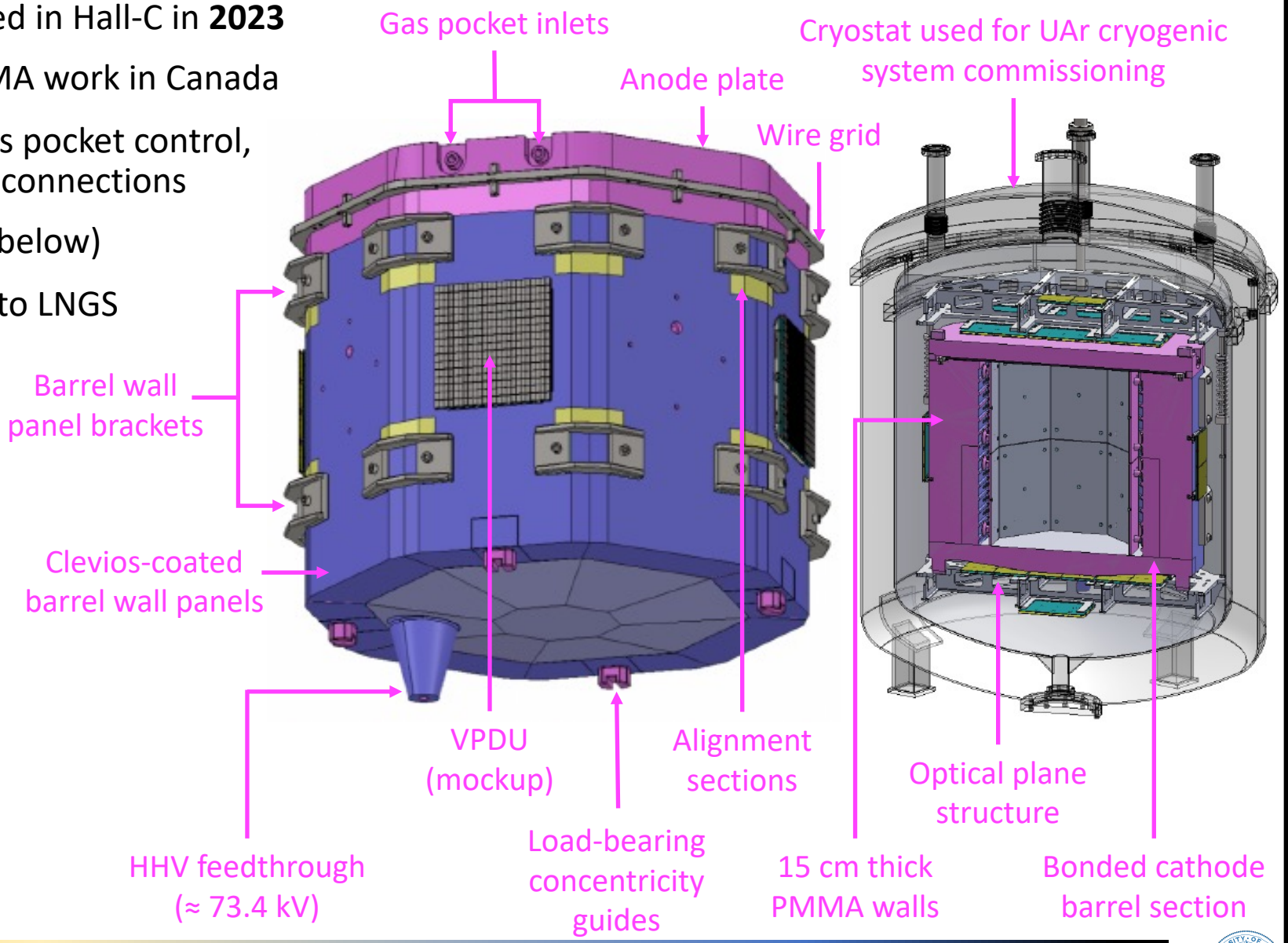


- Neutrons are moderated by the PMMA and capture on gadolinium
- γ-rays are emitted (totaling ≈ 8 MeV)
- UV photons from argon are wavelength shifted (PEN) in the veto region and detected by the veto photo detectors (VPDU)

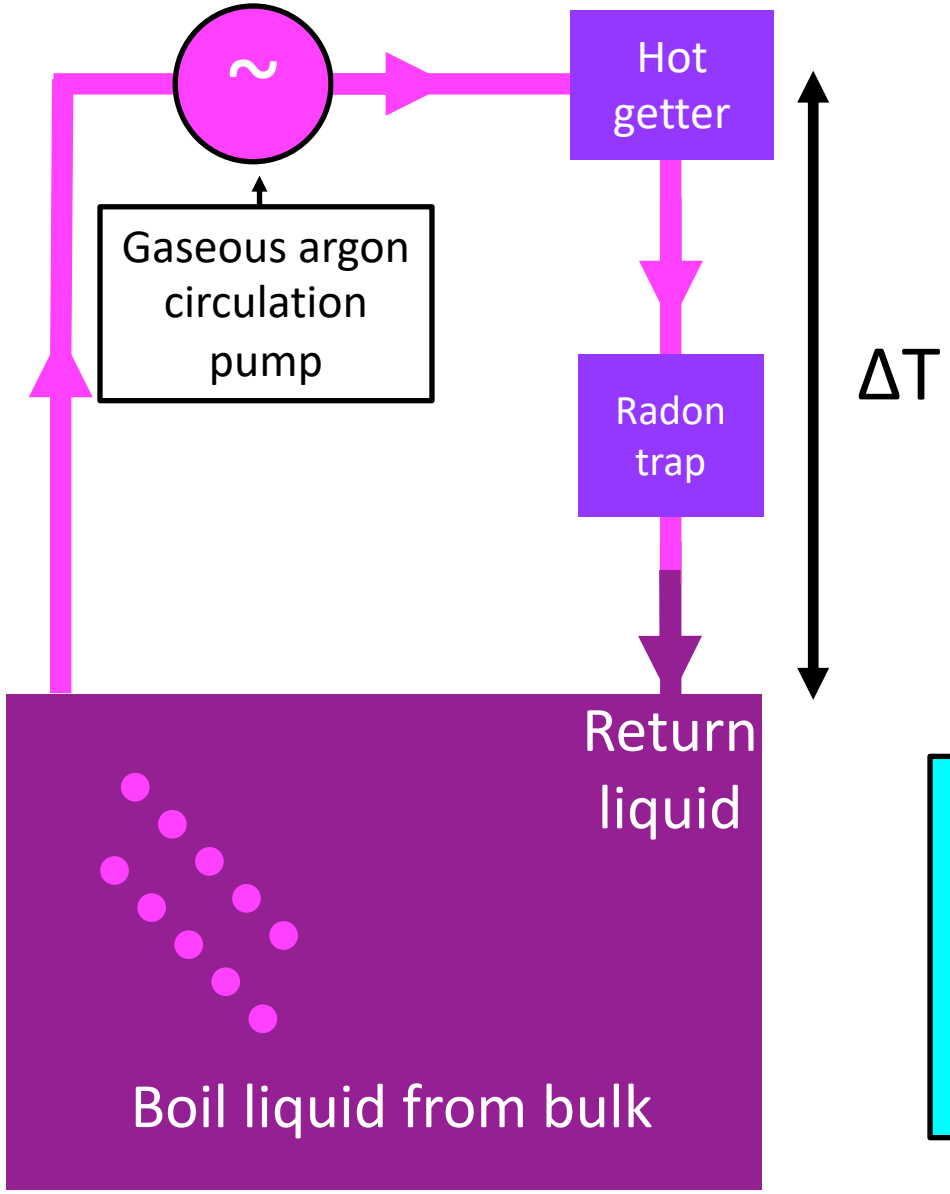
DarkSide-20k Mockup @ LNGS

- **Mechanical mockup** of DS-20k to be installed in Hall-C in **2023**
- Tests of collaboration process flow, i.e. PMMA work in Canada
- Tests of detector design, i.e. cold cycling, gas pocket control, high voltage (HHV), Clevios coating, service connections
- Tests of drift field connections (see graphic below)
- Will utilize **UAr cryogenic system** relocated to LNGS





DS-20k UAr Cryogenic System Concept



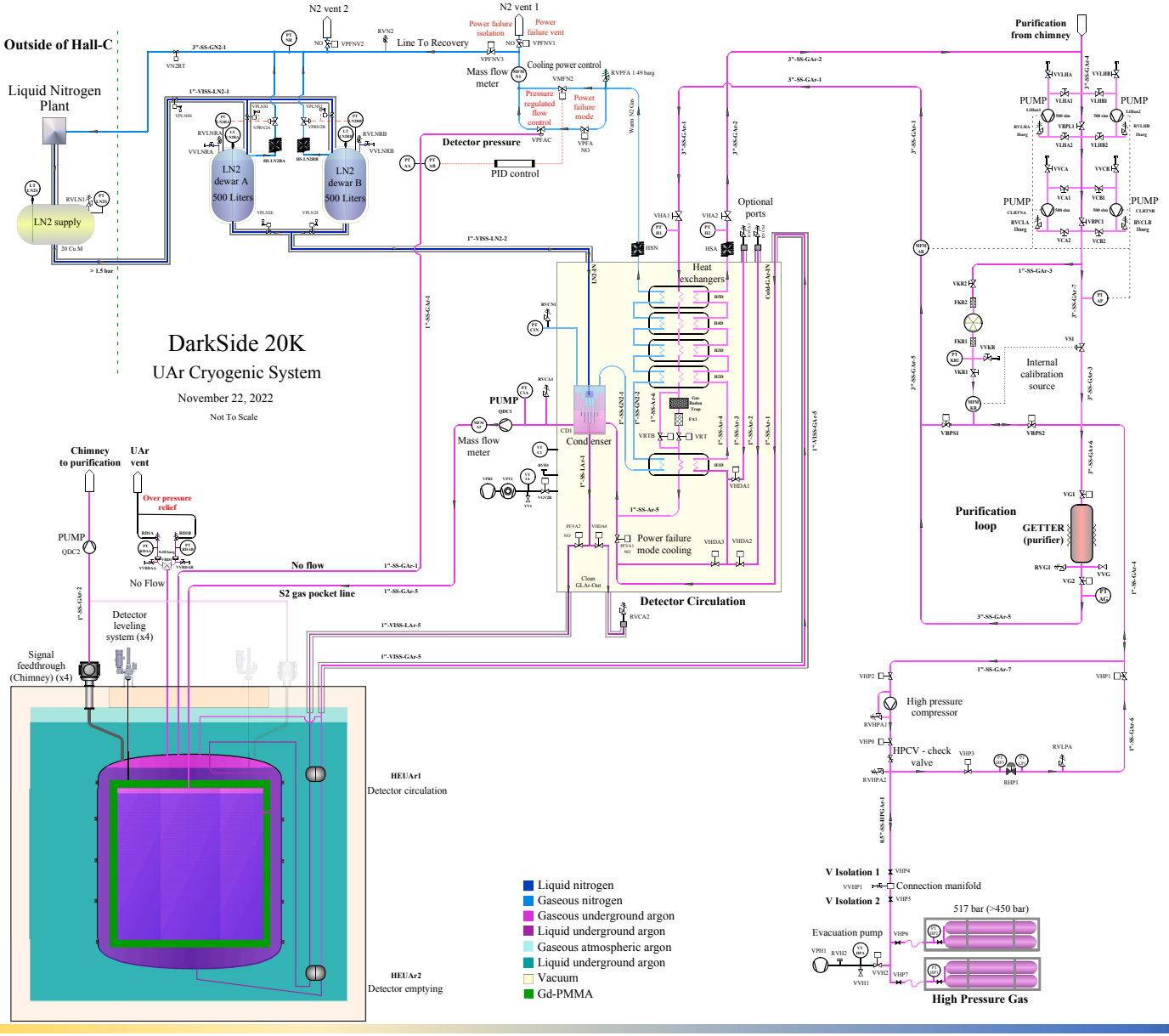
Some considerations:

1. Argon purification using a **hot getter** requires gaseous phase
2. **Radon removal** from argon is near 100% efficient in gaseous phase
3. **Gas pocket** is required for dual-phase TPC operation
4. Gaseous pumps are reliable and easy to maintain
5. A **highly efficient system** consumes less liquid nitrogen at a given cooling power ⇔ exploits cooling power from the bulk
6. During an emergency in an underground laboratory, electrical power may be interrupted and the **supply of liquid nitrogen** may become limited

Strategy:

Design a **safety-focused** system to circulate in **gaseous phase** while allowing heat exchange over the entire temperature gradient from room temperature down to liquid temperature, returning the clean liquid to the bulk.

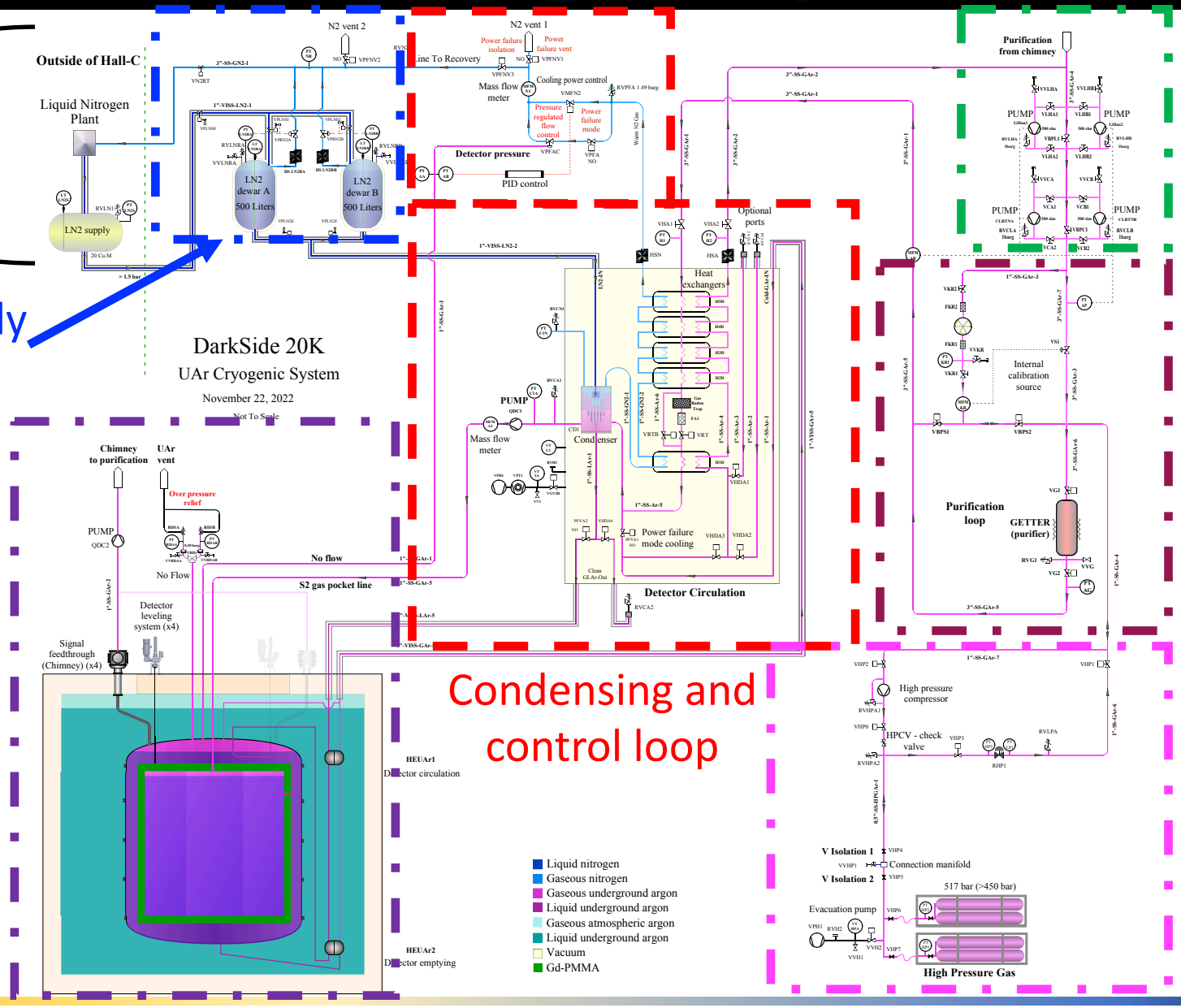
DS-20k UAr Cryogenic System P&ID



DS-20k UAr Cryogenic System P&ID

LNGS LN_2 supply

DS-20k LN_2 supply



Detector loop

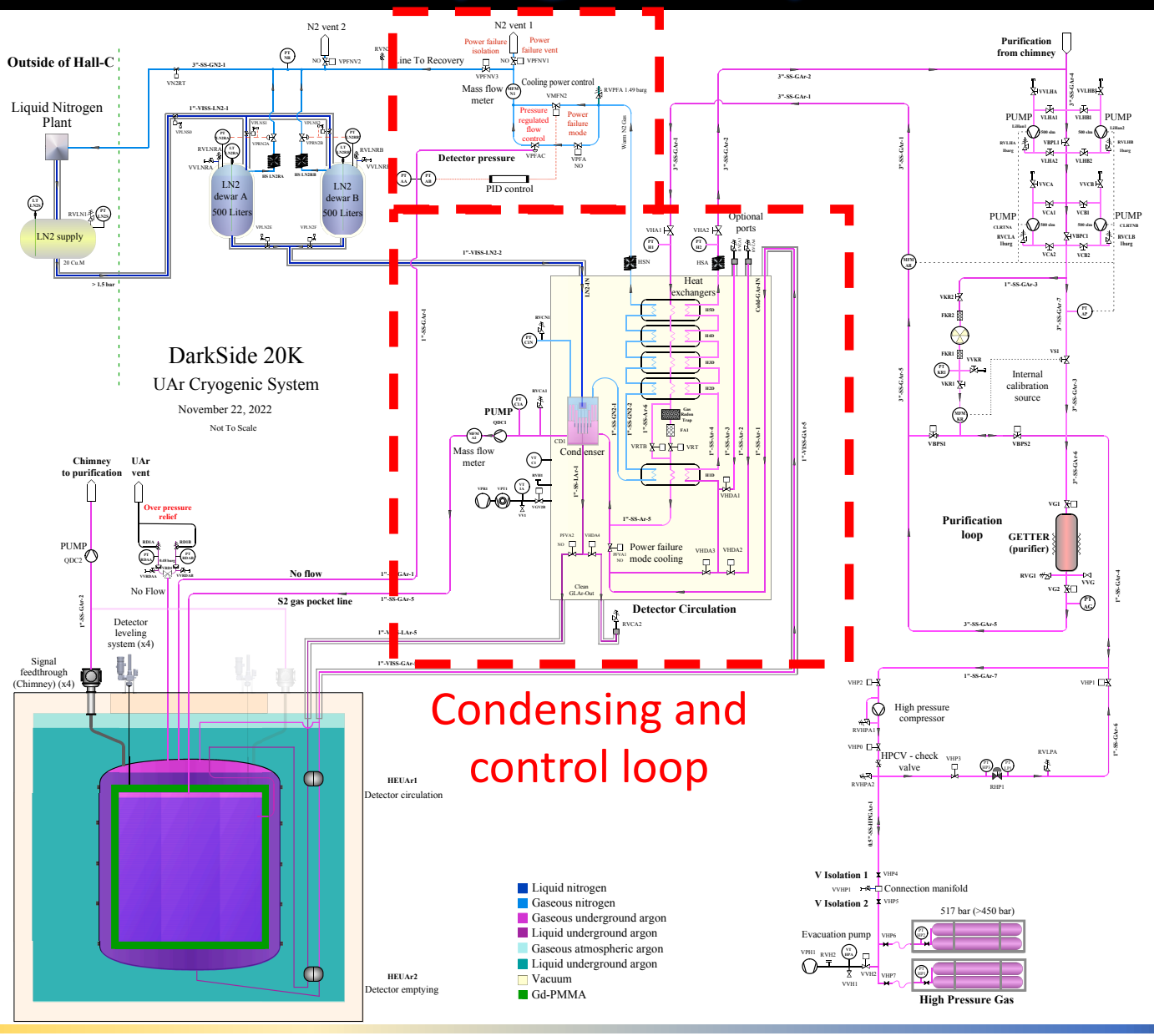
Condensing and control loop

Circulation pumps

Purification loop

UAr supply (high pressure)

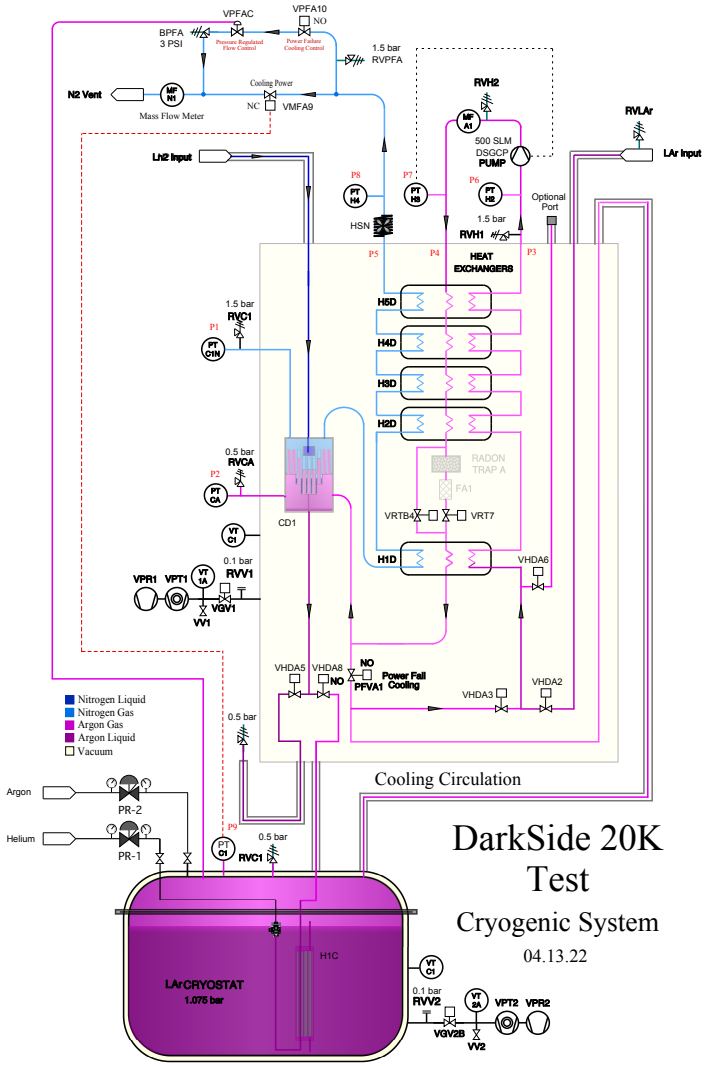
DS-20k UAr Cryogenic System P&ID



Condensing and control loop

DS-20k UAr Cryogenic Testbed at CERN

- Core of DS-20k UAr cryogenic system tested
- Getter and radon trap are not installed here
- Performance tests conducted in 2022
- Measured **cooling power recovery efficiency** of >99%
- Verified **detector circulation** in gaseous phase



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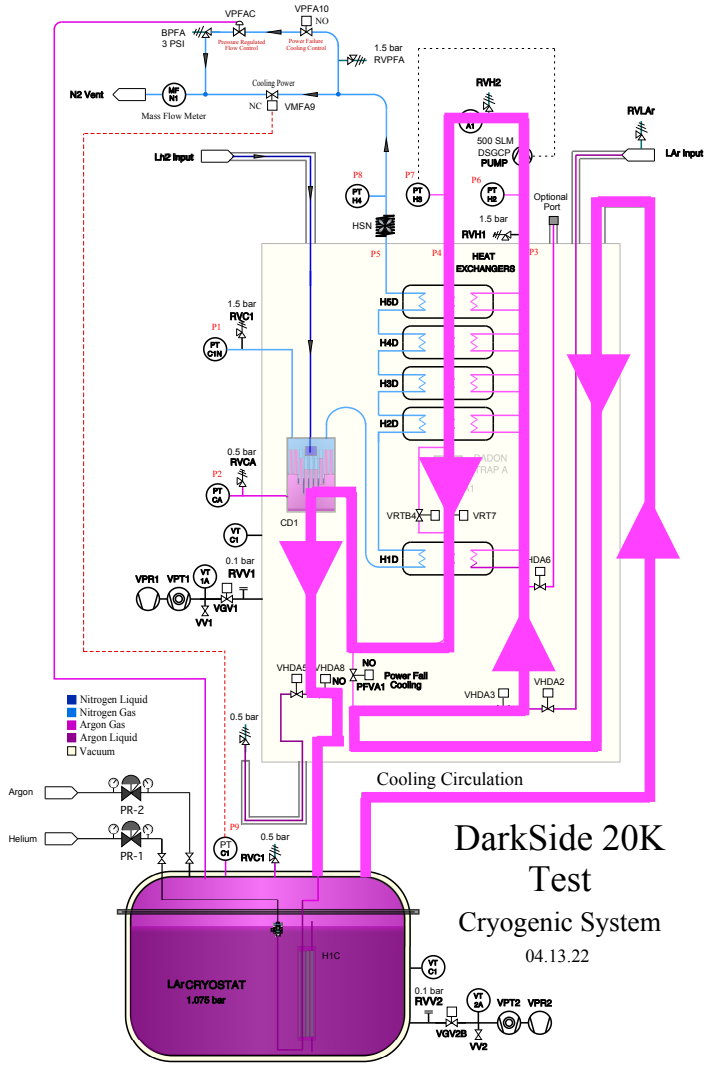
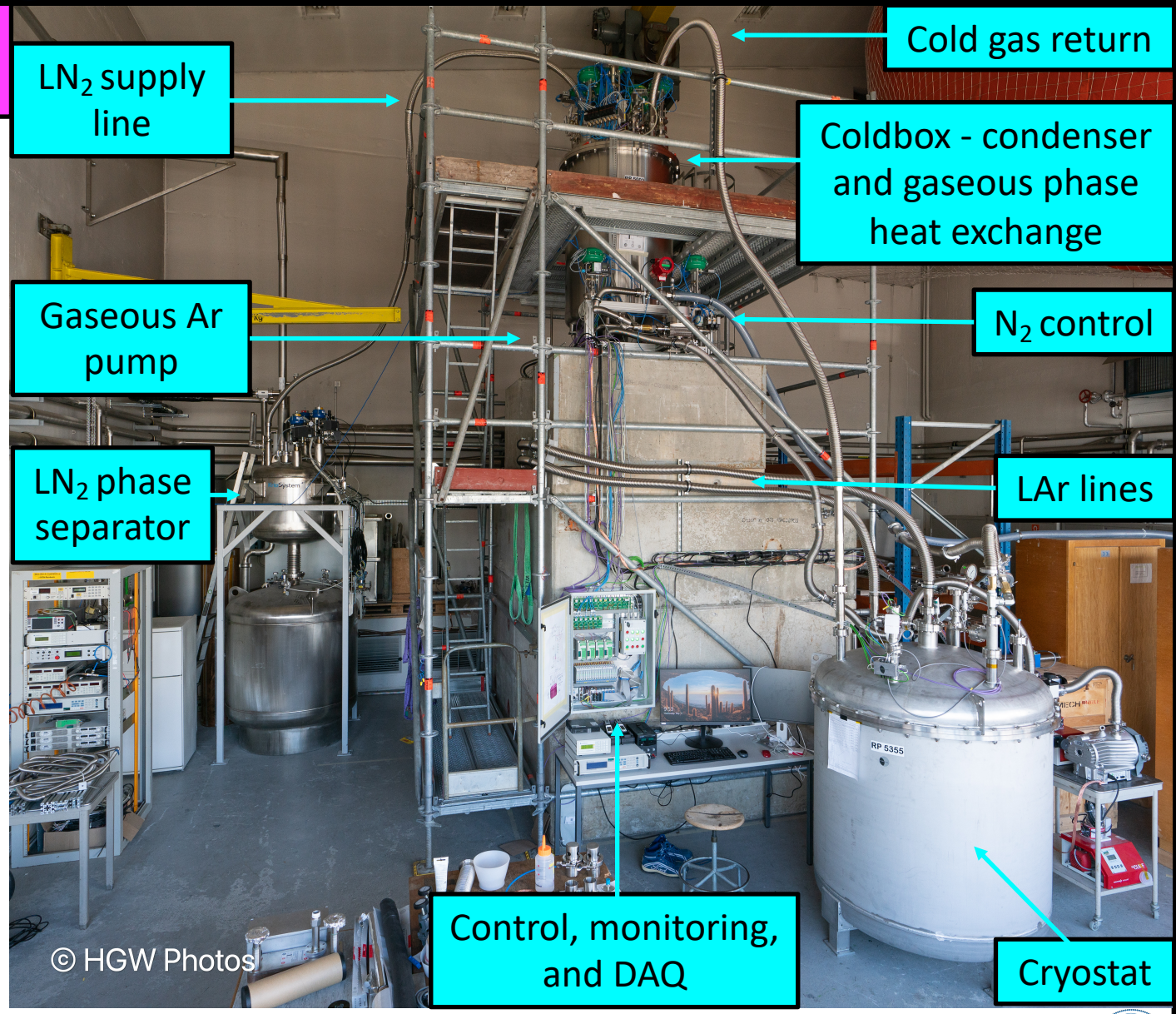
Closed argon loop with gaseous argon pump highlighted





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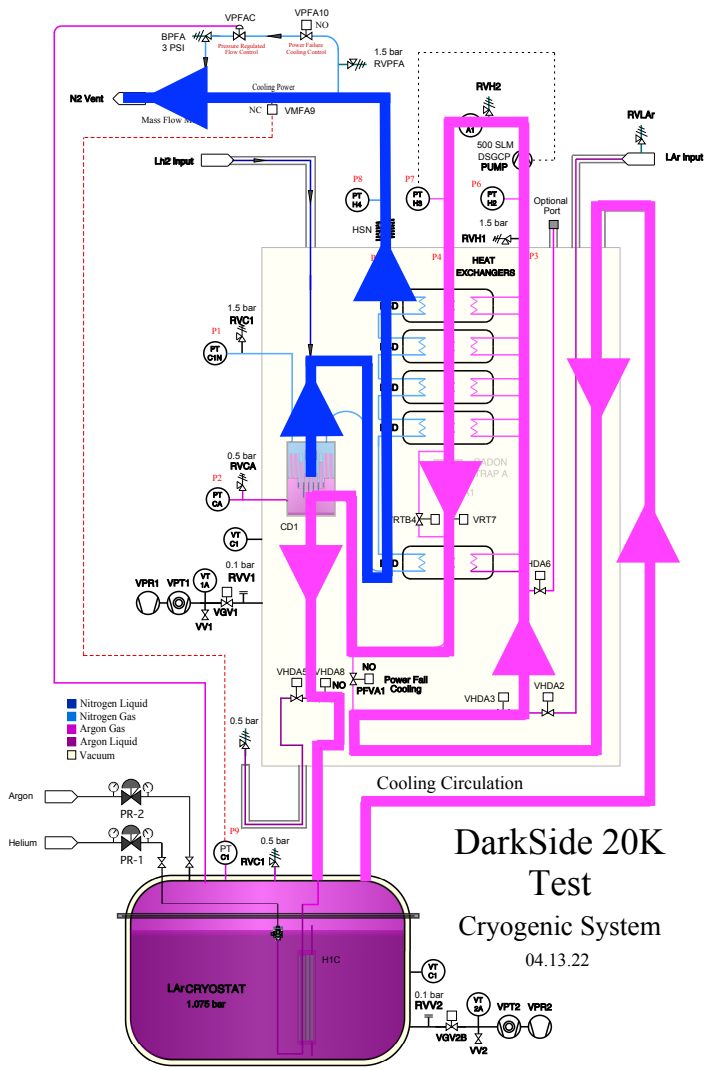
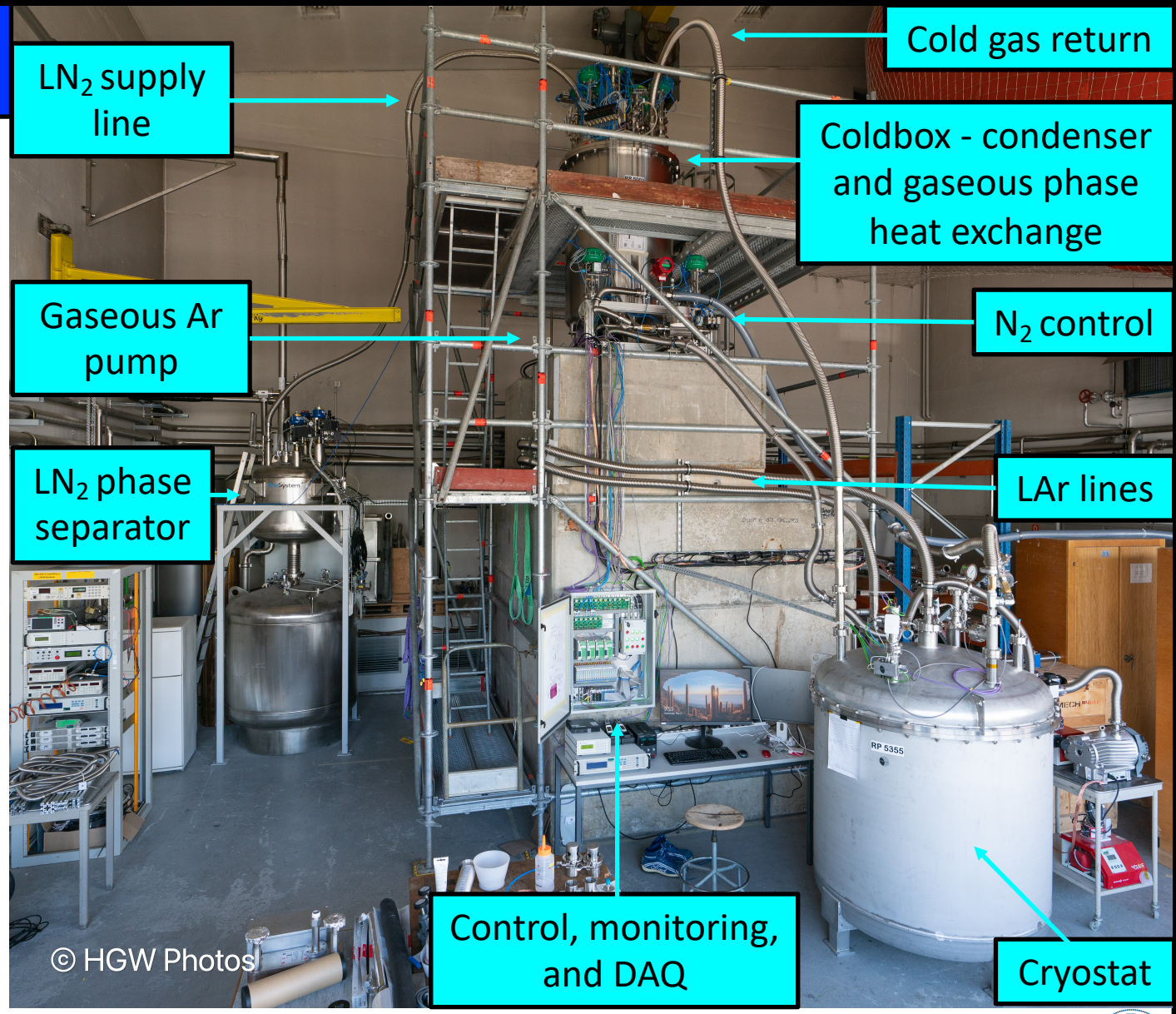
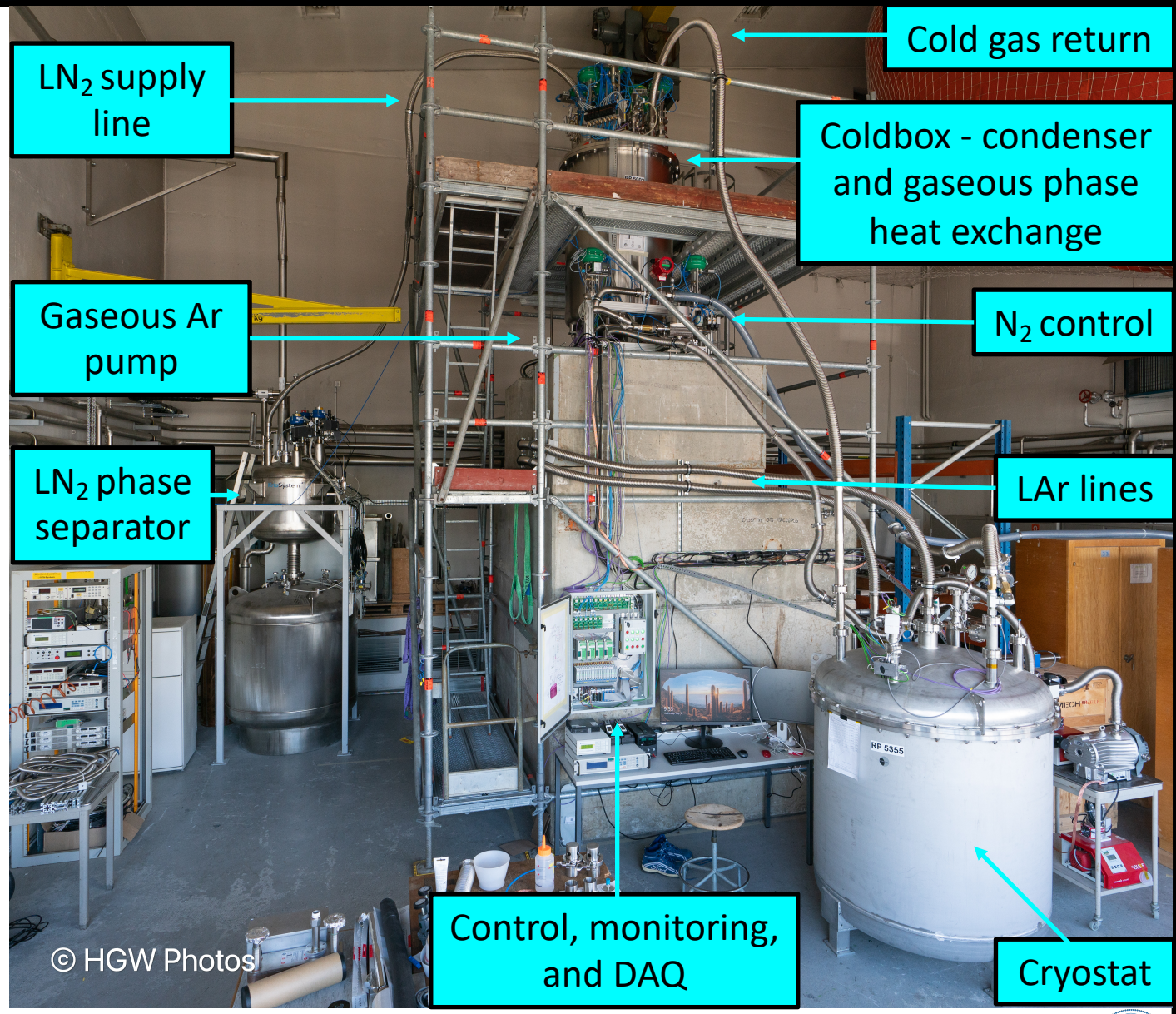
N_2 flow controls cooling power; coupled to vessel (Ar) pressure





DS-20k UAr Cryogenic System - Timeline

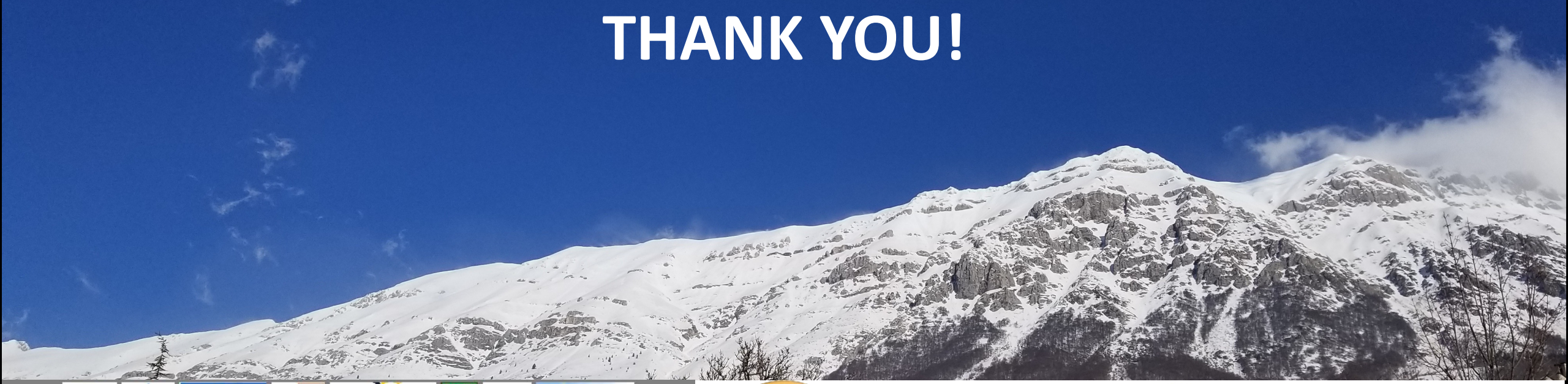
- Before 2018 – Prototyping and conceptual testing at Hanguo Wang's **UCLA** lab.
- Fall 2018 – Dedicated nitrogen supply system was built and space provided by CERN CryoLab.
- Summer 2019 – Coldbox manufacturing.
- 2019 - 2021 – System assembly.
- April 2021 – Data taking operational.
- July, 2021 **(TEST - 1.5 weeks**) – Preliminary system functionality and liquefaction.
- Early 2022 – System modifications/adjustments.
- April 2022 **(TEST - 3 weeks**) – Systematic testing. Full liquefaction; cooling power recovery efficiency and detector circulation tests.
- December 2022 – Arrival at LNGS!



Summary

- **DarkSide-20k: dual-phase time projection chamber** (TPC) for direct dark matter searches
- Low-radioactivity argon sourced from underground as target material
  - ≈ **20 t fiducial volume**; ≈ 50 t TPC active volume; ≈ 100 t total volume
- **Gd-loaded PMMA panels** will form the TPC mechanical structure (barrel)
  - PMMA (acrylic) = neutron moderator
  - Gadolinium (Gd) = neutron target material
- TPC design is in an advanced stage and assembly procedure is being finalized
- **Mechanical mockup** testing scheduled to take place at INFN-LNGS this year
- **Silicon Photomultiplier** based readout advanced to final production design
- Aria has shown first results of **isotopic separation** in argon
- **Underground argon** (UAr) cryogenic system has been successfully operated
- **Start of operations in Hall-C at LNGS in 2026!**

THANK YOU!




LNGS
GSSI
AUGUSTANA UNIVERSITY
Black Hills State University
BROOKHAVEN NATIONAL LABORATORY
Carleton
UNICAMP
CENTRO FERMI
Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
INFN LNS
ETH Zürich
UNIVERSITY OF HOUSTON
Instituto de Física
Universidade de São Paulo
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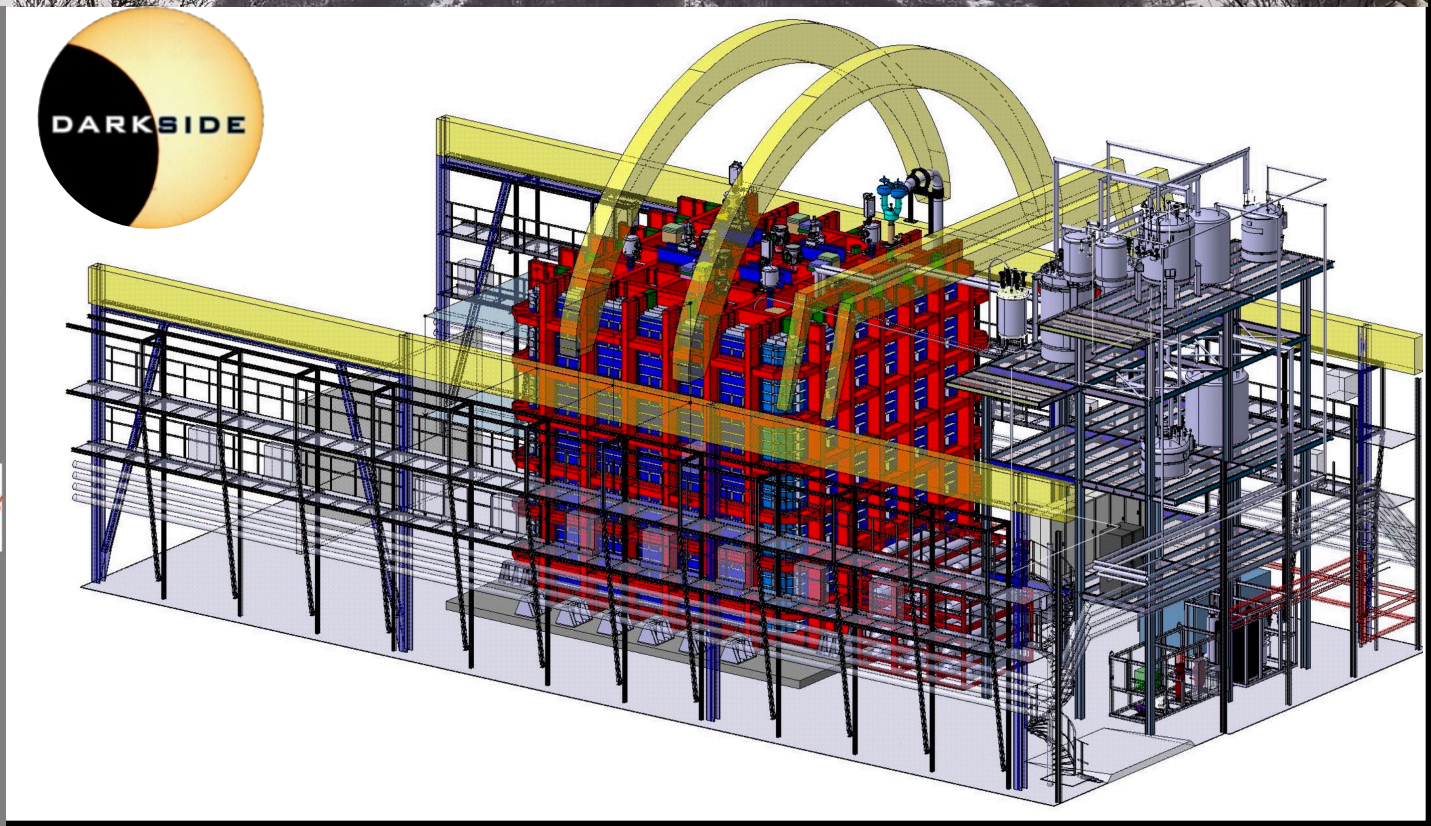
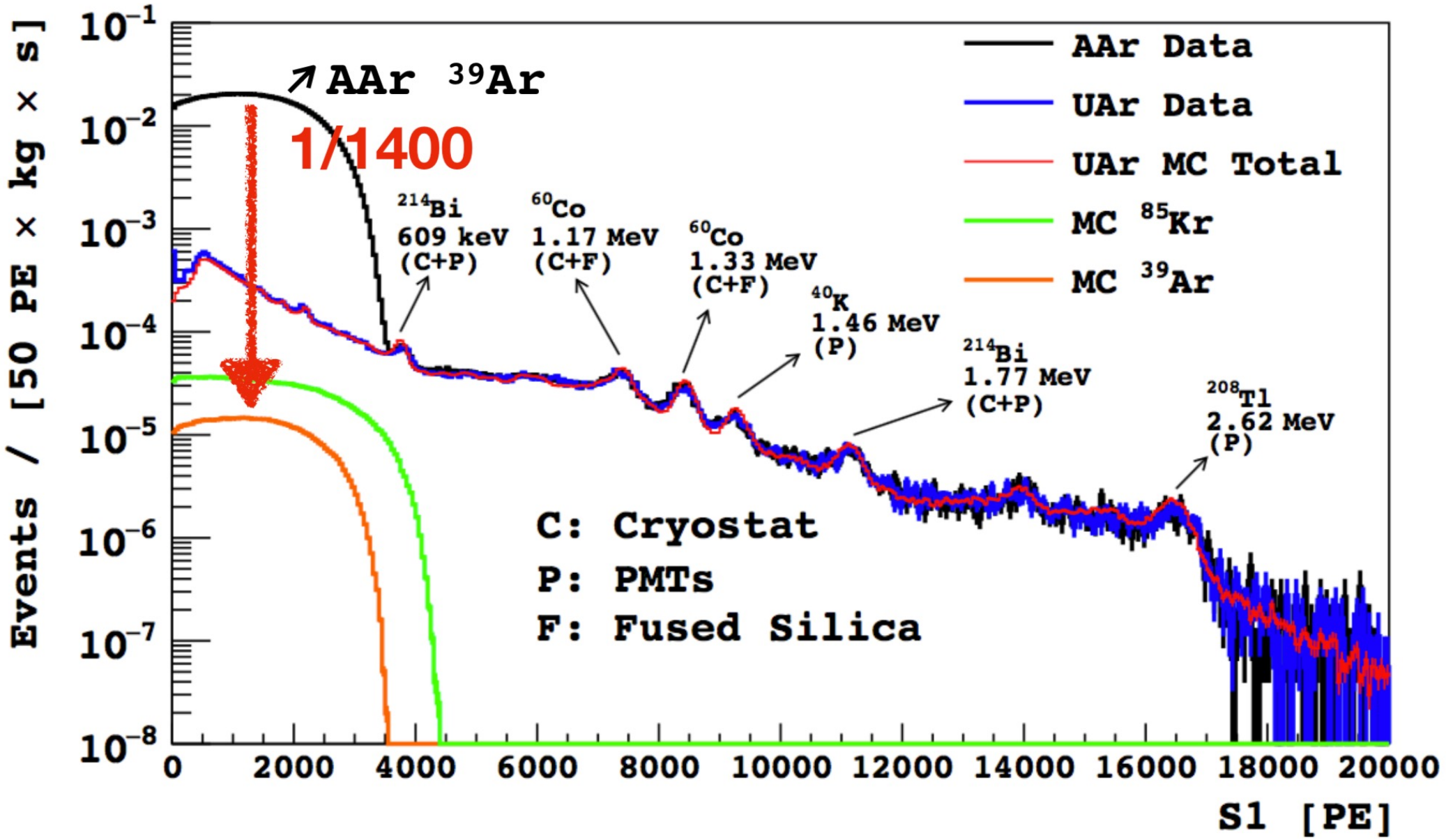

DARKSIDE

DarkSide-50 Underground Argon (UAr)

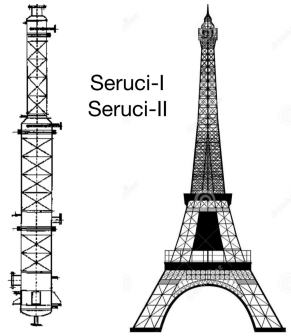


PRD, 93 (2016): 081101(R)

Industrial Scale Underground Argon (UAr)

Production – URANIA – Cortez, CO, US

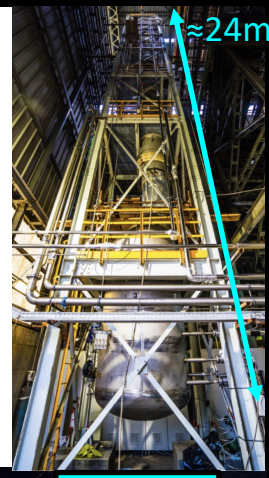
- Industrial scale extraction plant
- Extraction rate: 250-330 kg/day
- Production capability ≈ 120 t over two years for DS-20k
- UAr purity: 99.99%



Purification – Aria – Sardinia, IT

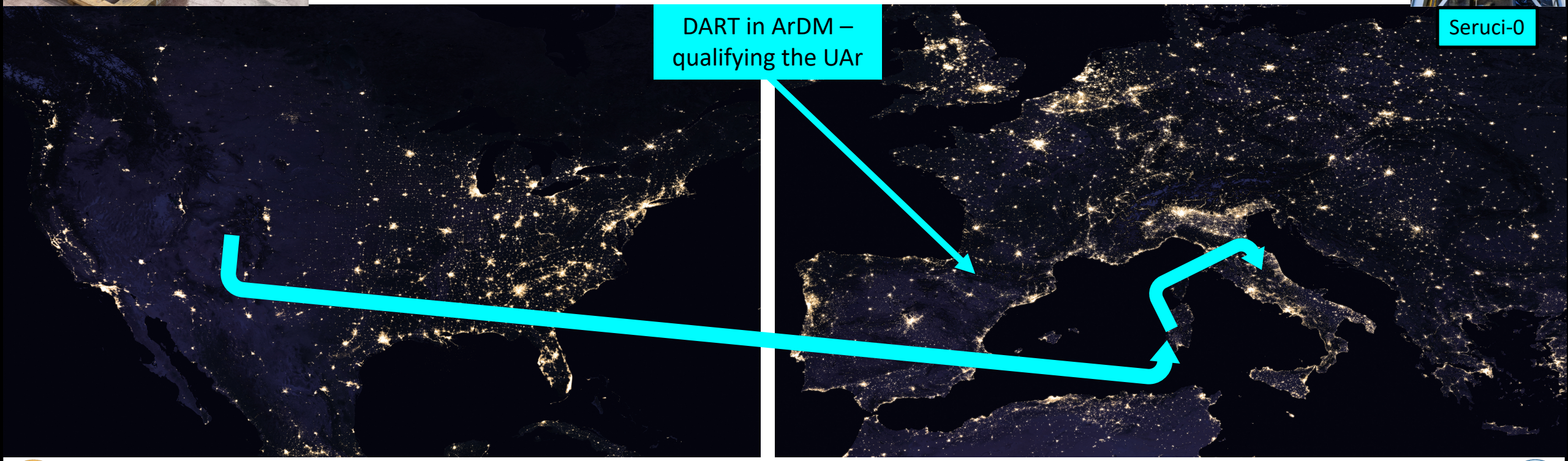
Eur. Phys. J. C (2021) 81:359

- Seruci-0 (demonstrator) tested
- 350 m cryogenic distillation column
- O(1 tonne)/day capability
- Resulting UAr purity: 99.999%

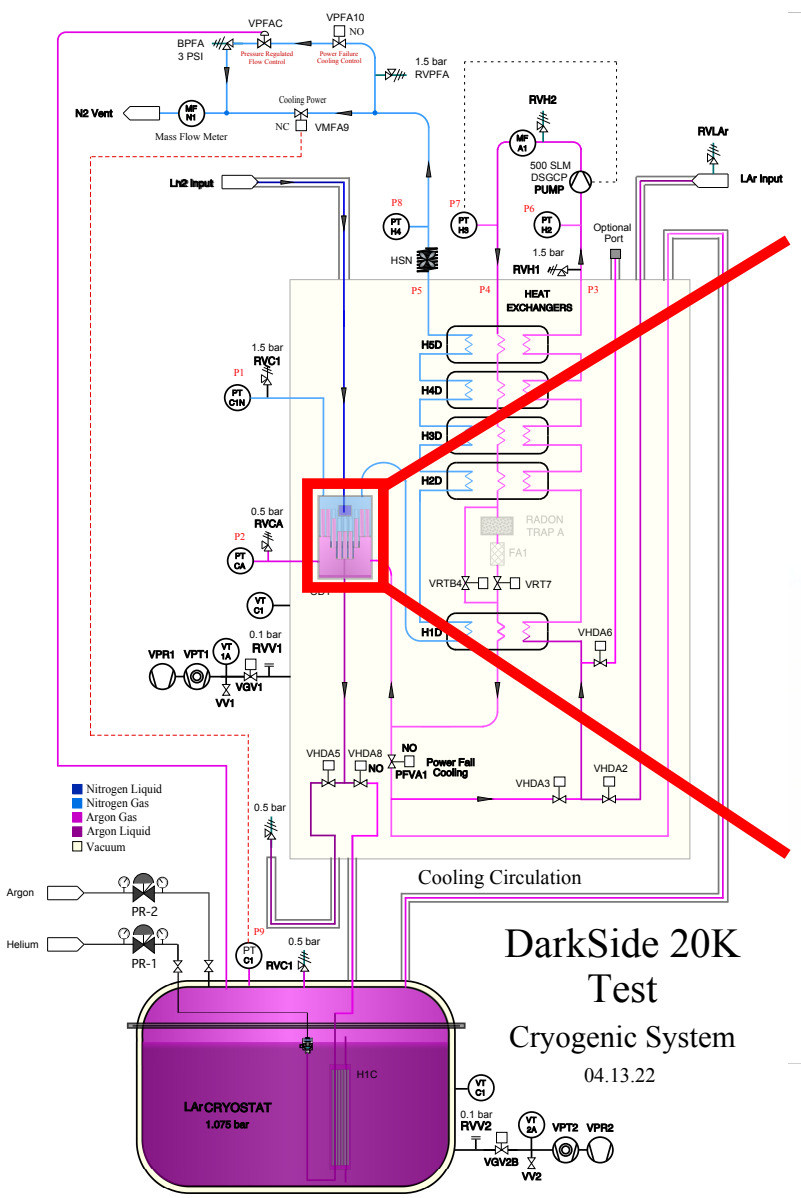


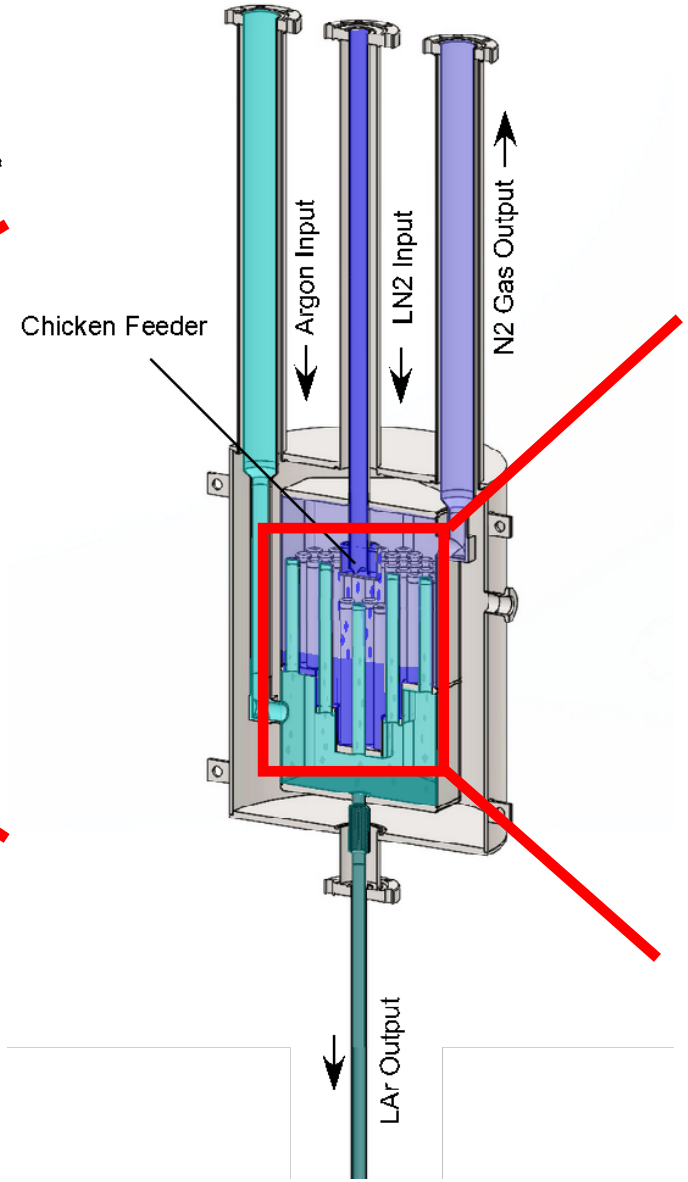
Seruci-0

DART in ArDM – qualifying the UAr



UAr Condenser – Core of the System



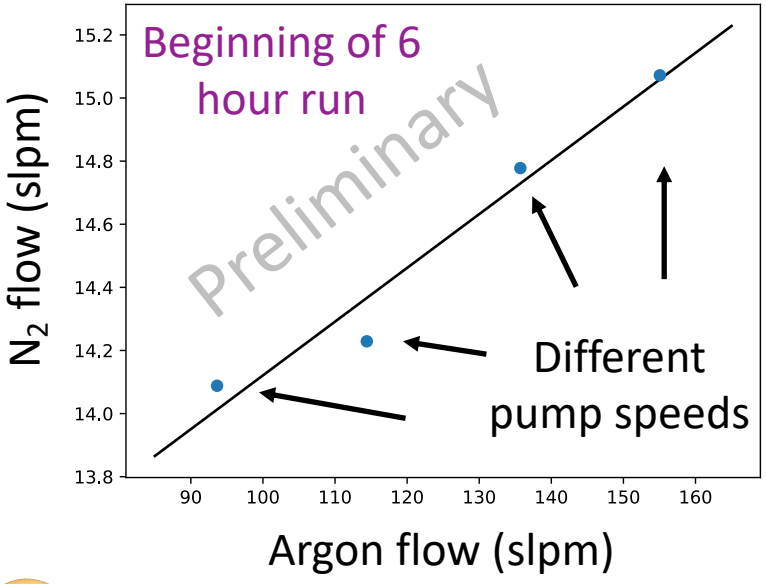


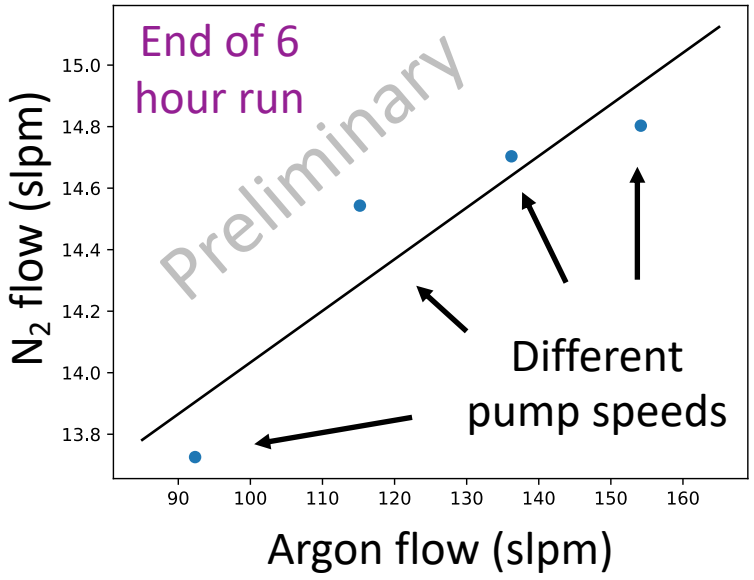
UCLA prototype – 2016-17

- No active temperature sensors or controls
- Measured 9W/inch for ½” tubing
- Gaseous N_2 flow controls the cooling power

Cooling Power Recovery Efficiency

- Obtain **nitrogen and argon flows** at different circulation pump speeds
- Plot **nitrogen vs. argon flow** for the different circulation pump speeds
- Obtain **average consumption** from slope of **nitrogen vs. argon flow**

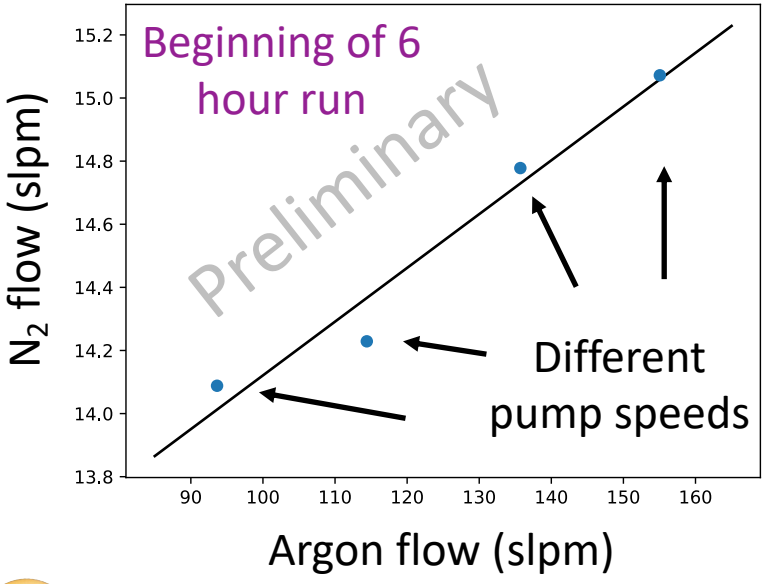


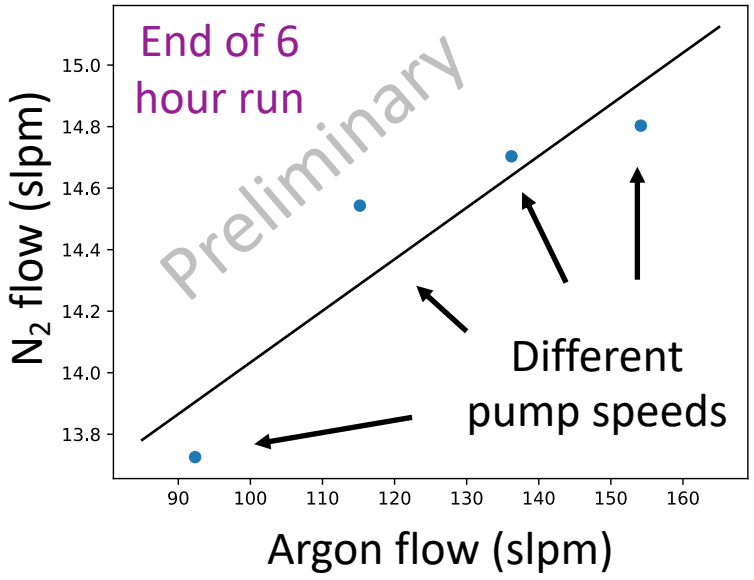


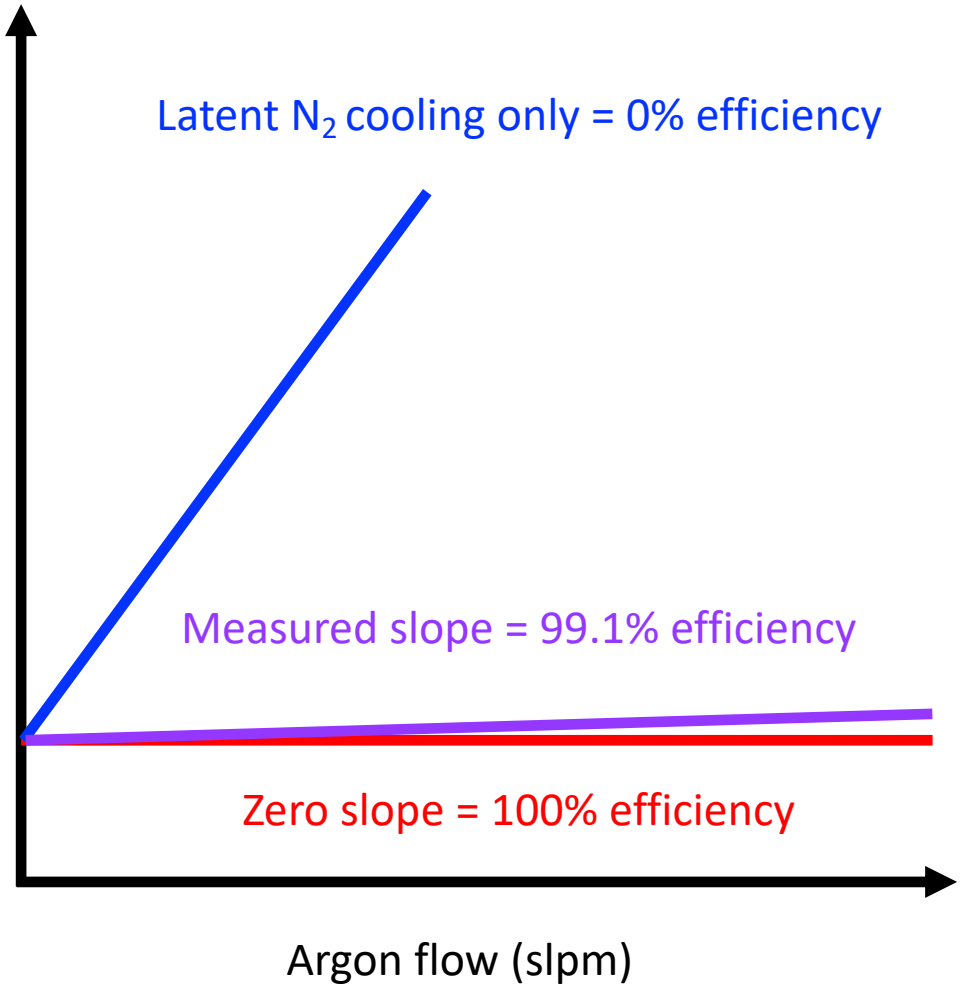
Average consumption = 0.0169 slpm N_2 / slpm Ar

Cooling Power Recovery Efficiency

- Obtain **nitrogen and argon flows** at different circulation pump speeds
- Plot **nitrogen vs. argon flow** for the different circulation pump speeds
- Obtain **average consumption** from slope of **nitrogen vs. argon flow**
- **0% efficiency** ⇔ Liquefying argon from 300 K w/ only N_2 latent heat
  - $m(L+c\Delta T)_{Ar} = (mL)_{N2}$
- **100% efficiency** ⇔ Zero N_2 consumption (zero slope)
- Determine our measured consumption as an efficiency (%)
- **Measure > 99.1% cooling power recovery efficiency**





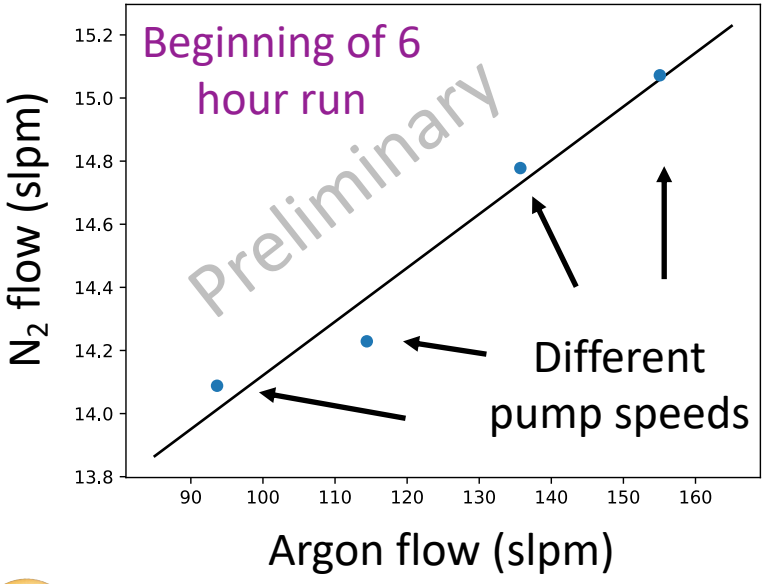


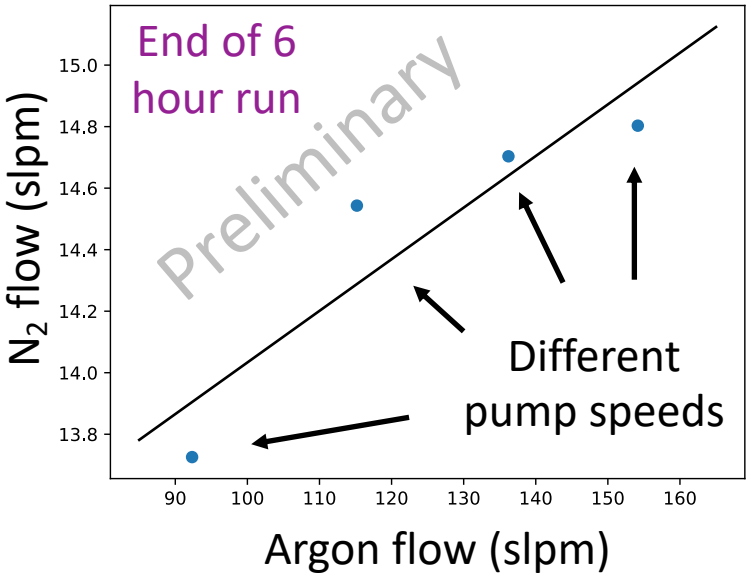
Average consumption = 0.0169 slpm N_2 / slpm Ar

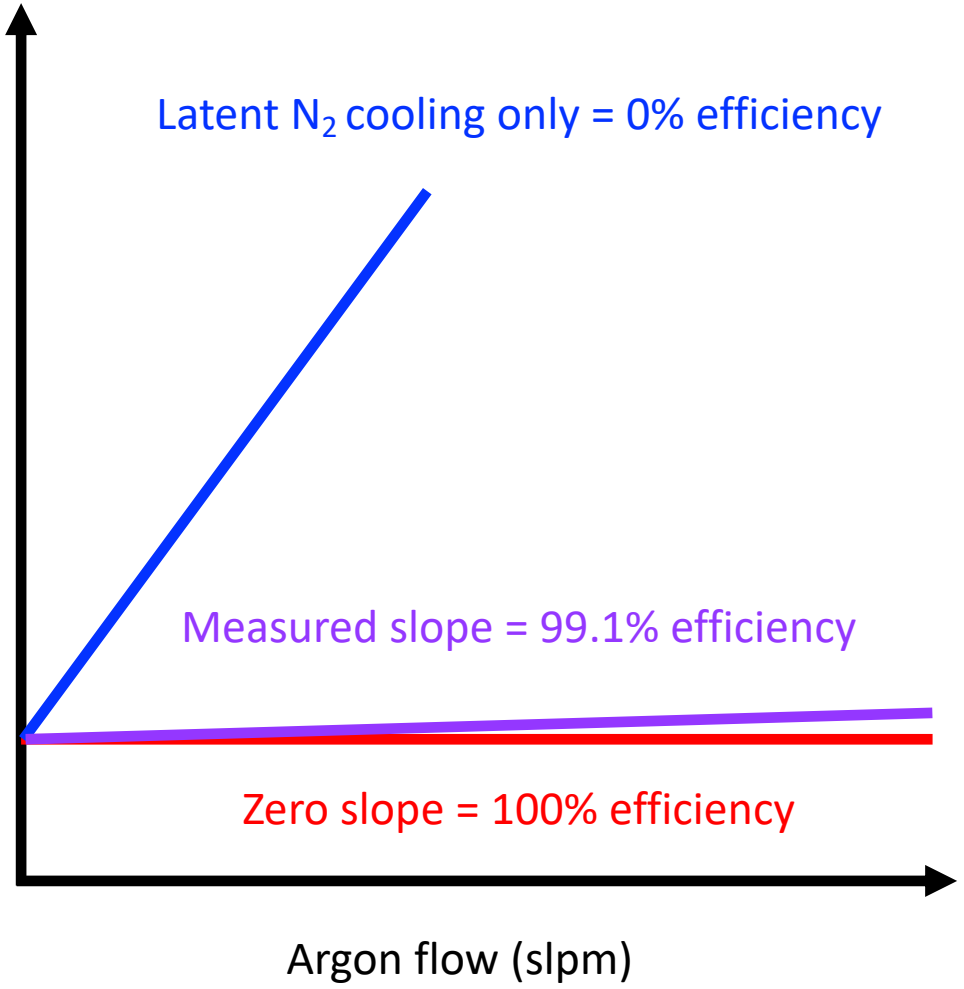
Cooling Power Recovery Efficiency

What does this mean?

- Cooling and condensing argon requires **only 0.9% of the cooling power** compared to using the latent heat from N_2 alone.
- Argon circulation (essentially) comes for free.



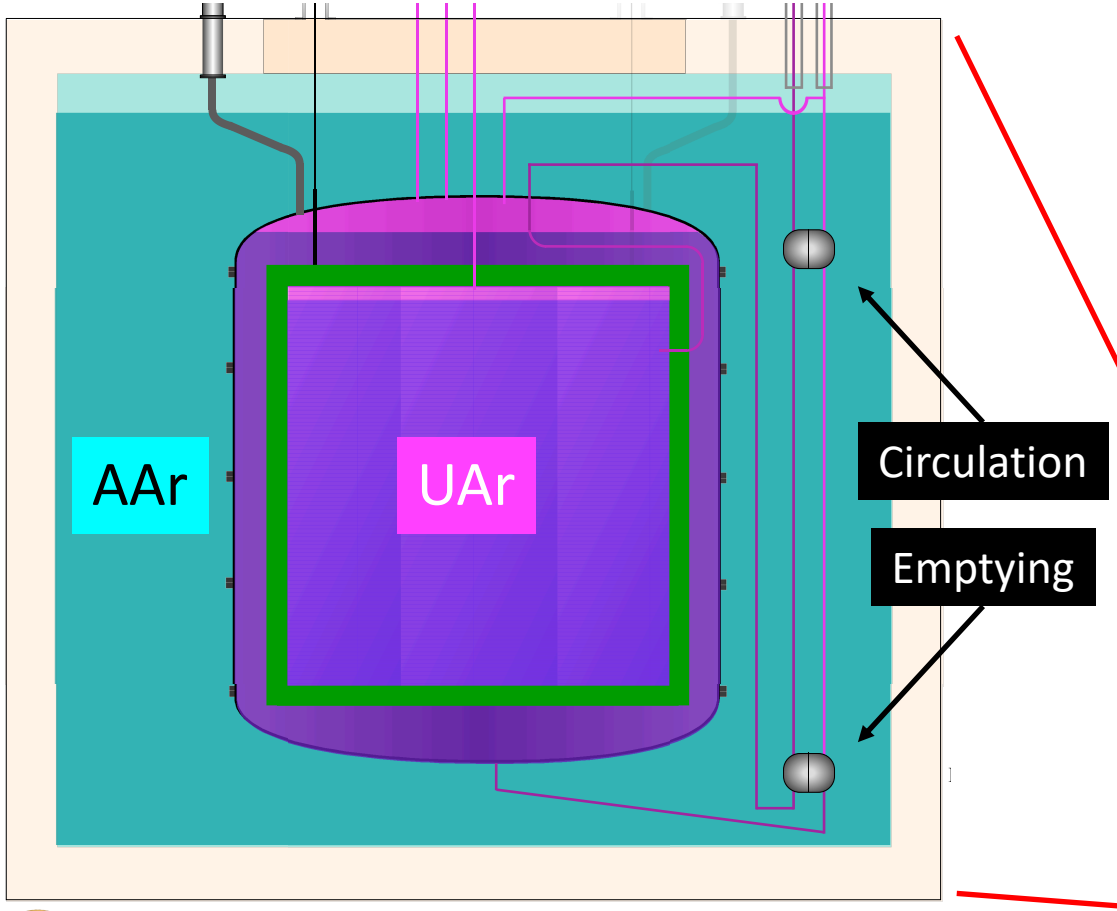


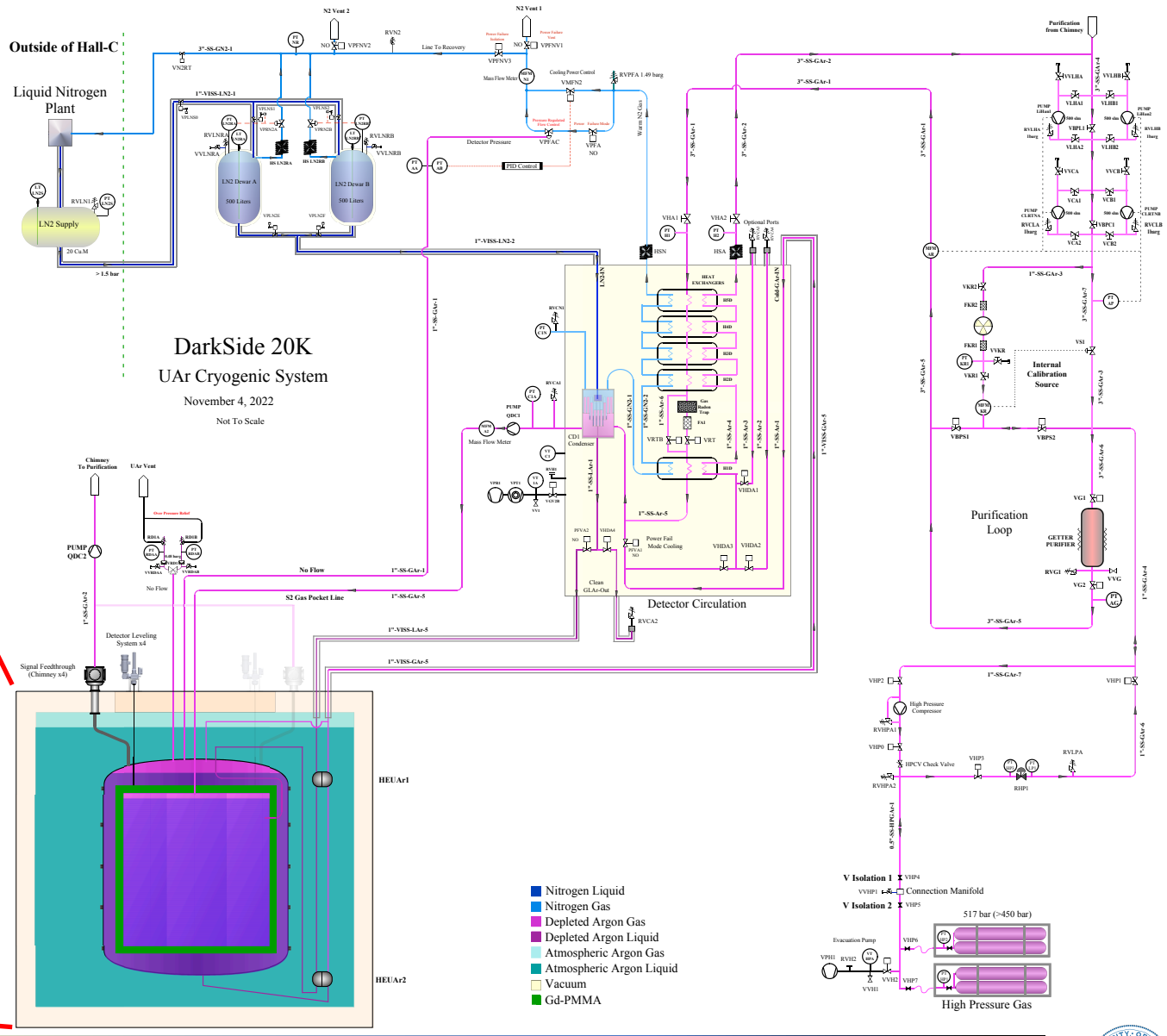


Average consumption = 0.0169 slpm N_2 / slpm Ar

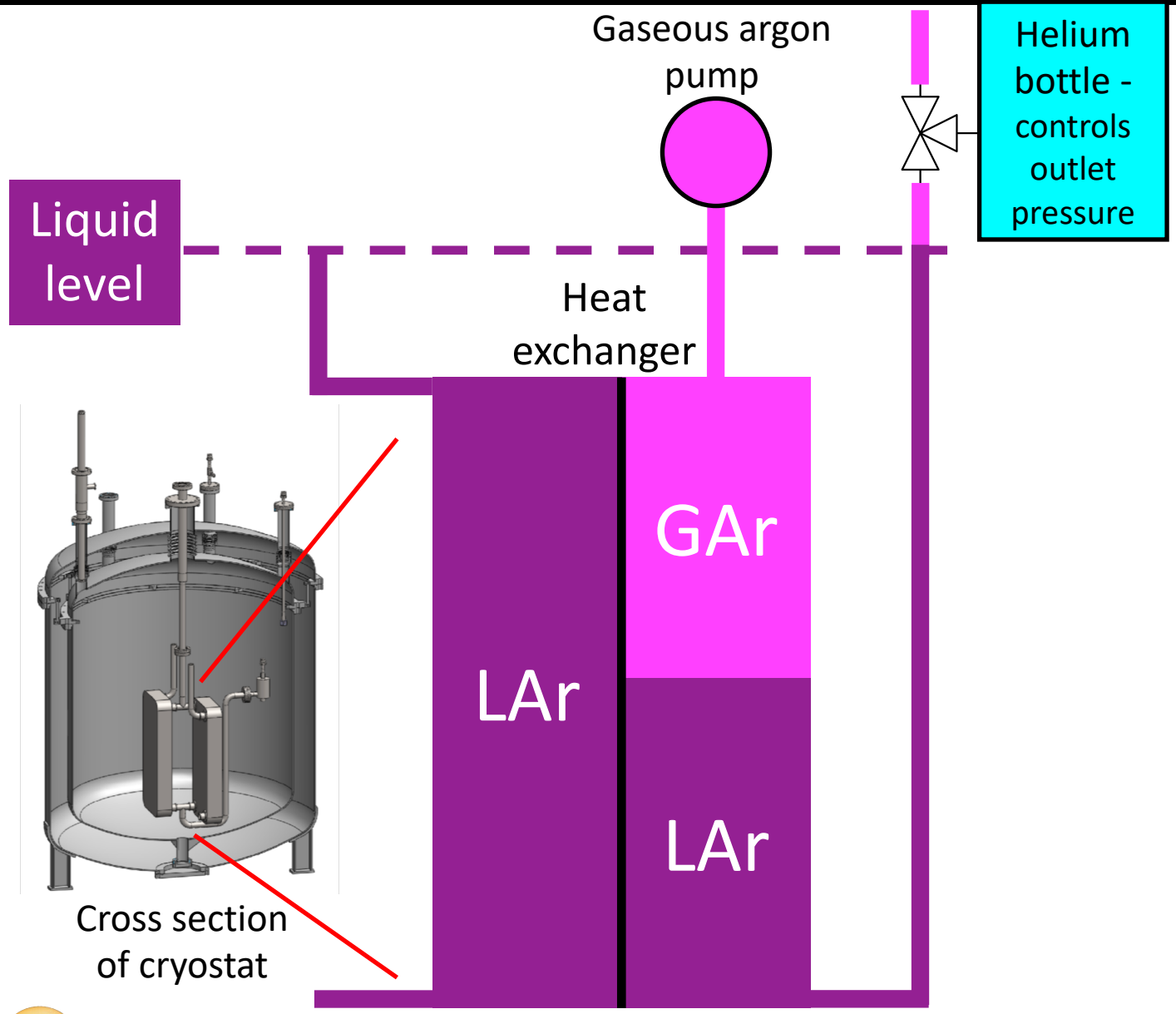
DS-20k Piping and Instrumentation Diagram

- Place heat exchangers for detector circulation and emptying in atmospheric argon (AAr) bulk
- Experimental tests determine exact shape and size



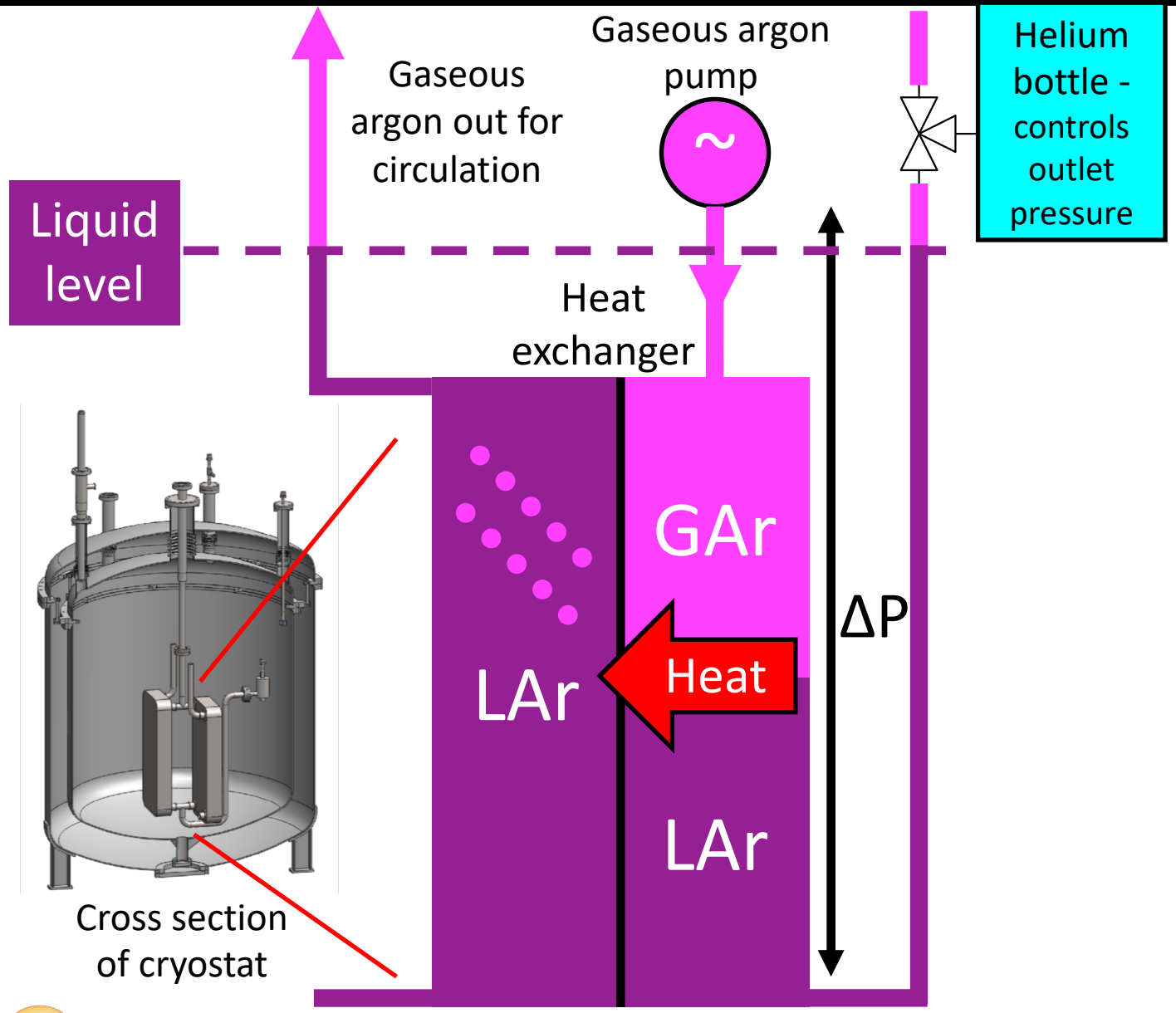


Argon Circulation Test



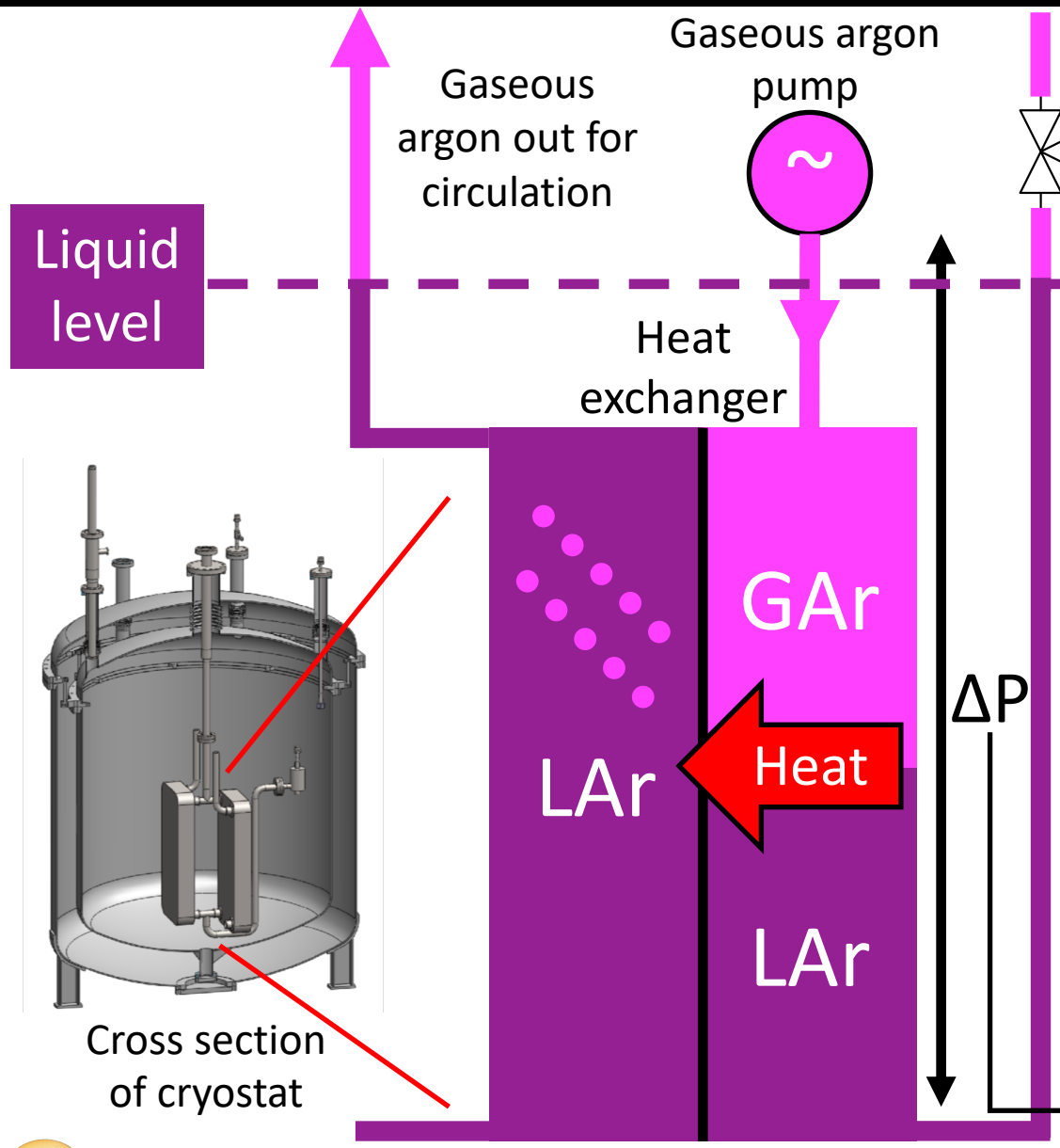
- One side of heat exchanger (inside cryostat) is filled with **liquid from the bulk**
- **Liquid/gas mixture** from circulation pump is routed through other side of heat exchanger

Argon Circulation Test



- One side of heat exchanger (inside cryostat) is filled with **liquid from the bulk**
- **Liquid/gas mixture** from circulation pump is routed through other side of heat exchanger
- **Pressure difference** turns liquid/gas mixture into liquid
- Heat is produced, **boiling liquid** from the bulk

Argon Circulation Test Results



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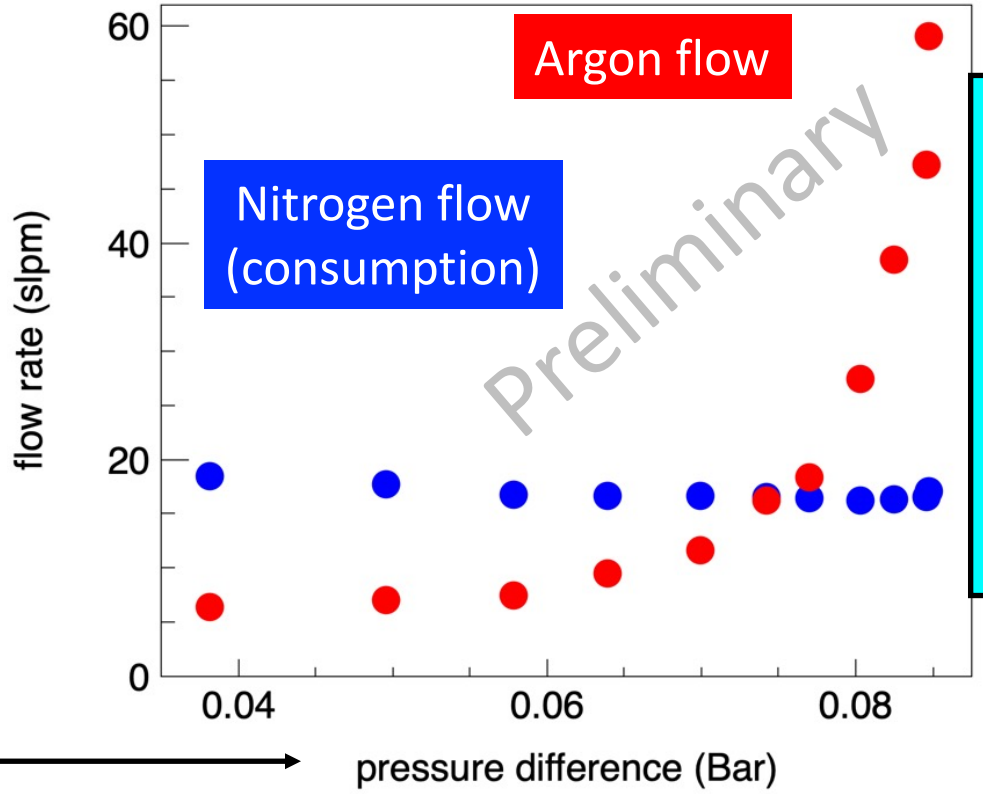

Punchline:
60 slpm of argon is being circulated and recondensed; Nitrogen consumption remains constant