Alec's HEPCAT Research Update:

Improvements for Next-Generation Noble Liquid Detectors

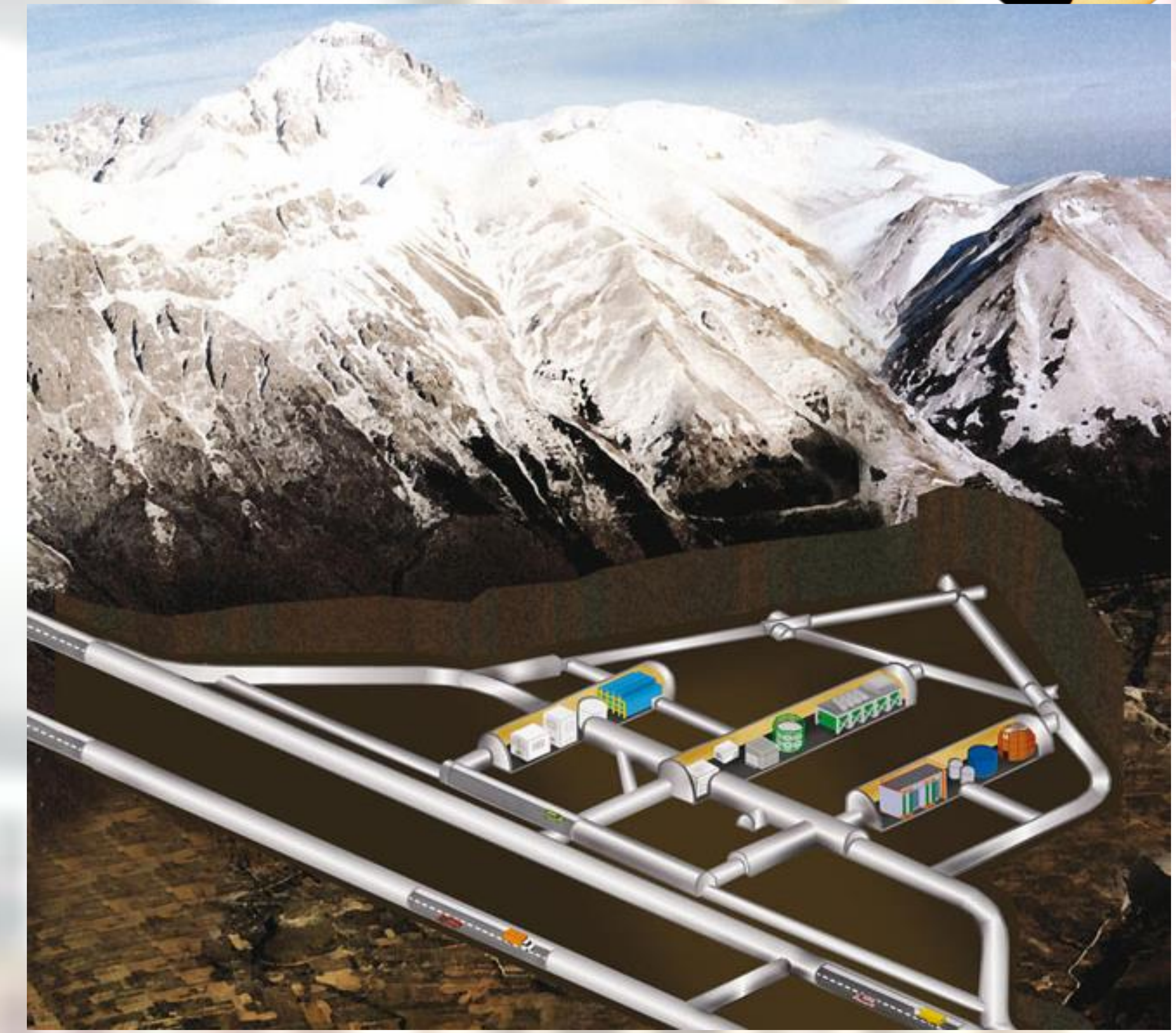
HEPCAT 2024 Annual Meeting

November 1, 2024, Alec Peck
University of California, Riverside; Advisor: Dr. Shawn Westerdale
& the DarkSide-20k Collaboration

DarkSide-20k: LAr Two-Phase TPC

Gran Sasso National Laboratory (LNGS)

- Funded by the National Institute for Nuclear Physics (INFN) in Assergi, Italy
- Houses **DM direct detection** & neutrino physics experiments; XENON-nT, DAMA/LIBRA, BOREXINO, and…



https://indico.cern.ch/event/199223/contributions/378074/attachments/295975/413582/arneodo_lngs_red.pdf

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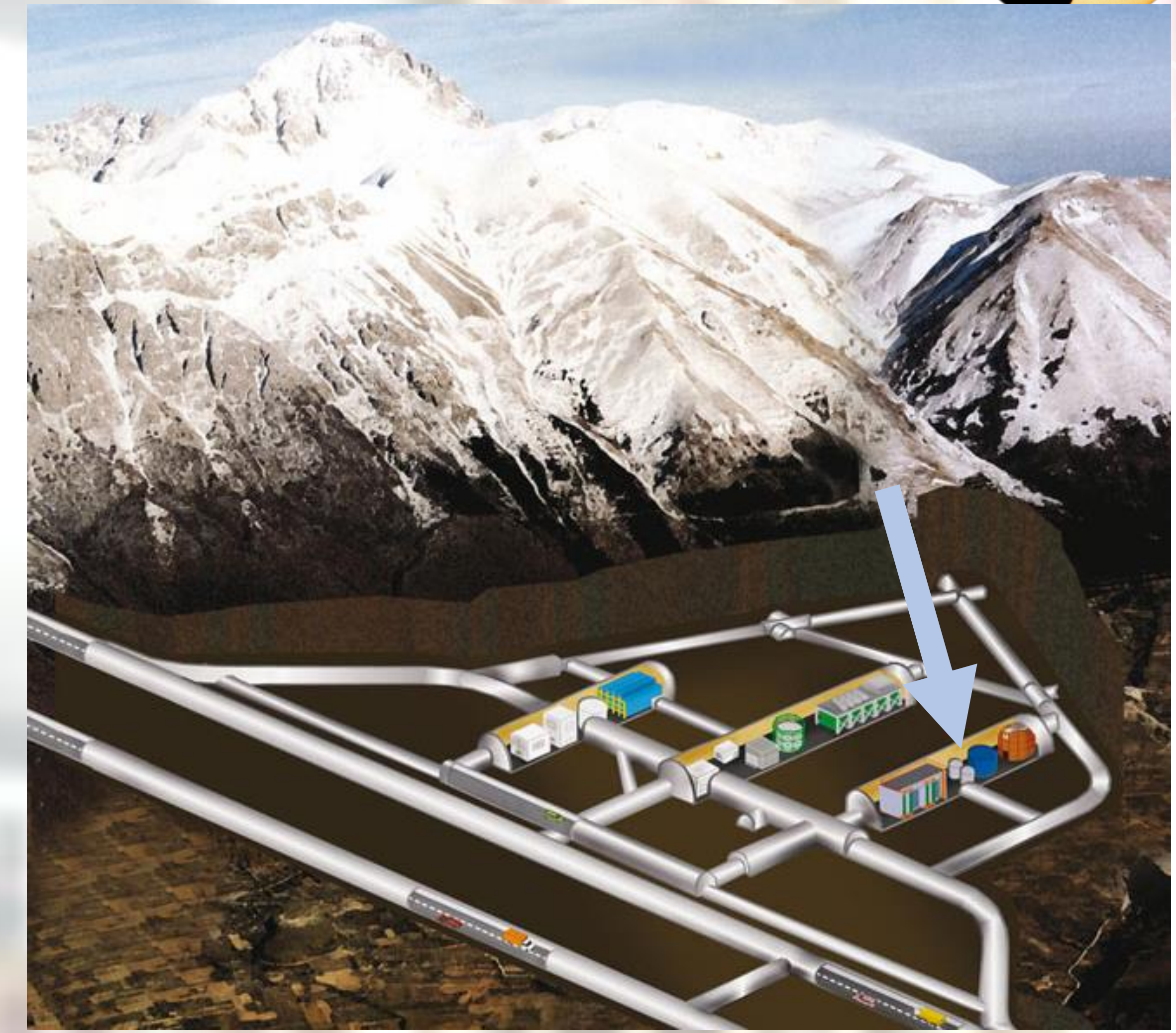
DarkSide-50 housed here

- Next generation: **DarkSide-20k, DarkSide-LM (Low-Mass)**
- DS20k under construction in Hall C for 2026



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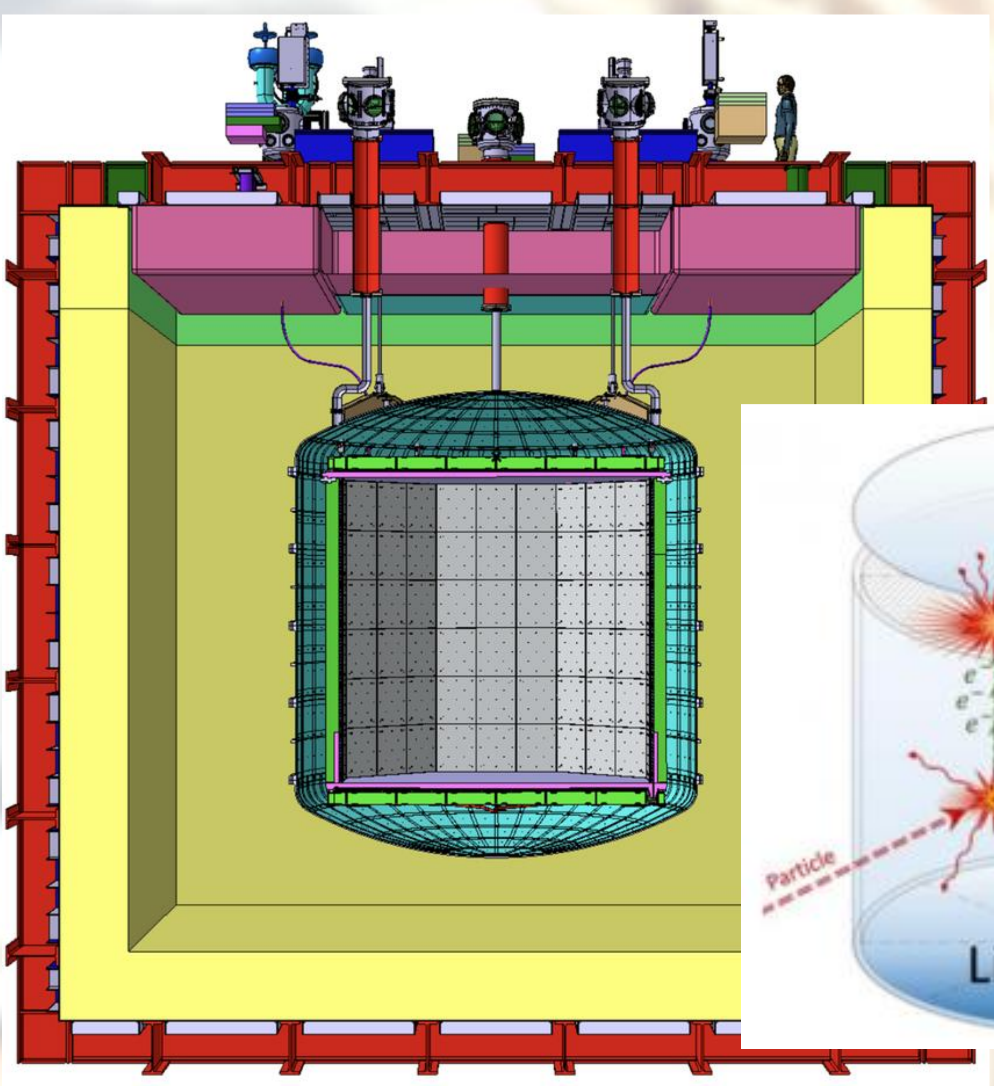
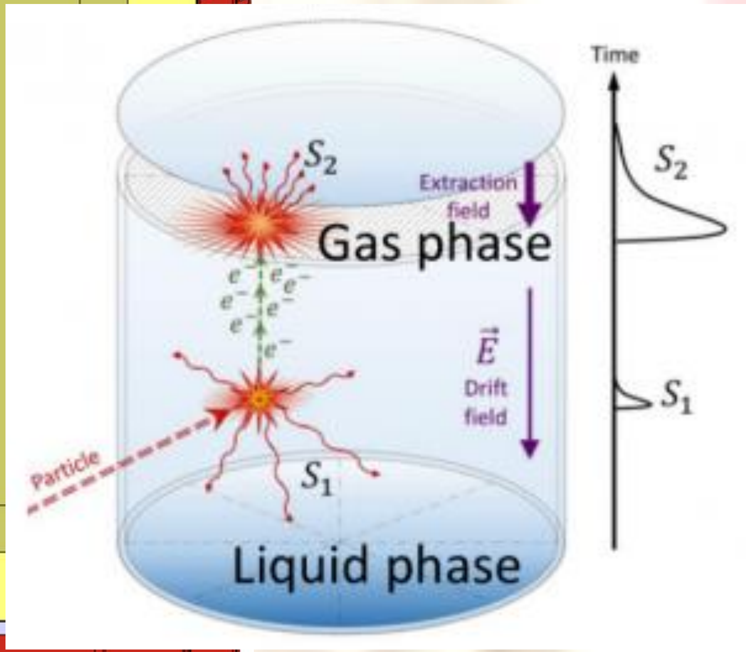
DarkSide-20k: LAr Two-Phase TPC

Two-Phase TPC

- 50 tonnes of underground liquid argon with gas layer at the top
- Sensitivity to **WIMP-like interactions**
  - nucleon cross sections of ~10^{-24} barns (10^{-48} cm^2)
  - Masses in 1 GeV to 1 TeV range
  - Neutrino physics, supernova detection
- **Scintillation** light in liquid & **ionization** in gas gives energy and position information





Note: image does not include HDPE neutron shielding or Outer Veto electronics
https://deap3600.ca/darkside-20k/
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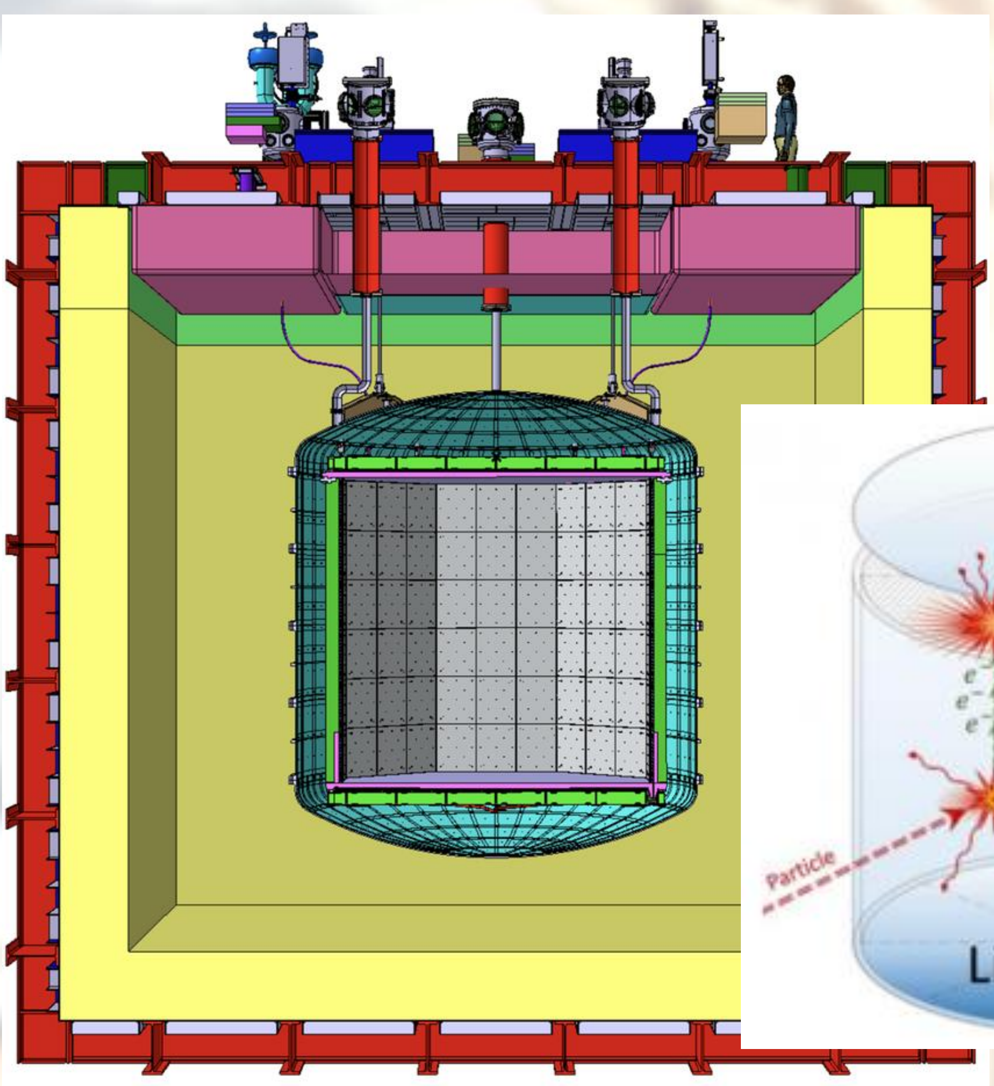
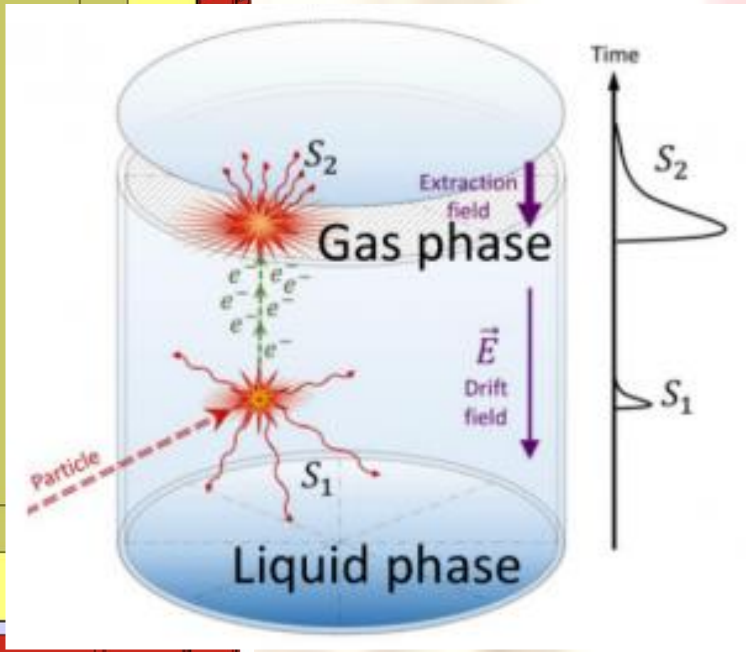
Future Improvements

- Impact of **Xenon-doping** on GAr
- Test of **reflector** material optics
- Design and simulation of **outer veto**





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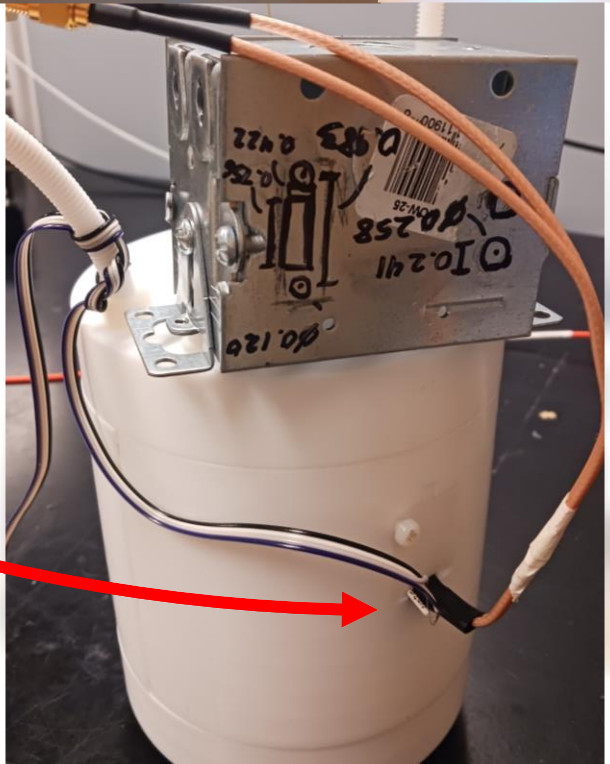
Optics: REFLECT



<u>Reflectance Effects From LAr Exposure Characterization Tool</u>

- PTFE test chamber "**integrating sphere**"
- UV/blue light delivered by optical fiber
    - Reflect off sample (black foil backing)
- Single SiPM unit captures **diffuse reflections**
    - Measure change in photon count for different reflectors

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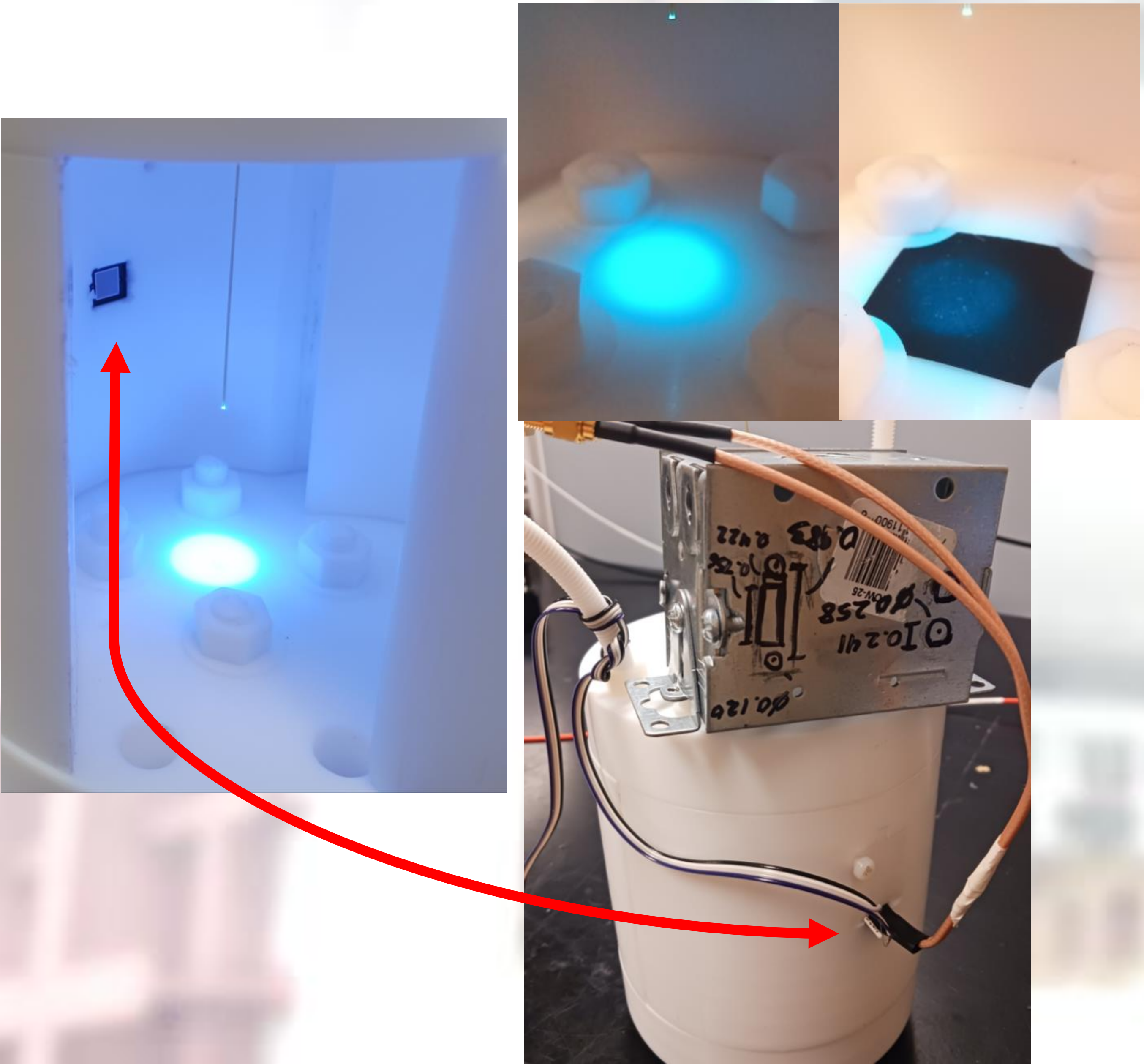

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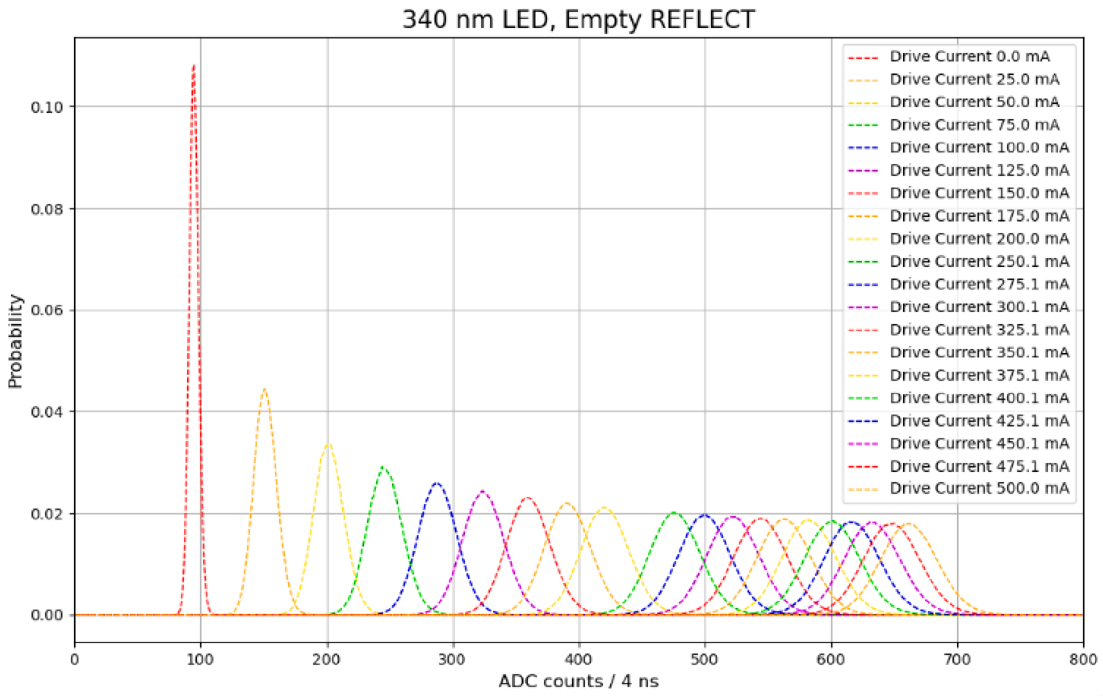
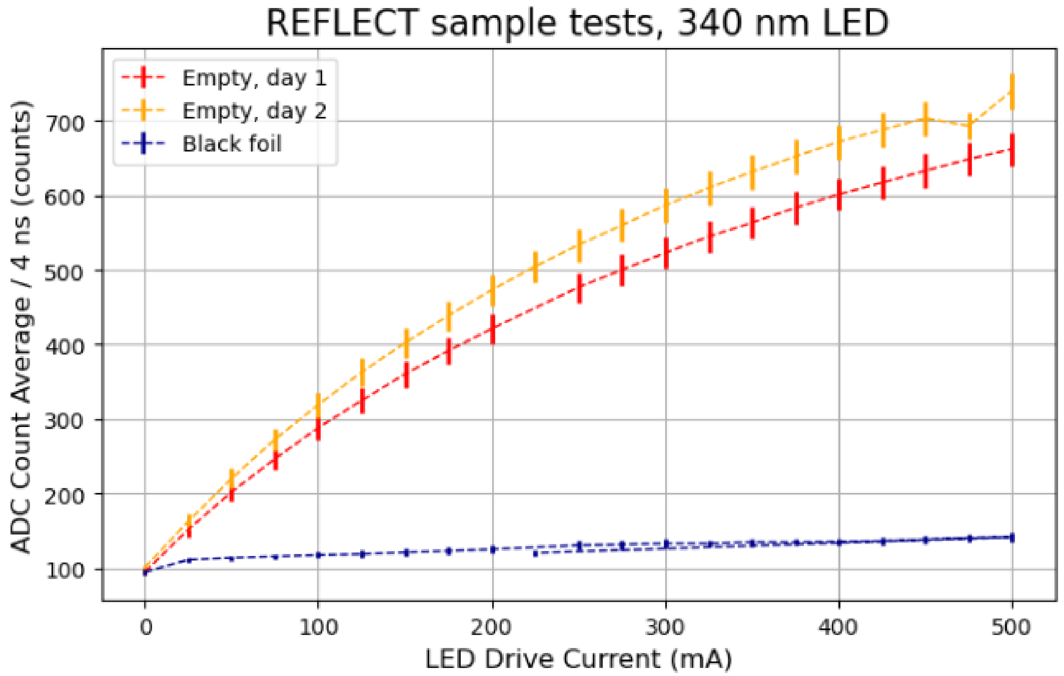
Cryogenic Conditions

- **Cold air** (100–150K): temp of reflectors in argon gas pockets
- **Cryogenic** (77–88K): temp of liquid argon
- Five broad wavelength LEDs to test reflectance spectra
  - Lumirror, Tyvek, ESR foil

Optics: REFLECT

- Signal strength v. optical power measured across linear SiPM dynamic range
- Calibrate empty REFLECT's response
  - Optimize optical design





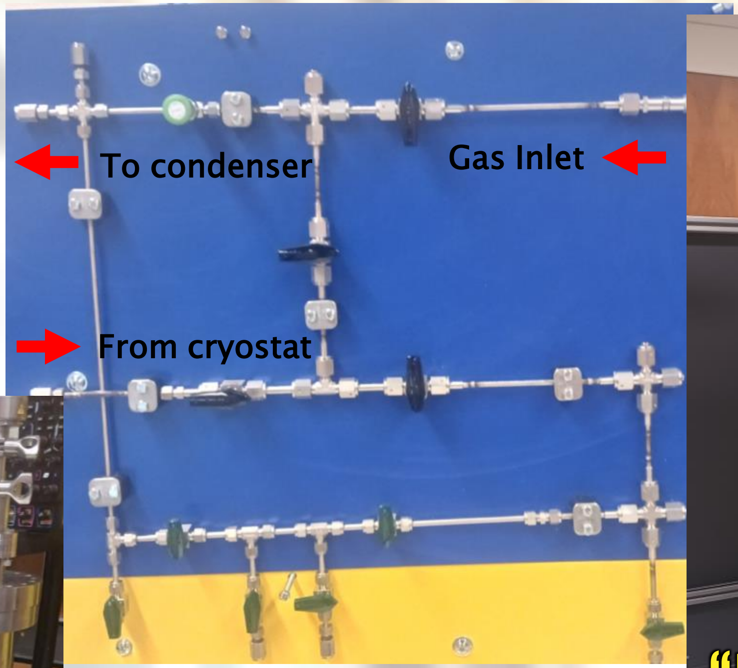
<u>Next Steps</u>

- Add reflector samples
- Low temperature (GAr and LAr temps)
- Reflectance spectra in 280–480 nm range

Xenon Doping: LOADED

<u>Low-energy Optimization And Doping for Enhanced Detection</u>

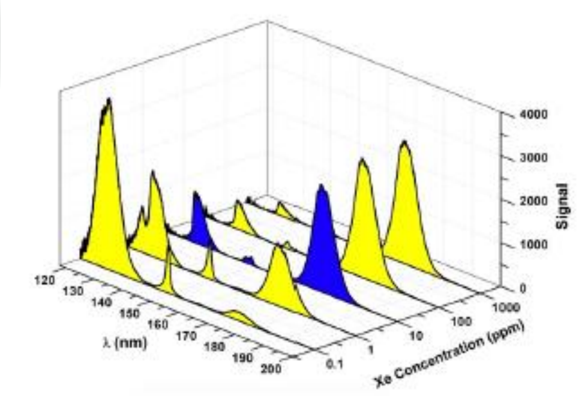
- Gas Panel mixes Ar/Xe and supplies to condenser
- Condenser liquifies Ar/Xe using N_2
  - Xenon freezes before argon liquifies, must dissolve xenon
- Large cryostat to test xenon-doped argon bath

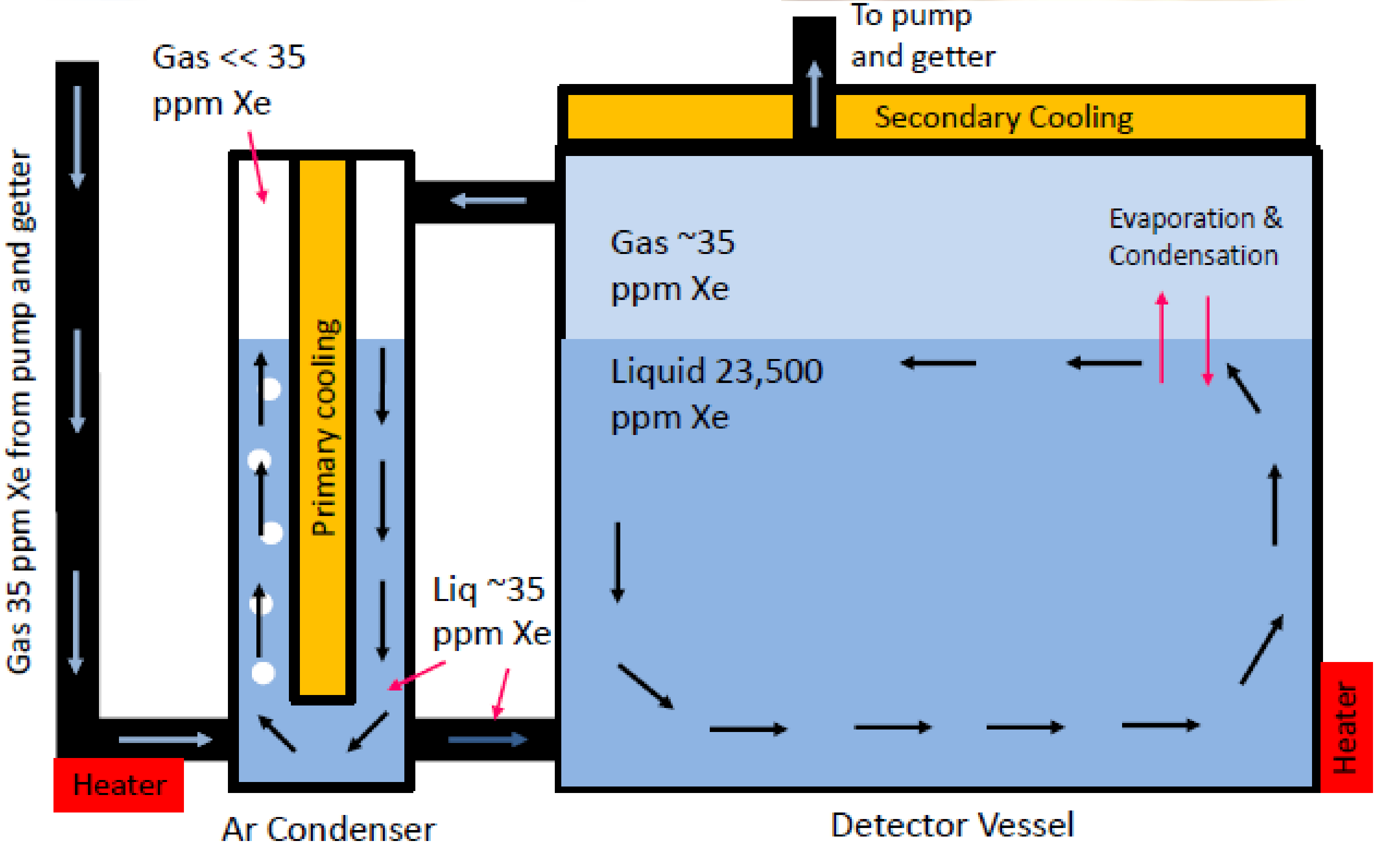


CHILLAX Doping Schematic

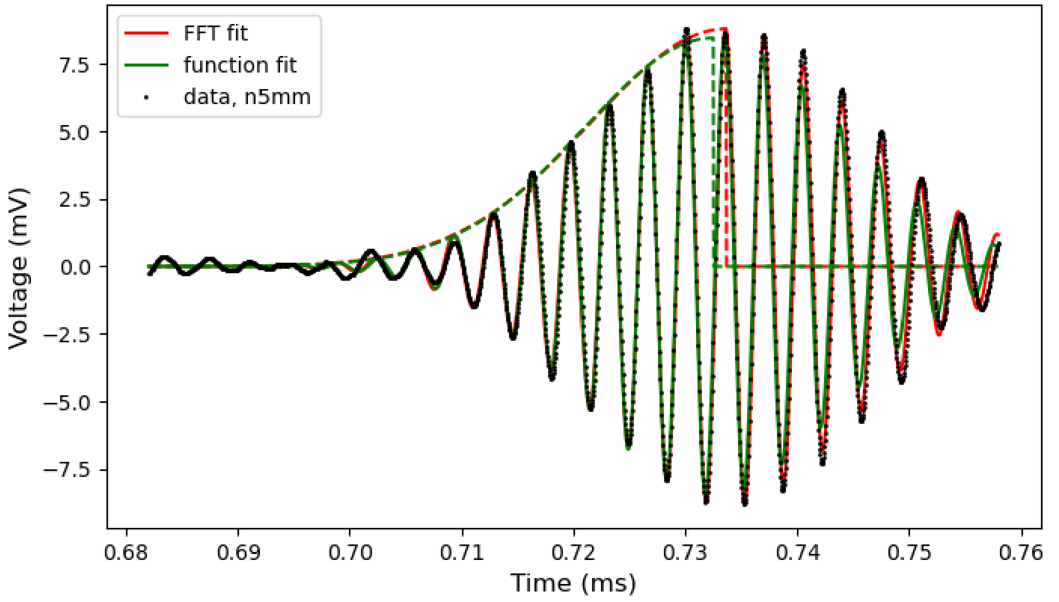
<u>CoHerent Ionization Limit in Liquid Argon and Xenon</u>

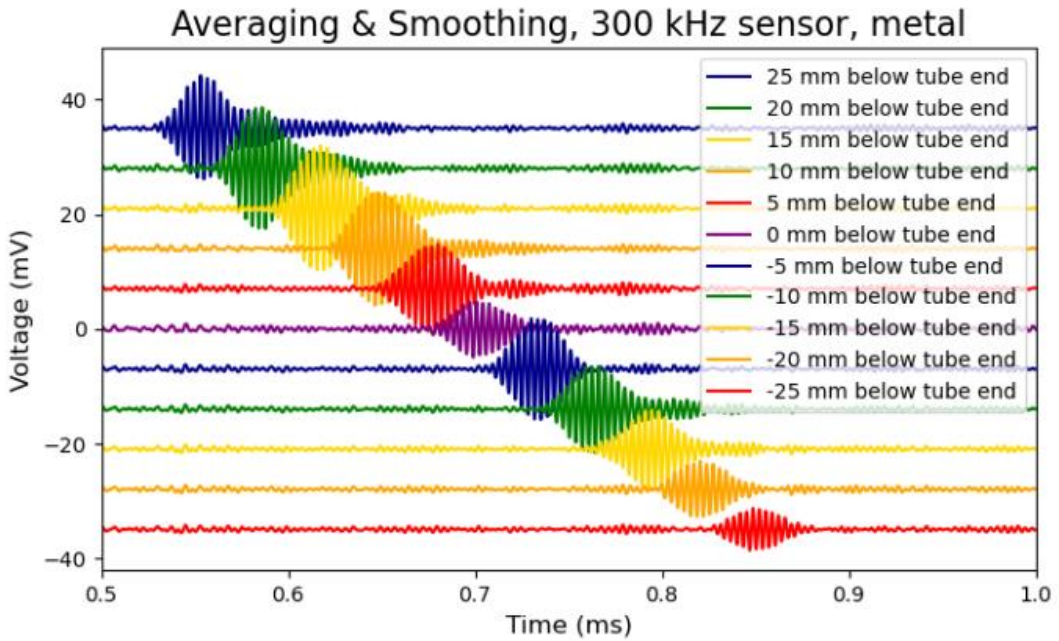
- Working with Dr. Jingke Xu's group at LLNL
  - LOADED based on previous w done here
  - Taking first Xe-doped LAr measurements
- Scalability testing
  - Thermodynamic stability for large detectors





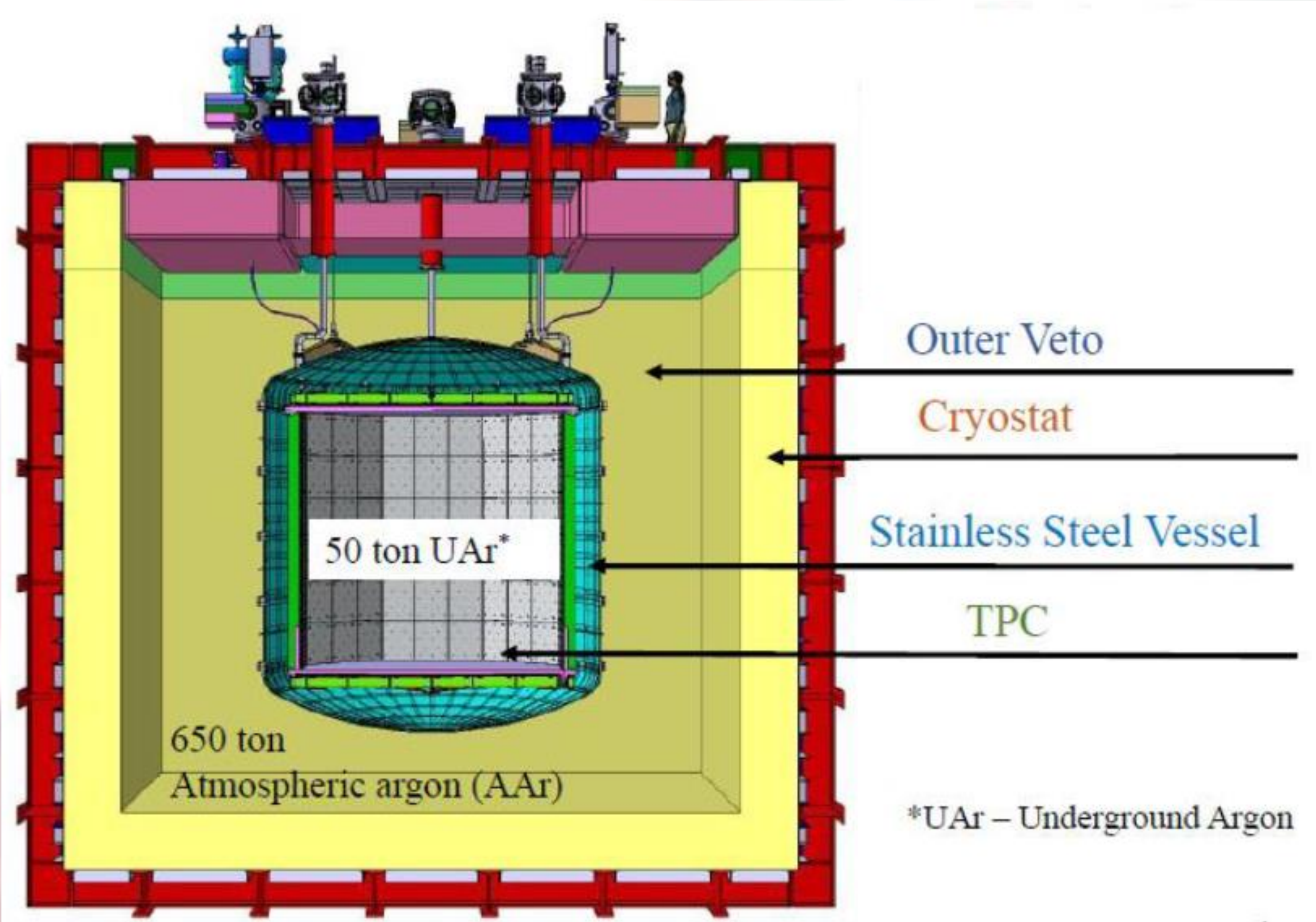
CHILLAX Upgrades





- My contribution: ultrasonic fill meter
  - Efficiency depends on width of gas pocket
  - Time of arrival of reflection pulse measures liquid level
  - Minimal heating
- Engineered pulse shape for sharp leading edge
- **Sub-mm precision** achieved in warm conditions

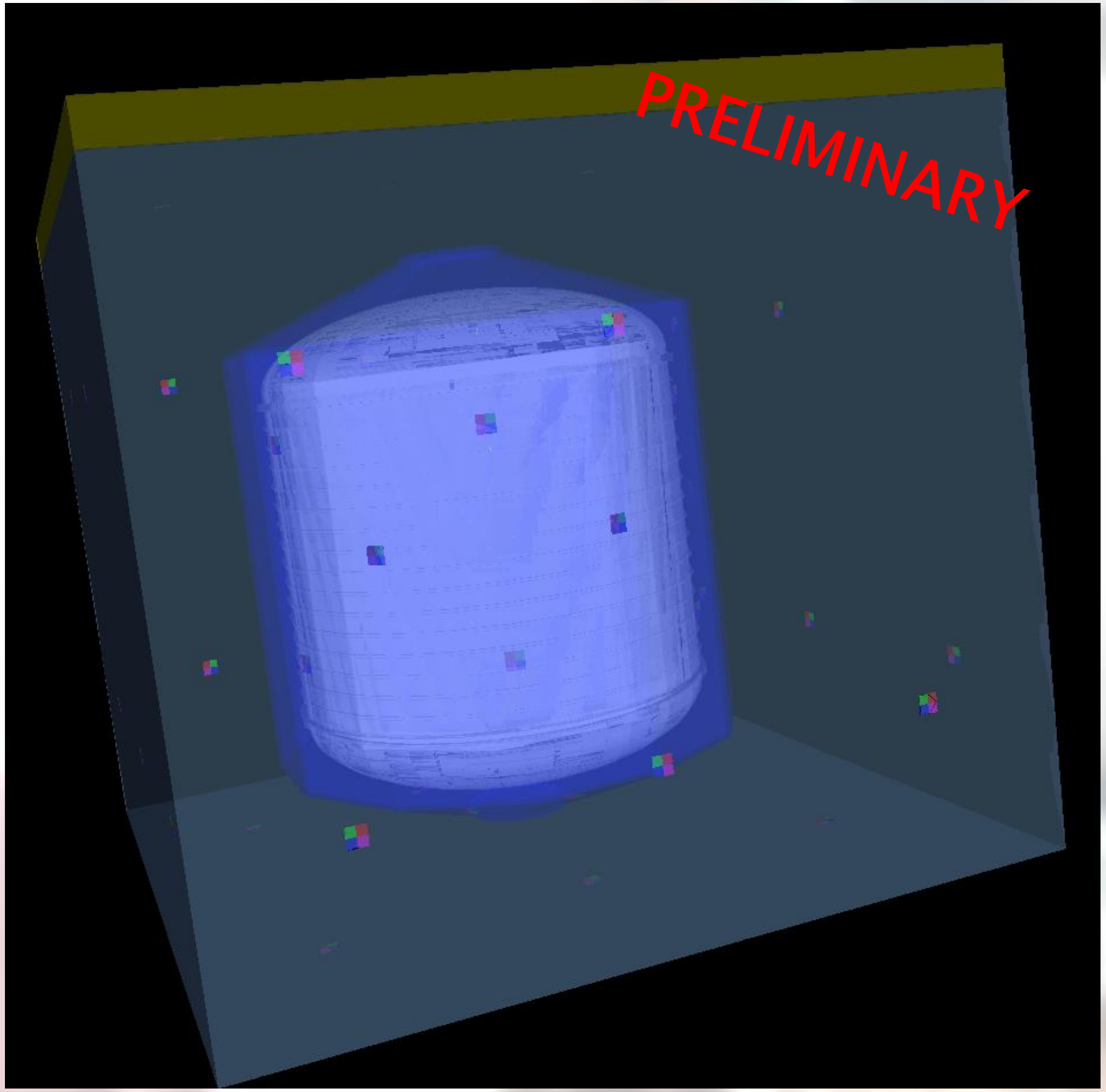
DarkSide-20k: The Muon Veto



https://www.lngs.infn.it/en/darkside

- 650 tons **atmospheric** argon , between the inner veto and Cryostat
  - Gas phase layer at top for stability
- **Passive shield** minimizes interactions
  - Cosmogenic neutrons generate muons and particle showers
- **Active scintillation** detection
  - Silicon Photomultiplier (SiPM) arrays give single-photon sensitivity
  - Tag cosmic ray events to veto for TPC analysis
  - Large volume gives potential for event detection
- Expected operation of DarkSide-20k by 2026

Muon Veto Design



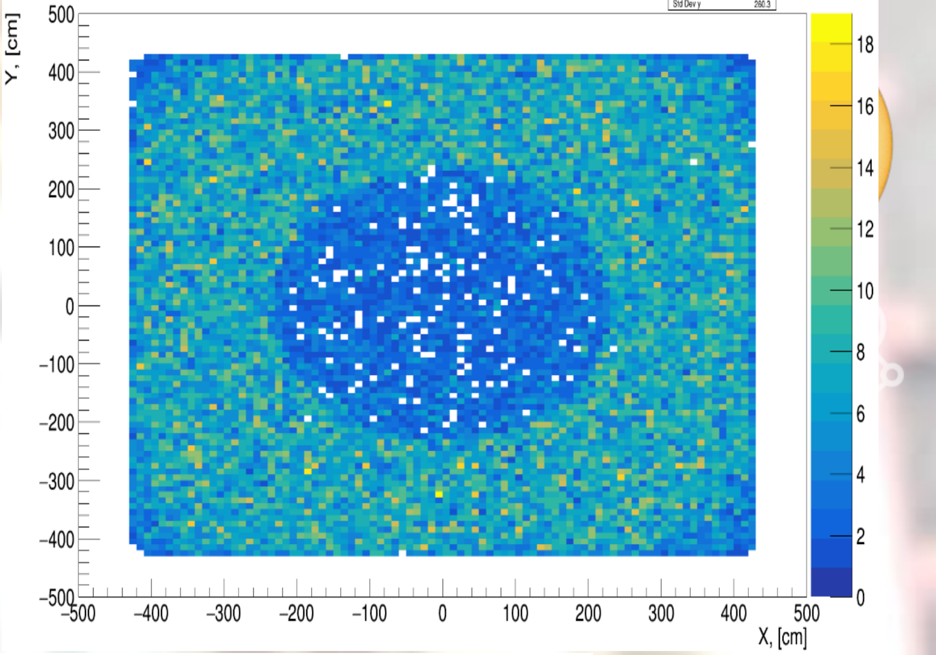
GEANT4 model of DarkSide-20k Cryostat. Liquid phase argon shown in light blue; gas phase argon shown in yellow; plastic shield shown in blue

- 32x16x24 (12,288) SiPM placed on interior of muon veto
- Argon scintillation light in UV (128 nm) is **wavelength shifted** to visible
- UV & visible light must be efficiently collected
  - Diffuse, **reflective interior** acts as large integrating sphere
  - Visible photons bounce between walls multiple times before detection

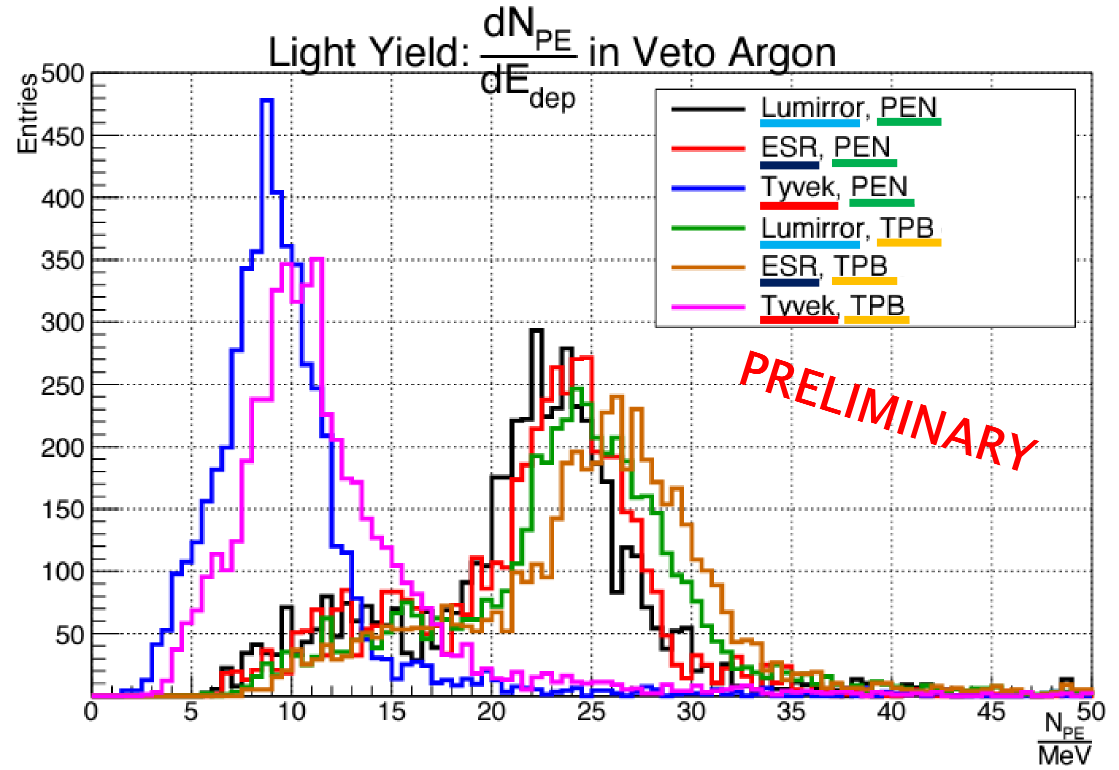
Muon Veto Simulations

Light Yield Optimization

- GEANT4 simulation of cosmic ray and background events
- Measure number of **detected** photons generated in all 32 PDU
- Light map specifies light yield per voxel for each individual sensor
- Confirming argon purity requirements



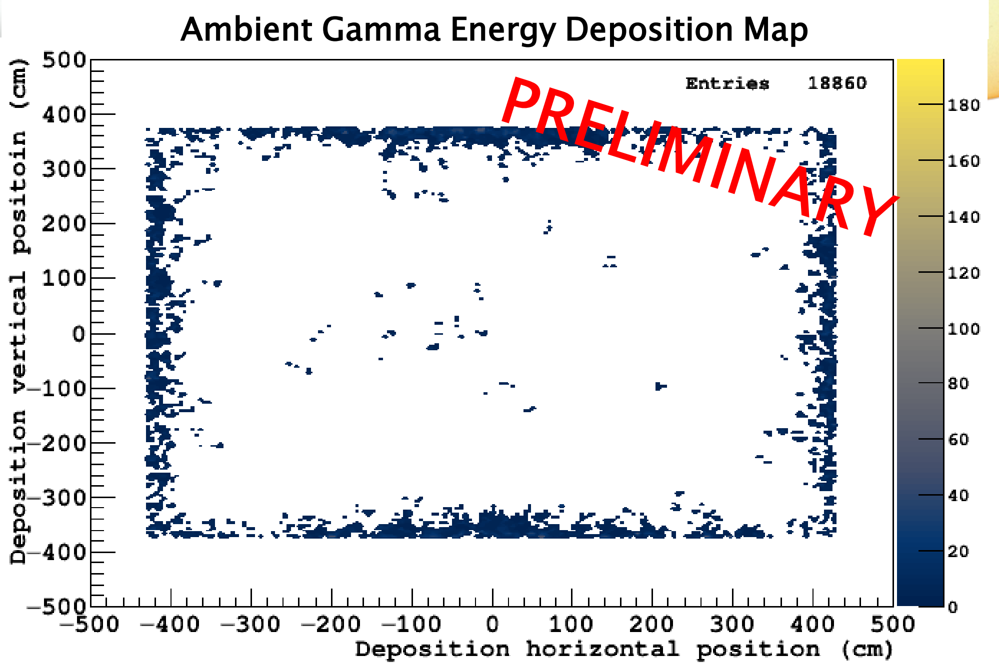
Work done by Taisiya Smirnova; University of California Riverside



Work done by Ashlea Kemp; DarkSide Collaboration; University of Oxford

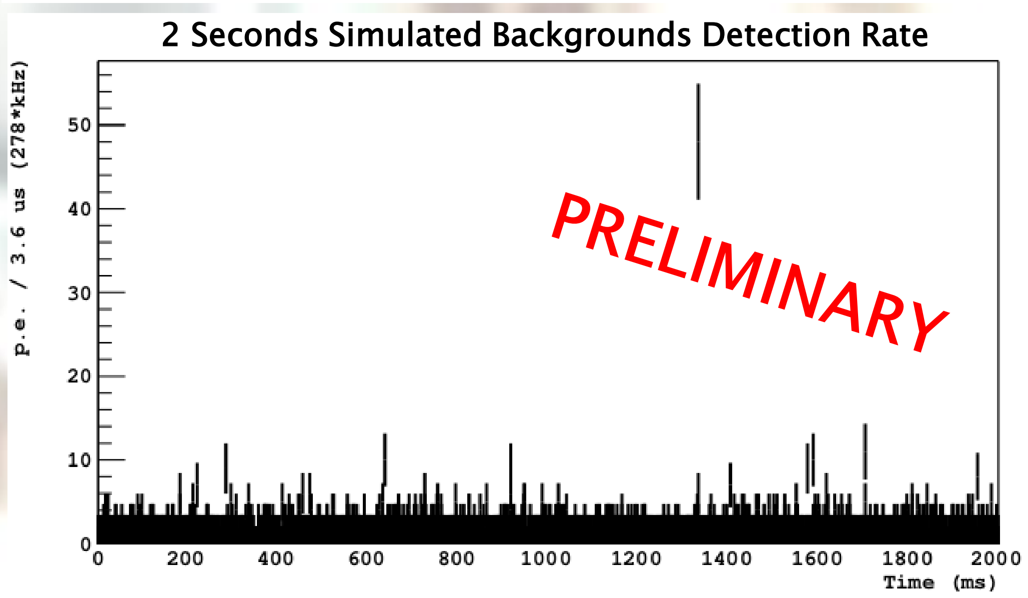
Muon Veto Simulations

- Spatial and temporal distribution of **radioactive backgrounds**
  - Good passive shield: interactions do not reach inner veto
  - Low background rate: Will detect high energy muons above background



<u>Upcoming Work</u>

- Estimation of data rates from active sensors
- Event detection analysis



Thank you!