Alec's HEPCAT Research Update:

Improvements for Next-Generation Noble Liquid Detectors

HEPCAT 2025 Annual Meeting

November 5, 2025, Alec Peck

University of California, Riverside; Advisor: Dr. Shawn Westerdale

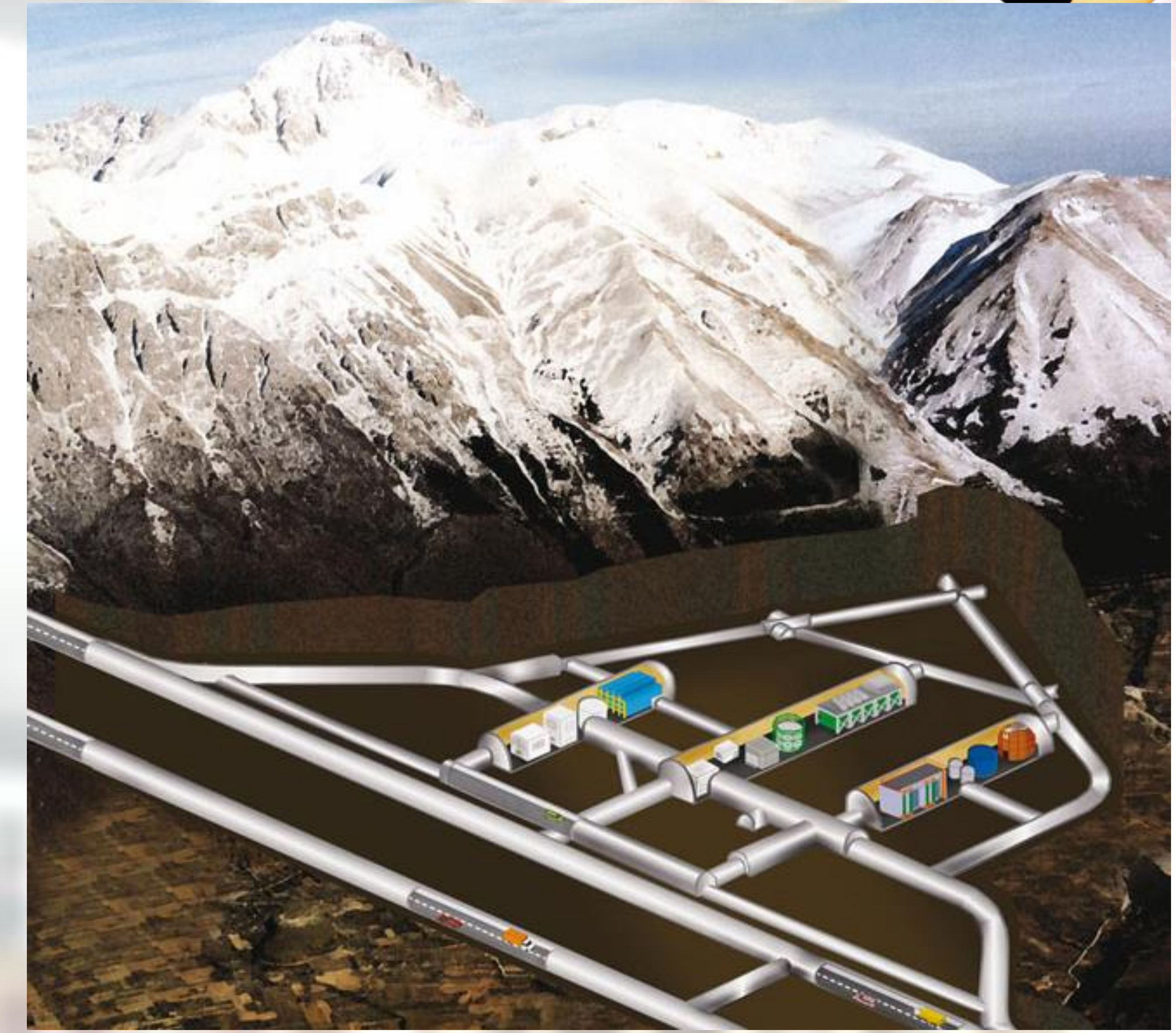
& the DarkSide-20k Collaboration

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

DarkSide-20k: LAr Two-Phase TPC

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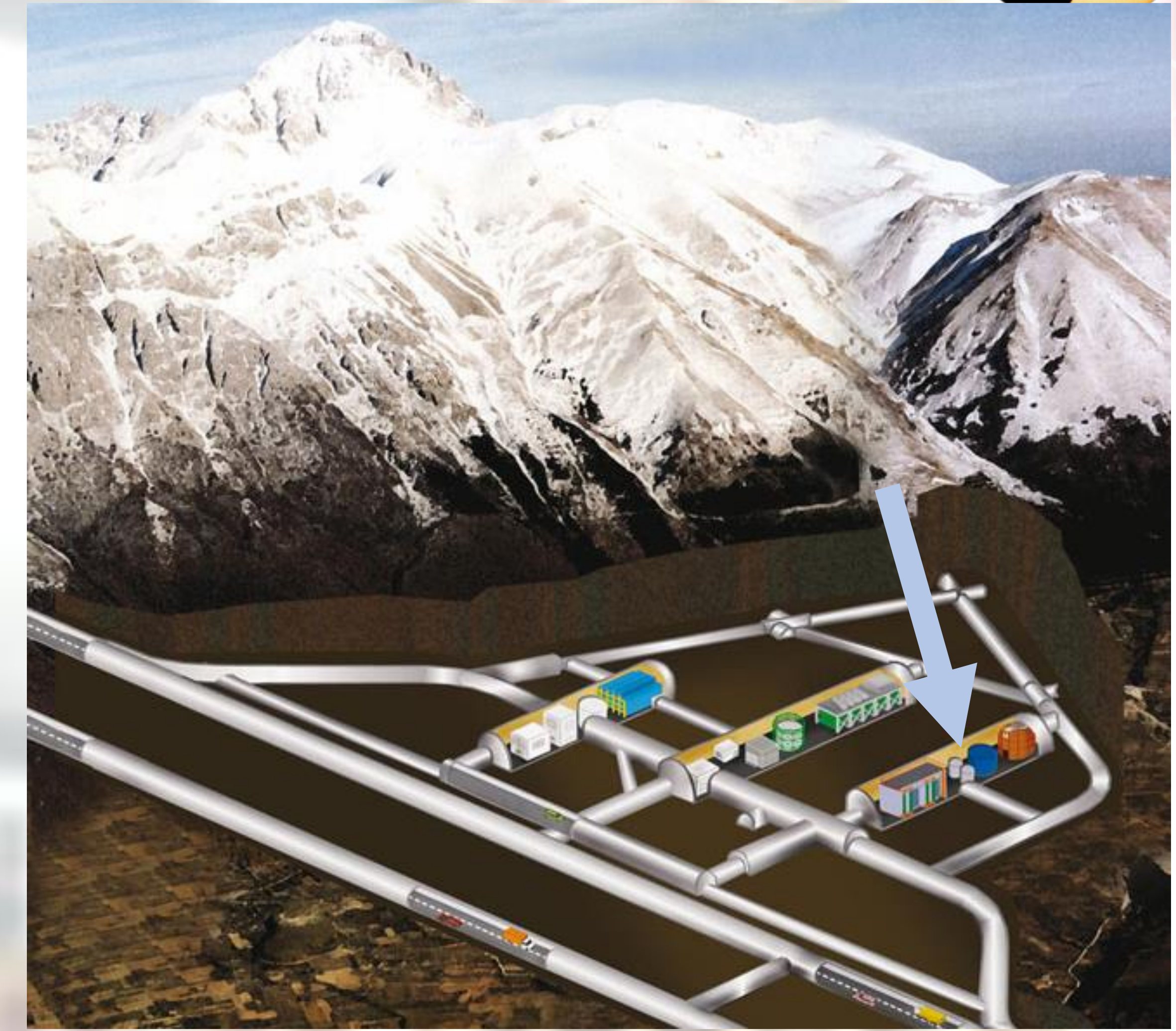
<ins>**DarkSide-50 housed here**</ins>

- Next generation: **DarkSide-20k**
- DarkSide-20k under construction in Hall C for 2026



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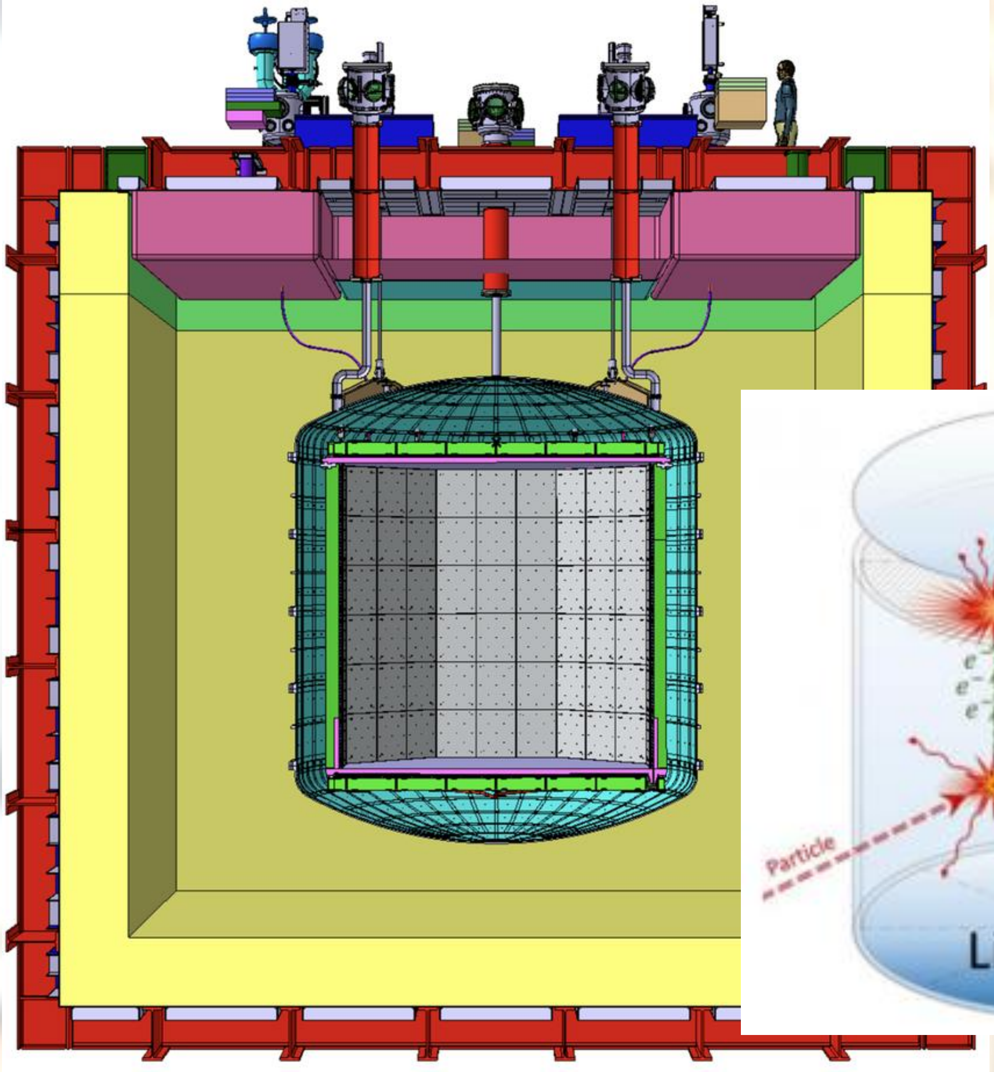
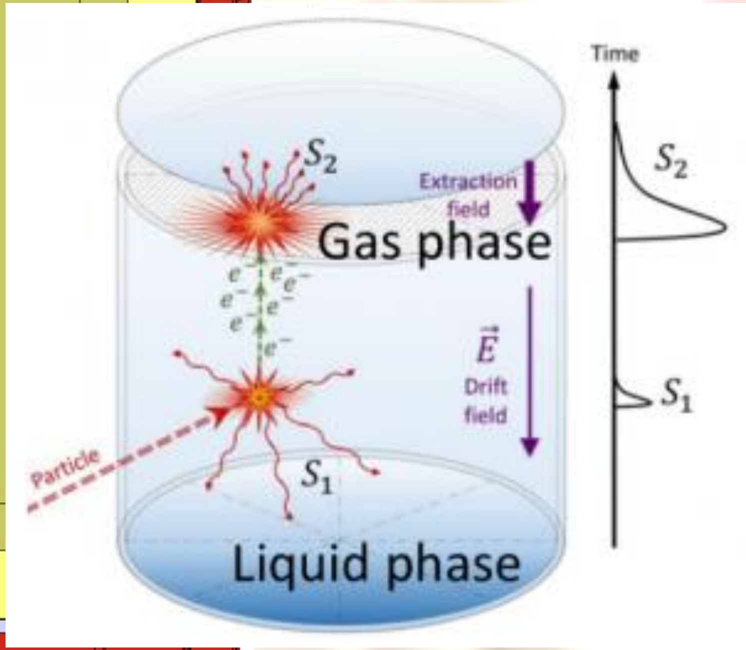
DarkSide-20k: LAr Two-Phase TPC

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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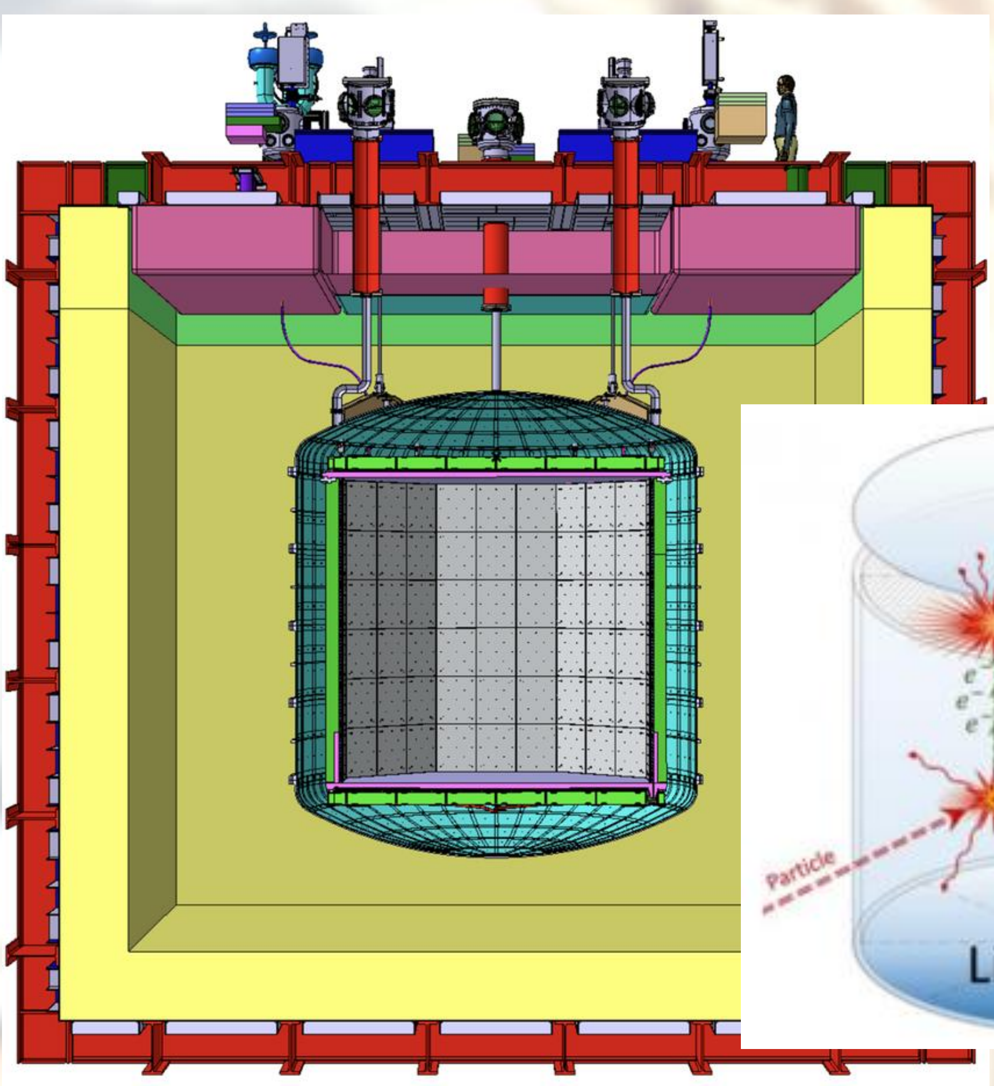
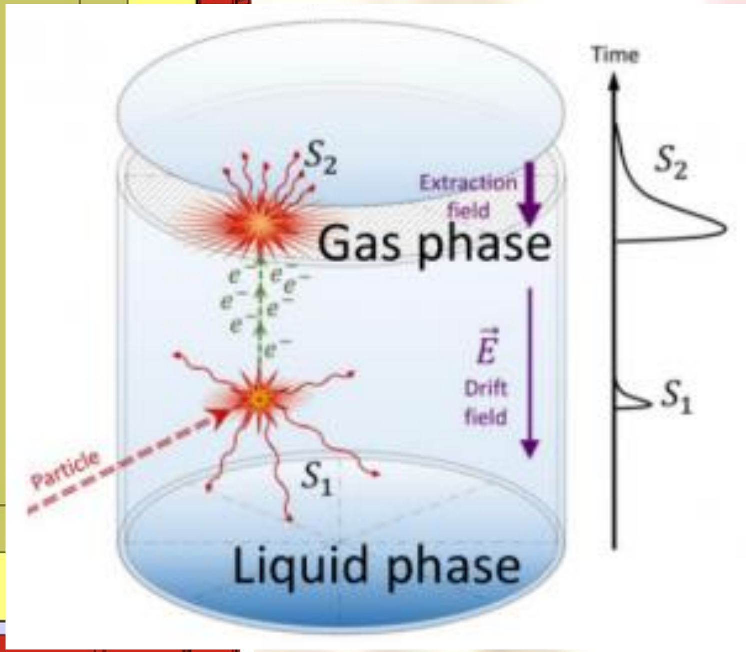
Future Improvements

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





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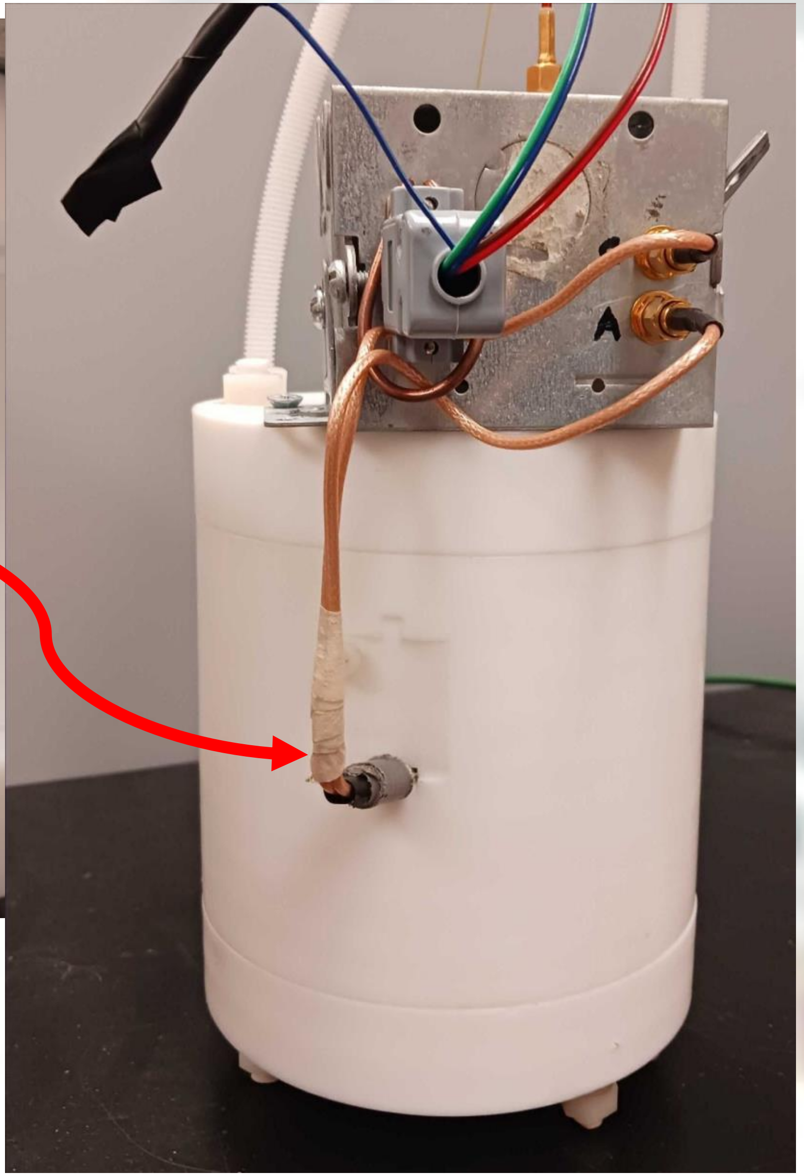
Reflector Tests



Reflectance Effects From LAr Exposure Characterization Tool

- 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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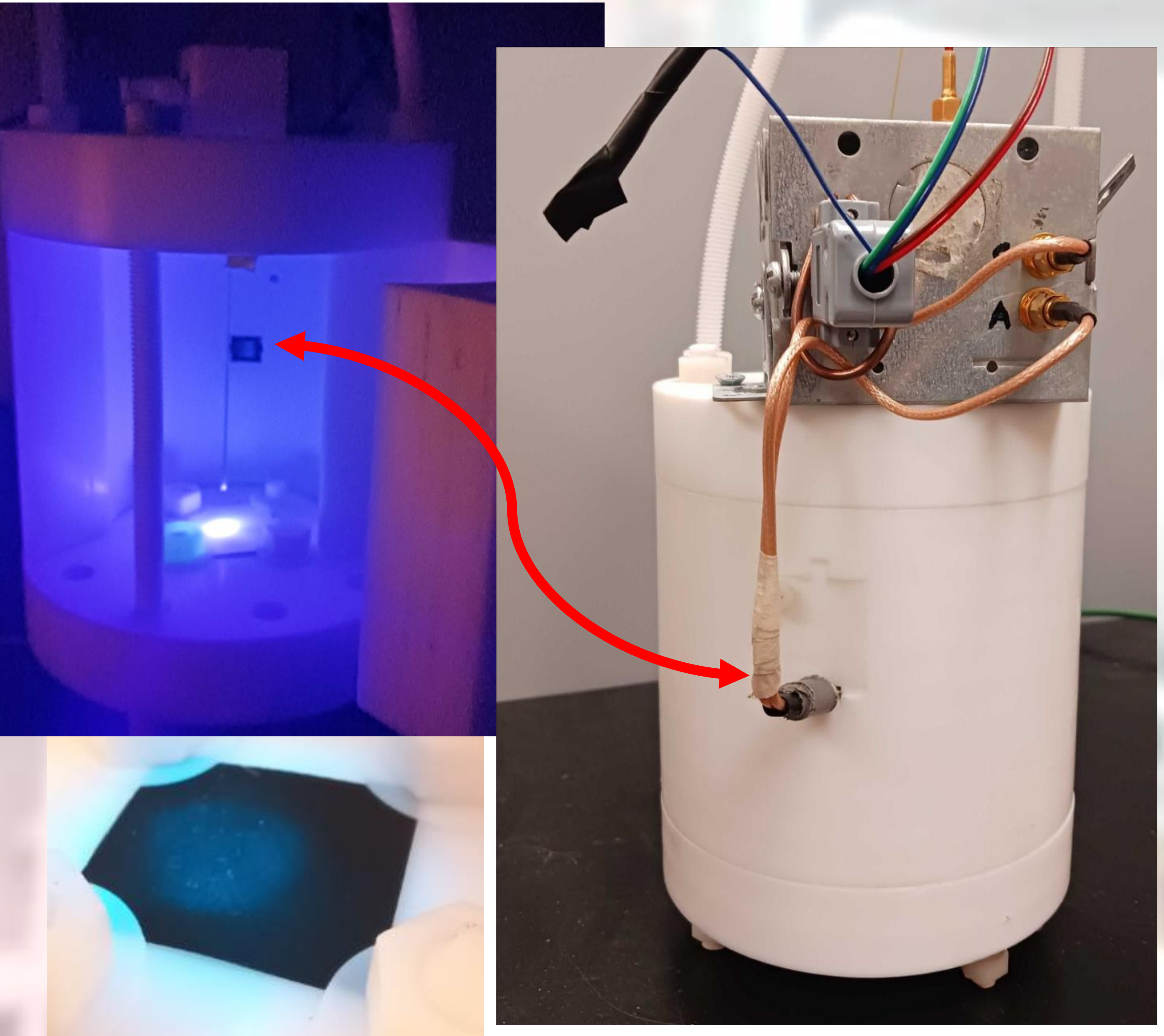

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Cryogenic Conditions

- **Cold air** (100–130K): temp of reflectors in argon gas pockets
- **Liquid Argon** (87K): Submerged in liquid
- Four broad wavelength LEDs to test reflectance spectra
  - Lumirror, Tyvek, ESR foil

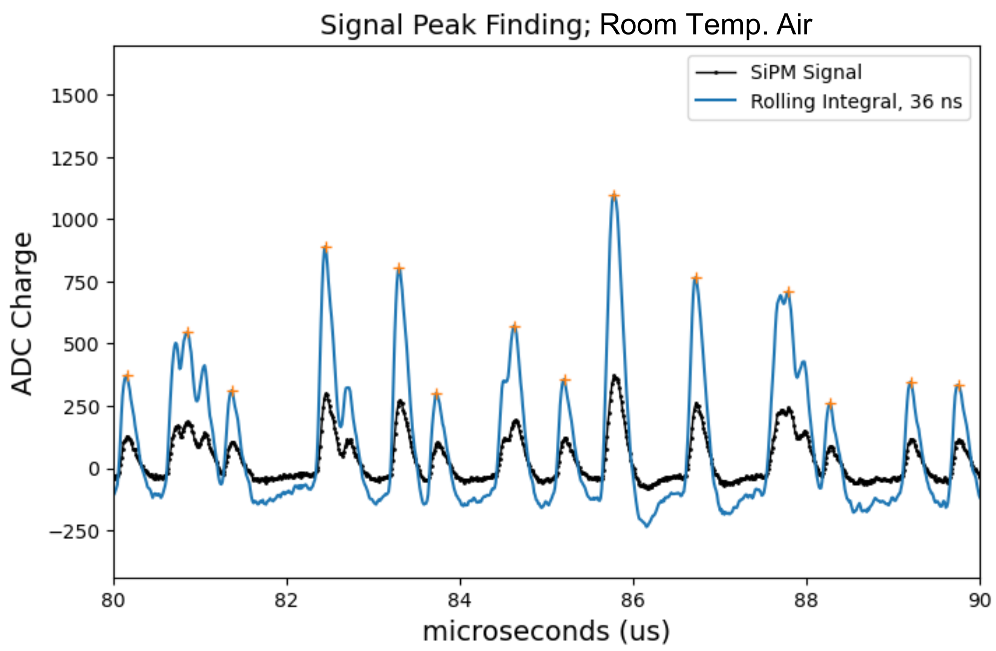
Reflector Tests

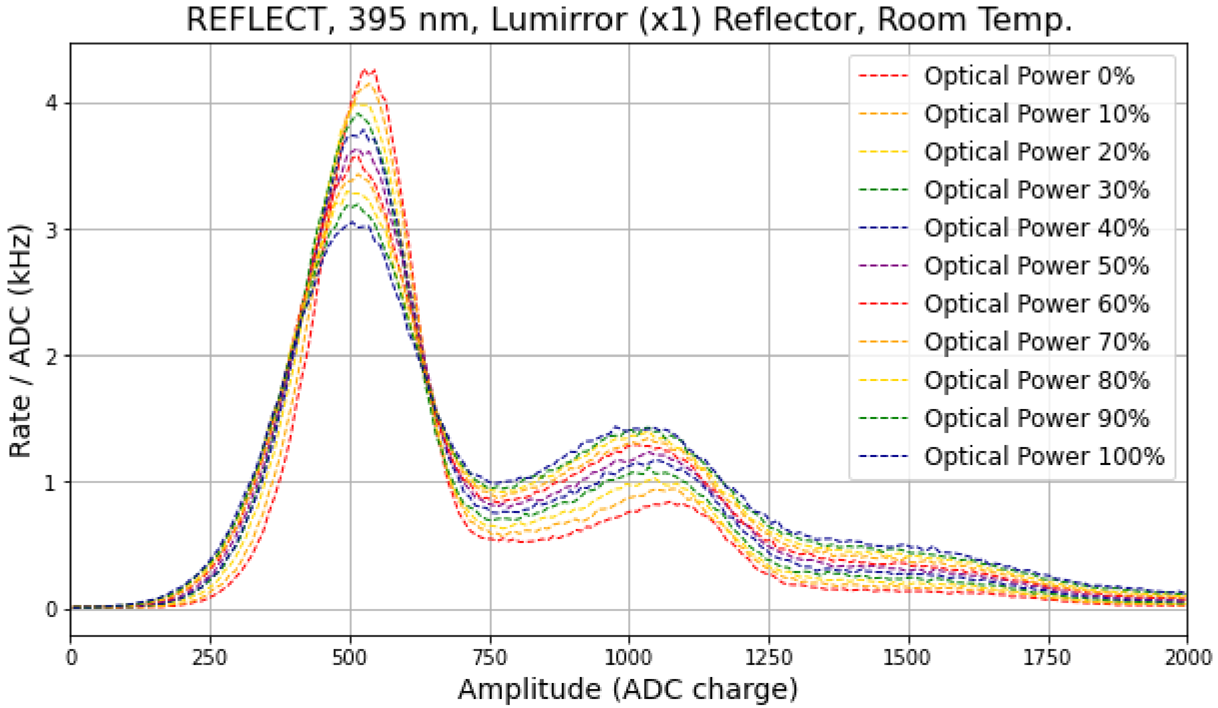
Room temperature baseline

- Large dark rate: 3 MHz
  - Adding optical power increases pulse coincidence

- Must generate finger plot to calibrate pulses

- Must calibrate pulses to make accurate finger plot





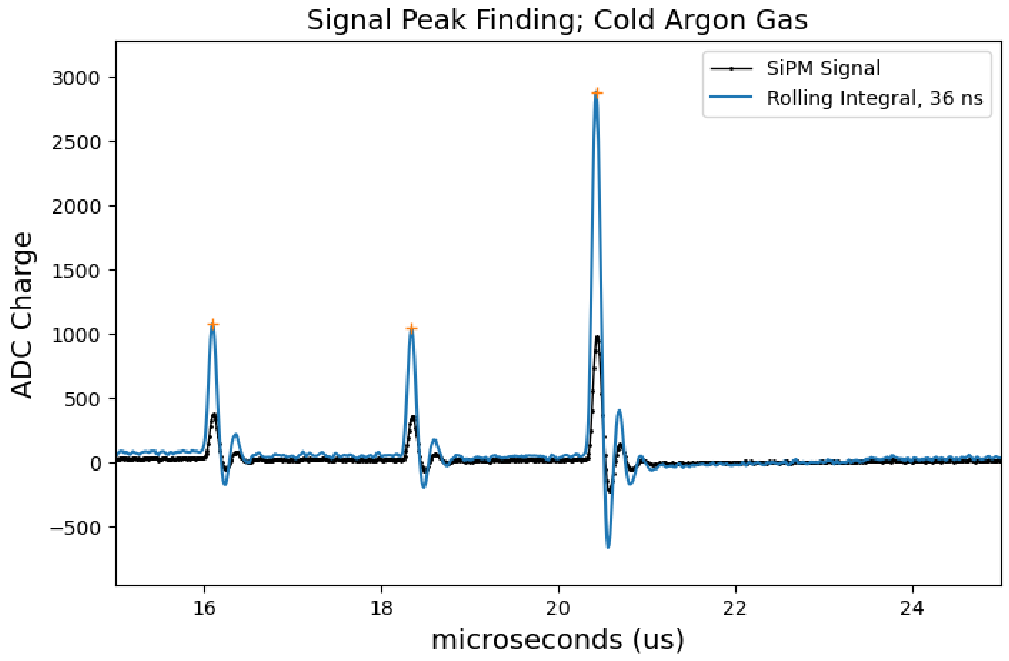
Reflector Tests

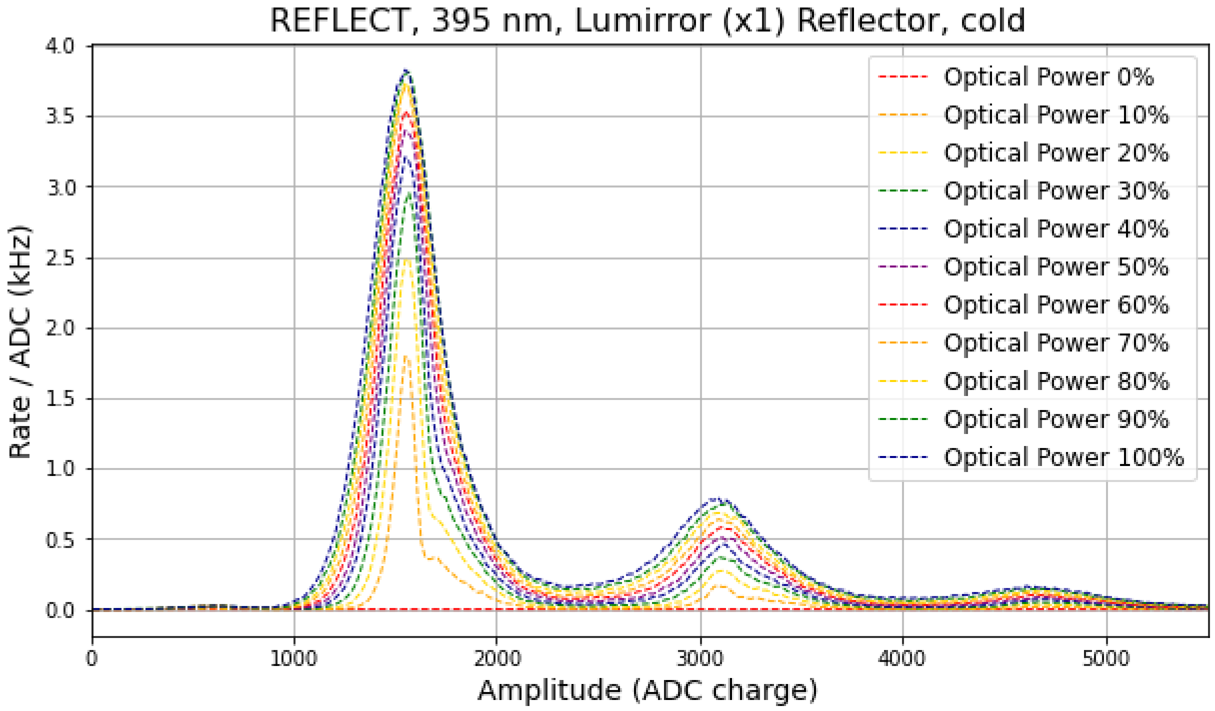
Cold Argon/N2 gas mixture

- Very low dark date: ~50 Hz (<3 Hz/mm^2)
- Taller, sharper pulses, ~3x warm SPE
- Changing pulse shape as diode changes junction capacitance

Wandering SPE charge

- Estimate SPE charge and zero-offset





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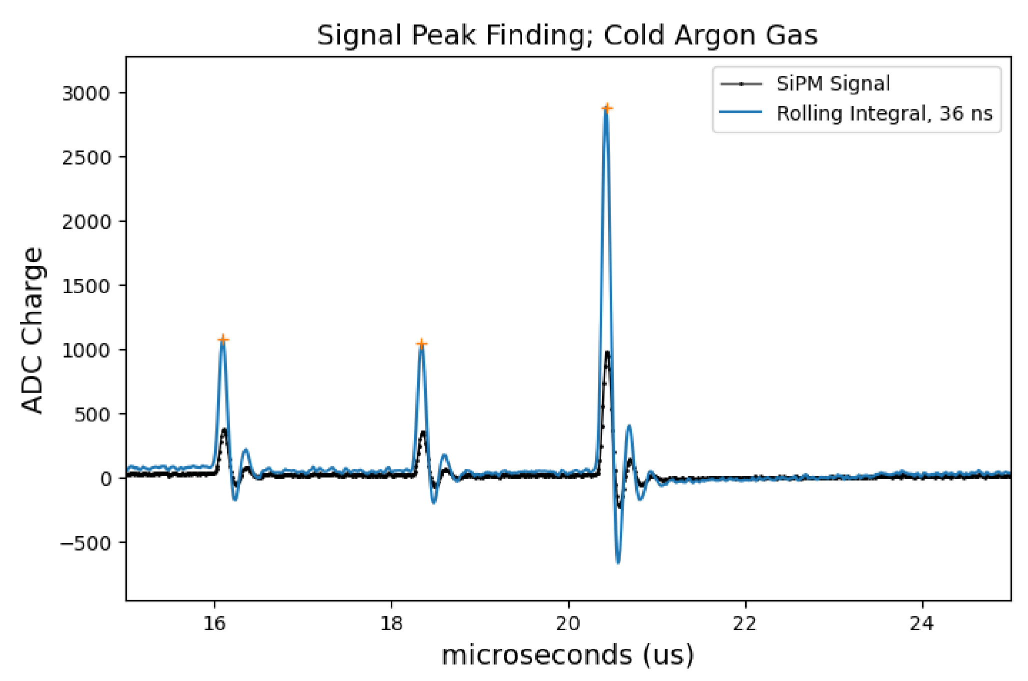
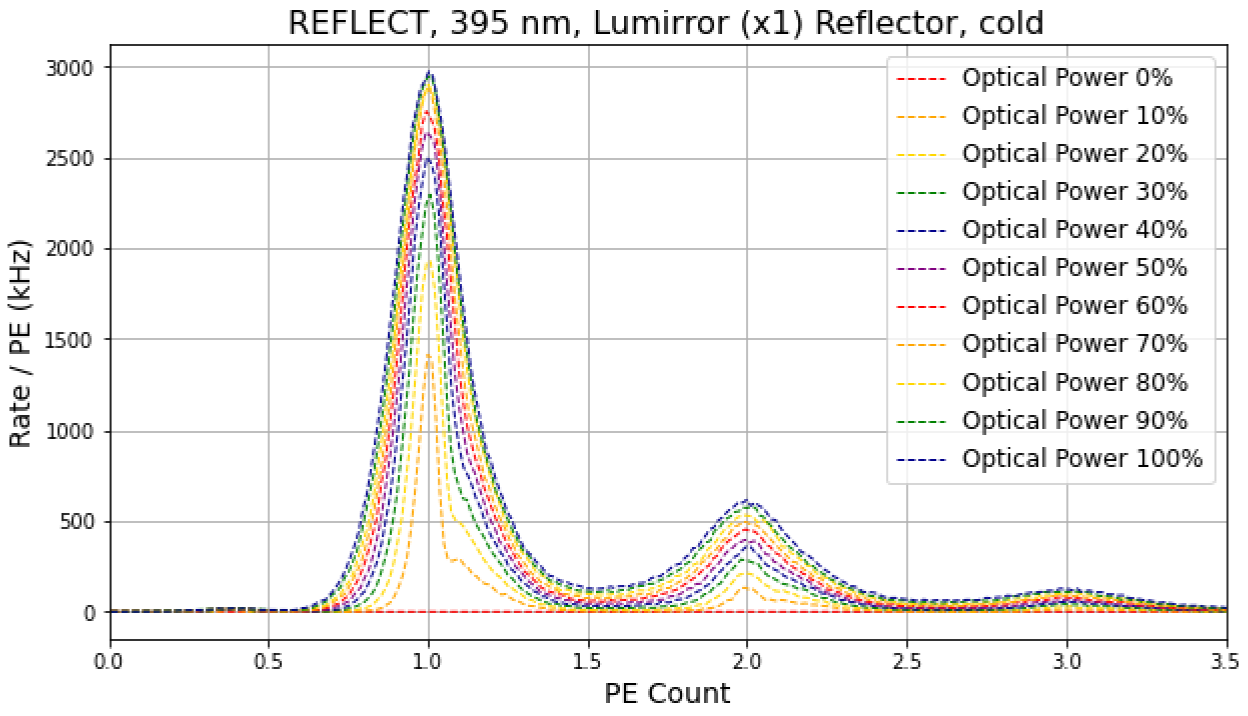
Wandering SPE charge

- Estimate SPE charge and zero-offset
- Re-calculate finger plot with known SPE

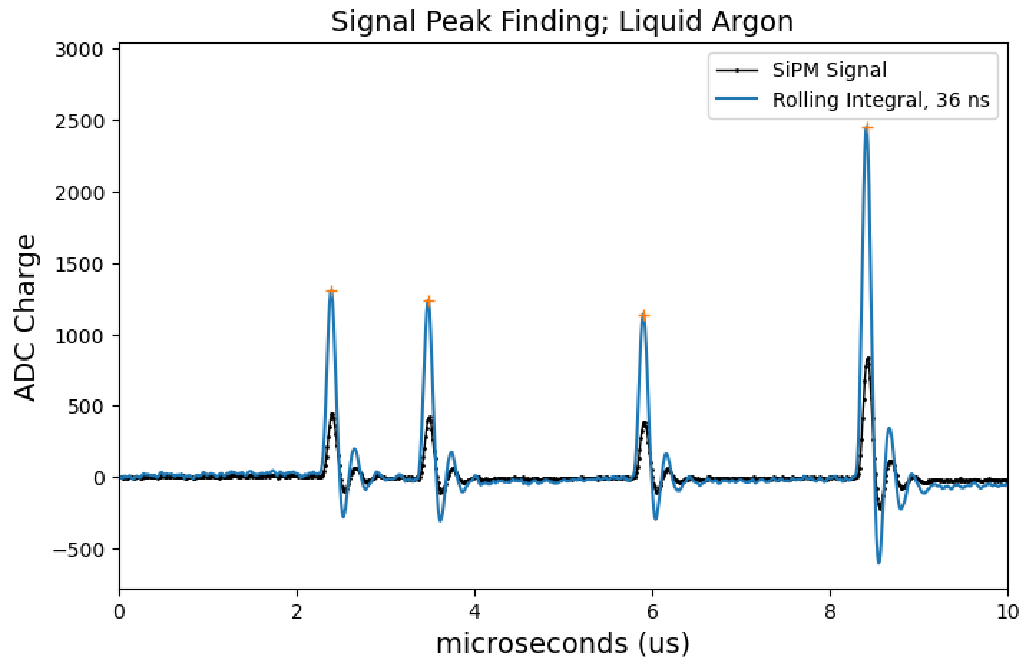


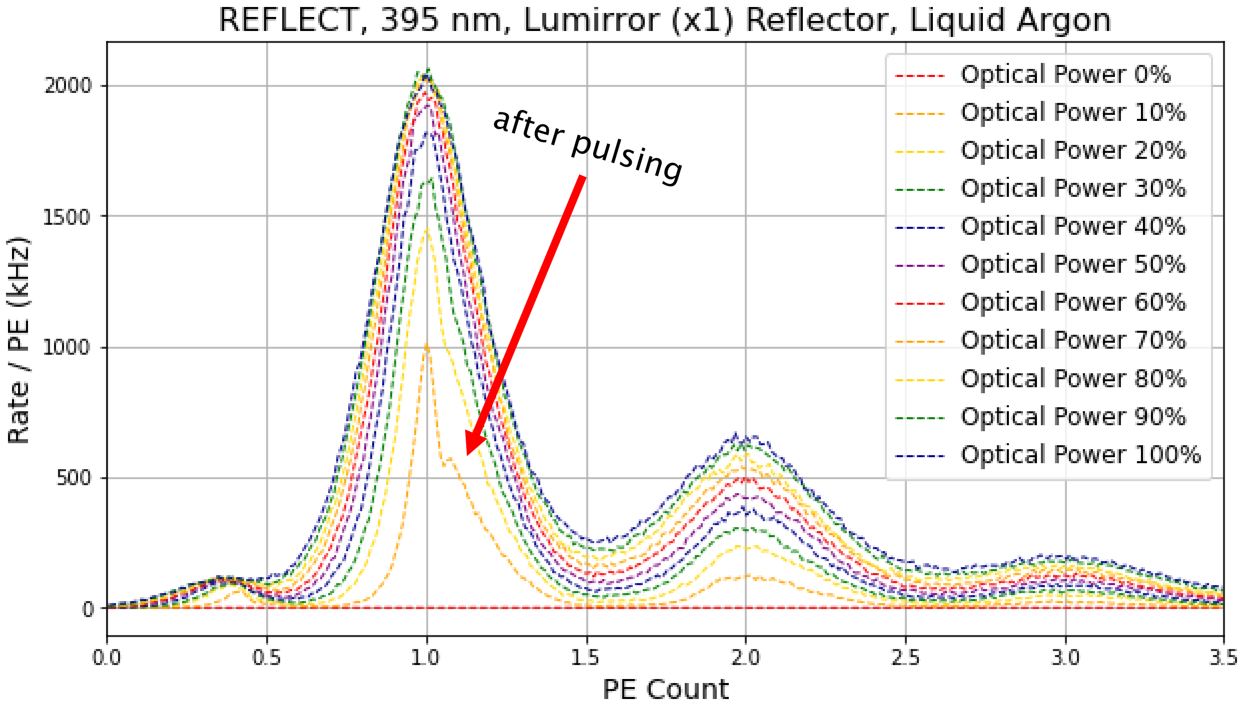


Reflector Tests

Liquid Argon submersion

- Slight increase in SPE charge
  - Significantly more after-pulsing
  - Larger apparent current draw
- Fingers have spread significantly
  - Long-lasting undershoot affects following pulse

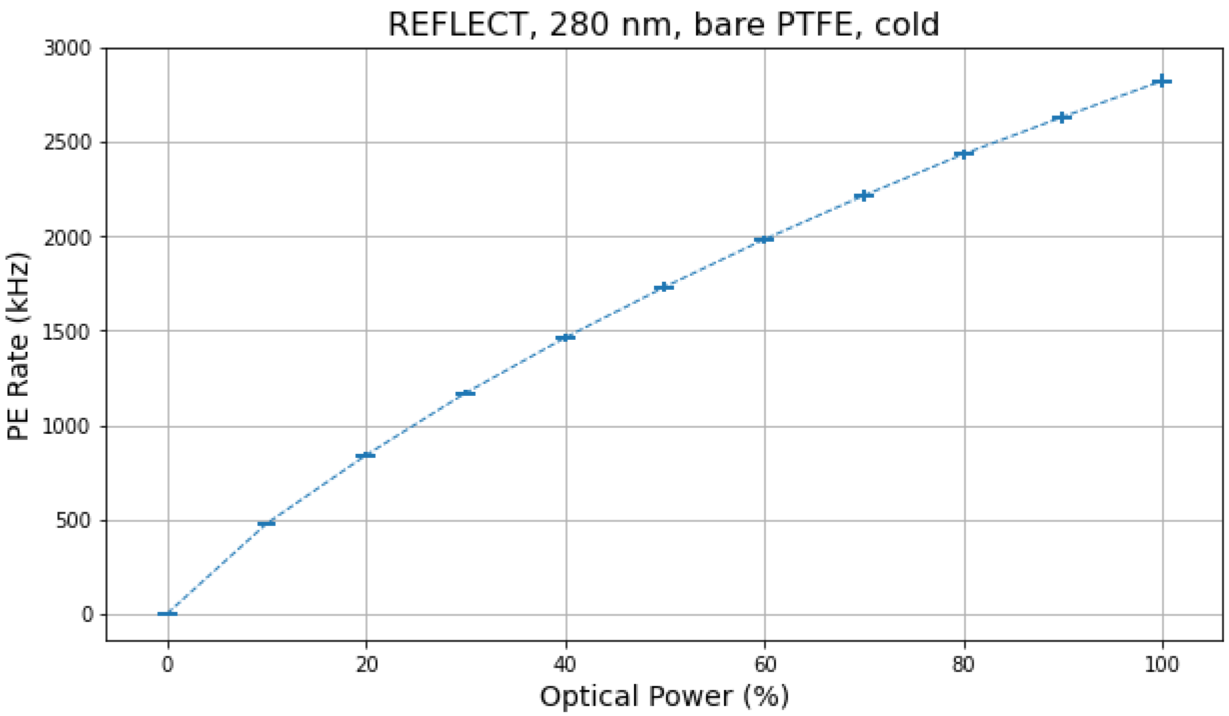


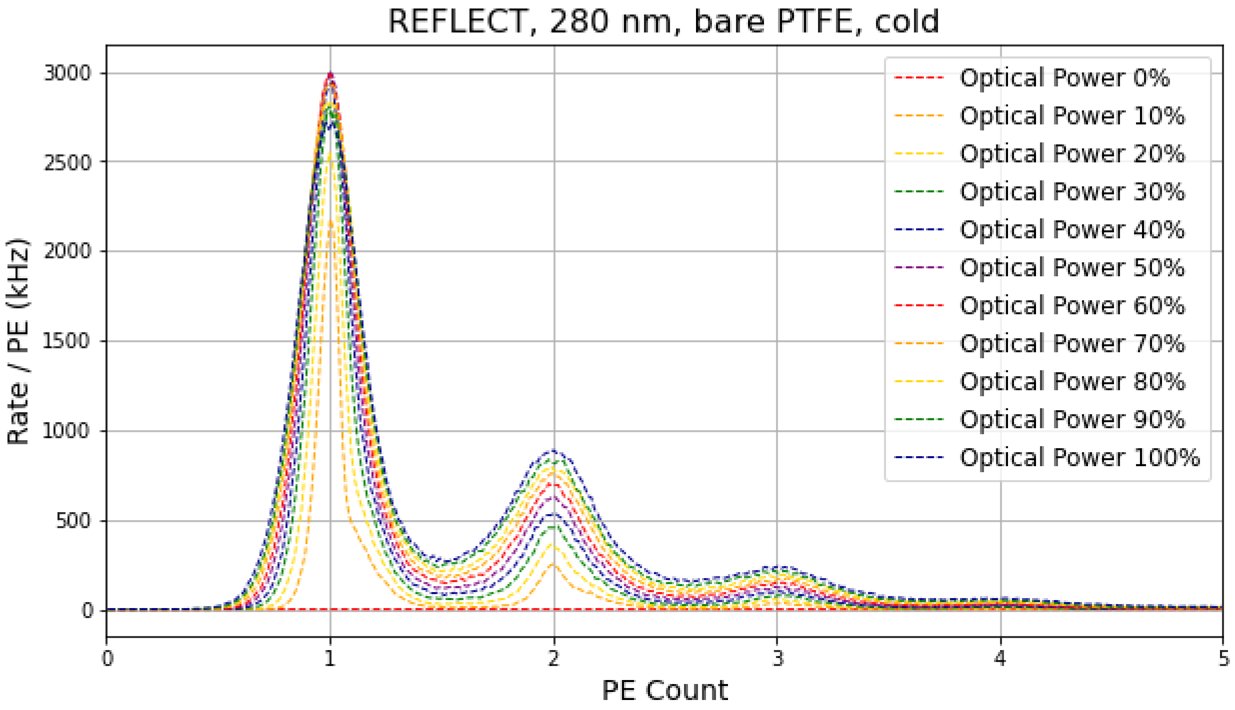


Reflector Tests

<u>Finger plot to photon rate</u>

- Calibrate pulse height to p.e. count from finger plot
- Integrate at each optical power level
- Apply first-order corrections
  - Subtract dark (0% optical power) rate for **excess** p.e. rate
  - Changes in overvoltage/junction capacitance appears in SPE charge





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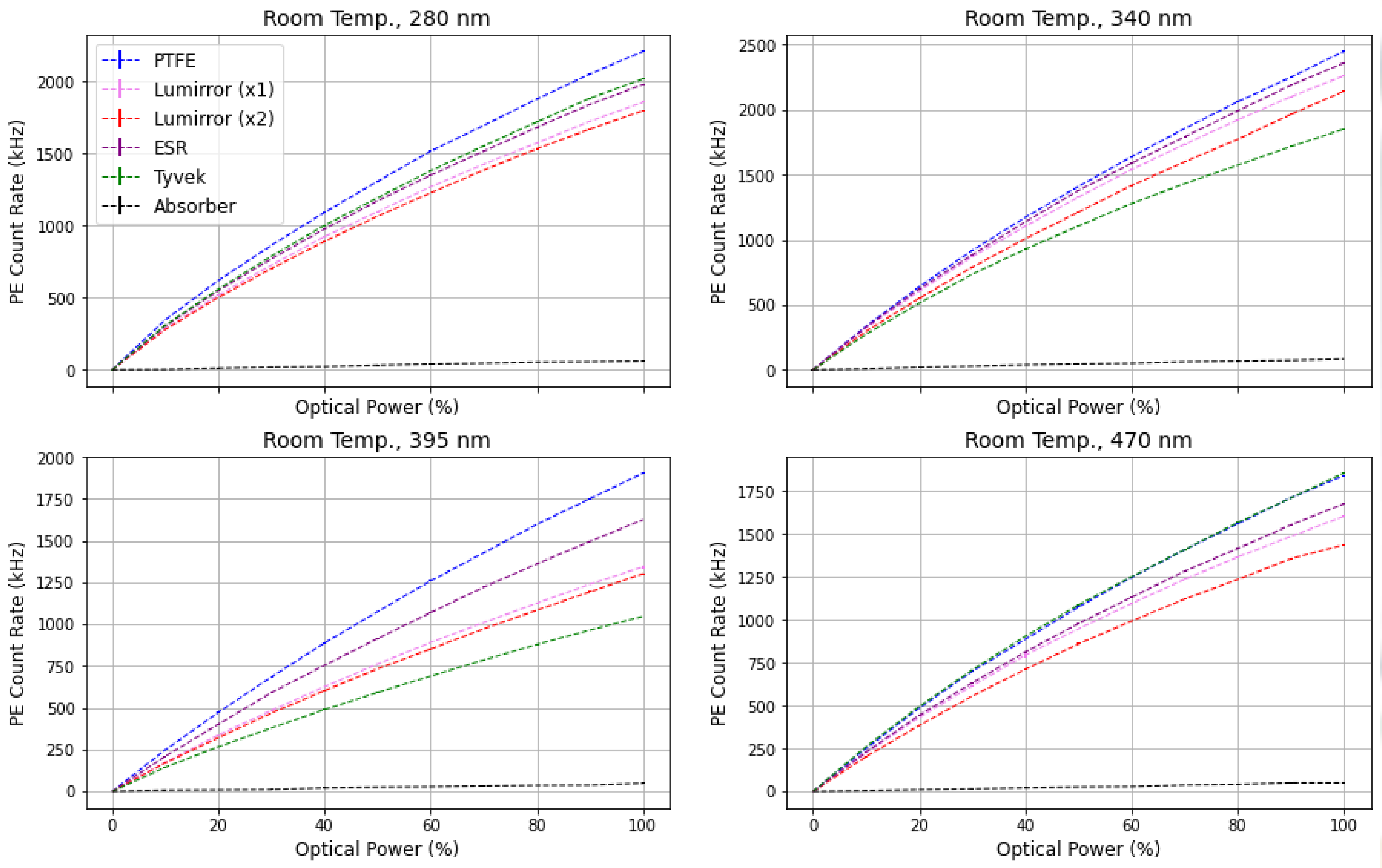


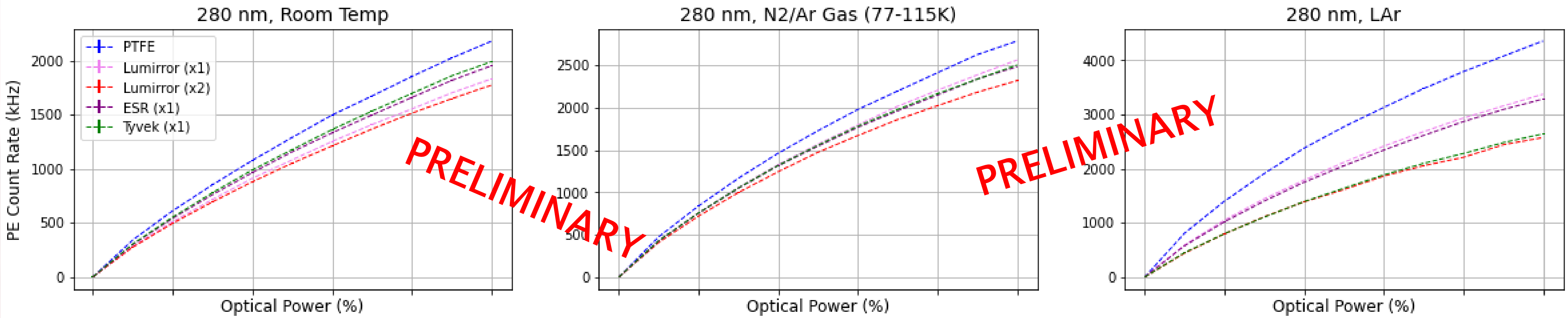
Photon rate to relative reflectance

- Compare different materials at each wavelength
  - Each optical power gives reflectance ratio

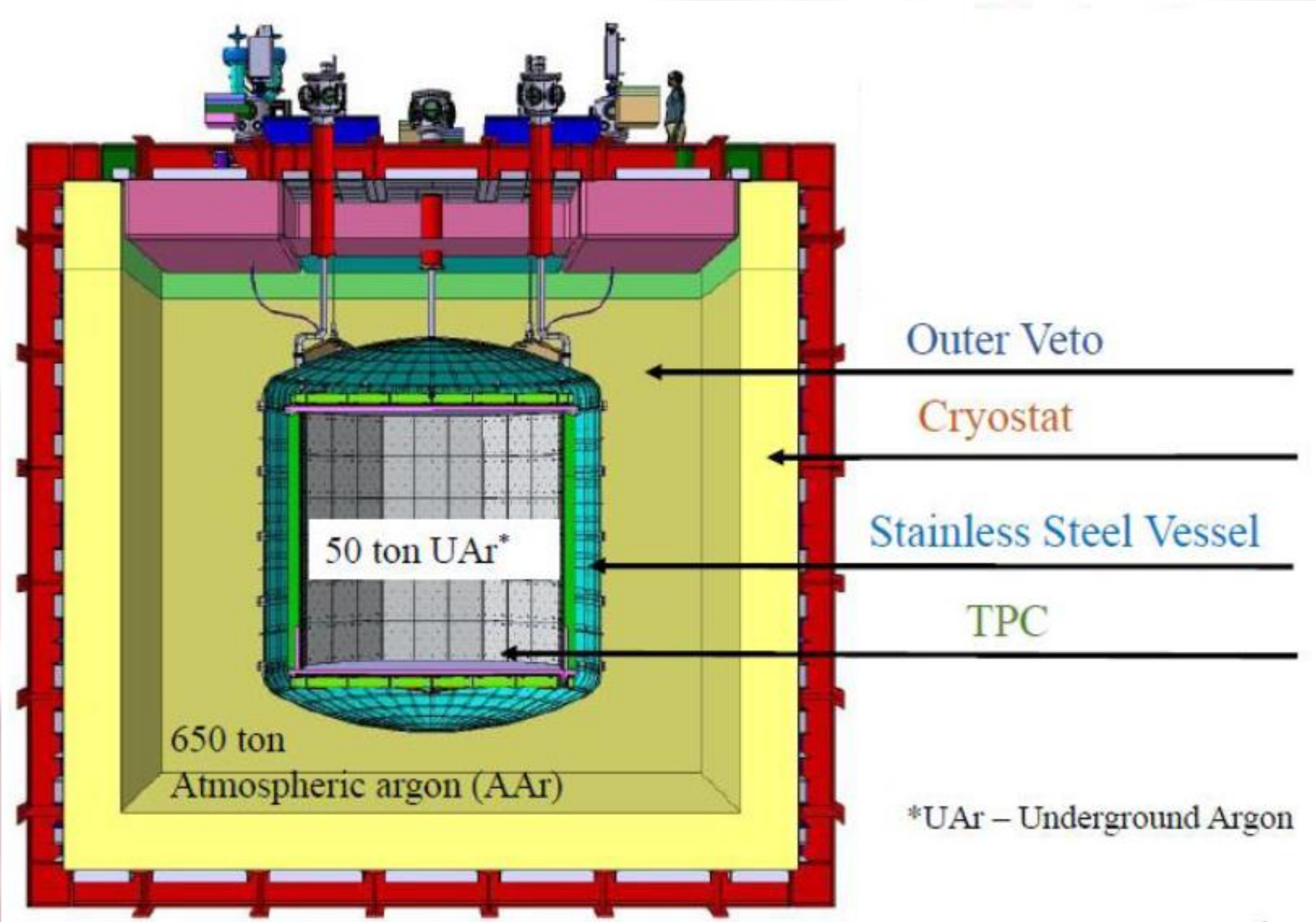
- Repeat this for cryogenic conditions…

Reflector Tests

- Next steps: apply corrections from optical uncertainties
- Purpose: outer veto material selection & analysis



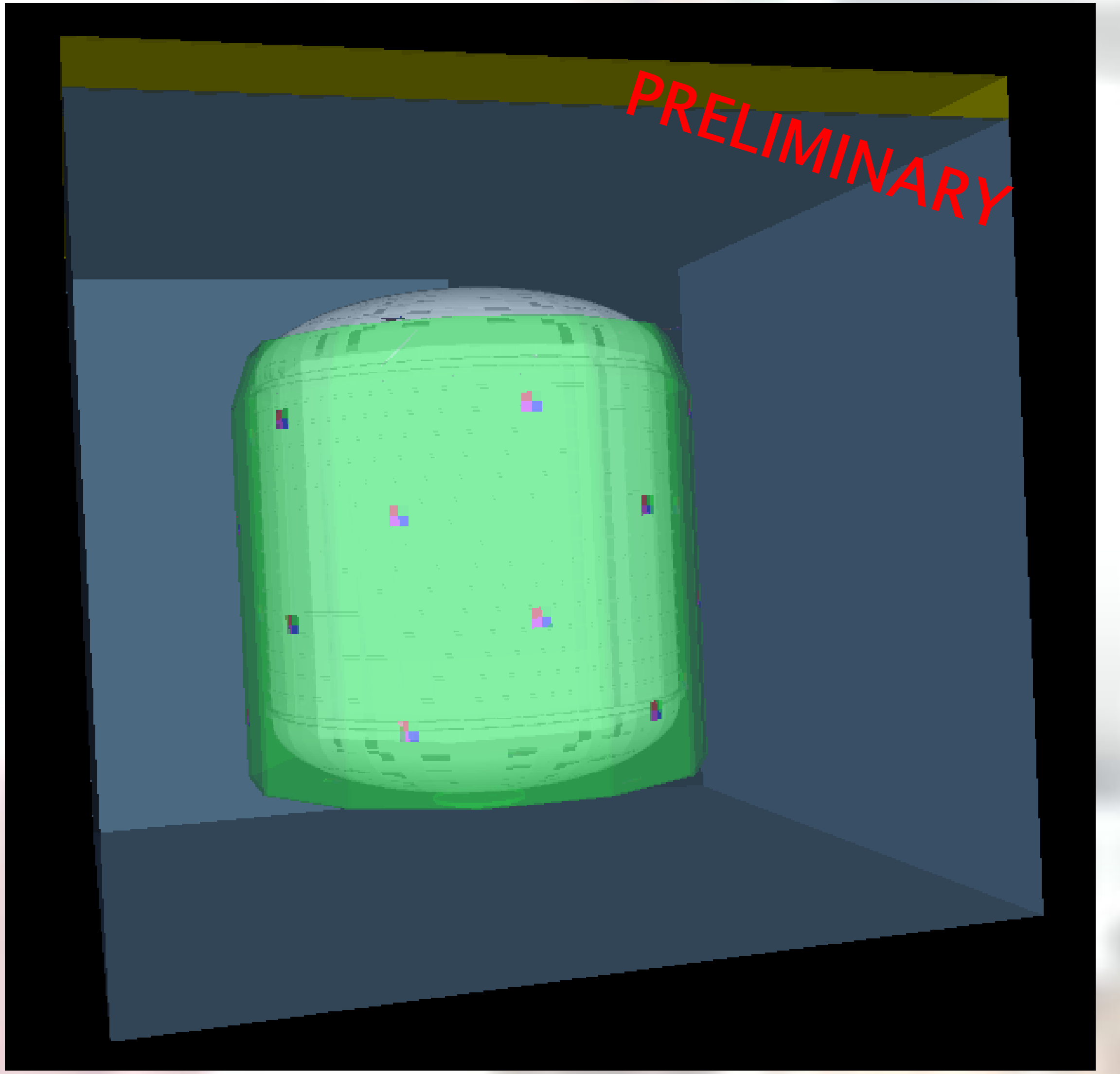
DarkSide-20k: The Muon Veto



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 Simulations



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

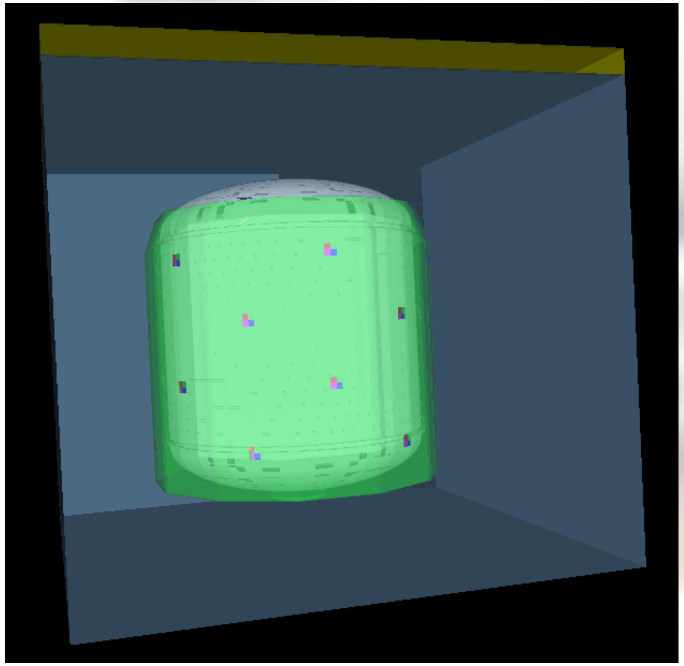
- 32x16x24 (12,288) SiPM placed on interior of muon veto
- Argon scintillation light in UV (128 nm) is **wavelength shifted** to visible
- UV & visible light must be efficiently collected
  - Diffuse, **reflective interior** acts as large integrating sphere
  - Visible photons bounce between walls multiple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

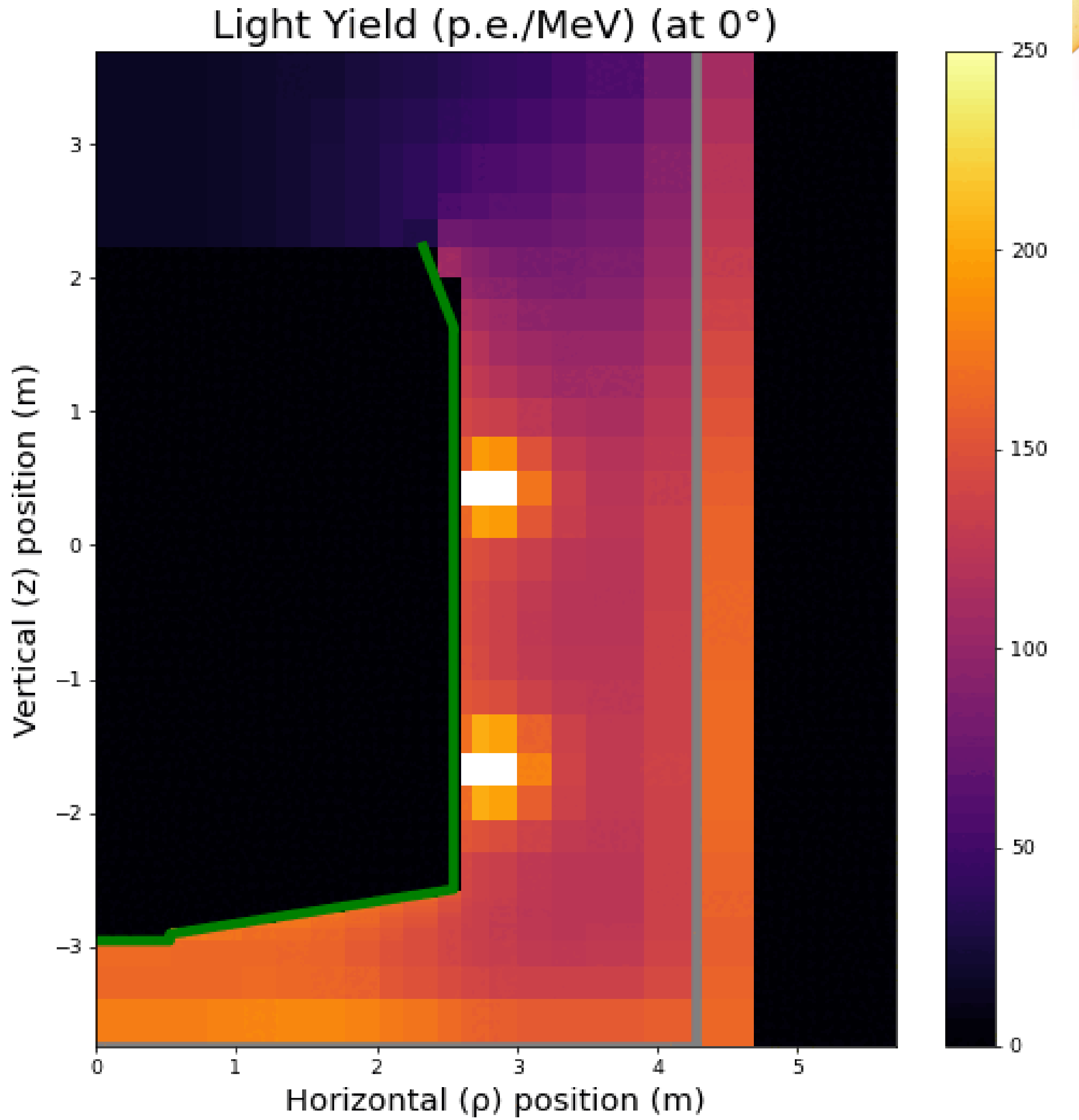
Muon Veto Simulations

<u>Light Yield Optimization</u>

- GEANT4 simulation of cosmic rays
  - Large energy depositions can take **hours** to manually track photons

- Measure number of **detected** photons (per MeV) generated in all 128 readout channels

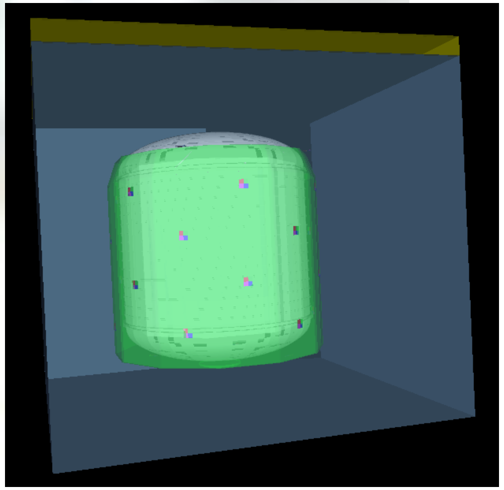


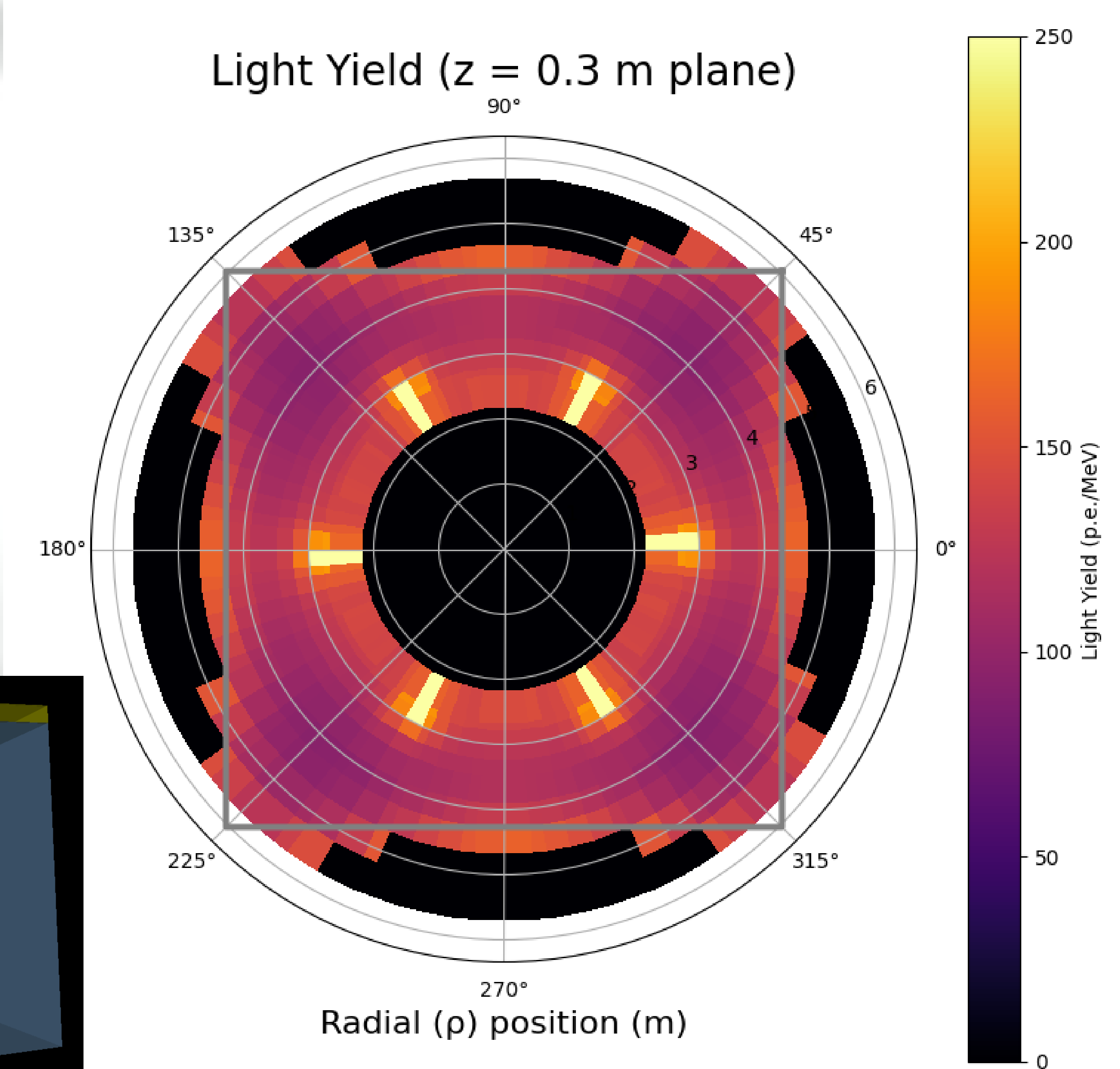


Muon Veto Simulations

Light Yield Optimization

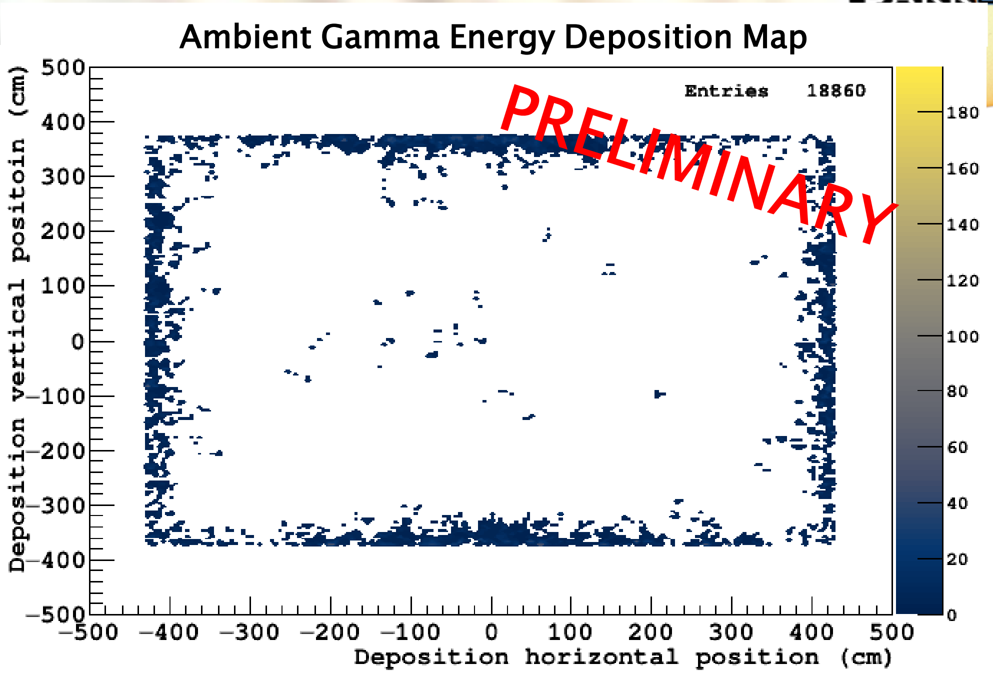
- GEANT4 simulation of cosmic rays
  - Large energy depositions can take **hours** to manually track photons
- Measure number of **detected** photons (per MeV) generated in all 128 readout channels
- Light map specifies light yield per voxel
  - Total p.e. generated
  - Channel distribution of p.e.
  - Time of flight to channel

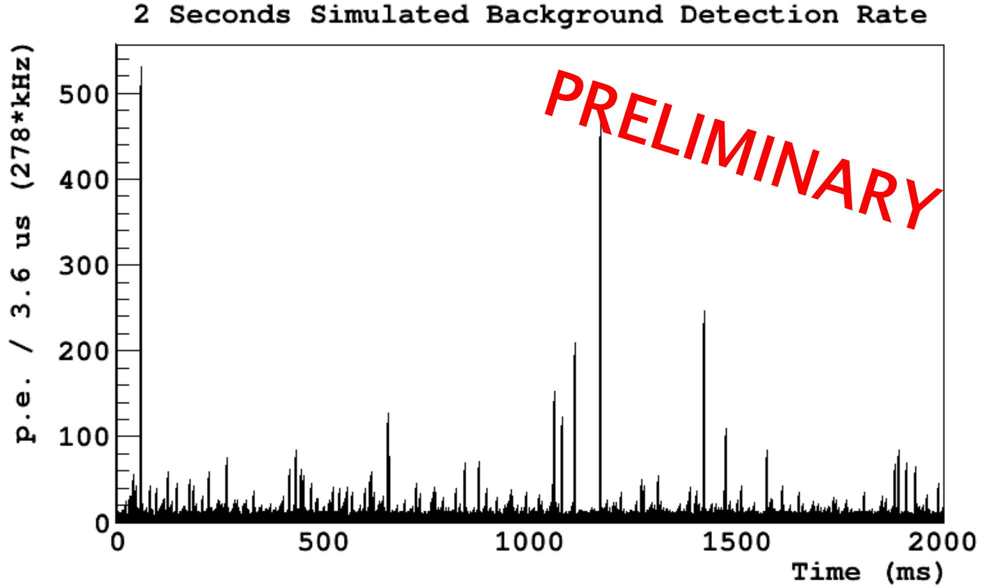




Muon Veto Simulations

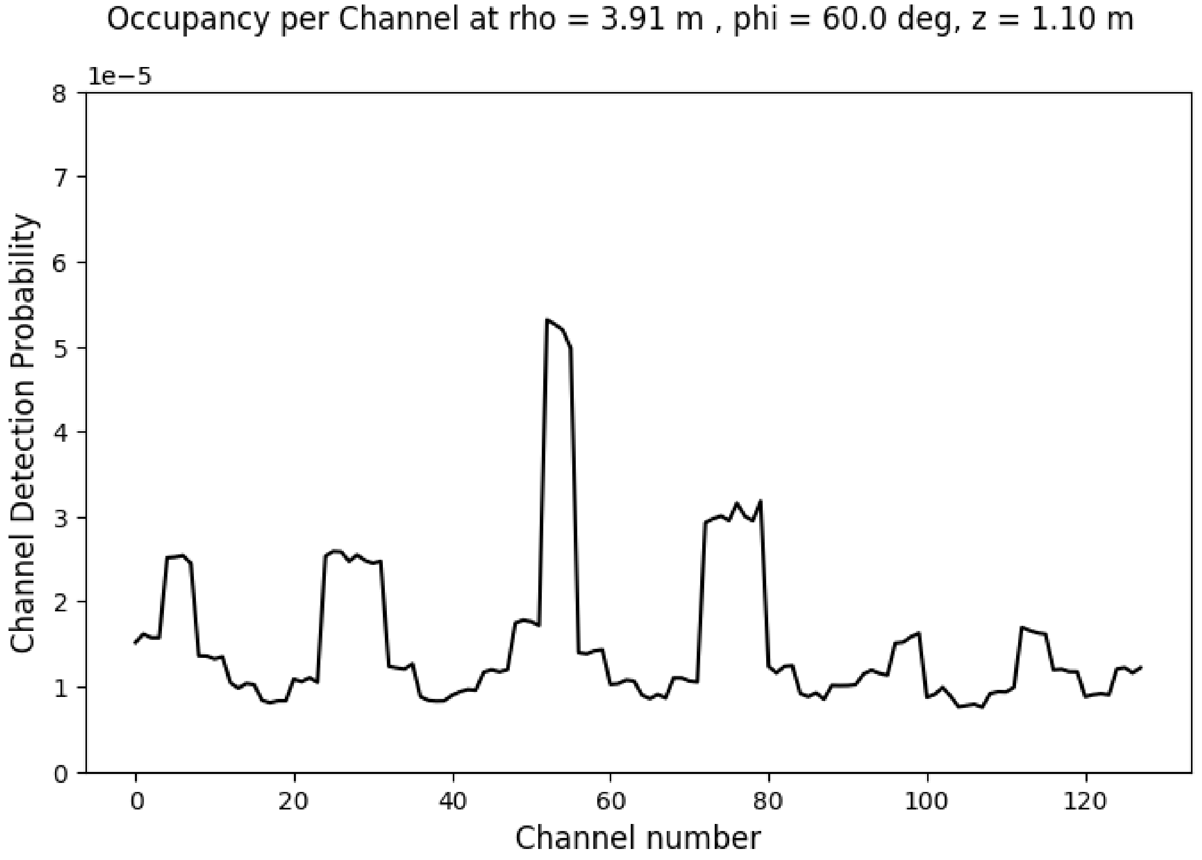
- Spatial and temporal distribution of **radioactive backgrounds**
  - Good passive shield: interactions do not reach inner veto
    - Generate constant ~200 kHz background rate per channel
  - Low background rate:
    - Can detect high energy muons above background
    - Rate changes may indicate supernova activity

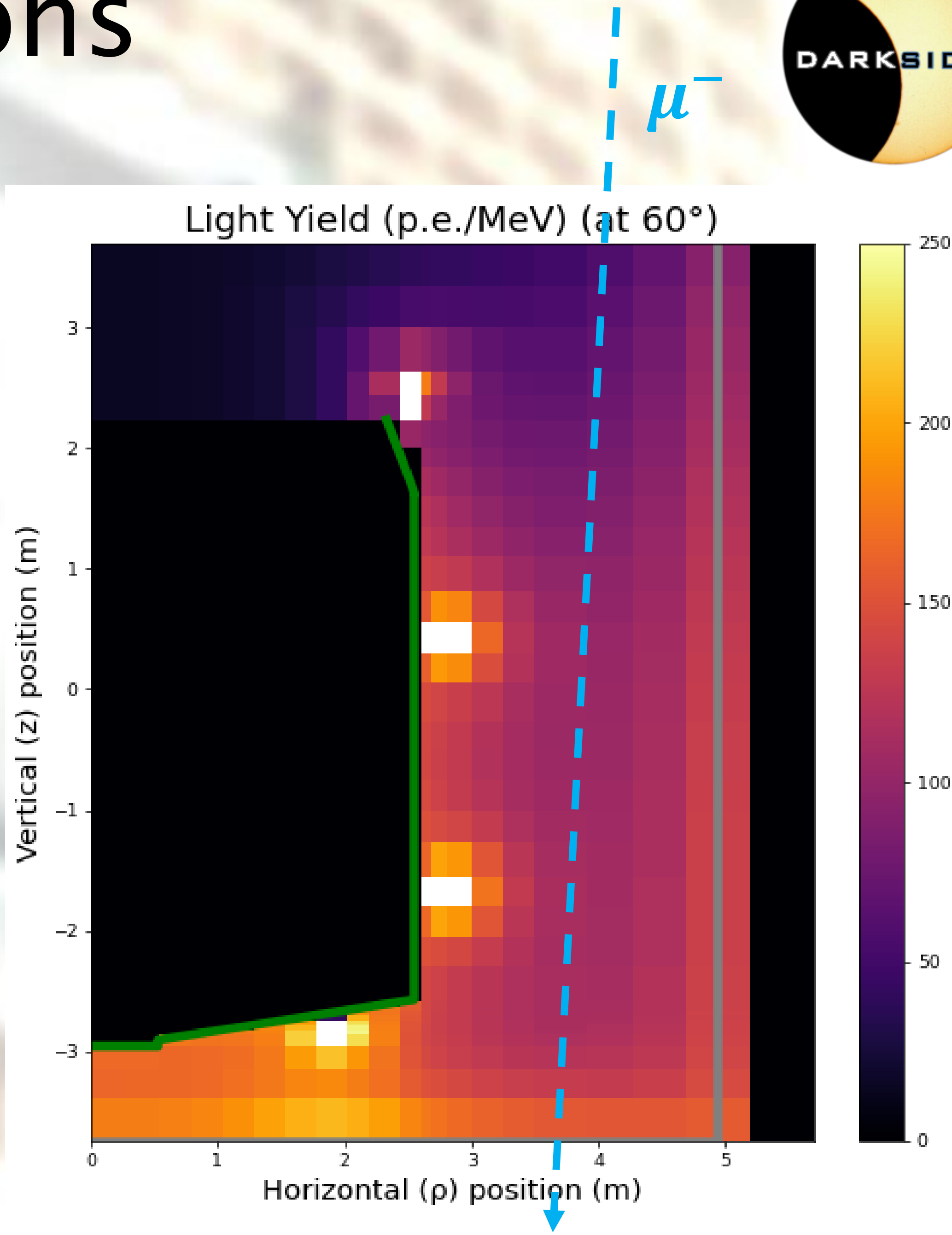




Muon Veto Simulations

- Event Simulation: interpolate light map
- Event Reconstruction: 128 channels of relative occupancy and time of arrival
  - Looking into GNN algorithms





Thank you!

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