# The SBND Photon Detection System

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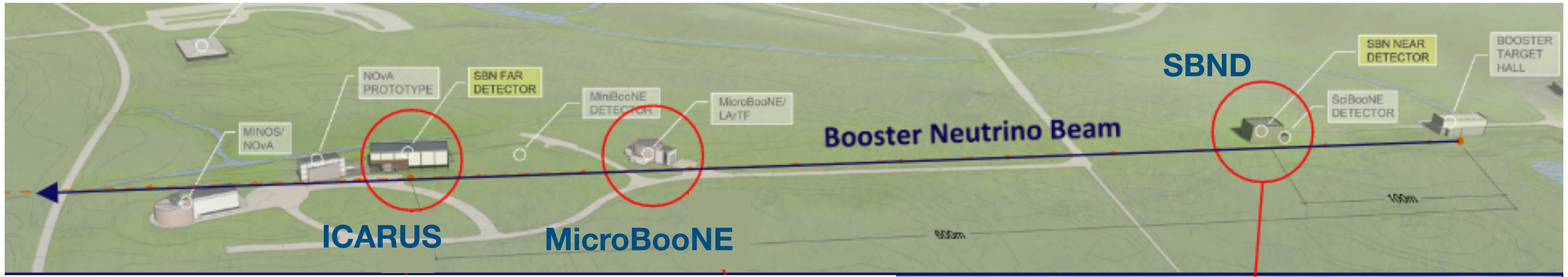
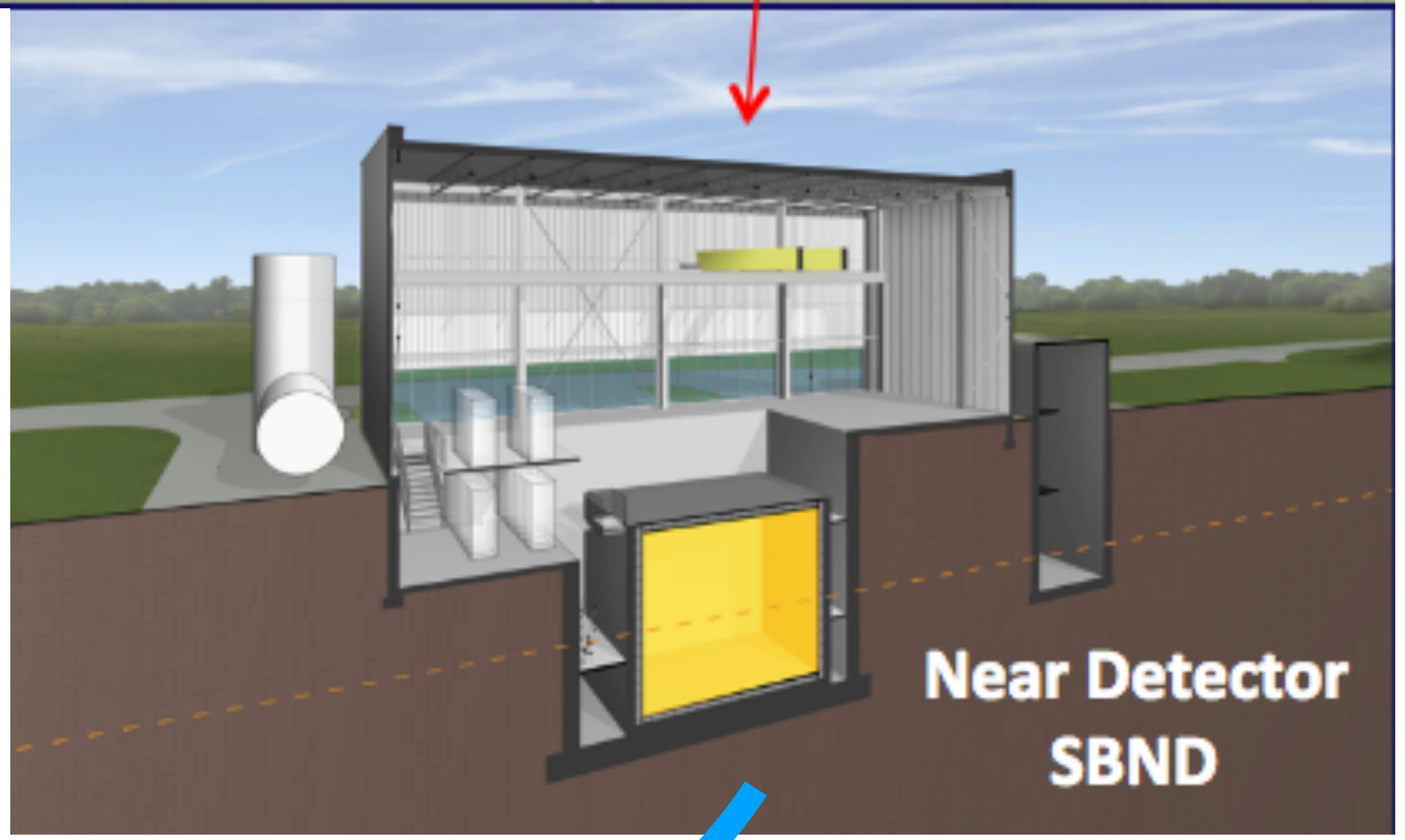
# SBND (Short Baseline Near Detector)

- Part of the Short Baseline Neutrino (SBN) program at Fermilab
  - Aims to search for light sterile $\nu$'s, perform $\nu$ interaction measurements, BSM physics
  - Liquid Argon Time projection Chamber (LArTPC) technology
- SBND installation complete, currently in the commissioning phase
  - Detector move tomorrow!



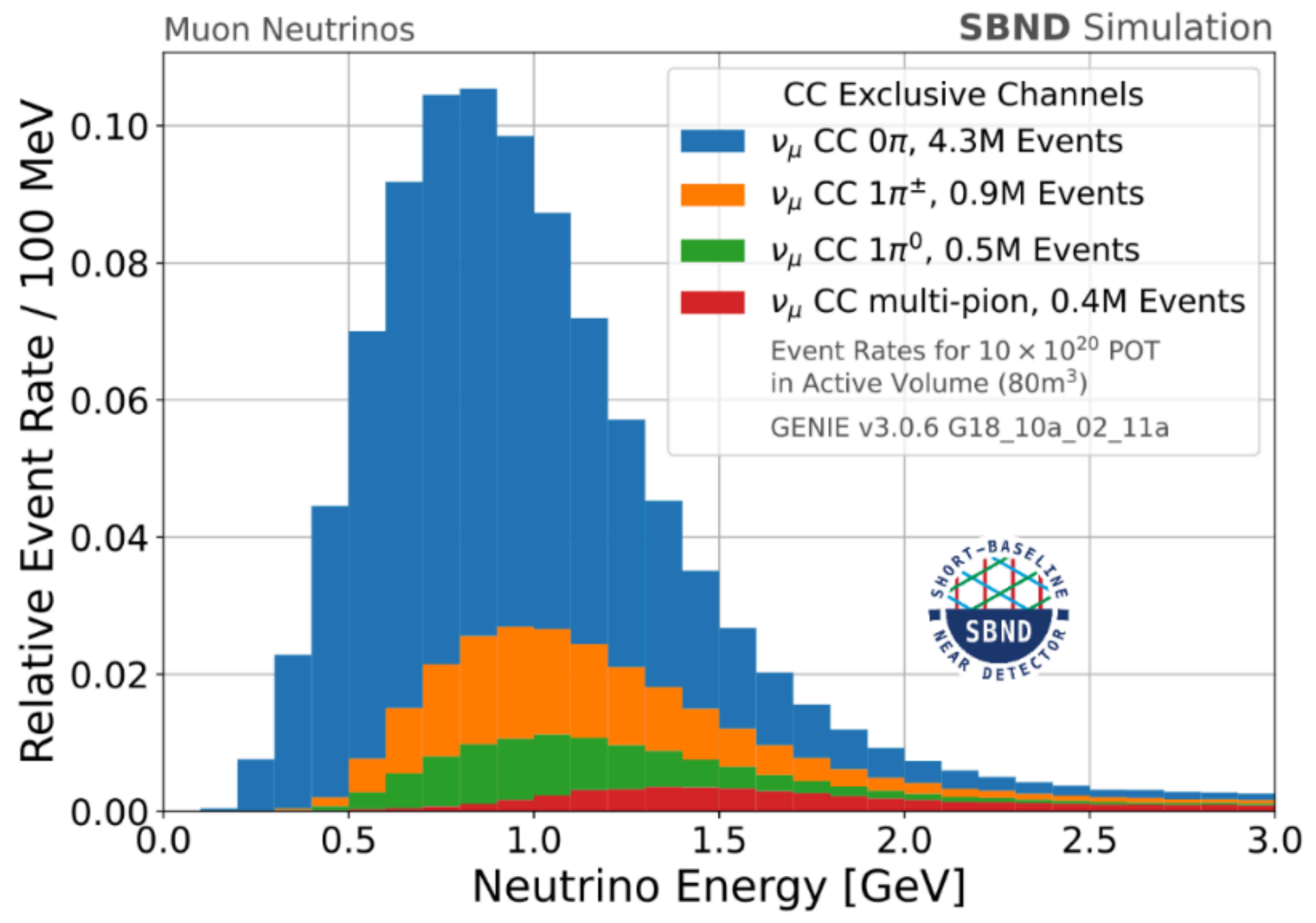




**SBND is located 110 m from the BNB target**

# The SBND Physics Program

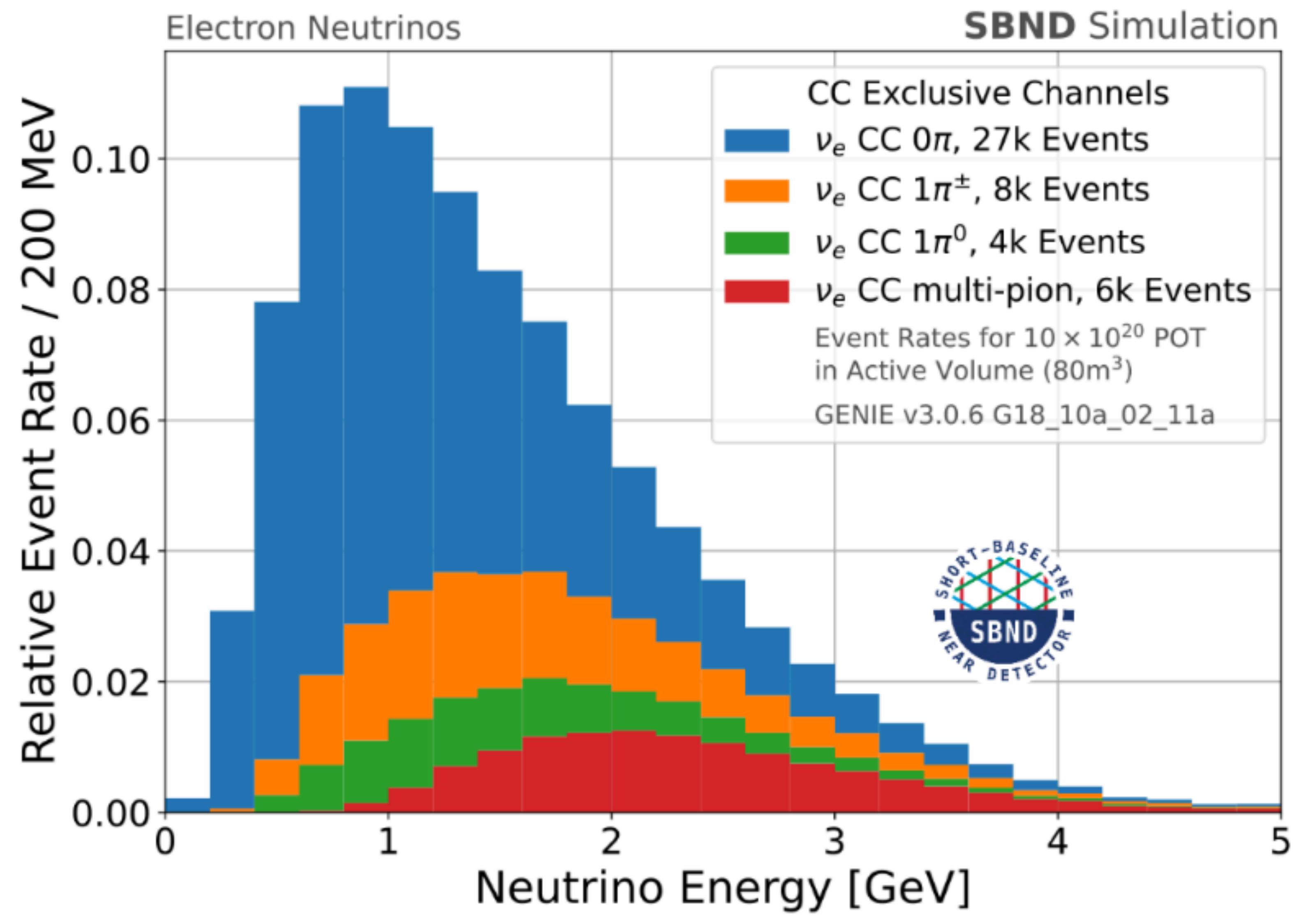
- As the detector nearest to the beam target, plan to measure un-oscillated neutrino flux for SBN
- Reduce systematic uncertainties for sterile neutrino search in SBN
    - Flux normalization and cross-section systematics
- SBND will have the largest statistics of $\nu$-Ar interactions ever recorded!
    - Perform high statistics cross-section measurements on LAr
    - Quantify $\nu$-Ar scattering effects
    - High-statistics at SBND aid BSM searches (possible new physics in BNB)
- R&D for future LArTPC experiments

CC event rate for 10e20 POT: ~6M $\nu_\mu$ CC (+ ~2M $\nu_\mu$ NC)



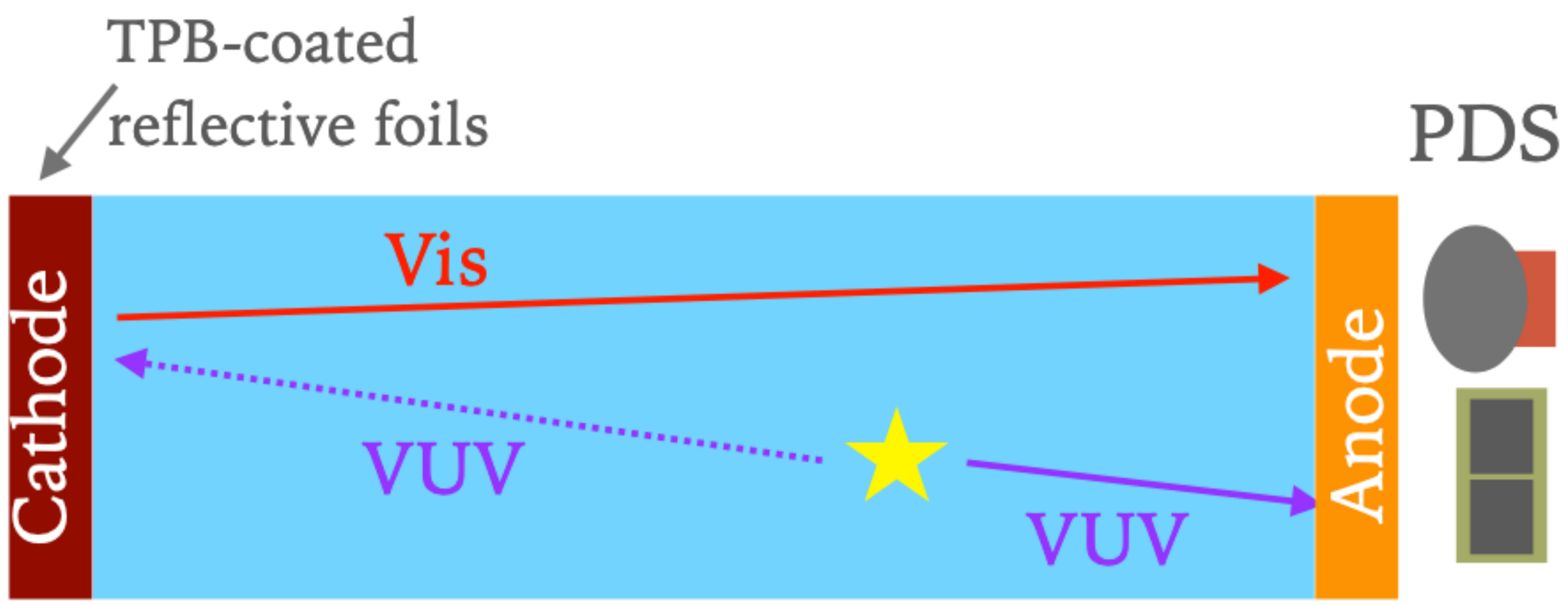

~1 GeV

CC event rate for 10e20 POT: ~50k $\nu_e$ CC



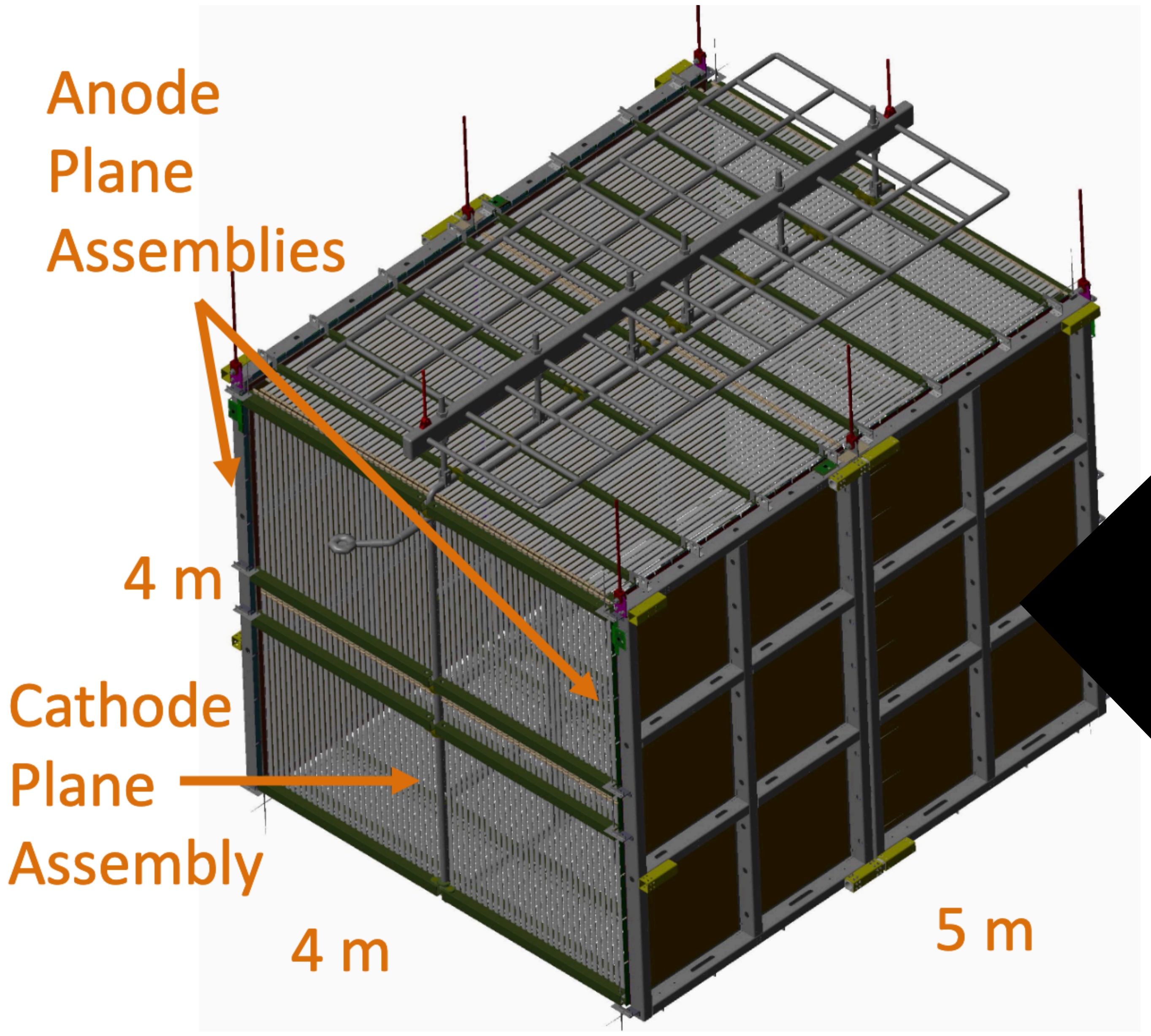
# Light in SBND

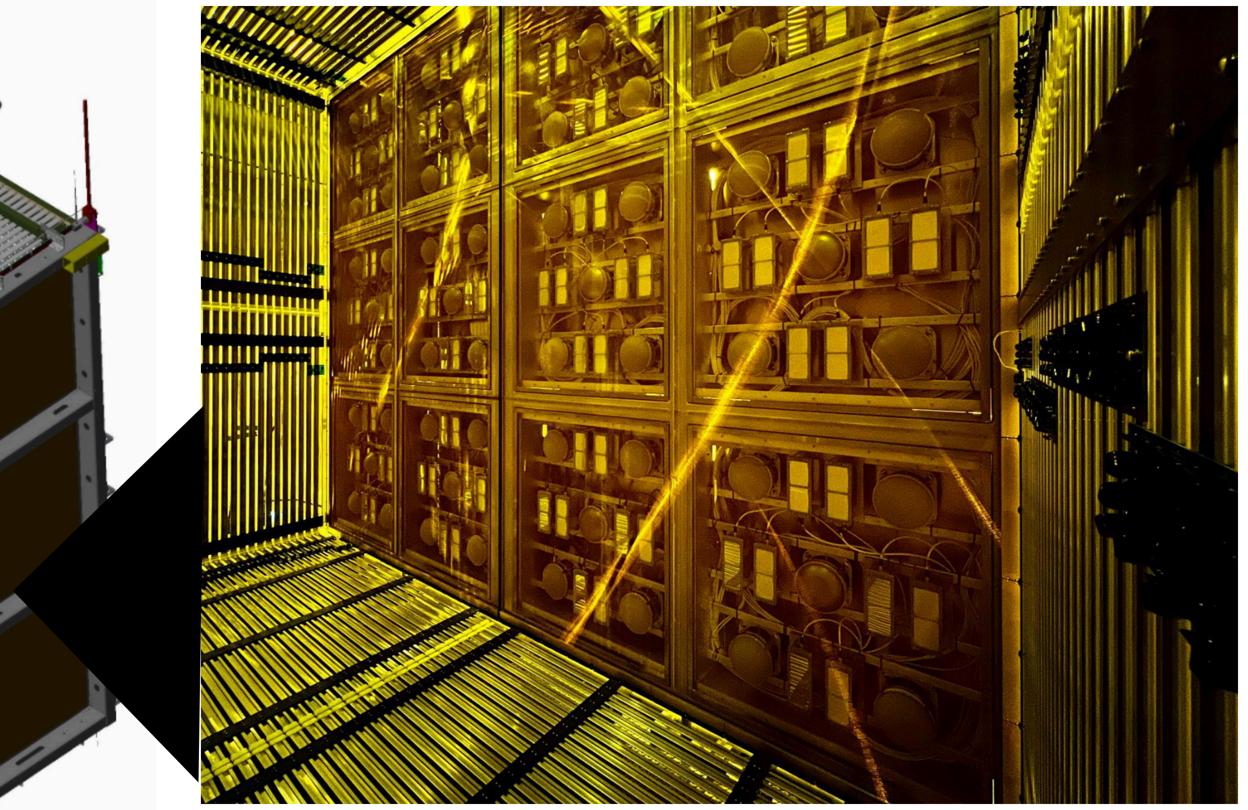
- Light information for low energy events
  - SBND is a surface detector
  - PE used for neutrino discrimination
- SBND will use an efficient and high resolution photon detection system, with enhanced light collection and uniformity
  - High density of optical channels
  - Different types of photodetection technology
  - Sensitivity to both vacuum ultraviolet (VUV) and visible light
    - VUV emitted in LAr volume from scintillation
    - Wavelength-shifter coated surfaces re-emit light in the visible spectrum
    - Will allow for x-position determination and possibly search for new physics (e.g. with Cherenkov light)



# The SBND Detector

- Detector dimensions: 4m x 4m x 5m
- 112 tons of active LAr
- Two TPCs, joined by cathode plane in the center
- Anode planes split into 3 wire planes with pitch of 3 mm
  - ~11,000 wires total per Anode Assembly Plane (APA)
- Will have a nominal electric field of 500 V/cm
- Photodetectors installed at anode planes

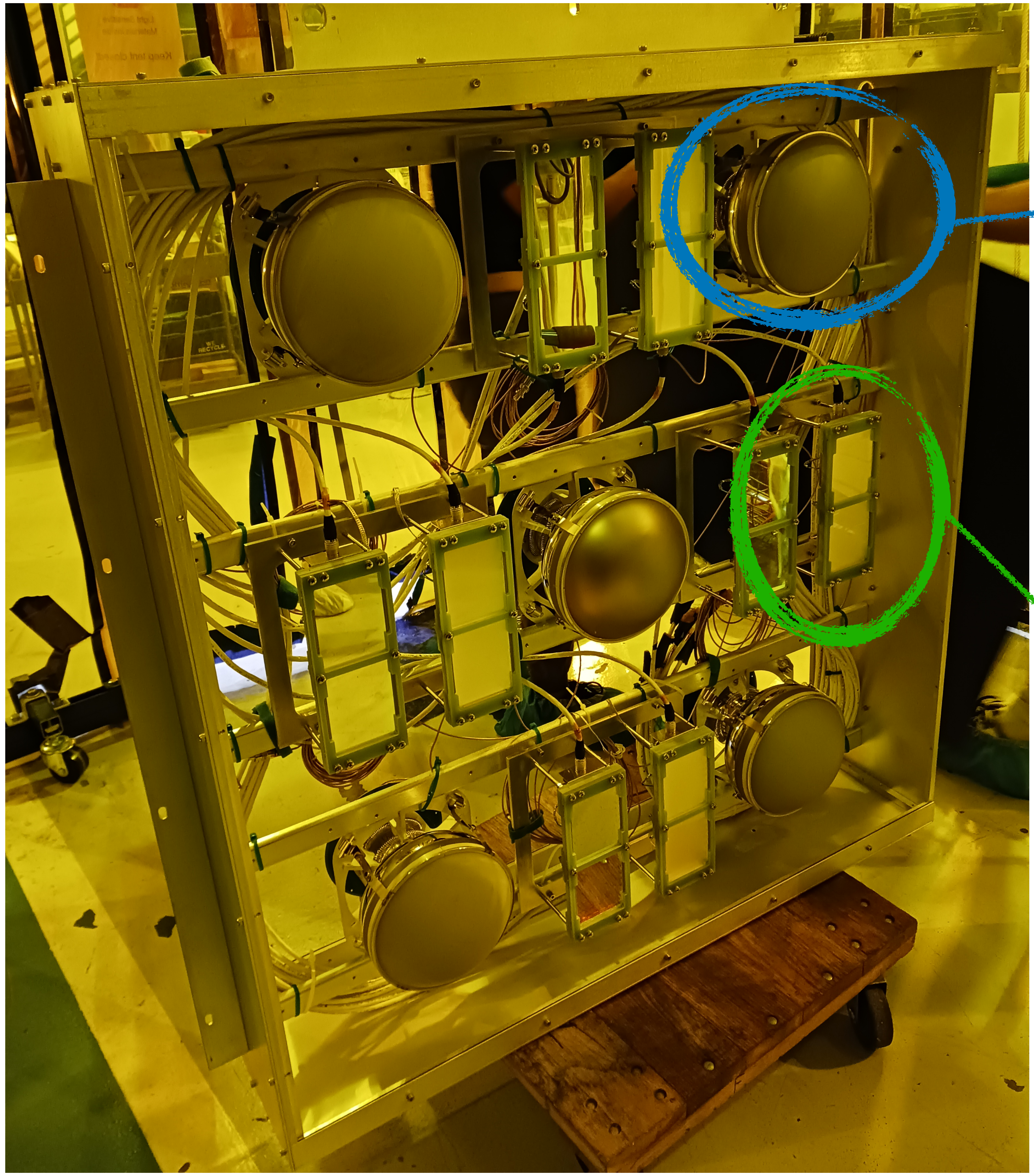


**Inside one of the two SBND TPCs**

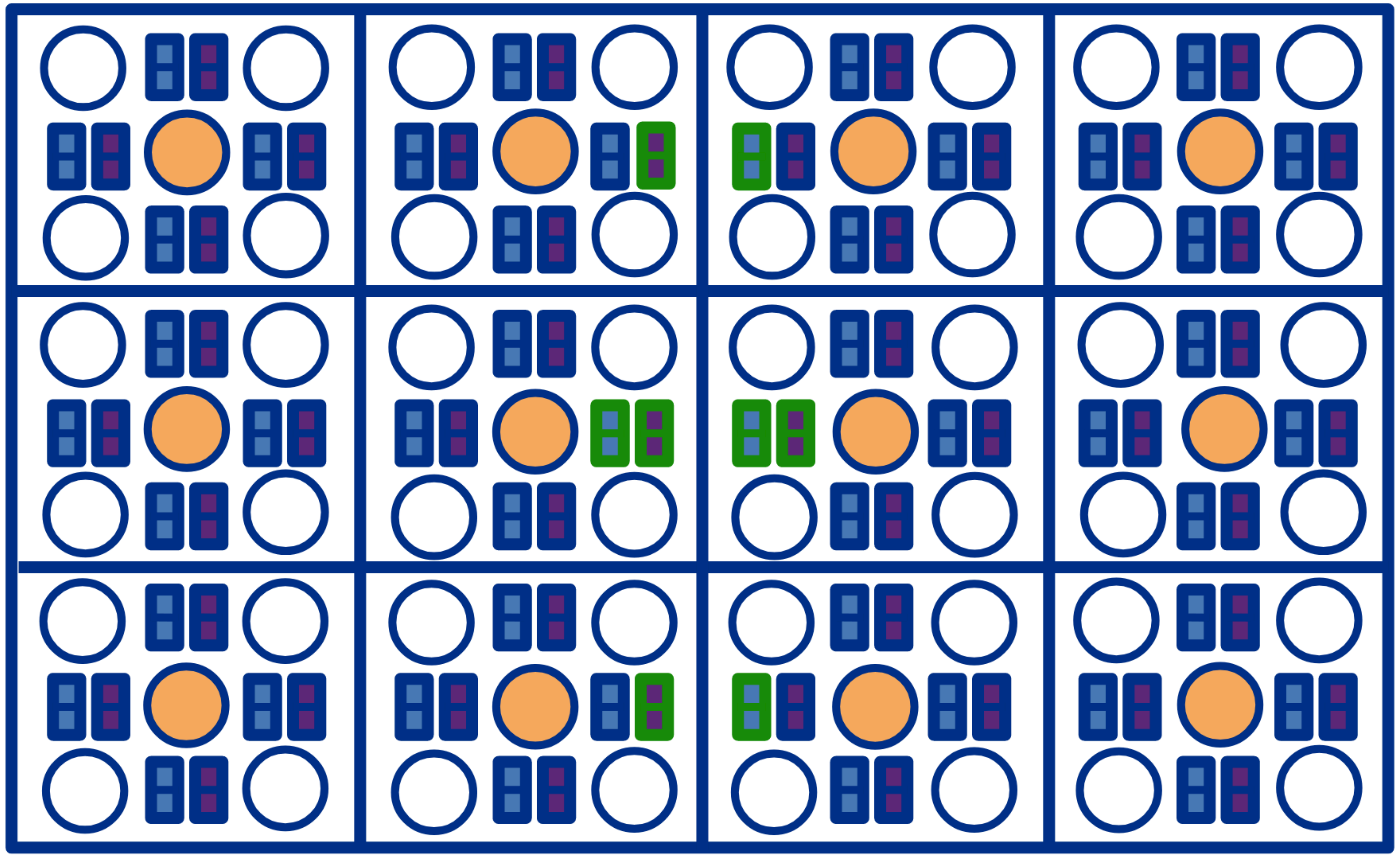
# Photon Detection System (PDS) Overview

- **SBND uses two sets of photodetection technology:**
  - **Photomultiplier tubes (PMTs)**
  - **A series of X-ARAPUCA devices (two types)**
- Fraction of photodetectors coated with wavelength shifter to detect scintillation VUV light, others detect only visible light
- SBND PDS also has:
  - Wavelength-shifting reflective plates installed at the cathode
  - A diffusers calibration system



# SBND PDS Boxes

- Total of 24 PDS boxes installed in SBND
- 12 behind each wire plane



Blue: X-ARAPUCA visible-sensitive

Purple: X-ARAPUCA VUV-sensitive

White: TPB-coated PMT (VUV + visible sensitive)

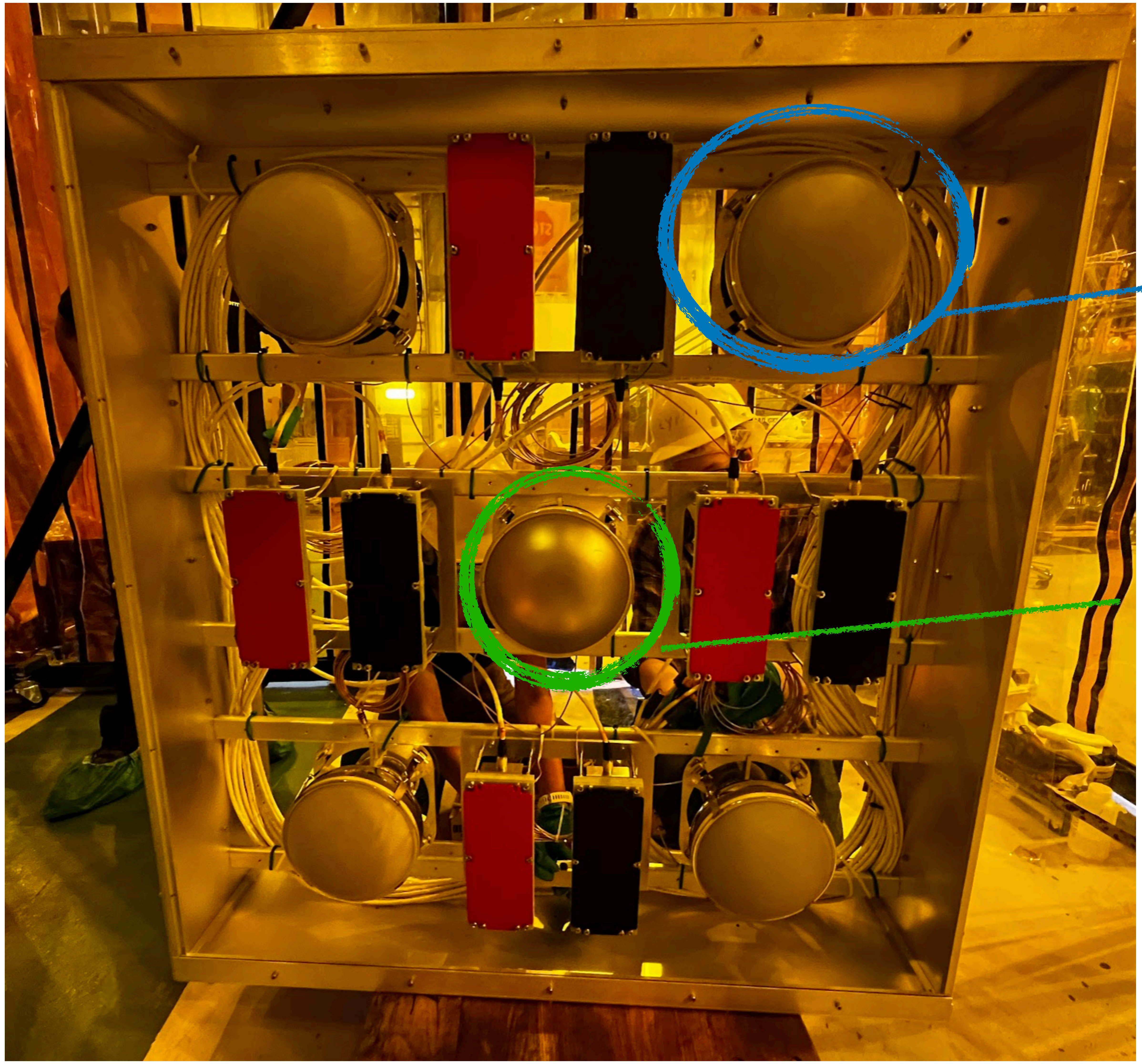
Green Outline: APSAIA X-ARAPUCA

Orange: Uncoated PMT (visible sensitive only)

Dark Blue Outline: DAPHNE X-ARAPUCA

# PMTs

- Total of 120 Hamamatsu 8" R5912 Cryogenic PMTs mounted behind the wire planes
  - 96 PMTs are coated with tetraphenyl-butadiene (TPB) to detect scintillation VUV
  - 24 are not TPB-coated to detect only visible light
- PMTs were tested/calibrated in the Coherent CAPTAIN-Mills detector at Los Alamos National Laboratory
- Use CAEN 1730B flash-ADC (500 MHz) readout electronics

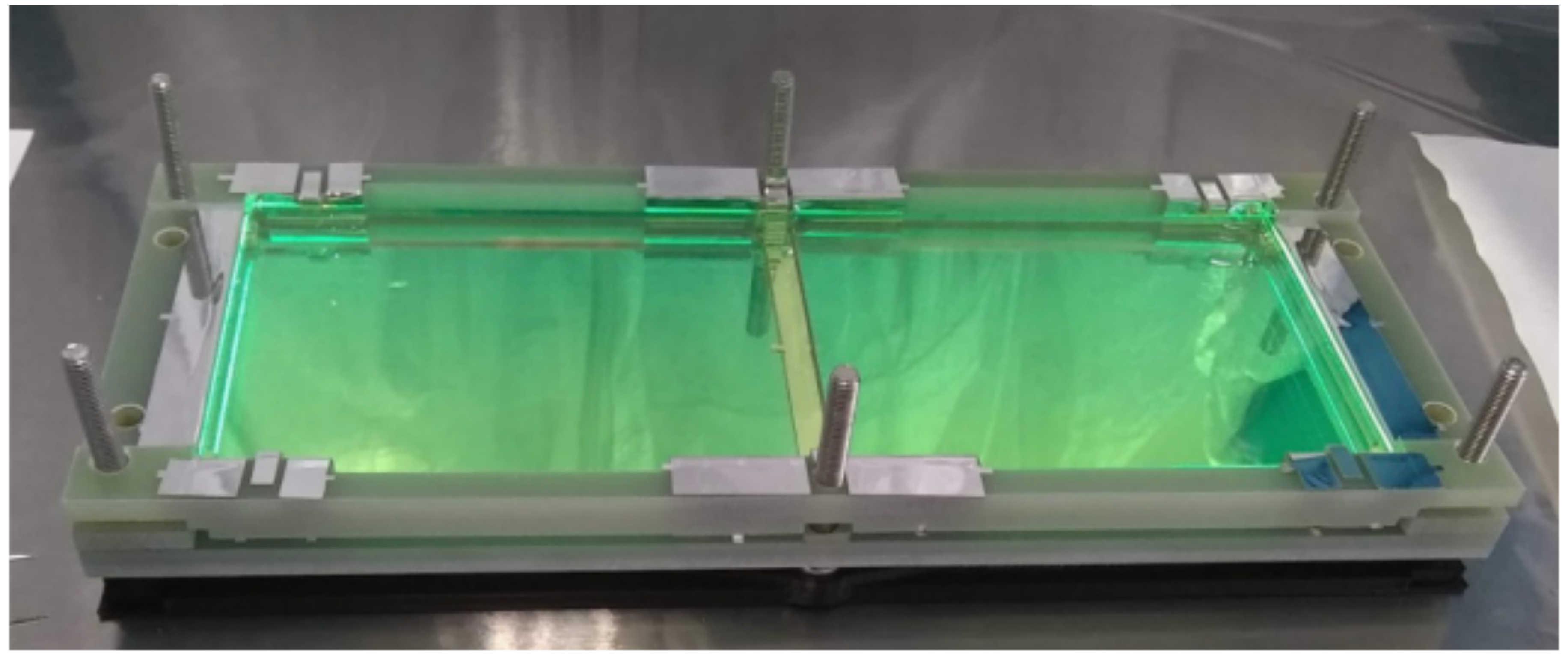


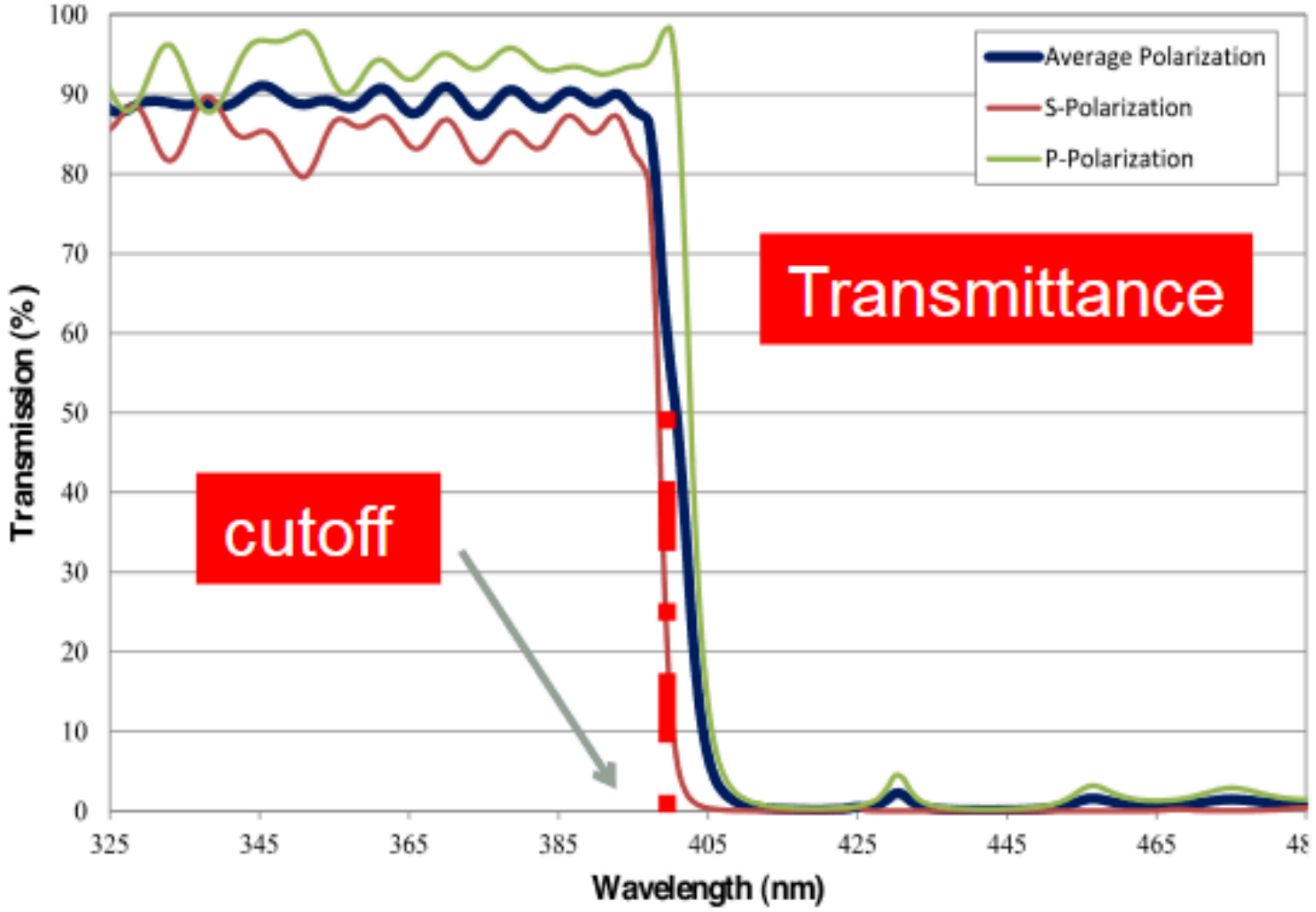
Wavelength shifter coated PMT

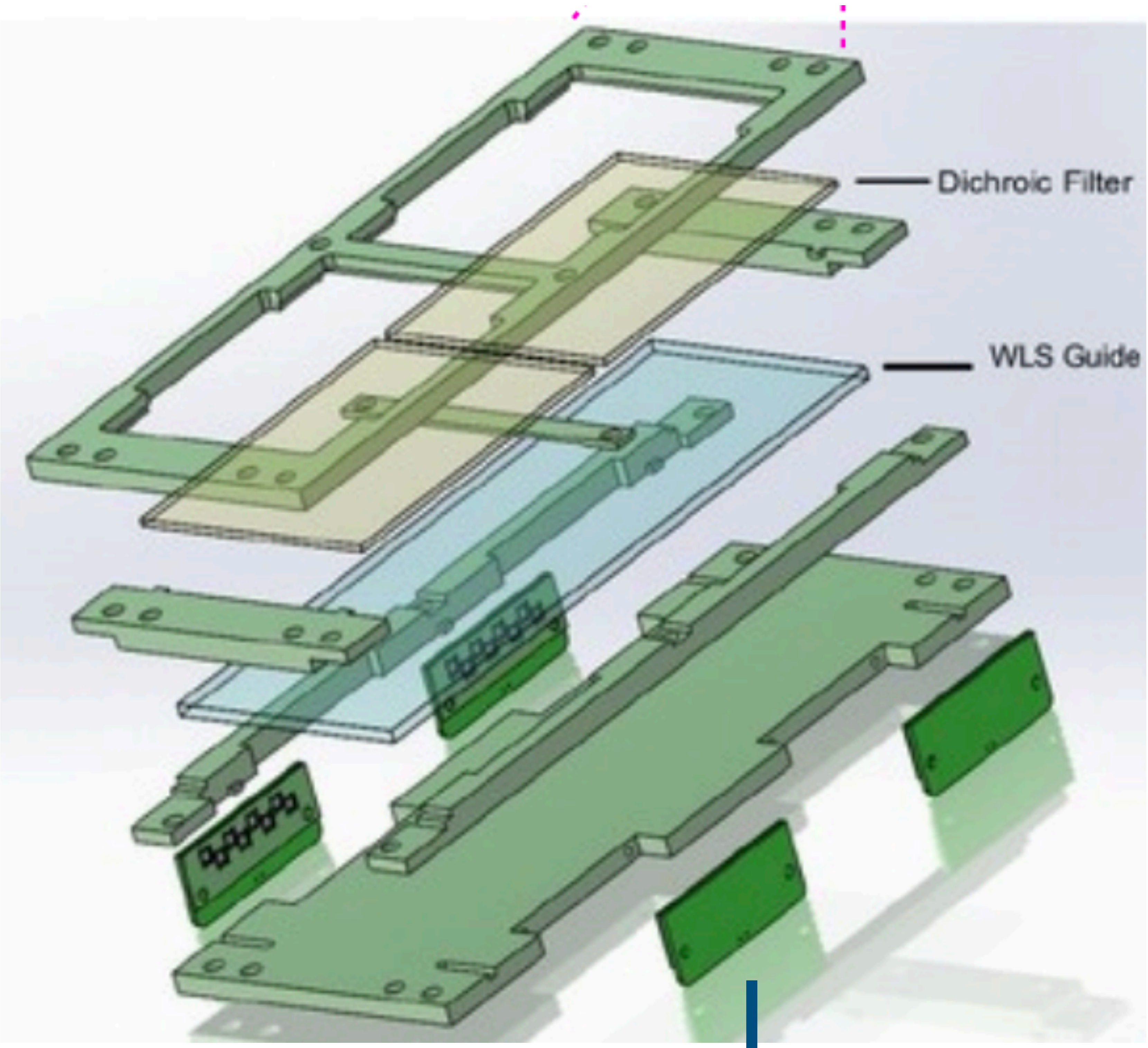
Uncoated PMT

# X-ARAPUCA Light Collection System

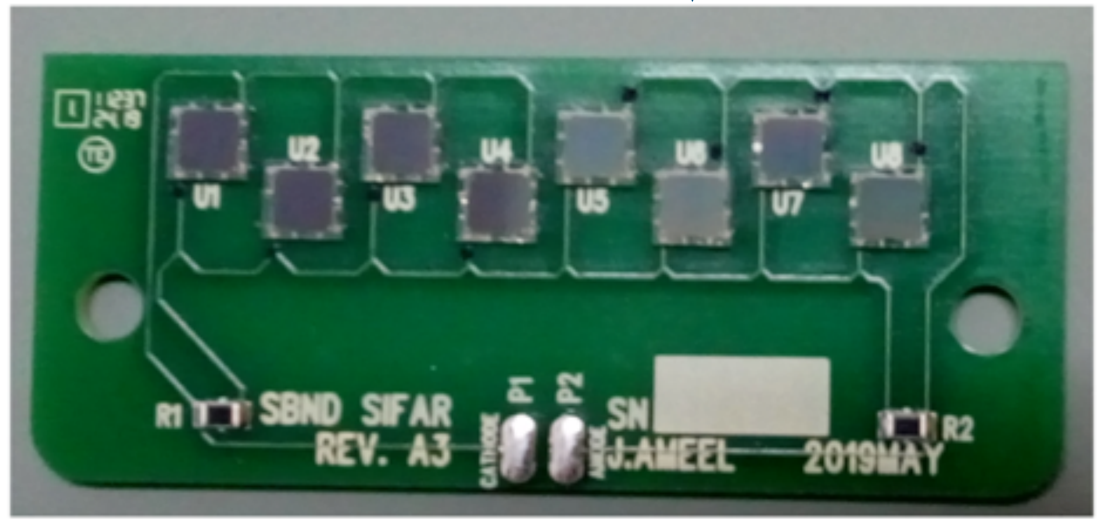
- "Arapuca:" Native Brazilian for "bird trap"
- An X-ARAPUCA unit is a light trap
  - Light enters through dichroic filter
    - Transmits photons below a cutoff wavelength
  - Wavelength shifted by light guides
    - Shifts light inside to wavelength where filter is reflective, trapping light
  - Light collected by a set of 4 boards containing an array of 8 SiPMS each





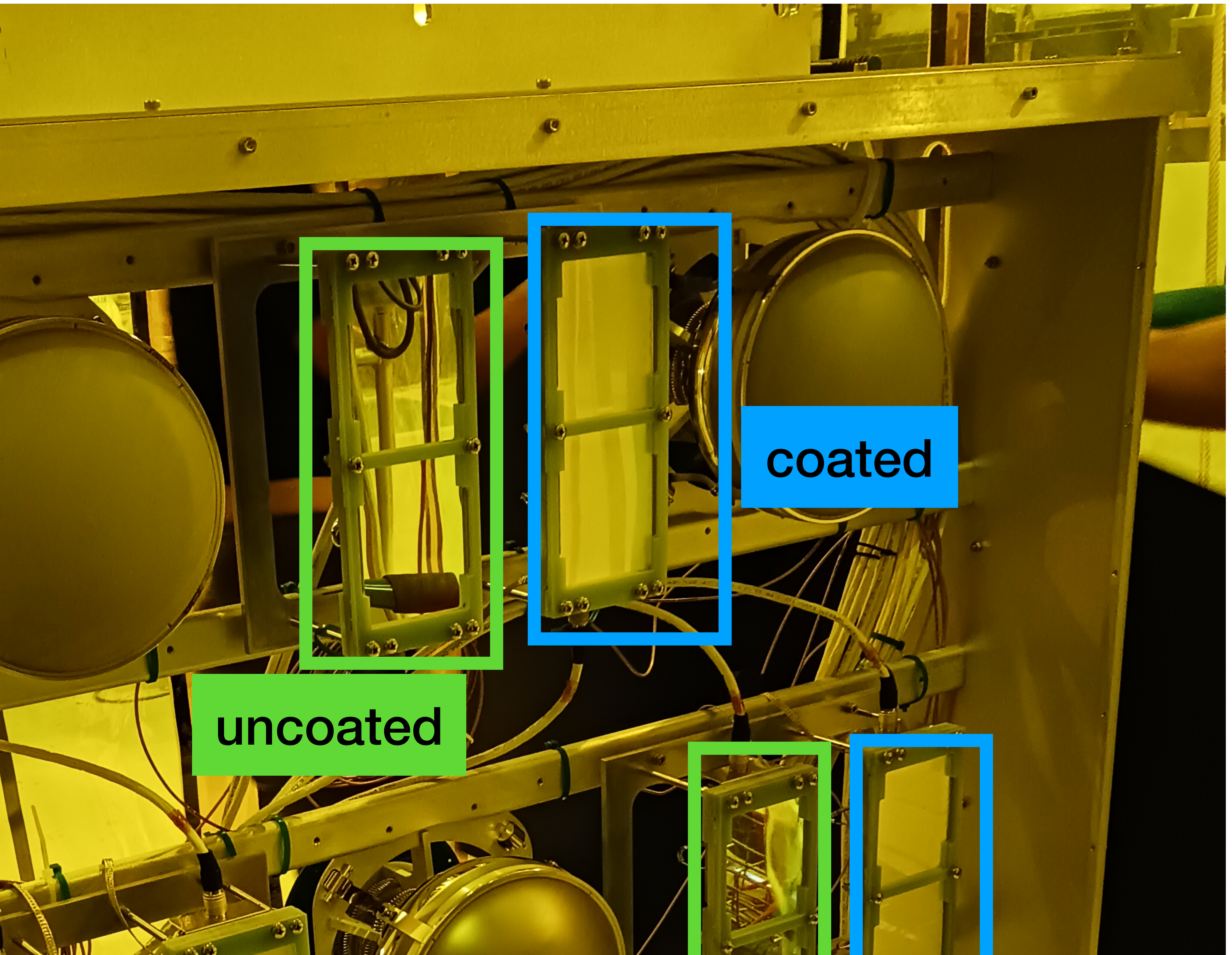

DUNE horizontal drift far detector PDS will also use similar X-ARAPUCA devices!

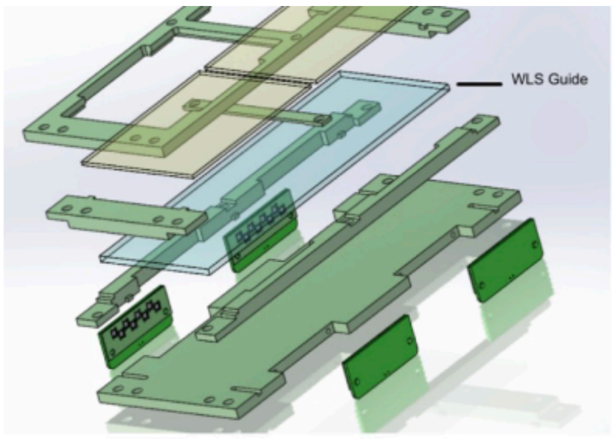



Example module and SiPM board for one of the types of X-ARAPUCA (DAPHNE)

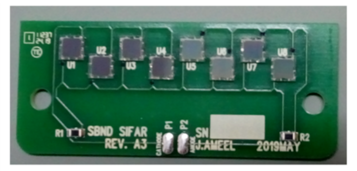
# SBND X-ARAPUCA System Overview

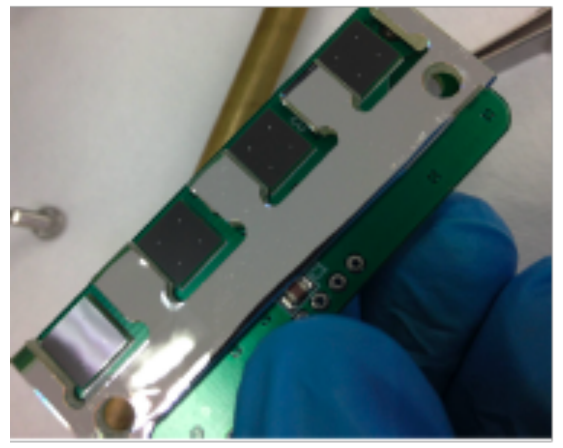
- Total of 192 X-ARAPUCA devices
  - Split between DAPHNE & APSAIA
    - Difference in readout, types of SiPMs used
- Half of devices sensitive to visible light, other half to VUV



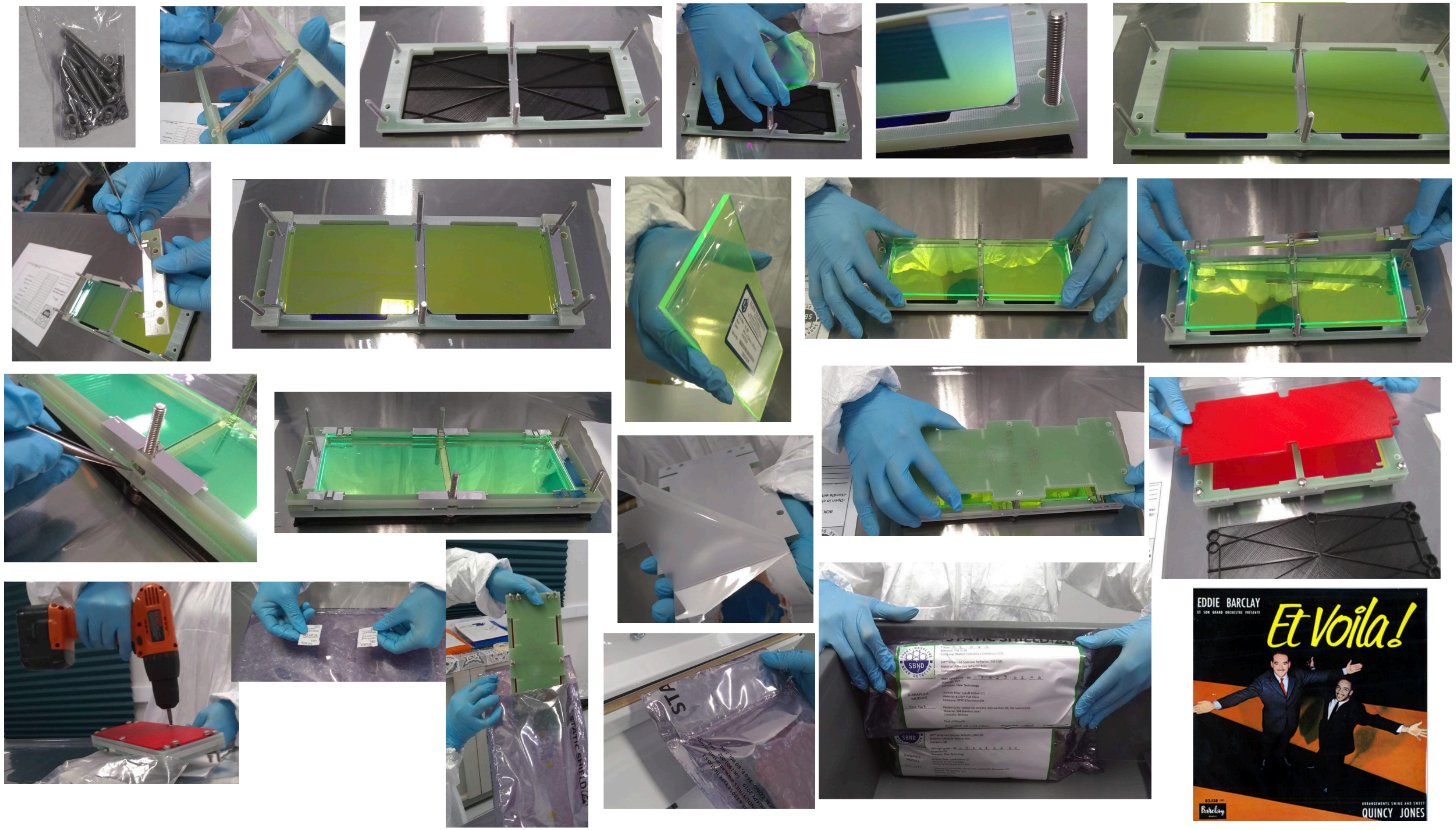

- **192 modules**
  - **176 DAPHNE** readout (SensL SiPM)
    - 88 VUV light (Even)
      - 400nm cutoff pTP coating EJ286
    - 88 Visible light (Odd)
      - 450nm cutoff EJ280
  - **16 APSAIA** readout (Hamamatsu SiPM)
    - 8 VUV light (Even)
      - 400nm cutoff pTP coating Glass to Power Blu
    - 8 Visible light (Odd)
      - 450nm cutoff Glass to Power Green





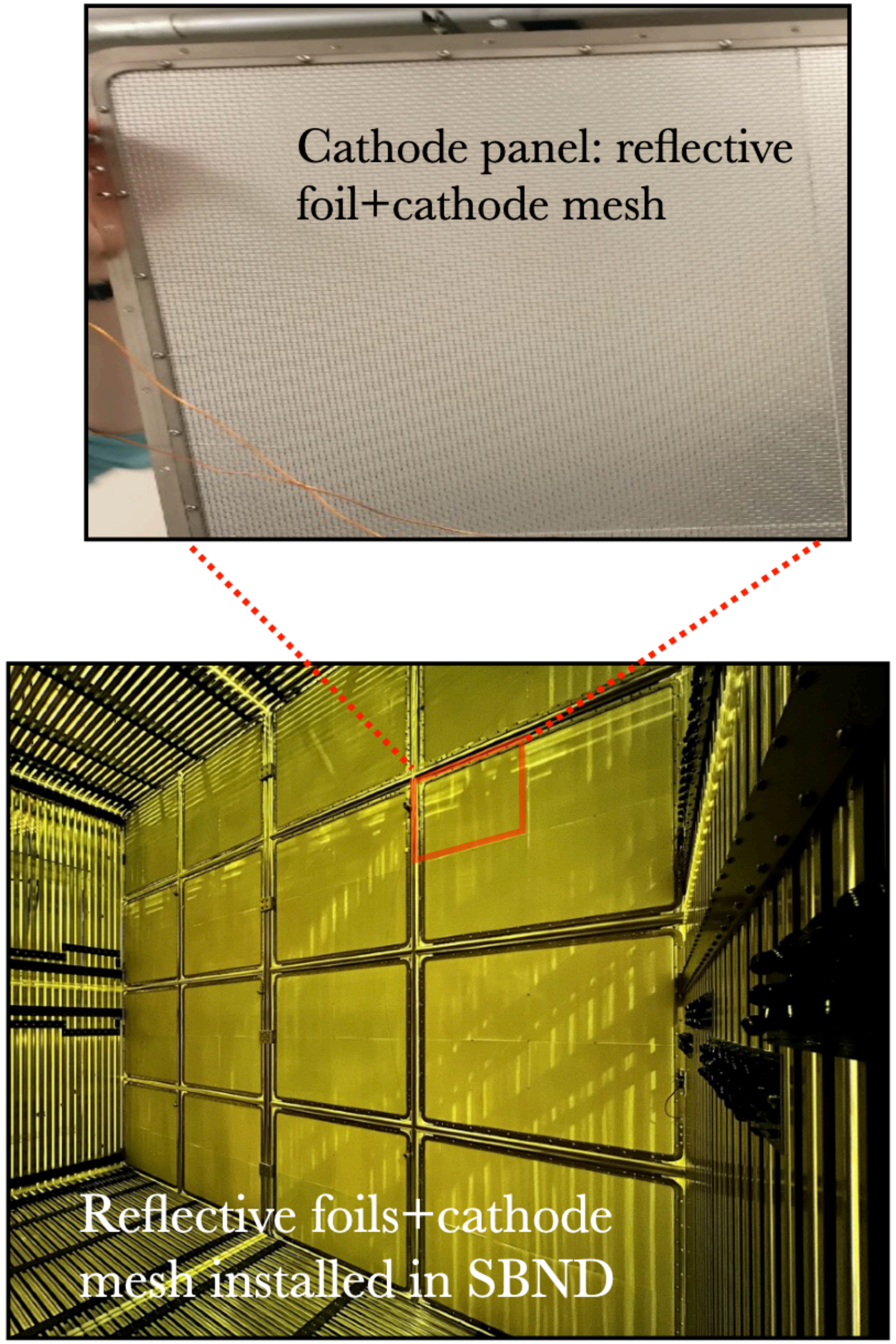
**Same SiPM and light guides that will be used for DUNE**

# X-ARAPUCA Module Assembly

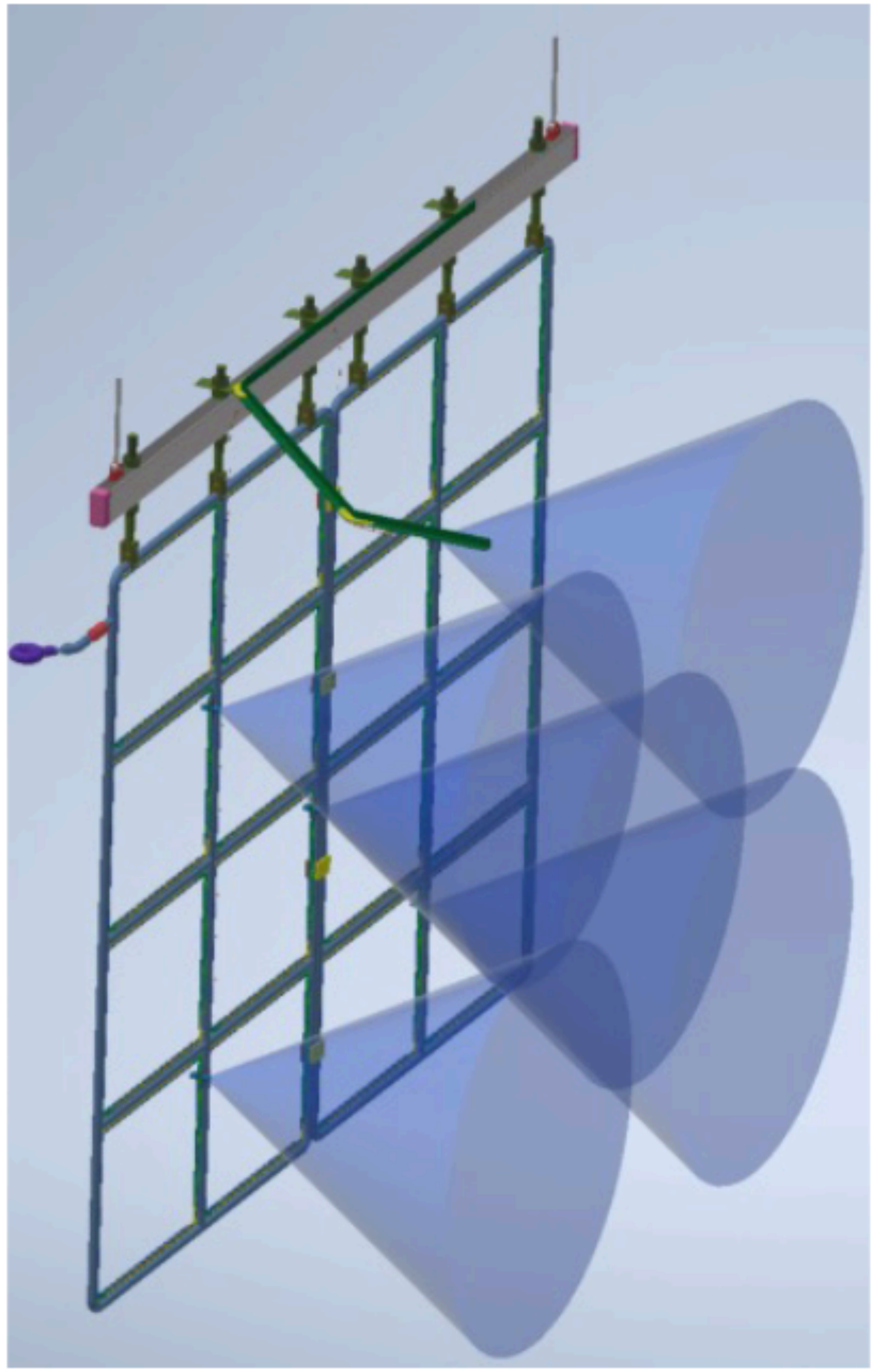


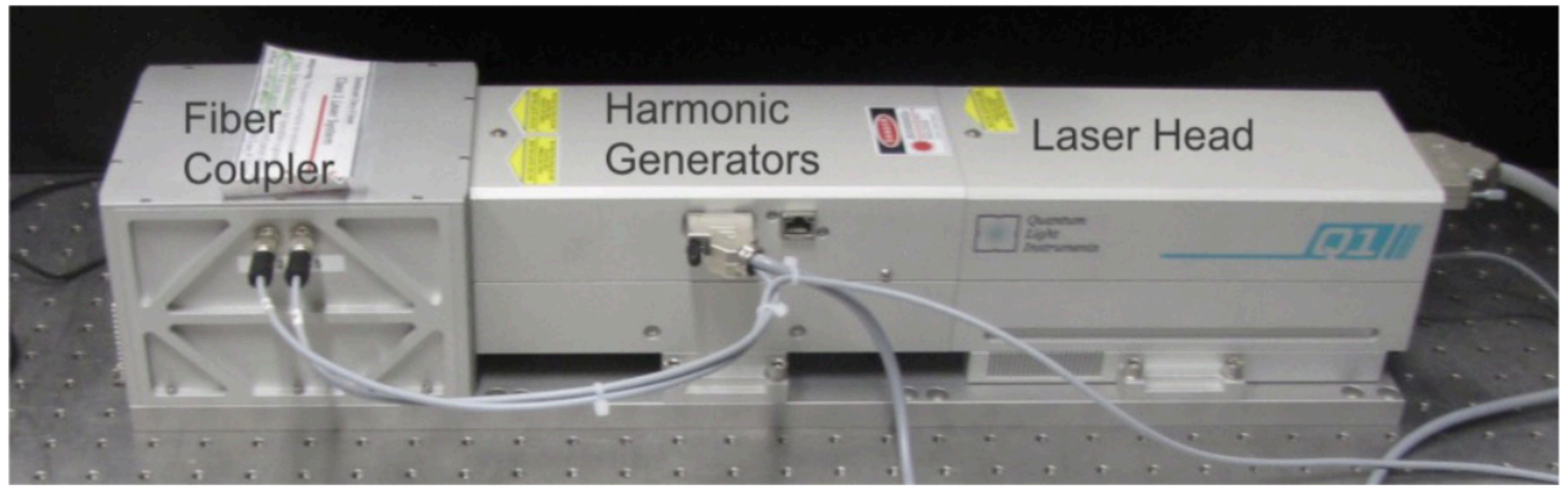
# Wavelength-Shifting Reflective Plates

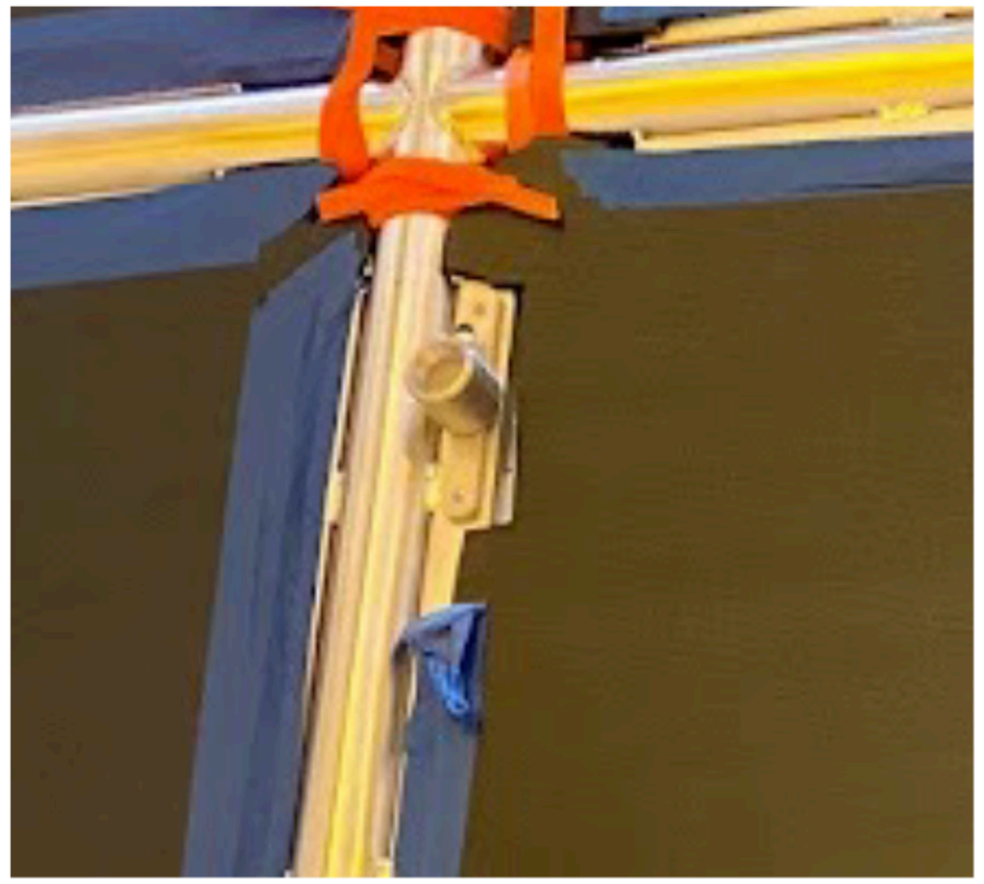
- Total of 64 double-sided wavelength-shifting plates located at the cathode
- Highly reflective surface coated with TPB
- Aim is to recover part of light emitted at cathode where we have no photodetectors



# Diffusers Calibration System



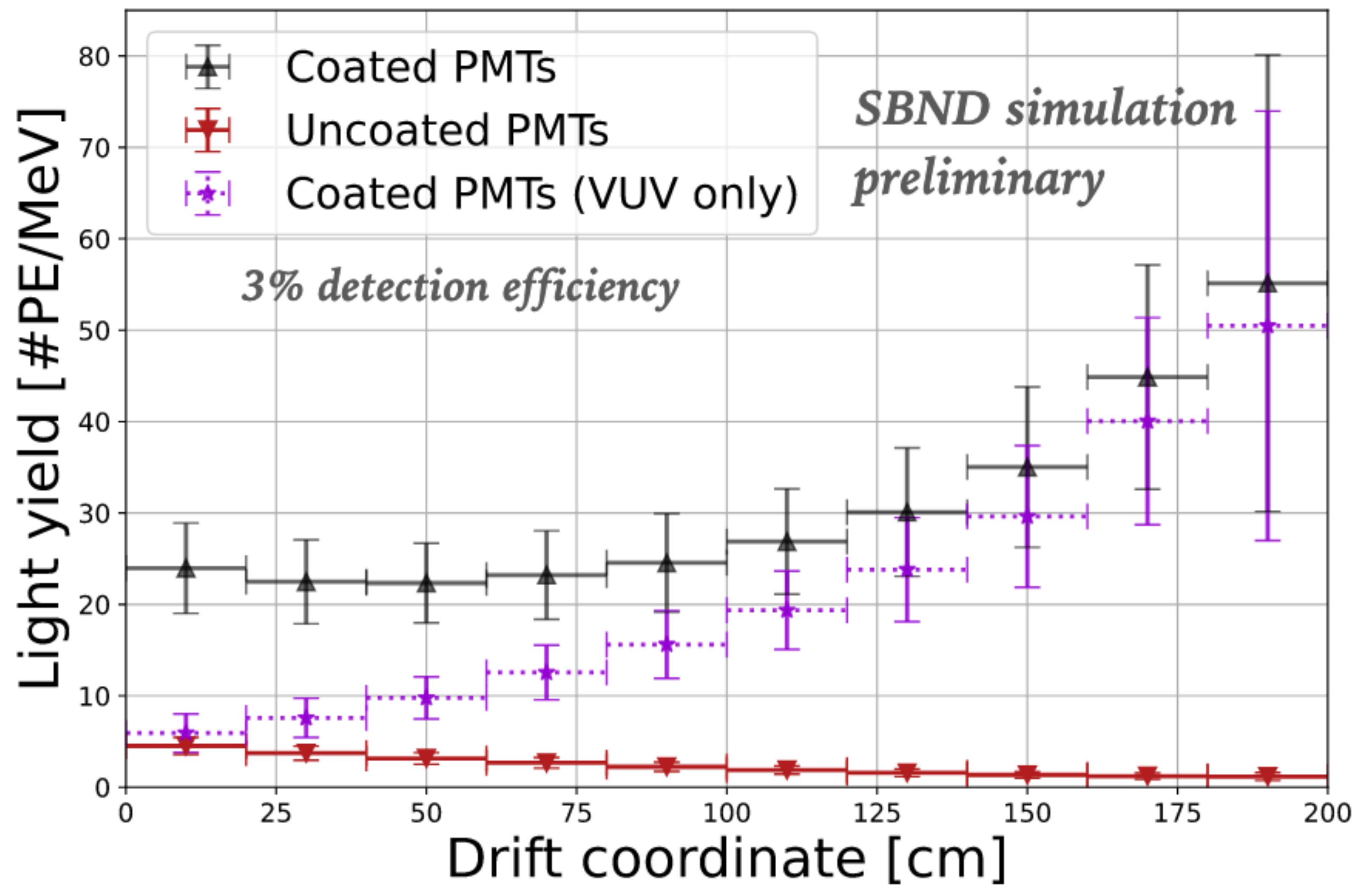


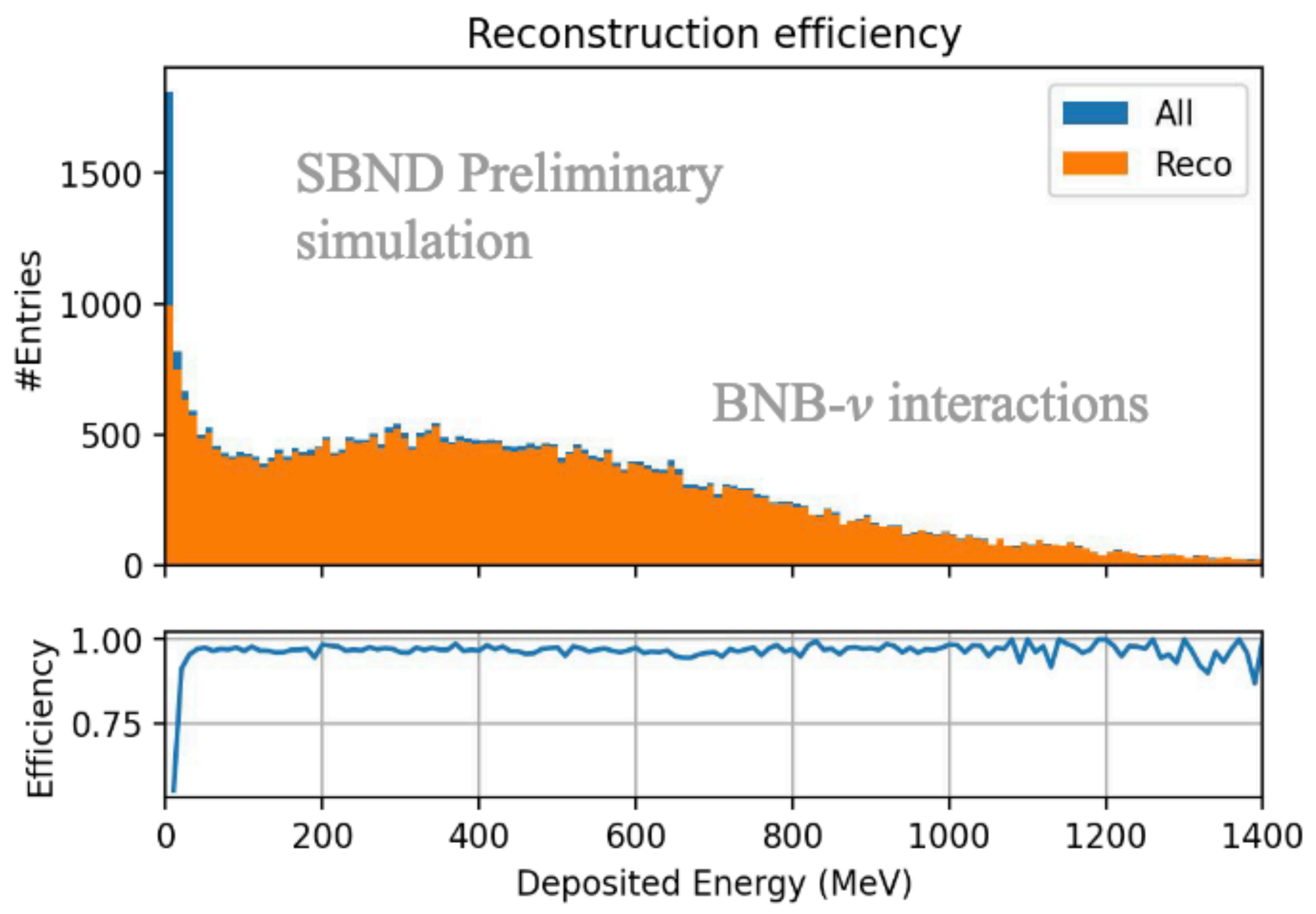



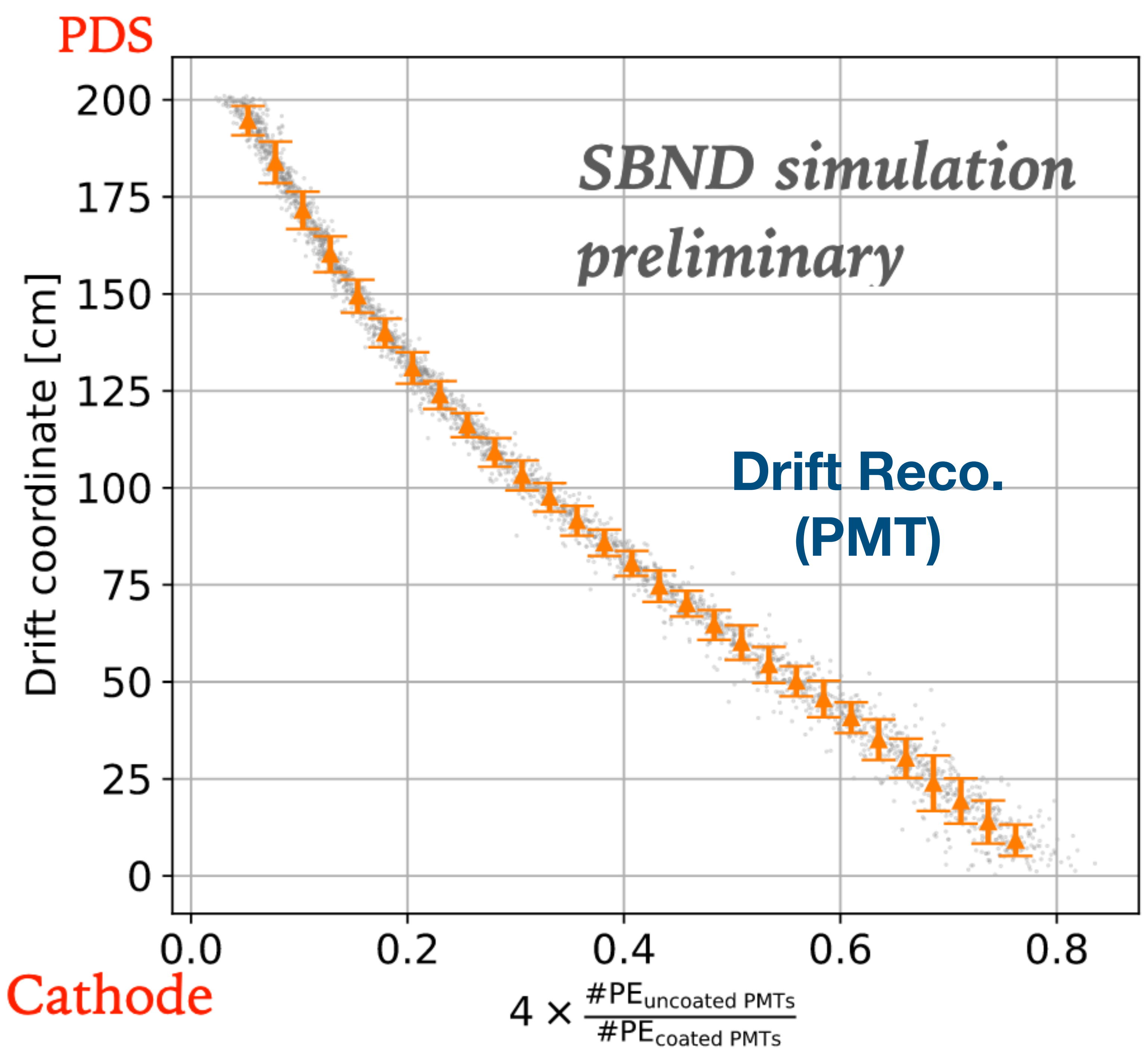
- Calibration system for the PDS on both sides of the cathode plane
- Two laser wavelengths (213 nm and 532 nm) will be provided to diffusers
  - Harmonic generator -> optical fibers

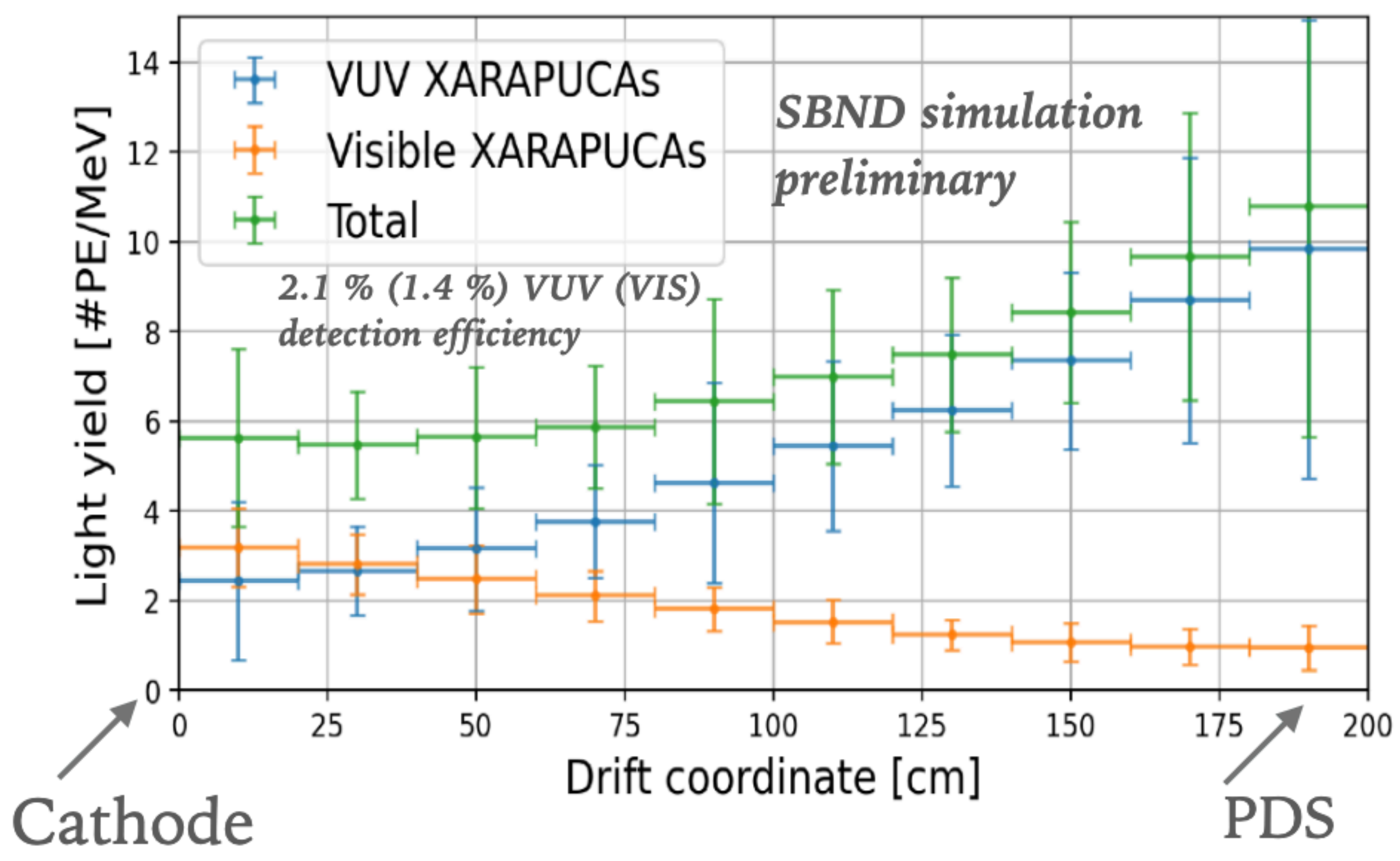
# SBND Light Simulation + Reconstruction

- Proper simulation and reconstruction helps boost SBND's performance and sensitivity
- High light yield, reconstruction efficiency
- Reconstruct drift coordinate, 3D using light information



# Summary and Current Status

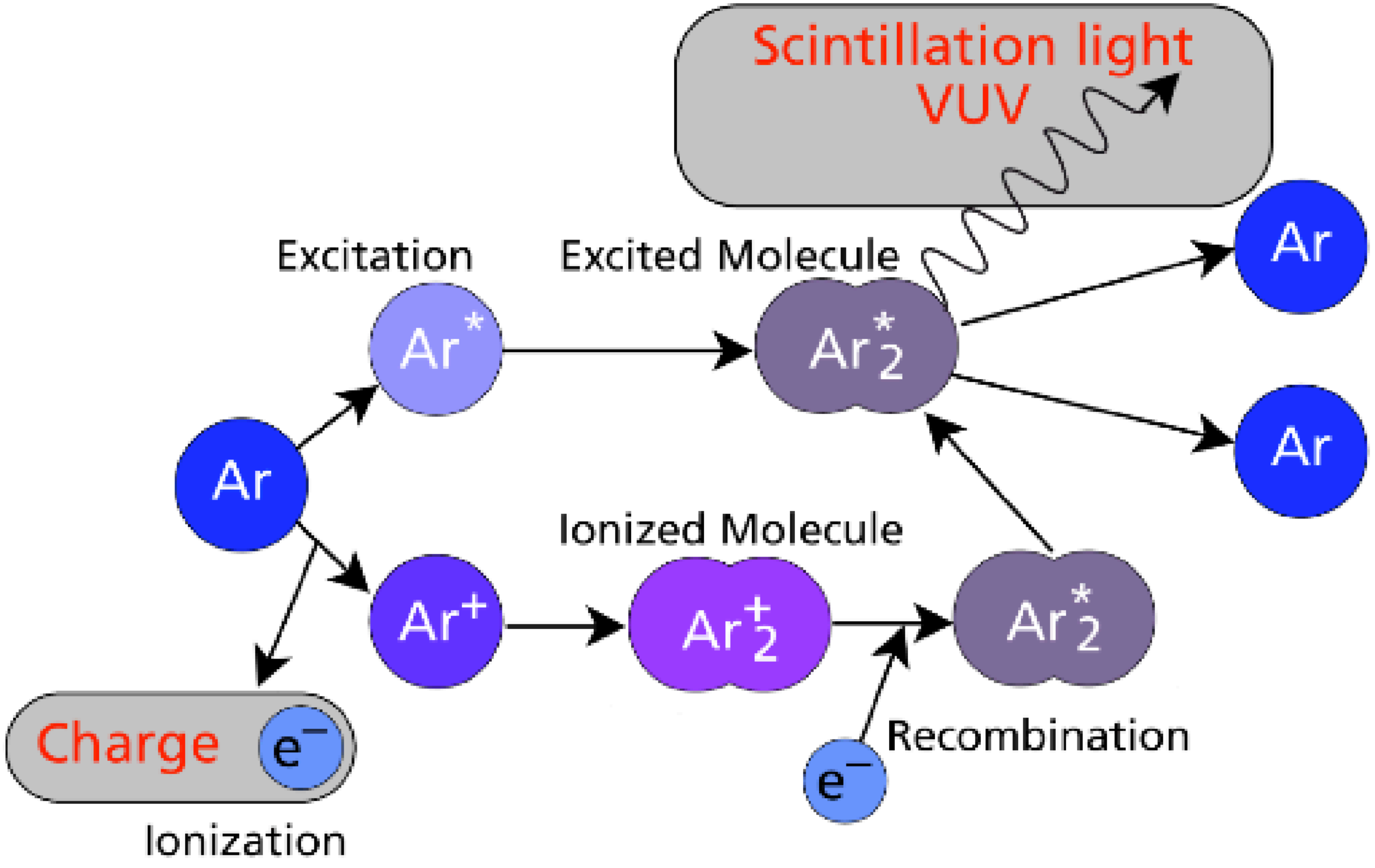
- SBND has implemented an efficient and high resolution photon detector system, with high light yield and uniform detection efficiency
  - Large coverage compared to other LArTPC detectors
  - Variety of photodetection technology
  - Distinction between VUV and visible light
- Testing and installation of the PDS is complete as of this year
  - PDS boxes were installed in the summer
- SBND PDS is currently in the commissioning phase, along with other subsystems
- SBND plans to take neutrino data in 2023
  - Detector move onto the BNB beamline is planned for tomorrow (weather permitting)!

Detector move planned for tomorrow, December 1!

# Backup

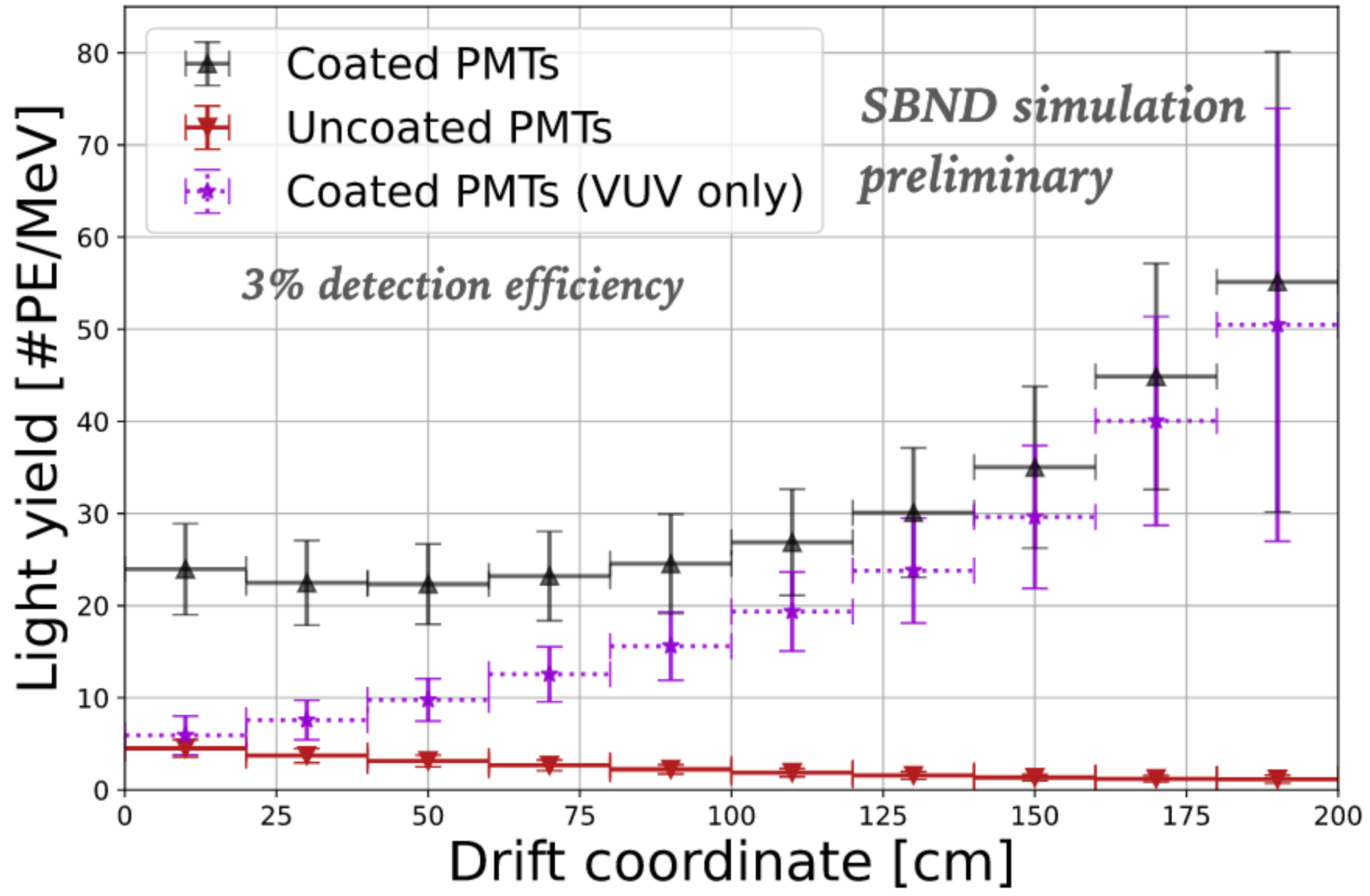
# Scintillation in Liquid Argon

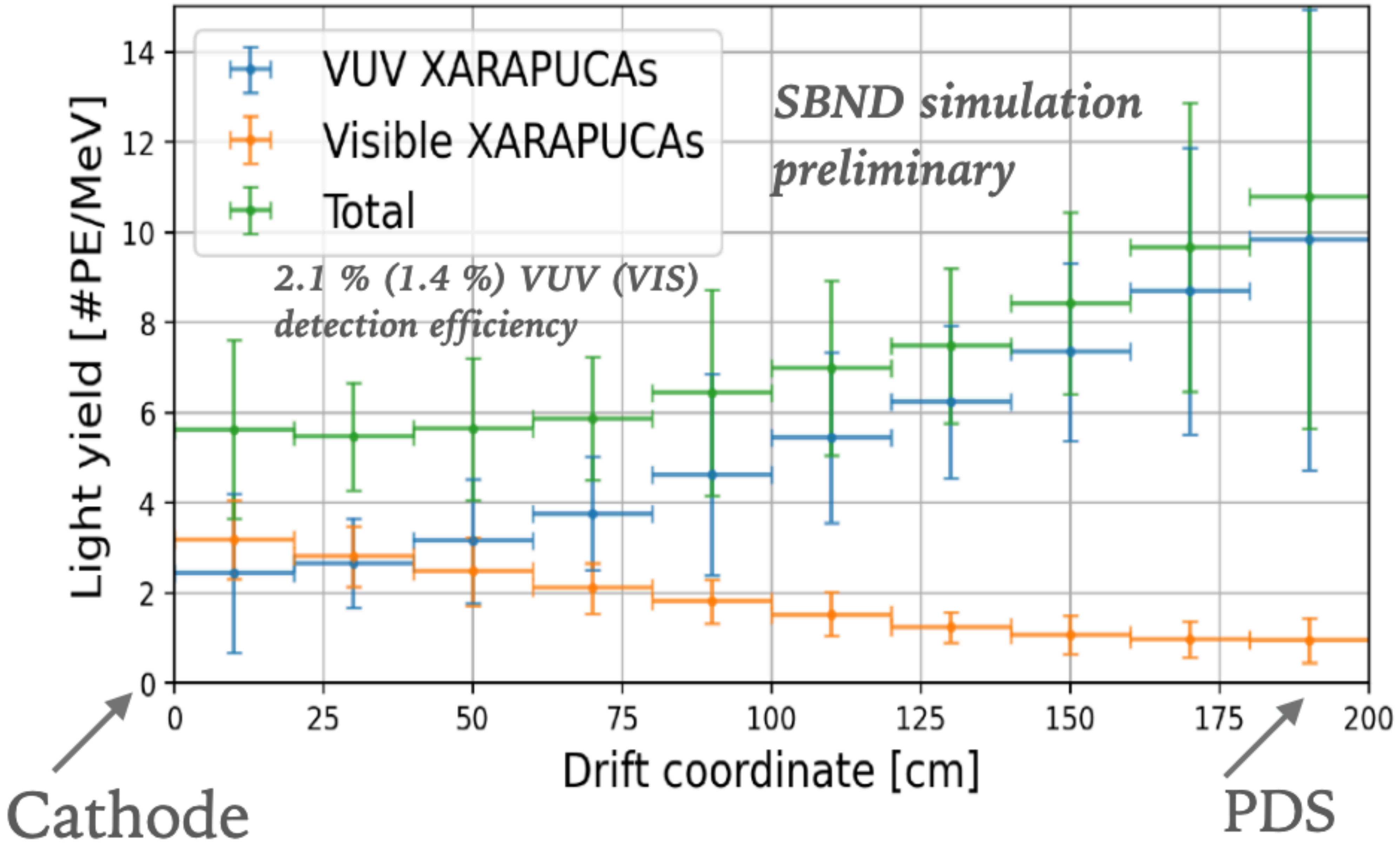
- Two pathways when E deposited:
    1. Excitation: Form excited $Ar_2$ dimers, photon emitted when dimer de-excites
    2. Ionization: Atom ionized, electrons emitted. Forms ionized dimer $Ar_2^+$. Emitted electron recombines with ionized dimer and emits photon via 1).
- Atoms can be excited into 2 states,"fast" (~ 6 ns) singlet and "slow" (~1600 ns) triplet



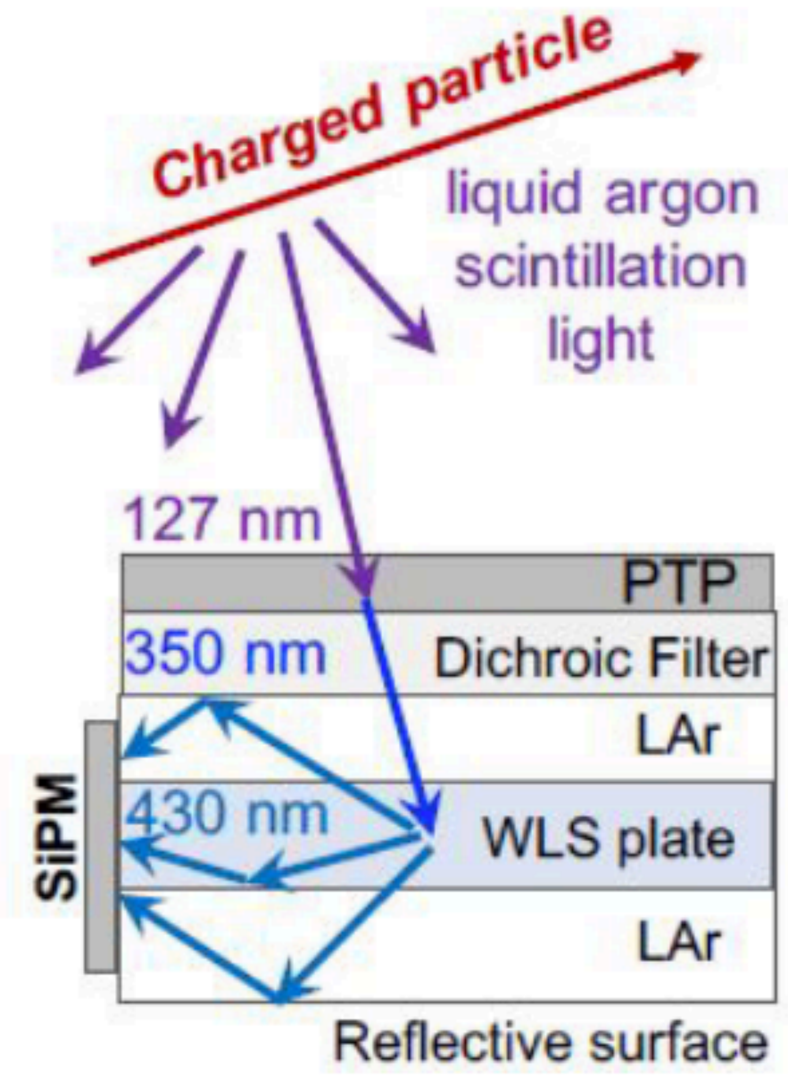
# Light Yield

- High light yield at SBND
  - Lower detection thresholds
  - Calorimetric/PID reconstruction using light
  - More photons -> improves resolution
- Enhanced light collection and uniformity at SBND
  - High density of optical channels
  - Wavelength-shifting foils installed at the cathode



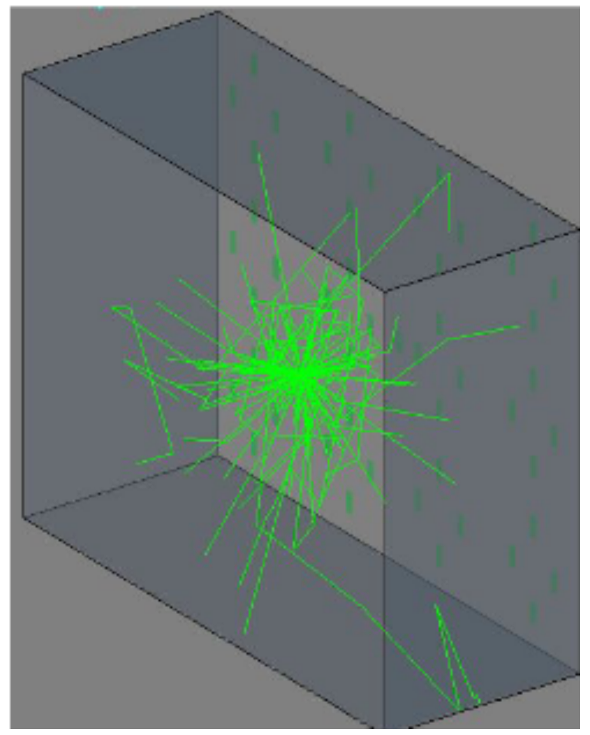



# VUV and Visible Light

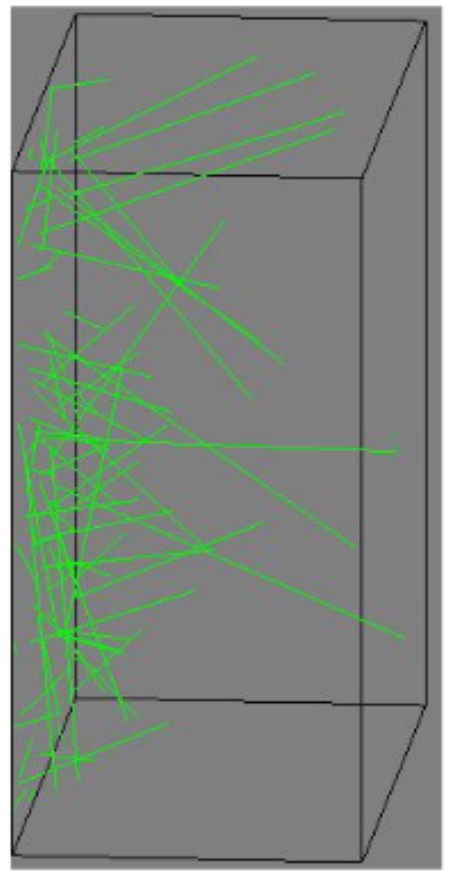


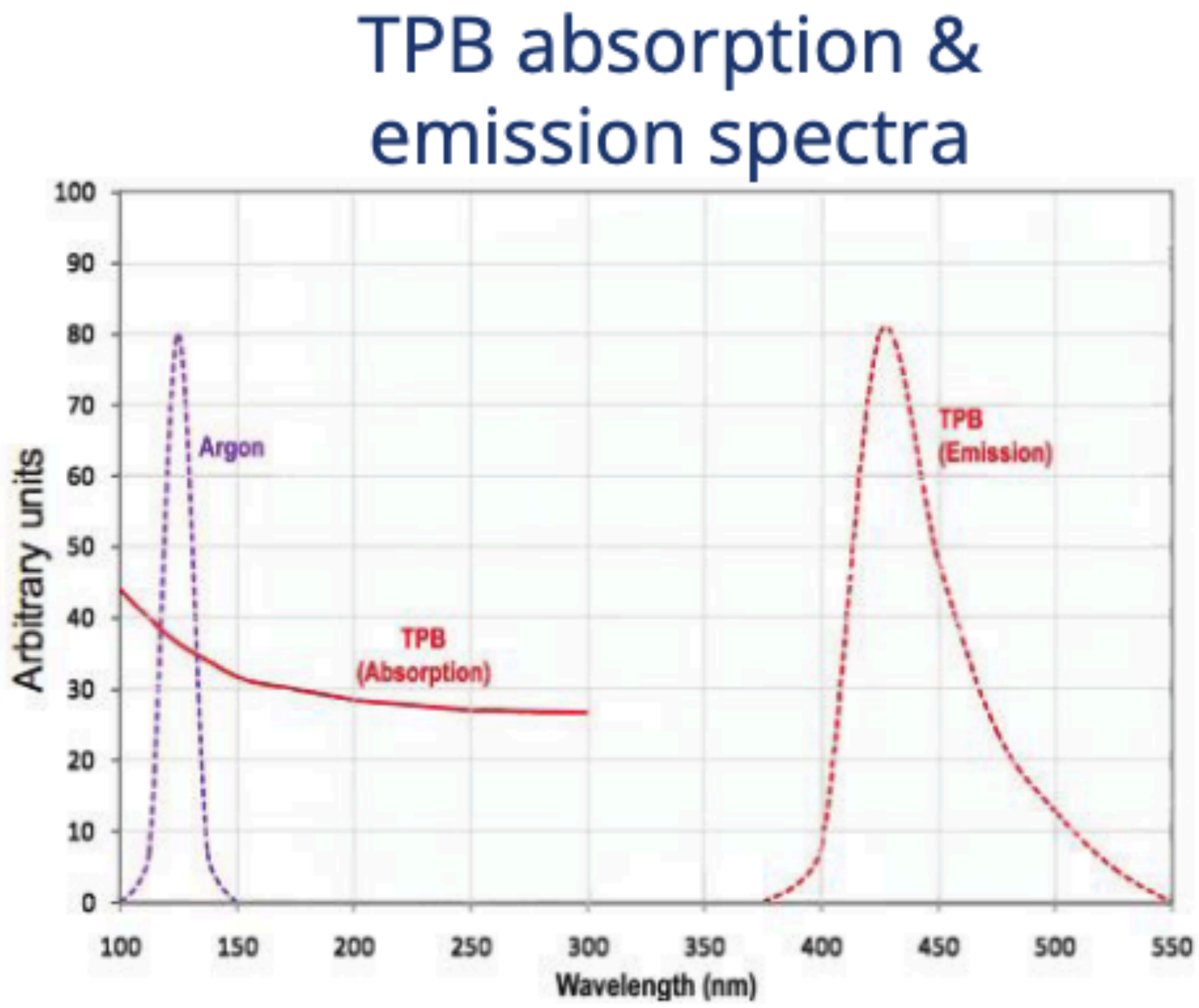

*Nucl. Instrum. Meth. A, 985 (2021)*

**VUV simulation**



**Visible light simulation**



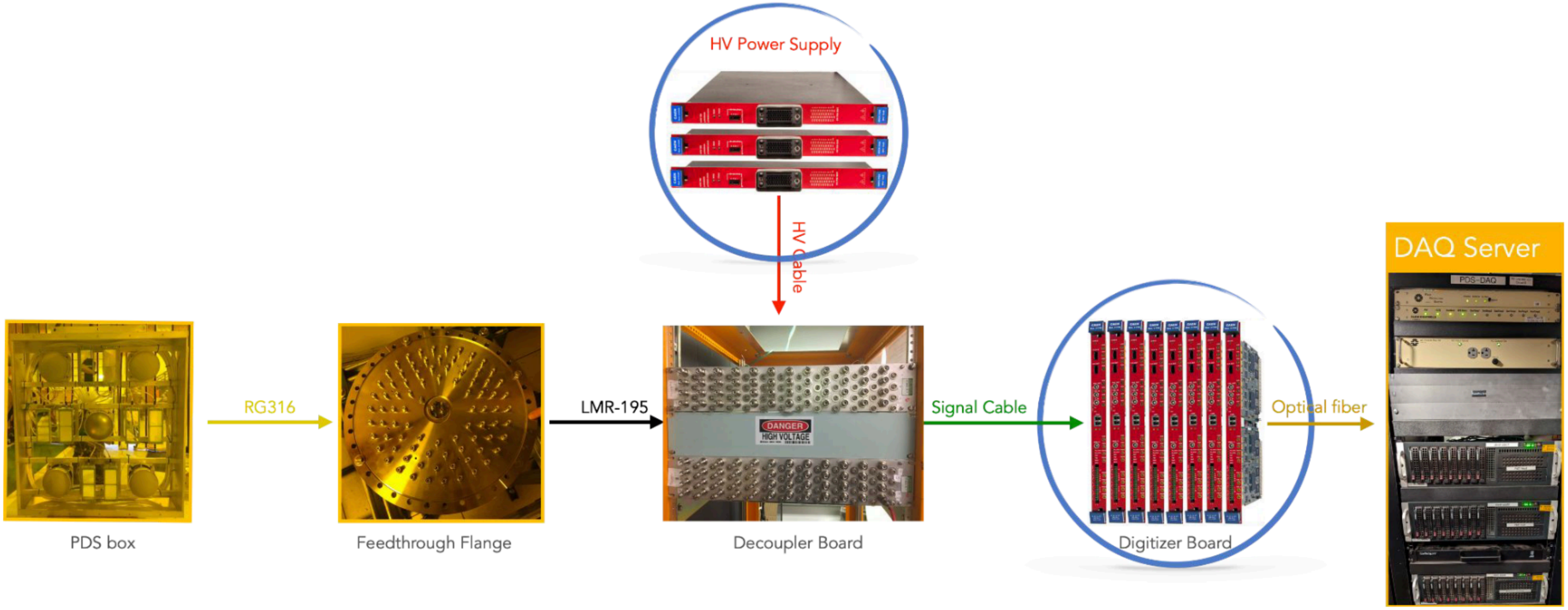



*Physics Procedia, 2012*

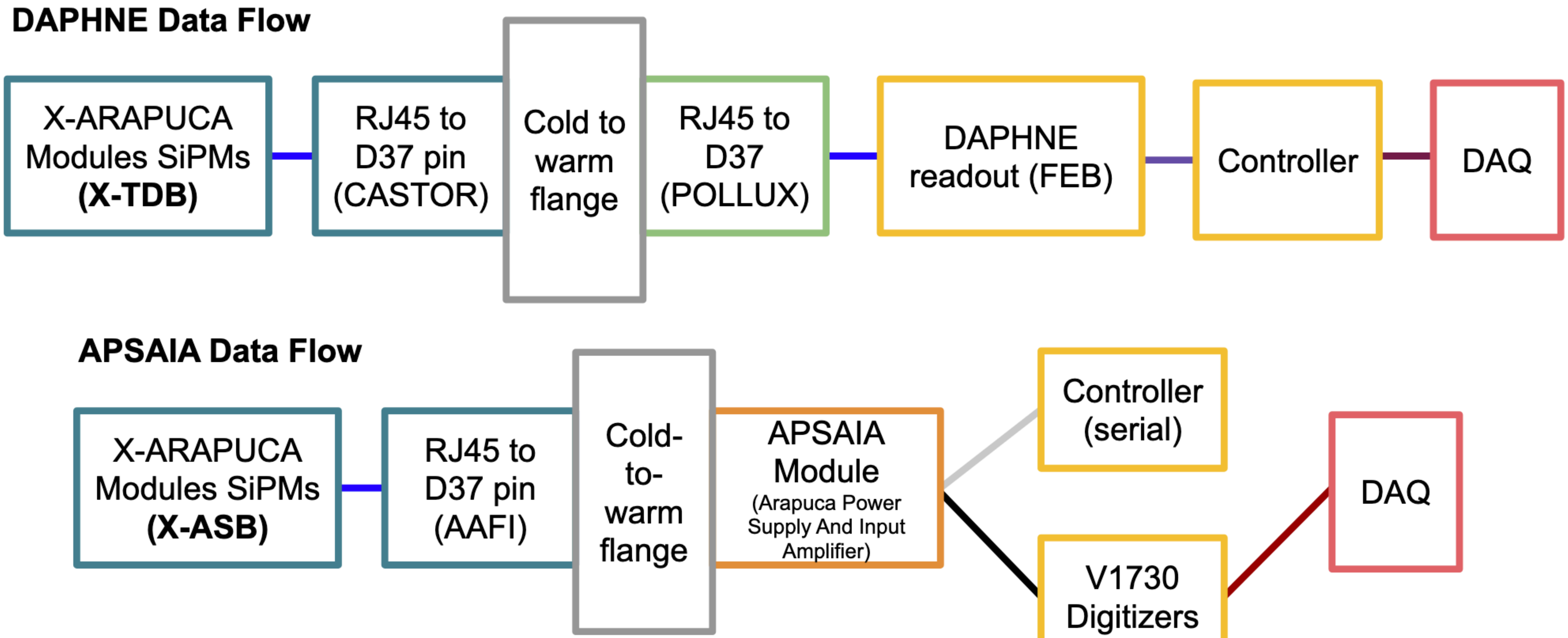
# Summary of PDS Systems

| Component | PMTs | DAPHNE | APSAIA |
|---|---|---|---|
| Light detector | Hamamatsu 8” PMTs | Sensl 3x3mm SiPMs | Hamamatsu 6x6mm SiPMs |
| Connections | 1 PMT per unit,<br>1 voltage+signal line | 32 SiPMs per unit,<br>4 voltage+signal lines | 16 SiPMs per unit,<br>2 voltage and 2 signal lines |
| Signal Output | One waveform per PMT | Waveforms summed over 8 SiPMs (4 wf per unit) | Waveforms summed over 8 SiPMs (2 wf per unit) |
| Digitization | CAEN 1730B (x8) | Custom | CAEN 1730 (x2) |

# PMT Electronics and Readout



# X-ARAPUCA Electronics and Readout



# X-TDBs (DAPHNE)

- X-"Tongue Depressor Board"
- Four 3x3 $mm^2$ SensL SiPMs wired in parallel
- Two 6x6 $mm^2$ active arrays wired in series to make 1 channel
- Anode and cathode signals connected via a backplane for bias and signal distribution
- Two 500 kΩ resistors R1 and R2